REVIEW OF PARTICLE PHYSICS*

Particle Data Group

Abstract

This biennial Review summarizes much of particle physics. Using data from previous editions, plus 2658 new measurements from 644 papers, we list, evaluate, and average measured properties of gauge bosons, leptons, quarks, mesons, and baryons. We summarize searches for hypothetical particles such as Higgs bosons, heavy neutrinos, and supersymmetric particles. All the particle properties and search limits are listed in Summary Tables. We also give numerous tables, figures, formulae, and reviews of topics such as the Standard Model, particle detectors, probability, and statistics. Among the 112 reviews are many that are new or heavily revised including those on Heavy-Quark and Soft-Collinear Effective Theory, Neutrino Cross Section Measurements, Monte Carlo Event Generators, Lattice QCD, Heavy Quarkonium Spectroscopy, Top Quark, Dark Matter, V_{cb} & V_{ub} , Quantum Chromodynamics, High-Energy Collider Parameters, Astrophysical Constants, Cosmological Parameters, and Dark Matter.

A booklet is available containing the Summary Tables and abbreviated versions of some of the other sections of this full *Review*. All tables, listings, and reviews (and errata) are also available on the Particle Data Group website: http://pdg.lbl.gov.

DOI: 10.1103/PhysRevD.86.010001

The 2012 edition of $Review \ of \ Particle \ Physics$ is published for the Particle Data Group as article 010001 in volume 86 of $Physical \ Review \ D$.

This edition should be cited as: J. Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001 (2012).

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*The publication of the Review of Particle Physics is supported by the Director, Office of Science, Office of High Energy and Nuclear Physics, the Division of High Energy Physics of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231; by the U.S. National Science Foundation under Agreement No. PHY-0652989; by the European Laboratory for Particle Physics (CERN); by an implementing arrangement between the governments of Japan (MEXT: Ministry of Education, Culture, Sports, Science and Technology) and the United States (DOE) on cooperative research and development; and by the Italian National Institute of Nuclear Physics (INFN).

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HIGHLIGHTS OF THE 2012 EDITION OF THE REVIEW OF PARTICLE PHYSICS

644 new papers with 2658 new measurements

- Over 100 papers from **LHC** experiments (AT-LAS, CMS, and LHCb).
- Major exclusions in **SUSY** results from the LHC.
- Latest from **B-meson** physics: 120 papers with 555 measurements, including first LHCb results. Stringent limits on $B_s \to \mu^+\mu^-$ from LHCb and CMS approaching the SM expectation.
- Updated and new results in **neutrino mixing**, including observation of mixing angle θ_{13} from reactor experiments.
- 63 new **top** results since 2010, many from LHC experiments.
- New CDF/D0 value of *W*-mass with very small error, impact on prediction of Higgs mass.
- New $\eta_c(1S)$ branching ratio fit removing circular dependencies.
- First observations of $h_b(1P)$, $h_b(2P)$, and the $\chi_b(3P)$ triplet, as well as two exotic charged states with bottomonium content (unconfirmed).

112 reviews (most are revised or new)

- New reviews on:
 - Heavy-Quark and Soft-Collinear Effective Theory
 - Neutrino Cross Section Measurements
 - Neutrino Beam Lines at High-Energy Proton Synchrotrons
 - Monte Carlo Event Generators
 - Lattice QCD
 - Scalar Meson and $\sigma(500)$ Parameters
 - Heavy Quarkonium Spectroscopy
- Significant update/revision to reviews on:
 - Higgs Boson (with addendum on new July 2012 results)
 - Astrophysical Constants (extended to include more cosmological parameters from the 7-year WMAP analysis)
 - Dark Matter
 - **Top Quark** with detailed coverage of LHC results
 - V_{cb} and V_{ub} CKM elements
 - Quantum Chromodynamics
 - **High-Energy Collider Parameters** (includes CLIC and latest LHC parameters)
 - Particle Detectors for Non-Accel. Physics (addition of Coherent Radio Cherenkov Detectors)

See **pdgLive.lbl.gov** for online access to PDG database.

See pdg.lbl.gov/AtomicNuclearProperties for Atomic Properties of Materials.

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INTRODUCTION

1. Overview

The Review of Particle Physics and the abbreviated version, the Particle Physics Booklet, are reviews of the field of Particle Physics. This complete Review includes a compilation/evaluation of data on particle properties, called the "Particle Listings." These Listings include 2,658 new measurements from 644 papers, in addition to the 29,495 measurements from 8,300 papers that first appeared in previous editions [1].

Both books include Summary Tables with our best values and limits for particle properties such as masses, widths or lifetimes, and branching fractions, as well as an extensive summary of searches for hypothetical particles. In addition, we give a long section of "Reviews, Tables, and Plots" on a wide variety of theoretical and experimental topics, a quick reference for the practicing particle physicist.

The *Review* and the *Booklet* are published in evennumbered years. This edition is an updating through January 2012 (and, in some areas, well into 2012). As described in the section "Online Particle Physics Information" following this introduction, the content of this *Review* is available on the World-Wide Web, and is updated between printed editions (http://pdg.lbl.gov/).

The Summary Tables give our best values of the properties of the particles we consider to be well established, a summary of search limits for hypothetical particles, and a summary of experimental tests of conservation laws.

The Particle Listings contain all the data used to get the values given in the Summary Tables. Other measurements considered recent enough or important enough to mention, but which for one reason or another are not used to get the best values, appear separately just beneath the data we do use for the Summary Tables. The Particle Listings also give information on unconfirmed particles and on particle searches, as well as short "reviews" on subjects of particular interest or controversy.

The Particle Listings were once an archive of all published data on particle properties. This is no longer possible because of the large quantity of data. We refer interested readers to earlier editions for data now considered to be obsolete.

We organize the particles into six categories:

Gauge and Higgs bosons

Leptons

Quarks

Mesons

Baryons

Searches for monopoles, supersymmetry,

compositeness, extra dimensions, etc.

The last category only includes searches for particles that do not belong to the previous groups; searches for heavy charged leptons and massive neutrinos, by contrast, are with the leptons.

In Sec. 2 of this Introduction, we list the main areas of responsibility of the authors, and also list our large number of consultants, without whom we would not have been able to produce this *Review*. In Sec. 4, we mention briefly the naming scheme for hadrons. In Sec. 5, we discuss our procedures for choosing among measurements of particle properties and for obtaining best values of the properties

from the measurements.

The accuracy and usefulness of this *Review* depend in large part on interaction between its users and the authors. We appreciate comments, criticisms, and suggestions for improvements of any kind. Please send them to the appropriate author, according to the list of responsibilities in Sec. 2 below, or to the LBNL addresses below.

To order a copy of the *Review* or the *Particle Physics Booklet* from North and South America, Australia, and the Far East, send email to PDG@LBL.GOV

or via the web at:

http://pdg.lbl.gov/pdgmail

or write to:

Particle Data Group, MS 50R6008 Lawrence Berkeley National Laboratory Berkeley, CA 94720-8166, USA

From all other areas email library.desk@cern.ch, see http://library.web.cern.ch/library/Library/request.html

or write to

CERN Scientific Information Service CH-1211 Geneva 23, Switzerland

2. Particle Listings responsibilities

* Asterisk indicates the people to contact with questions or comments about Particle Listings sections.

Gauge and Higgs bosons

γ C. Grab, D.E. Groom*
Gluons R.M. Barnett,* A.V. Manohar
Graviton D.E. Groom*

 $\begin{array}{lll} W,Z & \text{A. Gurtu,* M. Grünewald*} \\ \text{Higgs bosons} & \text{K. Hikasa, G. Weiglein*} \\ \text{Heavy bosons} & \text{K. Copic,* M. Tanabashi} \end{array}$

Axions K.A. Olive, F. Takahashi, G. Raffelt*

Leptons

Neutrinos M. Goodman, C.-J. Lin,* K. Nakamura,

K.A. Olive, A. Piepke, P. Vogel

 e, μ J.-F. Arguin,* C. Grab τ K.G. Hayes, K. Mönig*

Quarks

QuarksR.M. Barnett,* A.V. ManoharTop quarkJ.-F. Arguin,* K. Hagiwarab', t'K. Hagiwara, W.-M. Yao*

Free quark J. Beringer*

Mesons

 π, η J.-F. Arguin,* C. Grab

Unstable mesons C. Amsler, M. Doser, * S. Eidelman, *

T. Gutsche, C. Hanhart, B. Heltsley, J.J. Hernández-Rey, A. Masoni, S. Navas,

C. Patrignani, S. Spanier, N.A. Törnqvist,

G. Venanzoni

K (stable) G. D'Ambrosio, C.-J. Lin*

D.M. Asner, S. Blusk, C.G. Wohl*

B (stable) J.-F. Arguin*, M. Kreps, Y. Kwon, J.G. Smith,

W.-M. Yao*

Baryons

Stable baryons C. Grab, C.G. Wohl*

Unstable baryons E. Klempt, C.G. Wohl,* R.L. Workman

Charmed baryons S. Blusk, C.G. Wohl*

Bottom baryons M. Kreps, Y. Kwon, J.G. Smith, W.-M. Yao*

$\underline{Miscellaneous\ searches}$

Monopole D. Milstead*

Supersymmetry A. de Gouvêa, F. Moortgat,

K.A. Olive, L. Pape, G. Weiglein*

Technicolor M. Tanabashi, J. Terning*
Compositeness M. Tanabashi, J. Terning*
Extra Dimensions J.-F. Arguin*, T. Gherghetta

WIMPs and Other K. Hikasa,*

3. Consultants

The Particle Data Group benefits greatly from the assistance of some 700 physicists who are asked to verify every piece of data entered into this *Review*. Of special value is the advice of the PDG Advisory Committee which meets biennially and thoroughly reviews all aspects of our operation. The members of the 2012 committee are:

- D. Harris (FNAL)
- P. Janot (CERN)
- J. Olson (Princeton)
- G. Perez (Weizmann)
- J. Tanaka (Tokyo)

We have especially relied on the expertise of the following people for advice on particular topics:

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- V. B. Bezerra (UFPb)
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- T. Gershon (U. of Warwick, UK)
- E.W.N. Glover (Durham U)
- B. Golob (U. Ljubljana, Slovenia)
- O. Gonzalez Lopez (CIEMAT, Spain)
- M. Grazzini (U of Zurich)
- E. Gschwendtner (U. of Geneva)
- F. Harris (University of Hawaii)
- R. Harr (Wayne State University)
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- Y. Hayato (ICRR, U. of Tokyo)
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- K. Oide (KEK, Japan)
- J.R. Pelaez (UCM, Madrid)
- F. Petriello (Northwestern U.)
- S. Rahatlou (U. of Rome, INFN)
- H. Robertson (U. of Washington)
- N. Roe (LBNL)
- M. Roney (University of Victoria)
- G. Ross (Oxford)

- M. Ross (FNAL)
- M. Rotondo (Padova, INFN)
- K. Sachs (DESY)
- J.E. Sansonetti (NIST)
- D. Schulte (CERN)
- C. Schwanda (HEPHY, Vienna)
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- M. Wise (Caltech)
- M. Yokoyama (U. of Tokyo)
- C.Z. Yuan (IHEP, Beijing)
- C. Zhang (IHEP, Beijing)
- B. Zwaska (FNAL)

4. Naming scheme for hadrons

We introduced in the 1986 edition [2] a new naming scheme for the hadrons. Changes from older terminology affected mainly the heavier mesons made of u, d, and s quarks. Otherwise, the only important change to known hadrons was that the F^{\pm} became the D_s^{\pm} . None of the lightest pseudoscalar or vector mesons changed names, nor did the $c\bar{c}$ or $b\bar{b}$ mesons (we do, however, now use χ_c for the $c\bar{c}$ χ states), nor did any of the established baryons. The Summary Tables give both the new and old names whenever a change has occurred.

The scheme is described in "Naming Scheme for Hadrons" (p. 118) of this *Review*.

We give here our conventions on type-setting style. Particle symbols are italic (or slanted) characters: e^- , p, Λ , π^0 , K_L , D_s^+ , b. Charge is indicated by a superscript: B^- , Δ^{++} . Charge is not normally indicated for p, n, or the quarks, and is optional for neutral isosinglets: η or η^0 . Antiparticles and particles are distinguished by charge for charged leptons and mesons: τ^+ , K^- . Otherwise, distinct antiparticles are indicated by a bar (overline): $\overline{\nu}_\mu$, \overline{t} , \overline{p} , \overline{K}^0 , and $\overline{\Sigma}^+$ (the antiparticle of the Σ^-).

5. Procedures

5.1. Selection and treatment of data: The Particle Listings contain all relevant data known to us that are published in journals. With very few exceptions, we do not include results from preprints or conference reports. Nor do we include data that are of historical importance only (the Listings are not an archival record). We search every volume of 20 journals through our cutoff date for relevant data. We also include later published papers that are sent to us by the authors (or others).

In the Particle Listings, we clearly separate measurements that are used to calculate or estimate values given in the Summary Tables from measurements that are not used. We give explanatory comments in many such cases. Among the reasons a measurement might be excluded are the following:

- It is superseded by or included in later results.
- No error is given.
- It involves assumptions we question.
- It has a poor signal-to-noise ratio, low statistical significance, or is otherwise of poorer quality than other data available.
- It is clearly inconsistent with other results that appear to be more reliable. Usually we then state the criterion, which sometimes is quite subjective, for selecting "more reliable" data for averaging. See Sec. 5.4.
- It is not independent of other results.
- It is not the best limit (see below).
- It is quoted from a preprint or a conference report.

In some cases, *none* of the measurements is entirely reliable and no average is calculated. For example, the masses of many of the baryon resonances, obtained from partial-wave analyses, are quoted as estimated ranges thought to probably include the true values, rather than as averages with errors. This is discussed in the Baryon Particle Listings.

For upper limits, we normally quote in the Summary Tables the strongest limit. We do not average or combine upper limits except in a very few cases where they may be re-expressed as measured numbers with Gaussian errors.

As is customary, we assume that particle and antiparticle share the same spin, mass, and mean life. The Tests of Conservation Laws table, following the Summary Tables, lists tests of CPT as well as other conservation laws.

We use the following indicators in the Particle Listings to tell how we get values from the tabulated measurements:

- OUR AVERAGE—From a weighted average of selected data.
- OUR FIT—From a constrained or overdetermined multiparameter fit of selected data.
- OUR EVALUATION—Not from a direct measurement, but evaluated from measurements of related quantities.
- OUR ESTIMATE—Based on the observed range of the data. Not from a formal statistical procedure.
- OUR LIMIT—For special cases where the limit is evaluated by us from measured ratios or other data. Not from a direct measurement.

An experimentalist who sees indications of a particle will of course want to know what has been seen in that region in the past. Hence we include in the Particle Listings all reported states that, in our opinion, have sufficient statistical merit and that have not been disproved by more reliable data. However, we promote to the Summary Tables only those states that we feel are well established. This judgment is, of course, somewhat subjective and no precise criteria can be given. For more detailed discussions, see the minireviews in the Particle Listings.

- **5.2.** Averages and fits: We divide this discussion on obtaining averages and errors into three sections:
- (1) treatment of errors; (2) unconstrained averaging;
- (3) constrained fits.

5.2.1. Treatment of errors: In what follows, the "error" δx means that the range $x \pm \delta x$ is intended to be a 68.3% confidence interval about the central value x. We treat this error as if it were Gaussian. Thus when the error is Gaussian, δx is the usual one standard deviation (1σ) . Many experimenters now give statistical and systematic errors separately, in which case we usually quote both errors, with the statistical error first. For averages and fits, we then add the the two errors in quadrature and use this combined error for δx .

When experimenters quote asymmetric errors $(\delta x)^+$ and $(\delta x)^-$ for a measurement x, the error that we use for that measurement in making an average or a fit with other measurements is a continuous function of these three quantities. When the resultant average or fit \overline{x} is less than $x-(\delta x)^-$, we use $(\delta x)^-$; when it is greater than $x+(\delta x)^+$, we use $(\delta x)^+$. In between, the error we use is a linear function of x. Since the errors we use are functions of the result, we iterate to get the final result. Asymmetric output errors are determined from the input errors assuming a linear relation between the input and output quantities.

In fitting or averaging, we usually do not include correlations between different measurements, but we try to select data in such a way as to reduce correlations. Correlated errors are, however, treated explicitly when there are a number of results of the form $A_i \pm \sigma_i \pm \Delta$ that have identical systematic errors Δ . In this case, one can first average the $A_i \pm \sigma_i$ and then combine the resulting statistical error with Δ . One obtains, however, the same result by averaging $A_i \pm (\sigma_i^2 + \Delta_i^2)^{1/2}$, where $\Delta_i = \sigma_i \Delta [\sum (1/\sigma_j^2)]^{1/2}$. This procedure has the advantage that, with the modified systematic errors Δ_i , each measurement may be treated as independent and averaged in the usual way with other data. Therefore, when appropriate, we adopt this procedure. We tabulate Δ and invoke an automated procedure that computes Δ_i before averaging and we include a note saying that there are common systematic errors.

Another common case of correlated errors occurs when experimenters measure two quantities and then quote the two and their difference, e.g., m_1 , m_2 , and $\Delta = m_2 - m_1$. We cannot enter all of m_1 , m_2 and Δ into a constrained fit because they are not independent. In some cases, it is a good approximation to ignore the quantity with the largest error and put the other two into the fit. However, in some cases correlations are such that the errors on m_1 , m_2 and Δ are comparable and none of the three values can be ignored. In this case, we put all three values into the fit and invoke an automated procedure to increase the errors prior to fitting such that the three quantities can be treated as independent measurements in the constrained fit. We include a note saying that this has been done.

5.2.2. Unconstrained averaging: To average data, we use a standard weighted least-squares procedure and in some cases, discussed below, increase the errors with a "scale factor." We begin by assuming that measurements of a given quantity are uncorrelated, and calculate a weighted average and error as

$$\overline{x} \pm \delta \overline{x} = \frac{\sum_{i} w_i x_i}{\sum_{i} w_i} \pm \left(\sum_{i} w_i\right)^{-1/2} , \qquad (1)$$

where

$$w_i = 1/(\delta x_i)^2$$
.

Here x_i and δx_i are the value and error reported by the *i*th experiment, and the sums run over the N experiments. We then calculate $\chi^2 = \sum w_i(\overline{x} - x_i)^2$ and compare it with N-1, which is the expectation value of χ^2 if the measurements are from a Gaussian distribution.

If $\chi^2/(N-1)$ is less than or equal to 1, and there are no known problems with the data, we accept the results.

If $\chi^2/(N-1)$ is very large, we may choose not to use the average at all. Alternatively, we may quote the calculated average, but then make an educated guess of the error, a conservative estimate designed to take into account known problems with the data.

Finally, if $\chi^2/(N-1)$ is greater than 1, but not greatly so, we still average the data, but then also do the following:

(a) We increase our quoted error, $\delta \overline{x}$ in Eq. (1), by a scale factor S defined as

$$S = \left[\chi^2 / (N - 1) \right]^{1/2} . \tag{2}$$

Our reasoning is as follows. The large value of the χ^2 is likely to be due to underestimation of errors in at least one of the experiments. Not knowing which of the errors are underestimated, we assume they are all underestimated by the same factor S. If we scale up all the input errors by this factor, the χ^2 becomes N-1, and of course the output error $\delta \overline{x}$ scales up by the same factor. See Ref. 3.

When combining data with widely varying errors, we modify this procedure slightly. We evaluate S using only the experiments with smaller errors. Our cutoff or ceiling on δx_i is arbitrarily chosen to be

$$\delta_0 = 3N^{1/2} \, \delta \overline{x} \, ,$$

where $\delta \overline{x}$ is the unscaled error of the mean of all the experiments. Our reasoning is that although the low-precision experiments have little influence on the values \overline{x} and $\delta \overline{x}$, they can make significant contributions to the χ^2 , and the contribution of the high-precision experiments thus tends to be obscured. Note that if each experiment has the same error δx_i , then $\delta \overline{x}$ is $\delta x_i/N^{1/2}$, so each δx_i is well below the cutoff. (More often, however, we simply exclude measurements with relatively large errors from averages and fits: new, precise data chase out old, imprecise data.)

Our scaling procedure has the property that if there are two values with comparable errors separated by much more than their stated errors (with or without a number of other values of lower accuracy), the scaled-up error $\delta \overline{x}$ is approximately half the interval between the two discrepant values

We emphasize that our scaling procedure for errors in no way affects central values. And if you wish to recover the unscaled error $\delta \overline{x}$, simply divide the quoted error by S.

(b) If the number M of experiments with an error smaller than δ_0 is at least three, and if $\chi^2/(M-1)$ is greater than 1.25, we show in the Particle Listings an ideogram of the data. Figure 1 is an example. Sometimes one or two data points lie apart from the main body; other times the data split into two or more groups. We extract no numbers from these ideograms; they are simply visual aids, which the reader may use as he or she sees fit.

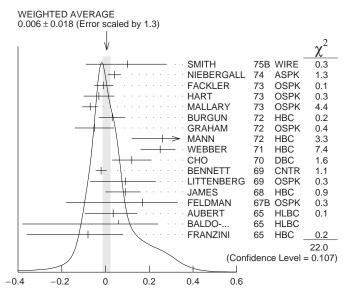


Figure 1: A typical ideogram. The arrow at the top shows the position of the weighted average, while the width of the shaded pattern shows the error in the average after scaling by the factor S. The column on the right gives the χ^2 contribution of each of the experiments. Note that the next-to-last experiment, denoted by the incomplete error flag (\bot) , is not used in the calculation of S (see the text).

Each measurement in an ideogram is represented by a Gaussian with a central value x_i , error δx_i , and area proportional to $1/\delta x_i$. The choice of $1/\delta x_i$ for the area is somewhat arbitrary. With this choice, the center of gravity of the ideogram corresponds to an average that uses weights $1/\delta x_i$ rather than the $(1/\delta x_i)^2$ actually used in the averages. This may be appropriate when some of the experiments have seriously underestimated systematic errors. However, since for this choice of area the height of the Gaussian for each measurement is proportional to $(1/\delta x_i)^2$, the peak position of the ideogram will often favor the high-precision measurements at least as much as does the least-squares average. See our 1986 edition [2] for a detailed discussion of the use of ideograms.

5.2.3. Constrained fits: In some cases, such as branching ratios or masses and mass differences, a constrained fit may be needed to obtain the best values of a set of parameters. For example, most branching ratios and rate measurements are analyzed by making a simultaneous least-squares fit to all the data and extracting the partial decay fractions P_i , the partial widths Γ_i , the full width Γ (or mean life), and the associated error matrix.

Assume, for example, that a state has m partial decay fractions P_i , where $\sum P_i = 1$. These have been measured in N_r different ratios R_r , where, e.g., $R_1 = P_1/P_2$, R_2

 $= P_1/P_3$, etc. [We can handle any ratio R of the form $\sum \alpha_i P_i/\sum \beta_i P_i$, where α_i and β_i are constants, usually 1 or 0. The forms $R = P_i P_j$ and $R = (P_i P_j)^{1/2}$ are also allowed.] Further assume that each ratio R has been measured by N_k experiments (we designate each experiment with a subscript k, e.g., R_{1k}). We then find the best values of the fractions P_i by minimizing the χ^2 as a function of the m-1 independent parameters:

$$\chi^2 = \sum_{r=1}^{N_r} \sum_{k=1}^{N_k} \left(\frac{R_{rk} - R_r}{\delta R_{rk}} \right)^2 , \qquad (3)$$

where the R_{rk} are the measured values and R_r are the fitted values of the branching ratios.

In addition to the fitted values \overline{P}_i , we calculate an error matrix $\langle \delta \overline{P}_i \ \delta \overline{P}_j \rangle$. We tabulate the diagonal elements of $\delta \overline{P}_i = \langle \delta \overline{P}_i \ \delta \overline{P}_i \rangle^{1/2}$ (except that some errors are scaled as discussed below). In the Particle Listings, we give the complete correlation matrix; we also calculate the fitted value of each ratio, for comparison with the input data, and list it above the relevant input, along with a simple unconstrained average of the same input.

Three comments on the example above:

- (1) There was no connection assumed between measurements of the full width and the branching ratios. But often we also have information on partial widths Γ_i as well as the total width Γ . In this case we must introduce Γ as a parameter in the fit, along with the P_i , and we give correlation matrices for the widths in the Particle Listings.
- (2) We try to pick those ratios and widths that are as independent and as close to the original data as possible. When one experiment measures all the branching fractions and constrains their sum to be one, we leave one of them (usually the least well-determined one) out of the fit to make the set of input data more nearly independent. We now do allow for correlations between input data.
- (3) We calculate scale factors for both the R_r and P_i when the measurements for any R give a larger-than-expected contribution to the χ^2 . According to Eq. (3), the double sum for χ^2 is first summed over experiments k=1 to N_k , leaving a single sum over ratios $\chi^2 = \sum \chi_r^2$. One is tempted to define a scale factor for the ratio r as $S_r^2 = \chi_r^2/\langle \chi_r^2 \rangle$. However, since $\langle \chi_r^2 \rangle$ is not a fixed quantity (it is somewhere between N_k and N_{k-1}), we do not know how to evaluate this expression. Instead we define

$$S_r^2 = \frac{1}{N_k} \sum_{k=1}^{N_k} \frac{\left(R_{rk} - \overline{R}_r\right)^2}{\left((R_{rk} - \overline{R}_r)^2\right)}.$$
 (4)

With this definition the expected value of S_r^2 is one. We can show that

$$\langle (R_{rk} - \overline{R}_r)^2 \rangle = \langle (\delta R_{rk})^2 \rangle - (\delta \overline{R}_r)^2 ,$$
 (5)

where $\delta \overline{R}_r$ is the fitted error for ratio r.

The fit is redone using errors for the branching ratios that are scaled by the larger of S_r and unity, from which new and often larger errors $\delta \overline{P}_i'$ are obtained. The scale factors we finally list in such cases are defined by $S_i = \delta \overline{P}_i'/\delta \overline{P}_i$. However, in line with our policy of not letting S affect the central values, we give the values of \overline{P}_i obtained from the original (unscaled) fit.

There is one special case in which the errors that are obtained by the preceding procedure may be changed. When a fitted branching ratio (or rate) \overline{P}_i turns out to be less than three standard deviations $(\delta \overline{P}'_i)$ from zero, a new smaller error $(\delta \overline{P}''_i)^-$ is calculated on the low side by requiring the area under the Gaussian between $\overline{P}_i - (\delta \overline{P}''_i)^-$ and \overline{P}_i to be 68.3% of the area between zero and \overline{P}_i . A similar correction is made for branching fractions that are within three standard deviations of one. This keeps the quoted errors from overlapping the boundary of the physical region.

5.3. Rounding: While the results shown in the Particle Listings are usually exactly those published by the experiments, the numbers that appear in the Summary Tables (means, averages and limits) are subject to a set of rounding rules.

The basic rule states that if the three highest order digits of the error lie between 100 and 354, we round to two significant digits. If they lie between 355 and 949, we round to one significant digit. Finally, if they lie between 950 and 999, we round up to 1000 and keep two significant digits. In all cases, the central value is given with a precision that matches that of the error. So, for example, the result (coming from an average) 0.827 ± 0.119 would appear as 0.83 ± 0.12 , while 0.827 ± 0.367 would turn into 0.8 ± 0.4 .

Rounding is not performed if a result in a Summary Table comes from a single measurement, without any averaging. In that case, the number of digits published in the original paper is kept, unless we feel it inappropriate. Note that, even for a single measurement, when we combine statistical and systematic errors in quadrature, rounding rules apply to the result of the combination. It should be noted also that most of the limits in the Summary Tables come from a single source (the best limit) and, therefore, are not subject to rounding.

Finally, we should point out that in several instances, when a group of results come from a single fit to a set of data, we have chosen to keep two significant digits for all the results. This happens, for instance, for several properties of the W and Z bosons and the τ lepton.

5.4. *Discussion*: The problem of averaging data containing discrepant values is nicely discussed by Taylor in Ref. 4. He considers a number of algorithms that attempt to incorporate inconsistent data into a meaningful average. However, it is difficult to develop a procedure that handles simultaneously in a reasonable way two basic types of situations: (a) data that lie apart from the main body of the data are incorrect (contain unreported errors); and (b) the opposite—it is the main body of data that is incorrect. Unfortunately, as Taylor shows, case (b) is not infrequent. He concludes that the choice of procedure is less significant than the initial choice of data to include or exclude.

We place much emphasis on this choice of data. Often we solicit the help of outside experts (consultants). Sometimes, however, it is simply impossible to determine which of a set of discrepant measurements are correct. Our scale-factor technique is an attempt to address this ignorance by increasing the error. In effect, we are saying that present experiments do not allow a precise determination of this quantity because of unresolvable discrepancies, and one must await further measurements. The reader is warned of this situation by the size of the scale factor, and if he or she desires can go back to the literature (via the Particle

Listings) and redo the average with a different choice of data.

Our situation is less severe than most of the cases Taylor considers, such as estimates of the fundamental constants like \hbar , etc. Most of the errors in his case are dominated by systematic effects. For our data, statistical errors are often at least as large as systematic errors, and statistical errors are usually easier to estimate. A notable exception occurs in partial-wave analyses, where different techniques applied to the same data yield different results. In this case, as stated earlier, we often do not make an average but just quote a range of values.

A brief history of early Particle Data Group averages is given in Ref. 3. Figure 2 shows some histories of our values of a few particle properties. Sometimes large changes occur. These usually reflect the introduction of significant new data or the discarding of older data. Older data are discarded in favor of newer data when it is felt that the newer data have smaller systematic errors, or have more checks on systematic errors, or have made corrections unknown at the time of the older experiments, or simply have much smaller errors. Sometimes, the scale factor becomes large near the time at which a large jump takes place, reflecting the uncertainty introduced by the new and inconsistent data. By and large, however, a full scan of our history plots shows a dull progression toward greater precision at central values quite consistent with the first data points shown.

We conclude that the reliability of the combination of experimental data and our averaging procedures is usually good, but it is important to be aware that fluctuations outside of the quoted errors can and do occur.

ACKNOWLEDGMENTS

The publication of the Review of Particle Physics is supported by the Director, Office of Science, Office of High Energy and Nuclear Physics, the Division of High Energy Physics of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231; by the U.S. National Science Foundation under Agreement No. PHY-0652989; by the European Laboratory for Particle Physics (CERN); by an implementing arrangement between the governments of Japan (Monbusho) and the United States (DOE) on cooperative research and development.

We thank all those who have assisted in the many phases of preparing this *Review*. We particularly thank the many who have responded to our requests for verification of data entered in the Listings, and those who have made suggestions or pointed out errors.

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- 3. A.H. Rosenfeld, Ann. Rev. Nucl. Sci. 25, 555 (1975).
- 4. B.N. Taylor, "Numerical Comparisons of Several Algorithms for Treating Inconsistent Data in a Least-Squares Adjustment of the Fundamental Constants," U.S. National Bureau of Standards NBSIR 81-2426 (1982).

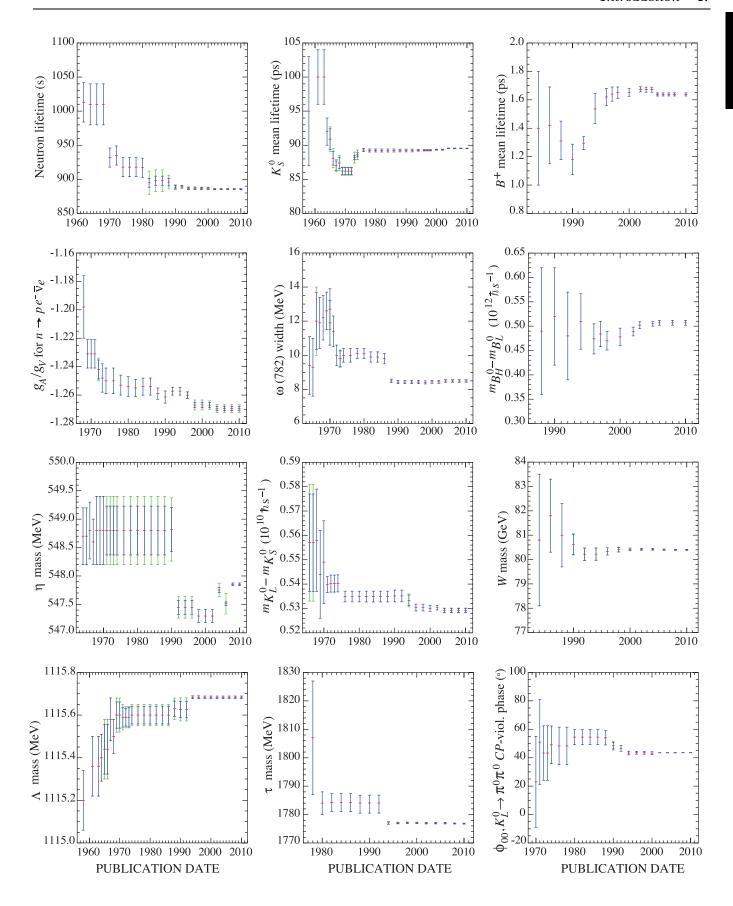


Figure 2: A historical perspective of values of a few particle properties tabulated in this *Review* as a function of date of publication of the *Review*. A full error bar indicates the quoted error; a dark portion indicates the same but without the "scale factor."

ONLINE PARTICLE PHYSICS INFORMATION

Updated Jan. 2012 by T. Basaglia (CERN), A. Holtkamp (CERN). †

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1. Introduction

The collection of online information resources in particle physics and related areas presented in this chapter is of necessity incomplete. An expanded and regularly updated online version can be found at

http://library.web.cern.ch/library/rpp.

Suggestions for additions and updates are very welcome. $\,$

2. Particle Data Group (PDG) resources

• REVIEW OF PARTICLE PHYSICS (RPP): A comprehensive report on the fields of particle physics and cosmology, including both review articles and a compilation/evaluation of data on particle properties. The review section includes articles, tables and plots on a wide variety of theoretical and experimental topics of interest to particle physicists and astrophysicists. The particle properties section provides tables of published measurements as well as the Particle Data Group's best values and limits for particle properties such as masses, widths, lifetimes, and branching fractions, and an extensive summary of searches for hypothetical particles. RPP is published as a 1400-page book every two years, with partial updates made available once each year on the web. All the contents of the 1400-page book version of RPP are available online at:

http://pdg.lbl.gov

 PARTICLE PHYSICS BOOKLET: An abridged version of the Review of Particle Physics available as a pocket-sized 300-page booklet. Although produced in print and available online only as a PDF file, the booklet is included in this guide because it is one of the most useful summaries of physics data. The booklet contains an abbreviated set of reviews and the summary tables from the most recent edition of the Review of Particle Physics.

The PDF file of the booklet can be downloaded:

http://pdg.lbl.gov/current/booklet.pdf.

The printed booklet can be ordered:

http://pdg.lbl.gov/current/html/receive_our_products.html.

PDGLive: A web application for browsing the contents of the PDG database that contains the information published in the Review of Particle Physics. It allows one to navigate to a particle of interest, see a summary of the information available, and then proceed to the detailed information published in the Review of Particle Physics. Data entries are directly linked to the corresponding bibliographic information in INSPIRE. pdgLive can be accessed at:

http://pdglive.lbl.gov

 COMPUTER-READABLE FILES: Data files that can be downloaded from PDG include tables of particle masses and widths, PDG Monte Carlo particle numbers, and cross-section data. The files are updated with each new edition of the Review of Particle Physics and are available at:

http://pdg.lbl.gov/current/html/computer_read.html

Of historical interest is the complete RPP collection which, apart from the very first version from the year 1957, can be found online at

http://tiny.cc/RPP_historical

3. Particle Physics Information Platforms

- SPIRES: This indispensable information tool for high energy physicists worldwide was replaced by INSPIRE in November 2011. SPIRES started as a bibliographic database SPIRES-HEP in 1974 hosted at SLAC in collaboration with DESY and became remotely accessible in the mid 80's. Several databases CONF, EXP, INST, HEPNames and JOBS followed and FermiLab joined the team. In December 1991 SPIRES became the first web server outside Europe, from the start closely related to the arXiv repository. For High Energy Physics SPIRES-HEP was the reference for publications, covering not only journal articles and preprints but also conference proceedings, technical reports, theses and other 'gray' literature, the value of the information enhanced by thorough proof-reading, keywords and links to the sister SPIRES databases and other information services. Content and service are now taken over by INSPIRE.
- INSPIRE: The time-honored SPIRES database suite has now been replaced by INSPIRE which combines the most successful aspects of SPIRES like comprehensive content and high-quality metadata with the modern technology of Invenio, the CERN open-source digital-library software, offering major improvements like increased speed and Google-like free-text search syntax. INSPIRE serves as one-stop information platform for the particle physics community, comprising 6 interlinked databases on literature, conferences, institutions, researchers, experiments, jobs. INSPIRE is jointly developed and maintained by the three laboratories that have been running SPIRES (DESY, Fermilab and SLAC) and CERN. Close interaction with the user community and with arXiv, ADS, HepData, PDG and publishers is the backbone of INSPIRE's evolution.

http://inspirehep.net/ More information on this project at

http://www.projecthepinspire.net/

4. Literature Databases

• ADS: The SAO/NASA Astrophysics Data System is a Digital Library portal for researchers in Astronomy and Physics, operated by the Smithsonian Astrophysical Observatory (SAO) under a NASA grant. The ADS maintains three bibliographic databases containing more than 9.3 million records: Astronomy and Astrophysics, Physics, and arXiv e-prints. The main body of data in the ADS consists of bibliographic records, which are searchable through highly customizable query forms, and full-text scans of much of the astronomical literature which can be browsed or searched via a full-text search interface. Integrated in its databases, the ADS provides access and pointers to a wealth of external resources, including electronic articles, data catalogues and archives. In addition, ADS provides the myADS Update Service, a free custom

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notification service promoting current awareness of the recent literature in astronomy and physics based on each individual subscriber's queries.

http://adswww.harvard.edu/

arXiv.org: A repository of full text papers in physics, mathematics, computer science, statistics, nonlinear sciences, quantitative finance and quantitative biology interlinked with ADS and INSPIRE.
 Papers are usually sent by their authors to arXiv in advance of submission to a journal for publication. Primarily covers 1991 to the present but authors are encouraged to post older papers retroactively. Permits searching by author, title, and words in abstract and experimentally also in the fulltext. Allows limiting by subfield archive or by date.

http://arXiv.org

 CDS: The CERN Document Server contains records of more than 1,000,000 CERN and non-CERN articles, preprints, theses. It includes records for internal and technical notes, official CERN committee documents, and multimedia objects. CDS is going to focus on its role as institutional repository covering all CERN material from the early 50s and reflecting the holdings of the CERN library. Non-CERN particle and accelerator physics content is in the process of being exported to INSPIRE.

http://cdsweb.cern.ch

• INSPIRE HEP: The HEP database serves almost 1 Mio bibliographic records covering particle physics and related topics with a growing number of fulltexts attached and metadata including author affiliations, abstracts, references, keywords as well as links to arXiv, PDG, HepData and publisher platforms. It provides fast metadata and fulltext searches, plots extracted from fulltext, author disambiguation, author profile pages and citation analysis and is expanding its content to e.g. experimental notes.

http://inspirehep.net

• JACoW: The Joint Accelerator Conference Website publishes the proceedings of APAC, EPAC, PAC, ABDW, BIW, COOL, CYCLOTRONS, DIPAC, ECR, FEL, ICALEPCS, ICAP, LINAC, North American PAC, PCaPAC, RuPAC, SRF. A custom interface allows searching on keywords, titles, authors, and in the fulltext.

http://www.JACoW.org/

• KISS (KEK INFORMATION SERVICE SYSTEM) FOR PREPRINTS: The KEK Library preprint and technical report database contains bibliographic records of preprints and technical reports held in the KEK library with links to the full text images of more than 100,000 papers scanned from their worldwide collection of preprints. Particularly useful for older scanned preprints:

http://www-lib.kek.jp/KISS/kiss_prepri.html

• OSTI: The Office of Scientific and Technical Information databases search collections of research results, including those produced throughout the DOE National Laboratory complex and by Departmental grantees. You can find current and legacy research results, search ongoing research and development project descriptions, browse scientific subject portals of interest, access and search scientific e-prints, sign up for alerts, search science conference papers and proceedings. Among the key resources are the Energy Citations Database, providing free access to over 2,450,000 science research citations and 292,000 electronic documents, primarily from 1943 forward, and Information Bridge, covering DOE R&D reports with searchable full-text and bibliographic citations.

http://www.osti.gov/

5. Particle Physics Journals and Conference Proceedings Series

A list of journals and conference series publishing particle physics content can be found at:

http://library.web.cern.ch/library/journals.html For each journal or conference series, information is given on Open Access and copyright policies and terms of use.

6. Conference Databases

• INSPIRE CONFERENCES: The database of more than 18,400 past, present and future conferences, schools, and meetings of interest to high-energy physics and related fields is searchable by title, acronym, series, date, location. Included are information about published proceedings, links to conference contributions in the INSPIRE HEP database, and links to the conference Web site when available. New conferences can be submitted from the entry page.

http://inspirehep.net/Conferences

7. Research Institutions

• INSPIRE INSTITUTIONS: The database of over 9,800 institutes, laboratories, and university departments in which research on particle physics and astrophysics is performed covers six continents and over a hundred countries. Included are address, e-mail address, and Web links where available as well as links to the papers from each institution in the HEP database. Searches can be performed by name, acronym, location, etc. The site offers an alphabetical list by country as well as a list of the top 500 HEP and astrophysics institutions sorted by country.

http://inspirehep.net/Institutions

8. People

• INSPIRE HEPNames: Searchable worldwide database of over 97,000 people associated with particle physics and related fields. The affiliation history of these researchers, their e-mail addresses, web pages, experiments they participated in, PhD advisor, information on their graduate students and links to their papers in the INSPIRE HEP, arXiv and ADS databases are provided as well as a user interface to update these information.

http://inspirehep.net/HepNames

9. Experiments

• SPIRES/INSPIRE EXPERIMENTS: Contains more than 2,400 past, present, and future experiments in particle physics. Lists both accelerator and non-accelerator experiments. Includes official experiment name and number, location, and collaboration lists. Simple searches by participant, title, experiment number, institution, date approved, accelerator, or detector, return a description of the experiment, including a complete list of authors, title, overview of the experiment's goals and methods, and a link to the experiment's Web page if available. Publication lists distinguish articles in refereed journals, theses, technical or instrumentation papers and those which rank among Topcite at 50 or more citations.

http://www.slac.stanford.edu/spires/experiments/soon to be replaced by

http://inspirehep.net/Experiments

• COSMIC RAY/GAMMA RAY/NEUTRINO AND SIMILAR EXPERIMENTS: This extensive collection of experimental Web sites is organized by focus of study and also by location. Additional sections link to educational materials, organizations, related Web sites, etc. The site is maintained at the Max Planck Institute for Nuclear Physics, Heidelberg:

 $\verb|http://www.mpi-hd.mpg.de/hfm/CosmicRay/CosmicRaySites.html|\\$

10. Jobs

 APS Careers: gateway for physicists, students, and physics enthusiasts to information about physics jobs and careers. Physics job listings, career advice, upcoming workshops and meetings, and career and job related resources provided by the American Physical Society:

http://www.aps.org/jobs/

BRIGHTRECRUITS.COM: A recruitment service run by IOP
 Publishing that connects employers from different industry sectors
 with jobseekers who have a background in physics and engineering

http://brightrecruits.com/

 IOP CAREERS: careers information and resources primarily aimed at university students provided by the UK Institute of Physics:

http://www.iop.org/careers/

 INSPIRE HEPJobs: lists academic and research jobs in high energy physics, nuclear physics, accelerator physics and astrophysics with the option to post a job or to receive email notices of new job listings. About 1300 jobs are currently listed.

http://inspirehep.net/Jobs

 PHYSICSTODAY JOBS: online recruitment advertising website forPhysics Todaymagazine, published by the American Institute of Physics. Physics TodayJobs is the managing partner of the AIP Career Network, an online job board network for the physical science, engineering, and computing disciplines. Over 8,500 resumes are currently available, and almost 3,000 jobs were posted in 2011.

http://www.physicstoday.org/jobs

11. Software Repositories

Particle Physics

 BSM Generators: a repository of codes relevant to Beyond-the-Standard-Model (BSM) physics

http://www.ippp.dur.ac.uk/montecarlo/BSM

 CERNLIB: The CERN PROGRAM LIBRARY contains a large collection of general purpose libraries and modules offered in both source code and object code forms. It provides programs applicable to a wide range of physics research problems such as general mathematics, data analysis, detectors simulation, data-handling, etc. It also includes links to commercial, free, and other software. Development of this site has been discontinued.

http://wwwasd.web.cern.ch/wwwasd/index.html

 FERMITOOLS: Fermilab's software tools program provides a repository of Fermilab-developed software packages of value to the HEP community. Permits searching for packages by title or subject category:

http://www.fnal.gov/fermitools/

FREEHEP: A collection of software and information about software
useful in high-energy physics and adjacent disciplines, focusing on
open-source software for data analysis and visualization. Searching
can be done by title, subject, date acquired, date updated, or by
browsing an alphabetical list of all packages. The site does not seem
to be updated any longer but still provides useful information.

http://www.freehep.org/

 GEANT4: Toolkit for the simulation of the passage of particles through matter, maintained by a world-wide collaboration of scientists and software engineers. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science.

http://geant4.cern.ch/

 GENSER: The Generator Services project collaborates with Monte Carlo (MC) generators authors and with LHC experiments in order to prepare validated LCG compliant code for both the theoretical and experimental communities at the LHC, sharing the user support duties, providing assistance for the development of the new object-oriented generators and guaranteeing the maintenance of the older packages on the LCG supported platforms. The project consists of the generators repository, validation, HepMC record and MCDB event databases.

http://sftweb.cern.ch/generators/

 HEPFORGE: A development environment for high-energy physics software development projects, in particular housing many eventgenerator related projects, that offers a ready-made, easy-to-use set of Web based tools, including shell account with up to date development tools, web page hosting, subversion and CVS code management systems, mailing lists, bug tracker and wiki system.

http://www.hepforge.org/

 PYTHIA: A program for the generation of high-energy physics events, i.e. for the description of collisions at high energies between elementary particles such as e+, e-, p and p-bar in various combinations. It contains theory and models for a number of physics aspects, including hard and soft interactions, parton distributions, initial- and final-state parton showers, multiple interactions, fragmentation and decay.

http://home.thep.lu.se/torbjorn/Pythia.html

 QUDA: library for performing calculations in lattice QCD on GPUs using NVIDIA's "C for CUDA" API. The current release includes optimized solvers for Wilson, Clover-improved Wilson. Twisted mass, Improved staggered (asqtad or HISQ) and Domain wall fermion actions

http://lattice.github.com/quda/

 ROOT: This framework for data processing in high-energy physics, born at CERN, offers applications to store, access, process, analyze and represent data or perform simulations.

http://root.cern.ch/drupal

 tmLQCD: This freely available software suite provides a set of tools to be used in lattice QCD simulations, mainly a (P)HMC implementation for Wilson and Wilson twisted mass fermions and inverter for different versions of the Dirac operator.

https://github.com/etmc/tmLQCD

• USQCD: The software suite enables lattice QCD computations to be performed with high performance across a variety of architectures. The page contains links to the project web pages of the individual software modules, as well as to complete lattice QCD application packages which use them.

http://usqcd.jlab.org/usqcd-software/

A list of Monte Carlo generators may be found at

http://cmsdoc.cern.ch/cms/PRS/gentools/www/geners/collection/

collection.html

The homepage of the SUSY Les Houches Accord contains links to codes relevant for supersymmetry calculations and phenomenology

http://home.fnal.gov/skands/slha/

A variety of codes and algorithmic tools for analysing supersymmetric phenomenology is described in ${\tt arXiv:0805.2088}$

http://arxiv.org/abs/0805.2088

Astrophysics

• IRAF: The Image Reduction and Analysis Facility is a general purpose software system for the reduction and analysis of astronomical data. IRAF is written and supported by the IRAF programming group at the National Optical Astronomy Observatories (NOAO) in Tucson, Arizona.

http://iraf.noao.edu/

• STARLINK: Starlink was a UK Project supporting astronomical data processing. It was shut down in 2005 but its open-source software continues to be developed at the Joint Astronomy Centre. The software products are a collection of applications and libraries, usually focused on a specific aspect of data reduction or analysis.

http://starlink.jach.hawaii.edu/starlink

Links to a large number of astronomy software archives are listed at http://heasarc.nasa.gov/docs/heasarc/astro-update/

12. Data repositories

Particle Physics

• HEPDATA: The HepData Project, funded by the STFC(UK) and based at the IPPP at Durham University, has for more than 30 years compiled a Reaction Data database, comprising total and differential cross sections, structure functions, fragmentation functions, distributions of jet measures, polarisations, etc from a wide range of particle physics scattering experiments worldwide. It is regularly updated to cover the latest data including those from the LHC. In addition, it provides a series of on-line data reviews on a wide variety of topics with links to the data in the Reaction Database. It also hosts a Parton Distribution Function server with an on-line PDF calculator and plotter.

http://durpdg.dur.ac.uk/

• ILDG: The International Lattice Data Grid is an international organization which provides standards, services, methods and tools that facilitates the sharing and interchange of lattice QCD gauge configurations among scientific collaborations, by uniting their regional data grids. It offers semantic access with local tools to worldwide distributed data. See e.g.

http://www.usqcd.org/ildg/

 MCPLOTS: mcplots is a repository of Monte Carlo plots comparing High Energy Physics event generators to a wide variety of available experimental data. The site is supported by the LHC Physics Centre at CERN.

http://mcplots.cern.ch/

Astrophysics

 SIMBAD: archives data in the form of object catalogues from many heterogeneous sources

http://simbad.u-strasbg.fr/simbad/

• NED: NASA/IPAC extragalactic database, operated by the Jet Propulsion Laboratory, California Institute of Technology

http://ned.ipac.caltech.edu/

 The NASA archives provide access to raw and processed datasets from numerous NASA missions.

Hubble telescope, other missions (UV, optical):

http://archive.stsci.edu/

Spitzer telescope, other missions (Infrared):

http://irsa.ipac.caltech.edu/

Chandra, Fermi telescopes, other missions:

http://heasarc.gsfc.nasa.gov/

 The Virtual Observatory provides a suite of resources to query for original data from a large number of archives. Two main tools are provided. One runs queries across multiple databases (such as the SDSS database) and combines the results. The other queries hundreds of archives for all datasets that fall on a particular piece of sky.

http://www.us-vo.org/

General Physics

NIST PHYSICAL MEASUREMENT LABORATORY: The National Institute of Standards and Technology provides access to physical reference data (physical constants, atomic spectroscopy data, x-ray and gamma-ray data, radiation dosimetry data, nuclear physics data and more) and measurements and calibrations data (dimensional measurements, electromagnetic measurements). The site points to a general interest page, linking to exhibits of the Physical Measurement Laboratory in the NIST Virtual Museum.

http://physics.nist.gov/

• SPRINGER MATERIALS - THE LANDOLT-BÖRNSTEIN DATABASE: Landolt-Börnstein is a high-quality data collection in all areas of physical sciences and engineering, among others particle physics, electronic structure and transport, magnetism, superconductivity. International experts scan the primary literature in more than 8,000 peer-reviewed journals and evaluate and select the most valid information to be included in the database. It includes more than 100,000 online documents, 1,2 million references, and covers 250,000 chemical substances. The search functionality is freely accessible and the search results are displayed in their context, whereas the full text is secured to subscribers:

http://www.springermaterials.com/

13. Data preservation

Particle Physics

• DPHEP: The efforts to define and coordinate Data Preservation and Long Term Analysis in HEP are coordinated by a study group formed to investigate the issues associated with these activities. The group, DPHEP, was initiated during 2008-2009 and includes all HEP major experiments and laboratories. It is endorsed by the International Committee for Future Accelerators (ICFA). Details of the organizational structure, the objectives, workshops and publications can be found at

http://dphep.org

The experiments at colliders: BaBar, Belle, BES-III, Cleo, CDF, D0, H1 and ZEUS and the associated computing centres at SLAC (USA), KEK (Japan), IHEP (China), Jlab (USA), BNL (USA), Fermilab (USA), DESY (Germany), and CERN are all represented in the group. The LHC collaborations have also joined the initiative in 2011. The participating experiments are in various stages of studying, preparing, or operating long-term data preservation and analysis systems. Technological methods, such as virtualization, and information management tools such as INSPIRE are also helpful in this area of research. Data access policies and outreach in HEP using real data are among the investigative areas of the DPHEP Study Group.

Astrophysics

More formal and advanced data preservation activity is ongoing in the field of Experimental Astrophysics, including

• SDSS

http://sdss.org

• Fermi

http://fermi.gsfc.nasa.gov/ssc/data

• IVOA

http://www.ivoa.net/

14. Particle Physics Education and Outreach Sites

Science Educators' Networks:

• IPPOG: The International Particle Physics Outreach Group is a network of particle physicists, researchers, informal science educators and science explainers aiming to raise awareness, understanding and standards of global outreach efforts in particle physics and general science by providing discussion forums and regular information exchange for science institutions, proposing and implementing strategies to share lessons learned and best practices and promoting current outreach efforts of network members:

http://ippog.web.cern.ch/ippog/

• Interactions.org: designed to serve as a central resource for communicators of particle physics. The daily updated site provides links to current particle physics news from the world's press, high-resolution photos and graphics from the particle physics laboratories of the world; links to education and outreach programs; information about science policy and funding; links to universities; a glossary; a conference calendar; and links to many educational sites

http://www.interactions.org

Physics Courses

 MIT OPENCOURSEWARE - PHYSICS: These MIT course materials reflect almost all the undergraduate and graduate subjects taught at MIT. In addition to physics courses, supplementary educational resources are also available.

http://ocw.mit.edu/courses/physics/

Master Classes

• INTERNATIONAL MASTERCLASSES: Each year about 6000 high school students in 28 countries come to one of about 130 nearby universities or research centres for one day in order to unravel the mysteries of particle physics. Lectures from active scientists give insight in topics and methods of basic research at the fundaments of matter and forces, enabling the students to perform measurements on real data from particle physics experiments themselves. At the end of each day, like in an international research collaboration, the participants join in a video conference for discussion and combination of their results.

http://physicsmasterclasses.org/

General Sites

• CONTEMPORARY PHYSICS EDUCATION PROJECT (CPEP): Provides charts, brochures, Web links, and classroom activities. Online interactive courses include: Fundamental Particles and Interactions; Plasma Physics and Fusion; History and Fate of the Universe; and Nuclear Science.

http://www.cpepweb.org/

 PHYSICSCENTRAL: This site maintained by the American Physical Society provides information about current research and people in physics, experiments that can be performed at home or at school and the possibility to get physics questions answered by physicists.

http://www.physicscentral.com

General Physics Lessons & Activities

 HYPERPHYSICS: An exploration environment for concepts in physics employing concept maps and other linking strategies and providing opportunities for numerical exploration.

http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html

PHYSICS2000: An interactive journey through modern physics.
 Have fun learning visually and conceptually about 20th century science and high-tech devices. Supported by the Colorado Commission on Higher Education and the National Science Foundation

http://www.colorado.edu/physics/2000

Particle Physics Lessons & Activities

 Angels and Demons: With the aim of looking at the myth versus the reality of science at CERN this site offers teacher resources, slide shows and videos of talks given to teachers visiting CERN

http://angelsanddemons.web.cern.ch/

 ANTIMATTER: MIRROR OF THE UNIVERSE: Find out what antimatter is, where it is made, the history behind its discovery, and how it is a part of our lives. Features colorful photos, illustrations, webcasts, a Kids Corner, and CERN physicists answering your questions on antimatter:

http://livefromcern.web.cern.ch/livefromcern/antimatter/

 BIG BANG: An exhibition of the UK Science Museum with an interactive game about the hunt for the Higgs

http://www.sciencemuseum.org.uk/antenna/bigbang/

• BIG BANG SCIENCE: EXPLORING THE ORIGINS OF MATTER: This Web site, produced by the Particle Physics and Astronomy Research Council of the UK (PPARC), explains what physicists are looking for with their giant instruments. Big Bang Science focuses on CERN particle detectors and on United Kingdom scientists' contribution to the search for the fundamental building blocks of matter.

http://hepwww.rl.ac.uk/pub/bigbang/part1.html

 CERNland: With a range of games, multimedia applications and films CERNland is the virtual theme park developed to bring the excitement of CERN's research to a young audience aged between 7 and 12. CERNland is designed to show children what is being done at CERN and inspire them with some physics at the same time.

http://www.cernland.net/

 Colliding particles: a series of films following a team of physicists involved in research at the LHC

http://www.collidingparticles.com/

 Lancaster Particle Physics: This site, suitable for 16+ students, offers a number of simulations and explanations of particle physics, including a section on the LHC.

http://www.lppp.lancs.ac.uk/

 PARTICLE ADVENTURE: One of the most popular Web sites for learning the fundamentals of matter and force. An award-winning interactive tour of quarks, neutrinos, antimatter, extra dimensions, dark matter, accelerators and particle detectors from the Particle Data Group of Lawrence Berkeley National Laboratory. Simple elegant graphics and translations into 15 languages:

http://ParticleAdventure.org

 PARTICLE DETECTIVES: This website, maintained by the Science and Technology Facilities Council (STFC), is for inquisitive 14-19 year olds, their teachers and for researchers who want to find out and talk about the world's biggest scientific adventure, the Large Hadron Collider, featuring e.g. An LHC experiment simulator.

http://www.lhc.ac.uk/The+Particle+Detectives/15273.aspx

 Quarked! - Adventures in the Subatomic Universe: This project, targeted to kids aged 7-12 (and their families), brings subatomic physics to life through a multimedia project including an interactive website, a facilitated program for museums and schools, and an educational outreach program

http://www.quarked.org/

• QUARKNET: QuarkNet brings the excitement of particle physics research to high school teachers and their students. Teachers join research groups at about 50 universities and labs across the country. These research groups are part of particle physics experiments at CERN or Fermilab. About 100,000 students from 500+ US high schools learn fundamental physics as they participate in inquiry-oriented investigations and analyze real data online. QuarkNet is supported in part by the National Science Foundation and the U.S. Department of Energy:

http://QuarkNet.fnal.gov

 Rewarding Learning videos about CERN: The three videos based on interviews with scientists and engineers at CERN introduce pupils to CERN and the type of research and work undertaken there and are accompanied by teachers' notes.

http://www.rewardinglearning.org.uk/STEM/cern/

Lab Education Offices

Brookhaven National Laboratory (BNL) Educational Programs:
 The Office of Educational Programs mission is to design, develop, implement, and facilitate workforce development and education initiatives that support the scientific mission at Brookhaven National Laboratory and the Department of Energy.

http://www.bnl.gov/education/

• CERN: The CERN education website offers information about teacher programmes and educational resources for schools

http://education.web.cern.ch/education/

 DESY: offers courses for pupils and teachers as well as information for the general public, mostly in German.

http://www.desy.de/information_services/education/

• FERMILAB EDUCATION OFFICE: provides education resources and information about activities for educators, physicists, students

and visitors to the Lab. In addition to information on 25 programs, the site provides online data-based investigations for high school students, online versions of exhibits in the Lederman Science Center, links to particle physics discovery resources, web-based instructional resources, what works for education and outreach, and links to the Lederman Science Center and the Teacher Resource Center.

http://ed.fnal.gov/

 LBL: Berkeley Lab's Center for Science & Engineering Education (CSEE) carries out the Department of Energy's education mission to train the next generation of scientists, as well as helping them to gain an understanding of the relationships among frontier science, technology, and society.

http://www.lbl.gov/Education/

 EXPLORING SLAC SCIENCE: This Stanford Linear Accelerator Center Web site explains physics concepts related to experiments conducted at SLAC.

http://www6.slac.stanford.edu/ExploringSLACScience.aspx

 Symmetry: This magazine about particle physics and its connections to other aspects of life and science, from interdisciplinary collaborations to policy to culture is published 6 times per year by Fermilab and SLAC.

http://www.symmetrymagazine.org

Educational Programs of Experiments

 ATLAS DISCOVERY QUEST: One of several access points to ATLAS education and outreach pages. This page gives access to explanations of physical concepts, blogs, ATLAS facts, news, and information for students and teachers.

http://www.atlas.ch/physics.html

 ATLAS eTours: give a description of the Large Hadron Collider, explain how the ATLAS detector at the LHC works and give an overview over the experiments and their physics goals.

http://www.atlas.ch/etours.html

CMS EDUCATION: Provides access to educational resources (Story
of the Universe, The Size of Things, What is a Particle), and to
multimedia material, such as interviews, movies and photos.

http://cms.web.cern.ch/content/cms-education

• EDUCATION AND OUTREACH @ ICECUBE: Educational pages of the IceCube (South Pole Neutrino Detector)

http://icecube.wisc.edu/outreach

• LIGO SCIENCE EDUCATION CENTER: The LIGO (Laser Interferometer Gravitational-wave Observatory) Science Education Center has over 40 interactive, hands-on exhibits that relate to the science of LIGO. The site hosts field trips for students, teacher training programs, and tours for the general public. Visitors can explore science concepts such as light, gravity, waves, and interference; learn about LIGO's search for gravitational waves; and interact with scientists and engineers.

 $\verb|http://www.ligo-la.caltech.edu/SEC.html||$

PIERRE AUGER OBSERVATORY'S EDUCATIONAL PAGES:
 The site offers information about cosmic rays and their detection,
 and provides material for students and teachers.

http://www.auger.org/cosmic_rays/

Art in Physics

 Arts@CERN: a 3-year artist's residency programme in Digital Arts and Dance/Performance

http://arts.web.cern.ch/collide/

 Art of Physics Competition: The Canadian Association of Physicists organizes this competition, the first was launched in 1992, with the aim of stimulating interest, especially among non-scientists, in some of the captivating imagery associated with physics. The challenge is to capture photographically a beautiful or unusual physics phenomenon and explain it in less than 200 words in terms that everyone can understand.

http://www.cap.ca/aop/art.html

 Photowalk: More than 200 amateur photographers from around the world had the opportunity to experience state-of-the-art accelerators and detectors. Five of the world's leading particle physics laboratories in Asia, Europe and North America offered special behind-the-scenes access to their scientific facilities. The winning photos can be viewed.

http://www.interactions.org/cms/?pid=1029664

Blogs

This is a very incomplete collection of particle physics related blogs:

• ATLAS blog

http://www.atlas.ch/blog

 U.S. LHC blog: The blog give a vivid account of the daily activity of US LHC researchers.

http://www.quantumdiaries.org/lab-81/

 Physics arXiv blog: Technology Review blog on new ideas at arXiv.org

http://www.technologyreview.com/blog/arxiv/

• CERN Love:

http://www.cernlove.org/blog/

 Not Even Wrong: Peter Woit's blog on topics in physics and mathematics

http://www.math.columbia.edu/woit/wordpress/

 Quantum diaries: Thoughts on work and life from particle physicists from around the world.

http://www.quantumdiaries.org/

 Science blogs: Launched in January 2006, ScienceBlogs features bloggers from a wide array of scientific disciplines, including physics:

http://scienceblogs.com/channel/physical-science/

 Life and Physics: Jon Butterworth's blog in the Guardian http://www.guardian.co.uk/science/life-and-physics

SUMMARY TABLES OF PARTICLE PHYSICS

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 $^{^{*}}$ There are also search limits in the Summary Tables for the Gauge and Higgs Bosons, the Leptons, the Quarks, and the Mesons.



SUMMARY TABLES OF PARTICLE PROPERTIES

Extracted from the Particle Listings of the Review of Particle Physics

J. Beringer et al.(PDG), PR D86, 010001 (2012)

Available at http://pdg.lbl.gov

Particle Data Group

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Technical Associates:

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GAUGE AND HIGGS BOSONS



$$I(J^{PC}) = 0.1(1^{-})$$

Mass $m < 1 \times 10^{-18}$ eV Charge $q < 1 \times 10^{-35}$ e Mean life $\tau =$ Stable



$$I(J^P) = 0(1^-)$$

Mass m = 0 [a] SU(3) color octet

graviton

$$J = 2$$

Mass $m < 7 \times 10^{-32}$ eV

W

J = 1

Charge =
$$\pm 1~e$$
 Mass $m = 80.385 \pm 0.015~{\rm GeV}$ $m_Z - m_W = 10.4 \pm 1.6~{\rm GeV}$ $m_{W^+} - m_{W^-} = -0.2 \pm 0.6~{\rm GeV}$ Full width $\Gamma = 2.085 \pm 0.042~{\rm GeV}$ $\langle N_{\pi^\pm} \rangle = 15.70 \pm 0.35$ $\langle N_{K^\pm} \rangle = 2.20 \pm 0.19$ $\langle N_p \rangle = 0.92 \pm 0.14$ $\langle N_{\rm charged} \rangle = 19.39 \pm 0.08$

 W^- modes are charge conjugates of the modes below.

| W+ DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (Me <i>V/c</i>) |
|----------------|--------------------------------------------------|-----------------------|-------------------------------|
| $\ell^+ \nu$ | [b] (10.80± 0.09) % | 6 | _ |
| $e^+ u$ | (10.75 ± 0.13) % | 6 | 40192 |
| $\mu^+ \nu$ | (10.57± 0.15) % | 6 | 40192 |
| $	au^+ u$ | (11.25 ± 0.20) % | 6 | 40173 |
| hadrons | (67.60± 0.27) % | 6 | _ |
| $\pi^+ \gamma$ | < 8 > | (10 ⁻⁵ 95% | 40192 |
| $D_s^+ \gamma$ | < 1.3 | <10 ^{−3} 95% | 40168 |
| сX | (33.4 ± 2.6) % | 6 | - |
| c <u>s</u> | $(31 \begin{array}{cc} +13 \\ -11 \end{array})$ | % | - |
| invisible | [c] (1.4 \pm 2.9) % | 6 | - |

Ζ

J = 1

Charge = 0 Mass
$$m = 91.1876 \pm 0.0021$$
 GeV $[d]$ Full width $\Gamma = 2.4952 \pm 0.0023$ GeV $\Gamma(\ell^+\ell^-) = 83.984 \pm 0.086$ MeV $[b]$ $\Gamma(\text{invisible}) = 499.0 \pm 1.5$ MeV $[e]$ $\Gamma(\text{hadrons}) = 1744.4 \pm 2.0$ MeV $\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-) = 1.0009 \pm 0.0028$ $\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-) = 1.0019 \pm 0.0032$ $[f]$

Average charged multiplicity

$$\langle N_{charged} \rangle = 20.76 \pm 0.16 \quad (S = 2.1)$$

Couplings to leptons

$$\begin{split} g_V^\ell &= -0.03783 \pm 0.00041 \\ g_V^u &= 0.25^{+}0.07 \\ -0.06 \\ g_V^d &= -0.33^{+}0.05 \\ g_A^\ell &= -0.50123 \pm 0.00026 \\ g_A^u &= 0.50^{+}0.04 \\ g_A^u &= 0.50^{+}0.04 \\ g_A^d &= -0.523^{+}0.050 \\ g_C^d &= -0.5038 \pm 0.0008 \\ g_V^{\nu_\ell} &= 0.503 \pm 0.09 \end{split}$$

$g^{ u\mu}=0.502\pm0.017$ Asymmetry parameters $^{[g]}$

 $A_e = 0.1515 \pm 0.0019$ $A_\mu = 0.142 \pm 0.015$ $A_\tau = 0.143 \pm 0.004$ $A_s = 0.90 \pm 0.09$ $A_c = 0.670 \pm 0.027$ $A_b = 0.923 \pm 0.020$

Charge asymmetry (%) at Z pole

 $A_{FB}^{(0e)} = 1.71 \pm 0.10$ $A_{FB}^{(0u)} = 4 \pm 7$ $A_{FB}^{(0s)} = 9.8 \pm 1.1$ $A_{FB}^{(0c)} = 7.07 \pm 0.35$ $A_{FB}^{(0b)} = 9.92 \pm 0.16$

Gauge & Higgs Boson Summary Table

| Z DECAY MODES | $\begin{array}{ccc} & & \text{Scale factor/} \\ & & \text{Fraction } (\Gamma_i/\Gamma) & & \text{Confidence level} \end{array}$ | <i>p</i> (MeV/ <i>c</i>) |
|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------|
| e+e- | (3.363 ±0.004) % | 45594 |
| $\mu^+_{\cdot}\mu^{\cdot}$ | (3.366 ± 0.007) % | 45594 |
| $\tau^+ \tau^-$ | (3.370 ± 0.008) % | 45559 |
| $\ell^+\ell^-$ | [b] (3.3658±0.0023) % | - |
| invisible | $(20.00 \pm 0.06) \%$ | - |
| hadrons | $(69.91 \pm 0.06) \%$ | _ |
| $(u\overline{u} + c\overline{c})/2$ | (11.6 ± 0.6) % | _ |
| $\left(\frac{d\overline{d} + s\overline{s} + b\overline{b}}{\right)/3$ | $(15.6 \pm 0.4) \%$ | _ |
| с с b <u>Б</u> | $(12.03 \pm 0.21)\%$ $(15.12 \pm 0.05)\%$ | _ |
| b b b b | $(15.12 \pm 0.05) \%$ $(3.6 \pm 1.3) \times 10^{-4}$ | _ |
| | (3.6 ±1.3)×10 < 1.1 % CL=95% | _ |
| $\pi^0 \gamma$ | $< 5.2 	 \times 10^{-5} 	 CL = 95\%$ | 45594 |
| $\eta \gamma$ | $< 5.1 	 \times 10^{-5} 	 CL = 95\%$ | 45592 |
| $\omega\gamma$ | $< 6.5 	 \times 10^{-4} 	 CL = 95\%$ | 45590 |
| $\eta'(958)\gamma$ | $< 4.2 \times 10^{-5} \text{ CL} = 95\%$ | 45589 |
| $\gamma \gamma$ | $< 5.2 \times 10^{-5} \text{ CL} = 95\%$ | 45594 |
| $\gamma\gamma\gamma$ | $< 1.0 \times 10^{-5} CL = 95\%$ | 45594 |
| $\pi^{\pm}W^{\mp}$ | $[h] < 7$ $\times 10^{-5}$ CL=95% | 10162 |
| $ ho^{\pm}W^{\mp}$ | $[h] < 8.3 	 \times 10^{-5} 	 CL = 95\%$ | 10136 |
| $J/\psi(1S)$ X | $(3.51 {}^{+0.23}_{-0.25}) \times 10^{-3} \qquad S=1.1$ | - |
| $\psi(2S)X$ | $(1.60 \pm 0.29) \times 10^{-3}$ | _ |
| $\chi_{c1}(1P)X$ | $(2.9 \pm 0.7) \times 10^{-3}$ | - |
| $\chi_{c2}(1P)X$ | $< 3.2 \times 10^{-3} \text{ CL} = 90\%$ | _ |
| $\Upsilon(1S) \times + \Upsilon(2S) \times + \Upsilon(3S) \times $ | $(1.0 \pm 0.5) \times 10^{-4}$ | _ |
| $\Upsilon(1S)X$ | $< 4.4 \times 10^{-5} \text{ CL} = 95\%$ | _ |
| $\Upsilon(2S)X$ | $< 1.39 \times 10^{-4} \text{ CL} = 95\%$ | _ |
| $\Upsilon(3S) \times (-2)^{1/2}$ | $< 9.4 \times 10^{-5} \text{ CL} = 95\%$ | - |
| (D^0/\overline{D}^0) X | $(20.7 \pm 2.0) \%$ | _ |
| D*X | (12.2 ±1.7) % | _ |
| $D^*(2010)^{\pm}X$ | [h] $(11.4 \pm 1.3)\%$ | _ |
| $D_{s1}(2536)^{\pm}X$ $D_{sJ}(2573)^{\pm}X$ | $(3.6 \pm 0.8) \times 10^{-3}$ $(5.8 \pm 2.2) \times 10^{-3}$ | _ |
| $D_{sJ}(2673)^{\pm}X$ $D^{*'}(2629)^{\pm}X$ | | _ |
| B+ X | searched for [i] (6.08 ± 0.13) $\%$ | _ |
| $B_s^0 X$ | [i] (0.08 ± 0.13) % | _ |
| D± 1/ | searched for | _ |
| $B_c^{\dagger} X$ $\Lambda_c^{\dagger} X$ | (1.54 ± 0.33) % | |
| $\Xi_0^0 X$ | , , | |
| С | seen | _ |
| $\Xi_b X$ | seen | _ |
| b -baryon X anomalous $\gamma+$ hadrons | [i] (1.38 ± 0.22) % [j] < 3.2 $\times 10^{-3}$ CL=95% | _ |
| $e^+e^-\gamma$ | $[j] < 5.2$ $\times 10^{-4}$ CL=95% $\times 10^{-4}$ CL=95% | 45594 |
| $\mu^+\mu^-\gamma$ | [j] < 5.2 × 10 CL=95% [j] < 5.6 × 10 ⁻⁴ CL=95% | 45594 |
| $\tau^+ \tau^- \gamma$ | $ j < 7.3$ $\times 10^{-4}$ CL=95% | 45559 |
| $\ell^+\ell^-\gamma\gamma$ | $[k] < 6.8 	 \times 10^{-6} \text{ CL} = 95\%$ | _ |
| $q \overline{q} \gamma \gamma$ | $[k] < 5.5$ $\times 10^{-6}$ CL=95% | - |
| $\nu \overline{\nu} \gamma \gamma$ | $[k] < 3.1 	 \times 10^{-6} 	 CL = 95\%$ | 45594 |
| | LF [h] < 1.7 $\times 10^{-6}$ CL=95% | 45594 |
| $e^{\pm} 	au^{\mp}$ | LF $[h] < 9.8 	 \times 10^{-6} \text{ CL} = 95\%$ | 45576 |
| , | LF $[h] < 1.2 	 \times 10^{-5} CL = 95\%$ | 45576 |
| • | $1.B$ < 1.8 $\times 10^{-6}$ CL=95% | 45589 |
| $\rho\mu$ | L,B < 1.8 $\times 10^{-6}$ CL=95% | 45589 |

Higgs Bosons — H^0 and H^{\pm} , Searches for

The July 2012 news about Higgs searches is described in the addendum to the Higgs review in the data listings, but is not reflected here.

The limits for H_1^0 and A^0 refer to the m_h^{\max} benchmark scenario for the supersymmetric parameters.

 \emph{H}^{0} Mass m>115.5 and none 127–600 GeV, CL =95%

H_1^0 in Supersymmetric Models $(m_{H_1^0} < m_{H_2^0})$

Mass m > 92.8 GeV, CL = 95%

A⁰ Pseudoscalar Higgs Boson in Supersymmetric Models [/]

Mass m > 93.4 GeV, CL = 95% $tan \beta > 0.4$

 H^{\pm} Mass m > 79.3 GeV. CL = 95%

See the Particle Listings for a Note giving details of Higgs Bosons.

Heavy Bosons Other Than Higgs Bosons, Searches for

Additional W Bosons

W' with standard couplings Mass $m > 2.150 \times 10^3$ GeV, CL = 95%

Additional Z Bosons

```
Z'_{SM} with standard couplings
  Mass m > 1.830 \times 10^3 \text{ GeV}, CL = 95%
                                                        (p\overline{p} \text{ direct search})
  Mass m > 1.500 \times 10^3 \text{ GeV}, CL = 95%
Z_{LR} of SU(2)_L \times SU(2)_R \times U(1) (with g_L = g_R)
  Mass m > 630 GeV, CL = 95\% (p\overline{p} \text{ direct search})
  Mass m > 1162 GeV, CL = 95\% (electroweak fit)
Z_{\chi} of SO(10) \rightarrow SU(5)\timesU(1)_{\chi} (with g_{\chi} = e/\cos\theta_W)
  Mass m > 1.640 \times 10^3 \text{ GeV}, CL = 95%
                                                        (p\overline{p} \text{ direct search})
  Mass m > 1.141 \times 10^3 \text{ GeV}, CL = 95%
                                                        (electroweak fit)
Z_{\psi} of E_6 \rightarrow SO(10) \times U(1)_{\psi} (with g_{\psi} = e/\cos\theta_W)
  Mass m > 1.490 \times 10^3 GeV, CL = 95\% (p\overline{p} direct search)
  Mass m > 476 GeV, CL = 95\% (electroweak fit)
Z_n of E_6 \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_n (with g_n = e/\cos\theta_W)
  Mass m > 1.540 \times 10^3 GeV, CL = 95\% (p\overline{p} direct search)
  Mass m > 619 GeV, CL = 95\% (electroweak fit)
```

Scalar Leptoquarks

```
Mass m>660 GeV, CL = 95% (1st generation, pair prod.)
Mass m>298 GeV, CL = 95% (1st gener., single prod.)
Mass m>422 GeV, CL = 95% (2nd gener., pair prod.)
Mass m>73 GeV, CL = 95% (2nd gener., single prod.)
Mass m>247 GeV, CL = 95% (3rd gener., pair prod.)
(See the Particle Listings for assumptions on leptoquark quantum numbers and branching fractions.)
```

Axions (A⁰) and Other Very Light Bosons, Searches for

The standard Peccei-Quinn axion is ruled out. Variants with reduced couplings or much smaller masses are constrained by various data. The Particle Listings in the full *Review* contain a Note discussing axion searches.

The best limit for the half-life of neutrinoless double beta decay with Majoron emission is $>7.2\times10^{24}$ years (CL = 90%).

Gauge & Higgs Boson Summary Table

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity. We do this when S > 1, which often indicates that the measurements are inconsistent. When S > 1.25, we also show in the Particle Listings an ideogram of the measurements. For more about S, see the Introduction.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

- [a] Theoretical value. A mass as large as a few MeV may not be precluded.
- [b] ℓ indicates each type of lepton $(e, \mu, \text{ and } \tau)$, not sum over them.
- [c] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p< 200 MeV.

- [d] The Z-boson mass listed here corresponds to a Breit-Wigner resonance parameter. It lies approximately 34 MeV above the real part of the position of the pole (in the energy-squared plane) in the Z-boson propagator.
- [e] This partial width takes into account Z decays into $\nu\overline{\nu}$ and any other possible undetected modes.
- [f] This ratio has not been corrected for the au mass.
- [g] Here $A \equiv 2g_V g_A / (g_V^2 + g_A^2)$.
- [h] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [i] This value is updated using the product of (i) the $Z \to b\overline{b}$ fraction from this listing and (ii) the b-hadron fraction in an unbiased sample of weakly decaying b-hadrons produced in Z-decays provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009/#FRACZ).
- [j] See the Z Particle Listings for the γ energy range used in this measurement.
- [k] For $m_{\gamma\gamma}=$ (60 \pm 5) GeV.
- [/] The limits assume no invisible decays.

Lepton Summary Table

LEPTONS

$J=\frac{1}{2}$

Mass $m = (548.57990946 \pm 0.00000022) \times 10^{-6} \text{ u}$ Mass $m=0.510998928\pm0.000000011~{\rm MeV}$ $|m_{e^+} - m_{e^-}|/m < 8 \times 10^{-9}$, CL = 90% $|q_{e^+} + q_{e^-}|/e < 4 \times 10^{-8}$ Magnetic moment anomaly $(g-2)/2 = (1159.65218076 \pm 0.00000027) \times 10^{-6}$ $(g_{e^+} - g_{e^-}) / g_{average} = (-0.5 \pm 2.1) \times 10^{-12}$ Electric dipole moment $d < 10.5 \times 10^{-28}~e$ cm, CL = 90% Mean life $\tau > 4.6 \times 10^{26}$ yr, CL = 90% [a]

μ

$J = \frac{1}{2}$

Mass $m = 0.1134289267 \pm 0.0000000029$ u Mass $m = 105.6583715 \pm 0.0000035 \text{ MeV}$ Mean life $au = (2.1969811 \pm 0.0000022) \times 10^{-6} \; \mathrm{s}$ $\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$ $c\tau = 658.6384 \text{ m}$ Magnetic moment anomaly (g-2)/2 = (11659209 \pm 6) imes 10⁻¹⁰ $(g_{\mu^+} - g_{\mu^-}) \ / \ g_{\rm average} = (-0.11 \pm 0.12) \times 10^{-8}$ Electric dipole moment $d = (-0.1 \pm 0.9) \times 10^{-19} e \text{ cm}$

Decay parameters [b]

 $\rho = 0.74979 \pm 0.00026$ $\eta = 0.057 \pm 0.034$ $\delta = 0.75047 \pm 0.00034$ $\xi P_{\mu} = 1.0009^{+0.0016}_{-0.0007}$ [c] $\xi P_{\mu} \delta / \rho = 1.0018^{+0.0016}_{-0.0007} [c]$ $\xi' = 1.00 \pm 0.04$ $\xi'' = 0.7 \pm 0.4$ $\alpha/A = (0 \pm 4) \times 10^{-3}$ $\alpha'/A = (-10 \pm 20) \times 10^{-3}$ $\beta/A = (4 \pm 6) \times 10^{-3}$ $\beta'/A = (2 \pm 7) \times 10^{-3}$ $\overline{\eta} = 0.02 \pm 0.08$

 μ^+ modes are charge conjugates of the modes below.

| μ ⁻ DECAY MOD | ES | Fraction (Γ_i/Γ) | Confidence level | (MeV/c) |
|-----------------------------------------|--------------------|--------------------------------|------------------|----------|
| $e^- \overline{\nu}_e \nu_\mu$ | | ≈ 100% | | 53 |
| $e^-\overline{\nu}_e u_\mu\gamma$ | [d] | (1.4 ± 0.4) % | | 53 |
| $e^- \overline{ u}_e u_\mu e^+ e^-$ | [<i>e</i> | $(3.4 \pm 0.4) \times 10^{-4}$ | 5 | 53 |
| | Lepton Family numb | er (<i>LF</i>) violating | modes | |
| a = | | 0 | 0.007 | |

| $e^- \nu_e \overline{\nu}_{\mu}$ | LF | [f] < 1.2 | % | 90% | 53 |
|----------------------------------|----|-----------|-------------------|-----|----|
| $e^-\gamma$ | LF | < 2.4 | $\times 10^{-12}$ | 90% | 53 |
| $e^{-}e^{+}e^{-}$ | LF | < 1.0 | $\times 10^{-12}$ | 90% | 53 |
| $e^- 2\gamma$ | LF | < 7.2 | $\times 10^{-11}$ | 90% | 53 |



$$J = \frac{1}{2}$$

 $(m_{\tau^+} - m_{\tau^-})/m_{\text{average}} < 2.8 \times 10^{-4}$, CL = 90% Mean life au= (290.6 $\stackrel{\smile}{\pm}$ 1.0) imes 10 $^{-15}$ s $c\tau = 87.11 \ \mu \text{m}$ Magnetic moment anomaly > -0.052 and < 0.013, CL = 95% $\mathrm{Re}(\mathit{d}_{\tau}) = -0.220~\mathrm{to}~0.45\times10^{-16}~\mathrm{ecm}$, CL =95% $Im(d_{\tau}) = -0.250 \text{ to } 0.0080 \times 10^{-16} \text{ ecm, CL} = 95\%$

Weak dipole moment

 $Re(d_{-}^{w}) < 0.50 \times 10^{-17} ecm, CL = 95\%$ $\text{Im}(d_{\tau}^{W}) < 1.1 \times 10^{-17} \text{ ecm, CL} = 95\%$

Weak anomalous magnetic dipole moment

Mass $m=1776.82\pm0.16~\mathrm{MeV}$

$${\rm Re}(\alpha_{\tau}^{W}) < 1.1 \times 10^{-3}, {\rm CL} = 95\% \ {\rm Im}(\alpha_{\tau}^{W}) < 2.7 \times 10^{-3}, {\rm CL} = 95\%$$

Decay parameters

See the au Particle Listings for a note concerning au-decay parameters.

$$\begin{array}{l} \rho(e \text{ or } \mu) = 0.745 \pm 0.008 \\ \rho(e) = 0.747 \pm 0.010 \\ \rho(\mu) = 0.763 \pm 0.020 \\ \xi(e \text{ or } \mu) = 0.985 \pm 0.030 \\ \xi(e) = 0.994 \pm 0.040 \\ \xi(\mu) = 1.030 \pm 0.059 \\ \eta(e \text{ or } \mu) = 0.013 \pm 0.020 \\ \eta(\mu) = 0.094 \pm 0.073 \\ (\delta \xi)(e \text{ or } \mu) = 0.746 \pm 0.021 \\ (\delta \xi)(e) = 0.734 \pm 0.028 \\ (\delta \xi)(\mu) = 0.778 \pm 0.037 \\ \xi(\pi) = 0.993 \pm 0.022 \\ \xi(\rho) = 0.994 \pm 0.008 \\ \xi(a_1) = 1.001 \pm 0.027 \\ \xi(\text{all hadronic modes}) = 0.995 \pm 0.007 \end{array}$$

 au^+ modes are charge conjugates of the modes below. " au^\pm " stands for π^{\pm} or K^{\pm} . " ℓ " stands for e or μ . "Neutrals" stands for γ 's and/or π^0 's.

| $	au^-$ DECAY MODES | | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | <i>p</i> (Me <i>V/c</i>) |
|------------------------------------------------------------------|--------------|------------------------------|-----------------------------------|-------------------------------|
| Modes v | vith on | e charged partic | :le | |
| particle ⁻ ≥ 0 neutrals $\geq 0 K^0$ ("1-prong") | $\nu_{	au}$ | (85.35 ±0.07) | % S=1.3 | - |
| particle ≥ 0 neutrals $\geq 0K_L^0$ | ν_{τ} | (84.71 ± 0.08) | % S=1.3 | - |
| $\mu^- \overline{\nu}_\mu \nu_\tau$ | [g] | (17.41 ± 0.04) | | 885 |
| | | | 3 | |

| ("1-prong") | | , | | , | | |
|------------------------------------------------------------------------------------------------|------|---------------------|---------------|------------------------------------------|--------|------------|
| particle $\stackrel{-}{=} \geq 0$ neutrals $\geq 0 K_L^0 u_	au$ | | (84.71 | ±0.08 |) % | S=1.3 | _ |
| $\mu^- \overline{ u}_\mu u_	au$ | [g] | (17.41 | ± 0.04 |) % | S=1.1 | 885 |
| $\mu^{-}\overline{\nu}_{\mu}\nu_{\tau}\gamma$ | [e] | (3.6 | ± 0.4 | $) \times 10^{-3}$ | | 885 |
| $e^-\overline{ u}_e u_	au$ | [g] | | | | | 888 |
| $e^{-}\overline{\nu}_{e}\nu_{\tau}\gamma$ | [e] | (1.75 | ±0.18 |) % | | 888 |
| $h^- \geq 0 K_L^0 \nu_{	au}$ | | (12.06 | ± 0.06 |) % | S=1.2 | 883 |
| $h^- u_	au$ | | (11.53 | ± 0.06 |) % | S=1.2 | 883 |
| $\pi^- u_	au$ | [g] | | ± 0.06 | | S=1.2 | 883 |
| $K^- u_	au$ | [g] | | | $) \times 10^{-3}$ | S=1.1 | 820 |
| $h^- \geq 1$ neutrals ν_{τ} | | | ± 0.10 | | S=1.2 | _ |
| $h^{-} \geq 1\pi^{0} \nu_{\tau} (\text{ex}.K^{0})$ | | | ± 0.10 | * | S=1.2 | _ |
| $^{h^-\pi^0}_{\pi^-\pi^0}_{ u_{	au}}$ | | | ±0.09 | * | S=1.1 | 878 |
| $\pi^-\pi^0 u_	au$ $\pi^-\pi^0$ non- $ ho$ (770) $ u_	au$ | [g] | (25.52 | | | S=1.1 | 878 |
| $K^-\pi^0\nu_{\tau}$ | [~] | (3.0 | ±3.2 | $) \times 10^{-3}$ $) \times 10^{-3}$ | | 878 814 |
| $h^- \geq 2\pi^0 \nu_{\tau}$ | [g] | | ±0.13 | | S=1.2 | - 014 |
| $h = 2\pi^0 \nu_{\tau}$ | | | ±0.11 | * | S=1.1 | 862 |
| $h^{-}2\pi^{0}\nu_{\tau}(\text{ex}.K^{0})$ | | | ±0.11 | * | S=1.2 | 862 |
| $\pi^{-} 2\pi^{0} \nu_{\tau} (ex.K^{0})$ | [g] | | |) % | | 862 |
| $\pi^{-} 2\pi^{0} \nu_{\tau} (ex.K^{0})$, | 101 | < 9 | | | CL=95% | 862 |
| $\pi^{-} \frac{scalar}{2\pi^0} u_{	au} (ex. K^0)$, | | | | _ | | |
| | | < 7 | | $\times 10^{-3}$ | CL=95% | 862 |
| κ^{-} vector κ^{-} $2\pi^{0}$ $ u_{	au}$ (ex. κ^{0}) | f _1 | ((= | 100 |) × 10 ⁻⁴ | | 706 |
| $h^- \geq 3\pi^0 \nu_{\tau}$ (ex. h^-) | [g] | | ±2.3 ±0.07 | | S=1.1 | 796 |
| $h^{-} \geq 3\pi^{0} \nu_{\tau}$ (ex. K^{0}) | | | ±0.07 | * | S=1.1 | _ |
| $h = 3\pi^0 \nu_{\tau}$ | | | ±0.07 | * | 3=1.1 | 836 |
| $\pi^{-} 3\pi^{0} \nu_{\tau} (\text{ex.} K^{0})$ | [g] | , | ±0.07 | * | | 836 |
| $K^{-}3\pi^{0}\nu_{\tau}$ (ex. K^{0} , | [g] | , | | $) \times 10^{-4}$ | | 765 |
| η) | | | | | | |
| $h^{-}4\pi^{0}\nu_{	au}({ m ex}.K^{0})$ | | (1.6 | | $) \times 10^{-3}$ | | 800 |
| $h^{-} 4\pi^{0} \nu_{\tau} (\text{ex.} K^{0}, \eta)$ | [g] | | | $) \times 10^{-3}$ | | 800 |
| $K^- \geq 0\pi^0 \geq 0K^0 \geq 0\gamma \nu_{\tau}$ | | | 2 ± 0.03 | | S=1.1 | 820 |
| $\mathcal{K}^- \geq 1 \; (\pi^0 \; 	ext{or} \; \mathcal{K}^0 \; 	ext{or} \; \gamma) \; u_	au$ | | (8.72 | ± 0.32 | $) \times 10^{-3}$ | S=1.1 | _ |
| Mo | des | with K ⁰ | 's | | | |
| K_a^0 (particles) $-\nu$ | | (9.2 | +0.4 | 1×10^{-3} | S=1.5 | _ |

K_S^0 (particles) $^-\nu_{ au}$ $(9.2 \pm 0.4) \times 10^{-3}$ $\begin{array}{c} h^-\overline{K}{}^0\nu_{\tau} \\ \pi^-\overline{\underline{K}}{}^0\nu_{\tau} \end{array}$ $(1.00 \pm 0.05)\%$ S=1.8 81.2 [g] $(8.4 \pm 0.4) \times 10^{-3}$ 812 $\pi^- \overline{K}{}^0$ $(5.4 \pm 2.1) \times 10^{-4}$ 812 $(\text{non-}K^*(892)^-)\nu_{\tau}$ $\begin{array}{c} K^{-}K^{0}\nu_{\tau} \\ K^{-}K^{0} \geq 0\pi^{0}\nu_{\tau} \\ h^{-}\overline{K^{0}}\pi^{0}\nu_{\tau} \\ \pi^{-}\overline{K^{0}}\pi^{0}\nu_{\tau} \end{array}$ [g] $(1.59 \pm 0.16) \times 10^{-3}$ $(3.18 \pm 0.23) \times 10^{-3}$ 737 ($5.5~\pm0.4~$) $\times\,10^{-3}$ 794 [g] $(4.0 \pm 0.4) \times 10^{-3}$ 794 $\frac{\pi}{K^0} \frac{K^1 \pi^1 \nu_{\tau}}{K^- K^0 \pi^0 \nu_{\tau}}$ $(2.2 \pm 0.5) \times 10^{-3}$ 612

[g] (1.59 ± 0.20) $\times 10^{-3}$

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Lepton Summary Table

| $\pi^-\overline{K}^0\geq1\pi^0 u_	au$ | | (3.2 | ±1.0) | $) \times 10^{-3}$ | | = | $K^*(892)^- \geq 0$ neutrals \geq | (1.42 ± 0.18) % | S=1.4 | 665 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| $\pi^-\overline{\mathcal{K}}{}^0\pi^{\overline{0}}\pi^0 u_	au$ | | (2.6 | | $) \times 10^{-4}$ | | 763 | $0K_L^0 u_	au$ | | | |
| $K^{-}K^{0}\pi^{0}\pi^{0}\nu_{\tau}$ | < | < 1.6 | | | CL=95% | 619 | $K^*(892)^-\nu_{\tau}$ | (1.20 \pm 0.07) % | S=1.8 | 665 |
| $\pi^- K^0 \overline{K}{}^0 \nu_{\tau}$ | | | | $) \times 10^{-3}$ | | 682 | $K^*(892)^- \nu_{\tau} \to \pi^- \overline{K}{}^0 \nu_{\tau}$ | $(7.8 \pm 0.5) \times 10$ | | - |
| $\pi^{-}K_{S}^{0}K_{S}^{0}\nu_{\tau}$ | | | | $) \times 10^{-4}$ | | 682 | $K^*(892)^0 K^- \geq 0$ neutrals ν_{τ} | | | 542 |
| $\pi^- K_{\underline{S}}^{0} K_{\underline{L}}^{0} \nu_{\tau}$ | [g] | | | $) \times 10^{-3}$ | | 682 | $K^*(892)^0 K^- \nu_{\tau}$ | $(\begin{array}{cc} 2.1 & \pm 0.4 \end{array}) \times 10$ | -3 | 542 |
| $\pi^- K^0 \overline{K}^0 \pi^{\bar{0}} \nu_{\tau}$ | | , | ±2.3) | $) \times 10^{-4}$ | | 614 | $\overline{K}^*(892)^0\pi^- \geq 0$ neutrals ν_{τ} | | | 655 |
| $\pi^{-}K_{S}^{0}K_{S}^{0}\pi^{0}\nu_{\tau}$ | | < 2.0 | | | CL=95% | 614 | $K^*(892)^0 \pi^- \nu_{\tau}$ | (2.2 ±0.5) × 10 | _ | 655 |
| $\pi^- K_S^{\breve{0}} K_L^{\breve{0}} \pi^0 \nu_{	au}$ | | | ±1.2) | | | 614 | $(\overline{K}^*(892)\pi)^-\nu_{\tau} \rightarrow$ | $(1.0 \pm 0.4) \times 10$ | -3 | _ |
| K^0 h^+ $h^ h^ \geq$ 0 neutrals $ u_	au$ | < | < 1.7 | | | CL=95% | 760 | $\pi^{-} \overline{K}{}^{0} \pi^{0} \nu_{\tau}$ | (| -3 | |
| $K^0h^+h^-h^-^- u_	au$ | | (2.3 | ±2.0) | $) \times 10^{-4}$ | | 760 | $K_1(1270)^- u_	au \ K_1(1400)^- u_	au$ | $(4.7 \pm 1.1) \times 10$ $(1.7 \pm 2.6) \times 10$ | | 433 335 |
| Modes with | three | e charge | ed parti | cles | | | | , | | |
| $h^- h^- h^+ \ge 0$ neutrals $\ge 0 K_I^0 \nu$ | | _ | ±0.08) | | S=1.3 | 861 | $K^*(1410)^- u_	au$ | $(1.5 {+1.4 \atop -1.0}) \times 10$ | | 326 |
| $h^- h^- h^+ > 0$ neutrals $\nu_{	au}$ | • | | ±0.07) | | S=1.3 | 861 | $K_0^*(1430)^- u_	au$ | | ⁻⁴ CL=95% | 317 |
| $(\text{ex. } K_S^{\overline{0}} \rightarrow \pi^+\pi^-)$ | | (= | | | | | $K_2^*(1430)^- \nu_{\tau}$ | < 3 × 10 | $^{-3}$ CL=95% | 316 |
| ("3-prong") | | | | | | | $\eta \pi^- u_{	au}$ | | ^{−5} CL=95% | 797 |
| $h^ h^ h^+$ $ u_	au$ | | (9.80 | ±0.07) |) % | S=1.2 | 861 | $\eta\pi^-\pi^0_0 u_{	au}$ | [g] (1.39 ± 0.10) $\times 10$ | | 778 |
| $h^- h^- h^+ \nu_{\tau} (\text{ex.} K^0)$ | | (9.46 | ±0.06) |) % | S=1.2 | 861 | $\eta\pi^-\pi^0\pi^0 u_	au$ | $(1.5 \pm 0.5) \times 10$ | | 746 |
| $h^-h^-h^+\nu_{\tau}(ex.K^0,\omega)$ | | (9.42 | ± 0.06) |) % | S=1.2 | 861 | $\eta K^- \nu_{	au}$ | [g] (1.52 ± 0.08) $\times 10$ | | 719 |
| $\pi^-\pi^+\pi^- u_	au$ | | (9.31 | ± 0.06) |) % | S=1.2 | 861 | $\eta K^*(892)^- \nu_{\tau}$ | (1.38 ±0.15) × 10 | | 511 |
| $\pi^- \pi^+ \pi^- \nu_{\tau} (\text{ex.} K_0^0)$ | | (9.02 | ± 0.06) |) % | S=1.1 | 861 | $\eta K^{-} \pi^{0} \nu_{\tau}$ | (4.8 ±1.2) × 10 | | 665 |
| $\pi^- \pi^+ \pi^- \nu_{\tau} (ex.K^0)$, | < | < 2.4 | | % | CL=95% | 861 | $\eta \frac{K^{-} \pi^{0}}{K^{0}}$ (non- $K^{*}(892)$) ν_{τ} | | ^{−5} CL=90% | _ |
| non-axial vector | [-1 | (0 00 | 1000 | 0/ | C 11 | 061 | $\eta \overline{K}{}^0 \pi^- \nu_{	au} $ $\eta \overline{K}{}^0 \pi^- \pi^0 \nu_{	au}$ | (9.3 ±1.5) × 10 | -5 -5 CL=90% | 661 |
| $\pi^-\pi^+\pi^- u_	au(ext{ex}.{\cal K}^0,\!\omega) \ h^-h^-h^+\geq 1$ neutrals $ u_	au$ | ιgΙ | | ±0.06) ±0.07) | | S=1.1 S=1.2 | 861 — | $\eta K^{\circ} \pi^{-} \pi^{\circ} \nu_{\tau}$ $\eta K^{-} K^{0} \nu_{\tau}$ | | -5 CL=90% -6 CL=90% | 590 430 |
| $h^-h^-h^+ \geq 1\pi^0 u_{	au} (\mathrm{ex.}\ K^0)$ | | , | ±0.07) | | S=1.2 S=1.2 | = | $\eta \pi^+ \pi^- \pi^- \geq 0$ neutrals $ u_{	au}$ | | -3 CL=90% -3 CL=90% | 430 743 |
| $h^{-}h^{-}h^{+}\pi^{0}\nu_{\tau}$ (ex. K) | | , | ±0.06) | | S=1.2 S=1.2 | 834 | $\eta \pi^- \pi^+ \pi^- \nu_{\tau} (\text{ex.} K^0)$ | (1.64 ±0.12) × 10 | | 743 |
| $h^- h^- h^+ \pi^0 \nu_{\tau} (\text{ex.} K^0)$ | | , | ±0.06) | * | S=1.2 | 834 | $\eta a_1(1260)^- \nu_{\tau} \rightarrow \eta \pi^- \rho^0$ | | ⁻⁴ CL=90% | - |
| $h^-h^-h^+\pi^0\nu_{\tau}(\text{ex. }K^0,\omega)$ | | , | ±0.08) | | S=1.2 | 834 | $\eta \eta \pi^- u_{	au}$ | | -6 CL=90% | 637 |
| $\pi^-\pi^+\pi^-\pi^0\nu_{\tau}$ | | , | ±0.06) | * | S=1.2 | 834 | $\eta\eta\pi^-\pi^0\nu_{	au}$ | | ⁻⁴ CL=95% | 559 |
| $\pi^- \pi^+ \pi^- \pi^0 \nu_{\pi} (\text{ex.} K^0)$ | | , | ±0.06) | | S=1.2 | 834 | $\eta \eta K^- u_{	au}$ | < 3.0 × 10 | ^{−6} CL=90% | 382 |
| $\pi^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}$ (ex. K^{0},ω) | [g] | (2.70 | ±0.08) |) % | S=1.2 | 834 | $\eta'(958) \pi^- \nu_{\tau}$ | < 7.2 × 10 | $^{-6}$ CL=90% | 620 |
| $h^- h^- h^+ > 2\pi^0 \nu_{\tau}$ (ex. | | | | $) \times 10^{-3}$ | | = | $\eta'(958) \pi^- \pi^0 \nu_{\tau}$ | < 8.0 × 10 | ⁻⁵ CL=90% | 591 |
| K^0) | | | | | | | $\phi \pi^- \nu_{	au}$ | $(3.4\pm0.6)\times10$ | -5 | 585 |
| $h^- h^- h^+ 2\pi^0 \nu_{\tau}$ | | | | $) \times 10^{-3}$ | | 797 | ϕ K $^ \nu_{	au}$ | (3.70 ± 0.33) \times 10 | | 445 |
| $h^- h^- h^+ 2\pi^0 \nu_{\tau} (\text{ex.} K^0)$ | | | | $) \times 10^{-3}$ | | 797 | $f_1(1285) \pi^- \nu_{\tau}$ | $(3.6 \pm 0.7) \times 10$ | | 408 |
| $h^- h^- h^+ 2\pi^0 \nu_{\tau} (\text{ex.} K^0, \omega, \eta)$ | [g] | (1.0 | ±0.4) | 1×10^{-3} | | 797 | $f_1(1285)\pi^-\nu_{	au} \rightarrow$ | $(1.11 \pm 0.08) \times 10$ | -4 | - |
| $h^- h^- h^+ 3\pi^0 \nu_{\tau}$ | | | |) × 10 ⁻⁴ | | 749 | $\eta \pi^- \pi^+ \pi^- \nu_{\tau}$ | | -4 51 000 | |
| $K^-h^+h^- \ge 0$ neutrals ν_{τ} | | | | $) \times 10^{-3}$ | | 794 | $\pi(1300)^-\nu_{\tau} \rightarrow (\rho\pi)^-\nu_{\tau} \rightarrow$ | < 1.0 × 10 | ⁻⁴ CL=90% | _ |
| $K^- h^+ \pi^- u_	au (ext{ex.} K^0) \ K^- h^+ \pi^- \pi^0 u_	au (ext{ex.} K^0)$ | | | | $) \times 10^{-3}$ | | 794 | $(3\pi)^- u_{	au}$ $\pi (1300)^- u_{	au} ightarrow$ | . 1010 | ⁻⁴ CL=90% | |
| | | | | $) \times 10^{-4}$ $) \times 10^{-3}$ | | 763 | . , . | < 1.9 × 10 | · CL=90% | _ |
| $K^-\pi^+\pi^- \geq 0$ neutrals $ u_{	au}$ $K^-\pi^+\pi^- \geq$ | | | | $) \times 10^{-3}$ | | 794 794 | $((\pi\pi)_{S-wave}\ \pi)^- u_	au	o$ | | | |
| $0\pi^0 \nu_{\tau} (\text{ex.} K^0)$ | | (3.15 | ±0.19) |) × 10 | 3=1.5 | 194 | $h^-\omega \geq 0$ neutrals $ u_{	au}$ | (2.41 ±0.09) % | S=1.2 | 708 |
| $K^-\pi^+\pi^-\nu_{	au}$ | | (3.49 | +0.16 | $) \times 10^{-3}$ | S=1.9 | 794 | $h^-\omega_{	au}$ | [g] (2.00 ±0.08) % | S=1.3 | 708 |
| $K^-\pi^+\pi^- u_{	au}(\text{ex}.K^0)$ | [2] | | | $\times 10^{-3}$ | | 794 | $K^-\omega u_{	au}$ | (4.1 ±0.9)×10 | | 610 |
| $K^- ho^0 u_{	au} ightarrow$ | | | | $\times 10^{-3}$ | | _ | $h^-\omega\pi^0\stackrel{\cdot}{ u_	au}$ | [g] (4.1 ±0.4)×10 | -3 | 684 |
| $K^-\pi^+\pi^-\nu$ | | , | · | | | | r - 0 0 · | | | |
| $\mathcal{K}^-\pi^+\pi^-\pi^0\nu_{	au}$ | | (1.35 | | | | | $h^-\omega2\pi^0 u_{	au}$ | $(1.4 \pm 0.5) \times 10$ | | 644 |
| $K^-\pi^+\pi^-\pi^0\nu_{\tau}^{0}$ (ex. K^0) | | | ± 0.14) | 1×10^{-3} | | 763 | $h^- 2\omega u_	au$ | < 5.4 × 10 | -4 -7 CL=90% | 644 249 |
| | | (8.1 | ±1.2) | $) \times 10^{-3}$ $) \times 10^{-4}$ | | 763 763 | $h = \omega 2\pi^{-} u_{	au}$ $h^{-} 2\omega u_{	au}$ $2h^{-} h^{+} \omega u_{	au}$ | | -4 -7 CL=90% | |
| $K^-\pi^+\pi^-\pi^0\nu_{\tau}$ (ex. K^0 , η) | [g] | (8.1 (7.8 | ±1.2) ±1.2) | $) \times 10^{-4}$ $) \times 10^{-4}$ | | | $h^- 2\omega u_	au$ $2h^- h^+ \omega u_	au$ | $<$ 5.4 \times 10 (1.20 \pm 0.22) \times 10 | -4 -7 CL=90% -4 | 249 |
| $K^-\pi^+\pi^-\pi^0 u_{	au} ({\rm ex.} K^0, \omega)$ |) | (8.1 (7.8 (3.7 | ±1.2) ±1.2) | $) \times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-4}$ | | 763 763 763 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family I | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $) \times$ 10 number (<i>LF</i>), Lepton number | -4 -7 CL=90% -4 | 249 |
| $K^-\pi^+\pi^-\pi^0 u_	au({ m ex}K^0,\omega$ $K^-\pi^+K^-\geq 0$ neut. $ u_	au$ |) < | (8.1 (7.8 (3.7 < 9 | ±1.2) ±1.2) ±0.9) | $) \times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ | CL=95% | 763 763 763 685 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family ${\bf r}$ or Baryon | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $) \times$ 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes | -4 -7 CL=90% -4 or (L) , | 249 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_\tau({\rm ex}.K^0,\omega)\\ K^-\pi^+K^-\geq 0\ {\rm neut.}\ \nu_\tau\\ K^-K^+\pi^-\geq 0\ {\rm neut.}\ \nu_\tau \end{array}$ |) < | (8.1 (7.8 (3.7 < 9 (1.50 | ±1.2) ±1.2) ±0.9) | $) \times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-3}$ | CL=95% S=1.8 | 763 763 763 685 685 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family r or Baryon | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $) \times$ 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ | -4 -7 CL=90% -4 er (L). i. | 249 |
| $K^-\pi^+\pi^-\pi^0 u_{	au} ({ m ex.} K^0, \omega \ K^-\pi^+K^- \ge 0 { m neut.} u_{	au} \ K^-K^+\pi^- \ge 0 { m neut.} u_{	au} \ K^-K^+\pi^- u_{	au}$ |) (g] | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) | $) \times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-3}$ $) \times 10^{-3}$ | CL=95% S=1.8 S=1.9 | 763 763 763 685 685 685 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family ${ m r}$ or Baryon ${ m L}$ means lepton number ${ m common}$ common usage, ${ m LF}$ means | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $)$ \times 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not | -4 -7 CL=90% -4 or (L), -7). Following epton number | 249 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_\tau ({\rm ex.} K^0,\!\omega \\ K^-\pi^+K^- \geq 0 {\rm neut.} \ \nu_\tau \\ K^-K^+\pi^- \geq 0 {\rm neut.} \ \nu_\tau \\ K^-K^+\pi^-\nu_\tau \\ K^-K^+\pi^-\nu_\tau \\ K^-K^+\pi^-\pi^0\nu_\tau \end{array}$ | [g] [g] | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 | 763 763 763 685 685 685 685 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family r or Baryon r means lepton number r common usage, r means violation (e.g. r r r r r r | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $)$ \times 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon numb | -4 -7 CL=90% -4 or (L), | 249 641 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_\tau ({\rm ex.} K^0,\!\omega \\ K^-\pi^+K^- \geq 0 {\rm neut.} \ \nu_\tau \\ K^-K^+\pi^- \geq 0 {\rm neut.} \ \nu_\tau \\ K^-K^+\pi^-\nu_\tau \\ K^-K^+\pi^-\nu_\tau \\ K^-K^+\pi^-\pi^0\nu_\tau \\ K^-K^+K^-\nu_\tau \end{array}$ | [g] [g] | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 | 763 763 763 685 685 685 618 | $h^- 2\omega u_{	au}$ $2h^- h^+ \omega u_{	au}$ Lepton Family r or Baryon r Lepton number r common usage, r LF means violation (e.g. r | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $)$ \times 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number $<$ 3.3 \times 10 | -4 -7 CL=90% -4 er (L), -7). Following epton number er violation8 CL=90% | 249 641 888 |
| $\begin{array}{l} K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}(\mathrm{ex}.K^{0},\!\omega) \\ K^{-}\pi^{+}K^{-} \geq 0 \; \mathrm{neut}.\;\;\nu_{\tau} \\ K^{-}K^{+}\pi^{-} \geq 0 \; \mathrm{neut}.\;\;\nu_{\tau} \\ K^{-}K^{+}\pi^{-}\nu_{\tau} \\ \kappa^{-}K^{+}\pi^{-}\pi^{0}\nu_{\tau} \\ K^{-}K^{+}K^{-}\nu_{\tau} \\ K^{-}K^{+}K^{-}\nu_{\tau}(\mathrm{ex}.\;\phi) \end{array}$ | (g) [g] [g] | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% | 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $<$ 5.4 \times 10 $($ 1.20 \pm 0.22 $)$ \times 10 number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number $=$ $<$ 3.3 \times 10 $=$ $<$ 4.4 \times 10 | -4 -7 CL=90% -4 er (L), | 249 641 888 885 |
| $\begin{array}{l} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}({\rm ex.} \ \phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \end{array}$ | (g) (g) (s) (s) (s) (s) (s) (s) (s) (s) (s) (s | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% | 763 763 763 685 685 685 618 471 - 345 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ selepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<<4.4$ \times 10 $<<5.8$ $<<5.0$ <5.0 | -4 -7 CL=90% -4 er (L), -7). Following epton number er violation8 CL=90% | 249 641 888 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}({\rm ex.} \ \phi) \\ K^-K^+K^-\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \end{array}$ | [g] [g] (s) | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=95% | 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ selepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<<4.4$ <10 $<<4.4$ <10 $<<4.4$ <10 $<<4.4$ <4.0 $<<4.5$ $<<4.4$ <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 $<4.$ | -4 -7 CL=90% -4 er (L), | 249 641 888 885 883 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}({\rm ex.} \ \phi) \\ K^-K^+K^-\nu_{\tau}({\rm ex.} \ \phi) \\ K^-K^+K^-\nu_{\tau} \geq 0 \ {\rm neut.} \ \ \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \end{array}$ | [g] [g] < | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-3} \\)\times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=95% | 763 763 763 685 685 685 618 471 - 345 794 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ selepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<<4.4$ <1.0 $<<4.4$ <1.0 $<<4.4$ <1.0 $<<4.4$ <4.0 $<<4.0$ $<<4.0$ $<<4.0$ <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 <4.0 | -4 -7 CL=90% -4 or (L), -1 -7). Following epton number er violation8 CL=90% -8 CL=90% -7 CL=90% | 249 641 888 885 883 880 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \ {\rm neut.} \ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ {\rm neut.} \ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ {\rm neut.} \ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ ({\rm ex.} \ \phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \ {\rm neut.} \ \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \end{array}$ | [g] [g] < < < | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 | $\begin{array}{cccc} \pm 1.2 &) \\ \pm 1.2 &) \\ \pm 0.9 &) \\ \\ \pm 0.06 &) \\ \pm 0.05 &) \\ \pm 2.5 &) \\ \pm 0.8 &) \\ \\ \\ \pm 1.5 &) \\ \end{array}$ | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=95% | 763 763 763 685 685 685 618 471 - 345 794 888 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ ({\rm ex.} \;\; \phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \end{array}$ | [g] [g] < < < | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=95% CL=90% | 763 763 763 685 685 685 618 471 - 345 794 888 885 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<$ $<$ 4.4 \times 10 $<$ $<$ 8.0 \times 10 $<$ $<$ 1.1 \times 10 $<$ $<$ 2.6 \times 1.1 \times 10 $<$ $<$ 2.6 \times 1.1 \times 10 $<$ $<$ 2.8 \times 2.8 \times 10 $<$ $<$ 2.8 \times 2.8 \times 10 $<$ $<$ 2.9 \times 2.8 \times 10 $<$ 2.9 \times 2.8 \times 10 $<$ 2.9 \times 2.9 \times 10 $<$ 2.9 \times 2.9 \times 10 | -4 -7 CL=90% -4 -7 CL=90% -7 (L), -7). Following epton number er violation8 CL=90% -8 CL=90% -7 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 815 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \ \mathrm{neut}.\ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ \mathrm{neut}.\ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-K^-K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-K^-K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-K^-K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^-$ | [g] [g] < < < | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=95% CL=90% | 763 763 763 685 685 685 618 471 - 345 794 888 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ | -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -7 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 815 804 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\;\phi) \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\;\phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [g] < < < | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 | ± 1.2) ± 1.2) ± 0.9) ± 0.06) ± 0.05) ± 2.5) ± 0.8) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=95% CL=90% | 763 763 763 685 685 685 618 471 - 345 794 888 885 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ | -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -7 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 815 804 800 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \ \mathrm{neut}.\ \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \ \mathrm{neut}.\ \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\ \phi) \\ K^-K^+K^-\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [g] < < < h five | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 Charge | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) |) × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻³) × 10 ⁻³) × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=95% CL=90% S=1.1 | 763 763 763 685 685 685 618 471 — 345 794 888 885 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number $=$ 3.3 $=$ 10 $=$ 4.4 $=$ 10 $=$ 5 $=$ 4.4 $=$ 10 $=$ 5 $=$ 5 $=$ 6.5 $=$ 1.1 $=$ 10 $=$ 6 $=$ 2.3 $=$ 10 $=$ 6 $=$ 2.5 $=$ 1.1 $=$ 10 $=$ 2.6 $=$ 1.1 $=$ 10 $=$ 2.6 $=$ 1.1 $=$ 10 $=$ 2.6 $=$ 1.1 $=$ 10 $=$ 2.7 $=$ 2.8 $=$ 10 $=$ 2.8 $=$ 2.9 $=$ 2 $=$ 10 $=$ 2.8 $=$ 2.8 $=$ 10 $=$ 2.8 $=$ 2.9 $=$ 2 $=$ 3.8 $=$ 10 $=$ 4.8 $=$ 10 $=$ 4.8 $=$ 10 $=$ 4.8 $=$ 10 | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 (L), -7 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 815 804 800 719 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\!\omega) \\ K^-\pi^+K^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} ({\rm ex.} \;\; \phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \end{array}$ | [g] [g] * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 Charge (1.02 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \\)\times 10^{-5} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=90% S=1.1 | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \to e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<$ $<$ 4.4 \times 10 $<$ $<$ $<$ 8.0 \times 10 $<$ $<$ $<$ 1.1 \times 10 $<$ $<$ $<$ $<$ 2.6 \times 10 $<$ $<$ $<$ $<$ 2.6 \times 10 $<$ $<$ $<$ $<$ $<$ 2.3 \times 10 $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ | -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -7 (L), -7 Following epton number er violation8 CL=90% -8 CL=90% -7 CL=90% -8 CL=90% | 249 641 888 885 883 880 819 815 804 800 719 715 716 711 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}({\rm ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ ({\rm ex}. \phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; {\rm neut.} \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [g] *** ** ** ** ** ** ** ** ** ** ** ** ** | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 charge (1.02 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-5} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=90% S=1.1 S=1.1 | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \to e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<$ $<$ 4.4 \times 10 $<$ $<$ $<$ 8.0 \times 10 $<$ $<$ $<$ 1.1 \times 10 $<$ $<$ $<$ $<$ 2.6 \times 1.1 \times 10 $<$ $<$ $<$ $<$ 2.6 \times 10 $<$ $<$ $<$ $<$ 2.3 \times 10 $<$ $<$ $<$ $<$ $<$ 2.4 \times 10 $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ | -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -7 (L), -7 CL=90% -8 CL=90% | 888 885 883 880 819 815 804 800 719 715 716 711 665 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ (\mathrm{ex}.\phi) \\ K^-K^+K^-\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [s] (s) | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 Charge (1.02 (8.39 (1.78 < 3.4) | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) sd partic ±0.04) ±0.35) ±0.37) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=90% S=1.1 | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$). Because substituting the street of the street | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% | 888 885 883 889 819 815 804 800 719 715 716 665 659 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\;\phi) \\ K^-K^+K^-\nu_{\tau}(\mathrm{ex}.\;\phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \; \mathrm{neut}. \;\; \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \\ & \qquad \qquad$ | [g] [g] (g] (g] (h five [g] (g] (g) (h five five five five five five five five | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 charge (1.02 (8.39 (1.78 < 3.4 her allon | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) ±0.35) ±0.27) |) × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵) × 10 ⁻⁵) × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻³) × 10 ⁻⁵) × 10 ⁻⁵) × 10 ⁻⁵ des) × 10 ⁻³ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=91 S=1.1 CL=90% | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ $<$ | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% | 888 885 883 880 819 815 804 800 719 716 711 665 665 665 665 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\text{ex}.K^0,\omega) \\ K^-\pi^+K^-\geq 0 \text{ neut. } \nu_{\tau} \\ K^-K^+\pi^-\geq 0 \text{ neut. } \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau}(\text{ex}.\phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^-\geq 0 \text{ neut. } \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [g] (s) | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 charge (1.02 (8.39 (1.78 < 3.4 her allon | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) ±0.35) ±0.27) |) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻³) × 10 ⁻³) × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ des) × 10 ⁻³) × 10 ⁻³) × 10 ⁻³ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=91% CL=90% CL=90% CL=90% | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$). Because and not $\pi^+\pi^-$). Because and not $\pi^+\pi^-$). Because $\pi^+\pi^-$ 0 and $\pi^+\pi^-$ 1 and $\pi^+\pi^-$ 2 and $\pi^+\pi^-$ 3 and $\pi^+\pi^-$ 4 and $\pi^+\pi^-$ 5 and $\pi^+\pi^-$ 5 and $\pi^+\pi^-$ 6 and $\pi^+\pi^-$ 7 and $\pi^+\pi^-$ 9 an | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% | 888 885 883 880 719 715 716 711 665 665 665 665 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\text{ex}.K^0,\omega) \\ K^-\pi^+K^-\geq 0 \text{ neut. } \nu_{\tau} \\ K^-K^+\pi^-\geq 0 \text{ neut. } \nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ (K^-K^+K^-\nu_{\tau}) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^-\geq 0 \text{ neut. } \nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] [g] (s) | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 charge (1.02 (8.39 (1.78 < 3.4 her allon | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) ±0.35) ±0.27) |) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻³) × 10 ⁻³) × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ des) × 10 ⁻³) × 10 ⁻³) × 10 ⁻³ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% CL=91 S=1.1 CL=90% | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% -7 CL=90% | 888 885 883 880 819 715 716 711 665 659 630 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ K^-K^+\pi^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ (\mathrm{ex}.\phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] | (8.1 (7.8 (3.7 < 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 2.5 (2.8 < 3.6 (1.02 (8.39 (1.78 < 3.4 (7.7 < 3.0 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) xd partic ±0.04) ±0.35) ±0.27) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-5} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-5} \\)\times 10^{-3} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% S=1.1 CL=90% CL=90% | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% -7 CL=90% -7 CL=90% -7 CL=90% -7 CL=90% | 888 885 883 880 819 815 716 711 665 659 665 669 630 625 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega\\ K^-\pi^+K^-\geq 0\ \mathrm{neut}.\ \nu_{\tau}\\ K^-K^+\pi^-\geq 0\ \mathrm{neut}.\ \nu_{\tau}\\ K^-K^+\pi^-\nu_{\tau}\\ K^-K^+\pi^-\nu_{\tau}\\ K^-K^+K^-\nu_{\tau}\\ K^-K^+K^-\nu_{\tau}\\ (\mathrm{ex}.\phi)\\ K^-K^+K^-\nu_{\tau}\\ \pi^-K^+\pi^-\geq 0\ \mathrm{neut}.\ \nu_{\tau}\\ e^-e^-e^+\overline{\nu}_e\nu_{\tau}\\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \end{array}$ | [g] [g] [s] [s] [s] [s] [s] [s] [s] [s] [s] [s | (8.1 (7.8 (3.7 < 9 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 3.6 Charge (1.02 (8.39 (1.78 < 3.4 her allow (7.7 < 3.0 < 4.3 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) d partic ±0.04) ±0.27) wed mo ±0.5) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=95% CL=90% S=1.1 CL=90% CL=90% CL=90% | 763 763 763 763 685 685 685 618 471 — 345 794 888 885 794 794 746 687 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number $=$ 3.3 \times 10 $=$ 4.4 \times 10 $=$ 5 $=$ 4.4 \times 10 $=$ 5 $=$ 4.4 \times 10 $=$ 6 $=$ 4.5 $=$ 1.1 \times 10 $=$ 4.6 \times 10 $=$ 4.7 \times 10 $=$ 4.8 \times 10 $=$ 4.7 \times 10 $=$ 4.8 \times 10 $=$ 5.9 \times 10 $=$ 5.0 \times 10 $=$ 6.1 \times 10 $=$ 6.1 \times 10 \times 10 $=$ 6.1 \times 10 | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 (L), -7 CL=90% -8 CL=90% -7 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% -8 CL=90% -7 CL=90% -7 CL=90% -7 CL=90% -8 CL=90% | 888 885 883 880 819 715 716 711 665 659 630 |
| $\begin{array}{c} K^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega) \\ K^-\pi^+K^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ K^-K^+\pi^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+\pi^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ K^-K^+K^-\nu_{\tau} \\ (\mathrm{ex}.\phi) \\ K^-K^+K^-\pi^0\nu_{\tau} \\ \pi^-K^+\pi^- \geq 0 \;\mathrm{neut.}\;\;\nu_{\tau} \\ e^-e^-e^+\overline{\nu}_e\nu_{\tau} \\ \mu^-e^-e^+\overline{\nu}_\mu\nu_{\tau} \\ \end{array}$ | [g] | (8.1 (7.8 (3.7 < 9 9 (1.50 (1.44 (6.1 (2.1 < 2.5 < 4.8 < 3.6 (1.02 (8.39 (1.78 < 3.4 her allow (7.7 < 3.0 < 4.3 < 2.5 | ±1.2) ±1.2) ±0.9) ±0.06) ±0.05) ±2.5) ±0.8) ±1.5) d partic ±0.04) ±0.27) wed mo ±0.5) | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\)\times 10^{-4} \\ \times 10^{-4} \\)\times 10^{-3} \\)\times 10^{-3} \\)\times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \end{array}$ | CL=95% S=1.8 S=1.9 S=1.4 S=5.4 CL=90% CL=90% S=1.1 CL=90% CL=90% | 763 763 763 763 685 685 685 618 471 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | <5.4 \times 10 $(1.20\pm0.22)\times10$ number (<i>LF</i>), Lepton number number (<i>B</i>) violating modes violation (e.g. $\tau^- \rightarrow e^+\pi^-\pi$ is lepton family violation and not $\pi^+\pi^-$). <i>B</i> means baryon number <3.3 \times 10 $<<4.4$ \times 10 $<<5.6$ $<<5.0$ \times 11 \times 10 $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<5.0$ $<<$ | -4 -7 CL=90% -4 -7 CL=90% -4 -7 CL=90% -7 CL=90% -8 CL=90% -7 CL=90% -7 CL=90% -7 CL=90% -7 CL=90% | 888 885 883 880 819 815 716 711 665 659 665 659 665 659 |

Lepton Summary Table

| $\mu^-\phi_{\perp}$ | LF | < 8.4 | $\times 10^{-8}$ CL=90% | 590 |
|-------------------------------------------|-----|-------|------------------------------------|------|
| $e^{-}e^{+}e^{-}$ | LF | < 2.7 | $\times 10^{-8}$ CL=90% | 888 |
| $e^-\mu^+\mu^-$ | LF | < 2.7 | $\times 10^{-8} \text{ CL} = 90\%$ | 882 |
| $e^{+}\mu^{-}\mu^{-}$ | LF | < 1.7 | $\times 10^{-8} \text{ CL} = 90\%$ | 882 |
| $\mu^-e^+e^-$ | LF | < 1.8 | $\times 10^{-8} \text{ CL} = 90\%$ | 885 |
| $\mu^{+} e^{-} e^{-}$ | LF | < 1.5 | $\times 10^{-8}$ CL=90% | 885 |
| $\mu^{-} \mu^{+} \mu^{-}$ | LF | < 2.1 | $\times 10^{-8}$ CL=90% | 873 |
| $e^-\pi^+\pi^-$ | LF | < 4.4 | $\times 10^{-8}$ CL=90% | 877 |
| $e^{+}\pi^{-}\pi^{-}$ | L | < 8.8 | $\times 10^{-8}$ CL=90% | 877 |
| $\mu^-\pi^+\pi^-$ | LF | < 3.3 | $\times 10^{-8}$ CL=90% | 866 |
| $\mu^{+}\pi^{-}\pi^{-}$ | L | < 3.7 | $\times 10^{-8}$ CL=90% | 866 |
| $e^-\pi^+$ K^- | LF | < 5.8 | $\times 10^{-8}$ CL=90% | 813 |
| $e^-\pi^-K^+$ | LF | < 5.2 | $\times 10^{-8} \text{ CL} = 90\%$ | 813 |
| $e^{+}\pi^{-}K^{-}$ | L | < 6.7 | $\times 10^{-8}$ CL=90% | 813 |
| $e^{-}K_{S}^{0}K_{S}^{0}$ | LF | < 7.1 | $\times 10^{-8}$ CL=90% | 736 |
| $e^- K^+ K^-$ | LF | < 5.4 | $\times 10^{-8} \text{ CL} = 90\%$ | 738 |
| $e^{+} K^{-} K^{-}$ | L | < 6.0 | $\times 10^{-8} \text{ CL} = 90\%$ | 738 |
| $\mu^{-}\pi^{+}K^{-}$ | LF | < 1.6 | $\times 10^{-7} \text{ CL} = 90\%$ | 800 |
| $\mu^{-}\pi^{-}K^{+}$ | LF | < 1.0 | $\times 10^{-7} \text{ CL} = 90\%$ | 800 |
| $\mu^{+}\pi^{-}K^{-}$ | L | < 9.4 | $\times 10^{-8} \text{ CL} = 90\%$ | 800 |
| $\mu^{-} K_{S}^{0} K_{S}^{0}$ | LF | < 8.0 | $\times 10^{-8} \text{ CL} = 90\%$ | 696 |
| $\mu^- K^+ K^-$ | LF | < 6.8 | $\times 10^{-8} \text{ CL} = 90\%$ | 699 |
| $\mu^{+} K^{-} K^{-}$ | L | < 9.6 | $\times 10^{-8} \text{ CL} = 90\%$ | 699 |
| $e^{-\pi^{0}\pi^{0}}$ | LF | < 6.5 | $\times 10^{-6} \text{ CL} = 90\%$ | 878 |
| $\mu^{-}\pi^{0}\pi^{0}$ | LF | < 1.4 | $\times 10^{-5}$ CL=90% | 867 |
| e-ηη | LF | < 3.5 | $\times 10^{-5}$ CL=90% | 699 |
| $\mu^-\eta\eta$ | LF | < 6.0 | $\times 10^{-5}$ CL=90% | 65 3 |
| $e^-\pi^0\eta$ | LF | < 2.4 | $\times 10^{-5}$ CL=90% | 798 |
| $\mu^-\pi^0\eta$ | LF | < 2.2 | $\times 10^{-5}$ CL=90% | 784 |
| $\frac{\overline{p}}{\overline{p}}\gamma$ | L,B | < 3.5 | $\times10^{-6}$ CL=90% | 641 |
| $\frac{1}{\overline{\rho}}\pi^0$ | L,B | < 1.5 | $\times10^{-5}$ CL=90% | 632 |
| $\frac{r}{\overline{\rho}}2\pi^0$ | L,B | < 3.3 | $\times 10^{-5}$ CL=90% | 604 |
| $\frac{\overline{D}}{\overline{D}}\eta$ | L,B | < 8.9 | $\times10^{-6}$ CL=90% | 475 |
| $\overline{p}\pi^0\eta$ | L,B | < 2.7 | $\times 10^{-5}$ CL=90% | 360 |
| $\Lambda \pi^{-}$ | L,B | < 7.2 | $\times 10^{-8} \text{ CL} = 90\%$ | 525 |
| $\overline{\Lambda}\pi^-$ | L,B | < 1.4 | $\times 10^{-7} \text{ CL} = 90\%$ | 525 |
| e^- light boson | LF | < 2.7 | $\times 10^{-3} \text{ CL} = 95\%$ | _ |
| μ^- light boson | LF | < 5 | $\times 10^{-3} \text{ CL} = 95\%$ | _ |
| | | • | | |

Heavy Charged Lepton Searches

L± - charged lepton

Mass m > 100.8 GeV, CL = 95% [h] Decay to νW .

L^{\pm} – stable charged heavy lepton

Mass m > 102.6 GeV, CL = 95%

Neutrino Properties

See the note on "Neutrino properties listings" in the Particle Listings.

Mass m < 2 eV (tritium decay)

Mean life/mass, $\tau/m > 300 \text{ s/eV}$, CL = 90% (reactor)

Mean life/mass, $\tau/m > 7 \times 10^9$ s/eV (solar)

Mean life/mass, $\tau/m > 15.4 \text{ s/eV}$, CL = 90% (accelerator)

Magnetic moment $\mu < 0.32 \times 10^{-10} \mu_B$, CL = 90% (solar)

Number of Neutrino Types

Number $N=2.984\pm0.008$ (Standard Model fits to LEP data) Number $N=2.92\pm0.05$ (S = 1.2) (Direct measurement of invisible Z width)

Neutrino Mixing

The following values are obtained through data analyses based on the 3-neutrino mixing scheme described in the review "Neutrino Mass, Mixing, and Oscillations" by K. Nakamura and S.T. Petcov in this *Review*.

```
\begin{array}{l} \sin^2(2\theta_{12}) = 0.857 \pm 0.024 \\ \Delta m^2_{21} = (7.50 \pm 0.20) \times 10^{-5} \text{ eV}^2 \\ \sin^2(2\theta_{23}) > 0.95 \text{ i}^1 \\ \Delta m^2_{32} = (2.32 ^{+0.12}_{-0.08}) \times 10^{-3} \text{ eV}^2 \text{ i}^1 \\ \sin^2(2\theta_{13}) = 0.098 \pm 0.013 \end{array}
```

Heavy Neutral Leptons, Searches for

For excited leptons, see Compositeness Limits below.

Stable Neutral Heavy Lepton Mass Limits

```
Mass m > 45.0 GeV, CL = 95\% (Dirac)
Mass m > 39.5 GeV, CL = 95\% (Majorana)
```

Neutral Heavy Lepton Mass Limits

```
Mass m>90.3 GeV, CL = 95% (Dirac \nu_L coupling to e, \mu, \tau; conservative case(\tau)) Mass m>80.5 GeV, CL = 95% (Majorana \nu_L coupling to e, \mu, \tau; conservative case(\tau))
```

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity. We do this when S > 1, which often indicates that the measurements are inconsistent. When S > 1.25, we also show in the Particle Listings an ideogram of the measurements. For more about S, see the Introduction.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

- [a] This is the best limit for the mode $e^- \to \nu \gamma$. The best limit for "electron disappearance" is 6.4×10^{24} yr.
- [b] See the "Note on Muon Decay Parameters" in the μ Particle Listings for definitions and details.
- [c] P_μ is the longitudinal polarization of the muon from pion decay. In standard V-A theory, $P_\mu=1$ and $\rho=\delta=3/4$.
- [d] This only includes events with the γ energy > 10 MeV. Since the $e^-\overline{\nu}_e\,\nu_\mu$ and $e^-\overline{\nu}_e\,\nu_\mu\gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.
- [e] See the relevant Particle Listings for the energy limits used in this measurement.
- [f] A test of additive vs. multiplicative lepton family number conservation.
- [g] Basis mode for the τ .
- [h] L^{\pm} mass limit depends on decay assumptions; see the Full Listings.
- [i] The limit quoted corresponds to the projection onto the $\sin^2(2\theta_{23})$ axis of the 90% CL contour in the $\sin^2(2\theta_{23}) \Delta m_{32}^2$ plane.
- [j] The sign of Δm_{32}^2 is not known at this time. The range quoted is for the absolute value.

QUARKS

The u--, d--, and s--quark masses are estimates of so-called "current-quark masses," in a mass-independent subtraction scheme such as $\overline{\text{MS}}$ at a scale $\mu\approx 2$ GeV. The c-- and b--quark masses are the "running" masses in the $\overline{\text{MS}}$ scheme. For the b---quark we also quote the 1S mass. These can be different from the heavy quark masses obtained in potential models.

и

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

$$m_u = 2.3^{+0.7}_{-0.5} \; {
m MeV} \ m_u/m_d = 0.38 - 0.58$$

Charge
$$= \frac{2}{3} e \quad I_Z = +\frac{1}{2}$$

d

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

$$\begin{array}{ll} m_d = 4.8^{+0.7}_{-0.3} \; {\rm MeV} & {\rm Charge} = -\frac{1}{3} \; e \quad {\it I}_z = -\frac{1}{2} \\ m_s/m_d = 17\text{-}22 \end{array}$$

$$\overline{m} = (m_u + m_d)/2 = 3.2-4.4 \text{ MeV}$$

$$I(J^P)=0(\tfrac{1}{2}^+)$$

$$m_{\rm S}=95\pm 5~{\rm MeV}~{\rm Charge}=-\frac{1}{3}~e~{\rm Strangeness}=-1$$
 $m_{\rm S}~/~((m_u+m_d)/2)=27\pm 1$

$$I(J^P) = 0(\frac{1}{2}^+)$$

$$m_c = 1.275 \pm 0.025 \text{ GeV}$$

$$\mathsf{Charge} = \tfrac{2}{3} \; e \quad \mathsf{Charm} = +1$$



$$I(J^P) = 0(\frac{1}{2}^+)$$

Charge
$$= -\frac{1}{3} e$$
 Bottom $= -1$

$$m_b(\overline{\text{MS}}) = 4.18 \pm 0.03 \text{ GeV}$$

 $m_b(1\text{S}) = 4.65 \pm 0.03 \text{ GeV}$



$$I(J^P) = 0(\frac{1}{2}^+)$$

Charge
$$=\frac{2}{3}e$$

$$\mathsf{Top} = +1$$

Mass (direct measurements) $m=173.5\pm0.6\pm0.8$ GeV $^{[a,b]}$ Mass ($\overline{\rm MS}$ from cross-section measurements) $m=160^{+5}_{-4}$ GeV $^{[a]}$ m $_t-m_{\overline{t}}=-1.4\pm2.0$ GeV $^{~}$ (S = 1.6) Full width $\Gamma=2.0^{+0.7}_{-0.6}$ GeV

$$\Gamma(W b)/\Gamma(W q (q = b, s, d)) = 0.91 \pm 0.04$$

| t DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|---------------------------|------------------------------|------------------|---------------|
| $\overline{Wq(q=b,s,d)}$ | | | _ |
| W b | | | _ |
| ℓu_ℓ a nything | [c,d] (9.4 ± 2.4) % | | _ |
| $\gamma q(q=u,c)$ | $[e]$ < 5.9 \times | 10^{-3} 95% | _ |
| $\Delta T = 1 \text{ w}$ | eak neutral current (7 | 1) modes | |
| Zq(q=u,c) | T1 $[f] < 3.2$ % | 95 % | _ |

b' (4th Generation) Quark, Searches for

```
Mass m>190 GeV, CL = 95% (p\overline{p}, \text{quasi-stable }b')
Mass m>199 GeV, CL = 95% (p\overline{p}, \text{neutral-current decays})
Mass m>128 GeV, CL = 95% (p\overline{p}, \text{charged-current decays})
Mass m>46.0 GeV, CL = 95% (e^+e^-, \text{all decays})
```

t' (4th Generation) Quark, Searches for

Mass
$$m$$
 $(p\overline{p}, t'\overline{t}' \text{ prod.}, t' \rightarrow W q)$
Mass m

Free Quark Searches

All searches since 1977 have had negative results.

NOTES

- [a] A discussion of the definition of the top quark mass in these measurements can be found in the review "The Top Quark."
- [b] Based on published top mass measurements using data from Tevatron Run-I and Run-II and LHC at $\sqrt{s}=7$ TeV. Including the most recent unpublished results from Tevatron Run-II, the Tevatron Electroweak Working Group reports a top mass of 173.2 \pm 0.9 GeV. See the note "The Top Quark' in the Quark Particle Listings of this $\it Review$.
- [c] ℓ means e or μ decay mode, not the sum over them.
- [d] Assumes lepton universality and W-decay acceptance.
- [e] This limit is for $\Gamma(t \to \gamma q)/\Gamma(t \to W b)$.
- [f] This limit is for $\Gamma(t \to Zq)/\Gamma(t \to Wb)$.

Meson Summary Table

LIGHT UNFLAVORED MESONS (S = C = B = 0)

For I=1 (π,b,ρ,∂) : $u\overline{d}$, $(u\overline{u}-d\overline{d})/\sqrt{2}$, $d\overline{u}$; for I=0 $(\eta,\eta',h,h',\omega,\phi,f,f')$: $c_1(u\overline{u}+d\overline{d})+c_2(s\overline{s})$



$$I^{G}(J^{P}) = 1^{-}(0^{-})$$

Mass $m=139.57018\pm0.00035$ MeV ${\rm (S=1.2)}$ Mean life $\tau=(2.6033\pm0.0005)\times10^{-8}$ s ${\rm (S=1.2)}$ $c_{\tau}=7.8045$ m

$\pi^{\pm} \rightarrow \ell^{\pm} \nu \gamma$ form factors [a]

 $F_V = 0.0254 \pm 0.0017 \\ F_A = 0.0119 \pm 0.0001 \\ F_V \ \text{slope parameter} \ a = 0.10 \pm 0.06 \\ R = 0.059^{+0.009}_{-0.008}$

 π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

| π^+ DECAY MODES | Fraction (| Γ _i /Γ) | Confidence level | <i>p</i> (MeV/ <i>c</i>) |
|---------------------------------------|-------------|--------------------|----------------------|-------------------------------|
| $\mu^+ \nu_{\mu}$ | [b] (99.987 | 70 ± 0.000 | 04) % | 30 |
| $\mu^{\dot+} u_{\mu}\gamma$ | [c] (2.00 | ±0.25 | $) \times 10^{-4}$ | 30 |
| $e^+ u_e$ | [b] (1.230 | ±0.004 | $) \times 10^{-4}$ | 70 |
| $e^+ u_e \gamma$ | [c] (7.39 | ±0.05 | $) \times 10^{-7}$ | 70 |
| $e^+ u_e\pi^0$ | (1.036 | ±0.006 | $) \times 10^{-8}$ | 4 |
| $e^+ u_e\;e^+e^-$ | (3.2 | ±0.5 | $) \times 10^{-9}$ | 70 |
| $e^+ \nu_{\alpha} \nu \overline{\nu}$ | < 5 | | $\times 10^{-6}$ 90% | 70 |

Lepton Family number (LF) or Lepton number (L) violating modes

| $\mu^+ \overline{\nu}_e$ | L | [d] < 1.5 | $\times 10^{-3} 90\%$ | 30 |
|--------------------------|----|-----------|-----------------------|----|
| $\mu^+ \nu_e$ | LF | [d] < 8.0 | $\times 10^{-3}$ 90% | 30 |
| $\mu^-e^+e^+ u$ | LF | < 1.6 | $\times 10^{-6}$ 90% | 30 |



$$I^{G}(J^{PC}) = 1^{-}(0^{-}+)$$

Mass $m=134.9766\pm0.0006$ MeV (S = 1.1) $m_{\pi^\pm}-m_{\pi^0}=4.5936\pm0.0005$ MeV Mean life $\tau=(8.52\pm0.18)\times10^{-17}$ s (S = 1.2) $c\tau=25.5$ nm

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion) and Other Light Boson (X^0) Searches, etc.).

| π^0 DECAY MODES | Fraction (Γ_i/Γ) | Scale fac Confidence l | tor/ <i>p</i> evel (MeV/ <i>c</i>) |
|------------------------------------|------------------------------|------------------------------------|----------------------------------------|
| 2γ | (98.823±0.03 | 4) % S= | =1.5 67 |
| $e^+e^-\gamma$ | (1.174 ± 0.03) | 5) % S= | =1.5 67 |
| γ positronium | (1.82 ±0.29 | $) \times 10^{-9}$ | 67 |
| $e^{+}e^{+}e^{-}e^{-}$ | (3.34 ±0.16 | $) \times 10^{-5}$ | 67 |
| e^+e^- | (6.46 ±0.33 | $) \times 10^{-8}$ | 67 |
| 4γ | < 2 | $\times 10^{-8} \text{ CL} = 0.00$ | 90% 67 |
| $\nu \overline{\nu}$ | [e] < 2.7 | $\times 10^{-7}$ CL= | 90% 67 |
| $ u_e \overline{ u}_e$ | < 1.7 | $\times 10^{-6}$ CL= | 90% 67 |
| $ u_{\mu} \overline{ u}_{\mu}$ | < 1.6 | $\times 10^{-6}$ CL= | 90% 67 |
| $\nu_{\tau} \overline{\nu}_{\tau}$ | < 2.1 | $\times 10^{-6} \text{ CL} = 0.00$ | 90% 67 |
| $\gamma \nu \overline{ u}$ | < 6 | $\times10^{-4}$ CL= | 90% 67 |
| | | | |

Charge conjugation (C) or Lepton Family number (LF) violating modes

| 3γ | С | < 3.1 | $\times 10^{-8}$ CL=90% | 67 |
|---------------------------------|----|-------|------------------------------------|----|
| μ^+ e^- | LF | < 3.8 | $\times10^{-10}{\rm CL}\!=\!90\%$ | 26 |
| $\mu^- e^+$ | LF | < 3.4 | $\times 10^{-9} \text{ CL} = 90\%$ | 26 |
| $\mu^{+} e^{-} + \mu^{-} e^{+}$ | LF | < 3.6 | $\times10^{-10}{\rm CL}\!=\!90\%$ | 26 |



$$I^{G}(J^{PC}) = 0^{+}(0^{-}+)$$

Mass $m=547.853\pm0.024$ MeV Full width $\Gamma=1.30\pm0.07$ keV

C-nonconserving decay parameters

 $\begin{array}{ll} \pi^+\pi^-\pi^0 & \text{left-right asymmetry} = (0.09 \, ^{+0.11}_{-0.12}) \times 10^{-2} \\ \pi^+\pi^-\pi^0 & \text{sextant asymmetry} = (0.12 \, ^{+0.10}_{-0.11}) \times 10^{-2} \\ \pi^+\pi^-\pi^0 & \text{quadrant asymmetry} = (-0.09 \pm 0.09) \times 10^{-2} \\ \pi^+\pi^-\gamma & \text{left-right asymmetry} = (0.9 \pm 0.4) \times 10^{-2} \\ \pi^+\pi^-\gamma & \beta \; (\text{D-wave}) = -0.02 \pm 0.07 \quad (\text{S} = 1.3) \end{array}$

CP-nonconserving decay parameters

 $\pi^+\pi^-\,e^+\,e^-$ decay-plane asymmetry $A_\phi=(-0.6\pm3.1) imes10^{-2}$

Scale factor/

Dalitz plot parameter

 $\pi^0 \pi^0 \pi^0$ $\alpha = -0.0315 \pm 0.0015$

| η DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | |
|----------------------------------|------------------------------|-------------------------|------|
| | Neutral modes | | |
| neutral modes | (71.91 ± 0.34) % | S=1.2 | _ |
| 2γ | (39.31±0.20) % | S=1.1 | 274 |
| $3\pi^{0}$ | (32.57 ± 0.23) % | S=1.1 | 179 |
| $\pi^0 2\gamma$ | $(2.7 \pm 0.5) \times$ | 10^{-4} S=1.1 | 25 7 |
| $2\pi^0 2\gamma$ | < 1.2 × | 10^{-3} CL=90% | 238 |
| 4γ | < 2.8 × | 10 ⁻⁴ CL=90% | 274 |
| invisible | < 6 × | 10 ⁻⁴ CL=90% | _ |
| | Charged modes | | |
| charged modes | (28.10±0.34) % | S=1.2 | - |
| $\pi^+\pi^-\pi^0$ | (22.74±0.28) % | S=1.2 | 174 |
| $\pi^+\pi^-\gamma$ | (4.60±0.16) % | S=2.0 | 236 |
| $e^+ e^- \gamma$ | (6.9 \pm 0.4) $	imes$ | 10 ⁻³ S=1.2 | 274 |
| $\mu^+\mu^-\gamma$ | $(3.1 \pm 0.4) \times$ | 10^{-4} | 25 3 |
| $e^+ e^-$ | < 5.6 × | 10 ⁻⁶ CL=90% | 274 |
| $\mu^+\mu^-$ | (5.8 \pm 0.8) $	imes$ | 10^{-6} | 25 3 |
| 2e ⁺ 2e ⁻ | $(2.40 \pm 0.22) \times$ | 10^{-5} | 274 |
| $\pi^+\pi^-e^+e^-(\gamma)$ | (2.68±0.11) × | 10^{-4} | 235 |
| $e^{+}\ e^{-}\ \mu^{+}\ \mu^{-}$ | < 1.6 × | | 25 3 |
| $2\mu^{+}2\mu^{-}$ | < 3.6 × | 10 ⁻⁴ CL=90% | 161 |
| $\mu^{+}\mu^{-}\pi^{+}\pi^{-}$ | < 3.6 × | 10 ⁻⁴ CL=90% | 113 |
| $\pi^+\pi^-$ 2 γ | | 10-3 | 236 |
| $\pi^+\pi^-\pi^0\gamma$ | | 10 ⁻⁴ CL=90% | 174 |
| $\pi^0\mu^+\mu^-\gamma$ | < 3 × | 10 ⁻⁶ CL=90% | 210 |

Charge conjugation (C), Parity (P), Charge conjugation \times Parity (CP), or Lepton Family number (LF) violating modes

| $\pi^0 \gamma$ | C | < | 9 | $\times 10^{-5}$ | CL=90% | 25 7 |
|---------------------------------|------|-----|-----|------------------|--------|------|
| $\pi^{+} \pi^{-}$ | P,CP | < | 1.3 | $\times 10^{-5}$ | CL=90% | 236 |
| $2\pi^{0}$ | P,CP | < | 3.5 | $\times 10^{-4}$ | CL=90% | 238 |
| $2\pi^0 \gamma$ | C | < | 5 | $\times 10^{-4}$ | CL=90% | 238 |
| $3\pi^0\gamma$ | C | < | 6 | $\times 10^{-5}$ | CL=90% | 179 |
| 3γ | C | < | 1.6 | $\times 10^{-5}$ | CL=90% | 274 |
| $4\pi^0$ | P,CP | < | 6.9 | $\times 10^{-7}$ | CL=90% | 40 |
| $\pi^0 e^+ e^-$ | C | [f] | 4 | $\times 10^{-5}$ | CL=90% | 25 7 |
| $\pi^0\mu^+\mu^-$ | C | [f] | 5 | $\times 10^{-6}$ | CL=90% | 210 |
| $\mu^{+} e^{-} + \mu^{-} e^{+}$ | LF | < | 6 | $\times 10^{-6}$ | CL=90% | 264 |
| | | | | | | |

$f_0(500)$ or $\sigma^{[g]}$ was $f_0(600)$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})^{+}$$

Mass m = (400-550) MeVFull width $\Gamma = (400-700) \text{ MeV}$

| f ₀ (500) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------|------------------------------|-----------|
| $\pi\pi$ | dominant | = |
| $\gamma \gamma$ | seen | _ |



$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

Mass $m=775.49\pm0.34$ MeV Full width $\Gamma=149.1\pm0.8$ MeV $\Gamma_{ee}=7.04\pm0.06$ keV

Meson Summary Table

| ρ(770) DECAY MODES | Fraction (Γ_i/Γ) | | Scale factor/ Confidence level | |
|---------------------------------------------------|------------------------------------|------------------------|-----------------------------------|------|
| $\pi\pi$ | ~ 100 | % | | 363 |
| | $\rho(770)^{\pm}$ dec | ays | | |
| $\pi^{\pm}\gamma$ | (4.5 ± 0.5 |)×10 ⁻⁴ | S=2.2 | 375 |
| $\pi^{\pm}\eta$ | < 6 | $\times 10^{-3}$ | CL=84% | 153 |
| $\pi^{\pm} \stackrel{,}{\pi^{+}} \pi^{-} \pi^{0}$ | < 2.0 | $\times 10^{-3}$ | CL=84% | 254 |
| | $ ho$ (770) 0 dec | ays | | |
| $\pi^+\pi^-\gamma$ | (9.9 ± 1.6) | $) \times 10^{-3}$ | | 362 |
| $\pi^0 \gamma$ | (6.0 ± 0.8 | | | 376 |
| $\eta \gamma$ | $(3.00 \pm 0.20$ | $) \times 10^{-4}$ | | 194 |
| $\eta \gamma \atop \pi^0 \pi^0 \gamma$ | (4.5 ± 0.8 | $) \times 10^{-5}$ | | 363 |
| $\mu^+\mu^-$ | [i] (4.55 ± 0.28 | | | 373 |
| e ⁺ e ⁻ | [i] (4.72 ± 0.05 | | | 388 |
| $\pi^+\pi^-\pi^0$ | $(1.01 {}^{+ 0.54}_{- 0.36} \pm$ | $0.34) \times 10^{-4}$ | | 323 |
| $\pi^{+} \pi^{-} \pi^{+} \pi^{-}$ | (1.8 ± 0.9) | $) \times 10^{-5}$ | | 251 |
| $\pi^{+} \pi^{-} \pi^{0} \pi^{0}$ | (1.6 ± 0.8 | _ | | 25 7 |
| $\pi^0 \; e^+ \; e^-$ | < 1.2 | ×10 ⁻⁵ | CL=90% | 376 |

 ω (782)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=782.65\pm0.12$ MeV (S = 1.9) Full width $\Gamma=8.49\pm0.08$ MeV $\Gamma_{ee}=0.60\pm0.02$ keV

| | | Scale factor/ | |
|--------------------------------------|------------------------------|-------------------------|----------|
| ω(782) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | (MeV/c) |
| $\pi^{+} \pi^{-} \pi^{0}$ | $(89.2 \pm 0.7)\%$ | | 327 |
| $\pi^0 \gamma$ | (8.28 ± 0.28) % | S=2.1 | 380 |
| $\pi^+\pi^-$ | $(1.53^{+0.11}_{-0.13})$ % | S=1.2 | 366 |
| neutrals (excluding $\pi^0\gamma$) | (8 +8)× | $_{10^{-3}}$ S=1.1 | - |
| $\eta \gamma \over \pi^0 e^+ e^-$ | (4.6 \pm 0.4) $	imes$ | 10 ⁻⁴ S=1.1 | 200 |
| | (7.7 \pm 0.6) \times | 10^{-4} | 380 |
| $\pi^0\mu^+\mu^-$ | (1.3 \pm 0.4) \times | 10^{-4} S=2.1 | 349 |
| e^+e^- | $(7.28\pm0.14)\times$ | 10 ⁻⁵ S=1.3 | 391 |
| $\pi^{+} \pi^{-} \pi^{0} \pi^{0}$ | < 2 × | 10 ⁻⁴ CL=90% | 262 |
| $\pi^+ \pi^- \gamma$ | < 3.6 × | 10^{-3} CL=95% | 366 |
| $\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ | < 1 × | 10 ⁻³ CL=90% | 25 6 |
| $\pi^0 \pi^0 \gamma$ | (6.6 ± 1.1) $	imes$ | 10-5 | 367 |
| $\eta \pi^0 \gamma$ | < 3.3 × | 10 ⁻⁵ CL=90% | 162 |
| $\mu^+\mu^-$ | $(9.0 \pm 3.1) \times$ | 10-5 | 377 |
| 3γ | < 1.9 × | 10 ⁻⁴ CL=95% | 391 |
| Charge conjugati | on (C) violating n | nodes | |
| $\eta \pi^0$ | < 2.1 × | 10 ⁻⁴ CL=90% | 162 |
| | < 2.1 × | 10 ⁻⁴ CL=90% | 367 |
| $3\pi^0$ | < 2.3 × | 10 ⁻⁴ CL=90% | 330 |

 $\eta'(958)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-}+)$$

Mass m= 957.78 \pm 0.06 MeV Full width $\Gamma=$ 0.199 \pm 0.009 MeV

| η'(958) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|-----------------------------------------------------------------------|---------------------------------------------------|------------------------|---------------|
| $\pi^+\pi^-\eta$ | (43.4 ±0.7)% | 6 | 232 |
| $ ho^0\gamma({ m including \ non-resonant} \ \pi^+ \ \pi^- \ \gamma)$ | (29.3 ±0.6) % | 6 | 165 |
| $\pi^0 \pi^0 \eta$ | (21.6 ± 0.8) % | 6 | 239 |
| $\omega \gamma$ | (2.75 ± 0.22) % | 6 | 159 |
| $\gamma \gamma$ | (2.18 ± 0.08) % | 6 | 479 |
| $3\pi^0$ | (1.68 ± 0.22) | < 10 ⁻³ | 430 |
| $\mu^+\mu^-\gamma$ | (1.07 ± 0.26) | < 10 ⁻⁴ | 467 |
| $\pi^+ \pi^- \mu^+ \mu^-$ | < 2.2 | < 10 ⁻⁴ 90% | 401 |
| $\pi^+ \pi^- \pi^0$ | $(3.6 \begin{array}{c} +1.1 \\ -0.9 \end{array})$ | × 10 ⁻³ | 428 |
| $\pi^{0} \rho^{0}$ | < 4 9 | 6 90% | 111 |
| $2(\pi^{+}\pi^{-})$ | < 2.4 | < 10 ^{−4} 90% | 372 |
| $\pi^{+} \pi^{-} 2\pi^{0}$ | < 2.6 | × 10 ⁻³ 90% | 376 |
| $2(\pi^+\pi^-)$ neutrals | < 1 % | 6 95% | _ |
| $2(\pi^{+}\pi^{-})\pi^{0}$ | < 1.9 | × 10 ⁻³ 90% | 298 |
| $2(\pi^{+}\pi^{-})2\pi^{0}$ | < 1 % | 6 95% | 197 |

| $3(\pi^+\pi^-)$ | < | 5 | $\times 10^{-4}$ | 90% | 189 |
|-----------------------|--------------------------------------------|---------------------------------------------------|--------------------|-----|------|
| $\pi^+\pi^-e^+e^-$ | | $(2.4 \begin{array}{c} +1.3 \\ -1.0 \end{array})$ | $) \times 10^{-3}$ | | 458 |
| $\gamma e^+ e^-$ | < | 9 | $\times 10^{-4}$ | 90% | 479 |
| $\pi^0 \gamma \gamma$ | < | 8 | $\times 10^{-4}$ | 90% | 469 |
| $4\pi^{0}$ | < | 5 | $\times 10^{-4}$ | 90% | 380 |
| $e^+ e^-$ | < | 2.1 | $\times 10^{-7}$ | 90% | 479 |
| invisible | < | 9 | $\times 10^{-4}$ | 90% | _ |
| j | Charge conjugation Lepton family number | | | | |
| $\pi^+\pi^-$ | P,CP < | 6 | $\times 10^{-5}$ | 90% | 458 |
| $\pi^{0} \pi^{0}$ | P,CP < | 4 | $\times 10^{-4}$ | 90% | 45 9 |
| $\pi^0 \; e^+ \; e^-$ | C [f] < | 1.4 | $\times 10^{-3}$ | 90% | 469 |
| ηe^+e^- | C [f] < | 2.4 | $\times 10^{-3}$ | 90% | 322 |
| 3γ | C < | 1.0 | $\times 10^{-4}$ | 90% | 479 |
| $\mu^+\mu^-\pi^0$ | C [f] < | 6.0 | $\times 10^{-5}$ | 90% | 445 |
| $\mu^+ \mu^- \eta$ | C [f] < | 1.5 | $\times 10^{-5}$ | 90% | 273 |
| $e\mu$ | LF < | 4.7 | $\times 10^{-4}$ | 90% | 473 |

f₀(980) [/]

$$I^{G}(J^{PC}) = 0^{+}(0^{+})^{+}$$

Mass $m=990\pm20~{\rm MeV}$ Full width $\Gamma=40~{\rm to}~100~{\rm MeV}$

| f ₀ (980) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------|------------------------------|-----------|
| $\pi\pi$ | dominant | 476 |
| $K\overline{K}$ | seen | 36 |
| $\gamma \gamma$ | seen | 495 |

a₀(980) [/]

$$I^{G}(J^{PC}) = 1^{-}(0^{+})^{+}$$

Mass $m=980\pm20~{\rm MeV}$ Full width $\Gamma=50~{\rm to}~100~{\rm MeV}$

| a ₀ (980) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------|------------------------------|------------|
| $\eta \pi$ | dominant | 319 |
| $K\overline{K}$ | seen | † |
| $\gamma \gamma$ | seen | 490 |

 $\phi(1020)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=1019.455\pm0.020$ MeV (S =1.1) Full width $\Gamma=4.26\pm0.04$ MeV (S =1.4)

| $\phi(1020)$ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-----------------------------------------------|---------------------------------------------------|-----------------------------------|-----|
| K+K- | (48.9 ±0.5 |) % S=1.1 | 127 |
| $K_L^0 K_S^0$ | (34.2 ± 0.4) |) % S=1.1 | 110 |
| $\rho \pi + \pi^{+} \pi^{-} \pi^{0}$ | (15.32 ± 0.32) |) % S=1.1 | - |
| $\eta \gamma$ | (1.309 ± 0.024) | | 363 |
| $\pi^0 \gamma$ | (1.27 ± 0.06) | $) \times 10^{-3}$ | 501 |
| $\ell^+\ell^-$ | _ | | 510 |
| e^+e^- | (2.954 ± 0.030) | | 510 |
| $\mu^+\mu^-$ | (2.87 ± 0.19) | | 499 |
| $\eta e^+ e^-$ | (1.15 ± 0.10) | | 363 |
| $\pi^{+}\pi^{-}$ | (7.4 ± 1.3) | | 490 |
| $\omega \pi^0$ | (4.7 ± 0.5) | , | 171 |
| $\omega \gamma$ | • | % CL=84% | 209 |
| $ ho\gamma$ | | $\times 10^{-5}$ CL=90% | 215 |
| $\pi^+\pi^-\gamma$ | (4.1 ± 1.3) | | 490 |
| $f_0(980)\gamma$ | (3.22 ± 0.19) | , | 29 |
| $\pi^0 \pi^0 \gamma$ | (1.13 ± 0.06) | • | 492 |
| $\pi^+\pi^-\pi^+\pi^-$ | $(4.0 \begin{array}{c} +2.8 \\ -2.2 \end{array})$ | $) \times 10^{-6}$ | 410 |
| $\pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0}$ | < 4.6 | $\times10^{-6}$ CL=90% | 342 |
| $\pi^0 \; e^+ \; e^-$ | (1.12 ± 0.28) |) × 10 ⁻⁵ | 501 |
| $\pi^0 \eta \gamma$ | (7.27 ± 0.30) | $) \times 10^{-5}$ S=1.5 | 346 |
| $a_0(980)\gamma$ | (7.6 ± 0.6) | $) \times 10^{-5}$ | 39 |
| $K^0\overline{K}^0\gamma$ | < 1.9 | $\times 10^{-8}$ CL=90% | 110 |
| $\eta'(958) \gamma$ | (6.25 ± 0.21) | $) \times 10^{-5}$ | 60 |
| $\eta \pi^0 \pi^0 \gamma$ | < 2 | $\times 10^{-5}$ CL=90% | 293 |
| $\mu^+ \mu^- \gamma$ | (1.4 ± 0.5) | $) \times 10^{-5}$ | 499 |
| $\rho\gamma\gamma$ | | $\times 10^{-4}$ CL=90% | 215 |
| $\eta \pi^+ \pi^-$ | < 1.8 | | 288 |
| $\eta \mu^+ \mu^-$ | < 9.4 | $\times 10^{-6}$ CL=90% | 321 |

Meson Summary Table

Lepton Faminly number (LF) violating modes

 $e^{\pm}\mu^{\mp}$ LF < 2 $imes 10^{-6}$ CL=90% 504

$h_1(1170)$

 $I^{G}(J^{PC}) = 0^{-}(1^{+})^{-}$

Mass $m=1170\pm20~{\rm MeV}$ Full width $\Gamma=360\pm40~{\rm MeV}$

| h ₁ (1170) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $\rho\pi$ | seen | 307 |

b₁ (1235)

$$I^{G}(J^{PC}) = 1^{+}(1^{+})$$

 $\label{eq:mass} \begin{array}{ll} \mbox{Mass} \ m = 1229.5 \pm 3.2 \ \mbox{MeV} & (\mbox{S} = 1.6) \\ \mbox{Full width} \ \Gamma = 142 \pm 9 \ \mbox{MeV} & (\mbox{S} = 1.2) \end{array}$

| b ₁ (1235) DECAY MODES | Fraction (f | · _i /Γ) | Confidence level | (MeV/c) |
|-----------------------------------------------------|----------------------|--------------------|------------------|----------|
| $\omega\pi$ [D/S amplitude ratio = 0.27 | domina 7 ± 0.027] | nt | | 348 |
| $\pi^{\pm}\gamma$ | (1.6±0 | .4) × 10 | _3 | 607 |
| ηho | seen | | | † |
| $\pi^{+} \pi^{+} \pi^{-} \pi^{0}$ | < 50 | % | 84% | 535 |
| $K^*(892)^{\pm} K^{\mp}$ | seen | | | † |
| $(K\overline{K})^{\pm}\pi^{0}$ | < 8 | % | 90% | 248 |
| $K_S^0 K_I^0 \pi^{\pm}$ | < 6 | % | 90% | 235 |
| K_S^0 K_L^0 π^\pm K_S^0 K_S^0 π^\pm | < 2 | % | 90% | 235 |
| $\phi\pi$ | < 1.5 | % | 84 % | 147 |

$a_1(1260)^{[k]}$

$$I^{G}(J^{PC}) = 1^{-}(1^{+})^{+}$$

Mass $m=1230\pm40$ MeV [/] Full width $\Gamma=250$ to 600 MeV

| $a_1(1260)$ DECAY MODES | Fraction (Γ_i/Γ) | $p \ (\text{MeV/}c)$ |
|--------------------------------------|------------------------------|-------------------------|
| $(\rho\pi)_{S-wave}$ | seen | 35 3 |
| $(ho\pi)_{D	ext{-wave}}$ | seen | 35 3 |
| $(\rho(1450)\pi)_{S-wave}$ | seen | † |
| $(\rho(1450)\pi)_{D-wave}$ | seen | † |
| $\sigma\pi$ | seen | - |
| $f_0(980)\pi$ | not seen | 179 |
| $f_0(1370)\pi$ | seen | † |
| $f_2(1270)\pi$ | seen | † |
| $K\overline{K}^*(892) + \text{c.c.}$ | seen | † |
| $\pi\gamma$ | seen | 608 |

f₂(1270)

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=1275.1\pm1.2~{\rm MeV}~{\rm (S=1.1)}$ Full width $\Gamma=185.1^{+2.9}_{-2.4}~{\rm MeV}~{\rm (S=1.5)}$

| f ₂ (1270) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-----------------------------------|------------------------------------------------------|-----------------------------------|-----|
| $\pi\pi$ | (84.8 + 2.4) % | S=1.2 | 623 |
| $\pi^{+} \pi^{-} 2 \pi^{0}$ | $(7.1 \begin{array}{c} +1.4 \\ -2.7 \end{array}) \%$ | S=1.3 | 562 |
| $K\overline{K}$ | $(4.6 \pm 0.4)\%$ | S=2.8 | 403 |
| $2\pi^{+}2\pi^{-}$ | $(2.8 \pm 0.4)\%$ | S=1.2 | 559 |
| $\eta\eta$ | (4.0 \pm 0.8) $	imes$ | 10^{-3} S=2.1 | 326 |
| $4\pi^0$ | (3.0 ± 1.0) $	imes$ | 10^{-3} | 564 |
| $\gamma\gamma$ | $(~1.64\pm0.19)~\times$ | 10^{-5} S=1.9 | 638 |
| $\eta \pi \pi$ | < 8 × | 10^{-3} CL=95% | 477 |
| $K^0 K^- \pi^+ + \text{ c.c.}$ | < 3.4 × | | 293 |
| $e^+ e^-$ | < 6 × | 10^{-10} CL=90% | 638 |

f₁ (1285)

$$I^{G}(J^{PC}) = 0^{+}(1^{+})$$

Mass $m=1282.1\pm0.6$ MeV (S = 1.7) Full width $\Gamma=24.2\pm1.1$ MeV (S = 1.3)

| f ₁ (1285) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-----------------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------------|-----|
| 4π | (33.1 + 2.1 / 1.8) % | S=1.3 | 568 |
| $\pi^0 \pi^0 \pi^+ \pi^-$ | $(22.0 {}^{+}_{-} {}^{1.4}_{1.2})$ % | S=1.3 | 566 |
| $2\pi^+2\pi^-$ | $(11.0{}^{+}_{-}{}^{0.7}_{0.6})$ % | S=1.3 | 563 |
| $ ho^0\pi^+\pi^-$ | $(11.0 {+} \atop {-} \ \stackrel{0.7}{0.6}) \%$ | S=1.3 | 336 |
| $4\pi^{0}$ ρ^{0} ρ^{0} | seen | | † |
| $4\pi^0$ | < 7 × 10 | $^{-4}$ CL=90% | 568 |
| $\eta \pi^+ \pi^-$ | $(35 \pm 15) \%$ | | 479 |
| $\eta\pi\pi$ | $(52.4^{+}_{-}\ \overset{1.9}{2.2})\ \%$ | S=1.2 | 482 |
| $a_0(980)\pi$ [ignoring $a_0(980) ightarrow \mathcal{K}\overline{\mathcal{K}}$] | (36 ± 7)% | | 238 |
| $\eta \pi \pi$ [excluding $a_0(980)\pi$] | $(16 \pm 7)\%$ | | 482 |
| $K\overline{K}\pi$ | $(9.0 \pm 0.4)\%$ | S=1.1 | 308 |
| <i>K</i> K *(892) | not seen | | † |
| $\pi^{+} \pi^{-} \pi^{0}$ | $(3.0 \pm 0.9) \times 10$ |)-3 | 603 |
| $\rho^{\pm}\pi^{\mp}$ | < 3.1 × 10 |) ⁻³ CL=95% | 390 |
| $\rho^{\pm}\pi^{\mp}$ $\gamma\rho^{0}$ | $(5.5 \pm 1.3)\%$ | S=2.8 | 407 |
| $\phi \gamma$ | (7.4 ± 2.6) × 10 |)-4 | 236 |

$\eta(1295)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

Mass m= 1294 \pm 4 MeV (S = 1.6) Full width $\Gamma=$ 55 \pm 5 MeV

| $\eta(1295)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------|------------------------------|-----------|
| $\eta \pi^+ \pi^-$ | seen | 487 |
| $a_0(980) \pi \\ \eta \pi^0 \pi^0$ | seen | 248 |
| $\eta \pi^0 \pi^0$ | seen | 490 |
| $\eta(\pi\pi)_{S-\text{wave}}$ | seen | - |

π (1300)

$$I^{G}(J^{PC}) = 1^{-}(0^{-})$$

Mass $m=1300\pm100$ MeV [/] Full width $\Gamma=200$ to 600 MeV

| $\pi(1300)$ DECAY MODES | Fraction (Γ_j/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| $\rho\pi$ | seen | 404 |
| $\pi(\pi\pi)_{S-\text{wave}}$ | seen | _ |

a₂(1320)

$$I^{G}(J^{PC}) = 1^{-}(2^{+})$$

Mass $m = 1318.3^{+0.5}_{-0.6}$ MeV (S = 1.2) Full width Γ = 107 ± 5 MeV [/]

| a ₂ (1320) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | <i>p</i> (MeV/ <i>c</i>) |
|-----------------------------------|------------------------------|-----------------------------------|-------------------------------|
| 3π | (70.1 ±2.7)% | S=1.2 | 624 |
| $\eta \pi$ | $(14.5 \pm 1.2) \%$ | | 5 35 |
| $\omega \pi \pi$ | (10.6 ± 3.2) % | S=1.3 | 366 |
| KΚ | $(4.9 \pm 0.8)\%$ | | 437 |
| $\eta'(958) \pi$ | (5.3 ± 0.9) $\times 1$ | .0-3 | 288 |
| $\pi^{\pm}\gamma$ | $(2.68 \pm 0.31) \times 1$ | .0-3 | 65 2 |
| $\gamma \gamma$ | $(9.4 \pm 0.7) \times 1$ | .0-6 | 65 9 |
| e ⁺ e ⁻ | < 5 × 1 | .0 ⁻⁹ CL=90% | 65 9 |

f₀(1370) [/]

 $I^{G}(J^{PC}) = 0^{+}(0^{+})$

Mass m=1200 to 1500 MeV Full width $\Gamma=200$ to 500 MeV

| f ₀ (1370) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $\pi\pi$ | seen | 672 |
| 4π | seen | 617 |
| $4\pi^0$ | seen | 617 |
| $2\pi^{+}2\pi^{-}$ | seen | 612 |
| $\pi^{+} \pi^{-} 2\pi^{0}$ | seen | 615 |
| ho ho | dominant | † |
| $2(\pi\pi)_{S-wave}$ | seen | - |
| $\pi(1300)\pi$ | seen | † |
| $a_1(1260)\pi$ | seen | 35 |
| $\eta \eta$ | seen | 411 |
| κ π | seen | 475 |
| $K\overline{K}$ n π | not seen | † |
| 6π | not seen | 508 |
| $\omega \omega$ | not seen | † |
| $\gamma \gamma$ | seen | 685 |
| e^+e^- | not seen | 685 |

π₁(1400) [m]

$$I^{G}(J^{PC}) = 1^{-}(1^{-})$$

Mass $m=1354\pm25~{\rm MeV}~{\rm (S}=1.8)$ Full width $\Gamma=330\pm35~{\rm MeV}$

| $\pi_1(1400)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------------|------------------------------|-----------|
| $\eta \pi^0$ | seen | 557 |
| $\eta \pi^-$ | seen | 556 |

 η (1405) [n]

$$I^{G}(J^{PC}) = 0^{+}(0^{-})$$

Mass m= 1408.9 \pm 2.4 MeV $^{[I]}$ (S = 2.3) Full width $\Gamma=$ 51.1 \pm 3.2 MeV $^{[I]}$ (S = 2.0)

| η(1405) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|-------------------------------------|------------------------------|------------------|---------------|
| $K\overline{K}\pi$ | seen | | 424 |
| $\eta \pi \pi$ | seen | | 562 |
| $a_0(980) \pi$ | seen | | 345 |
| $\eta(\pi\pi)_{S-wave}$ | seen | | _ |
| $f_0(980)\eta$ | seen | | † |
| 4π | seen | | 639 |
| ho ho | <58 % | 99.85% | † |
| $ ho^0 \overset{ ho}{\gamma}^{ ho}$ | seen | | 491 |
| $K^*(892) K$ | seen | | 123 |

f₁(1420) ^[o]

$$I^{G}(J^{PC}) = 0^{+}(1^{+})^{+}$$

Mass m= 1426.4 \pm 0.9 MeV (S = 1.1) Full width $\Gamma=$ 54.9 \pm 2.6 MeV

| f ₁ (1420) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------------|------------------------------|-----------|
| $\overline{K}\overline{K}\pi$ | dominant | 438 |
| $K\overline{K}^*(892) + \text{c.c.}$ | dominant | 163 |
| $\eta\pi\pi$ | possibly seen | 573 |
| $\phi\gamma$ | seen | 349 |

 ω (1420) [$^{
ho}$]

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass m (1400–1450) MeV Full width Γ (180–250) MeV

| ω(1420) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| $ ho\pi$ | dominant | 486 |
| $\omega \pi \pi$ | seen | 444 |
| $b_1(1235)\pi$ | seen | 125 |
| $e^{+}e^{-}$ | seen | 710 |

a₀(1450) ^[j]

$$I^{G}(J^{PC}) = 1^{-}(0^{+})$$

Mass $m=1474\pm19~{
m MeV}$ Full width $\Gamma=265\pm13~{
m MeV}$

| a ₀ (1450) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $\pi\eta$ | seen | 627 |
| $\pi \eta'(958)$ | seen | 410 |
| $K\overline{K}$ | seen | 547 |
| $\omega \pi \pi$ | seen | 484 |
| $a_0(980) \pi \pi$ | seen | 342 |
| $\gamma \gamma$ | seen | 737 |

ρ(1450) ^[q]

$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

Mass $m=1465\pm25$ MeV [/] Full width $\Gamma=400\pm60$ MeV [/]

| ho(1450) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------------|------------------------------|-----------|
| $\pi\pi$ | seen | 720 |
| 4π | seen | 669 |
| $e^+ e^-$ | seen | 732 |
| $\eta \rho$ | possibly seen | 310 |
| $a_2(1320)\pi$ | not seen | 54 |
| K K | not seen | 541 |
| $K\overline{K}^*(892) + \text{c.c.}$ | possibly seen | 229 |
| $\eta \gamma$ | possibly seen | 630 |
| $f_0(500)\gamma$ | not seen | = |
| $f_0(980)\gamma$ | not seen | 398 |
| $f_0(1370)\gamma$ | not seen | 92 |
| $f_2(1270)\gamma$ | not seen | 178 |

 $\eta(1475)^{[n]}$

$$I^{G}(J^{PC}) = 0^{+}(0^{-}+)$$

Mass $m=1476\pm4$ MeV (S = 1.3) Full width $\Gamma=85\pm9$ MeV (S = 1.5)

| η(1475) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------------|------------------------------|-----------|
| $K\overline{K}\pi$ | dominant | 477 |
| $K\overline{K}^*(892) + \text{c.c.}$ | seen | 245 |
| $a_0(980)\pi$ | seen | 396 |
| $\gamma \gamma$ | seen | 738 |
| | | |

f₀(1500) [m]

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

Mass $m=1505\pm 6~{\rm MeV}~{\rm (S=1.3)}$ Full width $\Gamma=109\pm 7~{\rm MeV}$

| f ₀ (1500) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor | <i>p</i> (Me <i>V/c</i>) |
|-----------------------------------|------------------------------|--------------|-------------------------------|
| $\pi\pi$ | (34.9±2.3) % | 1.2 | 741 |
| $\pi^+\pi^-$ | seen | | 740 |
| $2\pi^{0}$ | seen | | 741 |
| 4π | (49.5 ± 3.3) % | 1.2 | 691 |
| $4\pi^{0}$ | seen | | 691 |
| $2\pi^{+} 2\pi^{-}$ | seen | | 687 |
| $2(\pi\pi)_{S-wave}$ | seen | | - |
| ho ho | seen | | † |
| $\pi(1300)\pi$ | seen | | 144 |
| $a_1(1260)\pi$ | seen | | 218 |
| $\eta\eta$ | (5.1 ± 0.9) % | 1.4 | 516 |
| $\eta \eta'(958)$ | (1.9±0.8) % | 1.7 | † |
| $K\overline{K}$ | (8.6±1.0) % | 1.1 | 568 |
| $\gamma \gamma$ | not seen | | 75 3 |

f'₂(1525)

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=1525\pm 5~{\rm MeV}~{\rm [I]}$ Full width $\Gamma=73^{+6}_{-5}~{\rm MeV}~{\rm [I]}$

| $f_2'(1525)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|--------------------------------|-----------|
| KK | (88.7 ±2.2) % | 581 |
| $\eta \eta$ | (10.4 ± 2.2) % | 530 |
| $\pi\pi$ | $(8.2 \pm 1.5) \times 10^{-3}$ | 75 0 |
| $\gamma\gamma$ | $(1.11\pm0.14)\times10^{-6}$ | 763 |

π_1 (1600) [m]

$$I^G(J^{PC}) = 1^-(1^{-+})$$

Mass $m=1662^{+8}_{-9}~{\rm MeV}$ Full width $\Gamma=241\pm40~{\rm MeV}~{\rm (S=1.4)}$

| $\pi_1(1600)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------------|------------------------------|-----------|
| $\pi\pi\pi$ | not seen | 803 |
| $ ho^0 \pi^-$ | not seen | 641 |
| $f_2(1270)\pi^-$ | not seen | 318 |
| $b_1(1235)\pi$ | seen | 35 7 |
| $\eta'(958)\pi^-$ | seen | 543 |
| $f_1(1285)\pi$ | seen | 314 |

$\eta_2(1645)$

$$I^{G}(J^{PC}) = 0^{+}(2^{-}+)$$

Mass m= 1617 \pm 5 MeV Full width $\Gamma=$ 181 \pm 11 MeV

| $\eta_2(1645)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------|------------------------------|-----------|
| $a_2(1320)\pi$ | seen | 242 |
| $K\overline{K}\pi$ | seen | 580 |
| $K^*\overline{K}$ | seen | 404 |
| $\eta \pi^+ \pi^-$ | seen | 685 |
| $a_0(980)\pi$ | seen | 499 |
| $f_2(1270)\eta$ | not seen | † |

ω(1650) [r]

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass m= 1670 \pm 30 MeV Full width $\Gamma=$ 315 \pm 35 MeV

| $\omega(1650)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------|------------------------------|-----------|
| $\rho\pi$ | seen | 646 |
| $\omega \pi \pi$ | seen | 617 |
| $\omega \eta$ | seen | 500 |
| e^+e^- | seen | 835 |

$\omega_3(1670)$

$$I^{G}(J^{PC}) = 0^{-}(3^{-})$$

Mass $m=1667\pm4~{\rm MeV}$ Full width $\Gamma=168\pm10~{\rm MeV}$ [/]

| ω_3 (1670) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| $\rho\pi$ | seen | 645 |
| $\omega \pi \pi$ | seen | 615 |
| $b_1(1235)\pi$ | possibly seen | 361 |

$\pi_2(1670)$

$$I^{G}(J^{PC}) = 1^{-}(2^{-})$$

Mass $m=1672.2\pm3.0$ MeV $^{[I]}$ (S = 1.4) Full width $\Gamma=260\pm9$ MeV $^{[I]}$ (S = 1.2)

| $\pi_2(1670)$ DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | (MeV/c) |
|--------------------------------------|------------------------------|------------------|----------|
| 3π | (95.8±1.4) % | | 809 |
| $f_2(1270)\pi$ | (56.3 ± 3.2) % | | 329 |
| $ ho\pi$ | (31 ±4) % | | 648 |
| $\sigma\pi$ | (10.9 ± 3.4) % | | _ |
| $(\pi\pi)_{S-wave}$ | $(8.7 \pm 3.4) \%$ | | - |
| $K\overline{K}^*(892) + \text{c.c.}$ | $(4.2 \pm 1.4)\%$ | | 455 |
| $\omega \rho$ | $(2.7 \pm 1.1) \%$ | | 304 |
| $\gamma \gamma$ | < 2.8 × 1 | .0-7 90% | 836 |
| $\rho(1450)\pi$ | < 3.6 × 1 | 0^{-3} 97.7% | 147 |
| $b_1(1235)\pi$ | < 1.9 × 1 | 0^{-3} 97.7% | 365 |
| $f_1(1285)\pi$ | possibly seen | | 323 |
| $a_2(1320)\pi$ | not seen | | 292 |

$\phi(1680)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=1680\pm20$ MeV ^[/] Full width $\Gamma=150\pm50$ MeV ^[/]

| φ(1680) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| $K\overline{K}^*(892) + c.c.$ | dominant | 462 |
| $K_{\underline{S}}^{0}K\pi$ | seen | 621 |
| $K\overline{K}$ | seen | 680 |
| e^+e^- | seen | 840 |
| $\omega \pi \pi$ | not seen | 623 |
| $K^+ K^- \pi^+ \pi^-$ | seen | 544 |

$\rho_3(1690)$

$$I^{G}(J^{PC}) = 1^{+}(3^{-})$$

Mass $m=1688.8\pm 2.1$ MeV ^[/] Full width $\Gamma=161\pm 10$ MeV ^[/] (S = 1.5)

| $ ho_3(1690)$ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor | <i>p</i> (Me <i>V/c</i>) |
|-----------------------------------------------------|------------------------------|--------------|-------------------------------|
| 4π | (71.1 ± 1.9)% | | 790 |
| $\pi^{\pm} \pi^{+} \pi^{-} \pi^{0}$ | $(67 \pm 22)\%$ | | 787 |
| $\omega\pi$ | $(16 \pm 6)\%$ | | 655 |
| $\pi\pi$ | $(23.6 \pm 1.3)\%$ | | 834 |
| $K\overline{K}\pi$ | $(3.8 \pm 1.2)\%$ | | 629 |
| $K\overline{K}$ | (1.58 ± 0.26) % | 1.2 | 685 |
| $\eta \pi^+ \pi^-$ | seen | | 727 |
| $\rho(770)\eta$ | seen | | 520 |
| $\pi\pi\rho$ Excluding 2ρ and $a_2(1320)\pi$. | seen | | 633 |
| $a_2(1320)\pi$ | seen | | 307 |
| ho ho | seen | | 334 |

ρ(1700) [q]

$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

Mass $m=1720\pm20$ MeV $^{[I]}$ $(\eta \rho^0$ and $\pi^+\pi^-$ modes) Full width $\Gamma=250\pm100$ MeV $^{[I]}$ $(\eta \rho^0$ and $\pi^+\pi^-$ modes)

| ho(1700) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------------------|------------------------------|------------|
| $2(\pi^{+}\pi^{-})$ | large | 803 |
| $\rho\pi\pi$ | dominant | 653 |
| $ ho^0 \pi^+ \pi^- \ ho^\pm \pi^\mp \pi^0$ | large | 65 0 |
| $ ho^{\pm}\pi^{\mp}\pi^{0}$ | large | 65 2 |
| $a_1(1260)\pi$ | seen | 404 |
| $h_1(1170)\pi$ | seen | 447 |
| $\pi(1300)\pi$ | seen | 349 |
| ho ho | seen | 372 |
| $\pi^+ \pi^-$ | seen | 849 |
| $\pi\pi$ | seen | 849 |
| $K\overline{K}^*(892) + \text{c.c.}$ | seen | 496 |
| $\eta \rho$ | seen | 545 |
| a ₂ (1320)π | not seen | 334 |
| $K\overline{K}$ | seen | 704 |
| e+ e- | seen | 860 |
| $\pi^0 \omega$ | seen | 674 |

f₀(1710) [s]

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

Mass $m=1720\pm 6$ MeV (S=1.6) Full width $\Gamma=135\pm 8$ MeV (S=1.1)

| f ₀ (1710) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|------------|
| $\overline{\kappa}\overline{K}$ | seen | 704 |
| $\eta\eta$ | seen | 663 |
| $\pi\pi$ | seen | 849 |
| $\omega \omega$ | seen | 35 7 |

$\pi(1800)$

$$I^{G}(J^{PC}) = 1^{-}(0^{-}+)$$

Mass $m=1812\pm12~{\rm MeV}~{\rm (S}=2.3)$ Full width $\Gamma=208\pm12~{\rm MeV}$

| $\pi(1800)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------|------------------------------|-----------|
| $\pi^{+}\pi^{-}\pi^{-}$ | seen | 879 |
| $f_0(500)\pi^-$ | seen | _ |
| $f_0(980)\pi^-$ | seen | 625 |
| $f_0(1370)\pi^-$ | seen | 368 |
| $f_0(1500)\pi^-$ | not seen | 25 0 |
| $ ho\pi^-$ | not seen | 732 |
| $\eta \eta \pi^-$ | seen | 661 |
| $a_0(980) \eta$ | seen | 473 |
| $a_2(1320)\eta$ | not seen | † |
| $f_2(1270)\pi$ | not seen | 442 |
| $f_0(1370)\pi^-$ | not seen | 368 |
| $f_0(1500)\pi^-$ | seen | 25 0 |
| $\eta \eta'(958) \pi^-$ | seen | 375 |
| $K_0^*(1430)K^-$ | seen | † |
| K*(892) K- | not seen | 570 |
| | | |

$\phi_3(1850)$

$$I^{G}(J^{PC}) = 0^{-}(3^{-})$$

Mass $m=1854\pm7~\text{MeV}$ Full width $\Gamma=87^{+28}_{-23}~\text{MeV}~(S=1.2)$

| ϕ_3 (1850) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------------|------------------------------|-----------|
| KK | seen | 785 |
| $K\overline{K}^*(892) + \text{c.c.}$ | seen | 602 |

$\pi_2(1880)$

$$I^{G}(J^{PC}) = 1^{-}(2^{-})$$

Mass $m=1895\pm16~{\rm MeV}$ Full width $\Gamma=235\pm34~{\rm MeV}$

f₂(1950)

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass m= 1944 \pm 12 MeV (S = 1.5) Full width $\Gamma=$ 472 \pm 18 MeV

| f ₂ (1950) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $K^*(892)\overline{K}^*(892)$ | seen | 387 |
| $\pi^+\pi^-$ | seen | 962 |
| $\pi^{0}\pi^{0}$ | seen | 963 |
| 4π | seen | 925 |
| $\eta \eta_{\underline{}}$ | seen | 803 |
| KΚ | seen | 837 |
| $\gamma \gamma$ | seen | 972 |
| p p | seen | 254 |

$f_2(2010)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=2011^{+60}_{-80}~{\rm MeV}$ Full width $\Gamma=202\pm60~{\rm MeV}$

| f ₂ (2010) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $\phi \phi$ | seen | † |
| KΚ | seen | 876 |

a₄ (2040)

$$I^{G}(J^{PC}) = 1^{-}(4^{+})$$

Mass $m = 1996^{+10}_{-9} \text{ MeV} \quad (S = 1.1)$ Full width $\Gamma = 255^{+28}_{-24} \text{ MeV} \quad (S = 1.3)$

| a ₄ (2040) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------------|------------------------------|-----------|
| KK | seen | 868 |
| $\pi^{+} \pi^{-} \pi^{0}$ | seen | 974 |
| $ ho\pi$ | seen | 841 |
| $f_2(1270)\pi$ $\omega \pi^- \pi^0$ | seen | 580 |
| $\omega \pi^- \pi^0$ | seen | 819 |
| $\frac{\omega}{\eta} \frac{\rho}{\pi^0}$ | seen | 624 |
| | seen | 918 |
| $\eta'(958) \pi$ | seen | 761 |

f₄(2050)

$$I^{G}(J^{PC}) = 0^{+}(4^{+})$$

Mass $m=2018\pm11$ MeV (S = 2.1) Full width $\Gamma=237\pm18$ MeV (S = 1.9)

| f4(2050) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) | |
|----------------------|--------------------------------------|-----------|--|
| $\omega \omega$ | seen | 637 | |
| $\pi\pi$ | (17.0 ± 1.5) % | 1000 | |
| KK | $(6.8^{+3.4}_{-1.8}) \times 10^{-3}$ | 880 | |
| $\eta\eta$ | $(2.1\pm0.8)\times10^{-3}$ | 848 | |
| $4\pi^0$ | < 1.2 % | 964 | |
| $a_2(1320)\pi$ | seen | 567 | |

$\phi(2170)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=2175\pm15~{\rm MeV}~{\rm (S}=1.6)$ Full width $\Gamma=61\pm18~{\rm MeV}$

| $\phi(2170)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------------------------------------------------------------|------------------------------|-----------|
| e^+e^- | seen | 1087 |
| $\phi f_0(980)$ | seen | 416 |
| $K^+ K^- f_0(980) \rightarrow$ | seen | _ |
| $K^{+}K^{-}\pi^{+}\pi^{-}$ $K^{+}K^{-}f_{0}(980) \rightarrow K^{+}K^{-}\pi^{0}\pi^{0}$ | seen | - |
| $K^{*0}K^{\pm}\pi^{\mp}$ | not seen | 770 |
| $K^*(892)^0 \overline{K}^*(892)^0$ | not seen | 622 |

f₂(2300)

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=2297\pm28~{\rm MeV}$ Full width $\Gamma=149\pm40~{\rm MeV}$

| f ₂ (2300) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) | |
|-----------------------------------|------------------------------|-----------|--|
| φφ Κ <u>Κ</u> | seen | 5 29 | |
| $K\overline{K}$ | seen | 1037 | |
| $\gamma \gamma$ | seen | 1149 | |

$f_2(2340)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=2339\pm60$ MeV Full width $\Gamma=319^{+80}_{-70}$ MeV

| f ₂ (2340) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) | |
|-----------------------------------|------------------------------|------------|--|
| $\phi \phi$ | seen | 573 | |
| $\eta \eta$ | seen | 1033 | |

STRANGE MESONS $(S = \pm 1, C = B = 0)$

 $K^+ = u\overline{s}$, $K^0 = d\overline{s}$, $\overline{K}^0 = \overline{d}s$, $K^- = \overline{u}s$, similarly for K^* 's

Κ±

$$I(J^P) = \frac{1}{2}(0^-)$$

Mass $m=493.677\pm0.016$ MeV $^{[t]}$ (S = 2.8) Mean life $\tau=(1.2380\pm0.0021)\times10^{-8}$ s (S = 1.9) $c\tau=3.712$ m

Slope parameter $g^{[u]}$

(See Particle Listings for quadratic coefficients and alternative parametrization related to $\pi\pi$ scattering)

$$\begin{array}{ll} \mathcal{K}^{\pm} \rightarrow & \pi^{\pm}\pi^{+}\pi^{-} \; g = -0.21134 \; \pm \; 0.00017 \\ & (g_{+} - g_{-}) \; / \; (g_{+} + g_{-}) = (-1.5 \; \pm \; 2.2) \times 10^{-4} \\ \mathcal{K}^{\pm} \rightarrow & \pi^{\pm}\pi^{0} \, \pi^{0} \; g = \; 0.626 \; \pm \; 0.007 \\ & (g_{+} - g_{-}) \; / \; (g_{+} + g_{-}) = (1.8 \; \pm \; 1.8) \times 10^{-4} \end{array}$$

K^{\pm} decay form factors [a,v]

Assuming μ -e universality

$$\lambda_{+}(K_{\mu 3}^{+}) = \lambda_{+}(K_{e 3}^{+}) = (2.97 \pm 0.05) \times 10^{-2}$$

 $\lambda_{0}(K_{\mu 3}^{+}) = (1.95 \pm 0.12) \times 10^{-2}$

| Not assuming μ - e universality |
|----------------------------------------------------------------------------------------------------|
| $\lambda_{+}(K_{e3}^{+}) = (2.98 \pm 0.05) \times 10^{-2}$ |
| $\lambda_{+}(K_{\mu 3}^{+}) = (2.96 \pm 0.17) \times 10^{-2}$ |
| $\lambda_0(K_{\mu 3}^+) = (1.96 \pm 0.13) \times 10^{-2}$ |
| $K_{ m e3}$ form factor quadratic fit |
| λ'_+ (K^\pm_{e3}) linear coeff. $=(2.49\pm0.17)	imes10^{-2}$ |
| $\lambda''_{+}(K_{e3}^{\pm})$ quadratic coeff. $=(0.19\pm0.09)	imes10^{-2}$ |
| $K_{e3}^+ \mid f_S/f_+ \mid = (-0.3^{+0.8}_{-0.7}) \times 10^{-2}$ |
| $K_{e3}^+ f_T/f_+ = (-1.2 \pm 2.3) \times 10^{-2}$ |
| $K_{\mu 3}^{+} f_S/f_+ = (0.2 \pm 0.6) \times 10^{-2}$ |
| $K_{\mu 3}^{+} f_T/f_+ = (-0.1 \pm 0.7) \times 10^{-2}$ |
| $K^{+} \rightarrow e^{+} \nu_{e} \gamma F_{A} + F_{V} = 0.133 \pm 0.008 \text{ (S = 1.3)}$ |
| $K^+ \to \mu^+ \nu_\mu \gamma F_A + F_V = 0.165 \pm 0.013$ |
| $K^+ \rightarrow e^+ \nu_e \gamma F_A - F_V < 0.49$ |
| $K^+ ightarrow \left. \mu^+ u_\mu \gamma \left F_A - F_V ight = -$ 0.24 to 0.04, CL $= 90\%$ |
| harge Radius |
| /-/ 0.500 1.0.001 f |

Ch

 $\langle r \rangle = 0.560 \pm 0.031 \text{ fm}$

CP violation parameters

$$\begin{array}{l} \Delta(K_{\pi\,e\,e}^{\pm}) = (-2.2\pm1.6)\times10^{-2} \\ \Delta(K_{\pi\,\mu\,\mu}^{\pm}) = 0.010\pm0.023 \\ \Delta(K_{\pi\,\pi\,\gamma}^{\pm}) = (0.0\pm1.2)\times10^{-3} \\ A_{FB}(K_{\pi\,\mu\,\mu}^{\pm}) = \frac{\Gamma(\cos(\theta_{K\,\mu})>0) - \Gamma(\cos(\theta_{K\,\mu})<0)}{\Gamma(\cos(\theta_{K\,\mu})>0) + \Gamma(\cos(\theta_{K\,\mu})<0)} \ < \ 2.3\times10^{-2}, \, \mathrm{CL} \\ = 90\% \end{array}$$

T violation parameters

 $\pi^+ \gamma \gamma$

 π^+ 3 γ

$$\begin{array}{lll} \mathit{K}^{+} \rightarrow & \pi^{0} \, \mu^{+} \, \nu_{\mu} & \mathit{P}_{T} = (-1.7 \pm 2.5) \times 10^{-3} \\ \mathit{K}^{+} \rightarrow & \mu^{+} \, \nu_{\mu} \, \gamma & \mathit{P}_{T} = (-0.6 \pm 1.9) \times 10^{-2} \\ \mathit{K}^{+} \rightarrow & \pi^{0} \, \mu^{+} \, \nu_{\mu} & \mathrm{Im}(\xi) = -0.006 \pm 0.008 \end{array}$$

| K^- modes are charge con | ijugates of | the modes | below. | | |
|------------------------------------------------|-------------|-------------------------|-----------------------------------------------------------------|-----------------------------------|-----|
| K+ DECAY MODES | Frac | tion $(\Gamma_j/\Gamma$ |) Co | Scale factor/ onfidence level(| |
| Leptoni | c and sen | nileptonic | modes | | |
| $e^+ \nu_e$ | (| | 0.008) × 10 | -5 | 247 |
| $\mu^+ \nu_{\mu}$ | į. | 63.55 ± | 0.11) % | S=1.2 | 236 |
| $\pi^0 e^+ \nu_e$ | (| 5.07 ± | 0.04) % | S=2.1 | 228 |
| Called K_{e3}^+ . | | | | | |
| $\pi^0 \mu^+ u_\mu$ | (| $3.353\pm$ | 0.034) % | S=1.8 | 215 |
| Called $K_{\mu3}^+$. | | | | | |
| $\pi^0 \pi^0 e^+ \nu_e$ | (| 2.2 ± | 0.4)×10 | -5 | 206 |
| $\pi^{+} \pi^{-} e^{+} \nu_{e}$ | į. | | $0.10^{\circ}) \times 10^{-}$ | | 203 |
| $\pi^{+} \pi^{-} \mu^{+} \nu_{\mu}$ | (| 1.4 ± | 0.9)×10 ⁻ | -5 | 151 |
| $\pi^0 \pi^0 \pi^0 e^+ \nu_e$ | < | 3.5 | $\times 10^{-}$ | -6 CL=90% | 135 |
| | Hadronio | c modes | | | |
| $\pi^{+} \pi^{0}$ | (| $20.66 \pm$ | 0.08) % | S=1.2 | 205 |
| $\pi^{+} \pi^{0} \pi^{0}$ | (| $1.761\pm$ | 0.022) % | S=1.1 | 133 |
| $\pi^{+} \pi^{+} \pi^{-}$ | (| 5.59 ± | 0.04) % | S=1.3 | 125 |
| Leptonic and s | emileptor | nic modes | with phot | ons: | |
| $\mu^+ \nu_\mu \gamma$ | [w,x] (| 6.2 \pm | 0.8) × 10 ⁻ | -3 | 236 |
| $\mu^+ \nu_\mu \gamma (SD^+)$ | [a,y] (| $1.33~\pm$ | $0.22) \times 10^{-}$ | -5 | _ |
| $\mu^+ \dot{\nu_\mu} \gamma (SD^+ INT)$ | [a,y] < | 2.7 | $\times 10^{-}$ | ⁻⁵ CL=90% | - |
| $\mu^+ \dot{\nu_\mu} \gamma (SD^- + SD^- INT)$ | [a,y] < | 2.6 | $\times 10^{-}$ | -4 CL=90% | - |
| $e^+ \stackrel{\cdot}{\nu_e} \gamma$ | (| 9.4 ± | 0.4) × 10 ⁻ | -6 | 247 |
| $\pi^0 e^+ u_e \gamma$ | | | 0.16)×10 ⁻ | | 228 |
| $\pi^0_e e^+ \nu_e \gamma (SD)$ | [a,y] < | 5.3 | $\times 10^{-}$ | ⁻⁵ CL=90% | 228 |
| $\pi^0 \mu^+ u_\mu \gamma$ | [w,x] (| $1.25~\pm$ | $0.25) \times 10^{-}$ | -5 | 215 |
| $\pi^0 \pi^0 e^+ \nu_e \gamma$ | < | 5 | $\times 10^{-}$ | -6 CL=90% | 206 |
| Hadronic m | odes with | photons | or $\ell \overline{\ell}$ pair | S | |
| $\pi^+ \pi^0 \gamma (INT)$ | (- | | 0.9)×10 ⁻ | | - |
| $\pi^+ \pi^0 \gamma (DE)$ | [w,z] (| 6.0 \pm | 0.4) × 10 ⁻ | -6 | 205 |
| $\pi^+ \pi^0 \pi^0 \gamma$ | [w,x] (| 7.6 ⁺ | $\begin{array}{cc} 6.0 \\ 3.0 \end{array}$) × 10 ⁻¹ | -6 | 133 |
| $\pi^+\pi^+\pi^-\gamma$ | | | 0.31) × 10 ⁻ | -4 | 125 |
| _+ | | | 0.00) 1.0- | | 007 |

[w] $(1.10 \pm 0.32) \times 10^{-6}$

 $[w] < 1.0 \times 10^{-4} CL = 90\%$

($1.19~\pm0.13$) $\times\,10^{-8}$

| Leptonic i | modes | with $\ell \bar{\ell}$ | pairs | | |
|---------------------------------------------------------------------------------------------------------------------------------------------|-------|------------------------|--------------------------|--------|-----|
| $e^+ \nu_e \nu \overline{\nu}$ | < | 6 | $\times 10^{-5}$ | CL=90% | 247 |
| $\mu^+ \nu_\mu \nu \overline{\nu}$ | < | 6.0 | $\times 10^{-6}$ | CL=90% | 236 |
| $e^{+} \nu_{e} e^{+} e^{-}$ | (| 2.48 ± | $0.20) \times 10^{-8}$ | | 247 |
| $\mu^{+} \nu_{\mu} e^{+} e^{-}$ | (| $7.06 \pm$ | $0.31) \times 10^{-8}$ | | 236 |
| $e^{+} \nu_{e} \mu^{+} \mu^{-}$ | (| 1.7 ± | 0.5) $\times 10^{-8}$ | | 223 |
| $\mu^+ u_\mu \mu^+ \mu^-$ | < | 4.1 | $\times 10^{-7}$ | CL=90% | 185 |
| Lepton Family number (LF), Lepton number (L), $\Delta S = \Delta Q$ (SQ) violating modes, or $\Delta S = 1$ weak neutral current (S1) modes | | | | | |

| $\pi^+ \pi^+ e^- \overline{\nu}_e$ | SQ | < | 1.2 | $\times 10^{-8}$ | CL=90% | 203 |
|------------------------------------------|------------|--------|------|-------------------------------|--------|-----|
| $\pi^+ \pi^+ \mu^- \overline{\nu}_{\mu}$ | 5Q | < | 3.0 | $\times 10^{-6}$ | CL=95% | 151 |
| $\pi^{+} e^{+} e^{-}$ | <i>S</i> 1 | (| 3.00 | ± 0.09) $\times 10^{-7}$ | | 227 |
| $\pi^{+} \mu^{+} \mu^{-}$ | 51 | (| 9.4 | ± 0.6) $\times 10^{-8}$ | S=2.6 | 172 |
| $\pi^+ \nu \overline{\nu}$ | 51 | (| 1.7 | ± 1.1) $\times 10^{-10}$ | | 227 |
| $\pi^+ \pi^0 \nu \overline{\nu}$ | S1 | < | 4.3 | $\times 10^{-5}$ | CL=90% | 205 |
| $\mu^- u e^+ e^+$ | LF | < | 2.0 | $\times 10^{-8}$ | CL=90% | 236 |
| $\mu^+ \nu_e$ | LF | [d] < | 4 | $\times 10^{-3}$ | CL=90% | 236 |
| $\pi^{+}\mu^{+}e^{-}$ | LF | < | 1.3 | $\times 10^{-11}$ | CL=90% | 214 |
| $\pi^{+} \mu^{-} e^{+}$ | LF | < | 5.2 | $\times 10^{-10}$ | CL=90% | 214 |
| $\pi^- \mu^+ e^+$ | L | < | 5.0 | $\times 10^{-10}$ | CL=90% | 214 |
| $\pi^- e^+ e^+$ | L | < | 6.4 | $\times 10^{-10}$ | CL=90% | 227 |
| $\pi^{-}\mu^{+}\mu^{+}$ | L | [d] | 1.1 | $\times 10^{-9}$ | CL=90% | 172 |
| $\mu^+ \overline{\nu}_e$ | L | [d] < | 3.3 | $\times 10^{-3}$ | CL=90% | 236 |
| $\pi^0 e^+ \overline{\nu}_e$ | L | < | 3 | $\times 10^{-3}$ | CL=90% | 228 |
| $\pi^+ \gamma$ | | [aa] < | 2.3 | $\times 10^{-9}$ | CL=90% | 227 |
| | | | | | | |

 K^0

$$I(J^P)=\tfrac{1}{2}(0^-)$$

50% K_S, 50% K_L Mass $m = 497.614 \pm 0.024 \text{ MeV}$ (S = 1.6) $m_{K^0} - m_{K^\pm} = 3.937 \pm 0.028 \; \mathrm{MeV} \quad (\mathrm{S} = 1.8)$

Mean Square Charge Radius

$$\langle r^2 \rangle = -0.077 \pm 0.010 \text{ fm}^2$$

T-violation parameters in K^0 - \overline{K}^0 mixing [v]

Asymmetry A_T in $K^0 - \overline{K}^0$ mixing = $(6.6 \pm 1.6) \times 10^{-3}$

CPT-violation parameters [v]

Re
$$\delta = (2.5 \pm 2.3) \times 10^{-4}$$
 Im $\delta = (-1.5 \pm 1.6) \times 10^{-5}$ Re(y), K_{e3} parameter = $(0.4 \pm 2.5) \times 10^{-3}$ Re(x_), K_{e3} parameter = $(-2.9 \pm 2.0) \times 10^{-3}$ $\left|m_{K^0} - m_{\overline{K}^0}\right| / m_{\text{average}} < 6 \times 10^{-19}$, CL = 90% [bb] $\left(\Gamma_{K^0} - \Gamma_{\overline{K}^0}\right) / m_{\text{average}} = (8 \pm 8) \times 10^{-18}$

Tests of $\Delta S = \Delta Q$

Re(x₊),
$$K_{e3}$$
 parameter = $(-0.9 \pm 3.0) \times 10^{-3}$

227

227

227

$$I(J^P) = \frac{1}{2}(0^-)$$

Mean life $au = (0.8954 \pm 0.0004) \times 10^{-10} \, \text{s} \quad (\text{S} = 1.1)$ Assuming CPT Mean life $\tau = (0.89564 \pm 0.00033) \times 10^{-10}$ s Not assuming

 $c\tau = 2.6844$ cm Assuming *CPT*

CP-violation parameters [cc]

$$\begin{array}{ll} \text{Im}(\eta_{+-0}) &= -0.002 \pm 0.009 \\ \text{Im}(\eta_{000}) &= (-0.1 \pm 1.6) \times 10^{-2} \\ \left|\eta_{000}\right| &= \left|A(K_S^0 \to 3\pi^0)/A(K_L^0 \to 3\pi^0)\right| < 0.018, \, \text{CL} = 90\% \\ \textit{CP} \text{ asymmetry } \textit{A} \text{ in } \pi^+\pi^- \, \text{e}^+ \, \text{e}^- = (-0.4 \pm 0.8)\% \end{array}$$

| κ^0_S DECAY MODES | F | raction | (Γ_i/Γ) | | cale factor/ idence level | |
|----------------------------|------------------|---------|---------------------|--------------------|------------------------------|-----|
| | Hadroni | ic mod | es | | | |
| $\pi^0 \pi^0$ | | (30.69 | $\pm 0.05)$ % | 6 | | 209 |
| $\pi^+\pi^-$ | | (69.20 | $\pm 0.05)$ % | 6 | | 206 |
| $\pi^+\pi^-\pi^0$ | | (3.5 | +1.1)> | < 10 ⁻⁷ | | 133 |
| Мос | les with pho | otons (| or <i>ℓ</i> ℓpa | irs | | |
| $\pi^+\pi^-\gamma$ | [x,dd] | (1.79 | ±0.05)> | < 10 ⁻³ | | 206 |
| $\pi^{+}\pi^{-}e^{+}e^{-}$ | | (4.79 | $\pm 0.15)$ > | < 10 ⁻⁵ | | 206 |
| $\pi^0 \gamma \gamma$ | [dd] | (4.9 | ± 1.8) > | < 10-8 | | 231 |
| $\gamma \gamma$ | | (2.63 | $\pm 0.17) >$ | < 10 ⁻⁶ | S=3.0 | 249 |
| | Semilepto | nic m | odes | | | |
| $\pi^{\pm} e^{\mp} \nu_e$ | [ee] | (7.04 | $\pm 0.08) >$ | < 10 ⁻⁴ | | 229 |
| CP violating (CP) ar | d $\Delta S = 1$ | weak r | neutral c | urrent | (S1) mode | es |
| $3\pi^{0}$ | CP « | < 1.2 | > | < 10 ⁻⁷ | CL=90% | 139 |
| $\mu^+\mu^-$ | | | | | CL=90% | 225 |
| e^+e^- | S1 - | < 9 | > | < 10 ⁻⁹ | CL=90% | 249 |
| $\pi^0~e^+~e^-$ | S1 [dd] | (3.0 | +1.5) > | × 10 ⁻⁹ | | 230 |
| $\pi^0\mu^+\mu^-$ | S1 | (2.9 | +1.5) > | × 10 ⁻⁹ | | 177 |
| | | | | | | |

K_L^0

$$I(J^P) = \frac{1}{2}(0^-)$$

$$\begin{array}{llll} m_{K_L} - m_{K_S} \\ &= (0.5293 \pm 0.0009) \times 10^{10} \ \hbar \ {\rm s}^{-1} & ({\rm S} = 1.3) & {\rm Assuming} \ {\it CPT} \\ &= (3.484 \pm 0.006) \times 10^{-12} \ {\rm MeV} & {\rm Assuming} \ {\it CPT} \\ &= (0.5289 \pm 0.0010) \times 10^{10} \ \hbar \ {\rm s}^{-1} & {\rm Not} \ {\rm assuming} \ {\it CPT} \\ {\rm Mean} \ {\rm life} \ \tau = (5.116 \pm 0.021) \times 10^{-8} \ {\rm s} & ({\rm S} = 1.1) \\ &c\tau = 15.34 \ {\rm m} \end{array}$$

Slope parameter $g^{[u]}$

(See Particle Listings for quadratic coefficients) $K_I^0 \rightarrow \ \pi^+ \, \pi^- \, \pi^0 \colon g = 0.678 \pm 0.008 \quad (S=1.5)$

K_L decay form factors [v]

Linear parametrization assuming μ -e universality $\lambda_{+}(K_{\mu 3}^{0}) = \lambda_{+}(K_{e 3}^{0}) = (2.82 \pm 0.04) \times 10^{-2} \quad (S = 1.1)$ $\lambda_{0}(K_{\mu 3}^{0}) = (1.38 \pm 0.18) \times 10^{-2} \quad (S = 2.2)$

Quadratic parametrization assuming μ -e universality

$$\lambda'_{+}(K^{0}_{\mu 3}) = \lambda'_{+}(K^{0}_{e3}) = (2.40 \pm 0.12) \times 10^{-2}$$
 (S = 1.2)
 $\lambda''_{+}(K^{0}_{\mu 3}) = \lambda''_{+}(K^{0}_{e3}) = (0.20 \pm 0.05) \times 10^{-2}$ (S = 1.2)
 $\lambda_{0}(K^{0}_{\mu 3}) = (1.16 \pm 0.09) \times 10^{-2}$ (S = 1.2)

Pole parametrization assuming $\mu\text{-}e$ universality

$$\begin{array}{l} M_V^{\mu} \; ({\cal K}_{\mu 3}^0) = M_V^e \; ({\cal K}_{e 3}^0) = 878 \pm 6 \; {\rm MeV} \quad ({\rm S} = 1.1) \\ M_S^{\mu} \; ({\cal K}_{u 3}^0) = 1252 \pm 90 \; {\rm MeV} \quad ({\rm S} = 2.6) \end{array}$$

$$K_{e3}^0 \quad \left| f_S / f_+ \right| = (1.5 ^{+1.4}_{-1.6}) \times 10^{-2}$$

$$K_{e3}^0 \quad |f_T/f_+| = (5^{+4}_{-5}) \times 10^{-2}$$

$$K_{\mu 3}^{0} |f_T/f_+| = (12 \pm 12) \times 10^{-2}$$

$$K_{L}^{'} \rightarrow \ell^{+} \ell^{-} \gamma, K_{L} \rightarrow \ell^{+} \ell^{-} \ell'^{+} \ell'^{-} : \alpha_{K^{*}} = -0.205 \pm 0.022 \quad (S = 1.8)$$

$$K_L^0 \to \ell^+\ell^-\gamma$$
, $K_L^0 \to \ell^+\ell^-\ell'^+\ell'^-$: $\alpha_{DIP} = -1.69 \pm 0.08$ (S = 1.7)

$$K_L \rightarrow \pi^+ \pi^- e^+ e^-$$
: $a_1/a_2 = -0.737 \pm 0.014 \text{ GeV}^2$

$$K_L \to \pi^0 2\gamma$$
: $a_V = -0.43 \pm 0.06$ (S = 1.5)

$\it CP$ -violation parameters [cc]

$$\begin{array}{l} A_L = (0.332 \pm 0.006)\% \\ |\eta_{00}| = (2.220 \pm 0.011) \times 10^{-3} \quad (S=1.8) \\ |\eta_{+-}| = (2.232 \pm 0.011) \times 10^{-3} \quad (S=1.8) \\ |\epsilon| = (2.228 \pm 0.011) \times 10^{-3} \quad (S=1.8) \\ |\eta_{00}/\eta_{+-}| = 0.9950 \pm 0.0007^{[ff]} \quad (S=1.6) \\ \mathrm{Re}(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}^{[ff]} \quad (S=1.6) \end{array}$$

Assuming CPT $\phi_{+-} = (43.51 \pm 0.05)^{\circ} \quad (S = 1.2)$ $\phi_{00} = (43.52 \pm 0.05)^{\circ} \quad (S = 1.3)$ $\phi_{\epsilon} = \phi_{\text{SW}} = (43.52 \pm 0.05)^{\circ} \quad (S = 1.2)$ $lm(\epsilon'/\epsilon) = -(\phi_{00} - \phi_{+-})/3 = (-0.002 \pm 0.005)^{\circ}$ (S = 1.7) Not assuming CPT $\phi_{+-} = (43.4 \pm 0.5)^{\circ} \quad (S = 1.2)$ $\phi_{00} = (43.7 \pm 0.6)^{\circ} \quad (S = 1.2)$ $\phi_{\epsilon} = (43.5 \pm 0.5)^{\circ} \quad (S = 1.3)$ CP asymmetry A in $K_L^0 \rightarrow \pi^+\pi^-\,e^+\,e^-=(13.7\pm 1.5)\%$ β_{CP} from $K_L^0 \rightarrow e^+e^-e^+e^- = -0.19 \pm 0.07$ γ_{CP} from $K_L^0 \rightarrow e^+e^-e^+e^- = 0.01 \pm 0.11$ (S = 1.6) j for $\,K_L^0 \rightarrow ~\pi^+\pi^-\pi^0 =$ 0.0012 \pm 0.0008 f for $K_I^0 \to \pi^+ \pi^- \pi^0 = 0.004 \pm 0.006$ $\left| \eta_{+-\gamma} \right| = (2.35 \pm 0.07) \times 10^{-3}$ $\phi_{+-\gamma} = (44 \pm 4)^{\circ}$ $|\epsilon'_{+-\gamma}|/\epsilon$ < 0.3, CL = 90% $|{
m g}_{E1}|$ for ${
m K}_{L}^{0}
ightarrow \pi^{+} \pi^{-} \gamma < \,$ 0.21, CL $= \,$ 90%

T-violation parameters

$${\rm Im}(\xi) \ {\rm in} \ K_{\mu 3}^0 = -0.007 \pm 0.026$$

CPT invariance tests

$$\phi_{00} - \phi_{+-} = (0.34 \pm 0.32)^{\circ}$$
 $\text{Re}(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) - \frac{A_L}{2} = (-3 \pm 35) \times 10^{-6}$

$\Delta S = -\Delta Q$ in $K_{\ell 3}^0$ decay

Re $x = -0.002 \pm 0.006$ Im $x = 0.0012 \pm 0.0021$

| K ⁰ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ / Confidence level (Me | |
|-------------------------------------------------------|-----------------------------------|-----------------------------------------|------|
| | Semileptonic modes | | _ |
| $\pi^{\pm} e^{\mp} \nu_e$ Called K_{e3}^0 . | [ee] (40.55 ± 0.11) | % S=1.7 | 229 |
| $\pi^{\pm}\mu^{\mp} u_{\mu}$ Called $K_{\mu 3}^{0}$. | [ee] (27.04 ± 0.07) | % S=1.1 | 216 |
| $(\pi \mu atom) \nu$ | (1.05 ± 0.11) | $\times 10^{-7}$ | 188 |
| $\pi^0 \pi^{\pm} e^{\mp} \nu$ | [ee] (5.20 \pm 0.11) | | 207 |
| $\pi^{\pm} e^{\mp} \nu e^{+} e^{-}$ | [ee] (1.26 ± 0.04) | ×10 ⁻⁵ | 229 |
| Hadronic modes, inclu | ding Charge conjugation×Pari | ity Violating (<i>CPV</i>) mo | odes |
| $3\pi^{0}$ | (19.52 ± 0.12) | % S=1.6 | 139 |
| $\pi^{+} \pi^{-} \pi^{0}$ | (12.54 ± 0.05) | | 133 |
| $\pi^{+}\pi^{-}$ | CPV $[gg]$ (1.967 ± 0.010) | | 206 |
| $\pi^{0} \pi^{0}$ | CPV (8.64 ± 0.06) | × 10 ⁻⁴ S=1.8 | 209 |
| | Semileptonic modes with pho | tons | |
| $\pi^{\pm} e^{\mp} \nu_e \gamma$ | $[x,ee,hh]$ (3.79 \pm 0.06) | $\times 10^{-3}$ | 229 |
| $\pi^{\pm}\mu^{\mp}\nu_{\mu}\gamma$ | (5.65 ± 0.23) | ×10 ⁻⁴ | 216 |
| Had | ronic modes with photons or | $\ell \overline{\ell}$ pairs | |
| $\pi^0 \pi^0 \gamma$ | < 2.43 | | 209 |
| $\pi^+\pi^-\gamma$ | $[x,hh]$ (4.15 \pm 0.15) | $\times 10^{-5}$ S=2.8 | 206 |
| $\pi^+ \pi^- \gamma$ (DE) | (2.84 ± 0.11) | | 206 |
| $\pi^0 2\gamma$ | [hh] (1.273 ± 0.033) | | 231 |
| $\pi^0 \gamma e^+ e^-$ | (1.62 ± 0.17) | ×10 ⁻⁸ | 230 |
| Ot | ther modes with photons or ℓ | ₹ pairs | |
| 2γ | (5.47 ± 0.04) | $\times 10^{-4}$ S=1.1 | 249 |
| 3γ | < 7.4 | $\times 10^{-8}$ CL=90% | 249 |
| $e^+e^-\gamma$ | (9.4 ± 0.4) | | 249 |
| $\mu^+\mu^-\gamma$ | (3.59 ± 0.11) | | 225 |
| $e^+e^-\gamma\gamma$ | [hh] (5.95 \pm 0.33) | | 249 |
| $\mu^+ \mu^- \gamma \gamma$ | $[hh]$ $(1.0 + 0.8 \\ -0.6)$ | $\times 10^{-8}$ | 225 |

Charge conjugation \times Parity (*CP*) or Lepton Family number (*LF*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes

| $\mu^{+} \mu^{-}$ | S1 (| 6.84 ± 0.11) $\times 10^{-9}$ | 225 |
|------------------------------------|---------------------|------------------------------------|------------|
| e^+e^- | | 9 $^{+6}_{-4}$) $\times10^{-12}$ | 249 |
| $\pi^+\pi^-e^+e^-$ | S1 [hh] (| $3.11~\pm 0.19~) \times 10^{-7}$ | 206 |
| $\pi^0 \pi^0 e^+ e^-$ | S1 < | $6.6 	 \times 10^{-9}$ | CL=90% 209 |
| $\pi^0 \pi^0 \mu^+ \mu^-$ | S1 < | 9.2×10^{-11} | CL=90% 57 |
| $\mu^{+}\mu^{-}e^{+}e^{-}$ | 51 (| $2.69 \pm 0.27) \times 10^{-9}$ | 225 |
| $e^{+}e^{-}e^{+}e^{-}$ | S1 (| $3.56 \pm 0.21) \times 10^{-8}$ | 249 |
| $\pi^0\mu^+\mu^-$ | CP,S1 [ii] < | | CL=90% 177 |
| $\pi^0~e^+~e^-$ | CP,S1 [ii] < | $2.8 	 \times 10^{-10}$ | CL=90% 230 |
| $\pi^0 \nu \overline{\nu}$ | CP, $S1$ $[jj]$ $<$ | 2.6×10^{-8} | CL=90% 231 |
| $\pi^0 \pi^0 \nu \overline{\nu}$ | S1 < | 8.1×10^{-7} | CL=90% 209 |
| $e^{\pm}\mu^{\mp}$ | LF [ee] < | | CL=90% 238 |
| $e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$ | LF [ee] < | | CL=90% 225 |
| $\pi^0 \mu^\pm e^\mp$ | LF [ee] < | | CL=90% 217 |
| $\pi^{0}\pi^{0}\mu^{\pm}e^{\mp}$ | LF < | 1.7×10^{-10} | CL=90% 159 |

K*(892)

$$I(J^P) = \frac{1}{2}(1^-)$$

 $K^*(892)^{\pm}$ mass $m=891.66\pm0.26~{\rm MeV}$ Mass $m=895.5\pm0.8~{\rm MeV}$ $K^*(892)^0$ mass $m=895.94\pm0.22~{\rm MeV}$ (S = 1.4) $K^*(892)^{\pm}$ full width $\Gamma=50.8\pm0.9~{\rm MeV}$

Full width $\Gamma=46.2\pm1.3~\text{MeV}$

 $K^*(892)^0$ full width $\Gamma=48.7\pm0.8$ MeV (S = 1.7)

| K*(892) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|---------------------|------------------------------|----------------------|---------------|
| Κπ | ~ 100 | % | 289 |
| $K^0\gamma$ | (2.39 ± 0.21) | $\times 10^{-3}$ | 307 |
| $K^{\pm}\gamma$ | (9.9 ± 0.9) | $\times 10^{-4}$ | 309 |
| $K\pi\pi$ | < 7 | $\times 10^{-4}$ 95% | 223 |

$K_1(1270)$

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m=1272\pm7~{\rm MeV}^{[I]}$ Full width $\Gamma=90\pm20~{\rm MeV}^{[I]}$

| K ₁ (1270) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| $K\rho$ | (42 ±6)% | 45 |
| $K_0^*(1430)\pi$ | (28 ±4)% | † |
| $K^*(892)\pi$ | (16 ±5)% | 302 |
| $K\omega$ | (11.0±2.0) % | † |
| $K f_0(1370) \gamma K^0$ | (3.0 ± 2.0) % | † |
| γK^{0} | seen | 539 |

K₁ (1400)

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m=1403\pm7~{\rm MeV}$ Full width $\Gamma=174\pm13~{\rm MeV}~({\rm S}=1.6)$

| K ₁ (1400) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| K*(892)π | (94 ±6)% | 402 |
| $K\rho$ | (3.0 ± 3.0) % | 292 |
| $K f_0(1370)$ | (2.0±2.0) % | † |
| Κω | (1.0±1.0) % | 284 |
| $K_0^*(1430)\pi \\ \gamma K^0$ | not seen | † |
| γK^0 | seen | 613 |

K*(1410)

$$I(J^P) = \frac{1}{2}(1^-)$$

Mass m= 1414 \pm 15 MeV (S = 1.3) Full width $\Gamma=$ 232 \pm 21 MeV (S = 1.1)

| K*(1410) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (Me V/ <i>c</i>) |
|----------------------|------------------------------|------------------|--------------------------------|
| K*(892) π | > 40 % | 95 % | 410 |
| $K\pi$ | $(6.6 \pm 1.3)\%$ | | 612 |
| $K \rho \gamma K^0$ | < 7 % | 95% | 305 |
| γK^0 | seen | | 619 |

K*(1430) [kk]

$$I(J^P) = \frac{1}{2}(0^+)$$

Mass $m=1425\pm 50~{\rm MeV}$ Full width $\Gamma=270\pm 80~{\rm MeV}$

| K*(1430) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------|------------------------------|-----------|
| Κπ | (93±10) % | 619 |

$K_2^*(1430)$

$$I(J^P)=\tfrac{1}{2}(2^+)$$

 $K_2^*(1430)^\pm$ mass $m=1425.6\pm1.5$ MeV (S = 1.1) $K_2^*(1430)^0$ mass $m=1432.4\pm1.3$ MeV $K_2^*(1430)^\pm$ full width $\Gamma=98.5\pm2.7$ MeV (S = 1.1) $K_2^*(1430)^0$ full width $\Gamma=109\pm5$ MeV (S = 1.9)

| K ₂ *(1430) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | <i>p</i> (Me <i>V/c</i>) |
|------------------------------------|--------------------------------|-----------------------------------|-------------------------------|
| Κπ | (49.9±1.2) % | | 619 |
| $K^*(892)\pi$ | (24.7 ± 1.5) % | | 419 |
| $K^*(892)\pi\pi$ | (13.4 ± 2.2) % | | 372 |
| $K\rho$ | (8.7 ± 0.8) % | S=1.2 | 318 |
| $K\omega$ | $(2.9 \pm 0.8) \%$ | | 311 |
| $K^+\gamma$ | $(2.4 \pm 0.5) \times 10^{-5}$ | −3 S=1.1 | 627 |
| $K\eta$ | $(1.5 + 3.4) \times 10$ | -3 S=1.3 | 486 |
| $K\omega\pi$ | < 7.2 × 10 | -4 CL=95% | 100 |
| $K^0\gamma$ | < 9 × 10 | -4 CL=90% | 626 |

K*(1680)

$$I(J^P) = \frac{1}{2}(1^-)$$

Mass $m=1717\pm27~{\rm MeV}~{\rm (S}=1.4)$ Full width $\Gamma=322\pm110~{\rm MeV}~{\rm (S}=4.2)$

| K*(1680) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------|------------------------------|-----------|
| Κπ | (38.7±2.5) % | 781 |
| $K\rho$ | $(31.4^{+5.0}_{-2.1})$ % | 570 |
| $K^*(892)\pi$ | (29.9 + 2.2)% | 618 |

K₂(1770) [//]

$$I(J^P) = \frac{1}{2}(2^-)$$

Mass $m=1773\pm 8~{\rm MeV}$ Full width $\Gamma=186\pm 14~{\rm MeV}$

| K2(1770) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------|------------------------------|-----------|
| Κππ | | 794 |
| $K_2^*(1430)\pi$ | dominant | 288 |
| $K^{\bar{*}}(892)\pi$ | seen | 654 |
| $K f_2(1270)$ | seen | 55 |
| $K\phi$ | seen | 441 |
| $K\omega$ | seen | 607 |

K*(1780)

$$I(J^P) = \frac{1}{2}(3^-)$$

Mass $m=1776\pm7$ MeV (S = 1.1) Full width $\Gamma=159\pm21$ MeV (S = 1.3)

| K*(1780) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (MeV/ <i>c</i>) |
|----------------------|------------------------------|------------------|-------------------------------|
| Κρ | (31 ± 9)% | | 613 |
| $K^{*}(892)\pi$ | (20 ± 5) % | | 65 6 |
| $K\pi$ | (18.8 ± 1.0) % | | 813 |
| $K\eta$ | (30 ±13) % | | 719 |
| $K_2^*(1430)\pi$ | < 16 % | 95% | 291 |

K₂(1820) [mm]

$$I(J^P) = \frac{1}{2}(2^-)$$

Mass $m=1816\pm13~{\rm MeV}$ Full width $\Gamma=276\pm35~{\rm MeV}$

| K ₂ (1820) DECAY MODES | Fraction (Γ_i/Γ) | $p \; (\; \text{MeV/}c)$ |
|-----------------------------------|------------------------------|--------------------------|
| $K_2^*(1430)\pi$ | seen | 327 |
| $K^{\overline{*}}(892)\pi$ | seen | 681 |
| $K f_2(1270)$ | seen | 186 |
| $K \omega$ | seen | 638 |

K*(2045)

$$I(J^P) = \frac{1}{2}(4^+)$$

Mass $m=2045\pm 9~{\rm MeV}~{\rm (S}=1.1)$ Full width $\Gamma=198\pm 30~{\rm MeV}$

| K ₄ (2045) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| Κπ | (9.9±1.2) % | 95 8 |
| $K^*(892)\pi\pi$ | (9 ±5)% | 802 |
| $K^*(892)\pi\pi\pi$ | (7 ±5)% | 768 |
| $\rho K \pi$ | (5.7 ± 3.2) % | 741 |
| $\omega K \pi$ | (5.0 ± 3.0) % | 738 |
| $\phi K \pi$ | (2.8±1.4) % | 594 |
| $\phi K^*(892)$ | (1.4 ± 0.7) % | 363 |

CHARMED MESONS $(C = \pm 1)$

D±

$$I(J^P) = \frac{1}{2}(0^-)$$

Mass $m=1869.62\pm0.15$ MeV (S =1.1) Mean life $\tau=(1040\pm7)\times10^{-15}$ s $c\tau=311.8~\mu{\rm m}$

c-quark decays

 $\Gamma(c \to \ell^+ \text{anything}) / \Gamma(c \to \text{anything}) = 0.096 \pm 0.004 \frac{[nn]}{\Gamma(c \to D^*(2010)^+ \text{anything}) / \Gamma(c \to \text{anything})} = 0.255 \pm 0.017$

CP-violation decay-rate asymmetries

 $A_{CP}(\mu^{\pm}\nu) = (8 \pm 8)\%$ $A_{CP}(K_S^0 \pi^{\pm}) = (-0.54 \pm 0.14)\%$ $A_{CP}(K^{\mp}2\pi^{\pm}) = (-0.1 \pm 1.0)\%$ $A_{CP}(K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{0}) = (1.0 \pm 1.3)\%$ $A_{CP}(K_S^0 \pi^{\pm} \pi^0) = (0.3 \pm 0.9)\%$ $A_{CP}(K_S^{0}\pi^{\pm}\pi^{+}\pi^{-}) = (0.1 \pm 1.3)\%$ $A_{CP}(\pi^{\pm}\pi^{0}) = (2.9 \pm 2.9)\%$ $A_{CP}(\pi^{\pm}\eta) = (1.0 \pm 1.5)\%$ (S = 1.4) $A_{CP}(\pi^{\pm} \eta'(958)) = (-0.5 \pm 1.2)\%$ (S = 1.1) $A_{CP}(K_S^0K^{\pm}) = (-0.1 \pm 0.6)\%$ $A_{CP}(K^+K^-\pi^{\pm}) = (0.3 \pm 0.6)\%$ $A_{CP}(K^{\pm}K^{*0}) = (0.1 \pm 1.3)\%$ $A_{CP}(\phi \pi^{\pm}) = (0.42 \pm 0.28)\%$ $A_{CP}(K^{\pm}K_0^*(1430)^0) = (8^{+7}_{-6})\%$ $A_{CP}(K^{\pm}K_{2}^{*}(1430)^{0}) = (43_{-26}^{+20})\%$ $A_{CP}(K^{\pm}K_0^{*}(800)) = (-12^{+18}_{-13})\%$ $A_{CP}(a_0(1450)^0 \pi^{\pm}) = (-19^{+14}_{-16})\%$ $A_{CP}(\phi(1680)\pi^{\pm}) = (-9 \pm 26)\%$ $A_{CP}(\pi^{+}\pi^{-}\pi^{\pm}) = (-2 \pm 4)\%$ $A_{CP}(K_S^0 K^{\pm} \pi^+ \pi^-) = (-4 \pm 7)\%$ $A_{CP}(K^{\pm}\pi^{0}) = (-4 \pm 11)\%$

T-violation decay-rate asymmetry

$$A_T(K_S^0 K^{\pm} \pi^+ \pi^-) = (-12 \pm 11) \times 10^{-3}$$
 [oo]

D+ form factors

$$\begin{array}{l} f_{+}(0)\big|V_{cs}\big| \text{ in } \overline{K}^0\,\ell^+\nu_\ell=0.707\pm0.013\\ r_1\equiv a_1/a_0 \text{ in } \overline{K}^0\,\ell^+\nu_\ell=-1.7\pm0.5\\ r_2\equiv a_2/a_0 \text{ in } \overline{K}^0\,\ell^+\nu_\ell=-14\pm11\\ f_{+}(0)\big|V_{cd}\big| \text{ in } \pi^0\,\ell^+\nu_\ell=0.146\pm0.007\\ r_1\equiv a_1/a_0 \text{ in } \pi^0\,\ell^+\nu_\ell=-1.4\pm0.9\\ r_2\equiv a_2/a_0 \text{ in } \pi^0\,\ell^+\nu_\ell=-4\pm5\\ f_{+}(0)\big|V_{cd}\big| \text{ in } D^+\to\eta\,e^+\nu_e=0.086\pm0.006\\ r_1\equiv a_1/a_0 \text{ in } D^+\to\eta\,e^+\nu_e=-1.8\pm2.2\\ r_V\equiv V(0)/A_1(0) \text{ in } \overline{K}^*(892)^0\,\ell^+\nu_\ell=1.51\pm0.07 \quad (S=2.2)\\ r_2\equiv A_2(0)/A_1(0) \text{ in } \overline{K}^*(892)^0\,\ell^+\nu_\ell=0.807\pm0.025\\ r_3\equiv A_3(0)/A_1(0) \text{ in } \overline{K}^*(892)^0\,\ell^+\nu_\ell=0.0\pm0.4\\ \Gamma_L/\Gamma\,\tau \text{ in } \overline{K}^*(892)^0\,\ell^+\nu_\ell=1.13\pm0.08\\ \Gamma_+/\Gamma_- \text{ in } \overline{K}^*(892)^0\,\ell^+\nu_\ell=0.22\pm0.06 \quad (S=1.6) \end{array}$$

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K_S^0 modes, not as \overline{K}^0 modes. Nearly always it is a K_S^0 that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\Gamma(K_S^0) = \Gamma(\overline{K}^0)$.

| (3) | | | |
|-------------------------------------------------------------------------|------------------------------|-----------------------------------|-------------|
| D+ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | - |
| D. DECAT MODES | Traction (T _j /T) | Confidence level | (IVIE V/C) |
| | usive modes | | |
| <i>e</i> ⁺ semileptonic | (16.07 ± 0.30) % | | - |
| μ^+ anything | $(17.6 \pm 3.2) \%$ | | - |
| K [−] a nything | (25.7 ±1.4)% | | - |
| \overline{K}^0 anything $+ K^0$ anything | (61 ±5) % | | _ |
| K ⁺ a nything | (5.9 ±0.8)% | | _ |
| $K^*(892)^-$ anything | (6 ±5)% | | _ |
| $\overline{K}^*(892)^0$ anything | (23 ±5) % | | - |
| $K^*(892)^0$ anything | < 6.6 % | CL=90% | - |
| η anything | $(6.3 \pm 0.7)\%$ | | - |
| η' anything | (1.04 ± 0.18) % | | - |
| ϕ anything | (1.03 ± 0.12) % | | _ |
| Leptonic and | d semileptonic mod | es | |
| $e^+ \nu_e$ | < 8.8 × | 10 ⁻⁶ CL=90% | 935 |
| $\mu^+ \nu_{\mu}$ | $(3.82\pm0.33) \times$ | 10-4 | 932 |
| $	au^+ u_	au$ | < 1.2 × | 10 ⁻³ CL=90% | 91 |
| $\overline{K}^0 e^{+} \nu_e$ | (8.83±0.22) % | | 869 |
| $\overline{K}^0 \mu^+ \nu_{\mu}$ | $(9.2 \pm 0.6)\%$ | | 865 |
| $K^-\pi^+e^+\nu_e$ | (4.00±0.10) % | | 864 |
| $\overline{K}^*(892)^0 e^+ \nu_e$, $\overline{K}^*(892)^0 \rightarrow$ | (3.68±0.10) % | | 722 |
| $K^-\pi^+$ | | | |

| < 8.8 × 10 ° CL≡90° | % 935 |
|------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $(3.82\pm0.33)\times10^{-4}$ | 932 |
| $< 1.2 \times 10^{-3} \text{ CL} = 90^{\circ}$ | % 91 |
| (8.83±0.22) % | 869 |
| (9.2 ±0.6) % | 865 |
| (4.00±0.10) % | 864 |
| (3.68 ± 0.10) % | 722 |
| $(2.32\pm0.10)\times10^{-3}$ | _ |
| | % – |
| X 10 SE=30 | , v |
| $<$ 5 $\times 10^{-4}$ CL=90 | % – |
| | |
| $< 7 \times 10^{-3} \text{ CL} = 90^{\circ}$ | % 864 |
| $(3.8 \pm 0.4)\%$ | 851 |
| (3.52±0.10) % | 717 |
| | |
| $(2.0 \pm 0.5) \times 10^{-3}$ | 851 |
| $< 1.6 \times 10^{-3} \text{ CL} = 90^{\circ}$ | % 825 |
| $(4.05\pm0.18)\times10^{-3}$ | 930 |
| $(1.14\pm0.10)\times10^{-3}$ | 855 |
| $(2.2 \pm 0.4) \times 10^{-3}$ | 774 |
| $(2.4 \pm 0.4) \times 10^{-3}$ | 770 |
| $(1.6 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \times 10^{-3}$ | 771 |
| $(2.2 \pm 0.5) \times 10^{-4}$ | 689 |
| $< 9 \times 10^{-5} \text{ CL} = 90^{\circ}$ | % 657 |
| | $ \begin{array}{c} < 1.2 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ (\ 8.83 \pm 0.22) \ \% \\ (\ 9.2 \ \pm 0.6 \) \ \% \\ (\ 4.00 \pm 0.10) \ \% \\ (\ 3.68 \pm 0.10) \ \% \\ \\ < (\ 2.32 \pm 0.10) \times 10^{-3} \\ < 6 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ \\ < 5 & \times 10^{-4} & \text{CL} = 90^{\circ} \\ \\ < 7 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ \\ < 7 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ \\ < 7 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ \\ < 3.8 \ \pm 0.4 \) \ \% \\ (\ 3.52 \pm 0.10) \ \% \\ \\ \\ (\ 2.0 \ \pm 0.5 \) \times 10^{-3} \\ < 1.6 & \times 10^{-3} & \text{CL} = 90^{\circ} \\ \\ < 4.05 \pm 0.18) \times 10^{-3} \\ (\ 4.05 \pm 0.18) \times 10^{-3} \\ (\ 1.14 \pm 0.10) \times 10^{-3} \\ (\ 2.2 \ \pm 0.4 \) \times 10^{-3} \\ (\ 2.4 \ \pm 0.4 \) \times 10^{-3} \\ (\ 2.4 \ \pm 0.4 \) \times 10^{-3} \\ (\ 2.2 \ \pm 0.5 \) \times 10^{-4} \\ \end{array} $ |

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

| \overline{K}^* (892) 0 e^+ $ u_e$ | (5.52±0.15) % | 722 |
|----------------------------------------------------|------------------|------------------------|
| $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ | (5.28 ± 0.15) % | 6 717 |
| $\overline{K}_{0}^{*}(1430)^{0} \mu^{+} \nu_{\mu}$ | < 2.4 > | c 10 ⁻⁴ 380 |
| $\overline{K}^*(1680)^0 \mu^+ \nu_{\mu}$ | < 1.5 | $< 10^{-3}$ 105 |

| | ту гаріе | | | | | |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------|------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|-----------------------------------|
| Hadronic | modes with a \overline{K} or $\overline{K}K\overline{K}$ | | | $\mathcal{K}^+ \overline{\mathcal{K}}_0^* (1430)^0$, | $(1.79\pm0.34)\times10^{-3}$ | - |
| ${\mathcal K}^0_{\mathcal S} \pi^+ \ {\mathcal K}^0_{\mathcal L} \pi^+$ | (1.47 ± 0.07) % | S=2.0 | 863 | $\overline{K}_{0}^{(1430)^{0}} \rightarrow K^{-}\pi^{+}$ | | |
| $K_L^{0}\pi^+$ | (1.46 ± 0.05) % | | 863 | $K^{+}\overline{K}_{2}^{*}(1430)^{0}, \ \overline{K}_{2}^{*} \rightarrow$ | $(1.6 \begin{array}{c} +1.2 \\ -0.8 \end{array}) \times 10^{-4}$ | |
| $K^{-}2\pi^{+}$ | [pp] (9.13 ± 0.19) % | | 846 | $K^+K_2^-(1430)^+, K_2^- \rightarrow K^-\pi^+$ | (1.6 - 0.8) × 10 4 | = |
| $(K^{-}\pi^{+})_{S-\text{wave}}\pi^{+}$ | $(7.32 \pm 0.19) \%$ | | 846 | $K^+ \overline{K}_0^*(800), \overline{K}_0^* \rightarrow K^- \pi^+$ | $(6.7 \begin{array}{c} +3.4 \\ -2.1 \end{array}) \times 10^{-4}$ | |
| $\overline{K}_{\underline{0}}^{*}(1430)^{0}\pi^{+}$, | [qq] (1.21 ± 0.06) % | | 382 | V V | | |
| $\overline{K}_0^*(1430)^0 \to K^-\pi^+$ | | | | $a_0(1450)^0 \pi^+$, $a_0^0 	o$ | $(4.4 \begin{array}{c} +7.0 \\ -1.8 \end{array}) \times 10^{-4}$ | = |
| $\overline{K}^*(892)^0 \pi^+$, $\overline{K}^*(892)^0 \to K^- \pi^+$ | $(1.01 \pm 0.11) \%$ | | 714 | K+K- | . 4.0 | |
| $\overline{K}^*(1410)^0 \pi^+$, $\overline{K}^{*0} \rightarrow$ | not seen | | 381 | $\phi(1680)\pi^+$, $\phi ightarrow~K^+K^-$ | $(4.9 \ ^{+4.0}_{-1.9}) \times 10^{-5}$ | - |
| | not seen | | 301 | $K^+K^-\pi^+$ nonresonant | not seen | 744 |
| $rac{{\cal K}^-\pi^+}{{ar K}_2^*(1430)^0\pi^+}$, | [qq] $(2.2 \pm 0.7) \times 10^{-4}$ | | 371 | $K^+_S K^0_S \pi^+ \pi^-$ | $(1.75 \pm 0.18) \times 10^{-3}$ | 678 |
| $\overline{K}_{2}^{*}(1430)^{0} \rightarrow K^{-}\pi^{+}$ | | | | $K_{S}^{0}K^{-}2\pi^{+}$ | $(2.40\pm0.18)\times10^{-3}$ | 678 |
| $\overline{K}_{\underline{*}}(1680)^{0}\pi^{+}$, | [qq] $(2.1 \pm 1.1) \times 10^{-4}$ | | 58 | $K^+K^-2\pi^+\pi^-$ | $(2.2 \pm 1.2) \times 10^{-4}$ | 600 |
| $\overrightarrow{K}^*(1680)^0 \rightarrow K^-\pi^+$ | | | | A four poorly massured branchin | ur fractions | |
| $K^{-}(2\pi^{+})_{I=2}$ | (1.41 ± 0.26) % | | - | A few poorly measured branchin $\phi\pi^+\pi^0$ | = | 619 |
| $K_{S}^{0}\pi^{+}\pi^{0}$ | [pp] (6.99 ± 0.27) % | | 845 | $\phi n \cdot n = \phi \rho^+$ | (2.3 ±1.0) % < 1.5 % | CL=90% 259 |
| $\frac{K_S^0 \rho^+}{K^* (892)^0 \pi^+}$, | (4.8 ±1.0) % | | 677 | $K^+K^-\pi^+\pi^0$ non- ϕ | | |
| $K^{(892)} \stackrel{\text{N.}}{=} K^0_S \pi^0$ | $(1.3 \pm 0.6)\%$ | | 714 | ' | $(1.5 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \%$ | 682 |
| $K_S^0 \pi^+ \pi^0$ nonresonant | $(9 \pm 7) \times 10^{-3}$ | | 845 | $K^*(892)^+ K^0_S$ | (1.6 \pm 0.7) % | 612 |
| $K^-2\pi^+\pi^0$ | [rr] (5.99±0.18)% | | 816 | Doubly Cabib | bo-suppressed modes | |
| $K_S^0 2\pi^+\pi^-$ | [rr] (3.12 ± 0.11) % | | 814 | $\mathcal{K}^+\pi^0$ | $(1.83\pm0.26)\times10^{-4}$ | S=1.4 864 |
| $\kappa^{-3}\pi^{+}\pi^{-}$ | [pp] (5.6 ±0.5) × 10 ⁻³ | S=1.1 | 772 | $\mathcal{K}^+\eta$ | $(1.08\pm0.17)\times10^{-4}$ | 776 |
| \overline{K}^* (892) 0 2 $\pi^+\pi^-$, | $(1.2 \pm 0.4) \times 10^{-3}$ | | 645 | $K^{+}\eta'(958)$ | $(1.76\pm0.22)\times10^{-4}$ | 571 |
| $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | _ | | | $\stackrel{	extbf{K}^+\pi^+\pi^-}{	extbf{K}^+ ho^0}$ | $(5.27 \pm 0.23) \times 10^{-4}$ | 846 |
| $\overline{K}^*(892)^0 \rho^0 \pi^+$, | $(2.2 \pm 0.4) \times 10^{-3}$ | | 239 | $K^+ ho^- K^* (892)^0 \pi^+$, $K^* (892)^0 ightarrow$ | $(2.0 \pm 0.5) \times 10^{-4}$ $(2.5 \pm 0.4) \times 10^{-4}$ | 679 714 |
| $\overline{K}^*(892)^0 \to K^-\pi^+$ | r 1 (00 140) 40 -3 | | | $K^+\pi^-$ | (2.5 ±0.4) × 10 | 714 |
| $K^{-}\rho^{0}2\pi^{+}$ | [ss] $(9.0 \pm 1.8) \times 10^{-3}$ $(1.68 \pm 0.27) \times 10^{-3}$ | | † 524 | $K^{+} f_{0}(980)$, $f_{0}(980) ightarrow$ | (4.7 \pm 2.8) \times 10 ⁻⁵ | = |
| $K^-3\pi^+\pi^-$ nonresonant | $(3.9 \pm 2.9) \times 10^{-4}$ | | 772 | $\pi^{+}\pi^{-}$ | (| |
| $K^+ 2K_S^0$ | $(4.5 \pm 2.0) \times 10^{-3}$ | | 545 | $K_2^*(1430)^0\pi^+$, $K_2^*(1430)^0\to$ | $(4.2 \pm 2.9) \times 10^{-5}$ | - |
| $K^{+} K^{-3} K_{S}^{0} \pi^{+}$ | $(2.4 \pm 0.6) \times 10^{-4}$ | | 436 | $K^+\pi^- \ K^+\pi^+\pi^-$ nonresonant | not seen | 846 |
| 3 | Pionic modes | | | 2K+ K- | $(8.7 \pm 2.0) \times 10^{-5}$ | 550 |
| $\pi^+\pi^0$ | $(1.19\pm0.06)\times10^{-3}$ | | 925 | AC — 1 weak neut | ral current (C1) modes, | or |
| $2\pi^{+}\pi^{-}$ | $(3.18 \pm 0.18) \times 10^{-3}$ | | 909 | Lepton Family number (LF) of | | |
| $ ho^0\pi^+$ | $(8.1 \pm 1.5) \times 10^{-4}$ | | 767 | $\pi^+ e^+ e^-$ C1 | | CL=90% 930 |
| $\pi^+ (\pi^+ \pi^-)_{S-wave}$ | $(1.78 \pm 0.16) \times 10^{-3}$ | | 909 | | tt] $(1.7 \begin{array}{c} +1.4 \\ -0.9 \end{array}) \times 10^{-6}$ | _ |
| $\sigma \pi^+$, $\sigma \rightarrow \pi^+ \pi^-$ | $(1.34 \pm 0.12) \times 10^{-3}$ | | _ | | | |
| $f_0(980) \pi^+$, $f_0(980) \rightarrow \pi^+ \pi^-$ | $(1.52\pm0.33)\times10^{-4}$ | | 669 | $\pi^{+} \mu^{+} \mu^{-} \qquad C1$ $\pi^{+} \phi, \ \phi \rightarrow \mu^{+} \mu^{-} \qquad [$ | $< 3.9 \times 10^{-6}$ $[tt] (1.8 \pm 0.8) \times 10^{-6}$ | CL=90% 918 |
| $f_0(980) \rightarrow \pi \cdot \pi$ $f_0(1370) \pi^+$, | $(8 \pm 4) \times 10^{-5}$ | | _ | $\rho^+\mu^+\mu^-$ | < 5.6 ×10 ⁻⁴ | CL=90% 757 |
| $f_0(1370) \rightarrow \pi^+ \pi^-$ | (0 ±4) × 10 | | | | $[u] < 1.0 	 \times 10^{-6}$ | CL=90% 870 |
| $f_2(1270)\pi^+$, | $(4.9 \pm 0.9) \times 10^{-4}$ | | 485 | $K^+\mu^+\mu^-$ [u | $[u] < 4.3 	 \times 10^{-6}$ | CL=90% 856 |
| $f_2(1270) \to \pi^+\pi^-$ | | | | $\pi^+ e^+ \mu^-$ LF | $< 2.9 \times 10^{-6}$ | CL=90% 927 |
| $\rho(1450)^0\pi^+$, | < 8 ×10 ⁻⁵ | CL=95% | 338 | $\pi^+ e^- \mu^+$ LF | < 3.6 × 10 ⁻⁶ | CL=90% 927 |
| $\rho(1450)^0 \to \pi^+\pi^-$ | | | | $egin{array}{lll} {\cal K}^+ e^+ \mu^- & {}_{LF} \ {\cal K}^+ e^- \mu^+ & {}_{LF} \end{array}$ | $< 1.2 \times 10^{-6} $ $< 2.8 \times 10^{-6}$ | CL=90% 866 CL=90% 866 |
| $f_0(1500)\pi^+$, $f_0(1500) \rightarrow \pi^+\pi^-$ | $(1.1 \pm 0.4) \times 10^{-4}$ | | _ | $\pi^- 2e^+$ | < 1.1 × 10 ⁻⁶ | CL=90% 930 |
| $f_0(1300) \rightarrow \pi \cdot \pi$ $f_0(1710) \pi^+$, | < 5 × 10 ⁻⁵ | CL=95% | _ | $\pi^- 2\mu^+$ | < 2.0 × 10 ⁻⁶ | CL=90% 918 |
| $f_0(1710) \rightarrow \pi^+\pi^-$ | \ J \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | CL = 35 /6 | | $\pi^-e^+\mu^+$ | $< 2.0 \times 10^{-6}$ | CL=90% 927 |
| $f_0(1790)\pi^+$, | $< 6 \times 10^{-5}$ | CL=95% | _ | $ ho^- 2 \mu^+$ | $< 5.6 \times 10^{-4}$ | CL=90% 757 |
| $f_0(1790) \to \pi^+\pi^-$ | | | | K-2e ⁺ ι | < 9 ×10 ⁻⁷ | CL=90% 870 |
| $(\pi^+\pi^+)_{S-wave}\pi^-$ | $< 1.2 \times 10^{-4}$ | CL=95% | 909 | $K^-2\mu^+$ L | < 1.0 × 10 ⁻⁵ | CL=90% 856 |
| $2\pi^+\pi^-$ nonresonant | $< 1.1 \times 10^{-4}$ | CL=95% | 909 | $K^-e^+\mu^+$ L $K^*(892)^-2\mu^+$ L | $< 1.9 \times 10^{-6} $ $< 8.5 \times 10^{-4}$ | CL=90% 866 CL=90% 703 |
| $\pi^{+} 2\pi^{0} \ 2\pi^{+} \pi^{-} \pi^{0}$ | $(4.6 \pm 0.4) \times 10^{-3}$ | | 910 | K (0)2) 2μ | < 0.5 × 10 | CL=90/0 703 |
| $\eta \pi^+$, $\eta 	o \pi^+ \pi^- \pi^0$ | $(1.13\pm0.08)\%$ $(8.0\pm0.5)\times10^{-4}$ | | 883 848 | | Б. | |
| $\omega \pi^+$, $\omega \to \pi^+ \pi^- \pi^0$ | < 3 × 10 ⁻⁴ | CL=90% | 763 | D^0 | $I(J^P) = \frac{1}{2}(0^-)$ | |
| $3\pi^{+}2\pi^{-}$ | $(1.61 \pm 0.16) \times 10^{-3}$ | | 845 | Mass $m = 1864.86 \pm 0$ |) 12 Ma\/ | |
| | , | | | $m_{D^{\pm}} - m_{D^0} = 4.76 \pm 0$ | | |
| | following modes with resonances | | | $m_{D^\pm} - m_{D^0} = 4.70 \pm 0.00$ Mean life $	au = (410.1 \pm 0.00)$ | $(3 - 1.1) \times 10^{-15}$ s | |
| | les of particular charged-particle r o | nodes. | | $c\tau = 122.9 \ \mu \text{m}$ | = 1.0 / × 10 | |
| $\eta \pi^+ \ \eta \pi^+ \pi^0$ | $(3.53\pm0.21)\times10^{-3}$ | | 848 | $ m_{D_1^0} - m_{D_2^0} = (1.44)$ | $^{+0.48}_{0.50}) \times 10^{10} \ h \ s^{-1}$ | |
| $\eta \pi^+ \pi^- \omega \pi^+$ | $(1.38 \pm 0.35) \times 10^{-3}$ $< 3.4 \times 10^{-4}$ | CL=90% | 830 764 | D_1° D_2° D_2° | -0.50 | |
| $\eta'(958) \pi^+$ | $(4.67 \pm 0.29) \times 10^{-3}$ | CL = 30 /6 | 681 | $(\Gamma_{D_1^0} - \Gamma_{D_2^0})/\Gamma = 2y =$ | $(1.60 - 0.26) \times 10^{-2}$ | |
| $\eta'(958)\pi^+\pi^0$ | $(1.6 \pm 0.5) \times 10^{-3}$ | | 654 | $ q/p = 0.88 ^{+ 0.16}_{- 0.15}$ | _ | |
| , , , | | | | $A_{\Gamma} = (0.26 \pm 2.31) \times 10^{-1}$ | | |
| $K^+ K^0_S$ | c modes with a $K\overline{K}$ pair $(2.83 \pm 0.16) \times 10^{-3}$ | c 22 | 702 | | phase: $\cos \delta = 1.03^{+0.33}_{-0.18}$ | |
| $K^+K^-\pi^+$ | $(2.83 \pm 0.16) \times 10^{-3}$ [pp] $(9.54 \pm 0.26) \times 10^{-3}$ | S=2.2 S=1.1 | 793 744 | $\mathit{K}^-\pi^+\pi^0$ coherence fa | ctor $R_{K\pi\pi^0} = 0.78^{+0.11}_{-0.25}$ | |
| | | | 744 | $\mathcal{K}^-\pi^+\pi^0$ average relat | live strong phase $\delta^{K\pi\pi^0}$ | $= (239 + \frac{32}{28})^{\circ}$ |
| $\phi\pi^+$, $\phi ightarrow \ K^+ K^-$ | $(2.65 + 0.08 \atop -0.09) \times 10^{-3}$ | | 647 | $K^-\pi^-2\pi^+$ coherence t | factor $R_{K3\pi} = 0.36^{+0.24}_{-0.36}$ | 207 |
| $K + \overline{K}^* (892)^0$, | $(2.45 + 0.09 \\ -0.14) \times 10^{-3}$ | | 613 | | ative strong phase $\delta^{K3\pi}$ | |
| $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | ·= · | | | // 275.496161 | | -507 |

CP-violation decay-rate asymmetries (labeled by the D^0 decay)

```
A_{CP}(K^+K^-) = (-0.21 \pm 0.17)\%
A_{CP}(2K_S^0) = (-23 \pm 19)\%
A_{CP}(\pi^+\pi^-) = (0.22 \pm 0.21)\%
A_{CP}(2\pi^0) = (0 \pm 5)\%
A_{CP}(\pi^{+}\pi^{-}\pi^{0}) = (0.3 \pm 0.4)\%
A_{CP}(\rho(770)^{+}\pi^{-} \to \pi^{+}\pi^{-}\pi^{0}) = (1.2 \pm 0.9)\% [vv]
A_{CP}(\rho(770)^{0}\pi^{0} \to \pi^{+}\pi^{-}\pi^{0}) = (-3.1 \pm 3.0)\% [vv]
A_{CP}(\rho(770)^{-}\pi^{+} \rightarrow \pi^{+}\pi^{-}\pi^{0}) = (-1.0 \pm 1.7)\% [w]
A_{CP}(\rho(1450)^+\pi^- \to \pi^+\pi^-\pi^0) = (0 \pm 70)\%^{[W]}
A_{CP}(\rho(1450)^0 \pi^0 \to \pi^+ \pi^- \pi^0) = (-20 \pm 40)\% [vv]
A_{CP}(\rho(1450)^{-}\pi^{+} \rightarrow \pi^{+}\pi^{-}\pi^{0}) = (6 \pm 9)\%[w]
A_{CP}(\rho(1700)^{+}\pi^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}) = (-5 \pm 14)\% [w]
A_{CP}(\rho(1700)^0 \pi^0 \rightarrow \pi^+ \pi^- \pi^0) = (13 \pm 9)\%^{[\nu\nu]}
A_{CP}(\rho(1700)^{-}\pi^{+} \rightarrow \pi^{+}\pi^{-}\pi^{0}) = (8 \pm 11)\% [w]
A_{CP}(f_0(980)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 35)\%[w]
A_{CP}(f_0(1370)\pi^0 \to \pi^+\pi^-\pi^0) = (25 \pm 18)\% [vv]
A_{CP}(f_0(1500)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 18)\% [vv]
A_{CP}(f_0(1710)\pi^0 \to \pi^+\pi^-\pi^0) = (0 \pm 24)\% [vv]
A_{CP}(f_2(1270)\pi^0 \rightarrow \pi^+\pi^-\pi^0) = (-4 \pm 6)\% [vv]
A_{CP}(\sigma(400)\pi^0 \to \pi^+\pi^-\pi^0) = (6 \pm 8)\%^{[vv]}
A_{CP} (nonresonant \pi^+ \pi^- \pi^0) = (-13 \pm 23)\% [vv]
A_{CP}(K^+K^-\pi^0) = (-1.0 \pm 1.7)\%
A_{CP}(K^*(892)^+K^- \to K^+K^-\pi^0) = (-0.9 \pm 1.3)\% [w]

A_{CP}(K^*(1410)^+K^- \to K^+K^-\pi^0) = (-21 \pm 24)\% [w]
A_{CP}((K^{+}\pi^{0})_{S}K^{-} \rightarrow K^{+}K^{-}\pi^{0}) = (7 \pm 15)\% [vv]
A_{CP}(\phi(1020)\pi^0 \to K^+K^-\pi^0) = (1.1 \pm 2.2)\%^{[vv]}
A_{CP}(f_0(980)\pi^0 \to K^+K^-\pi^0) = (-3 \pm 19)\% [w]

A_{CP}(g_0(980)^0\pi^0 \to K^+K^-\pi^0) = (-5 \pm 16)\% [w]
A_{CP}(f_2'(1525)\pi^0 \to K^+ K^- \pi^0) = (0 \pm 160)\%^{[vv]}
A_{CP}(\bar{K^*}(892)^- K^+ \to K^+ K^- \pi^0) = (-5 \pm 4)\%^{[vv]}
A_{CP}(K^*(1410)^- K^+ \to K^+ K^- \pi^0) = (-17 \pm 29)\% [w]
A_{CP}((K^-\pi^0)_{S-wave}K^+ \to K^+K^-\pi^0) = (-10 \pm 40)\%^{[vv]}
A_{CP}(K_S^0\pi^0) = (-0.27 \pm 0.21)\%
A_{CP}(K_S^0 \eta) = (0.5 \pm 0.5)\%

A_{CP}(K_S^0 \eta') = (1.0 \pm 0.7)\%
A_{CP}(K_S^0\phi) = (-3 \pm 9)\%
A_{CP}(K^-\pi^+) = (0.1 \pm 0.7)\%

A_{CP}(K^+\pi^-) = (2.2 \pm 3.2)\%
A_{CP}(K^-\pi^+\pi^0) = (0.2 \pm 0.9)\%
A_{CP}(K^+\pi^-\pi^0) = (0 \pm 5)\%
A_{CP}(K_S^0\pi^+\pi^-) = (-0.9^{+2.6}_{-6.0})\%
A_{CP}(K_S^{*}N^{*}) = (0.5 - 6.0)^{10}

A_{CP}(K^{*}(892)^{-}\pi^{+} \to K_S^{0}\pi^{+}\pi^{-}) < 3.5 \times 10^{-4}, \text{CL} = 95\%

A_{CP}(K^{*}(892)^{+}\pi^{-} \to K_S^{0}\pi^{+}\pi^{-}) < 7.8 \times 10^{-4}, \text{CL} = 95\%

A_{CP}(\overline{K^{0}}\rho^{0} \to K_S^{0}\pi^{+}\pi^{-}) < 4.8 \times 10^{-4}, \text{CL} = 95\%
A_{CP}(\overline{K}^{0}\omega \to K_{S}^{0}\pi^{+}\pi^{-}) < 9.2 \times 10^{-4}, CL = 95\%
A_{CP}(\overline{K}^0 f_0(980) \rightarrow K_S^0 \pi^+ \pi^-) < 6.8 \times 10^{-4}, CL = 95\%
\begin{array}{lll} \mathcal{K}_{CP}(\overline{K}^0)(500) & \mathcal{K}_S^0\pi^+\pi^-) &< 13.5 \times 10^{-4}, \, \text{CL} = 95\% \\ \mathcal{A}_{CP}(\overline{K}^0)(1370) & \mathcal{K}_S^0\pi^+\pi^-) &< 25.5 \times 10^{-4}, \, \text{CL} = 95\% \\ \mathcal{A}_{CP}(K_0^*(1430)^-\pi^+ \rightarrow K_S^0\pi^+\pi^-) &< 9.0 \times 10^{-4}, \, \text{CL} = 95\% \\ \mathcal{A}_{CP}(K_2^*(1430)^-\pi^+ \rightarrow K_S^0\pi^+\pi^-) &< 6.5 \times 10^{-4}, \, \text{CL} = 95\% \\ \mathcal{A}_{CP}(K_2^*(1430)^-\pi^+ \rightarrow K_S^0\pi^+\pi^-) &< 6.5 \times 10^{-4}, \, \text{CL} = 95\% \\ \end{array}
A_{CP}(K^*(1680)^-\pi^+ \to K_S^0\pi^+\pi^-) < 28.4 \times 10^{-4}, CL = 95\%
A_{CP}(K^-\pi^+\pi^+\pi^-) = (0.7 \pm 1.0)\%
A_{CP}(K^+\pi^-\pi^+\pi^-) = (-2 \pm 4)\%
A_{CP}(K^+K^-\pi^+\pi^-) = (-8 \pm 7)\%
\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-0.65 \pm 0.18)\%
```

$\emph{T} ext{-violation decay-rate asymmetry}$

 $A_T(K^+K^-\pi^+\pi^-) = (1 \pm 7) \times 10^{-3}$ [oo]

CPT-violation decay-rate asymmetry

 $A_{CPT}(K^{\mp}\pi^{\pm}) = 0.008 \pm 0.008$

Form factors

| ** *= ==== | |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| ${ m r}_{V} \equiv { m V}(0)/{ m A}_{1}(0) \ { m in} \ { m \it D}^{0} ightarrow { m \it K}^{st}(892)^{-} \ell^{+} u_{\ell} = 1.7 \pm 1.0 \ { m m}$ | |
| $r_2 \; \equiv \; A_2(0)/A_1(0) \; in \; \mathcal{D}^0 ightarrow \; \mathcal{K}^*(892)^- \ell^+ u_\ell = 0.9 \; \pm 0.9$ | 0.4 |
| $f_{+}(0) \text{ in } D^{0} ightarrow \ K^{-} \ell^{+} u_{\ell} = 0.727 \pm 0.011$ | |
| $f_{+}(0) V_{cs} \text{ in } D^{0} \rightarrow K^{-}\ell^{+}\nu_{\ell} = 0.726 \pm 0.009$ | |
| $r_1 \equiv a_1/a_0 \text{ in } D^0 	o K^-\ell^+ u_\ell = -2.65 \pm 0.35$ | |
| $r_2\equiv a_1/a_0$ in $D^0 ightarrow~K^-\ell^+ u_\ell=13\pm9$ | |
| $f_{+}(0) V_{cd} \text{ in } D^{0} \rightarrow \pi^{-}\ell^{+}\nu_{\ell} = 0.152 \pm 0.005$ | |
| $r_1\equiv a_1/a_0$ in $D^0 ightarrow \ \pi^-\ell^+ u_\ell=-2.8\pm0.5$ | |
| $r_2 \equiv a_1/a_0 \; {\sf in} \; D^0 ightarrow \; \pi^- \ell^+ u_\ell = 6 \pm 3.0$ | |

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K_S^0 modes, not as \overline{K}^0 modes. Nearly always it is a K_S^0 that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2 \Gamma(K_S^0) = \Gamma(\overline{K}^0)$.

| D ⁰ DECAY MODES | | Fraction | $(\Gamma_i/\Gamma$ |) | | cale factor/ idence leve(| |
|------------------------------------------------------------------------------------------------------------------|----------------|----------|----------------------|--------------------|----------|------------------------------|------------|
| | Topolo | gical m | odes | | | | |
| 0-prongs | [ww] | - | ± 6 |) % | | | - |
| 2-prongs | | (70 | ± 6 | , | | | - |
| 4-prongs | [xx] | | ± 0 | | 4 | | _ |
| 6-prongs | [уу] | (6.4 | ± 1 | .3)×1 | .0-4 | | - |
| e^+ anything | Inclus [zz] | ive mo | | .11) % | | | _ |
| μ^+ anything | [22] | (6.7 | | | | | _ |
| K ⁻ anything | | (54.7 | ± 2 | , | | S=1.3 | _ |
| \overline{K}^0 anything + K^0 anything | | (47 | ± 4 |) % | | | _ |
| K^+ anything | | (3.4 | ± 0 | , | | | _ |
| $\frac{K^*(892)^-}{K^*(892)^0}$ anything | | (15 | ± 9 | , | | | - |
| \overline{K}^* (892) ⁰ anything | | (9 | ± 4 | , | | CI 000/ | _ |
| $K^*(892)^+$ anything $K^*(892)^0$ anything | | < 3.6 | ± 1 | % 3)% | | CL=90% | _ |
| η anything | | (9.5 | | , | | | _ |
| η' anything | | | | .27) % | | | _ |
| ϕ anything | | | | .11) % | | | - |
| S | Semilep | tonic m | nodes | | | | |
| $K^-e^+ u_e$ | | (3.55 | ± 0 | .04) % | | S=1.2 | 867 |
| $K^-\mu^+ u_\mu$ | | (3.30 |) ± 0 | .13) % | | | 864 |
| $K^*(892)^- e^+ \nu_e$ | | | | .16) % | | | 719 |
| $K^*(892)^-\mu^+\nu_\mu$ | | (1.90 | | .24) % | | | 714 |
| $K^-\pi^0e^+ u_e$ | | (1.6 | $^{+}_{-} ^{1}_{0}$ | .3 .5) % | | | 861 |
| $\overline{K}{}^0\pi^-e^+\nu_e$ | | (2.7 | + 0 - 0 | .9)% | | | 860 |
| $K^-\pi^+\pi^-e^+\nu_e$ | | (2.8 | + 1 - 1 | | 0-4 | | 843 |
| $K_1(1270)^- e^+ \nu_e$ | | (7.6 | + 4 - 3 | | | | 498 |
| $K^-\pi^+\pi^-\mu^+\nu_{\mu}$ | | < 1.2 | | | 0-3 | CL=90% | 821 |
| $(\overline{K}^*(892)\pi)^{-}\mu^{+}\nu_{\mu}$ | | < 1.4 | | × 1 | .0-3 | CL=90% | 692 |
| $\pi^-e^+\nu_e$ | | (2.89 | ± 0 | .08) × 1 | $^{0-3}$ | S=1.1 | 927 |
| $\pi^-\mu^+ u_\mu$ | | (2.37 | ' ± 0 | .24) × 1 | $^{0-3}$ | | 924 |
| $ ho^- e^+ u_e$ | | (1.9 | ± 0 | .4) × 1 | 0-3 | | 771 |
| | onic m | odes wi | | | | | |
| $K^-\pi^+ \\ K_S^0\pi^0$ | | | | .05) % .04) % | | S=1.2 | 861 860 |
| $K_{i}^{0}\pi^{0}$ | | (10.0 | | .7)×1 | 0^{-3} | | 860 |
| $\mathcal{K}_{S}^{0}\pi^{+}\pi^{-}$ | [<i>pp</i>] | | | .19) % | . • | S=1.1 | 842 |
| $K_s^0 \rho^0$ | 1, , , | (6.3 | + 0 - 0 | , | 0-3 | | 674 |
| J. | | • | | | | | |
| $K^0_{\mathcal{S}}\omega$, $\omega ightarrow \pi^+\pi^ K^0_{\mathcal{S}}(\pi^+\pi^-)_{\mathcal{S}-	ext{wave}}$ | | (2.0 | | .6) × 1 | | | 670 |
| • | | (3.4 | | .8)×1 | | | 842 |
| $K_S^0 f_0(980)$, | | (1.21 | + 0 | .40 .24) × 1 | 0-3 | | 549 |
| $f_0(980) \to \pi^+\pi^-$ | | | | | | | |
| $K_S^0 f_0(1370)$, | | (2.8 | + 0 | .9)×1 | 0-3 | | † |
| $f_0(1370) \to \pi^+ \pi^-$ | | | | | | | |
| $K_S^0 f_2(1270)$, | | (9 | + 10 - 6 |) × 1 | 10-5 | | 262 |
| $f_2(1270) \to \pi^+ \pi^-$ | | | . + 0 | 15 | | | |
| $K^*(892)^-\pi^+$, $K^*(892)^- \to K_S^0\pi^-$ | | (1.66 | , – 0 | .15 .17) % | | | 711 |
| $K_0^*(1430)^-\pi^+$, | | (2 60 | + 0 | .40 .33) × 1 | n-3 | | 378 |
| $K_0^*(1430)^- \to K_S^0 \pi^-$ | | (2.03 | _ 0 | .33 / ^ - | . • | | 310 |
| $K_2^*(1430)^-\pi^+$, | | (3.4 | + 1 | .9) × 1 | 0-4 | | 367 |
| $K_2^*(1430)^- \to K_S^0 \pi^-$ | | | - 1 | .0 / | | | |
| $K^*(1680)^-\pi^+$ | | (4 | ± 4 |) × 1 | 0^{-4} | | 46 |
| $K^*(1680)^- \to K_S^0 \pi^-$ | | | | | | | |
| $K^*(892)^+\pi^-$ | [aaa] | (1.13 | + 0 - 0 | .60 .34) × 1 | 0^{-4} | | 711 |
| $K^*(892)^+ \rightarrow K_S^0 \pi^+$ | , , | | | | 0-5 | CI 050: | |
| $K_0^*(1430)^+\pi^-$, | [aaa] | < 1.4 | | × 1 | .0 .5 | CL=95% | _ |
| $K_0^*(1430)^+ \rightarrow K_S^0 \pi^+ K_2^*(1430)^+ \pi^-,$ | [225] | _ 24 | | 1 | n-5 | CL=95% | |
| $K_2^*(1430)^+ \pi^-,$ $K_2^*(1430)^+ \to K_S^0 \pi^+$ | [888] | < 3.4 | | X J | .u - | CL=95% | _ |
| $\kappa_2(1430) \rightarrow \kappa_S \pi$ | | | | | | | |

| $K^0_S\pi^+\pi^-$ nonresonant | | $(2.5 \begin{array}{c} + 6.0 \\ - 1.6 \end{array}) \times 10^{-4}$ | | 842 | $\overline{\mathcal{K}}^*$ (892) $^0\pi^+\pi^-$ total | (2.4 ± 0.5) % | | 685 |
|------------------------------------------------------------------------------------------------------------------------|-------|--------------------------------------------------------------------------|---------|------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------|------------|
| $K^-\pi^+\pi^0$ | | (13.9 ± 0.5) % | S=1.7 | 844 | $K^*(892)^0 \pi^+ \pi^-$ 3-body | (1.48 \pm 0.34) % | | 685 |
| $K^-\rho^+$ | | (10.8 ± 0.7) % | 3=1.7 | 675 | $\overline{K}^*(892)^0 ho^0$ $\overline{K}^*(892)^0 ho^0$ transverse | (1.57 ± 0.34) % | | 417 |
| $K^- ho (1700)^+$, | | $(7.9 \pm 1.7) \times 10^{-3}$ | | † | $\overline{K}^*(892)^0 \rho^0$ S-wave | $(1.7 \pm 0.6)\%$ $(3.0 \pm 0.6)\%$ | | 417 417 |
| $\rho(1700)^+ \rightarrow \pi^+ \pi^0$ | | . 0.40 | | | \overline{K}^* (892) $^0 \rho^0$ S-wave long. | < 3 × 10 ⁻ | | 417 |
| $K^*(892)^-\pi^+, K^*(892)^- \to K^-\pi^0$ | | $(2.22 \ ^{+}_{-}\ 0.40 \) \%$ | | 711 | $\overline{K}^*(892)^0 \rho^0 P$ -wave | < 3 × 10 ⁻ | CL=90% | 417 |
| $\overline{K}^*(892) \xrightarrow{\longrightarrow} K \pi^{\circ}$ $\overline{K}^*(892)^0 \pi^0$, | | (1.88 ± 0.23) % | | 711 | $\overline{K}^*(892)^0 ho^0$ D -wave $K_1(1270)^-\pi^+$ | (2.1 ± 0.6) % | | 417 |
| $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | | (1.00 ± 0.25) /0 | | 111 | $K_1(1270)^{-}\pi^+$ | b] (1.6 ± 0.8) % < 1.2 % | CL=90% | 484 386 |
| $K_0^*(1430)^-\pi^+$, | | $(4.6 \pm 2.1) \times 10^{-3}$ | | 378 | $\overline{K}^*(892)^0 \pi^+ \pi^- \pi^0$ | (1.9 ± 0.9) % | 02-3070 | 644 |
| $K_0^*(1430)^- \to K^-\pi^0$ | | | | | $K = \pi^+ \omega$ | (3.0 \pm 0.6) % | | 605 |
| $\overline{K}_0^*(1430)^0\pi^0$, | | $(5.7 \begin{array}{cc} + & 5.0 \\ - & 1.5 \end{array}) \times 10^{-3}$ | | 379 | $\overline{K}^*(892)^0 \omega \ K^- \pi^+ \eta'(958)$ | $(1.1 \pm 0.5)\%$ $(7.5 \pm 1.9) \times 10^{-}$ | -3 | 410 |
| $\overline{K}_0^*(1430)^0 \to K^-\pi^+$ | | | | | $K^{-\eta} (938)$ $K^*(892)^0 \eta'(958)$ | $(7.5 \pm 1.9) \times 10^{-}$ $< 1.1 \times 10^{-}$ | | 479 120 |
| $K^*(1680)^-\pi^+$, $K^*(1680)^- 	o K^-\pi^0$ | | $(1.8 \pm 0.7) \times 10^{-3}$ | | 46 | | odes with three K's | | |
| $K^-\pi^+\pi^0$ nonresonant | | / 1 11 + 0.50 \ 0/ | | 044 | $K_S^0 K^+ K^-$ | $(4.45 \pm 0.34) \times 10^{-}$ | 3 | 544 |
| $K_S^0 2\pi^0$ | | (1.11 + 0.50) % | | 844 | $K_S^0 a_0(980)^0$, $a_0^0 	o K^+ K^-$ | (3.0 ± 0.4)×10 ⁻ | | _ |
| $K_S^0 (2\pi^0)$ -S-wave | | $(9.1 \pm 1.1) \times 10^{-3}$ $(2.6 \pm 0.7) \times 10^{-3}$ | S=2.2 | 843 | $K^{-}a_{0}(980)^{+}$, $a_{0}^{+} ightarrow K^{+}K_{S}^{0}$ | (6.0 \pm 1.8) \times 10^- | 4 | - |
| $\frac{K_S(2\pi)^{-3-\text{wave}}}{K^*(892)^0\pi^0}$, | | $(7.8 \pm 0.7) \times 10^{-3}$ | | 711 | $K^{+}_{0} a_{0} (980)^{-}, a_{0}^{-} \rightarrow K^{-} K_{S}^{0}$ | < 1.1 × 10 | | _ |
| $\overrightarrow{K}^*(892)^0 \rightarrow K_S^0 \pi^0$ | | (, | | | $K_{S}^{0} f_{0}(980), f_{0} \rightarrow K^{+} K^{-}$ | < 9 × 10 ⁻ | | - |
| \overline{K}^* (1430) $^0\pi^0$, $\overline{K}^{*reve{0}} ightarrow$ | | $(4 \pm 23) \times 10^{-5}$ | | _ | $K^0_S \phi$, $\phi \rightarrow K^+ K^-$ $K^0_S f_0(1370)$, $f_0 \rightarrow K^+ K^-$ | $(2.04 \pm 0.16) \times 10^{-1}$ $(1.7 \pm 1.1) \times 10^{-1}$ | | 520 — |
| $K_S^0 \pi^0$ | | | | | $3K_S^0$ | $(9.1 \pm 1.3) \times 10^{-}$ | _ | 539 |
| $\overline{K}^*(1680)^0\pi^0$, $\overline{K}^{*0} ightarrow$ | | $(1.0 \pm 0.4) \times 10^{-3}$ | | _ | $K^{+}2K^{-}\pi^{+}$ | (2.21 ± 0.31) × 10 ⁻¹ | | 434 |
| $K_S^0 f_2(1270), f_2 \rightarrow 2\pi^0$ | | $(2.3 \pm 1.1) \times 10^{-4}$ | | _ | $K^{+}_{\underline{K}}K^{-}\overline{K}^{*}(892)^{0}$, | $(4.4 \pm 1.7) \times 10^{-1}$ | 5 | † |
| $2K_S^0$, one $K_S^0 \rightarrow 2\pi^0$ | | $(3.2 \pm 1.1) \times 10^{-4}$ | | _ | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | (| . 5 | |
| $K^{-}2\pi^{+}\pi^{-}$ | [pp] | $(8.07 \ ^{+}\ 0.21 \) \%$ | S=1.3 | 813 | $K^-\pi^+\phi$, $\phi	o K^+K^-\phi\overline{K}^*(892)^0$, | $(4.0 \pm 1.7) \times 10^{-}$ $(1.06 \pm 0.20) \times 10^{-}$ | | 422 † |
| $K^-\pi^+ ho^0$ total | | (6.74 ± 0.33) % | | 609 | $\phi \rightarrow K^+ K^-$, | (1.00 ± 0.20) × 10 | | ' |
| $K^-\pi^+ ho^0$ 3-b ody | | $(5.1 \pm 2.3) \times 10^{-3}$ | | 609 | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | | F | |
| $\overline{K}^*(892)^0 \rho^0$, | | $(1.05 \pm 0.23)\%$ | | 416 | $K^+2K^-\pi^+$ nonresonant $2K^0_SK^\pm\pi^\mp$ | $(3.3 \pm 1.5) \times 10^{-}$ $(6.0 \pm 1.3) \times 10^{-}$ | | 434 427 |
| $\overrightarrow{K}^*(892)^0 \to K^-\pi^+ K^-a_1(1260)^+,$ | | (3.6 ± 0.6) % | | 327 | ğ. | | | 427 |
| $a_1(1260)^+ \rightarrow 2\pi^+\pi^-$ | | (3.0 ± 0.0) /0 | | 321 | $\pi^+\pi^-$ | onic modes $(1.401 \pm 0.027) \times 10^{-1}$ | ·3 S=1.1 | 922 |
| $\overline{K}^*(892)^0 \pi^+ \pi^- \text{total},$ | | $(1.6 \pm 0.4)\%$ | | 685 | $2\pi^0$ | $(8.0 \pm 0.5) \times 10^{-}$ | _ | 923 |
| $K^*(892)^0 \to K^-\pi^+$ | | (0 0 1 0 0) 10-3 | | | $\pi^+\pi^-\pi^0$ | (1.43 ± 0.06) % | S=1.9 | 907 |
| $\overline{K}^*(892)^0\pi^+\pi^-$ 3-b ody, $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | | $(9.9 \pm 2.3) \times 10^{-3}$ | | 685 | $\rho_{0}^{+} \pi_{0}^{-}$ | (9.8 ± 0.4) × 10 | | 764 |
| $K_1(1270)^-\pi^+$, | [bbb] | $(2.9 \pm 0.3) \times 10^{-3}$ | | 484 | $ ho^0\pi^0 \\ ho^-\pi^+$ | $(3.72 \pm 0.22) \times 10^{-}$ $(4.96 \pm 0.24) \times 10^{-}$ | _ | 764 764 |
| $K_1(1270)^- \to K^-\pi^+\pi^-$ | | | | | $\rho(1450)^{+}\pi^{-}$, $\rho(1450)^{+} \to$ | $(1.6 \pm 2.0) \times 10^{-}$ | _ | - |
| $K^-2\pi^+\pi^-$ nonresonant $K^0_S\pi^+\pi^-\pi^0$ | | (1.88 ± 0.26) % | | 813 | $_{\pi^+}$ $_{\pi^0}$ | , | | |
| $K_S^{\eta + \eta} \stackrel{\eta}{\longrightarrow} \pi^+ \pi^- \pi^0$ | | $(5.2 \pm 0.6)\%$ $(1.02 \pm 0.09) \times 10^{-3}$ | | 813 772 | $ ho(1450)^0\pi^0$, $ ho(1450)^0 ightarrow$ | $(4.3 \pm 1.9) \times 10^{-}$ | 5 | _ |
| $K_S^0\omega$, $\omega \to \pi^+\pi^-\pi^0$ | | $(9.9 \pm 0.5) \times 10^{-3}$ | | 670 | $\rho(1450)^-\pi^+$, $\rho(1450)^- \rightarrow$ | ($2.6~\pm~0.4~$) $\times10^-$ | 4 | - |
| $K^{-}2\pi^{+}\pi^{-}\pi^{0}$ | | (4.2 ± 0.4) % | | 771 | $\pi^-\pi^0 ho(1700)^+\pi^-$, $ ho(1700)^+ ightarrow$ | (5.9 ± 1.4)×10 | 4 | _ |
| $\overline{K}^*(892)^0 \pi^+ \pi^- \pi^0$, | | $(1.3 \pm 0.6)\%$ | | 643 | $\pi^+ \pi^0$ | | | |
| \overrightarrow{K}^* (892) $^0 \rightarrow K^- \pi^+$ $K^- \pi^+ \omega$, $\omega \rightarrow \pi^+ \pi^- \pi^0$ | | (2.7 ± 0.5) % | | 605 | $\rho(1700)^{0}\pi^{0}$, $\rho(1700)^{0}$ \rightarrow | (7.2 \pm 1.7) \times 10 ⁻ | 4 | - |
| $\overline{K}^*(892)^0\omega$, | | $(6.5 \pm 3.0) \times 10^{-3}$ | | 410 | $\pi^{+}\pi^{-}$ $ ho(1700)^{-}\pi^{+}$, $ ho(1700)^{-} ightarrow$ | $(4.6 \pm 1.1) \times 10^{-1}$ | 4 | _ |
| <u> </u> | | | | | $\pi^-\pi^0$ | | | |
| $K^{*}(892)^{0} \rightarrow K^{-}\pi^{+},$ $K^{0}_{S}\eta\pi^{0} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ | | $(5.5 \pm 1.1) \times 10^{-3}$ | | 721 | $f_0(980)\pi^0$, $f_0(980) \rightarrow \pi^+\pi^-$ | (3.6 ± 0.8)×10 | 3 | _ |
| $K_c^0 a_0(980), a_0(980) \rightarrow \eta \tau$ | 0 | $(6.5 \pm 2.0) \times 10^{-3}$ | | _ | $f_0(500)\pi^0$, $f_0(500) ightarrow$ | (1.18 ± 0.21) \times 10^{-} | 4 | - |
| $\overline{K}^{s}(892)^{0}\eta,$ $\overline{K}^{s}(892)^{0}\to K_{s}^{0}\pi^{0}$ | | $(1.6 \pm 0.5) \times 10^{-3}$ | | - | $f_0(1370)\pi^0$, $f_0(1370) 	o$ | (5.3 ± 2.0)×10 | 5 | _ |
| $\overline{K}^*(892)^0 \rightarrow K_S^0 \pi^0$ | | 2 | | | -+ | | | |
| $K_S^0 2\pi^+ 2\pi^- K_S^0 \rho^0 \pi^+ \pi^-$, no $K^*(892)^-$ | | $(2.68 \pm 0.30) \times 10^{-3}$ | | 768 | $f_0(1500)\pi^0$, $f_0(1500) \rightarrow$ | $(5.6 \pm 1.5) \times 10^{-}$ | 5 | - |
| | | $(1.1 \pm 0.7) \times 10^{-3}$ $(5 \pm 8) \times 10^{-4}$ | | 642 | $f_0(1710)\pi^0$, $f_0(1710) \rightarrow$ | (4.4 ± 1.5)×10 ⁻ | 5 | _ |
| $K^*(892)^- 2\pi^+ \pi^-,$ $K^*(892)^- \to K_S^0 \pi^-,$ | | (3 ± 0) × 10 | | 042 | $\pi^+\pi^-$ | | | |
| no $ ho^0$ | | | | | $f_2(\overset{n}{1270})\pi^0$, $f_2(1270) 	o $ | $(1.89 \pm 0.20) \times 10^{-}$ | 4 | _ |
| $K^*(892)^- \rho^0 \pi^+$, | | $(1.6 \pm 0.6) \times 10^{-3}$ | | 230 | $\pi^+ \pi^- \pi^0$ nonresonant | ($1.20~\pm~0.35~$) $\times~10^{-}$ | 4 | 907 |
| $K^*(892)^- ightarrow K_S^0 \pi^- \ K_S^0 2\pi^+ 2\pi^-$ nonresonant | | 1.2 × 10 ⁻³ | CL=90% | 76.8 | $3\pi^{0} \ 2\pi^{+} 2\pi^{-}$ | < 3.5 × 10 ⁻¹ | | 908 |
| $K^-3\pi^+2\pi^-$ nonresonant | | $1.2 	 \times 10^{-3}$ ($2.2 \pm 0.6 $) $\times 10^{-4}$ | CL=90% | 768 713 | $2\pi^+2\pi^- \ a_1(1260)^+\pi^-$, $a_1^+ ightarrow$ | $(7.42 \pm 0.21) \times 10^{-1}$ $(4.45 \pm 0.31) \times 10^{-1}$ | | 880 |
| -n -n | | 5.5 / ^ 10 | | | $2\pi^{+}\pi^{-}$ total | , | | |
| | | modes with resonances have | | | a_1 (1260) $^+$ π^- , a_1^+ $ ightarrow$ | ($3.21~\pm~0.25$) $\times~10^{-1}$ | 3 | - |
| | | cular charged-particle modes and $\overline{K}^*(892) ho$ submodes or | | | $\rho^0 \pi^+$ S-wave | (| .4 | |
| below.) | | (/ | A MESS! | | $a_1(1260)^+\pi^-$, $a_1^+ ightarrow ho^0\pi^+$ <i>D</i> -wave | (1.9 ± 0.5) × 10 | - | _ |
| $K_S^0 \eta$ | | $(4.78 \pm 0.30) \times 10^{-3}$ | | 772 | a_1 (1260) $^+$ π^- , a_1^+ $ ightarrow$ | (6.2 ± 0.7)×10 | 4 | _ |
| $K_{S}^{0}\omega$ | | (1.11 ± 0.06) % | | 670 | $\sigma\pi^+$ | | | |
| $K_S^0 \eta'(958) \ K^- a_1(1260)^+$ | | $(9.4 \pm 0.5) \times 10^{-3}$ | | 565 | $2 ho^{U}$ total | (1.82 ± 0.13) $\times10^-$ | | 518 |
| | | (78 ± 11 \0/ | | 327 | 0 -0 | | | |
| $K^{-}a_{2}(1320)^{+}$ | | $(7.8 \pm 1.1)\%$ 2×10^{-3} | CL=90% | 327 198 | $2 ho^0$, parallel helicities | (8.2 ± 3.2) × 10 | .5 | _ |

| $2 ho^0$, perpendicular helici- | $(4.7 \pm 0.6) \times 10^{-4}$ | | - | $K^*(892)^+\pi^-$, DC $(1.13 + 0.60 \atop -0.34) \times 10^{-4}$ 711 |
|-------------------------------------------------------------------------|-----------------------------------------------------|----------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ties | | | | $K^*(892)^+ \rightarrow K_S^0 \pi^+$ |
| $2\rho^0$, longitudinal helicities | $(1.25 \pm 0.10) \times 10^{-3}$ | | _ | $K_0^*(1430)^+\pi^-$, DC < 1.4 $\times 10^{-5}$ - |
| Resonant $(\pi^+\pi^-)\pi^+\pi^-$ | $(1.48 \pm 0.12) \times 10^{-3}$ | | - | $K_0^*(1430)^+ \to K_S^0 \pi^+$ |
| 3-body total | | | | |
| $\sigma\pi^+\pi^-$ | $(6.1 \pm 0.9) \times 10^{-4}$ | | - | $K_2^*(1430)^+\pi^-$, DC < 3.4 $\times 10^{-5}$ |
| $f_0(980)\pi^+\pi^-$, f_0 $ ightarrow$ | $(1.8 \pm 0.5) \times 10^{-4}$ | | - | $K_2^*(1430)^+ \to K_S^0 \pi^+$ |
| $\pi^{+}\pi^{-}$ | | | | $K^{+}\pi^{-}\pi^{0}$ DC (3.04 ± 0.17) × 10 ⁻⁴ 844 |
| $f_2(1270) \pi^+ \pi^-$, $f_2 \to$ | $(3.6 \pm 0.6) \times 10^{-4}$ | | _ | $\mathcal{K}^+\pi^-\pi^0$ via $\overline{D}{}^0$ (7.3 \pm 0.5) $	imes$ 10 $^{-4}$ — |
| $\pi^{+}\pi^{-}2\pi^{0}$ π^{0} | $(10.0 \pm 0.9) \times 10^{-3}$ | | 882 | $K^+\pi^+2\pi^-$ DC $(2.61 \ ^+0.21 \ _0.19 \) \times 10^{-4}$ 813 |
| $\eta \pi^0$ | | | | |
| | [ddd] (6.8 \pm 0.7) \times 10 ⁻⁴ | CI 000/ | 846 | $K^+\pi^+2\pi^-$ via \overline{D}^0 < 4 $\times 10^{-4}$ CL=90% 812 |
| $\frac{\omega \pi^0}{2\pi^+ 2\pi^- \pi^0}$ | [ddd] < 2.6 | CL=90% | 761 | μ^- anything via $\overline{D}{}^0$ $<$ 4 $	imes$ 10 ⁻⁴ CL=90% $-$ |
| | $(4.1 \pm 0.5) \times 10^{-3}$ | | 844 | $\Delta C = 1$ weak neutral current (C1) modes, |
| $\eta \pi^+_{} \pi^{}$ | [ddd] (1.09 \pm 0.16) \times 10 ⁻³ | | 827 | Lepton Family number (LF) violating modes, |
| | [ddd] (1.6 \pm 0.5) \times 10 ⁻³ | | 738 | Lepton (L) or Baryon (B) number violating modes |
| $3\pi^{+}3\pi^{-}$ | $(4.2 \pm 1.2) \times 10^{-4}$ | | 795 | 5 |
| $\eta'(958) \pi^0$ | $(8.9 \pm 1.4) \times 10^{-4}$ | | 678 | $ \begin{array}{ccccccccccccccccccccccccccccccccc$ |
| $\eta'(958)\pi^{+}\pi^{-}$ | $(4.5 \pm 1.7) \times 10^{-4}$ | | 65 0 | $\mu^{+} \mu^{-}$ C1 < 1.4 × 10 ⁻⁷ CL=90% 926 |
| 2η | $(1.67 \pm 0.20) \times 10^{-3}$ | | 755 | $\pi^0 e^+ e^-$ C1 < 4.5 × 10 ⁻⁵ CL=90% 928 |
| $\eta \eta'(958)$ | $(1.05 \pm 0.26) \times 10^{-3}$ | | 537 | $\pi^0 \mu^+ \mu^-$ C1 < 1.8 × 10 ⁻⁴ CL=90% 915 |
| Hadronio | modes with a $K\overline{K}$ pair | | | $ \eta e^{+}e^{-} $ C1 < 1.1 × 10 ⁻⁴ CL=90% 852 |
| K ⁺ K ⁻ | $(3.96 \pm 0.08) \times 10^{-3}$ | S=1.4 | 791 | $\eta e^+ e^-$ C1 < 5.3 × 10 ⁻⁴ CL=90% 838 |
| $2K_S^0$ | $(3.70 \pm 0.00) \times 10^{-4}$ | S=2.5 | 789 | $\pi^{+} \pi^{-} e^{+} e^{-}$ C1 < 3.73 × 10 ⁻⁴ CL=90% 922 |
| $K_S^0 K^- \pi^+$ | $(3.3 \pm 0.5) \times 10^{-3}$ | S=1.1 | 739 | $\rho^0 e^+ e^-$ C1 < 1.0 × 10 ⁻⁴ CL=90% 922 |
| V\$ 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | | | | $ \rho \in \mathcal{C} = C1 < 1.0 \times 10^{-5} \text{ CL} = 90\% \text{ 71} $ $ \pi^{+} \pi^{-} \mu^{+} \mu^{-} \qquad C1 < 3.0 \times 10^{-5} \text{ CL} = 90\% \text{ 894} $ |
| $\overline{K}^*(892)^0 K_S^0$, | $< 5 	 \times 10^{-4}$ | CL=90% | 608 | $\rho^0 \mu^+ \mu^-$ C1 < 2.2 × 10 ⁻⁵ CL=90% 694 |
| $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | 2 | | | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $K_{\mathcal{S}}^{0}K^{+}\pi^{-}$ | $(2.6 \pm 0.5) \times 10^{-3}$ | | 739 | $\omega \mu^+ \mu^-$ C1 < 8.3 × 10 ⁻⁴ CL=90% 751 |
| $K^*(892)^0 K_S^0$, | $< 2.8 \times 10^{-4}$ | CL=90% | 608 | $K^-K^+e^+e^-$ C1 < 3.15 × 10 ⁻⁴ CL=90% 791 |
| $K^*(892)^0 \to K^+\pi^-$ | | | | $\phi e^+ e^-$ C1 < 5.2 × 10 ⁻⁵ CL=90% 654 |
| $K^+K^-\pi^0$ | $(3.28 \pm 0.14) \times 10^{-3}$ | | 743 | $K^-K^+\mu^+\mu^-$ C1 < 3.3 × 10 ⁻⁵ CL=90% 710 |
| $K^*(892)^+ K^-$, | $(1.46 \pm 0.07) \times 10^{-3}$ | | - | $\phi \mu^+ \mu^-$ C1 < 3.1 × 10 ⁻⁵ CL=90% 631 |
| $K^*(892)^+ \to K^+ \pi^0$ | | | | $\frac{\varphi \mu}{K^0} e^+ e^-$ [uu] < 1.1 × 10 ⁻⁴ CL=90% 866 |
| $K^*(892)^- K^+$, | $(5.2 \pm 0.4) \times 10^{-4}$ | | - | $\overline{K}^{0}\mu^{+}\mu^{-}$ [uu] < 2.6 × 10 ⁻⁴ CL=90% 852 |
| $K^*(892)^- \to K^- \pi^0$ | | | | $K - \pi^{+} e^{+} e^{-}$ C1 < 3.85 × 10 ⁻⁴ CL=90% 861 |
| $(K^{+}\pi^{0})_{S-wave}K^{-}$ | $(2.34 \pm 0.17) \times 10^{-3}$ | | 743 | $\overline{K}^*(892)^0 e^+ e^-$ [uu] < 4.7 × 10 ⁻⁵ CL=90% 719 |
| $(K^-\pi^0)_{S-wave}K^+$ | $(1.3 \pm 0.4) \times 10^{-4}$ | | 743 | $K^-\pi^+\mu^+\mu^-$ C1 < 3.59 × 10 ⁻⁴ CL=90% 829 |
| $f_0(980)\pi^0$, $f_0 \to K^+K^-$ | $(3.4 \pm 0.6) \times 10^{-4}$ | | _ | $\overline{K}^*(892)^0 \mu^+ \mu^-$ [uu] < 2.4 × 10 ⁻⁵ CL=90% 700 |
| $\phi\pi^0$ $\phi \rightarrow K^+K^-$ | $(6.4 \pm 0.4) \times 10^{-4}$ | | _ | |
| $2K_S^0\pi^0$ | < 5.9 × 10 ⁻⁴ | | 740 | |
| $K^{+}K^{-}\pi^{+}\pi^{-}$ | [eee] (2.43 \pm 0.12) \times 10 ⁻³ | | 677 | · 0 · 1 · = |
| $\phi\pi^+\pi^-$ 3-body, $\phi\to$ | $(2.4 \pm 2.4) \times 10^{-5}$ | | 614 | 1 |
| | _ ,,,, | | | |
| ϕho^0 , $\phi ightarrow K^+ K^-$ | $(7.0 \pm 0.6) \times 10^{-4}$ | | 250 | 0 1 = ' |
| $K^+ K^- ho^0$ 3-body | $(5 \pm 7) \times 10^{-5}$ | | 302 | · 1 · = |
| $f_0(980)\pi^+\pi^-$, $f_0 \rightarrow K^+K^-$ | $-$ (3.6 \pm 0.9) \times 10 ⁻⁴ | | - | 1 |
| K^* (892) 0 $K^\mp\pi^\pm$ 3-body, | [fff] $(2.7 \pm 0.6) \times 10^{-4}$ | | 531 | |
| $K^{*0} \rightarrow \underline{K}^{\pm} \pi^{\mp}$ | - | | | 0 i |
| $K^*(892)^0 \overline{K}^*(892)^0$, $K^{*0} \rightarrow$ | $(7 \pm 5) \times 10^{-5}$ | | 272 | |
| $K^{\pm}\pi^{\mp}$ | | | | |
| $K_1(1270)^{\pm} K^{\mp}$, | $(8.0 \pm 1.8) \times 10^{-4}$ | | _ | |
| $K_1(1270)^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ | | | | $2\pi^{-}2e^{+} + c.c.$ L < 1.12 $\times 10^{-4}$ CL=90% 922 $2\pi^{-}2\mu^{+} + c.c.$ L < 2.9 $\times 10^{-5}$ CL=90% 894 |
| $K_1(1400)^{\pm}K^{\mp}$, | $(5.3 \pm 1.2) \times 10^{-4}$ | | _ | |
| $K_1(1400)^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ | | | . - - | 4 |
| $2K_{S}^{0}\pi^{+}\pi^{-}$ | $(1.23 \pm 0.23) \times 10^{-3}$ | | 673 | · · · · · · · · · · · · · · · · · · · |
| $K_{S}^{0}K^{-}2\pi^{+}\pi^{-}$ | $< 1.4 \times 10^{-4}$ | CL=90% | 595 | and the second s |
| $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ | $(3.1 \pm 2.0) \times 10^{-3}$ | | 600 | $2K^{-}2\mu^{+}$ + c.c. L < 9.4 $\times 10^{-6}$ CL=90% 710 $\pi^{-}\pi^{-}e^{+}\mu^{+}$ + c.c. L < 7.9 $\times 10^{-5}$ CL=90% 911 |
| | | | | |
| Other $K\overline{K}X$ modes. They | include all decay modes of the ϕ , η , | and ω . | | |
| $\phi\eta$ | $(1.4 \pm 0.5) \times 10^{-4}$ | | 489 | · · · · · · · · · · · · · · · · · · · |
| $\phi\omega$ | $< 2.1 \times 10^{-3}$ | CL=90% | 238 | pe^- |
| - | Dadiativa madas | | | $\overline{p} e^+$ L,B [hhh] < 1.1 $\times 10^{-5}$ CL=90% 696 |
| $ ho^0\gamma$ | Radiative modes $< 2.4 \times 10^{-4}$ | CL=90% | 771 | |
| • | < 2.4 | | 771 | $D^*(2007)^0$ $I(J^P) = \frac{1}{2}(1^-)$ |
| $\omega \gamma$ | $(2.70 \pm 0.35) \times 10^{-5}$ | CL=90% | 768 654 | I, J, P need confirmation. |
| $\frac{\phi \gamma}{K}$ *(892) $^0 \gamma$ | $(2.70 \pm 0.33) \times 10^{-4}$ | | 654 | |
| , , , | , | | 719 | Mass $m = 2006.98 \pm 0.15 \text{ MeV}$ |
| · · · · · · · · · · · · · · · · · · · | oo suppressed (DC) modes or | | | $m_{D^{*0}} - m_{D^0} = 142.12 \pm 0.07 \; \text{MeV}$ |
| | den via mixing (C2M) modes | | | Full width Γ $<$ 2.1 MeV, CL $=$ 90% |
| $K^+ \ell^- \overline{ u}_\ell$ via $ \overline{D}{}^0$ | $< 2.2 \times 10^{-5}$ | CL=90% | _ | $\overline{\mathcal{D}}^*(2007)^0$ modes are charge conjugates of modes below. |
| K^{+} or $K^{*}(892)^{+}e^{-}\overline{\nu}_{e}$ via | $< 6 \times 10^{-5}$ | CL=90% | - | = \ are endings conjugated or models below. |
| \overline{D}^0 | / a | _ | | $D^*(2007)^0$ DECAY MODES Fraction (Γ_i/Γ) p (MeV/c) |
| $K^+\pi^-$ DC | $(1.47 \pm 0.07) \times 10^{-4}$ | S=2.8 | 861 | |
| $K^+\pi^-$ via $ {	t DCS} \ K^+\pi^-$ via $ {	t \overline{D}}{	t 0} \ $ | $(1.31 \pm 0.08) \times 10^{-4}$ | C1 252 | - | $D^{0} \pi^{0} $ (61.9 ± 2.9) % 43 |
| $K^+\pi^-$ via D^0 $K^0_S\pi^+\pi^-$ in $D^0	o \overline D^0$ | < 1.6 × 10 ⁻⁵ | CL=95% | 861 | $D^0 \gamma$ (38.1±2.9) % |
| $N_S \pi \cdot \pi \text{III} D^z \rightarrow D^z$ | $< 1.8 \times 10^{-4}$ | CL=95% | _ | _ |
| | | | | |

$D^*(2010)^{\pm}$

 $I(J^P) = \frac{1}{2}(1^-)$ I, J, P need confirmation.

Mass $m=2010.28\pm0.13~\mathrm{MeV}$

 $m_{D^*(2010)^+} - m_{D^+} = 140.66 \pm 0.10 \; {\rm MeV} \quad ({\rm S} = 1.1)$ $m_{D^*(2010)^+}-m_{D^0}=145.421\pm 0.010~{\rm MeV}~{\rm (S}=1.1)$ Full width $\Gamma=96\pm 22~{\rm keV}$

 $D^*(2010)^-$ modes are charge conjugates of the modes below.

| D*(2010) DECAY MODES | Fraction (Γ _i /Γ) | p (MeV/c) |
|----------------------|------------------------------|------------|
| $D^0\pi^+$ | (67.7±0.5) % | 39 |
| $D^+\pi^0$ | (30.7±0.5) % | 38 |
| $D^+ \gamma$ | (1.6 ± 0.4) % | 136 |

$D_0^*(2400)^0$

 $I(J^P) = \frac{1}{2}(0^+)$

Mass $m = 2318 \pm 29 \text{ MeV}$ (S = 1.7) Full width $\Gamma = 267 \pm 40 \text{ MeV}$

| D*(2400)0 DECAY MODES | Fraction (Γ_j/Γ) | p (MeV/c) |
|-----------------------|------------------------------|-----------|
| $D^+\pi^-$ | seen | 385 |

$D_1(2420)^0$

 $I(J^P) = \frac{1}{2}(1^+)$ I needs confirmation.

Mass $m = 2421.3 \pm 0.6 \text{ MeV}$ (S = 1.2) $m_{D_{i}^{0}} - m_{D^{*+}} = 411.0 \pm 0.6 \quad (S = 1.2)$ Full width $\Gamma = 27.1 \pm 2.7 \text{ MeV}$ (S = 2.4)

 $\overline{\mathcal{D}}_1(2420)^0$ modes are charge conjugates of modes below.

| D ₁ (2420) 0 DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------------|------------------------------|-----------|
| $D^*(2010)^+ \pi^-$ $D^0 \pi^+ \pi^-$ | seen | 354 |
| $D^0 \pi^+ \pi^-$ | seen | 425 |
| $D^+\pi^-$ | not seen | 473 |
| $D^{*0} \pi^+ \pi^-$ | not seen | 279 |

$D_2^*(2460)^0$

$$I(J^P) = \frac{1}{2}(2^+)$$

 $J^P = 2^+$ assignment strongly favored.

Mass $m = 2462.6 \pm 0.7 \text{ MeV}$ (S = 1.3) $m_{D_{2}^{*0}} - m_{D^{+}} = 593.0 \pm 0.7 \text{ MeV} \quad (S = 1.3)$ $m_{D_{2}^{*0}}^{-} - m_{D^{*+}} = 452.3 \pm 0.7 \text{ MeV} \quad (S = 1.3)$ Full width $\Gamma = 49.0 \pm 1.4 \text{ MeV}$ (S = 1.7)

 $\overline{\mathcal{D}}_2^*(2460)^0$ modes are charge conjugates of modes below.

| D*(2460) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------------------------|------------------------------|-----------|
| $D^+\pi^-$ | seen | 507 |
| $D^*(2010)^+ \pi^- \ D^0 \pi^+ \pi^-$ | seen | 391 |
| | not seen | 463 |
| $D^{*0} \pi^+ \pi^-$ | not seen | 326 |

$D_2^*(2460)^{\pm}$

$$I(J^P) = \frac{1}{2}(2^+)$$

 $J^P = 2^+$ assignment strongly favored.

Mass $m = 2464.4 \pm 1.9 \text{ MeV}$ (S = 1.9) $m_{D_2^*(2460)^\pm} - m_{D_2^*(2460)^0} = \text{2.4} \pm \text{1.7 MeV}$ Full width $\Gamma = 37 \pm 6 \text{ MeV}$ (S = 1.4)

 $D_2^*(2460)^-$ modes are charge conjugates of modes below.

| $D_2^*(2460)^{\pm}$ DECAY MODES | Fraction (Γ_j/Γ) | p (MeV/c) |
|---------------------------------|------------------------------|------------|
| $D^0\pi^+$ | seen | 512 |
| $D^{*0} \pi^{+}$ | seen | 395 |
| $D^+\pi^+\pi^-$ | not seen | 461 |
| $D^{*+} \pi^{+} \pi^{-}$ | not seen | 325 |

CHARMED, STRANGE MESONS $(C=S=\pm 1)$

 $D_s^+ = c\overline{s}$, $D_s^- = \overline{c}s$, similarly for D_s^* 's

 D_s^{\pm}

$$I(J^P) = 0(0^-)$$

Mass $m = 1968.49 \pm 0.32 \text{ MeV}$ (S = 1.3) $m_{D^{\pm}}^{}-m_{D^{\pm}}^{}=98.87\pm0.29~{
m MeV}~({
m S}=1.4)$ Mean life $au=(500\pm7) imes10^{-15}$ s (S=1.3) $c\tau = 149.9 \ \mu \mathrm{m}$

CP-violating decay-rate asymmetries

 $A_{CP}(\mu^{\pm}\nu) = (5 \pm 6)\%$ $A_{CP}(K^{\pm}K_S^0) = (0.3 \pm 0.4)\%$ $A_{CP}(K^+ K^- \pi^{\pm}) = (0.3 \pm 1.4)\%$ $A_{CP}(K^+K^-\pi^{\pm}\pi^0) = (-6 \pm 4)\%$ $A_{CP}(K_S^0 K^{\mp} 2\pi^{\pm}) = (-1 \pm 4)\%$ $A_{CP}(\pi^{+}\pi^{-}\pi^{\pm}) = (2 \pm 5)\%$ $A_{CP}(\pi^{\pm}\eta) = (-4.6 \pm 2.9)\%$ $A_{CP}(\pi^{\pm}\eta') = (-6.1 \pm 3.0)\%$ $A_{CP}(K^{\pm}\pi^{0}) = (-27 \pm 24)\%$ $A_{CP}(K_S^0 \pi^{\pm}) = (6.6 \pm 3.3)\%$ (S = 1.4) $A_{CP}(K^{\pm}\pi^{+}\pi^{-}) = (11 \pm 7)\%$ $A_{CP}(K^{\pm}\eta) = (9 \pm 15)\%$ $A_{CP}(K^{\pm}\eta'(958)) = (6 \pm 19)\%$

T-violating decay-rate asymmetry

 $A_T(K_S^0 K^{\pm} \pi^+ \pi^-) = (-14 \pm 8) \times 10^{-3}$ [oo]

$D_s^+ \rightarrow \phi \ell^+ \nu_\ell$ form factors

 $r_2 = 0.84 \pm 0.11$ (S = 2.4) $r_{\rm V} = 1.80 \pm 0.08$ $\Gamma_L/\Gamma_T = 0.72 \pm 0.18$

Unless otherwise noted, the branching fractions for modes with a resonance in the final state include all the decay modes of the resonance. D_s^- modes are charge conjugates of the modes below.

| D+ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | <i>p</i> (Me <i>V/c</i>) |
|----------------------------------------|--------------------------------|-----------------------------------|-------------------------------|
| | Inclusive modes | | |
| e^+ semileptonic | [iii] (6.5 ±0.4) % | | _ |
| π^+ anything | $(119.3 \pm 1.4)\%$ | | - |
| π^- anything | (43.2 ± 0.9) % | | - |
| π^0 anything | (123 ±7) % | | - |
| K^- anything | (18.7 ± 0.5) % | | - |
| K^+ anything | (28.9 ± 0.7) % | | - |
| K_S^0 anything | (19.0 ±1.1) % | | _ |
| η anything | [jjj] (29.9 \pm 2.8) % | | _ |
| ω anything | (6.1 ±1.4) % | | _ |
| η' anything | [kkk] (11.7 \pm 1.8) % | | _ |
| $f_0(980)$ anything, $f_0 \rightarrow$ | $\pi^{+}\pi^{-}$ < 1.3 % | CL=90% | _ |
| ϕ anything | (15.7 ± 1.0) % | | _ |
| K ⁺ K [−] anything | (15.8 ± 0.7) % | | _ |
| $K_S^0 K^+$ anything | (5.8 ±0.5) % | | _ |
| $K_S^{\emptyset}K^-$ anything | (1.9 ±0.4) % | | _ |
| $2K_S^0$ anything | (1.70±0.32) % | | _ |
| 2K ⁺ anything | < 2.6 × | 10 ⁻³ CL=90% | _ |
| 2K ⁻ anything | < 6 × | 10 ⁻⁴ CL=90% | - |
| l | eptonic and semileptonic mode | 5 | |
| $e^+ \nu_e$ | < 1.2 × | 10 ⁻⁴ CL=90% | 984 |
| $\mu^+ \nu_{\mu}$ | $(5.90\pm0.33) \times$ | 10^{-3} | 981 |

$\tau^+\,\nu_\tau$ $(5.43\pm0.31)\%$ 182 $K^{+}K^{-}e^{+}\nu_{e}$ 851 $\phi\,e^+\,\nu_e$ [///] (2.49 ± 0.14) % 720 $\eta e^+ \nu_e + \eta'(958) e^+ \nu_e$ [///] (3.66 ± 0.37) % $\eta e^+ \nu_e$ [///] (2.67 ± 0.29) % 908 $\eta'(958) e^+ \nu_e$ [///] (9.9 ± 2.3) $\times 10^{-3}$ 751 $[mmm] < \quad 2.0 \qquad \qquad \times \, 10^{-3} \quad \mathsf{CL} \! = \! 90\%$ 829 $\omega e^+ \nu_e$ $K^{0}e^{+}\nu_{e}$ ($3.7~\pm1.0~)\times10^{-3}$ 921 $K^*(892)^0 e^+ \nu_e$ [III] $(1.8 \pm 0.7) \times 10^{-3}$ 782 $f_0(980) e^+ \nu_e$, $f_0 \rightarrow \pi^+ \pi^ (-2.00\pm0.32)\times10^{-3}$

| Hadronic | modes | with a <i>K</i> R pair | | |
|----------------------------------------------------------------------------------------------------|--------------------|----------------------------------------------------|-----------|-------------|
| $K^+ K^0_S$ | | 1.48±0.08) % | | 85 0 |
| $K^+K^-\pi^+$ | | 5.49±0.27) % | | 805 |
| | | 4.5 ±0.4) % | | 712 |
| $\phi \pi^+, \phi \to K^+K^-$ | - | 2.28±0.12) % | | 712 |
| $K^+\overline{K}^*(892)^0$, $\overline{K}^{*0} ightarrow$ | | 2.63±0.13) % | | 416 |
| $K^-\pi^+$ $f_0(980)\pi^+$, $f_0 \to K^+K^-$ | | 1.16±0.32) % | | 732 |
| $f_0(1370)\pi^+$, $f_0 \to K^+K^-$ | 1 | 7 ±5)×10 | | _ |
| $f_0(1710)\pi^+, f_0 \to K^+K^-$ | | 6.7 ±2.9)×10 | | 198 |
| $K^+\overline{K}_0^*(1430)^0, \overline{K}_0^* \to K^-\pi^+$ | 1 | 1.9 ±0.4)×10 ⁻ |) | 218 |
| $K^0 \frac{K^- \pi^+}{K^0 \pi^+}$ | | _ | | 802 |
| $K^*(892)^+ \overline{K}^0$ | [///] | 5.4 ±1.2) % | | 683 |
| $K^{+} K^{-} \pi^{+} \pi^{0}$ | 1 | 5.6 ±0.5) % | | 748 |
| $\phi \rho^+$ | [///] | 8.4 +1.9) % | | 401 |
| | | | | |
| $K_S^0 K^- 2\pi^+$ | | 1.64 ± 0.12) % | | 744 |
| $K^*(892)^+ \overline{K}^*(892)^0$ | [///] | 7.2 ±2.6) % | 2 | 417 |
| $K^{+} K^{0}_{S} \pi^{+} \pi^{-}$ | | 9.6 ±1.3)×10 ⁻ | _ | 744 |
| $K^{+}K^{-}2\pi^{+}\pi^{-}$ | | 8.8 ±1.6)×10 ⁻ |) | 673 |
| $\phi 2\pi^{+}\pi^{-}$ | [///] | $1.21 \pm 0.16)$ % | | 640 |
| $K^+K^- ho^0\pi^+$ non- ϕ | < | 2.6 × 10 | | 249 |
| $\phi \rho^0 \pi^+, \ \phi \rightarrow \ K^+ K^-$ | 1 | 6.6 ± 1.3) \times 10 $^-$ | _ | 181 |
| $\phi a_1(1260)^+$, $\phi ightarrow$ | 1 | 7.5 ± 1.3) $\times 10^-$ | 3 | † |
| $K^+ K^-$, $a_1^+ ightarrow ho^0 \pi^+$ | | | | |
| $K^+K^-2\pi^+\pi^-$ nonresonant | | 9 ±7)×10- | 1 | 673 |
| $2K_{S}^{0}2\pi^{+}\pi^{-}$ | | 8.3 ±3.5)×10 | | 669 |
| 9 | | | | |
| $_{\pi^{+}\pi^{0}}$ Hadror | | s without K 's $_{3.4}$ $	imes 10^{-4}$ | 1 (1 000/ | 075 |
| $2\pi^{+}\pi^{-}$ | < | | 1 CL=90% | 975 95 9 |
| $\rho^0 \pi^+$ | | 1.10±0.06) % | 1 | |
| $\pi^{+}(\pi^{+}\pi^{-})_{S-wave}$ | [] | 2.0 ±1.2) × 10 | | 825 |
| f (1070) -+ f+ | | 9.2 ±0.6)×10 ⁻ | | 95 9 |
| $f_2(1270)\pi^+$, $f_2 \rightarrow \pi^+\pi^ \rho(1450)^0\pi^+$, $\rho^0 \rightarrow \pi^+\pi^-$ | | $1.11 \pm 0.20) \times 10^{-1}$ | | 559 |
| $\rho(1430)$ π^+ , $\rho^- \rightarrow \pi^+\pi^-$ $\tau^+ 2\pi^0$ | | 3.0 ±2.0) × 10 | | 421 |
| $2\pi^{+} \pi^{-} \pi^{0}$ | | 6.5 ±1.3)×10 ⁻ | | 961 935 |
| $\eta \pi^+$ | run . | 1 02 0 15 \ 0/ | | 902 |
| $\omega \pi^+$ | | 1.83 ± 0.15) % 2.5 ± 0.7) × 10^{-1} | 3 | 822 |
| $3\pi^{+}2\pi^{-}$ | | | | |
| $2\pi^{+}\pi^{-}2\pi^{0}$ | | 8.0 ±0.9)×10 ⁻ | | 899 902 |
| $\eta \rho^+$ | run . | 8.9 ±0.8) % | | 724 |
| $\eta \pi^+ \pi^0$ 3-body | [///] | | CI 000/ | |
| $\omega \pi^+ \pi^0$ | [///] < | | CL=90% | 886 |
| $3\pi^{+} 2\pi^{-} \pi^{0}$ | [///] | 2.8 ±0.7) % | | 802 |
| $\omega 2\pi^+\pi^-$ | Fund . | 4.9 ±3.2) % | | 85 6 |
| 1/> | | 1.6 ±0.5) % | | 766 |
| | kkk,lll] | 3.94 ± 0.33) % | | 743 |
| $3\pi^{+} 2\pi^{-} 2\pi^{0}$ | | | | 803 |
| $\omega \eta \pi^+$ | [111] < | | CL=90% | 654 |
| $\eta'(958) \rho^+$ [| - | 12.5 ±2.2) % | | 465 |
| $\eta'(958) \pi^+ \pi^0$ 3-body | [111] < | 1.8 % | CL=90% | 720 |
| Modes | with one | e or three K's | | |
| $K^+\pi^0$ | | 6.2 ±2.1)×10 | 1 | 917 |
| $K_S^0 \pi^+$ | | | | 916 |
| κ^+_η | [///] | $1.75 \pm 0.35) \times 10^{-}$ | | 835 |
| $K^+\omega$ | [111] < | | | 741 |
| $K^{+} \eta'(958)$ | | 1.8 ±0.6)×10 ⁻ | | 646 |
| $K^+\pi^+\pi^-$ | | 6.9 ±0.5)×10 ⁻ | 3 | 900 |
| $K^+ \rho^0$ | | 2.7 ±0.5)×10 ⁻ | | 745 |
| $K^{+} \rho (1450)^{0}$, $\rho^{0} \rightarrow \pi^{+} \pi^{-}$ | | 7.3 ±2.6)×10 | | - |
| $K^*(892)^0 \pi^+$, $K^{*0} \rightarrow$ | | 1.50±0.26) × 10 | | 775 |
| $K^+\pi^-$ | | | | |
| $K^*(1410)^0\pi^+$, $K^{*0} ightarrow$ | 1 | $1.30\pm0.31)\times10^{-}$ | 3 | - |
| $K^*(1430)^0\pi^+$, $K^{*0} ightarrow$ | 1 | 5 ±4)×10- | 1 | = |
| $K^+\pi^+\pi^-$ nonresonant | 1 | 1.1 ±0.4)×10- | 3 | 900 |
| $K^0\pi^+\pi^0$ | | 1.00±0.18) % | | 900 |
| $K_S^0 2\pi^+\pi^-$ | | | 3 | 870 |
| $K^+\omega\pi^0$ | | | _ | 684 |
| $K^+\omega\pi^+\pi^-$ | [///] < | | _ | |
| $K^+\omega \pi^+\pi^-$ | [III] < [III] < | | _ | 603 367 |
| • | | | しし ニョリンツ | 30/ |
| 2K+K- | | | | |
| $2K^+K^-$ | | 2.20±0.23) × 10 | 1 | 628 |
| $ \phi K^+ K^- \phi K^+, \phi \to K^+ K^- $ | | | 1 | |

| D | oubly Ca | bibbo-su _l | pressed | modes | | |
|--------------------------------------------------|---------------|-----------------------|-------------------|--------------------------------------------------|--------|----------|
| $2K^{+}\pi^{-}$ $K^{+}K^{*}(892)^{0}$, K^{*0} | \rightarrow | (| | 14) × 10 ⁻⁴ 5) × 10 ⁻⁵ | | 805 — |
| p n | Baryo | on-a ntibai (| - | de 4)×10 ⁻³ | | 295 |
| | | amily nu | mber (<i>Ì f</i> | | , | |
| $\pi^+~e^+~e^-$ | | [<i>uu</i>] < | 1.3 | $\times10^{-5}$ | CL=90% | 979 |
| $\pi^+\phi$, $\phi ightarrow e^+e^-$ | | [tt] (| 6 +8 | $) \times 10^{-6}$ | | - |
| $\pi^{+} \mu^{+} \mu^{-}$ | | [uu] < | 2.6 | $\times 10^{-5}$ | CL=90% | 968 |
| $K^{+} e^{+} e^{-}$ | C1 | < | 3.7 | $\times 10^{-6}$ | CL=90% | 922 |
| $K^+\mu^+\mu^-$ | C1 | < | 2.1 | $\times 10^{-5}$ | CL=90% | 909 |
| $K^*(892)^+ \mu^+ \mu^-$ | C1 | < | 1.4 | | CL=90% | 765 |
| π^+ e^+ μ^- | LF | < | 1.2 | $\times 10^{-5}$ | CL=90% | 976 |
| $\pi^{+} e^{-} \mu^{+}$ | LF | < | 2.0 | $\times 10^{-5}$ | CL=90% | 976 |
| $K^+e^+\mu^-$ | LF | < | 1.4 | $\times 10^{-5}$ | CL=90% | 919 |
| $K^{+}e^{-}\mu^{+}$ | LF | < | 9.7 | | CL=90% | 919 |
| $\pi^{-}2e^{+}$ | L | < | 4.1 | $\times 10^{-6}$ | CL=90% | 979 |
| $\pi^{-}2\mu^{+}$ | L | < | 1.4 | $\times 10^{-5}$ | CL=90% | 968 |
| $\pi^{-}e^{+}\mu^{+}$ | L | < | 8.4 | $\times 10^{-6}$ | CL=90% | 976 |
| $K^{-}2e^{+}$ | L | < | 5.2 | $\times 10^{-6}$ | CL=90% | 922 |
| $K^{-}2\mu^{+}$ | L | < | 1.3 | $\times 10^{-5}$ | CL=90% | 909 |
| $K^{-}e^{+}\mu^{+}$ | L | < | 6.1 | $\times 10^{-6}$ | CL=90% | 919 |
| $K^*(892)^-2\mu^+$ | L | < | 1.4 | $\times 10^{-3}$ | CL=90% | 765 |
| | | | | | | |

$$I(J^P) = 0(??)$$

 ${\stackrel{-}{J}}^P$ is natural, width and decay modes consistent with 1^- .

Mass
$$m=2112.3\pm0.5~{\rm MeV}~{\rm (S}=1.1)$$
 $m_{D_s^{\pm\pm}}-m_{D_s^{\pm}}=143.8\pm0.4~{\rm MeV}$ Full width $\Gamma<1.9~{\rm MeV}$, CL = 90%

 D_s^{*-} modes are charge conjugates of the modes below.

| D*+ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------|------------------------------|-----------|
| $D_s^+ \gamma$ | (94.2±0.7) % | 139 |
| $D_s^+ \gamma D_s^+ \pi^0$ | (5.8 ± 0.7) % | 48 |

$D_{s0}^*(2317)^{\pm}$

$$I(J^P) = 0(0^+)$$

2317) $I(J^P) = 0(0^+)$ J^P is natural, low mass consistent with 0^+ . Mass $m = 2317.8 \pm 0.6 \text{ MeV}$ (S = 1.1)

Mass
$$m=2317.8\pm0.6$$
 MeV (S = 1.1) $m_{D_{s0}^*(2317)^\pm}-m_{D_s^\pm}=349.3\pm0.6$ MeV (S = 1.1) Full width Γ < 3.8 MeV, CL = 95%

 $D_{s0}^*(2317)^-$ modes are charge conjugates of modes below.

| D_{s0}^* (2317) $^{\pm}$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------------|------------------------------|-----------|
| $D_s^+ \pi^0$ | seen | 298 |
| $D_s^+ \pi^0 \pi^0$ | not seen | 205 |

$D_{s1}(2460)^{\pm}$

$$I(J^P) = 0(1^+)$$

Mass $m = 2459.6 \pm 0.6 \text{ MeV}$ (S = 1.1) $m_{D_{s1}(2460)^{\pm}} - m_{D_s^{*\pm}} = 347.2 \pm 0.7 \; {\rm MeV} \quad ({\rm S} = 1.2) \ m_{D_{s1}(2460)^{\pm}} - m_{D_s^{\pm}} = 491.1 \pm 0.7 \; {\rm MeV} \quad ({\rm S} = 1.1)$ Full width Γ < 3.5 MeV, CL = 95%

 $D_{s1}(2460)^{-}$ modes are charge conjugates of the modes below.

| D _{s1} (2460)+ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-------------------------------------|-------------------------------------|-----------------------------------|-----|
| $D_s^{*+} \pi^0$ | (48 ±11) % | | 297 |
| $D_s^+ \gamma$ | $(18 \pm 4)\%$ | | 442 |
| $D_s^+ \pi^+ \pi^-$ | $(4.3 \pm 1.3) \%$ | S=1.1 | 363 |
| $D_s^{*+} \gamma$ | < 8 % | CL=90% | 323 |
| $D_{s0}^*(2317)^+ \gamma$ | $(3.7^{+}_{-}\overset{5.0}{2.4})\%$ | | 138 |

$D_{s1}(2536)^{\pm}$

$$I(J^P) = O(1^+)$$

J, P need confirmation.

Mass $m = 2535.12 \pm 0.13 \text{ MeV}$ Full width $\Gamma=0.92\pm0.05\;\text{MeV}$

 $D_{s1}(2536)^{-}$ modes are charge conjugates of the modes below

| $D_{s1}(2536)^+$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------------------|------------------------------|-----------|
| $D^*(2010)^+ K^0$ | seen | 149 |
| $D^*(2007)^0 K^+$ | seen | 167 |
| D^+K^0 | not seen | 381 |
| $D^0 K^+$ | not seen | 391 |
| $D_{s}^{*+} \gamma \ D_{s}^{*} \pi^{+} \pi^{-}$ | possibly seen | 388 |
| $D_s^+ \pi^+ \pi^-$ | seen | 437 |

$D_{s2}^{*}(2573)$

$$I(J^P) = 0(??)$$

 ${\it J}^{\it P}$ is natural, width and decay modes consistent with 2^+ .

Mass
$$m=2571.9\pm0.8~{\rm MeV}$$

Full width $\Gamma=17\pm4~{\rm MeV}~({\rm S}=1.3)$

 $D_{s2}^*(2573)^-$ modes are charge conjugates of the modes below.

| $D_{s2}^{*}(2573)^{+}$ DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|------------------------------------|------------------------------|-----------------|
| $D^0 K^+$ | seen | 434 |
| $D^*(2007)^0 K^+$ | not seen | 243 |

BOTTOM MESONS $(B=\pm 1)$

 $B^+ = u \overline{b}$, $B^0 = d \overline{b}$, $\overline{B}{}^0 = \overline{d}b$, $B^- = \overline{u}b$, similarly for B^* 's

B-particle organization

Many measurements of B decays involve admixtures of Bhadrons. Previously we arbitrarily included such admixtures in the B^{\pm} section, but because of their importance we have created two new sections: " B^{\pm}/B^0 Admixture" for $\Upsilon(4S)$ results and " $B^{\pm}/B^0/B_s^0/b$ -baryon Admixture" for results at higher energies. Most inclusive decay branching fractions and $\chi_{\it b}$ at high energy are found in the Admixture sections. $B^0 - \overline{B}{}^0$ mixing data are found in the B^0 section, while B^0_s - \overline{B}_s^0 mixing data and B- \overline{B} mixing data for a B^0/B_s^0 admixture are found in the B_s^0 section. \overrightarrow{CP} -violation data are found in the B^{\pm} , B^{0} , and \tilde{B}^{\pm} B^{0} Admixture sections. b-baryons are found near the end of the Baryon section.

The organization of the B sections is now as follows, where bullets indicate particle sections and brackets indicate reviews

- B[±]
 - mass, mean life, CP violation, branching fractions
- B⁰
 - mass, mean life, $B^0 \overline{B}{}^0$ mixing, CP violation, branching fractions
- B[±] B⁰ Admixtures
 - CP violation, branching fractions
- $B^{\pm}/B^0/B_s^0/b$ -baryon Admixtures
 - mean life, production fractions, branching fractions
- B*
- mass
- $B_1(5721)^0$
- mass
- $B_2^*(5747)^0$
- mass B_s⁰

mass, mean life, $B_c^0 - \overline{B}_c^0$ mixing, CP violation, branching fractions

B[∗]_c

mass

- $B_{s1}(5830)^0$ mass
- $\bullet B_{s2}^* (5840)^0$ mass
- B[±]

mass, mean life, branching fractions

At the end of Baryon Listings:

- mass, mean life, branching fractions
- $\bullet \Sigma_b$ mass
- $\bullet \Sigma_b^*$

 $\bullet = \Xi_b^0, \Xi_b^-$

mass, mean life, branching fractions

mass, branching fractions

• b-baryon Admixture mean life, branching fractions

 B^{\pm}

$$I(J^P) = \frac{1}{2}(0^-)$$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass
$$m_{B^\pm}=5279.25\pm0.17~{
m MeV}$$
 Mean life $au_{B^\pm}=(1.641\pm0.008)\times10^{-12}~{
m s}$ $c au=492.0~\mu{
m m}$

CP violation

 $A_{CP}(B^+ \to J/\psi(1S)K^+) = (1 \pm 7) \times 10^{-3}$ (S = 1.8) $A_{CP}(B^+ \to J/\psi(1S)\pi^+) = 0.01 \pm 0.07$ (S = 1.3) $A_{CP}(B^+ \to J/\psi\rho^+) = -0.11 \pm 0.14$

 $A_{CP}(B^+ \to J/\psi K^*(892)^+) = -0.048 \pm 0.033$

 $A_{CP}(B^+ \to \eta_c K^+) = -0.16 \pm 0.08$

 $A_{CP}(B^+ \to \psi(2S)\pi^+) = 0.02 \pm 0.09$ $A_{CP}(B^+ \to \psi(2S) K^+) = -0.025 \pm 0.024$

 $A_{CP}(B^+ \to \psi(2S) K^*(892)^+) = 0.08 \pm 0.21$

 $A_{CP}(B^+ \to \chi_{c1}(1P)\pi^+) = 0.07 \pm 0.18$

 $A_{CP}(B^+ \to \chi_{c0} K^+) = -0.20 \pm 0.18$ (S = 1.5)

 $A_{CP}(B^+ \to \chi_{c1} K^+) = -0.009 \pm 0.033$

 $A_{CP}(B^+ \to \chi_{c1} K^*(892)^+) = 0.5 \pm 0.5$ $A_{CP}(B^+ \to \overline{D}^0 \pi^+) = -0.008 \pm 0.008$

 $A_{CP}(B^+ \to D_{CP(+1)}\pi^+) = 0.035 \pm 0.024$

 $A_{CP}(B^+ \to D_{CP(-1)}\pi^+) = 0.017 \pm 0.026$

 $A_{CP}(B^+ \to \overline{D}^0 K^+) = 0.07 \pm 0.04$

 $r_B(B^+ \to D^0 K^+) = 0.113^{+0.024}_{-0.021}$

 $\delta_B(B^+ \to D^0 K^+) = (125 \pm 16)^\circ$

 $r_B(B^+ \to DK^{*+}) = 0.34 \pm 0.09$ (S = 1.3) $\delta_B(B^+ \to DK^{*+}) = (157 \pm 70)^\circ$ (S = 2.0)

 $A_{CP}(B^+ \to [K^-\pi^+]_D K^+) = -0.58 \pm 0.21$

 $A_{CP}(B^+ \to [K^-\pi^+]_{\overline{D}}K^*(892)^+) = -0.3 \pm 0.5$

 $A_{CP}(B^+ \to [K^-\pi^+]_D^-\pi^+) = 0.00 \pm 0.09$

 $A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)}\pi^+) = -0.09 \pm 0.27$

 $A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)}\pi^+) = -0.7 \pm 0.6$

 $A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)}K^+) = 0.8 \pm 0.4$

 $A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)}K^+) = 0.4 \pm 1.0$ $A_{CP}(B^+ \to [\pi^+\pi^-\pi^0]_DK^+) = -0.02 \pm 0.15$

 $A_{CP}(B^+ \rightarrow D_{CP(+1)}K^+) = 0.24 \pm 0.06 \quad (S = 1.1)$

 $A_{CP}(B^+ \to D_{CP(-1)}K^+) = -0.10 \pm 0.07$ $A_{CP}(B^+ \to \overline{D}^{*0}\pi^+) = -0.014 \pm 0.015$

 $A_{CP}(B^+ \to (D_{CP(+1)}^*)^0 \pi^+) = -0.02 \pm 0.05$

 $A_{CP}(B^+ \to (D_{CP(-1)}^*)^0 \pi^+) = -0.09 \pm 0.05$

```
A_{CP}(B^+ \rightarrow D^{*0} K^+) = -0.07 \pm 0.04
r_B^*(B^+ \to D^{*0}K^+) = 0.123^{+0.026}_{-0.029}
\delta_B^*(B^+ \to D^{*0} K^+) = (300 \pm 30)^\circ \text{ (S = 1.7)}
A_{CP}^{B^+}(B^+ \to D_{CP(+1)}^{*0} K^+) = -0.12 \pm 0.08
A_{CP}(B^+ \to D^*_{CP(-1)}K^+) = 0.07 \pm 0.10
A_{CP}(B^+ \to D_{CP(+1)}K^*(892)^+) = 0.09 \pm 0.14
A_{CP}(B^+ \to D_{CP(-1)}K^*(892)^+) = -0.23 \pm 0.22
A_{CP}(B^+ \to D^{*+} \overline{D}^{*0}) = -0.15 \pm 0.11
A_{CP}(B^+ \to D^{*+} \overline{D}^0) = -0.06 \pm 0.13
A_{CP}(B^+ \to D^+ \overline{D}^{*0}) = 0.13 \pm 0.18
A_{CP}(B^+ \to D^+ \overline{D}^0) = -0.03 \pm 0.07
A_{CP}(B^+ \to K_S^0 \pi^+) = 0.009 \pm 0.029 \quad (S = 1.2)
A_{CP}(B^+ \to K^+ \pi^0) = 0.051 \pm 0.025
A_{CP}(B^+ \to \eta' K^+) = 0.013 \pm 0.017
A_{CP}(B^+ \to \eta' K^*(892)^+) = -0.26 \pm 0.27
A_{CP}(B^+ \to \eta' K_0^*(1430)^+) = 0.06 \pm 0.20

A_{CP}(B^+ \to \eta' K_2^*(1430)^+) = 0.15 \pm 0.13
A_{CP}(B^+ \rightarrow \eta K^+) = -0.37 \pm 0.08
A_{CP}(B^+ \to \eta K^*(892)^+) = 0.02 \pm 0.06
A_{CP}(B^+ \to \eta K_0^*(1430)^+) = 0.05 \pm 0.13
A_{CP}(B^+ \to \eta K_2^*(1430)^+) = -0.45 \pm 0.30
A_{CP}(B^+ \to \omega K^+) = 0.02 \pm 0.05
A_{CP}(B^+ \to \omega K^{*+}) = 0.29 \pm 0.35
A_{CP}(B^+ \to \omega(K\pi)_0^{*+}) = -0.10 \pm 0.09
A_{CP}(B^+ \to \omega K_2^*(1430)^+) = 0.14 \pm 0.15

A_{CP}(B^+ \to K^{*0}\pi^+) = -0.04 \pm 0.09 \quad (S = 2.1)
A_{CP}(B^+ \to K^*(892)^+ \pi^0) = -0.06 \pm 0.24
A_{CP}(B^+ \to K^+\pi^-\pi^+) = 0.038 \pm 0.022
A_{CP}(B^+ \to f_0(980)K^+) = -0.09^{+0.05}_{-0.04}
A_{CP}(B^+ \rightarrow f_2(1270)K^+) = -0.68^{+0.19}_{-0.17}
A_{CP}(B^+ \rightarrow f_0(1500)K^+) = 0.28 \pm 0.30
A_{CP}(B^+ \to \rho^0 K^+) = 0.37 \pm 0.10
A_{CP}(B^+ \to K_0^*(1430)^0 \pi^+) = 0.055 \pm 0.033
A_{CP}(B^+ \to K_2^*(1430)^0 \pi^+) = 0.05^{+0.29}_{-0.24}
A_{CP}(B^+ \to K^+ \pi^0 \pi^0) = -0.06 \pm 0.07
A_{CP}(B^+ \to K^0 \rho^+) = -0.12 \pm 0.17
A_{CP}(B^+ \to K^{*+}\pi^+\pi^-) = 0.07 \pm 0.08
A_{CP}(B^+ \to \rho^0 K^*(892)^+) = 0.31 \pm 0.13
A_{CP}(B^+ \to K^*(892)^+ f_0(980)) = -0.15 \pm 0.12
A_{CP}(B^+ \to a_1^+ K^0) = 0.12 \pm 0.11
A_{CP}(B^+ \to b_1^+ K^0) = -0.03 \pm 0.15
A_{CP}(B^+ \to K^*(892)^0 \rho^+) = -0.01 \pm 0.16
A_{CP}(B^+ \to b_1^0 K^+) = -0.46 \pm 0.20
A_{CP}(B^+ \to K^0 K^+) = 0.12 \pm 0.18
A_{CP}(B^+ \to K^+ K_S^0 K_S^0) = -0.04 \pm 0.11

A_{CP}(B^+ \to K^+ K^- \pi^+) = 0.00 \pm 0.10
A_{CP}(B^+ \to K^+K^-K^+) = -0.017 \pm 0.030
A_{CP}(B^+ \to \phi K^+) = -0.01 \pm 0.06
A_{CP}(B^+ \to X_0(1550)K^+) = -0.04 \pm 0.07
A_{CP}(B^+ \to K^{*+} K^+ K^-) = 0.11 \pm 0.09
A_{CP}(B^+ \to \phi K^*(892)^+) = -0.01 \pm 0.08
A_{CP}(B^+ \to \phi(K\pi)_0^{*+}) = 0.04 \pm 0.16
A_{CP}(B^+ \to \phi K_1(1270)^+) = 0.15 \pm 0.20
A_{CP}(B^+ \to \phi K_2^*(1430)^+) = -0.23 \pm 0.20
A_{CP}(B^+ \to K^+ \phi \phi) = -0.10 \pm 0.08
A_{CP}(B^+ \to K^+ [\phi \phi]_{\eta_c}) = 0.09 \pm 0.10
A_{CP}(B^+ \to K^*(892)^+ \gamma) = 0.018 \pm 0.029
A_{CP}(B^+ \to \eta K^+ \gamma) = -0.12 \pm 0.07
A_{CP}(B^+ \to \phi K^+ \gamma) = -0.13 \pm 0.11 (S = 1.1)
A_{CP}(B^+ \to \rho^+ \gamma) = -0.11 \pm 0.33
A_{CP}(B^+ \to \pi^+ \pi^0) = 0.06 \pm 0.05
A_{CP}(B^+ \to \pi^+ \pi^- \pi^+) = 0.03 \pm 0.06
A_{CP}(B^+ \to \rho^0 \pi^+) = 0.18^{+0.09}_{-0.17}
A_{CP}(B^+ \to f_2(1270)\pi^+) = 0.41 \pm 0.30
A_{CP}(B^+ \to \rho^0(1450)\pi^+) = -0.1^{+0.4}_{-0.5}
A_{CP}(B^+ \rightarrow f_0(1370)\pi^+) = 0.72 \pm 0.22
A_{CP}(B^+ \to \pi^+ \pi^- \pi^+ \text{ nonresonant}) = -0.14^{+0.23}_{-0.16}
A_{CP}(B^+ \to \rho^+ \pi^0) = 0.02 \pm 0.11
A_{CP}(B^+ \to \rho^+ \rho^0) = -0.05 \pm 0.05
A_{CP}(B^+ \rightarrow \omega \pi^+) = -0.04 \pm 0.06
A_{CP}(B^+ \to \omega \rho^+) = -0.20 \pm 0.09
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```
A_{CP}(B^+ \to \eta \pi^+) = -0.14 \pm 0.07 \quad (S = 1.4)
A_{CP}(B^+ \to \eta \rho^+) = 0.11 \pm 0.11
A_{CP}(B^+ \rightarrow \eta' \pi^+) = 0.06 \pm 0.16
A_{CP}(B^+ \rightarrow \eta' \rho^+) = 0.26 \pm 0.17
A_{CP}(B^+ \rightarrow b_1^0 \pi^+) = 0.05 \pm 0.16
A_{CP}(B^+ \to p \bar{p} \pi^+) = 0.00 \pm 0.04
A_{CP}(B^+ \to p \overline{p} K^+) = -0.16 \pm 0.07
A_{CP}(B^+ \to p\overline{p}K^*(892)^+) = 0.21 \pm 0.16 \quad (S = 1.4)
A_{CP}(B^+ \rightarrow p \overline{\Lambda} \gamma) = 0.17 \pm 0.17
A_{CP}(B^+ \to p \overline{\Lambda} \pi^0) = 0.01 \pm 0.17
A_{CP}(B^+ \to K^+ \ell^-) = -0.01 \pm 0.09 \quad (S = 1.1)
A_{CP}(B^+ \to K^+ e^+ e^-) = 0.14 \pm 0.14
A_{CP}(B^+ \to K^+ \mu^+ \mu^-) = -0.05 \pm 0.13
A_{CP}(B^+ \rightarrow K^{*+} \ell^+ \ell^-) = -0.09 \pm 0.14
A_{CP}(B^+ \to K^* e^+ e^-) = -0.14 \pm 0.23
A_{CP}(B^+ \to K^* \mu^+ \mu^-) = -0.12 \pm 0.24
\gamma(B^+ \to D^{(*)}K^{(*)+}) = (73 \pm 10)^\circ
```

 B^- modes are charge conjugates of the modes below. Modes which do not identify the charge state of the B are listed in the B^\pm/B^0 ADMIXTURE section

The branching fractions listed below assume 50% $B^0\overline{B}^0$ and 50% B^+B^- production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_S , D^* , and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, e.g., $B\to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

 $\begin{array}{ccc} & & \text{Scale factor} / & p \\ \textbf{B^+ DECAY MODES} & & \text{Fraction } (\Gamma_i/\Gamma) & & \text{Confidence level } (\text{MeV/c}) \end{array}$

```
Semileptonic and leptonic modes
\ell^+ \, \nu_\ell anything
                                                         [ppp] ( 10.99 \pm 0.28 ) %
    e^+ \nu_e X_c
                                                                      (10.8 \pm 0.4)\%
    D \ell^+ \nu_\ell a nything
                                                                      (9.8 \pm 0.7)\%
    \overline{D}^0 \ell^+ \nu_\ell
                                                          [ppp] ( 2.26 \pm 0.11 )%
                                                                                                                                       2310
    \overline{D}{}^0 \tau^+ \nu_{\tau}
                                                                      (\phantom{-}7.7\phantom{0}\pm2.5\phantom{0})\times10^{-3}
                                                                                                                                       1911
    \overline{D}^*(2007)^0 \ell^+ \nu_{\ell}
                                                         [ppp] ( 5.70 \pm0.19 )%
    \overline{D}^*(2007)^0 \tau^+ \nu_{\tau}
                                                                      (2.04 \pm 0.30)\%
                                                                                                                                       1839
    \frac{D^{-}\pi^{+}\ell^{+}\nu_{\ell}}{\overline{D}_{0}^{*}(2420)^{0}\ell^{+}\nu_{\ell}}\times
                                                                      (\phantom{-}4.2\phantom{0}\pm0.5\phantom{0})\times10^{-3}
                                                                                                                                       2306
                                                                      (\quad 2.5 \quad \pm 0.5 \quad) \times 10^{-3}
               B(\overline{D}_0^{*0} \rightarrow D^-\pi^+)
         \overline{D}_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}\times
                                                                      (1.53 \pm 0.16) \times 10^{-3}
                                                                                                                                       2065
              B(\overline{D}_2^{*0} \rightarrow D^-\pi^+)
    D^{(*)} \, \mathsf{n} \, \pi \, \ell^+ \, \nu_\ell \, (\mathsf{n} \geq 1)
                                                                      ( 1.87 \pm 0.26 ) %
        D^{*-}\,\pi^+\,\ell^+\,\nu_\ell
                                                                     (\phantom{-}6.1\phantom{0}\pm0.6\phantom{0})\times10^{-3}
                                                                                                                                       2254
D_s^{*-}\underline{K}^+\ell^+\nu_\ell
                                                                     (\phantom{-}6.1\phantom{0}\pm1.2\phantom{0})\times10^{-4\phantom{0}}
                                                                                                                                       2185
        \overline{D}_1(2420)^0\,\ell^+\,
u_\ell 	imes\,{\sf B}(\overline{D}_1^0\,
ightarrow
                                                                     (3.03 \pm 0.20) \times 10^{-3}
                                                                                                                                       2084
               D^{*-}\pi^{+}
         \overline{D}'_{1}(2430)^{0}\ell^{+}\nu_{\ell}\times
                                                                      (2.7 \pm 0.6) \times 10^{-3}
              B(\overline{D}_1^{\prime 0} \rightarrow D^{*-}\pi^+)
         \overline{D}_{2}^{*}(2\dot{4}6\dot{0})^{0}\ell^{+}\nu_{\ell}\times
                                                                      (1.01 \pm 0.24) \times 10^{-3}
                                                                                                                        S=2.0 2065
              B(\overline{D}_2^{*0} \rightarrow D^{*-}\pi^+)
    \pi^0\,\ell^+\,\nu_\ell
                                                                      ( 7.78 \pm 0.28 ) \times\,10^{-5}
                                                                                                                                       2638
                                                                      (\phantom{-}3.9\phantom{0}\pm0.8\phantom{0})\times10^{-5}
    \eta \ell^+ \nu_\ell
                                                                                                                        S=1.3 2611
    \eta'\ell^+\nu_\ell
                                                                     (\phantom{-}2.3\phantom{0}\pm0.8\phantom{0})\times10^{-5}
                                                                                                                                       2553
    \omega \ell^+ \nu_\ell
                                                         [ppp] ( 1.15 \pm 0.17 ) \times 10^{-4}
                                                                                                                                       2582
                                                          [ppp] ( 1.07 \pm 0.13 ) \times 10^{-4}

ho^0 \, \ell^+ \, \stackrel{\circ}{
u_\ell}
                                                                                                                                       2583
                                                                                                \times 10^{-3} CL=90%
    p \overline{p} e^+ \nu_e
                                                                < 5.2
                                                                   < 9.8
                                                                                                  \times\,10^{-7} CL=90%
    e^+ \nu_e
                                                                                                                                      2640
                                                                                                 \times\,10^{-6} CL=90%
    \mu^+ \nu_{\mu}
                                                                   < 1.0
                                                                                                                                       2639
    	au^+ 
u_	au
                                                                   ( 1.65 \pm 0.34 ) \times 10^{-4}
                                                                                                                                       2341
                                                                                                  \times\,10^{-5}\quad\text{CL}\!=\!90\%
    \ell^+ \nu_\ell \gamma
                                                                   < 1.56
                                                                                                                                       2640
                                                                                                  \times\,10^{-5} CL=90%
       e^+ \nu_e \gamma
                                                                   < 1.7
                                                                                                                                       2640
        \mu^+\,\nu_\mu\,\gamma
                                                                   < 2.4
                                                                                                  \times\,10^{-5} CL=90%
                                                                                                                                      2639
```

| -0 | Inclusive | | | | | | $\overline{D}_2^*(2462)^0 \pi^+ 	imes B(\overline{D}_2^{*0} 	o $ | < | 1.7 | $\times10^{-4}$ | CL=90% | _ |
|----------------------------------------------------------------------------------------------------------------------------|------------------|---------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------|---|-------------|-----------------------------------------------------------|------------------|--------------|
| <i>D</i> ⁰ <i>X</i> <i>D</i> ⁰ <i>X</i> | | (8.6 (79 | ±0.7 ±4 |) %) % | | _ | $\overline{\mathcal{D}}{}^0\pi^-\pi^+$ (nonresonant)) $\overline{\mathcal{D}}_2^*$ (2462) $^0\pi^+	imes$ B $(\overline{\mathcal{D}}_2^{*0}	o$ | , | 2.2 | 111) ~ 10-4 | | |
| $D^+ X$ | | (2.5 | ±0.5 |) % | | - | $D_2(2402) \stackrel{\pi}{\pi} \times B(D_2 \rightarrow D^*(2010) - \pi^+)$ | (| 2.2 | ± 1.1) $\times 10^{-4}$ | | _ |
| $D^{\perp}X$ | 1 | | ±1.2 | | | - | $\overline{D}_{0}^{*}(2400)^{0}\pi^{+}$ | (| 6.4 | ± 1.4) $\times10^{-4}$ | | 2128 |
| $D_s^+ X$ | | | -1.5 |) % | | = | $\times B(\overline{D}_{0}^{*}(2400)^{0} \to D^{-}\pi^{+})$ | , | | | | |
| $D_s^- X$ | 1 | (1.10 | |) % | | - | $\overline{D}_1(2421)^0\pi^+ 	imes B(\overline{D}_1(2421)^0 	o D^{*-}\pi^+)$ | (| 6.8 | ± 1.5) $\times 10^{-4}$ | | _ |
| $\Lambda_c^+ X$ | - | (2.1 | $^{+0.9}_{-0.6}$ |) % | | - | $\overline{D}_{2}^{*}(2462)^{0}\pi^{+}$ | (| 1.8 | ±0.5) $\times10^{-4}$ | | _ |
| $\overline{\Lambda}_c^- X$ | | (2.8 | $^{+1.1}_{-0.9}$ |) % | | = | $\times B(\overline{D}_{2}^{*}(2462)^{0} \rightarrow D^{*-}\pi^{+})$ $\overline{D}_{1}^{\prime}(2427)^{0}\pi^{+}$ | , | - 0 | | | |
| <u>₹</u> X | | 97 | |) % | | - | $D_1(2427)^{\circ}\pi^+$ $\times B(\overline{D}_1'(2427)^0 \to D^{*-}\pi^+)$ | (| 5.0 | ± 1.2) $\times 10^{-4}$ | | _ |
| cX | 1 | (23.4 | $^{+2.2}_{-1.8}$ |) % | | = | $\overline{D}_1 (2420)^{ar{0}} \pi^+ \! 	imes \! B (\overline{D}_1^0 	o$ | < | 6 | $\times10^{-6}$ | CL=90% | 2082 |
| <u> </u> | 1 | (120 | ±6 |) % | | = | $\overline{\mathcal{D}}^{*0}\pi^{+}\pi^{-}) \ \overline{\mathcal{D}}_{1}^{*}(2420)^{0} ho^{+}$ | | | 10-3 | CI 000/ | 1006 |
| $\overline{\mathcal{D}}{}^0\pi^+$ | , <i>D</i> *, or | | | 3 | | | $\frac{D_1}{D_2^*(2460)^0} \pi^+$ | | 1.4 | $\times 10^{-3} \times 10^{-3}$ | CL=90% CL=90% | 1996 2062 |
| | | | | $) \times 10^{-3}$ $) \times 10^{-3}$ | | 2308 | $\overline{D}_{2}^{*}(2460)^{0}\pi^{+}\timesB(\overline{D}_{2}^{*0}\rightarrow$ | < | 2.2 | $\times10^{-5}$ | CL=90% | 2062 |
| $D_{CP(-1)}\pi^{+}$ | [qqq] | | |) × 10 ⁻³ | | - | $\overline{D}^{*0}\pi^{+}\pi^{-}) \ \overline{D}_{2}^{*}(2460)^{0}\rho^{+}$ | | | 3 | G. 000/ | 4075 |
| $\overline{D}{}^0 ho^+$ | | (1.34 | | | | 2237 | $\frac{D_{2}^{*}(2460)^{\circ}}{D^{0}}D_{S}^{+}$ | | 4.7 10.0 | $\times 10^{-3}$ ± 1.7) $\times 10^{-3}$ | CL=90% | 1975 1815 |
| $\overline{\mathcal{D}}^0K^+ D_{CP(+1)}K^+$ | | , | | $) \times 10^{-4}$ $) \times 10^{-4}$ | | 2281 | $D_{s0}(2317)^{+} \overline{D}{}^{0} \times$ | | | +2.2 -1.7)×10 ⁻⁴ | | 1605 |
| $D_{CP(-1)}K^+$ | | | |) × 10 ⁻⁴ | | _ | $B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)$ | , | | -1.7 | | 1000 |
| $[K^-\pi^+]_D K^+$ | [rrr] < | | | $\times 10^{-7}$ | CL=90% | - | $D_{s0}(2317)^{+} \overline{D}^{0} \times$ | < | 7.6 | $\times 10^{-4}$ | CL=90% | 1605 |
| $[K^{+}\pi^{-}]_{D}K^{+} \ [K^{-}\pi^{+}]_{D}\pi^{+}$ | [rrr] < | | +11 | $\times 10^{-5}$) $\times 10^{-7}$ | CL=90% | _ | $B(D_{s0}(2317)^+ \rightarrow D_s^{*+} \gamma) D_{s0}(2317)^+ \overline{D}^* (2007)^0 \times$ | 1 | 9 | ±7)×10 ⁻⁴ | | 1511 |
| $[K^{+}\pi^{-}]_{D}\pi^{+}$ | | (2.0 | ±0.4 | $) \times 10^{-4}$ | | _ | $B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)$ | (| , | 17) / 10 | | 1511 |
| $\frac{[\pi^+\pi^-\pi^0]_D K^-}{D^0 K^* (892)^+}$ | | | | $) \times 10^{-6}$ $) \times 10^{-4}$ | | - 2213 | $D_{sJ}(2457)^+\overline{D}{}^0$ | (| 3.1 | $^{+1.0}_{-0.9}$) $\times 10^{-3}$ | | _ |
| B (400/) | | | | $) \times 10^{-4}$ | | - | $D_{s,J}$ (2457) $^+$ $\overline{D}{}^0$ $	imes$ | | | $^{+1.3}_{-1.1}$) × 10 ⁻⁴ | | _ |
| $D_{CP(+1)} {\cal K}^*(892)^+$ | | , | | $) \times 10^{-4}$ | | - | $B(D_{sJ}(2457)^+ \to D_s^+ \gamma)$ | , | | -1.1 | | |
| $\frac{\overline{D}^0}{\overline{D}^0} \frac{K^+ \overline{K}^0}{K^* (892)^0}$ | | | | $) \times 10^{-4}$ $) \times 10^{-4}$ | | 2189 | $D_{sJ}(2457) + \overline{D}^0 \times$ | < | 2.2 | × 10 ⁻⁴ | CL=90% | - |
| $\frac{D}{D^0} \pi^+ \pi^+ \pi^-$ | | | | $) \times 10^{-3}$ | S=3.6 | 2071 2289 | $B(D_{sJ}(2457)^+ ightarrow \ D_s^+ \pi^+ \pi^-)$ | | | | | |
| $rac{\overline{D}{}^0\pi^+\pi^+\pi^-$ nonresonant $\overline{D}{}^0\pi^+ ho^0$ | | 5 | | $) \times 10^{-3}$ | | 2289 | D_{sJ} (2457) $^+$ $\overline{D}{}^0$ $	imes$ | < | 2.7 | $\times10^{-4}$ | CL=90% | - |
| $\frac{D^{2}\pi^{3}\rho^{3}}{D^{0}}a_{1}(1260)^{+}$ | | (4.2 (4 | | $) \times 10^{-3}$ $) \times 10^{-3}$ | | 2207 2123 | $B(D_{sJ}(2457)^+ 	o D_s^+ \pi^0) \ D_{sJ}(2457)^+ \overline{D}{}^0 	imes$ | | | 10-4 | CI 000/ | |
| $\overline{D}{}^0\omega\pi^+$ | 1 | (4.1 | ± 0.9 | $) \times 10^{-3}$ | | 2206 | $B(D_{sJ}(2457)^+ \to D_s^{*+}\gamma)$ | < | 9.8 | × 10 · | CL=90% | _ |
| $D^*(2010)^- \pi^+ \pi^+ \over \overline{D}_1 (2420)^0 \pi^+ \times B(\overline{D}_1^0 \to 0)$ | | | | $) \times 10^{-3}$ $) \times 10^{-4}$ | | 2247 2082 | $D_{sJ}(2457)^+ \overline{D}^*(2007)^0$ | (| 1.20 | ±0.30) % | | - |
| $D^*(2010)^-\pi^+)$ | | | | , | | | $D_{sJ}(2457)^+ \overline{D}^*(2007)^0 \times$ | (| 1.4 | $^{+0.7}_{-0.6})\times10^{-3}$ | | - |
| $D^-\pi^+\pi^+ \ D^+ K^0$ | | | ± 0.05 | $) \times 10^{-3} \times 10^{-6}$ | CL=90% | 2299 2278 | $B(D_{s,J}(2457)^+ \to D_s^+ \gamma)$ | , | | | | 1447 |
| $D^+ K^{*0}$ | < | 3.0 | | × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × | CL=90% CL=90% | 2211 | $\overline{D}{}^0 D_{s1}(2536)^+ 	imes \ {\sf B}(D_{s1}(2536)^+ 	o$ | (| 4.0 | ± 1.0) $\times 10^{-4}$ | | 1447 |
| $\overline{D}_{\Sigma}^{*}(2007)^{0}\pi^{+}$ | | | | $) \times 10^{-3}$ | | 225 6 | $D^*(2007)^0 K^+$ + | | | | | |
| $D_{CP(+1)}^{*0}\pi^{+}$ | [sss] | | | $) \times 10^{-3}$ $) \times 10^{-3}$ | | _ | $\frac{D^*(2010)^+ K^0}{\overline{D}^0 D_{s1}(2536)^+ \times}$ | (| 2.2 | ± 0.7) $\times 10^{-4}$ | | 1447 |
| $\frac{D_{CP(-1)}^{*0}\pi^{+}}{\overline{D}^{*}(2007)^{0}\omega\pi^{+}}$ | [sss] | | | $) \times 10^{-3}$ | | 2149 | $B(D_{s1}(2536)^+ \to$ | , | | , | | |
| $\overline{D}^*(2007)^0 \rho^+$ | | 9.8 | ± 1.7 | $) \times 10^{-3}$ | | 2181 | $D^*(2007)^0 K^+) \over \overline{D}^*(2007)^0 D_{s1}(2536)^+ \times$ | (| 5.5 | ±1.6) × 10 ⁻⁴ | | 1339 |
| $\overline{D}^*(2007)^0 K^+ K^+$ | | | | $) \times 10^{-4}$ $) \times 10^{-4}$ | | 2227 | $B(D_{s1}(2536)^+ \to$ | , | 0.0 | ±110) × 10 | | 1007 |
| $egin{array}{c} \dot{\overline{D}}_{CP(+1)}^{*0} \mathit{K}^{+} \ \overline{D}_{CP(-1)}^{*0} \mathit{K}^{+} \end{array}$ | [sss] | ` | |) × 10 -4 | | _ | $D^*(2007)^0 K^+)$ $\overline{D}^0 D_{s1}(2536)^+ \times$ | 1 | 23 | ± 1.1) $\times 10^{-4}$ | | 1447 |
| $\overline{D}^*(2007)^0 K^*(892)^+$ | | | |) × 10 ⁻⁴ | | 2156 | $B(D_{s1}(2536)^+ \to D^{*+} K^0)$ | | | | | A-1-11 |
| $\overline{D}^*(2007)^0 K^+ \overline{K}^0$ $\overline{D}^*(2007)^0 K^+ K^*(892)^0$ | < | 1.06 | | $\times 10^{-3}$ | CL=90% | 2132 | $\overline{D}{}^0 D_{sJ}(2700)^+ 	imes$ | (| 1.13 | $^{+0.26}_{-0.40}\)\times 10^{-3}$ | | - |
| $\overline{D}^*(2007)^0 \pi^+ \pi^+ \pi^-$ | | | ± 0.4 ± 0.12 |) × 10 ⁻³ | | 2008 2236 | $\overline{D}^{*0} D_{sJ}(2700)^+ 	o D^0 K^+) \ \overline{D}^{*0} D_{s1}(2536)^+ 	imes$ | 1 | 3.9 | ±2.6)×10-4 | | 1339 |
| $\dot{\overline{D}}^*(2007)^0 a_1(1260)^+$ | | (1.9 | ±0.5 |) % | | 2063 | B $(D_{s1}(2536)^+ \rightarrow D^{*+}K^0)$ | | | | | |
| $\frac{\overline{D}^*(2007)^0 \pi^- \pi^+ \pi^+ \pi^0}{\overline{D}^{*0} 3\pi^+ 2\pi^-}$ | 1 | | ±0.4 |) %) × 10 ⁻³ | | 2219 2196 | $\overline{D}^{*0} D_{sJ}(2573)^+ 	imes \ {\sf B}(D_{sJ}(2573)^+ 	o D^0 {\sf K}^+)$ | < | 2 | × 10 ⁻⁴ | CL=90% | 1306 |
| $D^*(2010)^+ \pi^0$ | < | 3.6 | | $\times 10^{-6}$ | | 2255 | $\overline{D}^*(2007)^0 D_{s,I}(2573)^+ \times$ | < | 5 | $\times10^{-4}$ | CL=90% | 1306 |
| $D^*(2010)^+ K^0 \ D^*(2010)^- \pi^+ \pi^+ \pi^0$ | < | | ±0.7 | ×10 ⁻⁶ | CL=90% | 2225 2235 | $\overline{D}^{0} D_{sJ}^{*+} (2573)^{+} \rightarrow D^{0} K^{+})$ | , | 7.6 | ± 1.6) $\times 10^{-3}$ | | 1734 |
| $D^*(2010)^-\pi^+\pi^+\pi^+\pi^-$ | | (2.6 | ±0.4 | $) \times 10^{-3}$ | | 2217 | $\overline{D}^{s}(2007)^{0}D_{s}^{+}$ | (| | ± 1.0) × 10 ± 1.7) × 10 ⁻³ | | 1737 |
| $\overline{D}^{**0} \pi^+ \over \overline{D}_1^* (2420)^0 \pi^+$ | | | | $) \times 10^{-3}$ $) \times 10^{-3}$ | S=1.3 | _ 2082 | $\overline{D}^*(2007)^0 D_s^{*+}$ | (| | ±0.24) % | | 1651 |
| $\overline{D}_1(2420)^0 \pi^+ \times B(\overline{D}_1^0 \to$ | | • | |) × 10 °) × 10 −4 | S=1.3 S=4.0 | 2082 | $D_s^{(*)+}\overline{D}^{**0}$ | (| | ±1.2)% | | _ |
| $\overline{D}{}^0\pi^+\pi^-)$ | | (2.5 | -1.4 |) × 10 . | 3=4.0 | 2002 | $\overline{D}^*(2007)^0 D^*(2010)^+ \ \overline{D}^0 D^*(2010)^+ +$ | (| 8.1 1.30 | ±1.7) × 10 ⁻⁴ | CL=90% | 1713 1792 |
| $\overline{D}_1(2420)^0\pi^+ \times B(\overline{D}_1^0 \to \overline{D}_1^0)$ | | (2.3 | ± 1.0 | $) \times 10^{-4}$ | | 2082 | $\overline{D}^*(2007)^0 D^+$ | _ | | | | |
| $\overline{D}{}^0\pi^+\pi^-$ (nonresonant)) $\overline{D}_2^*(2462)^0\pi^+$ | | (3.5 | +04 |) × 10 ⁻⁴ | | _ | $rac{\overline{D}{}^0D^*(2010)^+}{\overline{D}{}^0D^+}$ | (| | ± 0.5) $\times 10^{-4}$ ± 0.4) $\times 10^{-4}$ | | 1792 1866 |
| \times B(\overline{D}_2^* (2462) $^0 \rightarrow D^-\pi^+$) | | , 5.5 | _ 0.4 | , ~ 10 | | | $\overline{\mathcal{D}}{}^0\mathcal{D}^+\mathcal{K}^0$ | (| 1.55 | ± 0.21) $\times 10^{-3}$ | | 1571 |
| $\overline{D}_{2}^{*}(2462)^{\overline{0}} \pi^{+} \times B(\overline{D}_{2}^{*0} \rightarrow$ | | (2.3 | ± 1.1 | $) \times 10^{-4}$ | | - | $\frac{D^+ \overline{D}^* (2007)^0}{\overline{D}^* (2007)^0 D^+ K^0}$ | (| | ± 1.7) $\times 10^{-4}$ ± 0.5) $\times 10^{-3}$ | | 1791 |
| $\overline{D}{}^0\pi^-\pi^+)$ | | | | | | | $\frac{D^{1}(2007)^{2}D^{1}K^{2}}{D^{0}D^{*}(2010)^{+}K^{0}}$ | (| | ± 0.5) × 10 3 ± 0.4) × 10 ⁻³ | | 1474 1476 |
| | | | | | | | | | | | | |

| $\overline{D}^*(2007)^0 D^*(2010)^+ K^0$ | , | 0.0 | . 1 2 | \1o-3 | | 1262 | 1/a/(15) K*(902)+ | , | 1.40 | 10.00 \10-3 | | 1571 |
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| D (2007) D (2010) N | | | |) × 10 ⁻³ | | 1362 | $J/\psi(1S) K^*(892)^+$ | (| | $\pm 0.08) \times 10^{-3}$ | | 1571 |
| $\overline{D}^0 D^0 K^+$ | | | | $) \times 10^{-3}$ | S = 2.6 | 1577 | $J/\psi(1S) K(1270)^+$ | (| | ± 0.5) $\times 10^{-3}$ | | 1390 |
| $\overline{D}^*(2007)^0 D^0 K^+$ | (| | | $) \times 10^{-3}$ | | 1481 | $J/\psi(1S)K(1400)^+$ | < | 5 | $\times 10^{-4}$ | CL=90% | 1308 |
| $\overline{D}{}^{0}D^{*}(2007)^{0}K^{+}$ | (| 6.3 | ± 0.5 | $) \times 10^{-3}$ | | 1481 | $J/\psi(1S)\eta K^+$ | (| 1.08 | $\pm 0.33) \times 10^{-4}$ | | 1510 |
| $\overline{D}^*(2007)^0 \acute{D}^*(2007)^0 K^+$ | (| 1.12 | ± 0.13 |) % | | 1368 | $J/\psi(1S)\eta'K^+$ | < | 8.8 | $\times 10^{-5}$ | CL=90% | 1273 |
| $D^{-}D^{+}K^{+}$ | (| 2.2 | ± 0.7 | $) \times 10^{-4}$ | | 1570 | $J/\psi(1S)\phi K^+$ | (| 5.2 | ± 1.7) $\times 10^{-5}$ | S=1.2 | 1227 |
| $D^-D^*(2010)^+K^+$ | | | |) × 10 ⁻⁴ | | 1475 | 7 . 7 . | , | | | | |
| $D^*(2010)^-D^+K^+$ | | | |) × 10 ⁻⁴ | | 1475 | $J/\psi(1S)\omegaK^+$ | (| 3.20 | $^{+0.60}_{-0.32}$) $\times10^{-4}$ | | 1388 |
| | | | | | | | $X(3872)K^+ \times B(X \rightarrow$ | (| 6.0 | ± 2.2) $\times 10^{-6}$ | | 1141 |
| $D^*(2010)^- D^*(2010)^+ K^+$ | | | | $) \times 10^{-3}$ | | 1363 | $J/\psi\omega$ | , | | , | | |
| $(\overline{D} + \overline{D}^*)(D + D^*)K$ | (| 4.05 | ± 0.30 |) % | | _ | , . , | | | .00 - | | |
| $D_s^+ \pi^0$ | (| 1.6 | ± 0.5 | $) \times 10^{-5}$ | | 2270 | $X(3915)K^+ \times B(X \rightarrow$ | (| 3.0 | $^{+0.9}_{-0.7}$) $\times10^{-5}$ | | 1104 |
| $D_{s}^{*+}\pi^{0}$ | < | 2.6 | | $\times 10^{-4}$ | CL=90% | 2215 | $J/\psi \omega)$ | | | | | |
| D+ m | | | | × 10 ⁻⁴ | CL=90% | 2235 | $J/\psi(1S)\pi^+$ | (| 4.9 | ± 0.4) $\times 10^{-5}$ | S=1.2 | 1727 |
| $D_s^+ \eta$ | < | 4 | | | | | $J/\psi(1S)\rho^+$ | ì | 5.0 | ± 0.8) $\times 10^{-5}$ | | 1611 |
| $D_s^{*+} \eta$ $D_s^{+} \rho^0$ | < | 6 | | $\times 10^{-4}$ | CL=90% | 2178 | $J/\psi(1S)\pi^+\pi^0$ nonresonant | <` | 7.3 | × 10 ⁻⁶ | CL=90% | 1717 |
| $D_{\circ}^{+} \rho^{0}$ | < | 3.0 | | $\times 10^{-4}$ | CL=90% | 2197 | | | | | | |
| $D_{s}^{*+}\rho^{0}$ | | 4 | | $\times 10^{-4}$ | CL=90% | 2138 | $J/\psi(1S) a_{1}(1260)^{+}$ | < | 1.2 | × 10 ⁻³ | CL=90% | 1415 |
| D + D+ | | | | | | | $J/\psi(1S) \underline{\rho} \overline{\Lambda}$ | (| | ± 0.31) $\times 10^{-5}$ | | 567 |
| $D_s^+\omega$ | < | 4 | | $\times 10^{-4}$ | CL=90% | 2195 | $J/\psi(1S)\overline{\Sigma}^0 p$ | < | 1.1 | $\times 10^{-5}$ | CL=90% | _ |
| $D_s^{*+}\omega$ | < | 6 | | $\times 10^{-4}$ | CL=90% | 2136 | $J/\psi(1S)D^{+}$ | < | 1.2 | $\times 10^{-4}$ | CL=90% | 870 |
| $D_s^{\stackrel{3}{+}} a_1 (1260)^0$ | < | 1.8 | | $\times 10^{-3}$ | CL=90% | 2079 | $J/\psi(1S)\overline{D}{}^0\pi^+$ | < | 2.5 | $\times 10^{-5}$ | CL=90% | 665 |
| D _S a ₁ (1200) | | | | | | | | | | ±0.30) × 10 ⁻⁵ | CL=3070 | 1347 |
| $D_s^{*+} a_1(1260)^0$ | < | 1.3 | | $\times 10^{-3}$ | CL=90% | 2015 | $\psi(2S)\pi^+$ | (| | | | |
| $D_s^+\phi$ | < | 1.9 | | $\times 10^{-6}$ | CL=90% | 2141 | $\psi(2S)K^+$ | (| 6.39 | ± 0.33) $\times 10^{-4}$ | | 1284 |
| $D_{*}^{s} + \phi$ | | 1.0 | | $\times 10^{-5}$ | | | $\psi(2S) K^*(892)^+$ | (| 6.7 | ± 1.4) $\times 10^{-4}$ | S=1.3 | 1115 |
| | | 1.2 | | | CL=90% | 2079 | $\psi(2S)K^{+}\pi^{+}\pi^{-}$ | i | 4.3 | ± 0.5) $\times 10^{-4}$ | | 1179 |
| $D_s^+ \overline{K}^0$ | < | 8 | | $\times 10^{-4}$ | CL=90% | 2242 | $\psi(3770) K^{+}$ | ì | 4.9 | ± 1.3) × 10 ⁻⁴ | | 1218 |
| $D_s^{*+} \overline{K}^0$ | < | 9 | | $\times10^{-4}$ | CL=90% | 2185 | $\psi(3770)K^{+} \times B(\psi \rightarrow D^{0}\overline{D}^{0})$ | , | | The state of the s | C 11 | |
| $D_{+}^{s} \overline{K}^{*}(892)^{0}$ | - | 4 | | × 10 ⁻⁴ | | | | (| 1.6 | ± 0.4) $\times 10^{-4}$ | S=1.1 | 1218 |
| 5 ` ' | < | 4 | | | CL=90% | 2172 | ψ (3770) $K^+ \times B(\psi \rightarrow D^+ D^-)$ | (| 9.4 | ± 3.5) $\times 10^{-5}$ | | 1218 |
| $D_s^{*+} \overline{K}^* (892)^0$ | < | 3.5 | | $\times 10^{-4}$ | CL = 90% | 2112 | $\chi_{c0}\pi^+ \times B(\chi_{c0} \rightarrow \pi^+\pi^-)$ | < | 1 | $\times 10^{-7}$ | CL=90% | 1531 |
| $D_s^{\stackrel{3}{=}} \pi^+ \stackrel{\stackrel{\circ}{K}^+}{}$ | (| 1,80 | 士0.22 | $) \times 10^{-4}$ | | 2222 | $\chi_{c0}(1P) K^+$ | , | | | | 1478 |
| D*= -+ V+ | | | | _ | | | | (| 1.34 | $^{+0.19}_{-0.16}$) $	imes$ 10 ⁻⁴ | | 14/8 |
| $D_s^{*-}\pi^+K^+$ | (| 1.45 | ±0.24 |) × 10 ⁻⁴ | | 2164 | $\chi_{c0} K^*$ (892) $^+$ | < | 2.1 | $\times 10^{-4}$ | CL=90% | 1341 |
| $D_{s}^{-}\pi^{+}K^{*}(892)^{+}$ | < | 5 | | $\times 10^{-3}$ | CL=90% | 2138 | $\chi_{c2}\pi^+ \times B(\chi_{c2} \to \pi^+\pi^-)$ | < | 1 | $\times 10^{-7}$ | CL=90% | 1437 |
| $D_s^{*-}\pi^+K^*(892)^+$ | < | 7 | | $\times 10^{-3}$ | CL=90% | 2076 | $\chi_{c2}K^+$ | | | ±0.4)×10 ⁻⁵ | CL_30/6 | 1379 |
| D= K+ K+ | | | | | 02-3070 | | χ _{c2} Λ΄ | (| | | | |
| $D_s^- K^+ K^+$ | (| 1.1 | ± 0.4 | $) \times 10^{-5}$ | | 2149 | $\chi_{c2} K^* (892)^+$ | < | 1.2 | $\times 10^{-4}$ | CL=90% | 1227 |
| $D_s^{*-}K^+K^+$ | < | 1.5 | | $\times 10^{-5}$ | CL=90% | 2088 | $\chi_{c1}(1P)\pi^{+}$ | (| 2.2 | ± 0.5) $\times 10^{-5}$ | | 1468 |
| | | | | | | | $\chi_{c1}(1P) K^+$ | (| 4.79 | $\pm 0.23) \times 10^{-4}$ | | 1412 |
| Charm | | | | | | | $\chi_{c1}(1P) K^*(892)^+$ | ì | 3.0 | ± 0.6) $\times 10^{-4}$ | S=1.1 | 1265 |
| $\eta_c K^+$ | (| 9.6 | ± 1.2 | $) \times 10^{-4}$ | | 1753 | $h_c(1P)K^+$ | , | 3.8 | × 10 ⁻⁵ | 3-1.1 | 1401 |
| $\eta_c {\it K}^+$, $\eta_c ightarrow {\it K}_S^0 {\it K}^\mp \pi^\pm$ | (| 2.7 | ± 0.6 | $) \times 10^{-5}$ | | - | $n_{\mathcal{C}}(1F)K$ | < | 3.0 | X 10 - | | 1401 |
| | | | | | | | ., | | | | | |
| | / | 4 4 | +0.5 | 10-3 | | 1640 | K | r K* | mode | 3 C | | |
| $\eta_c K^*(892)^+$ | (| 1.1 | $^{+0.5}_{-0.4}$ | $) \times 10^{-3}$ | | 1648 | κ ⁰ + | or <i>K</i> * | | - | | 2614 |
| | | | | | | | $\mathcal{K}^0\pi^+$ | or <i>K</i> * | 2.31 | ± 0.10) $\times 10^{-5}$ | | 2614 |
| $\eta_c(2S)K^+$ | (| 3.4 | ± 1.8 | $) \times 10^{-4}$ | | 1319 | $\stackrel{	extbf{K}^0\pi^+}{	extbf{K}^+\pi^0}$ | or K* (| 2.31 1.29 | $^{\pm 0.10}_{\pm 0.06})\times 10^{-5}_{}\\ ^{\pm 0.06})\times 10^{-5}_{}$ | | 2615 |
| $\eta_{c}(2S) K^{+}$ $\eta_{c}(2S) K^{+}$, $\eta_{c}(2S) \rightarrow$ | (| 3.4 | ± 1.8 | | | | $\mathcal{K}^0\pi^+$ | or K* ((| 2.31 1.29 | ± 0.10) $\times 10^{-5}$ | | |
| $\eta_{c}(2S) K^{+}$ $\eta_{c}(2S) K^{+}$, $\eta_{c}(2S) \rightarrow$ | (| 3.4 | ±1.8 | $) \times 10^{-4}$ | | 1319 | $egin{array}{c} \mathcal{K}^0\pi^+ \ \mathcal{K}^+\pi^0 \ \eta'\mathcal{K}^+ \end{array}$ | or K* ((| 2.31 1.29 7.06 | $\begin{array}{c} \pm 0.10 \text{)} \times 10^{-5} \\ \pm 0.06 \text{)} \times 10^{-5} \\ \pm 0.25 \text{)} \times 10^{-5} \end{array}$ | | 2615 2528 |
| $ \eta_c(2S) K^+ $ $ \eta_c(2S) K^+, \eta_c(2S) \rightarrow $ $ K_0^S K^{\mp} \pi^{\pm} $ | (| 3.4 | $\pm 1.8 \\ + 2.3 \\ - 1.6$ |) × 10 ⁻⁴) × 10 ⁻⁶ | | 1319 — | $K^{0}\pi^{+} \atop K^{+}\pi^{0} \atop \eta' K^{+} \atop \eta' K^{*}(892)^{+}$ | or K* (((| 2.31 1.29 7.06 4.8 | $\begin{array}{l} \pm 0.10 \text{)} \times 10^{-5} \\ \pm 0.06 \text{)} \times 10^{-5} \\ \pm 0.25 \text{)} \times 10^{-5} \\ + 1.8 \\ - 1.6 \text{)} \times 10^{-6} \end{array}$ | | 2615 |
| $ \eta_c(2S) K^+ \eta_c(2S) K^+, \eta_c(2S) \to K_0^8 K^{\mp} \pi^{\pm} J/\psi(1S) K^+ $ | (| 3.4 3.4 1.016 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ | c 21 | 1319 - 1683 | $K^{0}\pi^{+} \atop K^{+}\pi^{0} \atop \eta' K^{+} \atop \eta' K^{*}(892)^{+}$ | or K* ((((| 2.31 1.29 7.06 4.8 | $\begin{array}{l} \pm 0.10 \text{)} \times 10^{-5} \\ \pm 0.06 \text{)} \times 10^{-5} \\ \pm 0.25 \text{)} \times 10^{-5} \\ + 1.8 \\ - 1.6 \text{)} \times 10^{-6} \end{array}$ | | 2615 2528 |
| $ \eta_c(2S) K^+ \eta_c(2S) K^+, \eta_c(2S) \rightarrow K_S^0 K^{\mp} \pi^{\pm} J/\psi(1S) K^+ J/\psi(1S) K^+ \pi^+ \pi^- $ | (| 3.4 3.4 1.016 8.1 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ | S=2.5 | 1319 - 1683 1612 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K_{0}^{*}(1430)^{+}$ | or K* (((| 2.31 1.29 7.06 4.8 5.2 | $\begin{array}{l} \pm 0.10) \times 10^{-5} \\ \pm 0.06) \times 10^{-5} \\ \pm 0.25) \times 10^{-5} \\ + 1.8 \\ -1.6) \times 10^{-6} \\ \pm 2.1) \times 10^{-6} \end{array}$ | | 2615 2528 2472 — |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow $ $ K_{0}^{8} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow $ | (| 3.4 3.4 1.016 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ | S=2.5 CL=90% | 1319 - 1683 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}_{0}(1430)^{+}$ $\eta'K^{*}_{2}(1430)^{+}$ | or K* ((((((| 2.31 1.29 7.06 4.8 5.2 2.8 | $\begin{array}{l} \pm 0.10) \times 10^{-5} \\ \pm 0.06) \times 10^{-5} \\ \pm 0.25) \times 10^{-5} \\ + 1.8 \\ -1.6) \times 10^{-6} \\ \pm 2.1) \times 10^{-6} \\ \pm 0.5) \times 10^{-5} \end{array}$ | 6.17 | 2615 2528 2472 — 2346 |
| $ \eta_c(2S) K^+ \eta_c(2S) K^+, \eta_c(2S) \rightarrow K_S^0 K^{\mp} \pi^{\pm} J/\psi(1S) K^+ J/\psi(1S) K^+ \pi^+ \pi^- $ | (| 3.4 3.4 1.016 8.1 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ | | 1319 - 1683 1612 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ ηK^{+} | or K* ((((((((((((((((((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 | $\begin{array}{l} \pm 0.10) \times 10^{-5} \\ \pm 0.06) \times 10^{-5} \\ \pm 0.25) \times 10^{-5} \\ + 1.8 \\ -1.6) \times 10^{-6} \\ \pm 2.1) \times 10^{-6} \\ \pm 0.5) \times 10^{-5} \\ \pm 0.4) \times 10^{-6} \end{array}$ | S=1.7 | 2615 2528 2472 — 2346 2588 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow $ $ K_{0}^{8} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow $ | (((< < | 3.4 3.4 1.016 8.1 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ | | 1319 - 1683 1612 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ | or K* (((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 | $\begin{array}{l} \pm 0.10) \times 10^{-5} \\ \pm 0.06) \times 10^{-5} \\ \pm 0.25) \times 10^{-5} \\ + 1.8 \\ -1.6) \times 10^{-6} \\ \pm 2.1) \times 10^{-6} \\ \pm 0.5) \times 10^{-5} \end{array}$ | S=1.7 | 2615 2528 2472 — 2346 |
| $ \eta_c(2S) K^+ $ $ \eta_c(2S) K^+, \eta_c(2S) \rightarrow $ $ K_c^0 K^+ \pi^{\pm} $ $ J/\psi(1S) K^+ $ $ J/\psi(1S) K^+ \pi^+ \pi^- $ $ h_c(1P) K^+ \times B(h_c(1P) \rightarrow $ $ J/\psi \pi^+ \pi^-) $ $ X(3872) K^+ $ | (((< < < < | 3.4 3.4 1.016 8.1 3.4 3.2 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ $\times 10^{-6}$ $\times 10^{-4}$ | CL=90% | 1319 — 1683 1612 1401 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ | or K* (((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 | $\begin{array}{l} \pm 0.10) \times 10^{-5} \\ \pm 0.06) \times 10^{-5} \\ \pm 0.25) \times 10^{-5} \\ + 1.8 \\ -1.6) \times 10^{-6} \\ \pm 2.1) \times 10^{-6} \\ \pm 0.5) \times 10^{-5} \\ \pm 0.4) \times 10^{-6} \end{array}$ | S=1.7 | 2615 2528 2472 — 2346 2588 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow $ $ K_{S}^{0} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow $ $ J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow $ | (((< < < < | 3.4 3.4 1.016 8.1 3.4 3.2 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ $\times 10^{-6}$ | CL=90% | 1319 - 1683 1612 1401 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ | or K* (((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.7 | 2615 2528 2472 — 2346 2588 2534 — |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow K_{S}^{0} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \pi^{+} \pi^{-}) $ | (((< (() | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 ± 1.3 ± 0.8 | $\begin{array}{c}) \times 10^{-4} \\) \times 10^{-6} \\ 3) \times 10^{-3} \\) \times 10^{-4} \\ \times 10^{-6} \\ \\ \times 10^{-6} \\) \times 10^{-6} \end{array}$ | CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K_{0}^{*}(1430)^{+}$ $\eta'K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{2}^{*}(1430)^{+}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.7 | 2615 2528 2472 — 2346 2588 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \to \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \times B(X \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \to J/\psi\gamma) \end{array}$ | ((((((((((((((((((((| 3.4 3.4 1.016 8.1 3.4 3.2 8.6 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 ± 1.3 ± 0.8 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ $\times 10^{-6}$ $\times 10^{-4}$ $) \times 10^{-6}$ | CL=90% CL=90% S=1.1 | 1319 - 1683 1612 1401 1141 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.7 | 2615 2528 2472 — 2346 2588 2534 — |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow K^{0}_{S} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \pi^{+} \pi^{-}) $ | (((< (() | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 ± 1.3 ± 0.8 | $\begin{array}{c}) \times 10^{-4} \\) \times 10^{-6} \\ 3) \times 10^{-3} \\) \times 10^{-4} \\ \times 10^{-6} \\ \\ \times 10^{-6} \\) \times 10^{-6} \end{array}$ | CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 | $\begin{array}{c} K^0 \pi^+ \\ K^+ \pi^0 \\ \eta' K^+ \\ \eta' K^* (892)^+ \\ \eta' K_0^* (1430)^+ \\ \eta' K_2^* (1430)^+ \\ \eta K^+ \\ \eta K^* (892)^+ \\ \eta K_0^* (1430)^+ \\ \eta K_2^* (1430)^+ \\ \eta (1295) K^+ \times B(\eta(1295) \to 0) \end{array}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.7 | 2615 2528 2472 — 2346 2588 2534 — 2414 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \to \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \times B(X \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \to J/\psi\gamma) \end{array}$ | ((((((((((((((((((((| 3.4 3.4 1.016 8.1 3.4 3.2 8.6 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 ± 1.3 ± 0.8 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ $\times 10^{-6}$ $\times 10^{-4}$ $) \times 10^{-6}$ | CL=90% CL=90% S=1.1 | 1319 - 1683 1612 1401 1141 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{2}^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \to \\ K_{o}^{0}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \\ X(3872)K^{+}\timesB(X \to \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \to J/\psi\gamma) \\ X(3872)K^{+}\timesB(X \to J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \to J/\psi\gamma) \\ J/\psi\gamma) \end{array}$ | (((< ((< () | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{2}^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta(1405) \rightarrow 0)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.7 | 2615 2528 2472 — 2346 2588 2534 — 2414 |
| $ \eta_c(2S) K^+ $ $ \eta_c(2S) K^+, \eta_c(2S) \rightarrow K_0^8 K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^+ $ $ J/\psi(1S) K^+ \pi^+ \pi^- $ $ h_c(1P) K^+ \times B(h_c(1P) \rightarrow J/\psi \pi^+ \pi^-) $ $ X(3872) K^+ $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \pi^+ \pi^-) $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^*(892)^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^*(892)^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ | (((< ((< () | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 6 ± 0.03 ± 1.3 ± 0.8 | $) \times 10^{-4}$ $) \times 10^{-6}$ $3) \times 10^{-3}$ $) \times 10^{-4}$ $\times 10^{-6}$ $\times 10^{-4}$ $) \times 10^{-6}$ | CL=90% CL=90% S=1.1 | 1319 - 1683 1612 1401 1141 1141 1141 939 | $\begin{array}{c} K^0 \pi^+ \\ K^+ \pi^0 \\ \eta' K^+ \\ \eta' K^* (892)^+ \\ \eta' K_0^* (1430)^+ \\ \eta' K_2^* (1430)^+ \\ \eta K^+ \\ \eta K^* (892)^+ \\ \eta K_0^* (1430)^+ \\ \eta K_2^* (1430)^+ \\ \eta (1295) K^+ \times B(\eta(1295) \rightarrow \\ \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow \\ \eta \pi \pi) \end{array}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 3.0 \) \times 10^{-6} \\ - 0.7 \) \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 |
| $ \eta_c(2S) K^+ $ $ \eta_c(2S) K^+, \eta_c(2S) \rightarrow K_0^8 K^+ \pi^{\pm} $ $ K_0^8 K^+ \pi^{\pm} $ $ J/\psi(1S) K^+ $ $ J/\psi(1S) K^+ \pi^+ \pi^- $ $ h_c(1P) K^+ \times B(h_c(1P) \rightarrow J/\psi \pi^+ \pi^-) $ $ X(3872) K^+ $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^+ \otimes B(X \rightarrow \psi(2S) \gamma) $ | ((((((((((((((((((((| 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\ 3)\times 10^{-3} \\ \times 10^{-4} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 | 1319 - 1683 1612 1401 1141 1141 939 1141 | $\begin{array}{c} K^0 \pi^+ \\ K^+ \pi^0 \\ \eta' K^+ \\ \eta' K^+ \\ \eta' K^* (892)^+ \\ \eta' K_0^* (1430)^+ \\ \eta' K_2^* (1430)^+ \\ \eta K^+ \\ \eta K^* (892)^+ \\ \eta K_0^* (1430)^+ \\ \eta K_2^* (1430)^+ \\ \eta (1295) K^+ \times B(\eta(1295) \rightarrow \\ \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow \\ \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow \\ \end{array}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 3.0 \) \times 10^{-6} \\ - 0.7 \) \times 10^{-6} \\ \times 10^{-6} \end{array}$ | | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow K^{0}_{S} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ | (((< ((< () | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 | $\begin{array}{c} K^0 \pi^+ \\ K^+ \pi^0 \\ \eta' K^+ \\ \eta' K^* (892)^+ \\ \eta' K_0^* (1430)^+ \\ \eta' K_2^* (1430)^+ \\ \eta K^+ \\ \eta K^* (892)^+ \\ \eta K_0^* (1430)^+ \\ \eta K_2^* (1430)^+ \\ \eta (1295) K^+ \times B(\eta(1295) \rightarrow \\ \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow \\ \eta \pi \pi) \end{array}$ | ((((((((((((((((((((| 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 3.0 \) \times 10^{-6} \\ - 0.7 \) \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+} $, $\eta_{c}(2S) \rightarrow K_{0}^{+} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow \psi(2S) \gamma) $ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta' K^{+} \\ \eta' K^{*}(892)^{+} \\ \eta' K_{0}^{*}(1430)^{+} \\ \eta' K_{2}^{*}(1430)^{+} \\ \eta K^{*}(892)^{+} \\ \eta K_{0}^{*}(1430)^{+} \\ \eta K_{2}^{*}(1430)^{+} \\ \eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta(1405) K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta(1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.16 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+}, \eta_{c}(2S) \rightarrow K^{0}_{S} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \otimes B(X \rightarrow J/\psi \gamma) $ | ((((((((((((((((((((| 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 | 1319 - 1683 1612 1401 1141 1141 939 1141 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta' K^{+} \\ \eta' K^{+} \\ \eta' K^{*}(892)^{+} \\ \eta' K_{0}^{*}(1430)^{+} \\ \eta' K_{2}^{*}(1430)^{+} \\ \eta K^{*}(892)^{+} \\ \eta K_{0}^{*}(1430)^{+} \\ \eta K_{2}^{*}(1430)^{+} \\ \eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta (1405) K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta (1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 3.0 \) \times 10^{-6} \\ - 0.7 \) \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+} $, $\eta_{c}(2S) \rightarrow K_{0}^{+} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow \psi(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow \psi(2S) \gamma) $ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta'K^{+} \\ \eta'K^{+} (892)^{+} \\ \eta'K^{*}(892)^{+} \\ \eta'K^{*}_{2}(1430)^{+} \\ \eta K^{+} \\ \eta K^{*}_{3}(1430)^{+} \\ \eta K^{*}_{3}(1430)^{+} \\ \eta K^{*}_{2}(1430)^{+} \\ \eta K^{*}_{2}(1430)^{+} \\ \eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta (1405)K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta (1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.16 \) \times 10^{-6} \\ \pm 0.16 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ + 0.18 \) \times 10^{-5} \\ \end{array}$ | CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow D^{0}\overline{D}^{0}) \end{array}$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 | ± 1.8 $+ 2.3$ $- 1.6$ 5 ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta' K^{+} \\ \eta' K^{+} \\ \eta' K^{*}(892)^{+} \\ \eta' K_{0}^{*}(1430)^{+} \\ \eta' K_{2}^{*}(1430)^{+} \\ \eta K^{*}(892)^{+} \\ \eta K_{0}^{*}(1430)^{+} \\ \eta K_{2}^{*}(1430)^{+} \\ \eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta (1405) K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta (1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ + \frac{0.21}{-0.18} \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{0}\overline{D}^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \end{array}$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta'K^{+} \\ \eta'K^{+} (892)^{+} \\ \eta'K^{*}(892)^{+} \\ \eta'K^{*}_{2}(1430)^{+} \\ \eta K^{+} \\ \eta K^{*}_{3}(1430)^{+} \\ \eta K^{*}_{3}(1430)^{+} \\ \eta K^{*}_{2}(1430)^{+} \\ \eta K^{*}_{2}(1430)^{+} \\ \eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta (1405)K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta (1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ + \frac{0.21}{-0.18} \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+} $, $ \eta_{c}(2S) K^{+} $, $ \eta_{c}(2S) K^{+} $ $ K^{0}_{S} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta'K^+ \\ \eta'K^+ (892)^+ \\ \eta'K^*(892)^+ \\ \eta'K^*_2(1430)^+ \\ \eta K^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta (1295)K^+ \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ + \frac{0.21}{-0.18} \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\otimesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\otimesB(X \rightarrow \\ D^{0}\overline{D}^{0}\pi^{0}) \end{array}$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-5} \\)\times 10^{-4} \end{array}$ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 1141 1141 1 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K_{0}^{*}(1430)^{+}$ $\eta'K_{2}^{*}(1430)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta(1405) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta (1420) K^{+} \times B(\eta(1420) \rightarrow \eta \pi \pi)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 1.2 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 |
| $ \eta_{c}(2S) K^{+} $ $ \eta_{c}(2S) K^{+} $, $ \eta_{c}(2S) K^{+} $, $ \eta_{c}(2S) K^{+} $ $ K^{0}_{S} K^{\mp} \pi^{\pm} $ $ J/\psi(1S) K^{+} $ $ J/\psi(1S) K^{+} \pi^{+} \pi^{-} $ $ h_{c}(1P) K^{+} \times B(h_{c}(1P) \rightarrow J/\psi \pi^{+} \pi^{-}) $ $ X(3872) K^{+} $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow J/\psi \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ $ X(3872) K^{+} \times B(X \rightarrow U(2S) \gamma) $ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 1141 1141 1 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta' K^+ \\ \eta' K^*(892)^+ \\ \eta' K_0^*(1430)^+ \\ \eta' K_2^*(1430)^+ \\ \eta K^+ \\ \eta K^*(892)^+ \\ \eta K_0^*(1430)^+ \\ \eta K_2^*(1430)^+ \\ \eta(1295) K^+ \times B(\eta(1295) \rightarrow \\ \eta \pi \pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow \\ \eta \pi \pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow \\ K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow \\ K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow \\ K^*K) \\ f_1(1285) K^+ \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \\ \eta \pi \pi) \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 1.8 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{8}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+} \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{*}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow D^{0}\overline{D}^{0}) \\ X$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-5} \\)\times 10^{-4} \end{array}$ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 1141 1141 1 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta'K^{+} \\ \eta'K^{+} \\ \eta'K^{*}(892)^{+} \\ \eta'K_{0}^{*}(1430)^{+} \\ \eta'K_{2}^{*}(1430)^{+} \\ \eta K^{*}(892)^{+} \\ \eta K_{0}^{*}(1430)^{+} \\ \eta K_{2}^{*}(1430)^{+} \\ \eta(1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ \eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ f_{1}(1285)K^{+} \\ f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K) \\ f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.9 4.1 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2426 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{0}\overline{D^{0}}\pi^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{0}\overline{D^{0}}\pi^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \overline{D^{*}}D^{0}D^{0}) \end{array}$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-4} \\)\times 10^{-5} \end{array}$ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% S=1.4 | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta' K^+ \\ \eta' K^*(892)^+ \\ \eta' K_0^*(1430)^+ \\ \eta' K_2^*(1430)^+ \\ \eta K^+ \\ \eta K^*(892)^+ \\ \eta K_0^*(1430)^+ \\ \eta K_2^*(1430)^+ \\ \eta(1295) K^+ \times B(\eta(1295) \rightarrow \\ \eta \pi \pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow \\ \eta \pi \pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow \\ K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow \\ K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow \\ K^*K) \\ f_1(1285) K^+ \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \\ \eta \pi \pi) \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 1.2 2.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{0}\overline{D}^{0}\pi^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \overline{D}^{*0}D^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \overline{D}^{*0}D^{0$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 | $\begin{array}{c})\times 10^{-4} \\)\times 10^{-6} \\)\times 10^{-6} \\ 3)\times 10^{-3} \\)\times 10^{-4} \\ \times 10^{-6} \\ \times 10^{-6} \\)\times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \times 10^{-5} \\)\times 10^{-4} \\)\times 10^{-5} \end{array}$ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 939 1141 939 1141 1141 1 | $\begin{array}{c} K^{0}\pi^{+} \\ K^{+}\pi^{0} \\ \eta'K^{+} \\ \eta'K^{+} \\ \eta'K^{*}(892)^{+} \\ \eta'K_{0}^{*}(1430)^{+} \\ \eta'K_{2}^{*}(1430)^{+} \\ \eta K^{*}(892)^{+} \\ \eta K_{0}^{*}(1430)^{+} \\ \eta K_{2}^{*}(1430)^{+} \\ \eta(1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K) \\ \eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ \eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K) \\ f_{1}(1285)K^{+} \\ f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K) \\ f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.9 4.1 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2426 |
| $\begin{array}{l} \eta_{c}(2S)K^{+} \\ \eta_{c}(2S)K^{+},\eta_{c}(2S) \rightarrow \\ K_{0}^{S}K^{\mp}\pi^{\pm} \\ J/\psi(1S)K^{+} \\ J/\psi(1S)K^{+}\pi^{+}\pi^{-} \\ h_{c}(1P)K^{+}\timesB(h_{c}(1P) \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\pi^{+}\pi^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}(892)^{+}\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{+}D^{-}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ D^{0}\overline{D^{0}}\pi^{0}) \\ X(3872)K^{+}\timesB(X \rightarrow \\ \overline{D^{*}}D^{0}D^{0}) \end{array}$ | | 3.4 3.4 1.016 8.1 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta'K^+ \\ \eta'K^+ \\ \eta'K^*(892)^+ \\ \eta'K^*(892)^+ \\ \eta'K^*_2(1430)^+ \\ \eta K^* \\ \eta K^*(892)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta (1295)K^+ \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ f_1(1285)K^+ \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow \eta \pi \pi) \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow K^*K) \\ \phi(1680)K^+ \times B(\phi(1680) \rightarrow K^*K) \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 0.16 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times $ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2406 2458 2420 2420 |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+,\eta_c(2S) \to \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\timesB(h_c(1P) \to \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \\ X(3872)K^+\timesB(X \to \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\timesB(X \to \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\timesB(X \to \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\timesB(X \to \\ \psi(2S)\gamma) \\ X(3872)K^+(892)^+\timesB(X \to \\ \psi(2S)\gamma) \\ X(3872)K^+\timesB(X \to \\ D^+D^-) \\ X(3872)K^+\timesB(X \to \\ D^+D^-) \\ X(3872)K^+\timesB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \to \\ D^+D^-) \\ X(3872)K^+\timesB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\toB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\toB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\toB(X \to \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^0\toB(X \to \\$ | | 3.4 3.4 1.016 8.1 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% S=1.4 | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta'K^+ \\ \eta'K^+ (892)^+ \\ \eta'K^*(892)^+ \\ \eta'K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta (1295)K^+ \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ f_1(1285)K^+ \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow \eta\pi\pi) \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow K^*K) \\ \phi(1680)K^+ \times B(\phi(1680) \rightarrow K^*K) \\ \omega K^+ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.8 | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^*(892)^+ \times B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^*(892)^+ \times B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^*(892)^+ \times B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \times B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \times B(X \rightarrow \\ D^+D^-) \\ X(3872) K^+ \times B(X \rightarrow \\ D^+D^-) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ \overline{D}^{*0} D^0) \\ X(3872) K^+ \times B(X \rightarrow \\ \overline{D}^{*0} D^0) \\ X(3872) K^+ \times B(X \rightarrow \\ \overline{D}^{*0} D^0) \\ X(3872) K^+ \times B(X (3872) \rightarrow J/\psi(1S) \eta) \\ X(3872)^+ K^0 \times B(X(3872)^+ -[uuu] \\ J/\psi(1S) \pi^+ \pi^0) \end{array}$ | | 3.4 3.4 1.016 8.1 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}_{0}(1430)^{+}$ $\eta'K^{*}_{2}(1430)^{+}$ $\eta K^{*}_{0}(1430)^{+}$ $\eta K^{*}_{0}(1430)^{+}$ $\eta K^{*}_{2}(1430)^{+}$ $\eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $f_{1}(1285)K^{+}$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow \eta\pi\pi)$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K)$ $\phi (1680)K^{+} \times B(\phi(1680) \rightarrow K^{*}K)$ ωK^{+} $\omega K^{*}(892)^{+}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2406 2458 2420 2420 |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+, \eta_c(2S) \rightarrow \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\times B(h_c(1P) \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^*(892)^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^*(892)^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^*(892)^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^*D^0D^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^*D^0D^0) \\ X(3872)K^+\times B(X(3872) \rightarrow J/\psi(1S)\eta) \\ X(3872)^+K^0\times B(X(3872)^+-[uuu] \\ J/\psi(1S)\pi^+\pi^0) \end{array}$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{+}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ ηK^{+} $\eta K^{*}(892)^{+}$ $\eta K^{*}(1430)^{+}$ $\eta K^{*}(1430)^{+}$ $\eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $f_{1}(1285)K^{+}$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow \eta\pi\pi)$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K)$ $\phi (1680)K^{+} \times B(\phi(1680) \rightarrow K^{*}K)$ ωK^{+} $\omega K^{*}(892)^{+}$ $\omega (K\pi)_{0}^{*+}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10^$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.8 | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+,\eta_c(2S) \to \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\times B(h_c(1P) \to \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \\ X(3872)K^+\times B(X \to J/\psi\gamma) \\ X(3872)K^+\times B(X \to J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \to J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \to J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \to \psi(2S)\gamma) \\ X(3872)K^+\times B(X \to \psi(2S)\gamma) \\ X(3872)K^+\times B(X \to D^0\overline{D}^0) \\ X(3872)^+K^0\times B(X(3872)^+ -[uuu]_1, uu]_2, uu]_3, uu]_4, uu]_4, uu]_4, uu]_4, uu]_5, u$ | | 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}_{0}(1430)^{+}$ $\eta'K^{*}_{2}(1430)^{+}$ $\eta K^{*}_{0}(1430)^{+}$ $\eta K^{*}_{0}(1430)^{+}$ $\eta K^{*}_{2}(1430)^{+}$ $\eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi)$ $\eta (1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $f_{1}(1285)K^{+}$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow \eta\pi\pi)$ $f_{1}(1420)K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K)$ $\phi (1680)K^{+} \times B(\phi(1680) \rightarrow K^{*}K)$ ωK^{+} $\omega K^{*}(892)^{+}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.8 | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi (1S) \pi^+ \pi^0) \\ X(4430)^+ K^0 \times B(X^+ \rightarrow \\ J/\psi \pi^+) \end{array}$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta' K^+ \\ \eta' K^+ (892)^+ \\ \eta' K_0^*(1430)^+ \\ \eta' K_2^*(1430)^+ \\ \eta K_1^* (892)^+ \\ \eta K_2^*(1430)^+ \\ \eta K_2^*(1430)^+ \\ \eta(1295) K^+ \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405) K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475) K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475) K^+ \times B(\eta(1475) \rightarrow K^*K) \\ f_1(1285) K^+ \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \eta\pi\pi) \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow K^*K) \\ \omega K^+ \\ \omega K^*(892)^+ \\ \omega (K\pi)_0^{*+} \\ \omega K_0^*(1430)^+ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.8 | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 2557 2503 — |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B($ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{2}^{*}(1430)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{2}^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta (1295) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta (1405) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta (1405) \rightarrow K^{*} K)$ $\eta (1475) K^{+} \times B(\eta (1475) \rightarrow K^{*} K)$ $f_{1}(1285) K^{+}$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow \eta \pi \pi)$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow K^{*} K)$ $\phi (1680) K^{+} \times B(\phi (1680) \rightarrow K^{*} K)$ ωK^{+} $\omega K^{*}(892)^{+}$ $\omega (K\pi)_{0}^{*}(1430)^{+}$ $\omega K_{2}^{*}(1430)^{+}$ $\omega K_{2}^{*}(1430)^{+}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) $ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ U(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=95% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta' K^+ \\ \eta' K^+ (892)^+ \\ \eta' K_0^*(1430)^+ \\ \eta' K_2^*(1430)^+ \\ \eta K_1^* (892)^+ \\ \eta K_2^*(1430)^+ \\ \eta K_2^*(1430)^+ \\ \eta (1295) K^+ \times B(\eta(1295) \rightarrow \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow \eta \pi \pi) \\ \eta (1405) K^+ \times B(\eta(1405) \rightarrow K^* K) \\ \eta (1475) K^+ \times B(\eta(1475) \rightarrow K^* K) \\ \eta (1475) K^+ \times B(\eta(1475) \rightarrow K^* K) \\ f_1(1285) K^+ \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow \eta \pi \pi) \\ f_1(1420) K^+ \times B(f_1(1420) \rightarrow K^* K) \\ \phi (1680) K^+ \times B(\phi(1680) \rightarrow K^* K) \\ \omega K^+ \\ \omega K_1^* (892)^+ \\ \omega (K\pi)_0^{*+} \\ \omega K_2^* (1430)^+ \\ \omega K_2^* (1430)^+ \\ \omega (980)^+ K^0 \times B(a_0(980)^+ \rightarrow K^* K) \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) $ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.8 | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 2557 2503 — |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S) \gamma) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B(X \rightarrow \\ D^0 \overline{D}^0 \pi^0) \\ X(3872) K^+ \times B($ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta'K^+ \\ \eta'K^+ \\ \eta'K^+ \\ \eta'K^*(892)^+ \\ \eta'K^*_0(1430)^+ \\ \eta'K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta (1295)K^+ \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ f_1(1285)K^+ \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow \eta\pi\pi) \\ f_1(1420)K^+ \times B(f_1(1420) \rightarrow K^*K) \\ \phi(1680)K^+ \times B(\phi(1680) \rightarrow K^*K) \\ \omega K^+ \\ \omega K^*(892)^+ \\ \omega (K\pi)^*_0^+ \\ \omega K^*_2(1430)^+ \\ \omega K^*_2(1430)^+ \\ \omega (980)^+ K^0 \times B(a_0(980)^+ \rightarrow \eta\pi^+) \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 0.16 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 2557 2503 — |
| $\begin{array}{l} \eta_c(2S) K^+ \\ \eta_c(2S) K^+, \eta_c(2S) \rightarrow \\ K_0^S K^\mp \pi^\pm \\ J/\psi(1S) K^+ \\ J/\psi(1S) K^+ \pi^+ \pi^- \\ h_c(1P) K^+ \times B(h_c(1P) \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \times B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \pi^+ \pi^-) \\ X(3872) K^+ \otimes B(X \rightarrow \\ J/\psi \gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ U(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+ \otimes B(X \rightarrow \\ D^0 \overline{D^0} \pi^0) \\ X(3872) K^+$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=95% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ $\eta(1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $f_{1}(1285) K^{+}$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow \eta \pi \pi)$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K)$ $\omega K^{*}K$ $\omega K^{*}K$ $\omega K^{*}K$ $\omega K^{*}(892)^{+}$ $\omega (K\pi)^{*}_{0}^{+}$ $\omega K^{*}_{0}(1430)^{+}$ $\omega K^{*}_{2}(1430)^{+}$ $a_{0}(980)^{+} K^{0} \times B(a_{0}(980)^{+} \rightarrow \eta \pi^{+})$ $a_{0}(980)^{0} K^{+} \times B(a_{0}(980)^{0} \rightarrow K^{+}K)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.8 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 0.16 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 2557 2503 — |
| $\eta_c(2S) K^+$ $\eta_c(2S) K^+, \eta_c(2S) \rightarrow K_0^* K^\mp \pi^\pm$ $J/\psi(1S) K^+$ $J/\psi(1S) K^+ \pi^+ \pi^ h_c(1P) K^+ \times B(h_c(1P) \rightarrow J/\psi \pi^+ \pi^-)$ $X(3872) K^+ \times B(X \rightarrow J/\psi \gamma)$ $X(3872) K^+ \times B(X \rightarrow \psi(2S) \gamma)$ $X(3872) K^+ \times B(X \rightarrow \psi(2S) \gamma)$ $X(3872) K^+ \times B(X \rightarrow D^0 \overline{D}^0)$ $X(3872) K^+ \times B(X \rightarrow D^0$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=95% CL=95% CL=95% | 1319 - 1683 1612 1401 1141 1141 939 1141 1141 1141 - - - - | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ $\eta(1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $f_{1}(1285) K^{+}$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow \eta \pi \pi)$ $f_{1}(1420) K^{+} \times B(f_{1}(1420) \rightarrow K^{*}K)$ $\omega K^{*}K$ $\omega K^{*}K$ $\omega K^{*}K$ $\omega K^{*}(892)^{+}$ $\omega (K\pi)^{*}_{0}^{+}$ $\omega K^{*}_{0}(1430)^{+}$ $\omega K^{*}_{2}(1430)^{+}$ $a_{0}(980)^{+} K^{0} \times B(a_{0}(980)^{+} \rightarrow \eta \pi^{+})$ $a_{0}(980)^{0} K^{+} \times B(a_{0}(980)^{0} \rightarrow K^{+}K)$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.2 9.1 2.9 1.3 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 3.9 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 0.16 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \times 10^{-6} \\ \pm 0.8 \) \times 10^{-6} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.5 \) \times 10^{-5} \\ \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2420 2344 2557 2503 — |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+, \eta_c(2S) \rightarrow \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\timesB(h_c(1P) \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\timesB(X \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+\timesB(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\timesB(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\timesB(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^0\overline{D}^0\pi^0) \\ X(3872)K^+\timesB(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^-D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^-D^-) \\ X(3872)K^+\timesB(X \rightarrow \\ D^-D^-) \\ X(3872)K^-\timesB(X \rightarrow \\ D^$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁴ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁵ × 10 ⁻⁶ × 10 ⁻⁶ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=90% CL=95% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 939 1141 1141 | $\begin{array}{c} K^0\pi^+ \\ K^+\pi^0 \\ \eta'K^+ \\ \eta'K^+ \\ \eta'K^*(892)^+ \\ \eta'K^*(892)^+ \\ \eta'K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta K^*_2(1430)^+ \\ \eta (1295)K^+ \times B(\eta(1295) \rightarrow \eta\pi\pi) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1405)K^+ \times B(\eta(1405) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1475)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \eta(1420)K^+ \times B(\eta(1475) \rightarrow K^*K) \\ \psi(1680)K^+ \times B(\eta(1420) \rightarrow K^*K) \\ \psi(1680)K^+ \times B(\eta(1430) \rightarrow K^*K) \\ \psi K^+ \\ \psi K^*_2(1430)^+ \\ \psi K^*_2(1430)^+ \\ \psi K^*_2(1430)^+ \\ \psi (1480)^0 K^+ \times B(\eta(180)^0 \rightarrow \eta\pi^0) \\ \end{array}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.2 1.38 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 3.9 2.5 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2406 2420 2344 2557 2503 — 2380 — |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+, \eta_c(2S) \rightarrow \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\times B(h_c(1P) \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \times B(X \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 2.9 1.4 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=95% CL=95% CL=95% CL=95% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi)$ $\eta(1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi)$ $\eta(1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta(1420)K^{+} \times B(\eta(1420) \rightarrow \eta\pi\pi)$ $\eta(1420)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1430)^{+}$ $\psi(143$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.2 1.38 2.0 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 3.9 2.5 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2344 2557 2503 — — 2380 — |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+, \eta_c(2S) \rightarrow \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\times B(h_c(1P) \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B($ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 2.9 1.4 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=95% CL=95% CL=95% | 1319 - 1683 1612 1401 1141 1141 939 1141 1141 1141 - - - - | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta' K^{+}$ $\eta' K^{*}(892)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta' K_{0}^{*}(1430)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta K_{0}^{*}(1430)^{+}$ $\eta (1295) K^{+} \times B(\eta(1295) \rightarrow \eta \pi \pi)$ $\eta (1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1405) K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta (1475) K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta (1420) K^{+} \times B(\eta(1420) \rightarrow \eta \pi \pi)$ $\eta (1680) K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ ωK^{+} $\omega K^{*}(892)^{+}$ $\omega (K\pi)_{0}^{*}$ $\omega K^{*}(892)^{+}$ $\omega (K\pi)_{0}^{*}$ $\omega K_{0}^{*}(1430)^{+}$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.2 2.9 1.3 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 3.9 2.5 1.01 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-6} \\ \pm 0.10 \) \times 10^{-6} \\ \pm 0.0 \) \times 10^{-6} \\ \pm 0.0 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.09 \) \times 10^{-5} \\ \pm 1.9 \) \times 10^{-5} \\ \pm 1.9 \) \times 10^{-6} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2420 2420 2344 2557 2503 — — — — |
| $\begin{array}{l} \eta_c(2S)K^+ \\ \eta_c(2S)K^+, \eta_c(2S) \rightarrow \\ K_0^SK^\mp\pi^\pm \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+ \\ J/\psi(1S)K^+\pi^+\pi^- \\ h_c(1P)K^+\times B(h_c(1P) \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+ \times B(X \rightarrow \\ J/\psi\pi^+\pi^-) \\ X(3872)K^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ J/\psi\gamma) \\ X(3872)K^+(892)^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ \psi(2S)\gamma) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872)K^+\times B(X \rightarrow \\ D^+D^-) \\ X(3872)K^+\times B(X \rightarrow \\ D^0D^0\pi^0) \\ X(3872$ | | 3.4 3.4 1.016 8.1 3.4 3.2 8.6 2.1 4.8 4 2.8 6.0 4.0 1.0 8.5 7.7 6.1 1.5 4.7 2.9 1.4 | ± 1.8 $+ 2.3$ $- 1.6$ ± 0.03 ± 1.3 ± 0.8 ± 0.4 ± 4 |) × 10 ⁻⁴) × 10 ⁻⁶ 3) × 10 ⁻³) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶) × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁶ × 10 ⁻⁵ | CL=90% S=1.1 CL=90% S=2.5 CL=90% CL=90% CL=90% CL=95% CL=95% CL=95% CL=95% CL=90% | 1319 - 1683 1612 1401 1141 1141 1141 939 1141 1141 1141 | $K^{0}\pi^{+}$ $K^{+}\pi^{0}$ $\eta'K^{+}$ $\eta'K^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta'K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta K^{*}(892)^{+}$ $\eta (1295)K^{+} \times B(\eta(1295) \rightarrow \eta\pi\pi)$ $\eta(1405)K^{+} \times B(\eta(1405) \rightarrow \eta\pi\pi)$ $\eta(1405)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1405) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta(1475)K^{+} \times B(\eta(1475) \rightarrow K^{*}K)$ $\eta(1420)K^{+} \times B(\eta(1420) \rightarrow \eta\pi\pi)$ $\eta(1420)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1680)K^{+} \times B(\eta(1420) \rightarrow K^{*}K)$ $\psi(1430)^{+}$ $\psi(143$ | | 2.31 1.29 7.06 4.8 5.2 2.8 2.4 1.93 1.2 2.9 1.3 2.9 4.1 3.4 6.7 7.4 2.8 2.4 2.1 3.9 2.5 1.01 | $\begin{array}{c} \pm 0.10 \) \times 10^{-5} \\ \pm 0.06 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-5} \\ \pm 0.25 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-6} \\ \pm 2.1 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.4 \) \times 10^{-5} \\ \pm 0.7 \) \times 10^{-6} \\ \times 10$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 2615 2528 2472 — 2346 2588 2534 — 2414 2455 2425 2425 2426 2420 2344 2557 2503 — — 2380 — |

| V+ = + | (+ co +0.21) +c | _5 | 2402 | $\phi K_2^*(1770)^+$ | < | 1.50 | × 10 ⁻⁵ | CL=90% | |
|---------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------------------|--------------|------------------------------------------------------------------------------------------------------------------|----------|--------------|--------------------------------------------------|------------------|-------------------|
| $K^+\pi^-\pi^+$ nonresonant | $(1.63 \begin{array}{c} +0.21 \\ -0.15 \end{array}) \times 10$ | | 2609 | $\phi K_2^{(1110)}$ $\phi K_2^*(1820)^+$ | < | 1.63 | × 10 ⁻⁵ | CL=90% | _ |
| $\omega(782)K^+$ | (6 ±9)×10 | | 2557 | $a_1^+ K^{*0}$ | < | 3.6 | $\times 10^{-6}$ | CL=90% | _ |
| $K^+ f_0(980) \times B(f_0(980) \to \pi^+ \pi^-)$ | $(9.4 {}^{+1.0}_{-1.2}) \times 10$ | -0 | 2522 | $\mathcal{K}^+\phi\phi$ | (| 5.0 ± | :1.2) × 10 ⁻⁶ | S=2.3 | 2306 |
| $f_2(1270)^0 K^+$ | $(1.07 \pm 0.27) \times 10$ | -6 | _ | $\eta'\eta'K^+$ | < | 2.5 | × 10 ⁻⁵ | CL=90% | 2338 |
| $f_0(1370)^0 K^+ \times$ | < 1.07 × 10 | | - | $\omega \phi K^+ X(1812) K^+ \times B(X \to \omega \phi)$ | < | 1.9 3.2 | $\times 10^{-6} \times 10^{-7}$ | CL=90% CL=90% | 2374 |
| $B(f_0(1370)^0 \to \pi^+\pi^-)$ | | _ | | $K^*(892)^+ \gamma$ | < (| | 0.18) × 10 ⁻⁵ | CL=90% | 2564 |
| $\rho^{0}(1450)K^{+} \times$ | < 1.17 × 10 | ⁻⁵ CL=90% | - | $K_1(1270)^{+'}\gamma$ | (| | 1.3) × 10 ⁻⁵ | | 2486 |
| $B(\rho^0(1450) \to \pi^+ \pi^-)$ $f_0(1500) K^+ \times B(f_0(1500) \to$ | (7 ±5)×10 | - 7 | 2398 | $\eta K^+ \gamma$ | (| | $(0.9) \times 10^{-6}$ | | 2588 |
| $\pi^+\pi^-)$ | (7 ±3) × 10 | | 2390 | η' K $^+$ γ | (| 2.9 + | $(0.9)^{1.0} \times 10^{-6}$ | | 2528 |
| $f_2'(1525) K^+ \times$ | < 3.4 × 10 | -6 CL=90% | 2392 | $\phi K^+ \gamma$ | (| | 0.4) × 10 ⁻⁶ | S=1.2 | 2516 |
| $B(f_2'(1525) \to \pi^+\pi^-)$ | | | | $K^+\pi^-\pi^+\gamma$ | (| | $(0.22) \times 10^{-5}$ | S=1.2 | 2609 |
| $K^+ ho^{\dot 0}$ | $(3.7 \pm 0.5) \times 10$ | -6 | 2559 | K^* (892) $^0\pi^+\gamma$ | (| 2.0 + | (0.7) 0.6 $) \times 10^{-5}$ | | 2562 |
| $K_0^*(1430)^0\pi^+$ | $(4.5 \begin{array}{c} +0.9 \\ -0.7 \end{array}) \times 10$ | −5 S=1.5 | 2445 | $\mathcal{K}^+ ho^0\gamma$ | < | 2.0 | $\times10^{-5}$ | CL=90% | 2559 |
| $K_2^*(1430)^0\pi^+$ | $(5.6 {}^{+2.2}_{-1.5}) \times 10^{-1}$ | -6 | 2445 | $K^+\pi^-\pi^+\gamma$ nonresonant | < | 9.2 | × 10 ⁻⁶ | CL=90% | 2609 |
| $K^*(1410)^0\pi^+$ | < 4.5 × 10 | | 2448 | $K^0\pi^+\pi^0\gamma$ | (| | $(0.5) \times 10^{-5} \times 10^{-5}$ | 61 000/ | 2609 |
| $K^*(1680)^0\pi^+$ | < 1.2 × 10 | | 235 8 | $K_1(1400)^+ \gamma \ K_2^*(1430)^+ \gamma$ | < (| 1.5 1.4 ± | × 10 ° :0.4) × 10 ⁻⁵ | CL=90% | 245 3 244 7 |
| $K^{+}\pi^{0}\pi^{0}$ | (1.62 ± 0.19) \times 10 | - 5 | 2610 | $K_2^{(1.68)} \gamma$ $K^*(1680)^+ \gamma$ | < | 1.9 | × 10 ⁻³ | CL=90% | 2360 |
| $f_0(980) K^+ \times B(f_0 \to \pi^0 \pi^0)$ | $(2.8 \pm 0.8) \times 10$ | | 2522 | $K_3^*(1780)^+\gamma$ | < | 3.9 | $\times 10^{-5}$ | CL=90% | 2341 |
| $K^-\pi^+\pi^+ \ K^-\pi^+\pi^+$ nonresonant | < 9.5 × 10 < 5.6 × 10 | | 2609 2609 | $K_{4}^{*}(2045)^{+}\gamma$ | < | 9.9 | $\times 10^{-3}$ | CL=90% | 2244 |
| $K_1(1270)^0\pi^+$ | < 5.6 × 10 < 4.0 × 10 | | 2484 | Light unfl | lavored | meson | modes | | |
| $K_1(1400)^0\pi^+$ | < 3.9 × 10 | | 2451 | $ ho^+\gamma$ | (| | 2.5) × 10 ⁻⁷ | | 2583 |
| $K^{0}\pi^{+}\pi^{0}$ | < 6.6 × 10 | | 2609 | $\pi^+\pi^0$ | (| 5.7 ± | | S=1.4 | 2636 |
| $K^0 \rho^+$ | (8.0 ±1.5) × 10 | | 2558 | $\pi^{+} \pi^{+} \pi^{-}$ | (| | :0.14) × 10 ⁻⁵ | | 2630 |
| $K^*(892)^+ \pi^+ \pi^- K^*(892)^+ \rho^0$ | $(7.5 \pm 1.0) \times 10$ $(4.6 \pm 1.1) \times 10$ | | 2557 2504 | $ ho^0 \pi^+ \\ \pi^+ f_0(980) 	imes B(f_0(980) 	o$ | (| 8.3 ± | $(1.2) \times 10^{-6} \times 10^{-6}$ | CL=90% | 2581 2545 |
| $K^*(892)^+ f_0(980)$ | (4.2 ±0.7)×10 | | 2466 | $\pi^+\pi^-)$ | | 1.5 | × 10 | CL_90/0 | 2545 |
| $a_1^+ K^0$ | (3.5 ±0.7)×10 | | - | $\pi^+ f_2(1270)$ | (| 1.6 + | $(0.7 \ 0.4) \times 10^{-6}$ | | 2484 |
| $b_1^+ K^0 \times B(b_1^+ \to \omega \pi^+)$ | $(9.6 \pm 1.9) \times 10$ | | - | | | | | | |
| $K^*(892)^0 \rho^+$ | $(9.2 \pm 1.5) \times 10$ | | 2504 | $ ho(1450)^0\pi^+	imesB(ho^0	o \pi^+\pi^-)$ | (| 1.4 + | $(0.6 \ 0.9) \times 10^{-6}$ | | 2434 |
| $K_1(1400) + \rho^0$ | < 7.8 × 10 | | 2387 | $f_0(1370)\pi^+ \times B(f_0(1370) \rightarrow$ | < | 4.0 | $\times 10^{-6}$ | CL=90% | 2460 |
| $K_{2}^{*}(1430)^{+}\rho^{0}$ $b_{1}^{0}K^{+}\times B(b_{1}^{0}\to \omega\pi^{0})$ | $< 1.5 \times 10$ $(9.1 \pm 2.0) \times 10$ | | 2381 | $\pi^+\pi^-)$ | | | | ,* | |
| $b_1^+ K^{*0} \times B(b_1^+ \to \omega \pi^+)$ | < 5.9 × 10 | | _ | $f_0(500)\pi^+ \times B(f_0(500) \rightarrow$ | < | 4.1 | $\times 10^{-6}$ | CL=90% | _ |
| $b_1^0 K^{*+} \times B(b_1^0 \to \omega \pi^0)$ | < 6.7 × 10 | | _ | $\pi^+\pi^-)$ | | | 1.5 | | |
| $K^{+}\overline{K}^{0}$ | (1.36 ±0.27)×10 | | 2593 | $\pi^+\pi^-\pi^+$ nonresonant | (| 5.3 + | $(1.5 \ 1.1) \times 10^{-6}$ | | 2630 |
| $\overline{K}^0 K^+ \pi^0$ | < 2.4 × 10 | ⁻⁵ CL=90% | 2578 | $\pi^{+} \pi^{0} \pi^{0}$ | < | 8.9 | × 10 ⁻⁴ | CL=90% | 2631 |
| $K^+ K^0_S K^0_S$ | (1.15 ± 0.13) \times 10 | | 2521 | $ ho^+ \pi^0 \ \pi^+ \pi^- \pi^+ \pi^0$ | (| 1.09 ± | $(0.14) \times 10^{-5} \times 10^{-3}$ | CL=90% | 2581 2622 |
| $K_S^0 K_S^0 \pi^+$ | < 5.1 × 10 | | 2577 | $\rho^+\rho^0$ | < (| | × 10 -5 | CL=90% | 2523 |
| $K^+K^-\pi^+ K^+K^-\pi^+$ nonresonant | $(5.0 \pm 0.7) \times 10$ $< 7.5 \times 10$ | | 2578 2578 | $\rho^{+} f_{0}(980) \times B(f_{0}(980) \rightarrow$ | < | 2.0 | ×10 ⁻⁶ | CL=90% | 2486 |
| $K^+ \overline{K}^* (892)^0$ | < 1.1 × 10 | | 2540 | $(\pi^{+}\pi^{-})$ | | | _ | | |
| $K^{+}\overline{K}_{0}^{*}(1430)^{0}$ | < 2.2 × 10 | | 2421 | $a_1(1260)^+\pi^0 \ a_1(1260)^0\pi^+$ | (| | $(0.7) \times 10^{-5}$ | | 2494 |
| $K^+K^+\pi^-$ | < 1.6 × 10 | | 2578 | $\omega \pi^+$ | (| | $(0.6) \times 10^{-5}$ $(0.5) \times 10^{-6}$ | | 2494 2580 |
| $K^+K^+\pi^-$ nonresonant $K^{*+}\pi^+K^-$ | < 8.79 × 10 | | 2578 | $\omega \rho^+$ | (| | :0.21) × 10 ⁻⁵ | | 2522 |
| $K^*(892)^+ K^*(892)^0$ | $< 1.18 \times 10$ $(1.2 \pm 0.5) \times 10$ | | 2524 2484 | $\eta \pi^+$ | (| 4.02 ± | $(0.27) \times 10^{-6}$ | | 2609 |
| $K^{*+}K^{+}\pi^{-}$ | < 6.1 × 10 | | 2524 | $\eta \rho^+$ | (| | 2.9) × 10 ⁻⁶ | S=2.8 | 2553 |
| $K^+K^-K^+$ | (3.37 ± 0.22) \times 10 | _ | 2523 | $\eta'\pi^+ \ \eta' ho^+$ | (| | $(0.9) \times 10^{-6}$ $(2.2) \times 10^{-6}$ | S=1.9 | 2551 2492 |
| $K^{+}\phi$ | (8.3 ±0.7)×10 | | 2516 | $\phi\pi^+$ | < ' | 2.4 | × 10 ⁻⁷ | CL=90% | 2539 |
| $f_0(980) K^+ \times B(f_0(980) \to K^+ K^-)$ | < 2.9 × 10 | ^{−6} CL=90% | 2522 | ϕho^+ | < | 3.0 | $\times 10^{-6}$ | CL=90% | 2480 |
| $a_2(1320) K^+ \times$ | < 1.1 × 10 | -6 CL=90% | 2449 | $a_0(980)^0 \pi^+ \times B(a_0(980)^0 \rightarrow$ | < | 5.8 | $\times 10^{-6}$ | CL=90% | - |
| $B(a_2(1320) \to K^+ K^-)$ | | | | $\eta \pi^{0}$) $a_{0}(980)^{+} \pi^{0} \times B(a_{0}^{+} \to \eta \pi^{+})$ | | 1.4 | × 10 ⁻⁶ | CL=90% | |
| $f_2'(1525) K^+ \times$ | < 4.9 × 10 | ^{−6} CL=90% | 2392 | $\pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}$ | < | 8.6 | × 10 -4 | CL=90% CL=90% | 2608 |
| $B(f'_2(1525) \to K^+K^-)$ | , | 6 | | $\rho^0 a_1(1260)^+$ | < | 6.2 | × 10 ⁻⁴ | CL=90% | 2433 |
| $X_0(1550) K^+ \times B(X_0(1550) \to K^+ K^-)$ | $(4.3 \pm 0.7) \times 10$ | -0 | _ | $\rho^0 a_2(1320)^+$ | < | 7.2 | ×10 ⁻⁴ | CL=90% | 2410 |
| $\phi(1680) K^+ \times B(\phi(1680) \rightarrow$ | < 8 × 10 | -7 CL=90% | 2344 | $b_1^0 \pi^+ \times B(b_1^0 \to \omega \pi^0)$ | (| | :2.0) × 10 ⁻⁶ | | _ |
| K+K-) | | | | $b_1^{\hat{+}} \pi^0 \times B(b_1^{\hat{+}} \to \omega \pi^+)$ | < | 3.3 | × 10 ⁻⁶ | CL=90% | _ |
| $f_0(1710) K^+ \times B(f_0(1710) \to$ | $(1.7 \pm 1.0) \times 10$ | -6 | 2331 | $\pi^{+} \pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0}$ $b_{1}^{+} \rho^{0} \times B(b_{1}^{+} \to \omega \pi^{+})$ | < | 6.3 | $\times 10^{-3} \times 10^{-6}$ | CL=90% | 2592 |
| K+ K-) | .00 | r | | $a_1(1260)^+ a_1(1260)^0$ | < | 5.2 1.3 | × 10 ° | CL=90% CL=90% | 2336 |
| $K^+K^-K^+$ nonresonant | $(2.8 \begin{array}{c} +0.9 \\ -1.6 \end{array}) \times 10$ | ⁻⁵ S=3.3 | 2523 | $b_1^0 \rho^+ \times B(b_1^0 \to \omega \pi^0)$ | | 3.3 | × 10 ⁻⁶ | | |
| K*(892)+ K+ K- | $(3.6 \pm 0.5) \times 10$ | | 2466 | 1 | | | | | |
| $K^*(892)^+ \phi \ \phi (K\pi)_0^{*+}$ | (10.0 ± 2.0) \times 10 | | | Charged | particle | : (n-') I | modes | | |
| ULL DOUGLE | (00 110) 40 | - | _ | $h^{\pm}=K^{\pm} \text{ or } \pi^{\pm}$ | | | | | |
| | $(8.3 \pm 1.6) \times 10$ | _ | 2375 | | | | | | |
| $\phi K_1(1270)^+$ | $(6.1 \pm 1.9) \times 10$ | -6 | 2375 2339 | $h^{\perp} \equiv K^{\perp} \text{ or } \pi^{\perp}$ $h^{+} \pi^{0}$ | (| 1.6 + | $(0.7 \ 0.6) \times 10^{-5}$ | | 2636 |
| $\phi K_1(1270)^+ \ \phi K_1(1400)^+ \ \phi K^*(1410)^+$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | -6 -6 CL=90% -6 CL=90% | | $h^+ \pi^0$ | | | | | |
| $\phi K_1(1270)^+ \ \phi K_1(1400)^+$ | $(6.1 \pm 1.9) \times 10$ < 3.2×10 | -6 -6 CL=90% -6 CL=90% | 2339 | | | | $^{0.27}_{0.24}$) $\times 10^{-5}$ | CL=90% | 2636 2580 — |

| | Baryon m | odes | | | | $K^*(892)^+ e^- \mu^+$ LF < 9.9 $\times 10^{-7}$ CL=90% 256 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------------------------------------------------|----------------------------------------|----------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------|
| $\rho \overline{\rho} \pi^+$ | (: | 1.62 ±0.20 | | | 2439 | $K^*(892)^+ e^{\pm} \mu^{\mp}$ LF < 1.4 $\times 10^{-6}$ CL=90% 256 |
| $p\overline{p}\pi^+$ nonresonant | | 5.3 | × 10 ⁻⁵ | CL=90% | 2439 | $\pi^- e^+ e^+$ L < 1.6 × 10 ⁻⁶ CL=90% 263 |
| $ \frac{\overline{p}K^+}{\Theta(1710)^{++}\overline{p}\times} $ | , | | $) \times 10^{-6} \times 10^{-8}$ | S=1.5 | 2348 | $\pi^-\mu^+\mu^+$ |
| $B(\Theta(1710)^{++} \rightarrow I$ | | 9.1 | × 10 ° | CL=90% | _ | $\pi^- e^+ \mu^+$ L < 1.3 × 10 ⁻⁶ CL=90% 263 $\rho^- e^+ e^+$ L < 2.6 × 10 ⁻⁶ CL=90% 258 |
| $f_J(2220) K^+ \times B(f_J(22))$ | | 1.1 | $\times 10^{-7}$ | CL=90% | 2135 | $\rho^- \mu^+ \mu^+$ L < 5.0 ×10 ⁻⁶ CL=90% 257 |
| $p\overline{p}$) | / [] - | | | /* | | $\rho^-e^+\mu^+$ L < 3.3 × 10 ⁻⁶ CL=90% 258 |
| $p\overline{\Lambda}(1520)$ | < 1 | 1.5 | $\times 10^{-6}$ | CL=90% | 2322 | $K^-e^+e^+$ L < 1.0 × 10 ⁻⁶ CL=90% 261 |
| $p\overline{p}K^+$ nonresonant | < 8 | 3.9 | $\times 10^{-5}$ | CL = 90% | 2348 | $K^-\mu^+\mu^+$ L < 4.1 $\times 10^{-8}$ CL=90% 261 |
| <u></u> p K*(892) ⁺ | (3 | $\begin{array}{cc} +0.8 \\ -0.7 \end{array}$ | $) \times 10^{-6}$ | | 2215 | $K^-e^+\mu^+$ L < 2.0 × 10 ⁻⁶ CL=90% 261 |
| $f_J(2220) K^{*+} \times B(f_J(222))$ | 0) → < | 7.7 | × 10 ⁻⁷ | CL=90% | 205 9 | $K^*(892)^-e^+e^+$ L < 2.8 ×10 ⁻⁶ CL=90% 256 |
| (\overline{p}) | , | | | | | $K^*(892)^-\mu^+\mu^+$ L < 8.3 $\times 10^{-6}$ CL=90% 256 $K^*(892)^-e^+\mu^+$ L < 4.4 $\times 10^{-6}$ CL=90% 256 |
| o <u> </u> | < 3 | 3.2 | $\times 10^{-7}$ | CL=90% | 2430 | $D^-e^+e^+$ L < 2.6 ×10 ⁻⁶ CL=90% 230 |
| $\sigma \overline{\Lambda} \gamma$ | (2 | $\begin{array}{ccc} 2.4 & +0.5 \\ -0.4 & -0.4 \end{array}$ | $) \times 10^{-6}$ | | 2430 | $D^-e^+\mu^+$ L < 1.8 ×10 ⁻⁶ CL=90% 230 |
| $o \overline{\Lambda} \pi^0$ | | | | | 0400 | $D^-\mu^+\mu^+$ L < 1.1 ×10 ⁻⁶ CL=90% 230 |
| | (- | $\begin{array}{cc} 3.0 & +0.7 \\ -0.6 \end{array}$ |) × 10 ⁻⁶ | | 2402 | $\Lambda_{0}^{0}\mu^{+}$ L,B < 6 $\times 10^{-8}$ CL=90% |
| $0 \overline{\Sigma} (1385)^0$ | | 1.7 | $\times 10^{-7}$ | CL=90% | 2362 | $\Lambda^0 e^+$ L,B < 3.2 × 10 ⁻⁸ CL=90% |
| $\Delta^{+}\overline{\Lambda}_{ ho}$ $\overline{\Sigma}_{\gamma}$ | | 3.2 1.6 | $\times 10^{-7} \times 10^{-6}$ | CL=90% CL=90% | _ 2413 | $\overline{\Lambda}^0 \mu^+$ |
| $p \frac{Z}{\Lambda} \pi^+ \pi^-$ | | |) × 10 ⁻⁶ | CL=90% | 2367 | $\overline{\Lambda}{}^0 e^+$ L,B < 8 × 10 ⁻⁸ CL=90% |
| $p \overline{\Lambda} \rho^0$ | , | |) × 10 ⁻⁶ | | 2214 | |
| $p \frac{1}{\Lambda} f_2(1270)$ | , | |) × 10 ⁻⁶ | | 2026 | $I(J^P) = \frac{1}{2}(0^-)$ |
| $\Lambda \underline{\Lambda} \pi^{+}$ | < ' | 9.4 | $\times 10^{-7}$ | CL=90% | 2358 | |
| Λ Λ Κ ⁺ | (: | | $) \times 10^{-6}$ | | 2251 | I, J, P need confirmation. Quantum numbers shown are quark-model |
| Λ <u>Λ</u> Κ*+ | (: | $\begin{array}{ccc} 2.2 & +1.2 \\ -0.9 \end{array}$ | $) \times 10^{-6}$ | | 2098 | predictions. |
| $\overline{\Delta}{}^0 p$ | < 1 | 1.38 | $\times 10^{-6}$ | CL=90% | 2403 | Mass $m_{B^0} = 5279.58 \pm 0.17 \; { m MeV}$ |
| $\Delta^{++}\overline{p}$ | < 1 | 1.4 | $\times 10^{-7}$ | CL=90% | 2403 | $m_{B^0} - m_{B^\pm} = 0.32 \pm 0.06 \text{ MeV}$ |
| $D^+ \rho \overline{\rho}$ | < 1 | 1.5 | $\times 10^{-5}$ | CL=90% | 1860 | Mean life $	au_{B^0} = (1.519 \pm 0.007) 	imes 10^{-12} 	ext{ s}$ |
| $D^*(2010)^+ p \overline{p}$ | | 1.5 | × 10 ⁻⁵ | CL=90% | 1786 | $c\tau = 455.4 \ \mu\text{m}$ |
| p <u>7</u> 0 <u>D</u> 0 <u>4</u> 0 <u>D</u> *(2227)0 | , | 1.43 ±0.32 | | | _ | $	au_{B^+}/	au_{B^0} = 1.079 \pm 0.007$ (direct measurements) |
| $p \overline{\Lambda}{}^{0} \overline{D}^{*} (2007)^{0}$ | < 5 | | $\times 10^{-5}$) $\times 10^{-4}$ | CL=90% | 1000 | B^0 - $\overline{B^0}$ mixing parameters |
| $\overline{\Lambda}_c^- p \pi^+ \over \overline{\Lambda}_c^- \Delta (1232)^{++}$ | • | | × 10 ⁻⁵ | CL=90% | 1980 1928 | $\chi_d = 0.1862 \pm 0.0023$ |
| $\overline{\Lambda}_c^- \Delta_X(1600)^{++}$ | | 1.9 5.9 ±1.9 |) × 10 ⁻⁵ | CL=90% | 1920 | $\Delta m_{B^0} = m_{B_H^0} - m_{B_I^0} = (0.507 \pm 0.004) \times 10^{12} \ h \ s^{-1}$ |
| $\overline{\Lambda}_c^- \Delta_X^- (2420)^{++}$ | , | |) × 10 ⁻⁵ | | | $= (3.337 \pm 0.033) \times 10^{-10} \text{ MeV}$ |
| $(\overline{\Lambda}_c^- p)_s \pi^+$ | • | |) × 10) × 10 ⁻⁵ | | _ | $x_d = \Delta m_{B^0} / \Gamma_{B^0} = 0.770 \pm 0.008$ |
| $\frac{(N_c p)_s n}{\Sigma_c (2520)^0 p}$ | [www] (. | | × 10 ⁻⁶ | CL=90% | 1904 | $Re(\lambda_{CP} / \lambda_{CP}) Re(z) = 0.01 \pm 0.05$ |
| $\frac{\Sigma_{c}(2820)}{\Sigma_{c}(2800)^{0}} p$ | | |) × 10 ⁻⁵ | CL _ 70/0 | - | $\Delta\Gamma$ Re(z) = -0.007 ± 0.004 |
| $\overline{\Lambda}_c^- p \pi^+ \pi^0$ | , | | $) \times 10^{-3}$ | | 1935 | $Re(z) = (2 \pm 5) \times 10^{-2}$ |
| $\overline{\Lambda}_{c}^{-} p \pi^{+} \pi^{+} \pi^{-}$ | (2 | 2.2 ±0.7 | $) \times 10^{-3}$ | | 1880 | $lm(z) = (-0.8 \pm 0.4) \times 10^{-2}$ |
| $\frac{\pi^{c}}{\Lambda_{c}} p \pi^{+} \pi^{+} \pi^{-} \pi^{0}$ | < | 1.34 | % | CL=90% | 1823 | CP violation parameters |
| $\Lambda_c^+ \Lambda_c^- K^+$ | (8 | 3.7 ±3.5 | $) \times 10^{-4}$ | | _ | ${\sf Re}(\epsilon_{B^0})/(1+ \epsilon_{B^0} ^2)=(-0.8\pm0.8)	imes 10^{-3}$ |
| $\overline{\Sigma}_c(2455)^0 p$ | (: | 3.7 ±1.3 | $) \times 10^{-5}$ | | 1938 | $A_{T/CP} = 0.005 \pm 0.018$ |
| $\overline{\Sigma}_c(2455)^0 p \pi^0$ | (4 | 1.4 ±1.8 | $) \times 10^{-4}$ | | 1896 | $A_{CP}(B^0 \to D^*(2010)^+ D^-) = 0.02 \pm 0.04$ |
| $\sum_{c} (2455)^{0} p \pi^{-} \pi^{+}$ | * | |) × 10 ⁻⁴ | | 1845 | $A_{CP}(B^0 \to K^+\pi^-) = -0.097 \pm 0.012$ |
| $\frac{\overline{\Sigma}_c(2455)^{}p\pi^+\pi^+}{4}$ | | 2.8 ±1.2 | | CI 000/ | 1845 | $A_{CP}(B^0 \to \eta' K^*(892)^0) = 0.02 \pm 0.23$ |
| $\frac{\overline{\Lambda}_{c}(2593)^{-}/\overline{\Lambda}_{c}(2625)^{-}p}{\overline{\Xi}_{c}^{0}\Lambda_{c}^{+}\times B(\overline{\Xi}_{c}^{0}\to \overline{\Xi}^{+}\pi^{-})}$ | π^{+} < 1 | 1.9 3.0 ±1.1 | × 10 ⁻⁴ | CL=90% | 1144 | $A_{CP}(B^0 \to \eta' K_0^* (1430)^0) = -0.19 \pm 0.17$ |
| $\overline{\Xi}_c^0 \Lambda_c^+ \times B(\overline{\Xi}_c^0 \to AK^+)$ | | 2.6 ±1.1 | | C 11 | 1144 1144 | $A_{CP}(B^0 \to \eta' K_2^0(1430)^0) = 0.14 \pm 0.18$ |
| $-c^{\prime\prime}c^{\prime} \times D(-c^{\prime} \rightarrow \Lambda \Lambda^{\prime})$ | ") (. | 2.0 ±1.1 |) × 10 | S=1.1 | 1144 | $A_{CP}(B^0 \to \eta K^*(892)^0) = 0.19 \pm 0.05$ |
| Lepton Family number (| | | | | | $A_{CP}(B^0 \to \eta K_0^*(1430)^0) = 0.06 \pm 0.13$ |
| violating modes, or/ | | | | • | | $A_{CP}(B^0 \to \eta K_2^*(1430)^0) = -0.07 \pm 0.19$ |
| $\pi^{+} \ell^{+} \ell^{-}$ | | 4.9 | × 10 ⁻⁸ | | | $A_{CP}(B^0 \to b_1 \bar{K}^+) = -0.07 \pm 0.12$ |
| $\pi^+ e^+ e^- \\ \pi^+ \mu^+ \mu^-$ | | 8.0 | $\times 10^{-8} \times 10^{-8}$ | | 2638 | $A_{CP}(B^0 \to \omega K^{*0}) = 0.45 \pm 0.25$ |
| $\pi^+ \mu^+ \mu^- \pi^+ \nu \overline{\nu}$ | | 6.9 1.0 | × 10 ° × 10 −4 | | 2634 2638 | $A_{CP}(B^0 \to \omega(K\pi)_0^{*0}) = -0.07 \pm 0.09$ |
| $K^+\ell^+\ell^-$ | | |) × 10 ⁻⁷ | SZ = 70 /0 | 2617 | $A_{CP}(B^0 \to \omega K_2^*(1430)^0) = -0.37 \pm 0.17$ |
| $K^+ e^+ e^-$ | | |) × 10 ⁻⁷ | | 2617 | $A_{CP}(B^0 \to K^+\pi^-\pi^0) = (0 \pm 6) \times 10^{-2}$ |
| $K^+\mu^+\mu^-$ | | | $) \times 10^{-7}$ | | 2612 | $A_{CP}(B^0 \to \rho^- K^+) = 0.20 \pm 0.11$ |
| $K^+ \overline{\nu} \nu$ | | 1.3 | $\times 10^{-5}$ | CL=90% | 2617 | $A_{CP}(B^0 \to \rho(1450)^- K^+) = -0.10 \pm 0.33$ |
| $\rho^+ \nu \overline{\nu}$ | | 1.5 | × 10 ⁻⁴ | | 2583 | $A_{CP}(B^0 	o ho(1700)^- K^+) = -0.4 \pm 0.6$ $A_{CP}(B^0 	o K^+ \pi^- \pi^0 \text{nonresonant}) = 0.10 \pm 0.18$ |
| $K^*(892)^+ \ell^+ \ell^-$ | | 1.29 ± 0.21 | | | 2564 | $A_{CP}(B^0	o K^+\pi^-\pi^0$ nonresonant) = 0.10 \pm 0.18 $A_{CP}(B^0	o K^0\pi^+\pi^-) = -0.01 \pm 0.05$ |
| K*(892)+ e+ e- | | $1.55 \begin{array}{l} +0.40 \\ -0.31 \end{array}$ | | | 2564 | $A_{CP}(B^0 \to K^0\pi^+\pi^-) = -0.01 \pm 0.05$ $A_{CP}(B^0 \to K^*(892)^+\pi^-) = -0.22 \pm 0.06$ |
| $K^*(892)^+ \mu^+ \mu^-$ | B1 (| 1.07 ± 0.22 | | | 2560 | $A_{CP}(B^0 \to K_0)^{*+}\pi^-) = -0.22 \pm 0.00$ $A_{CP}(B^0 \to (K\pi)^{*+}\pi^-) = 0.09 \pm 0.07$ |
| $K^*(892)^+ \nu \overline{\nu}$ | B1 < | 8 | × 10 ⁻⁵ | | 2564 | $A_{CP}(B^0 	o (K\pi)_0^{*+}\pi^-) = 0.09 \pm 0.07 \ A_{CP}(B^0 	o (K\pi)_0^{*0}\pi^0) = -0.15 \pm 0.11$ |
| | | 6.4 | × 10 ⁻³ | | 2637 | $A_{CP}(B^0 \to (K^*)_0^{-1} K^0) = -0.15 \pm 0.11$ $A_{CP}(B^0 \to K^{*0} \pi^0) = -0.15 \pm 0.13$ |
| $\pi^{+} e^{+} \mu^{-}$ | | 6.4 | × 10 ⁻³ | | 2637 | $A_{CP}(B^0 \to K^-K^-) = -0.13 \pm 0.13$ $A_{CP}(B^0 \to K^*(892)^0 \pi^+ \pi^-) = 0.07 \pm 0.05$ |
| $\pi^{+} \stackrel{e^{+}}{e^{-}} \stackrel{\mu^{-}}{\mu^{+}} \pi^{+} \stackrel{e^{-}}{e^{-}} \stackrel{\mu^{+}}{\mu^{+}}$ | | 1.7 | ×10 ⁻⁷ ×10 ⁻⁸ | | | $A_{CP}(B^0 \to K^*(892)^0 \rho^0) = 0.09 \pm 0.19$ |
| $\pi^{+} \stackrel{e^{+}}{e^{-}} \stackrel{\mu^{-}}{\mu^{+}} = \mu^{+} = \mu^{+} = \mu^{\pm}$ | | 0.1 | V 111 V | CL=90% | 2615 | $A_{CP}(B^0 \to K^{*0} f_0(980)) = -0.17 \pm 0.28$ |
| $\pi^{+}\stackrel{\cdot}{e^{+}}\stackrel{\mu^{-}}{\mu^{-}} \\ \pi^{+}\stackrel{e^{-}}{e^{-}}\stackrel{\mu^{+}}{\mu^{+}} \\ \pi^{+}\stackrel{e^{\pm}}{e^{+}}\stackrel{\mu^{-}}{\mu^{-}}$ | LF < | 9.1 | | | 2615 | $N_{i}(P_{i}D_{i}) = 0.11 \pm 0.20$ |
| $\pi^{+} \stackrel{\cdot}{e^{+}} \mu^{-}$ $\pi^{+} \stackrel{\cdot}{e^{-}} \mu^{+}$ $\pi^{+} \stackrel{\cdot}{e^{\pm}} \mu^{\mp}$ $K^{+} \stackrel{\cdot}{e^{+}} \mu^{-}$ $K^{+} \stackrel{\cdot}{e^{-}} \mu^{+}$ | LF < | 1.3 | $\times 10^{-7}$ | CL=90% | 2615 2615 | |
| $\pi^{+} \stackrel{\cdot}{e}^{+} \mu^{-}$ $\pi^{+} \stackrel{\cdot}{e}^{-} \mu^{+}$ $\pi^{+} \stackrel{\cdot}{e}^{\pm} \mu^{\mp}$ $K^{+} \stackrel{\cdot}{e}^{+} \mu^{-}$ $K^{+} \stackrel{\cdot}{e}^{-} \mu^{+}$ $K^{+} \stackrel{\cdot}{e}^{\pm} \mu^{\mp}$ | LF < LF < LF < | | $\times 10^{-7} \times 10^{-8}$ | CL=90% CL=90% | 2615 2615 2298 | $A_{CP}(B^0 \to K^*(892)^0 K^+ K^-) = 0.01 \pm 0.05$ $A_{CP}(B^0 \to a_1^- K^+) = -0.16 \pm 0.12$ |
| $\pi^{+} \stackrel{\cdot}{e^{+}} \mu^{-}$ $\pi^{+} \stackrel{\cdot}{e^{-}} \mu^{+}$ $\pi^{+} \stackrel{\cdot}{e^{\pm}} \mu^{\mp}$ $K^{+} \stackrel{\cdot}{e^{+}} \mu^{-}$ $K^{+} \stackrel{\cdot}{e^{-}} \mu^{+}$ | LF < LF < LF < | 1.3 9.1 | $\times 10^{-7}$ | CL=90% CL=90% CL=90% | 2615 | $A_{CP}(B^0 \to K^*(892)^0 K^+ K^-) = 0.01 \pm 0.05$ |

 $S_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.4 \pm 0.5 \quad (S = 2.5)$

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C_{K_S^0 \pi^0 \gamma}(B^0 \to K_S^0 \pi^0 \gamma) = 0.36 \pm 0.33
A_{CP}(B^0 \to K^*(892)^0 K^- \pi^+) = 0.2 \pm 0.4
A_{CP}(B^0 \to \phi(K\pi)_0^{*0}) = 0.20 \pm 0.15
                                                                                                                                       S_{K_S^0 \pi^0 \gamma}(B^0 \to K_S^0 \pi^0 \gamma) = -0.8 \pm 0.6
A_{CP}(B^0 \to \phi K_2^*(1430)^0) = -0.08 \pm 0.13
                                                                                                                                       C_{K^{*0}\gamma} (B^0 \to K^*(892)^0 \gamma) = -0.04 \pm 0.16 (S = 1.2)
A_{CP}(B^0 \to K^*(892)^0 \gamma) = -0.016 \pm 0.023

A_{CP}(B^0 \to K^*_2(1430)^0 \gamma) = -0.08 \pm 0.15
                                                                                                                                       S_{K^{*0}\gamma}(B^0 \to K^*(892)^0\gamma) = -0.15 \pm 0.22
A_{CP}(B^0 \to \rho^+ \pi^-) = 0.08 \pm 0.12 \quad (S = 2.0)
                                                                                                                                       C_{\eta K^0 \gamma} (B^0 \to \eta K^0 \gamma) = -0.3 \pm 0.4
A_{CP}(B^0 \to \rho^- \pi^+) = -0.16 \pm 0.23 \quad (S = 1.7)
                                                                                                                                       S_{\eta K^0 \gamma} (B^0 \to \eta K^0 \gamma) = -0.2 \pm 0.5
A_{CP}(B^0 \to a_1(1260)^{\pm}\pi^{\mp}) = -0.07 \pm 0.07
                                                                                                                                       C_{K^0\phi\gamma}^{\phantom{0}\phantom{0}\phantom{0}\phantom{0}\phantom{0}}(B^0\to K^0\phi\gamma)=-0.3\pm0.6
A_{CP}(B^0 \to b_1 \pi^+) = -0.05 \pm 0.10
                                                                                                                                       S_{K^0 \phi \gamma} (B^0 \to K^0 \phi \gamma) = 0.7^{+0.7}_{-1.1}
A_{CP}(B^0 \to p\overline{p}K^*(892)^0) = 0.05 \pm 0.12
                                                                                                                                      \begin{array}{ll} K_{0}^{0}\rho\gamma & \text{for } \gamma \\ C(B^{0} \to K_{S}^{0}\rho^{0}\gamma) = -0.05 \pm 0.19 \\ S(B^{0} \to K_{S}^{0}\rho^{0}\gamma) = 0.11 \pm 0.34 \\ C(B^{0} \to \rho^{0}\gamma) = 0.4 \pm 0.5 \end{array}
A_{CP}(B^0 \to p \overline{\Lambda} \pi^-) = 0.04 \pm 0.07
A_{CP}(B^0 \to K^{*0} \ell^+ \ell^-) = -0.05 \pm 0.10
A_{CP}(B^0 \to K^{*0} e^+ e^-) = -0.21 \pm 0.19
                                                                                                                                      S(B^0 \to \rho^0 \gamma) = -0.8 \pm 0.7
A_{CP}(B^0 \to K^{*0} \mu^+ \mu^-) = 0.00 \pm 0.15
                                                                                                                                       C_{\pi\pi} (B_{\perp}^{0} \rightarrow \pi^{+} \pi^{-}) = -0.38 \pm 0.17 \text{ (S = 2.6)}
C_{D^{*-}D^{+}} (B^{0} \rightarrow D^{*}(2010)^{-}D^{+}) = 0.07 \pm 0.14
                                                                                                                                       S_{\pi\pi} (B^0 \rightarrow \pi^+\pi^-) = -0.61 \pm 0.08
S_{D^{*-}D^{+}} (B^{0} \rightarrow D^{*}(2010)^{-}D^{+}) = -0.78 \pm 0.21
                                                                                                                                       C_{\pi^0 \pi^0}(B^0 \to \pi^0 \pi^0) = -0.48 \pm 0.30
C_{D^{*+}D^{-}}(B^0 \to D^*(2010)^+D^-) = -0.09 \pm 0.22 \quad (S = 1.6)
                                                                                                                                      C_{\rho\pi} (B^0 \to \rho^+ \pi^-) = 0.01 \pm 0.14 \quad (S = 1.9)
S_{\rho\pi} (B^0 \to \rho^+ \pi^-) = 0.01 \pm 0.09
S_{D^{*+}D^{-}}(B^0 \rightarrow D^*(2010)^+D^-) = -0.61 \pm 0.19
C_{D^{*+}D^{*-}}(B^0 \rightarrow D^{*+}D^{*-}) = -0.01 \pm 0.09 \quad (S = 1.2)
                                                                                                                                       \Delta C_{\rho\pi} (B^0 \to \rho^+\pi^-) = 0.37 \pm 0.08
S_{D^{*+}D^{*-}}(B^0 \to D^{*+}D^{*-}) = -0.76 \pm 0.14

C_+(B^0 \to D^{*+}D^{*-}) = 0.00 \pm 0.12
                                                                                                                                       \Delta S_{\rho\pi}^{\bullet} (B^0 \to \rho^+ \pi^-) = -0.05 \pm 0.10
                                                                                                                                       C_{\rho^0 \pi^0} (B^0 \to \rho^0 \pi^0) = 0.3 \pm 0.4
S_{+} (B^{0} \rightarrow D^{*+}D^{*-}) = -0.76 \pm 0.16

C_{-} (B^{0} \rightarrow D^{*+}D^{*-}) = 0.4 \pm 0.5
                                                                                                                                       S_{\rho^0 \pi^0} (B^0 \to \rho^0 \pi^0) = 0.1 \pm 0.4
S_{-}(B^{0} \rightarrow D^{*+}D^{*-}) = -1.8 \pm 0.7
                                                                                                                                       C_{a_1 \pi} (B^0 \to a_1(1260)^+ \pi^-) = -0.10 \pm 0.17
C(B^0 \to D^*(2010)^+ D^*(2010)^- K_S^0) = 0.01 \pm 0.29
                                                                                                                                       S_{a_1\pi} (B^0 \to a_1(1260)^+\pi^-) = 0.37 \pm 0.22
S(B^0 \to D^*(2010)^+ D^*(2010)^- K_S^0) = 0.1 \pm 0.4
                                                                                                                                       \Delta \bar{C}_{a_1 \pi} (B^0 \to a_1 (1260)^+ \pi^-) = 0.26 \pm 0.17
C_{D^+D^-}(B^0 \to D^+D^-) = -0.5 \pm 0.4 \quad (S = 2.5)
                                                                                                                                       \Delta S_{a_1 \pi} \ (B^0 \to a_1 (1260)^+ \pi^-) = -0.14 \pm 0.22
S_{D^+D^-}(B^0 \rightarrow D^+D^-) = -0.87 \pm 0.26
                                                                                                                                       C(B^0 \rightarrow b_1^- K^+) = -0.22 \pm 0.24
C_{J/\psi(1S)\pi^0}(B^0 \to J/\psi(1S)\pi^0) = -0.13 \pm 0.13
                                                                                                                                      \Delta C (B^0 \to b_1^- \pi^+) = -1.04 \pm 0.24
C_{\rho^0 \rho^0} (B^0 \to \rho^0 \rho^0) = 0.2 \pm 0.9
S_{J/\psi(1S)\pi^0} (B^0 \rightarrow J/\psi(1S)\pi^0) = -0.94 \pm 0.29 (S = 1.9)
C_{D_{CP}^{(*)}h^0} (B^0 \to D_{CP}^{(*)}h^0) = -0.23 \pm 0.16
                                                                                                                                       S_{\rho^0\rho^0} (B^0 \to \rho^0\rho^0) = 0.3 \pm 0.7
                                                                                                                                       \dot{C}_{\rho\rho} (B^0 \to \rho^+ \rho^-) = -0.05 \pm 0.13
S_{D_{CP}^{(*)}h^0}(B^0 \to D_{CP}^{(*)}h^0) = -0.56 \pm 0.24
                                                                                                                                       S_{\rho\rho}(B^0 \to \rho^+ \rho^-) = -0.06 \pm 0.17
C_{K^0\pi^0}(B^0 \to K^0\pi^0) = 0.00 \pm 0.13 \quad (S = 1.4)
                                                                                                                                       |\dot{\lambda}| (B^0 \to J/\psi K^*(892)^0) < 0.25, CL = 95%
S_{K^0\pi^0} (B^0 \rightarrow K^0\pi^0) = 0.58 \pm 0.17
                                                                                                                                      \cos 2\beta \ (B^0 \to J/\psi K^*(892)^0) = 1.7^{+0.7}_{-0.9} \ \ (S = 1.6)
C_{\eta'(958)\,K_S^0}(B^0 \to \eta'(958)\,K_S^0) = -0.04 \pm 0.20 (S = 2.5)
                                                                                                                                       \cos 2\beta \ (B^0 \to [K_S^0 \pi^+ \pi^-]_{D^{(*)}} \ h^0) = 1.0^{+0.6}_{-0.7} \ (S = 1.8)
S_{\eta'(958) K_S^0}(B^0 \to \eta'(958) K_S^0) = 0.43 \pm 0.17 \quad (S = 1.5)
                                                                                                                                       (S_{+} + S_{-})/2 (B^{0} \rightarrow D^{*-}\pi^{+}) = -0.039 \pm 0.011
C_{\eta' K^0} (B^0 \to \eta' K^0) = -0.05 \pm 0.05
                                                                                                                                       (S_{-} - S_{+})/2 (B^{0} \rightarrow D^{*-}\pi^{+}) = -0.009 \pm 0.015
                                                                                                                                       (S_{+} + S_{-})/2 (B^{0} \rightarrow D^{-}\pi^{+}) = -0.046 \pm 0.023
S_{\eta',K^0}(B^0 \to \eta',K^0) = 0.60 \pm 0.07
                                                                                                                                       (S_{-} - S_{+})/2 (B^{0} \rightarrow D^{-}\pi^{+}) = -0.022 \pm 0.021
\dot{C_{\omega \, K_S^0}} \, (B^0 \to \ \omega \, K_S^0) = -0.30 \pm 0.28 \quad (S = 1.6)
                                                                                                                                       (S_{+} + S_{-})/2 (B^{0} \rightarrow D^{-} \rho^{+}) = -0.024 \pm 0.032
                                                                                                                                      (S_{-} - S_{+})/2 (B^{0} \rightarrow D^{-}\rho^{+}) = -0.10 \pm 0.06

C_{\eta_{c}} \kappa_{S}^{0} (B^{0} \rightarrow \eta_{c} \kappa_{S}^{0}) = 0.08 \pm 0.13
S_{\omega K_S^0} (B^0 \to \omega K_S^0) = 0.43 \pm 0.24
C(B^0 \to K_S^0 \pi^0 \pi^0) = 0.2 \pm 0.5

S(B^0 \to K_S^0 \pi^0 \pi^0) = 0.7 \pm 0.7
                                                                                                                                       S_{\eta_c K_S^0} (B^0 \rightarrow \eta_c K_S^0) = 0.93 \pm 0.17
C_{\rho^0 K_S^0} (B^0 \rightarrow \rho^0 K_S^0) = -0.04 \pm 0.20
                                                                                                                                       C_{c\,\overline{c}\,K^{(*)0}} (B^0 \to c\,\overline{c}\,K^{(*)0}) = (0.5 \pm 1.7) \times 10^{-2}
S_{\rho^0 K_S^0}(B^0 \to \rho^0 K_S^0) = 0.50^{+0.17}_{-0.21}
                                                                                                                                       \sin(2\beta) = 0.679 \pm 0.020
                                                                                                                                       C_{J/\psi({\rm n\,S})\,K^0}~(B^0
ightarrow~J/\psi({\rm n\,S})\,K^0) = (0.5\,\pm\,2.0)	imes 10^{-2}
C_{f_0 \ K_S^0} \ (B^0 \to f_0(980) K_S^0) = 0.14 \pm 0.17
                                                                                                                                       S_{J/\psi(nS)K^0}(B^0 \rightarrow J/\psi(nS)K^0) = 0.676 \pm 0.021
S_{f_0 \, K_S^0} (B^0 \to f_0(980) \, K_S^0) = -0.73^{+0.27}_{-0.09} \, (S = 1.6)
                                                                                                                                       C_{J/\psi K^{*0}} (B^0 \to J/\psi K^{*0}) = 0.03 \pm 0.10
S_{f_2,K_S^0}(B^0 \to f_2(1270)K_S^0) = -0.5 \pm 0.5
                                                                                                                                       S_{J/\psi K^{*0}} (B^0 \to J/\psi K^{*0}) = 0.60 \pm 0.25
C_{f_2 \ K_S^0} \ (B^0 \to f_2(1270) \, K_S^0) = 0.3 \pm 0.4
                                                                                                                                       C_{\chi_{c0} \, K_S^0} \, (B^0 \to \chi_{c0} \, K_S^0) = -0.3^{+\, 0.5}_{-\, 0.4}
                                                                                                                                      S_{\chi_{c0} K_S^0}(B^0 \to \chi_{c0} K_S^0) = -0.7 \pm 0.5
S_{f_x,K_S^0}(B^0 \to f_x(1300)K_S^0) = -0.2 \pm 0.5
C_{f_x K_S^0} (B^0 \to f_x(1300) K_S^0) = 0.13 \pm 0.35
                                                                                                                                      C_{\chi_{c1} K_S^0} (B^0 \to \chi_{c1} K_S^0) = 0.13 \pm 0.11
S_{K^0\pi^+\pi^-}(B^0 \to K^0\pi^+\pi^- \text{ nonresonant}) = -0.01 \pm 0.33
                                                                                                                                      S_{\chi_{c1} \kappa_S^0}(B^0 \rightarrow \chi_{c1} \kappa_S^0) = 0.61 \pm 0.16
C_{K^0\pi^+\pi^-}(B^0 \to K^0\pi^+\pi^- \text{ nonresonant}) = 0.01 \pm 0.26
                                                                                                                                       \sin(2\beta_{\rm eff})(B^0 \to \phi K^0) = 0.22 \pm 0.30
C_{K_S^0,K_S^0}(B^0 \to K_S^0,K_S^0) = 0.0 \pm 0.4 \quad (S = 1.4)
                                                                                                                                      \sin(2\beta_{\text{eff}})(B^0 \to \phi K_0^*(1430)^0) = 0.97^{+0.03}_{-0.52}
S_{K_S^0 K_S^0} (B^0 \to K_S^0 K_S^0) = -0.8 \pm 0.5
                                                                                                                                      \sin(2\beta_{\text{eff}})(B^0 \rightarrow K^+K^-K^0_S) = 0.77^{+0.13}_{-0.12}
C_{K^+K^-K^0_S} (B^0 \rightarrow K^+K^-K^0_S nonresonant) = 0.09 \pm 0.09
                                                                                                                                      \begin{split} & \sin(2\beta_{\rm eff})(B^0 \to [K_S^0 \, \pi^+ \, \pi^-]_{D^{(*)}} \, h^0) = 0.45 \pm 0.28 \\ & |\lambda| \, (B^0 \to [K_S^0 \, \pi^+ \, \pi^-]_{D^{(*)}} \, h^0) = 1.01 \pm 0.08 \end{split}
S_{K^+K^-K_s^0} (B^0 \to K^+K^-K_s^0 nonresonant) = -0.74^{+0.12}_{-0.10}
                                                                                                                                       |\sin(2\beta + \gamma)| > 0.40, CL = 90\%
C_{K^+K^-K_S^0} (B^0 \rightarrow K^+K^-K_S^0 inclusive) = 0.01 \pm 0.09
                                                                                                                                      2 \beta + \gamma = (83 \pm 60)^{\circ}
S_{K^+K^-K_5^0}(B^0 \to K^+K^-K_5^0 \text{ inclusive}) = -0.65 \pm 0.12
                                                                                                                                      \gamma(B^0 \to D^0 K^{*0}) = (162 \pm 60)^\circ
C_{\phi K_S^0} (B^0 \to \phi K_S^0) = 0.03 \pm 0.14
                                                                                                                                       \alpha = (90 \pm 5)^{\circ}
S_{\phi K_S^0} (B^0 \to \phi K_S^0) = 0.39 \pm 0.17
C_{K_S K_S K_S}(B^0 \to K_S K_S K_S) = -0.15 \pm 0.16 \quad (S = 1.1)
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| _ | | | | | |
|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------------------------------|---------------------------------------------------|-------------|
| <u>-</u> 01 | a contract by the contract of | | $D^*(2010)^- K^+ \overline{K}{}^0$ | 10-4 6 | |
| | gates of the modes below. Reactions indicat | | | $< 4.7 \times 10^{-4} \text{ CI}$ | |
| | do not include mixing. Modes which do no the B are listed in the B^\pm/B^0 ADMIXTUR | | $D^*(2010)^- K^+ \overline{K}^*(892)^0$ | $(1.29\pm 0.33) \times 10^{-3}$ | 2007 |
| section. | THE B are listed III the B-/B- ADMIXTOR | _ | $D^*(2010)^-\pi^+\pi^+\pi^-$ | $(7.0 \pm 0.8) \times 10^{-3}$ | S=1.3 2235 |
| | | | $(D^*(2010)^-\pi^+\pi^+\pi^-)$ non- | $(0.0 \pm 2.5) \times 10^{-3}$ | 2235 |
| The branching fractions liste | d below assume 50% $B^0\overline{B}{}^0$ and 50% B^+B^- | - | resonant | | |
| | e have attempted to bring older measurement | | $D^*(2010)^-\pi^+\rho^0$ | $(5.7 \pm 3.2) \times 10^{-3}$ | 215 0 |
| | ir assumed $\varUpsilon(4S)$ production ratio to 50:5 | | $D^*(2010)^- a_1(1260)^+$ | (1.30 ± 0.27) % | 2061 |
| | D*, and ψ branching ratios to current value | es | $D^*(2010)^-\pi^+\pi^+\pi^-\pi^0$ | (1.76± 0.27) % | 2218 |
| whenever this would affect o | our averages and best limits significantly. | | $D^{*-}3\pi^{+'}2\pi^{-}$ | $(4.7 \pm 0.9) \times 10^{-3}$ | 2195 |
| Indentation is used to indic | ate a subchannel of a previous reaction. A | II. | $\overline{D}^*(2010)^- \omega \pi^+$ | $(2.89\pm 0.30) \times 10^{-3}$ | 2148 |
| | been corrected for resonance branching frac | | $D_1(2430)^0 \omega \times$ | $(4.1 \pm 1.6) \times 10^{-4}$ | 1992 |
| tions to the final state so th | ne sum of the subchannel branching fraction | IS | $B(D_1(2430)) \xrightarrow{\omega} \times B(D_1(2430)) \xrightarrow{0} \rightarrow$ | (4.1 ± 1.6) × 10 | 1992 |
| can exceed that of the final | state. | | | | |
| For inclusive branching frag | ctions, e.g., $B ightarrow D^\pm$ anything, the value | ac . | $rac{D^{*-}\pi^+}{\overline{D}^{**-}\pi^+}$ | | |
| | ot branching fractions. They can be greate | | $D^{**-}\pi^+$ | [ttt] (2.1 \pm 1.0) \times 10 ⁻³ | = |
| than one. | or branching tractions. They can be greater | ., | $D_1(2420)^-\pi^+ \times B(D_1^- \to$ | $(1.00 + 0.21 \atop -0.25) \times 10^{-4}$ | _ |
| | | | $D^-\pi^+\pi^-$) | - 0.257 | |
| | Scale factor, | p | $D_1(2420)^-\pi^+ \times B(D_1^- \to 0)$ | < 3.3 × 10 ⁻⁵ CI | 1 000/ |
| B ⁰ DECAY MODES | Fraction (Γ_i/Γ) Confidence leve | (MeV/ <i>c</i>) | | < 5.5 × 10 Cl | L=90% - |
| | · | | $D^{*-}\pi^{+}\pi^{-}$ | | |
| $\ell^+ u_\ell$ anything | [ppp] (10.33± 0.28) % | _ | $\overline{D}_{2}^{*}(2460)^{-}\pi^{+}\times$ | $(2.15 \pm 0.35) \times 10^{-4}$ | 2062 |
| $e^{+}\nu_{e}X_{c}$ | $(10.1 \pm 0.4)\%$ | _ | $B(D_2^*(2460)^- \to D^0\pi^-)$ | | |
| $D\ell^+ u_\ell$ a nything | (9.2 ± 0.8) % | _ | $\overline{D}_{0}^{*}(2400)^{-}\pi^{+}\times$ | $(6.0 \pm 3.0) \times 10^{-5}$ | 2090 |
| $D^-\ell^+ u_\ell$ | [ppp] (2.18± 0.12) % | 2309 | $B(D_0^*(2400)^- \to D^0\pi^-)$ | · · · · · · · · · · · · · · · · · · · | |
| $D^- \tau^+ u_{	au}$ | $(1.1 \pm 0.4)\%$ | 1909 | $D_0^*(2460) \to D^* \pi^-$ $D_0^*(2460) \to D^* \pi^-$ | < 2.4 × 10 ⁻⁵ C | 1 _ 000/ |
| $D^*(2010)^- \ell^+ \nu_{\ell}$ | | | | $< 2.4 \times 10^{-5} \text{ C}$ | _ = 20 /0 = |
| $D^*(2010)^- \ell^+ \nu_\ell$ $D^*(2010)^- \tau^+ \nu_\tau$ | | 2257 | $D^{*-}\pi^{+}\pi^{-}$ | 2 | |
| | $(1.5 \pm 0.5)\%$ S=1.4 | | $\overline{D}_{2}^{*}(2460)^{-}\rho^{+}$ | < 4.9 × 10 ⁻³ CI | |
| $\overline{D}^0\pi^-\ell^+\nu_\ell$ | $(4.3 \pm 0.6) \times 10^{-3}$ | 2308 | $D^{\overline{0}} \overline{D^0}$ | $<$ 4.3 $\times 10^{-5}$ CI | |
| $D_0^*(2400)^- \ell^+ \nu_{\ell} \times$ | $(3.0 \pm 1.2) \times 10^{-3}$ S=1.8 | - | $D^{*0} \overline{D}{}^{0}$ | $<$ 2.9 $\times 10^{-4}$ CI | L=90% 1794 |
| $B(D_0^{*-} 	o \overline{D}{}^0\pi^-)$ | | | $D^- D^+$ | $(2.11 \pm 0.31) \times 10^{-4}$ | S=1.2 1864 |
| $D_2^*(2460)^- \ell^+ \nu_\ell \times$ | $(1.21 \pm 0.33) \times 10^{-3}$ S=1.8 | 2065 | $D^-D_s^+$ | $(7.2 \pm 0.8) \times 10^{-3}$ | 1812 |
| $B(D_2^{*-} \to \overline{D}{}^0\pi^-)$ | , | | $D^*(2010)^- D_s^+$ | $(8.0 \pm 1.1) \times 10^{-3}$ | 1735 |
| $\overline{D}^{(*)} \operatorname{n} \pi \ell^+ \nu_{\ell} (\operatorname{n} \geq 1)$ | (00 1 05) 0/ | | $D^{-}D_{s}^{*+}$ | $(7.4 \pm 1.6) \times 10^{-3}$ | 1732 |
| | $(2.3 \pm 0.5)\%$ | _ | | , , | |
| $\overline{D}^{*0}\pi^{-}\ell^{+}\nu_{\ell}$ | $(4.9 \pm 0.8) \times 10^{-3}$ | 225 6 | $D^*(2010)^- D_s^{*+}$ | (1.77± 0.14) % | 1649 |
| $D_1(2420)^{-}\ell^{+}\frac{\nu_{\ell}}{2}$ | $(2.80\pm 0.28) \times 10^{-3}$ | _ | $D_{s0}(2317)^- K^+ \times$ | $(4.2 \pm 1.4) \times 10^{-5}$ | 2097 |
| $B(D_1^- 	o \overline{D}^{*0}\pi^-)$ | | | $B(D_{s0}(2317)^- \to D_s^- \pi^0)$ | | |
| $D_1'(2430)^- \ell^+ \nu_\ell \times$ | $(3.1 \pm 0.9) \times 10^{-3}$ | _ | $D_{s0}(2317)^{-}\pi^{+}\times$ | $<$ 2.5 $\times 10^{-5}$ CI | L=90% 2128 |
| $B(D_1'^- \to \overline{D}^{*0}\pi^-)$ | | | $B(D_{s0}(2317)^{-} \rightarrow D_{s}^{-}\pi^{0})$ | | |
| $D_2^*(2460)^- \ell^+ \nu_{\ell} \times$ | $(6.8 \pm 1.2) \times 10^{-4}$ | 2065 | $D_{s,J}(2457)^{-}K^{+}\times$ | < 9.4 × 10 ⁻⁶ CI | L=90% - |
| $B(D_2^{*-} \to \overline{D}^{*0}\pi^-)$ | , | | $B(D_{sJ}(2457)^- \to D_s^- \pi^0)$ | • | |
| $\rho^-\ell^+ u_\ell$ | [ppp] (2.34 ± 0.28) × 10 ⁻⁴ | 25.02 | $D_{s,I}(2457)^{-}\pi^{+}\times$ | < 4.0 × 10 ⁻⁶ C | 1 000/ |
| $\frac{\rho}{\pi^-} \ell^+ \frac{\nu_\ell}{\nu_\ell}$ | [ppp] (2.34 ± 0.28) × 10 · · · · · · · · · · · · · · · · · · | 2583 | | < 4.0 × 10 ⁻⁶ CI | L=90% - |
| $\pi \in \mathcal{D}_{\ell}$ | $[ppp] (1.44 \pm 0.05) \times 10^{-5}$ | 2638 | $B(D_{sJ}(2457)^- \to D_s^- \pi^0)$ | - | |
| | nclusive modes | | $D_s^- D_s^+$ | $< 3.6 \times 10^{-5} \text{ C}$ | |
| K^\pm a nything | (78 ± 8)% | _ | $D_s^{*-}D_s^+$ | < 1.3 × 10 ⁻⁴ CI | L=90% 1674 |
| $D^0 X$ | (8.1 ± 1.5) % | _ | $D_{s}^{*-}D_{s}^{*+}$ | $< 2.4 \times 10^{-4} \text{ CI}$ | L=90% 1583 |
| $\overline{D}{}^{0}X$ | (47.4 ± 2.8) % | _ | | (0 = + 4.0) 10-4 | 6 1 5 1600 |
| $D^+ X$ | < 3.9 % CL=90% | . – | $D_{s0}(2317)^+D^-\times$ | $(9.7 \ ^{+} \ ^{4.0} _{-}) \times 10^{-4}$ | S=1.5 1602 |
| D^-X | (36.9 ± 3.3) % | _ | $B(D_{s0}(2317)^+ \to D_s^+ \pi^0)$ | | |
| $D_c^+ X$ | * | | $D_{s0}(2317)^+ D^- \times$ | < 9.5 × 10 ⁻⁴ CI | L=90% - |
| 3 | $(\ 10.3 \ \ \stackrel{+}{-} \ \ \stackrel{2.1}{1.8} \) \%$ | _ | $B(D_{s0}(2317)^+ \to D_s^{*+} \gamma)$ | | |
| $D_s^- X$ | < 2.6 % CL=90% | . – | $D_{s0}(2317)^+ D^*(2010)^- \times$ | $(1.5 \pm 0.6) \times 10^{-3}$ | 1509 |
| $\Lambda_c^{+} X$ | < 3.1 % CL=90% | . – | $B(D_{s0}(2317)^+ \to D_s^+ \pi^0)$ | _ , , , , | |
| | 21 | | $D_{sJ}(2457)^+D^-$ | (25 11) 10-3 | |
| $\overline{\Lambda}_c^- X$ | $(5.0\ \begin{array}{c}+2.1\\-1.5\end{array})$ % | _ | | $(3.5 \pm 1.1) \times 10^{-3}$ | - |
| <u>₹</u> X | (95 ± 5)% | _ | D_{sJ} (2457) $^+$ $D^ 	imes$ | $(6.5 + 1.7 \times 10^{-4}) \times 10^{-4}$ | = |
| c X | (24.6 ± 3.1) % | _ | $B(D_{s,J}(2457)^+ \to D_s^+ \gamma)$ | | |
| <u>₹</u> cX | (119 ± 6) % | _ | $D_{s,J}(2457)^+ D^- \times$ | < 6.0 × 10 ⁻⁴ CI | L=90% - |
| | | | $B(D_{sJ}(2457)^+ \rightarrow D_s^{*+}\gamma)$ | | · - |
| | D^* , or D_s modes | | $D_{s,I}(2457)^+ D^- \times$ | < 2.0 × 10 ⁻⁴ C | 1 000/ |
| $D^{-}\pi^{+}$ | $(2.68 \pm 0.13) \times 10^{-3}$ | 2306 | | < 2.0 × 10 ⁻⁴ Cl | L = 90% - |
| $D^-\rho^+$ | $(7.8 \pm 1.3) \times 10^{-3}$ | 2235 | $B(D_{sJ}(2457)^+ \rightarrow$ | | |
| $D^-K^0\pi^+$ | $(4.9 \pm 0.9) \times 10^{-4}$ | 225 9 | $D_s^+ \pi^+ \pi^-)$ | | |
| $D^-K^*(892)^+$ | $(4.5 \pm 0.7) \times 10^{-4}$ | 2211 | $D_{sJ}(2457)^{+} D^{-} \times$ | < 3.6 × 10 ⁻⁴ CI | L=90% - |
| $D^-\omega\pi^+$ | $(2.8 \pm 0.6) \times 10^{-3}$ | 2204 | $B(D_{sJ}(2457)^+ \rightarrow D_s^+ \pi^0)$ | | |
| D^-K^+ | $(1.97 \pm 0.21) \times 10^{-4}$ | 2279 | $D^*(2010)^- D_{sJ}(2457)^+$ | $(9.3 \pm 2.2) \times 10^{-3}$ | - |
| $D^- K^+ \overline{K}{}^0$ | $<$ 3.1 $\times 10^{-4}$ CL=90% | | $D_{sJ}(2457)^+ D^*(2010) \times$ | $(2.3 + 0.9 \atop -0.7) \times 10^{-3}$ | |
| $D^{-}K^{+}\overline{K}^{*}(892)^{0}$ | $(8.8 \pm 1.9) \times 10^{-4}$ | 2070 | | (2.3 - 0.7) × 10 3 | = |
| $\overline{D}^0\pi^+\pi^-$ | $(8.4 \pm 0.9) \times 10^{-4}$ | 2301 | $B(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)$ | | |
| $D^*(2010)^-\pi^+$ | $(2.76\pm 0.13) \times 10^{-3}$ | 2255 | $D^-D_{s1}(2536)^+ \times$ | $(2.8 \pm 0.7) \times 10^{-4}$ | 1444 |
| $D^{-}\pi^{+}\pi^{+}\pi^{-}$ | $(6.4 \pm 0.7) \times 10^{-3}$ | 2287 | $B(D_{s1}(2536)^+ \to D^{*0}K^+$ | | |
| $(D^-\pi^+\pi^+\pi^-)$ nonresonant | | 2287 | $+ D^{*+}K^{0}$ | | |
| $D^-\pi^+\rho^0$ | $(3.9 \pm 1.9) \times 10$ $(1.1 \pm 1.0) \times 10^{-3}$ | 2206 | $D^- D_{s1}(2536)^+ \times$ | $(1.7 \pm 0.6) \times 10^{-4}$ | 1444 |
| $D - a_1(1260)^+$ | $(6.0 \pm 3.3) \times 10^{-3}$ | 2121 | $B(D_{s1}(2536)^{+} \rightarrow$ | | |
| $D^*(2010)^-\pi^+\pi^0$ | | | $D^{*0} \overset{\frown}{K^+})$ | | |
| $D^*(2010) = \pi^+ \pi^0$ $D^*(2010) = \rho^+$ | $(1.5 \pm 0.5)\%$ | 2247 | $D^-D_{s1}(2536)^+ \times$ | $(2.6 \pm 1.1) \times 10^{-4}$ | 1444 |
| | $(6.8 \pm 0.9) \times 10^{-3}$ | 2180 | $B(D_{s1}(2536)^+ \to$ | • | |
| $D^*(2010)^- K^+$ $D^*(2010)^- K^0 -+$ | $(2.14 \pm 0.16) \times 10^{-4}$ | 2226 | $D^{*+}K^{0}$ | | |
| $D^*(2010)^- K^0 \pi^+$ | $(3.0 \pm 0.8) \times 10^{-4}$ | 2205 | , | | |
| $D^*(2010)^- K^*(892)^+$ | $(3.3 \pm 0.6) \times 10^{-4}$ | 2155 | | | |
| | | | | | |

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\overline{D}{}^{0}D^{*}(2007)^{0}K^{0}+
D^*(2010)^- D_{s1}(2536)^+ \times
                                                            (5.0 \pm 1.4) \times 10^{-4}
                                                                                                                 1336
                                                                                                                                                                                                  (1.1 \pm 0.5) \times 10^{-3}
                                                                                                                                                                                                                                                       1478
     B(D_{s1}(2536)^{+} \rightarrow^{'} D^{*0} K^{+}
                                                                                                                                            \overline{D}^*(2007)^0 D^0 K^0
                                                                                                                                       \overline{D}_{\underline{}}^{*}(2007)^{0} D^{*}(2007)^{0} K^{0}
      + D^{*+} K^{0}
                                                                                                                                                                                                  (2.4 \pm 0.9) \times 10^{-3}
                                                                                                                                                                                                                                                        1365
    D^*(2010)^{-}D_{s1}(2536)^+ \times
                                                            (3.3 \pm 1.1) \times 10^{-4}
                                                                                                                 1336
                                                                                                                                       (\overline{D} + \overline{D}^*)(D + D^*)K
                                                                                                                                                                                                  ( 3.68 + 0.26) %
         B(D_{s1}(2536)^+ \rightarrow
                                                                                                                                                                                   Charmonium modes
         D^{*0}K^{+}
                                                                                                                                       \eta_c\,K^0
                                                                                                                                                                                                      8.3 \pm 1.2 ) \times\,10^{-4}
                                                                                                                                                                                                                                                       1752
    D^{*-}D_{s1}(2536)^{+} \times
                                                            (5.0 + 1.7) \times 10^{-4}
                                                                                                                 1336
                                                                                                                                       \eta_c K^* (892)^0
                                                                                                                                                                                                      6.4 \pm 0.9 ) \times\,10^{-4}
                                                                                                                                                                                                                                                        1648
         B(D_{s1}(2536)^+ \rightarrow
                                                                                                                                       \eta_c(2S) K^{*0}
                                                                                                                                                                                                 < 3.9
                                                                                                                                                                                                                         \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                                       1157
         D^{*+}K^{0}
                                                                                                                                       h_c(1P)K^{*0}
                                                                                                                                                                                                                         \times 10^{-4} CL=90%
                                                                                                                                                                                                 < 4
                                                                                                                                                                                                                                                       1253
D^- D_{s,I}(2573)^+ \times
                                                                                  \times\,10^{-4}~\text{CL}\!=\!90\%
                                                          < 1
                                                                                                                 1414
                                                                                                                                       J/\psi(1S)\,K^0
                                                                                                                                                                                                  (\phantom{-}8.74 \pm \phantom{0}0.32) \times 10^{-4}
     B(D_{sJ}(2573)^+ \rightarrow D^0 K^+)
                                                                                                                                       J/\psi(1S)K^+\pi
                                                                                                                                                                                                  (1.2 \pm 0.6) \times 10^{-3}
                                                                                                                                                                                                                                                       1652
D^*(2010)^- D_{sJ}(2573)^+ \times
                                                                                   \times 10^{-4} CL=90%
                                                                                                                 1304
                                                                                                                                          J/\psi(1S)\,K^*(892)^0
                                                                                                                                                                                                     1.34 \pm 0.06) \times 10^{-3}
                                                                                                                                                                                                                                                       1571
      B(D_{sJ}(2573)^+ \to D^0 K^+)
                                                                                                                                                                                                  (8 \pm 4) \times 10^{-5}
                                                                                                                                       J/\psi(1S)\eta K_S^0
D^+\pi^-
                                                            ( 7.8~\pm~1.4 ) \times\,10^{-7}
                                                                                                                 2306
                                                                                                                                       J/\psi(1S)\eta'K_s^0
                                                                                                                                                                                                                        \times\,10^{-5} CL=90%
                                                                                                                                                                                                 < 2.5
                                                                                                                                                                                                                                                       1271
D_c^+\pi^-
                                                            (-2.16\pm\ 0.26)\times 10^{-5}
                                                                                                                 2270
                                                                                                                                       J/\psi(1S)\phi K^{0}
                                                                                                                                                                                                  (9.4 \pm 2.6) \times 10^{-5}
                                                                                                                                                                                                                                                       1224
D_{s}^{*+}\pi^{-}
                                                            ( 2.1~\pm~0.4 ) \times\,10^{-5}
                                                                                                                 2215
                                                                                                                                       J/\psi(1S)\omega K^0
                                                                                                                                                                                                      2.3~\pm~0.4~)\times10^{-4}
D_s^+ \rho^-
                                                                                                                                                                                                                                                       1386
                                                                                 \times 10^{-5} CL=90%
                                                               2.4
                                                                                                                 2197
                                                                                                                                          X(3872) K^0 \times B(X \rightarrow
                                                                                                                                                                                                  ( 6.0~\pm~3.2~)\times10^{-6}
D_s^{*+} \rho^-
                                                               4.1 \pm 1.3 ) \times 10<sup>-5</sup>
                                                                                                                 2138
D_s^+ \rho D_s^+ a_0^-
                                                                                                                                                J/\psi\omega
                                                                                  \times 10^{-5} CL=90%
                                                                                                                                          X(3915) K^0 \times B(X \rightarrow
                                                          <
                                                                1.9
                                                                                                                                                                                                  (2.1 \pm 0.9) \times 10^{-5}
                                                                                                                                                                                                                                                        1103
D_s^{s+} \tilde{a}_0^-
                                                                                  \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                3.6
                                                                                                                                                J/\psi\omega)
D_s^+ a_1 (1260)^-
                                                                                  \times\,10^{-3} CL=90%
                                                                                                                                       J/\psi(1S)K(1270)^{0}
                                                                                                                                                                                                  (1.3 \pm 0.5) \times 10^{-3}
                                                                2.1
                                                                                                                                                                                                                                                       1390
                                                                                                                 2080
D_s^{*+} a_1 (1260)^-

D_s^{+} a_2^-

D_s^{++} a_2^-

D_s^{-} K^+
                                                                                                                                       J/\psi(1S)\pi^{0}
                                                                                                                                                                                                  (-1.76 \pm \ 0.16) \times 10^{-5}
                                                                                  \times\,10^{-3} CL=90%
                                                                                                                                                                                                                                                       1728
                                                          <
                                                                1.7
                                                                                                                 2015
                                                                                                                                                                                                  (\phantom{-}9.5\phantom{0}\pm\phantom{0}1.9\phantom{0})\times10^{-6}
                                                                                                                                       J/\psi(1S)\eta
                                                                                                                                                                                                                                                       1672
                                                                                  \times\,10^{-4}~\text{CL}\!=\!90\%
                                                          <
                                                                1.9
                                                                                                                                       J/\psi(1S)\pi^{+}\pi^{-}
                                                                                                                                                                                                  ( 4.6~\pm~0.9 ) \times\,10^{-5}
                                                                                                                                                                                                                                                       1716
                                                                                  \times\,10^{-4} CL=90%
                                                                2.0
                                                                                                                                                                                                                         \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                                                                                           J/\psi(1S)\pi^+\pi^- nonresonant
                                                                                                                                                                                                 <
                                                                                                                                                                                                     1.2
                                                                                                                                                                                                                                                       1716
                                                           ( 2.2~\pm~0.5 ) \times\,10^{-5}
                                                                                              S=1.8
                                                                                                                 2242
                                                                                                                                                                                                                         \times\,10^{-6} CL=90%
                                                                                                                                          J/\psi(1S) f_2
                                                                                                                                                                                                     4.6
                                                            (-2.19\!\pm\ 0.30)\times 10^{-5}
D_{s}^{*-}K^{+}
                                                                                                                 2185
                                                                                                                                          J/\psi(1S)\rho^0
                                                                                                                                                                                                     2.7 \pm 0.4) \times 10^{-5}
                                                                                                                                                                                                                                                       1612
D_{c}^{-}K^{*}(892)^{+}
                                                            ( 3.5~\pm~1.0~)\times10^{-5}
                                                                                                                 2172
                                                                                                                                                                                                                         \times\,10^{-4} CL=90%
                                                                                                                                       J/\psi(1S)\omega
                                                                                                                                                                                                 <
                                                                                                                                                                                                      2.7
                                                                                                                                                                                                                                                       1609
                                                            (\phantom{-}3.2\phantom{0}^{\phantom{0}+\phantom{0}1.5\phantom{0}}\phantom{0})\times10^{-5\phantom{0}}
                                                                                                                                       J/\psi(1S)\phi
                                                                                                                                                                                                      9.4
                                                                                                                                                                                                                         \times\,10^{-7}~\text{CL}\!=\!90\%
                                                                                                                                                                                                                                                       1520
D_c^{*-}K^*(892)^+
                                                                                                                                                                                                <
                                                                                                                 2112
                                                                                                                                       J/\psi(1S)\eta'(958)
J/\psi(1S)K^0\pi^+\pi
                                                                                                                                                                                                                         \times 10^{-5} CL=90%
                                                                                                                                                                                                 < 6.3
                                                                                                                                                                                                                                                       1546
D_{s}^{-}\pi^{+}K^{0}
                                                           (1.10 \pm 0.33) \times 10^{-4}
                                                                                                                 2222
                                                                                                                                                                                                      1.0 \pm 0.4 ) \times 10^{-3}
                                                                                                                                                                                                                                                       1611
D_s^{*-}\pi^+K^0
                                                                                  \times\,10^{-4}~\text{CL}\!=\!90\%
                                                          <
                                                               1.10
                                                                                                                 2164
                                                                                                                                           J/\psi(1S)K^0\rho^0
                                                                                                                                                                                                  (5.4 \pm 3.0) \times 10^{-4}
                                                                                                                                                                                                                                                       1390
D_{s}^{-}\pi^{+}K^{*}(892)^{0}
                                                                                  \times\,10^{-3} CL=90%
                                                          <
                                                                3.0
                                                                                                                 2138
                                                                                                                                       J/\psi(1S)K^*(892)^+\pi^-
                                                                                                                                                                                                     8 \pm 4 ) \times 10<sup>-4</sup>
                                                                                                                                                                                                                                                       1514
                                                                                                                                       J/\psi(1S)K^*(892)^0\pi^+\pi^-
                                                                                  \times 10^{-3} \text{ CL} = 90\%
D_c^{*-}\pi^+K^*(892)^0
                                                                                                                 2076
                                                               1.6
                                                                                                                                                                                                  ( 6.6 \pm 2.2 ) \times 10<sup>-4</sup>
                                                                                                                                                                                                                                                        1447
\overline{D}^{\breve{0}}K^0
                                                           (5.2 \pm 0.7) \times 10^{-5}
                                                                                                                                                                                                                        \times 10^{-4} CL=90%
                                                                                                                 2280
                                                                                                                                       X(3872)^{-}K^{+}
                                                                                                                                                                                                 < 5
\overline{D}{}^0 K^+ \pi^-
                                                                                                                                                                                                                         \times 10^{-6} CL=90%
                                                            (8.8 \pm 1.7) \times 10^{-5}
                                                                                                                                       X(3872)^{-}K^{+}\times
                                                                                                                 2261
                                                                                                                                                                                        [uuu] < 4.2
    \overline{D}{}^{0}K^{*}(892)^{0}
                                                               4.2 \pm 0.6 ) \times\,10^{-5}
                                                                                                                 2213
                                                                                                                                            B(X(3872)^{-}
    D_2^*(24\dot{6}0)^{-'}K^+ \times
                                                            (1.8 \pm 0.5) \times 10^{-5}
                                                                                                                                            J/\psi(1S) \dot{\pi} \pi^0
                                                                                                                 2028
                                                                                                                                       X(3872)K^0 \times B(X \rightarrow
         B(D_2^*(2460)^- \to \overline{D}{}^0\pi^-)
                                                                                                                                                                                                  (4.3 \pm 1.3) \times 10^{-6}
                                                                                                                                                                                                                                                       1140
    \overline{D}{}^0\,K^+\,\pi^- non-resonant
                                                                                  \times 10^{-5} CL=90%
                                                                                                                                            J/\psi \pi^+ \pi^-
                                                          < 3.7
                                                                                                                                       X(3872) K^0 \times B(X \rightarrow J/\psi \gamma)
\overline{D}^0\pi^0
                                                                                                                                                                                                                         \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                       2.4
                                                                                                                                                                                                                                                        1140
                                                            (2.63 \pm 0.14) \times 10^{-4}
                                                                                                                 2308
                                                                                                                                                                                                                         \times\,10^{-6} CL=90%
\overline{D}^0 \rho^0
                                                                                                                                       X(3872) K^*(892)^0 \times B(X \to X)
                                                            (3.2 \pm 0.5) \times 10^{-4}
                                                                                                                                                                                                       2.8
                                                                                                                                                                                                                                                        940
                                                                                                                 2237
\overline{D}^0 f_2
                                                               1.2 \pm 0.4 \times 10^{-4}
                                                                                                                                            J/\psi \gamma)
\overline{D}^0 \eta
                                                                                                                                       X(3872)K^0 \times B(X \rightarrow
                                                                                                                                                                                                                         \times 10^{-6} \text{ CL} = 90\%
                                                                2.36 \pm 0.32) \times 10^{-4}
                                                                                                                 2274
                                                                                                                                                                                                      6.62
                                                                                                                                                                                                                                                       1140
\overline{D}^0 \dot{\eta}'
                                                            (1.38 \pm 0.16) \times 10^{-4}
                                                                                                                 2198
                                                                                                                                             \psi(2S)\gamma
                                                                                                  S = 1.3
\overline{D}^0\omega
                                                                                                                                       X(3872)K^*(892)^0 \times B(X \rightarrow
                                                                                                                                                                                                                         \times 10^{-6} \text{ CL} = 90\%
                                                               2.53 \!\pm\! 0.16) \times 10^{-4}
                                                                                                                                                                                                                                                        940
                                                                                                                                                                                                 < 4.4
                                                                                                                 2235
D^0 \phi
                                                                                                                                            \psi(2S)\gamma)
                                                                                  \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                1.16
                                                                                                                 2183
                                                                                                                                       X(3872)K^0 \times B(X \rightarrow
                                                           (6 \pm 4) \times 10^{-6}
                                                                                                                                                                                                  (1.7 \pm 0.8) \times 10^{-4}
                                                                                                                                                                                                                                                        1140
                                                                                                                 2261
                                                                                                                                            D^0 \overline{D}{}^0 \pi^0
                                                                                  \times\,10^{-5} CL=90%
    D^0 K^*(892)^0
                                                                                                                 2213
                                                          < 1.1
                                                                                                                                       X(3872) \overset{\checkmark}{K^0 \times} B(X \rightarrow \overline{D}^{*0} D^0)
                                                                                                                                                                                                  (1.2 \pm 0.4) \times 10^{-4}
\overline{D}^{*0} \gamma
                                                                                  \times\,10^{-5} CL=90%
                                                                                                                                                                                                                                                        1140
                                                                2.5
                                                                                                                 2258
\overline{D}^*(2007)^0 \pi^0
                                                           (2.2 \pm 0.6) \times 10^{-4}
                                                                                                                 2256
                                                                                                                                                                                                  (3.2 + 6.0 \times 10^{-5}) \times 10^{-5}
                                                                                                 S = 2.6
                                                                                                                                       X(4430)^{\pm} K^{\mp} \times B(X^{\pm} \rightarrow
                                                                                                                                                                                                                                                        621
\overline{D}^*(2007)^0 \rho^0
                                                                                  \times\,10^{-4} CL=90%
                                                                                                                 2182
                                                          < 5.1
                                                                                                                                            \psi(2S) \pi^{\pm})
\overline{D}^*(2007)^0 \eta
                                                           (2.3 \pm 0.6) \times 10^{-4}
                                                                                                                 2220
                                                                                                                                       X(4430)^{\pm}K^{\mp}\times B(X^{\pm}\rightarrow
                                                                                                                                                                                                                         \times 10^{-6} \text{ CL} = 95\%
                                                                                                                                                                                                 < 4
                                                                                                                                                                                                                                                        621
\overline{D}^*(2007)^0 \dot{\eta}'
                                                            (1.40 \pm 0.22) \times 10^{-4}
                                                                                                                 2141
                                                                                                                                            J/\psi \pi^{\pm})
\overline{D}^*(2007)^0 \pi^+ \pi
                                                            ( 6.2~\pm~2.2 ) \times\,10^{-4}
                                                                                                                 2248
                                                                                                                                       J/\psi(1S) p \overline{p}
                                                                                                                                                                                                                         \times\,10^{-7} CL=90%
\overline{D}^*(2007)^0 K^0
                                                           (3.6 \pm 1.2) \times 10^{-5}
                                                                                                                 2227
                                                                                                                                       J/\psi(1S)\gamma
                                                                                                                                                                                                                         \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                                                                                                                                       1731
                                                                                                                                                                                                     1.6
                                                                                                                                                                                                 /
\overline{D}^*(2007)^0 K^*(892)^0
                                                                                 \times 10^{-5} CL=90%
                                                                                                                                       J/\psi(1S)\dot{\overline{D}}^0
                                                          < 6.9
                                                                                                                 2157
                                                                                                                                                                                                                         \times\,10^{-5} CL=90%
                                                                                                                                                                                                      1.3
                                                                                                                                                                                                                                                        877
                                                                                  \times 10^{-5} CL=90%
D^*(2007)^0 K^*(892)^0
                                                          < 4.0
                                                                                                                 2157
                                                                                                                                       \psi(2S)K^{0}
                                                                                                                                                                                                  ( 6.2~\pm~0.5 ) \times\,10^{-4}
                                                                                                                                                                                                                                                        1283
D^*(2007)^0 \pi^+ \pi^+ \pi^- \pi^-
                                                               2.7 \pm 0.5 ) \times 10^{-3}
                                                                                                                                       \psi(3770) K^0 \times B(\psi \rightarrow \overline{D}{}^0 D^0)
                                                                                                                                                                                                                         \times\,10^{-4} CL=90%
                                                                                                                 2219
                                                                                                                                                                                                 < 1.23
                                                                                                                                                                                                                                                       1217
D^*(2010)^+ D^*(2010)^-
                                                            (8.2 \pm 0.9) \times 10^{-4}
                                                                                                                                       \psi(3770) K^0 \times B(\psi \rightarrow D^- D^+)
                                                                                                                                                                                                                         \times\,10^{-4}~\text{CL}\!=\!90\%
                                                                                                                 1711
                                                                                                                                                                                                      1.88
                                                                                                                                                                                                                                                       1217
\overline{D}^*(2007)^0 \omega
                                                            (\phantom{-}3.6\phantom{0}\pm\phantom{0}1.1\phantom{0})\times10^{-4\phantom{0}}
                                                                                                                 2180
                                                                                                                                       \psi(2S) K^{+} \pi^{-}
                                                                                                                                                                                                  (5.7 \pm 0.4) \times 10^{-4}
                                                                                                                                                                                                                                                       1238
D^*(2010)^+D^-
                                                           ( 6.1 \pm 1.5 ) \times 10^{-4}
                                                                                                                 1790
                                                                                                                                          \psi(2S) K^*(892)^0
                                                                                                                                                                                                      6.1~\pm~0.5~)\times10^{-4}
                                                                                                                                                                                                                                                       1116
D^*(2007)^0 \overline{D}^*(2007)^0
                                                                                 \times 10^{-5} CL=90%
                                                          < 9
                                                                                                                1715
                                                                                                                                       \chi_{c0}(1P)\,K^0
                                                                                                                                                                                                  ( 1.4 ^+ ^- 0.6 ) 	imes 10<sup>-4</sup>
                                                                                                                                                                                                                                                        1477
D^{-1}D^{0}K^{+}
                                                            (-1.07 \pm\ 0.11) \times 10^{-3}
                                                                                                                 1574
                                                                                                                                       \chi_{c0} \, K^* (892)^0
                                                                                                                                                                                                  (1.7 \pm 0.4) \times 10^{-4}
                                                                                                                                                                                                                                                       1341
D^-\,D^*(2007)^0\,K^+
                                                               3.5 \pm 0.4 \times 10^{-3}
                                                                                                                 1478
                                                                                                                                       \chi_{c2} K^0
                                                                                                                                                                                                                         \times\,10^{-5} CL=90%
D^*(2010) - D^0 K^+
                                                            (2.47 \pm 0.21) \times 10^{-3}
                                                                                                                                                                                                 < 1.5
                                                                                                                                                                                                                                                        1378
                                                                                                                 1479
D^*(2010)^- D^*(2007)^0 K^+ 
 D^- D^+ K^0
                                                                                                                                       \chi_{c2} K^* (892)^0
                                                                                                                                                                                                  (6.6 \pm 1.9) \times 10^{-5}
                                                                                                                                                                                                                                                        1228
                                                            (1.06 \pm 0.09) \%
                                                                                                                 1366
                                                                                                                                       \chi_{c1}(1P) \pi^{\bar{0}}
                                                                                                                                                                                                  (-1.12 \pm \ 0.28) \times 10^{-5}
                                                                                                                                                                                                                                                       1468
                                                               7.5 \pm 1.7 \times 10^{-4}
                                                                                                                 1568
                                                                                                                                       \chi_{c1}(1P)\overset{.}{K}^{0}
D^*(2010)^- D^+ K^0 +
                                                                                                                                                                                                      3.93 \pm 0.27) \times 10^{-4}
                                                                                                                                                                                                                                                       1411
                                                            ( 6.4~\pm~0.5 ) \times\,10^{-3}
                                                                                                                1473
                                                                                                                                       \chi_{c1}(1P)\,K^-\pi^+
                                                                                                                                                                                                  (3.8 \pm 0.4) \times 10^{-4}
                                                                                                                                                                                                                                                       1371
      D^- D^*(2010)^+ K^0
                                                            ( 8.1~\pm~0.7~)\times10^{-3}
                                                                                                                                          \chi_{c1}(1P)\,K^*(892)^0
D^*(2010)^- D^*(2010)^+ K^0
                                                                                                                                                                                                  (\quad 2.22^{\,+\,\phantom{0}0.40}_{\,-\,\phantom{0}0.31})\times 10^{-4}
                                                                                                                 1360
                                                                                                                                                                                                                                                       1265
                                                                                                                                                                                                                                        S=1.6
                                                            ( 8.0~\pm~2.4 ) \times\,10^{-4}
    D^{*-}D_{s1}(2536)^{+} \times
                                                                                                                 1336
                                                                                                                                                                                                  (\quad 3.0 \ ^{+}_{-} \ ^{4.0}_{1.8} \ )\times 10^{-5}
                                                                                                                                          X(4051)^+ K^- \times B(X^+ \rightarrow
         B(D_{s1}(2536)^{+} \rightarrow
                                                                                                                                                \chi_{c1} \pi^+)
         D^{*+}K^{0}
\overline{D}^0 D^0 K^0
                                                                                                                                                                                                  (4.0 \begin{array}{c} +20.0 \\ -1.0 \end{array}) \times 10^{-5}
                                                                                                                                           X(4248)^+ K^- \times B(X^+ \rightarrow
                                                            ( 2.7~\pm~1.1~)\times10^{-4}
                                                                                                                 1574
                                                                                                                                                \chi_{c1} \pi^+)
```

```
K or K* modes
                                                                                                                                                                                                                                   \times 10^{-5} CL=90%
                                                                                                                                             K_{S}^{0} K_{S}^{0} \pi^{0}
K_{S}^{0} K_{S}^{0} \eta
                                                                                                                                                                                                                                   \times 10^{-7} \text{ CL} = 90\%
                                                               (1.94 \pm 0.06) \times 10^{-5}
                                                                                                                     2615
                                                                                                                                                                                                         <
                                                                                                                                                                                                              9
                                                                                                                                                                                                                                                                  2578
K^{0}\pi^{0}
                                                                  9.5 \pm 0.8 ) \times 10<sup>-6</sup>
                                                                                                                     2615
                                                                                                      S = 1.3
                                                                                                                                                                                                                                   \times\,10^{-6} CL=90%
                                                                                                                                                                                                               1.0
                                                                                                                                                                                                                                                                   2515
                                                                                                                                                                                                         <
\eta' K^0
                                                                  6.6~\pm~0.4~)\times10^{-5}
                                                                                                                      2528
                                                                                                                                             K_S^0 K_S^0 \eta'
                                                                                                                                                                                                                                   \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                               2.0
                                                                                                                                                                                                                                                                   245 2
\eta' K^* (892)^0
                                                              (3.1 \pm 0.9) \times 10^{-6}
                                                                                                                      2472
                                                                                                                                             K^{\breve{0}}K^{\bar{+}}K^{\bar{-}}
                                                                                                                                                                                                               2.47 \!\pm\! 0.23) \times 10^{-5}
                                                                                                                                                                                                                                                                  2522
\eta' K_0^* (1430)^0
                                                              ( 6.3~\pm~1.6 ) \times\,10^{-6}
                                                                                                                     2346
                                                                                                                                                K^0 \phi
                                                                                                                                                                                                           ( 8.6 ^+_- ^{1.3}_{1.1} ) \times\,10^{-6}
                                                                                                                                                                                                                                                                   2516
\eta' K_2^* (1430)^0
                                                              (1.37 \pm 0.32) \times 10^{-5}
\eta K^0
                                                                                                                                             K_{S}^{0}K_{S}^{0}K_{S}^{0}
                                                                                                                                                                                                           (\phantom{-}6.2\ ^{+}\phantom{0}\overset{1.2}{\phantom{0}}\phantom{0})\times10^{-6}
                                                              (1.23^{+}_{-}0.27_{0.24}) \times 10^{-6}
                                                                                                                                                                                                                                                                   2521
                                                                                                                      2587
                                                                                                                                             K_{5}^{0}K_{5}^{0}K_{1}^{0}
                                                                                                                                                                                                                                  \times\,10^{-5} CL=90%
\eta K^*(892)^0
                                                              (1.59 \pm 0.10) \times 10^{-5}
                                                                                                                                                                                                         < 1.6
                                                                                                                                                                                                                                                                   2521
                                                                                                                      2534
\eta K_0^* (1430)^0
                                                              (-1.10\!\pm\ 0.22)\times 10^{-5}
                                                                                                                                             K^*(892)^{0}K^+K^-
                                                                                                                                                                                                           (-2.75\pm\ 0.26)\times 10^{-5}
                                                                                                                                                                                                                                                                   2467
                                                                                                                     2415
                                                                                                                                                K^*(892)^0 \phi
                                                                                                                                                                                                               9.8 \pm 0.6 \times 10^{-6}
\eta K_2^* (1430)^0
                                                              (9.6 \pm 2.1) \times 10^{-6}
                                                                                                                                                                                                                                                                   2460
                                                                                                                      2414
\omega K^{0}
                                                              ( 5.0~\pm~0.6 ) \times\,10^{-6}
                                                                                                                                             K^+K^-\pi^+\pi^- nonresonant
                                                                                                                                                                                                               7.17
                                                                                                                                                                                                                                  \times 10^{-5} CL=90%
                                                                                                                                                                                                                                                                   2559
                                                                                                                      2557
                                                                                                                                             K^*(892)^0 K^- \pi^+
                                                                                                                                                                                                           ( 4.5 \pm 1.3 ) \times\,10^{-6}
                                                                                                                                                                                                                                                                   2524
a_0(980)^0 K^0 \times B(a_0(980)^0 \rightarrow
                                                                  7.8
                                                                                                                                                \hat{K}^*(892)^0 \overline{K}^*(892)^0
                                                                                                                                                                                                               8 \pm 5) \times 10^{-7}
     (\eta \pi^{0})
                                                                                                                                                                                                                                                S=2.2
                                                                                                                                                                                                                                                                   2485
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
b_1^0 \overset{.}{K^0} \times B(b_1^0 \rightarrow \omega \pi^0)
                                                                                      \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                             K^+K^+\pi^-\pi^- nonresonant
                                                                                                                                                                                                         <
                                                                                                                                                                                                               6.0
                                                                                                                                                                                                                                                                   2559
                                                                 7.8
                                                                                                                                             K^*(892)^0 K^+ \pi^-
                                                                                                                                                                                                               2.2
                                                                                                                                                                                                                                  \times\,10^{-6} CL=90%
                                                                                                                                                                                                                                                                   2524
                                                                                      \times\,10^{-6}~\text{CL}\!=\!90\%
a_0(980)^{\pm} K^{\mp} \times B(a_0(980)^{\pm} \rightarrow
                                                            < 1.9
                                                                                                                                                \hat{K}^*(892)^0 K^*(892)^0
                                                                                                                                                                                                                                   \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                                                                               2
                                                                                                                                                                                                                                                                  2485
     \eta \pi^{\pm})
                                                                                                                                                                                                                                   \times\,10^{-6} CL=90%
                                                                                                                                             K*(892)+ K*(892)-
                                                                                                                                                                                                               2.0
                                                                                                                                                                                                                                                                   2485
b_1^- \dot{K}^+ \times B(b_1^- \rightarrow \omega \pi^-)
                                                              (7.4 \pm 1.4) \times 10^{-6}
                                                                                                                                             K_1(1400)^0 \phi
                                                                                                                                                                                                                                   \times 10^{-3} \text{ CL} = 90\%
                                                                                                                                                                                                               5.0
                                                                                                                                                                                                                                                                  2339
b_1^{\bar{0}} K^{*0} \times B(b_1^{\bar{0}} \to \omega \pi^0)
                                                                                      \times\,10^{-6} CL=90%
                                                             < 8.0
                                                                                                                                            \phi(K\pi)_0^{*6}
                                                                                                                                                                                                           ( 4.3~\pm~0.7~)\times10^{-6}
b_1^- K^{*+} \times \mathsf{B}(\bar{b}_1^- \to \omega \pi^-)
                                                                                      \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                             \begin{array}{lll} & \phi \left( K \pi \right)_0^{*0} \left( 1.60 < m_{K\pi} < 2.15 \right) [zzz] < & 1.7 \\ K_0^* (1430)^0 \ K^- \ \pi^+ & < & 3.18 \end{array}
                                                                  5.0
                                                                                                                                                                                                                                  \times\,10^{-6} CL=90%
a_0(1450)^{\pm} K^{\mp} \times
                                                                                      \times\,10^{-6} CL=90%
                                                                  3.1
                                                                                                                                                                                                                                   \times\,10^{-5} CL=90%
\begin{array}{c} \mathsf{B}(\mathsf{a}_0(1450) \xrightarrow{\mathsf{K}} \to \eta \pi^{\pm}) \\ \mathsf{K}_S^0 X^0 \text{ (Familion)} \end{array}
                                                                                                                                                                                                               3.18
                                                                                                                                                K_0^*(1430)^0\overline{K}^*(892)^0
                                                                                                                                                                                                                                  \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                               3.3
                                                                                                                                                                                                                                                                  2360
                                                                                      \times\,10^{-5} CL=90%
                                                                                                                                                 K_0^*(1430)^0\overline{K}_0^*(1430)^0
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                                                                                               8.4
                                                                                                                                                                                                                                                                   2222
\omega K^*(892)^0
                                                             ( 2.0~\pm~0.5 ) \times\,10^{-6}
                                                                                                                      2503
                                                                                                                                             K_0^*(1430)^0 \phi
                                                                                                                                                                                                           ( 3.9~\pm~0.8~)\times10^{-6}
\omega (K\pi)_0^{*0}
                                                              (1.84 \pm 0.25) \times 10^{-5}
                                                                                                                                             K_0^*(1430)^0 K^*(892)^0
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                                                                                         < 1.7
                                                                                                                                                                                                                                                                  2360
\omega K_0^* (1430)^0
                                                              (1.60\pm0.34)\times10^{-5}
                                                                                                                      2380
                                                                                                                                             K_0^*(1430)^0 K_0^*(1430)^0
                                                                                                                                                                                                                                  \times 10^{-6} CL=90%
\omega K_{2}^{*}(1430)^{0}
                                                                                                                                                                                                         <
                                                                                                                                                                                                               4.7
                                                                                                                                                                                                                                                                   2222
                                                              (-1.01 \pm \ 0.23) \times 10^{-5}
                                                                                                                      2380
                                                                                                                                             K^{*}(1680)^{0}\phi
                                                                                                                                                                                                                                   \times\,10^{-6} CL=90%
                                                                                                                                                                                                               3.5
                                                                                                                                                                                                                                                                   2238
                                                              ( 5.1~\pm~1.0 ) \times\,10^{-6}
\omega \, K^+ \, \pi^- nonresonant
                                                                                                                      2542
                                                                                                                                                                                                                                   \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                             K^*(1780)^0 \phi
                                                                                                                                                                                                               2.7
K^{+}\pi^{-}\pi^{0}
                                                              (3.78 \pm 0.32) \times 10^{-5}
                                                                                                                      2609
                                                                                                                                             K^*(2045)^0 \phi
                                                                                                                                                                                                                                   \times 10^{-5} CL=90%
                                                                                                                                                                                                         <
                                                                                                                                                                                                               1.53
    K^+ \rho^-
                                                              (7.0 \pm 0.9) \times 10^{-6}
                                                                                                                      2559
                                                                                                                                             K_2^*(1430)^0 \rho^0
                                                                                                                                                                                                                                   \times\,10^{-3} CL=90%
                                                                                                                                                                                                               1.1
                                                                                                                                                                                                                                                                  2381
    K^{+} \rho (1450)^{-}
                                                                  2.4~\pm~1.2~)\times10^{-6}
                                                                                                                                                                                                           ( 7.5 \pm 1.0 ) \times\,10^{-6}
                                                                                                                                             K_2^*(1430)^0 \phi
                                                              (\phantom{-}6\phantom{0}\pm\phantom{7}\phantom{0})\times10^{-7}
                                                                                                                                                                                                                                                                  2333
    K^+ \rho (1700)^-
                                                                                                                                             K^{0}\phi\phi
                                                                                                                                                                                                           ( 4.5 \pm 0.9 ) \times 10<sup>-6</sup>
                                                              (2.8 \pm 0.6) \times 10^{-6}
    (K^{+}\pi^{-}\pi^{0}) non-resonant
                                                                                                                                            \eta'\eta'\dot{K}^0
    (K\pi)_0^{*+}\pi^-\times B((K\pi)_0^{*+}\to
                                                                                                                                                                                                                                  \times 10^{-5} CL=90%
                                                              (3.4 \pm 0.5) \times 10^{-5}
                                                                                                                                                                                                         < 3.1
                                                                                                                                                                                                                                                                  2337
                                                                                                                                            \eta K^0 \gamma
                                                                                                                                                                                                              7.6 \pm 1.8 ) \times\,10^{-6}
         K^+\pi^0)
                                                                                                                                                                                                                                                                  2587
                                                                                                                                            \eta' K^0 \gamma
    (K\pi)_0^{*0}\pi^0 \times B((K\pi)_0^{*0} \rightarrow
                                                                                                                                                                                                                                 \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                         < 6.4
                                                                                                                                                                                                                                                                   2528
                                                              (8.6 \pm 1.7) \times 10^{-6}
                                                                                                                                             K^0 \phi \gamma
                                                                                                                                                                                                           (2.7 \pm 0.7) \times 10^{-6}
                                                                                                                                                                                                                                                                   2516
         K^{+}\pi^{-}
                                                                                                                                             K^+\pi^-
    K_2^*(1430)^0 \pi^0
                                                                                                                                                                                                              4.6 \pm 1.4 ) \times 10^{-6}
                                                                                                                                                                                                                                                                  2615
                                                                                      \times\,10^{-6}~\text{CL}\!=\!90\%
                                                             < 4.0
                                                                                                                      2445
                                                                                                                                             K^*(892)^0 \gamma
                                                                                                                                                                                                           (4.33\pm0.15)\times10^{-5}
    K^{\bar{*}}(1680)^{0}\pi^{0}
                                                                                      \times\,10^{-6} CL=90%
                                                             < 7.5
                                                                                                                                                K^*(1410)\gamma
                                                                                                                                                                                                                                  \times 10^{-4} \text{ CL} = 90\%
                                                                                                                                                                                                         < 1.3
                                                                                                                                                                                                                                                                   2451
K_X^{*0}\pi^0
K^0\pi^+\pi^- charmless
                                                    [xxx] ( 6.1 \pm 1.6 ) \times 10<sup>-6</sup>
                                                                                                                                                                                                                                   \times 10^{-6} CL=90%
                                                                                                                                                 K^+\pi^-\gamma nonresonant
                                                                                                                                                                                                               2.6
                                                                                                                                                                                                                                                                   2615
                                                              (4.96 \pm 0.20) \times 10^{-5}
                                                                                                                      2609
                                                                                                                                             K^*(892)^0 X(214) \times B(X \to
                                                                                                                                                                                                                                  \times\,10^{-8} CL=90%
                                                                                                                                                                                                               2.26
                                                                                                                                                                                              [aaaa] <
                                                              (1.47^{+}_{-})^{0.40}_{0.26}) \times 10^{-5}
    K^0\pi^+\pi^- non-resonant
                                                                                                      S = 2.1
                                                                                                                                                  \mu^{+}\mu^{-}
                                                                                                                                             K^{0}\pi^{+}\pi^{-}
                                                                                                                                                                                                           (1.95 \pm 0.22) \times 10^{-5}
                                                                                                                                                                                                                                                                  2609
    K^0 \rho^0
                                                              ( 4.7~\pm~0.6 ) \times\,10^{-6}
                                                                                                                      255.8
                                                                                                                                             K^+\pi^-\pi^0\gamma
                                                                                                                                                                                                           ( 4.1 \pm 0.4) \times 10^{-5}
                                                                                                                                                                                                                                                                   2609
    K^*(892)^+\pi^-
                                                              (8.4 \pm 0.8) \times 10^{-6}
                                                                                                                      2563
                                                                                                                                             K_1(1270)^{0'}\gamma
                                                                                                                                                                                                                                  \times\,10^{-5}~\text{CL}\!=\!90\%
                                                              ( 3.3~\pm~0.7 ) \times\,10^{-5}
                                                                                                                                                                                                         < 5.8
                                                                                                                                                                                                                                                                  2486
    K_0^*(1430)^+\pi^-
                                                                                                      S = 2.0
                                                                                                                                             K_1(1400)^0 \gamma
                                                                                                                                                                                                                                   \times\,10^{-5} CL=90%
                                                                                                                                                                                                               1.2
                                                                                                                                                                                                                                                                  2453
    K_{x}^{*+}\pi^{-}
                                                    [xxx] ( 5.1 \pm 1.6 ) \times 10<sup>-6</sup>
                                                                                                                                             K_2^*(1430)^0 \gamma
                                                                                                                                                                                                           (1.24 \pm 0.24) \times 10^{-5}
                                                                                                                                                                                                                                                                   2447
                                                                                     \times\,10^{-6}~\text{CL}\!=\!90\%
    K^*(1410)^+\pi^-\times
                                                             < 3.8
                                                                                                                                             K^{*}(1680)^{0}\gamma
                                                                                                                                                                                                                                  \times\,10^{-3} CL=90%
                                                                                                                                                                                                             2.0
                                                                                                                                                                                                                                                                   2361
         B(K^*(1410)^+ \to K^0\pi^+)
                                                                                                                                             K_3^*(1780)^0 \gamma
                                                                                                                                                                                                                                  \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                                                                                                                                                               8.3
                                                                                                                                                                                                                                                                   2341
                                                                                                                                                                                                         <
    f_0(980) \, \dot{K}^0 \times \, \dot{B}(f_0(980) \rightarrow
                                                              ( 7.0 \pm 0.9 ) \times 10^{-6}
                                                                                                                      2522
                                                                                                                                             K_{4}^{*}(2045)^{0}\gamma
                                                                                                                                                                                                                                   \times 10^{-3} CL=90%
                                                                                                                                                                                                               4.3
                                                                                                                                                                                                                                                                  2244
         \pi^{+}\pi^{-}
                                                                                                                                                                                  Light unflavored meson modes
    f_2(1270)K^0
                                                              (2.7 + 1.3 \times 10^{-6}) \times 10^{-6}
                                                                                                                                                                                                         ( 8.6 \pm 1.5 ) \times 10^{-7}
                                                                                                                                                                                                                                                                   2583
    f_X(1300) K^0 \times B(f_X \rightarrow
                                                              ( 1.8~\pm~0.7 ) \times\,10^{-6}

ho^0 X(214) 	imes {\sf B}(X 	o \mu^+ \mu^-) \ \ [aaaa] < 1.73
                                                                                                                                                                                                                                  \times 10^{-8} \text{ CL} = 90\%
\pi^{+}\pi^{-})
K^{*}(892)^{0}\pi^{0}
                                                             (3.3 \pm 0.6) \times 10^{-6}
                                                                                                                                                                                                               4.4 \begin{array}{c} + & 1.8 \\ - & 1.6 \end{array}) \times 10^{-7}
                                                                                                                      2563
                                                                                                                                            \omega \gamma
                                                                                                                                                                                                                                                                   2582
K_2^*(1430)^+\pi^-
                                                                                      \times 10^{-6} \text{ CL} = 90\%
                                                                                                                     2445
                                                            < 6
                                                                                                                                                                                                                                  \times\,10^{-7} CL=90%
                                                                                                                                            \phi \gamma
                                                                                                                                                                                                               8.5
                                                                                                                                                                                                                                                                   2541
                                                                                      \times 10^{-5} CL=90%
K^{*}(1680)^{+}\pi^{-}
                                                            < 1.0
                                                                                                                      2358
                                                                                                                                            \pi^{+}\pi^{-}
\pi^{0}\pi^{0}
                                                                                                                                                                                                                5.15 \pm \ 0.22) \times 10^{-6}
                                                                                                                                                                                                                                                                   2636
                                                    [yyy] < 2.3
                                                                                      \times 10^{-4} CL=90%
K^{+}\pi^{-}\pi^{+}\pi^{-}
                                                                                                                     2600
                                                                                                                                                                                                               1.62 \!\pm\! 0.31) \times 10^{-6}
                                                                                                                                                                                                                                                                   2636

ho^0 \, K^+ \, \pi^-
                                                              ( 2.8 \pm 0.7 ) \times 10^{-6}
                                                                                                                                            \eta \pi^{0}
                                                                                                                      2543
                                                                                                                                                                                                                                  \times\,10^{-6} CL=90%
                                                                                                                                                                                                         < 1.5
                                                                                                                                                                                                                                                                  261.0
                                                              ( 1.4 \ ^{+} \ ^{0.5} _{-} ) \times 10^{-6}
                                                                                                                                                                                                                                   \times\,10^{-6} CL=90%
    f_0(980) K^+ \pi^-
                                                                                                                      2506
                                                                                                                                            \eta\eta
                                                                                                                                                                                                               1.0
                                                                                                                                                                                                                                                                   2582
                                                                                                                                            \eta^{'}\pi^0
                                                                                                                                                                                                           (1.2 \pm 0.6) \times 10^{-6} S=1.7
                                                                                                                                                                                                                                                                  2551
                                                                                    \times 10^{-6}
    K^+\pi^-\pi^+\pi^- nonresonant
                                                            < 2.1
                                                                                                                      2600
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                            \eta' \eta'
                                                                                                                                                                                                               17
                                                                                                                                                                                                                                                                  2460
    K^*(892)^0\pi^+\pi^-
                                                              ( 5.5 \pm 0.5 ) \times 10<sup>-5</sup>
                                                                                                                      2557
                                                                                                                                                                                                                                   \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                            {\eta' \, \eta \atop \eta' \, \rho^0}
                                                                                                                                                                                                                                                                   2523
                                                                                                                                                                                                               1.2
        K^*(892)^0 \rho^0
                                                              (3.4 + 1.7 \atop -1.3) \times 10^{-6}
                                                                                                                      2504
                                                                                                                                                                                                                                  \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                               1.3
                                                                                                                                                                                                                                                                  2492
        K^*(892)^0 f_0(980)
                                                                                      \times\,10^{-6} CL=90%
                                                                                                                                                                                                                                  \times 10^{-7} CL=90%
                                                             < 22
                                                                                                                                             \eta' f_0(980) \times B(f_0(980) \rightarrow
                                                                                                                     2466
                                                                                                                                                                                                               9
                                                                                                                                                                                                                                                                   2454
    K_1(1270)^+\pi^-
                                                                  3.0
                                                                                      \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                                                                      2484
    K_1(1400)^+\pi^-
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                      \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                  2.7
                                                                                                                     2451
                                                                                                                                                                                                                                                                   2553
                                                                                                                                                                                                              1.5
                                                    [yyy] ( 1.6 \pm 0.4 ) \times 10<sup>-5</sup>
                                                                                                                                            \eta f_0(980) \times B(f_0(980) \to
                                                                                                                                                                                                                                  \times 10^{-7} \text{ CL} = 90\%
    a_1(1260)^-K^+
                                                                                                                      2471
                                                                                                                                                                                                               4
                                                                                                                                                                                                                                                                  2516
K^*(892)^+ \rho
                                                                                      \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                  1.20
                                                                                                                      2504
                                                                                                                                                  \pi^{+}\pi^{-}
K_1(1400)^0 \rho^0
                                                                                      \times\,10^{-3} CL=90%
                                                                  3.0
                                                                                                                     2388
                                                                                                                                                                                                           (9.4 + 4.0 \ ) \times 10^{-7}
                                                                                                                                                                                                                                                                  2552
                                                                                                                                            \omega n
                                                                                      ×10<sup>-7</sup> CL=90%
K^+K^-
                                                                  4.1
                                                                                                                      2593
                                                                                                                                                                                                           (1.0 \begin{array}{cc} + & 0.5 \\ - & 0.4 \end{array}) \times 10^{-6}
                                                                                                                                            \omega \eta'
                                                                                                                                                                                                                                                                  2491
K^0 \overline{K}^0
                                                              (\phantom{-}9.6 \ ^{+}_{-} \ ^{2.0}_{1.8} \ ) \times 10^{-7}
                                                                                                                      2592
                                                                                                                                            \omega \rho^0
                                                                                                                                                                                                                                  \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                                                                                         <
                                                                                                                                                                                                               1.6
K^0\,K^-\,\pi^+
                                                             ( 6.4 \pm 1.2 ) \times 10<sup>-6</sup>
                                                                                                                      2578
                                                                                                                                                                                                                                  \times\,10^{-6} CL=90%
                                                                                                                                            \omega f_0(980) \times B(f_0(980) \rightarrow
                                                                                                                                                                                                                                                                  2485
                                                                                                                                                                                                               1.5
\overline{K}^{*0}K^0 + K^{*0}\overline{K}^0
                                                                                      \times 10^{-6}
                                                                  1.9
                                                                                                                                                  \pi^{+}\pi^{-}
```

```
\times\,10^{-6} CL=90%
                                                                                                                                                        \overline{\Lambda}_{c}^{-} p \pi^{+} \pi^{-}
                                                                                                                                                                                                                            (1.3 \pm 0.4) \times 10^{-3}
                                                                        4.0
                                                                                                                                2521
ωω
                                                                  <
\phi \pi^0
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                  <
                                                                        2.8
                                                                                                                               2540
                                                                                                                                                        \overline{\Lambda}_{c}^{-} p
                                                                                                                                                                                                                                2.0 \pm 0.4) \times 10^{-5}
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                        \overline{\Lambda}_c^- p \pi^0
\phi \eta
                                                                        5
                                                                                                                                2511
                                                                                                                                                                                                                            (1.9 \pm 0.5) \times 10^{-4}
                                                                                             \times 10^{-7} \text{ CL} = 90\%
\phi n'
                                                                                                                               2448
                                                                  <
                                                                        5
                                                                                                                                                                                                                                                     \times\,10^{-5}
                                                                                                                                                         \Sigma_c(2455)^- p
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                3.0
\phi \dot{\rho}^0
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                        3.3
                                                                                                                               2480
                                                                                                                                                        \overline{\Lambda}_c^- p \pi^+ \pi^- \pi^0
                                                                                                                                                                                                                                                     \times\,10^{-3}~\text{CL}\!=\!90\%
                                                                                                                                                                                                                                 5.07
\phi f_0(980) \times B(f_0 \to \pi^+ \pi^-)
                                                                        3.8
                                                                                             \times 10<sup>-7</sup> CL=90%
                                                                                                                                2441
                                                                                                                                                        \overline{\Lambda}_{c}^{-} p \pi^{+} \pi^{-} \pi^{+} \pi^{-}
                                                                                                                                                                                                                                                     \times\,10^{-3} CL=90%
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                2.74
                                                                                             \times 10^{-6} CL=90%
                                                                  <
                                                                        1.2
                                                                                                                               2479
                                                                                                                                                        \overline{\Lambda}_c^- p \pi^+ \pi^-
                                                                                                                                                                                                                            (1.12\pm\ 0.32)\times10^{-3}
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                        2
                                                                                                                                2435
                                                                                                                                                             \overline{\Lambda}_{c}^{-} p \pi^{+} \pi^{-}  (nonresonant)
                                                                                                                                                                                                                            (6.4 \pm 1.9) \times 10^{-4}
a_0(980)^{\pm}\pi^{\mp}\times B(a_0(980)^{\pm}\to
                                                                        3.1
                                                                                             \times\,10^{-6} CL=90%
                                                                                                                                                             \overline{\Sigma}_{c}(2520)^{--}p\pi^{+}
                                                                                                                                                                                                                            ( 1.2 \pm 0.4) \times 10^{-4}
     \eta \pi^{\pm})
a_0(1450)^{\pm}\pi^{\mp} \times
                                                                                                                                                            \overline{\Sigma}_c(2520)^0 p \pi^-
                                                                                             \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                                                                                                3.8
                                                                                                                                                                                                                                                     \times 10^{-5} CL=90%
                                                                                                                                                                                                                          <
                                                                        2.3
                                                                                                                                                                c(2455)^{0}p\pi^{-}
     B(a_0(1450)^{\pm} \to \eta \pi^{\pm})
                                                                                                                                                                                                                            ( 1.5~\pm~0.5 ) \times\,10^{-4}
\pi^{+} \pi^{-} \pi^{0}
\rho^{0} \pi^{0}
                                                                                                                                                                 \frac{\overline{\Sigma}}{\Sigma}_c(2455)^0 N^0 \times B(N^0 \rightarrow
                                                                                                                                                                                                                            ( 8.0~\pm~2.9~)\times10^{-5}
                                                                                             \times\,10^{-4} CL=90%
                                                                  < 7.2
                                                                                                                                2631
                                                                   ( 2.0~\pm~0.5 ) \times\,10^{-6}
                                                                                                                                                                      p\pi^{-})
                                                                                                                                25.81
    \rho^{\mp}\pi^{\pm}
                                                                                                                                                            \overline{\Sigma}_c(2455)^{-1}
                                                                                                                                                                                 -p\pi^+
                                                                                                                                                                                                                            (2.2 \pm 0.7) \times 10^{-4}
                                                          [ee] (2.30\pm~0.23)\times10^{-5}
                                                                                                                                2581
                                                                                                                                                         \Lambda_{c}^{-} p K^{+} \pi^{-}
\Sigma_{c} (2455)^{--} p K^{+} \times
                                                                                             \times\,10^{-5} CL=90%
                                                                                                                                                                                                                            ( 4.3~\pm~1.4 ) \times\,10^{-5}
     \pi^{-}\pi^{+}\pi^{-}
                                                                 < 1.93
                                                                                                                               2621
    \rho^0 \pi^+ \pi
                                                                                             \times\,10^{-6} CL=90%
                                                                                                                                                                                                                            (1.1 \pm 0.4) \times 10^{-5}
                                                                  < 8.8
                                                                                                                               2575
    \rho^0 \rho^0
                                                                   ( 7.3 \pm 2.8) \times 10^{-7}
                                                                                                                                2523
                                                                                                                                                                  B(\overline{\Sigma}_c^{--} \to \overline{\Lambda}_c^- \pi^-)
    f_0(980)\pi^+\pi^-
                                                                                             \times\,10^{-6} CL=90%
                                                                        3.8
                                                                                                                               2539
                                                                                                                                                            \Lambda_c^- p K^* (892)^0
                                                                                                                                                                                                                                                     \times 10^{-5} CL=90%
                                                                                                                                                                                                                                2.42
                                                                                                                                                                                                                          <
                                                                                             \times\,10^{-7} CL=90%
     \rho^0 f_0(980) \times B(f_0(980) \rightarrow
                                                                  <
                                                                        3
                                                                                                                               2486
                                                                                                                                                        \frac{\overline{\Lambda}_c^-}{\overline{\Lambda}_c^-} \stackrel{\circ}{\Lambda_c^+} K^+
                                                                                                                                                                                                                                3.8 \pm 1.3 ) \times\,10^{-5}
                                                                                                                                                                                                                            (
          \pi^{+}\pi^{-}
                                                                                                                                                                                                                                                      \times\,10^{-5} CL=90%
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                6.2
                                                                                             \times 10^{-7} \text{ CL} = 90\%
     f_0(980) f_0(980) \times
                                                                       1
                                                                                                                                2447
                                                                                                                                                        \frac{\overline{\Lambda}_c}{\overline{\Lambda}_c(2593)^-} / \overline{\Lambda}_c(2625)^- p
\overline{\Xi}_c^- \Lambda_c^+ \times B(\overline{\Xi}_c^- \to \overline{\Xi}^+ \pi^- \pi^-)
\Lambda_c^+ \Lambda_c^- K^0
                                                                                                                                                                                                                                                     \times 10^{-4} \text{ CL} = 90\%
                                                                                                                                                                                                                                1.1
          B^2(f_0(980) \to \pi^+\pi^-)
                                                                                                                                                                                                                            ( 2.2~\pm~2.3~)\times10^{-5}
f_0(980) f_0(980) \times B(f_0 \rightarrow
                                                                                             \times\,10^{-7} CL=90%
                                                                  < 2.3
                                                                                                                                2447
                                                                                                                                                                                                                            ( 5.4~\pm~3.2~)\times10^{-4}
     \pi^+\pi^-) \times B(f_0 \rightarrow K^+K^-)
    a_1(1260)^{\mp}\pi^{\pm}
                                                          [ee] ( 3.3 \pm 0.5 ) \times\,10^{-5}
                                                                                                                                2494
                                                                                                                                                            Lepton Family number (LF) or Lepton number (L) or Baryon number (B)
    a_2(1320)^{\mp}\pi^{\pm}
                                                                                             \times\,10^{-4} CL=90%
                                                          [ee] < 3.0
                                                                                                                                2473
                                                                                                                                                                 violating modes, or/and \Delta B = 1 weak neutral current (B1) modes
\pi^{+} \pi^{-} \pi^{0} \pi^{0}
                                                                                             \times\,10^{-3} CL=90%
                                                                       3.1
                                                                                                                               2622
                                                                                                                                                                                                                          < 3.2
                                                                                                                                                                                                                                                     \times\,10^{-7} CL=90%
                                                                                                                                                                                                         В1
    \rho^+ \rho^-
                                                                   (-2.42 \pm\ 0.31) \times 10^{-5}
                                                                                                                                2523
                                                                                                                                                         e^+e^-
                                                                                                                                                                                                                                                     \times 10^{-8} \text{ CL} = 90\%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                8.3
    a_1(1260)^0 \pi^0
                                                                                             \times 10^{-3} \text{ CL} = 90\%
                                                                 <
                                                                        1.1
                                                                                                                                2495
                                                                                                                                                                                                                                                      \times 10^{-7} CL=90%
                                                                                                                                                        e^+e^-\gamma
                                                                                                                                                                                                         R1
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                1.2
   \omega\,\pi^0
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                2580
                                                                 <
                                                                        5
                                                                                                                                                        \mu^{+} \mu^{-}
                                                                                                                                                                                                                                                     \times\,10^{-9} CL=90%
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                                1.4
\pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0}
                                                                                             \times 10^{-3} \text{ CL} = 90\%
                                                                        9.0
                                                                                                                               2609
                                                                                                                                                        \mu^+ \mu^- \gamma
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                                                     \times\,10^{-7}~\text{CL}\!=\!90\%
                                                                                                                                                                                                                                1.6
                                                                                                                                                                                                                          <
    a_1(1260)^+ \rho^-
                                                                                             \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                 <
                                                                        6.1
                                                                                                                                2433
                                                                                                                                                        \tau^+\tau^-
                                                                                                                                                                                                                                                      \times\,10^{-3} CL=90%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                                 4.1
    a_{1}(1260)^{0} \rho^{0}
                                                                                             \times 10^{-3} CL = 90\%
                                                                        2.4
                                                                                                                                2433
                                                                                                                                                         \pi^0 \ell^+ \ell^-
                                                                                                                                                                                                                                                      \times\,10^{-7} CL=90%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                                 1.2
                                                                   (-1.09\!\pm\ 0.15)\times 10^{-5}
        F\pi^{\pm} \times B(b_1^{\mp} \rightarrow \omega \pi^{\mp})
                                                                                                                                                            \pi^0\,e^+\,e^-
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                                                     \times\,10^{-7} CL=90%
                                                                                                                                                                                                                                1.4
                                                                                                                                                                                                                          <
b_1^0 \pi^0 \times \mathsf{B}(b_1^0 \to \omega \pi^0)
                                                                 < 1.9
                                                                                             \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                            \pi^0 \mu^+ \mu^-
                                                                                                                                                                                                                                                      \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                1.8
b_1^- \rho^+ \times \mathsf{B}(b_1^- \to \omega \pi^-)
                                                                                             \times\,10^{-6}~\text{CL}\!=\!90\%
                                                                                                                                                         \pi^0 \nu \overline{\nu}
                                                                        1.4
                                                                 <
                                                                                                                                                                                                                                                      \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                2.2
                                                                                                                                                                                                         В1
b_1^{0} \rho^0 \times B(b_1^{0} \rightarrow \omega \pi^0)
                                                                                             \times\,10^{-6} CL=90%
                                                                        3.4
                                                                                                                                                         K^0\ell^+\ell^-
                                                                                                                                                                                                                [ppp] \quad (3.1 \ \frac{+}{-} \ 0.8 \ ) \times 10^{-7}
                                                                                                                                                                                                         В1
                                                                                             \times 10^{-3} \text{ CL} = 90\%
\pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{-}
                                                                        3.0
                                                                                                                                2592
                                                                                                                                                            K^0 e^+ e^-
    a_1(1260)^+ a_1(1260)^- \times
                                                                   (-1.18 \pm \ 0.31) \times 10^{-5}
                                                                                                                                                                                                                            (1.6 \ ^{+}_{-} \ ^{1.0}_{0.8}) \times 10^{-7}
                                                                                                                                                                                                         B1
                                                                                                                                2336
                                                                                                                                                            K^0\,\mu^+\,\mu^-
          B^2(a_1^+ \to 2\pi^+\pi^-)
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                            (\phantom{-}3.8\ \pm\ 0.8\ )\times 10^{-7}
                                                                                                                                                         K^0 \nu \overline{\nu}
\pi^{+} \pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{-} \pi^{-} \pi^{0}
                                                                                                          CL=90%
                                                                                                                                                                                                                                                     \times\,10^{-5} CL=90%
                                                                 < 1.1
                                                                                             %
                                                                                                                                2572
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                          < 5.6
                                                                                                                                                        \rho^0 \nu \overline{\nu}
                                                                                                                                                                                                                                                     \times 10^{-4} CL=90%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                4.4
                                                       Baryon modes
                                                                                                                                                         K^*(892)^0 \ell^+ \ell^-
                                                                                                                                                                                                                [ppp] (9.9 + 1.2 \atop -1.1) \times 10^{-7}
                                                                                                                                                                                                         В1
                                                                                             \times\,10^{-7} CL=90%
                                                                 < 1.1
                                                                                                                                2467
p \overline{p} \pi^+ \pi^-
                                                                                             \times 10^{-4} \text{ CL} = 90\%
                                                                  < 2.5
                                                                                                                               2406
                                                                                                                                                             K^*(892)^0 e^+ e^-
                                                                                                                                                                                                                            (1.03^{+}_{-}0.19^{0.19})\times 10^{-6}
                                                                                                                                                                                                         В1
p\overline{p}K^0
                                                                   (-2.66 \pm \ 0.32) \times 10^{-6}
                                                                                                                               2347
                                                                                                                                                            K^*(892)^0 \mu^+ \mu^-
                                                                                                                                                                                                                                1.06 \pm \ 0.10) \times 10^{-6}
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                            (
                                                                                             \times\,10^{-8} CL=90%
     \Theta(1540)^{+}\overline{p}\times
                                                      [bbbb] <
                                                                                                                                                         K^*(892)^0 \nu \overline{\nu}
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                                1.2
                                                                                                                                                                                                                                                     \times\,10^{-4}~\text{CL}\!=\!90\%
                                                                                                                                                                                                                          <
          B(\Theta(1540)^+ \rightarrow pK_S^0)
                                                                                                                                                                                                                                                     \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                                                                                                        \phi \nu \overline{\nu}
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                                5.8
                                                                                                                                                                                                                          <
     f_J(2220) K^0 \times B(f_J(2220) \rightarrow
                                                                                             \times\,10^{-7}~\text{CL}\!=\!90\%
                                                                                                                                2135
                                                                                                                                                         e^{\pm}\mu^{\mp}
                                                                                                                                                                                                                                                      \times\,10^{-8} CL=90%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                   [ee]\,<\,
                                                                                                                                                                                                                                 6.4
          p\overline{p}
                                                                                                                                                         \pi^0 e^{\pm} \mu^{\mp}
                                                                                                                                                                                                                                                      \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                 1.4
p\overline{p}K^*(892)^0
                                                                   (1.24 + 0.28 \atop -0.25) \times 10^{-6}
                                                                                                                                2216
                                                                                                                                                         K^0 e^{\pm'} \mu^{\mp}
                                                                                                                                                                                                                                                      \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                 2.7
                                                                                                                                                         K^*(892)^0 e^+ \mu^-
                                                                                                                                                                                                                                                      \times 10^{-7} \text{ CL} = 90\%
    f_J(2220) K_0^* \times B(f_J(2220) \rightarrow
                                                                                             \times\,10^{-7} CL=90%
                                                                                                                                                                                                         1 F
                                                                                                                                                                                                                                 5.3
                                                                                                                                                         K^*(892)^0 e^- \mu^+
                                                                                                                                                                                                                                                      \times 10^{-7} CL = 90\%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                 3.4
        p\overline{p}
p \overline{\Lambda} \pi^{-1}
                                                                                                                                                         K^*(892)^0 e^{\pm \mu}
                                                                                                                                                                                                                                                      \times 10^{-7} \text{ CL} = 90\%
                                                                       3.14 \pm 0.29) \times 10^{-6}
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                5.8
                                                                                                                                2401
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                                      \times\,10^{-5} CL=90%
                                                                                                                                                         e^{\pm} \dot{\tau}^{\mp}
p \overline{\Sigma} (1385)^{-}
                                                                                             \times 10^{-7} CL=90%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                 2.8
                                                                        2.6
                                                                                                                                2363
                                                                                                                                                                                                                   [ee] <
                                                                                                                                                        \mu^{\pm}\tau^{\mp}
\Delta^0 \overline{\Lambda}
                                                                                             \times\,10^{-7} CL=90%
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                                                                         LF
                                                                                                                                                                                                                                 2.2
                                                                        9.3
                                                                                                                                                                                                                  [ee] <
                                                                                                                               2364
p\overline{\Lambda}K^{-}
                                                                                             \times\,10^{-7} CL=90%
                                                                                                                                                        invisible
                                                                                                                                                                                                                                                      \times 10^{-4} CL=90%
                                                                                                                                                                                                         B1
                                                                                                                                                                                                                                 22
                                                                        8.2
                                                                                                                               2308
p \overline{\Sigma}^0 \pi
                                                                                             \times 10^{-6} \text{ CL} = 90\%
                                                                                                                                                        \nu \overline{\nu} \gamma
                                                                                                                                                                                                         В1
                                                                                                                                                                                                                                 4.7
                                                                                                                                                                                                                                                      \times\,10^{-5}~\text{CL}\!=\!90\%
                                                                 <
                                                                        3.8
                                                                                                                                2383
                                                                                             \times 10^{-7} \text{ CL} = 90\%
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
\overline{\Lambda}\Lambda
                                                                                                                                                         \Lambda_c^+ \mu^-
                                                                                                                                                                                                         L,B
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                1.8
                                                                        3.2
                                                                                                                               2392
                                                                  <
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
\overline{\Lambda}\Lambda K^0
                                                                       4.8 \begin{array}{c} + & 1.0 \\ - & 0.9 \end{array}) \times 10^{-6}
                                                                                                                                                         \Lambda_c^+ e^-
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                5
                                                                                                                                2250
                                                                   ( 2.5 \buildrel + 0.9 \buildrel - 0.8 \buildrel ) \times 10^{-6}
\overline{\Lambda}\Lambda K^{*0}
                                                                                                                                2098
                                                                                                                                                            B^{\pm}/B^{0} ADMIXTURE
\overline{\Lambda}\Lambda D^0
                                                                   (1.1 \ ^{+}_{-} \ 0.6 \ ) \times 10^{-5}
                                                                                                                               1661
\Delta^0 \overline{\Delta}{}^0
                                                                                             \times\,10^{-3}~\text{CL}\!=\!90\%
                                                                  < 1.5
                                                                                                                                2335
                                                                                                                                                                       CP violation
\Delta^{++}\overline{\Delta}
                                                                                             \times\,10^{-4} CL=90%
                                                                        1.1
                                                                                                                                2335
\overline{D}{}^0 p \overline{p}
                                                                   (-1.14 \pm \ 0.09) \times 10^{-4}
                                                                                                                                                                             A_{CP}(B \rightarrow K^*(892)\gamma) = -0.003 \pm 0.017
                                                                                                                               1863
D_s^{-1} \overline{\Lambda} p
                                                                   ( 2.8~\pm~0.9~)\times10^{-5}
                                                                                                                                                                             A_{CP}(b \rightarrow s\gamma) = -0.008 \pm 0.029
                                                                                                                               1710
\overline{D}^*(2007)^0 p \overline{p}
                                                                   (-1.03 \pm \ 0.13) \times 10^{-4}
                                                                                                                                                                             A_{CP}(b \rightarrow (s+d)\gamma) = -0.09 \pm 0.07
                                                                                                                               1788
                                                                        1.4 \pm 0.4 \times 10^{-3}
                                                                                                                                                                             A_{CP}(B \to X_S \ell^+ \ell^-) = -0.22 \pm 0.26
D^*(2010)^- p \overline{n}
                                                                                                                               1785
                                                                                                                                                                             A_{CP}(B \to K^* e^+ e^-) = -0.18 \pm 0.15
                                                                   (-3.38 \pm\ 0.32) \times 10^{-4}
D^- p \overline{p} \pi^+
                                                                                                                               1786
```

1707

1839

 $A_{CP}(B \rightarrow K^* \mu^+ \mu^-) = -0.03 \pm 0.13$

 $A_{CP}(B \to K^* \ell^+ \ell^-) = -0.07 \pm 0.08$

 $A_{CP}(B \rightarrow \eta \text{ anything}) = -0.13^{+0.04}_{-0.05}$

5.0 \pm 0.5) \times 10⁻⁴

9 <

1.0

< 1.4 $\times\,10^{-6}~\text{CL}\!=\!90\%$

 $\times\,10^{-5}~\text{CL}\!=\!90\%$

 $\times\,10^{-3}$ CL=90%

 $D^*(2010)^- p \overline{p} \pi^+$

- <u>⊿</u>++

 $\Theta_c \, \overline{p} \pi^+ \times B(\Theta_c \to D^- p)$

 $\underline{\Theta}_{c} \overline{p} \pi^{+} \times B(\Theta_{c}^{c} \rightarrow D^{*-} p)$

1934

2021

1982

1882

1821

1934

1934

1860

1860

1895

1895

1754

1767

1319

1147

2640

2640

2638

1952

2638

2638

2634

2638

2616

2616

2616

2583

2564

2564

2560

2564

2541

2639

2637

2615

2563

2563

2563

2341

2640

2143

The branching fraction measurements are for an admixture of B mesons at the $\Upsilon(4S)$. The values quoted assume that B($\Upsilon(4S) \to B\overline{B}$) = 100%. For inclusive branching fractions, e.g., $B o D^{\pm}$ anything, the treatment of multiple D's in the final state must be defined. One possibility would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical if only one D is allowed in the final state. Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross section. $\overline{\emph{B}}$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Scale factor/ B DECAY MODES Fraction (Γ_i/Γ) Confidence level (MeV/c) Semileptonic and leptonic modes $e^+\,
u_e$ anything [cccc] (10.72 \pm 0.13) % $\times 10^{-4}$ CL=90% $\overline{p} e^+ \nu_e$ anything < 5.9 $\mu^+\,
u_\mu$ anything [cccc] (10.72 \pm 0.13) % $\ell^+ \nu_\ell$ anything [ppp,cccc] (10.72 \pm 0.13) % $D^-\ell^+\nu_\ell$ anything [ppp] (2.8 ± 0.9) % $\overline{D}{}^0\,\ell^+\,
u_\ell\,$ a nything

[ppp] (7.2 \pm 1.4) %

| D & Veally clining | [PPP] | - / | 1.2 | | 1.4 |) /0 | | |
|---------------------------------------------------------------------------------------------------------------------------|----------------|-----|-------|-------|------|----------------------|--------|-------|
| $\overline{\mathcal{D}}\ell u_{\ell}$ | | (| 2.39 | \pm | 0.12 | | | 2310 |
| $D	au^+ u_	au$ | | (| 8.6 | \pm | 2.7 | $) \times 10^{-3}$ | | 1911 |
| $D^{*-}\ell^+ u_\ell$ a nything | [dddd] | (| 6.7 | \pm | 1.3 | $) \times 10^{-3}$ | | _ |
| $D^* \tau^+ u_{	au}$ | | ì | 1.62 | | 0.33 | | | 1837 |
| | pp,eeee] | ì | 2.7 | | 0.7 |) % | | |
| \overline{D}_1 (2420) ℓ^+ ν_ℓ a nythin | | (| 3.8 | | 1.3 | $) \times 10^{-3}$ | 6 24 | |
| | g | (| | | | * | S=2.4 | _ |
| $D\pi\ell^+ u_\ell$ anything $+$ | | (| 2.6 | ± | 0.5 |) % | S=1.5 | _ |
| $D^*\pi\ell^+ u_\ell$ anything | | | | | | | | |
| $D\pi\ell^+ u_\ell$ a nything | | (| 1.5 | \pm | 0.6 |) % | | _ |
| $D^*\pi\ell^+ u_\ell$ anything | | (| 1.9 | \pm | 0.4 | | | _ |
| $\overline{D}_2^*($ 2460 $)\ell^+ u_\ell$ a nythin | g | (| 4.4 | \pm | 1.6 | $) \times 10^{-3}$ | | _ |
| $D^{*-}\pi^+\ell^+ u_\ell$ anything | _ | (| 1.00 | + | 0.34 | | | _ |
| $D_s^-\ell^+\nu_\ell$ anything | [<i>ppp</i>] | , | 7 | _ | | ×10 ⁻³ | CL=90% | _ |
| | | | | | | | | |
| $D_s^-\ell^+ u_\ell K^+$ anything | [ppp] | | 5 | | | ×10 ⁻³ | CL=90% | _ |
| $D_s^-\ell^+ u_\ell K^0$ anything | [ppp] | < | 7 | | | $\times 10^{-3}$ | CL=90% | _ |
| $\ell^+ \overline{ u_\ell}$ charm | | (| 10.51 | \pm | 0.13 |) % | | _ |
| $X_{\mu}\ell^{+}\nu_{\ell}$ | | ì | | | | $) \times 10^{-3}$ | | _ |
| $K^+\ell^+ u_\ell$ a nything | [<i>ppp</i>] | ì | 6.2 | | 0.5 | | | _ |
| $K^-\ell^+\nu_\ell$ anything | | , | 10 | | 4 |) × 10 ⁻³ | | |
| $K^0/\overline{K}^0\ell^+\nu_\ell$ anything | [ppp] | | | | | | | |
| $\kappa / \kappa e^{-\nu_{\ell}}$ anything | [ppp] | (| 4.5 | ± | 0.5 |) % | | _ |
| | D, D* | or | D. n | nod | les | | | |
| D+ + | υ, υ | | | | | | | |
| D [±] anything | | (| 23.7 | | 1.3 |) % | | _ |
| D^0/\overline{D}^0 anything | | (| 62.7 | \pm | 2.9 |) % | S=1.3 | _ |
| $D^*(2010)^{\pm}$ anything | | (| 22.5 | \pm | 1.5 |) % | | _ |
| <i>D</i> *(2007) ⁰ anything | | (| 26.0 | \pm | 2.7 |) % | | _ |
| D_s^\pm anything | [ee] | (| 8.3 | \pm | 0.8 |) % | | _ |
| $D_s^{*\pm}$ anything | | (| 6.3 | + | 1.0 |) % | | _ |
| $D_s^{s\pm} \overline{D}^{(*)}$ | | , | | | | · | | |
| | | (| 3.4 | | 0.6 |) % | | _ |
| $D^{(*)} \overline{D}^{(*)} K^0 +$ | [ee,ffff] | (| 7.1 | + | 2.7 |) % | | _ |
| $D^{(*)}\overline{D}^{(*)}K^{\pm}$ | | , | | _ | 1.7 | , | | |
| $b \rightarrow c \overline{c} s$ | | (| 22 | ± | 4 |) % | | _ |
| $D_s(*)\overline{D}(*)$ | [ee,ffff] | (| 3.9 | | 0.4 |) % | | _ |
| $D^*D^*(2010)^{\pm}$ | - | , | 5.9 | _ | 0.4 | ×10 ⁻³ | CL=90% | 1711 |
| $DD^*(2010)^{\pm} + D^*D^{\pm}$ | [ee] | | | | | | | 1/11 |
| | [ee] | | 5.5 | | | $\times 10^{-3}$ | CL=90% | _ |
| DD^\pm | [ee] | < | 3.1 | | | $\times 10^{-3}$ | CL=90% | 1866 |
| $D_s^{(*)\pm}\overline{D}^{(*)}X(n\pi^{\pm})$ | [ee,ffff] | (| 9 | + | 5 |) % | | _ |
| | | | | _ | 4 | * | er | |
| $D^*(2010)\gamma$ | | < | 1.1 | | | ×10 ⁻³ | CL=90% | 225 7 |
| $D_s^+ \pi^-$, $D_s^{*+} \pi^-$, $D_s^+ \rho^-$, | [ee] | < | 4 | | | $\times 10^{-4}$ | CL=90% | _ |
| $D_s^{*+} \rho^-$, $D_s^+ \pi^0$, $D_s^{*+} \eta$ | τ^0 , | | | | | | | |
| D^{+}_{n} D^{*+}_{n} D^{+}_{0} | | | | | | | | |
| $D_{s}^{+}\eta$, $D_{s}^{*+}\eta$, $D_{s}^{+}\rho^{0}$, $D_{s}^{*+}\rho^{0}$, $D_{s}^{*+}\omega$, $D_{s}^{*+}\omega$ | | | | | | | | |
| 11*T № 11T (1 1)*T (1 | | | | | | | | |
| $D_s \rho, D_s \omega, D_s \omega$ | | | | | | | | |
| D_s ρ , D_s ω , D_s ω D_{s1} $(2536)^+$ anything | | < | 9.5 | | | $\times 10^{-3}$ | CL=90% | _ |
| D_s β , D_s ω , D_s ω D_{s1} $(2536)^+$ anything | | < | 9.5 | | | ×10 ⁻³ | CL=90% | _ |

| C | harm | on | ium m | od | es | | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|-----------------------------------------|
| $J/\psi(1S)$ anything | | (| 1.094 | ± | 0.032 | 2) % | S=1.1 | _ |
| $J/\psi(1S)$ (direct) anything | | (| 7.8 | | | $) \times 10^{-3}$ | S=1.1 | _ |
| $\psi(2S)$ a nything | | (| | | | $) \times 10^{-3}$ | | _ |
| $\chi_{c1}(1P)$ anything | | (| | | |) × 10 ⁻³ | | _ |
| $\chi_{c1}(1P)$ (direct) anything | | (| | | | $) \times 10^{-3}$ | | _ |
| $\chi_{c2}(1P)$ anything | | (| 1.3 | | | $) \times 10^{-3}$ | S=1.9 | _ |
| $\chi_{c2}(1P)$ (direct) anything | | (| 1.65 | ± | 0.31 | $) \times 10^{-3} \times 10^{-3}$ | CL 000/ | _ |
| $\eta_c(1S)$ anything KX (3872) $	imes$ B(X $ ightarrow$ | | < , | 9 1.2 | | 0.4 |) × 10 ⁻⁴ | CL=90% | 1141 |
| $D^0 \overline{D^0} \pi^0$ | | (| 1.2 | I | 0.4 |) × 10 | | 1141 |
| $KX(3872) \times B(X \rightarrow$ | | (| 8.0 | + | 2.2 | $) \times 10^{-5}$ | | 1141 |
| $D^{*0}D^{0}$ | | , | 0.0 | _ | 2.2 | / ^ 10 | | 1111 |
| $KX(3940) \times B(X \rightarrow$ | | < | 6.7 | | | $\times 10^{-5}$ | CL=90% | 1084 |
| $\hat{D}^{*0}D^{6}$) | | | | | | | | |
| $KX(3915) \times B(X \rightarrow \omega J/\psi)_{\delta}$ | gggg] | (| 7.1 | \pm | 3.4 | $) \times 10^{-5}$ | | 1104 |
| | Κn | , k | (* mo | dec | | | | |
| K^\pm a nything | [ee] | | 78.9 | | 2.5 |) % | | _ |
| K^+ anything | | | 66 | ± | |) % | | _ |
| K [−] anything | | (| 13 | \pm | 4 |) % | | _ |
| $K^0/\overline{K}{}^0$ anything | [ee] | (| 64 | \pm | 4 |) % | | _ |
| K^* (892) \pm anything | | (| 18 | \pm | 6 |) % | | _ |
| $K^*(892)^0 / \overline{K}^*(892)^0$ anything | [ee] | (| 14.6 | \pm | 2.6 |) % | | _ |
| $K^*(892)\gamma$ | | (| 4.2 | \pm | 0.6 | $) \times 10^{-5}$ | | 2564 |
| $\eta K \gamma$ | | (| 8.5 | + | 1.8 1.6 | $) \times 10^{-6}$ | | 2588 |
| K_1 (1400) γ | | < | 1.27 | | 1.0 | ×10 ⁻⁴ | CL=90% | 245 3 |
| = ' ' ' | | | | + | 0.6 | _ | CL=70/0 | |
| $K_2^*(1430)\gamma$ | | (| 1.7 | ÷ | 0.5 |) × 10 ⁻⁵ | | 2447 |
| $K_2(1770)\gamma$ | | < | 1.2 | | | ×10 ⁻³ | CL=90% | 2342 |
| $K_3^*(1780)\gamma$ | | < | 3.7 | | | $\times 10^{-5}$ | CL=90% | 2341 |
| $K_4^*(2045)\gamma$ | | < | 1.0 | | | ×10 ⁻³ | CL=90% | 2244 |
| $K\eta'(958)$ | | (| 8.3 | | 1.1 |) × 10 ⁻⁵ | | 2528 |
| $K^*(892)\eta'(958)$ | | (| 4.1 | ± | 1.1 |) × 10 ⁻⁶ | | 2472 |
| Kη K*(202) | | <, | 5.2 | | 0.5 | ×10 ⁻⁶ | CL=90% | 2588 |
| K*(892)η | | (| 1.8 | | 0.5 |) × 10 ⁻⁵ | | 2534 |
| $\frac{K\phi\phi}{5}$ | | (| 2.3 | | 0.9 | $) \times 10^{-6}$ $) \times 10^{-4}$ | | 2306 |
| $\frac{b}{\overline{c}} \rightarrow \frac{\overline{s}}{\overline{c}} \gamma$ | | (| 3.53 | ± | 0.24 | | | _ |
| $h \rightarrow d \sim$ | | - / | 0.2 | | 3 0 | 1 ~ 10-6 | | _ |
| $\frac{b}{h} \rightarrow \frac{d}{s} \gamma$ | | (| 9.2 6.8 | ± | 3.0 |)×10 ⁻⁶ | CI -90% | _ |
| $\overline{b} \rightarrow \overline{s}g uon$ | | < | 6.8 | | | % | CL=90% | - |
| $\overline{b} ightarrow \overline{s}$ gluon η anything | | < (| | + | 0.5 0.8 | %) × 10 ⁻⁴ | CL=90% | - - - |
| $\overline{b} ightarrow \overline{s}$ gluon η anything η' anything | | < | 6.8 2.6 4.2 | + | | %) × 10 ⁻⁴) × 10 ⁻⁴ | | - - - |
| $\overline{b} ightarrow \overline{s}$ gluon η anything η' anything K^+ gluon (charmless) | | < (| 6.8 2.6 4.2 1.87 | + - ± | 0.5 0.8 0.9 | % $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ | CL=90% | - - - - |
| $\overline{b} ightarrow \overline{s}$ gluon η anything η' anything | | < (| 6.8 2.6 4.2 | + - ± | 0.5 0.8 | %) × 10 ⁻⁴) × 10 ⁻⁴ | | - - - - - |
| $\overline{b} ightarrow \overline{s}$ gluon η anything η' anything K^+ gluon (charmless) | unflav | < ((< (| 6.8 2.6 4.2 1.87 1.9 | + + ± | 0.5 0.8 0.9 | % $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-4}$ | | - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) | unflav | < ((< (| 6.8 2.6 4.2 1.87 1.9 ed mes | + + + ± | 0.5 0.8 0.9 0.7 mod 0.25 | % $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-6}$ | | - - - - - 2583 |
| $\overline{b} ightarrow \overline{s} g$ luon η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) | | () () () () () () | 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 | + - ± ± 50n ± | 0.5 0.8 0.9 0.7 mod 0.25 0.23 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶ | CL=90% | |
| $\overline{b} ightarrow \overline{s} g$ luon η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) Light \mathfrak{t} $\rho \gamma$ $\rho/\omega \gamma$ π^\pm anything [ee, | unflav | < (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 | + + + ± ******************************* | 0.5 0.8 0.9 0.7 moc 0.25 0.23 7 | % $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-6}$ $) \times 10^{-6}$ $) \times 10^{-6}$ $) %$ | CL=90% S=1.2 | |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ' anything κ' gluon (charmless) κ^0 gluon (charmless) Light σ $\rho \gamma$ σ^{\pm} anything σ^0 anything | | < () () () () () () () () | 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 35.8 235 | + + + + ****************************** | 0.5 0.8 0.9 0.7 moc 0.25 0.23 7 | % $) \times 10^{-4}$ $) \times 10^{-4}$ $\times 10^{-4}$ $) \times 10^{-4}$ $) \times 10^{-6}$ $) \times 10^{-6}$ $) \times 10^{-6}$ $) %$ | CL=90% S=1.2 | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ $\text{Light } \mathbf{u}$ $\rho \gamma$ $\eta \neq \mathbf{u}$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ | | < (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 35 8 235 17.6 | + + + ± ******************************* | 0.5 0.8 0.9 0.7 mod 0.25 0.23 7 11 1.6 | %)×10 ⁻⁴)×10 ⁻⁴ ×10 ⁻⁴)×10 ⁻⁶)×10 ⁻⁶)×10 ⁻⁶)%)% | CL=90% S=1.2 | |
| $\overline{b} \to \overline{s} \dot{g} luon$ $\eta \ anything$ $\eta' \ anything$ $K^+ g luon \ (charmless)$ $K^0 g luon \ (charmless)$ $Light \ \iota$ $\rho \gamma$ $\eta \pm anything$ $\eta \ anything$ $\rho^0 \ anything$ $\rho^0 \ anything$ | | < (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 35 8 235 17.6 21 | + + + + ****************************** | 0.5 0.8 0.9 0.7 mod 0.25 0.23 7 11 1.6 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) %) % | CL=90% S=1.2 S=1.2 | 2583 - - - - - |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ Light in $\rho \gamma$ $\rho / \omega \gamma$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\rho^0 \text{ anything}$ $\omega \text{ anything}$ $\omega \text{ anything}$ | | < (() () () () () () () () () () () () () | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 35.8 235 17.6 21 81 | +- ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 mod 0.25 0.23 7 11 1.6 5 | $ \% \\) \times 10^{-4} \\) \times 10^{-4} \\) \times 10^{-4} \\) \times 10^{-4} \\) \times 10^{-6} \\) \times 10^{-6} \\) \% \\) \% \\) \% \\) \% \\ \% $ | CL=90% S=1.2 | 2583 - - - - - - - |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\text{Light } \iota$ $\rho \gamma$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\rho^0 \text{ anything}$ $\omega \text{ anything}$ $\omega \text{ anything}$ $\omega \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ | | < (() (() (() (() (() (() (() (() (() (() | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 35 8 235 17.6 21 81 3.43 | +- ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 mod 0.25 0.23 7 11 1.6 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) % %) % | CL=90% S=1.2 S=1.2 CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ^+ gluon (charmless) κ^0 gluon (charmless) κ^0 gluon (charmless) κ^0 gluon (charmless) κ^0 gluon κ^0 gluon κ^0 anything κ^0 | | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 35.8 235 17.6 21 81 3.43 2.2 | +- ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)×0-6)% %)% % %)% ×10-5 | CL=90% S=1.2 S=1.2 | 2583 - - - - 24460 |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\text{Light } \iota$ $\rho \gamma$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\rho^0 \text{ anything}$ $\omega \text{ anything}$ $\omega \text{ anything}$ $\omega \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ | hhhh) | () () () () () () () () () () () () () (| 6.8 2.6 4.2 1.87 1.9 ed mes 1.39 1.30 35 8 235 17.6 21 81 3.43 2.2 3.7 | +-± ± 501 ±±±±± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) % %) % | CL=90% S=1.2 S=1.2 CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ' anything κ' gluon (charmless) κ^0 anything κ^0 gluon (charmless) | hhhh) | () () () () () () () () () () () () () (| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 35.8 235 17.6 21 81 3.43 2.2 | +- ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)×0-6)% %)% % %)% ×10-5 | CL=90% S=1.2 S=1.2 CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ' anything κ' gluon (charmless) κ^0 anything | hhhh) | () () () () () () () () () () () () () (| 6.8 2.6 4.2 1.87 1.9 eed mee 1.39 1.30 3558 2235 17.6 21 81 3.43 2.2 3.7 | +- ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) % %) % × 10 ⁻⁵) × 10 ⁻⁴ | CL=90% S=1.2 S=1.2 CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ^+ gluon (charmless) κ^0 κ^0 κ^0 anything κ^0 κ^0 gluon (charmless) κ^0 | hhhh) | <pre></pre> | 6.8 2.6 4.2 1.87 1.9 eed mee 1.39 1.30 3558 2235 17.6 21 81 3.43 2.2 3.7 | +- ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | $\% \\) \times 10^{-4} \\) \times 10^{-4} \\ \times 10^{-4} \\) \times 10^{-4} \\) \times 10^{-6} \\) \times 10^{-6} \\) \% \\) \% \\) \% \\) \% \\ \times 10^{-5} \\) \times 10^{-5} \\) \times 10^{-4} \\ \end{cases}$ | CL=90% S=1.2 S=1.2 CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} \overline{g}$ luon η anything κ' anything κ' gluon (charmless) κ^0 gluon (charmless) κ^0 gluon (charmless) κ^0 gluon (charmless) κ^0 κ^0 anything κ^0 κ^0 gluon (charmless) κ^0 κ^0 κ^0 anything | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 3358 3358 17.6 21 3.43 2.2 3.7 | +- ± ± 50M ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 | $\begin{array}{c} \% \\) \times 10^{-4} \\) \times 10^{-4} \\ \times 10^{-4} \\) \times 10^{-4} \\ \end{array}$ | CL=90% S=1.2 S=1.2 CL=90% CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ^{+} gluon (charmless) κ^{0} gluon (charmless) Light $\rho \gamma$ $\rho/\omega \gamma$ π^{\pm} anything π^{0} anything η anything ρ^{0} anything ϕ π^{+} gluon (charmless) $\frac{\Lambda_{c}^{+}}{\Lambda_{c}^{-}}$ anything $\frac{\overline{\Lambda_{c}^{-}}}{\Lambda_{c}^{-}}$ ρ ρ ϕ | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 eed meet 1.39 1.30 325 17.6 21 81 3.43 2.2 3.7 mmod 4.5 1.1 | +- ± ± 50M ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) % × 10 ⁻⁵) × 10 ⁻⁵) × 10 ⁻⁴ | CL=90% S=1.2 S=1.2 CL=90% CL=90% | - - - - - |
| $\overline{b} ightarrow \overline{s} g$ luon η anything κ^{+} gluon (charmless) κ^{0} gluon (charmless) Light $\rho \gamma$ $\rho/\omega \gamma$ π^{\pm} anything π^{0} anything η anything ρ^{0} anything ϕ π^{+} gluon (charmless) $\frac{\Lambda_{c}^{+}}{\Lambda_{c}^{-}}$ anything $\frac{\overline{\Lambda_{c}^{-}}}{\Lambda_{c}^{-}}$ ρ ρ ϕ | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 325 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 | +- ± ± son ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) % %) % × 10 ⁻⁵) × 10 ⁻⁴ | CL=90% S=1.2 S=1.2 CL=90% CL=90% | |
| $\overline{b} ightarrow \overline{s} gluon$ η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) Light ι $\rho \gamma$ $\rho/\omega \gamma$ π^\pm anything π^0 anything η anything ϕ anything $\frac{\delta}{\Delta} - \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} $ | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 325 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 | +- ± ± son ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)×10-6)% ,%)% ×10-5)×10-4)% ×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% | |
| $\overline{b} ightarrow \overline{s} gluon$ η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) Light ι $\rho \gamma$ $\rho/\omega \gamma$ π^\pm anything π^0 anything η anything ϕ anything $\frac{\delta}{\Delta} - \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} = \frac{\delta}{\Delta} + \frac{\delta}{\Delta} = \frac{\delta}{\Delta} $ | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 358 235 17.6 21 3.43 2.2 3.7 m mod 4.5 1.1 2.6 1.0 4.2 9.6 | +-± ± 50 1 ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% | |
| $\overline{b} ightarrow \overline{s} gluon$ η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) Light ι $\rho \gamma$ π^+ anything π^0 anything η anything ϕ π^+ gluon (charmless) $\frac{\Lambda_c^+}{\Lambda_c^-} \rho$ anything $\overline{\Lambda}_c^- \rho$ anything | hhhh) | | 6.8 2.6 4.2 1.87 1.9 1.30 1.30 35.8 235 17.6 21 81 3.43 2.2 3.7 m mod 4.5 1.1 2.6 1.0 4.2 9.6 4.6 | +-± ± 50 1 ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)%)% % % % % % % >>×10-5)×10-4)% ×10-3)×10-3)×10-3)×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} ightarrow \overline{s} gluon$ η anything η' anything K^+ gluon (charmless) K^0 gluon (charmless) Light ι $\rho \gamma$ π^+ anything π^0 anything η anything ϕ π^+ gluon (charmless) $\frac{\Lambda_c^+}{\Lambda_c^-} \rho$ anything $\overline{\Lambda}_c^- \rho$ anything | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 2.6 4.6 4.6 1.5 | +- ± ± 501 ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)%)% % % % % >>>10-5)×10-3)×10-3 ×10-3 ×10-3 ×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\frac{\rho \gamma}{\rho / \omega \gamma}$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\phi \text{ anything}$ $\frac{\delta \kappa'' (\overline{\Lambda}_c^- \text{ anything})}{\pi^+ \text{ gluon (charmless)}}$ $\frac{\Lambda_c^+}{\Lambda_c^- \text{ anything}}$ $\frac{\overline{\Lambda}_c^- \rho \text{ anything}}{\overline{\Lambda}_c^- \rho \text{ anything}}$ | hhhh) | | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 2.6 4.6 4.6 1.5 | +- ± ± 501 ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)%)% % % % % % % >>×10-5)×10-4)% ×10-3)×10-3)×10-3)×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\frac{\rho \gamma}{\rho / \omega \gamma}$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\phi \text{ anything}$ $\frac{\sigma}{\lambda} \text{ anything}$ | hhhh) | | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 358 235 17.6 21 3.43 2.2 3.7 m mod 4.5 1.1 2.6 1.0 4.2 9.6 4.6 1.5 1.93 | +- ± ± 5011 ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 mot 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 2.4 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)×10-6)% ,%)% ×10-5)×10-4)% ×10-3)×10-3 ×10-3 ×10-3)×10-3 ×10-3)×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{\pi} \frac{\rho}{\pi} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\sigma}{\Lambda_c} \frac{\rho}{\pi} \text{ anything}$ $\frac{\overline{\Lambda_c}}{\Lambda_c} e^+ \text{ anything}$ $\frac{\overline{\Lambda_c}}{\Lambda_c} p \text{ anything}$ $\frac{\overline{\Lambda_c}}{\kappa} \frac{\rho}{\pi} \text{ anything}$ $\frac{\overline{\Lambda_c}}{\kappa} \frac{\rho}{\pi} \text{ anything}$ $\frac{\overline{\Lambda_c}}{\kappa} \frac{\rho}{\pi} \text{ anything}$ $\frac{\overline{\Lambda_c}}{\kappa} \text{ anything}$ | hhhh) | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 358 235 17.6 21 3.43 2.2 3.7 m mod 4.5 1.1 2.6 1.0 4.2 9.6 4.6 1.5 1.93 | +- ± ± 5011 ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)%)% % % % % >>>10-5)×10-3)×10-3 ×10-3 ×10-3 ×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\frac{\rho \gamma}{\rho / \omega \gamma}$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\rho^0 \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ $\phi \text{ anything}$ $\frac{\sigma}{\rho} \text{ anything}$ $\frac{\sigma}{\rho} \text{ anything}$ $\frac{\sigma}{\rho} \text{ anything}$ $\frac{\sigma}{\sigma} \text{ anything}$ $\frac{\sigma}{\sigma$ | Bal | | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 358 235 17.6 21 3.43 2.2 3.7 m mod 4.5 1.1 2.6 1.0 4.2 9.6 4.6 1.5 1.93 | +- ± ± 50 ± ± ± ± ± ± ± ± ± +- | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 2.4 0.30 | %)×10-4)×10-4 ×10-4 ×10-4)×10-6)×10-6)×10-6)% ,% ,% ,% ,% ,% ,% ,% ,% ,10-5 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 ,×10-3 | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ luon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ luon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ luon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ anything}$ $\frac{\rho}{\sigma} \text{ anything}$ $\frac{\rho}{\sigma} \text{ anything}$ $\frac{\sigma}{\kappa} \frac{\rho}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \frac{\rho}{\sigma} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \frac{\overline{\Lambda}_c}{\sigma} \text{ anything}$ $$ | Bal | | 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 358 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 2.6 1.0 4.2 9.6 4.6 1.5 1.93 4.5 | +-± ± ± 60n ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 mot 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 0.30 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)×10-6)% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\kappa} \frac{\rho}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \frac{\rho}{\eta} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\kappa \text{ B}(\overline{\Xi}_c^+ \rightarrow \overline{\Xi}^- \pi^+ \pi^+)$ $\overline{\Xi}_c^+ \text{ anything}$ $\kappa \text{ B}(\overline{\Xi}_c^+ \rightarrow \overline{\Xi}^- \pi^+ \pi^+)$ $\overline{\rho}/\overline{\rho} \text{ anything}$ $\rho/\overline{\rho} \text{ (direct) anything}$ | Bal | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 3558 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.0 4.2 9.6 4.6 1.5 1.93 4.5 | +-± ± ± son ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 mot 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 2.4 0.30 1.3 1.2 0.4 0.5 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)×10-6)% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\kappa' \text{ anything}$ $\kappa' \text{ gluon (charmless)}$ $\kappa^0 \text{ gluon (charmless)}$ $\frac{\rho}{\kappa'} \rho \omega \gamma$ $\pi^{\pm} \text{ anything}$ $\eta \text{ anything}$ $\eta \text{ anything}$ $\phi \text{ anything}$ $\frac{\sigma}{\kappa'} \overline{\Lambda}_c^- \text{ anything}$ $\overline{\Lambda}_c^- \rho \text{ anything}$ $\overline{\Sigma}_c^- \text{ anything}$ $\overline{\Sigma}_c^0 \text{ anything}$ $\times B(\Xi_c^- \to \Xi^- \pi^+)$ $\Xi_c^+ \text{ anything}$ $\times B(\Xi_c^+ \to \Xi^- \pi^+ \pi^+)$ $\rho/\overline{\rho} \text{ anything}$ $\rho/\overline{\rho} \text{ (direct) anything}$ $\rho/\overline{\rho} \text{ (direct) anything}$ $\rho/\overline{\rho} \text{ (direct) anything}$ | [ee] [ee] [ee] | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.1 2.6 4.6 1.5 1.93 4.5 8.0 5.5 4.0 | +-± ± ± con ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± ± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 0.30 1.3 1.2 0.5 0.5 | %) × 10 ⁻⁴) × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴) × 10 ⁻⁶) × 10 ⁻⁶) × 10 ⁻⁶) %) % × 10 ⁻⁵) × 10 ⁻³) % × 10 ⁻³) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³) × 10 ⁻⁴) × 10 ⁻⁴ | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |
| $\overline{b} \rightarrow \overline{s} \overline{g} \text{luon}$ $\eta \text{ anything}$ $\eta' \text{ anything}$ $K^+ \text{ gluon (charmless)}$ $K^0 \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ gluon (charmless)}$ $\frac{\rho}{\kappa} \frac{\rho}{g} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\eta} \text{ anything}$ $\frac{\rho}{\kappa} \frac{\rho}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \frac{\rho}{\eta} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\frac{\overline{\Lambda}_c}{\kappa} \text{ anything}$ $\kappa \text{ B}(\overline{\Xi}_c^+ \rightarrow \overline{\Xi}^- \pi^+ \pi^+)$ $\overline{\Xi}_c^+ \text{ anything}$ $\kappa \text{ B}(\overline{\Xi}_c^+ \rightarrow \overline{\Xi}^- \pi^+ \pi^+)$ $\overline{\rho}/\overline{\rho} \text{ anything}$ $\rho/\overline{\rho} \text{ (direct) anything}$ | Bal | (((((((((((((((((((| 6.8 2.6 4.2 1.87 1.9 ed mee 1.39 1.30 3558 235 17.6 21 81 3.43 2.2 3.7 n mod 4.5 1.0 4.2 9.6 4.6 1.5 1.93 4.5 | +-± ± 500±±±±±±± ± ± £85± ± ± ± +- ±±±± | 0.5 0.8 0.9 0.7 moo 0.25 0.23 7 11 1.6 5 0.12 0.8 1.2 0.8 2.4 0.30 1.3 1.2 0.5 0.5 | %)×10-4)×10-4 ×10-4)×10-6)×10-6)×10-6)% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% ,% | CL=90% S=1.2 S=1.2 CL=90% CL=90% CL=90% CL=90% CL=90% | |

ppanything

 $K^*(892) e^{\pm} \mu^{\mp}$

Meson Summary Table

| 1 | 2.77 | 1 0.23 |) /0 | | |
|------------------|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| [ee] (| 2.5 | ± 0.4 |) % | | _ |
| < | 5 | | $\times 10^{-3}$ | CL=90% | - |
| number | (LF) v | riolatin | g modes | or | |
| | | | | | |
| (| 4.7 | ± 1.3 | $) \times 10^{-6}$ | | - |
| (| 4.3 | ± 1.2 | $) \times 10^{-6}$ | | _ |
| [<i>ppp</i>] (| 4.5 | ± 1.0 | $) \times 10^{-6}$ | | _ |
| < | 6.2 | | $\times 10^{-8}$ | CL=90% | 2638 |
| (| 4.4 | ± 0.6 | $) \times 10^{-7}$ | | 2617 |
| (| 1.19 | ± 0.20 | $) \times 10^{-6}$ | S=1.2 | 2564 |
| (| 4.4 | ± 0.4 | $) \times 10^{-7}$ | | 2612 |
| (| 1.06 | ± 0.09 | $) \times 10^{-6}$ | | 2560 |
| (| 4.5 | ± 0.4 | $) \times 10^{-7}$ | | 2617 |
| (| 1.08 | ± 0.11 | $) \times 10^{-6}$ | | 2564 |
| < | 1.4 | | $\times 10^{-5}$ | CL=90% | 2617 |
| < | 8 | | $\times 10^{-5}$ | CL=90% | _ |
| [ee] < | 2.2 | | $\times 10^{-5}$ | CL=90% | _ |
| < | 9.2 | | $\times 10^{-8}$ | CL=90% | 2637 |
| < | 3.2 | | $\times 10^{-6}$ | CL=90% | 2582 |
| < | 3.8 | | $\times 10^{-8}$ | CL=90% | 2616 |
| | <pre>// number 22 k neutra</pre> | [ee] (2.5 : < 5 7 number (LF) v eak neutral curre (4.7 : (4.3 : [ppp] (4.5 : < 6.2 (4.4 : (1.06 : (4.5 : (1.08 : < 1.4 : < 1.06 : (1.08 : < 1.4 : < 8 & [ee] < 2.2 < 9.2 < 3.2 | [ee] (2.5 ± 0.4 < 5 y number (LF) violating the sak neutral current (BI) (4.7 ± 1.3 (4.3 ± 1.2 [ppp] (4.5 ± 1.0 < 6.2 (4.4 ± 0.6 (1.19 ± 0.20 (4.4 ± 0.4 (1.06 ± 0.09 (4.5 ± 0.4 (1.08 ± 0.11 < 1.4 < 8 [ee] < 2.2 < 9.2 < 9.2 < 3.2 | $ < 5 \times 10^{-3} \\ \textit{y number (LF) violating modes} \\ \textit{sak neutral current (B1) modes} \\ (4.7 \pm 1.3) \times 10^{-6} \\ (4.3 \pm 1.2) \times 10^{-6} \\ (4.5 \pm 1.0) \times 10^{-6} \\ < 6.2 \times 10^{-8} \\ (4.4 \pm 0.6) \times 10^{-7} \\ (1.19 \pm 0.20) \times 10^{-6} \\ (4.4 \pm 0.4) \times 10^{-7} \\ (1.06 \pm 0.09) \times 10^{-6} \\ (4.5 \pm 0.4) \times 10^{-7} \\ (1.08 \pm 0.11) \times 10^{-6} \\ < 1.4 \times 10^{-5} \\ < 8 \times 10^{-5} \\ (ee] < 2.2 \times 10^{-8} \\ < 3.2 \times 10^{-6} \\ \end{aligned} $ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

 $(2.47 \pm 0.23)\%$

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE

```
These measurements are for an admixture of bottom particles at high
energy (LHC, LEP, Tevatron, Sp\overline{p}S).
```

< 5.1

```
Mean life 	au = (1.568 \pm 0.009) 	imes 10^{-12} 	ext{ s}
Mean life \tau = (1.72 \pm 0.10) \times 10^{-12} s Charged b-hadron
    admixture
```

Mean life $au=(1.58\pm0.14) imes10^{-12}$ s Neutral b-hadron admixture

$$\begin{array}{l} \tau_{\rm charged\ b-hadron}/\tau_{\rm neutral\ b-hadron} = 1.09 \pm 0.13 \\ |\Delta\tau_b|/\tau_{b,\overline{b}} = -0.001 \pm 0.014 \\ {\rm Re}(\epsilon_b)\ /\ (1+|\epsilon_b|^2) = (-2.0 \pm 0.5) \times 10^{-3} \end{array}$$

The branching fraction measurements are for an admixture of B mesons and baryons at energies above the $\Upsilon(4S).$ Only the highest energy results (LHC, LEP, Tevatron, $Sp\overline{p}S$) are used in the branching fraction averages. In the following, we assume that the production fractions are the same at the LHC, LEP, and at the Tevatron.

For inclusive branching fractions, e.g., $B o D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater

The modes below are listed for a \overline{b} initial state. b modes are their charge conjugates. Reactions indicate the weak decay vertex and do not include mixing.

7 DECAY MODES

Scale factor/ Fraction (Γ_i/Γ) Confidence level (MeV/c)

 $\times 10^{-7}$ CL=90% 2563

PRODUCTION FRACTIONS

The production fractions for weakly decaying b-hadrons at high energy have been calculated from the best values of mean lives, mixing parameters, and branching fractions in this edition by the Heavy Flavor Averaging Group (HFAG) as described in the note " B^0 – \overline{B}^0 Mixing" in the B^0 Particle Listings. The production fractions in b-hadronic Z decay or $p\overline{p}$ collisions at the Tevatron are also listed at the end of the section. Values assume

$$\begin{array}{ll} B(\overline{b} \to B^+) = B(\overline{b} \to B^0) \\ B(\overline{b} \to B^+) + B(\overline{b} \to B^0) + B(\overline{b} \to B^0_S) + B(b \to b\text{-baryon}) = 100 \ \%. \end{array}$$

The correlation coefficients between production fractions are also reported:

 $cor(B_c^0, b\text{-baryon}) = -0.277$ $cor(B_c^{\bar{0}}, B^{\pm}=B^0) = -0.119$ cor(b-baryon, $B^{\pm}=B^{0}) = -0.921$.

The notation for production fractions varies in the literature $(f_d, d_{R^0},$ $f(b \to \overline{B}{}^0)$, ${\rm Br}(b \to \overline{B}{}^0))$. We use our own branching fraction notation here, $B(\overline{b} \rightarrow B^0)$.

Note these production fractions are b-hadronization fractions, not the conventional branching fractions of b-quark to a B-hadron, which may have considerable dependence on the initial and final state kinematic and pro-

 B^+ $(40.1 \pm 0.8)\%$ B^0 (40.1 \pm 0.8) % B_c^0 $(10.5 \pm 0.6)\%$ b-baryon $(9.3 \pm 1.6)\%$

DECAY MODES

```
Semileptonic and leptonic modes

u anything
                                                           (23.1 \pm 1.5)\%
    \ell^+
u_\ell anything
                                                 [ppp] ( 10.69± 0.22) %
    e^+ \nu_e anything
                                                           (10.86 \pm 0.35)\%
                                                           (\ 10.95 \, {}^{+}_{-} \ 0.29 \atop 0.25) \ \%
   \mu^+\,
u_\mu a nything
D^-\,\ell^+\,
u_\ell a nything
                                                 [ppp] ( 2.27 ± 0.35) %
                                                                                                 S=1.7
   D^-\pi^+\ell^+
u_\ell anything
                                                               4.9 \pm 1.9 )\times10^{-3}
    D^-\pi^-\ell^+
u_\ell^{\ell} anything
                                                               2.6 \pm 1.6 \times 10^{-3}
\begin{array}{c} \overline{D}{}^0\,\ell^+\,\nu_\ell\, {\rm anything} \\ \underline{\overline{D}}{}^0\,\pi^-\,\ell^+\,\nu_\ell\, {\rm anything} \end{array}
                                                 [ppp] ( 6.84 ± 0.35) %
                                                              1.07 ± 0.27) %
   rac{D}{D}{}^0\pi^+\ell^+
u_\ell a nything
                                                               2.3~\pm~1.6 ) \times\,10^{-3}
D^{*-}\ell^+\nu_\ell anything
                                                 [ppp] ( 2.75 ± 0.19) %
    D^{*-}\pi^{-}\ell^{+}\nu_{\ell} anything
                                                           (\phantom{-}6\phantom{0}\pm\phantom{7}\phantom{0})\times10^{-4}
   D^{*-}\pi^+\ell^+\nu_\ell anything
                                                              4.8 \pm 1.0 ) \times 10<sup>-3</sup>
       \overline{D}_i^0 \ell^+ \nu_\ell anything \times
                                             [ppp,iiii] ( 2.6 \pm 0.9 ) \times 10<sup>-3</sup>
            B(\overline{D}_i^0 \rightarrow D^{*+} \pi^-)
       D_i^- \ell^+ \nu_\ell anything 	imes
                                             [ppp,iiii] (7.0 \pm 2.3) \times 10^{-3}
            B(D_i^- \rightarrow D^0\pi^-)
       \overline{D}_2^*(2460)^0 \ell^+ \nu_\ell anything
                                                                                 \times\,10^{-3}~\text{CL}\!=\!90\%
             \times B(\overline{D}_2^*(2460)^0 \rightarrow
             D^{*-}\pi^{+})
       D_2^*(2460)^-\ell^+
u_\ell a nything
                                                           (4.2 \begin{array}{c} + 1.5 \\ - 1.8 \end{array}) \times 10^{-3}
             \times B(D_2^*(2460)^- \rightarrow
            D^0 \pi^-
       \overline{D}_2^*(2460)^0 \ell^+ \nu_\ell anything
                                                           (1.6 \pm 0.8) \times 10^{-3}
            \times B(\overline{D}_2^*(2460)^0 \rightarrow
             D^-\pi^+
charmless \ell \overline{\nu}_{\ell}
                                                         (1.7 \pm 0.5) \times 10^{-3}
	au^+ 
u_{	au} anything
                                                           (2.41 \pm 0.23) \%
   D^{*-} 	au 
u_{	au} anything
                                                           (9 \pm 4) \times 10^{-3}
\overline{c} \rightarrow \ell^- \overline{\nu}_{\ell} anything
                                                 [ppp] ( 8.02± 0.19) %
                                                           ( 1.6 \begin{array}{c} + & 0.4 \\ - & 0.5 \end{array}) \%
c \rightarrow \ell^+ \nu anything
                                Charmed meson and baryon modes
\overline{D}^0 anything
                                                           (59.8 \pm 2.9)\%
D^0D^{\pm}_{c} anything
                                                  [ee] (9.1 + 4.0 \\ -2.8) %
                                                  [ee] (4.0 + 2.3 \times 1.8)
D^{\mp}D_{s}^{\pm} anything
\overline{D}^0 D^0 anything
                                                  [ee] ( 5.1 + 2.0 ) %
                                                  [ee]\quad (\quad 2.7\ \ {}^{+}_{-}\ \ 1.8\ )\ \%
D^0 D^{\pm} anything
                                                  [ee] < 9
D^{\pm}D^{\mp} anything
                                                                               \times 10^{-3} \text{ CL} = 90\%
D^- anything
                                                           (23.3 \pm 1.7)\%
D^*(2010)^+ anything
                                                           (17.3 \pm 2.0)\%
D_1 (2420) ^0 a nything
                                                           ( 5.0 \pm 1.5 ) %
D^*(2010)^{\mp} D_s^{\pm} anything
                                                  [ee] (3.3 + 1.6 )\%
D^0 D^* (2010)^{\pm} anything
                                                  [ee] (3.0 + 1.1 \atop -0.9)\%
D^*(2010)^{\pm} D^{\mp} anything
                                                  [ee] (2.5 + 1.2)\%
D^*(2010)^{\pm} D^*(2010)^{\mp} anything [ee] ( 1.2 \pm 0.4 )%
                                                           (10 \quad ^{+11}_{-10} \quad )\%
\overline{D}D anything
D_2^*(2460)^0 anything
                                                           ( 4.7 \pm 2.7) %
D_s^- anything
                                                           (14.7 \pm 2.1)\%
D_s^+ anything
                                                          ( 10.1 \pm 3.1 ) %
\Lambda_c^+ anything
                                                           (9.7 \pm 2.9)\%
\overline{c}/c anything
                                               [hhhh] (116.2 \pm 3.2 ) %
                                            Charmonium modes
                                                           (\phantom{-}1.16 \pm \phantom{0}0.10)~\%
J/\psi(1S) a nything
\psi(2S) anything
                                                           ( 4.8 \pm 2.4 ) \times\,10^{-3}
\chi_{c1}(1P) anything
                                                           ( 1.4 \pm 0.4) %
                                               K or K* modes
\overline{s}\gamma
                                                         (3.1 \pm 1.1) \times 10^{-4}
                                                         < 6.4 \times 10^{-4} CL=90%
\overline{S}\overline{\nu}\nu
K^{\pm} anything
                                                           (74 \pm 6)\%
K_S^0 anything
                                                           (29.0 \pm 2.9)\%
```

Pion modes

 π^{\pm} anything

 π^0 anything

 ϕ anything

 $\begin{array}{ccc} & (397 & \pm 21 &) \% \\ [\mathit{hhhh}] & (278 & \pm 60 &) \% \end{array}$

 $(2.82 \pm 0.23)\%$

Baryon modes

 p/\overline{p} anything (13.1 ± 1.1)%

Other modes

charged anything [hhhh] (497 \pm 7)% hadron⁺ hadron⁻ (1.7 $^+_{0.7}^{1.0}$) \times 10⁻⁵ charmless (7 \pm 21) \times 10⁻³

Baryon modes

 Λ/Λ anything (5.9 \pm 0.6) % b-baryon anything (10.2 \pm 2.8) %

$\Delta B = 1$ weak neutral current (B1) modes

 $\mu^+\mu^-$ anything B1 < 3.2 \times 10⁻⁴ CL=90%

B*

$$I(J^P) = \frac{1}{2}(1^-)$$

 ${\it I}$, ${\it J}$, ${\it P}$ need confirmation. Quantum numbers shown are quark-model predictions.

Mass
$$m_{B^*} = 5325.2 \pm 0.4 \; {\rm MeV}$$
 $m_{B^*} - m_B = 45.78 \pm 0.35 \; {\rm MeV}$

| B* DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------|------------------------------|-----------|
| $B\gamma$ | dominant | 45 |

$B_1(5721)^0$

$$I(J^P) = \frac{1}{2}(1^+)$$

 $I, J, P \text{ need confirmation.}$

$$B_1(5721)^0$$
 MASS = 5723.5 \pm 2.0 MeV (S = 1.1) $m_{B^0} - m_{B^+} =$ 444.3 \pm 2.0 MeV (S = 1.1)

| B ₁ (5721) ⁰ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c |
|------------------------------------------------|------------------------------|-----------|
| $B^{*+}\pi^{-}$ | dominant | - |

B*(5747)0

$$I(J^P) = \frac{1}{2}(2^+)$$

I, J, P need confirmation.

$$B_2^*(5747)^0~{\rm MASS}=5743\pm 5~{\rm MeV}~({\rm S}=2.9)$$
 Full width $\Gamma=23^{+~5}_{-11}~{\rm MeV}$ $m_{B_2^{*0}}-m_{B_1^0}=19\pm 6~{\rm MeV}~({\rm S}=3.0)$

| B*(5747) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------|------------------------------|-----------|
| $B^+\pi^-$ | dominant | 424 |
| $B^{*+}\pi^{-}$ | dominant | - |

BOTTOM, STRANGE MESONS $(B = \pm 1, S = \mp 1)$

 $B_s^0 = s\overline{b}, \overline{B}_s^0 = \overline{s}b,$ similarly for B_s^* 's



$$I(J^P) = 0(0^-)$$

 ${\it I}$, ${\it J}$, ${\it P}$ need confirmation. Quantum numbers shown are quark-model predictions.

Mass
$$m_{B_s^0} = 5366.77 \pm 0.24$$
 MeV $m_{B_s^0} - m_B = 87.35 \pm 0.23$ MeV Mean life $\tau = (1.497 \pm 0.015) \times 10^{-12}$ s $c\tau = 449~\mu\text{m}$ $\Delta\Gamma_{B_s^0} = \Gamma_{B_s^0} - \Gamma_{B_{sH}^0} = (0.100 \pm 0.013) \times 10^{12} \,\text{s}^{-1}$

$B_s^0 - \overline{B}_s^0$ mixing parameters

$$\begin{split} \Delta m_{B_s^0} &= m_{B_{sH}^0} - m_{B_{sL}^0} = (17.69 \pm 0.08) \times 10^{12} \; \hbar \; \text{s}^{-1} \\ &= (116.4 \pm 0.5) \times 10^{-10} \; \text{MeV} \\ x_s &= \Delta m_{B_s^0} / \Gamma_{B_s^0} = 26.49 \pm 0.29 \\ \chi_s &= 0.499292 \pm 0.000016 \end{split}$$

CP violation parameters in B_s^0

$$\begin{array}{l} {\rm Re}(\epsilon_{B_s^0}) \ / \ (1 + |\epsilon_{B_s^0}|^2) = (-2.6 \pm 1.6) \times 10^{-3} \\ CP \ {\rm Violation \ phase} \ \beta_s = 0.08^{+0.05}_{-0.07} \\ A_{CP}(B_s \to \ \pi^+ K^-) = 0.39 \pm 0.17 \end{array}$$

These branching fractions all scale with $B(\overline{b} \rightarrow B_s^0)$.

The branching fraction ${\sf B}(B_s^0\to D_s^-\ell^+\nu_\ell$ anything) is not a pure measurement since the measured product branching fraction ${\sf B}(\overline{b}\to B_s^0)\times {\sf B}(B_s^0\to D_s^-\ell^+\nu_\ell$ anything) was used to determine ${\sf B}(\overline{b}\to B_s^0)$, as described in the note on " $B^0-\overline{B}^0$ Mixing"

For inclusive branching fractions, e.g., $B\to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one

| B _S DECAY MODES | | Fraction (Γ | · _i /Γ) | Confidence le | p evel (MeV/c) |
|------------------------------------------------|--------|------------------|----------------------|---------------|----------------------|
| D_ anything | | (93 : | ±25) % | 6 | _ |
| $\ell \nu_{\ell} X$ | | (9.5 : | ± 2.7) % | 6 | _ |
| $D_s^-\ell^+ u_\ell$ a nything | [jjjj] | (7.9 : | ± 2.4) % | , 0 | - |
| $D_{s1}(2536)^- \mu^+ \nu_{\mu}$, | | (2.5 : | ± 0.7)× | 10^{-3} | - |
| $D_{s1}^- \rightarrow D^{*-}K_S^0$ | | | | | |
| $D_{s1}(2536)^- X \mu^+ \nu$, | | (4.3 : | ± 1.7) × | 10-3 | - |
| $D_{s1}^- \rightarrow D^0 K^+$ | | | | | |
| $D_{s2}(2573)^- X \mu^+ \nu$, | | (2.6 : | ± 1.2) × | 10^{-3} | - |
| $D_{s2}^- \rightarrow \overline{D}^0 K^+$ | | | | | |
| $D_s^-\pi^+$ | | | ± 0.4) × | | 2320 |
| $D_s^- \rho^+$ | | | ± 1.7) × | | 2248 |
| $D_s^- \pi^+ \pi^+ \pi^-$ | | (6.5 | ± 1.2) × | 10-3 | 2301 |
| $D_s^{\mp} K^{\pm}$ | | (2.9 : | ± 0.6) × | 10-4 | 2293 |
| $D_s^+ D_s^-$ | | (5.3 : | ± 0.9) × | 10^{-3} | 1824 |
| $D_{c}^{*-}\pi^{+}$ | | (2.1 : | ± 0.6) × | 10^{-3} | 2265 |
| $D_{s}^{*-}\rho^{+}$ | | (1.03 : | ± 0.26) % | , 0 | 2190 |
| $D_{s}^{*+}D_{s}^{-}+D_{s}^{*-}D_{s}^{+}$ | | (1.24 : | ± 0.21) % | ó | 1742 |
| $D_{s}^{*+}D_{s}^{*-}$ | | (1.88 : | ± 0.34) % | ó | 1655 |
| $D_s^{(*)+}D_s^{(*)-}$ | | (4.5 | ± 1.4) % | 6 | _ |
| $\overline{D}^{0} \overline{K}^{*} (892)^{0}$ | | (4.7 : | ± 1.4) × | 10-4 | 2264 |
| $J/\psi(1S)\phi$ | | (1.09 | + 0.28 - 0.23) > | 10-3 | 1588 |
| $J/\psi(1S)\pi^0$ | | < 1.2 | | | 00% 1786 |
| $J/\psi(1S)\eta$ | | (5.1 | + 1.3) > | | 1733 |
| $J/\psi(1S)K^0$ | | | - 1.0 / ± 0.8) × | | 1743 |
| $J/\psi(1S) K^{*0}$ | | (9) | ± 4) × | 10-5 | - |
| $J/\psi(1S)\eta'$ | | | + 1.0) > | | 1612 |
| $J/\psi(1S) f_0(980), f_0 \to$ | | | + 0.35 - 0.28) > | | _ |
| $\pi^+\pi^-$ | | | | | |
| $J/\psi(1S) f_0(1370), f_0 \to$ | | (3.4 : | ± 1.4) × | 10-5 | - |
| $\pi^+\pi^-$ | | (| + 1.8 v | 10-4 | 1100 |
| $\psi(2S)\phi$ | | | + 1.8) > | | 1120 |
| $^{\pi^+\pi^-}_{\pi^0\pi^0}$ | | < 1.2 < 2.1 | | | 00% 2680 00% 2680 |
| $\eta \pi^0$ | | < 2.1 < 1.0 | | _ | 00% 2654 |
| $\eta \eta$ | | < 1.5 | | 2 | 00% 2627 |
| $\rho^0 \rho^0$ | | < 3.20 | | | 00% 2569 |
| $\phi \rho^0$ | | < 6.17 | > | 10-4 | 00% 2526 |
| $\phi \phi$ | | (1.9 | + 0.6 - 0.5) > | 10-5 | 2482 |
| π^+ K $^-$ | | (5.3 : | ± 1.0) × | | 265 9 |
| K^+K^- | | | ± 0.28) × | | 2638 |
| $K^0\overline{K}^0$ | | < 6.6 | | | 00% 2637 |
| $\overline{K}^*(892)^0 \rho^0$ | | < 7.67 | | | 00% 2550 |
| $\overline{K}^*(892)^0 K^*(892)^0$ | | | ± 0.7) × | | 2531 90% 2507 |
| $\phi K^*(892)^0$ | | < 1.013 < 5.9 | | - | 00% 2507 00% 2514 |
| $\gamma \gamma$ | В1 | < 8.7 | × | | 00% 2683 |
| $\phi\gamma$ | = | | + 2.2) > | | 2587 |
| Ψ 1 | | (3.7 | - 1.9 / / | . 10 | 2301 |

| $\Delta B = 1$ weak neutral current (B1) modes | | | | | | |
|------------------------------------------------|----|------------|-------------------------|-----|------|--|
| $\mu^+ \mu^-$ | B1 | < 6.4 | $\times 10^{-9}$ | 90% | 2681 | |
| e^+e^- | B1 | < 2.8 | $\times 10^{-7}$ | 90% | 2683 | |
| $e^{\pm}\mu^{\mp}$ | LF | [ee] < 2.0 | $\times 10^{-7}$ | 90% | 2682 | |
| ϕ (1020) $\mu^{+}\mu^{-}$ | В1 | (1.23 + 0) | $(0.40) \times 10^{-6}$ | | 2582 | |
| $\phi \nu \overline{\nu}$ | B1 | < 5.4 | $\times 10^{-3}$ | 90% | 2587 | |

Lepton Family number (LF) violating modes or



$$I(J^P) = 0(1^-)$$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass
$$m = 5415.4^{+2.4}_{-2.1} \text{ MeV}$$
 (S = 3.0) $m_{B_8^*} - m_{B_5} = 48.7^{+2.3}_{-2.1} \text{ MeV}$ (S = 2.8)

B* DECAY MODES $B_s \gamma$

Fraction (Γ_i/Γ)

dominant

$B_{s1}(5830)^0$

$$I(J^P) = 0(1^+)$$

I, J, P need confirmation.

Mass m= 5829.4 \pm 0.7 MeV $m_{B_{\,\mathrm{S}^{\,0}}^{\,0}} - m_{B^{*+}} = 504.41 \pm 0.25 \; \mathrm{MeV}$

| $B_{s1}(5830)^0$ | DECAY | MODES |
|------------------|-------|-------|
| B*+ K− | | |

Fraction
$$(\Gamma_j/\Gamma)$$
 p (Mominant

$$B_{s2}^*(5840)^0$$

$$I(J^P) = 0(2^+)$$

$$I(J') = 0(2^{+})$$

 $I, J, P \text{ need confirmation.}$

Mass $m=5839.7\pm0.6~\mathrm{MeV}$ $m_{B_{s2}^{*0}} - m_{B_{s1}^{0}} = 10.5 \pm 0.6 \; \mathrm{MeV}$

Fraction (Γ_i/Γ)

dominant

p (MeV/c)

 $B^+ K^-$

252

BOTTOM, CHARMED MESONS $(B = C = \pm 1)$

 $B_c^+ = c\overline{b}$, $B_c^- = \overline{c}b$, similarly for B_c^* 's



$$I(J^P) = 0(0^-)$$

I, J, P need confirmation.

Quantum numbers shown are quark-model predicitions. Mass $m = 6.277 \pm 0.006 \text{ GeV}$ (S = 1.6) Mean life $\tau = (0.453 \pm 0.041) \times 10^{-12}$ s

 B_c^- modes are charge conjugates of the modes below.

 B_c^+ DECAY MODES \times B($\overline{b} \rightarrow B_c$)

Fraction (Γ_i/Γ) Confidence level (MeV/c)

The following quantities are not pure branching ratios; rather the fraction $\Gamma_i/\Gamma \times \mathrm{B}(\overline{b} \to B_C).$

| $J/\psi(1S)\ell^+ u_\ell$ a nything | $(5.2 + 2.4 \\ -2.1$ |) × 10 ⁻⁵ | | _ |
|-------------------------------------|----------------------|----------------------|-----|-------|
| $J/\psi(1S)\pi^+$ | < 8.2 | $\times 10^{-5}$ | 90% | 2372 |
| $J/\psi(1S)\pi^{+}\pi^{+}\pi^{-}$ | < 5.7 | $\times 10^{-4}$ | 90% | 235 2 |
| $J/\psi(1S) a_1(1260)$ | < 1.2 | $\times 10^{-3}$ | 90% | 2171 |
| $D^*(2010)^+ \overline{D}{}^0$ | < 6.2 | $\times 10^{-3}$ | 90% | 2468 |

cc MESONS

 $\eta_c(1S)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-})$$

Mass $m = 2981.0 \pm 1.1 \text{ MeV}$ (S = 1.7) Full width $\Gamma = 29.7 \pm 1.0 \; \text{MeV}$

| $\eta_{\mathcal{C}}(1S)$ DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (Me <i>V/c</i>) |
|-----------------------------------------------|------------------------------|--------------------------------|-------------------------------|
| Decays involving | g hadronic resona | inces | |
| $\eta'(958) \pi \pi$ | (4.1 ±1.7)% | | 1322 |
| $\rho\rho$ | (1.8 ± 0.5) % | | 1273 |
| $K^*(892)^0 K^- \pi^+ + \text{c.c.}$ | $(2.0 \pm 0.7)\%$ | | 1276 |
| $K^*(892)\overline{K}^*(892)$ | (6.8 ± 1.3) \times | 10-3 | 1194 |
| $K^{*0} \overline{K}^{*0} \pi^{+} \pi^{-}$ | (1.1 \pm 0.5) % | | 1071 |
| $\phi K^+ K^-$ | (2.9 ± 1.4) \times | | 1102 |
| $\phi\phi$ | $(1.94\pm0.30)~\times$ | | 1087 |
| $\phi 2(\pi^+ \pi^-)$ | - | 10^{-3} 90% | 1249 |
| $a_0(980)\pi$ | < 2 % | 90% | 1326 |
| $a_2(1320) \underline{\pi}$ | < 2 % | 90% | 1194 |
| $K^*(892)\overline{K} + \text{c.c.}$ | < 1.28 % | 90% | 1308 |
| $f_2(1270)\eta$ | < 1.1 % | 90% | 1144 |
| $\omega \omega$ | | 10^{-3} 90% | 1268 |
| $\omega \phi$ | | 10^{-3} 90% | 1184 |
| $f_2(1270) f_2(1270)$ | (9.7 ± 2.5) × | | 772 |
| $f_2(1270) f_2'(1525)$ | $(9.3~\pm 3.1~)\times\\$ | 10-3 | 509 |
| Decays int | o stable hadrons | | |
| $K\overline{K}\pi$ | $(7.2 \pm 0.6)\%$ | | 1379 |
| $\eta \pi^+ \pi^-$ | $(4.9 \pm 1.8) \%$ | | 1426 |
| $K^{+}K^{-}\pi^{+}\pi^{-}$ | (6.1 ± 1.2) \times | $^{10}^{-3}$ | 1343 |
| $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ | (3.4 ± 0.6) % | | 1303 |
| $K^{+}K^{-}2(\pi^{+}\pi^{-})$ | (7.1 \pm 2.9) \times | | 1252 |
| $2(K^+K^-)$ | $(1.34\pm0.32)~\times$ | | 1054 |
| $2(\pi^{+}\pi^{-})$ | (8.6 ± 1.3) \times | 10-3 | 1458 |
| $3(\pi^{+}\pi^{-})$ | (1.5 ± 0.5) % | 2 | 1405 |
| р <u>р</u> | $(1.41\pm0.17)~\times$ | | 1158 |
| ΛΛ Κ Τ | (9.4 ± 3.2) × | | 988 |
| $K\overline{K}\eta$ $\pi^+\pi^-p\overline{p}$ | < 3.1 % | 90% | 1264 |
| π ' π ' ρ ρ | < 1.2 % | 90% | 1025 |
| Radia | tive decays | | |
| $\gamma \gamma$ | $(1.78\pm0.16)~\times$ | 10^{-4} | 1490 |
| Charge conjuga Lepton family num | ation (<i>C</i>), Parity | | |
| $\pi^+\pi^-$ P,CP | | 10 ⁻⁴ 90% | 1484 |
| | | 10 90% 10 ⁻⁵ 90% | 1484 |
| | | 10-4 90% | 1406 |
| $K_S^0 K_S^0$ P,CP | | | 1405 |

$J/\psi(1S)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m = 3096.916 \pm 0.011 \text{ MeV}$ Full width $\Gamma = 92.9 \pm 2.8 \text{ keV}$ (S = 1.1) $\Gamma_{e\,e}\,=\,5.55\,\pm\,0.14\,\pm\,0.02$ keV

| 0.0 | | |
|-----------------------------------------------------|---------------------------------------------------------------------|--------------------------------------------|
| $J/\psi(1S)$ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ p Confidence level(MeV/c) |
| hadrons | (87.7 ±0.5) % | |
| virtual $\gamma ightarrow $ hadrons | $(13.50 \pm 0.30)\%$ | = |
| ggg | $(64.1 \pm 1.0) \%$ | - |
| $\gamma g g$ | $(8.8 \pm 1.1)\%$ | - |
| e+ e- | $(5.94 \pm 0.06)\%$ | 1548 |
| $e^+e^-\gamma$ | [kkkk] (8.8 ± 1.4) \times 10 ⁻ | 3 1548 |
| $\mu^+ \mu^-$ | $(5.93 \pm 0.06)\%$ | 1545 |
| Decays i | nvolving hadronic resonances | |
| $\rho\pi$ | $(1.69 \pm 0.15)\%$ | S=2.4 1448 |
| $ ho^0 \pi^0$ | $(5.6 \pm 0.7) \times 10^{-1}$ | 3 1448 |
| $a_2(1320) \rho$ | (1.09 ± 0.22) % | 1123 |
| $\omega \pi^{+} \pi^{+} \pi^{-} \pi^{-}$ | $(8.5 \pm 3.4) \times 10^{-1}$ | |
| $\omega \pi^+ \pi^- \pi^0$ | $(4.0 \pm 0.7) \times 10^{-}$ | |
| $\omega \pi^+ \pi^-$ | $(8.6 \pm 0.7) \times 10^{-1}$ | |
| $\omega f_2(1270)$ | (4.3 ± 0.6) $\times 10^-$ | |
| $K^*(892)^0 \overline{K}^*(892)^0$ | $(2.3 \pm 0.7) \times 10^{-}$ | |
| $K^*(892)^{\pm}\overline{K}^*(892)^{\mp}$ | $(1.00 \begin{array}{c} +0.22 \\ -0.40 \end{array}) \times 10^{-1}$ | 3 1266 |
| $K^*(892)^{\pm}\overline{K}^*(800)^{\mp}$ | $(1.1 ^{+ 1.0}_{- 0.6}) \times 10^{-}$ | 3 _ |
| $\eta K^*(892)^0 \overline{K}^*(892)^0$ | $(1.15 \pm 0.26) \times 10^{-1}$ | 3 1003 |
| $K^*(892)^0 \overline{K}_2^*(1430)^0 + \text{c.c.}$ | $(6.0 \pm 0.6) \times 10^{-}$ | |
| $K^*(892)^0 \overline{K}_2(1770)^0 + \text{c.c.}$ | | |
| $K^*(892)^0 K^- \pi^+ + \text{c.c.}$ | | |
| $\omega K^*(892)\overline{K} + \text{c.c.}$ | $(6.1 \pm 0.9) \times 10^{-}$ | |
| $K^{+}\overline{K}^{*}(892)^{-}$ + c.c. | (5.12 ± 0.30) \times 10^- | 3 1373 |

| $K^{+}\overline{K}^{*}(892)^{-}+\text{ c.c.} \rightarrow$ | | (1.97 | $\pm 0.20) \times 10^{-3}$ | | _ | $K\overline{K}\pi$ | | $(6.1 \pm 1.0) \times 10^{-3}$ | | 1442 |
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| $K^+K^-\pi^0$ | | ` | · · | | | $2(\pi^{+}\pi^{-})$ | | $(3.55 \pm 0.23) \times 10^{-3}$ | | 1517 |
| $K^+\overline{K}^*(892)^- + \text{c.c.} \rightarrow$ $K^0K^{\pm}\pi^{\mp}$ | | (3.0 | ± 0.4) $\times 10^{-3}$ | | = | $3(\pi^{+}\pi^{-})$ | | $(4.3 \pm 0.4) \times 10^{-3}$ | | 1466 |
| $K^{0}\overline{K}^{*}(892)^{0}+\text{ c.c.}$ | | (4.39 | $\pm 0.31) \times 10^{-3}$ | | 1373 | $\frac{2(\pi^+\pi^-\pi^0)}{2(\pi^+\pi^-)\eta}$ | | $(1.62 \pm 0.21)\%$ $(2.29 \pm 0.24) \times 10^{-3}$ | | 1468 |
| $K^0\overline{K}^*(892)^0 + \text{c.c.} \rightarrow$ | | (3.2 | ± 0.4) $\times 10^{-3}$ | | - | $3(\pi^{+}\pi^{-})\eta$ | | $(7.2 \pm 1.5) \times 10^{-4}$ | | 1446 1379 |
| $K^0 K^{\pm} \pi^{\mp}$ | | (2 0 | 11.1 \ 10-3 | | 1170 | ρ ¯ D | | $(2.17 \pm 0.07) \times 10^{-3}$ | | 1232 |
| $\frac{K_1(1400)^{\pm} K^{\mp}}{K^*(892)^0 K^+ \pi^- + \text{c.c.}}$ | | (3.8 seen | ± 1.4) $\times 10^{-3}$ | | 1170 1343 | $p \overline{p} \pi^0$ | | $(1.19 \pm 0.08) \times 10^{-3}$ | S=1.1 | 1176 |
| $\omega \pi^0 \pi^0$ | | | ± 0.8) $\times 10^{-3}$ | | 1436 | $p \overline{p} \pi^+ \pi^-$ | | $(6.0 \pm 0.5) \times 10^{-3}$ | S=1.3 | 1107 |
| $b_1(1235)^{\pm}\pi^{\mp}$ | | | ± 0.5) $\times 10^{-3}$ | | 1300 | $\rho \overline{\overline{\rho}} \pi^+ \pi^- \pi^0$ | [////] | $(2.3 \pm 0.9) \times 10^{-3}$ | S=1.9 | 1033 |
| $\omega K^{\pm} K_{S}^{0} \pi^{\mp}$ | [ee] | (3.4 | ± 0.5) $\times 10^{-3}$ | | 1210 | ρ <u>ρ</u> η | | $(2.00 \pm 0.12) \times 10^{-3}$ $< 3.1 \times 10^{-4}$ | CL 000/ | 948 |
| $b_1(1235)^0 \pi^0$ | | | ± 0.6) $\times 10^{-3}$ | | 1300 | ρ <u>ρ</u> ρ ρ <u>ρ</u> ω | | $< 3.1 \times 10^{-4}$ $(1.10 \pm 0.15) \times 10^{-3}$ | CL=90% S=1.3 | 774 768 |
| $\eta K^{\pm} K_S^0 \pi^{\mp}$ | [ee] | | ± 0.4) $\times 10^{-3}$ | | 1278 | $p \overline{p} \omega$ $p \overline{p} \eta'(958)$ | | $(2.1 \pm 0.4) \times 10^{-4}$ | 5_1.5 | 596 |
| $\phi K^*(892)\overline{K} + \text{c.c.}$ | | | ± 0.23) $\times 10^{-3}$ | | 969 | $p \overline{p} \phi$ | | $(4.5 \pm 1.5) \times 10^{-5}$ | | 527 |
| $\omega K \overline{K}$ $\omega f_0(1710) \rightarrow \omega K \overline{K}$ | | | ± 0.32) $\times 10^{-3}$ ± 1.1) $\times 10^{-4}$ | | 1268 878 | n n | | $(2.2 \pm 0.4) \times 10^{-3}$ | | 1231 |
| $\phi_{2}(\pi^{+}\pi^{-})$ | | | ± 0.23) $\times 10^{-3}$ | | 1318 | $n \overline{n} \pi^+ \pi^- \Sigma^+ \overline{\Sigma}^-$ | | $(4 \pm 4) \times 10^{-3}$ | | 1106 |
| $\Delta(1232)^{++} \bar{p}\pi^{-}$ | | | ± 0.5) $\times 10^{-3}$ | | 1030 | $\sum_{i} 0 \frac{2}{\sum_{i} 0}$ | | $(1.50 \pm 0.24) \times 10^{-3}$ $(1.29 \pm 0.09) \times 10^{-3}$ | | 992 988 |
| $\omega \eta$ | | | ± 0.20) $\times 10^{-3}$ | S=1.6 | 1394 | $2(\pi^{+}\pi^{-})K^{+}K^{-}$ | | $(4.7 \pm 0.7) \times 10^{-3}$ | S=1.3 | 1320 |
| $\phi K K$ | | , | $\pm 0.24) \times 10^{-3}$ | S=1.5 | 1179 | $p \overline{n} \pi^-$ | | $(2.12 \pm 0.09) \times 10^{-3}$ | | 1174 |
| $\phi f_0(1710) \rightarrow \phi K \overline{K}$ | | , | ± 0.6) $\times 10^{-4}$ | | 875 | n N (1440) | | seen | | 978 |
| $\phi f_2(1270) \ \Delta(1232)^{++} \overline{\Delta}(1232)^{}$ | | | ± 1.3) $\times 10^{-4}$ ± 0.29) $\times 10^{-3}$ | | 1036 938 | n N (1520) | | seen | | 924 |
| $\Sigma(1385)^{-} \frac{\Sigma(1282)}{\Sigma(1385)^{+}}$ (or c.c.) | | , | ± 0.13) $\times 10^{-3}$ | | 697 | $n N (1535)$ $\Xi - \overline{\Xi}^+$ | | seen | 6 1 5 | 914 |
| $\phi f_2'(1525)$ | | , | ±4)×10 ⁻⁴ | S=2.7 | 871 | = = ' \(\lambda\)\(\overline{A}\) | | $(8.5 \pm 1.6) \times 10^{-4}$ $(1.61 \pm 0.15) \times 10^{-3}$ | S=1.5 S=1.9 | 807 1074 |
| $\phi \pi^{+} \pi^{-}$ | | (9.4 | ± 0.9) $\times 10^{-4}$ | S=1.2 | 1365 | $\Lambda \overline{\Sigma}^- \pi^+$ (or c.c.) | [ee] | $(8.3 \pm 0.7) \times 10^{-4}$ | S=1.2 | 950 |
| $\phi \pi^0 \pi^0$ | | , | ± 1.6) $\times 10^{-4}$ | | 1366 | $p K^{-} \overline{\Lambda}$ | | $(8.9 \pm 1.6) \times 10^{-4}$ | | 876 |
| $\phi K^{\pm} K_S^0 \pi^{\mp}$ | [<i>ee</i>] | • | ± 0.8) $\times 10^{-4}$ | | 1114 | $2(K^{+}K^{-})$ | | $(7.6 \pm 0.9) \times 10^{-4}$ | | 1131 |
| $\omega f_1(1420)$ | | | ± 2.4) $\times 10^{-4}$ ± 0.8) $\times 10^{-4}$ | S=1.5 | 1062 1320 | $pK - \overline{\Sigma}^0$ | | $(2.9 \pm 0.8) \times 10^{-4}$ | | 819 |
| $\phi \eta = 0 = 0$ | | , | $\pm 0.80 \times 10^{-3}$ | 3=1.3 | 818 | $egin{array}{c} \mathcal{K}^+ \mathcal{K}^- \ \mathcal{K}^0_{\underline{\mathcal{S}}} \mathcal{K}^0_{\underline{L}} \end{array}$ | | $(2.37 \pm 0.31) \times 10^{-4}$ $(1.46 \pm 0.26) \times 10^{-4}$ | S=2.7 | 1468 1466 |
| | | , | ± 1.5) $\times 10^{-4}$ | | 600 | $\frac{N_{S}N_{L}}{\Lambda\Lambda\eta}$ | | $(2.6 \pm 0.7) \times 10^{-4}$ | 3=2.1 | 672 |
| $p \dot{K}^{-} \overline{\Sigma} (1385)^{0}$ | | 5.1 | ± 3.2) $\times 10^{-4}$ | | 646 | $\Lambda \overline{\Lambda} \pi^0$ | | < 6.4 × 10 ⁻⁵ | CL=90% | 998 |
| $\omega \pi^0$ | | , | ± 0.5) $\times 10^{-4}$ | S=1.4 | 1446 | $\overline{\Lambda} n K_S^0 + \text{c.c.}$ | | $(6.5 \pm 1.1) \times 10^{-4}$ | | 872 |
| $\phi \eta'(958)$ | | , | ± 0.7) $\times 10^{-4}$ | S=2.1 | 1192 | $\pi_{\underline{}}^{+}\pi^{-}$ | | ($1.47~\pm0.23$) $\times10^{-4}$ | | 1542 |
| $\phi f_0(980)$ $\phi f_0(980) \rightarrow \phi \pi^+ \pi^-$ | | , | ± 0.9) $\times 10^{-4}$ ± 0.4) $\times 10^{-4}$ | S=1.9 | 1178 | $\Lambda \overline{\Sigma} + \text{c.c.}$ | | $< 1.5 \times 10^{-4}$ | CL=90% | 1034 |
| $\phi f_0(980) \rightarrow \phi \pi^0 \pi^0$ | | , | ± 0.7) $\times 10^{-4}$ | | _ | $K^0_S K^0_S$ | | $< 1 \times 10^{-6}$ | CL=95% | 1466 |
| $\eta \phi f_0(980) \rightarrow \eta \phi \pi^+ \pi^-$ | | | ± 1.0) $\times 10^{-4}$ | | _ | İ | Radia | tive decays | | |
| | | | | | | | | | | |
| $\phi a_0 (980)^0 \to \phi \eta \pi^0$ | | , | ± 4) $\times 10^{-6}$ | | - | 3γ | | $(1.2 \pm 0.4) \times 10^{-5}$ | | 1548 |
| $\Xi(1530)^0 \overline{\Xi}{}^0$ | | 3.2 | ± 1.4) $\times 10^{-4}$ | | 608 | 4γ | | $(1.2 \pm 0.4) \times 10^{-5}$ $< 9 \times 10^{-6}$ | CL=90% | 1548 |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ | | 3.2 | ± 1.4) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ | S_1 1 | 608 855 | $\overset{\cdot}{4\gamma}$ 5 γ | | $(1.2 \pm 0.4) \times 10^{-5}$ $< 9 \times 10^{-6}$ $< 1.5 \times 10^{-5}$ | CL=90% | 1548 1548 |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ $\phi f_1(1285)$ | [ee] | 3.2 (3.1 (2.6 | ± 1.4) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ | S=1.1 | 608 855 1032 | $4\gamma \ 5\gamma \ \gamma \eta_c (15)$ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 1548 1548 114 |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ | [ee] | 3.2 (3.1 (2.6 (4.0 | ± 1.4) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ | S=1.1 | 608 855 | $egin{array}{l} 4\gamma & & & & \\ 5\gamma & & & \\ \gamma \eta_c(1S) & & & \\ & & & \gamma \eta_c(1S) ightarrow & 3\gamma & & \end{array}$ | | $ \begin{array}{ccccc} (&1.2&\pm0.4&)\times10^{-5}\\ <&9&&\times10^{-6}\\ <&1.5&&\times10^{-5}\\ (&1.7&\pm0.4&)&\%\\ (&1.2&+\frac{2.7}{1.1}&)\times10^{-6} \end{array} $ | CL=90% | 1548 1548 114 — |
| $\Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958)$ | [ee] | (3.2 (3.1 (2.6 (4.0 (1.93 | ± 1.4) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ ± 1.7) $\times 10^{-4}$ | S=1.1 | 608 855 1032 1487 | $ \begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma \eta_c(1S) \\ \gamma \eta_c(1S) \rightarrow 3\gamma \\ \gamma \pi^+ \pi^- 2\pi^0 \end{array} $ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | 1548 1548 114 — 1518 |
| $\Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980)$ | [ee] | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 | $\begin{array}{cccc} \pm 1.4 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 1.7 &) \times 10^{-4} \\ \pm 0.23 &) \times 10^{-4} \\ \pm 0.21 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \end{array}$ | S=1.1 | 608 855 1032 1487 1396 1279 1267 | $ \begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma \eta_c(1S) \\ \gamma \eta_c(1S) \rightarrow 3\gamma \\ \gamma \pi^+ \pi^- 2\pi^0 \\ \gamma \eta \pi \pi \end{array} $ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | 1548 1548 114 — |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ $\phi f_1(1285)$ $\eta \pi^+ \pi^-$ $\rho \eta$ $\omega \eta'(958)$ $\omega f_0(980)$ $\rho \eta'(958)$ | [ee] | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 | $\begin{array}{c} \pm 1.4 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 1.7 &) \times 10^{-4} \\ \pm 0.23 &) \times 10^{-4} \\ \pm 0.21 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.18 &) \times 10^{-4} \end{array}$ | | 608 855 1032 1487 1396 1279 1267 1281 | $ \begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma \eta_c(1S) \\ \gamma \eta_c(1S) \rightarrow 3\gamma \\ \gamma \pi^+ \pi^- 2\pi^0 \end{array} $ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | 1548 1548 114 — 1518 |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ $\phi f_1(1285)$ $\eta \pi^+ \pi^-$ $\rho \eta$ $\omega \eta'(958)$ $\omega f_0(980)$ $\rho \eta'(958)$ $a_2(1320)^{\pm} \pi^{\mp}$ | [ee] [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \end{array}$ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma KK\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^{0} \end{array}$ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 | 1548 1548 114 — 1518 1487 |
| $ \begin{array}{l} \Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \\ a_2(1320)^\pm \pi^\mp \\ K \overline{K}_2^*(1430) + \text{c.c.} \end{array} $ | [ee] < [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 | $\begin{array}{c} \pm 1.4 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 1.7 &) \times 10^{-4} \\ \pm 0.23 &) \times 10^{-4} \\ \pm 0.21 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.18 &) \times 10^{-3} \\ & \times 10^{-3} \end{array}$ | CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^+\pi^- \end{array}$ | [<i>n</i>] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.6 S=1.8 | 1548 1548 114 — 1518 1487 — 1223 |
| $\Xi(1530)^0 \overline{\Xi}^0$ $\Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ $\phi f_1(1285)$ $\eta \pi^+ \pi^-$ $\rho \eta$ $\omega \eta'(958)$ $\omega f_0(980)$ $\rho \eta'(958)$ $a_2(1320)^{\pm} \pi^{\mp}$ | [ee] < [ee] < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \end{array}$ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \end{array}$ | [<i>n</i>] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 | 1548 1548 114 - 1518 1487 - 1223 1223 - - |
| $ \begin{array}{l} \Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \\ a_2(1320)^\pm \pi^\mp \\ K \overline{K}_2^*(1430) + \text{c.c.} \\ K_1(1270)^\pm K^\mp \end{array} $ | [ee] | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \end{array}$ | [<i>n</i>] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.6 S=1.8 CL=95% | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 |
| $\begin{split} & = (1530)^0 = 0 \\ & = \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K K_2^* (1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta(1405) \rightarrow \phi \eta \pi \pi \end{split}$ | [ee] < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-6} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma KK\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma\rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\rho \\ \gamma\rho\omega \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% | 1548 1548 114 - 1518 1487 - 1223 1223 - - |
| $\begin{split} & = \underbrace{\Xi(1530)^0 \overline{\Xi}^0}_{\Sigma(1385)} - \underbrace{\Sigma^+ (\text{or c.c.})}_{\Sigma^+ (\text{or c.c.})} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^\pm \pi^\mp \\ & K \overline{K}_2^* (1430) + \text{c.c.} \\ & K_1(1270)^\pm K^\mp \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \end{split}$ | [ee] < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 2.2 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\pi^{+}\pi^{-} \\ \gamma\rho\rho \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\eta'(958) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.6 S=1.8 CL=95% | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 1338 1258 1400 |
| $\begin{split} & = (1530)^0 = 0 \\ & = (1385)^{-} = \Sigma^{+} \text{ (or c.c.)} \\ & = \phi f_1(1285) \\ & = \eta \pi^{+} \pi^{-} \\ & = \rho \eta \\ & = \omega \eta'(958) \\ & = \omega f_0(980) \\ & = \rho \eta'(958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K K_2^* (1430)^{+} + \text{c.c.} \\ & = K_1(1270)^{\pm} K^{\mp} \\ & = K_2^* (1430)^0 = K_2^* (1430)^0 \\ & = \phi \pi^0 \\ & = \psi \eta'(1405) \rightarrow \psi \eta \pi \pi \\ & = \omega f_2'(1525) \\ & = \eta \phi(2170) \rightarrow \end{split}$ | [ee] < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-6} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta \\ \gamma\rho\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\eta'(958) \\ \gamma2\pi^+2\pi^- \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 1338 1258 1400 1517 |
| $\begin{split} & = (1530)^0 = 0 \\ & = \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta'(958) \\ & = \omega f_0(980) \\ & = \rho \eta'(958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430) + \text{c.c.} \\ & = K_1(1270)^{\pm} K^{\mp} \\ & = K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & = \phi \eta \pi \pi \\ & = \omega f_2' (1525) \\ & = \eta \phi (2170) \rightarrow \\ & = \eta K^* (\underline{892})^0 \overline{K}^* (892)^0 \end{split}$ | [ee] < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 2.2 2.52 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\eta'(958) \\ \gamma2\pi^+2\pi^- \\ \gamma f_2(1270) f_2(1270) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 1338 1258 1400 |
| $\begin{split} & = (1530)^0 = 0 \\ & = (1385)^{-} = \Sigma^{+} \text{ (or c.c.)} \\ & = \phi f_1(1285) \\ & = \eta \pi^{+} \pi^{-} \\ & = \rho \eta \\ & = \omega \eta'(958) \\ & = \omega f_0(980) \\ & = \rho \eta'(958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K K_2^* (1430)^{+} + \text{c.c.} \\ & = K_1(1270)^{\pm} K^{\mp} \\ & = K_2^* (1430)^0 = K_2^* (1430)^0 \\ & = \phi \pi^0 \\ & = \psi \eta'(1405) \rightarrow \psi \eta \pi \pi \\ & = \omega f_2'(1525) \\ & = \eta \phi(2170) \rightarrow \end{split}$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 2.2 | $\begin{array}{c} \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{c}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\pi'(958) \\ \gamma2\pi^{+}2\pi^{-} \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma f_{2}(1270) f_{2}(1270) (\text{non reso}) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 1338 1258 1400 1517 |
| $\begin{split} & = (1530)^0 \overline{\Xi}^0 \\ & = \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi f_1(1285) \\ & = \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta'(958) \\ & = \omega f_0(980) \\ & = \rho \eta'(958) \\ & = a_2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^*(1430) + \text{c.c.} \\ & = K_1(1270)^{\pm} K^{\mp} \\ & = K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ & = \phi \pi^0 \\ & = \phi \eta(1405) \rightarrow \phi \eta \pi \pi \\ & = \omega f_2'(1525) \\ & = \eta \phi(2170) \rightarrow \\ & = \eta K^*(892)^0 \overline{K}^*(892)^0 \\ & = \Sigma (1385)^0 \overline{\Lambda} \\ & = \Delta(1232)^{\pm} \overline{\rho} \\ & = \Theta(1540) \overline{\Theta}(1540) \rightarrow \end{split}$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 3.0 2.9 6.4 2.5 2.2 2.52 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\eta'(958) \\ \gamma2\pi^+2\pi^- \\ \gamma f_2(1270) f_2(1270) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 | 1548 1548 114 — 1518 1487 — 1223 1223 — — 1340 1338 1258 1400 1517 |
| $\begin{split} & = \underbrace{\Xi(1530)^0} \underbrace{\Xi^0} \\ & = \underbrace{\Sigma(1385)^-} \underbrace{\Sigma^+} \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^\pm \pi^\mp \\ & K \underbrace{K_2^*(1430)^+} K^\mp \\ & K_2^*(1430)^+ K^*_2(1430)^0 \\ & \phi \pi^0 \\ & \phi \eta \eta(1405) \to \phi \eta \pi \pi \\ & \omega f_2'(1525) \\ & \eta \phi(2170) \to \\ & \eta K^*(892)^0 \underbrace{K^*} (892)^0 \\ & \Xi(1385)^0 \overline{\Lambda} \\ & \Delta(1232)^+ \overline{\rho} \\ & \Theta(1540) \underbrace{\Theta(1540)}_{K_2^*} \theta(1540) \to \\ & K_2^* \rho K^- \overline{n} + \text{c.c.} \end{split}$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.3 (2.6 (4.0 (1.93 (1.4 (1.05 (1.0 (1.05 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (| ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \to 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \to \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \to \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \to \gamma\gamma\rho^0 \\ \gamma\eta(1405/1475) \to \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \to \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \to \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma2\pi^+2\pi^- \\ \gammaf_2(1270) f_2(1270) \\ \gamma f_2(1270) f_2(1270) \\ (\text{non resonant)} \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 | 1548 1548 114 - 1518 1487 - 1223 1223 - - 1340 1338 1258 1400 1517 879 - |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = \Sigma(1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K \overline{K}_2^*(1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ & \phi \pi^0 \\ & \phi \eta(1405) \to \phi \eta \pi \pi \\ & \omega f_2'(1525) \\ & \eta \phi(2170) \to \\ & \eta K^*(892)^0 \overline{K}^*(892)^0 \\ & \Sigma (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{\pm} \overline{p} \\ & \mathcal{O}(1540) \overline{\mathcal{O}}(1540) \to \\ & K_0^8 p K^- \overline{n} + \text{c.c.} \\ & \mathcal{O}(1540) K^- \overline{n} \to K_0^8 p K^- \overline{n} \end{split}$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — | 4γ 5γ $\gamma \eta_c(1S)$ $\gamma \eta_c(1S) \rightarrow 3\gamma$ $\gamma \pi^+ \pi^- 2\pi^0$ $\gamma \eta \pi \pi$ $\gamma \eta_2(1870) \rightarrow \gamma \eta \pi^+ \pi^ \gamma \eta(1405/1475) \rightarrow \gamma K K \pi$ $\gamma \eta(1405/1475) \rightarrow \gamma \gamma \rho^0$ $\gamma \eta(1405/1475) \rightarrow \gamma \gamma \rho^0$ $\gamma \eta(1405/1475) \rightarrow \gamma \gamma \rho$ $\gamma \rho \rho$ $\gamma \rho \rho$ $\gamma \rho \phi$ $\gamma \gamma (958)$ $\gamma 2\pi^+ 2\pi^ \gamma f_2(1270) f_2(1270)$ $\gamma f_2(1270) f_2(1270)$ $\gamma K^+ K^- \pi^+ \pi^ \gamma f_4(2050)$ $\gamma \omega \omega$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 1518 1487 1223 1223 1340 1338 1258 1400 1517 879 |
| $\begin{split} & = (1530)^0 \overline{\Xi}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi f_1 (1285) \\ & = \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta' (958) \\ & = \omega f_0 (980) \\ & = \rho \eta' (958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430)^{\pm} + \kappa^{\mp} \\ & = K \underline{K}_2^* (1430)^{\pm} + \kappa^{\mp} \\ & = K \underline{K}_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & = \varphi \pi^0 \\ & = \varphi \pi$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 (4.0 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho(958) \\ \gamma2\pi^{+}2\pi^{-} \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma\kappa^{+}K^{-}\pi^{+}\pi^{-} \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 | 1548 1548 114 - 1518 1487 - 1223 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi f_1 (1285) \\ & = \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta' (958) \\ & = \omega f_0 (980) \\ & = \rho \eta' (958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430) + \text{c.c.} \\ & = K_1 (1270)^{\pm} K^{\mp} \\ & = K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & = \phi \pi^0 \\ & = \phi \pi^0 \\ & = \phi \eta (1405) \rightarrow \phi \eta \pi \pi \\ & = \omega f_2' (1525) \\ & = \eta \phi (2170) \rightarrow \\ & = \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & = \Sigma (1385)^0 \overline{\Lambda} \\ & = \Delta (1322)^{+} \overline{p} \\ & = \Theta (1540) \overline{\Theta} (1540) \rightarrow \\ & = K_S^0 p K^{-} \overline{n} + \text{c.c.} \\ & = \Theta (1540) K^{-} \overline{n} \rightarrow K_S^0 p K^{-} \overline{n} \\ & = \Theta (1540) K^{+} \overline{n} \rightarrow K_S^0 \overline{p} K^{+} n \\ & = \overline{\Theta} (1540) K^{+} n \rightarrow K_S^0 \overline{p} K^{+} n \end{split}$ | [ee] < | (3.2 (3.1 (2.6 (4.0) 1.82 (1.4 (1.05 4.3 4.0) 2.9 (6.4 4.2.5 2.2 2.55 2 1 1.1 1.6 5.6 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rhof(958) \\ \gamma2\pi^+2\pi^- \\ \gamma f_2(1270) f_2(1270) \\ \gamma f_2(1270) f_2(1270) \\ \gamma K^+K^-\pi^+\pi^- \\ \gamma f_4(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^0\rho^0 \\ \gamma f_2(1270) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1223 1236 |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = \Sigma(1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K K_2^* (1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta^0 \\ & (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \\ & \eta \phi (2170) \to \\ & \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & \Sigma (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{p} \\ & \Theta (1540) \overline{\Theta} (1540) \to \\ & K_S^0 p K^- \overline{n} + \text{c.c.} \\ & \Theta (1540) K^- \overline{n} \to K_S^0 p K^- \overline{n} \\ & \Theta (1540) K^+ \overline{n} \to K_S^0 \overline{p} K^+ n \\ \hline{\Theta} (1540) K^+ \overline{n} \to K_S^0 \overline{p} K^+ n \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^+ n \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\ \hline{\Theta} (1540) K^0_S \overline{p} \to K_S^0 \overline{p} K^- \overline{n} \\$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0) 1.82 (1.44 (1.05 4.3 4.0) 2.9 (6.4 2.5 2.2 2.52 2.1 1.1 1.6 5.6 1.1 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho(958) \\ \gamma2\pi^{+}2\pi^{-} \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma\kappa^{+}K^{-}\pi^{+}\pi^{-} \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 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| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi f_1 (1285) \\ & = \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta' (958) \\ & = \omega f_0 (980) \\ & = \rho \eta' (958) \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430) + \text{c.c.} \\ & = K_1 (1270)^{\pm} K^{\mp} \\ & = K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & = \phi \pi^0 \\ & = \phi \pi^0 \\ & = \phi \eta (1405) \rightarrow \phi \eta \pi \pi \\ & = \omega f_2' (1525) \\ & = \eta \phi (2170) \rightarrow \\ & = \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & = \Sigma (1385)^0 \overline{\Lambda} \\ & = \Delta (1322)^{+} \overline{p} \\ & = \Theta (1540) \overline{\Theta} (1540) \rightarrow \\ & = K_S^0 p K^{-} \overline{n} + \text{c.c.} \\ & = \Theta (1540) K^{-} \overline{n} \rightarrow K_S^0 p K^{-} \overline{n} \\ & = \Theta (1540) K^{+} \overline{n} \rightarrow K_S^0 \overline{p} K^{+} n \\ & = \overline{\Theta} (1540) K^{+} n \rightarrow K_S^0 \overline{p} K^{+} n \end{split}$ | [ee] < < < < < < < < < < < < < < < < < < | (3.2 (3.1 (2.6 (4.0) 1.82 (1.4 (1.05 4.3 4.0) 2.9 (6.4 4.2.5 2.2 2.55 2 1 1.1 1.6 5.6 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \rightarrow 3\gamma \\ \gamma\pi^+\pi^-2\pi^0 \\ \gamma\eta\pi\pi \\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma \rho^0 \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\pi^+\pi^- \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\eta\phi \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho(958) \\ \gamma2\pi^+2\pi^- \\ \gamma f_2(1270) f_2(1270) \\ \gamma f_2(1270) f_2(1270) \\ \gamma K^+K^-\pi^+\pi^- \\ \gamma f_4(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^0\rho^0 \\ \gamma f_2(1270) \\ \gamma f_0(1710) \rightarrow \gamma K\overline{K} \\ \gamma f_0(1710) \rightarrow \gamma\pi\pi \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1226 1075 - |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = \Sigma(1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K K_2^*(1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ & \phi \pi^0 \\ & \phi \eta(1405) \to \phi \eta \pi \pi \\ & \omega f_2'(1525) \\ & \eta \phi(2170) \to \\ & \eta K^*(892)^0 \overline{K}^*(892)^0 \\ & \Sigma (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{\rho} \\ & \Theta (1540) \overline{\Theta} (1540) \to \\ & K_0^0 p K^- \overline{n} + \text{c.c.} \\ & \Theta (1540) K_0^- \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \Theta (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \Theta (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & 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K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ \overline{\rho} \to K_0^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^+ $ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.4 (2.5 (1.4 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 (1.0 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(1.0 (1.0 (1.0 (1.0 (1.0 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{r}(1S) \\ \gamma\eta\pi\pi \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta_{1}(1405/1475) \rightarrow \gamma\kappa K\pi \\ \gamma\eta_{1}(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta_{1}(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta_{1}(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\rho \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\eta'(958) \\ \gamma2\pi^{+}2\pi^{-} \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma f_{2}(1270) f_{2}(1270) \\ \gamma\kappa K^{+}K^{-}\pi^{+}\pi^{-} \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta_{1}(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \\ \gamma f_{2}(1270) \\ \gamma f_{0}(1710) \rightarrow \gamma\kappa K K \\ \gamma f_{0}(1710) \rightarrow \gamma\kappa\pi \\ \gamma f_{0}(1710) \rightarrow \gamma\omega\omega \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1286 1075 - |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = (1530)^0 \overline{\equiv}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1 (1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta' (958) \\ & \omega f_0 (980) \\ & \rho \eta' (958) \\ & a_2 (1320)^{\pm} \pi^{\mp} \\ & K K_2^* (1430) + \text{c.c.} \\ & K_1 (1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta^0 (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \\ & \eta \phi (2170) \to \\ & \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & \mathcal{L} (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{p} \\ & \Theta (1540) \overline{\Theta} (1540) \to \\ & K_S^0 p K^- \overline{n} + \text{c.c.} \\ & \Theta (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \Theta (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \Theta (1540) K^+_0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^+_0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- \overline{n} \\ & \overline{\Theta} (1540) K^0 \overline{n} \to K_S^0 p K^- n$ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.44 (1.05 4.3 4.0 (2.9 (2.5 2.2 2.52 (1.11 (1.6 (5.6 (1.1 (9)))))))))))))))))) | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.13) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — 912 1100 — — — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{c}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\kappa K K\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1286 1075 - 1500 |
| $\begin{split} & = (1530)^0 \overline{\Xi}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K \overline{K}_2^* (1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta^0 \\ & \psi \pi^0 \\ & \phi \eta^0 (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \\ & \eta \phi(2170) \to \\ & \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & \Sigma (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{\rho} \\ & \Theta (1540) \Theta \overline{(1540)} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \Theta (1540) K_0^8 \overline{\rho} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \Theta (1540) K_0^8 \overline{\rho} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 $ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.82 (1.44 (1.05 4.3 4.0 (2.9 (2.5 2.2 2.52 2.1 1.1 1.6 6.6 1.1 9) stable (4.1 (2.9 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻ | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — — — — — — — — — — — — — — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_\pi\pi \\ \gamma\eta_2(1870) \\ \gamma\eta\pi\pi \\ \gamma\eta_1(1405/1475) \\ \gamma\gamma\eta_1(1405/1475) \\ \gamma\gamma\eta_1(1405/1475) \\ \gamma\gamma\eta_1(1405/1475) \\ \gamma\gamma\eta_1(1405/1475) \\ \gamma\gamma\eta_0(1405/1475) \\ \gamma\gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho(958) \\ \gamma2\pi^+2\pi^- \\ \gamma f_2(1270) f_2(1270) \\ \gamma f_2(1270) f_2(1270) \\ \gamma f_2(1270) f_2(1270) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \\ \gamma\psi\omega \\ \gamma\eta_1(1405/1475) \\ \gamma\psi\omega \\ \gamma\eta_1(1405/1475) \\ \gamma\psi\omega \\ \gamma\eta_1(1710) \\ \gamma\psi\omega \\ \gamma\eta_1(1710) \\ \gamma\psi\omega \\ \gamma\eta \\ \gamma f_1(1710) \\ \gamma\psi\omega \\ \gamma\eta \\ \gamma\eta_1(1420) \\ \gamma\psi\kappa \\ \kappa\pi \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 - - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1286 1075 - 1500 1220 1500 1220 |
| $\begin{array}{c} \Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^{-} \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \\ a_2(1320)^{\pm} \pi^{\mp} \\ K \overline{K}_2^* (1430) + \text{c.c.} \\ K_1(1270)^{\pm} K^{\mp} \\ K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ \phi \pi^0 \\ \phi \eta(1405) \rightarrow \phi \eta \pi \pi \\ \omega f_2' (1525) \\ \eta \phi(2170) \rightarrow \\ \eta K^* (892)^0 \overline{K}^* (892)^0 \\ \Sigma (1385)^0 \overline{\Lambda} \\ \Delta (1232)^{+} \overline{p} \\ \Theta (1540) \overline{\Theta} (1540) \rightarrow \\ K_0^S p K^{-} \overline{n} + \text{c.c.} \\ \Theta (1540) K^{-} \overline{n} \rightarrow K_0^S p K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{+} n \rightarrow K_0^S \overline{p} K^{+} n \\ \overline{\Theta} (1540) K^{-}_S p \rightarrow K_0^S \overline{p} K^{+} n \\ \overline{\Theta} (1540) K^{-}_S p \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ 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n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta} (1540) K^{-}_T n \rightarrow K_0^S \overline{p} K^{-} \overline{n} \\ \overline{\Theta}$ | [ee] < | (3.2 (3.1 (2.6 (4.0) 1.0 2.9 (1.1 1) 9 (2.9 (2.07) 1.1 (2.9 (2.9 (2.07) 1.1 1) 1.1 (2.9 (2.9 (2.07) 1.1 1) 1.1 (2.9 (2.07) 1.1 1) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 (2.07) 1.1 (2.9 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\gamma\eta(1405/1475) \rightarrow \gamma\kappa K K\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 - 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1286 1075 - 1500 |
| $\begin{split} & = (1530)^0 \overline{\Xi}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1(1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta'(958) \\ & \omega f_0(980) \\ & \rho \eta'(958) \\ & a_2(1320)^{\pm} \pi^{\mp} \\ & K \overline{K}_2^* (1430) + \text{c.c.} \\ & K_1(1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \eta^0 \\ & \psi \pi^0 \\ & \phi \eta^0 (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \\ & \eta \phi(2170) \to \\ & \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & \Sigma (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{\rho} \\ & \Theta (1540) \Theta \overline{(1540)} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \Theta (1540) K_0^8 \overline{\rho} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \Theta (1540) K_0^8 \overline{\rho} \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \rho \to K_0^8 \rho K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 \gamma \to K_0^8 \gamma K^{-} \overline{\eta} \\ & \overline{\Theta} (1540) K_0^8 $ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.4 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 (1.05 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\gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\mu \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho(1270)f_{2}(1270) f_{2}(1270) \\ \gammaf_{2}(1270)f_{2}(1270) (\text{non reso nant}) \\ \gamma\kappa^{+}K^{-}\pi^{+}\pi^{-} \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \\ \gamma f_{2}(1270) \\ \gamma f_{0}(1710) \rightarrow \gamma\kappa\overline{\kappa} \\ \gamma f_{0}(1710) \rightarrow \gamma\pi\pi \\ \gamma f_{0}(1710) \rightarrow \gamma\omega\omega \\ \gamma\eta \\ \gamma f_{1}(1420) \rightarrow \gamma\kappa\overline{\kappa}\pi \\ \gamma f_{1}(1285) \\ \gamma f_{1}(1510) \rightarrow \gamma\eta\pi^{+}\pi^{-} \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 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| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = (11385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi_{1}(1285) \\ & \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta' \text{ (958)} \\ & = \omega f_0 \text{ (980)} \\ & = \rho \eta' \text{ (958)} \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430)^{\pm} \times K \overline{K}_2^* (1525) \\ & = \eta \phi (2170) \rightarrow \eta K^* (892)^{\pm} \overline{K}^* (892)^{\pm} \times (1385)^{\pm} \overline{K} \times K \overline{K}_2^* \times K \overline{K}_2^$ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.82 (1.82 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.84 (1.8 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.13) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — — — — — — — — — — — — — — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \rightarrow 3\gamma \\ \gamma\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{c}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma \gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\psi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho(1270)f_{2}(1270) \\ \gamma f_{2}(1270)f_{2}(1270) \\ \gamma f_{2}(1270)f_{2}(1270) \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \\ \gamma f_{2}(1270) \\ \gamma f_{0}(1710) \rightarrow \gamma K\overline{K} \\ \gamma f_{0}(1710) \rightarrow \gamma\pi\pi \\ \gamma f_{0}(1710) \rightarrow \gamma\omega\omega \\ \gamma\eta \\ \gamma f_{1}(1420) \rightarrow \gamma K\overline{K}\pi \\ \gamma f_{1}(1285) \\ \gamma f_{1}(1510) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma f_{2}'(1525) \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1223 1223 1223 1286 1075 - 1500 1220 1283 |
| $\begin{split} & = (1530)^0 \overline{\Xi}^0 \\ & = (1530)^0 \overline{\Xi}^0 \\ & = (1385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & \phi f_1 (1285) \\ & \eta \pi^+ \pi^- \\ & \rho \eta \\ & \omega \eta' (958) \\ & \omega f_0 (980) \\ & \rho \eta' (958) \\ & a_2 (1320)^{\pm} \pi^{\mp} \\ & K_{\chi}^* (1430) + \text{c.c.} \\ & K_1 (1270)^{\pm} K^{\mp} \\ & K_2^* (1430)^0 \overline{K}_2^* (1430)^0 \\ & \phi \pi^0 \\ & \phi \pi^0 \\ & \phi \eta (1405) \to \phi \eta \pi \pi \\ & \omega f_2' (1525) \\ & \eta \phi (2170) \to \\ & \eta K^* (892)^0 \overline{K}^* (892)^0 \\ & \mathcal{E} (1385)^0 \overline{\Lambda} \\ & \Delta (1232)^{+} \overline{p} \\ & \Theta (1540) \overline{\Theta} (1540) \to \\ & K_0^8 p K^- \overline{n} + \text{c.c.} \\ & \Theta (1540) K_0^{-} \overline{p} \to K_0^8 p K^- \overline{n} \\ & \Theta (1540) K_0^{-} \overline{p} \to K_0^8 p K^- \overline{n} \\ & \Theta (1540) K_0^8 \overline{p} \to K_0^8 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^8 p \to K_0^8 p K^- \overline{n} \\ & \overline{\Theta} (1540) K_0^8 p \to K_0^8 p K^- \overline{n} \\ & \overline{\Sigma}^0 \overline{\Lambda} \end{split}$ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 (2.9 2.5 2.2 2.52 2 1 1.1 1.6 5.6 1.1 9 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.13) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — — — — — — — — — — — — — — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{c}(1S) \\ \gamma\eta_{r}(1S) \\ \gamma\eta\pi^{+}\pi^{-}2\pi^{0} \\ \gamma\eta\pi\pi \\ \gamma\eta_{2}(1870) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\kappa K\pi \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^{0} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\eta\pi^{+}\pi^{-} \\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\phi \\ \gamma\rho\rho \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\mu \\ \gamma\rho\phi \\ \gamma\rho\psi \\ \gamma\rho\phi \\ \gamma\rho\omega \\ \gamma\rho\phi \\ \gamma\rho(1270)f_{2}(1270) f_{2}(1270) \\ \gammaf_{2}(1270)f_{2}(1270) (\text{non reso nant}) \\ \gamma\kappa^{+}K^{-}\pi^{+}\pi^{-} \\ \gamma f_{4}(2050) \\ \gamma\omega\omega \\ \gamma\eta(1405/1475) \rightarrow \gamma\rho^{0}\rho^{0} \\ \gamma f_{2}(1270) \\ \gamma f_{0}(1710) \rightarrow \gamma\kappa\overline{\kappa} \\ \gamma f_{0}(1710) \rightarrow \gamma\pi\pi \\ \gamma f_{0}(1710) \rightarrow \gamma\omega\omega \\ \gamma\eta \\ \gamma f_{1}(1420) \rightarrow \gamma\kappa\overline{\kappa}\pi \\ \gamma f_{1}(1285) \\ \gamma f_{1}(1510) \rightarrow \gamma\eta\pi^{+}\pi^{-} \end{array}$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 |
| $\begin{split} & = (1530)^0 \overline{\equiv}^0 \\ & = (11385)^{-} \overline{\Sigma}^+ \text{ (or c.c.)} \\ & = \phi_{1}(1285) \\ & \eta \pi^+ \pi^- \\ & = \rho \eta \\ & = \omega \eta' \text{ (958)} \\ & = \omega f_0 \text{ (980)} \\ & = \rho \eta' \text{ (958)} \\ & = 2(1320)^{\pm} \pi^{\mp} \\ & = K \overline{K}_2^* (1430)^{\pm} \times K \overline{K}_2^* (1525) \\ & = \eta \phi (2170) \rightarrow \eta K^* (892)^{\pm} \overline{K}^* (892)^{\pm} \times (1385)^{\pm} \overline{K} \times K \overline{K}_2^* \times K \overline{K}_2^$ | [ee] < | (3.2 (3.1 (2.6 (4.0 (1.93 (1.82 (1.4 (1.05 4.3 4.0 (2.9 2.5 2.2 2.52 2 1 1.1 1.6 5.6 1.1 9 | ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.13) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 | CL=90% | 608 855 1032 1487 1396 1279 1267 1281 1263 1159 1231 604 1377 946 1003 — — — — — — — — — — — — — — — — — — | $\begin{array}{c} 4\gamma \\ 5\gamma \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_c(1S) \\ \gamma\eta_{\pi} \\ \gamma\eta^{(1405/1475)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\gamma\eta^{(1405/1475)} \\ \gamma\gamma\eta^{(1405/1475)} \\ \gamma\gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho\phi \\ \gamma\rho(1270)f_2(1270) \\ \gamma(1270)f_2(1270) \\ \gamma\eta^{(1270)f_2(1270)} \\ \gamma\eta^{(1405/1475)} \\ \gamma\gamma^{(1270)f_2(1270)} \\ \gamma\sigma^{(1270)f_2(1270)} \\ \gamma\sigma^{(1270)f_2(1270)} \\ \gamma\sigma^{(1405/1475)} \\ \gamma\gamma^{(1405/1475)} \\ \gamma\gamma^{(14$ | [n] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 | 1548 1548 114 - 1518 1487 - 1223 1223 1340 1338 1258 1400 1517 879 - 1407 891 1336 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1223 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 1220 |

Meson Summary Table

| Meson Summary | rabie | | | | | | |
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| $\gamma f_2(1950) \rightarrow$ | (7.0 ±2.2)×10 ⁻⁴ | | = | $K^*(892)^- K^+ \pi^0 \rightarrow$ | $(4.7 \pm 1.2) \times 10^{-3}$ | | _ |
| $\gamma K^*(892) \overline{K}^*(892)$ | | | | $K^{+}\pi^{-}K^{0}\pi^{0}$ + c.c. | | | |
| $\gamma K^*(892) \overline{K}^*(892)$ | $(4.0 \pm 1.3) \times 10^{-3}$ | | 1266 | $K^0_SK^0_S\pi^+\pi^-$ | $(5.8 \pm 1.1) \times 10^{-3}$ | | 1579 |
| $\gamma \phi \phi$ | $(4.0 \pm 1.2) \times 10^{-4}$ | S=2.1 | 1166 | $K^+K^-\eta\pi^0$ | $(3.0 \pm 0.7) \times 10^{-3}$ | | 1468 |
| $\gamma p \overline{p}$ | $(3.8 \pm 1.0) \times 10^{-4}$ | | 1232 | $3(\pi^{+}\pi^{-})$ | (1.20 ± 0.18) % | | 1633 |
| $\gamma \eta$ (2225) | $(3.3 \pm 0.5) \times 10^{-4}$ | | 749 | $K + \overline{K}^* (892)^0 \pi^- + \text{c.c.}$ | $(7.3 \pm 1.6) \times 10^{-3}$ | | 1523 |
| $\gamma \eta(1760) \rightarrow \gamma \rho^0 \rho^0$ | $(1.3 \pm 0.9) \times 10^{-4}$ | | 1048 | $K^*(892)^0 \overline{K}^*(892)^0$ | $(1.7 \pm 0.6) \times 10^{-3}$ | | 1456 |
| $\gamma \eta(1760) \rightarrow \gamma \omega \omega$ | $(1.98 \pm 0.33) \times 10^{-3}$ | | _ | $\pi\pi$ | $(8.5 \pm 0.4) \times 10^{-3}$ | | 1702 |
| $\gamma X(1835) \rightarrow \gamma \pi^+ \pi^- \eta'$ | $(2.6 \pm 0.4) \times 10^{-4}$ | | 1006 | $\pi^0 \eta$ | $< 1.8 	 \times 10^{-4}$ | | 1661 |
| $\gamma X(1835) \rightarrow \gamma p \overline{p}$ | $(7.5 {}^{+1.9}_{-0.9}) \times 10^{-5}$ | | _ | $\pi^0 \eta'$ | $< 1.1 \times 10^{-3}$ | | 1570 |
| | | | | $\eta\eta$ | $(3.03\pm0.21)\times10^{-3}$ | | 1617 |
| $\gamma(K\overline{K}\pi)[J^{PC}=0^{-+}]$ | $(7 \pm 4) \times 10^{-4}$ | S=2.1 | 1442 | $\eta \eta'$ | $< 2.4 \times 10^{-4}$ | CL=90% | 1521 |
| $\gamma \pi^0$ | $(3.49 \begin{array}{c} +0.33 \\ -0.30 \end{array}) \times 10^{-5}$ | | 1546 | $\eta'\eta'$ | $(2.02\pm0.22)\times10^{-3}$ | | 1413 |
| $\gamma p \overline{p} \pi^+ \pi^-$ | < 7.9 × 10 ⁻⁴ | CL=90% | 1107 | $\omega \omega$ | $(9.8 \pm 1.1) \times 10^{-4}$ | | 1517 |
| $\gamma \Lambda \overline{\Lambda}$ | < 1.3 × 10 ⁻⁴ | CL=90% | 1074 | $\omega \phi$ | $(1.19 \pm 0.22) \times 10^{-4}$ | | 1447 |
| $\gamma f_J(2220)$ | > 2.50 × 10 ⁻³ | CL=99.9% | 745 | K+K- | $(6.06 \pm 0.35) \times 10^{-3}$ | | 1634 |
| $\gamma f_J(2220) \rightarrow \gamma \pi \pi$ | (8 ±4)×10 ⁻⁵ | CL=99.976 | 745 | $K^0_S K^0_S$ | $(3.14 \pm 0.18) \times 10^{-3}$ | | 1633 |
| $\gamma f_J(2220) \rightarrow \gamma K \overline{K}$ $\gamma f_J(2220) \rightarrow \gamma K \overline{K}$ | < 3.6 × 10 ⁻⁵ | | _ | $\pi^+\pi^-\eta$ | $< 2.0 \times 10^{-4}$ | CL=90% | 1651 |
| | $(1.5 \pm 0.8) \times 10^{-5}$ | | | $\pi^+\pi^-\eta'$ | < 4 $\times 10^{-4}$ | CL=90% | 1560 |
| $\gamma f_J(2220) \rightarrow \gamma p \overline{p}$ | $(1.5 \pm 0.8) \times 10^{-4}$ | | 1102 | $\overline{K}^0 K^+ \pi^- + \text{c.c.}$ | $< 1.0 	 \times 10^{-4}$ | CL=90% | 1610 |
| $\gamma f_0(1500)$ | ' ' | GL 000/ | 1183 | $K^+K^-\pi^0$ | < 6 × 10 ⁻⁵ | CL=90% | 1611 |
| $\gamma A \rightarrow \gamma$ invisible [mmmm] | $] < 6.3 	 \times 10^{-6}$ | CL=90% | _ | $K^+K^-\eta$ | < 2.3 × 10 ⁻⁴ | CL=90% | 1512 |
| | eak decays | | | $K + K - K_S^0 K_S^0$ | $(1.4 \pm 0.5) \times 10^{-3}$ | . • | 1331 |
| $D^- e^+ u_e + { m c.c.}$ | $< 1.2 \times 10^{-5}$ | CL=90% | 984 | $K^+K^-K^+K^-$ | $(2.79 \pm 0.29) \times 10^{-3}$ | | 1333 |
| $\overline{D}{}^{0}e^{+}e^{-}+\text{ c.c.}$ | < 1.1 × 10 ⁻⁵ | CL=90% | 987 | $K^+K^-\phi$ | $(9.8 \pm 2.5) \times 10^{-4}$ | | 1381 |
| $D_{c}^{-}e^{+}\nu_{e}+\text{c.c.}$ | < 3.6 | CL=90% | 923 | $\phi\phi$ | $(8.2 \pm 0.8) \times 10^{-4}$ | | 1370 |
| $D^{-}\pi^{+}$ + c.c. | < 7.5 × 10 ⁻⁵ | CL=90% | 977 | D D | $(2.23 \pm 0.13) \times 10^{-4}$ | | 1426 |
| $\overline{D}^0 \overline{K}^0 + \text{c.c.}$ | < 1.7 × 10 ⁻⁴ | CL=90% | 898 | $p \frac{r}{p} \pi^0$ | $(7.0 \pm 0.7) \times 10^{-4}$ | S=1.2 | 1379 |
| $D_s^- \pi^+ + \text{c.c.}$ | < 1.3 ×10 ⁻⁴ | CL=90% | 915 | $p \frac{\overline{p}}{\overline{p}} \eta$ | $(3.6 \pm 0.4) \times 10^{-4}$ | | 1187 |
| y . | | | | $p \overline{p} \omega$ | $(5.3 \pm 0.6) \times 10^{-4}$ | | 1043 |
| Charge conjug | (C), Parity (P) , | | | $p \overline{p} \phi$ | $(6.1 \pm 1.5) \times 10^{-5}$ | | 876 |
| Lepton Family num | $nber\ (LF)\ violating\ mod$ | es | | $p \overline{p} \pi^+ \pi^-$ | $(2.1 \pm 0.7) \times 10^{-3}$ | S=1.4 | 1320 |
| $\gamma\gamma$ C $e^{\pm}\mu^{\mp}$ LF | $< 5 \times 10^{-6}$ | CL=90% | 1548 | $p \overline{p} \pi^0 \pi^0$ | $(1.05 \pm 0.28) \times 10^{-3}$ | | 1324 |
| $e^{\pm}\mu^{\mp}$ LF | $< 1.1 \times 10^{-6}$ | CL=90% | 1547 | $p \overline{p} K^+ K^-$ (non-resonant) | $(1.23\pm0.27)\times10^{-4}$ | | 890 |
| $e^{\pm}	au^{\mp}$ LF | $< 8.3 \times 10^{-6}$ | CL=90% | 1039 | $p\overline{p}K_S^0K_S^0$ | < 8.8 × 10 ⁻⁴ | CL=90% | 884 |
| $\mu^{\pm} 	au^{\mp}$ LF | $< 2.0 \times 10^{-6}$ | CL=90% | 1035 | $p \frac{\pi}{n} \pi^{-}$ | $(1.14 \pm 0.31) \times 10^{-3}$ | | 1376 |
| 0+ | her decays | | | , <u>/</u> / // | $(3.3 \pm 0.4) \times 10^{-4}$ | | 1292 |
| invisible | < 7 × 10 ⁻⁴ | CL=90% | | $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | $< 4.0 \times 10^{-3}$ | CL=90% | 1153 |
| IIIVISIDIE | < 7 × 10 · | CL=90% | | $K^{+}\overline{p}\Lambda$ + c.c. | $(1.02 \pm 0.19) \times 10^{-3}$ | | 1132 |
| | | | | $K^{+}p\Lambda(1520) + \text{c.c.}$ | $(3.0 \pm 0.8) \times 10^{-4}$ | | 85 8 |
| $\chi_{c0}(1P)$ | $I^{G}(J^{PC}) = 0^{+}(0^{-})$ | + + ₁ | | $\Lambda(1520) \overline{\Lambda}(1520)$ | $(3.2 \pm 1.2) \times 10^{-4}$ | | 779 |
| XC0(2-) | , (3) = 0 (0 | , | | $\sum_{i} \overline{\sum}_{i} 0$ | $(4.2 \pm 0.7) \times 10^{-4}$ | | 1222 |
| Mass $m = 3414.75 \pm 0$ |).31 MeV | | | $\Sigma + \overline{\Sigma} -$ | $(3.1 \pm 0.7) \times 10^{-4}$ | | 1225 |
| Full width $\Gamma=10.4\pm0$ | 0.6 MeV | | | <u>=</u> 0 <u>=</u> 0 | $(3.2 \pm 0.8) \times 10^{-4}$ | | 1089 |
| | S | cale factor/ | р | <u>=-=</u> + | $(4.9 \pm 0.7) \times 10^{-4}$ | | 1081 |
| $\chi_{c0}(1P)$ DECAY MODES | | | MeV/c) | | Radiative decays | | |
| Had | ronic decays | | | $\gamma J/\psi(1S)$ | (1.17 ± 0.08) % | | 303 |
| $2(\pi^{+}\pi^{-})$ | (2.26 ± 0.19) % | | 1679 | $\gamma \rho^{0}$ | $< 9 \times 10^{-6}$ | CL=90% | 1619 |
| $\rho^0 \pi^+ \pi^-$ | $(8.8 \pm 2.8) \times 10^{-3}$ | | 1607 | $\gamma\omega$ | < 8 × 10 ⁻⁶ | CL=90% | 1618 |
| $f_0(980) f_0(980)$ | $(6.7 \pm 2.1) \times 10^{-4}$ | | 1391 | $\gamma \phi$ | $< 6 \times 10^{-6}$ | CL=90% | 1555 |
| | $(3.4 \pm 0.4)\%$ | | 1680 | $\gamma\gamma$ | $(2.23 \pm 0.17) \times 10^{-4}$ | | 1707 |
| $\pi^{+} \pi^{-} \pi^{0} \pi^{0}$ $\rho^{+} \pi^{-} \pi^{0} + \text{c.c.}$ $4 \pi^{0}$ | (2.9 ± 0.4) % | | 1607 | | | | |
| $4\pi^0$ | $(3.3 \pm 0.4) \times 10^{-3}$ | | 1681 | (1.5) | $I^{G}(J^{PC}) = 0^{+}(1^{+})$ | - + \ | |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ | (1.79 ± 0.15) % | | 1580 | $\chi_{c1}(1P)$ | $I^{\circ}(J^{\prime}^{\circ})=0^{+}(1^{+})$ | ') | |
| $K_0^*(1430)^0\overline{K}_0^*(1430)^0 \to$ | $(9.9 \begin{array}{c} +4.0 \\ -2.9 \end{array}) \times 10^{-4}$ | | _ | | | | |
| $\pi^{+}\pi^{-}K^{+}K^{-}$ | (5.5 – 2.9) × 10 | | | | $.66 \pm 0.07 \text{ MeV} (S = 1.5)$ | | |
| $K_0^*(1430)^0 \overline{K}_2^*(1430)^0 + \text{c.c.} \rightarrow$ | $(8.1 \begin{array}{c} +2.0 \\ -2.4 \end{array}) \times 10^{-4}$ | | | Full width $\Gamma=0$ | $0.86 \pm 0.05~\text{MeV}$ | | |
| $\pi^{+}\pi^{-}K^{+}K^{-}$ | (8.1 -2.4) × 10 | | | 4 1 | | ale factor/ | p |
| $K_1(1270)^+ K^- + \text{c.c.} \rightarrow$ | $(6.3\ \pm 1.9\)\times 10^{-3}$ | | - | $\chi_{c1}(1P)$ DECAY MODES | Fraction (Γ_i/Γ) Confi | dence level | (MeV/c) |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ | | CL=90% | | | Hadronic decays | | |
| $K_{-}(1400) + K_{-} + c.c.$ | < 2.7 | | _ | 2(_+) | $(5.8 \pm 1.4) \times 10^{-3}$ | S=1.2 | 1683 |
| $\pi^{+}\pi^{-}K^{+}K^{-}$ $K_{1}(1400)^{+}K^{-} + \text{c.c.} \rightarrow$ $\pi^{+}\pi^{-}K^{+}K^{-}$ | $< 2.7 	 \times 10^{-3}$ | CL = 90 /0 | | $3(\pi^{+}\pi^{-})$ | | | |
| $\pi^+\pi^-{\cal K}^+{\cal K}^-$ | | CL _ 90 /0 | 1201 | $2(\pi^{+}\pi^{-})$ | $(7.6 \pm 2.6) \times 10^{-3}$ | | 1728 |
| | $(1.6 \ ^{+}_{-}1.1 \atop -0.9) \times 10^{-4}$ | CL = 90 /6 | 1391 | $\frac{2(\pi^{+}\pi^{-})}{\pi^{+}\pi^{-}\pi^{0}\pi^{0}}$ | $(7.6 \pm 2.6) \times 10^{-3}$ $(1.26 \pm 0.17) \%$ | | 1729 |
| $\pi^+\pi^-{\cal K}^+{\cal K}^-$ | $(1.6 \ ^{+}_{-}1.1 \atop -0.9) \times 10^{-4}$ | CL = 90 /6 | 1391 584 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0}$ + c.c. | $(7.6 \pm 2.6) \times 10^{-3}$ $(1.26 \pm 0.17) \%$ $(1.53 \pm 0.26) \%$ | | 1729 1658 |
| $\pi^{+}\pi^{-}K^{+}K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ | $(1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4}$ $(8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4}$ | | 584 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0}+ \text{c.c.}$ $\rho^{0}\pi^{+}\pi^{-}$ | $(7.6 \pm 2.6) \times 10^{-3}$ $(1.26 \pm 0.17) \%$ $(1.53 \pm 0.26) \%$ $(3.9 \pm 3.5) \times 10^{-3}$ | | 1729 1658 1657 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ | $ \begin{array}{c} (1.6 \ \ ^{+1.1}_{-0.9} \) \times 10^{-4} \\ (8.0 \ \ ^{+2.0}_{-2.5} \) \times 10^{-4} \\ < 2.8 \ \ \times 10^{-4} \end{array} $ | CL=90% | 584 1019 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0}+ c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ | $(7.6 \pm 2.6) \times 10^{-3}$ $(1.26 \pm 0.17) \%$ $(1.53 \pm 0.26) \%$ $(3.9 \pm 3.5) \times 10^{-3}$ $(5.7 \pm 0.8) \times 10^{-4}$ | | 1729 1658 1657 1729 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ | $ \begin{array}{ccc} (1.6 & ^{+1.1}_{-0.9} &)\times 10^{-4} \\ (8.0 & ^{+2.0}_{-2.5} &)\times 10^{-4} \\ < 2.8 & \times 10^{-4} \\ < 1.7 & \times 10^{-4} \end{array} $ | | 584 1019 920 | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $(7.6 \pm 2.6) \times 10^{-3}$ $(1.26 \pm 0.17) \%$ $(1.53 \pm 0.26) \%$ $(3.9 \pm 3.5) \times 10^{-3}$ $(5.7 \pm 0.8) \times 10^{-4}$ $(4.5 \pm 1.0) \times 10^{-3}$ | | 1729 1658 1657 1729 1632 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ | $ \begin{array}{c} (1.6 \ \ ^{+1.1}_{-0.9} \) \times 10^{-4} \\ (8.0 \ \ ^{+2.0}_{-2.5} \) \times 10^{-4} \\ < 2.8 \ \ \times 10^{-4} \end{array} $ | CL=90% | 584 1019 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ | $ \begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ (6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ < 1.3 \\ \times 10^{-4} \end{array} $ | CL=90% | 584 1019 920 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ $f_{0}(1370) f_{0}(1710)$ | $ \begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ (6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ \end{array} $ | CL=90% CL=90% | 584 1019 920 723 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ $\rho^{+}K^{-}K^{0} + c.c.$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \\ (\ 5.3\ \pm 1.3\)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ $f_{0}(1370) f_{0}(1710)$ $f_{0}(1500) f_{0}(1370)$ $f_{0}(1500) f_{0}(1500)$ $f_{0}(1500) f_{0}(1710)$ | $ \begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ (6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ < 1.3 \\ \times 10^{-4} \end{array} $ | CL=90% CL=90% CL=90% | 584 1019 920 723 920 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ $\rho^{+}K^{-}K^{0} + c.c.$ $K^{*}(892)^{0}K^{0}\pi^{0} \rightarrow$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ $f_{0}(1370) f_{0}(1710)$ $f_{0}(1500) f_{0}(1370)$ $f_{0}(1500) f_{0}(1500)$ $f_{0}(1500) f_{0}(1710)$ $K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | $\begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ < 6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ < 1.3 \\ < 5 \end{array}$ | CL=90% CL=90% CL=90% CL=90% | 584 1019 920 723 920 805 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ $\rho^{+}K^{-}K^{0} + c.c.$ $K^{*}(892)^{0}K^{0}\pi^{0} \rightarrow$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \\ (\ 5.3\ \pm 1.3\)\times 10^{-3} \\ (\ 2.5\ \pm 0.7\)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 1514 |
| $\begin{array}{c} \pi^{+}\pi^{-}K^{+}K^{-} \\ f_{0}(980)f_{0}(980) \\ f_{0}(980)f_{0}(2200) \\ f_{0}(1370)f_{0}(1370) \\ f_{0}(1370)f_{0}(1500) \\ f_{0}(1370)f_{0}(1710) \\ f_{0}(1500)f_{0}(1370) \\ f_{0}(1500)f_{0}(1500) \\ f_{0}(1500)f_{0}(1710) \\ K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0} \\ K^{+}K^{-}\pi^{0}\pi^{0} \end{array}$ | $\begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ (6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ < 1.3 \\ \times 10^{-4} \\ < 5 \\ \times 10^{-5} \\ < 7 \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% CL=90% CL=90% | 584 1019 920 723 920 805 559 | $\begin{array}{c} 2(\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{-}\pi^{0}\pi^{0} \\ \rho^{+}\pi^{-}\pi^{0} + \text{c.c.} \\ \rho^{0}\pi^{+}\pi^{-} \\ 4\pi^{0} \\ \pi^{+}\pi^{-}K^{+}K^{-} \\ K^{+}K^{-}\pi^{0}\pi^{0} \\ K^{+}\pi^{-}K^{0}\pi^{0} + \text{c.c.} \\ \rho^{+}K^{-}K^{0}\pi^{0} + \text{c.c.} \\ K^{*}(892)^{0}K^{0}\pi^{0} \rightarrow \\ K^{+}\pi^{-}K^{0}\pi^{0} + \text{c.c.} \\ K^{+}K^{-}\pi^{0}\pi^{0} + \text{c.c.} \end{array}$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \\ (\ 5.3\ \pm 1.3\)\times 10^{-3} \\ (\ 2.5\ \pm 0.7\)\times 10^{-3} \\ \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 1514 — |
| $\pi^{+} \pi^{-} K^{+} K^{-}$ $f_{0}(980) f_{0}(980)$ $f_{0}(980) f_{0}(2200)$ $f_{0}(1370) f_{0}(1370)$ $f_{0}(1370) f_{0}(1500)$ $f_{0}(1370) f_{0}(1710)$ $f_{0}(1500) f_{0}(1370)$ $f_{0}(1500) f_{0}(1500)$ $f_{0}(1500) f_{0}(1710)$ $K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | $ \begin{array}{c} (1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-4} \\ (8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10^{-4} \\ < 2.8 \\ < 1.7 \\ \times 10^{-4} \\ (6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10^{-4} \\ < 1.3 \\ < 5 \\ \times 10^{-5} \\ < 7 \\ \times 10^{-5} \\ (1.13 \pm 0.27) \end{array} $ | CL=90% CL=90% CL=90% CL=90% | 584 1019 920 723 920 805 559 1545 | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ $\rho^{+}\pi^{-}\pi^{0} + c.c.$ $\rho^{0}\pi^{+}\pi^{-}$ $4\pi^{0}$ $\pi^{+}\pi^{-}K^{+}K^{-}$ $K^{+}K^{-}\pi^{0}\pi^{0}$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ $\rho^{+}K^{-}K^{0} + c.c.$ $K^{*}(892)^{0}K^{0}\pi^{0} \rightarrow$ $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ | $ \begin{array}{c} (\ 7.6\ \pm 2.6\)\times 10^{-3} \\ (\ 1.26\pm 0.17)\ \% \\ (\ 1.53\pm 0.26)\ \% \\ (\ 3.9\ \pm 3.5\)\times 10^{-3} \\ (\ 5.7\ \pm 0.8\)\times 10^{-4} \\ (\ 4.5\ \pm 1.0\)\times 10^{-3} \\ (\ 1.18\pm 0.29)\times 10^{-3} \\ (\ 9.0\ \pm 1.5\)\times 10^{-3} \\ (\ 5.3\ \pm 1.3\)\times 10^{-3} \\ (\ 2.5\ \pm 0.7\)\times 10^{-3} \end{array} $ | | 1729 1658 1657 1729 1632 1634 1632 1514 |

 $K^{+}K^{-}\eta$ $K^{0}K^{+}\pi^{-}$ + c.c.

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 $(7.3 \pm 0.6) \times 10^{-3}$

| $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ | $(1.0 \pm 0.4) \times 10^{-3}$ | | 1602 |
|----------------------------------------------------------------------|--------------------------------------------------------------------|------------|--------------|
| $K^*(892)^+ K^- + \text{c.c.}$ | $(1.5 \pm 0.7) \times 10^{-3}$ | | 1602 |
| $K_J^*(1430)^0\overline{K}^0+\text{c.c.}	o$ | $< 8 \times 10^{-4}$ | CL=90% | - |
| $K_S^0 K^+ \pi^- + \text{c.c.}$ | | | |
| $K_{I}^{*}(1430)^{+}K^{-}+\text{ c.c.} \rightarrow$ | $< 2.3 \times 10^{-3}$ | CL=90% | _ |
| $K_{S}^{0}K^{+}\pi^{-}+\text{c.c.}$ | | | |
| $K^+K^-\pi^0$ | $(1.91 \pm 0.26) \times 10^{-3}$ | | 1662 |
| $\eta \pi^+ \pi^-$ | $(5.0 \pm 0.5) \times 10^{-3}$ | | 1701 |
| $a_0(980)^+\pi^- + \text{c.c.} \rightarrow \eta \pi^+\pi^-$ | $(1.9 \pm 0.7) \times 10^{-3}$ | | _ |
| $f_2(1270)\eta$ | $(2.8 \pm 0.8) \times 10^{-3}$ | | 1468 |
| $\pi^+ \pi^- \eta'$ | $(2.4 \pm 0.5) \times 10^{-3}$ | | 1612 |
| $\pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$ | $< 6 \times 10^{-6}$ | CL=90% | - |
| $K^{+} \overline{K}^{*} (89\underline{2})^{0} \pi^{-} + \text{c.c.}$ | $(3.2 \pm 2.1) \times 10^{-3}$ | | 1577 |
| $K^*(892)^0 \overline{K}^*(892)^0$ | $(1.5 \pm 0.4) \times 10^{-3}$ | | 1512 |
| $K^+K^-K^0_SK^0_S$ | $< 5 \times 10^{-4}$ | CL=90% | 1390 |
| $K^+K^-K^+K^-$ | $(5.6 \pm 1.2) \times 10^{-4}$ | | 1393 |
| $K^+K^-\phi$ | $(4.3 \pm 1.6) \times 10^{-4}$ | | 1440 |
| $\omega\omega$ | $(6.0 \pm 0.7) \times 10^{-4}$ | | 1571 |
| $\omega \phi$ | $(2.2 \pm 0.6) \times 10^{-5}$ | | 1503 |
| $\phi \underline{\phi}$ | $(4.4 \pm 0.6) \times 10^{-4}$ | | 1429 |
| p <u>₱</u> | $(7.3 \pm 0.4) \times 10^{-5}$ | | 1484 |
| $p \overline{p} \pi^0$ | $(1.64 \pm 0.20) \times 10^{-4}$ | | 1438 |
| $p\overline{p}\eta$ | $(1.53\pm0.26)\times10^{-4}$ | | 1254 |
| $p \overline{p} \omega$ | $(2.24 \pm 0.33) \times 10^{-4}$ | G1 000/ | 1117 |
| $p\overline{p}\phi$ | < 1.8 × 10 ⁻⁵ | CL=90% | 962 |
| $p\overline{p}\pi^+\pi^-$ $p\overline{p}K^+K^-$ (non-resonant) | $(5.0 \pm 1.9) \times 10^{-4}$ $(1.34 \pm 0.24) \times 10^{-4}$ | | 1381 974 |
| $p\overline{p}K_S^0K_S^0$ | $(1.34\pm0.24)\times10^{-4}$ | CL=90% | 968 |
| $\Lambda \overline{\Lambda}$ | | CL = 30 /0 | |
| $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | $(1.18 \pm 0.19) \times 10^{-4}$ $< 1.5 \times 10^{-3}$ | CL=90% | 1355 1223 |
| $K^{+} \overline{p} \Lambda$ | $(3.2 \pm 1.0) \times 10^{-4}$ | CL = 30 /0 | 1203 |
| $K + p \Lambda(1520) + c.c.$ | $(3.2 \pm 1.0) \times 10$ $(1.8 \pm 0.5) \times 10^{-4}$ | | 950 |
| $\Lambda(1520) \overline{\Lambda}(1520)$ | < 1.0 ± 0.3) × 10 -4 | CL=90% | 879 |
| $\sum_{i=0}^{\infty} \sum_{i=0}^{\infty} \sum_{j=0}^{\infty}$ | < 4 ×10 ⁻⁵ | CL=90% | 1288 |
| $\sum + \frac{\sum}{\sum} -$ | < 6 × 10 ⁻⁵ | CL=90% | 1291 |
| =0 $=0$ | < 6 × 10 ⁻⁵ | CL=90% | 1163 |
| <u>=-=</u> + | $(8.4 \pm 2.3) \times 10^{-5}$ | | 1155 |
| $\pi^{+} \pi^{-} + K^{+} K^{-}$ | $< 2.1 \times 10^{-3}$ | | _ |
| $K_S^0 K_S^0$ | $< 6 \times 10^{-5}$ | CL=90% | 1683 |
| | ative decays | | |
| $\gamma J/\psi(1S)$ | (34.4 ±1.5) % | | 389 |
| $\gamma \rho^0$ | $(2.28 \pm 0.19) \times 10^{-4}$ | | 1670 |
| $\gamma \omega$ | $(7.1 \pm 0.9) \times 10^{-5}$ | | 1668 |
| $\gamma \phi$ | $(2.6 \pm 0.6) \times 10^{-5}$ | | 1607 |
| | | | |
| | C DC 3 . | | |

 $h_c(1P)$

$$I^{G}(J^{PC}) = ??(1+-)$$

Mass $m=3525.41\pm0.16~{\rm MeV}~{\rm (S}=1.2)$ Full width $\Gamma~<~1~{\rm MeV}$

| $h_C(1P)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------------|------------------------------|-----------|
| $J/\psi(1S)\pi\pi$ | not seen | 312 |
| $\eta_c(1S)\gamma$ | (51 ±6) % | 502 |
| $\pi^+\pi^-\pi^0$ | $< 2.2 \times 10^{-3}$ | 1749 |
| $2\pi^{+}2\pi^{-}\pi^{0}$ | $(2.2^{+0.8}_{-0.7})\%$ | 1716 |
| $3\pi^{+}3\pi^{-}\pi^{0}$ | < 2.9 % | 1661 |

 $\chi_{c2}(1P)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=3556.20\pm0.09~{\rm MeV}$ Full width $\Gamma=1.98\pm0.11~{\rm MeV}$

| Hadronic decays | | | |
|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (1.10±0.11) % | | | 175 |
| $(2.00\pm0.26)\%$ | | | 175 |
| (2.4 ± 0.4) % | _ | | 168 |
| | | | 175 |
| (2.2 \pm 0.5) $	imes$ | 10^{-3} | | 165 |
| (1.51 ± 0.22) % | 2 | | 165 |
| | | | 154 |
| $(3.2 \pm 0.9) \times$ | 10-3 | | - |
| (42 100) ~ | 10-3 | | |
| (4.2 ±0.9) x | 10 - | | |
| (4.1 +0.9) × | 10-3 | | |
| · - / / · | | | |
| (3.2 \pm 0.9) $	imes$ | $_{10}^{-3}$ | | |
| | | | |
| | | | 154 |
| , , , , , , , , , , , , , , , , , , , , | 10-3 | | 165 |
| | 2 | | 162 |
| | | | 160 |
| (2.5 ±0.5) × | 10-3 | | 153 |
| | | | 170 |
| | | | 145 |
| (9.2 ±1.1) × | 10-3 | | 159 177 |
| | | | 168 |
| | | | 172 |
| | | | 163 |
| | | | 169 |
| | | | 170 |
| | | | 170 |
| | | | 168 |
| | | | 168 |
| | | 90% | 159 |
| < 6 × | 10^{-5} | 90% | 160 |
| < 1.1 × | 10^{-4} | 90% | 149 |
| (2.4 \pm 0.6) $	imes$ | $_{10}^{-3}$ | | 165 |
| < 4 × | 10^{-4} | 90% | 141 |
| (1.78 ± 0.22) × | 10^{-3} | | 142 |
| | | | 146 |
| | | | 151 |
| | | | 146 |
| | | | 128 |
| | | | 115 |
| | | | 100 |
| | | | 141 |
| | | | 141 |
| | | 0001 | 101 |
| | | 90% | 100 |
| | | | 146 |
| | | | 138 |
| | | 90% | 125 |
| | | | 123 |
| | | | 99 |
| | _ | 000/ | 92 |
| | | | 131 |
| | | | 132 119 |
| | | JU 70 | 119 |
| | 10 | 90% | 118 |
| | | JU /0 | 10 |
| _ | | | 43 |
| | 10-5 | 90% | 169 |
| | | 90% | 169 |
| | | /0 | 100 |
| < 8 × | $_{10}^{-6}$ | 90% | 163 |
| | (1.10±0.11) % (2.00±0.26) % (2.4 ±0.4) % (1.21±0.17) × (2.2 ±0.5) × (1.51±0.22) % (4.5 ±1.4) × (3.2 ±0.9) × (4.1 ±0.9) × (4.1 ±0.9) × (1.4 ±0.5) × (9.1 ±1.1) × (1.3 ±0.4) % (2.3 ±1.2) × (2.5 ±0.5) × (8.6 ±1.8) × (1.14±0.12) × (9.2 ±1.1) × (5.5 ±2.0) × (5.9 ±0.5) × (1.09±0.08) × (5.8 ±0.5) × (1.40±0.20) × (3.3 ±0.8) × < 3.5 × < 6 × < 1.1 (2.4 ±0.6) × (1.78±0.22) × (1.78±0.22) × (1.55±0.33) × (7.2 ±0.4) × (5.1 ±0.5) × (1.90±0.28) × (3.9 ±0.5) × (3.0 ±1.0) × (3.1 ±0.4) × (5.1 ±0.5) × (1.186±0.27) × (3.1 ±0.4) × (7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × (1.1 ±0.4) × < 7.9 × < 1.1 × (1.55 ±0.35) × < 1.5 % Radiative decays (19.5 ±0.8) % < 2.1 × | $ \begin{array}{c} (\ 1.10\pm0.11)\ \% \\ (\ 2.00\pm0.26)\ \% \\ (\ 2.4\ \pm0.4\)\ \% \\ (\ 1.21\pm0.17)\ \times 10^{-3} \\ (\ 2.2\ \pm0.5\)\ \times 10^{-3} \\ (\ 1.51\pm0.22)\ \% \\ (\ 4.5\ \pm1.4\)\ \times 10^{-3} \\ (\ 3.2\ \pm0.9\)\ \times 10^{-3} \\ (\ 4.2\ \pm0.9\)\ \times 10^{-3} \\ (\ 4.2\ \pm0.9\)\ \times 10^{-3} \\ (\ 4.1\ \pm0.9\)\ \times 10^{-3} \\ (\ 9.1\ \pm1.1\)\ \times 10^{-3} \\ (\ 9.1\ \pm1.1\)\ \times 10^{-3} \\ (\ 2.3\ \pm1.2\)\ \times 10^{-3} \\ (\ 2.5\ \pm0.5\)\ \times 10^{-3} \\ (\ 2.5\ \pm0.5\)\ \times 10^{-3} \\ (\ 2.5\ \pm0.5\)\ \times 10^{-3} \\ (\ 3.6\ \pm1.8\)\ \times 10^{-3} \\ (\ 9.2\ \pm1.1\)\ \times 10^{-4} \\ (\ 2.4\ \pm0.13)\ \times 10^{-3} \\ (\ 4.0\ \pm1.7\)\ \times 10^{-3} \\ (\ 5.5\ \pm2.0\)\ \times 10^{-4} \\ (\ 5.9\ \pm0.5\)\ \times 10^{-4} \\ (\ 1.09\pm0.08)\ \times 10^{-3} \\ (\ 5.8\ \pm0.5\)\ \times 10^{-4} \\ (\ 1.09\pm0.08)\ \times 10^{-3} \\ (\ 5.8\ \pm0.5\)\ \times 10^{-4} \\ (\ 1.40\pm0.20)\ \times 10^{-3} \\ (\ 3.3\ \pm0.8\)\ \times 10^{-4} \\ (\ 1.40\pm0.22)\ \times 10^{-3} \\ (\ 1.4\ \pm0.6\)\ \times 10^{-3} \\ (\ 1.5\ \pm0.3)\ \times 10^{-4} \\ (\ 1.78\pm0.22)\ \times 10^{-3} \\ (\ 1.5\ \pm0.33)\ \times 10^{-4} \\ (\ 1.90\pm0.28)\ \times 10^{-4} \\ (\ 3.0\ \pm1.0\)\ \times 10^{-5} \\ (\ 1.3\ 2\pm0.34)\ \times 10^{-3} \\ (\ 1.86\pm0.27)\ \times 10^{-4} \\ (\ 3.1\ \pm0.7\)\ \times 10^{-4} \\ (\ 5.1\ \pm1.6\)\ \times 10^{-4} \\ (\ 5.1\ \pm1.6\)\ \times 10^{-5} \\ <\ 7\ \times 10^{-5} \\ <\ 1.1\ \times 10^{-4} \\ (\ 1.55\pm0.35)\ \times 10^{-4} \\ <\ 1.5\ \%$ | $\begin{array}{c} (\ 1.10 \pm 0.11) \ \% \\ (\ 2.00 \pm 0.26) \ \% \\ (\ 2.4 \ \pm 0.4 \) \ \% \\ (\ 1.21 \pm 0.17) \times 10^{-3} \\ (\ 2.2 \ \pm 0.5 \) \times 10^{-3} \\ (\ 1.51 \pm 0.22) \ \% \\ (\ 4.5 \ \pm 1.4 \) \times 10^{-3} \\ (\ 3.2 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.2 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.1 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.2 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.1 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.1 \ \pm 0.9 \) \times 10^{-3} \\ (\ 4.1 \ \pm 0.9 \) \times 10^{-3} \\ (\ 1.4 \ \pm 0.5 \) \times 10^{-3} \\ (\ 9.1 \ \pm 1.1 \) \times 10^{-3} \\ (\ 1.3 \ \pm 0.4 \) \ \% \\ (\ 2.3 \ \pm 1.2 \) \times 10^{-3} \\ (\ 3.6 \ \pm 1.8 \) \times 10^{-3} \\ (\ 3.6 \ \pm 1.8 \) \times 10^{-3} \\ (\ 3.6 \ \pm 1.8 \) \times 10^{-3} \\ (\ 3.6 \ \pm 1.8 \) \times 10^{-3} \\ (\ 3.6 \ \pm 1.8 \) \times 10^{-3} \\ (\ 3.2 \ \pm 1.4 \) \times 10^{-4} \\ (\ 2.4 \ \pm 0.13) \times 10^{-3} \\ (\ 4.0 \ \pm 1.7 \) \times 10^{-3} \\ (\ 5.9 \ \pm 0.5 \) \times 10^{-4} \\ (\ 5.9 \ \pm 0.5 \) \times 10^{-4} \\ (\ 1.09 \pm 0.08) \times 10^{-3} \\ (\ 5.8 \ \pm 0.5 \) \times 10^{-4} \\ (\ 1.40 \pm 0.20) \times 10^{-3} \\ (\ 3.3 \ \pm 0.8 \) \times 10^{-4} \\ (\ 5.8 \ \pm 0.5 \) \times 10^{-4} \\ (\ 1.4 \ \pm 0.6 \) \times 10^{-3} \\ (\ 4 \ \times 10^{-4} \) \times 10^{-5} \\ (\ 5.1 \ \pm 0.5 \) \times 10^{-4} \\ (\ 1.78 \pm 0.22) \times 10^{-3} \\ (\ 1.78 \pm 0.22) \times 10^{-3} \\ (\ 1.1 \ \times 10^{-4} \) \times 10^{-5} \\ (\ 5.1 \ \pm 0.5 \) \times 10^{-4} \\ (\ 1.99 \pm 0.38) \times 10^{-4} \\ (\ 3.0 \ \pm 1.0 \) \times 10^{-5} \\ (\ 5.1 \ \pm 0.5 \) \times 10^{-4} \\ (\ 3.0 \ \pm 1.0 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 \) \times 10^{-5} \\ (\ 1.1 \ \pm 0.4 $ |

| $\eta_c(25)$ | $I^{G}(J^{PC}) = 0^{+}(0^{-})$ | +) | | ω p p | $(6.9 \pm 2.1) \times 10^{-5}$ | CI 2221 | 124 |
|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|------------------|--------------|---------------------------------------------------------------------------------------------------|------------------------------------------------------------------|----------------|-------------------------|
| <u> </u> | , , , | , | | $\phi \rho \overline{ ho} $ | $< 2.4 \times 10^{-5}$ $(6.0 \pm 0.4) \times 10^{-4}$ | CL=90% | 110 ¹ 149 |
| Quantum numbers are | e quark model predictions. | | | $p\overline{n}\pi^-$ or c.c. | $(2.48\pm0.17)\times10^{-4}$ | | |
| Mass $m = 3638.9$ | | | | $p \overline{n} \pi^- \pi^0$ | $(3.2 \pm 0.7) \times 10^{-4}$ | | 149 |
| Full width $\Gamma=10$ | ± 4 MeV | | D | $\frac{2(\pi^+\pi^-\pi^0)}{\eta\pi^+\pi^-}$ | $(4.8 \pm 1.5) \times 10^{-3}$ $< 1.6 \times 10^{-4}$ | CL=90% | 177 179 |
| $\eta_{c}(2S)$ DECAY MODES | Fraction (Γ_i/Γ) Confid | lence level | | $\eta \pi^+ \pi^- \pi^0$ | $(9.5 \pm 1.7) \times 10^{-4}$ | CE = 7070 | 177 |
| hadrons | not seen | | | $2(\pi^{+}\pi^{-})\eta$ | $(1.2 \pm 0.6) \times 10^{-3}$ | | 175 |
| $K\overline{K}\pi$ | (1.9 ± 1.2) % | | 1730 | $\eta^{\prime} \pi^{+} \pi^{-} \pi^{0} \ \omega \pi^{+} \pi^{-}$ | $(4.5 \pm 2.1) \times 10^{-4}$ | C 21 | 169 174 |
| $2\pi^{+}2\pi^{-}$ | not seen | | 1793 | $b_{\pm}^{\pm}\pi^{\mp}$ | $(7.3 \pm 1.2) \times 10^{-4}$ $(4.0 \pm 0.6) \times 10^{-4}$ | S=2.1 S=1.1 | 163 |
| $\rho^{0} \rho^{0}$ $3\pi^{+} 3\pi^{-}$ | not seen not seen | | 1646 1750 | $b_0^0 \pi^0$ | $(2.4 \pm 0.6) \times 10^{-4}$ | | |
| $K^{+}K^{-}\pi^{+}\pi^{-}$ | not seen | | 1701 | $\omega f_2(1270)$ | $(2.2 \pm 0.4) \times 10^{-4}$ | | 151 |
| $K^{*0}\overline{K}^{*0}$ | not seen | | 1586 | $\pi^{+} \pi^{-} K^{+} K^{-}$ | $(7.5 \pm 0.9) \times 10^{-4}$ | S=1.9 | 172 |
| $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ | (1.4 ± 1.0) % | | 1668 | $ ho^0K^+K^-\ K^*(892)^0\overline{K}_2^*(1430)^0$ | $(2.2 \pm 0.4) \times 10^{-4}$ | | 161 |
| $K^+ K^- 2\pi^+ 2\pi^-$ $K_5^0 K^- 2\pi^+ \pi^- + \text{c.c.}$ | not seen | | 1628 1666 | $K^{+}K^{-}\pi^{+}\pi^{-}\eta$ | $(1.9 \pm 0.5) \times 10^{-4}$ $(1.3 \pm 0.7) \times 10^{-3}$ | | 141 157 |
| $2K^{+}2K^{-}$ | not seen not seen | | 1471 | $K^{+}K^{-}2(\pi^{+}\pi^{-})\pi^{0}$ | $(1.00\pm0.31)\times10^{-3}$ | | 161 |
| $\phi \phi$ | not seen | | 15 07 | $K^{+}K^{-}2(\pi^{+}\pi^{-})$ | $(1.9 \pm 0.9) \times 10^{-3}$ | | 165 |
| $\gamma \gamma$ | $< 5 	 \times 10^{-4}$ | 90% | 1819 | $K_1(1270)^{\pm}K^{\mp}$ | $(1.00\pm0.28)\times10^{-3}$ | | 158 |
| $\pi^+\pi^-\eta$ | not seen | | 1767 | $K_{S}^{0}K_{S}^{0}\pi^{+}\pi^{-}$ | $(2.2 \pm 0.4) \times 10^{-4}$ | | 172 |
| $\pi^+\pi^-\eta'$ $K^+K^-\eta$ | not seen | | 1681 | $\rho^0 \overline{p} \overline{p} \ K^+ \overline{K}^* (892)^0 \pi^- + \text{c.c.}$ | $(5.0 \pm 2.2) \times 10^{-5}$ $(6.7 \pm 2.5) \times 10^{-4}$ | | 125 167 |
| $\pi^+\pi^-\eta_c(1S)$ | not seen not seen | | 1638 541 | $2(\pi^{+}\pi^{-})$ | $(0.7 \pm 2.5) \times 10$ $(2.4 \pm 0.6) \times 10^{-4}$ | S=2.2 | 181 |
| " " "(C(20) | not seen | | 0.1 | $\rho^0 \pi^+ \pi^-$ | $(2.2 \pm 0.6) \times 10^{-4}$ | S=1.4 | 175 |
| //05) | $I^{G}(J^{PC}) = 0^{-}(1^{-})$ | _, | | $K^+K^-\pi^+\pi^-\pi^0$ | $(1.26\pm0.09)\times10^{-3}$ | | 169 |
| $\psi(2S)$ | $I^{\circ}(J^{r,\circ}) = 0 (1$ |) | | $\omega f_0(1710) \to \omega K^+ K^-$ | $(5.9 \pm 2.2) \times 10^{-5}$ | | |
| Mass m = 2606 1 | 0.0 ± 0.012 May | | | $K^*(892)^0 K^- \pi^+ \pi^0 + \text{c.c.}$ $K^*(892)^+ K^- \pi^+ \pi^- + \text{c.c.}$ | $(8.6 \pm 2.2) \times 10^{-4}$ $(9.6 \pm 2.8) \times 10^{-4}$ | | - |
| Mass $m = 3686.1$ Full width $\Gamma = 30$ | 09 - 0.014 IVIEV 4 + 9 keV | | | $K^*(892)^+K^-\rho^0$ + c.c. | $(7.3 \pm 2.6) \times 10^{-4}$ | | |
| $\Gamma_{ee} = 2.35 \pm 0.0$ | | | | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ | $(6.1 \pm 1.8) \times 10^{-4}$ | | |
| . 66 | | ale factor/ | р | $\eta K^+ K^-$ | $< 1.3 \times 10^{-4}$ | CL=90% | 166 |
| $\psi(2S)$ DECAY MODES | | lence level | | $\omega K^+ K^-$ | $(1.85 \pm 0.25) \times 10^{-4}$ | S=1.1 | 161 |
| hadrons | (97.85 ± 0.13) % | | = | $\frac{3(\pi^+\pi^-)}{p\overline{p}\pi^+\pi^-\pi^0}$ | $(3.5 \pm 2.0) \times 10^{-4}$ $(7.3 \pm 0.7) \times 10^{-4}$ | S=2.8 | 177 143 |
| virtual $\gamma ightarrow $ hadrons | $(1.73 \pm 0.14) \%$ | S=1.5 | _ | K+K- | $(6.3 \pm 0.7) \times 10^{-5}$ | | 177 |
| ggg | (10.6 ±1.6) % | | - | $K_S^0 K_I^0$ | $(5.4 \pm 0.5) \times 10^{-5}$ | | 177 |
| γgg light hadrons | (1.03 ± 0.29) % (15.4 ±1.5) % | | - | $\pi^{+}\pi^{-}\pi^{0}$ | $(1.68\pm0.26)\times10^{-4}$ | S=1.4 | 183 |
| e ⁺ e ⁻ | $(7.73 \pm 0.17) \times 10^{-3}$ | | 1843 | $ ho(2150)\pi ightarrow \pi^+\pi^-\pi^0$ | $(1.9 \begin{array}{c} +1.2 \\ -0.4 \end{array}) \times 10^{-4}$ | | |
| $\mu^{+} \mu^{-}$ | $(7.7 \pm 0.8) \times 10^{-3}$ | | 1840 | $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ | $(3.2 \pm 1.2) \times 10^{-5}$ | S=1.8 | |
| $\tau^+\tau^-$ | $(3.0 \pm 0.4) \times 10^{-3}$ | | 490 | $\pi^+\pi^-$ | $(8 \pm 5) \times 10^{-5}$ | | 183 |
| Decays i | into $J/\psi(1S)$ and anything | | | $egin{array}{c} {\cal K}_1(1400)^{\pm}{\cal K}^{\mp} \ {\cal K}^{+}{\cal K}^{-}\pi^0 \end{array}$ | < 3.1 × 10 ⁻⁴ | CL=90% | 153 |
| $J/\psi(1S)$ anything | (59.5 ±0.8)% | | - | | < 2.96 × 10 ⁻⁵ | CL=90% | 175 |
| $J/\psi(1S)$ neutrals | $(24.6 \pm 0.4) \%$ | | _ | $K^{+}\overline{K}^{*}(892)^{-} + \text{c.c.}$ | $(1.7 \begin{array}{c} +0.8 \\ -0.7 \end{array}) \times 10^{-5}$ | | 169 |
| $J/\psi(1S)\pi^{+}\pi^{-}$ | (33.6 ±0.4) % | | 477 | $K^*(892)^0\overline{K}^0+$ c.c. $\phi\pi^+\pi^-$ | $(1.09\pm0.20)\times10^{-4}$ | C 17 | 169 |
| $J/\psi(1S)\pi^0\pi^0$ $J/\psi(1S)\eta$ | $(17.75 \pm 0.34) \%$ $(3.28 \pm 0.07) \%$ | | 481 199 | $\phi \pi^+ \pi^- $ $\phi f_0(980) \rightarrow \pi^+ \pi^-$ | $(1.17\pm0.29) \times 10^{-4}$ $(6.8 \pm 2.5) \times 10^{-5}$ | S=1.7 S=1.1 | 169 |
| $J/\psi(1S)\pi^0$ | (3.20 ± 0.07) /6 $(1.30\pm0.10) \times 10^{-3}$ | S=1.4 | 528 | $2(K^+K^-)$ | $(6.0 \pm 1.4) \times 10^{-5}$ | 5-1.1 | 149 |
| | | | | $\phi K^+ K^-$ | $(7.0 \pm 1.6) \times 10^{-5}$ | | 154 |
| $\pi^0 h_c(1P)$ | Hadronic decays $(8.6 \pm 1.3) \times 10^{-4}$ | | 85 | $2(K^{+}K^{-})\pi^{0}$ | $(1.10\pm0.28)\times10^{-4}$ | | 144 |
| $3(\pi^{+}\pi^{-})\pi^{0}$ | $(3.5 \pm 1.6) \times 10^{-3}$ | | 1746 | $\phi\eta$ | $(2.8 \ ^{+1.0}_{-0.8}) \times 10^{-5}$ | | 165 |
| $2(\pi^{+}\pi^{-})\pi^{0}$ | $(2.9 \pm 1.0) \times 10^{-3}$ | S=4.6 | 1799 | $\phi \eta'$ | $(3.1 \pm 1.6) \times 10^{-5}$ | | 155 |
| $\rho a_2(1320)$ | $(2.6 \pm 0.9) \times 10^{-4}$ | | 1500 | $\omega\eta'$ | $(3.2 \begin{array}{c} +2.5 \\ -2.1 \end{array}) \times 10^{-5}$ | | 162 |
| $p\overline{p}$ | $(2.76 \pm 0.12) \times 10^{-4}$ | | 1586 | $\omega \pi^0$ | $(2.1 \pm 0.6) \times 10^{-5}$ | | 175 |
| $\Delta^{++}\overline{\Delta}^{}$ $\Lambda\overline{\Lambda}\pi^{0}$ | $(1.28 \pm 0.35) \times 10^{-4}$ $< 1.2 \times 10^{-4}$ | CL=90% | 1371 | $ ho\eta'$ | $(1.9 \begin{array}{c} +1.7 \\ -1.2 \end{array}) \times 10^{-5}$ | | 162 |
| $\Lambda \overline{\Lambda} \eta$ | $< 1.2 \times 10^{-4} < 4.9 \times 10^{-5}$ | CL=90% CL=90% | 1412 1197 | $ ho\eta$ | $(2.2 \pm 0.6) \times 10^{-5}$ | S=1.1 | 171 |
| $\Lambda \overline{\rho} \dot{K}^+$ | $(1.00\pm0.14)\times10^{-4}$ | - / • | 1327 | $\omega \eta$ | < 1.1 ×10 ⁻⁵ | CL=90% | 171 |
| $\Lambda \overline{p} K^+ \pi^+ \pi^-$ | $(1.8 \pm 0.4) \times 10^{-4}$ | | 1167 | $\phi \pi^0$ | $< 4 \times 10^{-6}$ | CL=90% | 169 |
| $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | $(2.8 \pm 0.6) \times 10^{-4}$ | c | 1346 | $\eta_c \pi^+ \pi^- \pi^0$ | < 1.0 × 10 ⁻³ | CL=90% | |
| $A\overline{A} = \sum_{-} -$ | $(2.8 \pm 0.5) \times 10^{-4}$ $(2.6 \pm 0.8) \times 10^{-4}$ | S=2.6 | 1467 1408 | $\frac{\rho \overline{\rho} K^+ K^-}{\Lambda n K_S^0 + \text{c.c.}}$ | $(2.7 \pm 0.7) \times 10^{-5}$ | | 111 |
| $\Sigma + \overline{\Sigma} - \Sigma 0$ | $(2.0 \pm 0.0) \times 10$ $(2.2 \pm 0.4) \times 10^{-4}$ | S=1.5 | 1405 | $\phi f_2'(1525)$ | $(8.1 \pm 1.8) \times 10^{-5}$ $(4.4 \pm 1.6) \times 10^{-5}$ | | 132 132 |
| $\Sigma(1385)^{+}\overline{\Sigma}(1385)^{-}$ | $(1.1 \pm 0.4) \times 10^{-4}$ | | 1218 | $\Theta(1540)\overline{\Theta}(1540) \rightarrow$ | < 8.8 ×10 ⁻⁶ | CL=90% | 132 |
| $ \Sigma (1385)^{+} \overline{\Sigma} (1385)^{-} $ $ \Xi - \overline{\Xi}^{+} $ $ \Xi^{0} \overline{\Xi}^{0} $ | $(1.8 \pm 0.6) \times 10^{-4}$ | S=2.8 | 1284 | $K_0^0 p K^{-\overline{n}} + \text{c.c.}$ | , ^1V | | |
| = '= '0 = (1530)0 = (1530)0 | $(2.8 \pm 0.9) \times 10^{-4}$ | CI 0001 | 1292 | $\Theta(15\overline{40}) K^{-} \overline{n} \rightarrow K_{S}^{0} p K^{-} \overline{n}$ | $< 1.0 \times 10^{-5}$ | CL=90% | |
| $\Xi(1530)^0\overline{\Xi}(1530)^0$ $\Omega^-\overline{\Omega}^+$ | $< 8.1 \times 10^{-5} $ $< 7.3 \times 10^{-5}$ | CL=90% CL=90% | 1025 774 | $\Theta(1540)K_S^{0}\overline{p} ightarrow K_S^{0}\overline{p}K^{+}$ n | $< 7.0 \times 10^{-6}$ | CL=90% | |
| $\pi^0 p \overline{p}$ | $(1.50\pm0.08)\times10^{-4}$ | S=1.1 | 1543 | $\overline{\Theta}(1540) K^{+} n \rightarrow K^{0}_{S} \overline{p} K^{+} n$ | $< 2.6 \times 10^{-5}$ | CL=90% | ٠ |
| $N_1^*(1440)\overline{p} \rightarrow \pi^0 p\overline{p}$ | $(8.1 \pm 0.8) \times 10^{-5}$ | | - | $\overline{\Theta}(1540) K_S^0 p \rightarrow K_S^{0} p K^{-} \overline{n}$ | $< 6.0 \times 10^{-6}$ | CL=90% | |
| $\pi^0 f_0(2100) \rightarrow \pi^0 p \overline{p}$ | $(1.1 \pm 0.4) \times 10^{-5}$ | | _ | $K_S^0 K_S^0$ | $< 4.6 \times 10^{-6}$ | | 177 |
| $\eta p \overline{p}$ | $(5.7 \pm 0.6) \times 10^{-5}$ | | 1373 | | | | |

 $(5.7 \pm 0.4) \times 10^{-5}$ $(5.7 \pm 0.6) \times 10^{-5}$ $(1.2 \pm 0.4) \times 10^{-5}$ $(4.4 \pm 0.7) \times 10^{-5}$

 $\eta f_0(2100) \to \eta \rho \overline{\rho} \\
N^*(1535) \overline{\rho} \to \eta \rho \overline{\rho}$

1862

Meson Summary Table

 $\times\,10^{-3}\quad\text{CL}\!=\!90\%$ $\times\,10^{-3}$ CL=90%

< 1.24 < 8.9

 $\begin{array}{l} \eta \, \pi^+ \, \pi^- \\ \pi^+ \, \pi^- \, 2 \pi^0 \\ \rho^0 \, \pi^+ \, \pi^- \end{array}$

| | Radiative decays | | |
|------------------------------------------------------------------------------|---------------------------------|----------------------|------|
| $\gamma \chi_{c0}(1P)$ | $(9.68 \pm 0.31)\%$ | | 261 |
| $\gamma \chi_{c1}(1P)$ | $(9.2 \pm 0.4)\%$ | | 171 |
| $\gamma \chi_{c2}(1P)$ | (8.72 ± 0.34) % | | 128 |
| $\gamma \eta_c(1S)$ | $(3.4 \pm 0.5) \times 10$ | -3 S=1.3 | 638 |
| $\gamma \eta_{c}(2S)$ | < 8 × 10 | ⁻⁴ CL=90% | 47 |
| $\gamma \pi^0$ | ($1.6~\pm0.4~) \times 10$ | -6 | 1841 |
| $\gamma \eta'$ (958) | $(1.23 \pm 0.06) \times 10$ | -4 | 1719 |
| $\gamma f_2(1270)$ | $(2.1 \pm 0.4) \times 10$ | -4 | 1623 |
| $\gamma f_0(1710) \rightarrow \gamma \pi \pi$ | ($3.0~\pm1.3$) \times 10 | -5 | - |
| $\gamma f_0(1710) \rightarrow \gamma K \overline{K}$ | ($6.0~\pm1.6$) \times 10 | -5 | - |
| $\gamma \gamma$ | < 1.4 × 10 | | 1843 |
| $\gamma \eta$ | (1.4 ± 0.5) \times 10 | -6 | 1802 |
| $\gamma \eta \pi^+ \pi^-$ | (8.7 ± 2.1) \times 10 | | 1791 |
| $\gamma \eta(1405) \rightarrow \gamma K K \pi$ | < 9 × 10 | | 1569 |
| $\gamma \eta (1405) \rightarrow \eta \pi^+ \pi^-$ | $(3.6 \pm 2.5) \times 10$ | | _ |
| $\gamma \eta(1475) \rightarrow K\overline{K}\pi$ | < 1.4 × 10 | | _ |
| $\gamma \eta (1475) \rightarrow \eta \pi^+ \pi^-$ | < 8.8 × 10 | | _ |
| $\gamma 2(\pi^+\pi^-)$ | $(4.0 \pm 0.6) \times 10$ | | 1817 |
| $\gamma K^{*0} K^{+} \pi^{-} + \text{c.c.}$ | $(3.7 \pm 0.9) \times 10$ | | 1674 |
| $\gamma K^{*0} \overline{K}^{*0}$ | $(2.4 \pm 0.7) \times 10$ | | 1613 |
| $\gamma K_{S}^{0} K^{+} \pi^{-} + \text{c.c.}$ | ($2.6~\pm0.5$) \times 10 | | 1753 |
| γ K ⁺ K ⁻ π ⁺ π ⁻ | (1.9 ± 0.5) $\times 10$ | | 1726 |
| γ p p | (3.9 ± 0.5) $\times 10$ | | 1586 |
| $\gamma f_2(1950) \rightarrow \gamma p \overline{p}$ | $(1.20 \pm 0.22) \times 10$ | | _ |
| $\gamma f_2(2150) \rightarrow \gamma p \overline{p}$ | (7.2 ± 1.8) \times 10 | | _ |
| $\gamma X(1835) \rightarrow \gamma p \overline{p}$ | < 1.6 × 10 | | - |
| $\gamma X \rightarrow \gamma p \overline{p}$ | $[nnnn] < 2 \times 10$ | | - |
| $\gamma \pi^+ \pi^- p \overline{p}$ | $(2.8 \pm 1.4) \times 10$ | _ | 1491 |
| $\gamma 2(\pi^+ \pi^-) K^+ K^-$ | < 2.2 × 10 | | 1654 |
| $\gamma 3(\pi^+\pi^-)$ | < 1.7 × 10 | | 1774 |
| γ K ⁺ K ⁻ K ⁺ K ⁻ | < 4 × 10 | ⁻⁵ CL=90% | 1499 |

$\psi(3770)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m = 3773.15 \pm 0.33 \text{ MeV}$ Full width Γ = 27.2 \pm 1.0 MeV $\Gamma_{ee} = 0.262 \pm 0.018 \; \text{keV} \quad (S = 1.4) \label{eq:ee}$

In addition to the dominant decay mode to $D\overline{D}$, $\psi(3770)$ was found to decay into the final states containing the J/ψ (BAI 05, ADAM 06). ADAMS 06 and HUANG 06A searched for various decay modes with light hadrons and found a statistically significant signal for the decay to $\phi\eta$ only (ADAMS 06).

| ψ (3770) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-------------------------------------------|------------------------------|-----------------------------------|------|
| $D\overline{D}$ | (93 + 8) % | S=2.0 | 285 |
| $D^0 \overline{D}{}^0$ | (52 ±5) % | S=2.0 | 285 |
| $D^+ D^-$ | (41 ±4)% | | 25 2 |
| $J/\psi \pi^+ \pi^-$ | $(1.93 \pm 0.28) \times$ | 10^{-3} | 560 |
| $J/\psi \pi^0 \pi^0$ | (8.0 ±3.0) × | | 564 |
| $J/\psi \eta$ | (9 ±4)× | 10^{-4} | 360 |
| $J/\psi \pi^0$ | < 2.8 × | 10^{-4} CL=90% | 603 |
| e^+e^- | (9.6 \pm 0.7) \times | 10^{-6} S=1.3 | 1887 |
| | Decays to light hadrons | | |
| $b_1(1235)\pi$ | < 1.4 × | 10^{-5} CL=90% | 1683 |
| $\phi \eta'$ | < 7 × | 10^{-4} CL=90% | 1607 |
| $\omega \eta'$ | | 10^{-4} CL=90% | 1672 |
| $\rho^0 \eta'$ | < 6 × | 10^{-4} CL=90% | 1674 |
| $\phi \eta$ | ($3.1~\pm0.7$) $	imes$ | | 1703 |
| $\omega \eta$ | | 10^{-5} CL=90% | 1762 |
| $\rho^0 \eta$ | | 10 ⁻⁴ CL=90% | 1764 |
| $\phi \pi^0$ | | 10 ⁻⁵ CL=90% | 1746 |
| $\omega \pi^0$ | | 10 ⁻⁴ CL=90% | 1803 |
| $\pi^{+} \pi^{-} \pi^{0}$ | | 10 ⁻⁶ CL=90% | 1874 |
| $ ho\pi$ | | 10 ⁻⁶ CL=90% | 1804 |
| $K^*(892)^+ K^- + \text{c.c.}$ | < 1.4 × | 10 ⁻⁵ CL=90% | 1745 |
| $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ | | 10^{-3} CL=90% | 1744 |
| $K_S^0 K_L^0$ | | 10 ⁻⁵ CL=90% | 1820 |
| $2(\pi^{+}\pi^{-})$ | | 10^{-3} CL=90% | 1861 |
| $2(\pi^{+}\pi^{-})\pi^{0}$ | | 10 ⁻³ CL=90% | 1843 |
| $2(\pi^{+}\pi^{-}\pi^{0})$ | < 5.85 % | | 1821 |
| $\omega \pi^+ \pi^-$ | | 10 ⁻⁴ CL=90% | 1794 |
| $3(\pi^{+}\pi^{-})$ | | 10-3 | 1819 |
| $3(\pi^{+}\pi^{-})\pi^{0}$ | < 1.37 % | | 1792 |
| $3(\pi^{+}\pi^{-})2\pi^{0}$ | < 11.74 % | CL=90% | 1760 |

| $\pi^{+} \pi^{-} 2\pi^{0}$ | < 8.9 | $\times 10^{-3}$ | CL=90% | 1862 |
|---------------------------------------------|------------------|----------------------------|------------------|------|
| $ ho^0\pi^+\pi^-$ | < 6.9 | $\times 10^{-3}$ | CL=90% | 1796 |
| $\eta 3\pi$ | < 1.34 | $\times 10^{-3}$ | CL=90% | 1824 |
| $\eta 2(\pi^{+}\pi^{-})$ | < 2.43 | % | | 1804 |
| $\eta \rho^0 \pi^+ \pi^-$ | < 1.45 | % | CL=90% | 1708 |
| $\eta' 3\pi$ | < 2.44 | $\times 10^{-3}$ | CL=90% | 1740 |
| $K^{+}K^{-}\pi^{+}\pi^{-}$ | < 9.0 | $\times 10^{-4}$ | CL=90% | 1772 |
| $\phi \pi^{+} \pi^{-}$ | < 4.1 | $\times 10^{-4}$ | CL=90% | 1737 |
| $K^{+}K^{-}2\pi^{0}$ | < 4.2 | ×10 ⁻³ | CL=90% | 1774 |
| $4(\pi^{+}\pi^{-})$ | < 1.67 | % | CL=90% | 1757 |
| $4(\pi^{+}\pi^{-})\pi^{0}$ | | | CL=90% | 1720 |
| | < 3.06 | % | | |
| $\phi f_0(980)$ $K^+K^-\pi^+\pi^-\pi^0$ | < 4.5 | ×10 ⁻⁴ | CL=90% | 1597 |
| | < 2.36 | $\times 10^{-3}$ | CL=90% | 1741 |
| $K^{+} K^{-} \rho^{0} \pi^{0}$ | < 8 | $\times 10^{-4}$ | CL=90% | 1624 |
| $K^+K^-\rho^+\pi^-$ | < 1.46 | % | CL=90% | 1622 |
| $\omega K^+ K^-$ | < 3.4 | $\times 10^{-4}$ | CL=90% | 1664 |
| $\phi \pi^+ \pi^- \pi^0$ | < 3.8 | $\times 10^{-3}$ | CL=90% | 1722 |
| $K^{*0}K^{-}\pi^{+}\pi^{0}$ + c.c. | < 1.62 | % | CL=90% | 1693 |
| $K^{*+}K^{-}\pi^{+}\pi^{-}$ + c.c. | < 3.23 | % | CL=90% | 1692 |
| $K^{+}K^{-}\pi^{+}\pi^{-}2\pi^{0}$ | < 2.67 | % | CL=90% | 1705 |
| $K^+K^-2(\pi^+\pi^-)$ | < 1.03 | % | CL=90% | 1702 |
| $K + K - 2(\pi + \pi^{-})\pi^{0}$ | < 3.60 | % | CL=90% | 1660 |
| $\eta K^+ K^-$ | | ×10 ⁻⁴ | CL=90% | 1712 |
| $\eta K^+ K^- \pi^+ \pi^-$ | | | CL=90% CL=90% | |
| | < 1.24 | % | | 1624 |
| $\rho^0 K^+ K^-$ | < 5.0 | ×10 ⁻³ | CL=90% | 1665 |
| 2(K+K-) | < 6.0 | $\times 10^{-4}$ | CL=90% | 1552 |
| φK ⁺ K ⁻ | < 7.5 | $\times 10^{-4}$ | CL=90% | 1598 |
| $2(K^{+}K^{-})\pi^{0}$ | < 2.9 | $\times 10^{-4}$ | CL=90% | 1493 |
| $2(K^{+}K^{-})\pi^{+}\pi^{-}$ | < 3.2 | $\times 10^{-3}$ | CL=90% | 1425 |
| $K_{S}^{0}K^{-}\pi^{+}$ | < 3.2 | $\times 10^{-3}$ | CL=90% | 1799 |
| $\kappa_{s}^{0} \kappa^{-} \pi^{+} \pi^{0}$ | < 1.33 | % | CL=90% | 1773 |
| $K_S^0 K^- \rho^+$ | < 6.6 | ×10 ⁻³ | CL=90% | 1664 |
| | | | | |
| $K_{S}^{0}K^{-}2\pi^{+}\pi^{-}$ | < 8.7 | $\times 10^{-3}$ | CL=90% | 1739 |
| $K_S^{0}K^-\pi^+ ho^0$ | < 1.6 | % | CL=90% | 1621 |
| $K_S^0 K^- \pi^+ \eta$ | < 1.3 | % | CL=90% | 1669 |
| $K_{S}^{0}K^{-}2\pi^{+}\pi^{-}\pi^{0}$ | < 4.18 | % | CL=90% | 1703 |
| $K_{5}^{0}K^{-}2\pi^{+}\pi^{-}\eta$ | < 4.8 | % | CL=90% | 1570 |
| $K_{S}^{0}K^{-}\pi^{+}2(\pi^{+}\pi^{-})$ | | | | |
| | < 1.22 | % | CL=90% | 1658 |
| $K_{S}^{0}K^{-}\pi^{+}2\pi^{0}$ | < 2.65 | % | CL=90% | 1742 |
| $K_S^0 K^- K^+ K^- \pi^+$ | < 4.9 | $\times 10^{-3}$ | CL=90% | 1490 |
| $K_{S}^{0}K^{-}K^{+}K^{-}\pi^{+}\pi^{0}$ | < 3.0 | % | CL=90% | 1427 |
| $K_{S}^{0}K^{-}K^{+}K^{-}\pi^{+}\eta$ | < 2.2 | % | CL=90% | 1214 |
| $K^{*0}K^{-}\pi^{+}$ + c.c. | < 9.7 | ×10 ⁻³ | CL=90% | 1722 |
| $p \overline{p} \pi^0$ | | ×10 ⁻³ | CL=90% | 1595 |
| | < 1.2 | × 10 ° | | |
| $p\overline{p}\pi^+\pi^-$ | < 5.8 | ×10 ⁻⁴ | CL=90% | 1544 |
| $A\overline{A}$ | < 1.2 | $\times 10^{-4}$ | CL=90% | 1521 |
| $p\overline{p}\pi^+\pi^-\pi^0$ | < 1.85 | $\times 10^{-3}$ | CL=90% | 1490 |
| ω <u>ρ</u> <u> </u> | < 2.9 | $\times 10^{-4}$ | CL=90% | 1309 |
| $\Lambda \overline{\Lambda} \pi^0$ | < 1.2 | $\times 10^{-3}$ | CL=90% | 1469 |
| $p\overline{p}2(\pi^+\pi^-)$ | < 2.6 | $\times 10^{-3}$ | CL=90% | 1425 |
| ηρρ | < 5.4 | $\times 10^{-4}$ | CL=90% | 1430 |
| $\eta p \overline{p} \pi^+ \pi^-$ | < 3.3 | $\times 10^{-3}$ | CL=90% | 1284 |
| $\rho^0 p \overline{p}$ | < 1.7 | ×10 ⁻³ | CL=90% | 1313 |
| $p \overline{p} K^+ K^-$ | < 3.2 | ×10 ⁻⁴ | CL=90% | 1185 |
| $\eta p \overline{p} K^+ K^-$ | < 6.9 | ×10 ×10 ⁻³ | CL=90% CL=90% | 736 |
| $\pi^0 p \overline{p} K^+ K^-$ | | ×10 3 ×10 ⁻³ | | |
| | < 1.2 | | CL=90% | 1093 |
| $\phi p \overline{p}$ | < 1.3 | ×10 ⁻⁴ | CL=90% | 1178 |
| $\Lambda\Lambda\pi^{+}\pi^{-}$ | < 2.5 | ×10 ⁻⁴ | CL=90% | 1405 |
| $\Lambda \overline{p} K^+$ | < 2.8 | ×10 ⁻⁴ | CL=90% | 1387 |
| $\Lambda \overline{p} K^+ \pi^+ \pi^-$ | < 6.3 | $\times 10^{-4}$ | CL=90% | 1234 |
| ĺ | Radiative decays | | | |
| | • | ×10 ⁻⁴ | CL=90% | 21.1 |
| $\gamma \chi_{c2}$ | | | CL=90% | 211 |
| $\gamma \chi_{c1}$ | (2.9 ±0.6 | | | 25 3 |
| $\gamma \chi_{c0}$ | (7.3 ±0.9 | | | 341 |
| $\gamma \eta'$ | < 1.8 | $\times 10^{-4}$ | CL=90% | 1765 |
| | | $\times 10^{-4}$ | CL=90% | 1847 |
| $\gamma \eta$ | < 1.5 | | 02-3070 | 10 |
| $\frac{\gamma \eta}{\gamma \pi}$ 0 | < 1.5 | ×10 ⁻⁴ | CL=90% | 1884 |

X(3872)

$$I^{G}(J^{PC}) = 0?(?^{?+})$$

Quantum numbers not established.

Mass $m=3871.68\pm0.17$ MeV $m_{X\,(3872)}-m_{J/\psi}=775\pm4$ MeV $m_{X\,(3872)}-m_{\psi(25)}$ Full width $\Gamma<1.2$ MeV, CL = 90%

| X(3872) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------|------------------------------|-----------|
| $\pi^+\pi^-J/\psi(1S)$ | >2.6 % | 65 0 |
| $\omega J/\psi(1S)$ | >1.9 % | † |
| $D^0 \overline{D}{}^0 \pi^0$ | $> 3.2 \times 10^{-3}$ | 116 |
| $\overline{D}^{*0} D^0$ | >5 × 10 ⁻³ | † |
| $\gamma J/\psi$ | >6 × 10 ⁻³ | 697 |
| $\gamma \psi(2S)$ | [0000] >3.0 % | 181 |

X(3915)

$$I^{G}(J^{PC}) = 0^{+}(?^{?+})$$

Observed in $\omega J/\psi$, thus $\mathcal{C}=+$

Mass $m=3917.5\pm2.7~{\rm MeV}$ Full width $\Gamma=27\pm10~{\rm MeV}~{\rm (S=1.4)}$

| X(3915) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| $\omega J/\psi$ | seen | 219 |
| $\gamma\gamma$ | seen | 1959 |

$\chi_{c2}(2P)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

Mass $m=3927.2\pm2.6~{\rm MeV}$ Full width $\Gamma=24\pm6~{\rm MeV}$

| $\chi_{c2}(2P)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|------------------------------|-----------|
| γ <u>γ_</u> | seen | 1964 |
| D \overline{D} | seen | 615 |
| $D^+ D^-$ | seen | 600 |
| $D^0 \overline{D}{}^0$ | seen | 615 |

ψ(4040) ^[pppp]

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

 $\begin{array}{l} {\rm Mass}~m=4039\pm1~{\rm MeV} \\ {\rm Full~width}~\Gamma=80\pm10~{\rm MeV} \\ {\rm \Gamma}_{ee}=0.86\pm0.07~{\rm keV} \end{array}$

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| ψ (4040) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | (MeV/c) |
|------------------------------------------------------|------------------------------|----------------------|----------|
| e^+e^- | $(1.07 \pm 0.16) \times$ | 10-5 | 2019 |
| $D\overline{D}$ | seen | | 775 |
| $D^0 \overline{D}{}^0$ | seen | | 775 |
| $D^+ D^-$ | seen | | 763 |
| $D^*\overline{D}$ + c.c. | seen | | 569 |
| $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.}$ | seen | | 575 |
| $D^*(2010)^+ D^- + \text{c.c.}$ | seen | | 561 |
| $D^*\overline{D}^*$ | seen | | 193 |
| $D^*(2007)^0 \overline{D}^*(2007)^0$ | seen | | 224 |
| $D^*(2010)^+ D^*(2010)^-$ | seen | | 193 |
| $D^0D^-\pi^+$ +c.c. (excl. | not seen | | _ |
| $D^*(2007)^0 \overline{D}{}^{0} + \text{c.c.},$ | | | |
| $D^*(2010)^+ D^- + c.c.$ | | | |
| $D\overline{D}^*\pi$ (excl. $D^*\overline{D}^*$) | not seen | | _ |
| $D^0 \overline{D}^{*-} \pi^+ + \text{c.c.}$ (excl. | seen | | _ |
| $D^*(2010)^+ D^*(2010)^-)$ | | | |
| $D_{s}^{+}D_{s}^{-}$ | seen | | 451 |
| $J/\psi \pi^+ \pi^-$ | < 4 × | 10^{-3} 90% | 794 |
| $J/\psi \pi^0 \pi^0$ | | 10-3 90% | 797 |
| $J/\psi \eta$ | < 7 × | 10-3 90% | 675 |
| $J/\psi\pi^0$ | < 2 × | 10 ⁻³ 90% | 823 |
| | | | |

| $J/\psi \pi^+ \pi^- \pi^0$ | < 2 | $\times10^{-3}$ | 90% | 746 |
|-------------------------------------|-------|------------------|-----|------|
| $\chi_{c1}\gamma$ | < 1.1 | % | 90% | 494 |
| $\chi_{c2}\gamma$ | < 1.7 | % | 90% | 454 |
| $\chi_{c1} \pi^{+} \pi^{-} \pi^{0}$ | < 1.1 | % | 90% | 306 |
| $\chi_{c2}\pi^{+}\pi^{-}\pi^{0}$ | < 3.2 | % | 90% | 233 |
| $h_c(1P) \pi^+ \pi^-$ | < 3 | $\times 10^{-3}$ | 90% | 403 |
| $\phi \pi^+ \pi^-$ | < 3 | $\times 10^{-3}$ | 90% | 1880 |

ψ (4160) [pppp]

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=4153\pm3~{\rm MeV}$ Full width $\Gamma=103\pm8~{\rm MeV}$ $\Gamma_{ee}=0.83\pm0.07~{\rm keV}$

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| ψ(4160) DECAY MODES | Fraction | (Γ_i/Γ) | Confidence level | <i>p</i> (Me <i>V/c</i>) |
|------------------------------------------------------------------------------------------|----------|------------------------|------------------|-------------------------------|
| e^+e^- | (8.1± | 0.9) × 10 ⁻ | 6 | 2076 |
| $D\overline{D}$ | seen | | | 913 |
| $D^0 \overline{D}{}^0$ | seen | | | 913 |
| $D^+ D^-$ | seen | | | 904 |
| $D^*\overline{D}$ + c.c. | seen | | | 746 |
| $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.}$ | seen | | | 75 1 |
| $D^*(2010)^+ D^- + \text{c.c.}$ | seen | | | 740 |
| $D^*\overline{D}^*$ | seen | | | 520 |
| $D^*(2007)^0 \overline{D}{}^*(2007)^0$ | seen | | | 533 |
| $D^*(2010)^+ D^*(2010)^-$ | seen | | | 520 |
| $D^0 D^- \pi^+ + \text{c.c.}$ (excl.) $D^* (2007)^0 \overline{D}{}^0 + \text{c.c.}$, | not se | en | | - |
| $D^*(2010)^+ D^- + c.c.$ | | | | |
| $D\overline{D}^*\pi + c.c.$ (excl. $D^*\overline{D}^*$) | seen | | | - |
| $D^0 D^{*-} \pi^+ + \text{c.c.}$ (excl. | not se | en | | - |
| $D^*(2010)^+ D^*(2010)^-)$ | | | | |
| $D_s^+ D_s^-$ | not se | en | | 661 |
| $D_s^{*+}D_s^-+\text{c.c.}$ | seen | | | 385 |
| $J/\psi \pi^+ \pi^-$ | < 3 | ×10 ⁻ | 3 90% | 888 |
| $J/\psi \pi^0 \pi^0$ | < 3 | ×10- | | 891 |
| $J/\psi K^+ K^-$ | < 2 | ×10 ⁻ | 3 90% | 324 |
| $J/\psi \eta$ | < 8 | $\times 10^{-}$ | 3 90% | 786 |
| $J/\psi \pi^0$ | < 1 | \times 10 $^-$ | | 914 |
| $J/\psi \eta'$ | < 5 | ×10 ⁻ | 3 90% | 385 |
| $J/\psi \pi^{+} \pi^{-} \pi^{0}$ | < 1 | × 10 [—] | 3 90% | 847 |
| $\psi(2S)\pi^{+}\pi^{-}$ | < 4 | $\times 10^{-}$ | 3 90% | 35 3 |
| $\chi_{c1}\gamma$ | < 7 | $\times 10^{-}$ | 3 90% | 593 |
| $\chi_{c2}\gamma$ | < 1.3 | % | 90% | 554 |
| $\chi_{c1} \pi^{+} \pi^{-} \pi^{0}$ | < 2 | \times 10 $^-$ | 3 90% | 45 2 |
| $\chi_{c2} \pi^{+} \pi^{-} \pi^{0}$ | < 8 | \times 10 $^-$ | | 398 |
| $h_{c}(1P)\pi^{+}\pi^{-}$ | < 5 | ×10 ⁻ | 3 90% | 519 |
| $h_c(1P)\pi^0\pi^0$ | < 2 | $\times 10^{-}$ | 3 90% | 523 |
| $h_{\mathcal{C}}(1P)\eta$ | < 2 | $\times 10^{-}$ | 3 90% | 282 |
| $h_c(1P)\pi^0$ | < 4 | × 10 | 4 90% | 567 |
| $\phi \pi^{+} \pi^{-}$ | < 2 | ×10 ⁻ | 3 90% | 1941 |

X(4260)

$$I^{G}(J^{PC}) = ??(1 - -)$$

Mass $m=4263^{+8}_{-9}~{\rm MeV}~{\rm (S=1.1)}$ Full width $\Gamma=95\pm14~{\rm MeV}$

| X(4260) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------------------------|------------------------------|-----------|
| $J/\psi \pi^+ \pi^-$ | seen | 976 |
| $J/\psi \pi^+ \pi^-$ $J/\psi \pi^0 \pi^0$ | seen | 978 |
| $J/\psi K^+ K^-$ | seen | 530 |
| $J/\psi \eta$ | not seen | 886 |
| $J/\psi \pi^0$ | not seen | 999 |
| $J/\psi \eta'$ | not seen | 569 |
| $J/\psi \pi^+ \pi^- \pi^0$ | not seen | 939 |
| $J/\psi \eta \eta$ | not seen | 339 |
| $\psi(2S) \pi^{+} \pi^{-}$ | not seen | 470 |
| $\psi(2S)\eta$ | not seen | 167 |
| $\chi_{c0}\omega$ | not seen | 292 |
| $\chi_{c1}\gamma$ | not seen | 686 |
| $\chi_{c2}\gamma$ | not seen | 648 |

| • | | |
|----------------------------------------------------------------------------------------------------------|----------|------|
| $\chi_{c1} \pi^+ \pi^- \pi^0$ | not seen | 571 |
| $\chi_{c2} \pi^{+} \pi^{-} \pi^{0}$ | not seen | 524 |
| $h_c^{-1}(1P)\pi^+\pi^-$ | not seen | 623 |
| $\phi \pi^{+} \pi^{-}$ | not seen | 1999 |
| $ \begin{array}{c} \phi \pi^+ \pi \\ \phi f_0(980) \to \phi \pi^+ \pi^- \\ D \overline{D} \end{array} $ | not seen | _ |
| | not seen | 1032 |
| $D^0 \overline{D}{}^0$ | not seen | 1032 |
| $D^+ D^-$ | not seen | 1023 |
| $D^*\overline{D}$ + c.c. | not seen | 887 |
| $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.}$ | not seen | _ |
| $D^*(2010)^+ D^- + \text{c.c.}$ | not seen | _ |
| $D^* \overline{D}^*$ | not seen | 708 |
| $D^*(2007)^0 \overline{D}^*(2007)^0$ | not seen | 717 |
| $D^*(2010)^+ D^*(2010)^-$ | not seen | 708 |
| $D^{0}D^{-}\pi^{+} + \text{c.c.} (\text{excl.} D^{*}(2007)^{0}\overline{D}^{*0} + \text{c.c.},$ | not seen | _ |
| $D^*(2007)^0 \overline{D}^{*0} + \text{c.c.},$ | | |
| $D^*(2010)^+ D^- + \text{c.c.}$ | | |
| $D\overline{D}^*\pi + \text{c.c.}$ (excl. $D^*\overline{D}^*$) | not seen | 723 |
| $D^0 D^{*-} \pi^+ + \text{c.c.}$ (excl. | not seen | - |
| $D^*(2010)^+ D^*(2010)^-)$ | | |
| $D^0 D^* (2010)^- \pi^+ + \text{c.c.}$ | not seen | 716 |
| $D^* \overline{D}^* \pi$ | not seen | 474 |
| $D_{s}^{+}D_{s}^{-}$ | not seen | 817 |
| $D_{s}^{*+}D_{s}^{-}+c.c.$ | not seen | 615 |
| $D_{s}^{++}D_{s}^{-} + c.c.$ $D_{s}^{++}D_{s}^{+-}$ $p\overline{p}$ $K_{s}^{0}K^{\pm}\pi^{\mp}$ | not seen | 284 |
| р р - | not seen | 1914 |
| $K_S^0 K^{\pm} \pi^{\mp}$ | not seen | 2054 |
| $K^{+}K^{-}\pi^{0}$ | not seen | 2055 |
| | | |

X(4360)

$$I^{G}(J^{PC}) = ??(1 - -)$$

 $X(4360)~{
m MASS} = 4361 \pm 13~{
m MeV}$ $X(4360) \text{ WIDTH} = 74 \pm 18 \text{ MeV}$

| X(4360) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------|------------------------------|-----------|
| $\psi(2S)\pi^+\pi^-$ | seen | 567 |

ψ (4415) [pppp]

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=4421\pm4$ MeV Full width $\Gamma=\,62\,\pm\,20$ MeV $\Gamma_{ee} = 0.58 \pm 0.07 \text{ keV}$

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| ψ(4415) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|----------------------------------------------------------------|--------------------------------|------------------|---------------|
| $D\overline{D}$ | not seen | | 1187 |
| $D^0 \overline{D}{}^0$ | seen | | 1187 |
| $D^+ D^-$ | seen | | 1179 |
| $D^*\overline{D}$ + c.c. | not seen | | 1063 |
| $D^*(2007)^0 \overline{D}{}^0 + \text{ c.c.}$ | seen | | 1066 |
| $D^*(2010)^+ D^- + \text{c.c.}$ | seen | | 1059 |
| <i>D</i> * D * | not seen | | 919 |
| $D^*(2007)^0 \overline{D}^*(2007)^0 + \text{c.c.}$ | seen | | 926 |
| $D^*(2010)^+ D^*(2010)^- + \text{c.c.}$ | seen | | 919 |
| $D^0 D^- \pi^+ (\text{excl. } D^* (2007)^0 \overline{D}{}^0$ | < 2.3 % | 90% | - |
| $+c.c., D^*(2010)^+ D^- +c.c.$ | | | |
| $D \overline{D}_2^* (2460) \to D^0 D^- \pi^+ + \text{c.c.}$ | $(10 \pm 4) \%$ | | - |
| $D^0 D^{*-} \pi^+ + \text{c.c.}$ | < 11 % | 90% | 926 |
| $D_{s}^{+}D_{s}^{-}$ | not seen | | 1006 |
| $D_{s}^{*+}D_{s}^{-}+c.c.$ | seen | | _ |
| $D_{s}^{*+}D_{s}^{*-}$ | not seen | | 651 |
| e ⁺ e ⁻ | $(9.4 \pm 3.2) \times 10^{-1}$ | -6 | 2210 |

X(4660)

$$I^{G}(J^{PC}) = ??(1 - -)$$

 $X(4660)~{
m MASS} = 4664 \pm 12~{
m MeV}$ $X(4660)~{\sf WIDTH}=48\pm15~{\sf MeV}$

| X(4660) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------|------------------------------|-----------|
| $\psi(2S)\pi^+\pi^-$ | seen | 838 |

$b\overline{b}$ MESONS

Fraction (Γ_i/Γ)

Hadronic decays

 $(\ 2.60 \pm 0.10)\ \%$

 $(\ 2.38 \!\pm\! 0.11)\ \%$

 $(2.48 \pm 0.05)\%$

T(15)

 $\tau^+ \tau^ e^+ e^-$

 $\mu^+\,\mu^-$

au(1s) decay modes

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Confidence level (MeV/c)

4384

4730

4729

Mass $m = 9460.30 \pm 0.26 \text{ MeV}$ (S = 3.3) Full width $\Gamma=\,54.02\,\pm\,1.25$ keV $\Gamma_{ee}\,=\,1.340\,\pm\,0.018\;\text{keV}$

| | mauronic | uecays | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-----------------|--------------------------|-----|------|
| ggg | (| 81.7 ± 0.7 |) % | | _ |
| $\gamma g g$ | (| 2.2 ±0.6 |) % | | _ |
| $\eta'(958)$ anything | (| 2.94±0.24 |) % | | _ |
| $J/\psi(1S)$ anything | i | 6.5 ± 0.7 | $\times 10^{-4}$ | | 4223 |
| χ_{c0} anything | < | | $\times 10^{-3}$ | 90% | _ |
| χ_{c1} anything | | 2.3 ±0.7 | | | _ |
| χ_{c2} anything | | 3.4 ±1.0 | | | _ |
| $\psi(2S)$ anything | | 2.7 ±0.9 | | | _ |
| $\rho\pi$ | < | 2.7 ±0.5 | ×10 ⁻⁴ | 90% | 4697 |
| $\pi^+\pi^-$ | | 5 | ×10 ⁻⁴ | 90% | 4728 |
| K+ K- | < | | | | |
| | < | | ×10 ⁻⁴ | 90% | 4704 |
| $p\overline{p}$ | < | | ×10 ⁻⁴ | 90% | 4636 |
| $\pi^{0} \pi^{+} \pi^{-}$ | | 1.84 | $\times 10^{-5}$ | 90% | 4725 |
| $\underline{D}^*(2010)^{\pm}$ anything | , | 2.52 ± 0.20 | | | - |
| \overline{d} anything | (| 2.86 ± 0.28 | $) \times 10^{-5}$ | | - |
| | Radiative | decave | | | |
| + - | | | 5 | | |
| $\gamma \pi^+ \pi^-$ | | 6.3 ±1.8 | | | 4728 |
| $\gamma \pi^0 \pi^0$ | (| 1.7 ± 0.7 | | | 4728 |
| $\gamma \pi^0 \eta$ | < | 2.4 | $\times 10^{-6}$ | 90% | 4713 |
| $\gamma K^+ K^-$ | [qqqq] (| 1.14 ± 0.13 | | | 4704 |
| $\gamma p \overline{p}$ | [rrrr] < | | $\times 10^{-6}$ | 90% | 4636 |
| $\gamma 2h^+2h^-$ | (| 7.0 ± 1.5 | $) \times 10^{-4}$ | | 4720 |
| γ 3 h^+ 3 h^- | | 5.4 ±2.0 | | | 4703 |
| γ 4 h^{+} 4 h^{-} | (| 7.4 ± 3.5 | $\times 10^{-4}$ | | 4679 |
| $\gamma \pi^+ \pi^- K^+ K^-$ | | 2.9 ±0.9 | | | 4686 |
| $\gamma 2\pi^{+} 2\pi^{-}$ | | 2.5 ±0.9 | | | 4720 |
| $\gamma 3\pi^{+} 3\pi^{-}$ | | | ×10 ⁻⁴ | | 4703 |
| $\gamma 2\pi^{+} 2\pi^{-} K^{+} K^{-}$ | , | 2.4 ±1.2 | | | 4658 |
| $\gamma \pi^+ \pi^- p \overline{p}$ | (| | | | 4604 |
| $\gamma 2\pi + 2\pi - p\overline{p}$ | (| | $\times 10^{-5}$ | | 4563 |
| $\gamma 2K + 2K - \gamma 2K - \gamma 2K + 2K - \gamma 2K - \gamma 2K - \gamma 2K + 2K - \gamma | , | | | | 4601 |
| | (| | | | |
| $\gamma \eta'(958)$ | < | 1.9 | ×10 ⁻⁶ | 90% | 4682 |
| $\gamma \eta$ | < | | ×10 ⁻⁶ | 90% | 4714 |
| $\gamma f_0(980)$ | < | | $\times 10^{-5}$ | 90% | 4678 |
| $\gamma f_2'(1525)$ | | 3.8 ±0.9 | | | 4607 |
| $\gamma f_2(1270)$ | (| 1.01 ± 0.09 | | | 4644 |
| $\gamma \eta (1405)$ | < | 8.2 | $\times 10^{-5}$ | 90% | 4625 |
| $\gamma f_0(1500)$ | < | 1.5 | $\times 10^{-5}$ | 90% | 4610 |
| $\gamma f_0(1710)$ | < | 2.6 | $\times 10^{-4}$ | 90% | 4574 |
| $\gamma f_0(1710) \rightarrow \gamma K^+ K^-$ | < | 7 | $\times 10^{-6}$ | 90% | _ |
| $\gamma f_0(1710) \rightarrow \gamma \pi^0 \pi^0$ | < | 1.4 | $\times 10^{-6}$ | 90% | _ |
| $\gamma f_0(1710) \rightarrow \gamma \eta \eta$ | < | 1.8 | $\times 10^{-6}$ | 90% | _ |
| $\gamma f_4(2050)$ | < | 5.3 | $\times 10^{-5}$ | 90% | 4515 |
| $\gamma f_0(2200) \rightarrow \gamma K^+ K^-$ | < | 2 | $\times 10^{-4}$ | 90% | 4475 |
| $\gamma f_J(2220) \rightarrow \gamma K^+ K^-$ | < | 8 | ×10 ⁻⁷ | 90% | 4469 |
| $\gamma f_J(2220) \rightarrow \gamma \pi^+ \pi^-$ | < | 6 | ×10 ⁻⁷ | 90% | - |
| $\gamma f_J(2220) \rightarrow \gamma p \overline{p}$ | < | 1.1 | ×10 ⁻⁶ | 90% | |
| $\gamma \eta(2225) \rightarrow \gamma \phi \phi$ $\gamma \eta(2225) \rightarrow \gamma \phi \phi$ | | | ×10 ×10 ⁻³ | 90% | 4469 |
| | < | 3 | | | |
| $\gamma \eta_c(1S)$ | < | 5.7 | $\times 10^{-5}$ | 90% | 4260 |
| $\gamma \chi_{c0}$ | < | 6.5 | ×10 ⁻⁴ | 90% | 4114 |
| $\gamma \chi_{c1}$ | < | 2.3 | ×10 ⁻⁵ | 90% | 4079 |
| $\gamma \chi_{c2}$ | < | 7.6 | $\times 10^{-6}$ | 90% | 4062 |
| $\gamma X(3872) \rightarrow \pi^+ \pi^- J/\psi$ | < | 1.6 | $\times 10^{-6}$ | 90% | - |
| $\gamma X(3872) \rightarrow \pi^+ \pi^- \pi^0 J/\psi$ | < | 2.8 | $\times 10^{-6}$ | 90% | _ |
| $\gamma X(3915) \rightarrow \omega J/\psi$ | < | 3.0 | $\times 10^{-6}$ | 90% | _ |
| | | | | | |

| $\gamma X(4140) \rightarrow \phi J/\psi$ | < 2.2 | $\times 10^{-6}$ | 90% | _ | |
|------------------------------------------------------|-----------------|--------------------|-----|------|--|
| γX | [ssss] < 4.5 | $\times 10^{-6}$ | 90% | _ | |
| $\gamma X \overline{X} (m_X < 3.1 \text{ GeV})$ | [tttt] < 1 | $\times 10^{-3}$ | 90% | _ | |
| $\gamma X \overline{X} (m_X < 4.5 \text{ GeV})$ | [uuuu] < 2.4 | $\times 10^{-4}$ | 90% | _ | |
| $\gamma X \rightarrow \gamma + \geq$ 4 prongs | [vvvv] < 1.78 | $\times 10^{-4}$ | 95% | _ | |
| $\gamma a_1^0 \rightarrow \gamma \mu^+ \mu^-$ | [wwww] < 9 | $\times 10^{-6}$ | 90% | _ | |
| $\gamma a_1^{ar{0}} ightarrow \ \gamma 	au^+ 	au^-$ | [qqqq] < 5.0 | $\times 10^{-5}$ | 90% | - | |
| Lepton Family number (LF) violating modes | | | | | |
| $\mu^{\pm} \tau^{\mp}$ | <i>LF</i> < 6.0 | $\times 10^{-6}$ | 95% | 4563 | |
| Other decays | | | | | |
| invisible | < 3.0 | × 10 ⁻⁴ | 90% | - | |

 $\chi_{b0}(1P)$ [xxxx]

$$I^G(J^{PC}) = 0^+(0^{++})$$

J needs confirmation.

Mass $m = 9859.44 \pm 0.42 \pm 0.31 \; \text{MeV}$

| Fraction $(\Gamma_i$ | /Γ) Confide | nce level | <i>p</i> (MeV/ <i>c</i>) |
|----------------------|--------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------------|
| (1.76±0 | .35) % | | 391 |
| < 10.4 | % | 90% | _ |
| < 1.6 | $\times 10^{-4}$ | 90% | 4875 |
| < 5 | $\times 10^{-5}$ | 90% | 4875 |
| < 5 | $\times 10^{-4}$ | 90% | 4846 |
| < 2.1 | $\times 10^{-4}$ | 90% | 4905 |
| (1.1 ± 0) | $.6) \times 10^{-4}$ | | 4861 |
| < 2.7 | $\times 10^{-4}$ | 90% | 4846 |
| < 5 | $\times 10^{-4}$ | 90% | 4828 |
| < 1.6 | $\times 10^{-4}$ | 90% | 4827 |
| < 8 | $\times 10^{-5}$ | 90% | 4904 |
| < 6 | $\times 10^{-4}$ | 90% | 4881 |
| (2.4 ± 1) | $.2) \times 10^{-4}$ | | 4827 |
| < 1.0 | $\times 10^{-3}$ | 90% | 4808 |
| < 8 | $\times 10^{-5}$ | 90% | 4880 |
| < 2.1 | $\times 10^{-3}$ | 90% | 4850 |
| | (1.76±0. < 10.4 < 1.6 < 5 < 5 < 2.1 (1.1 ±0. < 2.7 < 5 < 1.6 < 8 < 6 (2.4 ±1. < 8 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |

 $\chi_{b1}(1P)^{[xxxx]}$

$$I^G(J^{PC}) = 0^+(1^{++})$$

J needs confirmation.

Mass $m = 9892.78 \pm 0.26 \pm 0.31 \; \text{MeV}$

| $\chi_{b1}(1P)$ DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|-------------------------------------------|-----------------------------------|------------------|---------------|
| $\gamma \Upsilon(1S)$ | (33.9 ± 2.2) % | | 423 |
| $D^0 X$ | (12.6 ± 2.2) % | | - |
| $\pi^{+} \pi^{-} K^{+} K^{-} \pi^{0}$ | $(2.0 \pm 0.6) \times 10^{-6}$ | -4 | 4892 |
| $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | $(1.3 \pm 0.5) \times 10^{-6}$ | -4 | 4892 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 6 × 10 | -4 90% | 4863 |
| $2\pi^{+} 2\pi^{-} 2\pi^{0}$ | $(8.0 \pm 2.5) \times 10^{-6}$ | -4 | 4921 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(1.5 \pm 0.5) \times 10^{\circ}$ | -4 | 4878 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | $(3.5 \pm 1.2) \times 10^{-6}$ | -4 | 4863 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | $(8.6 \pm 3.2) \times 10^{-6}$ | | 4845 |
| $3\pi^{+}2\pi^{-}K^{-}K^{0}_{S}\pi^{0}$ | $(9.3 \pm 3.3) \times 10^{-6}$ | -4 | 4844 |
| $3\pi^{+}3\pi^{-}$ | $(1.9 \pm 0.6) \times 10^{-6}$ | -4 | 4921 |
| $3\pi^{+}3\pi^{-}2\pi^{0}$ | $(1.7 \pm 0.5) \times 10^{-6}$ | -3 | 4898 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-}$ | $(2.6 \pm 0.8) \times 10^{-6}$ | -4 | 4844 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}$ | $(7.5 \pm 2.6) \times 10^{-6}$ | -4 | 4825 |
| $4\pi^{+}4\pi^{-}$ | $(2.6 \pm 0.9) \times 10^{-6}$ | -4 | 4897 |
| $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.4 \pm 0.6) \times 10$ | -3 | 4867 |

 $h_b(1P)$

$$I^{G}(J^{PC}) = ??(1 + -)$$

Mass $m=9898.6\pm1.4~\mathrm{MeV}$

| h _b (1P) DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|---------------------------------|------------------------------|------------|
| $\eta_b(1S)\gamma$ | seen | 495 |

 $\chi_{b2}(1P)^{[xxxx]}$

$$I^G(J^{PC}) = 0^+(2^{++})$$

J needs confirmation.

Mass $\mathit{m} = 9912.21 \pm 0.26 \pm 0.31 \; \mathrm{MeV}$

| χ _{b2} (1P) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (Me V/ <i>c</i>) |
|------------------------------------------|------------------------------|------------------|--------------------------------|
| $\frac{1}{\gamma r(1S)}$ | (19.1 ± 1.2) % | | 442 |
| $D^0 X$ | < 7.9 % | 90% | - |
| $\pi^{+}\pi^{-}K^{+}K^{-}\pi^{0}$ | (8 ±5)×10 | -5 | 4902 |
| $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | < 1.0 × 10 | -4 90% | 4901 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | $(5.3 \pm 2.4) \times 10$ | -4 | 4873 |
| $2\pi^{+} 2\pi^{-} 2\pi^{0}$ | $(3.5 \pm 1.4) \times 10$ | -4 | 4931 |
| $2\pi^{+} 2\pi^{-} K^{+} K^{-}$ | $(1.1 \pm 0.4) \times 10$ | -4 | 4888 |
| $2\pi^{+} 2\pi^{-} K^{+} K^{-} \pi^{0}$ | $(2.1 \pm 0.9) \times 10$ | -4 | 4872 |
| $2\pi^{+} 2\pi^{-} K^{+} K^{-} 2\pi^{0}$ | $(3.9 \pm 1.8) \times 10$ | -4 | 4855 |
| $3\pi^{+}2\pi^{-}K^{-}K^{0}_{S}\pi^{0}$ | < 5 × 10 | -4 90% | 4854 |
| $3\pi^{+} 3\pi^{-}$ | $(7.0 \pm 3.1) \times 10$ | -5 | 4931 |
| $3\pi^{+} 3\pi^{-} 2\pi^{0}$ | $(1.0 \pm 0.4) \times 10$ | -3 | 4908 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-}$ | < 8 × 10 | -5 90% | 4854 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}$ | $(3.6 \pm 1.5) \times 10$ | -4 | 4835 |
| $4\pi^{+}4\pi^{-}$ | $(8 \pm 4) \times 10$ | - 5 | 4907 |
| $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.8 \pm 0.7) \times 10$ | -3 | 4877 |

T(25)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Scale factor /

Mass $m=10.02326\pm0.00031~{\rm GeV}$ $m_{\Upsilon(35)}-m_{\Upsilon(2S)}=331.50\pm0.13~{\rm MeV}$ Full width $\Gamma=31.98\pm2.63~{\rm keV}$ $\Gamma_{ee}=0.612\pm0.011~{\rm keV}$

| r(2s) decay modes | Fraction (Γ_i/Γ) | Confidence level | |
|----------------------------|------------------------------|-------------------------|------|
| $\gamma(1S)\pi^+\pi^-$ | (17.92± 0.26) % | | 475 |
| $\Upsilon(1S) \pi^0 \pi^0$ | $(8.6 \pm 0.4)\%$ | | 480 |
| $	au^+ 	au^-$ | (2.00 ± 0.21) % | | 4686 |
| $\mu^+ \mu^-$ | (1.93± 0.17) % | S=2.2 | 5011 |
| $e^+ e^-$ | $(1.91 \pm 0.16)\%$ | | 5012 |
| $\Upsilon(1S)\pi^0$ | < 1.8 × | 10 ⁻⁴ CL=90% | 531 |
| $\Upsilon(1S)\eta$ | $(2.34 \pm 0.31) \times$ | 10-4 | 126 |
| $J/\psi(1S)$ anything | < 6 × | 10^{-3} CL=90% | 4533 |
| \overline{d} anything | (3.4 \pm 0.6) \times | 10^{-5} | _ |
| hadrons | (94 ±11) % | | _ |
| ggg | $(58.8 \pm 1.2)\%$ | | _ |
| $\gamma g g$ | (8.8 \pm 1.1) % | | _ |

| Radiative decays | | | | | |
|-------------------|-------------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------|--|--|
| (6.9 ± 0.4) |) % | | 130 | | |
| (7.15 ± 0.35) |) % | | 110 | | |
| (3.8 ± 0.4) |) % | | 162 | | |
| < 5.9 | $\times 10^{-4}$ | CL=90% | 4864 | | |
| < 5.3 | $\times 10^{-4}$ | CL=90% | 4896 | | |
| < 2.41 | $\times 10^{-4}$ | CL=90% | 4931 | | |
| < 2.7 | $\times 10^{-5}$ | CL=90% | 4568 | | |
| < 1.0 | $\times 10^{-4}$ | CL=90% | 4430 | | |
| < 3.6 | $\times 10^{-6}$ | CL=90% | 4397 | | |
| < 1.5 | $\times 10^{-5}$ | CL=90% | 4381 | | |
| < 8 | $\times 10^{-7}$ | CL=90% | _ | | |
| < 2.4 | $\times 10^{-6}$ | CL=90% | _ | | |
| < 2.8 | $\times 10^{-6}$ | CL=90% | _ | | |
| < 1.2 | $\times 10^{-6}$ | CL=90% | _ | | |
| < 1.3 | $\times 10^{-6}$ | CL=90% | _ | | |
| $(~3.9~\pm~1.5$ | $) \times 10^{-4}$ | | 612 | | |
| [yyyy] < 1.95 | $\times 10^{-4}$ | CL=95% | _ | | |
| < 8 | $\times 10^{-5}$ | CL=90% | _ | | |
| | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | |

Lepton Family number (LF) violating modes

| $e^{\pm} 	au^{\mp}$ | LF | < | 3.2 | $\times10^{-6}$ | CL=90% | 4854 |
|-----------------------|----|---|-----|------------------|--------|------|
| $\mu^{\pm}\tau^{\mp}$ | LF | < | 3.3 | $\times 10^{-6}$ | CL=90% | 4854 |

Υ(1D)

$$I^{G}(J^{PC}) = 0^{-}(2^{-})$$

Mass $m = 10163.7 \pm 1.4 \text{ MeV}$ (S = 1.7)

| au(1D) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------|------------------------------|-----------|
| $\gamma \gamma \Upsilon(1S)$ | seen | 679 |
| $\gamma \chi_{bJ}(1P)$ | seen | 300 |
| $\eta \ \Upsilon(1S)$ | not seen | 426 |
| $\pi^+\pi^-\varUpsilon(1S)$ | $(6.6\pm1.6)\times10^{-3}$ | 623 |

 $\chi_{b0}(2P)^{[xxxx]}$

 $I^G(J^{PC}) = 0^+(0^{++})$ J needs confirmation.

Mass $m = 10.2325 \pm 0.0004 \pm 0.0005 \, \text{GeV}$

| $\chi_{b0}(2P)$ DECAY MODES | Fraction (| (Γ_i/Γ) | Confidence level | (MeV/c) |
|----------------------------------------------------------------------------|------------|---------------------|------------------|----------|
| $\gamma \Upsilon(2S)$ | (4.6±2 | .1) % | | 207 |
| $\gamma \Upsilon(1S)$ | (9 ±6 | $) \times 10^{-3}$ | | 743 |
| $D^0 X$ | < 8.2 | % | 90% | _ |
| $\pi^{+} \pi^{-} K^{+} K^{-} \pi^{0}$ | < 3.4 | $\times 10^{-5}$ | 90% | 5064 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}$ | < 5 | $\times 10^{-5}$ | 90% | 5063 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}$ $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 2.2 | $\times 10^{-4}$ | 90% | 5036 |
| $2\pi^{+}2\pi^{-}2\pi^{0}$ | < 2.4 | $\times 10^{-4}$ | 90% | 5092 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | < 1.5 | $\times 10^{-4}$ | 90% | 5 0 5 0 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | < 2.2 | $\times 10^{-4}$ | 90% | 5035 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | < 1.1 | $\times 10^{-3}$ | 90% | 5019 |
| $3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0}$ | < 7 | $\times 10^{-4}$ | 90% | 5018 |
| $3\pi^{+}3\pi^{-}$ | < 7 | $\times 10^{-5}$ | 90% | 5091 |
| $3\pi^{+} 3\pi^{-} 2\pi^{0}$ | < 1.2 | $\times 10^{-3}$ | 90% | 5070 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-}$ | < 1.5 | $\times 10^{-4}$ | 90% | 5017 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}$ | < 7 | $\times 10^{-4}$ | 90% | 4999 |
| $4\pi^{+}4\pi^{-}$ | < 1.7 | $\times 10^{-4}$ | 90% | 5069 |
| $4\pi^{+}4\pi^{-}2\pi^{0}$ | < 6 | $\times 10^{-4}$ | 90% | 5039 |
| | | | | |

 $\chi_{b1}(2P)^{[xxxx]}$

$$I^G(J^{PC}) = 0^+(1^{++})$$

J needs confirmation.

Mass $m=10.25546\pm0.00022\pm0.00050$ GeV $m_{\chi_{b1}(2P)}-m_{\chi_{b0}(2P)}=23.5\pm1.0$ MeV

| $\chi_{b1}(2P)$ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor | p (MeV/c) |
|--------------------------------------------------------|----------------------------------------------|--------------|---------------|
| $\omega \Upsilon(1S)$ | (1.63 ^{+0.40} _{-0.34}) % | | 135 |
| $\gamma \Upsilon(2S)$ | (19.9 ±1.9) % | | 230 |
| $\gamma \Upsilon(1S)$ | (9.2 ± 0.8) % | 1.1 | 764 |
| $\pi\pi\chi_{b1}(1P)$ | $(9.1 \pm 1.3) \times 10^{-3}$ | | 238 |
| D^0X | $(8.8 \pm 1.7)\%$ | | _ |
| $\pi^{+}\pi^{-}K^{+}K^{-}\pi^{0}$ | $(3.1 \pm 1.0) \times 10^{-4}$ | | 5075 |
| $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | $(1.1 \pm 0.5) \times 10^{-4}$ | | 5075 |
| $2\pi^{+}\pi^{-}K^{-}K_{5}^{0}2\pi^{0}$ | $(7.7 \pm 3.2) \times 10^{-4}$ | | 5047 |
| $2\pi^{+}2\pi^{-}2\pi^{0}$ | $(5.9 \pm 2.0) \times 10^{-4}$ | | 5104 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(10 \pm 4) \times 10^{-5}$ | | 5062 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | $(5.5 \pm 1.8) \times 10^{-4}$ | | 5047 |
| $2\pi^{+}2\pi^{-}\mathit{K}^{+}\mathit{K}^{-}2\pi^{0}$ | $(10 \pm 4) \times 10^{-4}$ | | 5030 |
| $3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0}$ | $(6.7 \pm 2.6) \times 10^{-4}$ | | 5029 |
| $3\pi^{+}3\pi^{-}$ | $(1.2 \pm 0.4) \times 10^{-4}$ | | 5103 |
| $3\pi^{+}3\pi^{-}2\pi^{0}$ | $(1.2 \pm 0.4) \times 10^{-3}$ | | 5081 |
| $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | $(2.0 \pm 0.8) \times 10^{-4}$ | | 5029 |
| $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | $(6.1 \pm 2.2) \times 10^{-4}$ | | 5011 |
| $4\pi^{+}4\pi^{-}$ | $(1.7 \pm 0.6) \times 10^{-4}$ | | 5080 |
| $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.9 \pm 0.7) \times 10^{-3}$ | | 5051 |

 $\chi_{b2}(2P)^{[xxxx]}$

$$I^G(J^{PC}) = 0^+(2^{++})$$

J needs confirmation.

Mass $m=10.26865\pm0.00022\pm0.00050$ GeV $m_{\chi_{b2}(2P)}-m_{\chi_{b1}(2P)}=13.5\pm0.6$ MeV

| $\chi_{b2}(2P)$ DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|-------------------------------------------|------------------------------|-----------------------------------|------|
| $\omega \Upsilon(1S)$ | $(1.10 + 0.34 \atop -0.30)$ | % | 194 |
| $\gamma \Upsilon(2S)$ | (10.6 ± 2.6) | % S=2.0 | 242 |
| $\gamma \Upsilon(1S)$ | (7.0 ± 0.7) | % | 777 |
| $\pi\pi\chi_{b2}(1P)$ | (5.1 ± 0.9) | × 10 ⁻³ | 229 |
| $D^0 X$ | < 2.4 | % CL=90% | _ |
| $\pi^{+} \pi^{-} K^{+} K^{-} \pi^{0}$ | < 1.1 | × 10 ⁻⁴ CL=90% | 5082 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}$ | < 9 | × 10 ⁻⁵ CL=90% | 5082 |
| $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 7 | × 10 ⁻⁴ CL=90% | 5054 |
| $2\pi^{+}2\pi^{-}2\pi^{0}$ | (3.9 ±1.6): | × 10 ⁻⁴ | 5110 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | (9 ±4): | × 10 ⁻⁵ | 5068 |
| $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | (2.4 ±1.1): | × 10 ⁻⁴ | 5054 |
| $2\pi^{+} 2\pi^{-} K^{+} K^{-} 2\pi^{0}$ | (4.7 ±2.3): | × 10 ⁻⁴ | 5037 |
| $3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0}$ | < 4 | × 10 ⁻⁴ CL=90% | 5036 |
| $3\pi^{+} 3\pi^{-}$ | (9 ±4): | × 10 ⁻⁵ | 5110 |

| $3\pi^{+} 3\pi^{-} 2\pi^{0}$ | $(1.2 \pm 0.4) \times 10^{-3}$ | 5088 |
|-----------------------------------------|---------------------------------|--------|
| $3\pi^{+} 3\pi^{-} K^{+} K^{-}$ | $(1.4 \pm 0.7) \times 10^{-4}$ | 5036 |
| $3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}$ | (4.2 ±1.7) × 10 ⁻⁴ | 5017 |
| $4\pi^{+}4\pi^{-}$ | (9 ±5) × 10 ⁻⁵ | 5087 |
| $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.3 \pm 0.5) \times 10^{-3}$ | 5 05 8 |

T(3*S*)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=10.3552\pm0.0005$ GeV $m_{\Upsilon(35)}-m_{\Upsilon(2S)}=331.50\pm0.13$ MeV Full width $\Gamma=20.32\pm1.85$ keV $\Gamma_{ee}=0.443\pm0.008$ keV

| 1 ee = 0.445 ± 0.0 | oo kev | | |
|-------------------------------------------------------|----------------------------------|-----------------------------------|------|
| T(3S) DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
| $\Upsilon(2S)$ anything | (10.6 ±0.8)% | | 296 |
| $\Upsilon(2S)\pi^+\pi^-$ | (2.82±0.18) % | S=1.6 | 177 |
| $\Upsilon(2S)\pi^0\pi^0$ | (1.85±0.14) % | | 190 |
| $r_{(2S)\gamma\gamma}$ | (5.0 ±0.7)% | | 32 |
| $\Upsilon(2S)\pi^0$ | < 5.1 × 1 | 0 ⁻⁴ CL=90% | 298 |
| $\Upsilon(1S)\pi^+\pi^-$ | $(4.37 \pm 0.08)\%$ | | 813 |
| $\Upsilon(1S)\pi^0\pi^0$ | $(2.20\pm0.13)\%$ | | 816 |
| $\Upsilon(1S)\eta$ | | 0 ⁻⁴ CL=90% | 67 |
| $\Upsilon(1S)\pi^0$ | < 7 ×1 | 0 ⁻⁵ CL=90% | 84 6 |
| $h_b(1P) \pi^0$ | < 1.2 ×1 | | 42 |
| $h_b(1P)\pi^0 \rightarrow \gamma \eta_b(1S)\pi^0$ | (4.3 ± 1.4) $	imes 1$ | | - |
| $h_b(1P) \pi^+ \pi^-$ | < 1.2 × 1 | 0 ⁻⁴ CL=90% | 35 3 |
| $\tau^+\tau^-$ | $(2.29\pm0.30)\%$ | | 4863 |
| $\mu^+\mu^-$ | $(2.18\pm0.21)\%$ | S=2.1 | 517 |
| e^+e^- | seen | | 5178 |
| ggg | (35.7 ±2.6) % | 2 | - |
| $\gamma g g$ | $(9.7 \pm 1.8) \times 1$ | 0-3 | - |
| | Radiative decays | | |
| $\gamma \chi_{b2}(2P)$ | $(13.1 \pm 1.6)\%$ | S=3.4 | 86 |
| $\gamma \chi_{b1}(2P)$ | $(12.6 \pm 1.2)\%$ | S=2.4 | 99 |
| $\gamma \chi_{b0}(2P)$ | (5.9 \pm 0.6) % | S=1.4 | 122 |
| $\gamma \chi_{b2}(1P)$ | (9.9 ± 1.3) $\times 1$ | | 434 |
| $\gamma A^0 \rightarrow \gamma$ hadrons | < 8 ×1 | | - |
| $\gamma \chi_{b1}(1P)$ | $(9 \pm 5) \times 1$ | | 45 2 |
| $\gamma \chi_{b0}(1P)$ | $(2.7 \pm 0.4) \times 1$ | | 484 |
| $\gamma \eta_b(2S)$ | < 6.2 × 1 | | - |
| $\gamma \eta_b(1S)$ | (5.1 ± 0.7) $\times 1$ | | 91 |
| $\gamma X \rightarrow \gamma + \geq 4 \text{ prongs}$ | $[zzzz] < 2.2 \times 1$ | | - |
| $\gamma a_1^0 \rightarrow \gamma \tau^+ \tau^-$ | $[aaaaa] < 1.6 \times 1$ | 0 ⁻⁴ CL=90% | - |
| | y number (<i>LF</i>) violating | modes | |
| $e^{\pm} 	au^{\mp}$ | < 4.2 × 1 | 0 ⁻⁶ CL=90% | 5025 |
| $\mu^{\pm} \tau^{\mp}$ LF | < 3.1 × 1 | 0 ⁻⁶ CL=90% | 5025 |
| | | | |

Υ(4S) or Υ(10580)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

 $\begin{aligned} \text{Mass } m &= 10.5794 \pm 0.0012 \text{ GeV} \\ \text{Full width } \Gamma &= 20.5 \pm 2.5 \text{ MeV} \\ \Gamma_{ee} &= 0.272 \pm 0.029 \text{ keV} \quad \text{(S} = 1.5) \end{aligned}$

| T(45) DECAY MODES | Fraction (Γ_i | /Γ) Confid | ence level | $(\mathrm{MeV}\!/\!c)$ |
|---------------------------------------|-----------------------|-----------------------|------------|------------------------|
| $B\overline{B}$ | > 96 | % | 95% | 327 |
| $B^+ B^-$ | (51.3 ±0 | .6) % | | 332 |
| D_s^+ anything $+$ c.c. | (17.8 ± 2) | .6) % | | - |
| $B^0 \overline{B}{}^0$ | (48.7 ±0 | .6)% | | 327 |
| $J/\psi K_S^0 (J/\psi, \eta_c) K_S^0$ | < 4 | $\times 10^{-7}$ | 90% | - |
| non- $B\overline{B}$ | < 4 | % | 95% | - |
| $e^+ e^-$ | (1.57±0 | $.08) \times 10^{-5}$ | | 5290 |
| $ ho^+ ho^-$ | < 5.7 | $\times 10^{-6}$ | 90% | 5233 |
| $J/\psi(1S)$ anything | < 1.9 | $\times 10^{-4}$ | 95% | _ |
| D^{*+} anything $+$ c.c. | < 7.4 | % | 90% | 5099 |
| ϕ anything | (7.1 ± 0) | .6)% | | 5240 |
| $\phi\eta$ | < 1.8 | $\times 10^{-6}$ | 90% | 5226 |
| $\phi\eta'$ | < 4.3 | $\times 10^{-6}$ | 90% | 5196 |
| $ ho\eta$ | < 1.3 | $\times 10^{-6}$ | 90% | 5247 |
| $ ho\eta'$ | < 2.5 | $\times 10^{-6}$ | 90% | 5217 |
| $\mathcal{T}(1S)$ anything | < 4 | $\times 10^{-3}$ | 90% | 1053 |
| $\Upsilon(1S) \pi^+ \pi^-$ | (8.1 ±0 | .6) $\times 10^{-5}$ | | 1026 |

| $\Upsilon(1S)\eta$ | $(1.96\pm0.11)\times10^{-4}$ | | 924 |
|---------------------------|--------------------------------|-----|-----|
| $\Upsilon(2S)\pi^+\pi^-$ | $(8.6 \pm 1.3) \times 10^{-5}$ | | 468 |
| $h_{b}(1P)\pi^{+}\pi^{-}$ | not seen | | 601 |
| ₫ anything | $< 1.3 \times 10^{-5}$ | 90% | _ |

T(10860)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=10876\pm11$ MeV Full width $\Gamma=55\pm28$ MeV $\Gamma_{ee}=0.31\pm0.07$ keV (S=1.3)

| 7(10860) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | $(MeV / \! c)$ |
|-----------------------------------------------------------|-------------------------------------------------------|-----------------------|-----------------|
| $B\overline{B}X$ | (75.9 +2.7) % | % | |
| В <u>Т</u> | (5.5 ±1.0) % | 6 | 1303 |
| <i>B</i> B * + c.c. | (13.7 ±1.6) % | 6 | - |
| <i>B</i> * <u>₿</u> * | (38.1 ±3.4) % | 6 | 1102 |
| $B\overline{B}^{(*)}\pi$ | < 19.7 | 6 90% | 990 |
| B <u>B</u> π | (0.0 ± 1.2) % | 6 | 990 |
| $B^* \overline{\underline{B}} \pi + B \overline{B}^* \pi$ | (7.3 ± 2.3) % | 6 | _ |
| $B^* \overline{B}^* \pi$ | (1.0 ± 1.4) % | | 701 |
| $B\overline{B}\pi\pi$ | < 8.9 % | 6 90% | 504 |
| $B_s^{(*)} \overline{B}_s^{(*)}$ | (19.9 ± 3.0) % | 6 | 877 |
| $B_s \overline{B}_s$ | (5 ±5)× | 10-3 | 877 |
| $B_s \overline{B}_s^* + \text{c.c.}$ | (1.5 ± 0.7) % | 6 | - |
| $B_s^* \overline{B}_s^*$ | (17.9 ±2.8) % | 6 | 495 |
| no open-bottom | $(4.2 \begin{array}{c} +5.0 \\ -0.6 \end{array})$ % | 6 | - |
| $e^+ e^-$ | $(5.6 \pm 3.1) \times$ | < 10−6 | 5438 |
| $\Upsilon(1S)\pi^+\pi^-$ | $(5.3 \pm 0.6) \times$ | _{< 10} -3 | 1297 |
| Υ (2S) π^+ π^- | (7.8 ± 1.3) \times | $< 10^{-3}$ | 774 |
| Υ (3 S) $\pi^+\pi^-$ | (4.8 +1.9) > | < 10-3 | 429 |
| Υ (1S) K $^+$ K $^-$ | (6.1 ± 1.8) \times | < 10-4 | 947 |
| $h_b(1P)\pi^+\pi^-$ | (3.5 +1.0) > | < 10-3 | 895 |
| $h_b(2P)\pi^+\pi^-$ | $(6.0 \begin{array}{c} +2.1 \\ -1.8 \end{array}) >$ | < 10-3 | 534 |

Inclusive Decays.

These decay modes are submodes of one or more of the decay modes above.

| ϕ anything | $(13.8 \begin{array}{c} +2.4 \\ -1.7 \end{array}) \%$ | - |
|-------------------------|-------------------------------------------------------|---|
| D^0 anything + c.c. | (108 ±8)% | _ |
| D_s anything $+$ c.c. | (46 ±6) % | _ |
| J/ψ anything | (2.06±0.21) % | _ |
| B^0 anything $+$ c.c. | (77 ±8)% | - |
| B^+ anything $+$ c.c. | (72 ±6) % | - |

γ(11020)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

Mass $m=11.019\pm0.008$ GeV Full width $\Gamma=79\pm16$ MeV $\Gamma_{ee}=0.130\pm0.030$ keV

| au(11020) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------|--------------------------------|-----------|
| e^+e^- | $(1.6 \pm 0.5) \times 10^{-6}$ | 5510 |

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity. We do this when S > 1, which often indicates that the measurements are inconsistent. When S > 1.25, we also show in the Particle Listings an ideogram of the measurements. For more about S, see the Introduction.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame.

- [a] See the "Note on $\pi^\pm\to\ell^\pm\nu\gamma$ and $K^\pm\to\ell^\pm\nu\gamma$ Form Factors" in the π^\pm Particle Listings for definitions and details.
- [b] Measurements of $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ always include decays with γ 's, and measurements of $\Gamma(e^+\nu_e\gamma)$ and $\Gamma(\mu^+\nu_\mu\gamma)$ never include low-energy γ 's. Therefore, since no clean separation is possible, we consider the modes with γ 's to be subreactions of the modes without them, and let $[\Gamma(e^+\nu_e) + \Gamma(\mu^+\nu_\mu)]/\Gamma_{\rm total} = 100\%$.
- [c] See the π^\pm Particle Listings for the energy limits used in this measurement; low-energy γ 's are not included.
- [d] Derived from an analysis of neutrino-oscillation experiments.
- [e] Astrophysical and cosmological arguments give limits of order 10 $^{-13}$; see the π^0 Particle Listings.
- [f] C parity forbids this to occur as a single-photon process.
- [g] See the "Note on scalar mesons" in the $f_0(500)$ Particle Listings . The interpretation of this entry as a particle is controversial.
- [h] See the "Note on ho(770)" in the ho(770) Particle Listings .
- [i] The $\omega \rho$ interference is then due to $\omega \rho$ mixing only, and is expected to be small. If $e \mu$ universality holds, $\Gamma(\rho^0 \to \mu^+ \mu^-) = \Gamma(\rho^0 \to e^+ e^-) \times 0.99785$.
- [j] See the "Note on scalar mesons" in the $f_0(500)$ Particle Listings .
- [k] See the "Note on $a_1(1260)$ " in the $a_1(1260)$ Particle Listings in PDG 06, Journal of Physics, G **33** 1 (2006).
- [/] This is only an educated guess; the error given is larger than the error on the average of the published values. See the Particle Listings for details.
- [m] See the "Note on non- $q\overline{q}$ mesons" in the Particle Listings in PDG 06, Journal of Physics, G **33** 1 (2006).
- [n] See the "Note on the $\eta(1405)$ " in the $\eta(1405)$ Particle Listings.
- [o] See the "Note on the f_1 (1420)" in the $\eta(1405)$ Particle Listings.
- [p] See also the $\omega(1650)$ Particle Listings.
- [q] See the "Note on the $\rho(1450)$ and the $\rho(1700)$ " in the $\rho(1700)$ Particle Listings.
- [r] See also the $\omega(1420)$ Particle Listings.
- [s] See the "Note on $f_0(1710)$ " in the $f_0(1710)$ Particle Listings in 2004 edition of *Review of Particle Physics*.
- [t] See the note in the K^{\pm} Particle Listings.
- [u] The definition of the slope parameter g of the $K \to 3\pi$ Dalitz plot is as follows (see also "Note on Dalitz Plot Parameters for $K \to 3\pi$ Decays" in the K^{\pm} Particle Listings):

$$|M|^2 = 1 + g(s_3 - s_0)/m_{\pi^+}^2 + \cdots$$

- [v] For more details and definitions of parameters see the Particle Listings.
- [w] See the K[±] Particle Listings for the energy limits used in this measurement.
- [x] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.
- [y] Structure-dependent part.
- [z] Direct-emission branching fraction.
- [aa] Violates angular-momentum conservation.
- [bb] Derived from measured values of ϕ_{+-} , ϕ_{00} , $|\eta|$, $|m_{K^0_L} m_{K^0_S}|$, and $\tau_{K^0_S}$, as described in the introduction to "Tests of Conservation Laws."
- [cc] The CP-violation parameters are defined as follows (see also "Note on CP Violation in $K_5 \to 3\pi$ " and "Note on CP Violation in K_L^0 Decay" in the Particle Listings):

$$\eta_{+-} = |\eta_{+-}| e^{i\phi_{+-}} = \frac{A(K_L^0 \to \pi^+ \pi^-)}{A(K_S^0 \to \pi^+ \pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}| e^{i\phi_{00}} = \frac{A(K_L^0 \to \pi^0 \pi^0)}{A(K_S^0 \to \pi^0 \pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K_L^0 \to \ \pi^-\ell^+\nu) - \Gamma(K_L^0 \to \ \pi^+\ell^-\nu)}{\Gamma(K_L^0 \to \ \pi^-\ell^+\nu) + \Gamma(K_L^0 \to \ \pi^+\ell^-\nu)} \ ,$$

$$\label{eq:mass_energy} {\rm Im}(\eta_{+-0})^2 = \frac{\Gamma(K_S^0 \to \ \pi^+ \, \pi^- \pi^0)^{CP \ viol.}}{\Gamma(K_L^0 \to \ \pi^+ \pi^- \pi^0)} \; .$$

$${\rm Im}(\eta_{000})^2 = rac{\Gamma(K_S^0 o \pi^0 \pi^0 \pi^0)}{\Gamma(K_I^0 o \pi^0 \pi^0 \pi^0)} \, .$$

where for the last two relations *CPT* is assumed valid, *i.e.*, ${\rm Re}(\eta_{+-0})\simeq$ 0 and ${\rm Re}(\eta_{000})\simeq~$ 0.

- [dd] See the K^0_S Particle Listings for the energy limits used in this measurement.
- [ee] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [ff] $\text{Re}(\epsilon'/\epsilon) = \epsilon'/\epsilon$ to a very good approximation provided the phases satisfy *CPT* invariance.
- [gg] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K_1^0 \to \pi^+\pi^-\gamma({\sf DE})$.
- [hh] See the K_L^0 Particle Listings for the energy limits used in this measurement.
- [ii] Allowed by higher-order electroweak interactions.
- [jj] Violates CP in leading order. Test of direct CP violation since the indirect CP-violating and CP-conserving contributions are expected to be suppressed.
- [kk] See the "Note on $f_0(1370)$ " in the $f_0(1370)$ Particle Listings and in the 1994 edition.
- [II] See the note in the L(1770) Particle Listings in Reviews of Modern Physics **56** S1 (1984), p. S200. See also the "Note on $K_2(1770)$ and the $K_2(1820)$ " in the $K_2(1770)$ Particle Listings .
- [mm] See the "Note on $K_2(1770)$ and the $K_2(1820)$ " in the $K_2(1770)$ Particle Listings .
- [nn] This result applies to $Z^0 \to c\,\overline{c}$ decays only. Here ℓ^+ is an average (not a sum) of e^+ and μ^+ decays.
- [00] See the Particle Listings for the (complicated) definition of this quantity.
- [pp] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the relevant papers in the Particle Listings.
- [qq] These subfractions of the $K^-2\pi^+$ mode are uncertain: see the Particle Listings.
- [rr] Submodes of the $D^+ \to K^- 2\pi^+ \pi^0$ and $K_S^0 2\pi^+ \pi^-$ modes were studied by ANJOS 92C and COFFMAN 92B, but with at most 142 events for the first mode and 229 for the second not enough for precise results. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.
- [ss] The unseen decay modes of the resonances are included.
- [tt] This is not a test for the Δ C=1 weak neutral current, but leads to the $\pi^+\ell^+\ell^-$ final state.
- [uu] This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks must change flavor in this decay.
- $[\nu\nu]$ In the 2010 Review, the values for these quantities were given using a measure of the asymmetry that was inconsistent with the usual definition.
- $[\mathit{ww}]$ This value is obtained by subtracting the branching fractions for 2-, 4- and 6-prongs from unity.
- [xx] This is the sum of our $K^-2\pi^+\pi^-$, $K^-2\pi^+\pi^-\pi^0$, $K^-2\pi^+\pi^-\pi^0$, $K^+2\pi^+\pi^-\pi^0$, $K^+2\pi^+\pi^-\pi^0$, branching fractions.
- [yy] This is the sum of our $K^-3\pi^+2\pi^-$ and $3\pi^+3\pi^-$ branching fractions.
- [zz] The branching fractions for the $K^-e^+\nu_e$, $K^*(892)^-e^+\nu_e$, $\pi^-e^+\nu_e$, and $\rho^-e^+\nu_e$ modes add up to 6.19 \pm 0.17 %.
- [aaa] This is a doubly Cabibbo-suppressed mode.
- [bbb] The two experiments measuring this fraction are in serious disagreement. See the Particle Listings.
- [ccc] Submodes of the $D^0 \to K_S^0 \pi^+ \pi^- \pi^0$ mode with a K^* and/or ρ were studied by COFFMAN 92B, but with only 140 events. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.

- [ddd] This branching fraction includes all the decay modes of the resonance in the final state.
- [eee] The experiments on the division of this charge mode amongst its submodes disagree, and the submode branching fractions here add up to considerably more than the charged-mode fraction.
- [fff] However, these upper limits are in serious disagreement with values obtained in another experiment.
- [ggg] This limit is for either D^0 or $\overline{D}{}^0$ to pe^- .
- [hhh] This limit is for either D^0 or $\overline{D}{}^0$ to $\overline{p}e^+$.
- [iii] This is the purely e^+ semileptonic branching fraction: the e^+ fraction from τ^+ decays has been subtracted off. The sum of our (non- τ) e^+ exclusive fractions an $e^+\nu_e$ with an $\eta,\,\eta',\,\phi,\,K^0,\,K^{*0}$, or $f_0(980)$ is $7.0\pm0.4~\%$
- [jjj] This fraction includes η from η' decays.
- [kkk] Two times (to include μ decays) the $\eta'\,e^+\,\nu_e$ branching fraction, plus the $\eta'\,\pi^+$, $\eta'\,\rho^+$, and $\eta'\,K^+$ fractions, is $(18.6\pm2.3)\%$, which considerably exceeds the inclusive η' fraction of $(11.7\pm1.8)\%$. Our best guess is that the $\eta'\,\rho^+$ fraction, $(12.5\pm2.2)\%$, is too large.
- [///] This branching fraction includes all the decay modes of the final-state resonance.
- [mmm] A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+ . Neither Cabibbo-favored nor Cabibbo-suppressed decays can contribute, and $\omega-\phi$ mixing is an unlikely explanation for any fraction above about 2×10^{-4} .
- [nnn] We decouple the $D_s^+ \to \phi \pi^+$ branching fraction obtained from mass projections (and used to get some of the other branching fractions) from the $D_s^+ \to \phi \pi^+$, $\phi \to K^+ K^-$ branching fraction obtained from the Dalitz-plot analysis of $D_s^+ \to K^+ K^- \pi^+$. That is, the ratio of these two branching fractions is not exactly the $\phi \to K^+ K^-$ branching fraction 0.491.
- [ooo] This is the average of a model-independent and a K-matrix parametrization of the $\pi^+\pi^-$ S-wave and is a sum over several f_0 mesons.
- [ppp] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [qqq] An $\mathit{CP}(\pm 1)$ indicates the $\mathit{CP}{=}+1$ and $\mathit{CP}{=}-1$ eigenstates of the $\mathit{D^0}\text{-}\overline{\mathit{D}^0}$ system.
- [rrr] D denotes D^0 or \overline{D}^0 .
- [sss] D^{*0}_{CP+} decays into $D^0\pi^0$ with the D^0 reconstructed in CP-even eigenstates K^+K^- and $\pi^+\pi^-$.
- [ttt] \overline{D}^{**} represents an excited state with mass 2.2 < M < 2.8 GeV/c².
- $[uuu] X (3872)^+$ is a hypothetical charged partner of the X(3872).
- $[vvv]\,\Theta(1710)^{++}$ is a possible narrow pentaquark state and G(2220) is a possible glueball resonance.
- [www] $(\overline{\Lambda}_c^- p)_s$ denotes a low-mass enhancement near 3.35 GeV/c².
- [xxx] Stands for the possible candidates of $K^*(1410),\ K_0^*(1430)$ and $K_2^*(1430).$
- [yyy] B^0 and B^0_s contributions not separated. Limit is on weighted average of the two decay rates.
- [zzz] This decay refers to the coherent sum of resonant and nonresonant J^P = 0^+ $K\pi$ components with 1.60 < $m_{K\pi}$ < 2.15 GeV/ c^2 .
- [aaaa] X(214) is a hypothetical particle of mass 214 MeV/c² reported by the HyperCP experiment, Physical Review Letters **94** 021801 (2005)
- [bbbb] $\Theta(1540)^+$ denotes a possible narrow pentaquark state.
- [cccc] These values are model dependent.
- [dddd] Here "anything" means at least one particle observed.
- [eeee] D^{**} stands for the sum of the $D(1\,^1\!P_1)$, $D(1\,^3\!P_0)$, $D(1\,^3\!P_1)$, $D(1\,^3\!P_2)$, $D(2\,^1\!S_0)$, and $D(2\,^1\!S_1)$ resonances.
- [ffff] $D^{(*)}\overline{D}^{(*)}$ stands for the sum of $D^*\overline{D}^*$, $D^*\overline{D}$, $D\overline{D}^*$, and $D\overline{D}$.
- [gggg] X(3915) denotes a near-threshold enhancement in the $\omega J/\psi$ mass spectrum.
- [hhhh] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.
- [iiii] D_j represents an unresolved mixture of pseudoscalar and tensor D^{**} (P-wave) states.
- [jjjj] Not a pure measurement. See note at head of B_s^0 Decay Modes.
- [kkkk] For $E_{\gamma} > 100$ MeV.
- [///] Includes $p \overline{p} \pi^+ \pi^- \gamma$ and excludes $p \overline{p} \eta$, $p \overline{p} \omega$, $p \overline{p} \eta'$.
- [mmmm] For a narrow state A with mass less than 960 MeV.
- [nnnn] For a narrow resonance in the range 2.2 < M(X) < 2.8 GeV.

[pppp] J^{PC} known by production in e^+e^- via single photon annihilation. I^G is not known; interpretation of this state as a single resonance is unclear because of the expectation of substantial threshold effects in this energy region.

[qqqq] $2m_{ au} < M(au^+ au^-) < 7500$ MeV [rrrr] $2 < m_{K^+ K^-} < 3$ GeV [ssss] X = scalar with <math>m < 8.0 GeV

[tttt] $X \overline{X} = \text{vectors with } m < 3.1 \text{ GeV}$

[uuuu] X and $\overline{X}={\sf zero}\,{\sf spin}\,\,{\sf with}\,\,m<$ 4.5 GeV

[vvvv] 1.5 GeV $< m_X <$ 5.0 GeV

 $[wwww]\,201 < {
m M}(\mu^+\mu^-) < 3565 \;{
m MeV}$

 $[{\ensuremath{\mathsf{xxxx}}}] Spectroscopic labeling for these states is theoretical, pending experimental information.$

[yyyy] 1.5 GeV $< m_X <$ 5.0 GeV

[zzzz] 1.5 GeV $< m_X <$ 5.0 GeV

[aaaaa] For $m_{\tau^+\tau^-}$ in the ranges 4.03–9.52 and 9.61–10.10 GeV.

See also the table of suggested $q\overline{q}$ quark-model assignments in the Quark Model section.

• Indicates particles that appear in the preceding Meson Summary Table. We do not regard the other entries as being established.

| LIGHT UNFLAVORED | | | STRANGE | | CHARMED, STRANGE | | CC (CC (PC) | | |
|--------------------------------------------|--------------------------------|-------------------------------------------|------------------------------------|-----------------------------------------|------------------------------|-------------------------------------------------|----------------------|-----------------------------------------------------|-----------------------------------|
| | $(S = C = G \cap PC)$ | = <i>B</i> = 0) ■ | iG (iPC) | $(S = \pm 1, C = B = 0)$ | | $(C = S = \pm 1)$ | | | $I^G(J^{PC})$ |
| | $I^{G}(J^{PC})$ | | $I^G(J^{PC})$ | | $I(J^P)$ | | $I(J^P)$ | • $\eta_c(1S)$ | 0+(0-+) |
| • π [±] | 1-(0-) | • $\pi_2(1670)$ | 1-(2-+) | • K [±] | 1/2(0-) | • D [±] _s | 0(0-) | J/ψ(1S) | 0-(1) |
| • π ⁰ | 1-(0-+) | • $\phi(1680)$ | 0-(1) | • K ⁰ | 1/2(0-) | • <i>D</i> ^{*±} _s | 0(??) | • $\chi_{c0}(1P)$ | $0^+(0^{++})$ |
| • η | 0+(0-+) | • $\rho_3(1690)$ | 1+(3) | • K _S ⁰ | 1/2(0-) | • $D_{s0}^*(2317)^{\pm}$ | 0(0+) | • $\chi_{c1}(1P)$ | $0^{+}(1^{+})$ |
| • $f_0(500)$ | $0^+(0^{++})$ | • ρ(1700) | 1+(1) | • K _L ⁰ | 1/2(0-) | • $D_{s1}(2460)^{\pm}$ | 0(1+) | $\bullet h_c(1P)$ | ??(1+-) |
| • ρ(770) | 1+(1) | $a_2(1700)$ | $1^{-(2++)}$ | $K_0^*(800)$ | $1/2(0^+)$ | • $D_{s1}(2536)^{\pm}$ | $0(1^{+})$ | • $\chi_{c2}(1P)$ | $0^{+}(2^{+})$ |
| • ω(782) | $0^{-}(1^{-})$ | • $f_0(1710)$ | 0+(0++) | • K*(892) | 1/2(1-) | • $D_{s2}(2573)$ | 0(??) | $\bullet \eta_c(2S)$ | $0^+(0^-+)$ |
| • η'(958) | 0+(0-+) | $\eta(1760)$ | 0+(0-+) | • $K_1(1270)$ | $1/2(1^+)$ | $D_{s1}^*(2700)^{\pm}$ | $0(1^{-})$ | • $\psi(2S)$ | 0-(1) |
| • $f_0(980)$ | $0^+(0^{++})$ $1^-(0^{++})$ | • $\pi(1800)$ | $1^{-}(0^{-}+)$ $0^{+}(2^{+}+)$ | • $K_1(1400)$ | $1/2(1^+)$ | $D_{sJ}^*(2860)^{\pm}$ | 0(??) | • $\psi(3770)$ | $0^{-}(1^{-})$ $0^{?}(?^{?+})$ |
| • $a_0(980)$ | $0^{-}(1^{-})$ | $f_2(1810)$ | 3!(3-+) | • K*(1410) | $1/2(1^{-})$ | $D_{sJ}(3040)^{\pm}$ | 0(??) | X(3872)X(3915) | 0+(??+) |
| $\bullet \phi(1020)$ $\bullet h_1(1170)$ | $0^{-}(1+-)$ | X(1835) | 0-(3) | • $K_0^*(1430)$ | $1/2(0^+)$ | ВОТТО | M | • $\chi_{c2}(2P)$ | $0^{+}(2^{+})$ |
| $\bullet h_1(1170)$ $\bullet b_1(1235)$ | 1+(1+-) | • $\phi_3(1850)$ $\eta_2(1870)$ | $0^{+}(3^{-})$ | • $K_2^*(1430)$ | 1/2(2+) | (B = ± | | X(3940) | (5,5) |
| $\bullet b_1(1233)$ $\bullet a_1(1260)$ | 1 - (1 + +) | • $\pi_2(1870)$ | $1^{-}(2^{-+})$ | K(1460) | 1/2(0-) | • B [±] | 1/2(0-) | • ψ(4040) | 0-(1) |
| • $f_2(1270)$ | $0^{+}(2^{+}+)$ | $\rho(1900)$ | $1^{+}(1^{-})$ | $K_2(1580)$ | $1/2(2^{-})$ | • B ⁰ | 1/2(0) | $X(4050)^{\pm}$ | ?(??) |
| • $f_1(1285)$ | $0^{+}(1^{+}+)$ | $f_2(1910)$ | 0+(2++) | K(1630) | 1/2(??) | • B±/B ⁰ ADM | | X(4140) | 0+(??+) |
| • $\eta(1295)$ | 0+(0-+) | • $f_2(1950)$ | $0^{+}(2^{+}+)$ | $K_1(1650)$ | $1/2(1^+)$ | • $B^{\pm}/B^{0}/B_{s}^{0}/B_{s}^{0}/B_{s}^{0}$ | | • ψ(4160) | $0^{-}(1^{-})$ |
| • $\pi(1300)$ | $1^{-(0-+)}$ | $\rho_3(1990)$ | 1+(3) | • K*(1680) | $1/2(1^{-})$ | ADMIXTURE | = | X(4160) | ??(???) |
| • $a_2(1320)$ | $1^{-(2++)}$ | • $f_2(2010)$ | $0^{+}(2^{+}+)$ | • $K_2(1770)$ • $K_3^*(1780)$ | $1/2(2^{-})$ | V_{cb} and V_{ub} | | $X(4250)^{\pm}$ | ?(?'?) |
| • $f_0(1370)$ | 0+(0++) | $f_0(2020)$ | 0+(0++) | • $K_3(1780)$ • $K_2(1820)$ | $1/2(3^{-})$ $1/2(2^{-})$ | trix Elements • B* | 1/2(1-) | • X(4260) | ? (1) |
| $h_1(1380)$ | ?-(1+-) | • $a_4(2040)$ | 1-(4++) | $K_2(1820)$ $K(1830)$ | 1/2(2) $1/2(0^{-})$ | $B_{I}^{*}(5732)$ | ?(??) | X(4350) | 0+(??+) |
| • $\pi_1(1400)$ | $1^{-(1-+)}$ | • $f_4(2050)$ | 0+(4++) | $K_0^*(1950)$ | $1/2(0^+)$ | • $B_1(5721)^0$ | 1/2(1 ⁺) | X(4360) | ??(1) |
| η(1405) | $0^+(0^-+)$ | $\pi_2(2100)$ | $1^{-}(2^{-+})$ | $K_0^*(1980)$ | $1/2(0^{+})$ | • $B_2^*(5747)^0$ | $1/2(1)$ $1/2(2^+)$ | ψ(4415) | 0-(1) |
| • $f_1(1420)$ | $0^+(1^{++})$ | $f_0(2100)$ | 0+(0++) | • $K_4^*(2045)$ | $1/2(2^{+})$ $1/2(4^{+})$ | _ | | $X(4430)^{\pm}$ | ?(??) |
| ω(1420) | 0-(1) | $f_2(2150)$ | $0^+(2^{++})$ | $K_4(2043)$ $K_2(2250)$ | 1/2(2-) | BOTTOM, S | | X(4660) | ??(1) |
| $f_2(1430)$ | $0^+(2^{++})$ | ho(2150) | $1^+(1^{-})$ | $K_2(2230)$ $K_3(2320)$ | $1/2(2^+)$ $1/2(3^+)$ | $(B=\pm 1, S)$ | | b | <u></u> |
| • $a_0(1450)$ | 1-(0++) | φ(2170) | 0-(1) | $K_5^*(2380)$ | $1/2(5^{-})$ | • B _s ⁰ | 0(0-) | | |
| • ρ(1450) | 1+(1) | $f_0(2200)$ | 0+(0++) | $K_4(2500)$ | 1/2(4-) | • B _s * | $0(1^{-})$ | $\eta_b(1S)$ | 0+(0-+) |
| • η(1475) | 0+(0-+) | f _J (2220) | 0+(2++ | K(3100) | ??(???) | • $B_{s1}(5830)^0$ | 0(1+) | $\bullet \ \Upsilon(1S)$ | $0^{-}(1^{-})$ $0^{+}(0^{+}+)$ |
| • $f_0(1500)$ | 0+(0++) | (2225) | or 4 + +) | | . , | $\bullet B_{s2}^* (5840)^0$ | $0(2^{+})$ | • $\chi_{b0}(1P)$ | $0^{+}(0^{+})$ |
| $f_1(1510)$ | $0^+(1^{++})$ | $\eta(2225)$ | 0+(0-+) | CHARM | | $B_{sJ}^{*}(5850)$ | ?(? [?]) | $\bullet \chi_{b1}(1P) \\ \bullet h_b(1P)$ | ??(1+-) |
| • $f_2'(1525)$ | $0^{+}(2^{+}+)$ | $\rho_3(2250)$ | $1^{+}(3^{-})$ $0^{+}(2^{+})$ | (C = ± | | воттом, Сн | HARMED | $\bullet \chi_{b2}(1P)$ | $0^{+}(2^{+})$ |
| $f_2(1565) \\ \rho(1570)$ | $0^+(2^{++})$ $1^+(1^{-})$ | • $f_2(2300)$ $f_4(2300)$ | $0^{+}(2^{+})$ | • D [±] | 1/2(0-) | (B = C = | | $\bullet \ \Upsilon(2S)$ | $0^{-}(1^{-})$ |
| $h_1(1570)$ | 0-(1+-) | $f_0(2330)$ | $0^{+}(0^{+}+)$ | • D*(0007)0 | 1/2(0-) | • B _c [±] | 0(0-) | • Υ(1D) | $0^{-(2^{-})}$ |
| $\bullet \pi_1(1599)$ | 1-(1-+) | • $f_2(2340)$ | $0^+(2^+)$ | • $D^*(2007)^0$ | $1/2(1^{-})$ | c | 3(3) | • $\chi_{b0}(2P)$ | 0+(0++) |
| $a_1(1640)$ | 1-(1++) | $\rho_5(2350)$ | $1^{+}(5^{-})$ | • $D^*(2010)^{\pm}$ | $1/2(1^{-})$ | | | $\bullet \chi_{b1}(2P)$ | 0+(1++) |
| $f_2(1640)$ | $0^{+}(2^{+}+)$ | $a_6(2450)$ | $1^{-(6++)}$ | $ D_0^*(2400)^0 \ D_0^*(2400)^\pm $ | $1/2(0^+)$ | | | $h_b(2P)$ | ??(1+-) |
| • $\eta_2(1645)$ | $0^{+}(2^{-}+)$ | $f_6(2510)$ | 0+(6++) | | $1/2(0^+)$ | | | • $\chi_{b2}(2P)$ | $0^{+}(2^{+}+)$ |
| • $\omega(1650)$ | $0^{-}(1^{-})$ | . , | | $\bullet D_1(2420)^0 \ D_1(2420)^{\pm}$ | $\frac{1/2(1^+)}{1/2(?^?)}$ | | | • ↑ (3S) | 0-(1) |
| • $\omega_3(1670)$ | 0-(3) | | LIGHT | $D_1(2420)^{-1}$ $D_1(2430)^{0}$ | 1/2(1+) $1/2(1+)$ | | | $\chi_b(3P)$ | 3;(3;+) |
| | , , | Further St | ates | $\bullet D_2^*(2460)^0$ | 1/2(1+) $1/2(2+)$ | | | Υ(4S) | 0-(1) |
| | | | | • $D_2^*(2460)^{\pm}$ | $1/2(2^+)$ | | | $X(10610)^{\pm}$ | |
| | | | | $D_2(2500)^0$ | 1/2(0-) | | | $X(10650)^{\pm}$ | , , |
| | | | | D(2600) | 1/2(?) | | | • \(\gamma(10860) \) | , , |
| | | | | $D^*(2640)^{\pm}$ | 1/2(??) | | | • \(\gamma(11020) \) | 0-(1) |
| | | | | D(2750) | $1/2(?^{?})$ | | | | |
| L | | | | ` / | , , , | | | l . | |

This short table gives the name, the quantum numbers (where known), and the status of baryons in the Review. Only the baryons with 3- or 4-star status are included in the Baryon Summary Table. Due to insufficient data or uncertain interpretation, the other entries in the table are not established baryons. The names with masses are of baryons that decay strongly. The spin-parity J^P (when known) is given with each particle. For the strongly decaying particles, the J^P values are considered to be part of the names.

| | | - | | | | ı | | | ı | | | | | |
|---------|------------------|------|-----------------|--------------------------------|------|-----------------|------------------|------|--------------------|----------------------|------|----------------------------------|-------------------------------|------|
| p | $1/2^{+}$ | **** | Δ (1232) | $3/2^{+}$ | **** | Σ^+ | $1/2^{+}$ | *** | Ξ0 | $1/2^{+}$ | **** | Λ_c^+ | $1/2^{+}$ | **** |
| n | | **** | $\Delta(1600)$ | 3/2+ | *** | Σ^0 | 1/2+ | *** | Ξ- | 1/2+ | **** | $\Lambda_c^{c}(2595)^{+}$ | 1/2- | *** |
| N(1440) | 1/2+ | **** | $\Delta(1620)$ | 1/2- | **** | Σ^- | $1/2^{+}$ | *** | $\Xi(1530)$ | 3/2 ⁺ | **** | $\Lambda_c(2625)^+$ | 3/2- | *** |
| N(1520) | 3/2- | **** | $\Delta(1700)$ | 3/2- | **** | $\Sigma(1385)$ | $3/2^{+}$ | *** | $\Xi(1620)$ | , | * | $\Lambda_c(2765)^+$ | -/ - | * |
| N(1535) | , | **** | $\Delta(1750)$ | 1/2+ | * | $\Sigma(1480)$ | , | * | <i>Ξ</i> (1690) | | *** | $\Lambda_c(2880)^+$ | 5/2 ⁺ | *** |
| N(1650) | 1/2- | **** | $\Delta(1900)$ | 1/2- | ** | $\Sigma(1560)$ | | ** | $\Xi(1820)$ | 3/2- | *** | $\Lambda_c(2940)^+$ | -/ - | *** |
| N(1675) | 5/2 [—] | **** | $\Delta(1905)$ | 5/2 ⁺ | **** | $\Sigma(1580)$ | $3/2^{-}$ | * | <i>Ξ</i> (1950) | , | *** | $\Sigma_c(2455)$ | $1/2^{+}$ | *** |
| N(1680) | 5/2 ⁺ | | $\Delta(1910)$ | 1/2+ | **** | $\Sigma(1620)$ | 1/2- | ** | $\Xi(2030)$ | $\geq \frac{5}{2}$? | *** | $\Sigma_c(2520)$ | 3/2 ⁺ | *** |
| N(1685) | , | * | $\Delta(1920)$ | $3/2^{+}$ | *** | $\Sigma(1660)$ | $1/2^{+}$ | *** | $\Xi(2120)$ | – 2 | * | $\Sigma_c(2800)$ | , | *** |
| N(1700) | $3/2^{-}$ | *** | $\Delta(1930)$ | 5/2- | *** | $\Sigma(1670)$ | 3/2- | *** | $\Xi(2250)$ | | ** | =+ c | 1/2 ⁺ | *** |
| N(1710) | | *** | $\Delta(1940)$ | 3/2- | ** | $\Sigma(1690)$ | , | ** | <i>Ξ</i> (2370) | | ** | $= \frac{c}{c}$ | 1/2+ | *** |
| N(1720) | $3/2^{+}$ | **** | $\Delta(1950)$ | 7/2 ⁺ | **** | $\Sigma(1750)$ | $1/2^{-}$ | *** | <i>Ξ</i> (2500) | | * | _ c ='+ | 1/2 ⁺ | *** |
| N(1860) | 5/2 ⁺ | ** | $\Delta(2000)$ | 5/2 ⁺ | ** | $\Sigma(1770)$ | $1/2^{+}$ | * | | | | ='+ c ='0 c | 1/2 ⁺ | *** |
| N(1875) | 3/2- | *** | $\Delta(2150)$ | 1/2- | * | $\Sigma(1775)$ | 5/2 | **** | Ω^- | $3/2^{+}$ | **** | $= \frac{-c}{E_c}$ (2645) | 3/2 ⁺ | *** |
| N(1880) | $1/2^{+}$ | ** | $\Delta(2200)$ | 7/2- | * | $\Sigma(1840)$ | $3/2^{+}$ | * | $\Omega(2250)^-$ | | *** | $\Xi_c(2043)$ $\Xi_c(2790)$ | $\frac{3}{2}$ $\frac{2}{1/2}$ | *** |
| N(1895) | $1/2^{-}$ | ** | $\Delta(2300)$ | 9 ['] /2 ⁺ | ** | $\Sigma(1880)$ | $1/2^{+}$ | ** | $\Omega(2380)^{-}$ | | ** | $\Xi_c(2815)$ | 3/2 | *** |
| N(1900) | $3/2^{+}$ | *** | $\Delta(2350)$ | 5/2- | * | Σ (1915) | 5/2 ⁺ | *** | $\Omega(2470)^{-}$ | | ** | $\Xi_c(2930)$ | 5/ 2 | * |
| N(1990) | $7/2^{+}$ | ** | $\Delta(2390)$ | 7/2+ | * | $\Sigma(1940)$ | 3/2- | *** | | | | $\Xi_c(2980)$ | | *** |
| N(2000) | 5/2 ⁺ | ** | $\Delta(2400)$ | $9/2^{-}$ | ** | $\Sigma(2000)$ | $1/2^{-}$ | * | | | | $\Xi_c(3055)$ | | ** |
| N(2040) | $3/2^{+}$ | * | $\Delta(2420)$ | 11/2+ | **** | Σ (2030) | $7/2^{+}$ | *** | | | | $\Xi_c(3080)$ | | *** |
| N(2060) | 5/2- | ** | $\Delta(2750)$ | 13/2- | | $\Sigma(2070)$ | 5/2 ⁺ | * | | | | $\Xi_c(3123)$ | | * |
| N(2100) | $1/2^{+}$ | | $\Delta(2950)$ | $15/2^{+}$ | ** | Σ (2080) | $3/2^{+}$ | ** | | | | Ω_c^0 | $1/2^{+}$ | *** |
| N(2120) | $3/2^{-}$ | | | | | $\Sigma(2100)$ | 7/2- | * | | | | $\Omega_c(2770)^0$ | 3/2 ⁺ | *** |
| N(2190) | 7/2- | | Λ | $1/2^{+}$ | **** | Σ (2250) | | *** | | | | 322(2110) | 0/2 | |
| N(2220) | 9/2 ⁺ | **** | <i>∧</i> (1405) | $1/2^{-}$ | **** | Σ (2455) | | ** | | | | Ξ_{cc}^{+} | | * |
| N(2250) | $9/2^{-}$ | | <i>∧</i> (1520) | 3/2- | **** | Σ (2620) | | ** | | | | -cc | | |
| N(2600) | $11/2^{-}$ | *** | <i>∧</i> (1600) | 1/2+ | *** | Σ (3000) | | * | | | | Λ_b^0 | $1/2^{+}$ | *** |
| N(2700) | 13/2+ | ** | <i>∧</i> (1670) | $1/2^{-}$ | **** | Σ (3170) | | * | | | | Σ_b | 1/2 ⁺ | *** |
| | | | <i>∧</i> (1690) | $3/2^{-}$ | **** | | | | | | | Σ_b^* | $3/2^{+}$ | *** |
| | | | <i>∧</i> (1800) | 1/2 | *** | | | | | | | $\equiv_{b}^{b}, \equiv_{b}^{-}$ | 1/2+ | *** |
| | | | <i>∧</i> (1810) | 1/2+ | *** | | | | | | | Ω_b^- | 1/2+ | *** |
| | | | <i>∧</i> (1820) | 5/2 ⁺ | **** | | | | | | | _D | -, - | |
| | | | <i>∧</i> (1830) | 5/2 | **** | | | | | | | | | |
| | | | <i>∧</i> (1890) | $3/2^{+}$ | **** | | | | | | | | | |
| | | | Λ(2000) | | * | | | | | | | | | |
| | | | Λ(2020) | 7/2+ | | | | | | | | | | |
| | | | <i>∧</i> (2100) | 7/2- | **** | | | | | | | | | |
| | | | Λ(2110) | 5/2 ⁺ | *** | | | | | | | | | |
| | | | Л(2325) | 3/2 | * | | | | | | | | | |
| | | | Λ(2350) | 9/2+ | *** | | | | | | | | | |
| | | | <i>∧</i> (2585) | | ** | | | | | | | | | |
| | | | | | | | | | | | | | | |

^{****} Existence is certain, and properties are at least fairly well explored.

^{***} Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined.

^{**} Evidence of existence is only fair.

^{*} Evidence of existence is poor.

| N BARY | ONS/ |
|------------|--------|
| (S = 0, I) | = 1/2) |
| | |

 $p, N^{+} = u u d; \quad n, N^{0} = u d d$

p

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

Mass $m=1.00727646681\pm0.000000000000000$ u Mass $m=938.272046\pm0.000021$ MeV $^{[a]}$ $|m_p-m_{\overline{p}}|/m_p<2\times10^{-9},$ CL =90% $^{[b]}$ $|\frac{q_p}{m_{\overline{p}}}|/(\frac{q_p}{m_p})=0.99999999991\pm0.000000000009$ $|q_p+q_{\overline{p}}|/e<2\times10^{-9},$ CL =90% $^{[b]}$ $|q_p+q_{\overline{p}}|/e<1\times10^{-21}$ $^{[c]}$ Magnetic moment $\mu=2.792847356\pm0.0000000023$ μ_N $(\mu_p+\mu_{\overline{p}})/\mu_p=(-0.1\pm2.1)\times10^{-3}$ Electric dipole moment $d<0.54\times10^{-23}$ ecm Electric polarizability $\alpha=(12.0\pm0.6)\times10^{-4}$ fm³ Magnetic polarizability $\beta=(1.9\pm0.5)\times10^{-4}$ fm³ Charge radius $=0.877\pm0.005$ fm Magnetic radius $=0.777\pm0.016$ fm Mean life $\tau>2.1\times10^{29}$ years, CL =90% $^{[d]}$ $(p\to invisible mode)$ Mean life $\tau>10^{31}$ to 10^{33} years $^{[d]}$ (mode dependent)

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. ${\bf D50}, 1173)$ for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_i , where τ is the total mean life and B_i is the branching fraction for the mode in question. For N decays, p and n indicate proton and neutron partial lifetimes

| | Partial mean life | | p |
|-----------------------------------------|-------------------------------|--------------|----------|
| p DECAY MODES | (10 ³⁰ years) Conf | idence level | (MeV/c) |
| | Antilepton + meson | | |
| $N ightarrow e^+ \pi$ | > 158 (n), > 8200 (p) | 90% | 45 9 |
| $N \rightarrow \mu^+ \pi$ | > 100 (n), > 6600 (p) | 90% | 45 3 |
| $N \rightarrow \nu \pi$ | > 112 (n), > 25 (p) | 90% | 45 9 |
| $p \rightarrow e^+ \eta$ | > 313 | 90% | 309 |
| $p \rightarrow \mu^+ \eta$ | > 126 | 90% | 297 |
| $n \rightarrow \nu \eta$ | > 158 | 90% | 310 |
| $N \rightarrow e^+ \rho$ | > 217 (n), > 75 (p) | 90% | 149 |
| $N \rightarrow \mu^+ \rho$ | > 228 (n), > 110 (p) | 90% | 113 |
| $N \rightarrow \nu \rho$ | > 19 (n), > 162 (p) | 90% | 149 |
| $p \rightarrow e^+ \omega$ | > 107 | 90% | 143 |
| $\rho \rightarrow \mu^+ \omega$ | > 117 | 90% | 105 |
| $n \rightarrow \nu \omega$ | > 108 | 90% | 144 |
| $N \rightarrow e^+ K$ | > 17 (n), > 150 (p) | 90% | 339 |
| $ ho ightarrow \ e^+ K^0_S$ | > 120 | 90% | 337 |
| $p \rightarrow e^+ K_L^{0}$ | > 51 | 90% | 337 |
| $N \rightarrow \mu^+ K$ | > 26 (n), > 120 (p) | 90% | 329 |
| $p \rightarrow \mu^+ K_S^0$ | > 150 | 90% | 326 |
| $p \rightarrow \mu^+ K_I^{0}$ | > 83 | 90% | 326 |
| $N \rightarrow \nu K$ | > 86 (n), > 670 (p) | 90% | 339 |
| $n \rightarrow \nu K_S^0$ | > 51 | 90% | 338 |
| $p \to e^+ K^* (892)^0$ | > 84 | 90% | 45 |
| $N \rightarrow \nu K^*(892)$ | $> 78 \ (n), > 51 \ (p)$ | 90% | 45 |
| | Antilepton + mesons | | |
| $p \rightarrow e^+ \pi^+ \pi^-$ | > 82 | 90% | 448 |
| $p \rightarrow e^+ \pi^0 \pi^0$ | > 147 | 90% | 449 |
| $n \rightarrow e^+ \pi^- \pi^0$ | > 52 | 90% | 449 |
| $p \rightarrow \mu^+ \pi^+ \pi^-$ | > 133 | 90% | 425 |
| $p \rightarrow \mu^+ \pi^0 \pi^0$ | > 101 | 90% | 427 |
| $n \rightarrow \mu^{+} \pi^{-} \pi^{0}$ | > 74 | 90% | 427 |
| $n \rightarrow e^+ K^0 \pi^-$ | > 18 | 90% | 319 |
| | Lepton + meson | | |
| $n \rightarrow e^-\pi^+$ | > 65 | 90% | 45 9 |
| $n \rightarrow \mu^- \pi^+$ | > 49 | 90% | 453 |
| $n \rightarrow e^- \rho^+$ | > 62 | 90% | 150 |
| $n \rightarrow \mu^- \rho^+$ | > 7 | 90% | 114 |
| $n \rightarrow e^- K^+$ | > 32 | 90% | 340 |
| $n \rightarrow \mu^- K^+$ | > 57 | 90% | 330 |
| | | | |

| L | epton + mesons | | |
|-------------------------------------|------------------------|------|------|
| $p \rightarrow e^- \pi^+ \pi^+$ | > 30 | 90% | 448 |
| $n \rightarrow e^- \pi^+ \pi^0$ | > 29 | 90% | 449 |
| $p \rightarrow \mu^- \pi^+ \pi^+$ | > 17 | 90% | 425 |
| $n \rightarrow \mu^- \pi^+ \pi^0$ | > 34 | 90% | 427 |
| $p \rightarrow e^- \pi^+ K^+$ | > 75 | 90% | 320 |
| $p \rightarrow \mu^- \pi^+ K^+$ | > 245 | 90% | 279 |
| Anti | lepton + photon(s) | | |
| $p \rightarrow e^+ \gamma$ | > 670 | 90% | 469 |
| $p \rightarrow \mu^+ \gamma$ | > 478 | 90% | 463 |
| $n \rightarrow \nu \gamma$ | > 28 | 90% | 470 |
| $p \rightarrow e^{+} \gamma \gamma$ | > 100 | 90% | 469 |
| $n \rightarrow \nu \gamma \gamma$ | > 219 | 90% | 470 |
| Thre | e (or more) leptons | | |
| $p \rightarrow e^+ e^+ e^-$ | > 793 | 90% | 469 |
| $p \rightarrow e^+ \mu^+ \mu^-$ | > 359 | 90% | 45 7 |
| $p \rightarrow e^+ \nu \nu$ | > 17 | 90% | 469 |
| $n ightarrow e^+ e^- u$ | > 257 | 90% | 470 |
| $n ightarrow \ \mu^+ \ e^- \ u$ | > 83 | 90% | 464 |
| $n ightarrow \mu^+ \mu^- u$ | > 79 | 90% | 458 |
| $p ightarrow \ \mu^+ \ e^+ \ e^-$ | > 529 | 90% | 463 |
| $p \rightarrow \mu^+ \mu^+ \mu^-$ | > 675 | 90% | 439 |
| $p ightarrow \ \mu^+ u u$ | > 21 | 90% | 463 |
| $p \rightarrow e^- \mu^+ \mu^+$ | > 6 | 90% | 45 7 |
| n 	o 3 u | > 0.0005 | 90% | 470 |
| | Inclusive modes | | |
| $N ightarrow e^+$ anything | > 0.6 (n, p) | 90% | _ |
| $N ightarrow \ \mu^+$ anything | > 12 (n, p) | 90% | _ |
| $N ightarrow e^+ \pi^0$ anything | > 0.6 (n, p) | 90% | - |
| $\Delta B =$ | = 2 dinucleon modes | | |
| The following are lifetime lii | mits per iron nucleus. | | |
| nn _+ _+ | . 0.7 | 000/ | |

90% $pp \rightarrow \pi^+ \pi^+$ > 0.7 > 2 > 0.7 90% $nn \rightarrow \pi^0 \pi^0$ > 3.490% > 5.8 90% $p p \rightarrow e^+ \mu^+$ 90% > 3.6 $pp \rightarrow \mu^+ \mu^+$ 90% > 1.7 $p n \rightarrow e^+ \overline{\nu}$ > 2.8 90% $pn \rightarrow \mu^{+}\overline{\nu}$ 90% > 1.6 $n \, n \,
ightarrow \, \nu_e \, \overline{
u}_e$ 90% > 0.000049 $>\!2.10\times10^{25}$ $pn \rightarrow invisible$ 90%

₱ DECAY MODES

> 0.00005

90%

| ₽ DECAY MODES | Partial mean life (years) | Confidence level | $p \pmod{/c}$ |
|------------------------------------------------|------------------------------|------------------|---------------|
| $\overline{p} \rightarrow e^- \gamma$ | > 7 × 10 ⁵ | 90% | 469 |
| $\overline{p} \rightarrow \mu^- \gamma$ | $> 5 \times 10^4$ | 90% | 463 |
| $\overline{p} \rightarrow e^{-}\pi^{0}$ | $>4 	imes 10^5$ | 90% | 45 9 |
| $\overline{p} \rightarrow \mu^- \pi^0$ | $> 5 \times 10^4$ | 90% | 45 3 |
| $\overline{p} \rightarrow e^- \eta$ | $> 2 \times 10^4$ | 90% | 309 |
| $\overline{p} \rightarrow \mu^- \eta$ | $> 8 \times 10^{3}$ | 90% | 297 |
| $\overline{p} \rightarrow e^- K_S^0$ | > 900 | 90% | 337 |
| $\overline{p} \rightarrow \mu^- K_S^0$ | $> 4 \times 10^{3}$ | 90% | 326 |
| $\overline{\rho} \rightarrow e^- K_I^{0}$ | $> 9 \times 10^{3}$ | 90% | 337 |
| $\overline{p} \rightarrow \mu^- K_I^0$ | $> 7 \times 10^3$ | 90% | 326 |
| $\overline{p} \rightarrow e^- \gamma \gamma$ | $> 2 \times 10^4$ | 90% | 469 |
| $\overline{p} \rightarrow \mu^- \gamma \gamma$ | $> 2 \times 10^4$ | 90% | 463 |
| $\overline{p} \rightarrow e^- \omega$ | > 200 | 90% | 143 |

n

 $pp \rightarrow \text{invisible}$

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

Mass $m=1.0086649160\pm0.00000000004$ u Mass $m=939.565379\pm0.000021$ MeV $^{[a]}$ $(m_n-m_{\overline{n}})/m_n=(9\pm6)\times10^{-5}$ $m_n-m_p=1.2933322\pm0.0000004$ MeV =0.00138844920(46) u Mean life $\tau=880.1\pm1.1$ s (S=1.8) $c_{\tau}=2.6383\times10^8$ km

Magnetic moment $\mu=-1.9130427\pm0.0000005~\mu_N$ Electric dipole moment $d<0.29\times10^{-25}~{\rm e\,cm,\,C\,L}=90\%$

Mean-square charge radius $\langle r_n^2 \rangle = -0.1161 \pm 0.0022$ fm 2 (S = 1.3) Magnetic radius $\sqrt{\langle r_M^2 \rangle} = 0.862^{+0.009}_{-0.008}$ fm Electric polarizability $\alpha = (11.6 \pm 1.5) \times 10^{-4}$ fm 3 Magnetic polarizability $\beta = (3.7 \pm 2.0) \times 10^{-4}$ fm 3 Charge $q = (-0.2 \pm 0.8) \times 10^{-21}$ e Mean $n \overline{n}$ -oscillation time $> 8.6 \times 10^7$ s, CL = 90% [fe] (bound n) Mean $n \overline{n}$ -oscillation time $> 1.3 \times 10^8$ s, CL = 90% [e] (bound n) Mean n n'-oscillation time > 414 s, CL = 90% [f]

$pe^-\nu_e$ decay parameters [g]

$$\begin{split} \lambda &\equiv g_A \ / \ g_V = -1.2701 \pm 0.0025 \quad \text{(S} = 1.9) \\ A &= -0.1176 \pm 0.0011 \quad \text{(S} = 2.1) \\ B &= 0.9807 \pm 0.0030 \\ C &= -0.2377 \pm 0.0026 \\ a &= -0.103 \pm 0.004 \\ \phi_{AV} &= (180.018 \pm 0.026)^{\circ} \ [h] \\ D &= (-1.2 \pm 2.0) \times 10^{-4} \ [i] \\ R &= 0.008 \pm 0.016 \ [i] \end{split}$$

| n DECAY MODES | | Fraction (Γ _i /Γ |) Confider | nce level | (MeV/c) |
|-----------------------------|--------------|-----------------------------|----------------------|-----------|----------|
| $pe^{-}\overline{\nu}_{e}$ | | 100 | % | | 1 |
| $pe^-\overline{ u}_e\gamma$ | | $[j]$ (3.09 \pm 0.3 | $32) \times 10^{-3}$ | | 1 |
| Ch | arge conserv | vation (Q) violat | ing mode | | |
| $p \nu_e \overline{\nu}_e$ | Q | < 8 | $\times 10^{-27}$ | 68% | 1 |

N(1440) 1/2+

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

Breit-Wigner mass = 1420 to 1470 (\approx 1440) MeV Breit-Wigner full width = 200 to 450 (\approx 300) MeV $p_{\rm beam} = 0.61~{\rm GeV}/c$ $4\pi\lambda^2 = 31.0~{\rm mb}$ Re(pole position) = 1350 to 1380 (\approx 1365) MeV $-2{\rm Im}({\rm pole~position}) = 160~{\rm to~220}~(\approx 190)$ MeV

| N(1440) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------------|------------------------------|-----------|
| Nπ | 55-75 % | 398 |
| $N\eta$ | (0.0 ± 1.0) % | † |
| $N\pi\pi$ | 30-40 % | 347 |
| $\Delta\pi$ | 20-30 % | 147 |
| ${\it \Delta}(1232)\pi$, ${\it P}$ -wave | 15-30 % | 147 |
| $N \rho$ | <8 % | † |
| $N\rho$, $S=1/2$, P -wave | (0.0 ± 1.0) % | † |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | 10-20 % | _ |
| $p\gamma$ | 0.035-0.048 % | 414 |
| $ ho\gamma$, helicity=1/2 | 0.035-0.048 % | 414 |
| n γ | 0.02-0.04 % | 413 |
| $n\gamma$, helicity=1/2 | 0.02-0.04 % | 413 |

N(1520) 3/2-

$$I(J^P)=\tfrac{1}{2}(\tfrac{3}{2}^-)$$

Breit-Wigner mass = 1515 to 1525 (\approx 1520) MeV Breit-Wigner full width = 100 to 125 (\approx 115) MeV $p_{\rm beam} = 0.74 \; {\rm GeV/c} \qquad 4\pi\lambda^2 = 23.5 \; {\rm mb}$ Re(pole position) = 1505 to 1515 (\approx 1510) MeV $-2 \, {\rm Im} ({\rm pole \; position}) = 105 \; {\rm to \; } 120 \; (\approx 110) \; {\rm MeV}$

| N(1520) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| Νπ | 55-65 % | 45 7 |
| $N\eta$ | $(2.3\pm0.4)\times10^{-3}$ | 154 |
| $N \pi \pi$ | 20-30 % | 414 |
| $\Delta\pi$ | 15-25 % | 230 |
| Δ (1232) π , S -wave | 10-20 % | 230 |
| $\Delta(1232)\pi$, $\it D-wave$ | 10-15 % | 230 |
| $N \rho$ | 15-25 % | † |
| $N\rho$, $S=3/2$, S -wave | (9.0 ± 1.0) % | † |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | <8 % | _ |
| $p\gamma$ | 0.31-0.52 % | 470 |
| $p\gamma$, helicity=1/2 | 0.01-0.02 % | 470 |
| $p\gamma$, helicity=3/2 | 0.30-0.50 % | 470 |
| $n\gamma$ | 0.30-0.53 % | 470 |
| $n\gamma$, helicity=1/2 | 0.04-0.10 % | 470 |
| $n\gamma$, helicity=3/2 | 0.25-0.45 % | 470 |

N(1535) 1/2-

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$$

Breit-Wigner mass = 1525 to 1545 (\approx 1535) MeV Breit-Wigner full width = 125 to 175 (\approx 150) MeV $p_{\rm beam}=0.76~{\rm GeV/c}$ $4\pi\lambda^2=22.5~{\rm mb}$ Re(pole position) = 1490 to 1530 (\approx 1510) MeV $-2{\rm Im}({\rm pole~position})=90$ to 250 (\approx 170) MeV

| N(1535) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| Nπ | 35-55 % | 468 |
| $N\eta$ | (42 ±10) % | 186 |
| $N\pi\pi$ | 1-10 % | 426 |
| $\Delta\pi$ | <1 % | 244 |
| Δ (1232) π , D -wave | 0-4 % | 244 |
| $N \rho$ | <4 % | † |
| $N \rho$, $S=1/2$, S -wave | (2.0 ± 1.0) % | † |
| $N\rho$, $S=3/2$, D -wave | (0.0 ± 1.0) % | † |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | (2 ± 1)% | = |
| $N(1440)\pi$ | (8 ± 3)% | † |
| $p\gamma$ | 0.15-0.30 % | 481 |
| $p\gamma$, helicity=1/2 | 0.15-0.30 % | 481 |
| n γ | 0.01-0.25 % | 480 |
| $n\gamma$, helicity=1/2 | 0.01-0.25 % | 480 |

N(1650) 1/2

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$$

Breit-Wigner mass = 1645 to 1670 (≈ 1655) MeV Breit-Wigner full width = 120 to 180 (≈ 150) MeV $p_{\rm beam} = 0.97~{\rm GeV}/c$ $4\pi\lambda^2 = 16.2~{\rm mb}$ Re(pole position) = 1640 to 1670 (≈ 1655) MeV $-2{\rm Im}({\rm pole~position}) = 100~{\rm to~170}~(\approx 135)~{\rm MeV}$

| N(1650) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------------|------------------------------|-----------|
| Nπ | 50-90 % | 551 |
| $N\eta$ | 5-15 % | 354 |
| ΛK | 3-11 % | 179 |
| $N\pi\pi$ | 10-20 % | 517 |
| $\Delta\pi$ | 0-25 % | 349 |
| ${\it \Delta}(1232)\pi$, ${\it D}$ -wave | 0-25 % | 349 |
| Nρ | 4-12 % | † |
| $N \rho$, $S=1/2$, S -wave | (1.0±1.0) % | † |
| $N\rho$, $S=3/2$, D -wave | (13.0±3.0) % | † |
| $N(\pi\pi)^{I=0}_{S-\text{wave}}$ | <4 % | - |
| $N(1440)\pi$ | <5 % | 156 |
| $p\gamma$ | 0.04-0.20 % | 562 |
| $p\gamma$, helicity=1/2 | 0.04-0.20 % | 562 |
| n γ | 0.003-0.17 % | 561 |
| $n\gamma$, helicity=1/2 | 0.003-0.17 % | 561 |

N(1675) 5/2

$$I(J^P) = \frac{1}{2}(\frac{5}{2})$$

Breit-Wigner mass = 1670 to 1680 (\approx 1675) MeV Breit-Wigner full width = 130 to 165 (\approx 150) MeV $p_{\rm beam} = 1.01~{\rm GeV/c}$ $4\pi\lambda^2 = 15.4~{\rm mb}$ Re(pole position) = 1655 to 1665 (\approx 1660) MeV $-2{\rm Im}({\rm pole~position}) = 125~{\rm to~150}~(\approx 135)~{\rm MeV}$

| N(1675) DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|-------------------------------------------|------------------------------|------------|
| Nπ | 35-45 % | 564 |
| $N\eta$ | (0.0 ± 1.0) % | 376 |
| ΛK | <1 % | 216 |
| $N\pi\pi$ | 50-60 % | 5 3 2 |
| $\Delta\pi$ | 50-60 % | 366 |
| ${\it \Delta}(1232)\pi$, ${\it D}$ -wave | (50 ±15)% | 366 |
| $N \rho$ | < 1-3 % | † |
| $N\rho$, $S=1/2$, D -wave | (0.0 ± 1.0) % | † |
| $N \rho$, $S=3/2$, D -wave | (1.0± 1.0) % | † |
| $N(\pi\pi)_{S-\text{wave}}^{l=0}$ | $(7.0 \pm 3.0) \%$ | - |
| $p\gamma$ | 0-0.02 % | 575 |
| $p\gamma$, helicity=1/2 | 0-0.01 % | 575 |
| $p\gamma$, helicity=3/2 | 0-0.01 % | 575 |
| n γ | 0-0.15 % | 574 |
| $n\gamma$, helicity=1/2 | 0-0.05 % | 574 |
| $n\gamma$, helicity=3/2 | 0-0.10 % | 574 |

N(1680) 5/2+

$$I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$$

Breit-Wigner mass = 1680 to 1690 (\approx 1685) MeV Breit-Wigner full width = 120 to 140 (\approx 130) MeV $p_{\rm beam} = 1.02~{\rm GeV}/c$ $4\pi\lambda^2 = 15.0~{\rm mb}$ Re(pole position) = 1665 to 1680 (\approx 1675) MeV $-2{\rm Im}({\rm pole~position}) = 110~{\rm to~}135~(\approx 120)~{\rm MeV}$

| N(1680) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------|------------------------------|-----------|
| Νπ | 65-70 % | 571 |
| $N\eta$ | (0.0 ± 1.0) % | 386 |
| $N\pi\pi$ | 30-40 % | 539 |
| $\Delta\pi$ | 5-15 % | 374 |
| $\Delta(1232)\pi$, $\it P-wave$ | (10 ±5)% | 374 |
| $\Delta(1232)\pi$, <i>F</i> -wave | 0-12 % | 374 |
| $N \rho$ | 3-15 % | † |
| $N\rho$, $S=3/2$, P -wave | <12;% | † |
| $N\rho$, $S=3/2$, F -wave | 1-5 % | † |
| $N(\pi\pi)^{I=0}_{S-\text{wave}}$ | $(11 \pm 5)\%$ | _ |
| $p\gamma$ | 0.21-0.32 % | 581 |
| $p\gamma$, helicity=1/2 | 0.001-0.011 % | 581 |
| $p\gamma$, helicity=3/2 | 0.20-0.32 % | 581 |
| $n\gamma$ | 0.021-0.046 % | 581 |
| $n\gamma$, helicity=1/2 | 0.004-0.029 % | 581 |
| $n\gamma$, helicity=3/2 | 0.01-0.024 % | 581 |

N(1700) 3/2

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Breit-Wigner mass = 1650 to 1750 (\approx 1700) MeV Breit-Wigner full width = 100 to 250 (\approx 150) MeV $p_{\rm beam} = 1.05~{\rm GeV/c}$ $4\pi\lambda^2 = 14.5~{\rm mb}$ Re(pole position) = 1650 to 1750 (\approx 1700) MeV $-2{\rm Im}({\rm pole~position}) = 100~{\rm to~300~MeV}$

| N(1700) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------------------------|------------------------------|-----------|
| Nπ | (12 ±5) % | 581 |
| $N\eta$ | (0.0 ± 1.0) % | 402 |
| ΛK | < 3 % | 255 |
| $N\pi\pi$ | 85-95 % | 550 |
| $\mathit{\Delta}(1232)\pi$, $\mathit{S}	ext{-}wave$ | 10-90 % | 386 |
| $\Delta(1232)\pi$, $\it D-wave$ | < 20 % | 386 |
| $N \rho$ | < 35 % | † |
| $N\rho$, $S=3/2$, S -wave | (7.0 ± 1.0) % | † |
| $p\gamma$ | 0.01-0.05 % | 591 |
| $p\gamma$, helicity=1/2 | 0.0-0.024 % | 591 |
| $p\gamma$, helicity=3/2 | 0.002-0.026 % | 591 |
| $n\gamma$ | 0.01-0.13 % | 590 |
| $n\gamma$, helicity=1/2 | 0.0-0.09 % | 590 |
| $n\gamma$, helicity=3/2 | 0.01-0.05 % | 590 |

N(1710) 1/2+

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

Breit-Wigner mass = 1680 to 1740 (\approx 1710) MeV Breit-Wigner full width = 50 to 250 (\approx 100) MeV $p_{\rm beam} = 1.07~{\rm GeV}/c$ $4\pi\lambda^2 = 14.2~{\rm mb}$ Re(pole position) = 1670 to 1770 (\approx 1720) MeV $-2{\rm Im}({\rm pole~position}) = 80$ to 380 (\approx 230) MeV

| N(1710) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|-----------|
| Νπ | 5-20 % | 588 |
| N η | 10-30 % | 412 |
| $N\omega$ | (13.0±2.0) % | † |
| ΛK | 5-25 % | 269 |
| $N\pi\pi$ | 40-90 % | 557 |
| $\Delta\pi$ | 15-40 % | 394 |
| $N \rho$ | 5-25 % | † |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | 10-40 % | = |
| $p\gamma$ | 0.002-0.08 % | 598 |
| $p\gamma$, helicity=1/2 | 0.002-0.08 % | 598 |
| $n\gamma$ | 0.0-0.02% | 597 |
| $n\gamma$, helicity=1/2 | 0.0-0.02% | 597 |

N(1720) 3/2+

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

Breit-Wigner mass = 1700 to 1750 (\approx 1720) MeV Breit-Wigner full width = 150 to 400 (\approx 250) MeV $p_{\rm beam} = 1.09~{\rm GeV}/c$ $4\pi\lambda^2 = 13.9~{\rm mb}$ Re(pole position) = 1660 to 1690 (\approx 1675) MeV $-2{\rm Im}({\rm pole~position}) = 150~{\rm to}~400~(\approx250)$ MeV

| N(1720) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------|------------------------------|------------|
| Νπ | (11± 3) % | 594 |
| $N\eta$ | (4 ± 1) % | 422 |
| ΛK | 1-15 % | 283 |
| $N\pi\pi$ | >70 % | 5 64 |
| Δ (1232) π , P -wave | (75 ±15) % | 402 |
| $N \rho$ | 70-85 % | 73 |
| $N \rho$, $S=1/2$, P -wave | large | 73 |
| $p\gamma$ | 0.05-0.25 % | 604 |
| $p\gamma$, helicity=1/2 | 0.05-0.15 % | 604 |
| $p\gamma$, helicity=3/2 | 0.002-0.16 % | 604 |
| $n\gamma$ | 0.0-0.016 % | 603 |
| $n\gamma$, helicity=1/2 | 0.0-0.01 % | 603 |
| $n\gamma$, helicity=3/2 | 0.0-0.015 % | 603 |

N(1875) 3/2

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Breit-Wigner mass = 1820 to 1920 (\approx 1875) MeV Breit-Wigner full width = 160 to 320 (\approx 220) MeV Re(pole position) = 1800 to 1950 MeV $-2 \ln(\text{pole position}) = 150 \text{ to } 250 \text{ MeV}$

| N(1875) DECAY MODES | Fraction (Γ_j/Γ) | Scale factor | <i>p</i> (Me V/ <i>c</i>) |
|-----------------------------------|------------------------------|--------------|--------------------------------|
| Νπ | (12 ±10)% | | 695 |
| $N\eta$ | (3.5 ± 3.5) % | 2.5 | 559 |
| $N\omega$ | (21 ± 7)% | | 371 |
| ΣΚ | $(7 \pm 4) \times 10^{-3}$ | | 384 |
| $\Delta(1232)\pi$, S -wave | (40 ±10) % | | 520 |
| $\Delta(1232)\pi$, D -wave | (17 ±10) % | | 520 |
| $N\rho$, $S=3/2$, S -wave | (6 ± 6)% | | 379 |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | $(24 \pm 24)\%$ | | _ |
| $p\gamma$ | 0.008-0.016 % | | 703 |
| $p\gamma$, helicity=1/2 | 0.006-0.010 % | | 703 |
| $p\gamma$, helicity=3/2 | 0.002-0.006 % | | 703 |

N(1900) 3/2+

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

 $\begin{array}{l} \mbox{Breit-Wigner mass} \approx 1900 \mbox{ MeV} \\ \mbox{Breit-Wigner full width} \sim 250 \mbox{ MeV} \\ \mbox{Re(pole position)} = 1900 \pm 30 \mbox{ MeV} \\ \mbox{-2Im(pole position)} = 200 {}^{+100}_{-60} \mbox{ MeV} \end{array}$

| N(1900) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| Nπ | ~ 10 % | 710 |
| $N\eta$ | \sim 12 % | 579 |
| $N\omega$ | (39 ±9)% | 401 |
| ΛK | 0-10 % | 477 |
| ΣΚ | (5.0 ± 2.0) % | 410 |

N(2190) 7/2⁻

$$I(J^P) = \frac{1}{2}(\frac{7}{2}^-)$$

Breit-Wigner mass = 2100 to 2200 (\approx 2190) MeV Breit-Wigner full width = 300 to 700 (\approx 500) MeV $p_{\rm beam}$ = 2.07 GeV/c 4 $\pi\lambda^2$ = 6.21 mb Re(pole position) = 2050 to 2100 (\approx 2075) MeV - 2Im(pole position) = 400 to 520 (\approx 450) MeV

| N(2190) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|------------|
| $N\pi$ | 10-20 % | 888 |
| $N\eta$ | (0.0 ± 1.0) % | 791 |
| $N\omega$ | seen | 676 |
| ΛK | seen | 712 |
| $N\pi\pi$ | seen | 870 |
| $N \rho$ | seen | 680 |
| $p\gamma$ | 0.02-0.06 % | 894 |
| $p\gamma$, helicity=1/2 | 0.02-0.04 % | 894 |
| $p\gamma$, helicity=3/2 | 0.002-0.02 % | 894 |

N(2220) 9/2+

$$I(J^P) = \frac{1}{2}(\frac{9}{2}^+)$$

Breit-Wigner mass = 2200 to 2300 (\approx 2250) MeV Breit-Wigner full width = 350 to 500 (\approx 400) MeV $p_{\rm beam} = 2.21 \ {\rm GeV/c} \qquad 4\pi \lambda^2 = 5.74 \ {\rm mb}$ Re(pole position) = 2130 to 2200 (\approx 2170) MeV $-2{\rm Im}({\rm pole \ position}) = 400 \ {\rm to \ }560 \ (\approx 480) \ {\rm MeV}$

| N(2220) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|------------|
| $N\pi$ | 15-25 % | 924 |

N(2250) 9/2

$$I(J^P)=\tfrac{1}{2}(\tfrac{9}{2}^-)$$

Breit-Wigner mass = 2200 to 2350 (\approx 2275) MeV Breit-Wigner full width = 230 to 800 (\approx 500) MeV $p_{\rm beam} = 2.27~{\rm GeV/c}$ $4\pi\lambda^2 = 5.56~{\rm mb}$ Re(pole position) = 2150 to 2250 (\approx 2200) MeV $-2{\rm Im}({\rm pole~position}) = 350~{\rm to~550}~(\approx 450)$ MeV

| N(2250) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|------------|
| Νπ | 5-15 % | 938 |

N(2600) 11/2-

$$I(J^P) = \frac{1}{2}(\frac{11}{2}^-)$$

Breit-Wigner mass = 2550 to 2750 (\approx 2600) MeV Breit-Wigner full width = 500 to 800 (\approx 650) MeV $p_{\rm beam} = 3.12~{\rm GeV}/c$ $4\pi\lambda^2 = 3.86~{\rm mb}$

| N(2600) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| Νπ | 5-10 % | 1126 |

\triangle BARYONS (S=0, I=3/2)

 $\Delta^{++} = u\,u\,u\,,\quad \Delta^{+} = u\,u\,d,\quad \Delta^{0} = u\,d\,d,\quad \Delta^{-} = d\,d\,d$

Δ(1232) 3/2⁺

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$

Breit-Wigner mass (mixed charges) = 1230 to 1234 (\approx 1232)

Breit-Wigner full width (mixed charges) = 114 to 120 (\approx 117) MeV

 $p_{\mathrm{beam}}=0.30~\mathrm{GeV}/c$ $4\pi\lambda^2=94.8~\mathrm{mb}$ Re(pole position) = 1209 to 1211 (\approx 1210) MeV $-2\mathrm{Im}(\mathrm{pole}\ \mathrm{position})=98$ to $102\ (\approx100)$ MeV

| △(1232) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 100 % | 229 |
| $N\gamma$ | 0.55-0.65 % | 25 9 |
| $N\gamma$, helicity=1/2 | 0.11-0.13 % | 25 9 |
| $N\gamma$, helicity=3/2 | 0.44-0.52 % | 25 9 |

△(1600) 3/2⁺

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$

Breit-Wigner mass = 1500 to 1700 (\approx 1600) MeV Breit-Wigner full width = 220 to 420 (\approx 320) MeV $p_{\rm beam} = 0.87~{\rm GeV}/c$ $4\pi\lambda^2 = 18.6~{\rm mb}$ Re(pole position) = 1460 to 1560 (\approx 1510) MeV $-2{\rm Im}({\rm pole~position}) = 200$ to 350 (\approx 275) MeV

| △(1600) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 10-25 % | 513 |
| $N\pi\pi$ | 75-90 % | 477 |
| $\Delta\pi$ | 40-70 % | 303 |
| $N \rho$ | <25 % | † |
| $N(1440)\pi$ | 10-35 % | 82 |
| $N\gamma$ | 0.001-0.035 % | 525 |
| $N\gamma$, helicity=1/2 | 0.0-0.02 % | 525 |
| $N\gamma$, helicity=3/2 | 0.001-0.015 % | 525 |

∆(1620) 1/2⁻

$$I(J^P) = \frac{3}{2}(\frac{1}{2}^-)$$

Breit-Wigner mass = 1600 to 1660 (\approx 1630) MeV Breit-Wigner full width = 130 to 150 (\approx 140) MeV $p_{\rm beam} = 0.93~{\rm GeV}/c$ $4\pi\lambda^2 = 17.2~{\rm mb}$ Re(pole position) = 1590 to 1610 (\approx 1600) MeV $-2{\rm Im}({\rm pole~position}) = 120~{\rm to~140}~(\approx 130)$ MeV

| △(1620) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 20-30 % | 534 |
| $N\pi\pi$ | 70-80 % | 499 |
| $\Delta \pi$ | 30-60 % | 328 |
| $N \rho$ | 7-25 % | † |
| $N\gamma$ | 0.03-0.10 % | 545 |
| $N\gamma$, helicity=1/2 | 0.03-0.10 % | 545 |

△(1700) 3/2⁻

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^-)$$

Breit-Wigner mass = 1670 to 1750 (\approx 1700) MeV Breit-Wigner full width = 200 to 400 (\approx 300) MeV $p_{\rm beam} = 1.05 \; {\rm GeV/c} \qquad 4\pi\lambda^2 = 14.5 \; {\rm mb}$ Re(pole position) = 1620 to 1680 (\approx 1650) MeV $-2{\rm Im}({\rm pole \; position}) = 160 \; {\rm to \; 300} \; (\approx 230) \; {\rm MeV}$

| △(1700) DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|------------------------------------|------------------------------|------------|
| Nπ | 10-20 % | 581 |
| $N\pi\pi$ | 80-90 % | 550 |
| $\Delta \pi$ | 30-60 % | 386 |
| Δ (1232) π , S-wave | 25-50 % | 386 |
| $\Delta(1232)\pi$, <i>D</i> -wave | 5-15 % | 386 |
| $N \rho$ | 30-55 % | † |
| $N\rho$, $S=3/2$, S -wave | 5-20 % | † |
| Δ (1232) η | (5.0 ± 2.0) % | † |
| $N\gamma$ | 0.22-0.60 % | 591 |
| $N\gamma$, helicity=1/2 | 0.12-0.30 % | 591 |
| $N\gamma$, helicity=3/2 | 0.10-0.30 % | 591 |

Δ(1905) 5/2⁺

$$I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$$

Breit-Wigner mass = 1855 to 1910 (\approx 1880) MeV Breit-Wigner full width = 270 to 400 (\approx 330) MeV $p_{\rm beam} = 1.40 \; {\rm GeV}/c$ $4\pi\lambda^2 = 10.1 \; {\rm mb}$ Re(pole position) = 1805 to 1835 (\approx 1820) MeV $-2{\rm Im}({\rm pole \; position}) = 265 \; {\rm to \; 300} \; (\approx 280) \; {\rm MeV}$

| △(1905) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 9-15 % | 698 |
| $N\pi\pi$ | 85-95 % | 673 |
| $\Delta\pi$ | <25 % | 524 |
| $N \rho$ | >60 % | 385 |
| $N\gamma$ | 0.012-0.036 % | 706 |
| $N\gamma$, helicity=1/2 | 0.002-0.006 % | 706 |
| $N\gamma$, helicity=3/2 | 0.01-0.03 % | 706 |

△(1910) 1/2⁺

$$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$$

Breit-Wigner mass = 1860 to 1910 (\approx 1890) MeV Breit-Wigner full width = 220 to 340 (\approx 280) MeV $p_{\rm beam} = 1.42~{\rm GeV}/c$ $4\pi\lambda^2 = 9.89~{\rm mb}$ Re(pole position) = 1830 to 1880 (\approx 1855) MeV $-2{\rm Im}({\rm pole~position}) = 200~{\rm to~500}~(\approx350)$ MeV

| △(1910) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 15-30 % | 704 |
| ΣΚ | (9± 5)% | 400 |
| $\Delta\pi$ | (60±28) % | 531 |
| $N\gamma$ | 0.0-0.02 % | 712 |
| $N\gamma$, helicity=1/2 | 0.0-0.02 % | 712 |

△(1920) 3/2⁺

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$

Breit-Wigner mass = 1900 to 1970 (\approx 1920) MeV Breit-Wigner full width = 180 to 300 (\approx 260) MeV $p_{\rm beam} = 1.48~{\rm GeV}/c$ $4\pi\lambda^2 = 9.37~{\rm mb}$ Re(pole position) = 1850 to 1950 (\approx 1900) MeV $-2{\rm Im}({\rm pole~position}) = 200~{\rm to~400}~(\approx 300)~{\rm MeV}$

| △(1920) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 5-20 % | 723 |
| ΣΚ | (2.14 ± 0.30) % | 431 |
| Δ (1232) η | (15 ±8) % | 336 |
| $N\gamma$ | 0.0-0.4 % | 731 |
| $N\gamma$, helicity=1/2 | 0.0-0.2 % | 731 |
| $N\gamma$, helicity=3/2 | 0.0-0.2 % | 731 |

△(1930) 5/2⁻

$$I(J^P) = \frac{3}{2}(\frac{5}{2}^-)$$

Breit-Wigner mass = 1900 to 2000 (\approx 1950) MeV Breit-Wigner full width = 220 to 500 (\approx 360) MeV $p_{\rm beam} = 1.54~{\rm GeV}/c$ $4\pi\lambda^2 = 8.91~{\rm mb}$ Re(pole position) = 1840 to 1960 (\approx 1900) MeV $-2{\rm Im}({\rm pole~position}) = 175~{\rm to~360~}(\approx270)~{\rm MeV}$

| △(1930) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| $N\pi$ | 5-15 % | 742 |
| $N\gamma$ | 0.0-0.02 % | 749 |
| $N\gamma$, helicity=1/2 | 0.0-0.01 % | 749 |
| $N\gamma$, helicity=3/2 | 0.0-0.01 % | 749 |

Δ(1950) 7/2⁺

$$I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$$

Breit-Wigner mass = 1915 to 1950 (\approx 1930) MeV Breit-Wigner full width = 235 to 335 (\approx 285) MeV $p_{\rm beam} = 1.50 \; {\rm GeV/c} \qquad 4\pi\lambda^2 = 9.21 \; {\rm mb}$ Re(pole position) = 1870 to 1890 (\approx 1880) MeV $-2 {\rm Im}({\rm pole \; position}) = 220 \; {\rm to \; 260} \; (\approx 240) \; {\rm MeV}$

| △(1950) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------|------------------------------|-----------|
| Nπ | 35-45 % | 729 |
| $N\pi\pi$ | | 706 |
| $\Delta\pi$ | 20-30 % | 560 |
| $N \rho$ | <10 % | 442 |
| $N\gamma$ | 0.08-0.13 % | 737 |
| $N\gamma$, helicity=1/2 | 0.03-0.055 % | 737 |
| $N\gamma$, helicity=3/2 | 0.05-0.075 % | 737 |

△(2420) 11/2⁺

$$I(J^P) = \frac{3}{2}(\frac{11}{2}^+)$$

Breit-Wigner mass = 2300 to 2500 (\approx 2420) MeV Breit-Wigner full width = 300 to 500 (\approx 400) MeV $p_{\rm beam} = 2.64~{\rm GeV}/c$ $4\pi\lambda^2 = 4.68~{\rm mb}$ Re(pole position) = 2260 to 2400 (\approx 2330) MeV $-2{\rm Im}({\rm pole~position}) = 350~{\rm to~750}~(\approx550)$ MeV

| △(2420) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| $N\pi$ | 5-15 % | 1023 |

$$\Lambda$$
 BARYONS $(S = -1, I = 0)$

$$\Lambda^0 = u ds$$

Λ

$$I(J^P)=0(\tfrac{1}{2}^+)$$

Mass $m=1115.683\pm0.006$ MeV $\left(m_{\Lambda}-m_{\overline{\Lambda}}\right)/m_{\Lambda}=\left(-0.1\pm1.1\right)\times10^{-5}~(S=1.6)$ Mean life $\tau=\left(2.632\pm0.020\right)\times10^{-10}$ s (S=1.6) $\left(\tau_{\Lambda}-\tau_{\overline{\Lambda}}\right)/\tau_{\Lambda}=-0.001\pm0.009$ $c\tau=7.89$ cm

Magnetic moment $\mu=-0.613\pm0.004~\mu_{N}$ Electric dipole moment $d<1.5\times10^{-16}~e\,{\rm cm}$, CL = 95%

Decay parameters

$$\begin{array}{lll} \rho\pi^{-} & \alpha_{-} = 0.642 \pm 0.013 \\ \overline{\rho}\pi^{+} & \alpha_{+} = -0.71 \pm 0.08 \\ \rho\pi^{-} & \phi_{-} = (-6.5 \pm 3.5)^{\circ} \\ \text{"} & \gamma_{-} = 0.76 \, [k] \\ \text{"} & \Delta_{-} = (8 \pm 4)^{\circ} \, [k] \\ n\pi^{0} & \alpha_{0} = 0.65 \pm 0.04 \\ \rho\,e^{-}\overline{\nu}_{e} & g_{A}/g_{V} = -0.718 \pm 0.015 \, [g] \end{array}$$

| A DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------------|----------------------------------------|-----------|
| $p\pi^-$ | (63.9 ± 0.5) % | 101 |
| $n\pi^0$ | $(35.8 \pm 0.5) \%$ | 104 |
| $n\gamma$ | $(1.75 \pm 0.15) \times 10^{-3}$ | 162 |
| $p\pi^-\gamma$ | [/] (8.4 ± 1.4) $\times 10^{-4}$ | 101 |
| $p e^- \overline{ u}_e$ | $(8.32 \pm 0.14) \times 10^{-4}$ | 163 |
| $p\mu^-\overline{ u}_\mu$ | $(1.57 \pm 0.35) \times 10^{-4}$ | 131 |

Λ(1405) 1/2⁻

$$I(J^P) = 0(\frac{1}{2}^-)$$

Mass $m=1405.1^{+1.3}_{-1.0}$ MeV Full width $\Gamma=50\pm2$ MeV Below $\overline{K}N$ threshold

| A(1405) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| $\Sigma \pi$ | 100 % | 155 |

Λ(1520) 3/2⁻

$$I(J^P) = 0(\frac{3}{2}^-)$$

Mass $m=1519.5\pm 1.0$ MeV [m] Full width $\Gamma=15.6\pm 1.0$ MeV [m] $p_{\mathrm{beam}}=0.39$ GeV/c $4\pi\lambda^2=82.8$ mb

| A(1520) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| NK | 45 ± 1% | 243 |
| $\Sigma \pi$ | 42 ± 1% | 268 |
| $\Lambda \pi \pi$ | $10\pm1\%$ | 259 |
| $\Sigma \pi \pi$ | $0.9\pm0.1\%$ | 169 |
| $\Lambda\gamma$ | $0.85\pm0.15\%$ | 35 0 |

Λ(1600) 1/2⁺

$$I(J^P)=0(\tfrac{1}{2}^+)$$

Mass m=1560 to 1700 (≈ 1600) MeV Full width $\Gamma=50$ to 250 (≈ 150) MeV $p_{\rm beam}=0.58~{\rm GeV}/c$ $4\pi\lambda^2=41.6~{\rm mb}$

| A(1600) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| N K | 15-30 % | 343 |
| $\Sigma \pi$ | 10-60 % | 338 |

Λ(1670) 1/2⁻

 $I(J^P) = 0(\frac{1}{2}^-)$

Mass m= 1660 to 1680 (\approx 1670) MeV Full width $\Gamma=$ 25 to 50 (\approx 35) MeV $p_{\rm beam}=$ 0.74 GeV/c $4\pi\lambda^2=$ 28.5 mb

| A(1670) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| NK | 20-30 % | 414 |
| $\Sigma \pi$ | 25-55 % | 394 |
| $\Lambda\eta$ | 10-25 % | 69 |

Λ(1690) 3/2⁻

 $I(J^P) = 0(\frac{3}{2}^-)$

Mass m= 1685 to 1695 (\approx 1690) MeV Full width $\Gamma=$ 50 to 70 (\approx 60) MeV $p_{\mathrm{beam}}=$ 0.78 GeV/c $4\pi\bar{\lambda}^2=$ 26.1 mb

| Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------|------------------------------|
| 20-30 % | 433 |
| 20-40 % | 410 |
| \sim 25 $\%$ | 419 |
| \sim 20 % | 35 8 |
| | 20-30 % 20-40 % ~ 25 % |

Λ(1800) 1/2⁻⁻

 $I(J^P) = 0(\frac{1}{2})$

Mass m=1720 to 1850 (\approx 1800) MeV Full width $\Gamma=200$ to 400 (\approx 300) MeV $p_{\mathrm{beam}}=1.01~\mathrm{GeV}/c$ $4\pi\lambda^2=17.5~\mathrm{mb}$

| A(1800) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------|------------------------------|-----------|
| NK | 25-40 % | 528 |
| $\Sigma \pi$ | seen | 494 |
| Σ (1385) π | seen | 349 |
| N K *(892) | seen | † |

Λ(1810) 1/2⁺

 $I(J^P) = 0(\frac{1}{2}^+)$

Mass m=1750 to $1850~(\approx 1810)~{\rm MeV}$ Full width $\Gamma=50$ to $250~(\approx 150)~{\rm MeV}$ $p_{{\rm beam}}=1.04~{\rm GeV}/c$ $4\pi\lambda^2=17.0~{\rm mb}$

| A(1810) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------------|------------------------------|-----------|
| NK | 20-50 % | 537 |
| $\Sigma \pi$ | 10-40 % | 501 |
| $\frac{\Sigma(1385)\pi}{NK^*(892)}$ | seen | 35 7 |
| N K *(892) | 30-60 % | † |

Λ(1820) 5/2⁺

 $I(J^P) = 0(\frac{5}{2}^+)$

Mass m= 1815 to 1825 (\approx 1820) MeV Full width $\Gamma=$ 70 to 90 (\approx 80) MeV $p_{\mathrm{beam}}=$ 1.06 GeV/c $4\pi\bar{\lambda}^2=$ 16.5 mb

| A(1820) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| NK | 55-65 % | 545 |
| $\Sigma \pi$ | 8-14 % | 509 |
| $\Sigma(1385)\pi$ | 5-10 % | 366 |

Λ(1830) 5/2⁻

 $I(J^P) = 0(\frac{5}{2}^-)$

Mass m=1810 to 1830 (\approx 1830) MeV Full width $\Gamma=60$ to 110 (\approx 95) MeV $p_{\rm beam}=1.08~{\rm GeV}/c$ $4\pi\lambda^2=16.0~{\rm mb}$

| A(1830) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------|------------------------------|-----------|
| NK | 3-10 % | 553 |
| $\Sigma \pi$ | 35-75 % | 516 |
| Σ (1385) π | >15 % | 374 |

Λ(1890) 3/2⁺

 $I(J^P) = 0(\frac{3}{2}^+)$

Mass m=1850 to 1910 (≈ 1890) MeV Full width $\Gamma=60$ to 200 (≈ 100) MeV $p_{\rm beam}=1.21~{\rm GeV}/c$ $4\pi\lambda^2=13.6~{\rm mb}$

| A(1890) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| NK | 20-35 % | 599 |
| $\Sigma \pi$ | 3-10 % | 560 |
| $\Sigma(1385)\pi$ $NK^*(892)$ | seen | 423 |
| $N\overline{K}^{*}(892)$ | seen | 236 |

Λ(2100) 7/2⁻

 $I(J^P) = 0(\frac{7}{2}^-)$

Mass m=2090 to 2110 (\approx 2100) MeV Full width $\Gamma=100$ to 250 (\approx 200) MeV $p_{\mathrm{beam}}=1.68~\mathrm{GeV}/c$ $4\pi\lambda^2=8.68~\mathrm{mb}$

| A(2100) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------------|------------------------------|-----------|
| NK | 25-35 % | 75 1 |
| $\Sigma \pi$ | \sim 5 % | 705 |
| $\Lambda\eta$ | <3 % | 617 |
| ΞK | <3 % | 491 |
| $\Lambda \omega$ $N\overline{K}^*(892)$ | <8 % | 443 |
| $N\overline{K}^{*}(892)$ | 10-20 % | 515 |

Λ(2110) 5/2⁺

 $I(J^P) = 0(\frac{5}{2}^+)$

Mass m=2090 to 2140 (\approx 2110) MeV Full width $\Gamma=150$ to 250 (\approx 200) MeV $p_{\mathrm{beam}}=1.70~\mathrm{GeV}/c$ $4\pi\lambda^2=8.53~\mathrm{mb}$

| A(2110) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------|------------------------------|-----------|
| NK | 5-25 % | 75 7 |
| $\Sigma \pi$ | 10-40 % | 711 |
| $\Lambda\omega$ | seen | 455 |
| $\Sigma(1385)\pi$ | seen | 591 |
| $N\overline{K}^*(892)$ | 10-60 % | 525 |

Л(2350) 9/2⁺

 $I(J^P) = 0(\frac{9}{2}^+)$

Mass m=2340 to 2370 (\approx 2350) MeV Full width $\Gamma=100$ to 250 (\approx 150) MeV $p_{\rm beam}=2.29~{\rm GeV}/c$ $4\pi\lambda^2=5.85~{\rm mb}$

| A(2350) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|------------|
| NK | ~ 12 % | 915 |
| $\Sigma \pi$ | \sim 10 % | 867 |

Σ BARYONS (S=-1, l=1)

 $\Sigma^+ = uus$, $\Sigma^0 = uds$, $\Sigma^- = dds$



 $I(J^P) = 1(\frac{1}{2}^+)$

 $\begin{array}{lll} \text{Mass } m = 1189.37 \pm 0.07 \; \text{MeV} & (\text{S} = 2.2) \\ \text{Mean life } \tau = (0.8018 \pm 0.0026) \times 10^{-10} \; \text{s} \\ c\tau = 2.404 \; \text{cm} \\ (\tau_{\Sigma^+} - \tau_{\overline{\Sigma}^-}) \ / \ \tau_{\Sigma^+} = (-0.6 \pm 1.2) \times 10^{-3} \\ \text{Magnetic moment } \mu = 2.458 \pm 0.010 \; \mu_N \quad (\text{S} = 2.1) \\ (\mu_{\Sigma^+} + \mu_{\overline{\Sigma}^-}) \ / \ \mu_{\Sigma^+} = 0.014 \pm 0.015 \\ \Gamma(\Sigma^+ \to n\ell^+\nu) \ / \Gamma(\Sigma^- \to n\ell^-\overline{\nu}) \ < \ 0.043 \end{array}$

Decay parameters

$$\begin{array}{lll} \rho\pi^0 & \alpha_0 = -0.980 \, {}^{+}_{-0.015}^{+0.017} \\ \text{"} & \phi_0 = (36 \pm 34)^\circ \\ \text{"} & \gamma_0 = 0.16 \, [k] \\ \text{"} & \Delta_0 = (187 \pm 6)^\circ \, [k] \\ \text{n} \pi^+ & \alpha_+ = 0.068 \pm 0.013 \\ \text{"} & \phi_+ = (167 \pm 20)^\circ \, (S = 1.1) \\ \text{"} & \gamma_+ = -0.97 \, [k] \\ \text{"} & \Delta_+ = (-73 \, {}^{+}_{-133}^{+133})^\circ \, [k] \\ \rho\gamma & \alpha_\gamma = -0.76 \pm 0.08 \end{array}$$

| Σ^+ DECAY MODES | Fraction (Γ_i) | /Γ) Confidence level | (MeV/c) |
|------------------------|-----------------------------------------------------------|------------------------|----------|
| $p\pi^0$ | (51.57±0. | 30) % | 189 |
| $n\pi^+$ | $(48.31 \pm 0.$ | 30) % | 185 |
| $p\gamma$ | $(1.23 \pm 0.$ | $05) \times 10^{-3}$ | 225 |
| $n\pi^+\gamma$ | [/] (4.5 ± 0.1 | 5) × 10 ⁻⁴ | 185 |
| $\Lambda e^+ u_e$ | (2.0 ± 0.1) | $5) \times 10^{-5}$ | 71 |
| | ΔQ (SQ) violating near veak neutral current (| | |
| n $e^+ u_e$ | SQ < 5 | ×10 ⁻⁶ 90% | 224 |
| n $\mu^+ u_\mu$ | SQ < 3.0 | $\times 10^{-5}$ 90% | 202 |
| p e + e - | S1 < 7 | $\times 10^{-6}$ | 225 |
| $p\mu^+\mu^-$ | S1 (9 + 9 | $) \times 10^{-8}$ | 121 |

Σ^0

$$I(J^P) = 1(\frac{1}{2}^+)$$

Mass $m=1192.642\pm0.024$ MeV $m_{\Sigma^-}-m_{\Sigma^0}=4.807\pm0.035$ MeV (S = 1.1) $m_{\Sigma^0}-m_A=76.959\pm0.023$ MeV Mean life $\tau=(7.4\pm0.7)\times10^{-20}$ s $c\tau=2.22\times10^{-11}$ m

Transition magnetic moment $|\mu_{\Sigma A}| = 1.61 \pm 0.08 \,\mu_{N}$

| Σ^0 DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | р (MeV/ <i>c</i>) |
|-------------------------|------------------------------|------------------|------------------------|
| $\Lambda\gamma$ | 100 % | | 74 |
| $\Lambda \gamma \gamma$ | < 3 % | 90% | 74 |
| $\Lambda e^+ e^-$ | [n] 5×10^{-3} | | 74 |



$$I(J^P) = 1(\frac{1}{2}^+)$$

Mass $m=1197.449\pm0.030$ MeV (S = 1.2) $m_{\Sigma^-}-m_{\Sigma^+}=8.08\pm0.08$ MeV (S = 1.9) $m_{\Sigma^-}-m_{\Lambda}=81.766\pm0.030$ MeV (S = 1.2) Mean life $\tau=(1.479\pm0.011)\times10^{-10}$ s (S = 1.3) $c\tau=4.434$ cm

Magnetic moment $\mu=-1.160\pm0.025~\mu_{\it N}~~({\rm S}=1.7)$ Σ^- charge radius $=0.78\pm0.10~{\rm fm}$

Decay parameters

$$\begin{array}{lll} n\pi^- & \alpha_- = -0.068 \pm 0.008 \\ \text{"} & \phi_- = (10 \pm 15)^\circ \\ \text{"} & \gamma_- = 0.98 \, [k] \\ \text{"} & \Delta_- = (249 + \frac{12}{120})^\circ \, [k] \\ ne^- \overline{\nu}_e & g_A/g_V = 0.340 \pm 0.017 \, [g] \\ \text{"} & f_2(0)/f_1(0) = 0.97 \pm 0.14 \\ \text{"} & D = 0.11 \pm 0.10 \\ \Lambda e^- \overline{\nu}_e & g_V/g_A = 0.01 \pm 0.10 \, [g] \\ \text{"} & g_{WM}/g_A = 2.4 \pm 1.7 \, [g] \end{array} \label{eq:decomposition}$$

| Σ- DECAY MODES | Fraction (Γ_{j}/Γ) | p (MeV/c) |
|--------------------------------|----------------------------------------|-----------|
| $n\pi^-$ | (99.848 ± 0.005) % | 193 |
| $n\pi^-\gamma$ | [1] (4.6 ± 0.6) $\times 10^{-4}$ | 193 |
| ne $^-\overline{ u}_e$ | $(1.017 \pm 0.034) \times 10^{-3}$ | 230 |
| n $\mu^-\overline{ u}_\mu$ | $(4.5 \pm 0.4) \times 10^{-4}$ | 210 |
| $\Lambda e^{-\frac{1}{\nu_e}}$ | $(5.73 \pm 0.27) \times 10^{-5}$ | 79 |

Σ(1385) 3/2⁺

$$I(J^P) = 1(\frac{3}{2}^+)$$

| Σ(1385) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | <i>p</i> (Me V/ <i>c</i>) |
|---------------------|------------------------------|------------------|--------------------------------|
| $\Lambda\pi$ | (87.0 ±1.5) % | | 208 |
| $\sum \pi$ | $(11.7 \pm 1.5) \%$ | | 129 |
| $\Lambda\gamma$ | $(1.25^{+0.13}_{-0.12})$ % | | 241 |
| $\Sigma^-\gamma$ | < 2.4 × 1 | 0-4 90% | 173 |

Σ(1660) 1/2⁺

$$I(J^P) = 1(\frac{1}{2}^+)$$

Mass m=1630 to $1690~(\approx 1660)$ MeV Full width $\Gamma=40$ to $200~(\approx 100)$ MeV $p_{\mathrm{beam}}=0.72~\mathrm{GeV}/c$ $4\pi\lambda^2=29.9~\mathrm{mb}$

| Σ(1660) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|------------|
| NK | 10-30 % | 405 |
| $\Lambda\pi$ | seen | 440 |
| $\Sigma \pi$ | seen | 387 |

$\Sigma(1670) \ 3/2^{-1}$

$$I(J^P) = 1(\frac{3}{2}^-)$$

Mass m = 1665 to 1685 (≈ 1670) MeV Full width $\Gamma = 40$ to 80 (≈ 60) MeV $p_{\rm beam} = 0.74~{\rm GeV}/c$ $4\pi\lambda^2 = 28.5~{\rm mb}$

| Σ(1670) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|------------|
| NK | 7–13 % | 414 |
| $\Lambda\pi$ | 5-15 % | 448 |
| $\sum \pi$ | 30-60 % | 394 |

Σ(1750) 1/2⁻

$$I(J^P) = 1(\frac{1}{2}^-)$$

Mass m=1730 to $1800~(\approx 1750)~{\rm MeV}$ Full width $\Gamma=60$ to $160~(\approx 90)~{\rm MeV}$ $p_{{\rm beam}}=0.91~{\rm GeV}/c$ $4\pi\lambda^2=20.7~{\rm mb}$

| Σ(1750) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| NK | 10-40 % | 486 |
| $\Lambda\pi$ | seen | 507 |
| $\Sigma \pi$ | <8 % | 45 6 |
| $\Sigma \eta$ | 15-55 % | 98 |

Σ(1775) 5/2⁻

$$I(J^P) = 1(\frac{5}{2}^-)$$

Mass m=1770 to $1780~(\approx 1775)~{\rm MeV}$ Full width $\Gamma=105$ to $135~(\approx 120)~{\rm MeV}$ $p_{{\rm beam}}=0.96~{\rm GeV}/c~4\pi\lambda^2=19.0~{\rm mb}$

| Σ (1775) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|------------------------------|-----------|
| NK | 37-43% | 508 |
| $\Lambda\pi$ | 14-20% | 525 |
| $\Sigma \pi$ | 2-5% | 475 |
| $\Sigma(1385)\pi$ | 8-12% | 327 |
| $\Lambda(1520)\pi$ | 17-23% | 201 |

Σ(1915) 5/2⁺

$$I(J^P) = 1(\frac{5}{2}^+)$$

Mass m=1900 to 1935 (\approx 1915) MeV Full width $\Gamma=80$ to 160 (\approx 120) MeV $p_{\mathrm{beam}}=1.26~\mathrm{GeV}/c$ $4\pi\lambda^2=12.8~\mathrm{mb}$

| Σ(1915) DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|---------------------|------------------------------|------------|
| NK | 5-15 % | 618 |
| $\Lambda\pi$ | seen | 623 |
| $\Sigma \pi$ | seen | 577 |
| $\Sigma(1385)\pi$ | <5 % | 443 |

Σ(1940) 3/2⁻

$$I(J^P) = 1(\frac{3}{2}^-)$$

Mass m=1900 to 1950 (\approx 1940) MeV Full width $\Gamma=150$ to 300 (\approx 220) MeV $p_{\mathrm{beam}}=1.32~\mathrm{GeV}/c$ $4\pi\lambda^2=12.1~\mathrm{mb}$

| Σ (1940) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|------------------------------|-----------|
| NK | <20 % | 637 |
| $\Lambda\pi$ | seen | 640 |
| $\Sigma \pi$ | seen | 595 |
| $\Sigma(1385)\pi$ | seen | 463 |
| Λ (1520) π | seen | 355 |
| $\Delta(1232)\overline{K}$ | seen | 410 |
| N K* (892) | seen | 322 |
| | | |

Σ(2030) 7/2⁺

$$I(J^P) = 1(\frac{7}{2}^+)$$

Mass m=2025 to 2040 (\approx 2030) MeV Full width $\Gamma=150$ to 200 (\approx 180) MeV $p_{\mathrm{beam}}=1.52~\mathrm{GeV}/c$ $4\pi\lambda^2=9.93~\mathrm{mb}$

| Σ(2030) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) | |
|------------------------------|------------------------------|------------|--|
| NK | 17-23 % | 702 | |
| $\Lambda\pi$ | 17-23 % | 700 | |
| $\Sigma \pi$ | 5-10 % | 65 7 | |
| $\equiv K$ | <2 % | 422 | |
| $\Sigma(1385)\pi$ | 5-15 % | 532 | |
| $\Lambda(1520)\pi$ | 10-20 % | 430 | |
| $\Delta(1232)\overline{K}$ | 10-20 % | 498 | |
| <i>N</i> K *(892) | <5 % | 439 | |

Σ(2250)

$$I(J^P) = 1(??)$$

Mass m=2210 to 2280 (≈ 2250) MeV Full width $\Gamma=60$ to 150 (≈ 100) MeV $p_{\mathrm{beam}}=2.04~\mathrm{GeV}/c$ $4\pi\lambda^2=6.76~\mathrm{mb}$

| Σ(2250) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| NK | <10 % | 851 |
| $\Lambda\pi$ | seen | 842 |
| $\Sigma \pi$ | seen | 803 |

Ξ BARYONS (S=-2, l=1/2)

$$\Xi^0 = uss$$
, $\Xi^- = dss$

Ξ0

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

P is not yet measured; + is the quark model prediction.

Mass
$$m=1314.86\pm0.20$$
 MeV $m_{\Xi^-}-m_{\Xi^0}=6.85\pm0.21$ MeV Mean life $\tau=(2.90\pm0.09)\times10^{-10}$ s $c\tau=8.71$ cm

Magnetic moment $\mu = -1.250 \pm 0.014~\mu_{N}$

Decay parameters

$$\begin{array}{lll} \varLambda \pi^0 & \alpha = -0.406 \pm 0.013 \\ \text{"} & \phi = (21 \pm 12)^\circ \\ \text{"} & \gamma = 0.85 \, [k] \\ \text{"} & \Delta = (218 \frac{+12}{-19})^\circ \, [k] \\ \varLambda \gamma & \alpha = -0.70 \pm 0.07 \\ \varLambda e^+ \, e^- & \alpha = -0.8 \pm 0.2 \\ \Sigma^0 \, \gamma & \alpha = -0.69 \pm 0.06 \\ \Sigma^+ \, e^- \overline{\nu}_e & g_1(0)/f_1(0) = 1.21 \pm 0.05 \\ \Sigma^+ \, e^- \overline{\nu}_e & f_2(0)/f_1(0) = 2.0 \pm 1.3 \end{array}$$

| ≡ 0 DECAY MODES | Frac | ction (Γ_i/Γ) | Confidence level | (Me V/c) |
|--------------------------------------|-----------------------|-------------------------------------------------|-----------------------------|-----------|
| $\Lambda\pi^0$ | (' | 99.5 25 ± 0.01 2) | % | 135 |
| $\Lambda\gamma$ | (| 1.17 ± 0.07) | $\times 10^{-3}$ | 184 |
| ∧ e ⁺ e [−] | (| 7.6 ± 0.6) | $\times 10^{-6}$ | 184 |
| $\Sigma^0 \gamma$ | (| 3.33 ± 0.10) | $\times 10^{-3}$ | 117 |
| $\Sigma^+ e^- \overline{ u}_e$ | (| $2.53\ \pm0.08\)$ | $\times 10^{-4}$ | 120 |
| $\Sigma^+ \mu^- \overline{ u}_{\mu}$ | (| $4.6 \begin{array}{c} +1.8 \\ -1.4 \end{array}$ | $\times10^{-6}$ | 64 |
| | $= \Delta Q (SQ)$ vio | | | |
| $\Sigma^-e^+ u_e$ | SQ < | 9 | × 10 ⁻⁴ 90% | 112 |
| $\Sigma^- \mu^+ u_{\mu}$ | SQ < | 9 | $\times10^{-4}\qquad 90\%$ | 49 |
| $p\pi^-$ | 52 < | | $\times 10^{-6}$ 90% | 299 |
| $p e^- \overline{\nu}_e$ | 52 < | 1.3 | $\times 10^{-3}$ | 323 |
| $p\mu^-\overline{\nu}_{\mu}$ | 52 < | 1.3 | $\times 10^{-3}$ | 309 |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

P is not yet measured; + is the quark model prediction.

Mass
$$m=1321.71\pm0.07$$
 MeV $(m_{\Xi^-}-m_{\overline{\Xi}^+})\ /\ m_{\Xi^-}=(-3\pm9)\times 10^{-5}$ Mean life $\tau=(1.639\pm0.015)\times 10^{-10}$ s $c\tau=4.91$ cm $(\tau_{\Xi^-}-\tau_{\overline{\Xi}^+})\ /\ \tau_{\Xi^-}=-0.01\pm0.07$ Magnetic moment $\mu=-0.6507\pm0.0025\ \mu_N$ $(\mu_{\Xi^-}+\mu_{\overline{\Xi}^+})\ /\ |\mu_{\Xi^-}|=+0.01\pm0.05$

Decay parameters

$$\begin{array}{lll} \varLambda\pi^{-} & \alpha = -0.458 \pm 0.012 & (S = 1.8) \\ [\alpha(\Xi^{-})\alpha_{-}(\varLambda) - \alpha(\overline{\Xi}^{+})\alpha_{+}(\overline{\varLambda})] \ / \ [\, sum\,] = (0 \pm 7) \times 10^{-4} \\ " & \phi = (-2.1 \pm 0.8)^{\circ} \\ " & \gamma = 0.89 \, [k] \\ " & \Delta = (175.9 \pm 1.5)^{\circ} \, [k] \\ \varLambda e^{-}\overline{\nu}_{e} & g_{A}/g_{V} = -0.25 \pm 0.05 \, [g] \end{array}$$

| ≡ − DECAY MODES | | Fraction (Γ_i/Γ) | Confiden | ce level | <i>p</i> (MeV/ <i>c</i>) |
|---------------------------------------|--------------------|--------------------------------------------------|---------------------|----------|-------------------------------|
| $\Lambda\pi^-$ | | (99.887±0.0 | 35)% | | 140 |
| $\Sigma^- \gamma$ | | (1.27 ± 0.2) | $3) \times 10^{-4}$ | | 118 |
| $\Lambda e^- \overline{\nu}_e$ | | (5.63 ± 0.3) | $1) \times 10^{-4}$ | | 190 |
| $\Lambda \mu^- \overline{ u}_\mu$ | | $(3.5 \begin{array}{c} +3.5 \\ -2.2 \end{array}$ | $) \times 10^{-4}$ | | 163 |
| $\Sigma^0 e^- \overline{\nu}_e$ | | (8.7 ±1.7 | $) \times 10^{-5}$ | | 123 |
| $\Sigma^0 \mu^- \overline{\nu}_{\mu}$ | | < 8 | $\times 10^{-4}$ | 90% | 70 |
| $\equiv^0 e^- \overline{\nu_e}$ | | < 2.3 | $\times 10^{-3}$ | 90% | 7 |
| | $\Delta S = 2$ for | bidden (S2) mo | od es | | |
| $n\pi^-$ | 52 | < 1.9 | $\times 10^{-5}$ | 90% | 304 |
| n e $^-\overline{ u}_e$ | 52 | < 3.2 | $\times 10^{-3}$ | 90% | 327 |
| n $\mu^-\overline{ u}_\mu$ | 52 | < 1.5 | % | 90% | 314 |
| $p\pi^-\pi^-$ | 52 | < 4 | $\times 10^{-4}$ | 90% | 223 |
| $p \pi^- e^- \overline{\nu}_e$ | 52 | < 4 | $\times 10^{-4}$ | 90% | 305 |
| $ ho \pi^- \mu^- \overline{ u}_{\mu}$ | 52 | < 4 | $\times 10^{-4}$ | 90% | 251 |
| $p \mu^{-} \mu^{-}$ | L | < 4 | $\times 10^{-8}$ | 90% | 272 |

Ξ(1530) 3/2⁺

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

 $\Xi(1530)^0$ mass $m = 1531.80 \pm 0.32$ MeV (S = 1.3)

 $\Xi(1530)^{-}$ mass $m = 1535.0 \pm 0.6$ MeV

 $\varXi(1530)^0$ full width $\Gamma=9.1\pm0.5~\text{MeV}$

 $\dot{\Xi(1530)^-} full \ width \ \Gamma = 9.9^{+1.7}_{-1.9} \ \text{MeV}$

| ≡(1530) DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c |
|-----------------------------|------------------------------|------------------|--------------|
| $\Xi \pi$ | 100 % | | 158 |
| $\equiv \gamma$ | <4 % | 90% | 202 |

Ξ(1690)

$$I(J^P) = \frac{1}{2}(??)$$

Mass m= 1690 \pm 10 MeV $^{[m]}$ Full width $\Gamma <$ 30 MeV

| ≡ (1690) DECAY MODES | Fraction (Γ_i/Γ) | $p \; (\; \text{MeV/}c)$ |
|-----------------------------|------------------------------|--------------------------|
| $\Lambda \overline{K}$ | seen | 240 |
| $\Sigma \overline{K}$ | seen | 70 |
| $\equiv \pi$ | seen | 311 |
| $\Xi^-\pi^+\pi^-$ | possibly seen | 213 |

Ξ(1820) 3/2[—]

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Mass m= 1823 \pm 5 MeV $^{[m]}$ Full width $\Gamma=$ 24 $^{+$ 15 $_{-}$ 10 MeV $^{[m]}$

| Ξ (1820) DECAY MODES | Fraction (Γ_i/Γ) | ρ (MeV/c) |
|-----------------------------|------------------------------|------------|
| $\Lambda \overline{K}$ | large | 402 |
| $\Sigma \overline{K}$ | small | 324 |
| $\Xi \pi$ | small | 421 |
| $\Xi(1530)\pi$ | small | 237 |

≡(1950)

$$I(J^P) = \frac{1}{2}(??)$$

Mass $m = 1950 \pm 15 \text{ MeV} [m]$ Full width $\Gamma = 60 \pm 20 \text{ MeV} [m]$

| ≡ (1950) DECAY MODES | Fraction (Γ_i/Γ) | $p \; (\; \text{MeV/}c)$ |
|-----------------------------|------------------------------|--------------------------|
| $\Lambda \overline{K}$ | seen | 522 |
| $\Sigma \overline{K}$ | possibly seen | 460 |
| $\Xi \pi$ | seen | 519 |

$\Xi(2030)$

$$I(J^P) = \frac{1}{2} (\geq \frac{5}{2}?)$$

Mass $m=2025\pm 5~{\rm MeV}~{}^{[m]}$ Full width $\Gamma=20^{+15}_{-5}~{\rm MeV}~{}^{[m]}$

| Ξ (2030) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|------------------------------|-----------|
| $\Lambda \overline{K}$ | ~ 20 % | 585 |
| $\Sigma \overline{K}$ | \sim 80 % | 529 |
| $\Xi \pi$ | small | 574 |
| $\Xi(1530)\pi$ | small | 416 |
| $\Lambda \overline{K} \pi$ | small | 499 |
| $\Sigma \overline{K} \pi$ | small | 428 |

Ω BARYONS (S=-3, I=0)

$$\Omega^- = sss$$

Ω-

$$I(J^P) = O(\frac{3}{2}^+)$$

 $J^P = \frac{3}{2}^+$ is the quark-model prediction; and J = 3/2 is fairly well established.

$$\begin{array}{l} \text{Mass } m = 1672.45 \pm 0.29 \; \text{MeV} \\ \left(m_{\varOmega^-} - m_{\overline{\Omega}^+}\right) \ / \ m_{\varOmega^-} = (-1 \pm 8) \times 10^{-5} \\ \text{Mean life } \tau = (0.821 \pm 0.011) \times 10^{-10} \; \text{s} \\ c\tau = 2.461 \; \text{cm} \\ \left(\tau_{\varOmega^-} - \tau_{\overline{\varOmega}^+}\right) \ / \ \tau_{\varOmega^-} = 0.00 \pm 0.05 \\ \text{Magnetic moment } \mu = -2.02 \pm 0.05 \; \mu_N \end{array}$$

Decay parameters

$$\begin{array}{ll} \varLambda K^{-} & \alpha = 0.0180 \pm 0.0024 \\ \varLambda K^{-}, \, \overline{\varLambda} K^{+} & (\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) = -0.02 \pm 0.13 \\ \Xi^{0} \, \pi^{-} & \alpha = 0.09 \pm 0.14 \\ \Xi^{-} \, \pi^{0} & \alpha = 0.05 \pm 0.21 \end{array}$$

| Ω- DECAY MODES | Fraction (Γ_i) | Γ) Confidence level | <i>p</i> (Me <i>V/c</i>) |
|--------------------------------------------------|---------------------------------|----------------------|-------------------------------|
| ΛK- | (67.8 ± 0.7) | % | 211 |
| $\Xi^0 \pi^-$ | (23.6 ± 0.7) | % | 294 |
| $= -\pi^0$ | (8.6 ± 0.4) | % | 289 |
| $\Xi^-\pi^+\pi^-$ | (3.7 + 0.7) | $) \times 10^{-4}$ | 189 |
| $\Xi (1530)^0 \pi^- \Xi^0 e^- \overline{\nu}_e$ | < 7 | $\times10^{-5}$ 90% | 17 |
| $\Xi^0 e^- \overline{\nu}_e$ | (5.6 ± 2.8) | $\times 10^{-3}$ | 319 |
| $\Xi^-\gamma$ | < 4.6 | $\times 10^{-4}$ 90% | 314 |
| | $\Delta S = 2$ forbidden (S2) n | nodes | |
| $\Lambda\pi^-$ | S2 < 2.9 | $\times 10^{-6}$ 90% | 449 |

$\Omega(2250)^{-}$

$$I(J^P) = 0(??)$$

Mass $m=2252\pm 9~{\rm MeV}$ Full width $\Gamma=55\pm 18~{\rm MeV}$

| $\Omega(2250)^-$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------|------------------------------|------------|
| $\Xi^-\pi^+K^-$ | seen | 532 |
| $\Xi(1530)^0 K^-$ | seen | 437 |

CHARMED BARYONS (C=+1)

$$\begin{array}{lll} \varLambda_c^+ = u\, d\, c, & \varSigma_c^{\,++} = u\, u\, c, & \varSigma_c^+ = u\, d\, c, & \varSigma_c^0 = d\, d\, c, \\ & \Xi_c^+ = u\, s\, c, & \Xi_c^0 = d\, s\, c, & \varOmega_c^0 = s\, s\, c \end{array}$$



$$I(J^P) = 0(\frac{1}{2}^+)$$

J is not well measured; $\frac{1}{2}$ is the quark-model prediction.

Mass
$$m=2286.46\pm0.14$$
 MeV Mean life $\tau=(200\pm6)\times10^{-15}$ s (S = 1.6) $c\tau=59.9~\mu\mathrm{m}$

Decay asymmetry parameters

```
\alpha = -0.91 \pm 0.15
\Lambda \pi^+
\Sigma^+\pi^0
                                           \alpha = -0.45 \pm 0.32
                                       \alpha = -0.86 \pm 0.04
\begin{array}{ll} (\alpha+\overline{\alpha})/(\alpha-\overline{\alpha}) \text{ in } \Lambda_c^+ \to \Lambda \pi^+, \, \overline{\Lambda_c^-} \to \overline{\Lambda} \pi^- = -0.07 \pm 0.31 \\ (\alpha+\overline{\alpha})/(\alpha-\overline{\alpha}) \text{ in } \Lambda_c^+ \to \Lambda e^+ \nu_e, \, \overline{\Lambda_c^-} \to \overline{\Lambda} e^- \overline{\nu}_e = 0.00 \pm 0.04 \end{array}
```

Nearly all branching fractions of the $\Lambda_{\mathcal{C}}^+$ are measured relative to the $p\ K^-\pi^+$ mode, but there are no model-independent measurements of this branching fraction. We explain how we arrive at our value of $B(\Lambda_c^+ \to 0)$ $ho \, K^- \, \pi^+)$ in a Note at the beginning of the branching-ratio measurements in the Listings. When this branching fraction is eventually well determined, all the other branching fractions will slide up or down proportionally as the true value differs from the value we use here.

| A+ DECAY | MODES |
|----------|-------|
|----------|-------|

Scale factor / Fraction (Γ_i/Γ) Confidence level (MeV/c)

| Hadronic mode | s with a | p: S = -1 final states | |
|-----------------------------------------|----------|--------------------------------|------|
| $p\overline{K}^0$ | | $(2.3 \pm 0.6)\%$ | 873 |
| $pK^-\pi^+$ | [0] | $(5.0 \pm 1.3)\%$ | 823 |
| p K *(892) ⁰ | $[\rho]$ | $(1.6 \pm 0.5)\%$ | 685 |
| Δ (1232) ⁺⁺ K^- | | $(8.6 \pm 3.0) \times 10^{-3}$ | 710 |
| $\Lambda(1520) \pi^{+}$ | $[\rho]$ | $(1.8 \pm 0.6)\%$ | 627 |
| $p K^- \pi^+$ nonresonant | | $(2.8 \pm 0.8)\%$ | 823 |
| $p \overline{K}^0 \pi^0$ | | $(3.3 \pm 1.0)\%$ | 823 |
| $p\overline{K}^0\eta$ | | $(1.2 \pm 0.4)\%$ | 568 |
| $p \overline{K}{}^0 \pi^+ \pi^-$ | | $(2.6 \pm 0.7)\%$ | 754 |
| $pK^-\pi^+\pi^0$ | | $(3.4 \pm 1.0)\%$ | 75 9 |
| p K*(892) ⁻ π ⁺ | [p] | $(1.1 \pm 0.5)\%$ | 580 |
| $p(K^-\pi^+)_{\text{nonresonant}}\pi^0$ | | $(3.6 \pm 1.2)\%$ | 75 9 |
| $\Delta(1232) \overline{K}^*(892)$ | | seen | 419 |
| $pK^{-}\pi^{+}\pi^{+}\pi^{-}$ | | $(1.1 \pm 0.8) \times 10^{-3}$ | 671 |
| $p K^- \pi^+ \pi^0 \pi^0$ | | $(8 \pm 4) \times 10^{-3}$ | 678 |

Hadronic modes with a p: S = 0 final states

| $\rho \pi^+ \pi^-$ | $(3.5 \pm 2.0) \times 10^{-3}$ | 927 |
|------------------------------------|--------------------------------|------|
| $p f_0(980)$ [p | $[2.8 \pm 1.9] \times 10^{-3}$ | 614 |
| $\rho \pi^+ \pi^+ \pi^- \pi^-$ | $(1.8 \pm 1.2) \times 10^{-3}$ | 85 2 |
| ρK ⁺ K ⁻ | $(7.7 \pm 3.5) \times 10^{-4}$ | 616 |
| $\rho \phi$ [ρ | $[8.2 \pm 2.7] \times 10^{-4}$ | 590 |
| $ ho K^+ K^-$ non- ϕ | $(3.5 \pm 1.7) \times 10^{-4}$ | 616 |

| p κ ' κ non- ϕ | $(3.5 \pm 1.7) \times 10^{-4}$ | | 616 |
|-----------------------------------------------------------------------|-----------------------------------------------------|--------|------|
| | a hyperon: $S = -1$ final s | tates | |
| $\Lambda \pi^+$ | (1.07 ± 0.28) % | | 864 |
| $\Lambda \pi^+ \pi^0$ | $(3.6 \pm 1.3)\%$ | | 844 |
| $\Lambda \rho^+$ | < 5 % | CL=95% | 635 |
| $\Lambda \pi^+ \pi^+ \pi^-$ | $(2.6 \pm 0.7)\%$ | | 807 |
| $\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} ightarrow$ | $(7 \pm 4) \times 10^{-3}$ | | 688 |
| $\Sigma (1385)^-\pi^+\pi^+$, $\Sigma^{*-} ightarrow$ | (5.5 \pm 1.7) $\times10^{-3}$ | | 688 |
| $\Lambda\pi^- \Lambda\pi^+ ho^0$ | $(1.1 \pm 0.5)\%$ | | 523 |
| Σ (1385) $^+$ $ ho^0$, $\Sigma^{*+} ightarrow \Lambda \pi^+$ | $(3.7 \pm 3.1) \times 10^{-3}$ | | 363 |
| $\Lambda \hat{\pi}^+ \pi^+ \hat{\pi}^-$ nonresonant | < 8 ×10 ⁻³ | CL=90% | 807 |
| $\Lambda \pi^+ \pi^+ \pi^- \pi^0$ total | $(1.8 \pm 0.8)\%$ | | 75 7 |
| $\Lambda \pi^+ \eta$ | [p] (1.8 ± 0.6) % | | 691 |
| $\Sigma(1385)^+\eta$ | [p] (8.5 \pm 3.3) \times 10 ⁻³ | | 570 |
| $\Lambda\pi^+\omega$ | [p] (1.2 ± 0.5) % | | 517 |
| $\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω | $< 7 \times 10^{-3}$ | CL=90% | 75 7 |
| $\Lambda K^+ \overline{K}{}^0$ | $(4.7 \pm 1.5) \times 10^{-3}$ | S=1.2 | 443 |
| $\Xi(1690)^0K^+$, $\Xi^{*0} ightarrow \Lambda \overline{K}{}^0$ | $(1.3 \pm 0.5) \times 10^{-3}$ | | 286 |
| $\Sigma^0 \pi^+$ | $(1.05 \pm 0.28) \%$ | | 825 |
| $\Sigma^+\pi^0$ | (1.00 ± 0.34) % | | 827 |
| $\Sigma^+ \eta$ | $(5.5 \pm 2.3) \times 10^{-3}$ | | 713 |
| $\Sigma^+\pi^+\pi^-$ | $(3.6 \pm 1.0)\%$ | | 804 |
| $\Sigma^+ ho^0$ | < 1.4 % | CL=95% | 575 |
| $\Sigma^-\pi^+\pi^+$ | $(1.7 \pm 0.5)\%$ | | 799 |
| $\Sigma^0_{}\pi^+\pi^0$ | $(1.8 \pm 0.8)\%$ | | 803 |
| $\Sigma^0 \pi^+ \pi^+ \pi^-$ | $(8.3 \pm 3.1) \times 10^{-3}$ | | 763 |
| $\Sigma^+\pi^+\pi^-\pi^0$ | _ | | 767 |
| $\Sigma^+\omega$ | [p] (2.7 ± 1.0) % | | 569 |
| $\Sigma^+ K^+ K^-$ | $(2.8 \pm 0.8) \times 10^{-3}$ | | 349 |
| $\Sigma^+\phi$ | [p] (3.1 \pm 0.9) \times 10 ⁻³ | | 295 |
| $\Xi(1690)^0K^+$, $\Xi^{*0} ightarrow$ | $(8.1 \pm 3.0) \times 10^{-4}$ | | 286 |
| $\Sigma^+ K^+ K^-$ nonresonant | $< 6 \times 10^{-4}$ | CL=90% | 349 |
| $\equiv^0 K^+$ | $(3.9 \pm 1.4) \times 10^{-3}$ | , • | 65 3 |
| $\Xi^-K^+\pi^+$ | $(5.1 \pm 1.4) \times 10^{-3}$ | | 565 |
| $\Xi(1530)^0 K^+$ | $[\rho]$ (2.6 ± 1.0) × 10 ⁻³ | | 473 |

| Hadronic modes with a hyperon: $S = 0$ final state | Hadronic m | odes with a | hvperon: | S = 0 | final states |
|----------------------------------------------------|------------|-------------|----------|-------|--------------|
|----------------------------------------------------|------------|-------------|----------|-------|--------------|

| ΛK^+ | (5.0 ± 1) | $1.6) \times 10^{-4}$ | | 781 |
|-----------------------------|------------------------|-----------------------|---------------|-----|
| $\Lambda K^+ \pi^+ \pi^-$ | < 4 | $\times 10^{-4}$ | CL=90% | 637 |
| $\Sigma^0 K^+$ | (4.2 ± 1) | $1.3) \times 10^{-4}$ | | 735 |
| $\Sigma^0 K^+ \pi^+ \pi^-$ | < 2.1 | $\times 10^{-4}$ | CL=90% | 574 |
| $\Sigma^+ K^+ \pi^-$ | (1.7 ± 0) | $0.7) \times 10^{-3}$ | | 670 |
| $\Sigma^{+} K^{*}(892)^{0}$ | $[\rho]$ (2.8 \pm 1 | $1.1) \times 10^{-3}$ | | 470 |
| $\Sigma^- K^+ \pi^+$ | < 1.0 | $\times 10^{-3}$ | $CL\!=\!90\%$ | 664 |
| | | | | |

Doubly Cabibbo-suppressed modes $\times\,10^{-4}$ CL=90%

< 2.3

823

| | Semileptonic modes | |
|---------------------------|-------------------------|-----|
| $\Lambda \ell^+ \nu_\ell$ | [q] (2.0 \pm 0.6) % | 871 |
| Λ $e^+ \nu_e$ | $(2.1 \pm 0.6)\%$ | 871 |
| $\Lambda \mu^+ u_\mu$ | $(2.0 \pm 0.7)\%$ | 867 |

Inclusive modes

| e^+ anything | | (4.5 | \pm 1.7 |) % | | - |
|------------------------------|-----|------|------------|-----|-------|---|
| $p e^+$ anything | | (1.8 | $\pm\ 0.9$ |) % | | - |
| p anything | | (50 | ± 16 |) % | | - |
| ho anything (no $arLambda$) | | (12 | ± 19 |) % | | - |
| n anything | | (50 | ± 16 |) % | | - |
| n anything (no $arLambda$) | | (29 | ± 17 |) % | | - |
| Λ anything | | (35 | ±11 |) % | S=1.4 | - |
| $arSigma^\pm$ anything | [r] | (10 | \pm 5 |) % | | - |
| 3prongs | | (24 | ± 8 |) % | | - |
| | | | | | | |

$\Delta C = 1$ weak neutral current (C1) modes, or Lepton Family number (LF), or Lepton number (L), or Baryon number (B) violating modes

| | • | . , | - | | |
|---------------------------------|-----|-------|------------------|--------|-----|
| p e ⁺ e ⁻ | C1 | < 5.5 | $\times 10^{-6}$ | CL=90% | 951 |
| $p\mu^+\mu^-$ | C1 | < 4.4 | | CL=90% | 937 |
| p e $^+\mu^-$ | LF | < 9.9 | $\times 10^{-6}$ | CL=90% | 947 |
| p e $^-\mu^+$ | LF | < 1.9 | $\times 10^{-5}$ | CL=90% | 947 |
| <u></u> 7 2 e ⁺ | L,B | < 2.7 | | CL=90% | 951 |
| $\overline{p} 2\mu^+$ | L,B | < 9.4 | $\times 10^{-6}$ | CL=90% | 937 |
| $\overline{p} e^+ \mu^+$ | L,B | < 1.6 | $\times 10^{-5}$ | CL=90% | 947 |
| $\Sigma^- \mu^+ \mu^+$ | L | < 7.0 | $\times 10^{-4}$ | CL=90% | 812 |
| | | | | | |

$\Lambda_c(2595)^+$

 $pK^+\pi^-$

$$I(J^P) = 0(\frac{1}{2})$$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant. This assumes that ${\it J}^{\it P}=$ $1/2^{+}$ for the $\Sigma_{c}(2455)$.

Mass
$$m=2592.25\pm0.28$$
 MeV $m-m_{\Lambda_c^+}=305.79\pm0.24$ MeV Full width $\Gamma=2.6\pm0.6$ MeV

 $\Lambda_{C}^{+}\pi\pi$ and its submode $\Sigma_{C}(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_{C}^{+} having this mass; and the submode seems to dominate.

| 1 _c (2595)+ DECAY MODES | Fraction (Γ _i /Γ) | p (MeV/c) |
|------------------------------------------|------------------------------|-----------|
| $\Lambda_c^+ \pi^+ \pi^-$ | [s] ≈ 67 % | 117 |
| $\Sigma_c(2455)^{++}\pi^-$ | 24 ± 7 % | † |
| $\Sigma_c(2455)^0\pi^+$ | 24 ± 7 % | † |
| $\Lambda_c^+ \pi^+ \pi^-$ 3-body | 18 \pm 10 $\%$ | 117 |
| $\Lambda_c^+ \pi^0$ $\Lambda_c^+ \gamma$ | [t] not seen | 25 8 |
| $\Lambda_c^+ \gamma$ | not seen | 288 |

$\Lambda_c(2625)^+$

$$I(J^P) = 0(\frac{3}{2}^-)$$

 J^P has not been measured; $\frac{3}{2}$ is the quark-model prediction.

Mass
$$m=2628.11\pm0.19$$
 MeV (S = 1.1) $m-m_{\Lambda_c^+}=341.65\pm0.13$ MeV (S = 1.1) Full width Γ < 0.97 MeV, CL = 90%

 Λ_c^+ π and its submode $\Sigma(2455)\,\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

| Λ _C (2625) ⁺ DECAY MODES | Fraction (Γ_i/Γ) | Confidence level | p (MeV/c) |
|------------------------------------------------|------------------------------|------------------|---------------|
| $\Lambda_c^+ \pi^+ \pi^-$ | [s] ≈ 67% | | 184 |
| $\Sigma_c(2455)^{++}\pi^-$ | <5 | 90% | 102 |
| $\Sigma_c(2455)^0 \pi^+$ | <5 | 90% | 102 |
| $\Lambda_c^+ \pi^+ \pi^-$ 3-body | large | | 184 |
| $\Lambda_c^+ \pi^0$ | [t] not seen | | 293 |
| $\Lambda_c^+ \gamma$ | not seen | | 319 |

$\Lambda_c(2880)^+$

$$I(J^P)=0(\tfrac{5}{2}^+)$$

There is some good evidence that indeed $J^P = 5/2^+$

Mass
$$m=2881.53\pm0.35$$
 MeV $m-m_{A_c^+}=595.1\pm0.4$ MeV Full width $\Gamma=5.8\pm1.1$ MeV

| Λ _C (2880)+ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------------|------------------------------|-----------|
| $\Lambda_c^+ \pi^+ \pi^-$ | seen | 471 |
| $\Sigma_c(2455)^{0}, ++\pi^{\pm}$ | seen | 376 |
| $\Sigma_c(2520)^0, ++\pi^{\pm}$ pD^0 | seen | 317 |
| p D ⁰ | seen | 316 |

$\Lambda_c(2940)^+$

$$I(J^P) = 0(??)$$

Mass
$$m=2939.3^{+1.4}_{-1.5}~{\rm MeV}$$

Full width $\Gamma=17^{+8}_{-6}~{\rm MeV}$

| 1 _c (2940)+ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------|------------------------------|-----------|
| p D ⁰ | seen | 420 |
| $\Sigma_c(2455)^{0,++}\pi^{\pm}$ | seen | = |

$\Sigma_c(2455)$

$$I(J^P) = 1(\frac{1}{2}^+)$$

$$\begin{split} & \Sigma_c(2455)^{++} \text{mass } m = 2453.98 \pm 0.16 \text{ MeV} \\ & \Sigma_c(2455)^{+} \quad \text{mass } m = 2452.9 \pm 0.4 \text{ MeV} \\ & \Sigma_c(2455)^{0} \quad \text{mass } m = 2453.74 \pm 0.16 \text{ MeV} \\ & M_{\Sigma_c^{+}} - M_{\Lambda_c^{+}} = 167.52 \pm 0.08 \text{ MeV} \\ & M_{\Sigma_c^{+}} - M_{\Lambda_c^{+}} = 166.4 \pm 0.4 \text{ MeV} \\ & M_{\Sigma_c^{0}} - M_{\Lambda_c^{+}} = 167.27 \pm 0.08 \text{ MeV} \\ & M_{\Sigma_c^{0}} - M_{\Lambda_c^{+}} = 167.27 \pm 0.09 \text{ MeV} \quad (\text{S} = 1.1) \\ & M_{\Sigma_c^{++}} - M_{\Sigma_c^{0}} = 0.24 \pm 0.09 \text{ MeV} \quad (\text{S} = 1.1) \\ & M_{\Sigma_c^{++}} - M_{\Sigma_c^{0}} = -0.9 \pm 0.4 \text{ MeV} \\ & \Sigma_c(2455)^{++} \text{full width } \Gamma = 2.26 \pm 0.25 \text{ MeV} \\ & \Sigma_c(2455)^{0} \quad \text{full width } \Gamma < 4.6 \text{ MeV, CL} = 90\% \\ & \Sigma_c(2455)^{0} \quad \text{full width } \Gamma = 2.16 \pm 0.26 \text{ MeV} \quad (\text{S} = 1.1) \end{split}$$

 $\Lambda_C^+\pi$ is the only strong decay allowed to a Σ_C having this mass.

| Σ_c (2455) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| $\Lambda_c^+ \pi$ | $\approx 100~\%$ | 94 |

$\Sigma_c(2520)$

$$I(J^P) = 1(\frac{3}{2}^+)$$

 J^P has not been measured; $\frac{3}{2}$ is the quark-model prediction.

$$\begin{split} & \Sigma_c(2520)^{++} \text{mass } m = 2517.9 \pm 0.6 \text{ MeV} \quad \text{(S} = 1.6) \\ & \Sigma_c(2520)^{+} \quad \text{mass } m = 2517.5 \pm 2.3 \text{ MeV} \\ & \Sigma_c(2520)^{0} \quad \text{mass } m = 2518.8 \pm 0.6 \text{ MeV} \quad \text{(S} = 1.5) \\ & m_{\Sigma_c(2520)^{++}} - m_{\Lambda_c^+} = 231.4 \pm 0.6 \text{ MeV} \quad \text{(S} = 1.6) \\ & m_{\Sigma_c(2520)^{+}} - m_{\Lambda_c^+} = 231.0 \pm 2.3 \text{ MeV} \\ & m_{\Sigma_c(2520)^{0}} - m_{\Lambda_c^+} = 232.3 \pm 0.5 \text{ MeV} \quad \text{(S} = 1.6) \\ & m_{\Sigma_c(2520)^{++}} - m_{\Sigma_c(2520)^{0}} \\ & \Sigma_c(2520)^{++} \quad \text{full width } \Gamma = 14.9 \pm 1.5 \text{ MeV} \\ & \Sigma_c(2520)^{+} \quad \text{full width } \Gamma < 17 \text{ MeV, CL} = 90\% \\ & \Sigma_c(2520)^{0} \quad \text{full width } \Gamma = 14.5 \pm 1.5 \text{ MeV} \end{split}$$

 $\Lambda_{C}^{+}\pi$ is the only strong decay allowed to a Σ_{C} having this mass.

| $\Sigma_{c}(2520)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------|------------------------------|-----------|
| $\Lambda_c^+\pi$ | ≈ 100 % | 179 |

$\Sigma_c(2800)$

$$I(J^P) = 1(??)$$

$$\begin{split} &\Sigma_c(2800)^{++} \text{ mass } m = 2801^{+4}_{-6} \text{ MeV} \\ &\Sigma_c(2800)^+ \text{ mass } m = 2792^{+14}_{-5} \text{ MeV} \\ &\Sigma_c(2800)^0 \text{ mass } m = 2806^{+5}_{-7} \text{ MeV} \quad \text{(S = 1.3)} \\ &m_{\Sigma_c(2800)^{++}} - m_{\Lambda_c^+} = 514^{+4}_{-6} \text{ MeV} \\ &m_{\Sigma_c(2800)^+} - m_{\Lambda_c^+} = 505^{+14}_{-5} \text{ MeV} \\ &m_{\Sigma_c(2800)^0} - m_{\Lambda_c^+} = 519^{+5}_{-7} \text{ MeV} \quad \text{(S = 1.3)} \\ &\Sigma_c(2800)^{++} \text{ full width } \Gamma = 75^{+22}_{-17} \text{ MeV} \\ &\Sigma_c(2800)^+ \text{ full width } \Gamma = 62^{+60}_{-40} \text{ MeV} \\ &\Sigma_c(2800)^0 \text{ full width } \Gamma = 72^{+22}_{-15} \text{ MeV} \end{split}$$

| $\Sigma_{c}(2800)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|--------------------------------|------------------------------|-----------|
| $\Lambda_c^+\pi$ | seen | 443 |

Ξ+

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

 J^P has not been measured; $rac{1}{2}^+$ is the quark-model prediction.

Mass
$$m=2467.8^{+0.4}_{-0.6}~{
m MeV}$$
 Mean life $au=(442\pm26)\times10^{-15}~{
m s}~({
m S}=1.3)$ $c au=132~{
m \mu m}$

E DECAY MODES

Fraction (Γ_i/Γ) Co

pConfidence level (MeV/c)

No absolute branching fractions have been measured. The following are branching ratios relative to $\Xi^-2\pi^+$.

Cabibbo-favored (S = -2) decays

| | cabibbo-lavorca (5 = -2) accays | | |
|---------------------------------------------|---------------------------------|-----|------|
| p2K ⁰ _S | [<i>u</i>] 0.087 ± 0.022 | | 767 |
| $\Lambda \overline{K}^0 \pi^+$ | _ | | 85 2 |
| $\Sigma (1385)^{+} \overline{K}^{0}$ | $[p,u]$ 1.0 \pm 0.5 | | 746 |
| $\Lambda K^- 2\pi^+$ | [u] 0.323 ± 0.033 | | 787 |
| $\Lambda \overline{K}^{*}(892)^{0} \pi^{+}$ | [p,u] < 0.2 | 90% | 608 |
| $\Sigma(1385)^{+} K^{-} \pi^{+}$ | [p,u] < 0.3 | 90% | 678 |
| Σ^+ K $^ \pi^+$ | [u] 0.94 ± 0.11 | | 810 |
| $\Sigma^{+}\overline{K}^{*}(892)^{0}$ | $[\rho, u]$ 0.81 \pm 0.15 | | 658 |
| $\Sigma^{0} K^{-} 2\pi^{+}$ | [u] 0.29 ± 0.16 | | 735 |
| $\Xi^0 \pi^+$ | [u] 0.55 ± 0.16 | | 877 |
| $\Xi^{-}2\pi^{+}$ | [u] DEFINED AS 1 | | 851 |
| $\Xi(1530)^{0}\pi^{+}$ | $[\rho, u] < 0.1$ | 90% | 75 0 |
| $\Xi^{0} \pi^{+} \pi^{0}$ | [u] 2.34 ± 0.68 | | 85 6 |
| $=0$ π^{-} $2\pi^{+}$ | [u] 1.74 ± 0.50 | | 818 |
| $\Xi^0 e^+ u_e$ | $[u]$ 2.3 $^{+0.7}_{-0.9}$ | | 884 |
| Ω^- K $^+$ π^+ | [<i>u</i>] 0.07 ± 0.04 | | 399 |

Cabibbo-suppressed decays

| $pK^-\pi^+$ | [<i>u</i>] | 0.21 | ±0.03 | | 944 |
|--------------------------------------------------|--------------|--------|-----------|-----|-----|
| p K *(892) ⁰ | [p,u] | 0.12 | ±0.02 | | 828 |
| $\Sigma^+\pi^+\pi^-$ | [<i>u</i>] | 0.48 | ±0.20 | | 922 |
| $\Sigma^- 2\pi^+$ | [<i>u</i>] | 0.18 | ±0.09 | | 918 |
| $\Sigma^+ K^+ K^-$ | [<i>u</i>] | 0.15 | ±0.07 | | 579 |
| $\Sigma^+\phi$ | [p,u] | < 0.11 | | 90% | 549 |
| $\varXi(1690)^0K^+$, $\varXi(1690)^0 ightarrow$ | [<i>u</i>] | < 0.05 | | 90% | 501 |
| $\nabla^{\pm} V^{-}$ | | | | | |

Ξ0

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

 J^P has not been measured; $rac{1}{2}^+$ is the quark-model prediction.

Mass
$$m=2470.88^{+0.34}_{-0.80}$$
 MeV (S = 1.1) $m_{\Xi_c^0}-m_{\Xi_c^+}=3.1^{+0.4}_{-0.5}$ MeV Mean life $\tau=(112^{+13}_{-10})\times 10^{-15}$ s $c\tau=33.6~\mu\mathrm{m}$

Decay asymmetry parameters

$$\Xi^- \pi^+ \qquad \alpha = -0.6 \pm 0.4$$

No absolute branching fractions have been measured. Several measurements of ratios of fractions may be found in the Listings that follow.

| Ξ_c^0 decay modes | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------------------------------------------------|------------------------------|-----------|
| p K - K - π + | seen | 676 |
| $p K^{-} \overline{K}^{*} (892)^{0}$ | seen | 413 |
| $pK^-K^-\pi^+$ no \overline{K}^* (892) 0 | seen | 676 |
| $rac{\Lambda K_{\mathcal{S}}^{0}}{\Lambda \overline{K}^{0}}\pi^{+}\pi^{-}$ | seen | 906 |
| $\Lambda \overline{K^0} \pi^+ \pi^-$ | seen | 787 |
| $\Lambda K^{-}\pi^{+}\pi^{+}\pi^{-}$ | seen | 703 |
| $\Xi^-\pi^+$ | seen | 875 |
| $\Xi^-\pi^+\pi^+\pi^-$ | seen | 816 |
| ΩK_+ | seen | 522 |
| $ar{arxi}^-e^+ u_e$ | seen | 882 |
| arxiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiiii | seen | = |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

 J^P has not been measured; $\frac{1}{2}$ is the quark-model prediction.

Mass
$$m = 2575.6 \pm 3.1 \text{ MeV}$$

 $m_{\Xi_c^{\prime +}} - m_{\Xi_c^{+}} = 107.8 \pm 3.0 \text{ MeV}$

The $\Xi_C^{\prime+}-\Xi_C^+$ mass difference is too small for any strong decay to occur.

| E'+ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|---------------------|------------------------------|-----------|
| $\equiv_c^+ \gamma$ | seen | 106 |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

 J^P has not been measured; $rac{1}{2}^+$ is the quark-model prediction.

Mass
$$m = 2577.9 \pm 2.9 \text{ MeV}$$

 $m_{\Xi_c^0} - m_{\Xi_c^0} = 107.0 \pm 2.9 \text{ MeV}$

The $\Xi_c^{\prime 0} - \Xi_c^0$ mass difference is too small for any strong decay to occur.

| ≡′0 DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------------|------------------------------|-----------|
| $=$ ⁰ _c γ | seen | 105 |

$\Xi_c(2645)$

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

 J^P has not been measured; $\frac{3}{2}$ is the quark-model prediction.

$$\begin{array}{l} \Xi_c(2645)^+ \; {\rm mass} \; m = 2645.9^{+0.5}_{-0.6} \; {\rm MeV} \quad ({\rm S}=1.1) \\ \Xi_c(2645)^0 \; {\rm mass} \; m = 2645.9^{+0.5}_{-0.6} \; {\rm MeV} \\ m_{\Xi_c(2645)^+} - m_{\Xi_c^0} = 175.0^{+0.8}_{-0.6} \; {\rm MeV} \quad ({\rm S}=1.2) \\ m_{\Xi_c(2645)^0} - m_{\Xi_c^+} = 178.1 \pm 0.6 \; {\rm MeV} \\ m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0} = 0.0 \pm 0.5 \; {\rm MeV} \\ \Xi_c(2645)^+ \; {\rm full} \; {\rm width} \; \Gamma < 3.1 \; {\rm MeV}, \; {\rm CL} = 90\% \\ \Xi_c(2645)^0 \; {\rm full} \; {\rm width} \; \Gamma < 5.5 \; {\rm MeV}, \; {\rm CL} = 90\% \end{array}$$

 $\Xi_{C}\,\pi$ is the only strong decay allowed to a Ξ_{C} resonance having this mass.

| $\Xi_{C}(2645)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------|------------------------------|-----------|
| $\Xi_c^0 \pi^+$ | seen | 102 |
| $\Xi_c^+\pi^-$ | seen | 107 |

$$\Xi_c$$
(2790)

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$$

 J^P has not been measured; $\frac{1}{2}$ is the quark-model prediction.

$$\begin{array}{l} \Xi_c(2790)^+ \; {\rm mass} = 2789.1 \pm 3.2 \; {\rm MeV} \\ \Xi_c(2790)^0 \; {\rm mass} = 2791.8 \pm 3.3 \; {\rm MeV} \\ m_{\Xi_c(2790)^+} - m_{\Xi_c^0} = 318.2 \pm 3.2 \; {\rm MeV} \\ m_{\Xi_c(2790)^0} - m_{\Xi_c^+} = 324.0 \pm 3.3 \; {\rm MeV} \\ \Xi_c(2790)^+ \; {\rm width} < 15 \; {\rm MeV}, \; {\rm CL} = 90\% \\ \Xi_c(2790)^0 \; {\rm width} < 12 \; {\rm MeV}, \; {\rm CL} = 90\% \end{array}$$

| Ξ _C (2790) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------------|------------------------------|------------|
| $\Xi_c'\pi$ | seen | 159 |

 $\Xi_c(2815)$

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

 $\overline{J^P}$ has not been measured; $\frac{3}{2}$ is the quark-model prediction.

$$\begin{split} &\Xi_c(2815)^+ \text{ mass } m = 2816.6 \pm 0.9 \text{ MeV} \\ &\Xi_c(2815)^0 \text{ mass } m = 2819.6 \pm 1.2 \text{ MeV} \\ &m_{\Xi_c(2815)^+} - m_{\Xi_c^+} = 348.8 \pm 0.9 \text{ MeV} \\ &m_{\Xi_c(2815)^0} - m_{\Xi_c^0} = 348.7 \pm 1.2 \text{ MeV} \\ &m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0} = -3.1 \pm 1.3 \text{ MeV} \\ &\Xi_c(2815)^+ \text{ full width } \Gamma < 3.5 \text{ MeV, CL} = 90\% \\ &\Xi_c(2815)^0 \text{ full width } \Gamma < 6.5 \text{ MeV, CL} = 90\% \end{split}$$

The $\Xi_C \pi \pi$ modes are consistent with being entirely via $\Xi_C(2645) \pi$.

| $\Xi_{C}(2815)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|----------------------------------|------------------------------|------------|
| $\Xi_c^+\pi^+\pi^-$ | seen | 196 |
| $\equiv_{C}^{0} \pi^{+} \pi^{-}$ | seen | 191 |

 $\Xi_c(2980)$

$$I(J^P) = \frac{1}{2}(??)$$

$$\begin{array}{lll} \overline{\Xi}_c(2980)^+ \ m = 2971.4 \pm 3.3 \ \text{MeV} & (\text{S} = 2.1) \\ \overline{\Xi}_c(2980)^0 \ m = 2968.0 \pm 2.6 \ \text{MeV} & (\text{S} = 1.2) \\ \overline{\Xi}_c(2980)^+ \ \text{width} \ \Gamma = 26 \pm 7 \ \text{MeV} & (\text{S} = 1.5) \\ \overline{\Xi}_c(2980)^0 \ \text{width} \ \Gamma = 20 \pm 7 \ \text{MeV} & (\text{S} = 1.3) \end{array}$$

| <u>≡</u> _c (2980) DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------------------------------------|------------------------------|-----------|
| $\Lambda_c^+ \overline{K} \pi$ | seen | 231 |
| Σ_c (2455) \overline{K} | seen | 134 |
| $\sum_{C} (2455) \overline{K}$ $\bigwedge_{C}^{+} \overline{K}$ | not seen | 414 |
| $=c2\pi$ | seen | - |
| $\Xi_c(2645)\pi$ | seen | 277 |

 $\Xi_c(3080)$

$$I(J^P) = \frac{1}{2}(??)$$

$$\Xi_c(3080)^+$$
 $m=3077.0\pm0.4$ MeV $\Xi_c(3080)^0$ $m=3079.9\pm1.4$ MeV (S = 1.3) $\Xi_c(3080)^+$ width Γ = 5.8 ± 1.0 MeV $\Xi_c(3080)^0$ width Γ = 5.6 ± 2.2 MeV

| $\Xi_{C}(3080)$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------------------------------|------------------------------|-----------|
| $\Lambda_c^+ \overline{K} \pi$ | seen | 415 |
| $\Sigma_c(2455)\overline{K}$ | seen | 342 |
| $\Sigma_c(2455)\overline{K} + \Sigma_c(2520)\overline{K}$ | seen | - |
| $\Lambda_c^+ \overline{K}$ | not seen | 536 |
| $\Lambda_c^+ \overline{K} \pi^+ \pi^-$ | not seen | 143 |

 Ω_c^0

$$I(J^P) = 0(\frac{1}{2}^+)$$

 J^P has not been measured; $\frac{1}{2}^+$ is the quark-model prediction.

Mass
$$m=2695.2\pm1.7$$
 MeV (S = 1.3) Mean life $\tau=(69\pm12)\times10^{-15}$ s $c\tau=21~\mu{\rm m}$

5 No absolute branching fractions have been measured.

| $arOmega_c^0$ decay modes | Fraction (Γ_i/Γ) | p (MeV/c) |
|-------------------------------|------------------------------|-----------|
| Σ^+ K $^-$ K $^ \pi^+$ | seen | 689 |
| $\Xi^0 K^- \pi^+$ | seen | 901 |
| $\Xi^- K^- \pi^+ \pi^+$ | seen | 830 |
| $\Omega^-e^+ u_e$ | seen | 829 |
| $\Omega^-\pi^+$ | seen | 821 |
| $\Omega^-\pi^+\pi^0$ | seen | 797 |
| $\Omega^-\pi^-\pi^+\pi^+$ | seen | 75 3 |

 $\Omega_c(2770)^0$

$$I(J^P) = 0(\frac{3}{2}^+)$$

 J^P has not been measured; $\frac{3}{2}$ is the quark-model prediction.

$$\begin{array}{l} {\rm Mass}~m=2765.9\pm2.0~{\rm MeV}~{\rm (S=1.2)} \\ m_{\varOmega_{\rm C}(2770)^0}-m_{\varOmega_{\rm C}^0}=70.7^{+~0.8}_{-~0.9}~{\rm MeV} \end{array}$$

The $\Omega_C(2770)^0$ – Ω_C^0 mass difference is too small for any strong decay to occur.

| $\Omega_{c}(2770)^{0}$ DECAY MODES | Fraction (Γ_i/Γ) | p (MeV/c) |
|------------------------------------|------------------------------|-----------|
| $\Omega_c^0 \gamma$ | presumably 100% | 70 |

BOTTOM BARYONS (B=-1)

$$\Lambda_b^0 = u\,d\,b,\, \Xi_b^0 = u\,s\,b,\, \Xi_b^- = d\,s\,b,\, \Omega_b^- = s\,s\,b$$



$$I(J^P) = 0(\frac{1}{2}^+)$$

$$I(J^P)$$
 not yet measured; $0(\frac{1}{2}^+)$ is the quark model prediction. Mass $m=5619.4\pm0.7~{\rm MeV}$
$$m_{A_b^0}-m_{B^0}=339.2\pm1.4~{\rm MeV}$$

$$m_{A_b^0}-m_{B^+}=339.7\pm0.7~{\rm MeV}$$
 Mean life $\tau=(1.425\pm0.032)\times10^{-12}~{\rm s}$
$$c\tau=427~{\rm \mu m}$$

$$A_{CP}(\Lambda_b\to p\pi^-)=0.03\pm0.18$$

$$A_{CP}(\Lambda_b\to pK^-)=0.37\pm0.17$$

The branching fractions B(b-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda^0_b \to \Lambda^+_c \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to b$ -baryon) were used to determine B($b \to b$ -baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, e.g., $\Lambda_b \to \overline{\Lambda}_C$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

| Λ ⁰ _b DECAY MODES | Fraction (Γ_i/Γ) | Scale factor/ Confidence level | |
|----------------------------------------------------------------------------------|---------------------------------------------------------------|-----------------------------------|--------------|
| $J/\psi(1S)\Lambda \times B(b \rightarrow \Lambda_b^0)$ | (5.8±0.8) × 10 | 5 | 1740 |
| $\Lambda_c^+ \pi^-$ | $(5.7^{+4.0}_{-2.6}) \times 10^{-1}$ | 3 S=1.6 | 2342 |
| $\Lambda_c^+ a_1(1260)^-$ | seen | | 215 2 |
| $\Lambda_c^+ \pi^+ \pi^- \pi^-$ | $(8 \ ^{+5}_{-4} \) \times 10^{-}$ | 3 S=1.6 | 2323 |
| $\Lambda_{c}(2595)^{+}\pi^{-}$, | $(3.7^{+2.8}_{-2.3}) \times 10^{-1}$ | 4 | 2210 |
| $\Lambda_c(2595)^+ \rightarrow \Lambda_c^+ \pi^+ \pi^-$ | | | |
| $\Lambda_{c}(2625)^{+}\pi^{-}$, | $(3.6^{+2.7}_{-2.1}) \times 10^{-}$ | 4 | 2193 |
| $\Lambda_c(2625)^+ \rightarrow \Lambda_c^+ \pi^+ \pi^-$ | | | |
| $\Sigma_c(2455)^0\pi^+\pi^-$, Σ_c^0 $ ightarrow$ | $\begin{pmatrix} 6 & +5 \\ -4 & \end{pmatrix} \times 10^{-1}$ | 4 | 2265 |
| $\Lambda_c^+ \pi^-$ | | | |
| Σ_{c} (2455) $^{++}$ π^{-} π^{-} , Σ_{c}^{++} $ ightarrow$ | $(3.5^{+2.8}_{-2.3}) \times 10^{-1}$ | 4 | 2265 |
| $\Lambda_c^+ \pi^+$ | | | |
| $arLambda_c^+ \ell^- \overline{ u}_\ell$ anything | [v] (9.8 ± 2.3) % | | = |
| $\Lambda_c^+ \ell^- \overline{ u}_\ell$ | $(6.5 + 3.2 \atop -2.5)$ % | S=1.8 | 2345 |
| $\Lambda_c^+ \pi^+ \pi^- \ell^- \overline{ u}_\ell$ | (5.6 ± 3.1) % | | 2335 |
| $\Lambda_c(2595)^+ \ell^- \overline{\nu}_\ell$ | $(8~\pm5~)\times10^-$ | 3 | 2212 |
| $\Lambda_c(2625)^+ \ell^- \overline{ u}_\ell$ | $(1.4^{+0.9}_{-0.7})$ % | | 2195 |
| p h — | $[w] < 2.3 \times 10^{-}$ | | 2730 |
| $p\pi^-$ | $(3.5\pm1.0)\times10^{-1}$ | | 2730 |
| p K- | $(5.5\pm1.4)\times10^{-1}$ | | 2708 |
| $\Lambda \mu^+ \mu^-$ $\Lambda \gamma$ | $(1.7\pm0.7) \times 10^{-}$ < 1.3 $\times 10^{-}$ | | 2695 2699 |
| 71.1 | < 1.5 × 10 | CL = 90 /6 | 2079 |

 Σ_b

$$I(J^P) = 1(\frac{1}{2}^+)$$
 I, J, P need confirmation.

$$\begin{array}{l} \text{Mass } m(\Sigma_b^+) = 5811.3 \pm 1.9 \text{ MeV} \\ \text{Mass } m(\Sigma_b^-) = 5815.5 \pm 1.8 \text{ MeV} \\ m_{\Sigma_b^+} - m_{\Sigma_b^-} = -4.2 \pm 1.1 \text{ MeV} \\ \Gamma(\Sigma_b^+) = 9.7^{+4.0}_{-3.0} \text{ MeV} \\ \Gamma(\Sigma_b^-) = 4.9^{+3.3}_{-2.4} \text{ MeV} \end{array}$$

 $\frac{\mathbf{E_b} \text{ DECAY MODES}}{ N_b^0 \pi} \qquad \qquad \text{Fraction } (\Gamma_i/\Gamma) \qquad \qquad p \text{ (MeV/c)} \\ \text{dominant} \qquad \qquad 134$

 Σ_b^*

$$I(J^P) = 1(\frac{3}{2}^+)$$

 I, J, P need confirmation.

$$\begin{array}{ll} \operatorname{Mass} \ m(\Sigma_b^{*+}) = 5832.1 \pm 1.9 \ \operatorname{MeV} \\ \operatorname{Mass} \ m(\Sigma_b^{*-}) = 5835.1 \pm 1.9 \ \operatorname{MeV} \\ m_{\Sigma_b^{*+}} - m_{\Sigma_b^{*-}} = -3.0^{+1.0}_{-0.9} \ \operatorname{MeV} \\ \Gamma(\Sigma_b^{*+}) = 11.5 \pm 2.8 \ \operatorname{MeV} \\ \Gamma(\Sigma_b^{*-}) = 7.5 \pm 2.3 \ \operatorname{MeV} \\ m_{\Sigma_b^{*-}} - m_{\Sigma_b} = 21.2 \pm 2.0 \ \operatorname{MeV} \end{array}$$

 \equiv_b^0, \equiv_b^-

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$

I, J, P need confirmation.

$$\begin{array}{l} m(\Xi_b^-) = 5791.1 \pm 2.2 \; \mathrm{MeV} \\ m(\Xi_b^0) = 5788 \pm 5 \; \mathrm{MeV} \\ m_{\Xi_b^-} - m_{\Xi_b^0} = 3 \pm 6 \; \mathrm{MeV} \\ \mathrm{Mean \; life} \; \tau_{\Xi_b^-} = (1.56 \pm 0.26) \times 10^{-12} \; \mathrm{s} \\ \mathrm{Mean \; life} \; \tau_{\Xi_b} = (1.49^{+0.19}_{-0.18}) \times 10^{-12} \; \mathrm{s} \end{array}$$

| Ξ _b DECAY MODES | Fraction (Γ_i/Γ) | Scale factor | <i>p</i> (Me <i>V/c</i>) |
|------------------------------------------------------------------------------------------------------------------|-----------------------------------------|--------------|-------------------------------|
| $\overline{\Xi}_b \to \overline{\Xi}^- \ell^- \overline{\nu}_\ell X \times B(\overline{b} \to \overline{\Xi}_b)$ | $(3.9 \pm 1.2) \times 10^{-4}$ | 1.4 | = |
| $\Xi_b^- \to J/\psi \Xi^- \times B(b \to \Xi_b^-)$ | $(1.02^{+0.26}_{-0.21}) \times 10^{-5}$ | | _ |

 Ω_b^-

$$I(J^P) = 0(\frac{1}{2}^+)$$
 I, J, P need confirmation.

Mass
$$m = 6071 \pm 40 \; {\rm MeV} \quad ({\rm S} = 6.2)$$
 Mean life $\tau = (1.1^{+0.5}_{-0.4}) \times 10^{-12} \; {\rm s}$

 $\underline{\Omega_b^-} \text{ DECAY MODES}$ Fraction (Γ_i/Γ) p (MeV/c) $J/\psi \Omega^- \times B(b \to \Omega_b) \qquad (2.9^{+1.1}_{-0.8}) \times 10^{-6} \qquad 1826$

b-baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$

Mean life
$$au = (1.382 \pm 0.029) \times 10^{-12} \text{ s}$$

These branching fractions are actually an average over weakly decaying b-baryons weighted by their production rates at the LHC, LEP, and Tevatron, branching ratios, and detection efficiencies. They scale with the b-baryon production fraction B($b \rightarrow b$ -baryon).

The branching fractions B(b-baryon $\to \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda^0_b \to \Lambda^+_c \ell^- \overline{\nu}_\ell$ anything) are not pure measurements because the underlying measured products of these with B($b \to b$ -baryon) were used to determine B($b \to b$ -baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, e.g., $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

| <i>b</i> -baryon | ADMIXTURE | DECAY | MODES |
|------------------|------------------|-------|-------|
| | | | |

| $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$ | Fraction (Γ_i/Γ) | p (MeV/c) |
|-----------------------------------------------|------------------------------|-----------|
| $p\mu^-\overline{\nu}$ anything | $(5.3 + 2.2 \atop -1.9)\%$ | _ |
| $p\ell\overline{ u}_\ell$ anything | (5.1± 1.2) % | - |
| <i>p</i> anything | (63 ±21)% | = |
| $\Lambda \ell^- \overline{ u}_\ell$ anything | (3.4 ± 0.6) % | = |
| $\Lambda/\overline{\Lambda}$ anything | (35 ± 8) % | = |
| $ar{\Xi}^-\ell^-\overline{ u}_\ell$ a nything | $(5.9\pm\ 1.6)\times10^{-3}$ | - |

NOTES

This Summary Table only includes established baryons. The Particle Listings include evidence for other baryons. The masses, widths, and branching fractions for the resonances in this Table are Breit-Wigner parameters, but pole positions are also given for most of the N and Δ resonances.

For most of the resonances, the parameters come from various partial-wave analyses of more or less the same sets of data, and it is not appropriate to treat the results of the analyses as independent or to average them together. Furthermore, the systematic errors on the results are not well understood. Thus, we usually only give ranges for the parameters. We then also give a best guess for the mass (as part of the name of the resonance) and for the width. The Note on N and Δ Resonances and the Note on N and Σ Resonances in the Particle Listings review the partial-wave analyses.

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as $S=\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity. We do this when S > 1, which often indicates that the measurements are inconsistent. When S > 1.25, we also show in the Particle Listings an ideogram of the measurements. For more about S, see the Introduction.

A decay momentum p is given for each decay mode. For a 2-body decay, p is the momentum of each decay product in the rest frame of the decaying particle. For a 3-or-more-body decay, p is the largest momentum any of the products can have in this frame. For any resonance, the nominal mass is used in calculating p. A dagger ("†") in this column indicates that the mode is forbidden when the nominal masses of resonances are used, but is in fact allowed due to the nonzero widths of the resonances.

- [a] The masses of the p and n are most precisely known in u (unified atomic mass units). The conversion factor to MeV, 1 u=931.494028(23) MeV, is less well known than are the masses in u.
- [b] The $|m_p-m_{\overline{\rho}}|/m_p$ and $|q_p+q_{\overline{\rho}}|/e$ are not independent, and both use the more precise measurement of $|q_{\overline{\rho}}/m_{\overline{\rho}}|/(q_p/m_p)$.
- [c] The limit is from neutrality-of-matter experiments; it assumes $q_n=q_p+q_e$. See also the charge of the neutron.

- [d] The first limit is for $p \to anything$ or "disappearance" modes of a bound proton. The second entry, a rough range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray \overline{p} 's is $\tau_{\overline{p}} > 10^7$ yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives $\tau_{\overline{p}}/B(\overline{p} \to e^-\gamma) > 7 \times 10^5$ yr.
- [e] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The first limit here is from reactor experiments with free neutrons.
- [f] Lee and Yang in 1956 proposed the existence of a mirror world in an attempt to restore global parity symmetry—thus a search for oscillations between the two worlds. Oscillations between the worlds would be maximal when the magnetic fields B and B' were equal. The limit for any B' in the range 0 to 12.5 μT is >12 s (95% CL).
- [g] The parameters g_A , g_V , and g_{WM} for semileptonic modes are defined by $\overline{B}_f[\gamma_\lambda(g_V+g_A\gamma_5)+i(g_{WM}/m_{B_i})\;\sigma_{\lambda\nu}\;q^\nu]B_i$, and ϕ_{AV} is defined by $g_A/g_V=|g_A/g_V|e^{i\phi_{AV}}$. See the "Note on Baryon Decay Parameters" in the neutron Particle Listings.
- [h] Time-reversal invariance requires this to be 0° or 180° .
- [i] This coefficient is zero if time invariance is not violated.
- [j] This limit is for γ energies between 15 and 340 keV.
- [k] The decay parameters γ and Δ are calculated from lpha and ϕ using

$$\gamma = \sqrt{1-\alpha^2} \cos \phi$$
, $\tan \Delta = -\frac{1}{\alpha} \sqrt{1-\alpha^2} \sin \phi$.

See the "Note on Baryon Decay Parameters" in the neutron Particle Listings.

- [/] See the Listings for the pion momentum range used in this measurement.
- [m] The error given here is only an educated guess. It is larger than the error on the weighted average of the published values.
- [n] A theoretical value using QED.
- [o] See the note on " Λ_c^+ Branching Fractions" in the Λ_c^+ Particle Listings.
- [p] This branching fraction includes all the decay modes of the final-state resonance
- [q] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [r] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [s] Assuming isospin conservation, so that the other third is $\Lambda_c^+ \pi^0 \pi^0$.
- [t] A test that the isospin is indeed 0, so that the particle is indeed a Λ_c^+ .
- [u] No absolute branching fractions have been measured. The value here is the branching ratio relative to $\Xi^-2\pi^+$.
- [v] Not a pure measurement. See note at head of Λ_h^0 Decay Modes.
- [w] Here h^- means π^- or K^- .

SEARCHES FOR MONOPOLES, SUPERSYMMETRY, TECHNICOLOR, COMPOSITENESS, EXTRA DIMENSIONS, etc.

Magnetic Monopole Searches

Isolated supermassive monopole candidate events have not been confirmed. The most sensitive experiments obtain negative results.

Best cosmic-ray supermassive monopole flux limit:

$$< 1.0 \times 10^{-15} \text{ cm}^{-2} \text{sr}^{-1} \text{s}^{-1}$$
 for $1.1 \times 10^{-4} < \beta < 0.1$

Supersymmetric Particle Searches

Limits are based on the Minimal Supersymmetric Standard Model. Assumptions include: 1) $\widetilde{\chi}_1^0$ (or $\widetilde{\gamma}$) is lightest supersymmetric particle; 2) R-parity is conserved; 3) With the exception of \widetilde{t} and \widetilde{b} , all scalar quarks are assumed to be degenerate in mass and $m_{\widetilde{q}_R} = m_{\widetilde{q}_L}$. 4) Limits for sleptons refer to the $\widetilde{\ell}_R$ states. 5) Gaugino mass unification at the GUT scale.

See the Particle Listings for a Note giving details of supersymmetry.

$$\begin{array}{l} \widetilde{\chi}_{i}^{0} - \text{neutralinos (mixtures of } \widetilde{\gamma}, \widetilde{Z}^{0}, \text{ and } \widetilde{H}_{i}^{0}) \\ \text{Mass } m_{\widetilde{\chi}_{1}^{0}} > 46 \text{ GeV, CL} = 95\% \\ \text{[all } \tan\beta, \text{ all } m_{0}, \text{ all } m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}}] \\ \text{Mass } m_{\widetilde{\chi}_{2}^{0}} > 62.4 \text{ GeV, CL} = 95\% \\ \text{[1<\tan}\beta < 40, \text{ all } m_{0}, \text{ all } m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}}] \\ \text{Mass } m_{\widetilde{\chi}_{3}^{0}} > 99.9 \text{ GeV, CL} = 95\% \\ \text{[1<\tan}\beta < 40, \text{ all } m_{0}, \text{ all } m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}}] \\ \text{Mass } m_{\widetilde{\chi}_{4}^{0}} > 116 \text{ GeV, CL} = 95\% \\ \text{[1<\tan}\beta < 40, \text{ all } m_{0}, \text{ all } m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}}] \\ \end{array}$$

$$\widetilde{\chi}_i^\pm$$
 — charginos (mixtures of \widetilde{W}^\pm and \widetilde{H}_i^\pm)
Mass $m_{\widetilde{\chi}_1^\pm} >$ 94 GeV, CL = 95%
 $[\tan \! eta < 40, \ m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0} >$ 3 GeV, all $m_0]$

 \tilde{e} — scalar electron (selectron)

Mass
$$m>~$$
 107 GeV, CL $=~$ 95% $[$ all $m_{\widetilde{e}_R}-m_{\widetilde{\chi}_1^0}]$

 $\widetilde{\mu}$ — scalar muon (smuon)

Mass
$$m>$$
 94 GeV, CL $=$ 95%
$$[1 \leq \tan\beta \leq$$
 40, $m_{\widetilde{\mu}_R} - m_{\widetilde{\chi}_+^0} >$ 10 GeV]

 $\widetilde{ au}$ — scalar tau (stau)

Mass
$$m>81.9$$
 GeV, CL = 95% $[m_{\widetilde{\tau}_R}-m_{\widetilde{\chi}_1^0}>$ >15 GeV, all $\theta_{\tau}]$

 \tilde{q} — scalar quark (squark)

These limits include the effects of cascade decays, evaluated assuming a fixed value of the parameters μ and $\tan\beta$. The limits are weakly sensitive to these parameters over much of parameter space. Limits assume GUT relations between gaugino masses and the gauge coupling.

Mass $m > 1.100 \times 10^3$ GeV, CL = 95% [tan β =10, μ >0, A_0 =0]

 \widetilde{b} — scalar bottom (sbottom)

Mass
$$m>$$
 89 GeV, CL = 95% $[m_{\widetilde{b}_1}-m_{\widetilde{\chi}_1^0}>$ 8 GeV, all θ_b]

 \tilde{t} — scalar top (stop)

$$\widetilde{g}$$
 — gluino

The limits summarised here refer to the high-mass region $(m_{\widetilde{g}} \gtrsim 5~{\rm GeV})$, and include the effects of cascade decays, evaluated assuming a fixed value of the parameters μ and $\tan\beta$. The limits are weakly sensitive to these parameters over much of parameter space. Limits assume GUT relations between gaugino masses and the gauge coupling,

Mass
$$m > 500$$
 GeV, $CL = 95\%$ [any $m_{\widetilde{a}}$]

Technicolor

Searches for a color-octet techni- ρ constrain its mass to be greater than 260 to 480 GeV, depending on allowed decay channels. Similar bounds exist on the color-octet techni- ω .

Quark and Lepton Compositeness, Searches for

Scale Limits A for Contact Interactions (the lowest dimensional interactions with four fermions)

If the Lagrangian has the form

$$\pm \frac{g^2}{2\Lambda^2} \, \overline{\psi}_{\mathsf{L}} \, \gamma_{\mu} \psi_{\mathsf{L}} \, \overline{\psi}_{\mathsf{L}} \, \gamma^{\mu} \psi_{\mathsf{L}}$$

(with $g^2/4\pi$ set equal to 1), then we define $\Lambda \equiv \Lambda_{LL}^{\pm}$. For the full definitions and for other forms, see the Note in the Listings on Searches for Quark and Lepton Compositeness in the full *Review* and the original literature.

$$\begin{array}{lll} \Lambda_{LL}^+(e\,e\,e\,e) &> 8.3 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^-(e\,e\,e\,e) &> 10.3 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^-(e\,e\,\mu\,\mu) &> 8.5 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^-(e\,e\,\mu\,\mu) &> 9.5 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,\tau\,\tau) &> 7.9 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,\tau\,\tau) &> 7.2 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,\tau\,\tau) &> 7.2 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(\ell\,\ell\ell\ell) &> 9.1 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(\ell\,\ell\ell\ell) &> 10.3 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,u\,u) &> 23.3 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,u\,u) &> 12.5 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,u\,u) &> 12.5 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,u\,d) &> 11.1 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,c\,d) &> 9.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,c\,c) &> 9.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(e\,e\,b\,b) &> 9.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(\mu\,\mu\,q\,q) &> 4.5 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(\mu\,\mu\,q\,q) &> 4.9 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(\mu\,\mu\,q\,q) &> 4.9 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(q\,q\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(q\,q\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(q\,q\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.6 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.0 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.0 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.0 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &> 5.4 \ {\rm TeV}, \ {\rm CL} = 95\% \\ \Lambda_{LL}^+(u\,\mu\,q\,q) &>$$

Excited Leptons

The limits from $\ell^{*+}\ell^{*-}$ do not depend on λ (where λ is the $\ell\ell^*$ transition coupling). The λ -dependent limits assume chiral coupling

 $e^{*\pm}$ — excited electron

Mass
$$m>103.2$$
 GeV, CL = 95% (from e^*e^*)
Mass $m>1.070\times 10^3$ GeV, CL = 95% (from $e\,e^*$)
Mass $m>356$ GeV, CL = 95% (if $\lambda_\gamma=1$)

Searches Summary Table

```
\mu^{*\pm} — excited muon
   Mass m > 103.2 GeV, CL = 95% (from \mu^* \mu^*)
   Mass m > 1.090 \times 10^3 GeV, CL = 95% (from \mu \mu^*)
	au^{*\pm} — excited tau
   Mass m > 103.2 GeV, CL = 95% (from \tau^* \tau^*)
   Mass m > 185 GeV, CL = 95% (from \tau \tau^*)

u^* — excited neutrino
   Mass m > 102.6 GeV, CL = 95% (from \nu^* \nu^*)
   Mass m > 213 GeV, CL = 95% (from \nu \nu^*)
q* — excited quark
   Mass m > 338 \text{ GeV}, CL = 95%
                                       (from q^* q^*)
   Mass m>~2.490\times10^3~{\rm GeV}, {\rm CL}=~95\% (from q^*{\rm X})
Color Sextet and Octet Particles
Color Sextet Quarks (q_6)
   Mass m > 84 GeV, CL = 95\%
Color Octet Charged Leptons (\ell_8)
   Mass m > 86 GeV, CL = 95\%
                                      (Stable \ell_8)
Color Octet Neutrinos (\nu_8)
   Mass m > 110 GeV, CL = 90%
                                       (\nu_8 \rightarrow \nu g)
```

Extra Dimensions

Please refer to the Extra Dimensions section of the full $\it Review for a discussion of the model-dependence of these bounds, and further constraints.$

Constraints on the fundamental gravity scale

```
\begin{array}{ll} \textit{M}_{TT} > 1.74 \text{ TeV, CL} = 95\% & (\text{dim-8 ops; } \Lambda = +1; \ \textit{pp} \rightarrow \ \gamma \gamma) \\ \textit{M}_{C} > 1.59 \text{ TeV, CL} = 95\% & (\text{compactification scale with TeV} \\ & \text{extra dimensions; } \textit{p} \, \overline{\textit{p}} \rightarrow \text{dijet, angular distrib.}) \\ \textit{M}_{D} > 1.63 \text{ TeV, CL} = 95\% & (\textit{pp} \rightarrow \ \textit{G} \rightarrow \ \ell \, \overline{\ell}) \\ \end{array}
```

Constraints on the radius of the extra dimensions, for the case of two-flat dimensions of equal radii

```
R<30~\mu{\rm m,\,CL}=95\%~~{\rm (direct\ tests\ of\ Newton's\ law)} R<72~\mu{\rm m,\,CL}=95\%~~(p\,p\to\,j\,G) R<0.16-916~{\rm nm}~~{\rm (astrophysics;\ limits\ depend\ on\ technique\ and\ assumptions)}
```

TESTS OF CONSERVATION LAWS

Updated May 2012 by L. Wolfenstein (Carnegie-Mellon University) and C.-J. Lin (LBNL) .

In keeping with the current interest in tests of conservation laws, we collect together a Table of experimental limits on all weak and electromagnetic decays, mass differences, and moments, and on a few reactions, whose observation would violate conservation laws. The Table is given only in the full Review of Particle Physics, not in the Particle Physics Booklet. For the benefit of Booklet readers, we include the best limits from the Table in the following text. Limits in this text are for CL=90% unless otherwise specified. The Table is in two parts: "Discrete Space-Time Symmetries," i.e., C, P, T, CP, and CPT; and "Number Conservation Laws," i.e., lepton, baryon, hadronic flavor, and charge conservation. The references for these data can be found in the the Particle Listings in the Review. A discussion of these tests follows.

CPT INVARIANCE

General principles of relativistic field theory require invariance under the combined transformation CPT. The simplest tests of CPT invariance are the equality of the masses and lifetimes of a particle and its antiparticle. The best test comes from the limit on the mass difference between K^0 and \overline{K}^0 . Any such difference contributes to the CP-violating parameter ϵ . Assuming CPT invariance, ϕ_{ϵ} , the phase of ϵ should be very close to 44°. (See the review "CP Violation in K_L decay" in this edition.) In contrast, if the entire source of CP violation in K^0 decays were a $K^0 - \overline{K}^0$ mass difference, ϕ_{ϵ} would be $44^{\circ} + 90^{\circ}$.

Assuming that there is no other source of CPT violation than this mass difference, it is possible to deduce that [1]

$$m_{\overline{K}^0} - m_{K^0} \approx \frac{2(m_{K_L^0} - m_{K_S^0}) \, |\eta| \, (\frac{2}{3}\phi_{+-} + \frac{1}{3}\phi_{00} - \phi_{\rm SW})}{\sin\phi_{\rm SW}} \; ,$$

where $\phi_{\rm SW}=(43.51\pm0.05)^\circ$, the superweak angle. Using our best values of the CP-violation parameters, we get $|(m_{\overline{K}^0}-m_{K^0})/m_{K^0}| \leq 0.6 \times 10^{-18}$ at CL=90%. Limits can also be placed on specific CPT-violating decay amplitudes. Given the small value of $(1-|\eta_{00}/\eta_{+-}|)$, the value of $\phi_{00}-\phi_{+-}$ provides a measure of CPT violation in $K_L^0 \to 2\pi$ decay. Results from CERN [1] and Fermilab [2] indicate no CPT-violating effect.

CP AND T INVARIANCE

Given CPT invariance, CP violation and T violation are equivalent. The original evidence for CP violation came from the measurement of $|\eta_{+-}| = |A(K_L^0 \to \pi^+\pi^-)/A(K_S^0 \to \pi^+\pi^-)| = (2.232 \pm 0.011) \times 10^{-3}$. This could be explained in terms of $K^0 - \overline{K}^0$ mixing, which also leads to the asymmetry $[\Gamma(K_L^0 \to \pi^- e^+ \nu) - \Gamma(K_L^0 \to \pi^+ e^- \overline{\nu})]/[\text{sum}] = (0.334 \pm 0.007)\%$. Evidence for CP violation in the kaon decay amplitude comes from the measurement of $(1 - |\eta_{00}/\eta_{+-}|)/3 = Re(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$. In the Standard Model much larger CP-violating effects are expected. The first of these, which is associated with $B - \overline{B}$ mixing, is the parameter $sin(2\beta)$ now measured

quite accurately to be 0.679 ± 0.020 . A number of other CP-violating observables are being measured in B decays; direct evidence for CP violation in the B decay amplitude comes from the asymmetry $[\Gamma(\overline{B}^0\to K^-\pi^+)-\Gamma(B^0\to K^+\pi^-)]/[\text{sum}]=-0.097\pm0.012$. Direct tests of T violation are much more difficult; a measurement by CPLEAR of the difference between the oscillation probabilities of K^0 to $\overline{K^0}$ and $\overline{K^0}$ to K^0 is related to T violation [3]. Other searches for CP or T violation involve effects that are expected to be unobservable in the Standard Model. The most sensitive are probably the searches for an electric dipole moment of the neutron, measured to be $<2.9\times10^{-26}~e$ cm, and the electron $(10.5\pm0.07)\times10^{-28}~e$ cm. A nonzero value requires both P and T violation.

CONSERVATION OF LEPTON NUMBERS

Present experimental evidence and the standard electroweak theory are consistent with the absolute conservation of three separate lepton numbers: electron number L_e , muon number L_{μ} , and tau number L_{τ} , except for the effect of neutrino mixing associated with neutrino masses. Searches for violations are of the following types:

- a) $\Delta L=2$ for one type of charged lepton. The best limit comes from the search for neutrinoless double beta decay $(Z,A) \to (Z+2,A) + e^- + e^-$. The best laboratory limit is $t_{1/2} > 1.9 \times 10^{25}$ yr (CL=90%) for ⁷⁶Ge.
- b) Conversion of one charged-lepton type to another. For purely leptonic processes, the best limits are on $\mu \to e \gamma$ and $\mu \to 3e$, measured as $\Gamma(\mu \to e \gamma)/\Gamma(\mu \to \text{all}) < 2.4 \times 10^{-12}$ and $\Gamma(\mu \to 3e)/\Gamma(\mu \to \text{all}) < 1.0 \times 10^{-12}$. For semileptonic processes, the best limit comes from the coherent conversion process in a muonic atom, $\mu^- + (Z,A) \to e^- + (Z,A)$, measured as $\Gamma(\mu^-\text{Ti} \to e^-\text{Ti})/\Gamma(\mu^-\text{Ti} \to \text{all}) < 4.3 \times 10^{-12}$. Of special interest is the case in which the hadronic flavor also changes, as in $K_L \to e \mu$ and $K^+ \to \pi^+ e^- \mu^+$, measured as $\Gamma(K_L \to e \mu)/\Gamma(K_L \to \text{all}) < 4.7 \times 10^{-12}$ and $\Gamma(K^+ \to \pi^+ e^- \mu^+)/\Gamma(K^+ \to \text{all}) < 1.3 \times 10^{-11}$. Limits on the conversion of τ into e or μ are found in τ decay and are much less stringent than those for $\mu \to e$ conversion, e.g., $\Gamma(\tau \to \mu \gamma)/\Gamma(\tau \to \text{all}) < 4.4 \times 10^{-8}$ and $\Gamma(\tau \to e \gamma)/\Gamma(\tau \to \text{all}) < 3.3 \times 10^{-8}$.
- c) Conversion of one type of charged lepton into another type of charged antilepton. The case most studied is $\mu^- + (Z,A) \rightarrow e^+ + (Z-2,A)$, the strongest limit being $\Gamma(\mu^-\text{Ti} \rightarrow e^+\text{Ca})/\Gamma(\mu^-\text{Ti} \rightarrow \text{all}) < 3.6 \times 10^{-11}$.
- d) Neutrino oscillations. It is expected even in the standard electroweak theory that the lepton numbers are not separately conserved, as a consequence of lepton mixing analogous to Cabibbo-Kobayashi-Maskawa quark mixing. However, if the only source of lepton-number violation is the mixing of low-mass neutrinos then processes such as $\mu \to e \gamma$ are expected to have extremely small unobservable probabilities. For small neutrino masses, the lepton-number violation would be observed first in neutrino oscillations, which have been the subject of extensive experimental studies. Compelling evidence for neutrino mixing has come from atmospheric, solar, accelerator, and

reactor neutrinos. Recently, the reactor neutrino experiments have measured the last neutrino mixing angle θ_{13} and found it to be relatively large. For a comprehensive review on neutrino mixing, including the latest results on θ_{13} , see the review "Neutrino Mass, Mixing, and Oscillations" by K. Nakamura and S.T. Petcov in this edition of RPP.

CONSERVATION OF HADRONIC FLAVORS

In strong and electromagnetic interactions, hadronic flavor is conserved, i.e. the conversion of a quark of one flavor (d, u, s, c, b, t) into a quark of another flavor is forbidden. In the Standard Model, the weak interactions violate these conservation laws in a manner described by the Cabibbo-Kobayashi-Maskawa mixing (see the section "Cabibbo-Kobayashi-Maskawa Mixing Matrix"). The way in which these conservation laws are violated is tested as follows:

- (a) $\Delta S = \Delta Q$ rule. In the strangeness-changing semileptonic decay of strange particles, the strangeness change equals the change in charge of the hadrons. Tests come from limits on decay rates such as $\Gamma(\Sigma^+ \to n e^+ \nu)/\Gamma(\Sigma^+ \to \text{all}) < 5 \times 10^{-6}$, and from a detailed analysis of $K_L \to \pi e \nu$, which yields the parameter x, measured to be $(\text{Re } x, \text{Im } x) = (-0.002 \pm 0.006, 0.0012 \pm 0.0021)$. Corresponding rules are $\Delta C = \Delta Q$ and $\Delta B = \Delta Q$.
- (b) Change of flavor by two units. In the Standard Model this occurs only in second-order weak interactions. The classic example is $\Delta S=2$ via $K^0-\overline{K}^0$ mixing, which is directly measured by $m(K_L)-m(K_S)=(0.5293\pm0.0009)\times10^{10}~\hbar s^{-1}.$ The $\Delta B=2$ transitions in the B^0 and B_s^0 systems via mixing are also well established. The measured mass differences between the eigenstates are $(m_{B_{\rm H}^0}-m_{B_{\rm L}^0})=(0.507\pm0.004)\times10^{12}~\hbar s^{-1}$ and $(m_{B_{\rm sH}^0}-m_{B_{\rm sL}^0})=(17.69\pm0.08)\times10^{12}~\hbar s^{-1}.$ There is now strong evidence of $\Delta C=2$ transition in the charm sector with the mass difference $m_{D_H^0}-m_{D_L^0}=(1.44^{+0.48}_{-0.50})\times10^{10}~\hbar s^{-1}.$ All results are consistent with the second-order calculations in the Standard Model.
- (c) Flavor-changing neutral currents. In the Standard Model the neutral-current interactions do not change flavor. The low rate $\Gamma(K_L \to \mu^+\mu^-)/\Gamma(K_L \to \text{all}) = (6.84 \pm 0.11) \times 10^{-9}$ puts limits on such interactions; the nonzero value for this rate is attributed to a combination of the weak and electromagnetic interactions. The best test should come from $K^+ \to \pi^+\nu\overline{\nu}$, which occurs in the Standard Model only as a second-order weak process with a branching fraction of $(0.4 \text{ to } 1.2) \times 10^{-10}$. Combining results from BNL-E787 and BNL-E949 experiments yield $\Gamma(K^+ \to \pi^+\nu\overline{\nu})/\Gamma(K^+ \to \text{all}) = (1.7 \pm 1.1) \times 10^{-10} [4]$. Limits for charm-changing or bottom-changing neutral currents are less stringent: $\Gamma(D^0 \to \mu^+\mu^-)/\Gamma(D^0 \to \text{all}) < 1.4 \times 10^{-7}$ and $\Gamma(B^0 \to \mu^+\mu^-)/\Gamma(B^0 \to \text{all}) < 1.4 \times 10^{-9}$. One cannot isolate flavor-changing neutral current (FCNC) effects in non leptonic

decays. For example, the FCNC transition $s \to d + (\overline{u} + u)$ is equivalent to the charged-current transition $s \to u + (\overline{u} + d)$. Tests for FCNC are therefore limited to hadron decays into lepton pairs. Such decays are expected only in second-order in the electroweak coupling in the Standard Model.

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TESTS OF DISCRETE SPACE-TIME SYMMETRIES

CHARGE CONJUGATION (C) INVARIANCE

```
\Gamma(\pi^0 \to 3\gamma)/\Gamma_{total}
                                                                                            <3.1 \times 10^{-8}, CL = 90%
\eta C-nonconserving decay parameters
                                                                                           \begin{array}{l} (0.09 \, {}^{+\, 0.11}_{-\, 0.12}) \times 10^{-2} \\ (0.12 \, {}^{+\, 0.10}_{-\, 0.11}) \times 10^{-2} \end{array}
          \pi^+\pi^-\pi^0 left-right asymmetry
          \pi^+\pi^-\pi^0 sextant asymmetry
          \pi^+\pi^-\pi^0 quadrant asymmetry
                                                                                           (-0.09 \pm 0.09) \times 10^{-2}
          \pi^+\pi^-\gamma left-right asymmetry
                                                                                           (0.9 \pm 0.4) \times 10^{-2}
          \pi^+\pi^-\gamma parameter \beta (D-wave)
                                                                                            -0.02 \pm 0.07 (S = 1.3)
\Gamma(\eta\to~\pi^0\,\gamma)/\Gamma_{total}
                                                                                            <\!9\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(\eta \rightarrow 2\pi^0 \gamma)/\Gamma_{\text{total}}
                                                                                            <5 \times 10^{-4}, CL = 90%
\Gamma(\eta \rightarrow 3\pi^0\gamma)/\Gamma_{\text{total}}
                                                                                           <6 \times 10^{-5}, CL = 90%
                                                                                            {<}1.6\times10^{-5}\text{, CL}\,=\,90\%
\Gamma(\eta \rightarrow 3\gamma)/\Gamma_{total}
\Gamma(\eta \to \pi^0 \, e^+ \, e^-)/\Gamma_{total}
                                                                                    [a] <4 \times 10^{-5}, CL = 90%
\Gamma(\eta \to \pi^0 \, \mu^+ \, \mu^-) / \Gamma_{
m total}
                                                                                    [a] <5 \times 10^{-6}, CL = 90%
\Gamma(\omega(782) \rightarrow \eta \pi^0)/\Gamma_{	ext{total}}
                                                                                            <2.1 \times 10^{-4}, CL = 90%
\Gamma(\omega(782) \rightarrow 2\pi^0)/\Gamma_{	ext{total}}
                                                                                            <2.1 \times 10<sup>-4</sup>, CL = 90%
\Gamma(\omega(782) \rightarrow 3\pi^0)/\Gamma_{	ext{total}}
                                                                                            <2.3 \times 10^{-4}, CL = 90%
asymmetry parameter for \eta'(958) \rightarrow
                                                                                            -0.03 \pm 0.04
          \pi^+\pi^-\gamma decay
\Gamma(\eta'(958) \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}
                                                                                    [a] <1.4 \times 10^{-3}, CL = 90%
                                                                                    [a] <2.4 \times 10^{-3}, CL = 90%
\Gamma(\eta'(958) \rightarrow \eta e^+ e^-)/\Gamma_{total}
\Gamma(\eta'(958) \rightarrow 3\gamma)/\Gamma_{\text{total}}

\Gamma(\eta'(958) \rightarrow \mu^{+} \mu^{-} \pi^{0})/\Gamma_{\text{total}}
                                                                                            <1.0 \times 10^{-4}, CL = 90%
                                                                                    [a] <6.0 \times 10^{-5}, CL = 90%
\Gamma(\eta'(958) \rightarrow \mu^+ \mu^- \eta)/\Gamma_{	ext{total}}
                                                                                    [a] <1.5 \times 10^{-5}, CL = 90%
                                                                                            <5 \times 10^{-6}, CL = 90%
\Gamma(J/\psi(1S) \rightarrow \gamma\gamma)/\Gamma_{\text{total}}
```

PARITY (P) INVARIANCE

```
{<}10.5\,\times10^{\displaystyle -28} ecm, CL \,=\,90\%
e electric dipole moment
                                                                                    (-0.1\,\pm\,0.9) \times 10^{-19}~e\,\text{cm}
\mu electric dipole moment
                                                                                    - 0.220 to 0.45 	imes 10^{-16} ecm, CL
Re(d_{\tau} = \tau \text{ electric dipole moment})
                                                                                    = 95\% <1.3\times10^{-5} , CL = 90\%
\Gamma(\eta \to \pi^+ \pi^-)/\Gamma_{
m total}
                                                                                    <3.5 \times 10^{-4}, CL = 90%
\Gamma(\eta \rightarrow 2\pi^0)/\Gamma_{total}
\Gamma(\eta \rightarrow 4\pi^0)/\Gamma_{\text{total}}
                                                                                    <6.9 \times 10^{-7}, CL = 90\%
                                                                                    {<}6\times10^{-5}\text{, CL}\,=\,90\%
\Gamma(\eta'(958) \rightarrow \pi^{+}\pi^{-})/\Gamma_{total}
\Gamma(\eta'(958) \rightarrow \pi^0\pi^0)/\Gamma_{\text{total}}
                                                                                    <4 \times 10^{-4}, CL = 90%
\Gamma(\eta_c(1S) \rightarrow \pi^+\pi^-)/\Gamma_{\text{total}}
                                                                                    < \! 1.1 \times 10^{-4} \text{, CL} = 90\%
\Gamma(\eta_{\mathcal{C}}(1S) \rightarrow \pi^0 \pi^0)/\Gamma_{\mathsf{total}}
                                                                                    <3.5 \times 10^{-5}, CL = 90%
\Gamma(\eta_{C}(1S) \rightarrow K^{+}K^{-})/\Gamma_{total}
                                                                                    <6 \times 10^{-4}, CL = 90%
\Gamma(\eta_c(1S) \rightarrow \kappa_S^0 \kappa_S^0)/\Gamma_{\text{total}}
                                                                                    <3.1 \times 10^{-4}, CL = 90%
                                                                                    <\!0.54\times 10^{-23}\;e\,{\rm cm}
p electric dipole moment
                                                                                    <\!0.29\times10^{-25} ecm, CL =\,90\%
n electric dipole moment
                                                                                    <1.5 \times 10^{-16} \text{ ecm, CL} = 95\%
A electric dipole moment
```

TIME REVERSAL (T) INVARIANCE

```
<10.5 	imes 10^{-28} e\,\mathrm{cm}, CL = 90%
e electric dipole moment
\mu electric dipole moment
                                                                                                                                                                                                                        (-0.1 \pm 0.9) \times 10^{-19} e \text{ cm}
\mu decay parameters
                                                                                                                                                                                                                        (-2 \pm 8) \times 10^{-3}
                     transverse e^+ polarization normal to
                                          plane of \mu spin, e^+ momentum
                                                                                                                                                                                                                        (-10 \pm 20) \times 10^{-3}
                                                                                                                                                                                                                        (2\pm7)\times10^{-3}
                    \beta'/A
                                                                                                                                                                                                                         -\,0.220 to 0.45\,\times10^{-16} ecm, CL
\mathrm{Re}(d_{\tau}=	au electric dipole moment)
                                                                                                                                                                                                                                            = 95%
P_T in K^+ \rightarrow \pi^0 \mu^+ \nu_\mu
                                                                                                                                                                                                                        (-1.7 \pm 2.5) \times 10^{-3}
P_T^- in K^+ 	o \mu^+ \nu_\mu \gamma
                                                                                                                                                                                                                        (-0.6 \pm 1.9) \times 10^{-2}
{
m Im}(\xi) \ {
m in} \ {
m \textit{K}}^+ 
ightarrow \ {\pi^0} {\hskip 1pt} {\hskip 1pt
                                                                                                                                                                                                                         -0.006 \pm 0.008
                  transverse \mu pol.)
asymmetry A_T in K^0 - \overline{K}^0 mixing
                                                                                                                                                                                                                       (\,6.6\,\pm1.6)\times10^{\textstyle -3}
\operatorname{Im}(\xi) in K^0_{\mu3} decay (from transverse \mu pol.)
                                                                                                                                                                                                                        -\,0.007\,\pm\,0.026
A_T(D^{\pm} \rightarrow K_S^0 K^{\pm} \pi^+ \pi^-)
                                                                                                                                                                                                      [b] (-12 \pm 11) \times 10^{-3}
A_T(D^0 \rightarrow K^+K^-\pi^+\pi^-)
                                                                                                                                                                                                      [b] (1 \pm 7) \times 10^{-3}
A_T(D_S^{\pm} \rightarrow K_S^0 K^{\pm} \pi^+ \pi^-)
                                                                                                                                                                                                      [b] (-14 \pm 8) \times 10^{-3}
                                                                                                                                                                                                                        < 0.54 \times 10^{-23} e \, \mathrm{cm}
p electric dipole moment
                                                                                                                                                                                                                         <0.29 \times 10^{-25} e cm, CL = 90%
n electric dipole moment
n \rightarrow pe^-\overline{\nu}_e decay parameters
                     \phi_{AV}, phase of g_A relative to g_V
                                                                                                                                                                                                      [c] (180.018 \pm 0.026)^{\circ}
                                                                                                                                                                                                      [d] (-1.2 \pm 2.0) \times 10^{-4}
                     triple correlation coefficient D
                     triple correlation coefficient R
                                                                                                                                                                                                     [d] 0.008 \pm 0.016
                                                                                                                                                                                                                         {<}1.5\times10^{-16}~\text{e}\,\text{cm}\,\text{,}\,\text{CL}\,=\,95\,\text{\%}
A electric dipole moment
triple correlation coefficient D for \Sigma^- 
ightarrow
                                                                                                                                                                                                                        0.11 \pm 0.10
```

CP INVARIANCE

```
< 0.50 \times 10^{-17} \text{ ecm, CL} = 95\%
Re(d_{-}^{W})
                                                                                                                                                                    <1.1 \times 10^{-17}~e\,\mathrm{cm}, CL =95\%
\operatorname{Im}(d_{\tau}^{W})
                                                                                                                                                                   (-0.6 \pm 3.1) \times 10^{-2}
\eta 
ightarrow \pi^+\pi^-\,e^+\,e^- decay-plane asymmetry
\Gamma(\eta \rightarrow \pi^+ \pi^-)/\Gamma_{\text{total}}
                                                                                                                                                                    <1.3 \times 10^{-5}, CL = 90%
\Gamma(\eta \rightarrow 2\pi^0)/\Gamma_{\text{total}}
                                                                                                                                                                   < 3.5 \times 10^{-4}. CL = 90%
\Gamma(\eta \to 4\pi^0)/\Gamma_{\text{total}}
                                                                                                                                                                    <6.9 \times 10^{-7}, CL = 90%
\Gamma(\eta'(958) \rightarrow \pi^{+}\pi^{-})/\Gamma_{total}
                                                                                                                                                                   <6 \times 10^{-5}, CL = 90%
\Gamma(\eta'(958) \rightarrow \pi^0 \pi^0)/\Gamma_{\text{total}}
                                                                                                                                                                    <4 \times 10^{-4}, CL = 90\%
K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-} rate difference/average
                                                                                                                                                                   (0.08 \pm 0.12)\%
\kappa^{\pm} \rightarrow \pi^{\pm} \pi^{0} \pi^{0} rate difference/average
                                                                                                                                                                   (0.0 \pm 0.6)\%
{\it K}^{\pm} \rightarrow ~\pi^{\pm}\pi^{0}\gamma rate difference/average
                                                                                                                                                                   (0.9 \pm 3.3)\%
K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-} (g_{+} - g_{-}) / (g_{+} + g_{-}) / (g_{
                                                                                                                                                                  (-1.5\,\pm\,2.2)\times10^{-4}
                g_)

\kappa^{\pm} \to \pi^{\pm} \pi^{0} \pi^{0} (g_{+} - g_{-}) / (g_{+} + g_{-})

\wedge (\kappa^{\pm}) = \frac{\Gamma(K_{\pi e}^{+}) - \Gamma(K_{\pi e}^{-})}{\Gamma(K_{\pi e}^{+})}

                                                                                                                                                                  (1.8 \pm 1.8) \times 10^{-4}
                                                                                                                                                                   (-2.2 \pm 1.6) \times 10^{-2}
                                         \Gamma(K_{\pi e e}^+) + \Gamma(K_{\pi e e}^-)
\Delta(K_{\pi\mu\mu}^{\pm}) = \frac{\Gamma(K_{\pi\mu\mu}^{+}) - \Gamma(K_{\pi\mu\mu}^{-})}{\Gamma(K_{\pi\mu\mu}^{+}) + \Gamma(K_{\pi\mu\mu}^{-})}
                                                                                                                                                                   0.010\,\pm\,0.023
\Delta(\kappa_{\pi\pi\gamma}^{\pm}) = \frac{\Gamma(\kappa_{\pi\pi\gamma}^{+}) - \Gamma(\kappa_{\pi\pi\gamma}^{-})}{\Gamma(\kappa_{\pi\pi\gamma}^{+}) + \Gamma(\kappa_{\pi\pi\gamma}^{-})}
                                                                                                                                                                  (0.0 \pm 1.2) \times 10^{-3}
A_S = [\; \Gamma(K_S^0 \rightarrow \; \pi^- \, e^+ \, \nu_e) \; \text{-} \; \Gamma(K_S^0 \rightarrow \;
                                                                                                                                                                   (2 \pm 10) \times 10^{-3}
             \pi^+ e^- \overline{\nu}_e)]/SUM
Im(\eta_{+-0}) = Im(A(K_S^0 \to \pi^+\pi^-\pi^0, CP^-))
                                                                                                                                                                   -0.002 \pm 0.009
                 violating) / A(K_L^{0} \rightarrow \pi^+\pi^-\pi^0))
 \begin{array}{c} \operatorname{Im}(\eta_{000}) = \operatorname{Im}(A(K_S^0 \to \pi^0 \pi^0 \pi^0)/A(K_L^0 \to \pi^0 \pi^0 \pi^0)) \end{array} 
                                                                                                                                                                  (-0.1 \pm 1.6) \times 10^{-2}
|\eta_{000}| = |A(K_S^0 \to 3\pi^0)/A(K_I^0 \to 3\pi^0)|
                                                                                                                                                                    <0.018, CL = 90%
CP asymmetry A in K_S^0 \rightarrow \pi^+\pi^-e^+e^-
                                                                                                                                                                  (-0.4 \pm 0.8)\%
\Gamma(K_S^0 \rightarrow 3\pi^0)/\Gamma_{total}
                                                                                                                                                                   <1.2 \times 10^{-7}, CL = 90%
linear coefficient j for K^0_L \to \ \pi^+ \, \pi^- \, \pi^0
                                                                                                                                                                  0.0012 \pm 0.0008
quadratic coefficient f for K_L^0 
ightarrow \pi^+\pi^-\pi^0
                                                                                                                                                                   0.004 \pm 0.006
|\epsilon_{+-\gamma}^{\prime}|/\epsilon for K_L^0 \to \pi^+\pi^-\gamma
                                                                                                                                                                   <0.3, CL = 90%
\begin{array}{c} |\mathbf{g}_{E1}| \text{ for } K_L^0 \rightarrow \pi^+\pi^-\gamma \\ \Gamma(K_L^0 \rightarrow \pi^0\mu^+\mu^-)/\Gamma_{\text{total}} \end{array}
                                                                                                                                                                   < 0.21, CL = 90\%
                                                                                                                                                     [e] < 3.8 \times 10^{-10}, CL = 90%
\Gamma(\kappa_I^{\bar{0}} \rightarrow \pi^0 e^+ e^-)/\Gamma_{\rm total}
                                                                                                                                                     [e] <2.8 \times 10^{-10}, CL = 90%
\Gamma(K_L^{0} \rightarrow \pi^0 \nu \overline{\nu})/\Gamma_{\text{total}}
                                                                                                                                                     [f] <2.6 \times 10^{-8}, CL = 90%
A_{CP}(D^{\pm} \rightarrow \mu^{\pm} \nu)
                                                                                                                                                                  (8 \pm 8)\%
A_{CP}(D^{\pm} \rightarrow K_S^0 \pi^{\pm})
                                                                                                                                                                   (-0.54 \pm 0.14)\%
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```
A_{CP}(D^{\pm} \rightarrow K^{\mp} 2\pi^{\pm})
                                                                         (-0.1 \pm 1.0)\%
A_{CP}(D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{0})
                                                                        (1.0 \pm 1.3)\%
A_{CP}(D^{\pm} \rightarrow \kappa_{\varsigma}^{0} \pi^{\pm} \pi^{0})
                                                                        (0.3 \pm 0.9)\%
A_{CP}(D^{\pm} \rightarrow \kappa_S^0 \pi^{\pm} \pi^+ \pi^-)
                                                                        (0.1 \pm 1.3)\%
A_{CP}(D^{\pm} \rightarrow \pi^{\pm}\pi^{0})
                                                                        (2.9 \pm 2.9)\%
A_{CP}(D^{\pm} \rightarrow \pi^{\pm} \eta)
                                                                        (1.0 \pm 1.5)\% (S = 1.4)
A_{CP}(D^{\pm} \rightarrow \pi^{\pm} \eta'(958))
                                                                        (-0.5 \pm 1.2)\% (S = 1.1)
A_{CP}(D^{\pm} \rightarrow \kappa_S^0 \kappa^{\pm})
                                                                        (-0.1 \pm 0.6)\%
A_{CP}(D^{\pm} \rightarrow K^{+}K^{-}\pi^{\pm})
                                                                        (0.3 \pm 0.6)\%
A_{CP}(D^{\pm} \rightarrow K^{\pm}K^{*0})
                                                                        (0.1 \pm 1.3)\%
A_{CP}(D^{\pm} \rightarrow \phi \pi^{\pm})
                                                                        (0.42 \pm 0.28)\%
A_{CP}(D^{\pm} \rightarrow K^{\pm}K_{0}^{*}(1430)^{0})
                                                                        (8^{+7}_{-6})\%
{\cal A}_{CP}(D^{\pm}\to \ {\it K}^{\pm}{\it K}_{2}^{*}(1430)^{0})
                                                                        (43 + 20 \atop -26)\%
A_{CP}(D^{\pm} \rightarrow K^{\pm}K_{0}^{*}(800))
                                                                        (-12^{+18}_{-13})\%
A_{CP}(D^{\pm} \rightarrow a_0(1450)^0 \pi^{\pm})
                                                                        (-19^{+14}_{-16})\%
A_{CP}(D^{\pm} \rightarrow \phi(1680) \pi^{\pm})
                                                                        (-9 \pm 26)\%
A_{CP}(D^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm})
                                                                        (-2 \pm 4)\%
A_{CP}(D^{\pm} \rightarrow \kappa_S^0 \kappa^{\pm} \pi^+ \pi^-)
                                                                        (-4 \pm 7)\%
A_{CP}(D^{\pm} \rightarrow \kappa^{\pm}\pi^{0})
                                                                        (-4 \pm 11)\%
|q/p| of D^0 - \overline{D}{}^0 mixing
                                                                        0.88 + 0.16 \\ -0.15
A_{\Gamma} of D^0 - \overline{D}{}^0 mixing
                                                                        (0.26 \pm 2.31) \times 10^{-3}
Where there is ambiguity, the \it CP test is labelled by the \it D^{\,0} decay mode.
A_{CP}(D^0 \rightarrow K^+ K^-)
                                                                       (-0.21 \pm 0.17)\%
A_{CP}(D^0 \rightarrow \kappa_S^0 \kappa_S^0)
                                                                        (-23 + 19)\%
A_{CP}(D^0 \rightarrow \pi^+\pi^-)
                                                                        (0.22 \pm 0.21)\%
A_{CP}(D^0 \rightarrow \pi^0\pi^0)
                                                                        (0 \pm 5)\%
A_{CP}(D^0 \rightarrow \pi^+\pi^-\pi^0)
                                                                       (0.3 \pm 0.4)\%
A_{CP}(D^0 \to \rho(770)^+\pi^- \to \pi^+\pi^-\pi^0)
                                                                  [g] (1.2 \pm 0.9)\%
A_{CP}(D^0 \to \rho(770)^0 \pi^0 \to \pi^+ \pi^- \pi^0)
                                                                  [g] (-3.1 \pm 3.0)\%
A_{CP}(D^0 \to \rho(770)^-\pi^+ \to \pi^+\pi^-\pi^0)
                                                                  [g] (-1.0 \pm 1.7)\%
A_{CP}(D^0 \to \rho(1450)^+\pi^- \to \pi^+\pi^-\pi^0)
                                                                  [g] (0 \pm 70)\%
A_{CP}(D^0 \to \rho(1450)^0 \pi^0 \to \pi^+ \pi^- \pi^0)
                                                                  [g] (-20 \pm 40)\%
A_{CP}(D^0 \to \rho(1450)^-\pi^+ \to \pi^+\pi^-\pi^0)
                                                                  [g] (6 \pm 9)\%
A_{CP}(D^0 \to \rho(1700)^+\pi^- \to \pi^+\pi^-\pi^0)
                                                                  [g] (-5 \pm 14)\%
A_{CP}(D^0 \to \rho(1700)^0 \pi^0 \to \pi^+ \pi^- \pi^0)
                                                                  [g] (13 \pm 9)\%
A_{CP}(D^0 \to \rho(1700)^-\pi^+ \to \pi^+\pi^-\pi^0)
                                                                  [g] (8 \pm 11)\%
A_{CP}(D^0 \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)
                                                                  [g] (0 \pm 35)\%
A_{CP}(D^0 \to f_0(1370)\pi^0 \to \pi^+\pi^-\pi^0)
                                                                  [g] (25 \pm 18)\%
A_{CP}(D^0 \to f_0(1500)\pi^0 \to \pi^+\pi^-\pi^0)
                                                                  [g] (0 \pm 18)\%
A_{CP}(D^0 \to f_0(1710)\pi^0 \to \pi^+\pi^-\pi^0)
                                                                  [g] (0 \pm 24)\%
A_{CP}(D^0 \to f_2(1270)\pi^0 \to \pi^+\pi^-\pi^0)
                                                                  [g] (-4 \pm 6)\%
A_{CP}(D^0 \to \sigma(400) \pi^0 \to \pi^+ \pi^- \pi^0)
                                                                  [g] (6 \pm 8)\%
A_{CP} (nonresonant D^0 \rightarrow \pi^+\pi^-\pi^0)
                                                                  [g] (-13 \pm 23)\%
A_{CP}(D^0 \rightarrow K^+K^-\pi^0)
                                                                        (-1.0 \pm 1.7)\%
A_{CP}^{(D^0)} \rightarrow K^*(892)^+ K^- \rightarrow K^+ K^- \pi^0)
                                                                  [g] (-0.9 \pm 1.3)\%
A_{CP}(D^0 \to K^*(1410)^+ K^- \to
                                                                  [g] (-21 \pm 24)\%
      K^{+}K^{-}\pi^{0}
A_{CP}(D^0 \rightarrow (K^+\pi^0)_S K^- \rightarrow
                                                                  [g] (7 \pm 15)\%
       \kappa^{+} \kappa^{-} \pi^{0}
A_{CP}(D^0 \to \phi(1020) \pi^0 \to K^+ K^- \pi^0)
                                                                  [g] (1.1 \pm 2.2)\%
A_{CP}(D^0 \to f_0(980)\pi^0 \to K^+K^-\pi^0)
                                                                  [g] (-3 \pm 19)\%
A_{CP}(D^0 \to a_0(980)^0 \pi^0 \to K^+ K^- \pi^0)
                                                                  [g] (-5 \pm 16)\%
A_{CP}(D^0 \to f_2'(1525)\pi^0 \to K^+K^-\pi^0)
                                                                  [g] (0 \pm 160)\%
A_{CP}(D^0 \to K^*(892)^- K^+ \to K^+ K^- \pi^0)
                                                                  [g] (-5 \pm 4)\%
[g] (-17 \pm 29)\%
      \kappa^{+} \kappa^{-} \pi^{0}
A_{CP}(D^0 \rightarrow (K^-\pi^0)_{S-wave}K^+ \rightarrow
                                                                  [g] (-10 \pm 40)\%
      K^{+}K^{-}\pi^{0}
A_{CP}(D^0 \rightarrow \kappa_5^0 \pi^0)
                                                                        (\,-\,0.27\,\pm\,0.21)\,\%
A_{CP}(D^0 \to \kappa_S^0 \eta)
                                                                        (0.5 \pm 0.5)\%
A_{CP}(D^0 \rightarrow \kappa_S^0 \eta')
                                                                        (1.0 \pm 0.7)\%
A_{CP}(D^0 \rightarrow \kappa_S^0 \phi)
                                                                        (-3 + 9)\%
A_{CP}(D^0 \rightarrow \kappa^-\pi^+)
                                                                        (0.1 \pm 0.7)\%
A_{CP}(D^0 \rightarrow K^+\pi^-)
                                                                        (2.2 \pm 3.2)\%
A_{CP}(D^0 \to K^-\pi^+\pi^0)
                                                                        (0.2 \pm 0.9)\%
A_{CP}(D^0 \to K^+\pi^-\pi^0)
                                                                        (0 \pm 5)\%
                                                                        (-0.9 + 2.6 \atop -6.0)\%
A_{CP}(D^0 \rightarrow \kappa_S^0 \pi^+ \pi^-)
A_{CP}(D^0 \to K^*(892)^-\pi^+ \to K^0_S\pi^+\pi^-)
                                                                        <\!3.5\times10^{-4}\text{, CL}\,=\,95\,\%
A_{CP}(D^0 \to K^*(892)^+\pi^- \to K_S^0\pi^+\pi^-)
                                                                         < 7.8 \times 10^{-4}, CL = 95%
A_{CP}(D^0 \to K_S^0 \rho^0 \to K_S^0 \pi^+ \pi^-)
                                                                         <4.8 \times 10^{-4}, CL = 95%
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| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | S = 2.1) |
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| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S = 2.1) |
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| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | S = 2.1) |
| $\begin{array}{c} R_0^2 \pi^+ \pi^- \\ A_{CP}(D^0 \to K_3^*(1430)^- \pi^+ \to \\ A_{CP}(D^0 \to K_3^*(1430)^- \pi^+ \to \\ K_0^2 \pi^+ \pi^-) \\ A_{CP}(D^0 \to K_3^*(1630)^- \pi^+ \to \\ K_0^2 \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^*(1630)^- \pi^+ \to \\ A_{CP}(B^0 \to K^*(1630)^- \pi^+ \to \\ A_{CP}(B^0 \to K^*(1630)^+ \to \\ K_0^2 \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^*(1630)^+ \to \\ K_0^2 \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^* \pi^+ \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^+ \pi^- \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^+ \pi^- \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^+ \pi^- \pi^+ \pi^-) \\ A_{CP}(D^0 \to K^+ K^- \pi^+ \pi^- \pi^+) \\ A_{CP}(D^0 \to K^+ K^- \pi^- \pi^+) \\ A_{CP}(D^0 \to K^+ K^- \pi^- \pi^+) \\ A_{CP}(D^0 \to K^- K^- \pi^+ \pi^- \pi^+) \\ A_{CP}(D^0 \to K^- K^- \pi^+ \pi^- \pi^+) \\ A_{CP}(D^0 \to K^- K^- \pi^- \pi^+) \\ A_{CP}(D^0 \to K^- K^- \pi^- \pi^+) \\ A_{CP}(D^0 \to K^- K^- \pi^- \pi^+) \\ A_$ | S = 2.1) |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | S = 2.1) |
| $\begin{array}{c} K_0^0 \pi^+ \pi^-) & A_{CP}(B^+ \to \eta' K^+) & 0.013 \pm 0.017 \\ A_{CP}(D^0 \to K^*(1680)^- \pi^+ \to & <28.4 \times 10^{-4}, \text{CL} = 95\% & A_{CP}(B^+ \to \eta' K^*(892)^+) & -0.26 \pm 0.27 \\ K_0^0 \pi^+ \pi^-) & A_{CP}(B^+ \to \eta' K^*_0(1430)^+) & 0.06 \pm 0.20 \\ A_{CP}(D^0 \to K^- \pi^+ \pi^+ \pi^-) & (0.7 \pm 1.0)\% & A_{CP}(B^+ \to \eta' K^*_0(1430)^+) & 0.15 \pm 0.13 \\ A_{CP}(D^0 \to K^- \pi^- \pi^+ \pi^-) & (-2 \pm 4)\% & A_{CP}(B^+ \to \eta K^*) & -0.37 \pm 0.08 \\ A_{CP}(D^0 \to K^+ K^- \pi^+ \pi^-) & (-0.65 \pm 0.18)\% & A_{CP}(B^+ \to \eta K^*) & 0.02 \pm 0.05 \\ A_{CP}(B^+ \to \eta^+ K^*) & A_{CP}(B^+ \to \eta^+ K^*) & 0.02 \pm 0.05 \\ A_{CP}(B^+ \to \eta^+ K^*) & A_{CP}(B^+ \to \eta^+ K^*) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to \mu^\pm \nu) & (5 \pm 6)\% & A_{CP}(B^+ \to \eta^+ K^*) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to K^+ K^- \pi^\pm) & (0.3 \pm 0.4)\% & A_{CP}(B^+ \to \eta^+ K^*) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to K^+ K^- \pi^\pm) & (0.3 \pm 0.4)\% & A_{CP}(B^+ \to W^{++}) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to K^+ K^- \pi^\pm) & (0.3 \pm 1.4)\% & A_{CP}(B^+ \to W^{++}) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to K^+ K^- \pi^\pm) & (-6 \pm 4)\% & A_{CP}(B^+ \to W^{++}) & 0.02 \pm 0.05 \\ A_{CP}(D^\pm_3 \to K^0_3 K^0 K^2 2 \pi^\pm) & (-1 \pm 4)\% & A_{CP}(B^+ \to W^{+}) & 0.14 \pm 0.15 \\ A_{CP}(D^\pm_3 \to K^0_3 K^0 K^2 2 \pi^\pm) & (-1 \pm 4)\% & A_{CP}(B^+ \to K^+ G^{0})^+ & 0.14 \pm 0.15 \\ A_{CP}(D^\pm_3 \to K^\pm_3 K^\pm) & (-1 \pm 3.0)\% & A_{CP}(B^+ \to K^+ G^{0})^+ & 0.04 \pm 0.09 \\ A_{CP}(D^\pm_3 \to \pi^\pm \eta) & (-4.6 \pm 2.9)\% & A_{CP}(B^+ \to K^+ G^{0})^+ & 0.038 \pm 0.022 \\ A_{CP}(D^\pm_3 \to K^\pm_3 K^-) & (-27 \pm 24)\% & A_{CP}(B^+ \to K^+ G^{0})^+ & 0.038 \pm 0.022 \\ A_{CP}(D^\pm_3 \to K^\pm_3 \pi^+) & (-6.6 \pm 3.3)\% (S = 1.4) & A_{CP}(B^+ \to K^*_3 (1430)^0 \pi^+) & 0.038 \pm 0.022 \\ A_{CP}(D^\pm_3 \to K^\pm_3 \pi^+) & (-1 \pm 1.0) + A_{CP}(B^+ \to K^*_3 (1430)^0 \pi^+) & 0.05 \pm 0.033 \\ A_{CP}(D^\pm_3 \to K^\pm_3 \pi^+) & (-1 \pm 0.08 + 0.007 (S = 1.8) & A_{CP}(B^+ \to K^*_3 (1430)^0 \pi^+) & 0.05 \pm 0.033 \\ A_{CP}(B^+ \to J/\psi K^+) & 0.01 \pm 0.07 (S = 1.3) & A_{CP}(B^+ \to K^*_3 (1430)^0 \pi^+) & 0.05 \pm 0.024 \\ A_{CP}(B^+ \to J/\psi K^+) & 0.01 \pm 0.007 (S = 1.3) & A_{CP}(B^+ \to K^*_3 (1430)^0 \pi^+) & 0.05 \pm 0.024 \\ A_{CP}(B^+ \to J/\psi K^+) & 0.01 \pm 0.08 \\ A_{CP}(B^+ \to J/\psi K^+) & 0.01 \pm 0.08 \\ A_{CP}(B^+ \to J/\psi$ | |
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| $\begin{array}{c} \Delta A_{CP}^{00} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) & (-0.65\pm0.18)\% & A_{CP}(B^+ \to \eta K_0^*(1430)^+) & 0.05\pm0.13 \\ A_{CP}(D_5^\pm \to \mu^\pm \nu) & (5\pm6)\% & A_{CP}(B^+ \to \eta K_2^*(1430)^+) & -0.45\pm0.30 \\ A_{CP}(D_5^\pm \to K^\pm K_0^*) & (0.3\pm0.4)\% & A_{CP}(B^+ \to \omega K^+) & 0.02\pm0.05 \\ A_{CP}(D_5^\pm \to K^+K^-\pi^\pm) & (0.3\pm1.4)\% & A_{CP}(B^+ \to \omega K^*) & 0.29\pm0.05 \\ A_{CP}(D_5^\pm \to K^+K^-\pi^\pm) & (-6\pm4)\% & A_{CP}(B^+ \to \omega K^*) & 0.29\pm0.35 \\ A_{CP}(D_5^\pm \to K^+K^-\pi^\pm) & (-6\pm4)\% & A_{CP}(B^+ \to \omega K_2^*(1430)^+) & 0.14\pm0.15 \\ A_{CP}(D_5^\pm \to K_2^0K^2\pi^\pm) & (-1\pm4)\% & A_{CP}(B^+ \to \omega K_2^*(1430)^+) & 0.14\pm0.15 \\ A_{CP}(D_5^\pm \to K_2^0K^2\pi^\pm) & (-4.6\pm2.9)\% & A_{CP}(B^+ \to K^*(892)^+\pi^0) & -0.04\pm0.09 \\ A_{CP}(D_5^\pm \to \pi^\pm \eta^-) & (-4.6\pm2.9)\% & A_{CP}(B^+ \to K^*(892)^+\pi^0) & -0.06\pm0.24 \\ A_{CP}(D_5^\pm \to K^\pm \pi^0) & (-6.1\pm3.0)\% & A_{CP}(B^+ \to K_2^0(980)K^+) & -0.09\pm0.035 \\ A_{CP}(D_5^\pm \to K^\pm \pi^0) & (-27\pm24)\% & A_{CP}(B^+ \to f_0(980)K^+) & -0.66\pm0.17 \\ A_{CP}(D_5^\pm \to K^\pm \pi^0) & (-27\pm24)\% & A_{CP}(B^+ \to f_0(1500)K^+) & 0.28\pm0.30 \\ A_{CP}(D_5^\pm \to K^\pm \pi^-) & (11\pm7)\% & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.033 \\ A_{CP}(D_5^\pm \to K^\pm \eta^-) & (9\pm15)\% & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.033 \\ A_{CP}(D_5^\pm \to K^\pm \eta^-) & (9\pm15)\% & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.033 \\ A_{CP}(B^+ \to J/\psi(15)K^+) & (1\pm7)\times10^{-3}(S=1.8) & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.033 \\ A_{CP}(B^+ \to J/\psi(15)K^+) & (0.11\pm0.14) & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.033 \\ A_{CP}(B^+ \to J/\psi(15)K^+) & (0.11\pm0.14) & A_{CP}(B^+ \to K_2^*(1430)^0\pi^+) & 0.05\pm0.024 \\ A_{CP}(B^+ \to J/\psi(25)K^+) & -0.01\pm0.033 & A_{CP}(B^+ \to K_2^*(932)^+f_0(980)) & -0.15\pm0.12 \\ A_{CP}(B^+ \to \psi(25)K^+) & -0.02\pm0.09 & A_{CP}(B^+ \to A_2^*(892)^+f_0(980)) & -0.15\pm0.12 \\ A_{CP}(B^+ \to \psi(25)K^+) & -0.02\pm0.09 & A_{CP}(B^+ \to A_2^*(892)^+f_0(980)) & -0.15\pm0.12 \\ A_{CP}(B^+ \to \psi(25)K^+) & -0.02\pm0.09 & A_{CP}(B^+ \to A_2^*(892)^+f_0(980)) & -0.15\pm0.12 \\ A_{CP}(B^+ \to \psi(25)K^+) & -0.02\pm0.09 & A_{CP}(B^+ \to A_2^*(892)^+f_0(980)) & -0.04\pm0.016 \\ A_{CP}(B^+ \to \psi(25)K^+) & -0.04\pm0.018 & A_{CP}(B^+ \to A_2^*(892)^+f_0(980)) & -0.04\pm0.016 \\ A$ | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| $\begin{array}{c} A_{CP}(D_s^{\pm} \to \kappa \pm \kappa_0^0) & (0.3 \pm 0.4)\% & A_{CP}(B^{\pm} \to \omega K^{\pm}) & 0.02 \pm 0.05 \\ A_{CP}(D_s^{\pm} \to \kappa + \kappa - \pi \pm) & (0.3 \pm 1.4)\% & A_{CP}(B^{\pm} \to \omega K^{\pm}) & 0.29 \pm 0.35 \\ A_{CP}(D_s^{\pm} \to \kappa + \kappa - \pi \pm) & (0.3 \pm 1.4)\% & A_{CP}(B^{\pm} \to \omega K^{\pm}) & 0.29 \pm 0.35 \\ A_{CP}(D_s^{\pm} \to \kappa + \kappa - \pi \pm \pi^0) & (-6 \pm 4)\% & A_{CP}(B^{\pm} \to \omega \kappa_2^* (1430)^{+}) & 0.14 \pm 0.15 \\ A_{CP}(D_s^{\pm} \to \kappa_s^0 \kappa \mp 2\pi \pm) & (-1 \pm 4)\% & A_{CP}(B^{\pm} \to \omega \kappa_2^* (1430)^{+}) & 0.14 \pm 0.15 \\ A_{CP}(D_s^{\pm} \to \kappa_s^0 \kappa \mp 2\pi \pm) & (-1 \pm 4)\% & A_{CP}(B^{\pm} \to \kappa^* 0\pi^{+}) & -0.04 \pm 0.09 \\ A_{CP}(D_s^{\pm} \to \pi^{\pm} \pi) & (-4.6 \pm 2.9)\% & A_{CP}(B^{\pm} \to \kappa^* 0\pi^{+}) & -0.04 \pm 0.09 \\ A_{CP}(D_s^{\pm} \to \pi^{\pm} \pi^{+}) & (-6.1 \pm 3.0)\% & A_{CP}(B^{\pm} \to \kappa^* 0\pi^{+}) & -0.038 \pm 0.022 \\ A_{CP}(D_s^{\pm} \to \pi^{\pm} \pi^{+}) & (-6.1 \pm 3.0)\% & A_{CP}(B^{\pm} \to \kappa^* (980) \kappa^{+}) & -0.09^{\pm 0.036} \kappa^{+} \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{0}) & (-27 \pm 24)\% & A_{CP}(B^{\pm} \to \kappa^{0} (980) \kappa^{+}) & -0.68^{\pm 0.13} \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{0}) & (-27 \pm 24)\% & A_{CP}(B^{\pm} \to \kappa^{0} (980) \kappa^{+}) & -0.68^{\pm 0.13} \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{0}) & (-27 \pm 24)\% & A_{CP}(B^{\pm} \to \kappa^{0} (1500) \kappa^{+}) & 0.28 \pm 0.30 \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{+} \pi^{-}) & (11 \pm 7)\% & A_{CP}(B^{\pm} \to \kappa^{0} (1500) \kappa^{+}) & 0.28 \pm 0.30 \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{+} \pi^{-}) & (11 \pm 7)\% & A_{CP}(B^{\pm} \to \kappa^{0} (1500) \kappa^{+}) & 0.05 \pm 0.033 \\ A_{CP}(D_s^{\pm} \to \kappa^{\pm} \pi^{+} (1958)) & (6 \pm 19)\% & A_{CP}(B^{\pm} \to \kappa^{0} (1430)^{0} \pi^{+}) & 0.05 \pm 0.024 \\ A_{CP}(B^{\pm} \to J/\psi (15) \kappa^{+}) & (1 \pm 7) \times 10^{-3} (5 \pm 1.8) & A_{CP}(B^{\pm} \to \kappa^{0} \pi^{0}) & -0.06 \pm 0.07 \\ A_{CP}(B^{\pm} \to J/\psi (15) \kappa^{+}) & -0.01 \pm 0.07 (5 \pm 1.3) & A_{CP}(B^{\pm} \to \kappa^{0} (892)^{+}) & -0.12 \pm 0.17 \\ A_{CP}(B^{\pm} \to \psi (25) \kappa^{+}) & -0.048 \pm 0.033 & A_{CP}(B^{\pm} \to \kappa^{0} (892)^{+}) & 0.31 \pm 0.13 \\ A_{CP}(B^{\pm} \to \psi (25) \kappa^{+}) & -0.02 \pm 0.024 & A_{CP}(B^{\pm} \to h^{\pm} \kappa^{0}) & -0.05 \pm 0.12 \\ A_{CP}(B^{\pm} \to \psi (25) \kappa^{+}) & -0.02 \pm 0.024 & A_{CP}(B^{\pm} \to h^{\pm} \kappa^{0}) & -0.01 \pm 0.16 \\ A_{CP}(B^{\pm} \to \psi (25) \kappa^{+}) & -0.02 \pm 0.024 & A_{CP}(B^{\pm} \to h^{\pm} \kappa^{0}) & -0.01 \pm 0.16 \\ A_{CP}(B^{\pm}$ | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | 5 = 1.1) |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 5 = 1.1) |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | |
| $\begin{array}{llll} A_{CP}(B^+ \to \psi(25)K^+) & -0.025 \pm 0.024 & A_{CP}(B^+ \to b_1^+ K^0) & -0.03 \pm 0.15 \\ A_{CP}(B^+ \to \psi(25)K^*(892)^+) & 0.08 \pm 0.21 & A_{CP}(B^+ \to K^*(892)^0 \rho^+) & -0.01 \pm 0.16 \\ A_{CP}(B^+ \to \chi_{C1}(1P)\pi^+) & 0.07 \pm 0.18 & A_{CP}(B^+ \to b_1^0 K^+) & -0.46 \pm 0.20 \end{array}$ | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| $A_{CP}(B^+ \to \chi_{c1}(P)\pi^+)$ 0.07 ± 0.18 $A_{CP}(B^+ \to h^0 K^+)$ -0.46 ± 0.20 | |
| | |
| $A_{CP}(B^+ \to \chi_{c0} K^+)$ = 0.20 ± 0.18 (S = 1.5) | |
| $ACP(B \rightarrow \chi_{c1} \land 1)$ = 0.009 ± 0.003 | |
| $A_{CP}(B^+ \rightarrow \chi_{c1} \land (652)^+)$ 0.5 ± 0.5 | |
| $A_{CP}(B^+ \rightarrow B^+\pi^+)$ = 0.000 \pm 0.000 |) |
| $A = (P^{+}) \times CP(+1)$ | |
| $A_{CP}(B^+ 	o D_{CP(-1)}\pi^+)$ 0.017 ± 0.026 $A_{CP}(B^+ 	o K^+)$ -0.04 ± 0.07 | |
| $A_{CP}(B^+ \to \overline{D}^0 K^+)$ 0.07 ± 0.04 $A_{CP}(B^+ \to K^{*+} K^+ K^-)$ 0.11 ± 0.09 | |
| $r_B(B^+ \to D^0 K^+)$ 0.113 $^{+0.024}_{-0.021}$ $A_{CP}(B^+ \to \phi K^*(892)^+)$ -0.01 \pm 0.08 | |
| $\delta_B(B^+ \to D^0 K^+)$ (125 ± 16)° $A_{CP}(B^+ \to \phi(K\pi)_0^{*+})$ 0.04 ± 0.16 | |
| $r_B(B^+ \to D K^{*+})$ 0.34 ± 0.09 (S = 1.3) $A_{CP}(B^+ \to \phi K_1(1270)^+)$ 0.15 ± 0.20 | |
| $\delta_B(B^+ \to D K^{*+})$ (157 ± 70)° (S = 2.0) $A_{CP}(B^+ \to \phi K_2^*(1430)^+)$ -0.23 ± 0.20 | |
| $A_{CP}(B^+ \to [K^-\pi^+]_D K^+)$ | |
| $A_{CP}(B^+ \to [K^-\pi^+]_{\overline{D}}K^*(892)^+)$ | |
| $A_{CP}(B^+ \to [K^-\pi^+]_D\pi^+)$ 0.00 ± 0.09 $A_{CP}(B^+ \to [K^-\pi^+]_D\pi^+)$ 0.018 ± 0.029 $A_{CP}(B^+ \to [K^-\pi^+]_D\pi^+)$ 0.018 ± 0.029 | |
| $A_{CP}(B^+ 	o \eta K^+ \gamma)$ = 0.12 ± 0.07 | |
| $A_{CP}(B^+ \to [K^-\pi^+]_{(D\gamma)}\pi^+)$ -0.7 ± 0.6 $A_{CP}(B^+ \to \phi K^+\gamma)$ $-0.13 \pm 0.11 + 0.00$ | S = 1.1) |
| $A_{CP}(B^+ \to [K^-\pi^+]_{(D\pi)}K^+)$ 0.8 ± 0.4 $A_{CP}(B^+ \to \rho^+\gamma)$ -0.11 ± 0.33 | |
| $A_{CP}(B^+ \to [\kappa^- \pi^+]_{(D\gamma)} \kappa^+)$ 0.4 ± 1.0 $A_{CP}(B^+ \to \pi^+ \pi^0)$ 0.06 ± 0.05 | |
| $A_{CP}(B^{+} \rightarrow [\pi^{+}\pi^{-}\pi^{0}]_{D}K^{+})$ 0.03 ± 0.15 $A_{CP}(B^{+} \rightarrow \pi^{+}\pi^{-}\pi^{+})$ 0.03 ± 0.06 | |
| $A_{CP}(B^{+} \rightarrow D_{CP(+1)}K^{+})$ 0.24 ± 0.06 (S = 1.1) $A_{CP}(B^{+} \rightarrow \rho^{0}\pi^{+})$ 0.18 $^{+}0.09$ | |
| $A_{CP}(B^+ \to D_{CP(-1)}K^+)$ 0.41 ± 0.30 $A_{CP}(B^+ \to D_{CP(-1)}K^+)$ 0.41 ± 0.30 0.1+0.4 | |
| $A_{CP}(B^+ \to \rho^{\circ}(1450)\pi^+)$ | |
| $A_{CP}(B^+ \to \pi^+\pi^-\pi^+ \text{nonresonant}) = -0.14^{+0.13}_{-0.16}$ | |
| $A_{CP}(B^+ \rightarrow \rho^+ \pi^*)$ 0.02 \pm 0.11 | |
| $P(P(D \rightarrow P P))$ | |
| $A_{CP}(B^+ \to D^{*0}K^+)$ | |
| $r_B^*(B^+ \to D^{*0}K^+)$ 0.123 $^+$ 0.026 $r_B^*(B^+ \to \omega \rho^+)$ -0.20 \pm 0.09 | _ |
| $\delta_B^*(B^+ \to D^{*0}K^+)$ (300 ± 30)° (S = 1.7) $A_{CP}(B^+ \to \eta \pi^+)$ -0.14 ± 0.07 | 5 = 1.4) |
| $A_{CP}(B^+ \to D_{CP(+1)}^{*0}K^+)$ | |
| $A_{CP}(B^+ 	o D^*_{CP(-1)} 	extbf{K}^+) \qquad 0.07 \pm 0.10 \qquad A_{CP}(B^+ 	o \eta' \pi^+) \qquad 0.06 \pm 0.16 \\ A_{CP}(B^+ 	o \eta' \rho^+) \qquad 0.26 \pm 0.17 $ | |
| $A (P^+, P) \qquad V^*(999)^+) \qquad 0.00 + 0.14$ | |
| $ACP(B^+ \to DCP(+1)^{-K} (692)^+)$ 0.09 \pm 0.14 $ACP(B^+ \to b_1^0 \pi^+)$ 0.05 \pm 0.16 | |

| $A_{CP}(B^+ \to p\overline{p}\pi^+)$ $A_{CP}(B^+ \to p\overline{p}K^+)$ | 0.00 ± 0.04 | $C_{\eta'(958) K_S^0} (B^0 \to \eta'(958) K_S^0)$ | $-0.04 \pm 0.20 \; (S=2.5)$ |
|-----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| $A_{CP}(B^+ \to ppK^+)$ $A_{CP}(B^+ \to p\overline{p}K^*(892)^+)$ | -0.16 ± 0.07 $0.21 \pm 0.16 \text{ (S} = 1.4)$ | $S_{\eta'(958) \ K_S^0} (B^0 \to \eta'(958) \ K_S^0)$ | $0.43\pm0.17\;(\text{S}=1.5)$ |
| $A_{CP}(B^+ \to p\overline{\Lambda}\gamma)$ | 0.17 ± 0.17 | $C_{\eta'K^0}(B^0 \to \eta'K^0)$ | -0.05 ± 0.05 |
| $A_{CP}(B^+ \to p\overline{\Lambda}\pi^0)$ | 0.01 ± 0.17 | $C_{\omega \kappa_S^0}(B^0 \to \omega \kappa_S^0)$ | $-0.30\pm0.28\;(S=1.6)$ |
| $A_{CP}(B^+ \to K^+\ell^+\ell^-)$ | $-0.01\pm0.09\;(S=1.1)$ | $S_{\omega \kappa_0^0}(B^0 \to \omega \kappa_0^0)$ | 0.43 ± 0.24 |
| $A_{CP}(B^+ \rightarrow K^+ e^+ e^-)$ | 0.14 ± 0.14 | $C(B^0 \to K_0^0 \pi^0 \pi^0)$ | |
| $A_{CP}(B^+ \to K^+ \mu^+ \mu^-)$ $A_{CP}(B^+ \to K^{*+} \ell^+ \ell^-)$ | -0.05 ± 0.13 -0.09 ± 0.14 | $S(B^0 \to K_S^0 \pi^0 \pi^0)$ $S(B^0 \to K_S^0 \pi^0 \pi^0)$ | 0.2 ± 0.5 0.7 ± 0.7 |
| $A_{CP}(B^+ \to K^+e^+e^-)$ | -0.09 ± 0.14 -0.14 ± 0.23 | $C_{\rho^0 \kappa_S^0}(B^0 \to \rho^0 \kappa_S^0)$ | -0.04 ± 0.20 |
| $A_{CP}(B^+ \rightarrow K^* \mu^+ \mu^-)$ | -0.12 ± 0.24 | $\rho^0 K_S^0 = 0.00$ | |
| $\operatorname{Re}(\epsilon_{B^0})/(1+ \epsilon_{B^0} ^2)$ | $(-0.8 \pm 0.8) \times 10^{-3}$ | $S_{\rho^0 K_S^0}(B^0 \rightarrow \rho^0 K_S^0)$ | $0.50 + 0.17 \\ -0.21$ |
| A T/CP | 0.005 ± 0.018 | $C_{f_0(980) K_S^0}(B^0 \to f_0(980) K_S^0)$ | 0.14 ± 0.17 |
| $A_{CP}(B^0 \to D^*(2010)^+D^-)$ | 0.02 ± 0.04 | $S_{f_0(980) K_S^0}(B^0 \to f_0(980) K_S^0)$ | $-0.73^{+0.27}_{-0.09}$ (S = 1.6) |
| $A_{CP}(B^0 \to \eta' K^*(892)^0)$ | 0.02 ± 0.23 | $S_{f_2(1270)}K_S^0$ $(B^0 \to f_2(1270)K_S^0)$ | -0.5 ± 0.5 |
| $A_{CP}(B^0 \to \eta' K_0^*(1430)^0)$ | -0.19 ± 0.17 | $f_2(1270) K_S^{\circ}$ (P0 + f (1270) K0) | 0.3 ± 0.4 |
| $A_{CP}(B^0 \to \eta' K_2^*(1430)^0)$ | 0.14 ± 0.18 | $C_{f_2(1270)} K_S^0 (B^0 \to f_2(1270) K_S^0)$ | |
| $A_{CP}(B^0 \to \eta K_0^*(1430)^0)$ $A_{CP}(B^0 \to \eta K_2^*(1430)^0)$ | 0.06 ± 0.13 -0.07 ± 0.19 | $S_{f_X(1300)} K_S^0 (B^0 \to f_X(1300) K_S^0)$ | -0.2 ± 0.5 |
| $A_{CP}(B^0 \to \eta \kappa_2^{(1430)})$ $A_{CP}(B^0 \to b_1 K^+)$ | -0.07 ± 0.19 -0.07 ± 0.12 | $C_{f_X}(1300) K_S^0 (B^0 \to f_X(1300) K_S^0)$ | 0.13 ± 0.35 |
| $A_{CP}(B^0 \to \omega K^{*0})$ | 0.45 ± 0.25 | $S_{K^0\pi^+\pi^-}^{(B^0\to K^0\pi^+\pi^-)}$ nonresonant) | -0.01 ± 0.33 |
| $A_{CP}(B^0 \to \omega(K\pi)^{*0}_0)$ | -0.07 ± 0.09 | $C_{\kappa^0\pi^+\pi^-}(B^0\to \kappa^0\pi^+\pi^-$ nonresonant) | 0.01 ± 0.26 |
| $A_{CP}(B^0 \to \omega K_2^*(1430)^0)$ | -0.37 ± 0.17 | $C_{K_S^0 K_S^0}(B^0 \to K_S^0 K_S^0)$ | $0.0\pm0.4\;({\rm S}=1.4)$ |
| $A_{CP}(B^0 \rightarrow \kappa^+\pi^-\pi^0)$ | $(0 \pm 6) \times 10^{-2}$ | $S_{\mathcal{K}_{S}^{0}\mathcal{K}_{S}^{0}}(B^{0} \rightarrow \mathcal{K}_{S}^{0}\mathcal{K}_{S}^{0})$ | -0.8 ± 0.5 |
| $A_{CP}(B_0^0 \rightarrow \rho^- K^+)$ | 0.20 ± 0.11 | $K_S^0 K_S^0$ S_S^0 | 0.09 ± 0.09 |
| $A_{CP}(B^0 \to \rho(1450)^- K^+)$ | -0.10 ± 0.33 | $C_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0)$ | 0.09 ± 0.09 |
| $A_{CP}(B^0 \rightarrow \rho(1700)^- K^+)$ $A_{CP}(B^0 \rightarrow K^+ \pi^- \pi^0 \text{ nonresonant})$ | -0.4 ± 0.6 0.10 ± 0.18 | nonresonant) $C_{K^{+}K^{-}K^{0}_{S}}(B^{0} \rightarrow K^{+}K^{-}K^{0}_{S} \text{ inclusive})$ | 0.01 ± 0.09 |
| $A_{CP}(B^0 \to K^0 \pi^+ \pi^-)$ | -0.01 ± 0.05 | | |
| $A_{CP}(B^0 \to K^*(892)^+\pi^-)$ | -0.22 ± 0.06 | $C_{\phi K_S^0} (B^0 \to \phi K_S^0)$ | 0.03 ± 0.14 |
| $A_{CP}(B^0 \to (K\pi)_0^{*+}\pi^-)$ | 0.09 ± 0.07 | $S_{\phi K_S^0}(B^0 \to \phi K_S^0)$ | 0.39 ± 0.17 |
| $A_{CP}(B^0 \to (K\pi)_0^{*0} \pi^0)$ | -0.15 ± 0.11 | $C_{K_S K_S K_S}(B^0 \rightarrow K_S K_S K_S)$ | $-0.15\pm0.16\;(S=1.1)$ |
| $A_{CP}(B^0 \rightarrow K^{*0}\pi^0)$ | -0.15 ± 0.13 | $s_{K_S K_S K_S}(B^0 \to K_S K_S K_S)$ | $-0.4\pm0.5(S=2.5)$ |
| $A_{CP}(B^0 \to K^*(892)^0 \pi^+ \pi^-)$ $A_{CP}(B^0 \to K^*(892)^0 \rho^0)$ | 0.07 ± 0.05 | $C_{K_S^0\pi^0\gamma}(B^0\to K_S^0\pi^0\gamma)$ | 0.36 ± 0.33 |
| $\begin{array}{ccc} A_{CP}(B^0 \rightarrow K^*(892)^* \rho^0) \\ A_{CP}(B^0 \rightarrow K^{*0} f_0(980)) \end{array}$ | 0.09 ± 0.19 - 0.17 ± 0.28 | $S_{\kappa_S^0\pi^0\gamma}(B^0 \to \kappa_S^0\pi^0\gamma)$ | -0.8 ± 0.6 |
| $A_{CP}(B^0 \to K^*(892)^0 K^+ K^-)$ | 0.01 ± 0.05 | $C_{K^*(892)^0\gamma}(B^0 \to K^*(892)^0\gamma)$ | $-0.04 \pm 0.16 (S = 1.2)$ |
| $A_{CP}(B^0 \rightarrow a_1^- K^+)$ | -0.16 ± 0.12 | $S_{K^*(892)^0 \gamma} (B^0 \to K^*(892)^0 \gamma)$ | -0.15 ± 0.22 |
| $A_{CP}(B^0 \rightarrow \kappa^0 \kappa^0)$ | -0.6 ± 0.7 | $S_{K^*(892)^0\gamma}(B) \rightarrow K(892)^{(9)}$ | |
| $A_{CP}(B_0^0 \rightarrow K^*(892)^0 \phi)$ | 0.01 ± 0.05 | $C_{\eta K^0 \gamma}(B^0 \to \eta K^0 \gamma)$ | -0.3 ± 0.4 |
| $A_{CP}(B^0 \to K^*(892)^0 K^- \pi^+)$ | 0.2 ± 0.4 | $S_{\eta K^0 \gamma}(B^0 \to \eta K^0 \gamma)$ | -0.2 ± 0.5 |
| $A_{CP}(B^0 \to \phi(K\pi)_0^{*0})$ | 0.20 ± 0.15 | $C_{K^0\phi\gamma}(B^0\to K^0\phi\gamma)$ | -0.3 ± 0.6 |
| $A_{CP}(B^0 \to \phi K_2^*(1430)^0)$ $A_{CP}(B^0 \to K^*(892)^0 \gamma)$ | -0.08 ± 0.13 -0.016 ± 0.023 | $S_{K^0 \phi \gamma}^{(B^0 \to K^0 \phi \gamma)}$ | $0.7 + 0.7 \\ -1.1$ |
| $A_{CP}(B \to K (092) \gamma)$ $A_{CP}(B^0 \to K_*(1430)^0 \gamma)$ | -0.010 ± 0.023 -0.08 ± 0.15 | $C(B^0 \to K_S^0 \rho^0 \gamma)$ | -0.05 ± 0.19 |
| $A_{CP}(B^0 \to \rho^+\pi^-)$ | $0.08 \pm 0.12 (S = 2.0)$ | $S(B^0 \to K_S^0 \rho^0 \gamma)$ | 0.11 ± 0.34 |
| $A_{CP}(B^0 \rightarrow \rho^- \pi^+)$ | $-0.16 \pm 0.23 \text{ (S} = 1.7)$ | $C(B^0 \to \rho^0 \gamma)$ $S(B^0 \to \rho^0 \gamma)$ | 0.4 ± 0.5 -0.8 ± 0.7 |
| $A_{CP}(B^0 \to a_1(1260)^{\pm}\pi^{\mp})$ | -0.07 ± 0.07 | $C_{\pi\pi} \stackrel{\rho}{(B^0 \to \rho^+ \gamma)} \gamma \qquad \qquad C_{\pi\pi} \stackrel{\rho}{(B^0 \to \pi^+ \pi^-)} \gamma$ | -0.8 ± 0.7 -0.38 ± 0.17 (S = 2.6) |
| $A_{CP}(B^0 \rightarrow b_1 \pi^+)$ | -0.05 ± 0.10 | $C_{-0} = 0 (B^0 \rightarrow \pi^0 \pi^0)$ | -0.48 ± 0.30 |
| $A_{CP}(B^0 \to \rho \overline{\rho} K^*(892)^0)$ $A_{CP}(B^0 \to \rho \overline{\Lambda} \pi^-)$ | 0.05 ± 0.12 | $C_{\alpha\pi}(B^0 \to \rho^+\pi^-)$ | $0.01\pm0.14\;(\text{S}=1.9)$ |
| $A_{CP}(B^0 \to p \Lambda \pi^-)$ $A_{CP}(B^0 \to K^{*0} \ell^+ \ell^-)$ | $\begin{array}{l} 0.04 \pm 0.07 \\ -0.05 \pm 0.10 \end{array}$ | $S_{ ho\pi} (B^0 	o ho^+\pi^-)$ | 0.01 ± 0.09 |
| $A_{CP}(B^0 \to K^{*0} e^+ e^-)$ | -0.21 ± 0.19 | $\Delta S_{\rho\pi} (B^0 \to \rho^+\pi^-)$ | -0.05 ± 0.10 |
| $A_{CP}(B^0 \to K^{*0} \mu^+ \mu^-)$ | 0.00 ± 0.15 | $C_{\rho^0 \pi^0} (B^0 \to \rho^0 \pi^0)$ | 0.3 ± 0.4 |
| $C_{D^*(2010)^-D^+}(B^0 \to D^*(2010)^-D^+)$ | 0.07 ± 0.14 | $S_{\rho^0 \pi^0} (B^0 \to \rho^0 \pi^0)$ | 0.1 ± 0.4 |
| $C_{D^*(2010)^+D^-}(B^0 \to D^*(2010)^+D^-)$ | $-0.09 \pm 0.22 \; (S = 1.6)$ | $C_{a_1 \pi} (B^0 \to a_1(1260)^+ \pi^-)$ | -0.10 ± 0.17 |
| $C_{D^{*+}D^{*-}}(B^0 \to D^{*+}D^{*-})$ | $-0.01 \pm 0.09 (S = 1.2)$ | $S_{a_1 \pi} (B^0 \to a_1(1260)^+ \pi^-)$ | 0.37 ± 0.22 |
| $C_{+} (B^{0} \rightarrow D^{*+}D^{*-})$ | 0.00 ± 0.12 | $\Delta C_{a_1 \pi} (B^0 \to a_1(1260)^+ \pi^-)$ | 0.26 ± 0.17 |
| $C_{-}(B^{0} \to D^{*+}D^{*-})$ | 0.4 ± 0.5 | $\Delta S_{a_1 \pi} (B^0 \to a_1(1260)^+ \pi^-)$ | -0.14 ± 0.22 |
| $S_{-}(B^{0} \rightarrow D^{*+}D^{*-})$ | -1.8 ± 0.7 | $C(B^0 \to b_1^- K^+)$ | -0.22 ± 0.24 |
| $C(B^0 \to D^*(2010)^+ D^*(2010)^- K_S^0)$ | 0.01 ± 0.29 | $\Delta C (B^0 \rightarrow b_1^- \pi^+)$ | -1.04 ± 0.24 |
| $S(B^0 \to D^*(2010)^+ D^*(2010)^- K_S^{\bar{0}})$ | 0.1 ± 0.4 | $C_{\rho^0\rho^0} (B^0 \to \rho^0\rho^0)$ | 0.2 ± 0.9 |
| $C_{D^+D^-}(B^0 \to D^+D^-)$ | $-0.5\pm0.4({\sf S}=2.5)$ | $S_{\rho^0 \rho^0} (B^0 \to \rho^0 \rho^0)$ | 0.3 ± 0.7 |
| $C_{J/\psi(1S)\pi^0} (B^0 \to J/\psi(1S)\pi^0)$ | -0.13 ± 0.13 | $C_{\rho\rho}(B^0 \to \rho^+ \rho^-)$ | -0.05 ± 0.13 |
| $C_{D_{CP}^{(*)}h^0}(B^0 \to D_{CP}^{(*)}h^0)$ | -0.23 ± 0.16 | $S_{\rho\rho} (B^0 \rightarrow \rho^+ \rho^-)$ | -0.06 ± 0.17 |
| $S_{D_{CP}^{(*)}h^0}^{(*)}(B^0 \to D_{CP}^{(*)}h^0)$ | -0.56 ± 0.24 | $ \lambda (B^0 \rightarrow J/\psi K^*(892)^0)$ | <0.25, CL $=$ 95% |
| $C_{K^0\pi^0}(B^0 \to K^0\pi^0)$ | $0.00\pm0.13\;(S=1.4)$ | $\cos 2\beta \ (B^0 \to J/\psi K^*(892)^0)$ $\cos 2\beta \ (B^0 \to [K_S^0 \pi^+ \pi^-]_{D(*)} h^0)$ | $1.7 + 0.7 \atop -0.9 $ (S = 1.6) $1.0 + 0.6 \atop -0.7 $ (S = 1.8) |
| Unless otherwise stated limits are given at the | 200/ confidence level while errors | - D., | -10.7 (5 = 1.0) |

| $(S_+ + S)/2 (B^0 \rightarrow D^{*-} \pi^+)$ | -0.039 ± 0.011 | ϕ_+ _, phase of η_+ _ | $(43.51 \pm 0.05)^{\circ} (S = 1.2)$ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------------|
| $(S_{-} - S_{+})/2 (B^{0} \rightarrow D^{*-}\pi^{+})$ | -0.009 ± 0.015 | ϕ_{00} , phase of η_{00} | $(43.52 \pm 0.05)^{\circ} (S = 1.3)$ |
| $(S_{+} + S_{-})/2 (B^{0} \rightarrow D^{-}\pi^{+})$ | -0.046 ± 0.023 | $\phi_{\epsilon}=(2\phi_{+-}+\phi_{00})/3$ | $(43.52 \pm 0.05)^{\circ} (S = 1.2)$ |
| $(S_{-} - S_{+})/2 (B^{0} \rightarrow D^{-}\pi^{+})$ | -0.022 ± 0.021 | Not assuming CPT | |
| $(S_+ + S)/2 (B^0 \rightarrow D^- \rho^+)$ | -0.024 ± 0.032 | ϕ_+ _, phase of η_+ _ | $(43.4 \pm 0.5)^{\circ} (S = 1.2)$ |
| $(S_{-} - S_{+})/2 (B^{0} \rightarrow D^{-} \rho^{+})$ | -0.10 ± 0.06 | ϕ_{00} , phase of η_{00} | $(43.7 \pm 0.6)^{\circ} (S = 1.2)$ |
| $C_{\eta_c K_S^0}(B^0 \to \eta_c K_S^0)$ | 0.08 ± 0.13 | $\phi_{\epsilon} = (2\phi_{+-} + \phi_{00})/3$ | $(43.5 \pm 0.5)^{\circ} (S = 1.3)$ |
| $C_{C\overline{C}K(*)0} (B^0 \to C\overline{C}K(*)0)$ | $(0.5 \pm 1.7) \times 10^{-2}$ | CP asymmetry A in $K_L^0 \rightarrow \pi^+\pi^-e^+e^-$ | $(13.7 \pm 1.5)\%$ |
| $c \subset K(*)^0$ (B $\rightarrow C \subset K(*)^0$) | * | eta_{CP} from $K^0_{\cline{L}} ightarrow e^+e^-e^+e^-$ | -0.19 ± 0.07 |
| $C_{J/\psi(nS) K^0}^{C K(\gamma)} (B^0 \rightarrow J/\psi(nS) K^0)$ | $(0.5 \pm 2.0) \times 10^{-2}$ | γ_{CP} from $K_L^{ar{0}} ightarrow e^+e^-e^+e^-$ | $0.01 \pm 0.11 (S = 1.6)$ |
| $C_{J/\psi K^{*0}}(B^0 \to J/\psi K^{*0})$ | 0.03 ± 0.10 | parameters for $K_L^0 ightarrow \pi^+ \pi^- \gamma$ decay | 2 |
| $S_{J/\psi K^{*0}}(B^0 \to J/\psi K^{*0})$ | 0.60 ± 0.25 | $ \eta_{+-\gamma} = A(K^0_L	o\pi^+\pi^-\gamma$, CP | $(2.35 \pm 0.07) \times 10^{-3}$ |
| $C_{\chi_{c0}}^{\prime\prime} \kappa_S^0 (B^0 \rightarrow \chi_{c0} \kappa_S^0)$ | $-0.3^{+0.5}_{-0.4}$ | violating)/A($\kappa_S^0 \rightarrow \pi^+\pi^-\gamma$) | |
| $S_{\chi_{c0} \kappa_S^0}(B^0 \to \chi_{c0} \kappa_S^0)$ | -0.7 ± 0.5 | $\phi_{+-\gamma} = \text{phase of } \eta_{+-\gamma}$ | $(44 \pm 4)^{\circ}$ |
| $C_{\chi_{c1} \kappa_S^0}(B^0 \to \chi_{c1} \kappa_S^0)$ | 0.13 ± 0.11 | $\Gamma(K_L^0 \to \pi^+\pi^-)/\Gamma_{\text{total}}$ | [i] $(1.967 \pm 0.010) \times 10^{-3} (S = 1.5)$ |
| $\chi_{c1} \kappa_s^0 \stackrel{(D \to \chi_{c1} \kappa_s)}{\longrightarrow} \chi_{c1} \kappa_s$ | 0.13 ± 0.11 | $\Gamma(\kappa_L^{\bar{0}} \to \pi^0 \pi^0)/\Gamma_{\text{total}}$ | $(8.64 \pm 0.06) \times 10^{-4} (S = 1.8)$ |
| $\sin(2\beta_{\rm eff})(B^0 \to \phi K^0)$ | 0.22 ± 0.30 | $A_{CP}(B^+ \rightarrow f_0(1370)\pi^+)$ | 0.72 ± 0.22 |
| $\sin(2\beta_{\rm eff})(B^0 \to \phi K_0^*(1430)^0)$ | $0.97 {}^{+ 0.03}_{- 0.52}$ | $\gamma(B^+ \to D^{(*)}K^{(*)+})$ | $(73 \pm 10)^{\circ}$ |
| $\sin(2\beta_{\rm eff})(B^0 \to [\kappa_S^0 \pi^+ \pi^-]_{D^{(*)}} h^0)$ | 0.45 ± 0.28 | $A_{CP}(B^0 \to K^+\pi^-) \\ A_{CP}(B^0 \to \eta K^*(892)^0)$ | -0.097 ± 0.012 |
| $ \lambda (B^0 \to [K_S^0 \pi^+ \pi^-]_{D^{(*)}} h^0)$ | 1.01 ± 0.08 | $A_{CP}(B^0 \rightarrow \eta K^{*}(892)^{\circ})$ | 0.19 ± 0.05 - 0.78 ± 0.21 |
| $\left \sin(2\beta + \gamma)\right $ | >0.40, CL $=$ 90% | $s_{D^*(2010)^-D^+} (B^0 \to D^*(2010)^-D^+)$ | |
| $2 \beta + \gamma$ | (83 ± 60)° | $S_{D^*(2010)^+D^-}(B^0 \to D^*(2010)^+D^-)$ | -0.61 ± 0.19 |
| $\gamma(B^0 \rightarrow D^0 K^{*0})$ | (162 ± 60)° | $s_{D^{*+}D^{*-}}(B^0 \to D^{*+}D^{*-})$ | -0.76 ± 0.14 |
| $A_{CP}(B \rightarrow K^*(892)\gamma)$ | -0.003 ± 0.017 | $S_{+} (B^{0} \rightarrow D^{*+}D^{*-})$ | -0.76 ± 0.16 |
| $A_{CP}(b 	o s\gamma)$ | -0.008 ± 0.029 | $s_{D^+D^-}^{'}(B^0 \to D^+D^-)$ | -0.87 ± 0.26 |
| $A_{CP}(b \rightarrow (s+d)\gamma)$ | -0.09 ± 0.07 | $S_{J/\psi(1S) \pi^0} (B^0 \to J/\psi(1S) \pi^0)$ | $-0.94 \pm 0.29 (S = 1.9)$ |
| $A_{CP}(B \to X_{S}\ell^{+}\ell^{-})$ | -0.22 ± 0.26 | $S_{K^0\pi^0}(B^0 \to K^0\pi^0)$ | 0.58 ± 0.17 |
| $A_{CP}(B \rightarrow K^*e^+e^-)$ | -0.18 ± 0.15 | $s_{\eta' \kappa^0} (B^0 \rightarrow \eta' \kappa^0)$ | 0.60 ± 0.07 |
| $A_{CP}(B \rightarrow K^* \mu^+ \mu^-)$ | -0.03 ± 0.13 | $3_{\eta'} K^0 (B \rightarrow \eta K)$ | |
| $A_{CP}(B 	o K^* \ell^+ \ell^-)$ $A_{CP}(B 	o \eta \text{ anything})$ | $\begin{array}{l} -0.07 \pm 0.08 \\ -0.13 {}^{+0.04}_{-0.05} \end{array}$ | $S_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0)$ nonresonant) | $-0.74 {}^{+ 0.1 2}_{- 0.1 0}$ |
| $\operatorname{Re}(\epsilon_{B_c^0}) / (1 + \epsilon_{B_c^0} ^2)$ | $(-2.6 \pm 1.6) \times 10^{-3}$ | $s_{K^+K^-K^0_S}(B^0 \to K^+K^-K^0_S \text{ inclusive})$ | -0.65 ± 0.12 |
| S_s CP Violation phase β_s | $0.08 + 0.05 \\ -0.07$ | $S_{\pi\pi} (B^0 \rightarrow \pi^+\pi^-)$ | -0.61 ± 0.08 |
| $A_{CP}(B_S \to \pi^+ K^-)$ | 0.39 ± 0.17 | $\Delta C_{\rho\pi} (B^0 \to \rho^+\pi^-)$ | 0.37 ± 0.08 |
| $\Gamma(\eta_c(1S) \to \pi^+\pi^-)/\Gamma_{\text{total}}$ | $<1.1 \times 10^{-4}$, CL = 90% | $S_{\eta_{c}K_{S}^{0}}(B^{0} \rightarrow \eta_{c}K_{S}^{0})$ | 0.93 ± 0.17 |
| $\Gamma(\eta_c(1S) \to \pi^0 \pi^0)/\Gamma_{total}$ | $<3.5 \times 10^{-5}$, CL = 90% | $\eta_c K_S^0 $ | |
| $\Gamma(\eta_{\mathcal{C}}(1S) \to K^+ K^-)/\Gamma_{\text{total}}$ $\Gamma(\eta_{\mathcal{C}}(1S) \to K^+ K^-)/\Gamma_{\text{total}}$ | $<6 \times 10^{-4}, CL = 90\%$ | $\sin(2\beta) \ (B^0 \to J/\psi K_S^0)$ | 0.679 ± 0.020 |
| $\Gamma(\eta_c(1S) \to K_S^0 K_S^0)/\Gamma_{\text{total}}$ | $<3.1 \times 10^{-4}$, CL = 90% | $S_{J/\psi(nS) \ K^0} \ (B^0 \rightarrow \ J/\psi(nS) \ K^0)$ | 0.676 ± 0.021 |
| $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) \text{ in } \Lambda \to p\pi^-, \overline{\Lambda} \to \overline{p}\pi^+$ | 0.006 ± 0.021 | $S_{\chi_{c1} \kappa_S^0}(B^0 \rightarrow \chi_{c1} \kappa_S^0)$ | 0.61 ± 0.16 |
| $\frac{\left[\alpha(\Xi^{-})\alpha_{-}(\Lambda) - \alpha(\overline{\Xi}^{+})\alpha_{+}(\overline{\Lambda})\right]}{\left[\alpha(\Xi^{-})\alpha_{-}(\Lambda) + \alpha(\overline{\Xi}^{+})\alpha_{+}(\overline{\Lambda})\right]}$ | $(0\pm7)\times10^{-4}$ | $\sin(2\beta_{\text{eff}})(B^0 \to K^+ K^- K_S^0)$ | $0.77 \begin{array}{l} + 0.13 \\ - 0.12 \end{array}$ |
| $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Omega^- \to \Lambda K^-, \overline{\Omega}^+ \to$ | -0.02 ± 0.13 | α | $(90 \pm 5)^{\circ}$ $(-2.0 \pm 0.5) \times 10^{-3}$ |
| $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) \text{ in } \Lambda_c^+ \to \Lambda \pi^+, \overline{\Lambda}_c^- \to$ | -0.07 ± 0.31 | $Re(\epsilon_{\pmb{b}}) \ / \ (1 \ + \ \left \epsilon_{\pmb{b}}\right ^2)$ | (-2.0 ± 0.5) × 10 |
| $\overline{\Lambda}\pi^-$ | | | |
| $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda e^+ \nu_e, \overline{\Lambda}_c^- \to$ | 0.00 ± 0.04 | CPT INVAF | RIANCE |
| $\overline{\Lambda}e^{-}\overline{\nu}_{e}$ | | (m m) / m | -0.002 ± 0.007 |
| $A_{CP}(\Lambda_b \to \rho \pi^-)$ | 0.03 ± 0.18 | $(m_{W^+} - m_{W^-}) / m_{\text{average}}$ | -0.002 ± 0.007 $< 8 \times 10^{-9}, CL = 90\%$ |
| $A_{CP}(\Lambda_b \rightarrow p K^-)$ | 0.37 ± 0.17 | $(m_{e^+} - m_{e^-}) / m_{\text{average}}$ | $< 8 \times 10^{-5}$, CL = 90% |
| | | | |

CP VIOLATION OBSERVED

| $Re(\epsilon)$ | | $(1.596 \pm 0.013) \times 10^{-3}$ |
|-----------------------------------------------------------|--------------|----------------------------------------------|
| charge asymmetry in $\kappa^0_{\ell 3}$ decays | | |
| $A_L = 	ext{weighted}$ average of $A_L(\mu)$ and $A_L(e)$ | | $(0.332 \pm 0.006)\%$ |
| $A_L(\mu) = [\Gamma(\pi^- \mu^+ \nu_\mu)$ | | $(0.304\pm0.025)\%$ |
| $-~\Gamma(\pi^+\mu^-\overline{ u}_\mu)]/{\sf sum}$ | | |
| $A_L(e) = [\Gamma(\pi^- e^+ \nu_e)$ | | $(0.334 \pm 0.007)\%$ |
| $-\Gamma(\pi^+e^-\overline{ u}_e)]/sum$ | | |
| parameters for $K_L^0	o 2\pi$ decay | | |
| $ \eta_{00} = A(K^0_L	o 2\pi^0) /$ | | $(2.220 \pm 0.011) \times 10^{-3} (S = 1.8)$ |
| $A(K_S^0 \rightarrow 2\pi^0)$ | | |
| $ \eta_{+-} = A(K_L^0 \to \pi^+\pi^-) $ | | $(2.232 \pm 0.011) \times 10^{-3} (S = 1.8)$ |
| $A(K_S^0 \rightarrow \pi^+\pi^-)$ | | |
| $ \epsilon = (2 \eta_{+-} + \eta_{00})/3$ | | $(2.228 \pm 0.011) \times 10^{-3} (S = 1.8)$ |
| $ \eta_{00}/\eta_{+-} $ | [<i>h</i>] | $0.9950\pm0.0007\;(S=1.6)$ |
| $Re(\epsilon'/\epsilon) = (1- \eta_{00}/\eta_{+-})/3$ | [<i>h</i>] | $(1.66 \pm 0.23) \times 10^{-3} (S = 1.6)$ |

| CPI INV | ARIANCE |
|----------------------------------------------------------------------------|--------------------------------------------|
| $(m_{W^+} - m_{W^-}) / m_{\text{average}}$ | -0.002 ± 0.007 |
| $(m_{e^+} - m_{e^-}) / m_{average}$ | $<$ 8 \times 10 $^{-9}$, CL $=$ 90% |
| $ q_{e^+} + q_{e^-} /e$ | $<4 \times 10^{-8}$ |
| $(g_{e^+} - g_{e^-}) / g_{\text{average}}$ | $(-0.5 \pm 2.1) \times 10^{-12}$ |
| $(au_{\mu^+} - 	au_{\mu^-}) / 	au_{average}$ | $(2 \pm 8) \times 10^{-5}$ |
| $(g_{\mu^+} - g_{\mu^-}) / g_{average}$ | $(-0.11 \pm 0.12) \times 10^{-8}$ |
| $(m_{\tau^+} - m_{\tau^-})/m_{\text{average}}$ | $<$ 2.8 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $m_{t}-m_{\overline{t}}$ | -1.4 ± 2.0 GeV (S $=1.6$) |
| $(m_{\pi^+} - m_{\pi^-}) / m_{\text{average}}$ | $(2 \pm 5) \times 10^{-4}$ |
| $(au_{\pi^+} - 	au_{\pi^-}) / 	au_{average}$ | $(6 \pm 7) \times 10^{-4}$ |
| $(m_{K^+} - m_{K^-}) / m_{\text{average}}$ | $(-0.6 \pm 1.8) \times 10^{-4}$ |
| $(\tau_{K^+} - \tau_{K^-}) / \tau_{\text{average}}$ | $(0.10\pm0.09)\%({\rm S}=1.2)$ |
| $\mathit{K}^{\pm} ightarrow \mu^{\pm} u_{\mu}$ rate difference/average | $(-0.5 \pm 0.4)\%$ |
| $\mathit{K}^{\pm} ightarrow \pi^{\pm} \pi^{0}$ rate difference/average | [j] $(0.8 \pm 1.2)\%$ |
| δ in $K^0-\overline{K}^0$ mixing | |
| real part of δ | $(2.5 \pm 2.3) \times 10^{-4}$ |
| imaginary part of δ | $(-1.5 \pm 1.6) \times 10^{-5}$ |
| Re(y), K_{e3} parameter | $(0.4 \pm 2.5) \times 10^{-3}$ |
| Re(x_), K _{e3} parameter | $(-2.9 \pm 2.0) \times 10^{-3}$ |
| $ m_{K^0} - m_{\overline{K^0}} / m_{\text{average}}$ | [k] $<$ 6 $	imes$ 10 $^{-19}$, CL $=$ 90% |
| $(\Gamma_{K^0} - \Gamma_{\overline{K^0}})/m_{\text{average}}$ | $(8 \pm 8) \times 10^{-18}$ |

Assuming CPT

| h dim | | (0.24 0.20)0 |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------------------------------------|
| phase difference ϕ_{00} – ϕ_{+-} | | $(0.34 \pm 0.32)^{\circ}$ |
| $Re(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) - \frac{A_L}{2}$ | | $(-3 \pm 35) \times 10^{-6}$ |
| $A_{CPT}(D^0 \rightarrow K^-\pi^+)$ | | 0.008 ± 0.008 |
| $ m_{P} - m_{\overline{P}} /m_{P_{q}}$ | [/] | $<2 \times 10^{-9}$, CL = 90% |
| $(\left \frac{q_{\overline{p}}}{m_{\overline{p}}}\right - \frac{q_{\overline{p}}}{m_{\overline{p}}}) / \frac{q_{\overline{p}}}{m_{\overline{p}}}$ | | $(-9 \pm 9) \times 10^{-11}$ |
| $ q_{\overline{D}} + q_{\overline{D}} /e$ | [/] | $<$ 2 $	imes$ 10 $^{-9}$, CL $=$ 90% |
| $(\mu_p + \overline{\mu_p}) / \mu_p$ | | $(-0.1\pm2.1)	imes10^{-3}$ |
| $(m_n - m_{\overline{n}})/m_n$ | | $(9 \pm 6) \times 10^{-5}$ |
| $(m_{\Lambda} - m_{\overline{\Lambda}}) / m_{\Lambda}$ | | $(-0.1 \pm 1.1) \times 10^{-5} \text{ (S} = 1.6)$ |
| $(\tau_{\Lambda} - \tau_{\overline{\Lambda}}) / \tau_{\Lambda}$ | | -0.001 ± 0.009 |
| $(au_{\Sigma^+} - 	au_{\overline{\Sigma}^-}) / 	au_{\Sigma^+}$ | | $(-0.6 \pm 1.2) \times 10^{-3}$ |
| $(\mu_{\Sigma^+} + \mu_{\overline{\Sigma}^-}) / \mu_{\Sigma^+}$ | | 0.014 ± 0.015 |
| $(m_{\Xi^-} - m_{\overline{\Xi}^+}) / m_{\Xi^-}$ | | $(-3 \pm 9) \times 10^{-5}$ |
| $(au_{\Xi^-} - 	au_{\overline{\Xi}^+}) / 	au_{\Xi^-}$ | | -0.01 ± 0.07 |
| $(\mu_{\Xi^-} + \mu_{\overline{\Xi}^+}) / \mu_{\Xi^-} $ | | $+\ 0.01\ \pm\ 0.05$ |
| $(m_{\Omega^-} - m_{\overline{\Omega}^+}) / m_{\Omega^-}$ | | $(-1 \pm 8) \times 10^{-5}$ |
| $(\tau_{\Omega^-} - \tau_{\overline{\Omega}^+}) / \tau_{\Omega^-}$ | | 0.00 ± 0.05 |
| $m_{\Sigma_h^+} - m_{\Sigma_h^-}$ | | -4.2 ± 1.1 MeV |
| v v | | $-3.0^{+1.0}_{-0.9}$ MeV |
| $m_{\Sigma_b^{*+}}-m_{\Sigma_b^{*-}}$ | | -0.9 |

TESTS OF NUMBER CONSERVATION LAWS

LEPTON FAMILY NUMBER

Lepton family number conservation means separate conservation of each of $L_{\ell},~L_{\mu},~L_{\tau}.$

```
[m] <1.7 × 10<sup>-6</sup>, CL = 95%
\Gamma(Z 
ightarrow e^{\pm} \mu^{\mp})/\Gamma_{	ext{total}}
\Gamma(Z \rightarrow e^{\pm} \tau^{\mp})/\Gamma_{\text{total}}
                                                                                        [m] <9.8 × 10<sup>-6</sup>, CL = 95%
                                                                                        [m] <1.2 × 10<sup>-5</sup>, CL = 95%
\Gamma(Z \rightarrow \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}
\sigma(e^+\,e^-\,\rightarrow\,\,e^{\pm}\,\tau^{\mp})\;/\;\sigma(e^+\,e^-\,\rightarrow\,
                                                                                                 < 8.9 \times 10^{-6}, CL = 95%
         \mu^{+} \mu^{-})
\sigma(e^+\,e^-\,\rightarrow\,\,\mu^{\pm}\,\tau^{\mp})\,\,/\,\,\sigma(e^+\,e^-\,\rightarrow\,
                                                                                                  <4.0 \times 10<sup>-6</sup>, CL = 95 %
       \mu^{+} \mu^{-}
limit on \mu^- \rightarrow e^- conversion
         \begin{array}{cccc} & \sigma & \mu & \rightarrow e & conversion \\ & \sigma (\mu^{-32} \mathrm{S} \rightarrow & e^{-32} \mathrm{S}) \ / \\ & & \sigma (\mu^{-32} \mathrm{S} \rightarrow & \nu_{\mu}^{32} \mathrm{P}^{*}) \end{array}
                                                                                                  <\!7\times10^{-11} , CL \,=\,90\%
                                                                                                  <\!\!4.3\times10^{-12} , CL \,=\,90\%
          \sigma(\mu^- \text{Ti} \rightarrow e^- \text{Ti})
                    \sigma(\mu^- \, {\sf Ti} \, 	o \, {\sf capture})
          \sigma(\mu^- Pb \rightarrow e^- Pb) /
                                                                                                  <4.6 \times 10^{-11}, CL = 90%
                   \sigma(\mu^- Pb \rightarrow capture)
limit\ on\ muonium\ \rightarrow\ antimuonium
                                                                                                  <0.0030, CL = 90%
          conversion R_g = G_C / G_F
\Gamma(\mu^- \to \ e^- \, \nu_e \, \overline{\nu}_\mu) / \Gamma_{\rm total}
                                                                                          [n] <1.2 × 10<sup>-2</sup>, CL = 90%
\Gamma(\mu^- \rightarrow e^- \gamma)/\Gamma_{\mathsf{total}}
                                                                                                  <2.4 \times 10^{-12}, CL = 90%
                                                                                                  <1.0 \times 10^{-12}, CL = 90%
\Gamma(\mu^- \rightarrow e^- e^+ e^-)/\Gamma_{total}
\Gamma(\mu^- \rightarrow e^- 2\gamma)/\Gamma_{\text{total}}
                                                                                                  < 7.2 \times 10^{-11}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \gamma)/\Gamma_{\text{total}}
                                                                                                  <3.3\times10^{-8}, CL =90\%
\Gamma(\tau^- \rightarrow \mu^- \gamma)/\Gamma_{\text{total}}
                                                                                                  <4.4 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \pi^0)/\Gamma_{\rm total}
                                                                                                  < 8.0 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- \pi^0)/\Gamma_{\text{total}}
                                                                                                  <1.1 \times 10^{-7}, CL = 90%
\Gamma(\tau^- \rightarrow e^- K_S^0)/\Gamma_{\text{total}}
                                                                                                  <\!2.6\times10^{-8}\text{, CL}\,=\,90\,\%
\Gamma(\tau^- 
ightarrow \, \mu^- \, K_S^{ar{0}})/\Gamma_{	ext{total}}
                                                                                                 <2.3 \times 10^{-8}, CL = 90%
\Gamma(\tau^- 
ightarrow e^- \eta)/\Gamma_{\mathsf{total}}
                                                                                                 <9.2 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \to \mu^- \eta)/\Gamma_{
m total}
                                                                                                 <6.5 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \rho^0)/\Gamma_{\text{total}}
                                                                                                  < \! 1.8 \times 10^{-8} , CL \, = \, 90 \, \%
\Gamma(\tau^- \to \mu^- \rho^0)/\Gamma_{\text{total}}
                                                                                                 <1.2 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \omega)/\Gamma_{\text{total}}
                                                                                                  {<}4.8\times10^{-8}\text{, CL}\,=\,90\%
                                                                                                  <4.7 \times 10^{-8}, CL = 90\%
\Gamma(\tau^- \to \mu^- \omega)/\Gamma_{\text{total}}
\Gamma(\tau^- \rightarrow e^- K^*(892)^0)/\Gamma_{\text{total}}
                                                                                                  <3.2 \times 10^{-8}, CL = 90%
                                                                                                  <5.9 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- K^*(892)^0)/\Gamma_{total}
\Gamma(\tau^- \rightarrow e^- \overline{K}^*(892)^0)/\Gamma_{\text{total}}
                                                                                                  <3.4 \times 10^{-8}, CL = 90%
                                                                                                  < 7.0 \times 10^{-8}, CL = 90\%
\Gamma(\tau^- \rightarrow \mu^- \overline{K}^*(892)^0)/\Gamma_{total}
\Gamma(\tau^- \rightarrow e^- \eta'(958))/\Gamma_{\text{total}}
                                                                                                  <\!\!1.6\times10^{-7}\text{, CL}\,=\,90\%
                                                                                                  <1.3 \times 10^{-7}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- \eta'(958))/\Gamma_{total}
                                                                                                  <3.2 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- f_0(980) \rightarrow e^- \pi^+ \pi^-)/\Gamma_{\text{total}}
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\Gamma(\tau^- \rightarrow \mu^- f_0(980) \rightarrow \mu^- \pi^+ \pi^-)/\Gamma_{\text{total}}
                                                                                            <3.4 \times 10^{-8}, CL = 90%
                                                                                           < 3.1 \times 10^{-8}, CL = 90%
\Gamma(	au^-
ightarrow~e^-\phi)/\Gamma_{	ext{total}}
\Gamma(\tau^- \rightarrow \mu^- \phi)/\Gamma_{\text{total}}
                                                                                           < 8.4 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- e^+ e^-)/\Gamma_{\text{total}}
                                                                                           <2.7 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                           <2.7 \times 10^{-8}, CL = 90%
                                                                                           <1.7 \times 10^{-8}, CL = 90\%
\Gamma(\tau^- \rightarrow e^+ \mu^- \mu^-)/\Gamma_{\text{total}}
\Gamma(\tau^- \rightarrow \mu^- e^+ e^-)/\Gamma_{\text{total}}
                                                                                           <1.8 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^+ e^- e^-)/\Gamma_{\text{total}}
                                                                                           < \! 1.5 \times 10^{-8} \text{, CL} = 90\%
\Gamma(\tau^- \to \mu^- \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                           <2.1 \times 10^{-8}, CL = 90%
                                                                                           <4.4 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \pi^+ \pi^-)/\Gamma_{\text{total}}
\Gamma(	au^- 
ightarrow \ \mu^- \, \pi^+ \, \pi^-)/\Gamma_{	ext{total}}
                                                                                           <3.3 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \pi^+ K^-)/\Gamma_{\text{total}}
                                                                                           <5.8 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^-\pi^-K^+)/\Gamma_{\text{total}}
                                                                                           <5.2 \times 10^{-8}, CL = 90%
                                                                                           < 7.1 \times 10^{-8} \text{, CL} = 90\%
\Gamma(\tau^- \rightarrow e^- \kappa_S^0 \kappa_S^0) / \Gamma_{\text{total}}
\Gamma(\tau^- 
ightarrow e^- \, {\it K}^+ \, {\it K}^-) / \Gamma_{
m total}
                                                                                           <5.4 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- \pi^+ K^-)/\Gamma_{\text{total}}
                                                                                           <1.6 \times 10^{-7}, CL = 90%
\Gamma(	au^- 
ightarrow \mu^- \pi^- K^+)/\Gamma_{
m total}
                                                                                           <1.0 \times 10^{-7}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- K_S^0 K_S^0) / \Gamma_{\text{total}}
                                                                                           < 8.0 \times 10^{-8}, CL = 90\%
\Gamma(\tau^- \rightarrow \mu^- \, K^+ \, K^-)/\Gamma_{
m total}
                                                                                           <6.8 \times 10^{-8}, CL = 90%
\Gamma(\tau^- \rightarrow e^- \pi^0 \pi^0) / \Gamma_{\text{total}}
                                                                                           <6.5 \times 10^{-6}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- \pi^0 \pi^0)/\Gamma_{\text{total}}
                                                                                           <1.4 \times 10^{-5}, CL = 90%
\stackrel{\cdot}{\Gamma(\tau^-} \rightarrow e^- \eta \eta)/\Gamma_{\sf total}
                                                                                           <3.5 \times 10^{-5}, CL = 90%
\Gamma(\tau^- \rightarrow \mu^- \eta \eta)/\Gamma_{\text{total}}
                                                                                           <6.0 \times 10^{-5}, CL = 90%
\Gamma(	au^- 
ightarrow e^- \pi^0 \eta) / \Gamma_{	ext{total}}
                                                                                           <\!2.4\times10^{-5} , CL =\,90\,\%
\Gamma(\tau^- 
ightarrow \, \mu^- \, \pi^0 \, \eta) / \Gamma_{
m total}
                                                                                           <2.2 \times 10^{-5}, CL = 90%
\Gamma(\tau^- \to e^- \, \text{light boson}) / \Gamma_{	ext{total}}
                                                                                           < 2.7 \times 10^{-3}, CL = 95%
\Gamma(\tau^- \to \mu^- \, \text{light boson}) / \Gamma_{	ext{total}}
                                                                                           <5 \times 10^{-3}, CL = 95%
LEPTON FAMILY NUMBER VIOLATION IN NEUTRINOS
         Solar Neutrinos
                   \sin^2(2\theta_{12})
                                                                                           0.85\,7\,\pm\,0.024
                                                                                           (7.50 \pm 0.20) \times 10^{-5} \text{ eV}^2
                   \Delta m_{21}^2
         Atmospheric Neutrinos
                    \sin^2(2\theta_{23})
                                                                                   [o] >0.95
                                                                                   [p] (2.32^{+0.12}_{-0.08}) \times 10^{-3} \text{ eV}^2
                    \Delta m_{32}^2
         Reactor Neutrinos
                   \sin^2(2\theta_{13})
                                                                                           0.098 \pm 0.013
                                                                                   [q] < 8.0 \times 10^{-3}, CL = 90\%
\Gamma(\pi^+ \to ~\mu^+ \, \nu_e)/\Gamma_{\rm total}
\Gamma(\pi^+ 
ightarrow \, \mu^- \, e^+ \, e^+ \, 
u) / \Gamma_{
m total}
                                                                                           <\!\!1.6\times10^{-6}\text{, CL}\,=\,90\,\%
\Gamma(\pi^0 \to \mu^+ e^-)/\Gamma_{\rm total}
                                                                                           <\!3.8\times10^{-10} , CL = 90%
\Gamma(\pi^0 \to \mu^- e^+)/\Gamma_{total}
                                                                                           <3.4 \times 10^{-9}, CL = 90%
\Gamma(\pi^0 \rightarrow \mu^+ e^- + \mu^- e^+)/\Gamma_{\text{total}}
                                                                                           < 3.6 \times 10^{-10}, CL = 90\%
\Gamma(\eta \rightarrow \mu^+ e^- + \mu^- e^+)/\Gamma_{\text{total}}
                                                                                           <6 \times 10^{-6}, CL = 90%
\Gamma(\eta'(958) \rightarrow e \mu)/\Gamma_{\mathsf{total}}
                                                                                           <\!\!4.7\times10^{-4}\text{, CL}\,=\,90\,\%
\Gamma(\phi(1020) \rightarrow e^{\pm} \mu^{\mp})/\Gamma_{	ext{total}}
                                                                                           <2 \times 10^{-6}. CL = 90%
\Gamma(K^+ \rightarrow \mu^- \nu e^+ e^+)/\Gamma_{\text{total}}
                                                                                           <\!2.0\times10^{-8}\text{, CL}\,=\,90\,\%
\Gamma(K^+ 	o \mu^+ \nu_e)/\Gamma_{
m total}
                                                                                   [q] <4 \times 10^{-3}, CL = 90%
\Gamma(K^+ \rightarrow \pi^+ \mu^+ e^-)/\Gamma_{\text{total}}
                                                                                           <1.3 \times 10^{-11}, CL = 90%
\Gamma(K^+ \rightarrow \pi^+ \mu^- e^+)/\Gamma_{\text{total}}
                                                                                           < 5.2 \times 10^{-10}, CL = 90%
\Gamma(\kappa_I^0 \to e^{\pm} \mu^{\mp})/\Gamma_{
m total}
                                                                                  [m] <4.7 × 10<sup>-12</sup>, CL = 90%
\Gamma(\kappa_I^{0} \rightarrow e^{\pm} e^{\pm} \mu^{\mp} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <4.12 × 10<sup>-11</sup>, CL = 90%
\Gamma(\kappa_I^{0} \rightarrow \pi^0 \mu^{\pm} e^{\mp})/\Gamma_{total}
                                                                                  [m] <7.6 × 10<sup>-11</sup>, CL = 90%
\Gamma(\kappa_{I}^{0} \rightarrow \pi^{0}\pi^{0}\mu^{\pm}e^{\mp})/\Gamma_{\text{total}}
                                                                                          <\!\!1.7\times10^{-10} , CL = 90%
\Gamma(D^{+} \rightarrow \pi^{+} e^{+} \mu^{-})/\Gamma_{\text{total}}
                                                                                           < 2.9 \times 10^{-6}, CL = 90%
\Gamma(D^+ \rightarrow \pi^+ \, e^- \, \mu^+) / \Gamma_{	ext{total}}
                                                                                           <\!3.6\times10^{-6}\text{, CL}\,=\,90\,\%
\Gamma(D^+ \rightarrow K^+ e^+ \mu^-)/\Gamma_{\text{total}}
                                                                                           <1.2 \times 10^{-6}, CL = 90%
\Gamma(D^+ \rightarrow K^+ e^- \mu^+)/\Gamma_{\text{total}}
                                                                                           <2.8 \times 10^{-6}, CL = 90%
\Gamma(D^0 \to \mu^{\pm} e^{\mp})/\Gamma_{
m total}
                                                                                  [m] <2.6 × 10<sup>-7</sup>, CL = 90%
\Gamma(D^0 \rightarrow \pi^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <8.6 × 10<sup>-5</sup>, CL = 90%
\Gamma(D^0 \to \eta e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <1.0 × 10<sup>-4</sup>, CL = 90%
\Gamma(D^0 \to \pi^+\pi^-\,e^\pm\,\mu^\mp)/\Gamma_{
m total}
                                                                                  [m] <1.5 × 10<sup>-5</sup>, CL = 90%
\Gamma(D^0 \to \rho^0 e^{\pm} \mu^{\mp})/\Gamma_{
m total}
                                                                                  [m] <4.9 × 10<sup>-5</sup>, CL = 90%
\Gamma(D^0 \to \omega e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <1.2 × 10<sup>-4</sup>, CL = 90%
\Gamma(D^0 \to \kappa^- \kappa^+ e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <1.8 × 10<sup>-4</sup>, CL = 90%
\Gamma(D^0 \to \phi e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m]~< 3.4 \times 10^{-5} , CL =~90\,\%
\Gamma(D^0 \to \overline{K}{}^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <1.0 × 10<sup>-4</sup>, CL = 90%
\Gamma(D^0 \to \kappa^- \pi^+ e^{\pm} \mu^{\mp})/\Gamma_{
m total}
                                                                                  [m] <5.53 × 10<sup>-4</sup>, CL = 90%
\Gamma(D^0 \to \overline{K}^*(892)^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}
                                                                                  [m] <8.3 × 10<sup>-5</sup>, CL = 90%
\Gamma(D_c^+ \to \pi^+ e^+ \mu^-)/\Gamma_{total}
                                                                                           <\!\!1.2\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(D_s^+ \to \pi^+ e^- \mu^+)/\Gamma_{total}
                                                                                           <\!\!2.0\times10^{-5}\text{, CL}\,=\,90\%
                                                                                           {<}1.4\times10^{-5}\text{, CL}\,=\,90\%
\Gamma(D_s^+ \to K^+ e^+ \mu^-)/\Gamma_{\text{total}}
                                                                                           <9.7 \times 10^{-6}, CL = 90%
\Gamma(D_s^+ \to K^+ e^- \mu^+)/\Gamma_{\text{total}}
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| $\begin{array}{ll} \Gamma(B^+ \to \ \pi^+ e^+ \mu^-)/\Gamma_{\mbox{total}} & <6.4 \times 10^{-3}, CL = 90 \\ \Gamma(B^+ \to \ \pi^+ e^- \mu^+)/\Gamma_{\mbox{total}} & <6.4 \times 10^{-3}, CL = 90 \end{array}$ | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| $\Gamma(P^{+}) = + e^{-} + 10^{-3} CL = 000$ | |
| $(B^+ \rightarrow \pi^+ e^- \mu^+)/\tau_{total}$ < 6.4 × 10 -, CL = 90 | % |
| $\Gamma(B^+ \rightarrow \pi^+ e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <1.7 × 10 ⁻⁷ , CL = 90° | % |
| $\Gamma(B^+ \to K^+ e^+ \mu^-)/\Gamma_{\text{total}}$ < 9.1 × 10 ⁻⁸ , CL = 90° | % |
| $\Gamma(B^+ \to K^+ e^- \mu^+)/\Gamma_{\text{total}}$ <1.3 × 10 ⁻⁷ , CL = 90° | % |
| $\Gamma(B^+ \rightarrow K^+ e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ < 9.1 × 10 ⁻⁸ , CL = 90° | % |
| $\Gamma(B^+ \to K^+ \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <7.7 × 10 ⁻⁵ , CL = 90° | % |
| $\Gamma(B^+ \to K^*(892)^+ e^+ \mu^-)/\Gamma_{\text{total}}$ <1.3 × 10 ⁻⁶ , CL = 90° | % |
| $\Gamma(B^+ \to K^*(892)^+ e^- \mu^+)/\Gamma_{\text{total}}$ < 9.9 × 10 ⁻⁷ , CL = 90° | % |
| $\Gamma(B^+ \to K^*(892)^+ e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <1.4 × 10 ⁻⁶ , CL = 90 | % |
| $\Gamma(B^0 \to e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ [m] <6.4 × 10 ⁻⁸ , CL = 90° | % |
| $\Gamma(B^0 \rightarrow \pi^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <1.4 × 10 ⁻⁷ , CL = 90° | % |
| $\Gamma(B^0 \to K^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <2.7 × 10 ⁻⁷ , CL = 90° | % |
| $\Gamma(B^0 \to K^*(892)^0 e^+ \mu^-)/\Gamma_{\text{total}}$ <5.3 × 10 ⁻⁷ , CL = 90° | |
| $\Gamma(B^0 \to K^*(892)^0 e^- \mu^+)/\Gamma_{\text{total}}$ <3.4 × 10 ⁻⁷ , CL = 90° | |
| $\Gamma(B^0 \to K^*(892)^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <5.8 × 10 ⁻⁷ , CL = 90 | % |
| $\Gamma(B^0 \to e^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ [m] $<2.8 \times 10^{-5}$, CL = 90 | % |
| $\Gamma(B^0 \to \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ [m] $\langle 2.2 \times 10^{-5}, \text{ CL} = 90^{\circ}$ | % |
| $\Gamma(B \rightarrow s e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ [m] $<2.2 \times 10^{-5}$, CL = 90° | % |
| $\Gamma(B \rightarrow \pi e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ < 9.2 × 10 ⁻⁸ , CL = 90 | % |
| $\Gamma(B \rightarrow \rho e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <3.2 × 10 ⁻⁶ , CL = 90 | |
| $\Gamma(B \rightarrow K e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <3.8 × 10 ⁻⁸ , CL = 90° | % |
| $\Gamma(B \to K^*(892) e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ <5.1 × 10 ⁻⁷ , CL = 90 | % |
| $\Gamma(B_s^0 \to e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ [m] $<2.0 \times 10^{-7}$, CL = 90 | % |
| $\Gamma(J/\psi(1S) \rightarrow e^{\pm}\mu^{\mp})/\Gamma_{total}$ <1.1 × 10 ⁻⁶ , CL = 90 | % |
| $\Gamma(J/\psi(1S) \rightarrow e^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <8.3 × 10 ⁻⁶ , CL = 90° | % |
| $\Gamma(J/\psi(1S) \rightarrow \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <2.0 × 10 ⁻⁶ , CL = 90 | % |
| $\Gamma(\Upsilon(1S) \rightarrow \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <6.0 × 10 ⁻⁶ , CL = 95 | % |
| $\Gamma(\Upsilon(2S) \rightarrow e^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <3.2 × 10 ⁻⁶ , CL = 90° | % |
| $\Gamma(\Upsilon(2S) \rightarrow \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <3.3 × 10 ⁻⁶ , CL = 90° | % |
| $\Gamma(\Upsilon(3S) \rightarrow e^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <4.2 × 10 ⁻⁶ , CL = 90° | % |
| $\Gamma(\Upsilon(3S) \rightarrow \mu^{\pm} \tau^{\mp})/\Gamma_{\text{total}}$ <3.1 × 10 ⁻⁶ , CL = 90 | % |
| $\Gamma(\Lambda_c^+ \to \rho e^+ \mu^-)/\Gamma_{\text{total}}$ <9.9 × 10 ⁻⁶ , CL = 90° | |
| $\Gamma(\Lambda_c^+ \to p e^- \mu^+)/\Gamma_{\text{total}}$ <1.9 × 10 ⁻⁵ , CL = 90° | % |

TOTAL LEPTON NUMBER

Violation of total lepton number conservation also implies violation of lepton family number conservation.

| $\Gamma(Z \rightarrow pe)/\Gamma_{total}$ | | $<1.8 \times 10^{-6}$, CL = 95% |
|-----------------------------------------------------------------------|-----|----------------------------------------------------------------------|
| $\Gamma(Z \rightarrow \rho \mu)/\Gamma_{total}$ | | $<1.8 \times 10^{-6}$, CL = 95% |
| limit on $\mu^- ightarrow e^+$ conversion | | |
| $\sigma(\mu^{-32}S \rightarrow e^{+32}Si^*)$ / | | $<$ 9 $	imes$ 10 $^{-10}$, CL $=$ 90% |
| $\sigma(\mu^{-32}S \rightarrow \nu_{\mu}^{32}P^*)$ | | |
| $\sigma(\mu^{-127}I \rightarrow e^{+127}Sb^*)$ / | | $<$ 3 $	imes$ 10 $^{-10}$, CL $=$ 90% |
| $\sigma(\mu^{-127} \rightarrow \text{anything})$ | | |
| $\sigma(\mu^-{\sf Ti} ightarrowe^+{\sf Ca})$ / | | $< 3.6 \times 10^{-11}$, CL = 90% |
| $\sigma(\mu^-{\sf Ti}	o{\sf capture})$ | | |
| $\Gamma(au^- ightarrow e^+ \pi^- \pi^-)/\Gamma_{total}$ | | $< 8.8 \times 10^{-8}$, CL = 90% |
| $\Gamma(au^- ightarrow \ \mu^+ \pi^- \pi^-)/\Gamma_{	ext{total}}$ | | $< 3.7 \times 10^{-8}$, CL = 90% |
| $\Gamma(au^- ightarrow~e^+\pi^-K^-)/\Gamma_{	ext{total}}$ | | $<6.7 \times 10^{-8}$, CL = 90% |
| $\Gamma(au^- ightarrow~e^+K^-K^-)/\Gamma_{	ext{total}}$ | | $<6.0 \times 10^{-8}$, CL = 90% |
| $\Gamma(\tau^- 	o \mu^+ \pi^- K^-)/\Gamma_{total}$ | | $< 9.4 \times 10^{-8}$, CL = 90% |
| $\Gamma(\tau^- \rightarrow \mu^+ K^- K^-)/\Gamma_{\text{total}}$ | | $< 9.6 \times 10^{-8}$, CL = 90% |
| $\Gamma(\tau^- \to \overline{p}\gamma)/\Gamma_{\text{total}}$ | | $< 3.5 \times 10^{-6}$, CL $= 90\%$ |
| $\Gamma(\tau^- 	o \overline{p}\pi^0)/\Gamma_{\text{total}}$ | | $<\!\!1.5\times10^{-5}$, CL $=90\%$ |
| $\Gamma(\tau^- \to \overline{p} 2\pi^0)/\Gamma_{\text{total}}$ | | $<$ 3.3 \times 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(\tau^- \to \overline{p}\eta)/\Gamma_{\text{total}}$ | | $< 8.9 \times 10^{-6}$, CL $= 90\%$ |
| $\Gamma(\tau^- \to \overline{p}\pi^0\eta)/\Gamma_{\text{total}}$ | | $<$ 2.7 \times 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(\tau^- \to \Lambda \pi^-)/\Gamma_{\text{total}}$ | | $< 7.2 \times 10^{-8}$, CL = 90% |
| $\Gamma(\tau^- \to \overline{\Lambda}\pi^-)/\Gamma_{\text{total}}$ | | $<1.4 \times 10^{-7}$, CL $= 90\%$ |
| $t_{1/5}($ $^{76}\text{Ge} \rightarrow {}^{76}\text{Se} + 2 e^{-})$ | | $> \! 1.9 \times 10^{25}$ yr, CL $= 90\%$ |
| $\Gamma(\pi^+ \to \mu^+ \overline{\nu}_e)/\Gamma_{\text{total}}$ | [a] | $<1.5 \times 10^{-3}$, CL = 90% |
| $\Gamma(K^+ \to \pi^- \mu^+ e^+)/\Gamma_{\text{total}}$ | [7] | $<5.0 \times 10^{-10}$, CL = 90% |
| $\Gamma(K^+ \to \pi^- e^+ e^+)/\Gamma_{\text{total}}$ | | $<6.4 \times 10^{-10}$, CL = 90% |
| $\Gamma(K^+ \to \pi^- \mu^+ \mu^+)/\Gamma_{\text{total}}$ | [a] | $<1.1 \times 10^{-9}$, CL = 90% |
| $\Gamma(K^+ \to \mu^+ \overline{\nu}_e)/\Gamma_{\text{total}}$ | | $<3.3 \times 10^{-3}$, CL = 90% |
| $\Gamma(K^+ \to \pi^0 e^+ \overline{\nu}_e)/\Gamma_{\text{total}}$ | [4] | $<3 \times 10^{-3}$. CL = 90% |
| $\Gamma(D^+ \to \pi^- 2e^+)/\Gamma_{\text{total}}$ | | $<1.1 \times 10^{-6}$, CL = 90% |
| | | $<1.1 \times 10^{-4}$, CL = 90% $<2.0 \times 10^{-6}$, CL = 90% |
| $\Gamma(D^+ \rightarrow \pi^- 2\mu^+)/\Gamma_{\text{total}}$ | | $< 2.0 \times 10^{-5}$, $CL = 90\%$ |

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\Gamma(D^+ \rightarrow \pi^- e^+ \mu^+)/\Gamma_{	ext{total}}
                                                                                      <2.0 \times 10^{-6}, CL = 90%
\Gamma(D^+ 
ightarrow 
ho^- 2 \mu^+)/\Gamma_{	ext{total}}
                                                                                      <5.6 \times 10^{-4}, CL = 90%
\Gamma(D^+ \rightarrow K^- 2e^+)/\Gamma_{\text{total}}
                                                                                      <\!9\times10^{-7}\text{, CL}\,=\,90\,\%
\Gamma(D^+ \to K^- 2\mu^+)/\Gamma_{\text{total}}
                                                                                      {<}1.0\times10^{-5}\text{, CL}\,=\,90\%
\Gamma(D^+ \rightarrow \kappa^- e^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <1.9 \times 10^{-6}, CL = 90%
                                                                                      <\!8.5\times10^{-4}\text{, CL}=90\%
\Gamma(D^+ \rightarrow K^*(892)^- 2\mu^+)/\Gamma_{\text{total}}
\Gamma(D^0 \rightarrow 2\pi^- 2e^+ + \text{c.c.})/\Gamma_{\text{total}}
                                                                                      <1.12 \times 10^{-4}, CL = 90%
\Gamma(D^0 \rightarrow 2\pi^- 2\mu^+ + \text{c.c.})/\Gamma_{\text{total}}
                                                                                      <\!2.9\times10^{-5} , CL =90\%
\Gamma(D^0 \rightarrow K^-\pi^- 2e^+ + c.c.)/\Gamma_{total}
                                                                                      < 2.06 \times 10^{-4}, CL = 90%
\Gamma(D^0 \rightarrow K^-\pi^- 2\mu^+ + c.c.)/\Gamma_{total}
                                                                                      < 3.9 \times 10^{-4}, CL = 90\%
\Gamma(D^0 \rightarrow 2K^-2e^+ + c.c.)/\Gamma_{total}
                                                                                      <1.52 \times 10^{-4}, CL = 90%
\Gamma(D^0 \rightarrow 2K^-2\mu^+ + c.c.)/\Gamma_{total}
                                                                                      <\!9.4\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(D^0 \rightarrow \pi^-\pi^-e^+\mu^+ + \text{c.c.})/\Gamma_{\text{total}}
                                                                                      < 7.9 \times 10^{-5}, CL = 90%
\Gamma(D^0 \rightarrow K^-\pi^-e^+\mu^+ + c.c.)/\Gamma_{total}
                                                                                      <\!2.18\times10^{-4} , CL =90\%
\Gamma(D^0 \rightarrow 2K^-e^+\mu^+ + c.c.)/\Gamma_{total}
                                                                                      <5.7 \times 10^{-5}, CL = 90%
\Gamma(D^0 \to \rho e^-)/\Gamma_{total}
                                                                               [r] <1.0 × 10<sup>-5</sup>, CL = 90%
\Gamma(D^0 \rightarrow \overline{p} e^+)/\Gamma_{total}
                                                                               [s] <1.1 \times 10^{-5}, CL = 90%
\Gamma(D_s^+ \to \pi^- 2e^+)/\Gamma_{total}
                                                                                      <4.1 \times 10^{-6}, CL = 90%
\Gamma(D_s^+ \to \pi^- 2\mu^+)/\Gamma_{\mathsf{total}}
                                                                                      <1.4 \times 10^{-5}, CL = 90%
\Gamma(D_{c}^{+} \rightarrow \pi^{-}e^{+}\mu^{+})/\Gamma_{total}
                                                                                      <\!8.4\times10^{-6}\text{, CL}\,=\,90\%
\Gamma(D_s^+ \to K^- 2e^+)/\Gamma_{total}
                                                                                      <\!\!5.2\times10^{-6}\text{, CL}\,=\,90\,\%
\Gamma(D_s^+ \to K^- 2\mu^+)/\Gamma_{total}
                                                                                      <\!\!1.3\times10^{-5}\text{, CL}\,=\,90\,\%
                                                                                      {<}6.1\times10^{-6}\text{, CL}\,=\,90\,\%
\Gamma(D_s^+ \to K^- e^+ \mu^+)/\Gamma_{total}
\Gamma(D_{c}^{+} \rightarrow K^{*}(892)^{-}2\mu^{+})/\Gamma_{total}
                                                                                      < \! 1.4 \times 10^{-3} \text{, CL} = 90\%
\Gamma(B^+ \to \pi^- e^+ e^+)/\Gamma_{\text{total}}
                                                                                      <1.6 \times 10^{-6}, CL = 90%
\Gamma(B^+ \rightarrow \pi^- \mu^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <4.4 \times 10^{-8}, CL = 90%
\Gamma(B^+ \rightarrow \pi^- e^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <1.3 \times 10^{-6}, CL = 90%
\Gamma(B^+ \rightarrow \rho^- e^+ e^+)/\Gamma_{\text{total}}
                                                                                      <2.6 \times 10^{-6}, CL = 90%
                                                                                      <5.0 \times 10<sup>-6</sup>, CL = 90%
\Gamma(B^+ \to \rho^- \mu^+ \mu^+)/\Gamma_{	ext{total}}
\Gamma(B^+ \rightarrow \rho^- e^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <3.3 \times 10^{-6}, CL = 90%
                                                                                      < \! 1.0 \times 10^{-6} , CL = 90\%
\Gamma(B^+ \rightarrow K^-e^+e^+)/\Gamma_{total}
\Gamma(B^+ \rightarrow K^- \mu^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <4.1 \times 10^{-8}, CL = 90%
                                                                                      < 2.0 \times 10^{-6}, CL = 90\%
\Gamma(B^+ \rightarrow K^- e^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <2.8 \times 10^{-6}, CL = 90%
\Gamma(B^+ \rightarrow K^*(892)^- e^+ e^+)/\Gamma_{total}
\Gamma(B^+ \rightarrow K^*(892)^- \mu^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      < 8.3 \times 10^{-6}, CL = 90\%
\Gamma(B^+ \rightarrow K^*(892)^- e^+ \mu^+)/\Gamma_{total}
                                                                                      <4.4 \times 10^{-6}, CL = 90%
\Gamma(B^+ \rightarrow D^- e^+ e^+)/\Gamma_{total}
                                                                                      <\!\!2.6\times10^{-6}\text{, CL}\,=\,90\,\%
                                                                                      <\!\!1.8\times10^{-6}\text{, CL}\,=\,90\%
\Gamma(B^+ \rightarrow D^-e^+\mu^+)/\Gamma_{\text{total}}
\Gamma(B^+ \rightarrow D^- \mu^+ \mu^+)/\Gamma_{\text{total}}
                                                                                      <1.1 \times 10^{-6}, CL = 90%
\Gamma(B^+ \to \Lambda^0 \mu^+)/\Gamma_{\text{total}}
                                                                                      <6 \times 10^{-8}, CL = 90%
\Gamma(B^+ \to \Lambda^0 e^+)/\Gamma_{\text{total}}
                                                                                      <3.2 \times 10^{-8}, CL = 90%
\Gamma(B^+ 	o \overline{\Lambda}{}^0 \mu^+)/\Gamma_{	ext{total}}
                                                                                      <\!6\times10^{-8}\text{, CL}\,=\,90\,\%
\Gamma(B^+ \to \overline{\Lambda}{}^0 e^+)/\Gamma_{\text{total}}
                                                                                      < 8 \times 10^{-8}. CL = 90%
\Gamma(B^0 \to \Lambda_c^+ \mu^-)/\Gamma_{
m total}
                                                                                      < \! 1.8 \times 10^{-6} \text{, CL} = 90\%
\Gamma(B^0 \to \Lambda_c^+ e^-)/\Gamma_{	ext{total}}
                                                                                      {<}5\times10^{-6}\text{, CL}\,=\,90\,\%
\Gamma(\Xi^- 
ightarrow \stackrel{\circ}{p}\mu^-\mu^-)/\Gamma_{
m total}
                                                                                      <4 \times 10^{-8}, CL = 90%
\Gamma(\Lambda_c^+ \to \overline{\rho} 2e^+)/\Gamma_{\text{total}}
                                                                                      < 2.7 \times 10^{-6}, CL = 90%
\Gamma(\Lambda_c^+ \to \overline{\rho} 2\mu^+)/\Gamma_{\text{total}}
                                                                                      <9.4 \times 10^{-6}, CL = 90%
\Gamma(\Lambda_c^+ \to \overline{p}e^+\mu^+)/\Gamma_{\text{total}}
                                                                                      <1.6 \times 10^{-5}, CL = 90%
\Gamma(\Lambda_c^+ \to \Sigma^- \mu^+ \mu^+)/\Gamma_{total}
                                                                                      < 7.0 \times 10^{-4}, CL = 90%
```

BARYON NUMBER

| $\Gamma(Z \rightarrow pe)/\Gamma_{total}$ | | $<1.8 \times 10^{-6}$, CL $= 95\%$ |
|--------------------------------------------------------------------|-----|----------------------------------------------|
| $\Gamma(Z \rightarrow p \mu)/\Gamma_{total}$ | | $<1.8 \times 10^{-6}$, CL = 95% |
| $\Gamma(\tau^- \to \overline{p}\gamma)/\Gamma_{\text{total}}$ | | $<3.5 \times 10^{-6}$, CL = 90% |
| $\Gamma(\tau^- 	o \overline{p}\pi^0)/\Gamma_{\text{total}}$ | | $<1.5 \times 10^{-5}$, CL $= 90\%$ |
| $\Gamma(au^- 	o \overline{p}2\pi^0)/\Gamma_{	ext{total}}$ | | $< 3.3 \times 10^{-5}$, CL $= 90\%$ |
| $\Gamma(\tau^- \to \overline{p}\eta)/\Gamma_{\text{total}}$ | | $< 8.9 \times 10^{-6}$, CL = 90% |
| $\Gamma(au^- 	o \overline{ ho} \pi^0 \eta) / \Gamma_{total}$ | | $< 2.7 \times 10^{-5}$, CL $= 90\%$ |
| $\Gamma(\tau^- \to \Lambda \pi^-)/\Gamma_{\text{total}}$ | | $< 7.2 \times 10^{-8}$, CL = 90% |
| $\Gamma(au^- 	o \overline{\Lambda} \pi^-)/\Gamma_{	ext{total}}$ | | $<1.4 \times 10^{-7}$, CL $= 90\%$ |
| $\Gamma(D^0 \to pe^-)/\Gamma_{\text{total}}$ | [r] | $<1.0 \times 10^{-5}$, CL $= 90\%$ |
| $\Gamma(D^0 \to \overline{p}e^+)/\Gamma_{\text{total}}$ | [s] | $<1.1 \times 10^{-5}$, CL $= 90\%$ |
| $\Gamma(B^+ \to \Lambda^0 \mu^+)/\Gamma_{\text{total}}$ | | $<$ 6 \times 10 ⁻⁸ , CL $=$ 90% |
| $\Gamma(B^+ \to \Lambda^0 e^+)/\Gamma_{\text{total}}$ | | $< 3.2 \times 10^{-8}$, CL $= 90\%$ |
| $\Gamma(B^+ \to \overline{\Lambda}^0 \mu^+)/\Gamma_{\text{total}}$ | | $<$ 6 \times 10 ⁻⁸ , CL $=$ 90% |
| $\Gamma(B^+ \to \overline{\Lambda}^0 e^+)/\Gamma_{\text{total}}$ | | $< 8 \times 10^{-8}$, CL = 90% |
| $\Gamma(B^0 \to \Lambda_c^+ \mu^-)/\Gamma_{\text{total}}$ | | $<\!\!1.8\times10^{-6}\text{, CL}=90\%$ |
| • | | |

| p mean life | [t] | >2.1 $	imes$ 10 ²⁹ years, CL $=$ 90% |
|-------------------------------------------------------------------------|------|-------------------------------------------------|
| A few examples of proton or bound neutron decay | foll | ow. For limits on many other nucleon |
| decay channels, see the Baryon Summary Table. | | |
| $\tau(N \rightarrow e^+\pi)$ | | $> 158 (n)$, $> 8200 (p) \times 10^{30}$ years |
| | | CL = 90% |
| $\tau(N \rightarrow \mu^+ \pi)$ | | $> 100 (n)$, $> 6600 (p) \times 10^{30}$ years |
| | | CL = 90% |
| $\tau(N \rightarrow e^+ K)$ | | $> 17 (n)$, $> 150 (p) \times 10^{30}$ years, |
| | | CL = 90% |
| $\tau(N \to \mu^+ K)$ | | $> 26 (n)$, $> 120 (p) \times 10^{30}$ years, |
| | | CL = 90% |
| limit on $n\overline{n}$ oscillations (free n) | | $>0.86 \times 10^8$ s, CL = 90% |
| limit on $n\overline{n}$ oscillations (bound n) | [u] | $>1.3 \times 10^8$ s, CL = 90% |
| $\Gamma(\Lambda_c^+ \to \overline{p} 2e^+)/\Gamma_{\text{total}}$ | | $<2.7 \times 10^{-6}$, CL = 90% |
| $\Gamma(\Lambda_c^+ \to \overline{p} 2\mu^+)/\Gamma_{total}$ | | $<$ 9.4 $	imes$ 10 $^{-6}$, CL $=$ 90% |
| $\Gamma(\Lambda_c^+ \to \overline{\rho}e^+\mu^+)/\Gamma_{\text{total}}$ | | ${<}1.6\times10^{-5}\text{, CL}=90\text{\%}$ |
| | | |

 ${<}5\times10^{-6}\text{, CL}\,=\,90\%$

 $\Gamma(B^0 \to \Lambda_c^+ e^-)/\Gamma_{total}$

ELECTRIC CHARGE (Q)

$$e\to\nu_e\gamma$$
 and astrophysical limits
$$[v]~>4.6\times10^{26}~yr,~CL=90\%$$

$$\Gamma(n\to\rho\nu_e\overline{\nu}_e)/\Gamma_{total}~~<8\times10^{-27},~CL=68\%$$

$\Delta S = \Delta Q$ RULE

Violations allowed in second-order weak interactions.

$$\begin{array}{lll} \Gamma(K^{+} \to \pi^{+}\pi^{+}e^{-}\overline{\nu}_{e})/\Gamma_{\rm total} & <1.2 \times 10^{-8}, \, {\rm CL} = 90\% \\ \Gamma(K^{+} \to \pi^{+}\pi^{+}\mu^{-}\overline{\nu}_{\mu})/\Gamma_{\rm total} & <3.0 \times 10^{-6}, \, {\rm CL} = 95\% \\ {\rm Re}({\rm x}_{+}), \, K_{\rm e3} \, {\rm parameter} & (-0.9 \pm 3.0) \times 10^{-3} \\ {\rm x} = {\rm A}(\overline{K}^{0} \to \pi^{-}\ell^{+}\nu)/{\rm A}(K^{0} \to \pi^{-}\ell^{+}\nu) = {\rm A}(\Delta S = -\Delta Q)/{\rm A}(\Delta S = \Delta Q) \\ {\rm real} \, {\rm part} \, {\rm of} \, x & -0.002 \pm 0.006 \\ {\rm imaginary} \, {\rm part} \, {\rm of} \, x & 0.0012 \pm 0.0021 \\ \Gamma(\Sigma^{+} \to n\ell^{+}\nu)/\Gamma(\Sigma^{-} \to n\ell^{-}\overline{\nu}) & <0.043 \\ \Gamma(\Sigma^{+} \to ne^{+}\nu_{e})/\Gamma_{\rm total} & <5 \times 10^{-6}, \, {\rm CL} = 90\% \\ \Gamma(\Xi^{0} \to \Sigma^{-}e^{+}\nu_{e})/\Gamma_{\rm total} & <9 \times 10^{-4}, \, {\rm CL} = 90\% \\ \Gamma(\Xi^{0} \to \Sigma^{-}\mu^{+}\nu_{\mu})/\Gamma_{\rm total} & <9 \times 10^{-4}, \, {\rm CL} = 90\% \\ \Gamma(\Xi^{0} \to \Sigma^{-}\mu^{+}\nu_{\mu})/\Gamma_{\rm total} & <9 \times 10^{-4}, \, {\rm CL} = 90\% \end{array}$$

$\Delta S = 2$ FORBIDDEN

Allowed in second-order weak interactions.

| $\Gamma(\Xi^0 \to p\pi^-)/\Gamma_{\text{total}}$ | $<$ 8 $	imes$ 10 $^{-6}$, CL $=$ 90% |
|------------------------------------------------------------------------|---------------------------------------|
| $\Gamma(\Xi^0 \to p e^- \overline{\nu}_e) / \Gamma_{\text{total}}$ | $< 1.3 \times 10^{-3}$ |
| $\Gamma(\Xi^0 	o ho \mu^- \overline{ u}_\mu)/\Gamma_{total}$ | $<1.3 \times 10^{-3}$ |
| $\Gamma(\Xi^- 	o n\pi^-)/\Gamma_{total}$ | $< 1.9 	imes 10^{-5}$, CL $= 90\%$ |
| $\Gamma(\Xi^- \to ne^-\overline{\nu}_e)/\Gamma_{\text{total}}$ | $< 3.2 \times 10^{-3}$, CL = 90% |
| $\Gamma(\Xi^- \to n\mu^-\overline{\nu}_\mu)/\Gamma_{\text{total}}$ | $<1.5 \times 10^{-2}$, CL = 90% |
| $\Gamma(\Xi^- 	o ho \pi^- \pi^-)/\Gamma_{	ext{total}}$ | $<$ 4 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(\Xi^- 	o p\pi^-e^-\overline{ u}_e)/\Gamma_{	ext{total}}$ | $<$ 4 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(\Xi^- 	o p\pi^-\mu^-\overline{\nu}_\mu)/\Gamma_{\text{total}}$ | $< 4 \times 10^{-4}$, CL = 90% |
| $\Gamma(\Omega^- \to \Lambda \pi^-)/\Gamma_{total}$ | $< 2.9 \times 10^{-6}$, CL = 90% |

$\Delta S = 2 \text{ VIA MIXING}$

Allowed in second-order weak interactions, e.g. mixing.

$$\begin{array}{ll} m_{\mbox{K_L^0}} - m_{\mbox{K_S^0}} & (0.5293 \pm 0.0009) \times 10^{10} \ \hbar \ {\rm s}^{-1} \ ({\rm S} \\ & = 1.3) \\ m_{\mbox{K_I^0}} - m_{\mbox{K_S^0}} & (3.484 \pm 0.006) \times 10^{-12} \ {\rm MeV} \end{array}$$

$\Delta C = 2 \text{ VIA MIXING}$

Allowed in second-order weak interactions, e.g. mixing.

$$\begin{array}{ll} |m_{D_1^0}-m_{D_2^0}| = x\Gamma & (1.44^{+0.48}_{-0.50})\times 10^{10}~\hbar~\mathrm{s}^{-1} \\ (\Gamma_{D_1^0}-\Gamma_{D_2^0})/\Gamma = 2y & (1.60^{+0.25}_{-0.26})\times 10^{-2} \end{array}$$

$\Delta B = 2 \text{ VIA MIXING}$

Allowed in second-order weak interactions, e.g. mixing.

$$\begin{array}{lll} \chi_{d} & 0.1862 \pm 0.0023 \\ \Delta m_{B^0} = m_{B^0_H} - m_{B^0_L} & (0.507 \pm 0.004) \times 10^{12} \ \hbar \ \mathrm{s}^{-1} \\ \chi_{d} = \Delta m_{B^0} / \Gamma_{B^0} & 0.770 \pm 0.008 \\ \Delta m_{B^0_S} = m_{B^0_{SH}} - m_{B^0_{SL}} & (17.69 \pm 0.08) \times 10^{12} \ \hbar \ \mathrm{s}^{-1} \\ \chi_{S} = \Delta m_{B^0_S} / \Gamma_{B^0_S} & 26.49 \pm 0.29 \\ \chi_{S} & 0.499292 \pm 0.000016 \end{array}$$

$\Delta S = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

| $\Gamma(K^+ \rightarrow \pi^+ e^+ e^-)/\Gamma_{\text{total}}$ | | $(3.00 \pm 0.09) \times 10^{-7}$ |
|-------------------------------------------------------------------------------------------------|-----|------------------------------------------|
| $\Gamma(K^+ \rightarrow \pi^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $(9.4 \pm 0.6) \times 10^{-8} (S = 2.6)$ |
| $\Gamma(K^+ \to \pi^+ \nu \overline{\nu})/\Gamma_{\text{total}}$ | | $(1.7 \pm 1.1) \times 10^{-10}$ |
| $\Gamma(K^+ \rightarrow \pi^+ \pi^0 \nu \overline{\nu}) / \Gamma_{\text{total}}$ | | $< 4.3 \times 10^{-5}$, CL = 90% |
| $\Gamma(\kappa_S^0 \to \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $< 3.2 \times 10^{-7}$, CL = 90% |
| $\Gamma(\kappa_S^0 \to e^+e^-)/\Gamma_{\text{total}}$ | | $<9 \times 10^{-9}$, CL = 90% |
| $\Gamma(\kappa_s) = 0$ $\alpha + \alpha = 1/\Gamma$ | Lud | $(3.0^{+1.5}_{-1.2}) \times 10^{-9}$ |
| $\Gamma(K_S^0 \to \pi^0 e^+ e^-)/\Gamma_{\text{total}}$ | [w] | 1·5 |
| $\Gamma(\kappa_S^0 \to \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $(2.9^{+1.5}_{-1.2}) \times 10^{-9}$ |
| $\Gamma(\kappa_L^0 \rightarrow \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $(6.84 \pm 0.11) \times 10^{-9}$ |
| $\Gamma(\kappa_L^0 \to e^+ e^-)/\Gamma_{\text{total}}$ | | $(9^{+6}_{-4}) \times 10^{-12}$ |
| $\Gamma(\kappa_L^{0} \rightarrow \pi^+\pi^-e^+e^-)/\Gamma_{	ext{total}}$ | [x] | $(3.11 \pm 0.19) \times 10^{-7}$ |
| $\Gamma(\kappa_L^0 \to \pi^0 \pi^0 e^+ e^-)/\Gamma_{\text{total}}$ | | $<$ 6.6 $	imes$ 10 $^{-9}$, CL $=$ 90% |
| $\Gamma(\kappa_L^0 \to \pi^0 \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $<\!9.2\times10^{-11}$, CL $=$ 90% |
| $\Gamma(\kappa_L^{0} \rightarrow \mu^+ \mu^- e^+ e^-)/\Gamma_{	ext{total}}$ | | $(2.69 \pm 0.27) \times 10^{-9}$ |
| $\Gamma(\kappa_L^{ar{0}} ightarrow e^+ e^- e^+ e^-)/\Gamma_{	ext{total}}$ | | $(3.56\pm0.21)\times10^{-8}$ |
| $\Gamma(\kappa_L^{\bar{0}} \rightarrow \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $<$ 3.8 $	imes$ 10 $^{-10}$, CL $=$ 90% |
| $\Gamma(\kappa_L^{\bar{0}} ightarrow \pi^0 e^+ e^-)/\Gamma_{ m total}$ | | $<$ 2.8 $	imes$ 10 $^{-10}$, CL $=$ 90% |
| $\Gamma(\kappa_L^{ar{0}} ightarrow \pi^0 u \overline{ u}) / \Gamma_{	ext{total}}$ | | $<$ 2.6 \times 10 $^{-8}$, CL $=$ 90% |
| $\Gamma(\kappa_L^{\bar{0}} \rightarrow \pi^0 \pi^0 \nu \overline{\nu}) / \Gamma_{\text{total}}$ | | $<\!8.1\times10^{-7}\text{, CL}=90\%$ |
| $\Gamma(\Sigma^+ \to p e^+ e^-)/\Gamma_{\text{total}}$ | | $< 7 \times 10^{-6}$ |
| $\Gamma(\Sigma^+ \to \rho \mu^+ \mu^-)/\Gamma_{\text{total}}$ | | $(9^{+9}_{-8}) \times 10^{-8}$ |
| | | |

$\Delta C = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

| , 0 | |
|---------------------------------------------------------------------------|----------------------------------------------|
| $\Gamma(D^+ 	o \pi^+ e^+ e^-)/\Gamma_{	ext{total}}$ | $< \! 1.1 \times 10^{-6} \text{, CL} = 90\%$ |
| $\Gamma(D^+ \rightarrow \pi^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 3.9 $	imes$ 10 $^{-6}$, CL $=$ 90% |
| $\Gamma(D^+ \rightarrow \rho^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 5.6 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \to \gamma \gamma)/\Gamma_{\text{total}}$ | $<$ 2.6 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow e^+ e^-)/\Gamma_{\text{total}}$ | $<$ 7.9 \times 10 $^{-8}$, CL $=$ 90% |
| $\Gamma(D^0 \to \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 1.4 $	imes$ 10 $^{-7}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}$ | $<$ 4.5 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \to \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 1.8 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \eta e^+ e^-)/\Gamma_{\text{total}}$ | $< 1.1 	imes 10^{-4}$, CL $= 90\%$ |
| $\Gamma(D^0 \to \eta \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 5.3 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \pi^+\pi^-e^+e^-)/\Gamma_{\text{total}}$ | $<$ 3.73 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \to \rho^0 e^+ e^-)/\Gamma_{\text{total}}$ | $<$ 1.0 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \pi^+\pi^-\mu^+\mu^-)/\Gamma_{\text{total}}$ | $<$ 3.0 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \to \rho^0 \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 2.2 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \omega e^+ e^-)/\Gamma_{\text{total}}$ | $<$ 1.8 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \to \omega \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 8.3 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow K^-K^+e^+e^-)/\Gamma_{\text{total}}$ | $<$ 3.15 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow \phi e^+ e^-)/\Gamma_{\text{total}}$ | $<$ 5.2 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow K^-K^+\mu^+\mu^-)/\Gamma_{\text{total}}$ | $<$ 3.3 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \to \phi \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<$ 3.1 $	imes$ 10 $^{-5}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow K^-\pi^+e^+e^-)/\Gamma_{\text{total}}$ | $<$ 3.85 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D^0 \rightarrow K^-\pi^+\mu^+\mu^-)/\Gamma_{\text{total}}$ | $< 3.59 \times 10^{-4}$, CL = 90% |
| $\Gamma(D^0 \rightarrow \pi^+\pi^-\pi^0\mu^+\mu^-)/\Gamma_{\text{total}}$ | $<$ 8.1 $	imes$ 10 $^{-4}$, CL $=$ 90% |
| $\Gamma(D_s^+ \to K^+ e^+ e^-)/\Gamma_{\text{total}}$ | $< 3.7 \times 10^{-6}$, CL = 90% |
| $\Gamma(D_s^+ \to K^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $<\!2.1\times10^{-5}\text{, CL}=90\%$ |
| $\Gamma(D_s^+ \to K^*(892)^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ | $< \! 1.4 \times 10^{-3} \text{, CL} = 90\%$ |

$$\begin{array}{lll} \Gamma(\Lambda_c^+ \to p \, e^+ \, e^-) / \Gamma_{\rm total} & <5.5 \times 10^{-6}, \, {\rm CL} = 90\% \\ \Gamma(\Lambda_c^+ \to p \, \mu^+ \, \mu^-) / \Gamma_{\rm total} & <4.4 \times 10^{-5}, \, {\rm CL} = 90\% \\ \end{array}$$

$\Delta B = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

```
\Gamma(B^+ \rightarrow \pi^+ \ell^+ \ell^-)/\Gamma_{\text{total}}
                                                                                                   <4.9 \times 10^{-8}, CL = 90%
\Gamma(B^+ \rightarrow \pi^+ e^+ e^-)/\Gamma_{\text{total}}
                                                                                                   {<}8.0\times10^{-8}\text{, CL}\,=\,90\%
\Gamma(B^+ \to \pi^+ \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                   <6.9 \times 10^{-8}, CL = 90%
                                                                                                   <1.0 \times 10^{-4}, CL = 90%
\Gamma(B^+ \rightarrow \pi^+ \nu \overline{\nu})/\Gamma_{\text{total}}
\Gamma(B^+ \to K^+ \ell^+ \ell^-)/\Gamma_{\text{total}}
                                                                                          [y] (5.1 \pm 0.5) \times 10^{-7}
                                                                                                   (5.5\,\pm\,0.7)\times10^{-7}
\Gamma(B^+ \rightarrow K^+ e^+ e^-)/\Gamma_{total}
\Gamma(B^+ 	o K^+ \mu^+ \mu^-)/\Gamma_{	ext{total}}
                                                                                                   (4.8 \pm 0.4) \times 10^{-7}
                                                                                                    {<}1.3\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(B^+ \rightarrow K^+ \overline{\nu} \nu) / \Gamma_{\text{total}}
\Gamma(B^+ \to \rho^+ \nu \overline{\nu}) / \Gamma_{\text{total}}
                                                                                                   {<}1.5\times10^{-4}\text{, CL}\,=\,90\,\%
\Gamma(B^+ \rightarrow K^*(892)^+ \ell^+ \ell^-)/\Gamma_{\text{total}}
                                                                                          [y] (1.29 \pm 0.21) \times 10^{-6}
                                                                                                   (1.55 \, {}^{+\, 0.40}_{-\, 0.31}) \times 10^{-6}
\Gamma(B^+ \rightarrow K^*(892)^+ e^+ e^-)/\Gamma_{total}
\Gamma(B^+ \rightarrow K^*(892)^+ \mu^+ \mu^-)/\Gamma_{total}
                                                                                                   (1.07\pm0.22)\times10^{-6}
\Gamma(B^+ \to K^*(892)^+ \nu \overline{\nu})/\Gamma_{\text{total}}
                                                                                                   {<}8\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(B^0 \to \gamma \gamma)/\Gamma_{	ext{total}}
                                                                                                   <3.2 \times 10^{-7}, CL = 90%
\Gamma(B^0 \rightarrow e^+ e^-)/\Gamma_{total}
                                                                                                   < 8.3 \times 10^{-8}, CL = 90%
\Gamma(B^0 \rightarrow e^+ e^- \gamma)/\Gamma_{\text{total}}
                                                                                                   < \! 1.2 \times 10^{-7} \text{, CL} = 90\%
\Gamma(B^0 
ightarrow \ \mu^+ \, \mu^-)/\Gamma_{	ext{total}}
                                                                                                   <1.4 \times 10^{-9}, CL = 90%
                                                                                                   {<}1.6\times10^{-7}\text{, CL}\,=\,90\%
\Gamma(B^0 \to \mu^+ \mu^- \gamma)/\Gamma_{\text{total}}
\Gamma(B^0 \to \tau^+ \tau^-)/\Gamma_{total}
                                                                                                   <\!\!4.1\times10^{-3}\text{, CL}\,=\,90\%
\Gamma(B^0 \rightarrow \pi^0 \ell^+ \ell^-)/\Gamma_{\text{total}}
                                                                                                   {<}1.2\times10^{-7}\text{, CL}\,=\,90\%
\Gamma(B^0 \rightarrow \pi^0 e^+ e^-)/\Gamma_{\text{total}}
                                                                                                   < \! 1.4 \times 10^{-7} \text{, CL} = 90\%
\Gamma(B^0 \rightarrow \pi^0 \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                   <1.8 \times 10^{-7}, CL = 90%
\Gamma(B^0 \to \pi^0 \nu \overline{\nu})/\Gamma_{total}
                                                                                                   < 2.2 \times 10^{-4}, CL = 90%
\Gamma(B^0 \to K^0 \ell^+ \ell^-)/\Gamma_{total}
                                                                                          [y] (3.1^{+0.8}_{-0.7}) \times 10^{-7}
(1.6^{+1.0}_{-0.8}) \times 10^{-7}
\Gamma(B^0 \rightarrow \kappa^0 e^+ e^-)/\Gamma_{total}
\Gamma(B^0 \to \kappa^0 \mu^+ \mu^-)/\Gamma_{total}
                                                                                                   (3.8 \pm 0.8) \times 10^{-7}
\Gamma(B^0 \to K^0 \nu \overline{\nu})/\Gamma_{\text{total}}
                                                                                                    <5.6 \times 10^{-5}, CL = 90%
                                                                                         <4.4 \times 10^{-4}, CL = 90%

<4.4 \times 10^{-4}, CL = 90%

[y] (9.9^{+1.2}_{-1.1}) \times 10^{-7}

(1.03^{+0.19}_{-0.17}) \times 10^{-6}
\Gamma(B^0 \to \rho^0 \nu \overline{\nu})/\Gamma_{total}
\Gamma(B^0 \rightarrow K^*(892)^0 \ell^+ \ell^-)/\Gamma_{total}
\Gamma(B^0 \rightarrow K^*(892)^0 e^+ e^-)/\Gamma_{total}
\Gamma(B^0 \to K^*(892)^0 \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                   (1.06 \pm 0.10) \times 10^{-6}
\Gamma(B^0 \to K^*(892)^0 \nu \overline{\nu})/\Gamma_{total}
                                                                                                   <1.2 \times 10^{-4}, CL = 90%
\Gamma(B^0 \to \phi \nu \overline{\nu})/\Gamma_{\text{total}}
                                                                                                   {<}5.8\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(\textit{B}^{\,0}\,\rightarrow\,\,\text{invisible})/\Gamma_{tot\,al}
                                                                                                   <\!2.2\times10^{-4}\text{, CL}\,=\,90\,\%
\Gamma(B^0 \to \nu \overline{\nu} \gamma)/\Gamma_{total}
                                                                                                   <4.7 \times 10^{-5}, CL = 90%
                                                                                                   (4.7\,\pm 1.3)\times 10^{-6}
\Gamma(B \rightarrow se^+e^-)/\Gamma_{total}
\Gamma(B \to s \mu^+ \mu^-)/\Gamma_{\sf total}
                                                                                                   (4.3 \pm 1.2) \times 10^{-6}
\Gamma(B \rightarrow s \ell^+ \ell^-)/\Gamma_{total}
                                                                                           [y] (4.5 \pm 1.0) \times 10^{-6}
\Gamma(B \to \pi \ell^+ \ell^-)/\Gamma_{\text{total}}
                                                                                                   {<}6.2\times10^{-8}\text{, CL}\,=\,90\,\%
\Gamma(B \to K e^+ e^-)/\Gamma_{\text{total}}
                                                                                                   (4.4\,\pm\,0.6)\times10^{-7}
\Gamma(B \rightarrow K^*(892) e^+ e^-)/\Gamma_{total}
                                                                                                   (1.19 \pm 0.20) \times 10^{-6} \text{ (S} = 1.2)
\Gamma(B \to K \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                   (4.4\,\pm\,0.4)\times10^{-7}
\Gamma(B \rightarrow K^*(892) \, \mu^+ \, \mu^-)/\Gamma_{\text{total}}
                                                                                                   (1.06\pm0.09)\times10^{-6}
\Gamma(B \to K \ell^+ \ell^-)/\Gamma_{total}
                                                                                                   (4.5 \pm 0.4) \times 10^{-7}
                                                                                                   (1.08\pm0.11)\times10^{-6}
\Gamma(B \rightarrow K^*(892) \ell^+ \ell^-)/\Gamma_{\text{total}}
\Gamma(B \to K \nu \overline{\nu}) / \Gamma_{\text{total}}
                                                                                                   <\!\!1.4\times10^{-5} , CL =90\,\%
                                                                                                   <\!8\times10^{-5}\text{, CL}\,=\,90\,\%
\Gamma(B \rightarrow K^* \nu \overline{\nu}) / \Gamma_{\text{total}}
\Gamma(\overline{b} \rightarrow e^+e^- \text{ anything})/\Gamma_{	ext{total}}
\Gamma(\overline{b} \to \mu^+ \mu^- \, {\rm anything}) / \Gamma_{
m total}
                                                                                                   <3.2 \times 10^{-4}, CL = 90\%
\Gamma(\overline{b} 
ightarrow \, 
u \overline{
u} \, {
m anything}) / \Gamma_{
m total}
\Gamma(B_{\,c}^{\,0}\, 
ightarrow\, \gamma\gamma)/\Gamma_{	ext{total}}
                                                                                                   < 8.7 \times 10^{-6}, CL = 90%
\Gamma(B_{c}^{\bar{0}} \rightarrow \mu^{+}\mu^{-})/\Gamma_{total}
                                                                                                   <\!6.4\times10^{-9}\text{, CL}\,=\,90\,\%
\Gamma(B_s^{0} \rightarrow e^+e^-)/\Gamma_{total}
                                                                                                    < 2.8 \times 10^{-7}, CL = 90%
                                                                                                   (1.23^{+0.40}_{-0.34}) \times 10^{-6}
\Gamma(B_s^0 \rightarrow \phi(1020) \, \mu^+ \, \mu^-) / \Gamma_{total}
                                                                                                   <5.4 \times 10^{-3}, CL = 90%
\Gamma(B_s^0 \to \phi \nu \overline{\nu})/\Gamma_{\text{total}}
```

$\Delta T = 1$ WEAK NEUTRAL CURRENT FORBIDDEN

Allowed by higher-order electroweak interactions.

$$\Gamma(t \rightarrow Z q(q=u,c))/\Gamma_{\text{total}}$$
 [z] $<3.2 \times 10^{-2}$, CL = 95%

NOTES

In this Summary Table:

When a quantity has "(S = ...)" to its right, the error on the quantity has been enlarged by the "scale factor" S, defined as S = $\sqrt{\chi^2/(N-1)}$, where N is the number of measurements used in calculating the quantity. We do this when S > 1, which often indicates that the measurements are inconsistent. When S > 1.25, we also show in the Particle Listings an ideogram of the measurements. For more about S, see the Introduction.

- $[a]\ C$ parity forbids this to occur as a single-photon process.
- [b] See the Particle Listings for the (complicated) definition of this quantity.
- [c] Time-reversal invariance requires this to be 0° or 180° .
- [d] This coefficient is zero if time invariance is not violated.
- [e] Allowed by higher-order electroweak interactions.
- [f] Violates CP in leading order. Test of direct CP violation since the indirect CP-violating and CP-conserving contributions are expected to be suppressed.
- [g] In the 2010 Review, the values for these quantities were given using a measure of the asymmetry that was inconsistent with the usual definition.
- $[\hbar]$ Re $(\epsilon'/\epsilon)=\epsilon'/\epsilon$ to a very good approximation provided the phases satisfy *CPT* invariance.
- [i] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K_I^0 \to \pi^+\pi^-\gamma({\sf DE})$.
- [j] Neglecting photon channels. See, e.g., A. Pais and S.B. Treiman, Phys. Rev. **D12**, 2744 (1975).
- [k] Derived from measured values of ϕ_{+-} , ϕ_{00} , $|\eta|$, $|m_{K^0_L}-m_{K^0_S}|$, and $\tau_{K^0_S}$, as described in the introduction to "Tests of Conservation Laws."
- [I] The $|m_P-m_{\overline{P}}|/m_P$ and $|q_P+q_{\overline{P}}|/e$ are not independent, and both use the more precise measurement of $|q_{\overline{P}}/m_{\overline{P}}|/(q_P/m_P)$.
- [m] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [n] A test of additive vs. multiplicative lepton family number conservation.
- [o] The limit quoted corresponds to the projection onto the $\sin^2(2\theta_{23})$ axis of the 90% CL contour in the $\sin^2(2\theta_{23}) \Delta m_{32}^2$ plane.
- [p] The sign of Δm^2_{32} is not known at this time. The range quoted is for the absolute value.
- [q] Derived from an analysis of neutrino-oscillation experiments.
- [r] This limit is for either D^0 or $\overline{D}{}^0$ to $p\,e^-$.
- [s] This limit is for either D^0 or $\overline{D}{}^0$ to $\overline{p}\,e^+$.
- [t] The first limit is for $p\to$ anything or "disappearance" modes of a bound proton. The second entry, a rough range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray \overline{p} 's is $\tau_{\overline{p}} > 10^7$ yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives $\tau_{\overline{p}}/B(\overline{p}\to e^-\gamma) > 7\times 10^5$ yr.
- [u] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The first limit here is from reactor experiments with free neutrons.
- [ν] This is the best limit for the mode e $^- \to \nu \gamma$. The best limit for "electron disappearance" is 6.4 \times 10²⁴ yr.
- [w] See the K_S^0 Particle Listings for the energy limits used in this measurement
- [x] See the \mathcal{K}^0_L Particle Listings for the energy limits used in this measurement.
- [y] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [z] This limit is for $\Gamma(t \to Zq)/\Gamma(t \to Wb)$.

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1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 2011 by P.J. Mohr (NIST). Mainly from the "CODATA Recommended Values of the Fundamental Physical Constants: 2010" by P.J. Mohr, B.N. Taylor, and D.B. Newell in arXiv:1203.5425 and Rev. Mod. Phys. (to be published). The last group of constants (beginning with the Fermi coupling constant) comes from the Particle Data Group. The figures in parentheses after the values give the 1-standard-deviation uncertainties in the last digits; the corresponding fractional uncertainties in parts per 109 (ppb) are given in the last column. This set of constants (aside from the last group) is recommended for international use by CODATA (the Committee on Data for Science and Technology). The full 2010 CODATA set of constants may be found at http://physics.nist.gov/constants. See also P.J. Mohr and D.B. Newell, "Resource Letter FC-1: The Physics of Fundamental Constants," Am. J. Phys, 78 (2010) 338.

| Quantity | Symbol, equation | Value | Uncertain | nty (ppb) |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| speed of light in vacuum Planck constant Planck constant, reduced | $\begin{array}{l} c \\ h \\ \hbar \equiv h/2\pi \end{array}$ | $299 792 458 \text{ m s}^{-1}$ $6.626 069 57(29) \times 10^{-34}$ $1.054 571 726(47) \times 10^{-3}$ | ⁴ J s | exact* 44 44 |
| electron charge magnitude conversion constant conversion constant | $e \over \hbar c (\hbar c)^2$ | $= 6.582 \ 119 \ 28(15) \times 10$ $1.602 \ 176 \ 565(35) \times 10^{-19}$ $197.326 \ 9718(44) \ \text{MeV ft}$ $0.389 \ 379 \ 338(17) \ \text{GeV}^2$ | $^{9} \text{ C} = 4.803\ 204\ 50(11) \times 10^{-10} \text{ est}$ m | 22 1 22, 22 22 44 |
| electron mass proton mass deuteron mass | $m_e \ m_p \ m_d$ | $938.272046(21)\mathrm{MeV}/c^2$ | | 22, 44 22, 44 0.089, 0.41 22 |
| unified atomic mass unit (u) permittivity of free space | (mass 12 C atom)/12 = (1 g)/(N_A mol) $\epsilon_0 = 1/\mu_0 c^2$ | 931.494 061(21) MeV/ c^2 8 854 187 817 ×10 ⁻¹ | $= 1.660 538 921(73) \times 10^{-27} \text{ kg}$ | 22, 44 exact |
| permeability of free space | μ_0 $\alpha = e^2 / 4\pi \epsilon_0 \hbar c$ | | $\frac{3}{3} = 1/137.035999074(44)^{\dagger}$ | exact |
| fine-structure constant classical electron radius $(e^-$ Compton wavelength)/ 2π Bohr radius $(m_{\rm nucleus} = \infty)$ wavelength of 1 eV/ c particle Rydberg energy Thomson cross section | $\alpha = e^{-4\pi\epsilon_{0}nc}$ $r_{e} = e^{2}/4\pi\epsilon_{0}m_{e}c^{2}$ $\lambda_{e} = \hbar/m_{e}c = r_{e}\alpha^{-1}$ $a_{\infty} = 4\pi\epsilon_{0}\hbar^{2}/m_{e}e^{2} = r_{e}\alpha^{-2}$ $hc/(1 \text{ eV})$ $hcR_{\infty} = m_{e}e^{4}/2(4\pi\epsilon_{0})^{2}\hbar^{2} = m_{e}c^{2}\alpha^{2}/2$ $\sigma_{T} = 8\pi r_{e}^{2}/3$ | $7.297\ 352\ 5698(24) \times 10$ $2.817\ 940\ 3267(27) \times 10^{-}$ $3.861\ 592\ 6800(25) \times 10^{-}$ $0.529\ 177\ 210\ 92(17) \times 10$ $1.239\ 841\ 930(27) \times 10^{-6}$ $13.605\ 692\ 53(30)\ eV$ $0.665\ 245\ 8734(13)\ barn$ | ¹⁵ m ¹³ m – ¹⁰ m | 0.32, 0.32 0.97 0.65 0.32 22 22 1.9 |
| Bohr magneton nuclear magneton electron cyclotron freq./field proton cyclotron freq./field | $\mu_B = e\hbar/2m_e$ $\mu_N = e\hbar/2m_p$ $\omega_{\text{cycl}}^e/B = e/m_e$ $\omega_{\text{cycl}}^p/B = e/m_p$ | $5.788 \ 381 \ 8066(38) \times 10^{-}$ $3.152 \ 451 \ 2605(22) \times 10^{-}$ $1.758 \ 820 \ 088(39) \times 10^{11}$ $9.578 \ 833 \ 58(21) \times 10^{7} \ ra$ | $^{14} \ \mathrm{MeV} \ \mathrm{T}^{-1}$ rad $\mathrm{s}^{-1} \ \mathrm{T}^{-1}$ | 0.65 0.71 22 22 |
| gravitational constant [‡] | G_N | $6.673 \ 84(80) \times 10^{-11} \ \text{m}^3$ = $6.708 \ 37(80) \times 10^{-39}$ | $kg^{-1} s^{-2}$ | 1.2×10^5 1.2×10^5 |
| standard gravitational accel. | g_N | $9.806~65~{\rm m~s^{-2}}$ | (60,70) | exact |
| Avogadro constant Boltzmann constant molar volume, ideal gas at STP Wien displacement law constant Stefan-Boltzmann constant | N_A k $N_A k (273.15 \text{ K})/(101 \ 325 \text{ Pa})$ $b = \lambda_{\text{max}} T$ $\sigma = \pi^2 k^4/60 \hbar^3 c^2$ | $\begin{array}{l} 6.022\ 141\ 29(27)\times 10^{23}\ \mathrm{n} \\ 1.380\ 6488(13)\times 10^{-23}\ \mathrm{J} \\ = 8.617\ 3324(78)\times 10^{-5} \\ 22.413\ 968(20)\times 10^{-3}\ \mathrm{m}^2 \\ 2.897\ 7721(26)\times 10^{-3}\ \mathrm{m} \\ 5.670\ 373(21)\times 10^{-8}\ \mathrm{W}\ \mathrm{n} \end{array}$ | K ⁻¹ 5 eV K ⁻¹ 3 mol ⁻¹ K | 44 910 910 910 910 3600 |
| Fermi coupling constant** | $G_F/(\hbar c)^3$ | $1.166\ 378\ 7(6) \times 10^{-5}\ \mathrm{Ge}$ | V^{-2} | 500 |
| weak-mixing angle W^{\pm} boson mass Z^0 boson mass strong coupling constant | $\sin^2 \widehat{	heta}(M_Z) \ (\overline{	ext{MS}})$ m_W m_Z $\alpha_s(m_Z)$ | $\begin{array}{c} 0.231\ 16(12)^{\dagger\dagger} \\ 80.385(15)\ \mathrm{GeV}/c^2 \\ 91.1876(21)\ \mathrm{GeV}/c^2 \\ 0.1184(7) \end{array}$ | | 5.2×10^{5} 1.9×10^{5} 2.3×10^{4} 5.9×10^{6} |
| $\pi = 3.141\ 592\ 653\ 5$ | | | $\gamma = 0.577 \ 215 \ 664 \ 901 \ 532 \ 861$ | |
| 1 in $\equiv 0.0254 \text{ m}$ 1 G $\equiv 10$ 1 Å $\equiv 0.1 \text{ nm}$ 1 dyne $\equiv 10$ 1 barn $\equiv 10^{-28} \text{ m}^2$ 1 erg $\equiv 10$ | | 76 $565(35) \times 10^{-19} \text{ J}$ 61 $845(39) \times 10^{-36} \text{ kg}$ 1 atmos | kT at 300 K = [38.681 731(5 0 °C \equiv 273.15 K sphere \equiv 760 Torr \equiv 101 325 Pa | 35)] ⁻¹ eV |

^{*} The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second. † At $Q^2 \approx m_W^2$ the value is $\sim 1/128$.

 $^{^\}ddagger$ Absolute lab measurements of G_N have been made only on scales of about 1 cm to 1 m.

^{**} See the discussion in Sec. 10, "Electroweak model and constraints on new physics."

^{††} The corresponding $\sin^2\theta$ for the effective angle is 0.23146(12).

2. ASTROPHYSICAL CONSTANTS AND PARAMETERS

Table 2.1. Revised February 2012 by E. Bergren and D.E. Groom (LBNL). The figures in parentheses after some values give the 1- σ uncertainties in the last digit(s). Physical constants are from Ref. 1. While every effort has been made to obtain the most accurate current values of the listed quantities, the table does not represent a critical review or adjustment of the constants, and is not intended as a primary reference. The values and uncertainties for the cosmological parameters depend on the exact data sets, priors, and basis parameters used in the fit.

The values and uncertainties for the cosmological parameters depend on the exact data sets, priors, and basis parameters used in the fit. Many of the derived parameters reported in this table have non-Gaussian likelihoods. Parameters may be highly correlated, so care must be taken in propagating errors. Unless otherwise specified, cosmological parameters are from six-parameter fits to a flat Λ CDM cosmology using 7-year WMAP data alone [2]. For more information see Ref. 3 and the original papers.

| Quantity Syr | nbol, equation | Value Ref | erence, footnote |
|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| speed of light | c | $299792458~{ m m~s^{-1}}$ | exact[4] |
| Newtonian gravitational constant | G_N | $6.6738(8) \times 10^{-11} \mathrm{m^3kg^{-1}s^{-2}}$ | [1] |
| Planck mass | $\sqrt{\hbar c/G_N}$ | $1.22093(7) \times 10^{19} \mathrm{GeV}/c^2$ | [1] |
| | | $=2.17651(13)\times10^{-8}$ kg | |
| Planck length | $\sqrt{\hbar G_N/c^3}$ | $1.61620(10) \times 10^{-35} \text{ m}$ | [1] |
| standard gravitational acceleration | g_N | $9.80665 \text{ m s}^{-2} \approx \pi^2$ | exact[1] |
| jansky (flux density) | Jy | $10^{-26} \text{ W m}^{-2} \text{ Hz}^{-1}$ | definition |
| tropical year (equinox to equinox) (2011) | yr | $31556925.2~{\rm s} \approx \pi \times 10^7~{\rm s}$ | [5] |
| sidereal year (fixed star to fixed star) (2011) | v | $31558149.8 \text{ s} \approx \pi \times 10^7 \text{ s}$ | [5] |
| mean sidereal day (2011) (time between vernal equir | ox transits) | $23^{\rm h}56^{\rm m}04^{\rm s}09053$ | [5] |
| astronomical unit | au, A | 149 597 870 700(3) m | [6] |
| parsec (1 $au/1$ arc sec) | рс | $3.0856776 \times 10^{16} \text{ m} = 3.262 \dots \text{ly}$ | [7] |
| light year (deprecated unit) | lv | 0.3066 pc = 0.946053×10^{16} m | [.] |
| Schwarzschild radius of the Sun | $2G_N M_{\odot}/c^2$ | 2.9532500770(2) km | [8] |
| Solar mass | M_{\odot} | $1.9885(2) \times 10^{30} \text{ kg}$ | [9] |
| Solar equatorial radius | R_{\odot} | $6.9551(4) \times 10^8 \text{ m}$ | [10] |
| Solar luminosity | L_{\odot}^{\odot} | $3.828 \times 10^{26} \text{ W}$ | [11] |
| Schwarzschild radius of the Earth | $2G_N M_{\oplus}/c^2$ | $8.87005594(2) \mathrm{mm}$ | [12] |
| Earth mass | M_{\oplus} | $5.9726(7) \times 10^{24} \text{ kg}$ | [13] |
| Earth mean equatorial radius | R_{\oplus}° | $6.378137\times10^6~{ m m}$ | [5] |
| luminosity conversion (deprecated) | L | $3.02 \times 10^{28} \times 10^{-0.4} M_{\text{bol}} W$ | [14] |
| rammostey conversion (deprecated) | L | $(M_{\rm bol} = {\rm absolute\ bolometric\ magnitude} = {\rm bolometric\ }$ | |
| flux conversion (deprecated) | F | $2.52 \times 10^{-8} \times 10^{-0.4} \mathrm{m_{bol} \ W \ m^{-2}}$ | from above |
| (, | - | $(m_{\text{bol}} = \text{apparent bolometric magnitude})$ | |
| ABsolute monochromatic magnitude | AB | $-2.5 \log_{10} f_{\nu} - 56.10 \text{ (for } f_{\nu} \text{ in W m}^{-2} \text{Hz}^{-1})$ | [15] |
| O Company | | $= -2.5 \log_{10} f_{\nu} + 8.90 \text{ (for } f_{\nu} \text{ in Jy)}$ | . 1 |
| Solar circular velocity v_0 at R_0 from Galactic center | v_{\circ}/R_{0} | $30.2 \pm 0.2 \text{ km s}^{-1} \text{ kpc}^{-1}$ | [16] |
| Solar distance from Galactic center | R_0 | 8.4(4) kpc | [17] |
| circular velocity at R_0 | v_0 or Θ_0 | $240(10) \text{ km s}^{-1}$ | [18] |
| local disk density | $\rho_{ m disk}$ | $3-12 \times 10^{-24} \text{ g cm}^{-3} \approx 2-7 \text{ GeV}/c^2 \text{ cm}^{-3}$ | [19] |
| local dark matter density | ρ_{χ} | canonical value $0.3 \text{ GeV}/c^2 \text{ cm}^{-3}$ within factor 23 | [20] |
| escape velocity from Galaxy | $v_{\rm esc}$ | $498 \text{ km/s} < v_{\text{esc}} < 608 \text{ km/s}$ | [21] |
| present day CMB temperature | T_0 | 2.7255(6) K | [22] |
| present day CMB dipole amplitude | 10 | 3.355(8) mK | [2] |
| Solar velocity with respect to CMB | | $369(1)$ km/s towards $(\ell, b) = (263.99(14)^{\circ}, 48.26($ | |
| Local Group velocity with respect to CMB | $v_{ m LG}$ | 627(22) km/s towards $(\ell, b) = (276(3)^{\circ}, 30(3)^{\circ})$ | [23] |
| entropy density/Boltzmann constant | s/k | $2889.2 (T/2.725)^3 \text{ cm}^{-3}$ | [14] |
| number density of CMB photons | n_{γ} | $410.5(T/2.725)^3 \text{ cm}^{-3}$ | [24] |
| baryon-to-photon ratio | $\eta = n_{\mathrm{b}}/n_{\gamma}$ | $6.19(15) \times 10^{-10}$ | [2] |
| , | V | $5.1 \times 10^{-10} \le \eta \le 6.5 \times 10^{-10} \text{ (95\% CL)}$ | [25] |
| number density of baryons | $n_{ m b}$ | $(2.54 \pm 0.06) \times 10^{-7} \text{ cm}^{-3}$ | from η in [2] |
| v | Б | $(2.1 \times 10^{-7} < n_{\rm b} < 2.7 \times 10^{-7}) {\rm cm}^{-3} (95\% {\rm C})$ | (L) from η in [25] |
| present day Hubble expansion rate | H_0 | $100 h \text{ km s}^{-1} \text{ Mpc}^{-1} = h \times (9.777752 \text{ Gyr})^{-1}$ | [26] |
| scale factor for Hubble expansion rate | h | 0.710(25) WMAP7; WMAP7⊕Cepheids=0.721(1 | |
| Hubble length | c/H_0 | $0.925063 \times 10^{26} h^{-1} \mathrm{m} = 1.28(5) \times 10^{26} \mathrm{m}$ | , , , , |
| scale factor for cosmological constant | $c^2/3H_0^2$ | $2.852 \times 10^{51} h^{-2} \mathrm{m}^2 = 5.5(5) \times 10^{51} \mathrm{m}^2$ | |
| critical density of the Universe | $\rho_{\rm c} = 3H_0^2/8\pi G$ | $_{N}$ 2.775 366 27 × 10 ¹¹ h^{2} $M_{\odot} \text{Mpc}^{-3}$ | |
| | 0, | $= 1.87847(23) \times 10^{-29} h^2 \text{ g cm}^{-3}$ | |
| | | = $1.05375(13) \times 10^{-5} h^2 (\text{GeV}/c^2) \text{ cm}^{-3}$ $^{\ddagger} 0.0226(6) h^{-2} = ^{\dagger} 0.045(3)$ | |
| baryon density of the Universe | $\Omega_{\rm b} = \rho_{\rm b}/\rho_{\rm c}$ | | [2,3] |
| cold dark matter density of the universe | $\Omega_{\rm cdm} = \rho_{\rm cdm}/\rho$ | ρ_c $^{\ddagger} 0.111(6) h^{-2} = ^{\dagger} 0.22(3)$ | [2,3] |
| dark energy density of the $\Lambda \mathrm{CDM}$ Universe | Ω_{Λ} | $^{\ddagger} 0.73(3)$ | [2,3] |
| pressureless matter density of the Universe | $\Omega_{\mathrm{m}} = \Omega_{\mathrm{cdm}} + \Omega_{\mathrm{cdm}}$ | $\Omega_{\rm b}$ 0.27 \pm 0.03 (From Ω_{Λ} and flatness constraint) | [2,3] |
| dark energy equation of state parameter | w | $^{\sharp} -0.98 \pm 0.05 \text{ (WMAP7+BAO+}H_0)$ | [28] |
| CMB radiation density of the Universe | $\Omega_{\gamma} = \rho_{\gamma}/\rho_{\rm c}$ | $2.471 \times 10^{-5} (T/2.725)^4 h^{-2} = 4.75(23) \times 10^{-1}$ | |
| | 0 | 0.0007 < 0.12 < 0.007 > 0.0000 < 0.000 | [0.0] |
| neutrino density of the Universe total energy density of the Universe (curvature) | $\Omega_{ u}$ | $0.0005 < \Omega_{\nu}h^2 < 0.025 \Rightarrow 0.0009 < \Omega_{\nu} < 0.04$. + Ω_{Λ} \$ 1.002 \pm 0.011 (WMAP7+BAO+ H_0) | .8 [29] [2,3] |

| Quantity | Symbol, equation | Value | Reference, footnote |
|--------------------------------------------------------------|--------------------------|-----------------------------------------------|---------------------|
| fluctuation amplitude at $8 h^{-1}$ Mpc scale | σ_8 | † 0.80(3) | [2,3] |
| curvature fluct. amplitude at $k_0 = 0.002 \text{ Mpc}^{-1}$ | $\Delta^2_{\mathcal{R}}$ | $^{\ddagger} 2.43(11) \times 10^{-9}$ | [2,3] |
| scalar spectral index | n_s | [‡] 0.963(14) | [2,3] |
| running spectral index slope, $k_0 = 0.002 \text{ Mpc}^{-1}$ | $dn_{\rm s}/d\ln k$ | $^{\sharp}-0.03(3)^{'}$ | [2] |
| tensor-to-scalar field perturbations ratio, | , | | • • |
| $k_0 = 0.002 \text{ Mpc}^{-1}$ | r = T/S | $^{\sharp}$ < 0.36 at 95% CL | [2,3] |
| redshift at decoupling | $z_{ m dec}$ | † 1091(1) | [2] |
| age at decoupling | t_* | $^{\dagger} 3.79(5) \times 10^{5} \text{ yr}$ | [2] |
| sound horizon at decoupling | $r_s(z_*)$ | [†] 147(2) Mpc | [2] |
| redshift of matter-radiation equality | $z_{ m eq}$ | $^{\dagger} 3200 \pm 130$ | [2] |
| redshift of reionization | $z_{ m reion}$ | † 10.5 ± 1.2 | [2] |
| age at reionization | $t_{ m reion}$ | $430^{+90}_{-70} \text{ Myr}$ | [2,30] |
| reionization optical depth | au | [‡] 0.088(15) | [2,3] |
| age of the Universe | t_0 | † 13.75 \pm 0.13 Gyr | [2] |

 $^{^{\}ddagger}$ Parameter in six-parameter $\Lambda {\rm CDM}$ fit [2]

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- While A is approximately equal to the semi-major axis of the Earth's orbit, it is not exactly so. Nor is it exactly the mean Earth-Sun distance. There are a number of reasons: a) the Earth's orbit is not exactly Keplerian due to relativity and to perturbations from other planets; b) the adopted value for the Gaussian gravitational constant k is not exactly equal to the Earth's mean motion; and c) the mean distance in a Keplerian orbit is not equal to the semi-major axis a: $\langle r \rangle = a(1 + e^2/2)$, where e is the eccentricity. (Discussion courtesy of Myles Standish, JPL).
- The distance at which 1 A subtends 1 arc sec: 1 A divided by $\pi/648\,000$.
- Product of $2/c^2$ and the heliocentric gravitational constant $G_N M_{\odot} = A^3 k^2 / 86400^2$, where k is the Gaussian gravitational constant, 0.01720209895 (exact) [5]. The value and error for A given in this table are used.
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- $4\pi A^2 \times (1361 \text{ W m}^{-2})$ [31]. Assumes isotropic irradiance. 11.
- Schwarzschild radius of the Sun (above) scaled by the Earth/Sun mass ratio given in Ref. 5.
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- If the Universe were reionized instantaneously at z_{reion} .
- 31. G. Kopp & J.L. Lean, Geophys. Res. Lett. 38, L01706 (2011). Kopp & Lean give $1360.8 \pm 0.6 \text{W m}^{-2}$, but given the scatter in the data we use the rounded value without quoting an error.

[†] Derived parameter in six-parameter ΛCDM fit [2].

[‡] Extended model parameter [2].

3. INTERNATIONAL SYSTEM OF UNITS (SI)

See "The International System of Units (SI)," NIST Special Publication 330, B.N. Taylor, ed. (USGPO, Washington, DC, 1991); and "Guide for the Use of the International System of Units (SI)," NIST Special Publication 811, 1995 edition, B.N. Taylor (USGPO, Washington, DC, 1995).

| DI I | NT. | |
|----------------------------------------|---------------------|----------------------|
| Physical quantity | Name of unit | Symbol |
| quantity | or unit | Symbol |
| В | ase units | |
| length | meter | m |
| mass | kilogram | kg |
| time | second | s |
| electric current | ampere | A |
| thermodynamic temperature | kelvin | K |
| amount of substance | mole | mol |
| luminous intensity | candela | cd |
| Derived units | s with special name | es . |
| plane angle | radian | rad |
| solid angle | steradian | sr |
| frequency | hertz | $_{ m Hz}$ |
| energy | joule | J |
| force | newton | N |
| pressure | pascal | Pa |
| power | watt | W |
| electric charge | coulomb | $^{\mathrm{C}}$ |
| electric potential | volt | V |
| electric resistance | ohm | Ω |
| electric conductance | siemens | \mathbf{S} |
| electric capacitance | farad | F |
| magnetic flux | weber | Wb |
| inductance | henry | Н |
| magnetic flux density | tesla | ${ m T}$ |
| luminous flux | lumen | lm |
| illuminance | lux | lx |
| celsius temperature | degree celsius | $^{\circ}\mathrm{C}$ |
| activity (of a | becquerel | Bq |
| radioactive source)* absorbed dose (of | gray | Gy |
| ionizing radiation)* dose equivalent* | sievert | Sv |

^{*}See our section 33, on "Radioactivity and radiation protection," p. 381.

| \mathbf{SI} | SI prefixes | | | | | | | |
|---------------|-------------|---------|--|--|--|--|--|--|
| 10^{24} | yotta | (Y) | | | | | | |
| 10^{21} | zetta | (Z) | | | | | | |
| 10^{18} | exa | (E) | | | | | | |
| 10^{15} | peta | (P) | | | | | | |
| 10^{12} | tera | (T) | | | | | | |
| 10^{9} | giga | (G) | | | | | | |
| 10^{6} | mega | (M) | | | | | | |
| 10^{3} | kilo | (k) | | | | | | |
| 10^{2} | hecto | (h) | | | | | | |
| 10 | deca | (da) | | | | | | |
| 10^{-1} | deci | (d) | | | | | | |
| 10^{-2} | centi | (c) | | | | | | |
| 10^{-3} | milli | (m) | | | | | | |
| 10^{-6} | micro | (μ) | | | | | | |
| 10^{-9} | nano | (n) | | | | | | |
| 10^{-12} | pico | (p) | | | | | | |
| 10^{-15} | femto | (f) | | | | | | |
| 10^{-18} | atto | (a) | | | | | | |
| 10^{-21} | zepto | (z) | | | | | | |
| 10^{-24} | yocto | (y) | | | | | | |

Tm 70

Er 69

Ho 68

Table 4.1. Revised 2011 by D.E. Groom (LBNL), and E. Bergren. Atomic weights of stable elements are adapted from the Commission on Isotopic Abundances and Atomic Weights, "Atomic Weights of the Elements 2007," http://www.chem.qmul.ac.uk/iupac/AtWt/. The atomic number (top left) is the number of protons in the nucleus. The atomic mass (bottom) of a stable elements is weighted by isotopic abundances in the Earth's surface. If the element has no stable isotope, the atomic mass (in parentheses) of the most stable isotope currently known is given. In this case the mass is from http://www.nndc.bnl.gov/amdc/masstables/Ame2003/mass.mas03 and the longest-lived isotope is from www.nndc.bnl.gov/ensdf/za_form.jsp. The exceptions are Th, Pa, and U, which do have characteristic terrestrial compositions. Atomic masses are relative to the mass of ¹²C, defined to be exactly 12 unified atomic mass units (u) (approx. g/mole). Relative isotopic abundances often vary considerably, both in natural and commercial samples; this is reflected in the number of significant figures given for the atomic mass. IUPAC does not accept the claims for elements 113, 115, 117, and 118 as conclusive at this time.

| 1 | | | | | | | | | | | | | | | | | 18 |
|-------------|-------------|-----------|-------------|-----------|-----------|------------|-----------|-----------|-----------|------------|-------------|------------|-----------|-----------|-------------|-------------|-------------|
| IA | | | | | | | | | | | | | | | | | VIIIA |
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| Hydrogen | 2 | | | | | | | | | | | 13 | 14 | 15 | 16 | 17 | Helium |
| 1.00794 | IIA | • | | | | | | | | | | IIIA | IVA | VA | VIA | VIIA | 4.002602 |
| 3 Li | 4 Be | | DDD. | TODIC | | | | T T N / T | N TODO | | | 5 B | 6 C | 7 N | 8 0 | 9 F | 10 Ne |
| Lithium | Beryllium | | PER. | IODIC | TABL | LE OF | THEE | LEMIE | INTS | | | Boron | Carbon | Nitrogen | Oxygen | Fluorine | Neon |
| 6.941 | 9.012182 | | | | | | | | | | | 10.811 | 12.0107 | 14.0067 | 15.9994 | 18.9984032 | 20.1797 |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 CI | 18 Ar |
| Sodium | Magnesium | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Aluminum | | Phosph. | Sulfur | Chlorine | Argon |
| 22.98976928 | 24.3050 | IIIB | IVB | VB | VIB | VIIB | | VIII | | IB | IIB | 26.9815386 | 28.0855 | 30.973762 | 32.065 | 35.453 | 39.948 |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| Potassium | Calcium | Scandium | | | | Manganese | | Cobalt | Nickel | Copper | Zinc | Gallium | German. | Arsenic | Selenium | Bromine | Krypton |
| 39.0983 | | 44.955912 | 47.867 | 50.9415 | | 54.938045 | | 58.933195 | | 63.546 | 65.38 | 69.723 | 72.64 | 74.92160 | 78.96 | 79.904 | 83.798 |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | - | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| Rubidium | Strontium | Yttrium | Zirconium | | Molybd. | Technet. | Ruthen. | | Palladium | Silver | Cadmium | Indium | Tin | Antimony | Tellurium | Iodine | Xenon |
| 85.4678 | 87.62 | 88.90585 | | 92.90638 | 95.96 | (97.90722) | 101.07 | 102.90550 | 106.42 | 107.8682 | | 114.818 | 118.710 | 121.760 | 127.60 | 126.90447 | 131.293 |
| 55 Cs | 56 Ba | 57–71 | - | | | | 76 Os | | | | 80 Hg | - | | 83 Bi | - | 85 At | 86 Rn |
| Cesium | Barium | Lantha- | | Tantalum | | Rhenium | Osmium | Iridium | Platinum | Gold | Mercury | Thallium | Lead | Bismuth | | Astatine | Radon |
| 132.9054519 | | nides | | 180.94788 | | 186.207 | 190.23 | 192.217 | | 196.966569 | | 204.3833 | 207.2 | 208.98040 | | (209.98715) | (222.01758) |
| 87 Fr | 88 Ra | 89–103 | | | _ | 107 Bh | 108 Hs | 109 Mt | | 111 Rg | | | 114 FI | | 116 Lv | | |
| Francium | Radium | Actinides | Rutherford. | | _ | Bohrium | Hassium | | | U | Copernicium | | Flerovium | | Livermorium | | |
| (223.01974) | (226.02541) | | (267.122) | (268.125) | (271.133) | (270.134) | (269.134) | (276.151) | (281.162) | (280.164) | (277) | | (289) | | (288) | | |

Sm 63

Pm 62

Pr 60

Lanthanide series

Actinide series

| han. | Cerium | Praseodym. | Neodym. | Prometh. | Samarium | Europium | Gadolin. | Terbium | Dyspros. | Holmium | Erbium | Thulium | Ytterbium | Lutetium |
|-------|-----------|------------|-------------------------------------------|------------------------------------------------|------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| 90547 | 140.116 | 140.90765 | 144.242 | (144.91275) | 150.36 | 151.964 | 157.25 | 158.92535 | 162.500 | 164.93032 | 167.259 | 168.93421 | 173.054 | 174.9668 |
| | | | | | | | | | | | | | | |
| Ac | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr |
| nium | Thorium | Protactin. | Uranium | Neptunium | Plutonium | Americ. | Curium | Berkelium | Californ. | Einstein. | Fermium | Mendelev. | Nobelium | Lawrenc. |
| 2775) | 232.03806 | 231.03588 | 238.02891 | (237.04817) | (244.06420) | (243.06138) | (247.07035) | (247.07031) | (251.07959) | (252.0830) | (257.09510) | (258.09843) | (259.1010) | (262.110) |
| r | Ac | Ac 90 Th | Ac 90 Th 91 Pa nium Thorium Protactin. | Ac 90 Th 91 Pa 92 U Uranium Protactin. Uranium | Ac 90 Th 91 Pa 92 U 93 Np nium Thorium Protactin. Uranium Neptunium | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu hium Thorium Protactin. Uranium Neptunium Plutonium | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 1 Protactin. Uranium Neptunium Plutonium Americ. | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 1 Thorium Protactin. Uranium Neptunium Plutonium Americ. Curium | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk iium Thorium Protactin. Uranium Neptunium Plutonium Americ. Curium Berkelium | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf hium Thorium Protactin. Uranium Neptunium Plutonium Americ. Curium Berkelium Californ. | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es hium Thorium Protactin. Uranium Neptunium Plutonium Americ. Curium Berkelium Californ. Einstein. | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 100 Thorium Protactin. Uranium Plutonium Plutonium Americ. Curium Berkelium Californ. Einstein. Fermium | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md Neptunium Plutonium Americ. Curium Berkelium Californ. Einstein. Fermium Mendelev. | Ac 90 Th 91 Pa 92 U 93 Np 94 Pu 95 Am 96 Cm 97 Bk 98 Cf 99 Es 100 Fm 101 Md 102 No |

Gd 65

Tb 66

Eu 64

5. ELECTRONIC STRUCTURE OF THE ELEMENTS

Table 5.1. Reviewed 2011 by J.E. Sansonetti (NIST). The electronic configurations and the ionization energies are from the NIST database, "Ground Levels and Ionization Energies for the Neutral Atoms," W.C. Martin, A. Musgrove, S. Kotochigova, and J.E. Sansonetti, http://www.nist.gov/pml/data/ion_energy.cfm. The electron configuration for, say, iron indicates an argon electronic core (see argon) plus six 3d electrons and two 4s electrons.

| | Elen | aant | Electron configuration $(3d^5 = \text{five } 3d \text{ electron})$ | | | Ground state ${}^{2S+1}L_J$ | Ionization energy |
|----------|---------------------|----------------------|--------------------------------------------------------------------|--------------|--------------|-------------------------------|----------------------|
| | | | ` | s, etc.) | | | (eV) |
| 1 | Н | Hydrogen | $\frac{1s}{1s^2}$ | | | ${}^{2}S_{1/2}$ | 13.5984 |
| 2 | Не | Helium | | | | $^{1}S_{0}$ | 24.5874 |
| 3 | Li | Lithium | (He) 2s | | | ${}^{2}S_{1/2}$ | 5.3917 |
| 4 | Ве | Beryllium | (He) $2s^2$ | | | ${}^{1}S_{0}^{'}$ | 9.3227 |
| 5 | В | Boron | (He) $2s^2 2p$ | | | ${}^{2}P_{1/2}$ | 8.2980 |
| 6 | C | Carbon | (He) $2s^2 2p^2$ | | | ${}^{3}P_{0}^{'}$ | 11.2603 |
| 7 | N | Nitrogen | (He) $2s^2 2p^3$ (He) $2s^2 2p^4$ | | | ${}^{4}S_{3/2}$ | 14.5341 |
| 8 9 | O F | Oxygen Fluorine | (He) $2s^2 - 2p^5$ (He) $2s^2 - 2p^5$ | | | ${}^{3}P_{2}$ ${}^{2}P_{3/2}$ | $13.6181 \\ 17.4228$ |
| 10 | r Ne | Neon | (He) $2s^2 2p^6$ | | | ${}^{1}S_{0}$ | 21.5645 |
| 11 | Na | Sodium | $\frac{\text{(Ne)}3s}{\text{(Ne)}3s}$ | | | $\frac{^{2}S_{1/2}}{^{2}}$ | 5.1391 |
| 12 | Mg | Magnesium | $(Ne)3s^2$ | | | ${}^{1}S_{0}^{1/2}$ | 7.6462 |
| 13 | Al | Aluminum | (Ne) $3s^2 3p$ | | | ${}^{2}P_{1/2}$ | 5.9858 |
| 14 | Si | Silicon | (Ne) $3s^2 - 3p^2$ | | | ${}^{3}P_{0}^{1/2}$ | 8.1517 |
| 15 | P | Phosphorus | (Ne) $3s^2 3p^3$ | | | ${}^{4}S_{3/2}$ | 10.4867 |
| 16 | S | Sulfur | (Ne) $3s^2 3p^4$ | | | ${}^{3}P_{2}$ | 10.3600 |
| 17 | Cl | Chlorine | (Ne) $3s^2 3p^5$ | | | ${}^{2}P_{3/2}$ | 12.9676 |
| 18 | Ar | Argon | (Ne) $3s^2 3p^6$ | | | $^{1}S_{0}^{^{3/2}}$ | 15.7596 |
| 19 | K | Potassium | (Ar) 4s | | | ${}^{2}S_{1/2}$ | 4.3407 |
| 20 | Ca | Calcium | (Ar) $4s^2$ | | | ${}^{1}S_{0}$ | 6.1132 |
| | | C 1: | | T | | | |
| 21 | Sc | Scandium | (Ar) $3d - 4s^2$ (Ar) $3d^2 - 4s^2$ | r | | $^{2}D_{3/2}$ $^{3}F_{2}$ | 6.5615 |
| 22 23 | Ti V | Titanium Vanadium | $(Ar) 3d^{3} 4s^{2}$ $(Ar) 3d^{3} 4s^{2}$ | a | e | ${}^{4}F_{3/2}$ | 6.8281 6.7462 |
| 23 24 | Cr | Chromium | (Ar) 3d5 4s $(Ar) 3d5 4s$ | n | 1 | ${}^{7}S_{3}^{7/2}$ | 6.7665 |
| 25 | Mn | Manganese | (Ar) $3d^5 4s^2$ | s | e | ${}^{6}S_{5/2}$ | 7.4340 |
| 26 | Fe | Iron | (Ar) $3d^6 4s^2$ | i | m e | $^{5}D_{4}^{5/2}$ | 7.4340 |
| 27 | Со | Cobalt | $(Ar) 3d^7 4s^2$ | t | n | ${}^{4}F_{9/2}$ | 7.8810 |
| 28 | Ni | Nickel | (Ar) $3d^8 4s^2$ | i | t | ${}^{3}F_{4}$ | 7.6399 |
| 29 | Cu | Copper | (Ar) $3d^{10}4s$ | 0 | S | ${}^{2}S_{1/2}$ | 7.7264 |
| 30 | Zn | Zinc | (Ar) $3d^{10}4s^2$ | n | | ${}^{1}S_{0}$ | 9.3942 |
| 31 | Ga | Gallium | (Ar) $3d^{10}4s^2 4p$ | | | | 5.9993 |
| 32 | Ge | Germanium | (Ar) $3d^{10}4s^2 4p^2$ | | | ${}^{2}P_{1/2}$ ${}^{3}P_{0}$ | 7.8994 |
| 33 | As | Arsenic | (Ar) $3d^{10}4s^2 4p^3$ | | | ${}^{4}S_{3/2}$ | 9.7886 |
| 34 | Se | Selenium | (Ar) $3d^{10}4s^2 4p^4$ | | | ${}^{3}P_{2}$ | 9.7524 |
| 35 | Br | Bromine | (Ar) $3d^{10}4s^2 4p^5$ | | | ${}^{2}P_{3/2}$ | 11.8138 |
| 36 | Kr | Krypton | (Ar) $3d^{10}4s^2 4p^6$ | | | ${}^{1}S_{0}$ | 13.9996 |
| 37 | Rb | Rubidium | (Kr) 5s | | | ${}^{2}S_{1/2}$ | 4.1771 |
| 38 | Sr | Strontium | (Kr) $5s^2$ | | | $^{1}S_{0}^{1/2}$ | 5.6949 |
| 39 | Y | Yttrium | $(Kr) 4d 5s^2$ | T | | $^{2}D_{3/2}$ | 6.2173 |
| 40 | Zr | Zirconium | $(Kr) 4d^2 5s^2$ | r | | ${}^{3}F_{2}$ | 6.6339 |
| 41 | Nb | Niobium | $(Kr)4d^4$ 5s $(Kr)4d^4$ 5s | a | e | $^{6}D_{1/2}$ | 6.7589 |
| 42 | Мо | Molybdenum | $(Kr)4d^5$ 5s | n | 1 | ${}^{7}S_{3}$ | 7.0924 |
| 43 | Тс | Technetium | $(Kr) 4d^5 5s^2$ | \mathbf{s} | e m | $^{6}S_{5/2}$ | 7.28 |
| 44 | Ru | Ruthenium | $(Kr)4d^7 5s$ | i | e | ${}^{5}F_{5}$ | 7.3605 |
| 45 | Rh | Rhodium | $(Kr) 4d^8 5s$ | t | n | ${}^{4}F_{9/2}$ | 7.4589 |
| 46 | Pd | Palladium | $(Kr) 4d^{10}$ | i | t | ${}^{1}S_{0}$ | 8.3369 |
| 47 | Ag | Silver | $(Kr) 4d^{10} 5s$ | o n | \mathbf{s} | ${}^{2}S_{1/2}$ | 7.5762 |
| 48 | Cd | Cadmium | $(Kr) 4d^{10} 5s^2$ | 11 | | ${}^{1}S_{0}$ | 8.9938 |

| 49 | In | Indium | $(Kr)4d^{10}5s^2$ 5p | | ${}^{2}P_{1/2}$ | 5.7864 |
|-----|---------------------|--------------|------------------------------------|-------------------------------------------------|--------------------------|---------|
| 50 | Sn | Tin | $(Kr) 4d^{10} 5s^2 5p^2$ | | $^{3}P_{0}$ | 7.3439 |
| 51 | Sb | Antimony | $(Kr)4d^{10}5s^2 5p^3$ | | $^{4}S_{3/2}$ | 8.6084 |
| 52 | Te | Tellurium | $(Kr) 4d^{10} 5s^2 5p^4$ | | $^{3}P_{2}$ | 9.0096 |
| 53 | I | Iodine | $(Kr) 4d^{10} 5s^2 5p^5$ | | $^{2}P_{3/2}$ | 10.4513 |
| 54 | Xe | Xenon | $(Kr) 4d^{10} 5s^2 5p^6$ | | $^{1}S_{0}$ | 12.1298 |
| 55 | Cs | Cesium | (Xe) 6s | | $^{2}S_{1/2}$ | 3.8939 |
| 56 | Ba | Barium | (Xe) $6s^2$ | | $^{1}S_{0}^{'}$ | 5.2117 |
| 57 | La | Lanthanum | (Xe) $5d 6s^2$ | | $^{2}D_{3/2}$ | 5.5769 |
| 58 | Се | Cerium | (Xe) $4f \ 5d \ 6s^2$ | | $^{1}G_{4}$ | 5.5387 |
| 59 | \Pr | Praseodymium | $(Xe)4f^3$ $6s^2$ | ${ m L}$ | $^{4}I_{9/2}$ | 5.473 |
| 60 | Nd | Neodymium | (Xe) $4f^4 = 6s^2$ | a | $_{c}^{5}I_{4}^{\prime}$ | 5.5250 |
| 61 | Pm | Promethium | (Xe) $4f^5 	 6s^2$ | $rac{	ext{n}}{	ext{t}}$ | $^{6}H_{5/2}$ | 5.582 |
| 62 | Sm | Samarium | $(Xe)4f^6 	 6s^2$ | h | ${}^{7}F_{0}$ | 5.6437 |
| 63 | Eu | Europium | $(Xe)4f^7 	 6s^2$ | a | ${}^{8}S_{7/2}$ | 5.6704 |
| 64 | Gd | Gadolinium | $(Xe)4f^7 \ 5d \ 6s^2$ | n | ${}^{9}D_{2}^{'}$ | 6.1498 |
| 65 | Tb | Terbium | (Xe) $4f^9 	 6s^2$ | i | $^{6}H_{15/2}$ | 5.8638 |
| 66 | Dy | Dysprosium | $(Xe)4f^{10}$ $6s^2$ | d | ${}^{5}I_{8}$ | 5.9389 |
| 67 | Но | Holmium | $(Xe)4f^{11}$ $6s^2$ | e | $^{4}I_{15/2}$ | 6.0215 |
| 68 | Er | Erbium | $(Xe)4f^{12} = 6s^2$ | S | $^{3}H_{6}$ | 6.1077 |
| 69 | Tm | Thulium | $(Xe)4f^{13} 	 6s^2$ | | $^{2}F_{7/2}$ | 6.1843 |
| 70 | Yb | Ytterbium | $(Xe)4f^{14}$ $6s^2$ | | ${}^{1}S_{0}$ | 6.2542 |
| 71 | Lu | Lutetium | $(Xe) 4f^{14}5d 6s^2$ | | $^{2}D_{3/2}$ | 5.4259 |
| 72 | $_{ m Hf}$ | Hafnium | $(Xe)4f^{14}5d^2 6s^2$ | ${f T}$ | $^{3}F_{2}$ | 6.8251 |
| 73 | Ta | Tantalum | $(Xe)4f^{14}5d^3 6s^2$ | $^{\mathrm{r}}$ $_{\mathrm{e}}$ | ${}^{4}F_{3/2}$ | 7.5496 |
| 74 | W | Tungsten | $(Xe)4f^{14}5d^4 6s^2$ | a î | $^{5}D_{0}$ | 7.8640 |
| 75 | Re | Rhenium | $(Xe)4f^{14}5d^5 6s^2$ | n e | $^{6}S_{5/2}$ | 7.8335 |
| 76 | Os | Osmium | (Xe) $4f^{14}5d^6 6s^2$ | s . m | $^{5}D_{4}$ | 8.4382 |
| 77 | Ir | Iridium | $(Xe)4f^{14}5d^7 6s^2$ | i e | $^{4}F_{9/2}$ | 8.9670 |
| 78 | Pt | Platinum | $(Xe)4f^{14}5d^9 6s$ | $\begin{array}{ccc} t & n \\ i & t \end{array}$ | 3D_3 | 8.9588 |
| 79 | Au | Gold | $(Xe)4f^{14}5d^{10}6s$ | t | $^{2}S_{1/2}$ | 9.2255 |
| 80 | Hg | Mercury | $(Xe)4f^{14}5d^{10}6s^2$ | n s | $^{1}S_{0}^{'}$ | 10.4375 |
| 81 | Tl | Thallium | $(Xe)4f^{14}5d^{10}6s^2$ 6p | | ${}^{2}P_{1/2}$ | 6.1082 |
| 82 | Pb | Lead | $(Xe)4f^{14}5d^{10}6s^2 6p^2$ | | ${}^{\mathfrak{d}}P_0$ | 7.4167 |
| 83 | $_{\mathrm{Bi}}$ | Bismuth | $(Xe)4f^{14}5d^{10}6s^2 6p^3$ | | $^{4}S_{3/2}$ | 7.2855 |
| 84 | Po | Polonium | $(Xe)4f^{14}5d^{10}6s^2 6p^4$ | | $^{3}P_{2}$ | 8.414 |
| 85 | At | Astatine | $(Xe)4f^{14}5d^{10}6s^2 6p^5$ | | ${}^{2}P_{3/2}$ | |
| 86 | Rn | Radon | $(Xe)4f^{14}5d^{10}6s^2 6p^6$ | | $^{1}S_{0}^{'}$ | 10.7485 |
| 87 | Fr | Francium | (Rn) 7s | | $^{2}S_{1/2}$ | 4.0727 |
| 88 | Ra | Radium | (Rn) $7s^2$ | | ${}^{1}S_{0}^{1/2}$ | 5.2784 |
| 89 | Ac | Actinium | (Rn) $6d 7s^2$ | | $^{2}D_{3/2}$ | 5.3807 |
| 90 | Th | Thorium | (Rn) $6d^2 7s^2$ | | ${}^{3}F_{2}^{-}$ | 6.3067 |
| 91 | Pa | Protactinium | $(Rn)5f^2 6d 7s^2$ | A | ${}^4K_{11/2}^*$ | 5.89 |
| 92 | U | Uranium | $(Rn)5f^3 6d 7s^2$ | \mathbf{c} | $5L_6^{**}$ | 6.1939 |
| 93 | Np | Neptunium | $(Rn)5f^4 6d 7s^2$ | t | $^{6}L_{11/2}^{}^{*}$ | 6.2657 |
| 94 | Pu | Plutonium | $(Rn)5f^6$ $7s^2$ | i | $^{7}F_{0}$ | 6.0260 |
| 95 | Am | Americium | $(Rn)5f^7$ $7s^2$ | n | $^{8}S_{7/2}$ | 5.9738 |
| 96 | Cm | Curium | $(\text{Rn})5f^7 \ 6d \ 7s^2$ | i | ${}^{9}D_{2}^{7/2}$ | 5.9914 |
| 97 | Bk | Berkelium | $(\operatorname{Rn})5f^9$ $7s^2$ | d | $^{6}H_{15/2}$ | 6.1979 |
| 98 | Cf | Californium | $(\text{Rn})5f^{10}$ $7s^2$ | e s | $^{5}I_{8}$ | 6.2817 |
| 99 | Es | Einsteinium | $(\text{Rn})5f^{11}$ $7s^2$ | ۵ | $^{4}I_{15/2}$ | 6.3676 |
| 100 | Fm | Fermium | $(Rn)5f^{12}$ $7s^2$ | | ${}^{3}H_{6}$ | 6.50 |
| 101 | Md | Mendelevium | $(\text{Rn})5f^{13}$ $7s^2$ | | ${}^{2}F_{7/2}$ | 6.58 |
| 102 | No | Nobelium | $(\text{Rn})5f^{14}$ $7s^2$ | | ${}^{1}S_{0}$ | 6.65 |
| 103 | Lr | Lawrencium | $(\text{Rn})5f^{14}$ $7s^2$ $7p$? | | ${}^{2}P_{1/2}$? | 4.9? |
| | | | $(\text{Rn})5f^{14}6d^2 7s^2$? | | $\frac{1}{3}F_{2}$? | |

^{*} The usual LS coupling scheme does not apply for these three elements. See the introductory note to the NIST table from which this table is taken.

6. ATOMIC AND NUCLEAR PROPERTIES OF MATERIALS

Table 6.1 Abridged from pdg.lbl.gov/AtomicNuclearProperties by D. E. Groom (2007). See web pages for more detail about entries in this table including chemical formulae, and for several hundred other entries. Quantities in parentheses are for NTP (20° C and 1 atm), and square brackets indicate quantities evaluated at STP. Boiling points are at 1 atm. Refractive indices n are evaluated at the sodium D line blend (589.2 nm); values $\gg 1$ in brackets are for $(n-1) \times 10^6$ (gases).

| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Material | Z | A | $\langle Z/A \rangle$ | length λ_T | Nucl.inter. length λ_I | X_0 | $\{ MeV $ | $\{ {\rm g \ cm^{-3}} \}$ | Melting point (K) | Boiling point (K) | Refract. index (@ Na D) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|----------|-----------------------|-----------------------|--------------------|--------------------------------|-------|-----------|---------------------------|----------------------|-------------------------|-------------------------------|
| D2 1 2.0141017780138 0.09650 51.31 71.8 125.97 (2.053) 1.0901(1.08) 18.7 23.65 18.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 14.29 1.14 1 | *** | - | 1 00504/5 | 0.00010 | | | | | | | | |
| He | | | | | | | | | | | | 1.11[132.] 1.11[138.] |
| Li | | | | | | | | | | 10.7 | | 1.02[35.0] |
| Re | | | \ / | | | | | () | \ / | 453.6 | | 1.02[00.0] |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $ | | | () | | | | | | | | | |
| N2 | | 6 | 12.0107(8) | 0.49955 | 59.2 | 85.8 | 42.70 | | 3.520 | | | 2.42 |
| O2 8 15.9994(3) 0.50002 61.3 90.2 34.24 (1.801) 1.14(1.332) 54.36 90.20 F2 9 18.998403(2) 0.47372 65.0 97.4 32.93 (1.676) 1.507(1.803) 55.53 88.03 Ne 10 20.177(6) 0.49515 65.7 99.0 28.93 (1.724) 1.204(0.839) 24.56 27.07 Si 14 28.0855(3) 0.48918 70.2 20.11 1.615 2.90 33.5 2792. Si 14 28.0855(3) 0.49818 70.2 108.4 21.82 1.664 2.229 108.7 338.8 Cl 1.3354(2) 0.45051 78.8 11.57 19.21 13.55 (1.50) 1.906 16.62 38.81 2.72 Fe 20 5.544(2) 0.4057 81.7 18.71 13.21 13.84 14.14 7.874 181.1 3134. Cu 29 63.544(3) 0.4053 <td>C graphite</td> <td>6</td> <td>12.0107(8)</td> <td>0.49955</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> | C graphite | 6 | 12.0107(8) | 0.49955 | | | | | | | | |
| F ₂ | | | () | | | | | () | \ / | | | 1.20[298.] |
| Ne 10 20,1797(6) 0,49555 65.7 99.0 28.93 (1.724) 1.204(0.839) 24.56 27.07 1.31 26.9815386(8) 0,48181 69.7 107.2 24.01 1.1615 2.099 33.5 2792 1.51 14 28.08553(8) 0.49848 70.2 108.4 21.82 1.664 2.329 167. 3538. Cl2 17 35.453(2) 0.47951 73.8 115.7 19.28 (1.639) 1.574(2.980) 17.16 239.1 1.71 1.71 1.71 1.71 1.71 1.71 1.71 1 | | | ` / | | | | | | | | | 1.22[271.] |
| Al 13 2 6.9815386(8) 0.48181 60.7 107.2 24.01 1.615 2.699 93.5 2792. Si 14 28.0855(3) 0.48818 70.2 108.4 21.82 1.664 2.329 1687. 3538. Cl2 17 35.453(2) 0.47951 73.8 115.7 19.28 (1.630) 1.574(2.980) 171.6 239.1 Ar 18 39.048(1) 0.45099 75.7 19.7 19.55 (1.59) 1.306(1.62) 83.81 87.26 1.7 19.57 19.57 19.57 19.57 19.59 1.506(1.62) 83.81 87.26 1.7 19.57 19.59 1.006 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1.000 1 | | | | | | | | , | (/ | | | [195.] |
| Si | | | · / | | | | | | , , | | | 1.09[67.1] |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | · , | | | | | | | | | 3.95 |
| Ar 18 39.948(1) 0.45059 75.7 119.7 19.55 (1.519) 1.396(1.662) 83.81 87.26 17 19.7 19.24 18.87(1) 0.45961 78.8 126.2 16.16 1.477 4.57 36.0 1941. 3560. 186 2.2 4 1.66 1.477 4.57 3.56 1.24 1.37 3.36 1.25 1.38 1.35 1.45 1.7 8.74 1811. 3134. 1.35 1.29 6.3 1.40 3.8 89.0 1358. 2835. 36 2.2 72.64(1) 0.44053 86.9 143.0 12.25 1.370 5.323 1211. 3106. Sn 50 118.710(7) 0.42119 98.2 166.7 8.82 1.263 7.310 5.05.1 2875. No 50 118.710(7) 0.42119 98.2 166.7 8.82 1.263 7.310 5.05.1 2875. No 50 118.710(7) 0.42119 98.2 166.7 8.82 1.263 7.310 5.05.1 2875. No 50 118.710(7) 0.42119 98.2 166.7 8.82 1.263 7.310 5.05.1 2875. No 74 132.34(1) 0.40252 110.4 191.9 6.76 1.145 19.300 3065. 5828. No 74 131.236(6) 0.4026 11.22 195.7 6.54 1.128 2.1450 2042. 4098. Au 79 196.966569(4) 0.40108 112.5 196.3 6.46 1.134 19.320 1337. 3129. Pb 82 207.2(1) 0.39575 114.1 199.6 6.37 1.122 113.50 600.6 2022. U 92 [238.02891(3)] 0.38651 118.6 209.0 6.00 1.081 18.950 1408. 4404. Air (dry, 1 atm) 0.49919 61.3 90.1 36.62 (1.815) (1.205) 78.80 Sluicking concrete 0.50274 65.1 97.5 26.57 1.711 2.300 Borosilicate glass (Pyrex) 0.49707 64.6 95.5 28.17 1.096 2.230 Lead glass 0.42101 95.9 158.0 7.87 1.255 6.20 Standard rock 0.50000 66.8 101.3 26.54 1.088 2.650 Standard rock 0.50000 66.8 101.3 26.54 1.088 2.650 North 1.08 10.2 North 1.08 North 1.0 | | | (/ | | | | | | | | | [773.] |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | () | | | | | | | | | 1.23[281.] |
| Fe 26 55.45(2) 0.46567 81.7 132.1 13.84 1.401 7.874 1811 3134 Cu 29 63.46(3) 0.45036 86.2 143.3 12.25 1.370 5.323 1211 3106 Sn 50 118.710(7) 0.42119 98.2 166.7 8.82 1.263 7.310 55.23 1211 3106 N 74 183.84(1) 0.40252 110.4 191.9 6.76 1.145 19.300 3695 5828. Pt 78 195.084(9) 0.30988 112.2 196.7 6.54 1.128 1.9300 3695 5828. Au 79 196.966569(4) 0.40108 112.5 196.3 6.46 1.128 19.300 360. 5828. Pb 82 2072(1) 0.39878 114.1 199.6 6.37 1.122 193.0 133.0 120.6 Grid (Jr.) 121.2 120.0 12.2 14.2 | | | ` ' | | | | | ` , | , , | | | |
| Ge 32 72 64(i) 0.44053 86.9 143.0 12.25 1.370 5.323 1211 3106. Sn 50 118.710(7) 0.42119 100.8 172.1 8.48 (1.255) 2.953(5.483) 161.4 165.1 W 74 183.84(1) 0.40252 110.4 191.9 6.76 1.145 19.300 3695. 5828. Pt 78 195.084(9) 0.39983 112.2 195.7 6.54 1.124 19.300 3695. 5828. Au 79 196.966569(4) 0.40108 112.5 196.3 6.46 1.134 19.320 1337. 3129. Pb 82 207.2(1) 0.39575 114.1 19.96 6.63 71.12 1.350 60.6 2022. U 92 [238.02891(3)] 0.38651 118.6 209.0 6.00 1.081 18.950 1408. 4404. Air (dry, 1 atm) 0.49019 61.3 90.1 36.6 | | | () | | | | | | | | | |
| Sn 50 | Cu | 29 | 63.546(3) | 0.45636 | 84.2 | 137.3 | 12.86 | 1.403 | 8.960 | 1358. | 2835. | |
| Xe 54 131,293(6) 0.41129 100.8 172,1 8.48 (1.255) 2.953(5.483) 161.4 165.1 1.18 174 183.84(1) 0.40252 110.4 191.9 6.76 1.145 19.300 3695 5828. Pt 78 195.084(9) 0.39983 112.2 195.7 6.54 1.128 21.450 2042. 4098. Au 79 196.966569(4) 0.40108 112.5 196.3 6.46 1.134 19.320 1337. 3129. Pb 82 207.2(1) 0.39575 114.1 199.6 6.37 1.122 11.350 600.6 2022. U 92 [238.02891(3)] 0.38651 118.6 209.0 6.00 1.081 18.950 1408. 4404. Air (dry, 1 atm) 0.49919 61.3 90.1 36.62 (1.815) (1.205) 78.80 Shielding concrete 0.50274 65.1 97.5 26.57 1.711 2.300 2.300 Borosilicate glass (Pyrex) 0.49707 64.6 96.5 28.17 1.696 2.230 Lead glass 0.42101 95.9 158.0 7.87 1.255 6.220 Standard rock 0.50000 66.8 101.3 26.54 1.688 2.650 Methane (CH4) 0.62334 54.0 73.8 46.47 (2.417 (0.667) 90.68 111.7 Ethane (C ₂ H ₆) 0.59861 55.0 75.9 45.66 (2.304) (1.263) 99.36 184.5 Propane (C ₃ H ₈) 0.58962 55.3 76.7 45.37 (2.262) 0.493(1.868) 85.52 231.0 Butane (C ₄ H ₁₀) 0.59497 55.5 77.1 45.23 (2.278) (2.489) 134.9 272.6 Cotane (C ₅ H ₁₈) 0.57778 55.8 77.8 44.57 2.079 0.89 Paraffin (CH ₂ (CH ₂) _{ln}) 0.57775 56.0 78.3 44.85 2.088 0.930 Paraffin (CH ₂ (CH ₂) _{ln}) 0.57697 58.3 83.6 41.50 1.886 1.20 Polyenthylene ([CH ₂ CH ₂] _{ln}) 0.57034 56.1 78.5 44.77 2.079 0.89 Polyethylene (CH ₂ CH ₂) _{ln} 0.57038 56.1 78.5 44.77 2.079 0.89 Polyethylene (CH ₂ CH ₂) _{ln} 0.57368 57.5 81.6 41.92 1.973 1.18 Polyenthylene (Telfon) 0.54997 58.1 82.8 40.55 1.929 1.19 Polypropylene 0.5998 56.1 78.5 44.77 2.079 0.89 Polyptyrene (T ₂ C ₄ H ₂ C ₅ C ₁ C ₂ C ₂ O ₂ O ₃ | Ge | 32 | 72.64(1) | 0.44053 | 86.9 | 143.0 | 12.25 | 1.370 | 5.323 | 1211. | 3106. | |
| W | | | () | | | | | | | | | |
| Pt | | | ` / | | | | | | | | | 1.39[701.] |
| Au 79 196,966569(4) 0.40108 112.5 196.3 6.46 1.134 19.320 1337 3129 Pb 82 207.2(1) 0.39575 114.1 199.6 6.37 1.122 11.350 600.6 2022. U 92 [238.02891(3)] 0.38661 118.6 209.0 6.00 1.081 18.950 1408. 4404. Air (dry, 1 atm) 0.49919 61.3 90.1 36.62 (1.815) (1.205) 78.80 Shielding concrete 0.50976 64.6 96.5 28.17 1.606 2.230 Lead glass 0.42101 95.9 158.0 7.87 1.255 6.220 Standard rock 0.50000 66.8 101.3 26.54 1.688 2.650 Methane (CH4) 0.62334 54.0 73.8 46.47 (2.417) (0.667) 90.68 111.7 Ethane (CH ₂) 0.59861 55.0 75.9 45.66 (2.304) 11.263 93.61 | | | ` ' | | | | | | | | | |
| Pb 82 207.2(1) 0.39575 114.1 199.6 6.37 1.122 11.350 600.6 2022. U 92 [238.02891(3)] 0.38651 118.6 209.0 6.00 1.081 18.950 1408. 4404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404. 404 | | | ` ' | | | | | | | | | |
| U 92 [238.02891(3)] 0.38651 118.6 209.0 6.00 1.081 18.950 1408. 4404. Air (dry, 1 atm) 0.49919 61.3 99.1 36.62 (1.815) (1.205) 78.80 Shielding concrete 0.50274 65.1 97.5 26.57 1.711 2.300 Borosilicate glass (Pyrex) 0.49707 64.6 96.5 28.17 1.711 2.300 Lead glass 0.42101 95.9 158.0 7.87 1.265 6.220 Katandard rock 0.50000 66.8 101.3 26.54 1.688 2.650 Methane (CH₄) 0.62334 54.0 73.8 46.47 (2.417) (0.667) 90.68 111.7 Ethane (CgH₀) 0.59861 55.0 75.9 45.66 (2.304) (1.636) 90.36 184.5 Propane (C3H₀) 0.599861 55.0 76.9 45.66 (2.304) (1.636) 90.36 184.5 Propane (C4H₁0) 0.59497 55.5 77.1 45.23 (2.278) (2.489) 134.9 272.6 Octane (CgH₁8) 0.57778 55.8 77.8 45.00 2.123 0.703 214.4 398.8 Paraffin (CH₄) 0.54790 57.5 81.6 41.92 1.973 1.18 Polycarbonate (Lexan) 0.52697 58.3 84.9 39.95 1.848 1.40 Polycethylene ([Ct½CtH₂] _n) 0.57034 56.1 78.5 44.77 2.079 0.89 Polycethylene ([Ct½CtH₂] _n) 0.53937 58.1 82.8 40.55 1.929 1.19 Polymythylmethacrylate (acrylic) 0.53937 58.1 82.8 40.55 1.929 1.19 Polymythylmethacrylate (acrylic) 0.53938 56.1 78.5 44.77 2.041 0.90 Polytetrafluoroethylene (Teflon) 0.47992 63.5 98.4 27.94 1.647 3.970 2327. 3273. Barium flouride (BaF₂) 0.4207 99.8 149.0 9.91 1.303 4.893 1641. 2533. Bismuth germanate (BGO) 0.42065 96.2 159.1 7.97 1.251 7.130 1317. Aluminum oxide (sapphire) 0.49038 65.5 98.4 27.94 1.647 3.970 2327. 3273. Barium flouride (BaF₂) 0.4207 99.8 149.0 9.91 1.303 4.893 1641. 2533. Bismuth germanate (BGO) 0.42065 96.2 159.1 7.97 1.251 7.130 1317. Sodium individe (CliH) 0.4626 61.0 88.7 39.26 1.614 2.635 1121. 1946. Ethical Cyline (CliH) 0.4626 61.0 88.7 39.26 1.614 2.635 1121. 1946. Ethium hydride (LiH) 0.50327 50.8 68.1 79.62 1.897 0.820 965. Sedium individe (NaCl) 0.45909 93.1 1546 9.49 1.305 3.6667 933.2 1577. | | | | | | | | | | | | |
| Air (dry, 1 atm) O.49919 O.49917 O.49077 O.40917 O.40918 O.50274 O.5 | | | · / | | | | | | | | | |
| Shielding concrete | | | [230.02031(3)] | | | | | | | 1400. | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | , , | | | 78.80 | |
| Lead glass 0.42101 95.9 158.0 7.87 1.255 6.220 Standard rock 0.50000 66.8 101.3 26.54 1.688 2.650 Methane (CH4) 0.62334 54.0 73.8 46.47 (2.417) (0.667) 90.68 111.7 Ethane (C ₂ H ₆) 0.59861 55.0 75.9 45.66 (2.304) (1.263) 90.36 184.5 Propane (C ₃ H ₈) 0.58962 55.3 76.7 45.37 (2.262) 0.493(1.868) 85.52 231.0 Octane (C ₈ H ₁₈) 0.57478 55.8 77.8 45.00 2.123 0.703 21.4 398.8 Paraffin (CH ₃ (CH ₂) _m) 0.57778 55.8 77.8 45.00 2.123 0.703 21.4 398.8 Paraffin (CH ₃ (CH ₂ CH ₂) _m) 0.57779 55.5 87.8 44.85 2.088 0.930 Polyearbonate (Lexan) 0.52697 58.3 83.6 41.50 1.886 1.20 Polyettylene ([CH ₂ CH ₂ H ₂) | | | | | | | | | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | giass (F | yrex) | | | | | | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | ck | | | | | | | | | | |
| $\begin{array}{c} Propane \left({\rm C_3H_8} \right) & 0.58962 & 55.3 & 76.7 & 45.37 & (2.262) & 0.493 (1.868) & 85.52 & 231.0 \\ Butane \left({\rm C_4H_{10}} \right) & 0.59497 & 55.5 & 77.1 & 45.23 & (2.278) & (2.489) & 134.9 & 272.6 \\ Octane \left({\rm C_8H_8} \right) & 0.57778 & 55.8 & 77.8 & 45.00 & 2.123 & 0.703 & 214.4 & 398.8 \\ Paraffin \left({\rm CH_3} ({\rm CH_2})_{n \approx 23} {\rm CH_3} \right) & 0.57275 & 56.0 & 78.3 & 44.85 & 2.088 & 0.930 \\ Nylon \left({\rm type} \ 6, 6/6 \right) & 0.54790 & 57.5 & 81.6 & 41.92 & 1.973 & 1.18 \\ Polycarbonate \left({\rm Lexan} \right) & 0.52697 & 58.3 & 83.6 & 41.50 & 1.886 & 1.20 \\ Polyethylene \left({\rm [CH_2CH_2]_n} \right) & 0.57034 & 56.1 & 78.5 & 44.77 & 2.079 & 0.89 \\ Polyethylene terephthalate \left({\rm Mylar} \right) & 0.52037 & 58.9 & 84.9 & 39.95 & 1.848 & 1.40 \\ Polyminde film \left({\rm Kapton} \right) & 0.51264 & 59.2 & 85.5 & 40.58 & 1.820 & 1.42 \\ Polymrethylmethacrylate \left({\rm acrylic} \right) & 0.53937 & 58.1 & 82.8 & 40.55 & 1.929 & 1.19 \\ Polypropylene & 0.55998 & 56.1 & 78.5 & 44.77 & 2.041 & 0.90 \\ Polystyrene \left({\rm [C_4E_5CHCH_2]_n} \right) & 0.53768 & 57.5 & 81.7 & 43.79 & 1.936 & 1.06 \\ Polytetrafluoroethylene \left({\rm Teflon} \right) & 0.47992 & 63.5 & 94.4 & 34.84 & 1.671 & 2.20 \\ Polyvinyltoluene & 0.54141 & 57.3 & 81.3 & 43.90 & 1.956 & 1.03 \\ Aluminum oxide \left({\rm sapphire} \right) & 0.49038 & 65.5 & 98.4 & 27.94 & 1.647 & 3.970 & 2327. & 3273. \\ Barium flouride \left({\rm BaF}_2 \right) & 0.4207 & 90.8 & 149.0 & 9.91 & 1.303 & 4.893 & 1641. & 2533. \\ Bismuth germanate \left({\rm BGO} \right) & 0.42065 & 96.2 & 159.1 & 7.97 & 1.251 & 7.130 & 1317. \\ Carbon dioxide gas \left({\rm CO}_2 \right) & 0.49989 & 60.7 & 88.9 & 36.20 & 1.787 & 1.563 & Sublimes at 194.7 K \\ Cesium iodide \left({\rm Csl} \right) & 0.41569 & 100.6 & 171.5 & 8.39 & 1.243 & 4.510 & 894.2 & 1553. \\ Lithium fluoride (LiF) & 0.46262 & 61.0 & 88.7 & 39.26 & 1.614 & 2.635 & 1121. & 1946. \\ Lithium fluoride (LiH) & 0.50321 & 50.8 & 68.1 & 79.62 & 1.897 & 0.820 & 965. \\ Lead tungstate \left({\rm PbWO}_4 \right) & 0.41315 & 100.6 & 168.3 & 7.39 & 1.299 & 8.300 & 1403. \\ Solidium iodide \left({\rm NaI} \right) & 0.42697 & 93.1 & 154.6 & 9.49 & 1.305 & 3.667 & 933.2 $ | Methane (Cl | $H_4)$ | | 0.62334 | 54.0 | 73.8 | 46.47 | (2.417) | (0.667) | 90.68 | 111.7 | [444.] |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Ethane (C ₂ F | H_6 | | 0.59861 | 55.0 | 75.9 | 45.66 | (2.304) | (1.263) | 90.36 | 184.5 | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | - , - | , | | | | | | , , | , , | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | CII) | | | | | | | 214.4 | 398.8 | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | n≈23CH ₃) | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | n) | | | | | | | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | · | , | , | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 1 | (, , | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | 1.49 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | , , , | | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | 1.59 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | v | | ene (Teflon) | | | | | | | | | 1.50 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | 1.58 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | | 1.77 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | 2533. | 1.47 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | 1317. | | 2.15 [449.] |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | _ , | -/ | | | | | | \ / | Sublime | s at 1047 | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | (ary rec) | | | | | | | | | 1.79 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | ?) | | | | | | | | | 1.79 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | , | , | | | | | | | | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | , | , | | | | | | | | | 2.20 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | | | | | | | 3223. | 1.46 |
| | Sodium chlo | ride (Na | Cl) | | | 110.1 | | | 2.170 | | 1738. | 1.54 |
| Water (H_2O) 0.55509 58.5 83.3 36.08 1.992 1.000 (0.756) 273.1 373.1 | | . , | | | | | | | 3.667 | | | 1.77 |
| | Water (H ₂ O |) | | 0.55509 | 58.5 | 83.3 | 36.08 | 1.992 | 1.000(0.756) | 273.1 | 373.1 | 1.33 |
| Silica aerogel 0.50093 65.0 97.3 27.25 1.740 0.200 $(0.03 \text{ H}_2\text{O}, 0.97 \text{ SiO})$ | Silica aeroge | el | | 0.50093 | 65.0 | 97.3 | 27.25 | 1.740 | 0.200 | (0.03 H_2) | O, 0.97 Si | O_2) |

| Material | Dielectric | Young's | Coeff. of | Specific | Electrical | Thermal |
|---------------------|-------------------------------------------|----------------------|------------------------------------------------------|------------|------------------------------|-----------------|
| | constant $(\kappa = \epsilon/\epsilon_0)$ | modulus | thermal | heat | resistivity | conductivity |
| | () is $(\kappa - 1) \times 10^6$ | $[10^6 \text{ psi}]$ | expansion | [cal/g-°C] | $[\mu\Omega cm(@^{\circ}C)]$ | [cal/cm-°C-sec] |
| | for gas | | $[10^{-6} \mathrm{cm/cm}\text{-}^{\circ}\mathrm{C}]$ | | | |
| H_2 | (253.9) | _ | _ | _ | _ | _ |
| He | (64) | | _ | _ | _ | _ |
| Li | _ | _ | 56 | 0.86 | $8.55(0^{\circ})$ | 0.17 |
| Be | _ | 37 | 12.4 | 0.436 | $5.885(0^{\circ})$ | 0.38 |
| С | _ | 0.7 | 0.6-4.3 | 0.165 | 1375(0°) | 0.057 |
| N_2 | (548.5) | _ | _ | _ | _ | _ |
| O_2 | (495) | _ | _ | _ | _ | _ |
| Ne | (127) | _ | _ | _ | _ | _ |
| Al | _ | 10 | 23.9 | 0.215 | $2.65(20^{\circ})$ | 0.53 |
| Si | 11.9 | 16 | 2.8 - 7.3 | 0.162 | _ | 0.20 |
| Ar | (517) | _ | _ | _ | | _ |
| Ti | _ | 16.8 | 8.5 | 0.126 | $50(0^{\circ})$ | _ |
| Fe | _ | 28.5 | 11.7 | 0.11 | 9.71(20°) | 0.18 |
| Cu | _ | 16 | 16.5 | 0.092 | $1.67(20^{\circ})$ | 0.94 |
| Ge | 16.0 | _ | 5.75 | 0.073 | _ | 0.14 |
| Sn | _ | 6 | 20 | 0.052 | $11.5(20^{\circ})$ | 0.16 |
| Xe | _ | _ | _ | _ | _ | |
| W | _ | 50 | 4.4 | 0.032 | $5.5(20^{\circ})$ | 0.48 |
| Pt | _ | 21 | 8.9 | 0.032 | $9.83(0^{\circ})$ | 0.17 |
| Pb | _ | 2.6 | 29.3 | 0.038 | $20.65(20^{\circ})$ | 0.083 |
| U | _ | | 36.1 | 0.028 | $29(20^{\circ})$ | 0.064 |

7. ELECTROMAGNETIC RELATIONS

Revised September 2005 by H.G. Spieler (LBNL).

| Quantity | Gaussian CGS | SI |
|------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Conversion factors: | | |
| Charge: | $2.99792458 \times 10^9 \text{ esu}$ | = 1 C = 1 A s |
| Potential: | (1/299.792458) statvolt $(ergs/esu)$ | $= 1 \text{ V} = 1 \text{ J C}^{-1}$ |
| Magnetic field: | $10^4 \text{ gauss} = 10^4 \text{ dyne/esu}$ | $= 1 \text{ T} = 1 \text{ N A}^{-1} \text{m}^{-1}$ |
| | $\mathbf{F} = q\left(\mathbf{E} + \frac{\mathbf{v}}{c} \times \mathbf{B}\right)$ | $\mathbf{F} = q\left(\mathbf{E} + \mathbf{v} \times \mathbf{B}\right)$ |
| | $\nabla \cdot \mathbf{D} = 4\pi \rho$ | $\nabla \cdot \mathbf{D} = \rho$ |
| | $\nabla \times \mathbf{H} - \frac{1}{c} \frac{\partial \mathbf{D}}{\partial t} = \frac{4\pi}{c} \mathbf{J}$ $\nabla \cdot \mathbf{B} = 0$ | $\nabla \times \mathbf{H} - \frac{\partial \mathbf{D}}{\partial t} = \mathbf{J}$ |
| | $\nabla \cdot \mathbf{B} = 0$ | $\nabla \cdot \mathbf{B} = 0$ |
| | $\mathbf{\nabla} \times \mathbf{E} + \frac{1}{c} \frac{\partial \mathbf{B}}{\partial t} = 0$ | $\nabla \times \mathbf{E} + \frac{\partial \mathbf{B}}{\partial t} = 0$ |
| Constitutive relations: | $\mathbf{D} = \mathbf{E} + 4\pi \mathbf{P}, \mathbf{H} = \mathbf{B} - 4\pi \mathbf{M}$ | $\mathbf{D} = \epsilon_0 \mathbf{E} + \mathbf{P}, \mathbf{H} = \mathbf{B}/\mu_0 - \mathbf{M}$ |
| Linear media: | $\mathbf{D} = \epsilon \mathbf{E}, \mathbf{H} = \mathbf{B}/\mu$ | $\mathbf{D} = \epsilon \mathbf{E}, \mathbf{H} = \mathbf{B}/\mu$ |
| | 1 | $\epsilon_0 = 8.854 \ 187 \dots \times 10^{-12} \ \mathrm{F \ m^{-1}}$ |
| | 1 | $\mu_0 = 4\pi \times 10^{-7} \text{ N A}^{-2}$ |
| | $\mathbf{E} = -\nabla V - \frac{1}{c} \frac{\partial \mathbf{A}}{\partial t}$ | $\mathbf{E} = -\nabla V - \frac{\partial \mathbf{A}}{\partial t}$ |
| | $\mathbf{B} = \mathbf{\nabla} \times \mathbf{A}$ | $\mathbf{B} = \mathbf{\nabla} \times \mathbf{A}$ |
| | $V = \sum_{\text{charges}} \frac{q_i}{r_i} = \int \frac{\rho(\mathbf{r}')}{ \mathbf{r} - \mathbf{r}' } d^3 x'$ | $V = \frac{1}{4\pi\epsilon_0} \sum_{\text{charges}} \frac{q_i}{r_i} = \frac{1}{4\pi\epsilon_0} \int \frac{\rho(\mathbf{r}')}{ \mathbf{r} - \mathbf{r}' } d^3x'$ |
| | $\mathbf{A} = \frac{1}{c} \oint \frac{I \mathbf{d} \ell}{ \mathbf{r} - \mathbf{r}' } = \frac{1}{c} \int \frac{\mathbf{J}(\mathbf{r}')}{ \mathbf{r} - \mathbf{r}' } d^3 x'$ | $\mathbf{A} = \frac{\mu_0}{4\pi} \oint \frac{I \mathbf{d}\boldsymbol{\ell}}{ \mathbf{r} - \mathbf{r}' } = \frac{\mu_0}{4\pi} \int \frac{\mathbf{J}(\mathbf{r}')}{ \mathbf{r} - \mathbf{r}' } d^3x'$ |
| | $\mathbf{E}_{\parallel}'=\mathbf{E}_{\parallel}$ | $\mathbf{E}_{\parallel}' = \mathbf{E}_{\parallel}$ |
| | $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \frac{1}{c}\mathbf{v} \times \mathbf{B})$ | $\mathbf{E}'_{\perp} = \gamma(\mathbf{E}_{\perp} + \mathbf{v} \times \mathbf{B})$ |
| | $\mathbf{B}_{\parallel}'=\mathbf{B}_{\parallel}$ | $\mathbf{B}_{\parallel}' = \mathbf{B}_{\parallel}$ |
| | $\mathbf{B}_{\perp}' = \gamma (\mathbf{B}_{\perp} - \frac{1}{c} \mathbf{v} \times \mathbf{E})$ | $\mathbf{B}'_{\perp} = \gamma(\mathbf{B}_{\perp} - \frac{1}{c^2}\mathbf{v} \times \mathbf{E})$ |
| $\frac{1}{4\pi\epsilon_0} = c^2 \times 10^{-7} \text{ N A}^{-2}$ | = 8.987 55 × 10 ⁹ m F ⁻¹ ; $\frac{\mu_0}{4\pi}$ = 10 ⁻⁷ N | A^{-2} ; $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 2.99792458 \times 10^8 \text{ m s}^{-1}$ |

7.1. Impedances (SI units)

 $\rho = \text{resistivity at room temperature in } 10^{-8} \,\Omega \text{ m}$:

For alternating currents, instantaneous current I, voltage V, angular frequency ω :

$$V = V_0 e^{j\omega t} = ZI . (7.1)$$

Impedance of self-inductance L: $Z = j\omega L$.

Impedance of capacitance $C\colon\thinspace Z=1/j\omega C$.

Impedance of free space: $Z = \sqrt{\mu_0/\epsilon_0} = 376.7 \ \Omega$.

High-frequency surface impedance of a good conductor:

$$Z = \frac{(1+j) \rho}{\delta} , \quad \text{where } \delta = \text{skin depth} ;$$
 (7.2)

$$\delta = \sqrt{\frac{\rho}{\pi \nu \mu}} \approx \frac{6.6 \text{ cm}}{\sqrt{\nu \text{ (Hz)}}} \text{ for Cu}.$$
 (7.3)

7.2. Capacitors, inductors, and transmission Lines

The capacitance between two parallel plates of area A spaced by the distance d and enclosing a medium with the dielectric constant ε is

$$C = K\varepsilon A/d, \tag{7.4}$$

where the correction factor K depends on the extent of the fringing field. If the dielectric fills the capacitor volume without extending beyond the electrodes. the correction factor $K\approx 0.8$ for capacitors of typical geometry.

The inductance at high frequencies of a straight wire whose length ℓ is much greater than the wire diameter d is

$$L \approx 2.0 \left[\frac{\mathrm{nH}}{\mathrm{cm}} \right] \cdot \ell \left(\ln \left(\frac{4\ell}{d} \right) - 1 \right)$$
 (7.5)

For very short wires, representative of vias in a printed circuit board, the inductance is

$$L(\text{in nH}) \approx \ell/d$$
. (7.6)

A transmission line is a pair of conductors with inductance L and capacitance C. The characteristic impedance $Z=\sqrt{L/C}$ and the phase velocity $v_p=1/\sqrt{LC}=1/\sqrt{\mu\varepsilon}$, which decreases with the inverse square root of the dielectric constant of the medium. Typical coaxial and ribbon cables have a propagation delay of about $5\,\mathrm{ns/cm}$. The impedance of a coaxial cable with outer diameter D and inner diameter d is

$$Z = 60 \Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln \frac{D}{d}, \qquad (7.7)$$

where the relative dielectric constant $\varepsilon_r = \varepsilon/\varepsilon_0$. A pair of parallel wires of diameter d and spacing $a>2.5\,d$ has the impedance

$$Z = 120 \,\Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln \frac{2a}{d} \,. \tag{7.8}$$

This yields the impedance of a wire at a spacing h above a ground plane,

$$Z = 60 \Omega \cdot \frac{1}{\sqrt{\varepsilon_r}} \ln \frac{4h}{d}. \tag{7.9}$$

A common configuration utilizes a thin rectangular conductor above a ground plane with an intermediate dielectric (microstrip). Detailed calculations for this and other transmission line configurations are given by Gunston.*

7.3. Synchrotron radiation (CGS units)

For a particle of charge e, velocity $v = \beta c$, and energy $E = \gamma mc^2$, traveling in a circular orbit of radius R, the classical energy loss per revolution δE is

$$\delta E = \frac{4\pi}{3} \, \frac{e^2}{R} \, \beta^3 \, \gamma^4 \, . \tag{7.10}$$

For high-energy electrons or positrons ($\beta \approx 1$), this becomes

$$\delta E \text{ (in MeV)} \approx 0.0885 \ [E(\text{in GeV})]^4 / R(\text{in m}) \ .$$
 (7.11)

For $\gamma \gg 1$, the energy radiated per revolution into the photon energy interval $d(\hbar\omega)$ is

$$dI = \frac{8\pi}{9} \alpha \gamma F(\omega/\omega_c) d(\hbar\omega) , \qquad (7.12)$$

where $\alpha = e^2/\hbar c$ is the fine-structure constant and

$$\omega_c = \frac{3\gamma^3 c}{2R} \tag{7.13}$$

is the critical frequency. The normalized function F(y) is

$$F(y) = \frac{9}{8\pi} \sqrt{3} y \int_{y}^{\infty} K_{5/3}(x) dx$$
, (7.14)

where $K_{5/3}\left(x\right)$ is a modified Bessel function of the third kind. For electrons or positrons,

$$\hbar\omega_c \,(\text{in keV}) \approx 2.22 \,\left[E(\text{in GeV})\right]^3 / R(\text{in m}) \,.$$
 (7.15)

Fig. 7.1 shows F(y) over the important range of y.

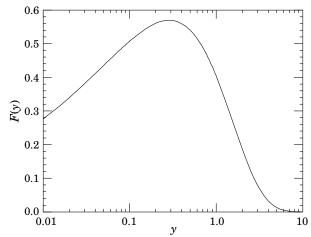


Figure 7.1: The normalized synchrotron radiation spectrum F(y).

For $\gamma \gg 1$ and $\omega \ll \omega_c$,

$$\frac{dI}{d(\hbar\omega)} \approx 3.3\alpha \left(\omega R/c\right)^{1/3} ,$$
 (7.16)

whereas for

$$\gamma \gg 1$$
 and $\omega \gtrsim 3\omega_c$.

$$\frac{dI}{d(\hbar\omega)} \approx \sqrt{\frac{3\pi}{2}} \, \alpha \, \gamma \left(\frac{\omega}{\omega_c}\right)^{1/2} e^{-\omega/\omega_c} \left[1 + \frac{55}{72} \frac{\omega_c}{\omega} + \ldots\right] \quad . \tag{7.17}$$

The radiation is confined to angles $\lesssim 1/\gamma$ relative to the instantaneous direction of motion. For $\gamma \gg 1$, where Eq. (7.12) applies, the mean number of photons emitted per revolution is

$$N_{\gamma} = \frac{5\pi}{\sqrt{3}} \alpha \gamma , \qquad (7.18)$$

and the mean energy per photon is

$$\langle \hbar \omega \rangle = \frac{8}{15\sqrt{3}} \hbar \omega_c \ . \tag{7.19}$$

When $\langle \hbar \omega \rangle \gtrsim O(E)$, quantum corrections are important.

See J.D. Jackson, Classical Electrodynamics, $3^{\rm rd}$ edition (John Wiley & Sons, New York, 1998) for more formulae and details. (Note that earlier editions had ω_c twice as large as Eq. (7.13).

 $^{^{\}ast}$ M.A.R. Gunston. Microwave Transmission Line Data, Noble Publishing Corp., Atlanta (1997) ISBN 1-884932-57-6, TK6565.T73G85.

8. NAMING SCHEME FOR HADRONS

Revised 2008 by M. Roos (University of Finland) and C.G. Wohl (LBNL).

8.1. Introduction

We introduced in the 1986 edition [1] a new naming scheme for the hadrons. Changes from older terminology affected mainly the heavier mesons made of the light (u, d, and s) quarks. Old and new names were listed alongside until 1994. Names also change from edition to edition because some characteristic like mass or spin changes. The Summary Tables give both the new and old names whenever a change occurred.

8.2. "Neutral-flavor" mesons (S=C=B=T=0)

Table 8.1 shows the names for mesons having the strangeness and all heavy-flavor quantum numbers equal to zero. The scheme is designed for all ordinary non-exotic mesons, but it will work for many exotic types too, if needed.

Table 8.1: Symbols for mesons with the strangeness and all heavy-flavor quantum numbers equal to zero.

| | $J^{PC} =$ | $\begin{cases} 0^{-+} \\ 2^{-+} \\ \vdots \end{cases}$ | 1 ⁺⁻ 3 ⁺⁻ : | 1 2 : | 0 ⁺⁺ 1 ⁺⁺ : |
|-----------------------------------------------------------|----------------|--------------------------------------------------------|-----------------------------------------|-----------------------|-----------------------------------------|
| $q\overline{q}$ content | $^{2S+1}L_J =$ | $^{1}(L \operatorname{even})_{J}$ | $^1(L \operatorname{odd})_J$ | $^3(L {\rm even})_J$ | $^3(L \text{ odd})_J$ |
| $u\overline{d}, u\overline{u} - d\overline{d},$ | | π | b | ρ | a |
| $d\overline{d} + u\overline{u}$ and/or $s\overline{s}$ | $ \} (I=0)$ | η,η' | h, h' | ω,ϕ | f, f' |
| $c\overline{c}$ | | η_c | h_c | ψ^\dagger | χ_c |
| $b\overline{b}$ | | η_b | h_b | Υ | χ_b |
| $t\overline{t}$ | | η_t | h_t | θ | χ_t |

[†]The J/ψ remains the J/ψ .

First, we assign names to those states with quantum numbers compatible with being $q\overline{q}$ states. The rows of the Table give the possible $q\overline{q}$ content. The columns give the possible parity/charge-conjugation states.

$$PC = -+, +-, --, \text{ and } ++;$$

these combinations correspond one-to-one with the angular-momentum state $^{2S+1}L_J$ of the $q\overline{q}$ system being

$$^{1}(L \text{ even})_{J}$$
, $^{1}(L \text{ odd})_{J}$, $^{3}(L \text{ even})_{J}$, or $^{3}(L \text{ odd})_{J}$.

Here S, L, and J are the spin, orbital, and total angular momenta of the $q\overline{q}$ system. The quantum numbers are related by $P=(-1)^{L+1}$, $C=(-1)^{L+S}$, and G parity $=(-1)^{L+S+I}$,

where of course the C quantum number is only relevant to neutral mesons.

The entries in the Table give the meson names. The spin J is added as a subscript except for pseudoscalar and vector mesons, and the mass is added in parentheses for mesons that decay strongly. However, for the lightest meson resonances, we omit the mass.

Measurements of the mass, quark content (where relevant), and quantum numbers $I,\ J,\ P,$ and C (or G) of a meson thus fix its symbol. Conversely, these properties may be inferred unambiguously from the symbol.

If the main symbol cannot be assigned because the quantum numbers are unknown, X is used. Sometimes it is not known whether a meson is mainly the isospin-0 mix of $u\overline{u}$ and $d\overline{d}$ or is mainly $s\overline{s}$. A prime (or pair ω , ϕ) may be used to distinguish two such mixing states.

We follow custom and use spectroscopic names such as $\Upsilon(1S)$ as the primary name for most of those ψ , Υ , and χ states whose spectroscopic identity is known. We use the form $\Upsilon(9460)$ as an alternative, and as the primary name when the spectroscopic identity is not known.

Names are assigned for $t\bar{t}$ mesons, although the top quark is evidently so heavy that it is expected to decay too rapidly for bound states to form.

Gluonium states or other mesons that are not $q\overline{q}$ states are, if the quantum numbers are *not* exotic, to be named just as are the $q\overline{q}$ mesons. Such states will probably be difficult to distinguish from $q\overline{q}$ states and will likely mix with them, and we make no attempt to distinguish those "mostly gluonium" from those "mostly $q\overline{q}$."

An "exotic" meson with J^{PC} quantum numbers that a $q\overline{q}$ system cannot have, namely $J^{PC}=0^{--},0^{+-},1^{-+},2^{+-},3^{-+},\cdots$, would use the same symbol as does an ordinary meson with all the same quantum numbers as the exotic meson except for the C parity. But then the J subscript may still distinguish it; for example, an isospin-0 1^{-+} meson could be denoted ω_1 .

8.3. Mesons with nonzero S, C, B, and/or T

Since the strangeness or a heavy flavor of these mesons is nonzero, none of them are eigenstates of charge conjugation, and in each of them one of the quarks is heavier than the other. The rules are:

 The main symbol is an upper-case italic letter indicating the heavier quark as follows:

$$s \to \overline{K}$$
 $c \to D$ $b \to \overline{B}$ $t \to T$.

We use the convention that the flavor and the charge of a quark have the same sign. Thus the strangeness of the s quark is negative, the charm of the c quark is positive, and the bottom of the b quark is negative. In addition, I_3 of the u and d quarks are positive and negative, respectively. The effect of this convention is as follows: Any flavor carried by a charged meson has the same sign as its charge. Thus the K^+ , D^+ , and B^+ have positive strangeness, charm, and bottom, respectively, and all have positive I_3 . The D_s^+ has positive charm and strangeness. Furthermore, the $\Delta(\text{flavor}) = \Delta Q$ rule, best known for the kaons, applies to every flavor.

- 2. If the lighter quark is not a u or a d quark, its identity is given by a subscript. The D_s^+ is an example.
- 3. If the spin-parity is in the "normal" series, $J^P = 0^+, 1^-, 2^+, \cdots$, a superscript "*" is added.
- The spin is added as a subscript except for pseudoscalar or vector mesons.

8.4. Ordinary (3-quark) baryons

The symbols N, Δ , Λ , Σ , Ξ , and Ω used for more than 30 years for the baryons made of light quarks (u, d, and s quarks) tell the isospin and quark content, and the same information is conveyed by the symbols used for the baryons containing one or more heavy quarks (c and b quarks). The rules are:

- Baryons with three u and/or d quarks are N's (isospin 1/2) or \(\Delta's \) (isospin 3/2).
- 2. Baryons with $two\ u$ and/or d quarks are Λ 's (isospin 0) or Σ 's (isospin 1). If the third quark is a c, b, or t quark, its identity is given by a subscript.
- Baryons with one u or d quark are Ξ's (isospin 1/2). One or two subscripts are used if one or both of the remaining quarks are heavy: thus Ξ_c, Ξ_{cc}, Ξ_b, etc.*
- 4. Baryons with no~u or d quarks are Ω 's (isospin 0), and subscripts indicate any heavy-quark content.
- 5. A baryon that decays strongly has its mass as part of its name. Thus $p, \Sigma^-, \Omega^-, \Lambda_c^+, etc.$, but $\Delta(1232)^0, \Sigma(1385)^-, \Xi_c(2645)^+, etc.$

In short, the number of u plus d quarks together with the isospin determine the main symbol, and subscripts indicate any content of heavy quarks. A Σ always has isospin 1, an Ω always has isospin 0, etc.

8.5. Exotic baryons

In 2003, several experiments reported finding a strangeness S=+1, charge Q=+1 baryon, and one experiment reported finding an $S=-2,\,Q=-2$ baryon. Baryons with such quantum numbers cannot be made from three quarks, and thus they are exotic. The S=+1 baryon, which once would have been called a Z, was quickly dubbed the $\Theta(1540)^+$, and we proposed to name the S=-2 baryon the $\Phi(1860)$. However, these "discoveries" were then completely ruled out by many experiments with far larger statistics: See our 2008 Review [2].

Footnote and Reference:

- * Sometimes a prime is necessary to distinguish two Ξ_c 's in the same $\mathrm{SU}(n)$ multiplet. See the "Note on Charmed Baryons" in the Charmed Baryon Listings.
- Particle Data Group: M. Aguilar-Benitez et al., Phys. Lett. 170B (1986).
- Particle Data Group: C. Amsler *et al.*, Phys. Lett. **B667**, 1 (2008).

9. QUANTUM CHROMODYNAMICS

Revised April 2012 by S. Bethke (MPP, Munich), G. Dissertori (ETH, Zurich) and G.P. Salam (CERN, Princeton University and LPTHE, Paris).

9.1. Basics

Quantum Chromodynamics (QCD), the gauge field theory that describes the strong interactions of colored quarks and gluons, is the SU(3) component of the SU(3)×SU(2)×U(1) Standard Model of Particle Physics.

The Lagrangian of QCD is given by

$$\mathcal{L} = \sum_{q} \bar{\psi}_{q,a} (i \gamma^{\mu} \partial_{\mu} \delta_{ab} - g_s \gamma^{\mu} t^{C}_{ab} \mathcal{A}^{C}_{\mu} - m_{q} \delta_{ab}) \psi_{q,b} - \frac{1}{4} F^{A}_{\mu\nu} F^{A \mu\nu} , \ (9.1)$$

where repeated indices are summed over. The γ^{μ} are the Dirac γ -matrices. The $\psi_{q,a}$ are quark-field spinors for a quark of flavor q and mass m_q , with a color-index a that runs from a=1 to $N_c=3$, i.e. quarks come in three "colors." Quarks are said to be in the fundamental representation of the SU(3) color group.

The \mathcal{A}^C_μ correspond to the gluon fields, with C running from 1 to $N_c^2-1=8$, i.e. there are eight kinds of gluon. Gluons are said to be in the adjoint representation of the SU(3) color group. The t^C_{ab} correspond to eight 3×3 matrices and are the generators of the SU(3) group (cf. the section on "SU(3) isoscalar factors and representation matrices" in this Review with $t^C_{ab}\equiv \lambda^C_{ab}/2$). They encode the fact that a gluon's interaction with a quark rotates the quark's color in SU(3) space. The quantity g_s is the QCD coupling constant. Finally, the field tensor $F^A_{\mu\nu}$ is given by

$$F_{\mu\nu}^{A} = \partial_{\mu} A_{\nu}^{A} - \partial_{\nu} A_{\mu}^{A} - g_{s} f_{ABC} A_{\mu}^{B} A_{\nu}^{C} \qquad [t^{A}, t^{B}] = i f_{ABC} t^{C} , \tag{9.2}$$

where the f_{ABC} are the structure constants of the SU(3) group.

Neither quarks nor gluons are observed as free particles. Hadrons are color-singlet (i.e. color-neutral) combinations of quarks, antiquarks, and gluons.

Ab-initio predictive methods for QCD include lattice gauge theory and perturbative expansions in the coupling. The Feynman rules of QCD involve a quark-antiquark-gluon $(q\bar{q}g)$ vertex, a 3-gluon vertex (both proportional to g_s), and a 4-gluon vertex (proportional to g_s^2). A full set of Feynman rules is to be found for example in Ref. 3.

Useful color-algebra relations include: $t_a^A t_b^A = C_F \delta_{ac}$, where $C_F \equiv (N_c^2-1)/(2N_c) = 4/3$ is the color-factor ("Casimir") associated with gluon emission from a quark; $f^{ACD} f^{BCD} = C_A \delta_{AB}$ where $C_A \equiv N_c = 3$ is the color-factor associated with gluon emission from a gluon; $t_{ab}^A t_{ab}^B = T_R \delta_{AB}$, where $T_R = 1/2$ is the color-factor for a gluon to split to a $q\bar{q}$ pair.

The fundamental parameters of QCD are the coupling g_s (or $\alpha_s=\frac{g_s^2}{4\pi}$) and the quark masses m_q .

There is freedom for an additional CP-violating term to be present in the QCD Lagrangian, $\theta \frac{\alpha_s}{8\pi} F_{\mu\nu}^A \tilde{F}^{A\mu\nu}$, where $F_{\mu\nu}^A \tilde{F}^{A\mu\nu}$ is the dual of the gluon field tensor, $\frac{1}{2} \epsilon_{\mu\nu\sigma\rho} F^{A\sigma\rho}$. Experimental limits on the neutron electric dipole moment [1] constrain the coefficient of this contribution to satisfy $|theta| \lesssim 10^{-10}$. Further discussion is to be found in Ref. 2 and Axions section in the Listings of this Review.

This section will concentrate mainly on perturbative aspects of QCD as they relate to collider physics. Related textbooks and reviews include Refs. 3–6. Aspects specific to Monte Carlo event generators are reviewed in a dedicated section Chap. 38. Lattice QCD is also reviewed in a section of its own Chap. 17, with additional discussion of non-perturbative aspects to be found in the sections on "Quark Masses", "The CKM quark-mixing matrix", "Structure Functions" and event generators in this *Review*. For an overview of some of the QCD issues and recent results in heavy-ion physics, see for example Refs. 7, 8.

9.1.1. Running coupling:

In the framework of perturbative QCD (pQCD), predictions for observables are expressed in terms of the renormalized coupling $\alpha_s(\mu_R^2)$, a function of an (unphysical) renormalization scale μ_R . When one takes μ_R close to the scale of the momentum transfer Q in a given process, then $\alpha_s(\mu_R^2 \simeq Q^2)$ is indicative of the effective strength of the strong interaction in that process.

The coupling satisfies the following renormalization group equation (RGE):

$$\mu_R^2 \frac{d\alpha_s}{d\mu_D^2} = \beta(\alpha_s) = -(b_0 \alpha_s^2 + b_1 \alpha_s^3 + b_2 \alpha_s^4 + \cdots)$$
 (9.3)

where $b_0=(11C_A-4n_fT_R)/(12\pi)=(33-2n_f)/(12\pi)$ is referred to as the 1-loop beta-function coefficient, the 2-loop coefficient is $b_1=(17C_A^2-n_fT_R(10C_A+6C_F))/(24\pi^2)=(153-19n_f)/(24\pi^2),$ and the 3-loop coefficient is $b_2=(2857-\frac{5033}{9}n_f+\frac{325}{27}n_f^2)/(128\pi^3).$ The 4-loop coefficient, b_3 , is to be found in Refs. 9, 10^{\dagger} . The minus sign in Eq. (9.3) is the origin of Asymptotic Freedom, i.e. the fact that the strong coupling becomes weak for processes involving large momentum transfers ("hard processes"), $\alpha_s\sim 0.1$ for momentum transfers in the 100 GeV – TeV range.

The β -function coefficients, the b_i , are given for the coupling of an effective theory in which n_f of the quark flavors are considered light $(m_q \ll \mu_R)$, and in which the remaining heavier quark flavors decouple from the theory. One may relate the coupling for the theory with n_f+1 light flavors to that with n_f flavors through an equation of the form

$$\alpha_s^{(n_f+1)}(\mu_R^2) = \alpha_s^{(n_f)}(\mu_R^2) \left(1 + \sum_{n=1}^{\infty} \sum_{\ell=0}^{n} c_{n\ell} \left[\alpha_s^{(n_f)}(\mu_R^2) \right]^n \ln^{\ell} \frac{\mu_R^2}{m_h^2} \right), \tag{9.4}$$

where m_h is the mass of the $(n_f+1)^{\rm th}$ flavor, and the first few $c_{n\ell}$ coefficients are $c_{11}=\frac{1}{6\pi},\ c_{10}=0,\ c_{22}=c_{11}^2,\ c_{21}=\frac{19}{24\pi^2},$ and $c_{20}=-\frac{11}{72\pi^2}$ when m_h is the $\overline{\rm MS}$ mass at scale m_h $(c_{20}=\frac{7}{24\pi^2}$ when m_h is the pole mass — mass definitions are discussed below and in the review on "Quark Masses"). Terms up to $c_{4\ell}$ are to be found in Refs. 11, 12. Numerically, when one chooses $\mu_R=m_h$, the matching is a modest effect, owing to the zero value for the c_{10} coefficient. Relations between n_f and (n_f+2) flavors where the two heavy flavors are close in mass are given to three loops in Ref. 13.

Working in an energy range where the number of flavors is taken constant, a simple exact analytic solution exists for Eq. (9.3) only if one neglects all but the b_0 term, giving $\alpha_s(\mu_R^2) = (b_0 \ln(\mu_R^2/\Lambda^2))^{-1}$. Here Λ is a constant of integration, which corresponds to the scale where the perturbatively-defined coupling would diverge, *i.e.* it is the non-perturbative scale of QCD. A convenient approximate analytic solution to the RGE that includes also the b_1 , b_2 , and b_3 terms is given by (see for example Ref. 14),

$$\alpha_s(\mu_R^2) \simeq \frac{1}{b_0 t} \left(1 - \frac{b_1}{b_0^2} \frac{\ln t}{t} + \frac{b_1^2 (\ln^2 t - \ln t - 1) + b_0 b_2}{b_0^4 t^2} \right)$$

$$-\frac{b_1^3(\ln^3 t - \frac{5}{2}\ln^2 t - 2\ln t + \frac{1}{2}) + 3b_0b_1b_2\ln t - \frac{1}{2}b_0^2b_3}{b_0^6t^3}\right), \quad t \equiv \ln\frac{\mu_R^2}{\Lambda^2},$$
(9.5)

again parametrized in terms of a constant Λ . Note that Eq. (9.5) is one of several possible approximate 4-loop solutions for $\alpha_s(\mu_R^2)$, and that a value for Λ only defines $\alpha_s(\mu_R^2)$ once one knows which particular approximation is being used. An alternative to the use of formulas such as Eq. (9.5) is to solve the RGE exactly, numerically (including the discontinuities, Eq. (9.4), at flavor thresholds). In such cases the quantity Λ is not defined at all. For these reasons, in determinations

 $^{^\}dagger$ One should be aware that the b_2 and b_3 coefficients are renormalization-scheme-dependent, and given here in the $\overline{\rm MS}$ scheme, as discussed below.

of the coupling, it has become standard practice to quote the value of α_s at a given scale (typically M_Z) rather than to quote a value for Λ .

The value of the coupling, as well as the exact forms of the b_2 , c_{10} (and higher order) coefficients, depend on the renormalization scheme in which the coupling is defined, *i.e.* the convention used to subtract infinities in the context of renormalization. The coefficients given above hold for a coupling defined in the modified minimal subtraction $(\overline{\text{MS}})$ scheme [15], by far the most widely used scheme.

A discussion of determinations of the coupling and a graph illustrating its scale dependence ("running") are to be found in Section 9.3.4.

9.1.2. Quark masses:

Free quarks are never observed, i.e. a quark never exists on its own for a time longer than $\sim 1/\Lambda$: up, down, strange, charm, and bottom quarks all hadronize, i.e. become part of a meson or baryon, on a timescale $\sim 1/\Lambda$; the top quark instead decays before it has time to hadronize. This means that the question of what one means by the quark mass is a complex one, which requires that one adopts a specific prescription. A perturbatively defined prescription is the pole mass, m_q , which corresponds to the position of the divergence of the propagator. This is close to one's physical picture of mass. However, when relating it to observable quantities, it suffers from substantial non-perturbative ambiguities (see e.g. Ref. 16). An alternative is the $\overline{\rm MS}$ mass, $\overline{m}_q(\mu_R^2)$, which depends on the renormalization scale μ_R .

Results for the masses of heavier quarks are often quoted either as the pole mass or as the $\overline{\rm MS}$ mass evaluated at a scale equal to the mass, $\overline{m}_q(\overline{m}_q^2)$; light quark masses are generally quoted in the $\overline{\rm MS}$ scheme at a scale $\mu_R\sim 2~{\rm GeV}$. The pole and $\overline{\rm MS}$ masses are related by a slowly converging series that starts $m_q=\overline{m}_q(\overline{m}_q^2)(1+\frac{4\alpha_s(\overline{m}_q^2)}{3\pi}+\mathcal{O}(\alpha_s^2)),$ while the scale-dependence of $\overline{\rm MS}$ masses is given by

$$\mu_R^2 \frac{d\overline{m}_q(\mu_R^2)}{d\mu_R^2} = \left[-\frac{\alpha_s(\mu_R^2)}{\pi} + \mathcal{O}(\alpha_s^2) \right] \overline{m}_q(\mu_R^2). \tag{9.6}$$

More detailed discussion is to be found in a dedicated section of the Review, "Quark Masses."

9.2. Structure of QCD predictions

9.2.1. Fully inclusive cross sections:

The simplest observables in QCD are those that do not involve initial-state hadrons and that are fully inclusive with respect to details of the final state. One example is the total cross section for $e^+e^- \to \text{hadrons}$ at center-of-mass energy Q, for which one can write

$$\frac{\sigma(e^+e^- \to \text{hadrons}, Q)}{\sigma(e^+e^- \to \mu^+\mu^-, Q)} \equiv R(Q) = R_{\text{EW}}(Q)(1 + \delta_{\text{QCD}}(Q)), \quad (9.7)$$

where $R_{\text{EW}}(Q)$ is the purely electroweak prediction for the ratio and $\delta_{\text{QCD}}(Q)$ is the correction due to QCD effects. To keep the discussion simple, we can restrict our attention to energies $Q \ll M_Z$, where the process is dominated by photon exchange $(R_{\text{EW}} = 3 \sum_q e_q^2)$, neglecting finite-quark-mass corrections),

$$\delta_{\text{QCD}}(Q) = \sum_{n=1}^{\infty} c_n \cdot \left(\frac{\alpha_s(Q^2)}{\pi}\right)^n + \mathcal{O}\left(\frac{\Lambda^4}{Q^4}\right) .$$
 (9.8)

The first four terms in the α_s series expansion are then to be found in Refs. 17, 18

$$c_1 = 1$$
, $c_2 = 1.9857 - 0.1152n_f$, (9.9a)

$$c_3 = -6.63694 - 1.20013n_f - 0.00518n_f^2 - 1.240\eta \tag{9.9b}$$

$$c_4 = -156.61 + 18.77n_f - 0.7974n_f^2 + 0.0215n_f^3 + C\eta$$
, (9.9c)

with $\eta = (\sum e_q)^2/(3\sum e_q^2)$ and where the coefficient C of the η -dependent piece in the α_s^4 term has yet to be determined. For

corresponding expressions including also Z exchange and finite-quark-mass effects, see Refs. 19, 20.

A related series holds also for the QCD corrections to the hadronic decay width of the τ lepton, which essentially involves an integral of R(Q) over the allowed range of invariant masses of the hadronic part of the τ decay (see e.g. Ref. 17). The series expansions for QCD corrections to Higgs-boson (partial) decay widths are summarized in Refs. 21, 22.

One characteristic feature of Eqs. (9.8) and (9.9) is that the coefficients of α_s^n increase rapidly order by order: calculations in perturbative QCD tend to converge more slowly than would be expected based just on the size of $\alpha_s^{\dagger\dagger}$. Another feature is the existence of an extra "power-correction" term $\mathcal{O}(\Lambda^4/Q^4)$ in Eq. (9.8), which accounts for contributions that are fundamentally non-perturbative. All high-energy QCD predictions involve such corrections, though the exact power of Λ/Q depends on the observable.

Scale dependence. In Eq. (9.8) the renormalization scale for α_s has been chosen equal to Q. The result can also be expressed in terms of the coupling at an arbitrary renormalization scale μ_R ,

$$\delta_{\rm QCD}(Q) = \sum_{n=1}^{\infty} \overline{c}_n \left(\frac{\mu_R^2}{Q^2} \right) \cdot \left(\frac{\alpha_s(\mu_R^2)}{\pi} \right)^n + \mathcal{O}\left(\frac{\Lambda^4}{Q^4} \right) \,, \tag{9.10}$$

where $\overline{c}_1(\mu_R^2/Q^2) \equiv c_1$, $\overline{c}_2(\mu_R^2/Q^2) = c_2 + \pi b_0 c_1 \ln(\mu_R^2/Q^2)$, $\overline{c}_3(\mu_R^2/Q^2) = c_3 + (2b_0 c_2 \pi + b_1 c_1 \pi^2) \ln(\mu_R^2/Q^2) + b_0^2 c_1 \pi^2 \ln^2(\mu_R^2/Q^2)$, etc. Given an infinite number of terms in the α_s expansion, the μ_R dependence of the $\overline{c}_n(\mu_R^2/Q^2)$ coefficients will exactly cancel that of $\alpha_s(\mu_R^2)$, and the final result will be independent of the choice of μ_R : physical observables do not depend on unphysical scales.

With just terms up to n=N, a residual μ_R dependence will remain, which implies an uncertainty on the prediction of R(Q) due to the arbitrariness of the scale choice. This uncertainty will be $\mathcal{O}(\alpha_s^{N+1})$, i.e. of the same order as the neglected terms. For this reason it is standard to use QCD predictions' scale dependence as an estimate of the uncertainties due to neglected terms. One usually takes a central value for $\mu_R \sim Q$, in order to avoid the poor convergence of the perturbative series that results from the large $\ln^{n-1}(\mu_R^2/Q^2)$ terms in the \overline{c}_n coefficients when $\mu_R \ll Q$ or $\mu_R \gg Q$.

9.2.1.1. Processes with initial-state hadrons:

Deep Inelastic Scattering. To illustrate the key features of QCD cross sections in processes with initial-state hadrons, let us consider deep-inelastic scattering (DIS), $ep \rightarrow e + X$, where an electron e with four-momentum k emits a highly off-shell photon (momentum q) that interacts with the proton (momentum p). For photon virtualities $Q^2 \equiv -q^2$ far above the squared proton mass (but far below the Z mass), the differential cross section in terms of the kinematic variables Q^2 , $x = Q^2/(2p \cdot q)$ and $y = (q \cdot p)/(k \cdot p)$ is

$$\frac{d^2\sigma}{dxdQ^2} = \frac{4\pi\alpha}{2xQ^4} \left[(1 + (1-y)^2)F_2(x,Q^2) - y^2F_L(x,Q^2) \right], \quad (9.11)$$

where α is the electromagnetic coupling and $F_2(x,Q^2)$ and $F_L(x,Q^2)$ are proton structure functions, which encode the interaction between the photon (in given polarization states) and the proton. In the presence of parity-violating interactions (e.g. νp scattering) an additional F_3 structure function is present. For an extended review, including equations for the full electroweak and polarized cases, see Sec. 18 of this Review.

Structure functions are not calculable in perturbative QCD, nor is any other cross section that involves initial-state hadrons. To zeroth order in α_s , the structure functions are given directly in terms of non-perturbative parton (quark or gluon) distribution functions (PDFs),

$$F_2(x,Q^2) = x \sum_q e_q^2 f_{q/p}(x) \,, \qquad F_L(x,Q^2) = 0 \,, \eqno(9.12)$$

 $^{^{\}dagger\dagger}$ The situation is significantly worse near thresholds, e.g. the $t\bar{t}$ production threshold. An overview of some of the effective field theory techniques used in such cases is to be found for example in Ref. 23.

where $f_{q/p}(x)$ is the PDF for quarks of type q inside the proton, *i.e.* the number density of quarks of type q inside a fast-moving proton that carry a fraction x of its longitudinal momentum (the quark flavor index q, here, is not to be confused with the photon momentum q in the lines preceding Eq. (9.11)). Since PDFs are non-perturbative, and difficult to calculate in lattice QCD [24], they must be extracted from data.

The above result, with PDFs $f_{q/p}(x)$ that are independent of the scale Q, corresponds to the "quark-parton model" picture in which the photon interacts with point-like free quarks, or equivalently, one has incoherent elastic scattering between the electron and individual constituents of the proton. As a consequence, in this picture also F_2 and F_L are independent of Q. When including higher orders in pQCD, Eq. (9.12) becomes

$$F_{2}(x, Q^{2}) = x \sum_{n=0}^{\infty} \frac{\alpha_{s}^{n}(\mu_{R}^{2})}{(2\pi)^{n}} \sum_{i=q,g} \int_{x}^{1} \frac{dz}{z} C_{2,i}^{(n)}(z, Q^{2}, \mu_{R}^{2}, \mu_{F}^{2}) f_{i/p}(\frac{x}{z}, \mu_{F}^{2}) + \mathcal{O}\left(\frac{\Lambda^{2}}{Q^{2}}\right).$$

$$(9.13)$$

Just as in Eq. (9.10), we have a series in powers $\alpha_s(\mu_R^2)$, each term involving a coefficient $C_{2,i}^{(n)}$ that can be calculated using Feynman graphs. An important difference relative to Eq. (9.10) stems from the fact that the quark's momentum, when it interacts with the photon, can differ from its momentum when it was extracted from the proton, because it may have radiated gluons in between. As a result, the $C_{2,i}^{(n)}$ coefficients are functions that depend on the ratio, z, of these two momenta, and one must integrate over z. At zeroth order, $C_{2,q}^{(0)} = e_q^2 \delta(1-z)$ and $C_{2,g}^{(0)} = 0$.

The majority of the emissions that modify a parton's momentum are collinear (parallel) to that parton, and don't depend on the fact that the parton is destined to interact with a photon. It is natural to view these emissions as modifying the proton's structure rather than being part of the coefficient function for the parton's interaction with the photon. Technically, one uses a procedure known as collinear factorization to give a well-defined meaning to this distinction, most commonly through the MS factorization scheme, defined in the context of dimensional regularization. The $\overline{\rm MS}$ factorization scheme involves an arbitrary choice of factorization scale, μ_F , whose meaning can be understood roughly as follows: emissions with transverse momenta above μ_F are included in the $C_{2,q}^{(n)}(z,Q^2,\mu_R^2,\mu_F^2)$; emissions with transverse momenta below μ_F are accounted for within the PDFs, $f_{i/p}(x,\mu_F^2)$. While collinear factorization is generally believed to be valid for suitable (sufficiently inclusive) observables in processes with hard scales, Ref. 35, which reviews the factorization proofs in detail, is cautious in the statements it makes about their exhaustivity, notably for the hadron-collider processes that we shall discuss below. Further discussion is to be found in Refs. 36.37.

The PDFs' resulting dependence on μ_F is described by the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equations [25], which to leading order (LO) read*

$$\mu^{2} \frac{\partial f_{i/p}(x, \mu_{F}^{2})}{\partial \mu_{F}^{2}} = \sum_{j} \frac{\alpha_{s}(\mu_{F}^{2})}{2\pi} \int_{x}^{1} \frac{dz}{z} P_{i \leftarrow j}^{(1)}(z) f_{j/p}\left(\frac{x}{z}, \mu_{F}^{2}\right), \quad (9.14)$$

with, for example, $P_{q \leftarrow g}^{(1)}(z) = T_R(z^2 + (1-z)^2)$. The other LO splitting functions are listed in Sec. 18 of this *Review*, while results up

to next-to-leading order (NLO), α_s^2 , and next-to-next-to-leading order (NNLO), α_s^3 , are given in Refs. 26 and 27 respectively. The coefficient functions are also μ_F dependent, for example $C_{2,i}^{(1)}(x,Q^2,\mu_R^2,\mu_F^2) = C_{2,i}^{(1)}(x,Q^2,\mu_R^2,Q^2) - \ln(\frac{\mu_F^2}{Q^2}) \sum_j \int_x^1 \frac{dz}{z} C_{2,j}^{(0)}(\frac{x}{z}) P_{j\leftarrow i}^{(1)}(z)$. For the electromagnetic component of DIS with light quarks and gluons they are known to $\mathcal{O}(\alpha_s^3)$ (N³LO) [28]. For weak currents they are known fully to α_s^2 (NNLO) [29] with substantial results known also at N³LO [30]. For heavy quark production they are known to $\mathcal{O}(\alpha_s^2)$ [31] (NLO insofar as the series starts at $\mathcal{O}(\alpha_s)$), with work ongoing towards NNLO [32,33].

As with the renormalization scale, the choice of factorization scale is arbitrary, but if one has an infinite number of terms in the perturbative series, the μ_F -dependences of the coefficient functions and PDFs will compensate each other fully. Given only N terms of the series, a residual $\mathcal{O}(\alpha_s^{N+1})$ uncertainty is associated with the ambiguity in the choice of μ_F . As with μ_R , varying μ_F provides an input in estimating uncertainties on predictions. In inclusive DIS predictions, the default choice for the scales is usually $\mu_R = \mu_F = Q$. Hadron-hadron collisions. The extension to processes with two initial-state hadrons is straightforward, and for example the total (inclusive) cross section for W boson production in collisions of

$$\begin{split} \sigma(h_1 h_2 \to W + X) &= \sum_{n=0}^{\infty} \alpha_s^n(\mu_R^2) \sum_{i,j} \int dx_1 dx_2 \, f_{i/h_1} \Big(x_1, \mu_F^2 \Big) f_{j/h_2} \Big(x_2, \mu_F^2 \Big) \\ &\times \hat{\sigma}_{ij \to W + X}^{(n)} \Big(x_1 x_2 s, \mu_R^2, \mu_F^2 \Big) \,, \end{split} \tag{9.15}$$

hadrons h_1 and h_2 can be written as

where s is the squared center-of-mass energy of the collision. At LO, n=0, the hard (partonic) cross section $\hat{\sigma}_{ij\to W+X}^{(0)}(x_1x_2s,\mu_R^2,\mu_F^2)$ is simply proportional to $\delta(x_1x_2s-M_W^2)$, in the narrow W-boson width approximation (see Sec. 44 of this Review for detailed expressions for this and other hard scattering cross sections). It is non-zero only for choices of i,j that can directly give a W, such as $i=u,\ j=\bar{d}$. At higher orders, $n\geq 1$, new partonic channels contribute, such as gq, and there is no restriction $x_1x_2s=M_W^2$.

Equation 9.15 involves a collinear factorization between hard cross section and PDFs, just like Eq. (9.13). As long as the same factorization scheme is used in DIS and pp or $p\bar{p}$ (usually the $\overline{\rm MS}$ scheme), then PDFs extracted in DIS can be directly used in pp and $p\bar{p}$ predictions [34,35] (with the anti-quark distributions in an anti-proton being the same as the quark distributions in a proton). Note that Eq. (9.15) only holds to within contributions that are suppressed by powers of m_p^2/m_W^2 .

Fully inclusive hard cross sections are known to NNLO, i.e. corrections up to relative order α_s^2 , for Drell-Yan (DY) lepton-pair and vector-boson production [38,39], Higgs-boson production via gluon fusion [39–41], Higgs-boson production in association with a vector boson [42] and Higgs-boson production via vector-boson fusion [43](in an approximation that factorizes the production of the two vector bosons). A review of fully inclusive Higgs-related results is to be found in Ref. 44.

Photoproduction. γp (and $\gamma \gamma$) collisions are similar to pp collisions, with the subtlety that the photon can behave in two ways: there is "direct" photoproduction, in which the photon behaves as a point-like particle and takes part directly in the hard collision, with hard subprocesses such as $\gamma g \to q\bar{q}$; there is also resolved photoproduction, in which the photon behaves like a hadron, with non-perturbative partonic substructure and a corresponding PDF for its quark and gluon content, $f_{i/\gamma}(x,Q^2)$.

While useful to understand the general structure of γp collisions, the distinction between direct and resolved photoproduction is not well defined beyond leading order, as discussed for example in Ref. 45.

The high-energy limit. In situations in which the total center-of-mass energy \sqrt{s} is much larger than other scales in the problem (e.g. Q in DIS, m_b for $b\bar{b}$ production in pp collisions, etc.), each power of α_s beyond LO can be accompanied by a power of $\ln(s/Q^2)$ (or $\ln(s/m_b^2)$, etc.). This is known as the high-energy or Balitsky-Fadin-Kuraev-Lipatov (BFKL) limit [46–48]. Currently it is possible to account

^{*} LO is generally taken to mean the lowest order at which a quantity is non-zero. This definition is nearly always unambiguous, the one major exception being for the case of the hadronic branching ratio of virtual photons, Z, τ , etc., for which two conventions exist: LO can either mean the lowest order that contributes to the hadronic branching fraction, *i.e.* the term "1" in Eq. (9.7); or it can mean the lowest order at which the hadronic branching ratio becomes sensitive to the coupling, n=1 in Eq. (9.8), as is relevant when extracting the value of the coupling from a measurement of the branching ratio. Because of this ambiguity, we avoided use of the term "LO" in that context.

for the dominant and first subdominant [49,50] power of $\ln s$ at each order of α_s , and also to estimate further subdominant contributions that are numerically large (see Refs. 51–53 and references therein).

Physically, the summation of all orders in α_s can be understood as leading to a growth with s of the gluon density in the proton. At sufficiently high energies this implies non-linear effects, whose treatment has been the subject of intense study (see for example Refs. 54, 55 and references thereto). Note that it is not straightforward to relate these results to the genuinely non-perturbative total, elastic and diffractive cross sections for hadron-hadron scattering (experimental results for which are summarized in section Chap. 46 of this Review).

9.2.2. Non fully inclusive cross-sections:

QCD final states always consist of hadrons, while perturbative QCD calculations deal with partons. Physically, an energetic parton fragments ("showers") into many further partons, which then, on later timescales, undergo a transition to hadrons ("hadronization"). Fixed-order perturbation theory captures only a small part of these dynamics.

This does not matter for the fully inclusive cross sections discussed above: the showering and hadronization stages are "unitary", i.e. they do not change the overall probability of hard scattering, because they occur long after it has taken place.

Less inclusive measurements, in contrast, may be affected by the extra dynamics. For those sensitive just to the main directions of energy flow (jet rates, event shapes, cf. Sec. 9.3.1) fixed order perturbation theory is often still adequate, because showering and hadronization don't substantially change the overall energy flow. This means that one can make a prediction using just a small number of partons, which should correspond well to a measurement of the same observable carried out on hadrons. For observables that instead depend on distributions of individual hadrons (which, e.g., are the inputs to detector simulations), it is mandatory to account for showering and hadronization. The range of predictive techniques available for QCD final states reflects this diversity of needs of different measurements.

While illustrating the different methods, we shall for simplicity mainly use expressions that hold for e^+e^- scattering. The extension to cases with initial-state partons will be mostly straightforward (space constraints unfortunately prevent us from addressing diffraction and exclusive hadron-production processes; extensive discussion is to be found in Refs. 56, 57).

9.2.2.1. Preliminaries: Soft and collinear limits:

Before examining specific predictive methods, it is useful to be aware of a general property of QCD matrix elements in the soft and collinear limits. Consider a squared tree-level matrix element $|M_n^2(p_1,\ldots,p_n)|$ for the process $e^+e^- \to n$ partons with momenta p_1,\ldots,p_n , and a corresponding phase-space integration measure $d\Phi_n$. If particle n is a gluon, and additionally it becomes collinear (parallel) to another particle i and its momentum tends to zero (it becomes "soft"), the matrix element simplifies as follows,

$$\begin{split} &\lim_{\theta_{in}\to 0, E_{n}\to 0} d\Phi_{n} |M_{n}^{2}(p_{1},\dots,p_{n})| \\ &= d\Phi_{n-1} |M_{n-1}^{2}(p_{1},\dots,p_{n-1})| \frac{\alpha_{s}C_{i}}{\pi} \frac{d\theta_{in}^{2}}{\theta_{in}^{2}} \frac{dE_{n}}{E_{n}} , \ (9.16) \end{split}$$

where $C_i=C_F$ (C_A) if i is a quark (gluon). This formula has non-integrable divergences both for the inter-parton angle $\theta_{in} \to 0$ and for the gluon energy $E_n \to 0$, which are mirrored also in the structure of divergences in loop diagrams. These divergences are important for at least two reasons: firstly, they govern the typical structure of events (inducing many emissions either with low energy or at small angle with respect to hard partons); secondly, they will determine which observables can be calculated within perturbative QCD.

9.2.2.2. Fixed-order predictions:

Let us consider an observable \mathcal{O} that is a function $\mathcal{O}_n(p_1,\ldots,p_n)$ of the four-momenta of the n particles in an event (whether partons or hadrons). In what follows, we shall consider the cross section for events weighted with the value of the observable, $\sigma_{\mathcal{O}}$. As examples, if $\mathcal{O}_n \equiv 1$ for all n, then $\sigma_{\mathcal{O}}$ is just the total cross section; if $\mathcal{O}_n \equiv \hat{\tau}(p_1,\ldots,p_n)$ where $\hat{\tau}$ is the value of the Thrust for that event (see Sec. 9.3.1.2), then the average value of the Thrust is $\langle \tau \rangle = \sigma_{\mathcal{O}}/\sigma_{\text{tot}}$; if $\mathcal{O}_n \equiv \delta(\tau - \hat{\tau}(p_1,\ldots,p_n))$ then one gets the differential cross section as a function of the Thrust, $\sigma_{\mathcal{O}} \equiv d\sigma/d\tau$.

In the expressions below, we shall omit to write the non-perturbative power correction term, which for most common observables is proportional to a single power of Λ/Q .

LO. If the observable $\mathcal O$ is non-zero only for events with at least n particles, then the LO QCD prediction for the weighted cross section in e^+e^- annihilation is

$$\sigma_{\mathcal{O},LO} = \alpha_s^{n-2}(\mu_R^2) \int d\Phi_n |M_n^2(p_1,\dots,p_n)| \mathcal{O}_n(p_1,\dots,p_n), \quad (9.17)$$

where the squared tree-level matrix element, $|M_n^2(p_1,\ldots,p_n)|$, includes relevant symmetry factors, has been summed over all subprocesses (e.g. $e^+e^-\to q\bar qq\bar q$, $e^+e^-\to q\bar qgg$) and has had all factors of α_s extracted in front. In processes other than e^+e^- collisions, the powers of the coupling are often brought inside the integrals, with the scale μ_R chosen event by event, as a function of the event kinematics.

Other than in the simplest cases (see the review on Cross Sections in this *Review*), the matrix elements in Eq. (9.17) are usually calculated automatically with programs such as CompHEP [58], MadGraph [59], Alpgen [60], Comix/Sherpa [61], and Helac/Phegas [62]. Some of these (CompHEP, MadGraph) use formulas obtained from direct evaluations of Feynman diagrams. Others (Alpgen, Helac/Phegas and Comix/Sherpa) use methods designed to be particularly efficient at high multiplicities, such as Berends-Giele recursion [63] (see also the reviews [64,65]), which builds up amplitudes for complex processes from simpler ones.

The phase-space integration is usually carried out by Monte Carlo sampling, in order to deal with the sometimes complicated cuts that are used in corresponding experimental measurements. Because of the divergences in the matrix element, Eq. (9.16), the integral converges only if the observable vanishes for kinematic configurations in which one of the n particles is arbitrarily soft or it is collinear to another particle. As an example, the cross section for producing any configuration of n partons will lead to an infinite integral, whereas a finite result will be obtained for the cross section for producing n deposits of energy (or jets, see Sec. 9.3.1.1), each above some energy threshold and well separated from each other in angle.

LO calculations can be carried out for $2 \to n$ processes with $n \lesssim 6-10$. The exact upper limit depends on the process, the method used to evaluate the matrix elements (recursive methods are more efficient), and the extent to which the phase-space integration can be optimized to work around the large variations in the values of the matrix elements.

NLO. Given an observable that is non-zero starting from n particles, its prediction at NLO involves supplementing the LO result with the (n+1)-particle tree-level matrix element $(|M_{n+1}^2|)$, and the interference of a n-particle tree-level and n-particle 1-loop amplitude $(2\text{Re}(M_nM_{n,1-\text{loop}}^*))$,

$$\begin{split} \sigma_{\mathcal{O}}^{NLO} &= \sigma_{\mathcal{O}}^{LO} + \alpha_s^{n-1}(\mu_R^2) \int \!\! d\Phi_{n+1} \\ &| M_{n+1}^2(p_1, \dots, p_{n+1})| \, \mathcal{O}_{n+1}(p_1, \dots, p_{n+1}) \\ &+ \alpha_s^{n-1}(\mu_R^2) \int \!\! d\Phi_n \, 2 \mathrm{Re}[M_n(p_1, \dots, p_n) \\ &M_{n,1-\mathrm{loop}}^*(p_1, \dots, p_n) \,] \, \mathcal{O}_n(p_1, \dots, p_n) \,. \end{split} \tag{9.18}$$

Relative to LO calculations, two important issues appear in the NLO calculations. Firstly, the extra complexity of loop-calculations relative to tree-level calculations means that their automation is at a comparatively early stage (see below). Secondly, loop amplitudes

are infinite in 4 dimensions, while tree-level amplitudes are finite, but their *integrals* are infinite, due to the divergences of Eq. (9.16). These two sources of infinities have the same soft and collinear origins and cancel after the integration only if the observable \mathcal{O} satisfies the property of infrared and collinear safety,

$$\mathcal{O}_{n+1}(p_1, \dots, p_s, \dots, p_n) \to \mathcal{O}_n(p_1, \dots, p_n) \quad \text{if } p_s \to 0
\mathcal{O}_{n+1}(p_1, \dots, p_a, p_b, \dots, p_n) \to \mathcal{O}_n(p_1, \dots, p_a + p_b, \dots, p_n)
\quad \text{if } p_a \mid\mid p_b. \tag{9.19}$$

Examples of infrared safe quantities include event-shape distributions and jet cross sections (with appropriate jet algorithms, see below). Unsafe quantities include the distribution of the momentum of the hardest QCD particle (which is not conserved under collinear splitting), observables that require the complete absence of radiation in some region of phase-space (e.g. rapidity gaps or 100% isolation cuts, which are affected by soft emissions), or the particle multiplicity (affected by both soft and collinear emissions). The non-cancellation of divergences at NLO due to infrared or collinear unsafety compromises the usefulness not only of the NLO calculation, but also that of a LO calculation, since LO is only an acceptable approximation if one can prove that higher order terms are smaller. Infrared and collinear unsafety usually also imply large non-perturbative effects.

As with LO calculations, the phase-space integrals in Eq. (9.18) are usually carried out by Monte Carlo integration, so as to facilitate the study of arbitrary observables. Various methods exist to obtain numerically efficient cancellation among the different infinities. These include notably dipole [66], FKS [67] and antenna [68] subtraction.

NLO calculations have existed for a while for a wide range of $2 \rightarrow n$ processes with $n \leq 3$, as reviewed in Ref. 69. Some of the corresponding codes are public, and those that provide access to multiple processes include NLOJet++ [70] for e^+e^- , DIS, and hadron-hadron processes involving just light partons in the final state, MCFM [71] for hadron-hadron processes with vector bosons and/or heavy quarks in the final state, VBFNLO for vector-boson fusion, di- and tri-boson processes [72], and the Phox family [73] for processes with photons in the final state. One forefront of NLO calculations is $2 \to 4$ and $2 \to 5$ processes in pp scattering (and for $1 \to 5$ in $e^+e^- \to \gamma/Z \to \text{hadrons}$ [74]), where recent results include $t\bar{t}b\bar{b}$ [80,81], $t\bar{t}+2\mathrm{jets}$ [82] and $b\bar{b}b\bar{b}$ [83], $pp \to W/Z+3\mathrm{jets}$ [75,76,77] and $pp \rightarrow W/Z + 4$ jets [78,79] as well as $W^+W^-b\bar{b}$ [84] and $W^+W^\pm + 2$ jets [85]. A related forefront is automation: a number of the above results have been obtained with partially automated approaches. A first example of full automation applied to a large number of processes has been presented recently in Ref. 86, and a public automated code is described in Ref. 87. A number of the above calculations have made use of unitarity-type techniques [88] and powerful integrand reduction methods (notably Ref. 89), which have seen significant development over the past few years, as reviewed in

NNLO. Conceptually, NNLO and NLO calculations are similar, except that one must add a further order in α_s , consisting of: the squared (n+2)-parton tree-level amplitude, the interference of the (n+1)-parton tree-level and 1-loop amplitudes, the interference of the n-parton tree-level and 2-loop amplitudes, and the squared n-parton 1-loop amplitude.

Each of these elements involves large numbers of soft and collinear divergences, satisfying relations analogous to Eq. (9.16) that now involve multiple collinear or soft particles and higher loop orders (see e.g. Refs. 88,91,92). Arranging for the cancellation of the divergences after numerical Monte Carlo integration is one of the significant challenges of NNLO calculations, as is the determination of the relevant 2-loop amplitudes. At the time of writing, the processes for which fully exclusive NNLO calculations exist include the 3-jet cross section in e^+e^- collisions [93,94] (for which NNLO means α_s^3), as well as vector-boson [95,96], Higgs-boson [97,98], WH [99] and di-photon [100] production in pp and $p\bar{p}$ collisions.

9.2.2.3. Resummation:

Many experimental measurements place tight constraints on emissions in the final state, for example, in e^+e^- events, that one minus the Thrust should be less than some value $\tau \ll 1$, or in $pp \to Z$ events that the Z-boson transverse momentum should be much smaller than its mass, $p_{t,Z} \ll M_Z$. A further example is the production of heavy particles or jets near threshold (so that little energy is left over for real emissions) in DIS and pp collisions.

In such cases, the constraint vetoes a significant part of the integral over the soft and collinear divergence of Eq. (9.16). As a result, there is only a partial cancellation between real emission terms (subject to the constraint) and loop (virtual) contributions (not subject to the constraint), causing each order of α_s to be accompanied by a large coefficient $\sim L^2$, where e.g. $L = \ln \tau$ or $L = \ln(M_Z/p_{t,Z})$. One ends up with a perturbative series whose terms go as $\sim (\alpha_s L^2)^n$. It is not uncommon that $\alpha_s L^2 \gg 1$, so that the perturbative series converges very poorly if at all.** In such cases one may carry out a "resummation," which accounts for the dominant logarithmically enhanced terms to all orders in α_s , by making use of known properties of matrix elements for multiple soft and collinear emissions, and of the all-orders properties of the divergent parts of virtual corrections, following original works such as Refs. 101-110 and also through soft-collinear effective theory [111,112] (cf. also the review in Ref. 113).

For cases with double logarithmic enhancements (two powers of logarithm per power of α_s), there are two classification schemes for resummation accuracy. Writing the cross section including the constraint as $\sigma(L)$ and the unconstrained (total) cross section as $\sigma_{\rm tot}$, the series expansion takes the form

$$\sigma(L) \simeq \sigma_{\text{tot}} \sum_{n=0}^{\infty} \sum_{k=0}^{2n} R_{nk} \alpha_s^n(\mu_R^2) L^k, \qquad L \gg 1$$
 (9.20)

and leading log (LL) resummation means that one accounts for all terms with k=2n, next-to-leading-log (NLL) includes additionally all terms with k=2n-1, etc. Often $\sigma(L)$ (or its Fourier or Mellin transform) exponentiates ‡ ,

$$\sigma(L) \simeq \sigma_{\text{tot}} \exp\left[\sum_{n=1}^{\infty} \sum_{k=0}^{n+1} G_{nk} \alpha_s^n(\mu_R^2) L^k\right], \qquad L \gg 1, \qquad (9.21)$$

where one notes the different upper limit on $k (\leq n+1)$ compared to Eq. (9.20). This is a more powerful form of resummation: the G_{12} term alone reproduces the full LL series in Eq. (9.20). With the form Eq. (9.21) one still uses the nomenclature LL, but this now means that all terms with k=n+1 are included, and NLL implies all terms with k=n, etc.

For a large number of observables, NLL resummations are available in the sense of Eq. (9.21) (see Refs. 117–119 and references therein). NNLL has been achieved for the DY and Higgs-boson p_t distributions [120,121,122,123] (in addition the NLL ResBos program [124] is still widely used), the back-to-back energy-energy correlation in e^+e^- [125], the production of top anti-top pairs near threshold [126–128] (and references therein), high- p_t W and Z production [129], and an event-shape type observable known as the beam Thrust [130]. Finally, the parts believed to be dominant in the N³LL resummation are available for the Thrust variable and

^{**} To be precise one should distinguish two causes of the divergence of perturbative series. That which interests us here is associated with the presence of a new large parameter (e.g. ratio of scales). Nearly all perturbative series also suffer from "renormalon" divergences $\alpha_s^n n!$ (reviewed in Ref. 16), which however have an impact only at very high perturbative orders and have a deep connection with non-perturbative uncertainties.

[‡] Whether or not this happens depends on the quantity being resummed. A classic example involves jet rates in e^+e^- collisions as a function of a jet-resolution parameter y_{cut} . The logarithms of $1/y_{\text{cut}}$ exponentiate for the k_t (Durham) jet algorithm [114], but not [115] for the JADE algorithm [116] (both are discussed below in Sec. 9.3.1.1).

heavy-jet mass in e^+e^- annihilations [131,132] (confirmed for Thrust at NNLL in Ref. 133), and for Higgs- and vector-boson production near threshold [134,135] in hadron collisions (NNLL in Refs. 136,137). The inputs and methods involved in these various calculations are somewhat too diverse to discuss in detail here, so we recommend that the interested reader consult the original references for further details.

9.2.2.4. Fragmentation functions:

Since the parton-hadron transition is non-perturbative, it is not possible to perturbatively calculate quantities such as the energy-spectra of specific hadrons in high-energy collisions. However, one can factorize perturbative and non-perturbative contributions via the concept of fragmentation functions. These are the final-state analogue of the parton distribution functions that are used for initial-state hadrons.

It should be added that if one ignores the non-perturbative difficulties and just calculates the energy and angular spectrum of partons in perturbative QCD with some low cutoff scale $\sim \Lambda$ (using resummation to sum large logarithms of \sqrt{s}/Λ), then this reproduces many features of the corresponding hadron spectra. This is often taken to suggest that hadronization is "local" in momentum space.

Sec. 19 of this *Review* provides further information (and references) on these topics, including also the question of heavy-quark fragmentation.

9.2.2.5. Parton-shower Monte Carlo generators:

Parton-shower Monte Carlo (MC) event generators like PYTHIA [138–140], HERWIG [141–143], SHERPA [144], and ARIADNE [145] provide fully exclusive simulations of QCD events. Because they provide access to "hadron-level" events they are a crucial tool for all applications that involve simulating the response of detectors to QCD events. Here we give only a brief outline of how they work and refer the reader to Chap. 38 and Ref. 146 for a full overview.

The MC generation of an event involves several stages. It starts with the random generation of the kinematics and partonic channels of whatever hard scattering process the user has requested at some high scale Q_0 . This is followed by a parton shower, usually based on the successive random generation of gluon emissions (or $g \to q\bar{q}$ splittings). Each is generated at a scale lower than the previous emission, following a (soft and collinear resummed) perturbative QCD distribution that depends on the momenta of all previous emissions. Common choices of scale for the ordering of emissions are virtuality, transverse momentum or angle. Parton showering stops at a scale of order 1 GeV, at which point a hadronization model is used to convert the resulting partons into hadrons. One widely-used model involves stretching a color "string" across quarks and gluons, and breaking it up into hadrons [147,148]. Another breaks each gluon into a $q\bar{q}$ pair and then groups quarks and anti-quarks into colorless "clusters"; which then give the hadrons [141]. For pp and γp processes, modeling is also needed to treat the collision between the two hadron remnants, which generates an underlying event (UE), usually implemented via additional $2 \rightarrow 2$ scatterings ("multiple parton interactions") at a scale of a few GeV, following Ref. 149.

A deficiency of the soft and collinear approximations that underlie parton showers is that they may fail to reproduce the full pattern of hard wide-angle emissions, important, for example, in many new physics searches. It is therefore common to use LO multi-parton matrix elements to generate hard high-multiplicity partonic configurations as additional starting points for the showering, supplemented with some prescription (CKKW [150], MLM [151]) for consistently merging samples with different initial multiplicities.

MCs, as described above, generate cross sections for the requested hard process that are correct at LO. For a number of processes there also exist MC implementations that are correct to NLO, using the MC@NLO [152] or POWHEG [153] prescriptions. Techniques also exist to combine NLO accuracy for a low order process, with LO accuracy for higher multiplicity processes [154,155].

9.2.3. Accuracy of predictions:

Estimating the accuracy of perturbative QCD predictions is not an exact science. It is often said that LO calculations are accurate to within a factor of two. This is based on experience with NLO corrections in the cases where these are available. In processes involving new partonic scattering channels at NLO and/or large ratios of scales (such as the production of high- p_t jets containing B-hadrons), the NLO to LO K-factors can be substantially larger than 2.

For calculations beyond LO, a conservative approach to estimate the perturbative uncertainty is to take it to be the last known perturbative order; a more widely used method is to estimate it from the change in the prediction when varying the renormalization and factorization scales around a central value Q that is taken close to the physical scale of the process. A conventional range of variation is $Q/2 < \mu_R, \mu_F < 2Q$, however this should not be assumed to give uncertainty estimates of guaranteed reliability. ††

There does not seem to be a broad consensus on whether μ_R and μ_F should be kept identical or varied independently. One option is to vary them independently with the restriction $\frac{1}{2}\mu_R < \mu_F < 2\mu_R$ [160]. This limits the risk of misleadingly small uncertainties due to fortuitous cancellations between the μ_F and μ_R dependence when both are varied together, while avoiding the appearance of large logarithms of μ_R^2/μ_F^2 when both are varied completely independently.

Calculations that involve resummations usually have an additional source of uncertainty associated with the choice of argument of the logarithms being resummed, e.g. $\ln(2\frac{p_{t,Z}}{M_Z})$ as opposed to $\ln(\frac{1}{2}\frac{p_{t,Z}}{M_Z})$. In addition to varying renormalization and factorization scales, it is therefore also advisable to vary the argument of the logarithm by a factor of two in either direction with respect to the "natural" argument.

The accuracy of QCD predictions is limited also by non-perturbative corrections, which typically scale as a power of Λ/Q . For measurements that are directly sensitive to the structure of the hadronic final state the corrections are usually linear in Λ/Q . The non-perturbative corrections are further enhanced in processes with a significant underlying event (i.e. in pp and $p\bar{p}$ collisions) and in cases where the perturbative cross sections fall steeply as a function of p_t or some other kinematic variable.

Non-perturbative corrections are commonly estimated from the difference between Monte Carlo events at the parton level and after hadronization. An issue to be aware of with this procedure is that "parton level" is not a uniquely defined concept. For example, in an event generator it depends on a (somewhat arbitrary and tunable) internal cutoff scale that separates the parton showering from the hadronization. In contrast no such cutoff scale exists in a NLO or NNLO partonic calculation. For this reason there are widespread reservations as to the appropriateness of deriving hadronization corrections from a Monte Carlo program and then applying them to NLO or NNLO prediction. There exist alternative methods for estimating hadronization corrections, which attempt to analytically deduce non-perturbative effects in one observable based on measurements of other observables (see the reviews [16,161]). While they directly address the problem of different possible definitions of parton level, it should also be said that they are far less flexible than Monte Carlo programs and not always able to provide equally good descriptions of the data.

9.3. Experimental QCD

Since we are not able to directly measure partons (quarks or gluons), but only hadrons and their decay products, a central issue for every experimental test of QCD is establishing a correspondence between observables obtained at the partonic and the hadronic level. The only theoretically sound correspondence is achieved by means of infrared and collinear safe quantities, which allow one to obtain finite predictions at any order of perturbative QCD.

^{‡‡} A number of prescriptions also exist for setting the scale automatically, e.g. Refs. 156–159, eliminating uncertainties from scale variation, though not from the truncation of the perturbative series itself.

As stated above, the simplest case of infrared and collinear safe observables are total cross sections. More generally, when measuring fully inclusive observables, the final state is not analyzed at all regarding its (topological, kinematical) structure or its composition. Basically the relevant information consists in the rate of a process ending up in a partonic or hadronic final state. In e^+e^- annihilation, widely used examples are the ratios of partial widths or branching ratios for the electroweak decay of particles into hadrons or leptons, such as Z or τ decays, (cf. Sec. 9.2.1). Such ratios are often favored over absolute cross sections or partial widths because of large cancellations of experimental and theoretical systematic uncertainties. The strong suppression of non-perturbative effects, $\mathcal{O}(\Lambda^4/Q^4)$, is one of the attractive features of such observables, however, at the same time the sensitivity to radiative QCD corrections is small, which for example affects the statistical uncertainty when using them for the determination of the strong coupling constant. In the case of τ decays not only the hadronic branching ratio is of interest, but also moments of the spectral functions of hadronic tau decays, which sample different parts of the decay spectrum and thus provide additional information. Other examples of fully inclusive observables are structure functions (and related sum rules) in DIS. These are extensively discussed in Sec. 18 of this Review.

On the other hand, often the structure or composition of the final state are analyzed and cross sections differential in one or more variables characterizing this structure are of interest. Examples are jet rates, jet substructure, event shapes or transverse momentum distributions of jets or vector bosons in hadron collisions. The case of fragmentation functions, *i.e.* the measurement of hadron production as a function of the hadron momentum relative to some hard scattering scale, is discussed in Sec. 19 of this *Review*.

It is worth mentioning that, besides the correspondence between the parton and hadron level, also a correspondence between the hadron level and the actually measured quantities in the detector has to be established. The simplest examples are corrections for finite experimental acceptance and efficiencies. Whereas acceptance corrections essentially are of theoretical nature, since they involve extrapolations from the measurable (partial) to the full phase space, other corrections such as for efficiency, resolution and response, are of experimental nature. For example, measurements of differential cross sections such as jet rates require corrections in order to relate, e.g. the energy deposits in a calorimeter to the jets at the hadron level. Typically detector simulations and/or data driven methods are used in order to obtain these corrections. Care should be taken here in order to have a clear separation between the parton-to-hadron level and hadron-to-detector level corrections. Finally, for the sake of an easy comparison to the results of other experiments and/or theoretical calculations, it is suggested to provide, whenever possible, measurements corrected for detector effects and/or all necessary information related to the detector response (e.g. the detector response matrix).

9.3.1. Hadronic final-state observables:

9.3.1.1. Jets:

In hard interactions, final-state partons and hadrons appear predominantly in collimated bunches. These bunches are generically called *jets*. To a first approximation, a jet can be thought of as a hard parton that has undergone soft and collinear showering and then hadronization. Jets are used both for testing our understanding and predictions of high-energy QCD processes, and also for identifying the hard partonic structure of decays of massive particles like top quarks.

In order to map observed hadrons onto a set of jets, one uses a jet definition. The mapping involves explicit choices: for example when a gluon is radiated from a quark, for what range of kinematics should the gluon be part of the quark jet, or instead form a separate jet? Good jet definitions are infrared and collinear safe, simple to use in theoretical and experimental contexts, applicable to any type of inputs (parton or hadron momenta, charged particle tracks, and/or energy deposits in the detectors) and lead to jets that are not too sensitive to non-perturbative effects. An extensive treatment of the topic of jet definitions is given in Ref. 162 (for e^+e^- collisions) and Refs. 163, 164 (for pp or $p\bar{p}$ collisions). Here we briefly review the two main

classes: cone algorithms, extensively used at older hadron colliders, and sequential recombination algorithms, more widespread in e^+e^- and ep colliders and at the LHC.

Very generically, most (iterative) cone algorithms start with some seed particle i, sum the momenta of all particles j within a cone of opening-angle R, typically defined in terms of (pseudo-)rapidity and azimuthal angle. They then take the direction of this sum as a new seed and repeat until the cone is stable, and call the contents of the resulting stable cone a jet if its transverse momentum is above some threshold $p_{t,\min}$. The parameters R and $p_{t,\min}$ should be chosen according to the needs of a given analysis.

There are many variants of cone algorithm, and they differ in the set of seeds they use and the manner in which they ensure a one-to-one mapping of particles to jets, given that two stable cones may share particles ("overlap"). The use of seed particles is a problem w.r.t. infrared and collinear safety, and seeded algorithms are generally not compatible with higher-order (or sometimes even leading-order) QCD calculations, especially in multi-jet contexts, as well as potentially subject to large non-perturbative corrections and instabilities. Seeded algorithms (JetCLU, MidPoint, and various other experiment-specific iterative cone algorithms) are therefore to be deprecated. A modern alternative is to use a seedless variant, SISCone [165].

Sequential recombination algorithms at hadron colliders (and in DIS) are characterized by a distance $d_{ij} = \min(k_{t,i}^{2p}, k_{t,j}^{2p}) \Delta_{ij}^2/R^2$ between all pairs of particles i, j, where Δ_{ij} is their distance in the rapidity-azimuthal plane, $k_{t,i}$ is the transverse momentum w.r.t. the incoming beams, and R is a free parameter. They also involve a "beam" distance $d_{iB}=k_{t,i}^{2p}$. One identifies the smallest of all the d_{ij} and d_{iB} , and if it is a d_{ij} , then i and j are merged into a new pseudo-particle (with some prescription, a recombination scheme, for the definition of the merged four-momentum). If the smallest distance is a d_{iB} , then i is removed from the list of particles and called a jet. As with cone algorithms, one usually considers only jets above some transverse-momentum threshold $p_{t,\min}$. The parameter p determines the kind of algorithm: p = 1 corresponds to the (inclusive-) k_t algorithm [114,166,167], p=0 defines the Cambridge-Aachen algorithm [168,169], while for p = -1 we have the anti- k_t algorithm [170]. All these variants are infrared and collinear safe to all orders of perturbation theory. Whereas the former two lead to irregularly shaped jet boundaries, the latter results in cone-like boundaries. The anti- k_t algorithm has become the de-facto standard for the LHC experiments.

In e^+e^- annihilations the k_t algorithm [114] uses $y_{ij}=2 \min(E_i^2,E_j^2)(1-\cos\theta_{ij})/Q^2$ as distance measure and repeatedly merges the pair with smallest y_{ij} , until all y_{ij} distances are above some threshold $y_{\rm cut}$, the jet resolution parameter. The (pseudo)-particles that remain at this point are called the jets. Here it is $y_{\rm cut}$ (rather than R and $p_{t,\rm min}$) that should be chosen according to the needs of the analysis. As mentioned above, the k_t algorithm has the property that logarithms $\ln(1/y_{\rm cut})$ exponentiate in resummation calculations. This is one reason why it is preferred over the earlier JADE algorithm [116], which uses the distance measure $y_{ij}=2\,E_i\,E_j\,(1-\cos\theta_{ij})/Q^2$.

Efficient implementations of the above algorithms are available through the FastJet package [171], which is also packaged within SpartyJet [172].

9.3.1.2. Event Shapes:

Event-shape variables are functions of the four momenta in the hadronic final state that characterize the topology of an event's energy flow. They are sensitive to QCD radiation (and correspondingly to the strong coupling) insofar as gluon emission changes the shape of the energy flow.

The classic example of an event shape is the $Thrust\ [173,174]$ in e^+e^- annihilations, defined as

$$\hat{\tau} = \max_{\vec{n}_{\tau}} \frac{\sum_{i} |\vec{p}_{i} \cdot \vec{n}_{\tau}|}{\sum_{i} |\vec{p}_{i}|}, \qquad (9.22)$$

where $\vec{p_i}$ are the momenta of the particles or the jets in the final-state and the maximum is obtained for the Thrust axis $\vec{n_\tau}$. In the Born

limit of the production of a perfect back-to-back $q\bar{q}$ pair the limit $\hat{\tau} \to 1$ is obtained, whereas a perfectly symmetric many-particle configuration leads to $\hat{\tau} \to 1/2$. Further event shapes of similar nature have been defined and extensively measured at LEP and at HERA, and for their definitions and reviews we refer to Refs. 3,4,161,175,176. Phenomenological discussions of event shapes at hadron colliders can be found in Refs. 177–179. Very recently, measurements of hadronic event-shape distributions have been published by CDF [180] and CMS [181].

Event shapes are used for many purposes. These include measuring the strong coupling, tuning the parameters of Monte Carlo programs, investigating analytical models of hadronization and distinguishing QCD events from events that might involve decays of new particles (giving event-shape values closer to the spherical limit).

9.3.1.3. Jet substructure, quark vs. gluon jets:

Jet substructure, which can be resolved by finding subjets or by measuring jet shapes, is sensitive to the details of QCD radiation in the shower development inside a jet and has been extensively used to study differences in the properties of quark and gluon induced jets, strongly related to their different color charges. In general there is clear experimental evidence that gluon jets are "broader" and have a softer particle spectrum than (light-) quark jets, whereas b-quark jets are similar to gluon jets. As an example of an observable, the jet shape $\Psi(r/R)$ is the fractional transverse momentum contained within a sub-cone of cone-size r for jets of cone-size R. It is sensitive to the relative fractions of quark and gluon jets in an inclusive jet sample and receives contributions from soft-gluon initial-state radiation and beam remnant-remnant interactions. Therefore, it has been widely employed for validation and tuning of Monte Carlo models. CDF has measured the jet shape $\Psi(r/R)$ for an inclusive jet sample [182] as well as for b-jets [183]. Similar measurements in photo-production and DIS at HERA have been reported in Refs. 184–186. First measurements at the LHC have been presented by ATLAS [187]. Further discussions, references and recent summaries can be found in Refs. 176, 188 and Sec. 4 of Ref. 189.

The use of jet substructure has also been suggested in order to distinguish QCD jets from jets that originate from hadronic decays of boosted massive particles (high- p_t electroweak bosons, top quarks and hypothesized new particles). For reviews and detailed references, see Ref. 189 and sec. 5.3 of Ref. 163.

9.3.2. State of the art QCD measurements at colliders:

There exists an enormous wealth of data on QCD-related measurements in e^+e^- , ep, pp, and $p\bar{p}$ collisions, to which a short overview like this would not be able to do any justice. Extensive reviews of the subject have been published in Refs. 175, 176 for e^+e^- colliders, whereas for hadron colliders comprehensive overviews are given in Refs. 164, 190, and recent summaries can be found in, e.g. Refs. 191–194. Below we concentrate our discussion on measurements that are most sensitive to hard QCD processes, in particular jet production.

9.3.2.1. e^+e^- colliders: Analyses of jet production in e^+e^- collisions are mostly based on JADE data at center-of-mass energies between 14 and 44 GeV, as well as on LEP data at the Z resonance and up to 209 GeV. They cover the measurements of (differential or exclusive) jet rates (with multiplicities typically up to 4, 5 or 6 jets), the study of 3-jet events and particle production between the jets as a tool for testing hadronization models, as well as 4-jet production and angular correlations in 4-jet events. The latter are useful for measurements of the strong coupling constant and putting constraints on the QCD color factors, thus probing the non-abelian nature of QCD. There have also been extensive measurements of event shapes. The tuning of parton shower MC models, typically matched to matrix elements for 3-jet production, has led to good descriptions of the available, highly precise data. Especially for the large LEP data sample at the Zpeak, the statistical errors are mostly negligible and the experimental systematic uncertainties are at the per-cent level or even below. These are usually dominated by the uncertainties related to the MC model dependence of the efficiency and acceptance corrections (often referred to as "detector corrections").

9.3.2.2. DIS and photoproduction: Multi-jet production in ep collisions at HERA, both in the DIS and photoproduction regime, allows for tests of QCD factorization (one initial-state proton and its associated PDF versus the hard scattering which leads to high- p_t jets) and NLO calculations which exist for 2- and 3-jet final states. Sensitivity is also obtained to the product of the coupling constant and the gluon PDF. By now experimental uncertainties of the order of 5-10% have been achieved, mostly dominated by jet energy scale uncertainties, whereas statistical errors are negligible to a large extent. For comparison to theoretical predictions, at large jet p_t the PDF uncertainty dominates the theoretical error (typically of order 5 - 10%, in some regions of phase-space up to 20%), therefore jet observables become useful inputs for PDF fits. In general, for Q^2 above $\sim 100 \, \mathrm{GeV^2}$ the data are well described by NLO matrix element calculations, combined with DGLAP evolution equations. Results at lower values ($Q^2 < 100 \,\mathrm{GeV^2}$) point to the necessity of including NNLO effects. Also, at low values of Q^2 and x, in particular for large jet pseudo-rapidities, there are indications for the need of BFKL-type evolution, though the predictions for such schemes are still limited. In the case of photoproduction, the data-theory comparisons are hampered by the uncertainties related to the photon PDF.

A few examples of recent measurements can be found in Refs. 195-200 for DIS and in Refs. 201-205 for photoproduction.

9.3.2.3. Hadron colliders: Jet measurements at the TEVATRON have been published for data samples up to $\sim 2\,{\rm fb}^{-1}$. Also, first results from the LHC have become available, for a center-of-mass energy of 7 TeV and sample sizes of up to $\sim 36\,\mathrm{pb}^{-1}$. Among the most important cross sections measured is the inclusive jet production as a function of the jet transverse energy (E_t) or the jet transverse momentum (p_t) , for several rapidity regions and for p_t up to 700 GeV at the TEVATRON and ~ 1 TeV at the LHC. The TEVATRON experiments have measurements based on the infrared- and collinear-safe k_t algorithm in addition to the more widely used Midpoint and JetCLU algorithms of the past, whereas the LHC experiments focus on the $anti-k_t$ algorithm. Results by the CDF and D0 collaborations can be found in Refs. 206-208, whereas first measurements of ATLAS and CMS have been published in Refs. 209 and 210, respectively. In general we observe a good description of the data by the NLO QCD predictions. The experimental systematic uncertainties are dominated by the jet energy scale error, by now quoted to be in the range of 1 to 3% and thus leading to uncertainties of 10 to 60% on the cross section, increasing with p_t . The PDF uncertainties dominate the theoretical error. In fact, inclusive jet data are important inputs to global PDF fits, in particular for constraining the high-x gluon PDF.

A rather comprehensive summary, comparing NLO QCD predictions to data for inclusive jet production in DIS, pp, and $p\bar{p}$ collisions, is given in Ref. 211 and reproduced here in Fig. 9.1.

Dijet events are analyzed in terms of their invariant mass and angular distributions, which allow one to put stringent limits on deviations from the Standard Model, such as quark compositeness (some recent examples can be found in Refs. 212–217). Furthermore, dijet azimuthal correlations between the two leading jets, normalized to the total dijet cross cross section, are an extremely valuable tool for studying the spectrum of gluon radiation in the event. For example, results from the TEVATRON [218] and the LHC [219,220] show that the LO (non-trivial) prediction for this observable, with at most three partons in the final state, is not able to describe the data for an azimuthal separation below $2\pi/3$, where NLO contributions (with 4 partons) restore the agreement with data. In addition, this observable can be employed to tune Monte Carlo predictions of soft gluon radiation. Beyond dijet final states, recently measurements of the production of three or more jets have been performed [221–223], as a means of testing perturbative QCD predictions, tuning MC models, constraining PDFs or determining the strong coupling constant.

Similarly important tests of QCD arise from measurements of vector boson (photon, W, Z) production together with jets. A recent analysis of photon+jet production by D0 [224] indicates that NLO calculations, combined with modern PDF sets, are unable to describe the shape of the photon p_t across the entire measured range, showing the need for an improved and consistent theoretical description of this

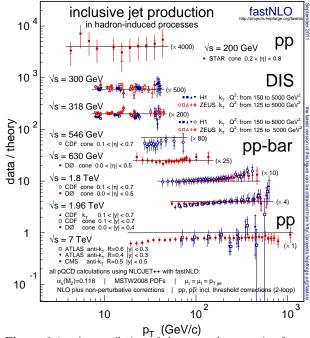


Figure 9.1: A compilation of data-over-theory ratios for inclusive jet cross sections as a function of jet transverse momentum (p_T) , measured in different hadron-induced processes at different center-of-mass energies; from Ref. 211. The various ratios are scaled by arbitrary numbers (indicated between parentheses) for better readability of the plot. The theoretical predictions have been obtained at NLO accuracy, for parameter choices (coupling constant, PDFs, renormalization, and factorization scales) as indicated at the bottom of the figure.

process.

In the case of Z+jets, the Z momentum can be precisely reconstructed using the leptons, allowing for a precise determination of the Z p_t distribution, which is sensitive to QCD radiation both at high and low scales and thus probes perturbative as well as non-perturbative effects. For example, a recent D0 result [225] quotes experimental statistical and systematic uncertainties of the order of 10%, increasing up to 20% in the lowest momentum range. The data are compared to predictions from NLO QCD and from different Monte Carlo models, where, for example, LO matrix elements for up to three partons are matched to a parton shower. Whereas the total cross section is underestimated, the shape is well reproduced over a large phase-space region. Similar conclusions are drawn from further results on Z (or W) plus jets production, both from the TEVATRON [226–231] and the LHC [232,233]. A very important recent development is the completion of NLO calculations for vector boson plus 3jet [75–77] and 4jet production [78,79], which is relevant also for background estimations in the searches for new physics. This type of process is an example where jets need to be found with an infrared and collinear safe jet algorithm in order to obtain finite NLO predictions. This would not be possible with algorithms such as Midpoint or JetCLU, used in analyses at the TEVATRON [228,231]. There the measurements are compared to the NLO QCD prediction obtained with SISCone as jet algorithm. Besides this inconsistency, the agreement appears to be reasonably good.

Finally, examples of recent TEVATRON measurements of heavy quark (b, c) jet production, inclusive or in association with vector bosons, can be found in Refs. 234–240. Also, first results for vector boson production in association with b-jets have been obtained at the LHC [241,242]. It is worth noting that for W+b production there is some tension between the measurements and the NLO predictions, in particular in the case of the CDF result [239].

9.3.3. Tests of the non-abelian nature of QCD:

QCD is a gauge theory with SU(3) as underlying gauge group. For a general gauge theory with a simple Lie group, the couplings of the fermion fields to the gauge fields and the self-interactions in the non-abelian case are determined by the coupling constant and Casimir operators of the gauge group, as introduced in Sec. 9.1. Measuring the eigenvalues of these operators, called color factors, probes the underlying structure of the theory in a gauge invariant way and provides evidence of the gluon self-interactions. Typically, cross sections can be expressed as functions of the color factors, for example $\sigma = f(\alpha_s C_F, C_A/C_F, n_f T_R/C_F)$. Sensitivity at leading order in perturbation theory can be achieved by measuring angular correlations in 4-jet events in e^+e^- annihilation or 3-jet events in DIS. Some sensitivity, although only at NLO, is also obtained from event-shape distributions. Scaling violations of fragmentation functions and the different subjet structure in quark and gluon induced jets also give access to these color factors. In order to extract absolute values, e.g. for C_F and C_A , certain assumptions have to be made for other parameters, such as T_R , n_f or α_s , since typically only combinations (ratios, products) of all the relevant parameters appear in the perturbative prediction. A recent compilation of results [176] quotes world average values of $C_A = 2.89 \pm 0.03 (\mathrm{stat}) \pm 0.21 (\mathrm{syst})$ and $C_F = 1.30 \pm 0.01 ({\rm stat}) \pm 0.09 ({\rm syst})$, with a correlation coefficient of 82%. These results are in perfect agreement with the expectations from SU(3) of $C_A = 3$ and $C_F = 4/3$. An overview of the history and the current status of tests of Asymptotic Freedom, closely related to the non-abelian nature of QCD, can be found in Ref. 243.

9.3.4. Measurements of the strong coupling constant:

If the quark masses are fixed, there is only one free parameter in the QCD Lagrangian, the strong coupling constant α_s . The coupling constant in itself is not a physical observable, but rather a quantity defined in the context of perturbation theory, which enters predictions for experimentally measurable observables, such as R in Eq. (9.7).

Many experimental observables are used to determine α_s . Considerations in such determinations include:

- The observable's sensitivity to α_s as compared to the experimental precision. For example, for the e^+e^- cross section to hadrons (cf. R in Sec. 9.2.1), QCD effects are only a small correction, since the perturbative series starts at order α_s^0 , 3-jet production or event shapes in e^+e^- annihilations are directly sensitive to α_s since they start at order α_s ; the hadronic decay width of heavy quarkonia, $\Gamma(\Upsilon \to \text{hadrons})$, is very sensitive to α_s since its leading order term is $\propto \alpha_s^3$.
- The accuracy of the perturbative prediction, or equivalently of the relation between α_s and the value of the observable. The minimal requirement is generally considered to be an NLO prediction. Some observables are predicted to NNLO (many inclusive observables, 3-jet rates and event shapes in e^+e^- collisions) or even N³LO (e^+e^- hadronic cross section and τ branching fraction to hadrons). In certain cases, fixed-order predictions are supplemented with resummation. The precise magnitude of theory uncertainties is usually estimated as discussed in Sec. 9.2.3.
- The size of uncontrolled non-perturbative effects (except for lattice-based determinations of α_s). Sufficiently inclusive quantities, like the e^+e^- cross section to hadrons, have small non-perturbative uncertainties $\sim \Lambda^4/Q^4$. Others, such as event-shape distributions, have uncertainties $\sim \Lambda/Q$.
- The scale at which the measurement is performed. An uncertainty δ on a measurement of $\alpha_s(Q^2)$, at a scale Q, translates to an uncertainty $\delta' = (\alpha_s^2(M_Z^2)/\alpha_s^2(Q^2)) \cdot \delta$ on $\alpha_s(M_Z^2)$. For example, this enhances the already important impact of precise low-Q measurements, such as from τ decays, in combinations performed at the M_Z scale.

In this review, we update the measurements of α_s summarized in the 2009 review, which was based on an analysis by Bethke [244], and we extract a new world average value of $\alpha_s(M_Z^2)$ from the most significant and complete results available today.

 $^{^{\}sharp}$ The time evolution of α_s combinations can be followed by consult-

While in general we follow the same selection strategy and summary procedure as applied in the 2009 review, here we restrict the selection of results from which to calculate the world average value of $\alpha_s(M_Z^2)$ to those which are

- published in a peer-reviewed journal
- based on the most complete perturbative QCD predictions, i.e. to those using NNLO or higher order expansions.

While this excludes e.g. results from jet production in DIS at HERA and at the Tevatron, as well as those from heavy quarkonia decays for which calculations are available in NLO only, these NLO results will nevertheless be listed and cited in this review as they are important ingredients for the experimental evidence of the energy dependence of α_s , i.e. for Asymptotic Freedom, one of the key features of QCD.

In addition, here we add an intermediate step of pre-averaging results within certain sub-fields like e^+e^- -annihilation, DIS and hadronic τ -decays, and calculate the overall world average from those pre-averages rather than from individual measurements. This is done because in a number of sub-fields one observes that different determinations of the strong coupling from substantially similar datasets lead to values of α_s that are only marginally compatible with each other, or with the final world average value, which presumably is a reflection of the challenges of evaluating systematic uncertainties. In such cases, a pre-average value will be determined, with a symmetric, overall error that encompasses the central values of all individual determinations.

$Hadronic \tau decays$

Several re-analyses of the hadronic τ decay width [17,246–250], based on the new N³LO predictions [17], have been performed, with different approaches towards the detailed treatment of the perturbative (fixed-order or contour-improved perturbative expansions) and nonperturbative contributions. We also include the result from τ decay and lifetime measurements, obtained in Sec. Electroweak Model and constraints on New Physics of this Review, which amounts, if converted to the τ -mass scale and for $n_f = 3$ quark flavours, to $\alpha_s(M_\tau)=0.327^{+0.019}_{-0.016}.$ This result and the one from Baikov et al. [17] include both fixed-order and contour-improved perturbation, while the others adhere to either one or the other of the two. All these results are summarized in Fig. 9.2(a). We note that there are more studies of α_s from τ -decays, [251–254], which are not yet available as peer-reviewed publications but which are compatible with the overall picture. Another recent study [255] argues that an improved treatment of non-perturbative effects results in values of α_s which are systematically lower than those discussed above. Results using the same analysis framework, but employing an updated version of the OPAL tau spectral function data are reported in Ref. 256, which at the time of writing was as yet unpublished.

We determine the pre-average result from τ -decays, to be used for calculating the final world average of $\alpha_s(M_Z^2)$, using the simple method defined above, as $\alpha_s(M_\tau^2) = 0.330 \pm 0.014$, which spans the range of central values obtained by the different groups. This value of $\alpha_s(M_\tau^2)$ corresponds, when evolved to the scale of the Z-boson, using the QCD 4-loop beta-function plus 3-loop matching at the charmand the bottom-quark masses (see Sec. Quark Masses in this Review), to $\alpha_s(M_Z^2) = 0.1197 \pm 0.0016$, unchanged from its value in the 2009 review.

Lattice QCD

There are several recent results on α_s from lattice QCD, see also Sec. Lattice QCD in this Review. The HPQCD collaboration [257] computes Wilson loops and similar short-distance quantities with lattice QCD and analyzes them with NNLO perturbative QCD. This yields a value for α_s , but the lattice scale must be related to a physical energy/momentum scale. This is achieved with the Υ' - Υ mass difference, however, many other quantities could be used as well [258]. HPQCD obtains $\alpha_s(M_Z^2) = 0.1184 \pm 0.0006$, where the uncertainty includes effects from truncating perturbation theory, finite lattice spacing and extrapolation of lattice data. An

independent perturbative analysis of a subset of the same lattice-QCD data yields $\alpha_s(M_Z^2) = 0.1192 \pm 0.0011$ [259]. Using another, independent methodology, the current-current correlator method, HPQCD obtains $\alpha_s(M_Z^2) = 0.1183 \pm 0.0007$ [257]. The analysis of Ref. 89, which avoids the staggered fermion treatment of Ref. 257, finds $\alpha_s(M_Z^2) = 0.1205 \pm 0.0008 \pm 0.0005 ^{+0.0000}_{-0.0017}$, where the first uncertainty is statistical and the others are from systematics. Since this approach uses a different discretization of lattice fermions and a different general methodology, it provides an independent cross check of other lattice extractions of α_s . Finally, the JLQCD collaboration - in an analysis of Adler functions - obtains $\alpha_s(M_Z^2) = 0.1181 \pm 0.0003 ^{+0.0014}_{-0.0012}$ [261]. A very recent but unpublished study of the ETM collaboration [262] used lattice data with u, d, s and c quarks in the sea, obtaining results which are compatible with those quoted above.

The published lattice results are summarized in Fig. 9.2(b). Since they are compatible with each other, we calculate a pre-average of lattice results using the same method as applied to determine the final world average value of the strong coupling, i.e. calculate a weighted average and a (correlated) error such that the overall χ^2 equals unity per degree of freedom - rather than using the simple method as applied in the case of τ decays. This gives $\alpha_s(M_Z^2) = 0.1185 \pm 0.0007$ which we take as result from the sub-field of lattice determinations.

Deep inelastic lepton-nucleon scattering (DIS)

Studies of DIS final states have led to a number of precise determinations of α_s : A combination [263] of precision measurements at HERA, based on NLO fits to inclusive jet cross sections in neutral current DIS at high Q^2 , quotes a combined result of $\alpha_s(M_Z^2) = 0.1198 \pm 0.0032$, which includes a theoretical uncertainty of ± 0.0026 . A combined analysis of non-singlet structure functions from DIS [264], based on QCD predictions up to N³LO in some of its parts, gave $\alpha_s(M_Z^2) = 0.1142 \pm 0.0023$, including a theoretical error of ± 0.0008 (BBG). Further studies of singlet and non-singlet structure functions, based on NNLO predictions, resulted in $\alpha_s(M_Z^2) = 0.1129 \pm 0.0014$ [265] (ABKM; updated in a recent unpublished note [266]) and in $\alpha_s(M_Z^2) = 0.1158 \pm 0.0035$ [267](JR). The MSTW group [268], also including data on jet production at the Tevatron, obtains, at NNLO $^{\sharp\sharp}$, $\alpha_s(M_Z^2) = 0.1171 \pm 0.0024$. Most recently, the NNPDF group [269] has presented a result, $\alpha_s(M_Z^2) = 0.1173 \pm 0.0011$. which is in line with the one from the MSTW group.

Summarizing these results from world data on structure functions, applying the same method as in the case of summarizing results from τ decays, leads to a pre-average value of $\alpha_s(M_Z^2) = 0.1151 \pm 0.0022$ (see Fig. 9.2(c)).

We note that criticism has been expressed on some of the above extractions. Among the issues raised, we mention the neglect of singlet contributions at $x \ge 0.3$ in pure non-singlet fits [270], the impact and detailed treatment of particular classes of data in the fits [270,271] and possible biases due to insufficiently flexible parametrizations of the PDFs [272].

Heavy quarkonia decays

The most recent extraction of the strong coupling constant from an analysis of radiative Υ decays [273] resulted in $\alpha_s(M_Z)=0.119^{+0.000}_{-0.005}$ This determination is based on QCD in NLO only, so it will not be considered for the final extraction of the world average value of α_s ; it is, however, an important ingredient for the demonstration of Asymptotic Freedom as given in Fig. 9.4.

Hadronic final states of e^+e^- annihilations

Re-analyses of event shapes in e^+e^- -annihilation, measured at the Z peak and LEP2 energies up to 209 GeV, using NNLO predictions matched to NLL resummation, resulted in $\alpha_s(M_Z^2)$ = 0.1224 ± 0.0039 [274], with a dominant theoretical uncertainty of 0.0035, and in $\alpha_s(M_Z^2)=0.1189\pm0.0043$ [275]. Similarly, an analysis of JADE data [276] at center-of-mass energies between 14 and 46 GeV gives $\alpha_s(M_Z^2) = 0.1172 \pm 0.0051$, with contributions from hadronization model (perturbative QCD) uncertainties of 0.0035 (0.0030). A precise determination of α_s from 3-jet production alone, in NNLO, resulted in

 $^{^{\}sharp\sharp}$ Note that for jet production at the hadron collider, only NLO predictions are available, while for the structure functions full NNLO was utilized.

 $\alpha_s(M_Z^2)=0.1175\pm0.0025$ [277]. Computation of the NLO corrections to 5-jet production and comparison to the measured 5-jet rates at LEP [74] gave $\alpha_s(M_Z^2)=0.1156^{+0.0041}_{-0.0034}$. More recently, a study using the world data of Thrust distributions and soft-collinear effective theory, including fixed order NNLO, gave $\alpha_s(M_Z^2)=0.1135\pm0.0010$ [278]. We note that there is criticism on both classes of α_s extractions just described: those based on corrections of non-perturbative hadronisation effects using QCD-inspired Monte Carlo generators (since the parton level of a Monte Carlo is not defined in a manner equivalent to that of a fixed-order calculation), as well as the studies based on effective field theory, as their systematics have not yet been verified e.g. by using observables other than Thrust.

A summary of the e^+e^- results based on NNLO predictions is shown in Fig. 9.2(d). They average, according to the simple procedure defined above, to $\alpha_s(M_Z^2)=0.1172\pm0.0037$.

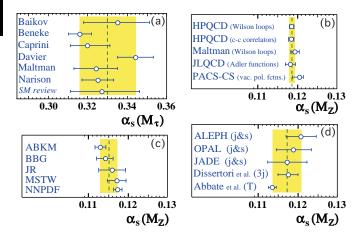


Figure 9.2: Summary of determinations of α_s from hadronic τ -decays (a), from lattice calculations (b), from DIS structure functions (c) and from event shapes and jet production in e^+e^- -annihilation (d). The shaded bands indicate the average values chosen to be included in the determination of the new world average of α_s .

Hadron collider jets

A determination of α_s from the p_T dependence of the inclusive jet cross section in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV, in the transverse momentum range of $50 < p_T < 145$ GeV, based on NLO $(\mathcal{O}(\alpha_s^3))$ QCD, led to $\alpha_s(M_Z^2)=0.1161^{+0.0041}_{-0.0048}$ [279], which is the most precise α_s result obtained at a hadron collider. Experimental uncertainties from the jet energy calibration, the p_T resolution and the integrated luminosity dominate the overall error.

Electroweak precision fits

The N³LO calculation of the hadronic Z decay width was used in a revision of the global fit to electroweak precision data [280], resulting in $\alpha_s(M_Z^2)=0.1193\pm0.0028$, claiming a negligible theoretical uncertainty. For this Review the value obtained in Sec. Electroweak model and constraints on new physics from data at the Z-pole, $\alpha_s(M_Z^2)=0.1197\pm0.0028$ will be used instead, as it is based on a more constrained data set where QCD corrections directly enter through the hadronic decay width of the Z. We note that all these results from electroweak precision data, however, strongly depend on the strict validity of Standard Model predictions and the existence of the minimal Higgs mechanism to implement electroweak symmetry breaking. Any - even small - deviation of nature from this model could strongly influence this extraction of α_s .

Determination of the world average value of $\alpha_s(M_Z^2)$

A non-trivial exercise consists in the evaluation of a world-average value for $\alpha_s(M_Z^2)$. A certain arbitrariness and subjective component is inevitable because of the choice of measurements to be included in the average, the treatment of (non-Gaussian) systematic uncertainties of mostly theoretical nature, as well as the treatment of correlations among the various inputs, of theoretical as well as experimental origin.

In earlier reviews [243–245] an attempt was made to take account of such correlations, using methods as proposed, e.g., in Ref. 281, and - likewise - to treat cases of apparent incompatibilities or possibly underestimated systematic uncertainties in a meaningful and well defined manner:

The central value is determined as the weighted average of the different input values. An initial error of the central value is determined treating the uncertainties of all individual measurements as being uncorrelated and being of Gaussian nature, and the overall χ^2 to the central value is determined. If this initial χ^2 is larger than the number of degrees of freedom, i.e. larger than the number of individual inputs minus one, then all individual errors are enlarged by a common factor such that $\chi^2/\text{d.o.f.}$ equals unity. If the initial value of χ^2 is smaller than the number of degrees of freedom, an overall, a-priori unknown correlation coefficient is introduced and determined by requiring that the total $\chi^2/\text{d.o.f.}$ of the combination equals unity. In both cases, the resulting final overall uncertainty of the central value of α_s is larger than the initial estimate of a Gaussian error.

This procedure is only meaningful if the individual measurements are known not to be correlated to large degrees, i.e. if they are not - for instance - based on the same input data, and if the input values are largely compatible with each other and with the resulting central value, within their assigned uncertainties. The list of selected individual measurements discussed above, however, violates both these requirements: there are several measurements based on (partly or fully) identical data sets, and there are results which apparently do not agree with others and/or with the resulting central value, within their assigned individual uncertainty. Examples for the first case are results from the hadronic width of the τ lepton, from DIS processes and from jets and event shapes in e^+e^- final states. An example of the second case is the apparent disagreement between results from the τ width and those from DIS [264] or from Thrust distributions in e^+e^- annihilation [278].

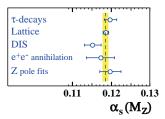


Figure 9.3: Summary of values of $\alpha_s(M_Z^2)$ obtained for various sub-classes of measurements (see Fig. 9.2 (a) to (d)). The new world average value of $\alpha_s(M_Z^2) = 0.1184 \pm 0.0007$ is indicated by the dashed line and the shaded band.

Due to these obstacles, we have chosen to determine pre-averages for each class of measurements, and then to combine those to the final world average value of $\alpha_s(M_Z)$, using the methods of error treatment as just described. The five pre-averages are summarized in Fig. 9.3; we recall that these are exclusively obtained from extractions which are based on (at least) full NNLO QCD predictions, and are published in peer-reviewed journals at the time of completing this Review. From these, we determine the new world average value of

$$\alpha_s(M_Z^2) = 0.1184 \pm 0.0007 ,$$
 (9.23)

with an uncertainty of well below 1 %.*** This world average value is - in spite of several new contributions to this determination - identical to and thus, in excellent agreement with the 2009 result [244]. For

^{***} The weighted average, treating all inputs as uncorrelated measurements with Gaussian errors, results in $\alpha_s(M_Z^2) = 0.11844 \pm 0.00059$ with $\chi^2/\text{d.o.f.} = 3.2/4$. Requiring $\chi^2/\text{d.o.f.}$ to reach unity leads to a common correlation factor of 0.19 which increases the overall error to 0.00072.

convenience, we also provide corresponding values for $\Lambda_{\overline{MS}}$ suitable for use with Eq. (9.5):

$$\Lambda_{\overline{MS}}^{(5)} = (213 \pm 8) \text{ MeV} , \qquad (9.24a)$$

$$\Lambda_{\overline{MS}}^{(4)} = (296 \pm 10) \text{ MeV} ,$$
 (9.24b)

$$\Lambda_{\overline{MS}}^{(3)} = (339 \pm 10) \text{ MeV} ,$$
 (9.24c)

for $n_f = 5$, 4 and 3 quark flavors, respectively.

In order to further test and verify the sensitivity of the new average value of $\alpha_s(M_Z^2)$ to the different pre-averages and classes of α_s determinations, we give each of the averages obtained when leaving out one of the five input values:

$$\alpha_s(M_Z^2) = 0.1182 \pm 0.0007 \text{ (w/o } \tau \text{ results)},$$
 (9.25a)

$$\alpha_s(M_Z^2) = 0.1183 \pm 0.0012 \text{ (w/o lattice results)},$$
 (9.25b)

$$\alpha_s(M_Z^2) = 0.1187 \pm 0.0009 \text{ (w/o DIS results)},$$
 (9.25c)

$$\alpha_s(M_Z^2) = 0.1185 \pm 0.0006 \text{ (w/o } e^+e^- \text{ results)}, \text{ and } (9.25d)$$

$$\alpha_s(M_Z^2) = 0.1184 \pm 0.0006$$
 (w/o res. from e.w. prec. fit)(9.25e)

They are well within the error of the overall world average quoted above. Most notably, the result from lattice calculations, which has the smallest assigned error, agrees well with the exclusive average of the other results. However, it largely determines the size of the (small) overall uncertainty.

There are apparent systematic differences between the various structure function results, and also between the new result from Thrust in e^+e^- annihilation and the other determinations. Expressing this in terms of a χ^2 between a given measurement and the world average as obtained when excluding that particular measurement, the largest values are $\chi^2 = 12.6$ and $\chi^2 = 16.1$, corresponding to 3.5 and 4.0 standard deviations, for the measurements of [265] and [278], respectively. We note that such and other differences between some of the measurements have been extensively discussed at a specific workshop on measurements of α_s , however none of the explanations proposed so far have obtained enough of a consensus to definitely resolve the tensions between different extractions [282].

Notwith standing these open issues, a rather stable and well defined world average value emerges from the compilation of current determinations of α_s :

$$\alpha_s(M_Z^2) = 0.1184 \pm 0.0007$$
.

The results also provide a clear signature and proof of the energy dependence of α_s , in full agreement with the QCD prediction of Asymptotic Freedom. This is demonstrated in Fig. 9.4, where results of $\alpha_s(Q^2)$ obtained at discrete energy scales Q, now also including those based just on NLO QCD, are summarized and plotted.

9.4. Acknowledgments

We are grateful to J.-F. Arguin, G. Altarelli, J. Butterworth, M. Cacciari, L. del Debbio, P. Gambino, N. Glover, M. Grazzini, A. Kronfeld, K. Kousouris, M. d'Onofrio, S. Sharpe, G. Sterman, D. Treille, N. Varelas, M. Wobisch, W.M. Yao, C.P. Yuan, and G. Zanderighi for their suggestions and comments on this and earlier versions of this review.

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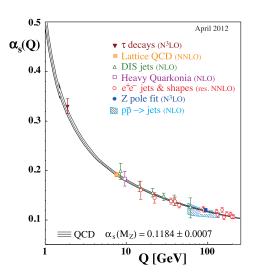


Figure 9.4: Summary of measurements of α_s as a function of the respective energy scale Q. The respective degree of QCD perturbation theory used in the extraction of α_s is indicated in brackets (NLO: next-to-leading order; NNLO: next-to-next-to leading order; res. NNLO: NNLO matched with resummed next-to-leading logs; N³LO: next-to-NNLO).

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10. ELECTROWEAK MODEL AND CONSTRAINTS ON NEW PHYSICS

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- 10.1 Introduction
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10.1. Introduction

The standard model of the electroweak interactions (SM) [1] is based on the gauge group SU(2) × U(1), with gauge bosons W_{μ}^{i} , i=1,2,3, and B_{μ} for the SU(2) and U(1) factors, respectively, and the corresponding gauge coupling constants g and g'. The left-handed fermion fields of the i^{th} fermion family transform as doublets

$$\begin{split} \Psi_i &= \begin{pmatrix} \nu_i \\ \ell_i^- \end{pmatrix} \text{ and } \begin{pmatrix} u_i \\ d_i' \end{pmatrix} \text{ under SU(2), where } d_i' \equiv \sum_j V_{ij} \, d_j, \text{ and } V \text{ is} \\ \text{the Cabibbo-Kobayashi-Maskawa mixing matrix. (Constraints on } V \\ \text{and tests of universality are discussed in Ref. 2 and in the Section on "The CKM Quark-Mixing Matrix". The extension of the formalism to allow an analogous leptonic mixing matrix is discussed in the Section on "Neutrino Mass, Mixing, and Oscillations".) The right-handed fields are SU(2) singlets. In the minimal model there are three fermion families. \end{split}$$

A complex scalar Higgs doublet, $\phi \equiv \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$, is added to the model for mass generation through spontaneous symmetry breaking with potential* given by,

$$V(\phi) = \mu^2 \phi^{\dagger} \phi + \frac{\lambda^2}{2} (\phi^{\dagger} \phi)^2. \tag{10.1}$$

For μ^2 negative, ϕ develops a vacuum expectation value, $v/\sqrt{2}$, where $v\approx 246.22$ GeV, breaking part of the electroweak (EW) gauge symmetry, after which only one neutral Higgs scalar, H, remains in the physical particle spectrum. In non-minimal models there are additional charged and neutral scalar Higgs particles [3].

After the symmetry breaking the Lagrangian for the fermion fields, ψ_i , is

$$\mathcal{L}_{F} = \sum_{i} \overline{\psi}_{i} \left(i \partial - m_{i} - \frac{g m_{i} H}{2 M_{W}} \right) \psi_{i}$$

$$- \frac{g}{2 \sqrt{2}} \sum_{i} \overline{\Psi}_{i} \gamma^{\mu} (1 - \gamma^{5}) (T^{+} W_{\mu}^{+} + T^{-} W_{\mu}^{-}) \Psi_{i}$$

$$- e \sum_{i} q_{i} \overline{\psi}_{i} \gamma^{\mu} \psi_{i} A_{\mu}$$

$$- \frac{g}{2 \cos \theta_{W}} \sum_{i} \overline{\psi}_{i} \gamma^{\mu} (g_{V}^{i} - g_{A}^{i} \gamma^{5}) \psi_{i} Z_{\mu} . \tag{10.2}$$

 $\theta_W \equiv \tan^{-1}(g'/g)$ is the weak angle; $e = g \sin \theta_W$ is the positron electric charge; and $A \equiv B \cos \theta_W + W^3 \sin \theta_W$ is the photon field (γ) . $W^{\pm} \equiv (W^1 \mp i W^2)/\sqrt{2}$ and $Z \equiv -B \sin \theta_W + W^3 \cos \theta_W$ are the charged and neutral weak boson fields, respectively. The Yukawa coupling of H to ψ_i in the first term in \mathcal{L}_F , which is flavor diagonal in the minimal model, is $gm_i/2M_W$. The boson masses in the EW sector are given (at tree level, *i.e.*, to lowest order in perturbation theory) by,

$$M_H = \lambda v, \tag{10.3a}$$

$$M_W = \frac{1}{2}g\,v = \frac{e\,v}{2\sin\theta_W},\tag{10.3b}$$

$$M_Z = \frac{1}{2} \sqrt{g^2 + g'^2} v = \frac{e \, v}{2 \sin \theta_W \cos \theta_W} = \frac{M_W}{\cos \theta_W},$$
 (10.3c)

$$M_{\gamma} = 0. \tag{10.3d}$$

The second term in \mathscr{L}_F represents the charged-current weak interaction [4–7], where T^+ and T^- are the weak isospin raising and lowering operators. For example, the coupling of a W to an electron and a neutrino is

$$-\frac{e}{2\sqrt{2}\sin\theta_W} \left[W_{\mu}^{-} \overline{e} \gamma^{\mu} (1 - \gamma^5) \nu + W_{\mu}^{+} \overline{\nu} \gamma^{\mu} (1 - \gamma^5) e \right]. \quad (10.4)$$

For momenta small compared to M_W , this term gives rise to the effective four-fermion interaction with the Fermi constant given by $G_F/\sqrt{2}=1/2v^2=g^2/8M_W^2$. CP violation is incorporated into the EW model by a single observable phase in V_{ij} .

The third term in \mathcal{L}_F describes electromagnetic interactions (QED) [8–10], and the last is the weak neutral-current interaction [5–7]. The vector and axial-vector couplings are

$$g_V^i \equiv t_{3L}(i) - 2q_i \sin^2 \theta_W, \tag{10.5a}$$

$$g_A^i \equiv t_{3L}(i), \tag{10.5b}$$

where $t_{3L}(i)$ is the weak isospin of fermion i (+1/2 for u_i and ν_i ; -1/2 for d_i and e_i) and q_i is the charge of ψ_i in units of e.

The first term in Eq. (10.2) also gives rise to fermion masses, and in the presence of right-handed neutrinos to Dirac neutrino masses. The possibility of Majorana masses is discussed in the Section on "Neutrino Mass, Mixing, and Oscillations".

10.2. Renormalization and radiative corrections

In addition to the Higgs boson mass, M_H , the fermion masses and mixings, and the strong coupling constant, α_s , the SM has three parameters. A particularly useful set contains the Z mass**, the Fermi constant, and the fine structure constant, which will be discussed in turn:

The Z boson mass, $M_Z=91.1876\pm0.0021$ GeV, has been determined from the Z lineshape scan at LEP 1 [11].

The Fermi constant, $G_F=1.1663787(6)\times 10^{-5}~{\rm GeV^{-2}},$ is derived from the muon lifetime formula***,

$$\frac{\hbar}{\tau_{\mu}} = \frac{G_F^2 m_{\mu}^5}{192\pi^3} F(\rho) \left[1 + H_1(\rho) \frac{\widehat{\alpha}(m_{\mu})}{\pi} + H_2(\rho) \frac{\widehat{\alpha}^2(m_{\mu})}{\pi^2} \right], \quad (10.6)$$

where $\rho = m_e^2/m_\mu^2$, and where

$$F(\rho) = 1 - 8\rho + 8\rho^3 - \rho^4 - 12\rho^2 \ln \rho = 0.99981295,$$
 (10.7a)

$$H_1(\rho) = \frac{25}{8} - \frac{\pi^2}{2} - \left(9 + 4\pi^2 + 12\ln\rho\right)\rho$$
$$+ 16\pi^2\rho^{3/2} + \mathcal{O}(\rho^2) = -1.80793, \tag{10.7b}$$

$$\begin{split} H_2(\rho) &= \frac{156815}{5184} - \frac{518}{81}\pi^2 - \frac{895}{36}\zeta(3) + \frac{67}{720}\pi^4 + \frac{53}{6}\pi^2\ln 2 \\ &- (0.042 \pm 0.002)_{\rm had} - \frac{5}{4}\pi^2\sqrt{\rho} + \mathcal{O}(\rho) = 6.64, \end{split} \tag{10.7c}$$

$$\hat{\alpha}(m_{\mu})^{-1} = \alpha^{-1} + \frac{1}{3\pi} \ln \rho + \mathcal{O}(\alpha) = 135.901$$
 (10.7d)

The massless corrections to H_1 and H_2 have been obtained in Refs. 13 and 14, respectively, where the term in parentheses is from the hadronic vacuum polarization [14]. The mass corrections to H_1 have been known for some time [15], while those to H_2 are more recent [16]. Notice the term linear in m_e whose appearance was

^{*} There is no generally accepted convention to write the quartic term. Our numerical coefficient simplifies Eq. (10.3a) below and the squared coupling preserves the relation between the number of external legs and the power counting of couplings at a given loop order. This structure also naturally emerges from physics beyond the SM, such as supersymmetry.

^{**} We emphasize that in the fits described in Sec. 10.6 and Sec. 10.7 the values of the SM parameters are affected by all observables that depend on them. This is of no practical consequence for α and G_F , however, since they are very precisely known.

^{***} In the spirit of the Fermi theory, we incorporated the small propagator correction, $3/5~m_{\mu}^2/M_W^2$, into Δr (see below). This is also the convention adopted by the MuLan collaboration [12]. While this breaks with historical consistency, the numerical difference was negligible in the past.

unforeseen and can be traced to the use of the muon pole mass in the prefactor [16]. The remaining uncertainty in G_F is experimental and has recently been reduced by an order of magnitude by the MuLan collaboration [12] at the PSI.

The fine structure constant, $\alpha = 1/137.035999074(44)$, is currently dominated by the e^{\pm} anomalous magnetic moment [10]. In most EW renormalization schemes, it is convenient to define a running α dependent on the energy scale of the process, with $\alpha^{-1} \sim 137$ appropriate at very low energy, i.e. close to the Thomson limit. (The running has also been observed [17] directly.) For scales above a few hundred MeV this introduces an uncertainty due to the low energy hadronic contribution to vacuum polarization. In the modified minimal subtraction (MS) scheme [18] (used for this Review), and with $\alpha_s(M_Z) = 0.120$, we have $\hat{\alpha}(m_\tau)^{-1} = 133.471 \pm 0.014$ and $\widehat{\alpha}(M_Z)^{-1} = 127.944 \pm 0.014$. (In this Section we denote quantities defined in the modified minimal subtraction (MS) scheme by a caret; the exception is the strong coupling constant, α_s , which will always correspond to the $\overline{\rm MS}$ definition and where the caret will be dropped.) The latter corresponds to a quark sector contribution (without the top) to the conventional (on-shell) QED coupling, $\alpha(M_Z) = \frac{\alpha}{1 - \Delta \alpha(M_Z)}$

of $\Delta\alpha_{\rm had}^{(5)}(M_Z)\approx 0.02772\pm 0.00010$. These values are updated from Ref. 19 with $\Delta\alpha_{\rm had}^{(5)}(M_Z)$ moved downwards and its uncertainty halved (partly due to a more precise charm quark mass). Its correlation with the μ^\pm anomalous magnetic moment (see Sec. 10.5), as well as the non-linear α_s dependence of $\widehat{\alpha}(M_Z)$ and the resulting correlation with the input variable α_s , are fully taken into account in the fits. This is done by using as actual input (fit constraint) instead of $\Delta\alpha_{\rm had}^{(5)}(M_Z)$ the analogous low energy contribution by the three light quarks, $\Delta\alpha_{\rm had}^{(3)}(1.8~{\rm GeV}) = (55.50\pm 0.78)\times 10^{-4}~[20]$, and by calculating the perturbative and heavy quark contributions to $\widehat{\alpha}(M_Z)$ in each call of the fits according to Ref. 19. Part of the uncertainty ($\pm 0.49\times 10^{-4}$) is from e^+e^- annihilation data below 1.8 GeV and τ decay data (including uncertainties from isospin breaking effects), but uncalculated higher order perturbative ($\pm 0.41\times 10^{-4}$) and non-perturbative ($\pm 0.44\times 10^{-4}$) QCD corrections and the $\overline{\rm MS}$ quark mass values (see below) also contribute. Various recent evaluations of $\Delta\alpha_{\rm had}^{(5)}$ are summarized in Table 10.1, where the leading order relation between the $\overline{\rm MS}$ and on-shell definitions is given by,

$$\Delta\widehat{\alpha}(M_Z) - \Delta\alpha(M_Z) = \frac{\alpha}{\pi} \left(\frac{100}{27} - \frac{1}{6} - \frac{7}{4} \ln \frac{M_Z^2}{M_W^2} \right) \approx 0.0072, \quad (10.8)$$

and where the first term is from fermions and the other two are from W^{\pm} loops which are usually excluded from the on-shell definition. Most of the older results relied on $e^+e^- \rightarrow \text{hadrons cross-section}$ measurements up to energies of 40 GeV, which were somewhat higher than the QCD prediction, suggested stronger running, and were less precise. The most recent results typically assume the validity of perturbative QCD (PQCD) at scales of 1.8 GeV and above, and are in reasonable agreement with each other. There is, however, some discrepancy between analyses based on $e^+e^- \rightarrow$ hadrons cross-section data and those based on τ decay spectral functions [20]. The latter utilize data from OPAL [43], CLEO [44], ALEPH [45], and Belle [46] and imply lower central values for the extracted M_H of about 6%. This discrepancy is smaller than in the past and at least some of it appears to be experimental. The dominant $e^+e^- \to \pi^+\pi^-$ crosssection was measured with the CMD-2 [47] and SND [48] detectors at the VEPP-2M e^+e^- collider at Novosibirsk and the results are (after an initial discrepancy due to a flaw in the Monte Carlo event generator used by SND) in good agreement with each other. As an alternative to cross-section scans, one can use the high statistics radiative return events at e^+e^- accelerators operating at resonances such as the Φ or the $\Upsilon(4S)$. The method [49] is systematics limited but dominates

over the Novosibirsk data throughout. The BaBar collaboration [50]studied multi-hadron events radiatively returned from the $\Upsilon(4S)$, reconstructing the radiated photon and normalizing to $\mu^{\pm}\gamma$ final states. Their result is higher compared to VEPP-2M and in fact agrees quite well with the τ analysis including the energy dependence (shape). In contrast, the shape and smaller overall cross-section from the $\pi^+\pi^-$ radiative return results from the Φ obtained by the KLOE collaboration [51] differs significantly from what is observed by BaBar. The discrepancy originates from the kinematic region $\sqrt{s} \gtrsim 0.6$ GeV, and is most pronounced for $\sqrt{s} \gtrsim 0.85$ GeV. All measurements including older data [52] and multi-hadron final states (there are also discrepancies in the $e^+e^- \rightarrow 2\pi^+2\pi^-$ channel [20]) are accounted for and corrections have been applied for missing channels [20]. Further improvement of this dominant theoretical uncertainty in the interpretation of precision data will require better measurements of the cross-section for $e^+e^- \rightarrow$ hadrons below the charmonium resonances including multi-pion and other final states. To improve the precisions in $\widehat{m}_c(\widehat{m}_c)$ and $\widehat{m}_b(\widehat{m}_b)$ it would help to remeasure the threshold regions of the heavy quarks as well as the electronic decay widths of the narrow $c\bar{c}$ and $b\bar{b}$ resonances.

Further free parameters entering into Eq. (10.2) are the quark and lepton masses, where m_i is the mass of the i^{th} fermion ψ_i . For the quarks these are the current masses. For the light quarks, as described in the note on "Quark Masses" in the Quark Listings, $\hat{m}_u = 2.5^{+0.6}_{-0.6}~{\rm MeV},~\hat{m}_d = 5.0^{+0.7}_{-0.9}~{\rm MeV},$ and $\hat{m}_s = 100^{+30}_{-20}~{\rm MeV}.$ These are running $\overline{\rm Ms}$ masses evaluated at the scale $\mu=2~{\rm GeV}.$ For the heavier quarks we use QCD sum rule [53] constraints [54] and recalculate their masses in each call of our fits to account for their direct α_s dependence. We find $\P,~\hat{m}_c(\mu=\hat{m}_c)=1.267^{+0.032}_{-0.042}~{\rm GeV}$ and $\hat{m}_b(\mu=\hat{m}_b)=4.197\pm0.025~{\rm GeV},$ with a correlation of 24%.

The top quark "pole" mass (the quotation marks are a reminder that quarks do not form asymptotic states), $m_t = 173.4 \pm 0.9$ GeV, is an average of published and preliminary CDF and DØ results from run I and II [56] with first results by the CMS [57] and ATLAS [58] collaborations averaged in ignoring correlations. To gauge the possible impact of the neglect of correlations involving the LHC experiments, we also averaged the results conservatively assuming that the entire 0.75 GeV systematic of the Tevatron average is fully correlated with a 0.75 GeV component in both CMS and ATLAS. Incidentally, this yields correlations of similar size as those between the two Tevatron experiments and the two Runs and reduces the central value by 0.15 GeV. Within round-off we expect a more refined average to coincide with ours. Our average\$ differs slightly from the value, $m_t = 173.5 \pm 0.6 \pm 0.8$ GeV, which appears in the top quark Listings in this *Review* and which is based exclusively on published results. We are working, however, with $\overline{\text{MS}}$ masses in all expressions to minimize theoretical uncertainties. Such a short distance mass definition (unlike the pole mass) is free from non-perturbative and renormalon [59] uncertainties. We therefore convert to the top quark $\overline{\text{MS}}$ mass,

$$\hat{m}_t(\mu = \hat{m}_t) = m_t [1 - \frac{4}{3} \frac{\alpha_s}{\pi} + \mathcal{O}(\alpha_s^2)],$$
 (10.9)

using the three-loop formula [60]. This introduces an additional uncertainty which we estimate to 0.5 GeV (the size of the three-loop term) and add in quadrature to the experimental pole mass error. This is convenient because we use the pole mass as an external constraint while fitting to the $\overline{\rm MS}$ mass. We are assuming that the kinematic

 $^{^{\}dagger}$ Eq. (10.8) is for illustration only. Higher order contributions are directly evaluated in the $\overline{\rm MS}$ scheme using the FORTRAN package GAPP [21], including three-loop QED contributions of both leptons and quarks. The leptonic three-loop contribution in the on-shell scheme has been obtained in Ref. 22.

Other authors [55] advocate to evaluate and quote $\widehat{m}_c(\mu=3~{\rm GeV})$ instead. We use $\widehat{m}_c(\mu=\widehat{m}_c)$ because in the global analysis it is convenient to nullify any explicitly m_c dependent logarithms. Note also that our uncertainty for m_c (and to a lesser degree for m_b) is larger than the one in Ref. 55, for example. The reason is that we determine the continuum contribution for charm pair production using only resonance data and theoretical consistency across various sum rule moments, and then use any difference to the experimental continuum data as an additional uncertainty. We also include an uncertainty for the condensate terms which grows rapidly for higher moments in the sum rule analysis.

[§] At the time of writing this review, the efforts to establish a top quark averaging group involving both the Tevatron and the LHC were still in progress. Therefore we perform a simplified average ourselves.

mass extracted from the collider events corresponds within this uncertainty to the pole mass. Using the BLM optimized [61] version of the two-loop perturbative QCD formula [62] (as we did in previous editions of this Review) gives virtually identical results. In summary, we will use $m_t = 173.4 \pm 0.9 \; (\text{exp.}) \pm 0.5 \; (\text{QCD}) \; \text{GeV} = 173.4 \pm 1.0 \; \text{GeV}$ (together with $M_H = 117 \; \text{GeV}$) for the numerical values quoted in Sec. 10.2–Sec. 10.5.

 $\sin^2 \theta_W$ and M_W can be calculated from M_Z , $\widehat{\alpha}(M_Z)$, and G_F , when values for m_t and M_H are given; conversely (as is done at present), M_H can be constrained by $\sin^2 \theta_W$ and M_W . The value of $\sin^2 \theta_W$ is extracted from neutral-current processes (see Sec. 10.3) and Z pole observables (see Sec. 10.4) and depends on the renormalization prescription. There are a number of popular schemes [63–70] leading to values which differ by small factors depending on m_t and M_H . The notation for these schemes is shown in Table 10.1.

Table 10.1: Notations used to indicate the various schemes discussed in the text. Each definition of $\sin^2 \theta_W$ leads to values that differ by small factors depending on m_t and M_H . Approximate values are also given for illustration.

| Scheme | Notation | Value |
|---------------------------------------|------------------------|--------|
| On-shell | s_W^2 | 0.2231 |
| NOV | $s_{M_Z}^2$ | 0.2310 |
| $\overline{ m MS}$ | \widehat{s}_Z^2 | 0.2312 |
| $\overline{\mathrm{MS}}\ \mathrm{ND}$ | $\hat{s}_{	ext{ND}}^2$ | 0.2314 |
| Effective angle | \overline{s}_f^2 | 0.2315 |

(i) The on-shell scheme [63] promotes the tree-level formula $\sin^2\theta_W = 1 - M_W^2/M_Z^2$ to a definition of the renormalized $\sin^2\theta_W$ to all orders in perturbation theory, i.e., $\sin^2\theta_W \to s_W^2 \equiv 1 - M_W^2/M_Z^2$:

$$M_W = \frac{A_0}{s_W (1 - \Delta r)^{1/2}} , \qquad M_Z = \frac{M_W}{c_W} , \qquad (10.10)$$

where $c_W \equiv \cos\theta_W$, $A_0 = (\pi\alpha/\sqrt{2}G_F)^{1/2} = 37.28039(1)$ GeV, and Δr includes the radiative corrections relating α , $\alpha(M_Z)$, G_F , M_W , and M_Z . One finds $\Delta r \sim \Delta r_0 - \rho_t/\tan^2\theta_W$, where $\Delta r_0 = 1 - \alpha/\widehat{\alpha}(M_Z) = 0.06635(10)$ is due to the running of α , and $\rho_t = 3G_F m_t^2/8\sqrt{2}\pi^2 = 0.00943 (m_t/173.4 \text{ GeV})^2$ represents the dominant (quadratic) m_t dependence. There are additional contributions to Δr from bosonic loops, including those which depend logarithmically on M_H . One has $\Delta r = 0.0358 \mp 0.0004 \pm 0.00010$, where the first uncertainty is from m_t and the second is from $\alpha(M_Z)$. Thus the value of s_W^2 extracted from M_Z includes an uncertainty (∓ 0.00012) from the currently allowed range of m_t . This scheme is simple conceptually. However, the relatively large ($\sim 3\%$) correction from ρ_t causes large spurious contributions in higher orders.

(ii) A more precisely determined quantity s_{MZ}^2 [64] can be obtained from M_Z by removing the (m_t, M_H) dependent term from Δr [65], i.e.,

$$s_{M_Z}^2 (1 - s_{M_Z}^2) \equiv \frac{\pi \alpha(M_Z)}{\sqrt{2} G_F M_Z^2}$$
 (10.11)

Using $\alpha(M_Z)^{-1}=128.93\pm0.02$ yields $s_{M_Z}^2=0.23102\mp0.00005$. The small uncertainty in $s_{M_Z}^2$ compared to other schemes is because the m_t dependence has been removed by definition. However, the m_t uncertainty reemerges when other quantities (e.g., M_W or other Z pole observables) are predicted in terms of M_Z .

Both s_W^2 and $s_{M_Z}^2$ depend not only on the gauge couplings but also on the spontaneous-symmetry breaking, and both definitions are awkward in the presence of any extension of the SM which perturbs the value of M_Z (or M_W). Other definitions are motivated by the tree-level coupling constant definition $\theta_W = \tan^{-1}(g'/g)$:

(iii) In particular, the modified minimal subtraction ($\overline{\rm MS}$) scheme introduces the quantity $\sin^2 \widehat{\theta}_W(\mu) \equiv \widehat{g}^{\prime 2}(\mu)/[\widehat{g}^{\,2}(\mu)+\widehat{g}^{\prime 2}(\mu)]$, where the couplings \widehat{g} and \widehat{g}^\prime are defined by modified minimal subtraction and the scale μ is conveniently chosen to be M_Z for many EW processes. The value of $\hat{s}_Z^2 = \sin^2 \hat{\theta}_W(M_Z)$ extracted from M_Z is less sensitive than s_W^2 to m_t (by a factor of $\tan^2 \theta_W$), and is less sensitive to most types of new physics than s_W^2 or $s_{M_Z}^2$. It is also very useful for comparing with the predictions of grand unification. There are actually several variant definitions of $\sin^2 \theta_W(M_Z)$, differing according to whether or how finite $\alpha \ln(m_t/M_Z)$ terms are decoupled (subtracted from the couplings). One cannot entirely decouple the $\alpha \ln(m_t/M_Z)$ terms from all EW quantities because $m_t \gg m_b$ breaks SU(2) symmetry. The scheme that will be adopted here decouples the $\alpha \ln(m_t/M_Z)$ terms from the γ -Z mixing [18,66], essentially eliminating any $\ln(m_t/M_Z)$ dependence in the formulae for asymmetries at the Z pole when written in terms of \hat{s}_Z^2 . (A similar definition is used for $\hat{\alpha}$.) The various definitions are related by

$$\hat{s}_Z^2 = c(m_t, M_H) s_W^2 = \overline{c}(m_t, M_H) s_{M_Z}^2 , \qquad (10.12)$$

where $c=1.0362\pm0.0004$ and $\overline{c}=1.0009\mp0.0002$. The quadratic m_t dependence is given by $c\sim 1+\rho_t/\tan^2\theta_W$ and $\overline{c}\sim 1-\rho_t/(1-\tan^2\theta_W)$, respectively. The expressions for M_W and M_Z in the $\overline{\rm MS}$ scheme are

$$M_W = \frac{A_0}{\hat{s}_Z (1 - \Delta \hat{r}_W)^{1/2}} , \qquad M_Z = \frac{M_W}{\hat{\rho}^{1/2} \, \hat{c}_Z} , \quad (10.13)$$

and one predicts $\Delta \hat{r}_W = 0.06951 \pm 0.00001 \pm 0.00010$. $\Delta \hat{r}_W$ has no quadratic m_t dependence, because shifts in M_W are absorbed into the observed G_F , so that the error in $\Delta \hat{r}_W$ is dominated by $\Delta r_0 = 1 - \alpha/\hat{\alpha}(M_Z)$ which induces the second quoted uncertainty. The quadratic m_t dependence has been shifted into $\hat{\rho} \sim 1 + \rho_t$, where including bosonic loops, $\hat{\rho} = 1.01051 \pm 0.00011$. Quadratic M_H effects are deferred to two-loop order, while the leading logarithmic M_H effect is a good approximation only for large M_H values which are clearly disfavored by the precision data. As an illustration, the shift in M_W due to a large M_H (for fixed M_Z) is given by

$$\Delta_H M_W = -\frac{11}{96} \frac{\alpha}{\pi} \frac{M_W}{c_W^2 - s_W^2} \ln \frac{M_H^2}{M_W^2} + \mathcal{O}(\alpha^2)$$

$$\sim -200 \text{ MeV (for } M_H = 10 M_W). \tag{10.14}$$

(iv) A variant $\overline{\rm MS}$ quantity $\widehat{s}_{\rm ND}^2$ (used in the 1992 edition of this Review) does not decouple the $\alpha \ln(m_t/M_Z)$ terms [67]. It is related to \widehat{s}_Z^2 by

$$\widehat{s}_Z^2 = \widehat{s}_{ND}^2 / \left(1 + \frac{\widehat{\alpha}}{\pi} d\right), \tag{10.15a}$$

$$d = \frac{1}{3} \left(\frac{1}{\hat{s}^2} - \frac{8}{3} \right) \left[(1 + \frac{\alpha_s}{\pi}) \, \ln \frac{m_t}{M_Z} - \frac{15\alpha_s}{8\pi} \right], \ \ (10.15b)$$

Thus, $\hat{s}_Z^2 - \hat{s}_{ND}^2 \approx -0.0002$.

(v) Yet another definition, the effective angle [68–70] \overline{s}_f^2 for the Z vector coupling to fermion f, is based on Z pole observables and described below.

Experiments are at such level of precision that complete $\mathcal{O}(\alpha)$ radiative corrections must be applied. For neutral-current and Z pole processes, these corrections are conveniently divided into two classes:

- 1. QED diagrams involving the emission of real photons or the exchange of virtual photons in loops, but not including vacuum polarization diagrams. These graphs often yield finite and gaugeinvariant contributions to observable processes. However, they are dependent on energies, experimental cuts, etc., and must be calculated individually for each experiment.
- 2. EW corrections, including $\gamma\gamma$, γZ , ZZ, and WW vacuum polarization diagrams, as well as vertex corrections, box graphs,

etc., involving virtual W and Z bosons. The one-loop corrections are included for all processes, and certain two-loop corrections are also important. In particular, two-loop corrections involving the top quark modify ρ_t in $\hat{\rho}$, Δr , and elsewhere by

$$\rho_t \to \rho_t [1 + R(M_H, m_t)\rho_t/3].$$
(10.16)

 $R(M_H,m_t)$ is best described as an expansion in M_Z^2/m_t^2 . The unsuppressed terms were first obtained in Ref. 71, and are known analytically [72]. Contributions suppressed by M_Z^2/m_t^2 were first studied in Ref. 73 with the help of small and large Higgs mass expansions, which can be interpolated. These contributions are about as large as the leading ones in Refs. 71 and 72. The complete two-loop calculation of Δr (without further approximation) has been performed in Refs. 74 and 75 for fermionic and purely bosonic diagrams, respectively. Similarly, the EW two-loop calculation for the relation between \overline{s}_ℓ^2 and s_W^2 is complete [76] including the recently obtained purely bosonic contribution [77]. For M_H above its lower direct limit, -17 < R < -13.

Mixed QCD-EW contributions to gauge boson self-energies of order $\alpha\alpha_sm_t^2$ [78] and $\alpha\alpha_s^2m_t^2$ [79] increase the predicted value of m_t by 6%. This is, however, almost entirely an artifact of using the pole mass definition for m_t . The equivalent corrections when using the $\overline{\rm MS}$ definition $\widehat{m}_t(\widehat{m}_t)$ increase m_t by less than 0.5%. The subleading $\alpha\alpha_s$ corrections [80] are also included. Further three-loop corrections of order $\alpha\alpha_s^2$ [81], $\alpha^3m_t^6$ [82,83], and $\alpha^2\alpha_sm_t^4$ (for $M_H=0$) [82], are rather small. The same is true for $\alpha^3M_H^4$ [84] corrections unless M_H approaches 1 TeV. Also known are the singlet contributions (pure gluonic intermediate states) of order $\alpha\alpha_s^2$ [85] and $\alpha\alpha_s^3$ [86]. Recently, the corresponding non-singlet contributions have been computed as well [87].

The leading EW two-loop terms for the $Z \to b\bar{b}$ -vertex of $\mathcal{O}(\alpha^2 m_t^4)$ have been obtained in Refs. 71 and 72, and the mixed QCD-EW contributions in Refs. 88 and 89. The authors of Ref. 90 completed the two-loop EW fermionic corrections to \overline{s}_b^2 . The $\mathcal{O}(\alpha \alpha_s)$ -vertex corrections involving massless quarks [91] add coherently, resulting in a sizable effect and shift $\alpha_s(M_Z)$ when extracted from Z lineshape observables (see Sec. 10.4) by $\approx +0.0007$.

Many of the EW corrections are absorbed into the renormalized Fermi constant defined in Eq. (10.6). Others modify the tree-level expressions for Z pole observables and neutral-current amplitudes. In particular, the relations in Eq. (10.5) now read,

 $\overline{g}_{V}^{f} = \sqrt{\rho_{f}} \, (t_{3L}^{(f)} - 2q_{f} \kappa_{f} \sin^{2} \theta_{W}), \qquad \overline{g}_{A}^{f} = \sqrt{\rho_{f}} \, t_{3L}^{(f)}, \qquad (10)$ where the EW radiative corrections have been absorbed into corrections $\rho_f - 1$ and $\kappa_f - 1$, which depend on the fermion f and on the renormalization scheme. In the on-shell scheme, the quadratic m_t dependence is given by $\rho_f \sim 1 + \rho_t$, $\kappa_f \sim 1 + \rho_t / \tan^2 \theta_W$, while in $\overline{\text{MS}}$, $\widehat{\rho}_f \sim \widehat{\kappa}_f \sim 1$, for $f \neq b$ $(\widehat{\rho}_b \sim 1 - \frac{4}{3}\rho_t, \, \widehat{\kappa}_b \sim 1 + \frac{2}{3}\rho_t)$. In the $\overline{\rm MS}$ scheme the normalization is changed according to $G_F M_Z^2/2\sqrt{2}\pi \to \hat{\alpha}/4\hat{s}_Z^2\hat{c}_Z^2$. (If one continues to normalize amplitudes by $G_F M_Z^2/2\sqrt{2}\pi$, as in the 1996 edition of this Review, then $\hat{\rho}_f$ contains an additional factor of $\widehat{\rho}(1-\Delta \widehat{r}_W)\widehat{\alpha}/\alpha$.) In practice, additional bosonic and fermionic loops, vertex corrections, leading higher order contributions, etc., must be included. For example, in the $\overline{\text{MS}}$ scheme one has $\widehat{\rho}_{\ell} = 0.9981$, $\widehat{\kappa}_{\ell} = 1.0013$, $\widehat{\rho}_{b} = 0.9869$, and $\widehat{\kappa}_b$ = 1.0067. It is convenient to define an effective angle $\overline{s}_f^2 \equiv \sin^2 \overline{\theta}_{Wf} \equiv \widehat{\kappa}_f \widehat{s}_Z^2 = \kappa_f s_W^2$, in terms of which \overline{g}_V^f and \overline{g}_A^f are given by $\sqrt{\rho_f}$ times their tree-level formulae. Because \overline{g}_V^ℓ is very small, not only $A_{LR}^0 = A_e$, $A_{FB}^{(0,\ell)}$, and \mathcal{P}_{τ} , but also $A_{FB}^{(0,b)}$, $A_{FB}^{(0,c)}$, $A_{FB}^{(0,s)},$ and the hadronic asymmetries are mainly sensitive to $\overline{s}_{\ell}^2.$ One finds that $\hat{\kappa}_f$ $(f \neq b)$ is almost independent of (m_t, M_H) , so that one can write

$$\overline{s}_{\ell}^2 \sim \hat{s}_Z^2 + 0.00029 \ .$$
 (10.18)

Thus, the asymmetries determine values of \overline{s}_{ℓ}^2 and \widehat{s}_Z^2 almost independent of m_t , while the κ 's for the other schemes are m_t dependent.

Table 10.2: Standard Model expressions for the neutral-current parameters for ν -hadron, ν -e, and e^- -scattering processes. At tree level, $\rho=\kappa=1,\;\lambda=0.$ If radiative corrections are included, $\rho_{\nu N}=1.0082,\;\hat{\kappa}_{\nu N}(\langle Q^2\rangle=-20~{\rm GeV^2})=0.9972,\;\hat{\kappa}_{\nu N}(\langle Q^2\rangle=-35~{\rm GeV^2})=0.9965,\;\lambda_{uL}=-0.0031,\;\lambda_{dL}=-0.0025~{\rm and}\;\lambda_R=3.7\times10^{-5}.$ For ν -e scattering, $\rho_{\nu e}=1.0128$ and $\hat{\kappa}_{\nu e}=0.9963$ (at $\langle Q^2\rangle=0.$). For atomic parity violation and the polarized DIS experiment at SLAC, $\rho_e'=0.9887,\;\rho_e=1.0007,\;\hat{\kappa}_e'=1.0038,\;\hat{\kappa}_e=1.0297,\;\lambda'=-1.8\times10^{-5},\;\lambda_u=-0.0118$ and $\lambda_d=0.0029.$ And for polarized Møller scattering with SLAC (JLab) kinematics, $\lambda_e=-0.0002$ ($\lambda_e=-0.0004$). The dominant m_t dependence is given by $\rho\sim1+\rho_t,$ while $\hat{\kappa}\sim1~(\overline{\rm MS})$ or $\kappa\sim1+\rho_t/\tan^2\theta_W$ (on-shell).

| Quantity | Standard Model Expression |
|---------------------|--------------------------------------------------------------------------------------------------------------------|
| $\epsilon_L(u)$ | $\rho_{\nu N} \left(\frac{1}{2} - \frac{2}{3} \widehat{\kappa}_{\nu N} \widehat{s}_Z^2 \right) + \lambda_{uL}$ |
| $\epsilon_L(d)$ | $\rho_{\nu N} \left(-\frac{1}{2} + \frac{1}{3} \widehat{\kappa}_{\nu N} \widehat{s}_Z^2 \right) + \lambda_{dL}$ |
| $\epsilon_R(u)$ | $\rho_{\nu N} \left(-\frac{2}{3} \widehat{\kappa}_{\nu N} \widehat{s}_Z^2 \right) + \lambda_R$ |
| $\epsilon_R(d)$ | $\rho_{\nu N} \left(\frac{1}{3} \widehat{\kappa}_{\nu N} \widehat{s}_Z^2 \right) + 2 \lambda_R$ |
| $g_V^{ u e}$ | $\rho_{\nu e} \left(-\frac{1}{2} + 2 \widehat{\kappa}_{\nu e} \widehat{s}_Z^2 \right)$ |
| $g_A^{ u e}$ | $ \rho_{\nu e}\left(-\frac{1}{2}\right) $ |
| $\overline{C_{1u}}$ | $\rho_e'\left(-\frac{1}{2} + \frac{4}{3}\widehat{\kappa}_e'\widehat{s}_Z^2\right) + \lambda'$ |
| C_{1d} | $\rho_e'\left(\frac{1}{2} - \frac{2}{3}\widehat{\kappa}_e'\widehat{s}_Z^2\right) - 2\lambda'$ |
| C_{2u} | $\rho_e \left(-\frac{1}{2} + 2 \widehat{\kappa}_e \widehat{s}_Z^2 \right) + \lambda_u$ |
| C_{2d} | $\rho_e \left(\frac{1}{2} - 2 \widehat{\kappa}_e \widehat{s}_Z^2 \right) + \lambda_d$ |
| C_{2e} | $\rho_e \left(\frac{1}{2} - 2 \widehat{\kappa}_e \widehat{s}_Z^2 \right) + \lambda_e$ |

Throughout this *Review* we utilize EW radiative corrections from the program GAPP [21], which works entirely in the $\overline{\rm MS}$ scheme, and which is independent of the package ZFITTER [70]. Another resource is the recently developed modular fitting toolkit Gfitter [92].

10.3. Low energy electroweak observables

In the following we discuss EW precision observables obtained at low momentum transfers [6], i.e. $Q^2 \ll M_Z^2$. It is convenient to write the four-fermion interactions relevant to ν -hadron, ν -e, as well as parity violating e-hadron and e-e neutral-current processes in a form that is valid in an arbitrary gauge theory (assuming massless left-handed neutrinos). One has,

$$-\mathcal{L}^{\nu h} = \frac{G_F}{\sqrt{2}} \overline{\nu} \gamma^{\mu} (1 - \gamma^5) \nu$$

$$\times \sum_{i} [\epsilon_L(i) \overline{q}_i \gamma_{\mu} (1 - \gamma^5) q_i + \epsilon_R(i) \overline{q}_i \gamma_{\mu} (1 + \gamma^5) q_i], \qquad (10.19)$$

$$-\mathcal{L}^{\nu e} = \frac{G_F}{\sqrt{2}} \bar{\nu}_{\mu} \gamma^{\mu} (1 - \gamma^5) \nu_{\mu} \, \bar{e} \, \gamma_{\mu} (g_V^{\nu e} - g_A^{\nu e} \gamma^5) e, \qquad (10.20)$$

$$-\mathscr{L}^{eh} = -\,\frac{G_F}{\sqrt{2}}\,\sum_i \Big[C_{1i}\,\overline{e}\,\gamma_\mu\gamma^5 e\,\overline{q}_i\,\gamma^\mu q_i + C_{2i}\,\overline{e}\,\gamma_\mu e\,\overline{q}_i\,\,\gamma^\mu\gamma^5 q_i\Big], (10.21)$$

$$-\mathcal{L}^{ee} = -\frac{G_F}{\sqrt{2}} C_{2e} \,\overline{e} \,\gamma_{\mu} \gamma^5 e \,\overline{e} \,\gamma^{\mu} e, \qquad (10.22)$$

where one must include the charged-current contribution for ν_{e} -e and $\overline{\nu}_{e}$ -e and the parity-conserving QED contribution for electron scattering.

The SM expressions for $\epsilon_{L,R}(i)$, $g_{V,A}^{\nu e}$, and C_{ij} are given in Table 10.2. Note, that $g_{V,A}^{\nu e}$ and the other quantities are coefficients of effective four-Fermi operators, which differ from the quantities defined in Eq. (10.5) in the radiative corrections and in the presence of possible physics beyond the SM.

10.3.1. Neutrino scattering: For a general review on ν -scattering we refer to Ref. 93 (nonstandard neutrino scattering interactions are surveyed in Ref. 94).

The cross-section in the laboratory system for $\nu_{\mu}e \rightarrow \nu_{\mu}e$ or $\overline{\nu}_{\mu}e \rightarrow \overline{\nu}_{\mu}e$ elastic scattering [95] is

$$\frac{d\sigma_{\nu,\bar{\nu}}}{dy} = \frac{G_F^2 m_e E_{\nu}}{2\pi} \left[(g_V^{\nu e} \pm g_A^{\nu e})^2 + (g_V^{\nu e} \mp g_A^{\nu e})^2 (1-y)^2 - (g_V^{\nu e2} - g_A^{\nu e2}) \frac{y \, m_e}{E_{\nu}} \right]$$
(10.23)

where the upper (lower) sign refers to $\nu_{\mu}(\overline{\nu}_{\mu})$, and $y \equiv T_e/E_{\nu}$ (which runs from 0 to $(1+m_e/2E_{\nu})^{-1}$) is the ratio of the kinetic energy of the recoil electron to the incident ν or $\overline{\nu}$ energy. For $E_{\nu} \gg m_e$ this yields a total cross-section

$$\sigma = \frac{G_F^2 m_e E_{\nu}}{2\pi} \left[(g_V^{\nu e} \pm g_A^{\nu e})^2 + \frac{1}{3} (g_V^{\nu e} \mp g_A^{\nu e})^2 \right]. \tag{10.24}$$

The most accurate measurements [95–100] of $\sin^2 \theta_W$ from ν -lepton scattering (see Sec. 10.6) are from the ratio $R \equiv \sigma_{\nu\mu e}/\sigma_{\bar{\nu}\mu e}$ in which many of the systematic uncertainties cancel. Radiative corrections (other than m_t effects) are small compared to the precision of present experiments and have negligible effect on the extracted $\sin^2 \theta_W$. The most precise experiment (CHARM II) [98] determined not only $\sin^2 \theta_W$ but $g_{V,A}^{\nu e}$ as well, which are shown in Fig. 10.1. The cross-sections for ν_{e^-e} and $\overline{\nu}_{e^-e}$ may be obtained from Eq. (10.23) by replacing $g_{V,A}^{\nu e}$ by $g_{V,A}^{\nu e} + 1$, where the 1 is due to the charged-current contribution.

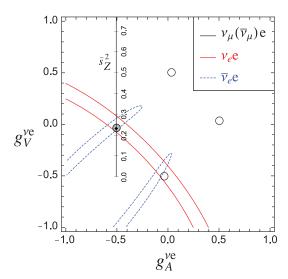


Figure 10.1: Allowed contours in $g_A^{\nu e}$ vs. $g_V^{\nu e}$ from neutrino-electron scattering and the SM prediction as a function of the weak mixing angle \hat{s}_Z^2 . (The SM best fit value $\hat{s}_Z^2=0.23116$ is also indicated.) The $\nu_e e$ [99] and $\bar{\nu}_e e$ [100] constraints are at 1 σ , while each of the four equivalent $\nu_\mu(\bar{\nu}_\mu)e$ [95–98] solutions $(g_{V,A} \to -g_{V,A})$ and $g_{V,A} \to g_{A,V}$ are at 90% C.L. The global best fit region (shaded) almost exactly coincides with the corresponding $\nu_\mu(\bar{\nu}_\mu)e$ region. The solution near $g_A=0,g_V=-0.5$ is eliminated by $e^+e^-\to \ell^+\ell^-$ data under the weak additional assumption that the neutral current is dominated by the exchange of a single Z boson.

A precise determination of the on-shell s_W^2 , which depends only very weakly on m_t and M_H , is obtained from deep inelastic scattering (DIS) of neutrinos from (approximately) isoscalar targets [101]. The ratio $R_{\nu} \equiv \sigma_{\nu N}^{NC}/\sigma_{\nu N}^{CC}$ of neutral-to-charged-current cross-sections has

been measured to 1% accuracy by CDHS [102] and CHARM [103] at CERN. CCFR [104] at Fermilab has obtained an even more precise result, so it is important to obtain theoretical expressions for R_{ν} and $R_{\bar{\nu}} \equiv \sigma_{\bar{\nu}N}^{NC}/\sigma_{\bar{\nu}N}^{CC}$ to comparable accuracy. Fortunately, many of the uncertainties from the strong interactions and neutrino spectra cancel in the ratio. A large theoretical uncertainty is associated with the c-threshold, which mainly affects σ^{CC} . Using the slow rescaling prescription [105] the central value of $\sin^2\theta_W$ from CCFR varies as 0.0111(m_c [GeV] - 1.31), where m_c is the effective mass which is numerically close to the $\overline{\rm MS}$ mass $\widehat{m}_c(\widehat{m}_c)$, but their exact relation is unknown at higher orders. For $m_c=1.31\pm0.24$ GeV (determined from ν -induced dimuon production [106]) this contributes ±0.003 to the total uncertainty $\Delta\sin^2\theta_W\sim\pm0.004$. (The experimental uncertainty is also ±0.003 .) This uncertainty largely cancels, however, in the Paschos-Wolfenstein ratio [107],

$$R^{-} = \frac{\sigma_{\nu N}^{NC} - \sigma_{\bar{\nu}N}^{NC}}{\sigma_{\nu N}^{CC} - \sigma_{\bar{\nu}N}^{CC}}.$$
 (10.25)

It was measured by Fermilab's NuTeV collaboration [108] for the first time, and required a high-intensity and high-energy anti-neutrino beam.

A simple zero th -order approximation is

$$R_{\nu} = g_L^2 + g_R^2 r$$
, $R_{\bar{\nu}} = g_L^2 + \frac{g_R^2}{r}$, $R^- = g_L^2 - g_R^2$, (10.26)

where

$$g_L^2 \equiv \epsilon_L(u)^2 + \epsilon_L(d)^2 \approx \frac{1}{2} - \sin^2 \theta_W + \frac{5}{9} \sin^4 \theta_W, (10.27a)$$

$$g_R^2 \equiv \epsilon_R(u)^2 + \epsilon_R(d)^2 \approx \frac{5}{9} \sin^4 \theta_W,$$
 (10.27b)

and $r \equiv \sigma^{CC}_{\bar{\nu}N}/\sigma^{CC}_{\nu N}$ is the ratio of $\bar{\nu}$ to ν charged-current cross-sections, which can be measured directly. (In the simple parton model, ignoring hadron energy cuts, $r \approx (\frac{1}{3}+\epsilon)/(1+\frac{1}{3}\epsilon)$, where $\epsilon \sim 0.125$ is the ratio of the fraction of the nucleon's momentum carried by antiquarks to that carried by quarks.) In practice, Eq. (10.26) must be corrected for quark mixing, quark sea effects, c-quark threshold effects, non-isoscalarity, W-Z propagator differences, the finite muon mass, QED and EW radiative corrections. Details of the neutrino spectra, experimental cuts, x and Q^2 dependence of structure functions, and longitudinal structure functions enter only at the level of these corrections and therefore lead to very small uncertainties. CCFR quotes $s^2_W = 0.2236 \pm 0.0041$ for $(m_t, M_H) = (175, 150)$ GeV with very little sensitivity to (m_t, M_H) .

The NuTeV collaboration found $s_W^2=0.2277\pm0.0016$ (for the same reference values), which was $3.0~\sigma$ higher than the SM prediction [108]. The deviation was in g_L^2 (initially $2.7~\sigma$ low) while g_R^2 was consistent with the SM. Since then a number of experimental and theoretical developments changed the interpretation of the measured cross section ratios, affecting the extracted $g_{L,R}^2$ (and thus s_W^2) including their uncertainties and correlation. In the following paragraph we give a semi-quantitative and preliminary discussion of these effects, but we stress that the precise impact of them needs to be evaluated carefully by the collaboration with a new and self-consistent set of PDFs, including new radiative corrections, while simultaneously allowing isospin breaking and asymmetric strange seas. This is an effort which is currently on its way and until it is completed we do not include the NuTeV constraints on $g_{L,R}^2$ in our default set of fits.

(i) In the original analysis NuTeV worked with a symmetric strange quark sea but subsequently measured [109] the difference between the strange and antistrange momentum distributions, $S^- \equiv \int_0^1 \mathrm{d}x x [s(x) - \bar{s}(x)] = 0.00196 \pm 0.00143$, from dimuon events utilizing the first complete next-to-leading order QCD description [110] and parton distribution functions (PDFs) according to Ref. 111. The global PDF fits in Ref. 112 give somewhat smaller values, $S^- = 0.0013(9)$ [$S^- = 0.0010(13)$], where the semi-leptonic charmed-hadron branching ratio, $B_\mu = 8.8 \pm 0.5\%$, has [not] been used as an external constraint. The resulting S^- also depends on the PDF

model used and on whether theoretical arguments (see Ref. 113 and references therein) are invoked favoring a zero crossing of $x[s(x) - \bar{s}(x)]$ at values much larger than seen by NuTeV and suggesting an effect of much smaller and perhaps negligible size. (ii) The measured branching ratio for K_{e3} decays enters crucially in the determination of the $\nu_e(\bar{\nu}_e)$ contamination of the $\nu_{\mu}(\bar{\nu}_{\mu})$ beam. This branching ratio has moved from $4.82 \pm 0.06\%$ at the time of the original publication [108] to the current value of $5.07 \pm 0.04\%$, i.e., a change by more than 4σ . This moves s_W^2 about one standard deviation further away from the SM prediction while reducing the $\nu_e(\bar{\nu}_e)$ uncertainty. (iii) PDFs seem to violate isospin symmetry at levels much stronger than generally expected [114]. A minimum χ^2 set of PDFs [115] allowing charge symmetry violation for both valence quarks $[d_V^p(x) \neq u_V^n(x)]$ and sea quarks $[\bar{d}^p(x) \neq \bar{u}^n(x)]$ shows a reduction in the NuTeV discrepancy by about 1σ . But isospin symmetry violating PDFs are currently not well constrained phenomenologically and within uncertainties the NuTeV anomaly could be accounted for in full or conversely made larger [115]. Still, the leading contribution from quark mass differences turns out to be largely model-independent [116] (at least in sign) and a shift, $\delta s_W^2 = -0.0015 \pm 0.0003$ [113], has been estimated. (iv) QED splitting effects also violate isospin symmetry with an effect on s_W^2 whose sign (reducing the discrepancy) is model-independent. The corresponding shift of $\delta s_W^2 = -0.0011$ has been calculated in Ref. 117 but has a large uncertainty. (v) Nuclear shadowing effects [118] are likely to affect the interpretation of the NuTeV result at some level, but the NuTeV collaboration argues that their data are dominated by values of Q^2 at which nuclear shadowing is expected to be relatively small. However, another nuclear effect, the isovector EMC effect [119], is much larger (because it affects all neutrons in the nucleus, not just the excess ones) and model-independently works to reduce the discrepancy. It is estimated to lead to a shift of $\delta s_W^2 = -0.0019 \pm 0.0006$ [113]. It would be important to verify and quantify this kind of effect experimentally, e.g., in polarized electron scattering. (vi) The extracted s_W^2 may also shift at the level of the quoted uncertainty when analyzed using the most recent QED and EW radiative corrections [120,121], as well as QCD corrections to the structure functions [122]. However, these are scheme-dependent and in order to judge whether they are significant they need to be adapted to the experimental conditions and kinematics of NuTeV, and have to be obtained in terms of observable variables and for the differential cross-sections. In addition, there is the danger of double counting some of the QED splitting effects. (vii) New physics could also affect $g_{L,R}^2$ [123] but it is difficult to convincingly explain the entire effect

${\bf 10.3.2.} \quad Parity\ violation:$

The SLAC polarized electron-deuteron DIS experiment [124] measured the right-left asymmetry,

$$A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \,, \tag{10.28}$$

where $\sigma_{R,L}$ is the cross-section for the deep-inelastic scattering of a right- or left-handed electron: $e_{R,L}N \to e{\rm X}$. In the quark parton model,

$$\frac{A}{Q^2} = a_1 + a_2 \frac{1 - (1 - y)^2}{1 + (1 - y)^2} \,, \tag{10.29}$$

where $Q^2 > 0$ is the momentum transfer and y is the fractional energy transfer from the electron to the hadrons. For the deuteron or other isoscalar targets, one has, neglecting the s-quark and anti-quarks,

$$a_1 = \frac{3G_F}{5\sqrt{2}\pi\alpha} \left(C_{1u} - \frac{1}{2}C_{1d} \right) \approx \frac{3G_F}{5\sqrt{2}\pi\alpha} \left(-\frac{3}{4} + \frac{5}{3}\sin^2\theta_W \right), \quad (10.30a)$$

$$a_2 = \frac{3G_F}{5\sqrt{2}\pi\alpha} \left(C_{2u} - \frac{1}{2}C_{2d} \right) \approx \frac{9G_F}{5\sqrt{2}\pi\alpha} \left(\sin^2\theta_W - \frac{1}{4} \right).$$
 (10.30b)

In another polarized-electron scattering experiment on deuterons, but in the quasi-elastic kinematic regime, the SAMPLE experiment [125] at MIT-Bates extracted the combination $C_{2u} - C_{2d}$ at Q^2 values of 0.1 GeV² and 0.038 GeV². What was actually determined were

nucleon form factors from which the quoted results were obtained by the removal of a multi-quark radiative correction [126]. Other linear combinations of the C_{iq} have been determined in polarized-lepton scattering at CERN in μ -C DIS, at Mainz in e-Be (quasi-elastic), and at Bates in e-C (elastic). See the review articles in Refs. 127 and 128 for more details. Recent polarized electron asymmetry experiments, i.e., SAMPLE, the PVA4 experiment at Mainz, and the HAPPEX and G0 experiments at Jefferson Lab, have focussed on the strange quark content of the nucleon. These are reviewed in Ref. 129, where it is shown that they can also provide significant constraints on C_{1u} and C_{1d} which complement those from atomic parity violation (see Fig. 10.2).

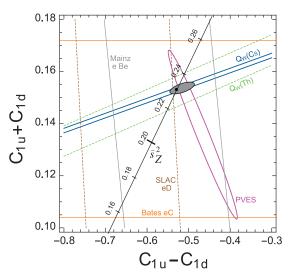


Figure 10.2: Constraints on the effective couplings, C_{1u} and C_{1d} , from recent (PVES) and older polarized parity violating electron scattering, and from atomic parity violation (APV) at 1 σ , as well as the 90% C.L. global best fit (shaded) and the SM prediction as a function of the weak mixing angle \hat{s}_Z^2 . (The SM best fit value $\hat{s}_Z^2 = 0.23116$ is also indicated.)

The parity violating asymmetry, A_{PV} , in fixed target polarized Møller scattering, $e^-e^- \rightarrow e^-e^-$, is defined as in Eq. (10.28) and reads [130],

$$\frac{A_{PV}}{Q^2} = -2 C_{2e} \frac{G_F}{\sqrt{2\pi\alpha}} \frac{1-y}{1+y^4+(1-y)^4} , \qquad (10.31)$$

where y is again the energy transfer. It has been measured at low $Q^2=0.026~{\rm GeV^2}$ in the SLAC E158 experiment [131], with the result $A_{PV}=(-1.31\pm0.14_{\rm stat.}\pm0.10_{\rm syst.})\times10^{-7}$. Expressed in terms of the weak mixing angle in the $\overline{\rm MS}$ scheme, this yields $\widehat{s}^2(Q^2)=0.2403\pm0.0013$, and established the scale dependence of the weak mixing angle (see Fig. 10.3) at the level of 6.4 standard deviations. One can also define the so-called weak charge of the electron (cf. Eq. (10.32) below) as $Q_W(e)\equiv -2\,C_{2e}=-0.0403\pm0.0053$ (the implications are discussed in Ref. 133).

In a similar experiment and at about the same Q^2 , Qweak at Jefferson Lab [136] will be able to measure the weak charge of the proton, $Q_W(p) = -2 [2 C_{1u} + C_{1d}]$, and $\sin^2 \theta_W$ in polarized ep scattering with relative precisions of 4% and 0.3%, respectively.

There are precise experiments measuring atomic parity violation (APV) [137] in cesium [138,139] (at the 0.4% level [138]), thallium [140], lead [141], and bismuth [142]. The EW physics is contained in the weak charges which are defined by,

$$Q_W(Z, N) \equiv -2 \left[C_{1u} \left(2Z + N \right) + C_{1d} (Z + 2N) \right] \approx Z (1 - 4 \sin^2 \theta_W) - N. \tag{10.32}$$

E.g., $Q_W(^{133}\mathrm{Cs})$ is extracted by measuring experimentally the ratio of the parity violating amplitude, E_{PNC} , to the Stark vector transition

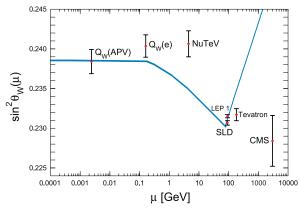


Figure 10.3: Scale dependence of the weak mixing angle defined in the $\overline{\text{MS}}$ scheme [132] (for the scale dependence of the weak mixing angle defined in a mass-dependent renormalization scheme, see Ref. 133). The minimum of the curve corresponds to $Q = M_W$, below which we switch to an effective theory with the W^{\pm} bosons integrated out, and where the β -function for the weak mixing angle changes sign. At the location of the W boson mass and each fermion mass there are also discontinuities arising from scheme dependent matching terms which are necessary to ensure that the various effective field theories within a given loop order describe the same physics. However, in the $\overline{\rm MS}$ scheme these are very small numerically and barely visible in the figure provided one decouples quarks at $Q = \hat{m}_q(\hat{m}_q)$. The width of the curve reflects the theory uncertainty from strong interaction effects which at low energies is at the level of $\pm 7 \times 10^{-5}$ [132]. Following the estimate [135] of the typical momentum transfer for parity violation experiments in Cs, the location of the APV data point is given by $\mu = 2.4$ MeV. For NuTeV we display the updated value from Ref. 134 and chose $\mu=\sqrt{20}$ GeV which is about half-way between the averages of $\sqrt{Q^2}$ for ν and $\overline{\nu}$ interactions at NuTeV. The Tevatron measurements are strongly dominated by invariant masses of the final state dilepton pair of $\mathcal{O}(M_Z)$ and can thus be considered as additional Z pole data points. However, for clarity we displayed the point horizontally to the right. Similar remarks apply to the first measurement at the LHC by the CMS collaboration.

polarizability, β , and by calculating theoretically $E_{\rm PNC}$ in terms of Q_W . One can then write,

$$Q_W = N \left(\frac{\operatorname{Im} E_{\text{PNC}}}{\beta} \right)_{\text{exp.}} \left(\frac{|e| \, a_B}{\operatorname{Im} E_{\text{PNC}}} \frac{Q_W}{N} \right)_{\text{th.}} \left(\frac{\beta}{a_B^3} \right)_{\text{exp.}+\text{th.}} \left(\frac{a_B^2}{|e|} \right).$$

The uncertainties associated with atomic wave functions are quite small for cesium [143]. The semi-empirical value of β used in early analyses added another source of theoretical uncertainty [144]. However, the ratio of the off-diagonal hyperfine amplitude to the polarizability was subsequently measured directly by the Boulder group [145]. Combined with the precisely known hyperfine amplitude [146] one finds, $\beta = 26.991 \pm 0.046$, in excellent agreement with the earlier results, reducing the overall theory uncertainty (while slightly increasing the experimental error). The recent stateof-the-art many body calculation [147] yields, $\operatorname{Im} E_{\text{PNC}} = (0.8906 \pm$ $0.0026) \times 10^{-11} |e| a_B Q_W/N$, while the two measurements [138,139] combine to give ${\rm Im}\,E_{\rm PNC}/\beta = -1.5924 \pm 0.0055$ mV/cm, and we obtain $Q_W(^{133}_{78}\text{Cs}) = -73.20 \pm 0.35$. Thus, the various theoretical efforts in Refs. 147 and 148 together with an update of the SM calculation [149] including a very recent dispersion analysis of the γZ -box contribution [150] removed an earlier 2.3 σ deviation from the SM (see the year 2000 edition of this Review). The theoretical uncertainties are 3% for thallium [151] but larger for the other atoms. The Boulder experiment in cesium also observed the parity-violating weak corrections to the nuclear electromagnetic vertex (the anapole moment [152]).

In the future it could be possible to further reduce the theoretical

wave function uncertainties by taking the ratios of parity violation in different isotopes [137,153]. There would still be some residual uncertainties from differences in the neutron charge radii, however [154]. Experiments in hydrogen and deuterium are another possibility for reducing the atomic theory uncertainties [155], while measurements of single trapped radium ions are promising [156] because of the much larger parity violating effect.

10.4. W and Z boson physics

10.4.1. e^+e^- scattering below the Z pole:

The forward-backward asymmetry for $e^+e^-\to \ell^+\ell^-,\,\ell=\mu$ or $\tau,$ is defined as

$$A_{FB} \equiv \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} \,, \tag{10.33}$$

where σ_F (σ_B) is the cross-section for ℓ^- to travel forward (backward) with respect to the e^- direction. A_{FB} and R, the total cross-section relative to pure QED, are given by

$$R = F_1 , A_{FB} = \frac{3}{4} \frac{F_2}{F_1} , (10.34)$$

where

$$F_1 = 1 - 2\chi_0 g_V^e g_V^\ell \cos \delta_R + \chi_0^2 \left(g_V^{e2} + g_A^{e2} \right) \left(g_V^{\ell2} + g_A^{\ell2} \right), \quad (10.35a)$$

$$F_2 = -2\chi_0 g_A^e g_A^\ell \cos \delta_R + 4\chi_0^2 g_A^e g_A^\ell g_V^\ell g_V^\ell , \qquad (10.35b)$$

$$\tan \delta_R = \frac{M_Z \Gamma_Z}{M_Z^2 - s} \; , \quad \chi_0 = \frac{G_F}{2\sqrt{2}\pi\alpha} \frac{sM_Z^2}{\left[(M_Z^2 - s)^2 + M_Z^2 \Gamma_Z^2\right]^{1/2}} \; , \eqno(10.36)$$

and where \sqrt{s} is the CM energy. Eqs. (10.35) are valid at tree level. If the data are radiatively corrected for QED effects (as described in Sec. 10.2), then the remaining EW corrections can be incorporated [157,158] (in an approximation adequate for existing PEP, PETRA, and TRISTAN data, which are well below the Z pole) by replacing χ_0 by $\chi(s) \equiv (1+\rho_t)\,\chi_0(s)\,\alpha/\alpha(s)$, where $\alpha(s)$ is the running QED coupling, and evaluating g_V in the $\overline{\rm MS}$ scheme. Reviews and formulae for $e^+e^-\to {\rm hadrons}$ may be found in Ref. 159.

10.4.2. Z pole physics:

At LEP 1 and the SLC, there were high-precision measurements of various Z pole observables [11,160–166], as summarized in Table 10.4. These include the Z mass and total width, Γ_Z , and partial widths $\Gamma(f\overline{f})$ for $Z \to f\overline{f}$ where fermion $f = e, \mu, \tau$, hadrons, b, or c. It is convenient to use the variables M_Z , Γ_Z , $R_{\ell} \equiv$ $\Gamma({\rm had})/\Gamma(\ell^+\ell^-)~(\ell=e,\mu,\tau),~\sigma_{\rm had}\equiv 12\pi\,\Gamma(e^+e^-)\,\Gamma({\rm had})/M_Z^2\,\Gamma_Z^2,~R_b\equiv\Gamma(b\overline{b})/\Gamma({\rm had}),~{\rm and}~R_c\equiv\Gamma(c\overline{c})/\Gamma({\rm had}),~{\rm most~of~which~are}$ weakly correlated experimentally. ($\Gamma(had)$ is the partial width into hadrons.) The three values for R_{ℓ} are not inconsistent with lepton universality (although R_{τ} is somewhat low compared to R_e and R_{μ}), but we use the general analysis in which the three observables are treated as independent. Similar remarks apply to $A_{FB}^{0,\ell}$ defined in Eq. (10.39) $(A_{FB}^{0,\tau})$ is somewhat high). $\mathcal{O}(\alpha^3)$ QED corrections introduce a large anti-correlation (-30%) between Γ_Z and $\sigma_{\rm had}$. The anti-correlation between R_b and R_c is -18% [11]. The R_ℓ are insensitive to m_t except for the $Z \to b\overline{b}$ vertex and final state corrections and the implicit dependence through $\sin^2 \theta_W$. Thus, they are especially useful for constraining α_s . The width for invisible decays [11], $\Gamma(\text{inv}) = \Gamma_Z - 3\Gamma(\ell^+\ell^-) - \Gamma(\text{had}) = 499.0 \pm 1.5 \text{ MeV},$ can be used to determine the number of neutrino flavors much lighter than $M_Z/2$, $N_{\nu} = \Gamma(\text{inv})/\Gamma^{\text{theory}}(\nu \overline{\nu}) = 2.984 \pm 0.009$ for $(m_t, M_H) = (173.4, 117) \text{ GeV}.$

There were also measurements of various Z pole asymmetries. These include the polarization or left-right asymmetry

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} , \qquad (10.37)$$

where $\sigma_L(\sigma_R)$ is the cross-section for a left-(right-)handed incident electron. A_{LR} was measured precisely by the SLD collaboration at

the SLC [162], and has the advantages of being extremely sensitive to $\sin^2 \theta_W$ and that systematic uncertainties largely cancel. In addition, SLD extracted the final-state couplings (defined below), A_b , A_c [11], A_s [163], A_τ , and A_μ [164], from left-right forward-backward asymmetries, using

$$A_{LR}^{FB}(f) = \frac{\sigma_{LF}^{f} - \sigma_{LB}^{f} - \sigma_{RF}^{f} + \sigma_{RB}^{f}}{\sigma_{LF}^{f} + \sigma_{LB}^{f} + \sigma_{RF}^{f} + \sigma_{RB}^{f}} = \frac{3}{4} A_{f} , \qquad (10.38)$$

where, for example, σ_{LF}^f is the cross-section for a left-handed incident electron to produce a fermion f traveling in the forward hemisphere. Similarly, A_{τ} was measured at LEP 1 [11] through the negative total τ polarization, \mathcal{P}_{τ} , and A_e was extracted from the angular distribution of \mathcal{P}_{τ} . An equation such as (10.38) assumes that initial state QED corrections, photon exchange, $\gamma - Z$ interference, the tiny EW boxes, and corrections for $\sqrt{s} \neq M_Z$ are removed from the data, leaving the pure EW asymmetries. This allows the use of effective tree-level expressions,

$$A_{LR} = A_e P_e , \qquad A_{FB} = \frac{3}{4} A_f \frac{A_e + P_e}{1 + P_e A_e} , \qquad (10.39)$$

where

$$A_f \equiv \frac{2\overline{g}_V^f \, \overline{g}_A^f}{\overline{g}_V^{f_2} + \overline{g}_A^{f_2}} \,. \tag{10.40}$$

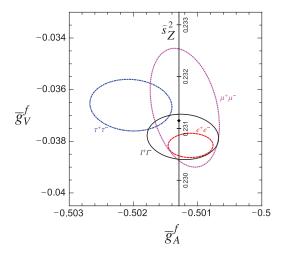


Figure 10.4: 1 σ (39.35% C.L.) contours for the Z-pole observables \bar{g}_A^f and \bar{g}_V^f , $f=e,\mu,\tau$ obtained at LEP and SLC [11], compared to the SM expectation as a function of \hat{s}_Z^2 . (The SM best fit value $\hat{s}_Z^2=0.23116$ is also indicated.) Also shown is the 90% CL allowed region in $\bar{g}_{A,V}^\ell$ obtained assuming lepton universality.

 P_e is the initial e^- polarization, so that the second equality in Eq. (10.38) is reproduced for $P_e=1$, and the Z pole forward-backward asymmetries at LEP 1 ($P_e=0$) are given by $A_{FB}^{(0,f)}=\frac{3}{4}A_eA_f$ where $f=e,~\mu,~\tau,~b,~c,~s~[165],~$ and q,~ and where $A_{FB}^{(0,q)}$ refers to the hadronic charge asymmetry. Corrections for t-channel exchange and s/t-channel interference cause $A_{FB}^{(0,e)}$ to be strongly anti-correlated with $R_e~(-37\%)$. The correlation between $A_{FB}^{(0,b)}$ and $A_{FB}^{(0,c)}$ amounts to 15%. The initial state coupling, A_e , was also determined through the left-right charge asymmetry [166] and in polarized Bhabba scattering [164] at the SLC.

As an example of the precision of the Z-pole observables, the values of \bar{g}_A^f and \bar{g}_J^V , $f=e,\mu,\tau,\ell$, extracted from the LEP and SLC lineshape and asymmetry data is shown in Fig. 10.4, which should be compared with Fig. 10.1. (The two sets of parameters coincide in the SM at tree-level.)

As for hadron colliders, the forward-backward asymmetry, A_{FB} , for e^+e^- final states (with invariant masses restricted to or dominated

by values around M_Z) in $p\bar{p}$ collisions has been measured by the DØ [167] and CDF [168] collaborations and values for \bar{s}_ℓ^2 were extracted, which combine to $\bar{s}_\ell^2 = 0.23200 \pm 0.00076$ (assuming common PDF uncertainties). By varying the invariant mass and the scattering angle (and assuming the electron couplings), information on the effective Z couplings to light quarks, $\bar{g}_{V,A}^{u,d}$, could also be obtained [167,169], but with large uncertainties and mutual correlations and not independently of \bar{s}_ℓ^2 above. Similar analyses have also been reported by the H1 and ZEUS collaborations at HERA [170] and by the LEP collaborations [11]. This kind of measurement is harder in the pp environment due to the difficulty to assign the initial quark and antiquark in the underlying Drell-Yan process to the protons. Nevertheless, the CMS collaboration [171] already reported a first measurement, $\bar{s}_Z^2 = 0.2287 \pm 0.0032$.

10.4.3. LEP 2:

LEP 2 [172] ran at several energies above the Z pole up to ~ 209 GeV. Measurements were made of a number of observables, including the cross-sections for $e^+e^- \to f\bar{f}$ for $f=q,\mu^-,\tau^-$; the differential cross-sections for $f=e^-,\mu^-,\tau^-$; R_q for q=b,c; $A_{FB}(f)$ for $f=\mu,\tau,b,c$; W branching ratios; and WW, $WW\gamma$, ZZ, single W, and single Z cross-sections. They are in good agreement with the SM predictions, with the exceptions of the total hadronic cross-section (1.7 σ high), R_b (2.1 σ low), and $A_{FB}(b)$ (1.6 σ low). Also, the negative result of the direct search for the SM Higgs boson excluded M_H values below 114.4 GeV at the 95% CL [173]. This result is complementary to and can be combined with [174] the limits inferred from the EW precision data.

The Z boson properties are extracted assuming the SM expressions for the $\gamma{-}Z$ interference terms. These have also been tested experimentally by performing more general fits [172,175] to the LEP 1 and LEP 2 data. Assuming family universality this approach introduces three additional parameters relative to the standard fit [11], describing the $\gamma{-}Z$ interference contribution to the total hadronic and leptonic cross-sections, $j_{\rm had}^{\rm tot}$ and $j_{\ell}^{\rm tot}$, and to the leptonic forward-backward asymmetry, $j_{\ell}^{\rm fb}$. E.g.,

$$j_{\rm had}^{\rm tot} \sim g_V^{\ell} g_V^{\rm had} = 0.277 \pm 0.065,$$
 (10.41)

which is in agreement with the SM expectation [11] of 0.21 ± 0.01 . These are valuable tests of the SM; but it should be cautioned that new physics is not expected to be described by this set of parameters, since (i) they do not account for extra interactions beyond the standard weak neutral-current, and (ii) the photonic amplitude remains fixed to its SM value.

Strong constraints on anomalous triple and quartic gauge couplings have been obtained at LEP 2 and the Tevatron as described in the Gauge & Higgs Bosons Particle Listings.

10.4.4. W and Z decays:

The partial decay width for gauge bosons to decay into massless fermions $f_1\overline{f}_2$ (the numerical values include the small EW radiative corrections and final state mass effects) is given by

$$\Gamma(W^+ \to e^+ \nu_e) = \frac{G_F M_W^3}{6\sqrt{2}\pi} \approx 226.36 \pm 0.05 \text{ MeV} ,$$
 (10.42a)

$$\Gamma(W^+ \to u_i \overline{d}_j) = \frac{CG_F M_W^3}{6\sqrt{2}\pi} |V_{ij}|^2 \approx 706.34 \pm 0.16 \text{ MeV } |V_{ij}|^2,$$
(10.42b)

$$\Gamma(Z \rightarrow \psi_i \overline{\psi}_i) = \frac{CG_F M_Z^3}{6\sqrt{2}\pi} \left[g_V^{i2} + g_A^{i2} \right]$$

$$\approx \begin{cases} 167.22 \pm 0.01 \text{ MeV } (\nu \overline{\nu}), \\ 84.00 \pm 0.01 \text{ MeV } (e^+e^-), \\ 300.26 \pm 0.05 \text{ MeV } (u\overline{u}), \\ 383.04 \pm 0.05 \text{ MeV } (d\overline{d}), \\ 375.08 \pm 0.03 \text{ MeV } (b\overline{b}) \end{cases}$$
(10.42c)

For leptons C = 1, while for quarks

$$C = 3 \left[1 + \frac{\alpha_s(M_V)}{\pi} + 1.409 \frac{\alpha_s^2}{\pi^2} - 12.77 \frac{\alpha_s^3}{\pi^3} - 80.0 \frac{\alpha_s^4}{\pi^4} \right], \quad (10.43)$$

where the 3 is due to color and the factor in brackets represents the universal part of the QCD corrections [176] for massless quarks [177]. The $\mathcal{O}(\alpha_s^4)$ contribution in Eq. (10.43) is recent [178]. The $Z \to f\bar{f}$ widths contain a number of additional corrections: which are different for vector and axial-vector partial widths and are included through order α_s^3 and $\widehat{m}_q^4(M_Z^2)$ unless they are tiny; and singlet contributions starting from two-loop order which are large, strongly top quark mass dependent, family universal, and flavor non-universal [181]. The QED factor $1 + 3\alpha q_f^2/4\pi$, as well as two-loop order $\alpha\alpha_s$ and α^2 self-energy corrections [182] are also included. Working in the on-shell scheme, i.e., expressing the widths in terms of $G_F M_{WZ}^3$, incorporates the largest radiative corrections from the running QED coupling [63,183]. $\stackrel{\smile}{\mathrm{EW}}$ corrections to the Z widths are then incorporated by replacing $g_{V,A}^{i2}$ by $\overline{g}_{V,A}^{i2}$. Hence, in the on-shell scheme the Z widths are proportional to $\rho_i \sim 1 + \rho_t$. The $\overline{\rm MS}$ normalization accounts also for the leading EW corrections [68]. There is additional (negative) quadratic m_t dependence in the $Z \to b\bar{b}$ vertex corrections [184] which causes $\Gamma(b\overline{b})$ to decrease with m_t . The dominant effect is to multiply $\Gamma(b\overline{b})$ by the vertex correction $1 + \delta \rho_{b\overline{b}}$, where $\delta \rho_{b\overline{b}} \sim 10^{-2} (-\frac{1}{2} \frac{m_t^2}{M_Z^2} + \frac{1}{5})$. In practice, the corrections are included in ρ_b and κ_b , as discussed in

For three fermion families the total widths are predicted to be

$$\Gamma_Z \approx 2.4960 \pm 0.0002 \; {\rm GeV} \; , \qquad \qquad \Gamma_W \approx 2.0915 \pm 0.0005 \; {\rm GeV} \; . \eqno(10.44)$$

We have assumed $\alpha_s(M_Z)=0.1200$. An uncertainty in α_s of ± 0.002 introduces an additional uncertainty of 0.06% in the hadronic widths, corresponding to ± 1 MeV in Γ_Z . These predictions are to be compared with the experimental results, $\Gamma_Z=2.4952\pm0.0023$ GeV [11] and $\Gamma_W=2.085\pm0.042$ GeV [185] (see the Gauge & Higgs Boson Particle Listings for more details).

10.5. Precision flavor physics

In addition to cross-sections, asymmetries, parity violation, W and Z decays, there is a large number of experiments and observables testing the flavor structure of the SM. These are addressed elsewhere in this Review, and are generally not included in this Section. However, we identify three precision observables with sensitivity to similar types of new physics as the other processes discussed here. The branching fraction of the flavor changing transition $b \to s \gamma$ is of comparatively low precision, but since it is a loop-level process (in the SM) its sensitivity to new physics (and SM parameters, such as heavy quark masses) is enhanced. A discussion can be found in earlier editions of this Review. The τ -lepton lifetime and leptonic branching ratios are primarily sensitive to α_s and not affected significantly by many types of new physics. However, having an independent and reliable low energy measurement of α_s in a global analysis allows the comparison with the Z lineshape determination of α_s which shifts easily in the presence of new physics contributions. By far the most precise observable discussed here is the anomalous magnetic moment of the muon (the electron magnetic moment is measured to even greater precision and can be used to determine α , but its new physics sensitivity is suppressed by an additional factor of m_e^2/m_μ^2). Its combined experimental and theoretical uncertainty is comparable to typical new physics contributions.

The extraction of α_s from the τ lifetime [186] is standing out from other determinations because of a variety of independent reasons: (i) the τ -scale is low, so that upon extrapolation to the Z scale (where it can be compared to the theoretically clean Z lineshape determinations) the α_s error shrinks by about an order of magnitude; (ii) yet, this scale is high enough that perturbation theory and the operator product expansion (OPE) can be applied; (iii) these observables are fully inclusive and thus free of fragmentation and hadronization effects that would have to be modeled or measured; (iv) duality violation (DV) effects are most problematic near the branch cut but there they are suppressed by a double zero at $s=m_{\tau}^2$; (v) there are data [43] to constrain non-perturbative effects both within $(\delta_{D=6,8})$ and breaking (δ_{DV}) the OPE; (vi) a complete four-loop order QCD calculation is available [178]; (vii) large effects associated

with the QCD β -function can be re-summed [187] in what has become known as contour improved perturbation theory (CIPT). However, while there is no doubt that CIPT shows faster convergence in the lower (calculable) orders, doubts have been cast on the method by the observation that at least in a specific model [188], which includes the exactly known coefficients and theoretical constraints on the large-order behavior, ordinary fixed order perturbation theory (FOPT) may nevertheless give a better approximation to the full result. We therefore use the expressions [54,177,178,189],

$$\tau_{\tau} = \hbar \frac{1 - \mathcal{B}_{\tau}^{s}}{\Gamma_{\tau}^{e} + \Gamma_{\tau}^{\mu} + \Gamma_{\tau}^{ud}} = 291.13 \pm 0.43 \text{ fs}, \qquad (10.45)$$

$$\Gamma_{\tau}^{ud} = \frac{G_F^2 m_{\tau}^5 |V_{ud}|^2}{64\pi^3} S(m_{\tau}, M_Z) \left(1 + \frac{3}{5} \frac{m_{\tau}^2 - m_{\mu}^2}{M_W^2} \right) \times$$

$$\left[1 + \frac{\alpha_s(m_\tau)}{\pi} + 5.202 \frac{\alpha_s^2}{\pi^2} + 26.37 \frac{\alpha_s^3}{\pi^3} + 127.1 \frac{\alpha_s^4}{\pi^4} + \frac{\widehat{\alpha}}{\pi} (\frac{85}{24} - \frac{\pi^2}{2}) + \delta_q\right],\tag{10.46}$$

and Γ_{τ}^{e} and Γ_{τ}^{μ} can be taken from Eq. (10.6) with obvious replacements. The relative fraction of decays with $\Delta S = -1$, $\mathcal{B}_{\tau}^{s} = 0.0286 \pm 0.0007$, is based on experimental data since the value for the strange quark mass, $\widehat{m}_s(m_\tau)$, is not well known and the QCD expansion proportional to \widehat{m}_s^2 converges poorly and cannot be trusted. $S(m_{\tau}, M_Z) = 1.01907 \pm 0.0003$ is a logarithmically enhanced EW correction factor with higher orders re-summed [190]. δ_q contains the dimension six and eight terms in the OPE, as well as DV effects, $\delta_{D=6,8} + \delta_{DV} = -0.004 \pm 0.012$ [191]. Depending on how $\delta_{D=6}$, $\delta_{D=8}$, and δ_{DV} are extracted, there are strong correlations not only between them, but also with the gluon condensate (D = 4) and possibly D > 8 terms. These latter are suppressed in Eq. (10.46) by additional factors of α_s , but not so for more general weight functions. A simultaneous fit to all non-perturbative terms [191] (as is necessary if one wants to avoid ad hoc assumptions) indicates that the α_s errors may have been underestimated in the past. Higher statistics τ decay data [45] and spectral functions from e^+e^- annihilation (providing a larger fit window and thus more discriminatory power and smaller correlations) are likely to reduce the δ_q error in the future. Also included in δ_q are quark mass effects and the D=4 condensate contributions. An uncertainty of similar size arises from the truncation of the FOPT series and is conservatively taken as the α_s^4 term (this is re-calculated in each call of the fits, leading to an α_s -dependent and thus asymmetric error) until a better understanding of the numerical differences between FOPT and CIPT has been gained. Our perturbative error covers almost the entire range from using CIPT to assuming that the nearly geometric series in Eq. (10.46) continues to higher orders. The experimental uncertainty in Eq. (10.45), is from the combination of the two leptonic branching ratios with the direct τ_{τ} . Included are also various smaller uncertainties (± 0.5 fs) from other sources which are dominated by the evolution from the Z scale. In total we obtain a $\sim 2\%$ determination of $\alpha_s(M_Z) = 0.1193^{+0.0022}_{-0.0020}$, which corresponds to $\alpha_s(m_\tau) = 0.327^{+0.019}_{-0.016}$, and updates the result of Refs. 54 and 192. For more details, see Refs. 191 and 193 where the τ spectral functions are used as additional input.

The world average of the muon anomalous magnetic moment $^{\frac{1}{4}}$,

$$a_{\mu}^{\rm exp} = \frac{g_{\mu} - 2}{2} = (1165920.80 \pm 0.63) \times 10^{-9},$$
 (10.47)

is dominated by the final result of the E821 collaboration at BNL [194]. The QED contribution has been calculated to four

 $^{^{\}dagger}$ In what follows, we summarize the most important aspects of $g_{\mu}-2,$ and give some details about the evaluation in our fits. For more details see the dedicated contribution by A. Höcker and W. Marciano in this Review. There are some small numerical differences (at the level of 0.1 standard deviation), which are well understood and mostly arise because internal consistency of the fits requires the calculation of all observables from analytical expressions and common inputs and fit parameters, so that an independent evaluation is necessary for this Section. Note, that in the spirit of a global analysis based on all available information we have chosen here to average in the τ decay data, as well.

loops [195] (fully analytically to three loops [196,197]) , and the leading logarithms are included to five loops [198,199]. The estimated SM EW contribution [200–202], $a_{\mu}^{\rm EW}=(1.52\pm0.03)\times10^{-9}$, which includes leading two-loop [201] and three-loop [202] corrections, is at the level of twice the current uncertainty.

The limiting factor in the interpretation of the result are the uncertainties from the two- and three-loop hadronic contribution. E.g., Ref. 20 obtained the value $a_{\mu}^{\rm had} = (69.23 \pm 0.42) \times 10^{-9}$ which combines CMD-2 [47] and SND [48] $e^+e^- \rightarrow$ hadrons cross-section data with radiative return results from BaBar [50] and KLOE [51]. This value suggests a 3.6 σ discrepancy between Eq. (10.47) and the SM prediction. An alternative analysis [20] using τ decay data and isospin symmetry (CVC) yields $a_{\mu}^{\rm had}=(70.15\pm0.47)\times10^{-9}$. This result implies a smaller conflict (2.4 σ) with Eq. (10.47). Thus, there is also a discrepancy between the spectral functions obtained from the two methods. For example, if one uses the e^+e^- data and CVC to predict the branching ratio for $\tau^- \to \nu_\tau \pi^- \pi^0$ decays [20] we obtain an average of $\mathcal{B}_{\text{CVC}} = 24.93 \pm 0.13 \pm 0.22_{\text{CVC}}$, while the average of the directly measured branching ratio yields 25.51 ± 0.09 , which is 2.3 σ higher. It is important to understand the origin of this difference, but two observations point to the conclusion that at least some of it is experimental: (i) There is also a direct discrepancy of $1.9~\sigma$ between $\mathcal{B}_{\mathrm{CVC}}$ derived from BaBar (which is not inconsistent with τ decays) and KLOE. (ii) Isospin violating corrections have been studied in detail in Ref. 203 and found to be largely under control. The largest effect is due to higher-order EW corrections [204] but introduces a negligible uncertainty [190]. Nevertheless, a_u^{had} is often evaluated excluding the τ decay data arguing [205] that CVC breaking effects (e.g., through a relatively large mass difference between the ρ^{\pm} and ρ^0 vector mesons) may be larger than expected. (This may also be relevant [205] in the context of the NuTeV result discussed above.) Experimentally [45], this mass difference is indeed larger than expected, but then one would also expect a significant width difference which is contrary to observation [45]. Fortunately, due to the suppression at large s (from where the conflicts originate) these problems are less pronounced as far as a_{μ}^{had} is concerned. In the following we view all differences in spectral functions as (systematic) fluctuations and average the results.

An additional uncertainty is induced by the hadronic three-loop light-by-light scattering contribution. Two recent and inherently different model calculations yield $a_\mu^{\rm LBLS}=(+1.36\pm0.25)\times10^{-9}$ [206] and $a_\mu^{\rm LBLS}=+1.37^{+0.15}_{-0.27}\times10^{-9}$ [207] which are higher than previous evaluations [208,209]. The sign of this effect is opposite [208] to the one quoted in the 2002 edition of this Review, and has subsequently been confirmed by two other groups [209]. There is also the upper bound $a_\mu^{\rm LBLS}<1.59\times10^{-9}$ [207] but this requires an $ad\ hoc$ assumption, too. The recent Ref. 210 quotes the value $a_\mu^{\rm LBLS}=(+1.05\pm0.26)\times10^{-9},$ which we shift by 2×10^{-11} to account for the more accurate charm quark treatment of Ref. 207. We also increase the error to cover all evaluations, and we will use $a_\mu^{\rm LBLS}=(+1.07\pm0.32)\times10^{-9}$ in the fits.

Other hadronic effects at three-loop order contribute [211] $a_{\mu}^{\rm had}(\alpha^3)=(-1.00\pm0.06)\times10^{-9}$. Correlations with the two-loop hadronic contribution and with $\Delta\alpha(M_Z)$ (see Sec. 10.2) were considered in Ref. 197 which also contains analytic results for the perturbative QCD contribution.

Altogether, the SM prediction is

$$a_{\mu}^{\text{theory}} = (1165918.41 \pm 0.48) \times 10^{-9} ,$$
 (10.48)

where the error is from the hadronic uncertainties excluding parametric ones such as from α_s and the heavy quark masses. Using a correlation of about 84% from the data input to the vacuum polarization integrals [20], we estimate the correlation of the total (experimental plus theoretical) uncertainty in a_μ with $\Delta\alpha(M_Z)$ as 24%. The overall 3.0 σ discrepancy between the experimental and theoretical a_μ values could be due to fluctuations (the E821 result is statistics dominated) or underestimates of the theoretical uncertainties. On the other hand, $g_\mu - 2$ is also affected by many types of new physics, such as supersymmetric models with large $\tan\beta$ and moderately light

Table 10.3: Principal non-Z pole observables, compared with the SM best fit predictions. The first M_W value is from the Tevatron [214] and the second one from LEP 2 [172]. e-DIS [129] and the ν -DIS constraints from CDHS [102], CHARM [103], and CCFR [104] are included, as well, but not shown in the Table. The world averages for $g_{V,A}^{\nu e}$ are dominated by the CHARM II [98] results, $g_V^{\nu e} = -0.035 \pm 0.017$ and $g_A^{\nu e} = -0.503 \pm 0.017$. The errors are the total (experimental plus theoretical) uncertainties. The τ_{τ} value is the τ lifetime world average computed by combining the direct measurements with values derived from the leptonic branching ratios [54]; in this case, the theory uncertainty is included in the SM prediction. In all other SM predictions, the uncertainty is from M_Z , M_H , m_t , m_b , m_c , $\widehat{\alpha}(M_Z)$, and α_s , and their correlations have been accounted for. The column denoted Pull gives the standard deviations for the principal fit with M_H free, while the column denoted Dev. (Deviation) is for $M_H = 124.5 \text{ GeV}$ [215] fixed.

| Quantity | Value | Standard Model | Pull | Dev. |
|---------------------------------------------|-------------------------------------|-------------------------------------|-------|------|
| m_t [GeV] | 173.4 ± 1.0 | 173.5 ± 1.0 | -0.1 | -0.3 |
| M_W [GeV] | 80.420 ± 0.031 | 80.381 ± 0.014 | 1.2 | 1.6 |
| | 80.376 ± 0.033 | | -0.2 | 0.2 |
| $g_V^{ u e}$ | -0.040 ± 0.015 | -0.0398 ± 0.0003 | 0.0 | 0.0 |
| $g_A^{ u e}$ | -0.507 ± 0.014 | -0.5064 ± 0.0001 | 0.0 | 0.0 |
| $Q_W(e)$ | -0.0403 ± 0.0053 | -0.0474 ± 0.0005 | 1.3 | 1.3 |
| $Q_W(Cs)$ | -73.20 ± 0.35 | -73.23 ± 0.02 | 0.1 | 0.1 |
| $Q_W(\mathrm{Tl})$ | -116.4 ± 3.6 | -116.88 ± 0.03 | 0.1 | 0.1 |
| τ_{τ} [fs] | 291.13 ± 0.43 | 290.75 ± 2.51 | 0.1 | 0.1 |
| $\frac{1}{2}(g_{\mu}-2-\frac{\alpha}{\pi})$ | $(4511.07 \pm 0.77) \times 10^{-9}$ | $(4508.70 \pm 0.09) \times 10^{-9}$ | 9 3.0 | 3.0 |

superparticle masses [212]. Thus, the deviation could also arise from physics beyond the SM.

10.6. Global fit results

In this section we present the results of global fits to the experimental data discussed in Sec. 10.3–Sec. 10.5. For earlier analyses see Refs. 128 and 213.

The values for m_t [56–58], M_W [172,214], neutrino scattering [96–104], the weak charges of the electron [131], cesium [138,139] and thallium [140], the muon anomalous magnetic moment [194], and the τ lifetime are listed in Table 10.3. Likewise, the principal Z pole observables can be found in Table 10.4 where the LEP 1 averages of the ALEPH, DELPHI, L3, and OPAL results include common systematic errors and correlations [11]. The heavy flavor results of LEP 1 and SLD are based on common inputs and correlated, as well [11]. Note that the values of $\Gamma(\ell^+\ell^-)$, $\Gamma(\text{had})$, and $\Gamma(\text{inv})$ are not independent of Γ_Z , the R_ℓ , and $\sigma_{\rm had}$ and that the SM errors in those latter are largely dominated by the uncertainty in α_s . Also shown in both Tables are the SM predictions for the values of M_Z , M_H , $\alpha_s(M_Z)$, $\Delta\alpha_{\rm had}^{(3)}$ and the heavy quark masses shown in Table 10.5. The predictions result from a global least-square (χ^2) fit to all data using the minimization package MINUIT [216] and the EW library GAPP [21]. In most cases, we treat all input errors (the uncertainties of the values) as Gaussian. The reason is not that we assume that theoretical and systematic errors are intrinsically bell-shaped (which they are not) but because in most cases the input errors are combinations of many different (including statistical) error sources, which should yield approximately Gaussian combined errors by the large number theorem. Thus, if either the statistical components dominate or there are many components of similar size. An exception is the theory dominated error on the τ lifetime, which we recalculate in each χ^2 -function call since it depends itself on α_s . Sizes and shapes of the output errors (the uncertainties of the predictions and the SM fit parameters) are fully determined by the fit, and 1 σ errors are defined to correspond to $\Delta \chi^2 = \chi^2 - \chi^2_{\min} = 1$, and do not necessarily correspond to the 68.3% probability range or the 39.3% probability contour (for 2 parameters).

Table 10.4: Principal Z pole observables and their SM predictions (cf. Table 10.3). The first $\overline{s}_\ell^2(A_{FB}^{(0,q)})$ is the effective angle extracted from the hadronic charge asymmetry, the second is the combined value from DØ [167] and CDF [168], and the third is from CMS [171]. The three values of A_e are (i) from A_{LR} for hadronic final states [162]; (ii) from A_{LR} for leptonic final states and from polarized Bhabba scattering [164]; and (iii) from the angular distribution of the τ polarization at LEP 1. The two A_τ values are from SLD and the total τ polarization, respectively.

| Quantity | Value | Standard Model | Pull Dev. |
|--------------------------------------|-----------------------|-----------------------|------------|
| M_Z [GeV] | 91.1876 ± 0.0021 | 91.1874 ± 0.0021 | 0.1 0.0 |
| Γ_Z [GeV] | 2.4952 ± 0.0023 | 2.4961 ± 0.0010 | -0.4 -0.2 |
| $\Gamma(\text{had}) \text{ [GeV]}$ | 1.7444 ± 0.0020 | 1.7426 ± 0.0010 | |
| $\Gamma(inv)$ [MeV] | 499.0 ± 1.5 | 501.69 ± 0.06 | |
| $\Gamma(\ell^+\ell^-)$ [MeV] | 83.984 ± 0.086 | 84.005 ± 0.015 | |
| $\sigma_{ m had}[m nb]$ | 41.541 ± 0.037 | 41.477 ± 0.009 | 1.7 	 1.7 |
| R_e | 20.804 ± 0.050 | 20.744 ± 0.011 | 1.2 	 1.3 |
| R_{μ} | 20.785 ± 0.033 | 20.744 ± 0.011 | 1.2 	 1.3 |
| R_{τ} | 20.764 ± 0.045 | 20.789 ± 0.011 | -0.6 -0.5 |
| R_b | 0.21629 ± 0.00066 | 0.21576 ± 0.00004 | 0.8 0.8 |
| R_c | 0.1721 ± 0.0030 | 0.17227 ± 0.00004 | -0.1 -0.1 |
| $A_{FB}^{(0,e)}$ | 0.0145 ± 0.0025 | 0.01633 ± 0.00021 | -0.7 -0.7 |
| $A_{FB}^{(0,\mu)}$ | 0.0169 ± 0.0013 | | 0.4 - 0.6 |
| $A_{FB}^{(0,	au)}$ | 0.0188 ± 0.0017 | | 1.5 1.6 |
| $A_{FB}^{(0,b)}$ | 0.0992 ± 0.0016 | 0.1034 ± 0.0007 | -2.6 - 2.3 |
| $A_{FB}^{(0,c)}$ | 0.0707 ± 0.0035 | 0.0739 ± 0.0005 | -0.9 -0.8 |
| $A_{FB}^{(0,s)}$ | 0.0976 ± 0.0114 | 0.1035 ± 0.0007 | -0.5 -0.5 |
| $\bar{s}_{\ell}^{2}(A_{FB}^{(0,q)})$ | 0.2324 ± 0.0012 | 0.23146 ± 0.00012 | 0.8 - 0.7 |
| V 12 | 0.23200 ± 0.00076 | | 0.7 - 0.6 |
| | 0.2287 ± 0.0032 | | -0.9 -0.9 |
| A_e | 0.15138 ± 0.00216 | 0.1475 ± 0.0010 | 1.8 2.1 |
| | 0.1544 ± 0.0060 | | 1.1 1.3 |
| | 0.1498 ± 0.0049 | | 0.5 0.6 |
| A_{μ} | 0.142 ± 0.015 | | -0.4 -0.3 |
| A_{τ} | 0.136 ± 0.015 | | -0.8 -0.7 |
| | 0.1439 ± 0.0043 | | -0.8 -0.7 |
| A_b | 0.923 ± 0.020 | 0.9348 ± 0.0001 | -0.6 -0.6 |
| A_c | 0.670 ± 0.027 | 0.6680 ± 0.0004 | 0.1 0.1 |
| A_s | 0.895 ± 0.091 | 0.9357 ± 0.0001 | -0.4 - 0.4 |

The agreement is generally very good. Despite the few discrepancies discussed in the following, the fit describes well the data with a $\chi^2/\text{d.o.f.} = 45.0/42$. The probability of a larger χ^2 is 35%. Only the final result for $g_\mu - 2$ from BNL and $A_{FB}^{(0,b)}$ from LEP 1 are currently showing large (3.0 σ and 2.6 σ) deviations. In addition, A_{LR}^0 (SLD) from hadronic final states differs by 1.8 σ . g_L^2 from NuTeV is nominally in conflict with the SM, as well, but the precise status is under investigation (see Sec. 10.3).

 A_b can be extracted from $A_{FB}^{(0,b)}$ when $A_e=0.1501\pm0.0016$ is taken from a fit to leptonic asymmetries (using lepton universality). The result, $A_b=0.881\pm0.017$, is $3.2~\sigma$ below the SM prediction and also $1.6~\sigma$ below $A_b=0.923\pm0.020$ obtained from $A_{LR}^{FB}(b)$ at SLD. Thus, it appears that at least some of the problem in $A_{FB}^{(0,b)}$ is experimental. Note, however, that the uncertainty in $A_{FB}^{(0,b)}$ is strongly statistics dominated. The combined value, $A_b=0.899\pm0.013$ deviates by $2.8~\sigma$.

It would be difficult to account for this 4.0% deviation by new physics that enters only at the level of radiative corrections since about a 20% correction to $\widehat{\kappa}_b$ would be necessary to account for the central value of A_b [217]. If this deviation is due to new physics, it is most likely of tree-level type affecting preferentially the third generation. Examples include the decay of a scalar neutrino resonance [218], mixing of the b quark with heavy exotics [219], and a heavy Z' with family-nonuniversal couplings [220,221]. It is difficult, however, to simultaneously account for R_b , which has been measured on the Z peak and off-peak [222] at LEP 1. An average of R_b measurements at LEP 2 at energies between 133 and 207 GeV is 2.1 σ below the SM prediction, while $A_{EB}^{(b)}$ (LEP 2) is 1.6 σ low [172].

The left-right asymmetry, $A_{LR}^0=0.15138\pm0.00216$ [162], based on all hadronic data from 1992–1998 differs $1.8~\sigma$ from the SM expectation of 0.1475 ± 0.0010 . The combined value of $A_\ell=0.1513\pm0.0021$ from SLD (using lepton-family universality and including correlations) is also $1.8~\sigma$ above the SM prediction; but there is experimental agreement between this SLD value and the LEP 1 value, $A_\ell=0.1481\pm0.0027$, obtained from a fit to $A_{FB}^{(0,\ell)}$, $A_e(\mathcal{P}_\tau)$, and $A_\tau(\mathcal{P}_\tau)$, again assuming universality.

The observables in Table 10.3 and Table 10.4, as well as some other less precise observables, are used in the global fits described below. In all fits, the errors include full statistical, systematic, and theoretical uncertainties. The correlations on the LEP 1 lineshape and τ polarization, the LEP/SLD heavy flavor observables, the SLD lepton asymmetries, and the deep inelastic and $\nu\text{-}e$ scattering observables, are included. The theoretical correlations between $\Delta\alpha_{\rm had}^{(5)}$ and $g_{\mu}-2$, and between the charm and bottom quark masses, are also accounted for.

The data allow a simultaneous determination of M_Z , M_H , m_t , and the strong coupling $\alpha_s(M_Z)$. $(\widehat{m}_c,\,\widehat{m}_b,\,$ and $\Delta\alpha_{\rm had}^{(3)}$ are also allowed to float in the fits, subject to the theoretical constraints [19,54] described in Sec. 10.2. These are correlated with α_s .) α_s is determined mainly from R_ℓ , Γ_Z , $\sigma_{\rm had}$, and τ_τ and is only weakly correlated with the other variables. The global fit to all data, including the hadron collider average $m_t=173.4\pm1.0~{\rm GeV}$, yields the result in Table 10.5 (the $\overline{\rm MS}$ top quark mass given there corresponds to $m_t=173.5\pm1.0~{\rm GeV}$). The weak mixing angle is determined to

$$\hat{s}_Z^2 = 0.23116 \pm 0.00012,$$
 $s_W^2 = 0.22296 \pm 0.00028,$

while the corresponding effective angle is related by Eq. (10.18), *i.e.*, $\overline{s}_{\ell}^2 = 0.23146 \pm 0.00012$.

As described in Sec. 10.2 and the paragraph following Eq. (10.47) in Sec. 10.5, there is considerable stress in the experimental $e^+e^$ spectral functions and also conflict when these are compared with au decay spectral functions. These are below or above the 2σ level (depending on what is actually compared) but not larger than the deviations of some other quantities entering our analyses. The number and size or these deviations are not inconsistent with what one would expect to happen as a result of random fluctuations. It is nevertheless instructive to study the effect of doubling the uncertainty in $\Delta\alpha_{\rm had}^{(3)}(1.8~{\rm GeV}) = (55.50 \pm 0.78) \times 10^{-4}$, (see Sec. 10.2) on the extracted Higgs mass. The result, $M_H = 95^{+28}_{-23}$ GeV, demonstrates that the uncertainty in $\Delta\alpha_{\rm had}$ is currently of only secondary importance. Note also, that a shift of ± 0.0001 in $\Delta\alpha_{\rm had}^{(3)}(1.8~{\rm GeV})$ corresponds to a shift of ∓ 5 GeV in M_H or about one fifth of its total uncertainty. The hadronic contribution to $\alpha(M_Z)$ is correlated with $g_{\mu}-2$ (see Sec. 10.5). The measurement of the latter is higher than the SM prediction, and its inclusion in the fit favors a larger $\alpha(M_Z)$ and a lower M_H (currently by about 4 GeV).

The weak mixing angle can be determined from Z pole observables, M_W , and from a variety of neutral-current processes spanning a very wide Q^2 range. The results (for the older low energy neutral-current data see Refs. 128 and 213) shown in Table 10.6 are in reasonable agreement with each other, indicating the quantitative success of the SM. The largest discrepancy is the value $\hat{s}_Z^2 = 0.23193 \pm 0.00028$ from the forward-backward asymmetries into bottom and charm quarks, which is 2.8 σ above the value 0.23116 \pm 0.00012 from the

[§] Alternatively, one can use $A_{\ell}=0.1481\pm0.0027$, which is from LEP 1 alone and in excellent agreement with the SM, and obtain $A_{b}=0.893\pm0.022$ which is 1.9 σ low. This illustrates that some of the discrepancy is related to the one in A_{LR} .

global fit to all data. Similarly, $\hat{s}_Z^2 = 0.23067 \pm 0.00029$ from the SLD asymmetries (in both cases when combined with M_Z) is 1.8 σ low. The SLD result has the additional difficulty (within the SM) of implying very low and excluded [173] Higgs masses. This is also true for $\hat{s}_Z^2 = 0.23098 \pm 0.00022$ from M_W and M_Z and — as a consequence — for the global fit. We have therefore included in Table 10.3 and Table 10.4 an additional column (denoted Deviation) indicating the deviations if $M_H = 124.5$ GeV [215] is fixed.

 (0.1172 ± 0.0037) and lattice simulations $(0.1185\pm0.0007),$ whereas the DIS average (0.1150 ± 0.0021) is somewhat lower. For more details, other determinations, and references, see Section 9 on "Quantum Chromodynamics" in this Review. Using $\alpha(M_Z)$ and \hat{s}_Z^2 as inputs, one can predict $\alpha_s(M_Z)$ assuming grand unification. One predicts [223] $\alpha_s(M_Z)=0.130\pm0.001\pm0.01$ for the simplest theories based on the minimal supersymmetric extension of the SM, where the first (second) uncertainty is from the inputs (thresholds).

Table 10.5: Principal SM fit result including mutual correlations (all masses in GeV). Note that $\widehat{m}_c(\widehat{m}_c)$ induces a significant uncertainty in the running of α beyond $\Delta \alpha_{\rm had}^{(3)}(1.8 \text{ GeV})$ resulting in a relatively large correlation with M_H . Since this effect is proportional to the quark's electric charge squared it is much smaller for $\widehat{m}_b(\widehat{m}_b)$.

| M_Z | 91.1874 ± 0.0021 | 1.00 - 0.01 | 0.00 | 0.00 - 0.01 | 0.00 0.14 |
|------------------------------------------------|---------------------------|---------------|-------|---------------|---------------|
| $\widehat{m}_t(\widehat{m}_t)$ | 163.71 ± 0.95 | -0.01 1.00 | 0.01 | -0.01 -0.15 | 0.00 0.31 |
| $\widehat{m}_b(\widehat{m}_b)$ | 4.197 ± 0.025 | 0.00 0.01 | 1.00 | 0.24 - 0.04 | 0.01 0.04 |
| $\widehat{m}_c(\widehat{m}_c)$ | $1.266^{+0.032}_{-0.040}$ | 0.00 - 0.01 | 0.24 | 1.00 0.09 | 0.03 0.14 |
| $\alpha_s(M_Z)$ | 0.1196 ± 0.0017 | -0.01 -0.15 | -0.04 | 0.09 1.00 | -0.01 -0.05 |
| $\Delta \alpha_{\rm had}^{(3)}(1.8~{\rm GeV})$ | 0.00561 ± 0.00008 | 0.00 0.00 | 0.01 | 0.03 - 0.01 | 1.00 - 0.16 |
| M_H | 99^{+28}_{-23} | 0.14 0.31 | 0.04 | 0.14 - 0.05 | -0.16 1.00 |

Table 10.6: Values of \hat{s}_Z^2 , \hat{s}_W^2 , α_s , and M_H [in GeV] for various (combinations of) observables. Unless indicated otherwise, the top quark mass, $m_t = 173.4 \pm 1.0$ GeV, is used as an additional constraint in the fits. The (†) symbol indicates a fixed parameter.

| Data | \widehat{s}_{Z}^{2} | s_W^2 | $\alpha_s(M_Z)$ | M_H |
|-------------------------------------------------|-----------------------|-------------|--------------------|---------------------|
| All data | 0.23116(12) | 0.22295(28) | 0.1196(17) | 99^{+28}_{-23} |
| All indirect (no m_t) | 0.23118(14) | 0.22285(35) | 0.1197(17) | 134^{+144}_{-65} |
| Z pole (no m_t) | 0.23121(17) | 0.22318(60) | 0.1197(28) | 102^{+133}_{-51} |
| LEP 1 (no m_t) | 0.23152(20) | 0.22383(67) | 0.1213(30) | 191^{+266}_{-105} |
| $SLD + M_Z$ | 0.23067(28) | 0.22204(54) | 0.1185 (†) | 39^{+31}_{-19} |
| $A_{FB}^{(b,c)} + M_Z$ | 0.23193(28) | 0.22494(76) | 0.1185 (†) | 444^{+300}_{-178} |
| $M_W + M_Z$ | 0.23098(22) | 0.22262(47) | 0.1185 (†) | 75^{+39}_{-30} |
| M_Z | 0.23124(5) | 0.22318(13) | 0.1185 (†) | 124.5 (†) |
| $Q_W(e)$ | 0.2332(15) | 0.2252(15) | 0.1185 (†) | 124.5 (†) |
| Q_W (APV) | 0.2311(16) | 0.2230(17) | $0.1185(\dagger)$ | $124.5 (\dagger)$ |
| ν_{μ} -N DIS (isoscalar) | 0.2332(39) | 0.2251(39) | 0.1185 (†) | 124.5 (†) |
| Elastic $\nu_{\mu}(\overline{\nu}_{\mu})$ -e | 0.2311(77) | 0.2230(77) | 0.1185 (†) | 124.5 (†) |
| $e	ext{-D}$ DIS (SLAC) | 0.222(18) | 0.214(18) | 0.1185 (†) | 124.5 (†) |
| Elastic $\nu_{\mu}(\overline{\nu}_{\mu})$ - p | 0.211(33) | 0.203(33) | $0.1185 (\dagger)$ | 124.5 (†) |

The extracted Z pole value of $\alpha_s(M_Z)$ is based on a formula with negligible theoretical uncertainty if one assumes the exact validity of the SM. One should keep in mind, however, that this value, $\alpha_s(M_Z)=0.1197\pm0.0028$, is very sensitive to such types of new physics as non-universal vertex corrections. In contrast, the value derived from τ decays, $\alpha_s(M_Z)=0.1193^{+0.0022}_{-0.0020}$, is theory dominated but less sensitive to new physics. The two values are in remarkable agreement with each other. They are also in perfect agreement with the averages from jet-event shapes in e^+e^- annihilation

This is slightly larger, but consistent with the experimental $\alpha_s(M_Z)=0.1196\pm0.0017$ from the Z lineshape and the τ lifetime, as well as with most other determinations. Non-supersymmetric unified theories predict the low value $\alpha_s(M_Z)=0.073\pm0.001\pm0.001$. See also the note on "Supersymmetry" in the Searches Particle Listings.

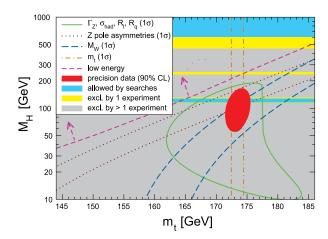


Figure 10.5: One-standard-deviation (39.35%) uncertainties in M_H as a function of m_t for various inputs, and the 90% CL region ($\Delta\chi^2 = 4.605$) allowed by all data. $\alpha_s(M_Z) = 0.1185$ is assumed except for the fits including the Z lineshape or low energy data. The bright (yellow) bands are excluded by one experiment and the remaining (gray) regions are ruled out by more than one experiment (95% CL).

The data indicate a preference for a small Higgs mass. There is a strong correlation between the quadratic m_t and logarithmic M_H terms in $\widehat{\rho}$ in all of the indirect data except for the $Z \to b\overline{b}$ vertex. Therefore, observables (other than R_b) which favor m_t values higher than the Tevatron range favor lower values of M_H . M_W has additional M_H dependence through $\Delta \widehat{r}_W$ which is not coupled to m_t^2 effects. The strongest individual pulls toward smaller M_H are from M_W and

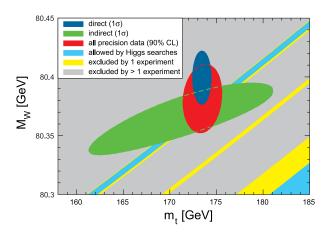


Figure 10.6: One-standard-deviation (39.35%) region in M_W as a function of m_t for the direct and indirect precision data, and the 90% CL region ($\Delta\chi^2=4.605$) allowed by all precision data. The SM predictions are also indicated, where the blue bands for Higgs masses between 115.5 and 127 GeV and beyond 600 GeV are currently allowed at the 95% CL. The yellow bands are excluded by one experiment and the remaining (gray) regions are ruled out by more than one experiment (95% CL).

 $A_{LR}^{0},$ while $A_{FB}^{(0,b)}$ favors higher values. The difference in χ^2 for the global fit is $\Delta\chi^2=\chi^2(M_H=314~{\rm GeV})-\chi^2_{\rm min}=25.$ Hence, the data favor a small value of $M_H,$ as in supersymmetric extensions of the SM. The central value of the global fit result, $M_H=99^{+28}_{-23}~{\rm GeV},$ is below the direct lower bound from LEP 2, $M_H\geq 114.4~{\rm GeV}$ (95% CL) [173], which was very recently extended slightly by ATLAS to $M_H\geq 115.5~{\rm GeV}$ [224].

The 90% central confidence range from all precision data is

$$68 \text{ GeV} \le M_H \le 155 \text{ GeV}.$$
 (10.49)

Including the results of the direct searches at LEP 2 [173] and the Tevatron [225] as extra contributions to the likelihood function reduces the 95% upper limit to $M_H \leq 150$ GeV. As two further refinements, we account for (i) theoretical uncertainties from uncalculated higher order contributions by allowing the T parameter (see next subsection) subject to the constraint $T=0\pm0.02$, (ii) the M_H dependence of the correlation matrix which gives slightly more weight to lower Higgs masses [226]. The resulting limits at 95 (90, 99)% CL are, respectively,

$$M_H \le 175 \text{ (148, 210) GeV.}$$
 (10.50)

In their Higgs searches in pp collisions with CM energy of 7 TeV, both ATLAS [224] and CMS [227] find results consistent with Eq. (10.50) and currently report $\gtrsim 2~\sigma$ excess fluctuation near $M_H=119.5~{\rm GeV}$ (CMS only), $M_H=124~{\rm GeV}$ (CMS), and $M_H=126~{\rm GeV}$ (ATLAS only). Of course, these excesses do not constitute a discovery. However, it is useful to take them at face value for comparison with the precision data in Table 10.3, Table 10.4, and Table 10.6. A combination of all available data yields (at the 68% CL) [215]

$$M_H = 124.5 \pm 0.8 \text{ GeV}.$$
 (10.51)

The resulting probability distribution has a twin peak structure (besides a smaller maximum at $M_H=118.5~{\rm GeV}$) with almost equal probability at $M_H=124~{\rm GeV}$ and $M_H=125~{\rm GeV}$ [215].

One can also carry out a fit to the indirect data alone, i.e., without including the constraint, $m_t=173.4\pm1.0$ GeV, from the hadron colliders. (The indirect prediction is for the $\overline{\rm MS}$ mass, $\widehat{m}_t(\widehat{m}_t)=167.5^{+8.9}_{-7.3}$ GeV, which is in the end converted to the pole mass). One obtains $m_t=177.5^{+9.4}_{-7.8}$ GeV, in perfect agreement with the direct Tevatron/LHC average. Using this indirect top mass value, the tendency for a light Higgs persists and Eq. (10.49) becomes 46 GeV $\leq M_H \leq 306$ GeV. The relations between M_H and m_t for various observables are shown in Fig. 10.5.

One can also determine the radiative correction parameters Δr : from the global fit one obtains $\Delta r = 0.0352 \pm 0.0009$ and $\Delta \hat{r}_W =$

Table 10.7: Values of the model-independent neutral-current parameters, compared with the SM predictions. There is a second $g_{VA}^{\nu e}$ solution, given approximately by $g_V^{\nu e} \leftrightarrow g_A^{\nu e}$, which is eliminated by e^+e^- data under the assumption that the neutral current is dominated by the exchange of a single Z boson. The ϵ_L , as well as the ϵ_R , are strongly correlated and non-Gaussian, so that for implementations we recommend the parametrization using g_i^2 and $\theta_i = \tan^{-1}[\epsilon_i(u)/\epsilon_i(d)]$, i=L or R. The analysis of more recent low energy experiments in polarized electron scattering performed in Ref. 129 is included by means of the two orthogonal constraints, $\cos \gamma \, C_{1d} - \sin \gamma \, C_{1u} = 0.342 \pm 0.063$ and $\sin \gamma \, C_{1d} + \cos \gamma \, C_{1u} = -0.0285 \pm 0.0043$, where $\tan \gamma \approx 0.445$. In the SM predictions, the uncertainty is from M_Z , M_H , m_t , m_b , m_c , $\widehat{\alpha}(M_Z)$, and α_s .

| Quantity | Experimental Value | SM | C | Correlatio | on |
|----------------------|--------------------------------|------------|------|------------------------|-------|
| $\epsilon_L(u)$ | 0.328 ± 0.016 | 0.3461(1) | | | |
| $\epsilon_L(d)$ | $-0.440\ \pm0.011$ | -0.4292(1) | n | on- | |
| $\epsilon_R(u)$ | -0.179 ± 0.013 | -0.1549(1) | C | laussian | |
| $\epsilon_R(d)$ | $-0.027 {}^{+0.077}_{-0.048}$ | 0.0775 | | | |
| g_L^2 | 0.3009 ± 0.0028 | 0.3040(2) | | | |
| $g_R^{\overline{2}}$ | $0.0328 {\pm} 0.0030$ | 0.0300 | | small | |
| $	heta_L$ | 2.50 ± 0.035 | 2.4630(1) | | | |
| θ_R | $4.56 ^{+0.42}_{-0.27}$ | 5.1765 | | | |
| $g_V^{ u e}$ | -0.040 ± 0.015 | -0.0399(2) | | | -0.05 |
| $g_A^{ u e}$ | -0.507 ± 0.014 | -0.5064(1) | | | |
| $C_{1u} + C_{1d}$ | 0.1537 ± 0.0011 | 0.1530(1) | 0.64 | -0.18 | -0.01 |
| $C_{1u} - C_{1d}$ | -0.516 ± 0.014 | -0.5300(3) | | -0.27 | -0.02 |
| $C_{2u} + C_{2d}$ | -0.21 ± 0.57 | -0.0089 | | | -0.30 |
| $C_{2u} - C_{2d}$ | -0.077 ± 0.044 | -0.0627(5) | | | |
| $Q_W(e) = -2C_{2e}$ | -0.0403 ± 0.0053 | -0.0474(5) | | | |

 $0.06945\pm0.00019.~M_W$ measurements [172,214] (when combined with $M_Z)$ are equivalent to measurements of $\Delta r=0.0342\pm0.0015,$ which is $0.9~\sigma$ below the result from all other data, $\Delta r=0.0358\pm0.0011.$ Fig. 10.6 shows the 1 σ contours in the M_W - m_t plane from the direct and indirect determinations, as well as the combined 90% CL region. The indirect determination uses M_Z from LEP 1 as input, which is defined assuming an s-dependent decay width. M_W then corresponds to the s-dependent width definition, as well, and can be directly compared with the results from the Tevatron and LEP 2 which have been obtained using the same definition. The difference to a constant width definition is formally only of $\mathcal{O}(\alpha^2)$, but is strongly enhanced since the decay channels add up coherently. It is about 34 MeV for M_Z and 27 MeV for M_W . The residual difference between working consistently with one or the other definition is about 3 MeV, i.e., of typical size for non-enhanced $\mathcal{O}(\alpha^2)$ corrections [74–77].

Most of the parameters relevant to ν -hadron, ν -e, e-hadron, and e^-e^\pm processes are determined uniquely and precisely from the data in "model-independent" fits (*i.e.*, fits which allow for an arbitrary EW gauge theory). The values for the parameters defined in Eqs. (10.19)–(10.22) are given in Table 10.7 along with the predictions of the SM. The agreement is very good. (The ν -hadron results including the original NuTeV data can be found in the 2006 edition of this Review, and fits with modified NuTeV constraints in the 2008 and 2010 editions.) The off Z pole e^+e^- results are difficult to present in a model-independent way because Z propagator effects are non-negligible at TRISTAN, PETRA, PEP, and LEP 2 energies. However, assuming e- μ - τ universality, the low energy lepton asymmetries imply [159] $4 (g_A^e)^2 = 0.99 \pm 0.05$, in good agreement with the SM prediction $\simeq 1$.

10.7. Constraints on new physics

The Z pole, W mass, and low energy data can be used to search for and set limits on deviations from the SM. We will mainly discuss the effects of exotic particles (with heavy masses $M_{\rm new}\gg M_Z$ in an expansion in $M_Z/M_{\rm new}$) on the gauge boson self-energies. (Brief remarks are made on new physics which is not of this type.) Most of the effects on precision measurements can be described by three gauge self-energy parameters $S,\ T,\ {\rm and}\ U.$ We will define these, as well as related parameters, such as $\rho_0,\ \epsilon_i,\ {\rm and}\ \hat{\epsilon}_i,$ to arise from new physics only. I.e., they are equal to zero $(\rho_0=1)$ exactly in the SM, and do not include any (loop induced) contributions that depend on m_t or M_H , which are treated separately. Our treatment differs from most of the original papers.

Many extensions of the SM can be described by the ρ_0 parameter,

$$\rho_0 \equiv \frac{M_W^2}{M_Z^2 \hat{c}_Z^2 \hat{\rho}} \,, \tag{10.52}$$

which describes new sources of SU(2) breaking that cannot be accounted for by the SM Higgs doublet or m_t effects. $\hat{\rho}$ is calculated as in Eq. (10.13) assuming the validity of the SM. In the presence of $\rho_0 \neq 1$, Eq. (10.52) generalizes the second Eq. (10.13) while the first remains unchanged. Provided that the new physics which yields $\rho_0 \neq 1$ is a small perturbation which does not significantly affect the radiative corrections, ρ_0 can be regarded as a phenomenological parameter which multiplies G_F in Eqs. (10.19)–(10.22), (10.36), and Γ_Z in Eq. (10.42c). There are enough data to determine ρ_0 , M_H , m_t , and α_s , simultaneously. From the global fit,

$$\rho_0 = 1.0004^{+0.0003}_{-0.0004}, \qquad (10.53)$$

$$115.5 \text{ GeV} \le M_H \le 127 \text{ GeV},$$
 (10.54)

$$m_t = 173.4 \pm 1.0 \text{ GeV},$$
 (10.55)

$$\alpha_s(M_Z) = 0.1195 \pm 0.0017,$$
 (10.56)

where the limits on M_H are nominal direct search bounds at the 95% CL [173,224,227]. In addition, the LHC is not yet sensitive to very large values of $M_H > 600$ GeV which are thus not ruled out either. In this very high mass scenario, we obtain,

$$\rho_0 = 1.0024^{+0.0010}_{-0.0003}, \qquad (10.57)$$

$$0.6 \text{ TeV} \le M_H \le 1.2 \text{ TeV},$$
 (10.58)

$$\alpha_s(M_Z) = 0.1191 \pm 0.0016,$$
 (10.59)

with the same m_t . Finally, if the direct search results are ignored entirely one finds $M_H=189^{+568}_{-114}$ GeV and $\rho_0=1.0008^{+0.0020}_{-0.0011}$. The result in Eq. (10.53) is slightly above but consistent with the SM expectation, $\rho_0=1$. It can be used to constrain higher-dimensional Higgs representations to have vacuum expectation values of less than a few percent of those of the doublets. Indeed, the relation between M_W and M_Z is modified if there are Higgs multiplets with weak isospin > 1/2 with significant vacuum expectation values. For a general (charge-conserving) Higgs structure,

$$\rho_0 = \frac{\sum_i [t(i)(t(i)+1) - t_3(i)^2] |v_i|^2}{2\sum_i t_3(i)^2 |v_i|^2},$$
(10.60)

where v_i is the expectation value of the neutral component of a Higgs multiplet with weak isospin t(i) and third component $t_3(i)$. In order to calculate to higher orders in such theories one must define a set of four fundamental renormalized parameters which one may conveniently choose to be α , G_F , M_Z , and M_W , since M_W and M_Z are directly measurable. Then \widehat{s}_Z^2 and ρ_0 can be considered dependent parameters.

Eq. (10.53) can also be used to constrain other types of new physics. For example, non-degenerate multiplets of heavy fermions or scalars break the vector part of weak SU(2) and lead to a decrease in the value of M_Z/M_W . A non-degenerate SU(2) doublet $\binom{f_1}{f_2}$ yields a positive contribution to ρ_0 [228] of

$$\frac{CG_F}{8\sqrt{2}\pi^2}\Delta m^2,\tag{10.61}$$

where

$$\Delta m^2 \equiv m_1^2 + m_2^2 - \frac{4m_1^2 m_2^2}{m_1^2 - m_2^2} \ln \frac{m_1}{m_2} \ge (m_1 - m_2)^2, \qquad (10.62)$$

and C=1 (3) for color singlets (triplets). Thus, in the presence of such multiplets,

$$\rho_0 = 1 + \frac{3G_F}{8\sqrt{2}\pi^2} \sum_i \frac{C_i}{3} \Delta m_i^2 , \qquad (10.63)$$

where the sum includes fourth-family quark or lepton doublets, $\binom{t'}{b'}$ or $\binom{E^0}{E^-}$, right-handed (mirror) doublets, non-degenerate vector-like fermion doublets (with an extra factor of 2), and scalar doublets such as $(\frac{\tilde{t}}{b})$ in Supersymmetry (in the absence of L-R mixing).

Eq. (10.53) taken together with Eq. (10.63) implies at the 95% CL,

$$\sum_{i} \frac{C_i}{3} \Delta m_i^2 \le (52 \text{ GeV})^2. \tag{10.64}$$

Non-degenerate multiplets usually imply $\rho_0 > 1$. Similarly, heavy Z' bosons decrease the prediction for M_Z due to mixing and generally lead to $\rho_0 > 1$ [229]. On the other hand, additional Higgs doublets which participate in spontaneous symmetry breaking [230] or heavy lepton doublets involving Majorana neutrinos [231], both of which have more complicated expressions, as well as the vacuum expectation values of Higgs triplets or higher-dimensional representations can contribute to ρ_0 with either sign. Allowing for the presence of heavy degenerate chiral multiplets (the S parameter, to be discussed below) affects the determination of ρ_0 from the data, at present leading to a larger value (for fixed M_H).

A number of authors [232–237] have considered the general effects on neutral-current and Z and W boson observables of various types of heavy (i.e., $M_{\rm new}\gg M_Z$) physics which contribute to the W and Z self-energies but which do not have any direct coupling to the ordinary fermions. In addition to non-degenerate multiplets, which break the vector part of weak SU(2), these include heavy degenerate multiplets of chiral fermions which break the axial generators. The effects of one degenerate chiral doublet are small, but in Technicolor theories there may be many chiral doublets and therefore significant effects [232].

Such effects can be described by just three parameters, S,T, and U, at the (EW) one-loop level. (Three additional parameters are needed if the new physics scale is comparable to M_Z [238]. Further generalizations, including effects relevant to LEP 2, are described in Ref. 239.) T is proportional to the difference between the W and Z self-energies at $Q^2=0$ (i.e., vector SU(2)-breaking), while S (S+U) is associated with the difference between the Z (W) self-energy at $Q^2=M_{Z,W}^2$ and $Q^2=0$ (axial SU(2)-breaking). Denoting the contributions of new physics to the various self-energies by $\Pi_{ij}^{\rm new}$, we have

$$\begin{split} \widehat{\alpha}(M_Z)T &\equiv \frac{\Pi_{WW}^{\text{new}}(0)}{M_W^2} - \frac{\Pi_{ZZ}^{\text{new}}(0)}{M_Z^2} \;, \\ \widehat{\alpha}(M_Z) \\ 4\,\widehat{s}_Z^2 \widehat{c}_Z^2 S &\equiv \frac{\Pi_{ZZ}^{\text{new}}(M_Z^2) - \Pi_{ZZ}^{\text{new}}(0)}{M_Z^2} - \\ &\qquad \qquad \frac{\widehat{c}_Z^2 - \widehat{s}_Z^2}{\widehat{c}_Z \widehat{s}_Z} \frac{\Pi_{Z\gamma}^{\text{new}}(M_Z^2)}{M_Z^2} - \frac{\Pi_{\gamma\gamma}^{\text{new}}(M_Z^2)}{M_Z^2} \;, \\ \widehat{\frac{\alpha}(M_Z)}{4\,\widehat{s}_Z^2} \left(S + U\right) &\equiv \frac{\Pi_{WW}^{\text{new}}(M_W^2) - \Pi_{WW}^{\text{new}}(0)}{M_W^2} - \\ &\qquad \qquad \frac{\widehat{c}_Z}{\widehat{s}_Z} \frac{\Pi_{Z\gamma}^{\text{new}}(M_Z^2)}{M_Z^2} - \frac{\Pi_{\gamma\gamma}^{\text{new}}(M_Z^2)}{M_Z^2} \;. \end{split} \tag{10.65c}$$

S, T, and U are defined with a factor proportional to $\widehat{\alpha}$ removed, so that they are expected to be of order unity in the presence of new physics. In the $\overline{\text{MS}}$ scheme as defined in Ref. 66, the last two terms in Eqs. (10.65b) and (10.65c) can be omitted (as was done in some earlier

editions of this *Review*). These three parameters are related to other parameters $(S_i, h_i, \widehat{\epsilon_i})$ defined in Refs. [66,233,234] by

$$\begin{split} T &= h_V = \widehat{\epsilon}_1/\widehat{\alpha}(M_Z), \\ S &= h_{AZ} = S_Z = 4\,\widehat{s}_Z^{\,2}\,\widehat{\epsilon}_3/\widehat{\alpha}(M_Z), \\ U &= h_{AW} - h_{AZ} = S_W - S_Z = -4\,\widehat{s}_Z^{\,2}\,\widehat{\epsilon}_2/\widehat{\alpha}(M_Z). \end{split} \ (10.66)$$

A heavy non-degenerate multiplet of fermions or scalars contributes positively to T as

$$\rho_0 - 1 = \frac{1}{1 - \widehat{\alpha}(M_Z)T} - 1 \simeq \widehat{\alpha}(M_Z)T, \tag{10.67}$$

where ρ_0 is given in Eq. (10.63). The effects of non-standard Higgs representations cannot be separated from heavy non-degenerate multiplets unless the new physics has other consequences, such as vertex corrections. Most of the original papers defined T to include the effects of loops only. However, we will redefine T to include all new sources of SU(2) breaking, including non-standard Higgs, so that T and ρ_0 are equivalent by Eq. (10.67).

A multiplet of heavy degenerate chiral fermions yields

$$S = \frac{C}{3\pi} \sum_{i} \left(t_{3L}(i) - t_{3R}(i) \right)^2, \tag{10.68}$$

where $t_{3L,R}(i)$ is the third component of weak isospin of the left-(right-)handed component of fermion i and C is the number of colors. For example, a heavy degenerate ordinary or mirror family would contribute $2/3\pi$ to S. In Technicolor models with QCD-like dynamics, one expects [232] $S \sim 0.45$ for an iso-doublet of techni-fermions, assuming $N_{TC}=4$ techni-colors, while $S\sim 1.62$ for a full techni-generation with $N_{TC} = 4$; T is harder to estimate because it is model-dependent. In these examples one has S > 0. However, the QCD-like models are excluded on other grounds (flavor changing neutral-currents, and too-light quarks and pseudo-Goldstone bosons [240]). In particular, these estimates do not apply to models of walking Technicolor [240], for which S can be smaller or even negative [241]. Other situations in which S < 0, such as loops involving scalars or Majorana particles, are also possible [242]. The simplest origin of S < 0 would probably be an additional heavy Z' boson [229], which could mimic S < 0. Supersymmetric extensions of the SM generally give very small effects. See Refs. 243 and 244 and the note on "Supersymmetry" in the Searches Particle Listings for a complete set of references.

Most simple types of new physics yield U=0, although there are counter-examples, such as the effects of anomalous triple gauge vertices [234].

The SM expressions for observables are replaced by

$$\begin{split} M_Z^2 &= M_{Z0}^2 \, \frac{1 - \widehat{\alpha}(M_Z)T}{1 - G_F M_{Z0}^2 S/2\sqrt{2}\pi} \;, \\ M_W^2 &= M_{W0}^2 \, \frac{1}{1 - G_F M_{W0}^2 (S+U)/2\sqrt{2}\pi} \;, \end{split} \tag{10.69}$$

where M_{Z0} and M_{W0} are the SM expressions (as functions of m_t and M_H) in the $\overline{\rm MS}$ scheme. Furthermore,

$$\Gamma_Z = \frac{M_Z^3 \beta_Z}{1 - \widehat{\alpha}(M_Z)T}, \quad \Gamma_W = M_W^3 \beta_W, \quad A_i = \frac{A_{i0}}{1 - \widehat{\alpha}(M_Z)T} , \quad (10.70)$$

where β_Z and β_W are the SM expressions for the reduced widths Γ_{Z0}/M_{Z0}^3 and Γ_{W0}/M_{W0}^3 , M_Z and M_W are the physical masses, and A_i (A_{i0}) is a neutral-current amplitude (in the SM).

The data allow a simultaneous determination of \widehat{s}_Z^2 (from the Z pole asymmetries), S (from M_Z), U (from M_W), T (mainly from Γ_Z), α_s (from R_ℓ , $\sigma_{\rm had}$, and τ_τ), and m_t (from the hadron colliders), with little correlation among the SM parameters:

$$S = 0.00^{+0.11}_{-0.10},$$

$$T = 0.02^{+0.11}_{-0.12},$$

$$U = 0.08 \pm 0.11,$$
 (10.71)

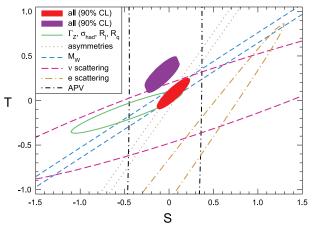


Figure 10.7: 1 σ constraints (39.35%) on S and T from various inputs combined with M_Z . S and T represent the contributions of new physics only. (Uncertainties from m_t are included in the errors.) The contours assume 115.5 GeV $< M_H < 127$ GeV except for the larger (violet) one for all data which is for $600~{\rm GeV} < M_H < 1~{\rm TeV}.$ Data sets not involving M_W are insensitive to U. Due to higher order effects, however, U=0 has to be assumed in all fits. α_s is constrained using the τ lifetime as additional input in all fits. The long-dashed (magenta) contour from ν scattering is now consistent with the global average (see Sec. 10.3). The long-dash-dotted (orange) contour from polarized e scattering [129,131] is the upper tip of an elongated ellipse centered at around S = -14 and T = -20. At first sight it looks as if it is deviating strongly but it is off by only 1.8 σ . This illusion arises because $\Delta \chi^2 > 0.77$ everywhere on the visible part of the contour.

and $\hat{s}_Z^2 = 0.23125 \pm 0.00016$, $\alpha_s(M_Z) = 0.1197 \pm 0.0018$, $m_t = 173.4 \pm 1.0$ GeV, where the uncertainties are from the inputs. We have used 115.5 GeV < M_H < 127 GeV which is the allowed low mass window from LEP and the LHC. The SM parameters (U) can be determined with no (little) M_H dependence. On the other hand, S, T, and M_H cannot be obtained simultaneously from the precision data alone, because the Higgs boson loops themselves are resembled approximately by oblique effects. Negative (positive) contributions to the S (T) parameter can weaken or entirely remove the strong constraints on M_H from the SM fits. Specific models in which a large M_H is compensated by new physics are reviewed in Ref. 245. The parameters in Eqs. (10.71), which by definition are due to new physics only, are in reasonable agreement with the SM values of zero. Fixing U=0 (as is also done in Fig. 10.7) moves S and T slightly upwards,

$$S = 0.04 \pm 0.09,$$

 $T = 0.07 \pm 0.08.$ (10.72)

The correlation between S and T in this fit amounts to 88%.

Using Eq. (10.67), the value of ρ_0 corresponding to T in Eq. (10.71) is 1.0001 ± 0.0009 , while the one corresponding to Eq. (10.72) is $1.0005^{+0.0007}_{-0.0006}$. The values of the $\hat{\epsilon}$ parameters defined in Eq. (10.66) are

$$\hat{\epsilon}_3 = 0.0000 \pm 0.0008,$$

$$\hat{\epsilon}_1 = 0.0001 \pm 0.0009$$

$$\hat{\epsilon}_2 = -0.0006 \pm 0.0009.$$
(10.73)

Unlike the original definition, we defined the quantities in Eqs. (10.73) to vanish identically in the absence of new physics and to correspond directly to the parameters $S,\ T,$ and U in Eqs. (10.71). There is a strong correlation (89%) between the S and T parameters. The U parameter is -49% (-70%) anti-correlated with S (T). The allowed regions in S-T are shown in Fig. 10.7. From Eqs. (10.71) one obtains $S \leq 0.17$ and $T \leq 0.20$ at 95% CL.

If one assumes that the excess Higgs candidates seen at the LHC are statistical fluctuations then (in the presence of new physics significantly affecting gauge boson self-energies) there is still the possibility for a heavy Higgs scenario. If one fixes $M_H=600~{\rm GeV}$ (as is still allowed by direct searches) and requires the constraint $S\geq 0$ (as is appropriate in QCD-like Technicolor models) then $S\leq 0.13$ (Bayesian) or $S\leq 0.11$ (frequentist). This rules out simple Technicolor models with many techni-doublets and QCD-like dynamics.

The S parameter can also be used to constrain the number of fermion families, under the assumption that there are no new contributions to T or U and therefore that any new families are degenerate; then an extra generation of SM fermions is excluded at the degenerate; then an extra generation of SN 161 model is consistent at $N_F = 2.91^{+0.19}_{-0.25}$ (with M_H in the allowed low mass window). This is in agreement with a fit to the number of light neutrinos, $N_{\nu} = 2.989 \pm 0.007$. However, the S parameter fits are valid even for a very heavy fourth family neutrino. This restriction can be relaxed by allowing T to vary as well, since T > 0 is expected from a non-degenerate extra family. Fixing $S=2/3\pi$, the global fit favors a fourth family contribution to T of 0.21 ± 0.04 . However, the quality of the fit deteriorates ($\Delta \chi^2 = 3.8$ relative to the SM fit with M_H forced not to drop below its ATLAS bound of 115.5 GeV) so that this tuned T scenario is also disfavored but less so than in the past. In fact, tuned mass splittings of the extra leptons and quarks [246] can yield fits with only moderately higher χ^2 values (by about 1 unit) than for the SM. A more detailed analysis is also required if the extra neutrino (or the extra down-type quark) is close to its direct mass limit [247]. Thus, a fourth family is disfavored but not excluded by the current EW precision data. Similar remarks apply to a heavy mirror family [248] involving right-handed SU(2) doublets and left-handed singlets. A more recent and detailed discussion can be found in Ref. 249. One important consequence of a heavy fourth family is to increase the Higgs production cross section by gluon fusion by a factor ~ 9 , which considerably strengthens the exclusion limits from direct searches at the Tevatron [250] and LHC [251]. Additional heavy ordinary or mirror generations may also require large Yukawa and Higgs couplings that may lead to Landau poles at low scales [252] In contrast, heavy degenerate non-chiral (also known as vector-like or exotic) multiplets, which are predicted in many grand unified theories [253] and other extensions of the SM, do not contribute to S, T, and U (or to ρ_0), and do not require large coupling constants. Such exotic multiplets may occur in partial families, as in E_6 models, or as complete vector-like families [254].

There is no simple parametrization to describe the effects of every type of new physics on every possible observable. The S, T, and Uformalism describes many types of heavy physics which affect only the gauge self-energies, and it can be applied to all precision observables. However, new physics which couples directly to ordinary fermions, such as heavy Z' bosons [229], mixing with exotic fermions [255], or leptoquark exchange [172,256] cannot be fully parametrized in the S, T, and U framework. It is convenient to treat these types of new physics by parameterizations that are specialized to that particular class of theories (e.g., extra Z' bosons), or to consider specific models (which might contain, e.g., Z' bosons and exotic fermions with correlated parameters). Fits to Supersymmetric models are described in Ref. 244. Models involving strong dynamics (such as (extended) Technicolor) for EW breaking are considered in Ref. 257. The effects of compactified extra spatial dimensions at the TeV scale are reviewed in Ref. 258, and constraints on Little Higgs models in Ref. 259. The implications of non-standard Higgs sectors, e.g., involving Higgs singlets or triplets, are discussed in Ref. 260, while additional Higgs doublets are considered in Ref. 230. Limits on new four-Fermi operators and on leptoquarks using LEP 2 and lower energy data are given in Refs. 172 and 261. Constraints on various types of new physics are reviewed in Refs. [7,128,149,161,262,263], and implications for the LHC in Ref. 264.

An alternate formalism [265] defines parameters, ϵ_1 , ϵ_2 , ϵ_3 , and ϵ_b in terms of the specific observables M_W/M_Z , $\Gamma_{\ell\ell}$, $A_{FB}^{(0,\ell)}$, and R_b . The definitions coincide with those for $\hat{\epsilon}_i$ in Eqs. (10.65) and (10.66) for physics which affects gauge self-energies only, but the ϵ 's now parametrize arbitrary types of new physics. However, the ϵ 's are not related to other observables unless additional model-dependent

Table 10.8: 95% CL lower mass limits (in GeV) from low energy and Z pole data on various extra Z' gauge bosons, appearing in models of unification and string theory. More general parametrizations are described in Refs. 267 and 272. The EW results [273] are for Higgs sectors consisting of doublets and singlets only ($\rho_0 = 1$) with unspecified U(1)' charges. The next two columns show the limits from ATLAS [274] and CMS [275] from the combination of both lepton channels. The CDF [276] and DØ [277] bounds from searches for $\bar{p}p \to \mu^+\mu^-$ and e^+e^- , respectively, are listed in the next two columns, followed by the LEP 2 $e^+e^- \to f\bar{f}$ bounds [172] (assuming $\theta = 0$). The Tevatron bounds would be moderately weakened if there are open supersymmetric or exotic decay channels [278]. The last column shows the 1 σ ranges for M_H when it is left unconstrained in the EW fits.

| Z' | EW | ATLAS | CMS | CDF | DØ | LEP 2 | M_H |
|-----------------------|------------------|-------|-------|-------|-------|-------|----------------------|
| $\overline{Z_{\chi}}$ | 1,141 | 1,640 | _ | 930 | 903 | 673 | 171^{+493}_{-89} |
| Z_{ψ} | 147 | 1,490 | 1,620 | 917 | 891 | 481 | $97^{+\ 31}_{-\ 25}$ |
| Z_{η} | 427 | 1,540 | _ | 938 | 923 | 434 | 423^{+577}_{-350} |
| Z_{LR} | 998 | _ | - | _ | _ | 804 | 804^{+174}_{-35} |
| Z_S | 1,257 | 1,600 | _ | 858 | 822 | _ | 149^{+353}_{-68} |
| Z_{SM} | 1,403 | 1,830 | 1,940 | 1,071 | 1,023 | 1,787 | 331^{+669}_{-246} |
| $Z_{ m string}$ | $_{\rm g}$ 1,362 | - | _ | _ | _ | _ | 134^{+209}_{-58} |

assumptions are made. Another approach [266] parametrizes new physics in terms of gauge-invariant sets of operators. It is especially powerful in studying the effects of new physics on non-Abelian gauge vertices. The most general approach introduces deviation vectors [262]. Each type of new physics defines a deviation vector, the components of which are the deviations of each observable from its SM prediction, normalized to the experimental uncertainty. The length (direction) of the vector represents the strength (type) of new physics.

One of the best motivated kinds of physics beyond the SM besides Supersymmetry are extra Z' bosons [267]. They do not spoil the observed approximate gauge coupling unification, and appear copiously in many Grand Unified Theories (GUTs), most Superstring models [268], as well as in dynamical symmetry breaking [257] and Little Higgs models [259]. For example, the SO(10) GUT contains an extra U(1) as can be seen from its maximal subgroup, $\mathrm{SU}(5) \times \mathrm{U}(1)_{\chi}$. Similarly, the E_6 GUT contains the subgroup $SO(10) \times U(1)_{\psi}$. The Z_{ψ} possesses only axial-vector couplings to the ordinary fermions, and its mass is generally less constrained. The Z_{η} boson is the linear combination $\sqrt{3/8} Z_{\chi} - \sqrt{5/8} Z_{\psi}$. The Z_{LR} boson occurs in left-right models with gauge group $\mathrm{SU}(3)_C\times\mathrm{SU}(2)_L\times\mathrm{SU}(2)_R\times\mathrm{U}(1)_{B-L}\subset\mathrm{SO}(10),$ and the secluded Z_S emerges in a supersymmetric bottom-up scenario [269]. The sequential Z_{SM} boson is defined to have the same couplings to fermions as the SM Z boson. Such a boson is not expected in the context of gauge theories unless it has different couplings to exotic fermions than the ordinary Z boson. However, it serves as a useful reference case when comparing constraints from various sources. It could also play the role of an excited state of the ordinary Z boson in models with extra dimensions at the weak scale [258]. Finally, we consider a Superstring motivated Z_{string} boson appearing in a specific model [270]. The potential Z' boson is in general a superposition of the SM Z and the new boson associated with the extra U(1). The mixing angle θ satisfies,

$$\tan^2\theta = \frac{M_{Z_1^0}^2 - M_Z^2}{M_{Z'}^2 - M_{Z_1^0}^2} \; ,$$

where $M_{Z_1^0}$ is the SM value for M_Z in the absence of mixing. Note, that $M_Z < M_{Z_1^0}$, and that the SM Z couplings are changed by the mixing. The couplings of the heavier Z' may also be modified by kinetic mixing [267,271]. If the Higgs U(1)' quantum numbers are

known, there will be an extra constraint,

$$\theta = C \, \frac{g_2}{g_1} \frac{M_Z^2}{M_{Z'}^2} \; ,$$

where $g_{1,2}$ are the U(1) and U(1)' gauge couplings with $g_2 =$ $\sqrt{\frac{5}{3}}\sin\theta_W\sqrt{\lambda}\,g_1$ and $g_1=\sqrt{g^2+g'^2}$. $\lambda\sim 1$ (which we assume) if the . GUT group breaks directly to SU(3) \times SU(2) \times U(1) \times U(1)'. C is a function of vacuum expectation values. For minimal Higgs sectors it can be found in Ref. 229. Table 10.8 shows the 95% CL lower mass limits [273] for $\rho_0 = 1$ and 114.4 GeV $\leq M_H \leq 1$ TeV. The last column shows the 1 σ ranges for M_H when it is left unconstrained. In cases of specific minimal Higgs sectors where C is known, the Z'mass limits from the EW precision data are generally pushed into the TeV region in which case they are still competitive with those from the LHC, and they are also competitive in the case of large g_2 [279]. The limits on $|\theta|$ are typically smaller than a few $\times 10^{-3}$. For more details see [267,273,280,281] and the note on "The Z' Searches" in the Gauge & Higgs Boson Particle Listings. Also listed in Table 10.8 are the direct lower limits on Z' production from the LHC [274,275] and the Tevatron [276,277], as well as the LEP 2 bounds [172].

Acknowledgments:

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We are indebted to M. Davier, B. Malaescu, and K. Maltman for providing us with additional information about their work in a form suitable to be included in our fits. We also thank R. H. Bernstein, K. S. McFarland, H. Schellman, and G. P. Zeller for discussions on the NuTeV analysis. This work was supported in part by CONACyT (México) contract 82291–F and by PASPA (DGAPA–UNAM).

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11. THE CKM QUARK-MIXING MATRIX

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11.1. Introduction

The masses and mixings of quarks have a common origin in the Standard Model (SM). They arise from the Yukawa interactions with the Higgs condensate,

$$\mathcal{L}_Y = -Y_{ij}^d \overline{Q_{Li}^I} \phi d_{Rj}^I - Y_{ij}^u \overline{Q_{Li}^I} \epsilon \phi^* u_{Rj}^I + \text{h.c.}, \qquad (11.1)$$

where $Y^{u,d}$ are 3×3 complex matrices, ϕ is the Higgs field, i,j are generation labels, and ϵ is the 2×2 antisymmetric tensor. Q_L^I are left-handed quark doublets, and d_R^I and u_R^I are right-handed down- and up-type quark singlets, respectively, in the weak-eigenstate basis. When ϕ acquires a vacuum expectation value, $\langle \phi \rangle = (0, v/\sqrt{2})$, Eq. (11.1) yields mass terms for the quarks. The physical states are obtained by diagonalizing $Y^{u,d}$ by four unitary matrices, $V_{L,R}^{u,d}$, as $M_{\mathrm{diag}}^f = V_L^f Y^f V_R^{\dagger\dagger}(v/\sqrt{2}), \ f = u,d.$ As a result, the charged-current W^\pm interactions couple to the physical u_{Lj} and d_{Lk} quarks with couplings given by

$$\frac{-g}{\sqrt{2}}(\overline{u_L},\,\overline{c_L},\,\overline{t_L})\gamma^{\mu}\,W_{\mu}^{+}\,V_{\rm CKM}\begin{pmatrix}d_L\\s_L\\b_L\end{pmatrix} + {\rm h.c.},$$

$$V_{\rm CKM} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}. \tag{11.2}$$

This Cabibbo-Kobayashi-Maskawa (CKM) matrix [1,2] is a 3×3 unitary matrix. It can be parameterized by three mixing angles and the CP-violating KM phase [2]. Of the many possible conventions, a standard choice has become [3]

$$V_{\text{CKM}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}, \tag{11.3}$$

where $s_{ij} = \sin \theta_{ij}$, $c_{ij} = \cos \theta_{ij}$, and δ is the phase responsible for all CP-violating phenomena in flavor-changing processes in the SM. The angles θ_{ij} can be chosen to lie in the first quadrant, so $s_{ij}, c_{ij} \geq 0$.

It is known experimentally that $s_{13} \ll s_{23} \ll s_{12} \ll 1$, and it is convenient to exhibit this hierarchy using the Wolfenstein parameterization. We define [4–6]

$$s_{12} = \lambda = \frac{|V_{us}|}{\sqrt{|V_{ud}|^2 + |V_{us}|^2}}, \qquad s_{23} = A\lambda^2 = \lambda \left| \frac{V_{cb}}{V_{us}} \right|,$$

$$s_{13}e^{i\delta} = V_{ub}^* = A\lambda^3(\rho + i\eta) = \frac{A\lambda^3(\bar{\rho} + i\bar{\eta})\sqrt{1 - A^2\lambda^4}}{\sqrt{1 - \lambda^2}[1 - A^2\lambda^4(\bar{\rho} + i\bar{\eta})]}.(11.4)$$

These relations ensure that $\bar{\rho}+i\bar{\eta}=-(V_{ud}V_{ub}^*)/(V_{cd}V_{cb}^*)$ is phase-convention-independent, and the CKM matrix written in terms of λ , A, $\bar{\rho}$, and $\bar{\eta}$ is unitary to all orders in λ . The definitions of $\bar{\rho},\bar{\eta}$ reproduce all approximate results in the literature. For example, $\bar{\rho}=\rho(1-\lambda^2/2+\ldots)$ and we can write $V_{\rm CKM}$ to $\mathcal{O}(\lambda^4)$ either in terms of $\bar{\rho},\bar{\eta}$ or, traditionally.

$$V_{\text{CKM}} = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4).$$
(11.5)

The CKM matrix elements are fundamental parameters of the SM, so their precise determination is important. The unitarity of the CKM matrix imposes $\sum_i V_{ij} V_{ik}^* = \delta_{jk}$ and $\sum_j V_{ij} V_{kj}^* = \delta_{ik}$. The six vanishing combinations can be represented as triangles in a complex plane, of which the ones obtained by taking scalar products of neighboring rows or columns are nearly degenerate. The areas of all triangles are the same, half of the Jarlskog invariant, J [7], which

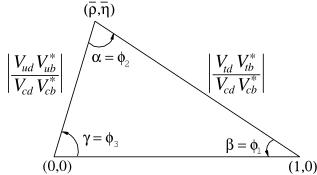


Figure 11.1: Sketch of the unitarity triangle.

is a phase-convention-independent measure of CP violation, defined by $\operatorname{Im} \left[V_{ij} V_{kl} V_{il}^* V_{kj}^* \right] = J \sum_{m,n} \varepsilon_{ikm} \varepsilon_{jln}$.

The most commonly used unitarity triangle arises from

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0, (11.6)$$

by dividing each side by the best-known one, $V_{cd}V_{cb}^*$ (see Fig. 1). Its vertices are exactly (0,0), (1,0), and, due to the definition in Eq. (11.4), $(\bar{\rho},\bar{\eta})$. An important goal of flavor physics is to overconstrain the CKM elements, and many measurements can be conveniently displayed and compared in the $\bar{\rho},\bar{\eta}$ plane.

Processes dominated by loop contributions in the SM are sensitive to new physics, and can be used to extract CKM elements only if the SM is assumed. We describe such measurements assuming the SM in Sec. 11.2 and 11.3, give the global fit results for the CKM elements in Sec. 11.4, and discuss implications for new physics in Sec. 11.5.

11.2. Magnitudes of CKM elements

11.2.1. $|V_{ud}|$:

The most precise determination of $|V_{ud}|$ comes from the study of superallowed $0^+ \to 0^+$ nuclear beta decays, which are pure vector transitions. Taking the average of the twenty most precise determinations [8] yields

$$|V_{ud}| = 0.97425 \pm 0.00022. \tag{11.7}$$

The error is dominated by theoretical uncertainties stemming from nuclear Coulomb distortions and radiative corrections. A precise determination of $|V_{ud}|$ is also obtained from the measurement of the neutron lifetime. The theoretical uncertainties are very small, but the determination is limited by the knowledge of the ratio of the axial-vector and vector couplings, $g_A = G_A/G_V$ [9]. The PIBETA experiment [10] has improved the measurement of the $\pi^+ \to \pi^0 e^+ \nu$ branching ratio to 0.6%, and quote $|V_{ud}| = 0.9728 \pm 0.0030$, in agreement with the more precise result listed above. The interest in this measurement is that the determination of $|V_{ud}|$ is very clean theoretically, because it is a pure vector transition and is free from nuclear-structure uncertainties.

11.2.2. $|V_{us}|$:

The product of $|V_{us}|$ and the form factor at $q^2=0$, $|V_{us}|\,f_+(0)$, has been extracted traditionally from $K_L^0\to\pi e\nu$ decays in order to avoid isospin-breaking corrections ($\pi^0-\eta$ mixing) that affect K^\pm semileptonic decay, and the complications induced by a second (scalar) form factor present in the muonic decays. The last round of measurements has lead to enough experimental constraints to justify the comparison between different decay modes. Systematic errors related to the experimental quantities, e.g., the lifetime of neutral or charged kaons, and the form factor determinations for electron and muonic decays, differ among decay modes, and the consistency between different determinations enhances the confidence in the final result. For this reason, we follow the prescription [11] to average $K_L^0\to\pi e\nu$, $K_L^0\to\pi \mu\nu$, $K^\pm\to\pi^0 e^\pm\nu$, $K^\pm\to\pi^0 \mu^\pm\nu$ and $K_S^0\to\pi e\nu$. The average of these five decay modes yields $|V_{us}|\,f_+(0)=0.21664\pm0.00048$. Results obtained from each decay

mode, and exhaustive references to the experimental data, are listed for instance in Ref. [9]. The form factor value $f_{+}(0) = 0.9644 \pm 0.0049$ [12] from a three-flavor unquenched lattice QCD calculation gives [9] $|V_{us}| = 0.2246 \pm 0.0012$. The broadly used classic calculation of $f_{+}(0)$ [13] is in good agreement with this value, while other calculations [14] differ by as much as 2%.

The calculation of the ratio of the kaon and pion decay constants enables one to extract $|V_{us}/V_{ud}|$ from $K \to \mu\nu(\gamma)$ and $\pi \to \mu\nu(\gamma)$, where (γ) indicates that radiative decays are included [15]. The KLOE measurement of the $K^+ \to \mu^+\nu(\gamma)$ branching ratio [16], combined with the lattice QCD calculation, $f_K/f_\pi=1.189\pm0.007$ [17], leads to $|V_{us}|=0.2259\pm0.0014$, where the accuracy is limited by the knowledge of the ratio of the decay constants. The average of these two determinations is quoted by Ref. 9 as

$$|V_{us}| = 0.2252 \pm 0.0009. \tag{11.8}$$

The latest determination from hyperon decays can be found in Ref. 19. The authors focus on the analysis of the vector form factor, protected from first order SU(3) breaking effects by the Ademollo-Gatto theorem [20], and treat the ratio between the axial and vector form factors g_1/f_1 as experimental input, thus avoiding first order SU(3) breaking effects in the axial-vector contribution. They find $|V_{us}| = 0.2250 \pm 0.0027$, although this does not include an estimate of the theoretical uncertainty due to second-order SU(3) breaking, contrary to Eq. (11.8). Concerning hadronic τ decays to strange particles, the latest determinations based on LEP, BABAR, and Belle data yield $|V_{us}| = 0.2208 \pm 0.0039$ [21]. A measurement of the ratio of branching fractions $\mathcal{B}(\tau \to K\nu)/\mathcal{B}(\tau \to \pi\nu)$ by BABAR [22] combined with the above f_K/f_π value gives $|V_{us}| = 0.2255 \pm 0.0024$.

11.2.3. $|V_{cd}|$:

The magnitude of V_{cd} can be extracted from semileptonic charm decays if theoretical knowledge of the form factors is available. Three-flavor unquenched lattice QCD calculations for $D \to K\ell\nu$ and $D \to \pi\ell\nu$ have been published [23]. Using these estimates and the average of recent CLEO-c [24] and Belle [25] measurements of $D \to \pi\ell\nu$ decays, one obtains $|V_{cd}| = 0.229 \pm 0.006 \pm 0.024$, where the first uncertainty is experimental, and the second is from the theoretical uncertainty of the form factor.

This determination is not yet as precise as the one based on neutrino and antineutrino interactions. The difference of the ratio of double-muon to single-muon production by neutrino and antineutrino beams is proportional to the charm cross section off valence d quarks, and therefore to $|V_{cd}|^2$ times the average semileptonic branching ratio of charm mesons, \mathcal{B}_{μ} . The method was used first by CDHS [26] and then by CCFR [27,28] and CHARM II [29]. Averaging these results is complicated, not only because it requires assumptions about the scale of the QCD corrections, but also because \mathcal{B}_{μ} is an effective quantity, which depends on the specific neutrino beam characteristics. Given that no new experimental input is available, we quote the average provided in a previous review, $\mathcal{B}_{\mu}|V_{cd}|^2=(0.463\pm0.034)\times10^{-2}$ [30] Analysis cuts make these experiments insensitive to neutrino energies smaller than 30 GeV. Thus, \mathcal{B}_{μ} should be computed using only neutrino interactions with visible energy larger than 30 GeV. An appraisal [31] based on charm-production fractions measured in neutrino interactions [32,33] gives $\mathcal{B}_{\mu} = 0.088 \pm 0.006$. Data from the CHORUS experiment [34] are sufficiently precise to extract \mathcal{B}_{μ} directly, by comparing the number of charm decays with a muon to the total number of charmed hadrons found in the nuclear emulsions. Requiring the visible energy to be larger than 30 GeV, CHORUS finds $\mathcal{B}_{\mu} = 0.085 \pm 0.009 \pm 0.006$. To extract $|V_{cd}|$, we use the average of these two determinations, $\mathcal{B}_{\mu} = 0.087 \pm 0.005$, and obtain

$$|V_{cd}| = 0.230 \pm 0.011. \tag{11.9}$$

11.2.4. $|V_{cs}|$:

The determination of $|V_{cs}|$ from neutrino and antineutrino scattering suffers from the uncertainty of the s-quark sea content. Measurements sensitive to $|V_{cs}|$ from on-shell W^{\pm} decays were performed at LEP-2. The branching ratios of the W depend on the six CKM matrix elements involving quarks with masses smaller than M_W . The W branching ratio to each lepton flavor is given by $1/\mathcal{B}(W \to \ell \bar{\nu}_{\ell}) = 3\left[1 + \sum_{u,c,d,s,b} |V_{ij}|^2 \left(1 + \alpha_s(m_W)/\pi\right)\right]$. The measurement assuming lepton universality, $\mathcal{B}(W \to \ell \bar{\nu}_{\ell}) = (10.83 \pm 0.07 \pm 0.07)\%$ [35], implies $\sum_{u,c,d,s,b} |V_{ij}|^2 = 2.002 \pm 0.027$. This is a precise test of unitarity, but only flavor-tagged W-decay measurements determine $|V_{cs}|$ directly. DELPHI measured tagged $W^+ \to c\bar{s}$ decays, obtaining $|V_{cs}| = 0.94^{+0.32}_{-0.26} \pm 0.13$ [36]. Hereafter, the first error is statistical and the second is systematic, unless mentioned otherwise.

The direct determination of $|V_{cs}|$ is possible from semileptonic D or leptonic D_s decays, using unquenched lattice QCD calculations of the semileptonic D form factor or the D_s decay constant. For muonic decays, the average of Belle [37], CLEO-c [38] and BABAR [39] gives $\mathcal{B}(D_s^+\to\mu^+\nu)=(5.90\pm0.33)\times10^{-3}$ [41]. For decays with τ leptons, the average of CLEO-c [38,42,43] and BABAR [39] gives $\mathcal{B}(D_s^+ \to \tau^+ \nu) = (5.29 \pm 0.28) \times 10^{-2}$ [41]. From each of these values, determinations of $|V_{cs}|$ can be obtained by using the PDG values for the mass and lifetime of the D_s , the masses of the leptons, and $f_{D_8} = (248.6 \pm 3.0) \,\mathrm{MeV}$ [44]. The average of these determinations gives $|V_{cs}| = 1.008 \pm 0.024$, where the error is dominated by the lattice QCD determination of f_{D_s} . In semileptonic D decays, unquenched lattice QCD calculations have predicted the normalization and the shape (dependence on the invariant mass of the lepton pair, q^2) of the form factors in $D \to K\ell\nu$ and $D \to \pi\ell\nu$ [23]. Using these theoretical results and the average of recent CLEO-c [24], Belle [25] and BABAR [45] measurements of $B \to K \ell \nu$ decays, one obtains $|V_{cs}| = 0.98 \pm 0.01 \pm 0.10$, where the first error is experimental and the second, which is dominant, is from the theoretical uncertainty of the form factor. Averaging the determinations from leptonic and semileptonic decays, we find

$$|V_{cs}| = 1.006 \pm 0.023. \tag{11.10}$$

11.2.5. $|V_{cb}|$:

This matrix element can be determined from exclusive and inclusive semileptonic decays of B mesons to charm. The inclusive determinations use the semileptonic decay rate measurement, together with the leptonic energy and the hadronic invariant-mass spectra. The theoretical foundation of the calculation is the operator product expansion [46,47]. It expresses the total rate and moments of differential energy and invariant-mass spectra as expansions in α_s , and inverse powers of the heavy quark mass. The dependence on m_b , m_c , and the parameters that occur at subleading order is different for different moments, and a large number of measured moments overconstrains all the parameters, and tests the consistency of the determination. The precise extraction of $|V_{cb}|$ requires using a "threshold" quark mass definition [48,49]. Inclusive measurements have been performed using B mesons from Z^0 decays at LEP, and at e^+e^- machines operated at the $\Upsilon(4S)$. At LEP, the large boost of B mesons from the Z^0 allows the determination of the moments throughout phase space, which is not possible otherwise, but the large statistics available at the B factories lead to more precise determinations. An average of the measurements and a compilation of the references are provided by Ref. [50]: $|V_{cb}| = (41.9 \pm 0.7) \times 10^{-3}$.

Exclusive determinations are based on semileptonic B decays to D and D^* . In the $m_{b,c}\gg \Lambda_{\rm QCD}$ limit, all form factors are given by a single Isgur-Wise function [51], which depends on the product of the four-velocities of the B and $D^{(*)}$ mesons, $w=v\cdot v'$. Heavy quark symmetry determines the normalization of the rate at w=1, the maximum momentum transfer to the leptons, and $|V_{cb}|$ is obtained from an extrapolation to w=1. The exclusive determination, $|V_{cb}|=(39.6\pm0.9)\times10^{-3}$ [50], is less precise than the inclusive one because of the theoretical uncertainty in the form factor and the experimental uncertainty in the rate near w=1. The V_{cb} and V_{ub} minireview [50] quotes a combination with a scaled error as

$$|V_{cb}| = (40.9 \pm 1.1) \times 10^{-3}.$$
 (11.11)

11.2.6. $|V_{ub}|$:

The determination of $|V_{ub}|$ from inclusive $B \to X_u \ell \bar{\nu}$ decay is complicated due to large $B \to X_c \ell \bar{\nu}$ backgrounds. In most regions of phase space where the charm background is kinematically forbidden, the hadronic physics enters via unknown nonperturbative functions, so-called shape functions. (In contrast, the nonperturbative physics for $|V_{ch}|$ is encoded in a few parameters.) At leading order in $\Lambda_{\rm OCD}/m_b$, there is only one shape function, which can be extracted from the photon energy spectrum in $B \to X_s \gamma$ [52,53], and applied to several spectra in $B \to X_u \ell \bar{\nu}$. The subleading shape functions are modeled in the current determinations. Phase space cuts for which the rate has only subleading dependence on the shape function are also possible [54]. The measurements of both the hadronic and the leptonic systems are important for an optimal choice of phase space. A different approach is to make the measurements more inclusive by extending them deeper into the $B \to X_c \ell \bar{\nu}$ region, and thus reduce the theoretical uncertainties. Analyses of the electron-energy endpoint from CLEO [55], BABAR [56], and Belle [57] quote $B \to X_u e \bar{\nu}$ partial rates for $|\vec{p}_e| \geq 2.0 \,\mathrm{GeV}$ and 1.9 GeV, which are well below the charm endpoint. The large and pure $B\overline{B}$ samples at the B factories permit the selection of $B \to X_u \ell \bar{\nu}$ decays in events where the other B is fully reconstructed [58]. With this full-reconstruction tag method, the four-momenta of both the leptonic and the hadronic systems can be measured. It also gives access to a wider kinematic region because of improved signal purity. Ref. 50 quotes an inclusive average as $|V_{ub}|=(4.41\pm0.15~^{+0.15}_{-0.19})\times10^{-3}$.

To extract $|V_{ub}|$ from an exclusive channel, the form factors have to be known. Experimentally, better signal-to-background ratios are offset by smaller yields. The $B\to\pi\ell\bar\nu$ branching ratio is now known to 5%. Unquenched lattice QCD calculations of the $B\to\pi\ell\bar\nu$ form factor are available [59,60] for the high q^2 region ($q^2>16$ or $18~{\rm GeV}^2$). A simultaneous fit to the experimental partial rates and lattice points versus q^2 yields $|V_{ub}|=(3.23\pm0.31)\times10^{-3}$ [60]. Light-cone QCD sum rules are applicable for $q^2<14~{\rm GeV}^2$ [61] and yield similar results.

The theoretical uncertainties in extracting $|V_{ub}|$ from inclusive and exclusive decays are different. A combination of the determinations is quoted by Ref. [50] as

$$|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}. (11.12)$$

A determination of $|V_{ub}|$ not included in this average is obtained from $\mathcal{B}(B \to \tau \bar{\nu}) = (1.67 \pm 0.30) \times 10^{-4}$ [40]. Using $f_B = (190.6 \pm 4.6) \,\mathrm{MeV}$ [44], we find $|V_{ub}| = (5.10 \pm 0.47) \times 10^{-3}$. This decay rate is sensitive, for example, to tree-level charged Higgs contributions, and is higher than other $|V_{ub}|$ determinations or the SM fit value.

11.2.7. $|V_{td}|$ and $|V_{ts}|$:

The CKM elements $|V_{td}|$ and $|V_{ts}|$ are not likely to be precisely measurable in tree-level processes involving top quarks, so one has to rely on determinations from $B-\overline{B}$ oscillations mediated by box diagrams with top quarks, or loop-mediated rare K and B decays. Theoretical uncertainties in hadronic effects limit the accuracy of the current determinations. These can be reduced by taking ratios of processes that are equal in the flavor SU(3) limit to determine $|V_{td}/V_{ts}|$.

The mass difference of the two neutral B meson mass eigenstates is very well measured, $\Delta m_d = (0.507 \pm 0.004)\,\mathrm{ps^{-1}}$ [62]. In the B_s^0 system, the average of the CDF [63] and recent LHCb [64] measurements yields $\Delta m_s = (17.719 \pm 0.043)\,\mathrm{ps^{-1}}$. Using the unquenched lattice QCD calculations [44], $f_{B_d}\sqrt{\widehat{B}_{B_d}} = (211 \pm 12)\,\mathrm{MeV},\,f_{B_s}\sqrt{\widehat{B}_{B_s}} = (248 \pm 15)\,\mathrm{MeV},\,\mathrm{and}$ assuming $|V_{tb}| = 1$, one finds

$$|V_{td}| = (8.4 \pm 0.6) \times 10^{-3}, \qquad |V_{ts}| = (42.9 \pm 2.6) \times 10^{-3}. \quad (11.13)$$

The uncertainties are dominated by lattice QCD. Several uncertainties are reduced in the calculation of the ratio $\xi = (f_{Bs}\sqrt{\widehat{B}_{Bs}})/(f_{Bd}\sqrt{\widehat{B}_{Bd}}) = 1.237 \pm 0.032$ [44], and therefore the constraint on $|V_{td}/V_{ts}|$ from $\Delta m_d/\Delta m_s$ is more reliable theoretically. These provide a new, theoretically clean, and significantly improved constraint

$$|V_{td}/V_{ts}| = 0.211 \pm 0.001 \pm 0.006.$$
 (11.14)

The inclusive branching ratio $\mathcal{B}(B \to X_s \gamma) = (3.55 \pm 0.26) \times 10^{-4}$ extrapolated to $E_{\gamma} > E_0 = 1.6 \,\mathrm{GeV}$ [65] is also sensitive to $V_{tb}V_{ts}^*$. In addition to t-quark penguins, a large part of the sensitivity comes from charm contributions proportional to $V_{cb}V_{cs}^*$ via the application of $3 \times 3 \,\mathrm{CKM}$ unitarity (which is used here; any CKM determination from loop processes necessarily assumes the SM). With the NNLO calculation of $\mathcal{B}(B \to X_s \gamma)_{E_{\gamma} > E_0} / \mathcal{B}(B \to X_c e \bar{\nu})$ [66], we obtain $|V_{ts}/V_{cb}| = 1.04 \pm 0.05$. The same CKM elements also determine the $B_s \to \mu^+\mu^-$ decay rate in the SM, and with the bounds approaching the SM level [67], this mode can soon provide a strong constraint.

A complementary determination of $|V_{td}/V_{ts}|$ is possible from the ratio of $B\to\rho\gamma$ and $K^*\gamma$ rates. The ratio of the neutral modes is theoretically cleaner than that of the charged ones, because the poorly known spectator-interaction contribution is expected to be smaller (W-exchange vs. weak annihilation). For now, because of low statistics we average the charged and neutral rates assuming the isospin symmetry and heavy quark limit motivated relation, $|V_{td}/V_{ts}|^2/\xi_\gamma^2 = [\Gamma(B^+\to\rho^+\gamma) + 2\Gamma(B^0\to\rho^0\gamma)]/[\Gamma(B^+\to K^{*+}\gamma) + \Gamma(B^0\to K^{*0}\gamma)] = (3.19\pm0.46)\%$ [65]. Here ξ_γ contains the poorly known hadronic physics. Using $\xi_\gamma = 1.2\pm0.2$ [68], and combining the experimental and theoretical errors in quadrature, gives $|V_{td}/V_{ts}| = 0.21\pm0.04$.

A theoretically clean determination of $|V_{td}V_{ts}^*|$ is possible from $K^+ \to \pi^+ \nu \bar{\nu}$ decay [69]. Experimentally, only seven events have been observed [70] and the rate is consistent with the SM with large uncertainties. Much more data are needed for a precision measurement.

11.2.8. $|V_{tb}|$:

The determination of $|V_{tb}|$ from top decays uses the ratio of branching fractions $R=\mathcal{B}(t\to Wb)/\mathcal{B}(t\to Wq)=|V_{tb}|^2/(\sum_q|V_{tq}|^2)=|V_{tb}|^2$, where q=b,s,d. The CDF and DØ measurements performed on data collected during Run II of the Tevatron give $|V_{tb}|>0.78$ [71] and $0.99>|V_{tb}|>0.90$ [72], respectively, at 95% CL. CMS recently measured the same quantity at 7 TeV and gives $|V_{tb}|>0.92$ [73] at 95% CL. The direct determination of $|V_{tb}|$ without assuming unitarity is possible from the single top-quark-production cross section. The $(2.71^{+0.44}_{-0.43})$ pb average cross section measured by DØ [74] and CDF [75,76] implies $|V_{tb}|=0.87\pm0.07$. The recent CMS measurement, (83.6 ± 29.8) pb [77] at 7 TeV, implies $|V_{tb}|=1.14\pm0.22$. The average of above gives

$$|V_{tb}| = 0.89 \pm 0.07. (11.15)$$

An attempt at constraining $|V_{tb}|$ from the precision electroweak data was made in Ref. 78. The result, mostly driven by the top-loop contributions to $\Gamma(Z \to b\bar{b})$, gives $|V_{tb}| = 0.77^{+0.18}_{-0.24}$.

11.3. Phases of CKM elements

As can be seen from Fig. 11.1, the angles of the unitarity triangle are

$$\beta = \phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),$$

$$\alpha = \phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),$$

$$\gamma = \phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right).$$
(11.16)

Since CP violation involves phases of CKM elements, many measurements of CP-violating observables can be used to constrain these angles and the $\bar{\rho}, \bar{\eta}$ parameters.

11.3.1. ϵ and ϵ' :

The measurement of CP violation in K^0 – \overline{K}^0 mixing, $|\epsilon|=(2.233\pm0.015)\times10^{-3}$ [79], provides important information about the CKM matrix. In the SM, in the basis where $V_{ud}V_{us}^*$ is real [80]

$$\begin{split} |\epsilon| &= \frac{G_F^2 f_K^2 m_K m_W^2}{12\sqrt{2} \, \pi^2 \Delta m_K} \, \widehat{B}_K \Big\{ \eta_1 S(x_c) \, \mathrm{Im}[(V_{cs} V_{cd}^*)^2] \\ &+ \eta_2 S(x_t) \, \mathrm{Im}[(V_{ts} V_{td}^*)^2] + 2 \eta_3 S(x_c, x_t) \, \mathrm{Im}(V_{cs} V_{cd}^* V_{ts} V_{td}^*) \Big\}, (11.17) \end{split}$$

where S is an Inami-Lim function [81], $x_q=m_q^2/m_W^2$, and η_i are perturbative QCD corrections. The constraint from ϵ in the $\bar{\rho},\bar{\eta}$ plane is bounded by approximate hyperbolas. The dominant uncertainties are due to the bag parameter, for which we use $\hat{B}_K=0.7674\pm0.0099$ from lattice QCD [44], and the parametric uncertainty proportional to $\sigma(A^4)$ from $(V_{ts}V_{ts}^*)^2$, which is approximately $\sigma(|V_{cb}|^4)$.

The measurement of $6 \operatorname{Re}(\epsilon'/\epsilon) = 1 - |\eta_{00}/\eta_{+-}|^2$, where η_{00} and η_{+-} are the CP-violating amplitude ratios of K_S^0 and K_L^0 decays to two pions, provides a qualitative test of the CKM mechanism. Its nonzero experimental average, $\operatorname{Re}(\epsilon'/\epsilon) = (1.67 \pm 0.23) \times 10^{-3}$ [79], demonstrates the existence of direct CP violation, a prediction of the KM ansatz. While $\operatorname{Re}(\epsilon'/\epsilon) \propto \operatorname{Im}(V_{td}V_{ts}^*)$, this quantity cannot easily be used to extract CKM parameters, because the electromagnetic penguin contributions tend to cancel the gluonic penguins for large m_t [82], thereby significantly increasing the hadronic uncertainties. Most estimates [83–86] agree with the observed value, indicating that $\bar{\eta}$ is positive. Progress in lattice QCD, in particular finite-volume calculations [87,88], may eventually provide a determination of the $K \to \pi\pi$ matrix elements.

11.3.2. β / ϕ_1 :

11.3.2.1. Charmonium modes:

CP-violation measurements in B-meson decays provide direct information on the angles of the unitarity triangle, shown in Fig. 11.1. These overconstraining measurements serve to improve the determination of the CKM elements, or to reveal effects beyond the SM.

The time-dependent CP asymmetry of neutral B decays to a final state f common to B^0 and \overline{B}^0 is given by [89,90]

$$\mathcal{A}_f = \frac{\Gamma(\overline{B}^0(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B}^0(t) \to f) + \Gamma(B^0(t) \to f)} = S_f \sin(\Delta m_d t) - C_f \cos(\Delta m_d t), \tag{11.18}$$

where

$$S_f = \frac{2 \operatorname{Im} \lambda_f}{1 + |\lambda_f|^2}, \qquad C_f = \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2}, \qquad \lambda_f = \frac{q}{p} \frac{\bar{A}_f}{A_f}.$$
 (11.19)

Here, q/p describes $B^0-\overline{B}{}^0$ mixing and, to a good approximation in the SM, $q/p = V_{tb}^*V_{td}/V_{tb}V_{td}^* = e^{-2i\beta+\mathcal{O}(\lambda^4)}$ in the usual phase convention. A_f (\bar{A}_f) is the amplitude of the $B^0\to f$ $(\overline{B}^0\to f)$ decay. If f is a CP eigenstate, and amplitudes with one CKM phase dominate the decay, then $|A_f|=|\bar{A}_f|,\,C_f=0,$ and $S_f=\sin(\arg\lambda_f)=\eta_f\sin2\phi,$ where η_f is the CP eigenvalue of f and 2ϕ is the phase difference between the $B^0\to f$ and $B^0\to \overline{B}^0\to f$ decay paths. A contribution of another amplitude to the decay with a different CKM phase makes the value of S_f sensitive to relative strong interaction phases between the decay amplitudes (it also makes $C_f\neq 0$ possible).

The $b\to c\bar cs$ decays to CP eigenstates $(B^0\to {\rm charmonium}\ K^0_{S,L})$ are the theoretically cleanest examples, measuring $S_f=-\eta_f\sin2\beta$. The $b\to sq\bar q$ penguin amplitudes have dominantly the same weak phase as the $b\to c\bar cs$ tree amplitude. Since only λ^2 -suppressed penguin amplitudes introduce a new CP-violating phase, amplitudes with a single weak phase dominate, and we expect $\left||\bar A_{\psi K}/A_{\psi K}|-1\right|<0.01$. The e^+e^- asymmetric-energy B-factory experiments, BABAR [92] and Belle [93], provide precise measurements. The world average is [94]

$$\sin 2\beta = 0.679 \pm 0.020. \tag{11.20}$$

This measurement has a four-fold ambiguity in β , which can be resolved by a global fit as mentioned in Sec. 11.4. Experimentally, the two-fold ambiguity $\beta \to \pi/2 - \beta$ (but not $\beta \to \pi + \beta$) can be resolved by a time-dependent angular analysis of $B^0 \to J/\psi K^{*0}$ [95,96], or a time-dependent Dalitz plot analysis of $B^0 \to \overline{D}^0 h^0$ ($h^0 = \pi^0, \eta, \omega$) with $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ [97,98]. These results indicate that negative $\cos 2\beta$ solutions are very unlikely, in agreement with the global CKM fit result.

The $b \to c\bar{c}d$ mediated transitions, such as $B^0 \to J/\psi\pi^0$ and $B^0 \to D^{(*)+}D^{(*)-}$, also measure approximately $\sin 2\beta$. However,

the dominant component of the $b\to d$ penguin amplitude has a different CKM phase $(V_{tb}^*V_{td})$ than the tree amplitude $(V_{cb}^*V_{cd})$, and its magnitudes are of the same order in λ . Therefore, the effect of penguins could be large, resulting in $S_f\neq -\eta_f\sin2\beta$ and $C_f\neq 0$. These decay modes have also been measured by BABAR and Belle. The world averages [94], $S_{J/\psi\pi^0}=-0.93\pm0.15$, $S_{D^+D^-}=-0.96\pm0.19$, and $S_{D^*+D^*-}=-0.77\pm0.14$ ($\eta_f=+1$ for these modes), are consistent with $\sin2\beta$ obtained from $B^0\to$ charmonium K^0 decays, and the C_f 's are consistent with zero, although the uncertainties are sizable.

The $b\to c\bar u d$ decays, $B^0\to \overline D^0 h^0$ with $\overline D^0\to CP$ eigenstates, have no penguin contributions and provide theoretically clean $\sin 2\beta$ measurements. BABAR measured $S_{D(*)h^0}=-0.56\pm0.25$ [91].

${\bf 11.3.2.2.} \quad \textit{Penguin-dominated modes:} \\$

The $b\to s\bar qq$ penguin-dominated decays have the same CKM phase as the $b\to c\bar cs$ tree level decays, up to corrections suppressed by λ^2 , since $V_{tb}^*V_{ts}=-V_{cb}^*V_{cs}[1+\mathcal{O}(\lambda^2)]$. Therefore, decays such as $B^0\to\phi K^0$ and $\eta'K^0$ provide $\sin 2\beta$ measurements in the SM. Any new physics contribution to the amplitude with a different weak phase would give rise to $S_f\neq -\eta_f\sin 2\beta$, and possibly $C_f\neq 0$. Therefore, the main interest in these modes is not simply to measure $\sin 2\beta$, but to search for new physics. Measurements of many other decay modes in this category, such as $B\to\pi^0K_S^0$, $K_S^0K_S^0$, etc., have also been performed by BABAR and Belle. The results and their uncertainties are summarized in Fig. 12.3 and Table 12.1 of Ref. 90.

11.3.3. α / ϕ_2 :

Since α is the phase between $V_{tb}^*V_{td}$ and $V_{ub}^*V_{ud}$, only time-dependent CP asymmetries in $b \to u\bar{u}d$ decay dominated modes can directly measure $\sin 2\alpha$, in contrast to $\sin 2\beta$, where several different transitions can be used. Since $b \to d$ penguin amplitudes have a different CKM phase than $b \to u\bar{u}d$ tree amplitudes, and their magnitudes are of the same order in λ , the penguin contribution can be sizable, which makes the determination of α complicated. To date, α has been measured in $B \to \pi\pi$, $\rho\pi$ and $\rho\rho$ decay modes.

11.3.3.1. $B \to \pi \pi$:

It is now experimentally well established that there is a sizable contribution of $b\to d$ penguin amplitudes in $B\to\pi\pi$ decays. Thus, $S_{\pi^+\pi^-}$ in the time-dependent $B^0\to\pi^+\pi^-$ analysis does not measure $\sin2\alpha$, but

$$S_{\pi^{+}\pi^{-}} = \sqrt{1 - C_{\pi^{+}\pi^{-}}^{2}} \sin(2\alpha + 2\Delta\alpha),$$
 (11.21)

where $2\Delta\alpha$ is the phase difference between $e^{2i\gamma}\bar{A}_{\pi^+\pi^-}$ and $A_{\pi^+\pi^-}$. The value of $\Delta\alpha$, hence α , can be extracted using the isospin relation among the amplitudes of $B^0\to\pi^+\pi^-$, $B^0\to\pi^0\pi^0$, and $B^+\to\pi^+\pi^0$ decays [99],

$$\frac{1}{\sqrt{2}}A_{\pi^{+}\pi^{-}} + A_{\pi^{0}\pi^{0}} - A_{\pi^{+}\pi^{0}} = 0, \tag{11.22}$$

and a similar expression for the $\bar{A}_{\pi\pi}$'s. This method utilizes the fact that a pair of pions from $B\to\pi\pi$ decay must be in a zero angular momentum state, and, because of Bose statistics, they must have even isospin. Consequently, $\pi^0\pi^\pm$ is in a pure isospin-2 state, while the penguin amplitudes only contribute to the isospin-0 final state. The latter does not hold for the electroweak penguin amplitudes, but their effect is expected to be small. The isospin analysis uses the world averages [94,100] $S_{\pi^+\pi^-} = -0.65 \pm 0.07$, $C_{\pi^+\pi^-} = -0.38 \pm 0.06$, the branching fractions of all three modes, and the direct CP asymmetry $C_{\pi^0\pi^0} = -0.43^{+0.25}_{-0.24}$. This analysis leads to 16 mirror solutions for $0 \le \alpha < 2\pi$. Because of this, and the sizable experimental error of the $B^0 \to \pi^0\pi^0$ rate and CP asymmetry, only a loose constraint on α can be obtained at present [101], $0^\circ < \alpha < 7^\circ$, $81^\circ < \alpha < 103^\circ$, $121^\circ < \alpha < 150^\circ$, and $166^\circ < \alpha < 180^\circ$ at 68% CL.

11.3.3.2. $B \to \rho \rho$:

The decay $B^0 \to \rho^+ \rho^-$ contains two vector mesons in the final state, which in general is a mixture of CP-even and CP-odd components. Therefore, it was thought that extracting α from this mode would be complicated.

However, the longitudinal polarization fractions (f_L) in $B^+ \to \rho^+ \rho^0$ and $B^0 \to \rho^+ \rho^-$ decays were measured to be close to unity [102], which implies that the final states are almost purely CP-even. Furthermore, $\mathcal{B}(B^0 \to \rho^0 \rho^0) = (0.73^{+0.27}_{-0.28}) \times 10^{-6}$ is much smaller than $\mathcal{B}(B^0 \to \rho^+ \rho^-) = (24.2^{+3.1}_{-3.2}) \times 10^{-6}$ and $\mathcal{B}(B^+ \to \rho^+ \rho^0) = (24.0^{+1.9}_{-2.0}) \times 10^{-6}$ [40], which implies that the effect of the penguin diagrams is small. The isospin analysis using the world averages, $S_{\rho^+ \rho^-} = -0.05 \pm 0.17$ and $C_{\rho^+ \rho^-} = -0.06 \pm 0.13$ [40], together with the time-dependent CP asymmetry, $S_{\rho^0 \rho^0} = -0.3 \pm 0.7$ and $C_{\rho^0 \rho^0} = -0.2 \pm 0.9$ [103], and the above-mentioned branching fractions, gives $\alpha = (89.9 \pm 5.4)^\circ$ [101], with a mirror solution at $3\pi/2 - \alpha$. A possible small violation of Eq. (11.22) due to the finite width of the ρ [104] is neglected.

11.3.3.3. $B \to \rho \pi$:

The final state in $B^0 \to \rho^+\pi^-$ decay is not a CP eigenstate, but this decay proceeds via the same quark-level diagrams as $B^0 \to \pi^+\pi^-$, and both B^0 and \overline{B}^0 can decay to $\rho^+\pi^-$. Consequently, mixing-induced CP violations can occur in four decay amplitudes, $B^0 \to \rho^\pm\pi^\mp$ and $\overline{B}^0 \to \rho^\pm\pi^\mp$. The time-dependent Dalitz plot analysis of $B^0 \to \pi^+\pi^-\pi^0$ decays permits the extraction of α with a single discrete ambiguity, $\alpha \to \alpha + \pi$, since one knows the variation of the strong phases in the interference regions of the $\rho^+\pi^-$, $\rho^-\pi^+$, and $\rho^0\pi^0$ amplitudes in the Dalitz plot [105]. The combination of Belle [106] and BABAR [107] measurements gives $\alpha = (120^{+11}_{-7})^{\circ}$ [101]. This constraint is still moderate, and there are also solutions around 30° and 90° within 2σ significance level.

Combining the above-mentioned three decay modes [101], α is constrained as

$$\alpha = (89.0^{+4.4}_{-4.2})^{\circ}. \tag{11.23}$$

A different statistical approach [108] gives similar constraint from the combination of these measurements.

11.3.4. γ / ϕ_3 :

By virtue of Eq. (11.16), γ does not depend on CKM elements involving the top quark, so it can be measured in tree-level B decays. This is an important distinction from the measurements of α and β , and implies that the measurements of γ are unlikely to be affected by physics beyond the SM.

11.3.4.1. $B^{\pm} \to DK^{\pm}$:

The interference of $B^- \to D^0 K^ (b \to c \bar{u} s)$ and $B^- \to \overline{D}{}^0 K^ (b \to u \bar{c} s)$ transitions can be studied in final states accessible in both D^0 and $\overline{D}{}^0$ decays [89]. In principle, it is possible to extract the B and D decay amplitudes, the relative strong phases, and the weak phase γ from the data.

A practical complication is that the precision depends sensitively on the ratio of the interfering amplitudes

$$r_B = \left| A(B^- \to \overline{D}{}^0 K^-) / A(B^- \to D^0 K^-) \right|,$$
 (11.24)

which is around 0.1–0.2. The original GLW method [109,110] considers D decays to CP eigenstates, such as $B^{\pm} \to D_{CP}^{(*)}(\to \pi^+\pi^-)K^{\pm(*)}$. To alleviate the smallness of r_B and make the interfering amplitudes (which are products of the B and D decay amplitudes) comparable in magnitude, the ADS method [111] considers final states where Cabibbo-allowed \overline{D}^0 and doubly-Cabibbo-suppressed D^0 decays interfere. Extensive measurements have been made by the B factories [112,113], CDF [114] and LHCb [115] using both methods.

It was realized that both D^0 and \overline{D}^0 have large branching fractions to certain three-body final states, such as $K_S\pi^+\pi^-$, and the analysis can be optimized by studying the Dalitz plot dependence of the interferences [116,117]. The best present determination of γ comes from this method. Belle [118] and BABAR [119] obtained

 $\gamma=(78^{+11}_{-12}\pm4\pm9)^\circ$ and $\gamma=(68\pm14\pm4\pm3)^\circ$, respectively, where the last uncertainty is due to the D-decay modeling. The error is sensitive to the central value of the amplitude ratio r_B (and r_B^* for the D^*K mode), for which Belle found somewhat larger central values than BABAR. The same values of $r_B^{(*)}$ enter the ADS analyses, and the data can be combined to fit for $r_B^{(*)}$ and γ . The $D^0-\overline{D}^0$ mixing has been neglected in all measurements, but its effect on γ is far below the present experimental accuracy [120], unless $D^0-\overline{D}^0$ mixing is due to CP-violating new physics, in which case it can be included in the analysis [121].

Combining the GLW, ADS, and Dalitz analyses [101], γ is constrained as

$$\gamma = (68^{+10}_{-11})^{\circ}. \tag{11.25}$$

Similar results are found in Ref. [108].

11.3.4.2. $B^0 \to D^{(*)\pm}\pi^{\mp}$:

The interference of $b \to u$ and $b \to c$ transitions can be studied in $\overline B{}^0 \to D^{(*)+}\pi^-$ ($b \to c \overline u d$) and $\overline B{}^0 \to B^0 \to D^{(*)+}\pi^-$ ($\overline b \to \overline u c \overline d$) decays and their CP conjugates, since both B^0 and $\overline B{}^0$ decay to $D^{(*)\pm}\pi^\mp$ (or $D^\pm \rho^\mp$, etc.). Since there are only tree and no penguin contributions to these decays, in principle, it is possible to extract from the four time-dependent rates the magnitudes of the two hadronic amplitudes, their relative strong phase, and the weak phase between the two decay paths, which is $2\beta + \gamma$.

A complication is that the ratio of the interfering amplitudes is very small, $r_{D\pi}=A(B^0\to D^+\pi^-)/A(\overline B^0\to D^+\pi^-)=\mathcal O(0.01)$ (and similarly for $r_{D^*\pi}$ and $r_{D\rho}$), and therefore it has not been possible to measure it. To obtain $2\beta+\gamma$, SU(3) flavor symmetry and dynamical assumptions have been used to relate $A(\overline B^0\to D^-\pi^+)$ to $A(\overline B^0\to D_s^-\pi^+)$, so this measurement is not model-independent at present. Combining the $D^\pm\pi^\mp$, $D^{*\pm}\pi^\mp$ and $D^\pm\rho^\mp$ measurements [122] gives $\sin(2\beta+\gamma)>0.68$ at 68% CL [101], consistent with the previously discussed results for β and γ . The amplitude ratio is much larger in the analogous $B_s^0\to D_s^\pm K^\mp$ decays, so it will be possible at LHCb to measure it and model-independently extract $\gamma-2\beta_s$ [123] (where $\beta_s=\arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$ is related to the phase of B_s mixing).

11.4. Global fit in the Standard Model

Using the independently measured CKM elements mentioned in the previous sections, the unitarity of the CKM matrix can be checked. We obtain $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=0.9999\pm0.0006$ (1st row), $|V_{cd}|^2+|V_{cs}|^2+|V_{cb}|^2=1.067\pm0.047$ (2nd row), $|V_{ud}|^2+|V_{cd}|^2+|V_{td}|^2=1.002\pm0.005$ (1st column), and $|V_{us}|^2+|V_{cs}|^2+|V_{ts}|^2=1.065\pm0.046$ (2nd column), respectively. The uncertainties in the second row and column are dominated by that of $|V_{cs}|$. For the second row, a more stringent check is obtained from the measurement of $\sum_{u,c,d,s,b}|V_{ij}|^2$ in Sec. 11.2.4 minus the sum in the first row above: $|V_{cd}|^2+|V_{cs}|^2+|V_{cb}|^2=1.002\pm0.027$. These provide strong tests of the unitarity of the CKM matrix. The sum of the three angles of the unitarity triangle, $\alpha+\beta+\gamma=(178^{+11}_{-12})^\circ$, is also consistent with the SM expectation.

The CKM matrix elements can be most precisely determined by a global fit that uses all available measurements and imposes the SM constraints (*i.e.*, three generation unitarity). The fit must also use theory predictions for hadronic matrix elements, which sometimes have significant uncertainties. There are several approaches to combining the experimental data. CKMfitter [6,101] and Ref. 124 (which develops [125,126] further) use frequentist statistics, while UTfit [108,127] uses a Bayesian approach. These approaches provide similar results.

The constraints implied by the unitarity of the three generation CKM matrix significantly reduce the allowed range of some of the CKM elements. The fit for the Wolfenstein parameters defined in Eq. (11.4) gives

$$\begin{split} \lambda &= 0.22535 \pm 0.00065 \,, \qquad A = 0.811^{+0.022}_{-0.012} \,, \\ \bar{\rho} &= 0.131^{+0.026}_{-0.013} \,, \qquad \qquad \bar{\eta} = 0.345^{+0.013}_{-0.014} \,. \end{split} \tag{11.26}$$

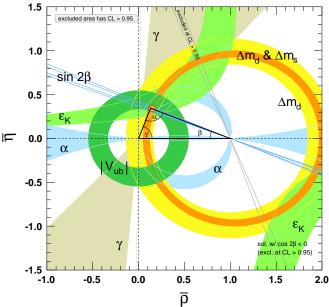


Figure 11.2: Constraints on the $\bar{\rho},\bar{\eta}$ plane. The shaded areas have 95% CL.

These values are obtained using the method of Refs. [6,101]. Using the prescription of Refs. [108,127] gives $\lambda=0.22535\pm0.00065,$ $A=0.817\pm0.015,$ $\bar{\rho}=0.136\pm0.018,$ $\bar{\eta}=0.348\pm0.014$ [128]. The fit results for the magnitudes of all nine CKM elements are

and the Jarlskog invariant is $J=(2.96^{+0.20}_{-0.16})\times 10^{-5}.$

Figure 11.2 illustrates the constraints on the $\bar{\rho}, \bar{\eta}$ plane from various measurements and the global fit result. The shaded 95% CL regions all overlap consistently around the global fit region. This consistency gets noticeably worse if $B \to \tau \bar{\nu}$ is included in the fit.

11.5. Implications beyond the SM

The effects in B, K, and D decays and mixings due to high-scale physics (W, Z, t, h) in the SM, and new physics particles) can be parameterized by operators made of SM fields, obeying the $SU(3) \times SU(2) \times U(1)$ gauge symmetry. The beyond SM (BSM) contributions to the coefficients of these operators are suppressed by powers of the scale of new physics. At lowest order, there are of order a hundred flavor-changing operators of dimension-6, and the observable effects of BSM interactions are encoded in their coefficients. In the SM, these coefficients are determined by just the four CKM parameters, and the W, Z, and quark masses. For example, Δm_d , $\Gamma(B \to \rho \gamma)$, and $\Gamma(B \to X_d \ell^+ \ell^-)$ are all proportional to $|V_{td}V_{tb}^*|^2$ in the SM, however, they may receive unrelated contributions from new physics. The new physics contributions may or may not obey the SM relations. (For example, the flavor sector of the MSSM contains 69 CP-conserving parameters and 41 CP-violating phases, i.e., 40 new ones [129]). Thus, similar to the measurements of $\sin 2\beta$ in tree- and loop-dominated decay modes, overconstraining measurements of the magnitudes and phases of flavor-changing neutral-current amplitudes give good sensitivity to new physics.

To illustrate the level of suppression required for BSM contributions, consider a class of models in which the unitarity of the CKM matrix is maintained, and the dominant effect of new physics is to modify the neutral meson mixing amplitudes [130] by $(z_{ij}/\Lambda^2)(\overline{q}_i\gamma^\mu P_L q_j)^2$ (for recent reviews, see [131,132]). It is only known since the measurements of γ and α that the SM gives the leading contribution to $B^0-\overline{B}^0$ mixing [6,133]. Nevertheless, new physics with a generic weak phase may still contribute to neutral meson mixings at a significant fraction of the SM [134,127]. The existing data imply that $\Lambda/|z_{ij}|^{1/2}$ has to

exceed about 10^4 TeV for $K^0-\overline{K}^0$ mixing, 10^3 TeV for $D^0-\overline{D}^0$ mixing, 500 TeV for $B^0-\overline{B}^0$ mixing, and 100 TeV for $B^0_s-\overline{B}^0_s$ mixing [127,132]. (Some other operators are even better constrained [127].) The constraints are the strongest in the kaon sector, because the CKM suppression is the most severe. Thus, if there is new physics at the TeV scale, $|z_{ij}| \ll 1$ is required. Even if $|z_{ij}|$ are suppressed by a loop factor and $|V^*_{ti}V_{tj}|^2$ (in the down quark sector), similar to the SM, one expects percent-level effects, which may be observable in forthcoming flavor physics experiments. To constrain such extensions of the SM, many measurements irrelevant for the SM-CKM fit, such as the CP asymmetry in semileptonic $B^0_{d,s}$ decays, $A^{d,s}_{\rm SL}$, are important [135]. A DØ measurement sensitive to the approximate linear combination $0.6A^d_{\rm SL}+0.4A^s_{\rm SL}$ shows a 3.9σ hint of a deviation from the SM [136].

Many key measurements which are sensitive to BSM flavor physics are not useful to think about in terms of constraining the unitarity triangle in Fig. 11.1. For example, besides the angles in Eq. (11.16), a key quantity in the B_s system is $\beta_s = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*)$, which is the small, λ^2 -suppressed, angle of a "squashed" unitarity triangle, obtained by taking the scalar product of the second and third columns. This angle can be measured via time-dependent CP violation in $B_s^0 \to J/\psi \phi$, similar to β in $B^0 \to J/\psi K^0$. Since the $J/\psi \phi$ final state is not a CP eigenstate, an angular analysis of the decay products is needed to separate the CP-even and CP-odd components, which give opposite asymmetries. In the SM, the asymmetry for the CP-even part is $2\beta_s$ (sometimes the notation $\phi_s = -2\beta_s$ plus a possible BSM contribution to the B_s mixing phase is used). Checking if the data agrees with the SM prediction, $\beta_s = 0.018 \pm 0.001$ [101], is another sensitive test of the SM. After the first CP-asymmetry measurements of $B_s^0 \to J/\psi \phi$ hinted at a possible large deviation from the SM, the latest Tevatron results [137] are consistent with the SM, within the sizable uncertainties. So is the much more precise LHCb measurement obtained from 1 fb⁻¹ data, including the $J/\psi \pi\pi$ mode, yielding $\beta_s = 0.001 \pm 0.044$ [138]. This uncertainty is still more than twice the SM central value and 40 times the SM uncertainty; thus a lot will be learned from higher precision measurements in the future.

In the kaon sector, the two measured CP-violating observables ϵ and ϵ' are tiny, so models in which all sources of CP violation are small were viable before the B-factory measurements. Since the measurement of $\sin 2\beta$, we know that CP violation can be an $\mathcal{O}(1)$ effect, and only flavor mixing is suppressed between the three quark generations. Thus, many models with spontaneous CP violation are excluded. In the kaon sector, a very clean test of the SM will come from measurements of $K^+ \to \pi^+ \nu \bar{\nu}$ and $K^0_L \to \pi^0 \nu \bar{\nu}$. These loop-induced rare decays are sensitive to new physics, and will allow a determination of β independent of its value measured in B decays [139].

The CKM elements are fundamental parameters, so they should be measured as precisely as possible. The overconstraining measurements of CP asymmetries, mixing, semileptonic, and rare decays have started to severely constrain the magnitudes and phases of possible new physics contributions to flavor-changing interactions. When new particles are observed at the LHC, it will be important to know the flavor parameters as precisely as possible to understand the underlying physics.

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12. CP VIOLATION IN MESON DECAYS

Revised May 2012 by D. Kirkby (UC Irvine) and Y. Nir (Weizmann Institute).

The CP transformation combines charge conjugation C with parity P. Under C, particles and antiparticles are interchanged, by conjugating all internal quantum numbers, e.g., $Q \to -Q$ for electromagnetic charge. Under P, the handedness of space is reversed, $\vec{x} \to -\vec{x}$. Thus, for example, a left-handed electron e_L^- is transformed under CP into a right-handed positron, e_R^+ .

If CP were an exact symmetry, the laws of Nature would be the same for matter and for antimatter. We observe that most phenomena are C- and P-symmetric, and therefore, also CP-symmetric. In particular, these symmetries are respected by the gravitational, electromagnetic, and strong interactions. The weak interactions, on the other hand, violate C and P in the strongest possible way. For example, the charged W bosons couple to left-handed electrons, e_L^- , and to their CP-conjugate right-handed positrons, e_R^+ , but to neither their C-conjugate left-handed positrons, e_L^+ , nor their P-conjugate right-handed electrons, e_R^- . While weak interactions violate C and Pseparately, CP is still preserved in most weak interaction processes. The CP symmetry is, however, violated in certain rare processes, as discovered in neutral K decays in 1964 [1], and observed in recent years in B decays. A K_L meson decays more often to $\pi^- e^+ \overline{\nu}_e$ than to $\pi^+e^-\nu_e$, thus allowing electrons and positrons to be unambiguously distinguished, but the decay-rate asymmetry is only at the 0.003 level. The CP-violating effects observed in B decays are larger: the CPasymmetry in B^0/\overline{B}^0 meson decays to CP eigenstates like $J/\psi K_S$ is about 0.7 [2.3]. These effects are related to $K^0 - \overline{K}^0$ and $B^0 - \overline{B}^0$ mixing, but CP violation arising solely from decay amplitudes has also been observed, first in $K \to \pi\pi$ decays [4–6], and more recently in various neutral B [7,8] and charged B [9–11] decays. Evidence for CPviolation in the decay amplitude at a level higher than 3σ (but still lower than 5σ) has also been achieved in neutral D [12] and B_s [13] decays. CP violation has not yet been observed in the lepton sector.

In addition to parity and to continuous Lorentz transformations, there is one other spacetime operation that could be a symmetry of the interactions: time reversal $T, t \to -t$. Violations of T symmetry have been observed in neutral K decays [14], and are expected as a corollary of CP violation if the combined CPT transformation is a fundamental symmetry of Nature [15]. All observations indicate that CPT is indeed a symmetry of Nature. Furthermore, one cannot build a Lorentz-invariant quantum field theory with a Hermitian Hamiltonian that violates CPT. (At several points in our discussion, we avoid assumptions about CPT, in order to identify cases where evidence for CP violation relies on assumptions about CPT.)

Within the Standard Model, CP symmetry is broken by complex phases in the Yukawa couplings (that is, the couplings of the Higgs scalar to quarks). When all manipulations to remove unphysical phases in this model are exhausted, one finds that there is a single CP-violating parameter [16]. In the basis of mass eigenstates, this single phase appears in the 3×3 unitary matrix that gives the W-boson couplings to an up-type antiquark and a down-type quark. (If the Standard Model is supplemented with Majorana mass terms for the neutrinos, the analogous mixing matrix for leptons has three CP-violating phases.) The beautifully consistent and economical Standard-Model description of CP violation in terms of Yukawa couplings, known as the Kobayashi-Maskawa (KM) mechanism [16]. agrees with all measurements to date. (The measurement of the dimuon asymmetry in semi-leptonic b-hadron decays deviates from the Standard Model prediction by 3.9σ [17]. Pending confirmation, we do not discuss it further in this review.) Furthermore, one can fit the data allowing new physics contributions to loop processes to compete with, or even dominate over, the Standard Model ones [18,19]. Such an analysis provides a model-independent proof that the KM phase is different from zero, and that the matrix of three-generation quark mixing is the dominant source of CP violation in meson decays.

The current level of experimental accuracy and the theoretical uncertainties involved in the interpretation of the various observations leave room, however, for additional subdominant sources of CP violation from new physics. Indeed, almost all extensions of the

Standard Model imply that there are such additional sources. Moreover, CP violation is a necessary condition for baryogenesis, the process of dynamically generating the matter-antimatter asymmetry of the Universe [20]. Despite the phenomenological success of the KM mechanism, it fails (by several orders of magnitude) to accommodate the observed asymmetry [21]. This discrepancy strongly suggests that Nature provides additional sources of CP violation beyond the KM mechanism. (The evidence for neutrino masses implies that CP can be violated also in the lepton sector. This situation makes leptogenesis [22], a scenario where CP-violating phases in the Yukawa couplings of the neutrinos play a crucial role in the generation of the baryon asymmetry, a very attractive possibility.) The expectation of new sources motivates the large ongoing experimental effort to find deviations from the predictions of the KM mechanism.

CP violation can be experimentally searched for in a variety of processes, such as meson decays, electric dipole moments of neutrons, electrons and nuclei, and neutrino oscillations. Meson decays probe flavor-changing CP violation. The search for electric dipole moments may find (or constrain) sources of CP violation that, unlike the KM phase, are not related to flavor-changing couplings. Future searches for CP violation in neutrino oscillations might provide further input on leptogenesis.

The present measurements of CP asymmetries provide some of the strongest constraints on the weak couplings of quarks. Future measurements of CP violation in K, D, B, and B_s meson decays will provide additional constraints on the flavor parameters of the Standard Model, and can probe new physics. In this review, we give the formalism and basic physics that are relevant to present and near future measurements of CP violation in meson decays.

Before going into details, we list here the observables where CP violation has been observed at a level above 5σ [23–25]:

• Indirect CP violation in $K\to\pi\pi$ and $K\to\pi\ell\nu$ decays, and in the $K_L\to\pi^+\pi^-e^+e^-$ decay, is given by

$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$$
 (12.1)

• Direct CP violation in $K \to \pi\pi$ decays is given by

$$\Re(\epsilon'/\epsilon) = (1.65 \pm 0.26) \times 10^{-3}.$$
 (12.2)

• CP violation in the interference of mixing and decay in the tree-dominated $b \to c\bar{c}s$ transitions, such as $B \to \psi K^0$, is given by (we use K^0 throughout to denote results that combine K_S and K_L modes, but use the sign appropriate to K_S):

$$S_{\psi K^0} = +0.679 \pm 0.020. \tag{12.3} \label{eq:spike}$$

• CP violation in the interference of mixing and decay in various modes related to $b \to q\bar{q}s$ (penguin) transitions is given by

$$S_{n'K^0} = +0.59 \pm 0.07,$$
 (12.4)

$$S_{\phi K^0} = +0.74^{+0.11}_{-0.13},$$
 (12.5)

$$S_{f_0K^0} = +0.69^{+0.10}_{-0.12},$$
 (12.6)

$$S_{K^+K^-K_S} = +0.68^{+0.09}_{-0.10}, \tag{12.7} \label{eq:12.7}$$

• CP violation in the interference of mixing and decay in the $B\to \pi^+\pi^-$ mode is given by

$$S_{\pi^{+}\pi^{-}} = -0.65 \pm 0.07.$$
 (12.8)

• Direct CP violation in the $B \to \pi^+\pi^-$ mode is given by

$$C_{\pi^{+}\pi^{-}} = -0.36 \pm 0.06.$$
 (12.9)

• CP violation in the interference of mixing and decay in various modes related to $b\to c\bar cd$ transitions is given by

$$S_{\psi\pi^0} = -0.93 \pm 0.15,$$
 (12.10)

$$S_{D^+D^-} = -0.98 \pm 0.17.$$
 (12.11)

$$S_{D^{*+}D^{*-}} = -0.77 \pm 0.10.$$
 (12.12)

• Direct CP violation in the $\overline{B}{}^0 \to K^-\pi^+$ mode is given by

$$A_{K^{\mp}\pi^{\pm}} = -0.087 \pm 0.008. \tag{12.13}$$

• Direct CP violation in $B^{\pm} \to D_+ K^{\pm}$ decays (D_+ is the CP-even neutral D state) is given by

$$A_{D+K^{\pm}} = +0.19 \pm 0.03.$$
 (12.14)

12.1. Formalism

The phenomenology of CP violation is superficially different in K, D, B, and B_s decays. This is primarily because each of these systems is governed by a different balance between decay rates, oscillations, and lifetime splitting. However, the underlying mechanisms of CP violation are identical for all pseudoscalar mesons.

In this section, we present a general formalism for, and classification of, CP violation in the decay of a pseudoscalar meson M that might be a charged or neutral K, D, B, or B_s meson. Subsequent sections describe the CP-violating phenomenology, approximations, and alternative formalisms that are specific to each system.

12.1.1. Charged- and neutral-meson decays: We define decay amplitudes of M (which could be charged or neutral) and its CP conjugate \overline{M} to a multi-particle final state f and its CP conjugate \overline{f} as

$$A_f = \langle f | \mathcal{H} | M \rangle$$
 , $\overline{A}_f = \langle f | \mathcal{H} | \overline{M} \rangle$,
 $A_{\overline{f}} = \langle \overline{f} | \mathcal{H} | M \rangle$, $\overline{A}_{\overline{f}} = \langle \overline{f} | \mathcal{H} | \overline{M} \rangle$, (12.15)

where \mathcal{H} is the Hamiltonian governing weak interactions. The action of CP on these states introduces phases ξ_M and ξ_f that depend on their flavor content, according to

$$CP|M\rangle = e^{+i\xi_M}|\overline{M}\rangle$$
 , $CP|f\rangle = e^{+i\xi_f}|\overline{f}\rangle$, (12.16)

with

$$CP|\overline{M}\rangle = e^{-i\xi_M}|M\rangle$$
 , $CP|\overline{f}\rangle = e^{-i\xi_f}|f\rangle$ (12.17)

so that $(CP)^2=1$. The phases ξ_M and ξ_f are arbitrary and unphysical because of the flavor symmetry of the strong interaction. If CP is conserved by the dynamics, $[CP,\mathcal{H}]=0$, then A_f and $\overline{A}_{\overline{f}}$ have the same magnitude and an arbitrary unphysical relative phase

$$\overline{A_f} = e^{i(\xi_f - \xi_M)} A_f . \qquad (12.18)$$

12.1.2. Neutral-meson mixing: A state that is initially a superposition of M^0 and \overline{M}^0 , say

$$|\psi(0)\rangle = a(0)|M^0\rangle + b(0)|\overline{M}^0\rangle, \qquad (12.19)$$

will evolve in time acquiring components that describe all possible decay final states $\{f_1, f_2, \ldots\}$, that is,

$$|\psi(t)\rangle = a(t)|M^{0}\rangle + b(t)|\overline{M}^{0}\rangle + c_{1}(t)|f_{1}\rangle + c_{2}(t)|f_{2}\rangle + \cdots$$
 (12.20)

If we are interested in computing only the values of a(t) and b(t) (and not the values of all $c_i(t)$), and if the times t in which we are interested are much larger than the typical strong interaction scale, then we can use a much simplified formalism [26]. The simplified time evolution is determined by a 2×2 effective Hamiltonian ${\bf H}$ that is not Hermitian, since otherwise the mesons would only oscillate and not decay. Any complex matrix, such as ${\bf H}$, can be written in terms of Hermitian matrices ${\bf M}$ and ${\bf \Gamma}$ as

$$\mathbf{H} = \mathbf{M} - \frac{i}{2} \mathbf{\Gamma} . \tag{12.21}$$

M and Γ are associated with $(M^0, \overline{M}^0) \leftrightarrow (M^0, \overline{M}^0)$ transitions via off-shell (dispersive), and on-shell (absorptive) intermediate states, respectively. Diagonal elements of **M** and Γ are associated with

the flavor-conserving transitions $M^0 \to M^0$ and $\overline{M}^0 \to \overline{M}^0$, while off-diagonal elements are associated with flavor-changing transitions $M^0 \leftrightarrow \overline{M}^0$.

The eigenvectors of \mathbf{H} have well-defined masses and decay widths. To specify the components of the strong interaction eigenstates, M^0 and \overline{M}^0 , in the light (M_L) and heavy (M_H) mass eigenstates, we introduce three complex parameters: p, q, and, for the case that both CP and CPT are violated in mixing, z:

$$|M_L\rangle \propto p\sqrt{1-z} |M^0\rangle + q\sqrt{1+z} |\overline{M}^0\rangle$$

 $|M_H\rangle \propto p\sqrt{1+z} |M^0\rangle - q\sqrt{1-z} |\overline{M}^0\rangle$, (12.22)

with the normalization $|q|^2 + |p|^2 = 1$ when z = 0. (Another possible choice, which is in standard usage for K mesons, defines the mass eigenstates according to their lifetimes: K_S for the short-lived and K_L for the long-lived state. The K_L is experimentally found to be the heavier state.)

The real and imaginary parts of the eigenvalues $\omega_{L,H}$ corresponding to $|M_{L,H}\rangle$ represent their masses and decay widths, respectively. The mass and width splittings are

$$\Delta m \equiv m_H - m_L = \Re e(\omega_H - \omega_L) \quad ,$$

$$\Delta \Gamma \equiv \Gamma_H - \Gamma_L = -2 \mathcal{I} m(\omega_H - \omega_L) \ . \tag{12.23}$$

Note that here Δm is positive by definition, while the sign of $\Delta \Gamma$ is to be experimentally determined. The sign of $\Delta \Gamma$ has not yet been established for the B mesons, while $\Delta \Gamma < 0$ is established for K and B_s mesons and $\Delta \Gamma > 0$ is established for D mesons. The Standard Model predicts $\Delta \Gamma < 0$ also for B mesons (for this reason, $\Delta \Gamma = \Gamma_L - \Gamma_H$, which is still a signed quantity, is often used in the B and B_s literature and is the convention used in the PDG experimental summaries).

Solving the eigenvalue problem for H vields

$$\left(\frac{q}{p}\right)^2 = \frac{\mathbf{M}_{12}^* - (i/2)\mathbf{\Gamma}_{12}^*}{\mathbf{M}_{12} - (i/2)\mathbf{\Gamma}_{12}}$$
(12.24)

and

$$z \equiv \frac{\delta m - (i/2)\delta\Gamma}{\Delta m - (i/2)\Delta\Gamma} , \qquad (12.25)$$

where

$$\delta m \equiv \mathbf{M}_{11} - \mathbf{M}_{22} \quad , \quad \delta \Gamma \equiv \mathbf{\Gamma}_{11} - \mathbf{\Gamma}_{22}$$
 (12.26)

are the differences in effective mass and decay-rate expectation values for the strong interaction states M^0 and \overline{M}^0 .

If either CP or CPT is a symmetry of \mathbf{H} (independently of whether T is conserved or violated), then the values of δm and $\delta \Gamma$ are both zero, and hence z=0. We also find that

$$\omega_H - \omega_L = 2\sqrt{\left(\mathbf{M}_{12} - \frac{i}{2}\mathbf{\Gamma}_{12}\right)\left(\mathbf{M}_{12}^* - \frac{i}{2}\mathbf{\Gamma}_{12}^*\right)}$$
 (12.27)

If either CP or T is a symmetry of \mathbf{H} (independently of whether CPT is conserved or violated), then $\Gamma_{12}/\mathbf{M}_{12}$ is real, leading to

$$\left(\frac{q}{p}\right)^2 = e^{2i\xi_M} \quad \Rightarrow \quad \left|\frac{q}{p}\right| = 1 , \qquad (12.28)$$

where ξ_M is the arbitrary unphysical phase introduced in Eq. (12.17). If, and only if, CP is a symmetry of \mathbf{H} (independently of CPT and T), then both of the above conditions hold, with the result that the mass eigenstates are orthogonal

$$\langle M_H | M_L \rangle = |p|^2 - |q|^2 = 0.$$
 (12.29)

12.1.3. CP-violating observables: All CP-violating observables in M and \overline{M} decays to final states f and \overline{f} can be expressed in terms of phase-convention-independent combinations of A_f , $\overline{A_f}$, and $\overline{A_f}$, together with, for neutral-meson decays only, q/p. CP violation in charged-meson decays depends only on the combination $|\overline{A_f}/A_f|$, while CP violation in neutral-meson decays is complicated by $M^0 \leftrightarrow \overline{M}^0$ oscillations, and depends, additionally, on |q/p| and on $\lambda_f \equiv (q/p)(\overline{A_f}/A_f)$.

The decay rates of the two neutral K mass eigenstates, K_S and K_L , are different enough $(\Gamma_S/\Gamma_L\sim 500)$ that one can, in most cases, actually study their decays independently. For neutral D, B, and B_s mesons, however, values of $\Delta\Gamma/\Gamma$ (where $\Gamma\equiv (\Gamma_H+\Gamma_L)/2$) are relatively small, and so both mass eigenstates must be considered in their evolution. We denote the state of an initially pure $|M^0\rangle$ or $|\overline{M}^0\rangle$ after an elapsed proper time t as $|M^0_{\rm phys}(t)\rangle$ or $|\overline{M}^0_{\rm phys}(t)\rangle$, respectively. Using the effective Hamiltonian approximation, but not assuming CPT is a good symmetry, we obtain

$$|M_{\rm phys}^{0}(t)\rangle = (g_{+}(t) + z g_{-}(t)) |M^{0}\rangle - \sqrt{1 - z^{2}} \frac{q}{p} g_{-}(t) |\overline{M}^{0}\rangle,$$

$$|\overline{M}_{\rm phys}^{0}(t)\rangle = (g_{+}(t) - z g_{-}(t)) |\overline{M}^{0}\rangle - \sqrt{1 - z^{2}} \frac{p}{q} g_{-}(t) |M^{0}\rangle,$$
(12.30)

where

$$g_{\pm}(t) \equiv \frac{1}{2} \left(e^{-im_H t - \frac{1}{2}\Gamma_H t} \pm e^{-im_L t - \frac{1}{2}\Gamma_L t} \right)$$
 (12.31)

and z = 0 if either CPT or CP is conserved.

Defining $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta \Gamma/(2\Gamma)$, and assuming z=0, one obtains the following time-dependent decay rates:

$$\begin{split} \frac{d\Gamma\big[M_{\rm phys}^0(t) \to f\big]/dt}{e^{-\Gamma t} \mathcal{N}_f} &= \\ & \left(|A_f|^2 + |(q/p)\overline{A}_f|^2\right) \cosh(y\Gamma t) + \left(|A_f|^2 - |(q/p)\overline{A}_f|^2\right) \cos(x\Gamma t) \\ &+ 2 \,\mathcal{R}e((q/p)A_f^*\overline{A}_f) \sinh(y\Gamma t) - 2 \,\mathcal{I}m((q/p)A_f^*\overline{A}_f) \sin(x\Gamma t) \;, \end{split}$$

$$(12.32)$$

$$\begin{split} \frac{d\Gamma[\overline{M}_{\rm phys}^0(t) \to f]/dt}{e^{-\Gamma t} \mathcal{N}_f} &= \\ & \left(|(p/q)A_f|^2 + |\overline{A}_f|^2 \right) \cosh(y\Gamma t) - \left(|(p/q)A_f|^2 - |\overline{A}_f|^2 \right) \cos(x\Gamma t) \\ &+ 2 \mathcal{R}e((p/q)A_f \overline{A}_f^*) \sinh(y\Gamma t) - 2 \mathcal{I}m((p/q)A_f \overline{A}_f^*) \sin(x\Gamma t) \;, \end{split}$$

where \mathcal{N}_f is a common, time-independent, normalization factor. Decay rates to the CP-conjugate final state \overline{f} are obtained analogously, with $\mathcal{N}_f = \mathcal{N}_{\overline{f}}$ and the substitutions $A_f \to A_{\overline{f}}$ and $\overline{A}_f \to \overline{A}_{\overline{f}}$ in Eqs. (12.32, 12.33). Terms proportional to $|A_f|^2$ or $|\overline{A}_f|^2$ are associated with decays that occur without any net $M \to \overline{M}$ oscillation, while terms proportional to $|(q/p)\overline{A}_f|^2$ or $|(p/q)A_f|^2$ are associated with decays following a net oscillation. The $\sin(y\Gamma t)$ and $\sin(x\Gamma t)$ terms of Eqs. (12.32, 12.33) are associated with the interference between these two cases. Note that, in multi-body decays, amplitudes are functions of phase-space variables. Interference may be present in some regions but not others, and is strongly influenced by resonant substructure.

When neutral pseudoscalar mesons are produced coherently in pairs from the decay of a vector resonance, $V \to M^0 \overline{M}^0$ (for example, $\Upsilon(4S) \to B^0 \overline{B}^0$ or $\phi \to K^0 \overline{K}^0$), the time-dependence of their subsequent decays to final states f_1 and f_2 has a similar form to Eqs. (12.32, 12.33):

$$\begin{split} \frac{d\Gamma \big[V_{\rm phys}(t_1,t_2) \to f_1 f_2 \big] / d(\Delta t)}{e^{-\Gamma |\Delta t|} \mathcal{N}_{f_1 f_2}} &= \\ \Big(|a_+|^2 + |a_-|^2 \Big) \cosh(y \Gamma \Delta t) + \Big(|a_+|^2 - |a_-|^2 \Big) \cos(x \Gamma \Delta t) \\ &- 2 \, \mathcal{R}e(a_+^* a_-) \sinh(y \Gamma \Delta t) + 2 \, \mathcal{I}m(a_+^* a_-) \sin(x \Gamma \Delta t) \;, \end{split}$$
(12.34)

where $\Delta t \equiv t_2 - t_1$ is the difference in the production times, t_1 and t_2 , of f_1 and f_2 , respectively, and the dependence on the average decay time and on decay angles has been integrated out. The coefficients in Eq. (12.34) are determined by the amplitudes for no net oscillation from $t_1 \rightarrow t_2$, $\overline{A}_{f_1} A_{f_2}$, and $A_{f_1} \overline{A}_{f_2}$, and for a net oscillation, $(q/p)\overline{A}_{f_1} \overline{A}_{f_2}$ and $(p/q)A_{f_1} A_{f_2}$, via

$$a_{+} \equiv \overline{A}_{f_{1}} A_{f_{2}} - A_{f_{1}} \overline{A}_{f_{2}} ,$$
 (12.35)

$$a_- \equiv \; - \sqrt{1-z^2} \left(\frac{q}{p} \overline{A}_{f_1} \overline{A}_{f_2} - \frac{p}{q} A_{f_1} A_{f_2} \right) + z \left(\overline{A}_{f_1} A_{f_2} + A_{f_1} \overline{A}_{f_2} \right) \; . \label{alpha}$$

Assuming CPT conservation, z=0, and identifying $\Delta t \to t$ and $f_2 \to f$, we find that Eqs. (12.34) and (12.35) reduce to Eq. (12.32) with $A_{f_1}=0$, $\overline{A}_{f_1}=1$, or to Eq. (12.33) with $\overline{A}_{f_1}=0$, $A_{f_1}=1$. Indeed, such a situation plays an important role in experiments. Final states f_1 with $A_{f_1}=0$ or $\overline{A}_{f_1}=0$ are called tagging states, because they identify the decaying pseudoscalar meson as, respectively, \overline{M}^0 or M^0 . Before one of M^0 or \overline{M}^0 decays, they evolve in phase, so that there is always one M^0 and one \overline{M}^0 present. A tagging decay of one meson sets the clock for the time evolution of the other: it starts at t_1 as purely M^0 or \overline{M}^0 , with time evolution that depends only on t_2-t_1 .

When f_1 is a state that both M^0 and \overline{M}^0 can decay into, then Eq. (12.34) contains interference terms proportional to $A_{f_1}\overline{A}_{f_1}\neq 0$ that are not present in Eqs. (12.32, 12.33). Even when f_1 is dominantly produced by M^0 decays rather than \overline{M}^0 decays, or vice versa, $A_{f_1}\overline{A}_{f_1}$ can be non-zero owing to doubly-CKM-suppressed decays (with amplitudes suppressed by at least two powers of λ relative to the dominant amplitude, in the language of Section 12.3), and these terms should be considered for precision studies of CP violation in coherent $V \to M^0\overline{M}^0$ decays [27].

12.1.4. Classification of CP-violating effects: We distinguish three types of CP-violating effects in meson decays:

I. CP violation in decay is defined by

$$|\overline{A_f}/A_f| \neq 1. \tag{12.36}$$

In charged meson decays, where mixing effects are absent, this is the only possible source of CP asymmetries:

$$A_{f\pm} \equiv \frac{\Gamma(M^{-} \to f^{-}) - \Gamma(M^{+} \to f^{+})}{\Gamma(M^{-} \to f^{-}) + \Gamma(M^{+} \to f^{+})} = \frac{|\overline{A}_{f^{-}}/A_{f^{+}}|^{2} - 1}{|\overline{A}_{f^{-}}/A_{f^{+}}|^{2} + 1} . \quad (12.37)$$

II. CP (and T) violation in mixing is defined by

$$|q/p| \neq 1$$
. (12.38)

In charged-current semileptonic neutral meson decays $M, \overline{M} \to \ell^{\pm} X$ (taking $|A_{\ell^+ X}| = |\overline{A}_{\ell^- X}|$ and $A_{\ell^- X} = \overline{A}_{\ell^+ X} = 0$, as is the case in the Standard Model, to lowest order in G_F , and in most of its reasonable extensions), this is the only source of CP violation, and can be measured via the asymmetry of "wrong-sign" decays induced by oscillations:

$$\mathcal{A}_{\rm SL}(t) \equiv \frac{d\Gamma/dt \left[\overline{M}_{\rm phys}^{0}(t) \to \ell^{+} X\right] - d\Gamma/dt \left[M_{\rm phys}^{0}(t) \to \ell^{-} X\right]}{d\Gamma/dt \left[\overline{M}_{\rm phys}^{0}(t) \to \ell^{+} X\right] + d\Gamma/dt \left[M_{\rm phys}^{0}(t) \to \ell^{-} X\right]}$$
$$= \frac{1 - |q/p|^{4}}{1 + |q/p|^{4}}. \tag{12.39}$$

Note that this asymmetry of time-dependent decay rates is actually time-independent. $\,$

III. CP violation in interference between a decay without mixing, $M^0 \to f$, and a decay with mixing, $M^0 \to \overline{M}^0 \to f$ (such an effect occurs only in decays to final states that are common to M^0 and \overline{M}^0 , including all CP eigenstates), is defined by

$$\mathcal{I}m(\lambda_f) \neq 0 , \qquad (12.40)$$

with

$$\lambda_f \equiv \frac{q}{p} \frac{\overline{A}_f}{A_f} \ . \tag{12.41}$$

This form of CP violation can be observed, for example, using the asymmetry of neutral meson decays into final CP eigenstates f_{CP}

$$\mathcal{A}_{f_{CP}}(t) \equiv \frac{d\Gamma/dt \left[\overline{M}_{\text{phys}}^{0}(t) \to f_{CP} \right] - d\Gamma/dt \left[M_{\text{phys}}^{0}(t) \to f_{CP} \right]}{d\Gamma/dt \left[\overline{M}_{\text{phys}}^{0}(t) \to f_{CP} \right] + d\Gamma/dt \left[M_{\text{phys}}^{0}(t) \to f_{CP} \right]}. \tag{12.4}$$

If $\Delta\Gamma=0$ and |q/p|=1, as expected to a good approximation for B_d mesons, but not for K and B_s mesons, then \mathcal{A}_{fCP} has a particularly simple form (see Eq. (12.86), below). If, in addition, the decay amplitudes fulfill $|\overline{A}_{fCP}|=|A_{fCP}|,$ the interference between decays with and without mixing is the only source of the asymmetry and $\mathcal{A}_{fCP}(t)=\mathcal{I}m(\lambda_{fCP})\sin(x\Gamma t).$

Examples of these three types of CP violation will be given in Sections 12.4, 12.5, and 12.6.

12.2. Theoretical Interpretation: General Considerations

Consider the $M \to f$ decay amplitude A_f , and the CP conjugate process, $\overline{M} \to \overline{f}$, with decay amplitude $\overline{A}_{\overline{f}}$. There are two types of phases that may appear in these decay amplitudes. Complex parameters in any Lagrangian term that contributes to the amplitude will appear in complex conjugate form in the ${\it CP}$ -conjugate amplitude. Thus, their phases appear in A_f and $\overline{A_f}$ with opposite signs. In the Standard Model, these phases occur only in the couplings of the W^{\pm} bosons, and hence, are often called "weak phases." The weak phase of any single term is convention-dependent. However, the difference between the weak phases in two different terms in A_f is conventionindependent. A second type of phase can appear in scattering or decay amplitudes, even when the Lagrangian is real. Their origin is the possible contribution from intermediate on-shell states in the decay process. Since these phases are generated by CP-invariant interactions, they are the same in A_f and $\overline{A_f}$. Usually the dominant rescattering is due to strong interactions; hence the designation "strong phases" for the phase shifts so induced. Again, only the relative strong phases between different terms in the amplitude are physically meaningful.

The 'weak' and 'strong' phases discussed here appear in addition to the 'spurious' CP-transformation phases of Eq. (12.18). Those spurious phases are due to an arbitrary choice of phase convention, and do not originate from any dynamics or induce any CP violation. For simplicity, we set them to zero from here on.

It is useful to write each contribution a_i to A_f in three parts: its magnitude $|a_i|$, its weak phase ϕ_i , and its strong phase δ_i . If, for example, there are two such contributions, $A_f = a_1 + a_2$, we have

$$A_f = |a_1|e^{i(\delta_1 + \phi_1)} + |a_2|e^{i(\delta_2 + \phi_2)},$$

$$\overline{A_f} = |a_1|e^{i(\delta_1 - \phi_1)} + |a_2|e^{i(\delta_2 - \phi_2)}.$$
(12.43)

Similarly, for neutral meson decays, it is useful to write

$$\mathbf{M}_{12} = |\mathbf{M}_{12}|e^{i\phi_M} \quad , \quad \mathbf{\Gamma}_{12} = |\mathbf{\Gamma}_{12}|e^{i\phi_{\Gamma}} .$$
 (12.44)

Each of the phases appearing in Eqs. (12.43, 12.44) is convention-dependent, but combinations such as $\delta_1-\delta_2,\ \phi_1-\phi_2,\ \phi_M-\phi_\Gamma,$ and $\phi_M+\phi_1-\overline{\phi}_1$ (where $\overline{\phi}_1$ is a weak phase contributing to \overline{A}_f) are physical.

It is now straightforward to evaluate the various asymmetries in terms of the theoretical parameters introduced here. We will do so with approximations that are often relevant to the most interesting measured asymmetries.

1. The CP asymmetry in charged meson decays [Eq. (12.37)] is given by

$$\mathcal{A}_{f^{\pm}} = -\frac{2|a_1 a_2| \sin(\delta_2 - \delta_1) \sin(\phi_2 - \phi_1)}{|a_1|^2 + |a_2|^2 + 2|a_1 a_2| \cos(\delta_2 - \delta_1) \cos(\phi_2 - \phi_1)}.$$
 (12.45)

The quantity of most interest to theory is the weak phase difference $\phi_2 - \phi_1$. Its extraction from the asymmetry requires, however, that the amplitude ratio $|a_2/a_1|$ and the strong phase difference $\delta_2 - \delta_1$ are known. Both quantities depend on non-perturbative hadronic parameters that are difficult to calculate.

2. In the approximation that $|\Gamma_{12}/M_{12}| \ll 1$ (valid for B and B_s mesons), the CP asymmetry in semileptonic neutral-meson decays [Eq. (12.39)] is given by

$$\mathcal{A}_{SL} = -\left|\frac{\Gamma_{12}}{\mathbf{M}_{12}}\right| \sin(\phi_M - \phi_\Gamma). \tag{12.46}$$

The quantity of most interest to theory is the weak phase $\phi_M - \phi_\Gamma$. Its extraction from the asymmetry requires, however, that $|\Gamma_{12}/\mathbf{M}_{12}|$ is known. This quantity depends on long-distance physics that is difficult to calculate.

3. In the approximations that only a single weak phase contributes to decay, $A_f = |a_f|e^{i(\delta_f + \phi_f)}$, and that $|\Gamma_{12}/\mathbf{M}_{12}| = 0$, we obtain $|\lambda_f| = 1$, and the CP asymmetries in decays to a final CP eigenstate f [Eq. (12.42)] with eigenvalue $\eta_f = \pm 1$ are given by

$$\mathcal{A}_{f_{CP}}(t) = \mathcal{I}m(\lambda_f) \sin(\Delta m t) \text{ with } \mathcal{I}m(\lambda_f) = \eta_f \sin(\phi_M + 2\phi_f). \tag{12.47}$$

Note that the phase so measured is purely a weak phase, and no hadronic parameters are involved in the extraction of its value from $\mathcal{I}m(\lambda_f)$.

The discussion above allows us to introduce another classification of ${\cal CP}\text{-}{\rm violating}$ effects:

- 1. Indirect CP violation is consistent with taking $\phi_M \neq 0$ and setting all other CP violating phases to zero. CP violation in mixing (type II) belongs to this class.
- 2. Direct CP violation cannot be accounted for by just $\phi_M \neq 0$. CP violation in decay (type I) belongs to this class.

As concerns type III CP violation, observing $\eta_{f_1} Im(\lambda_{f_1}) \neq \eta_{f_2} Im(\lambda_{f_2})$ (for the same decaying meson and two different final CP eigenstates f_1 and f_2) would establish direct CP violation. The significance of this classification is related to theory. In superweak models [28], CP violation appears only in diagrams that contribute to \mathbf{M}_{12} , hence they predict that there is no direct CP violation. In most models and, in particular, in the Standard Model, CP violation is both direct and indirect. The experimental observation of $\epsilon' \neq 0$ (see Section 12.4) excluded the superweak scenario.

12.3. Theoretical Interpretation: The KM Mechanism

Of all the Standard Model quark parameters, only the Kobayashi-Maskawa (KM) phase is CP-violating. Having a single source of CP violation, the Standard Model is very predictive for CP asymmetries: some vanish, and those that do not are correlated.

To be precise, CP could be violated also by strong interactions. The experimental upper bound on the electric-dipole moment of the neutron implies, however, that $\theta_{\rm QCD}$, the non-perturbative parameter that determines the strength of this type of CP violation, is tiny, if not zero. (The smallness of $\theta_{\rm QCD}$ constitutes a theoretical puzzle, known as 'the strong CP problem.') In particular, it is irrelevant to our discussion of meson decays.

The charged current interactions (that is, the W^{\pm} interactions) for quarks are given by

$$-\mathcal{L}_{W^{\pm}} = \frac{g}{\sqrt{2}} \overline{u_{Li}} \gamma^{\mu} (V_{\text{CKM}})_{ij} d_{Lj} W_{\mu}^{+} + \text{h.c.}$$
 (12.48)

Here i,j=1,2,3 are generation numbers. The Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix for quarks is a 3×3 unitary matrix [29] Ordering the quarks by their masses, *i.e.*, $(u_1,u_2,u_3) \rightarrow (u,c,t)$ and $(d_1,d_2,d_3) \rightarrow (d,s,b)$, the elements of V_{CKM} are written as follows:

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} . \tag{12.49}$$

While a general 3×3 unitary matrix depends on three real angles and six phases, the freedom to redefine the phases of the quark mass eigenstates can be used to remove five of the phases, leaving a single physical phase, the Kobayashi-Maskawa phase, that is responsible for all CP violation in meson decays in the Standard Model.

The fact that one can parametrize $V_{\rm CKM}$ by three real and only one imaginary physical parameters can be made manifest by choosing an explicit parametrization. The Wolfenstein parametrization [30,31] is particularly useful:

$$V_{CKM} =$$

$$\begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3[1 - (1 - \frac{1}{2}\lambda^2)(\rho + i\eta)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix}$$
(12.50)

Here $\lambda \approx 0.23$ (not to be confused with λ_f), the sine of the Cabibbo angle, plays the role of an expansion parameter, and η represents the CP-violating phase. Terms of $\mathcal{O}(\lambda^6)$ were neglected.

The unitarity of the CKM matrix, $(VV^{\dagger})_{ij} = (V^{\dagger}V)_{ij} = \delta_{ij}$, leads to twelve distinct complex relations among the matrix elements. The six relations with $i \neq j$ can be represented geometrically as triangles in the complex plane. Two of these,

$$\begin{split} V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* &= 0 \\ V_{td}V_{ud}^* + V_{ts}V_{us}^* + V_{tb}V_{ub}^* &= 0 \ , \end{split}$$

have terms of equal order, $\mathcal{O}(A\lambda^3)$, and so have corresponding triangles whose interior angles are all $\mathcal{O}(1)$ physical quantities that can be independently measured. The angles of the first triangle (see Fig. 12.1) are given by

$$\alpha \equiv \varphi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) \simeq \arg\left(-\frac{1-\rho-i\eta}{\rho+i\eta}\right),$$

$$\beta \equiv \varphi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) \simeq \arg\left(\frac{1}{1-\rho-i\eta}\right),$$

$$\gamma \equiv \varphi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) \simeq \arg\left(\rho+i\eta\right). \tag{12.51}$$

The angles of the second triangle are equal to (α, β, γ) up to corrections of $\mathcal{O}(\lambda^2)$. The notations (α, β, γ) and $(\varphi_1, \varphi_2, \varphi_3)$ are both in common usage but, for convenience, we only use the first convention in the following.

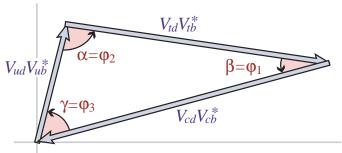


Figure 12.1: Graphical representation of the unitarity constraint $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ as a triangle in the complex plane.

Another relation that can be represented as a triangle,

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0 , \qquad (12.52)$$

and, in particular, its small angle, of $\mathcal{O}(\lambda^2)$,

$$\beta_s \equiv \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right),\tag{12.53}$$

is convenient for analyzing CP violation in the B_s sector.

All unitarity triangles have the same area, commonly denoted by J/2 [32]. If CP is violated, J is different from zero and can be taken as the single CP-violating parameter. In the Wolfenstein parametrization of Eq. (12.50), $J \simeq \lambda^6 A^2 \eta$.

12.4. K Decays

CP violation was discovered in $K \to \pi\pi$ decays in 1964 [1]. The same mode provided the first evidence for direct CP violation [4–6].

The decay amplitudes actually measured in neutral K decays refer to the mass eigenstates K_L and K_S , rather than to the K and \overline{K} states referred to in Eq. (12.15). The final $\pi^+\pi^-$ and $\pi^0\pi^0$ states are CP-even. In the CP limit, $K_S(K_L)$ would be CP-even (odd), and therefore would (would not) decay to two pions. We define CP-violating amplitude ratios for two-pion final states,

$$\eta_{00} \equiv \frac{\langle \pi^0 \pi^0 | \mathcal{H} | K_L \rangle}{\langle \pi^0 \pi^0 | \mathcal{H} | K_S \rangle} \quad , \quad \eta_{+-} \equiv \frac{\langle \pi^+ \pi^- | \mathcal{H} | K_L \rangle}{\langle \pi^+ \pi^- | \mathcal{H} | K_S \rangle} \ . \tag{12.54}$$

Another important observable is the asymmetry of time-integrated semileptonic decay rates:

$$\delta_L \equiv \frac{\Gamma(K_L \to \ell^+ \nu_\ell \pi^-) - \Gamma(K_L \to \ell^- \overline{\nu}_\ell \pi^+)}{\Gamma(K_L \to \ell^+ \nu_\ell \pi^-) + \Gamma(K_L \to \ell^- \overline{\nu}_\ell \pi^+)} \ . \tag{12.55}$$

CP violation has been observed as an appearance of K_L decays to two-pion final states [23],

$$|\eta_{00}| = (2.221 \pm 0.011) \times 10^{-3}$$
 $|\eta_{+-}| = (2.232 \pm 0.011) \times 10^{-3}$ (12.56)
 $|\eta_{00}/\eta_{+-}| = 0.9951 \pm 0.0008$, (12.57)

where the phase ϕ_{ij} of the amplitude ratio η_{ij} has been determined both assuming CPT invariance:

$$\phi_{00} = (43.52 \pm 0.06)^{\circ}, \qquad \phi_{+-} = (43.51 \pm 0.05)^{\circ}, \qquad (12.58)$$

and without assuming CPT invariance:

$$\phi_{00} = (43.7 \pm 0.8)^{\circ}, \qquad \phi_{+-} = (43.4 \pm 0.7)^{\circ}.$$
 (12.59)

CP violation has also been observed in semileptonic K_L decays [23]

$$\delta_L = (3.32 \pm 0.06) \times 10^{-3} \,, \tag{12.60}$$

where δ_L is a weighted average of muon and electron measurements, as well as in K_L decays to $\pi^+\pi^-\gamma$ and $\pi^+\pi^-e^+e^-$ [23]. CP violation in $K \to 3\pi$ decays has not yet been observed [23,33].

Historically, CP violation in neutral K decays has been described in terms of parameters ϵ and ϵ' . The observables η_{00} , η_{+-} , and δ_L are related to these parameters, and to those of Section 12.1, by

$$\eta_{00} = \frac{1 - \lambda_{\pi^0 \pi^0}}{1 + \lambda_{\pi^0 \pi^0}} = \epsilon - 2\epsilon' ,$$

$$\eta_{+-} = \frac{1 - \lambda_{\pi^+ \pi^-}}{1 + \lambda_{\pi^+ \pi^-}} = \epsilon + \epsilon' ,$$

$$\delta_L = \frac{1 - |q/p|^2}{1 + |q/p|^2} = \frac{2\Re e(\epsilon)}{1 + |\epsilon|^2} ,$$
(12.61)

where, in the last line, we have assumed that $\left|A_{\ell^+\nu_\ell\pi^-}\right|=\left|\overline{A}_{\ell^-\overline{\nu}_\ell\pi^+}\right|$ and $\left|A_{\ell^-\overline{\nu}_\ell\pi^+}\right|=\left|\overline{A}_{\ell^+\nu_\ell\pi^-}\right|=0$. (The convention-dependent parameter $\tilde{\epsilon}\equiv (1-q/p)/(1+q/p)$, sometimes used in the literature, is, in general, different from ϵ but yields a similar expression, $\delta_L=2\mathcal{R}e(\tilde{\epsilon})/(1+|\tilde{\epsilon}|^2)$.) A fit to the $K\to\pi\pi$ data yields [23]

$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$$
,
 $\Re e(\epsilon'/\epsilon) = (1.65 \pm 0.26) \times 10^{-3}$. (12.62)

In discussing two-pion final states, it is useful to express the amplitudes $A_{\pi^0\pi^0}$ and $A_{\pi^+\pi^-}$ in terms of their isospin components via

$$\begin{split} A_{\pi^0\pi^0} &= \sqrt{\frac{1}{3}} \, |A_0| \, e^{i(\delta_0 + \phi_0)} - \sqrt{\frac{2}{3}} \, |A_2| \, e^{i(\delta_2 + \phi_2)}, \\ A_{\pi^+\pi^-} &= \sqrt{\frac{2}{3}} \, |A_0| \, e^{i(\delta_0 + \phi_0)} + \sqrt{\frac{1}{3}} \, |A_2| \, e^{i(\delta_2 + \phi_2)} \,, \end{split}$$
 (12.63)

where we parameterize the amplitude $A_I(\overline{A}_I)$ for $K^0(\overline{K}^0)$ decay into two pions with total isospin I=0 or 2 as

$$\begin{split} A_I &\equiv \langle (\pi\pi)_I \, | \mathcal{H} | \, K^0 \rangle = |A_I| \, e^{i(\delta_I + \phi_I)} \; , \\ \overline{A}_I &\equiv \langle (\pi\pi)_I \, | \mathcal{H} | \, \overline{K}^0 \rangle = |A_I| \, e^{i(\delta_I - \phi_I)} \; . \end{split} \tag{12.64}$$

The smallness of $|\eta_{00}|$ and $|\eta_{+-}|$ allows us to approximate

$$\epsilon \simeq \frac{1}{2} (1 - \lambda_{(\pi\pi)_{I=0}}), \qquad \epsilon' \simeq \frac{1}{6} (\lambda_{\pi^0 \pi^0} - \lambda_{\pi^+ \pi^-}) .$$
 (12.65)

The parameter ϵ represents indirect CP violation, while ϵ' parameterizes direct CP violation: $\mathcal{R}e(\epsilon')$ measures CP violation in decay (type I), $\mathcal{R}e(\epsilon)$ measures CP violation in mixing (type II), and $\mathcal{I}m(\epsilon)$ and $\mathcal{I}m(\epsilon')$ measure the interference between decays with and without mixing (type III).

The following expressions for ϵ and ϵ' are useful for theoretical evaluations:

$$\epsilon \simeq \frac{e^{i\pi/4}}{\sqrt{2}} \frac{\mathcal{I}m(\mathbf{M}_{12})}{\Delta m}, \qquad \epsilon' = \frac{i}{\sqrt{2}} \left| \frac{A_2}{A_0} \right| e^{i(\delta_2 - \delta_0)} \sin(\phi_2 - \phi_0). \tag{12.66}$$

The expression for ϵ is only valid in a phase convention where $\phi_2=0$, corresponding to a real $V_{ud}V_{us}^*$, and in the approximation that also $\phi_0=0$. The phase of ϵ , $\arg(\epsilon)\approx\arctan(-2\Delta m/\Delta\Gamma)$, is independent of the electroweak model and is experimentally determined to be about $\pi/4$. The calculation of ϵ benefits from the fact that $\mathcal{I}m(\mathbf{M}_{12})$ is dominated by short distance physics. Consequently, the main source of uncertainty in theoretical interpretations of ϵ are the values of matrix elements, such as $\langle K^0 | (\overline{sd})_{V-A}(\overline{sd})_{V-A}| \overline{K^0} \rangle$. The expression for ϵ' is valid to first order in $|A_2/A_0| \sim 1/20$. The phase of ϵ' is experimentally determined, $\pi/2 + \delta_2 - \delta_0 \approx \pi/4$, and is independent of the electroweak model. Note that, accidentally, ϵ'/ϵ is real to a good approximation.

A future measurement of much interest is that of CP violation in the rare $K \to \pi \nu \overline{\nu}$ decays. The signal for CP violation is simply observing the $K_L \to \pi^0 \nu \overline{\nu}$ decay. The effect here is that of interference between decays with and without mixing (type III) [34]:

$$\frac{\Gamma(K_L \to \pi^0 \nu \overline{\nu})}{\Gamma(K^+ \to \pi^+ \nu \overline{\nu})} = \frac{1}{2} \left[1 + |\lambda_{\pi \nu \overline{\nu}}|^2 - 2 \, \Re e(\lambda_{\pi \nu \overline{\nu}}) \right] \simeq 1 - \Re e(\lambda_{\pi \nu \overline{\nu}}), \tag{12.6}$$

where in the last equation we neglect CP violation in decay and in mixing (expected, model-independently, to be of order 10^{-5} and 10^{-3} , respectively). Such a measurement would be experimentally very challenging and theoretically very rewarding [35]. Similar to the CP asymmetry in $B \to J/\psi K_S$, the CP violation in $K \to \pi \nu \overline{\nu}$ decay is predicted to be large (that is, the ratio in Eq. (12.67) is neither CKM- nor loop-suppressed) and can be very cleanly interpreted.

Within the Standard Model, the $K_L \to \pi^0 \nu \overline{\nu}$ decay is dominated by an intermediate top quark contribution and, consequently, can be interpreted in terms of CKM parameters [36]. (For the charged mode, $K^+ \to \pi^+ \nu \overline{\nu}$, the contribution from an intermediate charm quark is not negligible, and constitutes a source of hadronic uncertainty.) In particular, $\mathcal{B}(K_L \to \pi^0 \nu \overline{\nu})$ provides a theoretically clean way to determine the Wolfenstein parameter η [37]:

$$\mathcal{B}(K_L \to \pi^0 \nu \overline{\nu}) = \kappa_L [X(m_t^2/m_W^2)]^2 A^4 \eta^2,$$
 (12.68)

where $\kappa_L \sim 2 \times 10^{-10}$ incorporates the value of the four-fermion matrix element which is deduced, using isospin relations, from $\mathcal{B}(K^+ \to \pi^0 e^+ \nu)$, and $X(m_t^2/m_W^2)$ is a known function of the top mass.

12.5. D Decays

Evidence for $D^0-\overline{D}^0$ mixing has been obtained in recent years [38–40]. The experimental constraints read [25,41] $x\equiv \Delta m/\Gamma=0.0063\pm0.0019$ and $y\equiv \Delta\Gamma/(2\Gamma)=0.0075\pm0.0012$. Long-distance contributions make it difficult to calculate the Standard Model prediction for the $D^0-\overline{D}^0$ mixing parameters. Therefore, the goal of the search for $D^0-\overline{D}^0$ mixing is not to constrain the CKM parameters, but rather to probe new physics. Here CP violation plays an important role. Within the Standard Model, the CP-violating effects are predicted to be small, since the mixing and the relevant decays are described, to an excellent approximation, by physics of the first two generations. The expectation is that the Standard Model size of CP violation in D decays is of $\mathcal{O}(10^{-3})$ or less, but theoretical work is ongoing to understand whether QCD effects can significantly enhance it. At present, the most sensitive searches involve the $D\to K^+K^-$, $D\to \pi^+\pi^-$ and $D\to K^\pm\pi^\mp$ modes.

The neutral D mesons decay via a singly-Cabibbo-suppressed transition to the CP eigenstates K^+K^- and $\pi^+\pi^-$. These decays are dominated by Standard-Model tree diagrams. Thus, we can write, for $f=K^+K^-$ or $\pi^+\pi^-$,

$$\begin{split} A_f &= A_f^T e^{+i\phi_f^T} \left[1 + r_f e^{i(\delta_f + \phi_f)} \right] , \\ \bar{A}_f &= A_f^T e^{-i\phi_f^T} \left[1 + r_f e^{i(\delta_f - \phi_f)} \right] , \end{split} \tag{12.69}$$

where $A_f^T e^{\pm i\phi_f^T}$ is the SM tree level contribution, ϕ_f^T and ϕ_f are weak, CP violating phases, δ_f is a strong phase, and r_f is the ratio between a subleading $(r_f \ll 1)$ contribution with a weak phase different from ϕ_f^T and the SM tree level contribution. Neglecting r_f , λ_f is universal, and we can define a phase ϕ_D via

$$\lambda_f \equiv -|q/p|e^{i\phi_D}.\tag{12.70}$$

(In the limit of CP conservation, choosing $\phi_D = 0$ is equivalent to defining the mass eigenstates by their CP eigenvalue: $|D_{\mp}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$, with $D_-(D_+)$ being the CP-odd (CP-even) state; that is, the state that does not (does) decay into K^+K^- .)

We define the time integrated ${\cal CP}$ asymmetry for a final ${\cal CP}$ eigenstate f as follows:

$$a_f \equiv \frac{\int_0^\infty \Gamma(D_{\rm phys}^0(t) \to f) dt - \int_0^\infty \Gamma(\overline{D}_{\rm phys}^0(t) \to f) dt}{\int_0^\infty \Gamma(D_{\rm phys}^0(t) \to f) dt + \int_0^\infty \Gamma(\overline{D}_{\rm phys}^0(t) \to f) dt}.$$
 (12.71)

(This expression corresponds to the D meson being tagged at production, hence the integration goes from 0 to $+\infty$; measurements are also possible with $\psi(3770) \to D\bar{D}$, in which case the integration goes from $-\infty$ to $+\infty$.) We take $x,y,r_f\ll 1$ and expand to leading order in these parameters. Then, we can separate the contribution to a_f to three parts [42],

$$a_f = a_f^d + a_f^m + a_f^i, (12.72)$$

with the following underlying mechanisms:

1. a_f^d signals CP violation in decay (similar to Eq. (12.37)):

$$a_f^d = 2r_f \sin \phi_f \sin \delta_f. \tag{12.73}$$

2. a_f^m signals CP violation in mixing (similar to Eq. (12.46)). With our approximations, it is universal:

$$a^{m} = -\frac{y}{2} \left(\left| \frac{q}{p} \right| - \left| \frac{p}{q} \right| \right) \cos \phi_{D}. \tag{12.74}$$

3. a_f^i signals CP violation in the interference of mixing and decay (similar to Eq. (12.47)). With our approximations, it is universal:

$$a^{i} = \frac{x}{2} \left(\left| \frac{q}{p} \right| + \left| \frac{p}{q} \right| \right) \sin \phi_{D}. \tag{12.75}$$

One can isolate the effects of direct CP violation by taking the difference between the CP asymmetries in the K^+K^- and $\pi^+\pi^-$ modes:

$$\Delta a_{CP} \equiv a_{K^+K^-} - a_{\pi^+\pi^-} = a_{K^+K^-}^d - a_{\pi^+\pi^-}^d, \eqno(12.76)$$

where we neglected a residual, experiment-dependent, contribution from indirect CP violation due to the fact that there is a time dependent acceptance function that can be different for the K^+K^- and $\pi^+\pi^-$ channels. Recently, evidence for such direct CP violation has been obtained [25]:

$$a_{K^+K^-}^d - a_{\pi^+\pi^-}^d = (-6.4 \pm 1.8) \times 10^{-3}.$$
 (12.77)

One can also isolate the effects of indirect CP violation in the following way. Consider the time dependent decay rates in Eq. (12.32) and Eq. (12.33). The mixing processes modify the time dependence from a pure exponential. However, given the small values of x and y, the time dependences can be recast, to a good approximation, into purely exponential form, but with modified decay-rate parameters [43]:

$$\begin{split} &\Gamma_{D^0 \to K^+K^-} = \Gamma \times \left[1 + |q/p| \left(y\cos\phi_D - x\sin\phi_D\right)\right] \;, \\ &\Gamma_{\overline{D^0 \to K^+K^-}} = \Gamma \times \left[1 + |p/q| \left(y\cos\phi_D + x\sin\phi_D\right)\right] \;. \end{split} \tag{12.78}$$

One can define CP-conserving and CP-violating combinations of these two observables (normalized to the true width Γ):

$$\begin{split} y_{CP} &\equiv \frac{\Gamma_{\overline{D}^0 \to K^+ K^-} + \Gamma_{D^0 \to K^+ K^-}}{2\Gamma} - 1 \\ &= (y/2) \left(|q/p| + |p/q| \right) \cos \phi_D - (x/2) \left(|q/p| - |p/q| \right) \sin \phi_D \;, \\ A_{\Gamma} &\equiv \frac{\Gamma_{D^0 \to K^+ K^-} - \Gamma_{\overline{D}^0 \to K^+ K^-}}{2\Gamma} \\ &= - \left(a^m + a^i \right) \;. \end{split} \tag{12.79}$$

In the limit of CP conservation (and, in particular, within the Standard Model), $y_{CP}=(\Gamma_+-\Gamma_-)/2\Gamma$ (where $\Gamma_+(\Gamma_-)$ is the decay width of the CP-even (-odd) mass eigenstate) and $A_\Gamma=0$. Indeed, present measurements imply that CP violation is small [25],

$$y_{CP} = + (1.06 \pm 0.21) \times 10^{-2},$$

 $A_{\Gamma} = + (0.03 \pm 0.23) \times 10^{-2}.$

The $K^{\pm}\pi^{\mp}$ states are not CP eigenstates, but they are still common final states for D^0 and \overline{D}^0 decays. Since $D^0(\overline{D}^0) \to K^-\pi^+$ is a Cabibbo-favored (doubly-Cabibbo-suppressed) process, these processes are particularly sensitive to x and/or $y=\mathcal{O}(\lambda^2)$. Taking into account that $\left|\lambda_{K^-\pi^+}\right|, \left|\lambda_{K^+\pi^-}^{-1}\right| \ll 1$ and $x,y \ll 1$, assuming that there is no direct CP violation (these are Standard Model tree-level decays dominated by a single weak phase, and there is no contribution from penguin-like and chromomagnetic operators), and expanding the time-dependent rates for $xt,yt\lesssim \Gamma^{-1}$, one obtains

$$\Gamma[D^{0}_{\text{phys}}(t) \to K^{+}\pi^{-}] = e^{-\Gamma t} |\overline{A}_{K^{-}\pi^{+}}|^{2}$$

$$\times \left[r_{d}^{2} + r_{d} \left| \frac{q}{p} \right| (y' \cos \phi_{D} - x' \sin \phi_{D}) \Gamma t + \left| \frac{q}{p} \right|^{2} \frac{y^{2} + x^{2}}{4} (\Gamma t)^{2} \right] ,$$

$$\Gamma[\overline{D}^{0}_{\text{phys}}(t) \to K^{-}\pi^{+}] = e^{-\Gamma t} |\overline{A}_{K^{-}\pi^{+}}|^{2}$$

$$\times \left[r_{d}^{2} + r_{d} \left| \frac{p}{q} \right| (y' \cos \phi_{D} + x' \sin \phi_{D}) \Gamma t + \left| \frac{p}{q} \right|^{2} \frac{y^{2} + x^{2}}{4} (\Gamma t)^{2} \right] ,$$

$$(12.86)$$

where

$$y' \equiv y \cos \delta - x \sin \delta$$
,
 $x' \equiv x \cos \delta + y \sin \delta$. (12.81)

The weak phase ϕ_D is the same as that of Eq. (12.70) (a consequence of neglecting direct CP violation), δ is a strong-phase difference for these processes, and $r_d = \mathcal{O}(\tan^2\theta_c)$ is the amplitude ratio, $r_d = \left|\overline{A}_{K^-\pi^+}/A_{K^-\pi^+}\right| = \left|A_{K^+\pi^-}/\overline{A}_{K^+\pi^-}\right|$, that is, $\lambda_{K^-\pi^+} = r_d|q/p|e^{-i(\delta-\phi_D)}$ and $\lambda_{K^+\pi^-}^{-1} = r_d|p/q|e^{-i(\delta+\phi_D)}$. By fitting to the six coefficients of the various time-dependences, one can extract r_d , |q/p|, (x^2+y^2) , $y'\cos\phi_D$, and $x'\sin\phi_D$. In particular, finding CP violation $(|q/p|\neq 1$ and/or $\sin\phi_D\neq 0$) at a level much higher than 10^{-3} would constitute evidence for new physics.

A fit to all data [25] yields no evidence for indirect CP violation:

$$1 - |q/p| = +0.12 \pm 0.17,$$

$$\phi_D = -0.18 \pm 0.16.$$

More details on various theoretical and experimental aspects of $D^0 - \overline{D}^0$ mixing can be found in Ref. [44].

12.6. B and B_s Decays

The upper bound on the CP asymmetry in semileptonic B decays [24] implies that CP violation in $B^0 - \overline{B}^0$ mixing is a small effect (we use $\mathcal{A}_{\mathrm{SL}}/2 \approx 1 - |q/p|$, see Eq. (12.39)):

$$\mathcal{A}_{\mathrm{SL}}^d = (-3.3 \pm 3.3) \times 10^{-3} \implies |q/p| = 1.0017 \pm 0.0017. \quad (12.82)$$

The Standard Model prediction is

$$\mathcal{A}_{\mathrm{SL}}^{d} = \mathcal{O}\left[(m_{c}^{2}/m_{t}^{2})\sin\beta\right] \lesssim 0.001. \tag{12.83}$$

In models where $\Gamma_{12}/\mathbf{M}_{12}$ is approximately real, such as the Standard Model, an upper bound on $\Delta\Gamma/\Delta m \approx \mathcal{R}e(\Gamma_{12}/\mathbf{M}_{12})$ provides yet another upper bound on the deviation of |q/p| from one. This constraint does not hold if $\Gamma_{12}/\mathbf{M}_{12}$ is approximately imaginary. (An alternative parameterization uses $q/p = (1-\tilde{\epsilon}_B)/(1+\tilde{\epsilon}_B)$, leading to $\mathcal{A}_{\mathrm{SL}} \simeq 4\mathcal{R}e(\tilde{\epsilon}_B)$.)

The small deviation (less than one percent) of |q/p| from 1 implies that, at the present level of experimental precision, CP violation in B mixing is a negligible effect. Thus, for the purpose of analyzing CP asymmetries in hadronic B decays, we can use

$$\lambda_f = e^{-i\phi_M(B)} (\overline{A}_f/A_f) , \qquad (12.84)$$

where $\phi_{M(B)}$ refers to the phase of \mathbf{M}_{12} appearing in Eq. (12.44) that is appropriate for $B^0 - \overline{B}^0$ oscillations. Within the Standard Model, the corresponding phase factor is given by

$$e^{-i\phi_{M(B)}} = (V_{tb}^* V_{td})/(V_{tb} V_{td}^*)$$
 (12.85)

Some of the most interesting decays involve final states that are common to B^0 and \overline{B}^0 [45,46]. It is convenient to rewrite Eq. (12.42) for B decays as [47–49]

$$\mathcal{A}_f(t) = S_f \sin(\Delta m t) - C_f \cos(\Delta m t),$$

$$S_f \equiv \frac{2\mathcal{I}m(\lambda_f)}{1 + |\lambda_f|^2}, \quad C_f \equiv \frac{1 - |\lambda_f|^2}{1 + |\lambda_f|^2},$$
 (12.86)

where we assume that $\Delta\Gamma=0$ and |q/p|=1. An alternative notation in use is $A_f\equiv -C_f$, but this A_f should not be confused with the A_f of Eq. (12.15).

A large class of interesting processes proceed via quark transitions of the form $\overline{b} \to \overline{q}q\overline{q}'$ with q'=s or d. For q=c or u, there are contributions from both tree (t) and penguin $(p^{qu},$ where $q_u=u,c,t$ is the quark in the loop) diagrams (see Fig. 12.2) which carry different weak phases:

$$A_f = \left(V_{qb}^* V_{qq'}\right) t_f + \sum_{q_u = u, c, t} \left(V_{qub}^* V_{quq'}\right) p_f^{q_u} . \tag{12.87}$$

(The distinction between tree and penguin contributions is a heuristic one; the separation by the operator that enters is more precise. For a detailed discussion of the more complete operator product approach, which also includes higher order QCD corrections, see, for example, Ref. [50].) Using CKM unitarity, these decay amplitudes can always be written in terms of just two CKM combinations. For example, for $f=\pi\pi$, which proceeds via $\overline{b} \to \overline{u}u\overline{d}$ transition, we can write

$$A_{\pi\pi} = (V_{ub}^* V_{ud}) T_{\pi\pi} + (V_{tb}^* V_{td}) P_{\pi\pi}^t, \tag{12.88}$$

where $T_{\pi\pi} = t_{\pi\pi} + p_{\pi\pi}^u - p_{\pi\pi}^c$ and $P_{\pi\pi}^t = p_{\pi\pi}^t - p_{\pi\pi}^c$. *CP*-violating phases in Eq. (12.88) appear only in the CKM elements, so that

$$\frac{\overline{A}_{\pi\pi}}{A_{\pi\pi}} = \frac{\left(V_{ub}V_{ud}^*\right)T_{\pi\pi} + \left(V_{tb}V_{td}^*\right)P_{\pi\pi}^t}{\left(V_{ub}^*V_{ud}\right)T_{\pi\pi} + \left(V_{tb}^*V_{td}\right)P_{\pi\pi}^t}.$$
(12.89)

For $f = J/\psi K$, which proceeds via $\overline{b} \to \overline{c}c\overline{s}$ transition, we can write

$$A_{\psi K} = (V_{cb}^* V_{cs}) T_{\psi K} + (V_{ub}^* V_{us}) P_{\psi K}^u, \tag{12.90}$$

where $T_{\psi K} = t_{\psi K} + p^c_{\psi K} - p^t_{\psi K}$ and $P^u_{\psi K} = p^u_{\psi K} - p^t_{\psi K}$. A subtlety arises in this decay that is related to the fact that B^0 decays into a final $J/\psi K^0$ state while \overline{B}^0 decays into a final $J/\psi \overline{K}^0$ state. A common final state, e.g., $J/\psi K_S$, is reached only via $K^0 - \overline{K}^0$ mixing. Consequently, the phase factor (defined in Eq. (12.44)) corresponding to neutral K mixing, $e^{-i\phi_M(K)} = (V^*_{cd}V_{cs})/(V_{cd}V^*_{cs})$, plays a role:

$$\frac{\overline{A}_{\psi K_S}}{A_{\psi K_S}} = -\frac{\left(V_{cb}V_{cs}^*\right)T_{\psi K} + \left(V_{ub}V_{us}^*\right)P_{\psi K}^u}{\left(V_{cb}^*V_{cs}\right)T_{\psi K} + \left(V_{ub}^*V_{us}\right)P_{\psi K}^u} \times \frac{V_{cd}^*V_{cs}}{V_{cd}V_{cs}^*}. \tag{12.91}$$

For q=s or d, there are only penguin contributions to A_f , that is, $t_f=0$ in Eq. (12.87). (The tree $\overline{b} \to \overline{u}u\overline{q}'$ transition followed by $\overline{u}u \to \overline{q}q$ rescattering is included below in the P^u terms.) Again, CKM unitarity allows us to write A_f in terms of two CKM combinations. For example, for $f=\phi K_S$, which proceeds via $\overline{b} \to \overline{s}s\overline{s}$ transition, we can write

$$\frac{\overline{A}_{\phi K_S}}{A_{\phi K_S}} = -\frac{\left(V_{cb}V_{cs}^*\right)P_{\phi K}^c + \left(V_{ub}V_{us}^*\right)P_{\phi K}^u}{\left(V_{cb}^*V_{cs}\right)P_{\phi K}^c + \left(V_{ub}^*V_{us}\right)P_{\phi K}^u} \times \frac{V_{cd}^*V_{cs}}{V_{cd}V_{cs}^*}, \tag{12.92}$$

where
$$P_{\phi K}^c = p_{\phi K}^c - p_{\phi K}^t$$
 and $P_{\phi K}^u = p_{\phi K}^u - p_{\phi K}^t$.

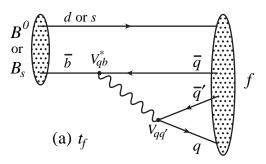
Since the amplitude A_f involves two different weak phases, the corresponding decays can exhibit both CP violation in the interference of decays with and without mixing, $S_f \neq 0$, and CP violation in decays, $C_f \neq 0$. (At the present level of experimental precision, the contribution to C_f from CP violation in mixing is negligible, see Eq. (12.82).) If the contribution from a second weak phase is suppressed, then the interpretation of S_f in terms of Lagrangian CP-violating parameters is clean, while C_f is small. If such a second contribution is not suppressed, S_f depends on hadronic parameters and, if the relevant strong phase is large, C_f is large.

A summary of $\overline{b} \to \overline{q}\overline{q}q'$ modes with q'=s or d is given in Table 12.1. The $\overline{b} \to \overline{d}d\overline{q}$ transitions lead to final states that are similar to the $\overline{b} \to \overline{u}u\overline{q}$ transitions and have similar phase dependence. Final states that consist of two-vector mesons $(\psi\phi$ and $\phi\phi)$ are not CP eigenstates, and angular analysis is needed to separate the CP-even from the CP-odd contributions.

The cleanliness of the theoretical interpretation of S_f can be assessed from the information in the last column of Table 12.1. In case of small uncertainties, the expression for S_f in terms of CKM phases can be deduced from the fourth column of Table 12.1 in combination with Eq. (12.85) (and, for $b \to q \overline{q} s$ decays, the example in Eq. (12.91)). Here we consider several interesting examples.

For $B \to J/\psi K_S$ and other $\overline{b} \to \overline{c}c\overline{s}$ processes, we can neglect the P^u contribution to A_f , in the Standard Model, to an approximation that is better than one percent:

$$\lambda_{\psi K_S} = -e^{-2i\beta} \implies S_{\psi K_S} = \sin 2\beta, \quad C_{\psi K_S} = 0.$$
 (12.93)



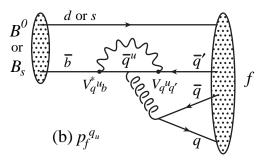


Figure 12.2: Feynman diagrams for (a) tree and (b) penguin amplitudes contributing to $B^0 \to f$ or $B_s \to f$ via a $\overline{b} \to \overline{q}q\overline{q}$ quark-level process.

Table 12.1: Summary of $\overline{b} \to \overline{q}q\overline{q}'$ modes with q'=s or d. The second and third columns give examples of final hadronic states. The fourth column gives the CKM dependence of the amplitude A_f , using the notation of Eqs. (12.88, 12.90,12.92), with the dominant term first and the subdominant second. The suppression factor of the second term compared to the first is given in the last column. "Loop" refers to a penguin versus tree-suppression factor (it is mode-dependent and roughly $\mathcal{O}(0.2-0.3)$) and $\lambda=0.23$ is the expansion parameter of Eq. (12.50).

| $\overline{b} 	o \overline{q} q \overline{q}'$ | $B^0 \to f$ | $B_s \to f$ | CKM dependence of A_f | Suppression |
|------------------------------------------------|--------------|--------------|---------------------------------------------|----------------------------------|
| $\bar{b} \to \bar{c}c\bar{s}$ | ψK_S | $\psi\phi$ | $(V_{cb}^*V_{cs})T + (V_{ub}^*V_{us})P^u$ | $\mathrm{loop} \times \lambda^2$ |
| $\bar{b} \to \bar{s} s \bar{s}$ | ϕK_S | $\phi\phi$ | $(V_{cb}^*V_{cs})P^c + (V_{ub}^*V_{us})P^u$ | λ^2 |
| $\bar{b} \to \bar{u} u \bar{s}$ | $\pi^0 K_S$ | K^+K^- | $(V_{cb}^*V_{cs})P^c + (V_{ub}^*V_{us})T$ | λ^2/loop |
| $\bar{b} \to \bar{c} c \bar{d}$ | D^+D^- | ψK_S | $(V_{cb}^*V_{cd})T + (V_{tb}^*V_{td})P^t$ | loop |
| $\bar{b} \to \bar{s} s \bar{d}$ | K_SK_S | ϕK_S | $(V_{tb}^*V_{td})P^t + (V_{cb}^*V_{cd})P^c$ | $\lesssim 1$ |
| $\bar{b} \to \bar{u}u\bar{d}$ | $\pi^+\pi^-$ | $\rho^0 K_S$ | $(V_{ub}^*V_{ud})T + (V_{tb}^*V_{td})P^t$ | loop |

In the presence of new physics, A_f is still likely to be dominated by the T term, but the mixing amplitude might be modified. We learn that, model-independently, $C_f \approx 0$ while S_f cleanly determines the mixing phase $(\phi_M - 2 \arg(V_{cb}V_{cd}^*))$. The experimental measurement [25], $S_{\psi K} = 0.665 \pm 0.022$, gave the first precision test of the Kobayashi-Maskawa mechanism, and its consistency with the predictions for $\sin 2\beta$ makes it very likely that this mechanism is indeed the dominant source of CP violation in meson decays.

For $B\to \phi K_S$ and other $\overline{b}\to \overline{s}s\overline{s}$ processes (as well as some $\overline{b}\to \overline{u}u\overline{s}$ processes), we can neglect the subdominant contributions, in the Standard Model, to an approximation that is good on the order of

a few percent:

$$\lambda_{\phi K_S} = -e^{-2i\beta} \ \Rightarrow \ S_{\phi K_S} = \sin 2\beta, \quad C_{\phi K_S} = 0 \ . \eqno(12.94)$$

In the presence of new physics, both A_f and \mathbf{M}_{12} can get contributions that are comparable in size to those of the Standard Model and carry new weak phases. Such a situation gives several interesting consequences for penguin-dominated $b \to q\overline{q}s$ decays (q=u,d,s) to a final state f:

- 1. The value of $-\eta_f S_f$ may be different from $S_{\psi K_S}$ by more than a few percent, where η_f is the CP eigenvalue of the final state.
- 2. The values of $\eta_f S_f$ for different final states f may be different from each other by more than a few percent (for example, $S_{\phi K_S} \neq S_{\eta' K_S}$).
- 3. The value of C_f may be different from zero by more than a few percent.

While a clear interpretation of such signals in terms of Lagrangian parameters will be difficult because, under these circumstances, hadronic parameters do play a role, any of the above three options will clearly signal new physics. Fig. 12.3 summarizes the present experimental results: none of the possible signatures listed above is unambiguously established, but there is definitely still room for new physics.

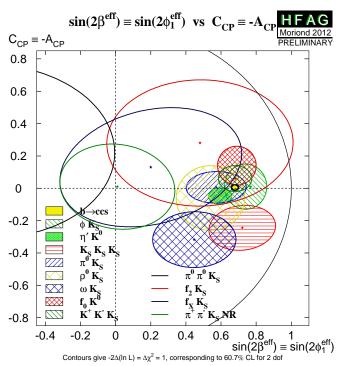


Figure 12.3: Summary of the results [25] of time-dependent analyses of $b\to q\overline{q}s$ decays, which are potentially sensitive to new physics.

For $B\to\pi\pi$ and other $\overline{b}\to\overline{u}u\overline{d}$ processes, the penguin-to-tree ratio can be estimated using SU(3) relations and experimental data on related $B\to K\pi$ decays. The result is that the suppression is on the order of 0.2-0.3 and so cannot be neglected. The expressions for $S_{\pi\pi}$ and $C_{\pi\pi}$ to leading order in $R_{PT}\equiv (|V_{tb}V_{td}|\,P_{\pi\pi}^t)/(|V_{ub}V_{ud}|\,T_{\pi\pi})$ are:

$$\lambda_{\pi\pi} = e^{2i\alpha} \left[(1 - R_{PT}e^{-i\alpha}) / (1 - R_{PT}e^{+i\alpha}) \right] \Rightarrow$$

 $S_{\pi\pi} \approx \sin 2\alpha + 2 \, \mathcal{R}e(R_{PT}) \cos 2\alpha \sin \alpha, \quad C_{\pi\pi} \approx 2 \, \mathcal{I}m(R_{PT}) \sin \alpha.$ (12.95)

Note that R_{PT} is mode-dependent and, in particular, could be different for $\pi^+\pi^-$ and $\pi^0\pi^0$. If strong phases can be neglected, then R_{PT} is real, resulting in $C_{\pi\pi} = 0$. The size of $C_{\pi\pi}$ is an indicator of how large the strong phase is. The present experimental range is

 $C_{\pi\pi} = -0.38 \pm 0.06$ [25]. As concerns $S_{\pi\pi}$, it is clear from Eq. (12.95) that the relative size or strong phase of the penguin contribution must be known to extract α . This is the problem of penguin pollution.

The cleanest solution involves isospin relations among the $B\to\pi\pi$ amplitudes [51]:

$$\frac{1}{\sqrt{2}}A_{\pi^{+}\pi^{-}} + A_{\pi^{0}\pi^{0}} = A_{\pi^{+}\pi^{0}}.$$
 (12.96)

The method exploits the fact that the penguin contribution to $P^t_{\pi\pi}$ is pure $\Delta I = \frac{1}{2}$ (this is not true for the electroweak penguins which, however, are expected to be small), while the tree contribution to $T_{\pi\pi}$ contains pieces which are both $\Delta I = \frac{1}{2}$ and $\Delta I = \frac{3}{2}$. A simple geometric construction then allows one to find R_{PT} and extract α cleanly from $S_{\pi^+\pi^-}$. The key experimental difficulty is that one must measure accurately the separate rates for $B^0, \overline{B}^0 \to \pi^0\pi^0$.

CP asymmetries in $B \to \rho \pi$ and $B \to \rho \rho$ can also be used to determine α . In particular, the $B \to \rho \rho$ measurements are presently very significant in constraining α . The extraction proceeds via isospin analysis similar to that of $B \to \pi\pi$. There are, however, several important differences. First, due to the finite width of the ρ mesons, a final $(\rho\rho)_{I=1}$ state is possible [52]. The effect is, however, small, on the order of $(\Gamma_{\rho}/m_{\rho})^2 \sim 0.04$. Second, due to the presence of three helicity states for the two-vector mesons, angular analysis is needed to separate the CP-even and CP-odd components. The theoretical expectation is, however, that the CP-odd component is small. This expectation is supported by experiments which find that the $\rho^+\rho^-$ and $\rho^{\pm}\rho^0$ modes are dominantly longitudinally polarized. Third, an important advantage of the $\rho\rho$ modes is that the penguin contribution is expected to be small due to different hadronic dynamics. This expectation is confirmed by the smallness of $\mathcal{B}(B^0 \to \rho^0 \rho^0) = (0.73 \pm 0.28) \times 10^{-6}$ compared to $\mathcal{B}(B^0 \to \rho^+ \rho^-) = (24.2 \pm 3.1) \times 10^{-6}$. Thus, $S_{\rho^+ \rho^-}$ is not far from $\sin 2\alpha$. Finally, both $S_{\rho^0\rho^0}$ and $C_{\rho^0\rho^0}$ are experimentally accessible, which may allow a precision determination of α . The consistency between the range of α determined by the $B \to \pi\pi, \rho\pi, \rho\rho$ measurements and the range allowed by CKM fits (excluding these direct determinations) provides further support to the Kobayashi-Maskawa mechanism.

An interesting class of decay modes is that of the tree level decays $B^{\pm} \to D^{(*)0} K^{\pm}$. These decays provide golden methods for a clean determination of the angle γ [53–56]. The method uses the decays $B^+ \to D^0 K^+$, which proceeds via the quark transition $\overline{b} \to \overline{u} c \overline{s}$, and $B^+ \to \overline{D}^0 K^+$, which proceeds via the quark transition $\overline{b} \to \overline{c} u \overline{s}$, with the D^0 and \overline{D}^0 decaying into a common final state. The decays into common final states, such $(\pi^0 K_S)_D K^+$, involve interference effects between the two amplitudes, with sensitivity to the relative phase, $\delta + \gamma$ (δ is the relevant strong phase). The *CP*-conjugate processes are sensitive to $\delta - \gamma$. Measurements of branching ratios and CP asymmetries allow an extraction of γ and δ from amplitude triangle relations. The extraction suffers from discrete ambiguities but involves no hadronic uncertainties. However, the smallness of the CKM-suppressed $b \rightarrow u$ transitions makes it difficult at present to use the simplest methods [53–55] to determine γ . These difficulties are overcome (and the discrete ambiguities are removed) by performing a Dalitz plot analysis for multi-body D decays [56]. The consistency between the range of γ determined by the $B \to DK$ measurements and the range allowed by CKM fits (excluding these direct determinations) provides further support to the Kobayashi-Maskawa mechanism.

The upper bound on the CP asymmetry in semileptonic B_s decays [25] implies that CP violation in $B_s - \overline{B_s}$ mixing is a small effects:

$$\mathcal{A}_{\mathrm{SL}}^{s} = (-10.5 \pm 6.4) \times 10^{-3} \implies |q/p| = 1.0052 \pm 0.0032. (12.97)$$

Neglecting the deviation of |q/p| from 1, implies that we can use

$$\lambda_f = e^{-i\phi_M(B_s)} (\overline{A}_f / A_f). \tag{12.98}$$

Within the Standard Model,

$$e^{-i\phi_{M}(B_{s})} = (V_{th}^{*}V_{ts})/(V_{th}V_{ts}^{*}).$$
 (12.99)

Note that $\Delta\Gamma/\Gamma=0.15\pm0.02$ [25] and therefore y should not be put to zero in Eqs. (12.32, 12.33). However, |q/p|=1 is expected to hold to an even better approximation than for B mesons. The $B_s\to J/\psi\phi$ decay proceeds via the $b\to c\bar cs$ transition. The CP asymmetry in in this mode thus determines (with angular analysis to disentangle the CP-even and CP-odd components of the final state) $\sin 2\beta_s$, where β_s is defined in Eq. (12.53). The combination of CDF, D0 and LHCb measurements yields [25]

$$\beta_s = 0.07^{+0.06}_{-0.08},$$
 (12.100)

consistent with the Standard Model prediction, $\beta_s = 0.018 \pm 0.001$ [18].

12.7. Summary and Outlook

CP violation has been experimentally established in K and B meson decays. A full list of CP asymmetries that have been measured at a level higher than 5σ is given in the introduction to this review. In Section 12.1.4 we introduced three types of CP-violating effects. Examples of these three types include the following:

1. All three types of CP violation have been observed in $K \to \pi\pi$ decays:

$$\mathcal{R}e(\epsilon') = \frac{1}{6} \left(\left| \frac{\overline{A}_{\pi^0 \pi^0}}{A_{\pi^0 \pi^0}} \right| - \left| \frac{\overline{A}_{\pi^+ \pi^-}}{A_{\pi^+ \pi^-}} \right| \right) = (2.5 \pm 0.4) \times 10^{-6} (I)$$

$$\mathcal{R}e(\epsilon) = \frac{1}{2} \left(1 - \left| \frac{q}{p} \right| \right) = (1.66 \pm 0.02) \times 10^{-3}$$
 (II)

$$\mathcal{I}m(\epsilon) = -\frac{1}{2}\mathcal{I}m(\lambda_{(\pi\pi)I=0}) = (1.57 \pm 0.02) \times 10^{-3} . \quad \text{(III)}$$
(12.101)

2. Direct CP violation has been observed in, for example, the $B^0 \to K^+\pi^-$ decays, while CP violation in interference of decays with and without mixing has been observed in, for example, the $B \to J/\psi K_S$ decay:

$$\begin{split} \mathcal{A}_{K^{+}\pi^{-}} &= \frac{|\overline{A}_{K^{-}\pi^{+}}/A_{K^{+}\pi^{-}}|^{2} - 1}{|\overline{A}_{K^{-}\pi^{+}}/A_{K^{+}\pi^{-}}|^{2} + 1} = -0.087 \pm 0.008 \quad \text{(I)} \\ S_{\psi K} &= \mathcal{I}m(\lambda_{\psi K}) = +0.679 \pm 0.020 \; . \end{split} \tag{III)} \tag{12.102} \end{split}$$

Based on Standard Model predictions, further observation of CP violation in D, B and B_s decays seems promising for the near future, at both LHCb and a possible higher-luminosity asymmetric-energy B factory [58]. Observables that are subject to clean theoretical interpretation, such as $S_{\psi K_S}$, $\mathcal{B}(K_L \to \pi^0 \nu \overline{\nu})$ and CP violation in $B \to DK$ decays, are of particular value for constraining the values of the CKM parameters and probing the flavor sector of extensions to the Standard Model. Other probes of CP violation now being pursued experimentally include the electric dipole moments of the neutron and electron, and the decays of tau leptons. Additional processes that are likely to play an important role in future CP studies include top-quark production and decay, and neutrino oscillations.

All measurements of CP violation to date are consistent with the predictions of the Kobayashi-Maskawa mechanism of the Standard Model. Actually, it is now established that the KM mechanism plays a major role in the CP violation measured in meson decays. However, a dynamically-generated matter-antimatter asymmetry of the universe requires additional sources of CP violation, and such sources are naturally generated by extensions to the Standard Model. New sources might eventually reveal themselves as small deviations from the predictions of the KM mechanism in meson decay rates, or else might not be observable in meson decays at all, but observable with future probes such as neutrino oscillations or electric dipole moments. We cannot guarantee that new sources of CP violation will ever be found experimentally, but the fundamental nature of CP violation demands a vigorous effort.

A number of excellent reviews of CP violation are available [59–67], where the interested reader may find a detailed discussion of the various topics that are briefly reviewed here.

We thank Tim Gershon for significant contributions to the 2012 update.

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13. NEUTRINO MASS, MIXING, AND OSCILLATIONS

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The experiments with solar, atmospheric, reactor and accelerator neutrinos have provided compelling evidences for oscillations of neutrinos caused by nonzero neutrino masses and neutrino mixing. The data imply the existence of 3-neutrino mixing in vacuum. We review the theory of neutrino oscillations, the phenomenology of neutrino mixing, the problem of the nature - Dirac or Majorana, of massive neutrinos, the issue of CP violation in the lepton sector, and the current data on the neutrino masses and mixing parameters. The open questions and the main goals of future research in the field of neutrino mixing and oscillations are outlined.

13.1. Introduction: Massive neutrinos and neutrino mixing

It is a well-established experimental fact that the neutrinos and antineutrinos which take part in the standard charged current (CC) and neutral current (NC) weak interaction are of three varieties (types) or flavours: electron, ν_e and $\bar{\nu}_e$, muon, ν_μ and $\bar{\nu}_\mu$, and tauon, ν_τ and $\bar{\nu}_\tau$. The notion of neutrino type or flavour is dynamical: ν_e is the neutrino which is produced with e^+ , or produces an e^- in CC weak interaction processes; ν_μ is the neutrino which is produced with μ^+ , or produces μ^- , etc. The flavour of a given neutrino is Lorentz invariant. Among the three different flavour neutrinos and antineutrinos, no two are identical. Correspondingly, the states which describe different flavour neutrinos must be orthogonal (within the precision of the current data): $\langle \nu_{\ell'} | \nu_{\ell} \rangle = \delta_{\ell' \ell}$, $\langle \bar{\nu}_{\ell'} | \bar{\nu}_{\ell} \rangle = \delta_{\ell' \ell}$, $\langle \bar{\nu}_{\ell'} | \nu_{\ell} \rangle = 0$.

It is also well-known from the existing data (all neutrino experiments were done so far with relativistic neutrinos or antineutrinos), that the flavour neutrinos ν_l (antineutrinos $\bar{\nu}_l$), are always produced in weak interaction processes in a state that is predominantly left-handed (LH) (right-handed (RH)). To account for this fact, ν_l and $\bar{\nu}_l$ are described in the Standard Model (SM) by a chiral LH flavour neutrino field $\nu_{lL}(x)$, $l = e, \mu, \tau$. For massless ν_l , the state of ν_l ($\bar{\nu}_l$) which the field $\nu_{lL}(x)$ annihilates (creates) is with helicity (-1/2) (helicity +1/2). If ν_l has a non-zero mass $m(\nu_l)$, the state of ν_l ($\bar{\nu}_l$) is a linear superposition of the helicity (-1/2) and (+1/2) states, but the helicity +1/2 state (helicity (-1/2) state) enters into the superposition with a coefficient $\propto m(\nu_l)/E$, E being the neutrino energy, and thus is strongly suppressed. Together with the LH charged lepton field $l_L(x)$, $\nu_{lL}(x)$ forms an $SU(2)_L$ doublet. In the absence of neutrino mixing and zero neutrino masses, $\nu_{lL}(x)$ and $l_L(x)$ can be assigned one unit of the additive lepton charge L_l and the three charges L_l , $l=e,\mu,\tau,$ are conserved by the weak interaction.

At present there is no compelling evidence for the existence of states of relativistic neutrinos (antineutrinos), which are predominantly righthanded, ν_R (left-handed, $\bar{\nu}_L$). If RH neutrinos and LH antineutrinos exist, their interaction with matter should be much weaker than the weak interaction of the flavour LH neutrinos ν_l and RH antineutrinos $\bar{\nu}_l, i.e., \nu_R \ (\bar{\nu}_L)$ should be "sterile" or "inert" neutrinos (antineutrinos) [1]. In the formalism of the Standard Model, the sterile ν_R and $\bar{\nu}_L$ can be described by $SU(2)_L$ singlet RH neutrino fields $\nu_R(x)$. In this case, ν_R and $\bar{\nu}_L$ will have no gauge interactions, *i.e.*, will not couple to the weak W^\pm and Z^0 bosons. If present in an extension of the Standard Model, the RH neutrinos can play a crucial role i) in the generation of neutrino masses and mixing, ii) in understanding the remarkable disparity between the magnitudes of neutrino masses and the masses of the charged leptons and quarks, and iii) in the generation of the observed matter-antimatter asymmetry of the Universe (via the leptogenesis mechanism [2]) . In this scenario which is based on the see-saw theory [3], there is a link between the generation of neutrino masses and the generation of the baryon asymmetry of the Universe. The simplest hypothesis (based on symmetry considerations) is that to each LH flavour neutrino field $\nu_{lL}(x)$ there corresponds a RH neutrino field $\nu_{lR}(x)$, $l=e,\mu,\tau$, although schemes with less (more) than three RH neutrinos are also being considered.

The experiments with solar, atmospheric and reactor neutrinos [4–16] have provided compelling evidences for the existence of neutrino oscillations [17,18], transitions in flight between the different flavour neutrinos ν_e , ν_μ , ν_τ (antineutrinos $\bar{\nu}_e$, $\bar{\nu}_\mu$, $\bar{\nu}_\tau$), caused by nonzero neutrino masses and neutrino mixing.

The existence of flavour neutrino oscillations implies that if a neutrino of a given flavour, say ν_{μ} , with energy E is produced in some weak interaction process, at a sufficiently large distance L from the ν_{μ} source the probability to find a neutrino of a different flavour, say ν_{τ} , $P(\nu_{\mu} \to \nu_{\tau}; E, L)$, is different from zero. $P(\nu_{\mu} \to \nu_{\tau}; E, L)$ is called the $\nu_{\mu} \to \nu_{\tau}$ oscillation or transition probability. If $P(\nu_{\mu} \to \nu_{\tau}; E, L) \neq 0$, the probability that ν_{μ} will not change into a neutrino of a different flavour, i.e., the " ν_{μ} survival probability" $P(\nu_{\mu} \rightarrow \nu_{\mu}; E, L)$, will be smaller than one. If only muon neutrinos ν_{μ} are detected in a given experiment and they take part in oscillations, one would observe a "disappearance" of muon neutrinos on the way from the ν_{μ} source to the detector. Disappearance of the solar ν_{e} , reactor $\bar{\nu}_e$ and of atmospheric ν_μ and $\bar{\nu}_\mu$ due to the oscillations have been observed respectively, in the solar neutrino [4-12], KamLAND [15,16] and Super-Kamokande [13,14] experiments. Strong evidences for disappearance of muon neutrinos due to oscillations were obtained also in the long-baseline accelerator neutrino experiments K2K [19] and MINOS [20,21]. As a consequence of the results of the experiments quoted above the existence of oscillations or transitions of the solar ν_e , atmospheric ν_μ and $\bar{\nu}_\mu$, accelerator ν_μ (at $L\sim 250$ km and $L \sim 730$ km) and reactor $\bar{\nu}_e$ (at $L \sim 180$ km), driven by nonzero neutrino masses and neutrino mixing, was firmly established. There are strong indications that the solar ν_e transitions are affected by the solar matter [22,23]. In June of 2011, the T2K [24] Collaboration reported indication of $\nu_{\mu} \rightarrow \nu_{e}$ oscillations, i.e., "appearance" of ν_{e} in a beam of ν_{μ} at a significance of 2.5 σ . Also MINOS [25] Collaboration obtained data consistent with $\nu_{\mu} \rightarrow \nu_{e}$ oscillations. In March and April, 2012, the Daya Bay [26] and RENO [27] experiments reported strong evidence for reactor $\bar{\nu}_e$ disappearance respectively at $L\sim 1.65$ km and $L\sim 1.38$ km and with statistical significance of 5.2σ and $4.9\sigma.$

Oscillations of neutrinos are a consequence of the presence of flavour neutrino mixing, or lepton mixing, in vacuum. In the formalism of local quantum field theory, used to construct the Standard Model, this means that the LH flavour neutrino fields $\nu_{\text{IL}}(x)$, which enter into the expression for the lepton current in the CC weak interaction Lagrangian, are linear combinations of the fields of three (or more) neutrinos ν_j , having masses $m_j \neq 0$:

$$\nu_{lL}(x) = \sum_{j} U_{lj} \nu_{jL}(x), \quad l = e, \mu, \tau,$$
 (13.1)

where $\nu_{j{\rm L}}(x)$ is the LH component of the field of ν_{j} possessing a mass m_{j} and U is a unitary matrix - the neutrino mixing matrix [1,17,18]. The matrix U is often called the Pontecorvo-Maki-Nakagawa-Sakata (PMNS) or Maki-Nakagawa-Sakata (MNS) mixing matrix. Obviously, Eq. (13.1) implies that the individual lepton charges $L_{l},\ l=e,\mu,\tau,$ are not conserved.

All existing neutrino oscillation data, except for the LSND [28] and the MiniBooNE [29] results (see below), can be described assuming 3-flavour neutrino mixing in vacuum. The data on the invisible decay width of the Z^0 -boson is compatible with only 3 light flavour neutrinos coupled to Z^0 [30]. The number of massive neutrinos ν_j , n, can, in general, be bigger than 3, n>3, if, for instance, there exist sterile neutrinos and they mix with the flavour neutrinos. It follows from the existing data that at least 3 of the neutrinos ν_j , say ν_1 , ν_2 , ν_3 , must be light, $m_{1,2,3} \lesssim 1$ eV, and must have different masses, $m_1 \neq m_2 \neq m_3$.

The short-baseline accelerator experiment LSND [28] observed a possible indication of $\bar{\nu}_{\mu} \to \bar{\nu}_{e}$ oscillations. Performing a $\bar{\nu}_{\mu} \to \bar{\nu}_{e}$ oscillation search, the MiniBooNE Collaboration reported a 1.5σ excess of $\bar{\nu}_{e}$ events [29], which is marginally consistent with the LSND indication of $\bar{\nu}_{\mu} \to \bar{\nu}_{e}$ oscillations. However, in the MiniBooNE experiment no indications of $\nu_{\mu} \to \nu_{e}$ oscillations were found so far [31]. Interpreting the LSND [28] and the MiniBooNE [29,31] results in terms of neutrino oscillations requires the introduction of at least two more light neutrinos with masses in the 1 eV range [32], and thus of two sterile neutrino fields which mix with the ν_{e} and ν_{μ} fields.

However, further experimental investigations are definitely needed since the excess of $\bar{\nu}_e$ events observed in the MiniBooNE experiment has a relatively low statistical significance.

Hints (at $\sim 2.5\sigma$) for existence of additional light neutrinos beyond the three firmly established were obtained in the re-analysis [33] of the old short baseline (SBL) reactor $\bar{\nu}_e$ oscillation data using the results of a new and very detailed calculation of the reactor $\bar{\nu}_e$ fluxes [34]. The latter were found in Ref. 34 to be by approximately 3% larger than the fluxes calculated in Ref. 35 and widely used in the interpretation of the results of the SBL reactor $\bar{\nu}_e$ oscillation experiments. It should be added that the results for the reactor $\bar{\nu}_e$ fluxes have an uncertainty associated, e.g., with the weak magnetism term contribution to the corresponding β -decay rates, which can be larger than the 3% difference between the "old" and "new" fluxes [36].

On the basis of the preceding discussion we can conclude that at present there are no compelling experimental evidences for the existence of more than 3 light neutrinos.

Being electrically neutral, the neutrinos with definite mass ν_j can be Dirac fermions or Majorana particles [37,38]. The first possibility is realised when there exists a lepton charge carried by the neutrinos ν_j , which is conserved by the particle interactions. This could be, e.g., the total lepton charge $L = L_e + L_{\mu} + L_{\tau}$: $L(\nu_j) = 1$, j = 1, 2, 3. In this case the neutrino ν_j has a distinctive antiparticle $\bar{\nu}_j$: $\bar{\nu}_j$ differs from ν_j by the value of the lepton charge L it carries, $L(\bar{\nu}_j) = -1$. The massive neutrinos ν_j can be Majorana particles if no lepton charge is conserved (see, e.g., Ref. 39). A massive Majorana particle χ_j is identical with its antiparticle $\bar{\chi}_j$: $\chi_j \equiv \bar{\chi}_j$. On the basis of the existing neutrino data it is impossible to determine whether the massive neutrinos are Dirac or Majorana fermions.

In the case of n neutrino flavours and n massive neutrinos, the $n\times n$ unitary neutrino mixing matrix U can be parametrised by n(n-1)/2 Euler angles and n(n+1)/2 phases. If the massive neutrinos ν_j are Dirac particles, only (n-1)(n-2)/2 phases are physical and can be responsible for CP violation in the lepton sector. In this respect the neutrino (lepton) mixing with Dirac massive neutrinos is similar to the quark mixing. For n=3 there is just one CP violating phase in U, which is usually called "the Dirac CP violating phase." CP invariance holds if (in a certain standard convention) U is real, $U^* = U$.

If, however, the massive neutrinos are Majorana fermions, $\nu_j \equiv \chi_j$, the neutrino mixing matrix U contains n(n-1)/2 CP violation phases [40,41], *i.e.*, by (n-1) phases more than in the Dirac neutrino case: in contrast to Dirac fields, the massive Majorana neutrino fields cannot "absorb" phases. In this case U can be cast in the form [40]

$$U = V P \tag{13.2}$$

where the matrix V contains the (n-1)(n-2)/2 Dirac CP violation phases, while P is a diagonal matrix with the additional (n-1) Majorana CP violation phases $\alpha_{21}, \alpha_{31}, ..., \alpha_{n1}$,

$$P = diag\left(1, e^{i\frac{\alpha_{21}}{2}}, e^{i\frac{\alpha_{31}}{2}}, ..., e^{i\frac{\alpha_{n1}}{2}}\right). \tag{13.3}$$

The Majorana phases will conserve CP if [42] $\alpha_{j1} = \pi q_j$, $q_j = 0, 1, 2$, j = 2, 3, ..., n. In this case $\exp[i(\alpha_{j1} - \alpha_{k1})] = \pm 1$ has a simple physical interpretation: this is the relative CP-parity of Majorana neutrinos χ_j and χ_k . The condition of CP invariance of the leptonic CC weak interaction in the case of mixing and massive Majorana neutrinos reads [39]:

$$U_{lj}^* = U_{lj} \rho_j, \quad \rho_j = \frac{1}{i} \eta_{CP}(\chi_j) = \pm 1,$$
 (13.4)

where $\eta_{CP}(\chi_j)=i\rho_j=\pm i$ is the CP parity of the Majorana neutrino χ_j [42]. Thus, if CP invariance holds, the elements of U are either real or purely imaginary.

In the case of n=3 there are altogether 3 CP violation phases - one Dirac and two Majorana. Even in the mixing involving only 2 massive Majorana neutrinos there is one physical CP violation Majorana phase. In contrast, the CC weak interaction is automatically CP-invariant in the case of mixing of two massive Dirac neutrinos or of two quarks.

13.2. Neutrino oscillations in vacuum

Neutrino oscillations are a quantum mechanical consequence of the existence of nonzero neutrino masses and neutrino (lepton) mixing, Eq. (13.1), and of the relatively small splitting between the neutrino masses. The neutrino mixing and oscillation phenomena are analogous to the $K^0 - \bar{K^0}$ and $B^0 - \bar{B^0}$ mixing and oscillations.

In what follows we will present a simplified version of the derivation of the expressions for the neutrino and antineutrino oscillation probabilities. The complete derivation would require the use of the wave packet formalism for the evolution of the massive neutrino states, or, alternatively, of the field-theoretical approach, in which one takes into account the processes of production, propagation and detection of neutrinos [43].

Suppose the flavour neutrino ν_l is produced in a CC weak interaction process and after a time T it is observed by a neutrino detector, located at a distance L from the neutrino source and capable of detecting also neutrinos $\nu_{l'}$, $l' \neq l$. We will consider the evolution of the neutrino state $|\nu_l\rangle$ in the frame in which the detector is at rest (laboratory frame). The oscillation probability, as we will see, is a Lorentz invariant quantity. If lepton mixing, Eq. (13.1), takes place and the masses m_j of all neutrinos ν_j are sufficiently small, the state of the neutrino ν_l , $|\nu_l\rangle$, will be a coherent superposition of the states $|\nu_j\rangle$ of neutrinos ν_j :

$$|\nu_l\rangle = \sum_j U_{lj}^* |\nu_j; \tilde{p}_j\rangle, \quad l = e, \mu, \tau,$$
 (13.5)

where U is the neutrino mixing matrix and \tilde{p}_j is the 4-momentum of ν_j [44].

We will consider the case of relativistic neutrinos ν_j , which corresponds to the conditions in both past and currently planned future neutrino oscillation experiments [46]. In this case the state $|\nu_j, \tilde{p}_j\rangle$ practically coincides with the helicity (-1) state $|\nu_j, L; \tilde{p}_j\rangle$ of the neutrino ν_j , the admixture of the helicity (+1) state $|\nu_j, R; \tilde{p}_j\rangle$ in $|\nu_j; \tilde{p}_j\rangle$ being suppressed due to the factor $\sim m_j/E_j$, where E_j is the energy of ν_j . If ν_j are Majorana particles, $\nu_j \equiv \chi_j$, due to the presence of the helicity (+1) state $|\chi_j, R; \tilde{p}_j\rangle$ in $|\chi_j; \tilde{p}_j\rangle$, the neutrino ν_l can produce an l^+ (instead of l^-) when it interacts with nucleons. The cross section of such a $|\Delta L_l| = 2$ process is suppressed by the factor $(m_j/E_j)^2$, which renders the process unobservable at present.

If the number n of massive neutrinos ν_j is bigger than 3 due to a mixing between the active flavour and sterile neutrinos, one will have additional relations similar to that in Eq. (13.5) for the state vectors of the (predominantly LH) sterile antineutrinos. In the case of just one RH sterile neutrino field $\nu_{sR}(x)$, for instance, we will have in addition to Eq. (13.5):

$$|\bar{\nu}_{sL}\rangle = \sum_{j=1}^{4} U_{sj}^{*} |\nu_{j}; \tilde{p}_{j}\rangle \cong \sum_{j=1}^{4} U_{sj}^{*} |\nu_{j}, L; \tilde{p}_{j}\rangle,$$
 (13.6)

where the neutrino mixing matrix U is now a 4×4 unitary matrix.

For the state vector of RH flavour antineutrino $\bar{\nu}_l$, produced in a CC weak interaction process we similarly get:

$$|\bar{\nu}_l\rangle = \sum_j U_{lj} \, |\bar{\nu}_j; \tilde{p}_j\rangle \cong \sum_{j=1} U_{lj} \, |\bar{\nu}_j, R; \tilde{p}_j\rangle, \quad l = e, \mu, \tau \,, \eqno(13.7)$$

where $|\bar{\nu}_j, R; \tilde{p}_j\rangle$ is the helicity (+1) state of the antineutrino $\bar{\nu}_j$ if ν_j are Dirac fermions, or the helicity (+1) state of the neutrino $\nu_j \equiv \bar{\nu}_j \equiv \chi_j$ if the massive neutrinos are Majorana particles. Thus, in the latter case we have in Eq. (13.7): $|\bar{\nu}_j; \tilde{p}_j\rangle \cong |\nu_j, R; \tilde{p}_j\rangle \equiv |\chi_j, R; \tilde{p}_j\rangle$. The presence of the matrix U in Eq. (13.7) (and not of U^*) follows directly from Eq. (13.1).

We will assume in what follows that the spectrum of masses of neutrinos is not degenerate: $m_j \neq m_k, j \neq k$. Then the states $|\nu_j; \tilde{p}_j\rangle$ in the linear superposition in the r.h.s. of Eq. (13.5) will have, in general, different energies and different momenta, independently of whether they are produced in a decay or interaction process: $\tilde{p}_j \neq \tilde{p}_k$,

or
$$E_j \neq E_k$$
, $\mathbf{p}_j \neq \mathbf{p}_k$, $j \neq k$, where $E_j = \sqrt{p_j^2 + m_j^2}$, $p_j \equiv |\mathbf{p}_j|$.

The deviations of E_j and p_j from the values for a massless neutrino E and p=E are proportional to m_j^2/E_0 , E_0 being a characteristic energy of the process, and are extremely small. In the case of $\pi^+ \to \mu^+ + \nu_\mu$ decay at rest, for instance, we have: $E_j = E + m_j^2/(2m_\pi)$, $p_j = E - \xi m_j^2/(2E)$, where $E = (m_\pi/2)(1 - m_\mu^2/m_\pi^2) \cong 30$ MeV, $\xi = (1 + m_\mu^2/m_\pi^2)/2 \cong 0.8$, and m_μ and m_π are the μ^+ and π^+ masses. Taking $m_j = 1$ eV we find: $E_j \cong E (1 + 1.2 \times 10^{-16})$ and $p_j \cong E (1 - 4.4 \times 10^{-16})$.

Suppose that the neutrinos are observed via a CC weak interaction process and that in the detector's rest frame they are detected after time T after emission, after traveling a distance L. Then the amplitude of the probability that neutrino ν_l will be observed if neutrino ν_l was produced by the neutrino source can be written as [43,45,47]:

$$A(\nu_l \to \nu_{l'}) = \sum_j U_{l'j} D_j U_{jl}^{\dagger}, \quad l, l' = e, \mu, \tau,$$
 (13.8)

where $D_j = D_j(p_j; L, T)$ describes the propagation of ν_j between the source and the detector, U_{jl}^{\dagger} and $U_{l'j}$ are the amplitudes to find ν_j in the initial and in the final flavour neutrino state, respectively. It follows from relativistic Quantum Mechanics considerations that [43,45]

$$D_j \equiv D_j(\tilde{p}_j; L, T) = e^{-i\tilde{p}_j(x_f - x_0)} = e^{-i(E_j T - p_j L)}, \qquad p_j \equiv |\mathbf{p}_j|,$$
(13.9)

where [48] x_0 and x_f are the space-time coordinates of the points of neutrino production and detection, $T=(t_f-t_0)$ and $L=\mathbf{k}(\mathbf{x}_f-\mathbf{x}_0)$, \mathbf{k} being the unit vector in the direction of neutrino momentum, $\mathbf{p}_j=\mathbf{k}\mathbf{p}_j$. What is relevant for the calculation of the probability $P(\nu_l\to\nu_{l'})=|A(\nu_l\to\nu_{l'})|^2$ is the interference factor $D_jD_k^*$ which depends on the phase

$$\delta\varphi_{jk} = (E_j - E_k)T - (p_j - p_k)L = (E_j - E_k)\left[T - \frac{E_j + E_k}{p_j + p_k}L\right] + \frac{m_j^2 - m_k^2}{p_j + p_k}L.$$
(13.10)

Some authors [49] have suggested that the distance traveled by the neutrinos L and the time interval T are related by $T=(E_j+E_k)\,L/(p_j+p_k)=L/\bar{v},\,\bar{v}=(E_j/(E_j+E_k))v_j+(E_k/(E_j+E_k))v_k$ being the "average" velocity of ν_j and ν_k , where $\nu_{j,k}=p_{j,k}/E_{j,k}$. In this case the first term in the r.h.s. of Eq. (13.10) vanishes. The indicated relation has not emerged so far from any dynamical wave packet calculations. We arrive at the same conclusion concerning the term under discussion in Eq. (13.10) if one assumes [50] that $E_j=E_k=E_0$. Finally, it was proposed in Ref. 47 and Ref. 51 that the states of ν_j and $\bar{\nu}_j$ in Eq. (13.5) and Eq. (13.7) have the same 3-momentum, $p_j=p_k=p$. Under this condition the first term in the r.h.s. of Eq. (13.10) is negligible, being suppressed by the additional factor $(m_j^2+m_k^2)/p^2$ since for relativistic neutrinos L=T up to terms $\sim m_{j,k}^2/p^2$. We arrive at the same conclusion if $E_j\neq E_k$, $p_j\neq p_k$, $j\neq k$, and we take into account that neutrinos are relativistic and therefore, up to corrections $\sim m_{j,k}^2/E_{j,k}^2$, we have $L\cong T$ (see, e.g., C. Giunti quoted in Ref. 43).

Although the cases considered above are physically quite different, they lead to the same result for the phase difference $\delta\varphi_{jk}$. Thus, we have:

$$\delta \varphi_{jk} \cong \frac{m_j^2 - m_k^2}{2p} L = 2\pi \frac{L}{L_{jk}^v} \operatorname{sgn}(m_j^2 - m_k^2),$$
 (13.11)

where $p = (p_j + p_k)/2$ and

$$L_{jk}^{v} = 4\pi \frac{p}{|\Delta m_{jk}^{2}|} \cong 2.48 \text{ m} \frac{p[MeV]}{|\Delta m_{jk}^{2}|[eV^{2}]}$$
 (13.12)

is the neutrino oscillation length associated with Δm_{jk}^2 . We can safely neglect the dependence of p_j and p_k on the masses m_j and m_k and

consider p to be the zero neutrino mass momentum, p=E. The phase difference $\delta\varphi_{jk}$, Eq. (13.11), is Lorentz-invariant.

Eq. (13.9) corresponds to a plane-wave description of the propagation of neutrinos ν_i . It accounts only for the movement of the center of the wave packet describing ν_j . In the wave packet treatment of the problem, the interference between the states of ν_i and ν_k is subject to a number of conditions [43], the localisation condition and the condition of overlapping of the wave packets of ν_i and ν_k at the detection point being the most important. For relativistic neutrinos, the localisation condition in space, for instance, reads: $\sigma_{xP}, \sigma_{xD} < L^{v}_{jk}/(2\pi), \ \sigma_{xP(D)}$ being the spatial width of the production (detection) wave packet. Thus, the interference will not be suppressed if the spatial width of the neutrino wave packets determined by the neutrino production and detection processes is smaller than the corresponding oscillation length in vacuum. In order for the interference to be nonzero, the wave packets describing ν_i and ν_k should also overlap in the point of neutrino detection. This requires that the spatial separation between the two wave packets at the point of neutrinos detection, caused by the two wave packets having different group velocities $v_i \neq v_k$, satisfies $|(v_i - v_k)T| \ll \max(\sigma_{xP}, \sigma_{xD})$. If the interval of time T is not measured, T in the preceding condition must be replaced by the distance L between the neutrino source and the detector (for further discussion see, e.g., Refs. [43,45,47])

For the $\nu_l \to \nu_{l'}$ and $\bar{\nu}_l \to \bar{\nu}_{l'}$ oscillation probabilities we get from Eq. (13.8), Eq. (13.9), and Eq. (13.11):

$$P(\nu_l \to \nu_{l'}) = \sum_{j} |U_{l'j}|^2 |U_{lj}|^2 + 2 \sum_{j>k} |U_{l'j} U_{l'j}^* U_{lk} U_{l'k}^*|$$

$$\cos(\frac{\Delta m_{jk}^2}{2p} L - \phi_{l'l;jk}), \qquad (13.13)$$

$$P(\bar{\nu}_l \to \bar{\nu}_{l'}) = \sum_j |U_{l'j}|^2 |U_{lj}|^2 + 2 \sum_{j>k} |U_{l'j} U_{lj}^* U_{lk} U_{l'k}^*|$$

$$\cos(\frac{\Delta m_{jk}^2}{2n} L + \phi_{l'l;jk}), \qquad (13.14)$$

where $l,l'=e,\mu,\tau$ and $\phi_{l'l;jk}=\arg\left(U_{l'j}\,U_{lj}^*\,U_{lk}\,U_{l'k}^*\right)$. It follows from Eq. (13.8) - Eq. (13.10) that in order for neutrino oscillations to occur, at least two neutrinos ν_j should not be degenerate in mass and lepton mixing should take place, $U\neq \mathbf{1}$. The neutrino oscillations effects can be large if we have

$$\frac{|\Delta m_{jk}^2|}{2p} L = 2\pi \frac{L}{L_{jk}^v} \gtrsim 1 \,, \ j \neq k \,. \tag{13.15}$$

at least for one Δm_{jk}^2 . This condition has a simple physical interpretation: the neutrino oscillation length L_{jk}^v should be of the order of, or smaller, than source-detector distance L, otherwise the oscillations will not have time to develop before neutrinos reach the detector.

We see from Eq. (13.13) and Eq. (13.14) that $P(\nu_l \to \nu_{l'}) = P(\bar{\nu}_{l'} \to \bar{\nu}_{l}), \ l, l' = e, \mu, \tau$. This is a consequence of CPT invariance. The conditions of CP and T invariance read [40,52,53]: $P(\nu_l \to \nu_{l'}) = P(\bar{\nu}_l \to \bar{\nu}_{l'}), \ l, l' = e, \mu, \tau$ (CP), $P(\nu_l \to \nu_{l'}) = P(\nu_{l'} \to \nu_{l'}), \ l, l' = e, \mu, \tau$ (T). In the case of CPT invariance, which we will assume to hold throughout this article, we get for the survival probabilities: $P(\nu_l \to \nu_l) = P(\bar{\nu}_l \to \bar{\nu}_l), \ l, l' = e, \mu, \tau$. Thus, the study of the "disappearance" of ν_l and $\bar{\nu}_l$, caused by oscillations in vacuum, cannot be used to test whether CP invariance holds in the lepton sector. It follows from Eq. (13.13) and Eq. (13.14) that we can have CP violation effects in neutrino oscillations only if $\phi_{l'l;jk} \neq \pi q, q = 0, 1, 2, i.e.$, if $U_{l'j}U_{l'j}^*U_{lk}U_{l'k}^*$, and therefore U itself, is not real. As a measure of CP and T violation in neutrino oscillations we can consider the asymmetries:

$$A_{\rm CP}^{(l'l)} \equiv P(\nu_l \to \nu_{l'}) - P(\bar{\nu}_l \to \bar{\nu}_{l'}) \,, \quad A_{\rm T}^{(l'l)} \equiv P(\nu_l \to \nu_{l'}) - P(\nu_{l'} \to \nu_l) \,. \tag{13.16}$$

CPT invariance implies: $A_{\rm CP}^{(l'l)} = -A_{\rm CP}^{(ll')}, A_{\rm T}^{(l'l)} = P(\bar{\nu}_{l'} \to \bar{\nu}_l) - P(\bar{\nu}_l \to \bar{\nu}_{l'}) = A_{\rm CP}^{(l'l)}$. It follows further directly from Eq. (13.13) and Eq. (13.14) that

$$A_{\text{CP}}^{(l'l)} = 4 \sum_{j>k} \text{Im} \left(U_{l'j} U_{lj}^* U_{lk} U_{l'k}^* \right) \sin \frac{\Delta m_{jk}^2}{2p} L, \quad l, l' = e, \mu, \tau.$$
(13.1)

Eq. (13.2) and Eq. (13.13) - Eq. (13.14) imply that $P(\nu_l \to \nu_{l'})$ and $P(\bar{\nu}_l \to \bar{\nu}_{l'})$ do not depend on the Majorana CP violation phases in the neutrino mixing matrix U [40]. Thus, the experiments investigating the $\nu_l \to \nu_{l'}$ and $\bar{\nu}_l \to \bar{\nu}_{l'}$ oscillations, $l, l' = e, \mu, \tau$, cannot provide information on the nature - Dirac or Majorana, of massive neutrinos. The same conclusions hold also when the $\nu_l \to \nu_{l'}$ and $\bar{\nu}_l \to \bar{\nu}_{l'}$ oscillations take place in matter [54]. In the case of $\nu_l \leftrightarrow \nu_{l'}$ and $\bar{\nu}_l \leftrightarrow \bar{\nu}_{l'}$ oscillations in vacuum, only the Dirac phase(s) in U can cause CP violating effects leading to $P(\nu_l \to \nu_{l'}) \neq P(\bar{\nu}_l \to \bar{\nu}_{l'}), l \neq l'$.

In the case of 3-neutrino mixing all different $\text{Im}(U_{l'j}U_{lj}^*U_{lk}U_{l'k}^*) \neq 0$, $l' \neq l = e, \mu, \tau, j \neq k = 1, 2, 3$, coincide up to a sign as a consequence of the unitarity of U. Therefore one has [55]:

$$A_{\text{CP}}^{(\mu e)} = -A_{\text{CP}}^{(\tau e)} = A_{\text{CP}}^{(\tau \mu)} = 4 J_{\text{CP}} \left(\sin \frac{\Delta m_{32}^2}{2p} L + \sin \frac{\Delta m_{21}^2}{2p} L + \sin \frac{\Delta m_{13}^2}{2p} L \right) (13.18)$$

where

$$J_{\rm CP} = {\rm Im} \left(U_{\mu 3} U_{e3}^* U_{e2} U_{\mu 2}^* \right),$$
 (13.19)

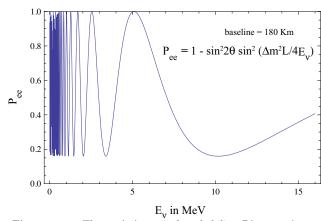


Figure 13.1: The ν_e ($\bar{\nu}_e$) survival probability $P(\nu_e \to \nu_e) = P(\bar{\nu}_e \to \bar{\nu}_e)$, Eq. (13.30), as a function of the neutrino energy for L=180 km, $\Delta m^2=7.0\times 10^{-5}~{\rm eV}^2$ and $\sin^2 2\theta=0.84$ (from Ref. 62).

is the "rephasing invariant" associated with the Dirac CP violation phase in U. It is analogous to the rephasing invariant associated with the Dirac CP violating phase in the CKM quark mixing matrix [56]. It is clear from Eq. (13.18) that $J_{\rm CP}$ controls the magnitude of CP violation effects in neutrino oscillations in the case of 3-neutrino mixing. If $\sin(\Delta m_{ij}^2/(2p))L\cong 0$ for (ij)=(32), or (21), or (13),

we get $A_{\mathrm{CP}}^{(l'l)}\cong 0$. Thus, if as a consequence of the production, propagation and/or detection of neutrinos, effectively oscillations due only to one non-zero neutrino mass squared difference take place, the CP violating effects will be strongly suppressed. In particular, we get $A_{\mathrm{CP}}^{(l'l)}=0$, unless all three $\Delta m_{ij}^2\neq 0$, (ij)=(32),(21),(13).

If the number of massive neutrinos n is equal to the number of neutrino flavours, n=3, one has as a consequence of the unitarity of the neutrino mixing matrix: $\sum_{l'=e,\mu,\tau} P(\nu_l \to \nu_{l'}) = 1$, $l=e,\mu,\tau$, $\sum_{l=e,\mu,\tau} P(\nu_l \to \nu_{l'}) = 1$, $l'=e,\mu,\tau$. Similar "probability conservation" equations hold for $P(\bar{\nu}_l \to \bar{\nu}_{l'})$. If, however, the number of light massive neutrinos is bigger than the number of flavour

neutrinos as a consequence, e.g., of a flavour neutrino - sterile neutrino mixing, we would have $\sum_{l'=e,\mu,\tau} P(\nu_l \to \nu_{l'}) = 1 - P(\nu_l \to \bar{\nu}_{sL})$, $l=e,\mu,\tau$, where we have assumed the existence of just one sterile neutrino. Obviously, in this case $\sum_{l'=e,\mu,\tau} P(\nu_l \to \nu_{l'}) < 1$ if $P(\nu_l \to \bar{\nu}_{sL}) \neq 0$. The former inequality is used in the searches for oscillations between active and sterile neutrinos.

Consider next neutrino oscillations in the case of one neutrino mass squared difference "dominance": suppose that $|\Delta m_{j1}^2| \ll |\Delta m_{n1}^2|$, $j=2,...,(n-1),\,|\Delta m_{n1}^2|\,L/(2p)\gtrsim 1$ and $|\Delta m_{j1}^2|\,L/(2p)\ll 1$, so that $\exp[i(\Delta m_{j1}^2\,L/(2p)]\cong 1,\,j=2,...,(n-1)$. Under these conditions we obtain from Eq. (13.13) and Eq. (13.14), keeping only the oscillating terms involving Δm_{n1}^2 :

$$P(\nu_{l(l')} \to \nu_{l'(l)}) \cong P(\bar{\nu}_{l(l')} \to \bar{\nu}_{l'(l)}) \cong \delta_{ll'} - 2|U_{ln}|^2 \left[\delta_{ll'} - |U_{l'n}|^2 \right]$$

$$(1 - \cos \frac{\Delta m_{n1}^2}{2p} L).$$
(13.20)

It follows from the neutrino oscillation data (Sections 13.4 and 13.5) that in the case of 3-neutrino mixing, one of the two independent neutrino mass squared differences, say Δm_{21}^2 , is much smaller in absolute value than the second one, Δm_{31}^2 : $|\Delta m_{21}^2| \ll |\Delta m_{31}^2|$. The data imply:

$$\begin{split} |\Delta m_{21}^2| &\cong 7.6 \times 10^{-5} \text{ eV}^2 \,, \\ |\Delta m_{31}^2| &\cong 2.4 \times 10^{-3} \text{ eV}^2 \,, \\ |\Delta m_{21}^2| / |\Delta m_{31}^2| &\cong 0.032 \,. \end{split} \tag{13.21}$$

Neglecting the effects due to Δm^2_{21} we get from Eq. (13.20) by setting n=3 and choosing, e.g., i) l=l'=e and ii) $l=e(\mu), \, l'=\mu(e)$ [57]:

$$P(\nu_e \to \nu_e) = P(\bar{\nu}_e \to \bar{\nu}_e) \cong 1 - 2|U_{e3}|^2 \left(1 - |U_{e3}|^2\right) \left(1 - \cos\frac{\Delta m_{31}^2}{2p} L\right),$$
(13.22)

$$P(\nu_{\mu(e)} \to \nu_{e(\mu)}) \cong 2 |U_{\mu 3}|^2 |U_{e 3}|^2 \left(1 - \cos \frac{\Delta m_{31}^2}{2p} L\right)$$

$$= \frac{|U_{\mu 3}|^2}{1 - |U_{e 3}|^2} P^{2\nu} \left(|U_{e 3}|^2, m_{31}^2\right), \qquad (13.23)$$

Table 13.1: Sensitivity of different oscillation experiments.

| Source | Type of ν | $\overline{E}[\mathrm{MeV}]$ | $L[\mathrm{km}]$ | $\min(\Delta m^2)[\mathrm{eV}^2]$ |
|----------------------|-------------------------------------|------------------------------|---------------------|-----------------------------------|
| Reactor | $\overline{ u}_e$ | ~ 1 | 1 | $\sim 10^{-3}$ |
| Reactor | $\overline{ u}_e$ | ~ 1 | 100 | $\sim 10^{-5}$ |
| Accelerator | $ u_{\mu}, \overline{ u}_{\mu}$ | $\sim 10^3$ | 1 | ~ 1 |
| Accelerator | $ u_{\mu}, \overline{ u}_{\mu}$ | $\sim 10^3$ | 1000 | $\sim 10^{-3}$ |
| Atmospheric ν 's | $ u_{\mu,e}, \overline{ u}_{\mu,e}$ | $\sim 10^3$ | 10^{4} | $\sim 10^{-4}$ |
| Sun | $ u_e$ | ~ 1 | 1.5×10^{8} | $\sim 10^{-11}$ |

and $P(\bar{\nu}_{\mu(e)} \to \bar{\nu}_{e(\mu)}) = P(\nu_{\mu(e)} \to \nu_{e(\mu)})$. Here $P^{2\nu}(|U_{e3}|^2, m_{31}^2)$ is the probability of the 2-neutrino transition $\nu_e \to (s_{23}\nu_\mu + c_{23}\nu_\tau)$ due to Δm_{31}^2 and a mixing with angle θ_{13} , where

$$\sin^2 \theta_{13} = |U_{e3}|^2, \quad s_{23}^2 \equiv \sin^2 \theta_{23} = \frac{|U_{\mu 3}|^2}{1 - |U_{e3}|^2},$$

$$c_{23}^2 \equiv \cos^2 \theta_{23} = \frac{|U_{\tau 3}|^2}{1 - |U_{e3}|^2}.$$
(13.24)

Eq. (13.22) describes with a relatively high precision the oscillations of reactor $\bar{\nu}_e$ on a distance $L\sim 1$ km in the case of 3-neutrino mixing. It was used in the analysis of the data of the Chooz [58], Double Chooz [59], Daya Bay [26] and RENO [27] experiments. Eq. (13.20) with n=3 and $l=l'=\mu$ describes with a relatively good precision the effects of oscillations of the accelerator ν_μ , seen in the K2K [19]

and MINOS [20,21] experiments. The $\nu_{\mu} \to \nu_{\tau}$ oscillations, which the OPERA experiment [60,61] is aiming to detect, can be described by Eq. (13.20) with n=3 and $l=\mu$, $l'=\tau$. Finally, the probability Eq. (13.23) describes with a good precision the $\nu_{\mu} \to \nu_{e}$ and $\bar{\nu}_{\mu} \to \bar{\nu}_{e}$ oscillations under the conditions of the K2K experiment.

In certain cases the dimensions of the neutrino source, ΔL , are not negligible in comparison with the oscillation length. Similarly, when analyzing neutrino oscillation data one has to include the energy resolution of the detector, ΔE , etc. in the analysis. As can be shown [39], if $2\pi\Delta L/L_{jk}^v\gg 1$, and/or $2\pi(L/L_{jk}^v)(\Delta E/E)\gg 1$, the oscillating terms in the neutrino oscillation probabilities will be strongly suppressed. In this case (as well as in the case of sufficiently large separation of the ν_j and ν_k wave packets at the detection point) the interference terms in $P(\nu_l \to \nu_{l'})$ and $P(\bar{\nu}_{l'} \to \bar{\nu}_{l})$ will be negligibly small and the neutrino flavour conversion will be determined by the average probabilities:

$$\bar{P}(\nu_l \to \nu_{l'}) = \bar{P}(\bar{\nu}_l \to \bar{\nu}_{l'}) \cong \sum_j |U_{l'j}|^2 |U_{lj}|^2.$$
 (13.25)

Suppose next that in the case of 3-neutrino mixing, $|\Delta m_{21}^2| L/(2p) \sim 1$, while at the same time $|\Delta m_{31(32)}^2| L/(2p) \gg 1$, and the oscillations due to Δm_{31}^2 and Δm_{32}^2 are strongly suppressed (averaged out) due to integration over the region of neutrino production, the energy resolution function, etc. In this case we get for the ν_e and $\bar{\nu}_e$ survival probabilities:

$$P(\nu_e \to \nu_e) = P(\bar{\nu}_e \to \bar{\nu}_e) \cong |U_{e3}|^4 + (1 - |U_{e3}|^2)^2 P^{2\nu}(\nu_e \to \nu_e),$$
(13.26)

$$\begin{split} P^{2\nu}(\nu_e \to \nu_e) &= P^{2\nu}(\bar{\nu}_e \to \bar{\nu}_e) \equiv P_{ee}^{2\nu}(\theta_{12}, \Delta m_{21}^2) \\ &= 1 - \frac{1}{2} \sin^2 2\theta_{12} \left(1 - \cos \frac{\Delta m_{21}^2}{2p} L \right) \quad (13.27) \end{split}$$

being the ν_e and $\bar{\nu}_e$ survival probability in the case of 2-neutrino oscillations "driven" by the angle θ_{12} and Δm_{21}^2 , with θ_{12} determined by

$$\cos^2 \theta_{12} = \frac{|U_{e1}|^2}{1 - |U_{e3}|^2}, \quad \sin^2 \theta_{12} = \frac{|U_{e2}|^2}{1 - |U_{e3}|^2}.$$
 (13.28)

Eq. (13.26) with $P^{2\nu}(\bar{\nu}_e \to \bar{\nu}_e)$ given by Eq. (13.27) describes the effects of neutrino oscillations of reactor $\bar{\nu}_e$ observed by the KamLAND experiment.

In the case of 3-neutrino mixing with $0 < \Delta m_{21}^2 < |\Delta m_{31(32)}^2|$ and $|U_{e3}|^2 = |\sin\theta_{13}|^2 \ll 1$ (see Section 13.6), one can identify Δm_{21}^2 and θ_{12} as the neutrino mass squared difference and mixing angle responsible for the solar ν_e oscillations, and Δm_{31}^2 and θ_{23} as those associated with the dominant atmospheric ν_μ and $\bar{\nu}_\mu$ oscillations. Thus, θ_{12} and θ_{23} are often called "solar" and "atmospheric" neutrino mixing angles and denoted as $\theta_{12} = \theta_{\odot}$ and $\theta_{23} = \theta_{\rm A}$ (or $\theta_{\rm atm}$), while Δm_{21}^2 and Δm_{31}^2 are often referred to as the "solar" and "atmospheric" neutrino mass squared differences and denoted as $\Delta m_{21}^2 \equiv \Delta m_{\odot}^2$ and $\Delta m_{31}^2 \equiv \Delta m_{\rm A}^2$ (or $\Delta m_{\rm atm}^2$).

The data of ν -oscillations experiments is often analyzed assuming 2-neutrino mixing:

$$|\nu_l\rangle = |\nu_1\rangle\cos\theta + |\nu_2\rangle\sin\theta$$
, $|\nu_x\rangle = -|\nu_1\rangle\sin\theta + |\nu_2\rangle\cos\theta$, (13.29)

where θ is the neutrino mixing angle in vacuum and ν_x is another flavour neutrino or sterile (anti-) neutrino, $x = l' \neq l$ or $\nu_x \equiv \bar{\nu}_{sL}$. In this case we have [51]:

$$P^{2\nu}(\nu_l \to \nu_l) = 1 - \frac{1}{2}\sin^2 2\theta \left(1 - \cos 2\pi \frac{L}{L^v}\right),$$

$$P^{2\nu}(\nu_l \to \nu_x) = 1 - P^{2\nu}(\nu_l \to \nu_l),$$
(13.30)

where $L^v = 4\pi p/\Delta m^2$, $\Delta m^2 = m_2^2 - m_1^2 > 0$. Combining the CPT invariance constraints with the probability conservation one obtains: $P(\nu_l \to \nu_x) = P(\bar{\nu}_l \to \bar{\nu}_x) = P(\nu_x \to \nu_l) = P(\bar{\nu}_x \to \bar{\nu}_l)$.

These equalities and Eq. (13.30) with $l=\mu$ and $x=\tau$ were used, for instance, in the analysis of the Super-K atmospheric neutrino data [13], in which the first compelling evidence for oscillations of neutrinos was obtained. The probability $P^{2\nu}(\nu_l\to\nu_x)$, Eq. (13.30), depends on two factors: on $(1-\cos 2\pi L/L^v)$, which exhibits oscillatory dependence on the distance L and on the neutrino energy p=E (hence the name "neutrino oscillations"), and on $\sin^2 2\theta$, which determines the amplitude of the oscillations. In order to have $P^{2\nu}(\nu_l\to\nu_x)\cong 1$, two conditions have to be fulfilled: one should have $\sin^2 2\theta\cong 1$ and $L^v\lesssim 2\pi L$ with $\cos 2\pi L/L^v\cong -1$. If $L^v\gg 2\pi L$, the oscillations do not have enough time to develop on the way to the neutrino detector and $P(\nu_l\to\nu_x)\cong 0$. This is illustrated in Fig. 1 showing the dependence of the probability $P^{2\nu}(\nu_e\to\nu_e)=P^{2\nu}(\bar{\nu}_e\to\bar{\nu}_e)$ on the neutrino energy.

A given experiment searching for neutrino oscillations is specified, in particular, by the average energy of the neutrinos being studied, \bar{E} , and by the source-detector distance L. The requirement $L^v_{jk}\lesssim 2\pi L$ determines the minimal value of a generic neutrino mass squared difference $\Delta m^2>0$, to which the experiment is sensitive (figure of merit of the experiment): $\min(\Delta m^2)\sim 2\bar{E}/L$. Because of the interference nature of neutrino oscillations, experiments can probe, in general, rather small values of Δm^2 (see, e.g., Ref. 47). Values of $\min(\Delta m^2)$, characterizing qualitatively the sensitivity of different experiments are given in Table 1. They correspond to the reactor experiments Chooz ($L\sim 1~{\rm km}$) and KamLAND ($L\sim 100~{\rm km}$), to accelerator experiments - past ($L\sim 1~{\rm km}$), recent, current and future (K2K, MINOS, OPERA, T2K, NO ν A [63]), $L\sim (300\div 1000)~{\rm km}$), to the Super-Kamiokande experiment studying atmospheric neutrino oscillations, and to the solar neutrino experiments.

13.3. Matter effects in neutrino oscillations

The presence of matter can change drastically the pattern of neutrino oscillations: neutrinos can interact with the particles forming the matter. Accordingly, the Hamiltonian of the neutrino system in matter H_m , differs from the Hamiltonian in vacuum H_0 , $H_m = H_0 + H_{int}$, where H_{int} describes the interaction of neutrinos with the particles of matter. When, for instance, ν_e and ν_μ propagate in matter, they can scatter (due to H_{int}) on the electrons (e⁻), protons (p) and neutrons (n) present in matter. The incoherent elastic and the quasi-elastic scattering, in which the states of the initial particles change in the process (destroying the coherence between the neutrino states), are not of interest - they have a negligible effect on the solar neutrino propagation in the Sun and on the solar, atmospheric and reactor neutrino propagation in the Earth [64]: even in the center of the Sun, where the matter density is relatively high ($\sim 150 \text{ g/cm}^3$), a ν_e with energy of 1 MeV has a mean free path with respect to the indicated scattering processes $\sim 10^{10}$ km. We recall that the solar radius is much smaller: $R_{\odot} = 6.96 \times 10^5$ km. The oscillating ν_e and ν_{μ} can scatter also elastically in the forward direction on the e⁻, p and n, with the momenta and the spin states of the particles remaining unchanged. In such a process the coherence of the neutrino states is

The ν_e and ν_μ coherent elastic scattering on the particles of matter generates nontrivial indices of refraction of the ν_e and ν_μ in matter [22]: $\kappa(\nu_e) \neq 1$, $\kappa(\nu_\mu) \neq 1$. Most importantly, we have $\kappa(\nu_e) \neq \kappa(\nu_\mu)$. The difference $\kappa(\nu_e) - \kappa(\nu_\mu)$ is determined essentially by the difference of the real parts of the forward $\nu_e - e^-$ and $\nu_\mu - e^$ elastic scattering amplitudes [22] Re $[F_{\nu_e-e^-}(0)]-Re~[F_{\nu_\mu-e^-}(0)]:$ due to the flavour symmetry of the neutrino - quark (neutrino - nucleon) neutral current interaction, the forward $\nu_e - p, n$ and $\nu_{\mu} - p, n$ elastic scattering amplitudes are equal and therefore do not contribute to the difference of interest [65]. The imaginary parts of the forward scattering amplitudes (responsible, in particular, for decoherence effects) are proportional to the corresponding total scattering cross-sections and in the case of interest are negligible in comparison with the real parts. The real parts of the amplitudes $F_{\nu_{\rm e}-{\rm e}^-}(0)$ and $F_{\nu_{\mu}-{\rm e}^-}(0)$ can be calculated in the Standard Model. To leading order in the Fermi constant G_F , only the term in ${\cal F}_{\nu_{
m e}-{
m e}^-}(0)$ due to the diagram with exchange of a virtual W^\pm -boson contributes to ${\cal F}_{\nu_{
m e}-{
m e}^-}(0)-{\cal F}_{\nu_{\mu}-{
m e}^-}(0)$. One finds the following result for $\kappa(\nu_e) - \kappa(\nu_\mu)$ in the rest frame of the scatters [22,67,68]:

$$\kappa(\nu_e) - \kappa(\nu_\mu) = \frac{2\pi}{p^2} \left(\text{Re } [F_{\nu_e - e^-}(0)] - \text{Re } [F_{\nu_\mu - e^-}(0)] \right)$$
$$= -\frac{1}{p} \sqrt{2} G_F N_e , \qquad (13.31)$$

where N_e is the electron number density in matter. Given $\kappa(\nu_e) - \kappa(\nu_\mu)$, the system of evolution equations describing the $\nu_e \leftrightarrow \nu_\mu$ oscillations in matter reads [22]:

$$i\frac{d}{dt}\begin{pmatrix} A_e(t,t_0) \\ A_\mu(t,t_0) \end{pmatrix} = \begin{pmatrix} -\epsilon(t) & \epsilon' \\ \epsilon' & \epsilon(t) \end{pmatrix} \begin{pmatrix} A_e(t,t_0) \\ A_\mu(t,t_0) \end{pmatrix}$$
(13.32)

where $A_e(t,t_0)$ $(A_{\mu}(t,t_0))$ is the amplitude of the probability to find ν_e (ν_{μ}) at time t of the evolution of the system if at time $t_0 \leq t$ the neutrino ν_e or ν_{μ} has been produced and

$$\epsilon(t) = \frac{1}{2} \left[\frac{\Delta m^2}{2E} \cos 2\theta - \sqrt{2}G_F N_e(t) \right], \quad \epsilon' = \frac{\Delta m^2}{4E} \sin 2\theta. \quad (13.33)$$

The term $\sqrt{2}G_FN_e(t)$ in $\epsilon(t)$ accounts for the effects of matter on neutrino oscillations. The system of evolution equations describing the oscillations of antineutrinos $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$ in matter has exactly the same form except for the matter term in $\epsilon(t)$ which changes sign. The effect of matter in neutrino oscillations is usually called the Mikheyev, Smirnov, Wolfenstein (or MSW) effect.

Consider first the case of $\nu_e \leftrightarrow \nu_\mu$ oscillations in matter with constant density: $N_e(t) = N_e = const.$ Due to the interaction term H_{int} in H_m , the eigenstates of the Hamiltonian of the neutrino system in vacuum, $|\nu_{1,2}\rangle$ are not eigenstates of H_m . For the eigenstates $|\nu_{1,2}^m\rangle$ of H_m , which diagonalize the evolution matrix in the r.h.s. of the system Eq. (13.32) we have:

$$|\nu_e\rangle = |\nu_1^m\rangle \cos\theta_m + |\nu_2^m\rangle \sin\theta_m , \quad |\nu_\mu\rangle = -|\nu_1^m\rangle \sin\theta_m + |\nu_2^m\rangle \cos\theta_m .$$
(13.34)

Here θ_m is the neutrino mixing angle in matter [22]

$$\sin 2\theta_m = \frac{\tan 2\theta}{\sqrt{(1 - \frac{N_e}{N_e^{res}})^2 + \tan^2 2\theta}}, \cos 2\theta_m = \frac{1 - N_e/N_e^{res}}{\sqrt{(1 - \frac{N_e}{N_e^{res}})^2 + \tan^2 2\theta}},$$
(13.35)

where the quantity

$$N_e^{res} = \frac{\Delta m^2 \cos 2\theta}{2E\sqrt{2}G_F} \cong 6.56 \times 10^6 \ \frac{\Delta m^2 [\text{eV}^2]}{E[\text{MeV}]} \ \cos 2\theta \ \text{cm}^{-3} \ \text{N}_\text{A} \,, \eqno(13.36)$$

is called (for $\Delta m^2\cos 2\theta>0$) "resonance density" [23,67], N_A being Avogadro's number. The "adiabatic" states $|\nu_{1,2}^m\rangle$ have energies $E_{1,2}^m$ whose difference is given by

$$E_2^m - E_1^m = \frac{\Delta m^2}{2E} \left((1 - \frac{N_e}{N_e^{res}})^2 \cos^2 2\theta + \sin^2 2\theta \right)^{\frac{1}{2}} \equiv \frac{\Delta M^2}{2E}.$$
(13.3)

The probability of $\nu_e \to \nu_\mu$ transition in matter with $N_e = const.$ has the form [22,67]

$$\begin{split} P_m^{2\nu}(\nu_e \to \nu_\mu) &= |A_\mu(t)|^2 = \frac{1}{2} \sin^2 2\theta_m \ [1 - \cos 2\pi \frac{L}{L_m} \] \\ L_m &= 2\pi/(E_2^m - E_1^m) \,, \end{split} \tag{13.38}$$

where L_m is the oscillation length in matter. As Eq. (13.35) indicates, the dependence of $\sin^2 2\theta_m$ on N_e has a resonance character [23]. Indeed, if $\Delta m^2 \cos 2\theta > 0$, for any $\sin^2 2\theta \neq 0$ there exists a value of N_e given by N_e^{res} , such that when $N_e = N_e^{res}$ we have $\sin^2 2\theta_m = 1$ independently of the value of $\sin^2 2\theta < 1$. This implies that the presence of matter can lead to a strong enhancement of the oscillation probability $P_m^{2\nu}(\nu_e \to \nu_\mu)$ even when the $\nu_e \leftrightarrow \nu_\mu$ oscillations in vacuum are suppressed due to a small value of $\sin^2 2\theta$. For obvious reasons

$$N_e = N_e^{res} \equiv \frac{\Delta m^2 \cos 2\theta}{2E\sqrt{2}G_F} \,, \tag{13.39}$$

is called the "resonance condition" [23,67], while the energy at which Eq. (13.39) holds for given N_e and $\Delta m^2\cos 2\theta$, is referred to as the "resonance energy", E^{res} . The oscillation length at resonance is given by [23] $L_m^{res} = L^v/\sin 2\theta$, while the width in N_e of the resonance at half height reads $\Delta N_e^{res} = 2N_e^{res}\tan 2\theta$. Thus, if the mixing angle in vacuum is small, the resonance is narrow, $\Delta N_e^{res} \ll N_e^{res}$, and $L_m^{res} \gg L^v$. The energy difference $E_2^m - E_1^m$ has a minimum at the resonance: $(E_2^m - E_1^m)^{res} = \min (E_2^m - E_1^m) = (\Delta m^2/(2E)) \sin 2\theta$.

It is instructive to consider two limiting cases. If $N_e \ll N_e^{res}$, we have from Eq. (13.35) and Eq. (13.37), $\theta_m \cong \theta$, $L_m \cong L^v$ and neutrinos oscillate practically as in vacuum. In the limit $N_e \gg N_e^{res}$, $N_e^{res} \tan^2 2\theta$, one finds $\theta_m \cong \pi/2$ ($\cos 2\theta_m \cong -1$) and the presence of matter suppresses the $\nu_e \leftrightarrow \nu_\mu$ oscillations. In this case $|\nu_e\rangle \cong |\nu_2^m\rangle$, $|\nu_\mu\rangle = -|\nu_1^m\rangle$, i.e., ν_e practically coincides with the heavier matter-eigenstate, while ν_μ coincides with the lighter one.

Since the neutral current weak interaction of neutrinos in the Standard Model is flavour symmetric, the formulae and results we have obtained are valid for the case of $\nu_e - \nu_\tau$ mixing and $\nu_e \leftrightarrow \nu_\tau$ oscillations in matter as well. The case of $\nu_\mu - \nu_\tau$ mixing, however, is different: to a relatively good precision we have [69] $\kappa(\nu_\mu) \cong \kappa(\nu_\tau)$ and the $\nu_\mu \leftrightarrow \nu_\tau$ oscillations in the matter of the Earth and the Sun proceed practically as in vacuum [70].

The analogs of Eq. (13.35) to Eq. (13.38) for oscillations of antineutrinos, $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$, in matter can formally be obtained by replacing N_e with $(-N_e)$ in the indicated equations. It should be clear that depending on the sign of $\Delta m^2 \cos 2\theta$, the presence of matter can lead to resonance enhancement either of the $\nu_e \leftrightarrow \nu_\mu$ or of the $\bar{\nu}_e \leftrightarrow \bar{\nu}_\mu$ oscillations, but not of both types of oscillations [67]. For $\Delta m^2 \cos 2\theta < 0$, for instance, the matter can only suppress the $\nu_e \to \nu_\mu$ oscillations, while it can enhance the $\bar{\nu}_e \to \bar{\nu}_\mu$ transitions. This disparity between the behavior of neutrinos and that of antineutrinos is a consequence of the fact that the matter in the Sun or in the Earth we are interested in is not charge-symmetric (it contains e^- , p and n, but does not contain their antiparticles) and therefore the oscillations in matter are neither CP- nor CPT- invariant [54]. Thus, even in the case of 2-neutrino mixing and oscillations we have, e.g., $P_m^{2\nu}(\nu_e \to \nu_{\mu(\tau)}) \neq P_m^{2\nu}(\bar{\nu}_e \to \bar{\nu}_{\mu(\tau)})$.

The matter effects in the $\nu_e \leftrightarrow \nu_{\mu(\tau)}$ ($\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu(\tau)}$) oscillations will be invariant with respect to the operation of time reversal if the N_e distribution along the neutrino path is symmetric with respect to this operation [55,71]. The latter condition is fulfilled (to a good approximation) for the N_e distribution along a path of a neutrino crossing the Earth [72].

13.3.1. Effects of Earth matter on oscillations of neutrinos:

The formalism we have developed can be applied, e.g., to the study of matter effects in the $\nu_e \leftrightarrow \nu_{\mu(\tau)} \ (\nu_{\mu(\tau)} \leftrightarrow \nu_e)$ and $\bar{\nu}_e \leftrightarrow \bar{\nu}_{\mu(\tau)}$ $(\bar{\nu}_{\mu(\tau)} \leftrightarrow \bar{\nu}_e)$ oscillations of neutrinos which traverse the Earth [73] Indeed, the Earth density distribution in the existing Earth models [72] is assumed to be spherically symmetric and there are two major density structures - the core and the mantle, and a certain number of substructures (shells or layers). The Earth radius is $R_{\oplus} = 6371$ km; the Earth core has a radius of $R_c = 3486$ km, so the Earth mantle depth is 2885 km. For a spherically symmetric Earth density distribution, the neutrino trajectory in the Earth is specified by the value of the nadir angle θ_n of the trajectory. For $\theta_n \leq 33.17^o$, or path lengths $L \geq 10660$ km, neutrinos cross the Earth core. The path length for neutrinos which cross only the Earth mantle is given by $L=2R_{\oplus}\cos\theta_n$. If neutrinos cross the Earth core, the lengths of the paths in the mantle, $2L^{\text{man}}$, and in the core, L^{core} , are determined by: $L^{\text{man}} = R_{\oplus} \cos \theta_n - (R_c^2 - R_{\oplus}^2 \sin^2 \theta_n)^{\frac{1}{2}}, L^{\text{core}} = 2(R_c^2 - R_{\oplus}^2 \sin^2 \theta_n)^{\frac{1}{2}}.$ The mean electron number densities in the mantle and in the core according to the PREM model read [72]: $\bar{N}_e^{man} \cong 2.2 \text{ cm}^{-3} \text{ N}_A$, $\bar{N}_e^c \cong 5.4 \text{ cm}^{-3} \text{ N}_A$. Thus, we have $\bar{N}_e^c \cong 2.5 \ \bar{N}_e^{man}$. The change of N_e from the mantle to the core can well be approximated by a step function [72]. The electron number density N_e changes relatively little around the indicated mean values along the trajectories of neutrinos which cross a substantial part of the Earth mantle, or the mantle and the core, and the two-layer constant density approximation, $N_e^{man} = const. = \tilde{N}_e^{man}, N_e^c = const. = \tilde{N}_e^c, \tilde{N}_e^{man}$ and \tilde{N}_e^c being the mean densities along the given neutrino path in

the Earth, was shown to be sufficiently accurate in what concerns the calculation of neutrino oscillation probabilities [55,75,76] (and references quoted in [75,76]) in a large number of specific cases. This is related to the fact that the relatively small changes of density along the path of the neutrinos in the mantle (or in the core) take place over path lengths which are typically considerably smaller than the corresponding oscillation length in matter.

In the case of 3-neutrino mixing and for neutrino energies of $E \gtrsim 2$ GeV, the effects due to Δm_{21}^2 ($|\Delta m_{21}^2| \ll |\Delta m_{31}^2|$, see Eq. (13.21)) in the neutrino oscillation probabilities are sub-dominant and to leading order can be neglected: the corresponding resonance density $|N_{e21}^{res}| \lesssim 0.25~cm^{-3}~N_A \ll \bar{N}_e^{man,c}$ and the Earth matter strongly suppresses the oscillations due to Δm_{21}^2 . For oscillations in vacuum this approximation is valid as long as the leading order contribution due to Δm_{31}^2 in the relevant probabilities is bigger than approximately 10^{-3} . In this case the 3-neutrino $\nu_e \to \nu_{\mu(\tau)} \ (\bar{\nu}_e \to \bar{\nu}_{\mu(\tau)})$ and $\nu_{\mu(\tau)} \rightarrow \nu_e \ (\bar{\nu}_{\mu(\tau)} \rightarrow \bar{\nu}_e)$ transition probabilities for neutrinos traversing the Earth, reduce effectively to a 2-neutrino transition probability (see, e.g., Refs. [76–78]), with Δm_{31}^2 and θ_{13} playing the role of the relevant 2-neutrino vacuum oscillation parameters. As will be discussed in Sections 13.6 and 13.7, the value of $\sin^2 2\theta_{13}$ has been determined recently with a rather high precision in the Daya Bay [26] and RENO [27] experiments. The best fit values found in the two experiments read, respectively, $\sin^2 2\theta_{13} = 0.092$ and 0.113, while the 3σ allowed range reported in [26] is $0.04 \lesssim \sin^2 2\theta_{13} \lesssim 0.14$. The 3-neutrino oscillation probabilities of the atmospheric and accelerator $\nu_{e,\mu}$ having energy E and crossing the Earth along a trajectory characterized by a nadir angle θ_n , for instance, have the following

$$P_m^{3\nu}(\nu_e \to \nu_e) \cong 1 - P_m^{2\nu},$$
 (13.40)

$$P_{m}^{3\nu}(\nu_{e} \to \nu_{\mu}) \cong P_{m}^{3\nu}(\nu_{\mu} \to \nu_{e}) \cong s_{23}^{23} P_{m}^{2\nu}, \quad P_{m}^{3\nu}(\nu_{e} \to \nu_{\tau}) \cong c_{23}^{23} P_{m}^{2\nu},$$

$$(13.41)$$

$$P_m^{3\nu}(\nu_{\mu} \to \nu_{\mu}) \cong 1 - s_{23}^4 \ P_m^{2\nu} - 2c_{23}^2 s_{23}^2 \ \left[1 - Re \ \left(e^{-i\kappa} A_m^{2\nu}(\nu' \to \nu') \right) \right], \tag{13.42}$$

$$P_m^{3\nu}(\nu_\mu \to \nu_\tau) = 1 - P_m^{3\nu}(\nu_\mu \to \nu_\mu) - P_m^{3\nu}(\nu_\mu \to \nu_e). \tag{13.43}$$

Here $P_m^{2\nu} \equiv P_m^{2\nu}(\Delta m_{31}^2, \theta_{13}; E, \theta_n)$ is the probability of the 2-neutrino $\nu_e \to \nu' \equiv (s_{23}\nu_\mu + c_{23}\nu_\tau)$ oscillations in the Earth, and κ and $A_m^{2\nu}(\nu' \to \nu') \equiv A_m^{2\nu}$ are known phase and 2-neutrino transition probability amplitude (see, e.g., Refs. [76,77]). We note that Eq. (13.40) to Eq. (13.42) are based only on the assumptions that $|N_e^{res}|$ is much smaller than the densities in the Earth mantle and core and that $|\Delta m_{21}^2| \ll |\Delta m_{31}^2|$, and does not rely on the constant density approximation. Similar results are valid for the corresponding antineutrino oscillation probabilities: one has just to replace $P_m^{2\nu}$, κ and $A_m^{2\nu}$ in the expressions given above with the corresponding quantities for antineutrinos (the latter are obtained from those for neutrinos by changing the sign in front of N_e). Obviously, we have: $P(\nu_{e(\mu)} \to \nu_{\mu(e)})$, $P(\bar{\nu}_{e(\mu)} \to \bar{\nu}_{\mu(e)}) \leq \sin^2\theta_{23}$, and $P(\nu_e \to \nu_\tau)$, $P(\bar{\nu}_e \to \bar{\nu}_\tau) \leq \cos^2\theta_{23}$. The one Δm^2 dominance approximation and correspondingly Eq. (13.40) to Eq. (13.43) were used by the Super-Kamiokande Collaboration in their 2006 neutrino oscillation analysis of the multi-GeV atmospheric neutrino data [79].

In the case of neutrinos crossing only the Earth mantle and in the constant density approximation, $P_m^{2\nu}$ is given by the r.h.s. of Eq. (13.38) with θ and Δm^2 replaced by θ_{13} and Δm_{31}^2 , while for κ and $A_m^{2\nu}$ we have (see, e.g., Ref. 76):

$$\begin{split} \kappa &\cong \frac{1}{2} [\frac{\Delta m_{31}^2}{2E} \ L + \sqrt{2} G_F \bar{N}_e^{man} L - \frac{\Delta M^2 L}{2E}], \\ A_m^{2\nu} &= 1 + (e^{-i\frac{\Delta M^2 L}{2E}} - 1) \cos^2 \theta_m' \ , \end{split} \tag{13.44}$$

where ΔM^2 is defined in Eq. (13.37) (with $\theta=\theta_{13}$ and $\Delta m^2=\Delta m_{31}^2$), θ_m' is the mixing angle in the mantle which coincides in vacuum with θ_{13} (Eq. (13.35) with $N_e=\bar{N}_e^{man}$ and $\theta=\theta_{13}$), and $L=2R_\oplus\cos\theta_n$ is the distance the neutrino travels in the mantle.

It follows from Eq. (13.40) and Eq. (13.41) that for $\Delta m_{31}^2 \cos 2\theta_{13} > 0$, the oscillation effects of interest, e.g., in the $\nu_{e(\mu)} \to \nu_{\mu(e)}$ and $\nu_e \to \nu_\tau$ transitions will be maximal if $P_n^{2\nu} \cong 1$, i.e., if Eq. (13.39)

leading to $\sin^2 2\theta_m \cong 1$ is fulfilled, and ii) $\cos(\Delta M^2 L/(2E)) \cong -1$. Given the value of \bar{N}_n^{man} , the first condition determines the neutrino's energy, while the second determines the path length L, for which one can have $P_m^{2\nu} \cong 1$. For $\Delta m_{31}^2 \cong 2.4 \times 10^{-3} \text{ eV}^2$, $\sin^2 2\theta_{13} \lesssim 0.14$ and $\bar{N}_n^{man} \cong 2.2 \text{ N}_A \text{cm}^{-3}$, one finds that $E_{res} \cong 7.2 \text{ GeV}$ and $L \cong 2370/\sin 2\theta_{13} \text{ km} \gtrsim 6267.3 \text{ km}$. Since for neutrinos crossing only the mantle $L \lesssim 10660 \text{ km}$, the second condition can be satisfied only if $\sin \theta_{13} \gtrsim 0.11$, which falls in the range of the experimentally allowed values of $\sin \theta_{13}$. Thus, for $\Delta m_{31}^2 > 0$, the Earth matter effects can amplify P_m^2 , and therefore $P(\nu_{e(\mu)} \to \nu_{\mu(e)})$ and $P(\nu_e \to \nu_\tau)$, maximally when the neutrinos cross only the mantle for $E \sim 7$ GeV and $L \gtrsim 5400 \text{ km}$, or $\cos \theta_n \gtrsim 0.43$, provided $\sin \theta_{13} \gtrsim 0.1$. If $\Delta m_{31}^2 < 0$ the same considerations apply for the corresponding antineutrino oscillation probabilities $\bar{P}_m^{2\nu} = \bar{P}_m^{2\nu} (\bar{\nu}_e \to (s_{23}\bar{\nu}_\mu + c_{23}\bar{\nu}_\tau))$ and correspondingly for $P(\bar{\nu}_{e(\mu)} \to \bar{\nu}_{\mu(e)})$ and $P(\bar{\nu}_e \to \bar{\nu}_\tau)$. For $\Delta m_{31}^2 > 0$, the $\bar{\nu}_{e(\mu)} \to \bar{\nu}_{\mu(e)}$ and $\bar{\nu}_e \to \bar{\nu}_\tau$ oscillations are suppressed by the Earth matter, while if $\Delta m_{31}^2 < 0$, the same conclusion holds for the $\nu_{e(\mu)} \to \nu_{\mu(e)}$ and $\nu_e \to \nu_\tau$, oscillations.

In the case of neutrinos crossing the Earth core, new resonance-like effects become possible in the $\nu_{\mu} \rightarrow \nu_{e}$ and $\nu_{e} \rightarrow \nu_{\mu(\tau)}$ (or $\bar{\nu}_{\mu} \rightarrow \bar{\nu}_{e}$ and $\bar{\nu}_e \to \bar{\nu}_{\mu(\tau)}$) transitions [75–77,80–82]. For $\sin^2 \theta_{13} \lesssim 0.05$ and $\Delta m_{31}^2>0$, we can have [81] $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})\cong 1$, and correspondingly maximal $P_m^{3\nu}(\nu_e\to\nu_\mu)=P_m^{3\nu}(\nu_\mu\to\nu_e)\cong s_{23}^2$, only due to the effect of maximal constructive interference between the amplitudes of the $\nu_e \to \nu'$ transitions in the Earth mantle and in the Earth core. The effect differs from the MSW one and the enhancement happens in the case of interest at a value of the energy between the MSW resonance energies corresponding to the density in the mantle and that of the core, or at a value of the resonance density N_e^{res} which lies between the values of N_e in the mantle and in the core [75]. In Refs. [75,76] the enhancement was called "neutrino oscillation length resonance", while in Refs. [77,80] the term "parametric resonance" for the same effect was used [83]. The mantle-core enhancement effect is caused by the existence (for a given neutrino trajectory through the Earth core) of points of resonance-like maximal neutrino conversion, $P_m^{2\nu}(\Delta m_{31}^2, \theta_{13})=1$, in the corresponding space of neutrino oscillation parameters [81]. For $\Delta m_{31}^2<0$ the mantle-core enhancement can take place for the antineutrino transitions, $\bar{\nu}_{\mu} \to \bar{\nu}_{e}$ and $\bar{\nu}_{e} \to \bar{\nu}_{\mu(\tau)}$.

A rather complete set of values of $\Delta m_{31}^2/E>0$ and $\sin^22\theta_{13}$ for which $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})=1$ was found in Ref. 81. The location of these points in the $\Delta m_{31}^2/E-\sin^22\theta_{13}$ plane determines the regions in the plane where $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})$ is large, $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})\gtrsim 0.5$. These regions vary slowly with the nadir angle, being remarkably wide in the nadir angle and rather wide in the neutrino energy [81], so that the transitions of interest can produce noticeable effects in the measured observables. For $\sin^2\theta_{13}\lesssim 0.05$, there are two sets of values of $(\Delta m_{31}^2/E,\sin^2\theta_{13})$ for which $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})=1$, and thus two regions in $\Delta m_{31}^2/E-\sin^22\theta_{13}$ plane where $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})\gtrsim 0.5$. For $\Delta m_{31}^2=2.4\times 10^{-3}$ eV² and nadir angle, e.g., θ_n =0 (Earth center crossing neutrinos), we have $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})=1$ at $(E,\sin^22\theta_{13})=(3.3~{\rm GeV},0.034)$ and (5.0 ${\rm GeV},0.15$). At the same time for $E=3.3~{\rm GeV}$ (5.0 ${\rm Gev}$), the probability $P_m^{2\nu}(\Delta m_{31}^2,\theta_{13})\gtrsim 0.5$ for the values of $\sin^22\theta_{13}\lesssim 0.26$). Similar results hold for neutrinos crossing the Earth core along the trajectories with $\theta_n\neq 0$ (for further details see the last article in Ref. 81; see also the last article in Ref. 82).

The mantle-core enhancement of $P_m^{2\nu}$ (or $\bar{P}_m^{2\nu}$) is relevant, in particular, for the searches of sub-dominant $\nu_{e(\mu)} \to \nu_{\mu(e)}$ (or $\bar{\nu}_{e(\mu)} \to \bar{\nu}_{\mu(e)}$) oscillations of atmospheric neutrinos having energies $E \gtrsim 2$ GeV and crossing the Earth core on the way to the detector (see Ref. 75 to Ref. 82 and the references quoted therein). The effects of Earth matter on the oscillations of atmospheric and accelerator neutrinos have not been observed so far. At present there are no compelling evidences for oscillations of the atmospheric ν_e and/or $\bar{\nu}_e$.

The expression for the probability of the $\nu_e \rightarrow \nu_\mu$ oscillations taking place in the Earth mantle in the case of 3-neutrino mixing, in which both neutrino mass squared differences Δm_{21}^2 and Δm_{31}^2 contribute and the CP violation effects due to the Dirac phase in the neutrino mixing matrix are taken into account, has the following

form in the constant density approximation and keeping terms up to second order in the two small parameters $|\alpha| \equiv |\Delta m_{21}^2|/|\Delta m_{31}^2| \ll 1$ and $\sin^2\theta_{13} \ll 1$ [84]:

$$P_m^{3\nu \ man}(\nu_e \to \nu_\mu) \cong P_0 + P_{\sin \delta} + P_{\cos \delta} + P_3.$$
 (13.45)

Here

$$P_0 = \sin^2 \theta_{23} \frac{\sin^2 2\theta_{13}}{(A-1)^2} \sin^2[(A-1)\Delta]$$

$$P_3 = \alpha^2 \cos^2 \theta_{23} \frac{\sin^2 2\theta_{12}}{A^2} \sin^2(A\Delta), \qquad (13.46)$$

$$P_{\sin\delta} = \alpha \; \frac{8 \, J_{CP}}{A(1-A)} \left(\sin\Delta\right) \left(\sin A\Delta\right) \, \left(\sin[(1-A)\Delta]\right) \, , \qquad (13.47)$$

$$P_{\cos\delta} = \alpha \; \frac{8 \, J_{CP} \cot \delta}{A(1-A)} \left(\cos \Delta\right) \left(\sin A\Delta\right) \; \left(\sin[(1-A)\Delta]\right) \; , \quad \ (13.48)$$

where

$$\alpha = \frac{\Delta m_{21}^2}{\Delta m_{31}^2} \,, \ \ \Delta = \frac{\Delta m_{31}^2 \, L}{4E} \,, \ \ A = \sqrt{2} G_{\rm F} N_e^{man} \frac{2E}{\Delta m_{31}^2} \,, \eqno(13.49)$$

and $\cot\delta=J_{CP}^{-1}{\rm Re}(U_{\mu3}U_{e3}^*U_{e2}U_{\mu2}^*),\ J_{CP}={\rm Im}(U_{\mu3}U_{e3}^*U_{e2}U_{\mu2}^*).$ The analytic expression for $P_m^{3\nu}$ $^{man}(\nu_e\to\nu_\mu)$ given above is valid for [84] neutrino path lengths in the mantle $(L\le 10660~{\rm km})$ satisfying $L\lesssim 10560~{\rm km}~E[{\rm GeV}]~(7.6\times 10^{-5}~{\rm eV}^2/\Delta m_{21}^2),$ and energies $E\gtrsim 0.34~{\rm GeV}(\Delta m_{21}^2/7.6\times 10^{-5}~{\rm eV}^2)~(1.4~{\rm cm}^{-3}N_A/N_e^{man}).$ The expression for the $\bar{\nu}_e\to\bar{\nu}_\mu$ oscillation probability can be obtained formally from that for $P_m^{3\nu}$ $^{man}(\nu_e\to\nu_\mu)$ by making the changes $A\to -A$ and $J_{CP}\to -J_{CP}$, with $J_{CP}\cot\delta\equiv{\rm Re}(U_{\mu3}U_{e3}^*U_{e2}U_{\mu2}^*)$ remaining unchanged. The term $P_{\sin\delta}$ in $P_m^{3\nu}$ $^{man}(\nu_e\to\nu_\mu)$ would be equal to zero if the Dirac phase in the neutrino mixing matrix U possesses a CP-conserving value. Even in this case, however, we have $A_{CP}^{(\mu e)}$ $^{man}\equiv(P_m^{3\nu}$ $^{man}(\nu_e\to\nu_\mu)-P_m^{3\nu}$ $^{man}(\bar{\nu}_e\to\bar{\nu}_\mu))\neq 0$ due to the effects of the Earth matter. It will be important to experimentally disentangle the effects of the Earth matter and of J_{CP} in $A_{CP}^{(\mu e)}$ man : this will allow to get information about the Dirac CP violation phase in U. In the vacuum limit of $N_e^{man}=0$ (A=0) we have $A_{CP}^{(\mu e)}$ $^{man}=A_{CP}^{(\mu e)}$ (see Eq. (13.18)) and only the term $P_{\sin\delta}$ contributes to the asymmetry $A_{CP}^{(\mu e)}$.

13.3.2. Oscillations of solar neutrinos:

Consider next the oscillations of solar ν_e while they propagate from the central part of the Sun, where they are produced, to the surface of the Sun [23,74](see also Ref. 22 and, e.g., Ref. 85) Details concerning the production, spectrum, magnitude and particularities of the solar neutrino flux, the methods of detection of solar neutrinos, description of solar neutrino experiments and of the data they provided will be discussed in the next section (see also Ref. 86). The electron number density N_e changes considerably along the neutrino path in the Sun: it decreases monotonically from the value of $\sim 100~{\rm cm}^{-3}~N_A$ in the center of the Sun to 0 at the surface of the Sun. According to the contemporary solar models (see, e.g., Ref. [86,87]), N_e decreases approximately exponentially in the radial direction towards the surface of the Sun:

$$N_e(t) = N_e(t_0) \exp\left\{-\frac{t - t_0}{r_0}\right\} ,$$
 (13.50)

where $(t-t_0)\cong d$ is the distance traveled by the neutrino in the Sun, $N_e(t_0)$ is the electron number density at the point of ν_e production in the Sun, r_0 is the scale-height of the change of $N_e(t)$ and one has [86,87] $r_0\sim 0.1R_{\odot}$.

Consider the case of 2-neutrino mixing, Eq. (13.34). Obviously, if N_e changes with t (or equivalently with the distance) along the neutrino trajectory, the matter-eigenstates, their energies, the mixing angle and the oscillation length in matter, become, through their dependence on N_e , also functions of $t: |\nu_{1,2}^m\rangle = |\nu_{1,2}^m(t)\rangle$, $E_{1,2}^m = E_{1,2}^m(t)$, $\theta_m = \theta_m(t)$ and $L_m = L_m(t)$. It is not difficult to understand qualitatively the possible behavior of the neutrino system when solar neutrinos propagate from the center to the surface of the

Sun if one realizes that one is dealing effectively with a two-level system whose Hamiltonian depends on time and admits "jumps" from one level to the other (see Eq. (13.32)). Consider the case of $\Delta m^2 \cos 2\theta > 0$. Let us assume first for simplicity that the electron number density at the point of a solar ν_e production in the Sun is much bigger than the resonance density, $N_e(t_0) \gg N_e^{res}$. Actually, this is one of the cases relevant to the solar neutrinos. In this case we have $\theta_m(t_0) \cong \pi/2$ and the state of the electron neutrino in the initial moment of the evolution of the system practically coincides with the heavier of the two matter-eigenstates:

$$|\nu_e\rangle \cong |\nu_2^m(t_0)\rangle. \tag{13.51}$$

Thus, at t_0 the neutrino system is in a state corresponding to the "level" with energy $E_2^m(t_0)$. When neutrinos propagate to the surface of the Sun they cross a layer of matter in which $N_e=N_e^{res}$: in this layer the difference between the energies of the two "levels" $(E_2^m(t)-E_1^m(t))$ has a minimal value on the neutrino trajectory (Eq. (13.37) and Eq. (13.39)). Correspondingly, the evolution of the neutrino system can proceed basically in two ways. First, the system can stay on the "level" with energy $E_2^m(t)$, i.e., can continue to be in the state $|\nu_2^m(t)\rangle$ up to the final moment t_s , when the neutrino reaches the surface of the Sun. At the surface of the Sun $N_e(t_s)=0$ and therefore $\theta_m(t_s)=\theta$, $|\nu_{1,2}^m(t_s)\rangle\equiv |\nu_{1,2}\rangle$ and $E_{1,2}^m(t_s)=E_{1,2}$. Thus, in this case the state describing the neutrino system at t_0 will evolve continuously into the state $|\nu_2\rangle$ at the surface of the Sun. Using Eq. (13.29) with l=e and $x=\mu$, it is easy to obtain the probabilities to find ν_e and ν_μ at the surface of the Sun:

$$P(\nu_e \to \nu_e; t_s, t_0) \cong |\langle \nu_e | \nu_2 \rangle|^2 = \sin^2 \theta$$

$$P(\nu_e \to \nu_\mu; t_s, t_0) \cong |\langle \nu_\mu | \nu_2 \rangle|^2 = \cos^2 \theta.$$
 (13.52)

It is clear that under the assumption made and if $\sin^2\theta \ll 1$, practically a total $\nu_e \to \nu_\mu$ conversion is possible. This type of evolution of the neutrino system and the $\nu_e \to \nu_\mu$ transitions taking place during the evolution, are called [23] "adiabatic." They are characterized by the fact that the probability of the "jump" from the upper "level" (having energy $E_2^m(t)$) to the lower "level" (with energy $E_1^m(t)$), P', or equivalently the probability of the $\nu_2^m(t_0) \to \nu_1^m(t_s)$ transition, $P' \equiv P'(\nu_2^m(t_0) \to \nu_1^m(t_s))$, on the whole neutrino trajectory is negligible:

$$P' \equiv P'(\nu_2^m(t_0) \to \nu_1^m(t_s)) \cong 0$$
 : adiabatic transitions. (13.53)

The second possibility is realized if in the resonance region, where the two "levels" approach each other closest the system "jumps" from the upper "level" to the lower "level" and after that continues to be in the state $|\nu_1^m(t)\rangle$ until the neutrino reaches the surface of the Sun. Evidently, now we have $P'\equiv P'(\nu_2^m(t_0)\to\nu_1^m(t_s))\sim 1$. In this case the neutrino system ends up in the state $|\nu_1^m(t_s)\rangle\equiv |\nu_1\rangle$ at the surface of the Sun and

$$P(\nu_e \to \nu_e; t_s, t_0) \cong |\langle \nu_e | \nu_1 \rangle|^2 = \cos^2 \theta$$

$$P(\nu_e \to \nu_\mu; t_s, t_0) \cong |\langle \nu_\mu | \nu_1 \rangle|^2 = \sin^2 \theta.$$
 (13.54)

Obviously, if $\sin^2\theta \ll 1$, practically no transitions of the solar ν_e into ν_μ will occur. The considered regime of evolution of the neutrino system and the corresponding $\nu_e \to \nu_\mu$ transitions are usually referred to as "extremely nonadiabatic."

Clearly, the value of the "jump" probability P' plays a crucial role in the the $\nu_e \to \nu_\mu$ transitions: it fixes the type of the transition and determines to a large extent the $\nu_e \to \nu_\mu$ transition probability [74,88,89]. We have considered above two limiting cases. Obviously, there exists a whole spectrum of possibilities since P' can have any value from 0 to $\cos^2\theta$ [90,91]. In general, the transitions are called "nonadiabatic" if P' is non-negligible.

Numerical studies have shown [23] that solar neutrinos can undergo both adiabatic and nonadiabatic $\nu_e \to \nu_\mu$ transitions in the Sun and the matter effects can be substantial in the solar neutrino oscillations for $10^{-8}~{\rm eV}^2 \lesssim \Delta m^2 \lesssim 10^{-4}~{\rm eV}^2, 10^{-4} \lesssim \sin^2 2\theta < 1.0.$

The condition of adiabaticity of the solar ν_e transitions in Sun can be written as [74.88]

$$\gamma(t) \equiv \sqrt{2}G_F \frac{(N_e^{res})^2}{|\dot{N}_e(t)|} \tan^2 2\theta \left(1 + \tan^{-2} 2\theta_m(t)\right)^{\frac{3}{2}} \gg 1$$
adiabatic transitions, (13.55)

while if $\gamma(t) \lesssim 1$ the transitions are nonadiabatic (see also Ref. 91), where $\dot{N}_e(t) \equiv \frac{d}{dt} N_e(t)$. Condition in Eq. (13.55) implies that the $\nu_e \to \nu_{\mu(\tau)}$ transitions in the Sun will be adiabatic if $N_e(t)$ changes sufficiently slowly along the neutrino path. In order for the transitions to be adiabatic, condition in Eq. (13.55) has to be fulfilled at any point of the neutrino's path in the Sun.

Actually, the system of evolution equations Eq. (13.32) can be solved exactly for N_e changing exponentially, Eq. (13.50), along the neutrino path in the Sun [90,92]. More specifically, the system in Eq. (13.32) is equivalent to one second order differential equation (with appropriate initial conditions). The latter can be shown [93] to coincide in form, in the case of N_e given by Eq. (13.50), with the Schroedinger equation for the radial part of the nonrelativistic wave function of the Hydrogen atom [94]. On the basis of the exact solution, which is expressed in terms of confluent hypergeometric functions, it was possible to derive a complete, simple and very accurate analytic description of the matter-enhanced transitions of solar neutrinos in the Sun for any values of Δm^2 and θ [22,90,91,95,96] (see also Refs. [23,74,89,97,98]).

The probability that a ν_e , produced at time t₀ in the central part of the Sun, will not transform into $\nu_{\mu(\tau)}$ on its way to the surface of the Sun (reached at time t_s) is given by

$$P_{\odot}^{2\nu}(\nu_e \to \nu_e; t_s, t_0) = \bar{P}_{\odot}^{2\nu}(\nu_e \to \nu_e; t_s, t_0) + Oscillating terms.$$
(13.56)

Here

$$\bar{P}_{\odot}^{2\nu}(\nu_{e} \to \nu_{e}; t_{s}, t_{0}) \equiv \bar{P}_{\odot} = \frac{1}{2} + \left(\frac{1}{2} - P'\right) \cos 2\theta_{m}(t_{0}) \cos 2\theta ,$$
(13.5)

is the average survival probability for ν_e having energy E \cong p [89],

$$P' = \frac{\exp\left[-2\pi r_0 \frac{\Delta m^2}{2E} \sin^2 \theta\right] - \exp\left[-2\pi r_0 \frac{\Delta m^2}{2E}\right]}{1 - \exp\left[-2\pi r_0 \frac{\Delta m^2}{2E}\right]},$$
 (13.58)

is [90] the "jump" probability for exponentially varying N_e , and $\theta_m(t_0)$ is the mixing angle in matter at the point of ν_e production [97]. The expression for $\bar{P}_{\odot}^{2\nu}(\nu_e \to \nu_e; t_s, t_0)$ with P' given by Eq. (13.58) is valid for $\Delta m^2 > 0$, but for both signs of $\cos 2\theta \neq 0$ [90,98]; it is valid for any given value of the distance along the neutrino trajectory and does not take into account the finite dimensions of the region of ν_e production in the Sun. This can be done by integrating over the different neutrino paths, *i.e.*, over the region of ν_e production.

The oscillating terms in the probability $P_{\odot}^{2\nu}(\nu_e \to \nu_e; t_s, t_0)$ [95,93] were shown [96] to be strongly suppressed for $\Delta m^2 \gtrsim 10^{-7} \text{ eV}^2$ by the various averagings one has to perform when analyzing the solar neutrino data. The current solar neutrino and KamLAND data suggest that $\Delta m^2 \cong 7.6 \times 10^{-5} \text{ eV}^2$. For $\Delta m^2 \gtrsim 10^{-7} \text{ eV}^2$, the averaging over the region of neutrino production in the Sun etc. renders negligible all interference terms which appear in the probability of ν_e survival due to the $\nu_e \leftrightarrow \nu_{\mu(\tau)}$ oscillations in vacuum taking place on the way of the neutrinos from the surface of the Sun to the surface of the Earth. Thus, the probability that ν_e will remain ν_e while it travels from the central part of the Sun to the surface of the Earth is effectively equal to the probability of survival of the ν_e while it propagates from the central part to the surface of the Sun and is given by the average probability $\bar{P}_{\odot}(\nu_e \to \nu_e; t_s, t_0)$ (determined by Eq. (13.57) and Eq. (13.58)).

If the solar ν_e transitions are adiabatic $(P'\cong 0)$ and $\cos 2\theta_m(t_0)\cong -1$ (i.e., $N_e(t_0)/|N_e^{res}|\gg 1$, $|\tan 2\theta|$, the ν_e are born "above" (in N_e) the resonance region), one has [23]

$$\bar{P}^{2\nu}(\nu_e \to \nu_e; t_s, t_0) \cong \frac{1}{2} - \frac{1}{2}\cos 2\theta.$$
 (13.59)

The regime under discussion is realised for $\sin^2 2\theta \cong 0.8$ (suggested by the data, Section 13.4), if $E/\Delta m^2$ lies approximately in the range $(2\times 10^4-3\times 10^7)~{\rm MeV/eV^2}$ (see Ref. 91). This result is relevant for the interpretation of the Super-Kamiokande and SNO solar neutrino data. We see that depending on the sign of $\cos 2\theta \neq 0$, $\bar{P}^{2\nu}(\nu_e \to \nu_e)$ is either bigger or smaller than 1/2. It follows from the solar neutrino data that in the range of validity (in $E/\Delta m^2$) of Eq. (13.59) we have $\bar{P}^{2\nu}(\nu_e \to \nu_e) \cong 0.3$. Thus, the possibility of $\cos 2\theta \leq 0$ is ruled out by the data. Given the choice $\Delta m^2 > 0$ we made, the data imply that $\Delta m^2 \cos 2\theta > 0$.

If $E/\Delta m^2$ is sufficiently small so that $N_e(t_0)/|N_e^{res}| \ll 1$, we have $P' \cong 0$, $\theta_m(t_0) \cong \theta$ and the oscillations take place in the Sun as in vacuum [23]:

$$\bar{P}^{2\nu}(\nu_e \to \nu_e; t_s, t_0) \cong 1 - \frac{1}{2}\sin^2 2\theta,$$
 (13.60)

which is the average two-neutrino vacuum oscillation probability. This expression describes with good precision the transitions of the solar pp neutrinos (Section 13.4). The extremely nonadiabatic ν_e transitions in the Sun, characterised by $\gamma(t) \ll 1$, are also described by the average vacuum oscillation probability (Eq. (13.60)) (for $\Delta m^2 \cos 2\theta > 0$ in this case we have (see e.g., Refs. [90,91]) $\cos 2\theta_m(t_0) \cong -1$ and $P' \cong \cos^2 \theta$).

The probability of ν_e survival in the case 3-neutrino mixing takes a simple form for $|\Delta m_{31}^2| \cong 2.4 \times 10^{-3} \ {\rm eV}^2 \gg |\Delta m_{21}^2|$. Indeed, for the energies of solar neutrinos $E \lesssim 10$ MeV, N^{res} corresponding to $|\Delta m_{31}^2|$ satisfies $N_{e31}^{res} \gtrsim 10^3 \ {\rm cm}^{-3} \ {\rm N_A}$ and is by a factor of 10 bigger than N_e in the center of the Sun. As a consequence, the oscillations due to Δm_{31}^2 proceed as in vacuum. The oscillation length associated with $|\Delta m_{31}^2|$ satisfies $L_{31}^v \lesssim 10 \ {\rm km} \ll \Delta R$, ΔR being the dimension of the region of ν_e production in the Sun. We have for the different components of the solar ν_e flux [86] $\Delta R \cong (0.04-0.20)R_{\odot}$. Therefore the averaging over ΔR strongly suppresses the oscillations due to Δm_{31}^2 and we get [78,99]:

$$P_{\odot}^{3\nu} \cong \sin^4 \theta_{13} + \cos^4 \theta_{13} \ P_{\odot}^{2\nu}(\Delta m_{21}^2, \theta_{12}; N_e \cos^2 \theta_{13}),$$
 (13.61)

where $P_{\odot}^{2\nu}(\Delta m_{21}^2, \theta_{12}; N_e \cos^2\theta_{13})$ is given by Eq. (13.56) to Eq. (13.58) in which $\Delta m^2 = \Delta m_{21}^2$, $\theta = \theta_{12}$ and the solar e^- number density N_e is replaced by $N_e \cos^2\theta_{13}$. Thus, the solar ν_e transitions observed by the Super-Kamiokande and SNO experiments are described approximately by:

$$P_{\odot}^{3\nu} \cong \sin^4 \theta_{13} + \cos^4 \theta_{13} \sin^2 \theta_{12}$$
. (13.62)

The data show that $P_{\odot}^{3\nu} \cong 0.3$, which is a strong evidence for matter effects in the solar ν_e transitions [100] since in the case of oscillations in vacuum $P_{\odot}^{3\nu} \cong \sin^4\theta_{13} + (1-0.5\sin^22\theta_{12})\cos^4\theta_{13} \gtrsim 0.49$, where we have used $\sin^2\theta_{13} \lesssim 0.040$ and $\sin^22\theta_{12} \lesssim 0.93$ (see Section 13.7).

13.4. Measurements of Δm_{\odot}^2 and θ_{\odot}

13.4.1. Solar neutrino observations:

Observation of solar neutrinos directly addresses the theory of stellar structure and evolution, which is the basis of the standard solar model (SSM). The Sun as a well-defined neutrino source also provides extremely important opportunities to investigate nontrivial neutrino properties such as nonzero mass and mixing, because of the wide range of matter density and the great distance from the Sun to the Earth.

The solar neutrinos are produced by some of the fusion reactions in the pp chain or CNO cycle. The combined effect of these reactions is written as

$$4p \to {}^{4}\text{He} + 2e^{+} + 2\nu_{e}.$$
 (13.63)

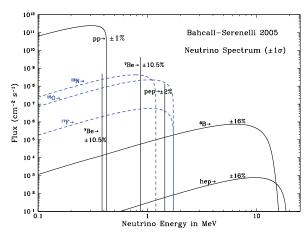


Figure 13.2: The solar neutrino spectrum predicted by the BS05(OP) standard solar model [101]. The neutrino fluxes are given in units of ${\rm cm}^{-2}{\rm s}^{-1}{\rm MeV}^{-1}$ for continuous spectra and ${\rm cm}^{-2}{\rm s}^{-1}$ for line spectra. The numbers associated with the neutrino sources show theoretical errors of the fluxes. This figure is taken from the late John Bahcall's web site, http://www.sns.ias.edu/~jnb/.

Positrons annihilate with electrons. Therefore, when considering the solar thermal energy generation, a relevant expression is

$$4p + 2e^- \rightarrow {}^{4}\text{He} + 2\nu_e + 26.73 \text{ MeV} - E_{\nu} ,$$
 (13.64)

where E_{ν} represents the energy taken away by neutrinos, with an average value being $\langle E_{\nu} \rangle \sim 0.6$ MeV. There have been efforts to calculate solar neutrino fluxes from these reactions on the basis of SSM. A variety of input information is needed in the evolutionary calculations. The most elaborate SSM calculations have been developed by Bahcall and his collaborators, who define their SSM as the solar model which is constructed with the best available physics and input data. Therefore, their SSM calculations have been rather frequently updated. SSM's labelled as BS05(OP) [101], BSB06(GS) and BSB06(AGS) [87], and BPS08(GS) and BPS08(AGS) [102] represent some of recent model calculations. Here, "OP" means that newly calculated radiative opacities from the "Opacity Project" are used. The later models are also calculated with OP opacities. "GS" and "AGS" refer to old and new determinations of solar abundances of heavy elements. There are significant differences between the old, higher heavy element abundances (GS) and the new, lower heavy element abundances (AGS). The models with GS are consistent with helioseismological data, but the models with AGS are not.

The prediction of the BPS08(GS) model for the fluxes from neutrino-producing reactions is given in Table 13.2. Fig. 13.2 shows the solar-neutrino spectra calculated with the BS05(OP) model which is similar to the BPS08(GS) model. Here we note that in Ref. 103 the authors point out that electron capture on ¹³N, ¹⁵O, and ¹⁷F produces line spectra of neutrinos, which have not been considered in the SSM calculations quoted above.

In 2011, a new SSM calculations [104] have been presented by A.M. Serenelli, W.C. Haxton, and C. Peña-Garay, by adopting the newly analyzed nuclear fusion cross sections. Their high metalicity SSM is labelled as SHP11(GS). For the same solar abundances as used in Ref. 101 and Ref. 87, the most significant change is a decrease of $^8{\rm B}$ flux by $\sim 5\%$.

So far, solar neutrinos have been observed by chlorine (Homestake) and gallium (SAGE, GALLEX, and GNO) radiochemical detectors and water Cherenkov detectors using light water (Kamiokande and Super-Kamiokande) and heavy water (SNO). Recently, a liquid scintillation detector (Borexino) successfully observed low energy solar neutrinos

A pioneering solar neutrino experiment by Davis and collaborators at Homestake using the 37 Cl - 37 Ar method proposed by Pontecorvo [105] started in the late 1960's. This experiment exploited

Table 13.2: Neutrino-producing reactions in the Sun (first column) and their abbreviations (second column). The neutrino fluxes predicted by the BPS08(GS) model [102] are listed in the third column.

| Reaction | Abbr. | Flux $(cm^{-2} s^{-1})$ |
|--------------------------------------------------------|-------------------|---------------------------------------|
| $pp \to d e^+ \nu$ | pp | $5.97(1 \pm 0.006) \times 10^{10}$ |
| $pe^-p \to d \nu$ | pep | $1.41(1 \pm 0.011) \times 10^8$ |
| ${}^{3}\mathrm{He}\;p^{4}\mathrm{He}\;e^{+}\nu$ | hep | $7.90(1 \pm 0.15) \times 10^3$ |
| $^{7}\mathrm{Be}\;e^{-}^{7}\mathrm{Li}\;\nu+(\gamma)$ | $^7\mathrm{Be}$ | $5.07(1 \pm 0.06) \times 10^9$ |
| $^8\mathrm{B} \to {}^8\mathrm{Be^*}\; e^+\nu$ | $^8\mathrm{B}$ | $5.94(1 \pm 0.11) \times 10^6$ |
| $^{13}\mathrm{N} \rightarrow ^{13}\mathrm{C}~e^{+}\nu$ | $^{13}\mathrm{N}$ | $2.88(1 \pm 0.15) \times 10^8$ |
| $^{15}{ m O} \to ^{15}{ m N}\; e^+ u$ | $^{15}\mathrm{O}$ | $2.15(1^{+0.17}_{-0.16}) \times 10^8$ |
| $^{17}\mathrm{F} \rightarrow ^{17}\mathrm{O}~e^{+}\nu$ | $^{17}\mathrm{F}$ | $5.82(1_{-0.17}^{+0.19}) \times 10^6$ |

 ν_e absorption on $^{37}{\rm Cl}$ nuclei followed by the produced $^{37}{\rm Ar}$ decay through orbital e^- capture,

$$\nu_e + ^{37} \mathrm{Cl} \rightarrow ^{37} \mathrm{Ar} + e^- \text{ (threshold 814 keV)}.$$
 (13.65)

The $^{37}\mathrm{Ar}$ atoms produced are radioactive, with a half life $(\tau_{1/2})$ of 34.8 days. After an exposure of the detector for two to three times $\tau_{1/2},$ the reaction products were chemically extracted and introduced into a low-background proportional counter, where they were counted for a sufficiently long period to determine the exponentially decaying signal and a constant background. Solar-model calculations predict that the dominant contribution in the chlorine experiment came from $^8\mathrm{B}$ neutrinos, but $^7\mathrm{Be},~pep,~^{13}\mathrm{N},$ and $^{15}\mathrm{O}$ neutrinos also contributed (for notations, refer to Table 13.2).

From the very beginning of the solar-neutrino observation [106], it was recognized that the observed flux was significantly smaller than the SSM prediction, provided nothing happens to the electron neutrinos after they are created in the solar interior. This deficit has been called "the solar-neutrino problem."

Table 13.3: Results from radiochemical solar-neutrino experiments. The predictions of a recent standard solar model BPS08(GS) are also shown. The first and the second errors in the experimental results are the statistical and systematic errors, respectively. SNU (Solar Neutrino Unit) is defined as 10^{-36} neutrino captures per atom per second.

| | $^{37}\text{Cl}\rightarrow^{37}\text{Ar} (\text{SNU})$ | $^{71}\mathrm{Ga} \rightarrow ^{71}\mathrm{Ge} \ (\mathrm{SNU})$ |
|-----------------------|--------------------------------------------------------|------------------------------------------------------------------|
| Homestake [4] | $2.56 \pm 0.16 \pm 0.16$ | _ |
| GALLEX [8] | _ | $77.5 \pm 6.2^{+4.3}_{-4.7}$ |
| GALLEX- | | |
| Reanalysis [107] | = | $73.4^{+6.1+3.7}_{-6.0-4.1}$ |
| GNO [9] | _ | $62.9^{+5.5}_{-5.3} \pm 2.5$ |
| GNO+GALLEX [9] | = | $69.3 \pm 4.1 \pm 3.6$ |
| GNO+GALLEX- | | |
| Reanalysis [107] | _ | $67.6^{+4.0+3.2}_{-4.0-3.2}$ |
| SAGE [6] | _ | $65.4_{-3.0-2.8}^{+3.1+2.6}$ |
| SSM [BPS08(GS)] [102] | $8.46^{+0.87}_{-0.88}$ | $127.9^{+8.1}_{-8.2}$ |

Gallium experiments (GALLEX and GNO at Gran Sasso in Italy and SAGE at Baksan in Russia) utilize the reaction

$$\nu_e + {}^{71}\text{Ga} \rightarrow {}^{71}\text{Ge} + e^- \text{ (threshold 233 keV)}.$$
 (13.66)

They are sensitive to the most abundant pp solar neutrinos. The solar-model calculations predict that more than 80% of the capture

rate in gallium is due to low energy pp and $^7\mathrm{Be}$ solar neutrinos with the pp rate being about twice the $^7\mathrm{Be}$ rate. SAGE reported the first results in 1991 [108]. They observed the capture rate to be $20^{+15}_{-20} \pm 32$ SNU, or a 90% confidence-level upper limit of 79 SNU. In 1992, GALLEX reported the observed capture rate of $83 \pm 19 \pm 8$ SNU [7]. It was the first evidence for low-energy solar-neutrino observation. Later, SAGE observed similar flux [109] to GALLEX. The latest SAGE results are published in Ref. 6. The GALLEX Collaboration finished observations in early 1997 [8,107]. Since April, 1998, a newly defined collaboration, GNO (Gallium Neutrino Observatory) continued the observations until April 2003. The GNO results are published in Ref. 9. The GNO + GALLEX joint analysis results are also presented in Ref. 9 and Ref. 107. The results from radiochemical solar neutrino experiments are shown in Table 13.3.

In 1987, the Kamiokande experiment in Japan succeeded in real-time solar neutrino observation, utilizing νe scattering,

$$\nu_x + e^- \to \nu_x + e^-$$
, (13.67)

in a large water-Cherenkov detector. This experiment takes advantage of the directional correlation between the incoming neutrino and the recoil electron. This feature greatly helps the clear separation of the solar-neutrino signal from the background. The Kamiokande result gave the first direct evidence that neutrinos come from the direction of the Sun [110]. Later, the high-statistics Super-Kamiokande experiment [111–114] with a 50-kton water Cherenkov detector replaced the Kamiokande experiment. Due to the high thresholds (7 MeV in Kamiokande and 5 MeV at present in Super-Kamiokande) the experiments observe pure ⁸B solar neutrinos. It should be noted that the reaction (Eq. (13.67)) is sensitive to all active neutrinos, $x = e, \mu$, and τ . However, the sensitivity to ν_{μ} and ν_{τ} is much smaller than the sensitivity to ν_{e} , $\sigma(\nu_{\mu,\tau}e) \approx 0.16 \, \sigma(\nu_{e}e)$.

In 1999, a new real time solar-neutrino experiment, SNO (Sudbury Neutrino Observatory), in Canada started observation. This experiment used 1000 tons of ultra-pure heavy water ($\rm D_2O$) contained in a spherical acrylic vessel, surrounded by an ultra-pure $\rm H_2O$ shield. SNO measured $^8\rm B$ solar neutrinos via the charged-current (CC) and neutral-current (NC) reactions

$$\nu_e + d \to e^- + p + p$$
 (CC), (13.68)

and

$$\nu_x + d \to \nu_x + p + n \tag{NC}, \tag{13.69}$$

as well as νe scattering, (Eq. (13.67)). The CC reaction, (Eq. (13.68)), is sensitive only to ν_e , while the NC reaction, (Eq. (13.69)), is sensitive to all active neutrinos. This is a key feature to solve the solar neutrino problem. If it is caused by flavour transitions such as neutrino oscillations, the solar neutrino fluxes measured by CC and NC reactions would show a significant difference.

The Q-value of the CC reaction is -1.4 MeV and the e^- energy is strongly correlated with the ν_e energy. Thus, the CC reaction provides an accurate measure of the shape of the $^8\mathrm{B}$ neutrino spectrum. The contributions from the CC reaction and ν_e scattering can be distinguished by using different $\cos\theta$ distributions, where θ is the angle of the e^- momentum with respect to the Sun-Earth axis. While the ν_e scattering events have a strong forward peak, CC events have an approximate angular distribution of $1-1/3\cos\theta$.

The neutrino energy threshold of the NC reaction is 2.2 MeV. In the pure D_2O [11,12], the signal of the NC reaction was neutron capture in deuterium, producing a 6.25-MeV γ -ray. In this case, the capture efficiency was low and the deposited energy was close to the detection threshold of 5 MeV. In order to enhance both the capture efficiency and the total γ -ray energy (8.6 MeV), 2 tons of NaCl were added to the heavy water in the second phase of the experiment [115]. Subsequently NaCl was removed and an array of ³He neutron counters were installed for the third phase measurement [116]. These neutron counters provided independent NC measurement with different systematics from that of the second phase, and thus strengthened the reliability of the NC measurement. The SNO experiment completed data acquisition in 2006. Recently, the SNO group presented the

results of Phase I and Phase II joint analysis [117] as well as the results of a combined analysis of all three phases [118].

Table 13.4 shows the ⁸B solar neutrino results from real time experiments. The standard solar model predictions are also shown. Table 13.4 includes the results from the SNO group's recent joint analysis of the SNO Phase I and Phase II data with the analysis threshold as low as 3.5 MeV (effective electron kinetic energy) and significantly improved systematic uncertainties [117]. Also, the recent result from a combined analysis of all three phases [118] is included. It is seen from these tables that the results from all the solar-neutrino experiments, except SNO's NC result, indicate significantly less flux than expected from the solar-model predictions.

Table 13.4: ⁸B solar neutrino results from real time experiments. The predictions of BPS08(GS) and SHP11(GS) standard solar models are also shown. The first and the second errors in the experimental results are the statistical and systematic errors, respectively.

| | Reaction | $^{8}\text{B }\nu \text{ flux}$ $(10^{6}\text{cm}^{-2}\text{s}^{-1})$ |
|-----------------------------|----------------------------------------|-----------------------------------------------------------------------|
| Kamiokande [5] | νe | $2.80 \pm 0.19 \pm 0.33$ |
| Super-K I [112,114] | νe | $2.38 \pm 0.02 \pm 0.08$ |
| Super-K II [113,114] | νe | $2.41 \pm 0.05^{+0.16}_{-0.15}$ |
| Super-K III [114] | νe | $2.32 \pm 0.04 \pm 0.05$ |
| SNO Phase I [12] | CC | $1.76^{+0.06}_{-0.05} \pm 0.09$ |
| (pure D_20) | νe | $2.39^{+0.24}_{-0.23} \pm 0.12$ |
| | NC | $5.09_{-0.43-0.43}^{+0.44+0.46}$ |
| SNO Phase II [115] | CC | $1.68 \pm 0.06^{+0.08}_{-0.09}$ |
| $(NaCl in D_2O)$ | νe | $2.35 \pm 0.22 \pm 0.15$ |
| | NC | $4.94 \pm 0.21^{+0.38}_{-0.34}$ |
| SNO Phase III [116] | CC | $1.67^{+0.05}_{-0.04}^{+0.05}_{-0.08}^{+0.07}$ |
| (³ He counters) | u e | $1.77^{+0.24+0.09}_{-0.21-0.10}$ |
| | NC | $5.54^{+0.33}_{-0.31}^{+0.36}_{-0.34}$ |
| SNO Phase I+II [117] | NC | $5.140^{+0.160+0.132}_{-0.158-0.117}$ |
| | Φ_B from fit to all reacts. | $5.046^{+0.159}_{-0.152}^{+0.107}_{-0.123}$ |
| SNO Phase I+II+III [118] | $\Phi_{\rm B}$ from fit to all reacts. | $5.25 \pm 0.16^{+0.11}_{-0.13}$ |
| Borexino [123] | νe | $2.4 \pm 0.4 \pm 0.1$ |
| SSM [BPS08(GS)] [102] | _ | $5.94(1 \pm 0.11)$ |
| SSM [SHP11(GS)] [104] | _ | $5.58(1 \pm 0.14)$ |

Another real time solar neutrino experiment, Borexino at Gran Sasso in Italy, started solar neutrino observation in 2007. This experiment measures solar neutrinos via νe scattering in 300 tons of ultra-pure liquid scintillator. With a detection threshold as low as 250 keV, the flux of monochromatic 0.862 MeV $^7\mathrm{Be}$ solar neutrinos has been directly observed for the first time (see Table 13.5). The observed energy spectrum shows the characteristic Comptonedge over the background [119,120]. Borexino also reported an observation of null day-night asymmetry of the $^7\mathrm{Be}$ neutrino flux, $A_{dn} = 2(R_N - R_D)/(R_N + R_D) = 0.001 \pm 0.012 \pm 0.007$ [121], where R_N and R_D are the night and day count rates of $^7\mathrm{Be}$ neutrinos.

Further, Borexino measured the flux of monochromatic 1.44 MeV pep solar neutrinos [122]. The absence of the pep solar neutrino signal is disfavored at 98% CL. The pep solar neutrino flux measured via νe scattering (calculated from the measured interaction rate and the expected one with the assumption of no neutrino oscillations and the SHP11(GS) SSM [104], both given in [122]) is shown in Table 13.6 and compared with the SSM predictions. Also, an upper limit of the "unoscillated" CNO solar neutrino flux is determined [122] as $<7.7\times10^8~{\rm cm}^{-2}{\rm s}^{-1}$ (95% CL) by assuming the MSW large mixing angle solution with $\Delta m_{\odot}^2=(7.6\pm0.2)\times10^{-5}~{\rm eV}^2$ and

 $\tan^2\!\theta_\odot=0.47^{+0.05}_{-0.04}$ and the SHP11(GS) SSM prediction [104] for the $pep~\nu$ flux.

Borexino also measured ⁸B solar neutrinos with an energy threshold of 3 MeV [123]. Measurements of low energy solar neutrinos are important not only to test the SSM further, but also to study the MSW effect over the energy region spanning from sub-MeV to 10 MeV.

Table 13.5: ⁷Be solar neutrino result from Borexino [120]. The predictions of BPS08(GS) and SHP11(GS) standard solar models are also shown.

| | Reaction | $^{7}{\rm Be} \ \nu \ {\rm flux}$ $(10^{9}{\rm cm}^{-2}{\rm s}^{-1})$ |
|------------------------------------------------|----------|-----------------------------------------------------------------------|
| Borexino [120] | νe | 3.10 ± 0.15 |
| SSM [BPS08(GS)] [102] SSM [SHP11(GS)] [104] | - | $5.07(1 \pm 0.06)$ $5.00(1 \pm 0.07)$ |

Table 13.6: pep solar neutrino result from Borexino [122]. The predictions of BPS08(GS) and SHP11(GS) standard solar models are also shown.

| | Reaction | $pep \ \nu \ flux$ $(10^8 cm^{-2} s^{-1})$ |
|-----------------------|----------|--------------------------------------------|
| Borexino [122] | νe | 1.0 ± 0.2 |
| SSM [BPS08(GS)] [102] | = | $1.41(1 \pm 0.011)$ |
| SSM [SHP11(GS)] [104] | _ | $1.44(1\pm 0.012)$ |

$13.4.2. \ \ Evidence\ for\ solar\ neutrino\ flavour\ conversion:$

Solar neutrino experiments achieved remarkable progress in the past ten years, and the solar-neutrino problem, which had remained unsolved for more than 30 years, has been understood as due to neutrino flavour conversion. In 2001, the initial SNO CC result combined with the Super-Kamiokande's high-statistics νe elastic scattering result [124] provided direct evidence for flavour conversion of solar neutrinos [11]. Later, SNO's NC measurements further strengthened this conclusion [12,115,116]. From the salt-phase measurement [115], the fluxes measured with CC, ES, and NC events were obtained as

$$\phi_{\text{SNO}}^{\text{CC}} = (1.68 \pm 0.06_{-0.09}^{+0.08}) \times 10^{6} \text{cm}^{-2} \text{s}^{-1} ,$$
 (13.70)

$$\phi_{\rm SNO}^{\rm ES} = (2.35 \pm 0.22 \pm 0.15) \times 10^6 {\rm cm}^{-2} {\rm s}^{-1} \; , \eqno (13.71)$$

$$\phi_{\text{SNO}}^{\text{NC}} = (4.94 \pm 0.21^{+0.38}_{-0.34}) \times 10^6 \text{cm}^{-2} \text{s}^{-1} ,$$
 (13.72)

where the first errors are statistical and the second errors are systematic. In the case of $\nu_e \to \nu_{\mu,\tau}$ transitions, Eq. (13.72) is a mixing-independent result and therefore tests solar models. It shows good agreement with the ⁸B solar-neutrino flux predicted by the solar model [101]. Fig. 13.3 shows the salt phase result of $\phi(\nu_{\mu} \text{ or } \tau)$ versus the flux of electron neutrinos $\phi(\nu_e)$ with the 68%, 95%, and 99% joint probability contours. The flux of non- ν_e active neutrinos, $\phi(\nu_{\mu} \text{ or } \tau)$, can be deduced from these results. It is

$$\phi(\nu_{\mu \text{ or } \tau}) = \left(3.26 \pm 0.25^{+0.40}_{-0.35}\right) \times 10^6 \text{cm}^{-2} \text{s}^{-1}. \tag{13.73}$$

The non-zero $\phi(\nu_{\mu}\ _{\rm or}\ _{\tau})$ is strong evidence for neutrino flavor conversion. These results are consistent with those expected from the LMA (large mixing angle) solution of solar neutrino oscillation in matter [22,23] with $\Delta m_{\odot}^2 \sim 5 \times 10^{-5}\ {\rm eV}^2$ and $\tan^2\!\theta_{\odot} \sim 0.45$. However, with the SNO data alone, the possibility of other solutions cannot be excluded with sufficient statistical significance.

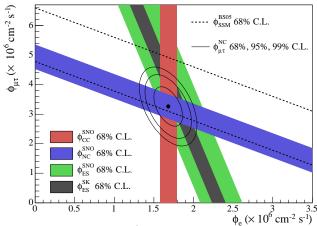


Figure 13.3: Fluxes of ^8B solar neutrinos, $\phi(\nu_e)$, and $\phi(\nu_{\mu} \text{ or } \tau)$, deduced from the SNO's CC, ES, and NC results of the salt phase measurement [115]. The Super-Kamiokande ES flux is from Ref. 125. The BS05(OP) standard solar model prediction [101] is also shown. The bands represent the 1σ error. The contours show the 68%, 95%, and 99% joint probability for $\phi(\nu_e)$ and $\phi(\nu_{\mu} \text{ or } \tau)$. The figure is from Ref. 115.

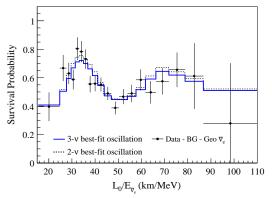


Figure 1.4: The ratio of the background and geoneutrino-subtracted $\bar{\nu}_e$ spectrum to the predicted one without oscillations (survival probability) as a function of L₀/E, where L₀=180 km. The histograms show the expected distributions based on the best-fit parameter values from the two- and three-flavor neutrino oscillation analyses. The figure is from Ref. 128.

$13.4.3. \quad KamLAND \ experiment:$

KamLAND is a 1-kton ultra-pure liquid scintillator detector located at the old Kamiokande's site in Japan. The primary goal of the KamLAND experiment was a long-baseline (flux-weighted average distance of ~ 180 km) neutrino oscillation studies using $\bar{\nu}_e$'s emitted from nuclear power reactors. The reaction $\bar{\nu}_e+p\to e^++n$ is used to detect reactor $\bar{\nu}_e$'s and a delayed coincidence of the positron with a 2.2 MeV γ -ray from neutron capture on a proton is used to reduce the backgrounds. With the reactor $\bar{\nu}_e$'s energy spectrum (< 8 MeV) and a prompt-energy analysis threshold of 2.6 MeV, this experiment has a sensitive Δm^2 range down to $\sim 10^{-5}$ eV². Therefore, if the LMA solution is the real solution of the solar neutrino problem, KamLAND should observe reactor $\bar{\nu}_e$ disappearance, assuming CPT invariance.

The first KamLAND results [15] with 162 ton-yr exposure were reported in December 2002. The ratio of observed to expected (assuming no $\bar{\nu}_e$ oscillations) number of events was

$$\frac{N_{\rm obs} - N_{\rm BG}}{N_{\rm NoOsc}} = 0.611 \pm 0.085 \pm 0.041 \tag{13.74}$$

with obvious notation. This result showed clear evidence of an event deficit expected from neutrino oscillations. The 95% CL allowed

regions are obtained from the oscillation analysis with the observed event rates and positron spectrum shape. A combined global solar + KamLAND analysis showed that the LMA is a unique solution to the solar neutrino problem with > 5σ CL [126]. With increased statistics [16,127,128], KamLAND observed not only the distortion of the $\bar{\nu}_e$ spectrum, but also for the first time the periodic feature of the $\bar{\nu}_e$ survival probability expected from neutrino oscillations (see Fig. 13.4).

13.5. Measurements of $|\Delta m_{\rm A}^2|$ and $\theta_{\rm A}$

13.5.1. Atmospheric neutrino results:

The first compelling evidence for the neutrino oscillation was presented by the Super-Kamiokande Collaboration in 1998 [13] from the observation of atmospheric neutrinos produced by cosmic-ray interactions in the atmosphere. The zenith-angle distributions of the μ -like events which are mostly muon-neutrino and muon antineutrino initiated charged-current interactions, showed a clear deficit compared to the no-oscillation expectation. Note that a water Cherenkov detector cannot measure the charge of the final-state leptons, and therefore neutrino and antineutrino induced events cannot be discriminated. Neutrino events having their vertex in the 22.5 kton fiducial volume in Super-Kamiokande are classified into fully contained (FC) events and partially contained (PC) events. The FC events are required to have no activity in the anti-counter. Single-ring events have only one charged lepton which radiates Cherenkov light in the final state, and particle identification is particularly clean for single-ring FC events. A ring produced by an e-like (e^{\pm}, γ) particle exhibits a more diffuse pattern than that produced by a μ -like (μ^{\pm} , π^{\pm}) particle, since an e-like particle produces an electromagnetic shower and low-energy electrons suffer considerable multiple Coulomb scattering in water. All the PC events were assumed to be μ -like since the PC events comprise a 98% pure charged-current ν_{μ} sample.

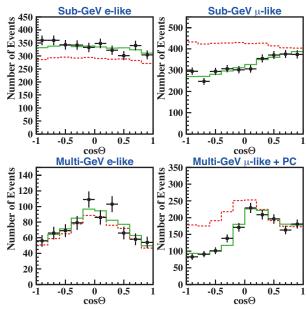


Figure 13.5: The zenith angle distributions for fully contained 1-ring e-like and μ -like events with visible energy < 1.33 GeV (sub-GeV) and > 1.33 GeV (multi-GeV). For multi-GeV μ -like events, a combined distribution with partially contained (PC) events is shown. The dotted histograms show the non-oscillated Monte Carlo events, and the solid histograms show the best-fit expectations for $\nu_{\mu} \leftrightarrow \nu_{\tau}$ oscillations. (This figure is provided by the Super-Kamiokande Collab.)

Fig. 13.5 shows the zenith-angle distributions of e-like and μ -like events from the SK-I measurement [129]. $\cos\theta = 1$ corresponds to the downward direction, while $\cos\theta = -1$ corresponds to the upward

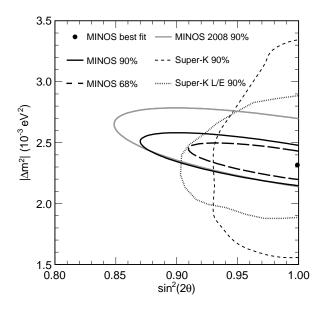


Figure 13.6: Allowed region for the $\nu_{\mu} \leftrightarrow \nu_{\tau}$ oscillation parameters from the MINOS results published in 2011. The 68 % and 90 % CL allowed regions are shown together with the Super-Kamiokande and MINOS 2008 90% CL allowed regions. This figure is taken from Ref. 130.

direction. Events included in these plots are single-ring FC events subdivided into sub-GeV (visible energy < 1.33 GeV) events and multi-GeV (visible energy > 1.33 GeV) events. The zenith-angle distribution of the multi-GeV μ -like events is shown combined with that of the PC events. The final-state leptons in these events have good directional correlation with the parent neutrinos. The dotted histograms show the Monte Carlo expectation for neutrino events. If the produced flux of atmospheric neutrinos of a given flavour remains unchanged at the detector, the data should have similar distributions to the expectation. However, the zenith-angle distribution of the μ -like events shows a strong deviation from the expectation. On the other hand, the zenith-angle distribution of the e-like events is consistent with the expectation. This characteristic feature may be interpreted that muon neutrinos coming from the opposite side of the Earth's atmosphere, having travelled $\sim 10,000$ km, oscillate into other neutrinos and disappeared, while oscillations still do not take place for muon neutrinos coming from above the detector, having travelled from a few to a few tens km. Disappeared muon neutrinos may have oscillated into tau neutrinos because there is no indication of electron neutrino appearance. The atmospheric neutrinos corresponding to the events shown in Fig. 13.5 have $E=1\sim 10$ GeV. With L=10000 km, the hypothesis of neutrino oscillations suggests $\Delta m^2 \sim 10^{-3} - 10^{-4}$ eV². The solid histograms show the best-fit results of a two-neutrino oscillation analysis with the hypothesis of $\nu_{\mu} \leftrightarrow \nu_{\tau}$. For the allowed parameter region, see Fig. 13.6.

Also, a search for a ν_{τ} appearance signal by using the SK-I atmospheric neutrino data has been made by the Super-Kamiokande Collaboration [131], and no ν_{τ} appearance hypothesis is disfavored at 2.4 σ

Although the SK-I atmospheric neutrino observations gave compelling evidence for muon neutrino disappearance which is consistent with two-neutrino oscillation $\nu_{\mu} \leftrightarrow \nu_{\tau}$ [131], the question may be asked whether the observed muon neutrino disappearance is really due to neutrino oscillations. First, other exotic explanations such as neutrino decay [132] and quantum decoherence [133] cannot be completely ruled out from the zenith-angle distributions alone. To confirm neutrino oscillation, characteristic sinusoidal behavior of the conversion probability as a function of neutrino energy E for a fixed distance L in the case of long-baseline neutrino oscillation experiments, or as a function of L/E in the case of atmospheric neutrino experiments, should be observed. By selecting events with

high L/E resolution, evidence for the dip in the L/E distribution was observed at the right place expected from the interpretation of the SK-I data in terms of $\nu_{\mu} \leftrightarrow \nu_{\tau}$ oscillations [14], see Fig. 13.7. This dip cannot be explained by alternative hypotheses of neutrino decay and neutrino decoherence, and they are excluded at more than 3σ in comparison with the neutrino oscillation interpretation. For the constraints obtained from the L/E analysis, see Fig. 13.6.

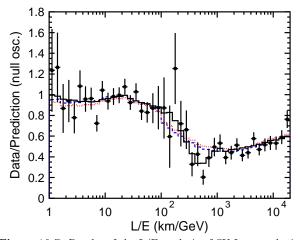


Figure 13.7: Results of the L/E analysis of SK-I atmospheric neutrino data. The points show the ratio of the data to the Monte Carlo prediction without oscillations, as a function of the reconstructed L/E. The error bars are statistical only. The solid line shows the best fit with 2-flavour $\nu_{\mu} \leftrightarrow \nu_{\tau}$ oscillations. The dashed and dotted lines show the best fit expectations for neutrino decay and neutrino decoherence hypotheses, respectively. (From Ref. 14.)

${\bf 13.5.2.} \ \ Results \ from \ accelerator \ experiments:$

The $\Delta m^2 \geq 2 \times 10^{-3} \ {\rm eV}^2$ region can be explored by accelerator-based long-baseline experiments with typically $E \sim 1$ GeV and $L \sim$ several hundred km. With a fixed baseline distance and a narrower, well understood neutrino spectrum, the value of $|\Delta m_{\rm A}^2|$ and, with higher statistics, also the mixing angle, are potentially better constrained in accelerator experiments than from atmospheric neutrino observations.

The K2K (KEK-to-Kamioka) long-baseline neutrino oscillation experiment [19] is the first accelerator-based experiment with a neutrino path length extending hundreds of kilometers. K2K aimed at confirmation of the neutrino oscillation in ν_{μ} disappearance in the $|\Delta m_{\rm A}^2| \geq 2 \times 10^{-3}~{\rm eV}^2$ region. A horn-focused wide-band muon neutrino beam having an average $L/E_{\nu} \sim 200~(L=250~{\rm km},$ $\langle E_{\nu} \rangle \sim 1.3~{\rm GeV}),$ was produced by 12-GeV protons from the KEK-PS and directed to the Super-Kamiokande detector. The spectrum and profile of the neutrino beam were measured by a near neutrino detector system located 300 m downstream from the production target.

The construction of the K2K neutrino beam line and the near detector began before Super-Kamiokande's discovery of atmospheric neutrino oscillations. K2K experiment started data-taking in 1999 and was completed in 2004. The total number of protons on target (POT) for physics analysis amounted to 0.92×10^{20} . The observed number of beam-originated FC events in the 22.5 kton fiducial volume of Super-Kamiokande was 112, compared with an expectation of $158.1^{+9.2}_{-8.6}$ events without oscillation. For 58 1-ring μ -like subset of the data, the neutrino energy was reconstructed from measured muon momentum and angle, assuming CC quasi-elastic kinematics. The measured energy spectrum showed the distortion expected from neutrino oscillations. The probability that the observations are due to a statistical fluctuation instead of neutrino oscillation is 0.0015% or 4.3 σ [19].

MINOS is the second long-baseline neutrino oscillation experiment with near and far detectors. Neutrinos are produced by the NuMI

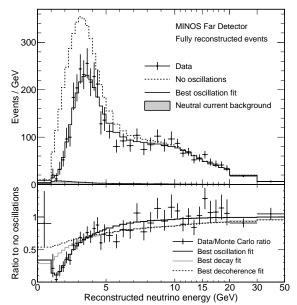


Figure 13.8: The top panel shows the energy spectra of fully reconstructed events in the MINOS far detector classified as CC interactions. The bottom panel shows the background subtracted ratios of data to the no-oscillation hypothesis. The best fit with the hypothesis of $\nu_{\mu} \rightarrow \nu_{\tau}$ oscillations as well as the best fit to alternative models (neutrino decay and decoherence) is also shown. This figure is taken from Ref. 130.

(Neutrinos at the Main Injector) facility using 120 GeV protons from the Fermilab Main Injector. The far detector is a 5.4 kton (total mass) iron-scintillator tracking calorimeter with toroidal magnetic field, located underground in the Soudan mine. The baseline distance is 735 km. The near detector is also an iron-scintillator tracking calorimeter with toroidal magnetic field, with a total mass of 0.98 kton. The neutrino beam is a horn-focused wide-band beam. Its energy spectrum can be varied by moving the target position relative to the first horn and changing the horn current.

MINOS started the neutrino-beam run in 2005. Earlier ν_{μ} disappearance results were reported in Ref. 20 with 1.27×10^{20} POT and in Ref. 21 with 3.36×10^{20} POT. The updated results corresponding to a total POT of 7.25×10^{20} have been published recently [130]. Most of the data were taken with a "low-energy" option for the spectrum of the neutrino beam (the flux was enhanced in the 1-5 GeV energy range, peaking at 3 GeV). In the far detector, a total of 1986 fully reconstructed CC events were produced by the NuMI beam, compared to the unoscillated expectation of 2451 events. Fig. 13.8 shows the observed energy spectra and the expected spectra with no oscillation. Fig. 13.6 shows the 68% and 90% CL allowed regions obtained from the $u_{\mu} \rightarrow
u_{\tau}$ oscillation analysis. The results are compared with the 90% CL allowed regions obtained from the earlier MINOS [21], SK-I zenith-angle dependence [129,79], and the SK-I L/E analysis [14]. The MINOS results constrain the oscillation parameters as $|\Delta m_{\rm A}^2| = (2.32^{+0.12}_{-0.08}) \times 10^{-3} \ {\rm eV^2}$ and $\sin^2 2\theta_{\rm A} > 0.90$ at 90% CL. The alternative models to explain the ν_{μ} disappearance, neutrino decay and quantum decoherence of neutrinos, are disfavored at the 7σ and 9σ , respectively, by the MINOS data (see Fig. 13.8).

In addition to ν_{μ} disappearance, MINOS first observed muon antineutrino disappearance [134] with the NUMI beam line optimized for $\bar{\nu}_{\mu}$ production. MINOS recently released $\bar{\nu}_{\mu}$ disappearance result corresponding to POT = 2.95×10^{20} [135]. With increased statistics, the best-fit oscillation parameters are $|\Delta\bar{m}_{\rm A}^2|=(2.62^{+0.31}_{-0.28}\pm0.09)\times10^{-3}~{\rm eV^2}$ and $\sin^22\bar{\theta}_{\rm A}=0.95^{+0.10}_{-0.11}\pm0.01,$ or $\sin^22\bar{\theta}_{\rm A}>0.75$ at 90% CL. These results are consistent with their neutrino counterparts.

The regions of neutrino parameter space favored or excluded by various neutrino oscillation experiments are shown in Fig. 13.9.

Although the atmospheric neutrino oscillations and accelerator long-baseline ν_{μ} disappearance data are fully consistent with $\nu_{\mu} \to \nu_{\tau}$

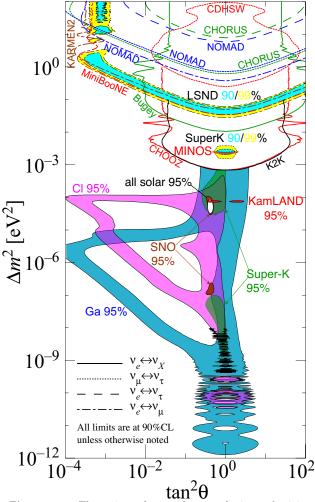


Figure 13.9: The regions of squared-mass splitting and mixing angle favored or excluded by various experiments based on two-flavor neutrino oscillation analyses. The figure was contributed by H. Murayama (University of California, Berkeley, and IPMU, University of Tokyo). References to the data used in the figure can be found at http://hitoshi.berkeley.edu/neutrino.

oscillations, appearance of ν_{τ} remained to be confirmed. For this purpose, a promising method is an accelerator long-baseline experiment using emulsion technique to identify short-lived τ leptons event-by-event. The only experiment of this kind is OPERA with a neutrino source at CERN and a detector at Gran Sasso with the baseline distance of 730 km. The detector is a combination of the "Emulsion Cloud Chamber" and magnetized spectrometer. The CNGS (CERN Neutrinos to Gran Sasso) neutrino beam with $\langle E_{\nu} \rangle = 17$ GeV is produced by high-energy protons from the CERN SPS. So far, OPERA reported observation of one ν_{τ} candidate in the hadronic decay channel of τ , corresponding to an exposure of 5.30 \times 10¹⁹ POT with a target mass of 1290 tons in 2008 and 2009 runs [60,61], with expectation of 1.65 signal events [61].

13.6. Measurements of θ_{13}

Reactor $\bar{\nu}_e$ disappearance experiments with $L \sim 1$ km, $\langle E \rangle \sim 3$ MeV are sensitive to $\sim E/L \sim 3 \times 10^{-3} \ {\rm eV^2} \sim |\Delta m_{\rm A}^2|$. At this baseline distance, the reactor $\bar{\nu}_e$ oscillations driven by Δm_{\odot}^2 are negligible. Therefore, as can be seen from Eq. (13.22) and Eq. (13.24), θ_{13} can be directly measured. A reactor neutrino oscillation experiment at the Chooz nuclear power station in France [58] was the first experiment of this kind. The detector was located in an underground laboratory with 300 mwe (meter water equivalent) rock overburden, at about 1 km from the neutrino source. It consisted of a central 5-ton target filled with 0.09% gadolinium loaded liquid scintillator,

surrounded by an intermediate 17-ton and outer 90-ton regions filled with undoped liquid scintillator. Reactor $\bar{\nu}_e$'s were detected via the reaction $\bar{\nu}_e + p \rightarrow e^+ + n$. Gd-doping was chosen to maximize the neutron capture efficiency. The Chooz experiment [58] found no evidence for $\bar{\nu}_e$ disappearance. The 90% CL upper limit for $|\Delta m_{\rm A}^2| = 2.0 \times 10^{-3} \ {\rm eV}^2$ is $\sin^2\!2\theta_{13} < 0.19$, and for the MINOS 2008 measurement [21] of $|\Delta m_{\rm A}^2| = 2.43 \times 10^{-3} \ {\rm eV}$ it is $\sin^2\!2\theta_{13} < 0.15$, both at 90% CL.

In the accelerator neutrino oscillation experiments with conventional neutrino beams, θ_{13} can be measured using $\nu_{\mu} \rightarrow \nu_{e}$ appearance. K2K was the first long-baseline experiment to search for ν_{e} appearance signal due to the $\nu_{\mu} \rightarrow \nu_{e}$ oscillations [136]. Based on the dominant term in the probability of $\nu_{\mu} \rightarrow \nu_{e}$ oscillations (see Eq. (13.23) and Eq. (13.24)),

$$P(\nu_{\mu} \to \nu_{e}) = \sin^{2} 2\theta_{13} \cdot \sin^{2} \theta_{23} \cdot \sin^{2}(1.27\Delta m_{A}^{2}L/E)$$
$$\sim \frac{1}{2} \sin^{2} 2\theta_{13} \sin^{2}(1.27\Delta m_{A}^{2}L/E) . \tag{13.75}$$

K2K set the 90% CL upper limit $\sin^2 2\theta_{13} < 0.26$.

By examining the expression for the probability of $\nu_{\mu} \rightarrow \nu_{e}$ oscillations in matter (given by Eq. (13.45) in which the sign of the $P_{\sin\delta}$ term is flipped), however, it is understood that subleading terms could have rather large effects and the unknown CP-violating phase δ causes uncertainties in determining the value of θ_{13} . Actually, from the measurement of $\nu_{\mu} \rightarrow \nu_{e}$ appearance, θ_{13} is given as a function of δ for a given sign of $\Delta m_{\rm A}^2$, or of $\Delta m_{32}^2 \cong \Delta m_{31}^2$. (Also, deviations from maximal θ_{23} mixing would cause a further uncertainty.) Therefore, a single experiment with a neutrino beam cannot determine the value of θ_{13} , although it is possible to establish a non-zero θ_{13} . In 2010, MINOS [137] set the limits for 2 $\sin^2\theta_{23} \sin^22\theta_{13}$ as a function of δ . At $\delta=0$, the 90% CL upper limit is 0.12 (0.20) for $\Delta m_{\rm A}^2>0$ ($\Delta m_{\rm A}^2<0$).

In 2011, experimental indications of $\nu_{\mu} \rightarrow \nu_{e}$ oscillations and a non-zero θ_{13} have been reported by the T2K [24] experiment. Also, MINOS [25] searched for $\nu_{\mu} \rightarrow \nu_{e}$ appearance and disfavored the $\theta_{13}=0$ hypothesis at the 89% CL.

The T2K experiment is the first off-axis long-baseline neutrino oscillation experiment. The baseline distance is 295 km between the J-PARC in Tokai, Japan and Super-Kamiokande. A narrow-band ν_{μ} beam produced by 30 GeV protons from the J-PARC Main Ring is directed 2.5° off-axis to SK. With this configuration, the ν_{μ} beam is tuned to the first oscillation maximum. With 1.43 \times 10 20 POT, the T2K [24] Collaboration observed six candidate ν_e events having all characteristics of being due to $\nu_{\mu} \rightarrow \nu_e$ oscillations, while the expectation for $\theta_{13}=0$ is 1.5 ± 0.3 events. The probability to observe six or more candidate events when 1.5 ± 0.3 events are predicted is 7×10^{-3} , implying a non-zero θ_{13} with statistical significance of 2.5σ . At $\delta=0$, $\sin^22\theta_{23}=1$ and $|\Delta m_A^2|=2.4\times10^{-3}$ eV², this result gives a best fit value of $\sin^22\theta_{13}=0.11$ (0.14) and a 90% CL interval of 0.03 (0.04) $<\sin^22\theta_{13}<0.28$ (0.34) for $\Delta m_A^2>0$ ($\Delta m_A^2<0$).

The MINOS Collaboration [25] also searched for the $\nu_{\mu} \rightarrow \nu_{e}$ appearance signal. Though dependent on the definition of the signal, typically 62 candidate events are observed with an exposure of 8.2×10^{20} POT, while the expectation for $\theta_{13}=0$ is $49.6\pm 7.0\pm 2.7$ events. At the 90% CL, the MINOS result implies that $2\,\sin^{2}\!2\theta_{13}$ $\sin^{2}\!\theta_{23}<0.12$ (0.20) for $\Delta m_{\rm A}^{2}>0$ ($\Delta m_{\rm A}^{2}<0$) and $\delta=0$, with a best fit value $2\,\sin^{2}\!\theta_{23}\,\sin^{2}\!2\theta_{13}=0.041^{+0.047}_{-0.031}$ (0.079 $^{+0.071}_{-0.053}$). The MINOS data disfavored the $\theta_{13}=0$ hypothesis at the 89% CL [25].

Recently, the three reactor neutrino experiments Double Chooz [59], Daya Bay [26], and RENO [27] reported their first results on reactor $\bar{\nu}_e$ disappearance. Daya Bay and RENO measured reactor $\bar{\nu}_e$ s with near and far detectors. The first results of Double Chooz was obtained with only a far detector, though this experiment is planning to have a near detector in 2012. The $\bar{\nu}_e$ detectors of all the three experiments have similar structures; an antineutrino detector consisting of three layers and an optically independent outer veto detector. The innermost layer of the antineutrino detector is filled with Gd-doped liquid scintillator (LS), which is surrounded by a " γ -catcher" layer filled with Gd-free LS, and outside the γ -catcher is a buffer layer filled with mineral oil.

An outer veto detector is filled with purified water (Daya Bay and RENO) or LS (Double Chooz).

The Daya Bay experiment [26] measured $\bar{\nu}_e$ s from the Daya Bay nuclear power complex (six 2.9 GW_{th} reactors) in China with six functionally identical detectors deployed in two near (470 m and 576 m of flux-weighted baselines) and one far (1648 m) underground halls. With live time of 55 days, the ratio of the observed to expected number of $\bar{\nu}_e$ s at the far hall is $R=0.940\pm0.011\pm0.004$ and the rate-only analysis yielded

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016 \pm 0.005. \tag{13.76}$$

From this result, θ_{13} is non-zero with a significance of 5.2σ .

The RENO experiment [27] measured $\bar{\nu}_e$ s from six 2.8 GW_{th} reactors at Yonggwang Nuclear Power Plant in Korea with two identical detectors located at 294 m and 1383 m from the reactor array center. With 229 days of running time, the ratio of the observed to expected number of $\bar{\nu}_e$ s in the far detector is $R = 0.920 \pm 0.009 \pm 0.014$, and from a rate-only analysis the following result is obtained:

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013 \pm 0.019 \tag{13.77}$$

This result excludes the no-oscillation hypothesis at the 4.9σ level.

The Double Chooz experiment [59] measured $\bar{\nu}_e$ s from two 4.25 GW_{th} reactors with a far detector at 1050 m from the two reactor cores. With 101 days of running, this experiment obtained $\sin^2 2\theta_{13} = 0.086 \pm 0.041 \pm 0.030$, or $0.017 < \sin^2 2\theta_{13} < 0.16$ at the 90% CL, by analyzing the rate and energy spectrum of prompt positrons using the reactor $\bar{\nu}_e$ spectrum of Ref. 36 and Ref. 34 and the Bugey4 rate measurement [138].

Turning to atmospheric and solar neutrino observations, Eq. (13.40) to Eq. (13.43) and Eq. (13.62) indicate that they are sensitive to θ_{13} through sub-leading effects. So far, the SK, SNO, and KamLAND Collaborations presented their own θ_{13} analyses by adding or updating their own data. In the atmospheric neutrino sector, the SK group analyzed its atmospheric neutrino data [79,139], and in the solar neutrino sector, SNO [117], SK [114], and KamLAND [128] analyzed the data from all solar neutrino experiments, with or without the KamLAND data, in terms of 3-neutrino oscillations. In addition, KamLAND [128] made a global analysis of all available neutrino data incorporating the Chooz, atmospheric and accelerator data. All these results are consistent with the recent results from accerelator [24,25] and reactor [59,26,27] experiments.

13.7. The three neutrino mixing

All existing compelling data on neutrino oscillations can be described assuming 3-flavour neutrino mixing in vacuum. This is the minimal neutrino mixing scheme which can account for the currently available data on the oscillations of the solar (ν_e) , atmospheric $(\nu_{\mu}$ and $\bar{\nu}_{\mu})$, reactor $(\bar{\nu}_e)$ and accelerator (ν_{μ}) neutrinos. The (left-handed) fields of the flavour neutrinos ν_e , ν_{μ} and ν_{τ} in the expression for the weak charged lepton current in the CC weak interaction Lagrangian, are linear combinations of the LH components of the fields of three massive neutrinos ν_i :

$$\mathcal{L}_{\text{CC}} = -\frac{g}{\sqrt{2}} \sum_{l=e,\mu,\tau} \overline{l_L}(x) \gamma_\alpha \nu_{lL}(x) W^{\alpha\dagger}(x) + h.c.,$$

$$\nu_{lL}(x) = \sum_{i=1}^3 U_{lj} \nu_{jL}(x), \qquad (13.78)$$

where U is the 3×3 unitary neutrino mixing matrix [17,18]. The mixing matrix U can be parameterized by 3 angles, and, depending on whether the massive neutrinos ν_j are Dirac or Majorana particles, by 1 or 3 CP violation phases [40,41]:

$$U = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{bmatrix}$$

$$\times \operatorname{diag}(1, e^{i\frac{\alpha_{21}}{2}}, e^{i\frac{\alpha_{31}}{2}}) . \tag{13.79}$$

where $c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$, the angles $\theta_{ij} = [0, \pi/2]$, $\delta = [0, 2\pi]$ is the Dirac CP violation phase and α_{21} , α_{31} are two Majorana CP violation phases. Thus, in the case of massive Dirac neutrinos, the neutrino mixing matrix U is similar, in what concerns the number of mixing angles and CP violation phases, to the CKM quark mixing matrix. The presence of two additional physical CP violation phases in U if ν_j are Majorana particles is a consequence of the special properties of the latter (see, e.g., Refs. [39,40]).

As we see, the fundamental parameters characterizing the 3-neutrino mixing are: i) the 3 angles θ_{12} , θ_{23} , θ_{13} , ii) depending on the nature of massive neutrinos ν_j - 1 Dirac (δ) , or 1 Dirac + 2 Majorana $(\delta, \alpha_{21}, \alpha_{31})$, CP violation phases, and iii) the 3 neutrino masses, m_1 , m_2 , m_3 . Thus, depending on whether the massive neutrinos are Dirac or Majorana particles, this makes 7 or 9 additional parameters in the minimally extended Standard Model of particle interactions with massive neutrinos.

The neutrino oscillation probabilities depend (Section 13.2), in general, on the neutrino energy, E, the source-detector distance L, on the elements of U and, for relativistic neutrinos used in all neutrino experiments performed so far, on $\Delta m_{ij}^2 \equiv (m_i^2 - m_j^2), i \neq j$. In the case of 3-neutrino mixing there are only two independent neutrino mass squared differences, say $\Delta m_{21}^2 \neq 0$ and $\Delta m_{31}^2 \neq 0$. The numbering of massive neutrinos ν_i is arbitrary. It proves convenient from the point of view of relating the mixing angles θ_{12} , θ_{23} and θ_{13} to observables, to identify $|\Delta m_{21}^2|$ with the smaller of the two neutrino mass squared differences, which, as it follows from the data, is responsible for the solar ν_e and, the observed by KamLAND, reactor $\bar{\nu}_e$ oscillations. We will number (just for convenience) the massive neutrinos in such a way that $m_1 < m_2$, so that $\Delta m_{21}^2 > 0$. With these choices made, there are two possibilities: either $m_1 < m_2 < m_3$, or $m_3 < m_1 < m_2$. Then the larger neutrino mass square difference $|\Delta m_{31}^2|$ or $|\Delta m_{32}^2|$, can be associated with the experimentally observed oscillations of the atmospheric ν_{μ} and $\bar{\nu}_{\mu}$ and accelerator ν_{μ} . The effects of Δm_{31}^2 or Δm_{32}^2 in the oscillations of solar ν_e , and of Δm_{21}^2 in the oscillations of atmospheric ν_{μ} and $\bar{\nu}_{\mu}$ and of accelerator ν_{μ} , are relatively small and subdominant as a consequence of the facts that i) L, E and L/Ein the experiments with solar ν_e and with atmospheric ν_μ and $\bar{\nu}_\mu$ or accelerator ν_{μ} , are very different, ii) the conditions of production and propagation (on the way to the detector) of the solar ν_e and of the atmospheric ν_{μ} and $\bar{\nu}_{\mu}$ or accelerator ν_{μ} , are very different, and iii) $|\Delta m_{21}^2|$ and $|\Delta m_{31}^2|$ ($|\Delta m_{32}^2|$) in the case of $m_1 < m_2 < m_3$ $(m_3 < m_1 < m_2)$, as it follows from the data, differ by approximately a factor of 30, $|\Delta m_{21}^2| \ll |\Delta m_{31(32)}^2|$, $|\Delta m_{21}^2| / |\Delta m_{31(32)}^2| \cong 0.03$. This implies that in both cases of $m_1 < m_2 < m_3$ and $m_3 < m_1 < m_2$ we have $\Delta m_{32}^2 \cong \Delta m_{31}^2$ with $|\Delta m_{31}^2 - \Delta m_{32}^2| = |\Delta m_{21}^2| \ll |\Delta m_{31,32}^2|$.

It follows from the results of the Chooz experiment with reactor $\bar{\nu}_e$ [58] and from the more recent data discussed in the preceding subsection that, in the convention we use, in which $0 < \Delta m_{21}^2 < |\Delta m_{31(32)}^2|$, the element $|U_{e3}| = \sin\theta_{13}$ of the neutrino mixing matrix U, as the results of the Daya Bay and RENO experiments show, is small. This makes it possible to identify the angles θ_{12} and θ_{23} as the neutrino mixing angles associated with the solar ν_e and the dominant atmospheric ν_μ (and $\bar{\nu}_\mu$) oscillations, respectively. The angles θ_{12} and θ_{23} are often called "solar" and "atmospheric" neutrino mixing angles, and are often denoted as $\theta_{12} = \theta_\odot$ and $\theta_{23} = \theta_A$ (or $\theta_{\rm atm}$) while Δm_{21}^2 and Δm_{31}^2 are often referred to as the "solar" and "atmospheric" neutrino mass squared differences and are often denoted as $\Delta m_{21}^2 \equiv \Delta m_\odot^2$, $\Delta m_{31}^2 \equiv \Delta m_A^2$ (or $\Delta m_{\rm atm}^2$).

The solar neutrino data tell us that $\Delta m^2_{21}\cos 2\theta_{12}>0.$ In the convention employed by us we have $\Delta m^2_{21}>0.$ Correspondingly, in this convention one must have $\cos 2\theta_{12}>0.$

Global analyses [140,141] of the existing neutrino oscillation data, including the T2K [24] and MINOS [25] (but not the Daya Bay [26] and RENO [27]) results, allowed us to determine the parameters which drive the solar neutrino and the dominant atmospheric neutrino oscillations, $\Delta m_{\odot}^2 = \Delta m_{21}^2$, θ_{12} , and $|\Delta m_{\rm A}^2| = |\Delta m_{31}^2| \cong |\Delta m_{32}^2|$, θ_{23} , with a relatively good precision, and to establish that the angle $\theta_{13} \neq 0$ at $\gtrsim 99.73\%$ CL. The Daya Bay and RENO experiments provided a rather precise determination of the angle θ_{13} . Analyses of

the global neutrino oscillation data, in which the Daya Bay and RENO results on θ_{13} are also included, are lacking at present. Therefore we present in Table 13.7 the best fit values and the 99.73% CL allowed ranges of Δm^2_{21} , $\sin^2\theta_{12}$, $|\Delta m^2_{31(32)}|$, $\sin^2\theta_{23}$ and $\sin^2\theta_{13}$, found in Ref. 140 as well as the PDG average [142] of the results of the three recent reactor experiments [26,27,59]. Since the PDG average of $\sin^2 \theta_{13}$ is very close to that obtained in the global analysis in Ref. 140, and since the other oscillation parameter ranges are almost uncorrelated from θ_{13} , we do not expect that the inclusion of the Daya Bay and RENO data will change significantly the results (neither the central values nor the errors) for Δm_{21}^2 , $\sin^2 \theta_{12}$, $|\Delta m_{31(32)}^2|$ and $\sin^2 \theta_{23}$ obtained in Ref. 140. Obviously, the uncertainty in the value of $\sin^2\theta_{13}$ will shrink considerably. We note also that the results from Ref. 140 quoted in Table 13.7 are derived by marginalizing over $\operatorname{sgn}(\Delta m_{31}^2) = \pm 1$ and over $\cos \delta = \pm 1$ and that the values (the values in brackets) of $\sin^2 \theta_{12}$ and $\sin^2 \theta_{13}$ are obtained in Ref. 140 using the reactor $\bar{\nu}_e$ fluxes from Ref. 35 (from Ref. 34).

Table 13.7: The best-fit values and 3σ allowed ranges of the 3-neutrino oscillation parameters, derived from a global fit of the current neutrino oscillation data, including the T2K and MINOS (but not the Daya Bay and RENO) results (from [140]). The PDG average of the results of the three recent reactor experiments [26,27,59] is given in the last line [142]. The values (values in brackets) of $\sin^2\theta_{12}$ and $\sin^2\theta_{13}$ are obtained using the "old" [35] ("new" [34]) reactor $\bar{\nu}_e$ fluxes in the analysis.

| Parameter | best-fit $(\pm 1\sigma)$ | 3σ |
|---------------------------------------------------|-------------------------------------|-------------------------------------|
| $\Delta m_{\odot}^2 \ [10^{-5} \ {\rm eV}^{\ 2}]$ | $7.58^{+0.22}_{-0.26}$ | 6.99 - 8.18 |
| $ \Delta m_A^2 [10^{-3} \text{ eV }^2]$ | $2.35_{-0.09}^{+0.12}$ | 2.06 - 2.67 |
| $\sin^2 \theta_{12}$ | $0.306 \ (0.312)^{+0.018}_{-0.015}$ | $0.259 \ (0.265) - 0.359 \ (0.364)$ |
| $\sin^2\theta_{23}$ | $0.42^{+0.08}_{-0.03}$ | 0.34 - 0.64 |
| $\sin^2 \theta_{13}$ [140] | $0.021 \ (0.025)^{+0.007}_{-0.008}$ | $0.001 \ (0.005) - 0.044 \ (0.050)$ |
| $\sin^2 \theta_{13}$ [142] | 0.0251 ± 0.0034 | 0.015 - 0.036 |

A combined analysis of the data on θ_{13} from the T2K, MINOS, Double Chooz, Daya Bay and RENO experiments was performed in Ref. 145. The authors find that $\theta_{13} \neq 0$ at 7.7σ :

$$\sin^2 2\theta_{13} = 0.096 \pm 0.013 \ (\pm 0.040) \ \text{at} \ 1\sigma \ (3\sigma)$$
 (13.80)

In this analysis the positive or negative sign of $\Delta m_{\rm A}^2$ was used as input and the values of $\sin^2 2\theta_{23}$ and $|\Delta m_{\rm A}^2|$ were varied imposing Gaussian priors based on the results of the atmospheric neutrino [139] and MINOS [130] experiments. The value of $\sin^2 2\theta_{13}$ thus obtained showed a statistically insignificant dependence on the Dirac phase δ .

It follows from the results given in Table 13.7 that $\theta_{23} \cong \pi/4$, $\theta_{12} \cong \pi/5.4$ and that $\theta_{13} \cong \pi/20$. Correspondingly, the pattern of neutrino mixing is drastically different from the pattern of quark mixing.

Note also that Δm^2_{21} , $\sin^2\theta_{12}$, $|\Delta m^2_{31(32)}|$, $\sin^2\theta_{23}$ and $\sin^2\theta_{13}$ are determined from the data with a 1σ uncertainty (= 1/6 of the 3σ range) of approximately 2.6%, 5.4%, 4.3%, 12% and absolute error 0.42×10^{-2} , respectively.

The existing SK atmospheric neutrino, K2K and MINOS data do not allow to determine the sign of $\Delta m_{31(32)}^2$. Maximal solar neutrino mixing, *i.e.*, $\theta_{12}=\pi/4$, is ruled out at more than 6σ by the data. Correspondingly, one has $\cos 2\theta_{12} \geq 0.27$ (at 99.73% CL).

At present no experimental information on the Dirac and Majorana CP violation phases in the neutrino mixing matrix is available. Thus, the status of CP symmetry in the lepton sector is unknown. With $\theta_{13} \neq 0$, the Dirac phase δ can generate CP violation effects in neutrino oscillations [40,52,53]. The magnitude of CP violation in $\nu_l \rightarrow \nu_{l'}$ and $\bar{\nu}_l \rightarrow \bar{\nu}_{l'}$ oscillations, $l \neq l' = e, \mu, \tau$, is determined, as we have seen, by the rephasing invariant J_{CP} (see Eq. (13.19)), which

in the "standard" parametrisation of the neutrino mixing matrix (Eq. (13.79)) has the form:

$$J_{CP} \equiv \operatorname{Im} \left(U_{\mu 3} \, U_{e3}^* \, U_{e2} \, U_{\mu 2}^* \right) = \frac{1}{8} \, \cos \theta_{13} \sin 2\theta_{12} \, \sin 2\theta_{23} \, \sin 2\theta_{13} \, \sin \delta \,.$$

$$(13.81)$$

Thus, given the fact that $\sin 2\theta_{12}$, $\sin 2\theta_{23}$ and $\sin 2\theta_{13}$ have been determined experimentally with a relatively good precision, the size of CP violation effects in neutrino oscillations depends essentially only on the magnitude of the currently unknown value of the Dirac phase δ . The current data implies $|J_{CP}| \lesssim 0.045$, where we have used the 3σ ranges of $\sin^2\theta_{12}$, $\sin^2\theta_{23}$ and $\sin^2\theta_{13}$ given in Table 13.7 and Eq. (13.76), respectively.

As we have indicated, the existing data do not allow one to determine the sign of $\Delta m_{\rm A}^2=\Delta m_{31(2)}^2.$ In the case of 3-neutrino mixing, the two possible signs of $\Delta m_{31(2)}^2$ correspond to two types of neutrino mass spectrum. In the widely used conventions of numbering the neutrinos with definite mass in the two cases, the two spectra read:

- i) spectrum with normal ordering:

$$\begin{split} & m_1 < m_2 < m_3, \, \Delta m_{\rm A}^2 = \Delta m_{31}^2 > 0, \\ & \Delta m_{\odot}^2 = \Delta m_{21}^2 > 0, \, m_{2(3)} = (m_1^2 + \Delta m_{21(31)}^2)^{\frac{1}{2}}; \end{split}$$

- ii) spectrum with inverted ordering (IO):

$$m_3 < m_1 < m_2, \, \Delta m_{\rm A}^2 = \Delta m_{32}^2 < 0, \, \Delta m_{\odot}^2 \equiv \Delta m_{21}^2 > 0,$$

 $m_2 = (m_3^2 + \Delta m_{23}^2)^{\frac{1}{2}}, \, m_1 = (m_3^2 + \Delta m_{23}^2 - \Delta m_{21}^2)^{\frac{1}{2}}.$

Depending on the values of the lightest neutrino mass [143], $\min(m_j)$, the neutrino mass spectrum can also be:

- Normal Hierarchical (NH):

$$m_1 \ll m_2 < m_3, \ m_2 \cong (\Delta m_{\odot}^2)^{\frac{1}{2}} \cong 0.0086 \text{ eV},$$

 $m_3 \cong |\Delta m_{\Delta}^2|^{\frac{1}{2}} \cong 0.048 \text{ eV}; \text{ or}$

- Inverted Hierarchical (IH):

$$m_3 \ll m_1 < m_2$$
, with $m_{1,2} \cong |\Delta m_{\rm A}^2|^{\frac{1}{2}} \cong 0.048$ eV; or – Quasi-Degenerate (QD):

$$m_1 \cong m_2 \cong m_3 \cong m_0, \ m_j^2 \gg |\Delta m_A^2|, \ m_0 \gtrsim 0.10 \text{ eV}.$$

All three types of spectrum are compatible with the existing constraints on the absolute scale of neutrino masses m_j . Information about the latter can be obtained, e.g., by measuring the spectrum of electrons near the end point in ${}^3{\rm H}$ β -decay experiments [146–149] and from cosmological and astrophysical data. The most stringent upper bounds on the $\bar{\nu}_e$ mass were obtained in the Troitzk [147,148] experiment:

$$m_{\bar{\nu}_e} < 2.05 \text{ eV}$$
 at 95% CL. (13.82)

We have $m_{\bar{\nu}e} \cong m_{1,2,3}$ in the case of QD spectrum. The KATRIN experiment [149] is planned to reach sensitivity of $m_{\bar{\nu}e} \sim 0.20$ eV, *i.e.*, it will probe the region of the QD spectrum.

The Cosmic Microwave Background (CMB) data of the WMAP experiment, combined with supernovae data and data on galaxy clustering can be used to obtain an upper limit on the sum of neutrinos masses (see review on Cosmological Parameters [150] and e.g., Ref. 151). Depending on the model complexity and the input data used one obtains [151]: $\sum_j m_j \lesssim (0.3-1.3)$ eV, 95% CL.

It follows from these data that neutrino masses are much smaller than the masses of charged leptons and quarks. If we take as an indicative upper limit $m_j \lesssim 0.5\,$ eV, we have $m_j/m_{l,q} \lesssim 10^{-6},$ $l=e,\mu,\tau,~q=d,s,b,u,c,t.$ It is natural to suppose that the remarkable smallness of neutrino masses is related to the existence of a new fundamental mass scale in particle physics, and thus to new physics beyond that predicted by the Standard Model.

13.7.1. The see-saw mechanism and the baryon asymmetry of the Universe:

A natural explanation of the smallness of neutrino masses is provided by the (type I) see-saw mechanism of neutrino mass generation [3]. An integral part of this rather simple mechanism [152] are the RH neutrinos ν_{lR} (RH neutrino fields $\nu_{lR}(x)$). The latter are assumed to possess a Majorana mass term as well as Yukawa type coupling $\mathcal{L}_{\rm Y}(x)$ with the Standard Model lepton and Higgs doublets, $\psi_{lL}(x)$ and $\Phi(x)$, respectively, $(\psi_{lL}(x))^T=(\nu_{lL}^T(x)\ l_L^T(x)),$ $l=e,\mu,\tau,(\Phi(x))^T=(\Phi^{(0)}\ \Phi^{(-)}).$ In the basis in which the Majorana mass matrix of RH neutrinos is diagonal, we have:

$$\mathcal{L}_{Y,M}(x) = \left(\lambda_{il} \, \overline{N_{iR}}(x) \, \Phi^{\dagger}(x) \, \psi_{lL}(x) + \text{h.c.}\right) - \frac{1}{2} \, M_i \, \overline{N_i}(x) \, N_i(x) \,, \tag{13.83}$$

where λ_{il} is the matrix of neutrino Yukawa couplings and N_i $(N_i(x))$ is the heavy RH Majorana neutrino (field) possessing a mass $M_i > 0$. When the electroweak symmetry is broken spontaneously, the neutrino Yukawa coupling generates a Dirac mass term: $m_{il}^D \overline{N_{iR}}(x) \nu_{lL}(x) + \text{h.c.}$, with $m^D = v\lambda$, v = 174 GeV being the Higgs doublet v.e.v. In the case when the elements of m^D are much smaller than $M_k, |m_{il}^D| \ll M_k, i, k = 1, 2, 3, l = e, \mu, \tau$, the interplay between the Dirac mass term and the mass term of the heavy (RH) Majorana neutrinos N_i generates an effective Majorana mass (term) for the LH flavour neutrinos [3]: $m_{l'l}^{LL} \cong -(m^D)_{l'j}^T M_j^{-1} m_{jl}^D$. In grand unified theories, m^D is typically of the order of the charged fermion masses. In SO(10) theories, for instance, m^D coincides with the up-quark mass matrix. Taking indicatively $m^{LL}\sim 0.1$ eV, $m^D\sim 100$ GeV, one finds $M \sim 10^{14}$ GeV, which is close to the scale of unification of the electroweak and strong interactions, $M_{GUT} \cong 2 \times 10^{16}$ GeV. In GUT theories with RH neutrinos one finds that indeed the heavy Majorana neutrinos N_j naturally obtain masses which are by few to several orders of magnitude smaller than M_{GUT} . Thus, the enormous disparity between the neutrino and charged fermion masses is explained in this approach by the huge difference between effectively the electroweak symmetry breaking scale and M_{GUT} .

An additional attractive feature of the see-saw scenario is that the generation and smallness of neutrino masses is related via the leptogenesis mechanism [2] to the generation of the baryon asymmetry of the Universe. The Yukawa coupling in Eq. (13.83), in general, is not CP conserving. Due to this CP-nonconserving coupling the heavy Majorana neutrinos undergo, e.g., the decays $N_j \to l^+ + \Phi^{(-)}, \ N_j \to l^- + \Phi^{(+)}, \ \text{which have different rates:}$ $\Gamma(N_j \to l^+ + \Phi^{(-)}) \neq \Gamma(N_j \to l^- + \Phi^{(+)}).$ When these decays occur in the Early Universe at temperatures somewhat below the mass of, say, N_1 , so that the latter are out of equilibrium with the rest of the particles present at that epoch, CP violating asymmetries in the individual lepton charges L_l , and in the total lepton charge L, of the Universe are generated. These lepton asymmetries are converted into a baryon asymmetry by (B-L) conserving, but (B+L) violating, sphaleron processes, which exist in the Standard Model and are effective at temperatures $T \sim (100-10^{12})$ GeV. If the heavy neutrinos N_i have hierarchical spectrum, $M_1 \ll M_2 \ll M_3$, the observed baryon asymmetry can be reproduced provided the mass of the lightest one satisfies $M_1 \gtrsim 10^9$ GeV [153]. Thus, in this scenario, the neutrino masses and mixing and the baryon asymmetry have the same origin - the neutrino Yukawa couplings and the existence of (at least two) heavy Majorana neutrinos. Moreover, quantitative studies based on recent advances in leptogenesis theory [154] have shown that the Dirac and/or Majorana phases in the neutrino mixing matrix U can provide the CP violation, necessary in leptogenesis for the generation of the observed baryon asymmetry of the Universe [155]. This implies, in particular, that if the CP symmetry is established not to hold in the lepton sector due to U, at least some fraction (if not all) of the observed baryon asymmetry might be due to the Dirac and/or Majorana CP violation present in the neutrino mixing.

13.7.2. The nature of massive neutrinos:

The experiments studying flavour neutrino oscillations cannot provide information on the nature - Dirac or Majorana, of massive neutrinos [40,54]. Establishing whether the neutrinos with definite mass ν_i are Dirac fermions possessing distinct antiparticles, or Majorana fermions, i.e. spin 1/2 particles that are identical with their antiparticles, is of fundamental importance for understanding the origin of ν -masses and mixing and the underlying symmetries of particle interactions (see e.g., Ref. 66). The neutrinos with definite mass ν_i will be Dirac fermions if the particle interactions conserve some additive lepton number, e.g., the total lepton charge $L = L_e + L_{\mu} + L_{\tau}$. If no lepton charge is conserved, ν_i will be Majorana fermions (see e.g., Ref. 39). The massive neutrinos are predicted to be of Majorana nature by the see-saw mechanism of neutrino mass generation [3]. The observed patterns of neutrino mixing and of neutrino mass squared differences can be related to Majorana massive neutrinos and the existence of an approximate symmetry in the lepton sector corresponding, e.g., to the conservation of the lepton charge $L' = L_e - L_{\mu} - L_{\tau}$ [156]. Determining the nature of massive neutrinos ν_i is one of the fundamental and most challenging problems in the future studies of neutrino mixing.

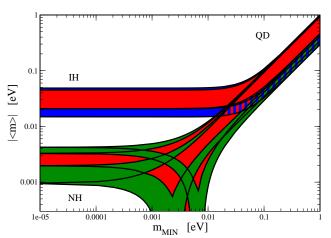


Figure 13.10: The effective Majorana mass |<m>| (including a 2σ uncertainty), as a function of $\min(m_j)$ for $\sin^2\theta_{13}=0.0236\pm0.0042$ [26] and $\delta=0$. The figure is obtained using also the best fit values and 1σ errors of Δm_{21}^2 , $\sin^2\theta_{12}$, and $|\Delta m_{31}^2|\cong |\Delta m_{32}^2|$ from Ref. 140 (given in Table 13.7). For $\sin^2\theta_{12}$ the results found with the "old" reactor $\bar{\nu}_e$ fluxes [35] were employed. The phases $\alpha_{21,31}$ are varied in the interval $[0,\pi]$. The predictions for the NH, IH and QD spectra are indicated. The red regions correspond to at least one of the phases $\alpha_{21,31}$ and $(\alpha_{31}-\alpha_{21})$ having a CP violating value, while the blue and green areas correspond to $\alpha_{21,31}$ possessing CP conserving values. (Update by S. Pascoli of a figure from the last article quoted in Ref. 160.)

The Majorana nature of massive neutrinos ν_j manifests itself in the existence of processes in which the total lepton charge L changes by two units: $K^+ \to \pi^- + \mu^+ + \mu^+$, $\mu^- + (A,Z) \to \mu^+ + (A,Z-2)$, etc. Extensive studies have shown that the only feasible experiments having the potential of establishing that the massive neutrinos are Majorana particles are at present the experiments searching for $(\beta\beta)_{0\nu}$ -decay: $(A,Z) \to (A,Z+2) + e^- + e^-$ (see e.g., Ref. 157). The observation of $(\beta\beta)_{0\nu}$ -decay and the measurement of the corresponding half-life with sufficient accuracy, would not only be a proof that the total lepton charge is not conserved, but might also provide unique information on the i) type of neutrino mass spectrum (see, e.g., Ref. 158), ii) Majorana phases in U [144,159] and iii) the absolute scale of neutrino masses (for details see Ref. 157 to Ref. 160 and references quoted therein).

Under the assumptions of $3-\nu$ mixing, of massive neutrinos ν_j being Majorana particles, and of $(\beta\beta)_{0\nu}$ -decay generated only by the (V-A) charged current weak interaction via the exchange of the

three Majorana neutrinos ν_j having masses $m_j \lesssim$ few MeV, the $(\beta\beta)_{0\nu}$ -decay amplitude has the form (see, e.g., Ref. 39 and Ref. 157): $A(\beta\beta)_{0\nu} \cong \langle m \rangle M$, where M is the corresponding nuclear matrix element which does not depend on the neutrino mixing parameters, and

$$|\langle m \rangle| = \left| m_1 U_{e1}^2 + m_2 U_{e2}^2 + m_3 U_{e3}^2 \right|$$

$$= \left| \left(m_1 c_{12}^2 + m_2 s_{12}^2 e^{i\alpha_{21}} \right) c_{13}^2 + m_3 s_{13}^2 e^{i(\alpha_{31} - 2\delta)} \right|, (13.84)$$

is the effective Majorana mass in $(\beta\beta)_{0\nu}$ -decay. In the case of CP-invariance one has [42], $\eta_{21} \equiv e^{i\alpha_{21}} = \pm 1$, $\eta_{31} \equiv e^{i\alpha_{31}} = \pm 1$, $e^{-i2\delta} = 1$. The three neutrino masses $m_{1,2,3}$ can be expressed in terms of the two measured Δm_{jk}^2 and, e.g., $\min(m_j)$. Thus, given the neutrino oscillation parameters Δm_{21}^2 , $\sin^2\theta_{12}$, Δm_{31}^2 and $\sin^2\theta_{13}$, |< m>| is a function of the lightest neutrino mass $\min(m_j)$, the Majorana (and Dirac) CP violation phases in U and of the type of neutrino mass spectrum. In the case of NH, IH and QD spectrum we have (see, e.g., Ref. 144 and Ref. 160):

$$|\!<\!m\!>\!|\cong \left|\sqrt{\Delta m_{21}^2}s_{12}^2c_{13}^2+\sqrt{\Delta m_{31}^2}s_{13}^2e^{i(\alpha_{31}-\alpha_{21}-2\delta)}\right|\,,\quad {\rm NH}\,, \eqno(13.85)$$

$$|\langle m \rangle| \cong \tilde{m} \left(1 - \sin^2 2\theta_{12} \sin^2 \frac{\alpha_{21}}{2}\right)^{\frac{1}{2}}$$
, IH (IO) and QD, (13.86)

where $\tilde{m} \equiv \sqrt{\Delta m_{23}^2 + m_3^2}$ and $\tilde{m} \equiv m_0$ for IH (IO) and QD spectrum, respectively. In Eq. (13.86) we have exploited the fact that $\sin^2\theta_{13} \ll \cos 2\theta_{12}$. The CP conserving values of the Majorana phases $(\alpha_{31} - \alpha_{21})$ and α_{21} determine the intervals of possible values of |< m>|, corresponding to the different types of neutrino mass spectrum. Using the 3σ ranges of the allowed values of the neutrino oscillation parameters from Table 13.7 and Eq. (13.76) one finds that: i) 2.3×10^{-4} eV $\lesssim |< m>| \lesssim 5.0 \times 10^{-3}$ eV in the case of NH spectrum; ii) $\sqrt{\Delta m_{23}^2 \cos 2\theta_{12}} \lesssim |< m>| \lesssim \sqrt{\Delta m_{23}^2}$, or 1.3×10^{-2} eV $\lesssim |< m>| \lesssim 5.2 \times 10^{-2}$ eV in the case of IH spectrum; iii) $m_0 \cos 2\theta_{12} \lesssim |< m>| \lesssim m_0$, or 2.8×10^{-2} eV $\lesssim |< m>| \lesssim m_0$ eV, $m_0 \gtrsim 0.10$ eV, in the case of QD spectrum. The difference in the ranges of |< m>| in the cases of NH, IH and QD spectrum opens up the possibility to get information about the type of neutrino mass spectrum from a measurement of |< m>| [158]. The predicted $(\beta\beta)_{0\nu}$ -decay effective Majorana mass |< m>| as a function of the lightest neutrino mass $\min(m_j)$ is shown in Fig. 13.10.

13.8. Outlook

After the spectacular experimental progress made in the studies of neutrino oscillations, further understanding of the pattern of neutrino masses and neutrino mixing, of their origins and of the status of CP symmetry in the lepton sector requires an extensive and challenging program of research. The main goals of such a research program, outlined in the 2010 PDG edition of the Review of Particle Physics, included:

- Determining the nature Dirac or Majorana, of massive neutrinos ν_j. This is of fundamental importance for making progress in our understanding of the origin of neutrino masses and mixing and of the symmetries governing the lepton sector of particle interactions.
- Determination of the sign of $\Delta m_{\rm A}^2~(\Delta m_{31}^2)$ and of the type of neutrino mass spectrum.
- Determining or obtaining significant constraints on the absolute scale of neutrino masses.
- Measurement of, or improving by at least a factor of (5 10) the existing upper limit on, the small neutrino mixing angle θ_{13} . Together with the Dirac CP-violating phase, the angle θ_{13} determines the magnitude of CP-violation effects in neutrino oscillations.
- \bullet Determining the status of CP symmetry in the lepton sector.
- High precision measurement of Δm_{21}^2 , θ_{12} , and $|\Delta m_{31}^2|$, θ_{23} .

• Understanding at a fundamental level the mechanism giving rise to neutrino masses and mixing and to L_l-non-conservation. This includes understanding the origin of the patterns of ν-mixing and ν-masses suggested by the data. Are the observed patterns of ν-mixing and of Δm²_{21,31} related to the existence of a new fundamental symmetry of particle interactions? Is there any relation between quark mixing and neutrino mixing, e.g., does the relation θ₁₂ + θ_c=π/4, where θ_c is the Cabibbo angle, hold? What is the physical origin of CP violation phases in the neutrino mixing matrix U? Is there any relation (correlation) between the (values of) CP violation phases and mixing angles in U? Progress in the theory of neutrino mixing might also lead to a better understanding of the mechanism of generation of baryon asymmetry of the Universe.

The successful realization of this research program, which would be a formidable task and would require many years, already began during the last two years with the results of the T2K and MINOS experiments on the value of θ_{13} , of the global analyses of the neutrino oscillation data, which showed that $\theta_{13} \neq 0$ at 3σ , and with the subsequent rather precise measurements of the value of $\sin^2 2\theta_{13}$ in the Daya Bay and RENO experiments. Averaging the results of the three recent reactor experiments with the standard PDG method, one obtains $\sin^2 2\theta_{13} = 0.098 \pm 0.013$ [142]. These results on θ_{13} have far reaching implications. The measured relatively large value of θ_{13} opens up the possibilities, in particular,

- i) for searching for CP violation effects in neutrino oscillation experiments with high intensity accelerator neutrino beams, like T2K, NO ν A, etc. NO ν A [63], an off-axis ν_e appearance experiment using the NuMI beam, is under construction and expected to be complete in 2014. The sensitivities of T2K and NO ν A on CP violation in neutrino oscillations are discussed in, e.g., Ref. 162.
- ii) for determining the sign of Δm_{32}^2 , and thus the type of neutrino mass spectrum in the long baseline neutrino oscillation experiments at accelerators, in the experiments studying the oscillations of atmospheric neutrinos (see, e.g., Ref. 82), as well as in experiments with reactor antineutrinos [161]. A value of $\sin\theta_{13}\gtrsim 0.09$ is a necessary condition for a successful "flavoured" leptogenesis with hierarchical heavy Majorana neutrinos when the CP violation required for the generation of the matter-antimatter asymmetry of the Universe is provided entirely by the Dirac CP violating phase in the neutrino mixing matrix [155].

With the measurement of θ_{13} , the first steps on the long "road" leading to a comprehensive understanding of the patterns of neutrino masses and mixing, of their origin and implications, were made.

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14. QUARK MODEL

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14.1. Quantum numbers of the quarks

Quantum chromodynamics (QCD) is the theory of the strong interactions. QCD is a quantum field theory and its constituents are a set of fermions, the quarks, and gauge bosons, the gluons. Strongly interacting particles, the hadrons, are bound states of quark and gluon fields. As gluons carry no intrinsic quantum numbers beyond color charge, and because color is believed to be permanently confined, most of the quantum numbers of strongly interacting particles are given by the quantum numbers of their constituent quarks and antiquarks. The description of hadronic properties which strongly emphasizes the role of the minimum-quark-content part of the wave function of a hadron is generically called the quark model. It exists on many levels: from the simple, almost dynamics-free picture of strongly interacting particles as bound states of quarks and antiquarks, to more detailed descriptions of dynamics, either through models or directly from QCD itself. The different sections of this review survey the many approaches to the spectroscopy of strongly interacting particles which fall under the umbrella of the quark model.

Quarks are strongly interacting fermions with spin 1/2 and, by convention, positive parity. Antiquarks have negative parity. Quarks have the additive baryon number 1/3, antiquarks -1/3. Table 14.1 gives the other additive quantum numbers (flavors) for the three generations of quarks. They are related to the charge Q (in units of the elementary charge e) through the generalized Gell-Mann-Nishijima formula

$$Q = I_z + \frac{B + S + C + B + T}{2} , \qquad (14.1)$$

where \mathcal{B} is the baryon number. The convention is that the flavor of a quark (I_z, S, C, B, or T) has the same sign as its charge Q. With this convention, any flavor carried by a charged meson has the same sign as its charge, e.g., the strangeness of the K^+ is +1, the bottomness of the B^+ is +1, and the charm and strangeness of the D_s^- are each -1. Antiquarks have the opposite flavor signs.

14.2. Mesons

Mesons have baryon number $\mathcal{B}=0$. In the quark model, they are $q\overline{q}'$ bound states of quarks q and antiquarks \overline{q}' (the flavors of q and q' may be different). If the orbital angular momentum of the $q\overline{q}'$ state is ℓ , then the parity P is $(-1)^{\ell+1}$. The meson spin J is given by the usual relation $|\ell-s| \leq J \leq |\ell+s|$, where s is 0 (antiparallel quark spins) or 1 (parallel quark spins). The charge conjugation, or C-parity $C=(-1)^{\ell+s}$, is defined only for the $q\overline{q}$ states made of quarks and their own antiquarks. The C-parity can be generalized to the G-parity $G=(-1)^{I+\ell+s}$ for mesons made of quarks and their own antiquarks (isospin $I_z=0$), and for the charged $u\overline{d}$ and $d\overline{u}$ states (isospin I=1).

Table 14.1: Additive quantum numbers of the quarks.

| | d | u | s | c | b | t |
|--------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Q – electric charge | $-\frac{1}{3}$ | $+\frac{2}{3}$ | $-\frac{1}{3}$ | $+\frac{2}{3}$ | $-\frac{1}{3}$ | $+\frac{2}{3}$ |
| I – isospin | $\frac{1}{2}$ | $\frac{1}{2}$ | 0 | 0 | 0 | 0 |
| I_z – isospin z -component | $-\frac{1}{2}$ | $+\frac{1}{2}$ | 0 | 0 | 0 | 0 |
| S – strangeness | 0 | 0 | -1 | 0 | 0 | 0 |
| C – charm | 0 | 0 | 0 | +1 | 0 | 0 |
| B – bottomness | 0 | 0 | 0 | 0 | -1 | 0 |
| T – topness | 0 | 0 | 0 | 0 | 0 | +1 |

The mesons are classified in J^{PC} multiplets. The $\ell=0$ states are the pseudoscalars (0^{-+}) and the vectors (1^{--}) . The orbital excitations $\ell=1$ are the scalars (0^{++}) , the axial vectors (1^{++}) and (1^{+-}) , and the tensors (2^{++}) . Assignments for many of the known mesons are given in Tables 14.2 and 14.3. Radial excitations are denoted by the principal quantum number n. The very short lifetime of the t quark makes it likely that bound-state hadrons containing t quarks and/or antiquarks do not exist.

States in the natural spin-parity series $P=(-1)^J$ must, according to the above, have s=1 and hence, CP=+1. Thus, mesons with natural spin-parity and CP=-1 (0⁺⁻, 1⁻⁺, 2⁺⁻, 3⁻⁺, etc.) are forbidden in the $q\bar{q}'$ model. The $J^{PC}=0^{--}$ state is forbidden as well. Mesons with such exotic quantum numbers may exist, but would lie outside the $q\bar{q}'$ model (see section below on exotic mesons).

Following SU(3), the nine possible $q\bar{q}'$ combinations containing the light $u,\ d,$ and s quarks are grouped into an octet and a singlet of light quark mesons:

$$\mathbf{3} \otimes \mathbf{\overline{3}} = \mathbf{8} \oplus \mathbf{1} \ . \tag{14.2}$$

A fourth quark such as charm c can be included by extending SU(3) to SU(4). However, SU(4) is badly broken owing to the much heavier c quark. Nevertheless, in an SU(4) classification, the sixteen mesons are grouped into a 15-plet and a singlet:

$$\mathbf{4} \otimes \overline{\mathbf{4}} = \mathbf{15} \oplus \mathbf{1} \ . \tag{14.3}$$

The weight diagrams for the ground-state pseudoscalar (0^{-+}) and vector (1^{--}) mesons are depicted in Fig. 14.1. The light quark mesons are members of nonets building the middle plane in Fig. 14.1(a) and (b).

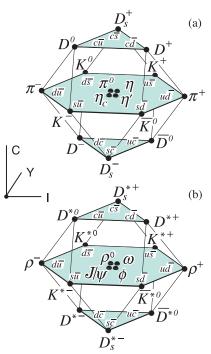


Figure 14.1: SU(4) weight diagram showing the 16-plets for the pseudoscalar (a) and vector mesons (b) made of the u, d, s, and c quarks as a function of isospin I, charm C, and hypercharge $\mathsf{Y} = \mathsf{S} + \mathcal{B} - \frac{\mathsf{C}}{3}$. The nonets of light mesons occupy the central planes to which the $c\bar{c}$ states have been added.

Isoscalar states with the same J^{PC} will mix, but mixing between the two light quark isoscalar mesons, and the much heavier charmonium or bottomonium states, are generally assumed to be negligible. In the

Table 14.2: Suggested $q\overline{q}$ quark-model assignments for some of the observed light mesons. Mesons in bold face are included in the Meson Summary Table. The wave functions f and f' are given in the text. The singlet-octet mixing angles from the quadratic and linear mass formulae are also given for the well established nonets. The classification of the 0^{++} mesons is tentative and the mixing angle uncertain due to large uncertainties in some of the masses. Also, the $f_0(1710)$ and $f_0(1370)$ are expected to mix with the $f_0(1500)$. The latter is not in this table as it is hard to accommodate in the scalar nonet. The light scalars $a_0(980)$, $f_0(980)$, and $f_0(500)$ are often considered as meson-meson resonances or four-quark states, and are therefore not included in the table. See the "Note on Scalar Mesons" in the Meson Listings for details and alternative schemes.

| $n^{2s+1}\ell_J$ | J^{PC} | $ \begin{aligned} I &= 1 \\ u\overline{d}, \overline{u}d, \frac{1}{\sqrt{2}}(d\overline{d} - u\overline{u}) \end{aligned} $ | $ \begin{aligned} I &= \frac{1}{2} \\ u\overline{s}, d\overline{s}; \overline{ds}, -\overline{u}s \end{aligned} $ | I = 0 f' | I = 0 f | $	heta_{	ext{quad}}$ [°] | $	heta_{ m lin}$ [°] |
|-------------------------------|----------|-------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|--------------------|------------------|--------------------------|----------------------|
| $1 {}^{1}S_{0}$ | 0-+ | π | K | η | $\eta'(958)$ | -11.5 | -24.6 |
| 1 ³ S ₁ | 1 | ho(770) | $K^*(892)$ | $\phi(1020)$ | $\omega(782)$ | 38.7 | 36.0 |
| 1 ¹ P ₁ | 1+- | $b_1(1235)$ | K_{1B}^{\dagger} | $h_1(1380)$ | $h_1(1170)$ | | |
| $1 {}^{3}P_{0}$ | 0++ | $a_0(1450)$ | $K_0^*(1430)$ | $f_0(1710)$ | $f_0(1370)$ | | |
| $1 {}^{3}P_{1}$ | 1++ | $a_1(1260)$ | $oldsymbol{K_{1A}}^\dagger$ | $f_1(1420)$ | $f_1(1285)$ | | |
| $1 {}^{3}P_{2}$ | 2++ | $a_2(1320)$ | $K_2^*(1430)$ | $f_2^\prime(1525)$ | $f_2(1270)$ | 29.6 | 28.0 |
| $1 ^{1}D_{2}$ | 2-+ | $\pi_2(1670)$ | $K_2(1770)^\dagger$ | $\eta_2(1870)$ | $\eta_2(1645)$ | | |
| $1 {}^3D_1$ | 1 | ho(1700) | $K^*(1680)$ | | $\omega(1650)$ | | |
| $1 {}^3D_2$ | 2 | | $K_2(1820)$ | | | | |
| $1 {}^3D_3$ | 3 | $ ho_3(1690)$ | $K_3^*(1780)$ | $\phi_3(1850)$ | $\omega_3(1670)$ | 32.0 | 31.0 |
| $1\ ^{3}F_{4}$ | 4++ | $a_4(2040)$ | $K_4^*(2045)$ | | $f_4(2050)$ | | |
| $1{}^3G_5$ | 5 | $\rho_5(2350)$ | $K_5^*(2380)$ | | | | |
| $1{}^{3}H_{6}$ | 6++ | $a_6(2450)$ | | _ | $f_6(2510)$ | | |
| $2 {}^1S_0$ | 0-+ | $\pi(1300)$ | K(1460) | $\eta(1475)$ | $\eta(1295)$ | | |
| 2 3S1 | 1 | ho(1450) | $K^*(1410)$ | $\phi(1680)$ | $\omega(1420)$ | | |

[†] The 1^{+±} and 2^{-±} isospin $\frac{1}{2}$ states mix. In particular, the K_{1A} and K_{1B} are nearly equal (45°) mixtures of the $K_1(1270)$ and $K_1(1400)$. The physical vector mesons listed under 1³ D_1 and 2³ S_1 may be mixtures of 1³ D_1 and 2³ S_1 , or even have hybrid components.

Table 14.3: $q\overline{q}$ quark-model assignments for the observed heavy mesons. Mesons in bold face are included in the Meson Summary Table.

| $n^{\;2s+1}\ell_J J^{PC}$ | $I = 0$ $c\overline{c}$ | $I = 0$ $b\overline{b}$ | $ \begin{aligned} I &= \frac{1}{2} \\ c\overline{u}, c\overline{d}; \overline{c}u, \overline{c}d \end{aligned} $ | $ \begin{aligned} I &= 0\\ c\overline{s}; \overline{c}s \end{aligned} $ | $ \begin{aligned} I &= \frac{1}{2} \\ b\overline{u}, b\overline{d}; \overline{b}u, \overline{b}d \end{aligned} $ | $ \begin{aligned} \mathbf{I} &= 0\\ b\overline{s}; \overline{b}s \end{aligned} $ | $ \begin{array}{c} \mathbf{I} = 0 \\ b\overline{c}; \overline{b}c \end{array} $ |
|------------------------------------------------|-------------------------|-------------------------|---------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| $1 ^1S_0 \qquad 0^{-+}$ | $\eta_c(1S)$ | $\eta_b(1S)$ | D | D_s^\pm | В | $m{B}_s^{m{0}}$ | B_c^\pm |
| 1 ³ S ₁ 1 | $J/\psi(1S)$ | $\Upsilon(1S)$ | D^* | $oldsymbol{D}_{s}^{*\pm}$ | B^* | B_s^* | |
| 1 ¹ P ₁ 1 ⁺⁻ | $h_c(1P)$ | $h_b(1P)$ | $D_1(2420)$ | $D_{s1}(2536)^{\pm}$ | $B_1(5721)$ | $B_{s1}(5830)^0$ | |
| $1^{3}P_{0}$ 0^{++} | $\chi_{c0}(1P)$ | $\chi_{b0}(1P)$ | $D_0^*(2400)$ | $D_{s0}^*(2317)^{\pm\dagger}$ | | | |
| $1^{3}P_{1}$ 1^{++} | $\chi_{c1}(1P)$ | $\chi_{b1}(1P)$ | $D_1(2430)$ | $D_{s1}(2460)^{\pm\dagger}$ | | | |
| $1^{3}P_{2}$ 2^{++} | $\chi_{c2}(1P)$ | $\chi_{b2}(1P)$ | $D_{2}^{st}(2460)$ | $D_{s2}^*(2573)^{\pm}$ | $B_2^*(5747)$ | $B_{s2}^{st}(5840)^{0}$ | |
| $1 {}^{3}D_{1}$ $1^{}$ | $\psi(3770)$ | | | $D_{s1}^*(2700)^{\pm}$ | | | |
| $2 {}^{1}S_{0}$ 0^{-+} | $\eta_c(2S)$ | | | | | | |
| 2 3 S1 1 | $\psi(2S)$ | $\Upsilon(2S)$ | | | | | |
| $2 {}^{3}P_{0,1,2} {}^{0++}, 1^{++}, 2^{++}$ | $\chi_{c2}(2P)$ | $\chi_{b0,1,2}(2P)$ | | | | | |

[†] The masses of these states are considerably smaller than most theoretical predictions. They have also been considered as four-quark states (See the "Note on Non- $q\bar{q}$ Mesons" at the end of the Meson Listings). The open flavor states in the 1⁺⁺ and 1⁺⁺ rows are mixtures of the 1^{+±} states.

following, we shall use the generic names a for the I=1, K for the I=1/2, and f and f' for the I=0 members of the light quark nonets. Thus, the physical isoscalars are mixtures of the SU(3) wave function ψ_8 and ψ_1 :

$$f' = \psi_8 \cos \theta - \psi_1 \sin \theta , \qquad (14.4)$$

$$f = \psi_8 \sin \theta + \psi_1 \cos \theta \,\,\,\,(14.5)$$

where θ is the nonet mixing angle and

$$\psi_8 = \frac{1}{\sqrt{6}} (u\bar{u} + d\bar{d} - 2s\bar{s}) , \qquad (14.6)$$

$$\psi_1 = \frac{1}{\sqrt{3}} (u\bar{u} + d\bar{d} + s\bar{s})$$
 (14.7)

These mixing relations are often rewritten to exhibit the $u\bar{u}+d\bar{d}$ and $s\bar{s}$ components which decouple for the "ideal" mixing angle θ_i , such that $\tan\theta_i=1/\sqrt{2}$ (or $\theta_i{=}35.3^\circ$). Defining $\alpha=\theta+54.7^\circ$, one obtains the physical isoscalar in the flavor basis

$$f' = \frac{1}{\sqrt{2}} (u\bar{u} + d\bar{d}) \cos \alpha - s\bar{s} \sin \alpha , \qquad (14.8)$$

and its orthogonal partner f (replace α by $\alpha - 90^{\circ}$). Thus for ideal mixing ($\alpha_i = 90^{\circ}$), the f' becomes pure $s\bar{s}$ and the f pure $u\bar{u} + d\bar{d}$. The mixing angle θ can be derived from the mass relation

$$\tan \theta = \frac{4m_K - m_a - 3m_{f'}}{2\sqrt{2}(m_a - m_K)} , \qquad (14.9)$$

which also determines its sign or, alternatively, from

$$\tan^2 \theta = \frac{4m_K - m_a - 3m_{f'}}{-4m_K + m_a + 3m_f} \,. \tag{14.10}$$

Eliminating θ from these equations leads to the sum rule [1]

$$(m_f + m_{f'})(4m_K - m_a) - 3m_f m_{f'} = 8m_K^2 - 8m_K m_a + 3m_a^2. \eqno(14.11)$$

This relation is verified for the ground-state vector mesons. We identify the $\phi(1020)$ with the f' and the $\omega(783)$ with the f. Thus

$$\phi(1020) = \psi_8 \cos \theta_V - \psi_1 \sin \theta_V , \qquad (14.12)$$

$$\omega(782) = \psi_8 \sin \theta_V + \psi_1 \cos \theta_V , \qquad (14.13)$$

with the vector mixing angle $\theta_V=35^\circ$ from Eq. (14.9), very close to ideal mixing. Thus $\phi(1020)$ is nearly pure $s\bar{s}$. For ideal mixing, Eq. (14.9) and Eq. (14.10) lead to the relations

$$m_K = \frac{m_f + m_{f'}}{2} , \quad m_a = m_f , \qquad (14.14)$$

which are satisfied for the vector mesons.

The situation for the pseudoscalar and scalar mesons is not so clear cut, either theoretically or experimentally. For the pseudoscalars, the mixing angle is small. This can be understood qualitatively via gluon-line counting of the mixing process. The size of the mixing process between the nonstrange and strange mass bases scales as α_s^2 , not α_s^3 , because of two rather than three gluon exchange as it does for the vector mesons. It may also be that the lightest isoscalar pseudoscalars mix more strongly with excited states or with states of substantial non- $\bar{q}q$ content, as will be discussed below.

A variety of analysis methods lead to similar results: First, for these states, Eq. (14.11) is satisfied only approximately. Then Eq. (14.9) and Eq. (14.10) lead to somewhat different values for the mixing angle. Identifying the η with the f' one gets

$$\eta = \psi_8 \cos \theta_P - \psi_1 \sin \theta_P , \qquad (14.15)$$

$$\eta' = \psi_8 \sin \theta_P + \psi_1 \cos \theta_P \ . \tag{14.16}$$

Following chiral perturbation theory, the meson masses in the mass formulae (Eq. (14.9) and Eq. (14.10)) might be replaced by their squares. Table 14.2 lists the mixing angle $\theta_{\rm lin}$ from Eq. (14.10) and the corresponding $\theta_{\rm quad}$ obtained by replacing the meson masses by their squares throughout.

The pseudoscalar mixing angle θ_P can also be measured by comparing the partial widths for radiative J/ψ decay into a vector and a pseudoscalar [2], radiative $\phi(1020)$ decay into η and η' [3], or $\bar{p}p$ annihilation at rest into a pair of vector and pseudoscalar or into two pseudoscalars [4,5]. One obtains a mixing angle between -10° and -20° . More recently, a lattice QCD simulation, Ref. 6, has successfully reproduced the masses of the η and η' , and as a byproduct find a mixing angle $\theta_{lin} = -14.1(2.8)^\circ$ We return to this point in Sec. 14.6.

The nonet mixing angles can be measured in $\gamma\gamma$ collisions, e.g., for the 0^{-+} , 0^{++} , and 2^{++} nonets. In the quark model, the amplitude for the coupling of neutral mesons to two photons is proportional to $\sum_i Q_i^2$, where Q_i is the charge of the *i*-th quark. The 2γ partial width of an isoscalar meson with mass m is then given in terms of the mixing angle α by

$$\Gamma_{2\gamma} = C(5\cos\alpha - \sqrt{2}\sin\alpha)^2 m^3 , \qquad (14.17)$$

for f' and f ($\alpha \to \alpha - 90^\circ$). The coupling C may depend on the meson mass. It is often assumed to be a constant in the nonet. For the isovector a, one then finds $\Gamma_{2\gamma}=9$ C m^3 . Thus the members of an ideally mixed nonet couple to 2γ with partial widths in the ratios f:f':a=25:2:9. For tensor mesons, one finds from the ratios of the measured 2γ partial widths for the $f_2(1270)$ and $f'_2(1525)$ mesons a mixing angle α_T of $(81\pm 1)^\circ$, or $\theta_T=(27\pm 1)^\circ$, in accord with the linear mass formula. For the pseudoscalars, one finds from the ratios of partial widths $\Gamma(\eta'\to 2\gamma)/\Gamma(\eta\to 2\gamma)$ a mixing angle $\theta_P=(-18\pm 2)^\circ$, while the ratio $\Gamma(\eta'\to 2\gamma)/\Gamma(\pi^0\to 2\gamma)$ leads to ~ -24 °. SU(3) breaking effects for pseudoscalars are discussed in Ref. 7.

Table 14.4: SU(3) couplings γ^2 for quarkonium decays as a function of nonet mixing angle α , up to a common multiplicative factor C ($\phi \equiv 54.7^{\circ} + \theta_P$).

| Isospin | Decay channel | γ^2 |
|---------------|-----------------|-------------------------------------------------------------------------------------------|
| 0 | $\pi\pi$ | $3\cos^2\alpha$ |
| | $K\overline{K}$ | $(\cos \alpha - \sqrt{2} \sin \alpha)^2$ |
| | $\eta\eta$ | $(\cos\alpha\cos^2\phi - \sqrt{2}\sin\alpha\sin^2\phi)^2$ |
| | $\eta\eta'$ | $\frac{1}{2}\sin^2 2\phi \ (\cos\alpha + \sqrt{2}\sin\alpha)^2$ |
| 1 | $\eta\pi$ | $2\cos^2\phi$ |
| | $\eta'\pi$ | $2\sin^2\phi$ |
| | $K\overline{K}$ | 1 |
| $\frac{1}{2}$ | $K\pi$ | $\frac{3}{2}$ |
| | $K\eta$ | $(\sin \phi - \frac{\cos \phi}{\sqrt{2}})^2$ |
| | $K\eta'$ | $(\sin \phi - \frac{\cos \phi}{\sqrt{2}})^2$ $(\cos \phi + \frac{\sin \phi}{\sqrt{2}})^2$ |

The partial width for the decay of a scalar or a tensor meson into a pair of pseudoscalar mesons is model-dependent. Following Ref. 8,

$$\Gamma = C \times \gamma^2 \times |F(q)|^2 \times q \ . \tag{14.18}$$

C is a nonet constant, q the momentum of the decay products, F(q) a form factor, and γ^2 the SU(3) coupling. The model-dependent form factor may be written as

$$|F(q)|^2 = q^{2\ell} \times \exp(-\frac{q^2}{8\beta^2}),$$
 (14.19)

where ℓ is the relative angular momentum between the decay products. The decay of a $q\bar{q}$ meson into a pair of mesons involves the creation of a $q\bar{q}$ pair from the vacuum, and SU(3) symmetry assumes that the

matrix elements for the creation of $s\bar{s}$, $u\bar{u}$, and $d\bar{d}$ pairs are equal. The couplings γ^2 are given in Table 14.4, and their dependence upon the mixing angle α is shown in Fig. 14.2 for isoscalar decays. The generalization to unequal $s\bar{s}$, $u\bar{u}$, and $d\bar{d}$ couplings is given in Ref. 8. An excellent fit to the tensor meson decay widths is obtained assuming SU(3) symmetry, with $\beta \simeq 0.5$ GeV/c, $\theta_V \simeq 26$ ° and $\theta_P \simeq -17$ ° [8].

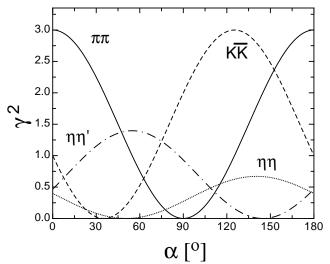


Figure 14.2: SU(3) couplings as a function of mixing angle α for isoscalar decays, up to a common multiplicative factor C and for $\theta_P = -17.3^{\circ}$.

14.3. Exotic mesons

The existence of a light nonet composed of four quarks with masses below 1 GeV was suggested a long time ago [9]. Coupling two triplets of light quarks u, d, and s, one obtains nine states, of which the six symmetric (uu, dd, ss, ud+du, us+su, ds+sd) form the six dimensional representation $\mathbf{6}$, while the three antisymmetric (ud-du, us-su, ds-sd) form the three dimensional representation $\overline{\mathbf{3}}$ of SU(3):

$$\mathbf{3} \otimes \mathbf{3} = \mathbf{6} \oplus \mathbf{\bar{3}} \ . \tag{14.20}$$

Combining with spin and color and requiring antisymmetry, one finds that the most deeply bound diquark (and hence the lightest) is the one in the $\overline{\bf 3}$ and spin singlet state. The combination of the diquark with an antidiquark in the $\bf 3$ representation then gives a light nonet of four-quark scalar states. Letting the number of strange quarks determine the mass splitting, one obtains a mass inverted spectrum with a light isosinglet $(ud\bar{u}d\bar{d})$, a medium heavy isodoublet $(e.g., ud\bar{s}d)$ and a heavy isotriplet $(e.g., ds\bar{u}\bar{s})$ + isosinglet $(e.g., us\bar{u}\bar{s})$. It is then tempting to identify the lightest state with the $f_0(500)$, and the heaviest states with the $a_0(980)$, and $f_0(980)$. Then the meson with strangeness $\kappa(800)$ would lie in between.

QCD predicts the existence of extra isoscalar mesons. In the pure gauge theory, they contain only gluons, and are called the glueballs. The ground state glueball is predicted by lattice gauge theories to be 0^{++} , the first excited state 2^{++} . Errors on the mass predictions are large. From Ref. 11 one obtains 1750 (50) (80) MeV for the mass of the lightest 0^{++} glueball from quenched QCD. As an example for the glueball mass spectrum, we show in Fig. 14.3 a recent calculation from Ref. 10. A mass of 1710 MeV is predicted for the ground state, also with an error of about 100 MeV. Earlier work by other groups produced masses at 1650 MeV [12] and 1550 MeV [13] (see also [14]). The first excited state has a mass of about 2.4 GeV, and the lightest glueball with exotic quantum numbers (2^{+-}) has a mass of about 4 GeV

These calculations are made in the so-called "quenched approximation" which neglects $q\bar{q}$ loops. However, both glue and $q\bar{q}$ states will couple to singlet scalar mesons. Therefore glueballs will mix

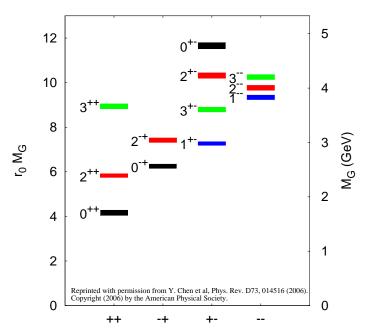


Figure 14.3: Predicted glueball mass spectrum from the lattice, in quenched approximation, (from Ref. 10).

with nearby $q\bar{q}$ states of the same quantum numbers. For example, the two isoscalar 0^{++} mesons around 1500 MeV will mix with the pure ground state glueball to generate the observed physical states $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$ [8,15]. Lattice calculations are only beginning to include these effects. We return to a discussion of this point in Sec. 14.6.

The existence of three singlet scalar mesons around 1.5 GeV suggests additional degrees of freedom such as glue, since only two mesons are predicted in this mass range. The $f_0(1500)$ [8,15] or, alternatively, the $f_0(1710)$ [12], have been proposed as candidates for the scalar glueball, both states having considerable mixing also with the $f_0(1370)$. Other mixing schemes, in particular with the $f_0(500)$ and the $f_0(980)$, have also been proposed (more details can be found in the "Note on Scalar Mesons" in the Meson Listings and in Ref. 16).

Mesons made of $q\bar{q}$ pairs bound by excited gluons g, the hybrid states $q\bar{q}g$, are also predicted. They should lie in the 1.9 GeV mass region, according to gluon flux tube models [17]. Lattice QCD also predicts the lightest hybrid, an exotic 1^{-+} , at a mass of 1.8 to 1.9 GeV [18]. However, the bag model predicts four nonets, among them an exotic 1^{-+} around or above 1.4 GeV [19,20]. There are so far two candidates for exotic states with quantum numbers 1^{-+} , the $\pi_1(1400)$ and $\pi_1(1600)$, which could be hybrids or four-quark states (see the "Note on Non- $q\bar{q}$ Mesons" in the 2006 issue of this Review [21] and in Ref. 16).

14.4. Baryons: qqq states

Baryons are fermions with baryon number $\mathcal{B}=1,\ i.e.,$ in the most general case, they are composed of three quarks plus any number of quark - antiquark pairs. So far all established baryons are 3-quark (qqq) configurations. The color part of their state functions is an SU(3) singlet, a completely antisymmetric state of the three colors. Since the quarks are fermions, the state function must be antisymmetric under interchange of any two equal-mass quarks (up and down quarks in the limit of isospin symmetry). Thus it can be written as

$$|qqq\rangle_A = |\operatorname{color}\rangle_A \times |\operatorname{space}, \operatorname{spin}, \operatorname{flavor}\rangle_S,$$
 (14.21)

where the subscripts S and A indicate symmetry or antisymmetry under interchange of any two equal-mass quarks. Note the contrast with the state function for the three nucleons in $^3\mathrm{H}$ or $^3\mathrm{He}$:

$$|NNN\rangle_A = |\operatorname{space}, \operatorname{spin}, \operatorname{isospin}\rangle_A$$
. (14.22)

This difference has major implications for internal structure, magnetic moments, etc. (For a nice discussion, see Ref. 22.)

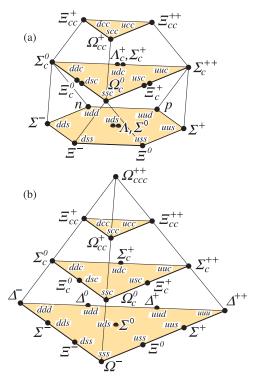


Figure 14.4: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) octet. (b) The 20-plet with an SU(3) decuplet.

The "ordinary" baryons are made up of u, d, and s quarks. The three flavors imply an approximate flavor $\mathrm{SU}(3)$, which requires that baryons made of these quarks belong to the multiplets on the right side of

$$\mathbf{3} \otimes \mathbf{3} \otimes \mathbf{3} = \mathbf{10}_S \oplus \mathbf{8}_M \oplus \mathbf{8}_M \oplus \mathbf{1}_A \tag{14.23}$$

(see Sec. 42, on "SU(n) Multiplets and Young Diagrams"). Here the subscripts indicate symmetric, mixed-symmetry, or antisymmetric states under interchange of any two quarks. The 1 is a uds state (Λ_1), and the octet contains a similar state (Λ_8). If these have the same spin and parity, they can mix. The mechanism is the same as for the mesons (see above). In the ground state multiplet, the SU(3) flavor singlet Λ_1 is forbidden by Fermi statistics. Section 41, on "SU(3) Isoscalar Factors and Representation Matrices," shows how relative decay rates in, say, $\mathbf{10} \to \mathbf{8} \otimes \mathbf{8}$ decays may be calculated.

The addition of the c quark to the light quarks extends the flavor symmetry to SU(4). However, due to the large mass of the c quark, this symmetry is much more strongly broken than the SU(3) of the three light quarks. Figures 14.4(a) and 14.4(b) show the SU(4) baryon multiplets that have as their bottom levels an SU(3) octet, such as the octet that includes the nucleon, or an SU(3) decuplet, such as the decuplet that includes the $\Delta(1232)$. All particles in a given SU(4) multiplet have the same spin and parity. The charmed baryons are discussed in more detail in the "Note on Charmed Baryons" in the Particle Listings. The addition of a b quark extends the flavor symmetry to SU(5); the existence of baryons with t-quarks is very unlikely due to the short lifetime of the top.

Table 14.5: N and Δ states in the N=0,1,2 harmonic oscillator bands. L^P denotes angular momentum and parity, S the three-quark spin and 'sym'=A,S,M the symmetry of the spatial wave function. Only dominant components indicated. Assignments in the N=2 band are partly tentative.

| | | | the | e N=2 ban | d are part | ly tentativ | ve. | | | | |
|---|--------------|---------|-----|----------------|----------------|----------------|-----------|-----------------|----------------|----------------|----------------|
| N | syn | n L^P | S | | N(I = | 1/2) | | $\Delta(I=3/2)$ | | | |
| 2 | A | 1+ | 1/2 | 1/2+ | $3/2^{+}$ | | | | | | |
| 2 | ${\bf M}$ | 2^+ | 3/2 | $1/2^{+}$ | $3/2^{+}$ | $5/2^{+}$ | $7/2^{+}$ | | | | |
| 2 | ${\bf M}$ | 2^{+} | 1/2 | | $3/2^{+}$ | $5/2^{+}$ | | | $3/2^{+}$ | $5/2^{+}$ | |
| 2 | ${\bf M}$ | 0^{+} | 3/2 | | $3/2^{+}$ | | | | | | |
| 2 | ${\bf M}$ | 0+ | 1/2 | $1/2^{+}$ | | | | $1/2^{+}$ | | | |
| | | | | $P_{11}(1710)$ | | | | $P_{31}(1750)$ | | | |
| 2 | $_{\rm S}$ | 2^+ | 3/2 | | | | | $1/2^{+}$ | $3/2^{+}$ | $5/2^{+}$ | $7/2^{+}$ |
| | | | | | | | | $P_{31}(1910)$ | $P_{33}(1920)$ | $F_{35}(1905)$ | $F_{37}(1950)$ |
| 2 | \mathbf{S} | 2^{+} | 1/2 | | $3/2^{+}$ | $5/2^{+}$ | | | | | |
| | | | | | $P_{13}(1720)$ | $F_{15}(1680)$ | | | | | |
| 2 | $_{\rm S}$ | 0_{+} | 3/2 | | | | | | $3/2^{+}$ | | |
| | | | | | | | | | $P_{33}(1600)$ | | |
| 2 | $_{\rm S}$ | 0+ | 1/2 | $1/2^{+}$ | | | | | | | |
| | | | | $P_{11}(1440)$ | | | | | | | |
| 1 | ${\bf M}$ | 1^{-} | 3/2 | $1/2^{-}$ | $3/2^{-}$ | $5/2^{-}$ | | | | | |
| | | | | $S_{11}(1650)$ | $D_{13}(1700)$ | $D_{15}(1675)$ | | | | | |
| 1 | ${\bf M}$ | 1- | 1/2 | $1/2^{-}$ | $3/2^{-}$ | | | $1/2^{-}$ | $3/2^{-}$ | | |
| | | | | $S_{11}(1535)$ | $D_{13}(1520)$ | | | $S_{31}(1620)$ | $D_{33}(1700)$ | | |
| 0 | S | 0^+ | 3/2 | | | | | | 3/2+ | | |
| | | | | | | | | | $P_{33}(1232)$ | | |
| 0 | \mathbf{S} | 0+ | 1/2 | $1/2^{+}$ | | | | | | | |
| | | | | $P_{11}(938)$ | | | | | | | |

For the "ordinary" baryons (no c or b quark), flavor and spin may be combined in an approximate flavor-spin SU(6), in which the six basic states are $d \uparrow$, $d \downarrow$, \cdots , $s \downarrow$ (\uparrow , \downarrow = spin up, down). Then the baryons belong to the multiplets on the right side of

$$\mathbf{6} \otimes \mathbf{6} \otimes \mathbf{6} = \mathbf{56}_S \oplus \mathbf{70}_M \oplus \mathbf{70}_M \oplus \mathbf{20}_A . \tag{14.24}$$

These SU(6) multiplets decompose into flavor SU(3) multiplets as follows:

$$\mathbf{56} = {}^{4}\mathbf{10} \oplus {}^{2}\mathbf{8} \tag{14.25a}$$

$$70 = {}^{2}10 \oplus {}^{4}8 \oplus {}^{2}8 \oplus {}^{2}1 \tag{14.25b}$$

$$20 = {}^{2}8 \oplus {}^{4}1 , \qquad (14.25c)$$

where the superscript (2S+1) gives the net spin S of the quarks for each particle in the SU(3) multiplet. The $J^P=1/2^+$ octet containing the nucleon and the $J^P=3/2^+$ decuplet containing the $\Delta(1232)$ together make up the "ground-state" 56-plet, in which the orbital angular momenta between the quark pairs are zero (so that the spatial part of the state function is trivially symmetric). The $\bf 70$ and $\bf 20$ require some excitation of the spatial part of the state function in order to make the overall state function symmetric. States with nonzero orbital angular momenta are classified in ${\rm SU}(6)\otimes {\rm O}(3)$ supermultiplets.

It is useful to classify the baryons into bands that have the same number N of quanta of excitation. Each band consists of a number of supermultiplets, specified by (D,L_N^P) , where D is the dimensionality of the SU(6) representation, L is the total quark orbital angular momentum, and P is the total parity. Supermultiplets contained in bands up to N = 12 are given in Ref. 24. The N = 0 band, which contains the nucleon and $\Delta(1232)$, consists only of the $(56,0_0^+)$ supermultiplet. The N = 1 band consists only of the $(70,1_1^-)$ multiplet and contains the negative-parity baryons with masses below about 1.9 GeV. The N = 2 band contains five supermultiplets: $(56,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(70,0_2^+),\,(7$

The wave functions of the non-strange baryons in the harmonic oscillator basis are often labeled by $|X^{2S+1}L_\pi J^P\rangle$, where S,L,J,P are as above, X=N or Δ , and $\pi=S,M$ or A denotes the symmetry of the spatial wave function. The possible model states for the bands with N=0,1,2 are given in Table 14.5. The assignment of experimentally observed states is only complete and well established up to the N=1 band. Some more tentative assignments for higher multiplets are suggested in Ref. 25.

In Table 14.6, quark-model assignments are given for many of the established baryons whose $\mathrm{SU}(6)\otimes\mathrm{O}(3)$ compositions are relatively unmixed. One must, however, keep in mind that apart from the mixing of the Λ singlet and octet states, states with same J^P but different L,S combinations can also mix. In the quark model with one-gluon exchange motivated interactions, the size of the mixing is determined by the relative strength of the tensor term with respect to the contact term (see below). The mixing is more important for the decay patterns of the states than for their positions. An example are the lowest lying $(70,1_1^-)$ states with $J^P\!=\!1/2^-$ and $3/2^-$. The physical states are:

$$|S_{11}(1535)\rangle = \cos(\Theta_S)|N^2P_M1/2^-\rangle - \sin(\Theta_S)|N^4P_M1/2^-\rangle$$
 (14.26)

$$|D_{13}(1520)\rangle = \cos(\Theta_D)|N^2 P_M 3/2^-\rangle - \sin(\Theta)_D|N^4 P_M 3/2^-\rangle$$
 (14.27)

and the orthogonal combinations for $S_{11}(1650)$ and $D_{13}(1700)$. The mixing is large for the $J^P = 1/2^-$ states ($\Theta_S \approx -32^o$), but small for the $J^P = 3/2^-$ states ($\Theta_D \approx +6^o$) [26,31].

All baryons of the ground state multiplets are known. Many of their properties, in particular their masses, are in good agreement even with the most basic versions of the quark model, including harmonic (or linear) confinement and a spin-spin interaction, which is responsible for the octet - decuplet mass shifts. A consistent description of the ground-state electroweak properties, however, requires refined relativistic constituent quark models.

Table 14.6: Quark-model assignments for some of the known baryons in terms of a flavor-spin SU(6) basis. Only the dominant representation is listed. Assignments for several states, especially for the $\Lambda(1810)$, $\Lambda(2350)$, $\Xi(1820)$, and $\Xi(2030)$, are merely educated guesses. † recent suggestions for assignments and re-assignments from ref. [28]. For assignments of the charmed baryons, see the "Note on Charmed Baryons" in the Particle Listings.

| J^P | (D,L_N^P) | S Octet | members | | Singlets | |
|------------------|------------------|-----------------------------|--------------------------|-------------|---------------------------|--|
| $1/2^{+}$ | $(56,0_0^+)$ | $1/2 N(939) \Lambda(1116)$ | $\Sigma(1193)$ | Ξ(1318) | | |
| $1/2^{+}$ | $(56,0_2^+)$ | $1/2 N(1440) \Lambda(1600)$ | $\Sigma(1660)$ | Ξ(1690) | | |
| $1/2^{-}$ | $(70,1_1^-)$ | $1/2 N(1535) \Lambda(1670)$ | $\Sigma(1620)$ | $\Xi(?)$ | $\Lambda(1405)$ | |
| | | | $\Sigma(1560)^{\dagger}$ | | | |
| $3/2^{-}$ | $(70,1_1^-)$ | $1/2 N(1520) \Lambda(1690)$ | $\Sigma(1670)$ | $\Xi(1820)$ | $\Lambda(1520)$ | |
| $1/2^{-}$ | $(70,1_1^-)$ | $3/2 N(1650) \Lambda(1800)$ | $\Sigma(1750)$ | $\Xi(?)$ | | |
| | | | $\Sigma(1620)^{\dagger}$ | | | |
| $3/2^{-}$ | $(70,1_1^-)$ | $3/2 N(1700) \Lambda(?)$ | $\Sigma(1940)^{\dagger}$ | Ξ(?) | | |
| $5/2^{-}$ | $(70,1_1^-)$ | $3/2 N(1675) \Lambda(1830)$ | $\Sigma(1775)$ | Ξ(1950) | | |
| $1/2^{+}$ | $(70,0_2^+)$ | $1/2 N(1710) \Lambda(1810)$ | $\Sigma(1880)$ | $\Xi(?)$ | $\Lambda(1810)^{\dagger}$ | |
| $3/2^{+}$ | $(56,2^+_2)$ | $1/2 N(1720) \Lambda(1890)$ | $\Sigma(?)$ | $\Xi(?)$ | | |
| $5/2^{+}$ | $(56,2^+_2)$ | $1/2 N(1680) \Lambda(1820)$ | $\Sigma(1915)$ | $\Xi(2030)$ | | |
| $7/2^{-}$ | $(70,3_3^-)$ | $1/2 N(2190) \Lambda(?)$ | $\Sigma(?)$ | $\Xi(?)$ | $\Lambda(2100)$ | |
| $9/2^{-}$ | $(70,3^{-}_{3})$ | $3/2 N(2250) \Lambda(?)$ | $\Sigma(?)$ | Ξ(?) | | |
| | | $1/2N(2220)\Lambda(2350)$ | $\Sigma(?)$ | Ξ(?) | | |
| Decuplet members | | | | | | |

The situation for the excited states is much less clear. The assignment of some experimentally observed states with strange quarks to model configurations is only tentative and in many cases candidates are completely missing. Recently, Melde, Plessas and Sengl [28] have calculated baryon properties in relativistic constituent quark models, using one-gluon exchange and Goldstone-boson exchange for the modeling of the hyperfine interactions (see Sec. 14.5 on Dynamics). Both types of models give qualitatively comparable results, and underestimate in general experimentally observed decay widths. Nevertheless, in particular on the basis of the observed decay patterns, the authors have assigned some additional states with strangeness to the SU(3) multiplets and suggest re-assignments for a few others. Among the new assignments are states with weak experimental evidence (two or three star ratings) and partly without firm spin/parity assignments, so that further experimental efforts are necessary before final conclusions can be drawn. We have added their suggestions in Table 14.6.

In the non-strange sector there are two main problems which are illustrated in Fig. 14.5, where the experimentally observed excitation spectrum of the nucleon (N and Δ resonances) is compared to the results of a typical quark model calculation [27]. The lowest states from the N=2 band, the P₁₁(1440), and the P₃₃(1600), appear lower than the negative parity states from the N=1 band (see Table 14.5) and much lower than predicted by most models. Also negative parity Δ states from the N=3 band (S₃₁(1900), D₃₃(1940), and D₃₅(1930)) are too low in energy. Part of the problem could be experimental. Among the negative parity Δ states, only the D₃₅ has three stars and

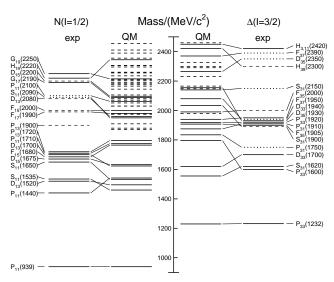


Figure 14.5: Excitation spectrum of the nucleon. Compared are the positions of the excited states identified in experiment, to those predicted by a relativized quark model calculation. Left hand side: isospin I=1/2 N-states, right hand side: isospin I=3/2 Δ -states. Experimental: (columns labeled 'exp'), three-and four-star states are indicated by full lines (two-star dashed lines, one-star dotted lines). At the very left and right of the figure, the spectroscopic notation of these states is given. Quark model [27]: (columns labeled 'QM'), all states for the N=1,2 bands, low-lying states for the N=3,4,5 bands. Full lines: at least tentative assignment to observed states, dashed lines: so far no observed counterparts. Many of the assignments between predicted and observed states are highly tentative.

the uncertainty in the position of the $\mathrm{P}_{33}(1600)$ is large (1550 - 1700 MeV).

Furthermore, many more states are predicted than observed. This has been known for a long time as the 'missing resonance' problem [26]. Up to an excitation energy of 2.4 GeV, about 45 Nstates are predicted, but only 12 are established (four- or three-star; see Note on N and Δ Resonances for the rating of the status of resonances) and 7 are tentative (two- or one-star). Even for the N=2 band, up to now only half of the predicted states have been observed. The most recent partial wave analysis of elastic pion scattering and charge exchange data by Arndt and collaborators [29] has made the situation even worse. They found no evidence for almost half of the states listed in this review (and included in Fig. 14.5). Such analyses are of course biased against resonances which couple only weakly to the $N\pi$ channel. Quark model predictions for the couplings to other hadronic channels and to photons are given in Ref. 27. A large experimental effort is ongoing at several electron accelerators to study the baryon resonance spectrum with real and virtual photon-induced meson production reactions. This includes the search for as-yet-unobserved states, as well as detailed studies of the properties of the low lying states (decay patterns, electromagnetic couplings, magnetic moments, etc.) (see Ref. 30 for recent reviews). This experimental effort has currently entered its final phase with the measurement of single and double polarization observables for many different meson production channels, so that a much better understanding of the experimental spectrum can be expected for the near future.

In quark models, the number of excited states is determined by the effective degrees of freedom, while their ordering and decay properties are related to the residual quark - quark interaction. An overview of quark models for baryons is given in Ref. 31, a recent discussion of baryon spectroscopy is given in Ref. 25. The effective degrees of freedom in the standard nonrelativistic quark model are three equivalent valence quarks with one-gluon exchange-motivated, flavor-independent color-magnetic interactions. A different class of models uses interactions which give rise to a quark - diquark clustering

of the baryons (for a review see Ref. 32). If there is a tightly bound diquark, only two degrees of freedom are available at low energies, and thus fewer states are predicted. Furthermore, selection rules in the decay pattern may arise from the quantum numbers of the diquark. More states are predicted by collective models of the baryon like the algebraic approach in Ref. 33. In this approach, the quantum numbers of the valence quarks are distributed over a Y-shaped string-like configuration, and additional states arise e.g., from vibrations of the strings. More states are also predicted in the framework of flux-tube models (see Ref. 34), which are motivated by lattice QCD. In addition to the quark degrees of freedom, flux-tubes responsible for the confinement of the quarks are considered as degrees of freedom. These models include hybrid baryons containing explicit excitations of the gluon fields. However, since all half integral J^P quantum numbers are possible for ordinary baryons, such 'exotics' will be very hard to identify, and probably always mix with ordinary states. So far, the experimentally observed number of states is still far lower even than predicted by the quark-diquark models.

Recently, the influence of chiral symmetry on the excitation spectrum of the nucleon has been hotly debated from a somewhat new perspective. Chiral symmetry, the fundamental symmetry of QCD, is strongly broken for the low lying states, resulting in large mass differences of parity partners like the $J^P=1/2^+$ P₁₁(938) ground state and the $J^P=1/2^-$ S₁₁(1535) excitation. However, at higher excitation energies there is some evidence for parity doublets and even some very tentative suggestions for full chiral multiplets of N^* and Δ resonances. An effective restoration of chiral symmetry at high excitation energies due to a decoupling from the quark condensate of the vacuum has been discussed (see Ref. 35 for recent reviews) as a possible cause. In this case, the mass generating mechanisms for low and high lying states would be essentially different. As a further consequence, the parity doublets would decouple from pions, so that experimental bias would be worse. However, parity doublets might also arise from the spin-orbital dynamics of the 3-quark system. Presently, the status of data does not allow final conclusions.

The most recent developments on the theory side are the first unquenched lattice calculations for the excitation spectrum discussed in Sec. 14.6. The results are basically consistent with the level counting of $\mathrm{SU}(6)\otimes\mathrm{O}(3)$ in the standard non-relativistic quark model and show no indication for quark-diquark structures or parity doubling. Consequently, there is as yet no indication from lattice that the mis-match between the excitation spectrum predicted by the standard quark model and experimental observations is due to inappropriate degrees of freedom in the quark model.

14.5. Dynamics

Quantum chromodynamics (QCD) is well-established as the theory for the strong interactions. As such, one of the goals of QCD is to predict the spectrum of strongly-interacting particles. To date, the only first-principles calculations of spectroscopy from QCD use lattice methods. These are the subject of Sec. 14.6. These calculations are difficult and unwieldy, and many interesting questions do not have a good lattice-based method of solution. Therefore, it is natural to build models, whose ingredients are abstracted from QCD, or from the low-energy limit of QCD (such as chiral Lagrangians) or from the data itself. The words "quark model" are a shorthand for such phenomenological models. Many specific quark models exist, but most contain a similar basic set of dynamical ingredients. These include:

- i) A confining interaction, which is generally spin-independent (e.g., harmonic oscillator or linear confinement);
- ii) Different types of spin-dependent interactions:
 - a) commonly used is a color-magnetic flavor-independent interaction modeled after the effects of gluon exchange in QCD (see e.g., Ref. 36). For example, in the S-wave states, there is a spin-spin hyperfine interaction of the form

$$H_{HF} = -\alpha_S M \sum_{i>j} (\overrightarrow{\sigma} \lambda_a)_i (\overrightarrow{\sigma} \lambda_a)_j , \qquad (14.28)$$

where M is a constant with units of energy, λ_a ($a = 1, \dots, 8$,) is the set of SU(3) unitary spin matrices, defined in Sec. 41,

on "SU(3) Isoscalar Factors and Representation Matrices," and the sum runs over constituent quarks or antiquarks. Spin-orbit interactions, although allowed, seem to be small in general, but a tensor term is responsible for the mixing of states with the same J^P but different L,S combinations.

b) other approaches include flavor-dependent short-range quark forces from instanton effects (see e.g., Ref. 37). This interaction acts only on scalar, isoscalar pairs of quarks in a relative S-wave state:

$$\langle q^2; S, L, T | W | q^2; S, L, T \rangle = -4g \delta_{S,0} \delta_{L,0} \delta_{L,0} \mathcal{W}$$
 (14.29)

where W is the radial matrix element of the contact interaction. c) a rather different and controversially discussed approach is

c) a rather different and controversially discussed approach is based on flavor-dependent spin-spin forces arising from one-boson exchange. The interaction term is of the form:

$$H_{HF} \propto \sum_{i < j} V(\overrightarrow{r}_{ij}) \lambda_i^F \cdot \lambda_j^F \overrightarrow{\sigma}_i \cdot \overrightarrow{\sigma}_j$$
 (14.30)

where the λ_i^F are in flavor space (see e.g., Ref. 38).

- iii) A strange quark mass somewhat larger than the up and down quark masses, in order to split the SU(3) multiplets;
- iv) In the case of spin-spin interactions (iia,c), a flavor-symmetric interaction for mixing $q\overline{q}$ configurations of different flavors (e.g., $u\overline{u} \leftrightarrow d\overline{d} \leftrightarrow s\overline{s}$), in isoscalar channels, so as to reproduce e.g., the η η' and ω ϕ mesons.

These ingredients provide the basic mechanisms that determine the hadron spectrum in the standard quark model.

14.6. Lattice Calculations of Hadronic Spectroscopy

Lattice calculations are a major source of information about QCD masses and matrix elements. The necessary theoretical background is given in Sec. 17 of this *Review*. Here we confine ourselves to some general comments and illustrations of lattice calculations for spectroscopy.

In general, the cleanest lattice results come from computations of processes in which there is only one particle in the simulation volume. These quantities include masses of hadrons, simple decay constants, like pseudoscalar meson decay constants, and semileptonic form factors (such as the ones appropriate to $B \to Dl\nu$, $Kl\nu$, $\pi l\nu$). The cleanest predictions for masses are for states which have narrow decay widths and are far below any thresholds to open channels, since the effects of final state interactions are not yet under complete control on the lattice. As a simple corollary, the lightest state in a channel is easier to study than the heavier ones. "Difficult" states for the quark model (such as exotics) are also difficult for the lattice because of the lack of simple operators which couple well to them.

Good-quality modern lattice calculations will present multi-part error budgets with their predictions. A small part of the uncertainty is statistical, from sample size. Typically, the quoted statistical uncertainty includes uncertainty from a fit: it is rare that a simulation computes one global quantity which is the desired observable. Simulations which include virtual quark-antiquark pairs (also known as "dynamical quarks" or "sea quarks") are often done at up and down quark mass values heavier than the experimental ones, and it is then necessary to extrapolate in these quark masses. Simulations can work at the physical values of the heavier quarks' masses. They are always done at nonzero lattice spacing, and so it is necessary to extrapolate to zero lattice spacing. Some theoretical input is needed to do this. Much of the uncertainty in these extrapolations is systematic, from the choice of fitting function. Other systematics include the effect of finite simulation volume, the number of flavors of dynamical quarks actually simulated, and technical issues with how these dynamical quarks are included. The particular choice of a fiducial mass (to normalize other predictions) is not standardized; there are many possible choices, each with its own set of strengths and weaknesses, and determining it usually requires a second lattice simulation from that used to calculate the quantity under consideration.

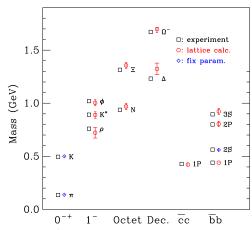


Figure 14.6: A recent calculation of spectroscopy with dynamical u, d, and s quarks. The pion and kaon fix the light quark masses. Only the mass splittings relative to the 1S states in the heavy quark sectors are shown. The Υ 2S-1S splitting sets the overall energy scale.

A systematic error of major historical interest is the "quenched approximation," in which dynamical quarks are simply left out of the simulation. This was done because the addition of these virtual pairs presented an expensive computational problem. No generally-accepted methodology has ever allowed one to correct for quenching effects, short of redoing all calculations with dynamical quarks. Recent advances in algorithms and computer hardware have rendered it obsolete.

With these brief remarks, we turn to examples. The field of lattice QCD simulations is vast, and so it is not possible to give a comprehensive review of them in a small space. The history of lattice QCD simulations is a story of thirty years of incremental improvements in physical understanding, algorithm development, and ever faster computers, which have combined to bring the field to a present state where it is possible to carry out very high quality calculations. We present a few representative illustrations, to show the current state of the art.

By far, the major part of all lattice spectroscopy is concerned with that of the light hadrons, and so we illustrate results from two groups. First, a recent calculation of spectroscopy with dynamical $u,\ d,$ and s quarks is shown in Fig. 14.6. The pion and kaon masses are used to set the light quark masses. The Υ 2S-1S splitting is used to set the lattice spacing or equivalently, the overall energy scale in the lattice calculation. This is an updated figure from Ref. 39, using results from Ref. 41 and Ref. 42 (D. Toussaint, private communication).

These results come from simulations using dynamical up and down quarks which are heavier than their physical values. As a result, the error bars on all the particles which decay strongly and are above their decay thresholds (the vector mesons and the Δ , for example) do not include the effect of coupling to the decay channels.

A more recent result by Ref. 40 goes farther, in that its simulations include the coupling of resonances to open channels in their analysis. Their plot of light hadron spectroscopy is shown in Fig. 14.7.

Flavor singlet mesons are at the frontier of lattice QCD calculations, because one must include the effects of "annihilation graphs," for the valence q and \bar{q} . Recently, the RBC and UKQCD collaborations, Ref. 6, have reported a calculation of the η and η' mesons, finding masses of 573(6) and 947(142) MeV, respectively. The singlet-octet mixing angle (in the conventions of Table 14.2) is $\theta_{lin}=-14.1(2.8)^{\circ}$.

The spectroscopy of mesons containing heavy quarks has become a truly high-precision endeavor. These simulations use Non-Relativistic QCD (NRQCD) or Heavy Quark Effective Theory (HQET), systematic expansions of the QCD Lagrangian in powers of the heavy quark velocity, or the heavy quark mass. Terms in the Lagrangian have obvious quark model analogs, but are derived directly from QCD. For example, the heavy quark potential is a derived quantity, extracted from simulations. Fig. 14.8 shows the mass spectrum for mesons containing at least one heavy (b or c) quark from Ref. 42 and Ref. 43.

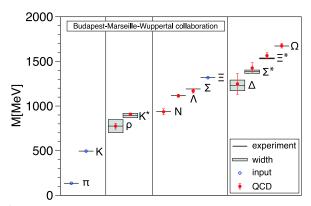


Figure 14.7: Light hadron spectroscopy from Ref. 40.

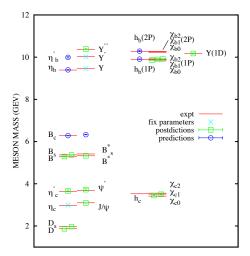


Figure 14.8: Spectroscopy for mesonic systems containing one or more heavy quarks (adapted from Ref. 42 and Ref. 43). Particles whose masses are used to fix lattice parameters are shown with crosses; the authors distinguish between "predictions" and "postdictions" of their calculation. Lines represent experiment.

The calculations uses a discretization of nonrelativistic QCD for bottom quarks with charm and lighter quarks being handled with an improved relativistic action. Three flavors of light dynamical quarks are included.

Finally, Fig. 14.9 shows recent lattice calculations of singly and double charmed baryons. Here we are at the forefront of theory and experiment.

Recall that lattice calculations take operators which are interpolating fields with quantum numbers appropriate to the desired states, compute correlation functions of these operators, and fit the correlation functions to functional forms parameterized by a set of masses and matrix elements. As we move away from hadrons which can be created by the simplest quark model operators (appropriate to the lightest meson and baryon multiplets) we encounter a host of new problems: either no good interpolating fields, or too many possible interpolating fields, and many states with the same quantum numbers. Techniques for dealing with these interrelated problems vary from collaboration to collaboration, but all share common features: typically, correlation functions from many different interpolating fields are used, and the signal is extracted in what amounts to a variational calculation using the chosen operator basis. In addition to mass spectra, wave function information can be garnered from the form of the best variational wave function. Of course, the same problems which are present in the spectroscopy of the lightest hadrons (the need to extrapolate to infinite volume, physical values of the light quark masses, and zero lattice spacing) are also present. We briefly touch on three different kinds of hadrons: excited states of baryons, glueballs,

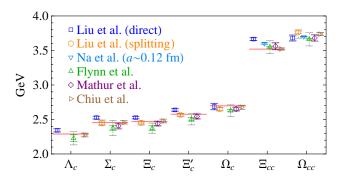


Figure 14.9: Lattice predictions for masses of charmed baryons. Data are Liu, et al., Ref. 44; Na et al., Ref. 45; Flynn et al., Ref. 46; Mathur et al., Ref. 47; and Chiu et al., Ref. 48. The first two references use full QCD; the latter three are quenched. Two mass extractions are taken from Ref. 44; the lighter (orange) circular points come from a calculation of mass splittings while the darker (blue) square points are from a direct mass extrapolation. Lines are from experiment.

and hybrid mesons. The quality of the data is not as good as for the ground states, and so the results continue to evolve.

Ref. 49 is a good recent review of excited baryon spectroscopy. The interesting physics questions to be addressed are precisely those enumerated in the last section. An example of a recent calculation, due to Ref. 50 is shown in Fig. 14.10. Notice that the pion is not yet at its physical value. The lightest positive parity state is the nucleon, and the Roper resonance has not yet appeared as a light state.

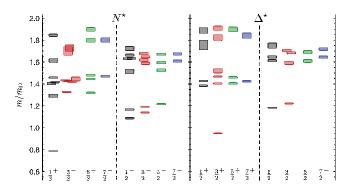


Figure 14.10: Spin-identified spectrum of nucleons and deltas, from lattices where $m_{\pi}=396$ MeV, in units of the calculated Ω mass, from Ref. 50. The colors just correspond to the different J assignments: grey for J=1/2, red for J=3/2, green for 5/2, blue for J=7/2.

Exotic mesons share the difficulties of ordinary excited states, and some recent calculations actually include both kinds of states in their combined fits. Ref. 51 provides a good summary of the theoretical and experimental situation regarding mesons with exotic quantum numbers, including a compilation of lattice data. The lightest exotics, the h_0, η_1 , and h_2 , have long been targets of lattice studies. Recently, the authors of Ref. 52 have presented new results for isoscalar and isovector meson spectroscopy, which observe the three states around 2 GeV. Again, the light quark masses in the simulations are higher than in nature; the pion is at 396 MeV.

Finally, glueballs. In Fig. 14.3 we showed a figure from Ref. 10 showing a lattice prediction for the glueball mass spectrum in quenched approximation. A true QCD prediction of the glueball spectrum requires dynamical light quarks and (because glueball operators are intrinsically noisy) high statistics. Only recently have the first useful such calculations appeared. Fig. 14.11 shows results from Ref. 53, done with dynamical $u,\ d$ and s quarks at two lattice spacings, 0.123 and 0.092 fm, along with comparisons to the quenched lattice calculation of Ref. 11 and to experimental isosinglet mesons.

The dynamical simulation is, of course, not the last word on this subject, but it shows that the effects of quenching seem to be small.

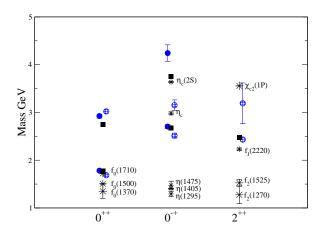


Figure 14.11: Lattice QCD predictions for glueball masses. The open and closed circles are the larger and smaller lattice spacing data of the full QCD calculation of glueball masses of Ref. 53. Squares are the quenched data for glueball masses of Ref. 11. The bursts labeled by particle names are experimental states with the appropriate quantum numbers.

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15. GRAND UNIFIED THEORIES

Revised October 2011 by S. Raby (Ohio State University).

15.1. Grand Unification

15.1.1. Standard Model: An Introduction:

In spite of all the successes of the Standard Model [SM] it is unlikely to be the final theory. It leaves many unanswered questions. Why the local gauge interactions $SU(3)_C \times SU(2)_L \times U(1)_V$ and why 3 families of quarks and leptons? Moreover why does one family consist of the states $[Q, u^c, d^c; L, e^c]$ transforming as $[(3, 2, 1/3), (\bar{3}, 1, -4/3),$ $(\bar{3},1,2/3); (1,2,-1), (1,1,2)], \text{ where } Q=(u,d) \text{ and } L=(\nu,e) \text{ are }$ $SU(2)_L$ doublets and u^c , d^c , e^c are charge conjugate $SU(2)_L$ singlet fields with the $U(1)_Y$ quantum numbers given? [We use the convention that electric charge $Q_{EM} = T_{3L} + Y/2$ and all fields are left handed Weyl spinors.] Note the SM gauge interactions of quarks and leptons are completely fixed by their gauge charges. Thus if we understood the origin of this charge quantization, we would also understand why there are no fractionally charged hadrons. Finally, what is the origin of quark and lepton masses or the apparent hierarchy of family masses and quark and leptonic mixing angles? Perhaps if we understood this, we would also know the origin of CP violation, the solution to the strong CP problem, the origin of the cosmological matter - antimatter asymmetry. In addition, it lacks an explanation for the observed dark matter and dark energy of the universe.

The SM has 19 arbitrary parameters; their values are chosen to fit the data. Three arbitrary gauge couplings: g_3 , g, g' (where g, g' are the $SU(2)_L$, $U(1)_Y$ couplings, respectively) or equivalently $\alpha_s = (g_3^2/4\pi)$, $\alpha_{EM} = (e^2/4\pi)$ ($e = g \sin\theta_W$) and $\sin^2\theta_W = (g')^2/(g^2+(g')^2)$. In addition there are 13 parameters associated with the 9 charged fermion masses and the four mixing angles in the CKM matrix. The remaining 3 parameters are v, λ [the Higgs VEV and quartic coupling] (or equivalently M_Z , m_h^0) and the QCD θ parameter. In addition, data from neutrino oscillation experiments provide convincing evidence for neutrino masses. With 3 light Majorana neutrinos there are at least 9 additional parameters in the neutrino sector; 3 masses and 6 mixing angles and phases. In summary, the SM has too many arbitrary parameters and leaves open too many unresolved questions to be considered complete. These are the problems which grand unified theories hope to address.

15.1.2. Charge Quantization:

In the Standard Model, quarks and leptons are on an equal footing; both fundamental particles without substructure. It is now clear that they may be two faces of the same coin; unified, for example, by extending QCD (or $SU(3)_C$) to include leptons as the fourth color, $SU(4)_C$ [1]. The complete Pati-Salam gauge group is $SU(4)_C \times SU(2)_L \times SU(2)_R$ with the states of one family $[(Q,L),(Q^c,L^c)]$ transforming as $[(4,2,1),(\bar{4},1,\bar{2})]$ where $Q^c = (d^c,u^c),\ L^c = (e^c,\nu^c)$ are doublets under $SU(2)_R$. Electric charge is now given by the relation $Q_{EM} = T_{3L} + T_{3R} + 1/2(B-L)$ and $SU(4)_C$ contains the subgroup $SU(3)_C \times (B-L)$ where B(L) is baryon (lepton) number. Note ν^c has no SM quantum numbers and is thus completely "sterile". It is introduced to complete the $SU(2)_R$ lepton doublet. This additional state is desirable when considering neutrino masses.

Although quarks and leptons are unified with the states of one family forming two irreducible representations of the gauge group; there are still 3 independent gauge couplings (two if one also imposes parity, i.e. $L \leftrightarrow R$ symmetry). As a result the three low energy gauge couplings are still independent arbitrary parameters. This difficulty is resolved by embedding the SM gauge group into the simple unified gauge group, Georgi-Glashow SU(5), with one universal gauge coupling α_G defined at the grand unification scale M_G [2]. Quarks and leptons still sit in two irreducible representations, as before, with a $\mathbf{10} = [Q, u^c, e^c]$ and $\mathbf{\bar{5}} = [d^c, L]$. Nevertheless, the three low energy gauge couplings are now determined in terms of two independent parameters: α_G and M_G . Hence there is one prediction.

In order to break the electroweak symmetry at the weak scale and give mass to quarks and leptons, Higgs doublets are needed which can sit in either a ${\bf 5_H}$ or ${\bf \bar 5_H}$. The additional 3 states are color triplet Higgs scalars. The couplings of these color triplets violate baryon and

lepton number and nucleons decay via the exchange of a single color triplet Higgs scalar. Hence in order not to violently disagree with the non-observation of nucleon decay, their mass must be greater than $\sim 10^{11}$ GeV [3]. Moreover, in supersymmetric GUTs, in order to cancel anomalies as well as give mass to both up and down quarks, both Higgs multiplets $\mathbf{5_{H}}$, $\mathbf{\bar{5}_{H}}$ are required. As we shall discuss later, nucleon decay now constrains the color triplet Higgs states in a SUSY GUT to have mass significantly greater than M_G .

Complete unification is possible with the symmetry group SO(10)with one universal gauge coupling α_G and one family of quarks and leptons sitting in the 16 dimensional spinor representation $16 = [10 + \overline{5} + 1]$ [4]. The SU(5) singlet 1 is identified with ν^c . In Table 1 we present the states of one family of quarks and leptons, as they appear in the 16. It is an amazing and perhaps even profound fact that all the states of a single family of quarks and leptons can be represented digitally as a set of 5 zeros and/or ones or equivalently as the tensor product of 5 "spin" 1/2 states with $\pm = |\pm \frac{1}{2}>$ and with the condition that we have an even number of |+> spins. The first three "spins" correspond to $SU(3)_C$ color quantum numbers, while the last two are $SU(2)_L$ weak quantum numbers. In fact an $SU(3)_C$ rotation just raises one color index and lowers another, thereby changing colors $\{r,\ b,\ y\}$. Similarly an $SU(2)_L$ rotation raises one weak index and lowers another, thereby flipping the weak isospin from up to down or vice versa. In this representation weak hypercharge Y is given by the simple relation $Y = -2/3(\sum \text{ color spins}) + (\sum \text{ weak spins})$. SU(5)rotations [in particular, the ones NOT in $SU(3)_C \times SU(2)_L \times U(1)_Y$] then raise (or lower) a color index, while at the same time lowering (or raising) a weak index. It is easy to see that such rotations can mix the states $\{Q, u^c, e^c\}$ and $\{d^c, L\}$ among themselves and ν^c is a singlet. The new SO(10) rotations [not in SU(5)] are then given by either raising or lowering any two spins. For example, by raising the two weak indices ν^c rotates into e^c , etc.

Table 15.1: The quantum numbers of the ${\bf 16}$ dimensional representation of SO(10).

| State | Y | Color | Weak |
|----------------------|------|-------|------|
| $ u^c $ | 0 | | |
| e^c | 2 | | ++ |
| u_r | 1/3 | + | -+ |
| d_r | 1/3 | + | +- |
| $oldsymbol{u}_b$ | 1/3 | - + - | -+ |
| d_b | 1/3 | -+- | +- |
| $oldsymbol{u}_y$ | 1/3 | + | -+ |
| d_y | 1/3 | + | +- |
| $oldsymbol{u}_r^c$ | -4/3 | - + + | |
| \boldsymbol{u}_b^c | -4/3 | + - + | |
| $oldsymbol{u}_y^c$ | -4/3 | + + - | |
| d_r^c | 2/3 | -++ | ++ |
| $oldsymbol{d}_b^c$ | 2/3 | + - + | ++ |
| $oldsymbol{d}_y^c$ | 2/3 | + + - | ++ |
| ν | -1 | +++ | -+ |
| e | -1 | +++ | +- |

SO(10) has two inequivalent maximal breaking patterns. $SO(10) \rightarrow SU(5) \times U(1)_X$ and $SO(10) \rightarrow SU(4)_C \times SU(2)_L \times SU(2)_R$. In the first case we obtain Georgi-Glashow SU(5) if Q_{EM} is given in terms of SU(5) generators alone or so-called flipped SU(5) [5] if Q_{EM} is partly in $U(1)_X$. In the latter case we have the Pati-Salam symmetry. If SO(10) breaks directly to the SM at M_G , then we retain the prediction for gauge coupling unification. However more possibilities for breaking (hence more breaking scales and more parameters) are available in SO(10). Nevertheless with one breaking pattern $SO(10) \rightarrow SU(5) \rightarrow$ SM, where the last breaking scale is M_G , the predictions from gauge coupling unification are preserved. The Higgs multiplets in

minimal SO(10) are contained in the fundamental $\mathbf{10_H} = [\mathbf{5_H}, \ \mathbf{\bar{5}_H}]$ representation. Note, only in SO(10) does the gauge symmetry distinguish quark and lepton multiplets from Higgs multiplets.

Finally, larger symmetry groups have been considered. For example, E(6) has a fundamental representation ${\bf 27}$ which under SO(10) transforms as a $[{\bf 16+10+1}]$. The breaking pattern $E(6) \to SU(3)_C \times SU(3)_L \times SU(3)_R$ is also possible. With the additional permutation symmetry Z(3) interchanging the three SU(3)s we obtain so-called "trinification" [6] with a universal gauge coupling. The latter breaking pattern has been used in phenomenological analyses of the heterotic string [7]. However, in larger symmetry groups, such as E(6), SU(6), etc., there are now many more states which have not been observed and must be removed from the effective low energy theory. In particular, three families of ${\bf 27}$ s in E(6) contain three Higgs type multiplets transforming as ${\bf 10}$ s of SO(10). This makes these larger symmetry groups unattractive starting points for model building.

15.1.3. String Theory and Orbifold GUTs:

Orbifold compactification of the heterotic string [8-10], and recent field theoretic constructions known as orbifold GUTs [11], contain grand unified symmetries realized in 5 and 6 dimensions. However, upon compactifying all but four of these extra dimensions, only the MSSM is recovered as a symmetry of the effective four dimensional field theory. These theories can retain many of the nice features of four dimensional SUSY GUTs, such as charge quantization, gauge coupling unification and sometimes even Yukawa unification; while at the same time resolving some of the difficulties of 4d GUTs, in particular problems with unwieldy Higgs sectors necessary for spontaneously breaking the GUT symmetry, and problems with doublet-triplet Higgs splitting or rapid proton decay. We will comment further on the corrections to the four dimensional GUT picture due to orbifold GUTs in the following sections. Finally, recent progress has been made in finding MSSM-like theories in the string landscape. This success is made possible by incorporating SUSY GUTs at an intermediate step in the construction. For a brief discussion, see Sec. 15.1.

${\bf 15.1.4.} \quad \textit{Gauge coupling unification}:$

The biggest paradox of grand unification is to understand how it is possible to have a universal gauge coupling g_G in a grand unified theory [GUT] and yet have three unequal gauge couplings at the weak scale with $g_3 > g > g'$. The solution is given in terms of the concept of an effective field theory [EFT] [18]. The GUT symmetry is spontaneously broken at the scale M_G and all particles not in the SM obtain mass of order M_G . When calculating Green's functions with external energies $E \gg M_G$, we can neglect the mass of all particles in the loop and hence all particles contribute to the renormalization group running of the universal gauge coupling. However, for $E \ll M_G$ one can consider an effective field theory

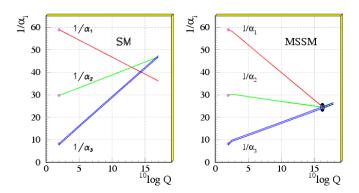


Figure 15.1: Gauge coupling unification in non-SUSY GUTs on the left vs. SUSY GUTs on the right using the LEP data as of 1991. Note, the difference in the running for SUSY is the inclusion of supersymmetric partners of standard model particles at scales of order a TeV (Fig. taken from Ref. 24). Given the present accurate measurements of the three low energy couplings, in particular $\alpha_s(M_Z)$, GUT scale threshold corrections are now needed to precisely fit the low energy data. The dark blob in the plot on the right represents these model dependent corrections.

including only the states with mass $< E \ll M_G$. The gauge symmetry of the EFT is $SU(3)_C \times SU(2)_L \times U(1)_Y$ and the three gauge couplings renormalize independently. The states of the EFT include only those of the SM; 12 gauge bosons, 3 families of quarks and leptons and one or more Higgs doublets. At M_G the two effective theories [the GUT itself is most likely the EFT of a more fundamental theory defined at a higher scale] must give identical results; hence we have the boundary conditions $g_3 = g_2 = g_1 \equiv g_G$ where at any scale $\mu < M_G$ we have $g_2 \equiv g$ and $g_1 = \sqrt{5/3} \ g'$. Then using two low energy couplings, such as $\alpha_s(M_Z)$, $\alpha_{EM}(M_Z)$, the two independent parameters α_G , M_G can be fixed. The third gauge coupling, $\sin^2\theta_W$ in this case, is then predicted. This was the procedure up until about 1991 [19,20]. Subsequently, the uncertainties in $\sin^2\theta_W$ were reduced ten fold. Since then, $\alpha_{EM}(M_Z)$, $\sin^2\theta_W$ have been used as input to predict α_G , M_G and $\alpha_s(M_Z)$ [21].

We emphasize that the above boundary condition is only valid when using one loop renormalization group [RG] running. With precision electroweak data, however, it is necessary to use two loop RG running. Hence one must include one loop threshold corrections to gauge coupling boundary conditions at both the weak and GUT scales. In this case it is always possible to define the GUT scale as the point where $\alpha_1(M_G) = \alpha_2(M_G) \equiv \tilde{\alpha}_G$ and $\alpha_3(M_G) = \tilde{\alpha}_G (1 + \epsilon_3)$. The threshold correction ϵ_3 is a logarithmic function of all states with mass of order M_G and $\tilde{\alpha}_G = \alpha_G + \Delta$ where α_G is the GUT coupling constant above M_G and Δ is a one loop threshold correction. Note, the popular code "SOFTSUSY" [22] has defined the GUT scale in just this way. The value of ϵ_3 can be read off from the output data. To the extent that gauge coupling unification is perturbative, the GUT threshold corrections are small and calculable. This presumes that the GUT scale is sufficiently below the Planck scale or any other strong coupling extension of the GUT, such as a strongly coupled string theory.

Supersymmetric grand unified theories [SUSY GUTs] are an extension of non-SUSY GUTs [23]. The key difference between SUSY GUTs and non-SUSY GUTs is the low energy effective theory. The low energy effective field theory in a SUSY GUT is assumed to satisfy N=1 supersymmetry down to scales of order the weak scale in addition to the SM gauge symmetry. Hence the spectrum includes all the SM states plus their supersymmetric partners. It also includes one pair (or more) of Higgs doublets; one to give mass to up-type quarks and the other to down-type quarks and charged leptons. Two doublets with opposite hypercharge Y are also needed to cancel fermionic triangle anomalies. Finally, it is important to recognize that a low energy SUSY breaking scale (the scale at which the SUSY partners of SM particles obtain mass) is necessary to solve the gauge hierarchy problem.

Also, in recent years there has been a great deal of progress in constructing three and four family models in Type IIA string theory with intersecting D6 branes [12]. Although these models can incorporate SU(5) or a Pati-Salam symmetry group in four dimensions, they typically have problems with gauge coupling unification. In the former case this is due to charged exotics which affect the RG running, while in the latter case the $SU(4)\times SU(2)_L\times SU(2)_R$ symmetry never unifies. Local models, however, with D-branes at singularities have had some more success in obtaining gauge coupling unification [13]. heterotic string theory models also exist whose low energy effective 4d field theory is a SUSY GUT [14]. These models have all the virtues and problems of 4d GUTs. Finally, many heterotic string models have been constructed with the standard model gauge symmetry in 4d and no intermediate GUT symmetry in less than 10d. Some minimal 3 family supersymmetric models have been constructed [15,16]. These theories may retain some of the symmetry relations of GUTs, however the unification scale would typically be the string scale, of order 5×10^{17} GeV, which is inconsistent with low energy data. A way out of this problem was discovered in the context of the strongly coupled heterotic string, defined in an effective 11 dimensions [17]. In this case the 4d Planck scale (which controls the value of the string scale) now unifies with the GUT scale.

Simple non-SUSY SU(5) is ruled out; initially by the increased accuracy in the measurement of $\sin^2 \theta_W$ and by early bounds on the proton lifetime (see below) [20]. However, by now LEP data [21] has conclusively shown that SUSY GUTs is the new standard model; by which we mean the theory used to guide the search for new physics beyond the present SM (see Fig. Fig. 15.1). SUSY extensions of the SM have the property that their effects decouple as the effective SUSY breaking scale is increased. Any theory beyond the SM must have this property simply because the SM works so well. However, the SUSY breaking scale cannot be increased with impunity, since this would reintroduce a gauge hierarchy problem. Unfortunately there is no clear-cut answer to the question, when is the SUSY breaking scale too high. A conservative bound would suggest that the third generation quarks and leptons must be lighter than about 1 TeV, in order that the one loop corrections to the Higgs mass from Yukawa interactions remains of order the Higgs mass bound itself.

At present gauge coupling unification within SUSY GUTs works extremely well. Exact unification at M_G , with two loop renormalization group running from M_G to M_Z , and one loop threshold corrections at the weak scale, fits to within 3 σ of the present precise low energy data. A small threshold correction at M_G ($\epsilon_3\sim$ - 3% to - 4%) is sufficient to fit the low energy data precisely [25,26,27]. 2 This may be compared to non-SUSY GUTs where the fit misses by \sim 12 σ and a precise fit requires new weak scale states in incomplete GUT multiplets or multiple GUT breaking scales. 3

Following the analysis of Ref. 27 let us try to understand the need for the GUT threshold correction and its order of magnitude. The renormalization group equations relate the low energy gauge coupling constants $\alpha_i(M_Z)$, i=1,2,3 to the value of the unification scale Λ_U and the GUT coupling α_U by the expression

$$\frac{1}{\alpha_i(M_Z)} = \frac{1}{\alpha_U} + \frac{b_i}{2\pi} \log\left(\frac{\Lambda_U}{M_Z}\right) + \delta_i \tag{15.1}$$

where Λ_U is the GUT scale evaluated at one loop and the threshold corrections, δ_i , are given by $\delta_i = \delta_i^{(2)} + \delta_i^{(l)} + \delta_i^{(g)}$ with $\delta_i^{(2)}$ representing two loop running effects, $\delta_i^{(l)}$ the light threshold corrections at the SUSY breaking scale and $\delta_i^{(g)} = \delta_i^{(h)} + \delta_i^{(b)}$ representing GUT scale threshold corrections. Note, in this analysis, the two loop RG running is treated on the same footing as weak and GUT scale threshold corrections. One then obtains the prediction

$$(\alpha_3(M_Z) - \alpha_3^{LO}(M_Z))/\alpha_3^{LO}(M_Z) = -\alpha_3^{LO}(M_Z) \delta_s$$
 (15.2)

where $\alpha_3^{LO}(M_Z)$ is the leading order one loop RG result and $\delta_s = \frac{1}{7}(5\delta_1 - 12\delta_2 + 7\delta_3)$ is the net threshold correction. [A similar formula applies at the GUT scale with the GUT threshold correction, ϵ_3 , given by $\epsilon_3 = -\tilde{\alpha}_G \ \delta_s^{(g)}$.] Given the experimental inputs [31,32]:

$$\begin{split} \alpha_{em}^{-1}(M_Z) &= 127.916 \pm 0.015 \\ \sin^2\!\theta_W(M_Z) &= 0.23116 \pm 0.00013 \\ \alpha_3(M_Z) &= 0.1184 \pm 0.0007 \end{split} \tag{15.3}$$

and taking into account the light threshold corrections, assuming an ensemble of 10 SUSY spectra [27](corresponding to the Snowmass benchmark points), we have

$$\alpha_3^{LO}(M_Z) \approx 0.118 \tag{15.4}$$

and

$$\begin{split} \delta_s^{(2)} &\approx -0.82 \\ \delta_s^{(l)} &\approx -0.50 + \frac{19}{28\pi} \log \frac{M_{SUSY}}{M_Z}. \end{split}$$

For $M_{SUSY}=1$ TeV, we have $\delta_s^{(2)}+\delta_s^{(l)}\approx-0.80$. Since the one loop result $\alpha_3^{LO}(M_Z)$ is very close to the experimental value, we need $\delta_s\approx0$ or equivalently, $\delta_s^{(g)}\approx0.80$. This corresponds, at the GUT scale, to $\epsilon_3\approx-3\%$. Note, this result depends implicitly on the assumption of universal soft SUSY breaking masses at the GUT scale, which directly affect the spectrum of SUSY particles at the weak scale. For example, if gaugino masses were not unified at M_G and, in particular, gluinos were lighter than winos at the weak scale, then it is possible that, due to weak scale threshold corrections, a much smaller or even slightly positive threshold correction at the GUT scale would be consistent with gauge coupling unification [34].

In four dimensional SUSY GUTs, the threshold correction ϵ_3 receives a positive contribution from Higgs doublets and triplets.⁴ Thus a larger, negative contribution must come from the GUT breaking sector of the theory. This is certainly possible in specific SO(10) [35] or SU(5) [36] models, but it is clearly a significant constraint on the 4d GUT sector of the theory. In five or six dimensional orbifold GUTs, on the other hand, the "GUT scale" threshold correction comes from the Kaluza-Klein modes between the compactification scale, M_c , and the effective cutoff scale M_* .⁵ Thus, in orbifold GUTs, gauge coupling unification at two loops is only consistent with the low energy data with a fixed value for M_c and M_* .6 Typically, one finds $M_c < M_G = 3 \times 10^{16}$ GeV, where M_G is the 4d GUT scale. Since the grand unified gauge bosons, responsible for nucleon decay, get mass at the compactification scale, the result $M_c < M_G$ for orbifold GUTs has significant consequences for nucleon decay.

A few final comments are in order. We do not consider the scenario of split supersymmetry [39] in this review. In this scenario squarks and sleptons have mass at a scale $\tilde{m}\gg M_Z$, while gauginos and Higgsinos have mass of order the weak scale. Gauge coupling unification occurs at a scale of order 10^{16} GeV, provided that the scale \tilde{m} lies in the range 10^3-10^{11} GeV [40]. A serious complaint concerning the split SUSY scenario is that it does not provide a solution to the gauge hierarchy problem. Moreover, it is only consistent with grand unification if it also postulates an "intermediate" scale, \tilde{m} , for scalar masses. In addition, it is in conflict with $b-\tau$ Yukawa unification, unless $\tan\beta$ is fine-tuned to be close to 1 [40]. 7

⁵ In string theory, the cutoff scale is the string scale.

² This result implicitly assumes universal GUT boundary conditions for soft SUSY breaking parameters at M_G . In the simplest case we have a universal gaugino mass $M_{1/2}$, a universal mass for squarks and sleptons m_{16} and a universal Higgs mass m_{10} , as motivated by SO(10). In some cases, threshold corrections to gauge coupling unification can be exchanged for threshold corrections to soft SUSY parameters. See for example, Ref. 28 and references therein.

 $^{^3}$ Non-SUSY GUTs with a more complicated breaking pattern can still fit the data. For example, non-SUSY $SO(10) \rightarrow SU(4)_C \times SU(2)_L \times SU(2)_R \rightarrow SM$ with the second breaking scale of order an intermediate scale, determined by light neutrino masses using the see-saw mechanism, can fit the low energy data for gauge couplings [29] and at the same time survive nucleon decay bounds [30], discussed in the following section.

 $^{^4}$ Note, the Higgs contribution is given by $\epsilon_3 = \frac{3\tilde{\alpha}_G}{5\pi}\log|\frac{\tilde{M}_t}{M_G}|$ where \tilde{M}_t is the effective color triplet Higgs mass (setting the scale for dimension 5 baryon and lepton number violating operators) and $\gamma = \lambda_b/\lambda_t$ at M_G . Since \tilde{M}_t is necessarily greater than M_G , the Higgs contribution to ϵ_3 is positive.

 $^{^6}$ It is interesting to note that a ratio $M_*/M_c \sim 100$, needed for gauge coupling unification to work in orbifold GUTs is typically the maximum value for this ratio consistent with perturbativity [37]. In addition, in orbifold GUTs brane-localized gauge kinetic terms may destroy the successes of gauge coupling unification. However, for values of $M_*/M_c = M_*\pi R \gg 1$ the unified bulk gauge kinetic terms can dominate over the brane-localized terms [38].

 $^{^7~}b-\tau$ Yukawa unification only works for $\tilde{m}<10^4$ for $\tan\beta\geq 1.5.$ This is because the effective theory between the gaugino mass scale and \tilde{m} includes only one Higgs doublet, as in the standard model. In this case, the large top quark Yukawa coupling tends to increase the ratio λ_b/λ_τ as one runs down in energy below \tilde{m} . This is opposite to what happens in MSSM where the large top quark Yukawa coupling decreases the ratio λ_b/λ_τ [41].

We have also neglected to discuss non-supersymmetric GUTs in four dimensions which still survive once one allows for several scales of GUT symmetry breaking [29]. Finally, it has been shown that non-supersymmetric GUTs in warped 5 dimensional orbifolds can be consistent with gauge coupling unification, assuming that the right-handed top quark and the Higgs doublets are composite-like objects with a compositeness scale of order a TeV [42]. However perturbative unification seems to fail.

15.1.5. Nucleon Decay:

Baryon number is necessarily violated in any GUT [43]. In SU(5), nucleons decay via the exchange of gauge bosons with GUT scale masses, resulting in dimension 6 baryon number violating operators suppressed by $(1/M_G^2)$. The nucleon lifetime is calculable and given by $\tau_N \propto M_G^4/(\alpha_G^2 m_p^5)$. The dominant decay mode of the proton (and the baryon violating decay mode of the neutron), via gauge exchange, is $p \to e^+ \pi^0$ $(n \to e^+ \pi^-)$. In any simple gauge symmetry, with one universal GUT coupling and scale (α_G, M_G) , the nucleon lifetime from gauge exchange is calculable. Hence, the GUT scale may be directly observed via the extremely rare decay of the nucleon. Experimental searches for nucleon decay began with the Kolar Gold Mine, Homestake, Soudan, NUSEX, Frejus, HPW, and IMB detectors [19]. The present experimental bounds come from Super-Kamiokande and Soudan II. We discuss these results shortly. Non-SUSY GUTs are also ruled out by the non-observation of nucleon decay [20]. In SUSY GUTs, the GUT scale is of order 3×10^{16} GeV, as compared to the GUT scale in non-SUSY GUTs which is of order 10^{15} GeV. Hence the dimension 6 baryon violating operators are significantly suppressed in SUSY GUTs [23] with $\tau_p \sim 10^{34-38}$ yrs.

However, in SUSY GUTs there are additional sources for baryon number violation – dimension 4 and 5 operators [44]. Although our notation does not change, when discussing SUSY GUTs all fields are implicitly chiral superfields and the operators considered are the so-called F terms which contain two fermionic components and the rest scalars or products of scalars. Within the context of SU(5) the dimension 4 and 5 operators have the form $(\mathbf{10}\ \mathbf{5}\ \mathbf{\bar{5}}) \supset (u^c\ d^c\ d^c) + (Q\ L\ d^c) + (e^c\ L\ L)$ and $(\mathbf{10}\ \mathbf{10}\ \mathbf{10}\ \mathbf{\bar{5}}) \supset (Q\ Q\ Q\ L) + (u^c\ u^c\ d^c\ e^c) + B$ and L conserving terms, respectively. The dimension 4 operators are renormalizable with dimensionless couplings; similar to Yukawa couplings. On the other hand, the dimension 5 operators have a dimensionful coupling of order $(1/M_G)$.

The dimension 4 operators violate baryon number or lepton number, respectively, but not both. The nucleon lifetime is extremely short if both types of dimension 4 operators are present in the low energy theory. However both types can be eliminated by requiring R parity. In SU(5) the Higgs doublets reside in a $\mathbf{5_H}$, $\mathbf{\bar{5}_H}$ and R parity distinguishes the $\mathbf{\bar{5}}$ (quarks and leptons) from $\mathbf{\bar{5}_H}$ (Higgs). R parity [45](or its cousin, family reflection symmetry (or matter parity) (see Dimopoulos and Georgi [23] and DRW [46]) takes $F \to -F$, $H \to H$ with $F = \{\mathbf{10}, \, \mathbf{\bar{5}}\}$, $H = \{\mathbf{\bar{5}_H}, \, \mathbf{5_H}\}$. This forbids the dimension 4 operator $(\mathbf{10} \, \mathbf{\bar{5}} \, \mathbf{\bar{5}})$, but allows the Yukawa couplings of the form $(\mathbf{10} \, \mathbf{\bar{5}} \, \mathbf{\bar{5}_H})$ and $(\mathbf{10} \, \mathbf{10} \, \mathbf{5_H})$. It also forbids the dimension 3, lepton number violating, operator $(\mathbf{\bar{5}} \, \mathbf{5_H}) \supset (L \, H_u)$ with a coefficient with dimensions of mass which, like the μ parameter, could be of order the weak scale and the dimension 5, baryon number violating, operator $(\mathbf{10} \, \mathbf{10} \, \mathbf{\bar{5}_H}) \supset (Q \, Q \, H_d) + \cdots$.

Note, in the MSSM it is possible to retain R parity violating operators at low energy as long as they violate either baryon number or lepton number only but not both. Such schemes are natural if one assumes a low energy symmetry, such as lepton number, baryon number, baryon triality [47] or proton hexality [48]. However these symmetries cannot be embedded in a GUT. Thus, in a SUSY GUT, only R parity can prevent all the dimension three and four baryon and lepton number violating operators. This does not mean to say that R parity is guaranteed to be satisfied in any GUT. For example the authors of Refs. [51,52] use constrained matter content to selectively generate safe effective R parity violating operators in a GUT. For a review on R parity violating interactions, see [53]. In Ref. [52], the authors show how to obtain the effective R parity violating operator $O^{ijk} = (\bar{5}^j \cdot \bar{5}^k)_{1\bar{5}} \cdot (10^i \cdot \Sigma)_{1\bar{5}}$ where Σ is an SU(5) adjoint field and the subscripts $\overline{15}$, 15 indicate that the product of fields in parentheses

have been projected into these SU(5) directions. As a consequence the operator O^{ijk} is symmetric under interchange of the two $\bar{\bf 5}$ states, $O^{ijk} = O^{ikj}$, and out of ${\bf 10} \ \bar{\bf 5} \ \bar{\bf 5}$ only the lepton number/R parity violating operator $QL\bar{D}$ survives.

Note also, R parity distinguishes Higgs multiplets from ordinary families. In SU(5), Higgs and quark/lepton multiplets have identical quantum numbers; while in E(6), Higgs and families are unified within the fundamental **27** representation. Only in SO(10) are Higgs and ordinary families distinguished by their gauge quantum numbers. Moreover the Z(4) center of SO(10) distinguishes **10**s from **16**s and can be associated with R parity [49].

Dimension 5 baryon number violating operators may be forbidden at tree level by symmetries in SU(5), etc. These symmetries are typically broken however by the VEVs responsible for the color triplet Higgs masses. Consequently these dimension 5 operators are generically generated via color triplet Higgsino exchange. Hence, the color triplet partners of Higgs doublets must necessarily obtain mass of order the GUT scale. [It is also important to note that Planck or string scale physics may independently generate dimension 5 operators, even without a GUT. These contributions must be suppressed by some underlying symmetry; for example, the same flavor symmetry which may be responsible for hierarchical fermion Yukawa matrices.]

The dominant decay modes from dimension 5 operators are $p \to K^+ \bar{\nu} \ (n \to K^0 \bar{\nu})$. This is due to a simple symmetry argument; the operators $(Q_i \ Q_j \ Q_k \ L_l)$, $(u_i^c \ u_j^c \ d_k^c \ e_l^c)$ (where i, j, k, l = 1, 2, 3 are family indices and color and weak indices are implicit) must be invariant under $SU(3)_C$ and $SU(2)_L$. As a result their color and weak doublet indices must be anti-symmetrized. However since these operators are given by bosonic superfields, they must be totally symmetric under interchange of all indices. Thus the first operator vanishes for i=j=k and the second vanishes for i=j. Hence a second or third generation member must exist in the final state [46].

Recent Super-Kamiokande bounds on the proton lifetime severely constrain these dimension 6 and 5 operators with (172.8 kt-yr) of data they find $\tau_{(p \to e^+ \pi^0)} > 1.0 \times 10^{34} \ {\rm yrs}, \ \tau_{(p \to K^+ \bar{\nu})} > 3.3 \times 10^{33} \ {\rm yrs}$ and $\tau_{(n \to e^+ \pi^-)} > 2 \times 10^{33} \ {\rm yrs}$ at (90% CL) [54]. These constraints are now sufficient to rule out minimal SUSY SU(5) [55]. 8 Non-minimal Higgs sectors in SU(5) or SO(10) theories still survive [26,36]. The upper bound on the proton lifetime from these theories are approximately a factor of 10 above the experimental bounds. They are also being pushed to their theoretical limits. Hence if SUSY GUTs are correct, then nucleon decay must be seen soon.

Is there a way out of this conclusion? Orbifold GUTs and string theories, see Sec. 15.1, contain grand unified symmetries realized in higher dimensions. In the process of compactification and GUT symmetry breaking, color triplet Higgs states are removed (projected out of the massless sector of the theory). In addition, the same projections typically rearrange the quark and lepton states so that the massless states which survive emanate from different GUT multiplets. In these models, proton decay due to dimension 5 operators can be severely suppressed or eliminated completely. However, proton decay due to dimension 6 operators may be enhanced, since the gauge bosons mediating proton decay obtain mass at the compactification scale, M_c , which is typically less than the 4d GUT scale (see the discussion at the end of Sec. 15.1), or suppressed, if the states of one family come from different irreducible representations. Which effect dominates is a model dependent issue. In some complete 5d orbifold

⁸ This conclusion relies on the mild assumption that the three-by-three matrices diagonalizing squark and slepton mass matrices are not so different from their fermionic partners. It has been shown that if this caveat is violated, then dimension five proton decay in minimal SUSY SU(5) may not be ruled out [56]. This is however a very fine-tuned resolution of the problem. Another possible way out is to allow for a more complicated SU(5) breaking Higgs sector in the otherwise minimal model [57]. I have also implicitly assumed a hierarchical structure for Yukawa matrices in this analysis. It is however possible to fine-tune a hierarchical structure for quarks and leptons which baffles the family structure. In this case it is possible to avoid the present constraints on minimal SUSY SU(5), for example see [58].

GUT models [59,27] the lifetime for the decay $\tau(p \to e^+\pi^0)$ can be near the excluded bound of 1×10^{34} years with, however, large model dependent and/or theoretical uncertainties. In other cases, the modes $p \to K^+\bar{\nu}$ and $p \to K^0\mu^+$ may be dominant [27]. To summarize, in either 4d or orbifold string/field theories, nucleon decay remains a premier signature for SUSY GUTs. Moreover, the observation of nucleon decay may distinguish extra-dimensional orbifold GUTs from four dimensional ones.

As a final note, in orbifold GUTs or string theory new discrete symmetries consistent with SUSY GUTs can forbid all dimension 3 and 4 baryon [B] and lepton [L] number violating operators and even forbid the mu term and dimension 5 B and L violating operators to all orders in perturbation theory [50]. The mu term and dimension 5 B and L violating operators may then be generated, albeit sufficiently suppressed, via non-perturbative effects. The simplest example of this is a Z_4^R symmetry which is the unique discrete R symmetry consistent with SO(10) [50]. In this case, proton decay is completely dominated by dimension 6 operators.

Before concluding the topic of baryon number violation, consider the status of $\Delta B=2$ neutron- anti-neutron oscillations. Generically the leading operator for this process is the dimension 9 six quark operator $G_{(\Delta B=2)}$ (u^c d^c d^c u^c d^c d^c) with dimensionful coefficient $G_{(\Delta B=2)} \sim 1/M^5$. The present experimental bound $\tau_{n-\bar{n}} \geq 0.86 \times 10^8$ sec. at 90% CL [60] probes only up to the scale $M \leq 10^6$ GeV. For $M \sim M_G$, $n-\bar{n}$ oscillations appear to be unobservable for any GUT (for a recent discussion see [61]).

15.1.6. Yukawa coupling unification:

15.1.6.1. 3rd generation, $b - \tau$ or $t - b - \tau$ unification:

If quarks and leptons are two sides of the same coin, related by a new grand unified gauge symmetry, then that same symmetry relates the Yukawa couplings (and hence the masses) of quarks and leptons. In SU(5), there are two independent renormalizable Yukawa interactions given by λ_t (10 10 5_H) + λ (10 $\bar{\bf 5}$ $\bar{\bf 5}_H$). These contain the SM interactions λ_t (Q u^c H_u) + λ (Q d^c H_d + e^c L H_d). Hence, at the GUT scale we have the tree level relation, $\lambda_b = \lambda_\tau \equiv \lambda$ [41]. In SO(10) there is only one independent renormalizable Yukawa interaction given by λ (16 16 10_H) which gives the tree level relation, $\lambda_t = \lambda_b = \lambda_\tau \equiv \lambda$ [62,63]. Note, in the discussion above we assume the minimal Higgs content with Higgs in $\bar{\bf 5}$, $\bar{\bf 5}$ for SU(5) and 10 for SO(10). With Higgs in higher dimensional representations there are more possible Yukawa couplings [75,76,77].

In order to make contact with the data, one now renormalizes the top, bottom and τ Yukawa couplings, using two loop RG equations, from M_G to M_Z . One then obtains the running quark masses $m_t(M_Z) = \lambda_t(M_Z) \ v_u, \quad m_b(M_Z) = \lambda_b(M_Z) \ v_d$ and $m_\tau(M_Z) = \lambda_\tau(M_Z) \ v_d$ where $< H_u^0 > \equiv v_u = \sin\beta \ v/\sqrt{2}, < H_d^0 > \equiv v_d = \cos\beta \ v/\sqrt{2}, v_u/v_d \equiv \tan\beta$ and $v \sim 246$ GeV is fixed by the Fermi constant, G_μ .

Including one loop threshold corrections at M_Z and additional RG running, one finds the top, bottom and τ pole masses. In SUSY, $b-\tau$ unification has two possible solutions with $\tan\beta\sim 1$ or 40-50. The small $\tan\beta$ solution is now disfavored by the LEP limit, $\tan\beta>2.4$ [64]. ⁹ The large $\tan\beta$ limit overlaps the SO(10) symmetry relation.

When $\tan \beta$ is large there are significant weak scale threshold corrections to down quark and charged lepton masses from either gluino and/or chargino loops [66]. Yukawa unification (consistent with low energy data) is only possible in a restricted region of SUSY parameter space with important consequences for SUSY searches [67]. More recent analyses of Yukawa unification can be found in Refs. [68,69,70,71]. There seems to be at least four possible choices of soft SUSY breaking parameters which fit the data, possibly more. Each case then leads to a distinct sparticle spectrum and phenomenology for LHC and dark matter experiments. They correspond to:

- universal squark and slepton masses (m_{16}) , universal A parameter (A_0) and gaugino masses $(M_{1/2})$, and non-universal Higgs masses (m_{H_u}, m_{H_d}) with "just-so" splitting [67,68].
- a universal squark and slepton mass term for the first two families $(m_{16_{1,2}})$ which is larger than the universal scalar mass for the third family (m_{16_3}) , universal A parameter (A_0) and gaugino masses $(M_{1/2})$ and universal Higgs mass term (m_{10}) . However all scalar masses then receive a D-term contribution to their masses given by the U(1) from SO(10) which commutes with SU(5). This is of the form

$$\begin{split} m_Q^2 &= m_E^2 = m_U^2 = m_{16}^2 + M_D^2, \\ m_D^2 &= m_L^2 = m_{16}^2 - 3 M_D^2, \\ m_{\bar{\nu}}^2 &= m_{16}^2 + 5 M_D^2, \\ m_{H_{u,d}}^2 &= m_{10}^2 \mp 2 M_D^2. \end{split}$$

This is the so-called "DR3 splitting" [69]. The R is associated with taking into account the renormalization group [RG] running of the right-handed neutrino from the GUT scale to the nominal value of its mass of order 10^{10-14} GeV, as indicated by light neutrino masses via the See-Saw mechanism. This RG running contributes to an additional splitting of the H_u and H_d masses [67].

- universal squark and slepton masses (m_0) , split Higgs masses and non-universal gaugino masses satisfying $(M_1 = \frac{3}{5}M_2 + \frac{2}{5}M_3)$, and $\mu, M_2 < 0$ [70], and
- universal squark and slepton mass term (m_{16}) , A parameter (A_0) , Higgs mass term (m_{10}) . All scalar masses then receive a D-term contribution to their masses given by the U(1) from SO(10) which commutes with SU(5), as above. Finally, non-universal gaugino masses satisfying $(M_3: M_2: M_1 = 2: -3: -1)$ with $M_3 > 0$ and $\mu < 0$ [71].

15.1.6.2. *Three families:*

Simple Yukawa unification is not possible for the first two generations of quarks and leptons. Consider the SU(5) GUT scale relation $\lambda_b = \lambda_\tau$. If extended to the first two generations one would have $\lambda_s = \lambda_\mu$, $\lambda_d = \lambda_e$ which gives $\lambda_s/\lambda_d = \lambda_\mu/\lambda_e$. The last relation is a renormalization group invariant and is thus satisfied at any scale. In particular, at the weak scale one obtains $m_s/m_d = m_\mu/m_e$ which is in serious disagreement with the data with $m_s/m_d \sim 20$ and $m_\mu/m_e \sim 200$. An elegant solution to this problem was given by Georgi and Jarlskog [72]. For a recent analysis in the context of supersymmetric GUTs, see Ref. [73]. Of course, a three family model must also give the observed CKM mixing in the quark sector. Note, although there are typically many more parameters in the GUT theory above M_G , it is possible to obtain effective low energy theories with many fewer parameters making strong predictions for quark and lepton masses.

Three family models which make significant predictions for low energy experiments have been constructed in the context of supersymmetric GUTs. It is important to note that grand unification alone is not sufficient to obtain predictive theories of fermion masses and mixing angles. Other ingredients are needed. In one approach additional global family symmetries are introduced (non-abelian family symmetries can significantly reduce the number of arbitrary parameters in the Yukawa matrices). These family symmetries constrain the set of effective higher dimensional fermion mass operators. In addition, sequential breaking of the family symmetry is correlated with the hierarchy of fermion masses. Three-family models exist which fit all the data, including neutrino masses and mixing [74]. In a completely separate approach for SO(10) models, the Standard Model Higgs bosons are contained in the higher dimensional Higgs representations including the 10, $\overline{126}$ and/or 120. Such theories have been shown to make predictions for neutrino masses and mixing angles [75-77]. A recent paper on this subject argues the necessity of split supersymmetry [78].

⁹ However, this bound disappears if one takes $M_{SUSY}=2$ TeV and $m_t=180$ GeV [65]. This apparent loop hole is now inconsistent with the observed top quark mass.

15.1.7. Neutrino Masses:

Atmospheric and solar neutrino oscillations, along with long baseline accelerator and reactor experiments, require neutrino masses. Adding three "sterile" neutrinos ν^c with the Yukawa coupling λ_{ν} (ν^c **L** $\mathbf{H_u}$), one easily obtains three massive Dirac neutrinos with mass $m_{\nu} = \lambda_{\nu} \ v_u.^{10}$ However in order to obtain a tau neutrino with mass of order 0.1 eV, one needs $\lambda_{\nu_{\tau}}/\lambda_{\tau} \leq 10^{-10}$. The see-saw mechanism, on the other hand, can naturally explain such small neutrino masses [79,80]. Since ν^c has no SM quantum numbers, there is no symmetry (other than global lepton number) which prevents the mass term $\frac{1}{2} \ \nu^c \ M \ \nu^c$. Moreover one might expect $M \sim M_G$. Heavy "sterile" neutrinos can be integrated out of the theory, defining an effective low energy theory with only light active Majorana neutrinos with the effective dimension 5 operator $\frac{1}{2}$ ($\mathbf{L} \ \mathbf{H_u}$) $\lambda_{\nu}^T \ M^{-1} \ \lambda_{\nu}$ ($\mathbf{L} \ \mathbf{H_u}$). This then leads to a 3×3 Majorana neutrino mass matrix $\mathbf{m} = m_{\nu}^T \ M^{-1} \ m_{\nu}$.

Atmospheric neutrino oscillations require neutrino masses with $\Delta m_{\nu}^2 \sim 3 \times 10^{-3} \ {\rm eV}^2$ with maximal mixing, in the simplest two neutrino scenario. With hierarchical neutrino masses $m_{\nu_{\tau}} = \sqrt{\Delta m_{\nu}^2} \sim 0.055 \ {\rm eV}$. Moreover via the "see-saw" mechanism $m_{\nu_{\tau}} = m_t (m_t)^2/(3M)$. Hence one finds $M \sim 2 \times 10^{14} \ {\rm GeV}$; remarkably close to the GUT scale. Note we have related the neutrino Yukawa coupling to the top quark Yukawa coupling $\lambda_{\nu_{\tau}} = \lambda_t$ at M_G as given in SO(10) or $SU(4) \times SU(2)_L \times SU(2)_R$. However at low energies they are no longer equal and we have estimated this RG effect by $\lambda_{\nu_{\tau}}(M_Z) \approx \lambda_t(M_Z)/\sqrt{3}$.

Neutrinos pose a special problem for SUSY GUTs. The question is why are the quark mixing angles in the CKM matrix small, while there are two large lepton mixing angles in the PMNS matrix. For a recent discussion of neutrino masses and mixing angles, see Refs. [81] and [82]. For SUSY GUT models which fit quark and lepton masses, see Ref. [74]. Finally, for a compilation of the range of SUSY GUT predictions for neutrino mixing, see [83].

15.1.8. Selected Topics:

15.1.8.1. Magnetic Monopoles:

In the broken phase of a GUT there are typically localized classical solutions carrying magnetic charge under an unbroken U(1)symmetry [84]. These magnetic monopoles with mass of order M_G/α_G are produced during the GUT phase transition in the early universe. The flux of magnetic monopoles is experimentally found to be less than $\sim 10^{-16} \, {\rm cm}^{-2} \, {\rm s}^{-1} \, {\rm sr}^{-1}$ [85]. Many more are however predicted, hence the GUT monopole problem. In fact, one of the original motivations for an inflationary universe is to solve the monopole problem by invoking an epoch of rapid inflation after the GUT phase transition [86]. This would have the effect of diluting the monopole density as long as the reheat temperature is sufficiently below M_G . Other possible solutions to the monopole problem include: sweeping them away by domain walls [87], U(1) electromagnetic symmetry breaking at high temperature [88] or GUT symmetry non-restoration [89]. Parenthetically, it was also shown that GUT monopoles can catalyze nucleon decay [90]. A significantly lower bound on the monopole flux can then be obtained by considering X-ray emission from radio pulsars due to monopole capture and the subsequent nucleon decay catalysis [91].

15.1.8.2. Baryogenesis via Leptogenesis:

Baryon number violating operators in SU(5) or SO(10) preserve the global symmetry B-L. Hence the value of the cosmological B-L density is an initial condition of the theory and is typically assumed to be zero. On the other hand, anomalies of the electroweak symmetry violate B+L while also preserving B-L. Hence thermal fluctations in the early universe, via so-called sphaleron processes, can drive B+L to zero, washing out any net baryon number generated in the early universe at GUT temperatures.

One way out of this dilemma is to generate a net B-L dynamically in the early universe. We have just seen that neutrino oscillations suggest a new scale of physics of order 10^{14} GeV. This scale is associated with heavy Majorana neutrinos with mass M. If in the early universe, the decay of the heavy neutrinos is out of equilibrium and violates both lepton number and CP, then a net lepton number may be generated. This lepton number will then be partially converted into baryon number via electroweak processes [92].

15.1.8.3. *GUT symmetry breaking:*

The grand unification symmetry is necessarily broken spontaneously. Scalar potentials (or superpotentials) exist whose vacua spontaneously break SU(5) and SO(10). These potentials are ad hoc (just like the Higgs potential in the SM) and therefore it is hoped that they may be replaced with better motivated sectors. Gauge coupling unification now tests GUT breaking sectors, since it is one of the two dominant corrections to the GUT threshold correction ϵ_3 . The other dominant correction comes from the Higgs sector and doublet-triplet splitting. This latter contribution is always positive $\epsilon_3 \propto \ln(M_T/M_G)$ (where M_T is an effective color triplet Higgs mass), while the low energy data typically requires $\epsilon_3 < 0$. Hence the GUT breaking sector must provide a significant (of order -8%) contribution to ϵ_3 to be consistent with the Super-K bound on the proton lifetime [35,26,36,74].

In string theory (and GUTs in extra-dimensions), GUT breaking may occur due to boundary conditions in the compactified dimensions [8,11]. This is still ad hoc. The major benefit is that it does not require complicated GUT breaking sectors.

15.1.8.4. Doublet-triplet splitting:

The minimal supersymmetric standard model has a μ problem; why is the coefficient of the bilinear Higgs term in the superpotential μ ($\mathbf{H_u} \; \mathbf{H_d}$) of order the weak scale when, since it violates no low energy symmetry, it could be as large as M_G . In a SUSY GUT, the μ problem is replaced by the problem of doublet-triplet splitting – giving mass of order M_G to the color triplet Higgs and mass μ to the Higgs doublets. Several mechanisms for natural doublet-triplet splitting have been suggested, such as the sliding singlet [93], missing partner or missing VEV [94], and pseudo-Nambu-Goldstone boson mechanisms. Particular examples of the missing partner mechanism for SU(5) [36], the missing VEV mechanism for SO(10) [74,26] and the pseudo-Nambu-Goldstone boson mechanism for SU(6) [95] have been shown to be consistent with gauge coupling unification and proton decay. There are also several mechanisms for explaining why μ is of order the SUSY breaking scale [96]. Finally, for a recent review of the μ problem and some suggested solutions in SUSY GUTs and string theory, see Ref. [97,10,98,50] and references therein.

Once again, in string theory (and orbifold GUTs), the act of breaking the GUT symmetry via orbifolding projects certain states out of the theory. It has been shown that it is possible to remove the color triplet Higgs while retaining the Higgs doublets in this process. Hence the doublet-triplet splitting problem is finessed. As discussed earlier (see Sec. 15.1), this can have the effect of eliminating the contribution of dimension 5 operators to nucleon decay.

15.1.9. String theory:

String theory has made significant progress in locating the minimal supersymmetric standard model [MSSM] in the string landscape. Random searches for MSSM-like models have found some success, see for example Ref. 99. However, recently a solid leap forward has been made by imposing a supersymmetric GUT locally in the extra dimensions of the string. Many MSSM-like models have been found in $E(8) \times E(8)$ heterotic orbifold constructions [100–103] or more recently on smooth Calabi-Yau three-folds [104]. See also in F theory constructions [105–107]. There appear, however, to be some problems associated with large threshold corrections to gauge coupling unification in the F theory constructions which make use of a non-vanishing hypercharge field strength to break SU(5)to $SU(3)_C \times SU(2)_L \times U(1)_Y$ [108]. Nevertheless, a SUSY GUT guarantees the correct particle content of the Standard Model and also allows for reasonable looking hierarchical Yukawa matrices. For a more detailed discussion, see [109].

¹⁰ Note, these "sterile" neutrinos are quite naturally identified with the right-handed neutrinos necessarily contained in complete families of SO(10) or Pati-Salam.

15.2. Conclusion

Grand unification of the strong and electroweak interactions requires that the three low energy gauge couplings unify (up to small threshold corrections) at a unique scale, M_G . Supersymmetric grand unified theories provide, by far, the most predictive and economical framework allowing for perturbative unification.

The three pillars of SUSY GUTs are:

- gauge coupling unification at $M_G \sim 3 \times 10^{16}$ GeV;
- low-energy supersymmetry [with a large SUSY desert], and
- nucleon decay.

The first prediction has already been verified (see Fig. Fig. 15.1). Perhaps the next two will soon appear. Whether or not Yukawa couplings unify is more model dependent. Nevertheless, the "digital" 16 dimensional representation of quarks and leptons in SO(10) is very compelling and may yet lead to an understanding of fermion masses and mixing angles.

In any event, the experimental verification of the first three pillars of SUSY GUTs would forever change our view of Nature. Moreover, the concomitant evidence for a vast SUSY desert would expose a huge lever arm for discovery. For then it would become clear that experiments probing the TeV scale could reveal physics at the GUT scale and perhaps beyond. Of course, some questions will still remain: Why do we have three families of quarks and leptons? How is the grand unified symmetry and possible family symmetries chosen by Nature? At what scale might stringy physics become relevant? Etc.

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16. HEAVY-QUARK AND SOFT-COLLINEAR EFFECTIVE THEORY

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16.1. Effective Field Theories

Quantum field theories represent the most precise computational tool for describing physics at the highest energies. One of their characteristic features is that they almost inevitably involve multiple length scales. When trying to determine the value of an observable, quantum field theory demands that all possible virtual states and hence all particles be included in the calculation. Since these particles have widely different masses, the final prediction is sensitive to many scales. This fact represents a formidable challenge from a practical point of view. No realistic quantum field theories can be solved exactly, so that one has to resort to approximation schemes; these, however, are typically most straightforward when only a single scale is involved at a time.

Effective field theories (EFTs) provide a general theoretical framework to deal with the multi-scale problems of realistic quantum field theories. This framework aims to reduce such problems to a combination of separate and simpler single-scale problems; simultaneously, however, it provides an organizational scheme whereby the other scales are not omitted but allowed to play their role in a separate step of the computation. The philosophy and basic principles of this approach are very generic, and correspondingly EFTs represent a widely used method in many different areas of high-energy physics, from the low energy scales of atomic and nuclear physics to the high energy scales of (partly yet unknown) elementary particle physics. EFTs can play a role both within analytic perturbative computations and in the context of non-perturbative numerical simulations; see [1–3] for some early references. One of the simplest applications of EFTs to particle physics is to describe an underlying theory that is only probed at energy scales $E < \Lambda$. Any particle with mass $m > \Lambda$ cannot be produced as a real state and therefore only leads to short-distance virtual effects. Thus, one can construct an effective theory in which the quantum fluctuations of such heavy particles are "integrated out" from the generating functional integral for Green functions. This results in a simpler theory containing only those degrees of freedom that are relevant to the energy scales under consideration. In fact, the standard model of particle physics itself is widely viewed as an EFT of some vet unknown, more fundamental theory.

The development of any effective theory starts by identifying the degrees of freedom that are relevant to describe the physics at a given energy (or length) scale, and constructing the Lagrangian describing the interactions among these fields. Short-distance quantum fluctuations associated with much smaller length scales are absorbed into the coefficients of the various operators in the effective Lagrangian. These coefficients are determined in a matching procedure, by requiring that the EFT reproduces the matrix elements of the full theory up to power corrections. In many cases the effective Lagrangian exhibits enhanced symmetries compared with the fundamental theory, allowing for simple and sometimes striking predictions relating different observables.

16.2. Heavy-Quark Effective Theory

Heavy-quark systems provide prime examples for applications of the EFT technology, because the hierarchy $m_Q\gg\Lambda_{\rm QCD}$ (with Q=b,c) provides a natural separation of scales. Physics at the scale m_Q is of a short-distance nature and can be treated perturbatively, while for heavy-quark systems there is always also some hadronic physics governed by the confinement scale $\Lambda_{\rm QCD}$. Being able to separate the short-distance and long-distance effects associated with these two scales is crucial for any quantitative description in heavy-quark physics. For instance, if the long-distance hadronic matrix elements are obtained from lattice QCD, then it is necessary to analytically compute the short-distance effects, which come from short-wavelength modes that do not fit on present-day lattices. In many other instances, the long-distance hadronic physics can be encoded in a small number of universal parameters.

16.2.1. General idea and derivation of the effective

Lagrangian: The simplest effective theory for heavy-quark systems is the heavy-quark effective theory (HQET) [4–7] (see [8,9] for detailed discussions). It provides a simplified description of the soft interactions of a single heavy quark interacting with soft, light partons. This includes the interactions that bind the heavy quark with other light partons inside heavy mesons (B, B^*, \ldots) and baryons $(\Lambda_b, \Sigma_b, \ldots)$.

A softly interacting heavy quark is nearly on-shell. Its momentum may be decomposed as $p_Q=m_Qv+k$, where v is the 4-velocity of the hadron containing the heavy quark, and the "residual momentum" $k\sim \Lambda_{\rm QCD}$ results from the soft interactions of the heavy quark with its environment. In the limit $m_Q\gg \Lambda_{\rm QCD}$, the soft interactions do not change the 4-velocity of the heavy quark, which is therefore a conserved quantum number that is often used as a label on the effective heavy-quark fields. A nearly on-shell Dirac spinor has two large and two small components. We define

$$Q(x) = e^{-im_Q v \cdot x} \left[h_v(x) + H_v(x) \right], \tag{16.1}$$

where

$$h_v(x) = e^{im_Q v \cdot x} \frac{1 + \not p}{2} Q(x), \qquad H_v(x) = e^{im_Q v \cdot x} \frac{1 - \not p}{2} Q(x)$$
 (16.2)

are the large ("upper") and small ("lower") components of the Dirac spinor, respectively. The extraction of the phase factor in Eq. (16.1) implies that the fields h_v and H_v carry the residual momentum k. These fields obey the projection relations $\phi h_v = h_v$ and $\phi H_v = -H_v$. Inserting these definitions into the Dirac Lagrangian yields

$$\mathcal{L}_{Q} = \bar{h}_{v} iv \cdot D h_{v} + \bar{H}_{v} (-iv \cdot D - 2m_{Q}) H_{v} + \bar{h}_{v} i \vec{\not D} H_{v} + \bar{H}_{v} i \vec{\not D} h_{v}, \quad (16.3)$$

where $i\vec{D}^{\mu}=iD^{\mu}-v^{\mu}\,iv\cdot D$ is the "spatial" covariant derivative (note that $v^{\mu}=(1,\vec{0})$ in the heavy-hadron rest frame). The interpretation of Eq. (16.3) is that the field h_v describes a massless fermion, while H_v describes a heavy fermion with mass $2m_Q$. Both modes are coupled to each other via the last two terms. Soft interactions cannot excite the heavy fermion, so we integrate it out from the generating functional of the theory. The light field which remains describes the fluctuations of the heavy quark about its mass shell. Solving the classical equation of motion for the field H_v yields

$$H_{v} = \frac{1}{2m_{Q} + iv \cdot D} i \vec{\not}D h_{v} = \frac{1}{2m_{Q}} \sum_{n=0}^{\infty} \left(-\frac{iv \cdot D}{2m_{Q}} \right)^{n} i \vec{\not}D h_{v} , \quad (16.4)$$

which implies $H_v = O(\Lambda_{\rm QCD}/m_Q)\,h_v$, provided the residual momenta are small. The effective Lagrangian of HQET is obtained by inserting this result into Eq. (16.3). At subleading order in $1/m_Q$ one finds

$$\mathcal{L}_{\text{HQET}} = \bar{h}_v \, iv \cdot D_s \, h_v + \frac{1}{2m_Q} \times$$

$$\left[\bar{h}_v(i\vec{D}_s)^2 h_v + C_{\text{mag}}(\mu) \frac{g}{2} \bar{h}_v \,\sigma_{\mu\nu} \,G_s^{\mu\nu} h_v\right] + \dots \,. \tag{16.5}$$

Note that the covariant derivative $iD_s^\mu=i\partial^\mu+gA_s^\mu$ contains only the soft gluon field. Hard gluons have been integrated out, and their effects are contained in the Wilson coefficients of the various operators in the effective Lagrangian. From the leading operator one derives the Feynman rules of HQET. The new operators entering at subleading order are referred to as the "kinetic energy" and "chromo-magnetic interaction". The kinetic-energy operator corresponds to the first correction term in the Taylor expansion of the relativistic energy $E=m_Q+\vec{p}^2/2m_Q+\ldots$ Lorentz invariance, which is encoded as a reparametrization invariance of the effective Lagrangian [10], ensures that its Wilson coefficient is not renormalized $(C_{\rm kin}\equiv 1)$. The coefficient of the chromo-magnetic operator, $C_{\rm mag}(\mu)=1+\mathcal{O}(\alpha_s)$, receives corrections starting at one-loop order.

16.2.2. Spin-flavor symmetry and applications in

spectroscopy: The leading term in the HQET Lagrangian exhibits a global spin-flavor symmetry. Its physical meaning is that, in the infinite mass limit, the properties of hadronic systems containing a single heavy quark are insensitive to the spin and flavor of the heavy quark [11,12]. The spin symmetry results from the fact that there appear no Dirac matrices in the leading term in the effective Lagrangian Eq. (16.5), implying that the interactions of the heavy quark with soft gluons leave its spin unchanged. The flavor symmetry arises since the mass of the heavy quark does not appear at leading order. When there are n_Q heavy quarks moving at the same velocity, one can simply extend Eq. (16.5) by summing over n_Q identical terms for heavy-quark fields h_v^i . The result is invariant under rotations in flavor space. When combined with the spin symmetry, the symmetry group becomes promoted to $SU(2n_Q)$. The flavor symmetry is broken by the operators arising at order $1/m_Q$ and higher. However, at first order only the chromo-magnetic operator breaks the spin symmetry.

The spin-flavor symmetry leads to many interesting relations between the properties of hadrons containing a heavy quark. The most direct consequences concern the spectroscopy of such states [13]. In the heavy-quark limit, the spin of the heavy quark and the total angular momentum j of the light degrees of freedom are separately conserved by the strong interactions. Because of heavyquark symmetry, the dynamics is independent of the spin and mass of the heavy quark. Hadronic states can thus be classified by the quantum numbers (flavor, spin, parity, etc.) of the light degrees of freedom. The spin symmetry predicts that, for fixed $j \neq 0$, there is a doublet of degenerate states with total spin $J = j \pm 1/2$. The flavor symmetry relates the properties of states with different heavy quark flavor. In the case of the ground-state mesons containing a heavy quark, the light degrees of freedom have the quantum numbers of an antiquark, and the degenerate states are the pseudoscalar (J=0) and vector (J=1) mesons. Their masses are split by hyperfine corrections of order $1/m_Q$, such that one expects $m_{B^*}-m_B=O(1/m_b)$ and $m_{D^*}-m_D=O(1/m_c)$. It follows that $m_{B^*}^2-m_B^2\simeq m_{D^*}^2-m_D^2\simeq {\rm const.}$ The data are compatible with this result: $m_{B^*}^2-m_B^2\simeq 0.49\,{\rm GeV^2}$ and $m_{D^*}^2-m_D^2\simeq 0.55\,{\rm GeV^2}$.

16.2.3. Weak decay form factors: Of particular interest are the relations between the weak decay form factors of heavy mesons, which parametrize hadronic matrix elements of currents between two meson states containing a heavy quark. These relations have been derived by Isgur and Wise [12], generalizing ideas developed by Nussinov and Wetzel [14] and Voloshin and Shifman [15]. For the purpose of this discussion, it is convenient to work with a mass-independent normalization of meson states and use velocity rather than momentum variables.

Consider the elastic scattering of a pseudoscalar meson, $P(v) \to P(v')$, induced by an external vector current coupled to the heavy quark contained in P, which acts as a color source moving with the meson's velocity v. The action of the current is to replace instantaneously the color source by one moving at velocity v'. Soft gluons need to be exchanged in order to rearrange the light degrees of freedom and build the final state meson moving at velocity v'. This rearrangement leads to a form factor suppression. The important observation is that, in the $m_Q \to \infty$ limit, the form factor can only depend on the Lorentz boost $\gamma = v \cdot v'$ connecting the rest frames of the initial and final-state mesons (as long as $\gamma = \mathcal{O}(1)$). In the effective theory, which provides the appropriate framework to consider the limit $m_Q \to \infty$ with the quark velocities kept fixed, the hadronic matrix element describing the scattering process can be written as

$$\langle P(v')|\bar{h}_{v'}\gamma^{\mu}h_{v}|P(v)\rangle = \xi(v\cdot v')(v+v')^{\mu},\tag{16.6}$$

with a form factor $\xi(v \cdot v')$ that is real and does not depend on m_Q . By flavor symmetry, the form factor remains identical when one replaces the heavy quark Q in one of the meson states by a heavy quark Q' of a different flavor, thereby turning P into another pseudoscalar meson P'. At the same time, the current becomes a flavor-changing vector current. This universal form factor is called the Isgur-Wise function [12]. For equal velocities the vector current $J^{\mu} = \bar{h}_v \gamma^{\mu} h_v$ is conserved in the effective theory, irrespective of the

flavor of the heavy quarks. The corresponding conserved charges are the generators of the flavor symmetry. It follows that the Isgur-Wise function is normalized at the point of equal velocities: $\xi(1)=1$. Since $E_{\rm recoil}=m_{P'}(v\cdot v'-1)$ is the recoil energy of the daughter meson P' in the rest frame of the parent meson P, the point $v\cdot v'=1$ is referred to as the zero recoil limit. The heavy-quark spin symmetry leads to additional relations among weak decay form factors. It can be used to relate matrix elements involving vector mesons to those involving pseudoscalar mesons, which once again can be described completely in terms of the universal Isgur-Wise function.

These form factor relations imposed by heavy-quark symmetry describe the semileptonic decay processes $\bar{B} \to D \, \ell \, \bar{\nu}$ and $\bar{B} \to D^* \ell \, \bar{\nu}$ in the limit of infinite heavy-quark masses. They are model-independent consequences of QCD. The known normalization of the Isgur-Wise function at zero recoil can be used to obtain a model-independent measurement of the element $|V_{cb}|$ of the Cabibbo-Kobayashi-Maskawa (CKM) matrix. The semileptonic decay $\bar{B} \to D^* \ell \, \bar{\nu}$ is ideally suited for this purpose [16]. Experimentally, this is a particularly clean mode, since the reconstruction of the D^* meson mass provides a powerful rejection against background. From the theoretical point of view, it is ideal since the decay rate at zero recoil is protected by Luke's theorem against first-order power corrections in $1/m_Q$ [17]. This is described in more detail in Section 11 of the PDG Book.

16.2.4. Decoupling transformation: At leading order in $1/m_Q$, the couplings of soft gluons to heavy quarks in the effective Lagrangian Eq. (16.5) can be removed by the field redefinition $h_v(x) = Y_v(x) \, h_v^{(0)}(x)$, where $Y_v(x)$ denotes a time-like Wilson line along the direction of v, extending from minus infinity to the point x. In terms of the new fields, the HQET Lagrangian becomes

$$\mathcal{L}_{\text{HOET}} = \bar{h}_v^{(0)} i v \cdot \partial h_v^{(0)} + O(1/m_Q). \tag{16.7}$$

At leading order in $1/m_Q$, this is a free theory as far as the strong interactions of heavy quarks are concerned. However, the theory is nevertheless non-trivial in the presence of external sources. Consider, e.g., the case of a weak-interaction heavy-quark current

$$\bar{h}_{v'}\gamma^{\mu}(1-\gamma_5)h_v = \bar{h}_{v'}^{(0)}\gamma^{\mu}(1-\gamma_5)Y_{v'}^{\dagger}Y_v h_v^{(0)}, \qquad (16.8)$$

where v and v' are the velocities of the heavy mesons containing the heavy quarks. Unless the two velocities are equal, the object $Y_{v'}^{\dagger}Y_v$ is non-trivial, and hence the soft gluons do not decouple from the heavy quarks inside the current operator. One may interpret $Y_{v'}^{\dagger}Y_v$ as a Wilson loop with a cusp at the point x, where the two paths parallel to the different velocity vectors intersect. The presence of the cusp leads to non-trivial ultra-violet behavior (for $v \neq v'$), which is described by a cusp anomalous dimension $\Gamma_c(v \cdot v')$ that was calculated at two-loop order in [18]. It coincides with the velocity-dependent anomalous dimension of heavy-quark currents, which was rediscovered later in the context of HQET [19]. The interpretation of heavy quarks as Wilson lines is a useful tool, which was put forward in some of the very first papers on the subject [4]. This technology will be useful in the study of the interactions of heavy quarks with collinear degrees of freedom discussed later in this review.

16.2.5. Heavy-quark expansion for inclusive decays: The theoretical description of inclusive decays of hadrons containing a heavy quark exploits two observations [20–24]: bound-state effects related to the initial state can be calculated using the heavy-quark expansion, and the fact that the final state consists of a sum over many hadronic channels eliminates the sensitivity to the properties of individual final-state hadrons. The second feature rests on the hypothesis of quark-hadron duality, i.e. the assumption that decay rates are calculable in QCD after a smearing procedure has been applied [25]. In semileptonic decays, the integration over the lepton spectrum provides a smearing over the invariant hadronic mass of the final state (global duality). For nonleptonic decays, where the total hadronic mass is fixed, the summation over many hadronic final states provides an averaging (local duality).

Using the optical theorem, the inclusive decay width of a hadron H_b containing a b quark can be written in the form

$$\Gamma(H_b) = \frac{1}{M_{H_b}} \operatorname{Im} \langle H_b | i \int d^4 x \, T \left\{ \mathcal{H}_{\text{eff}}(x), \mathcal{H}_{\text{eff}}(0) \right\} | H_b \rangle. \tag{16.9}$$

The effective weak Hamiltonian for b-quark decays consists of dimension-6 four-fermion operators and dipole operators [80]. It follows that the leading contributions to the inclusive decay rate in Eq. (16.9) arise from two-loop diagrams. Because of the large mass of the b quark, the momenta flowing through the internal propagators are large. It is thus possible to construct an operator-product expansion (OPE) for the transition operator, in which it is represented as a series of local operators containing two b-quark fields. The operator with the lowest dimension is $\bar{b}b$. The next non-trivial operator has dimension 5 and contains the gluon field. It arises from diagrams in which a soft gluon is emitted from one of the internal lines of the two-loop diagrams. From dimension 6 on, an increasing number of operators appears. For dimensional reasons, the matrix elements of higher-dimensional operators are suppressed by inverse powers of the b-quark mass. Thus, the total inclusive decay rate of a hadron H_b can be written as [21,47]

$$\Gamma(H_b) = \frac{G_F^2 m_b^5 |V_{cb}|^2}{192 \pi^3} \times$$

$$\left\{c_3 \langle \bar{b}b \rangle + c_5 \frac{\langle \bar{b} g \sigma_{\mu\nu} G^{\mu\nu} b \rangle}{m_b^2} + \sum_n c_6^{(n)} \frac{\langle O_6^{(n)} \rangle}{m_b^3} + \ldots \right\}, \qquad (16.10)$$

where the prefactor arises from the loop integrations, c_i are calculable coefficient functions, and $\langle O_i \rangle$ are the (normalized) forward matrix elements between H_b states. These matrix elements can be systematically expanded in powers of $1/m_b$ using HQET. The result is [21,47]

$$\langle \bar{b}b \rangle = 1 - \frac{\mu_{\pi}^2(H_b) - \mu_G^2(H_b)}{2m_b^2} + \dots, \qquad \frac{\langle \bar{b} \, g \sigma_{\mu\nu} G^{\mu\nu} b \rangle}{m_b^2} = \frac{2\mu_G^2(H_b)}{m_b^2} + \dots,$$

$$(16.11)$$

where $\mu_{\pi}^2(H_b)$ and $\mu_G^2(H_b)$ are the matrix elements of the heavy-quark kinetic energy and chromomagnetic interaction inside the hadron H_b , respectively [27]. For the ground-state heavy mesons and baryons, one can extract $\mu_G^2(B) = 3(m_{B^*}^2 - m_B^2)/4 \simeq 0.36\,\mathrm{GeV}^2$ and $\mu_G^2(\Lambda_b) = 0$ from spectroscopy.

From the fully inclusive width Eq. (16.10) one can obtain the lifetime of a heavy hadron via $\tau(H_b)=1/\Gamma(H_b)$. Due to the universality of the leading term in the heavy-quark expansion, lifetime ratios such as $\tau(B^-)/\tau(\bar{B}^0)$, $\tau(\bar{B}^0_s)/\tau(\bar{B}^0)$, and $\tau(\Lambda_b)/\tau(\bar{B}^0)$ are particularly sensitive to the hadronic parameters determining the power corrections in the expansion. In order to understand these ratios theoretically, it is necessary to include phase-space enhanced power corrections of order $(\Lambda_{\rm QCD}/m_b)^3$ as well as short-distance perturbative effects in the calculation [28,29].

A formula analogous to Eq. (16.10) can be derived for differential distributions in specific inclusive decay processes, assuming that these distributions are integrated over sufficiently large portions of phase space to ensure quark-hadron duality. Important examples are the distributions in lepton energy $(d\Gamma/dE_\ell)$ or lepton invariant mass $(d\Gamma/dq^2)$, as well as moments of the invariant hadronic mass distribution, in the semileptonic processes $\bar{B} \to X_u \, \ell \, \bar{\nu}$ and $\bar{B} \to X_c \, \ell \, \bar{\nu}$, as well as the photon energy spectrum $(d\Gamma/dE_\gamma)$ in the radiative process $\bar{B} \to X_s \gamma$. While the latter process is primarily used to test the Standard Model and search for hints of new physics, an analysis of decay distributions in the semileptonic processes can be employed to perform a global fit determining the CKM matrix elements $|V_{ub}|$ and $|V_{cb}|$ along with heavy-quark parameters such as the masses m_b, m_c and the hadronic parameters $\mu_\pi^2(B)$, $\mu_G^2(B)$. These determinations provide some of the most accurate values for these parameters [30].

16.2.6. Shape functions and non-local power corrections: In certain regions of phase space, in which the hadronic final state in an inclusive heavy-hadron decay is made up of light energetic partons, the local OPE for inclusive decays must be replaced by a more complicated expansion involving hadronic matrix elements of non-local light-ray operators [52,53]. Prominent examples are the radiative decay $\bar{B} \to X_s \gamma$ for large photon energy E_γ near $m_B/2$, and the semileptonic decay $\bar{B} \to X_u \ell \bar{\nu}$ at large lepton energy or small hadronic invariant mass. In these cases, the differential decay rates at leading order in the heavy-quark expansion can be written in the factorized form $d\Gamma \propto H \, J \otimes S$ [33], where the hard function H and the jet function J are calculable in perturbation theory. The characteristic scales for these functions are set by m_b and $(m_b \Lambda_{\rm QCD})^{1/2}$, respectively. The soft function

$$S(\omega) = \int \frac{dt}{4\pi} e^{-i\omega t} \langle \bar{B}(v) | \bar{h}_v(tn) Y_n(tn) Y_n^{\dagger}(0) h_v(0) | \bar{B}(v) \rangle \quad (16.12)$$

is a genuinely non-perturbative object, called the shape function [52,53]. Here Y_n are soft Wilson lines along a light-like direction n aligned with the momentum of the hadronic final-state jet. The jet function and the shape function share a common variable $\omega \sim \Lambda_{\rm QCD}$, and the symbol \otimes denotes a convolution in this variable.

While the hard function is different for the two decays, the jet and soft functions are identical at leading order in $\Lambda_{\rm QCD}/m_Q$. This is particularly important for the soft function. It is this shape function that introduces non-perturbative physics into the theoretical predictions for the cross sections of $\bar{B} \to X_s \gamma$ and $\bar{B} \to X_u \, \ell \bar{\nu}$ in the regions of experimental interest. The fact that both decays depend on the same non-perturbative function made it possible to determine this non-perturbative information from the measured shape of the photon spectrum in $\bar{B} \to X_s \gamma$, allowing for a better understanding of the process used to determine the CKM element $|V_{ub}|$. In higher orders of the heavy-quark expansion, an increasing number of subleading jet and soft functions is required to describe the decay distributions [34]. These have been analyzed in detail at order $1/m_b$ [35–37]. The technology for deriving the corresponding factorization theorems relies on SCET, which is discussed below.

16.3. Soft-Collinear Effective Theory

As discussed in the previous section, soft gluons that bind a heavy quark inside a heavy meson cannot change the virtuality of that heavy quark by a significant amount. The ratio of $\Lambda_{\rm QCD}/m_Q$ provided the expansion parameter in HQET, which is a small parameter since $m_Q\gg\Lambda_{\rm QCD}$. This obviously does not work when considering light quarks. However, if the energy Q of the quarks is large, the ratio $\Lambda_{\rm QCD}/Q$ provides a small parameter which can be used to construct an effective theory. One major difference to HQET is that light energetic quarks cannot only emit soft gluons, but they can also emit collinear gluons (an energetic gluon in the same direction as the original quark), without parametrically changing their virtuality. Thus, to fully reproduce the long-distance physics of energetic quarks requires that one includes their interactions with both soft and collinear particles. The resulting effective theory is therefore called soft-collinear effective theory (SCET) [38–40].

SCET is applicable for processes containing particles with energy much in excess of their mass, and it has therefore a wide range of applications. In this brief review we will outline the main features of this effective theory and mention a few selected applications.

16.3.1. General idea of the expansion: Consider a quark with energy Q and virtuality $m \ll Q$, moving along the direction \vec{n} . It is convenient to parameterize the momentum p_n of this particle in terms of its light-cone components, defined by $(p_n^-, p_n^+, p_n^\perp) = (\bar{n} \cdot p_n, n \cdot p_n, p_n^\perp)$, where $n^\mu = (1, \vec{n})$ and $\bar{n}^\mu = (1, -\vec{n})$ are light-like 4-vectors, and $n \cdot p_\perp = \bar{n} \cdot p_\perp = 0$. A subscript n has been added to the momentum to identify it as a collinear particle in direction n (more precisely, a particle with energy much larger than its virtuality moving along a direction \vec{n}). In terms of these light-cone components, the virtuality satisfies $m^2 = p_n^+ p_n^- + p_n^{\perp 2}$. The individual components of the momentum satisfy

$$(p_n^-, p_n^+, p_n^\perp) \sim (Q, m^2/Q, m) \equiv Q(1, \lambda^2, \lambda),$$
 (16.13)

where $\lambda = m/Q$ is the expansion parameter of SCET.

The virtuality of such an energetic particle remains parametrically unchanged if it interacts with energetic particles in the same direction n, or with soft particles with momentum scaling as

$$(p_s^-, p_s^+, p_s^\perp) \sim Q(\lambda^2, \lambda^2, \lambda^2).$$
 (16.14)

Thus, it is the interactions of collinear and soft degrees of freedom that give rise to the long-distance physics. SCET, which is constructed to reproduce this long-distance dynamics, is therefore an effective theory describing the interactions of collinear and soft particles.

The above power counting treats the soft momentum to be of order m^2/Q , where m denotes the mass of a collinear system. If the mass of the collinear system is of order $\Lambda_{\rm QCD}$, as would be the case for a single energetic hadron, this power counting is no longer applicable, since $\Lambda_{\rm QCD}$ provides a natural cutoff to QCD and the soft momentum cannot be below this scale. To describe such systems requires a modified version of SCET, called SCET_{II}, in which the scaling of the soft modes is $Q(\lambda, \lambda, \lambda)$. In this review we will focus only on SCET with the scaling discussed before, which is sometimes called SCET_I.

16.3.2. Leading-order Lagrangian: The derivation of the SCET Lagrangian follows similar steps as the derivation of the HQET Lagrangian in Section 16.2.1, but care has to be taken to properly account for the interactions of collinear fields with one another. We begin by deriving the Lagrangian for a theory containing only a single type of collinear degrees of freedom. We are interested in the interactions of fermion fields $q_n(x)$ with gluon fields $A_n(x)$, which have collinear momentum in the same light-like direction n. Similar to HQET, one can separate the full QCD field into two components, $q_n(x) = \psi_n(x) + \Xi_n(x)$, where

$$\psi_n(x) = \frac{n \overline{n}}{4} q_n(x), \qquad \Xi_n(x) = \frac{\overline{n} n}{4} q_n(x).$$

In terms of these fields, the QCD Lagrangian is

$$\mathcal{L}_{n} = \bar{\psi}_{n}(x)\frac{\vec{\eta}}{2}in \cdot D_{n}\,\psi_{n}(x) + \bar{\Xi}_{n}(x)\frac{\vec{\eta}}{2}i\bar{n} \cdot D_{n}\,\Xi_{n}(x) + \bar{\psi}_{n}(x)i\,\mathcal{D}_{n}^{\perp}\,\Xi_{n}(x) + \bar{\Xi}_{n}(x)i\,\mathcal{D}_{n}^{\perp}\,\psi_{n}(x),$$

$$(16.15)$$

where we have defined the transverse derivative $D_n^{\perp \mu} = D_n^{\mu} - \frac{n^{\mu}}{2}\bar{n} \cdot D_n - \frac{\bar{n}^{\mu}}{2}n \cdot D_n$. Since $\bar{n} \cdot p_n \gg 1$ the field $\Xi_n(x)$ has no pole in its propagator, similar to the field $H_v(x)$ in Eq. (16.3). It can therefore be integrated out using its equation of motion. Inserting this back into Eq. (16.15), we find

$$\mathcal{L}_{n} = \bar{\psi}_{n}(x) \left[i n \cdot D_{n} + i \not \!\! D_{n}^{\perp} \frac{1}{i \bar{n} \cdot D_{n}} i \not \!\! D_{n}^{\perp} \right] \frac{\vec{\eta}}{2} \psi_{n}(x). \tag{16.16}$$

While this Lagrangian leads to the correct Feynman rules of SCET, there is one feature that warrants extra discussion. In contrast to the Lagrangian of HQET given in Eq. (16.5), where the derivative scales like the residual momentum k of the heavy quark, the derivatives in Eq. (16.16) pick up both the large momentum components of order Q and $Q\lambda$, as well as the residual momentum of order $Q\lambda^2$. One can separate the large and residual momentum components using a procedure similar to the HQET case. Separating the collinear momentum into a "label" and a residual component, $p^{\mu} = P^{\mu} + k^{\mu}$, and performing a phase redefinition on the collinear fields $\psi_n(x) = e^{iP \cdot x} \xi_n(x)$, derivatives acting on the fields $\xi_n(x)$ now only pick out the residual momentum. Since the label momentum in SCET is not conserved as in HQET, one defines a label operator \mathcal{P}^{μ} acting as $\mathcal{P}^{\mu}\xi_n(x) = P^{\mu}\xi_n(x)$ [39], as well as a corresponding covariant label operator $i\mathcal{D}^{\mu}_n = \mathcal{P}^{\mu} + gA_n(x)$.

The final step to complete the Lagrangian of SCET is to include the interactions of collinear fields with soft fields. These interactions can be included by adding the soft gluons to the covariant derivatives, while preserving the power counting. This leads to the final SCET Lagrangian [39–41]

$$\mathcal{L}_{n} = \bar{\xi}_{n}(x) \left[in \cdot D_{n} + gn \cdot A_{s} + i \mathcal{P}_{n}^{\perp} \frac{1}{i\bar{n} \cdot \mathcal{D}_{n}} i \mathcal{P}_{n}^{\perp} \right] \frac{\vec{n}}{2} \xi_{n}(x). \quad (16.17)$$

The leading-order Lagrangian describing collinear fields in different light-like directions is simply given by the sum of the Lagrangians for each direction n separately, i.e. $\mathcal{L} = \sum_n \mathcal{L}_n$. The soft gluons are the same in each individual Lagrangian. An alternative way to understand the separation between large and small momentum components is to derive the Lagrangian of SCET in position space. In this case no label operators are required to describe interactions in SCET, and the dependence on short-distance effects is contained in non-localities at short distances. An important difference between SCET and HQET is that the SCET Lagrangian is not corrected by short distance fluctuations [42].

16.3.3. Collinear gauge invariance and Wilson lines: An important aspect of SCET is the gauge structure of the theory. Because the effective field operators in SCET describe modes with certain momentum scalings, the effective Lagrangian respects only residual gauge symmetries. One of them satisfies the collinear scaling

$$(\bar{n} \cdot \partial_n, n \cdot \partial_n, \partial_n^{\perp}) U_n(x) \sim Q(1, \lambda^2, \lambda) U_n(x),$$
 (16.18)

and one the soft scaling

$$(\bar{n} \cdot \partial_n, n \cdot \partial_n, \partial_n^{\perp}) U_s(x) \sim Q(\lambda^2, \lambda^2, \lambda^2) U_s(x).$$
 (16.19)

The fact that collinear fields in different directions do not transform under the same gauge transformations implies that each collinear sector, containing particles with large momenta along a certain direction, has to be separately gauge invariant. This is achieved by the introduction of collinear Wilson lines [39]

$$W_n(x) = P \exp\left[-ig \int_{-\infty}^0 ds \,\bar{n} \cdot A_n(s\bar{n} + x)\right],\tag{16.20}$$

which transform under collinear gauge transformations according to $W_n \to U_n W_n$. Thus, the combination $\chi_n \equiv W_n^\dagger \psi_n$ is gauge invariant. In a similar manner, one can define the gauge-invariant gluon field $B_n^\mu = g^{-1} W_n^\dagger i D_n^\mu W_n$ [43]. Operators in SCET are typically constructed from such gauge-invariant collinear fields.

16.3.4. Decoupling of soft gluons: Soft gluons in SCET couple to collinear quarks only through the term $\bar{\xi}_n gn \cdot A_s \frac{\vec{n}}{2} \xi_n$ in the effective Lagrangian in Eq. (16.17). This coupling is similar to the coupling of soft gluons to heavy quarks in HQET, and soft gluons in SCET can be decoupled from collinear fields in a way similar as explained in Section 16.2.4. Written in terms of the redefined fields

$$\psi_n(x) = Y_n(x)\psi_n^{(0)}(x), \qquad A_n(x) = Y_n(x)A_n^{(0)}(x)Y_n^{\dagger}(x), \quad (16.21)$$

the soft gluons decouple from the SCET Lagrangian [40]. This fact greatly facilitates proofs of factorization theorems in SCET.

16.3.5. Factorization Theorems: One of the important applications of SCET is to understand how to factorize cross sections involving energetic particles in different directions into simpler pieces that can either be calculated perturbatively or determined from data. Factorization theorems have been around for much longer than SCET. For a review on the subject, see [44]. However, the effective theory allows for a conceptually simpler understanding of certain classes of factorization theorems [45], since most simplifications happen already at the level of the Lagrangian. The discussion in this section is valid to leading order in the power counting of the effective theory.

As discussed in the previous section, the Lagrangian of SCET does not involve any couplings between collinear degrees of freedom in different light-like directions, or between soft and collinear degrees of freedom after the field redefinition Eq. (16.21) has been performed. An operator describing the scattering and production of collinear partons at short distances can thus be written as

$$\langle O(x) \rangle \simeq C_O(\mu) \times$$

$$\left\langle \mathcal{C}_{n_a}^{(0)}(x)\mathcal{C}_{n_b}^{(0)}(x)\mathcal{C}_{n_1}^{(0)}(x)\dots\mathcal{C}_{n_N}^{(0)}(x)[\mathcal{Y}_{n_a}\mathcal{Y}_{n_b}\mathcal{Y}_{n_1}\dots\mathcal{Y}_{n_N}](x)\right\rangle_{\mu}.$$
 (16.22)

Here $C_n(x)$ denotes a gauge-invariant combination of collinear fields (either quark or gluon fields) in the direction n, and the matching coefficient accounting for short-distance effects is denoted by C_O . The soft Wilson lines can either be in a color triplet or color octet representation, and are collectively denoted by \mathcal{Y}_n . Both the matrix elements and the coefficient C_O depend on the renormalization scale μ .

Having defined the operator mediating a given process, one can calculate the cross section by squaring the operator, taking the forward matrix element and integrating over the phase space of all final-state particles. The absence of interactions between collinear degrees of freedom moving along different directions or soft degrees of freedom implies that the forward matrix element of the operator can be factorized as

$$\left\langle \operatorname{in} \left| O(x) O^{\dagger}(0) \right| \operatorname{in} \right\rangle = \left\langle \operatorname{in}_{a} \left| \mathcal{C}_{n_{a}}(x) \mathcal{C}_{n_{a}}^{\dagger}(0) \right| \operatorname{in}_{a} \right\rangle \left\langle \operatorname{in}_{b} \left| \mathcal{C}_{n_{b}}(x) \mathcal{C}_{n_{b}}^{\dagger}(0) \right| \operatorname{in}_{b} \right\rangle$$

$$\times \left\langle 0 \left| \mathcal{C}_{n_{1}}(x) \mathcal{C}_{n_{1}}^{\dagger}(0) \right| 0 \right\rangle \cdots \left\langle 0 \left| \mathcal{C}_{n_{N}}(x) \mathcal{C}_{n_{N}}^{\dagger}(0) \right| 0 \right\rangle$$

$$\times \left\langle 0 \left| \left[\mathcal{Y}_{n_{a}} \dots \mathcal{Y}_{n_{N}} \right] (x) \left[\mathcal{Y}_{n_{a}} \dots \mathcal{Y}_{n_{N}} \right]^{\dagger} (0) \right| 0 \right\rangle.$$

$$\left\langle 0 \left| \left[\mathcal{C}_{n_{a}} \left(\mathcal{C}_{n_{a}} \right) \left(\mathcal{C}_{$$

Thus, the matrix element required for the differential cross section has factorized into a product of simpler structures, each of which can be evaluated separately.

For most applications the matrix elements of incoming collinear fields are non-perturbative objects given in terms of the well-known parton distribution functions, while the matrix elements of outgoing collinear fields are determined by perturbatively calculable jet functions $J_i(\mu)$. Finally, the vacuum matrix element of the soft Wilson lines defines a so-called soft function, commonly denoted by $S(\mu)$. The common dependence on x in the above equation implies that in momentum space the various components of the factorization theorem are convoluted with one another. Deriving this convolution requires a careful treatment of the phase-space integration, in particular treating the large and residual components of each momentum appropriately.

Putting all information together, the differential cross section can be written as

$$d\sigma \sim H(\mu) \otimes \left[f_{p_1/P}(\mu) f_{p_2/P}(\mu) \right] \otimes \left[J_1(\mu) \dots J_N(\mu) \right] \otimes S(\mu).$$
 (16.24)

The hard coefficient is equal to the square of the matching coefficient, $H(\mu) = |C_O(\mu)|^2$. It should be mentioned that the most difficult part of traditional factorization proofs involves showing that so-called Glauber gluons do not spoil the above factorization theorem. This question has not yet been fully addressed in the context of SCET.

16.3.6. Resummation of large logarithms: SCET can be used to sum the large logarithmic terms that arise in perturbative calculations. In general, perturbation theory will generate a logarithmic dependence on any ratio of scales r in a problem, and for processes that involve initial or final states with energy much in excess of their mass there are two powers of logarithms for every power of the strong coupling constant. Thus, for widely separated scales these large logarithms can spoil fixed-order perturbation theory, and a much better convergence is achieved by expanding in α_s , but holding $\alpha_s \log^2 r$ fixed, such that the first term in the new expansion resums powers of $\alpha_s \log^2 r$ to all orders. More precisely, a proper resummation requires to sum logarithms of the form $\alpha_s^n \log^m r$ with $m \leq n+1$ in the logarithm of a cross-section.

The important ingredient in achieving this resummation is the fact that SCET factorizes a given cross section into simpler pieces, as discussed in the previous section. Each of the ingredients of the factorization theorem depends on a single physical scale, and the only dependence on that scale can arise through logarithms of its ratio with the renormalization scale μ . Thus, for each of the components in the factorization theorem one can choose a renormalization scale μ for which the large logarithmic terms are absent.

Of course, the factorization formula requires a common renormalization scale μ in all its components, and one therefore has to use the RG to evolve the various component functions from their preferred

scale to the common scale μ . For example, for the hard coefficient $H(\mu)$, the RG equation can be written as

$$\mu \frac{\mathrm{d}}{\mathrm{d}\mu} H(\mu) = \gamma_H(\mu) H(\mu). \tag{16.25}$$

In general, the anomalous dimension is of the form $\gamma_H(\mu) = c_H \Gamma_{\rm cusp}(\alpha_s) \log(Q/\mu) + \gamma(\alpha_s)$, where c_H is a process-dependent coefficient and $\Gamma_{\rm cusp}$ denotes the so-called cusp anomalous dimension [18,46]. The non-cusp part of the anomalous dimension γ is again process dependent. The presence of a logarithm of the hard scale Q in the anomalous dimension is characteristic of Sudakov problems and arises since the perturbative series contains double logarithms of scale ratios. The anomalous dimension γ_H is known at two-loop order for arbitrary n-parton amplitudes containing massless or massive external partons [47–50]. Solving the RG equation yields

$$H(\mu) = U_H(\mu, \mu_h)H(\mu_h),$$
 (16.26)

which can be used to write the hard function at a scale $\mu_h \sim Q$, where its perturbative expression does not contain any large logarithms, in terms of the common renormalization scale μ . The RG evolution factor $U_H(\mu,\mu_h)$ sums logarithms of the form μ/μ_h . By calculating the anomalous dimension $\gamma_H(\mu)$ to higher and higher orders in perturbation theory, one can resum more and more logarithms in the evolution kernel. The RG equations for the jet and soft functions are more complicated, since they involve convolutions over the relevant momentum variables.

16.3.7. Applications: Most of the applications of SCET are either in flavor physics, where the decay of a heavy B meson can give rise to energetic light partons, or in collider physics, where the presence of jets naturally leads to collimated sets of energetic particles. For several of these applications alternative approaches existed before the invention of SCET, but the effective theory has opened up alternative ways to understand the physics of these processes. There are, however, many examples for which SCET has allowed new insights that were not available or possible without the effective theory. In particular, it has provided a field-theoretic basis for the QCD factorization approach to exclusive, non-leptonic decays of B mesons [51]. Using SCET methods, proofs of factorization were derived for the color-allowed decay $\bar{B}^0 \to D^+\pi^-$ [52], the color-suppressed decay $\bar{B}^0 \to D^0\pi^0$ [53], and the radiative decay $\bar{B} \to K^* \gamma$ [54]. Further examples are factorization theorems and the resummation of endpoint logarithms for quarkonia production [55], factorization theorems for cross sections defined through jet algorithms [56], the resummation of large logarithmic terms for the thrust [57] and jet broadening [58] distributions in e^+e^- annihilation beyond NLL order, the development of new factorizable observables to veto extra jets [59], all-orders factorization theorems for processes containing electroweak Sudakov logarithms [60], as well as the resummation of threshold (soft gluon) logarithms for several important processes at hadron colliders [61,62]. We describe two of these applications in more detail.

Event-shape distributions, in particular the thrust distribution, have been measured to high accuracy at LEP [63]. Comparing these data to precise theoretical predictions allows for a determination of the strong coupling constant α_s . For small values of $\tau \equiv 1-T$, the distribution can be factorized into the form [64,65]

$$\frac{1}{Q\sigma_0}\frac{\mathrm{d}\sigma}{\mathrm{d}\tau} = H(\mu)\int\mathrm{d}s\int\mathrm{d}k\,J(s,\mu)\,S(Q\tau-s/Q-k,\mu). \eqno(16.27)$$

Here Q denotes the center-of-mass energy of the collision, σ_0 is the total hadronic cross section, and $H,\ J$ and S are the hard, jet and soft functions in SCET. Large logarithms of the form $(\alpha_s^n \ln^{2n-1}\tau)/\tau$ become important and have to be resummed. Furthermore, for $\tau \sim \Lambda_{\rm QCD}/Q$ non-perturbative effects in the soft function become important. Using SCET the resummation of these large logarithms has been performed to N³LL, which is two orders beyond what was previously available [57]. The factorization in the effective theory has also allowed to include the non-perturbative physics through a shape function, very similar to the B-physics case discussed above.

The known perturbative effects for large values of τ can be included by matching the SCET result to the known two-loop spectrum [66,67]. Comparing the predicted to the measured thrust distribution allows for a precise determination of the strong coupling constant α_s [68].

For quarkonium produced in e^+e^- annihilation or photo-production, large logarithms arise in the region of phase space where the energy of the produced $Q\bar{Q}$ state is close to its maximum value. In this region the quarkonium is predominantly produced in a color-octet configuration and recoils against a collinear hadronic system. Then logarithms of the form $\log(1-E_{\Psi}/E_{\rm max})$ as well as non-perturbative effects become important and should be included in attempts to describe the data. While some of these issues had been addressed without the use of an effective theory (see [69] and references therein), a complete treatment of the endpoint region has only been achieved using SCET [55]. It was shown that including both effects consistently, theory and data can be brought into better agreement.

16.4. Open issues and perspectives

HQET has successfully passed many experimental tests, and there are not too many open questions that still need to be addressed. One issue that has not been derived from first principles is quark-hadron duality. The validity of global duality (at energies even lower than those relevant in B decays) has been tested experimentally using high-precision data on semileptonic B decays and on hadronic τ decays, and there has been good agreement between theory and data. However, assigning a theoretical uncertainty to possible duality violations is difficult. Another known issue is the that the measured value of the CKM element $|V_{cb}|$ is different depending of whether one uses inclusive or exclusive B decays to derive it (see the relevant section in the Particle Data Book). Both measurements rely on the heavy-quark limit, and the uncertainties quoted include the effects from power corrections arising from the finite b-quark mass.

SCET, on the other hand, is still an active field of research, and there are several open questions that need to be answered. In this review we have not discussed any issues having to do with SCET_{II}, which is the appropriate effective theory describing the interactions of collinear particles with soft particles having momentum scaling as $Q(\lambda,\lambda,\lambda)$. This is important, for example, to describe exclusive decays of B mesons into light, energetic mesons, or in collider-physics applications such as the p_T resummation for Drell-Yan production. There are still open issues in how to properly formulate SCET_{II}, which are under active investigation. They include the treatment of endpoint singularities of convolution integrals, double counting between overlapping momentum regions, and the breakdown of the naive factorization of soft and collinear modes due to quantum effects. Glauber gluons are known to affect factorization theorems, but how to properly include them in SCET is still an open question.

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17. LATTICE QUANTUM CHROMODYNAMICS

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17.1. Lattice regularization of QCD

Gauge theories form the building blocks of the Standard Model. While the SU(2) and U(1) parts have weak couplings and can be studied accurately with perturbative methods, the SU(3) component-QCD—is only amenable to a perturbative treatment at high energies. The growth of the coupling constant in the infrared—the flip-side of asymptotic freedom—requires the use of non-perturbative methods to determine the low energy properties of QCD. Lattice gauge theory, proposed by K. Wilson in 1974 [1], provides such a method, for it gives a non-perturbative definition of vector-like gauge field theories like QCD. In lattice regularized QCD—commonly called lattice QCD or LQCD—Euclidean space-time is discretized, usually on a hypercubic lattice with lattice spacing a, with quark fields placed on sites and gauge fields on the links between sites. The lattice spacing plays the role of the ultraviolet regulator, rendering the quantum field theory finite. The continuum theory is recovered by taking the limit of vanishing lattice spacing, which can be reached by tuning the bare coupling constant to zero according to the renormalization group.

Unlike dimensional regularization, which is commonly used in continuum QCD calculations, the definition of LQCD does not rely on the perturbative expansion. Indeed, LQCD allows non-perturbative calculations by numerical evaluation of the path integral that defines the theory.

Practical LQCD calculations are limited by the availability of computational resources and the efficiency of algorithms. Because of this, LQCD results come with both statistical and systematic errors, the former arising from the use of Monte-Carlo integration, the latter, for example, from the use of non-zero values of a. There are also different ways in which the QCD action can be discretized, and all must give consistent results in the continuum limit. It is the purpose of this review to provide an outline of the methods of LQCD, with particular focus on applications to particle physics, and an overview of the various sources of error. This should allow the reader to better understand the LQCD results that are presented in other sections for a variety of quantities (quark masses, the hadron spectrum and several electroweak matrix elements). For more extensive explanations the reader should consult the available text books, the most up-to-date of which are Refs. [2,3,4].

17.1.1. Gauge invariance, gluon fields and the gluon action:

A key feature of the lattice formulation of QCD is that it preserves gauge invariance. This is in contrast to perturbative calculations, where gauge fixing is an essential step. The preservation of gauge invariance leads to considerable simplifications, e.g. restricting the form of operators that can mix under renormalization.

The gauge transformations of lattice quark fields are just as in the continuum: $q(x) \longrightarrow V(x)q(x)$ and $\bar{q}(x) \longrightarrow \bar{q}(x)V^{\dagger}(x)$, with V(x) an arbitrary element of SU(3). The only difference is that the Euclidean space-time positions x are restricted to lie on the sites of the lattice, i.e. $x = a(n_1, n_2, n_3, n_4)$ for a hypercubic lattice, with the n_i being integers. Quark bilinears involving different lattice points can be made gauge invariant by introducing the gluon field $U_{\mu}(x)$. For example, for adjacent points the bilinear is $\bar{q}(x)U_{\mu}(x)q(x+a\hat{\mu})$, with $\hat{\mu}$ the unit vector in the μ 'th direction. (This form is used in the construction of the lattice covariant derivative.) The gluon field (or "gauge link") is an element of the group, SU(3), in contrast to the continuum field A_{μ} which takes values in the Lie algebra. The bilinear is invariant if U_{μ} transforms as $U_{\mu}(x) \to V(x)U_{\mu}(x)V^{\dagger}(x+a\hat{\mu})$. The lattice gluon field is naturally associated with the link joining x and $x+a\hat{\mu}$, and corresponds in the continuum to a Wilson line connecting these two points, $P \exp(i \int_x^{x+a\hat{\mu}} dx_{\mu} A_{\mu}^{\rm cont}(x))$ (where P indicates a path-ordered integral, and the superscript on A_{μ} indicates that it is a continuum field). The trace of a product of the $U_{\mu}(x)$ around any closed loop is easily seen to be gauge invariant and is the lattice version of a Wilson

The simplest possible gauge action, usually called the Wilson gauge action, is given by the product of gauge links around elementary

plaquettes:

$$S_g = \beta \sum_{x,\mu\nu} [1 - \text{ReTr}[U_{\mu}(x)U_{\nu}(x+a\hat{\mu})U_{\mu}^{\dagger}(x+a\hat{\nu})U_{\nu}^{\dagger}(x)]/3]. \quad (17.1)$$

For small a, assuming that the fields are slowly varying, one can expand the action in powers of a using $U_{\mu}(x) = \exp(iaA_{\mu}(x))$. Keeping only the leading non-vanishing term, and replacing the sum with an integral, one finds the continuum form,

$$S_g \longrightarrow \int d^4x \frac{1}{4g_{\rm lat}^2} \text{Tr}[F_{\mu\nu}^2(x)], \qquad (F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + i[A_\mu, A_\nu])$$

$$(17.2)$$

as long as one chooses $\beta=6/g_{\rm lat}^2$ for the lattice coupling. In this expression, $g_{\rm lat}$ is the bare coupling constant in the lattice scheme, which can be related (by combining continuum and lattice perturbation theory) to a more conventional coupling constant such as that in the $\overline{\rm MS}$ scheme (see Sec. 17.3.4 below).

In practice, the lattice spacing a is non-zero, leading to discretization errors. In particular, the lattice breaks Euclidean rotational invariance (which is the Euclidean version of Lorentz invariance) down to a discrete hypercubic subgroup. One wants to reduce discretization errors as much as possible. A very useful tool in this regard is the Symanzik effective action: the interactions of quarks and gluons with momenta low compared to the lattice cutoff ($|p| \ll 1/a$) are described by a continuum action consisting of the standard continuum terms (e.g. the gauge action given in Eq. (17.2)) augmented by higher dimensional operators suppressed by powers of a [5]. For the Wilson lattice gauge action, the leading correction comes in at $\mathcal{O}(a^2).$ It takes the form $\sum_j a^2 O_6^{(j)},$ with the sum running over all dimension-six operators $O_6^{(j)}$ allowed by the *lattice* symmetries. Some of these operators violate Euclidean invariance, and all of them lead to discretization errors proportional to a^2 . These errors can, however, be reduced by adding corresponding operators to the lattice action and tuning their coefficients to eliminate the dimension-six operators in the effective action to a given order in perturbation theory. This is the idea of the Symanzik improvement program [5]. In the case of the gauge action, one adds loops involving six gauge links (as opposed to the four links needed for the original plaquette action, Eq. (17.1) to define the $\mathcal{O}(a^2)$ improved (or "Symanzik") action [6]. In practical implementations, the improvement is either at tree-level (so that residual errors are proportional to $\alpha_s a^2$, where the coupling is evaluated at a scale $\sim 1/a$), or at one loop order (errors proportional to $\alpha_s^2 a^2$). Another popular choice is motivated by studies of renormalization group (RG) flow. It has the same terms as the $\mathcal{O}(a^2)$ improved action but with different coefficients, and is called the RG-improved or "Iwasaki" action [7].

17.1.2. Lattice fermions:

Naive discretization of the continuum fermion action $S_f=\int d^4x \bar{q}[i\partial_\mu\gamma_\mu+m]q$, in which one replaces the derivative $\partial_\mu q$ by a discrete difference $[q(x+a\hat{\mu})-q(x-a\hat{\mu})]/2a$, leads to the fermion doubling problem—the resulting action describes 2^d equivalent fermion fields in the continuum limit in d dimensions. The appearance of the extra "doubler" fermions is related to the deeper theoretical problem of formulating chirally symmetric fermions on the lattice. This is encapsulated by the Nielsen-Ninomiya theorem [8]: one cannot define lattice fermions having exact, continuum-like chiral symmetry without producing doublers. Naive lattice fermions do have chiral symmetry but at the cost of introducing 15 unwanted doublers (for d=4).

The doubling problem has been addressed in various ways, each coming with different pros and cons. Wilson fermions [1] add a term proportional to $a\bar{q}\Delta q$ to the fermion action (the "Wilson term"—in which Δ is a covariant lattice Laplacian). This gives a mass of $\mathcal{O}(1/a)$ to the doublers, so that they decouple in the continuum limit. The Wilson term, however, violates chiral symmetry, and also introduces discretization errors linear in a. A commonly used variant that eliminates the $\mathcal{O}(a)$ discretization error is the $\mathcal{O}(a)$ -improved Wilson (or "clover") fermion [9]. In this application of Symanzik improvement, methods have been developed to remove $\mathcal{O}(a)$ terms to all orders in perturbation theory using auxiliary simulations to tune parameters ("non-perturbative improvement") [10].

The advantages of Wilson fermions are their theoretical simplicity and relatively small computational cost. The disadvantage is their lack of chiral symmetry, which makes them difficult to use in cases where mixing with wrong chirality operators can occur, particularly if this involves divergences proportional to powers of 1/a. A related problem is potential numerical instabilities due to spurious near-zero modes. Ongoing work has, however, been successful at ameliorating these problems and increasing the range of quantities for which Wilson fermions can be used.

Twisted-mass fermions [11] are a variant of Wilson fermions which remove the numerical instability problem by treating two flavors of fermions together and adding an isospin-breaking mass term (the "twisted mass" term). Another advantage of this approach is that all errors linear in a are automatically removed (without the need for tuning of parameters) by a clever choice of twisted mass and operators.

Staggered fermions are a reduced version of naive fermions in which there is only a single fermion Dirac component on each lattice site, with the full Dirac structure built up from neighboring sites [12]. They have the advantages of being somewhat faster to simulate than Wilson-like fermions, of preserving some chiral symmetry, and of having discretization errors of $\mathcal{O}(a^2)$. Their disadvantage is that they retain some of the doublers (3 for d=4). The action thus describes four degenerate fermions in the continuum limit. The resulting SU(4) flavor symmetry is usually called "taste symmetry", and the preserved chiral symmetry in this formulation has non-singlet taste. Practical applications usually introduce one staggered fermion for each physical flavor, and remove contributions from the unwanted tastes by taking the fourth-root of the fermion determinant appearing in the path integral. The validity of this "rooting" procedure is not obvious because taste symmetry is violated for non-zero lattice spacing. Theoretical arguments, supported by numerical evidence, suggest that the procedure is valid as long as one takes the continuum limit before approaching the light quark mass region [13].

Just as for Wilson fermions, the staggered action can be improved, so as to reduce discretization errors. The widely used "asqtad" action [14] removes tree-level $\mathcal{O}(a^2)$ errors, and leads to substantial reduction in the breaking of taste symmetry. More recently, a highly improved staggered quark ("HISQ") action has been introduced [15], which further reduces taste symmetry-breaking and can also be used for heavy quarks such as charm.

There is an important class of lattice fermions that possess a continuum-like chiral symmetry without introducing unwanted doublers. The Dirac operator D for these fermions satisfies the Ginsparg-Wilson relation $D\gamma_5 + \gamma_5 D = aD\gamma_5 D$ [16]. In the continuum, the right-hand-side vanishes due to chiral symmetry. On the lattice, it is non-vanishing, but with a particular form (with two factors of D) that restricts the violations of chiral symmetry in Ward-Takahashi identities to short-distance terms that do not contribute to physical matrix elements. In fact, one can define a modified chiral transformation on the lattice (by including dependence on the gauge fields) such that "Ginsparg-Wilson fermions" have an exact chiral symmetry [17]. The net result is that such fermions essentially have the same properties under chiral transformations as do continuum fermions. Their leading discretization errors are of $\mathcal{O}(a^2)$.

Two types of Ginsparg-Wilson fermions are being used in large-scale projects. The first are Domain-wall fermions (DWF). These are defined on a five-dimensional space, in which the fifth dimension is fictitious [18]. The action is chosen so that the low-lying modes are chiral, with left- and right-handed modes localized on opposite four-dimensional surfaces. For an infinite fifth dimension, these fermions satisfy the Ginsparg-Wilson relation. In practice, the fifth dimension is kept finite, and there remains a small, controllable violation of chiral symmetry. The second type are Overlap fermions. These appeared from a completely different context and have an explicit form that exactly satisfies the Ginsparg-Wilson relation [19]. Their numerical implementation requires an approximation of the matrix sign function of a Wilson-like fermion operator, which is costly, instead of treating five-dimensional fields in the case of DWF.

As noted above, each fermion formulation has its own advantages and disadvantages. For instance, domain-wall and overlap fermions are

theoretically preferred as they have chiral symmetry without doublers, but their computational cost is at least an order of magnitude greater than for other choices. If the physics application of interest does not require near-exact chiral symmetry, there is no strong motivation to use these expensive formulations. On the other hand, there is a class of applications (including the calculation of the $\Delta I=1/2$ amplitude for $K\to\pi\pi$ decays and the S-parameter [20]) where chiral symmetry plays an essential role and for which the use of Ginsparg-Wilson fermions is strongly favored.

17.1.3. Heavy quarks on the lattice:

The fermion formulations described in the previous subsection are useful only for quarks whose masses are small compared to the lattice cutoff, $m \lesssim 1/a$. This is because there are discretization errors proportional to powers of am, and if $am \gtrsim 1$ these errors are large and uncontrolled. Present LQCD simulations typically have cutoffs in the range of 1/a = 2-4 GeV (corresponding to $a \approx 0.1-0.05$ fm), so that bottom quarks (with $m_b \approx 4.5$ GeV) require alternative discretizations while charm quarks ($m_c \approx 1.5$ GeV) are a borderline case.

For the charm quark, a straightforward approach is to simultaneously reduce the lattice spacing and to improve the fermion action so as to reduce the size of errors proportional to powers of am_c . This approach has, for example, been followed successfully by the HPQCD collaboration using the HISQ action [15]. It is important to note, however, that reducing a increases the computational cost because an increased number of lattice points are needed for the same physical volume. One cannot reduce the spatial size below 2-3 fm without introducing finite volume errors. Present lattices have sizes up to $\sim 64^3 \times 144$ (with the long direction being Euclidean time), and thus allow a lattice cutoff up to $1/a \sim 4$ GeV.

Other choices for the heavy quark action are motivated by effective field theories. For a bottom quark in heavy-light hadrons, one can use Heavy Quark Effective Theory (HQET) to expand about the infinite quark-mass limit, in which the bottom quark is a static color source [21]. Corrections, proportional to powers of $1/m_b$, can be introduced as operator insertions, with coefficients that can be determined non-perturbatively using existing techniques [22].

Another way of introducing the $1/m_b$ corrections is to include the relevant terms in the effective action. This leads to a non-relativistic QCD (NRQCD) action, in which the heavy quark is described by a two-component spinor [23]. This approach has the advantage over HQET that it can also be used for heavy-heavy systems, such as the Upsilon states. A disadvantage is that some of the parameters in this effective theory are determined perturbatively (in practice at tree-level, or in some cases at one-loop), which limits the precision of the final results. Although discretization effects can be controlled within NRQCD, at fine enough lattice spacings the NRQCD effective theory no longer applies since power divergent terms become important, and taking the continuum limit would require fine-tuning a large number of couplings non-perturbatively.

This problem can be avoided if one uses HQET power counting to reduce heavy-quark discretization effects. This can be accomplished by tuning the parameters of an improved Wilson quark action so that the leading HQET corrections to the static quark limit are correctly accounted for. As the lattice spacing becomes finer, the action smoothly goes over to that of a light Wilson quark action, where the continuum limit can be taken as usual. In principle, one can improve the action in the heavy quark regime up to arbitrarily high orders using HQET, but so far large-scale simulations have typically used clover improved Wilson quarks, where tuning the parameters of the action corresponds to including all corrections through next-to-leading order in HQET. Three different methods for tuning the parameters of the clover action are being used: the Fermilab [24], Tsukuba [25] and Columbia [26] approaches. An advantage of this HQET approach is that the c and b quarks can be treated on the same footing. On the other hand, as in NRQCD the tuning of the parameters in the effective action is typically done perturbatively, though a first attempt to tune them non-perturbatively has been made [27].

17.1.4. Basic inputs for lattice calculations:

Since LQCD is a regularization of QCD, the number of input parameters is the same as for continuum QCD—the strong coupling constant $\alpha_s = g^2/(4\pi)$, the quark masses for each flavor, and the CP violating phase θ . The θ parameter is usually assumed to be zero, while the other parameters must be determined using experimental inputs.

17.1.4.1. Lattice spacing: In QCD, the coupling constant is a function of scale. With lattice regularization, this scale is the inverse lattice spacing 1/a, and choosing the bare coupling constant is equivalent to fixing the lattice spacing.

In principle, a can be determined using any dimensionful quantity measured by experiments. For example, using the mass of hadron H one has $a=(am_H)^{\rm lat}/m_H^{\rm exp}$. (Of course, one must first tune the quark masses to their physical values, as discussed below.) In practice, one chooses quantities that can be calculated accurately on the lattice, and that are only weakly dependent on the light quark masses. The latter property minimizes errors from extrapolating to the physical light quark masses or from mistuning of these masses. Two commonly used choices are the spin-averaged 1S-1P or 1S-2S splittings in the Upsilon system, and the mass of the Ω^- baryon. The former has the advantage that it is insensitive to the b-quark mass, but the disadvantage that it requires a discretized heavy quark action.

The determination of a using quantities involving light (up and down) quarks—such as the nucleon mass or the pion decay constant—is more challenging. Most current lattice simulations are done using light quark masses heavier than those in nature. One thus has to extrapolate the lattice data towards the physical quark masses. This "chiral extrapolation" is non-trivial because the quark mass dependence may involve non-analytic terms due to the loops of nearly massless pions, as predicted by Chiral Perturbation Theory (ChPT) [28].

17.1.4.2. Light quark masses: In LQCD simulations, the up, down and strange quarks are usually referred to as the light quarks, in the sense that $m_q < \Lambda_{\rm QCD}$. (The standard definition of $\Lambda_{\rm QCD}$ is given in the "Quantum Chromodynamics" review; in this review we are using it only to indicate the approximate non-perturbative scale of QCD.) This condition is stronger than that used above to distinguish quarks with small discretization errors, $m_q < 1/a$. Loop effects from light quarks must be included in the simulations to accurately represent QCD. At present, most simulations are done in the isospin symmetric limit $m_u = m_d \equiv m_\ell$, and are often referred to as " $N_f = 2 + 1$ " simulations. Precision is now reaching the point where isospin breaking effects, as well as those of electromagnetism (EM) must be included. This can be done approximately using ChPT and other theoretical input, but ultimately one needs to simulate directly with $m_u \neq m_d$ and including QED corrections. Such work is now beginning.

To tune m_ℓ and m_s to their physical values, the most commonly used quantities are, respectively, m_π and m_K . If the scale is being set by m_Ω , then one adjusts the lattice light quark masses until the ratios m_π/m_Ω and m_K/m_Ω take their physical values. At leading order in ChPT, one has the Gell-Mann-Oakes-Renner relations $m_{\pi^0}^2 \propto (m_u + m_d)$ and $m_K^2 \propto (m_d + m_s)$, which shows the sensitivity of these quantities to the quark masses. In practice one uses higher order ChPT (or other fit functions) to extrapolate or interpolate the lattice results so as to match the desired ratios, correcting for the (small) effects of isospin breaking and electromagnetic corrections. Most present calculations need to extrapolate to the physical value of m_ℓ , while simulating directly at or near to the physical value of m_s .

17.1.4.3. Heavy quark masses: Heavy quarks (c and b) are usually treated only as valence quarks, with no loop effects included. Generically, the errors introduced by this approximation are $\sim \alpha_s(m_c) \Lambda_{\rm QCD}^2/m_c^2$ and are small. For high precision, however, dynamical charm quarks may be necessary, and simulations are beginning to include them.

The heavy quark masses can be tuned by setting heavy-heavy or heavy-light meson masses to their experimental values. For the charm quark, for example, one could use the J/ψ or the D_s meson.

Consistency between these two determinations provides an important check on the lattice formulation used for the heavy quark [29].

17.1.5. Sources of systematic error:

Lattice results have statistical and systematic errors that must be quantified for any calculation in order for the result to be a useful input to phenomenology. The statistical error is due to the use of Monte Carlo importance sampling to evaluate the path integral (a method discussed below) and is the most straightforward error to estimate. There are, in addition, a number of systematic errors that are always present to some degree in lattice calculations, although the size of any given error depends on the particular quantity under consideration and the parameters of the lattices being used. The most common lattice errors are reviewed below.

17.1.5.1. Continuum limit: Physical results are obtained in the limit that the lattice spacing a goes to zero. The Symanzik effective theory determines the scaling of lattice errors with a. Most lattice calculations use improved actions with leading discretizations errors of $\mathcal{O}(a^2\Lambda^2)$ or $\mathcal{O}(\alpha_s a\Lambda)$, where Λ is a typical momentum scale in the system. Knowledge of the scaling of the leading discretization errors allows controlled extrapolation to a=0 when multiple lattice spacings are available, as in current state-of-the-art calculations. Residual errors arise from the exclusion of subleading a dependence from the fits

For many quantities the typical momentum scale in the system is $\sim \Lambda_{\rm QCD} \approx 300$ MeV. Discretization errors are expected to be larger for quantities involving larger scales, for example form factors or decays involving particles with momenta larger than $\Lambda_{\rm QCD}$.

17.1.5.2. Infinite volume limit: LQCD calculations are necessarily carried out in finite space-time boxes, leading to departures of physical quantities (masses, decay constants, etc.) from their measured, infinite volume values. These finite-volume shifts are an important systematic that must be estimated and minimized.

Typical lattices are asymmetric, with N_s points in the three spatial directions and N_t in the (Euclidean) temporal direction. The spatial and temporal sizes in physical units are thus $L_s = aN_s$ and $L_t = aN_t$, respectively. (Anisotropic lattice spacings are also sometimes used, as discussed below in Sec. 17.3.1.) Typically, $L_t \geq 2L_s$, so that the dominant impact of using finite volume is from the presence of a finite spatial box.

At present, high-precision LQCD calculations are of quantities involving no more than a single particle in initial and final states. For such quantities, once the volume exceeds about 2 fm (so that the particle is not "squeezed"), the dominant finite-volume effect comes from virtual pions wrapping around the lattice in the spatial directions. This effect is exponentially suppressed as the volume becomes large, roughly as $\sim \exp(-m_\pi L_s)$, and has been estimated using ChPT [30] or other methods [31]. The estimates suggest that finite volume shifts are sub-percent effects when $m_\pi L_s \gtrsim 4$, and most large-scale simulations use lattices satisfying this condition. This becomes challenging as one approaches the physical pion mass, for which $L_s \gtrsim 5$ fm is required. At present, this can only be achieved by using relatively coarse lattices, $a \gtrsim 0.07$ fm.

Finite volume errors are usually determined by repeating the simulations on two or more different volumes (with other parameters fixed). If different volumes are not available, the ChPT estimate can be used, often inflated to account for the fact that the ChPT calculation is truncated at some order.

In the future, LQCD calculations involving more than a single hadron will become increasingly precise. Examples include the calculation of resonance parameters and $K \to \pi\pi$ amplitudes. Finite volume effects are much larger in these cases, with power-law terms (e.g. $1/L_s^3$) in addition to exponential dependence. Indeed, as will be discussed in Sec. 17.2.4, one can use the volume dependence to indirectly extract infinite-volume quantities such as scattering lengths. Doing so, however, requires a set of lattice volumes satisfying $m_\pi L_s \gtrsim 4$ and is thus more challenging than for single-particle quantities.

17.1.5.3. Chiral extrapolation: An important source of systematic error in most LQCD calculations is the need to extrapolate in m_u and m_d (or, equivalently, in m_π). To do this, one needs a functional form that is, at least approximately, valid for pion masses ranging from the unphysical values used in simulations down to the physical value. A theoretically favored choice is to use the predictions of SU(3) or SU(2) ChPT. This is a valid description of QCD for $m_q \ll \Lambda_{QCD}$ (or $m_\pi \ll m_\rho$), but it is not known a priori the extent to which it applies at larger pion masses. This concern is exacerbated in practice since one must truncate the ChPT expressions, typically at one-loop or two-loop order. Experience to date suggests that one-loop expressions are not sufficiently accurate if $m_\pi \gtrsim 400$ MeV [32].

Another choice of fit function is based on the observation that one does not need to extrapolate to the chiral limit, but only to the physical, non-zero, value of m_{π} , and thus an analytic description might suffice. In practice, of course, one must truncate the analytic form at low order, and a concern is whether the curvature from known non-analytic terms is adequately reproduced.

In either approach, extrapolation errors are estimated by varying the fit function and the number of data points included. We also note that, in many calculations, additional input to the chiral extrapolation is obtained from "partially quenched" results in which the valence and sea-quark masses differ [33].

Very recently, simulations with physical light quark masses (except that $m_u = m_d = (m_u^{\rm phys} + m_d^{\rm phys})/2$) have been undertaken [34]. This is a major step forward as it removes the need for chiral extrapolation. As noted above, such simulations require large boxes, and thus very large lattices, and to date the results have been used to compute a limited number of observables. In the future, however, such simulations will play an increasingly important role in the determination of physical quantities.

17.1.5.4. Operator matching: Many of the quantities that LQCD can calculate precisely involve hadronic matrix elements of operators from the electroweak Hamiltonian. Examples include the pion and kaon decay constants, semileptonic form factors and the kaon mixing parameter B_K (the latter defined in Eq. (17.12)). The operators in the lattice matrix elements are defined in the lattice regularization scheme. To be used in tests of the Standard Model, however, they must be matched to the continuum regularization scheme in which the corresponding Wilson coefficients have been calculated. The only case in which such matching is not needed is if the operator is a conserved or partially conserved current. Similar matching is also needed for the conversion of lattice bare quark masses to those in the continuum $\overline{\rm MS}$ scheme.

Three methods are used to calculate the matching factors: perturbation theory (usually to one- or two-loop order), non-perturbative renormalization (NPR) using Landau-gauge quark and gluon propagators [35], and NPR using gauge-invariant methods based on the Schrödinger functional [36]. The NPR methods replace truncation errors (which can only be approximately estimated) by statistical and systematic errors which can be determined reliably and systematically reduced.

A common issue that arises in many such calculations (e.g. for quark masses and B_K) is that, using NPR, one ends up with operators regularized in a MOM-like (or Schrödinger functional) scheme, rather than the $\overline{\rm MS}$ scheme mostly used for calculating the Wilson coefficients. To make contact with this scheme requires a purely continuum perturbative matching calculation. The resultant truncation error can, however, be minimized by pushing up the momentum scale at which the matching is done using step-scaling techniques as part of the NPR calculation [37]. It should also be noted that this final step in the conversion to the $\overline{\rm MS}$ scheme could be avoided if continuum calculations used a MOM-like scheme.

17.2. Methods and status

Once the lattice action is chosen, it is straightforward to define the quantum theory using the path integral formulation. The Euclidean-space partition function is

$$Z = \int [dU] \prod_{f} [dq_f] [d\bar{q}_f] e^{-S_g[U] - \sum_{f} \bar{q}_f(D[U] + m_f) q_f}, \qquad (17.3)$$

where link variables are integrated over the SU(3) manifold, q_f and \bar{q}_f are Grassmann (anticommuting) quark and antiquark fields of flavor f, and D[U] is the chosen lattice Dirac operator with m_f the quark mass in lattice units. Integrating out the quark and antiquark fields, one arrives at a form suitable for simulation:

$$Z = \int [dU]e^{-S_g[U]} \prod_f \det(D[U] + m_f).$$
 (17.4)

The building blocks for calculations are expectation values of multi-local gauge-invariant operators,

$$\mathcal{O}(U,q,\bar{q})\rangle =$$

$$(1/Z)\int [dU]\prod_{f}[dq_{f}][d\bar{q}_{f}]\mathcal{O}(U,q,\bar{q})e^{-S_{g}[U]-\sum_{f}\bar{q}_{f}(D[U]+m_{f})q_{f}}.$$

$$(17.5)$$

If the operators depend on the (anti-)quark fields q_f and \bar{q}_f , then integrating these fields out leads not only to the fermion determinant but also, through Wick's theorem, a series of quark "propagators", $(D[U]+m_f)^{-1}$, connecting the positions of the fields.

17.2.1. Monte-Carlo method:

Since the number of integration variables U is huge $(N_s^3 \times N_t \times 4 \times 9)$, direct numerical integration is impractical and one has to use Monte-Carlo techniques. In this method, one generates a Markov chain of gauge configurations (a "configuration" being the set of U's on all links) distributed according to the probability measure $[dU]e^{-S_g[U]}\prod_f \det(D[U]+m_f)$. Once the configurations are generated, expectation values $\langle \mathcal{O}(U,q,\bar{q})\rangle$ are calculated by averaging over those configurations. In this way the configurations can be used repeatedly for many different calculations, and there are several large collections of ensembles of configurations (with a range of values of a, lattice sizes and quark masses) that are generally available. As the number of the configurations, N, is increased, the error decreases as $1/\sqrt{N}$, as long as the configurations are statistically independent.

The most challenging part of the generation of gauge configurations is the need to include the fermion determinant. Direct evaluation of the determinant is not feasible, as it requires $\mathcal{O}((N_s^3 \times N_t)^3)$ computations. Instead, one rewrites it in terms of "pseudofermion" fields ϕ (auxiliary fermion fields with bosonic statistics). For example, for two degenerate quarks one has

$$\det(D[U] + m_f)^2 = \int [d\phi] e^{-\phi^{\dagger}(D[U] + m_f)^{-2}\phi}.$$
 (17.6)

By treating the pseudofermions as additional integration variables in the path integral, one obtains a totally bosonic representation. The price one pays is that the pseudofermion effective action is highly non-local since it includes the inverse Dirac operator $(D[U]+m_f)^{-1}$. Thus, the large sparse matrix (D[U]+m) has to be inverted every time one needs an evaluation of the effective action.

Present simulations generate gauge configurations using the Hybrid Monte Carlo (HMC) algorithm [38], or variants thereof. This algorithm combines molecular dynamics (MD) evolution in a fictitious time (which is also discretized) with a Metropolis "accept-reject" step. It makes a global update of the configuration, and is made exact by the Metropolis step. In its original form it can be used only for two degenerate flavors, but extensions (particularly the rational HMC [39]) are available for single flavors. Considerable speed-up of the algorithms has been achieved over the last two decades using a variety of techniques.

All these algorithms spend the bulk of their computational time on the repeated inversion of (D[U] + m) acting on a source (which

is required at every step of the MD evolution). Inversions are done using iterative algorithms such as the conjugate gradient algorithm and its generalizations. In this class of algorithms, computational cost is proportional to the condition number of the matrix, which is the ratio of maximum and minimum eigenvalues. For (D[U]+m) the smallest eigenvalue is $\approx m$, so the condition number and cost are inversely proportional to the quark mass. This is a major reason why simulations at the physical quark mass are challenging. Recent algorithmic improvements, however, promise to significantly reduce or remove this problem.

A practical concern is the inevitable presence of correlations between configurations in the Markov chain. These are characterized by an autocorrelation length in the fictitious MD time. One aims to use configurations separated in MD time by greater than this autocorrelation length. In practice, it is difficult to measure this length accurately, and this leads to some uncertainty in the resulting statistical errors.

For most of the applications of LQCD discussed in this review, the cost of generating gauge configurations is larger than that of performing the "measurements" on those configurations. The computational cost of the HMC and related algorithms grows with the lattice volume, $V_{\rm lat} = N_s^3 N_t$, as $V_{\rm lat}^{5/4}$ [40]. This provides a (time-dependent) limit on the largest lattice volumes that can be simulated. At present, the largest lattices being used have $N_s = 64$ and $N_t = 144$. Typically one aims to create an ensemble of $\sim 10^3$ statistically independent configurations at each choice of parameters $(a, m_q \text{ and } V_{\rm lat})$. For most physical quantities of interest, this is sufficient to make the resulting statistical errors smaller than or comparable to the systematic errors.

17.2.2. Two-point functions:

One can extract properties of stable hadrons using two-point correlation functions, $\langle O_X(x)O_Y^{\dagger}(0)\rangle$. Here $O_{X,Y}(x)$ are operators that have non-zero overlaps with the hadronic state of interest $|H\rangle$, i.e. $\langle 0|O_{X,Y}(x)|H\rangle \neq 0$. One usually Fourier-transforms in the spatial directions and considers correlators as a function of Euclidean time:

$$C_{XY}(t;\vec{p}) = \sum_{\vec{x}} \langle O_X(t,\vec{x}) O_Y^{\dagger}(0) \rangle e^{-i\vec{p}\cdot\vec{x}}. \tag{17.7}$$

(Here and throughout this section all quantities are expressed in dimensionless lattice units, so that, for example, $\vec{p}=a\vec{p}_{\rm phys}$.) By inserting a complete set of states having spatial momentum \vec{p} , the two-point function can be written as

$$C_{XY}(t;\vec{p}) = \sum_{i=0}^{\infty} \frac{1}{2E_i(\vec{p})} \langle 0|O_X(0)|H_i(\vec{p})\rangle \langle H_i(\vec{p})|O_Y^{\dagger}(0)|0\rangle e^{-E_i(\vec{p})t},$$
(17)

where the energy of the *i*-th state $E_i(\vec{p})$ appears as an eigenvalue of the time evolution operator e^{-Ht} in the Euclidean time direction. The factor of $1/[2E_i(\vec{p})]$ is due to the relativistic normalization used for the states. For large enough t, the dominant contribution is that of the lowest energy state $|H_0(\vec{p})\rangle$:

$$C_{XY}(t) \overset{t \to \infty}{\longrightarrow} \frac{1}{2E_0(\vec{p})} \langle 0|O_X(0)|H_0(\vec{p})\rangle \langle H_0(\vec{p})|O_Y^\dagger(0)|0\rangle e^{-E_0(\vec{p})t} \ . \ \ (17.9)$$

One can thus obtain the energy $E_0(\vec{p})$, which equals the hadron mass m_H when $\vec{p} = 0$, and the product of matrix elements $\langle 0|O_X(0)|H_i(\vec{p})\rangle\langle H_i(\vec{p})|O_Y^\dagger(0)|0\rangle$.

This method can be used to determine the masses of all the stable mesons and baryons by making appropriate choices of operators. For example, if one uses the axial current, $O_X = O_Y = A_\mu = \bar{d}\gamma_\mu\gamma_5 u$, then one can determine m_{π^+} from the rate of exponential fall-off, and in addition the decay constant f_π from the coefficient of the exponential. A complication arises for states with high spins $(j \geq 4 \text{ for bosons})$ because the spatial rotation group on the lattice is a discrete subgroup of the continuum group SO(3). This implies that lattice operators, even when chosen to lie in irreducible representations of the lattice rotation group, have overlap with states that have a number of values of j in the continuum limit [41]. For example j=0 operators can

also create mesons with j = 4. A method to overcome this problem has recently been introduced [42].

The expression given above for the correlator $C_{XY}(t;\vec{p})$ shows how, in principle, one can determine the energies of the excited hadron states having the same quantum numbers as the operators $O_{X,Y}$, by fitting the correlation function to a sum of exponentials. In practice, this usually requires using a large basis of operators and adopting the variational approach such as that of Ref. [43]. One can also use an anisotropic lattice in which a_t , the lattice spacing in the time direction, is smaller than its spatial counterpart a_s . This allows better separation of the different exponentials. Using a combination of these and other technical improvements extensive excited-state spectra have recently been obtained [42,44].

17.2.3. Three-point functions:

Weak matrix elements needed to calculate semileptonic form factors and neutral meson mixing amplitudes can be computed from three-point correlation functions. We discuss here, as a representative example, the $D \to K$ amplitude. As in the case of two-point correlation functions one constructs operators O_D and O_K having overlap, respectively, with the D and K mesons. We are interested in calculating the matrix element $\langle K|V_{\mu}|D\rangle$, with $V_{\mu}=\bar{c}\gamma_{\mu}s$ the vector current. To obtain this, we use the three-point correlator

$$C_{KV\mu D}(t_x, t_y; \vec{p}) = \sum_{\vec{x}, \vec{y}} \langle O_K(t_x, \vec{x}) V_\mu(0) O_D^{\dagger}(t_y, \vec{y}) \rangle e^{-i\vec{p} \cdot \vec{x}}, \quad (17.10)$$

and focus on the limit $t_x\to\infty$, $t_y\to-\infty$. In this example we set the D-meson at rest while the kaon carries three-momentum \vec{p} . Momentum conservation then implies that the weak operator V_μ inserts three-momentum $-\vec{p}$. Inserting a pair of complete sets of states between each pair of operators, we find

$$\times \langle 0|O_K(t_x, \vec{x})|K_i(\vec{p})\rangle \langle K_i(\vec{p})|V_{\mu}(0)|D_j(\vec{0})\rangle \langle D_j(\vec{0})|O_D^{\dagger}(0)|0\rangle. \tag{17.11}$$

The matrix element $\langle K_i(\vec{p})|V_{\mu}(0)|D_j(\vec{0})\rangle$ can then be extracted, since all other quantities in this expression can be obtained from two-point correlation functions. Typically one is interested in the weak matrix elements of ground states, such as the lightest pseudoscalar mesons. In the limit of large separation between the three operators in Euclidean time, the three-point correlation function yields the weak matrix element of the transition between ground states.

17.2.4. Scattering amplitudes and resonances:

The methods described thus far yield matrix elements involving single, stable particles (where by stable here we mean absolutely stable to strong interaction decays). Most of the particles listed in the Review of Particle Properties are, however, unstable—they are resonances decaying into final states consisting of multiple strongly interacting particles. LQCD simulations cannot directly calculate resonance properties, but methods have been developed to do so indirectly for resonances coupled to two-particle final states in the elastic regime [45].

The difficulty faced by LQCD calculations is that, to obtain resonance properties, or, more generally, scattering phase-shifts, one must calculate multiparticle scattering amplitudes in momentum space and put the external particles on their mass-shells. This requires analytically continuing from Euclidean to Minkowski momenta. Although it is straightforward in LQCD to generalize the methods described above to calculate four- and higher-point correlation functions, one necessarily obtains them at a discrete and finite set of Euclidean momenta. Analytic continuation to $p_E^2 = -m^2$ is then an ill-posed and numerically unstable problem. The same problem arises for single-particle states, but can be overcome by picking out the exponential fall-off of the Euclidean correlator, as described above. With a multi-particle state, however, there is no corresponding trick, except for two particles at threshold [46].

What LQCD can calculate are the energies of the eigenstates of the QCD Hamiltonian in a finite box. The energies of states containing two stable particles, e.g. two pions, clearly depend on the interactions between the particles. It is possible to invert this dependence and, with plausible assumptions, determine the scattering phase-shifts at a discrete set of momenta from a calculation of the two-particle energy levels for a variety of spatial volumes [45]. This is a challenging calculation, but it has recently been carried through for pions with $m_{\pi} \sim 300-400$ MeV for the I=2 $\pi\pi$ system (where there is no resonance) [47] and for the I=1 system, where the parameters of the ρ resonance can be determined from the phase shifts (ignoring the small inelasticity) [48,49]. Extensions to nucleon interactions are also being actively studied [50].

It is also possible to extend the methodology to calculate electroweak decay amplitudes to two particles below the inelastic threshold, e.g. $\Gamma(K \to \pi\pi)$ [51]. First results using this methodology are now appearing. An extension to decays above the elastic threshold, e.g. hadronic B decays, has yet to be formulated.

17.2.5. Status of LQCD simulations:

Until the 1990s, most large-scale lattice simulations were limited to the "quenched" approximation, wherein the fermion determinant is omitted from the path integral. While much of the basic methodology was developed in this era, the results obtained had uncontrolled systematic errors and were not suitable for use in placing precision constraints on the Standard Model. During the 1990s, more extensive simulations including the fermion determinant (also known as simulations with "dynamical" fermions) were begun, but with unphysically high quark masses ($m_{\ell} \sim 50 - 100 \text{ MeV}$), such that the extrapolation to the physical light quark masses was a source of large systematic errors [52]. In the last 5-10 years, advances in both algorithms and computers have allowed simulations to reach much smaller quark masses ($m_{\ell} \sim 10-20 \text{ MeV}$) and even, as noted above, to work at the physical light quark mass [34]. The net effect is that LQCD calculations of selected quantities now have all sources of error controlled and small, such that they can be used effectively in phenomenological analyses.

On a more qualitative level, analytic and numerical results from LQCD have demonstrated that QCD confines color and spontaneously breaks chiral symmetry. Confinement can be seen as a linearly rising potential between heavy quark and anti-quark in the absence of quark loops. Analytically, this can be shown in the strong coupling limit $g_{\rm lat} \to \infty$ [1]. At weaker couplings there are precise numerical calculations of the potential that clearly show that this behavior persists in the continuum limit [2,3,4].

Chiral symmetry breaking was also demonstrated in the strong coupling limit on the lattice [12,53], and there have been a number of numerical studies showing that this holds also in the continuum limit. The accumulation of low-lying modes of the Dirac operator, which is the analog of Cooper pair condensation in superconductors, has been observed, yielding a determination of the chiral condensate [54]. Many relations among physical quantities that can be derived under the assumption of broken chiral symmetry have been confirmed by a number of lattice groups.

17.3. Physics applications

In this section we describe the main applications of LQCD that are both computationally mature and relevant for the determination of particle properties.

A general feature to keep in mind is that, since there are many different choices for lattice actions, all of which lead to the same continuum theory, a crucial test is that results for any given quantity are consistent. In many cases, different lattice calculations are completely independent and often have very different systematic errors. Thus final agreement, if found, is a highly non-trivial check, just as it is for different experimental measurements.

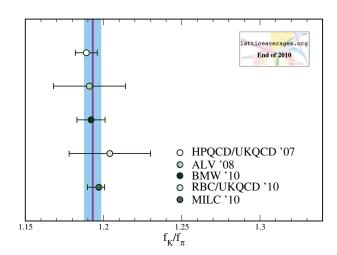


Figure 17.1: Results for f_K/f_π from simulations with $N_f=2+1$. These are from the HPQCD/UKQCD [29], ALV [58], BMW [60], RBC/UKQCD [61] and MILC [62] collaborations. The resulting average is 1.1931 ± 0.0053 .

17.3.1. Spectrum:

The most basic prediction of LQCD is of the hadron spectrum. Once the input parameters are fixed as described in Sec. 17.1.4, the masses or resonance parameters of all other states can be predicted. This includes hadrons composed of light $(u,\ d\ {\rm and}\ s)$ quarks, as well as heavy-light and heavy-heavy hadrons. It also includes quark-model exotics (e.g. $J^{PC}=1^{-+}$ mesons) and glueballs. Thus, in principle, LQCD calculations should be able to reproduce many of the experimental results compiled in the Review of Particle Properties. Doing so would test both that the error budgets of LQCD calculations are accurate and that QCD indeed describes the strong interactions in the low-energy domain. The importance of the latter test can hardly be overstated.

What is the status of this fundamental test? As discussed in Sec. 17.2, LQCD calculations are most straightforward for stable, low-lying hadrons. Resonances which can decay into only two particles are more challenging, though ultimately tractable, while those with decays to more than two particles are not yet accessible. It is also more challenging to calculate masses of flavor singlet states (which can annihilate into purely gluonic intermediate states) than those of flavor non-singlets. The present status for light hadrons is that fully controlled results are available for the masses of the octet light baryons, while results with less than complete control are available for the decuplet baryon resonances, the vector meson resonances and the η and η' . There are more extensive results for heavy-light (D and B systems) and heavy-heavy (J/ψ and Υ systems). All present results, which are discussed in the "Quark Model" review, are consistent with experimental values.

17.3.2. Decay constants and bag parameters:

The pseudoscalar decay constants can be determined from two point correlation functions involving the axial-vector current, as discussed in Sec. 17.2.2. The decay constant f_P of a meson P is extracted from the weak matrix element involving the axial-vector current using the relation $\langle 0|A_{\mu}(x)|P(\vec{p})\rangle = f_P p_{\mu} \exp(-ip \cdot x)$, where p_{μ} is the momentum of P and $A_{\mu}(x)$ is the axial-vector current. For the pion and kaon decay constants, this calculation is by now straightforward. The ratio f_K/f_{π} is especially important for the extraction of $|V_{us}|/|V_{ud}|$ from experiment, and many of the systematic errors in the lattice calculation cancel or are significantly reduced when forming the ratio. A number of lattice groups have calculated this ratio with precision at the percent level or better; all the results are in good agreement, with sub-percent precision in the world average [55,56]. A recent summary from Ref. [57] is shown in Fig. 17.1.

The heavy-light decay constants f_D and f_{D_s} involve a charm valence quark, which requires special treatment because of the relatively large charm quark mass. The different approaches in use have been discussed in Sec. 17.1.3. The HISQ action allows the charm quark to be treated in the same way as the light quarks, and has enabled HPQCD to quote precise values for the charm decay constants [29]. Calculations using less improved quark actions give consistent results, but with larger errors [59,63].

The bottom meson decay constants f_B and f_{B_s} require a valence b quark. Lattice calculations of these quantities are available using the Fermilab formulation or NRQCD to treat the bottom quark (from Refs. [64] and [65], respectively), or using an interpolation between results from around m_c to infinite quark mass [66].

The kaon bag parameter B_K is needed to turn the precise measurement of CP-violation in kaon mixing into a constraint on the Standard Model. It is defined by

$$\frac{8}{3}m_K^2 f_K^2 B_K(\mu) = \langle \overline{K}^0 | Q_{\Delta_S = 2}(\mu) | K^0 \rangle, \tag{17.12}$$

where m_K is the kaon mass, f_K is the kaon decay constant, $Q_{\Delta S=2}=\overline{s}\gamma_{\mu}(1-\gamma_5)d\overline{s}\gamma_{\mu}(1-\gamma_5)d$ is the four-quark operator of the effective electroweak Hamiltonian and μ is the renormalization scale. The short distance contribution to the electroweak Hamiltonian can be calculated perturbatively, but the long-distance matrix element parameterized by B_K must be computed using non-perturbative methods. In order to be of use to phenomenology, the renormalization factor of the four-quark operator must be matched to a continuum renormalization scheme, e.g. to \overline{MS} , as described in Sec. 17.1.5.4. Determinations with percent-level precision using different fermion actions are now available with DWF [67], staggered fermions [68], DWF valence on staggered sea quarks [69], twisted mass fermions [70] and Wilson fermions [71]. The results are all consistent.

The bag parameters for B and B_s meson mixing are defined analogously to that of kaon mixing. The B and B_s mesons contain a valence b-quark so that calculations of these quantities must use one of the methods for heavy quarks described above. These quantities have been calculated by HPQCD using NRQCD for the b-quark [65]. The ratio $\xi = f_{B_s} \sqrt{B_{B_s}}/(f_B\sqrt{B_B})$ is especially useful in CKM studies because many of the lattice systematic uncertainties cancel in the ratio, including most of the operator matching needed to convert to a continuum scheme. The dominant error in the ratio is the error associated with the chiral extrapolation of the light quark masses. The ratio ξ has been calculated in unquenched LQCD using different treatments for the b-quark [65,72], with results that are consistent.

The results discussed in this section are used in the reviews "The CKM Quark-Mixing Matrix," " V_{ud} , V_{us} , the Cabibbo Angle and CKM Unitarity," and " $B_0 - \bar{B}_0$ Mixing."

17.3.3. Form factors ($K \to \pi \ell \nu, D \to K \ell \nu, B \to \pi \ell \nu, B \to D^{(*)} \ell \nu$):

Semileptonic decay rates can be used to extract CKM matrix elements once the semileptonic form factors are known from lattice calculations. For example, the matrix element of a pseudoscalar meson P undergoing semileptonic decay to another pseudoscalar meson D is mediated by the vector current, and can be written in terms of form factors as

$$\langle D(p_D)|V_{\mu}|P(p_P)\rangle = f_{+}(q^2)(p_D + p_P - \Delta)_{\mu} + f_0(q^2)\Delta_{\mu},$$
 (17.13)

where $q = p_D - p_P$, $\Delta_{\mu} = (m_D^2 - m_P^2)q_{\mu}/q^2$ and V_{μ} is the quark vector current. The shape of the form factor is typically well determined by experiment, and the value of $f_+(q^2)$ at some reference value of q^2 is needed from the lattice in order to extract CKM matrix elements. Typically $f_+(q^2)$ dominates the decay rate, since the contribution from $f_0(q^2)$ is suppressed when the final state lepton is light.

The form factor $f_{+}(0)$ for $K \to \pi \ell \nu$ decays is highly constrained by the Ademollo-Gatto theorem [73] and chiral symmetry. Old estimates using chiral perturbation theory combined with quark models quote sub-percent precision [74], though they suffer from some model dependence. The lattice has now matched this precision while also

eliminating the model dependence; good agreement with the old estimate is found [75,76].

Charm meson semileptonic decays have been calculated by different groups using methods similar to those used for charm decay constants, and results are steadily improving in precision [77,78,79]. For semileptonic decays involving a bottom quark, one uses HQET or NROCD to control the discretization errors of the bottom quark. The form factors for the semileptonic decay $B \to \pi \ell \nu$ have been calculated in unquenched lattice QCD by two groups: HPQCD [80] and the Fermilab/MILC Collaborations [81]. These B semileptonic form factors are difficult to calculate at low q^2 , i.e. when the momentum transfer to the leptons is small and the pion carries significant momentum. The low q^2 region has large discretization errors and very large statistical errors, while the high q^2 region is much more accessible to the lattice. For experiment, the opposite is true. To combine lattice and experimental results it has proved helpful to use the z-parameter expansion [82]. This provides a theoretically constrained parameterization of the entire q^2 range, and allows one to obtain $|V_{ub}|$ with minimal model dependence [83,81].

The semileptonic decays $B\to D\ell\nu$ and $B\to D^*\ell\nu$ can be used to extract $|V_{cb}|$ once the corresponding form factors are known. At present only one unquenched calculation exists for the $B\to D^*\ell\nu$ form factor, where the Fermilab formulation of the heavy quark was adopted [84]. This calculation is done at zero-recoil because that is where the lattice systematic errors are smallest. Calculations of the necessary form factors for both processes at non-zero recoil have been done in the quenched approximation [85]. using a step-scaling approach for the heavy quarks. Lattice calculations at non-zero recoil are needed in order to decrease the error associated with the extrapolation of the experimental data to the zero-recoil point.

The results discussed in this section are used in the reviews "The CKM Quark-Mixing Matrix," " V_{ud} , V_{us} , the Cabibbo Angle and CKM Unitarity," and " V_{cb} and V_{ub} CKM Matrix Elements."

$17.3.4. \ \ Strong\ coupling\ constant:$

As explained in Sec. 17.1.4.1, for a given lattice action, the choice of bare lattice coupling constant, $g_{\rm lat}$, determines the lattice spacing a. If one then calculates a as described in Sec. 17.1.4.1, one knows the strong coupling constant in the bare lattice scheme at the scale 1/a, $\alpha_{\rm lat} = g_{\rm lat}^2/(4\pi)$. This is not, however, useful for comparing to results for α_s obtained from experiment. This is because the latter results give α_s in the $\overline{\rm MS}$ scheme, and the conversion factor between these two schemes is known to converge extremely poorly in perturbation theory. Instead one must use a method which directly determines α_s in a scheme closer to $\overline{\rm MS}$.

Several such methods have been used, all following a similar strategy. One calculates a short-distance quantity K both perturbatively $(K^{\rm PT})$ and non-perturbatively $(K^{\rm NP})$ on the lattice, and requires equality: $K^{\rm NP}=K^{\rm PT}=\sum_{i=0}^n c_i \alpha_s^i$. Solving this equation one obtains α_s at a scale related to the quantity being used. Often, α_s thus obtained is not defined in the conventional $\overline{\rm MS}$ scheme, and one has to convert among the different schemes using perturbation theory. Unlike for the bare lattice scheme, the required conversion factors are reasonably convergent. As a final step, one uses the renormalization group to run the resulting coupling to a canonical scale (such as M_Z).

In the work of the HPQCD collaboration [86], the short-distance quantities are Wilson loops of several sizes and their ratios, which are perturbatively calculated to $\mathcal{O}(\alpha_s^3)$ using the V-scheme defined through the heavy quark potential. The coefficients of even higher orders are estimated with the lattice data at various values of a.

Another choice of short-distance quantities are current-current correlators. Appropriate moments of these correlators are ultraviolet finite, and by matching lattice results to the *continuum* perturbative predictions, one can directly extract the $\overline{\rm MS}$ coupling. The JLQCD collaboration [87] uses this approach with light overlap fermions, while the HPQCD collaboration uses charm-quark correlators and HISQ fermions [88].

With a definition of α_s given using the Schrödinger functional, one can non-perturbatively control the evolution of α_s to high-energy scales, such as 100 GeV, where the perturbative expansion converges

very well. This method developed by the ALPHA collaboration [37] has been applied to 2+1-flavor QCD by the PACS-CS collaboration [89].

Results are summarized in the review of "Quantum Chromodynamics".

17.3.5. Quark masses:

Once the quark mass parameters are tuned in the lattice action, the remaining task is to convert them to those of the conventional definition. Since the quarks do not appear as asymptotic states due to confinement, the pole mass of the quark propagator is not a physical quantity. Instead, one defines the quark mass after subtracting the ultra-violet divergences in some particular way. The conventional choice is again the $\overline{\rm MS}$ scheme at a canonical scale such as 2 or 3 GeV.

As discussed in Sec. 17.1.5.4, one must convert the lattice bare quark mass to that in the $\overline{\rm MS}$ scheme. The most common approaches used for doing so are perturbation theory and the NPR method, the latter using an RI/MOM intermediate scheme.

Alternatively, one can use a definition based on the Schrödinger functional, which allows one to evolve the quark mass to a high scale non-perturbatively [90]. In practice, one can reach scales as high as ~ 100 GeV, at which matching to the $\overline{\rm MS}$ scheme can be reliably calculated in perturbation theory.

Another approach available for heavy quarks is to match currentcurrent correlators at short distances calculated on the lattice to those obtained in continuum perturbation theory in the $\overline{\rm MS}$ scheme. This has allowed an accurate determination of $m_c(\overline{\rm MS})$ [91].

Results are summarized in the review of "Quark Masses".

17.3.6. Other applications:

In this review we have concentrated on applications of LQCD that are relevant to the quantities discussed in the Review of Particle Properties. We have not discussed at all several other applications which are being actively pursued by simulations. Here we list the major such applications. The reader can consult the texts [2,3,4] for further details.

LQCD can be used, in principle, to simulate QCD at non-zero temperature and density, and in particular to study how confinement and chiral-symmetry breaking are lost as T and μ (the chemical potential) are increased. This is of relevance to heavy-ion collisions, the early Universe and neutron-star structure. In practice, finite temperature simulations are computationally tractable and relatively mature, while simulations at finite μ suffer from a "sign problem" and are at a rudimentary stage.

Another topic under active investigation is nucleon structure (generalized structure functions) and inter-nucleon interactions.

Finally, we note that there is much recent interest in studying QCD-like theories with more fermions, possibly in other representations of the gauge group. The main interest is to find nearly conformal theories which might be candidates for "walking technicolor" models.

17.4. Outlook

While LQCD calculations have made major strides in the last decade, and are now playing an important role in constraining the Standard Model, there are many calculations that could be done in principle but are not yet mature due to limitations in computational resources. As we move to exascale resources (e.g. 10^{18} floating point operations per second), the list of mature calculations will grow. Examples that we expect to mature in the next few years are results for excited hadrons, including quark-model exotics; $\langle N|\bar{s}s|N\rangle$ and related matrix elements (needed for dark-matter searches); results for moments of structure functions; $K \to \pi\pi$ amplitudes (allowing a prediction of ϵ'/ϵ from the Standard Model); $\bar{K} \leftrightarrow K$ and $\bar{B} \leftrightarrow B$ mixing amplitudes from operators arising in models of new physics (allowing one to constrain these models in a manner complementary to the direct searches at the LHC); hadronic vacuum polarization contributions to muon q-2, the running of $\alpha_{\rm EM}$ and α_s ; $\pi \to \gamma \gamma$ and related amplitudes; and perhaps the long-distance contribution to $\overline{K} \leftrightarrow K$ mixing and the light-by-light contribution to muon g-2. There will also be steady improvement in the precision attained

for the mature quantities discussed above. As already noted, this will ultimately require simulations with $m_u \neq m_d$ and including electromagnetic effects.

17.5. Acknowledgments

We are grateful to Jean-Francois Arguin, Christine Davies, Max Hansen, Andreas Kronfeld, Laurent Lellouch, Vittorio Lubicz and Paul Mackenzie for comments.

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18. STRUCTURE FUNCTIONS

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18.1. Deep inelastic scattering

High-energy lepton-nucleon scattering (deep inelastic scattering) plays a key role in determining the partonic structure of the proton. The process $\ell N \to \ell' X$ is illustrated in Fig. 18.1. The filled circle in this figure represents the internal structure of the proton which can be expressed in terms of structure functions.

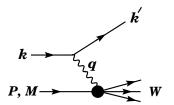


Figure 18.1: Kinematic quantities for the description of deep inelastic scattering. The quantities k and k' are the four-momenta of the incoming and outgoing leptons, P is the four-momentum of a nucleon with mass M, and W is the mass of the recoiling system X. The exchanged particle is a γ , W^{\pm} , or Z; it transfers four-momentum q = k - k' to the nucleon.

Invariant quantities:

$$\nu = \frac{q \cdot P}{M} = E - E' \text{ is the lepton's energy loss in the nucleon rest}$$
 frame (in earlier literature sometimes $\nu = q \cdot P$). Here,
 E and E' are the initial and final lepton energies in the nucleon rest frame.

$$\begin{split} Q^2 = -q^2 = 2(EE' - \overrightarrow{k} \cdot \overrightarrow{k}') - m_\ell^2 - m_{\ell'}^2 \text{ where } m_\ell(m_{\ell'}) \text{ is the initial} \\ \text{(final) lepton mass. If } EE' \sin^2(\theta/2) \gg m_\ell^2, \, m_{\ell'}^2, \, \text{then} \end{split}$$

 $\approx 4EE'\sin^2(\theta/2)$, where θ is the lepton's scattering angle with respect to the lepton beam direction.

$$x = \frac{Q^2}{2M\nu}$$
 where, in the parton model, x is the fraction of the nucleon's momentum carried by the struck quark.

$$y = \frac{q \cdot P}{k \cdot P} = \frac{\nu}{E}$$
 is the fraction of the lepton's energy lost in the nucleon

 $W^2=(P+q)^2=M^2+2M\nu-Q^2$ is the mass squared of the system X recoiling against the scattered lepton.

$$s=(k+P)^2=\frac{Q^2}{xy}+M^2+m_\ell^2 \text{ is the center-of-mass energy squared}$$
 of the lepton-nucleon system.

The process in Fig. 18.1 is called deep $(Q^2\gg M^2)$ inelastic $(W^2\gg M^2)$ scattering (DIS). In what follows, the masses of the initial and scattered leptons, m_ℓ and $m_{\ell'}$, are neglected.

$18.1.1. \ \ DIS\ cross\ sections$

$$\frac{d^2\sigma}{dx\,dy} = x\left(s - M^2\right) \frac{d^2\sigma}{dx\,dQ^2} = \frac{2\pi\,M\nu}{E'} \frac{d^2\sigma}{d\Omega_{\rm Nrest}\,dE'} \ . \tag{18.1}$$

In lowest-order perturbation theory, the cross section for the scattering of polarized leptons on polarized nucleons can be expressed in terms of the products of leptonic and hadronic tensors associated with the coupling of the exchanged bosons at the upper and lower vertices in Fig. 18.1 (see Refs. 1–4)

$$\frac{d^2\sigma}{dxdy} = \frac{2\pi y \alpha^2}{Q^4} \sum_{j} \eta_j L_j^{\mu\nu} W_{\mu\nu}^j . \qquad (18.2)$$

For neutral-current processes, the summation is over $j=\gamma,Z$ and γZ representing photon and Z exchange and the interference between

them, whereas for charged-current interactions there is only W exchange, j=W. (For transverse nucleon polarization, there is a dependence on the azimuthal angle of the scattered lepton.) $L_{\mu\nu}$ is the lepton tensor associated with the coupling of the exchange boson to the leptons. For incoming leptons of charge $e=\pm 1$ and helicity $\lambda=\pm 1$.

$$L_{\mu\nu}^{\gamma} = 2 \left(k_{\mu} k_{\nu}' + k_{\mu}' k_{\nu} - k \cdot k' g_{\mu\nu} - i \lambda \varepsilon_{\mu\nu\alpha\beta} k^{\alpha} k'^{\beta} \right),$$

$$L_{\mu\nu}^{\gamma Z} = (g_{V}^{e} + e \lambda g_{A}^{e}) L_{\mu\nu}^{\gamma}, \qquad L_{\mu\nu}^{Z} = (g_{V}^{e} + e \lambda g_{A}^{e})^{2} L_{\mu\nu}^{\gamma},$$

$$L_{\mu\nu}^{W} = (1 + e \lambda)^{2} L_{\mu\nu}^{\gamma}, \qquad (18.3)$$

where
$$g_V^e = -\frac{1}{2} \, + \, 2 \sin^2 \theta_W, \qquad g_A^e \, = \, -\frac{1}{2}$$
 .

Although here the helicity formalism is adopted, an alternative approach is to express the tensors in Eq. (18.3) in terms of the polarization of the lepton.

The factors η_j in Eq. (18.2) denote the ratios of the corresponding propagators and couplings to the photon propagator and coupling squared

$$\eta_{\gamma} = 1 \quad ; \quad \eta_{\gamma Z} = \left(\frac{G_F M_Z^2}{2\sqrt{2}\pi\alpha}\right) \left(\frac{Q^2}{Q^2 + M_Z^2}\right);$$

$$\eta_{Z} = \eta_{\gamma Z}^2 \quad ; \quad \eta_{W} = \frac{1}{2} \left(\frac{G_F M_W^2}{4\pi\alpha} \frac{Q^2}{Q^2 + M_W^2}\right)^2. \quad (18.4)$$

The hadronic tensor, which describes the interaction of the appropriate electroweak currents with the target nucleon, is given by

$$W_{\mu\nu} = \frac{1}{4\pi} \int d^4z \, e^{iq\cdot z} \left\langle P, S \left| \left[J_{\mu}^{\dagger}(z), J_{\nu}(0) \right] \right| P, S \right\rangle, \tag{18.5}$$

where S denotes the nucleon-spin 4-vector, with $S^2=-M^2$ and $S\cdot P=0.$

18.2. Structure functions of the proton

The structure functions are defined in terms of the hadronic tensor (see Refs. 1–3)

$$\begin{split} W_{\mu\nu} &= \left(-g_{\mu\nu} \, + \, \frac{q_{\mu}q_{\nu}}{q^2} \right) \, F_1(x,Q^2) + \frac{\hat{P}_{\mu}\hat{P}_{\nu}}{P \cdot q} \, F_2(x,Q^2) \\ &- \, i\varepsilon_{\mu\nu\alpha\beta} \, \frac{q^{\alpha}P^{\beta}}{2P \cdot q} \, F_3(x,Q^2) \\ &+ \, i\varepsilon_{\mu\nu\alpha\beta} \, \frac{q^{\alpha}}{P \cdot q} \, \left[S^{\beta}g_1(x,Q^2) + \left(S^{\beta} \, - \, \frac{S \cdot q}{P \cdot q} \, P^{\beta} \right) \, g_2(x,Q^2) \right] \\ &+ \, \frac{1}{P \cdot q} \, \left[\frac{1}{2} \left(\hat{P}_{\mu}\hat{S}_{\nu} \, + \, \hat{S}_{\mu}\hat{P}_{\nu} \right) - \frac{S \cdot q}{P \cdot q} \, \hat{P}_{\mu}\hat{P}_{\nu} \right] \, g_3(x,Q^2) \\ &+ \, \frac{S \cdot q}{P \cdot q} \, \left[\frac{\hat{P}_{\mu}\hat{P}_{\nu}}{P \cdot q} \, g_4(x,Q^2) + \left(-g_{\mu\nu} \, + \, \frac{q_{\mu}q_{\nu}}{q^2} \right) \, g_5(x,Q^2) \right] (18.6) \end{split}$$

where

$$\hat{P}_{\mu} = P_{\mu} - \frac{P \cdot q}{q^2} q_{\mu}, \qquad \hat{S}_{\mu} = S_{\mu} - \frac{S \cdot q}{q^2} q_{\mu}.$$
 (18.7)

In Ref. 2, the definition of $W_{\mu\nu}$ with $\mu \leftrightarrow \nu$ is adopted, which changes the sign of the $\varepsilon_{\mu\nu\alpha\beta}$ terms in Eq. (18.6), although the formulae given here below are unchanged. Ref. 1 tabulates the relation between the structure functions defined in Eq. (18.6) and other choices available in the literature.

The cross sections for neutral- and charged-current deep inelastic scattering on unpolarized nucleons can be written in terms of the structure functions in the generic form

$$\frac{d^2 \sigma^i}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2} \eta^i \left\{ \left(1 - y - \frac{x^2 y^2 M^2}{Q^2} \right) F_2^i + y^2 x F_1^i \mp \left(y - \frac{y^2}{2} \right) x F_3^i \right\},$$
(18.8)

where $i={
m NC},{
m CC}$ corresponds to neutral-current $(eN\to eX)$ or charged-current $(eN\to \nu X$ or $\nu N\to eX)$ processes, respectively. For incoming neutrinos, $L_{\mu\nu}^W$ of Eq. (18.3) is still true, but with e,λ corresponding to the outgoing charged lepton. In the last term of Eq. (18.8), the - sign is taken for an incoming e^+ or $\overline{\nu}$ and the + sign for an incoming e^- or ν . The factor $\eta^{\rm NC}=1$ for unpolarized e^\pm beams, whereas*

$$\eta^{\rm CC} = (1 \pm \lambda)^2 \eta_W \tag{18.9}$$

with \pm for ℓ^{\pm} ; and where λ is the helicity of the incoming lepton and η_W is defined in Eq. (18.4); for incoming neutrinos $\eta^{\rm CC} = 4\eta_W$. The CC structure functions, which derive exclusively from W exchange, are

$$F_1^{\text{CC}} = F_1^W, \ F_2^{\text{CC}} = F_2^W, \ xF_3^{\text{CC}} = xF_3^W.$$
 (18.10)

The NC structure functions $F_2^{\gamma}, F_2^{\gamma Z}, F_2^{Z}$ are, for $e^{\pm}N \to e^{\pm}X$, given by Ref. 5,

$$F_2^{\text{NC}} = F_2^{\gamma} - (g_V^e \pm \lambda g_A^e) \eta_{\gamma Z} F_2^{\gamma Z} + (g_V^{e^2} + g_A^{e^2} \pm 2\lambda g_V^e g_A^e) \eta_Z F_2^{Z}$$
(18.11)

and similarly for F_1^{NC} , whereas

$$xF_{3}^{\rm NC} = -(g_A^e \pm \lambda g_V^e)\eta_{\gamma Z} xF_{3}^{\gamma Z} + [2g_V^e g_A^e \pm \lambda (g_V^{e^2} + g_A^{e^2})]\eta_Z xF_{3}^Z \ . \eqno(18.12)$$

The polarized cross-section difference

$$\Delta \sigma = \sigma(\lambda_n = -1, \lambda_\ell) - \sigma(\lambda_n = 1, \lambda_\ell) , \qquad (18.13)$$

where $\lambda_{\ell}, \lambda_n$ are the helicities (± 1) of the incoming lepton and nucleon, respectively, may be expressed in terms of the five structure functions $g_{1,\dots,5}(x,Q^2)$ of Eq. (18.6). Thus,

$$\frac{d^2 \Delta \sigma^i}{dx dy} \; = \; \frac{8 \pi \alpha^2}{x y Q^2} \; \eta^i \left\{ -\lambda_\ell y \left(2 - y - 2 x^2 y^2 \frac{M^2}{Q^2} \right) \; x g_1^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i \right\} \; dx dy + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \; g_2^i + \lambda_\ell 4 x^3 y^2 \; \frac{M^2}{Q^2} \;$$

$$+ \ 2 x^2 y \frac{M^2}{Q^2} \left(1 - y - x^2 y^2 \frac{M^2}{Q^2} \right) \ g_3^i$$

$$- \left(1 + 2x^2 y \frac{M^2}{Q^2}\right) \left[\left(1 - y - x^2 y^2 \frac{M^2}{Q^2}\right) g_4^i + x y^2 g_5^i \right] \right\}$$
 (18.14)

with $i=\mathrm{NC}$ or CC as before. The Eq. (18.13) corresponds to the difference of antiparallel minus parallel spins of the incoming particles for e^- or ν initiated reactions, but the difference of parallel minus antiparallel for e^+ or $\overline{\nu}$ initiated processes. For longitudinal nucleon polarization, the contributions of g_2 and g_3 are suppressed by powers of M^2/Q^2 . These structure functions give an unsuppressed contribution to the cross section for transverse polarization [1], but in this case the cross-section difference vanishes as $M/Q \to 0$.

Because the same tensor structure occurs in the spin-dependent and spin-independent parts of the hadronic tensor of Eq. (18.6) in the $M^2/Q^2 \to 0$ limit, the differential cross-section difference of Eq. (18.14) may be obtained from the differential cross section Eq. (18.8) by replacing

$$F_1 \rightarrow -g_5 , \quad F_2 \rightarrow -g_4 , \quad F_3 \rightarrow 2g_1 , \qquad (18.15)$$

and multiplying by two, since the total cross section is the average over the initial-state polarizations. In this limit, Eq. (18.8) and Eq. (18.14) may be written in the form

$$\frac{d^2\sigma^i}{dxdy} = \frac{2\pi\alpha^2}{xyQ^2} \eta^i \left[Y_+ F_2^i \mp Y_- x F_3^i - y^2 F_L^i \right],
\frac{d^2\Delta\sigma^i}{dxdy} = \frac{4\pi\alpha^2}{xyQ^2} \eta^i \left[-Y_+ g_4^i \mp Y_- 2x g_1^i + y^2 g_L^i \right],$$
(18.16)

with i = NC or CC, where $Y_{+} = 1 \pm (1 - y)^{2}$ and

$$F_L^i = F_2^i - 2xF_1^i, g_L^i = g_4^i - 2xg_5^i. (18.17)$$

In the naive quark-parton model, the analogy with the Callan-Gross relations [6] $F_L^i = 0$, are the Dicus relations [7] $g_L^i = 0$. Therefore, there are only two independent polarized structure functions: g_1 (parity conserving) and g_5 (parity violating), in analogy with the unpolarized structure functions F_1 and F_3 .

18.2.1. Structure functions in the quark-parton model:

In the quark-parton model [8,9], contributions to the structure functions F^i and g^i can be expressed in terms of the quark distribution functions $q(x,Q^2)$ of the proton, where $q=u,\overline{u},d,\overline{d}$ etc. The quantity $q(x,Q^2)dx$ is the number of quarks (or antiquarks) of designated flavor that carry a momentum fraction between x and x+dx of the proton's momentum in a frame in which the proton momentum is large.

For the neutral-current processes $ep \rightarrow eX$,

$$\begin{split} \left[F_{2}^{\gamma},\ F_{2}^{\gamma Z},\ F_{2}^{Z}\right] &= x \sum_{q} \left[e_{q}^{2},\ 2e_{q}g_{V}^{q},\ g_{V}^{q\,2} + g_{A}^{q\,2}\right]\ (q + \overline{q})\ , \\ \left[F_{3}^{\gamma},\ F_{3}^{\gamma Z},\ F_{3}^{Z}\right] &= \sum_{q} \left[0,\ 2e_{q}g_{A}^{q},\ 2g_{V}^{q}g_{A}^{q}\right]\ (q - \overline{q})\ , \\ \left[g_{1}^{\gamma},\ g_{1}^{\gamma Z},\ g_{1}^{Z}\right] &= \frac{1}{2} \sum_{q} \left[e_{q}^{2},\ 2e_{q}g_{V}^{q},\ g_{V}^{q\,2} + g_{A}^{q\,2}\right]\ (\Delta q + \Delta \overline{q})\ , \\ \left[g_{5}^{\gamma},\ g_{5}^{\gamma Z},\ g_{5}^{Z}\right] &= \sum_{q} \left[0,\ e_{q}g_{A}^{q},\ g_{V}^{q}g_{A}^{q}\right]\ (\Delta q - \Delta \overline{q})\ , \end{split} \tag{18.18}$$

where $g_V^q = \pm \frac{1}{2} - 2e_q \sin^2 \theta_W$ and $g_A^q = \pm \frac{1}{2}$, with \pm according to whether q is a u- or d-type quark respectively. The quantity Δq is the difference $q\uparrow - q\downarrow$ of the distributions with the quark spin parallel and antiparallel to the proton spin.

For the charged-current processes $e^-p \to \nu X$ and $\overline{\nu}p \to e^+X$, the structure functions are:

$$F_{2}^{W^{-}} = 2x(u + \overline{d} + \overline{s} + c \dots) ,$$

$$F_{3}^{W^{-}} = 2(u - \overline{d} - \overline{s} + c \dots) ,$$

$$g_{1}^{W^{-}} = (\Delta u + \Delta \overline{d} + \Delta \overline{s} + \Delta c \dots) ,$$

$$g_{5}^{W^{-}} = (-\Delta u + \Delta \overline{d} + \Delta \overline{s} - \Delta c \dots) ,$$

$$(18.19)$$

where only the active flavors are to be kept and where CKM mixing has been neglected. For $e^+p \to \overline{\nu} X$ and $\nu p \to e^- X$, the structure functions F^{W^+}, g^{W^+} are obtained by the flavor interchanges $d \leftrightarrow u, s \leftrightarrow c$ in the expressions for F^{W^-}, g^{W^-} . The structure functions for scattering on a neutron are obtained from those of the proton by the interchange $u \leftrightarrow d$. For both the neutral- and charged-current processes, the quark-parton model predicts $2xF_1^i=F_2^i$ and $g_4^i=2xg_5^i$.

Neglecting masses, the structure functions g_2 and g_3 contribute only to scattering from transversely polarized nucleons (for which $S \cdot q = 0$), and have no simple interpretation in terms of the quark-parton model. They arise from off-diagonal matrix elements $\langle P, \lambda' | [J^{\dagger}_{\mu}(z), J_{\nu}(0)] | P, \lambda \rangle$, where the proton helicities satisfy $\lambda' \neq \lambda$. In fact, the leading-twist contributions to both g_2 and g_3 are both twist-2 and twist-3, which contribute at the same order of Q^2 . The Wandzura-Wilczek relation [10] expresses the twist-2 part of g_2 in terms of g_1 as

$$g_2^i(x) = -g_1^i(x) + \int_x^1 \frac{dy}{y} g_1^i(y)$$
 (18.20)

However, the twist-3 component of g_2 is unknown. Similarly, there is a relation expressing the twist-2 part of g_3 in terms of g_4 . A complete set of relations, including M^2/Q^2 effects, can be found in Ref. 11.

18.2.2. Structure functions and QCD:

One of the most striking predictions of the quark-parton model is that the structure functions F_i,g_i scale, i.e., $F_i(x,Q^2)\to F_i(x)$ in the Bjorken limit that Q^2 and $\nu\to\infty$ with x fixed [12]. This property is related to the assumption that the transverse momentum of the partons in the infinite-momentum frame of the proton is small. In QCD, however, the radiation of hard gluons from the quarks violates this assumption, leading to logarithmic scaling violations, which are particularly large at small x, see Fig. 18.2. The radiation of gluons produces the evolution of the structure functions. As Q^2 increases, more and more gluons are radiated, which in turn split into $q\overline{q}$ pairs. This process leads both to the softening of the initial quark momentum distributions and to the growth of the gluon density and the $q\overline{q}$ sea as x decreases.

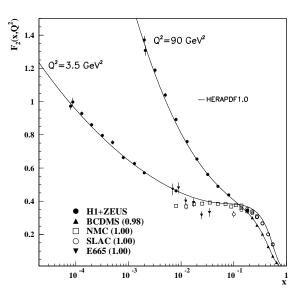


Figure 18.2: The proton structure function F_2^p given at two Q^2 values (3.5 GeV² and 90 GeV²), which exhibit scaling at the 'pivot' point $x \sim 0.14$. See the captions in Fig. 18.8 and Fig. 18.10 for the references of the data. The various data sets have been renormalized by the factors shown in brackets in the key to the plot, which were globally determined in the full HERAPDF analysis [46]. In practice, data for the reduced cross section, $F_2(x,Q^2) - (y^2/Y_+)F_L(x,Q^2)$, are fitted, rather than F_2 and F_L separately.

In QCD, the above process is described in terms of scale-dependent parton distributions $f_a(x, \mu^2)$, where a = g or q and, typically, μ is the scale of the probe Q. For $Q^2 \gg M^2$, the structure functions are of the form

$$F_i = \sum_{a} C_i^a \otimes f_a, \tag{18.21}$$

where \otimes denotes the convolution integral

$$C \otimes f = \int_{x}^{1} \frac{dy}{y} C(y) f\left(\frac{x}{y}\right),$$
 (18.22)

and where the coefficient functions C_i^a are given as a power series in α_s . The parton distribution f_a corresponds, at a given x, to the density of parton a in the proton integrated over transverse momentum k_t up to μ . Its evolution in μ is described in QCD by a DGLAP equation (see Refs. 14–17) which has the schematic form

$$\frac{\partial f_a}{\partial \ln \mu^2} \sim \frac{\alpha_s(\mu^2)}{2\pi} \sum_b (P_{ab} \otimes f_b) , \qquad (18.23)$$

where the P_{ab} , which describe the parton splitting $b \to a$, are also given as a power series in α_s . Although perturbative QCD can predict, via Eq. (18.23), the evolution of the parton distribution functions from a particular scale, μ_0 , these DGLAP equations cannot predict them a priori at any particular μ_0 . Thus they must be measured at a starting point μ_0 before the predictions of QCD can be compared to the data at other scales, μ . In general, all observables involving a hard hadronic interaction (such as structure functions) can be expressed as a convolution of calculable, process-dependent coefficient functions and these universal parton distributions, e.g. Eq. (18.21).

It is often convenient to write the evolution equations in terms of the gluon, non-singlet (q^{NS}) and singlet (q^S) quark distributions, such that

$$q^{NS} = q_i - \overline{q}_i \text{ (or } q_i - q_j), \qquad q^S = \sum_i (q_i + \overline{q}_i) .$$
 (18.24)

The non-singlet distributions have non-zero values of flavor quantum numbers, such as isospin and baryon number. The DGLAP evolution

equations then take the form

$$\begin{split} \frac{\partial q^{NS}}{\partial \ln \mu^2} &= \frac{\alpha_s(\mu^2)}{2\pi} \; P_{qq} \; \otimes \; q^{NS} \; , \\ \frac{\partial}{\partial \ln \mu^2} \; \begin{pmatrix} q^S \\ g \end{pmatrix} &= \frac{\alpha_s(\mu^2)}{2\pi} \; \begin{pmatrix} P_{qq} & 2n_f \; P_{qg} \\ P_{gq} & P_{gg} \end{pmatrix} \; \otimes \; \begin{pmatrix} q^S \\ g \end{pmatrix}, (18.25) \end{split}$$

where P are splitting functions that describe the probability of a given parton splitting into two others, and n_f is the number of (active) quark flavors. The leading-order Altarelli-Parisi [16] splitting functions are

$$P_{qq} = \frac{4}{3} \left[\frac{1+x^2}{(1-x)} \right]_{\perp} = \frac{4}{3} \left[\frac{1+x^2}{(1-x)_{+}} \right] + 2\delta(1-x) ,$$
 (18.26)

$$P_{qg} = \frac{1}{2} \left[x^2 + (1 - x)^2 \right] , \qquad (18.27)$$

$$P_{gq} = \frac{4}{3} \left[\frac{1 + (1 - x)^2}{x} \right] , \qquad (18.28)$$

$$P_{gg} = 6 \left[\frac{1-x}{x} + x(1-x) + \frac{x}{(1-x)_{+}} \right] + \left[\frac{11}{2} - \frac{n_f}{3} \right] \delta(1-x),$$
 (18.29)

where the notation $[F(x)]_+$ defines a distribution such that for any sufficiently regular test function, f(x),

$$\int_0^1 dx f(x) [F(x)]_+ = \int_0^1 dx \ (f(x) - f(1)) F(x) \ . \tag{18.30}$$

In general, the splitting functions can be expressed as a power series in α_s . The series contains both terms proportional to $\ln \mu^2$ and to $\ln 1/x$. The leading-order DGLAP evolution sums up the $(\alpha_s \ln \mu^2)^n$ contributions, while at next-to-leading order (NLO) the sum over the $\alpha_s (\alpha_s \ln \mu^2)^{n-1}$ terms is included [18,19]. In fact, the NNLO contributions to the splitting functions and the DIS coefficient functions are now also all known [20–22].

In the kinematic region of very small x, it is essential to sum leading terms in $\ln 1/x$, independent of the value of $\ln \mu^2$. At leading order, LLx, this is done by the BFKL equation for the unintegrated distributions (see Refs. [23,24]). The leading-order $(\alpha_s \ln(1/x))^n$ terms result in a power-like growth, $x^{-\omega}$ with $\omega = (12\alpha_s \ln 2)/\pi$, at asymptotic values of $\ln 1/x$. More recently, the next-to-leading $\ln 1/x$ (NLLx) contributions have become available [25,26]. They are so large (and negative) that the result appears to be perturbatively unstable. Methods, based on a combination of collinear and small xresummations, have been developed which reorganize the perturbative series into a more stable hierarchy [27–30]. There are indications that small x resummations become necessary for real precision for $x \lesssim 10^{-3}$ at low scales. On the other hand, there is no convincing indication that, for $Q^2 \gtrsim 2 \text{ GeV}^2$, we have entered the 'non-linear' regime where the gluon density is so high that gluon-gluon recombination effects become significant.

The precision of the contemporary experimental data demands that at least NLO, and preferably NNLO, DGLAP evolution be used in comparisons between QCD theory and experiment. Beyond the leading order, it is necessary to specify, and to use consistently, both a renormalization and a factorization scheme. The renormalization scheme used is almost universally the modified minimal subtraction $(\overline{\rm MS})$ scheme [31,32]. There are two popular choices for factorization scheme, in which the form of the correction for each structure function is different. The most-used factorization scheme is again $\overline{\rm MS}$ [33]. However, sometimes the DIS [34] scheme is adopted, in which there are no higher-order corrections to the F_2 structure function. The two schemes differ in how the non-divergent pieces are assimilated in the parton distribution functions.

The u,d, and s quarks are taken to be massless, and the effects of the c and b-quark masses have been studied up to NNLO, for example, in [35–42]. An approach using a 'general mass variable flavor number scheme' (GM-VFNS) is now generally adopted, in which evolution

Table 18.1: The main processes relevant to global PDF analyses, ordered in three groups: fixed-target experiments, HERA and the $p\bar{p}$ Tevatron (pp LHC). For each process we give an indication of their dominant partonic subprocesses, the primary partons which are probed and the approximate range of x constrained by the data. The Table is adapted from [13].

| Process | Subprocess | Partons | x range |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $ \begin{array}{l} \ell^{\pm}\left\{p,n\right\} \to \ell^{\pm}X \\ \ell^{\pm}n/p \to \ell^{\pm}X \\ pp \to \mu^{+}\mu^{-}X \\ pn/pp \to \mu^{+}\mu^{-}X \\ \nu(\bar{\nu})N \to \mu^{-}(\mu^{+})X \\ \nuN \to \mu^{-}\mu^{+}X \\ \bar{\nu}N \to \mu^{+}\mu^{-}X \end{array} $ | $\gamma^* q \to q$ $\gamma^* d/u \to d/u$ $u\bar{u}, d\bar{d} \to \gamma^*$ $(u\bar{d})/(u\bar{u}) \to \gamma^*$ $W^* q \to q'$ $W^* s \to c$ $W^* \bar{s} \to \bar{c}$ | $\begin{array}{c} q,\bar{q},g\\ d/u\\ \bar{q}\\ \bar{d}/\bar{u}\\ q,\bar{q}\\ s\\ \bar{s} \end{array}$ | $\begin{array}{l} x \gtrsim 0.01 \\ x \gtrsim 0.01 \\ 0.015 \lesssim x \lesssim 0.35 \\ 0.015 \lesssim x \lesssim 0.35 \\ 0.01 \lesssim x \lesssim 0.5 \\ 0.01 \lesssim x \lesssim 0.2 \\ 0.01 \lesssim x \lesssim 0.2 \end{array}$ |
| $e^{\pm} p \rightarrow e^{\pm} X$ $e^{+} p \rightarrow \bar{\nu} X$ $e^{\pm} p \rightarrow e^{\pm} c\bar{c} X, e^{\pm} b\bar{b} X$ $e^{\pm} p \rightarrow \text{jet} + X$ | $\gamma^* q \to q$ $W^+ \{d, s\} \to \{u, c\}$ $\gamma^* c \to c, \gamma^* g \to c\bar{c}$ $\gamma^* g \to q\bar{q}$ | $g,q,ar{q}$ d,s c,b,g g | $\begin{array}{c} 0.0001 \lesssim x \lesssim 0.1 \\ x \gtrsim 0.01 \\ 0.0001 \lesssim x \lesssim 0.01 \\ 0.01 \lesssim x \lesssim 0.1 \end{array}$ |
| $ \begin{array}{l} p\bar{p}, pp \to \text{ jet} + X \\ p\bar{p} \to (W^{\pm} \to \ell^{\pm}\nu) X \\ pp \to (W^{\pm} \to \ell^{\pm}\nu) X \\ p\bar{p}(pp) \to (Z \to \ell^{+}\ell^{-})X \\ pp \to (\gamma^{*} \to \ell^{+}\ell^{-})X \\ pp \to b\bar{b} X \\ pp \to \gamma X \end{array} $ | $gg, qg, qq \rightarrow 2j$ $ud \rightarrow W^+, \bar{u}\bar{d} \rightarrow W^-$ $u\bar{d} \rightarrow W^+, d\bar{u} \rightarrow W^-$ $uu, dd,(u\bar{u},) \rightarrow Z$ $u\bar{u}, d\bar{d}, \rightarrow \gamma^*$ $gg \rightarrow b\bar{b}$ $gq \rightarrow \gamma q, g\bar{q} \rightarrow \gamma \bar{q}$ | $g,q \\ u,d,\bar{u},\bar{d} \\ u,d,\bar{u},\bar{d} \\ u,d,\dots \\ \bar{q} \\ g \\ g$ | $\begin{array}{c} 0.005 \lesssim x \lesssim 0.5 \\ x \gtrsim 0.05 \\ x \gtrsim 0.001 \\ x \gtrsim 0.001 \\ x \gtrsim 10^{-5} \\ x \gtrsim 10^{-5} \\ x \gtrsim 0.005 \end{array}$ |

with $n_f = 3$ is matched to that with $n_f = 4$ at the charm threshold, with an analogous matching at the bottom threshold.

The discussion above relates to the Q^2 behavior of leading-twist (twist-2) contributions to the structure functions. Higher-twist terms, which involve their own non-perturbative input, exist. These die off as powers of Q; specifically twist-n terms are damped by $1/Q^{n-2}$. The higher-twist terms appear to be numerically unimportant for Q^2 above a few GeV², except for x close to 1.

18.3. Determination of parton distributions

The parton distribution functions (PDFs) can be determined from data for deep inelastic lepton-nucleon scattering and for related hard-scattering processes initiated by nucleons. Table 18.1 highlights some processes and their primary sensitivity to PDFs. The kinematic ranges of fixed-target and collider experiments are complementary (as is shown in Fig. 18.3), which enables the determination of PDFs over a wide range in x and Q^2 . As precise LHC data for W^{\pm} , Z, γ , jet, $b\bar{b}$ and $t\bar{t}$ production become available, the kinematic reach of the data will further widen, and tighter constraints on the PDFs are expected.

Recent determinations of the unpolarized PDF's have been made by six groups: MSTW [13], CT(EQ) [43], NNPDF [44,45], HERAPDF [46], ABKM [47] and GJR [48,49]. Distinguishing features of the various analyses have been reviewed in [50,51]. Most groups use input PDFs of the form $xf=x^a(...)(1-x)^b$ with 10-25 free parameters in total. Note, however, that NNPDF combine a Monte Carlo representation of the probability measure in the space of PDFs with the use of neural networks to give a set of unbiased input distributions, while GJR generate 'dynamical' PDFs from a valence-like input at some very low starting scale, $Q_0^2=0.5~{\rm GeV}^2$. All groups, except CT, present PDFs at NLO and NNLO. The results of one analysis are shown in Fig. 18.4 at scales $\mu^2=10$ and $10^4~{\rm GeV}^2$.

MSTW, CT and NNPDF are 'global' analyses in that they fit to a full range of the types of data that are available (and use GM-VFNS). The most recent determinations of these three groups have converged, so that now a reasonable agreement has been achieved between the resulting PDFs, the value obtained for $\alpha_s(M_Z^2)$, and their predictions for the LHC. The values of α_s found by MSTW [13,52] may be taken

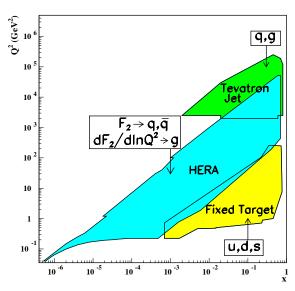


Figure 18.3: Kinematic domains in x and Q^2 probed by fixed-target and collider experiments, shown together with the parton distributions that are most strongly constrained by the indicated regions.

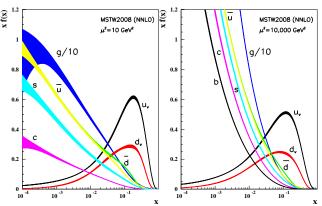


Figure 18.4: Distributions of x times the unpolarized parton distributions f(x) (where $f = u_v, d_v, \overline{u}, \overline{d}, s, c, b, g$) and their associated uncertainties using the NNLO MSTW2008 parameterization [13] at a scale $\mu^2 = 10 \text{ GeV}^2$ and $\mu^2 = 10,000 \text{ GeV}^2$.

as representative of that found in global fits to DIS and related hard scattering data $\,$

$$\begin{aligned} \text{NLO}: \alpha_s(M_Z^2) &= 0.1202^{+0.0012}_{-0.0015} \pm 0.003, \\ \text{NNLO}: \alpha_s(M_Z^2) &= 0.1171 \pm 0.0014 \pm 0.002, \end{aligned}$$

where the first error (at 68% C.L.) corresponds to the uncertainties in the data fitted and the second is an estimate of the theory error (that is, the uncertainty which might be expected at higher orders).

The PDFs of the remaining three groups are obtained without including the Tevatron W,Z production data; and the HERAPDF and ABKM groups do not fit to the Tevatron jet data. The importance of carefully including the latter data is discussed in detail in [53], and is shown to be responsible for the anomalously low value of α_s found by ABKM [47].

Spin-dependent (or polarized) PDFs have been obtained through NLO global analyses which include measurements of the g_1 structure function in inclusive polarized DIS, 'flavour-tagged' semi-inclusive DIS data, and results from polarized pp scattering at RHIC. Recent NLO analyses are given in Refs. [54–57]. Improved parton-to-hadron fragmentation functions, needed to describe the semi-inclusive DIS data, can be found in [58–60]. Fig. 18.5 shows several global analyses at a scale of 2.5 $\,\mathrm{GeV}^2$ along with the data from semi-inclusive DIS.

Comprehensive sets of PDFs are available as program-callable functions from the HepData website [66], which includes comparison graphics of PDFs, and from the LHAPDF library [67], which can be linked directly into a users programme to provide access to recent PDFs in a standard format.

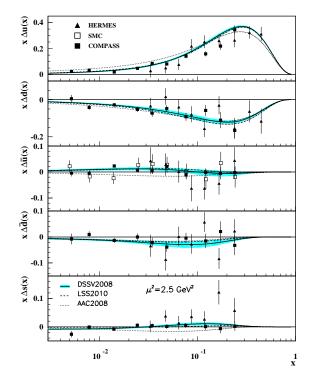


Figure 18.5: Distributions of x times the polarized parton distributions $\Delta q(x)$ (where $q=u,d,\overline{u},\overline{d},s$) using the LSS2010 [57], AAC2008 [54], and DSSV2008 [55] parameterizations at a scale $\mu^2=2.5~{\rm GeV}^2$, showing the error corridor of the latter set (corresponding to a one-unit increase in χ^2). See also BB2010 [56]. Points represent data from semi-inclusive positron (HERMES [61,62]) and muon (SMC [63] and COMPASS [64,65]) deep inelastic scattering given at $Q^2=2.5~{\rm GeV}^2$. SMC results are extracted under the assumption that $\Delta\overline{u}(x)=\Delta\overline{d}(x)$.

18.4. The hadronic structure of the photon

Besides the direct interactions of the photon, it is possible for it to fluctuate into a hadronic state via the process $\gamma \to q\overline{q}$. While in this state, the partonic content of the photon may be resolved, for example, through the process $e^+e^-\to e^+e^-\gamma^*\gamma\to e^+e^-X$, where the virtual photon emitted by the DIS lepton probes the hadronic structure of the quasi-real photon emitted by the other lepton. The perturbative LO contributions, $\gamma \to q\overline{q}$ followed by $\gamma^*q \to q$, are subject to QCD corrections due to the coupling of quarks to gluons.

Often the equivalent-photon approximation is used to express the differential cross section for deep inelastic electron–photon scattering in terms of the structure functions of the transverse quasi-real photon times a flux factor N_T^{γ} (for these incoming quasi-real photons of transverse polarization)

$$\frac{d^2\sigma}{dxdQ^2} = N_\gamma^T \frac{2\pi\alpha^2}{xQ^4} \left[\left(1+(1-y)^2\right) F_2^\gamma(x,Q^2) - y^2 F_L^\gamma(x,Q^2) \right], \label{eq:delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delta_delt$$

where we have used $F_2^{\gamma}=2xF_T^{\gamma}+F_L^{\gamma}$, not to be confused with F_2^{γ} of Sec. 18.2. Complete formulae are given, for example, in the comprehensive review of Ref. 68.

The hadronic photon structure function, F_2^γ , evolves with increasing Q^2 from the 'hadron-like' behavior, calculable via the vector-meson-dominance model, to the dominating 'point-like' behaviour, calculable in perturbative QCD. Due to the point-like coupling, the logarithmic evolution of F_2^γ with Q^2 has a positive slope for all values of x, see Fig. 18.15. The 'loss' of quarks at large x due to gluon radiation is over-compensated by the 'creation' of quarks via the point-like $\gamma \to q\bar{q}$ coupling. The logarithmic evolution was first predicted in the quark–parton model $(\gamma^*\gamma \to q\bar{q})$ [69,70], and then in QCD in the limit of large Q^2 [71]. The evolution is now known to NLO [72–74]. NLO data analyses to determine the parton densities of the photon can be found in [75–77].

18.5. Diffractive DIS (DDIS)

Some 10% of DIS events are diffractive, $\gamma^*p \to X + p$, in which the slightly deflected proton and the cluster X of outgoing hadrons are well-separated in rapidity. Besides x and Q^2 , two extra variables are needed to describe a DDIS event: the fraction $x_{I\!P}$ of the proton's momentum transferred across the rapidity gap and t, the square of the 4-momentum transfer of the proton. The DDIS data [78–83] are usually analyzed using two levels of factorization. First, the diffractive structure function F_2^D satisfies collinear factorization, and can be expressed as the convolution [84]

$$F_2^{\rm D} = \sum_{a=a,a} C_2^a \otimes f_{a/p}^{\rm D},$$
 (18.31)

with the same coefficient functions as in DIS (see Eq. (18.21)), and where the diffractive parton distributions $f_{a/p}^{\rm D}$ (a=q,g) satisfy DGLAP evolution. Second, Regge factorization is assumed [85],

$$f_{a/p}^{\rm D}(x_{I\!\!P}, t, z, \mu^2) = f_{I\!\!P/p}(x_{I\!\!P}, t) f_{a/I\!\!P}(z, \mu^2),$$
 (18.32)

where $f_{a/I\!\!P}$ are the parton densities of the Pomeron, which itself is treated like a hadron, and $z \in [x/x_{I\!\!P},1]$ is the fraction of the Pomeron's momentum carried by the parton entering the hard subprocess. The Pomeron flux factor $f_{I\!\!P/p}(x_{I\!\!P},t)$ is taken from Regge phenomenology. There are also secondary Reggeon contributions to Eq. (18.32). A sample of the t-integrated diffractive parton densities, obtained in this way, is shown in Fig. 18.6.

Although collinear factorization holds as $\mu^2 \to \infty$, there are non-negligible corrections for finite μ^2 and small $x_{I\!P}$. Besides the resolved interactions of the Pomeron, the perturbative QCD Pomeron may also interact directly with the hard subprocess, giving rise to an inhomogeneous evolution equation for the diffractive parton densities analogous to the photon case. The results of the MRW analysis [87], which includes these contributions, are also shown in Fig. 18.6. Unlike the inclusive case, the diffractive parton densities cannot be directly used to calculate diffractive hadron-hadron cross sections, since account must first be taken of "soft" rescattering effects.

18.6. Generalized parton distributions

The parton distributions of the proton of Sec. 18.3 are given by the diagonal matrix elements $\langle P, \lambda | \hat{O} | P, \lambda \rangle$, where P and λ are the 4-momentum and helicity of the proton, and \hat{O} is a twist-2 quark or gluon operator. However, there is new information in the so-called generalised parton distributions (GPDs) defined in terms of the off-diagonal matrix elements $\langle P', \lambda' | \hat{O} | P, \lambda \rangle$; see Refs. 89–93 for reviews. Unlike the diagonal PDFs, the GPDs cannot be regarded as parton densities, but are to be interpreted as probability amplitudes.

The physical significance of GPDs is best seen using light-cone coordinates, $z^{\pm}=(z^0\pm z^3)/\sqrt{2}$, and in the light-cone gauge, $A^+=0$. It is conventional to define the generalised quark distributions in terms of quark operators at light-like separation

$$\begin{split} F_{q}(x,\xi,t) &= \frac{1}{2} \int \frac{dz^{-}}{2\pi} e^{ix\bar{P}^{+}z^{-}} \langle P' | \bar{\psi}(-z/2) \gamma^{+} \psi(z/2) | P \rangle \bigg|_{z^{+}=z^{1}=z^{2}=0} \\ &= \frac{1}{2\bar{P}^{+}} \left(H_{q}(x,\xi,t) \ \bar{u}(P') \gamma^{+} u(P) \ + \ E_{q}(x,\xi,t) \ \bar{u}(P') \frac{i\sigma^{+\alpha} \Delta_{\alpha}}{2m} u(P) \right) \end{split}$$

$$(18.34)$$

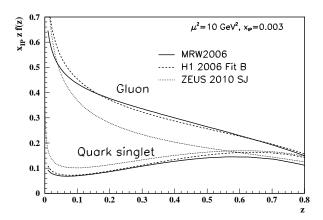


Figure 18.6: Diffractive parton distributions, $x_{I\!\!P} z f_{a/p}^D$, obtained from fitting to the ZEUS data with $Q^2 > 5 \text{ GeV}^2$ [86], H1 data with $Q^2 > 8.5 \text{ GeV}^2$ assuming Regge factorization [81], and using a more perturbative QCD approach [87]. Only the Pomeron contributions are shown and not the secondary Reggeon contributions, which are negligible at the value of $x_{I\!\!P} = 0.003$ chosen here. The H1 2007 Jets distribution [88] is similar to H1 2006 Fit B.

with $\bar{P}=(P+P')/2$ and $\Delta=P'-P$, and where we have suppressed the helicity labels of the protons and spinors. We now have two extra kinematic variables:

$$t = \Delta^2,$$
 $\xi = -\Delta^+/(P + P')^+.$ (18.35)

We see that $-1 \le \xi \le 1$. Similarly, we may define GPDs \tilde{H}_q and \tilde{E}_q with an additional γ_5 between the quark operators in Eq. (18.33); and also an analogous set of gluon GPDs, H_g , E_g , \tilde{H}_g and \tilde{E}_g . After a Fourier transform with respect to the transverse components of Δ , we are able to describe the spatial distribution of partons in the impact parameter plane in terms of GPDs [94,95].

For $P'=P,\ \lambda'=\lambda$ the matrix elements reduce to the ordinary PDFs of Sec. 18.2.1

$$H_q(x,0,0) = q(x), H_q(-x,0,0) = -\bar{q}(x), H_g(x,0,0) = xg(x),$$
(18.36)

$$\tilde{H}_q(x,0,0) = \Delta q(x), \quad \tilde{H}_q(-x,0,0) = \Delta \bar{q}(x), \quad \tilde{H}_g(x,0,0) = x\Delta g(x),$$

where $\Delta q = q \uparrow - q \downarrow$ as in Eq. (18.18). No corresponding relations exist for E, \tilde{E} as they decouple in the forward limit, $\Delta = 0$.

 H_g, E_g are even functions of x, and \tilde{H}_g, \tilde{E}_g are odd functions of x. We can introduce valence and 'singlet' quark distributions which are even and odd functions of x respectively. For example

$$H_q^V(x,\xi,t) \equiv H_q(x,\xi,t) + H_q(-x,\xi,t) = H_q^V(-x,\xi,t), \qquad (18.38)$$

$$H_q^S(x,\xi,t) \equiv H_q(x,\xi,t) - H_q(-x,\xi,t) = -H_q^S(-x,\xi,t).$$
 (18.39)

All the GPDs satisfy relations of the form

$$H(x, -\xi, t) = H(x, \xi, t)$$
 and $H(x, -\xi, t)^* = H(x, \xi, t),$
(18.40)

and so are real-valued functions. Moreover, the moments of GPDs, that is the x integrals of x^nH_q etc., are polynomials in ξ of order n+1. Another important property of GPDs are Ji's sum rules [89]

$$\frac{1}{2} \int_{-1}^{1} dx \ x \left(H_q(x,\xi,t) + E_q(x,\xi,t) \right) = J_q(t), \tag{18.41}$$

where $J_q(0)$ is the total angular momentum carried by quarks and antiquarks of flavour q, with a similar relation for gluons.

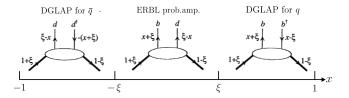


Figure 18.7: Schematic diagrams of the three distinct kinematic regions of (the imaginary part of) H_q . The proton and quark momentum fractions refer to \bar{P}^+ , and x covers the interval (-1,1). In the ERBL domain the GPDs are generalisations of distribution amplitudes which occur in processes such as $p\bar{p} \to J/\psi$.

To visualize the physical content of H_q , we Fourier expand ψ and $\bar{\psi}$ in terms of quark, antiquark creation (b,d) and annihilation $(b^{\dagger},d^{\dagger})$ operators, and sketch the result in Fig. 18.7. There are two types of domain: (i) the time-like or 'annihilation' domain, with $|x|<|\xi|$, where the GPDs describe the wave functions of a t-channel $q\bar{q}$ (or gluon) pair and evolve according to modified ERBL equations [96,97]; (ii) the space-like or 'scattering' domain, with $|x|>|\xi|$, where the GPDs generalise the familiar \bar{q} , q (and gluon) PDFs and describe 'deeply virtual Compton scattering' $(\gamma^*p\to\gamma p), \ \gamma p\to J/\psi p,$ etc., and evolve according to modified DGLAP equations. The splitting functions for the evolution of GPDs are known to NLO [98].

GPDs describe new aspects of proton structure and must be determined from experiment. We can parametrise them in terms of 'double distributions' [99,100], which reduce to diagonal PDFs as $\xi \to 0$. With an additional physically reasonable 'Regge' assumption of no extra singularity at $\xi = 0$, GPDs at low ξ are uniquely given in terms of diagonal PDFs to $O(\xi)$, and have been used [101] to describe $\gamma p \to J/\psi p$ data. Alternatively, flexible SO(3)-based parametrisations have been used to determine GPDs from DVCS data [102].

* The value of $\eta^{\rm CC}$ deduced from Ref. 1 is found to be a factor of two too small; $\eta^{\rm CC}$ of Eq. (18.9) agrees with Refs. [2,3].

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NOTE: THE FIGURES IN THIS SECTION ARE INTENDED TO SHOW THE REPRESENTATIVE DATA. THEY ARE NOT MEANT TO BE COMPLETE COMPILATIONS OF ALL THE WORLD'S RELIABLE DATA.

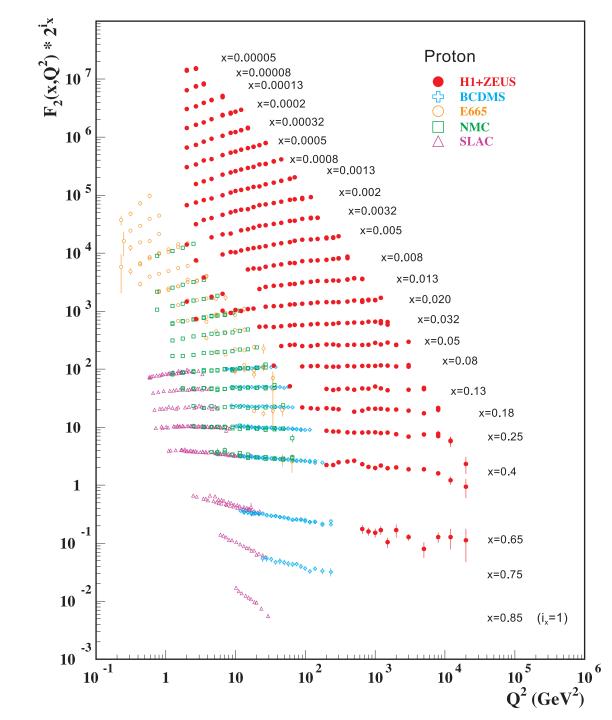


Figure 18.8: The proton structure function F_2^p measured in electromagnetic scattering of electrons and positrons on protons (collider experiments H1 and ZEUS for $Q^2 \ge 2 \text{ GeV}^2$), in the kinematic domain of the HERA data (see Fig. 18.10 for data at smaller x and Q^2), and for electrons (SLAC) and muons (BCDMS, E665, NMC) on a fixed target. Statistical and systematic errors added in quadrature are shown. The data are plotted as a function of Q^2 in bins of fixed x. Some points have been slightly offset in Q^2 for clarity. The H1+ZEUS combined binning in x is used in this plot; all other data are rebinned to the x values of these data. For the purpose of plotting, F_2^p has been multiplied by 2^{ix} , where i_x is the number of the x bin, ranging from $i_x = 1$ (x = 0.85) to $i_x = 24$ (x = 0.00005). References: H1 and ZEUS—F.D. Aaron et al., JHEP 1001, 109 (2010); BCDMS—A.C. Benvenuti et al., Phys. Lett. B223, 485 (1989) (as given in [66]); E665—M.R. Adams et al., Phys. Rev. D54, 3006 (1996); NMC—M. Arneodo et al., Nucl. Phys. B483, 3 (1997); SLAC—L.W. Whitlow et al., Phys. Lett. B282, 475 (1992).

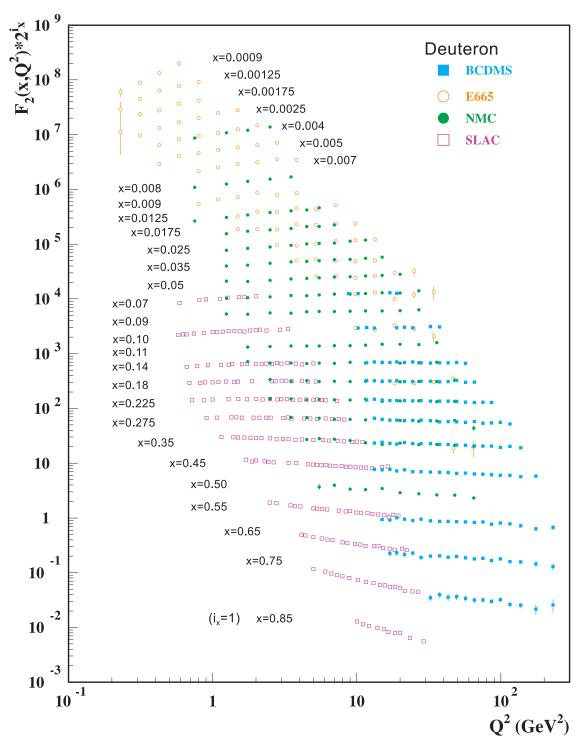


Figure 18.9: The deuteron structure function F_2^d measured in electromagnetic scattering of electrons (SLAC) and muons (BCDMS, E665, NMC) on a fixed target, shown as a function of Q^2 for bins of fixed x. Statistical and systematic errors added in quadrature are shown. For the purpose of plotting, F_2^d has been multiplied by 2^{ix} , where i_x is the number of the x bin, ranging from 1 (x = 0.85) to 29 (x = 0.0009). References: BCDMS—A.C. Benvenuti et al., Phys. Lett. B237, 592 (1990). E665, NMC, SLAC—same references as Fig. 18.8.

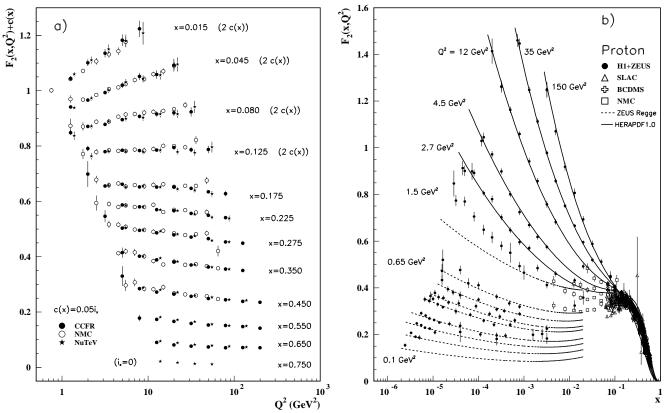


Figure 18.10: a) The deuteron structure function F_2 measured in deep inelastic scattering of muons on a fixed target (NMC) is compared to the structure function F_2 from neutrino-iron scattering (CCFR and NuTeV) using $F_2^{\mu} = (5/18)F_2^{\nu} - x(s+\overline{s})/6$, where heavy-target effects have been taken into account. The data are shown versus Q^2 , for bins of fixed x. The NMC data have been rebinned to CCFR and NuTeV x values. For the purpose of plotting, a constant $c(x) = 0.05i_x$ is added to F_2 , where i_x is the number of the x bin, ranging from 0 (x = 0.75) to 7 (x = 0.175). For $i_x = 8$ (x = 0.125) to 11 (x = 0.015), 2c(x) has been added. References: NMC—M. Arneodo et al., Nucl. Phys. B483, 3 (1997); CCFR/NuTeV—U.K. Yang et al., Phys. Rev. Lett. 86, 2741 (2001); NuTeV—M. Tzanov et al., Phys. Rev. D74, 012008 (2006).

b) The proton structure function F_2^p mostly at small x and Q^2 , measured in electromagnetic scattering of electrons and positrons (H1, ZEUS), electrons (SLAC), and muons (BCDMS, NMC) on protons. Lines are ZEUS Regge and HERAPDF parameterizations for lower and higher Q^2 , respectively. The width of the bins can be up to 10% of the stated Q^2 . Some points have been slightly offset in x for clarity. References: **H1 and ZEUS**—F.D. Aaron *et al.*, JHEP **1001**, 109 (2010) (for both data and HERAPDF parameterization); **ZEUS**—J. Breitweg *et al.*, Phys. Lett. **B487**, 53 (2000) (ZEUS Regge parameterization); **BCDMS**, **NMC**, **SLAC**—same references as Fig. 18.8.

Statistical and systematic errors added in quadrature are shown for both plots.

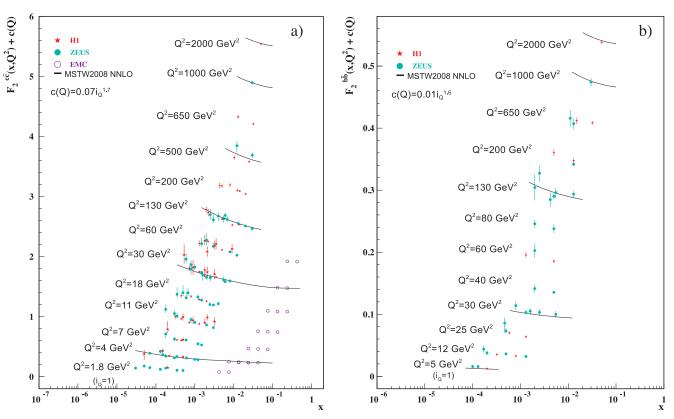


Figure 18.11: a) The charm quark structure function $F_2^{c\overline{c}}(x)$, i.e. that part of the inclusive structure function F_2^p arising from the production of charm quarks, measured in electromagnetic scattering of positrons on protons (H1, ZEUS) and muons on iron (EMC). For the purpose of plotting, a constant $c(Q) = 0.07i_Q^{1.7}$ is added to $F_2^{c\overline{c}}$ where i_Q is the number of the Q^2 bin, ranging from 1 ($Q^2 = 1.8 \text{ GeV}^2$) to 13 ($Q^2 = 2000 \text{ GeV}^2$). References: **ZEUS**—J. Breitweg *et al.*, Eur. Phys. J. **C12**, 35 (2000); S. Chekanov *et al.*, Phys. Rev. **D69**, 012004 (2004); S. Chekanov *et al.*, JHEP **07**, 074 (2007); S. Chekanov *et al.*, Eur. Phys. J. **C65**, 65 (2010); **H1**—C. Adloff *et al.*, Z. Phys. **C72**, 593 (1996); C. Adloff *et al.*, Phys. Lett. **B528**, 199 (2002); F.D. Aaron *et al.*, Phys. Lett. **B686**, 91 (2010); F.D. Aaron *et al.*, Eur. Phys. J. **C65**, 89 (2010); **EMC**—J.J. Aubert *et al.*, Nucl. Phys. **B213**, 31 (1983).

b) The bottom quark structure function $F_2^{b\overline{b}}(x)$. For the purpose of plotting, a constant $c(Q)=0.01i_Q^{1.6}$ is added to $F_2^{b\overline{b}}$ where i_Q is the number of the Q^2 bin, ranging from 1 ($Q^2=5~{\rm GeV^2}$) to 12 ($Q^2=2000~{\rm GeV^2}$). References: **ZEUS**—S. Chekanov *et al.*, Eur. Phys. J. **C65**, 65 (2010); H. Abramowicz *et al.*, Eur. Phys. J. **C69**, 347 (2010); H. Abramowicz *et al.*, Eur. Phys. J. **C71**, 1573 (2010); **H1**—F.D. Aaron *et al.*, Eur. Phys. J. **C65**, 89 (2010).

For both plots, statistical and systematic errors added in quadrature are shown. The data are given as a function of x in bins of Q^2 . Points may have been slightly offset in x for clarity. Some data have been rebinned to common Q^2 values. Also shown is the MSTW2008 parameterization given at several Q^2 values (A.D. Martin *et al.*, Eur. Phys. J. **C63**, 189 (2009)).

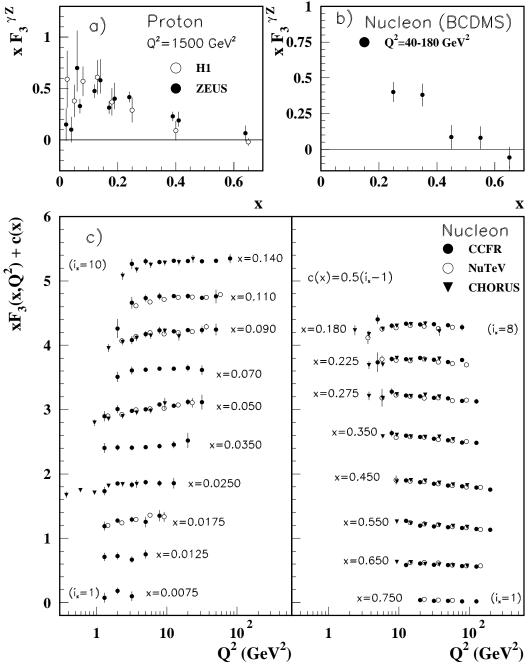


Figure 18.12: The structure function $xF_3^{\gamma Z}$ measured in electroweak scattering of a) electrons on protons (H1 and ZEUS) and b) muons on carbon (BCDMS). The ZEUS points have been slightly offset in x for clarity. References: H1—C. Adloff et~al., Eur. Phys. J. C30, 1 (2003); ZEUS—S. Chekanov et~al., Eur. Phys. J. C28, 175 (2003); S. Chekanov et~al., Eur. Phys. J. C62, 625 (2009); BCDMS—A. Argento et~al., Phys. Lett. B140, 142 (1984).

c) The structure function xF_3 of the nucleon measured in ν -Fe scattering. The data are plotted as a function of Q^2 in bins of fixed x. For the purpose of plotting, a constant $c(x)=0.5(i_x-1)$ is added to xF_3 , where i_x is the number of the x bin as shown in the plot. The NuTeV and CHORUS points have been shifted to the nearest corresponding x bin as given in the plot and slightly offset in Q^2 for clarity. References: CCFR—W.G. Seligman et al., Phys. Rev. Lett. **79**, 1213 (1997); NuTeV—M. Tzanov et al., Phys. Rev. D**74**, 012008 (2006); CHORUS—G. Önengüt et al., Phys. Lett. B**632**, 65 (2006).

Statistical and systematic errors added in quadrature are shown for all plots.

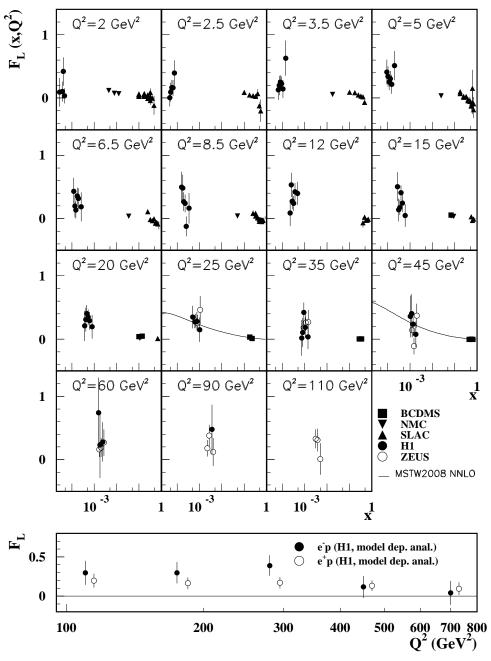


Figure 18.13: Top panel: The longitudinal structure function F_L as a function of x in bins of fixed Q^2 measured on the proton (except for the SLAC data which also contain deuterium data). BCDMS, NMC, and SLAC results are from measurements of R (the ratio of longitudinal to transverse photon absorption cross sections) which are converted to F_L by using the BDCMS parameterization of F_2 (A.C. Benvenuti et al., Phys. Lett. B223, 485 (1989)). It is assumed that the Q^2 dependence of the fixed-target data is small within a given Q^2 bin. Some of the other data may have been rebinned to common Q^2 values. Also shown is the MSTW2008 parameterization given at two Q^2 values (A.D. Martin et al., Eur. Phys. J. C63, 189 (2009)). References: H1—F.D. Aaron et al., Phys. Lett. B665, 139 (2008); F.D. Aaron et al., Eur. Phys. J. C71, 1579 (2011); ZEUS—S. Chekanov et al., Phys. Lett. B682, 8 (2009); BCDMS—A. Benvenuti et al., Phys. Lett. B223, 485 (1989); NMC—M. Arneodo et al., Nucl. Phys. B483, 3 (1997); SLAC—L.W. Whitlow et al., Phys. Lett. B250, 193 (1990) and numerical values from the thesis of L.W. Whitlow (SLAC-357).

Bottom panel: Higher Q^2 values of the longitudinal structure function F_L as a function of Q^2 given at the measured x for e^+/e^- -proton scattering. Points have been slightly offset in Q^2 for clarity. References: **H1**—C. Adloff $et\ al.$, Eur. Phys. J. **C30**, 1 (2003).

The H1 results shown in the bottom plot require the assumption of the validity of the QCD form for the F_2 structure function in order to extract F_L . Statistical and systematic errors added in quadrature are shown for both plots.

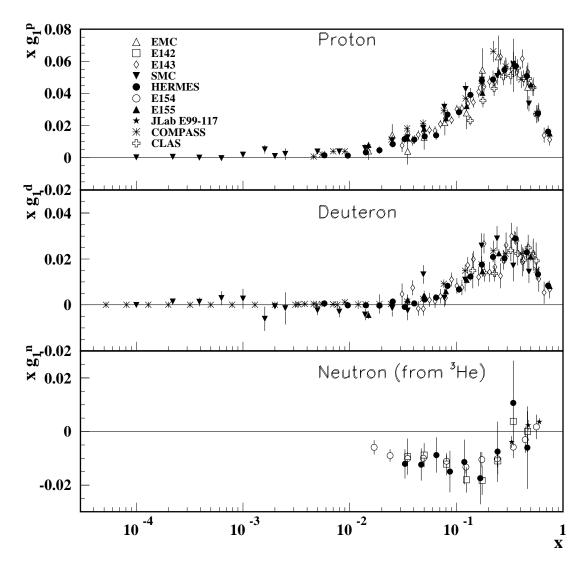


Figure 18.14: The spin-dependent structure function $xg_1(x)$ of the proton, deuteron, and neutron (from 3 He target) measured in deep inelastic scattering of polarized electrons/positrons: E142 ($Q^2 \sim 0.3-10~{\rm GeV}^2$), E143 ($Q^2 \sim 0.3-10~{\rm GeV}^2$), E154 ($Q^2 \sim 1-17~{\rm GeV}^2$), E155 ($Q^2 \sim 1-40~{\rm GeV}^2$), JLab E99-117 ($Q^2 \sim 2.71-4.83~{\rm GeV}^2$), HERMES ($Q^2 \sim 0.18-20~{\rm GeV}^2$), CLAS ($Q^2 \sim 1-5~{\rm GeV}^2$) and muons: EMC ($Q^2 \sim 1.5-100~{\rm GeV}^2$), SMC ($Q^2 \sim 0.01-100~{\rm GeV}^2$), COMPASS ($Q^2 \sim 0.001-100~{\rm GeV}^2$), shown at the measured Q^2 (except for EMC data given at $Q^2=10.7~{\rm GeV}^2$ and E155 data given at $Q^2=5~{\rm GeV}^2$). Note that $g_1^n(x)$ may also be extracted by taking the difference between $g_1^d(x)$ and $g_1^p(x)$, but these values have been omitted in the bottom plot for clarity. Statistical and systematic errors added in quadrature are shown. References: EMC—J. Ashman *et al.*, Nucl. Phys. B328, 1 (1989); E142—P.L. Anthony *et al.*, Phys. Rev. D54, 6620 (1996); E143—K. Abe *et al.*, Phys. Rev. D58, 112003 (1998); SMC—B. Adeva *et al.*, Phys. Rev. D58, 112001 (1998), B. Adeva *et al.*, Phys. Rev. D60, 072004 (1999) and Erratum-Phys. Rev. D62, 079902 (2000); HERMES—A. Airapetian *et al.*, Phys. Rev. D75, 012007 (2007) and K. Ackerstaff *et al.*, Phys. Lett. B404, 383 (1997); E154—K. Abe *et al.*, Phys. Rev. Lett. 79, 26 (1997); E155—P.L. Anthony *et al.*, Phys. Lett. B463, 339 (1999) and P.L. Anthony *et al.*, Phys. Lett. B493, 19 (2000); Jlab-E99-117—X. Zheng *et al.*, Phys. Rev. C70, 065207 (2004); COMPASS—V.Yu. Alexakhin *et al.*, Phys. Lett. B647, 8 (2007), E.S. Ageev *et al.*, Phys. Lett. B647, 330 (2007), and M.G. Alekseev *et al.*, Phys. Lett. B690, 466 (2010); CLAS—K.V. Dharmawardane *et al.*, Phys. Lett. B641, 11 (2006) (which also includes resonance region data not shown on this plot).

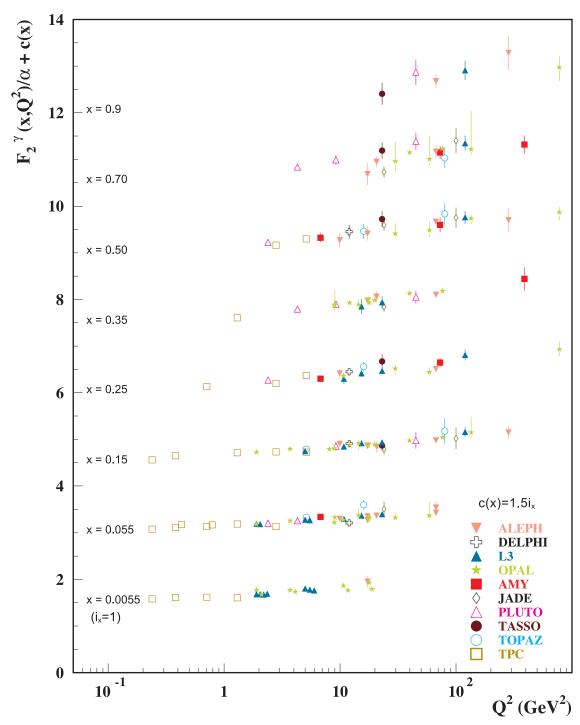


Figure 18.15: The hadronic structure function of the photon F_2^{γ} divided by the fine structure constant α measured in e^+e^- scattering, shown as a function of Q^2 for bins of x. Data points have been shifted to the nearest corresponding x bin as given in the plot. Some points have been offset in Q^2 for clarity. Statistical and systematic errors added in quadrature are shown. For the purpose of plotting, a constant $c(x)=1.5i_x$ is added to F_2^{γ}/α where i_x is the number of the x bin, ranging from 1 (x=0.0055) to 8 (x=0.9). References: ALEPH-R. Barate et al., Phys. Lett. B458, 152 (1999); A. Heister et al., Eur. Phys. J. C30, 145 (2003); DELPHI-P. Abreu et al., Phys. C69, 223 (1995); L3-M. Acciarri et al., Phys. Lett. B436, 403 (1998); M. Acciarri et al., Phys. Lett. B447, 147 (1999); M. Acciarri et al., Phys. Lett. B483, 373 (2000); OPAL-A. Ackerstaff et al., Phys. Lett. B411, 387 (1997); A. Ackerstaff et al., Z. Phys. C74, 33 (1997); G. Abbiendi et al., Eur. Phys. J. C18, 15 (2000); G. Abbiendi et al., Phys. Lett. B533, 207 (2002) (note that there is overlap of the data samples in these last two papers); AMY-S.K. Sahu et al., Phys. Lett. B346, 208 (1995); T. Kojima et al., Phys. Lett. B400, 395 (1997); JADE-W. Bartel et al., Z. Phys. C24, 231 (1984); PLUTO-C. Berger et al., Phys. Lett. 142B, 111 (1984); C. Berger et al., Nucl. Phys. B281, 365 (1987); TASSO-M. Althoff et al., Z. Phys. C31, 527 (1986); TOPAZ-K. Muramatsu et al., Phys. Lett. B332, 477 (1994); TPC/Two Gamma-H. Aihara et al., Z. Phys. C34, 1 (1987).

19. FRAGMENTATION FUNCTIONS IN e^+e^- , ep AND pp COLLISIONS

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19.1. Introduction to fragmentation

The term 'fragmentation functions' is widely used for two related if conceptually different sets of functions describing final-state single particle energy distributions in hard scattering processes (see Refs. [1,2] for introductory reviews, and Refs. [3,4] for summaries of recent experimental and theoretical research in this field).

The first are cross-section observables such as the functions $F_{T,L,A}(x,s)$ in semi-inclusive e^+e^- annihilation at center-of-mass (CM) energy \sqrt{s} via an intermediate photon or Z-boson, $e^+e^- \rightarrow \gamma/Z \rightarrow h+X$, given by

$$\frac{1}{\sigma_0} \frac{d^2 \sigma^h}{dx \, d\cos \theta} = \frac{3}{8} (1 + \cos^2 \theta) F_T^h + \frac{3}{4} \sin^2 \theta \, F_L^h + \frac{3}{4} \cos \theta \, F_A^h \, . \tag{19.1}$$

Here $x=2E_h/\sqrt{s}\leq 1$ is the scaled energy of the hadron h (in practice the approximation $x\simeq x_p=2p_h/\sqrt{s}$ is often used), and θ is its angle relative to the electron beam in the CM frame. Eq. (19.1) is the most general form for unpolarized inclusive single-particle production via vector bosons [5]. The transverse and longitudinal fragmentation functions F_T and F_L represent the contributions from γ/Z polarizations transverse or longitudinal with respect to the direction of motion of the hadron. The parity-violating term with the asymmetric fragmentation function F_A arises from the interference between vector and axial-vector contributions. Normalization factors σ_0 used in the literature range from the total cross section $\sigma_{\rm tot}$ for $e^+e^- \to {\rm hadrons}$, including all weak and QCD contributions, to $\sigma_0 = 4\pi\alpha^2N_c/3s$ with $N_c=3$, the lowest-order QED cross section for $e^+e^- \to \mu^+\mu^-$ times the number of colors N_c . LEP1 measurements of all three fragmentation functions are shown in Fig. 19.1.

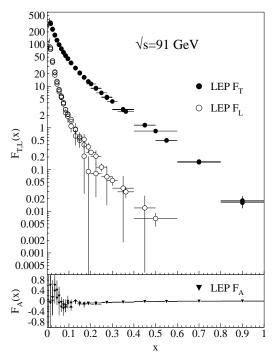


Figure 19.1: LEP1 measurements of total transverse (F_T) , longitudinal (F_L) , and asymmetric (F_A) fragmentation functions [6–8]. Data points with relative errors greater than 100% are omitted.

Integration of Eq. (19.1) over θ yields the total fragmentation function $F^h = F_T^h + F_L^h$,

$$\frac{1}{\sigma_0} \frac{d\sigma^h}{dx} = F^h(x, s) = \sum_i \int_x^1 \frac{dz}{z} C_i(z, \alpha_s(\mu), \frac{s}{\mu^2}) D_i^h(\frac{x}{z}, \mu^2) + \mathcal{O}(\frac{1}{\sqrt{s}})$$
(19.2)

with $i=u,\,\bar{u},\,d,\,\bar{d},\,\ldots,\,g$. Here we have introduced the second set of functions mentioned in the first paragraph, the parton fragmentation functions (or fragmentation densities) D_i^h . These functions are the final-state analogue of the initial-state parton distributions addressed in Section 18 of this *Review*. Due to the different sign of the squared four-momentum q^2 of the intermediate gauge boson these two sets of distributions are also referred to as the timelike $(e^+e^-$ annihilation, $q^2>0$) and spacelike (deep-inelastic scattering (DIS), $q^2<0$) parton distributions. The function $D_i^h(z,\mu^2)$ encodes the

probability that the parton i fragments into a hadron h carrying a fraction z of the parton's momentum. Beyond the leading order (LO) of perturbative QCD these universal functions are factorization-scheme dependent, with 'reasonable' scheme choices retaining certain quark-parton-model (QPM) constraints such as the momentum sum rule

$$\sum_{i} \int_{0}^{1} dz \, z \, D_{i}^{h}(z, \mu^{2}) \, = \, 1 \, . \tag{19.3}$$

The dependence of the functions D_i^h on the factorization (or fragmentation) scale μ^2 (in Eq. (19.2) and below identified with the renormalization scale) is discussed in Section 19.2.

The second ingredient in Eq. (19.2), and analogous expressions for the functions $F_{T,L,A}$, are the observable-dependent coefficient functions C_i . At the zeroth order in the strong coupling $\alpha_{\rm S}$ the coefficient functions C_g for gluons are zero, while for (anti-) quarks $C_i = g_i(s) \, \delta(1-z)$ except for F_L , where $g_i(s)$ is the appropriate electroweak coupling. In particular, $g_i(s)$ is proportional to the squared charge of the quark i at $s \ll M_Z^2$, when weak effects can be neglected. The full electroweak prefactors $g_i(s)$ can be found in Ref. [5]. The power corrections in Eq. (19.2) arise from quark and hadron mass terms and from non-perturbative effects.

Measurements of fragmentation in lepton-hadron and hadron-hadron scattering are complementary to those in e^+e^- annihilation. The latter provides a clean environment (no initial-state hadron remnant) and stringent constraints on the combinations $D_{q_i}^h + D_{\bar{q}_i}^h$. However e^+e^- annihilation is far less sensitive to D_g^h and insensitive to the charge asymmetries $D_{q_i}^h - D_{\bar{q}_i}^h$. These quantities are best constrained in proton–(anti-)proton and electron-proton scattering, respectively. Especially the latter provides a more complicated environment with which it is possible to study the influence on the fragmentation process from initial state QCD radiation, the partonic and spin structure of the hadron target, and the target remnant system (see Ref. [9] for a comprehensive review of the measurements and models of fragmentation in lepton-hadron scattering).

Moreover, unlike e^+e^- annihilation where $q^2=s$ is fixed by the collider energy, lepton-hadron scattering has two independent scales, $Q^2=-q^2$ and the invariant mass W^2 of the hadronic final state, which both can vary by several orders of magnitudes for a given CM energy, thus allowing the study of fragmentation in different environments by a single experiment. E.g., in photoproduction the exchanged photon is quasi-real $(Q^2\approx 0)$ leading to processes akin to hadron-hadron scattering. In DIS $(Q^2\gg 1~{\rm GeV}^2)$, using the QPM, the hadronic fragments of the struck quark can be directly compared with quark fragmentation in e^+e^- in a suitable frame. Results from lepton-hadron experiments quoted in this report primarily concern fragmentation in the DIS regime. Studies performed by lepton-hadron experiments of fragmentation with photoproduction data containing high transverse momentum jets or particles are also reported, when these are directly comparable to DIS and e^+e^- results.

Fragmentation studies at HERA are usually performed in one of two frames in which the target hadron and the exchanged boson are collinear. The hadronic center-of-mass frame (HCMS) is defined as the rest system of the exchanged boson and incoming hadron, with the z^* -axis defined along the direction of the exchanged boson. The positive z^* direction defines the so-called current region. Fragmentation measurements performed in the HCMS often use the Feynman-x variable $x_F=2p_z^*/W,$ where p_z^* is the longitudinal momentum of the particle in this frame. As W is the invariant mass of the hadronic final state, x_F ranges between -1 and 1.

The Breit system [10] is connected to the HCMS by a longitudinal boost such that the time component of q vanishes, i.e, q=(0,0,0,-Q). In the QPM, the struck parton then has the longitudinal momentum Q/2 which becomes -Q/2 after the collision. As compared with the HCMS, the current region of the Breit frame is more closely matched to the partonic scattering process, and is thus appropriate for direct comparisons of fragmentation functions in DIS with those from e^+e^- annihilation. The variable $x_p=2p^*/Q$ is used at HERA for measurements in the Breit frame, ensuring rather directly comparable DIS and e^+e^- results, where p^* is the particle's momentum in the current region of the Breit frame.

19.2. Scaling violation

The simplest parton-model approach would predict scale-independent x-distributions ('scaling') for both the fragmentation function F^h and the parton fragmentation functions D^h_i . Perturbative QCD corrections lead, after factorization of the final-state collinear singularities for light partons, to logarithmic scaling violations via the evolution equations

$$\frac{\partial}{\partial \ln \mu^2} D_i(x, \mu^2) = \sum_j \int_x^1 \frac{dz}{z} P_{ji}(z, \alpha_s(\mu^2)) D_j(\frac{x}{z}, \mu^2) . \tag{19.4}$$

Usually this system of equations is decomposed into a 2×2 flavour-singlet sector comprising gluon and the sum of all quark and antiquark fragmentation functions, and scalar ('non-singlet') equations for quark-antiquark and flavour differences. Notice that the singlet splitting-function matrix is now P_{ji} , rather than P_{ij} as for the initial-state parton distributions, since D_j represents the fragmentation of the final parton.

The splitting functions in Eq. (19.4) have perturbative expansion of

$$P_{ji}(z,\alpha_{\rm s}) = \frac{\alpha_{\rm s}}{2\pi} P_{ji}^{(0)}(z) + \left(\frac{\alpha_{\rm s}}{2\pi}\right)^2 P_{ji}^{(1)}(z) + \left(\frac{\alpha_{\rm s}}{2\pi}\right)^3 P_{ji}^{(2)}(z) + \dots (19.5)$$

where the leading-order (LO) functions $P^{(0)}(z)$ [11,12] are the same as those for the initial-state parton distributions. The next-to-leading order (NLO) corrections $P^{(1)}(z)$ have been calculated in Refs. [13–17] (there are well-known misprints in the journal version of Ref. [14]). Ref. [17] also includes the spin-dependent case. These functions are different from, but related to their space-like counterparts, see also Ref. [18]. These relations have facilitated recent calculations of the next-to-next-to-leading order (NNLO) quantities $P_{qq}^{(2)}(z)$ and $P_{gg}^{(2)}(z)$ in Eq. (19.5) [19,20]. The corresponding off-diagonal quantities $P_{qg}^{(2)}$ and $P_{gq}^{(2)}$ were recently obtained in Ref. [21] by using similar relations supplemented with constrains from the momentum sum rule Eq. (19.3) [20] and the supersymmetric limit. An uncertainty, which does not affect the logarithmic behaviour at small and large momentum fractions, still remains on the $P_{qg}^{(2)}$ kernel. All these results refer to the standard $\overline{\rm MS}$ scheme, with the exception of Refs. [16], with a fixed number $n_{\it f}$ of light flavours. The NLO treatment of flavour thresholds in the evolution has been addressed in Ref. [22].

The QCD parts of the coefficient functions for $F_{T,L,A}(x,s)$ in Eq. (19.1) and the total fragmentation function $F_2^h \equiv F^h$ in Eq. (19.2) are given by

$$C_{a,i}(z,\alpha_{\rm S}) = (1 - \delta_{aL}) \, \delta_{iq} + \frac{\alpha_{\rm S}}{2\pi} \, c_{a,i}^{(1)}(z) + \left(\frac{\alpha_{\rm S}}{2\pi}\right)^2 c_{a,i}^{(2)}(z) + \dots$$
 (19.6)

The first-order corrections have been calculated a long time ago in Refs. [23], and the second-order terms in [24]. The latter results have recently been verified (and some typos corrected) in Refs. [19,25]. Thus the coefficient functions are known to NNLO except for F_L where the leading contribution is of order α_8 .

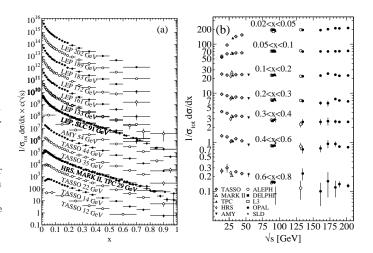


Figure 19.2: The e^+e^- fragmentation function for all charged particles is shown [8, 26–42] (a) for different CM energies \sqrt{s} versus x and (b) for various ranges of x versus \sqrt{s} . For the purpose of plotting (a), the distributions were scaled by $c(\sqrt{s}) = 10^i$ with i ranging from i = 0 ($\sqrt{s} = 12$ GeV) to i = 13 ($\sqrt{s} = 202$ GeV).

The effect of the evolution is similar in the timelike and spacelike cases: as the scale increases, one observes a scaling violation in which the x-distribution is shifted towards lower values. This can be seen from Fig. 19.2 where a large amount of measurements of the total fragmentation function in e^+e^- annihilation are summarized. QCD analyses of these data are discussed in Section 19.5 below.

Unlike the splitting functions in Eq. (19.5), see Refs. [18–20], the coefficient functions for $F_{2,T,A}$ in Eq. (19.6) show a threshold enhancement with terms up to $\alpha_s^{\ n}(1-z)^{-1}\ln^{2n-1}(1-z)$. Such logarithms can be resummed to all orders in α_s using standard soft-gluon techniques [43–45]. Recently this resummation has been extended to the subleading (and for F_L leading) class $\alpha_s^{\ n} \ln^k(1-z)$ of large-x logarithms [46,47].

In Refs. [23] the NLO coefficient functions have been calculated also for single hadron production in lepton-proton scattering, $ep \rightarrow e + h + X$. More recently corresponding results have been obtained for the case that a non-vanishing transverse momentum is required in the HCMS frame [48].

Scaling violations in DIS are shown in Fig. 19.3 for both HCMS and Breit frame. In Fig. 1.3(a) the distribution in terms of $x_F = 2p_z^*/W$ shows a steeper slope in ep data than for the lower-energy μp data for $x_F > 0.15$, indicating the scaling violations. At smaller values of x_F in the current jet region, the multiplicity of particles substantially increases with W owing to the increased phase space available for the fragmentation process. The EMC data access both the current region and the region of the fragmenting target remnant system. At higher values of $|x_F|$, due to the extended nature of the remnant, the multiplicity in the target region far exceeds that in the current region. For acceptance reasons the remnant hemisphere of the HCMS is only accessible by the lower-energy fixed-target experiments.

Using hadrons from the current hemisphere in the Breit frame, measurements of fragmentation functions and the production properties of particles in ep scattering have been made by Refs. [53–58]. Fig. 19.3(b) compares results from ep scattering and e^+e^- experiments, the latter results are halved as they cover both event hemispheres. The agreement between the DIS and e^+e^- results is fairly good. However, processes in DIS which are not present in e^+e^- annihilation, such as boson-gluon fusion and initial state QCD radiation, can depopulate the current region. These effects become most prominent at low values of Q and x_p . Hence, when compared with e^+e^- annihilation data at $\sqrt{s}=5.2$, 6.5 GeV [60] not shown here, the DIS particle rates tend to lie below those from e^+e^- annihilation. A recent ZEUS study [61] finds that the direct comparability of the ep data to e^+e^- results at low scales is improved if twice the energy in the current hemisphere of

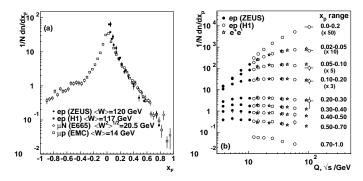


Figure 19.3: (a) The distribution $1/N \cdot dN/dx_F$ for all charged particles in DIS lepton-hadron experiments at different values of W, and measured in the HCMS [49–52]. (b) Scaling violations of the fragmentation function for all charged particles in the current region of the Breit frame of DIS [53,58] and in e^+e^- interactions [41,59]. The data are shown as a function of \sqrt{s} for e^+e^- results, and as a function of Q for the DIS results, each within the same indicated intervals of the scaled momentum x_P . The data for the four lowest intervals of x_P are multiplied by factors 50, 10, 5, and 3, respectively for clarity.

the Breit frame, $2E_R^{\rm cr}$, is used instead of Q as the fragmentation scale.

19.3. Fragmentation functions for small particle momenta

The higher-order timelike splitting functions in Eq. (19.5) are very singular at small x. They show a double-logarithmic (LL) enhancement with leading terms of the form $\alpha_s^n \ln^{2n-2} x$ corresponding to poles $\alpha_s^n (N-1)^{1-2n}$ for the Mellin moments

$$P^{(n)}(N) = \int_0^1 dx \ x^{N-1} \ P^{(n)}(x) \ . \tag{19.7}$$

Despite large cancellations between leading and non-leading logarithms at non-asymptotic value of x, the resulting small-x rise in the timelike splitting functions dwarfs that of their spacelike counterparts for the evolution of the parton distributions in Section 18 of this Review, see Fig. 1 of Ref. [20]. Consequently the fixed-order approximation to the evolution breaks down orders of magnitude in x earlier in fragmentation than in DIS.

The pattern of the known coefficients and other considerations suggest that the LL terms sum to all-order expressions without any pole at N=1 such as [62,63]

$$P_{gg}^{\rm LL}(N) = -\frac{1}{4}(N - 1 - \sqrt{(N - 1)^2 \cdot 24 \,\alpha_{\rm s}/\pi})$$
 (19.8)

Keeping the first three terms in the resulting expansion of Eq. (19.4) around N=1 yields a Gaussian in the variable $\xi=\ln(1/x)$ for the small-x fragmentation functions,

$$xD(x,s) \propto \exp\left[-\frac{1}{2\sigma^2}(\xi - \xi_p)^2\right],$$
 (19.9)

with the peak position and width varying with the energy as [64] (see also Ref. [2])

$$\xi_p \simeq \frac{1}{4} \ln \left(\frac{s}{\Lambda^2} \right) , \quad \sigma \propto \left[\ln \left(\frac{s}{\Lambda^2} \right) \right]^{3/4} .$$
 (19.10)

Next-to-leading order corrections to the above predictions have been calculated [65]. In the method of Ref. [66], see also Refs. [67,68], the corrections are included in an analytical form known as the 'modified leading logarithmic approximation' (MLLA). Alternatively they can be used to compute higher-moment corrections to the shape in Eq. (19.9) [69]. Double-logarithmic contributions to the gluonic coefficient were derived in the standard $\overline{\rm MS}$ scheme in Ref. [70]. The resummation of the dominant small x terms for the flavour-singlet splitting kernels and coefficient functions was recently studied in [71].

Fig. 19.4 shows the ξ distribution for charged particles produced in the current region of the Breit frame in DIS and in e^+e^- annihilation. Consistent with Eq. (19.9) (the 'hump backed plateau') and Eq. (19.10) the distributions have a Gaussian shape with the peak position and area increasing with the CM energy (e^+e^-) and Q^2 (DIS).

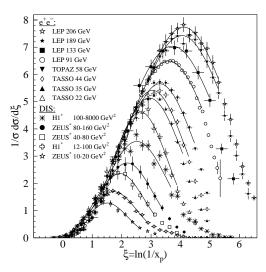


Figure 19.4: Distribution of $\xi = \ln(1/x_p)$ at several CM energies (e⁺e⁻) [26–28,33–36,41,72–75] and intervals of Q^2 (DIS) [56,57]. At each energy only one representative measurement is displayed. For clarity some measurements at intermediate CM energies (e⁺e⁻) or Q^2 ranges (DIS) are not shown. The DIS measurements (*) have been scaled by a factor of 2 for direct comparability with the e^+e^- results. Fits of simple Gaussian functions are overlaid for illustration.

The predicted energy dependence Eq. (19.10) of the peak in the ξ distribution is explained by soft gluon coherence (angular ordering) which correctly predicts the suppression of hadron production at small x. Of course, a decrease at very small x is expected on purely kinematical grounds, but this would occur at particle energies proportional to their masses, i.e., at $x \propto m/\sqrt{s}$ and hence $\xi \sim \frac{1}{2} \ln s$. Thus, if the suppression were purely kinematic, the peak position ξ_p would vary twice as rapidly with the energy, which is ruled out by the data in Fig. 19.5. The e⁺e⁻ and DIS data agree well with each other, demonstrating the universality of hadronization, and the MLLA prediction. Measurements of the higher moments of the ξ distribution in e^+e^- [41,75–77] and DIS [57] have also been performed and show consistency with each other.

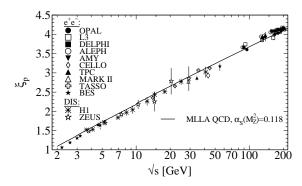


Figure 19.5: Evolution of the peak position, ξ_p , of the ξ distribution with the CM energy \sqrt{s} . The MLLA QCD prediction using $\alpha_S(s=M_Z^2)=0.118$ is superimposed to the data of Refs. [26,28,29,32–34,36,41,55,56,73,74,77–85].

19.4. Fragmentation models

Although the scaling violation can be calculated perturbatively, the actual form of the parton fragmentation functions is non-perturbative. Perturbative evolution gives rise to a shower of quarks and gluons (partons). Multi-parton final states from leading and higher order matrix element calculations are linked to these parton showers using factorization prescriptions, also called matching schemes, see Ref. [86] for an overview. Phenomenological schemes are then used to model the carry-over of parton momenta and flavor to the hadrons. Two of the very popular models are the string fragmentation [87,88], implemented in the JETSET [89], PYTHIA [90] and UCLA [91] Monte Carlo event generation programs, and the cluster fragmentation of the HERWIG [92] and SHERPA [93] Monte Carlo event generators. For details see Chap. 38 of this Review.

19.5. Quark and gluon fragmentation functions

The fragmentation functions are solutions to the evolution equations Eq. (19.4), but need to be parametrized at some initial scale μ_0^2 (usually around 1 GeV² for light quarks and gluons and m_Q^2 for heavy quarks). A usual parametrization for light hadrons is [94–100]

$$D_i^h(x,\mu_0^2) = N x^\alpha (1-x)^\beta \left(1 + \gamma (1-x)^\delta\right) \; , \eqno(19.11)$$

where the normalization N, and the parameters α , β , γ and δ in general depend on the energy scale μ_0^2 , and also on the type of the parton, i, and the hadron, h. Frequently the term involving γ and δ is left out [96–99]. Heavy flavor fragmentation into heavy mesons is discussed in Sec. 19.9. The parameters of Eq. (19.11) (see [94–99]) are obtained by performing global fits to data on various hadron types for different combinations of partons and hadrons in e^+e^- , lepton-hadron and hadron-hadron collisions.

Data from e^+e^- annihilation present the cleanest experimental source for the measurement of fragmentation functions, but can not contribute to disentangle quark from antiquark distributions. Since the bulk of the e^+e^- annihilation data is obtained at the mass of the Z-boson, where the electroweak couplings are roughly the same for the different partons, it provides the most precise determination of the flavor-singlet quark fragmentation. Flavor tagged results [101], distinguishing between the light quark, charm and bottom contributions are of particular value for flavor decomposition, even though those measurements can not be unambiguously interpreted in perturbative QCD.

The most relevant source for quark-antiquark (and also flavor) separation is provided by data from semi-inclusive DIS (SIDIS). Semi-inclusive measurements are usually performed at much lower scales than for e^+e^- annihilation. The inclusion of SIDIS data in global fits allows for a wider coverage in the evolution of the fragmentation functions, resulting at the same time in a stringent test of the universality of these distributions. Charged-hadron production data in hadronic collisions also presents a sensitivity on (anti-)quark fragmentation functions.

The gluon fragmentation function $D_g(x)$ can be extracted, in principle, from the longitudinal fragmentation function F_L in Eq. (19.2), as the coefficient functions $C_{L,i}$ for quarks and gluons are comparable at order α_s . However at NLO, i.e., including the $\mathcal{O}(\alpha_s^2)$ coefficient functions $C_{L,i}^{(2)}$ [24], quark fragmentation is dominant in F_L over a large part of the kinematic range, reducing the sensitivity on D_g . This distribution could be determined also analyzing the evolution of the fragmentation functions. This possibility is limited by the lack of sufficiently precise data at energy scales away from the Z-resonance and the dominance of the quark contributions and at medium and large values of x.

 D_g can also be deduced from the fragmentation of three-jet events in which the gluon jet is identified, for example, by tagging the other two jets with heavy quark decays. To leading order, the measured distributions of $x=E_{\rm had}/E_{\rm jet}$ for particles in gluon jets can be identified directly with the gluon fragmentation functions $D_g(x)$. At higher orders the theoretical interpretation of this observable is ambiguous.

A direct constraint on D_g is provided by $pp, p\bar{p} \to hX$ data. At variance with e^+e^- annihilation and SIDIS, for this process gluon fragmentation starts to contribute at the lowest order in the coupling constant, introducing a strong sensitivity on D_g . At large $x \gtrsim 0.5$, where information from e^+e^- is sparse, data from hadronic colliders facilitate significantly improved extractions of D_g [94,95].

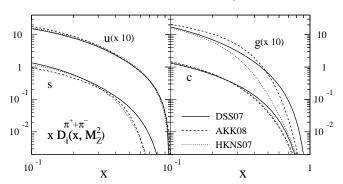


Figure 19.6: Comparison of up, strange, charm and gluon NLO fragmentation functions for $\pi^+ + \pi^-$ at the mass of the Z. The different lines correspond to the result of the most recent analyses performed in Refs. [94,95,99].

A comparison of recent fits of NLO fragmentation functions for $\pi^+ + \pi^-$ obtained by DSS07 [94], AKK08 [95] and HKNS07 [99] is shown in Fig. 19.6. Differences between the sets are large especially for the gluon fragmentation function over the full range of x and for the quark distribution at large momentum fractions. Those discrepancies can be considered as a first estimate of the present uncertainties involved in the extraction of the fragmentation functions. The differences are even larger for other species of hadrons like kaons and protons [94,95,99].

19.6. Identified particles in e^+e^- and semi-inclusive DIS

A great wealth of measurements of e^+e^- fragmentation into identified particles exists. A collection of references for data on fragmentation into identified particles is given on Table 46.1. Representative of this body of data is Fig. 19.7 which shows fragmentation functions as the scaled momentum spectra of charged particles at several CM energies.

Quantitative results of studies of scaling violation in e^+e^- fragmentation have been reported in [6,39,103,104]. The values of α_s obtained are consistent with the world average (see review on QCD in Section 9 of this Review).

Many studies have been made of identified particles produced in lepton-hadron scattering, although fewer particle species have been measured than in e^+e^- collisions. References [105–110] and [111–117] are representative of the data from fixed target and ep collider experiments, respectively.

QCD calculations performed at NLO provide an overall good description of the HERA data [52,53,57,112,118,119] for both SIDIS [120] and the hadron transverse momentum distribution [48] in the kinematic regions in which the calculations are predictive.

Fig. 19.8(a) compares lower-energy fixed-target and HERA data on strangeness production, showing that the HERA spectra have substantially increased multiplicities, albeit with insufficient statistical precision to study scaling violations. The fixed-target data show that the Λ rate substantially exceeds the $\overline{\Lambda}$ rate in the remnant region, owing to the conserved baryon number from the baryon target. Fig. 19.8(b) shows neutral and charged pion fragmentation functions $1/N \cdot dn/dz$, where z is defined as the ratio of the pion energy to that of the exchanged boson, both measured in the laboratory frame. Results are shown from HERMES and the EMC experiments, where HERMES data have been evolved with NLO QCD to $\langle Q^2 \rangle = 25~{\rm GeV^2}$ in order to be consistent with the EMC. Each of the experiments uses various kinematic cuts to ensure that the measured particles lie in

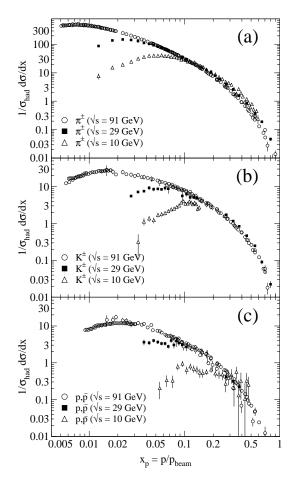


Figure 19.7: Scaled momentum spectra of (a) π^{\pm} , (b) K^{\pm} , and (c) p/\overline{p} at $\sqrt{s}=10, 29,$ and 91 GeV [38,42,82,102].

the region which is expected to be associated with the struck quark. In the DIS kinematic regime accessed at these experiments, and over the range in z shown in Fig. 19.8, the z and x_F variables have similar values [49]. The precision data on identified particles can be used in the study of the quark flavor content of the proton [121].

Data on identified particle production can aid the investigation of the universality of jet fragmentation in e^+e^- and DIS. The strangeness suppression factor γ_s , as derived principally from tuning the Lund string model [88] within JETSET [89], is typically found to be around 0.3 in e^+e^- experiments [72], although values closer to 0.2 [122] have also been obtained. A number of measurements of so-called V^0 -particles (K^0, Λ^0) and the relative rates of V^0 's and inclusively produced charged particles have been performed at HERA [111,113,117] and fixed target experiments [105]. These typically favour a stronger suppression $(\gamma_s \approx 0.2)$ than usually obtained from e^+e^- data although values close to 0.3 have also been obtained [123,124].

However, when comparing the description of QCD-based models for lepton-hadron interactions and e^+e^- collisions, it is important to note that the overall description by event generators of inclusively produced hadronic final states is more accurate in e^+e^- collisions than lepton-hadron interactions [125]. Predictions of particle rates in lepton-hadron scattering are affected by uncertainties in the modelling of the parton composition of the proton and photon, the extended target remnant, and initial and final state QCD radiation. Furthermore, the tuning of event generators for e^+e^- collisions is typically based on a larger set of parameters and uses more observables [72] than are used when optimizing models for lepton-hadron data [126].

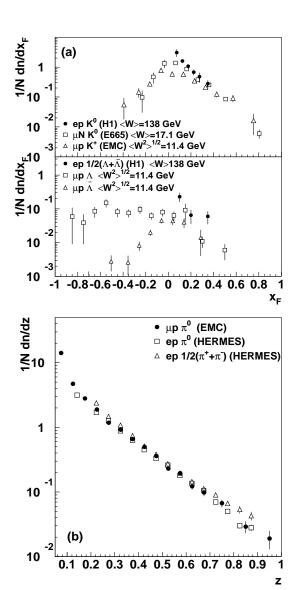


Figure 19.8: (a) $1/N \cdot dn/dx_F$ for identified strange particles in DIS at various values of W [105,108,111]. (b) $1/N \cdot dn/dz$ for measurements of pions from fixed-target DIS experiment [106,109,110].

19.7. Fragmentation in hadron-hadron collisions

An extensive set on high-transverse momentum (p_T) single-inclusive hadron data has been collected in $h_1h_2 \to hX$ scattering processes, both at high energy colliders and fixed-target experiments [127–145]. Only the transverse momentum p_T is considered in hadron-hadron collisions because of lack of knowledge of the longitudinal momentum of the hard subprocess. Fig. 19.9 shows a compilation of neutral pion and charged hadron production data for energies in the range $\sqrt{s}\approx 23$ - 800 GeV.

The differential cross-section for high-transverse momentum distributions has been computed to next-to-leading order accuracy in perturbative QCD [146]. NLO calculations yield a good description of the collider data, but significantly under-predict the cross-section for several fixed-target energy data sets [147,148]. Data collected at high energy colliders are either included in global fit analyses or used as a test for the universality of fragmentation functions.

Different strategies have been developed to a meliorate the theoretical description at fixed-target energies. A possible phenomenological approach involves the introduction of a non-perturbative in trinsic partonic transverse momentum [145,149,150]. From the perturbative side, the resummation of the dominant higher order corrections at

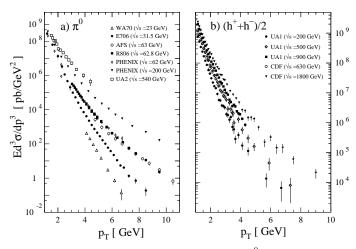


Figure 19.9: Selection of inclusive (a) π^0 and (b) charged-hadron production data from pp [135,142–145] and $p\bar{p}$ [127,130,133] collisions.

threshold produces an enhancement of the theoretical calculation that significantly improves the description of the data [151,152].

Measurements of hadron production in longitudinally polarized pp collisions are used mainly in the determination of the polarized gluon distribution in the proton [153,154].

Hadron production provides a critical observable for probing the high energy-density matter produced in heavy-ion collisions. Measurements at colliders show a suppression of inclusive hadron yields at high transverse momentum for AA collisions compared to pp scattering, indicating the formation of a dense medium opaque to quark and gluons, see e.g. [155].

19.8. Spin-dependent fragmentation

Measurements of charged-hadron production in unpolarized leptonhadron scattering provide a unique tool to perform a flavor-separation determination of polarized parton densities from DIS interactions with longitudinally polarized targets [156–160].

Polarized scattering presents the possibility to measure the spin transfer from the struck quark to the final hadron, and thus develop spin-dependent fragmentation functions [161,162]. Early measurements of the longitudinal spin transfer to Lambda hyperons have been presented in [163,164]. This process is also useful in the study of the quark transversity distribution [165], which describes the probability of finding a transversely polarized quark with its spin aligned or anti-aligned with the spin of a transversely polarized nucleon. The transversity function is chiral-odd, and therefore not accessible through measurements of inclusive lepton-hadron scattering. Semi-inclusive DIS, in which another chiral-odd observable may be involved, provides a valuable tool to probe transversity. The Collins fragmentation function [166] relates the transverse polarization of the quark to that of the final hadron. It is chiral-odd and naive T-odd, leading to a characteristic single spin asymmetry in the azimuthal angular distribution of the produced hadron in the hadron scattering plane. Azimuthal angular distributions in semi-inclusive DIS can also be produced by other processes requiring non-polarized fragmentation functions, like the Sivers mechanism [167].

A number of experiments have measured these asymmetries [168–178]. Collins and Sivers asymmetries have been shown experimentally to be non zero by the HERMES measurements on transversely polarized proton targets [169–171]. Independent information on the Collins function has been provided by the BELLE Collaboration [172–173]. Measurements performed by the COMPASS collaboration on deuteron targets show results compatible with zero for both asymmetries [174–176].

19.9. Heavy quark fragmentation

It was recognized very early [179] that a heavy flavored meson should retain a large fraction of the momentum of the primordial heavy quark, and therefore its fragmentation function should be much harder than that of a light hadron. In the limit of a very heavy quark, one expects the fragmentation function for a heavy quark to go into any heavy hadron to be peaked near x=1.

When the heavy quark is produced at a momentum much larger than its mass, one expects important perturbative effects, enhanced by powers of the logarithm of the transverse momentum over the heavy quark mass, to intervene and modify the shape of the fragmentation function. In leading logarithmic order (i.e., including all powers of $\alpha_{\rm s}\log m_{\rm Q}/p_T$), the total (i.e., summed over all hadron types) perturbative fragmentation function is simply obtained by solving the leading evolution equation for fragmentation functions, Eq. (19.4), with the initial condition at a scale $\mu^2=m_{\rm Q}^2$ given by $D_{\rm Q}(z,m_{\rm Q}^2)=\delta(1-z)$ and $D_i(z,m_{\rm Q}^2)=0$ for $i\neq {\rm Q}$ (here $D_i(z)$, stands for the probability to produce a heavy quark Q from parton i with a fraction z of the parton momentum).

Several extensions of the leading logarithmic result have appeared in the literature. Next-to-leading-log (NLL) order results for the perturbative heavy quark fragmentation function have been obtained in [180]. The resummation of the dominant logarithmic contributions at large z was performed in [43] to next-to-leading-log accuracy. Fixed-order calculations of the fragmentation function at order $\alpha_{\rm s}^2$ in e^+e^- annihilation have appeared in [181] while the initial condition for the perturbative heavy quark fragmentation function has been extended to NNLO in [182].

Inclusion of non-perturbative effects in the calculation of the heavy-quark fragmentation function is done by convoluting the perturbative result with a phenomenological non-perturbative form [183–188], see also section 17.8 of [189]. The parameters entering the non-perturbative forms are fitted together with some model of hard radiation, which can be either a shower Monte Carlo, a leading-log or NLL calculation (which may or may not include Sudakov resummation), or a fixed order calculation [181,190].

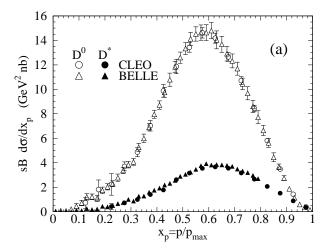
A more conventional approach [191] involves the introduction of a unique set of heavy quark fragmentation functions of non-perturbative nature that obey the usual massless evolution equations in Eq. (19.4). Finite mass terms of the form $(m_{\rm Q}/p_T)^n$ are kept in the corresponding short distance coefficient function for each scattering process. Within this approach, the initial condition for the perturbative fragmentation function provides the term needed to define the correct subtraction scheme to match the massless limit for the coefficient function (see e.g. [192]) . Such implementation is in line with the variable flavor number scheme introduced for parton distributions functions, as described in Section 18 of this Review.

High statistics data for charmed mesons production near the Υ resonance (excluding decay products of B mesons) have been published [193,194]. They include results for D and D^* , D_s (see also [195,196]) and Λ_c . Shown in Fig. 19.10(a) are the CLEO and BELLE inclusive cross-sections times branching ratio \mathcal{B} , $s \cdot \mathcal{B} d\sigma/dx_p$, for the production of D^0 and D^{*+} . The variable x_p approximates the light-cone momentum fraction z, but is not identical to it. The two measurements are consistent with each other.

The branching ratio \mathcal{B} represents $D^0 \to K^-\pi^+$ for the D^0 results and for the D^{*+} the product branching fraction: $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$. Given the high precision of CLEO's and BELLE's data, a superposition of different parametric forms for the non-perturbative contribution is needed to obtain a good fit [22]. Older studies are reported in Refs. [197–199]. Charmed meson spectra on the Z peak have been published by OPAL and ALEPH [200,201].

Charm quark production has also been extensively studied at HERA by the H1 and ZEUS collaborations. Measurements have been made of $D^{*\pm}$, D^{\pm} , and D_s^{\pm} mesons; see, for example, Refs. [202,203]. The production of the Λ_c baryon has also been studied [204].

Experimental studies of the fragmentation function for b quarks, shown in Fig. 19.10(b), have been performed at LEP and SLD [205–207]. Commonly used methods identify the B meson



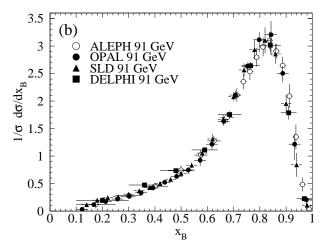


Figure 19.10: (a) Efficiency-corrected inclusive cross-section measurements for the production of D^0 and D^{*+} in e^+e^- measurements at $\sqrt{s}\approx 10.6$ GeV, excluding B decay products [193,194]. (b) Measured e^+e^- fragmentation function of b quarks into B hadrons at $\sqrt{s}\approx 91$ GeV [206].

through its semileptonic decay or based upon tracks emerging from the B secondary vertex. The studies in [206] fit the B spectrum using a Monte Carlo shower model supplemented with non-perturbative fragmentation functions yielding consistent results.

The experiments measure primarily the spectrum of B mesons. This defines a fragmentation function which includes the effect of the decay of higher mass excitations, like the B^* and B^{**} . In the literature, there is sometimes ambiguity in what is defined to be the bottom fragmentation function. Instead of using what is directly measured (i.e., the B meson spectrum) corrections are applied to account for B^* or B^{**} production in some cases. For a more detailed discussion see section 17.8 of [189].

Heavy-flavor production in e^+e^- collisions is the primary source of information for the role of fragmentation effects in heavy-flavor production in hadron-hadron and lepton-hadron collisions. The QCD calculations tend to underestimate the data in certain regions of phase space. The discrepancy observed between theoretical calculations and the measured B meson spectrum at the hadron colliders [208] is substantially reduced when a more refined use of information on heavy flavor production from e^+e^- data is made [209] and when up-to-date parton distributions and strong coupling constant values are considered [210].

Both bottomed- and charmed-mesons spectra have been measured at the Tevatron with unprecedented accuracy [211]. The measured spectra are in good agreement with QCD calculations (including non-perturbative fragmentation effects inferred from $\mathrm{e^+e^-}$ data [212]),

no longer supporting the previously reported discrepancies [208].

The HERA collaborations have produced a number of measurements of beauty production; see, for example, Refs. [202,213–215]. As for the Tevatron data, the HERA results are described well by QCD-based calculations using fragmentation models optimised with $\rm e^+e^-$ data.

Besides degrading the fragmentation function by gluon radiation, QCD evolution can also generate soft heavy quarks, increasing in the small x region as \sqrt{s} increases. Several theoretical studies are available on the issue of how often $b\bar{b}$ or $c\bar{c}$ pairs are produced indirectly, via a gluon splitting mechanism [216–218]. Experimental results from studies on charm and bottom production via gluon splitting, given in [201,219–223], yield weighted averages of $\overline{n}_{g\to c\overline{c}}=3.05\pm0.45\%$ and $\overline{n}_{g\to b\overline{b}}=0.277\pm0.072\%$, respectively.

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20. EXPERIMENTAL TESTS OF GRAVITATIONAL THEORY

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Einstein's General Relativity, the current "standard" theory of gravitation, describes gravity as a universal deformation of the Minkowski metric:

$$g_{\mu\nu}(x^{\lambda}) = \eta_{\mu\nu} + h_{\mu\nu}(x^{\lambda})$$
, where $\eta_{\mu\nu} = \text{diag}(-1, +1, +1, +1)$. (20.1)

General Relativity is classically defined by two postulates. One postulate states that the Lagrangian density describing the propagation and self-interaction of the gravitational field is

$$\mathcal{L}_{\rm Ein}[g_{\mu\nu}] = \frac{c^4}{16\pi G_N} \sqrt{g} g^{\mu\nu} R_{\mu\nu}(g) , \qquad (20.2)$$

$$R_{\mu\nu}(g) = \partial_{\alpha}\Gamma^{\alpha}_{\mu\nu} - \partial_{\nu}\Gamma^{\alpha}_{\mu\alpha} + \Gamma^{\beta}_{\alpha\beta}\Gamma^{\alpha}_{\mu\nu} - \Gamma^{\beta}_{\alpha\nu}\Gamma^{\alpha}_{\mu\beta} , \qquad (20.3)$$

$$\Gamma^{\lambda}_{\mu\nu} = \frac{1}{2}g^{\lambda\sigma}(\partial_{\mu}g_{\nu\sigma} + \partial_{\nu}g_{\mu\sigma} - \partial_{\sigma}g_{\mu\nu}) , \qquad (20.4)$$

where G_N is Newton's constant, $g = -\det(g_{\mu\nu})$, and $g^{\mu\nu}$ is the matrix inverse of $g_{\mu\nu}$. A second postulate states that $g_{\mu\nu}$ couples universally, and minimally, to all the fields of the Standard Model by replacing everywhere the Minkowski metric $\eta_{\mu\nu}$. Schematically (suppressing matrix indices and labels for the various gauge fields and fermions and for the Higgs doublet),

$$\mathcal{L}_{SM}[\psi, A_{\mu}, H, g_{\mu\nu}] = -\frac{1}{4} \sum \sqrt{g} g^{\mu\alpha} g^{\nu\beta} F^{a}_{\mu\nu} F^{a}_{\alpha\beta}$$

$$- \sum \sqrt{g} \overline{\psi} \gamma^{\mu} D_{\mu} \psi$$

$$- \frac{1}{2} \sqrt{g} g^{\mu\nu} \overline{D_{\mu} H} D_{\nu} H - \sqrt{g} V(H)$$

$$- \sum \lambda \sqrt{g} \overline{\psi} H \psi , \qquad (20.5)$$

where $\gamma^{\mu}\gamma^{\nu} + \gamma^{\nu}\gamma^{\mu} = 2g^{\mu\nu}$, and where the covariant derivative D_{μ} contains, besides the usual gauge field terms, a spin-dependent gravitational contribution. From the total action follow Einstein's field equations,

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G_N}{c^4} T_{\mu\nu} \ . \tag{20.6}$$

Here $R=g^{\mu\nu}R_{\mu\nu}$, $T_{\mu\nu}=g_{\mu\alpha}g_{\nu\beta}T^{\alpha\beta}$, and $T^{\mu\nu}=(2/\sqrt{g})\delta \mathcal{L}_{\rm SM}/\delta g_{\mu\nu}$ is the (symmetric) energy-momentum tensor of the Standard Model matter. The theory is invariant under arbitrary coordinate transformations: $x'^{\mu}=f^{\mu}(x^{\nu})$. To solve the field equations Eq. (20.6), one needs to fix this coordinate gauge freedom. E.g., the "harmonic gauge" (which is the analogue of the Lorenz gauge, $\partial_{\mu}A^{\mu}=0$, in electromagnetism) corresponds to imposing the condition $\partial_{\nu}(\sqrt{g}g^{\mu\nu})=0$.

In this Review, we only consider the classical limit of gravitation (i.e. classical matter and classical gravity). Considering quantum matter in a classical gravitational background already poses interesting challenges, notably the possibility that the zero-point fluctuations of the matter fields generate a nonvanishing vacuum energy density $\rho_{\rm vac}$, corresponding to a term $-\sqrt{g}~\rho_{\rm vac}$ in $\mathcal{L}_{\rm SM}$ [1]. This is equivalent to adding a "cosmological constant" term $+\Lambda~g_{\mu\nu}$ on the left-hand side of Einstein's equations Eq. (20.6), with $\Lambda = 8\pi G_N~\rho_{\rm vac}/c^4$. Recent cosmological observations (see the following Reviews) suggest a positive value of Λ corresponding to $\rho_{\rm vac} \approx (2.3 \times 10^{-3} {\rm eV})^4$. Such a small value has a negligible effect on the tests discussed below.

20.1. Experimental tests of the coupling between matter and gravity

The universality of the coupling between $g_{\mu\nu}$ and the Standard Model matter postulated in Eq. (20.5) ("Equivalence Principle") has many observable consequences [2,3]. First, it predicts that the outcome of a local non-gravitational experiment, referred to local standards, does not depend on where, when, and in which locally inertial frame, the experiment is performed. This means, for instance, that local experiments should neither feel the cosmological evolution of the universe (constancy of the "constants"), nor exhibit preferred directions in spacetime (isotropy of space, local Lorentz

invariance). These predictions are consistent with many experiments and observations. Stringent limits on a possible time variation of the basic coupling constants have been obtained by analyzing a natural fission reactor phenomenon which took place at Oklo, Gabon, two billion years ago [4,5]. These limits are at the 1×10^{-7} level for the fractional variation of the fine-structure constant $\alpha_{\rm em}$ [5], and at the 4×10^{-9} level for the fractional variation of the ratio between the light quark masses and Λ_{QCD} [6]. The determination of the lifetime of Rhenium 187 from isotopic measurements of some meteorites dating back to the formation of the solar system (about 4.6 Gyr ago) yields comparably strong limits [7]. Measurements of absorption lines in astronomical spectra also give stringent limits on the variability of both $\alpha_{\rm em}$ (at the 10^{-5} level [8]) , and $\mu=m_p/m_e$, e.g.

$$|\Delta\mu/\mu| < 1.8 \times 10^{-6} (95\% \ C.L.)$$
, (20.7)

at a redshift z=0.68466 [9], and $\Delta\mu/\mu=(0.3\pm3.2_{\rm stat}\pm1.9_{\rm sys})\times10^{-6}$ at the large redshift z=2.811 [10]. Direct laboratory limits on the (present) time variation of $\alpha_{\rm em}$ (based on monitoring the frequency ratio of several different atomic clocks) have recently reached the level [11]:

$$\dot{\alpha}_{\rm em}/\alpha_{\rm em} = (-1.6 \pm 2.3) \times 10^{-17} {\rm yr}^{-1}.$$

There are also experimental limits on a possible dependence of coupling constants on the gravitational potential [12]. See [13] for a review of the issue of "variable constants."

The highest precision tests of the isotropy of space have been performed by looking for possible quadrupolar shifts of nuclear energy levels [14]. The (null) results can be interpreted as testing the fact that the various pieces in the matter Lagrangian Eq. (20.5) are indeed coupled to one and the same external metric $g_{\mu\nu}$ to the 10^{-29} level. For astrophysical constraints on possible Planck-scale violations of Lorentz invariance, see Ref. 15.

The universal coupling to $g_{\mu\nu}$ postulated in Eq. (20.5) implies that two (electrically neutral) test bodies dropped at the same location and with the same velocity in an external gravitational field fall in the same way, independently of their masses and compositions. The universality of the acceleration of free fall has been verified at the 10^{-13} level for laboratory bodies, notably Beryllium and Titanium test bodies [16],

$$(\Delta a/a)_{\text{BeTi}} = (0.3 \pm 1.8) \times 10^{-13} ,$$
 (20.8)

as well as for the gravitational accelerations of the Earth and the Moon toward the Sun [17],

$$(\Delta a/a)_{\text{EarthMoon}} = (-1.0 \pm 1.4) \times 10^{-13}$$
. (20.9)

The latter result constrains not only how $g_{\mu\nu}$ couples to matter, but also how it couples to itself [18]("strong equivalence principle"; see Eq. (20.15) below, and the end of the section on binary pulsar tests). See also Ref. 19 for a review of torsion balance experiments.

Finally, Eq. (20.5) also implies that two identically constructed clocks located at two different positions in a static external Newtonian potential $U(\boldsymbol{x}) = \sum G_N m/r$ exhibit, when intercompared by means of electromagnetic signals, the (apparent) difference in clock rate, $\tau_1/\tau_2 = \nu_2/\nu_1 = 1 + [U(\boldsymbol{x}_1) - U(\boldsymbol{x}_2)]/c^2 + O(1/c^4)$, independently of their nature and constitution. This universal gravitational redshift of clock rates has been verified at the 10^{-4} level by comparing a hydrogen-maser clock flying on a rocket up to an altitude $\sim 10,000$ km to a similar clock on the ground [20]. The redshift due to a height change of only 33 cm has been recently detected by comparing two optical clocks based on $^{27}\text{Al}^+$ ions [21].

20.2. Tests of the dynamics of the gravitational field in the weak field regime

The effect on matter of one-graviton exchange, *i.e.*, the interaction Lagrangian obtained when solving Einstein's field equations Eq. (20.6) written in, say, the harmonic gauge at first order in $h_{\mu\nu}$,

$$\Box h_{\mu\nu} = -\frac{16\pi G_N}{c^4} (T_{\mu\nu} - \frac{1}{2} T \eta_{\mu\nu}) + O(h^2) + O(hT) , \qquad (20.10)$$

reads $-(8\pi G_N/c^4)T^{\mu\nu}\Box^{-1}(T_{\mu\nu}-\frac{1}{2}T\eta_{\mu\nu})$. For a system of N moving point masses, with free Lagrangian $L^{(1)}=\sum_{A=1}^N-m_Ac^2\sqrt{1-v_A^2/c^2}$, this interaction, expanded to order v^2/c^2 , reads (with $r_{AB}\equiv |x_A-x_B|$, $n_{AB}\equiv (x_A-x_B)/r_{AB}$)

$$L^{(2)} = \frac{1}{2} \sum_{A \neq B} \frac{G_N m_A m_B}{r_{AB}} \left[1 + \frac{3}{2c^2} (\mathbf{v}_A^2 + \mathbf{v}_B^2) - \frac{7}{2c^2} (\mathbf{v}_A \cdot \mathbf{v}_B) - \frac{1}{2c^2} (\mathbf{n}_{AB} \cdot \mathbf{v}_A) (\mathbf{n}_{AB} \cdot \mathbf{v}_B) + O\left(\frac{1}{c^4}\right) \right].$$
(20.11)

The two-body interactions, Eq. (20.11), exhibit v^2/c^2 corrections to Newton's 1/r potential induced by spin-2 exchange ("gravito-magnetism"). Consistency at the "post-Newtonian" level $v^2/c^2 \sim G_N \, m/rc^2$ requires that one also considers the three-body interactions induced by some of the three-graviton vertices and other nonlinearities (terms $O(h^2)$ and O(hT) in Eq. (20.10)),

$$L^{(3)} = -\frac{1}{2} \sum_{B \neq A \neq C} \frac{G_N^2 m_A m_B m_C}{r_{AB} r_{AC} c^2} + O\left(\frac{1}{c^4}\right) . \tag{20.12}$$

All currently performed gravitational experiments in the solar system, including perihelion advances of planetary orbits, the bending and delay of electromagnetic signals passing near the Sun, and very accurate ranging data to the Moon obtained by laser echoes, are compatible with the post-Newtonian results Eqs. (20.10)-(20.12). The "gravito-magnetic" interactions $\propto v_A v_B$ contained in Eq. (20.11) are involved in many of these experimental tests. They have been particularly tested in lunar laser ranging data [17], in the LAGEOS satellite observations [22], and in the dedicated Gravity Probe B mission [23].

Similar to what is done in discussions of precision electroweak experiments, it is useful to quantify the significance of precision gravitational experiments by parameterizing plausible deviations from General Relativity. The addition of a mass-term in Einstein's field equations leads to a score of theoretical difficulties which have not yet received any consensual solution. We shall, therefore, not consider here the ill-defined "mass of the graviton" as a possible deviation parameter from General Relativity (see, however, Ref. 24). Deviations from Einstein's pure spin-2 theory are then defined by adding new, bosonic light or massless, macroscopically coupled fields. The possibility of new gravitational-strength couplings leading (on small, and possibly large, scales) to deviations from Einsteinian (and Newtonian) gravity is suggested by String Theory [25], and by Brane World ideas [26]. For reviews of experimental constraints on Yukawatype additional interactions, see Refs. [19,27]. Recent experiments have set limits on non-Newtonian forces below 0.056 mm [28].

Here, we shall focus on the parametrization of long-range deviations from relativistic gravity obtained by adding a strictly massless (i.e. without self-interaction $V(\varphi)=0$) scalar field φ coupled to the trace of the energy-momentum tensor $T=g_{\mu\nu}T^{\mu\nu}$ [29]. The most general such theory contains an arbitrary function $a(\varphi)$ of the scalar field, and can be defined by the Lagrangian

$$\mathcal{L}_{\text{tot}}[g_{\mu\nu}, \varphi, \psi, A_{\mu}, H] = \frac{c^4}{16\pi G} \sqrt{g} (R(g_{\mu\nu}) - 2g^{\mu\nu} \partial_{\mu} \varphi \partial_{\nu} \varphi) + \mathcal{L}_{\text{SM}}[\psi, A_{\mu}, H, \tilde{g}_{\mu\nu}] , \qquad (20.13)$$

where G is a "bare" Newton constant, and where the Standard Model matter is coupled not to the "Einstein" (pure spin-2) metric $g_{\mu\nu}$, but to the conformally related ("Jordan-Fierz") metric $\widetilde{g}_{\mu\nu}=\exp(2a(\varphi))g_{\mu\nu}$. The scalar field equation $\Box_g\varphi=-(4\pi G/c^4)\alpha(\varphi)T$ displays $\alpha(\varphi)\equiv\partial a(\varphi)/\partial\varphi$ as the basic (field-dependent) coupling between φ and matter [30]. The one-parameter (ω) Jordan-Fierz-Brans-Dicke theory [29] is the special case $a(\varphi)=\alpha_0\varphi$ leading to a field-independent coupling $\alpha(\varphi)=\alpha_0$ (with $\alpha_0^2=1/(2\omega+3)$). The addition of a self-interaction term $V(\varphi)$ in Eq. (20.13) introduces new phenomenological possibilities; notably the "chameleon mechanism" [31].

In the weak-field slow-motion limit appropriate to describing gravitational experiments in the solar system, the addition of φ modifies Einstein's predictions only through the appearance of two "post-Einstein" dimensionless parameters: $\overline{\gamma} = -2\alpha_0^2/(1+\alpha_0^2)$ and $\overline{\beta} =$ $+\frac{1}{2}\beta_0\alpha_0^2/(1+\alpha_0^2)^2$, where $\alpha_0 \equiv \alpha(\varphi_0)$, $\beta_0 \equiv \partial\alpha(\varphi_0)/\partial\varphi_0$, φ_0 denoting the vacuum expectation value of φ . These parameters show up also naturally (in the form $\gamma_{PPN} = 1 + \overline{\gamma}$, $\beta_{PPN} = 1 + \overline{\beta}$) in phenomenological discussions of possible deviations from General Relativity [2]. The parameter $\overline{\gamma}$ measures the admixture of spin 0 to Einstein's graviton, and contributes an extra term $+\overline{\gamma}(v_A-v_B)^2/c^2$ in the square brackets of the two-body Lagrangian Eq. (20.11). The parameter $\overline{\beta}$ modifies the three-body interaction Eq. (20.12) by an overall multiplicative factor $1 + 2\overline{\beta}$. Moreover, the combination $\eta \equiv 4\overline{\beta} - \overline{\gamma}$ parameterizes the lowest order effect of the self-gravity of orbiting masses by modifying the Newtonian interaction energy terms in Eq. (20.11) into $G_{AB}m_Am_B/r_{AB}$, with a body-dependent gravitational "constant" $G_{AB}=G_N[1+\eta(E_A^{\rm grav}/m_Ac^2+E_B^{\rm grav}/m_Bc^2)+O(1/c^4)]$, where $G_N=G\exp[2a(\varphi_0)](1+\alpha_0^2)$ and where $E_A^{\rm grav}$ denotes the gravitational binding energy of body A.

The best current limits on the post-Einstein parameters $\overline{\gamma}$ and $\overline{\beta}$ are (at the 68% confidence level):

$$\overline{\gamma} = (2.1 \pm 2.3) \times 10^{-5} ,$$
 (20.14)

deduced from the additional Doppler shift experienced by radio-wave beams connecting the Earth to the Cassini spacecraft when they passed near the Sun [32], and

$$4\overline{\beta} - \overline{\gamma} = (4.4 \pm 4.5) \times 10^{-4}$$
, (20.15)

from Lunar Laser Ranging measurements [17] of a possible polarization of the Moon toward the Sun [18]. More stringent limits on $\overline{\gamma}$ are obtained in models (e.g., string-inspired ones [25]) where scalar couplings violate the Equivalence Principle.

20.3. Tests of the dynamics of the gravitational field in the radiative and/or strong field regimes

The discovery of pulsars (i.e., rotating neutron stars emitting a beam of radio noise) in gravitationally bound orbits [33,34] has opened up an entirely new testing ground for relativistic gravity, giving us an experimental handle on the regime of radiative and/or strong gravitational fields. In these systems, the finite velocity of propagation of the gravitational interaction between the pulsar and its companion generates damping-like terms at order $(v/c)^5$ in the equations of motion [35]. These damping forces are the local counterparts of the gravitational radiation emitted at infinity by the system ("gravitational radiation reaction"). They cause the binary orbit to shrink and its orbital period P_b to decrease. The remarkable stability of pulsar clocks has allowed one to measure the corresponding very small orbital period decay $\dot{P}_b \equiv dP_b/dt \sim -(v/c)^5 \sim -10^{-12}$ in several binary systems, thereby giving us a direct experimental confirmation of the propagation properties of the gravitational field, and, in particular, an experimental confirmation that the speed of propagation of gravity is equal to the velocity of light to better than a part in a thousand. In addition, the surface gravitational potential of a neutron star $h_{00}(R) \simeq 2Gm/c^2R \simeq 0.4$ being a factor $\sim 10^8$ higher than the surface potential of the Earth, and a mere factor 2.5 below the black hole limit $(h_{00}(R) = 1)$, pulsar data have allowed one to obtain several accurate tests of the strong-gravitational-field regime, as we discuss next.

Binary pulsar timing data record the times of arrival of successive electromagnetic pulses emitted by a pulsar orbiting around the center of mass of a binary system. After correcting for the Earth motion around the Sun and for the dispersion due to propagation in the interstellar plasma, the time of arrival of the Nth pulse t_N can be described by a generic, parameterized "timing formula" [36] whose functional form is common to the whole class of tensor-scalar gravitation theories:

$$t_N - t_0 = F[T_N(\nu_p, \dot{\nu}_p, \ddot{\nu}_p); \{p^K\}; \{p^{PK}\}].$$
 (20.16)

Here, T_N is the pulsar proper time corresponding to the Nth turn given by $N/2\pi = \nu_p T_N + \frac{1}{2}\dot{\nu}_p T_N^2 + \frac{1}{6}\ddot{\nu}_p T_N^3$ (with $\nu_p \equiv 1/P_p$ the spin frequency of the pulsar, etc.), $\{p^K\} = \{P_b, T_0, e, \omega_0, x\}$ is the set of "Keplerian" parameters (notably, orbital period P_b , eccentricity e, periastron longitude ω_0 and projected semi-major axis $x = a \sin i/c$), and $\{p^{PK}\} = \{k, \gamma_{\text{timing}}, \dot{P}_b, r, s, \delta_\theta, \dot{e}, \dot{x}\}$ denotes the set of (separately measurable) "post-Keplerian" parameters. Most important among these are: the fractional periastron advance per orbit $k \equiv \dot{\omega} P_b/2\pi$, a dimensionful time-dilation parameter γ_{timing} , the orbital period derivative \dot{P}_b , and the "range" and "shape" parameters of the gravitational time delay caused by the companion, r and s.

Without assuming any specific theory of gravity, one can phenomenologically analyze the data from any binary pulsar by least-squares fitting the observed sequence of pulse arrival times to the timing formula Eq. (20.16). This fit yields the "measured" values of the parameters $\{\nu_p, \dot{\nu}_p, \ddot{\nu}_p\}$, $\{p^K\}$, $\{p^{FK}\}$. Now, each specific relativistic theory of gravity predicts that, for instance, k, $\gamma_{\text{timing}}, \dot{P}_b$, r and s (to quote parameters that have been successfully measured from some binary pulsar data) are some theory-dependent functions of the Keplerian parameters and of the (unknown) masses m_1 , m_2 of the pulsar and its companion. For instance, in General Relativity, one finds (with $M \equiv m_1 + m_2$, $n \equiv 2\pi/P_b$)

$$\begin{split} k^{\text{GR}}(m_1, m_2) = & 3(1 - e^2)^{-1} (G_N M n/c^3)^{2/3} , \\ \gamma^{\text{GR}}_{\text{timing}}(m_1, m_2) = & en^{-1} (G_N M n/c^3)^{2/3} m_2 (m_1 + 2m_2)/M^2 , \\ \dot{P}_b^{\text{GR}}(m_1, m_2) = & - (192\pi/5)(1 - e^2)^{-7/2} \left(1 + \frac{73}{24}e^2 + \frac{37}{96}e^4\right) \\ & \times (G_N M n/c^3)^{5/3} m_1 m_2/M^2 , \\ r(m_1, m_2) = & G_N m_2/c^3 , \\ s(m_1, m_2) = & nx(G_N M n/c^3)^{-1/3} M/m_2 . \end{split}$$
(20.17)

In tensor-scalar theories, each of the functions $k^{\mathrm{theory}}(m_1, m_2)$, $\gamma_{\mathrm{timing}}^{\mathrm{theory}}(m_1, m_2)$, $\dot{P}_b^{\mathrm{theory}}(m_1, m_2)$, etc., is modified by quasi-static strong field effects (associated with the self-gravities of the pulsar and its companion), while the particular function $\dot{P}_b^{\mathrm{theory}}(m_1, m_2)$ is further modified by radiative effects (associated with the spin 0 propagator) [30,37,38].

Let us give some highlights of the current experimental situation (see Ref. 39 for a more extensive review). In the first discovered binary pulsar PSR1913 + 16 [33,34], it has been possible to measure with accuracy three post-Keplerian parameters: k, $\gamma_{\rm timing}$ and \dot{P}_b . The three equations $k^{\rm measured} = k^{\rm theory}(m_1, m_2)$, $\dot{P}_{\rm timing}^{\rm measured} = \gamma_{\rm timing}^{\rm theory}(m_1, m_2)$, $\dot{P}_b^{\rm measured} = \dot{P}_b^{\rm theory}(m_1, m_2)$ determine, for each given theory, three curves in the two-dimensional mass plane. This yields one (combined radiative/strong-field) test of the specified theory, according to whether the three curves meet at one point, as they should. After subtracting a small ($\sim 10^{-14}$ level in $\dot{P}_b^{\rm obs} = (-2.423 \pm 0.001) \times 10^{-12}$), but significant, Newtonian perturbing effect caused by the Galaxy [40], one finds that General Relativity passes this $(k - \gamma_{\rm timing} - \dot{P}_b)_{1913+16}$ test with complete success at the 10^{-3} level [34,41,42]

$$\[\frac{\dot{P}_b^{\text{obs}} - \dot{P}_b^{\text{galactic}}}{\dot{P}_b^{\text{GR}}[k^{\text{obs}}, \gamma_{\text{timing}}^{\text{obs}}]} \right]_{1913 + 16} = 0.997 \pm 0.002 \ . \tag{20.18}$$

Here $\dot{P}_b^{\rm GR}[k^{\rm obs}, \gamma_{\rm timing}^{\rm obs}]$ is the result of inserting in $\dot{P}_b^{\rm GR}(m_1, m_2)$ the values of the masses predicted by the two equations $k^{\rm obs} =$

 $k^{\mathrm{GR}}(m_1,m_2),~\gamma_{\mathrm{timing}}^{\mathrm{obs}}=\gamma_{\mathrm{timing}}^{\mathrm{GR}}(m_1,m_2).$ This yields experimental evidence for the reality of gravitational radiation damping forces at the $(-3\pm2)\times10^{-3}$ level.

The discovery of the binary pulsar PSR1534 + 12 [43] has allowed one to measure five post-Keplerian parameters: k, $\gamma_{\rm timing}$, r, s, and (with less accuracy) \dot{P}_b [44,45]. This allows one to obtain three (five observables minus two masses) tests of relativistic gravity. Two among these tests probe strong field gravity, without mixing of radiative effects [44]. General Relativity passes all these tests within the measurement accuracy. The most precise of the new, pure strong-field tests is the one obtained by combining the measurements of k, γ , and s. Using the most recent data [45], one finds agreement at the 1% level:

$$\left[\frac{s^{\text{obs}}}{s^{\text{GR}}[k^{\text{obs}}, \gamma_{\text{timing}}^{\text{obs}}]}\right]_{1534+12} = 1.000 \pm 0.007.$$
 (20.19)

The discovery of the binary pulsar PSR J1141 - 6545 [46](whose companion is probably a white dwarf) has allowed one to measure four observable parameters: $k, \gamma_{\text{timing}}, \dot{P}_b$ [47,48], and the parameter s [49,48]. The latter parameter (which is equal to the sine of the inclination angle, $s = \sin i$) was consistently measured in two ways: from a scintillation analysis [49], and from timing measurements [48]. General Relativity passes all the corresponding tests within measurement accuracy. See Fig. 20.1 which uses the (more precise) scintillation measurement of $s = \sin i$.

The discovery of the remarkable double binary pulsar PSR J0737 — 3039 A and B [50,51] has led to the measurement of seven independent parameters [52,53]: five of them are the post-Keplerian parameters $k, \gamma_{\text{timing}}, r, s$ and \dot{P}_b entering the relativistic timing formula of the fast-spinning pulsar PSR J0737 - 3039 A, a sixth is the ratio $R = x_B/x_A$ between the projected semi-major axis of the more slowly spinning companion pulsar PSR J0737 - 3039 B, and that of PSR J0737 - 3039 A. [The theoretical prediction for the ratio $R = x_B/x_A$, considered as a function of the (inertial) masses $m_1 = m_A$ and $m_2 = m_B$, is $R^{\text{theory}} = m_1/m_2 + O((v/c)^4)$ [36], independently of the gravitational theory considered.] Finally, the seventh parameter $\Omega_{\rm SO,B}$ is the angular rate of (spin-orbit) precession of PSR J0737 - 3039 B around the total angular momentum [53]. These seven measurements give us five tests of relativistic gravity [52,54]. General Relativity passes all those tests with flying colors (see Fig. 20.1). Let us highlight here two of them.

One test is a new, precise confirmation of the reality of gravitational radiation

$$\left[\frac{\dot{P}_b^{\text{obs}}}{\dot{P}_b^{\text{GR}}[k^{\text{obs}}, R^{\text{obs}}]}\right]_{0737-3039} = 1.003 \pm 0.014 \ .$$
(20.20)

Another one is an accurate (5 \times 10⁻⁴ level) new strong-field confirmation of General Relativity:

$$\left[\frac{s^{\rm obs}}{s^{\rm GR}[k^{\rm obs},R^{\rm obs}]}\right]_{0737-3039} = 0.99987 \pm 0.00050 \ . \eqno(20.21)$$

Fig. 20.1 illustrates all the tests of strong-field and radiative gravity derived from the above-mentioned binary pulsars: (3-2=) one test from PSR1913 + 16, (5-2=) 3 tests from PSR1534 + 12, (4-2=) 2 tests from PSR J1141 - 6545, and (7-2=) 5 tests from PSR J0737 - 3039

Data from several nearly circular binary systems (made of a neutron star and a white dwarf) have also led to strong-field confirmations (at the 4.6×10^{-3} level) of the 'strong equivalence principle,' *i.e.*, the fact that neutron stars and white dwarfs fall with the same acceleration in the gravitational field of the Galaxy [55,56]. The measurements of \dot{P}_b in some pulsar-white dwarf systems lead to strong constraints on the variation of Newton's G_N , and on the existence of gravitational dipole radiation [57,58]. In addition, arrays of millisecond pulsars are sensitive detectors of (very low frequency) gravitational waves [59].

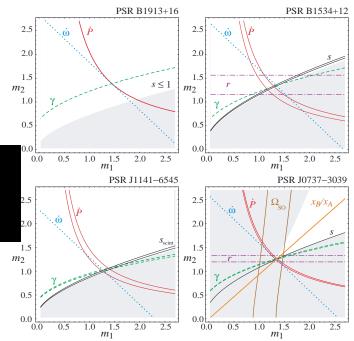


Figure 20.1: Illustration of the *eleven* tests of relativistic gravity obtained in the four different binary pulsar systems: PSR1913 + 16 (one test), PSR1534 + 12 (3 tests), PSR J1141 – 6545 (2 tests), and PSR J0737 – 3039 A,B (5 tests). Each curve (or strip) in the mass plane corresponds to the interpretation, within General Relativity, of some observable parameter among: \dot{P}_b , $k \equiv \dot{\omega} P_b/2\pi$, $\gamma_{\rm timing}$, r, $s = \sin i$, $\Omega_{\rm SO,B}$ and R. (Figure updated from [61]; courtesy of G. Esposito-Farèse.)

They constrain the contribution $\Omega_{gw}(f)$ to the critical cosmological density of a stochastic background of gravitational waves to the level $\Omega_{gw}(1/(8\mathrm{yr})) < 2 \times 10^{-8} h^{-2}$ [60](here, h denotes the normalized Hubble expansion rate).

The constraints on tensor-scalar theories provided by the various binary-pulsar "experiments" have been analyzed in [38,61,62] and shown to exclude a large portion of the parameter space allowed by solar-system tests. Finally, measurements over several years of the pulse profiles of various pulsars have detected secular profile changes compatible with the prediction [63] that the general relativistic spin-orbit coupling should cause a secular change in the orientation of the pulsar beam with respect to the line of sight ("geodetic precession"). Such confirmations of general-relativistic spin-orbit effects were obtained in PSR 1913+16 [64], PSR B1534+12 [65], PSR J1141-6545 [66], and PSR J0737 - 3039 [53].

The tests considered above have examined the gravitational interaction on scales between a fraction of a millimeter and a few astronomical units. On the other hand, the general relativistic action on light and matter of an external gravitational field have been verified on much larger scales in many gravitational lensing systems. For quantitative tests on kiloparsec scales see Ref. 67. Some tests on cosmological scales are also available [68].

20.4. Conclusions

All present experimental tests are compatible with the predictions of the current "standard" theory of gravitation: Einstein's General Relativity. The universality of the coupling between matter and gravity (Equivalence Principle) has been verified around the 10^{-13} level. Solar system experiments have tested the weak-field predictions of Einstein's theory at the 10^{-4} level (and down to the 2×10^{-5} level for the post-Einstein parameter $\overline{\gamma}$). The propagation properties of relativistic gravity, as well as several of its strong-field aspects, have been verified at the 10^{-3} level in binary pulsar experiments. Recent laboratory experiments have also set strong constraints on sub-millimeter modifications of Newtonian gravity.

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21. BIG-BANG COSMOLOGY

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21.1. Introduction to Standard Big-Bang Model

The observed expansion of the Universe [1,2,3] is a natural (almost inevitable) result of any homogeneous and isotropic cosmological model based on general relativity. However, by itself, the Hubble expansion does not provide sufficient evidence for what we generally refer to as the Big-Bang model of cosmology. While general relativity is in principle capable of describing the cosmology of any given distribution of matter, it is extremely fortunate that our Universe appears to be homogeneous and isotropic on large scales. Together, homogeneity and isotropy allow us to extend the Copernican Principle to the Cosmological Principle, stating that all spatial positions in the Universe are essentially equivalent.

The formulation of the Big-Bang model began in the 1940s with the work of George Gamow and his collaborators. Alpher and Herman. In order to account for the possibility that the abundances of the elements had a cosmological origin, they proposed that the early Universe which was once very hot and dense (enough so as to allow for the nucleosynthetic processing of hydrogen), and has expanded and cooled to its present state [4,5]. In 1948, Alpher and Herman predicted that a direct consequence of this model is the presence of a relic background radiation with a temperature of order a few K [6,7]. Of course this radiation was observed 16 years later as the microwave background radiation [8]. Indeed, it was the observation of the 3 K background radiation that singled out the Big-Bang model as the prime candidate to describe our Universe. Subsequent work on Big-Bang nucleosynthesis further confirmed the necessity of our hot and dense past. (See the review on BBN—Sec. 22 of this Review for a detailed discussion of BBN.) These relativistic cosmological models face severe problems with their initial conditions, to which the best modern solution is inflationary cosmology, discussed in Sec. 21.3.5. If correct, these ideas would strictly render the term 'Big Bang' redundant, since it was first coined by Hoyle to represent a criticism of the lack of understanding of the initial conditions.

21.1.1. The Robertson-Walker Universe:

The observed homogeneity and isotropy enable us to describe the overall geometry and evolution of the Universe in terms of two cosmological parameters accounting for the spatial curvature and the overall expansion (or contraction) of the Universe. These two quantities appear in the most general expression for a space-time metric which has a (3D) maximally symmetric subspace of a 4D space-time, known as the Robertson-Walker metric:

$$ds^{2} = dt^{2} - R^{2}(t) \left[\frac{dr^{2}}{1 - kr^{2}} + r^{2} \left(d\theta^{2} + \sin^{2}\theta \, d\phi^{2} \right) \right] . \tag{21.1}$$

Note that we adopt c=1 throughout. By rescaling the radial coordinate, we can choose the curvature constant k to take only the discrete values +1, -1, or 0 corresponding to closed, open, or spatially flat geometries. In this case, it is often more convenient to re-express the metric as

$$ds^{2} = dt^{2} - R^{2}(t) \left[d\chi^{2} + S_{k}^{2}(\chi) \left(d\theta^{2} + \sin^{2}\theta \, d\phi^{2} \right) \right] , \qquad (21.2)$$

where the function $S_k(\chi)$ is $(\sin\chi,\chi,\sinh\chi)$ for k=(+1,0,-1). The coordinate r (in Eq. (21.1)) and the 'angle' χ (in Eq. (21.2)) are both dimensionless; the dimensions are carried by R(t), which is the cosmological scale factor which determines proper distances in terms of the comoving coordinates. A common alternative is to define a dimensionless scale factor, $a(t)=R(t)/R_0$, where $R_0\equiv R(t_0)$ is R at the present epoch. It is also sometimes convenient to define a dimensionless or conformal time coordinate, η , by $d\eta=dt/R(t)$. Along constant spatial sections, the proper time is defined by the time coordinate, t. Similarly, for $dt=d\theta=d\phi=0$, the proper distance is given by $R(t)\chi$. For standard texts on cosmological models see e.g., Refs. [9–16].

21.1.2. The redshift:

The cosmological redshift is a direct consequence of the Hubble expansion, determined by R(t). A local observer detecting light from a distant emitter sees a redshift in frequency. We can define the redshift as

$$z \equiv \frac{\nu_1 - \nu_2}{\nu_2} \simeq \frac{\nu_{12}}{c} \ , \tag{21.3}$$

where ν_1 is the frequency of the emitted light, ν_2 is the observed frequency and v_{12} is the relative velocity between the emitter and the observer. While the definition, $z=(\nu_1-\nu_2)/\nu_2$ is valid on all distance scales, relating the redshift to the relative velocity in this simple way is only true on small scales (*i.e.*, less than cosmological scales) such that the expansion velocity is non-relativistic. For light signals, we can use the metric given by Eq. (21.1) and $ds^2=0$ to write

$$\frac{v_{12}}{c} = \dot{R} \, \delta r = \frac{\dot{R}}{R} \, \delta t = \frac{\delta R}{R} = \frac{R_2 - R_1}{R_1} \,,$$
 (21.4)

where $\delta r(\delta t)$ is the radial coordinate (temporal) separation between the emitter and observer. Thus, we obtain the simple relation between the redshift and the scale factor

$$1 + z = \frac{\nu_1}{\nu_2} = \frac{R_2}{R_1} \ . \tag{21.5}$$

This result does not depend on the non-relativistic approximation.

21.1.3. The Friedmann-Lemaître equations of motion:

The cosmological equations of motion are derived from Einstein's equations ${\bf r}$

$$\mathcal{R}_{\mu\nu} - \frac{1}{2}g_{\mu\nu}\mathcal{R} = 8\pi G_{\rm N}T_{\mu\nu} + \Lambda g_{\mu\nu} . \qquad (21.6)$$

Gliner [17] and Zeldovich [18] have pioneered the modern view, in which the Λ term is taken to the rhs and interpreted as an effective energy–momentum tensor $T_{\mu\nu}$ for the vacuum of $\Lambda g_{\mu\nu}/8\pi G_{\rm N}$. It is common to assume that the matter content of the Universe is a perfect fluid, for which

$$T_{\mu\nu} = -pg_{\mu\nu} + (p+\rho)u_{\mu}u_{\nu} , \qquad (21.7)$$

where $g_{\mu\nu}$ is the space-time metric described by Eq. (21.1), p is the isotropic pressure, ρ is the energy density and u=(1,0,0,0) is the velocity vector for the isotropic fluid in co-moving coordinates. With the perfect fluid source, Einstein's equations lead to the Friedmann-Lemaître equations

$$H^2 \equiv \left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G_N \rho}{3} - \frac{k}{R^2} + \frac{\Lambda}{3}$$
, (21.8)

and

$$\frac{\ddot{R}}{R} = \frac{\Lambda}{3} - \frac{4\pi G_{\rm N}}{3} \ (\rho + 3p) \ , \tag{21.9}$$

where H(t) is the Hubble parameter and Λ is the cosmological constant. The first of these is sometimes called the Friedmann equation. Energy conservation via $T^{\mu\nu}_{;\mu}=0$, leads to a third useful equation [which can also be derived from Eq. (21.8) and Eq. (21.9)]

$$\dot{\rho} = -3H\left(\rho + p\right) \ . \tag{21.10}$$

Eq. (21.10) can also be simply derived as a consequence of the first law of thermodynamics.

Eq. (21.8) has a simple classical mechanical analog if we neglect (for the moment) the cosmological term Λ . By interpreting $-k/R^2$ Newtonianly as a 'total energy', then we see that the evolution of the Universe is governed by a competition between the potential energy, $8\pi G_{\rm N} \rho/3$, and the kinetic term $(\dot{R}/R)^2$. For $\Lambda=0$, it is clear that the Universe must be expanding or contracting (except at the turning point prior to collapse in a closed Universe). The ultimate fate of the Universe is determined by the curvature constant k. For k=+1, the Universe will recollapse in a finite time, whereas for k=0,-1, the Universe will expand indefinitely. These simple conclusions can be altered when $\Lambda \neq 0$ or more generally with some component with $(\rho+3p)<0$.

${\bf 21.1.4.} \quad Definition \ of \ cosmological \ parameters:$

In addition to the Hubble parameter, it is useful to define several other measurable cosmological parameters. The Friedmann equation can be used to define a critical density such that k=0 when $\Lambda=0$,

$$\rho_c \equiv \frac{3H^2}{8\pi G_{\rm N}} = 1.88 \times 10^{-26} \, h^2 \, \text{kg m}^{-3}$$
$$= 1.05 \times 10^{-5} \, h^2 \, \text{GeV cm}^{-3} , \qquad (21.11)$$

where the scaled Hubble parameter, h, is defined by

$$H \equiv 100 h \text{ km s}^{-1} \text{ Mpc}^{-1}$$

 $\Rightarrow H^{-1} = 9.78 h^{-1} \text{ Gyr}$ (21.12)
 $= 2998 h^{-1} \text{ Mpc}$.

The cosmological density parameter Ω_{tot} is defined as the energy density relative to the critical density,

$$\Omega_{\text{tot}} = \rho/\rho_c \ . \tag{21.13}$$

Note that one can now rewrite the Friedmann equation as

$$k/R^2 = H^2(\Omega_{\text{tot}} - 1)$$
 (21.14)

From Eq. (21.14), one can see that when $\Omega_{\rm tot} > 1$, k = +1 and the Universe is closed, when $\Omega_{\rm tot} < 1$, k = -1 and the Universe is open, and when $\Omega_{\rm tot} = 1$, k = 0, and the Universe is spatially flat.

It is often necessary to distinguish different contributions to the density. It is therefore convenient to define present-day density parameters for pressureless matter $(\Omega_{\rm m})$ and relativistic particles $(\Omega_{\rm r})$, plus the quantity $\Omega_{\Lambda} = \Lambda/3H^2$. In more general models, we may wish to drop the assumption that the vacuum energy density is constant, and we therefore denote the present-day density parameter of the vacuum by $\Omega_{\rm v}$. The Friedmann equation then becomes

$$k/R_0^2 = H_0^2(\Omega_{\rm m} + \Omega_{\rm r} + \Omega_{\rm v} - 1)$$
, (21.15)

where the subscript 0 indicates present-day values. Thus, it is the sum of the densities in matter, relativistic particles, and vacuum that determines the overall sign of the curvature. Note that the quantity $-k/R_0^2H_0^2$ is sometimes referred to as Ω_k . This usage is unfortunate: it encourages one to think of curvature as a contribution to the energy density of the Universe, which is not correct.

21.1.5. Standard Model solutions:

Much of the history of the Universe in the standard Big-Bang model can be easily described by assuming that either matter or radiation dominates the total energy density. During inflation and again today the expansion rate for the Universe is accelerating, and domination by a cosmological constant or some other form of dark energy should be considered. In the following, we shall delineate the solutions to the Friedmann equation when a single component dominates the energy density. Each component is distinguished by an equation of state parameter $w=p/\rho$.

21.1.5.1. Solutions for a general equation of state:

Let us first assume a general equation of state parameter for a single component, w which is constant. In this case, Eq. (21.10) can be written as $\dot{\rho} = -3(1+w)\rho\dot{R}/R$ and is easily integrated to yield

$$\rho \propto R^{-3(1+w)}$$
 (21.16)

Note that at early times when R is small, the less singular curvature term k/R^2 in the Friedmann equation can be neglected so long as w>-1/3. Curvature domination occurs at rather late times (if a cosmological constant term does not dominate sooner). For $w\neq -1$, one can insert this result into the Friedmann equation Eq. (21.8), and if one neglects the curvature and cosmological constant terms, it is easy to integrate the equation to obtain,

$$R(t) \propto t^{2/[3(1+w)]}$$
 . (21.17)

21.1.5.2. A Radiation-dominated Universe:

In the early hot and dense Universe, it is appropriate to assume an equation of state corresponding to a gas of radiation (or relativistic particles) for which w=1/3. In this case, Eq. (21.16) becomes $\rho \propto R^{-4}$. The 'extra' factor of 1/R is due to the cosmological redshift; not only is the number density of particles in the radiation background decreasing as R^{-3} since volume scales as R^3 , but in addition, each particle's energy is decreasing as $E \propto \nu \propto R^{-1}$. Similarly, one can substitute w=1/3 into Eq. (21.17) to obtain

$$R(t) \propto t^{1/2}$$
; $H = 1/2t$. (21.18)

21.1.5.3. A Matter-dominated Universe:

At relatively late times, non-relativistic matter eventually dominates the energy density over radiation (see Sec. 21.3.8). A pressureless gas (w=0) leads to the expected dependence $\rho \propto R^{-3}$ from Eq. (21.16) and, if k=0, we get

$$R(t) \propto t^{2/3}$$
; $H = 2/3t$. (21.19)

21.1.5.4. A Universe dominated by vacuum energy:

If there is a dominant source of vacuum energy, V_0 , it would act as a cosmological constant with $\Lambda = 8\pi G_{\rm N} V_0$ and equation of state w=-1. In this case, the solution to the Friedmann equation is particularly simple and leads to an exponential expansion of the Universe

$$R(t) \propto e^{\sqrt{\Lambda/3}t}$$
 (21.20)

A key parameter is the equation of state of the vacuum, $w \equiv p/\rho$: this need not be the w=-1 of Λ , and may not even be constant [19,20,21]. There is now much interest in the more general possibility of a dynamically evolving vacuum energy, for which the name 'dark energy' has become commonly used. A variety of techniques exist whereby the vacuum density as a function of time may be measured, usually expressed as the value of w as a function of epoch [22,23]. The best current measurement for the equation of state (assumed constant, but without assuming zero curvature) is $w=-1.00\pm0.06$ [24]. Unless stated otherwise, we will assume that the vacuum energy is a cosmological constant with w=-1 exactly.

The presence of vacuum energy can dramatically alter the fate of the Universe. For example, if $\Lambda < 0$, the Universe will eventually recollapse independent of the sign of k. For large values of $\Lambda > 0$ (larger than the Einstein static value needed to halt any cosmological expansion or contraction), even a closed Universe will expand forever. One way to quantify this is the deceleration parameter, q_0 , defined as

$$q_0 = -\frac{R\ddot{R}}{\dot{R}^2}\Big|_{0} = \frac{1}{2}\Omega_{\rm m} + \Omega_{\rm r} + \frac{(1+3w)}{2}\Omega_{\rm v}$$
 (21.21)

This equation shows us that w<-1/3 for the vacuum may lead to an accelerating expansion. To the continuing astonishment of cosmologists, such an effect has been observed; one piece of direct evidence is the Supernova Hubble diagram [26–32] (see Fig. 21.1 below); current data indicate that vacuum energy is indeed the largest contributor to the cosmological density budget, with $\Omega_{\rm v}=0.73\pm0.03$ and $\Omega_{\rm m}=0.27\pm0.03$ if k=0 is assumed (7-year mean WMAP) [24].

The existence of this constituent is without doubt the greatest puzzle raised by the current cosmological model; the final section of this review discusses some of the ways in which the vacuum-energy problem is being addressed.

21.2. Introduction to Observational Cosmology

21.2.1. Fluxes, luminosities, and distances:

The key quantities for observational cosmology can be deduced quite directly from the metric.

(1) The proper transverse size of an object seen by us to subtend an angle $d\psi$ is its comoving size $d\psi \, S_k(\chi)$ times the scale factor at the time of emission:

$$d\ell = d\psi \ R_0 S_k(\chi)/(1+z)$$
 . (21.22)

(2) The apparent flux density of an object is deduced by allowing its photons to flow through a sphere of current radius $R_0S_k(\chi)$; but photon energies and arrival rates are redshifted, and the bandwidth $d\nu$ is reduced. The observed photons at frequency ν_0 were emitted at frequency $\nu_0(1+z)$, so the flux density is the luminosity at this frequency, divided by the total area, divided by 1+z:

$$S_{\nu}(\nu_0) = \frac{L_{\nu}([1+z]\nu_0)}{4\pi R_0^2 S_{\nu}^2(\chi)(1+z)}.$$
 (21.23)

These relations lead to the following common definitions:

angular-diameter distance:
$$D_{\rm A} = (1+z)^{-1} R_0 S_k(\chi)$$

luminosity distance: $D_{\rm L} = (1+z) R_0 S_k(\chi)$. (21.24)

These distance-redshift relations are expressed in terms of observables by using the equation of a null radial geodesic $(R(t)d\chi = dt)$ plus the Friedmann equation:

$$R_0 d\chi = \frac{1}{H(z)} dz = \frac{1}{H_0} \left[(1 - \Omega_{\rm m} - \Omega_{\rm v} - \Omega_{\rm r}) (1 + z)^2 + \Omega_{\rm v} (1 + z)^{3+3w} + \Omega_{\rm m} (1 + z)^3 + \Omega_{\rm r} (1 + z)^4 \right]^{-1/2} dz .$$
(21.25)

The main scale for the distance here is the Hubble length, $1/H_0$.

The flux density is the product of the specific intensity I_{ν} and the solid angle $d\Omega$ subtended by the source: $S_{\nu} = I_{\nu} \ d\Omega$. Combining the angular size and flux-density relations thus gives the relativistic version of surface-brightness conservation:

$$I_{\nu}(\nu_0) = \frac{B_{\nu}([1+z]\nu_0)}{(1+z)^3} , \qquad (21.26)$$

where B_{ν} is surface brightness (luminosity emitted into unit solid angle per unit area of source). We can integrate over ν_0 to obtain the corresponding total or bolometric formula:

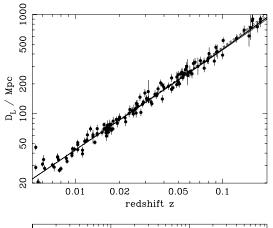
$$I_{\text{tot}} = \frac{B_{\text{tot}}}{(1+z)^4} \ .$$
 (21.27)

This cosmology-independent form expresses Liouville's Theorem: photon phase-space density is conserved along rays.

21.2.2. Distance data and geometrical tests of cosmology:

In order to confront these theoretical predictions with data, we have to bridge the divide between two extremes. Nearby objects may have their distances measured quite easily, but their radial velocities are dominated by deviations from the ideal Hubble flow, which typically have a magnitude of several hundred ${\rm km\,s^{-1}}.$ On the other hand, objects at redshifts $z\gtrsim 0.01$ will have observed recessional velocities that differ from their ideal values by $\lesssim 10\%,$ but absolute distances are much harder to supply in this case. The traditional solution to this problem is the construction of the distance ladder: an interlocking set of methods for obtaining relative distances between various classes of object, which begins with absolute distances at the 10 to 100 pc level, and terminates with galaxies at significant redshifts. This is reviewed in the review on Cosmological Parameters—Sec. 23 of this Review.

By far the most exciting development in this area has been the use of type Ia Supernovae (SNe), which now allow measurement of relative distances with 5% precision. In combination with Cepheid data from the HST and a direct geometrical distance to the maser



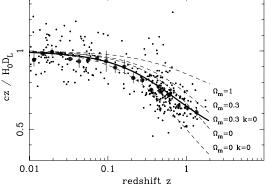


Figure 21.1: The type Ia supernova Hubble diagram [26–30]. The first panel shows that for $z \ll 1$ the large-scale Hubble flow is indeed linear and uniform; the second panel shows an expanded scale, with the linear trend divided out, and with the redshift range extended to show how the Hubble law becomes nonlinear. ($\Omega_{\rm r}=0$ is assumed.) Larger points with errors show median values in redshift bins. Comparison with the prediction of Friedmann-Lemaître models appears to favor a vacuum-dominated Universe.

galaxy NGC4258, SNe results extend the distance ladder to the point where deviations from uniform expansion are negligible, leading to the best existing direct value for H_0 : $73.8 \pm 2.4 \, \mathrm{km \, s^{-1} Mpc^{-1}}$ [25]. Better still, the analysis of high-z SNe has allowed the first meaningful test of cosmological geometry to be carried out: as shown in Fig. 21.1 and Fig. 21.2, a combination of supernova data and measurements of microwave-background anisotropies strongly favors a k=0 model dominated by vacuum energy. (See the review on Cosmological Parameters—Sec. 23 of this Review for a more comprehensive review of Hubble parameter determinations.)

21.2.3. Age of the Universe:

The most striking conclusion of relativistic cosmology is that the Universe has not existed forever. The dynamical result for the age of the Universe may be written as

$$H_0 t_0 = \int_0^\infty \frac{dz}{(1+z)H(z)}$$

$$= \int_0^\infty \frac{dz}{(1+z)\left[(1+z)^2(1+\Omega_{\rm m}z) - z(2+z)\Omega_{\rm v}\right]^{1/2}} , \quad (21.28)$$

where we have neglected $\Omega_{\rm r}$ and chosen w=-1. Over the range of interest $(0.1 \lesssim \Omega_{\rm m} \lesssim 1, \ |\Omega_{\rm v}| \lesssim 1)$, this exact answer may be approximated to a few % accuracy by

$$H_0 t_0 \simeq \frac{2}{3} (0.7\Omega_{\rm m} + 0.3 - 0.3\Omega_{\rm v})^{-0.3}$$
 (21.29)

For the special case that $\Omega_{\rm m}+\Omega_{\rm v}=1,$ the integral in Eq. (21.28) can be expressed analytically as

$$H_0 t_0 = \frac{2}{3\sqrt{\Omega_{\rm v}}} \ln \frac{1 + \sqrt{\Omega_{\rm v}}}{\sqrt{1 - \Omega_{\rm v}}} \quad (\Omega_{\rm m} < 1) .$$
 (21.30)

The most accurate means of obtaining ages for astronomical objects is based on the natural clocks provided by radioactive decay. The use of these clocks is complicated by a lack of knowledge of the initial conditions of the decay. In the Solar System, chemical fractionation of different elements helps pin down a precise age for the pre-Solar nebula of 4.6 Gyr, but for stars it is necessary to attempt an a priori calculation of the relative abundances of nuclei that result from supernova explosions. In this way, a lower limit for the age of stars in the local part of the Milky Way of about 11 Gyr is obtained [36,37].

The other major means of obtaining cosmological age estimates is based on the theory of stellar evolution. In principle, the main-sequence turnoff point in the color-magnitude diagram of a globular cluster should yield a reliable age. However, these have been controversial owing to theoretical uncertainties in the evolution model, as well as observational uncertainties in the distance, dust extinction, and metallicity of clusters. The present consensus favors ages for the oldest clusters of about 12 Gyr [38,39].

These methods are all consistent with the age deduced from studies of structure formation, using the microwave background and large-scale structure: $t_0=13.77\pm0.13$ Gyr [24], where the extra accuracy comes at the price of assuming the Cold Dark Matter model to be true.

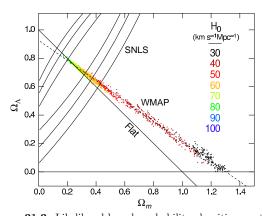


Figure 21.2: Likelihood-based probability densities on the plane Ω_{Λ} (i.e., $\Omega_{\rm v}$ assuming w=-1) vs $\Omega_{\rm m}$. The colored Monte-Carlo points derive from WMAP [34] and show that the CMB alone requires a flat universe $\Omega_{\rm v}+\Omega_{\rm m}\simeq 1$ if the Hubble constant is not too high. The SNe Ia results [35] very nearly constrain the orthogonal combination $\Omega_{\rm v}-\Omega_{\rm m}$. The intersection of these constraints is the most direct (but far from the only) piece of evidence favoring a flat model with $\Omega_{\rm m}\simeq 0.25$.

21.2.4. Horizon, isotropy, flatness problems:

For photons, the radial equation of motion is just $c dt = R d\chi$. How far can a photon get in a given time? The answer is clearly

$$\Delta \chi = \int_{t_1}^{t_2} \frac{dt}{R(t)} \equiv \Delta \eta , \qquad (21.31)$$

i.e., just the interval of conformal time. We can replace dt by dR/\dot{R} , which the Friedmann equation says is $\propto dR/\sqrt{\rho R^2}$ at early times. Thus, this integral converges if $\rho R^2 \to \infty$ as $t_1 \to 0$, otherwise it diverges. Provided the equation of state is such that ρ changes faster than R^{-2} , light signals can only propagate a finite distance between the Big Bang and the present; there is then said to be a particle horizon. Such a horizon therefore exists in conventional Big-Bang models, which are dominated by radiation $(\rho \propto R^{-4})$ at early times.

At late times, the integral for the horizon is largely determined by the matter-dominated phase, for which

$$D_{\rm H} = R_0 \, \chi_{\rm H} \equiv R_0 \, \int_0^{t(z)} \frac{dt}{R(t)} \simeq \frac{6000}{\sqrt{\Omega z}} \, h^{-1} \,{\rm Mpc} \quad (z \gg 1) \,. \quad (21.32)$$

The horizon at the time of formation of the microwave background ('last scattering:' $z \simeq 1100$) was thus of order 100 Mpc in size, subtending an angle of about 1°. Why then are the large number of causally disconnected regions we see on the microwave sky all at the same temperature? The Universe is very nearly isotropic and homogeneous, even though the initial conditions appear not to permit such a state to be constructed.

A related problem is that the $\Omega = 1$ Universe is unstable:

$$\Omega(a) - 1 = \frac{\Omega - 1}{1 - \Omega + \Omega_{\rm v} a^2 + \Omega_{\rm m} a^{-1} + \Omega_{\rm r} a^{-2}} , \qquad (21.33)$$

where Ω with no subscript is the total density parameter, and $a(t) = R(t)/R_0$. This requires $\Omega(t)$ to be unity to arbitrary precision as the initial time tends to zero; a universe of non-zero curvature today requires very finely tuned initial conditions.

21.3. The Hot Thermal Universe

21.3.1. Thermodynamics of the early Universe:

As alluded to above, we expect that much of the early Universe can be described by a radiation-dominated equation of state. In addition, through much of the radiation-dominated period, thermal equilibrium is established by the rapid rate of particle interactions relative to the expansion rate of the Universe (see Sec. 21.3.3 below). In equilibrium, it is straightforward to compute the thermodynamic quantities, ρ, p , and the entropy density, s. In general, the energy density for a given particle type i can be written as

$$\rho_i = \int E_i \, dn_{q_i} \,, \tag{21.34}$$

with the density of states given by

$$dn_{q_i} = \frac{g_i}{2\pi^2} \left(\exp[(E_{q_i} - \mu_i)/T_i] \pm 1 \right)^{-1} q_i^2 dq_i ,$$
 (21.35)

where g_i counts the number of degrees of freedom for particle type i, $E_{q_i}^2 = m_i^2 + q_i^2$, μ_i is the chemical potential, and the \pm corresponds to either Fermi or Bose statistics. Similarly, we can define the pressure of a perfect gas as

$$p_i = \frac{1}{3} \int \frac{q_i^2}{E_i} \, dn_{q_i} \ . \tag{21.36}$$

The number density of species i is simply

$$n_i = \int dn_{q_i} , \qquad (21.37)$$

and the entropy density is

$$s_i = \frac{\rho_i + p_i - \mu_i n_i}{T} \ . \tag{21.38}$$

In the Standard Model, a chemical potential is often associated with baryon number, and since the net baryon density relative to the photon density is known to be very small (of order 10^{-10}), we can neglect any such chemical potential when computing total thermodynamic quantities.

For photons, we can compute all of the thermodynamic quantities rather easily. Taking $g_i=2$ for the 2 photon polarization states, we have (in units where $\hbar=k_B=1$)

$$\rho_{\gamma} = \frac{\pi^2}{15} T^4 \; ; \quad \ p_{\gamma} = \frac{1}{3} \rho_{\gamma} \; ; \quad \ s_{\gamma} = \frac{4 \rho_{\gamma}}{3T} \; ; \quad \ n_{\gamma} = \frac{2 \zeta(3)}{\pi^2} T^3 \; , \quad (21.39)$$

with $2\zeta(3)/\pi^2 \simeq 0.2436$. Note that Eq. (21.10) can be converted into an equation for entropy conservation. Recognizing that $\dot{p} = s\dot{T}$, Eq. (21.10) becomes

$$d(sR^3)/dt = 0. (21.40)$$

For radiation, this corresponds to the relationship between expansion and cooling, $T \propto R^{-1}$ in an adiabatically expanding universe. Note also that both s and n_{γ} scale as T^3 .

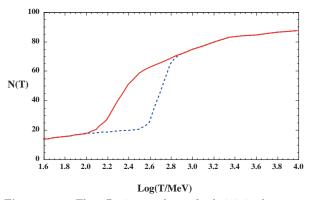


Figure 21.3: The effective numbers of relativistic degrees of freedom as a function of temperature. The sharp drop corresponds to the quark-hadron transition. The solid curve assume a QCD scale of $150~{\rm MeV}$, while the dashed curve assumes $450~{\rm MeV}$.

21.3.2. Radiation content of the Early Universe:

At the very high temperatures associated with the early Universe, massive particles are pair produced, and are part of the thermal bath. If for a given particle species i we have $T\gg m_i$, then we can neglect the mass in Eq. (21.34) to Eq. (21.38), and the thermodynamic quantities are easily computed as in Eq. (21.39). In general, we can approximate the energy density (at high temperatures) by including only those particles with $m_i\ll T$. In this case, we have

$$\rho = \left(\sum_{B} g_{B} + \frac{7}{8} \sum_{F} g_{F}\right) \frac{\pi^{2}}{30} T^{4} \equiv \frac{\pi^{2}}{30} N(T) T^{4} , \qquad (21.41)$$

where $g_{B(F)}$ is the number of degrees of freedom of each boson (fermion) and the sum runs over all boson and fermion states with $m \ll T$. The factor of 7/8 is due to the difference between the Fermi and Bose integrals. Eq. (21.41) defines the effective number of degrees of freedom, N(T), by taking into account new particle degrees of freedom as the temperature is raised. This quantity is plotted in Fig. 21.3 [40].

The value of N(T) at any given temperature depends on the particle physics model. In the standard $\mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1)$ model, we can specify N(T) up to temperatures of $\mathrm{O}(100)$ GeV. The change in N (ignoring mass effects) can be seen in the table below.

| Temperature | New Particles | 4N(T) |
|---------------------------------|----------------------------------------------|-------|
| $T < m_e$ | γ 's + ν 's | 29 |
| $m_e < T < m_\mu$ | e^{\pm} | 43 |
| $m_{\mu} < T < m_{\pi}$ | μ^{\pm} | 57 |
| $m_{\pi} < T < {T_c}^{\dagger}$ | π 's | 69 |
| $T_c < T < m_{\text{strange}}$ | π 's + u, \bar{u}, d, \bar{d} + gluons | 205 |
| $m_s < T < m_{\rm charm}$ | $s,ar{s}$ | 247 |
| $m_c < T < m_{\tau}$ | $c, ar{c}$ | 289 |
| $m_{\tau} < T < m_{ m bottom}$ | $	au^\pm$ | 303 |
| $m_b < T < m_{W,Z}$ | $b, ar{b}$ | 345 |
| $m_{W,Z} < T < m_{ m Higgs}$ | W^{\pm}, Z | 381 |
| $m_H < T < m_{\rm top}$ | H^0 | 385 |
| $m_t < T$ | $t,ar{t}$ | 427 |

 $^{\dagger}T_{c}$ corresponds to the confinement-deconfinement transition between quarks and hadrons.

At higher temperatures, N(T) will be model-dependent. For example, in the minimal SU(5) model, one needs to add 24 states to N(T) for the X and Y gauge bosons, another 24 from the adjoint Higgs, and another 6 (in addition to the 4 already counted in W^{\pm} , Z, and H) from the $\overline{5}$ of Higgs. Hence for $T>m_X$ in minimal SU(5), N(T)=160.75. In a supersymmetric model this would at least double, with some changes possibly necessary in the table if the lightest supersymmetric particle has a mass below m_t .

In the radiation-dominated epoch, Eq. (21.10) can be integrated (neglecting the T-dependence of N) giving us a relationship between the age of the Universe and its temperature

$$t = \left(\frac{90}{32\pi^3 G_N N(T)}\right)^{1/2} T^{-2} . \tag{21.42}$$

Put into a more convenient form

$$tT_{\text{MeV}}^2 = 2.4[N(T)]^{-1/2}$$
, (21.43)

where t is measured in seconds and T_{MeV} in units of MeV.

21.3.3. Neutrinos and equilibrium: Due to the expansion of the Universe, certain rates may be too slow to either establish or maintain equilibrium. Quantitatively, for each particle i, as a minimal condition for equilibrium, we will require that some rate Γ_i involving that type be larger than the expansion rate of the Universe or

$$\Gamma_i > H \ . \tag{21.44}$$

Recalling that the age of the Universe is determined by H^{-1} , this condition is equivalent to requiring that on average, at least one interaction has occurred over the lifetime of the Universe.

A good example for a process which goes in and out of equilibrium is the weak interactions of neutrinos. On dimensional grounds, one can estimate the thermally averaged scattering cross section

$$\langle \sigma v \rangle \sim O(10^{-2})T^2/m_{\rm W}^4$$
 (21.45)

for $T \lesssim m_{\rm W}$. Recalling that the number density of leptons is $n \propto T^3$, we can compare the weak interaction rate, $\Gamma_{\rm wk} \sim n \langle \sigma v \rangle$, with the expansion rate,

$$H = \left(\frac{8\pi G_{\rm N}\rho}{3}\right)^{1/2} = \left(\frac{8\pi^3}{90}N(T)\right)^{1/2}T^2/M_{\rm P}$$
$$\sim 1.66N(T)^{1/2}T^2/M_{\rm P},$$
 (21.46)

where the Planck mass $M_{\rm P} = G_{\rm N}^{-1/2} = 1.22 \times 10^{19} \; {\rm GeV}.$

Neutrinos will be in equilibrium when $\Gamma_{\rm wk} > H$ or

$$T > (500 \, m_W^4 / M_P)^{1/3} \sim 1 \text{ MeV}$$
 (21.47)

However, this condition assumes $T \ll m_{\rm W}$; for higher temperatures, we should write $\langle \sigma v \rangle \sim O(10^{-2})/T^2$, so that $\Gamma \sim 10^{-2}T$. Thus, in the very early stages of expansion, at temperatures $T \gtrsim 10^{-2} M_{\rm P}/\sqrt{N}$, equilibrium will not have been established.

Having attained a quasi-equilibrium stage, the Universe then cools further to the point where the interaction and expansion timescales match once again. The temperature at which these rates are equal is commonly referred to as the neutrino decoupling or freeze-out temperature and is defined by $\Gamma_{\rm wk}(T_d)=H(T_d)$. For $T< T_d$, neutrinos drop out of equilibrium. The Universe becomes transparent to neutrinos and their momenta simply redshift with the cosmic expansion. The effective neutrino temperature will simply fall with $T\sim 1/R$.

Soon after decoupling, e^{\pm} pairs in the thermal background begin to annihilate (when $T \lesssim m_e$). Because the neutrinos are decoupled, the energy released due to annihilation heats up the photon background relative to the neutrinos. The change in the photon temperature can be easily computed from entropy conservation. The neutrino entropy must be conserved separately from the entropy of interacting particles. A straightforward computation yields

$$T_{\nu} = (4/11)^{1/3} T_{\gamma} \simeq 1.9 \text{ K} .$$
 (21.48)

Today, the total entropy density is therefore given by

$$s = \frac{4}{3} \frac{\pi^2}{30} \left(2 + \frac{21}{4} (T_{\nu}/T_{\gamma})^3 \right) T_{\gamma}^3 = \frac{4}{3} \frac{\pi^2}{30} \left(2 + \frac{21}{11} \right) T_{\gamma}^3 = 7.04 \, n_{\gamma} . \tag{21.49}$$

Similarly, the total relativistic energy density today is given by

$$\rho_r = \frac{\pi^2}{30} \left[2 + \frac{21}{4} (T_\nu / T_\gamma)^4 \right] T_\gamma^4 \simeq 1.68 \rho_\gamma . \tag{21.50}$$

In practice, a small correction is needed to this, since neutrinos are not totally decoupled at e^{\pm} annihilation: the effective number of massless neutrino species is 3.04, rather than 3 [41].

This expression ignores neutrino rest masses, but current oscillation data require at least one neutrino eigenstate to have a mass exceeding 0.05 eV. In this minimal case, $\Omega_{\nu}h^2=5\times 10^{-4}$, so the neutrino contribution to the matter budget would be negligibly small (which is our normal assumption). However, a nearly degenerate pattern of mass eigenstates could allow larger densities, since oscillation experiments only measure differences in m^2 values. Note that a 0.05-eV neutrino has $kT_{\nu}=m_{\nu}$ at $z\simeq 297$, so the above expression for the total present relativistic density is really only an extrapolation. However, neutrinos are almost certainly relativistic at all epochs where the radiation content of the Universe is dynamically significant.

21.3.4. Field Theory and Phase transitions:

It is very likely that the Universe has undergone one or more phase transitions during the course of its evolution [42–45]. Our current vacuum state is described by $\mathrm{SU}(3)_c\times\,\mathrm{U}(1)_\mathrm{em},$ which in the Standard Model is a remnant of an unbroken $\mathrm{SU}(3)_c\times\,\mathrm{SU}(2)_L\times\,\mathrm{U}(1)_Y$ gauge symmetry. Symmetry breaking occurs when a non-singlet gauge field (the Higgs field in the Standard Model) picks up a non-vanishing vacuum expectation value, determined by a scalar potential. For example, a simple (non-gauged) potential describing symmetry breaking is $V(\phi)=\frac{1}{4}\lambda\phi^4-\frac{1}{2}\mu^2\phi^2+V(0).$ The resulting expectation value is simply $\langle\phi\rangle=\mu/\sqrt{\lambda}.$

In the early Universe, finite temperature radiative corrections typically add terms to the potential of the form $\phi^2 T^2$. Thus, at very high temperatures, the symmetry is restored and $\langle \phi \rangle = 0$. As the Universe cools, depending on the details of the potential, symmetry breaking will occur via a first order phase transition in which the field tunnels through a potential barrier, or via a second order transition in which the field evolves smoothly from one state to another (as would be the case for the above example potential).

The evolution of scalar fields can have a profound impact on the early Universe. The equation of motion for a scalar field ϕ can be derived from the energy-momentum tensor

$$T_{\mu\nu} = \partial_{\mu}\phi\partial_{\nu}\phi - \frac{1}{2}g_{\mu\nu}\partial_{\rho}\phi\partial^{\rho}\phi - g_{\mu\nu}V(\phi) . \qquad (21.51)$$

By associating $\rho = T_{00}$ and $p = R^{-2}(t)T_{ii}$ we have

$$\begin{split} \rho &= \frac{1}{2} \dot{\phi}^2 + \frac{1}{2} R^{-2}(t) (\nabla \phi)^2 + V(\phi) \\ p &= \frac{1}{2} \dot{\phi}^2 - \frac{1}{6} R^{-2}(t) (\nabla \phi)^2 - V(\phi) \ , \end{split} \tag{21.52}$$

and from Eq. (21.10) we can write the equation of motion (by considering a homogeneous region, we can ignore the gradient terms)

$$\ddot{\phi} + 3H\dot{\phi} = -\partial V/\partial\phi \ . \tag{21.53}$$

21.3.5. *Inflation* :

In Sec. 21.2.4, we discussed some of the problems associated with the standard Big-Bang model. However, during a phase transition, our assumptions of an adiabatically expanding universe are generally not valid. If, for example, a phase transition occurred in the early Universe such that the field evolved slowly from the symmetric state to the global minimum, the Universe may have been dominated by the vacuum energy density associated with the potential near $\phi \approx 0$. During this period of slow evolution, the energy density due to radiation will fall below the vacuum energy density, $\rho \ll V(0)$. When this happens, the expansion rate will be dominated by the constant V(0), and we obtain the exponentially expanding solution given in Eq. (21.20). When the field evolves towards the global minimum it will

begin to oscillate about the minimum, energy will be released during its decay, and a hot thermal universe will be restored. If released fast enough, it will produce radiation at a temperature $NT_R^{\ 4} \lesssim V(0)$. In this reheating process, entropy has been created and the final value of RT is greater than the initial value of RT. Thus, we see that, during a phase transition, the relation $RT \sim \text{constant}$ need not hold true. This is the basis of the inflationary Universe scenario [46–48].

If, during the phase transition, the value of RT changed by a factor of $O(10^{29})$, the cosmological problems discussed above would be solved. The observed isotropy would be generated by the immense expansion; one small causal region could get blown up, and thus our entire visible Universe would have been in thermal contact some time in the past. In addition, the density parameter Ω would have been driven to 1 (with exponential precision). Density perturbations will be stretched by the expansion, $\lambda \sim R(t)$. Thus it will appear that $\lambda \gg H^{-1}$ or that the perturbations have left the horizon, where in fact the size of the causally connected region is now no longer simply H^{-1} . However, not only does inflation offer an explanation for large scale perturbations, it also offers a source for the perturbations themselves through quantum fluctuations.

Early models of inflation were based on a first order phase transition of a Grand Unified Theory [49]. Although these models led to sufficient exponential expansion, completion of the transition through bubble percolation did not occur, and lack of bubble collisions meant that the interior of the bubbles was not reheated. Subsequent models of inflation [50,51] considered second-order transitions within Grand Unified theories, thus successfully ending inflation with reheating from oscillations of the scalar field. But these models predicted too high an amplitude of relic density fluctuations. As a result, current models of inflation postulate second-order transitions in a completely new scalar field: the inflaton, ϕ . The potential of this field, $V(\phi)$, needs to have a very low gradient and curvature in order to match observed metric fluctuations.

In viable inflation models of this type, reheated bubbles again typically do not percolate, so inflation is 'eternal' and continues with exponential expansion in the region outside bubbles. These causally disconnected bubble universes constitute a 'multiverse', where low-energy physics can vary between different bubbles. This has led to a controversial 'anthropic' approach to cosmology [82–84], where observer selection within the multiverse can be introduced as a means of understanding e.g. why the observed level of vacuum energy is so low (because larger values suppress growth of structure).

${\bf 21.3.6.} \quad Baryogenesis:$

The Universe appears to be populated exclusively with matter rather than antimatter. Indeed antimatter is only detected in accelerators or in cosmic rays. However, the presence of antimatter in the latter is understood to be the result of collisions of primary particles in the interstellar medium. There is in fact strong evidence against primary forms of antimatter in the Universe. Furthermore, the density of baryons compared to the density of photons is extremely small, $\eta \sim 10^{-10}$.

The production of a net baryon asymmetry requires baryon number violating interactions, C and CP violation and a departure from thermal equilibrium [52]. The first two of these ingredients are expected to be contained in grand unified theories as well as in the non-perturbative sector of the Standard Model, the third can be realized in an expanding universe where as we have seen interactions come in and out of equilibrium.

There are several interesting and viable mechanisms for the production of the baryon asymmetry. While, we can not review any of them here in any detail, we mention some of the important scenarios. In all cases, all three ingredients listed above are incorporated. One of the first mechanisms was based on the out of equilibrium decay of a massive particle such as a superheavy GUT gauge of Higgs boson [53,54]. A novel mechanism involving the decay of flat directions in supersymmetric models is known as the Affleck-Dine scenario [55]. There is also the possibility of generating the baryon asymmetry at the electro-weak scale using the non-perturbative interactions of sphalerons [56]. Because these interactions conserve the sum of baryon and lepton number, B+L, it is possible to first

generate a lepton asymmetry (e.g., by the out-of-equilibrium decay of a superheavy right-handed neutrino), which is converted to a baryon asymmetry at the electro-weak scale [57]. This mechanism is known as lepto-baryogenesis.

${\bf 21.3.7.} \quad Nucleosynthesis:$

An essential element of the standard cosmological model is Big-Bang nucleosynthesis (BBN), the theory which predicts the abundances of the light element isotopes D, 3 He, 4 He, and 7 Li. Nucleosynthesis takes place at a temperature scale of order 1 MeV. The nuclear processes lead primarily to 4 He, with a primordial mass fraction of about 25%. Lesser amounts of the other light elements are produced: about 10^{-5} of D and 3 He and about 10^{-10} of 7 Li by number relative to H. The abundances of the light elements depend almost solely on one key parameter, the baryon-to-photon ratio, η . The nucleosynthesis predictions can be compared with observational determinations of the abundances of the light elements. Consistency between theory and observations leads to a conservative range of

$$5.1 \times 10^{-10} < \eta < 6.5 \times 10^{-10}$$
 (21.54)

 η is related to the fraction of Ω contained in baryons, $\Omega_{\rm b}$

$$\Omega_{\rm b} = 3.66 \times 10^7 \eta \, h^{-2} \,, \tag{21.55}$$

or $10^{10}\eta=274\Omega_{\rm b}h^2$. The WMAP result [24] for $\Omega_{\rm b}h^2$ of 0.0225 ± 0.0006 translates into a value of $\eta=6.16\pm0.15$. This result can be used to 'predict' the light element abundance which can in turn be compared with observation [58]. The resulting D/H abundance is in excellent agreement with that found in quasar absorption systems. It is in reasonable agreement with the helium abundance observed in extra-galactic HII regions (once systematic uncertainties are accounted for), but is in poor agreement with the Li abundance observed in the atmospheres of halo dwarf stars [59]. (See the review on BBN—Sec. 22 of this *Review* for a detailed discussion of BBN or references [60,61].)

21.3.8. The transition to a matter-dominated Universe:

In the Standard Model, the temperature (or redshift) at which the Universe undergoes a transition from a radiation dominated to a matter dominated Universe is determined by the amount of dark matter. Assuming three nearly massless neutrinos, the energy density in radiation at temperatures $T \ll 1$ MeV, is given by

$$\rho_r = \frac{\pi^2}{30} \left[2 + \frac{21}{4} \left(\frac{4}{11} \right)^{4/3} \right] T^4 . \tag{21.56}$$

In the absence of non-baryonic dark matter, the matter density can be written as

$$\rho_m = m_{\rm N} \eta \, n_{\gamma} \,, \tag{21.57}$$

where $m_{\rm N}$ is the nucleon mass. Recalling that $n_{\gamma} \propto T^3$ [cf. Eq. (21.39)], we can solve for the temperature or redshift at the matter-radiation equality when $\rho_r = \rho_m$,

$$T_{eq} = 0.22 \, m_{\rm N} \, \eta$$
 or $(1 + z_{\rm eq}) = 0.22 \, \eta \frac{m_{\rm N}}{T_0}$, (21.58)

where T_0 is the present temperature of the microwave background. For $\eta = 6.2 \times 10^{-10}$, this corresponds to a temperature $T_{\rm eq} \simeq 0.13$ eV or $(1+z_{\rm eq}) \simeq 550$. A transition this late is very problematic for structure formation (see Sec. 21.4.5).

The redshift of matter domination can be pushed back significantly if non-baryonic dark matter is present. If instead of Eq. (21.57), we write

$$\rho_m = \Omega_{\rm m} \rho_c \left(\frac{T}{T_0}\right)^3 \,, \tag{21.59}$$

we find that

$$T_{eq} = 0.9 \frac{\Omega_{\rm m} \rho_c}{T_0^3}$$
 or $(1 + z_{eq}) = 2.4 \times 10^4 \Omega_{\rm m} h^2$. (21.60)

21.4. The Universe at late times

21.4.1. The CMB:

One form of the infamous Olbers' paradox says that, in Euclidean space, surface brightness is independent of distance. Every line of sight will terminate on matter that is hot enough to be ionized and so scatter photons: $T\gtrsim 10^3$ K; the sky should therefore shine as brightly as the surface of the Sun. The reason the night sky is dark is entirely due to the expansion, which cools the radiation temperature to 2.73 K. This gives a Planck function peaking at around 1 mm to produce the microwave background (CMB).

The CMB spectrum is a very accurate match to a Planck function [62]. (See the review on CBR—Sec. 25 of this *Review*.) The COBE estimate of the temperature is [63]

$$T = 2.7255 \pm 0.0006 \,\mathrm{K}$$
 (21.61)

The lack of any distortion of the Planck spectrum is a strong physical constraint. It is very difficult to account for in any expanding universe other than one that passes through a hot stage. Alternative schemes for generating the radiation, such as thermalization of starlight by dust grains, inevitably generate a superposition of temperatures. What is required in addition to thermal equilibrium is that $T \propto 1/R$, so that radiation from different parts of space appears identical.

Although it is common to speak of the CMB as originating at "recombination," a more accurate terminology is the era of "last scattering." In practice, this takes place at $z\simeq 1100$, almost independently of the main cosmological parameters, at which time the fractional ionization is very small. This occurred when the age of the Universe was a few hundred thousand years. (See the review on CBR–Sec. 25 of this Review for a full discussion of the CMB.)

21.4.2. Matter in the Universe:

One of the main tasks of cosmology is to measure the density of the Universe, and how this is divided between dark matter and baryons. The baryons consist partly of stars, with $0.002 \lesssim \Omega_* \lesssim 0.003$ [64] but mainly inhabit the intergalactic medium (IGM). One powerful way in which this can be studied is via the absorption of light from distant luminous objects such as quasars. Even very small amounts of neutral hydrogen can absorb rest-frame UV photons (the Gunn-Peterson effect), and should suppress the continuum by a factor $\exp(-\tau)$, where

$$\tau \simeq 10^{4.62} h^{-1} \left[\frac{n_{\rm HI}(z)/{\rm m}^{-3}}{(1+z)\sqrt{1+\Omega_{\rm m}z}} \right] ,$$
 (21.62)

and this expression applies while the Universe is matter dominated $(z\gtrsim 1$ in the $\Omega_{\rm m}=0.3~\Omega_{\rm v}=0.7$ model). It is possible that this general absorption has now been seen at z=6.2-6.4 [65]. In any case, the dominant effect on the spectrum is a 'forest' of narrow absorption lines, which produce a mean $\tau=1$ in the Ly α forest at about z=3, and so we have $\Omega_{\rm HI}\simeq 10^{-6.7}h^{-1}$. This is such a small number that clearly the IGM is very highly ionized at these redshifts.

The Ly α forest is of great importance in pinning down the abundance of deuterium. Because electrons in deuterium differ in reduced mass by about 1 part in 4000 compared to hydrogen, each absorption system in the Ly α forest is accompanied by an offset deuterium line. By careful selection of systems with an optimal HI column density, a measurement of the D/H ratio can be made. This has now been done in 7 quasars, with relatively consistent results [66]. Combining these determinations with the theory of primordial nucleosynthesis yields a baryon density of $\Omega_{\rm b}h^2=0.019-0.024$ (95% confidence). (See also the review on BBN—Sec. 22 of this Review.)

Ionized IGM can also be detected in emission when it is densely clumped, via bremsstrahlung radiation. This generates the spectacular X-ray emission from rich clusters of galaxies. Studies of this phenomenon allow us to achieve an accounting of the total baryonic material in clusters. Within the central $\simeq 1~\mathrm{Mpc},$ the masses in stars, X-ray emitting gas and total dark matter can be determined with reasonable accuracy (perhaps 20% rms), and this allows a minimum baryon fraction to be determined [67,68]:

$$\frac{M_{\text{baryons}}}{M_{\text{total}}} \gtrsim 0.009 + (0.066 \pm 0.003) \, h^{-3/2} \,.$$
 (21.63)

Because clusters are the largest collapsed structures, it is reasonable to take this as applying to the Universe as a whole. This equation implies a minimum baryon fraction of perhaps 12% (for reasonable h), which is too high for $\Omega_{\rm m}=1$ if we take $\Omega_{\rm b}h^2\simeq 0.02$ from nucleosynthesis. This is therefore one of the more robust arguments in favor of $\Omega_{\rm m}\simeq 0.3$. (See the review on Cosmological Parameters—Sec. 23 of this Review.) This argument is also consistent with the inference on $\Omega_{\rm m}$ that can be made from Fig. 21.2.

This method is much more robust than the older classical technique for weighing the Universe: ' $L \times M/L$.' The overall light density of the Universe is reasonably well determined from redshift surveys of galaxies, so that a good determination of mass M and luminosity L for a single object suffices to determine $\Omega_{\rm m}$ if the mass-to-light ratio is universal.

21.4.3. Gravitational lensing:

A robust method for determining masses in cosmology is to use gravitational light deflection. Most systems can be treated as a geometrically thin gravitational lens, where the light bending is assumed to take place only at a single distance. Simple geometry then determines a mapping between the coordinates in the intrinsic source plane and the observed image plane:

$$\alpha(D_{\rm L}\theta_{\rm I}) = \frac{D_{\rm S}}{D_{\rm LS}}(\theta_{\rm I} - \theta_{\rm S}) , \qquad (21.64)$$

where the angles $\theta_{\rm I}, \theta_{\rm S}$ and α are in general two-dimensional vectors on the sky. The distances $D_{\rm LS}$ etc. are given by an extension of the usual distance-redshift formula:

$$D_{\rm LS} = \frac{R_0 S_k (\chi_{\rm S} - \chi_{\rm L})}{1 + z_{\rm S}} \ . \tag{21.65}$$

This is the angular-diameter distance for objects on the source plane as perceived by an observer on the lens.

Solutions of this equation divide into weak lensing, where the mapping between source plane and image plane is one-to-one, and strong lensing, in which multiple imaging is possible. For circularly-symmetric lenses, an on-axis source is multiply imaged into a 'caustic' ring, whose radius is the Einstein radius:

$$\theta_{\rm E} = \left(4GM \frac{D_{\rm LS}}{D_{\rm L}D_{\rm S}}\right)^{1/2}$$

$$= \left(\frac{M}{10^{11.09} M_{\odot}}\right)^{1/2} \left(\frac{D_{\rm L}D_{\rm S}/D_{\rm LS}}{\rm Gpc}\right)^{-1/2} \quad \text{arcsec} .$$
(21.66)

The observation of 'arcs' (segments of near-perfect Einstein rings) in rich clusters of galaxies has thus given very accurate masses for the central parts of clusters—generally in good agreement with other indicators, such as analysis of X-ray emission from the cluster IGM [69].

Gravitational lensing has also developed into a particularly promising probe of cosmological structure on 10 to 100 Mpc scales. Weak image distortions manifest themselves as an additional ellipticity of galaxy images ('shear'), which can be observed by averaging many images together (the corresponding flux amplification is less readily detected). The result is a 'cosmic shear' field of order 1% ellipticity, coherent over scales of around 30 arcmin, which is directly related to the cosmic mass field, without any astrophysical uncertainties. For this reason, weak lensing is seen as potentially the cleanest probe of matter fluctuations, next to the CMB. Already, impressive results have been obtained in measuring cosmological parameters, based on survey data from only $\sim 50~{\rm deg^2}$ [85]. The particular current strength of this technique is the ability to measure the amplitude of mass fluctuations; this can be deduced from the CMB only subject to uncertainty over the optical depth due to Thomson scattering after reionization.

21.4.4. Density Fluctuations:

The overall properties of the Universe are very close to being homogeneous; and yet telescopes reveal a wealth of detail on scales varying from single galaxies to large-scale structures of size exceeding 100 Mpc. The existence of these structures must be telling us something important about the initial conditions of the Big Bang, and about the physical processes that have operated subsequently. This motivates the study of the density perturbation field, defined as

$$\delta(\mathbf{x}) \equiv \frac{\rho(\mathbf{x}) - \langle \rho \rangle}{\langle \rho \rangle} \ . \tag{21.67}$$

A critical feature of the δ field is that it inhabits a universe that is isotropic and homogeneous in its large-scale properties. This suggests that the statistical properties of δ should also be statistically homogeneous—*i.e.*, it is a stationary random process.

It is often convenient to describe δ as a Fourier superposition:

$$\delta(\mathbf{x}) = \sum \delta_{\mathbf{k}} e^{-i\mathbf{k} \cdot \mathbf{x}} \ . \tag{21.68}$$

We avoid difficulties with an infinite universe by applying periodic boundary conditions in a cube of some large volume V. The crossterms vanish when we compute the variance in the field, which is just a sum over modes of the power spectrum

$$\langle \delta^2 \rangle = \sum |\delta_{\mathbf{k}}|^2 \equiv \sum P(k) .$$
 (21.69)

Note that the statistical nature of the fluctuations must be isotropic, so we write P(k) rather than $P(\mathbf{k})$. The $\langle \ldots \rangle$ average here is a volume average. Cosmological density fields are an example of an ergodic process, in which the average over a large volume tends to the same answer as the average over a statistical ensemble.

The statistical properties of discrete objects sampled from the density field are often described in terms of N-point correlation functions, which represent the excess probability over random for finding one particle in each of N boxes in a given configuration. For the 2-point case, the correlation function is readily shown to be identical to the autocorrelation function of the δ field: $\xi(r) = \langle \delta(x)\delta(x+r) \rangle$.

The power spectrum and correlation function are Fourier conjugates, and thus are equivalent descriptions of the density field (similarly, k-space equivalents exist for the higher-order correlations). It is convenient to take the limit $V \to \infty$ and use k-space integrals, defining a dimensionless power spectrum, which measures the contribution to the fractional variance in density per unit logarithmic range of scale, as $\Delta^2(k) = d\langle \delta^2 \rangle/d \ln k = V k^3 P(k)/2\pi^2$:

$$\xi(r) = \int \Delta^2(k) \, \frac{\sin kr}{kr} \, d \ln k; \quad \Delta^2(k) = \frac{2}{\pi} k^3 \int_0^\infty \xi(r) \, \frac{\sin kr}{kr} \, r^2 \, dr \; . \eqno(21.70)$$

For many years, an adequate approximation to observational data on galaxies was $\xi = (r/r_0)^{-\gamma}$, with $\gamma \simeq 1.8$ and $r_0 \simeq 5\,h^{-1}\,{\rm Mpc}$. Modern surveys are now able to probe into the large-scale linear regime where unaltered traces of the curved post-recombination spectrum can be detected [70,71,72].

${\bf 21.4.5.} \quad Formation \ of \ cosmological \ structure:$

The simplest model for the generation of cosmological structure is gravitational instability acting on some small initial fluctuations (for the origin of which a theory such as inflation is required). If the perturbations are adiabatic (*i.e.*, fractionally perturb number densities of photons and matter equally), the linear growth law for matter perturbations is simple:

$$\delta \propto \begin{cases} a^2(t) & \text{(radiation domination; } \Omega_{\rm r} = 1) \\ a(t) & \text{(matter domination; } \Omega_{\rm m} = 1) \end{cases} . \tag{21.71}$$

For low density universes, the present-day amplitude is suppressed by a factor $q(\Omega)$, where

$$g(\Omega) \simeq \frac{5}{2}\Omega_{\rm m} \left[\Omega_{\rm m}^{4/7} - \Omega_{\rm v} + (1 + \Omega_{\rm m}/2)(1 + \frac{1}{70}\Omega_{\rm v})\right]^{-1}$$
 (21.72)

is an accurate fit for models with matter plus cosmological constant. The alternative perturbation mode is isocurvature: only the equation of state changes, and the total density is initially unperturbed. These modes perturb the total entropy density, and thus induce additional large-scale CMB anisotropies [73]. Although the character of perturbations in the simplest inflationary theories are purely adiabatic, correlated adiabatic and isocurvature modes are predicted in many models; the simplest example is the curvaton, which is a scalar field that decays to yield a perturbed radiation density. If the matter content already exists at this time, the overall perturbation field will have a significant isocurvature component. Such a prediction is inconsistent with current CMB data [74], and most analyses of CMB and LSS data assume the adiabatic case to hold exactly.

Linear evolution preserves the shape of the power spectrum. However, a variety of processes mean that growth actually depends on the matter content:

(1) Pressure opposes gravity effectively for wavelengths below the horizon length while the Universe is radiation dominated. The comoving horizon size at z_{eq} is therefore an important scale:

$$D_{\rm H}(z_{\rm eq}) = \frac{2(\sqrt{2} - 1)}{(\Omega_{\rm m} z_{\rm eq})^{1/2} H_0} = \frac{16.0}{\Omega_{\rm m} h^2} {\rm Mpc} \ .$$
 (21.73)

- (2) At early times, dark matter particles will undergo free streaming at the speed of light, and so erase all scales up to the horizon—a process that only ceases when the particles go nonrelativistic. For light massive neutrinos, this happens at z_{eq}; all structure up to the horizon-scale power-spectrum break is in fact erased. Hot(cold) dark matter models are thus sometimes dubbed large(small)-scale damping models.
- (3) A further important scale arises where photon diffusion can erase perturbations in the matter–radiation fluid; this process is named Silk damping.

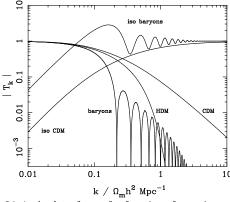


Figure 21.4: A plot of transfer functions for various models. For adiabatic models, $T_k \to 1$ at small k, whereas the opposite is true for isocurvature models. For dark-matter models, the characteristic wavenumber scales proportional to $\Omega_{\rm m}h^2$. The scaling for baryonic models does not obey this exactly; the plotted cases correspond to $\Omega_{\rm m}=1,\,h=0.5$.

The overall effect is encapsulated in the transfer function, which gives the ratio of the late-time amplitude of a mode to its initial value (see Fig. 21.4). The overall power spectrum is thus the primordial power-law, times the square of the transfer function:

$$P(k) \propto k^n T_k^2 \ . \tag{21.74}$$

The most generic power-law index is n=1: the 'Zeldovich' or 'scale-invariant' spectrum. Inflationary models tend to predict a small 'tilt:' $|n-1|\lesssim 0.03$ [12,13]. On the assumption that the dark matter is cold, the power spectrum then depends on 5 parameters: $n, h, \Omega_{\rm b}, \Omega_{\rm cdm} \ (\equiv \Omega_{\rm m} - \Omega_{\rm b})$ and an overall amplitude. The latter is often specified as σ_8 , the linear-theory fractional rms in density when a spherical filter of radius $8\,h^{-1}$ Mpc is applied in linear theory. This

scale can be probed directly via weak gravitational lensing, and also via its effect on the abundance of rich galaxy clusters. The favored value is approximately [34,75]

$$\sigma_8 \simeq (0.803 \pm 0.011) (\Omega_{\rm m}/0.25)^{-0.47}$$
. (21.75)

A direct measure of mass inhomogeneity is valuable, since the galaxies inevitably are biased with respect to the mass. This means that the fractional fluctuations in galaxy number, $\delta n/n$, may differ from the mass fluctuations, $\delta \rho/\rho$. It is commonly assumed that the two fields obey some proportionality on large scales where the fluctuations are small, $\delta n/n = b\delta \rho/\rho$, but even this is not guaranteed [76].

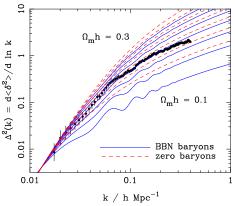


Figure 21.5: The galaxy power spectrum from the 2dFGRS [71], shown in dimensionless form, $\Delta^2(k) \propto k^3 P(k)$. The solid points with error bars show the power estimate. The window function correlates the results at different k values, and also distorts the large-scale shape of the power spectrum An approximate correction for the latter effect has been applied. The solid and dashed lines show various CDM models, all assuming n=1. For the case with non-negligible baryon content, a big-bang nucleosynthesis value of $\Omega_{\rm b}h^2=0.02$ is assumed, together with h=0.7. A good fit is clearly obtained for $\Omega_{\rm m}h\simeq0.2$.

The main shape of the transfer function is a break around the horizon scale at $z_{\rm eq}$, which depends just on $\Omega_{\rm m}h$ when wavenumbers are measured in observable units ($h\,{\rm Mpc^{-1}}$). For reasonable baryon content, weak oscillations in the transfer function are also expected, and these BAOs (Baryon Acoustic Oscillations) have been clearly detected [77,78]. As well as directly measuring the baryon fraction, the scale of the oscillations directly measures the acoustic horizon at decoupling; this can be used as an additional standard ruler for cosmological tests, and the BAO method is likely to be important in future large galaxy surveys. Overall, current power-spectrum data [70,71,72] favor $\Omega_{\rm m}h\simeq 0.20$ and a baryon fraction of about 0.15 for n=1 (see Fig. 21.5).

In principle, accurate data over a wide range of k could determine both Ωh and n, but in practice there is a strong degeneracy between these. In order to constrain n itself, it is necessary to examine data on anisotropies in the CMB.

${\bf 21.4.6.} \quad CMB \ anisotropies:$

The CMB has a clear dipole anisotropy, of magnitude 1.23×10^{-3} . This is interpreted as being due to the Earth's motion, which is equivalent to a peculiar velocity for the Milky Way of

$$v_{\rm MW} \simeq 600 \,\rm km \, s^{-1} \quad towards \quad (\ell, b) \simeq (270^{\circ}, 30^{\circ}) \; .$$
 (21.76)

All higher-order multipole moments of the CMB are however much smaller (of order 10^{-5}), and interpreted as signatures of density fluctuations at last scattering ($\simeq 1100$). To analyze these, the sky is expanded in spherical harmonics as explained in the review on CBR–Sec. 25 of this *Review*. The dimensionless power per $\ln k$ or 'bandpower' for the CMB is defined as

$$\mathcal{T}^{2}(\ell) = \frac{\ell(\ell+1)}{2\pi} C_{\ell} . \tag{21.77}$$

This function encodes information from the three distinct mechanisms that cause CMB anisotropies:

- Gravitational (Sachs-Wolfe) perturbations. Photons from highdensity regions at last scattering have to climb out of potential wells, and are thus redshifted.
- (2) Intrinsic (adiabatic) perturbations. In high-density regions, the coupling of matter and radiation can compress the radiation also, giving a higher temperature.
- (3) Velocity (Doppler) perturbations. The plasma has a non-zero velocity at recombination, which leads to Doppler shifts in frequency and hence shifts in brightness temperature.

Because the potential fluctuations obey Poisson's equation, $\nabla^2 \Phi = 4\pi G \rho \delta$, and the velocity field satisfies the continuity equation $\nabla \cdot \mathbf{u} = -\dot{\delta}$, the resulting different powers of k ensure that the Sachs-Wolfe effect dominates on large scales and adiabatic effects on small scales.

The relation between angle and comoving distance on the last-scattering sphere requires the comoving angular-diameter distance to the last-scattering sphere; because of its high redshift, this is effectively identical to the horizon size at the present epoch, $D_{\rm H}$:

$$\begin{split} D_{\rm H} &= \frac{2}{\Omega_{\rm m} H_0} \quad (\Omega_{\rm v} = 0) \\ D_{\rm H} &\simeq \frac{2}{\Omega_{\rm m}^{0.4} H_0} \quad ({\rm flat}: \Omega_{\rm m} + \Omega_{\rm v} = 1) \; . \end{split} \tag{21.78}$$

These relations show how the CMB is strongly sensitive to curvature: the horizon length at last scattering is $\propto 1/\sqrt{\Omega_m}$, so that this subtends an angle that is virtually independent of Ω_m for a flat model. Observations of a peak in the CMB power spectrum at relatively large scales ($\ell \simeq 225$) are thus strongly inconsistent with zero- Λ models with low density: current CMB + BAO +SN data require $\Omega_m + \Omega_v = 1.006 \pm 0.007$ [24]. (See e.g., Fig. 21.2).

In addition to curvature, the CMB encodes information about several other key cosmological parameters. Within the compass of simple adiabatic CDM models, there are 9 of these:

$$\omega_c, \ \omega_b, \ \Omega_t, \ h, \ \tau, \ n_s, \ n_t, \ r, \ Q \ .$$
 (21.79)

The symbol ω denotes the physical density, Ωh^2 : the transfer function depends only on the densities of CDM (ω_c) and baryons (ω_b). Transcribing the power spectrum at last scattering into an angular power spectrum brings in the total density parameter ($\Omega_t \equiv \Omega_{\rm m} + \Omega_{\rm v} = \Omega_c + \Omega_{\rm b} + \Omega_{\rm v}$) and h: there is an exact geometrical degeneracy [79] between these that keeps the angular-diameter distance to last scattering invariant, so that models with substantial spatial curvature and large vacuum energy cannot be ruled out without prior knowledge of the Hubble parameter. Alternatively, the CMB alone cannot measure the Hubble parameter.

The other main parameter degeneracy involves the tensor contribution to the CMB anisotropies. These are important at large scales (up to the horizon scales); for smaller scales, only scalar fluctuations (density perturbations) are important. Each of these components is characterized by a spectral index, n, and a ratio between the power spectra of tensors and scalars (r). See the review on Cosmological Parameters—Sec. 23 of this Review for a technical definition of the r parameter. Finally, the overall amplitude of the spectrum must be specified (Q), together with the optical depth to Compton scattering owing to recent reionization (τ) . The tensor degeneracy operates as follows: the main effect of adding a large tensor contribution is to reduce the contrast between low ℓ and the peak at $\ell \simeq 225$ (because the tensor spectrum has no acoustic component). The required height of the peak can be recovered by increasing n_s to increase the small-scale power in the scalar component; this in turn over-predicts the power at $\ell \sim 1000$, but this effect can be counteracted by raising the baryon density [80]. In order to break this degeneracy, additional data are required. For example, an excellent fit to the CMB data is obtained with a scalar-only model with zero curvature and $\omega_{\rm b} = 0.0225, \, \omega_{\rm c} = 0.1120, \, h = 0.704, \, n_{\rm s} = 0.967 \, [24].$ However, this is indistinguishable from a model where tensors dominate at $\ell \lesssim 100$,

if we raise $\omega_{\rm b}$ to 0.03 and $n_{\rm s}$ to 1.2. This baryon density is too high for nucleosynthesis, which disfavors the high-tensor solution [81].

The reason the tensor component is introduced, and why it is so important, is that it is the only non-generic prediction of inflation. Slow-roll models of inflation involve two dimensionless parameters:

$$\epsilon \equiv \frac{M_{\rm P}^2}{16\pi} \left(\frac{V'}{V}\right)^2 \qquad \eta \equiv \frac{M_{\rm P}^2}{8\pi} \left(\frac{V''}{V}\right) , \qquad (21.80)$$

where V is the inflaton potential, and dashes denote derivatives with respect to the inflation field. In terms of these, the tensor-to-scalar ratio is $r \simeq 16\epsilon$, and the spectral indices are $n_s = 1 - 6\epsilon + 2\eta$ and $n_{\rm t}=-2\epsilon$. The natural expectation of inflation is that the quasi-exponential phase ends once the slow-roll parameters become significantly non-zero, so that both $n_s \neq 1$ and a significant tensor component are expected. These prediction can be avoided in some models, but it is undeniable that observation of such features would be a great triumph for inflation. Cosmology therefore stands at a fascinating point given that the most recent CMB data appear to reject the zero-tensor $n_s = 1$ model at around 2.4σ : $n_s = 0.967 \pm 0.014$ [24]. If we insist on $n_s = 1$, then a very substantial tensor fraction would be required $(r \simeq 0.2)$, although the fit is better with r = 0. Assuming that no systematic error in this result can be identified, cosmology has passed a critical hurdle; the years ahead will be devoted to the task of breaking the tensor degeneracy — for which the main tool will be the polarization of the CMB [14].

21.4.7. Probing dark energy and the nature of gravity:

The most radical element of our current cosmological model is the dark energy that accelerates the expansion. The energy density of this component is approximately $(2.4\,\mathrm{meV})^4$ (for w=-1, $\Omega_v=0.75$, h=0.73), or roughly $10^{-123}M_\mathrm{P}^4$, and such an un-naturally small number is hard to understand. Various quantum effects (most simply zero-point energy) should make contributions to the vacuum energy density: these may be truncated by new physics at high energy, but this presumably occurs at $>1\,\mathrm{TeV}$ scales, not meV; thus the apparent energy scale of the vacuum is at least 10^{15} times smaller than its natural value. This situation is well analysed in [82], which lists extreme escape routes – especially the multiverse viewpoint, according to which low values of Λ are rare, but high values suppress the formation of structure and observers. It is certainly impressive that Weinberg used such reasoning to predict the value of Λ before any data strongly indicated a non-zero value.

But it may be that the phenomenon of dark energy is entirely illusory. The necessity for this constituent arises from using the Friedmann equation to describe the evolution of the cosmic expansion; if this equation is incorrect, it would require the replacement of Einstein's relativistic theory of gravity with some new alternative. A frontier of current cosmological research is to distinguish these possibilities [87,88]. We also note that it has been suggested that dark energy might be an illusion even within general relativity, owing to an incorrect treatment of averaging in an inhomogeneous Universe [89,90]. Many would argue that a standard Newtonian treatment of such issues should be adequate inside the cosmological horizon, but debate on this issue continues.

Dark Energy can differ from a classical cosmological constant in being a dynamical phenomenon [33,91], e.g., a rolling scalar field (sometimes dubbed 'quintessence'). Empirically, this means that it is endowed with two thermodynamic properties that astronomers can try to measure: the bulk equation of state and the sound speed. If the sound speed is close to the speed of light, the effect of this property is confined to very large scales, and mainly manifests itself in the large-angle multipoles of the CMB anisotropies [92]. The equation of state parameter governs the rate of change of the vacuum density: $d \ln \rho_v / d \ln a = -3(1+w)$, so it can be accessed via the evolving expansion rate, H(a). This can be measured most cleanly by using the inbuilt natural ruler of large-scale structure: the Baryon Acoustic Oscillation horizon scale [93]:

$$D_{\rm BAO} \simeq 147 \, (\Omega_{\rm m} h^2 / 0.13)^{-0.25} (\Omega_{\rm b} h^2 / 0.023)^{-0.08} \,{\rm Mpc} \,.$$
 (21.81)

H(a) is measured by radial clustering, since dr/dz = c/H; clustering in the plane of the sky measures the integral of this. The expansion

rate is also measured by the growth of density fluctuations, where the pressure-free growth equation for the density perturbation is $\ddot{\delta} + 2H(a)\dot{\delta} = 4\pi G\rho_0 \delta$. Thus, both the scale and amplitude of density fluctuations are sensitive to w(a) – but only weakly. These observables change by only typically 0.2% for a 1% change in w. Current constraints [24] are -1.11 < w < -0.89 (95% confidence), so a substantial improvement will require us to limit systematics in data to a few parts in 1000.

Testing whether theories of gravity require revision can also be done using data on cosmological inhomogeneities. Two separate issues arise, concerning the metric perturbation potentials Ψ and Φ , which affect respectively the time and space parts of the metric. In Einstein gravity, these potentials are both equal to the Newtonian gravitational potential, which satisfies Poisson's equation: $\nabla^2 \Phi / a^2 = 4\pi G \bar{\rho} \delta$. Empirically, modifications of gravity require us to explore a change with scale and with time of the 'slip' (Ψ/Φ) and the effective G on the rhs of the Poisson equation. The former aspect can only be probed via gravitational lensing, whereas the latter can be addressed on 10-100 Mpc scales via the growth of clustering. Various schemes for parameterising modified gravity exist, but a practical approach is to assume that the growth rate can be tied to the density parameter: $d \ln \delta / d \ln a = \Omega_{\rm m}^{\gamma}(a)$ [94]. The parameter γ is close to 0.55 for standard relativistic gravity, but can differ by around 0.1 from this value in many non-standard models. Clearly this parameterization is incomplete, since it explicitly rejects the possibility of early dark energy $(\Omega_{\rm m}(a) \to 1 \text{ as } a \to 0)$, but it is a convenient way of capturing the power of various experiments. Current data are consistent with standard Λ CDM [86], and exclude variations in slip or effective G of larger than a few times 10%.

Current planning envisages a set of satellite probes that, a decade hence, will pursue these fundamental tests via gravitational lensing measurements over thousands of square degrees, $> 10^8$ redshifts, and photometry of > 1000 supernovae (WFIRST in the USA, Euclid in Europe) [22,23]. These experiments will measure both w and the perturbation growth rate to an accuracy of around 1%. The outcome will be either a validation of the standard relativistic vacuum-dominated big bang cosmology at a level of precision far beyond anything attempted to date, or the opening of entirely new directions in cosmological models.

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22. BIG-BANG NUCLEOSYNTHESIS

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Big-Bang nucleosynthesis (BBN) offers the deepest reliable probe of the early Universe, being based on well-understood Standard Model physics [1–8]. Predictions of the abundances of the light elements, D, 3 He, 4 He, and 7 Li, synthesized at the end of the 'first three minutes', are in good overall agreement with the primordial abundances inferred from observational data, thus validating the standard hot Big-Bang cosmology (see [9] for a review). This is particularly impressive given that these abundances span nine orders of magnitude – from 4 He/H ~ 0.08 down to 7 Li/H $\sim 10^{-10}$ (ratios by number). Thus BBN provides powerful constraints on possible deviations from the standard cosmology, and on new physics beyond the Standard Model [4–7].

22.1. Theory

The synthesis of the light elements is sensitive to physical conditions in the early radiation-dominated era at a temperature $T \sim 1$ MeV, corresponding to an age $t \sim 1$ s. At higher temperatures, weak interactions were in thermal equilibrium, thus fixing the ratio of the neutron and proton number densities to be $n/p = e^{-Q/T}$, where Q = 1.293 MeV is the neutron-proton mass difference. As the temperature dropped, the neutron-proton inter-conversion rate, $\Gamma_{n \leftarrow p} \sim G_{\rm F}^2 T^5$, fell faster than the Hubble expansion rate, $H \sim \sqrt{g_* G_N} T^2$, where g_* counts the number of relativistic particle species determining the energy density in radiation (see 'Big Bang Cosmology' review). This resulted in departure from chemical equilibrium ('freeze-out') at $T_{\rm fr} \sim (g_* G_{\rm N}/G_{\rm F}^4)^{1/6} \simeq 1$ MeV. The neutron fraction at this time, $n/p = e^{-Q/T_{\rm fr}} \simeq 1/6$, is thus sensitive to every known physical interaction, since Q is determined by both strong and electromagnetic interactions while $T_{\rm fr}$ depends on the weak as well as gravitational interactions. Moreover, the sensitivity to the Hubble expansion rate affords a probe of e.g., the number of relativistic neutrino species [10]. After freeze-out, the neutrons were free to β -decay, so the neutron fraction dropped to $n/p \simeq 1/7$ by the time nuclear reactions began. A simplified analytic model of freeze-out yields the n/p ratio to an accuracy of $\sim 1\%$ [11,12].

The rates of these reactions depend on the density of baryons (strictly speaking, nucleons), which is usually expressed normalized to the relic blackbody photon density as $\eta \equiv n_{\rm b}/n_{\gamma}$. As we shall see, all the light-element abundances can be explained with $\eta_{10} \equiv \eta \times 10^{10}$ in the range 5.1–6.5 (95% CL). With n_{γ} fixed by the present CMB temperature 2.725 K (see 'Cosmic Microwave Background' review), this can be stated as the allowed range for the baryon mass density today, $\rho_{\rm b} = (3.5-4.5) \times 10^{-31}~{\rm g\,cm}^{-3}$, or as the baryonic fraction of the critical density, $\Omega_{\rm b} = \rho_{\rm b}/\rho_{\rm crit} \simeq \eta_{10}h^{-2}/274 = (0.019-0.024)h^{-2}$, where $h \equiv H_0/100~{\rm km\,s}^{-1}~{\rm Mpc}^{-1} = 0.72 \pm 0.08$ is the present Hubble parameter (see Cosmological Parameters review).

The nucleosynthesis chain begins with the formation of deuterium in the process $p(n,\gamma)$ D. However, photo-dissociation by the high number density of photons delays production of deuterium (and other complex nuclei) well after T drops below the binding energy of deuterium, $\Delta_{\rm D}=2.23$ MeV. The quantity $\eta^{-1}{\rm e}^{-\Delta_{\rm D}/T}$, i.e., the number of photons per baryon above the deuterium photo-dissociation threshold, falls below unity at $T\simeq 0.1$ MeV; nuclei can then begin to form without being immediately photo-dissociated again. Only 2-body reactions, such as ${\rm D}(p,\gamma)^3{\rm He}$, $^3{\rm He}({\rm D},p)^4{\rm He}$, are important because the density by this time has become rather low – comparable to that of air!

Nearly all neutrons end up bound in the most stable light element $^4\mathrm{He}$. Heavier nuclei do not form in any significant quantity both because of the absence of stable nuclei with mass number 5 or 8 (which impedes nucleosynthesis via $n^4\mathrm{He}$, $p^4\mathrm{He}$ or $^4\mathrm{He}^4\mathrm{He}$ reactions), and the large Coulomb barriers for reactions such as $^3\mathrm{He}(^4\mathrm{He},\gamma)^7\mathrm{Li}$ and $^3\mathrm{He}(^4\mathrm{He},\gamma)^7\mathrm{Be}$. Hence the primordial mass fraction of $^4\mathrm{He}$, conventionally referred to as Y_p , can be estimated by the simple counting argument

$$Y_{\rm p} = \frac{2(n/p)}{1 + n/p} \simeq 0.25 \ .$$
 (22.1)

There is little sensitivity here to the actual nuclear reaction rates, which are, however, important in determining the other 'left-over'

abundances: D and 3 He at the level of a few times 10^{-5} by number relative to H, and 7 Li/H at the level of about 10^{-10} (when η_{10} is in the range 1–10). These values can be understood in terms of approximate analytic arguments [12,13]. The experimental parameter most important in determining $Y_{\rm p}$ is the neutron lifetime, τ_n , which normalizes (the inverse of) $\Gamma_{n\!-\!p}$. The experimental uncertainty in τ_n has been thought small, at $\tau_n=885.7\pm0.8$ s but recent measurements and re-analyses suggest possible systematic errors ~ 6 times larger (see N Baryons Listing).

The elemental abundances shown in Fig. 22.1 as a function of η_{10} were calculated [14] using an updated version [15] of the Wagoner code [1]; other modern versions [16,17] are publicly available. The ⁴He curve includes small corrections due to radiative processes at zero and finite temperatures [18], non-equilibrium neutrino heating during e^{\pm} annihilation [19], and finite nucleon mass effects [20]; the range reflects primarily the 2σ uncertainty in the neutron lifetime. The spread in the curves for D, ³He, and ⁷Li corresponds to the 2σ uncertainties in nuclear cross sections, as estimated by Monte Carlo methods [21–22]. The input nuclear data have been carefully reassessed [14, 23-27], leading to improved precision in the abundance predictions. In particular, the uncertainty in ⁷Li/H at interesting values of η has been reduced recently by a factor ~ 2 , a consequence of a similar reduction in the error budget [28] for the dominant mass-7 production channel ${}^{3}\text{He}({}^{4}\text{He},\gamma){}^{7}\text{Be}$. Polynomial fits to the predicted abundances and the error correlation matrix have been given [22,29]. The boxes in Fig. 22.1 show the observationally inferred primordial abundances with their associated statistical and systematic uncertainties, as discussed below.

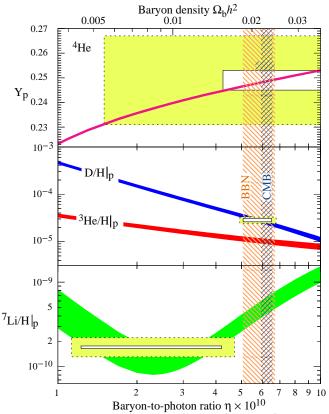


Figure 22.1: The abundances of ^4He , D, ^3He , and ^7Li as predicted by the standard model of Big-Bang nucleosynthesis [14] — the bands show the 95% CL range. Boxes indicate the observed light element abundances (smaller boxes: $\pm 2\sigma$ statistical errors; larger boxes: $\pm 2\sigma$ statistical and systematic errors). The narrow vertical band indicates the CMB measure of the cosmic baryon density, while the wider band indicates the BBN concordance range (both at 95% CL).

22.2. Light Element Abundances

BBN theory predicts the universal abundances of D, $^3\mathrm{He},^4\mathrm{He},$ and $^7\mathrm{Li},$ which are essentially fixed by $t\sim180\,\mathrm{s}.$ Abundances are, however, usually observed at much later epochs, after stellar nucleosynthesis has commenced. The ejected remains of this stellar processing can alter the light element abundances from their primordial values, and also produce heavy elements such as C, N, O, and Fe ('metals'). Thus, one seeks astrophysical sites with low metal abundances, in order to measure light element abundances which are closer to primordial. For all of the light elements, systematic errors are an important (and often dominant) limitation to the precision with which primordial abundances can be inferred.

High-resolution spectra reveal the presence of D in high-redshift, low-metallicity quasar absorption systems via its isotope-shifted Lyman-α absorption [30–33]. It is believed that there are no astrophysical sources of deuterium [34], so any detection provides a lower limit to primordial D/H, and thus an upper limit on η ; for example, the local interstellar value of D/H|_p = $(1.56\pm0.04)\times10^{-5}$ [35] requires $\eta_{10} \leq 9$. Recent observations find an unexpected scatter of a factor of ~ 2 [36], as well as correlations with heavy element abundances which suggest that interstellar D may suffer stellar processing (astration), but also partly reside in dust particles which evade gas-phase observations. This is supported by a measurement in the lower halo [37], which indicates that the Galactic D abundance has been reduced by a factor of only 1.12±0.13 since its formation. For the high-redshift systems, conventional models of galactic nucleosynthesis (chemical evolution) do not predict either of these effects for D/H [38].

The observed extragalactic D values are bracketed by the non-detection of D in a high-redshift system, $\mathrm{D/H|_p} < 6.7 \times 10^{-5}$ at 1σ [39], and low values in some (damped Lyman- α) systems [30,31]. Averaging the seven most precise observations of deuterium in quasar absorption systems gives $\mathrm{D/H} = (2.82 \pm 0.12) \times 10^{-5}$, where the error is statistical only [32,33]. However, there remains concern over systematic errors, the dispersion between the values being much larger than is expected from the individual measurement errors ($\chi^2 = 17.7$ for $\nu = 6$ d.o.f.). Increasing the error by a factor $\sqrt{\chi^2/\nu}$ gives, as shown in Fig. 22.1:

$$D/H|_{p} = (2.82 \pm 0.21) \times 10^{-5}.$$
 (22.2)

⁴He can be observed in clouds of ionized hydrogen (H II regions), the most metal-poor of which are in dwarf galaxies. There is now a large body of data on ⁴He and CNO in such systems [40]. These data confirm that the small stellar contribution to helium is positively correlated with metal production. Extrapolating to zero metallicity gives the primordial ⁴He abundance [41]

$$Y_{\rm p} = 0.249 \pm 0.009.$$
 (22.3)

Here the latter error is a careful (and significantly enlarged) estimate of the systematic uncertainties which dominate, and is based on the scatter in different analyses of the physical properties of the H II regions [40,41]. Other recent extrapolations to zero metallicity give $Y_{\rm p}=0.247\pm0.001$ or 0.252 ± 0.001 depending on which set of He I emissivities are used [42], and $Y_{\rm p}=0.248\pm0.003$ [43]. These are consistent (given the systematic errors) with the above estimate [41], which appears in Fig. 22.1. The CMB damping tail (see Cosmic Microwave Background review) is sensitive to the primordial ⁴He abundance [44]. Recent measurements find $Y_{\rm p}=0.296\pm0.030$ [45], consistent with the above; future Planck measurements should tighten this result.

As we will see in more detail below, the primordial abundance of lithium now plays a central role in BBN, and possibly points to new physics. The systems best suited for Li observations are metal-poor stars in the spheroid (Pop II) of our Galaxy, which have metallicities going down to at least 10^{-4} , and perhaps 10^{-5} of the Solar value [46]. Observations have long shown [47–51] that Li does not vary significantly in Pop IIstars with metallicities $\lesssim 1/30$ of Solar — the 'Spite plateau' [47]. Precision data suggest a small but significant correlation between Li and Fe [48], which

can be understood as the result of Li production from Galactic cosmic rays [49]. Extrapolating to zero metallicity, one arrives at a primordial value Li/H|_p = $(1.23 \pm 0.06^{+0.68}_{-0.32}) \times 10^{-10}$ [50], where the first error given is statistical and is very small due to the relatively large sample of 22 stars used. One source of systematic error stems from the differences in techniques used to determine the physical parameters (e.g., the temperature) of the stellar atmosphere in which the Li absorption line is formed. Alternative analyses, using methods that give systematically higher temperatures, and in some cases different stars and stellar systems (globular clusters), yield ${\rm Li/H|_p} = (2.19 \pm 0.28) \times 10^{-10} \, [51], \ {\rm Li/H|_p} = (2.34 \pm 0.32) \times 10^{-10} \, [52],$ and ${\rm Li/H|_p} = (1.26 \pm 0.26) \times 10^{-10} \, [53];$ the differences with [50] indicate a systematic uncertainty of a factor of ~ 2 . Moreover, it is possible that the Li in Pop II stars has been partially destroyed, due to mixing of the outer layers with the hotter interior [54]. Such processes can be constrained by the absence of significant scatter in Li versus Fe [48], and by observations of the fragile isotope ⁶Li [49]. Nevertheless, some depletion is likely to exist: a factor as large as ~ 1.8 has been suggested [55](and recent observations find a puzzling drop in Li/H in ultra-metal-poor stars [56]) . Including these systematics, we estimate a primordial Li range which spans the ranges above, as shown in Fig. 22.1:

$$\text{Li/H}|_{\text{p}} = (1.7 \pm 0.06 \pm 0.44) \times 10^{-10}.$$
 (22.4)

Stellar determination of Li abundances typically sum over both stable isotopes $^6\mathrm{Li}$ and $^7\mathrm{Li}$. Recent high-precision measurements are sensitive to the tiny isotopic shift in Li absorption (which manifests itself in the shape of the blended, thermally broadened line) and indicate $^6\mathrm{Li}/^7\mathrm{Li} \leq 0.15$ [57]. This confirms that $^7\mathrm{Li}$ is dominant, but surprisingly there is indication of a $^6\mathrm{Li}$ plateau (analogous to the $^7\mathrm{Li}$ plateau) which suggests a significant primordial $^6\mathrm{Li}$ abundance. However, caution must be exercised since convective motions in the star can generate similar asymmetries in the line shape, hence the deduced $^6\mathrm{Li}$ abundance is presently best interpreted as an upper limit [58].

Turning to ³He, the only data available are from the Solar system and (high-metallicity) H II regions in our Galaxy [59]. This makes inferring the primordial abundance difficult, a problem compounded by the fact that stellar nucleosynthesis models for ³He are in conflict with observations [60]. Consequently, it is no longer appropriate to use ³He as a cosmological probe; instead, one might hope to turn the problem around and constrain stellar astrophysics using the predicted primordial ³He abundance [61].

22.3. Concordance, Dark Matter, and the CMB

We now use the observed light element abundances to test the theory. We first consider standard BBN, which is based on Standard Model physics alone, so $N_{\nu}=3$ and the only free parameter is the baryon-to-photon ratio η . (The implications of BBN for physics beyond the Standard Model will be considered below, §4). Thus, any abundance measurement determines η , while additional measurements overconstrain the theory and thereby provide a consistency check.

First we note that the overlap in the η ranges spanned by the larger boxes in Fig. 22.1 indicates overall concordance. More quantitatively, when we account for theoretical uncertainties, as well as the statistical and systematic errors in observations, there is acceptable agreement among the abundances when

$$5.1 \le \eta_{10} \le 6.5 \text{ (95\% CL)}.$$
 (22.5)

However, the agreement is much less satisfactory if we use only the quoted statistical errors in the observations. In particular, as seen in Fig. 22.1, D and $^4{\rm He}$ are consistent with each other, but favor a value of η which is higher by a factor of at least 2.4, and by at least $\sim 4.2\sigma$ from that indicated by the $^7{\rm Li}$ abundance determined in stars. Furthermore, if the $^6{\rm Li}$ plateau [57] reflects a primordial component, it is ~ 1000 times that expected in standard BBN; both these "lithium problems" may indicate new physics (see below).

Even so, the overall concordance is remarkable: using well-established microphysics we have extrapolated back to an age of $\sim 1~\rm s$

to correctly predict light element abundances spanning 9 orders of magnitude. This is a major success for the standard cosmology, and inspires confidence in extrapolation back to still earlier times.

This concordance provides a measure of the baryon content

$$0.019 \le \Omega_{\rm b} h^2 \le 0.024 \ (95\% \ {\rm CL}),$$
 (22.6)

a result that plays a key role in our understanding of the matter budget of the Universe. First we note that $\Omega_{\rm b} \ll 1,~i.e.,$ baryons cannot close the Universe [62]. Furthermore, the cosmic density of (optically) luminous matter is $\Omega_{\rm lum} \simeq 0.0024h^{-1}$ [63], so that $\Omega_{\rm b} \gg \Omega_{\rm lum}:$ most baryons are optically dark, probably in the form of a diffuse intergalactic medium [64]. Finally, given that $\Omega_{\rm m} \sim 0.3$ (see Dark Matter and Cosmological Parameters reviews), we infer that most matter in the Universe is not only dark, but also takes some non-baryonic (more precisely, non-nucleonic) form.

The BBN prediction for the cosmic baryon density can be tested through precision observations of CMB temperature fluctuations (see Cosmic Microwave Background review). One can determine η from the amplitudes of the acoustic peaks in the CMB angular power spectrum [65], making it possible to compare two measures of η using very different physics, at two widely separated epochs. In the standard cosmology, there is no change in η between BBN and CMB decoupling, thus, a comparison of $\eta_{\rm BBN}$ and $\eta_{\rm CMB}$ is a key test. Agreement would endorse the standard picture while disagreement could point to new physics during/between the BBN and CMB epochs.

The release of the WMAP results was a landmark event in this test of BBN. As with other cosmological parameter determinations from CMB data, the derived $\eta_{\rm CMB}$ depends on the adopted priors [66], in particular the form assumed for the power spectrum of primordial density fluctuations. If this is taken to be a scale-free power-law, the five-year WMAP data imply $\Omega_{\rm b}h^2=0.02273\pm0.00062$ or $\eta_{10}=6.23\pm0.17$ [67] as shown in Fig. 22.1. Other assumptions for the shape of the power spectrum can lead to baryon densities as low as $\Omega_{\rm b}h^2=0.0175\pm0.0007$ [68]. Thus, outstanding uncertainties regarding priors are a source of systematic error which presently exceeds the statistical error in the prediction for η .

It is remarkable that the CMB estimate of the baryon density is consistent with the BBN range quoted in Eq. (22.6), and in very good agreement with the value inferred from recent high-redshift D/H measurements [33] and 4 He determinations; together these observations span diverse environments from redshifts z=1000 to the present.

Bearing in mind the importance of priors, the promise of precision determinations of the baryon density using the CMB motivates the use of this value as an input to BBN calculations. Within the context of the Standard Model, BBN then becomes a zero-parameter theory, and the light element abundances are completely determined to within the uncertainties in $\eta_{\rm CMB}$ and the BBN theoretical errors. Comparison with the observed abundances then can be used to test the astrophysics of post-BBN light element evolution [71]. Alternatively, one can consider possible physics beyond the Standard Model (e.g., which might change the expansion rate during BBN) and then use all of the abundances to test such models; this is the subject of our final section.

22.4. The Lithium Problem

As Fig. 22.1 shows, stellar Li/H measurements are inconsistent with the CMB (and D/H), given the error budgets we have quoted. Recent updates in nuclear cross sections, stellar abundance systematics, and the WMAP results all *increase* the discrepancy to as much as 5.3σ , depending on the stellar abundance analysis adopted. [14].

The question then becomes more pressing as to whether this mismatch comes from systematic errors in the observed abundances, and/or uncertainties in stellar astrophysics or nuclear inputs, or whether there might be new physics at work [7]. Nucleosynthesis models in which the baryon-to-photon ratio is inhomogeneous can alter abundances for a given $\eta_{\rm BBN}$, but will overproduce ⁷Li [69]. Entropy generation by some non-standard process could have decreased η between the BBN era and CMB decoupling, however the lack of

spectral distortions in the CMB rules out any significant energy injection upto a redshift $z\sim 10^7$ [70]. The most intriguing resolution of the lithium problem thus involves new physics during BBN [5–6].

For now this is a central unresolved issue in BBN. Nevertheless, the remarkable concordance between the CMB and D/H, as well as 4 He, remain as non-trivial successes, and open windows onto the early Universe and particle physics, as we now discuss.

22.5. Beyond the Standard Model

Given the simple physics underlying BBN, it is remarkable that it still provides the most effective test for the cosmological viability of ideas concerning physics beyond the Standard Model. Although baryogenesis and inflation must have occurred at higher temperatures in the early Universe, we do not as yet have 'standard models' for these, so BBN still marks the boundary between the established and the speculative in Big Bang cosmology. It might appear possible to push the boundary back to the quark-hadron transition at $T \sim \Lambda_{\rm QCD}$, or electroweak symmetry breaking at $T \sim 1/\sqrt{G_{\rm F}}$; however, so far no observable relics of these epochs have been identified, either theoretically or observationally. Thus, although the Standard Model provides a precise description of physics up to the Fermi scale, cosmology cannot be traced in detail before the BBN era.

Limits on particle physics beyond the Standard Model come mainly from the observational bounds on the ⁴He abundance. This is proportional to the n/p ratio which is determined when the weakinteraction rates fall behind the Hubble expansion rate at $T_{\rm fr} \sim 1$ MeV. The presence of additional neutrino flavors (or of any other relativistic species) at this time increases g_* , hence the expansion rate, leading to a larger value of $T_{\rm fr},~n/p,$ and therefore $Y_{\rm p}$ [10,72]. In the Standard Model, the number of relativistic particle species at 1 MeV is $g_* = 5.5 + \frac{7}{4}N_{\nu}$, where the factor 5.5 accounts for photons and e^{\pm} . and N_{ν} is the effective number of (nearly massless) neutrino flavors (see Big Bang Cosmology review). The helium curves in Fig. 22.1 were computed taking $N_{\nu} = 3$; small corrections for non-equilibrium neutrino heating [19] are included in the thermal evolution and lead to an effective $N_{\nu} = 3.04$ compared to assuming instantaneous neutrino freezeout (see, e.g., Big Bang Cosmology review). The computed ⁴He abundance scales as $\Delta Y_{\rm p} \simeq 0.013 \Delta N_{\nu}$ [11]. Clearly the central value for N_{ν} from BBN will depend on η , which is independently determined (with weaker sensitivity to N_{ν}) by the adopted D or ⁷Li abundance. For example, if the best value for the observed primordial ⁴He abundance is 0.249, then, for $\eta_{10} \sim 6$, the central value for N_{ν} is very close to 3. This limit depends sensitively on the adopted light element abundances, particularly $Y_{\rm p}$. A maximum likelihood analysis on η and N_{ν} based on the above ⁴He and D abundances finds the (correlated) 95% CL ranges to be $4.9 < \eta_{10} < 7.1$ and $1.8 < N_{\nu} < 4.5$ [73]. Similar results were obtained in another study [74] which presented a simpler method to extract such bounds based on χ^2 statistics, given a set of input abundances. Using the CMB determination of η improves the constraints: including the most recent WMAP data yields $N_{\nu} < 4.2 \ (95\% \ {\rm CL}) \ [75]$. It is also worth noting that CMB damping tail measurements alone now find $N_{\nu} = 3.85 \pm 0.62$ [45].

Just as one can use the measured helium abundance to place limits on g_* [72], any changes in the strong, weak, electromagnetic, or gravitational coupling constants, arising e.g., from the dynamics of new dimensions, can be similarly constrained [76], as can be any speed-up of the expansion rate in e.g. scalar-tensor theories of gravity [77].

The limits on N_{ν} can be translated into limits on other types of particles or particle masses that would affect the expansion rate of the Universe during nucleosynthesis. For example, consider 'sterile' neutrinos with only right-handed interactions of strength $G_{\rm R} < G_{\rm F}$. Such particles would decouple at higher temperature than (left-handed) neutrinos, so their number density ($\propto T^3$) relative to neutrinos would be reduced by any subsequent entropy release, e.g., due to annihilations of massive particles that become non-relativistic between the two decoupling temperatures. Thus (relativistic) particles with less than full strength weak interactions contribute less to the energy density than particles that remain in equilibrium up to the time of nucleosynthesis [78]. If we impose $N_{\nu} < 4$ as an

illustrative constraint, then the three right-handed neutrinos must have a temperature $3(T_{\nu_{\rm R}}/T_{\nu_{\rm L}})^4 < 1$. Since the temperature of the decoupled ν_R 's is determined by entropy conservation (see Big Bang Cosmology review), $T_{\nu_{\rm R}}/T_{\nu_{\rm L}}=[(43/4)/g_*(T_{\rm d})]^{1/3}<0.76$, where $T_{\rm d}$ is the decoupling temperature of the $\nu_{\rm R}$'s. This requires $g_*(T_{\rm d})>24$, so decoupling must have occurred at $T_{\rm d} > 140$ MeV. The decoupling temperature is related to $G_{\rm R}$ through $(G_{\rm R}/G_{\rm F})^2 \sim (T_{\rm d}/3\,{\rm MeV})^{-3}$, where 3 MeV is the decoupling temperature for $\nu_{\rm L}$ s. This yields a limit $G_{\rm R} \lesssim 10^{-2} G_{\rm F}$. The above argument sets lower limits on the masses of new Z' gauge bosons to which right-handed neutrinos would be coupled in models of superstrings [79], or extended technicolor [80]. Similarly a Dirac magnetic moment for neutrinos, which would allow the right-handed states to be produced through scattering and thus increase q_* , can be significantly constrained [81], as can any new interactions for neutrinos which have a similar effect [82]. Righthanded states can be populated directly by helicity-flip scattering if the neutrino mass is large enough, and this property has been used to infer a bound of $m_{\nu_{\tau}} \lesssim 1$ MeV taking $N_{\nu} < 4$ [83]. If there is mixing between active and sterile neutrinos then the effect on BBN is more complicated [84].

The limit on the expansion rate during BBN can also be translated into bounds on the mass/lifetime of non-relativistic particles which decay during BBN. This results in an even faster speed-up rate, and typically also change the entropy [85]. If the decays include Standard Model particles, the resulting electromagnetic [86–87] and/or hadronic [88] cascades can strongly perturb the light elements, which leads to even stronger constraints. Such arguments have been applied to rule out a MeV mass ν_{τ} , which decays during nucleosynthesis [89].

Such arguments have proved very effective in constraining supersymmetry. For example, if the gravitino is very light and contributes to g_* , the illustrative BBN limit $N_{\nu} < 4$ requires its mass to exceed ~ 1 eV [90]. Alternatively, much recent interest has focussed on the case in which the next-to-lightest supersymmetric particle is metastable and decays during or after BBN. The constraints on unstable particles discussed above imply stringent bounds on the allowed abundance of such particles [88]; if the metastable particle is charged (e.g., the stau), then it is possible for it to form atom-like electromagnetic bound states with nuclei, and the resulting impact on light elements can be quite complex [91]. Such decays can destroy ⁷Li and/or produce ⁶Li, leading to a possible supersymmetric solution to the lithium problems noted above [92](see [5] for a review). In addition, these arguments impose powerful constraints on supersymmetric inflationary cosmology [87-88], in particular thermal leptogenesis [93]. These can be evaded only if the gravitino is massive enough to decay before BBN, i.e., $m_{3/2} \gtrsim 50 \text{ TeV } [94]($ which would be unnatural), or if it is in fact the lightest supersymmetric particle and thus stable [87,95]. Similar constraints apply to moduli – very weakly coupled fields in string theory which obtain an electroweak-scale mass from supersymmetry breaking [96].

Finally, we mention that BBN places powerful constraints on the possibility that there are new large dimensions in nature, perhaps enabling the scale of quantum gravity to be as low as the electroweak scale [97]. Thus, Standard Model fields may be localized on a 'brane,' while gravity alone propagates in the 'bulk.' It has been further noted that the new dimensions may be non-compact, even infinite [98], and the cosmology of such models has attracted considerable attention. The expansion rate in the early Universe can be significantly modified, so BBN is able to set interesting constraints on such possibilities [99].

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23. THE COSMOLOGICAL PARAMETERS

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23.1. Parametrizing the Universe

Rapid advances in observational cosmology have led to the establishment of a precision cosmological model, with many of the key cosmological parameters determined to one or two significant figure accuracy. Particularly prominent are measurements of cosmic microwave background (CMB) anisotropies, led by the seven-year results from the Wilkinson Microwave Anisotropy Probe (WMAP) [1–3]. However the most accurate model of the Universe requires consideration of a wide range of different types of observation, with complementary probes providing consistency checks, lifting parameter degeneracies, and enabling the strongest constraints to be placed.

The term 'cosmological parameters' is forever increasing in its scope, and nowadays includes the parametrization of some functions, as well as simple numbers describing properties of the Universe. The original usage referred to the parameters describing the global dynamics of the Universe, such as its expansion rate and curvature. Also now of great interest is how the matter budget of the Universe is built up from its constituents: baryons, photons, neutrinos, dark matter, and dark energy. We need to describe the nature of perturbations in the Universe, through global statistical descriptors such as the matter and radiation power spectra. There may also be parameters describing the physical state of the Universe, such as the ionization fraction as a function of time during the era since recombination. Typical comparisons of cosmological models with observational data now feature between five and ten parameters.

23.1.1. The global description of the Universe:

Ordinarily, the Universe is taken to be a perturbed Robertson–Walker space-time with dynamics governed by Einstein's equations. This is described in detail by Olive and Peacock in this volume. Using the density parameters Ω_i for the various matter species and Ω_{Λ} for the cosmological constant, the Friedmann equation can be written

$$\sum_{i} \Omega_i + \Omega_{\Lambda} - 1 = \frac{k}{R^2 H^2}, \qquad (23.1)$$

where the sum is over all the different species of material in the Universe. This equation applies at any epoch, but later in this article we will use the symbols Ω_i and Ω_{Λ} to refer to the present values. A typical collection would be baryons, photons, neutrinos, and dark matter (given charge neutrality, the electron density is guaranteed to be too small to be worth considering separately and is included with the baryons).

The complete present state of the homogeneous Universe can be described by giving the current values of all the density parameters and of the Hubble parameter h. These also allow us to track the history of the Universe back in time, at least until an epoch where interactions allow interchanges between the densities of the different species, which is believed to have last happened at neutrino decoupling, shortly before Big Bang Nucleosynthesis (BBN). To probe further back into the Universe's history requires assumptions about particle interactions, and perhaps about the nature of physical laws themselves.

23.1.2. *Neutrinos* :

The standard neutrino sector has three flavors. For neutrinos of mass in the range $5\times 10^{-4}\,\mathrm{eV}$ to 1 MeV, the density parameter in neutrinos is predicted to be

$$\Omega_{\nu}h^2 = \frac{\sum m_{\nu}}{93 \,\text{eV}},\tag{23.2}$$

where the sum is over all families with mass in that range (higher masses need a more sophisticated calculation). We use units with c=1 throughout. Results on atmospheric and Solar neutrino oscillations [4] imply non-zero mass-squared differences between the three neutrino flavors. These oscillation experiments cannot tell us the absolute neutrino masses, but within the simple assumption of a mass hierarchy suggest a lower limit of approximately 0.05 eV on the sum of the neutrino masses.

For a total mass as small as $0.1\,\mathrm{eV}$, this could have a potentially observable effect on the formation of structure, as neutrino free-streaming damps the growth of perturbations. Present cosmological observations have shown no convincing evidence of any effects from either neutrino masses or an otherwise non-standard neutrino sector, and impose quite stringent limits, which we summarize in Section 23.3.4. Accordingly, the usual assumption is that the masses are too small to have a significant cosmological impact at present data accuracy. However, we note that the inclusion of neutrino mass as a free parameter can affect the derived values of other cosmological parameters.

The cosmological effect of neutrinos can also be modified if the neutrinos have decay channels, or if there is a large asymmetry in the lepton sector manifested as a different number density of neutrinos versus anti-neutrinos. This latter effect would need to be of order unity to be significant (rather than the 10^{-9} seen in the baryon sector), which may be in conflict with nucleosynthesis [5].

23.1.3. Inflation and perturbations:

A complete model of the Universe should include a description of deviations from homogeneity, at least in a statistical way. Indeed, some of the most powerful probes of the parameters described above come from the evolution of perturbations, so their study is naturally intertwined in the determination of cosmological parameters.

There are many different notations used to describe the perturbations, both in terms of the quantity used to describe the perturbations and the definition of the statistical measure. We use the dimensionless power spectrum Δ^2 as defined in Olive and Peacock (also denoted $\mathcal P$ in some of the literature). If the perturbations obey Gaussian statistics, the power spectrum provides a complete description of their properties.

From a theoretical perspective, a useful quantity to describe the perturbations is the curvature perturbation \mathcal{R} , which measures the spatial curvature of a comoving slicing of the space-time. A case of particular interest is the Harrison–Zel'dovich spectrum, which corresponds to a constant $\Delta^2_{\mathcal{R}}$. More generally, one can approximate the spectrum by a power-law, writing

$$\Delta_{\mathcal{R}}^2(k) = \Delta_{\mathcal{R}}^2(k_*) \left[\frac{k}{k_*} \right]^{n-1} , \qquad (23.3)$$

where n is known as the spectral index, always defined so that n=1 for the Harrison–Zel'dovich spectrum, and k_* is an arbitrarily chosen scale. The initial spectrum, defined at some early epoch of the Universe's history, is usually taken to have a simple form such as this power-law, and we will see that observations require n close to one, which corresponds to the perturbations in the curvature being independent of scale. Subsequent evolution will modify the spectrum from its initial form.

The simplest viable mechanism for generating the observed perturbations is the inflationary cosmology, which posits a period of accelerated expansion in the Universe's early stages [6,7]. It is a useful working hypothesis that this is the sole mechanism for generating perturbations, and it may further be assumed to be the simplest class of inflationary model, where the dynamics are equivalent to that of a single scalar field ϕ slowly rolling on a potential $V(\phi)$. One may seek to verify that this simple picture can match observations and to determine the properties of $V(\phi)$ from the observational data. Alternatively, more complicated models, perhaps motivated by contemporary fundamental physics ideas, may be tested on a model-by-model basis.

Inflation generates perturbations through the amplification of quantum fluctuations, which are stretched to astrophysical scales by the rapid expansion. The simplest models generate two types, density perturbations which come from fluctuations in the scalar field and its corresponding scalar metric perturbation, and gravitational waves which are tensor metric fluctuations. The former experience gravitational instability and lead to structure formation, while the latter can influence the CMB anisotropies. Defining slow-roll parameters, with primes indicating derivatives with respect to the scalar field, as

$$\epsilon = \frac{m_{\rm Pl}^2}{16\pi} \left(\frac{V'}{V}\right)^2 \quad ; \quad \eta = \frac{m_{\rm Pl}^2 V''}{8\pi V},$$
(23.4)

which should satisfy ϵ , $|\eta| \ll 1$, the spectra can be computed using the slow-roll approximation as

$$\Delta_{\mathcal{R}}^2(k) \simeq \frac{8}{3m_{\text{Pl}}^4} \frac{V}{\epsilon} \bigg|_{k=aH} \quad ; \quad \Delta_{\text{grav}}^2(k) \simeq \frac{128}{3m_{\text{Pl}}^4} V \bigg|_{k=aH} \quad . \quad (23.5)$$

In each case, the expressions on the right-hand side are to be evaluated when the scale k is equal to the Hubble radius during inflation. The symbol ' \simeq ' here indicates use of the slow-roll approximation, which is expected to be accurate to a few percent or better.

From these expressions, we can compute the spectral indices

$$n \simeq 1 - 6\epsilon + 2\eta$$
 ; $n_{\text{grav}} \simeq -2\epsilon$. (23.6)

Another useful quantity is the ratio of the two spectra, defined by

$$r \equiv \frac{\Delta_{\text{grav}}^2(k_*)}{\Delta_{\mathcal{D}}^2(k_*)} \,. \tag{23.7}$$

This convention matches that used by WMAP [2] (there are some alternative historical definitions which lead to a slightly different prefactor in the following equation). We have

$$r \simeq 16\epsilon \simeq -8n_{\rm grav}$$
, (23.8)

which is known as the consistency equation.

In general, one could consider corrections to the power-law approximation, which we discuss later. However, for now we make the working assumption that the spectra can be approximated by power laws. The consistency equation shows that r and $n_{\rm grav}$ are not independent parameters, and so the simplest inflation models give initial conditions described by three parameters, usually taken as $\Delta^2_{\mathcal{R}}$, n, and r, all to be evaluated at some scale k_* , usually the 'statistical center' of the range explored by the data. Alternatively, one could use the parametrization V, ϵ , and η , all evaluated at a point on the putative inflationary potential.

After the perturbations are created in the early Universe, they undergo a complex evolution up until the time they are observed in the present Universe. While the perturbations are small, this can be accurately followed using a linear theory numerical code such as CMBFAST or CAMB [8]. This works right up to the present for the CMB, but for density perturbations on small scales non-linear evolution is important and can be addressed by a variety of semi-analytical and numerical techniques. However the analysis is made, the outcome of the evolution is in principle determined by the cosmological model, and by the parameters describing the initial perturbations, and hence can be used to determine them.

Of particular interest are CMB anisotropies. Both the total intensity and two independent polarization modes are predicted to have anisotropies. These can be described by the radiation angular power spectra C_ℓ as defined in the article of Scott and Smoot in this volume, and again provide a complete description if the density perturbations are Gaussian.

${\bf 23.1.4.} \quad The \ standard \ cosmological \ model:$

We now have most of the ingredients in place to describe the cosmological model. Beyond those of the previous subsections, there are two parameters which are essential: a measure of the ionization state of the Universe and the galaxy bias parameter. The Universe is known to be highly ionized at low redshifts (otherwise radiation from distant quasars would be heavily absorbed in the ultra-violet), and the ionized electrons can scatter microwave photons altering the pattern of observed anisotropies. The most convenient parameter to describe this is the optical depth to scattering τ (i.e., the probability that a given photon scatters once); in the approximation of instantaneous and complete reionization, this could equivalently be described by the redshift of reionization z_{ion} . The bias parameter, described fully later, is needed to relate the observed galaxy power spectrum to the predicted dark matter power spectrum. The basic set of cosmological parameters is therefore as shown in Table 23.1. The spatial curvature does not appear in the list, because it can be determined from the other parameters using Eq. (23.1) (and is assumed zero for the observed

values shown). The total present matter density $\Omega_{\rm m} = \Omega_{\rm cdm} + \Omega_{\rm b}$ is sometimes used in place of the dark matter density.

Most attention to date has been on parameter estimation, where a set of parameters is chosen by hand and the aim is to constrain them. Interest has been growing towards the higher-level inference problem of model selection, which compares different choices of parameter sets. Bayesian inference offers an attractive framework for cosmological model selection, setting a tension between model predictiveness and ability to fit the data.

Table 23.1: The basic set of cosmological parameters. We give values (with some additional rounding) as obtained using a fit of a spatially-flat Λ CDM cosmology with a power-law initial spectrum to WMAP7 data alone: Table 10, left column of Ref. 2. Tensors are assumed zero except in quoting a limit on them. The exact values and uncertainties depend on both the precise data-sets used and the choice of parameters allowed to vary. Limits on Ω_{Λ} and h weaken if the Universe is not assumed flat. The density perturbation amplitude is specified by the derived parameter σ_8 . Uncertainties are one-sigma/68% confidence unless otherwise stated.

| Parameter | Symbol | Value |
|-----------------------------------------------------------|--------------------------|-------------------------------------------|
| Hubble parameter | h | 0.704 ± 0.025 |
| Cold dark matter density | $\Omega_{ m cdm}$ | $\Omega_{\rm cdm} h^2 = 0.112 \pm 0.006$ |
| Baryon density | $\Omega_{ m b}$ | $\Omega_{\rm b}h^2 = 0.0225 \pm 0.0006$ |
| Cosmological constant | Ω_{Λ} | 0.73 ± 0.03 |
| Radiation density | $\Omega_{ m r}$ | $\Omega_{\rm r}h^2 = 2.47 \times 10^{-5}$ |
| Neutrino density | $\Omega_{ u}$ | See Sec. 23.1.2 |
| Density perturb. amplitude at $k = 0.002 \text{Mpc}^{-1}$ | $\Delta_{\mathcal{R}}^2$ | $(2.43 \pm 0.11) \times 10^{-9}$ |
| Density perturb. spectral index | n | 0.967 ± 0.014 |
| Tensor to scalar ratio | r | $r < 0.36 \ (95\% \ \text{conf.})$ |
| Ionization optical depth | au | 0.088 ± 0.015 |
| Bias parameter | b | See Sec. 23.3.4 |

As described in Sec. 23.4, models based on these eleven parameters are able to give a good fit to the complete set of high-quality data available at present, and indeed some simplification is possible. Observations are consistent with spatial flatness, and indeed the inflation models so far described automatically generate negligible spatial curvature, so we can set k = 0; the density parameters then must sum to unity, and so one can be eliminated. The neutrino energy density is often not taken as an independent parameter. Provided the neutrino sector has the standard interactions, the neutrino energy density, while relativistic, can be related to the photon density using thermal physics arguments, and it is currently difficult to see the effect of the neutrino mass, although observations of large-scale structure have already placed interesting upper limits. This reduces the standard parameter set to nine. In addition, there is no observational evidence for the existence of tensor perturbations (though the upper limits are fairly weak), and so r could be set to zero. Presently n is in a somewhat uncertain position regarding whether it needs to be varied in a fit, or can be set to the Harrison-Zel'dovich value n=1. Parameter estimation [3] indicates n=1 is disfavoured at over $2-\sigma$, but Bayesian model selection techniques [9] suggest the data is not conclusive. With n set to one, this leaves seven parameters, which is the smallest set that can usefully be compared to the present cosmological data set. This model (usually with n kept as a parameter) is referred to by various names, including ΛCDM , the concordance cosmology, and the standard cosmological model.

Of these parameters, only $\Omega_{\rm r}$ is accurately measured directly. The radiation density is dominated by the energy in the CMB, and the COBE satellite FIRAS experiment determined its temperature to be $T=2.7255\pm0.0006\,{\rm K}$ [10], corresponding to $\Omega_{\rm r}=2.47\times10^{-5}h^{-2}$. It typically need not be varied in fitting other data. If galaxy clustering

data are not included in a fit, then the bias parameter is also unnecessary.

In addition to this minimal set, there is a range of other parameters which might prove important in future as the data-sets further improve, but for which there is so far no direct evidence, allowing them to be set to a specific value for now. We discuss various speculative options in the next section. For completeness at this point, we mention one other interesting parameter, the helium fraction, which is a non-zero parameter that can affect the CMB anisotropies at a subtle level. Presently, BBN provides the best measurement of this parameter (see the Fields and Sarkar article in this volume), and it is usually fixed in microwave anisotropy studies, but the data are just reaching a level where allowing its variation may become mandatory.

23.1.5. Derived parameters:

The parameter list of the previous subsection is sufficient to give a complete description of cosmological models which agree with observational data. However, it is not a unique parametrization, and one could instead use parameters derived from that basic set. Parameters which can be obtained from the set given above include the age of the Universe, the present horizon distance, the present neutrino background temperature, the epoch of matter-radiation equality, the epochs of recombination and decoupling, the epoch of transition to an accelerating Universe, the baryon-to-photon ratio, and the baryon to dark matter density ratio. In addition, the physical densities of the matter components, $\Omega_i h^2$, are often more useful than the density parameters. The density perturbation amplitude can be specified in many different ways other than the large-scale primordial amplitude, for instance, in terms of its effect on the CMB, or by specifying a short-scale quantity, a common choice being the present linear-theory mass dispersion on a scale of $8 h^{-1}$ Mpc, known as σ_8 , whose WMAP7 value is 0.81 ± 0.03 [2].

Different types of observation are sensitive to different subsets of the full cosmological parameter set, and some are more naturally interpreted in terms of some of the derived parameters of this subsection than on the original base parameter set. In particular, most types of observation feature degeneracies whereby they are unable to separate the effects of simultaneously varying several of the base parameters.

23.2. Extensions to the standard model

This section discusses some ways in which the standard model could be extended. At present, there is no positive evidence in favor of any of these possibilities, which are becoming increasingly constrained by the data, though there always remains the possibility of trace effects at a level below present observational capability.

23.2.1. More general perturbations:

The standard cosmology assumes adiabatic, Gaussian perturbations. Adiabaticity means that all types of material in the Universe share a common perturbation, so that if the space-time is foliated by constant-density hypersurfaces, then all fluids and fields are homogeneous on those slices, with the perturbations completely described by the variation of the spatial curvature of the slices. Gaussianity means that the initial perturbations obey Gaussian statistics, with the amplitudes of waves of different wavenumbers being randomly drawn from a Gaussian distribution of width given by the power spectrum. Note that gravitational instability generates non-Gaussianity; in this context, Gaussianity refers to a property of the initial perturbations, before they evolve significantly.

The simplest inflation models, based on one dynamical field, predict adiabatic perturbations and a level of non-Gaussianity which is too small to be detected by any experiment so far conceived. For present data, the primordial spectra are usually assumed to be power laws.

23.2.1.1. Non-power-law spectra:

For typical inflation models, it is an approximation to take the spectra as power laws, albeit usually a good one. As data quality improves, one might expect this approximation to come under pressure, requiring a more accurate description of the initial spectra, particularly for the density perturbations. In general, one can expand $\ln \Delta_{\mathcal{R}}^2$ as

$$\ln \Delta_{\mathcal{R}}^2(k) = \ln \Delta_{\mathcal{R}}^2(k_*) + (n_* - 1) \ln \frac{k}{k_*} + \frac{1}{2} \left. \frac{dn}{d \ln k} \right|_{*} \ln^2 \frac{k}{k_*} + \cdots, (23.9)$$

where the coefficients are all evaluated at some scale k_* . The term $dn/d\ln k|_*$ is often called the running of the spectral index [11]. Once non-power-law spectra are allowed, it is necessary to specify the scale k_* at which the spectral index is defined.

23.2.1.2. *Isocurvature perturbations:*

An isocurvature perturbation is one which leaves the total density unperturbed, while perturbing the relative amounts of different materials. If the Universe contains N fluids, there is one growing adiabatic mode and N-1 growing isocurvature modes (for reviews see Ref. 12 and Ref. 7). These can be excited, for example, in inflationary models where there are two or more fields which acquire dynamically-important perturbations. If one field decays to form normal matter, while the second survives to become the dark matter, this will generate a cold dark matter isocurvature perturbation.

In general, there are also correlations between the different modes, and so the full set of perturbations is described by a matrix giving the spectra and their correlations. Constraining such a general construct is challenging, though constraints on individual modes are beginning to become meaningful, with no evidence that any other than the adiabatic mode must be non-zero.

23.2.1.3. Seeded perturbations:

An alternative to laying down perturbations at very early epochs is that they are seeded throughout cosmic history, for instance by topological defects such as cosmic strings. It has long been excluded that these are the sole original of structure, but they could contribute part of the perturbation signal, current limits being approximately ten percent [13]. In particular, cosmic defects formed in a phase transition ending inflation is a plausible scenario for such a contribution.

23.2.1.4. Non-Gaussianity:

Multi-field inflation models can also generate primordial non-Gaussianity (reviewed, e.g., in Ref. 7). The extra fields can either be in the same sector of the underlying theory as the inflaton, or completely separate, an interesting example of the latter being the curvaton model [14]. Current upper limits on non-Gaussianity are becoming stringent, but there remains much scope to push down those limits and perhaps reveal trace non-Gaussianity in the data. If non-Gaussianity is observed, its nature may favor an inflationary origin, or a different one such as topological defects.

23.2.2. Dark matter properties:

Dark matter properties are discussed in the article by Drees and Gerbier in this volume. The simplest assumption concerning the dark matter is that it has no significant interactions with other matter, and that its particles have a negligible velocity as far as structure formation is concerned. Such dark matter is described as 'cold,' and candidates include the lightest supersymmetric particle, the axion, and primordial black holes. As far as astrophysicists are concerned, a complete specification of the relevant cold dark matter properties is given by the density parameter $\Omega_{\rm cdm}$, though those seeking to directly detect it are as interested in its interaction properties.

Cold dark matter is the standard assumption and gives an excellent fit to observations, except possibly on the shortest scales where there remains some controversy concerning the structure of dwarf galaxies and possible substructure in galaxy halos. It has long been excluded for all the dark matter to have a large velocity dispersion, so-called 'hot' dark matter, as it does not permit galaxies to form; for thermal relics the mass must be below about 1 keV to satisfy this

constraint, though relics produced non-thermally, such as the axion, need not obey this limit. However, in future further parameters might need to be introduced to describe dark matter properties relevant to astrophysical observations. Suggestions which have been made include a modest velocity dispersion (warm dark matter) and dark matter self-interactions. There remains the possibility that the dark matter comprises two separate components, e.g., a cold one and a hot one, an example being if massive neutrinos have a non-negligible effect.

23.2.3. Dark energy:

While the standard cosmological model given above features a cosmological constant, in order to explain observations indicating that the Universe is presently accelerating, further possibilities exist under the general heading 'dark energy'. One possibility, usually called quintessence, is that a scalar field is responsible, with the mechanism mimicking that of early Universe inflation [15]. As described by Olive and Peacock, a fairly model-independent description of dark energy can be given using the equation of state parameter w, with w=-1 corresponding to a cosmological constant and w potentially varying with redshift. For high-precision predictions of CMB anisotropies, the scalar-field description has the advantage of a self-consistent evolution of the 'sound speed' associated with the dark energy perturbations.

A competing possibility is that the observed acceleration is due to a modification of gravity, i.e., the left-hand side of Einstein's equation rather than the right (for a review see Ref. 16). Observations of expansion kinematics alone cannot distinguish these two possibilities, but probes of the growth rate of structure formation may be able to. It is possible that certain modified theories of gravity could explain the late-time acceleration of the Universe without recourse to any dark energy or cosmological constant. In a 'Newtonian' gauge the perturbed metric can be written with two potentials. Non-relativistic particles only respond to the temporal one, essentially the Newtonian potential, while relativistic particles, e.g., photons, respond to the full metric in the form of the sum of the two potentials. In standard general relativity the two potentials are the same (in absence of anisotropic stress). Measurements of redshift distortions from spectroscopic surveys and weak lensing from imaging surveys can in principle distinguish between the Dark Energy and Modified Gravity alternatives (e.g., Ref. 17).

While present observations are consistent with a cosmological constant, to test dark energy models w must be varied. The most popular option is $w(a) = w_0 + (1-a)w_a$ with w_0 and w_a constants to be determined [18]. Additionally the weak energy condition $w \ge -1$ may be imposed. Future data may require a more sophisticated parametrization of the dark energy, including its sound speed which influences structure formation.

23.2.4. Complex ionization history:

The full ionization history of the Universe is given by the ionization fraction as a function of redshift z. The simplest scenario takes the ionization to have the small residual value left after recombination up to some redshift $z_{\rm ion}$, at which point the Universe instantaneously reionizes completely. Then there is a one-to-one correspondence between τ and $z_{\rm ion}$ (that relation, however, also depending on other cosmological parameters). An accurate treatment of this process will track separate histories for hydrogen and helium. While currently rapid ionization appears to be a good approximation, as data improve a more complex ionization history may need to be considered.

23.2.5. Varying 'constants':

Variation of the fundamental constants of Nature over cosmological times is another possible enhancement of the standard cosmology. There is a long history of study of variation of the gravitational constant G, and more recently attention has been drawn to the possibility of small fractional variations in the fine-structure constant. There is presently no observational evidence for the former, which is tightly constrained by a variety of measurements. Evidence for

the latter has been claimed from studies of spectral line shifts in quasar spectra at redshifts of order two [19], but this is presently controversial and in need of further observational study.

23.2.6. Cosmic topology:

The usual hypothesis is that the Universe has the simplest topology consistent with its geometry, for example that a flat Universe extends forever. Observations cannot tell us whether that is true, but they can test the possibility of a non-trivial topology on scales up to roughly the present Hubble scale. Extra parameters would be needed to specify both the type and scale of the topology, for example, a cuboidal topology would need specification of the three principal axis lengths. At present, there is no direct evidence for cosmic topology, though the low values of the observed cosmic microwave quadrupole and octupole have been cited as a possible signature [20].

23.3. Probes

The goal of the observational cosmologist is to utilize astronomical information to derive cosmological parameters. The transformation from the observables to the key parameters usually involves many assumptions about the nature of the objects, as well as about the nature of the dark matter. Below we outline the physical processes involved in each probe, and the main recent results. The first two subsections concern probes of the homogeneous Universe, while the remainder consider constraints from perturbations.

In addition to statistical uncertainties we note three sources of systematic uncertainties that will apply to the cosmological parameters of interest: (i) due to the assumptions on the cosmological model and its priors (i.e., the number of assumed cosmological parameters and their allowed range); (ii) due to the uncertainty in the astrophysics of the objects (e.g., light curve fitting for supernovae or the mass–temperature relation of galaxy clusters); and (iii) due to instrumental and observational limitations (e.g., the effect of 'seeing' on weak gravitational lensing measurements, or beam shape on CMB anisotropy measurements).

23.3.1. Direct measures of the Hubble constant:

In 1929, Edwin Hubble discovered the law of expansion of the Universe by measuring distances to nearby galaxies. The slope of the relation between the distance and recession velocity is defined to be the Hubble constant H_0 . Astronomers argued for decades on the systematic uncertainties in various methods and derived values over the wide range, $40\,\mathrm{km\,s^{-1}\,Mpc^{-1}} \lesssim H_0 \lesssim 100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$.

One of the most reliable results on the Hubble constant comes from the Hubble Space Telescope Key Project [21]. This study used the empirical period–luminosity relations for Cepheid variable stars to obtain distances to 31 galaxies, and calibrated a number of secondary distance indicators—Type Ia Supernovae (SNe Ia), the Tully–Fisher relation, surface-brightness fluctuations, and Type II Supernovae—measured over distances of 400 to 600 Mpc. They estimated $H_0=72\pm3$ (statistical) ±7 (systematic) km s $^{-1}$ Mpc $^{-1}$. \ddagger

A recent study [22] of over 600 Cepheids in the host galaxies of eight recent SNe Ia, observed with an improved camera on board the Hubble Space Telescope, was used to calibrate the magnitude–redshift relation for 240 SNe Ia. This yielded an even more accurate figure, $H_0 = 73.8 \pm 2.4 \, \mathrm{km \, s^{-1} \, Mpc^{-1}}$ (including both statistical and systematic errors). The major sources of uncertainty in this result are due to the heavy element abundance of the Cepheids and the distance to the fiducial nearby galaxy, the Large Magellanic Cloud, relative to which all Cepheid distances are measured. It is impressive that this result is in such good agreement with the result derived from the WMAP CMB measurements combined with other probes (see Table 23.2).

[†] It is actually the negative pressure of this material, not its energy, that is responsible for giving the acceleration. Furthermore, while generally in physics matter and energy are interchangeable terms, dark matter and dark energy are quite distinct concepts.

[‡] Unless stated otherwise, all quoted uncertainties in this article are one-sigma/68% confidence. Cosmological parameters often have significantly non-Gaussian uncertainties. Throughout we have rounded central values, and especially uncertainties, from original sources in cases where they appear to be given to excessive precision.

${\bf 23.3.2.} \quad Supernovae \ as \ cosmological \ probes:$

The relation between observed flux and the intrinsic luminosity of an object depends on the luminosity distance $D_{\rm L}$, which in turn depends on cosmological parameters:

$$D_{\rm L} = (1+z)r_e(z)\,, (23.10)$$

where $r_e(z)$ is the coordinate distance. For example, in a flat Universe

$$r_e(z) = \int_0^z \frac{dz'}{H(z')}$$
 (23.11)

For a general dark energy equation of state $w(z) = p_{\rm de}(z)/\rho_{\rm de}(z)$, the Hubble parameter is, still considering only the flat case,

$$\frac{H^2(z)}{H_0^2} = (1+z)^3 \Omega_{\rm m} + \Omega_{\rm de} \exp[3X(z)], \qquad (23.12)$$

where

$$X(z) = \int_0^z [1 + w(z')](1 + z')^{-1} dz', \qquad (23.13)$$

and Ω_{de} is the present density parameter of the dark energy component. If a general equation of state is allowed, then one has to solve for w(z) (parametrized, for example, as $w(z) = w = \mathrm{const.}$, or $w(z) = w_0 + w_1 z$) as well as for Ω_{de} .

Empirically, the peak luminosity of SNe Ia can be used as an efficient distance indicator (e.g., Ref. 23). The favorite theoretical explanation for SNe Ia is the thermonuclear disruption of carbon–oxygen white dwarfs. Although not perfect 'standard candles,' it has been demonstrated that by correcting for a relation between the light curve shape, color, and the luminosity at maximum brightness, the dispersion of the measured luminosities can be greatly reduced. There are several possible systematic effects which may affect the accuracy of the use of SNe Ia as distance indicators, e.g., evolution with redshift and interstellar extinction in the host galaxy and in the Milky Way.

Two major studies, the Supernova Cosmology Project and the High-z Supernova Search Team, found evidence for an accelerating Universe [24], interpreted as due to a cosmological constant or a dark energy component. Representative results from the 'Union sample' [25] of over 300 SNe Ia are shown in Fig. 23.1 (see also further results in Ref. 26). When combined with the CMB data (which indicates flatness, i.e., $\Omega_{\rm m} + \Omega_{\Lambda} \approx 1$), the best-fit values are $\Omega_{\rm m} \approx 0.3$ and $\Omega_{\Lambda} \approx 0.7$. Most results in the literature are consistent with the w=-1 cosmological constant case. As an example of recent results, the SNLS3 team found, for a constant equation of state parameter, $w=-0.91^{+0.16}_{-0.20} ({\rm stat.})^{+0.07}_{-0.14} ({\rm sys.})$ [27]. This includes a correction for the recently-discovered relationship between host galaxy mass and supernova absolute brightness. This agrees with earlier results [25,28]. Future experiments will aim to set constraints on the cosmic equation of state w(z), though given the integral relation between the luminosity distance and w(z) it is not straightforward to recover w(z) (e.g., Ref. 29).

${\bf 23.3.3.} \quad Cosmic\ microwave\ background:$

The physics of the CMB is described in detail by Scott and Smoot in this volume. Before recombination, the baryons and photons are tightly coupled, and the perturbations oscillate in the potential wells generated primarily by the dark matter perturbations. After decoupling, the baryons are free to collapse into those potential wells. The CMB carries a record of conditions at the time of last scattering, often called primary anisotropies. In addition, it is affected by various processes as it propagates towards us, including the effect of a time-varying gravitational potential (the integrated Sachs-Wolfe effect), gravitational lensing, and scattering from ionized gas at low redshift.

The primary anisotropies, the integrated Sachs-Wolfe effect, and scattering from a homogeneous distribution of ionized gas, can all be calculated using linear perturbation theory. Available codes include CMBFAST and CAMB [8], the latter widely used embedded within the analysis package CosmoMC [30]. Gravitational lensing is also calculated in these codes. Secondary effects such as inhomogeneities in the reionization process, and scattering from gravitationally-collapsed gas (the Sunyaev–Zel'dovich effect), require more complicated, and more uncertain, calculations.

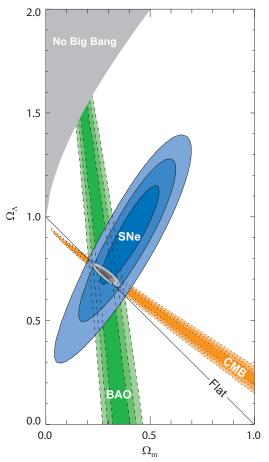


Figure 23.1: Confidence level contours of 68.3%, 95.4% and 99.7% in the Ω_{Λ} - $\Omega_{\rm m}$ plane from the CMB, BAOs and the Union SNe Ia set, as well as their combination (assuming w=-1). [Courtesy of Kowalski *et al.* [25]]

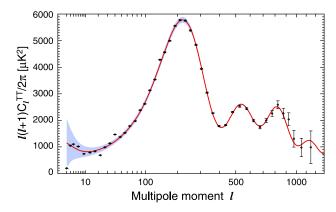


Figure 23.2: The angular power spectrum of the CMB temperature anisotropies from WMAP7, from Ref. 2. The grey band indicates the cosmic variance uncertainty. The solid line shows the prediction from the best-fitting Λ CDM model. [Figure courtesy NASA/WMAP Science Team.]

The upshot is that the detailed pattern of anisotropies depends on all of the cosmological parameters. In a typical cosmology, the anisotropy power spectrum [usually plotted as $\ell(\ell+1)C_\ell$] features a flat plateau at large angular scales (small ℓ), followed by a series of oscillatory features at higher angular scales, the first and most prominent being at around one degree ($\ell \simeq 200$). These features, known as acoustic peaks, represent the oscillations of the photon-baryon fluid around the time of decoupling. Some features can be

closely related to specific parameters—for instance, the location of the first peak probes the spatial geometry, while the relative heights of the peaks probes the baryon density—but many other parameters combine to determine the overall shape.

The seven-year data release from the WMAP satellite [1], henceforth WMAP7, has provided the most powerful results to date on the spectrum of CMB anisotropies, with a precision determination of the temperature power spectrum up to $\ell \simeq 900$, shown in Fig. 23.2, as well as measurements of the spectrum of E-polarization anisotropies and the correlation spectrum between temperature and polarization (those spectra having first been detected by DASI [31]) . These are consistent with models based on the parameters we have described, and provide accurate determinations of many of those parameters [2].

WMAP7 provides an exquisite measurement of the location of the first acoustic peak, determining the angular-diameter distance of the last-scattering surface. In combination with other data this strongly constrains the spatial geometry, in a manner consistent with spatial flatness and excluding significantly-curved Universes. WMAP7 also gives a precision measurement of the age of the Universe. It gives a baryon density consistent with, and at higher precision than, that coming from BBN. It affirms the need for both dark matter and dark energy. It shows no evidence for dynamics of the dark energy, being consistent with a pure cosmological constant (w = -1). The density perturbations are consistent with a power-law primordial spectrum, with indications that the spectral slope may be less than the Harrison–Zel'dovich value n=1 [2]. There is no indication of tensor perturbations, but the upper limit is quite weak. WMAP7's current best-fit for the reionization optical depth, $\tau = 0.088$, is in reasonable agreement with models of how early structure formation induces reionization.

WMAP7 is consistent with other experiments and its dynamic range can be enhanced by including information from small-angle CMB experiments such as ACBAR, QUaD, the South Pole Telescope (SPT), and the Atacama Cosmology Telescope (ACT), which gives extra constraining power on some parameters. ACT has also announced the first detection of gravitational lensing of the CMB from the four-point correlation of temperature variations [32], agreeing with the expected effect in the standard cosmology.

23.3.4. Galaxy clustering:

The power spectrum of density perturbations depends on the nature of the dark matter. Within the Λ CDM model, the power spectrum shape depends primarily on the primordial power spectrum and on the combination $\Omega_{\rm m}h$ which determines the horizon scale at matter–radiation equality, with a subdominant dependence on the baryon density.

The matter distribution is most easily probed by observing the galaxy distribution, but this must be done with care as the galaxies do not perfectly trace the dark matter distribution. Rather, they are a 'biased' tracer of the dark matter. The need to allow for such bias is emphasized by the observation that different types of galaxies show bias with respect to each other. In particular scale-dependent and stochastic biasing may introduce a systematic effect on the determination of cosmological parameters from redshift surveys. Prior knowledge from simulations of galaxy formation or from gravitational lensing data could help to quantify biasing. Furthermore, the observed 3D galaxy distribution is in redshift space, i.e., the observed redshift is the sum of the Hubble expansion and the line-of-sight peculiar velocity, leading to linear and non-linear dynamical effects which also depend on the cosmological parameters. On the largest length scales, the galaxies are expected to trace the location of the dark matter, except for a constant multiplier b to the power spectrum, known as the linear bias parameter. On scales smaller than 20 h^{-1} Mpc or so, the clustering pattern is 'squashed' in the radial direction due to coherent infall, which depends approximately on the parameter $\beta \equiv \Omega_{\rm m}^{0.6}/b$ (on these shorter scales, more complicated forms of biasing are not excluded by the data). On scales of a few h^{-1} Mpc, there is an effect of elongation along the line of sight (colloquially known as the 'finger of God' effect) which depends on the galaxy velocity dispersion.

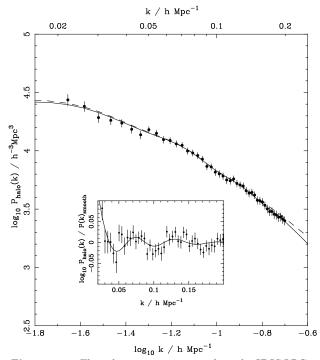


Figure 23.3: The galaxy power spectrum from the SDSS LRGs. The best-fit LRG+WMAP Λ CDM model is shown for two sets of nuisance parameters (solid and dashed lines). The BAO inset shows the same data and model divided by a spline fit to the smooth component. [Figure courtesy B. Reid/W. Percival; see Ref. 35.]

23.3.4.1. Baryonic Acoustic Oscillations (BAOs):

The Fourier power spectra of the 2-degree Field (2dF) Galaxy Redshift Survey and the Sloan Digital Sky Survey (SDSS) are well fitted by a $\Lambda \rm{CDM}$ model and both surveys show evidence for BAOs [33,34]. Further analyses used the Luminous Red Galaxies (LRGs) in the SDSS 7th Data Release [35], shown in Fig. 23.3. Combining the so-called 'halo' power spectrum measurement with the then-current WMAP5 results, for the flat $\Lambda \rm{CDM}$ model they find $\Omega_{\rm m}=0.289\pm0.019$ and $H_0=69.4\pm1.6$ km s $^{-1}$ Mpc $^{-1}$. A new survey, WiggleZ, combined with the 6dF and SDSS-LRG surveys, CMB and SNIa data, yields a constant equation of state $w=-1.03\pm0.08$ for a flat universe, consistent with a cosmological constant. However, allowing for epoch-dependent $w(a)=w_0+(1-a)w_a$ they find that the uncertainties are much larger, $w_0=-1.09\pm0.17$ and $w_a=0.19\pm0.69$ [36]. Further BAO results are expected from the BOSS survey.

23.3.4.2. Integrated Sachs-Wolfe effect:

The integrated Sachs–Wolfe (ISW) effect, described in the article by Scott and Smoot, is the change in CMB photon energy when propagating through the changing gravitational potential wells of developing cosmic structures. In linear theory, the ISW signal is expected in universes where there is dark energy, curvature or modified gravity. Correlating the large-angle CMB anisotropies with very large scale structures, first proposed in Ref. 37, has provided results which vary from no detection of this effect to 4σ detection [38,39].

23.3.4.3. Limits on neutrino mass from galaxy surveys and other probes:

Large-scale structure data can put an upper limit on Ω_{ν} due to the neutrino 'free streaming' effect [40–43]. Upper limits on neutrino mass are commonly estimated by comparing the observed galaxy power spectrum with a four-component model of baryons, cold dark matter, a cosmological constant, and massive neutrinos. Such analyses also assume that the primordial power spectrum is adiabatic, scale-invariant, and Gaussian. Potential systematic effects include biasing of the galaxy distribution and non-linearities of the

power spectrum. An upper limit can also be derived from CMB anisotropies alone, but it is typically not below 2 eV [44]. Additional cosmological data sets can improve the results. Recent results using a photometric redshift sample of LRGs combined with WMAP, BAO, Hubble constant and SNe Ia data brought the upper limit on the total neutrino mass down to 0.28 eV [45], with a similar result for a combination of other data sets [46]. As the lower limit on neutrino mass from terrestrial experiments is 0.05 eV, it looks promising that cosmological surveys will detect the neutrino mass. Another probe of neutrino mass is the intergalactic medium, which manifests itself in quasar absorption lines (the Lyman- α forest), yielding from the SDSS flux power spectrum an upper limit of 0.9 eV (95% confidence) [47].

23.3.5. Clusters of galaxies:

A cluster of galaxies is a large collection of galaxies held together by their mutual gravitational attraction. The largest ones are around 10^{15} Solar masses, and are the largest gravitationally-collapsed structures in the Universe. Even at the present epoch they are relatively rare, with only a few percent of galaxies being in clusters. They provide various ways to study the cosmological parameters.

The first objects of a given kind form at the rare high peaks of the density distribution, and if the primordial density perturbations are Gaussian distributed, their number density is exponentially sensitive to the size of the perturbations, and hence can strongly constrain it. Clusters are an ideal application in the present Universe. They are usually used to constrain the amplitude σ_8 , as a box of side $8 h^{-1}$ Mpc contains about the right amount of material to form a cluster. The most useful observations at present are of X-ray emission from hot gas lying within the cluster, whose temperature is typically a few keV, and which can be used to estimate the mass of the cluster. A theoretical prediction for the mass function of clusters can come either from semi-analytic arguments or from numerical simulations. The same approach can be adopted at high redshift (which for clusters means redshifts of order one) to attempt to measure σ_8 at an earlier epoch. The evolution of σ_8 is primarily driven by the value of the matter density $\Omega_{\rm m}$, with a sub-dominant dependence on the dark energy properties.

At present, the main uncertainty is the relation between the observed gas temperature and the cluster mass, despite extensive study using simulations. Mantz et al. [48] used a large sample of X-ray selected clusters to find $\sigma_8=0.82\pm0.05,\,\Omega_{\rm m}=0.23\pm0.04,$ and $w=-1.01\pm0.20$ for a constant dark energy equation of state w. This agrees well with the values predicted in cosmologies compatible with WMAP7.

A further use of clusters is to measure the ratio of baryon to dark matter mass, through modelling of the way the hot cluster gas is confined by the total gravitational potential. Allen *et al.* [49] give examples of constraints that can be obtained this way on both dark matter and dark energy using Chandra data across a range of redshifts.

23.3.6. Clustering in the inter-galactic medium:

It is commonly assumed, based on hydrodynamic simulations, that the neutral hydrogen in the inter-galactic medium (IGM) can be related to the underlying mass distribution. It is then possible to estimate the matter power spectrum on scales of a few megaparsecs from the absorption observed in quasar spectra, the so-called Lyman- α forest. The usual procedure is to measure the power spectrum of the transmitted flux, and then to infer the mass power spectrum. Photo-ionization heating by the ultraviolet background radiation and adiabatic cooling by the expansion of the Universe combine to give a simple power-law relation between the gas temperature and the baryon density. It also follows that there is a power-law relation between the optical depth τ and $\rho_{\rm b}$. Therefore, the observed flux $F=\exp(-\tau)$ is strongly correlated with $\rho_{\rm b}$, which itself traces the mass density. The matter and flux power spectra can be related by

$$P_{\rm m}(k) = b^2(k) P_F(k),$$
 (23.14)

where b(k) is a bias function which is calibrated from simulations. Croft *et al.* [50] derived cosmological parameters from Keck Telescope observations of the Lyman- α forest at redshifts z=2 to 4. Their derived power spectrum corresponds to that of a CDM model, which is in good agreement with the 2dF galaxy power spectrum. A recent study using VLT spectra [51] agrees with the flux power spectrum of Ref. 50. This method depends on various assumptions. Seljak et al. [52] pointed out that uncertainties are sensitive to the range of cosmological parameters explored in the simulations, and the treatment of the mean transmitted flux. Nevertheless, this method has the potential of measuring accurately the power spectrum of mass perturbations in a different way to other methods.

23.3.7. Gravitational lensing:

Images of background galaxies are distorted by the gravitational effect of mass variations along the line of sight. Deep gravitational potential wells such as galaxy clusters generate 'strong lensing', leading to arcs, arclets and multiple images, while more moderate perturbations give rise to 'weak lensing'. Weak lensing is now widely used to measure the mass power spectrum in selected regions of the sky (see Ref. 53 for recent reviews). As the signal is weak, the image of deformed galaxy shapes (the 'shear map') must be analyzed statistically to measure the power spectrum, higher moments, and cosmological parameters.

The shear measurements are mainly sensitive to the combination of $\Omega_{\rm m}$ and the amplitude σ_8 . For example, the weak lensing signal detected by the CFHT Legacy Survey has been analyzed to yield $\sigma_8(\Omega_{\rm m}/0.25)^{0.64}=0.78\pm0.04$ [54] and $\sigma_8(\Omega_{\rm m}/0.24)^{0.59}=0.84\pm0.05$ [55] assuming a $\Lambda{\rm CDM}$ model. Earlier results are summarized in Ref. 53. There are various systematic effects in the interpretation of weak lensing, e.g., due to atmospheric distortions during observations, the redshift distribution of the background galaxies, the intrinsic correlation of galaxy shapes, and non-linear modeling uncertainties.

23.3.8. Peculiar velocities:

Deviations from the Hubble flow directly probe the mass perturbations in the Universe, and hence provide a powerful probe of the dark matter [56]. Peculiar velocities are deduced from the difference between the redshift and the distance of a galaxy. The observational difficulty is in accurately measuring distances to galaxies. Even the best distance indicators (e.g., the Tully–Fisher relation) give an uncertainty of 15% per galaxy, hence limiting the application of the method at large distances. Peculiar velocities are mainly sensitive to $\Omega_{\rm m}$, not to Ω_{Λ} or dark energy. While at present cosmological parameters derived from peculiar velocities are strongly affected by random and systematic errors, a new generation of surveys may improve their accuracy. Three promising approaches are the 6dF near-infrared survey of 15,000 peculiar velocities, peculiar velocities of SNe Ia, and the kinematic Sunyaev–Zel'dovich effect.

There is also a renewed interest in 'redshift distortion'. As the measured redshift of a galaxy is the sum of its redshift due to the Hubble expansion and its peculiar velocity, this distortion depends on cosmological parameters [57] via the perturbation growth rate $f(z) = d \ln \delta/d \ln a \approx \Omega^{\gamma}(z)$, where $\gamma = 0.55$ for a concordance ΛCDM model, and is different for a modified gravity model. Recent observational results [58,59] show that by measuring f(z) with redshift it is feasible to constrain γ and rule out certain modified gravity models.

23.4. Bringing observations together

Although it contains two ingredients—dark matter and dark energy—which have not yet been verified by laboratory experiments, the $\Lambda \mathrm{CDM}$ model is almost universally accepted by cosmologists as the best description of the present data. The basic ingredients are given by the parameters listed in Sec. 23.1.4, with approximate values of some of the key parameters being $\Omega_\mathrm{b} \approx 0.05$, $\Omega_\mathrm{cdm} \approx 0.23$, $\Omega_\Lambda \approx 0.72$, and a Hubble constant $h \approx 0.70$. The spatial geometry is very close to flat (and usually assumed to be precisely flat), and the initial perturbations Gaussian, adiabatic, and nearly scale-invariant.

The most powerful single experiment is WMAP7, which on its own supports all these main tenets. Values for some parameters, as given in Larson *et al.* [2] and Komatsu *et al.* [3], are reproduced in Table 23.2. These particular results presume a flat Universe. The

constraints are somewhat strengthened by adding additional data-sets, as shown in the Table, though most of the constraining power resides in the WMAP7 data.

Table 23.2: Parameter constraints reproduced from Larson et al. [2] and Komatsu et al. [3], with some additional rounding. All columns assume the ΛCDM cosmology with a power-law initial spectrum, no tensors, spatial flatness, and a cosmological constant as dark energy. Above the line are the six parameter combinations actually fit to the data; those below the line are derived from these. Two different data combinations are shown to highlight the extent to which this choice matters. The first column is WMAP7 alone, while the second column shows a combination of WMAP7 with BAO and H_0 data as described in Ref. 3. The perturbation amplitude $\Delta_{\mathcal{R}}^2$ is specified at the scale $0.002\,\mathrm{Mpc}^{-1}$. Uncertainties are shown at 68% confidence.

| | WMAP7 alone | WMAP7 + BAO + H_0 |
|--------------------------------------|---------------------|---------------------|
| $\Omega_{\rm b}h^2$ | 0.0225 ± 0.0006 | 0.0226 ± 0.0005 |
| $\Omega_{\rm cdm} h^2$ | 0.112 ± 0.006 | 0.113 ± 0.004 |
| Ω_{Λ} | 0.73 ± 0.03 | 0.725 ± 0.016 |
| n | 0.967 ± 0.014 | 0.968 ± 0.012 |
| au | 0.088 ± 0.015 | 0.088 ± 0.014 |
| $\Delta_{\mathcal{R}}^2 \times 10^9$ | 2.43 ± 0.11 | 2.43 ± 0.09 |
| h | 0.704 ± 0.025 | 0.702 ± 0.014 |
| σ_8 | 0.81 ± 0.03 | 0.816 ± 0.024 |
| $\Omega_{\mathrm{m}}h^{2}$ | 0.134 ± 0.006 | 0.135 ± 0.004 |
| | | • |

If the assumption of spatial flatness is lifted, it turns out that WMAP7 on its own only weakly constrains the spatial curvature, due to a parameter degeneracy in the angular-diameter distance. However inclusion of other data readily removes this, e.g., inclusion of BAO and H_0 data, plus the assumption that the dark energy is a cosmological constant, yields a constraint on $\Omega_{\rm tot} \equiv \sum \Omega_i + \Omega_\Lambda$ of $\Omega_{\rm tot} = 1.002 \pm 0.011$ [3]. Results of this type are normally taken as justifying the restriction to flat cosmologies.

The baryon density $\Omega_{\rm b}$ is now measured with quite high accuracy from the CMB and large-scale structure, and is consistent with the determination from BBN; Fields and Sarkar in this volume quote the range $0.019 \leq \Omega_{\rm b}h^2 \leq 0.024$ (95% confidence).

While Ω_{Λ} is measured to be non-zero with very high confidence, there is no evidence of evolution of the dark energy density. The WMAP team find the constraint $w=-0.98\pm0.05$ on a constant equation of state from a compilation of data including SNe Ia, with the cosmological constant case w=-1 giving an excellent fit to the data. Allowing more complicated forms of dark energy weakens the limits.

The data provide strong support for the main predictions of the simplest inflation models: spatial flatness and adiabatic, Gaussian, nearly scale-invariant density perturbations. But it is disappointing that there is no sign of primordial gravitational waves, with WMAP7 alone providing only an upper limit r < 0.36 at 95% confidence [2] (this assumes no running, weakening to 0.49 if running is allowed). The spectral index n is placed in an interesting position, with indications that n < 1 is required by the data. However, the confidence with which n = 1 is ruled out is still rather weak, and in our view it is premature to conclude that n = 1 is no longer viable.

Tests have been made for various types of non-Gaussianity, a particular example being a parameter $f_{\rm NL}$ which measures a quadratic contribution to the perturbations. Various non-gaussianity shapes are possible (see Ref. 3 for details), and current constraints on the popular 'local', 'equilateral', and 'orthogonal' types are $-10 < f_{\rm NL}^{\rm local} < 74$,

 $-210 < f_{\rm NL}^{\rm equil} < 270,$ and $-410 < f_{\rm NL}^{\rm orthog} < 6$ at 95% confidence (these look weak, but prominent non-Gaussianity requires the product $f_{\rm NL}\Delta_{\mathcal{R}}$ to be large, and $\Delta_{\mathcal{R}}$ is of order $10^{-5}).$ There is presently no secure indication of primordial non-gaussianity.

One parameter which is very robust is the age of the Universe, as there is a useful coincidence that for a flat Universe the position of the first peak is strongly correlated with the age. The WMAP7 result is 13.77 ± 0.13 Gyr (assuming flatness). This is in good agreement with the ages of the oldest globular clusters and radioactive dating.

23.5. Outlook for the future

The concordance model is now well established, and there seems little room left for any dramatic revision of this paradigm. A measure of the strength of that statement is how difficult it has proven to formulate convincing alternatives.

Should there indeed be no major revision of the current paradigm, we can expect future developments to take one of two directions. Either the existing parameter set will continue to prove sufficient to explain the data, with the parameters subject to ever-tightening constraints, or it will become necessary to deploy new parameters. The latter outcome would be very much the more interesting, offering a route towards understanding new physical processes relevant to the cosmological evolution. There are many possibilities on offer for striking discoveries, for example:

- The cosmological effects of a neutrino mass may be unambiguously detected, shedding light on fundamental neutrino properties;
- Compelling detection of deviations from scale-invariance in the initial perturbations would indicate dynamical processes during perturbation generation by, for instance, inflation;
- Detection of primordial non-Gaussianities would indicate that non-linear processes influence the perturbation generation mechanism:
- Detection of variation in the dark-energy density (i.e., $w \neq -1$) would provide much-needed experimental input into the nature of the properties of the dark energy.

These provide more than enough motivation for continued efforts to test the cosmological model and improve its accuracy.

Over the coming years, there are a wide range of new observations which will bring further precision to cosmological studies. Indeed, there are far too many for us to be able to mention them all here, and so we will just highlight a few areas.

The CMB observations will improve in several directions. A current frontier is the study of polarization, first detected in 2002 by DASI and for which power spectrum measurements have now been made by several experiments. Future measurements may be able to separately detect the two modes of polarization. Another area of development is pushing accurate power spectrum measurements to smaller angular scales, currently well underway with ACT and SPT. Finally, we mention the *Planck* satellite, launched in 2009, which is making high-precision all-sky maps of temperature and polarization, utilizing a very wide frequency range to improve understanding of foreground contaminants, and to compile a large sample of clusters via the Sunyaev–Zel'dovich effect. Its main cosmological results will be published in early 2013.

An impressive array of ground-based dark energy surveys are also already operational, under construction, or proposed, including ground-based imaging surveys the Dark Energy Survey, Pan-STARRS, and LSST, spectroscopic surveys such as BigBOSS and DESpec, and proposed space missions Euclid and WFIRST.

An exciting new area for the future will be radio surveys of the redshifted 21-cm line of hydrogen. Because of the intrinsic narrowness of this line, by tuning of the bandpass the emission from narrow redshift slices of the Universe will be measured to extremely high redshift, probing the details of the reionization process at redshifts up to perhaps 20. LOFAR is the first instrument able to do this and is at an advanced construction and commissioning stage. In the longer term, the Square Kilometer Array (SKA) will take these studies to a precision level.

The above future surveys will address fundamental questions of physics well beyond just testing the 'concordance' Λ CDM model and minor variations. By learning about both the geometry of the universe and the growth of perturbations, it will be possible to test theories of modified gravity and inhomogeneous universes.

The development of the first precision cosmological model is a major achievement. However, it is important not to lose sight of the motivation for developing such a model, which is to understand the underlying physical processes at work governing the Universe's evolution. On that side, progress has been much less dramatic. For instance, there are many proposals for the nature of the dark matter, but no consensus as to which is correct. The nature of the dark energy remains a mystery. Even the baryon density, now measured to an accuracy of a few percent, lacks an underlying theory able to predict it even within orders of magnitude. Precision cosmology may have arrived, but at present many key questions remain to motivate and challenge the cosmology community.

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24. DARK MATTER

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24.1. Theory

24.1.1. Evidence for Dark Matter:

The existence of Dark (i.e., non-luminous and non-absorbing) Matter (DM) is by now well established [1,2]. The earliest, and perhaps still most convincing, evidence for DM came from the observation that various luminous objects (stars, gas clouds, globular clusters, or entire galaxies) move faster than one would expect if they only felt the gravitational attraction of other visible objects. An important example is the measurement of galactic rotation curves. The rotational velocity v of an object on a stable Keplerian orbit with radius r around a galaxy scales like $v(r) \propto \sqrt{M(r)/r}$, where M(r)is the mass inside the orbit. If r lies outside the visible part of the galaxy and mass tracks light, one would expect $v(r) \propto 1/\sqrt{r}$. Instead, in most galaxies one finds that v becomes approximately constant out to the largest values of r where the rotation curve can be measured; in our own galaxy, $v \simeq 240$ km/s at the location of our solar system, with little change out to the largest observable radius. This implies the existence of a dark halo, with mass density $\rho(r) \propto 1/r^2$, i.e., $M(r) \propto r$; at some point ρ will have to fall off faster (in order to keep the total mass of the galaxy finite), but we do not know at what radius this will happen. This leads to a lower bound on the DM mass density, $\Omega_{\rm DM} \gtrsim 0.1$, where $\Omega_X \equiv \rho_X/\rho_{\rm crit}$, $\rho_{\rm crit}$ being the critical mass density (i.e., $\Omega_{\text{tot}} = 1$ corresponds to a flat Universe).

The observation of clusters of galaxies tends to give somewhat larger values, $\Omega_{\rm DM} \simeq 0.2$. These observations include measurements of the peculiar velocities of galaxies in the cluster, which are a measure of their potential energy if the cluster is virialized; measurements of the X-ray temperature of hot gas in the cluster, which again correlates with the gravitational potential felt by the gas; and—most directly—studies of (weak) gravitational lensing of background galaxies on the cluster.

A particularly compelling example involves the bullet cluster (1E0657-558) which recently (on cosmological time scales) passed through another cluster. As a result, the hot gas forming most of the clusters' baryonic mass was shocked and decelerated, whereas the galaxies in the clusters proceeded on ballistic trajectories. Gravitational lensing shows that most of the total mass also moved ballistically, indicating that DM self-interactions are indeed weak [1].

The currently most accurate, if somewhat indirect, determination of $\Omega_{\rm DM}$ comes from global fits of cosmological parameters to a variety of observations; see the Section on Cosmological Parameters for details. For example, using measurements of the anisotropy of the cosmic microwave background (CMB) and of the spatial distribution of galaxies, Ref. 3 finds a density of cold, non-baryonic matter

$$\Omega_{\rm nbm}h^2 = 0.112 \pm 0.006 \,\,\,\,(24.1)$$

where h is the Hubble constant in units of 100 km/(s·Mpc). Some part of the baryonic matter density [3],

$$\Omega_{\rm b}h^2 = 0.022 \pm 0.001 \;, \tag{24.2}$$

may well contribute to (baryonic) DM, e.g., MACHOs [4] or cold molecular gas clouds [5].

The DM density in the "neighborhood" of our solar system is also of considerable interest. This was first estimated as early as 1922 by J.H. Jeans, who analyzed the motion of nearby stars transverse to the galactic plane [2]. He concluded that in our galactic neighborhood, the average density of DM must be roughly equal to that of luminous matter (stars, gas, dust). Remarkably enough, the most recent estimate, based on a detailed model of our galaxy constrained by a host of observables including the galactic rotation curve, finds a quite similar result for the smooth component of the local Dark Matter density [6]:

$$\rho_{\rm DM}^{\rm local} = (0.39 \pm 0.03) \frac{{\rm GeV}}{{\rm cm}^3} .$$
(24.3)

This value may have to be increased by a factor of 1.2 ± 0.2 since the baryons in the galactic disk, in which the solar system is located, also increase the local DM density [7]. Small substructures (minihaloes, streams) are not likely to change the local DM density significantly [1].

24.1.2. Candidates for Dark Matter:

Analyses of structure formation in the Universe indicate that most DM should be "cold" or "cool", i.e., should have been non-relativistic at the onset of galaxy formation (when there was a galactic mass inside the causal horizon) [1]. This agrees well with the upper bound [3] on the contribution of light neutrinos to Eq. (24.1),

$$\Omega_{\nu}h^2 < 0.0062 \quad 95\% \text{ CL}$$
 (24.4)

Candidates for non-baryonic DM in Eq. (24.1) must satisfy several conditions: they must be stable on cosmological time scales (otherwise they would have decayed by now), they must interact very weakly with electromagnetic radiation (otherwise they wouldn't qualify as dark matter), and they must have the right relic density. Candidates include primordial black holes, axions, sterile neutrinos, and weakly interacting massive particles (WIMPs).

Primordial black holes must have formed before the era of Big-Bang nucleosynthesis, since otherwise they would have been counted in Eq. (24.2) rather than Eq. (24.1). Such an early creation of a large number of black holes is possible only in certain somewhat contrived cosmological models [8].

The existence of axions [9] was first postulated to solve the strong CP problem of QCD; they also occur naturally in superstring theories. They are pseudo Nambu-Goldstone bosons associated with the (mostly) spontaneous breaking of a new global "Peccei-Quinn" (PQ) U(1) symmetry at scale f_a ; see the Section on Axions in this Review for further details. Although very light, axions would constitute cold DM, since they were produced non-thermally. At temperatures well above the QCD phase transition, the axion is massless, and the axion field can take any value, parameterized by the "misalignment angle" θ_i . At $T \lesssim 1$ GeV, the axion develops a mass m_a due to instanton effects. Unless the axion field happens to find itself at the minimum of its potential ($\theta_i = 0$), it will begin to oscillate once m_a becomes comparable to the Hubble parameter H. These coherent oscillations transform the energy originally stored in the axion field into physical axion quanta. The contribution of this mechanism to the present axion relic density is [1]

$$\Omega_a h^2 = \kappa_a \left(f_a / 10^{12} \text{ GeV} \right)^{1.175} \theta_i^2 ,$$
 (24.5)

where the numerical factor κ_a lies roughly between 0.5 and a few. If $\theta_i \sim \mathcal{O}(1)$, Eq. (24.5) will saturate Eq. (24.1) for $f_a \sim 10^{11}$ GeV, comfortably above laboratory and astrophysical constraints [9]; this would correspond to an axion mass around 0.1 meV. However, if the post-inflationary reheat temperature $T_R > f_a$, cosmic strings will form during the PQ phase transition at $T \simeq f_a$. Their decay will give an additional contribution to Ω_a , which is often bigger than that in Eq. (24.5) [1], leading to a smaller preferred value of f_a , i.e., larger m_a . On the other hand, values of f_a near the Planck scale become possible if θ_i is for some reason very small.

"Sterile" $SU(2) \times U(1)_Y$ singlet neutrinos with keV masses [10] could alleviate the "cusp/core problem" [1] of cold DM models. If they were produced non-thermally through mixing with standard neutrinos, they would eventually decay into a standard neutrino and a photon.

Weakly interacting massive particles (WIMPs) χ are particles with mass roughly between 10 GeV and a few TeV, and with cross sections of approximately weak strength. Within standard cosmology, their present relic density can be calculated reliably if the WIMPs were in thermal and chemical equilibrium with the hot "soup" of Standard Model (SM) particles after inflation. In this case, their density would become exponentially (Boltzmann) suppressed at $T < m_{\chi}$. The WIMPs therefore drop out of thermal equilibrium ("freeze out") once the rate of reactions that change SM particles into WIMPs or vice

versa, which is proportional to the product of the WIMP number density and the WIMP pair annihilation cross section into SM particles σ_A times velocity, becomes smaller than the Hubble expansion rate of the Universe. After freeze out, the co-moving WIMP density remains essentially constant; if the Universe evolved adiabatically after WIMP decoupling, this implies a constant WIMP number to entropy density ratio. Their present relic density is then approximately given by (ignoring logarithmic corrections) [11]

$$\Omega_{\chi} h^2 \simeq const. \cdot \frac{T_0^3}{M_{\rm Pl}^3 \langle \sigma_A v \rangle} \simeq \frac{0.1 \text{ pb} \cdot c}{\langle \sigma_A v \rangle} .$$
 (24.6)

Here T_0 is the current CMB temperature, $M_{\rm Pl}$ is the Planck mass, c is the speed of light, σ_A is the total annihilation cross section of a pair of WIMPs into SM particles, v is the relative velocity between the two WIMPs in their cms system, and $\langle \ldots \rangle$ denotes thermal averaging. Freeze out happens at temperature $T_F \simeq m_\chi/20$ almost independently of the properties of the WIMP. This means that WIMPs are already non-relativistic when they decouple from the thermal plasma; it also implies that Eq. (24.6) is applicable if $T_R > T_F$. Notice that the 0.1 pb in Eq. (24.6) contains factors of T_0 and $M_{\rm Pl}$; it is, therefore, quite intriguing that it "happens" to come out near the typical size of weak interaction cross sections.

The seemingly most obvious WIMP candidate is a heavy neutrino. However, an SU(2) doublet neutrino will have too small a relic density if its mass exceeds $M_Z/2$, as required by LEP data. One can suppress the annihilation cross section, and hence increase the relic density, by postulating mixing between a heavy SU(2) doublet and some sterile neutrino. However, one also has to require the neutrino to be stable; it is not obvious why a massive neutrino should not be allowed to decay.

The currently best motivated WIMP candidate is, therefore, the lightest superparticle (LSP) in supersymmetric models [12] with exact R-parity (which guarantees the stability of the LSP). Searches for exotic isotopes [13] imply that a stable LSP has to be neutral. This leaves basically two candidates among the superpartners of ordinary particles, a sneutrino, and a neutralino. The negative outcome of various WIMP searches (see below) rules out "ordinary" sneutrinos as primary component of the DM halo of our galaxy. (In models with gauge-mediated SUSY breaking, the lightest "messenger sneutrino" could make a good WIMP [14].) The most widely studied WIMP is therefore the lightest neutralino. Detailed calculations [1] show that the lightest neutralino will have the desired thermal relic density Eq. (24.1) in at least four distinct regions of parameter space. χ could be (mostly) a bino or photino (the superpartner of the $U(1)_Y$ gauge boson and photon, respectively), if both χ and some sleptons have mass below ~ 150 GeV, or if m_{χ} is close to the mass of some sfermion (so that its relic density is reduced through co-annihilation with this sfermion), or if $2m_{\chi}$ is close to the mass of the *CP*-odd Higgs boson present in supersymmetric models. Finally, Eq. (24.1) can also be satisfied if χ has a large higgsino or wino component.

Many non-supersymmetric extensions of the Standard Model also contain viable WIMP candidates [1]. Examples are the lightest T-odd particle in "Little Higgs" models with conserved T-parity, or "techni-baryons" in scenarios with an additional, strongly interacting ("technicolor" or similar) gauge group.

There also exist models where the DM particles, while interacting only weakly with ordinary matter, have quite strong interactions within an extended "dark sector" of the theory. These were motivated by measurements by the PAMELA, ATIC and Fermi satellites indicating excesses in the cosmic e^+ and/or e^- fluxes at high energies. However, these excesses are relative to background estimates that are clearly too simplistic (e.g., neglecting primary sources of electrons and positrons, and modeling the galaxy as a homogeneous cylinder). Moreover, the excesses, if real, are far too large to be due to usual WIMPs, but can be explained by astrophysical sources. It therefore seems unlikely that they are due to Dark Matter [15]. Similarly, claims of positive signals for direct WIMP detection by the DAMA and, more recently, CoGeNT and CRESST collaborations (see below) led to the development of tailor-made models to alleviate tensions with null experiments. Since we are not convinced that these data indeed signal WIMP detection, and these models (some of which were quickly excluded by improved measurements) lack independent motivation, we will not discuss them any further in this Review.

Although thermally produced WIMPs are attractive DM candidates because their relic density naturally has at least the right order of magnitude, non-thermal production mechanisms have also been suggested, e.g., LSP production from the decay of some moduli fields [16], from the decay of the inflaton [17], or from the decay of "Q-balls" (non-topological solitons) formed in the wake of Affleck-Dine baryogenesis [18]. Although LSPs from these sources are typically highly relativistic when produced, they quickly achieve kinetic (but not chemical) equilibrium if T_R exceeds a few MeV [19](but stays below $m_{\chi}/20$). They therefore also contribute to cold DM. Finally, if the WIMPs aren't their own antiparticles, an asymmetry between WIMPs and antiWIMPs might have been created in the early Universe, possibly by the same (unknown) mechanism that created the baryon antibaryon asymmetry. In such "asymmetric DM" models [20] the WIMP anti-WIMP annihilation cross section $\langle \sigma_A v \rangle$ should be significantly larger than 1 pb \cdot c, cf Eq. (24.6).

Primary black holes (as MACHOs), axions, sterile neutrinos, and WIMPs are all (in principle) detectable with present or near-future technology (see below). There are also particle physics DM candidates which currently seem almost impossible to detect, unless they decay; the present lower limit on their lifetime is of order 10^{25} to 10^{26} s for 100 GeV particles. These include the gravitino (the spin-3/2 superpartner of the graviton) [1], states from the "hidden sector" thought responsible for supersymmetry breaking [14], and the axino (the spin-1/2 superpartner of the axion) [1].

24.2. Experimental detection of Dark Matter

24.2.1. The case of baryonic matter in our galaxy:

The search for hidden galactic baryonic matter in the form of MAssive Compact Halo Objects (MACHOs) has been initiated following the suggestion that they may represent a large part of the galactic DM and could be detected through the microlensing effect [4]. The MACHO, EROS, and OGLE collaborations have performed a program of observation of such objects by monitoring the luminosity of millions of stars in the Large and Small Magellanic Clouds for several years. EROS concluded that MACHOs cannot contribute more than 8% to the mass of the galactic halo [21], while MACHO observed a signal at 0.4 solar mass and put an upper limit of 40%. Overall, this strengthens the need for non-baryonic DM, also supported by the arguments developed above.

24.2.2. Axion searches:

Axions can be detected by looking for $a \to \gamma$ conversion in a strong magnetic field [1]. Such a conversion proceeds through the loop-induced $a\gamma\gamma$ coupling, whose strength $g_{a\gamma\gamma}$ is an important parameter of axion models. There currently are two experiments searching for axionic DM. They both employ high quality cavities. The cavity "Q factor" enhances the conversion rate on resonance, i.e., for $m_a(c^2 + v_a^2/2) = \hbar \omega_{\rm res}$. One then needs to scan the resonance frequency in order to cover a significant range in m_a or, equivalently, f_a . The bigger of the two experiments, the ADMX experiment [22], originally situated at the LLNL in California but now running at the University of Washington, started taking data in the first half of 1996. It now uses SQUIDs as first-stage amplifiers; their extremely low noise temperature (1.2 K) enhances the conversion signal. Published results [23], combining data taken with conventional amplifiers and SQUIDs, exclude axions with mass between 1.9 and 3.53 μeV , corresponding to $f_a \simeq 4 \cdot 10^{13}$ GeV, for an assumed local DM density of 0.45 GeV/cm³, if $g_{a\gamma\gamma}$ is near the upper end of the theoretically expected range. An about five times better limit on $g_{a\gamma\gamma}$ was achieved [24] for 1.98 $\mu eV \leq m_a \leq 2.18~\mu eV$, if a large fraction of the local DM density is due to a single flow of axions with very low velocity dispersion. The ADMX experiment is being upgraded by reducing the cavity and SQUID temperature from the current 1.2 K to about 0.1 K. This should increase the frequency scanning speed for given sensitivity by more than two orders of magnitude, or increase the sensitivity for fixed observation time.

The smaller "CARRACK" experiment now being developed in Kyoto, Japan [25] uses Rydberg atoms (atoms excited to a very high state, n=111) to detect the microwave photons that would result from axion conversion. This allows almost noise-free detection of single photons. Their ultimate goal is to probe the range between 2 and 50 μ eV with sensitivity to all plausible axion models, if axions form most of DM.

${\bf 24.2.3.} \quad Searches \ for \ keV \ Neutrinos:$

Relic keV neutrinos ν_s can only be detected if they mix with the ordinary neutrinos. This mixing leads to radiative $\nu_s \to \nu \gamma$ decays, with lifetime $\tau_{\nu_s} \simeq 1.8 \cdot 10^{21} \text{ s} \cdot (\sin \theta)^{-2} \cdot (1 \text{ keV}/m_{\nu_s})^5$, where θ is the mixing angle [10]. This gives rise to a flux of mono-energetic photons with $E_{\gamma} = m_{\nu_s}/2$, which might be observable by X-ray satellites. In the simplest case the relic ν_s are produced only by oscillations of standard neutrinos. Assuming that all lepton-antilepton asymmetries are well below 10^{-3} , the ν_s relic density can then be computed uniquely in terms of the mixing angle θ and the mass m_{ν_s} . The combination of lower bounds on m_{ν_s} from analyses of structure formation (in particular, the Ly α "forest") and upper bounds on X-ray fluxes from various (clusters of) galaxies exclude this scenario if ν_s forms all of DM. This conclusion can be evaded if ν_s forms only part of DM, and/or if there is a lepton asymmetry $\geq 10^{-3}$ (i.e. some 7 orders of magnitude above the observed baryon-antibaryon asymmetry), and/or if there is an additional source of ν_s production in the early Universe, e.g. from the decay of heavier particles [10].

24.2.4. Basics of direct WIMP search:

As stated above, WIMPs should be gravitationally trapped inside galaxies and should have the adequate density profile to account for the observed rotational curves. These two constraints determine the main features of experimental detection of WIMPs, which have been detailed in the reviews in [1].

Their mean velocity inside our galaxy relative to its center is expected to be similar to that of stars, *i.e.*, a few hundred kilometers per second at the location of our solar system. For these velocities, WIMPs interact with ordinary matter through elastic scattering on nuclei. With expected WIMP masses in the range 10 GeV to 10 TeV, typical nuclear recoil energies are of order of 1 to 100 keV.

The shape of the nuclear recoil spectrum results from a convolution of the WIMP velocity distribution, usually taken as a Maxwellian distribution in the galactic rest frame, shifted into the Earth rest frame, with the angular scattering distribution, which is isotropic to first approximation but forward-peaked for high nuclear mass (typically higher than Ge mass) due to the nuclear form factor. Overall, this results in a roughly exponential spectrum. The higher the WIMP mass, the higher the mean value of the exponential. This points to the need for low nuclear recoil energy threshold detectors.

On the other hand, expected interaction rates depend on the product of the local WIMP flux and the interaction cross section. The first term is fixed by the local density of dark matter, taken as $0.39~{\rm GeV/cm^3}$ [see Eq. (24.3)], the mean WIMP velocity, typically 220 km/s, the galactic escape velocity, typically 544 km/s [26] and the mass of the WIMP. The expected interaction rate then mainly depends on two unknowns, the mass and cross section of the WIMP (with some uncertainty [6] due to the halo model). This is why the experimental observable, which is basically the scattering rate as a function of energy, is usually expressed as a contour in the WIMP mass—cross section plane.

The cross section depends on the nature of the couplings. For non-relativistic WIMPs, one in general has to distinguish spin-independent and spin-dependent couplings. The former can involve scalar and vector WIMP and nucleon currents (vector currents are absent for Majorana WIMPs, e.g., the neutralino), while the latter involve axial vector currents (and obviously only exist if χ carries spin). Due to coherence effects, the spin-independent cross section scales approximately as the square of the mass of the nucleus, so higher mass nuclei, from Ge to Xe, are preferred for this search. For spin-dependent coupling, the cross section depends on the nuclear spin factor; used target nuclei include ¹⁹F, ²³Na, ⁷³Ge, ¹²⁷I, ¹²⁹Xe, ¹³¹Xe, and ¹³³Cs.

Cross sections calculated in MSSM models [27] induce rates of at most 1 evt $\mathrm{day}^{-1}~\mathrm{kg}^{-1}$ of detector, much lower than the usual radioactive backgrounds. This indicates the need for underground laboratories to protect against cosmic ray induced backgrounds, and for the selection of extremely radio-pure materials.

The typical shape of exclusion contours can be anticipated from this discussion: at low WIMP mass, the sensitivity drops because of the detector energy threshold, whereas at high masses, the sensitivity also decreases because, for a fixed mass density, the WIMP flux decreases $\propto 1/m_{\chi}$. The sensitivity is best for WIMP masses near the mass of the recoiling nucleus.

Two important points are to be kept in mind when comparing exclusion curves from various experiments between them or with positive indications of a signal.

For an experiment with a fixed nuclear recoil energy threshold, the lower is the considered WIMP mass, the lower is the fraction of the spectrum to which the experiment is sensitive. This fraction may be extremely small in some cases. For instance CoGeNT [28], using a Germanium detector with an energy threshold of around 2 keV, is sensitive to about 10 % of the total recoil spectrum of a 7 GeV WIMP, while for XENON100 [29], using a liquid Xenon detector with a threshold of 8.4 keV, this fraction is only 0.05 % (that is the extreme tail of the distribution), for the same WIMP mass. The two experiments are then sensitive to very different parts of the WIMP velocity distribution.

A second important point to consider is the energy resolution of the detector. Again at low WIMP mass, the expected roughly exponential spectrum is very steep and when the characteristic energy of the exponential becomes of the same order as the energy resolution, the energy smearing becomes important. In particular, a significant fraction of the expected spectrum below effective threshold is smeared above threshold, increasing artificially the sensitivity. For instance, a Xenon detector with a threshold of 8 keV and infinitely good resolution is actually insensitive to a 7 GeV mass WIMP, because the expected energy distribution has a cut-off at roughly 5 keV. When folding in the experimental resolution of XENON100 (corresponding to a photostatistics of 0.5 photoelectron per keV), then around 1 % of the signal is smeared above 5 keV and 0.05 % above 8 keV. Setting reliable cross section limits in this mass range thus requires a complete understanding of the response of the detector at energies well below the nominal threshold.

In order to homogenize the reliability of the presented exclusion curves, and save the reader the trouble of performing tedious (though easy to do) calculations, we propose to set cross section limits only for WIMP mass above a "WIMP safe" minimal mass value defined as the maximum of 1) the mass where the increase of sensitivity from infinite resolution to actual experimental resolution is not more than a factor two, and 2) the mass where the experiment is sensitive to at least 1 % of the total WIMP signal recoil spectrum. These recommendations are irrespective of the content of the experimental data obtained by the experiments.

${\bf 24.2.5.} \quad {\it Status \ and \ prospects \ of \ direct \ WIMP \ searches:}$

Given the intense activity of the field, readers interested in more details than the ones given below may refer to [1], as well as to presentations at recent conferences [30].

The first searches have been performed with ultra-pure semiconductors installed in pure lead and copper shields in underground environments. Combining a priori excellent energy resolutions and very pure detector material, they produced the first limits on WIMP searches (Heidelberg-Moscow, IGEX, COSME-II, HDMS) [1]. Planned experiments using several tens of kg to a ton of Germanium run at liquid nitrogen temperature (designed for double-beta decay search)—GERDA, MAJORANA—are based in addition on passive reduction of the external and internal electromagnetic and neutron background by using segmented detectors, minimal detector housing, close electronics, pulse shape discrimination and large liquid nitrogen or argon shields. Their sensitivity to WIMP interactions will depend on their ability to lower the energy threshold sufficiently, while keeping the background rate small.

The use of so called Point Contact Germanium detectors, with a very small capacitance allowing to reach sub-keV thresholds, has given rise to new results. The CoGeNT collaboration [31] has operated a single 440 g Germanium detector with an effective threshold of 400 eV in the Soudan Underground Laboratory for 56 days [28]. After applying a rise time cut on the pulse shapes in order to remove the surface interactions known to suffer from incomplete charge collection, the resulting spectrum below 4 keV is said by the authors to exhibit an irreducible excess of events, with energy spectrum roughly exponential, compatible with a light mass WIMP in the 7-11 GeV range, and cross section around 10^{-4} pb. However, this conclusion crucially depends on the energy dependent rise time cut applied to the data and a sizeable leaking of surface events into the kept spectrum cannot be excluded. The authors acknowledge themselves that a possible instrumental effect, leading to such an excess, is worth investigating. Nevertheless, considerable attention has been paid to the WIMP interpretation, largely due to the temptation to consider it as a confirmation of the low mass WIMP DAMA/LIBRA solution, without channeling (see below). A recent unpublished analysis, presented at the TAUP 2011 conference, indicates a reduction of the claimed signal by a factor 10. Further results [32] based on data accumulated during one year led to the claim of a 2.8 sigma modulation said to be compatible with a WIMP. Here again, the claim is considerably weakened by the fact that the amplitude of the curve describing the expected WIMP modulation in the 0.5-3 keV bin is too high by roughly a factor 2 (or more, if the unmodulated "signal" has to be reduced) and wrongly leads to the conclusion that the modulation is compatible with a standard WIMP in a standard halo. This is also noted in [33].

A new consortium, CDEX/TEXONO, plans to build a 10 kg array of small and very low (200 eV) threshold detectors, and to operate them in the new Chinese Jinping underground laboratory, the deepest in the world.

In order to make further progress in the reliability of any claimed signal, active background rejection and signal identification questions have to be addressed. This is the focus of a growing number of investigations and improvements. Active background rejection in detectors relies on the relatively small ionization in nuclear recoils due to their low velocity. This induces a reduction ("quenching") of the ionization/scintillation signal for nuclear recoil signal events relative to e or γ induced backgrounds. Energies calibrated with gamma sources are then called "electron equivalent energies" (keVee unit used below). This effect has been both calculated and measured [1]. It is exploited in cryogenic detectors described later. In scintillation detectors, it induces in addition a difference in decay times of pulses induced by e/γ events vs nuclear recoils. In most cases, due to the limited resolution and discrimination power of this technique at low energies, this effect allows only a statistical background rejection. It has been used in NaI(Tl) (DAMA, LIBRA, NAIAD, Saclay NaI), in CsI(Tl) (KIMS), and Xe (ZEPLIN-I) [1,30]. Pulse shape discrimination is particularly efficient in liquid argon. Using a high energy threshold, it has been used for an event by event discrimination by the WARP experiment, but the high threshold also leads to a moderate signal sensitivity. No observation of nuclear recoils has been reported by these experiments.

Two experimental signatures are predicted for true WIMP signals. One is a strong daily forward/backward asymmetry of the nuclear recoil direction, due to the alternate sweeping of the WIMP cloud by the rotating Earth. Detection of this effect requires gaseous detectors or anisotropic response scintillators (stilbene). The second is a few percent annual modulation of the recoil rate due to the Earth speed adding to or subtracting from the speed of the Sun. This tiny effect can only be detected with large masses; nuclear recoil identification should also be performed, as the otherwise much larger background may also be subject to seasonal modulation.

The DAMA collaboration has reported results from a total of 6 years exposure with the LIBRA phase involving 250 kg of detectors, plus the earlier 6 years exposure of the original DAMA/NaI experiment with 100 kg of detectors [34], for a cumulated exposure of 1.17 t·y. They observe an annual modulation of the signal in the 2 to 6 keVee bin, with the expected period (1 year) and phase (maximum around June 2), at 8.9 σ level. If interpreted within the standard halo model described above, two possible explanations have been proposed: a

WIMP with $m_{\chi} \simeq 50$ GeV and $\sigma_{\chi p} \simeq 7 \cdot 10^{-6}$ pb (central values) or at low mass, in the 6 to 10 GeV range with $\sigma_{\chi p} \sim 10^{-3}$ pb; the cross section could be somewhat lower if there is a significant channeling effect [1].

Interpreting these observations as positive WIMP signal raises several issues of internal consistency. First, the proposed WIMP solutions would induce a sizeable fraction of nuclear recoils in the total measured rate in the 2 to 6 keVee bin. No pulse shape analysis has been reported by the authors to check whether the unmodulated signal was detectable this way. Secondly, the residual e/γ -induced background, inferred by subtracting the signal predicted by the WIMP interpretation from the data, has an unexpected shape [35], starting near zero at threshold and quickly rising to reach its maximum near 3 to 3.5 keVee; from general arguments one would expect the background (e.g. due to electronic noise) to increase towards the threshold. Finally, the amplitude of the annual modulation shows a somewhat troublesome tendency to decrease with time. The original DAMA data, taken 1995 to 2001, gave an amplitude of the modulation of 20.0 ± 3.2 in units of 10^{-3} counts/(kg·day·keVee), in the 2-6 keVee bin. During the first phase of DAMA/LIBRA, covering data taken between 2003 and 2007, this amplitude became 10.7 ± 1.9 , and in the second phase of DAMA/LIBRA, covering data taken between 2007 and 2009, it further decreased to 8.5 ± 2.2 . The ratio of amplitudes inferred from the DAMA/LIBRA phase 2 and original DAMA data is 0.43 ± 0.13 , differing from the expected value of 1 by more than 4 standard deviations. (The results for the DAMA/LIBRA phase 2 have been calculated by us using published results for the earlier data alone [36] as well as for the latest grand total [34].) Similar conclusions can be drawn from analyses of the 2-4 and 2-5 keVee bins.

Concerning compatibility with other experiments (see below), the high mass solution is clearly excluded by several null observations (CDMS, EDELWEISS, XENON), while possibly a small parameter space remains available for the low mass solution (according to [35] this possibility is excluded if the energy spectrum measured by DAMA/LIBRA is taken into account). It should be noted that these comparisons have to make assumptions about the WIMP velocity distribution (see above), but varying this within reasonable limits does not resolve the tension [35]. Moreover, one usually assumes that the WIMP scatters elastically, and that the spin-independent cross section for scattering off protons and neutrons is roughly the same. These assumptions are satisfied by all models we know that are either relatively simple (i.e. do not introduce many new particles) or have independent motivation (e.g. attempting to solve the hierarchy problem). As noted earlier, recently models have been constructed where these assumptions do not hold, but at least some of these are no longer able to make the WIMP interpretation of the DAMA(/LIBRA) observations compatible with all null results from other experiments. Finally, appealing to spin-dependent interactions does not help, either [37], in view of null results from direct searches as well as limits on neutrino fluxes from the Sun (see the subsection on indirect WIMP detection below).

No other annual modulation analysis with comparable sensitivity has been reported by any experiment. ANAIS [30], a 100 kg NaI(Tl) project planned to be run at the Canfranc lab, is in the phase of crystal selection and purification. DM-ice is a new project with the aim of checking the DAMA/LIBRA modulation signal in the southern hemisphere. It will consist of 250 kg of NaI(Tl) installed in the heart of the IceCube array. The counting rate of crystals from the previous NAIAD array recently measured in situ is currently dominated by internal radioactivity.

KIMS [38], an experiment operating 12 crystals of CsI(Tl) with a total mass of 104.4 kg in the Yang Yang laboratory in Korea, has accumulated several years of continuous operation. They should soon be able to set an upper limit on annual modulation amplitude lower than DAMA value if no annual modulation is present, or confirm the DAMA value at 3 $\sigma.$

At mK temperature, the simultaneous measurement of the phonon and ionization signals in semiconductor detectors permits event by event discrimination between nuclear and electronic recoils down to 5 to 10 keV recoil energy. This feature is being used by the CDMS [30] and EDELWEISS [30] collaborations. Surface interactions,

exhibiting incomplete charge collection, are an important residual background, which is treated by two different techniques: CDMS uses the timing information of the phonon pulse, while EDELWEISS uses the ionization pulses in an interleaved electrodes scheme. New limits on the spin-independent coupling of WIMPs were obtained by CDMS, after operating 19 Germanium cryogenic detectors at the Soudan mine during new runs involving a total exposure of around 612 kg·d (around 300 kg·d fiducial) [39]. Two events were found in the pre-defined signal region, while 0.9 background event were expected. Given these figures, no observation of a signal is claimed. While this data set alone provided a worse limit than the previous runs, the combined data sets provide an improved upper limit on the spin-independent cross section for the scattering of a 70 GeV/c² WIMP on a nucleon of 3.8×10^{-8} pb, at 90% CL. The "WIMP safe" minimal mass (see the discussion at the end of sec. 1.2.4) of this analysis is about 12 GeV.

An independent analysis of data at low energy (i.e. above 2 keV recoil energy) has also been performed by CDMS [40]. From the knowledge of the quenching factor of Germanium recoils down to 2 keV recoil energy, the energy spectrum is reconstructed using only the measured phonon energy. The obtained spectrum, once corrected for quenching, has a shape somewhat similar to that reported by CoGeNT, but with a lower amplitude (especially for one of the detector modules, which was used to set the limit) so that CDMS concludes that their data are inconsistent with the original WIMP interpretation of the CoGeNT data (note that both detectors use the same target material, so this comparison really is model-independent), as well as with the standard WIMP interpretation of the DAMA data. New detectors with interleaved electrode schemes are being built.

EDELWEISS has operated ten 400 g Germanium detectors equipped with different thermal sensors and an interdigitised charge collection electrode scheme, during one year at the Laboratoire Souterrain de Modane [41]. A total of 5 events were observed in the signal region for a fiducial exposure of 384 kg·d, while 3 events were expected from backgrounds. No WIMP signal was claimed. A similar sensitivity to CDMS is obtained at high mass, while the high 20 keV analysis threshold induces a somewhat poorer limit at masses lower than 50 GeV. New larger detectors with a complete coverage of the crystal with annular electrodes, and better rejection of non-recoil events are being built.

Given their similar sensitivities, the two collaborations combined their data sets. Using a simple combination method, a gain of 1.6 relative to the best limit has been obtained at WIMP masses larger than 700 GeV, and an improved limit of 3.3×10^{-8} pb for a 90 GeV WIMP mass [42].

The cryogenic experiment CRESST [30] uses the scintillation of CaWO₄ as second variable for background discrimination. CRESST has recently submitted for publication [43] the result of the analysis of 730 kg-d exposure performed with 8 detectors. The observation of 67 events in the signal region does not match the about 40 expected background events, originating from e/ γ leakage, neutron recoils, as well as leakage from α and Pb recoils. The event excess is said to be compatible with WIMPs. A likelihood method provides two solutions, respectively for 12 and 25 GeV masses, stating also that the background hypothesis alone is more than 4 sigma away from the observed data. However, some other potential sources of background are insufficiently adressed, like "no-light" events, a category of events which previously plagued the sensitivity of this experiment.

Other inorganic scintillators are also being explored, e.g. by the ROSEBUD collaboration [30].

The experimental programs of CDMS II, EDELWEISS II and CRESST II aim at an increase of sensitivity by a factor of 10, by operating around 40 kg of detectors. The next stage SuperCDMS and EURECA-I (a combination of EDELWEISS and CRESST) projects will involve typically 150 kg of detectors. Then GEODM and EURECA-2 will turn to 1 t goals.

Noble gas detectors for dark matter detection are now being developed rapidly by several groups [1]. Dual (liquid and gas) phase detectors allow to measure both the primary scintillation and the ionization electrons drifted through the liquid and amplified in the gas, which is used for background rejection.

The XENON collaboration [30] has successfully operated the 161 kg XENON100 setup at Gran Sasso laboratory during a 100 day data taking period. Within a fiducial mass of 48 kg, 3 events were observed in the signal region, while 1.8 were expected, out of which 1.2 originate from a sizeable contamination of Krypton 85 in the liquid [29]. This allowed to set the best limits at all masses on spin-independent interactions of WIMPs, with a minimum of cross section at 7.0×10^{-9} pb for a mass of 50 GeV. However, the reliability of limits set at masses lower than 10 GeV, especially wrt the relative light efficiency factor, have been discussed in the community. Moreover, as underlined near the end of section 1.2.4, the limits at low mass can be set only thanks to the poor energy resolution at threshold -8.4 keV- due to the low photoelectron yield of 0.5 pe/keV. With infinite energy resolution, a Xe detector with the same threshold of 8.4 keV is not sensitive to a WIMP mass of 7 GeV. Folding in the XENON100 resolution, the expected fraction of a 7 GeV WIMP signal above 8.4 keV is around 0.05 % (in strong contrast with the 10 % to which CoGeNT is sensitive). If one follows the recommendation made above, the "WIMP safe" minimal mass for XENON100 is around 12 GeV.

A reanalysis of part of the XENON10 data [44], using the ionization signal only, with an ionization yield of around 3.5 electron/keV at a threshold of 1.4 keV, sets a more convincing limit in the 7 GeV range, about one order of magnitude below the original CoGeNT claim (see above). The "WIMP safe" minimal mass for this XENON10 analysis is around 5 GeV. The XENON10 limit for spin dependent WIMPs with pure neutron couplings is still the best published limit at all masses [45] (but likely to be soon superseded by an analysis of XENON100 data). XENON1t, the successor of XENON100 planned to be run at Gran Sasso lab, is in its preparation phase. One should note that, presumably, the planned increase of distance between planes of PMT's will lead to a lower photoelectron yield for scintillation light than at XENON100. This was the case when going from XENON10 (around 1 pe/keV) to XENON100 (around 0.5 pe/keV). For comparison, a 0.25 pe yield per keV would correspond to a "WIMP safe" mass of order of 20 GeV.

A new liquid Xenon based project, PANDA-X, with pancake geometry, planned to be housed in the new Jinping lab, will perform a dedicated low mass WIMP search.

ZEPLIN III [30], using a similar principle and with an active mass of 12 kg of Xenon, operated in the Boulby laboratory, has been upgraded for a lower background, has acquired new data, and is now stopped. XMASS [30] in Japan is close to operate a single-phase 800 kg detector (100 kg fiducial mass) installed in a large pure water shield at the SuperKamiokande site. With no pulse shape analysis, the expected performance relies heavily on the self-shielding effect to lower the background [1].

The LUX detector [1], a 300 kg double phase Xenon detector, planned to be operated in the new SURF (previous Sanford) laboratory in US, is in the commissioning phase, in a water shield at surface, before transport underground to the 4850 level.

The WARP collaboration [30] is currently installing a 100 l Argon detector at the Gran Sasso laboratory. Thanks to a double-background rejection method based on the asymmetry between scintillating and ionizing pulses and extremely efficient pulse shape discrimination of scintillating pulses, it looks possible to achieve very high background rejection, even in the presence of the radioactive isotope ³⁹Ar. The ArDM project [30] is using a similar technique with a much larger (1,100 kg) mass. It should be installed soon and take data at the newly opened Canfranc laboratory. MiniCLEAN and DEAP-3600 [30], both measuring only scintillation signals in spherical geometries in single phase mode, are being assembled at SNOLab and will operate respectively 500 kg of Ar/Ne and 3600 kg of Ar [1]. DARK SIDE [30], is another Argon based, double phase project, involving in a first step about 50 kg of ³⁹Ar depleted Argon, to be installed in Gran Sasso lab.

The low pressure Time Projection Chamber technique is the only convincing way to measure the direction of nuclear recoils and prove the galactic origin of a possible signal [1]. The DRIFT collaboration [30] has operated a 1 $\rm m^3$ volume detector in the UK Boulby mine. Though the background due to internal radon contamination was lowered, no new competitive limit has yet been

set. The MIMAC collaboration [30] is investigating a sub-keV energy threshold TPC detector. Additional sensitive measurements of Fluor nuclei quenching factor and recoil imaging have been performed recently by this group down to few keV. A 2.5 l 1000 channel prototype is going to be operated soon in the Fréjus laboratory. Other groups developing similar techniques, though with lower sensitivity, are DMTPC in the US and NewAge in Japan.

The following more unconventional detectors use ¹⁹F nuclei to set limits on the spin dependent coupling of WIMPs, with less than kg mass detectors. The bubble chamber like detector, COUPP [30], run at Fermilab, has provided a new limit [46] for spin dependent proton coupling WIMPs for masses above 20 GeV, superseding an earlier KIMS result. PICASSO [30], a superheated droplet detector run at SNOLAB, obtained a better limit below 20 GeV on the same type of WIMPs [47]. Finally, SIMPLE [30], a similar experiment run at Laboratoire Souterrain de Rustrel, submitted results for publication that claim to provide the currently best limit on the spin-dependent WIMP-proton cross section for all WIMP masses [48].

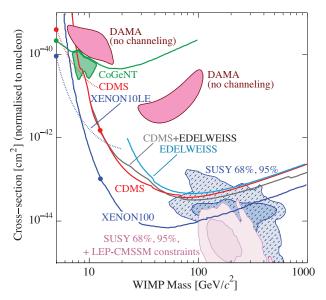


Figure 24.1: Cross sections (normalised to nucleon assuming A^2 dependence, see section 1.2.4) for spin independent coupling versus mass diagrams. References to the experimental results are given in the text. The big dots on some curves show the "WIMP safe" minimal mass for the corresponding experimental result (see details in text). DAMA candidates region (no channeling) are from [50], shaded 68% and 95% regions are SUSY predictions by [51], together with recent constraints (crosshatched 68% and 95% regions) set by LHC experiments (CMSSM) [52]. Here equal cross sections for scattering from protons and neutrons have been assumed.

Figures 24.1 and 24.2 illustrate the limits and positive claims forf cross sections, normalised to nucleon, for spin independent and spin dependent couplings, respectively, as functions of WIMP mass, where only the two currently best limits are presented. Also shown are constraints from indirect observations (see the next section) and typical regions of SUSY models, before and after recent LHC results. These figures have been made with the dmtools web page, thanks to the very efficient collaboration of dmtools team [55].

Sensitivities down to $\sigma_{\chi p}$ of 10^{-10} pb, as needed to probe large regions of MSSM parameter space [27], will be reached with detectors of typical masses of 1 ton, assuming nearly perfect background discrimination capabilities. Note that the expected WIMP rate is then 5 evts/ton/year for Ge. The ultimate neutron background will only be identified by its multiple interactions in a finely segmented or multiple-interaction-sensitive detector, and/or by operating detectors containing different target materials within the same set-up. Larger mass projects are envisaged by the DARWIN European consortium

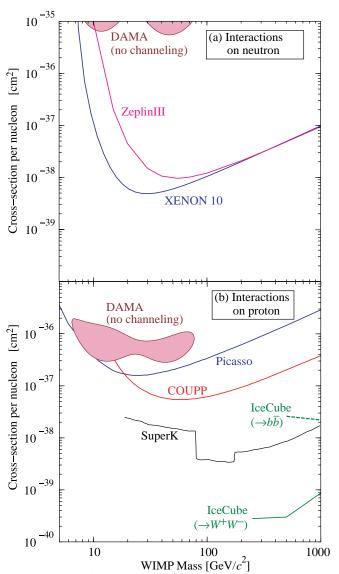


Figure 24.2: Cross sections for spin dependent coupling versus mass diagrams. References to the experimental results are given in the text. The DAMA candidates region (no channeling) are from [50]: (a) interactions on neutron; (b) interactions on proton.

and the MAX project in the US (liquid Xe and Ar multiton project) [30].

24.2.6. Status and prospects of indirect WIMP searches:

WIMPs can annihilate and their annihilation products can be detected; these include neutrinos, gamma rays, positrons, antiprotons, and antinuclei [1]. These methods are complementary to direct detection and might be able to explore higher masses and different coupling scenarios. "Smoking gun" signals for indirect detection are GeV neutrinos coming from the center of the Sun or Earth, and monoenergetic photons from WIMP annihilation in space.

WIMPs can be slowed down, captured, and trapped in celestial objects like the Earth or the Sun, thus enhancing their density and their probability of annihilation. This is a source of muon neutrinos which can interact in the Earth. Upward going muons can then be detected in large neutrino telescopes such as MACRO, BAKSAN, SuperKamiokande, Baikal, AMANDA, ANTARES, NESTOR, and the large sensitive area IceCube [1]. The best upper limit for relatively soft muons, of $\simeq 1000~{\rm muons/km^2/year}$ for muons with energy above $\sim 2~{\rm GeV}$ [53], comes from SuperKamiokande [30] using through-going muons. For more energetic muons a slightly more stringent limit

has been set by IceCube22 (using 22 strings), e.g. excluding a flux above 610 muons/km²/year from the Sun for a WIMP model with average muon energy of 150 GeV [54]. In the framework of the MSSM and with standard halo velocity profiles, only the limits from the Sun, which mostly probe spin-dependent couplings, are competitive with direct WIMP search limits. IceCube80 [30] will increase this sensitivity by a factor $\simeq 5$ at masses higher than 200 GeV while IceCube Deep Core will allow to reach masses down to 50 GeV [1].

WIMP annihilation in the halo can give a continuous spectrum of gamma rays and (at one-loop level) also monoenergetic photon contributions from the $\gamma\gamma$ and γZ channels. These channels also allow to search for WIMPs for which direct detection experiments have little sensitivity, e.g., almost pure higgsinos. However, the size of this signal depends very strongly on the halo model, but is expected to be most prominent near the galactic center. The central region of our galaxy hosts a strong TeV point source discovered [56] by the H.E.S.S. Cherenkov telescope [57]. Moreover, FERMI/LAT [30] data revealed a new extended source of GeV photons near the galactic center above and below the galactic plane [58]. Both of these sources are most likely of astrophysical origin. The presence of these unexpected backgrounds makes it more difficult to discover WIMPs in this channel, and no convincing signal has been claimed. FERMI/LAT observations of the galactic halo are in agreement with predictions based on purely astrophysical sources (in contrast to a re-analysis of earlier EGRET data [59]), and rule out many WIMP models that were constructed to explain the PAMELA and FERMI/LAT excesses in the e^{\pm} channel [60]. Similarly, Cherenkov telescope and FERMI/LAT observations of nearby dwarf galaxies, globular clusters, and clusters of galaxies only yielded upper limits on photon fluxes from WIMP annihilation. While limits from individual observations are still above the predictions of most WIMP models, a very recent combination [61] of limits from dwarf galaxies excludes WIMPs annihilating hadronically with the standard cross section needed for thermal relics, if the WIMP mass is below 25 GeV; assumptions are annihilation from an S-wave initial state, and a dark matter density distribution scaling like the inverse of the distance from the center of the dwarf galaxy at small radii.

Antiparticles arise as additional WIMP annihilation products in the halo. To date the best measurement of the antiproton flux comes from the PAMELA satellite [30], and covers kinetic energies between 60 MeV and 180 GeV [62]. The result is in good agreement with secondary production and propagation models. These data exclude WIMP models that attempt to explain the e^\pm excesses via annihilation into W^\pm or Z^0 boson pairs; however, largely due to systematic uncertainties they do not significantly constrain conventional WIMP models.

The best measurements of the positron (and electron) flux at (tens of) GeV energies again comes from PAMELA [63], showing a rather marked rise of the positron fraction between 10 and 100 GeV. The observed spectrum falls within the one order of magnitude span (largely due to differences in the propagation model used) of positron fraction values predicted by secondary production models [64]. Measurements of the total electron+positrons energy spectrum by ATIC [65], FERMI/LAT [66] and H.E.S.S. [67] between 100 and 1000 GeV also exceed the predicted purely secondary spectrum, but with very large dispersion of the magnitude of these excesses. While it has been recognized that astrophysical sources may account for all these features, many ad-hoc Dark Matter models have been built to account for these excesses. As mentioned in section 1, given the amount of jerking and twisting needed to build such models not to contradict any observation, it seems very unlikely that Dark Matter is at the origin of these excesses.

Last but not least, an antideuteron signal [1], as potentially observable by AMS2 or PAMELA, could constitute a signal for WIMP annihilation in the halo.

An interesting comparison of respective sensitivities to MSSM parameter space of future direct and various indirect searches has been performed with the DARKSUSY tool [68]. A web-based up-to-date collection of results from direct WIMP searches, theoretical predictions, and sensitivities of future experiments can be found in [55]. Also, the web page [69] allows to make predictions for WIMP

signals in various experiments, within a variety of SUSY models and to extract limits from simply parametrised data. Integrated analysis of all data from direct and indirect WIMP detection, and also from LHC experiments should converge to a comprehensive approach, required to fully unravel the mysteries of dark matter.

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25. COSMIC MICROWAVE BACKGROUND

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25.1. Introduction

The energy content in radiation from beyond our Galaxy is dominated by the cosmic microwave background (CMB), discovered in 1965 [1]. The spectrum of the CMB is well described by a blackbody function with $T=2.7255\,\mathrm{K}$, this spectral form being one of the main pillars of the hot Big Bang model for the early Universe. The lack of any observed deviations from a blackbody spectrum constrains physical processes over cosmic history at redshifts $z\lesssim10^7$ (see earlier versions of this review). All viable cosmological models predict a very nearly Planckian spectrum inside the current observational limits.

Another observable quantity inherent in the CMB is the variation in temperature (or intensity) from one part of the microwave sky to another [2]. Since the first detection of these anisotropies by the COBE satellite [3], there has been intense activity to map the sky at increasing levels of sensitivity and angular resolution by ground-based and balloon-borne measurements. These were joined in 2003 by the first results from NASA's Wilkinson Microwave Anisotropy Probe (WMAP) [4], which were improved upon by analysis of the 3-year, 5-year, and 7-year WMAP data [5,6,7]. Together these observations have led to a stunning confirmation of the 'Standard Model of Cosmology.' In combination with other astrophysical data, the CMB anisotropy measurements place quite precise constraints on a number of cosmological parameters, and have launched us into an era of precision cosmology. This is expected to continue with the improved capabilities of ESA's Planck satellite [8,9].

25.2. Description of CMB Anisotropies

Observations show that the CMB contains anisotropies at the 10^{-5} level, over a wide range of angular scales. These anisotropies are usually expressed by using a spherical harmonic expansion of the CMB sky:

$$T(\theta, \phi) = \sum_{\ell m} a_{\ell m} Y_{\ell m}(\theta, \phi).$$

The vast majority of the cosmological information is contained in the temperature 2-point function, *i.e.*, the variance as a function only of angular separation, since we notice no preferred direction. Equivalently, the power per unit $\ln \ell$ is $\ell \sum_m |a_{\ell m}|^2 / 4\pi$.

25.2.1. The Monopole:

The CMB has a mean temperature of $T_{\gamma}=2.7255\pm0.0006\,\mathrm{K}$ (1σ) [10], which can be considered as the monopole component of CMB maps, $a_{00}.$ Since all mapping experiments involve difference measurements, they are insensitive to this average level. Monopole measurements can only be made with absolute temperature devices, such as the FIRAS instrument on the COBE satellite [11]. Such measurements of the spectrum are consistent with a blackbody distribution over more than three decades in frequency (with some recent evidence for deviation at low frequencies [12]) . A blackbody of the measured temperature corresponds to $n_{\gamma}=(2\zeta(3)/\pi^2)\,T_{\gamma}^3\simeq411\,\mathrm{cm}^{-3}$ and $\rho_{\gamma}=(\pi^2/15)\,T_{\gamma}^4\simeq4.64\times10^{-34}\,\mathrm{g\,cm}^{-3}\simeq0.260\,\mathrm{eV\,cm}^{-3}.$

25.2.2. The Dipole:

The largest anisotropy is in the $\ell=1$ (dipole) first spherical harmonic, with amplitude $3.355\pm0.008\,\mathrm{mK}$ [6]. The dipole is interpreted to be the result of the Doppler shift caused by the solar system motion relative to the nearly isotropic blackbody field, as broadly confirmed by measurements of the radial velocities of local galaxies (although with some debate [13]) . The motion of an observer with velocity $\beta\equiv v/c$ relative to an isotropic Planckian radiation field of temperature T_0 produces a Doppler-shifted temperature pattern

$$T(\theta) = T_0 (1 - \beta^2)^{1/2} / (1 - \beta \cos \theta)$$

$$\simeq T_0 \left(1 + \beta \cos \theta + \left(\beta^2 / 2 \right) \cos 2\theta + O\left(\beta^3 \right) \right).$$

At every point in the sky, one observes a blackbody spectrum, with temperature $T(\theta)$. The spectrum of the dipole is the differential of a blackbody spectrum, as confirmed by Ref. 14.

The implied velocity for the solar system barycenter is $v=369.0\pm0.9\,\mathrm{km\,s^{-1}}$, assuming a value $T_0=T_\gamma$, towards $(\ell,b)=(263.99^\circ\pm0.14^\circ,48.26^\circ\pm0.03^\circ)$ [6,15]. Such a solar system motion implies a velocity for the Galaxy and the Local Group of galaxies relative to the CMB. The derived value is $v_{\mathrm{LG}}=627\pm22\,\mathrm{km\,s^{-1}}$ towards $(\ell,b)=(276^\circ\pm3^\circ,30^\circ\pm3^\circ)$, where most of the error comes from uncertainty in the velocity of the solar system relative to the Local Group.

The dipole is a frame-dependent quantity, and one can thus determine the 'absolute rest frame' as that in which the CMB dipole would be zero. Our velocity relative to the Local Group, as well as the velocity of the Earth around the Sun, and any velocity of the receiver relative to the Earth, is normally removed for the purposes of CMB anisotropy study.

25.2.3. Higher-Order Multipoles:

The variations in the CMB temperature maps at higher multipoles $(\ell \geq 2)$ are interpreted as being mostly the result of perturbations in the density of the early Universe, manifesting themselves at the epoch of the last scattering of the CMB photons. In the hot Big Bang picture, the expansion of the Universe cools the plasma so that by a redshift $z \simeq 1100$ (with little dependence on the details of the model), the hydrogen and helium nuclei can bind electrons into neutral atoms, a process usually referred to as recombination [16]. Before this epoch, the CMB photons are tightly coupled to the baryons, while afterwards they can freely stream towards us.

Theoretical models generally predict that the $a_{\ell m}$ modes are Gaussian random fields to high precision, e.g., standard slow-roll inflation's non-Gaussian contribution is expected to be one or two orders of magnitude below current observational limits [17]. Although non-Gaussianity of various forms is possible in early Universe models, tests show that Gaussianity is an extremely good simplifying approximation [18], with only some relatively weak indications of non-Gaussianity or statistical anisotropy at large scales. Such signatures found in existing WMAP data are generally considered to be subtle foreground or instrumental artifacts [19].

A statistically isotropic sky means that all m's are equivalent, i.e., there is no preferred axis. Together with the assumption of Gaussian statistics, the variance of the temperature field (or equivalently the power spectrum in ℓ) then fully characterizes the anisotropies. The power summed over all m's at each ℓ is $(2\ell+1)C_\ell/(4\pi)$, where $C_\ell \equiv \langle |a_{\ell m}|^2 \rangle$. Thus averages of $a_{\ell m}$'s over m can be used as estimators of the C_ℓ 's to constrain their expectation values, which are the quantities predicted by a theoretical model. For an idealized full-sky observation, the variance of each measured C_ℓ (i.e., the variance of the variance) is $[2/(2\ell+1)]C_\ell^2$. This sampling uncertainty (known as 'cosmic variance') comes about because each C_ℓ is χ^2 distributed with $(2\ell+1)$ degrees of freedom for our observable volume of the Universe. For fractional sky coverage, $f_{\rm sky}$, this variance is increased by $1/f_{\rm sky}$ and the modes become partially correlated.

It is important to understand that theories predict the expectation value of the power spectrum, whereas our sky is a single realization. Hence the cosmic variance is an unavoidable source of uncertainty when constraining models; it dominates the scatter at lower ℓ 's, while the effects of instrumental noise and resolution dominate at higher ℓ 's [20].

25.2.4. Angular Resolution and Binning:

There is no one-to-one conversion between multipole ℓ and the angle subtended by a particular spatial scale projected onto the sky. However, a single spherical harmonic $Y_{\ell m}$ corresponds to angular variations of $\theta \sim \pi/\ell$. CMB maps contain anisotropy information from the size of the map (or in practice some fraction of that size) down to the beam-size of the instrument, σ . One can think of the effect of a Gaussian beam as rolling off the power spectrum with the function $\mathrm{e}^{-\ell(\ell+1)\sigma^2}$.

For less than full sky coverage, the ℓ modes become correlated. Hence, experimental results are usually quoted as a series of 'band powers', defined as estimators of $\ell(\ell+1)C_\ell/2\pi$ over different ranges of ℓ . Because of the strong foreground signals in the Galactic Plane, even 'all-sky' surveys, such as WMAP and Planck involve a cut sky. The amount of binning required to obtain uncorrelated estimates of power also depends on the map size.

25.3. Cosmological Parameters

The current 'Standard Model' of cosmology contains around 10 free parameters (see The Cosmological Parameters—Sec. 23 of this Review). The basic framework is the Friedmann-Robertson-Walker (FRW) metric (i.e., a universe that is approximately homogeneous and isotropic on large scales), with density perturbations laid down at early times and evolving into today's structures (see Big-Bang cosmology—Sec. 21 of this Review). The most general possible set of density variations is a linear combination of an adiabatic density perturbation and some isocurvature perturbations. Adiabatic means that there is no change to the entropy per particle for each species, i.e., $\delta\rho/\rho$ for matter is $(3/4)\delta\rho/\rho$ for radiation. Isocurvature means that the set of individual density perturbations adds to zero, for example, matter perturbations compensate radiation perturbations so that the total energy density remains unperturbed, i.e., $\delta \rho$ for matter is $-\delta \rho$ for radiation. These different modes give rise to distinct (temporal) phases during growth, with those of the adiabatic scenario being strongly preferred by the data. Models that generate mainly isocurvature type perturbations (such as most topological defect scenarios) are no longer considered to be viable. However, an admixture of the adiabatic mode with up to about 10% isocurvature contribution is still allowed [21].

Within the adiabatic family of models, there is, in principle, a free function describing the variation of comoving curvature perturbations, $\mathcal{R}(\mathbf{x},t)$. The great virtue of \mathcal{R} is that it is constant in time for a purely adiabatic perturbation. There are physical reasons to anticipate that the variance of these perturbations will be described well by a power-law in scale, i.e., in Fourier space $\langle |\mathcal{R}|_k^2 \rangle \propto k^{n-4}$, where k is wavenumber and n is the usual definition of spectral index. So-called 'scale-invariant' initial conditions (meaning gravitational potential fluctuations which are independent of k) correspond to n = 1. In inflationary models [22], perturbations are generated by quantum fluctuations, which are set by the energy scale of inflation, together with the slope and higher derivatives of the inflationary potential. One generally expects that the Taylor series expansion of $\ln \mathcal{R}_k(\ln k)$ has terms of steadily decreasing size. For the simplest models, there are thus two parameters describing the initial conditions for density perturbations: the amplitude and slope of the power spectrum. These can be explicitly defined, for example, through:

$$\Delta_{\mathcal{R}}^{2} \equiv (k^{3}/2\pi^{2}) \left\langle |\mathcal{R}|_{k}^{2} \right\rangle = A \left(k/k_{0} \right)^{n-1},$$

with $A \equiv \Delta_{\mathcal{R}}^2(k_0)$ and $k_0 = 0.002\,\mathrm{Mpc}^{-1}$, say. There are many other equally valid definitions of the amplitude parameter (see also Sec. 21 and Sec. 23 of this *Review*), and we caution that the relationships between some of them can be cosmology-dependent. In 'slow roll' inflationary models, this normalization is proportional to the combination $V^3/(V')^2$, for the inflationary potential $V(\phi)$. The slope n also involves V'', and so the combination of A and n can, in principle, constrain potentials.

Inflation generates tensor (gravitational wave) modes, as well as scalar (density perturbation) modes. This fact introduces another parameter, measuring the amplitude of a possible tensor component, or equivalently the ratio of the tensor to scalar contributions. The tensor amplitude is $A_{\rm T} \propto V$, and thus one expects a larger gravitational wave contribution in models where inflation happens at higher energies. The tensor power spectrum also has a slope, often denoted $n_{\rm T}$, but since this seems unlikely to be measured in the near future, it is sufficient for now to focus only on the amplitude of the gravitational wave component. It is most common to define the tensor contribution through r, the ratio of tensor to scalar perturbation spectra at some small value of k (although sometimes it is defined in terms of the ratio of contributions at $\ell=2$). Different inflationary potentials will lead to different predictions, e.g., for $\lambda \phi^4$ inflation with 50 e-folds, r=0.32, and for $m^2\phi^2$ inflation $r\simeq 0.15$, while other models can have arbitrarily small values of r. In any case, whatever the specific definition, and whether they come from inflation or something else, the 'initial conditions' give rise to a minimum of 3 parameters: A, nand r.

The background cosmology requires an expansion parameter (the Hubble Constant, H_0 , often represented through $H_0 = 100 \, h \, \mathrm{km \, s^{-1} Mpc^{-1}}$) and several parameters to describe the matter

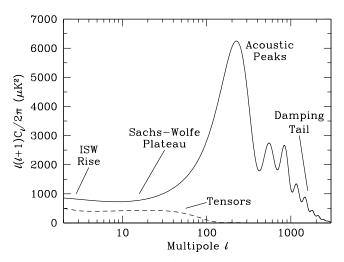


Figure 25.1: The theoretical CMB anisotropy power spectrum, using a standard Λ CDM model from CMBFAST. The x-axis is logarithmic here. The regions, each covering roughly a decade in ℓ , are labeled as in the text: the ISW rise; Sachs-Wolfe plateau; acoustic peaks; and damping tail. Also shown is the shape of the tensor (gravitational wave) contribution, with an arbitrary normalization.

and energy content of the Universe. These are usually given in terms of the critical density, *i.e.*, for species 'x', $\Omega_{\rm x} \equiv \rho_{\rm x}/\rho_{\rm crit}$, where $\rho_{\rm crit} \equiv 3H_0^2/8\pi G$. Since physical densities $\rho_{\rm x} \propto \Omega_{\rm x} h^2 \equiv \omega_{\rm x}$ are what govern the physics of the CMB anisotropies, it is these ω 's that are best constrained by CMB data. In particular CMB, observations constrain $\Omega_{\rm b}h^2$ for baryons and $\Omega_{\rm m}h^2$ for baryons plus cold dark matter.

The contribution of a cosmological constant Λ (or other form of dark energy) is usually included via a parameter which quantifies the curvature, $\Omega_{\rm K} \equiv 1-\Omega_{\rm tot}$, where $\Omega_{\rm tot} = \Omega_{\rm m} + \Omega_{\Lambda}$. The radiation content, while in principle a free parameter, is precisely enough determined by the measurement of T_{γ} , and makes a < 10^{-4} contribution to $\Omega_{\rm tot}$ today.

The main effect of astrophysical processes on the C_ℓ 's comes through reionization. The Universe became reionized at some redshift $z_{\rm i}$, long after recombination, affecting the CMB through the integrated Thomson scattering optical depth:

$$\tau = \int_0^{z_{\rm i}} \sigma_{\rm T} n_{\rm e}(z) \frac{dt}{dz} dz,$$

where $\sigma_{\rm T}$ is the Thomson cross-section, $n_{\rm e}(z)$ is the number density of free electrons (which depends on astrophysics), and dt/dz is fixed by the background cosmology. In principle, τ can be determined from the small-scale matter power spectrum, together with the physics of structure formation and feedback processes. However, this is a sufficiently intricate calculation that τ needs to be considered as a free parameter.

Thus, we have eight basic cosmological parameters: A, n, r, h, $\Omega_{\rm b}h^2$, $\Omega_{\rm m}h^2$, $\Omega_{\rm tot}$, and τ . One can add additional parameters to this list, particularly when using the CMB in combination with other data sets. The next most relevant ones might be: $\Omega_{\nu}h^2$, the massive neutrino contribution; $w \ (\equiv p/\rho)$, the equation of state parameter for the dark energy; and $dn/d\ln k$, measuring deviations from a constant spectral index. To these 11 one could of course add further parameters describing additional physics, such as details of the reionization process, features in the initial power spectrum, a sub-dominant contribution of isocurvature modes, etc.

As well as these underlying parameters, there are other quantities that can be obtained from them. Such derived parameters include the actual Ω 's of the various components (e.g., $\Omega_{\rm m}$), the variance of density perturbations at particular scales (e.g., σ_8), the age of the Universe today (t_0), the age of the Universe at recombination, reionization, etc.

25.4. Physics of Anisotropies

The cosmological parameters affect the anisotropies through the well understood physics of the evolution of linear perturbations within a background FRW cosmology. There are very effective, fast, and publicly available software codes for computing the CMB anisotropy, polarization, and matter power spectra, e.g., CMBFAST [23] and CAMB [24]. These have been tested over a wide range of cosmological parameters and are considered to be accurate to better than the 1% level [25].

A description of the physics underlying the C_{ℓ} 's can be separated into three main regions, as shown in Fig. 25.1.

25.4.1. The ISW rise, $\ell \lesssim 10$, and Sachs-Wolfe plateau, $10 \lesssim \ell \lesssim 100$:

The horizon scale (or more precisely, the angle subtended by the Hubble radius) at last scattering corresponds to $\ell \simeq 100$. Anisotropies at larger scales have not evolved significantly, and hence directly reflect the 'initial conditions'. $\delta T/T = -(1/5)\mathcal{R}(\mathbf{x}_{\rm LSS}) \simeq (1/3)\delta\phi/c^2$, here $\delta\phi$ is the perturbation to the gravitational potential, evaluated on the last scattering surface (LSS). This is a result of the combination of gravitational redshift and intrinsic temperature fluctuations and is usually referred to as the Sachs-Wolfe effect [26].

Assuming that a nearly scale-invariant spectrum of curvature and corresponding density perturbations was laid down at early times (i.e., $n \simeq 1$, meaning equal power per decade in k), then $\ell(\ell+1)C_{\ell} \simeq \text{constant}$ at low ℓ 's. This effect is hard to see unless the multipole axis is plotted logarithmically (as in Fig. 25.1, but not Fig. 25.2).

Time variation of the potentials (i.e., time-dependent metric perturbations) leads to an upturn in the C_ℓ 's in the lowest several multipoles; any deviation from a total equation of state w=0 has such an effect. So the dominance of the dark energy at low redshift makes the lowest ℓ 's rise above the plateau. This is sometimes called the integrated Sachs-Wolfe effect (or ISW rise), since it comes from the line integral of $\dot{\phi}$; it has been confirmed through correlations between the large-angle anisotropies and large-scale structure [27]. Specific models can also give additional contributions at low ℓ (e.g., perturbations in the dark energy component itself [28]), but typically these are buried in the cosmic variance.

In principle, the mechanism that produces primordial perturbations could generate scalar, vector, and tensor modes. However, the vector (vorticity) modes decay with the expansion of the Universe. The tensors (transverse trace-free perturbations to the metric) generate temperature anisotropies through the integrated effect of the locally anisotropic expansion of space. Since the tensor modes also redshift away after they enter the horizon, they contribute only to angular scales above about 1° (see Fig. 25.1). Hence some fraction of the low ℓ signal could be due to a gravitational wave contribution, although small amounts of tensors are essentially impossible to discriminate from other effects that might raise the level of the plateau. However, the tensors can be distinguished using polarization information (see Sec. 25.6).

25.4.2. The acoustic peaks, $100 \lesssim \ell \lesssim 1000$:

On sub-degree scales, the rich structure in the anisotropy spectrum is the consequence of gravity-driven acoustic oscillations occurring before the atoms in the Universe became neutral. Perturbations inside the horizon at last scattering have been able to evolve causally and produce anisotropy at the last scattering epoch, which reflects this evolution. The frozen-in phases of these sound waves imprint a dependence on the cosmological parameters, which gives CMB anisotropies their great constraining power.

The underlying physics can be understood as follows. Before the Universe became neutral, the proton-electron plasma was tightly coupled to the photons, and these components behaved as a single 'photon-baryon fluid.' Perturbations in the gravitational potential, dominated by the dark matter component, were steadily evolving. They drove oscillations in the photon-baryon fluid, with photon pressure providing most of the restoring force and baryons giving some additional inertia. The perturbations were quite small in amplitude, $O(10^{-5})$, and so evolved linearly. That means each Fourier mode developed independently, and hence can be described by a driven harmonic oscillator, with frequency determined by the sound speed in

the fluid. Thus the fluid density underwent oscillations, giving time variations in temperature. These combine with a velocity effect which is $\pi/2$ out of phase and has its amplitude reduced by the sound speed.

After the Universe recombined, the radiation decoupled from the baryons and could travel freely towards us. At that point, the phases of the oscillations were frozen-in, and became projected on the sky as a harmonic series of peaks. The main peak is the mode that went through 1/4 of a period, reaching maximal compression. The even peaks are maximal under-densities, which are generally of smaller amplitude because the rebound has to fight against the baryon inertia. The troughs, which do not extend to zero power, are partially filled by the Doppler effect because they are at the velocity maxima.

The physical length scale associated with the peaks is the sound horizon at last scattering, which can be straightforwardly calculated. This length is projected onto the sky, leading to an angular scale that depends on the geometry of space, as well as the distance to last scattering. Hence the angular position of the peaks is a sensitive probe of the spatial curvature of the Universe (i.e., $\Omega_{\rm tot}$), with the peaks lying at higher ℓ in open universes and lower ℓ in closed geometry.

One additional effect arises from reionization at redshift $z_{\rm i}$. A fraction of photons (τ) will be isotropically scattered at $z < z_{\rm i}$, partially erasing the anisotropies at angular scales smaller than those subtended by the Hubble radius at $z_{\rm i}$. This corresponds typically to ℓ 's above about a few 10s, depending on the specific reionization model. The acoustic peaks are therefore reduced by a factor $e^{-2\tau}$ relative to the plateau.

These peaks were a clear theoretical prediction going back to about 1970 [29]. One can think of them as a snapshot of stochastic standing waves. Since the physics governing them is simple and their structure rich, then one can see how they encode extractable information about the cosmological parameters. Their empirical existence started to become clear around 1994 [30], and the emergence, over the following decade, of a coherent series of acoustic peaks and troughs is a triumph of modern cosmology. This picture has received further confirmation with the detection in the power spectrum of galaxies (at redshifts close to zero) of the imprint of these same acoustic oscillations in the baryon component [33–33].

25.4.3. The damping tail, $\ell \gtrsim 1000$:

The recombination process is not instantaneous, which imparts a thickness to the last scattering surface. This leads to a damping of the anisotropies at the highest ℓ 's, corresponding to scales smaller than that subtended by this thickness. One can also think of the photon-baryon fluid as having imperfect coupling, so that there is diffusion between the two components, and hence the amplitudes of the oscillations decrease with time. These effects lead to a damping of the C_{ℓ} 's, sometimes called Silk damping [34], which cuts off the anisotropies at multipoles above about 2000.

An extra effect at high ℓ 's comes from gravitational lensing, caused mainly by non-linear structures at low redshift. The C_{ℓ} 's are convolved with a smoothing function in a calculable way, partially flattening the peaks, generating a power-law tail at the highest multipoles, and complicating the polarization signal [35]. The effects of lensing on the CMB have recently been detected by correlating temperature gradients and small-scale filtered anisotropies from WMAP with lensing potentials traced using galaxies [36], as well as through the effect on the shape of the C_{ℓ} 's [37] and directly through the CMB 4-point function [38]. This is an example of a 'secondary effect,' i.e., the processing of anisotropies due to relatively nearby structures (see Sec. 25.7.2). Galaxies and clusters of galaxies give several such effects; all are expected to be of low amplitude and typically affect only the highest ℓ 's, but they carry additional cosmological information and will be increasingly important as experiments push to higher sensitivity and angular resolution [39].

25.5. Current Anisotropy Data

There has been a steady improvement in the quality of CMB data that has led to the development of the present-day cosmological model. Probably the most robust constraints currently available come from the combination of the WMAP 7-year data [40] with smaller scale results from the ACT [41] and SPT [42] experiments (together with constraints from other cosmological data-sets). We plot power spectrum estimates from these experiments, as well as ACBAR [43] and QUAD [44] in Fig. 25.2. Other recent experiments also give powerful constraints, which are quite consistent with what we describe below. There have been some comparisons among data-sets [45]. which indicate very good agreement, both in maps and in derived power spectra (up to systematic uncertainties in the overall calibration for some experiments). This makes it clear that systematic effects are largely under control. However, a fully self-consistent joint analysis of all the current data-sets has not been attempted, one of the reasons being that it would require a careful treatment of the overlapping sky coverage.

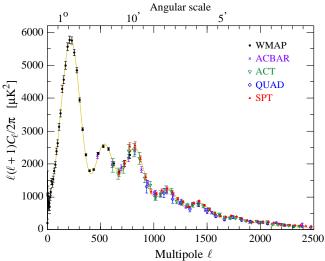


Figure 25.2: Band-power estimates from the WMAP, ACBAR, ACT, QUAD, and SPT experiments (omitting some band-powers which have larger error bars). Note that the widths of the ℓ -bands vary between experiments and have not been plotted. This figure represents only a selection of available experimental results, with some other data-sets being of similar quality. The multipole axis here is linear, so the Sachs-Wolfe plateau is hard to see. However, the acoustic peaks and damping region are very clearly observed, with no need for a theoretical curve to guide the eye; the curve plotted is a best-fit model from WMAP plus other CMB data. At high ℓ there is some departure from the model due to secondary anisotropies.

The band-powers shown in Fig. 25.2 are in very good agreement with a ' Λ CDM' model. As described earlier, several of the peaks and troughs are quite apparent. For details of how these estimates were arrived at, the strength of any correlations between band-powers and other information required to properly interpret them, the original papers should be consulted.

25.6. CMB Polarization

Since Thomson scattering of an anisotropic radiation field also generates linear polarization, the CMB is predicted to be polarized at the level of roughly 5% of the temperature anisotropies [46]. Polarization is a spin-2 field on the sky, and the algebra of the modes in ℓ -space is strongly analogous to spin-orbit coupling in quantum mechanics [47]. The linear polarization pattern can be decomposed in a number of ways, with two quantities required for each pixel in a map, often given as the Q and U Stokes parameters. However, the most intuitive and physical decomposition is a geometrical one, splitting the polarization pattern into a part that comes from a

divergence (often referred to as the 'E-mode') and a part with a curl (called the 'B-mode') [48]. More explicitly, the modes are defined in terms of second derivatives of the polarization amplitude, with the Hessian for the E-modes having principle axes in the same sense as the polarization, while the B-mode pattern can be thought of as a 45° rotation of the E-mode pattern. Globally one sees that the E-modes have $(-1)^{\ell}$ parity (like the spherical harmonics), while the B-modes have $(-1)^{\ell+1}$ parity.

The existence of this linear polarization allows for six different cross power spectra to be determined from data that measure the full temperature and polarization anisotropy information. Parity considerations make two of these zero, and we are left with four potential observables: $C_\ell^{\rm TT}$, $C_\ell^{\rm TE}$, $C_\ell^{\rm EE}$, and $C_\ell^{\rm BB}$. Because scalar perturbations have no handedness, the B-mode power spectrum can only be sourced by vectors or tensors. Moreover, since inflationary scalar perturbations give only E-modes, while tensors generate roughly equal amounts of E- and B-modes, then the determination of a non-zero B-mode signal is a way to measure the gravitational wave contribution (and thus potentially derive the energy scale of inflation), even if it is rather weak. However, one must first eliminate the foreground contributions and other systematic effects down to very low levels.

The oscillating photon-baryon fluid also results in a series of acoustic peaks in the polarization C_ℓ 's. The main 'EE' power spectrum has peaks that are out of phase with those in the 'TT' spectrum, because the polarization anisotropies are sourced by the fluid velocity. The 'TE' part of the polarization and temperature patterns comes from correlations between density and velocity perturbations on the last scattering surface, which can be both positive and negative, and is of larger amplitude than the EE signal. There is no polarization Sachs-Wolfe effect, and hence no large-angle plateau. However, scattering during a recent period of reionization can create a polarization 'bump' at large angular scales.

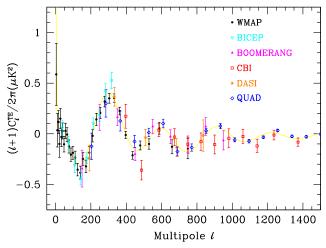


Figure 25.3: Cross power spectrum of the temperature anisotropies and E-mode polarization signal from WMAP, together with estimates from BICEP, BOOMERANG, CBI, DASI, and QUAD, several of which extend to higher ℓ . Note that the y-axis here is not multiplied by the additional ℓ , which helps to show both the large and small angular scale features.

Because the polarization anisotropies have only a fraction of the amplitude of the temperature anisotropies, they took longer to detect. The first measurement of a polarization signal came in 2002 from the DASI experiment [49], which provided a convincing detection, confirming the general paradigm, but of low enough significance that it lent little constraint to models. As well as the *E*-mode signal, DASI also made a statistical detection of the TE correlation.

The TE signal has now been mapped out quite accurately through data from WMAP [50], together with the BICEP [51], BOOMERANG [52], CBI [53], DASI [54], and QUAD [55] experiments, which are shown in Fig. 25.3. The anti-correlation

at $\ell \simeq 150$ and the peak at $\ell \simeq 300$ are now quite distinct. The measured shape of the cross-correlation power spectrum provides supporting evidence for the adiabatic nature of the perturbations, as well as directly constraining the thickness of the last scattering surface. Since the polarization anisotropies are generated in this scattering surface, the existence of correlations at angles above about a degree demonstrates that there were super-Hubble fluctuations at the recombination epoch. The sign of this correlation also confirms the adiabatic paradigm.

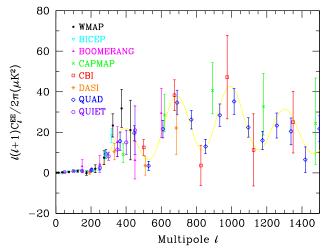


Figure 25.4: Power spectrum of *E*-mode polarization from several different experiments, plotted along with a theoretical model which fits WMAP plus other CMB data. Note that the widths of the bands have been suppressed for clarity, but that in some cases they are almost as wide as the features in the power spectrum.

Experimental band-powers for $C_\ell^{\rm EE}$ from WMAP plus BICEP [51], BOOMERANG [56], CAPMAP [57], CBI [53], DASI [54], QUAD [55] and QUIET [58] are shown in Fig. 25.4. Without the benefit of correlating with the temperature anisotropies (i.e., measuring $C_\ell^{\rm TE}$), the polarization anisotropies are very weak and challenging to measure. Nevertheless, there is a highly significant overall detection which is consistent with expectation. The data convincingly show the peak at $\ell \simeq 140$ (hard to see on this scale), the next peak at $\ell \simeq 400$ (corresponding to the first trough in $C_\ell^{\rm TT}$) and the generally oscillatory structure.

Several experiments have reported upper limits on C_ℓ^{BB} , but they are currently not very constraining. This situation should change as increasingly ambitious experiments report results.

The most distinctive novel from the polarization measurements is at the largest angular scales ($\ell < 10$) in C_ℓ^{TE} , where there is an excess signal compared to that expected from the temperature power spectrum alone. This is precisely the signal anticipated from an early period of reionization, arising from Doppler shifts during the partial scattering at $z < z_i$. The effect is also confirmed in the WMAP C_ℓ^{EE} results at $\ell = 2-7$ [50]. The amplitude of the signal indicates that the first stars, presumably the source of the ionizing radiation, formed around $z \simeq 10$ (although the uncertainty is still quite large). Since this corresponds to scattering optical depth $\tau \simeq 0.1$, then roughly 10% of CMB photons were re-scattered at the reionization epoch, with the other 90% last scattering at $z \simeq 1100$.

25.7. Complications

There are a number of issues which complicate the interpretation of CMB anisotropy data (and are considered to be *signal* by many astrophysicists), some of which we sketch out below.

25.7.1. Foregrounds:

The microwave sky contains significant emission from our Galaxy and from extra-galactic sources [59,60]. Fortunately, the frequency dependence of these various sources is in general substantially different from that of the CMB anisotropy signals. The combination of Galactic synchrotron, bremsstrahlung, and dust emission reaches a minimum at a wavelength of roughly 3 mm (or about 100 GHz). As one moves to greater angular resolution, the minimum moves to slightly higher frequencies, but becomes more sensitive to unresolved (point-like) sources.

At frequencies around 100 GHz, and for portions of the sky away from the Galactic Plane, the foregrounds are typically 1 to 10% of the CMB anisotropies. By making observations at multiple frequencies, it is relatively straightforward to separate the various components and determine the CMB signal to the few per cent level. For greater sensitivity, it is necessary to use the spatial information and statistical properties of the foregrounds to separate them from the CMB.

The foregrounds for CMB polarization follow a similar pattern, but are less well studied, and are intrinsically more complicated. WMAP has shown that the polarized foregrounds dominate at large angular scales, and that they must be well characterized in order to be discriminated [60]. Whether it is possible to achieve sufficient separation to detect *B*-mode CMB polarization is still an open question. However, for the time being, foreground contamination is not a fundamental limit for CMB experiments.

25.7.2. Secondary Anisotropies:

With increasingly precise measurements of the primary anisotropies, there is growing theoretical and experimental interest in 'secondary anisotropies,' pushing experiments to higher angular resolution and sensitivity. These secondary effects arise from the processing of the CMB due to ionization history and the evolution of structure, including gravitational lensing and patchy reionization effects [61]. Additional information can thus be extracted about the Universe at $z\ll 1000$. This tends to be most effectively done through correlating CMB maps with other cosmological probes of structure. Secondary signals are also typically non-Gaussian, unlike the primary CMB anisotropies.

A secondary signal of great current interest is the Sunyaev-Zeldovich (SZ) effect [62], which is Compton scattering ($\gamma e \to \gamma' e'$) of the CMB photons by hot electron gas. This creates spectral distortions by transferring energy from the electrons to the photons. It is particularly important for clusters of galaxies, through which one observes a partially Comptonized spectrum, resulting in a decrement at radio wavelengths and an increment in the submillimeter.

The imprint on the CMB sky is of the form $\Delta T/T = y f(x)$, with the y-parameter being the integral of Thomson optical depth times $kT_{\rm e}/m_{\rm e}c^2$ through the cluster, and f(x) describing the frequency dependence. This is simply $x \coth(x/2) - 4$ for a non-relativistic gas (the electron temperature in a cluster is typically a few keV), where the dimensionless frequency $x \equiv h\nu/kT_{\gamma}$. As well as this 'thermal' SZ effect, there is also a smaller 'kinetic' effect due to the bulk motion of the cluster gas, giving $\Delta T/T \sim \tau(v/c)$, with either sign, but having the same spectrum as the primary CMB anisotropies.

A significant advantage in finding galaxy clusters this way is that the SZ effect is largely independent of redshift, so in principle clusters can be found to arbitrarily large distances. The SZ effect can be used to find and study individual clusters, and to obtain estimates of the Hubble constant. There is also the potential to constrain the equation of state of the dark energy through counts of detected clusters as a function of redshift [63]. Many experiments are currently in operation which will probe clusters in this way. The promise of the method has been realized through detections of clusters purely through the SZ effect, by SPT [64], ACT [65] and Planck [66].

${\bf 25.7.3.} \quad Higher-order\ Statistics:$

Although most of the CMB anisotropy information is contained in the power spectra, there will also be weak signals present in higher-order statistics. These can measure any primordial non-Gaussianity in the perturbations, as well as non-linear growth of the fluctuations on small scales and other secondary effects (plus residual foreground contamination of course). Although there are an infinite variety of ways in which the CMB could be non-Gaussian [17], there is a

generic form to consider for the initial conditions, where a quadratic contribution to the curvature perturbations is parameterized through a dimensionless number $f_{\rm NL}$. This weakly non-linear component can be constrained using measurements of the bispectrum or Minkowski functionals, for example. The constraints depend on the shape of the triangles in harmonic space, and it has become common to distinguish the 'local' or 'squeezed' configuration (in which one side is much smaller than the other two) from the 'equilateral' configuration. The results from the WMAP team are $-10 < f_{\rm NL} < 74$ (95% confidence region), for the local mode and $-214 < f_{\rm NL} < 266$ for the equilateral mode [40]. Different estimators used by other authors give results of similar magnitude [67].

The level of $f_{\rm NL}$ expected is small, so that a detection of $f_{\rm NL} \gtrsim 10$ would rule out all single field, slow-roll inflationary models. However, with the capabilities of Planck and other future experiments, it seems that a measurement of primordial non-Gaussianity may be feasible for a wide class of models, and therefore much effort is expected to be devoted to predictions and measurements in the coming years.

25.8. Constraints on Cosmologies

The most striking outcome of the newer experimental results is that the standard cosmological paradigm is in very good shape. A large amount of high precision data on the power spectrum is adequately fit with fewer than 10 free parameters. The framework is that of FRW models, which have nearly flat geometry, containing dark matter and dark energy, and with adiabatic perturbations having close to scale invariant initial conditions.

Within this basic picture, the values of the cosmological parameters can be constrained. Of course, much more stringent bounds can be placed on models which cover a restricted parameter space, e.g., assuming that $\Omega_{\rm tot}=1,\ n=1$ or r=0. More generally, the constraints depend upon the adopted prior probability distributions, even if they are implicit, for example by restricting the parameter freedom or their ranges (particularly where likelihoods peak near the boundaries), or by using different choices of other data in combination with the CMB. When the data become even more precise, these considerations will be less important, but for now we caution that restrictions on model space and choice of priors need to be kept in mind when adopting specific parameter values and uncertainties.

There are some combinations of parameters that fit the CMB anisotropies almost equivalently. For example, there is a nearly exact geometric degeneracy, where any combination of $\Omega_{\rm m}$ and Ω_{Λ} that gives the same angular diameter distance to last scattering will give nearly identical C_ℓ 's. There are also other less exact degeneracies among the parameters. Such degeneracies can be broken when using the CMB results in combination with other cosmological data-sets. Particularly useful are complementary constraints from galaxy clustering, the abundance of galaxy clusters, baryon acoustic oscillations, weak gravitational lensing measurements, Type Ia supernova distances, and the distribution of Lyman α forest clouds. For an overview of some of these other cosmological constraints, see The Cosmological Parameters—Sec. 23 of this Review.

The 7-year WMAP data alone, within the context of a six parameter family of models (which fixes $\Omega_{\rm tot}=1$ and r=0), yield the following results [50]: $A=(2.43\pm0.11)\times10^{-9};~n=0.967\pm0.014;~h=0.704\pm0.025;~\Omega_{\rm b}h^2=0.0225\pm0.0006;~\Omega_{\rm m}h^2=0.134\pm0.006;~{\rm and}~\tau=0.088\pm0.015.$ There has been little substantive change compared with earlier results, although it is now possible to obtain this 6-parameter set without using additional cosmological data-sets. Compared with the earliest WMAP results, the better measurement of the third acoustic peak, together with improved understanding of calibration issues has led to tighter error bars on dark matter density and overall normalization. The evidence for non-zero reionization optical depth is now very compelling, while the evidence for n<1 is still only at the roughly 3σ level.

Other combinations of data, e.g., including additional CMB measurements, or using other cosmological data-sets, lead to consistent results to those given above, sometimes with smaller error bars, and with the precise values depending on data selection [33,55,68,42] (see Sec. 23 of this Review). Note that for h, the CMB data alone provide only a very weak constraint, unless spatial flatness or some other cosmological data are used. For $\Omega_{\rm b}h^2$, the precise value depends

sensitively on how much freedom is allowed in the shape of the primordial power spectrum (see Sec. 22 of this Review). The addition of other data-sets also allows for constraints to be placed on further parameters.

For $\Omega_{\rm tot}$, perhaps the best WMAP constraint is 1.002 ± 0.006 [40], from the combination with Hubble constant [22] and baryon acoustic oscillation [33] constraints (and setting w=-1). The 95% confidence upper limit on r is 0.36 using WMAP alone [50], tightening to r<0.17 with the addition of other data [42]. This limit depends on how the slope n is restricted and whether $dn/d\ln k \neq 0$ is allowed. Nevertheless, it is clear that $\lambda\phi^4$ (sometimes called self-coupled) inflation is disfavored by the data, while the $m^2\phi^2$ (sometimes called mass term) inflationary model is still allowed [40]. Gravitational wave constraints coming directly from B-mode limits are at the level of r<0.73 [51].

There are also constraints on parameters over and above the basic eight that we have described, usually requiring extra cosmological data to break degeneracies. For example, the addition of the dark energy equation of state w adds the partial degeneracy of being able to fit a ridge in (w,h) space, extending to low values of both parameters. This degeneracy is broken when the CMB is used in combination with independent H_0 limits, or other data. For example, WMAP plus baryon acoustic oscillation and supernova data [70] yields $w=-1.00\pm0.06$, even without assuming flatness.

For the optical depth τ , the best-fit corresponds to a reionization redshift centered on 10.5 in the best-fit cosmology, and assuming instantaneous reionization. This redshift appears to be higher that that suggested from studies of absorption in high-z quasar spectra [71], perhaps indicating that the process of reionization was complex. The important constraint provided by CMB polarization, in combination with astrophysical measurements, allows us to investigate how the first stars formed and brought about the end of the cosmic dark ages.

25.9. Particle Physics Constraints

CMB data are beginning to put limits on parameters which are directly relevant for particle physics models. For example, there is a limit on the neutrino contribution $\Omega_{\nu}h^2 < 0.0062$ (95% confidence) from a combination of WMAP and other data [18]. This directly implies a limit on neutrino mass, $\sum m_{\nu} < 0.58\,\mathrm{eV}$, assuming the usual number density of fermions which decoupled when they were relativistic. Some tighter constraints can be derived using the CMB in combination with other data-sets [72].

The current suite of data suggests that n<1, with a best-fitting value about 0.03 below unity. If borne out, this would be quite constraining for inflationary models. Moreover, it gives a real target for B-mode searches, since the value of r in simple models may be in the range of detectability, e.g., $r\sim0.12$ for $m^2\phi^2$ inflation if $n\simeq0.97$. In addition, a combination of the WMAP data with other data-sets constrains the running of the spectral index, although at the moment there is no evidence for $dn/d\ln k \neq 0$ [40].

One other possible hint of new physics lies in the fact that the quadrupole seems anomalously low and also appears remarkably well aligned with the octupole. Additionally there is some weak evidence for a large scale modulation of the smaller-scale power [73]. These effects might be expected in a universe which has a large-scale cut-off, or anisotropy in the initial power spectrum, or is topologically non-trivial. However, cosmic variance, a posteriori statistics, possible foregrounds, apparent correlations between modes (as mentioned in Sec. 25.2), etc., limit the significance of these anomalies, and for now the general view is that such features are not unreasonably unlikely within the Λ CDM paradigm [19].

It is also possible to put limits on other pieces of physics [74], for example the neutrino chemical potentials, contribution of warm dark matter, decaying particles, parity violation, time variation of the fine-structure constant, topological defects, or physics beyond general relativity. Further particle physics constraints will follow as the anisotropy measurements increase in precision.

Careful measurement of the CMB power spectra and non-Gaussianity can in principle put constraints on physics at the highest energies, including ideas of string theory, extra dimensions, colliding branes, etc. At the moment any calculation of predictions appears to be far from definitive. However, there is a great deal of activity on

implications of string theory for the early Universe, and hence a very real chance that there might be observational implications for specific scenarios.

25.10. Fundamental Lessons

More important than the precise values of parameters is what we have learned about the general features which describe our observable Universe. Beyond the basic hot Big Bang picture, the CMB has taught us that:

- The Universe recombined at $z\simeq 1100$ and started to become ionized again at $z\simeq 10$.
- The geometry of the Universe is close to flat.
- Both dark matter and dark energy are required.
- Gravitational instability is sufficient to grow all of the observed large structures in the Universe.
- Topological defects were not important for structure formation.
- There are 'synchronized' super-Hubble modes generated in the early Universe.
- The initial perturbations were predominantly adiabatic in nature.
- The perturbations had close to Gaussian (i.e., maximally random) initial conditions.

It is very tempting to make an analogy between the status of the cosmological 'Standard Model' and that of particle physics (see earlier Sections of this *Review*). In cosmology there are about 10 free parameters, each of which is becoming well determined, and with a great deal of consistency between different measurements. However, none of these parameters can be calculated from a fundamental theory, and so hints of the bigger picture, 'physics beyond the Standard Model,' are being searched for with ever more ambitious experiments.

Despite this analogy, there are some basic differences. For one thing, many of the cosmological parameters change with cosmic epoch, and so the measured values are simply the ones determined today, and hence they are not 'constants,' like particle masses for example (although they are deterministic, so that if one knows their values at one epoch, they can be calculated at another). Moreover, the parameter set is not as well defined as it is in the particle physics Standard Model; different researchers will not necessarily agree on which parameters should be considered as free, and the set can be extended as the quality of the data improves. In addition, parameters like τ , which come from astrophysics, are in principle calculable from known physical processes. On top of all this, other parameters might be 'stochastic' in that they may be fixed only in our observable patch of the Universe or among certain vacuum states in the 'Landscape' [76].

In a more general sense, the cosmological 'Standard Model' is much further from the underlying 'fundamental theory,' which will ultimately provide the values of the parameters from first principles. Nevertheless, any genuinely complete 'theory of everything' must include an explanation for the values of these cosmological parameters as well as the parameters of the Standard Model of particle physics.

25.11. Future Directions

Given the significant progress in measuring the CMB sky, which has been instrumental in tying down the cosmological model, what can we anticipate for the future? There will be a steady improvement in the precision and confidence with which we can determine the appropriate cosmological parameters. Ground-based experiments operating at smaller angular scales will continue to place tighter constraints on the damping tail. New polarization experiments will push down the limits on primordial B-modes. The third generation CMB satellite mission, Planck, was launched successfully in May 2009, and has already led to many papers on foregrounds and secondary anisotropies [9]. Cosmological results from the primary CMB anisotropies are expected from Planck in early 2013 and are keenly anticipated.

Despite the increasing improvement in the results, the addition of the latest experiments has not significantly changed the established cosmological model. It is, therefore, appropriate to ask: what should we expect to come from *Planck* and from other future experiments? *Planck* certainly has the advantage of high sensitivity and a full-sky survey. A precise measurement of the third acoustic peak provides

a good determination of the matter density; this can only be done by measurements which are accurate relative to the first two peaks (which themselves constrain the curvature and the baryon density). A detailed measurement of the damping tail region will also significantly improve the determination of n and any running of the slope. Planck should be capable of measuring $C_\ell^{\rm EE}$ quite well, providing both a strong check on the cosmological Standard Model and extra constraints that will improve parameter estimation.

A set of cosmological parameters is now known to roughly 10% accuracy, and that may seem sufficient for many people. However, we should certainly demand more of measurements which describe the entire observable Universe! Hence a lot of activity in the coming years will continue to focus on determining those parameters with increasing precision. This necessarily includes testing for consistency among different predictions of the cosmological Standard Model, and searching for signals which might require additional physics.

A second area of focus will be the smaller scale anisotropies and 'secondary effects.' There is a great deal of information about structure formation at $z\ll 1000$ encoded in the CMB sky. This may involve higher-order statistics as well as spectral signatures, with many new experiments targeting the galaxy cluster SZ effect. Such investigations can also provide constraints on the dark energy equation of state, for example. Planck, as well as new telescopes aimed at the highest ℓ 's, should be able to make a lot of progress in this arena.

A third direction is increasingly sensitive searches for specific signatures of physics at the highest energies. The most promising of these may be the primordial gravitational wave signals in $C_\ell^{\rm BB}$, which could be a probe of the $\sim 10^{16}\,\rm GeV$ energy range. As well as *Planck*, there are several ground- and balloon-based experiments underway which are designed to search for the polarization *B*-modes. Whether the amplitude of the effect coming from inflation will be detectable is unclear, but the prize makes the effort worthwhile, and the indications that $n\simeq 0.95$ give some genuine optimism that r (the tensor to scalar ratio) may be of order 0.1, and hence within reach soon.

Anisotropies in the CMB have proven to be the premier probe of cosmology and the early Universe. Theoretically the CMB involves well understood physics in the linear regime, and is under very good calculational control. A substantial and improving set of observational data now exists. Systematics appear to be under control and not a limiting factor. And so for the next few years we can expect an increasing amount of cosmological information to be gleaned from CMB anisotropies, with the prospect also of some genuine surprises.

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26. COSMIC RAYS

Revised August 2011 by J.J. Beatty (Ohio State Univ.) and J. Matthews (Louisiana State Univ. and Southern Univ.); revised August 2009 by T.K. Gaisser and T. Stanev (Bartol Research Inst., Univ. of Delaware).

26.1. Primary spectra

The cosmic radiation incident at the top of the terrestrial atmosphere includes all stable charged particles and nuclei with lifetimes of order 10⁶ years or longer. Technically, "primary" cosmic rays are those particles accelerated at astrophysical sources and "secondaries" are those particles produced in interaction of the primaries with interstellar gas. Thus electrons, protons and helium, as well as carbon, oxygen, iron, and other nuclei synthesized in stars, are primaries. Nuclei such as lithium, beryllium, and boron (which are not abundant end-products of stellar nucleosynthesis) are secondaries. Antiprotons and positrons are also in large part secondary. Whether a small fraction of these particles may be primary is a question of current interest.

Apart from particles associated with solar flares, the cosmic radiation comes from outside the solar system. The incoming charged particles are "modulated" by the solar wind, the expanding magnetized plasma generated by the Sun, which decelerates and partially excludes the lower energy galactic cosmic rays from the inner solar system. There is a significant anticorrelation between solar activity (which has an alternating eleven-year cycle) and the intensity of the cosmic rays with energies below about 10 GeV. In addition, the lower-energy cosmic rays are affected by the geomagnetic field, which they must penetrate to reach the top of the atmosphere. Thus the intensity of any component of the cosmic radiation in the GeV range depends both on the location and time.

There are four different ways to describe the spectra of the components of the cosmic radiation: (1) By particles per unit rigidity. Propagation (and probably also acceleration) through cosmic magnetic fields depends on gyroradius or magnetic rigidity, R, which is gyroradius multiplied by the magnetic field strength:

$$R = \frac{pc}{Ze} = r_L B \ . \tag{26.1}$$

(2) By particles per energy-per-nucleon. Fragmentation of nuclei propagating through the interstellar gas depends on energy per nucleon, since that quantity is approximately conserved when a nucleus breaks up on interaction with the gas. (3) By nucleons per energy-per-nucleon. Production of secondary cosmic rays in the atmosphere depends on the intensity of nucleons per energy-per-nucleon, approximately independently of whether the incident nucleons are free protons or bound in nuclei. (4) By particles per energy-per-nucleus. Air shower experiments that use the atmosphere as a calorimeter generally measure a quantity that is related to total energy per particle.

The units of differential intensity I are $[m^{-2}s^{-1}sr^{-1}\mathcal{E}^{-1}]$, where \mathcal{E} represents the units of one of the four variables listed above.

The intensity of primary nucleons in the energy range from several GeV to somewhat beyond 100 TeV is given approximately by

$$I_N(E) \approx 1.8 \times 10^4 \; (E/1 \; {\rm GeV})^{-\alpha} \; \frac{\rm nucleons}{\rm m^2 \; s \; sr \; GeV} \; ,$$
 (26.2)

where E is the energy-per-nucleon (including rest mass energy) and $\alpha \ (\equiv \gamma+1)=2.7$ is the differential spectral index of the cosmic ray flux and γ is the integral spectral index. About 79% of the primary nucleons are free protons and about 70% of the rest are nucleons bound in helium nuclei. The fractions of the primary nuclei are nearly constant over this energy range (possibly with small but interesting variations). Fractions of both primary and secondary incident nuclei are listed in Table 26.1. Figure 26.1 shows the major components for energies greater than 2 GeV/nucleon.

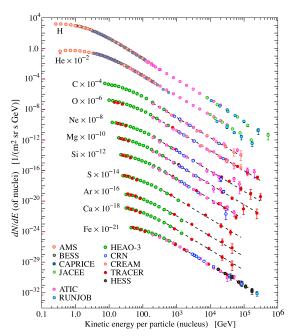


Figure 26.1: Fluxes of nuclei of the primary cosmic radiation in particles per energy-per-nucleus are plotted vs energy-per-nucleus using data from Refs. [1–12]. The figure was created by P. Boyle and D. Muller.

The composition and energy spectra of nuclei are typically interpreted in the context of propagation models, in which the sources of the primary cosmic radiation are located within the galaxy [16]. The ratio of secondary to primary nuclei is observed to decrease with increasing energy, a fact interpreted to mean that the lifetime of cosmic rays in the galaxy decreases with energy. Measurements of radioactive "clock" isotopes in the low energy cosmic radiation are consistent with a lifetime in the galaxy of about 15 Myr.

Table 26.1: Relative abundances F of cosmic-ray nuclei at 10.6 GeV/nucleon normalized to oxygen ($\equiv 1$) [6]. The oxygen flux at kinetic energy of 10.6 GeV/nucleon is $3.26 \times 10^{-2} \text{ (m}^2 \text{ s sr GeV/nucleon)}^{-1}$. Abundances of hydrogen and helium are from Refs. [2,3]. Note that one can not use these values to extend the cosmic ray flux to high energy because the power law indicies for each element may differ slightly.

| \overline{Z} | Element | F | \overline{Z} | Element | F |
|----------------|---------|------|----------------|------------------------|------|
| 1 | Н | 540 | 13–14 | Al-Si | 0.19 |
| 2 | He | 26 | 15 - 16 | P-S | 0.03 |
| 3-5 | Li-B | 0.40 | 17 - 18 | Cl-Ar | 0.01 |
| 6-8 | C-O | 2.20 | 19 - 20 | K-Ca | 0.02 |
| 9 - 10 | F-Ne | 0.30 | 21 - 25 | $\operatorname{Sc-Mn}$ | 0.05 |
| 11-12 | Na-Mg | 0.22 | 26-28 | Fe-Ni | 0.12 |

Cosmic rays are nearly isotropic at most energies due to diffusive propagation in the galactic magnetic field. Milagro [13], IceCube [14], and The Tibet-III air shower array [15] have observed anisotropy at the level of about 10^{-3} for cosmic rays with energy of a few TeV, possibly due to nearby sources.

The spectrum of electrons and positrons incident at the top of the atmosphere is expected to steepen by one power of E at an energy of ~ 5 GeV because of the strong synchrotron energy loss in the galactic magnetic fields. The ATIC experiment [21] measured an excess of electrons above 100 GeV followed by a steepening above 1,000 GeV. The Fermi/LAT γ -ray observatory confirmed the relatively

flat electron spectrum [23] without confirming the peak of the ATIC excess at ${\sim}800$ GeV.

The PAMELA satellite experiment [24] measured the positron to electron ratio to increase above 10 GeV instead of the expected decrease [25] at higher energy. The structure in the electron spectrum as well as the increase in the positron fraction could be related to contributions from individual nearby sources emerging above a background suppressed at high energy by synchrotron losses [26]. The low positron to electron ratio below 10 GeV is due to the new solar magnetic field polarity after the year 2001.

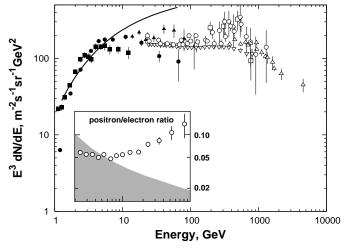


Figure 26.2: Differential spectrum of electrons plus positrons multiplied by E^3 (data from [17–23]). The line shows the proton spectrum multiplied by 0.01. The inset shows the positron to electron ratio measured by PAMELA [24] compared to the expected decrease [25].

The ratio of antiprotons to protons is $\sim 2 \times 10^{-4}$ [27] at around 10–20 GeV, and there is clear evidence [28] for the kinematic suppression at lower energy that is the signature of secondary antiprotons. The \overline{p}/p ratio also shows a strong dependence on the phase and polarity of the solar cycle [29] in the opposite sense to that of the positron fraction. There is at this time no evidence for a significant primary component of antiprotons. No antihelium or antideuteron has been found in the cosmic radiation. The best measured upper limit on the ratio antihelium/helium is currently approximately 1×10^{-7} [30] The upper limit on the flux of antideuterons around 1 GeV/nucleon is approximately 2×10^{-4} (m² s sr GeV/nucleon)⁻¹ [31].

26.2. Cosmic rays in the atmosphere

Figure 26.3 shows the vertical fluxes of the major cosmic ray components in the atmosphere in the energy region where the particles are most numerous (except for electrons, which are most numerous near their critical energy, which is about 81 MeV in air). Except for protons and electrons near the top of the atmosphere, all particles are produced in interactions of the primary cosmic rays in the air. Muons and neutrinos are products of the decay chain of charged mesons, while electrons and photons originate in decays of neutral mesons.

Most measurements are made at ground level or near the top of the atmosphere, but there are also measurements of muons and electrons from airplanes and balloons. Fig. 26.3 includes recent measurements of negative muons [32–36]. Since $\mu^+(\mu^-)$ are produced in association with $\nu_{\mu}(\overline{\nu}_{\mu})$, the measurement of muons near the maximum of the intensity curve for the parent pions serves to calibrate the atmospheric ν_{μ} beam [37]. Because muons typically lose almost 2 GeV in passing through the atmosphere, the comparison near the production altitude is important for the sub-GeV range of $\nu_{\mu}(\overline{\nu}_{\mu})$ energies.

The flux of cosmic rays through the atmosphere is described by a set of coupled cascade equations with boundary conditions at the

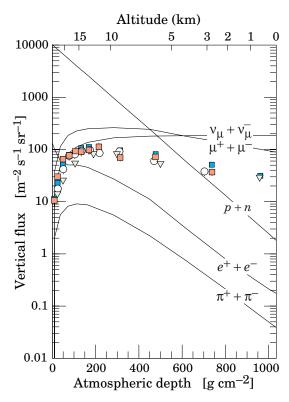


Figure 26.3: Vertical fluxes of cosmic rays in the atmosphere with E>1 GeV estimated from the nucleon flux of Eq. (26.2). The points show measurements of negative muons with $E_{\mu}>1$ GeV [32–36].

top of the atmosphere to match the primary spectrum. Numerical or Monte Carlo calculations are needed to account accurately for decay and energy-loss processes, and for the energy-dependences of the cross sections and of the primary spectral index γ . Approximate analytic solutions are, however, useful in limited regions of energy [38,39]. For example, the vertical intensity of charged pions with energy $E_\pi \ll \epsilon_\pi = 115~{\rm GeV}$ is

$$I_{\pi}(E_{\pi}, X) \approx \frac{Z_{N\pi}}{\lambda_N} I_N(E_{\pi}, 0) e^{-X/\Lambda} \frac{X E_{\pi}}{\epsilon_{\pi}},$$
 (26.3)

where Λ is the characteristic length for exponential attenuation of the parent nucleon flux in the atmosphere. This expression has a maximum at $X=\Lambda\approx 121\pm 4~{\rm g~cm^{-2}}$ [40], which corresponds to an altitude of 15 kilometers. The quantity $Z_{N\pi}$ is the spectrum-weighted moment of the inclusive distribution of charged pions in interactions of nucleons with nuclei of the atmosphere. The intensity of low-energy pions is much less than that of nucleons because $Z_{N\pi}\approx 0.079$ is small and because most pions with energy much less than the critical energy ϵ_{π} decay rather than interact.

26.3. Cosmic rays at the surface

26.3.1. Muons: Muons are the most numerous charged particles at sea level (see Fig. 26.3). Most muons are produced high in the atmosphere (typically 15 km) and lose about 2 GeV to ionization before reaching the ground. Their energy and angular distribution reflect a convolution of the production spectrum, energy loss in the atmosphere, and decay. For example, 2.4 GeV muons have a decay length of 15 km, which is reduced to 8.7 km by energy loss. The mean energy of muons at the ground is ≈ 4 GeV. The energy spectrum is almost flat below 1 GeV, steepens gradually to reflect the primary spectrum in the 10–100 GeV range, and steepens further at higher energies because pions with $E_\pi > \epsilon_\pi$ tend to interact in the atmosphere before they decay. Asymptotically ($E_\mu \gg 1$ TeV), the energy spectrum of atmospheric muons is one power steeper than the primary spectrum.

The integral intensity of vertical muons above 1 GeV/c at sea level is $\approx 70~{\rm m}^{-2}{\rm s}^{-1}{\rm sr}^{-1}$ [41,42], with recent measurements [43–45] favoring a lower normalization by 10-15%. Experimentalists are familiar with this number in the form $I\approx 1~{\rm cm}^{-2}~{\rm min}^{-1}$ for horizontal detectors. The overall angular distribution of muons at the ground is $\propto \cos^2\theta$, which is characteristic of muons with $E_{\mu}\sim 3~{\rm GeV}$. At lower energy the angular distribution becomes increasingly steep, while at higher energy it flattens, approaching a $\sec\theta$ distribution for $E_{\mu}\gg\epsilon_{\pi}$ and $\theta<70^{\circ}$.

Figure 26.4 shows the muon energy spectrum at sea level for two angles. At large angles low energy muons decay before reaching the surface and high energy pions decay before they interact, thus the average muon energy increases. An approximate extrapolation formula valid when muon decay is negligible $(E_{\mu} > 100/\cos\theta~{\rm GeV})$ and the curvature of the Earth can be neglected $(\theta < 70^{\circ})$ is

$$\frac{dN_{\mu}}{dE_{\mu}d\Omega} \approx \frac{0.14 E_{\mu}^{-2.7}}{\text{cm}^2 \text{ s sr GeV}} \times \left\{ \frac{1}{1 + \frac{1.1E_{\mu}\cos\theta}{115 \text{ GeV}}} + \frac{0.054}{1 + \frac{1.1E_{\mu}\cos\theta}{850 \text{ GeV}}} \right\} , \quad (26.4)$$

where the two terms give the contribution of pions and charged kaons. Eq. (26.4) neglects a small contribution from charm and heavier flavors which is negligible except at very high energy [50].

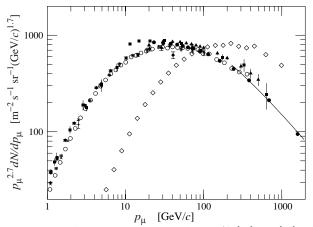


Figure 26.4: Spectrum of muons at $\theta = 0^{\circ}$ (\blacklozenge [41], \blacksquare [46], \checkmark [47], \blacktriangle [48], \times , + [43], \circ [44], and \bullet [45] and $\theta = 75^{\circ} \diamond$ [49]). The line plots the result from Eq. (26.4) for vertical showers.

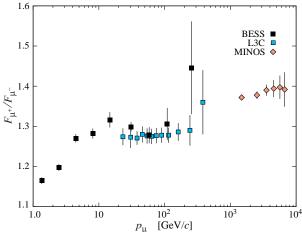


Figure 26.5: Muon charge ratio as a function of the muon momentum from Refs. [44,45,51].

The muon charge ratio reflects the excess of π^+ over π^- and K^+ over K^- in the forward fragmentation region of proton initiated interactions together with the fact that there are more protons than neutrons in the primary spectrum. The increase with energy of μ^+/μ^- shown in Fig. 26.5 reflects the increasing importance of kaons in the TeV range [51] and indicates a significant contribution of associated production by cosmic-ray protons $(p \to \Lambda + K^+)$. The same process is even more important for atmospheric neutrinos at high energy.

26.3.2. Electromagnetic component: At the ground, this component consists of electrons, positrons, and photons primarily from cascades initiated by decay of neutral and charged mesons. Muon decay is the dominant source of low-energy electrons at sea level. Decay of neutral pions is more important at high altitude or when the energy threshold is high. Knock-on electrons also make a small contribution at low energy [52]. The integral vertical intensity of electrons plus positrons is very approximately 30, 6, and $0.2 \text{ m}^{-2}\text{s}^{-1}\text{sr}^{-1}$ above 10, 100, and 1000 MeV respectively [42,53], but the exact numbers depend sensitively on altitude, and the angular dependence is complex because of the different altitude dependence of the different sources of electrons [52–54]. The ratio of photons to electrons plus positrons is approximately 1.3 above 1 GeV and 1.7 below the critical energy [54].

26.3.3. Protons: Nucleons above 1 GeV/c at ground level are degraded remnants of the primary cosmic radiation. The intensity is approximately $I_N(E,0) \times \exp(-X/\cos\theta\Lambda)$ for $\theta < 70^\circ$. At sea level, about 1/3 of the nucleons in the vertical direction are neutrons (up from $\approx 10\%$ at the top of the atmosphere as the n/p ratio approaches equilibrium). The integral intensity of vertical protons above 1 GeV/c at sea level is $\approx 0.9~\text{m}^{-2}\text{s}^{-1}\text{sr}^{-1}$ [42,55].

26.4. Cosmic rays underground

Only muons and neutrinos penetrate to significant depths underground. The muons produce tertiary fluxes of photons, electrons, and hadrons.

26.4.1. *Muons*: As discussed in Section 30.6 of this *Review*, muons lose energy by ionization and by radiative processes: bremsstrahlung, direct production of e^+e^- pairs, and photonuclear interactions. The total muon energy loss may be expressed as a function of the amount of matter traversed as

$$-\frac{dE_{\mu}}{dX} = a + b E_{\mu} , \qquad (26.5)$$

where a is the ionization loss and b is the fractional energy loss by the three radiation processes. Both are slowly varying functions of energy. The quantity $\epsilon \equiv a/b$ (≈ 500 GeV in standard rock) defines a critical energy below which continuous ionization loss is more important than radiative losses. Table 26.2 shows a and b values for standard rock, and b for ice, as a function of muon energy. The second column of Table 26.2 shows the muon range in standard rock ($A=22, Z=11, \rho=2.65 \text{ g cm}^{-3}$). These parameters are quite sensitive to the chemical composition of the rock, which must be evaluated for each location.

Table 26.2: Average muon range R and energy loss parameters a and b calculated for standard rock [56] and the total energy loss parameter b for ice. Range is given in km-water-equivalent, or 10^5 g cm⁻².

| | | ${\rm ^{a}~MeVg^{-1}cm^{2}}$ | | | | | $\sum b(ice)$ |
|-------|------|------------------------------|------|------|------|------|---------------|
| 10 | 0.05 | 2.17 | 0.70 | 0.70 | 0.50 | 1.90 | 1.66 |
| 100 | 0.41 | 2.44 | 1.10 | 1.53 | 0.41 | 3.04 | 2.51 |
| 1000 | 2.45 | 2.68 | 1.44 | 2.07 | 0.41 | 3.92 | 3.17 |
| 10000 | 6.09 | 2.93 | 1.62 | 2.27 | 0.46 | 4.35 | 3.78 |

The intensity of muons underground can be estimated from the muon intensity in the atmosphere and their rate of energy loss. To the extent that the mild energy dependence of a and b can be neglected, Eq. (26.5) can be integrated to provide the following relation between the energy $E_{\mu,0}$ of a muon at production in the atmosphere and its average energy E_{μ} after traversing a thickness X of rock (or ice or water):

$$E_{\mu,0} = (E_{\mu} + \epsilon) e^{bX} - \epsilon . \qquad (26.6)$$

Especially at high energy, however, fluctuations are important and an accurate calculation requires a simulation that accounts for stochastic energy-loss processes [57].

There are two depth regimes for which Eq. (26.6) can be simplified. For $X \ll b^{-1} \approx 2.5$ km water equivalent, $E_{\mu,0} \approx E_{\mu}(X) + aX$, while for $X \gg b^{-1}$ $E_{\mu,0} \approx (\epsilon + E_{\mu}(X)) \exp(bX)$. Thus at shallow depths the differential muon energy spectrum is approximately constant for $E_{\mu} < aX$ and steepens to reflect the surface muon spectrum for $E_{\mu} > aX$, whereas for X > 2.5 km.w.e. the differential spectrum underground is again constant for small muon energies but steepens to reflect the surface muon spectrum for $E_{\mu} > \epsilon \approx 0.5$ TeV. In the deep regime the shape is independent of depth although the intensity decreases exponentially with depth. In general the muon spectrum at slant depth X is

$$\frac{dN_{\mu}(X)}{dE_{\mu}} = \frac{dN_{\mu}}{dE_{\mu,0}} \frac{dE_{\mu,0}}{dE_{\mu}} = \frac{dN_{\mu}}{dE_{\mu,0}} e^{bX} , \qquad (26.7)$$

where $E_{\mu,0}$ is the solution of Eq. (26.6) in the approximation neglecting fluctuations.

Fig. 26.6 shows the vertical muon intensity versus depth. In constructing this "depth-intensity curve," each group has taken account of the angular distribution of the muons in the atmosphere, the map of the overburden at each detector, and the properties of the local medium in connecting measurements at various slant depths and zenith angles to the vertical intensity. Use of data from a range of angles allows a fixed detector to cover a wide range of depths. The flat portion of the curve is due to muons produced locally by charged-current interactions of ν_{μ} . The inset shows the vertical intensity curve for water and ice published in Refs. [59–62]. It is not as steep as the one for rock because of the lower muon energy loss in water.

26.4.2. Neutrinos:

Because neutrinos have small interaction cross sections, measurements of atmospheric neutrinos require a deep detector to avoid backgrounds. There are two types of measurements: contained (or semi-contained) events, in which the vertex is determined to originate inside the detector, and neutrino-induced muons. The latter are muons that enter the detector from zenith angles so large (e.g., nearly horizontal or upward) that they cannot be muons produced in the atmosphere. In neither case is the neutrino flux measured directly. What is measured is a convolution of the neutrino flux and cross section with the properties of the detector (which includes the surrounding medium in the case of entering muons).

Contained and semi-contained events reflect neutrinos in the sub-GeV to multi-GeV region where the product of increasing cross section and decreasing flux is maximum. In the GeV region the neutrino flux and its angular distribution depend on the geomagnetic location of the detector and, to a lesser extent, on the phase of the solar cycle. Naively, we expect $\nu_{\mu}/\nu_{e}=2$ from counting neutrinos of the two flavors coming from the chain of pion and muon decay. Contrary to expectation, however, the numbers of the two classes of events are similar rather than different by a factor of two. This is now understood to be a consequence of neutrino flavor oscillations [70]. (See the article on neutrino properties in this Review.)

Two well-understood properties of atmospheric cosmic rays provide a standard for comparison of the measurements of atmospheric neutrinos to expectation. These are the "sec θ effect" and the "eastwest effect" [69]. The former refers originally to the enhancement of the flux of > 10 GeV muons (and neutrinos) at large zenith angles because the parent pions propagate more in the low density

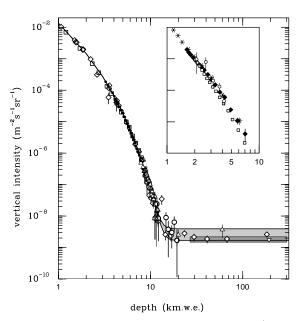


Figure 26.6: Vertical muon intensity vs depth (1 km.w.e. = 10^5 g cm⁻²of standard rock). The experimental data are from: \Diamond : the compilations of Crouch [58], \Box : Baksan [63], \circ : LVD [64], \bullet : MACRO [65], \blacksquare : Frejus [66], and \triangle : SNO [67]. The shaded area at large depths represents neutrino-induced muons of energy above 2 GeV. The upper line is for horizontal neutrino-induced muons, the lower one for vertically upward muons. Darker shading shows the muon flux measured by the SuperKamiokande experiment. The inset shows the vertical intensity curve for water and ice published in Refs. [59–62].

upper atmosphere where decay is enhanced relative to interaction. For neutrinos from muon decay, the enhancement near the horizontal becomes important for $E_{\nu}>1$ GeV and arises mainly from the increased pathlength through the atmosphere for muon decay in flight. Fig. 26.7 from Ref. 68 shows a comparison between measurement and expectation for the zenith angle dependence of multi-GeV electron-like (mostly ν_e) and muon-like (mostly ν_{μ}) events separately. The ν_e show an enhancement near the horizontal and approximate equality for nearly upward ($\cos\theta\approx-1$) and nearly downward ($\cos\theta\approx1$) events. There is, however, a very significant deficit of upward ($\cos\theta<0$) ν_{μ} events, which have long pathlengths comparable to the radius of the Earth. This feature is the principal signature for oscillations [70].

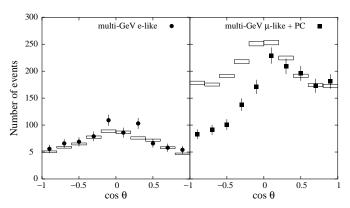


Figure 26.7: Zenith-angle dependence of multi-GeV neutrino interactions from SuperKamiokande [68]. The shaded boxes show the expectation in the absence of any oscillations.

Muons that enter the detector from outside after production in charged-current interactions of neutrinos naturally reflect a higher energy portion of the neutrino spectrum than contained events because

Table 26.3: Measured fluxes $(10^{-9} \text{ m}^{-2} \text{ s}^{-1} \text{ sr}^{-1})$ of neutrino-induced muons as a function of the effective minimum muon energy E_{μ} .

| $E_{\mu} >$ | · 1 GeV | 1 GeV | 1 GeV | 2 GeV | 3 GeV | 3 GeV |
|-------------|-----------------|-----------------|-----------------|-------------------|-------------------|-----------------|
| Ref. | CWI [71] | Baksan [72] | MACRO [73] | IMB [74] | Kam [75] | SuperK [76] |
| F_{μ} | $2.17{\pm}0.21$ | 2.77 ± 0.17 | 2.29 ± 0.15 | $2.26 {\pm} 0.11$ | $1.94 {\pm} 0.12$ | $1.74{\pm}0.07$ |

the muon range increases with energy as well as the cross section. The relevant energy range is $\sim 10 < E_{\nu} < 1000$ GeV, depending somewhat on angle. Neutrinos in this energy range show a $\sec\theta$ effect similar to muons (see Eq. (26.4)). This causes the flux of horizontal neutrino-induced muons to be approximately a factor two higher than the vertically upward flux. The upper and lower edges of the horizontal shaded region in Fig. 26.6 correspond to horizontal and vertical intensities of neutrino-induced muons. Table 26.3 gives the measured fluxes of upward-moving neutrino-induced muons averaged over the lower hemisphere. Generally the definition of minimum muon energy depends on where it passes through the detector. The tabulated effective minimum energy estimates the average over various accepted trajectories.

26.5. Air showers

So far we have discussed inclusive or uncorrelated fluxes of various components of the cosmic radiation. An air shower is caused by a single cosmic ray with energy high enough for its cascade to be detectable at the ground. The shower has a hadronic core, which acts as a collimated source of electromagnetic subshowers, generated mostly from $\pi^0 \to \gamma \gamma$ decays. The resulting electrons and positrons are the most numerous charged particles in the shower. The number of muons, produced by decays of charged mesons, is an order of magnitude lower. Air showers spread over a large area on the ground, and arrays of detectors operated for long times are useful for studying cosmic rays with primary energy $E_0 > 100$ TeV, where the low flux makes measurements with small detectors in balloons and satellites difficult.

Greisen [77] gives the following approximate expressions for the numbers and lateral distributions of particles in showers at ground level. The total number of muons N_{μ} with energies above 1 GeV is

$$N_{\mu}(> 1 \text{ GeV}) \approx 0.95 \times 10^5 \left(N_e/10^6\right)^{3/4} ,$$
 (26.8)

where N_e is the total number of charged particles in the shower (not just e^{\pm}). The number of muons per square meter, ρ_{μ} , as a function of the lateral distance r (in meters) from the center of the shower is

$$\rho_{\mu} = \frac{1.25 \, N_{\mu}}{2\pi \, \Gamma(1.25)} \left(\frac{1}{320}\right)^{1.25} \, r^{-0.75} \, \left(1 + \frac{r}{320}\right)^{-2.5} \, , \tag{26.9}$$

where Γ is the gamma function. The number density of charged particles is

$$\rho_e = C_1(s, d, C_2) x^{(s-2)} (1+x)^{(s-4.5)} (1+C_2 x^d) . \tag{26.10}$$

Here s, d, and C_2 are parameters in terms of which the overall normalization constant $C_1(s,d,C_2)$ is given by

$$C_1(s, d, C_2) = \frac{N_e}{2\pi r_1^2} [B(s, 4.5 - 2s) + C_2 B(s + d, 4.5 - d - 2s)]^{-1},$$
(26.11)

where B(m,n) is the beta function. The values of the parameters depend on shower size (N_e) , depth in the atmosphere, identity of the primary nucleus, etc. For showers with $N_e \approx 10^6$ at sea level, Greisen uses s=1.25, d=1, and $C_2=0.088$. Finally, x is r/r_1 , where r_1 is the Molière radius, which depends on the density of the atmosphere and hence on the altitude at which showers are detected. At sea level $r_1 \approx 78$ m. It increases with altitude as the air density decreases. (See

the section on electromagnetic cascades in the article on the passage of particles through matter in this Review).

The lateral spread of a shower is determined largely by Coulomb scattering of the many low-energy electrons and is characterized by the Molière radius. The lateral spread of the muons (ρ_{μ}) is larger and depends on the transverse momenta of the muons at production as well as multiple scattering.

There are large fluctuations in development from shower to shower, even for showers of the same energy and primary mass—especially for small showers, which are usually well past maximum development when observed at the ground. Thus the shower size N_e and primary energy E_0 are only related in an average sense, and even this relation depends on depth in the atmosphere. One estimate of the relation is [84]

$$E_0 \sim 3.9 \times 10^6 \text{ GeV } (N_e/10^6)^{0.9}$$
 (26.12)

for vertical showers with $10^{14} < E < 10^{17}$ eV at 920 g cm⁻² (965 m above sea level). As E_0 increases the shower maximum (on average) moves down into the atmosphere and the relation between N_e and E_0 changes. Moreover, because of fluctuations, N_e as a function of E_0 is not correctly obtained by inverting Eq. (26.12). At the maximum of shower development, there are approximately 2/3 particles per GeV of primary energy.

There are three common types of air shower detectors: shower arrays that study the shower size N_e and the lateral distribution on the ground, Cherenkov detectors that detect the Cherenkov radiation emitted by the charged particles of the shower, and fluorescence detectors that study the nitrogen fluorescence excited by the charged particles in the shower. The fluorescence light is emitted isotropically so the showers can be observed from the side. Detailed simulations and cross-calibrations between different types of detectors are necessary to establish the primary energy spectrum from air-shower experiments.

Figure 26.8 shows the "all-particle" spectrum. The differential energy spectrum has been multiplied by $E^{2.6}$ in order to display the features of the steep spectrum that are otherwise difficult to discern. The steepening that occurs between 10^{15} and 10^{16} eV is known as the knee of the spectrum. The feature around $10^{18.5}$ eV is called the ankle of the spectrum.

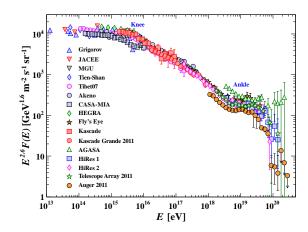


Figure 26.8: The all-particle spectrum as a function of E (energy-per-nucleus) from air shower measurements [79–90,100–104].

Measurements of flux with small air shower experiments in the knee region differ by as much as a factor of two, indicative of systematic uncertainties in interpretation of the data. (For a review see Ref. 78.) In establishing the spectrum shown in Fig. 26.8, efforts have been made to minimize the dependence of the analysis on the primary composition. Ref. 87 uses an unfolding procedure to obtain the spectra of the individual components, giving a result for the all-particle spectrum between 10¹⁵ and 10¹⁷ eV that lies toward the upper range of the data shown in Fig. 26.8. In the energy range above 10¹⁷ eV, the fluorescence technique [89] is particularly useful because it can establish the primary energy in a model-independent way by observing most of the longitudinal development of each shower, from which E_0 is obtained by integrating the energy deposition in the atmosphere. The result, however, depends strongly on the light absorption in the atmosphere and the calculation of the detector's aperture.

Assuming the cosmic ray spectrum below 10^{18} eV is of galactic origin, the *knee* could reflect the fact that most cosmic accelerators in the galaxy have reached their maximum energy. Some types of expanding supernova remnants, for example, are estimated not to be able to accelerate protons above energies in the range of 10^{15} eV. Effects of propagation and confinement in the galaxy [91] also need to be considered. The KASCADE-Grande experiment [90] has reported observation of a second steepening of the spectrum near 8×10^{16} eV, with evidence that this structure is accompanied a transition to heavy primaries.

Concerning the ankle, one possibility is that it is the result of a higher energy population of particles overtaking a lower energy population, for example an extragalactic flux beginning to dominate over the galactic flux (e.g. Ref. 89). Another possibility is that the dip structure in the region of the ankle is due to $\gamma p \rightarrow e^+ + e^-$ energy losses of extragalactic protons on the 2.7 K cosmic microwave radiation (CMB) [93]. This dip structure has been cited as a robust signature of both the protonic and extragalactic nature of the highest energy cosmic rays [92]. If this interpretation is correct, then the galactic cosmic rays do not contribute significantly to the flux above 10^{18} eV, consistent with the maximum expected range of acceleration by supernova remnants.

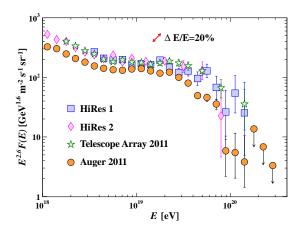


Figure 26.9: Expanded view of the highest energy portion of the cosmic-ray spectrum from data of HiRes 1&2 [101], the Telescope Array [103], and the Auger Observatory [104]. The HiRes stereo spectrum [112] is consistent with the HiRes 1&2 monocular results. The differential cosmic ray flux is multiplied by $E^{2.6}$. The red arrow indicates the change in the plotted data for a systematic shift in the energy scale of 20%.

The energy-dependence of the composition from the knee through the ankle is useful in discriminating between these two viewpoints, since a heavy composition above 10^{18} eV is inconsistent with the formation of the ankle by pair production losses on the CMB.

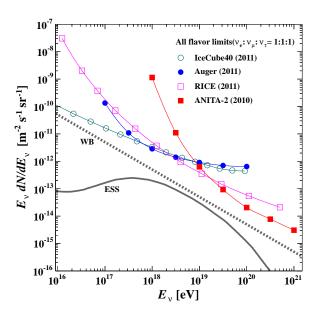


Figure 26.10: Differential limits on the flux of cosmogenic neutrinos set by four neutrino experiments. The curves show the Waxman-Bahcall benchmark flux (WB, [111]) and a representative midrange model for the expected flux of cosmogenic neutrinos (ESS, [110]). The expected flux is uncertain by over an order of magnitude in either direction.

The HiRes and Auger experiments, however, present very different interpretations of data on the depth of shower maximum X_{max} , a quantity that correlates strongly with the interaction cross section of the primary particle. If these results are interpreted using standard extrapolations of measured proton and nuclear cross sections, then the HiRes data [94] is consistent with the ultrahigh-energy cosmic ray (UHECR) composition getting lighter and containing only protons and helium above 10^{19} eV, while Auger [95,96] sees a composition getting lighter up to 2×10^{18} eV and becoming heavier after that, intermediate between protons and iron at 3×10^{19} eV. This may mean that the extragalactic cosmic rays have a mixed composition at acceleration similar to the GeV galactic cosmic rays. It is important to note that the measurements of X_{max} may be interpreted with equal validity in terms of a changing proton-air cross-section and no change in composition.

If the cosmic ray flux at the highest energies is cosmological in origin, there should be a rapid steepening of the spectrum (called the GZK feature) around 5×10^{19} eV, resulting from the onset of inelastic interactions of UHE cosmic rays with the cosmic microwave background [97,98]. Photo-dissociation of heavy nuclei in the mixed composition model [99] would have a similar effect. UHECR experiments have detected events of energy above 10^{20} eV [89,100–102]. The AGASA experiment [100] did not observe the expected GZK feature. The HiRes fluorescence experiment [101,112] has detected evidence of the GZK supression, and the Auger observatory [102–104] has presented spectra showing this supression based on surface detector measurements calibrated against its fluorescence detector using events detected in hybrid mode, i.e. with both the surface and the fluorescence detectors. Recent observations by the Telescope Array [103] also exhibit this supression.

Figure 26.9 gives an expanded view of the high energy end of the spectrum, showing only the more recent data. This figure shows the differential flux multiplied by $E^{2.6}$. The experiments are consistent in normalization if one takes quoted systematic errors in the energy scales into account. The continued power law type of flux beyond the GZK cutoff previously claimed by the AGASA experiment [100] is not supported by the HiRes, Telescope Array, and Auger data.

One half of the energy that UHECR protons lose in photoproduction interactions that cause the GZK effects ends up in neutrinos [105].

Measuring this cosmogenic neutrino flux above 10^{18} eV would help resolve the UHECR uncertainties mentioned above. The magnitude of this flux depends strongly on the cosmic ray spectrum at acceleration, the cosmic ray composition, and the cosmological evolution of the cosmic ray sources. In the case that UHECR have mixed composition only the proton fraction would produce cosmogenic neutrinos. Heavy nuclei propagation produces mostly $\bar{\nu}_e$ at lower energy from neutron decay.

The expected rate of cosmogenic neutrinos is lower than current limits obtained by IceCube [106], the Auger observatory [108], RICE [107], and ANITA-2 [109], which are shown in Figure 26.10 together with a model for cosmogenic neutrino production [110] and the Waxman-Bahcall benchmark flux of neutrinos produced in cosmic ray sources [111]. At production, the dominant component of neutrinos comes from π^{\pm} decays and has flavor content $\nu_e:\nu_{\mu}:\nu_{\tau}=1:2:0$. After oscillations, the arriving cosmogenic neutrinos are expected to be an equal mixture of all three flavors. The sensitivity of each experiment depends on neutrino flavor. IceCube, RICE, and ANITA are sensitive to all three flavors, and the sensitivity to different flavors is energy dependent. The limit of Auger is only for ν_{τ} and $\bar{\nu}_{\tau}$ which should be about 1/3 of the total neutrino flux after oscillations, so this limit is plotted multiplied by a factor of three for comparison with the other limits and with the theoretical estimates.

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27. ACCELERATOR PHYSICS OF COLLIDERS

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27.1. Luminosity

This article provides background for the High-Energy Collider Parameter Tables that follow. The number of events, N_{exp} , is the product of the cross section of interest, σ_{exp} , and the time integral over the instantaneous luminosity, \mathcal{L} :

$$N_{exp} = \sigma_{exp} \times \int \mathcal{L}(t)dt.$$
 (27.1)

Today's colliders all employ bunched beams. If two bunches containing n_1 and n_2 particles collide head-on with frequency f, a basic expression for the luminosity is

$$\mathcal{L} = f \frac{n_1 n_2}{4\pi \sigma_x \sigma_y} \tag{27.2}$$

where σ_x and σ_y characterize the rms transverse beam sizes in the horizontal (bend) and vertical directions. In this form it is assumed that the bunches are identical in transverse profile, that the profiles are Gaussian and independent of position along the bunch, and the particle distributions are not altered during bunch crossing.

Whatever the distribution at the source, by the time the beam reaches high energy, the normal form is a useful approximation as suggested by the σ -notation. In the case of an electron storage ring, synchrotron radiation leads to a Gaussian distribution in equilibrium, but even in the absence of radiation the central limit theorem of probability and the diminished importance of space charge effects produces a similar result.

The luminosity may be obtained directly by measurement of the beam properties in Eq. (27.2), but the beam measurements are apt to interfere with data acquisition, so this method though valuable to establish collider performance is not suitable for continuous use. A similar expression to Eq. (27.1) with N_{ref} from a known reference cross section, σ_{ref} , may be used to determine σ_{exp} according to $\sigma_{exp} = (N_{exp}/N_{ref})\sigma_{ref}$.

In the Tables, luminosity is stated in units of $\rm cm^{-2}s^{-1}$. Integrated luminosity, on the other hand is usually quoted as the inverse of the standard measures of cross section such as femtobarns and, recently, attoharns

Subsequent sections in this report enlarge briefly on the dynamics behind collider design, comment on the realization of collider performance in a selection of today's facilities, and end with some remarks on future possibilities.

27.2. Beam Dynamics

The first concern of beam dynamics is stability. While a reference particle proceeds along the design, or reference, trajectory other particles in the bunch are to remain close by. Assume that the reference particle carries a right-handed Cartesian coordinate system, with the z-coordinate pointed in the direction of motion along the reference trajectory. The independent variable is the distance s of the reference particle along this trajectory rather than time, and for simplicity this path is taken to be planar. The transverse coordinates are x and y, where $\{x, z\}$ defines the plane of the reference trajectory.

Several time scales are involved, and the approximations used in writing the equations of motion reflect that circumstance. All of today's high energy colliders are alternating gradient synchrotrons [1,2], and the shortest time scale is that associated with transverse stability, the betatron oscillations, so called because of their analysis for the betatron accelerator species years ago. The linearized equations of motion of a particle displaced from the reference particle are

$$x'' + K_x x = 0, K_x \equiv \frac{e}{p} \frac{\partial B}{\partial x} + \frac{1}{\rho^2}$$

$$y'' + K_y y = 0, K_y \equiv -\frac{e}{p} \frac{\partial B}{\partial x}$$

$$z' = -x/\rho$$
(27.3)

where the magnetic field B(s) is only in the y direction, contains only dipole and quadrupole terms, and is treated as static here. The radius of curvature due to the field on the reference orbit is ρ ; p and e are the particle's momentum and charge respectively. The prime denotes d/ds.

The equations for x and y are those of harmonic oscillators but with restoring force periodic in s, that is, they are instances of Hill's equation. The solution may be written in the form

$$x(s) = A_x \sqrt{\beta_x} \cos \psi_x$$

$$x'(s) = -\frac{A_x}{\sqrt{\beta_x}} \left[\alpha \cos \psi_x + \sin \psi_x \right]$$
(27.4)

where A_x is a constant of integration, $\alpha \equiv -(1/2)d\beta_x(s)/ds$, and the envelope of the motion is modulated by the *amplitude function*, β_x . A solution of the same form describes the motion in y. The subscripts will be suppressed in the following discussion.

The amplitude function satisfies

$$2\beta\beta'' - \beta'^2 + 4\beta^2 K = 4, (27.5)$$

and in a region free of magnetic field it should be noted that the solution of Eq. (27.5) is a parabola. Expressing A in terms of x, x' yields

$$A^{2} = \gamma x^{2} + 2\alpha x x' + \beta x'^{2}$$

$$= \frac{1}{\beta} \left[x^{2} + (\alpha x + \beta x')^{2} \right]$$
(27.6)

with $\gamma \equiv (1+\alpha^2)/\beta$. In a single pass system such as a linac, the Courant-Snyder parameters α , β , γ may be selected to match the $x\,x'$ distribution of the input beam; in a recursive system, the parameters are usually defined by the structure rather than by the beam.

The relationships between the parameters and the structure may be seen by treatment of a simple lattice consisting of equally spaced thin lens quadrupoles equal in magnetic field gradient magnitude but alternating in sign. For this discussion, the weak focusing effects of the bending magnets may be neglected. The propagation of $X \equiv \{x, x'\}$ through a repetition period may be written $X_2 = MX_1$, with the matrix M = FODO composed of the matrices

$$F = \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix}, \ D = \begin{pmatrix} 1 & 0 \\ 1/f & 1 \end{pmatrix}, \ O = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix},$$

where f is the magnitude of the focal length and L the lens spacing. Then

$$M = \begin{pmatrix} 1 + \frac{L}{f} & 2L + \frac{L^2}{f} \\ -\frac{L}{f^2} & 1 - \frac{L}{f} - \frac{L^2}{f^2} \end{pmatrix}. \tag{27.7}$$

The matrix for y is identical in form differing only by a change in sign of terms linear in f. An eigenvector-eigenvalue analysis of the matrix M shows that the motion is stable provided f > L/2. While that criterion is easily met, in practice instability may be caused by many other factors. including the beam-beam interaction itself.

Standard focus-drift-defocus-drift, or FODO, cells such as characterized in simple form by Eq. (27.7) occupy most of the layout of a large collider ring and may be used to set the scale of the amplitude function and related phase advance. Conversion of Eq. (27.4) to a matrix form equivalent to Eq. (27.7) gives

$$M = \begin{pmatrix} c + \alpha s & \beta s \\ -\gamma s & c - \alpha s \end{pmatrix} \tag{27.8}$$

where $c \equiv \cos \Delta \psi$, $s \equiv \sin \Delta \psi$, and the relation between structure and amplitude function is specified by setting the values of the latter to be the same at both ends of the cell. By comparison of Eq. (27.7) and Eq. (27.8) one finds $c = 1 - L^2/(2f^2)$, so the choice $f = L/\sqrt{2}$ would give a phase advance $\Delta \psi$ of 90 degrees for the standard cell. The amplitude function – a maximum at the focusing quadrupole – would then be 2.7L, illustrating the relationship of alternating gradient focusing amplitudes to relatively local aspects of the design. Other functions such as injection, extraction, and HEP experiments

are included by lattice sections matched to the β , α standard cell parameters at the insertion points.

The phase advances according to $d\psi/ds=1/\beta$; that is, β also plays the role of a local $\lambda/2\pi$, and the tune, ν , is the number of such oscillations per turn about the closed path. In the neighborhood of an interaction point (IP), the beam optics of the ring is configured so as to produce a near focus; the value of the amplitude function at this point is designated β^* .

The motion as it develops with s describes an ellipse in $\{x,x'\equiv dx/ds\}$ phase space the area of which is πA^2 , where A is the constant in Eq. (27.4). If the interior of that ellipse is populated by an ensemble of non-interacting particles, that area, given the name *emittance* and denoted by ε , would change only with energy. For a beam with a Gaussian distribution in x,x', the area containing one standard deviation σ_x is the definition of emittance in the Tables:

$$\varepsilon_x \equiv \pi \frac{\sigma_x^2}{\beta_x},\tag{27.9}$$

with a corresponding expression in the other transverse direction, y. This definition includes 39% of the beam. For most of the entries in the Tables the standard deviation is used as the beam radius.

To complete the coordinates used to describe the motion, we take as the variable conjugate to z the fractional momentum deviation $\delta p/p$ from that of the reference particle. Radiofrequency electric fields in the s direction provide a means for longitudinal oscillations, and the frequency determines the bunch length. The frequency of this system appears in the Tables as does the rms value of $\delta p/p$ characterized as "energy spread" of the beam.

For HEP bunch length is a significant quantity for a variety of reasons, but in the present context if the bunch length becomes larger than β^* the luminosity is adversely affected. This is because β grows parabolically as one proceeds away from the interaction point and so the beam size increases thus lowering the contribution to the luminosity from such locations. This is often called the "hourglass" effect.

The other major external electromagnetic field interaction in the single particle context is the production of synchrotron radiation due to centripetal acceleration, given by the Larmor formula multiplied by a relativistic magnification factor of γ^4 [3]. In the case of electron rings this process determines the equilibrium emittance through a balance between radiation damping and excitation of oscillations, and further serves as the barrier to future higher energy versions in this variety of collider.

27.3. Impediments to High Luminosity

Eq. (27.2) can be recast in terms of emittances and amplitude functions as

$$\mathscr{L} = f \frac{n_1 n_2}{4\sqrt{\epsilon_x \, \beta_x^* \, \epsilon_y \, \beta_y^*}} \ . \tag{27.10}$$

So to achieve high luminosity, all one has to do is make high population bunches of low emittance collide at high frequency at locations where the beam optics provides as low values of the amplitude functions as possible.

Such expressions as Eq. (27.10) of the luminosity are special cases of the more general forms available elsewhere [4]. But while there are no fundamental limits to the process, there are certainly challenges. Here we have space to mention only a few of these. The beam-beam tune shift appears in the Tables. A bunch in beam 1 presents a (nonlinear) lens to a particle in beam 2 resulting in changes to the particle's transverse tune with a range characterized by the parameter [4]

$$\xi_{y,2} = \frac{r_e n_1 \beta_{y,2}^*}{2\pi \gamma_2 \sigma_{y,1} (\sigma_{x,1} + \sigma_{y,1})}$$
(27.11)

where $r_e = e^2/(4\pi\varepsilon_0 mc^2)$ is the classical radius of the electron. The transverse oscillations are susceptible to resonant perturbations from a variety of sources such as imperfections in the magnetic guide field, so certain values of the tune must be avoided. Accordingly, the tune spread arising from ξ is limited, but limited to a value difficult to

predict. But a glance at the Tables shows that electrons are more for giving than protons thanks to the damping effects of synchrotron radiation; the ξ -values for the former are about an order of magnitude larger than those for protons.

A subject of present intense interest is the electron-cloud effect [5,6]; actually a variety of related processes come under this heading. They typically involve a buildup of electron density in the vacuum chamber due to emission from the chamber walls stimulated by electrons or photons originating from the beam itself. For instance, there is a process closely resembling the multipacting effects familiar from radiofrequency system commissioning. Low energy electrons are ejected from the walls by photons from positron or proton beam-produced synchrotron radiation. These electrons are accelerated toward a beam bunch, but by the time they reach the center of the vacuum chamber the bunch has gone and so the now-energetic electrons strike the opposite wall to produce more secondaries. These secondaries are now accelerated by a subsequent bunch, and so on. Among the disturbances that this electron accumulation can produce is enhancement of the tune spread within the bunch; the near-cancellation of bunch-induced electric and magnetic fields is no longer in effect.

The benefits of low emittance are clear in Eq. (27.10). For electron synchrotrons, radiation damping provides an automatic route. For hadrons, particularly antiprotons, two inventions have played a prominent role. Stochastic cooling [7] was employed first in the $S\bar{p}pS$ and subsequently in the Tevatron. Electron cooling [8] was also used in the Tevatron complex to great advantage. Further innovations are underway due to the needs of potential future projects; these are noted in the final section.

27.4. Comments on Present Facilities

Collider accelerator physics of course goes far beyond the elements of the preceding sections. In this section elaboration is made on various issues associated with some of the recently operating colliders, particularly factors which impact integrated luminosity. The various colliders utilizing hadrons have important unique differences and hence are broken out separately. As space is limited, general references are provided where much further information can be obtained.

27.4.1. LHC: [9] The superconducting Large Hadron Collider is the world's highest energy collider. Operation for HEP is currently conducted with 3.5 TeV protons in each beam. Progress is rapid and current status is best checked at the Web site referenced in the heading of this subsection. To meet its luminosity goals the LHC will have to contend with a high beam current of 0.5 A, leading to stored energies of several hundred MJ per beam. Component protection, beam collimation, and controlled energy deposition will be given very high priorities. Additionally, at energies of 5-7 TeV per particle, synchrotron radiation will move from being a curiosity to a challenge in a hadron accelerator for the first time. At design beam current the system must remove roughly 7 kW at 1.8 K due to synchrotron radiation. As the photons are emitted their interactions with the vacuum chamber wall can generate free electrons, with consequent "electron cloud" development. Much care was taken to design a special liner for the chamber to mitigate this issue.

The two proton beams are contained in separate pipes throughout most of the circumference, but naturally must be brought together into a single pipe at the interaction points. The large number of bunches, and subsequent short bunch spacing, would lead to approximately 30 head-on collisions through 120 m of common beam pipe at each IP. Thus, a small crossing angle is employed, which reduces the luminosity by about 15%. Still, the bunches moving in one direction will have long-range encounters with the counter-rotating bunches and the resulting perturbations of the particle motion constitute a continued course of study. Initial luminosity measurements were made by the "van der Meer scan" as was done long ago on the ISR [10]. The detectors will have measurements based on a reference cross section; for an example see the discussion in the ATLAS design report [11]. The Tables also show the performance anticipated for Pb-Pb collisions. The ALICE [12] experiment is designed to concentrate on these high energy-density phenomena.

In the coming years, an ambitious upgrade program, Super LHC [13], has as its target an order-of-magnitude increase in luminosity.

27.4.2. *Tevatron*: [14] The first superconducting synchrotron in history, the Tevatron was the highest energy collider for 25 years. Operation was terminated in September 2011. The route to high integrated luminosity in the Tevatron was governed by the antiproton production rate, the turn-around time to produce another store, and the resulting optimization of store time. The overall reliability of the accelerator complex plays a crucial role, as it can take many hours to produce an adequate number of antiprotons for collisions.

Unlike the LHC, the beams in the Tevatron circulated in a single vacuum pipe and thus were placed on separated orbits which wrap around each other in a helical pattern outside of the interaction regions. Hence, long-range encounters played an important role here as well, though the effects could be different from the LHC where the encounters are more or less "in phase" with each other through a single interaction region. In the Tevatron, the 70 long-range encounters were distributed about the synchrotron and their mitigation was limited by the available aperture.

In recent years the antiproton bunch intensities approached those of the proton bunches, and their emittances were greatly reduced using improved beam cooling, so much so that detrimental effects on the proton beam became apparent. The antiproton beam emittance was adjusted prior to collision conditions to optimize the proton bunch lifetime during the store [15]. The Tevatron ultimately achieved luminosities a factor of 400 over the original design specification.

27.4.3. e^+e^- Rings: As should be expected, synchrotron radiation plays a major role in the design and optimization of e^+e^- colliders. While vacuum stability and electron clouds can be of concern in the positron rings, synchrotron radiation along with the restoration of longitudinal momentum by the RF system have the positive effect of generating very small transverse beam sizes and small momentum spread. Further reduction of beam size at the interaction points using standard beam optics techniques and successfully contending with high beam currents has led to record luminosities in these rings, far exceeding those of hadron colliders. To maximize integrated luminosity the beam can be "topped off" by injecting new particles without removing existing ones — a feature difficult to imitate in hadron colliders.

Asymmetric energies of the two beams have allowed for the enhancement of B-physics research and for interesting interaction region designs. As the bunch spacing can be quite short, the lepton beams sometimes pass through each other at an angle and hence have reduced luminosity. Recently, however, the invention of high frequency "crab crossing" schemes have produced full restoration of the luminous region. KEK-B has attained over 1 fb⁻¹ of integrated luminosity in a single day, and its upgrade plans are aiming for initial luminosities of $8 \times 10^{35} \, \mathrm{cm}^{-2} \mathrm{s}^{-1}$ [16].

27.4.4. HERA: [17] Now decommissioned, HERA was the first facility to employ both applications of superconductivity: magnets and accelerating structures. Its next-generation cold-iron superconducting magnets for the proton beam were the culmination of lessons learned from the Tevatron experience and extensive development of the technology since then. The HERA team felt comfortable with a larger dynamic range of the magnet system, enabling the use of the existing DESY complex for injection. Though the HERA magnets could reach fields consistent with energies above 1 TeV, other accelerator systems precluded operation above 920 GeV.

The lepton beams (positrons or electrons) were provided by the existing complex, and were accelerated to 27.5 GeV using conventional magnets. The interaction region where the beams had common vacuum chambers had the interesting feature that the lepton beam could be manipulated without detrimental effects on the proton beam due to the large difference in magnetic rigidity. A 4-times higher frequency RF system was used at collision to generate shorter bunches, thus helping alleviate the hour glass effect at the collision points. As in any high energy lepton storage ring, the lepton beam naturally would become transversely polarized (within about 40 minutes, for

HERA). "Spin rotators" were implemented on either side of an IP to produce longitudinal polarization at the experiment.

27.4.5. *RHIC*: [18] The Relativistic Heavy Ion Collider employs superconducting magnets, and collides combinations of fully-stripped ions such as H-H (p-p), Au-Au, Cu-Cu, and d-Au.

The high charge per particle (+79 for gold, for instance) makes intra-beam scattering of particles within the bunch of special concern, even for seemingly modest bunch intensities. Another special feature of accelerating heavy ions in RHIC is that the beams experience a "transition energy" during acceleration – a point where the derivative with respect to momentum of the revolution period is zero. This is more typical of low-energy accelerators, where the necessary phase jump required of the RF system is implemented rapidly and little time is spent near this condition. In the case of RHIC with heavy ions, the superconducting magnets do not ramp very quickly and the period of time spent crossing transition is long and must be dealt with carefully. For p-p operation the beams are always above their transition energy and so this condition is completely avoided.

RHIC is also distinctive in its ability to accelerate and collide polarized proton beams. As proton beam polarization must be maintained from its low-energy source, successful acceleration through the myriad of depolarizing resonance conditions in high energy circular accelerators has taken years to accomplish. An energy of 250 GeV per proton with $\sim 48\%$ final polarization per beam has been realized.

27.5. Future Prospects

Present design activity emphasizes a lepton collider as the next major HEP project contingent upon the initial results from the LHC. Synchrotron radiation precludes a higher energy successor to LEP. Four alternatives are noted in this section: two approaches to an electron-positron linear collider, a muon ring collider, and potential use of plasma acceleration.

27.5.1. Electron-Positron Linear Colliders: A major problem confronting a high energy, high luminosity single pass collider design is the power requirement, so measures must be taken to keep the demand within bounds as illustrated in a transformed Eq. (27.2) as developed in the TESLA Design Report [19]:

$$\mathcal{L} = \frac{1}{4\pi r_e^{3/2}} \frac{P_b}{E_{cm}} \left(\frac{\pi \delta_E}{\gamma \varepsilon_y}\right)^{1/2} H_D. \tag{27.12}$$

Here, P_b is the total power of both beams and E_{cm} their cms energy. Management of P_b leads to an upward push on the product of collision frequency and bunch population with an attendant rise in the energy radiated due to the electromagnetic field of one bunch acting on the particles of the other. The fractional spread in the collision energy that results from this radiation is represented by δ_E and keeping a significant fraction of the luminosity within a percent or so of the nominal energy represents a design goal. A consequence is the use of flat beams, where δ_E is managed by the beam width, and luminosity adjusted by the beam height, thus the explicit appearance of the vertical emittance ε_y . The final factor in Eq. (27.12), H_D , represents the enhancement of luminosity due to the pinch effect during bunch crossing.

The approach designated by the International Linear Collider (ILC) is presented in the Tables, and the contrast with the collision-point parameters of the circular colliders is striking, though reminiscent in direction of those of the SLAC Linear Collider that are no longer shown. The ILC Reference Design Report [20] has a baseline cms energy of 500 GeV with upgrade provision for 1 TeV, and luminosity comparable to the LHC. The ILC is based on superconducting accelerating structures of the 1.3 GHz TESLA variety.

At CERN, a design effort is underway on the Compact Linear Collider (CLIC), each linac of which is itself a two-beam accelerator, in that a high energy, low current beam is fed by a low energy, high current driver [21]. The CLIC design employs normal conducting 12 GHz accelerating structures at a gradient of 100 MeV/m, some three times the current capability of the superconducting ILC cavities. The design cms energy is 3 TeV.

27.5.2. Muon Collider: The muon to electron mass ratio of 210 implies less concern about synchrotron radiation by a factor of about 2×10^9 and its 1.6 μ s lifetime means that it will last for some 150B turns in a ring about half of which is occupied by bend magnets with average field B (tesla). Design effort became serious in the mid 1990s and a collider outline emerged quickly [22].

Removal of the synchrotron radiation barrier reduces collider facility scale to a level compatible with on-site placement at some locations. If a Higgs particle is detected the $(m_{\mu}/m_e)^2$ cross section advantage in s-channel production would be valuable. And a neutrino factory could potentially be realized in the course of construction [23].

The challenges to luminosity achievement were clear and very attractive for R&D: targetting, collection, and emittance reduction are three that come immediately to mind. The proton source needs to deliver a beam power of several MW, collection would be aided by magnetic fields common on neutron stars (though scaled back for application on earth), and the emittance requirements have inspired fascinating investigations into phase space manipulation that are finding application in other facilities. A summary of the status may be found in a presentation to the HEPAP P5 Panel [24].

27.5.3. Plasma Acceleration: At the 1956 CERN Symposium, a paper by Veksler in which he suggested acceleration of protons to the TeV scale using a bunch of electrons anticipated current interest in plasma acceleration [25]. A half-century later this is more than a suggestion, with the demonstration, as a striking example, of energy enhancement of 28.5 GeV at SLAC [26].

How plasma acceleration will find application in an HEP facility is not yet clear, given the necessity of coordinating multiple plasma chambers. Active R&D is underway; for recent discussion of parameters for a laser-plasma based electron positron collider, see, for example, relevant papers in an Advanced Accelerator Concepts Workshop [27].

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HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders (I)

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). The table shows parameter values as achieved by January 1, 2012. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; H and V indicate horizontal and vertical directions; s.c. stands for superconducting. Parameters for the defunct SPEAR, DORIS, PETRA, PEP, SLC, TRISTAN, and VEPP-2M colliders may be found in our 1996 edition (Phys. Rev. **D54**, 1 July 1996, Part I).

| | VEPP-2000 (Novosibirsk) | VEPP-4M (Novosibirsk) | BEPC (China) | BEPC-II (China) | DAΦNE (Frascati) |
|-----------------------------------------------------------|----------------------------------|--------------------------|-------------------------------------|----------------------------------------|------------------------------------------------|
| Physics start date | 2010 | 1994 | 1989 | 2008 | 1999 |
| Physics end date | | | 2005 | _ | _ |
| Maximum beam energy (GeV) | 1.0 | 6 | 2.5 | 1.89 (2.3 max) | 0.510 |
| Delivered integrated luminosity per exp. (fb^{-1}) | 0.030 | 0.027 | 0.11 | 3.74 | ≈ 4.7 in 2001-2007 2.7 w/crab-waist |
| Luminosity (10^{30} cm ⁻² s ⁻¹) | 100 | 20 | 12.6 at 1.843 GeV 5 at 1.55 GeV | 649 | 453 |
| Time between collisions (μs) | 0.04 | 0.6 | 0.8 | 0.008 | 0.0027 |
| Full crossing angle (μ rad) | 0 | 0 | 0 | 2.2×10^{4} | 5×10^{4} |
| Energy spread (units 10^{-3}) | 0.64 | 1 | $0.58~\mathrm{at}~2.2~\mathrm{GeV}$ | 0.52 | 0.40 |
| Bunch length (cm) | 4 | 5 | ≈ 5 | ≈ 1.5 | low current: 1 at 15mA: 2 |
| Beam radius (10 ⁻⁶ m) | 125 (round) | H: 1000 V: 30 | H: 890 V: 37 | H: 380 V: 5.7 | H: 260 V: 4.8 |
| Free space at interaction point (m) | ±1 | ±2 | ±2.15 | ±0.63 | ± 0.295 |
| Luminosity lifetime (hr) | continuous | 2 | 7–12 | 1.5 | 0.2 |
| Turn-around time (min) | continuous | 18 | 32 | 26 | 2 (topping up) |
| Injection energy (GeV) | 0.2–1.0 | 1.8 | 1.55 | 1.89 | on energy |
| Transverse emittance $(10^{-9}\pi \text{ rad-m})$ | H: 250 V: 250 | H: 200 V: 20 | H: 660 V: 28 | H: 144 V: 2.2 | H: 260 V: 2.6 |
| β^* , amplitude function at interaction point (m) | H: 0.06 - 0.11 V: 0.06 - 0.10 | H: 0.75 V: 0.05 | H: 1.2 V: 0.05 | H: 1.0 V: 0.015 | H: 0.26 V: 0.009 |
| Beam-beam tune shift per crossing (units 10^{-4}) | H: 750 V: 750 | 500 | 350 | 327 | 440 |
| RF frequency (MHz) | 172 | 180 | 199.53 | 499.8 | 356 |
| Particles per bunch (units 10 ¹⁰) | 16 | 15 | 20 at 2 GeV 11 at 1.55 GeV | 4.1 | e^{-} : 3.2 e^{+} : 2.1 |
| Bunches per ring per species | 1 | 2 | 1 | 88 | 100 to 105 (120 buckets) |
| Average beam current per species (mA) | 150 | 80 | 40 at 2 GeV 22 at 1.55 GeV | 725 | e ⁻ : 1500 e ⁺ : 1000 |
| Circumference or length (km) | 0.024 | 0.366 | 0.2404 | 0.23753 | 0.098 |
| Interaction regions | 2 | 1 | 2 | 1 | 1 |
| Magnetic length of dipole (m) | 1.2 | 2 | 1.6 | outer ring: 1.6 inner ring: 1.41 | outer ring: 1.2 inner ring: 1 |
| Length of standard cell (m) | 12 | 7.2 | 6.6 | outer ring: 6.6 inner ring: 6.2 | n/a |
| Phase advance per cell (deg) | H: 738 V: 378 | 65 | ≈ 60 | 60–90 non-standard cells | _ |
| Dipoles in ring | 8 | 78 | 40 + 4 weak | 84 + 8 weak | 8 |
| Quadrupoles in ring | 20 | 150 | 68 | 134+2 s.c. | 48 |
| Peak magnetic field (T) | 2.4 | 0.6 | 0.903 at 2.8 GeV | outer ring: 0.677 inner ring: 0.766 | 1.2 |

HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders (II)

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). For existing colliders, the table shows parameter values as achieved by January 1, 2012. For future colliders, design values are quoted. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; H and V indicate horizontal and vertical directions; s.c. stands for superconducting.

| | CESR (Cornell) | CESR-C (Cornell) | LEP (CERN) | ILC (TBD) | CLIC (TBD) |
|---------------------------------------------------------|----------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------------|----------------------------------------------------|
| Physics start date | 1979 | 2002 | 1989 | TBD | TBD |
| Physics end date | 2002 | 2008 | 2000 | _ | _ |
| Maximum beam energy (GeV) | 6 | 6 | 100 - 104.6 | 250 (upgradeable to 500) | 1500 (first phase: 250) |
| Delivered integrated luminosity per exp. (fb^{-1}) | 41.5 | 2.0 | 0.221 at Z peak 0.501 at 65 - 100 GeV 0.275 at >100 GeV | _ | _ |
| Luminosity ($10^{30} \text{ cm}^{-2} \text{s}^{-1}$) | 1280 at 5.3 GeV | 76 at 2.08 GeV | 24 at Z peak 100 at > 90 GeV | 1.5×10^{4} | 6×10^4 |
| Time between collisions (μs) | 0.014 to 0.22 | 0.014 to 0.22 | 22 | 0.55^{\dagger} | 0.0005^{\ddagger} |
| Full crossing angle (μ rad) | ±2000 | ±3300 | 0 | 14000 | 20000 |
| Energy spread (units 10^{-3}) | 0.6 at 5.3 GeV | 0.82 at 2.08 GeV | 0.7→1.5 | 1 | 3.4 |
| Bunch length (cm) | 1.8 | 1.2 | 1.0 | 0.03 | 0.0044 |
| Beam radius (μ m) | H: 460 V: 4 | H: 340 V: 6.5 | $\begin{array}{c} H \colon 200 \to 300 \\ V \colon 2.5 \to 8 \end{array}$ | H: 0.474 V: 0.0059 | H: 0.045 * V: 0.0009 |
| Free space at interaction point (m) | $\pm 2.2~(\pm 0.6$ to REC quads) | $\pm 2.2~(\pm 0.3$ to PM quads) | ±3.5 | ±3.5 | ±3.5 |
| Luminosity lifetime (hr) | 2-3 | 2–3 | 20 at Z peak 10 at > 90 GeV | n/a | n/a |
| Turn-around time (min) | 5 (topping up) | 1.5 (topping up) | 50 | n/a | n/a |
| Injection energy (GeV) | 1.8-6 | 1.5-6 | 22 | n/a | n/a |
| Transverse emittance $(10^{-9}\pi \text{ rad-m})$ | H: 210 V: 1 | H: 120 V: 3.5 | $\begin{array}{c} H\colon 2045 \\ V\colon 0.25 \to 1 \end{array}$ | H: 0.02 $V: 7 \times 10^{-5}$ | $H: 2.2 \times 10^{-4}$ $V: 6.8 \times 10^{-6}$ |
| β^* , amplitude function at interaction point (m) | H: 1.0 V: 0.018 | H: 0.94 V: 0.012 | H: 1.5 V: 0.05 | H: 0.01 $V: 5 \times 10^{-4}$ | H: 0.0069 $V: 6.8 \times 10^{-5}$ |
| Beam-beam tune shift per crossing (units 10^{-4}) | H: 250 V: 620 | e ⁻ : 420 (H), 280 (V) e ⁺ : 410 (H), 270 (V) | 830 | n/a | 7.7 |
| RF frequency (MHz) | 500 | 500 | 352.2 | 1300 | 11994 |
| Particles per bunch (units 10 ¹⁰) | 1.15 | 4.7 | 45 in collision 60 in single beam | 2 | 0.37 |
| Bunches per ring per species | 9 trains of 5 bunches | 8 trains of 3 bunches | 4 trains of 1 or 2 | 1312 | 312 (in train) |
| Average beam current per species (mA) | 340 | 72 | $\begin{array}{c} 4 \text{ at Z peak} \\ 4 \rightarrow 6 \text{ at} > 90 \text{ GeV} \end{array}$ | 6 (in pulse) | 1205 (in train) |
| Beam polarization (%) | _ | _ | 55 at 45 GeV 5 at 61 GeV | $e^-: > 80\%$ $e^+: > 60\%$ | e^- : 70% at IP |
| Circumference or length (km) | 0.768 | 0.768 | 26.66 | 31 | 48 |
| Interaction regions | 1 | 1 | 4 | 1 | 1 |
| Magnetic length of dipole (m) | 1.6-6.6 | 1.6-6.6 | 11.66/pair | n/a | n/a |
| Length of standard cell (m) | 16 | 16 | 79 | n/a | n/a |
| Phase advance per cell (deg) | 45–90 (no standard cell) | 45–90 (no standard cell) | 102/90 | n/a | n/a |
| Dipoles in ring | 86 | 84 | 3280 + 24 inj. + 64 weak | n/a | n/a |
| Quadrupoles in ring | 101 + 4 s.c. | 101 + 4 s.c. | 520 + 288 + 8 s.c. | n/a | n/a |
| Peak magnetic field (T) | 0.3 / 0.8 at 8 GeV | 0.3 / 0.8 at 8 GeV, 2.1 wigglers at 1.9 GeV | 0.135 | n/a | n/a |

 $^{^\}dagger \mathrm{Time}$ between bunch trains: 200ms.

[‡]Time between bunch trains: 20ms.

^{*}Effective beam size including non-linear and chromatic effects.

HIGH-ENERGY COLLIDER PARAMETERS: e^+e^- Colliders (III)

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). For existing colliders, the table shows parameter values as achieved by January 1, 2012. For future colliders, design values are quoted. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; H and V indicate horizontal and vertical directions; s.c. stands for superconducting.

| | KEKB (KEK) | PEP-II (SLAC) | SuperB (Italy) | SuperKEKB (KEK) |
|---------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Physics start date | 1999 | 1999 | TBD | 2015 |
| Physics end date | 2010 | 2008 | _ | _ |
| Maximum beam energy (GeV) | e^- : 8.33 (8.0 nominal) e^+ : 3.64 (3.5 nominal) | e^- : 7–12 (9.0 nominal) e^+ : 2.5–4 (3.1 nominal) (nominal $E_{\rm CM}=10.5~{\rm GeV})$ | e ⁻ : 4.2 e ⁺ : 6.7 | e ⁻ : 7 e ⁺ : 4 |
| Delivered integrated luminosity per exp. (fb^{-1}) | 1040 | 557 | _ | _ |
| Luminosity ($10^{30} \text{ cm}^{-2} \text{s}^{-1}$) | 21083 | 12069 (design: 3000) | 1.0×10^{6} | 8×10^5 |
| Time between collisions (μs) | 0.00590 or 0.00786 | 0.0042 | 0.0042 | 0.004 |
| Full crossing angle (μ rad) | $\pm 11000^{\dagger}$ | 0 | ±33000 | ±41500 |
| Energy spread (units 10^{-3}) | 0.7 | e^-/e^+ : 0.61/0.77 | e^-/e^+ : 0.73/0.64 | e^-/e^+ : 0.64/0.81 |
| Bunch length (cm) | 0.65 | e^{-}/e^{+} : 1.1/1.0 | 0.5 | e^-/e^+ : 0.5/0.6 |
| Beam radius (μm) | H: 124 (e ⁻), 117 (e ⁺) V: 1.9 | H: 157 V: 4.7 | H: 9 (e ⁻), 7 (e ⁺) V: 0.04 | e^- : 11 (H), 0.062 (V) e^+ : 10 (H), 0.048 (V) |
| Free space at interaction point (m) | +0.75/-0.58 (+300/-500) mrad cone | ± 0.2 , $\pm 300 \text{ mrad cone}$ | ±0.35 | $e^-: +1.20/-1.28, e^+: +0.78/-0.73$ (+300/-500) mrad cone |
| Luminosity lifetime (hr) | continuous | continuous | continuous | continuous |
| Turn-around time (min) | continuous | continuous | continuous | continuous |
| Injection energy (GeV) | $e^-/e^+: 8/3.5$ | 2.5–12 | $e^-/e^+:4.2/6.7$ | $e^-/e^+:7/4$ |
| Transverse emittance $(10^{-9}\pi \text{ rad-m})$ | e^- : 24 (57*) (H), 0.61 (V) e^+ : 18 (55*) (H), 0.56 (V) | e ⁻ : 48 (H), 1.8 (V) e ⁺ : 24 (H), 1.8 (V) | e^- : 2.5 (H), 0.006 (V) e^+ : 2.0 (H), 0.005 (V) | e^- : 4.6 (H), 0.013 (V) e^+ : 3.2 (H), 0.0086 (V) |
| β^* , amplitude function at interaction point (m) | e^- : 1.2 (0.27*) (H), 0.0059 (V) e^+ : 1.2 (0.23*) (H), 0.0059 (V) | e^- : 0.50 (H), 0.012 (V) e^+ : 0.50 (H), 0.012 (V) | e^- : 0.032 (H), 0.00021 (V) e^+ : 0.026 (H), 0.00025 (V) | e^- : 0.025 (H), 3×10^{-4} (V) e^+ : 0.032 (H), 2.7×10^{-4} (V) |
| Beam-beam tune shift per crossing (units 10^{-4}) | e^- : 1020 (H), 900 (V) e^+ : 1270 (H), 1290 (V) | e ⁻ : 703 (H), 498 (V) e ⁺ : 510 (H), 727 (V) | 20 (H), 950 (V) | e ⁻ : 12 (H), 807 (V) e ⁺ : 28 (H), 881 (V) |
| RF frequency (MHz) | 508.887 | 476 | 476 | 508.887 |
| Particles per bunch (units 10 ¹⁰) | e^{-}/e^{+} : 4.7/6.4 | e^{-}/e^{+} : 5.2/8.0 | e^-/e^+ : 6.5/5.1 | e^{-}/e^{+} : 6.53/9.04 |
| Bunches per ring per species | 1585 | 1732 | 978 | 2500 |
| Average beam current per species (mA) | e^-/e^+ : 1188/1637 | e^{-}/e^{+} : 1960/3026 | e^{-}/e^{+} : 1900/2400 | e^-/e^+ : 2600/3600 |
| Beam polarization (%) | _ | _ | $> 80 (e^{-})$ | _ |
| Circumference or length (km) | 3.016 | 2.2 | 1.258 | 3.016 |
| Interaction regions | 1 | 1 | 1 | 1 |
| Magnetic length of dipole (m) | $e^-/e^+: 5.86/0.915$ | e^{-}/e^{+} : 5.4/0.45 | e^-/e^+ : 0.9/5.4 | $e^-/e^+: 5.9/4.0$ |
| Length of standard cell (m) | $e^-/e^+:75.7/76.1$ | 15.2 | 40 | $e^-/e^+:75.7/76.1$ |
| Phase advance per cell (deg) | 450 | e^{-}/e^{+} : 60/90 | 360 (V), 1080 (H) | 450 |
| Dipoles in ring | $e^-/e^+: 116/112$ | e^-/e^+ : 192/192 | e^-/e^+ : 186/102 | e^-/e^+ : 116/112 |
| Quadrupoles in ring | $e^-/e^+:452/452$ | e^-/e^+ : 290/326 | e^-/e^+ : 290/300 | $e^-/e^+:466/460$ |
| Peak magnetic field (T) | $e^-/e^+: 0.25/0.72$ | e^-/e^+ : 0.18/0.75 | e^-/e^+ : 0.52/0.25 | $e^-/e^+: 0.22/0.19$ |

 $^{^\}dagger {\rm KEKB}$ was operated with crab crossing from 2007 to 2010.

 $^{{}^{*}}$ With dynamic beam-beam effect.

HIGH-ENERGY COLLIDER PARAMETERS: $ep, \overline{p}p, pp$ Colliders

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). The table shows parameter values as achieved by January 1, 2012. For LHC, the parameters expected for running in 2012 and nominal values are also given. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; H and V indicate horizontal and vertical directions; s.c. stands for superconducting; pk and avg denote peak and average values.

| | HERA (DESY) | TEVATRON* (Fermilab) | RHIC (Brookhaven) | | LHC (CERN) | |
|------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------|----------------------------------------------------------------------------|----------------------|--------------------------------|---------------------|
| Physics start date | 1992 | 1987 | 2001 | 2009 | 2012 (expected) | nominal |
| Physics end date | 2007 | 2011 | _ | | _ | |
| Particles collided | ep | $p\overline{p}$ | pp (polarized) | | pp | |
| Maximum beam energy (TeV) | e: 0.030 p: 0.92 | 0.980 | 0.25 $48%$ polarization | 3.5 | 4.0 | 7.0 |
| Delivered integrated luminosity per exp. (fb^{-1}) | 8.0 | 12 | up to 0.14 at 100 GeV/n up to 0.15 at 200 GeV/n | up to 5.6 | | _ |
| Luminosity $(10^{30} \text{ cm}^{-2} \text{s}^{-1})$ | 75 | 431 | 145 (pk) 90 (avg) | 3.7×10^{3} | 5×10^3 | 1.0×10^{4} |
| Time between collisions (ns) | 96 | 396 | 107 | 49.90 | 49.90 | 24.95 |
| Full crossing angle (μ rad) | 0 | 0 | 0 | 240 | ≈ 300 | ≈ 300 |
| Energy spread (units 10^{-3}) | e: 0.91 p: 0.2 | 0.14 | 0.15 | 0.116 | 0.116 | 0.113 |
| Bunch length (cm) | e: 0.83 p: 8.5 | p: 50 p̄: 45 | 70 | 9 | 9 | 7.5 |
| Beam radius (10^{-6} m) | e: 110(H), 30(V) p: 111(H), 30(V) | p: 28 p : 16 | 90 | 26 | 20 | 16.6 |
| Free space at interaction point (m) | ±2 | ±6.5 | 16 | 38 | 38 | 38 |
| Initial luminosity decay time, $-L/(dL/dt)$ (hr) | 10 | 6 (avg) | 5.5 | 8 | 8 | 14.9 |
| Turn-around time (min) | e: 75, p: 135 | 90 | 200 | ≈ 180 | ≈ 180 | ≈ 180 |
| Injection energy (TeV) | e: 0.012 p: 0.040 | 0.15 | 0.023 | 0.450 | 0.450 | 0.450 |
| Transverse emittance $(10^{-9}\pi \text{ rad-m})$ | e: 20(H), 3.5(V) p: 5(H), 5(V) | <i>p</i> : 3 | 15 | 0.7 | 0.6 | 0.5 |
| β^* , ampl. function at interaction point (m) | e: 0.6(H), 0.26(V) p: 2.45(H), 0.18(V) | 0.28 | 0.6 | 1.0 | 0.6 | 0.55 |
| Beam-beam tune shift per crossing (units 10^{-4}) | e: 190(H), 450(V) p: 12(H), 9(V) | p: 120 p : 120 | 50 | 23 | 60 | 34 |
| RF frequency (MHz) | e: 499.7 p: 208.2/52.05 | 53 | accel: 9 store: 28 | 400.8 | 400.8 | 400.8 |
| Particles per bunch (units 10 ¹⁰) | e: 3 p: 7 | p: 26 <u>p</u> : 9 | 16.5 | 15 | 15 | 11.5 |
| Bunches per ring per species | e: 189 p: 180 | 36 | 109 | 1380 | 1380 | 2808 |
| Average beam current per species (mA) | e: 40 p: 90 | p: 70 p : 24 | 180 | 374 | 374 | 584 |
| Circumference (km) | 6.336 | 6.28 | 3.834 | | 26.659 | |
| Interaction regions | $\begin{array}{c} 2 \text{ colliding beams} \\ 1 \text{ fixed target } (e \text{ beam}) \end{array}$ | 2 high $\mathcal L$ | 6 total, 2 high ${\mathscr L}$ | | 4 total, 2 high ${\mathscr L}$ | |
| Magnetic length of dipole (m) | e: 9.185 p: 8.82 | 6.12 | 9.45 | | 14.3 | |
| Length of standard cell (m) | e: 23.5 p: 47 | 59.5 | 29.7 | 106.90 | | |
| Phase advance per cell (deg) | e: 60 p: 90 | 67.8 | 84 | 90 | | |
| Dipoles in ring | e: 396 p: 416 | 774 | 192 per ring + 12 common | 1232 main dipoles | | |
| Quadrupoles in ring | e: 580 p: 280 | 216 | 246 per ring | | 482 2-in-1 24 1-in-1 | |
| | e: C-shaped | s.c. | s.c. $\cos \theta$ | | s.c. | |
| Magnet type | p: s.c., collared, cold iron | $\cos \theta$ warm iron | cold iron | | 2 in 1 cold iron | |
| Peak magnetic field (T) | e: 0.274, p: 5 | 4.4 | 3.5 | | 8.3 | |

^{*}Additional TEVATRON parameters: \overline{p} source accum. rate: 25×10^{10} hr⁻¹; max. no. of \overline{p} stored: 3.4×10^{12} (Accumulator), 6.1×10^{12} (Recycler).

HIGH-ENERGY COLLIDER PARAMETERS: Heavy Ion Colliders

Updated in early 2012 with numbers received from representatives of the colliders (contact J. Beringer, LBNL). The table shows parameter values as achieved by January 1, 2012. For LHC, the parameters expected for running in 2012 and nominal values are also given. Quantities are, where appropriate, r.m.s.; unless noted otherwise, energies refer to beam energy; s.c. stands for superconducting; pk and avg denote peak and average values.

| | | RHIC (Brookhaven) | | | LHC (CERN) | |
|----------------------------------------------------------------|------------------------------|------------------------------|--------------------------------------------------------|-----------------------------|------------------------------------------------------------------|-------------------------|
| Physics start date | 2000 | 2004 | 2002 | 2010 | 2012 (expected) | nominal |
| Physics end date | | _ | | | _ | |
| Particles collided | Au Au | Cu Cu | d Au | Pb Pb | p Pb | Pb Pb |
| Maximum beam energy (TeV/n) | 0.1 | 0.1 | 0.1 | 1.38 | p: 4 Pb: 1.58 | 2.76 |
| $\sqrt{s_{NN}}$ (TeV) | 0.2 | 0.2 | 0.2 | 2.76 | 5.0 | 5.5 |
| Delivered int. nucloen-pair lumin. per exp. (pb^{-1}) | up to 568 (at 100 GeV/n) | up to 65 (at 100 GeV/n) | up to 103 (at 100 GeV/n) | ≈ 7.4 | _ | _ |
| Luminosity $(10^{27} \text{ cm}^{-2} \text{s}^{-1})$ | 5.0 (pk) 3.0 (avg) | 20 (pk) 0.8 (avg) | 270 (pk) 140 (avg) | 0.5 | 85 | 1.0 |
| Time between collisions (ns) | 107 | 321 | 107 | 199.6 | 99.8 | 99.8 |
| Full crossing angle (μ rad) | 0 | 0 | 0 | 160 | 160 | ≤ 100 |
| Energy spread (units 10 ⁻³) | 0.75 | 0.75 | 0.75 | 0.11 | 0.11 | 0.11 |
| Bunch length (cm) | 30 | 30 | 30 | 9.7 | p: 9 Pb: 9.7 | 7.9 |
| Beam radius (10 ⁻⁶ m) | 135 | 145 | 145 | 50 | 23 | 15.9 |
| Free space at interaction point (m) | 16 | 16 | 16 | 38 | 38 | 38 |
| Initial luminosity decay time, $-L/(dL/dt)$ (hr) | 1.2 | 1.8 | 1.5 | 5 | ≈ 8 | 10.9 - 3.6 [‡] |
| Turn-around time (min) | 100 | 145 | 145 | 180 | ≈ 200 | ≈ 180 |
| Injection energy (TeV) | 0.011 TeV/n | 0.011 TeV/n | $\begin{array}{c} 0.012 \\ \mathrm{TeV/n} \end{array}$ | 0.177 TeV/n | p: 0.45 TeV/n Pb: 0.177 TeV/n | 0.177 TeV/ |
| Transverse emittance $(10^{-9}\pi \text{ rad-m})$ | 23 | 23 | 25 | 1.0 | 0.9 | 0.5 |
| β*, ampl. function at interaction point (m) | 0.75 | 0.9 | 0.85 | 1.0 | 0.6 | 0.5 |
| Beam-beam tune shift per crossing (units 10 ⁻⁴) | 16 | 30 | d: 21 Au: 17 | 3 | 4 | 2 |
| RF frequency (MHz) | accel: 28 store: 197 | accel: 28 store: 197 | accel: 28 store: 197 | 400.8 | 400.8 | 400.8 |
| Particles per bunch (units 10 ¹⁰) | 0.13 | 0.45 | d: 10 Au: 0.1 | 0.011 (r.m.s.) | p: 1.1 Pb: 0.008 | 0.007 |
| Bunches per ring per species | 111 | 37 | 95 | 356 | 560 | 592 |
| Average beam current per species (mA) | 145 | 60 | d: 119 Au: 94 | 6.85 | p: 11 Pb: 9.9 | 6.12 |
| Circumference (km) | | 3.834 | | | 26.659 | |
| Interaction regions | | 6 total, 2 high $\mathcal L$ | | 1 dedicated +2 | $\begin{array}{c} 3 \text{ high } \mathscr{L} \\ +1 \end{array}$ | 1 dedicated +2 |
| Magnetic length of dipole (m) | | 9.45 | | | 14.3 | |
| Length of standard cell (m) | | 29.7 | | | 106.90 | |
| Phase advance per cell (deg) | 93 84 d: 84 Au: 93 | | | | 90 | |
| Dipoles in ring | 192 per ring + 12 common | | | 1232 main dipoles | | |
| Quadrupoles in ring | 246 per ring | | | | 482 2-in-1 24 1-in-1 | |
| Magnet type | s.c. $\cos \theta$ cold iron | | | s.c. 2 in 1 cold iron | | |
| Peak magnetic field (T) | | 3.5 | | | 8.3 | |

 $^{^{\}ddagger}$ For 1 - 3 experiments.

29. NEUTRINO BEAM LINES AT HIGH-ENERGY PROTON SYNCHROTRONS

Created in May 2012 with numbers verified by representatives of the synchrotrons (contact C.-J. Lin, LBNL). For existing (future) neutrino beam lines the latest achieved (design) values are given.

The main source of neutrinos at proton synchrotrons is from the decay of pions and kaons produced by protons striking a nuclear target. There are different schemes to focus the secondary particles to enhance neutrino flux and/or tune the neutrino energy profile. In wide-band beams (WBB), the neutrino parent mesons are focused over a wide momentum range to obtain maximum neutrino intensity. In narrow-band beams (NBB), the secondary particles are first momentum-selected to produce a monochromatic parent beam. Another approach to generate a narrow-band neutrino spectrum is to select neutrinos that decay off-axis relative to the momentum of the parent mesons. For a comprehensive review of the topic, including other historical neutrino beam lines, see the article by S. E. Kopp, "Accelerator-based neutrino beams," Phys. Rept. 439, 101 (2007).

| | | PS (CER | | | | SPS (CERI | | | PS (KEK) | Main Ring (JPARC) |
|------------------------------------------|--------------------|--------------------|---------------------------|----------------|-------------------------|-----------------------------|------------------|-------------------|---------------|----------------------|
| Date | 1963 | 1969 | 1972 | 1983 | 1977 | 1977 | 1995 | 2006 | 1999 | 2009 |
| Proton Kinetic Energy (GeV) | 20.6 | 20.6 | 26 | 19 | 350 | 350 | 450 | 400 | 12 | 30 (50) |
| Protons per Pulse (10 ¹²) | 0.7 | 0.6 | 5 | 5 | 10 | 10 | 18 | 50 | 6 | 135 (330) |
| Cycle Time (s) | 3 | 2.3 | - | - | - | - | 14.4 | 6 | 2.2 | 2.56 (3.5) |
| Beam Power (kW) | 0.8 | 0.9 | - | - | - | - | 55 | 510 | 5 | 250 (750) |
| Secondary Focussing | 1-horn WBB | 3-horn WBB | 2-horn WBB | bare target | dichromatic NBB | 2-horn WBB | 2-horn WBB | 2-horn WBB | 2-horn WBB | 3-horn off-axis |
| Decay Pipe Length (m) | 60 | 60 | 60 | 45 | 290 | 290 | 290 | 994 | 200 | 96 |
| $\langle E_{\nu} \rangle \text{ (GeV)}$ | 1.5 | 1.5 | 1.5 | 1 | $50,150^{\dagger}$ | 20 | 24.3 | 17 | 1.3 | 0.6 |
| Experiments | HLBC, Spark Ch. | HLBC, Spark Ch. | GGM, Aachen- Padova | CDHS, CHARM | CDHS, CHARM, BEBC | GGM,CDHS, CHARM, BEBC | NOMAD, CHORUS | OPERA, INCARUS | K2K | T2K |

| | | Main Ring (Fermilab) | | | | | | | | Injector nilab) |
|------------------------------------------|----------------|-------------------------|--------------------------|---------------|----------------|------------------|-------------|------------------------|-------------------------|-------------------------------------|
| Date | 1975 | 1975 | 1974 | 1979 | 1976 | 1991 | 1998 | 2002 | 2005 | 2013 |
| Proton Kinetic Energy (GeV) | 300,400 | 300,400 | 300 | 400 | 350 | 800 | 800 | 8 | 120 | 120 |
| Protons per Pulse (10 ¹²) | 10 | 10 | 10 | 10 | 13 | 10 | 12 | 4.5 | 37 | (49) |
| Cycle Time (s) | - | - | - | - | - | 60 | 60 | 0.5 | 2 | (1.333) |
| Beam Power (kW) | - | - | - | - | - | 20 | 25 | 12 | 350 | (700) |
| Secondary Focussing | bare target | quad trip., SSBT | dichromatic NBB | 2-horn WBB | 1-horn WBB | quad trip. | SSQT WBB | 1-horn WBB | 2-horn WBB | 2-horn off-axis |
| Decay Pipe Length (m) | 350 | 350 | 400 | 400 | 400 | 400 | 400 | 50 | 675 | 675 |
| $\langle E_{\nu} \rangle \text{ (GeV)}$ | 40 | $50{,}180^{\dagger}$ | $50,180^{\dagger}$ | 25 | 100 | 90,260 | 70,180 | 1 | $3-20^{\ddagger}$ | 2 |
| Experiments | HPWF | CITF, HPWF | CITF, HPWF, 15' BC | 15' BC | HPWF 15' BC | 15' BC, CCFRR | NuTeV | MiniBooNE, SciBooNE | MINOS, MINER ν A | $NO\nu A$, $MINER\nu A$, $MINOS+$ |

[†]Pion and kaon peaks in the momentum-selected channel.

[‡]Tunable WBB energy spectrum.

30. PASSAGE OF PARTICLES THROUGH MATTER

Revised January 2012 by H. Bichsel (University of Washington), D.E. Groom (LBNL), and S.R. Klein (LBNL).

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30.1. Notation

Table 30.1: Summary of variables used in this section. The kinematic variables β and γ have their usual meanings.

| Symbol | Definition | Units or Value |
|---------------------|---------------------------------------------|------------------------------------------------------------------|
| α | Fine structure constant | 1/137.035 999 11(46) |
| | $(e^2/4\pi\epsilon_0\hbar c)$ | |
| M | Incident particle mass | MeV/c^2 |
| E | Incident part. energy γMc^2 | MeV |
| T | Kinetic energy | MeV |
| $m_e c^2$ | Electron mass $\times c^2$ | $0.510998918(44)\mathrm{MeV}$ |
| r_e | Classical electron radius | 2.817940325(28) fm |
| | $e^2/4\pi\epsilon_0 m_e c^2$ | |
| N_A | Avogadro's number | $6.0221415(10) \times 10^{23} \text{ mol}^{-1}$ |
| ze | Charge of incident particle | |
| Z | Atomic number of absorber | |
| A | Atomic mass of absorber | $g \text{ mol}^{-1}$ |
| K/A | $4\pi N_A r_e^2 m_e c^2/A$ | $0.307075 \text{ MeV g}^{-1} \text{ cm}^2$ |
| | | for $A = 1 \text{ g mol}^{-1}$ |
| I | Mean excitation energy | eV (Nota bene!) |
| $\delta(eta\gamma)$ | Density effect correction to ic | |
| $\hbar\omega_p$ | Plasma energy | $\sqrt{\rho \langle Z/A \rangle} \times 28.816 \text{ eV}$ |
| | $(\sqrt{4\pi N_e r_e^3} \ m_e c^2/\alpha)$ | $(\rho \text{ in g cm}^{-3})$ |
| N_e | Electron density | (units of r_e) ⁻³ |
| w_{j} | Weight fraction of the j th ele | ement in a compound or mixture |
| n_{j} | | ns in a compound or mixture |
| | $4\alpha r_e^2 N_A / A \qquad (716.408)$ | $(g \text{ cm}^{-2})^{-1} \text{ for } A = 1 \text{ g mol}^{-1}$ |
| X_0 | Radiation length | $\mathrm{g~cm^{-2}}$ |
| E_c | Critical energy for electrons | MeV |
| $E_{\mu c}$ | Critical energy for muons | GeV |
| $\dot{E_s}$ | Scale energy $\sqrt{4\pi/\alpha} \ m_e c^2$ | $21.2052~\mathrm{MeV}$ |
| R_M | Molière radius | $\mathrm{g}\;\mathrm{cm}^{-2}$ |

30.2. Electronic energy loss by heavy particles [1–34]

30.2.1. Moments and cross sections:

The electronic interactions of fast charged particles with speed $v=\beta c$ occur in single collisions with energy losses E [1], leading to ionization, atomic, or collective excitation. Most frequently the energy losses are small (for 90% of all collisions the energy losses are less than 100 eV). In thin absorbers few collisions will take place and the total energy loss will show a large variance [1]; also see Sec. 30.2.7 below. For particles with charge ze more massive than electrons ("heavy" particles), scattering from free electrons is adequately described by the Rutherford differential cross section [2], * †

$$\frac{d\sigma_R(E;\beta)}{dE} = \frac{2\pi r_e^2 m_e c^2 z^2}{\beta^2} \frac{(1-\beta^2 E/T_{\rm max})}{E^2} , \qquad (30.1)$$

where $T_{\rm max}$ is the maximum energy transfer possible in a single collision. But in matter electrons are not free. E must be finite and depends on atomic and bulk structure. For electrons bound

^{*} For spin 0 particles. The β dependence in the parentheses is different for spin 1/2 and spin 1 particles, but it is not important except at energies far above atomic binding energies.

 $^{^{\}dagger}$ In high-energy physics E normally means total energy, $T+mc^2$. In stopping power discussions, E means kinetic energy, and we follow that convention (with some inconsistency).

in atoms Bethe [3] used "Born Theorie" to obtain the differential cross section

$$\frac{d\sigma_B(E;\beta)}{dE} = \frac{d\sigma_R(E,\beta)}{dE}B(E) \ . \tag{30.2}$$

Examples of B(E) and $d\sigma_B/dE$ can be seen in Figs. 5 and 6 of Ref. 1.

of a few %. With the symbol definitions and values given in Table 30.1, the units are MeV $g^{-1}cm^2$. At the lower limit the projectile velocity becomes comparable to atomic electron "velocities" (Sec. 30.2.3), and at the upper limit radiative effects begin to be important (Sec. 30.6). Both limits are Z dependent.

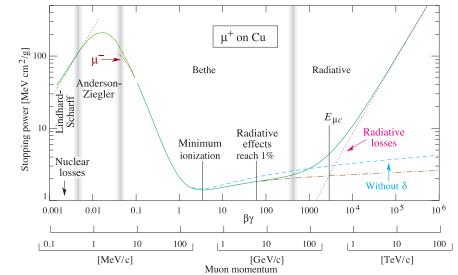


Fig. 30.1: Stopping power (= $\langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta \gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta \gamma \approx 0.1$ are taken from ICRU 49 [4], and data at higher energies are from Ref. 5. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled " μ " illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies [6].

Bethe's theory extends only to some energy above which atomic effects were not important. The free-electron cross section (Eq. (30.1)) can be used to extend the cross section to $T_{\rm max}$. At high energies σ_B is further modified by polarization of the medium, and this "density effect," discussed in Sec. 30.2.4, must also be included. Less important corrections are discussed below

The mean number of collisions with energy loss between E and E+dE occurring in a distance δx is $N_e \delta x \, (d\sigma/dE) dE$, where $d\sigma(E;\beta)/dE$ contains all contributions. It is convenient to define the moments

$$M_j(\beta) = N_e \, \delta x \int E^j \frac{d\sigma(E;\beta)}{dE} dE , \qquad (30.3)$$

so that M_0 is the mean number of collisions in δx , M_1 is the mean energy loss in δx , $M_2-M_1^2$ is the variance, etc. The number of collisions is Poisson-distributed with mean M_0 . N_e is either measured in electrons/g ($N_e=N_AZ/A$) or electrons/cm³ ($N_e=N_A\,\rho Z/A$). The former is used throughout this chapter, since quantities of interest (dE/dx, X_0 , etc.) vary smoothly with composition when there is no density dependence.

30.2.2. Stopping power at intermediate energies:

The mean rate of energy loss by moderately relativistic charged heavy particles, $M_1/\delta x$, is well-described by the "Bethe" equation,

$$-\left\langle \frac{dE}{dx}\right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\text{max}}}{I^2} - \beta^2 - \frac{\delta(\beta \gamma)}{2} \right]. \tag{30.4}$$

It describes the mean rate of energy loss in the region $0.1\lesssim \beta\gamma\lesssim 1000$ for intermediate-Z materials with an accuracy

Here $T_{\rm max}$ is the maximum kinetic energy which can be imparted to a free electron in a single collision, and the other variables are defined in Table 30.1. A minor dependence on M at the highest energies is introduced through $T_{\rm max}$, but for all practical purposes $\langle dE/dx \rangle$ in a given material is a function of β alone.

For heavy projectiles, like ions, additional terms are required to account for higher-order photon coupling to the target, and to account for the finite size of the target radius. These can change dE/dx by a factor of two or more for the heaviest nuclei in certain kinematic regimes [7].

Few concepts in high-energy physics are as misused as $\langle dE/dx \rangle$. The main problem is that the mean is weighted by very rare events with large single-collision energy deposits. Even with samples of hundreds of events a dependable value for the mean energy loss cannot be obtained. Far better and more easily measured is the most probable energy loss, discussed in Sec. 30.2.7. The most probable energy loss in a detector is considerably below the mean given by the Bethe equation.

In a TPC (Sec. 31.6.5), the mean of 50%–70% of the samples with the smallest signals is often used as an estimator.

Although it must be used with cautions and caveats, $\langle dE/dx \rangle$ as described in Eq. (30.4) still forms the basis of much of our understanding of energy loss by charged particles. Extensive tables are available[5,4, pdg.lbl.gov/AtomicNuclearProperties/].

The function as computed for muons on copper is shown as the "Bethe" region of Fig. 30.1. Mean energy loss behavior below this region is discussed in Sec. 30.2.3, and the radiative effects at high energy are discussed in Sec. 30.6. Only in the Bethe region is it a function of β alone; the mass dependence

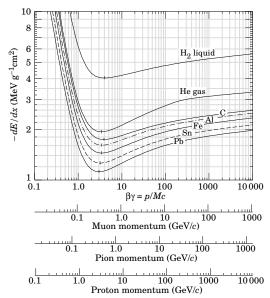


Figure 30.2: Mean energy loss rate in liquid (bubble chamber) hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. Radiative effects, relevant for muons and pions, are not included. These become significant for muons in iron for $\beta\gamma\gtrsim 1000$, and at lower momenta for muons in higher-Z absorbers. See Fig. 30.23.

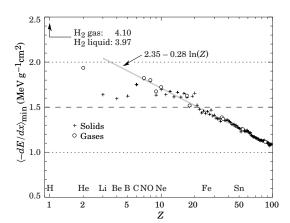


Figure 30.3: Stopping power at minimum ionization for the chemical elements. The straight line is fitted for Z > 6. A simple functional dependence on Z is not to be expected, since $\langle -dE/dx \rangle$ also depends on other variables.

is more complicated elsewhere. The stopping power in several other materials is shown in Fig. 30.2. Except in hydrogen, particles with the same velocity have similar rates of energy loss in different materials, although there is a slow decrease in the rate of energy loss with increasing Z. The qualitative behavior difference at high energies between a gas (He in the figure) and the other materials shown in the figure is due to the density-effect correction, $\delta(\beta\gamma)$, discussed in Sec. 30.2.4. The stopping power functions are characterized by broad minima whose position drops from $\beta\gamma=3.5$ to 3.0 as Z goes from 7 to 100. The values of minimum ionization as a function of atomic number are shown in Fig. 30.3.

In practical cases, most relativistic particles (e.g., cosmic-ray muons) have mean energy loss rates close to the minimum; they are "minimum-ionizing particles," or mip's.

Eq. (30.4) may be integrated to find the total (or partial) "continuous slowing-down approximation" (CSDA) range R for

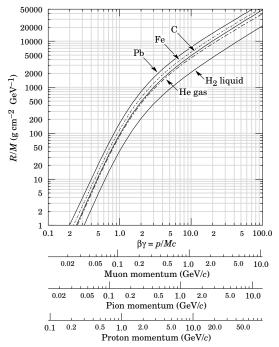


Figure 30.4: Range of heavy charged particles in liquid (bubble chamber) hydrogen, helium gas, carbon, iron, and lead. For example: For a K^+ whose momentum is 700 MeV/c, $\beta\gamma = 1.42$. For lead we read $R/M \approx 396$, and so the range is 195 g cm⁻².

a particle which loses energy only through ionization and atomic excitation. Since dE/dx depends only on β , R/M is a function of E/M or pc/M. In practice, range is a useful concept only for low-energy hadrons ($R \lesssim \lambda_I$, where λ_I is the nuclear interaction length), and for muons below a few hundred GeV (above which radiative effects dominate). R/M as a function of $\beta\gamma = p/Mc$ is shown for a variety of materials in Fig. 30.4.

The mass scaling of dE/dx and range is valid for the electronic losses described by the Bethe equation, but not for radiative losses, relevant only for muons and pions.

For a particle with mass M and momentum $M\beta\gamma c$, $T_{\rm max}$ is given by

$$T_{\text{max}} = \frac{2m_e c^2 \,\beta^2 \gamma^2}{1 + 2\gamma m_e / M + (m_e / M)^2} \,. \tag{30.5}$$

In older references [2,8] the "low-energy" approximation $T_{\rm max}=2m_ec^2\,\beta^2\gamma^2$, valid for $2\gamma m_e/M\ll 1$, is often implicit. For a pion in copper, the error thus introduced into dE/dx is greater than 6% at 100 GeV.

At energies of order 100 GeV, the maximum 4-momentum transfer to the electron can exceed 1 GeV/c, where hadronic structure effects significantly modify the cross sections. This problem has been investigated by J.D. Jackson [9], who concluded that for hadrons (but not for large nuclei) corrections to dE/dx are negligible below energies where radiative effects dominate. While the cross section for rare hard collisions is modified, the average stopping power, dominated by many softer collisions, is almost unchanged.

"The determination of the mean excitation energy is the principal non-trivial task in the evaluation of the Bethe stopping-power formula" [10]. Recommended values have varied substantially with time. Estimates based on experimental stopping-power measurements for protons, deuterons, and alpha particles and on oscillator-strength distributions and dielectric-response functions were given in ICRU 49 [4]. See also ICRU

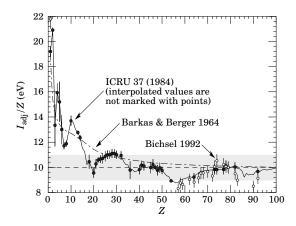


Figure 30.5: Mean excitation energies (divided by Z) as adopted by the ICRU [11]. Those based on experimental measurements are shown by symbols with error flags; the interpolated values are simply joined. The grey point is for liquid H_2 ; the black point at 19.2 eV is for H_2 gas. The open circles show more recent determinations by Bichsel [13]. The dotted curve is from the approximate formula of Barkas [14] used in early editions of this *Review*.

37 [11]. These values, shown in Fig. 30.5, have since been widely used. Machine-readable versions can also be found [12]. These values are widely used.

30.2.3. Energy loss at low energies: Shell corrections C/Z must be included in the square brackets of of Eq. (30.4) [4,11,13,14] to correct for atomic binding having been neglected in calculating some of the contributions to Eq. (30.4). The Barkas form [14] was used in generating Fig. 30.1. For copper it contributes about 1% at $\beta\gamma=0.3$ (kinetic energy 6 MeV for a pion), and the correction decreases very rapidly with increasing energy.

Equation 30.2, and therefore Eq. (30.4), are based on a first-order Born approximation. Higher-order corrections, again important only at lower energies, are normally included by adding the "Bloch correction" $z^2L_2(\beta)$ inside the square brackets (Eq.(2.5) in [4]).

An additional "Barkas correction" $zL_1(\beta)$ reduces the stopping power for a negative particle below that for a positive particle with the same mass and velocity. In a 1956 paper, Barkas *et al.* noted that negative pions had a longer range than positive pions [6]. The effect has been measured for a number of negative/positive particle pairs, including a detailed study with antiprotons [15].

A detailed discussion of low-energy corrections to the Bethe formula is given in ICRU Report 49 [4]. When the corrections are properly included, the Bethe treatment is accurate to about 1% down to $\beta \approx 0.05$, or about 1 MeV for protons.

For $0.01 < \beta < 0.05$, there is no satisfactory theory. For protons, one usually relies on the phenomenological fitting formulae developed by Andersen and Ziegler [4,16]. As shown in ICRU 49 [4] (using data taken from Ref. 16), the nuclear plus electronic proton stopping power in copper is 113 MeV cm² g⁻¹ at T=10 keV, rises to a maximum of 210 MeV cm² g⁻¹ at 100–150 keV, then falls to 120 MeV cm² g⁻¹ at 1 MeV.

For particles moving more slowly than $\approx 0.01c$ (more or less the velocity of the outer atomic electrons), Lindhard has been quite successful in describing electronic stopping power, which is proportional to β [17]. Finally, we note that at even lower energies, e.g., for protons of less than several hundred eV, non-ionizing nuclear recoil energy loss dominates the total energy loss [4,17,18].

30.2.4. Density effect: As the particle energy increases, its electric field flattens and extends, so that the distant-collision contribution to Eq. (30.4) increases as $\ln \beta \gamma$. However, real media become polarized, limiting the field extension and effectively truncating this part of the logarithmic rise [2–8,19–21]. At very high energies,

$$\delta/2 \to \ln(\hbar\omega_p/I) + \ln\beta\gamma - 1/2$$
, (30.6)

where $\delta(\beta\gamma)/2$ is the density effect correction introduced in Eq. (30.4) and $\hbar\omega_p$ is the plasma energy defined in Table 30.1. A comparison with Eq. (30.4) shows that |dE/dx| then grows as $\ln\beta\gamma$ rather than $\ln\beta^2\gamma^2$, and that the mean excitation energy I is replaced by the plasma energy $\hbar\omega_p$. The ionization stopping power as calculated with and without the density effect correction is shown in Fig. 30.1. Since the plasma frequency scales as the square root of the electron density, the correction is much larger for a liquid or solid than for a gas, as is illustrated by the examples in Fig. 30.2.

The density effect correction is usually computed using Sternheimer's parameterization [19]:

$$\delta(\beta\gamma) = \begin{cases} 2(\ln 10)x - \overline{C} & \text{if } x \ge x_1; \\ 2(\ln 10)x - \overline{C} + a(x_1 - x)^k & \text{if } x_0 \le x < x_1; \\ 0 & \text{if } x < x_0 \text{ (nonconductors)}; \\ \delta_0 10^{2(x - x_0)} & \text{if } x < x_0 \text{ (conductors)} \end{cases}$$
(30.7)

Here $x = \log_{10} \eta = \log_{10}(p/Mc)$. \overline{C} (the negative of the C used in Ref. 19) is obtained by equating the high-energy case of Eq. (30.7) with the limit given in Eq. (30.6). The other parameters are adjusted to give a best fit to the results of detailed calculations for momenta below $Mc\exp(x_1)$. Parameters for elements and nearly 200 compounds and mixtures of interest are published in a variety of places, notably in Ref. 21. A recipe for finding the coefficients for nontabulated materials is given by Sternheimer and Peierls [22], and is summarized in Ref. 5.

The remaining relativistic rise comes from the $\beta^2 \gamma^2$ growth of $T_{\rm max}$, which in turn is due to (rare) large energy transfers to a few electrons. When these events are excluded, the energy deposit in an absorbing layer approaches a constant value, the Fermi plateau (see Sec. 30.2.6 below). At extreme energies (e.g., > 332 GeV for muons in iron, and at a considerably higher energy for protons in iron), radiative effects are more important than ionization losses. These are especially relevant for high-energy muons, as discussed in Sec. 30.6.

30.2.5. Energetic knock-on electrons (δ rays): The distribution of secondary electrons with kinetic energies $T \gg I$ is [2]

$$\frac{d^2N}{dTdx} = \frac{1}{2} K z^2 \frac{Z}{A} \frac{1}{\beta^2} \frac{F(T)}{T^2}$$
 (30.8)

for $I \ll T \leq T_{\rm max}$, where $T_{\rm max}$ is given by Eq. (30.5). Here β is the velocity of the primary particle. The factor F is spin-dependent, but is about unity for $T \ll T_{\rm max}$. For spin-0 particles $F(T) = (1-\beta^2 T/T_{\rm max})$; forms for spins 1/2 and 1 are also given by Rossi [2](Sec. 2.3, Eqns. 7 and 8). For incident electrons, the indistinguishability of projectile and target means that the range of T extends only to half the kinetic energy of the incident particle. Additional formulae are given in Ref. 23. Equation (30.8) is inaccurate for T close to I [24].

 δ rays of even modest energy are rare. For a $\beta \approx 1$ particle, for example, on average only one collision with $T_e > 10$ keV will occur along a path length of 90 cm of Ar gas [1].

A δ ray with kinetic energy T_e and corresponding momentum p_e is produced at an angle θ given by

$$\cos \theta = (T_e/p_e)(p_{\text{max}}/T_{\text{max}}) , \qquad (30.9)$$

where p_{max} is the momentum of an electron with the maximum possible energy transfer T_{max} .

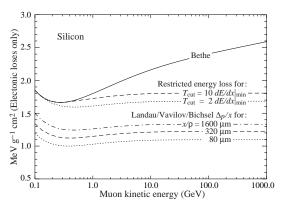


Figure 30.6: Bethe dE/dx, two examples of restricted energy loss, and the Landau most probable energy per unit thickness in silicon. The change of Δ_p/x with thickness x illustrates its $a \ln x + b$ dependence. Minimum ionization $(dE/dx|_{\min})$ is 1.664 MeV g⁻¹ cm². Radiative losses are excluded. The incident particles are muons.

30.2.6. Restricted energy loss rates for relativistic ionizing particles: Further insight can be obtained by examining the mean energy deposit by an ionizing particle when energy transfers are restricted to $T \leq T_{\rm cut} \leq T_{\rm max}$. The restricted energy loss rate is

$$-\frac{dE}{dx}\bigg|_{T < T_{\text{cut}}} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{\text{cut}}}{I^2} - \frac{\beta^2}{2} \left(1 + \frac{T_{\text{cut}}}{T_{\text{max}}} \right) - \frac{\delta}{2} \right].$$
(30.10)

This form approaches the normal Bethe function (Eq. (30.4)) as $T_{\rm cut} \to T_{\rm max}$. It can be verified that the difference between Eq. (30.4) and Eq. (30.10) is equal to $\int_{T_{\rm cut}}^{T_{\rm max}} T(d^2N/dTdx)dT$, where $d^2N/dTdx$ is given by Eq. (30.8).

Since $T_{\rm cut}$ replaces $T_{\rm max}$ in the argument of the logarithmic term of Eq. (30.4), the $\beta\gamma$ term producing the relativistic rise in the close-collision part of dE/dx is replaced by a constant, and $|dE/dx|_{T< T_{\rm cut}}$ approaches the constant "Fermi plateau." (The density effect correction δ eliminates the explicit $\beta\gamma$ dependence produced by the distant-collision contribution.) This behavior is illustrated in Fig. 30.6, where restricted loss rates for two examples of $T_{\rm cut}$ are shown in comparison with the full Bethe dE/dx and the Landau-Vavilov most probable energy loss (to be discussed in Sec. 30.2.7 below).

30.2.7. Fluctuations in energy loss: For detectors of moderate thickness x (e.g. scintillators or LAr cells),* the energy loss probability distribution $f(\Delta; \beta \gamma, x)$ is adequately described by the highly-skewed Landau (or Landau-Vavilov) distribution [25,26]. The most probable energy loss is [27]

$$\Delta_p = \xi \left[\ln \frac{2mc^2 \beta^2 \gamma^2}{I} + \ln \frac{\xi}{I} + j - \beta^2 - \delta(\beta \gamma) \right] , \quad (30.11)$$

where $\xi = (K/2) \langle Z/A \rangle (x/\beta^2)$ MeV for a detector with a thickness x in g cm⁻², and j = 0.200 [27]. † While dE/dx is independent of thickness, Δ_p/x scales as $a \ln x + b$. The density correction $\delta(\beta\gamma)$ was not included in Landau's or Vavilov's work, but it was later included by Bichsel [27]. The high-energy

behavior of $\delta(\beta\gamma)$ (Eq. (30.6)) is such that

$$\Delta_p \xrightarrow[\beta\gamma\gtrsim 100]{} \xi \left[\ln \frac{2mc^2\xi}{(\hbar\omega_p)^2} + j \right] .$$
(30.12)

Thus the Landau-Vavilov most probable energy loss, like the restricted energy loss, reaches a Fermi plateau. The Bethe dE/dx and Landau-Vavilov-Bichsel Δ_p/x in silicon are shown as a function of muon energy in Fig. 30.6. The energy deposit in the 1600 μ m case is roughly the same as in a 3 mm thick plastic scintillator.

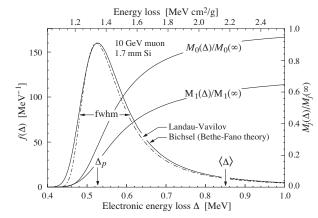


Figure 30.7: Electronic energy deposit distribution for a 10 GeV muon traversing 1.7 mm of silicon, the stopping power equivalent of about 0.3 cm of PVC scintillator [1,13,29]. The Landau-Vavilov function (dot-dashed) uses a Rutherford cross section without atomic binding corrections but with a kinetic energy transfer limit of $T_{\rm max}$. The solid curve was calculated using Bethe-Fano theory. $M_0(\Delta)$ and $M_1(\Delta)$ are the cumulative 0th moment (mean number of collisions) and 1st moment (mean energy loss) in crossing the silicon. (See Sec. 30.2.1. The fwhm of the Landau-Vavilov function is about 4ξ for detectors of moderate thickness. Δ_p is the most probable energy loss, and $\langle \Delta \rangle$ divided by the thickness is the Bethe $\langle dE/dx \rangle$.

The distribution function for the energy deposit by a 10 GeV muon going through a detector of about this thickness is shown in Fig. 30.7. In this case the most probable energy loss is 62\% of the mean $(M_1(\langle \Delta \rangle)/M_1(\infty))$. Folding in experimental resolution displaces the peak of the distribution, usually toward a higher value. 90% of the collisions $(M_1(\langle \Delta \rangle)/M_1(\infty))$ contribute to energy deposits below the mean. It is the very rare high-energytransfer collisions, extending to T_{max} at several GeV, that drives the mean into the tail of the distribution. The mean of the energy loss given by the Bethe equation, Eq. (30.4), is thus ill-defined experimentally and is not useful for describing energy loss by single particles.* It rises as $\ln \beta \gamma$ because $T_{\rm max}$ increases as $\beta^2 \gamma^2$. The large single-collision energy transfers that increasingly extend the long tail are rare, making the mean of an experimental distribution consisting of a few hundred events subject to large fluctuations and sensitive to cuts. The most probable energy loss should be used.

The Landau distribution fails to describe energy loss in thin absorbers such as gas TPC cells [1] and Si detectors [27], as shown clearly in Fig. 1 of Ref. 1 for an argon-filled TPC cell. Also

^{*} $G \lesssim 0.05$ –0.1, where G is given by Rossi [Ref. 2, Eq. 2.7.10]. It is Vavilov's κ [26].

[†] Rossi [2], Talman [28], and others give somewhat different values for j. The most probable loss is not sensitive to its value.

 $^{\ ^*}$ It does find application in do simetry, where only bulk deposit is relevant.

 $^{^{\}dagger}$ An alternative approach is taken in TPC analysis, where some fraction of the highest energy deposit signals along a track, e.g. 20%, are discarded before taking the average.

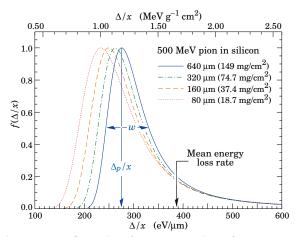


Figure 30.8: Straggling functions in silicon for 500 MeV pions, normalized to unity at the most probable value δ_p/x . The width w is the full width at half maximum.

see Talman [28]. While Δ_p/x may be calculated adequately with Eq. (30.11), the distributions are significantly wider than the Landau width $w=4\xi$ [Ref. 27, Fig. 15]. Examples for 500 MeV pions incident on thin silicon detectors are shown in Fig. 30.8. For very thick absorbers the distribution is less skewed but never approaches a Gaussian.

The most probable energy loss, scaled to the mean loss at minimum ionization, is shown in Fig. 30.9 for several silicon detector thicknesses.

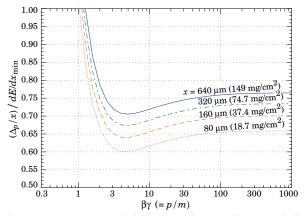


Figure 30.9: Most probable energy loss in silicon, scaled to the mean loss of a minimum ionizing particle, 388 eV/ μ m (1.66 MeV g⁻¹cm²).

30.2.8. Energy loss in mixtures and compounds: A mixture or compound can be thought of as made up of thin layers of pure elements in the right proportion (Bragg additivity). In this case,

$$\frac{dE}{dx} = \sum w_j \left. \frac{dE}{dx} \right|_j \,, \tag{30.13}$$

where $dE/dx|_j$ is the mean rate of energy loss (in MeV g cm⁻²) in the jth element. Eq. (30.4) can be inserted into Eq. (30.13) to find expressions for $\langle Z/A \rangle$, $\langle I \rangle$, and $\langle \delta \rangle$; for example, $\langle Z/A \rangle = \sum w_j Z_j/A_j = \sum n_j Z_j/\sum n_j A_j$. However, $\langle I \rangle$ as defined this way is an underestimate, because in a compound electrons are more tightly bound than in the free elements, and $\langle \delta \rangle$ as calculated this way has little relevance, because it is the electron density that matters. If possible, one uses the tables given in Refs. 21 and 30, which include effective excitation energies and interpolation coefficients for calculating the density effect correction for the chemical elements and nearly 200 mixtures and com-

pounds. If a compound or mixture is not found, then one uses the recipe for δ given in Ref. 22 (repeated in Ref. 5), and calculates $\langle I \rangle$ according to the discussion in Ref. 10. (Note the "13%" rule!)

30.2.9. Ionization yields: Physicists frequently relate total energy loss to the number of ion pairs produced near the particle's track. This relation becomes complicated for relativistic particles due to the wandering of energetic knock-on electrons whose ranges exceed the dimensions of the fiducial volume. For a qualitative appraisal of the nonlocality of energy deposition in various media by such modestly energetic knock-on electrons, see Ref. 31. The mean local energy dissipation per local ion pair produced, W, while essentially constant for relativistic particles, increases at slow particle speeds [32]. For gases, W can be surprisingly sensitive to trace amounts of various contaminants [32]. Furthermore, ionization yields in practical cases may be greatly influenced by such factors as subsequent recombination [33].

30.3. Multiple scattering through small angles

A charged particle traversing a medium is deflected by many small-angle scatters. Most of this deflection is due to Coulomb scattering from nuclei, and hence the effect is called multiple Coulomb scattering. (However, for hadronic projectiles, the strong interactions also contribute to multiple scattering.) The Coulomb scattering distribution is well represented by the theory of Molière [35]. It is roughly Gaussian for small deflection angles, but at larger angles (greater than a few θ_0 , defined below) it behaves like Rutherford scattering, with larger tails than does a Gaussian distribution.

If we define

$$\theta_0 = \theta_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{2}} \theta_{\text{space}}^{\text{rms}}$$
 (30.14)

then it is sufficient for many applications to use a Gaussian approximation for the central 98% of the projected angular distribution, with a width given by [36,37]

$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta cp} z \sqrt{x/X_0} \Big[1 + 0.038 \ln(x/X_0) \Big] . \tag{30.15}$$

Here p, βc , and z are the momentum, velocity, and charge number of the incident particle, and x/X_0 is the thickness of the scattering medium in radiation lengths (defined below). This value of θ_0 is from a fit to Molière distribution for singly charged particles with $\beta=1$ for all Z, and is accurate to 11% or better for $10^{-3} < x/X_0 < 100$.

Eq. (30.15) describes scattering from a single material, while the usual problem involves the multiple scattering of a particle traversing many different layers and mixtures. Since it is from a fit to a Molière distribution, it is incorrect to add the individual θ_0 contributions in quadrature; the result is systematically too small. It is much more accurate to apply Eq. (30.15) once, after finding x and X_0 for the combined scatterer.

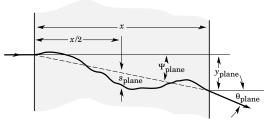


Figure 30.10: Quantities used to describe multiple Coulomb scattering. The particle is incident in the plane of the figure.

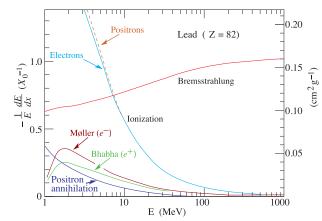


Figure 30.11: Fractional energy loss per radiation length in lead as a function of electron or positron energy. Electron (positron) scattering is considered as ionization when the energy loss per collision is below 0.255 MeV, and as Møller (Bhabha) scattering when it is above. Adapted from Fig. 3.2 from Messel and Crawford, *Electron-Photon Shower Distribution Function Tables for Lead, Copper, and Air Absorbers*, Pergamon Press, 1970. Messel and Crawford use $X_0(\text{Pb}) = 5.82 \text{ g/cm}^2$, but we have modified the figures to reflect the value given in the Table of Atomic and Nuclear Properties of Materials $(X_0(\text{Pb}) = 6.37 \text{ g/cm}^2)$.

The nonprojected (space) and projected (plane) angular distributions are given approximately by [35]

$$\frac{1}{2\pi\,\theta_0^2} \exp\left(-\frac{\theta_{\text{space}}^2}{2\theta_0^2}\right) d\Omega \,, \tag{30.16}$$

$$\frac{1}{\sqrt{2\pi}\,\theta_0} \exp\left(-\frac{\theta_{\text{plane}}^2}{2\theta_0^2}\right) d\theta_{\text{plane}} \,, \tag{30.17}$$

where θ is the deflection angle. In this approximation, $\theta_{\mathrm{space}}^2 \approx (\theta_{\mathrm{plane},x}^2 + \theta_{\mathrm{plane},y}^2)$, where the x and y axes are orthogonal to the direction of motion, and $d\Omega \approx d\theta_{\mathrm{plane},x} \, d\theta_{\mathrm{plane},y}$. Deflections into $\theta_{\mathrm{plane},x}$ and $\theta_{\mathrm{plane},y}$ are independent and identically distributed.

Fig. 30.10 shows these and other quantities sometimes used to describe multiple Coulomb scattering. They are

$$\psi_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} \theta_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} \theta_0 , \qquad (30.18)$$

$$y_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} x \theta_{\text{plane}}^{\text{rms}} = \frac{1}{\sqrt{3}} x \theta_0,$$
 (30.19)

$$s_{\text{plane}}^{\text{rms}} = \frac{1}{4\sqrt{3}} x \theta_{\text{plane}}^{\text{rms}} = \frac{1}{4\sqrt{3}} x \theta_0. \qquad (30.20)$$

All the quantitative estimates in this section apply only in the limit of small $\theta_{\rm plane}^{\rm rms}$ and in the absence of large-angle scatters. The random variables $s,\ \psi,\ y,\$ and θ in a given plane are correlated. Obviously, $y\approx x\psi.$ In addition, y and θ have the correlation coefficient $\rho_{y\theta}=\sqrt{3}/2\approx 0.87.$ For Monte Carlo generation of a joint $(y_{\rm plane},\theta_{\rm plane})$ distribution, or for other calculations, it may be most convenient to work with independent Gaussian random variables (z_1,z_2) with mean zero and variance one, and then set

$$y_{\text{plane}} = z_1 x \theta_0 (1 - \rho_{y\theta}^2)^{1/2} / \sqrt{3} + z_2 \rho_{y\theta} x \theta_0 / \sqrt{3}$$
 (30.21)

$$= z_1 x \theta_0 / \sqrt{12} + z_2 x \theta_0 / 2 ; \qquad (30.22)$$

$$\theta_{\text{plane}} = z_2 \,\theta_0 \,. \tag{30.23}$$

Note that the second term for y_{plane} equals $x \theta_{\text{plane}}/2$ and represents the displacement that would have occurred had the deflection θ_{plane} all occurred at the single point x/2.

For heavy ions the multiple Coulomb scattering has been measured and compared with various theoretical distributions [38].

30.4. Photon and electron interactions in matter

30.4.1. Radiation length: High-energy electrons predominantly lose energy in matter by bremsstrahlung, and high-energy photons by e^+e^- pair production. The characteristic amount of matter traversed for these related interactions is called the radiation length X_0 , usually measured in g cm⁻². It is both (a) the mean distance over which a high-energy electron loses all but 1/e of its energy by bremsstrahlung, and (b) $\frac{7}{9}$ of the mean free path for pair production by a high-energy photon [39]. It is also the appropriate scale length for describing high-energy electromagnetic cascades. X_0 has been calculated and tabulated by Y.S. Tsai [40]:

$$\frac{1}{X_0} = 4\alpha r_e^2 \frac{N_A}{A} \left\{ Z^2 [L_{\rm rad} - f(Z)] + Z L'_{\rm rad} \right\}.$$
 (30.24)

For $A=1~{\rm g~mol^{-1}}$, $4\alpha r_e^2 N_A/A=(716.408~{\rm g~cm^{-2}})^{-1}$. $L_{\rm rad}$ and $L'_{\rm rad}$ are given in Table 30.2. The function f(Z) is an infinite sum, but for elements up to uranium can be represented to 4-place accuracy by

$$f(Z) = a^{2} \left[(1 + a^{2})^{-1} + 0.20206 -0.0369 a^{2} + 0.0083 a^{4} - 0.002 a^{6} \right],$$
 (30.25)

where $a = \alpha Z$ [41].

Table 30.2: Tsai's $L_{\rm rad}$ and $L'_{\rm rad}$, for use in calculating the radiation length in an element using Eq. (30.24).

| Element | Z | L_{rad} | $L'_{ m rad}$ |
|------------------|----|-----------------------|---------------------|
| H | 1 | 5.31 | 6.144 |
| $_{\mathrm{He}}$ | 2 | 4.79 | 5.621 |
| ${ m Li}$ | 3 | 4.74 | 5.805 |
| ${\rm Be}$ | 4 | 4.71 | 5.924 |
| Others | >4 | $\ln(184.15Z^{-1/3})$ | $\ln(1194Z^{-2/3})$ |

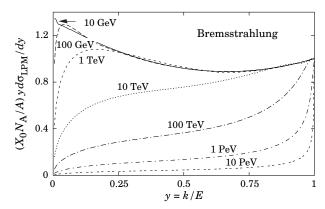


Figure 30.12: The normalized bremsstrahlung cross section $k \, d\sigma_{LPM}/dk$ in lead versus the fractional photon energy y=k/E. The vertical axis has units of photons per radiation length.

The radiation length in a mixture or compound may be approximated by

$$1/X_0 = \sum w_j/X_j , \qquad (30.26)$$

where w_j and X_j are the fraction by weight and the radiation length for the jth element.

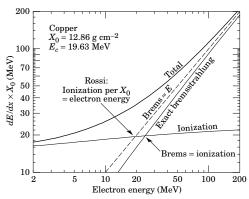


Figure 30.13: Two definitions of the critical energy E_c .

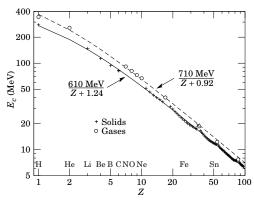


Figure 30.14: Electron critical energy for the chemical elements, using Rossi's definition [2]. The fits shown are for solids and liquids (solid line) and gases (dashed line). The rms deviation is 2.2% for the solids and 4.0% for the gases. (Computed with code supplied by A. Fassó.)

30.4.2. Energy loss by electrons: At low energies electrons and positrons primarily lose energy by ionization, although other processes (Møller scattering, Bhabha scattering, e^+ annihilation) contribute, as shown in Fig. 30.11. While ionization loss rates rise logarithmically with energy, bremsstrahlung losses rise nearly linearly (fractional loss is nearly independent of energy), and dominates above a few tens of MeV in most materials (See Sec. 30.4.3 below.)

Ionization loss by electrons and positrons differ somewhat, and both differ from loss by heavy particles because of the kinematics, spin, and the identity of the incident electron with the electrons which it ionizes. Complete discussions and tables can be found in Refs. 10, 11, and 30.

At very high energies and except at the high-energy tip of the bremsstrahlung spectrum, the cross section can be approximated in the "complete screening case" as [40]

$$d\sigma/dk = (1/k)4\alpha r_e^2 \{ (\frac{4}{3} - \frac{4}{3}y + y^2)[Z^2(L_{\text{rad}} - f(Z)) + ZL'_{\text{rad}}] + \frac{1}{9}(1-y)(Z^2 + Z) \},$$
(30.27)

where y=k/E is the fraction of the electron's energy transfered to the radiated photon. At small y (the "infrared limit") the term on the second line ranges from 1.7% (low Z) to 2.5% (high Z) of the total. If it is ignored and the first line simplified with the definition of X_0 given in Eq. (30.24), we have

$$\frac{d\sigma}{dk} = \frac{A}{X_0 N_A k} \left(\frac{4}{3} - \frac{4}{3} y + y^2\right) . \tag{30.28}$$

This cross section (times k) is shown by the top curve in Fig. 30.12.

This formula is accurate except in near y = 1, where

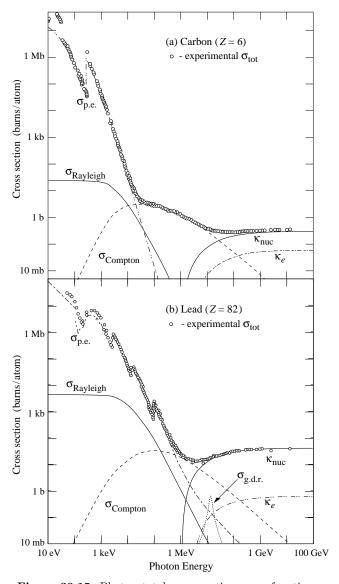


Figure 30.15: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes [48]:

 $\sigma_{\text{p.e.}} = \text{Atomic photoelectric effect (electron ejection, photon absorption)}$

 $\sigma_{\text{Rayleigh}} = \text{Rayleigh (coherent)}$ scattering–atom neither ionized nor excited

 $\sigma_{\text{Compton}} = \text{Incoherent scattering (Compton scattering off an electron)}$

 $\kappa_{\mathrm{nuc}} = \text{Pair production, nuclear field}$

 κ_e = Pair production, electron field

 $\sigma_{\rm g.d.r.}$ = Photonuclear interactions, most notably the Giant Dipole Resonance [49]. In these interactions, the target nucleus is broken up.

Original figures through the courtesy of John H. Hubbell (NIST).

screening may become incomplete, and near y=0, where the infrared divergence is removed by the interference of bremsstrahlung amplitudes from nearby scattering centers (the LPM effect) [42,43] and dielectric suppression [44,45]. These and other suppression effects in bulk media are discussed in Sec. 30.4.5.

With decreasing energy ($E \lesssim 10 \text{ GeV}$) the high-y cross section drops and the curves become rounded as $y \to 1$. Curves of this

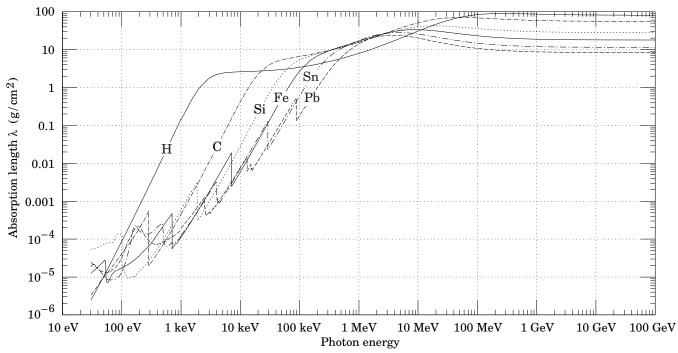


Fig. 30.16: The photon mass attenuation length (or mean free path) $\lambda = 1/(\mu/\rho)$ for various elemental absorbers as a function of photon energy. The mass attenuation coefficient is μ/ρ , where ρ is the density. The intensity I remaining after traversal of thickness t (in mass/unit area) is given by $I = I_0 \exp(-t/\lambda)$. The accuracy is a few percent. For a chemical compound or mixture, $1/\lambda_{\rm eff} \approx \sum_{\rm elements} w_Z/\lambda_Z$, where w_Z is the proportion by weight of the element with atomic number Z. The processes responsible for attenuation are given in Fig. 30.11. Since coherent processes are included, not all these processes result in energy deposition. The data for 30 eV < E < 1 keV are obtained from http://www-cxro.lbl.gov/optical_constants (courtesy of Eric M. Gullikson, LBNL). The data for 1 keV < E < 100 GeV are from http://physics.nist.gov/PhysRefData, through the courtesy of John H. Hubbell (NIST).

familar shape can be seen in Rossi [2] (Figs. 2.11.2,3); see also the review by Koch & Motz [46].

Except at these extremes, and still in the complete-screening approximation, the number of photons with energies between k_{\min} and k_{\max} emitted by an electron travelling a distance $d \ll X_0$ is

$$N_{\gamma} = \frac{d}{X_0} \left[\frac{4}{3} \ln \left(\frac{k_{\text{max}}}{k_{\text{min}}} \right) - \frac{4(k_{\text{max}} - k_{\text{min}})}{3E} + \frac{k_{\text{max}}^2 - k_{\text{min}}^2}{2E^2} \right]. \tag{30.29}$$

30.4.3. Critical energy: An electron loses energy by bremsstrahlung at a rate nearly proportional to its energy, while the ionization loss rate varies only logarithmically with the electron energy. The critical energy E_c is sometimes defined as the energy at which the two loss rates are equal [47]. Among alternate definitions is that of Rossi [2], who defines the critical energy as the energy at which the ionization loss per radiation length is equal to the electron energy. Equivalently, it is the same as the first definition with the approximation $|dE/dx|_{\text{brems}} \approx E/X_0$. This form has been found to describe transverse electromagnetic shower development more accurately (see below). These definitions are illustrated in the case of copper in Fig. 30.13.

The accuracy of approximate forms for E_c has been limited by the failure to distinguish between gases and solid or liquids, where there is a substantial difference in ionization at the relevant energy because of the density effect. We distinguish these two cases in Fig. 30.14. Fits were also made with functions of the form $a/(Z+b)^{\alpha}$, but α was found to be essentially unity. Since E_c also depends on A, I, and other factors, such forms are at best approximate.

Values of E_c for both electrons and positrons in more than 300 materials can be found at pdg.lbl.gov/AtomicNuclearProperties.

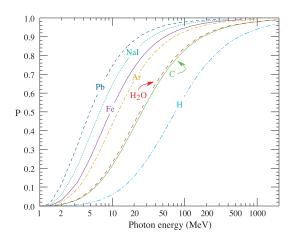


Figure 30.17: Probability P that a photon interaction will result in conversion to an e^+e^- pair. Except for a few-percent contribution from photonuclear absorption around 10 or 20 MeV, essentially all other interactions in this energy range result in Compton scattering off an atomic electron. For a photon attenuation length λ (Fig. 30.16), the probability that a given photon will produce an electron pair (without first Compton scattering) in thickness t of absorber is $P[1 - \exp(-t/\lambda)]$.

30.4.4. Energy loss by photons: Contributions to the photon cross section in a light element (carbon) and a heavy element (lead) are shown in Fig. 30.15. At low energies it is seen that the photoelectric effect dominates, although Compton scattering, Rayleigh scattering, and photonuclear absorption also contribute. The photoelectric cross section is characterized by discontinuities (absorption edges) as thresholds for photoionization of various atomic levels are reached. Photon attenuation lengths for a variety of elements are shown in Fig. 30.16, and data for $30~{\rm eV} < k < 100~{\rm GeV}$ for all elements is available from the web pages given in the caption. Here k is the photon energy.

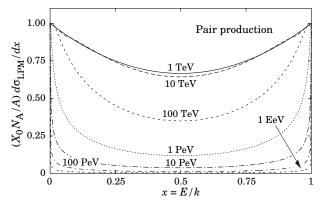


Figure 30.18: The normalized pair production cross section $d\sigma_{LPM}/dy$, versus fractional electron energy x=E/k.

The increasing domination of pair production as the energy increases is shown in Fig. 30.17. Using approximations similar to those used to obtain Eq. (30.28), Tsai's formula for the differential cross section [40] reduces to

$$\frac{d\sigma}{dx} = \frac{A}{X_0 N_A} \left[1 - \frac{4}{3} x (1 - x) \right]$$
 (30.30)

in the complete-screening limit valid at high energies. Here x=E/k is the fractional energy transfer to the pair-produced electron (or positron), and k is the incident photon energy. The cross section is very closely related to that for bremsstrahlung, since the Feynman diagrams are variants of one another. The cross section is of necessity symmetric between x and 1-x, as can be seen by the solid curve in Fig. 30.18. See the review by Motz, Olsen, & Koch for a more detailed treatment [50].

Eq. (30.30) may be integrated to find the high-energy limit for the total e^+e^- pair-production cross section:

$$\sigma = \frac{7}{9}(A/X_0N_A) \ . \tag{30.31}$$

Equation Eq. (30.31) is accurate to within a few percent down to energies as low as 1 GeV, particularly for high-Z materials.

30.4.5. Bremsstrahlung and pair production at very high energies: At ultrahigh energies, Eqns. 30.27–30.31 will fail because of quantum mechanical interference between amplitudes from different scattering centers. Since the longitudinal momentum transfer to a given center is small ($\propto k/E(E-k)$, in the case of bremsstrahlung), the interaction is spread over a comparatively long distance called the formation length ($\propto E(E-k)/k$) via the uncertainty principle. In alternate language, the formation length is the distance over which the highly relativistic electron and the photon "split apart." The interference is usually destructive. Calculations of the "Landau-Pomeranchuk-Migdal" (LPM) effect may be made semi-classically based on the average multiple scattering, or more rigorously using a quantum transport approach [42,43].

In amorphous media, bremsstrahlung is suppressed if the photon energy k is less than $E^2/(E+E_{LPM})$ [43], where*

$$E_{LPM} = \frac{(m_e c^2)^2 \alpha X_0}{4\pi\hbar c\rho} = (7.7 \text{ TeV/cm}) \times \frac{X_0}{\rho} .$$
 (30.32)

Since physical distances are involved, X_0/ρ , in cm, appears. The energy-weighted bremsstrahlung spectrum for lead, $k\,d\sigma_{LPM}/dk$, is shown in Fig. 30.12. With appropriate scaling by X_0/ρ , other materials behave similarly.

For photons, pair production is reduced for $E(k-E) > k E_{LPM}$. The pair-production cross sections for different photon energies are shown in Fig. 30.18.

If $k \ll E$, several additional mechanisms can also produce suppression. When the formation length is long, even weak factors can perturb the interaction. For example, the emitted photon can coherently forward scatter off of the electrons in the media. Because of this, for $k < \omega_p E/m_e \sim 10^{-4}$, bremsstrahlung is suppressed by a factor $(km_e/\omega_p E)^2$ [45]. Magnetic fields can also suppress bremsstrahlung.

In crystalline media, the situation is more complicated, with coherent enhancement or suppression possible. The cross section depends on the electron and photon energies and the angles between the particle direction and the crystalline axes [52].

30.4.6. Photonuclear and electronuclear interactions at still higher energies: At still higher photon and electron energies, where the bremsstrahlung and pair production cross-sections are heavily suppressed by the LPM effect, photonuclear and electronuclear interactions predominate over electromagnetic interactions.

At photon energies above about 10^{20} eV, for example, photons usually interact hadronically. The exact cross-over energy depends on the model used for the photonuclear interactions. At still higher energies ($\gtrsim 10^{23}$ eV), photonuclear interactions can become coherent, with the photon interaction spread over multiple nuclei. Essentially, the photon coherently converts to a ρ^0 , in a process that is somewhat similar to kaon regeneration [53]. These processes are illustrated in Fig. 30.19.

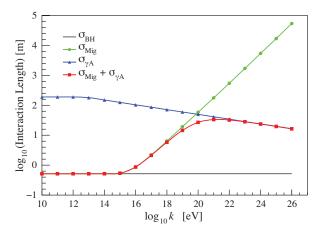


Figure 30.19: Interaction length for a photon in ice as a function of photon energy for the Bethe-Heitler (BH), LPM (Mig) and photonuclear (γA) cross sections [53]. The Bethe-Heitler interaction length is $9X_0/7$, and X_0 is 0.393 m in ice.

Similar processes occur for electrons. As electron energies increase and the LPM effect suppresses bremsstrahlung,

^{*} This definition differs from that of Ref. 51 by a factor of two. E_{LPM} scales as the 4th power of the mass of the incident particle, so that $E_{LPM} = (1.4 \times 10^{10} \text{ TeV/cm}) \times X_0/\rho$ for a muon.

electronuclear interactions become more important. At energies above 10^{21} eV, these electronuclear interactions dominate electron energy loss [53].

30.5. Electromagnetic cascades

When a high-energy electron or photon is incident on a thick absorber, it initiates an electromagnetic cascade as pair production and bremsstrahlung generate more electrons and photons with lower energy. The longitudinal development is governed by the high-energy part of the cascade, and therefore scales as the radiation length in the material. Electron energies eventually fall below the critical energy, and then dissipate their energy by ionization and excitation rather than by the generation of more shower particles. In describing shower behavior, it is therefore convenient to introduce the scale variables

$$t = x/X_0$$
, $y = E/E_c$, (30.33)

so that distance is measured in units of radiation length and energy in units of critical energy.

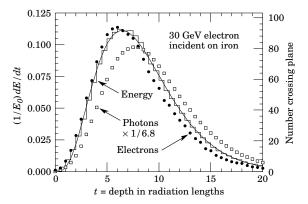


Figure 30.20: An EGS4 simulation of a 30 GeV electroninduced cascade in iron. The histogram shows fractional energy deposition per radiation length, and the curve is a gamma-function fit to the distribution. Circles indicate the number of electrons with total energy greater than 1.5 MeV crossing planes at $X_0/2$ intervals (scale on right) and the squares the number of photons with $E \geq 1.5$ MeV crossing the planes (scaled down to have same area as the electron distribution).

Longitudinal profiles from an EGS4 [54] simulation of a 30 GeV electron-induced cascade in iron are shown in Fig. 30.20. The number of particles crossing a plane (very close to Rossi's Π function [2]) is sensitive to the cutoff energy, here chosen as a total energy of 1.5 MeV for both electrons and photons. The electron number falls off more quickly than energy deposition. This is because, with increasing depth, a larger fraction of the cascade energy is carried by photons. Exactly what a calorimeter measures depends on the device, but it is not likely to be exactly any of the profiles shown. In gas counters it may be very close to the electron number, but in glass Cherenkov detectors and other devices with "thick" sensitive regions it is closer to the energy deposition (total track length). In such detectors the signal is proportional to the "detectable" track length T_d , which is in general less than the total track length T. Practical devices are sensitive to electrons with energy above some detection threshold E_d , and $T_d = T F(E_d/E_c)$. An analytic form for $F(E_d/E_c)$ obtained by Rossi [2] is given by Fabjan [55]; see also Amaldi [56]

The mean longitudinal profile of the energy deposition in an electromagnetic cascade is reasonably well described by a gamma

distribution [57]:

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$
(30.34)

The maximum t_{max} occurs at (a-1)/b. We have made fits to shower profiles in elements ranging from carbon to uranium, at energies from 1 GeV to 100 GeV. The energy deposition profiles are well described by Eq. (30.34) with

$$t_{\text{max}} = (a-1)/b = 1.0 \times (\ln y + C_i), \qquad j = e, \gamma, \quad (30.35)$$

where $C_e=-0.5$ for electron-induced cascades and $C_\gamma=+0.5$ for photon-induced cascades. To use Eq. (30.34), one finds (a-1)/b from Eq. (30.35) and Eq. (30.33), then finds a either by assuming $b\approx 0.5$ or by finding a more accurate value from Fig. 30.21. The results are very similar for the electron number profiles, but there is some dependence on the atomic number of the medium. A similar form for the electron number maximum was obtained by Rossi in the context of his "Approximation B," [2] (see Fabjan's review in Ref. 55), but with $C_e=-1.0$ and $C_\gamma=-0.5$; we regard this as superseded by the EGS4 result.

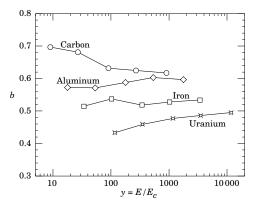


Figure 30.21: Fitted values of the scale factor b for energy deposition profiles obtained with EGS4 for a variety of elements for incident electrons with $1 \le E_0 \le 100$ GeV. Values obtained for incident photons are essentially the same.

The "shower length" $X_s = X_0/b$ is less conveniently parameterized, since b depends upon both Z and incident energy, as shown in Fig. 30.21. As a corollary of this Z dependence, the number of electrons crossing a plane near shower maximum is underestimated using Rossi's approximation for carbon and seriously overestimated for uranium. Essentially the same b values are obtained for incident electrons and photons. For many purposes it is sufficient to take $b \approx 0.5$.

The length of showers initiated by ultra-high energy photons and electrons is somewhat greater than at lower energies since the first or first few interaction lengths are increased via the mechanisms discussed above.

The gamma function distribution is very flat near the origin, while the EGS4 cascade (or a real cascade) increases more rapidly. As a result Eq. (30.34) fails badly for about the first two radiation lengths; it was necessary to exclude this region in making fits.

Because fluctuations are important, Eq. (30.34) should be used only in applications where average behavior is adequate. Grindhammer *et al.* have developed fast simulation algorithms in which the variance and correlation of a and b are obtained by fitting Eq. (30.34) to individually simulated cascades, then generating profiles for cascades using a and b chosen from the correlated distributions [58].

The transverse development of electromagnetic showers in different materials scales fairly accurately with the *Molière radius* R_M , given by [59,60]

$$R_M = X_0 E_s / E_c , (30.36)$$

where $E_s \approx 21$ MeV (Table 30.1), and the Rossi definition of E_c is used.

In a material containing a weight fraction w_j of the element with critical energy E_{cj} and radiation length X_j , the Molière radius is given by

$$\frac{1}{R_M} = \frac{1}{E_s} \sum \frac{w_j E_{cj}}{X_j} \ . \tag{30.37}$$

Measurements of the lateral distribution in electromagnetic cascades are shown in Refs. 59 and 60. On the average, only 10% of the energy lies outside the cylinder with radius R_M . About 99% is contained inside of $3.5R_M$, but at this radius and beyond composition effects become important and the scaling with R_M fails. The distributions are characterized by a narrow core, and broaden as the shower develops. They are often represented as the sum of two Gaussians, and Grindhammer [58] describes them with the function

$$f(r) = \frac{2r\,R^2}{(r^2 + R^2)^2}\;, \tag{30.38}$$

where R is a phenomenological function of x/X_0 and $\ln E$.

At high enough energies, the LPM effect (Sec. 30.4.5) reduces the cross sections for bremsstrahlung and pair production, and hence can cause significant elongation of electromagnetic cascades [43].

30.6. Muon energy loss at high energy

At sufficiently high energies, radiative processes become more important than ionization for all charged particles. For muons and pions in materials such as iron, this "critical energy" occurs at several hundred GeV. (There is no simple scaling with particle mass, but for protons the "critical energy" is much, much higher.) Radiative effects dominate the energy loss of energetic muons found in cosmic rays or produced at the newest accelerators. These processes are characterized by small cross sections, hard spectra, large energy fluctuations, and the associated generation of electromagnetic and (in the case of photonuclear interactions) hadronic showers [61–69]. As a consequence, at these energies the treatment of energy loss as a uniform and continuous process is for many purposes inadequate.

It is convenient to write the average rate of muon energy loss as [70]

$$-dE/dx = a(E) + b(E) E. (30.39)$$

Here a(E) is the ionization energy loss given by Eq. (30.4), and b(E) is the sum of e^+e^- pair production, bremsstrahlung, and photonuclear contributions. To the approximation that these slowly-varying functions are constant, the mean range x_0 of a muon with initial energy E_0 is given by

$$x_0 \approx (1/b) \ln(1 + E_0/E_{\mu c})$$
, (30.40)

where $E_{\mu c} = a/b$. Fig. 30.22 shows contributions to b(E) for iron. Since $a(E) \approx 0.002 \text{ GeV g}^{-1} \text{ cm}^2$, b(E)E dominates the energy loss above several hundred GeV, where b(E) is nearly constant. The rates of energy loss for muons in hydrogen, uranium, and iron are shown in Fig. 30.23 [5].

The "muon critical energy" $E_{\mu c}$ can be defined more exactly as the energy at which radiative and ionization losses are equal, and can be found by solving $E_{\mu c} = a(E_{\mu c})/b(E_{\mu c})$. This definition corresponds to the solid-line intersection in Fig. 30.13, and is different from the Rossi definition we used for electrons. It serves the same function: below $E_{\mu c}$ ionization losses dominate, and above $E_{\mu c}$ radiative effects dominate. The dependence of $E_{\mu c}$ on atomic number Z is shown in Fig. 30.24.

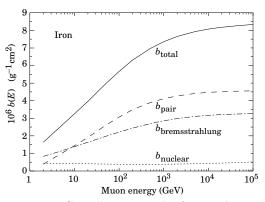


Figure 30.22: Contributions to the fractional energy loss by muons in iron due to e^+e^- pair production, bremsstrahlung, and photonuclear interactions, as obtained from Groom *et al.* [5] except for post-Born corrections to the cross section for direct pair production from atomic electrons.

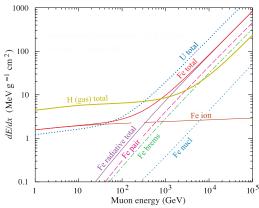


Figure 30.23: The average energy loss of a muon in hydrogen, iron, and uranium as a function of muon energy. Contributions to dE/dx in iron from ionization and the processes shown in Fig. 30.22 are also shown.

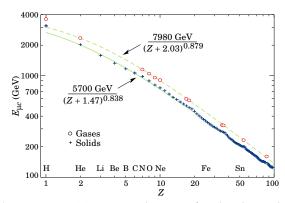


Figure 30.24: Muon critical energy for the chemical elements, defined as the energy at which radiative and ionization energy loss rates are equal [5]. The equality comes at a higher energy for gases than for solids or liquids with the same atomic number because of a smaller density effect reduction of the ionization losses. The fits shown in the figure exclude hydrogen. Alkali metals fall 3–4% above the fitted function, while most other solids are within 2% of the function. Among the gases the worst fit is for radon (2.7% high).

The radiative cross sections are expressed as functions of the fractional energy loss ν . The bremsstrahlung cross section goes roughly as $1/\nu$ over most of the range, while for the pair production case the distribution goes as ν^{-3} to ν^{-2} "Hard" losses are therefore more probable in bremsstrahlung, and in fact energy losses due to pair production may very nearly be treated as continuous. The simulated [69] momentum distribution of an incident 1 TeV/c muon beam after it crosses 3 m of iron is shown in Fig. 30.25. The most probable loss is 8 GeV, or 3.4 MeV $\rm g^{-1}cm^2.$ The full width at half maximum is 9 GeV/c, or 0.9%. The radiative tail is almost entirely due to bremsstrahlung, although most of the events in which more than 10% of the incident energy lost experienced relatively hard photonuclear interactions. The latter can exceed detector resolution [72], necessitating the reconstruction of lost energy. Tables [5] list the stopping power as $9.82 \text{ MeV g}^{-1}\text{cm}^2$ for a 1 TeV muon, so that the mean loss should be 23 GeV ($\approx 23 \text{ GeV}/c$), for a final momentum of 977 GeV/c, far below the peak. This agrees with the indicated mean calculated from the simulation. Electromagnetic and hadronic cascades in detector materials can obscure muon tracks in detector planes and reduce tracking efficiency [73].

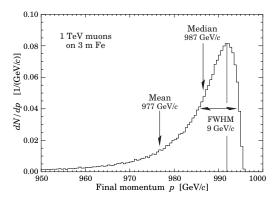


Figure 30.25: The momentum distribution of 1 TeV/c muons after traversing 3 m of iron as calculated with the MARS15 Monte Carlo code [69] by S.I. Striganov [5].

30.7. Cherenkov and transition radiation [74,75,34]

A charged particle radiates if its velocity is greater than the local phase velocity of light (Cherenkov radiation) or if it crosses suddenly from one medium to another with different optical properties (transition radiation). Neither process is important for energy loss, but both are used in high-energy and cosmic-ray physics detectors.

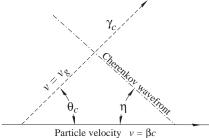


Figure 30.26: Cherenkov light emission and wavefront angles. In a dispersive medium, $\theta_c + \eta \neq 90^0$.

30.7.1. Optical Cherenkov radiation: The angle θ_c of Cherenkov radiation, relative to the particle's direction, for a particle with velocity βc in a medium with index of refraction n is

$$\begin{array}{ll} \cos\theta_c = (1/n\beta) \\ \text{or} & \tan\theta_c = \sqrt{\beta^2 n^2 - 1} \\ & \approx \sqrt{2(1-1/n\beta)} & \text{for small $\theta_c, e.g. in gas} \text{(30.41)} \end{array}$$

The threshold velocity β_t is 1/n, and $\gamma_t = 1/(1-\beta_t^2)^{1/2}$. Therefore, $\beta_t \gamma_t = 1/(2\delta + \delta^2)^{1/2}$, where $\delta = n-1$. Values of δ for various commonly used gases are given as a function of pressure and wavelength in Ref. 76. For values at atmospheric pressure, see Table 6.1. Data for other commonly used materials are given in Ref. 77.

Practical Cherenkov radiator materials are dispersive. Let ω be the photon's frequency, and let $k=2\pi/\lambda$ be its wavenumber. The photons propage at the group velocity $v_g=d\omega/dk=c/[n(\omega)+\omega(dn/d\omega)]$. In a non-dispersive medium, this simplies to $v_g=c/n$.

In his classical paper, Tamm [78] showed that for dispersive media the radiation is concentrated in a thin conical shell whose vertex is at the moving charge, and whose opening half-angle η is given by

$$\cot \eta = \left[\frac{d}{d\omega} (\omega \tan \theta_c) \right]_{\omega_0}$$

$$= \left[\tan \theta_c + \beta^2 \omega \, n(\omega) \, \frac{dn}{d\omega} \cot \theta_c \right]_{\omega_0} , \qquad (30.42)$$

where ω_0 is the central value of the small frequency range under consideration. (See Fig. 30.26.) This cone has a opening half-angle η , and, unless the medium is non-dispersive $(dn/d\omega = 0)$, $\theta_c + \eta \neq 90^0$. The Cherenkov wavefront 'sideslips' along with the particle [79]. This effect may have timing implications for ring imaging Cherenkov counters [80], but it is probably unimportant for most applications.

The number of photons produced per unit path length of a particle with charge ze and per unit energy interval of the photons is

$$\frac{d^2N}{dEdx} = \frac{\alpha z^2}{\hbar c} \sin^2 \theta_c = \frac{\alpha^2 z^2}{r_e m_e c^2} \left(1 - \frac{1}{\beta^2 n^2(E)} \right)$$

$$\approx 370 \sin^2 \theta_c(E) \text{ eV}^{-1} \text{cm}^{-1} \qquad (z = 1) , (30.43)$$

or, equivalently,

$$\frac{d^2N}{dxd\lambda} = \frac{2\pi\alpha z^2}{\lambda^2} \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right) . \tag{30.44}$$

The index of refraction n is a function of photon energy $E=\hbar\omega$, as is the sensitivity of the transducer used to detect the light. For practical use, Eq. (30.43) must be multiplied by the the transducer response function and integrated over the region for which $\beta\,n(\omega)>1$. Further details are given in the discussion of Cherenkov detectors in the Particle Detectors section (Sec. 31 of this Review).

When two particles are close together (lateral separation $\lesssim 1$ wavelength), the electromagnetic fields from the particles may add coherently, affecting the Cherenkov radiation. Because of their opposite charges, the radiation from an e^+e^- pair at close separation is suppressed compared to two independent leptons [81].

30.7.2. Coherent radio Cherenkov radiation:

Coherent Cherenkov radiation is produced by many charged particles with a non-zero net charge moving through matter on an approximately common "wavefront"—for example, the electrons and positrons in a high-energy electromagnetic cascade. The signals can be visible above backgrounds for shower energies as low as 10^{17} eV; see Sec. 32.3.2 for more details. The

phenomenon is called the Askaryan effect [82]. Near the end of a shower, when typical particle energies are below E_c (but still relativistic), a charge imbalance develops. The photons can Compton-scatter atomic electrons, and positrons can annihilate with atomic electrons to contribute even more photons which can in turn Compton scatter. These processes result in a roughly 20% excess of electrons over positrons in a shower. The net negative charge leads to coherent radio Cherenkov emission. The radiation includes a component from the decellerating charges (as in bremsstrahlung). Because the emission is coherent, the electric field strength is proportional to the shower energy and the signal power increases as its square. The electric field strength also increases linearly with frequency, up to a maximum frequency determined by the lateral spread of the shower. This cutoff occurs at about 1 GHz in ice, and scales inversely with the Moliere radius. At low frequencies, the radiation is roughly isotropic, but, as the frequency rises toward the cutoff frequency, the radiation becomes increasingly peaked around the Cherenkov angle. The radiation is linearly polarized in the plane containing the shower axis and the photon direction. A measurement of the signal polarization can be used to help determine the shower direction. The characteristics of this radiation have been nicely demonstrated in a series of experiments at SLAC [83]. A detailed discussion of the radiation can be found in Ref. 84.

30.7.3. Transition radiation: The energy radiated when a particle with charge ze crosses the boundary between vacuum and a medium with plasma frequency ω_p is

$$I = \alpha z^2 \gamma \hbar \omega_p / 3 , \qquad (30.45)$$

where

$$\hbar\omega_p = \sqrt{4\pi N_e r_e^3} \ m_e c^2/\alpha = \sqrt{\rho \ (\text{in g/cm}^3) \ \langle Z/A \rangle} \times 28.81 \ \text{eV} \ .$$
(30.46)

For styrene and similar materials, $\hbar\omega_p\approx 20$ eV; for air it is 0.7 eV.

The number spectrum $dN_{\gamma}/d(\hbar\omega)$ diverges logarithmically at low energies and decreases rapidly for $\hbar\omega/\gamma\hbar\omega_p>1$. About half the energy is emitted in the range $0.1\leq\hbar\omega/\gamma\hbar\omega_p\leq1$. Inevitable absorption in a practical detector removes the divergence. For a particle with $\gamma=10^3$, the radiated photons are in the soft x-ray range 2 to 40 keV. The γ dependence of the emitted energy thus comes from the hardening of the spectrum rather than from an increased quantum yield.

The number of photons with energy $\hbar\omega > \hbar\omega_0$ is given by the answer to problem 13.15 in Ref. 34,

$$N_{\gamma}(\hbar\omega > \hbar\omega_0) = \frac{\alpha z^2}{\pi} \left[\left(\ln \frac{\gamma \hbar \omega_p}{\hbar\omega_0} - 1 \right)^2 + \frac{\pi^2}{12} \right] , \qquad (30.47)$$

within corrections of order $(\hbar\omega_0/\gamma\hbar\omega_p)^2$. The number of photons above a fixed energy $\hbar\omega_0\ll\gamma\hbar\omega_p$ thus grows as $(\ln\gamma)^2$, but the number above a fixed fraction of $\gamma\hbar\omega_p$ (as in the example above) is constant. For example, for $\hbar\omega>\gamma\hbar\omega_p/10$, $N_\gamma=2.519\,\alpha z^2/\pi=0.59\%\times z^2$.

The particle stays "in phase" with the x ray over a distance called the formation length, $d(\omega)$. Most of the radiation is produced in a distance $d(\omega) = (2c/\omega)(1/\gamma^2 + \theta^2 + \omega_p^2/\omega^2)^{-1}$. Here θ is the x-ray emission angle, characteristically $1/\gamma$. For $\theta = 1/\gamma$ the formation length has a maximum at $d(\gamma\omega_p/\sqrt{2}) = \gamma c/\sqrt{2}\omega_p$. In practical situations it is tens of μ m.

Since the useful x-ray yield from a single interface is low, in practical detectors it is enhanced by using a stack of N foil radiators—foils L thick, where L is typically several formation lengths—separated by gas-filled gaps. The amplitudes at successive interfaces interfere to cause oscillations about the single-interface spectrum. At increasing frequencies above the position of the last interference maximum $(L/d(w) = \pi/2)$, the formation zones, which have opposite phase, overlap more and

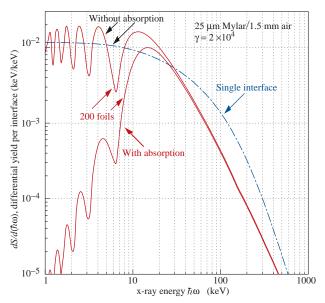


Figure 30.27: X-ray photon energy spectra for a radiator consisting of 200 $25 \,\mu\mathrm{m}$ thick foils of Mylar with 1.5 mm spacing in air (solid lines) and for a single surface (dashed line). Curves are shown with and without absorption. Adapted from Ref. 85.

more and the spectrum saturates, $dI/d\omega$ approaching zero as $L/d(\omega) \rightarrow 0$. This is illustrated in Fig. 30.27 for a realistic detector configuration.

For regular spacing of the layers fairly complicated analytic solutions for the intensity have been obtained [85]. (See also Ref. 86 and references therein.) Although one might expect the intensity of coherent radiation from the stack of foils to be proportional to N^2 , the angular dependence of the formation length conspires to make the intensity $\propto N$.

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31.1. Introduction

This review summarizes the detector technologies employed at accelerator particle physics experiments. Several of these detectors are also used in a non-accelerator context and examples of such applications will be provided. The detector techniques which are specific to non-accelerator particle physics experiments are the subject of Chap. 32. More detailed discussions of detectors and their underlying physics can be found in books by Ferbel [1], Kleinknecht [2], Knoll [3], Green [4], Leroy & Rancoita [5], and Grupen [6].

In Table 31.1 are given typical resolutions and deadtimes of common charged particle detectors. The quoted numbers are usually based on typical devices, and should be regarded only as rough approximations for new designs. The spatial resolution refers to the intrinsic detector resolution, i.e. without multiple scattering. We note that analog detector readout can provide better spatial resolution than digital readout by measuring the deposited charge in neighboring channels. Quoted ranges attempt to be representative of both possibilities. The time resolution is defined by how accurately the time at which a particle crossed the detector can be determined. The deadtime is the minimum separation in time between two resolved hits on the same channel. Typical performance of calorimetry and particle identification are provided in the relevant sections below.

Table 31.1: Typical resolutions and deadtimes of common charged particle detectors. Revised November 2011.

| Detector Type | Intrinsinc Spatial Resolution (rms) | | Dead Time |
|-----------------------------|----------------------------------------|------------------------------|-----------------------------|
| Resistive plate chamber | $\lesssim 10 \text{ mm}$ | 1-2 ns | |
| Streamer chamber | $300 \; \mu {\rm m}^{a}$ | $2 \mu s$ | 100 ms |
| Liquid argon drift [7] | ${\sim}175450~\mu\mathrm{m}$ | $\sim 200~\mathrm{ns}$ | $\sim 2~\mu \mathrm{s}$ |
| Scintillation tracker | $\sim 100 \ \mu \mathrm{m}$ | $100 \text{ ps}/n^{b}$ | 10 ns |
| Bubble chamber | $10150~\mu\mathrm{m}$ | 1 ms | 50 ms^c |
| Proportional chamber | $50-100 \ \mu \text{m}^d$ | 2 ns | $20\mbox{-}200~\mathrm{ns}$ |
| Drift chamber | 50–100 $\mu \mathrm{m}$ | 2 ns^e | $20\text{-}100~\mathrm{ns}$ |
| Micro-pattern gas detectors | $3040~\mu\mathrm{m}$ | $<10~\rm ns$ | $10\text{-}100~\mathrm{ns}$ |
| Silicon strip | $pitch/(3 to 7)^f$ | ${\rm few}~{\rm ns}^g$ | $\lesssim 50~\mathrm{ns}^g$ |
| Silicon pixel | $\lesssim 10 \ \mu \mathrm{m}$ | few $\mathbf{n}\mathbf{s}^g$ | $\lesssim 50 \text{ ns}^g$ |
| Emulsion | $1~\mu\mathrm{m}$ | _ | _ |

- ^a 300 μ m is for 1 mm pitch (wirespacing/ $\sqrt{12}$).
- b = n = index of refraction.
- ^c Multiple pulsing time.
- d Delay line cathode readout can give $\pm 150~\mu\mathrm{m}$ parallel to a node wire.
- e For two chambers.
- f The highest resolution ("7") is obtained for small-pitch detectors ($\lesssim \! 25~\mu \mathrm{m})$ with pulse-height-weighted center finding.
- ^g Limited by the readout electronics [8].

31.2. Photon detectors

Updated August 2011 by D. Chakraborty (Northern Illinois U) and T. Sumiyoshi (Tokyo Metro U).

Most detectors in high-energy, nuclear, and astrophysics rely on the detection of photons in or near the visible range, $100\,\mathrm{nm}\lesssim\lambda\lesssim1000\,\mathrm{nm},$ or $E\approx$ a few eV. This range covers scintillation and Cherenkov radiation as well as the light detected in many astronomical observations.

Generally, photodetection involves generating a detectable electrical signal proportional to the (usually very small) number of incident photons. The process involves three distinct steps:

- Generation of a primary photoelectron or electron-hole (e-h) pair by an incident photon by the photoelectric or photoconductive effect,
- Amplification of the p.e. signal to detectable levels by one or more multiplicative bombardment steps and/or an avalanche process (usually), and,

- 3. Collection of the secondary electrons to form the electrical signal.

 The important characteristics of a photodetector include the following in statistical averages:
- 1. Quantum efficiency (QE or ϵ_Q): the number of primary photoelectrons generated per incident photon ($0 \le \epsilon_Q \le 1$; in silicon more than one e-h pair per incident photon can be generated for $\lambda \lesssim 165$ nm),
- 2. Collection efficiency (CE or ϵ_C): the overall acceptance factor other than the generation of photoelectrons ($0 \le \epsilon_C \le 1$),
- Gain (G): the number of electrons collected for each photoelectron generated.
- 4. Dark current or dark noise: the electrical signal when there is no photon,
- 5. Energy resolution: electronic noise (ENC or N_e) and statistical fluctuations in the amplification process compound the Poisson distribution of n_{γ} photons from a given source:

$$\frac{\sigma(E)}{\langle E \rangle} = \sqrt{\frac{f_N}{n_{\gamma} \epsilon_O \epsilon_C} + \left(\frac{N_e}{G n_{\gamma} \epsilon_O \epsilon_C}\right)^2},$$
 (31.1)

where f_N , or the excess noise factor (ENF), is the contribution to the energy distribution variance due to amplification statistics [9],

- 6. Dynamic range: the maximum signal available from the detector (this is usually expressed in units of the response to noise-equivalent power, or NEP, which is the optical input power that produces a signal-to-noise ratio of 1).
- 7. Time dependence of the response: this includes the transit time, which is the time between the arrival of the photon and the electrical pulse, and the transit time spread, which contributes to the pulse rise time and width, and
- Rate capability: inversely proportional to the time needed, after the arrival of one photon, to get ready to receive the next.

requirements, power consumption, calibration needs, aging, cost, and so on. Several technologies employing different phenomena for the three steps described above, and many variants within each, offer a wide range of solutions to choose from. The salient features of the main technologies and the common variants are described below. Some key characteristics are summarized in Table 31.2.

31.2.1. Vacuum photodetectors: Vacuum photodetectors can be broadly subdivided into three types: photomultiplier tubes, microchannel plates, and hybrid photodetectors.

31.2.1.1. Photomultiplier tubes: A versatile class of photon detectors, vacuum photomultiplier tubes (PMT) has been employed by a vast majority of all particle physics experiments to date [9]. Both "transmission-" and "reflection-type" PMT's are widely used. In the former, the photocathode material is deposited on the inside of a transparent window through which the photons enter, while in the latter, the photocathode material rests on a separate surface that the incident photons strike. The cathode material has a low work function, chosen for the wavelength band of interest. When a photon hits the cathode and liberates an electron (the photoelectric effect), the latter is accelerated and guided by electric fields to impinge on a secondary-emission electrode, or dynode, which then emits a few (~ 5) secondary electrons. The multiplication process is repeated typically 10 times in series to generate a sufficient number of electrons, which are collected at the anode for delivery to the external circuit. The total gain of a PMT depends on the applied high voltage V as $G = AV^{kn}$, where $k \approx 0.7-0.8$ (depending on the dynode material), n is the number of dynodes in the chain, and A a constant (which also depends on n). Typically, G is in the range of 10^5 – 10^6 . Pulse risetimes are usually in the few nanosecond range. With e.g. two-level discrimination the effective time resolution can be much better.

Table 31.2: Representative characteristics of some photodetectors commonly used in particle physics. The time resolution of the devices listed here vary in the 10–2000 ps range.

| Туре | λ (nm) | $\epsilon_Q \epsilon_C$ | Gain | Risetime (ns) | Area (mm ²) | 1-p.e noise (Hz) | HV (V) | Price (USD) |
|----------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| PMT* MCP* HPD* GPM* APD PPD VLPC | 115-1700 100-650 115-850 115-500 300-1700 320-900 500-600 | $\begin{array}{c} 0.150.25 \\ 0.010.10 \\ 0.10.3 \\ 0.150.3 \\ \sim 0.7 \\ 0.150.3 \\ \sim 0.9 \end{array}$ | $10^{3}-10^{7}$ $10^{3}-10^{7}$ $10^{3}-10^{4}$ $10^{3}-10^{6}$ $10-10^{8}$ $10^{5}-10^{6}$ $\sim 5 \times 10^{4}$ | $0.7-10 \\ 0.15-0.3 \\ 7 \\ O(0.1) \\ O(1) \\ \sim 1 \\ \sim 10$ | $ \begin{array}{c} 10^2 - 10^5 \\ 10^2 - 10^4 \\ 10^2 - 10^5 \\ O(10) \\ 10 - 10^3 \\ 1 - 10 \\ 1 \end{array} $ | $ \begin{array}{c} 10-10^4 \\ 0.1-200 \\ 10-10^3 \\ 10-10^3 \\ 1-10^3 \\ O(10^6) \\ O(10^4) \end{array} $ | $500-3000$ $500-3500$ $\sim 2 \times 10^{4}$ $300-2000$ $400-1400$ $30-60$ ~ 7 | $\begin{array}{c} 100-5000 \\ 10-6000 \\ \sim 600 \\ O(10) \\ O(100) \\ O(100) \\ \sim 1 \end{array}$ |

^{*}These devices often come in multi-anode configurations. In such cases, area, noise, and price are to be considered on a "per readout-channel" basis.

The QE is a strong function of the photon wavelength (λ) , and is usually quoted at maximum, together with a range of λ where the QE is comparable to its maximum. Spatial uniformity and linearity with respect to the number of photons are highly desirable in a photodetector's response.

Optimization of these factors involves many trade-offs and vary widely between applications. For example, while a large gain is desirable, attempts to increase the gain for a given device also increases the ENF and after-pulsing ("echos" of the main pulse). In solid-state devices, a higher QE often requires a compromise in the timing properties. In other types, coverage of large areas by focusing increases the transit time spread.

Other important considerations also are highly application-specific. These include the photon flux and wavelength range, the total area to be covered and the efficiency required, the volume available to accommodate the detectors, characteristics of the environment such as chemical composition, temperature, magnetic field, ambient background, as well as ambient radiation of different types and, mode of operation (continuous or triggered), bias (high-voltage)

A large variety of PMT's, including many just recently developed, covers a wide span of wavelength ranges from infrared (IR) to extreme ultraviolet (XUV) [10]. They are categorized by the window materials, photocathode materials, dynode structures, anode configurations, etc. Common window materials are borosilicate glass for IR to near-UV. fused quartz and sapphire (Al₂O₃) for UV, and MgF₂ or LiF for XUV. The choice of photocathode materials include a variety of mostly Csand/or Sb-based compounds such as CsI, CsTe, bi-alkali (SbRbCs, SbKCs), multi-alkali (SbNa₂KCs), GaAs(Cs), GaAsP, etc. Sensitive wavelengths and peak quantum efficiencies for these materials are summarized in Table 31.3. Typical dynode structures used in PMT's are circular cage, line focusing, box and grid, venetian blind, and fine mesh. In some cases, limited spatial resolution can be obtained by using a mosaic of multiple anodes. Fast PMT's with very large windows—measuring up to 508 mm across—have been developed in recent years for detection of Cherenkov radiation in neutrino experiments such as Super-Kamiokande and KamLAND among many others. Specially prepared low-radioactivity glass is used to make these PMT's, and they are also able to withstand the high pressure of the surrounding liquid.

PMT's are vulnerable to magnetic fields—sometimes even the geomagnetic field causes large orientation-dependent gain changes. A high-permeability metal shield is often necessary. However, proximity-focused PMT's, e.g. the fine-mesh types, can be used even in a high magnetic field (≥ 1 T) if the electron drift direction is parallel to the field. CMS uses custom-made vacuum phototriodes (VPT) mounted on the back face of projective lead tungstate crystals to detect scintillation light in the endcap sections of its electromagnetic calorimeters, which are inside a 3.8 T superconducting solenoid. A VPT employs a single dynode (thus, $G \approx 10$) placed close to the photocathode, and a mesh anode plane between the two, to help it cope with the strong magnetic field, which is not too unfavorably oriented with respect to the photodetector axis in the endcaps (within 25°), but where the radiation level is too high for Avalanche Photodiodes (APD's) like those used in the barrel section.

31.2.1.2. Microchannel plates: A typical Microchannel plate (MCP) photodetector consists of one or more ~2 mm thick glass plates with densely packed $O(10 \mu m)$ -diameter cylindrical holes, or "channels", sitting between the transmission-type photocathode and anode planes, separated by O(1 mm) gaps. Instead of discrete dynodes, the inner surface of each cylindrical tube serves as a continuous dynode for the entire cascade of multiplicative bombardments initiated by a photoelectron. Gain fluctuations can be minimized by operating in a saturation mode, whence each channel is only capable of a binary output, but the sum of all channel outputs remains proportional to the number of photons received so long as the photon flux is low enough to ensure that the probability of a single channel receiving more than one photon during a single time gate is negligible. MCP's are thin, offer good spatial resolution, have excellent time resolution ($\sim 20 \text{ ps}$), and can tolerate random magnetic fields up to 0.1 T and axial fields up to ~ 1 T. However, they suffer from relatively long recovery time per channel and short lifetime. MCP's are widely employed as image-intensifiers, although not so much in HEP or astrophysics.

31.2.1.3. Hybrid photon detectors: Hybrid photon detectors (HPD) combine the sensitivity of a vacuum PMT with the excellent spatial and energy resolutions of a Si sensor [11]. A single photoelectron ejected from the photocathode is accelerated through a potential difference of \sim 20 kV before it impinges on the silicon sensor/anode. The gain nearly equals the maximum number of e-h pairs that could be created from the entire kinetic energy of the accelerated electron: $G \approx \text{eV}/w$, where e is the electronic charge, V is the applied potential difference, and $w \approx 3.7 \text{ eV}$ is the mean energy required to create an e-h pair in Si at room temperature. Since the gain is achieved in a single step, one might expect to have the excellent resolution of a simple Poisson statistic with large mean, but in fact it is even better, thanks to the Fano effect discussed in Sec. 31.7.

Low-noise electronics must be used to read out HPD's if one intends to take advantage of the low fluctuations in gain, e.g. when counting small numbers of photons. HPD's can have the same $\epsilon_Q\,\epsilon_C$ and window geometries as PMT's and can be segmented down to $\sim\!50$ $\mu\mathrm{m}$. However, they require rather high biases and will not function in a magnetic field. The exception is proximity-focused devices (\Rightarrow no (de)magnification) in an axial field. With time resolutions of $\sim\!10$ ps and superior rate capability, proximity-focused HPD's can be an alternative to MCP's. Current applications of HPD's include the CMS hadronic calorimeter and the RICH detector in LHCb. Large-size HPD's with sophisticated focusing may be suitable for future water Cherenkov experiments.

Hybrid APD's (HAPD's) add an avalanche multiplication step following the electron bombardment to boost the gain by a factor of ~ 50 . This affords a higher gain and/or lower electrical bias, but also degrades the signal definition.

Table 31.3: Properties of photocathode and window materials commonly used in vacuum photodetectors [10].

| Photocathode material | λ (nm) | Window material | Peak ϵ_Q (λ/nm) |
|--------------------------|----------------|--------------------|---------------------------------------------|
| CsI | 115-200 | MgF_2 | 0.11 (140) |
| CsTe | 115 - 320 | MgF_2 | 0.14(240) |
| Bi-alkali | 300 – 650 | Borosilicate | 0.27(390) |
| | 160 - 650 | Synthetic Silica | 0.27(390) |
| "Ultra Bi-alkali" | 300 – 650 | Borosilicate | 0.43(350) |
| | 160 - 650 | Synthetic Silica | 0.43(350) |
| Multi-alkali | 300 - 850 | Borosilicate | 0.20 (360) |
| | 160-850 | Synthetic Silica | 0.20(360) |
| $GaAs(Cs)^*$ | 160 - 930 | Synthetic Silica | 0.23(280) |
| GaAsP(Cs) | 300 - 750 | Borosilicate | 0.50(500) |
| InP/InGaAsP [†] | 350-1700 | Borosilicate | 0.01 (1100) |

^{*}Reflection type photocathode is used. †Requires cooling to $\sim -80 ^{\circ} \rm C.$

31.2.2. Gaseous photon detectors: In gaseous photomultipliers (GPM) a photoelectron in a suitable gas mixture initiates an avalanche in a high-field region, producing a large number of secondary impactionization electrons. In principle the charge multiplication and collection processes are identical to those employed in gaseous tracking detectors such as multiwire proportional chambers, micromesh gaseous detectors (Micromegas), or gas electron multipliers (GEM). These are discussed in Sec. 31.6.4.

The devices can be divided into two types depending on the photocathode material. One type uses solid photocathode materials much in the same way as PMT's. Since it is resistant to gas mixtures typically used in tracking chambers, CsI is a common choice. In the other type, photoionization occurs on suitable molecules vaporized and mixed in the drift volume. Most gases have photoionization work functions in excess of 10 eV, which would limit their sensitivity to wavelengths far too short. However, vapors of TMAE (tetrakis dimethyl-amine ethylene) or TEA (tri-ethyl-amine), which have smaller work functions (5.3 eV for TMAE and 7.5 eV for TEA), are suited for XUV photon detection [12]. Since devices like GEM's offer sub-mm spatial resolution, GPM's are often used as position-sensitive photon detectors. They can be made into flat panels to cover large areas $(O(1 \text{ m}^2))$, can operate in high magnetic fields, and are relatively inexpensive. Many of the ring imaging Cherenkov (RICH) detectors to date have used GPM's for the detection of Cherenkov light [13]. Special care must be taken to suppress the photon-feedback process in GPM's. It is also important to maintain high purity of the gas as minute traces of O_2 can significantly degrade the detection efficiency.

31.2.3. Solid-state photon detectors: In a phase of rapid development, solid-state photodetectors are competing with vacuum- or gas-based devices for many existing applications and making way for a multitude of new ones. Compared to traditional vacuum- and gaseous photodetectors, solid-state devices are more compact, lightweight, rugged, tolerant to magnetic fields, and often cheaper. They also allow fine pixelization, are easy to integrate into large systems, and can operate at low electric potentials, while matching or exceeding most performance criteria. They are particularly well suited for detection of γ - and X-rays. Except for applications where coverage of very large areas or dynamic range is required, solid-state detectors are proving to be the better choice. Some hybrid devices attempt to combine the best features of different technologies while applications of nanotechnology are opening up exciting new possibilities.

Silicon photodiodes (PD) are widely used in high-energy physics as particle detectors and in a great number of applications (including solar cells!) as light detectors. The structure is discussed in some detail in Sec. 31.7. In its simplest form, the PD is a reverse-biased p-n junction. Photons with energies above the indirect bandgap energy (wavelengths shorter than about 1050 nm, depending on the temperature) can create e-h pairs (the photoconductive effect), which are collected on the p and n sides, respectively. Often, as in the PD's

used for crystal scintillator readout in CLEO, L3, Belle, BaBar, and GLAST, intrinsic silicon is doped to create a p-i-n structure. The reverse bias increases the thickness of the depleted region; in the case of these particular detectors, to full depletion at a depth of about 100 μ m. Increasing the depletion depth decreases the capacitance (and hence electronic noise) and extends the red response. Quantum efficiency can exceed 90%, but falls toward the red because of the increasing absorption length of light in silicon. The absorption length reaches 100 μ m at 985 nm. However, since G=1, amplification is necessary. Optimal low-noise amplifiers are slow, but, even so, noise limits the minimum detectable signal in room-temperature devices to several hundred photons.

Very large arrays containing $O(10^7)$ of $O(10 \ \mu \text{m}^2)$ -sized photodiodes pixelizing a plane are widely used to photograph all sorts of things from everyday subjects at visible wavelengths to crystal structures with X-rays and astronomical objects from infrared to UV. To limit the number of readout channels, these are made into charge-coupled devices (CCD), where pixel-to-pixel signal transfer takes place over thousands of synchronous cycles with sequential output through shift registers [14]. Thus, high spatial resolution is achieved at the expense of speed and timing precision. Custom-made CCD's have virtually replaced photographic plates and other imagers for astronomy and in spacecraft. Typical QE's exceed 90% over much of the visible spectrum, and "thick" CCD's have useful QE up to $\lambda=1~\mu m$. Active Pixel Sensor (APS) arrays with a preamplifier on each pixel and CMOS processing afford higher speeds, but are challenged at longer wavelengths. Much R&D is underway to overcome the limitations of both CCD and CMOS imagers.

In APD's, an exponential cascade of impact ionizations initiated by the original photogenerated e-h pair under a large reverse-bias voltage leads to an avalanche breakdown [15]. As a result, detectable electrical response can be obtained from low-intensity optical signals down to single photons. Excellent junction uniformity is critical, and a guard ring is generally used as a protection against edge breakdown. Well-designed APD's, such as those used in CMS' crystal-based electromagnetic calorimeter, have achieved $\epsilon_Q\,\epsilon_C\approx 0.7$ with sub-ns response time. The sensitive wavelength window and gain depend on the semiconductor used. The gain is typically 10–200 in linear and up to 10^8 in Geiger mode of operation. Stability and close monitoring of the operating temperature are important for linear-mode operation, and substantial cooling is often necessary. Position-sensitive APD's use time information at multiple anodes to calculate the hit position.

One of the most promising recent developments in the field is that of devices consisting of large arrays $(O(10^3))$ of tiny APD's packed over a small area $(O(1 \text{ mm}^2))$ and operated in a limited Geiger mode [16]. Among different names used for this class of photodetectors, "PPD" (for "Pixelized Photon Detector") is most widely accepted (formerly "SiPM"). Although each cell only offers a binary output, linearity with respect to the number of photons is achieved by summing the cell outputs in the same way as with a MCP in saturation mode (see above). PPD's are being adopted as the preferred solution for various purposes including medical imaging, e.g. positron emission tomography (PET). These compact, rugged, and economical devices allow auto-calibration through decent separation of photoelectron peaks and offer gains of $O(10^6)$ at a moderate bias voltage ($\sim 50 \text{ V}$). However, the single-photoelectron noise of a PPD, being the logical "or" of $O(10^3)$ Geiger APD's, is rather large: $O(1 \text{ MHz/mm}^2)$ at room temperature. PPD's are particularly well-suited for applications where triggered pulses of several photons are expected over a small area, e.g. fiber-guided scintillation light. Intense R&D is expected to lower the noise level and improve radiation hardness, resulting in coverage of larger areas and wider applications. Attempts are being made to combine the fabrication of the sensors and the front-end electronics (ASIC) in the same process with the goal of making PPD's and other finely pixelized solid-state photodetectors extremely easy to

Of late, much R&D has been directed to p-i-n diode arrays based on thin polycrystalline diamond films formed by chemical vapor deposition (CVD) on a hot substrate (~ 1000 K) from a hydrocarbon-containing gas mixture under low pressure (~ 100 mbar). These devices have maximum sensitivity in the extreme- to moderate-UV

region [17]. Many desirable characteristics, including high tolerance to radiation and temperature fluctuations, low dark noise, blindness to most of the solar radiation spectrum, and relatively low cost make them ideal for space-based UV/XUV astronomy, measurement of synchrotron radiation, and luminosity monitoring at (future) lepton collider(s).

Visible-light photon counters (VLPC) utilize the formation of an impurity band only 50 meV below the conduction band in As-doped Si to generate strong ($G\approx 5\times 10^4$) yet sharp response to single photons with $\epsilon_Q\approx 0.9$ [18]. The smallness of the band gap considerably reduces the gain dispersion. Only a very small bias (~ 7 V) is needed, but high sensitivity to infrared photons requires cooling below 10 K. The dark noise increases sharply and exponentially with both temperature and bias. The Run 2 DØ detector used 86000 VLPC's to read the optical signal from its scintillating-fiber tracker and scintillator-strip preshower detectors.

31.3. Organic scintillators

Revised August 2011 by Kurtis F. Johnson (FSU).

Organic scintillators are broadly classed into three types, crystalline, liquid, and plastic, all of which utilize the ionization produced by charged particles (see Sec. 30.2 of this Review) to generate optical photons, usually in the blue to green wavelength regions [19]. Plastic scintillators are by far the most widely used, liquid organic scintillator is finding increased use, and crystal organic scintillators are practically unused in high-energy physics. Plastic scintillator densities range from 1.03 to 1.20 g cm $^{-3}$. Typical photon yields are about 1 photon per 100 eV of energy deposit [20]. A one-cm-thick scintillator traversed by a minimum-ionizing particle will therefore yield $\approx 2\times 10^4$ photons. The resulting photoelectron signal will depend on the collection and transport efficiency of the optical package and the quantum efficiency of the photodetector.

Organic scintillator does not respond linearly to the ionization density. Very dense ionization columns emit less light than expected on the basis of dE/dx for minimum-ionizing particles. A widely used semi-empirical model by Birks posits that recombination and quenching effects between the excited molecules reduce the light yield [21]. These effects are more pronounced the greater the density of the excited molecules. Birks' formula is

$$\frac{d\mathcal{L}}{dx} = \mathcal{L}_0 \frac{dE/dx}{1 + k_B dE/dx} , \qquad (31.2)$$

where \mathscr{L} is the luminescence, \mathscr{L}_0 is the luminescence at low specific ionization density, and k_B is Birks' constant, which must be determined for each scintillator by measurement. Decay times are in the ns range; rise times are much faster. The high light yield and fast response time allow the possibility of sub-ns timing resolution [22]. The fraction of light emitted during the decay "tail" can depend on the exciting particle. This allows pulse shape discrimination as a technique to carry out particle identification. Because of the hydrogen content (carbon to hydrogen ratio ≈ 1) plastic scintillator is sensitive to proton recoils from neutrons. Ease of fabrication into desired shapes and low cost has made plastic scintillator a common detector element. In the form of scintillating fiber it has found widespread use in tracking and calorimetry [23].

Demand for large volume detectors has lead to increased use of liquid organic scintillator, which has the same scintillation mechanism as plastic scintillator, due to its cost advantage. The containment vessel defines the detector shape; photodetectors or waveshifters may be immersed in the liquid.

31.3.1. Scintillation mechanism:

A charged particle traversing matter leaves behind it a wake of excited molecules. Certain types of molecules, however, will release a small fraction ($\approx 3\%$) of this energy as optical photons. This process, scintillation, is especially marked in those organic substances which contain aromatic rings, such as polystyrene (PS) and polyvinyltoluene (PVT). Liquids which scintillate include toluene, xylene and pseudocumene.

In fluorescence, the initial excitation takes place via the absorption of a photon, and de-excitation by emission of a longer wavelength photon. Fluors are used as "waveshifters" to shift scintillation light to a more convenient wavelength. Occurring in complex molecules, the absorption and emission are spread out over a wide band of photon energies, and have some overlap, that is, there is some fraction of the emitted light which can be re-absorbed [24]. This "self-absorption" is undesirable for detector applications because it causes a shortened attenuation length. The wavelength difference between the major absorption and emission peaks is called the Stokes shift. It is usually the case that the greater the Stokes shift, the smaller the self absorption thus, a large Stokes shift is a desirable property for a fluor.

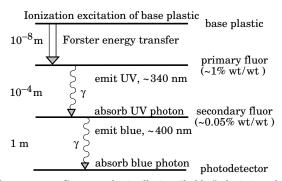


Figure 31.1: Cartoon of scintillation "ladder" depicting the operating mechanism of organic scintillator. Approximate fluor concentrations and energy transfer distances for the separate sub-processes are shown.

The plastic scintillators used in high-energy physics are binary or ternary solutions of selected fluors in a plastic base containing aromatic rings. (See the appendix in Ref. 25 for a comprehensive list of components.) Virtually all plastic scintillators contain as a base either PVT or PS. PVT-based scintillator can be up to 50% brighter.

Ionization in the plastic base produces UV photons with short attenuation length (several mm). Longer attenuation lengths are obtained by dissolving a "primary" fluor in high concentration (1% by weight) into the base, which is selected to efficiently re-radiate absorbed energy at wavelengths where the base is more transparent (see Fig. 31.1).

The primary fluor has a second important function. The decay time of the scintillator base material can be quite long – in pure polystyrene it is 16 ns, for example. The addition of the primary fluor in high concentration can shorten the decay time by an order of magnitude and increase the total light yield. At the concentrations used (1% and greater), the average distance between a fluor molecule and an excited base unit is around 100 Å, much less than a wavelength of light. At these distances the predominant mode of energy transfer from base to fluor is not the radiation of a photon, but a resonant dipole-dipole interaction, first described by Foerster, which strongly couples the base and fluor [26]. The strong coupling sharply increases the speed and the light yield of the plastic scintillators.

Unfortunately, a fluor which fulfills other requirements is usually not completely adequate with respect to emission wavelength or attenuation length, so it is necessary to add yet another waveshifter (the "secondary" fluor), at fractional percent levels, and occasionally a third (not shown in Fig. 31.1).

External wavelength shifters are widely used to aid light collection in complex geometries. Scintillation light is captured by a lightpipe

comprising a wave-shifting fluor dissolved in a nonscintillating base. The wavelength shifter must be insensitive to ionizing radiation and Cherenkov light. A typical wavelength shifter uses an acrylic base because of its good optical qualities, a single fluor to shift the light emerging from the plastic scintillator to the blue-green, and contains ultra-violet absorbing additives to deaden response to Cherenkov light.

31.3.2. Caveats and cautions:

Plastic scintillators are reliable, robust, and convenient. However, they possess quirks to which the experimenter must be alert. Exposure to solvent vapors, high temperatures, mechanical flexing, irradiation, or rough handling will aggravate the process. A particularly fragile region is the surface which can "craze" develop microcracks which degrade its transmission of light by total internal reflection. Crazing is particularly likely where oils, solvents, or *fingerprints* have contacted the surface.

They have a long-lived luminescence which does not follow a simple exponential decay. Intensities at the 10^{-4} level of the initial fluorescence can persist for hundreds of ns [19,27].

They will decrease their light yield with increasing partial pressure of oxygen. This can be a 10% effect in an artificial atmosphere [28]. It is not excluded that other gases may have similar quenching effects.

Their light yield may be changed by a magnetic field. The effect is very nonlinear and apparently not all types of plastic scintillators are so affected. Increases of $\approx 3\%$ at 0.45 T have been reported [29]. Data are sketchy and mechanisms are not understood.

Irradiation of plastic scintillators creates color centers which absorb light more strongly in the UV and blue than at longer wavelengths. This poorly understood effect appears as a reduction both of light yield and attenuation length. Radiation damage depends not only on the integrated dose, but on the dose rate, atmosphere, and temperature, before, during and after irradiation, as well as the materials properties of the base such as glass transition temperature, polymer chain length, etc. Annealing also occurs, accelerated by the diffusion of atmospheric oxygen and elevated temperatures. The phenomena are complex, unpredictable, and not well understood [30]. Since color centers are less disruptive at longer wavelengths, the most reliable method of mitigating radiation damage is to shift emissions at every step to the longest practical wavelengths, e.g., utilize fluors with large Stokes shifts (aka the "Better red than dead" strategy).

31.3.3. Scintillating and wavelength-shifting fibers:

The clad optical fiber comprising scintillator and wavelength shifter (WLS) is particularly useful [31]. Since the initial demonstration of the scintillating fiber (SCIFI) calorimeter [32], SCIFI techniques have become mainstream [33]. SCIFI calorimeters are fast, dense, radiation hard, and can have leadglass-like resolution. SCIFI trackers can handle high rates and are radiation tolerant, but the low photon yield at the end of a long fiber (see below) forces the use of sensitive photodetectors. WLS scintillator readout of a calorimeter allows a very high level of hermeticity since the solid angle blocked by the fiber on its way to the photodetector is very small. The sensitive region of scintillating fibers can be controlled by splicing them onto clear (non-scintillating/non-WLS) fibers.

A typical configuration would be fibers with a core of polystyrenebased scintillator or WLS (index of refraction n = 1.59), surrounded by a cladding of PMMA (n = 1.49) a few microns thick, or, for added light capture, with another cladding of fluorinated PMMA with n = 1.42, for an overall diameter of 0.5 to 1 mm. The fiber is drawn from a boule and great care is taken during production to ensure that the intersurface between the core and the cladding has the highest possible uniformity and quality, so that the signal transmission via total internal reflection has a low loss. The fraction of generated light which is transported down the optical pipe is denoted the capture fraction and is about 6% for the single-clad fiber and 10% for the double-clad fiber. The number of photons from the fiber available at the photodetector is always smaller than desired, and increasing the light yield has proven difficult. A minimum-ionizing particle traversing a high-quality 1 mm diameter fiber perpendicular to its axis will produce fewer than 2000 photons, of which about 200 are captured. Attenuation may eliminate 95% of these photons in a large collider

A scintillating or WLS fiber is often characterized by its attenuation

length, over which the signal is attenuated to 1/e of its original value. Many factors determine the attenuation length, including the importance of re-absorption of emitted photons by the polymer base or dissolved fluors, the level of crystallinity of the base polymer, and the quality of the total internal reflection boundary [34]. Attenuation lengths of several meters are obtained by high quality fibers. However, it should be understood that the attenuation length is not the sole measure of fiber quality. Among other things, it is not constant with distance from the excitation source and it is wavelength dependent.

31.4. Inorganic scintillators:

Revised September 2009 by R.-Y. Zhu (California Institute of Technology) and C.L. Woody (BNL).

Inorganic crystals form a class of scintillating materials with much higher densities than organic plastic scintillators (typically $\sim 4\text{--}8~\text{g/cm}^3)$ with a variety of different properties for use as scintillation detectors. Due to their high density and high effective atomic number, they can be used in applications where high stopping power or a high conversion efficiency for electrons or photons is required. These include total absorption electromagnetic calorimeters (see Sec. 31.9.1), which consist of a totally active absorber (as opposed to a sampling calorimeter), as well as serving as gamma ray detectors over a wide range of energies. Many of these crystals also have very high light output, and can therefore provide excellent energy resolution down to very low energies (\sim few hundred keV).

Some crystals are intrinsic scintillators in which the luminescence is produced by a part of the crystal lattice itself. However, other crystals require the addition of a dopant, typically fluorescent ions such as thallium (Tl) or cerium (Ce) which is responsible for producing the scintillation light. However, in both cases, the scintillation mechanism is the same. Energy is deposited in the crystal by ionization, either directly by charged particles, or by the conversion of photons into electrons or positrons which subsequently produce ionization. This energy is transferred to the luminescent centers which then radiate scintillation photons. The efficiency η for the conversion of energy deposit in the crystal to scintillation light can be expressed by the relation [35]

$$\eta = \beta \cdot S \cdot Q \ . \tag{31.3}$$

where β is the efficiency of the energy conversion process, S is the efficiency of energy transfer to the luminescent center, and Q is the quantum efficiency of the luminescent center. The value of η ranges between 0.1 and \sim 1 depending on the crystal, and is the main factor in determining the intrinsic light output of the scintillator. In addition, the scintillation decay time is primarily determined by the energy transfer and emission process. The decay time of the scintillator is mainly dominated by the decay time of the luminescent center. For example, in the case of thallium doped sodium iodide (NaI(Tl)), the value of η is \sim 0.5, which results in a light output \sim 40,000 photons per MeV of energy deposit. This high light output is largely due to the high quantum efficiency of the thallium ion (Q \sim 1), but the decay time is rather slow ($\tau \sim$ 250 ns).

Table 31.4 lists the basic properties of some commonly used inorganic crystal scintillators. NaI(Tl) is one of the most common and widely used scintillators, with an emission that is well matched to a bialkali photomultiplier tube, but it is highly hygroscopic and difficult to work with, and has a rather low density. CsI(Tl) has high light yield, an emission that is well matched to solid state photodiodes, and is mechanically robust (high plasticity and resistance to cracking). However, it needs careful surface treatment and is slightly hygroscopic. Compared with CsI(Tl), pure CsI has identical mechanical properties, but faster emission at shorter wavelengths and light output approximately an order of magnitude lower. BaF2 has a fast component with a sub-nanosecond decay time, and is the fastest known scintillator. However, it also has a slow component with a much longer decay time (~ 630 ns). Bismuth gemanate (Bi₄Ge₃O₁₂ or BGO) has a high density, and consequently a short radiation length X_0 and Molière radius R_M . BGO's emission is well-matched to the spectral sensitivity of photodiodes, and it is easy to handle and not hygroscopic. Lead tungstate (PbWO₄ or PWO) has a very high density, with a very short X_0 and R_M , but its intrinsic light yield is rather low.

Cerium doped lutetium oxyorthosilicate (Lu_2SiO_5 :Ce, or LSO:Ce) [36] and cerium doped lutetium-yttrium oxyorthosilicate ($\text{Lu}_{2(1-x)}\text{Y}_{2x}\text{SiO}_5$, LYSO:Ce) [37] are dense crystal scintillators which have a high light yield and a fast decay time. Only properties of LSO:Ce is listed in Table 31.4 since the properties of LYSO:Ce are similar to that of LSO:Ce except a little lower density than LSO:Ce depending on the yttrium fraction in LYSO:Ce. This material is also featured with excellent radiation hardness [38], so is expected to be used where extraordinary radiation hardness is required.

Table 31.4 also includes cerium doped lanthanum tri-halides, such as LaBr₃ [39], which is brighter and faster than LSO:Ce, but it is highly hygroscopic and has a lower density. The FWHM energy resolution measured for this material coupled to a PMT with bi-alkali photocathode for 0.662 MeV γ -rays from a ^{137}Cs source is about 3%, which is the best among all inorganic crystal scintillators. For this reason, LaBr₃ is expected to be widely used in applications where a good energy resolution for low energy photons are required, such as homeland security.

Beside the crystals listed in Table 31.4, a number of new crystals are being developed that may have potential applications in high energy or nuclear physics. Of particular interest is the family of yttrium and lutetium perovskites, which include YAP (YAlO3:Ce) and LuAP (LuAlO3:Ce) and their mixed compositions. These have been shown to be linear over a large energy range [40], and have the potential for providing extremely good intrinsic energy resolution. In addition, other fluoride crystals such as ${\rm CeF_3}$ have been shown to provide excellent energy resolution in calorimeter applications.

Aiming at the best jet-mass resolution inorganic scintillators are being investigated for HEP calorimeters with dual readout for both Cherenkov and scintillation light to be used at future linear colliders. These materials may be used for an electromagnetic calorimeter [41] or a homogeneous hadronic calorimetry (HHCAL) detector concept, including both electromagnetic and hadronic parts [42]. Because of the unprecedented volume (70 to 100 m³) foreseen for the HHCAL detector concept the materials must be (1) dense (to minimize the leakage) and (2) cost-effective. It should also be UV transparent (for effective collection of the Cherenkov light) and allow for a clear discrimination between the Cherenkov and scintillation light. The preferred scintillation light is thus at a longer wavelength, and not necessarily bright or fast. Dense crystals, scintillating glasses and ceramics offer a very attractive implementation for this detector concept. Inorganic crystals being investigated are lead fluoride (PbF₂), lead chroride fluoride (PbFCl) and BSO [43].

Table 31.4 gives the light output of other crystals relative to NaI(Tl) and their dependence to the temperature variations measured for crystal samples of 1.5 X_0 cube with a Tyvek paper wrapping and a full end face coupled to a photodetector [44]. The quantum efficiencies of the photodetector is taken out to facilitate a direct comparison of crystal's light output. However, the useful signal produced by a scintillator is usually quoted in terms of the number of photoelectrons per MeV produced by a given photodetector. The relationship between the number of photons/MeV produced and photoelectrons/MeV detected involves the factors for the light collection efficiency L and the quantum efficiency QE of the photodetector:

$$N_{\text{p.e.}}/\text{MeV} = L \cdot QE \cdot N_{\gamma}/\text{MeV}$$
 (31.4)

L includes the transmission of scintillation light within the crystal (i.e., the bulk attenuation length of the material), reflections and scattering from the surfaces, and the size and shape of the crystal. These factors can vary considerably depending on the sample, but can be in the range of $\sim 10-60\%$. The internal light transmission depends on the intrinsic properties of the material, e.g. the density and type of the scattering centers and defects that can produce internal absorption within the crystal, and can be highly affected by factors such as radiation damage, as discussed below.

The quantum efficiency depends on the type of photodetector used to detect the scintillation light, which is typically ${\sim}15{-}20\%$ for photomultiplier tubes and ${\sim}70\%$ for silicon photodiodes for visible wavelengths. The quantum efficiency of the detector is usually highly wavelength dependent and should be matched to the particular crystal of interest to give the highest quantum yield at the wavelength

corresponding to the peak of the scintillation emission. Fig. 31.2 shows the quantum efficiencies of two photodetectors, a Hamamatsu R2059 PMT with bi-alkali cathode and quartz window and a Hamamatsu S8664 avalanche photodiode (APD) as a function of wavelength. Also shown in the figure are emission spectra of three crystal scintillators, BGO, LSO:Ce/LYSO:Ce and CsI(Tl), and the numerical values of the emission weighted quantum efficiency. The area under each emission spectrum is proportional to crystal's light yield, as shown in Table 31.4, where the quantum efficiencies of the photodetector has been taken out. Results with different photodetectors can be significantly different. For example, the response of CsI(Tl) relative to NaI(Tl) with a standard photomultiplier tube with a bi-alkali photo-cathode, e.g. Hamamatsu R2059, would be 45 rather than 165 because of the photomultiplier's low quantum efficiency at longer wavelengths. For scintillators which emit in the UV, a detector with a quartz window should be used.

For very low energy applications (typically below 1 MeV), nonproportionality of the scintillation light yield may be important. It has been known for a long time that the conversion factor between the energy deposited in a crystal scintillator and the number of photons produced is not constant. It is also known that the energy resolution measured by all crystal scintillators for low energy γ -rays is significantly worse than the contribution from photo-electron statistics alone, indicating an intrinsic contribution from the scintillator itself. Precision measurement using low energy electron beam shows that this non-proportionality is crystal dependent [45]. Recent study on this issue also shows that this effect is also sample dependent even for the same crystal [46]. Further work is therefore needed to fully understand this subject.

One important issue related to the application of a crystal scintillator is its radiation hardness. Stability of its light output, or the ability to track and monitor the variation of its light output in a radiation environment, is required for high resolution and precision calibration [47]. All known crystal scintillators suffer from radiation damage. A common damage phenomenon is the appearance of radiation induced absorption caused by the formation of color centers originated from the impurities or point defects in the crystal. This radiation induced absorption reduces the light attenuation length in the crystal, and hence its light output. For crystals with high defect density, a severe reduction of light attenuation length may cause a distortion of the light response uniformity, leading to a degradation of the energy resolution. Additional radiation damage effects may include a reduced intrinsic scintillation light yield (damage to the luminescent centers) and an increased phosphorescence (afterglow). For crystals to be used in the construction a high precision calorimeter in a radiation environment, its scintillation mechanism must not be damaged and its light attenuation length in the expected radiation environment must be long enough so that its light response uniformity, and thus its energy resolution, does not change [48].

Most of the crystals listed in Table 31.4 have been used in high energy or nuclear physics experiments when the ultimate energy resolution for electrons and photons is desired. Examples are the Crystal Ball NaI(Tl) calorimeter at SPEAR, the L3 BGO calorimeter at LEP, the CLEO CsI(Tl) calorimeter at CESR, the KTeV CsI calorimeter at the Tevatron, the BaBar, BELLE and BES II CsI(Tl) calorimeters at PEP-II, KEK and BEPC III. Because of its high density and relative low cost, PWO calorimeters are widely used by CMS and ALICE at LHC, by CLAS and PrimEx at CEBAF, and by PANDA at GSI. Recently, investigations have been made aiming at using LSO:Ce or LYSO:Ce crystals for future high energy or nuclear physics experiments [38].

| Table 31.4: Properties of several inorganic crystal scintillators. | Most |
|--------------------------------------------------------------------|------|
| of the notation is defined in Sec. 6 of this <i>Review</i> . | |

| Parameter Units: | r: ρ g/cm ³ | MP °C | X_0^* cm | R_M^* cm | dE^*/dx MeV/cm | λ_I^* cm | $	au_{ m decay}$ ns | λ_{\max} nm | $n^{ atural}$ | Relative output [†] | | $d(LY)/dT$ $\%/^{\circ}C^{\ddagger}$ |
|-----------------------|---------------------------|----------|------------|------------|------------------|------------------|---------------------|---------------------|---------------|---------------------------------|--------|--------------------------------------|
| NaI(Tl) | 3.67 | 651 | 2.59 | 4.13 | 4.8 | 42.9 | 245 | 410 | 1.85 | 100 | yes | -0.2 |
| BGO | 7.13 | 1050 | 1.12 | 2.23 | 9.0 | 22.8 | 300 | 480 | 2.15 | 21 | no | -0.9 |
| BaF_2 | 4.89 | 1280 | 2.03 | 3.10 | 6.5 | 30.7 | 650^{s} | 300^s | 1.50 | 36^s | no | -1.9^{s} |
| | | | | | | | 0.9^{f} | 220^f | | 4.1^{f} | | 0.1^{f} |
| CsI(Tl) | 4.51 | 621 | 1.86 | 3.57 | 5.6 | 39.3 | 1220 | 550 | 1.79 | 165 | slight | 0.4 |
| CsI(pure) | 4.51 | 621 | 1.86 | 3.57 | 5.6 | 39.3 | 30^s | 420^s | 1.95 | 3.6^{s} | slight | -1.4 |
| | | | | | | | 6^f | 310^{f} | | 1.1^{f} | | |
| $PbWO_4$ | 8.3 | 1123 | 0.89 | 2.00 | 10.1 | 20.7 | 30^s | 425^s | 2.20 | 0.3^{s} | no | -2.5 |
| | | | | | | | 10^{f} | 420^f | | 0.077^{f} | | |
| LSO(Ce) | 7.40 | 2050 | 1.14 | 2.07 | 9.6 | 20.9 | 40 | 402 | 1.82 | 85 | no | -0.2 |
| LaBr ₃ (Ce |) 5.29 | 788 | 1.88 | 2.85 | 6.9 | 30.4 | 20 | 356 | 1.9 | 130 | yes | 0.2 |

^{*} Numerical values calculated using formulae in this review.

Refractive index at the wavelength of the emission maximum.

Relative light output measured for samples of 1.5 X₀ cube with a

Tyvek paper wrapping and a full end face coupled to a photodetector. The quantum efficiencies of the photodetector are taken out.

[‡] Variation of light yield with temperature evaluated at the room temperature.

f = fast component, s = slow component

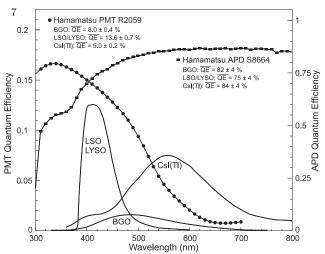


Figure 31.2: The quantum efficiencies of two photodetectors, a Hamamatsu R2059 PMT with bi-alkali cathode and a Hamamatsu S8664 avalanche photodiode (APD), are shown as a function of wavelength. Also shown in the figure are emission spectra of three crystal scintillators, BGO, LSO and CsI(Tl), and the numerical values of the emission weighted quantum efficiencies. The area under each emission spectrum is proportional to crystal's light yield.

31.5. Cherenkov detectors

Revised September 2009 by B.N. Ratcliff (SLAC).

Although devices using Cherenkov radiation are often thought of as only particle identification (PID) detectors, in practice they are used over a broader range of applications including; (1) fast particle counters; (2) hadronic PID; and (3) tracking detectors performing complete event reconstruction. Examples of applications from each category include; (1) the BaBar luminosity detector [49]; (2) the hadronic PID detectors at the B factory detectors—DIRC in BaBar [50] and the aerogel threshold Cherenkov in Belle [51]; and (3) large water Cherenkov counters such as Super-Kamiokande [53]. Cherenkov counters contain two main elements; (1) a radiator through which the charged particle passes, and (2) a photodetector. As Cherenkov radiation is a weak source of photons, light collection and detection must be as efficient as possible. The refractive index n and the particle's path length through the radiator L appear in the Cherenkov relations allowing the tuning of these quantities for particular applications.

Cherenkov detectors utilize one or more of the properties of Cherenkov radiation discussed in the Passages of Particles through Matter section (Sec. 30 of this Review): the prompt emission of a light pulse; the existence of a velocity threshold for radiation; and the dependence of the Cherenkov cone half-angle θ_c and the number of emitted photons on the velocity of the particle and the refractive index of the medium.

The number of photoelectrons $(N_{\rm p.e.})$ detected in a given device is

$$N_{\rm p.e.} = L \frac{\alpha^2 z^2}{r_e \, m_e c^2} \int \epsilon(E) \, \sin^2 \theta_c(E) dE , \qquad (31.5)$$

where $\epsilon(E)$ is the efficiency for collecting the Cherenkov light and transducing it into photoelectrons, and $\alpha^2/(r_e m_e c^2) = 370 \text{ cm}^{-1} \text{eV}^{-1}$.

The quantities ϵ and θ_c are functions of the photon energy E. As the typical energy dependent variation of the index of refraction is modest, a quantity called the *Cherenkov detector quality factor* N_0 can be defined as

$$N_0 = \frac{\alpha^2 z^2}{r_e \, m_e c^2} \int \epsilon \, dE \,, \tag{31.6}$$

so that, taking z = 1 (the usual case in high-energy physics),

$$N_{\rm p.e.} \approx L N_0 \langle \sin^2 \theta_c \rangle$$
 (31.7)

This definition of the quality factor N_0 is not universal, nor, indeed, very useful for those common situations where ϵ factorizes as $\epsilon = \epsilon_{\rm coll} \epsilon_{\rm det}$ with the geometrical photon collection efficiency ($\epsilon_{\rm coll}$) varying substantially for different tracks while the photon detector efficiency (ϵ_{det}) remains nearly track independent. In this case, it can be useful to explicitly remove (ϵ_{coll}) from the definition of N_0 . A typical value of N_0 for a photomultiplier (PMT) detection system working in the visible and near UV, and collecting most of the Cherenkov light, is about 100 cm⁻¹. Practical counters, utilizing a variety of different photodetectors, have values ranging between about 30 and 180 cm⁻¹. Radiators can be chosen from a variety of transparent materials (Sec. 30 of this Review and Table 6.1). In addition to refractive index, the choice requires consideration of factors such as material density, radiation length and radiation hardness, transmission bandwidth, absorption length, chromatic dispersion, optical workability (for solids), availability, and cost. When the momenta of particles to be identified is high, the refractive index must be set close to one, so that the photon yield per unit length is low and a long particle path in the radiator is required. Recently, the gap in refractive index that has traditionally existed between gases and liquid or solid materials has been partially closed with transparent silica aerogels with indices that range between about 1.007 and 1.13.

Cherenkov counters may be classified as either *imaging* or *threshold* types, depending on whether they do or do not make use of Cherenkov angle (θ_c) information. Imaging counters may be used to track particles as well as identify them. The recent development of very fast photodetectors such as micro-channel plate PMTs (MCP PMT) (see Sec. 31.2 of this *Review*) also potentially allows very fast Cherenkov based time of flight (TOF) detectors of either class [57].

Threshold Cherenkov detectors [54], in their simplest form, make a yes/no decision based on whether the particle is above or below the Cherenkov threshold velocity $\beta_t = 1/n$. A straightforward enhancement of such detectors uses the number of observed photoelectrons (or a calibrated pulse height) to discriminate between species or to set probabilities for each particle species [55]. This strategy can increase the momentum range of particle separation by a modest amount (to a momentum some 20% above the threshold momentum of the heavier particle in a typical case).

Careful designs give $\langle \epsilon_{\rm coll} \rangle \gtrsim 90\%$. For a photomultiplier with a typical bialkali cathode, $\int \epsilon_{\rm det} dE \approx 0.27$ eV, so that

$$N_{\rm p.e.}/L \approx 90 \text{ cm}^{-1} \langle \sin^2 \theta_c \rangle$$
 (i.e., $N_0 = 90 \text{ cm}^{-1}$). (31.8)

Suppose, for example, that n is chosen so that the threshold for species a is p_t ; that is, at this momentum species a has velocity $\beta_a=1/n$. A second, lighter, species b with the same momentum has velocity β_b , so $\cos\theta_c=\beta_a/\beta_b$, and

$$N_{\text{p.e.}}/L \approx 90 \text{ cm}^{-1} \frac{m_a^2 - m_b^2}{p_t^2 + m_a^2}$$
 (31.9)

For K/π separation at $p=p_t=1(5)$ GeV/c, $N_{\rm p.e.}/L\approx 16(0.8)$ cm⁻¹ for π 's and (by design) 0 for K's.

For limited path lengths $N_{\rm p.e.}$ will usually be small. The overall efficiency of the device is controlled by Poisson fluctuations, which can be especially critical for separation of species where one particle type is dominant. Moreover, the effective number of photoelectrons is often less than the average number calculated above due to additional equivalent noise from the photodetector (see the discussion of the excess noise factor in Sec. 31.2 of this Review). It is common to design for at least 10 photoelectrons for the high velocity particle in order to obtain a robust counter. As rejection of the particle that is below threshold depends on not seeing a signal, electronic and other background noise can be important. Physics sources of light production for the below threshold particle, such as decay to an above threshold particle or the production of delta rays in the radiator, often limit the separation attainable, and need to be carefully considered. Well designed, modern multi-channel counters, such as the ACC at Belle [51], can attain adequate particle separation performance over a substantial momentum range for essentially the full solid angle of the spectrometer.

Imaging counters make the most powerful use of the information available by measuring the ring-correlated angles of emission of the individual Cherenkov photons. Since low-energy photon detectors can measure only the position (and, perhaps, a precise detection time) of the individual Cherenkov photons (not the angles directly), the photons must be "imaged" onto a detector so that their angles can be derived [56]. Typically the optics map the Cherenkov cone onto (a portion of) a distorted "circle" at the photodetector. Though the imaging process is directly analogous to familiar imaging techniques used in telescopes and other optical instruments, there is a somewhat bewildering variety of methods used in a wide variety of counter types with different names. Some of the imaging methods used include (1) focusing by a lens; (2) proximity focusing (i.e., focusing by limiting the emission region of the radiation); and (3) focusing through an aperture (a pinhole). In addition, the prompt Cherenkov emission coupled with the speed of modern photon detectors allows the use of (4) time imaging, a method which is little used in conventional imaging technology. Finally, (5) correlated tracking (and event reconstruction) can be performed in large water counters by combining the individual space position and time of each photon together with the constraint that Cherenkov photons are emitted from each track at the same polar angle (Sec. 32.3.1 of this Review).

In a simple model of an imaging PID counter, the fractional error on the particle velocity (δ_{β}) is given by

$$\delta_{\beta} = \frac{\sigma_{\beta}}{\beta} = \tan \theta_c \sigma(\theta_c) \quad , \tag{31.10}$$

where

$$\sigma(\theta_c) = \frac{\langle \sigma(\theta_i) \rangle}{\sqrt{N_{\text{p.e.}}}} \oplus C , \qquad (31.11)$$

and $\langle \sigma(\theta_i) \rangle$ is the average single photoelectron resolution, as defined by the optics, detector resolution and the intrinsic chromaticity spread of the radiator index of refraction averaged over the photon detection bandwidth. C combines a number of other contributions to resolution including, (1) correlated terms such as tracking, alignment, and multiple scattering, (2) hit ambiguities, (3) background hits from random sources, and (4) hits coming from other tracks. The actual separation performance is also limited by physics effects such as decays in flight and particle interactions in the material of the detector. In many practical cases, the performance is limited by these effects.

For a $\beta \approx 1$ particle of momentum (p) well above threshold entering a radiator with index of refraction (n), the number of σ separation (N_{σ}) between particles of mass m_1 and m_2 is approximately

$$N_{\sigma} \approx \frac{|m_1^2 - m_2^2|}{2p^2\sigma(\theta_c)\sqrt{n^2 - 1}}$$
 (31.12)

In practical counters, the angular resolution term $\sigma(\theta_c)$ varies between about 0.1 and 5 mrad depending on the size, radiator, and photodetector type of the particular counter. The range of momenta over which a particular counter can separate particle species extends from the point at which the number of photons emitted becomes sufficient for the counter to operate efficiently as a threshold device ($\sim 20\%$ above the threshold for the lighter species) to the value in the imaging region given by the equation above. For example, for $\sigma(\theta_c) = 2 \text{mrad}$, a fused silica radiator(n = 1.474), or a fluorocarbon gas radiator (C_5F_{12} , n = 1.0017), would separate π/K 's from the threshold region starting around 0.15(3) GeV/c through the imaging region up to about 4.2(18) GeV/c at better than 3σ .

Many different imaging counters have been built during the last several decades [57]. Among the earliest examples of this class of counters are the very limited acceptance Differential Cherenkov detectors, designed for particle selection in high momentum beam lines. These devices use optical focusing and/or geometrical masking to select particles having velocities in a specified region. With careful design, a velocity resolution of $\sigma_{\beta}/\beta \approx 10^{-4}$ – 10^{-5} can be obtained [54].

Practical multi-track <u>Ring-Imaging Cherenkov detectors</u> (generically called RICH counters) are a more recent development. RICH counters are sometimes further classified by 'generations' that differ based on historical timing, performance, design, and photodetection techniques.

Prototypical examples of first generation RICH counters are those used in the DELPHI and SLD detectors at the LEP and SLC Z factory e^+e^- colliders [57]. They have both liquid (C₆F₁₄, n=1.276) and gas $(C_5F_{12}, n = 1.0017)$ radiators, the former being proximity imaged with the latter using mirrors. The phototransducers are a TPC/wire-chamber combination. They are made sensitive to photons by doping the TPC gas (usually, ethane/methane) with $\sim 0.05\%$ TMAE (tetrakis(dimethylamino)ethylene). Great attention to detail is required, (1) to avoid absorbing the UV photons to which TMAE is sensitive, (2) to avoid absorbing the single photoelectrons as they drift in the long TPC, and (3) to keep the chemically active TMAE vapor from interacting with materials in the system. In spite of their unforgiving operational characteristics, these counters attained good $e/\pi/K/p$ separation over wide momentum ranges (from about 0.25 to 20 GeV/c) during several years of operation at LEP and SLC. Related but smaller acceptance devices include the OMEGA RICH at the CERN SPS, and the RICH in the balloon-borne CAPRICE detector [57].

Later generation counters [57] generally operate at much higher rates, with more detection channels, than the first generation detectors just described. They also utilize faster, more forgiving photon detectors, covering different photon detection bandwidths. Radiator choices have broadened to include materials such as lithium fluoride, fused silica, and aerogel. Vacuum based photodetection systems (e.g., single or multi anode PMTs, MCP PMTs, or hybrid photodiodes (HPD)) have become increasingly common (see Sec. 31.2 of this Review). They handle high rates, and can be used with a wide choice of radiators. Examples include (1) the SELEX RICH at Fermilab, which mirror focuses the Cherenkov photons from a neon radiator onto a camera array made of ~ 2000 PMTs to separate hadrons over a wide momentum range (to well above 200 GeV/c for heavy hadrons); (2) the HERMES RICH at HERA, which mirror focuses photons from $C_4F_{10}(n=1.00137)$ and aerogel(n=1.0304) radiators within the same volume onto a PMT camera array to separate hadrons in the momentum range from 2 to 15 GeV/c; and (3) the LHCb detector now being brought into operation at the LHC. It uses two separate counters. One volume, like HERMES, contains two radiators (aerogel and C_4F_{10}) while the second volume contains CF_4 . Photons are mirror focused onto detector arrays of HPDs to cover a π/K separation momentum range between 1 and 150 $\,\mathrm{GeV}/c$.

Other fast detection systems that use solid cesium iodide (CsI) photocathodes or triethylamine (TEA) doping in proportional chambers are useful with certain radiator types and geometries. Examples include (1) the CLEO-III RICH at CESR that uses a LiF radiator with TEA doped proportional chambers; (2) the ALICE detector at the LHC that uses proximity focused liquid (C_6F_{14} radiators and solid CSI photocathodes (similar photodectors have been used for several years by the HADES and COMPASS detectors), and the hadron blind detector (HBD) in the PHENIX detector at RHIC that couples a low index CF_4 radiator to a photodetector based on electron multiplier (GEM) chambers with reflective CSI photocathodes [57].

A DIRC (Detection [of] Internally Reflected Cherenkov [light]) is a distinctive, compact RICH subtype first used in the BaBar detector [52]. A DIRC "inverts" the usual RICH principle for use of light from the radiator by collecting and imaging the total internally reflected light rather than the transmitted light. It utilizes the optical material of the radiator in two ways, simultaneously; first as a Cherenkov radiator, and second, as a light pipe. The magnitudes of the photon angles are preserved during transport by the flat, rectangular cross section radiators, allowing the photons to be efficiently transported to a detector outside the path of the particle where they may be imaged in up to three independent dimensions (the usual two in space and, due to the long photon paths lengths, one in time). Because the index of refraction in the radiator is large (~ 1.48 for fused silica), the momentum range with good π/K separation is rather low. The BaBar DIRC range extends up to $\sim 4~{\rm GeV}/c$. It is plausible, but difficult, to extend it up to about 10 $\,\mathrm{GeV}/c$ with an improved design. New DIRC detectors are being developed that take advantage of the new, very fast, pixelated photodetectors becoming available, such as flat panel PMTs and MCP PMTs. They

typically utilize either time imaging or mirror focused optics, or both, leading not only to a precision measurement of the Cherenkov angle, but in some cases, to a precise measurement of the particle time of flight, and/or to correction of the chromatic dispersion in the radiator. Examples include (1) the time of propagation (TOP) counter being developed for the BELLE-II upgrade at KEKB which emphasizes precision timing for both Cherenkov imaging and TOF; (2) the full 3-dimensional imaging FDIRC for the SuperB detector at the Italian SuperB collider which uses precision timing not only for improving the angle reconstruction and TOF, but also to correct the chromatic dispersion; and (3) the DIRCs being developed for the PANDA detector at FAIR that use elegant focusing optics and fast timing [57].

31.6. Gaseous detectors

31.6.1. Energy loss and charge transport in gases: Revised March 2010 by F. Sauli (CERN) and M. Titov (CEA Saclay).

Gas-filled detectors localize the ionization produced by charged particles, generally after charge multiplication. The statistics of ionization processes having asymmetries in the ionization trails, affect the coordinate determination deduced from the measurement of drift time, or of the center of gravity of the collected charge. For thin gas layers, the width of the energy loss distribution can be larger than its average, requiring multiple sample or truncated mean analysis to achieve good particle identification. In the truncated mean method for calculating $\langle dE/dx \rangle$, the ionization measurements along the track length are broken into many samples and then a fixed fraction of high-side (and sometimes also low-side) values are rejected [58].

The energy loss of charged particles and photons in matter is discussed in Sec. 30. Table 31.5 provides values of relevant parameters in some commonly used gases at NTP (normal temperature, 20° C, and pressure, 1 atm) for unit-charge minimum-ionizing particles (MIPs) [59–65]. Values often differ, depending on the source, so those in the table should be taken only as approximate. For different conditions and for mixtures, and neglecting internal energy transfer processes (e.g., Penning effect), one can scale the density, N_P , and N_T with temperature and pressure assuming a perfect gas law.

Table 31.5: Properties of noble and molecular gases at normal temperature and pressure (NTP: 20° C, one atm). E_X , E_I : first excitation, ionization energy; W_I : average energy per ion pair; $dE/dx|_{\min}$, N_P , N_T : differential energy loss, primary and total number of electron-ion pairs per cm, for unit charge minimum ionizing particles.

| Gas | Density, mgcm^{-3} | E_x eV | E_I eV | W_I eV | $\frac{dE/dx _{\min}}{\text{keV cm}^{-1}}$ | $\frac{N_P}{\mathrm{cm}^{-1}}$ | ${ m N}_T$ cm ⁻¹ |
|---------------------|-------------------------------|----------|----------|----------|--------------------------------------------|--------------------------------|-----------------------------|
| Не | 0.179 | 19.8 | 24.6 | 41.3 | 0.32 | 3.5 | 8 |
| Ne | 0.839 | 16.7 | 21.6 | 37 | 1.45 | 13 | 40 |
| Ar | 1.66 | 11.6 | 15.7 | 26 | 2.53 | 25 | 97 |
| Xe | 5.495 | 8.4 | 12.1 | 22 | 6.87 | 41 | 312 |
| CH_4 | 0.667 | 8.8 | 12.6 | 30 | 1.61 | 28 | 54 |
| C_2H_6 | 1.26 | 8.2 | 11.5 | 26 | 2.91 | 48 | 112 |
| iC_4H_{10} | 2.49 | 6.5 | 10.6 | 26 | 5.67 | 90 | 220 |
| CO_2 | 1.84 | 7.0 | 13.8 | 34 | 3.35 | 35 | 100 |
| CF_4 | 3.78 | 10.0 | 16.0 | 54 | 6.38 | 63 | 120 |

When an ionizing particle passes through the gas it creates electron-ion pairs, but often the ejected electrons have sufficient energy to further ionize the medium. As shown in Table 31.5, the total number of electron-ion pairs (N_T) is usually a few times larger than the number of primaries (N_P) .

The probability for a released electron to have an energy E or larger follows an approximate $1/E^2$ dependence (Rutherford law), shown in Fig. 31.3 for Ar/CH₄ at NTP (dotted line, left scale). More detailed estimates taking into account the electronic structure of the medium are shown in the figure, for three values of the particle velocity factor $\beta\gamma$ [60]. The dot-dashed line provides, on the right scale, the

practical range of electrons (including scattering) of energy E. As an example, about 0.6% of released electrons have 1 keV or more energy, substantially increasing the ionization loss rate. The practical range of 1 keV electrons in argon (dot-dashed line, right scale) is 70 μ m and this can contribute to the error in the coordinate determination.

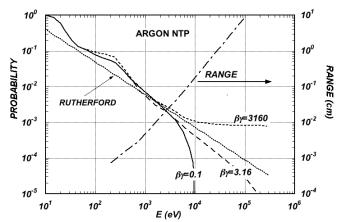


Figure 31.3: Probability of single collisions in which released electrons have an energy E or larger (left scale) and practical range of electrons in Ar/CH_4 (P10) at NTP (dot-dashed curve, right scale) [60].

The number of electron-ion pairs per primary ionization, or cluster size, has an exponentially decreasing probability; for argon, there is about 1% probability for primary clusters to contain ten or more electron-ion pairs [61].

Once released in the gas, and under the influence of an applied electric field, electrons and ions drift in opposite directions and diffuse towards the electrodes. The scattering cross section is determined by the details of atomic and molecular structure. Therefore, the drift velocity and diffusion of electrons depend very strongly on the nature of the gas, specifically on the inelastic cross-section involving the rotational and vibrational levels of molecules. In noble gases, the inelastic cross section is zero below excitation and ionization thresholds. Large drift velocities are achieved by adding polyatomic gases (usually CH₄, CO₂, or CF₄) having large inelastic cross sections at moderate energies, which results in "cooling" electrons into the energy range of the Ramsauer-Townsend minimum (at ~ 0.5 eV) of the elastic cross-section of argon. The reduction in both the total electron scattering cross-section and the electron energy results in a large increase of electron drift velocity (for a compilation of electron-molecule cross sections see Ref. 62). Another principal role of the polyatomic gas is to absorb the ultraviolet photons emitted by the excited noble gas atoms. Extensive collections of experimental data [63] and theoretical calculations based on transport theory [64] permit estimates of drift and diffusion properties in pure gases and their mixtures. In a simple approximation, gas kinetic theory provides the drift velocity v as a function of the mean collision time τ and the electric field E: $v = eE\tau/m_e$ (Townsend's expression). Values of drift velocity and diffusion for some commonly used gases at NTP are given in Fig. 31.4 and Fig. 31.5. These have been computed with the MAGBOLTZ program [65]. For different conditions, the horizontal axis must be scaled inversely with the gas density. Standard deviations for longitudinal (σ_L) and transverse diffusion (σ_T) are given for one cm of drift, and scale with the square root of the drift distance. Since the collection time is inversely proportional to the drift velocity, diffusion is less in gases such as CF₄ that have high drift velocities. In the presence of an external magnetic field, the Lorentz force acting on electrons between collisions deflects the drifting electrons and modifies the drift properties. The electron trajectories, velocities and diffusion parameters can be computed with MAGBOLTZ. A simple theory, the friction force model, provides an expression for the vector drift velocity v as a function of electric and magnetic field vectors E and B, of the

Larmor frequency $\omega = eB/m_e$, and of the mean collision time τ :

$$\boldsymbol{v} = \frac{e}{m_e} \frac{\tau}{1 + \omega^2 \tau^2} \left(\boldsymbol{E} + \frac{\omega \tau}{B} (\boldsymbol{E} \times \boldsymbol{B}) + \frac{\omega^2 \tau^2}{B^2} (\boldsymbol{E} \cdot \boldsymbol{B}) \boldsymbol{B} \right) \quad (31.13)$$

To a good approximation, and for moderate fields, one can assume that the energy of the electrons is not affected by B, and use for τ the values deduced from the drift velocity at B=0 (the Townsend expression). For \boldsymbol{E} perpendicular to \boldsymbol{B} , the drift angle to the relative to the electric field vector is $\tan\theta_B=\omega\tau$ and $v=(E/B)(\omega\tau/\sqrt{1+\omega^2\tau^2})$. For parallel electric and magnetic fields, drift velocity and longitudinal diffusion are not affected, while the transverse diffusion can be strongly reduced: $\sigma_T(B)=\sigma_T(B=0)/\sqrt{1+\omega^2\tau^2}$. The dotted line in Fig. 31.5 represents σ_T for the classic Ar/CH₄ (90:10) mixture at 4 T. Large values of $\omega\tau\sim 20$ at 5 T are consistent with the measurement of diffusion coefficient in Ar/CF₄/iC₄H₁₀ (95:3:2). This reduction is exploited in time projection chambers (Sec. 31.6.5) to improve spatial resolution.

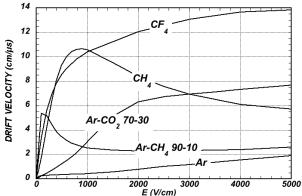


Figure 31.4: Computed electron drift velocity as a function of electric field in several gases at NTP and B = 0 [65].

In mixtures containing electronegative molecules, such as O_2 or $\mathrm{H}_2\mathrm{O}$, electrons can be captured to form negative ions. Capture cross-sections are strongly energy-dependent, and therefore the capture probability is a function of applied field. For example, the electron is attached to the oxygen molecule at energies below 1 eV. The three-body electron attachment coefficients may differ greatly for the same additive in different mixtures. As an example, at moderate fields (up to 1 kV/cm) the addition of 0.1% of oxygen to an Ar/CO₂ mixture results in an electron capture probability about twenty times larger than the same addition to Ar/CH₄.

Carbon tetrafluoride is not electronegative at low and moderate fields, making its use attractive as drift gas due to its very low diffusion. However, CF₄ has a large electron capture cross section at fields above ~ 8 kV/cm, before reaching avalanche field strengths. Depending on detector geometry, some signal reduction and resolution loss can be expected using this gas.

If the electric field is increased sufficiently, electrons gain enough energy between collisions to ionize molecules. Above a gas-dependent threshold, the mean free path for ionization, λ_i , decreases exponentially with the field; its inverse, $\alpha = 1/\lambda_i$, is the first Townsend coefficient. In wire chambers, most of the increase of avalanche particle density occurs very close to the anode wires, and a simple electrostatic consideration shows that the largest fraction of the detected signal is due to the motion of positive ions receding from the wires. The electron component, although very fast, contributes very little to the signal. This determines the characteristic shape of the detected signals in the proportional mode: a fast rise followed by a gradual increase. The slow component, the so-called "ion tail" that limits the time resolution of the detector, is usually removed by differentiation of the signal. In uniform fields, N_0 initial electrons multiply over a length xforming an electron avalanche of size $N = N_0 e^{\alpha x}$; N/N_0 is the gain of the detector. Fig. 31.6 shows examples of Townsend coefficients for several gas mixtures, computed with MAGBOLTZ [65].

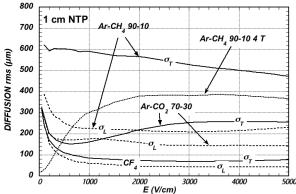


Figure 31.5: Electron longitudinal diffusion (σ_L) (dashed lines) and transverse diffusion (σ_T) (full lines) for 1 cm of drift at NTP and B=0. The dotted line shows σ_T for the P10 mixture at 4 T [65].

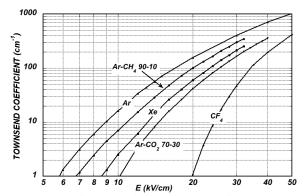


Figure 31.6: Computed first Townsend coefficient α as a function of electric field in several gases at NTP [65].

Positive ions released by the primary ionization or produced in the avalanches drift and diffuse under the influence of the electric field. Negative ions may also be produced by electron attachment to gas molecules. The drift velocity of ions in the fields encountered in gaseous detectors (up to few kV/cm) is typically about three orders of magnitude less than for electrons. The ion mobility μ , the ratio of drift velocity to electric field, is constant for a given ion type up to very high fields. Values of mobility at NTP for ions in their own and other gases are given in Table 31.6 [66]. For different temperatures and pressures, the mobility can be scaled inversely with the density assuming an ideal gas law. For mixtures, due to a very effective charge transfer mechanism, only ions with the lowest ionization potential survive after a short path in the gas. Both the lateral and transverse diffusion of ions are proportional to the square root of the drift time, with a coefficient that depends on temperature but not on the ion mass. Accumulation of ions in the gas drift volume may induce field distortions (see Sec. 31.6.5).

Table 31.6: Mobility of ions in gases at NTP [66].

| Gas | Ion | $\begin{array}{c} \text{Mobility } \mu \\ (\text{cm}^2 \ \text{V}^{-1} \ \text{s}^{-1}) \end{array}$ |
|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| $\begin{array}{c} \text{He} \\ \text{Ne} \\ \text{Ar} \\ \text{Ar/CH}_4 \\ \text{Ar/CO}_2 \\ \text{CH}_4 \end{array}$ | He ⁺ Ne ⁺ Ar ⁺ CH ₄ CO ₂ CH ₄ CO ₂ CO ₂ | 10.4 4.7 1.54 1.87 1.72 2.26 1.09 |

31.6.2. *Multi-Wire Proportional and Drift Chambers*: Revised March 2010 by Fabio Sauli (CERN) and Maxim Titov (CEA Saclay).

Single-wire counters that detect the ionization produced in a gas by a charged particle, followed by charge multiplication and collection around a thin wire have been used for decades. Good energy resolution is obtained in the proportional amplification mode, while very large saturated pulses can be detected in the streamer and Geiger modes [3].

Multiwire proportional chambers (MWPCs) [67,68], introduced in the late '60's, detect, localize and measure energy deposit by charged particles over large areas. A mesh of parallel anode wires at a suitable potential, inserted between two cathodes, acts almost as a set of independent proportional counters (see Fig. 31.7a). Electrons released in the gas volume drift towards the anodes and produce avalanches in the increasing field. Analytic expressions for the electric field can be found in many textbooks. The fields close to the wires E(r), in the drift region E_D , and the capacitance C per unit length of anode wire are approximately given by

$$E(r) = \frac{CV_0}{2\pi\epsilon_0} \frac{1}{r}$$
 $E_D = \frac{CV_0}{2\epsilon_0 s}$ $C = \frac{2\pi\epsilon_0}{\pi(\ell/s) - \ln(2\pi a/s)}$, (31.14)

where r is the distance from the center of the anode, s the wire spacing, ℓ and V_0 the distance and potential difference between anode and cathode, and a the anode wire radius.

Because of electrostatic forces, a node wires are in equilibrium only for a perfect geometry. Small deviations result in forces displacing the wires alternatively below and above the symmetry plane, sometimes with catastrophic results. These displacement forces are countered by the mechanical tension of the wire, up to a maximum unsupported stable length, L_M [58], above which the wire deforms:

$$L_M = \frac{s}{CV_0} \sqrt{4\pi\epsilon_0 T_M} \tag{31.15}$$

The maximum tension T_M depends on the wire diameter and modulus of elasticity. Table 31.7 gives approximate values for tungsten and the corresponding maximum stable wire length under reasonable assumptions for the operating voltage ($V_0 = 5 \,\mathrm{kV}$) [69]. Internal supports and spacers can be used in the construction of longer detectors to overcome limits on the wire length imposed by Eq. (31.15).

Table 31.7: Maximum tension T_M and stable unsupported length L_M for tungsten wires with spacing s, operated at $V_0 = 5$ kV. No safety factor is included.

| Wire diameter (μm) | T_M (newton) | s (mm) | L_M (cm) |
|--------------------|----------------|--------|------------|
| 10 | 0.16 | 1 | 25 |
| 20 | 0.65 | 2 | 85 |

Detection of charge on the wires over a predefined threshold provides the transverse coordinate to the wire with an accuracy comparable to that of the wire spacing. The coordinate along each wire can be obtained by measuring the ratio of collected charge at the two ends of resistive wires. Making use of the charge profile induced on segmented cathodes, the so-called center-of gravity (COG) method, permits localization of tracks to sub-mm accuracy. Due to the statistics of energy loss and asymmetric ionization clusters, the position accuracy is $\sim 50\,\mu\mathrm{m}$ rms for tracks perpendicular to the wire plane, but degrades to $\sim 250\,\mu\mathrm{mat}$ 30° to the normal [70]. The intrinsic bi-dimensional characteristic of the COG readout has found numerous applications in medical imaging.

Drift chambers, developed in the early '70's, can be used to estimate the longitudinal position of a track by exploiting the arrival time of electrons at the anodes if the time of interaction is known [71]. The distance between anode wires is usually several cm, allowing coverage of large areas at reduced cost. In the original design, a thicker wire (the field wire) at the proper voltage, placed between the anode wires, reduces the field at the mid-point between anodes and improves

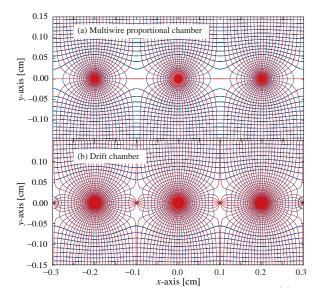


Figure 31.7: Electric field lines and equipotentials in (a) a multiwire proportional chamber and (b) a drift chamber.

charge collection (Fig. 31.7b). In some drift chamber designs, and with the help of suitable voltages applied to field-shaping electrodes, the electric field structure is adjusted to improve the linearity of space-to-drift-time relation, resulting in better spatial resolution [72].

Drift chambers can reach a longitudinal spatial resolution from timing measurement of order 100 µm (rms) or better for minimum ionizing particles, depending on the geometry and operating conditions. However, a degradation of resolution is observed [73] due to primary ionization statistics for tracks close to the anode wires, caused by the spread in arrival time of the nearest ionization clusters. The effect can be reduced by operating the detector at higher pressures. Sampling the drift time on rows of anodes led to the concept of multiple arrays such as the multi-drift module [74] and the JET chamber [75]. A measurement of drift time, together with the recording of charge sharing from the two ends of the anode wires provides the coordinates of segments of tracks. The total charge gives information on the differential energy loss and is exploited for particle identification. The time projection chamber (TPC) [76] combines a measurement of drift time and charge induction on cathodes, to obtain excellent tracking for high multiplicity topologies occurring at moderate rates (see Sec. 31.6.5). In all cases, a good knowledge of electron drift velocity and diffusion properties is required. This has to be combined with the knowledge of the electric fields in the structures, computed with commercial or custom-developed software [65,77]. For an overview of detectors exploiting the drift time for coordinate measurement see Refs. 6 and 58.

Multiwire and drift chambers have been operated with a variety of gas fillings and operating modes, depending on experimental requirements. The so-called "Magic Gas," a mixture of argon, isobutane and Freon [68], permits very high and saturated gains ($\sim 10^6$). This gas mixture was used in early wire chambers, but was found to be susceptible to severe aging processes. With present-day electronics, proportional gains around 10^4 are sufficient for detection of minimum ionizing particles, and noble gases with moderate amounts of polyatomic gases, such as methane or carbon dioxide, are used.

Although very powerful in terms of performance, multi-wire structures have reliability problems when used in harsh or hard-to-access environments, since a single broken wire can disable the entire detector. Introduced in the '80's, straw and drift tube systems make use of large arrays of wire counters encased in individual enclosures, each acting as an independent wire counter [78]. Techniques for low-cost mass production of these detectors have been developed for large experiments, such as the Transition Radiation Tracker and the Drift Tubes arrays for CERN's LHC experiments [79].

31.6.3. *High Rate Effects*: Revised March 2010 by Fabio Sauli (CERN) and Maxim Titov (CEA Saclay).

The production of positive ions in the avalanches and their slow drift before neutralization result in a rate-dependent accumulation of positive charge in the detector. This may result in significant field distortion, gain reduction and degradation of spatial resolution. As shown in Fig. 31.8 [80], the proportional gain drops above a charge production rate around 10^9 electrons per second and mm of wire, independently of the avalanche size. For a proportional gain of 10^4 and 100 electrons per track, this corresponds to a particle flux of $10^3 \, \mathrm{s^{-1}mm^{-1}}$ (1 kHz/mm² for 1 mm wire spacing).

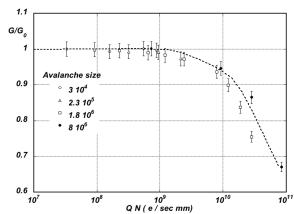


Figure 31.8: Charge rate dependence of normalized gas gain G/G_0 (relative to zero counting rate) in proportional thin-wire detectors [80]. Q is the total charge in single avalanche; N is the particle rate per wire length.

At high radiation fluxes, a fast degradation of detectors due to the formation of polymers deposits (aging) is often observed. The process has been extensively investigated, often with conflicting results. Several causes have been identified, including organic pollutants and silicone oils. Addition of small amounts of water in many (but not all) cases has been shown to extend the lifetime of the detectors. Addition of fluorinated gases (e.g., CF₄) or oxygen may result in an etching action that can overcome polymer formation, or even eliminate already existing deposits. However, the issue of long-term survival of gas detectors with these gases is controversial [81]. Under optimum operating conditions, a total collected charge of a few coulombs per cm of wire can usually be reached before noticeable degradation occurs. This corresponds, for one mm spacing and at a gain of 10^4 , to a total particle flux of $\sim 10^{14}$ MIPs/cm².

31.6.4. *Micro-Pattern Gas Detectors*: Revised March 2010 by Fabio Sauli (CERN) and Maxim Titov (CEA Saclay)

Despite various improvements, position-sensitive detectors based on wire structures are limited by basic diffusion processes and space charge effects to localization accuracies of $50\text{--}100\,\mu\mathrm{m}$ [82]. Modern photolithographic technology led to the development of novel Micro-Pattern Gas Detector (MPGD) concepts [83], revolutionizing cell size limitations for many gas detector applications. By using pitch size of a few hundred $\mu\mathrm{m}$, an order of magnitude improvement in granularity over wire chambers, these detectors offer intrinsic high rate capability (> 10^6 Hz/mm²), excellent spatial resolution ($\sim 30~\mu\mathrm{m}$), multi-particle resolution ($\sim 500~\mu\mathrm{m}$), and single photo-electron time resolution in the ns range.

The Micro-Strip Gas Chamber (MSGC), invented in 1988, was the first of the micro-structure gas chambers [84]. It consists of a set of tiny parallel metal strips laid on a thin resistive support, alternatively connected as anodes and cathodes. Owing to the small anode-to-cathode distance ($\sim 100~\mu m$), the fast collection of positive ions reduces space charge build-up, and provides a greatly increased rate capability. Unfortunately, the fragile electrode structure of the MSGC turned out to be easily destroyed by discharges induced by heavily ionizing particles [85]. Nevertheless, detailed studies of their properties, and in particular, on the radiation-induced processes

leading to discharge breakdown, led to the development of the more powerful devices: GEM and Micromegas. These have improved reliability and radiation hardness. The absence of space-charge effects in GEM detectors at the highest rates reached so far and the fine granularity of MPGDs improve the maximum rate capability by more than two orders of magnitude (Fig. 31.9) [72,86]. Even larger rate capability has been reported for Micromegas [87].

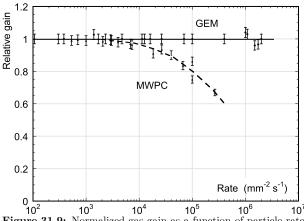


Figure 31.9: Normalized gas gain as a function of particle rate for MWPC [72] and GEM [86].

The Gas Electron Multiplier (GEM) detector consists of a thin-foil copper-insulator-copper sandwich chemically perforated to obtain a high density of holes in which avalanches occur [88]. The hole diameter is typically between 25 μ m and 150 μ m, while the corresponding distance between holes varies between 50 μ m and 200 μ m. The central insulator is usually (in the original design) the polymer Kapton, with a thickness of 50 μ m. Application of a potential difference between the two sides of the GEM generates the electric fields indicated in Fig. 31.10. Each hole acts as an independent proportional counter. Electrons released by the primary ionization particle in the upper conversion region (above the GEM foil) drift into the holes, where charge multiplication occurs in the high electric field (50-70 kV/cm). Most of avalanche electrons are transferred into the gap below the GEM. Several GEM foils can be cascaded, allowing the multi-layer GEM detectors to operate at overall gas gain above 10⁴ in the presence of highly ionizing particles, while strongly reducing the risk of discharges. This is a major advantage of the GEM technology [89]. Localization can then be performed by collecting the charge on a patterned one- or two-dimensional readout board of arbitrary pattern, placed below the last GEM.

The micro-mesh gaseous structure (Micromegas) is a thin parallelplate avalanche counter, as shown in Fig. 31.11 [90]. It consists of a drift region and a narrow multiplication gap (25–150 μ m) between a thin metal grid (micromesh) and the readout electrode (strips or pads of conductor printed on an insulator board). Electrons from the primary ionization drift through the holes of the mesh into the narrow multiplication gap, where they are amplified. The electric field is homogeneous both in the drift (electric field ~1 kV/cm) and amplification (50-70 kV/cm) gaps. In the narrow multiplication region, gain variations due to small variations of the amplification gap are approximately compensated by an inverse variation of the amplification coefficient, resulting in a more uniform gain. The small amplification gap produces a narrow avalanche, giving rise to excellent spatial resolution: 12 μ m accuracy, limited by the micro-mesh pitch, has been achieved for MIPs, as well as very good time resolution and energy resolution ($\sim 12\%$ FWHM with 6 keV x rays) [91].

The performance and robustness of GEM and Micromegas have encouraged their use in high-energy and nuclear physics, UV and visible photon detection, astroparticle and neutrino physics, neutron detection and medical physics. Most structures were originally optimized for high-rate particle tracking in nuclear and high-energy physics experiments. COMPASS, a high-luminosity experiment at CERN, pioneered the use of large-area ($\sim 40 \times 40~\text{cm}^2$) GEM and

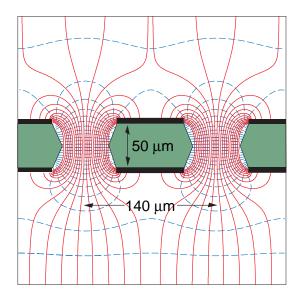


Figure 31.10: Schematic view and typical dimensions of the hole structure in the GEM amplification cell. Electric field lines (solid) and equipotentials (dashed) are shown.

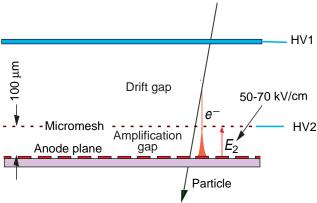


Figure 31.11: Schematic drawing of the Micromegas detector.

Micromegas detectors close to the beam line with particle rates of $25~\mathrm{kHz/mm^2}$. Both technologies achieved a tracking efficiency of close to 100% at gas gains of about 10^4 , a spatial resolution of $70{\text -}100~\mu\mathrm{m}$ and a time resolution of $\sim 10~\mathrm{ns}$. GEM detectors are also used for triggering in the LHCb Muon System and for tracking in the TOTEM Telescopes. Both GEM and Micromegas devices are foreseen for the upgrade of the LHC experiments and for one of the readout options for the Time Projection Chamber (TPC) at the International Linear Collider (ILC). The development of new fabrication techniques—"bulk" Micromegas technology [92] and single-mask GEMs [93] —is a big step toward industrial production of large-size MPGDs. In some applications requiring very large-area coverage with moderate spatial resolution, coarse macro-patterned detectors, such as Thick GEMs (THGEM) [94] or patterned resistive-plate devices [95] might offer economically interesting solutions.

Sensitive and low-noise electronics enlarge the range of the MPGD applications. Recently, the GEM and Micromegas detectors were read out by high-granularity ($\sim 50~\mu\mathrm{m}$ pitch) CMOS chips assembled directly below the GEM or Micromegas amplification structures [96]. These detectors use the bump-bonding pads of a pixel chip as an integrated charge collecting anode. With this arrangement signals are induced at the input gate of a charge-sensitive preamplifier (top metal layer of the CMOS chip). Every pixel is then directly connected to the amplification and digitization circuits, integrated in the underlying active layers of the CMOS technology, yielding timing and charge measurements as well as precise spatial information in 3D.

The operation of a MPGD with a Timepix CMOS chip has

demonstrated the possibility of reconstructing 3D-space points of individual primary electron clusters with $\sim\!30\,\mu\mathrm{m}$ spatial resolution and event-time resolution with nanosecond precision. This has become indispensable for tracking and triggering and also for discriminating between ionizing tracks and photon conversions. The GEM, in conjunction with a CMOS ASIC,* can directly view the absorption process of a few keV x-ray quanta and simultaneously reconstruct the direction of emission, which is sensitive to the x-ray polarization. Thanks to these developments, a micro-pattern device with finely segmented CMOS readout can serve as a high-precision "electronic bubble chamber." This may open new opportunities for x-ray polarimeters, detection of weakly interacting massive particles (WIMPs) and axions, Compton telescopes, and 3D imaging of nuclear recoils.

An elegant solution for the construction of the Micromegas with pixel readout is the integration of the amplification grid and CMOS chip by means of an advanced "wafer post-processing" technology [97]. This novel concept is called "Ingrid" (see Fig. 31.12). With this technique, the structure of a thin $(1\,\mu\mathrm{m})$ aluminum grid is fabricated on top of an array of insulating pillars. which stands $\sim 50\,\mu\mathrm{m}$ above the CMOS chip. The sub- $\mu\mathrm{m}$ precision of the grid dimensions and avalanche gap size results in a uniform gas gain. The grid hole size, pitch and pattern can be easily adapted to match the geometry of any pixel readout chip.

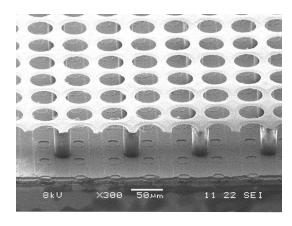


Figure 31.12: Photo of the Micromegas "Ingrid" detector. The grid holes can be accurately aligned with readout pixels of CMOS chip. The insulating pillars are centered between the grid holes, thus avoiding dead regions.

Recent developments in radiation hardness research with state-of-the-art MPGDs are reviewed in Ref. 98. Earlier aging studies of GEM and Micromegas concepts revealed that they might be even less vulnerable to radiation-induced performance degradation than standard silicon microstrip detectors.

The RD51 collaboration was established in 2008 to further advance technological developments of micro-pattern detectors and associated electronic-readout systems for applications in basic and applied research [99].

^{*} Application Specific Integrated Circuit

31.6.5. *Time-projection chambers*: Reviser October 2011 by D. Karlen (U. of Victoria and TRIUMF, Canada)

The Time Projection Chamber (TPC) concept, invented by David Nygren in the late 1970's [76], is the basis for charged particle tracking in a large number of particle and nuclear physics experiments. A uniform electric field drifts tracks of electrons produced by charged particles traversing a medium, either gas or liquid, towards a surface segmented into 2D readout pads. The signal amplitudes and arrival times are recorded to provide full 3D measurements of the particle trajectories. The intrinsic 3D segmentation gives the TPC a distinct advantage over other large volume tracking detector designs which record information only in a 2D projection with less overall segmentation, particularly for pattern recognition in events with large numbers of particles.

Gaseous TPC's are often designed to operate within a strong magnetic field (typically parallel to the drift field) so that particle momenta can be estimated from the track curvature. For this application, precise spatial measurements in the plane transverse to the magnetic field are most important. Since the amount of ionization along the length of the track depends on the velocity of the particle, ionization and momentum measurements can be combined to identify the types of particles observed in the TPC. The estimator for the energy deposit by a particle is usually formed as the truncated mean of the energy deposits, using the 50%–70% of the samples with the smallest signals. Variance due to energetic δ -ray production is thus reduced.

Gas amplification of 10^3-10^4 at the readout endplate is usually required in order to provide signals with sufficient amplitude for conventional electronics to sense the drifted ionization. Until recently, the gas amplification system used in TPC's have exclusively been planes of anode wires operated in proportional mode placed close to the readout pads. Performance has been recently improved by replacing these wire planes with micro-pattern gas detectors, namely GEM [88] and Micromegas [90] devices. Advances in electronics miniaturization have been important in this development, allowing pad areas to be reduced to the 10 mm² scale or less, well matched to the narrow extent of signals produced with micro-pattern gas detectors. Presently, the ultimate in fine segmentation TPC readout are silicon sensors, with 0.05 mm \times 0.05 mm pixels, in combination with GEM or Micromegas [100]. With such fine granularity it is possible to count the number of ionization clusters along the length of a track which, in principle, can improve the particle identification capability.

Examples of two modern large volume gaseous TPC's are shown in Fig. 31.13 and Fig. 31.14. The particle identification performance is illustrated in Fig. 31.15, for the original TPC in the PEP-4/9 experiment [101].

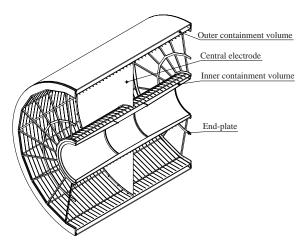


Figure 31.13: The ALICE TPC shown in a cutaway view [102]. The drift volume is 5 m long with a 5 m diameter. Gas amplification is provided by planes of anode wires.

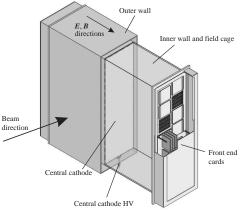


Figure 31.14: One of the 3 TPC modules for the near detector of the T2K experiment [103]. The drift volume is $2 \text{ m} \times 2 \text{ m} \times 0.8 \text{ m}$. Micromegas devices are used for gas amplification and readout.

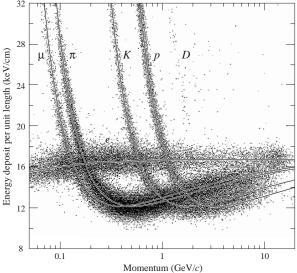


Figure 31.15: The PEP4/9-TPC energy deposit measurements (185 samples, 8.5 atm Ar-CH₄ 80:20). The ionization rate at the Fermi plateau (at high β) is 1.4 times that for the minimum at lower β . This ratio increases to 1.6 at atmospheric pressure.

The greatest challenges for a large TPC arise from the long drift distance, typically 100 times further than in a comparable wire chamber design. In particular, the long drift distance can make the device sensitive to small distortions in the electric field. Distortions can arise from a number of sources, such as imperfections in the TPC construction, deformations of the readout surface, or the presence of ions in the active medium.

For a gaseous TPC operated in a magnetic field, the electron drift velocity \boldsymbol{v} is defined by Eq. (31.13). With a strong magnetic field parallel to the electric field and a gas with a large value of $\omega\tau$ (also favored to reduce transverse diffusion as discussed below), the transverse displacements of the drifting electrons due to electric field distortions are reduced. In this mode of operation, it is essential to precisely map the magnetic field as the electron drift lines closely follow the magnetic field lines. Corrections for electric and/or magnetic field non-uniformities can be determined from control samples of electrons produced by ionizing the gas with UV laser beams, from photoelectrons produced on the cathode, or from tracks emanating from calibration reactions.

The long drift distance means that there is a delay, typically $10-100~\mu s$ in a large gaseous TPC, for signals to arrive at the endplate. For experiments with shorter intervals between events, this

can produce ambiguities in the starting time for the drift of ionization. This can be resolved by matching the TPC data with that from an auxiliary detector providing additional spatial or timing information.

In a gaseous TPC, the motion of positive ions is much slower than the electrons, and so the positive ions produced by many events may exist in the active volume. Of greatest concern is the ions produced in the gas amplification stage. Large gaseous TPC's built until now with wire planes have included a gating grid that prevent the positive ions from escaping into the drift volume in the interval between event triggers. Micro-pattern gas detectors release much less positive ions than wire planes operating at the same gain, which may allow operation of a TPC without a gating grid.

Given the long drift distance in a large TPC, the active medium must remain very pure, as small amounts of contamination can absorb the ionization signal. For example, in a typical large gaseous TPC, O_2 must be kept below a few parts in 10^5 , otherwise a large fraction of the drifting electrons will become attached. Special attention must be made in the choice of construction materials in order to avoid the release of other electronegative contaminants.

Diffusion degrades the position information of ionization that drifts a long distance. For a gaseous TPC, the effect can be alleviated by the choice of a gas with low intrinsic diffusion or by operating in a strong magnetic field parallel to the drift field with a gas which exhibits a significant reduction in transverse diffusion with magnetic field. For typical operation without magnetic field, the transverse extent of the electrons, σ_{Dx} , is a few mm after drifting 1 m due to diffusion. With a strong magnetic field, σ_{Dx} can be reduced by as much as a factor of 10,

$$\sigma_{Dx}(B)/\sigma_{Dx}(0) = \frac{1}{\sqrt{1+\omega^2\tau^2}}$$
 (31.16)

where $\omega \tau$ is defined above. The diffusion limited position resolution from the information collected by a single row of pads is

$$\sigma_x = \frac{\sigma_{Dx}}{\sqrt{n}} \tag{31.17}$$

where n is the effective number of electrons collected by the pad row, giving an ultimate single row resolution of order 100 μ m.

Diffusion is significantly reduced in a negative-ion TPC [104], which uses a special gas mixture that attaches electrons immediately as they are produced. The drifting negative ions exhibit much less diffusion than electrons. The slow drift velocity and small $\omega \tau$ of negative ions must be compatible with the experimental environment.

The spatial resolution achieved by a TPC is determined by a number of factors in addition to diffusion. Non-uniform ionization along the length of the track is a particularly important factor, and is responsible for the so-called "track angle" and " $E \times B$ " effects. If the boundaries between pads in a row are not parallel to the track, the ionization fluctuations will increase the variance in the position estimate from that row. For this reason, experiments with a preferred track direction should have pad boundaries aligned with that direction. Traditional TPC's with wire plane amplification suffer from the effects of non-parallel electric and magnetic fields near the wires that rotate ionization segments, thereby degrading the resolution because of the non-uniform ionization. Micro-pattern gas detectors exhibit a much smaller $E \times B$ effect, since their feature size is much smaller than that of a wire grid.

31.6.6. Transition radiation detectors (TRD's): Written August 2007 by P. Nevski (BNL) and A. Romaniouk (Moscow Eng. & Phys. Inst.)

Transition radiation (TR) x rays are produced when a highly relativistic particle ($\gamma \gtrsim 10^3$) crosses a refractive index interface, as discussed in Sec. 30.7. The x rays, ranging from a few keV to a few dozen keV, are emitted at a characteristic angle $1/\gamma$ from the particle trajectory. Since the TR yield is about 1% per boundary crossing, radiation from multiple surface crossings is used in practical detectors. In the simplest concept, a detector module might consist of low-Z foils followed by a high-Z active layer made of proportional counters filled with a Xe-rich gas mixture. The atomic number considerations follow from the dominant photoelectric absorption cross section per atom going roughly as Z^n/E_x^3 , where n varies between 4 and 5 over

the region of interest, and the x-ray energy is E_x .* To minimize self-absorption, materials such as polypropylene, Mylar, carbon, and (rarely) lithium are used as radiators. The TR signal in the active regions is in most cases superimposed upon the particle's ionization losses. These drop a little faster than Z/A with increasing Z, providing another reason for active layers with high Z.

The TR intensity for a single boundary crossing always increases with γ , but for multiple boundary crossings interference leads to saturation near a Lorentz factor $\gamma_{\rm sat}=0.6~\omega_1\sqrt{\ell_1\ell_2}/c~[105]$, where ω_1 is the radiator plasma frequency, ℓ_1 is its thickness, and ℓ_2 the spacing. In most of the detectors used in particle physics the radiator parameters are chosen to provide $\gamma_{\rm sat}\approx 2000$. Those detectors normally work as threshold devices, ensuring the best electron/pion separation in the momentum range 1 GeV/ $c\lesssim p\lesssim 150~{\rm GeV}/c$.

One can distinguish two design concepts—"thick" and "thin" detectors:

- 1. The radiator, optimized for a minimum total radiation length at maximum TR yield and total TR absorption, consists of few hundred foils (for instance 300 20 μm thick polypropylene foils). A dominant fraction of the soft TR photons is absorbed in the radiator itself. To increase the average TR photon energy further, part of the radiator far from the active layers is often made of thicker foils. The detector thickness, about 2 cm for Xe-filled gas chambers, is optimized to absorb the shaped x-ray spectrum. A classical detector is composed of several similar modules which respond nearly independently. Such detectors were used in the NA34 [106], and are being used in the ALICE experiment [107].
- 2. In another TRD concept a fine granular radiator/detector structure exploits the soft part of the TR spectrum more efficiently. This can be achieved, for instance, by distributing small-diameter straw-tube detectors uniformly or in thin layers throughout the radiator material (foils or fibers). Even with a relatively thin radiator stack, radiation below 5 keV is mostly lost in the radiators themselves. However for photon energies above this value the absorption becomes smaller and the radiation can be registered by several consecutive detector layers, thus creating a strong TR build-up effect. Descriptions of detectors using this approach can be found in both accelerator and space experiments [107]. For example, in the ATLAS TR tracker charged particles cross about 35 effective straw tube layers embedded in the radiator material [107]. The effective thickness of the Xe gas per straw is about 2.3 mm and the average number of foils per straw is about 40 with an effective foil thickness of about 20 μ m.

Both TR photon absorption and the TR build-up significantly affect the detector performance. Although the values mentioned above are typical for most of the plastic radiators used with Xe-based detectors, they vary significantly depending on detector parameters: radiator material, thickness and spacing, the construction of the sensitive chambers, their position, etc. Thus careful simulations are usually needed to build a detector optimized for a particular application.

The discrimination between electrons and pions can be based on the charge deposition measured in each detection module, on the number of clusters—energy depositions observed above an optimal threshold (usually in the 5 to 7 keV region), or on more sophisticated methods analyzing the pulse shape as a function of time. The total energy measurement technique is more suitable for thick gas volumes, which absorb most of the TR radiation and where the ionization loss fluctuations are small. The cluster-counting method works better for detectors with thin gas layers, where the fluctuations of the ionization losses are big. Cluster-counting replaces the Landau-Vavilov distribution of background ionization energy losses with the Poisson statistics of δ -electrons, responsible for the distribution tails. The latter distribution is narrower that the Landau-Vavilov distribution.

The major factor in the performance of any TRD is its overall length. This is illustrated in Fig. 31.16, which shows, for a variety of detectors, the pion efficiency at a fixed electron efficiency of 90% as a function of the overall detector length. The experimental data, covering a range of particle energies from a few GeV to 40 GeV, are

^{*} Photon absorption coefficients for the elements (via a NIST link), and $dE/dx|_{\rm min}$ and plasma energies for many materials are given in pdg.lbl.gov/AtomicNuclearProperties.

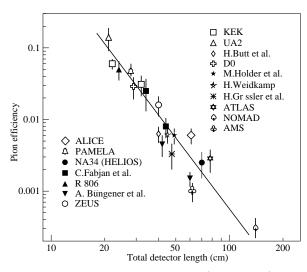


Figure 31.16: Pion efficiency measured (or predicted) for different TRDs as a function of the detector length for a fixed electron efficiency of 90%. The plot is taken from [106] with efficiencies of more recent detectors added [107].

rescaled to an energy of 10 GeV when possible. Phenomenologically, the rejection power against pions increases as $5\cdot 10^{L/38}$, where the range of validity is $L\approx 20$ –100 cm.

Many recent TRDs combine particle identification with charged-track measurement in the same detector [107]. This provides a powerful tool for electron identification even at very high particle densities. Another example of this combination is described by Brigida et al. in Ref. 107. In this work Si-microstrip detectors operating in a magnetic filed are used both for particle and TR detection. The excellent coordinate resolution of the Si detectors allows spatial separation of the TR photons from particle ionization tracks with relatively modest distances between radiator and detector.

Recent TRDs for particle astrophysics are designed to directly measure the Lorentz factor of high-energy nuclei by using the quadratic dependence of the TR yield on nuclear charge; see Cherry and Müller papers in Ref. 107. The radiator configuration (ℓ_1, ℓ_2) is tuned to extend the TR yield rise up to $\gamma \lesssim 10^5$ using more energetic part of the TR spectrum (up to 100 keV). Exotic radiator materials such as aluminum and unusual TR detection methods (Compton scattering) are used such cases.

31.6.7. Resistive-plate chambers: Revised September 2007 by H.R. Band (U. Wisconsin).

The resistive-plate chamber (RPC) was developed by Santonico and Cardarelli in the early 1980's [108] as a low-cost alternative to large scintillator planes.* Most commonly, an RPC is constructed from two parallel high-resistivity $(10^9-10^{13} \ \Omega\text{-cm})$ glass or phenolic (Bakelite)/melamine laminate plates with a few-mm gap between them which is filled with atmospheric-pressure gas. The gas is chosen to absorb UV photons in order to limit transverse growth of discharges. The backs of the plates are coated with a lower-resistivity paint or ink $(\sim 10^5 \,\Omega/\Box)$, and a high potential (7–12 kV) is maintained between them. The passage of a charged particle initiates an electric discharge, whose size and duration are limited since the current reduces the local potential to below that needed to maintain the discharge. The sensitivity of the detector outside of this region is unaffected. The signal readout is via capacitive coupling to metallic strips on both sides of the detector which are separated from the high voltage coatings by thin insulating sheets. The x and y position of the discharge can be measured if the strips on opposite sides of the gap are orthogonal. When operated in streamer mode, the induced signals on the strips can be quite large (~300 mV), making sensitive electronics unnecessary. An example of an RPC structure is shown in Fig. 31.17.

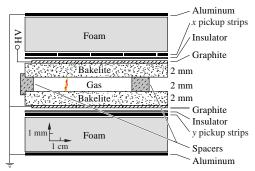


Figure 31.17: Schematic cross section of a typical RPC, in this case the single-gap streamer-mode BaBar RPC.

RPC's have inherent rate limitations since the time needed to re-establish the field after a discharge is proportional to the chamber capacitance and plate resistance. The average charge per streamer is 100-1000 pC. Typically, the efficiency of streamer-mode glass RPC's begins to fall above $\sim 0.4~{\rm Hz/cm^2}$. Because of Bakelite's lower bulk resistivity, Bakelite RPC's can be efficient at $10-100~{\rm Hz/cm^2}$. The need for higher rate capability led to the development of avalanchemode RPC's, in which the gas and high voltage have been tuned to limit the growth of the electric discharge, preventing streamer formation. Typical avalanchemode RPC's have a signal charge of about $10~{\rm pC}$ and can be efficient at $1~{\rm kHz/cm^2}$. The avalanche discharge produces a much smaller induced signal on the pickup strips ($\sim 1~{\rm mV}$) than streamers, and thus requires a more sophisticated and careful electronic design.

Many variations of the initial RPC design have been built for operation in either mode. Efficiencies of $\gtrsim 92\%$ for single gaps can be improved by the use of two or more gas gaps with shared pickup strips. Non-flammable and more environmentally friendly gas mixtures have been developed. In streamer mode, various mixtures of argon with isobutane and tetrafluoroethane have been used. For avalanche mode operation, a gas mixture of tetrafluoroethane (C₂H₂F₄) with 2–5% isobutane and 0.4–10% sulfur hexafluoride (SF₆) is typical. An example of large-scale RPC use is provided by the muon system being built for the ATLAS detector, where three layers of pairs of RPC's are used to trigger the drift tube arrays between the pairs. The total area is about 10,000 m². These RPC's provide a spatial resolution of 1 cm and a time resolution of 1 ns at an efficiency $\geq 99\%$.

Developments of multiple-gap RPC's [110] lead to RPC designs with much better timing resolution ($\sim 50\,\mathrm{ps}$) for use in time-of-flight particle identification systems. A pioneering design used by the HARP experiment [111] has two sets of 2 thin gas gaps (0.3 mm) separated by thin(0.7 mm) glass plates. The outer plates are connected to high voltage and ground while the inner plate is electrically isolated and floats to a stable equilibrium potential. The observed RPC intrinsic time resolution of 127 ps may have been limited by amplifier noise. Fonte provides useful review [112] of other RPC designs.

Operational experience with RPC's has been mixed. Several experiments (e.g., L3 and HARP) have reported reliable performance. However, the severe problems experienced with the BaBar RPC's have raised concerns about the long-term reliability of Bakelite RPC's.

Glass RPC's have had fewer problems, as seen by the history of the BELLE chambers. A rapid growth in the noise rate and leakage current in some of the BELLE glass RPC's was observed during commissioning. It was found that water vapor in the input gas was reacting with fluorine (produced by the disassociation of the tetrafluoroethane in the streamers) to produce hydrofluoric acid. The acid etched the glass surfaces, leading to increased noise rates and lower efficiencies. The use of copper gas piping to insure the dryness of the input gas stopped the problem. The BELLE RPC's have now operated reliably for more than 5 years.

Several different failure modes diagnosed in the first-generation BaBar Bakelite RPC's caused the average efficiency of the barrel RPC's to fall from $\gtrsim 90\%$ to 35% in five years. The linseed oil which is used in Bakelite RPC's to coat the inner surface [113] had not been completely cured. Under warm conditions (32° C)

^{*} It was based on earlier work on a spark counter with one high-resistivity plate [109].

and high voltage, oil collected on the spacers between the gaps or formed oil-drop bridges between the gaps. This led to large leakage currents (50–100 μ A in some chambers) which persisted even when the temperature was regulated at 20° C. In addition, the graphite layer used to distribute the high voltage over the Bakelite became highly resistive $(100 \,\mathrm{k}\Omega/\Box \to 10 \,\mathrm{M}\Omega/\Box)$, resulting in lowered efficiency in some regions and the complete death of whole chambers.

The BaBar problems and the proposed use of Bakelite RPC's in the LHC detectors prompted detailed studies of RPC aging and have led to improved construction techniques and a better understanding of RPC operational limits. The graphite layer has been improved and should be stable with integrated currents of $\lesssim 600 \,\mathrm{mC/cm^2}$. Molded gas inlets and improved cleanliness during construction have reduced the noise rate of new chambers. Unlike glass RPC's, Bakelite RPC's have been found to require humid input gases to prevent drying of the Bakelite (increasing the bulk resistivity) which would decrease the rate capability. Second-generation BaBar RPC's incorporating many of the above improvements have performed reliably for over two years [114].

With many of these problems solved, new-generation RPC's are now being or soon will be used in about a dozen cosmic-ray and HEP detectors. Their comparatively low cost, ease of construction, good time resolution, high efficiency, and moderate spatial resolution make them attractive in many situations, particularly those requiring fast timing and/or large-area coverage.

31.7. Semiconductor detectors

Updated August 2011 by H. Spieler.

Semiconductor detectors provide a unique combination of energy and position resolution. In collider detectors they are most widely used as position sensing devices and photodetectors (Sec. 31.2). Integrated circuit technology allows the formation of high-density micron-scale electrodes on large (15–20 cm diameter) wafers, providing excellent position resolution. Furthermore, the density of silicon and its small ionization energy yield adequate signals with active layers only 100–300 μ m thick, so the signals are also fast (typically tens of ns). The high energy resolution is a key parameter in x-ray, gamma, and charged particle spectroscopy, e.g., in neutrinoless double beta decay searches. Silicon and germanium are the most commonly used materials, but gallium-arsenide, CdTe, CdZnTe, and other materials are also useful. CdZnTe provides a higher stopping power and the ratio of Cd to Zn concentrations changes the bandgap. Ge detectors are commonly operated at liquid nitrogen temperature to reduce the bias current, which depends exponentially on temperature. Semiconductor detectors depend crucially on low-noise electronics (see Sec. 31.8), so the detection sensitivity is determined by signal charge and capacitance. For a comprehensive discussion of semiconductor detectors and electronics see Ref. 115.

31.7.1. Materials Requirements:

Semiconductor detectors are essentially solid state ionization chambers. Absorbed energy forms electron-hole pairs, i.e., negative and positive charge carriers, which under an applied electric field move towards their respective collection electrodes, where they induce a signal current. The energy required to form an electron-hole pair is proportional to the bandgap. In tracking detectors the energy loss in the detector should be minimal, whereas for energy spectroscopy the stopping power should be maximized, so for gamma rays high-Zmaterials are desirable.

Measurements on silicon photodiodes [116] show that for photon energies below 4 eV one electron-hole (e-h) pair is formed per incident photon. The mean energy E_i required to produce an e-h pair peaks at 4.4 eV for a photon energy around 6 eV. Above $\sim 1.5 \text{ keV}$ it assumes a constant value, 3.67 eV at room temperature. It is larger than the bandgap energy because momentum conservation requires excitation of lattice vibrations (phonons). For minimum-ionizing particles, the most probable charge deposition in a 300 μ m thick silicon detector is about 3.5 fC (22000 electrons). Other typical ionization energies are 2.96 eV in Ge, 4.2 eV in GaAs, and 4.43 eV in CdTe.

Since both electronic and lattice excitations are involved, the variance in the number of charge carriers $N = E/E_i$ produced by an absorbed energy E is reduced by the Fano factor F (about 0.1 in Si and Ge). Thus, $\sigma_N = \sqrt{FN}$ and the energy resolution

 $\sigma_E/E = \sqrt{FE_i/E}$. However, the measured signal fluctuations are usually dominated by electronic noise or energy loss fluctuations in the detector. The electronic noise contributions depend on the pulse shaping in the signal processing electronics, so the choice of the shaping time is critical (see Sec. 31.8).

A smaller bandgap would produce a larger signal and improve energy resolution, but the intrinsic resistance of the material is critical. Thermal excitation, given by the Fermi-Dirac distribution, promotes electrons into the conduction band, so the thermally excited carrier concentration increases exponentially with decreasing bandgaps. In pure Si the carrier concentration is $\sim 10^{10} \text{cm}^{-3}$ at 300 K, corresponding to a resistivity $\rho \approx 400\,\mathrm{k}\Omega\,\mathrm{cm}$. In reality, crystal imperfections and minute impurity concentrations limit Si carrier concentrations to $\sim 10^{11}~{\rm cm}^{-3}$ at 300 K, corresponding to a resistivity $\rho \approx 40\,{\rm k}\Omega\,{\rm cm}.$ In practice, resistivities up to $20 \,\mathrm{k}\Omega\,\mathrm{cm}$ are available, with mass production ranging from 5 to $10 \,\mathrm{k}\Omega\,\mathrm{cm}$. Signal currents at keV scale energies are of order μ A. However, for a resistivity of $10^4~\Omega cm$ a 300 μ m thick sensor with 1 cm² area would have a resistance of $300\,\Omega$, so 30 V would lead to a current flow of 100 mA and a power dissipation of 3 W. On the other hand, high-quality single crystals of Si and Ge can be grown economically with suitably large volumes. so to mitigate the effect of resistivity one resorts to reverse-biased diode structures. Although this reduces the bias current relative to a resistive material, the thermally excited leakage current can still be excessive at room temperature, so Ge diodes are typically operated at liquid nitrogen temperature (77 K).

A major effort is to find high-Z materials with a bandgap that is sufficiently high to allow room-temperature operation while still providing good energy resolution. Compound semiconductors, e.g., CdZnTe, can allow this, but typically suffer from charge collection problems, characterized by the product $\mu\tau$ of mobility and carrier lifetime. In Si and Ge $\mu\tau > 1\,\mathrm{cm}^2\,\mathrm{V}^{-1}$ for both electrons and holes, whereas in compound semiconductors it is in the range 10^{-3} – 10^{-8} . Since for holes $\mu\tau$ is typically an order of magnitude smaller than for electrons, detector configurations where the electron contribution to the charge signal dominates—e.g., strip or pixel structures—can provide better performance.

31.7.2. Detector Configurations:

A p-n junction operated at reverse bias forms a sensitive region depleted of mobile charge and sets up an electric field that sweeps charge liberated by radiation to the electrodes. Detectors typically use an asymmetric structure, e.g., a highly doped p electrode and a lightly doped n region, so that the depletion region extends predominantly into the lightly doped volume.

In a planar device the thickness of the depleted region is

$$W = \sqrt{2\epsilon (V + V_{bi})/Ne} = \sqrt{2\rho\mu\epsilon(V + V_{bi})}, \qquad (31.18)$$

where V = external bias voltage

 V_{bi} = "built-in" voltage ($\approx 0.5 \text{ V}$ for resistivities typically used in Si detectors)

N =doping concentration

e = electronic charge

 $\epsilon = \text{dielectric constant} = 11.9 \ \epsilon_0 \approx 1 \ \text{pF/cm} \ \text{in Si}$

 $\rho = \text{resistivity (typically 1-10 k}\Omega \text{ cm in Si)}$

 $\mu = \text{charge carrier mobility}$

 $= 1350 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1} \text{ for electrons in Si}$ $= 450 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1} \text{ for holes in Si}$

In Si

$$W=0.5~\left[\mu\mathrm{m}/\sqrt{\Omega\text{-cm}\cdot\mathrm{V}}\right]\times\sqrt{\rho(V+V_{bi})}~\mathrm{for}~n\text{-type Si, and}$$

$$W = 0.3 \ [\mu \text{m}/\sqrt{\Omega \cdot \text{cm} \cdot \text{V}}] \times \sqrt{\rho (V + V_{bi})} \text{ for } p\text{-type Si.}$$

The conductive p and n regions together with the depleted volume form a capacitor with the capacitance per unit area

$$C = \epsilon/W \approx 1 \,[\text{pF/cm}]/W \text{ in Si.}$$
 (31.19)

In strip and pixel detectors the capacitance is dominated by the fringing capacitance. For example, the strip-to-strip Si fringing capacitance is $\sim 1-1.5 \text{ pF cm}^{-1}$ of strip length at a strip pitch of Large volume ($\sim 10^2-10^3~{\rm cm}^3$) Ge detectors are commonly configured as coaxial detectors, e.g., a cylindrical n-type crystal with 5–10 cm diameter and 10 cm length with an inner 5–10 mm diameter n⁺ electrode and an outer p⁺ layer forming the diode junction. Ge can be grown with very low impurity levels, $10^9-10^{10}~{\rm cm}^{-3}$ (HPGe), so these large volumes can be depleted with several kV.

31.7.3. Signal Formation:

The signal pulse shape depends on the instantaneous carrier velocity $v(x)=\mu E(x)$ and the electrode geometry, which determines the distribution of induced charge (e.g., see Ref. 115, pp. 71–83). Charge collection time decreases with increasing bias voltage, and can be reduced further by operating the detector with "overbias," i.e., a bias voltage exceeding the value required to fully deplete the device. The collection time is limited by velocity saturation at high fields (in Si approaching 10^7 cm/s at $E>10^4$ V/cm); at an average field of 10^4 V/cm the collection time is about 15 ps/ μ m for electrons and 10^9 ps/ μ m for holes. In typical fully-depleted detectors 10^9 m thick, electrons are collected within about 10^9 ns, and holes within about 10^9 ns.

Position resolution is limited by transverse diffusion during charge collection (typically 5 μ m for 300 μ m thickness) and by knock-on electrons. Resolutions of 2–4 μ m (rms) have been obtained in beam tests. In magnetic fields, the Lorentz drift deflects the electron and hole trajectories and the detector must be tilted to reduce spatial spreading (see "Hall effect" in semiconductor textbooks).

Electrodes can be in the form of cm-scale pads, strips, or μ m-scale pixels. Various readout structures have been developed for pixels, e.g., CCDs, DEPFETs, monolithic pixel devices that integrate sensor and electronics (MAPS), and hybrid pixel devices that utilize separate sensors and readout ICs connected by two-dimensional arrays of solder bumps. For an overview and further discussion see Ref. 115.

In gamma ray spectroscopy ($E_{\gamma} > 10^2 \text{ keV}$) Compton scattering dominates, so for a significant fraction of events the incident gamma energy is not completely absorbed, i.e., the Compton scattered photon escapes from the detector and the energy deposited by the Compton electron is only a fraction of the total. Distinguishing multi-interaction events, e.g., multiple Compton scatters with a final photoelectric absorption, from single Compton scatters allows background suppression. Since the individual interactions take place in different parts of the detector volume, these events can be distinguished by segmenting the outer electrode of a coaxial detector and analyzing the current pulse shapes. The different collection times can be made more distinguishable by using "point" electrodes, where most of the signal is induced when charges are close to the electrode, similarly to strip or pixel detectors. Charge clusters arriving from different positions in the detector will arrive at different times and produce current pulses whose major components are separated in time. Point electrodes also reduce the electrode capacitance, which reduces electronic noise, but careful design is necessary to avoid low-field regions in the detector volume.

31.7.4. *Radiation Damage*: Radiation damage occurs through two basic mechanisms:

- 1. Bulk damage due to displacement of atoms from their lattice sites. This leads to increased leakage current, carrier trapping, and build-up of space charge that changes the required operating voltage. Displacement damage depends on the nonionizing energy loss and the energy imparted to the recoil atoms, which can initiate a chain of subsequent displacements, i.e., damage clusters. Hence, it is critical to consider both particle type and energy.
- 2. Surface damage due to charge build-up in surface layers, which leads to increased surface leakage currents. In strip detectors the inter-strip isolation is affected. The effects of charge build-up are strongly dependent on the device structure and on fabrication details. Since the damage is proportional to the absorbed energy (when ionization dominates), the dose can be specified in rad (or Gray) independent of particle type.

The increase in reverse bias current due to bulk damage is $\Delta I_r = \alpha \Phi$ per unit volume, where Φ is the particle fluence and α the damage coefficient ($\alpha \approx 3 \times 10^{-17}$ A/cm for minimum ionizing protons

and pions after long-term annealing; $\alpha \approx 2 \times 10^{-17}$ A/cm for 1 MeV neutrons). The reverse bias current depends strongly on temperature

$$\frac{I_R(T_2)}{I_R(T_1)} = \left(\frac{T_2}{T_1}\right)^2 \exp\left[-\frac{E}{2k} \left(\frac{T_1 - T_2}{T_1 T_2}\right)\right] , \qquad (31.20)$$

where E=1.2 eV, so rather modest cooling can reduce the current substantially (\sim 6-fold current reduction in cooling from room temperature to 0°C).

Displacement damage forms acceptor-like states. These trap electrons, building up a negative space charge, which in turn requires an increase in the applied voltage to sweep signal charge through the detector thickness. This has the same effect as a change in resistivity, i.e., the required voltage drops initially with fluence, until the positive and negative space charge balance and very little voltage is required to collect all signal charge. At larger fluences the negative space charge dominates, and the required operating voltage increases $(V \propto N)$. The safe limit on operating voltage ultimately limits the detector lifetime. Strip detectors specifically designed for high voltages have been extensively operated at bias voltages >500 V. Since the effect of radiation damage depends on the electronic activity of defects, various techniques have been applied to neutralize the damage sites. For example, additional doping with oxygen can increase the allowable charged hadron fluence roughly three-fold [117]. Detectors with columnar electrodes normal to the surface can also extend operational lifetime [118]. The increase in leakage current with fluence, on the other hand, appears to be unaffected by resistivity and whether the material is n or p-type. At fluences beyond $10^{15}~\mathrm{cm}^{-2}$ decreased carrier lifetime becomes critical [119,120].

Strip and pixel detectors have remained functional at fluences beyond $10^{15} \,\mathrm{cm}^{-2}$ for minimum ionizing protons. At this damage level, charge loss due to recombination and trapping becomes significant and the high signal-to-noise ratio obtainable with lowcapacitance pixel structures extends detector lifetime. The higher mobility of electrons makes them less sensitive to carrier lifetime than holes, so detector configurations that emphasize the electron contribution to the charge signal are advantageous, e.g., n⁺ strips or pixels on a p- or n-substrate. The occupancy of the defect charge states is strongly temperature dependent; competing processes can increase or decrease the required operating voltage. It is critical to choose the operating temperature judiciously $(-10 \text{ to } 0^{\circ}\text{C} \text{ in typical})$ collider detectors) and limit warm-up periods during maintenance. For a more detailed summary see Ref. 121 and and the web-sites of the ROSE and RD50 collaborations at http://RD48.web.cern.ch/rd48 and http://RD50.web.cern.ch/rd50. Materials engineering, e.g., introducing oxygen interstitials, can improve certain aspects and is under investigation. At high fluences diamond is an alternative, but operates as an insulator rather than a reverse-biased diode.

Currently, the lifetime of detector systems is still limited by the detectors; in the electronics use of standard "deep submicron" CMOS fabrication processes with appropriately designed circuitry has increased the radiation resistance to fluences $> 10^{15}~{\rm cm}^{-2}$ of minimum ionizing protons or pions. For a comprehensive discussion of radiation effects see Ref. 122.

31.8. Low-noise electronics

Revised August 2011 by H. Spieler.

Many detectors rely critically on low-noise electronics, either to improve energy resolution or to allow a low detection threshold. A typical detector front-end is shown in Fig. 31.18.

The detector is represented by a capacitance C_d , a relevant model for most detectors. Bias voltage is applied through resistor R_b and the signal is coupled to the preamplifier through a blocking capacitor C_c . The series resistance R_s represents the sum of all resistances present in the input signal path, e.g. the electrode resistance, any input protection networks, and parasitic resistances in the input transistor. The preamplifier provides gain and feeds a pulse shaper, which tailors the overall frequency response to optimize signal-to-noise ratio while limiting the duration of the signal pulse to accommodate the signal pulse rate. Even if not explicitly stated, all amplifiers provide some form of pulse shaping due to their limited frequency response.

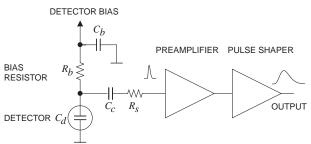


Figure 31.18: Typical detector front-end circuit.

The equivalent circuit for the noise analysis (Fig. 31.19) includes both current and voltage noise sources. The leakage current of a semiconductor detector, for example, fluctuates due to electron emission statistics. The statistical fluctuations in the charge measurement will scale with the square root of the total number of recorded charges, so this noise contribution increases with the width of the shaped output pulse. This "shot noise" i_{nd} is represented by a current noise generator in parallel with the detector. Resistors exhibit noise due to thermal velocity fluctuations of the charge carriers. This yields a constant noise power density vs. frequency, so increasing the bandwidth of the shaped output pulse, i.e. reducing the shaping time, will increase the noise. This noise source can be modeled either as a voltage or current generator. Generally, resistors shunting the input act as noise current sources and resistors in series with the input act as noise voltage sources (which is why some in the detector community refer to current and voltage noise as "parallel" and "series" noise). Since the bias resistor effectively shunts the input, as the capacitor C_b passes current fluctuations to ground, it acts as a current generator i_{nb} and its noise current has the same effect as the shot noise current from the detector. Any other shunt resistances can be incorporated in the same way. Conversely, the series resistor R_s acts as a voltage generator. The electronic noise of the amplifier is described fully by a combination of voltage and current sources at its input, shown as e_{na} and i_{na} .

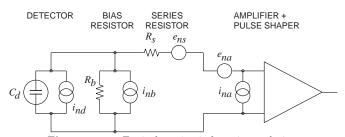


Figure 31.19: Equivalent circuit for noise analysis.

Shot noise and thermal noise have a "white" frequency distribution, i.e. the spectral power densities $dP_n/df \propto di_n^2/df \propto de_n^2/df$ are constant with the magnitudes

$$i_{nd}^2 = 2eI_d$$
,
 $i_{nb}^2 = \frac{4kT}{R_b}$,
 $e_{ns}^2 = 4kTR_s$, (31.21)

where e is the electronic charge, I_d the detector bias current, k the Boltzmann constant and T the temperature. Typical amplifier noise parameters e_{na} and i_{na} are of order nV/ $\sqrt{\rm Hz}$ and pA/ $\sqrt{\rm Hz}$. Trapping and detrapping processes in resistors, dielectrics and semiconductors can introduce additional fluctuations whose noise power frequently exhibits a 1/f spectrum. The spectral density of the 1/f noise voltage is

$$e_{nf}^2 = \frac{A_f}{f}$$
, (31.22)

where the noise coefficient A_f is device specific and of order 10^{-10} – 10^{-12} V².

A fraction of the noise current flows through the detector capacitance, resulting in a frequency-dependent noise voltage $i_n/(\omega C_d)$, which is added to the noise voltage in the input circuit. Thus, the current noise contribution increases with lowering frequency, so its contribution increases with shaping pulse width. Since the individual noise contributions are random and uncorrelated, they add in quadrature. The total noise at the output of the pulse shaper is obtained by integrating over the full bandwidth of the system. Superimposed on repetitive detector signal pulses of constant magnitude, purely random noise produces a Gaussian signal distribution.

Since radiation detectors typically convert the deposited energy into charge, the system's noise level is conveniently expressed as an equivalent noise charge Q_n , which is equal to the detector signal that yields a signal-to-noise ratio of one. The equivalent noise charge is commonly expressed in Coulombs, the corresponding number of electrons, or the equivalent deposited energy (eV). For a capacitive sensor

$$Q_n^2 = i_n^2 F_i T_S + e_n^2 F_v \frac{C^2}{T_S} + F_{vf} A_f C^2 , \qquad (31.23)$$

where C is the sum of all capacitances shunting the input, F_i , F_v , and F_{vf} depend on the shape of the pulse determined by the shaper and T_s is a characteristic time, for example, the peaking time of a semi-gaussian pulse or the sampling interval in a correlated double sampler. The form factors F_i , F_v are easily calculated

$$F_i = \frac{1}{2T_S} \int_{-\infty}^{\infty} [W(t)]^2 dt$$
, $F_v = \frac{T_S}{2} \int_{-\infty}^{\infty} \left[\frac{dW(t)}{dt} \right]^2 dt$, (31.24)

where for time-invariant pulse-shaping W(t) is simply the system's impulse response (the output signal seen on an oscilloscope) for a short input pulse with the peak output signal normalized to unity. For more details see Refs. 123 and 124.

A pulse shaper formed by a single differentiator and integrator with equal time constants has $F_i = F_v = 0.9$ and $F_{vf} = 4$, independent of the shaping time constant. The overall noise bandwidth, however, depends on the time constant, i.e. the characteristic time T_s . The contribution from noise currents increases with shaping time, i.e., pulse duration, whereas the voltage noise decreases with increasing shaping time. Noise with a 1/f spectrum depends only on the ratio of upper to lower cutoff frequencies (integrator to differentiator time constants), so for a given shaper topology the 1/f contribution to Q_n is independent of T_s . Furthermore, the contribution of noise voltage sources to Q_n increases with detector capacitance. Pulse shapers can be designed to reduce the effect of current noise, e.g., mitigate radiation damage. Increasing pulse symmetry tends to decrease F_i and increase F_v (e.g., to 0.45 and 1.0 for a shaper with one CRdifferentiator and four cascaded integrators). For the circuit shown in Fig. 31.19,

$$Q_n^2 = \left(2eI_d + 4kT/R_b + i_{na}^2\right)F_iT_S + \left(4kTR_s + e_{na}^2\right)F_vC_d^2/T_S + F_{vf}A_fC_d^2.$$
(31.25)

As the characteristic time T_S is changed, the total noise goes through a minimum, where the current and voltage contributions are equal. Fig. 31.20 shows a typical example. At short shaping times the voltage noise dominates, whereas at long shaping times the current noise takes over. The noise minimum is flattened by the presence of 1/f noise. Increasing the detector capacitance will increase the voltage noise and shift the noise minimum to longer shaping times.

For quick estimates, one can use the following equation, which assumes an FET amplifier (negligible i_{na}) and a simple CR-RC shaper with time constants τ (equal to the peaking time):

$$(Q_n/e)^2 = 12 \left[\frac{1}{\text{nA} \cdot \text{ns}} \right] I_{d\tau} + 6 \times 10^5 \left[\frac{\text{k}\Omega}{\text{ns}} \right] \frac{\tau}{R_b} + 3.6 \times 10^4 \left[\frac{\text{ns}}{(\text{pF})^2 (\text{nV})^2 / \text{Hz}} \right] e_n^2 \frac{C^2}{\tau} .$$
(31.26)

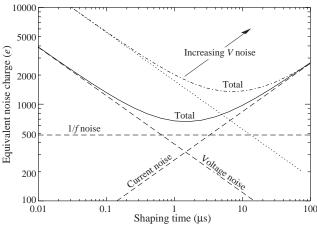


Figure 31.20: Equivalent noise charge vs shaping time. Changing the voltage or current noise contribution shifts the noise minimum. Increased voltage noise is shown as an example.

Noise is improved by reducing the detector capacitance and leakage current, judiciously selecting all resistances in the input circuit, and choosing the optimum shaping time constant.

The noise parameters of the amplifier depend primarily on the input device. In field effect transistors, the noise current contribution is very small, so reducing the detector leakage current and increasing the bias resistance will allow long shaping times with correspondingly lower noise. In bipolar transistors, the base current sets a lower bound on the noise current, so these devices are best at short shaping times. In special cases where the noise of a transistor scales with geometry, i.e., decreasing noise voltage with increasing input capacitance, the lowest noise is obtained when the input capacitance of the transistor is equal to the detector capacitance, albeit at the expense of power dissipation. Capacitive matching is useful with field-effect transistors, but not bipolar transistors. In bipolar transistors, the minimum obtainable noise is independent of shaping time, but only at the optimum collector current I_C , which does depend on shaping time.

$$Q_{n,\mathrm{min}}^2 = 4kT\frac{C}{\sqrt{\beta_{DC}}}\sqrt{F_iF_v} \ \ \mathrm{at} \ \ I_c = \frac{kT}{e}C\sqrt{\beta_{DC}}\sqrt{\frac{F_v}{F_i}}\frac{1}{T_S} \ , \ \ (31.27)$$

where β_{DC} is the DC current gain. For a CR--RC shaper and $\beta_{DC}=100,$

$$Q_{n,\min}/e \approx 250\sqrt{C/\mathrm{pF}}$$
 . (31.28)

Practical noise levels range from $\sim 1e$ for CCD's at long shaping times to $\sim 10^4~e$ in high-capacitance liquid argon calorimeters. Silicon strip detectors typically operate at $\sim 10^3$ electrons, whereas pixel detectors with fast readout provide noise of several hundred electrons.

In timing measurements, the slope-to-noise ratio must be optimized, rather than the signal-to-noise ratio alone, so the rise time t_r of the pulse is important. The "jitter" σ_t of the timing distribution is

$$\sigma_t = \frac{\sigma_n}{(dS/dt)_{S_T}} \approx \frac{t_r}{S/N} , \qquad (31.29)$$

where σ_n is the rms noise and the derivative of the signal dS/dt is evaluated at the trigger level S_T . To increase dS/dt without incurring excessive noise, the amplifier bandwidth should match the rise-time of the detector signal. The 10 to 90% rise time of an amplifier with bandwidth f_U is $0.35/f_U$. For example, an oscilloscope with 350 MHz bandwidth has a 1 ns rise time. When amplifiers are cascaded, which is invariably necessary, the individual rise times add in quadrature.

$$t_r \approx \sqrt{t_{r1}^2 + t_{r2}^2 + \dots + t_{rn}^2} \ . \tag{31.30}$$

Increasing signal-to-noise ratio also improves time resolution, so minimizing the total capacitance at the input is also important. At high signal-to-noise ratios, the time jitter can be much smaller than the rise time. The timing distribution may shift with signal

level ("walk"), but this can be corrected by various means, either in hardware or software [8].

The basic principles discussed above apply to both analog and digital signal processing. In digital signal processing the pulse shaper shown in Fig. 31.18 is replaced by an analog to digital converter (ADC) followed by a digital processor that determines the pulse shape. Digital signal processing allows great flexibility in implementing filtering functions. The software can be changed readily to adapt to a wide variety of operating conditions and it is possible to implement filters that are impractical or even impossible using analog circuitry. However, this comes at the expense of increased circuit complexity and increased demands on the ADC compared to analog shaping.

If the sampling rate of the ADC is too low, high frequency components will be transferred to lower frequencies ("aliasing"). The sampling rate of the ADC must be high enough to capture the maximum frequency component of the input signal. Apart from missing information on the fast components of the pulse, undersampling introduces spurious artifacts. If the frequency range of the input signal is much greater, the noise at the higher frequencies will be transferred to lower frequencies and increase the noise level in the frequency range of pulses formed in the subsequent digital shaper. The Nyquist criterion states that the sampling frequency must be at least twice the maximum relevant input frequency. This requires that the bandwith of the circuitry preceding the ADC must be limited. The most reliable technique is to insert a low-pass filter.

The digitization process also introduces inherent noise, since the voltage range ΔV corresponding to a minimum bit introduces quasi-random fluctuations relative to the exact amplitude

$$\sigma_n = \frac{\Delta V}{\sqrt{12}} \ . \tag{31.31}$$

When the Nyquist condition is fulfilled the noise bandwidth Δf_n is spread nearly uniformly and extends to 1/2 the sampling frequency f_S , so the spectral noise density

$$e_n = \frac{\sigma_n}{\sqrt{\Delta f_n}} = \frac{\Delta V}{\sqrt{12}} \cdot \frac{1}{\sqrt{f_S/2}} = \frac{\Delta V}{\sqrt{6f_S}} . \tag{31.32}$$

Sampling at a higher frequency spreads the total noise over a larger frequency range, so oversampling can be used to increase the effective resolution. In practice, this quantization noise is increased by differential nonlinearity. Furthermore, the equivalent input noise of ADCs is often rather high, so the overall gain of the stages preceding the ADC must be sufficiently large for the preamplifier input noise to override.

When implemented properly, digital signal processing provides significant advantages in systems where the shape of detector signal pulses changes greatly, for example in large semiconductor detectors for gamma rays or in gaseous detectors (e.g. TPCs) where the duration of the current pulse varies with drift time, which can range over orders of magnitude. Where is analog signal processing best (most efficient)? In systems that require fast time response the high power requirements of high-speed ADCs are prohibitive. Systems that are not sensitive to pulse shape can use fixed shaper constants and rather simple filters, which can be either continuous or sampled. In high density systems that require small circuit area and low power (e.g. strip and pixel detectors), analog filtering often yields the required response and tends to be most efficient.

For a more detailed introduction to detector signal processing and electronics see Ref. 115.

31.9. Calorimeters

A calorimeter is designed to measure the energy deposition and its direction for a contained electromagnetic (EM) or hadronic shower. The characteristic interaction distance for an electromagnetic interaction is the radiation length X_0 , which ranges from 13.8 g cm⁻² in iron to 6.0 g $\rm cm^{-2}$ in uranium.* Similarly, the characteristic nuclear interaction length λ_I varies from 132.1 g cm⁻² (Fe) to 209 g cm⁻² (U). In either case, a calorimeter must be many interaction lengths deep, where "many" is determined by physical size, cost, and other factors. EM calorimeters tend to be 15–30 X_0 deep, while hadronic calorimeters are usually compromised at 5–8 λ_I . In real experiments there is likely to be an EM calorimeter in front of the hadronic section, which in turn has less sampling density in the back, so the hadronic cascade occurs in a succession of different structures.

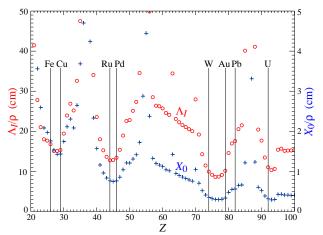


Figure 31.21: Nuclear interaction length λ_I/ρ (circles) and radiation length X_0/ρ (+'s) in cm for the chemical elements with Z > 20 and $\lambda_I < 50$ cm.

In all cases there is a premium on small λ_I/ρ and X_0/ρ (both with units of length). These quantities are shown for Z>20 for the chemical elements in Fig. 31.21. For the hadronic case, metallic absorbers in the W-Au region are best, followed by U. The Ru-Pd region elements are rare and expensive. Lead is a bad choice. Given cost considerations, Fe and Cu might be appropriate choices. For EM calorimeters high Z is preferred, and lead is not a bad choice.

These considerations are for sampling calorimeters consisting of metallic absorber sandwiched or (threaded) with an active material which generates signal. The active medium may be a scintillator, an ionizing noble liquid, a gas chamber, a semiconductor, or a Cherenkov radiator. The average interaction length is thus greater than that of the absorber alone, sometimes substantially so.

There are also homogeneous calorimeters, in which the entire volume is sensitive, i.e., contributes signal. Homogeneous calorimeters (so far usually electromagnetic) may be built with inorganic heavy (high density, high $\langle Z \rangle$) scintillating crystals, or non-scintillating Cherenkov radiators such as lead glass and lead fluoride. Scintillation light and/or ionization in noble liquids can be detected. Nuclear interaction lengths in inorganic crystals range from 17.8 cm (LuAlO₃) to 42.2 cm (NaI). Popular choices have been BGO with $\lambda_I = 22.3$ cm and $X_0 = 1.12 \,\mathrm{cm}$, and PbWO₄ (20.3 cm and 0.89 cm). Properties of these and other commonly used inorganic crystal scintillators can be found in Table 31.4.

31.9.1. Electromagnetic calorimeters:

Revised October 2009 by R.-Y. Zhu (California Inst. of Technology).

The development of electromagnetic showers is discussed in the section on "Passage of Particles Through Matter" (Sec. 30 of this Review).

Formulae are given which approximately describe average showers, but since the physics of electromagnetic showers is well understood, detailed and reliable Monte Carlo simulation is possible. EGS4 [125] and GEANT [126] have emerged as the standards.

There are homogeneous and sampling electromagnetic calorimeters. In a homogeneous calorimeter the entire volume is sensitive, i.e., contributes signal. Homogeneous electromagnetic calorimeters may be built with inorganic heavy (high-Z) scintillating crystals such as BGO, CsI, NaI, and PWO, non-scintillating Cherenkov radiators such as lead glass and lead fluoride, or ionizing noble liquids. Properties of commonly used inorganic crystal scintillators can be found in Table 31.4. A sampling calorimeter consists of an active medium which generates signal and a passive medium which functions as an absorber. The active medium may be a scintillator, an ionizing noble liquid, a gas chamber, or a semiconductor. The passive medium is usually a material of high density, such as lead, iron, copper, or depleted uranium.

The energy resolution σ_E/E of a calorimeter can be parametrized as $a/\sqrt{E} \oplus b \oplus c/E$, where \oplus represents addition in quadrature and E is in GeV. The stochastic term a represents statistics-related fluctuations such as intrinsic shower fluctuations, photoelectron statistics, dead material at the front of the calorimeter, and sampling fluctuations. For a fixed number of radiation lengths, the stochastic term a for a sampling calorimeter is expected to be proportional to $\sqrt{t/f}$, where t is plate thickness and f is sampling fraction [127,128]. While a is at a few percent level for a homogeneous calorimeter, it is typically 10% for sampling calorimeters. The main contributions to the systematic, or constant, term b are detector non-uniformity and calibration uncertainty. In the case of the hadronic cascades discussed below, non-compensation also contributes to the constant term. One additional contribution to the constant term for calorimeters built for modern high-energy physics experiments, operated in a high-beam intensity environment, is radiation damage of the active medium. This can be minimized by developing radiation-hard active media [48] and by frequent in situ calibration and monitoring [47,128]. With effort, the constant term b can be reduced to below one percent. The term c is due to electronic noise summed over readout channels within a few Molière radii. The best energy resolution for electromagnetic shower measurement is obtained in total absorption homogeneous calorimeters, e.g. calorimeters built with heavy crystal scintillators. These are used when ultimate performance is pursued.

The position resolution depends on the effective Molière radius and the transverse granularity of the calorimeter. Like the energy resolution, it can be factored as $a/\sqrt{E} \oplus b$, where a is a few to 20 mm and b can be as small as a fraction of mm for a dense calorimeter with fine granularity. Electromagnetic calorimeters may also provide direction measurement for electrons and photons. This is important for photon-related physics when there are uncertainties in event origin, since photons do not leave information in the particle tracking system. Typical photon angular resolution is about 45 $mrad/\sqrt{E}$, which can be provided by implementing longitudinal segmentation [129] for a sampling calorimeter or by adding a preshower detector [130] for a homogeneous calorimeter without longitudinal segmentation.

Novel technologies have been developed for electromagnetic calorimetry. New heavy crystal scintillators, such as PWO and LSO:Ce (see Sec. 31.4), have attracted much attention for homogeneous calorimetry. In some cases, such as PWO, it has received broad applications in high-energy and nuclear physics experiments. The "spaghetti" structure has been developed for sampling calorimetry with scintillating fibers as the sensitive medium. The "accordion" structure has been developed for sampling calorimetry with ionizing noble liquid as the sensitive medium. Table 31.8 provides a brief description of typical electromagnetic calorimeters built recently for high-energy physics experiments. Also listed in this table are calorimeter depths in radiation lengths (X_0) and the achieved energy resolution. Whenever possible, the performance of calorimeters in

^{*} $X_0 = 120 \ \mathrm{g\,cm^{-2}}\ Z^{-2/3}$ to better than 5% for Z > 23. † $\lambda_I = 37.8 \ \mathrm{g\,cm^{-2}}\ A^{0.312}$ to within 0.8% for Z > 15. See pdg.lbl.gov/AtomicNuclearProperties for actual values.

| Table 31.8: | Resolution of typical electromagnetic calorimeters. |
|--------------|-----------------------------------------------------|
| E is in GeV. | |

| ${\it Technology}~({\it Experiment})$ | Depth | Energy resolution | Date |
|-------------------------------------------|---------------------|----------------------------------------------|------|
| NaI(Tl) (Crystal Ball) | $20X_0$ | $2.7\%/\mathrm{E}^{1/4}$ | 1983 |
| $\mathrm{Bi_4Ge_3O_{12}}$ (BGO) (L3) | $22X_0$ | $2\%/\sqrt{E} \oplus 0.7\%$ | 1993 |
| CsI (KTeV) | $27X_0$ | $2\%/\sqrt{E} \oplus 0.45\%$ | 1996 |
| CsI(Tl) (BaBar) | $16-18X_0$ | $2.3\%/E^{1/4} \oplus 1.4\%$ | 1999 |
| CsI(Tl) (BELLE) | $16X_0$ | 1.7% for $E_{\gamma} > 3.5~{\rm GeV}$ | 1998 |
| $PbWO_4$ (PWO) (CMS) | $25X_0$ | $3\%/\sqrt{E} \oplus 0.5\% \oplus 0.2/E$ | 1997 |
| Lead glass (OPAL) | $20.5X_0$ | $5\%/\sqrt{E}$ | 1990 |
| Liquid Kr (NA48) | $27X_0$ | $3.2\%/\sqrt{E} \oplus 0.42\% \oplus 0.09/E$ | 1998 |
| Scintillator/depleted U (ZEUS) | 20-30X ₀ | $18\%/\sqrt{E}$ | 1988 |
| Scintillator/Pb (CDF) | $18X_0$ | $13.5\%/\sqrt{E}$ | 1988 |
| Scintillator fiber/Pb spaghetti (KLOE) | $15X_0$ | $5.7\%/\sqrt{E} \oplus 0.6\%$ | 1995 |
| Liquid Ar/Pb (NA31) | $27X_0$ | $7.5\%/\sqrt{E} \oplus 0.5\% \oplus 0.1/E$ | 1988 |
| Liquid Ar/Pb (SLD) | $21X_0$ | $8\%/\sqrt{E}$ | 1993 |
| Liquid Ar/Pb (H1) | $20 – 30X_0$ | $12\%/\sqrt{E}\oplus 1\%$ | 1998 |
| Liquid Ar/depl. U (DØ) | $20.5X_0$ | $16\%/\sqrt{E} \oplus 0.3\% \oplus 0.3/E$ | 1993 |
| Liquid Ar/Pb accordion (ATLAS) | $25X_0$ | $10\%/\sqrt{E} \oplus 0.4\% \oplus 0.3/E$ | 1996 |

situ is quoted, which is usually in good agreement with prototype test beam results as well as EGS or GEANT simulations, provided that all systematic effects are properly included. Detailed references on detector design and performance can be found in Appendix C of reference [128] and Proceedings of the International Conference series on Calorimetry in Particle Physics.

31.9.2. *Hadronic calorimeters*: [1–5,128] Revised October 2011 by D. E. Groom (LBNL).

A relatively new variant is the detection of Cerenkov light in hadron calorimetry. Such a calorimeter is sensitive to e^{\pm} 's in the EM showers plus a few relativistic pions. An example is the radiation-hard forward calorimeter in CMS, with iron absorber and quartz fiber readout by PMT's.

Ideally the calorimeter is segmented in ϕ and θ (or $\eta = -\ln\tan(\theta/2)$). Fine segmentation, while desirable, is limited by cost, readout complexity, practical geometry, and the transverse size of the cascades—but see [132]. An example, a wedge of the ATLAS central barrel calorimeter, is shown in Fig. 31.22(b).

In an inelastic hadronic collision a significant fraction f_{em} of the energy is removed from further hadronic interaction by the production of secondary π^0 's and η 's, whose decay photons generate high-energy electromagnetic (EM) showers. Charged secondaries (π^{\pm} , p, ...) deposit energy via ionization and excitation, but also interact with

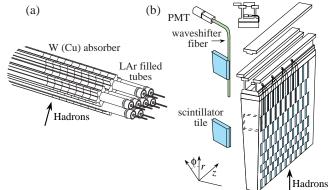


Figure 31.22: (a) ATLAS forward hadronic calorimeter structure (FCal2, 3). Tubes containing LAr are embedded in a mainly tungsten matrix. (b) ATLAS central calorimeter wedge; iron with plastic scintillator tile with wavelength-shifting fiber readout.

nuclei, producing spallation protons and neutrons, evaporation neutrons, and spallation products. The charged collision products produce detectable ionization, as do the showering γ -rays from the prompt de-excitation of highly excited nuclei. The recoiling nuclei generate little or no detectable signal. The neutrons lose kinetic energy in elastic collisions over hundreds of ns, gradually thermalize, and are captured, with the production of more γ -rays—usually outside the acceptance gate of the electronics. Between endothermic spallation losses, nuclear recoils, and late neutron capture, a significant fraction of the hadronic energy (20%–40%, depending on the absorber and energy of the incident particle) is invisible.

In contrast to EM showers, hadronic cascade processes are characterized by the production of relatively few high-energy particles. The lost energy and f_{em} , the $\pi^0 \to \gamma \gamma$ fraction are highly variable from event to event. Until there is event-by-event knowledge of both the invisible energy loss and EM deposit (to be discussed below), the energy resolution of a hadron calorimeter will remain significantly worse than that of an EM calorimeter.

It has been shown by a simple induction argument, and verified by experiment, that the decrease in the average value of the hadronic energy fraction $(\langle f_h \rangle = 1 - \langle f_{em} \rangle)$ as the projectile energy E increases is fairly well described by the power law [133,135]

$$\langle f_h \rangle \approx (E/E_0)^{m-1} \quad \text{(for } E > E_0) , \qquad (31.33)$$

at least up to a few hundred GeV. The exponent m depends logarithmically on the mean multiplicity and the mean fractional loss to π^0 production in a single interaction. It is in the range 0.80–0.87, but must be obtained experimentally for each calorimeter configuration. E_0 is roughly the energy for the onset of inelastic collisions. It is 1 GeV or a little less for incident pions [133].

In a hadron-nucleus collision a large fraction of the incident energy is carried by a "leading particle" with the same quark content as the incident hadron. If the projectile is a charged pion, the leading particle is usually a pion, which can be neutral and hence contributes to the EM sector. This is not true for incident protons. The result is an increased mean hadronic fraction for incident protons: in Eq. (31.34b) $E_0 \approx 2.6~{\rm GeV}~[133,134,136].$

The EM energy deposit is usually detected more efficiently than the hadronic energy deposit. If the detection efficiency for the EM sector is e and that for the hadronic sector is h, then the ratio of the mean response to a pion to that for an electron is

$$\pi/e = \langle f_{em} \rangle + \langle f_h \rangle h/e = 1 - (1 - h/e) \langle f_h \rangle$$

$$\approx 1 - (1 - h/e) (E/E_0)^{m-1} .$$
(31.34a)
$$(31.34b)$$

If $h \neq e$ the hadronic response is not a linear function of energy. Only the product $(1-h/e)E_0^{1-m}$ can be obtained by measuring π/e as a function of energy. Since 1-m is small and $E_0 \approx 1$ GeV for the usual pion-induced cascades, this fact is usually ignored and h/e is reported.

The discussion above assumes an idealized calorimeter, with the same structure throughout and without leakage. "Real" calorimeters

usually have an EM detector in front and a coarse "catcher" in the back. Complete containment is generally impractical.

By definition, $0 \le f_{em} \le 1$. Its variance changes only slowly with energy, but perforce $\langle f_{em} \rangle \to 1$ as the projectile energy increases. An empirical power law $\sigma_{f_{em}} = (E/E_1)^{1-\ell}$ (where $\ell < 1$) describes the energy dependence adequately and has the right asymptotic properties. For $h/e \ne 1$, fluctuations in f_{em} significantly contribute to the resolution, in particular contributing a larger fraction of the variance at high energies. Since the f_{em} distribution has a tail on the high side, the calorimeter response is non-Gaussian with a high-energy tail if h/e < 1. Noncompensation $(h/e \ne 1)$ thus seriously degrades resolution as well as producing a nonlinear response.

It is clearly desirable to *compensate* the response, *i.e.*, to design the calorimeter such that h/e=1. This is possible only with a sampling calorimeter, where several variables can be chosen or tuned:

- 1. Decrease the EM sensitivity. EM cross sections increase with Z,[†] and most of the energy in an EM shower is deposited by low-energy electrons. A disproportionate fraction of the EM energy is thus deposited in the higher-Z absorber. Lower-Z cladding, such as the steel cladding on ZEUS U plates, preferentially absorbs low-energy γ's in EM showers and thus also lowers the electronic response. G10 signal boards in the DØ calorimeters had the same effect. The degree of EM signal suppression can be somewhat controlled by tuning the sensor/absorber thickness ratio.
- 2. Increase the hadronic sensitivity. The abundant neutrons produced in the cascade have a large n-p scattering cross section, with the production of low-energy scattered protons in hydrogenous sampling materials such as butane-filled proportional counters or plastic scintillator. (When scattering from a nucleus with mass number A, a neutron can at most lose $4/(1+A)^2$ of its kinetic energy.) The down side in the scintillator case is that the signal from a highly-ionizing proton stub can be reduced by as much as 90% by recombination and quenching (Birk's Law, Eq. (31.2)).
- 3. Fabjan and Willis proposed that the additional signal generated in the aftermath of fission in ²³⁸U absorber plates should compensate nuclear fluctuations [137]. The production of fission fragments due to fast n capture was later observed [138]. However, while a very large amount of energy is released, it is mostly carried by low-velocity, very highly ionizing fission fragments which produce very little observable signal because of recombination and quenching. The approach seemed promising for awhile. But, for example, much of the compensation observed with the ZEUS ²³⁸U/scintillator calorimeter was mainly the result of methods 2 and 3 above.

Motivated very much by the work of Brau, Gabriel, Brückmann, and Wigmans [139], several groups built calorimeters which were very nearly compensating. The degree of compensation was sensitive to the acceptance gate width, and so could be somewhat further tuned. These included

- a) HELIOS with 2.5 mm thick scintillator plates sandwiched between 2 mm thick $^{238}{\rm U}$ plates (one of several structures); $\sigma/E=0.34/\sqrt{E}$ was obtained,
- b) ZEUS, 2.6 cm thick scintillator plates between 3.3 mm 238 U plates; $\sigma/E = 0.35/\sqrt{E}$,
- c) a ZEUS prototype with 10 mm Pb plates and 2.5 mm scintillator sheets; $\sigma/E = 0.44/\sqrt{E}$, and
- d) DØ, where the sandwich cell consists of a 4–6 mm thick 238 U plate, 2.3 mm LAr, a G-10 signal board, and another 2.3 mm LAr gap. Given geometrical and cost constraints, the calorimeters used in modern collider detectors are not compensating: $h/e \approx 0.7$, for the ATLAS central barrel calorimeter, is typical.

A more versatile approach to compensation is provided by a dual-readout calorimeter, in which the signal is sensed by two readout systems with highly contrasting h/e. Although the concept is more than two decades old [140], it has only recently been implemented by the DREAM collaboration [141]. The test beam calorimeter consisted of copper tubes, each filled with scintillator and quartz fibers. If the two signals Q and S (quartz and scintillator) are both normalized to

[†] The asymptotic pair-production cross section scales roughly as $Z^{0.75}$, and |dE/dx| slowly decreases with increasing Z.

electron response, then for each event Eq. (31.34) takes the form:

$$Q = E[f_{em} + h/e|_{Q}(1 - f_{em})]$$

$$S = E[f_{em} + h/e|_{S}(1 - f_{em})]$$
(31.35)

These equations are linear in 1/E and f_{em} , and are easily solved to obtain estimators of the *corrected* energy and f_{em} for each event. Both are subject to resolution effects, but effects due to fluctuations in f_{em} are eliminated. The solution for the corrected energy is given by [135]:

$$E = \frac{RS - Q}{R - 1}$$
, where $R = \frac{1 - h/e|_Q}{1 - h/e|_S}$ (31.36)

R is the energy-independent slope of the event locus on a plot of Q vs S. It can be found either from the fitted slope or by measuring π/e as a function of E.

Although the usually-dominant contribution of the f_{em} distribution to the resolution can be minimized by compensation or the use of dual calorimetry, there remain significant contributions to the resolution:

- Incomplete corrections for leakage, differences in light collection efficiency, and electronics calibration.
- Readout transducer shot noise (usually photoelectron statistics), plus electronic noise.
- 3. Sampling fluctuations. Only a small part of the energy deposit takes place in the scintillator or other sensor, and that fraction is subject to large fluctuations. This can be as high as $40\%/\sqrt{E}$ (lead/scintillator). It is even greater in the Fe/scint case because of the very small sampling fraction (if the calorimeter is to be compensating), and substantially lower in a U/scint calorimeter. It is obviously zero for a homogeneous calorimeter.
- 4. Intrinisic fluctuations. The many ways ionization can be produced in a hadronic shower have different detection efficiencies and are subject to stochastic fluctuations. In particular, a very large fraction of the hadronic energy (~20% for Fe/scint, ~40% for U/scint) is "invisible," going into nuclear dissociation, thermalized neutrons, etc. The lost fraction depends on readout—it will be greater for a Cherenkov readout, less for a heterogeneous active medium such as organic scintillator.

Except in a sampling calorimeter especially designed for the purpose, sampling and intrinsic resolution contributions cannot be separated. This may have been best studied by Drews $et\ al.\ [142]$, who used a calorimeter in which even- and odd-numbered scintillators were separately read out. Sums and differences of the variances were used to separate sampling and intrinsic contributions.

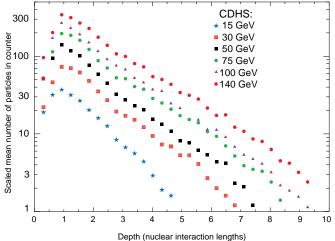


Figure 31.23: Mean profiles of π^+ (mostly) induced cascades in the CDHS neutrino detector [143].

The fractional resolution can be represented by

$$\frac{\sigma}{E} = \frac{a_1(E)}{\sqrt{E}} \oplus \left| 1 - \frac{h}{e} \right| \left(\frac{E}{E_1} \right)^{1-\ell} \tag{31.37}$$

The coefficient a_1 is expected to have mild energy dependence for a number of reasons. For example, the sampling variance is $(\pi/e)E$ rather than E. $(E/E_1)^{1-\ell}$ is the parameterization of σ_{fem} discussed above. At a time when data were of lower quality, a plot of $(\sigma/E)^2$ vs 1/E was apparently well-described by a straight line (constant a_1) with a finite intercept—the square of the right term in Eq. (31.37), then called "the constant term." Modern data show the slight downturn [131].

After the first interaction of the incident hadron, the average longitudinal distribution rises to a smooth peak. The peak position increases slowly with energy. The distribution becomes a reasonably exponential after several interaction length. Examples from the CDHS magnetized iron-scintillator sandwich calorimeter test beam calibration runs [143] are shown in Fig. 31.23. Proton-induced cascades are somewhat shorter and broader than pion-induced cascades [136]. A gamma distribution fairly well describes the longitudinal development of an EM shower, as discussed in Sec. 30.5. Following this logic, Bock et al. suggested that the profile of a hadronic cascade could be fitted by the sum of two gamma distributions, one with a characteristic length X_0 and the other with length λ_I [144]. Fits to this 4-parameter function are commonly used, e.g., by the ATLAS Tilecal collaboration [136]. If the interaction point is not known (the usual case), the distribution must be convoluted with an exponential in the interaction length of the incident particle. Adragna et al. give an analytic form for the convoluted function [136].

The transverse energy deposit is characterized by a central core dominated by EM cascades, together with a wide "skirt" produced by wide-angle hadronic interactions [145].

The CALICE collaboration has tested a "tracking" calorimeter (AHCAL) with highly granular scintillator readout [132]. Since the position of the first interaction is observed, the average longitudinal and radial shower distributions are obtained.

31.9.3. Free electron drift velocities in liquid ionization chambers:

Written August 2009 by W. Walkowiak (U. Siegen)

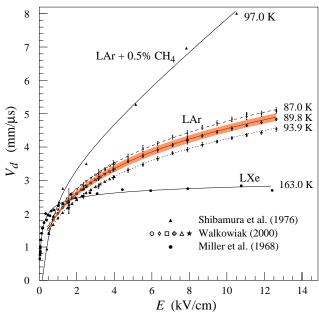


Figure 31.24: Drift velocity of free electrons as a function of electric field strength for LAr [146], LAr + 0.5% CH₄ [148] and LXe [147]. The average temperatures of the liquids are indicated. Results of a fit to an empirical function [152] are superimposed. In case of LAr at 91 K the error band for the global fit [146] including statistical and systematic errors as well as correlations of the data points is given. Only statistical errors are shown for the individual LAr data points.

Drift velocities of free electrons in LAr [146] are given as a function of electric field strength for different temperatures of the medium in

Fig. 31.24. The drift velocites in LAr have been measured using a double-gridded drift chamber with electrons produced by a laser pulse on a gold-plated cathode. The average temperature gradient of the drift velocity of the free electrons in LAr is described [146] by

$$\frac{\Delta v_d}{\Delta T \, v_d} = (-1.72 \pm 0.08) \, \%/\text{K}.$$

Earlier measurements [147–150] used different techniques and show systematic deviations of the drift velocities for free electrons which cannot be explained by the temperature dependence mentioned above.

Drift velocities of free electrons in LXe [148] as a function of electric field strength are also displayed in Fig. 31.24. The drift velocity saturates for |E| > 3 kV/cm, and decreases with increasing temperature for LXe as well as measured e.g. by [151].

The addition of small concentrations of other molecules like N_2 , H_2 and CH_4 in solution to the liquid typically increases the drift velocities of free electrons above the saturation value [148,149], see example for CH_4 admixture to LAr in Fig. 31.24. Therefore, actual drift velocities are critically dependent on even small additions or contaminations.

31.10. Superconducting magnets for collider detectors

Revised September 2011 by A. Yamamoto (KEK); revised October 2001 by R.D. Kephart (FNAL)

31.10.1. Solenoid Magnets: In all cases SI unit are assumed, so that the magnetic field, B, is in Tesla, the stored energy, E, is in joules, the dimensions are in meters, and $\mu_0 = 4\pi \times 10^{-7}$.

The magnetic field (B) in an ideal solenoid with a flux return iron yoke, in which the magnetic field is < 2 T, is given by

$$B = \mu_0 \, n \, I \tag{31.38}$$

where n is the number of turns/meter and I is the current. In an air-core solenoid, the central field is given by

$$B(0,0) = \mu_0 \, n \, I \frac{L}{\sqrt{L^2 + 4R^2}} \,, \tag{31.39}$$

where L is the coil length and R is the coil radius.

In most cases, momentum analysis is made by measuring the circular trajectory of the passing particles according to $p=mv\gamma=q\,rB$, where p is the momentum, m the mass, q the charge, r the bending radius. The sagitta, s, of the trajectory is given by

$$s = q B \ell^2 / 8p , \qquad (31.40)$$

where ℓ is the path length in the magnetic field. In a practical momentum measurement in colliding beam detectors, it is more effective to increase the magnetic volume than the field strength, since

$$dp/p \propto p/B \ell^2 \,\,\,\,(31.41)$$

where ℓ corresponds to the solenoid coil radius R. The energy stored in the magnetic field of any magnet is calculated by integrating B^2 over all space:

$$E = \frac{1}{2\mu_0} \int B^2 dV {31.42}$$

If the coil thin, (which is the case if it is to superconducting coil), then

$$E \approx (B^2/2\mu_0)\pi R^2 L$$
 (31.43)

For a detector in which the calorimetry is outside the aperture of the solenoid, the coil must be thin in terms of radiation and absorption lengths. This usually means that the coil is superconducting and that the vacuum vessel encasing it is of minimum real thickness and fabricated of a material with long radiation length. There are two major contributors to the thickness of a thin solenoid:

| Experiment | Laboratory | B | | Length | Energy | X/X_0 | E/M |
|------------|---------------|------|-------------|--------|----------------|----------|---------|
| | | [T] | [m] | [m] | [MJ] | | [kJ/kg] |
| TOPAZ* | KEK | 1.2 | 1.45 | 5.4 | 20 | 0.70 | 4.3 |
| CDF* | Tsukuba/Fermi | 1.5 | 1.5 | 5.07 | 30 | 0.84 | 5.4 |
| VENUS* | KEK | 0.75 | 1.75 | 5.64 | 12 | 0.52 | 2.8 |
| AMY* | KEK | 3 | 1.29 | 3 | 40 | † | |
| CLEO-II* | Cornell | 1.5 | 1.55 | 3.8 | 25 | 2.5 | 3.7 |
| ALEPH* | Saclay/CERN | 1.5 | 2.75 | 7.0 | 130 | 2.0 | 5.5 |
| DELPHI* | RAL/CERN | 1.2 | 2.8 | 7.4 | 109 | 1.7 | 4.2 |
| ZEUS* | INFN/DESY | 1.8 | 1.5 | 2.85 | 11 | 0.9 | 5.5 |
| H1* | RAL/DESY | 1.2 | 2.8 | 5.75 | 120 | 1.8 | 4.8 |
| BaBar* | INFN/SLAC | 1.5 | 1.5 | 3.46 | 27 | † | 3.6 |
| D0* | Fermi | 2.0 | 0.6 | 2.73 | 5.6 | 0.9 | 3.7 |
| BELLE* | KEK | 1.5 | 1.8 | 4 | 42 | † | 5.3 |
| BES-III | IHEP | 1.0 | 1.475 | 3.5 | 9.5 | † | 2.6 |
| ATLAS-CS | ATLAS/CERN | 2.0 | 1.25 | 5.3 | 38 | 0.66 | 7.0 |
| ATLAS-BT | ATLAS/CERN | 1 | 4.7 - 9.7 | 5 26 | 1080 | (Toroid) | † |
| ATLAS-ET | ATLAS/CERN | 1 | 0.825 - 5.3 | 5 5 | 2×250 | (Toroid) | † |
| CMS | CMS/CERN | 4 | 6 | 12.5 | 2600 | † | 12 |

Table 31.9: Progress of superconducting magnets for particle physics detectors.

1) The conductor consisting of the current-carrying superconducting material (usually NbTi/Cu) and the quench protecting stabilizer (usually aluminum) are wound on the inside of a structural support cylinder (usually aluminum also). The coil thickness scales as B^2R , so the thickness in radiation lengths (X_0) is

$$t_{\text{coil}}/X_0 = (R/\sigma_h X_0)(B^2/2\mu_0)$$
, (31.44)

where $t_{\rm coil}$ is the physical thickness of the coil, X_0 the average radiation length of the coil/stabilizer material, and σ_h is the hoop stress in the coil [155]. $B^2/2\mu_0$ is the magnetic pressure. In large detector solenoids, the aluminum stabilizer and support cylinders dominate the thickness; the superconductor (NbTI/Cu) contributes a smaller fraction. The main coil and support cylinder components typically contribute about 2/3 of the total thickness in radiation lengths.

2) Another contribution to the material comes from the outer cylindrical shell of the vacuum vessel. Since this shell is susceptible to buckling collapse, its thickness is determined by the diameter, length and the modulus of the material of which it is fabricated. The outer vacuum shell represents about 1/3 of the total thickness in radiation length.

31.10.2. Properties of collider detector magnets:

The physical dimensions, central field stored energy and thickness in radiation lengths normal to the beam line of the superconducting solenoids associated with the major collider are given in Table 31.9 [154]. Fig. 31.25 shows thickness in radiation lengths as a function of B^2R in various collider detector solenoids.

The ratio of stored energy to cold mass (E/M) is a useful performance measure. It can also be expressed as the ratio of the stress, σ_h , to twice the equivalent density, ρ , in the coil [155]:

$$\frac{E}{M} = \frac{\int (B^2/2\mu_0)dV}{\rho V_{\text{coil}}} \approx \frac{\sigma_h}{2\rho}$$
 (31.45)

The E/M ratio in the coil is approximately equivalent to H,* the enthalpy of the coil, and it determines the average coil temperature rise after energy absorption in a quench:

$$E/M = H(T_2) - H(T_1) \approx H(T_2)$$
 (31.46)

where T_2 is the average coil temperature after the full energy absorption in a quench, and T_1 is the initial temperature. E/M ratios of 5, 10, and 20 kJ/kg correspond to \sim 65, \sim 80, and \sim 100 K, respectively. The E/M ratios of various detector magnets are shown in Fig. 31.26 as a function of total stored energy. One would like the cold mass to be as small as possible to minimize the thickness, but temperature rise during a quench must also be minimized. An E/M ratio as large as 12 kJ/kg is designed into the CMS solenoid, with the possibility that about half of the stored energy can go to an external dump resistor. Thus the coil temperature can be kept below 80 K if the energy extraction system work well. The limit is set by the maximum temperature that the coil design can tolerate during a quench. This maximum local temperature should be <130 K (50 K + 80 K), so that thermal expansion effects in the coil are manageable.

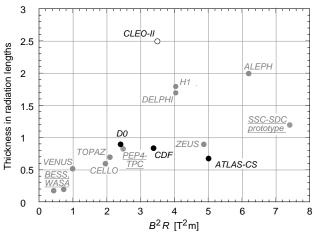


Figure 31.25: Magnet wall thickness in radiation length as a function of B^2R for various detector solenoids. Gray entries are for magnets no longer in use, and entries underlined are not listed in Table 31.9. Open circles are for magnets not designed to be "thin." The SSC-SDC prototype provided important R&D for LHC magnets.

^{*} No longer in service

[†] EM calorimeter is inside solenoid, so small X/X_0 is not a goal

^{*} The enthalpy, or heat content, is called H in the thermodynamics literature. It is not to be confused with the magnetic field intensity B/μ .

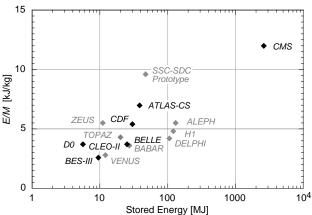


Figure 31.26: Ratio of stored energy to cold mass for major detector solenoids. Gray indicates magnets no longer in operation.

$31.10.3. \quad Toroidal \ magnets:$

Toroidal coils uniquely provide a closed magnetic field without the necessity of an iron flux-return yoke. Because no field exists at the collision point and along the beam line, there is, in principle, no effect on the beam. On the other hand, the field profile generally has 1/r dependence. The particle momentum may be determined by measurements of the deflection angle combined with the sagitta. The deflection (bending) power BL is

$$BL \approx \int_{R_i}^{R_0} \frac{B_i R_i dR}{R \sin \theta} = \frac{B_i R_i}{\sin \theta} \ln(R_0/R_i) , \qquad (31.47)$$

where R_i is the inner coil radius, R_0 is the outer coil radius, and θ is the angle between the particle trajectory and the beam line axis. The momentum resolution given by the deflection may be expressed as

$$\frac{\Delta p}{p} \propto \frac{p}{BL} \approx \frac{p \sin \theta}{B_i R_i \ln(R_0/R_i)} \ . \tag{31.48}$$

The momentum resolution is better in the forward/backward (smaller θ) direction. The geometry has been found to be optimal when $R_0/R_i \approx 3$ –4. In practical designs, the coil is divided into 6–12 lumped coils in order to have reasonable acceptance and accessibility. This causes the coil design to be much more complex. The mechanical structure needs to sustain the decentering force between adjacent coils, and the peak field in the coil is 3–5 times higher than the useful magnetic field for the momentum analysis [153].

31.11. Measurement of particle momenta in a uniform magnetic field [156,157]

The trajectory of a particle with momentum p (in GeV/c) and charge ze in a constant magnetic field \overrightarrow{B} is a helix, with radius of curvature R and pitch angle λ . The radius of curvature and momentum component perpendicular to \overrightarrow{B} are related by

$$p\cos\lambda = 0.3 z B R , \qquad (31.49)$$

where B is in tesla and R is in meters.

The distribution of measurements of the curvature $k\equiv 1/R$ is approximately Gaussian. The curvature error for a large number of uniformly spaced measurements on the trajectory of a charged particle in a uniform magnetic field can be approximated by

$$(\delta k)^2 = (\delta k_{\rm res})^2 + (\delta k_{\rm ms})^2$$
, (31.50)

where $\delta k = \text{curvature error}$

 $\delta k_{\rm res} = {
m curvature\ error\ due\ to\ finite\ measurement\ resolution}$

 $\delta k_{\rm ms} = {\rm curvature~error~due~to~multiple~scattering}.$

If many (≥ 10) uniformly spaced position measurements are made along a trajectory in a uniform medium,

$$\delta k_{\rm res} = \frac{\epsilon}{L'^2} \sqrt{\frac{720}{N+4}} , \qquad (31.51)$$

where N = number of points measured along track

L' = the projected length of the track onto the bending plane

 $\epsilon =$ measurement error for each point, perpendicular to the trajectory.

If a vertex constraint is applied at the origin of the track, the coefficient under the radical becomes 320.

For arbitrary spacing of coordinates s_i measured along the projected trajectory and with variable measurement errors ϵ_i the curvature error $\delta k_{\rm res}$ is calculated from:

$$(\delta k_{\rm res})^2 = \frac{4}{w} \frac{V_{ss}}{V_{ss}V_{s^2s^2} - (V_{ss^2})^2} , \qquad (31.52)$$

where V are covariances defined as $V_{s^ms^n} = \langle s^ms^n \rangle - \langle s^m \rangle \langle s^n \rangle$ with $\langle s^m \rangle = w^{-1} \sum_i (s_i^m/\epsilon_i^2)$ and $w = \sum_i \epsilon_i^{-2}$.

The contribution due to multiple Coulomb scattering is approximately

$$\delta k_{\rm ms} \approx \frac{(0.016)({\rm GeV}/c)z}{Lp\beta\cos^2\lambda} \sqrt{\frac{L}{X_0}} , \qquad (31.53)$$

where p = momentum (GeV/c)

z = charge of incident particle in units of e

 $L={
m the\ total\ track\ length}$

 X_0 = radiation length of the scattering medium (in units of length; the X_0 defined elsewhere must be multiplied by density)

 β = the kinematic variable v/c.

More accurate approximations for multiple scattering may be found in the section on Passage of Particles Through Matter (Sec. 30 of this Review). The contribution to the curvature error is given approximately by $\delta k_{\rm ms} \approx 8 s_{\rm plane}^{\rm rms}/L^2$, where $s_{\rm plane}^{\rm rms}$ is defined there.

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Updated 2011 (see the various sections for authors).

32. PARTICLE DETECTORS FOR NON-ACCELERATOR PHYSICS

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32.1. Introduction

Non-accelerator experiments have become increasingly important in particle physics. These include classical cosmic ray experiments, neutrino oscillation measurements, and searches for double-beta decay, dark matter candidates, and magnetic monopoles. The experimental methods are sometimes those familiar at accelerators (plastic scintillators, drift chambers, TRD's, etc.) but there is also instrumentation either not found at accelerators or applied in a radically different way. Examples are atmospheric scintillation detectors (Fly's Eye), massive Cherenkov detectors (Super-Kamiokande, IceCube), ultracold solid state detectors (CDMS). And, except for the cosmic ray detectors, radiologically ultra-pure materials are required.

In this section, some more important detectors special to terrestrial non-accelerator experiments are discussed. Techniques used in both accelerator and non-accelerator experiments are described in Sec. 28, Particle Detectors at Accelerators, some of which have been modified to accommodate the non-accelerator nuances.

Space-based detectors also use some unique instrumentation, but these are beyond the present scope of RPP.

32.2. High-energy cosmic-ray hadron and gammaray detectors

$32.2.1. \quad Atmospheric\ fluorescence\ detectors:$

Updated August 2011 by L.R. Wiencke (Colorado School of Mines).

Cosmic-ray fluorescence detectors (FD) use the atmosphere as a giant calorimeter to measure isotropic scintillation light that traces the development profiles of extensive air showers (EAS). The EASs observed are produced by the interactions of high-energy $(E>10^{17}~{\rm eV})$ subatomic particles in the stratosphere and upper troposphere, independent of the primary species. Experiments with FDs include the pioneering Fly's Eye [1], HiRes [2], the Telescope Array [3], and the Pierre Auger Observatory [4]. The proposed JEM-EUSO [5] FD would tilt down to sweep across a much larger area from space.

The scintillation light is emitted between 290 and 430 nm (Fig. 32.1), when relativistic charged particles, primarily electrons and positrons, excite nitrogen molecules in air, resulting in transitions of the 1P and 2P systems. Reviews and references for the pioneering and ongoing laboratory measurements of fluorescence yield, $Y(\lambda, P, T, u)$, including dependence on wavelength (λ) , temperature (T), pressure (p), and humidity (u) may be found in Refs. 6 and 7.

An FD element (telescope) consists of a non-tracking spherical mirror (3.5–13 m^2 and less than astronomical quality), a close-packed "camera" of PMTs (for example, Hamamatsu R9508 or Photonis XP3062) near the focal plane, and flash ADC readout system with a pulse and track-finding trigger scheme [8]. Simple reflector optics (12° \times 16° degree field of view (FOV) on 256 PMTs) and Schmidt optics (30° \times 30° FOV on 440 PMTs), including a correcting element, have been used. Segmented mirrors have been fabricated from slumped or slumped/polished glass with anodized aluminium coating and from chemically anodized AlMgSiO5 affixed to shaped aluminum. A broadband UV filter (custom fabricated or Schott MUG-6) covers the camera face or much larger entrance aperture to reduce background light such as starlight, airglow, man-made light pollution, and airplane strobelights.

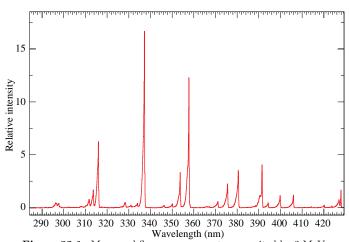


Figure 32.1: Measured fluorescence spectrum excited by 3 MeV electrons in dry air at 800 hPa and 293 K [9].

At $10^{20}\,\mathrm{eV}$, where the flux drops below 1 EAS/km²century, the aperture for an eye of adjacent FD telescopes that span the horizon can reach $10^4~\mathrm{km^2}$ sr. FD operation requires (nearly) moonless nights and clear atmospheric conditions, which imposes a duty cycle of about 10%. Arrangements of LEDs, calibrated diffuse sources [10], pulsed UV

lasers [11], LIDARs* and cloud monitors are used for photometric calibration, atmospheric calibration [12], and determination of exposure [13].

The EAS generates a track consistent with a light source moving at v=c across the FOV. The number of photons (N_{γ}) as a function of atmospheric depth (X) can be expressed as [7]

$$\frac{\mathrm{d}N_{\gamma}}{\mathrm{d}X} = \frac{dE_{\mathrm{dep}}^{\mathrm{tot}}}{dX} \int Y(\lambda, P, T, u) \cdot \tau_{\mathrm{atm}}(\lambda, X) \cdot \varepsilon_{\mathrm{FD}}(\lambda) \mathrm{d}\lambda \quad , \tag{32.1}$$

where $\tau_{atm}(\lambda, X)$ is atmospheric transmission, including wavelength (λ) dependence, and $\varepsilon_{\rm FD}(\lambda)$ is FD efficiency. $\varepsilon_{\rm FD}(\lambda)$ includes geometric factors and collection efficiency of the optics, quantum efficiency of the PMTs, and other throughput factors. The typical systematic uncertainties, Y (10–15%), $\tau_{\rm atm}$ (10%) and $\varepsilon_{\rm FD}$ (photometric calibration 10%), currently dominate the total reconstructed EAS energy uncertainty. $\Delta E/E$ of 20–25% is possible, provided the geometric fit of the EAS axis is constrained by multi-eye stereo projection, or by timing from a colocated sparse array of surface detectors.

Analysis methods to reconstruct the EAS profile and deconvolute the contributions of re-scattered scintillation light, and direct and scattered Cherenkov light are described in [1] and more recently in [14]. The EAS energy is typically obtained by integrating over the Gaisser-Hillas function [15]

$$E_{\rm cal} = \int_0^\infty w_{\rm max} \left(\frac{X-X_0}{X_{\rm max}-X_0}\right)^{(X_{\rm max}-X_0)/\lambda} e^{(X_{\rm max}-X)/\lambda} {\rm d}X \ , \eqno(32.2)$$

where X_{max} is the depth at which the shower reaches its maximum energy deposit w_{max} . X_0 and λ are two shape parameters.

32.2.2. Atmospheric Cherenkov telescopes for high-energy γ -ray astronomy:

Written August 2009 by J. Holder (Bartol Research Inst., Univ. of Delaware).

A wide variety of astrophysical objects are now known to produce high-energy γ -ray photons. Leptonic or hadronic particle populations, accelerated to relativistic energies in the source, produce γ rays typically through inverse Compton boosting of ambient photons, or through the decay of neutral pions produced in hadronic interactions. At energies below ~ 30 GeV, γ -ray emission can be detected directly using satellite or balloon-borne instrumentation, with an effective area approximately equal to the size of the detector (< 1 m²). At higher energies, a technique with much larger effective collection area is required to measure astrophysical γ -ray fluxes, which decrease rapidly with increasing energy. Atmospheric Cherenkov detectors achieve effective collection areas of $\sim 10^5$ m² by employing the Earth's atmosphere as an intrinsic part of the detection technique.

As described in Chapter 26, a hadronic cosmic ray or high energy γ -ray incident on the Earth's atmosphere triggers a particle cascade, or air shower. Relativistic charged particles in the cascade produce Cherenkov radiation, which is emitted along the shower direction, resulting in a light pool on the ground with a radius of ~ 130 m. Cherenkov light is produced throughout the cascade development, with the maximum emission occurring when the number of particles in the cascade is largest, at an altitude of ~ 10 km for primary energies of $100\,\text{GeV}{-}1\,\text{TeV}$. Following absorption and scattering in the atmosphere, the Cherenkov light at ground level peaks at a wavelength, $\lambda \approx 300{-}350$ nm. The photon density is typically ~ 100 photons/m² at 1 TeV, arriving in a brief flash of a few nanoseconds duration. This Cherenkov pulse can be detected from any point within the light pool radius by using large reflecting surfaces to focus the Cherenkov light on to fast photon detectors (Fig. 32.2).

Modern atmospheric Cherenkov telescopes, such as those built and operated by the H.E.S.S. [17], MAGIC [18] and VERITAS [16] collaborations, consist of large (> $100\,\mathrm{m}^2$) segmented mirrors on steerable altitude-azimuth mounts. A camera, made from an array of

up to 1000 photomultiplier tubes (PMTs) covering a field-of-view of up to 5.0° in diameter, is placed at the mirror focus and used to record a Cherenkov image of each air shower. Images are recorded at a rate of a few hundred Hz, the vast majority of which are due to showers with hadronic cosmic-ray primaries. The shape and orientation of the Cherenkov images are used to discriminate γ -ray photon events from this cosmic-ray background, and to reconstruct the photon energy and arrival direction. γ -ray images result from purely electromagnetic cascades and appear as narrow, elongated ellipses in the camera plane. The long axis of the ellipse corresponds to the vertical extension of the air shower, and points back towards the source position in the field-of-view. If multiple telescopes are used to view the same shower ("stereoscopy"), the source position is simply the intersection point of the various image axes. Cosmic-ray primaries produce secondaries with large transverse momenta, which initiate sub-showers. Their images are consequently wider and less regular than those with γ -ray primaries and, since the original charged particle has been deflected by galactic magnetic fields before reaching the Earth, the images have no preferred orientation.

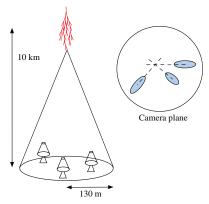


Figure 32.2: A schematic illustration of an atmospheric Cherenkov telescope array. The primary particle initiates an air shower, resulting in a cone of Cherenkov radiation. Telescopes within the Cherenkov light pool record elliptical images; the intersection of the long axes of these images indicates the arrival direction of the primary, and hence the location of a γ -ray source in the sky.

The measurable differences in Cherenkov image orientation and morphology provide the background discrimination which makes ground-based γ -ray astronomy possible. For point-like sources, such as distant Active Galactic Nuclei (AGNs), modern instruments can reject up to 99.999% of the triggered cosmic-ray events, while retaining up to 50% of the γ -ray population. In the case of spatially extended sources, such as Galactic supernova remnants (SNR), the background rejection is less efficient, but the technique can be used to produce γ -ray maps of the emission from the source. The angular resolution depends upon the energy of the primary γ -ray, but is typically 0.1° per event (68% containment radius) at energies above a few hundred GeV.

The total Cherenkov yield from the air shower is proportional to the energy of the primary particle. The image intensity, combined with the reconstructed distance of the shower core from each telescope, can therefore be used to estimate the primary energy. The energy resolution of this technique, also energy-dependent, is typically 15–20% at energies above a few hundred GeV. Energy spectra of γ -ray sources can be measured over a wide range; potentially from ~ 50 GeV to ~ 100 TeV, depending upon the instrument characteristics, source strength, and exposure time. To a first approximation, the lower energy threshold at the trigger level, E_T , depends upon the mirror area, A, the photon collection efficiency, $\eta(\lambda)$, the Cherenkov light yield, $C(\lambda)$, the night sky background light, $B(\lambda)$, the solid angle, Ω , and the trigger resolving time, τ , as follows [19]:

$$E_T \propto \frac{1}{C(\lambda)} \sqrt{\frac{B(\lambda)\Omega\tau}{\eta(\lambda)A}}$$
 (32.3)

^{*} This acronym for "Light Detection and Ranging," refers here to systems that measure atmospheric properties from the light scattered backwards from laser pulses directed into the sky.

In practice, this function may be modified by the properties of the detector; for example, by complex, multi-level, combinatorial trigger systems and highly pixellated fields of view. In addition, the useful scientific threshold, after the application of analysis cuts to select γ -ray events, is always somewhat higher than this.

The first astrophysical source to be convincingly detected using the imaging atmospheric Cherenkov technique was the Crab Nebula [20], with a flux of 2.1×10^{-11} photons cm⁻² s⁻¹ above 1 TeV [21]. Modern arrays have sensitivity sufficient to detect sources with 1% of the Crab Nebula's flux in a few tens of hours, and the TeV source catalog now consists of more than 80 sources. The majority of these have been detected by scanning the Galactic plane from the southern hemisphere with the H.E.S.S. telescope array [22].

32.3. Large neutrino detectors

Large water Cherenkov and scintillator detectors (see Table 32.1) usually consist of a volume of transparent liquid viewed by photomultiplier tubes (PMTs) (see Sec. 31.2); the liquid serves as active target. PMT hit charges and times are recorded and digitized, and triggering is usually based on coincidence of PMTs hits within a time window comparable to the detector's light-crossing time. Because photosensors lining an inner surface represent a driving cost that scales as surface area, very large volumes can be used for comparatively reasonable cost. Some detectors are segmented into subvolumes individually viewed by PMTs, and may include other detector elements (e.g., tracking detectors). Devices to increase light collection, e.g., reflectors or waveshifter plates, may be employed. A common configuration is to have at least one concentric outer layer of liquid material separated from the inner part of the detector to serve as shielding against ambient background. If optically separated and

Table 32.1: Properties of large detectors for rare processes. If total target mass is divided into large submodules, the number of subdetectors is indicated in parentheses.

| Detector | Fid. mass, kton (modules) | PMTs (diameter, cm) | ξ | p.e./MeV | Dates |
|--------------|---------------------------------------|------------------------|-------------------|-----------|-------------|
| Baksan | 0.33, scint (3150) | 1/module (15) | segmented | 40 | 1980- |
| MACRO | 0.6, scint (476) | 2-4/module (20) | segmented | 18 | 1989 - 2000 |
| LVD | 1, scint. (840) | 3/module (15) | segmented | 15 | 1992 - |
| KamLAND | 1, scint | 1325(43)+554(51)* | 34% | 460 | 2002 - |
| Borexino | 0.1, scint | 2212 (20) | 30% | 500 | 2007- |
| SNO+ | 0.78, scint | 9438 (20) | 54% | 400 - 900 | Future |
| CHOOZ | 0.005, scint (Gd) | 192 (20) | 15% | 130 | 1997 - 1998 |
| Double Chooz | 0.020, scint $(Gd)(2)$ | 534/module(20) | 13% | 180 | 2011- |
| Daya Bay | 0.160, scint (Gd)(8) | 192/module (20) | $5.6\%^\dagger$ | 100 | 2011- |
| RENO | 0.030, scint (Gd)(2) | 342/module (25) | 12.6% | 100 | 2011- |
| IMB-1 | $3.3, H_2O$ | 2048 (12.5) | 1% | 0.25 | 1982 - 1985 |
| IMB-2 | $3.3, H_2O$ | 2048 (20) | 4.5% | 1.1 | 1987 - 1990 |
| Kam I | $0.88/0.78,\mathrm{H_2O}$ | 1000/948 (50) | 20% | 3.4 | 1983 - 1985 |
| Kam II | $1.04, H_2O$ | 948 (50) | 20% | 3.4 | 1986-1990 |
| Kam III | $1.04, H_2O$ | 948 (50) | $20\%^{\ddagger}$ | 4.3 | 1990 - 1995 |
| SK I | $22.5, H_2O$ | 11146 (50) | 39% | 6 | 1996 - 2001 |
| SK II | $22.5, H_2O$ | 5182 (50) | 19% | 3 | 2002 - 2005 |
| SK III+ | $22.5, H_2O$ | 11129 (50) | 39% | 6 | 2006- |
| SNO | $1, \mathrm{D_2O}/1.7, \mathrm{H_2O}$ | 9438 (20) | 31% § | 9 | 1999-2006 |

 $^{^{\}ast}$ The 51 cm PMTs were added in 2003.

32.3.1. Deep liquid detectors for rare processes:

Revised November 2011 by K. Scholberg & C.W. Walter (Duke University)

Deep, large detectors for rare processes tend to be multi-purpose with physics reach that includes not only solar, reactor, supernova and atmospheric neutrinos, but also searches for baryon number violation, searches for exotic particles such as magnetic monopoles, and neutrino and cosmic ray astrophysics in different energy regimes. The detectors may also serve as targets for long-baseline neutrino beams for neutrino oscillation physics studies. In general, detector design considerations can be divided into high-and low-energy regimes, for which background and event reconstruction issues differ. The high-energy regime, from about 100 MeV to a few hundred GeV, is relevant for proton decay searches, atmospheric neutrinos and high-energy astrophysical neutrinos. The low-energy regime (a few tens of MeV or less) is relevant for supernova, solar, reactor and geological neutrinos.

instrumented with PMTs, an outer layer may also serve as an active veto against entering cosmic rays and other background events. The PMTs for large detectors typically range in size from 20 cm to 50 cm diameter, and typical quantum efficiencies are in the 20-25% range. The active liquid volume requires purification and there may be continuous recirculation of liquid. For large homogeneous detectors, the event interaction vertex is determined using relative timing of PMT hits, and energy deposition is determined from the number of recorded photoelectrons. A "fiducial volume" is usually defined within the full detector volume, some distance away from the PMT array. Inside the fiducial volume, enough PMTs are illuminated per event that reconstruction is considered reliable, and furthermore, entering background from the enclosing walls is suppressed by a buffer of self-shielding. PMT and detector optical parameters are calibrated using laser, LED, or other light sources. Quality of event reconstruction typically depends on photoelectron yield, pixelization and timing.

 $[\]dagger$ The effective Daya Bay coverage is 12% with top and bottom reflectors.

 $[\]ddagger$ The effective Kamiokande III coverage was 25% with light collectors.

 $[\]S$ The effective SNO coverage was 54% with light collectors.

Because in most cases one is searching for rare events, large detectors are usually sited underground to reduce cosmic-ray related background (see Chapter 26). The minimum depth required varies according to the physics goals [23].

32.3.1.1. Liquid scintillator detectors:

Past and current large underground detectors based on hydrocarbon scintillators include LVD, MACRO, Baksan, Borexino, KamLAND and SNO+. Experiments at nuclear reactors include CHOOZ. Double CHOOZ, Daya Bay, and RENO. Organic liquid scintillators (see Sec. 31.3.0) for large detectors are chosen for high light yield and attenuation length, good stability, compatibility with other detector materials, high flash point, low toxicity, appropriate density for mechanical stability, and low cost. They may be doped with waveshifters and stabilizing agents. Popular choices are pseudocumene (1,2,4-trimethylbenzene) with a few g/L of the PPO (2,5-diphenyloxazole) fluor, and linear alkylbenzene (LAB). In a typical detector configuration there will be active or passive regions of undoped scintillator, non-scintillating mineral oil or water surrounding the inner neutrino target volume. A thin vessel or balloon made of nylon, acrylic or other material transparent to scintillation light may contain the inner target; if the scintillator is buoyant with respect to its buffer, ropes may hold the balloon in place. For phototube surface coverages in the 20-40% range, yields in the few hundreds of photoelectrons per MeV of energy deposition can be obtained. Typical energy resolution is about $7\%/\sqrt{E(\text{MeV})}$, and typical position reconstruction resolution is a few tens of cm at ~ 1 MeV, scaling as $\sim N^{-1/2}$, where N is the number of photoelectrons detected.

Shallow detectors for reactor neutrino oscillation experiments require excellent muon veto capabilities. For $\bar{\nu}_e$ detection via inverse beta decay on free protons, $\bar{\nu}_e + p \rightarrow n + e^+$, the neutron is captured by a proton on a ~180 μ s timescale, resulting in a 2.2 MeV γ ray, observable by Compton scattering and which can be used as a tag in coincidence with the positron signal. The positron annihilation γ rays may also contribute. Inverse beta decay tagging may be improved by addition of Gd at ~0.1% by mass, which for natural isotope abundance has a ~49,000 barn cross-section for neutron capture (in contrast to the 0.3 barn cross-section for capture on free protons). Gd capture takes ~30 μ s, and is followed by a cascade of γ rays adding up to about 8 MeV. Gadolinium doping of scintillator requires specialized formulation to ensure adequate attenuation length and stability.

Scintillation detectors have an advantage over water Cherenkov detectors in the lack of Cherenkov threshold and the high light yield. However, scintillation light emission is nearly isotropic, and therefore directional capabilities are relatively weak. Liquid scintillator is especially suitable for detection of low-energy events. Radioactive backgrounds are a serious issue, and include long-lived cosmogenics. To go below a few MeV, very careful selection of materials and purification of the scintillator is required (see Sec. 32.6). Fiducialization and tagging can reduce background. A recent idea, not yet realized, is to dissolve neutrinoless double beta decay $(0\nu\beta\beta)$ isotopes in scintillator (for instance 150 Nd in SNO+). Although energy resolution is poor compared to typical $0\nu\beta\beta$ search experiments, the quantity of isotope could be so large that the kinematic signature of $0\nu\beta\beta$ would be visible as a clear feature in the spectrum.

${\bf 32.3.1.2.} \quad \textit{Water Cherenkov detectors:} \\$

Very large-imaging water detectors reconstruct ten-meter-scale Cherenkov rings produced by charged particles (see Sec. 31.5.0). The first such large detectors were IMB and Kamiokande. The only currently existing instance of this class of detector, with fiducial volume of 22.5 kton and total mass of 50 kton, is Super-Kamiokande (Super-K). For volumes of this scale, absorption and scattering of Cherenkov light are non-negligible, and a wavelength-dependent factor $\exp(-d/L(\lambda))$ (where d is the distance from emission to the sensor and $L(\lambda)$ is the attenuation length of the medium) must be included in the integral of Eq. (31.5) for the photoelectron yield. Attenuation lengths on the order of 100 meters have been achieved.

Cherenkov detectors are excellent electromagnetic calorimeters, and the number of Cherenkov photons produced by an e/γ is nearly proportional to its kinetic energy. For massive particles, the number of photons produced is also related to the energy, but not linearly. For any type of particle, the visible energy $E_{\rm vis}$ is defined as the

energy of an electron which would produce the same number of Cherenkov photons. The number of collected photoelectrons depends on the scattering and attenuation in the water along with the photocathode coverage, quantum efficiency and the optical parameters of any external light collection systems or protective material surrounding them. Event-by-event corrections are made for geometry and attenuation. For a typical case, in water $N_{\rm p.e.} \sim 15 \, \xi \, E_{\rm vis}({\rm MeV})$, where ξ is the effective fractional photosensor coverage. Cherenkov photoelectron yield per MeV of energy is relatively small compared to that for scintillator, e.g., ~ 6 pe/MeV for Super-K with a PMT surface coverage of $\sim 40\%$. In spite of light yield and Cherenkov threshold issues, the intrinsic directionality of Cherenkov light allows individual particle tracks to be reconstructed. Vertex and direction fits are performed using PMT hit charges and times, requiring that the hit pattern be consistent with a Cherenkov ring.

High-energy (~100 MeV or more) neutrinos from the atmosphere or beams interact with nucleons; for the nucleons bound inside the ¹⁶O nucleus, the nuclear effects both at the interaction, and as the particles leave the nucleus must be considered when reconstructing the interaction. Various event topologies can be distinguished by their timing and fit patterns, and by presence or absence of light in a veto. "Fully-contained" events are those for which the neutrino interaction final state particles do not leave the inner part of the detector; these have their energies relatively well measured. Neutrino interactions for which the lepton is not contained in the inner detector sample have higher-energy parent neutrino energy distributions. For example, in "partially-contained" events, the neutrino interacts inside the inner part of the detector but the lepton (almost always a muon, since only muons are penetrating) exits. "Upward-going muons" can arise from neutrinos which interact in the rock below the detector and create muons which enter the detector and either stop, or go all the way through (entering downward-going muons cannot be distinguished from cosmic rays). At high energies, multi-photoelectron hits are likely and the charge collected by each PMT (rather than the number of PMTs firing) must be used; this degrades the energy resolution to approximately $2\%/\sqrt{\xi E_{\text{vis}}(\text{GeV})}$. The absolute energy scale in this regime can be known to $\approx 2-3\%$ using cosmic-ray muon energy deposition, Michel electrons and π^0 from atmospheric neutrino interactions. Typical vertex resolutions for GeV energies are a few tens of cm [24]. Angular resolution for determination of the direction of a charged particle track is a few degrees. For a neutrino interaction, because some final-state particles are usually below Cherenkov threshold, knowledge of direction of the incoming neutrino direction itself is generally worse than that of the lepton direction, and dependent on neutrino energy.

Multiple particles in an interaction (so long as they are above Cherenkov threshold) may be reconstructed, allowing for the exclusive reconstruction of final states. In searches for proton decay, multiple particles can be kinematically reconstructed to form a decaying nucleon. High-quality particle identification is also possible: γ rays and electrons shower, and electrons scatter, which results in fuzzy rings, whereas muons, pions and protons make sharp rings. These patterns can be quantitatively separated with high reliability using maximum likelihood methods [25]. A e/μ misidentification probability of $\sim 0.4\%/\xi$ in the sub-GeV range is consistent with the performance of several experiments for $4\% < \xi < 40\%$. Sources of background for high energy interactions include misidentified cosmic muons and anomalous light patterns when the PMTs sometimes "flash" and emit photons themselves. The latter class of events can be removed using its distinctive PMT signal patterns, which may be repeated. More information about high energy event selection and reconstruction may be found in reference [26].

In spite of the fairly low light yield, large water Cherenkov detectors may be employed for reconstructing low-energy events, down to e.g. \sim 4-5 MeV for Super-K [27]. Low-energy neutrino interactions of solar neutrinos in water are predominantly elastic scattering off atomic electrons; single electron events are then reconstructed. At solar neutrino energies, the visible energy resolution $(\sim 30\%/\sqrt{\xi\,E_{\rm vis}({\rm MeV})})$ is about 20% worse than photoelectron counting statistics would imply. Using an electron LINAC and/or nuclear sources, 0.5–1.5% determination of the absolute energy scale

has been achieved at solar neutrino energies. Angular resolution is limited by multiple scattering in this energy regime (25–30°). At these energies, radioactive backgrounds become a dominant issue. These backgrounds include radon in the water itself or emanated by detector materials, and γ rays from the rock and detector materials. In the few to few tens of MeV range, radioactive products of cosmic ray muon-induced spallation are troublesome, and are removed by proximity in time and space to preceding muons, at some cost in dead time.

The Sudbury Neutrino Observatory (SNO) detector [28] is the only instance of a large heavy water detector and deserves mention here. In addition to an outer 1.7 kton of light water, SNO contained 1 kton of D₂O, giving it unique sensitivity to neutrino neutral current $(\nu_x + d \rightarrow \nu_x + p + n)$, and charged current $(\nu_e + d \rightarrow p + p + e^-)$ deuteron breakup reactions. The neutrons were detected in three ways: In the first phase, via the reaction $n + d \rightarrow t + \gamma + 6.25$ MeV; Cherenkov radiation from electrons Compton-scattered by the γ rays was observed. In the second phase, NaCl was dissolved in the water. 35 Cl captures neutrons, $n + ^{35}$ Cl \rightarrow 36 Cl $+ \gamma + 8.6$ MeV. The γ rays were observed via Compton scattering. In a final phase, specialized low-background 3 He counters ("neutral current detectors" or NCDs) were deployed in the detector. These detected neutrons via $n + ^{3}$ He $\rightarrow p + t + 0.76$ MeV, and ionization charge from energy loss of the products was recorded in proportional counters.

32.3.2. Coherent radio Cherenkov radiation detectors : Written October 2011 by S.R. Klein (LBNL)

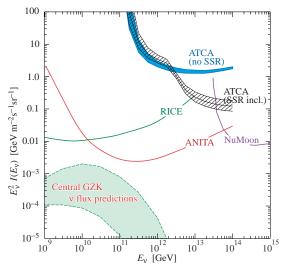


Figure 32.3: Representative ν flux limits from radio-detection experiments, illustrating the energy ranges for different techniques. Shown are limits from the Rice, ANITA, NuMoon and Lunaska (ATCA) collaborations. NuMoon and Lunaska are low and high frequency lunar scans respectively, showing the strengths of the two different frequency bands. The two separate limits for ATCA are for different models of the lunar regolith; their separation is a measure of the resultant uncertainty. Also shown, for comparison is the mid-range of flux predictions for GZK neutrinos from Ref. 34.

Radio detectors sensitive to coherent Cherenkov radiation provide an attractive way to search for ultra-high energy cosmic neutrinos. These neutrinos are the only long-range probe of the ultra-high energy cosmos. Protons and heavier nuclei with energies $\gtrsim 5 \times 10^{19}$ eV are limited to ranges of less than 100 Mpc by interactions with CMB photons (the GZK effect [29]) , and gamma rays pair-produce from the CMB. The decay products of the particles produced in the hadronic interactions include neutrinos. To detect a useful number of these "GZK neutrinos" annually (assuming that ultra-high energy cosmic rays are protons) requires a detector of about 100 km³ in volume. This is too big for an optical Cherenkov detector. Optical attenuation lengths are less than 200 m in ice or water, so a 100 km³ detector would require a prohibitive number of sensors.

Electromagnetic and hadronic showers produce radio pulses via the Askaryan effect [30], as discussed in Sec. 30. The shower contains more electrons than positrons, leading to coherent emission. The electric field strength is proportional to the neutrino energy; the radiated power goes as its square. Detectors with antennas placed in the active volume have thresholds around $10^{17}~{\rm eV}$.

The electric field strength increases linearly with frequency, up to a cut-off wavelength set by the transverse size of the shower. The cut-off is about 1 GHz in ice, and 2.5 GHz in rock/lunar regolith. The broadband spectrum argues for a wide detection bandwidth, but, dispersion during signal transmission can cause technical challenges. The angular distribution depends on the frequency. Near the cutoff frequency, radiation is emitted in a narrow cone, centered around the Cherenov angle (about 56° in ice) [31]. At lower frequencies, the angular distribution broadens, eventually becoming largely isotropic. The signal is linearly polarized in the plane containing the shower direction and the photon direction. This polarization is a useful check that any observed signal is indeed coherent Cherenkov radiation. Polarization measurements can be used to help reconstruct the neutrino direction.

Radiodetection requires a dielectric medium, with a long absorption length for radio waves. The huge target volumes require that this be a commonly available natural material, usually Antarctic ice or the lunar regolith [32].

When viewed from near the Cherenkov angle, the experimental signal is a short wideband radio pulse coming from a shower-sized region within a solid. The initial pulse width is ≈ 1 ns, but it may be broadened by dispersion as it propagates. As long as the dispersion can be accounted for, a large bandwidth detector is the most sensitive. Because the angular distribution depends on the frequency, spectral information can be used to help reconstruct the neutrino direction.

Radio detectors have observed cosmic-ray air showers in the atmosphere. The physics of radio-wave generation in air showers is more complex because there are contributions due to charge separation by charged particles, and from synchrotron radiation from e^{\pm} , both due to the Earth's magnetic field. Several experiments have also set limits on radiation due to magnetic monopoles.

32.3.2.1. The Moon as a target:

Because of it's large size and non-conducting regolith, and the availability of large radio-telescopes, the moon is an attractive target [33]; several representative lunar experiments are listed in Table 32.2. Conventional radio-telescopes are reasonably well suited to lunar neutrino searches, with natural beam widths not too dissimilar from the size of the Moon. Still, there are some experimental challenges in understanding the signal. The composition of the lunar regolith is not well known, and the attenuation length for radio waves must be estimated. An attenuation length of $9/f({\rm GHz})$ (m) is often used. The big limitation of lunar experiments is that the 240,000 km target-antenna separation leads to neutrino energy thresholds far above 10^{20} eV.

Table 32.2: Experiments that have set limits on neutrino interactions in the Moon; current limits are shown in Fig. 32.3 [32].

| Experiment | Year | Dish Size | Frequency | Bandwidth | Obs. Time |
|------------|--------|--------------------------------|-----------------------|------------------------------|-----------------------|
| Parkes | 1995 | 64 m | $1425~\mathrm{MHz}$ | $500~\mathrm{MHz}$ | 10 hrs |
| Glue | 1999 + | $70~\mathrm{m},~34~\mathrm{m}$ | $2200~\mathrm{MHz}$ | $40\text{-}150~\mathrm{MHz}$ | $120 \; \mathrm{hrs}$ |
| NuMoon | 2008 | $11{\times}25~\mathrm{m}$ | $115180~\mathrm{MHz}$ | _ | 50 hrs |
| Lunaska | 2008 | $3\times$ 22 m | $12001800~\rm{MHz}$ | _ | 6 nights |
| Resun | 2008 | $4 \times 25 \text{ m}$ | $1450~\mathrm{MHz}$ | $50~\mathrm{MHz}$ | 45 hours |

The frequency range affects the sensitive volume. At low frequencies, radiation is relatively isotropic, so signals can be detected from most of the Moon's surface, for most angles of incidence. At higher frequencies, the signal is stronger, but radiation is concentrated near the Cherenkov angle, and the geometry limits the sensitivity to interactions near the Moon's limb, where the neutrino also arrives within a fairly narrow angular range. The larger high-frequency attenuation limits the depth that can be probed.

So, higher frequency searches probe lower neutrino energies, but lower frequency searches can set tighter flux limits on high-energy neutrinos. An alternative approach, increasingly viable with modern technology, is to search over a wide frequency range. This introduces a technical challenge in the form of dispersion (frequency dependent time delays) in the ionosphere. The Parkes experiment pioneered the use of de-dispersion filters; this has been taken to a high art by the Lunaska collaboration.

Lunar experiments use several techniques to reject backgrounds, which are mostly anthropogenic. Many experiments use multiple antennas, separated by at least hundreds of meters; by requiring a coincidence within a small time window, anthropogenic noise can be rejected. An alternative approach is to use beam forming with multiple receivers in a single antenna, to ensure that the signal points back to the moon. The limits set by representative lunar experiments are shown in Fig. 32.3.

These efforts have considerable scope for expansion. In the near future, several large radio detector arrays should reach significantly lower limits. The LOFAR array is beginning to take data with 36 detector clusters spread over Northwest Europe. In the longer term, the Square Kilometer Array (SKA) with 1 km² effective area will push thresholds down to near 10^{20} eV.

${\bf 32.3.2.2.} \quad \textit{The ANITA balloon experiment:} \\$

To reduce the energy threshold, it is necessary to reduce the antenna-target separation. Most of these experiments use Antarctic ice as a medium. One such experiment is the ANITA balloon experiment which made two flights around Antarctica, floating at an altitude around 35 km [34]. Its 40 (32 in the first flight) dual-polarization horn antennas scanned the surrounding ice, out to the horizon (650 km away). Because of the small angle of incidence, ANITA was able to make use of polarization information; ν signals should be vertically polarized, while most background from cosmicray air showers is expected to be horizontally polarized. By using the several-meter separation between antennas, ANITA achieved a pointing accuracy of 0.2-0.40 in elevation, and 0.5-1.10 in azimuth.

Antarctic experiments must consider the inhomogeneities in the ice: varying density in the upper ice (the firn) and the variation in radio attenuation length with temperature. ANITA also had to consider the surface roughness, which affects the transition from ice to air. All of these affect the propagation of radio-waves from the ν -induced shower to the antennas.

The 'firn' is the top 100-200 m of Antarctic ice, where there is a transition from packed snow at the surface to solid ice (density 0.92 g/cm^3) below, where the density increases gradually with depth. The index of refraction depends on the density, so radio waves bend downward in the firn. This bending reduces the effectiveness of surface or aerial antennas. The thickness of the firn varies with location; it is thicker in central Antarctica than in the coastal ice sheets.

The attenuation length of radio waves depends on the frequency and ice temperature, with attenuation higher in warmer ice. A recent measurement, by the ARA collaboration at the South Pole found an average attenuation length of 670^{+180}_{-66} m [35]. On the Ross Ice Shelf, ARIANNA finds attenuation lengths of 300-500 m, depending on frequency [36].

ANITA verified the accuracy of their calibrations by observing radio sources that they buried in the ice. ANITA has also recently observed radio waves from cosmic-ray air showers; these showers are differentiated from neutrino showers on the basis of the radio polarization and zenith angle distribution [37].

As with the lunar experiments, ANITA had to contend with anthropogenic backgrounds. They used their good pointing accuracy to remove all candidate events that pointed toward known or suspected areas of human habitation. The limit from their two flights is shown in Fig. 32.3. These are the most stringent limits on GZK neutrinos to date. Because of the significant target to detector separation, ANITA is most sensitive at energies above 10¹⁹ eV, above the peak of the GZK neutrino spectrum.

32.3.2.3. Active Volume Detectors:

The use of radio antennas located in the active volume was pioneered by the RICE experiment, which buried radio antennas in holes drilled for AMANDA [38] at the South Pole. RICE was comprised of 18 half-wave dipole antennas, sensitive from 200 MHz to 1 GHz, buried between 100 and 300 m deep. Each antenna fed an in-situ preamplifier which transmitted the signals to surface digitizing electronics. The array triggered when four or more stations fired discriminators within 1.2 μ s, giving it a threshold of about 10^{17} eV.

Two groups are prototyping detectors, with the goal of a detector with an active volume in the $100~\rm km^3$ range. Both techniques are modular, so the detector volume scales roughly linearly with the available funding. The Askaryan Radio Array (ARA) is located at the South Pole, while the Antarctic Ross Iceshelf ANtenna Neutrino Array (ARIANNA) is on the Ross Ice Shelf. Both experiments use local triggers based on a coincidence between multiple antennas in a single station/cluster.

One big difference between the two experiments is the depth of their antennas. ARA buries antennas up to 200 m deep in the ice, to avoid the firn. Because of the refraction, a surface antenna cannot 'see' a signal from a near-surface interaction some distance away. Burying antennas avoids this problem. However, drilling holes has costs, and the limited hole diameter (15 cm in ARA) requires compromises between antenna design (particularly for horizontally polarized waves), mechanical support, power and communications. In contrast, ARIANNA places antennas in shallow, near-surface holes. This greatly simplifies deployment and avoid limitations on antenna design, but at a cost of reduced sensitivity to neutrino interactions near the surface.

The current ARA proposal, ARA-37 [35], calls for an array of 37 stations, each consisting of 16 embedded antennas deployed up to 200 m deep below the firn) in several 15-cm diameter boreholes. ARA will detect signals in the frequency range from 150 to 850 MHz for vertical polarization, and 250 MHz to 850 MHz for horizontal polarization. ARA plans to use bicone antennas for vertical polarization, and quad-slotted cylinders for horizontal polarization. The collaboration uses notch filters and surface veto antennas to eliminate most anthropogenic noise, and vetos events when aircraft are in the area, or weather balloons are being launched.

ARIANNA will be located in Moore's Bay, on the Ross Ice Shelf, where $\approx 575\,\mathrm{m}$ of ice sits atop the Ross Sea [36]. The site was chosen because the ice-seawater interface is smooth there, so the interface acts as a mirror for radio waves. The major advantage of this approach is that ARIANNA is sensitive to downward going neutrinos, and should be able to see more of the Cherenkov cone for horizontal neutrinos. One disadvantage of the site is that the ice is warmer, so the radio attenuation length will be shorter. Each ARIANNA station will use 8 log-periodic dipole antennas, pointing downward and arranged in an octagon. The multiple antennas allow for single-station directional and polarization measurements. The ARIANNA site is about 110 km from McMurdo station, and is shielded by Minna Bluff.

32.4. Large time-projection chambers for rare event detection

Written August 2009 by M. Heffner (LLNL).

The Time Projection Chamber (TPC) concept (Sec. 31.6.5) has been applied to many projects outside of particle physics and the accelerator-based experiments for which it was initially developed. TPCs in non-accelerator particle physics experiments are principally focused on rare event detection (e.g., neutrino and dark matter experiments) and the physics of these experiments can place dramatically different constraints on the TPC design (only extensions of the traditional TPCs are discussed here). The drift gas or liquid is usually the target or matter under observation and due to very low signal rates a TPC with the largest possible active mass is desired. The large mass complicates particle tracking of short and sometimes very low-energy particles. Other special design issues include efficient light collection, background rejection, internal triggering, and optimal energy resolution.

Backgrounds from γ rays and neutrons are significant design issues in the construction of these TPCs. These are generally placed

deep underground to shield them from cosmogenic particles and are surrounded with shielding to reduce radiation from the local surroundings. The construction materials are carefully screened for radiopurity, as they are in close contact with the active mass and can be a significant source of background. The TPC excels in reducing this internal background because the mass inside the field cage forms one monolithic volume from which fiducial cuts can be made ex post facto to isolate quiet drift mass. The liquid (gas) can be circulated and purified to a very high level. Self-shielding in these large mass systems can be significant and the effect improves with density and size. (See Sec. 32.6.)

The liquid-phase TPC can have a high density at low pressure that results in very good self-shielding and compact installation with lightweight containment. The down sides are the need for cryogenics, slower charge drift, tracks shorter than typical electron diffusion distances, lower-energy resolution (e.g., xenon) and limited charge readout options. Slower charge drift requires long electron lifetimes, placing strict limits on the oxygen and other impurities with high electron affinity. A significant variation of the liquid-phase TPC that improves the charge readout is the dual-phase TPC, where a gas phase layer is formed above the liquid into which the drifting electrons are extracted and amplified, typically with electroluminescence (i.e., secondary scintillation or proportional scintillation (Fig. 32.4)). The successful transfer of electrons across the phase boundary requires careful control of its position and setting up an appropriate electric field.

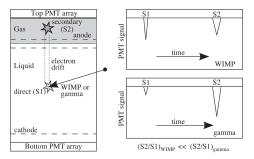


Figure 32.4: The configuration of a dual phase detector is shown on the left with the locations of where the primary and secondary light are generated. On the right is a schematic view of the signals of both an electron and nuclear interaction illustrating the discrimination power of this method. This figure is slightly modified from Ref. 39.

A high-pressure gas phase TPC has no cryogenics and density is easily optimized for the signal, but a large heavy-pressure vessel is required. Although self shielding is reduced, it can in some cases approach that of the liquid phase; in xenon at 50 atm the density is about half that of water or about 1/6 of liquid xenon. A significant feature of high pressure xenon gas is the energy resolution. Below a density of about $0.5\,\mathrm{g\,cm^{-3}}$ the intrinsic resolution is only a few times that of high purity germanium [40]. A neutrinoless double beta decay $(0\nu2\beta)$ search with a TPC operated below this density limit could enjoy excellent energy resolution and maintain particle tracking for background rejection.

An observable interaction with the TPC results in a charged particle that travels in the drift matter, exciting and ionizing the atoms until the initial energy is converted into ionization, scintillation, or heat with relatively large fluctuations around the mean. Rare-event TPCs can be designed to detect scintillation light as well as charge to exploit the anti-correlation to improve energy resolution and/or signal to noise [41]. An electric drift field separates the electrons and positive ions from the ionization although the separation is not complete and some electrons are captured, exciting atoms and releasing more light than the primary excitation alone. The average partition between the scintillation and ionization can be manipulated to increase the ionization (at the expense of scintillation) by a number of methods, such as increasing the strength of the electric field up to saturation of the ionization yield, increasing the temperature to enhance the diffusion of the ionized electrons, and adding dopants

such as triethylamine that can be photoionized by the scintillation photons releasing more ionization.

Scintillation light is typically collected with photomultiplier tubes (PMTs) and avalanche photo diodes (APDs) although any fast (compared to the ionization drift speed) light collector capable of detecting the typically UV photons, maintaining high radiopurity, and perhaps withstanding pressure would work. (CCDs are slow and therefore only record two dimensions, integrating over the time direction. Some of the 3D information can be recovered by a few PMTs.) In most cases, coating the optics or adding a wavelength shifter is required [41], although some work has been done to directly readout the 175 nm light from xenon with a silicon detector. In a typical cylindrical geometry, the light detectors are placed at the ends on an equipotential of the field cage simplifying the design, but limiting the collection efficiency. The field cage can be made of UV-reflective materials such as Teflon, to increase the light-collection efficiency.

Charge collection can be accomplished with proportional avalanche in the manner used in a traditional TPC (even in the liquid state), although the final signal suffers from rather large fluctuations caused by small fluctuations early in the avalanche that are amplified by the process. Inductive readout of passing charges and direct collection of the unamplified charge do not rely on an avalanche, and are effective where energy resolution is of paramount importance, but depend on low-noise amplifiers and relatively large signals (e.q., in $0\nu2\beta$ decay).

Electroluminescence can be used to proportionally amplify the the drifted ionization, and it does not suffer the fluctuations of an avalanche or the small signals of direct collection. It works by setting up at the positive end of the drift volume parallel meshes or wire arrays with an electric field larger than the drift field, but less than the field needed for avalanche. In xenon, this is $3-6~{\rm kV\,cm^{-1}\,bar^{-1}}$ for good energy resolution. Eq. (32.4) shows the dependence of the yield (Y) in zenon in units of photons/(electron cm bar) as a function of pressure (p) in units of bar and electric field (E) in units of ${\rm kV/cm}$ [42]:

$$Y/p = 140 E/p - 116 . (32.4)$$

The amplification can be adjusted with the length of the electroluminescence region, pressure and electric field.

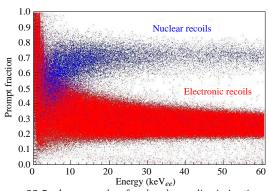


Figure 32.5: An example of pulse-shape discrimination of nuclear recoils and electrons in argon. The prompt fraction is a measure of the pulse shape that clearly separates the two interactions down to very low energy. Figure from Ref. 43.

Differentiation of nuclear and electron recoils at low-energy deposition is important as a means of background rejection. The nuclear recoil deposits a higher density of ionization than an electron recoil and this results in a higher geminate recombination resulting in a higher output of primary scintillation and lower charge. The ratio of scintillation to charge can be used to distinguish the two. In the case of an electroluminescence readout, this is done simply with the ratio of primary light to secondary light. Optically transparent grids with PMT or APD readout combine to make a elegant setup wherein the same array can measure the primary scintillation (S1), and the electroluminescence (S2) eliminating the necessity of two sets of readout detectors. Fig. 32.4 illustrates this method that works in

the gas phase and in dual phase detectors. The time evolution of the primary light is also affected by the type of recoil that results from different populations of excimers in the singlet and triplet states [43]. This alone has resulted in excellent discrimination, particularly in gasses where the decay times are significantly different (see Table 32.3). An example of the discrimination is displayed in Fig. 32.5, where nuclear recoils and electrons can be identified down to 10's of keV $_{ee}$, in argon. Nuclear recoils deposit less ionization than electrons at a given energy. For this reason, nuclear recoil energy is typically reported in equivalent electron energy loss, keV $_{ee}$, when compared with electrons.

The composition of the drift matter is an important choice in TPC design, and the noble gasses are frequently selected as the bulk element in the mix (Table 32.3). The noble gases have no electron affinity in the ground state, resulting in good free-electron lifetime and a good amount of scintillation that is useful for particle identification and t_0 determination. In the case of argon and xenon, the low average energy to produce an ion pair results in good energy resolution. The noble gases are easily purified to a high level that, combined with moderate cost, enables the construction of large monolithic detectors. Of the noble gases one isotope of xenon (136 Xe) is a candidate for ($^{0}\nu2\beta$).

Table 32.3: Properties of the noble gasses typically used in non-accelerator TPCs [44,45]. W is the average energy spent to produce one electron ion pair.

| Element | W (eV) | | length | decay time (fast/slow) | cost* (\$/kg) |
|-------------------------|----------------------|----------------|-----------------|------------------------------------------------------------------------------------------------------|----------------------|
| Helium Neon Argon | 46.0 36.6 26.4 | 50 30 40 | 80 77 128 | $10 \text{ ns}/1.6 \mu\text{s}$ $10 \text{ ns}/3.9 \mu\text{s}$ $4 \text{ ns}/1.6 \mu\text{s}$ | \$52 \$330 \$5 |
| Xenon | 21.7 | 42 | 175 | $4 \text{ ns}/1.0 \mu\text{s}$ 4 ns/22 ns | + - |

^{*} Prices from chemcool.com as updated in 2011.

The negative-ion TPC [46] uses an electronegative gas $(e.g., \text{CS}_2)$ either as the drift gas or as a dopant to the drift gas that captures the primary electrons, forming negative ions that drift in the electric field. Upon reaching the gas-gain region of the TPC, the electron is stripped from the ion in the high electric field, and the electron avalanches in the normal manner. The larger mass of the the negative ion keeps the kinetic energy of the ion thermal at high electric fields, and therefore such a TPC exhibits far less diffusion. The reduction of diffusion over large distance (time) enables detailed tracking of small tracks in a large volume without the benefit of a magnetic field to limit diffusion (which would be prohibitively expensive for a large volume). The trade-off is orders-of-magnitude slower drift, placing a limit on the trigger rate.

32.5. Sub-Kelvin detectors

Written September 2009 by S. Golwala (Caltech).

Detectors operating below 1 K, also known as "low-temperature" or "cryogenic" detectors, use ≲meV quanta (phonons, superconducting quasiparticles) to provide better energy resolution than is typically available from conventional technologies. Such resolution can provide unique advantages to applications reliant on energy resolution, such as beta-decay experiments seeking to measure the ν_e mass or searches for neutrinoless double-beta decay. In addition, the sub-Kelvin mode is combined with conventional (eV quanta) ionization or scintillation measurements to provide discrimination of nuclear recoils from electron recoils, critical for searches for WIMP dark matter and for coherent neutrino-nucleus scattering. We describe the techniques in generic fashion in the text and provide a list of experiments using these techniques in An excellent review [47] is available that covers this material and other applications of low-temperature detectors. The proceedings of the Low Temperature Detectors Workshops are also useful [48].

32.5.1. Thermal Phonons:

The most basic kind of low-temperature detector employs a dielectric absorber coupled to a thermal bath via a weak link. A thermistor monitors the temperature of the absorber. The energy E deposited by a particle interaction causes a calorimetric temperature change by increasing the population of thermal phonons. The fundamental sensitivity is

$$\sigma_E^2 = \xi^2 kT [T C(T) + \beta E] ,$$
 (32.5)

where C is the heat capacity of the detector, T is the temperature of operation, k is Boltzmann's constant, and ξ is a dimensionless factor of order unity that is precisely calculable from the nature of the thermal link and the non-thermodynamic noises (e.g., Johnson and/or readout noise). The first term is imposed by statistical fluctuations in the number of thermally excited phonons and on the energy in the absorber due to exchange with the thermal bath (see, e.g., Ref. 49 and references therein). The second term is due to statistical fluctuations in the number of phonons excited by the absorbed radiation. The factor β is also dimensionless and $\mathcal{O}(1)$ and is also precisely calculable from the nature of the thermal link. The ratio of the second term to the first term is equal to the fractional absorber temperature change due to an energy deposition. Thus, the second term becomes appreciable when this fractional temperature change is appreciable. at which point nonlinear effects also come into play. The energy resolution typically acquires an additional energy dependence due to deviations from an ideal calorimetric model that cause position and/or energy dependence in the signal shape.

The rise time of response is limited by the internal thermal conductivity of the absorber. The decay time constant, describing the time required for the absorbed energy to flow out to the bath, is $\tau = C/G$, where G is the thermal conductance of the weak link. The above formula immediately suggests the use of crystalline dielectric absorbers and low temperatures because of the linear factor of T and because T for crystalline dielectrics drops as T^3 for T well below the material's Debye temperature (Θ_D , typically hundreds of K). Specifically, the Debye model indicates that a crystal consisting of T atoms has

$$C = \frac{12\pi^4}{5} N k \left(\frac{T}{\Theta_D}\right)^3 \tag{32.6}$$

which gives $\sigma_E = 5.2 \, \xi$ eV for 1 kg of germanium operated at T=10 mK. (For a detector of this size the 2nd term in Eq. (32.5) is negligible.) In practice, a number of factors degrade the above result by about an order of magnitude (thermistor heat capacity and power dissipation, readout noise, etc.), but the predicted energy resolution for such a large mass remains attractive.

Neutron-transmutation-doped (NTD) germanium and implanted silicon semiconductors are used for thermistors. Conduction is via phonon-assisted hopping between impurity sites, vielding an exponentially decreasing resistance as a function of temperature, R(T), with negative slope, dR/dT. Attachment to the absorber is usually by eutectic bonding or epoxy or by direct implantation into the absorber. Another type of temperature sensor is the superconducting phase-transition thermometers (SPT) or transition-edge sensor (TES). A SPT or TES is a superconducting film operated in the transition from superconductive to normal resistance at the transition temperature, T_c , where its resistance is a strong function of temperature with positive dR/dT. This can provide strong electrothermal negative feedback, which improves linearity, speeds up response, and mitigates variations in T_c among multiple TESs on the same absorber. Nb_xSi_{1-x} is another thermistor material that ranges between the semiconducting and superconducting regimes as a function of the stoichiometry (defined by x). SPTs/TESs and Nb $_x$ Si $_{1-x}$ thermistors are frequently deposited directly onto the absorber by sputtering or evaporation.

The readout method depends on the type of thermometer used. Doped semiconductors typically have high impedances and are well matched to low-noise JFET-based readout while SPTs/TESs are low-impedance devices requiring SQUID amplifiers.

Table 32.4: Selected experiments using sub-Kelvin detectors. The table is not exhaustive. Operation mode, detector and excitation sensor construction, baseline energy resolution, and energy resolution at a particular energy of interest E_0 are given. We quote the energy and energy resolution for "total" phonon signal, where the total phonon signal includes both recoil energy and, where relevant, drift heating. Ionization and scintillation energies are normalized so that, for electron recoils, the energy in these channels is equal to the recoil energy ("electronequivalent" energies). For scintillation energy, this is the electron-equivalent energy deposited in the target detector, not the energy received by the photon absorber. Approximate dates of operation are also given. Key to comments: "a-Si" and "a-Ge" = amorphous silicon or germanium layers in ionization electrodes. "H-a-Si" = hydrogenated amorphous silicon. "P-implanted" = phosphorous implantation. "Interdig." = interdigitated ionization electrode design that provides some z information from ionization signal asymmetry. "Surface-event discrimination" = ability to reject events near surfaces that suffer reduced ionization yield and can be misidentified as WIMPs. "w/phonons" = using athermal phonon pulse rising edge (faster for surface events). "w/ioniz. asym." = using the asymmetry of the ionization signal on electrodes on opposite faces of interdigitated-electrode detectors. "w/phonon asym." = using the asymmetry of the phonon signal detected on opposite detector faces. "U" = not known by author. SuperCDMS energy resolutions have not been fully reported yet but are likely no worse than CDMS II.

| Experiment | technique | ${\rm substrate} \\ + {\rm mass}$ | sensor | ΔE_{FWHM} at $E=0$ | $ \begin{array}{c} \text{f [keV]} \\ \text{at } E_0 \end{array} $ | E_0 [keV] | comments |
|-------------------------|------------|-----------------------------------|---------------|----------------------------|-------------------------------------------------------------------|--------------|----------------------------|
| WIMP dark mat | tter | | | | | | |
| CDMS I | thermal | Ge | NTD Ge | 0.3 | 0.7 | 12 | nuclear recoil |
| (1996-2000) | phonon, | $0.16~\mathrm{kg}$ | thermistor, | | | | discrimination |
| | ionization | | H-a-Si/Al | 0.9 | 1.1 | 10.4 | w/ionization |
| | | | electrode | | | | yield |
| CDMS II | athermal | Ge | tungsten | 0.4 | 2.4 | 20.7 | CDMS I+ |
| (2001-2008) | phonon, | $0.25~\mathrm{kg}$ | TES, | | | | surface-event |
| | ionization | | a-Si/Al | 0.7 | 0.8 | 10.4 | ${\it discrimination}$ |
| | | | electrode | | | | w/phonons |
| SuperCDMS- | athermal | Ge | tungsten | 0.4 | U | U | CDMS II+ |
| SNOLAB, | phonon, | $0.64~\mathrm{kg}$ | TES, | | | | surface-event |
| in develop- | ionization | | a-Si/Al | 0.7 | U | \mathbf{U} | discr.w/ioniz.+ |
| ment | | | interdig. | | | | phonon z asym |
| EDELWEISS I | thermal | Ge | NTD Ge | 2.3 | 2.3 | 24.2 | nuclear recoil |
| (1996-2005) | phonon, | $0.32~\mathrm{kg}$ | thermistor, | | | | ${\it discrimination}$ |
| | ionization | | a-Si/Al | 1.1 | 1.1 | 10.4 | w/ionization |
| | | | a-Ge/Al | | | | yield |
| EDELWEISS II | thermal | Ge | NTD Ge | 3.6 | 3.6 | 38.0 | EDELWEISS I |
| (2006-) | phonon, | $0.4~\mathrm{kg}$ | thermistor, | | | | +surface-event |
| | ionization | | a-Si/Al | 1.0 | 1.0 | 10.4 | ${\it discrimination}$ |
| | | | interdig. | | | | w/ioniz.asym. |
| CRESST I | athermal | Al_2O_3 | tungsten | 0.20 | 0.24 | 1.5 | no NR discr. |
| (1996-2002) | phonon | $0.26~\mathrm{kg}$ | SPT | | | | |
| CRESST II | athermal | $CaWO_4$ | tungsten | 0.3 | 0.3 | 8.1 | NR discr. |
| (2003-) | phonon, | 0.3 kg | SPT | | | | w/scint. |
| | scint. | $(ZnWO_4)$ | (target and | 1.0 | 3.5 | 10 | yield |
| | | | photon abs.) | | | | |
| α decay | | | | | | | |
| ROSEBUD | athermal | BGO | NTD Ge | 6 | 5500 | 18 | α discr. |
| (1996-) | phonon, | 46 g | thermistor | | | | w/scint.yield, |
| | scint. | | (target & | U | U | U | first det. of |
| | | | photon abs.) | | | | 209 Bi α decay |
| β decay | | | | | | | |
| Oxford ⁶³ Ni | athermal | InSb | Al STJ | 1.24 | 1.24 | 67 | |
| (1994–1995) | phonon | 3.3 g | | | | | |
| MARE | thermal | $AgReO_4$ | P-implanted | U | 0.033 | 2.6 | |
| (2009–) | phonon | $0.5~\mathrm{mg}$ | Si thermistor | | | | |
| $0\nu\beta\beta$ decay | | | | | | | |
| CUORE | thermal | TeO_2^* | NTD Ge | U | 7 | 2527 | |
| (2003-) | phonon | 0.75 kg | thermistor | | | | |

^{*} The CUORE energy resolution is worse than can be obtained with Ge diode detectors.

32.5.2. Athermal Phonons and Superconducting Quasiparticles:

The advantage of thermal phonons is also a disadvantage: energy resolution degrades as \sqrt{M} where M is the detector mass. This motivates the use of athermal phonons. There are three steps in the development of the phonon signal. The recoiling particle deposits energy along its track, with the majority going directly into phonons. (A minority of the energy goes directly into scintillation and ionization. Energy deposited in ionization is recovered when the carriers recombine.) The recoil and bandgap energy scales (keV and higher, and eV, respectively) are much larger than phonon energies (meV), so the full energy spectrum of phonons is populated, with phase space favoring the most energetic phonons. However, these initial energetic phonons do not propagate because of isotopic scattering (scattering due to variations in lattice ion atomic mass, rate $\propto \nu^4$ where ν is the phonon frequency) and anharmonic decay (scattering wherein a single phonon splits into two phonons, rate $\propto \nu^5$). Anharmonic decay downshifts the phonon spectrum, which increases the phonon mean free path, so that eventually phonons can propagate the characteristic dimension of the detector. These phonons travel quasiballistically, preserve information about the position of the parent interaction, and are not affected by an increase in detector mass (modulo the concomitant larger distance to the surface where they can be sensed). Anharmonic decay continues until a thermal distribution is reached (µeV at mK temperatures), which is exhibited as a thermal increase in the temperature of the detector. If one can detect the athermal phonons at the crystal surface, keep the density of such sensors fixed as the detector surface area increases with mass, and the crystals are pure enough that the athermal phonons can propagate to the surface prior to thermalization, then an increase in detector mass need not degrade energy resolution, and can in fact improve position reconstruction. Sensors for athermal phonons are similar to those for superconducting quasiparticles described below.

Another mode is detection of superconducting quasiparticles in superconducting crystals. Energy absorption breaks superconducting Cooper pairs and yields quasiparticles, electron-like excitations that can diffuse through the material and that recombine after the quasiparticle lifetime. In crystals with very large mean free path against scattering, the diffusion length (distance traveled in a quasiparticle lifetime) is large enough (mm to cm) that the quasiparticles reach the surface and can be detected, usually in a superconducting tunnel junction (STJ) or TES/SPT.

A similar technique is applied to detect athermal phonons. Athermal phonons reaching a superconducting film on the detector surface generate quasiparticles as above. Such thin films have diffusion lengths much shorter than for superconducting crystalline substrates, only of order 100 $\mu \rm m$ to 1 mm. Thus, the superconducting film must be segmented on this length scale and have a quasiparticle sensor for each segment. The sensors may, however, be connected in series or parallel in large groups to reduce readout channel count.

The readout for athermal phonon and quasiparticle sensing depends on the type of quasiparticle detector. Tunnel junctions match well to JFET-based readouts, while TESs/SPTs use SQUID amplifiers.

32.5.3. Ionization and Scintillation:

While ionization and scintillation detectors usually operate at much higher temperatures, ionization and scintillation can be measured at low temperature and can be combined with a "sub-Kelvin" technique to discriminate nuclear recoils from background interactions producing electron recoils, which is critical for WIMP searches and coherent neutrino-nucleus scattering. With ionization, such techniques are based on Lindhard theory [50], which predicts substantially reduced ionization yield for nuclear recoils relative to electron recoils. For scintillation, application of Birks' law (Sec. 31.3.0) yields a similar prediction. (The reduced ionization or scintillation yield for nuclear recoils is frequently referred to as "quenching".)

Specifically, consider the example of measuring thermal phonons and ionization. All the deposited energy eventually appears in the thermal phonon channel, regardless of recoil type (modulo some loss to permanent crystal defect creation). Thus, the ionization yield—the number of charge pairs detected per unit detected energy in phonons—provides a means to discriminate nuclear recoils from

electron recoils. Similar discrimination is observed with athermal phonons and ionization and with phonons and scintillation.

In semiconducting materials of sufficient purity—germanium and silicon—electron-hole pairs created by recoiling particles can be drifted to surface electrodes by applying an electric field, similar to how this is done at 77 K in high-purity germanium photon spectrometers (Sec. 31.7). There are three important differences, however, that result in the use of low fields—of order 1 V/cm—instead of the hundreds to thousands of V/cm used in 77 K detectors. First, high fields are required at 77K to deplete the active volume of thermally excited mobile carriers. At low temperature and in crystals of purity high enough to drift ionization with negligible trapping, the population of thermally excited carriers is exponentially suppressed due to the low ambient thermal energy. Second, high fields in 77K operation prevent trapping of drifting carriers on ionized impurities and crystalline defects and/or overcome space charge effects. At low temperatures, ionized impurities and space charge can be neutralized (using free charge created by photons from LEDs or radioactive sources) and remain in this state for minutes to hours. This reduces trapping exponentially and allows low-field drift. Third, a high field in a sub-Kelvin detector would result in a massive phonon signal from the drifting carriers, fully correlated with the ionization signal and thereby eliminating nuclear recoil discrimination. Readout of the charge signal is typically done with a conventional JFET-based transimpedance amplifier.

A number of materials that scintillate on their own (i.e., without doping) continue to do so at low temperatures, including BaF₂, BGO, CaWO₄, ZnWO₄, PbWO₄, and other tungstates and molybdates. In and of itself, there is little advantage to a low-temperature scintillation measurement because detecting the scintillation is nontrivial, the quanta are large, and the detection efficiency is usually poor. Such techniques are pursued only in order to obtain nuclear-recoil discrimination. Conventional photodetectors do not operate at such low temperatures, so one typically detects the scintillation photons in an adjacent low-temperature detector that is thermally disconnected from but resides in an optically reflective cavity with the target detector.

32.6. Low-radioactivity background techniques

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The physics reach of low-energy rare event searches e.g. for dark matter, neutrino oscillations, or double beta decay is often limited by background caused by radioactivity. Depending on the chosen detector design, the separation of the physics signal from this unwanted interference can be achieved on an event-by-event basis by active event tagging, utilizing some unique event feature, or by reducing the radiation background by appropriate shielding and material selection. In both cases, the background rate is proportional to the flux of background-creating radiation. Its reduction is thus essential for realizing the full physics potential of the experiment. In this context, "low energy" may be defined as the regime of natural, anthropogenic, or cosmogenic radioactivity, all at energies up to about 10 MeV. Following the classification of [51], sources of background may be categorized into the following classes:

- 1. environmental radioactivity,
- 2. radioimpurities in detector or shielding components,
- 3. radon and its progeny,
- 4. cosmic rays,
- 5. neutrons from natural fission, (α, n) reactions and from cosmic-ray muon spallation and capture.

32.6.1. Defining the problem: The application defines the requirements. Background goals can be as demanding as a few low-energy events per year in a ton-size detector. The strength of the physics signal to be measured can often be estimated theoretically or from limits derived by earlier experiments. The experiments are then designed for the desired signal-to-background ratio. This requires finding the right balance between clarity of measurement, ease of construction, and budget. In a practical sense, it is important to formulate background goals that are sufficient for the task at hand but doable, in a finite time. It is now standard practice to use a detector simulation to translate the background requirements into

limits for the radioactivity content of various detector components, requirements for the radiation shielding, and allowable cosmic-ray flux. This strategy allows identifing the most critical components early and the allocation of analysis and development resources accordingly. The CERN code GEANT4 is a widely used tool for this task. It contains sufficient nuclear physics to allow accurate background estimations. Custom-written event generators, modeling particle correlations in complex decay schemes, are used as well.

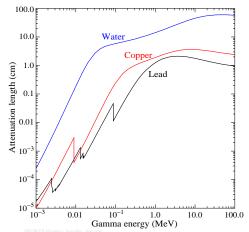


Figure 32.6: γ-ray attenuation lengths in some common shielding materials. The mass attenuation data has been taken from the NIST data base XCOM; see "Atomic Nuclear Properties" at pdg.lbl.gov.

32.6.2. Environmental radioactivity: The long-lived natural radioisotopes 40 K, 232 Th, and 238 U have average abundances of 2.4, 9.6 and 2.7 ppm in the earth's crust, with large local variations. In most applications, γ radiation emitted by natural radioactivity constitutes the dominant contribution to the local radiation field. Typical low-background applications require levels of natural radioactivity on the order of ppb or ppt in the detector components. Passive or active shielding is used to suppress external γ radiation down to that level. Fig. 32.6 shows the energy-dependent attenuation length $\lambda(E_{\gamma})$ as a function of γ ray energy E_{γ} for three common shielding materials (water, copper, lead). The thickness ℓ required to reduce the external flux by a factor f>1 is estimated assuming exponential damping:

$$\ell = \lambda(E_{\gamma}) \cdot \ln f . \tag{32.7}$$

At 100 keV, a typical energy scale for dark matter searches (or 2.615 MeV, for a typical double-beta decay experiment), attenuation by a factor $f=10^5$ requires 67(269) cm of H₂O, 2.8(34) cm of Cu, or 0.18(23) cm of Pb. Such estimates allows for an order-of-magnitude estimate of the experiment dimensions. A precise estimation of the leakage of external γ radiation, including scattering and the effect of energy cuts, requires Monte Carlo simulations and determination of the radioactivity present in the laboratory. Detailed modeling of the γ flux in a large laboratory, or inside hermetic shielding, needs to cope with very small detector-hit efficiencies. It is often advantageous to calculate solid angle and mass attenuation separately. This approach reduces the computation time required for a statistically meaningful number of detector hits to manageable levels.

Because of its low density, water has relatively long attenuation lengths, resulting in rather voluminous shields. However, because water can be obtained relatively cheaply in large amounts, it has become the medium of choice for most large detectors. Water purification technology is effective and commercially available, an important consideration in view of the intrinsic radioactivity of the shield, to be discussed below. High-purity water, instrumented with photo multiplier tubes, can further serve as a Cherenkov cosmic-ray veto detector. Liquefied gases are being used for shielding as well.

32.6.3. Radioimpurities in detector or shielding components

: After suppressing the effect of external radioactivity, radioactive impurities contained in the detector components or attached to its surfaces become important. Any material is radioactive at some level. The activity can be natural, cosmogenic, or man-made. The determination of the activity content of a specific material or component requires case-by-case analysis, and is almost never obtainable from the manufacturer. However, there are some general rules than can be used to guide the pre-selection. For detectors designed to look for electrons (for example in double-beta decay searches or neutrino detection via inverse beta decay or elastic scattering), this is the principal source of background. For devices detecting nuclear recoils (for example in dark matter searches), this is often of secondary importance as ionization signals can be actively suppressed on an event-by-event basis.

For natural radioactivity, a rule of thumb is that synthetic substances are cleaner than natural materials. Typically, more highly processed materials have lower activity content. Substances with smaller chemical reactivity tend to be cleaner. The refining process tends to remove K, Th, and U. For example, Al is often found to contain considerable amounts of Th and U, while electrolytic Cu is very low in primordial activities. Plastics or liquid hydrocarbons, having been refined by distillation, are often quite radiopure. Tabulated radioactivity screening results for a wide range of materials can be found in Refs. 52 and 53.

The long-lived $^{238}\mathrm{U}$ daughter $^{210}\mathrm{Pb}$ $(T_{1/2}{=}22.3~\mathrm{y})$ is found in all shielding lead, and is a background concern at low energies. This is due to the relatively high endpoint energy $(\mathrm{Q}_{\beta}{=}1.162~\mathrm{MeV})$ of its beta-unstable daughter $^{210}\mathrm{Bi}$. Lead parts made from selected low-U ores have specific activities of about 5–30 mBq/kg. For lower activity, ancient lead (for example from Roman ships) has been used. Because the ore processing and lead refining removed most of the $^{238}\mathrm{U}$, the $^{210}\mathrm{Pb}$ decayed during the long waiting time to the level supported by the U-content of the refined lead. Lining the lead with copper to range out the low-energy radiation is another remedy. However, intermediate Z materials are an activation risk when handled above ground, as will be discussed below. $^{210}\mathrm{Pb}$ is also found in solders.

The fission product $^{137}\mathrm{Cs}$ can be found attached to the surface of materials. The radioactive noble gas $^{85}\mathrm{Kr}$, released into the atmosphere by nuclear reactors and nuclear fuel re-processing, is also important, especially due to its high solubility in organic materials. Post-World War II steel typically contains a few tens of mBq/kg of $^{60}\mathrm{Co}$.

Surface activity is not a material property but is added during manufacturing and handling. It can often be effectively removed by etching. Installation of low-background detectors is often done in clean rooms to avoid this contamination. Surface contamination can be quantified by means of wipe-testing with acid or alcohol wetted Whatman 41 filters. The paper filters are ashed after wiping and the residue is digested in acid. Subsequent analysis by means of mass spectroscopy or neutron activation analysis is capable of detecting less than 1 pg/cm² of Th and U. The most demanding low-rate experiments require screening of all components, which can be a time consuming task. The requirements for activity characterization depend on the experiment and the location and amount of a particular component. Monte Carlo simulations are used to quantify these requirements. Activities of the order $\mu Bq/kg$ or even below may need to be detected in the process. At such level of sensitivity, the characterization becomes a challenging problem in itself. Low-background α , β , and γ ray counting, mass spectroscopy, and neutron activation analysis are used.

32.6.4. Radon and its progeny: The noble gas $^{222}\mathrm{Rn}$, a pure $\alpha\text{-emitter}$, is a $^{238}\mathrm{U}$ decay product. Due to its half-life of 3.8 d it is released by surface soil and is found in the atmosphere everywhere. $^{220}\mathrm{Rn}$ ($^{232}\mathrm{Th}$ decay product) is unimportant because of its short half-life. $^{222}\mathrm{Rn}$ activity in air ranges from 10 to 100 mBq/L outdoors and 100 to thousands of mBq/L indoors. The natural radon concentration depends on the weather and shows daily and seasonal variations. Radon levels are lowest above the oceans. For electron detectors, it is not the Rn itself that creates background, but its progeny $^{214}\mathrm{Pb},$ $^{210}\mathrm{Bi},$ which emit energetic beta and γ radiation. Thus, not

only the detector itself has to be separated from contact with air, but also internal voids in the shield which contain air can be a background concern. Radon is quite soluble in water and even more so in organic solvents. For large liquid scintillation detectors, radon mobility due to convection and diffusion is a concern. To define a scale: typical double-beta-decay searches are disturbed by a μ Bq (or 1/11.6 d) activity of 222 Rn contained in the detector medium. This corresponds to a steady-state population of 0.5 atoms in 50 μ L of air (assuming 20 mBq/L of radon in the air). The criteria for leak tightness are thus quite demanding. The decay of Rn itself is a concern for some recoil type detectors, as nuclear recoil energies in α decays are substantial (76 keV in case of 222 Rn).

Low-activity detectors are often kept sealed from the air and continuously flushed with boil-off nitrogen, which contains only small amounts of Rn. For the most demanding applications, the nitrogen is purified by multiple distillations. Then only the Rn outgassing of the piping (due to its U internal content) determines the radon concentration. Radon diffuses readily through thin plastic barriers. If the detector is to be isolated from its environment by means of a membrane, the right choice of material is important [54].

If energies below 1 MeV are to be measured, additional care has to be taken to avoid plate-out of the long-lived radon daughter ²¹⁰Pb on the surfaces. This can be reduced by keeping the parts under a protective low-radon cover gas.

Radon can be detected even at the level of few atoms with solid state, scintillation, or gas detectors by exploiting the fast decay sequences of $^{214}\mathrm{Bi}$ and $^{214}\mathrm{Po}$. The efficiency of these devices is sometimes boosted by electrostatic collection of charged radon into a small detector.

32.6.5. Cosmic rays: Cosmic radiation, discussed in detail in Chapter 26, is a source of background for just about any non-accelerator experiment. Primary cosmic rays are about 90% protons, 9% alpha particles, and the rest heavier nuclei (Fig. 26.1). They are totally attenuated within the first the first few hg/cm² of atmospheric thickness. At sea level secondary particles $(\pi^{\pm}:p:e^{\pm}:n:\mu^{\pm})$ are observed with relative intensities (1:13:340:480:1420) for E<1 GeV (Ref. 55; also see Fig. 26.3).

All but the muon and the neutron components are readily absorbed by overburden such as building ceilings and passive shielding. Only if there is very little overburden (less than a few \times 10 g cm⁻² in rock) do pions and protons need to be considered when estimating the production rate of cosmogenic radioactivity.

Sensitive experiments are thus operated deep underground where essentially only muons penetrate. As shown in Fig. 26.6, the muon intensity falls off rapidly with depth. Active detection systems capable of tagging events correlated in time with cosmic-ray activity are needed, depending on the overburden. Such experiments are described in Sec. 32.3.1.

The muonic background is only related to low-radioactivity techniques insofar as photonuclear interactions of muons can produce long-lived radioactivity. This happens at any depth, and it constitutes an essentially irreducible background.

Cosmogenic activation of components brought from the surface is also an issue. Proper management of parts and materials above ground during machining and detector assembly minimizes the accumulation of long-lived activity. Cosmogenic activation is most important for intermediate Z materials such as Cu and Fe. For the most demanding applications, metals are stored and transported under sufficient shielding to stop the hadronic component of the cosmic rays. Parts, e.g., the nickel tubes for the ³He counters in SNO, can be stored underground for long periods before being used. Underground machine shops are also sometimes used to limit the duration of exposure at the surface.

32.6.6. Neutrons: Neutrons contribute to the background of low-energy experiments in different ways: directly through nuclear recoil in the detector medium, and indirectly, through the production of radio nuclides inside the detector and its components. The latter mechanism allows even remote materials to contribute to the background by means of penetrating γ radiation, since inelastic scattering of fast neutrons or radiative capture of slow neutrons can result in the emission of γ radiation. Neutrons are thus an important source of

low-energy background. They are produced in different ways:

- At the earth's surface neutrons are the most frequent cosmic-ray secondaries other than muons;
- Energetic tertiary neutrons are produced by cosmic-ray muons in nuclear spallation reactions with the detector and laboratory walls;
- In high Z materials, often used in radiation shields, nuclear capture of negative muons results in emission of neutrons;
- 4. Natural radioactivity has a neutron component through spontaneous fission and $(\alpha,n)\text{-reactions}.$

A calculation with the hadronic simulation code FLUKA, using the known energy distribution of secondary neutrons at the earth's surface [56], yields a mass attenuation of 1.5 hg/cm² in concrete for secondary neutrons. If energy-dependent neutron-capture cross sections are known, then such calculations can be used to obtain the production rate of radio nuclides.

At an overburden of only few meters, water equivalent neutron production by muons becomes the dominant mechanism. Neutron production rates are high in high-Z shielding materials. A high-Z radiation shield, discussed earlier as being effective in reducing background due to external radioactivity, thus acts as a source for cosmogenic tertiary high-energy neutrons. Depending on the overburden and the radioactivity content of the laboratory, there is an optimal shielding thickness. Water shields, although bulky, are an attractive alternative due to their low neutron production yield and self-shielding.

Neutron shields made from plastic or water are commonly used to reduce the neutron flux. The shield is sometimes doped with a substance having a high thermal neutron capture cross section (such as boron) to absorb thermal neutrons more quickly. The hydrogen serves as a target for elastic scattering, and is effective in reducing the neutron energy. Neutrons from natural radioactivity have relatively low energies and can be effectively suppressed by a neutron shield. Such a neutron shield should be inside the lead to be effective for tertiary neutrons. However, this is rarely done as it increases the neutron production target (in form of the passive shield), and costs increase as the cube of the dimensions. An active cosmic-ray veto is an effective solution, correlating a neutron with its parent muon. This solution works best if the veto system is as far removed from the detector as feasible (outside the radiation shield) to correlate as many background-producing muons with neutrons as possible. The vetoed time after a muon hit needs to be sufficiently long to assure neutron thermalization. The average thermalization and capture time in lead is about 900 μ s [51]. The veto-induced deadtime, and hence muon hit rate on the veto detector, is the limiting factor for the physical size of the veto system (besides the cost). The background caused by neutron-induced radioactivity with live times exceeding the veto time cannot be addressed in this way. Moving the detector deep underground, and thus reducing the muon flux, is the only technique addressing all sources of neutron background.

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33. RADIOACTIVITY AND RADIATION PROTECTION

Revised August 2011 by S. Roesler and M. Silari (CERN).

33.1. Definitions [1,2]

33.1.1. Physical quantities:

• Fluence, Φ (unit: $1/m^2$): The fluence is the quotient of dN by da, where dN is the number of particles incident upon a small sphere of cross-sectional area da

$$\Phi = dN/da . (33.1)$$

In dosimetric calculations, fluence is frequently expressed in terms of the lengths of the particle trajectories. It can be shown that the fluence, Φ , is given by

$$\Phi = dl/dV$$

where dl is the sum of the particle trajectory lengths in the volume dV

- \bullet Absorbed dose, D (unit: gray, 1 Gy=1 J/kg=100 rad): The absorbed dose is the energy imparted by ionizing radiation in a volume element of a specified material divided by the mass of this volume element
- Kerma, K (unit: gray): Kerma is the sum of the initial kinetic energies of all charged particles liberated by indirectly ionizing radiation in a volume element of the specified material divided by the mass of this volume element.
- Linear energy transfer, L or LET (unit: J/m, often given in $\text{keV}/\mu\text{m}$): The linear energy transfer is the mean energy, dE, lost by a charged particle owing to collisions with electrons in traversing a distance dl in matter. Low-LET radiation: x rays and gamma rays (accompanied by charged particles due to interactions with the surrounding medium) or light charged particles such as electrons that produce sparse ionizing events far apart at a molecular scale $(L < 10 \text{ keV}/\mu\text{m})$. High-LET radiation: neutrons and heavy charged particles that produce ionizing events densely spaced at a molecular scale $(L > 10 \text{ keV}/\mu\text{m})$.
- Activity, A (unit: becquerel, 1 Bq=1/s=27 picocurie): Activity is the expectation value of the number of nuclear decays occurring in a given quantity of material per unit time.

${\bf 33.1.2.} \quad Protection \ quantities:$

Protection quantities are dose quantities developed for radiological protection that allow quantification of the extent of exposure of the human body to ionizing radiation from both whole and partial body external irradiation and from intakes of radionuclides.

• Organ absorbed dose, D_T (unit: gray): The mean absorbed dose in an organ or tissue T of mass m_T is defined as

$$D_T = \frac{1}{m_T} \int_{m_T} D dm \ .$$

• Equivalent dose, H_T (unit: sievert, 1 Sv=100 rem): The equivalent dose H_T in an organ or tissue T is equal to the sum of the absorbed doses $D_{T,R}$ in the organ or tissue caused by different radiation types R weighted with so-called radiation weighting factors w_R :

$$H_T = \sum_R w_R \times D_{T,R} \ . \tag{33.2}$$

It expresses long-term risks (primarily cancer and leukemia) from low-level chronic exposure. The values for w_R recommended by ICRP [2] are given in Table 33.1.

• Effective dose, E (unit: sievert): The sum of the equivalent doses, weighted by the tissue weighting factors w_T ($\sum_T w_T = 1$) of several organs and tissues T of the body that are considered to be most sensitive [2], is called "effective dose":

$$E = \sum_{T} w_T \times H_T \ . \tag{33.3}$$

Table 33.1: Radiation weighting factors, w_R .

| Radiation type | w_R |
|--------------------------------------------|-----------------------------------------------|
| Photons, electrons and muons | 1 |
| Neutrons, $E_n < 1 \text{ MeV}$ | $2.5 + 18.2 \times \exp[-(\ln E_n)^2/6]$ |
| $1 \text{ MeV} \le E_n \le 50 \text{ MeV}$ | $5.0 + 17.0 \times \exp[-(\ln(2E_n))^2/6]$ |
| $E_n > 50 \text{ MeV}$ | $2.5 + 3.25 \times \exp[-(\ln(0.04E_n))^2/6]$ |
| Protons and charged pions | 2 |
| Alpha particles, fission | |
| fragments, heavy ions | 20 |

${\bf 33.1.3.} \quad Operational \ quantities:$

The body-related protection quantities, equivalent dose and effective dose, are not measurable in practice. Therefore, operational quantities are used for the assessment of effective dose or mean equivalent doses in tissues or organs. These quantities aim to provide a conservative estimate for the value of the protection quantity.

- Ambient dose equivalent, $H^*(10)$ (unit: sievert): The dose equivalent at a point in a radiation field that would be produced by the corresponding expanded and aligned field in a 30 cm diameter sphere of unit density tissue (ICRU sphere) at a depth of 10 mm on the radius vector opposing the direction of the aligned field. Ambient dose equivalent is the operational quantity for area monitoring.
- Personal dose equivalent, $H_p(d)$ (unit: sievert): The dose equivalent in ICRU tissue at an appropriate depth, d, below a specified point on the human body. The specified point is normally taken to be where the individual dosimeter is worn. For the assessment of effective dose, $H_p(10)$ with a depth d=10 mm is chosen, and for the assessment of the dose to the skin and to the hands and feet the personal dose equivalent, $H_p(0.07)$, with a depth d=0.07 mm, is used. Personal dose equivalent is the operational quantity for individual monitoring.

${\bf 33.1.4.} \quad Dose\ conversion\ coefficients:$

Dose conversion coefficients allow direct calculation of protection or operational quantities from particle fluence and are functions of particle type, energy and irradiation configuration. The most common coefficients are those for effective dose and ambient dose equivalent. The former are based on simulations in which the dose to organs of anthropomorphic phantoms is calculated for approximate actual conditions of exposure, such as irradiation of the front of the body (antero-posterior irradiation) or isotropic irradiation.

Conversion coefficients from fluence to effective dose are given for anterior-posterior irradiation and various particles in Fig. 33.1 [3]. For example, the effective dose from an anterior-posterior irradiation in a field of 1-MeV neutrons with a fluence of 1 neutron per $\rm cm^2$ is about 290 pSv. In Monte Carlo simulations such coefficients allow multiplication with fluence at scoring time such that effective dose to a human body at the considered location is directly obtained.

33.2. Radiation levels [4]

- Natural background radiation: On a worldwide average, the annual whole-body dose equivalent due to all sources of natural background radiation ranges from 1.0 to 13 mSv (0.1–1.3 rem) with an annual average of 2.4 mSv [5]. In certain areas values up to 50 mSv (5 rem) have been measured. A large fraction (typically more than 50%) originate from inhaled natural radioactivity, mostly radon and radon daughters. The latter can vary by more than one order of magnitude: it is 0.1–0.2 mSv in open areas, 2 mSv on average in a house and more than 20 mSv in poorly ventilated mines.
- Cosmic ray background radiation: At sea level, the whole-body dose equivalent due to cosmic ray background radiation is dominated by muons; at higher altitudes also nucleons contribute. Dose equivalent rates range from less than $0.1~\mu \text{Sv/h}$ at sea level to a few $\mu \text{Sv/h}$ at aircraft altitudes. Details on cosmic ray fluence levels are given in the Cosmic Rays section (Sec. 26 of this Review).

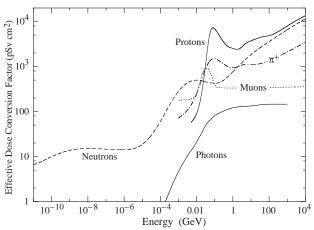


Figure 33.1: Fluence to effective dose conversion coefficients for anterior-posterior irradiation and various particles [3].

• Fluence to deposit one Gy: Charged particles: The fluence necessary to deposit a dose of one Gy (in units of cm⁻²) is about $6.24 \times 10^9/(dE/dx)$, where dE/dx (in units of MeV g⁻¹ cm²) is the mean energy loss rate that may be obtained from Figs. 30.2 and 30.4 in Sec. 30 of this Review, and from http://pdg.lbl.gov/AtomicNuclearProperties. For example, it is approximately 3.5×10^9 cm⁻² for minimum-ionizing singly-charged particles in carbon. Photons: This fluence is about $6.24 \times 10^9/(Ef/\ell)$ for photons of energy E (in MeV), an attenuation length ℓ (in g cm⁻²), and a fraction $f \lesssim 1$, expressing the fraction of the photon energy deposited in a small volume of thickness $\ll \ell$ but large enough to contain the secondary electrons. For example, it is approximately 2×10^{11} cm⁻² for 1 MeV photons on carbon ($f \approx 1/2$).

33.3. Health effects of ionizing radiation

Radiation can cause two types of health effects, deterministic and stochastic:

- ullet **Deterministic effects** are tissue reactions which cause injury to a population of cells if a given threshold of absorbed dose is exceeded. The severity of the reaction increases with dose. The quantity in use for tissue reactions is the absorbed dose, D. When particles other than photons and electrons (low-LET radiation) are involved, a Relative Biological Effectiveness (RBE)-weighted dose may be used. The RBE of a given radiation is the reciprocal of the ratio of the absorbed dose of that radiation to the absorbed dose of a reference radiation (usually x rays) required to produce the same degree of biological effect. It is a complex quantity that depends on many factors such as cell type, dose rate, fractionation, etc.
- Stochastic effects are malignant diseases and heritable effects for which the probability of an effect occurring, but not its severity, is a function of dose without threshold.
- Lethal dose: The whole-body dose from penetrating ionizing radiation resulting in 50% mortality in 30 days (assuming no medical treatment) is 2.5–4.5 Gy (250–450 rad) † , as measured internally on the body longitudinal center line. The surface dose varies due to variable body attenuation and may be a strong function of energy.
- Cancer induction: The cancer induction probability is about 5% per Sv on average for the entire population [2].
- Recommended effective dose limits: The International Commission on Radiological Protection (ICRP) recommends a limit for radiation workers of 20 mSv effective dose per year averaged over 5 years, with the provision that the dose should not exceed 50 mSv in any single year [2]. The limit in the EU-countries and Switzerland is 20 mSv per year, in the U.S. it is 50 mSv per year (5 rem per year). Many physics laboratories in the U.S. and elsewhere set lower limits. The effective dose limit for general public is typically 1 mSv per year.

33.4. Prompt neutrons at accelerators

Neutrons dominate the particle environment outside thick shielding (e.g., > 1 m of concrete) for high energy (> a few hundred MeV) electron and hadron accelerators.

33.4.1. Electron accelerators:

At electron accelerators, neutrons are generated via photonuclear reactions from bremsstrahlung photons. In the photon energy range from threshold (few MeV) to about 30 MeV, neutron production is via the Giant Dipole Resonance (GDR) mechanism. The reaction consists in a collective excitation of the nucleus, in which neutrons and protons oscillate in the direction of the photon electric field. The oscillation is damped by friction in a few cycles, with the photon energy being transfered to the nucleus in a process similar to evaporation. Nucleons emitted in the dipolar interaction have an anisotropic angular distribution, with a maximum at 90°, while those leaving the nucleus as a result of evaporation are emitted isotropically with a Maxwellian energy distribution described as [6]:

$$\frac{dN}{dE_n} = \frac{E_n}{T^2} e^{-E_n/T} \ , \tag{33.4} \label{eq:33.4}$$

where T is a nuclear 'temperature' (in units of MeV) characteristic of the particular target nucleus and its excitation energy. For heavy nuclei the 'temperature' generally lies in the range of T=0.5–1.0 MeV. For higher energy photons, the quasi-deuteron (between about 30 MeV and 250 MeV), delta resonance (250 MeV–1.2 GeV) and vector meson dominance ($\gtrsim 1.2$ GeV) mechanisms become important.

Neutron yields from semi-infinite targets per kW of electron beam power are plotted in Fig. 33.2 as a function of the electron beam energy [6].

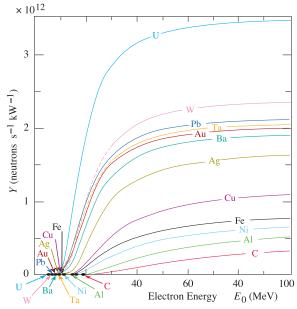


Figure 33.2: Neutron yields from semi-infinite targets per kW of electron beam power, as a function of the electron beam energy, disregarding target self-shielding [6].

Typical neutron energy spectra outside of concrete (80 cm thick, $2.35~{\rm g/cm^3}$) and iron (40 cm thick) shields are shown in Fig. 33.3. In order to compare these spectra to those caused by proton beams (see below) the spectra are scaled by a factor of 100, which roughly corresponds to the difference in the high energy hadronic cross sections for photons and hadrons (e.g., the fine structure constant). The shape of these spectra are generally characterized by a low-energy peak at around 1 MeV (evaporation neutrons) and a high-energy shoulder at around 70–80 MeV. In case of concrete shielding, the spectrum also shows a pronounced peak at thermal neutron energies.

 $^{^{\}dagger}$ RBE-weighted when necessary

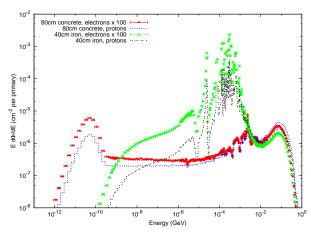


Figure 33.3: Neutron energy spectra calculated with the FLUKA code [7,8] from 25 GeV proton and electron beams on a thick copper target. Spectra are evaluated at 90° to the beam direction behind 80 cm of concrete or 40 cm of iron. All spectra are normalized per beam particle. In addition, spectra for electron beam are multiplied by a factor of 100.

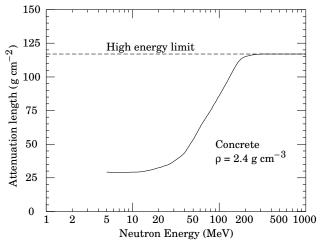


Figure 33.4: The variation of the attenuation length for mono-energetic neutrons in concrete as a function of neutron energy [9].

${\bf 33.4.2.} \quad Proton\ accelerators:$

At proton accelerators, neutron yields emitted per incident proton by different target materials are roughly independent of proton energy between 20 MeV and 1 GeV, and are given by the ratio C: Al: Cu-Fe: Sn: Ta-Pb = 0.3:0.6:1.0:1.5:1.7 [9]. Above about 1 GeV, the neutron yield is proportional to E^m , where $0.80 \le m \le 0.85$ [10].

Typical neutron energy spectra outside of concrete and iron shielding are shown in Fig. 33.3. Here, the radiation fields are caused by a 25 GeV proton beam interacting with a thick copper target. The comparison of these spectra with those for an electron beam of the same energy reflects the difference in the hadronic cross sections between photons and hadrons above a few 100 MeV. Differences are increasing towards lower energies because of different interaction mechanisms. Furthermore, the slight shift in energy above about 100 MeV follows from the fact that the energies of the interacting photons are lower than 25 GeV. Apart from this the shapes of the two spectra are similar.

The neutron-attenuation length is shown in Fig. 33.4 for concrete and mono-energetic broad-beam conditions. As can be seen in the figure it reaches a value of about $117~\rm g/cm^2$ above 200 MeV. As the cascade through thick shielding is carried by high-energy particles this value is equal to the equilibrium attenuation length at 90 degrees in concrete.

33.5. Photon sources

The dose equivalent rate in tissue (in mSv/h) from a gamma point source emitting one photon of energy E (in MeV) per second at a distance of 1 m is $4.6 \times 10^{-9} \, \mu_{en}/\rho \, E$, where μ_{en}/ρ is the mass energy absorption coefficient. The latter has a value of $0.029 \pm 0.004 \, \mathrm{cm}^2/\mathrm{g}$ for photons in tissue over an energy range between 60 keV and 2 MeV (see Ref. 11 for tabulated values).

Similarly, the dose equivalent rate in tissue (in mSv/h) at the surface of a semi-infinite slab of uniformly activated material containing 1 Bq/g of a gamma emitter of energy E (in MeV) is $2.9 \times 10^{-4} R_{\mu} E$, where R_{μ} is the ratio of the mass energy absorption coefficients of the photons in tissue and in the material.

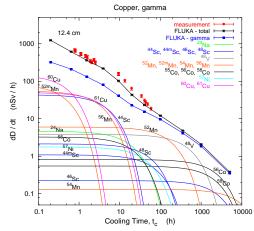


Figure 33.5: Contribution of individual gamma-emitting nuclides to the total dose rate at 12.4 cm distance to an activated copper sample [12].

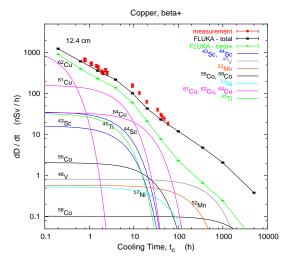


Figure 33.6: Contribution of individual positron-emitting nuclides to the total dose rate at 12.4 cm distance to an activated copper sample [12].

33.6. Accelerator-induced radioactivity

Typical medium- and long-lived activation products in metallic components of accelerators are 22 Na, 46 Sc, 48 V, 51 Cr, 54 Mn, 55 Fe, 59 Fe, 56 Co, 57 Co, 58 Co, 60 Co, 63 Ni and 65 Zn. Gamma-emitting nuclides dominate doses by external irradiation at longer decay times (more than one day) while at short decay times β^+ emitters are also important (through photons produced by β^+ annihilation). Due to their short range, β^- emitters are relevant, for example, only for

dose to the skin and eyes or for doses due to inhalation or ingestion. Fig. 33.5 and Fig. 33.6 show the contributions of gamma and β^+ emitters to the total dose rate at 12.4 cm distance to an activated copper sample [12]. Typically, dose rates at a certain decay time are mainly determined by radionuclides having a half-life of the order of the decay time. Extended irradiation periods might be an exception to this general rule as in this case the activity of long-lived nuclides can built up sufficiently so that it dominates that one of short-lived even at short cooling times.

Activation in concrete is dominated by 24 Na (short decay times) and 22 Na (long decay times). Both nuclides can be produced either by low-energy neutron reactions on the sodium-component in the concrete or by spallation reactions on silicon and calcium. At long decay times nuclides of radiological interest in activated concrete can also be 60 Co, 152 Eu, 154 Eu and 134 Cs, all of which produced by (n,γ) -reactions with traces of natural cobalt, europium and cesium, Thus, such trace elements might be important even if their content in concrete is only a few parts per million or less by weight.

The explicit simulation of radionuclide production with general-purpose Monte Carlo codes has become the most commonly applied method to calculate induced radioactivity and its radiological consequences. Nevertheless, other more approximative approaches, such as " ω -factors" [9], can still be useful for fast order-of-magnitude estimates. These ω -factors give the dose rate per unit star density (inelastic reactions above a certain energy threshold, e.g. 50 MeV) on contact to an extended, uniformly activated object after a 30-day irradiation and 1-day decay. For steel or iron, $\omega \simeq 3 \times 10^{-12}$ (Sv cm³/star). This does not include possible contributions from thermal-neutron activation.

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34. COMMONLY USED RADIOACTIVE SOURCES

Table 34.1. Revised November 1993 by E. Browne (LBNL).

| | | | Parti | | | oton |
|----------------------------------------|----------------------------------------------------------|--------------------------------------------|-----------------------------------|------------------------------------------------------|----------------------|---------------------------------|
| N 1: .1 . | TT - 1¢ 1:¢- | | | Emission | | y Emission |
| Nuclide ²² Na | 2 603 v | $\frac{\text{decay}}{\beta^+, \text{ EC}}$ | (MeV) | 90% | 0.511 |) prob. Annih. |
| 11 ¹ Na | 2.003 y | ρ , EC | 0.040 | 9070 | 1.275 | 100% |
| $^{54}_{25}\mathrm{Mn}$ | 0.855 y | EC | | | 0.835 Cr K x | 100% x rays 26% |
| ⁵⁵ ₂₆ Fe | 2.73 y | EC | | | | x rays: |
| 20 | J | | | | 0.0059 | 0 24.4% 9 2.86% |
| 57Co | 0.744 y | EC | | | 0.014 | 9% |
| | | | | | 0.122 | 86% |
| | | | | | 0.136 | |
| | | | | | Fe K x | rays 58% |
| $_{27}^{60}$ Co | 5.271 y | β^- | 0.316 | 100% | 1.173 1.333 | |
| $_{32}^{68}$ Ge | 0.742 y | EC | | | | x rays 44% |
| $\rightarrow {}^{68}_{31}\mathrm{Ga}$ | | β^+ , EC | 1 899 | 90% | 0.511 | Annih. |
| 31 04 | | р , вс | 1.000 | 3070 | 1.077 | 3% |
| $^{90}_{38}{ m Sr}$ | 28.5 y | β^- | 0.546 | 100% | | |
| $\rightarrow {}^{90}_{39}\mathrm{Y}$ | | β^- | 2.283 | 100% | | |
| $\frac{{39}^{90}Y}{_{44}^{106}Ru}$ | 1.020 y | β^- | 0.039 | 100% | | |
| $\rightarrow {}^{106}_{45}\mathrm{Ri}$ | 1 | β^- | 3.541 | 79% | 0.512 | 21% |
| 40 | | • | | | 0.622 | 10% |
| ¹⁰⁹ Cd | 1.267 y | EC | $0.063 \ e^{-}$ | 41% | 0.088 | 3.6% |
| | | | $0.084\ e^{-}$ | | Ag K | k rays 100% |
| | | | $0.087 \ e^{-}$ | 9% | | |
| $^{113}_{50}{\rm Sn}$ | 0.315 y | EC | $0.364 \ e^{-}$ | | 0.392 | |
| | | | $0.388 \ e^{-}$ | | | rays 97% |
| $^{137}_{55}\mathrm{Cs}$ | $30.2 	ext{ y}$ | β^{-} | 0.514 | 94% | 0.662 | 85% |
| | | | 1.176 | 6% | | |
| $^{133}_{56} Ba$ | 10.54 y | EC | $0.045 \ e^{-}$ | 50% | 0.081 | |
| | | | $0.075 \ e^{-}$ | 6% | 0.356 | 62% |
| | | | | | Cs K x | rays 121% |
| $^{207}_{83}{ m Bi}$ | 31.8 y | EC | $0.481 \ e^{-}$ | | 0.569 | |
| | | | $0.975 \ e^{-}$ | | 1.063 | 75% |
| | | | $1.047 e^{-}$ | 2% | 1.770 Db.K. | 7% |
| 228.00 | 1.010 | | T 0 14 . | 0 =0= | | x rays 78% |
| $^{228}_{90}$ Th | 1.912 y | 6α : | 5.341 to | | 0.239 | 44% |
| | | $3\beta^-$: | 0.334 to | 2.240 | 0.583 2.614 | $31\% \\ 36\%$ |
| $(\rightarrow^{224}_{99} Ra$ | $\rightarrow {}^{220}_{86}I$ | $\operatorname{Rn} \longrightarrow {}^{2}$ | ²¹⁶ ₈₄ Po - | $\rightarrow {}^{212}_{82} \mathrm{Pb} \rightarrow$ | 2.014 212 83Bi | $\rightarrow {}^{212}_{84} Po)$ |
| $\frac{^{241}_{95}Am}{^{241}_{95}Am}$ | $ ightarrow rac{220}{86}$ I $ ightarrow 432.7 	ext{ y}$ | α | 5.443 | 13% | 0.060 | 36% |
| 9511111 | 102.1 y | а | 5.486 | 85% | | c rays 38% |
| $^{241}_{95}\mathrm{Am/Be}$ | 432.2 y | | | ons (4–8 Me' .43 MeV) per | | av |
| $\frac{244}{96}$ Cm | 18.11 y | α | 5.763 | 24% | | $rays \sim 9\%$ |
| 96 CIII | 10.11 y | а | 5.805 | 76% | ruba | 1 1 ays - 570 |
| ²⁵² ₉₈ Cf | 2.645 y | α (97%) | 6.076 | 15% | | |
| | | , | 6.118 | 82% | | |
| | | Fission | | ~ | | |
| | | | | sion; $80\% < 1$ | | MoV |
| | | ≈ 4 | neutron | s/fission; $\langle E_n \rangle$ | $_{j} = 2.14$ | IVIE V |
| | | | | | | |

"Emission probability" is the probability per decay of a given emission; because of cascades these may total more than 100%. Only principal emissions are listed. EC means electron capture, and e^- means monoenergetic internal conversion (Auger) electron. The intensity of 0.511 MeV e^+e^- annihilation photons depends upon the number of stopped positrons. Endpoint β^\pm energies are listed. In some cases when energies are closely spaced, the γ -ray values are approximate weighted averages. Radiation from short-lived daughter isotopes is included where relevant.

Half-lives, energies, and intensities are from E. Browne and R.B. Firestone, *Table of Radioactive Isotopes* (John Wiley & Sons, New York, 1986), recent *Nuclear Data Sheets*, and *X-ray and Gamma-ray Standards for Detector Calibration*, IAEA-TECDOC-619 (1991).

Neutron data are from Neutron Sources for Basic Physics and Applications (Pergamon Press, 1983).

35. PROBABILITY

Revised September 2011 by G. Cowan (RHUL).

35.1. General [1–8]

An abstract definition of probability can be given by considering a set S, called the sample space, and possible subsets A, B, \ldots , the interpretation of which is left open. The probability P is a real-valued function defined by the following axioms due to Kolmogorov [9]:

- 1. For every subset A in S, $P(A) \ge 0$;
- 2. For disjoint subsets (i.e., $A \cap B = \emptyset$), $P(A \cup B) = P(A) + P(B)$;
- 3. P(S) = 1.

In addition, one defines the conditional probability P(A|B) (read P of A given B) as

$$P(A|B) = \frac{P(A \cap B)}{P(B)}. \tag{35.1}$$

From this definition and using the fact that $A \cap B$ and $B \cap A$ are the same, one obtains Bayes' theorem,

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)}$$
 (35.2)

From the three axioms of probability and the definition of conditional probability, one obtains the law of total probability,

$$P(B) = \sum_{i} P(B|A_i)P(A_i) ,$$
 (35.3)

for any subset B and for disjoint A_i with $\bigcup_i A_i = S$. This can be combined with Bayes' theorem (Eq. (35.2)) to give

$$P(A|B) = \frac{P(B|A)P(A)}{\sum_{i} P(B|A_{i})P(A_{i})},$$
 (35.4)

where the subset A could, for example, be one of the A_i .

The most commonly used interpretation of the subsets of the sample space are outcomes of a repeatable experiment. The probability P(A)is assigned a value equal to the limiting frequency of occurrence of A. This interpretation forms the basis of frequentist statistics.

The subsets of the sample space can also be interpreted as hypotheses, i.e., statements that are either true or false, such as 'The mass of the W boson lies between 80.3 and 80.5 GeV.' In the frequency interpretation, such statements are either always or never true, i.e., the corresponding probabilities would be 0 or 1. Using subjective probability, however, P(A) is interpreted as the degree of belief that the hypothesis A is true. Subjective probability is used in Bayesian (as opposed to frequentist) statistics. Bayes' theorem can be written

$$P(\text{theory}|\text{data}) \propto P(\text{data}|\text{theory})P(\text{theory})$$
, (35.5)

where 'theory' represents some hypothesis and 'data' is the outcome of the experiment. Here P(theory) is the *prior* probability for the theory, which reflects the experimenter's degree of belief before carrying out the measurement, and P(data|theory) is the probability to have gotten the data actually obtained, given the theory, which is also called the likelihood.

Bayesian statistics provides no fundamental rule for obtaining the prior probability, which may depend on previous measurements, theoretical prejudices, etc. Once this has been specified, however, Eq. (35.5) tells how the probability for the theory must be modified in the light of the new data to give the posterior probability, P(theory|data). As Eq. (35.5) is stated as a proportionality, the probability must be normalized by summing (or integrating) over all possible hypotheses.

35.2. Random variables

A random variable is a numerical characteristic assigned to an element of the sample space. In the frequency interpretation of probability, it corresponds to an outcome of a repeatable experiment. Let x be a possible outcome of an observation. If x can take on any value from a continuous range, we write $f(x;\theta)dx$ as the probability that the measurement's outcome lies between x and x + dx. The function $f(x;\theta)$ is called the *probability density function* (p.d.f.), which may depend on one or more parameters θ . If x can take on only discrete values (e.g., the non-negative integers), then $f(x;\theta)$ is itself a probability.

The p.d.f. is always normalized to unit area (unit sum, if discrete). Both x and θ may have multiple components and are then often written as vectors. If θ is unknown, we may wish to estimate its value from a given set of measurements of x; this is a central topic of statistics (see Sec. 36).

The cumulative distribution function F(a) is the probability that

$$F(a) = \int_{-\infty}^{a} f(x) \, dx \,. \tag{35.6}$$

Here and below, if x is discrete-valued, the integral is replaced by a sum. The endpoint a is expressly included in the integral or sum. Then $0 \le F(x) \le 1$, F(x) is nondecreasing, and $P(a < x \le b) = F(b) - F(a)$. If x is discrete, F(x) is flat except at allowed values of x, where it has discontinuous jumps equal to f(x).

Any function of random variables is itself a random variable, with (in general) a different p.d.f. The expectation value of any function u(x) is

$$E[u(x)] = \int_{-\infty}^{\infty} u(x) f(x) dx , \qquad (35.7)$$

assuming the integral is finite. For u(x) and v(x), any two functions of x, E[u+v] = E[u] + E[v]. For c and k constants, E[cu+k] = cE[u] + k. The n^{th} moment of a random variable x is

$$\alpha_n \equiv E[x^n] = \int_{-\infty}^{\infty} x^n f(x) dx$$
, (35.8a)

and the n^{th} central moment of x (or moment about the mean, $\alpha_1)$ is

$$m_n \equiv E[(x - \alpha_1)^n] = \int_{-\infty}^{\infty} (x - \alpha_1)^n f(x) dx$$
. (35.8b)

The most commonly used moments are the mean μ and variance σ^2 :

$$\mu \equiv \alpha_1$$
, (35.9a)

$$\mu \equiv \alpha_1 , \qquad (35.9a)$$

$$\sigma^2 \equiv V[x] \equiv m_2 = \alpha_2 - \mu^2 . \qquad (35.9b)$$

The mean is the location of the "center of mass" of the p.d.f., and the variance is a measure of the square of its width. Note that $V[cx+k] = c^2V[x]$. It is often convenient to use the standard deviation of x, σ , defined as the square root of the variance.

Any odd moment about the mean is a measure of the skewness of the p.d.f. The simplest of these is the dimensionless coefficient of skewness $\gamma_1 = m_3/\sigma^3$.

The fourth central moment m_4 provides a convenient measure of the tails of a distribution. For the Gaussian distribution (see Sec. 35.4), one has $m_4 = 3\sigma^4$. The kurtosis is defined as $\gamma_2 = m_4/\sigma^4 - 3$, i.e., it is zero for a Gaussian, positive for a leptokurtic distribution with longer tails, and negative for a platykurtic distribution with tails that die off more quickly than those of a Gaussian.

The quantile x_{α} is the value of the random variable x at which the cumulative distribution is equal to α . That is, the quantile is the inverse of the cumulative distribution function, i.e., $x_{\alpha} = F^{-1}(\alpha)$. An important special case is the median, x_{med} , defined by $F(x_{\text{med}}) = 1/2$, i.e., half the probability lies above and half lies below x_{med} . (More rigorously, $x_{\rm med}$ is a median if $P(x \ge x_{\rm med}) \ge 1/2$ and $P(x \le x_{\text{med}}) \ge 1/2$. If only one value exists, it is called 'the median.')

Under a monotonic change of variable $x \to y(x)$, the quantiles of a distribution (and hence also the median) obey $y_{\alpha} = y(x_{\alpha})$. In general the expectation value and *mode* (most probable value) of a distribution do not, however, transform in this way.

Let x and y be two random variables with a *joint* p.d.f. f(x, y). The *marginal* p.d.f. of x (the distribution of x with y unobserved) is

$$f_1(x) = \int_{-\infty}^{\infty} f(x, y) \, dy$$
, (35.10)

and similarly for the marginal p.d.f. $f_2(y)$. The conditional p.d.f. of y given fixed x (with $f_1(x) \neq 0$) is defined by $f_3(y|x) = f(x,y)/f_1(x)$, and similarly $f_4(x|y) = f(x,y)/f_2(y)$. From these, we immediately obtain Bayes' theorem (see Eqs. (35.2) and (35.4)),

$$f_4(x|y) = \frac{f_3(y|x)f_1(x)}{f_2(y)} = \frac{f_3(y|x)f_1(x)}{\int f_3(y|x')f_1(x') dx'}.$$
 (35.11)

The mean of x is

$$\mu_x = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} x f(x, y) dx dy = \int_{-\infty}^{\infty} x f_1(x) dx, \qquad (35.12)$$

and similarly for y. The covariance of x and y is

$$cov[x, y] = E[(x - \mu_x)(y - \mu_y)] = E[xy] - \mu_x \mu_y.$$
 (35.13)

A dimensionless measure of the covariance of x and y is given by the correlation coefficient,

$$\rho_{xy} = \text{cov}[x, y] / \sigma_x \sigma_y , \qquad (35.14)$$

where σ_x and σ_y are the standard deviations of x and y. It can be shown that $-1 \le \rho_{xy} \le 1$.

Two random variables x and y are *independent* if and only if

$$f(x,y) = f_1(x)f_2(y)$$
. (35.15)

If x and y are independent, then $\rho_{xy}=0$; the converse is not necessarily true. If x and y are independent, E[u(x)v(y)]=E[u(x)]E[v(y)], and V[x+y]=V[x]+V[y]; otherwise, $V[x+y]=V[x]+V[y]+2\mathrm{cov}[x,y]$, and E[uv] does not necessarily factorize.

Consider a set of n continuous random variables $\mathbf{x} = (x_1, \dots, x_n)$ with joint p.d.f. $f(\mathbf{x})$, and a set of n new variables $\mathbf{y} = (y_1, \dots, y_n)$, related to \mathbf{x} by means of a function $\mathbf{y}(\mathbf{x})$ that is one-to-one, *i.e.*, the inverse $\mathbf{x}(\mathbf{y})$ exists. The joint p.d.f. for \mathbf{y} is given by

$$g(\mathbf{y}) = f(\mathbf{x}(\mathbf{y}))|J| \quad , \tag{35.16}$$

where |J| is the absolute value of the determinant of the square matrix $J_{ij} = \partial x_i/\partial y_j$ (the Jacobian determinant). If the transformation from \boldsymbol{x} to \boldsymbol{y} is not one-to-one, the \boldsymbol{x} -space must be broken into regions where the function $\boldsymbol{y}(\boldsymbol{x})$ can be inverted, and the contributions to $g(\boldsymbol{y})$ from each region summed.

Given a set of functions $\boldsymbol{y} = (y_1, \dots, y_m)$ with m < n, one can construct n-m additional independent functions, apply the procedure above, then integrate the resulting $g(\boldsymbol{y})$ over the unwanted y_i to find the marginal distribution of those of interest.

For a one-to-one transformation of discrete random variables, simply substitute; no Jacobian is necessary because now f is a probability rather than a probability density. If the transformation is not one-to-one, then sum the probabilities for all values of the original variable that contribute to a given value of the transformed variable. If f depends on a set of parameters θ , a change to a different parameter set $\eta(\theta)$ is made by simple substitution; no Jacobian is used.

35.3. Characteristic functions

The characteristic function $\phi(u)$ associated with the p.d.f. f(x) is essentially its Fourier transform, or the expectation value of e^{iux} :

$$\phi(u) = E\left[e^{iux}\right] = \int_{-\infty}^{\infty} e^{iux} f(x) dx. \qquad (35.17)$$

Once $\phi(u)$ is specified, the p.d.f. f(x) is uniquely determined and vice versa; knowing one is equivalent to the other. Characteristic functions are useful in deriving a number of important results about moments and sums of random variables.

It follows from Eqs. (35.8a) and (35.17) that the n^{th} moment of a random variable x that follows f(x) is given by

$$i^{-n} \frac{d^n \phi}{du^n}\Big|_{u=0} = \int_{-\infty}^{\infty} x^n f(x) dx = \alpha_n.$$
 (35.18)

Thus it is often easy to calculate all the moments of a distribution defined by $\phi(u)$, even when f(x) cannot be written down explicitly.

If the p.d.f.s $f_1(x)$ and $f_2(y)$ for independent random variables x and y have characteristic functions $\phi_1(u)$ and $\phi_2(u)$, then the characteristic function of the weighted sum ax + by is $\phi_1(au)\phi_2(bu)$. The rules of addition for several important distributions (e.g., that the sum of two Gaussian distributed variables also follows a Gaussian distribution) easily follow from this observation.

Let the (partial) characteristic function corresponding to the conditional p.d.f. $f_2(x|z)$ be $\phi_2(u|z)$, and the p.d.f. of z be $f_1(z)$. The characteristic function after integration over the conditional value is

$$\phi(u) = \int \phi_2(u|z) f_1(z) dz . {(35.19)}$$

Suppose we can write ϕ_2 in the form

$$\phi_2(u|z) = A(u)e^{ig(u)z}$$
 (35.20)

Then

$$\phi(u) = A(u)\phi_1(g(u)) . (35.21)$$

The cumulants (semi-invariants) κ_n of a distribution with characteristic function $\phi(u)$ are defined by the relation

$$\phi(u) = \exp\left[\sum_{n=1}^{\infty} \frac{\kappa_n}{n!} (iu)^n\right] = \exp\left(i\kappa_1 u - \frac{1}{2}\kappa_2 u^2 + \dots\right) . \quad (35.22)$$

The values κ_n are related to the moments α_n and m_n . The first few relations are

$$\begin{split} \kappa_1 &= \alpha_1 \ (= \mu, \ \text{the mean}) \\ \kappa_2 &= m_2 \ = \alpha_2 - \alpha_1^2 \ (= \sigma^2, \ \text{the variance}) \\ \kappa_3 &= m_3 = \alpha_3 - 3\alpha_1\alpha_2 + 2\alpha_1^3 \ . \end{split} \tag{35.23}$$

35.4. Some probability distributions

Table 35.1 gives a number of common probability density functions and corresponding characteristic functions, means, and variances. Further information may be found in Refs. [1–8], [17], and [11], which has particularly detailed tables. Monte Carlo techniques for generating each of them may be found in our Sec. 37.4 and in Ref. 17. We comment below on all except the trivial uniform distribution.

35.4.1. Binomial distribution:

A random process with exactly two possible outcomes which occur with fixed probabilities is called a *Bernoulli* process. If the probability of obtaining a certain outcome (a "success") in an individual trial is p, then the probability of obtaining exactly r successes $(r=0,1,2,\ldots,N)$ in N independent trials, without regard to the order of the successes and failures, is given by the binomial distribution f(r;N,p) in Table 35.1. If r and s are binomially distributed with parameters (N_r,p) and (N_s,p) , then t=r+s follows a binomial distribution with parameters (N_r+N_s,p) .

Table 35.1. Some common probability density functions, with corresponding characteristic functions and means and variances. In the Table, $\Gamma(k)$ is the gamma function, equal to (k-1)! when k is an integer; ${}_1F_1$ is the confluent hypergeometric function of the 1st kind [11].

| Distribution | Probability density function f (variable; parameters) | Characteristic function $\phi(u)$ | Mean | Variance σ^2 |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|------------------------------------------------------|--------------------------------------------------------|
| Uniform | $f(x; a, b) = \begin{cases} 1/(b-a) & a \le x \le b \\ 0 & \text{otherwise} \end{cases}$ | $\frac{e^{ibu} - e^{iau}}{(b-a)iu}$ | $\frac{a+b}{2}$ | $\frac{(b-a)^2}{12}$ |
| Binomial | $f(r; N, p) = \frac{N!}{r!(N-r)!} p^r q^{N-r}$ $r = 0, 1, 2, \dots, N ; 0 \le p \le 1 ; q = 1-p$ | $(q + pe^{iu})^N$ | Np | Npq |
| Poisson | $f(n;\nu) = \frac{\nu^n e^{-\nu}}{n!}$; $n = 0, 1, 2,$; $\nu > 0$ | $\exp[\nu(e^{iu}-1)]$ | ν | ν |
| Normal (Gaussian) | $f(x; \mu, \sigma^2) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-(x - \mu)^2/2\sigma^2)$ $-\infty < x < \infty \; ; -\infty < \mu < \infty \; ; \sigma > 0$ | $\exp(i\mu u - \frac{1}{2}\sigma^2 u^2)$ | μ | σ^2 |
| Multivariate Gaussian | $f(\boldsymbol{x}; \boldsymbol{\mu}, V) = \frac{1}{(2\pi)^{n/2} \sqrt{ V }}$ $\times \exp\left[-\frac{1}{2} (\boldsymbol{x} - \boldsymbol{\mu})^T V^{-1} (\boldsymbol{x} - \boldsymbol{\mu})\right]$ | $\exp\left[i\boldsymbol{\mu}\cdot\boldsymbol{u}-\frac{1}{2}\boldsymbol{u}^TV\boldsymbol{u}\right]$ | μ | V_{jk} |
| χ^2 | $-\infty < x_j < \infty; -\infty < \mu_j < \infty; V > 0$ $f(z;n) = \frac{z^{n/2 - 1} e^{-z/2}}{2^{n/2} \Gamma(n/2)}; z \ge 0$ | $(1-2iu)^{-n/2}$ | n | 2n |
| Student's t | $f(t;n) = \frac{1}{\sqrt{n\pi}} \frac{\Gamma[(n+1)/2]}{\Gamma(n/2)} \left(1 + \frac{t^2}{n}\right)^{-(n+1)/2}$ $-\infty < t < \infty ; \qquad n \text{ not required to be integer}$ | - | $ \begin{cases} 0 \\ \text{for } n > 1 \end{cases} $ | n/(n-2) for $n > 2$ |
| Gamma | $f(x;\lambda,k) = \frac{x^{k-1}\lambda^k e^{-\lambda x}}{\Gamma(k)}\;; \qquad 0 \le x < \infty\;;$ $k \text{ not required to be integer}$ | $(1 - iu/\lambda)^{-k}$ | k/λ | k/λ^2 |
| Beta | $f(x; \alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha - 1} (1 - x)^{\beta - 1}$ $0 \le x \le 1$ | $_1F_1(\alpha;\alpha+\beta;iu)$ | $\frac{\alpha}{\alpha + \beta}$ | $\frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$ |

35.4.2. Poisson distribution:

The Poisson distribution $f(n;\nu)$ gives the probability of finding exactly n events in a given interval of x (e.g., space or time) when the events occur independently of one another and of x at an average rate of ν per the given interval. The variance σ^2 equals ν . It is the limiting case $p \to 0$, $N \to \infty$, $Np = \nu$ of the binomial distribution. The Poisson distribution approaches the Gaussian distribution for large ν .

For example, a large number of radioactive nuclei of a given type will result in a certain number of decays in a fixed time interval. If this interval is small compared to the mean lifetime, then the probability for a given nucleus to decay is small, and thus the number of decays in the time interval is well modeled as a Poisson variable.

35.4.3. Normal or Gaussian distribution:

The normal (or Gaussian) probability density function $f(x; \mu, \sigma^2)$ given in Table 35.1 has mean $E[x] = \mu$ and variance $V[x] = \sigma^2$. Comparison of the characteristic function $\phi(u)$ given in Table 35.1 with Eq. (35.22) shows that all cumulants κ_n beyond κ_2 vanish; this is a unique property of the Gaussian distribution. Some other properties are:

 $P(x \text{ in range } \mu \pm \sigma) = 0.6827,$

 $P(x \text{ in range } \mu \pm 0.6745\sigma) = 0.5,$

$$E[|x - \mu|] = \sqrt{2/\pi}\sigma = 0.7979\sigma,$$

half-width at half maximum = $\sqrt{2 \ln 2} \sigma = 1.177 \sigma$.

For a Gaussian with $\mu=0$ and $\sigma^2=1$ (the *standard* Gaussian), the cumulative distribution, Eq. (35.6), is related to the error function $\operatorname{erf}(y)$ by

$$F(x;0,1) = \frac{1}{2} \left[1 + \text{erf}(x/\sqrt{2}) \right]$$
 (35.24)

The error function and standard Gaussian are tabulated in many references (e.g., Ref. [11,12]) and are available in software packages such as ROOT [5]. For a mean μ and variance σ^2 , replace x by $(x-\mu)/\sigma$. The probability of x in a given range can be calculated with Eq. (36.55).

For x and y independent and normally distributed, z = ax + by follows $f(z; a\mu_x + b\mu_y, a^2\sigma_x^2 + b^2\sigma_y^2)$; that is, the weighted means and variances add.

The Gaussian derives its importance in large part from the central $limit\ theorem$:

If independent random variables x_1, \ldots, x_n are distributed according to any p.d.f. with finite mean and variance, then the sum $y = \sum_{i=1}^n x_i$ will have a p.d.f. that approaches a Gaussian for large n. If the p.d.f.s of the x_i are not identical, the theorem still holds under somewhat more restrictive conditions. The mean and variance are given by the sums of corresponding terms from the individual x_i . Therefore, the sum of a large number of fluctuations x_i will be distributed as a Gaussian, even if the x_i themselves are not.

(Note that the product of a large number of random variables is not Gaussian, but its logarithm is. The p.d.f. of the product is log-normal. See Ref. 8 for details.)

For a set of n Gaussian random variables x with means μ and covariances $V_{ij}=\text{cov}[x_i,x_j],$ the p.d.f. for the one-dimensional

Gaussian is generalized to

$$f(x; \mu, V) = \frac{1}{(2\pi)^{n/2} \sqrt{|V|}} \exp\left[-\frac{1}{2}(x - \mu)^T V^{-1}(x - \mu)\right], \quad (35.25)$$

where the determinant |V| must be greater than 0. For diagonal V (independent variables), $f(x; \mu, V)$ is the product of the p.d.f.s of n Gaussian distributions. For n = 2, $f(x; \mu, V)$ is

$$f(x_1, x_2; \ \mu_1, \mu_2, \sigma_1, \sigma_2, \rho) = \frac{1}{2\pi\sigma_1\sigma_2\sqrt{1-\rho^2}} \ \times$$

$$\exp\left\{\frac{-1}{2(1-\rho^2)}\left[\frac{(x_1-\mu_1)^2}{\sigma_1^2} - \frac{2\rho(x_1-\mu_1)(x_2-\mu_2)}{\sigma_1\sigma_2} + \frac{(x_2-\mu_2)^2}{\sigma_2^2}\right]\right\}.$$
(35.26)

The characteristic function for the multivariate Gaussian is

$$\phi(\boldsymbol{u}; \boldsymbol{\mu}, V) = \exp\left[i\boldsymbol{\mu} \cdot \boldsymbol{u} - \frac{1}{2}\boldsymbol{u}^T V \boldsymbol{u}\right].$$
 (35.27)

If the components of \boldsymbol{x} are independent, then Eq. (35.27) is the product of the c.f.s of n Gaussians.

For a multi-dimensional Gaussian distribution for variables x_i , $i=1,\ldots,n$, the marginal distribution for any single x_i is is a one-dimensional Gaussian with mean μ_i and variance V_{ii} . V is $n\times n$, symmetric, and positive definite. For any vector \boldsymbol{X} , the quadratic form $\boldsymbol{X}^TV^{-1}\boldsymbol{X}=C$, where C is any positive number, traces an n-dimensional ellipsoid as \boldsymbol{X} varies. If $X_i=x_i-\mu_i$, then C is a random variable obeying the χ^2 distribution with n degrees of freedom, discussed in the following section. The probability that \boldsymbol{X} corresponding to a set of Gaussian random variables x_i lies outside the ellipsoid characterized by a given value of C (= χ^2) is given by $1-F_{\chi^2}(C;n)$, where F_{χ^2} is the cumulative χ^2 distribution. This may be read from Fig. 36.1. For example, the "s-standard-deviation ellipsoid" occurs at $C=s^2$. For the two-variable case (n=2), the point \boldsymbol{X} lies outside the one-standard-deviation ellipsoid with 61% probability. The use of these ellipsoids as indicators of probable error is described in Sec. 36.3.2.4; the validity of those indicators assumes that $\boldsymbol{\mu}$ and V are correct.

35.4.4. χ^2 distribution:

If x_1,\ldots,x_n are independent Gaussian random variables, the sum $z=\sum_{i=1}^n(x_i-\mu_i)^2/\sigma_i^2$ follows the χ^2 p.d.f. with n degrees of freedom, which we denote by $\chi^2(n)$. More generally, for n correlated Gaussian variables as components of a vector \boldsymbol{X} with covariance matrix V, $z=\boldsymbol{X}^TV^{-1}\boldsymbol{X}$ follows $\chi^2(n)$ as in the previous section. For a set of z_i , each of which follows $\chi^2(n_i)$, $\sum z_i$ follows $\chi^2(\sum n_i)$. For large n, the χ^2 p.d.f. approaches a Gaussian with a mean and variance give by $\mu=n$ and $\sigma^2=2n$, respectively (here the formulae for μ and σ^2 are valid for all n).

The χ^2 p.d.f. is often used in evaluating the level of compatibility between observed data and a hypothesis for the p.d.f. that the data might follow. This is discussed further in Sec. 36.2.2 on tests of goodness-of-fit.

${\bf 35.4.5.} \quad \textit{Student's t distribution}:$

Suppose that y and x_1, \ldots, x_n are independent and Gaussian distributed with mean 0 and variance 1. We then define

$$z = \sum_{i=1}^{n} x_i^2$$
 and $t = \frac{y}{\sqrt{z/n}}$. (35.28)

The variable z thus follows a $\chi^2(n)$ distribution. Then t is distributed according to Student's t distribution with n degrees of freedom, f(t;n), given in Table 35.1.

The Student's t distribution resembles a Gaussian but has wider tails. As $n\to\infty$, the distribution approaches a Gaussian. If n=1, it is a Cauchy or Breit-Wigner distribution. This distribution is symmetric about zero (its mode), but the expectation value is undefined. For the Student's t, the mean is well defined only for n>1 and the variance is finite only for n>2, so the central limit theorem is

not applicable to sums of random variables following the t distribution for n=1 or 2.

As an example, consider the sample mean $\overline{x} = \sum x_i/n$ and the sample variance $s^2 = \sum (x_i - \overline{x})^2/(n-1)$ for normally distributed x_i with unknown mean μ and variance σ^2 . The sample mean has a Gaussian distribution with a variance σ^2/n , so the variable $(\overline{x} - \mu)/\sqrt{\sigma^2/n}$ is normal with mean 0 and variance 1. The quantity $(n-1)s^2/\sigma^2$ is independent of this and follows $\chi^2(n-1)$. The ratio

$$t = \frac{(\overline{x} - \mu)/\sqrt{\sigma^2/n}}{\sqrt{(n-1)s^2/\sigma^2(n-1)}} = \frac{\overline{x} - \mu}{\sqrt{s^2/n}}$$
 (35.29)

is distributed as f(t;n-1). The unknown variance σ^2 cancels, and t can be used to test the hypothesis that the true mean is some particular value μ .

In Table 35.1, n in f(t;n) is not required to be an integer. A Student's t distribution with non-integral n>0 is useful in certain applications.

35.4.6. Gamma distribution:

For a process that generates events as a function of x (e.g., space or time) according to a Poisson distribution, the distance in x from an arbitrary starting point (which may be some particular event) to the k^{th} event follows a gamma distribution, $f(x; \lambda, k)$. The Poisson parameter μ is λ per unit x. The special case k = 1 (i.e., $f(x; \lambda, 1) = \lambda e^{-\lambda x}$) is called the exponential distribution. A sum of k' exponential random variables x_i is distributed as $f(\sum x_i; \lambda, k')$.

The parameter k is not required to be an integer. For $\lambda=1/2$ and k=n/2, the gamma distribution reduces to the $\chi^2(n)$ distribution.

$35.4.7. \ Beta \ distribution:$

The beta distribution describes a continuous random variable x in the interval [0,1]; this can easily be generalized by scaling and translation to have arbitrary endpoints. In Bayesian inference about the parameter p of a binomial process, if the prior p.d.f. is a beta distribution $f(p;\alpha,\beta)$ then the observation of r successes out of N trials gives a posterior beta distribution $f(p;r+\alpha,N-r+\beta)$ (Bayesian methods are discussed further in Sec. 36). The uniform distribution is a beta distribution with $\alpha=\beta=1$.

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36. STATISTICS

Revised September 2011 by G. Cowan (RHUL).

This chapter gives an overview of statistical methods used in high-energy physics. In statistics, we are interested in using a given sample of data to make inferences about a probabilistic model, e.g., to assess the model's validity or to determine the values of its parameters. There are two main approaches to statistical inference, which we may call frequentist and Bayesian. In frequentist statistics, probability is interpreted as the frequency of the outcome of a repeatable experiment. The most important tools in this framework are parameter estimation, covered in Section 36.1, and statistical tests, discussed in Section 36.2. Frequentist confidence intervals, which are constructed so as to cover the true value of a parameter with a specified probability, are treated in Section 36.3.2. Note that in frequentist statistics one does not define a probability for a hypothesis or for a parameter.

Frequentist statistics provides the usual tools for reporting the outcome of an experiment objectively, without needing to incorporate prior beliefs concerning the parameter being measured or the theory being tested. As such, they are used for reporting most measurements and their statistical uncertainties in high-energy physics.

In Bayesian statistics, the interpretation of probability is more general and includes degree of belief (called subjective probability). One can then speak of a probability density function (p.d.f.) for a parameter, which expresses one's state of knowledge about where its true value lies. Bayesian methods allow for a natural way to input additional information, which in general may be subjective; in fact they require the prior p.d.f. as input for the parameters, i.e., the degree of belief about the parameters' values before carrying out the measurement. Using Bayes' theorem Eq. (35.4), the prior degree of belief is updated by the data from the experiment. Bayesian methods for interval estimation are discussed in Sections 36.3.1 and 36.3.2.6

Bayesian techniques are often used to treat systematic uncertainties, where the author's beliefs about, say, the accuracy of the measuring device may enter. Bayesian statistics also provides a useful framework for discussing the validity of different theoretical interpretations of the data. This aspect of a measurement, however, will usually be treated separately from the reporting of the result. In some analyses, both the frequentist and Bayesian approaches are used together. One may, for example, treat systematic uncertainties in a model using Bayesian methods, but then construct a frequentist statistical test of that model.

For many inference problems, the frequentist and Bayesian approaches give similar numerical answers, even though they are based on fundamentally different interpretations of probability. For small data samples, however, and for measurements of a parameter near a physical boundary, the different approaches may yield different results, so we are forced to make a choice. For a discussion of Bayesian vs. non-Bayesian methods, see references written by a statistician [1], by a physicist [2], or the more detailed comparison in Ref. 3.

Following common usage in physics, the word "error" is often used in this chapter to mean "uncertainty." More specifically it can indicate the size of an interval as in "the standard error" or "error propagation," where the term refers to the standard deviation of an estimator.

36.1. Parameter estimation

Here we review *point estimation* of parameters, first with an overview of the frequentist approach and its two most important methods, maximum likelihood and least squares, treated in Sections 36.1.2 and 36.1.3. The Bayesian approach is outlined in Sec. 36.1.4.

An estimator θ (written with a hat) is a function of the data used to estimate the value of the parameter θ . Sometimes the word 'estimate' is used to denote the value of the estimator when evaluated with given data. There is no fundamental rule dictating how an estimator must be constructed. One tries, therefore, to choose that estimator which has the best properties. The most important of these are (a) consistency, (b) bias, (c) efficiency, and (d) robustness.

(a) An estimator is said to be *consistent* if the estimate $\hat{\theta}$ converges to the true value θ as the amount of data increases. This property is so important that it is possessed by all commonly used estimators.

(b) The bias, $b=E[\widehat{\theta}]-\theta$, is the difference between the expectation value of the estimator and the true value of the parameter. The expectation value is taken over a hypothetical set of similar experiments in which $\widehat{\theta}$ is constructed in the same way. When b=0, the estimator is said to be unbiased. The bias depends on the chosen metric, i.e., if $\widehat{\theta}$ is an unbiased estimator of θ , then $\widehat{\theta}^2$ is not in general an unbiased estimator for θ^2 . If we have an estimate \widehat{b} for the bias, we can subtract it from $\widehat{\theta}$ to obtain a new $\widehat{\theta}'=\widehat{\theta}-\widehat{b}$. The estimate \widehat{b} may, however, be subject to statistical or systematic uncertainties that are larger than the bias itself, so that the new $\widehat{\theta}'$ may not be better than the original.

(c) Efficiency is the ratio of the minimum possible variance for any estimator of θ to the variance $V[\widehat{\theta}]$ of the estimator actually used. Under rather general conditions, the minimum variance is given by the Rao-Cramér-Frechet bound,

$$\sigma_{\min}^2 = \left(1 + \frac{\partial b}{\partial \theta}\right)^2 / I(\theta) , \qquad (36.1)$$

where

$$I(\theta) = E \left[\left(\frac{\partial}{\partial \theta} \sum_{i} \ln f(x_i; \theta) \right)^2 \right]$$
 (36.2)

is the *Fisher information*. The sum is over all data, assumed independent, and distributed according to the p.d.f. $f(x;\theta)$, b is the bias, if any, and the allowed range of x must not depend on θ .

The mean-squared error,

$$MSE = E[(\widehat{\theta} - \theta)^2] = V[\widehat{\theta}] + b^2, \qquad (36.3)$$

is a measure of an estimator's quality which combines bias and

(d) Robustness is the property of being insensitive to departures from assumptions in the p.d.f., e.g., owing to uncertainties in the distribution's tails.

Simultaneously optimizing for all the measures of estimator quality described above can lead to conflicting requirements. For example, there is in general a trade-off between bias and variance. For some common estimators, the properties above are known exactly. More generally, it is possible to evaluate them by Monte Carlo simulation. Note that they will often depend on the unknown θ .

36.1.1. Estimators for mean, variance and median:

Suppose we have a set of N independent measurements, x_i , assumed to be unbiased measurements of the same unknown quantity μ with a common, but unknown, variance σ^2 . Then

$$\hat{\mu} = \frac{1}{N} \sum_{i=1}^{N} x_i \tag{36.4}$$

$$\widehat{\sigma^2} = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \widehat{\mu})^2$$
 (36.5)

are unbiased estimators of μ and σ^2 . The variance of $\widehat{\mu}$ is σ^2/N and the variance of $\widehat{\sigma^2}$ is

$$V\left[\widehat{\sigma^2}\right] = \frac{1}{N} \left(m_4 - \frac{N-3}{N-1} \sigma^4 \right) , \qquad (36.6)$$

where m_4 is the 4th central moment of x. For Gaussian distributed x_i , this becomes $2\sigma^4/(N-1)$ for any $N\geq 2$, and for large N, the standard deviation of $\widehat{\sigma}$ (the "error of the error") is $\sigma/\sqrt{2N}$. Again, if the x_i are Gaussian, $\widehat{\mu}$ is an efficient estimator for μ , and the estimators $\widehat{\mu}$ and $\widehat{\sigma^2}$ are uncorrelated. Otherwise the arithmetic mean (36.4) is not necessarily the most efficient estimator; this is discussed further in Sec. 8.7 of Ref. 4.

If σ^2 is known, it does not improve the estimate $\widehat{\mu}$, as can be seen from Eq. (36.4); however, if μ is known, substitute it for $\widehat{\mu}$ in Eq. (36.5) and replace N-1 by N to obtain an estimator of σ^2 still

with zero bias but smaller variance. If the x_i have different, known variances σ_i^2 , then the weighted average

$$\hat{\mu} = \frac{1}{w} \sum_{i=1}^{N} w_i x_i \tag{36.7}$$

is an unbiased estimator for μ with a smaller variance than an unweighted average; here $w_i=1/\sigma_i^2$ and $w=\sum_i w_i$. The standard deviation of $\widehat{\mu}$ is $1/\sqrt{w}$.

As an estimator for the median $x_{\rm med}$, one can use the value $\widehat{x}_{\rm med}$ such that half the x_i are below and half above (the sample median). If the sample median lies between two observed values, it is set by convention halfway between them. If the p.d.f. of x has the form $f(x-\mu)$ and μ is both mean and median, then for large N the variance of the sample median approaches $1/[4Nf^2(0)]$, provided f(0)>0. Although estimating the median can often be more difficult computationally than the mean, the resulting estimator is generally more robust, as it is insensitive to the exact shape of the tails of a distribution.

36.1.2. The method of maximum likelihood:

Suppose we have a set of N measured quantities $\mathbf{x} = (x_1, \dots, x_N)$ described by a joint p.d.f. $f(\mathbf{x}; \boldsymbol{\theta})$, where $\boldsymbol{\theta} = (\theta_1, \dots, \theta_n)$ is set of n parameters whose values are unknown. The *likelihood function* is given by the p.d.f. evaluated with the data \mathbf{x} , but viewed as a function of the parameters, i.e., $L(\boldsymbol{\theta}) = f(\mathbf{x}; \boldsymbol{\theta})$. If the measurements x_i are statistically independent and each follow the p.d.f. $f(\mathbf{x}; \boldsymbol{\theta})$, then the joint p.d.f. for \mathbf{x} factorizes and the likelihood function is

$$L(\boldsymbol{\theta}) = \prod_{i=1}^{N} f(x_i; \boldsymbol{\theta}) . \tag{36.8}$$

The method of maximum likelihood takes the estimators $\widehat{\boldsymbol{\theta}}$ to be those values of $\boldsymbol{\theta}$ that maximize $L(\boldsymbol{\theta})$.

Note that the likelihood function is not a p.d.f. for the parameters θ ; in frequentist statistics this is not defined. In Bayesian statistics, one can obtain the posterior p.d.f. for θ from the likelihood, but this requires multiplying by a prior p.d.f. (see Sec. 36.3.1).

It is usually easier to work with $\ln L$, and since both are maximized for the same parameter values $\boldsymbol{\theta}$, the maximum likelihood (ML) estimators can be found by solving the *likelihood equations*,

$$\frac{\partial \ln L}{\partial \theta_i} = 0 \; , \qquad i = 1, \dots, n \; .$$
 (36.9)

Often the solution must be found numerically. Maximum likelihood estimators are important because they are approximately unbiased and efficient for large data samples, under quite general conditions, and the method has a wide range of applicability.

In evaluating the likelihood function, it is important that any normalization factors in the p.d.f. that involve $\boldsymbol{\theta}$ be included. However, we will only be interested in the maximum of L and in ratios of L at different values of the parameters; hence any multiplicative factors that do not involve the parameters that we want to estimate may be dropped, including factors that depend on the data but not on $\boldsymbol{\theta}$.

Under a one-to-one change of parameters from $\boldsymbol{\theta}$ to $\boldsymbol{\eta}$, the ML estimators $\widehat{\boldsymbol{\theta}}$ transform to $\boldsymbol{\eta}(\widehat{\boldsymbol{\theta}})$. That is, the ML solution is invariant under change of parameter. However, other properties of ML estimators, in particular the bias, are not invariant under change of parameter.

The inverse V^{-1} of the covariance matrix $V_{ij} = \text{cov}[\widehat{\theta}_i, \widehat{\theta}_j]$ for a set of ML estimators can be estimated by using

$$(\widehat{V}^{-1})_{ij} = -\left. \frac{\partial^2 \ln L}{\partial \theta_i \partial \theta_j} \right|_{\widehat{\theta}} . \tag{36.10}$$

For finite samples, however, Eq. (36.10) can result in an underestimate of the variances. In the large sample limit (or in a linear model with Gaussian errors), L has a Gaussian form and $\ln L$ is (hyper)parabolic. In this case, it can be seen that a numerically equivalent way of

determining s-standard-deviation errors is from the contour given by the $\boldsymbol{\theta}'$ such that

$$\ln L(\theta') = \ln L_{\text{max}} - s^2/2,$$
 (36.11)

where $\ln L_{\rm max}$ is the value of $\ln L$ at the solution point (compare with Eq. (36.58)). The extreme limits of this contour on the θ_i axis give an approximate s-standard-deviation confidence interval for θ_i (see Section 36.3.2.4).

In the case where the size n of the data sample x_1,\ldots,x_n is small, the unbinned maximum likelihood method, i.e., use of equation (36.8), is preferred since binning can only result in a loss of information, and hence larger statistical errors for the parameter estimates. The sample size n can be regarded as fixed, or the analyst can choose to treat it as a Poisson-distributed variable; this latter option is sometimes called "extended maximum likelihood" (see, e.g., Refs. [6–8]) .

If the sample is large, it can be convenient to bin the values in a histogram, so that one obtains a vector of data $\mathbf{n} = (n_1, \dots, n_N)$ with expectation values $\mathbf{v} = E[\mathbf{n}]$ and probabilities $f(\mathbf{n}; \mathbf{v})$. Then one may maximize the likelihood function based on the contents of the bins (so i labels bins). This is equivalent to maximizing the likelihood ratio $\lambda(\boldsymbol{\theta}) = f(\mathbf{n}; \mathbf{v}(\boldsymbol{\theta}))/f(\mathbf{n}; \mathbf{n})$, or to minimizing the equivalent quantity $-2 \ln \lambda(\boldsymbol{\theta})$. For independent Poisson distributed n_i this is [9]

$$-2\ln\lambda(\boldsymbol{\theta}) = 2\sum_{i=1}^{N} \left[\nu_i(\boldsymbol{\theta}) - n_i + n_i \ln\frac{n_i}{\nu_i(\boldsymbol{\theta})}\right], \qquad (36.12)$$

where for bins with $n_i = 0$, the last term in (36.12) is zero. The expression (36.12) without the terms $\nu_i - n_i$ also gives $-2 \ln \lambda(\theta)$ for multinomially distributed n_i , *i.e.*, when the total number of entries is regarded as fixed. In the limit of zero bin width, maximizing (36.12) is equivalent to maximizing the unbinned likelihood function (36.8).

A benefit of binning is that it allows for a goodness-of-fit test (see Sec. 36.2.2). Assuming the model is correct, then according to Wilks' theorem, for sufficiently large ν_i and providing certain regularity conditions are met, the minimum of $-2\ln\lambda$ as defined by Eq. (36.12) follows a χ^2 distribution (see, e.g., Ref. 3). If there are N bins and m fitted parameters, then the number of degrees of freedom for the χ^2 distribution is N-m if the data are treated as Poisson-distributed, and N-m-1 if the n_i are multinomially distributed.

Suppose the n_i are Poisson-distributed and the overall normalization $\nu_{\rm tot} = \sum_i \nu_i$ is taken as an adjustable parameter, so that $\nu_i = \nu_{\rm tot} p_i(\boldsymbol{\theta})$, where the probability to be in the ith bin, $p_i(\boldsymbol{\theta})$, does not depend on $\nu_{\rm tot}$. Then by minimizing Eq. (36.12), one obtains that the area under the fitted function is equal to the sum of the histogram contents, i.e., $\sum_i \nu_i = \sum_i n_i$. This is not the case for parameter estimation methods based on a least-squares procedure with traditional weights (see, e.g., Ref. 8).

${\bf 36.1.3.} \quad \textit{The method of least squares}:$

The method of least squares (LS) coincides with the method of maximum likelihood in the following special case. Consider a set of N independent measurements y_i at known points x_i . The measurement y_i is assumed to be Gaussian distributed with mean $F(x_i; \theta)$ and known variance σ_i^2 . The goal is to construct estimators for the unknown parameters θ . The likelihood function contains the sum of squares

$$\chi^{2}(\boldsymbol{\theta}) = -2 \ln L(\boldsymbol{\theta}) + \text{ constant } = \sum_{i=1}^{N} \frac{(y_{i} - F(x_{i}; \boldsymbol{\theta}))^{2}}{\sigma_{i}^{2}}.$$
 (36.13)

The set of parameters θ which maximize L is the same as those which minimize χ^2

The minimum of Equation (36.13) defines the least-squares estimators $\hat{\boldsymbol{\theta}}$ for the more general case where the y_i are not Gaussian distributed as long as they are independent. If they are not independent but rather have a covariance matrix $V_{ij} = \text{cov}[y_i, y_j]$, then the LS estimators are determined by the minimum of

$$\chi^{2}(\boldsymbol{\theta}) = (\boldsymbol{y} - \boldsymbol{F}(\boldsymbol{\theta}))^{T} V^{-1} (\boldsymbol{y} - \boldsymbol{F}(\boldsymbol{\theta})), \qquad (36.14)$$

where $\mathbf{y} = (y_1, \dots, y_N)$ is the vector of measurements, $\mathbf{F}(\boldsymbol{\theta})$ is the corresponding vector of predicted values (understood as a column vector in (36.14)), and the superscript T denotes the transposed (*i.e.*, row) vector.

In many practical cases, one further restricts the problem to the situation where $F(x_i; \theta)$ is a linear function of the parameters, *i.e.*,

$$F(x_i; \boldsymbol{\theta}) = \sum_{j=1}^{m} \theta_j h_j(x_i) . \qquad (36.15)$$

Here the $h_j(x)$ are m linearly independent functions, e.g., $1, x, x^2, \ldots, x^{m-1}$, or Legendre polynomials. We require m < N and at least m of the x_i must be distinct.

Minimizing χ^2 in this case with m parameters reduces to solving a system of m linear equations. Defining $H_{ij} = h_j(x_i)$ and minimizing χ^2 by setting its derivatives with respect to the θ_i equal to zero gives the LS estimators,

$$\hat{\boldsymbol{\theta}} = (H^T V^{-1} H)^{-1} H^T V^{-1} \boldsymbol{y} \equiv D \boldsymbol{y} .$$
 (36.16)

The covariance matrix for the estimators $U_{ij} = \text{cov}[\hat{\theta}_i, \hat{\theta}_j]$ is given by

$$U = DVD^T = (H^TV^{-1}H)^{-1}, (36.17)$$

or equivalently, its inverse U^{-1} can be found from

$$(U^{-1})_{ij} = \frac{1}{2} \frac{\partial^2 \chi^2}{\partial \theta_i \partial \theta_j} \Big|_{\theta = \hat{\theta}} = \sum_{k,l=1}^N h_i(x_k) (V^{-1})_{kl} h_j(x_l) . \tag{36.18}$$

The LS estimators can also be found from the expression

$$\widehat{\boldsymbol{\theta}} = U\boldsymbol{g} \,, \tag{36.19}$$

where the vector g is defined by

$$g_i = \sum_{j,k=1}^{N} y_j h_i(x_k) (V^{-1})_{jk} . \tag{36.20}$$

For the case of uncorrelated y_i , for example, one can use (36.19) with

$$(U^{-1})_{ij} = \sum_{k=1}^{N} \frac{h_i(x_k)h_j(x_k)}{\sigma_k^2} , \qquad (36.21)$$

$$g_i = \sum_{k=1}^{N} \frac{y_k h_i(x_k)}{\sigma_k^2} \,. \tag{36.22}$$

Expanding $\chi^2(\boldsymbol{\theta})$ about $\widehat{\boldsymbol{\theta}}$, one finds that the contour in parameter space defined by

$$\chi^{2}(\boldsymbol{\theta}) = \chi^{2}(\widehat{\boldsymbol{\theta}}) + 1 = \chi_{\min}^{2} + 1 \tag{36.23}$$

has tangent planes located at approximately plus-or-minus-one standard deviation $\sigma_{\widehat{\theta}}$ from the LS estimates $\widehat{\pmb{\theta}}.$

In constructing the quantity $\chi^2(\theta)$, one requires the variances or, in the case of correlated measurements, the covariance matrix. Often these quantities are not known a priori and must be estimated from the data; an important example is where the measured value y_i represents a counted number of events in the bin of a histogram. If, for example, y_i represents a Poisson variable, for which the variance is equal to the mean, then one can either estimate the variance from the predicted value, $F(x_i; \boldsymbol{\theta})$, or from the observed number itself, y_i . In the first option, the variances become functions of the fitted parameters, which may lead to calculational difficulties. The second option can be undefined if y_i is zero, and in both cases for small y_i , the variance will be poorly estimated. In either case, one should constrain the normalization of the fitted curve to the correct value, i.e., one should determine the area under the fitted curve directly from the number of entries in the histogram (see Ref. 8, Section 7.4). A further alternative is to use the method of maximum likelihood; for binned data this can be done by minimizing Eq. (36.12)

As the minimum value of the χ^2 represents the level of agreement between the measurements and the fitted function, it can be used for assessing the goodness-of-fit; this is discussed further in Section 36.2.2.

36.1.4. The Bayesian approach:

In the frequentist methods discussed above, probability is associated only with data, not with the value of a parameter. This is no longer the case in Bayesian statistics, however, which we introduce in this section. Bayesian methods are considered further in Sec. 36.3.1 for interval estimation and in Sec. 36.2.3 for model selection. For general introductions to Bayesian statistics see, e.g., Refs. [20–23].

Suppose the outcome of an experiment is characterized by a vector of data \boldsymbol{x} , whose probability distribution depends on an unknown parameter (or parameters) $\boldsymbol{\theta}$ that we wish to determine. In Bayesian statistics, all knowledge about $\boldsymbol{\theta}$ is summarized by the posterior p.d.f. $p(\boldsymbol{\theta}|\boldsymbol{x})$, whose integral over any given region gives the degree of belief for $\boldsymbol{\theta}$ to take on values in that region, given the data \boldsymbol{x} . It is obtained by using Bayes' theorem,

$$p(\boldsymbol{\theta}|\boldsymbol{x}) = \frac{L(\boldsymbol{x}|\boldsymbol{\theta})\pi(\boldsymbol{\theta})}{\int L(\boldsymbol{x}|\boldsymbol{\theta}')\pi(\boldsymbol{\theta}')\,d\boldsymbol{\theta}'},$$
 (36.24)

where $L(\boldsymbol{x}|\boldsymbol{\theta})$ is the likelihood function, *i.e.*, the joint p.d.f. for the data viewed as a function of $\boldsymbol{\theta}$, evaluated with the data actually obtained in the experiment, and $\pi(\boldsymbol{\theta})$ is the prior p.d.f. for $\boldsymbol{\theta}$. Note that the denominator in Eq. (36.24) serves to normalize the posterior p.d.f. to unity.

As it can be difficult to report the full posterior p.d.f. $p(\boldsymbol{\theta}|\boldsymbol{x})$, one would usually summarize it with statistics such as the mean (or median), and covariance matrix. In addition one may construct intervals with a given probability content, as is discussed in Sec. 36.3.1 on Bayesian interval estimation.

36.1.4.1. *Priors:*

Bayesian statistics supplies no unique rule for determining the prior $\pi(\theta)$; this reflects the experimenter's subjective degree of belief (or state of knowledge) about θ before the measurement was carried out. For the result to be of value to the broader community, whose members may not share these beliefs, it is important to carry out a sensitivity analysis, that is, to show how the result changes under a reasonable variation of the prior probabilities.

One might like to construct $\pi(\boldsymbol{\theta})$ to represent complete ignorance about the parameters by setting it equal to a constant. A problem here is that if the prior p.d.f. is flat in $\boldsymbol{\theta}$, then it is not flat for a nonlinear function of $\boldsymbol{\theta}$, and so a different parametrization of the problem would lead in general to a non-equivalent posterior p.d.f.

For the special case of a constant prior, one can see from Bayes' theorem (36.24) that the posterior is proportional to the likelihood, and therefore the mode (peak position) of the posterior is equal to the ML estimator. The posterior mode, however, will change in general upon a transformation of parameter. A summary statistic other than the mode may be used as the Bayesian estimator, such as the median, which is invariant under parameter transformation. But this will not in general coincide with the ML estimator.

The difficult and subjective nature of encoding personal knowledge into priors has led to what is called *objective Bayesian statistics*, where prior probabilities are based not on an actual degree of belief but rather derived from formal rules. These give, for example, priors which are invariant under a transformation of parameters or which result in a maximum gain in information for a given set of measurements. For an extensive review see, *e.g.*, Ref. 24.

Objective priors do not in general reflect degree of belief, but they could in some cases be taken as possible, although perhaps extreme, subjective priors. The posterior probabilities as well therefore do not necessarily reflect a degree of belief. However one may regard investigating a variety of objective priors to be an important part of the sensitivity analysis. Furthermore, use of objective priors with Bayes' theorem can be viewed as a recipe for producing estimators or intervals which have desirable frequentist properties.

An important procedure for deriving objective priors is due to Jeffreys. According to Jeffreys' rule one takes the prior as

$$\pi(\boldsymbol{\theta}) \propto \sqrt{\det(I(\boldsymbol{\theta}))}$$
, (36.25)

where

$$I_{ij}(\boldsymbol{\theta}) = -E\left[\frac{\partial^2 \ln L(\boldsymbol{x}|\boldsymbol{\theta})}{\partial \theta_i \partial \theta_j}\right] = -\int \frac{\partial^2 \ln L(\boldsymbol{x}|\boldsymbol{\theta})}{\partial \theta_i \partial \theta_j} L(\boldsymbol{x}|\boldsymbol{\theta}) d\boldsymbol{x} \quad (36.26)$$

is the Fisher information matrix. One can show that the Jeffreys prior leads to inference that is invariant under a transformation of parameters. One should note that the Jeffreys prior depends on the likelihood function, and thus contains information about the measurement model itself, which goes beyond one's degree of belief about the value of a parameter. As examples, the Jeffreys prior for the mean μ of a Gaussian distribution is a constant, and for the mean of a Poisson distribution one finds $\pi(\mu) \propto 1/\sqrt{\mu}$.

Neither the constant nor $1/\sqrt{\mu}$ priors can be normalized to unit area and are said to be *improper*. This can be allowed because the prior always appears multiplied by the likelihood function, and if the likelihood falls off sufficiently quickly then one may have a normalizable posterior density.

An important type of objective prior is the reference prior due to Bernardo and Berger [25]. To find the reference prior for a given problem one considers the Kullback-Leibler divergence $D_n[\pi,p]$ of the posterior $p(\boldsymbol{\theta}|\boldsymbol{x})$ relative to a prior $\pi(\boldsymbol{\theta})$, obtained from a set of data $\boldsymbol{x}=(x_1,\ldots,x_n)$, which are assumed to consist of n independent and identically distributed values of x:

$$D_n[\pi, p] = \int p(\boldsymbol{\theta}|\boldsymbol{x}) \ln \frac{p(\boldsymbol{\theta}|\boldsymbol{x})}{\pi(\boldsymbol{\theta})} d\boldsymbol{\theta}.$$
 (36.27)

This is effectively a measure of the gain in information provided by the data. The reference prior is chosen so that the expectation value of this information gain is maximized for the limiting case of $n \to \infty$, where the expectation is computed with respect to the marginal distribution of the data,

$$p(\mathbf{x}) = \int L(\mathbf{x}|\boldsymbol{\theta})\pi(\boldsymbol{\theta}) d\boldsymbol{\theta} . \tag{36.28}$$

For a single, continuous parameter the reference prior is usually identical to Jeffreys' prior. In the multiparameter case an iterative algorithm exists, which requires sorting the parameters by order of inferential importance. Often the result does not depend on this order, but when it does, this can be part of a robustness analysis. Further discussion and applications to particle physics problems can be found in Ref. 26.

36.1.4.2. Bayesian treatment of nuisance parameters:

Bayesian statistics provides a framework for incorporating systematic uncertainties into a result. Suppose, for example, that a model depends not only on parameters of interest θ , but on nuisance parameters ν , whose values are known with some limited accuracy. For a single nuisance parameter ν , for example, one might have a p.d.f. centered about its nominal value with a certain standard deviation σ_{ν} . Often a Gaussian p.d.f. provides a reasonable model for one's degree of belief about a nuisance parameter; in other cases, more complicated shapes may be appropriate. If, for example, the parameter represents a non-negative quantity then a log-normal or gamma p.d.f. can be a more natural choice than a Gaussian truncated at zero. The likelihood function, prior, and posterior p.d.f. sthen all depend on both θ and ν , and are related by Bayes' theorem, as usual. One can obtain the posterior p.d.f. for θ alone by integrating over the nuisance parameters, i.e.,

$$p(\boldsymbol{\theta}|\boldsymbol{x}) = \int p(\boldsymbol{\theta}, \boldsymbol{\nu}|\boldsymbol{x}) d\boldsymbol{\nu}. \tag{36.29}$$

Such integrals can often not be carried out in closed form, and if the number of nuisance parameters is large, then they can be difficult to compute with standard Monte Carlo methods. *Markov Chain Monte Carlo* (MCMC) is often used for computing integrals of this type (see Sec. 37.5).

If the prior joint p.d.f. for θ and ν factorizes, then integrating the posterior p.d.f. over ν is equivalent to replacing the likelihood function by the marginal likelihood (see Ref. 27),

$$L_{\rm m}(\boldsymbol{x}|\boldsymbol{\theta}) = \int L(\boldsymbol{x}|\boldsymbol{\theta}, \boldsymbol{\nu}) \pi(\boldsymbol{\nu}) \, d\boldsymbol{\nu} . \tag{36.30}$$

The marginal likelihood can also be used together with frequentist methods that employ the likelihood function such as ML estimation of parameters. The results then have a mixed frequentist/Bayesian character, where the systematic uncertainty due to limited knowledge of the nuisance parameters is built in (see Ref. 28). Although this may make it more difficult to disentangle statistical from systematic effects, such a hybrid approach may satisfy the objective of reporting the result in a convenient way. The marginal likelihood may be compared with the profile likelihood, which is discussed in Sec. 36.3.2.3.

36.1.5. Propagation of errors:

Consider a set of n quantities $\boldsymbol{\theta}=(\theta_1,\ldots,\theta_n)$ and a set of m functions $\boldsymbol{\eta}(\boldsymbol{\theta})=(\eta_1(\boldsymbol{\theta}),\ldots,\eta_m(\boldsymbol{\theta}))$. Suppose we have estimated $\widehat{\boldsymbol{\theta}}=(\widehat{\theta}_1,\ldots,\widehat{\theta}_n)$, using, say, maximum-likelihood or least-squares, and we also know or have estimated the covariance matrix $V_{ij}=\operatorname{cov}[\widehat{\theta}_i,\widehat{\theta}_j]$. The goal of error propagation is to determine the covariance matrix for the functions, $U_{ij}=\operatorname{cov}[\widehat{\eta}_i,\widehat{\eta}_j]$, where $\widehat{\boldsymbol{\eta}}=\boldsymbol{\eta}(\widehat{\boldsymbol{\theta}})$. In particular, the diagonal elements $U_{ii}=V[\widehat{\eta}_i]$ give the variances. The new covariance matrix can be found by expanding the functions $\boldsymbol{\eta}(\boldsymbol{\theta})$ about the estimates $\widehat{\boldsymbol{\theta}}$ to first order in a Taylor series. Using this one finds

$$U_{ij} \approx \sum_{k,l} \left. \frac{\partial \eta_i}{\partial \theta_k} \frac{\partial \eta_j}{\partial \theta_l} \right|_{\widehat{\theta}} V_{kl} . \tag{36.31}$$

This can be written in matrix notation as $U \approx AVA^T$ where the matrix of derivatives A is

$$A_{ij} = \frac{\partial \eta_i}{\partial \theta_j} \Big|_{\widehat{\theta}} , \qquad (36.32)$$

and A^T is its transpose. The approximation is exact if $\eta(\theta)$ is linear (it holds, for example, in equation (36.17)). If this is not the case, the approximation can break down if, for example, $\eta(\theta)$ is significantly nonlinear close to $\widehat{\theta}$ in a region of a size comparable to the standard deviations of $\widehat{\theta}$.

36.2. Statistical tests

In addition to estimating parameters, one often wants to assess the validity of certain statements concerning the data's underlying distribution. Frequentist hypothesis tests, described in Sec. 36.2.1, provide a rule for accepting or rejecting hypotheses depending on the outcome of a measurement. In significance tests, covered in Sec. 36.2.2, one gives the probability to obtain a level of incompatibility with a certain hypothesis that is greater than or equal to the level observed with the actual data. In the Bayesian approach, the corresponding procedure is based fundamentally on the posterior probabilities of the competing hypotheses. In Sec. 36.2.3 we describe a related construct called the Bayes factor, which can be used to quantify the degree to which the data prefer one or another hypothesis.

36.2.1. Hypothesis tests:

Consider an experiment whose outcome is characterized by a vector of data \boldsymbol{x} . A *hypothesis* is a statement about the distribution of \boldsymbol{x} . It could, for example, define completely the p.d.f. for the data (a simple hypothesis), or it could specify only the functional form of the p.d.f., with the values of one or more parameters left open (a composite hypothesis).

A statistical test is a rule that states for which values of \boldsymbol{x} a given hypothesis (often called the null hypothesis, H_0) should be rejected. This is done by defining a region of \boldsymbol{x} -space called the critical region, w, such that there is no more than a specified probability under H_0 , α , called the size or significance level of the test, to find $\boldsymbol{x} \in w$. If the data are discrete, it may not possible to find a critical region with exact probability content α , and thus we require $P(\boldsymbol{x} \in w|H_0) \leq \alpha$. If the data are observed in the critical region, H_0 is rejected.

There are in general a large (often infinite) number of regions of the data space that have probability content α and thus qualify as possible critical regions. To choose one of them one should take into account the probabilities for the data predicted by some alternative hypothesis (or set of alternatives) H_1 . Rejecting H_0 if it is true is

called a type-I error, and occurs by construction with probability no greater than α . Not rejecting H_0 if an alternative H_1 is true is called a type-II error, and for a given test this will have a certain probability β . The quantity $1-\beta$ is called the *power* of the test of H_0 with respect to the alternative H_1 . A strategy for defining the critical region can therefore be to maximize the power with respect to some alternative (or alternatives) given a fixed size α .

In high-energy physics, the components of \boldsymbol{x} might represent the measured properties of candidate events, and the critical region is defined by the cuts that one imposes in order to reject background and thus accept events likely to be of a certain desired type. Here H_0 could represent the background hypothesis and the alternative H_1 could represent the sought after signal. In other cases, H_0 could be the hypothesis that an entire event sample consists of background events only, and the alternative H_1 may represent the hypothesis of a mixture of background and signal.

Often rather than using the full set of quantities \boldsymbol{x} , it is convenient to define a test statistic, t, which can be a single number, or in any case a vector with fewer components than \boldsymbol{x} . Each hypothesis for the distribution of \boldsymbol{x} will determine a distribution for t, and the acceptance region in \boldsymbol{x} -space will correspond to a specific range of values of t.

To maximize the power of a test of H_0 with respect to the alternative H_1 , the Neyman-Pearson lemma states that the critical region w should be chosen such that for all data values x inside w, the ratio

$$\lambda(\boldsymbol{x}) = \frac{f(\boldsymbol{x}|H_1)}{f(\boldsymbol{x}|H_0)}, \qquad (36.33)$$

is greater than a given constant, the value of which is determined by the size of the test α . Here H_0 and H_1 must be simple hypotheses, i.e., they should not contain undetermined parameters.

The lemma is equivalent to the statement that (36.33) represents the optimal test statistic where the critical region is defined by a single cut on λ . This test will lead to the maximum power (e.g., probability to reject the background hypothesis if the signal hypothesis is true) for a given probability α to reject the background hypothesis if it is in fact true. It can be difficult in practice, however, to determine $\lambda(x)$, since this requires knowledge of the joint p.d.f.s $f(x|H_0)$ and $f(x|H_1)$.

In the usual case where the likelihood ratio (36.33) cannot be used explicitly, there exist a variety of other multivariate classifiers that effectively separate different types of events. Methods often used in HEP include neural networks or Fisher discriminants (see Ref. 10). Recently, further classification methods from machine-learning have been applied in HEP analyses; these include probability density estimation (PDE) techniques, kernel-based PDE (KDE or Parzen window), support vector machines, and decision trees. Techniques such as "boosting" and "bagging" can be applied to combine a number of classifiers into a stronger one with greater stability with respect to fluctuations in the training data. Descriptions of these methods can be found in [11–13], and Proceedings of the PHYSTAT conference series [14]. Software for HEP includes the TMVA [15] and StatPatternRecognition [16] packages.

36.2.2. Significance tests:

Often one wants to quantify the level of agreement between the data and a hypothesis without explicit reference to alternative hypotheses. This can be done by defining a statistic t, which is a function of the data whose value reflects in some way the level of agreement between the data and the hypothesis. The analyst must decide what values of the statistic correspond to better or worse levels of agreement with the hypothesis in question; for many goodness-of-fit statistics, there is an obvious choice.

The hypothesis in question, say, H_0 , will determine the p.d.f. $g(t|H_0)$ for the statistic. The significance of a discrepancy between the data and what one expects under the assumption of H_0 is quantified by giving the p-value, defined as the probability to find t in the region of equal or lesser compatibility with H_0 than the level of compatibility observed with the actual data. For example, if t is defined such that large values correspond to poor agreement with the hypothesis, then

the p-value would be

$$p = \int_{t_{\text{obs}}}^{\infty} g(t|H_0) dt , \qquad (36.34)$$

where t_{obs} is the value of the statistic obtained in the actual experiment.

The p-value should not be confused with the size (significance level) of a test, or the confidence level of a confidence interval (Section 36.3), both of which are pre-specified constants. We may formulate a hypothesis test, however, by defining the critical region to correspond to the data outcomes that give the lowest p-values, so that finding $p < \alpha$ implies that the data outcome was in the critical region. When constructing a p-value, one generally takes the region of data space deemed to have lower compatibility with the model being tested to have higher compatibility with a given alternative, and thus the corresponding test will have a high power with respect to this alternative.

The p-value is a function of the data, and is therefore itself a random variable. If the hypothesis used to compute the p-value is true, then for continuous data, p will be uniformly distributed between zero and one. Note that the p-value is not the probability for the hypothesis; in frequentist statistics, this is not defined. Rather, the p-value is the probability, under the assumption of a hypothesis H_0 , of obtaining data at least as incompatible with H_0 as the data actually observed.

When searching for a new phenomenon, one tries to reject the hypothesis H_0 that the data are consistent with known, e.g., Standard Model processes. If the p-value of H_0 is sufficiently low, then one is willing to accept that some alternative hypothesis is true. Often one converts the p-value into an equivalent significance Z, defined so that a Z standard deviation upward fluctuation of a Gaussian random variable would have an upper tail area equal to p, i.e.,

$$Z = \Phi^{-1}(1 - p) . \tag{36.35}$$

Here Φ is the cumulative distribution of the Standard Gaussian, and Φ^{-1} is its inverse (quantile) function. Often in HEP, the level of significance where an effect is said to qualify as a discovery is Z=5, i.e., a 5σ effect, corresponding to a p-value of 2.87×10^{-7} . One's actual degree of belief that a new process is present, however, will depend in general on other factors as well, such as the plausibility of the new signal hypothesis and the degree to which it can describe the data, one's confidence in the model that led to the observed p-value, and possible corrections for multiple observations out of which one focuses on the smallest p-value obtained (the "look-elsewhere effect"). For a review of how to incorporate systematic uncertainties into p-values see, e.g., Ref. 17; a computationally fast method that provides an approximate correction for the look-elsewhere effect is described in Ref. 18

When estimating parameters using the method of least squares, one obtains the minimum value of the quantity χ^2 (36.13). This statistic can be used to test the *goodness-of-fit*, *i.e.*, the test provides a measure of the significance of a discrepancy between the data and the hypothesized functional form used in the fit. It may also happen that no parameters are estimated from the data, but that one simply wants to compare a histogram, *e.g.*, a vector of Poisson distributed numbers $\mathbf{n}=(n_1,\ldots,n_N)$, with a hypothesis for their expectation values $\nu_i=E[n_i]$. As the distribution is Poisson with variances $\sigma_i^2=\nu_i$, the χ^2 (36.13) becomes Pearson's χ^2 statistic,

$$\chi^2 = \sum_{i=1}^{N} \frac{(n_i - \nu_i)^2}{\nu_i} \,. \tag{36.36}$$

If the hypothesis $\mathbf{\nu}=(\nu_1,\dots,\nu_N)$ is correct, and if the expected values ν_i in (36.36) are sufficiently large (or equivalently, if the measurements n_i can be treated as following a Gaussian distribution), then the χ^2 statistic will follow the χ^2 p.d.f. with the number of degrees of freedom equal to the number of measurements N minus the number of fitted parameters.

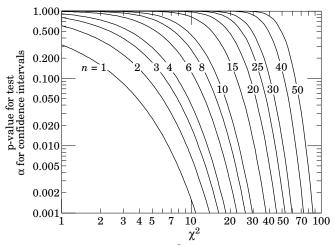


Figure 36.1: One minus the χ^2 cumulative distribution, $1 - F(\chi^2; n)$, for n degrees of freedom. This gives the p-value for the χ^2 goodness-of-fit test as well as one minus the coverage probability for confidence regions (see Sec. 36.3.2.4).

Alternatively, one may fit parameters and evaluate goodness-of-fit by minimizing $-2\ln\lambda$ from Eq. (36.12). One finds that the distribution of this statistic approaches the asymptotic limit faster than does Pearson's χ^2 , and thus computing the *p*-value with the χ^2 p.d.f. will in general be better justified (see Ref. 9 and references therein).

Assuming the goodness-of-fit statistic follows a χ^2 p.d.f., the p-value for the hypothesis is then

$$p = \int_{\chi^2}^{\infty} f(z; n_{\rm d}) dz , \qquad (36.37)$$

where $f(z; n_{\rm d})$ is the χ^2 p.d.f. and $n_{\rm d}$ is the appropriate number of degrees of freedom. Values can be obtained from Fig. 36.1 or from the ROOT function TMath::Prob. If the conditions for using the χ^2 p.d.f. do not hold, the statistic can still be defined as before, but its p.d.f. must be determined by other means in order to obtain the p-value, e.g., using a Monte Carlo calculation.

Since the mean of the χ^2 distribution is equal to $n_{\rm d}$, one expects in a "reasonable" experiment to obtain $\chi^2\approx n_{\rm d}$. Hence the quantity $\chi^2/n_{\rm d}$ is sometimes reported. Since the p.d.f. of $\chi^2/n_{\rm d}$ depends on $n_{\rm d}$, however, one must report $n_{\rm d}$ as well if one wishes to determine the p-value. The p-values obtained for different values of $\chi^2/n_{\rm d}$ are shown in Fig. 36.2.

If one finds a χ^2 value much greater than $n_{\rm d}$, and a correspondingly small p-value, one may be tempted to expect a high degree of uncertainty for any fitted parameters. Poor goodness-of-fit, however, does not mean that one will have large statistical errors for parameter estimates. If, for example, the error bars (or covariance matrix) used in constructing the χ^2 are underestimated, then this will lead to underestimated statistical errors for the fitted parameters. The standard deviations of estimators that one finds from, say, Eq. (36.11) reflect how widely the estimates would be distributed if one were to repeat the measurement many times, assuming that the hypothesis and measurement errors used in the χ^2 are also correct. They do not include the systematic error which may result from an incorrect hypothesis or incorrectly estimated measurement errors in the χ^2 .

36.2.3. Bayesian model selection :

In Bayesian statistics, all of one's knowledge about a model is contained in its posterior probability, which one obtains using Bayes' theorem (36.24). Thus one could reject a hypothesis H if its posterior probability $P(H|\mathbf{x})$ is sufficiently small. The difficulty here is that $P(H|\mathbf{x})$ is proportional to the prior probability P(H), and there will not be a consensus about the prior probabilities for the existence of new phenomena. Nevertheless one can construct a quantity called the Bayes factor (described below), which can be used to quantify the

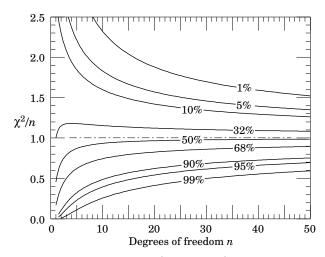


Figure 36.2: The 'reduced' χ^2 , equal to χ^2/n , for n degrees of freedom. The curves show as a function of n the χ^2/n that corresponds to a given p-value.

degree to which the data prefer one hypothesis over another, and is independent of their prior probabilities.

Consider two models (hypotheses), H_i and H_j , described by vectors of parameters $\boldsymbol{\theta}_i$ and $\boldsymbol{\theta}_j$, respectively. Some of the components will be common to both models and others may be distinct. The full prior probability for each model can be written in the form

$$\pi(H_i, \boldsymbol{\theta}_i) = P(H_i)\pi(\boldsymbol{\theta}_i|H_i) , \qquad (36.38)$$

Here $P(H_i)$ is the overall prior probability for H_i , and $\pi(\boldsymbol{\theta}_i|H_i)$ is the normalized p.d.f. of its parameters. For each model, the posterior probability is found using Bayes' theorem,

$$P(H_i|\mathbf{x}) = \frac{\int L(\mathbf{x}|\boldsymbol{\theta}_i, H_i)P(H_i)\pi(\boldsymbol{\theta}_i|H_i) d\boldsymbol{\theta}_i}{P(\mathbf{x})},$$
 (36.39)

where the integration is carried out over the internal parameters θ_i of the model. The ratio of posterior probabilities for the models is therefore

$$\frac{P(H_i|\mathbf{x})}{P(H_i|\mathbf{x})} = \frac{\int L(\mathbf{x}|\boldsymbol{\theta}_i, H_i)\pi(\boldsymbol{\theta}_i|H_i) d\boldsymbol{\theta}_i}{\int L(\mathbf{x}|\boldsymbol{\theta}_i, H_i)\pi(\boldsymbol{\theta}_i|H_i) d\boldsymbol{\theta}_i} \frac{P(H_i)}{P(H_i)}.$$
 (36.40)

The Bayes factor is defined as

$$B_{ij} = \frac{\int L(\boldsymbol{x}|\boldsymbol{\theta}_i, H_i)\pi(\boldsymbol{\theta}_i|H_i) d\boldsymbol{\theta}_i}{\int L(\boldsymbol{x}|\boldsymbol{\theta}_j, H_j)\pi(\boldsymbol{\theta}_j|H_j) d\boldsymbol{\theta}_j}.$$
 (36.41)

This gives what the ratio of posterior probabilities for models i and j would be if the overall prior probabilities for the two models were equal. If the models have no nuisance parameters i.e., no internal parameters described by priors, then the Bayes factor is simply the likelihood ratio. The Bayes factor therefore shows by how much the probability ratio of model i to model j changes in the light of the data, and thus can be viewed as a numerical measure of evidence supplied by the data in favour of one hypothesis over the other.

Although the Bayes factor is by construction independent of the overall prior probabilities $P(H_i)$ and $P(H_j)$, it does require priors for all internal parameters of a model, *i.e.*, one needs the functions $\pi(\theta_i|H_i)$ and $\pi(\theta_j|H_j)$. In a Bayesian analysis where one is only interested in the posterior p.d.f. of a parameter, it may be acceptable to take an unnormalizable function for the prior (an improper prior) as long as the product of likelihood and prior can be normalized. But improper priors are only defined up to an arbitrary multiplicative constant, and so the Bayes factor would depend on this constant. Furthermore, although the range of a constant normalized prior is unimportant for parameter determination (provided it is wider than the likelihood), this is not so for the Bayes factor when such a prior

is used for only one of the hypotheses. So to compute a Bayes factor, all internal parameters must be described by normalized priors that represent meaningful probabilities over the entire range where they are defined

An exception to this rule may be considered when the identical parameter appears in the models for both numerator and denominator of the Bayes factor. In this case one can argue that the arbitrary constants would cancel. One must exercise some caution, however, as parameters with the same name and physical meaning may still play different roles in the two models.

Both integrals in equation (36.41) are of the form

$$m = \int L(\boldsymbol{x}|\boldsymbol{\theta})\pi(\boldsymbol{\theta}) d\boldsymbol{\theta} , \qquad (36.42)$$

which is called the *marginal likelihood* (or in some fields called the *evidence*). A review of Bayes factors including a discussion of computational issues can be found in Ref. 30.

36.3. Intervals and limits

When the goal of an experiment is to determine a parameter θ , the result is usually expressed by quoting, in addition to the point estimate, some sort of interval which reflects the statistical precision of the measurement. In the simplest case, this can be given by the parameter's estimated value $\widehat{\theta}$ plus or minus an estimate of the standard deviation of $\widehat{\theta}$, $\sigma_{\widehat{\theta}}$. If, however, the p.d.f. of the estimator is not Gaussian or if there are physical boundaries on the possible values of the parameter, then one usually quotes instead an interval according to one of the procedures described below.

In reporting an interval or limit, the experimenter may wish to

- communicate as objectively as possible the result of the experiment;
- provide an interval that is constructed to cover the true value of the parameter with a specified probability;
- provide the information needed by the consumer of the result to draw conclusions about the parameter or to make a particular decision;
- draw conclusions about the parameter that incorporate stated prior beliefs.

With a sufficiently large data sample, the point estimate and standard deviation (or for the multiparameter case, the parameter estimates and covariance matrix) satisfy essentially all of these goals. For finite data samples, no single method for quoting an interval will achieve all of them.

In addition to the goals listed above, the choice of method may be influenced by practical considerations such as ease of producing an interval from the results of several measurements. Of course the experimenter is not restricted to quoting a single interval or limit; one may choose, for example, first to communicate the result with a confidence interval having certain frequentist properties, and then in addition to draw conclusions about a parameter using a judiciously chosen subjective Bayesian prior.

It is recommended, however, that there be a clear separation between these two aspects of reporting a result. In the remainder of this section, we assess the extent to which various types of intervals achieve the goals stated here.

$36.3.1. \;\; Bayesian \; intervals:$

As described in Sec. 36.1.4, a Bayesian posterior probability may be used to determine regions that will have a given probability of containing the true value of a parameter. In the single parameter case, for example, an interval (called a Bayesian or credible interval) $[\theta_{\rm lo}, \theta_{\rm up}]$ can be determined which contains a given fraction $1-\alpha$ of the posterior probability, *i.e.*,

$$1 - \alpha = \int_{\theta_{10}}^{\theta_{\text{up}}} p(\theta|\boldsymbol{x}) d\theta . \qquad (36.43)$$

Sometimes an upper or lower limit is desired, *i.e.*, θ_{lo} or θ_{up} can be set to a physical boundary or to plus or minus infinity. In other cases, one

might choose θ_{lo} and θ_{up} such that $p(\theta|\mathbf{x})$ is higher everywhere inside the interval than outside; these are called *highest posterior density* (HPD) intervals. Note that HPD intervals are not invariant under a nonlinear transformation of the parameter.

If a parameter is constrained to be non-negative, then the prior p.d.f. can simply be set to zero for negative values. An important example is the case of a Poisson variable n, which counts signal events with unknown mean s, as well as background with mean b, assumed known. For the signal mean s, one often uses the prior

$$\pi(s) = \begin{cases} 0 & s < 0 \\ 1 & s \ge 0 \end{cases}$$
 (36.44)

This prior is regarded as providing an interval whose frequentist properties can be studied, rather than as representing a degree of belief. In the absence of a clear discovery, (e.g., if n=0 or if in any case n is compatible with the expected background), one usually wishes to place an upper limit on s (see, however, Sec. 36.3.2.6 on "flip-flopping" concerning frequentist coverage). Using the likelihood function for Poisson distributed n,

$$L(n|s) = \frac{(s+b)^n}{n!} e^{-(s+b)} , \qquad (36.45)$$

along with the prior (36.44) in (36.24) gives the posterior density for s. An upper limit $s_{\rm up}$ at confidence level (or here, rather, credibility level) $1-\alpha$ can be obtained by requiring

$$1 - \alpha = \int_{-\infty}^{\sup} p(s|n)ds = \frac{\int_{-\infty}^{\sup} L(n|s) \pi(s) ds}{\int_{-\infty}^{\infty} L(n|s) \pi(s) ds},$$
 (36.46)

where the lower limit of integration is effectively zero because of the cut-off in $\pi(s)$. By relating the integrals in Eq. (36.46) to incomplete gamma functions, the equation reduces to

$$\alpha = e^{-s_{\text{up}}} \frac{\sum_{m=0}^{n} (s_{\text{up}} + b)^m / m!}{\sum_{m=0}^{n} b^m / m!} .$$
 (36.47)

This must be solved numerically for the limit $s_{\rm up}$. For the special case of b=0, the sums can be related to the quantile $F_{\chi^2}^{-1}$ of the χ^2 distribution (inverse of the cumulative distribution) to give

$$s_{\rm up} = \frac{1}{2} F_{\chi^2}^{-1} (1 - \alpha; n_{\rm d}) ,$$
 (36.48)

where the number of degrees of freedom is $n_{\rm d}=2(n+1)$. The quantile of the χ^2 distribution can be obtained using the ROOT function TMath::ChisquareQuantile. It so happens that for the case of b=0, the upper limits from Eq. (36.48) coincide numerically with the values of the frequentist upper limits discussed in Section 36.3.2.5. Values for $1-\alpha=0.9$ and 0.95 are given by the values $\nu_{\rm up}$ in Table 36.3. The frequentist properties of confidence intervals for the Poisson mean in this way are discussed in Refs. [2] and [19].

As in any Bayesian analysis, it is important to show how the result would change if one uses different prior probabilities. For example, one could consider the Jeffreys prior as described in Sec. 36.1.4. For this problem one finds the Jeffreys prior $\pi(s) \propto 1/\sqrt{s+b}$ for $s \geq 0$ and zero otherwise. As with the constant prior, one would not regard this as representing one's prior beliefs about s, both because it is improper and also as it depends on s. Rather it is used with Bayes' theorem to produce an interval whose frequentist properties can be studied.

36.3.2. Frequentist confidence intervals:

The unqualified phrase "confidence intervals" refers to frequentist intervals obtained with a procedure due to Neyman [29], described below. These are intervals (or in the multiparameter case, regions) constructed so as to include the true value of the parameter with a probability greater than or equal to a specified level, called the coverage probability. In this section, we discuss several techniques for producing intervals that have, at least approximately, this property.

36.3.2.1. The Neyman construction for confidence intervals:

Consider a p.d.f. $f(x;\theta)$ where x represents the outcome of the experiment and θ is the unknown parameter for which we want to construct a confidence interval. The variable x could (and often does) represent an estimator for θ . Using $f(x;\theta)$, we can find for a pre-specified probability $1-\alpha$, and for every value of θ , a set of values $x_1(\theta,\alpha)$ and $x_2(\theta,\alpha)$ such that

$$P(x_1 < x < x_2; \theta) = 1 - \alpha = \int_{x_1}^{x_2} f(x; \theta) dx$$
. (36.49)

This is illustrated in Fig. 36.3: a horizontal line segment $[x_1(\theta, \alpha), x_2(\theta, \alpha)]$ is drawn for representative values of θ . The union of such intervals for all values of θ , designated in the figure as $D(\alpha)$, is known as the *confidence belt*. Typically the curves $x_1(\theta, \alpha)$ and $x_2(\theta, \alpha)$ are monotonic functions of θ , which we assume for this discussion.

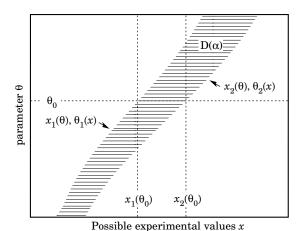


Figure 36.3: Construction of the confidence belt (see text).

Upon performing an experiment to measure x and obtaining a value x_0 , one draws a vertical line through x_0 . The confidence interval for θ is the set of all values of θ for which the corresponding line segment $[x_1(\theta, \alpha), x_2(\theta, \alpha)]$ is intercepted by this vertical line. Such confidence intervals are said to have a *confidence level* (CL) equal to $1 - \alpha$.

Now suppose that the true value of θ is θ_0 , indicated in the figure. We see from the figure that θ_0 lies between $\theta_1(x)$ and $\theta_2(x)$ if and only if x lies between $x_1(\theta_0)$ and $x_2(\theta_0)$. The two events thus have the same probability, and since this is true for any value θ_0 , we can drop the subscript 0 and obtain

$$1 - \alpha = P(x_1(\theta) < x < x_2(\theta)) = P(\theta_2(x) < \theta < \theta_1(x)). \tag{36.50}$$

In this probability statement, $\theta_1(x)$ and $\theta_2(x)$, *i.e.*, the endpoints of the interval, are the random variables and θ is an unknown constant. If the experiment were to be repeated a large number of times, the interval $[\theta_1, \theta_2]$ would vary, covering the fixed value θ in a fraction $1 - \alpha$ of the experiments.

The condition of coverage in Eq. (36.49) does not determine x_1 and x_2 uniquely, and additional criteria are needed. One possibility is to choose central intervals such that the probabilities excluded below x_1 and above x_2 are each $\alpha/2$. In other cases, one may want to report only an upper or lower limit, in which case the probability excluded below x_1 or above x_2 can be set to zero. Another principle based on likelihood ratio ordering for determining which values of x should be included in the confidence belt is discussed below.

When the observed random variable x is continuous, the coverage probability obtained with the Neyman construction is $1-\alpha$, regardless of the true value of the parameter. If x is discrete, however, it is not possible to find segments $[x_1(\theta,\alpha),x_2(\theta,\alpha)]$ that satisfy Eq. (36.49) exactly for all values of θ . By convention, one constructs the confidence belt requiring the probability $P(x_1 < x < x_2)$ to be greater than or equal to $1-\alpha$. This gives confidence intervals that include the true parameter with a probability greater than or equal to $1-\alpha$.

An equivalent method of constructing confidence intervals is to consider a test (see Sec. 36.2) of the hypothesis that the parameter's true value is θ (assume one constructs a test for all physical values of θ). One then excludes all values of θ where the hypothesis would be rejected at a significance level less than α . The remaining values constitute the confidence interval at confidence level $1-\alpha$.

In this procedure, one is still free to choose the test to be used; this corresponds to the freedom in the Neyman construction as to which values of the data are included in the confidence belt. One possibility is to use a test statistic based on the *likelihood ratio*.

$$\lambda = \frac{f(x;\theta)}{f(x;\widehat{\theta})}, \qquad (36.51)$$

where $\widehat{\theta}$ is the value of the parameter which, out of all allowed values, maximizes $f(x;\theta)$. This results in the intervals described in Ref. 31 by Feldman and Cousins. The same intervals can be obtained from the Neyman construction described above by including in the confidence belt those values of x which give the greatest values of λ .

36.3.2.2. Parameter exclusion in cases of low sensitivity:

An important example of a statistical test arises in the search for a new signal process. Suppose the parameter μ is defined such that it is proportional to the signal cross section. A statistical test may be carried out for hypothesized values of μ , which may be done by computing a p-value, p_{μ} , for each hypothesized μ . Those values not rejected in a test of size α , i.e., for which one does not find $p_{\mu} < \alpha$, constitute a confidence interval with confidence level $1-\alpha$.

In general one will find that for some regions in the parameter space of the signal model, the predictions for data are almost indistinguishable from those of the background-only model. This corresponds to the case where μ is very small, as would occur, e.g., if one searches for a Higgs boson with a mass so high that its production rate in a given experiment is negligible. That is, one has essentially no experimental sensitivity to such a model.

One would prefer that if the sensitivity to a model (or a point in a model's parameter space) is very low, then it should not be excluded. Even if the outcomes predicted with or without signal are identical, however, the probability to reject the signal model will equal α , the type-I error rate. As one often takes α to be 5%, this would mean that in a large number of searches covering a broad range of a signal model's parameter space, there would inevitably be excluded regions in which the experimental sensitivity is very small, and thus one may question whether it is justified to regard such parameter values as disfavored.

Exclusion of models to which one has little or no sensitivity occurs, for example, if the data fluctuate very low relative to the expectation of the background-only hypothesis. In this case the resulting upper limit on the predicted rate (cross section) of a signal model may be anomalously low. As a means of controlling this effect one often determines the mean or median limit under assumption of the background-only hypothesis using a simplified Monte Carlo simulation of the experiment. An upper limit found significantly below the background-only expectation may indicate a strong downward fluctuation of the data, or perhaps as well an incorrect estimate of the background rate.

The $\mathrm{CL_s}$ method aims to mitigate the problem of excluding models to which one is not sensitive by effectively penalizing the p-value of a tested parameter by an amount that increases with decreasing sensitivity [32,33]. The procedure is based on a statistic called $\mathrm{CL_s}$, which is defined as

$$CL_s = \frac{p_{\mu}}{1 - p_0}$$
, (36.52)

where p_0 is the *p*-value of the background-only hypothesis. In the usual formulation of the method, the *p*-values for μ and 0 are defined using a single test statistic, and the definition of CL_s above assumes this statistic is continuous; more details can be found in Refs. [32,33].

A point in a model's parameter space is regarded as excluded if one finds ${\rm CL_s} < \alpha$. As the denominator in Eq. (36.52) is always less than or equal to unity, the exclusion criterion based on ${\rm CL_s}$

is more stringent than the usual requirement $p_{\mu} < \alpha$. In this sense the CL_s procedure is conservative, and the coverage probability of the corresponding intervals will exceed the nominal confidence level $1-\alpha$. If the experimental sensitivity to a given value of μ is very low, then one finds that as p_{μ} decreases, so does the denominator $1-p_0$, and thus the condition CL_s < α is effectively prevented from being satisfied. In this way the exclusion of parameters in the case of low sensitivity is suppressed.

The CL_s procedure has the attractive feature that the resulting intervals coincide with those obtained from the Bayesian method in two important cases: the mean value of a Poisson or Gaussian distributed measurement with a constant prior. The CL_s intervals overcover for all values of the parameter μ , however, by an amount that depends on μ .

The problem of excluding parameter values to which one has little sensitivity is particularly acute when one wants to set a one-sided limit, e.g., an upper limit on a cross section. Here one tests a value of a rate parameter μ against the alternative of a lower rate, and therefore the critical region of the test is taken to correspond to data outcomes with a low event yield. If the number of events found in the search region fluctuates low enough, however, it can happen that all physically meaningful signal parameter values, including those to which one has very little sensitivity, are rejected by the test. Another solution to the problem, therefore, is to replace the one-sided test by one based on the likelihood ratio, where the critical region is not restricted to low rates. This is the approach followed in the Feldman-Cousins procedure described above. Further properties of Feldman-Cousins intervals are discussed below in Section 36.3.2.6.

36.3.2.3. Profile likelihood and treatment of nuisance parameters:

As mentioned in Section 36.3.1, one may have a model containing parameters that must be determined from data, but which are not of any interest in the final result (nuisance parameters). Suppose the likelihood $L(\theta, \nu)$ depends on parameters of interest θ and nuisance parameters ν . The nuisance parameters can be effectively removed from the problem by constructing the *profile likelihood*, defined by

$$L_{\mathbf{p}}(\boldsymbol{\theta}) = L(\boldsymbol{\theta}, \widehat{\widehat{\boldsymbol{\nu}}}(\boldsymbol{\theta})) ,$$
 (36.53)

where $\widehat{\widehat{\nu}}(\theta)$ is given by the ν that maximizes the likelihood for fixed θ . The profile likelihood may then be used to construct tests of intervals for the parameters of interest. This is in contrast to the marginal likelihood (36.30) used in the Bayesian approach. For example, one may construct the profile likelihood ratio,

$$\lambda_p(\boldsymbol{\theta}) = \frac{L_p(\boldsymbol{\theta})}{L(\widehat{\boldsymbol{\theta}}, \widehat{\boldsymbol{\nu}})},$$
 (36.54)

where $\hat{\boldsymbol{\theta}}$ and $\hat{\boldsymbol{\nu}}$ are the ML estimators. The ratio $\lambda_{\rm p}$ can be used in place of the likelihood ratio (36.51) for inference about $\boldsymbol{\theta}$. The resulting intervals for the parameters of interest are not guaranteed to have the exact coverage probability for all values of the nuisance parameters, but in cases of practical interest the approximation is found to be very good. Further discussion on use of the profile likelihood can be found in, e.g., Refs. [37–39] and other contributions to the PHYSTAT conferences [14].

36.3.2.4. Gaussian distributed measurements:

An important example of constructing a confidence interval is when the data consists of a single random variable x that follows a Gaussian distribution; this is often the case when x represents an estimator for a parameter and one has a sufficiently large data sample. If there is more than one parameter being estimated, the multivariate Gaussian is used. For the univariate case with known σ ,

$$1 - \alpha = \frac{1}{\sqrt{2\pi}\sigma} \int_{\mu-\delta}^{\mu+\delta} e^{-(x-\mu)^2/2\sigma^2} dx = \operatorname{erf}\left(\frac{\delta}{\sqrt{2}\sigma}\right)$$
 (36.55)

is the probability that the measured value x will fall within $\pm \delta$ of the true value μ . From the symmetry of the Gaussian with respect to x and μ , this is also the probability for the interval $x \pm \delta$ to include μ . Fig. 36.4 shows a $\delta = 1.64\sigma$ confidence interval unshaded. The choice $\delta = \sigma$ gives an interval called the *standard error* which has $1-\alpha = 68.27\%$ if σ is known. Values of α for other frequently used choices of δ are given in Table 36.1.

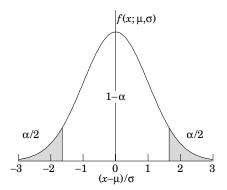


Figure 36.4: Illustration of a symmetric 90% confidence interval (unshaded) for a measurement of a single quantity with Gaussian errors. Integrated probabilities, defined by $\alpha = 0.1$, are as shown.

Table 36.1: Area of the tails α outside $\pm \delta$ from the mean of a Gaussian distribution.

| α | δ | α | δ |
|-----------------------|-----------|-----------|--------------|
| 0.3173 | 1σ | 0.2 | 1.28σ |
| 4.55×10^{-2} | 2σ | 0.1 | 1.64σ |
| 2.7×10^{-3} | 3σ | 0.05 | 1.96σ |
| 6.3×10^{-5} | 4σ | 0.01 | 2.58σ |
| 5.7×10^{-7} | 5σ | 0.001 | 3.29σ |
| 2.0×10^{-9} | 6σ | 10^{-4} | 3.89σ |

We can set a one-sided (upper or lower) limit by excluding above $x+\delta$ (or below $x-\delta$). The values of α for such limits are half the values in Table 36.1.

The relation (36.55) can be re-expressed using the cumulative distribution function for the χ^2 distribution as

$$\alpha = 1 - F(\chi^2; n) , \qquad (36.56)$$

for $\chi^2 = (\delta/\sigma)^2$ and n=1 degree of freedom. This can be obtained from Fig. 36.1 on the n=1 curve or by using the ROOT function

For multivariate measurements of, say, n parameter estimates $\widehat{\boldsymbol{\theta}}=(\widehat{\theta}_1,\ldots,\widehat{\theta}_n)$, one requires the full covariance matrix $V_{ij}=\cos[\widehat{\theta}_i,\widehat{\theta}_j]$, which can be estimated as described in Sections 36.1.2 and 36.1.3. Under fairly general conditions with the methods of maximum-likelihood or least-squares in the large sample limit, the estimators will be distributed according to a multivariate Gaussian centered about the true (unknown) values $\boldsymbol{\theta}$, and furthermore, the likelihood function itself takes on a Gaussian shape.

The standard error ellipse for the pair $(\widehat{\theta}_i, \widehat{\theta}_j)$ is shown in Fig. 36.5, corresponding to a contour $\chi^2 = \chi^2_{\min} + 1$ or $\ln L = \ln L_{\max} - 1/2$. The ellipse is centered about the estimated values $\widehat{\boldsymbol{\theta}}$, and the tangents to the ellipse give the standard deviations of the estimators, σ_i and σ_j . The angle of the major axis of the ellipse is given by

$$\tan 2\phi = \frac{2\rho_{ij}\sigma_i\sigma_j}{\sigma_j^2 - \sigma_i^2}, \qquad (36.57)$$

where $\rho_{ij} = \text{cov}[\hat{\theta}_i, \hat{\theta}_j]/\sigma_i \sigma_j$ is the correlation coefficient.

The correlation coefficient can be visualized as the fraction of the distance σ_i from the ellipse's horizontal center-line at which the ellipse becomes tangent to vertical, *i.e.*, at the distance $\rho_{ij}\sigma_i$ below the center-line as shown. As ρ_{ij} goes to +1 or -1, the ellipse thins to a diagonal line.

It could happen that one of the parameters, say, θ_j , is known from previous measurements to a precision much better than σ_j , so that the current measurement contributes almost nothing to the knowledge of θ_j . However, the current measurement of θ_i and its dependence on θ_j may still be important. In this case, instead of quoting both parameter

Table 36.2: $\Delta \chi^2$ or $2\Delta \ln L$ corresponding to a coverage probability $1-\alpha$ in the large data sample limit, for joint estimation of m parameters.

| $(1-\alpha)$ (%) | m = 1 | m = 2 | m = 3 |
|------------------|-------|-------|-------|
| 68.27 | 1.00 | 2.30 | 3.53 |
| 90. | 2.71 | 4.61 | 6.25 |
| 95. | 3.84 | 5.99 | 7.82 |
| 95.45 | 4.00 | 6.18 | 8.03 |
| 99. | 6.63 | 9.21 | 11.34 |
| 99.73 | 9.00 | 11.83 | 14.16 |

estimates and their correlation, one sometimes reports the value of θ_i , which minimizes χ^2 at a fixed value of θ_j , such as the PDG best value. This θ_i value lies along the dotted line between the points where the ellipse becomes tangent to vertical, and has statistical error σ_{inner} as shown on the figure, where $\sigma_{\text{inner}} = (1 - \rho_{ij}^2)^{1/2} \sigma_i$. Instead of the correlation ρ_{ij} , one reports the dependency $d\hat{\theta}_i/d\theta_j$ which is the slope of the dotted line. This slope is related to the correlation coefficient by $d\hat{\theta}_i/d\theta_j = \rho_{ij} \times \frac{\sigma_i}{\sigma_i}$.

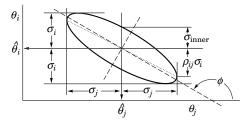


Figure 36.5: Standard error ellipse for the estimators $\hat{\theta}_i$ and $\hat{\theta}_i$. In this case the correlation is negative.

As in the single-variable case, because of the symmetry of the Gaussian function between θ and $\hat{\theta}$, one finds that contours of constant $\ln L$ or χ^2 cover the true values with a certain, fixed probability. That is, the confidence region is determined by

$$\ln L(\boldsymbol{\theta}) \ge \ln L_{\text{max}} - \Delta \ln L , \qquad (36.58)$$

or where a χ^2 has been defined for use with the method of least-squares,

$$\chi^2(\boldsymbol{\theta}) \le \chi^2_{\min} + \Delta \chi^2 \ . \tag{36.59}$$

Values of $\Delta \chi^2$ or $2\Delta \ln L$ are given in Table 36.2 for several values of the coverage probability and number of fitted parameters.

For finite non-Gaussian data samples, the probability for the regions determined by equations (36.58) or (36.59) to cover the true value of θ will depend on θ , so these are not exact confidence regions according to our previous definition. Nevertheless, they can still have a coverage probability only weakly dependent on the true parameter, and approximately as given in Table 36.2. In any case, the coverage probability of the intervals or regions obtained according to this procedure can in principle be determined as a function of the true parameter(s), for example, using a Monte Carlo calculation.

One of the practical advantages of intervals that can be constructed from the log-likelihood function or χ^2 is that it is relatively simple to produce the interval for the combination of several experiments. If N independent measurements result in log-likelihood functions $\ln L_i(\boldsymbol{\theta})$, then the combined log-likelihood function is simply the sum,

$$\ln L(\boldsymbol{\theta}) = \sum_{i=1}^{N} \ln L_i(\boldsymbol{\theta}) . \tag{36.60}$$

This can then be used to determine an approximate confidence interval or region with Eq. (36.58), just as with a single experiment.

36.3.2.5. Poisson or binomial data:

Another important class of measurements consists of counting a certain number of events, n. In this section, we will assume these are all events of the desired type, *i.e.*, there is no background. If n represents the number of events produced in a reaction with cross section σ , say, in a fixed integrated luminosity \mathcal{L} , then it follows a Poisson distribution with mean $\nu = \sigma \mathcal{L}$. If, on the other hand, one has selected a larger sample of N events and found n of them to have a particular property, then n follows a binomial distribution where the parameter p gives the probability for the event to possess the property in question. This is appropriate, e.g., for estimates of branching ratios or selection efficiencies based on a given total number of events.

For the case of Poisson distributed n, the upper and lower limits on the mean value ν can be found from the Neyman procedure to be

$$\nu_{\rm lo} = \frac{1}{2} F_{\chi^2}^{-1}(\alpha_{\rm lo}; 2n) ,$$
 (36.61a)

$$\nu_{\rm up} = \frac{1}{2} F_{\chi^2}^{-1} (1 - \alpha_{\rm up}; 2(n+1)) , \qquad (36.61b)$$

where the upper and lower limits are at confidence levels of $1-\alpha_{\rm lo}$ and $1-\alpha_{\rm up}$, respectively, and $F_{\chi^2}^{-1}$ is the quantile of the χ^2 distribution (inverse of the cumulative distribution). The quantiles $F_{\chi^2}^{-1}$ can be obtained from standard tables or from the ROOT routine TMath::ChisquareQuantile. For central confidence intervals at confidence level $1-\alpha$, set $\alpha_{\rm lo}=\alpha_{\rm up}=\alpha/2$.

Table 36.3: Lower and upper (one-sided) limits for the mean ν of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

| | $1 - \alpha = 90$ | $1 - \alpha = 95\%$ | | |
|----------------|-------------------|---------------------|--------------------|--------------------|
| \overline{n} | $ u_{ m lo}$ | $ u_{\mathrm{up}}$ | $ u_{\mathrm{lo}}$ | $ u_{\mathrm{up}}$ |
| 0 | _ | 2.30 | _ | 3.00 |
| 1 | 0.105 | 3.89 | 0.051 | 4.74 |
| 2 | 0.532 | 5.32 | 0.355 | 6.30 |
| 3 | 1.10 | 6.68 | 0.818 | 7.75 |
| 4 | 1.74 | 7.99 | 1.37 | 9.15 |
| 5 | 2.43 | 9.27 | 1.97 | 10.51 |
| 6 | 3.15 | 10.53 | 2.61 | 11.84 |
| 7 | 3.89 | 11.77 | 3.29 | 13.15 |
| 8 | 4.66 | 12.99 | 3.98 | 14.43 |
| 9 | 5.43 | 14.21 | 4.70 | 15.71 |
| 10 | 6.22 | 15.41 | 5.43 | 16.96 |

It happens that the upper limit from Eq. (36.61b) coincides numerically with the Bayesian upper limit for a Poisson parameter, using a uniform prior p.d.f. for ν . Values for confidence levels of 90% and 95% are shown in Table 36.3. For the case of binomially distributed n successes out of N trials with probability of success p, the upper and lower limits on p are found to be

$$p_{\text{lo}} = \frac{nF_F^{-1}[\alpha_{\text{lo}}; 2n, 2(N-n+1)]}{N-n+1 + nF_F^{-1}[\alpha_{\text{lo}}; 2n, 2(N-n+1)]},$$
 (36.62a)

$$p_{\rm up} = \frac{(n+1)F_F^{-1}[1 - \alpha_{\rm up}; 2(n+1), 2(N-n)]}{(N-n) + (n+1)F_F^{-1}[1 - \alpha_{\rm up}; 2(n+1), 2(N-n)]} . (36.62b)$$

Here ${\cal F}_F^{-1}$ is the quantile of the F distribution (also called the Fisher–Snedecor distribution; see Ref. 4).

36.3.2.6. Difficulties with intervals near a boundary:

A number of issues arise in the construction and interpretation of confidence intervals when the parameter can only take on values in a restricted range. An important example is where the mean of a Gaussian variable is constrained on physical grounds to be non-negative. This arises, for example, when the square of the neutrino mass is estimated from $\hat{m}^2 = \hat{E}^2 - \hat{p}^2$, where \hat{E} and \hat{p} are independent, Gaussian-distributed estimates of the energy and momentum. Although the true m^2 is constrained to be positive, random errors in \hat{E} and \hat{p} can easily lead to negative values for the estimate \hat{m}^2 .

If one uses the prescription given above for Gaussian distributed measurements, which says to construct the interval by taking the estimate plus-or-minus-one standard deviation, then this can give intervals that are partially or entirely in the unphysical region. In fact, by following strictly the Neyman construction for the central confidence interval, one finds that the interval is truncated below zero; nevertheless an extremely small or even a zero-length interval can result.

An additional important example is where the experiment consists of counting a certain number of events, n, which is assumed to be Poisson-distributed. Suppose the expectation value $E[n] = \nu$ is equal to s+b, where s and b are the means for signal and background processes, and assume further that b is a known constant. Then $\hat{s} = n - b$ is an unbiased estimator for s. Depending on true magnitudes of s and b, the estimate \hat{s} can easily fall in the negative region. Similar to the Gaussian case with the positive mean, the central confidence interval or even the interval that gives the upper limit for s may be of zero length.

An additional difficulty arises when a parameter estimate is not significantly far away from the boundary, in which case it is natural to report a one-sided confidence interval (often an upper limit). It is straightforward to force the Neyman prescription to produce only an upper limit by setting $x_2 = \infty$ in Eq. (36.49). Then x_1 is uniquely determined and the upper limit can be obtained. If, however, the data come out such that the parameter estimate is not so close to the boundary, one might wish to report a central confidence interval (i.e., an interval based on a two-sided test with equal upper and lower tail areas). As pointed out by Feldman and Cousins [31], however, if the decision to report an upper limit or two-sided interval is made by looking at the data ("flip-flopping"), then in general there will be parameter values for which the resulting intervals have a coverage probability less than $1-\alpha$.

With the confidence intervals suggested in [31], the prescription determines whether the interval is one- or two-sided in a way which preserves the coverage probability (and are thus said to be unified) and in addition they avoid the problem of null intervals. The intervals based on the Feldman-Cousins prescription are of this type. For a given choice of $1-\alpha$, if the parameter estimate is sufficiently close to the boundary, the method gives a one-sided limit. In the case of a Poisson variable in the presence of background, for example, this would occur if the number of observed events is compatible with the expected background. For parameter estimates increasingly far away from the boundary, i.e., for increasing signal significance, the interval makes a smooth transition from one- to two-sided, and far away from the boundary, one obtains a central interval.

The intervals according to this method for the mean of Poisson variable in the absence of background are given in Table 36.4. (Note that α in Ref. 31 is defined following Neyman [29] as the coverage probability; this is opposite the modern convention used here in which the coverage probability is $1-\alpha$.) The values of $1-\alpha$ given here refer to the coverage of the true parameter by the whole interval $[\nu_1, \nu_2]$. In Table 36.3 for the one-sided upper limit, however, $1-\alpha$ refers to the probability to have $\nu_{\rm up} \geq \nu$ (or $\nu_{\rm lo} \leq \nu$ for lower limits).

A potential difficulty with unified intervals arises if, for example, one constructs such an interval for a Poisson parameter s of some yet to be discovered signal process with, say, $1-\alpha=0.9$. If the true signal parameter is zero, or in any case much less than the expected background, one will usually obtain a one-sided upper limit on s. In a certain fraction of the experiments, however, a two-sided interval

Table 36.4: Unified confidence intervals $[\nu_1, \nu_2]$ for a the mean of a Poisson variable given n observed events in the absence of background, for confidence levels of 90% and 95%.

| | $1 - \alpha = 90$ | % | $1 - \alpha = 95\%$ | | |
|----------------|-------------------|---------|---------------------|---------|--|
| \overline{n} | ν_1 | ν_2 | ν_1 | ν_2 | |
| 0 | 0.00 | 2.44 | 0.00 | 3.09 | |
| 1 | 0.11 | 4.36 | 0.05 | 5.14 | |
| 2 | 0.53 | 5.91 | 0.36 | 6.72 | |
| 3 | 1.10 | 7.42 | 0.82 | 8.25 | |
| 4 | 1.47 | 8.60 | 1.37 | 9.76 | |
| 5 | 1.84 | 9.99 | 1.84 | 11.26 | |
| 6 | 2.21 | 11.47 | 2.21 | 12.75 | |
| 7 | 3.56 | 12.53 | 2.58 | 13.81 | |
| 8 | 3.96 | 13.99 | 2.94 | 15.29 | |
| 9 | 4.36 | 15.30 | 4.36 | 16.77 | |
| 10 | 5.50 | 16.50 | 4.75 | 17.82 | |

for s will result. Since, however, one typically chooses $1-\alpha$ to be only 0.9 or 0.95 when setting limits, the value s=0 may be found below the lower edge of the interval before the existence of the effect is well established. It must then be communicated carefully that in excluding s=0 from the interval, one is not necessarily claiming to have discovered the effect.

It must then be communicated carefully that in excluding s=0 at, say, 90 or 95% confidence level from the interval, one is not necessarily claiming to have discovered the effect, for which one would usually require a higher level of significance (e.g., 5 σ).

The intervals constructed according to the unified procedure in Ref. 31 for a Poisson variable n consisting of signal and background have the property that for n=0 observed events, the upper limit decreases for increasing expected background. This is counterintuitive, since it is known that if n=0 for the experiment in question, then no background was observed, and therefore one may argue that the expected background should not be relevant. The extent to which one should regard this feature as a drawback is a subject of some controversy (see, e.g., Ref. 36).

Another possibility is to construct a Bayesian interval as described in Section 36.3.1. The presence of the boundary can be incorporated simply by setting the prior density to zero in the unphysical region. More specifically, the prior may be chosen using formal rules such as the reference prior or Jeffreys prior mentioned in Sec. 36.1.4. The use of such priors is currently receiving increased attention in HEP.

In HEP a widely used prior for the mean μ of a Poisson distributed measurement has been uniform for $\mu \geq 0$. This prior does not follow from any fundamental rule nor can it be regarded as reflecting a reasonable degree of belief, since the prior probability for μ to lie between any two finite limits is zero. It is more appropriately regarded as a procedure for obtaining intervals with frequentist properties that can be investigated. The resulting upper limits have a coverage probability that depends on the true value of the Poisson parameter, and is nowhere smaller than the stated probability content. Lower limits and two-sided intervals for the Poisson mean based on flat priors undercover, however, for some values of the parameter, although to an extent that in practical cases may not be too severe [2,19]. Intervals constructed in this way have the advantage of being easy to derive; if several independent measurements are to be combined then one simply multiplies the likelihood functions (cf. Eq. (36.60)).

An additional alternative is presented by the intervals found from the likelihood function or χ^2 using the prescription of Equations (36.58) or (36.59). However, the coverage probability is not, in general, independent of the true parameter, and these intervals can for some parameter values undercover. The coverage probability can, of course, be determined with some extra effort and reported with the result. These intervals are also invariant under transformation of the

parameter; this is not true for Bayesian intervals with a conventional flat prior, because a uniform distribution in, say, θ will not be uniform if transformed to $1/\theta$. A study of the coverage of different intervals for a Poisson parameter can be found in [34]. Use of the likelihood function to determine approximate confidence intervals is discussed further in [35].

In any case, it is important to always report sufficient information so that the result can be combined with other measurements. Often this means giving an unbiased estimator and its standard deviation, even if the estimated value is in the unphysical region.

It can also be useful with a frequentist interval to calculate its subjective probability content using the posterior p.d.f. based on one or several reasonable guesses for the prior p.d.f. If it turns out to be significantly less than the stated confidence level, this warns that it would be particularly misleading to draw conclusions about the parameter's value from the interval alone.

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37. MONTE CARLO TECHNIQUES

Revised September 2011 by G. Cowan (RHUL).

Monte Carlo techniques are often the only practical way to evaluate difficult integrals or to sample random variables governed by complicated probability density functions. Here we describe an assortment of methods for sampling some commonly occurring probability density functions.

37.1. Sampling the uniform distribution

Most Monte Carlo sampling or integration techniques assume a "random number generator," which generates uniform statistically independent values on the half open interval [0,1); for reviews see, e.g., [1,2].

Uniform random number generators are available in software libraries such as CERNLIB [3], CLHEP [4], and ROOT [5]. For example, in addition to a basic congruential generator TRandom (see below), ROOT provides three more sophisticated routines: TRandom1 implements the RANLUX generator [6] based on the method by Lüscher, and allows the user to select different quality levels, trading off quality with speed; TRandom2 is based on the maximally equidistributed combined Tausworthe generator by L'Ecuyer [7]; the TRandom3 generator implements the Mersenne twister algorithm of Matsumoto and Nishimura [8]. All of the algorithms produce a periodic sequence of numbers, and to obtain effectively random values, one must not use more than a small subset of a single period. The Mersenne twister algorithm has an extremely long period of $2^{19937}-1$.

The performance of the generators can be investigated with tests such as DIEHARD [9] or TestU01 [10]. Many commonly available congruential generators fail these tests and often have sequences (typically with periods less than 2^{32}), which can be easily exhausted on modern computers. A short period is a problem for the TRandom generator in ROOT, which, however, has the advantage that its state is stored in a single 32-bit word. The generators TRandom1, TRandom2, or TRandom3 have much longer periods, with TRandom3 being recommended by the ROOT authors as providing the best combination of speed and good random properties. For further information see, e.g., Ref. 11.

37.2. Inverse transform method

If the desired probability density function is f(x) on the range $-\infty < x < \infty$, its cumulative distribution function (expressing the probability that $x \leq a$) is given by Eq. (35.6). If a is chosen with probability density f(a), then the integrated probability up to point a, F(a), is itself a random variable which will occur with uniform probability density on [0,1]. Suppose u is generated according to a uniformly distributed in (0,1). If x can take on any value, and ignoring the endpoints, we can then find a unique x chosen from the p.d.f. f(x) for a given u if we set

$$u = F(x) , (37.1)$$

provided we can find an inverse of F, defined by

$$x = F^{-1}(u) . (37.2)$$

This method is shown in Fig. 37.1a. It is most convenient when one can calculate by hand the inverse function of the indefinite integral of f. This is the case for some common functions f(x) such as $\exp(x)$, $(1-x)^n$, and $1/(1+x^2)$ (Cauchy or Breit-Wigner), although it does not necessarily produce the fastest generator. Standard libraries contain software to implement this method numerically, working from functions or histograms in one or more dimensions, e.g., the UNU.RAN package [12], available in ROOT.

For a discrete distribution, F(x) will have a discontinuous jump of size $f(x_k)$ at each allowed $x_k, k = 1, 2, \cdots$. Choose u from a uniform distribution on (0,1) as before. Find x_k such that

$$F(x_{k-1}) < u \le F(x_k) \equiv \text{Prob}(x \le x_k) = \sum_{i=1}^k f(x_i);$$
 (37.3)

then x_k is the value we seek (note: $F(x_0) \equiv 0$). This algorithm is illustrated in Fig. 37.1b.

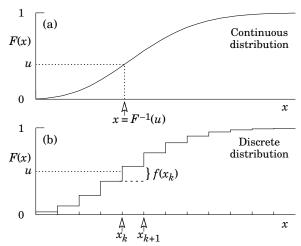


Figure 37.1: Use of a random number u chosen from a uniform distribution (0,1) to find a random number x from a distribution with cumulative distribution function F(x).

37.3. Acceptance-rejection method (Von Neumann)

Very commonly an analytic form for F(x) is unknown or too complex to work with, so that obtaining an inverse as in Eq. (37.2) is impractical. We suppose that for any given value of x, the probability density function f(x) can be computed, and further that enough is known about f(x) that we can enclose it entirely inside a shape which is C times an easily generated distribution h(x), as illustrated in Fig. 37.2. That is, $Ch(x) \geq f(x)$ must hold for all x.

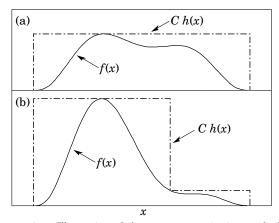


Figure 37.2: Illustration of the acceptance-rejection method. Random points are chosen inside the upper bounding figure, and rejected if the ordinate exceeds f(x). The lower figure illustrates a method to increase the efficiency (see text).

Frequently h(x) is uniform or is a normalized sum of uniform distributions. Note that both f(x) and h(x) must be normalized to unit area, and therefore, the proportionality constant C>1. To generate f(x), first generate a candidate x according to h(x). Calculate f(x) and the height of the envelope Ch(x); generate u and test if $uCh(x) \leq f(x)$. If so, accept x; if not reject x and try again. If we regard x and uCh(x) as the abscissa and ordinate of a point in a two-dimensional plot, these points will populate the entire area Ch(x) in a smooth manner; then we accept those which fall under f(x). The efficiency is the ratio of areas, which must equal 1/C; therefore we must keep C as close as possible to 1.0. Therefore, we try to choose Ch(x) to be as close to f(x) as convenience dictates, as in the lower part of Fig. 37.2.

37.4. Algorithms

Algorithms for generating random numbers belonging to many different distributions are given for example by Press [13], Ahrens and Dieter [14], Rubinstein [15], Devroye [16], Walck [17] and Gentle [18]. For many distributions, alternative algorithms exist, varying in complexity, speed, and accuracy. For time-critical applications, these algorithms may be coded in-line to remove the significant overhead often encountered in making function calls.

In the examples given below, we use the notation for the variables and parameters given in Table 35.1. Variables named "u" are assumed to be independent and uniform on [0,1). Denominators must be verified to be non-zero where relevant.

37.4.1. Exponential decay:

This is a common application of the inverse transform method, and uses the fact that if u is uniformly distributed in [0,1], then (1-u) is as well. Consider an exponential p.d.f. $f(t)=(1/\tau)\exp(-t/\tau)$ that is truncated so as to lie between two values, a and b, and renormalized to unit area. To generate decay times t according to this p.d.f., first let $\alpha=\exp(-a/\tau)$ and $\beta=\exp(-b/\tau)$; then generate u and let

$$t = -\tau \ln(\beta + u(\alpha - \beta)). \tag{37.4}$$

For $(a,b)=(0,\infty),$ we have simply $t=-\tau \ln u.$ (See also Sec. 37.4.6.)

37.4.2. Isotropic direction in 3D:

Isotropy means the density is proportional to solid angle, the differential element of which is $d\Omega = d(\cos\theta)d\phi$. Hence $\cos\theta$ is uniform $(2u_1-1)$ and ϕ is uniform $(2\pi u_2)$. For alternative generation of $\sin\phi$ and $\cos\phi$, see the next subsection.

37.4.3. Sine and cosine of random angle in 2D:

Generate u_1 and u_2 . Then $v_1=2u_1-1$ is uniform on (-1,1), and $v_2=u_2$ is uniform on (0,1). Calculate $r^2=v_1^2+v_2^2$. If $r^2>1$, start over. Otherwise, the sine (S) and cosine (C) of a random angle (i.e., uniformly distributed between zero and $2\pi)$ are given by

$$S = 2v_1v_2/r^2$$
 and $C = (v_1^2 - v_2^2)/r^2$. (37.5)

37.4.4. Gaussian distribution:

If u_1 and u_2 are uniform on (0,1), then

$$z_1 = \sin(2\pi u_1)\sqrt{-2\ln u_2}$$
 and $z_2 = \cos(2\pi u_1)\sqrt{-2\ln u_2}$ (37.6) are independent and Gaussian distributed with mean 0 and $\sigma = 1$.

There are many variants of this basic algorithm, which may be faster. For example, construct $v_1=2u_1-1$ and $v_2=2u_2-1$, which are uniform on (-1,1). Calculate $r^2=v_1^2+v_2^2$, and if $r^2>1$ start over. If $r^2<1$, it is uniform on (0,1). Then

$$z_1 = v_1 \sqrt{\frac{-2 \ln r^2}{r^2}}$$
 and $z_2 = v_2 \sqrt{\frac{-2 \ln r^2}{r^2}}$ (37.7)

are independent numbers chosen from a normal distribution with mean 0 and variance 1. $z_i' = \mu + \sigma z_i$ distributes with mean μ and variance σ^2

For a multivariate Gaussian with an $n \times n$ covariance matrix V, one can start by generating n independent Gaussian variables, $\{\eta_j\}$, with mean 0 and variance 1 as above. Then the new set $\{x_i\}$ is obtained as $x_i = \mu_i + \sum_j L_{ij}\eta_j$, where μ_i is the mean of x_i , and L_{ij} are the components of L, the unique lower triangular matrix that fulfils $V = LL^T$. The matrix L can be easily computed by the following recursive relation (Cholesky's method):

$$L_{jj} = \left(V_{jj} - \sum_{k=1}^{j-1} L_{jk}^2\right)^{1/2}, \qquad (37.8a)$$

$$L_{ij} = \frac{V_{ij} - \sum_{k=1}^{j-1} L_{ik} L_{jk}}{L_{jj}}, \ j = 1, ..., n; \ i = j+1, ..., n, (37.8b)$$

where $V_{ij} = \rho_{ij}\sigma_i\sigma_j$ are the components of V. For n=2 one has

$$L = \begin{pmatrix} \sigma_1 & 0\\ \rho \sigma_2 & \sqrt{1 - \rho^2} \sigma_2 \end{pmatrix} , \qquad (37.9)$$

and therefore the correlated Gaussian variables are generated as $x_1 = \mu_1 + \sigma_1 \eta_1$, $x_2 = \mu_2 + \rho \sigma_2 \eta_1 + \sqrt{1 - \rho^2} \sigma_2 \eta_2$.

37.4.5. $\chi^2(n)$ distribution :

To generate a variable following the χ^2 distribution for n degrees of freedom, use the Gamma distribution with k=n/2 and $\lambda=1/2$ using the method of Sec. 37.4.6.

37.4.6. Gamma distribution:

All of the following algorithms are given for $\lambda = 1$. For $\lambda \neq 1$, divide the resulting random number x by λ .

- If k=1 (the exponential distribution), accept $x=-\ln u$. (See also Sec. 37.4.1.)
- If 0 < k < 1, initialize with $v_1 = (e + k)/e$ (with e = 2.71828... being the natural log base). Generate u_1, u_2 . Define $v_2 = v_1u_1$.

Case 1: $v_2 \le 1$. Define $x = v_2^{1/k}$. If $u_2 \le e^{-x}$, accept x and stop, else restart by generating new u_1, u_2 .

Case 2: $v_2 > 1$. Define $x = -\ln([v_1 - v_2]/k)$. If $u_2 \le x^{k-1}$, accept x and stop, else restart by generating new u_1 , u_2 . Note that, for k < 1, the probability density has a pole at x = 0, so that return values of zero due to underflow must be accepted or otherwise dealt with.

• Otherwise, if k > 1, initialize with c = 3k - 0.75. Generate u_1 and compute $v_1 = u_1(1 - u_1)$ and $v_2 = (u_1 - 0.5)\sqrt{c/v_1}$. If $x = k + v_2 - 1 \le 0$, go back and generate new u_1 ; otherwise generate u_2 and compute $v_3 = 64v_1^3u_2^2$. If $v_3 \le 1 - 2v_2^2/x$ or if $\ln v_3 \le 2\{[k-1]\ln[x/(k-1)] - v_2\}$, accept x and stop; otherwise go back and generate new u_1 .

$37.4.7. \quad Binomial \ distribution:$

Begin with k=0 and generate u uniform in [0,1). Compute $P_k=(1-p)^n$ and store P_k into B. If $u\leq B$ accept $r_k=k$ and stop. Otherwise, increment k by one; compute the next P_k as $P_k\cdot (p/(1-p))\cdot (n-k)/(k+1)$; add this to B. Again, if $u\leq B$, accept $r_k=k$ and stop, otherwise iterate until a value is accepted. If p>1/2, it will be more efficient to generate r from f(r;n,q), i.e., with p and q interchanged, and then set $r_k=n-r$.

37.4.8. Poisson distribution:

Iterate until a successful choice is made: Begin with k=1 and set A=1 to start. Generate u. Replace A with uA; if now $A<\exp(-\mu)$, where μ is the Poisson parameter, accept $n_k=k-1$ and stop. Otherwise increment k by 1, generate a new u and repeat, always starting with the value of A left from the previous try.

Note that the Poisson generator used in ROOT's TRandom classes before version 5.12 (including the derived classes TRandom1, TRandom2, TRandom3) as well as the routine RNPSSN from CERNLIB, use a Gaussian approximation when μ exceeds a given threshold. This may be satisfactory (and much faster) for some applications. To do this, generate z from a Gaussian with zero mean and unit standard deviation; then use $x=\max(0,[\mu+z\sqrt{\mu}+0.5])$ where $[\]$ signifies the greatest integer \leq the expression. The routines from Numerical Recipes [13] and CLHEP's routine RandPoisson do not make this approximation (see, e.g., Ref. 11).

37.4.9. Student's t distribution:

Generate u_1 and u_2 uniform in (0,1); then $t = \sin(2\pi u_1)[n(u_2^{-2/n} - 1)]^{1/2}$ follows the Student's t distribution for n > 0 degrees of freedom (n not necessarily an integer).

Alternatively, generate x from a Gaussian with mean 0 and $\sigma^2 = 1$ according to the method of 37.4.4. Next generate y, an independent gamma random variate, according to 37.4.6 with $\lambda = 1/2$ and k = n/2. Then $z = x/\sqrt{y/n}$ is distributed as a t with n degrees of freedom.

For the special case n=1, the Breit-Wigner distribution, generate u_1 and u_2 ; set $v_1=2u_1-1$ and $v_2=2u_2-1$. If $v_1^2+v_2^2\leq 1$ accept $z=v_1/v_2$ as a Breit-Wigner distribution with unit area, center at 0.0, and FWHM 2.0. Otherwise start over. For center M_0 and FWHM Γ , use $W=z\Gamma/2+M_0$.

37.4.10. Beta distribution:

The choice of an appropriate algorithm for generation of beta distributed random numbers depends on the values of the parameters α and β . For, e.g., $\alpha=1$, one can use the transformation method to find $x=1-u^{1/\beta}$, and similarly if $\beta=1$ one has $x=u^{1/\alpha}$. For more general cases see, e.g., Refs. [17,18] and references therein.

37.5. Markov Chain Monte Carlo

In applications involving generation of random numbers following a multivariate distribution with a high number of dimensions, the transformation method may not be possible and the acceptance-rejection technique may have too low of an efficiency to be practical. If it is not required to have independent random values, but only that they follow a certain distribution, then Markov Chain Monte Carlo (MCMC) methods can be used. In depth treatments of MCMC can be found, e.g., in the texts by Robert and Casella [19], Liu [20], and the review by Neal [21].

MCMC is particularly useful in connection with Bayesian statistics, where a p.d.f. $p(\theta)$ for an n-dimensional vector of parameters $\boldsymbol{\theta} = (\theta_1, \dots, \theta_n)$ is obtained, and one needs the marginal distribution of a subset of the components. Here one samples $\boldsymbol{\theta}$ from $p(\boldsymbol{\theta})$ and simply records the marginal distribution for the components of interest.

A simple and broadly applicable MCMC method is the Metropolis-Hastings algorithm, which allows one to generate multidimensional points $\boldsymbol{\theta}$ distributed according to a target p.d.f. that is proportional to a given function $p(\boldsymbol{\theta})$. It is not necessary to have $p(\boldsymbol{\theta})$ normalized to unit area, which is useful in Bayesian statistics, as posterior probability densities are often determined only up to an unknown normalization constant.

To generate points that follow $p(\theta)$, one first needs a proposal p.d.f. $q(\theta;\theta_0)$, which can be (almost) any p.d.f. from which independent random values θ can be generated, and which contains as a parameter another point in the same space θ_0 . For example, a multivariate Gaussian centered about θ_0 can be used. Beginning at an arbitrary starting point θ_0 , the Hastings algorithm iterates the following steps:

- 1. Generate a value θ using the proposal density $q(\theta; \theta_0)$;
- 2. Form the Hastings test ratio, $\alpha = \min \left[1, \frac{p(\boldsymbol{\theta})q(\boldsymbol{\theta}_0; \boldsymbol{\theta})}{p(\boldsymbol{\theta}_0)q(\boldsymbol{\theta}; \boldsymbol{\theta}_0)}\right]$;
- 3. Generate a value u uniformly distributed in [0, 1];
- 4. If $u \leq \alpha$, take $\theta_1 = \theta$. Otherwise, repeat the old point, *i.e.*, $\theta_1 = \theta_0$.
- 5. Set $\theta_0 = \theta_1$ and return to step 1.

If one takes the proposal density to be symmetric in θ and θ_0 , then this is the *Metropolis*-Hastings algorithm, and the test ratio becomes $\alpha = \min[1, p(\theta)/p(\theta_0)]$. That is, if the proposed θ is at a value of probability higher than θ_0 , the step is taken. If the proposed step is rejected, the old point is repeated.

Methods for assessing and optimizing the performance of the algorithm are discussed in, e.g., Refs. [19–21]. One can, for example, examine the autocorrelation as a function of the lag $k,\ i.e.$, the correlation of a sampled point with that k steps removed. This should decrease as quickly as possible for increasing k.

Generally one chooses the proposal density so as to optimize some quality measure such as the autocorrelation. For certain problems it has been shown that one achieves optimal performance when the acceptance fraction, that is, the fraction of points with $u \leq \alpha$, is around 40%. This can be adjusted by varying the width of the proposal density. For example, one can use for the proposal p.d.f. a multivariate Gaussian with the same covariance matrix as that of the target p.d.f., but scaled by a constant.

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38. MONTE CARLO EVENT GENERATORS

Written January 2012 by P. Nason (INFN, Milan) and P.Z. Skands (CERN).

General-purpose Monte Carlo (GPMC) generators like HERWIG [1], HERWIG++ [2], PYTHIA 6 [3], PYTHIA 8 [4], and SHERPA [5], provide fully exclusive modeling of high-energy collisions. They play an essential role in QCD modeling (in particular for aspects beyond fixed-order perturbative QCD), in data analysis, where they are used together with detector simulation to provide a realistic estimate of the detector response to collision events, and in the planning of new experiments, where they are used to estimate signals and backgrounds in high-energy processes. They are built from several components, that describe the physics starting from very short distance scales, up to the typical scale of hadron formation and decay. Since QCD is weakly interacting at short distances (below a femtometer), the components of the GPMC dealing with short-distance physics are based upon perturbation theory. At larger distances, all soft hadronic phenomena, like hadronization and the formation of the underlying event, cannot be computed from first principles, and one must rely upon QCD-inspired models.

The purpose of this review is to illustrate the main components of these generators. It is divided into four sections. The first one deals with short-distance, perturbative phenomena. The basic concepts leading to the simulations of the dominant QCD processes are illustrated here. In the second section, hadronization phenomena are treated. The two most popular hadronization models for the formation of primary hadrons, the string and cluster models, are illustrated. The basics of the implementation of primary-hadron decays into stable ones is also illustrated here. In the third section, models for soft hadron physics are discussed. These include models for the underlying event, and for minimum-bias interactions. Issues of Bose-Einstein and color-reconnection effects are also discussed here. The fourth section briefly introduces the problem of MC tuning.

We use natural units throughout, such that c=1 and $\hbar=1$, with energy, momenta and masses measured in GeV, and time and distances measured in GeV⁻¹.

38.1. Short-distance physics in GPMC generators

The short-distance components of a GPMC generator deal with the computation of the primary process at hand, with decays of short-lived particles, and with the generation of QCD and QED radiation, on time scales below $1/\Lambda$, with Λ denoting a typical hadronic scale of a few hundred MeV, corresponding roughly to an inverse femtometer. In e^+e^- annihilation, for example, the short-distance physics describes the evolution of the system from the instant when the e^+e^- pair annihilates up to a time when the size of the produced system is just below a femtometer.

In the present discussion we take the momentum scale of the primary process to be $Q\gg \Lambda$, so that the corresponding time and distance scale 1/Q is small. Soft- and collinear-safe inclusive observables, such as total decay widths or inclusive cross sections, can be reliably computed in QCD perturbation theory (pQCD), with the perturbative expansion truncated at any fixed order n, and the remainder suppressed by $\alpha_{\rm S}(Q)^{n+1}$.

Less inclusive observables, however, can receive large enhancements that destroy the convergence of the fixed-order expansion. This is due to the presence of collinear and infrared singularities in QCD. Thus, for example, a correction in which a parton from the primary interaction splits collinearly into two partons of comparable energy, is of order $\alpha_{\rm S}(Q) \ln(Q/\Lambda)$, where the logarithm arises from an integral over a singularity regulated by the hadronic scale Λ . Since $\alpha_{\rm S}(Q) \propto 1/\ln(Q/\Lambda)$, the corresponding cross section receives a correction of order unity. Two subsequent collinear splittings yield $\alpha_{\rm S}^2(Q) \ln^2(Q/\Lambda)$, and so on. Thus, corrections of order unity arise at all orders in perturbation theory. The dominant region of phase space is the one where radiation is strongly ordered in a measure of hardness and/or angle. This means that, from a typical final-state configuration, by clustering together final-state parton pairs with, say, the smallest angle, recursively, we can reconstruct a branching tree, that may be viewed as the splitting history of the event. This history necessarily has some dependence on which measure is used to

order the clusterings. However, strong ordering in energy times angle, in virtuality or in transverse momenta are in fact equivalent in the dominant region. In fact, in the small-angle limit, the virtuality t of a parton of energy E, splitting into two on-shell partons is given by

$$t = E^2 z (1 - z)(1 - \cos \theta) \approx \frac{z(1 - z)}{2} E^2 \theta^2,$$
 (38.1)

where z and 1-z are the energy fractions carried by the produced partons, and θ is their relative angle. The transverse momentum of the final partons relative to the direction of the incoming one is given by

$$p_T^2 \approx z^2 (1-z)^2 E^2 \theta^2.$$
 (38.2)

Thus, significant differences between these measures only arise in regions with very small z or 1-z values. In QCD, because of soft divergences, these regions are in fact important, and the choice of the appropriate ordering variable is very relevant (see Sec. 38.3).

The so called KLN theorem [6,7] guarantees that large logarithmically divergent corrections, arising from final-state collinear splitting and from soft emissions, cancel against the virtual corrections in the total cross section, order by order in perturbation theory. Furthermore, the factorization theorem guarantees that initial-state collinear singularities can be factorized into the parton density functions (PDFs). Therefore, the cross section for the basic process remains accurate up to corrections of higher orders in $\alpha_{\rm S}(Q)$, provided it is interpreted as an inclusive cross section, rather than as a bare partonic cross section. Thus, for example, the leading order (LO) cross section for $e^+e^- \to q\bar{q}$ is a good LO estimate of the e^+e^- cross section for the production of a pair of quarks accompanied by an arbitrary number of collinear and soft gluons, but is not a good estimate of the cross section for the production of a $q\bar{q}$ pair with no extra radiation.

Shower algorithms are used to compute the cross section for generic hard processes including all leading-logarithmic (LL) corrections. These algorithms begin with the generation of the kinematics of the basic process, performed with a probability proportional to its LO partonic cross section, which is interpreted physically as the inclusive cross section for the basic process, followed by an arbitrary sequence of small-angle splittings. A probability is then assigned to each splitting sequence. Thus, the initial LO cross section is partitioned into the cross sections for a multitude of final states of arbitrary multiplicity. The sum of all these partial cross sections equals that of the primary process. This property of the GPMCs reflects the KLN cancellation mentioned earlier, and it is often called "unitarity of the shower process", a name that reminds us that the KLN cancellation itself is a consequence of unitarity. The fact that a quantum mechanical process can be described in terms of composition of probabilities, rather than amplitudes, follows from the LL approximation. In fact, in the dominant, strongly ordered region, subsequent splittings are separated by increasingly large times and distances, and this suppresses interference effects.

We now illustrate the basic parton-shower algorithm, as first introduced in Ref. 8. The purpose of this illustration is to give a schematic representation of how shower algorithms work, to introduce some concepts that will be referred to in the following, and to show the relationship between shower algorithms and Feynman-diagram results. For simplicity, we consider the example of e^+e^- annihilation into $q\bar{q}$ pairs. With each dominant (i.e. strongly ordered) final-state configuration one can associate a unique ordered tree diagram, by recursively clustering together final-state parton pairs with the smallest angle, and ending up with the hard production vertex (i.e. the $\gamma^* \to q\bar{q}$). The momenta of all intermediate lines of the tree diagram are then uniquely determined from the final-state momenta. Virtualities in the graph are also strongly ordered. One assigns to each splitting vertex a virtuality t, equal to the invariant mass of the pair of generated partons, the energy fractions z and 1-z of the two generated partons, and the azimuth ϕ of the splitting process with respect to the momentum of the incoming parton. For definiteness, we assume that z and ϕ are defined in the center-of-mass (CM) frame of the e^+e^- collision, although other definitions are possible that differ only beyond the LL approximation. The differential cross section for

a given final state is given by the product of the differential cross section for the initial $e^+e^-\to q\bar q$ process, multiplied by a factor

$$\Delta_{i}(t,t')\frac{\alpha_{\rm S}(t)}{2\pi}P_{i,jk}(z)\frac{dt}{t}dz\frac{d\phi}{2\pi} \tag{38.3}$$

for each intermediate line ending in a splitting vertex. We have denoted with t' the maximal virtuality that is allowed for the line, with t its virtuality, and z and ϕ refer to the splitting process. $\Delta(t,t')$ is the so-called Sudakov form factor

$$\Delta_i(t, t') = \exp\left[-\int_t^{t'} \frac{dq^2}{q^2} \frac{\alpha_S(q^2)}{2\pi} \sum_{jk} P_{i,jk}(z) dz \frac{d\phi}{2\pi}\right].$$
(38.4)

The suffixes i and jk represent the parton species of the incoming and final partons, respectively, and $P_{i,jk}(z)$ are the Altarelli-Parisi [9] splitting kernels. Final-state lines that do not undergo any further splitting are associated with a factor

$$\Delta_i(t_0, t') , \qquad (38.5)$$

where t_0 is an infrared cutoff defined by the shower hadronization scale (at which the charges are screened by hadronization) or, for an unstable particle, its width (a source cannot emit radiation with a period exceeding its lifetime).

Notice that the definition of the Sudakov form factor is such that

$$\Delta_{i}(t_{2}, t_{1}) + \int_{t_{2}}^{t_{1}} \frac{dt}{t} dz \frac{d\phi}{2\pi} \sum_{ik} \Delta_{i}(t, t_{1}) \frac{\alpha_{S}(t)}{2\pi} P_{i, jk}(z) = 1.$$
 (38.6)

This implies that the cross section for developing the shower up to a given stage does not depend on what happens next, since subsequent factors for further splitting or not splitting add up to one.

The shower cross section can then be formulated in a probabilistic way. The Sudakov form factor $\Delta_i(t_2, t_1)$ is interpreted as the probability for a splitting not to occur, for a parton of type i, starting from a branching vertex at the scale t_1 , down to a scale t_2 . Notice that $0 < \Delta_i(t_2, t_1) \le 1$, where the upper extreme is reached for $t_2 = t_1$, and the lower extreme is approached for $t_2 = t_0$. From Eq. (38.4), it seems that the Sudakov form factor should vanish if $t_2 = 0$. However, because of the presence of the running coupling in the integrand, t_2 cannot be taken smaller than some cutoff scale of the order of Λ , so that at its lower extreme the Sudakov form factor is small, but not zero. Event generation then proceeds as follows. One gets a uniform random number $0 \le r \le 1$, and seeks a solution of the equation $r = \Delta_i(t_2, t_1)$ as a function of t_2 . If r is too small and no solution exists, no splitting is generated, and the line is interpreted as a final parton. If a solution t_2 exists, a branching is generated at the scale t_2 . Its z value and the final parton species jk are generated with a probability proportional to $P_{i,jk}(z)$. The azimuth is generated uniformly. This procedure is started with both the initial quark and the antiquark, and is applied recursively to all generated partons, thus producing two shower cascades. It may generate an arbitrary number of partons, and it stops when no final-state partons undergo further splitting.

We emphasize that the shower cross section described above can be derived from perturbative QCD by keeping only the collinear-dominant real and virtual contributions to the cross section. In particular, up to terms that vanish after azimuthal averaging, the product of the cross section for the basic process, times the factors

$$\frac{\alpha_{\rm S}}{2\pi} \frac{dt}{t} dz \frac{d\phi}{2\pi} P_{i,jk}(z) \tag{38.7}$$

at each branching vertex, gives the leading collinear contribution to the tree-level cross section for the same process. The dominant virtual corrections in the same approximation are provided by the running coupling at each vertex and by the Sudakov form factors in the intermediate lines. 38.1.1. Angular correlations: In gluon splitting processes $(q \to q\bar{q}, q \to qq)$ in the collinear approximation, the distribution of the split pair is not uniform in azimuth, and the Altarelli-Parisi splitting functions are recovered only after azimuthal averaging. This dependence is due to the interference of positive and negative helicity states for the gluon that undergoes splitting. Spin correlations propagate through the splitting process, and determine acausal correlations of the EPR kind [10]. A method to partially account for these effects was introduced in Ref. 11, in which the azimuthal correlation between two successive splittings is computed by averaging over polarizations. This can then be applied at each branching step. Acausal correlations are argued to be small, and are discarded with this method, that is still used in the PYTHIA code [139]. A method that fully includes spin correlation effects was later proposed by Collins [12], and has been implemented in the fortran HERWIG code [13].

38.1.2. *Initial-state radiation*: Initial-state radiation (ISR) arises because incoming charged particles can radiate before entering the hard-scattering process. In doing so, they acquire a non-vanishing transverse momentum, and their virtuality becomes negative (spacelike). The dominant logarithmic region is the collinear one, where virtualities become larger and larger in absolute value with each emission, up to a limit given by the hardness of the basic process itself. A shower that starts by considering the highest virtualities first would thus have to work backward in time for ISR. A corresponding backwards-evolution algorithm was formulated by Sjöstrand [14], and was basically adopted in all shower models.

The key point in backwards evolution is that the evolution probability depends on the amount of partons that could have given rise to the one being evolved. This is reflected by introducing the ratio of the PDF after the branching to the PDF before the branching in the definition of the backward-evolution Sudakov form factor,

$$\Delta_i^{\text{ISR}}(t, t') = \exp\left[-\int_{t'}^t \frac{dt''}{t''} \frac{\alpha_{\text{S}}(t'')}{2\pi} \int_x^1 \frac{dz}{z} \sum_{jk} P_{j,ik}(z) \frac{f_j(t'', x/z)}{f_i(t'', x)}\right].$$
(38.8)

Notice that there are two uses of the PDFs: they are used to compute the cross section for the basic hard process, and they control ISR via backward evolution. Since the evolution is generated with leading-logarithmic accuracy, it is acceptable to use two different PDF sets for these two tasks, provided they agree at the LO level.

In the context of GPMC evolution, each ISR emission generates a finite amount of transverse momentum. Details on how the recoils generated by these transverse "kicks" are distributed among other partons in the event, in particular the ones involved in the hard process, constitute one of the main areas of difference between existing algorithms, see Ref. 15. An additional $\mathcal{O}(1\,\mathrm{GeV})$ of "primordial k_T " is typically added, to represent the sum of unresolved and/or non-perturbative motion below the shower cutoff scale.

38.1.3. Soft emissions and QCD coherence: In massless field theories like QCD, there are two sources of large logarithms of infrared origin. One has to do with collinear singularities, which arise when two final-state particles become collinear, or when a final-state particle becomes collinear to an initial-state one. The other has to do with the emission of soft gluons at arbitrary angles. Because of that, it turns out that in QCD perturbation theory two powers of large logarithms can arise for each power of $\alpha_{\rm S}$. The expansion in leading soft and collinear logarithms is often referred to as the double-logarithmic expansion.

Within the conventional parton-shower formalism, based on collinear factorization, it was shown in a sequel of publications (see Ref. 16 and references therein) that the double-logarithmic region can be correctly described by using the angle of the emissions as the ordering variable, rather than the virtuality, and that the argument of $\alpha_{\rm S}$ at the splitting vertex should be the relative parton transverse momentum after the splitting. Physically, the ordering in angle approximates the coherent interference arising from large-angle soft emission from a bunch of collinear partons. Without this effect,

the particle multiplicity would grow too rapidly with energy, in conflict with e^+e^- data. For this reason, angular ordering is used as the evolution variable in both the HERWIG [16] and HERWIG++ [17] programs, and an angular veto is imposed on the virtuality-ordered evolution in PYTHIA 6 [18].

A radical alternative formulation of QCD cascades first proposed in Ref. 19 focuses upon soft emission, rather than collinear emission, as the basic splitting mechanism. It then becomes natural to consider a branching process where it is a parton pair (i.e. a dipole) rather than a single parton, that emits a soft parton. Adding a suitable correction for non-soft, collinear partons, one can achieve in this framework the correct logarithmic structure for both soft and collinear emissions in the limit of large number of colors N_c , without any explicit angular-ordering requirement. The ARIADNE [20] and VINCIA [21] programs are based on this approach. In SHERPA, the default shower [22] is also of a dipole type [23], while the p_{\perp} -ordered showers in PYTHIA 6 and 8 represent a hybrid, combining collinear splitting kernels with dipole kinematics [24].

38.1.4. Massive quarks: Quark masses act as cut-off on collinear singularities. If the mass of a quark is below, or of the order of Λ , its effect in the shower is small. For larger quark masses, like in c or b production, it is the mass, rather than the typical hadronic scale, that cuts off collinear radiation. For a quark with energy E and mass m_Q , the divergent behavior $d\theta/\theta$ of the collinear splitting process is regulated for $\theta \leq \theta_0 = m_Q/E$. We thus expect less collinear activity for heavy quarks than for light ones, which in turn is the reason why heavy quarks carry a larger fraction of the momentum acquired in the hard production process.

This feature can be implemented with different levels of sophistication. Using the fact that soft emission exhibits a zero at zero emission angle, older parton shower algorithms simply limited the shower emission to be not smaller than the angle θ_0 . More modern approaches are used in both PYTHIA, where mass effects are included using a kind of matrix-element correction method [25], and in HERWIG++ and SHERPA, where a generalization of the Altarelli-Parisi splitting kernel is used for massive quarks [26].

38.1.5. Color information: Shower MC generators track large- N_c color information during the development of the shower. In the large- N_c limit, a quark is represented by a color line, i.e. a line with an arrow in the direction of the shower development, an antiquark by an anticolor line, with the arrow in the opposite direction, and a gluon by a pair of color-anticolor lines. The rules for color propagation are:

At the end of the shower development, partons are connected by color lines. We can have a quark directly connected by a color line to an antiquark, or via an arbitrary number of intermediate gluons, as shown in Fig. 38.1.

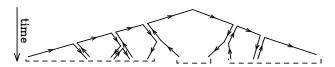


Figure 38.1: Color development of a shower in e^+e^- annihilation. Systems of color-connected partons are indicated by the dashed lines.

It is also possible for a set of gluons to be connected cyclically in color, as e.g. in the decay $\Upsilon \to ggg$.

The color information is used in angular-ordered showers, where the angle of color-connected partons determines the initial angle for the shower development, and in dipole showers, where dipoles are always color-connected partons. It is also used in hadronization models, where the initial strings or clusters used for hadronization are formed by systems of color-connected partons.

38.1.6. Electromagnetic corrections: The physics of photon emission from light charged particles can also be treated with a shower MC algorithm. A high-energy electron, for example, is accompanied by bremsstrahlung photons, which considerably affect its dynamics. Also here, similarly to the QCD case, electromagnetic corrections are of order $\alpha_{\rm em} \ln Q/m_e$, or even of order $\alpha_{\rm em} \ln Q/m_e \ln E_{\gamma}/E$ in the region where soft photon emission is important, so that their inclusion in the simulation process is mandatory. This can be done with a Monte Carlo algorithm. In case of photons emitted by leptons, at variance with the QCD case, the shower can be continued down to values of the lepton virtuality that are arbitrarily close to its mass shell. In practice, photon radiation must be cut off below a certain energy, in order for the shower algorithm to terminate. Therefore, there is always a minimum energy for emitted photons that depends upon the implementations (and so does the MC truth for a charged lepton). In the case of electrons, this energy is typically of the order of its mass. Electromagnetic radiation below this scale is not enhanced by collinear singularities, and is thus bound to be soft, so that the electron momentum is not affected by it.

For photons emitted from quarks, we have instead the obvious limitation that the photon wavelength cannot exceed the typical hadronic size. Longer-wavelength photons are in fact emitted by hadrons, rather than quarks. This last effect is in practice never modeled by existing shower MC implementations. Thus, electromagnetic radiation from quarks is cut off at a typical hadronic scale

38.1.7. Beyond-the-Standard-Model Physics: The inclusion of processes for physics beyond the Standard Model (BSM) in event generators is to some extent just a matter of implementing the relevant hard processes and (chains of) decays, with the level of difficulty depending on the complexity of the model and the degree of automation [27,28]. Notable exceptions are long-lived colored particles [29], particles in exotic color representations, and particles showering under new gauge symmetries, with a growing set of implementations documented in the individual GPMC manuals. Further complications that may be relevant are finite-width effects (discussed in Sec. 38.1.8) and the assumed threshold behavior.

In addition to code-specific implementations [15], there are a few commonly adopted standards that are useful for transferring information and events between codes. Currently, the most important of these is the Les Houches Event File (LHEF) standard [30], normally used to transfer parton-level events from a hard-process generator to a shower generator. Another important standard is the Supersymmetry Les Houches Accord (SLHA) format [31], originally used to transfer information on supersymmetric particle spectra and couplings, but by now extended to apply also to more general BSM frameworks and incorporated within the LHEF standard [32].

38.1.8. Decay Chains and Particle Widths: In most BSM processes and some SM ones, an important aspect of the event simulation is how decays of short-lived particles, such as top quarks, electroweak and Higgs bosons, and new BSM resonances, are handled. We here briefly summarize the spectrum of possibilities, but emphasize that there is no universal standard. Users are advised to check whether the treatment of a given code is adequate for the physics study at hand.

The appearance of an unstable resonance as a physical particle at some intermediate stage of the event generation implies that its production and decay processes are treated as being factorized. This is valid up to corrections of order Γ/m_0 , with Γ the width and m_0 the pole mass. States whose widths are a substantial fraction of their mass should not be treated as "physical particles," but rather as intrinsically off-shell internal propagator lines.

For states treated as physical particles, two aspects are relevant: the mass distribution of the decaying particle itself and the distributions of its decay products. For the former, matrix-element generators often use a simple δ function at m_0 . The next level up, typically used in GPMCs, is to use a Breit-Wigner distribution (relativistic or non-relativistic), which formally resums higher-order virtual corrections to the mass distribution. Note, however, that this still only generates an

improved picture for moderate fluctuations away from m_0 . Similarly to above, particles that are significantly off-shell (in units of Γ) should not be treated as resonant, but rather as internal off-shell propagator lines. In most GPMCs, further refinements are included, for instance by letting Γ be a function of m ("running widths") and by limiting the magnitude of the allowed fluctuations away from m_0 .

For the distributions of the decay products, the simplest treatment is again to assign them their respective m_0 values, with a uniform phase-space distribution. A more sophisticated treatment distributes the decay products according to the differential decay matrix elements, capturing at least the internal dynamics and helicity structure of the decay process, including EPR-like correlations. Further refinements include polarizations of the external states [33] and assigning the decay products their own Breit-Wigner distributions, the latter of which opens the possibility to include also intrinsically off-shell decay channels, like $H \to WW^*$.

During subsequent showering of the decay products, most partonshower models will preserve their total invariant mass, so as not to skew the original resonance shape.

When computing partial widths and/or modifying decay tables, one should be aware of the danger of double-counting intermediate on-shell particles, see Sec. 38.2.3.

38.1.9. *Matching with Matrix Elements*: Shower algorithms are based upon a combination of the collinear (small-angle) and soft (small-energy) approximations and are thus inaccurate for hard, large-angle emissions. They also lack next-to-leading order (NLO) corrections to the basic process.

Traditional GPMCs, like HERWIG and PYTHIA, have included for a long time the so called Matrix Element Corrections (MEC), first formulated in Ref. 34 with later developments summarized in Ref. 15. They are available for processes involving two incoming and one outgoing or one incoming and two outgoing particles, like DIS, vector boson and Higgs production and decays, and top decays. The MEC corrects the emission of the hardest jets at large angles, so that it becomes exact at leading order.

In the past decade, considerable progress has taken place in order to improve the parton shower description of hard collisions, in two different directions: the so called Matrix Elements and Parton Shower matching (ME+PS from now on), and the matching of NLO calculations and Parton Showers (NLO+PS).

The ME+PS method allows one to use tree-level matrix elements for hard, large-angle emissions. It was first formulated in the so-called CKKW paper [35], and several variants have appeared, including the CKKW-L, MLM, and pseudoshower methods, see Refs. 36, 15 for summaries. Truncated showers are required [37] in order to maintain color coherence when interfacing matrix-element calculations to angular-ordered parton showers using these methods. It is also important to ensure consistent $\alpha_{\rm S}$ choices between the real (ME-driven) and virtual (PS-driven) corrections [38].

In the ME+PS method one typically starts by generating exact matrix elements for the production of the basic process plus a certain number $\leq n$ of other partons. A minimum separation is imposed on the produced partons, requiring, for example, that the relative transverse momentum in any pair of partons is above a given cut $Q_{\rm cut}$. One then reweights these amplitudes in such a way that, in the strongly ordered region, the virtual effects that are included in the shower algorithm (i.e. running couplings and Sudakov form factors) are also accounted for. At this stage the generated configurations are tree-level accurate at large angle, and at small angle they match the results of the shower algorithm, except that there are no emissions below the scale Q_{cut} , and no final states with more than n partons. These kinematic configurations are thus fed into a GPMC, that must generate all splittings with relative transverse momentum below the scale Q_{cut} , for initial events with less than n partons, or below the scale of the smallest pair transverse momentum, for events with exactly n partons. The matching parameter Q_{cut} must be chosen to be large enough for fixed-order perturbation theory to hold, but small enough so that the shower is accurate for emissions below it. Notice that the accuracy achieved with MEC is equivalent to that of ME+PS with n=1, where MEC has the advantage of not having a matching parameter $Q_{\mathrm{cut}}.$

The popularity of the ME+PS method is due to the fact that processes with many jets appear often as background of new physics searches. These jets are typically required to be well separated, and to have large transverse momenta. These kinematical configurations, away from the small-angle region, are precisely those where GPMCs fail to be accurate, and it is thus mandatory to describe them using exact tree-level matrix element calculations.

The NLO+PS methods extend the accuracy of the generation of the basic process at the NLO level in QCD. They must thus include the radiation of an extra parton with full tree-level accuracy, since this radiation constitutes a NLO correction to the basic process. They must also include NLO virtual corrections. They can be viewed as an extension of the MEC method with the inclusion of NLO virtual corrections. They are however more general, since they are applicable to processes of arbitrary complexity. Two of these methods are now widely used: MC@NLO [39] and POWHEG [37,40], with several alternative methods now also being pursued, see Ref. 15 and references therein.

NLO+PS generators should produce NLO accurate distributions for inclusive quantities, and should generate the hardest jet with tree-level accuracy even at large angle. It should be recalled, though, that in $2 \to 1$ processes like Z/W production, GPMCs including MEC and weighted by a constant K factor may perform nearly as well, and, if suitably tuned, may even yield a better description of data. It may thus be wise to consider tuning also the NLO+PS generators for these processes.

ME+PS generators should be preferred over NLO+PS ones when one needs an accurate description of hard, large-angle emissions, beyond the hardest jet. Attempts to merge ME+PS and NLO+PS, in order to get event samples that have the advantage of both methods have appeared, see Refs. 41, 15, and references therein.

Several ME+PS implementations use existing LO generators, like ALPGEN [42], MADGRAPH [43], and others summarized in Ref. 36, for the calculation of the matrix element, and feed the partonic events to a GPMC like PYTHIA or HERWIG using the Les Houches Interface for User Processes (LHI/LHEF) [44,30]. SHERPA and HERWIG++ also include their own matrix-element generators and matching algorithms.

Several NLO+PS processes are implemented in the MC@NLO program [39], together with the new AMC@NLO development [45], and in the POWHEG BOX framework [40]. Again, SHERPA and HERWIG++, also include their own POWHEG implementation, suitably adapted with the inclusion of vetoed and truncated showers, for several processes.

38.2. Hadronization Models

In the context of event generators, hadronization denotes the process by which a set of colored partons (after showering) is transformed into a set of color-singlet primary hadrons, which may then subsequently decay further. This non-perturbative transition takes place at the $hadronization\ scale\ Q_{\rm had}$, which by construction is identical to the infrared cutoff of the parton shower. In the absence of a first-principles solution to the relevant dynamics, event generators use QCD-inspired phenomenological models to describe this transition.

A key difference between MC hadronization models and the fragmentation-function (FF) formalism used to describe inclusive hadron spectra in perturbative QCD (see Chap. 9 of PDG book) is that the former is always defined at the hadronization scale, while the latter can be defined at an arbitrary perturbative scale Q. They can therefore only be compared directly if the perturbative evolution between Q and $Q_{\rm had}$ is taken into account. FFs are calculable in pQCD, given a non-perturbative initial condition obtained by fits to hadron spectra. In the MC context, one can prove that the correct QCD evolution of the FFs arises from the shower formalism, with the hadronization model providing an explicit parametrization of the non-perturbative component. It should be kept in mind, however, that the MC modeling of shower and hadronization includes much more information on the final state since it is fully exclusive (i.e., it addresses all particles in the final state explicitly), while FFs only describe inclusive spectra. This exclusivity also enables MC models to make use of the color-flow information coming from the perturbative shower evolution (see Sec. 38.1.5) to determine between which partons the confining potentials should arise.

If one had an exact hadronization model, its dependence upon the hadronization scale $Q_{\rm had}$ would be compensated by the corresponding scale dependence of the shower algorithm, which stops generating branchings at the scale $Q_{\rm had}$. However, due to their complicated and fully exclusive nature, it is generally not possible to enforce this compensation automatically in MC models of hadronization. One must therefore be aware that the model must be "retuned" by hand if changes are made to the perturbative evolution, in particular if the infrared cutoff is modified. Tuning is discussed briefly in Sec. 38.4.

An important result in "quenched" lattice QCD (see Chap. 17 of PDG book) is that the potential of the color-dipole field between a charge and an anticharge appears to grow linearly with the separation of the charges, at distances greater than about a femtometer. This is known as "linear confinement", and it forms the starting point for the *string model of hadronization*, discussed below in Sec. 38.2.1. Alternatively, a property of perturbative QCD called "preconfinement" is the basis of the *cluster model of hadronization*, discussed in Sec. 38.2.2.

Finally, it should be emphasized that the so-called "parton level" that can be obtained by switching off hadronization in a GPMC, is not a universal concept, since each model defines the hadronization scale differently (e.g. by a cutoff in p_{\perp} , invariant mass, etc., with different tunes using different values for the cutoff). Comparisons to distributions at this level may therefore be used to provide an idea of the overall impact of hadronization corrections within a given model, but should be avoided in the context of physical observables.

38.2.1. The String Model: Starting from early concepts [46], several hadronization models based on strings have been proposed [15]. Of these, the most widely used today is the so-called Lund model [47,48], implemented in PYTHIA [139,140]. We concentrate on that particular model here, though many of the overall concepts would be shared by any string-inspired method.

Consider a color-connected quark-antiquark pair with no intermediate gluons emerging from the parton shower (like the $\bar{q}q$ pair in the center of Fig. 38.1), e.g. a red q and an antired \bar{q} . As the charges move apart, linear confinement implies that a potential $V(r)=\kappa\,r$ is reached for large distances r. (At short distances, there is a Coulomb term $\propto 1/r$ as well, but this is neglected in the Lund string.) This potential describes a string with tension $\kappa \sim 1\,\mathrm{GeV/fm} \sim 0.2\,\mathrm{GeV^2}$. The physical picture is that of a color flux tube being stretched between the q and the \bar{q} .

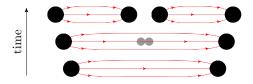


Figure 38.2: Illustration of string breaking by quark paircreation in the string field.

As the string grows, the non-perturbative creation of quark-antiquark pairs can break the string, via the process $(q\bar{q}) \rightarrow (q\bar{q}') + (q'\bar{q})$, illustrated in Fig. 38.2. More complicated color-connected quark-antiquark configurations involving intermediate gluons (like the $\bar{q}gggq$ and $\bar{q}gq$ systems on the left and right part of Fig. 38.1) are treated by representing gluons as transverse "kinks." Thus soft gluons effectively build up a transverse structure in the originally one-dimensional object, with infinitely soft ones smoothly absorbed into the string. For strings with finite-energy kinks, the space-time evolution is slightly more involved [48], but the main point is that there are no separate free parameters for gluon jets. Differences with respect to quark fragmentation arise simply because quarks are only connected to a single string piece, while gluons have one on either side, increasing their relative energy loss (per unit

invariant time) by a factor of 2, similar to the ratio of color Casimirs $C_A/C_F=2.25.$

Since the string breaks are causally disconnected (as can be realized from space-time diagrams [48]), they do not have to be considered in any specific time-ordered sequence. In the Lund model, the string breaks are generated starting with the leading ("outermost") hadrons, containing the endpoint quarks, and iterating inwards towards the center of the string, alternating randomly between the left and right sides. One can thereby split off a single on-shell hadron in each step, making it straightforward to ensure that only states consistent with known hadron states are produced.

For each breakup vertex, quantum mechanical tunneling is assumed to control the masses and p_{\perp} kicks that can be produced, leading to a Gaussian suppression

$$\operatorname{Prob}(m_q^2, p_{\perp q}^2) \propto \exp\left(\frac{-\pi m_q^2}{\kappa}\right) \exp\left(\frac{-\pi p_{\perp q}^2}{\kappa}\right) ,$$
 (38.10)

where m_q is the mass of the produced quark flavor and p_\perp is the non-perturbative transverse momentum imparted to it by the breakup process (the antiquark has the same mass and opposite p_\perp), with a universal average value of $\left\langle p_{\perp q}^2 \right\rangle = \kappa/\pi \sim (250\,\mathrm{MeV})^2$. The charm and bottom masses are sufficiently heavy that they are not produced at all in the soft fragmentation. The transverse direction is defined with respect to the string axis, so the p_\perp in a frame where the string is moving will be modified by a Lorentz boost. Note that the effective amount of "non-perturbative" p_\perp , in a Monte Carlo model with a fixed shower cutoff $Q_{\rm had}$, may be larger than the purely non-perturbative κ/π above, to account for effects of additional unresolved soft-gluon radiation below $Q_{\rm had}$. In principle, the magnitude of this additional component should scale with the cutoff, but in practice it is up to the user to enforce this by retuning the relevant parameter when changing the hadronization scale.

Since quark masses are difficult to define for light quarks, the value of the strangeness suppression is determined from experimental observables, such as the K/π and K^*/ρ ratios. The partonshower evolution generates a small amount of strangeness as well, through perturbative $g \to s\bar{s}$ splittings. The optimal value for the non-perturbative 2s/(u+d) ratio should therefore exhibit a mild anticorrelation with the amount of quarks produced in the perturbative stage.

Baryon production can also be incorporated, by allowing string breaks to produce pairs of diquarks, loosely bound states of two quarks in an overall $\bar{3}$ representation. Again, since diquark masses are difficult to define, the relative rate of diquark to quark production is extracted, e.g. from the p/π ratio, and since the perturbative shower splittings do not produce diquarks, the effective value for this parameter is mildly correlated with the amount of $g \to q\bar{q}$ splittings occurring on the shower side. More advanced scenarios for baryon production have also been proposed, see Ref. 48. Within the PYTHIA framework, a fragmentation model including baryon string junctions [49] is also available.

The next step of the algorithm is the assignment of the produced quarks within hadron multiplets. Using a nonrelativistic classification of spin states, the fragmenting q may combine with the \vec{q}' from a newly created breakup to produce a meson — or baryon, if diquarks are involved — of a given valence quark spin S and angular momentum L. The lowest-lying pseudoscalar and vector meson multiplets, and spin-1/2 and -3/2 baryons, are assumed to dominate in a string framework¹, but individual rates are not predicted by the model. This is therefore the sector that contains the largest amount of free parameters.

 $^{^{1}}$ The PYTHIA implementation includes the lightest pseudoscalar and vector mesons, with the four L=1 multiplets (scalar, tensor, and 2 pseudovectors) available but disabled by default, largely because several states are poorly known and thus may result in a worse overall description when included. For baryons, the lightest spin-1/2 and -3/2 multiplets are included.

From spin counting, the ratio V/P of vectors to pseudoscalars is expected to be 3, but in practice this is only approximately true for B mesons. For lighter flavors, the difference in phase space caused by the V-P mass splittings implies a suppression of vector production. When extracting the corresponding parameters from data, it is advisable to begin with the heaviest states, since so-called feed-down from the decays of higher-lying hadron states complicates the extraction for lighter particles, see Sec. 38.2.3. For diquarks, separate parameters control the relative rates of spin-1 diquarks vs. spin-0 ones and, likewise, have to be extracted from data.

With p_{\perp}^2 and m^2 now fixed, the final step is to select the fraction, z, of the fragmenting endpoint quark's longitudinal momentum that is carried by the created hadron, an aspect for which the string model is highly predictive. The requirement that the fragmentation be independent of the sequence in which breakups are considered (causality) imposes a "left-right symmetry" on the possible form of the fragmentation function, f(z), with the solution

$$f(z) \propto \frac{1}{z} (1-z)^a \exp\left(-\frac{b(m_h^2 + p_{\perp h}^2)}{z}\right)$$
, (38.11)

which is known as the Lund symmetric fragmentation function (normalized to unit integral). The dimensionless parameter a dampens the hard tail of the fragmentation function, towards $z \to 1$, and may in principle be flavor-dependent, while b, with dimension GeV^{-2} , is a universal constant related to the string tension [48] which determines the behavior in the soft limit, $z \to 0$. Note that the explicit mass dependence in f(z) implies a harder fragmentation function for heavier hadrons (in the rest frame of the string).

As a by-product, the probability distribution in invariant time τ of $q'\bar{q}$ breakup vertices, or equivalently $\Gamma=(\kappa\tau)^2$, is also obtained, with $dP/d\Gamma \propto \Gamma^a \exp(-b\Gamma)$ implying an area law for the color flux, and the average breakup time lying along a hyperbola of constant invariant time $\tau_0 \sim 10^{-23} {\rm s}$ [48].

For massive endpoints (e.g. c and b quarks, or hypothetical hadronizing new-physics particles), which do not move along straight lightcone sections, the exponential suppression with string area leads to modifications of the form $f(z) \to f(z)/z^{bm_Q^2}$, with m_Q the mass of the heavy quark [50]. Although different forms can also be used to describe inclusive heavy-meson spectra (see Sec 19.9 of PDG book), such choices are not consistent with causality in the string framework and hence are theoretically disfavored in this context, one well-known example being the Peterson formula [51],

$$f(z) \propto \frac{1}{z} \left(1 - \frac{1}{z} - \frac{\epsilon_Q}{1 - z} \right)^{-2} ,$$
 (38.12)

with ϵ_Q a free parameter expected to scale $\propto 1/m_Q^2$.

38.2.2. The Cluster Model: The cluster hadronization model is based on preconfinement, i.e., on the observation [52,53] that the color structure of a perturbative QCD shower evolution at any scale Q_0 is such that color-singlet subsystems of partons (labeled "clusters") occur with a universal invariant mass distribution that only depends on Q_0 and on $\Lambda_{\rm QCD}$, not on the starting scale Q, for $Q\gg Q_0\gg \Lambda_{\rm QCD}$. Further, this mass distribution is power-suppressed at large masses.

Following early models based on this universality [8,54], the cluster model developed by Webber [55] has for many years been a hallmark of the HERWIG and HERWIG++ generators, with an alternative implementation [56] now available in the SHERPA generator. The key idea, in addition to preconfinement, is to force "by hand" all gluons to split into quark-antiquark pairs at the end of the parton shower. Compared with the string description, this effectively amounts to viewing gluons as "seeds" for string breaks, rather than as kinks in a continuous object. After the splittings, a new set of low-mass color-singlet clusters is obtained, formed only by quark-antiquark pairs. These can be decayed to on-shell hadrons in a simple manner.

The algorithm starts by generating the forced $g \to q\bar{q}$ breakups, and by assigning flavors and momenta to the produced quark pairs. For a typical shower cutoff corresponding to a gluon virtuality

of $Q_{\rm had} \sim 1\,{\rm GeV}$, the p_{\perp} generated by the splittings can be neglected. The constituent light-quark masses, $m_{u,d} \sim 300\,{\rm MeV}$ and $m_s \sim 450\,{\rm MeV}$, imply a suppression (typically even an absence) of strangeness production. In principle, the model also allows for diquarks to be produced at this stage, but due to the larger constituent masses this would only become relevant for shower cutoffs larger than $1\,{\rm GeV}$

If a cluster formed in this way has an invariant mass above some cutoff value, typically 3–4 GeV, it is forced to undergo sequential $1 \rightarrow 2$ cluster breakups, along an axis defined by the constituent partons of the original cluster, until all sub-cluster masses fall below the cutoff value. Due to the preservation of the original axis in these breakups, this treatment has some resemblance to the string-like picture.

Next, on the low-mass side of the spectrum, some clusters are allowed to decay directly to a single hadron, with nearby clusters absorbing any excess momentum. This improves the description of the high-z part of the fragmentation spectrum — where the hadron carries almost all the momentum of its parent jet — at the cost of introducing one additional parameter, controlling the probability for single-hadron cluster decay.

Having obtained a final distribution of small-mass clusters, now with a strict cutoff at 3-4 GeV and with the component destined to decay to single hadrons already removed, the remaining clusters are interpreted as a smoothed-out spectrum of excited mesons, each of which decays isotropically to two hadrons, with relative probabilities proportional to the available phase space for each possible two-hadron combination that is consistent with the cluster's internal flavors, including spin degeneracy. It is important that all the light members (containing only uds) of each hadron multiplet be included, as the absence of members can lead to unphysical isospin or SU(3) flavor violation. Typically, the lightest pseudoscalar, vector, scalar, even and odd charge conjugation pseudovector, and tensor multiplets of light mesons are included. In addition, some excited vector multiplets of light mesons may be available. For baryons, usually only the lightest octet, decuplet and singlet baryons are present, although both the HERWIG++ and SHERPA implementations now include some heavier baryon multiplets as well.

Contrary to the case in the string model, the mechanism of phase-space suppression employed here leads to a natural enhancement of the lighter pseudoscalars, and no parameters beyond the spectrum of hadron masses need to be introduced at this point. The phase space also limits the transverse momenta of the produced hadrons relative to the jet axis.

Note that, since the masses and decays of excited heavy-flavor hadrons in particular are not well known, there is some freedom in the model to adjust these, which in turn will affect their relative phase-space populations.

38.2.3. Hadron and τ Decays: Of the so-called primary hadrons, originating directly from string breaks and/or cluster decays (see above), many are unstable and so decay further, until a set of particles is obtained that can be considered stable on time scales relevant to the given measurement². The decay modeling can therefore have a significant impact on final particle yields and spectra, especially for the lowest-lying hadronic states, which receive the largest relative contributions from decays (feed-down). Note that the interplay between primary production and feed-down implies that the hadronization parameters should be retuned if significant changes to the decay treatment are made.

Particle summary tables, such as those given elsewhere in this *Review*, represent a condensed summary of the available experimental measurements and hence may be incomplete and/or exhibit inconsistencies within the experimental precision. In an MC decay package, on the other hand, all information must be quantified and consistent, with all branching ratios summing to unity.

² E.g., a typical hadron-collider definition of a "stable particle" is $c\tau \geq 10 \text{ mm}$, which includes the weakly-decaying strange hadrons $(K, \Lambda, \Sigma^{\pm}, \bar{\Sigma}^{\pm}, \Xi, \Omega)$.

When adapting particle summary information for use in a decay package, a number of choices must therefore be made. The amount of ambiguity increases as more excited hadron multiplets are added to the simulation, about which less and less is known from experiment, with each GPMC making its own choices.

A related choice is how to distribute the decay products differentially in phase space, in particular which matrix elements to use. Historically, MC generators contained matrix elements only for selected (generator-specific) classes of hadron and τ decays, coupled with a Breit-Wigner smearing of the masses, truncated at the edges of the physical decay phase space (the treatment of decay thresholds can be important for certain modes [15]) . A more sophisticated treatment can then be obtained by reweighting the generated events using the obtained particle four-momenta and/or by using specialized external packages such as EVTGEN [57] for hadron decays and TAUOLA [58] for τ decays.

More recently, HERWIG++ and SHERPA include helicity-dependence in τ decays [59,60], with a more limited treatment available in PYTHIA 8 [140]. The HERWIG++ and SHERPA generators have also included significantly improved internal simulations of hadronic decays, which include spin correlations between those decays for which matrix elements are used.

HERWIG++ and PYTHIA include the probability for B mesons to oscillate into \bar{B} ones before decay. SHERPA and EVTGEN also include CP-violating effects and, for common decay modes of the neutral meson and its antiparticle, the interference between the direct decay and oscillation followed by decay.

We end on a note of warning on double counting. This may occur if a particle can decay via an intermediate on-shell resonance. An example is $a_1 \to \pi\pi\pi$ which may proceed via $a_1 \to \rho\pi$, $\rho \to \pi\pi$. If these decay channels of the a_1 are both included, each with their full partial width, a double counting of the on-shell $a_1 \to \rho\pi$ contribution would result. Such cases are normally dealt with consistently in the default MC generator packages, so this warning is mostly relevant for users that wish to edit decay tables on their own.

38.3. Models for Soft Hadron-Hadron Physics

38.3.1. Minimum-Bias and Diffraction: The term "minimum bias" (MB) originates from the experimental requirement of a minimal number of tracks (or hits) in a given instrumented region. In order to make MC predictions for such observables, all possible contributions to the relevant phase-space region must be accounted for. There are essentially four types of physics processes, which together make up the total hadron-hadron (hh) cross section: 1) elastic scattering³: $hh \to hh$, 2) single diffractive dissociation: $hh \to h + \text{gap} + X$, with X denoting anything that is not the original beam particle, and "gap" denoting a rapidity region devoid of observed activity; 3) double diffractive dissociation: $hh \to X + \text{gap} + X$, and 4) inelastic non-diffractive scattering: everything else. A fifth class may also be defined, called central diffraction $(hh \rightarrow h + \text{gap} + X + \text{gap} + h)$. Some differences exist between theoretical and experimental terminology [61]. In the experimental setting, diffraction is defined by an observable gap, of some minimal size in rapidity. In the MC context, each diffractive physics process typically produces a whole spectrum of gaps, with small ones suppressed but not excluded.

The inelastic non-diffractive part of the cross section is typically modeled either by smoothly regulating and extending the perturbative QCD scattering cross sections all the way to zero p_{\perp} [62] (PYTHIA 6, PYTHIA 8, and SHERPA), or by regulating the QCD cross sections with a sharp cutoff [63](HERWIG+JIMMY) and adding a separate class of intrinsically soft scatterings below that scale [64](HERWIG++). See also Sec. 38.3.2. In all cases, the three most important ingredients are: 1) the IR regularization of the perturbative scattering cross sections, including their PDF dependence, 2) the assumed matter distribution of the colliding hadrons, possibly including multi-parton correlations [49] and/or x dependence [65], and 3) additional soft-QCD effects

such as color reconnections and/or other collective effects, discussed in Sec. 38.3.3.

Currently, there are essentially three methods for simulating diffraction in the main MC models: 1) in PYTHIA 6, one picks a diffractive mass according to parametrized cross sections \propto dM^2/M^2 [66]. This mass is represented as a string, which is fragmented as described in Sec. 38.2.1, though differences in the effective scale of the hadronization may necessitate a (re)tuning of the fragmentation parameters for diffraction; 2) in PYTHIA 8, the high-mass tail beyond $M \sim 10\,\mathrm{GeV}$ is augmented by a partonic description in terms of pomeron PDFs [67], allowing diffractive jet production including showers and underlying event [68]; 3) the PHOJET and DPMJET programs also include central diffraction and rely directly on a formulation in terms of pomerons (color-singlet multi-gluon states) [69–71]. Cut pomerons correspond to exchanges of soft gluons while uncut ones give elastic and diffractive topologies as well as virtual corrections that help preserve unitarity. So-called "hard pomerons" provide a transition to the perturbative regime. Fragmentation is still handled using the Lund string model, so there is some overlap with the above models at the hadronization stage. In addition, a pomeron-based package exists for HERWIG [72], and an effort is underway to construct an MC implementation of the "KMR" model [73] within the SHERPA generator. Color reconnections (Sec. 38.3.3) may also play a role in creating rapidity gaps and the underlying event (Sec. 38.3.2) in destroying them.

38.3.2. Underlying Event and Jet Pedestals: In the event-generator context, the term underlying event (UE) denotes any additional activity beyond the basic process and its associated ISR and FSR activity. The dominant contribution to this is believed to come from additional color exchanges between the beam particles, which can be represented either as multiple parton-parton interactions (MPI) or as so-called cut pomerons (Sec. 38.3.1). The experimentally observed fact that the UE is more active than MB events at the same CM energy is called the "jet pedestal" effect.

The most easily identifiable consequence of MPI is arguably the possibility of observing several hard parton-parton interactions in one and the same hadron-hadron event. This tends to produce largely uncorrelated back-to-back jet pairs, with each pair having a small value of sum(\vec{p}_{\perp}). For comparison, jets from bremsstrahlung tend to be aligned with the direction of their parent initial- or final-state partons. The fraction of MPI that give rise to additional reconstructible jets is, however, quite small. Soft interactions that do not give rise to observable jets are much more plentiful, and can give significant corrections to the color flow and total scattered energy of the event. This affects the final-state activity in a more global way, increasing multiplicity and summed E_T distributions, and contributing to the break-up of the beam remnants in the forward direction.

The first detailed Monte Carlo model for perturbative MPI was proposed in Ref. 62, and with some variation this still forms the basis for most modern implementations. Some useful additional references can be found in Ref. 15. The first crucial observation is that the t-channel propagators appearing in perturbative QCD 2 \rightarrow 2 scattering almost go on shell at low p_{\perp} , causing the differential cross sections to become very large, behaving roughly as

$$d\sigma_{2\rightarrow2} \propto \frac{dt}{t^2} \sim \frac{dp_{\perp}^2}{p_{\perp}^4}$$
 (38.13)

This cross section is an inclusive number. Thus, if a single hadron-hadron event contains two parton-parton interactions, it will "count" twice in $\sigma_{2\rightarrow 2}$ but only once in $\sigma_{\rm tot}$, and so on. In the limit that all the interactions are independent and equivalent, one would have

$$\sigma_{2\to 2}(p_{\perp \min}) = \langle n \rangle (p_{\perp \min}) \ \sigma_{\text{tot}} \ ,$$
 (38.14)

with $\langle n \rangle (p_{\perp \rm min})$ giving the average of a Poisson distribution in the number of parton-parton interactions above $p_{\perp \rm min}$ per hadron-hadron collision.

$$\mathcal{P}_n(p_{\perp \min}) = (\langle n \rangle (p_{\perp \min}))^n \frac{\exp\left(-\langle n \rangle (p_{\perp \min})\right)}{n!} . \tag{38.15}$$

 $^{^3\,}$ The QED elastic-scattering cross section diverges and is normally a non-default option in MC models.

This simple argument in fact expresses unitarity; instead of the total interaction cross section diverging as $p_{\perp \min} \to 0$ (which would violate unitarity), we have restated the problem so that it is now the number of MPI per collision that diverges, with the total cross section remaining finite. At LHC energies, the $2 \to 2$ scattering cross sections computed using the full LO QCD cross section folded with modern PDFs becomes larger than the total pp one for p_{\perp} values of order 4–5 GeV [74]. One therefore expects the average number of perturbative MPI to exceed unity at around that scale.

Two important ingredients remain to fully regulate the remaining divergence. Firstly, the interactions cannot use up more momentum than is available in the parent hadron. This suppresses the large-n tail of the estimate above. In PYTHIA-based models, the MPI are ordered in p_{\perp} , and the parton densities for each successive interaction are explicitly constructed so that the sum of x fractions can never be greater than unity. In the HERWIG models, instead the uncorrelated estimate of $\langle n \rangle$ above is used as an initial guess, but the generation of actual MPI is stopped once the energy-momentum conservation limit is reached.

The second ingredient invoked to suppress the number of interactions, at low p_{\perp} and x, is color screening; if the wavelength \sim $1/p_{\perp}$ of an exchanged colored parton becomes larger than a typical color-anticolor separation distance, it will only see an average color charge that vanishes in the limit $p_{\perp} \to 0$, hence leading to suppressed interactions. This provides an infrared cutoff for MPI similar to that provided by the hadronization scale for parton showers. A first estimate of the color-screening cutoff would be the proton size, $p_{\perp \rm min} \approx \hbar/r_p \approx 0.3\,{\rm GeV} \approx \Lambda_{\rm QCD}$, but empirically this appears to be far too low. In current models, one replaces the proton radius r_p in the above formula by a "typical color screening distance," i.e., an average size of a region within which the net compensation of a given color charge occurs. This number is not known from first principles [73] and is perceived of simply as an effective cutoff parameter. The simplest choice is to introduce a step function $\Theta(p_{\perp} - p_{\perp \min})$. Alternatively, one may note that the jet cross section is divergent like $\alpha_{\rm S}^2(p_\perp^2)/p_\perp^4$, cf. Eq. (38.13), and that therefore a factor

$$\frac{\alpha_{\rm S}^2(p_{\perp 0}^2 + p_{\perp}^2)}{\alpha_{\rm S}^2(p_{\perp}^2)} \frac{p_{\perp}^4}{(p_{\perp 0}^2 + p_{\perp}^2)^2}$$
(38.16)

would smoothly regulate the divergences, now with $p_{\perp 0}$ as the free parameter. Regardless of whether it is imposed as a smooth (PYTHIA and SHERPA) or steep (HERWIG++) function, this is effectively the main "tuning" parameter in such models.

Note that the numerical value obtained for the cross section depends upon the PDF set used, and therefore the optimal value to use for the cutoff will also depend on this choice. Note also that the cutoff does not have to be energy-independent. Higher energies imply that parton densities can be probed at smaller x values, where the number of partons rapidly increases. Partons then become closer packed and the color screening distance d decreases. The uncertainty on the energy and/or x scaling of the cutoff is a major concern when extrapolating between different collider energies [75].

We now turn to the origin of the observational fact that hard jets appear to sit on top of a higher "pedestal" of underlying activity than events with no hard jets. This is interpreted as a consequence of impact-parameter-dependence: in peripheral collisions, only a small fraction of events contain any high- p_{\perp} activity, whereas central collisions are more likely to contain at least one hard scattering; a high- p_{\perp} triggered sample will therefore be biased towards small impact parameters, b. The ability of a model to describe the shape of the pedestal (e.g. to describe both MB and UE distributions simultaneously) therefore depends upon its modeling of the b-dependence, and correspondingly the impact-parameter shape constitutes another main tuning parameter.

For each impact parameter b, the number of interactions $\tilde{n}(b)$ can then still be assumed to be distributed according to Eq. (38.15), again modulo momentum conservation, but now with the mean value of the Poisson distribution depending on impact parameter, $\langle \tilde{n}(b) \rangle$. This causes the final n-distribution (integrated over b) to be wider than a Poissonian

Finally, there are two perturbative modeling aspects which go beyond the introduction of MPI themselves: 1) parton showers off the MPI, and 2) perturbative parton-rescattering effects. Without showers, MPI models would generate very sharp peaks for backto-back MPI jets, caused by unshowered partons passed directly to the hadronization model. However, with the exception of the oldest PYTHIA6 model, all GPMC models do include such showers [15], and hence should exhibit more realistic (i.e., broader and more decorrelated) MPI jets. On the initial-state side, the main questions are whether and how correlated multi-parton densities are taken into account and, as discussed previously, how the showers are regulated at low p_{\perp} and/or low x. Although none of the MC models currently impose a rigorous correlated multi-parton evolution, all of them include some elementary aspects. The most significant for parton-level results is arguably momentum conservation, which is enforced explicitly in all the models. The so-called "interleaved" models [24] attempt to go a step further, generating an explicitly correlated multi-parton evolution in which flavor sum rules are imposed to conserve, e.g. the total numbers of valence and sea quarks [49].

Perturbative rescattering in the final state can occur if partons are allowed to undergo several distinct interactions, with showering activity possibly taking place in-between. This has so far not been studied extensively, but a first exploratory model is available [76]. In the initial state, parton rescattering/recombination effects have so far not been included in any of the GPMC models.

38.3.3. Bose-Einstein and Color-Reconnection Effects: In the context of e^+e^- collisions, Bose-Einstein (BE) correlations have mostly been discussed as a source of uncertainty on high-precision W mass determinations at LEP [77]. In hadron-hadron (and nucleus-nucleus) collisions, however, BE correlations are used extensively to study the space-time structure of hadronizing matter ("femtoscopy").

In MC models of hadronization, each string break and/or particle/cluster decay is normally factorized from all other ones. This reduces the number of variables that must be considered simultaneously, but also makes the introduction of correlations among particles from different breaks/decays intrinsically difficult to address. In the context of GPMCs, a few semi-classical models are available within the PYTHIA 6 and 8 generators [78], in which the BE effect is mimicked by an attractive interaction between pairs of identical particles in the final state, with no higher correlations included. This "force" acts after the decays of very short-lived particles, like $\rho,$ but before decays of longer-lived ones, like π^0 . The main differences between the variants of this model is the assumed shape of the correlation function and how overall momentum conservation is handled.

As discussed in Sec. 38.2, leading-color ("planar") color flows are used to set up the hadronizing systems (clusters or strings) at the hadronization stage. If the systems do not overlap significantly in space and time, subleading-color ambiguities and/or non-perturbative reconnections are expected to be small. However, if the density of displaced color charges is sufficiently high that several systems can overlap significantly, full-color and/or reconnection effects should become progressively larger.

In the specific context of MPI, a crucial question is how color is neutralized between different MPI systems, including the remnants. The large rapidity differences involved imply large invariant masses (though normally low p_{\perp}), and hence large amounts of (soft) particle production. Indeed, in the context of soft-inclusive physics, it is these "inter-system" strings/clusters that furnish the dominant particle-production mechanism, and hence their modeling is an essential part of the soft-physics description, affecting topics such as MB/UE multiplicity and p_{\perp} distributions, rapidity gaps, and precision mass measurements. A more comprehensive review of color-reconnection effects can be found in Ref. 15.

38.4. Parameters and Tuning

The achievable accuracy in GPMC models depends both on the inclusiveness of the chosen observable and on the sophistication of the simulation. An important driver for the latter is obviously the development of improved theoretical models, discussed in the preceding sections; but it also depends crucially on the available constraints on the remaining free parameters. Using existing data to constrain these is referred to as generator tuning.

Although MC models may appear to have a bewildering array of adjustable parameters, most of them only control relatively small (exclusive) details of the event generation. The majority of the (inclusive) physics is determined by only a few, very important ones, such as the value of $\alpha_{\rm S}$, in the perturbative domain, and the properties of the non-perturbative fragmentation functions, in the non-perturbative one. One may therefore take a factorized approach, first constraining the perturbative parameters and thereafter the non-perturbative ones, each ordered in a measure of their relative significance to the overall modeling.

At LO×LL, perturbation theory is doing well if it agrees with an IR safe measurement within 10%. It would therefore not make much sense to tune a GPMC beyond roughly 5% (it might even be dangerous, due to overfitting). The advent of NLO Monte Carlos may reduce this number slightly, but only for quantities for which one expects NLO precision. For LO Monte Carlos, distributions should be normalized to unity, since the NLO normalization is not tunable. For quantities governed by non-perturbative physics, uncertainties are larger. For some quantities, e.g. ones for which the underlying modeling is known to be poor, an order-of-magnitude agreement or worse may have to be accepted.

In the context of LO×LL GPMC tuning, subleading aspects of coupling-constant and PDF choices are relevant. In particular, one should be aware that the choice of QCD Λ parameter $\Lambda_{\rm MC}=1.569\Lambda_{\overline{\rm MS}}$ (for 5 active flavors) improves the predictions of coherent shower algorithms at the NLL level [79], and hence this scheme is typically considered the baseline for shower tuning. The question of LO vs. NLO PDFs is more involved [15], but it should be emphasized that the low-x gluon in particular is important for determining the level of the underlying event in MPI models (Sec. 38.3.2), and hence the MB/UE tuning (and energy scaling [75]) is linked to the choice of PDF in such models. Further issues and an example of a specific recipe that could be followed in a realistic set-up can be found in Ref. 80.

Recent years have seen the emergence of automated tools that attempt to reduce the amount of both computer and manpower required for tuning [81]. Automating the human expert input is more difficult. In the tools currently on the market, this question is addressed by a combination of input solicited from the generator authors (e.g., which parameters and ranges to consider, which observables constitute a complete set, etc) and a set of weights determining the relative priority given to each bin in each distribution. The field is still burgeoning, however, and future sophistications are to be expected. Nevertheless, the overall quality of the automated tunes appear to at least be competitive with the manual ones.

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39. MONTE CARLO PARTICLE NUMBERING SCHEME

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The Monte Carlo particle numbering scheme presented here is intended to facilitate interfacing between event generators, detector simulators, and analysis packages used in particle physics. The numbering scheme was introduced in 1988 [1] and a revised version [2,3] was adopted in 1998 in order to allow systematic inclusion of quark model states which are as yet undiscovered and hypothetical particles such as SUSY particles. The numbering scheme is used in several event generators, e.q. HERWIG, PYTHIA, and SHERPA, and interfaces, e.g. /HEPEVT/ and HepMC.

The general form is a 7-digit number:

$$\pm n\; n_r\; n_L\; n_{q_1}\; n_{q_2}\; n_{q_3}\; n_J\;.$$

This encodes information about the particle's spin, flavor content, and internal quantum numbers. The details are as follows:

- 1. Particles are given positive numbers, antiparticles negative numbers. The PDG convention for mesons is used, so that K^+ and B^+ are particles.
- 2. Quarks and leptons are numbered consecutively starting from 1 and 11 respectively; to do this they are first ordered by family and within families by weak isospin.
- 3. In composite quark systems (diquarks, mesons, and baryons) $n_{q_{1-3}}$ are quark numbers used to specify the quark content, while the rightmost digit $n_J = 2J + 1$ gives the system's spin (except for the K_S^0 and K_L^0). The scheme does not cover particles of spin
- 4. Diquarks have 4-digit numbers with $n_{q_1} \geq n_{q_2}$ and $n_{q_3} = 0$. 5. The numbering of mesons is guided by the nonrelativistic (L–S decoupled) quark model, as listed in Tables 14.2 and 14.3.
 - a. The numbers specifying the meson's quark content conform to the convention $n_{q_1}=0$ and $n_{q_2}\geq n_{q_3}.$ The special case K_I^0 is the sole exception to this rule.
 - b. The quark numbers of flavorless, light (u, d, s) mesons are: 11 for the member of the isotriplet (π^0, ρ^0, \ldots) , 22 for the lighter isosinglet (η, ω, \ldots) , and 33 for the heavier isosinglet (η', ϕ, \ldots) . Since isosinglet mesons are often large mixtures of $u\overline{u} + d\overline{d}$ and $s\overline{s}$ states, 22 and 33 are assigned by mass and do not necessarily specify the dominant quark composition.
 - c. The special numbers 310 and 130 are given to the K_S^0 and K_L^0 respectively.
 - d. The fifth digit n_L is reserved to distinguish mesons of the same total (J) but different spin (S) and orbital (L) angular momentum quantum numbers. For J > 0 the numbers are: $(L,S) = (J-1,1) n_L = 0, (J,0) n_L = 1, (J,1) n_L = 2$ and (J+1,1) $n_L=3$. For the exceptional case J=0 the numbers are (0,0) $n_L = 0$ and (1,1) $n_L = 1$ (i.e. $n_L = L$). See Table 39.1.

Table 39.1: Meson numbering logic. Here qq stands for $n_{q2} n_{q3}$

| | L = J | -1, S | ' = 1 | L = J | S = 0 | 0 | L = J | $S = \frac{1}{2}$ | 1 | L = J | +1, i | S = 1 |
|----------------|-------|----------|-------|-------|----------|---|-------|-------------------|---|-------|----------|-------|
| \overline{J} | code | J^{PC} | L | code | J^{PC} | L | code | J^{PC} | L | code | J^{PC} | L |
| 0 | _ | _ | _ | | | | _ | | | | | 1 |
| 1 | 00qq3 | 1 | | | | | 20qq3 | | | 30qq3 | $1^{}$ | 2 |
| 2 | 00qq5 | 2^{++} | 1 | 10qq5 | 2^{-+} | 2 | 20qq5 | $2^{}$ | 2 | 30qq5 | 2^{++} | 3 |
| | 00qq7 | | | | | | 20qq7 | | | 30qq7 | | 4 |
| 4 | 00qq9 | 4++ | 3 | 10qq9 | 4^{-+} | 4 | 20qq9 | 4 | 4 | 30qq9 | 4++ | 5 |

e. If a set of physical mesons correspond to a (non-negligible) mixture of basis states, differing in their internal quantum numbers, then the lightest physical state gets the smallest basis state number. For example the $K_1(1270)$ is numbered 10313 (1 $^{1}P_{1}$ K_{1B}) and the $K_{1}(1400)$ is numbered 20313 $(1^3P_1 K_{1A}).$

- f. The sixth digit n_r is used to label mesons radially excited above the ground state.
- g. Numbers have been assigned for complete $n_r = 0$ S- and P-wave multiplets, even where states remain to be identified.
- h. In some instances assignments within the $q\bar{q}$ meson model are only tentative; here best guess assignments are made.
- i. Many states appearing in the Meson Listings are not yet assigned within the $q\bar{q}$ model. Here $n_{q_{2}-3}$ and n_{J} are assigned according to the state's likely flavors and spin; all such unassigned light isoscalar states are given the flavor code 22. Within these groups $n_L = 0, 1, 2, ...$ is used to distinguish states of increasing mass. These states are flagged using n = 9. It is to be expected that these numbers will evolve as the nature of the states are elucidated. Codes are assigned to all mesons which are listed in the one-page table at the end of the Meson Summary Table as long as they have a prefered or established spin. Additional heavy meson states expected from heavy quark spectroscopy are also assigned
- 6. The numbering of baryons is again guided by the nonrelativistic quark model, see Table 14.6. This numbering scheme is illustrated through a few examples in Table 39.2.
 - a. The numbers specifying a baryon's quark content are such
 - that in general $n_{q_1} \ge n_{q_2} \ge n_{q_3}$. b. Two states exist for J=1/2 baryons containing 3 different types of quarks. In the lighter baryon $(\Lambda, \Xi, \Omega, ...)$ the light quarks are in an antisymmetric (J=0) state while for the heavier baryon $(\Sigma^0, \Xi', \Omega', ...)$ they are in a symmetric (J=1) state. In this situation n_{q_2} and n_{q_3} are reversed for the lighter state, so that the smaller number corresponds to the lighter baryon.
 - c. For excited baryons a scheme is adopted, where the n_r label is used to denote the excitation bands in the harmonic oscillator model, see Sec. 14.4. Using the notation employed there, n_r is given by the N-index of the D_N band identifier.
 - d. Further degeneracies of excited hadron multiplets with the same excitation number n_r and spin J are lifted by labelling such multiplets with the n_L index according to their mass, as given by its N or Δ -equivalent.
 - e. In such excited multiplets extra singlets may occur, the $\Lambda(1520)$ being a prominent example. In such cases the ordering is reversed such that the heaviest quark label is pushed to the last position: $n_{q_3} > n_{q_1} > n_{q_2}$.
 - f. For pentaquark states $n=9, n_r n_L n_{q_1} n_{q_2}$ gives the four quark numbers in order $n_r \geq n_L \geq n_{q_1} \geq n_{q_2}$, n_{q_3} gives the antiquark number, and $n_J = 2J+1$, with the assumption that J = 1/2 for the states currently reported.
- 7. The gluon, when considered as a gauge boson, has official number 21. In codes for glueballs, however, 9 is used to allow a notation in close analogy with that of hadrons.
- 8. The pomeron and odderon trajectories and a generic reggeon trajectory of states in QCD are assigned codes 990, 9990, and 110 respectively, where the final 0 indicates the indeterminate nature of the spin, and the other digits reflect the expected "valence" flavor content. We do not attempt a complete classification of all reggeon trajectories, since there is currently no need to distinguish a specific such trajectory from its lowest-lying member.
- 9. Two-digit numbers in the range 21-30 are provided for the Standard Model gauge bosons and Higgs.
- 10. Codes 81-100 are reserved for generator-specific pseudoparticles and concepts.
- 11. The search for physics beyond the Standard Model is an active area, so these codes are also standardized as far as possible.
 - a. A standard fourth generation of fermions is included by analogy with the first three.
 - b. The graviton and the boson content of a two-Higgs-doublet scenario and of additional $SU(2)\times U(1)$ groups are found in the range 31-40.
 - c. "One-of-a-kind" exotic particles are assigned numbers in the range 41-80.
 - Fundamental supersymmetric particles are identified by adding a nonzero \boldsymbol{n} to the particle number. The superpartner of a boson or a left-handed fermion has n = 1 while the

| J^P | (D,L_N^P) | $n_r n_L n_{q_1} n_{q_2} n_{q_3} n_J$ | N | Λ_8 | Σ | Ξ | Λ_1 |
|-----------|------------------------------|---------------------------------------|---------|-------------|-------------|---------|-------------|
| | Oc | tet | 211,221 | 312 | 311,321,322 | 331,332 | 213 |
| 1/2+ | $({\bf 56},{\bf 0_0^+})$ | 00qqq2 | (939) | (1116) | (1193) | (1318) | |
| $1/2^{+}$ | $({\bf 56},{f 0_2^+})$ | 20qqq2 | (1440) | (1600) | (1660) | (1690) | _ |
| $1/2^{+}$ | $({\bf 70},{\bf 0_2^+})$ | 21qqq2 | (1710) | (1810) | (1880) | (?) | (?) |
| $1/2^{-}$ | $({f 70},{f 1}^{f 1})$ | 10qqq2 | (1535) | (1670) | (1620) | (1750) | (1405) |
| J^P | (D, L_N^P) | $n_r n_L n_{q_1} n_{q_2} n_{q_3} n_J$ | Δ | 7 | Σ | Ξ | Ω |
| | Deci | ıplet | 111,211 | ,221,222 | 311,321,322 | 331,332 | 333 |
| 3/2+ | $({\bf 56},{\bf 0_0^+})$ | 00qqq4 | (12 | 32) | (1385) | (1530) | (1672) |
| $3/2^{+}$ | $({f 56}, {f 0_2^+})$ | 20qqq4 | (16 | 00) | (1690) | (?) | (?) |
| $1/2^{-}$ | $({f 70},{f 1_1^-})$ | 11qqq2 | (1620) | | (1750) | (?) | (?) |
| $3/2^{-}$ | $(70, \overline{1}_{1}^{-})$ | 12qqq4 | (1700) | | (?) | (?) | (?) |

Table 39.2: Some examples of octet (top) and decuplet (bottom) members for the numbering scheme for excited baryons. Here qqq stands for $n_{q_1}n_{q_2}n_{q_3}$. See the text for the definition of the notation. The numbers in parenthesis correspond to the mass of the baryons. The states marked as (?) are not experimentally confirmed.

superpartner of a right-handed fermion has n=2. When mixing occurs, such as between the winos and charged Higgsinos to give charginos, or between left and right sfermions, the lighter physical state is given the smaller basis state number.

- e. Technicolor states have n=3, with technifermions treated like ordinary fermions. States which are ordinary color singlets have $n_r=0$. Color octets have $n_r=1$. If a state has non-trivial quantum numbers under the topcolor groups $\mathrm{SU}(3)_1 \times \mathrm{SU}(3)_2$, the quantum numbers are specified by tech, ij , where i and j are 1 or 2. n_L is then 2i+j. The coloron, V_8 , is a heavy gluon color octet and thus is 3100021.
- f. Excited (composite) quarks and leptons are identified by setting n=4 and $n_r=0$.
- Within several scenarios of new physics, it is possible to have colored particles sufficiently long-lived for color-singlet hadronic states to form around them. In the context of supersymmetric scenarios, these states are called R-hadrons, since they carry odd R-parity. R-hadron codes, defined here, should be viewed as templates for corresponding codes also in other scenarios, for any long-lived particle that is either an unflavored color octet or a flavored color triplet. The R-hadron code is obtained by combining the SUSY particle code with a code for the light degrees of freedom, with as many intermediate zeros removed from the former as required to make place for the latter at the end. (To exemplify, a sparticle $n00000n_{\tilde{q}}$ combined with quarks q_1 and q_2 obtains code $n00n_{\tilde{q}}n_{q_1}n_{q_2}n_J$.) Specifically, the new-particle spin decouples in the limit of large masses, so that the final n_J digit is defined by the spin state of the light-quark system alone. An appropriate number of n_q digits is used to define the ordinary-quark content. As usual, 9 rather than 21 is used to denote a gluon/gluino in composite states. The sign of the hadron agrees with that of the constituent new particle (a color triplet) where there is a distinct new antiparticle, and else is defined as for normal hadrons. Particle names are R with the flavor content as lower index.
- h. A black hole in models with extra dimensions has code 5000040. Kaluza-Klein excitations in models with extra dimensions have n=5 or n=6, to distinquish excitations of left- or right-handed fermions or, in case of mixing, the lighter or heavier state (cf. 11d). The nonzero n_r digit gives the radial excitation number, in scenarios where the level spacing allow these to be distinguished. Should the model also contain supersymmetry, excited SUSY states would be denoted by an $n_r>0$, with n=1 or 2 as usual. Should some colored states be long-lived enough that hadrons would form around them, the coding strategy of 11g applies, with the initial two nn_r digits preserved in the combined code.

- i. Magnetic monopoles and dyons are assumed to have one unit of Dirac monopole charge and a variable integer number $n_{q1}n_{q2}n_{q3}$ units of electric charge. Codes $411n_{q1}n_{q2}n_{q3}0$ are then used when the magnetic and electrical charge sign agree and $412n_{q1}n_{q2}n_{q3}0$ when they disagree, with the overall sign of the particle set by the magnetic charge. For now no spin information is provided.
- 12. Occasionally program authors add their own states. To avoid confusion, these should be flagged by setting $nn_T = 99$.
- 13. Concerning the non-99 numbers, it may be noted that only quarks, excited quarks, squarks, and diquarks have $n_{q_3}=0$; only diquarks, baryons (including pentaquarks), and the odderon have $n_{q_1}\neq 0$; and only mesons, the reggeon, and the pomeron have $n_{q_1}=0$ and $n_{q_2}\neq 0$. Concerning mesons (not antimesons), if n_{q_1} is odd then it labels a quark and an antiquark if even.
- 14. Nuclear codes are given as 10-digit numbers ±10LZZZAAAI. For a (hyper)nucleus consisting of n_p protons, n_n neutrons and n_Λ Λ's, A = n_p + n_n + n_Λ gives the total baryon number, Z = n_p the total charge and L = n_Λ the total number of strange quarks. I gives the isomer level, with I = 0 corresponding to the ground state and I > 0 to excitations, see [4], where states denoted m, n, p, q translate to I = 1 4. As examples, the deuteron is 1000010020 and ²³⁵U is 1000922350. To avoid ambiguities, nuclear codes should not be applied to a single hadron, like p, n or Λ⁰, where quark-contents-based codes already exist.

This text and full lists of particle numbers, including excited baryons particles from physics beyond the standard model, can be found on the WWW [5]. The StdHep Monte Carlo standardization project [6] maintains the list of PDG particle numbers, as well as numbering schemes from most event generators and software to convert between the different schemes.

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| QUARKS | | DIQUARKS | $\mathop{\bf LIGHT}_{\pi^0} I =$ | | LIGHT $I =$ | |
|-------------------------------------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------------|-----------------------------|----------------------------|
| d 1 | | $(dd)_1$ 1103 | π° π^{+} | 111 211 | | \overline{s} Admixtures) |
| $\begin{array}{ccc} u & 2 \\ s & 3 \end{array}$ | | $(ud)_0$ 2101 | $a_0(980)^0$ | 9000111 | $\eta \\ \eta'(958)$ | 221 |
| c 4 | | $(ud)_1$ 2103 | $a_0(980)^+$ | 9000211 | | 331 9000221 |
| b 5 | | $(uu)_1$ 2203 | $\pi(1300)^0$ | 100111 | $f_0(600)$ | 9010221 |
| $\begin{array}{ccc} t & & \epsilon \\ b' & & 7 \end{array}$ | | $(sd)_0$ 3101 | $\pi(1300)^{+}$ | 100211 | $f_0(980)$ | 100221 |
| t' 8 | | $(sd)_1$ 3103 | $a_0(1450)^0$ | 10111 | $\eta(1295)$ | 100221 |
| | | $(su)_0$ 3201 | $a_0(1450)^+$ | 10211 | $f_0(1370)$ $\eta(1405)$ | 9020221 |
| LEPTON | | $(su)_1$ 3203 | $\pi(1800)^0$ | 9010111 | $\eta(1405)$ $\eta(1475)$ | 100331 |
| | 1 2 | $(ss)_1$ 3303 | $\pi(1800)^{+}$ | 9010211 | , | 9030221 |
| | 3 | $(cd)_0$ 4101 | $\rho(770)^{0}$ | 113 | $f_0(1500)$ | 10331 |
| • | 4 | $(cd)_1$ 4103 | $\rho(770)^{+}$ | 213 | $f_0(1710)$ $\eta(1760)$ | 9040221 |
| , | 5 | $(cu)_0$ 4201 | $b_1(1235)^0$ | 10113 | | |
| | .6 | $(cu)_1$ 4203 | $b_1(1235)^+$ | 10213 | $f_0(2020)$ | 9050221 |
| • | 7 | $(cs)_0$ 4301 | $a_1(1260)^0$ | 20113 | $f_0(2100)$ | 9060221 |
| $\nu_{\tau'}$ 1 | .8 | $(cs)_1$ 4303 | $a_1(1260)^+$ | 20213 | $f_0(2200)$ | 9070221 |
| ~ | | $(cc)_1$ 4403 | $\pi_1(1400)^0$ | 9000113 | $\eta(2225)$ | 9080221 |
| GAUGE . HIGGS B | | $(bd)_0$ 5101 | $\pi_1(1400)^+$ | 9000213 | $\omega(782)$ | 223 |
| g | (9) 21 | $(bd)_1$ 5103 | $\rho(1450)^{0}$ | 100113 | $\phi(1020)$ | 333 |
| γ | 22 | $(bu)_0$ 5201 | $\rho(1450)^{+}$ | 100213 | $h_1(1170)$ | 10223 |
| $\overset{'}{Z}{}^{0}$ | 23 | $(bu)_1$ 5203 | $\pi_1(1600)^0$ | 9010113 | $f_1(1285)$ | 20223 |
| W^+ | 24 | $(bs)_0$ 5301 | $\pi_1(1600)^+$ | 9010213 | $h_1(1380)$ | 10333 |
| h^0/H_1^0 | 25 | $(bs)_1$ 5303 | $a_1(1640)^0$ | 9020113 | $f_1(1420)$ | 20333 |
| Z'/Z_2^0 | 32 | $(bc)_0$ 5401 | $a_1(1640)^+$ | 9020213 | $\omega(1420)$ | 100223 |
| Z''/Z_3^0 | 33 | $(bc)_1$ 5403 | $\rho(1700)^0$ | 30113 | $f_1(1510)$ | 9000223 |
| W'/W_2^+ | 34 | $(bb)_1$ 5503 | $\rho(1700)^{+}$ | 30213 | $h_1(1595)$ | 9010223 |
| H^0/H_2^0 | 35 | arias. | $\rho(1900)^0$ | 9030113 | $\omega(1650)$ | 30223 |
| A^{0}/H_{3}^{0} | 36 | SUSY PARTICLES | $\rho(1900)^{+}$ | 9030213 | $\phi(1680)$ | 100333 |
| H^+ | 37 | \widetilde{d}_L 1000001 | $\rho(2150)^0$ | 9040113 | $f_2(1270)$ | 225 |
| | | \widetilde{u}_L 1000002 | $\rho(2150)^{+}$ | 9040213 | $f_2(1430)$ | 9000225 |
| SPECIAL | | \widetilde{s}_L 1000003 | $a_2(1320)^0$ | 115 | $f_2'(1525)$ | 335 |
| PARTICI G (gravitor | | \widetilde{c}_L 1000004 | $a_2(1320)^+$ | 215 | $f_2(1565)$ | 9010225 |
| R^0 | 41 | \widetilde{b}_1 1000005 ^a \widetilde{t}_1 1000006 ^a | $\pi_2(1670)^0$ | 10115 | $f_2(1640)$ | 9020225 |
| LQ^c | 42 | $\tilde{t}_1 = 1000006^a$ | $\pi_2(1670)^+$ | 10215 | $\eta_2(1645)$ | 10225 |
| reggeon | 110 | $\widetilde{e_L}$ 1000011 | $a_2(1700)^0$ | 9000115 | $f_2(1810)$ | 9030225 |
| pomeron | 990 | $\widetilde{ u}_{eL}$ 1000012 | $a_2(1700)^+$ | 9000215 | $\eta_2(1870)$ | 10335 |
| odderon | 9990 | $\widetilde{\mu}_L^-$ 1000013 | $\pi_2(2100)^0$ | 9010115 | $f_2(1910)$ | 9040225 |
| | | $\widetilde{ u}_{\mu L}$ 1000014 | $\pi_2(2100)^+$ | 9010215 | $f_2(1950)$ | 9050225 |
| | | $\widetilde{\tau}_1$ 1000015 ^a | $\rho_3(1690)^0$ | 117 | $f_2(2010)$ | 9060225 |
| for MC inte | | $\widetilde{\nu}_{\tau L}$ 1000016 | $\rho_3(1690)^+$ | 217 | $f_2(2150)$ | 9070225 |
| use 81–100 | | $\widetilde{\widetilde{d}}_R^L$ 2000001 | $\rho_3(1990)^0$ | 9000117 | $f_2(2300)$ | 9080225 |
| | | \widetilde{u}_R 2000002 | $\rho_3(1990)^+$ | 9000217 | $f_2(2340)$ | 9090225 |
| | | \widetilde{s}_R 2000003 | $\rho_3(1350)$ $\rho_3(2250)^0$ | 9010117 | $\omega_3(1670)$ | 227 |
| | | \widetilde{c}_R 2000004 | $\rho_3(2250)^+$ | 9010217 | $\phi_3(1850)$ | 337 |
| | | \widetilde{b}_2 2000005 ^a | $a_4(2040)^0$ | 119 | $f_4(2050)$ | 229 |
| | | \widetilde{t}_2 2000006 ^a | $a_4(2040)^+$ | 219 | $f_J(2220)$ | 9000229 |
| | | $\begin{array}{cc} \widetilde{t}_2 & 2000006^a \\ \widetilde{e}_R^- & 2000011 \end{array}$ | 44(2040) | 213 | $f_4(2300)$ | 9010229 |
| | | $\widetilde{\mu}_R^-$ 2000013 | | | | |
| | | $\widetilde{\tau}_2$ 2000015 ^a | | | | |
| | | \widetilde{g} 1000021 | | | | |
| | | $\tilde{\chi}_{1}^{0} = 1000021^{b}$ | | | | |
| | | $\widetilde{\chi}_{2}^{0}$ 1000023 ^b | | | | |
| | | $\widetilde{\chi}_{1}^{+}$ 1000024 ^b | | | | |
| | | $\begin{array}{ccc} \chi_1 & 1000024 \\ \widetilde{\chi}_3^0 & 1000025^b \end{array}$ | | | | |
| | | χ ₂ 1000025" | | | | |
| | | ~0 10000=h | | | | |
| | | $\tilde{\chi}_{4}^{0} = 1000035^{b}$ | | | | |
| | | $\begin{array}{ccc} \widetilde{\chi}_{4}^{0} & 1000035^{b} \\ \widetilde{\chi}_{2}^{+} & 1000037^{b} \\ \widetilde{G} & 1000039 \end{array}$ | | | | |

| STRANGE MESONS | E | CHARM: MESONS | | $c\overline{c}$ MESON | C C | LIG | HT RYONS | BOT" | TOM YONS |
|----------------------------------------|---------|--------------------------------------------|-------------|------------------------------------|-------------|-------------------------------------|---------------------|-------------------------|-------------|
| K_L^0 | 130 | D^+ | 411 | $\eta_c(1S)$ | 4 41 | p p | 2212 | Λ_b^0 | 5122 |
| K_S^0 | 310 | D^0 | 421 | $\chi_{c0}(1P)$ | 10441 | n | 9119 | Σ_b^- | 5112 |
| $K_S = K^0$ | 311 | $D_0^*(2400)^+$ | 10411 | $\eta_c(2S)$ | 100441 | Δ^{++} | 2224 | | |
| K^+ | 321 | $D_0^*(2400)^0$ | 10421 | $J/\psi(1S)$ | 443 | Δ^+ | 2214 | Σ_b^0 | 5212 |
| $K_0^*(800)^0$ | 9000311 | $D^*(2010)^+$ | 413 | $h_c(1P)$ | 10443 | Δ^0 | 2114 | Σ_b^+ | 5222 |
| $K_0^*(800)^+$ | 9000321 | $D^*(2007)^0$ | 423 | $\chi_{c1}(1P)$ | 20443 | Δ^{-} | 1114 | Σ_b^{*-} | 5114 |
| $K_0^*(1430)^0$ | 10311 | $D_1(2420)^+$ | 10413 | $\psi(2S)$ | 100443 | STF | RANGE | Σ_b^{*0} | 5214 |
| $K_0^*(1430)^+$ | 10321 | $D_1(2420)^0$ | | $\psi(23)$ $\psi(3770)$ | 30443 | | RYONS | Σ_b^{*+} | 5224 |
| $K(1460)^0$ | 100311 | $D_1(H)^+$ | 20413 | $\psi(3770)$ $\psi(4040)$ | 9000443 | Λ | 3122 | Ξ_b^- | 5132 |
| $K(1460)^+$ | 100311 | $D_1(2430)^0$ | 20423 | | | $\Sigma^+ \\ \Sigma^0$ | $\frac{3222}{3212}$ | Ξ_b^0 | 5232 |
| $K(1400)$ $K(1830)^0$ | 9010311 | $D_2^*(2460)^+$ | | $\psi(4160)$ | 9010443 | Σ^- | 3112 | $\Xi_b^{\prime-}$ | 5312 |
| $K(1830)^+$ | 9010311 | $D_2^*(2460)^0$ | | $\psi(4415)$ | 9020443 | Σ^{*+} | 3224^{c} | $\Xi_b^{\prime 0}$ | 5322 |
| $K_0^*(1950)^0$ | | D_s^+ | 431 | $\chi_{c2}(1P)$ | 445 | $\sum_{i=1}^{\infty}$ | 3214^{c} | Ξ_b^{*-} | 5314 |
| | 9020311 | $D_{s0}^{*}(2317)^{-1}$ | | $\chi_{c2}(2P)$ | 100445 | Σ^{*-} | 3114^{c} | | |
| $K_0^*(1950)^+$ | 9020321 | $D_{s0}^{(2311)}$ D_{s}^{*+} | 433 | $b\overline{b}$ | | =- =, | $3322 \\ 3312$ | Ξ_{b}^{*0} | 5324 |
| $K^*(892)^0$ | 313 | | | MESON | S | \(\frac{\pi_0}{\pi_0}\)\(\pi_{*0}\) | 3324^{c} | Ω_b^- | 5332 |
| $K^*(892)^+$ | 323 | $D_{s1}(2536)^{-1}$ $D_{s1}(2460)^{-1}$ | | $\eta_b(1S)$ | 551 | Ξ*- | 3314^{c} | Ω_b^{*-} | 5334 |
| $K_1(1270)^0$ | 10313 | | | $\chi_{b0}(1P)$ | 10551 | Ω_{-} | 3334 | Ξ_{bc}^0 | 5142 |
| $K_1(1270)^+$ | 10323 | $D_{s2}^*(2573)^{-1}$ | + 435 | $\eta_b(2S)$ | 100551 | СН | ARMED | Ξ_{bc}^{+} | 5242 |
| $K_1(1400)^0$ | 20313 | BOTTON | Л | $\chi_{b0}(2P)$ | 110551 | | RYONS | $\Xi_{bc}^{\prime0}$ | 5412 |
| $K_1(1400)^+$ | 20323 | MESONS | 3 | $\eta_b(3S)$ | 200551 | Λ_c^+ | 4122 | $\Xi_{bc}^{\prime+}$ | 5422 |
| $K^*(1410)^0$ | 100313 | B^0 | 511 | $\chi_{b0}(3P)$ | 210551 | Σ_c^{++} | 4222 | Ξ_{bc}^{*0} | 5414 |
| $K^*(1410)^+$ | 100323 | B^+ | 521 | $\Upsilon(1S)$ | 553 | Σ_c^+ | 4212 | Ξ_{bc}^{*+} | 5424 |
| $K_1(1650)^0$ | 9000313 | B_0^{*0} | 10511 | $h_b(1P)$ | 10553 | Σ_c^0 | 4112 | -bc | |
| $K_1(1650)^+$ | 9000323 | B_0^{*+} | 10521 | $\chi_{b1}(1P)$ | 20553 | Σ_c^{*+} | + 4224 | Ω_{bc}^{0} | 5342 |
| $K^*(1680)^0$ | 30313 | $\stackrel{B^{*0}}{B^{*+}}$ | 513 | $\Upsilon_1(1D)$ | 30553 | Σ_c^{*+} | 4214 | $\Omega_{bc}^{\prime0}$ | 5432 |
| $K^*(1680)^+$ | 30323 | $B_1(L)^0$ | 523 10513 | $\Upsilon(2S)$ | 100553 | Σ_c^{*0} | 4114 | Ω_{bc}^{*0} | 5434 |
| $K_2^*(1430)^0$ | 315 | $B_1(L)^+$ | 10523 | $h_b(2P)$ | 110553 | Ξ_c^+ | 4232 | Ω_{bcc}^{+} | 5442 |
| $K_2^*(1430)^+$ | 325 | $B_1(E)$ $B_1(H)^0$ | 20513 | $\chi_{b1}(2P)$ | 120553 | Ξ_c^0 | 4132 | Ω_{bcc}^{*+} | 5444 |
| $K_2(1580)^0$ | 9000315 | $B_1(H)^+$ | 20523 | $\Upsilon_1(2D)$ | 130553 | $\Xi_c^{\prime+}$ | 4322 | Ξ_{bb}^{-} | 5512 |
| $K_2(1580)^+$ | 9000325 | B_2^{*0} | 515 | $\Upsilon(3S)$ | 200553 | $\Xi_c^{\prime 0}$ | 4312 | Ξ_{bb}^0 | 5522 |
| $K_2(1770)^0$ | 10315 | B_2^{*+} | 525 | $h_b(3P)$ | 210553 | Ξ_c^{*+} | 4324 | Ξ_{bb}^{*-} | 5514 |
| $K_2(1770)^+$ | 10325 | B_s^0 | | $\chi_{b1}(3P)$ | 220553 | Ξ_c^{*0} | 4314 | Ξ_{bb}^{*0} | 5524 |
| $K_2(1820)^0$ | 20315 | | 531 | $\Upsilon(4S)$ | 300553 | Ω_c^0 | 4332 | Ω_{bb}^{-} | 5532 |
| $K_2(1820)^+$ | 20325 | B_{s0}^{*0} | 10531 | $\Upsilon(10860)$ | 9000553 | Ω_c^{*0} | 4334 | Ω_{bb}^{*-} | 5534 |
| $K_2^*(1980)^0$ | 9010315 | B_s^{*0} | 533 | $\Upsilon(11020)$ | 9010553 | Ξ_{cc}^{+} | 4412 | | 5542 |
| $K_2^*(1980)^+$ | 9010325 | $B_{s1}(L)^0$ | 10533 | $\chi_{b2}(1P)$ | 555 | Ξ_{cc}^{++} | | Ω_{bbc}^{0} | |
| $K_2(2250)^0$ | 9020315 | $B_{s1}(H)^0$ | 20533 | $\eta_{b2}(1D)$ | 10555 | Ξ_{cc}^{*+} | 4414 | Ω_{bbc}^{*0} | 5544 |
| $K_2(2250)^+$ | 9020325 | B_{s2}^{*0} | 535 | $\Upsilon_2(1D)$ | 20555 | Ξ_{cc}^{*+} | | Ω_{bbb}^{-} | 5554 |
| $K_3^*(1780)^0$ | 317 | B_c^+ | 541 | | 100555 | Ω_{cc}^{+} | 4432 | | |
| $K_3^*(1780)^+$ | 327 | B_{c0}^{*+} | 10541 | $\chi_{b2}(2P)$ | | Ω_{cc}^{*+} | 4434 | | |
| $K_3(2320)^0$ | 9010317 | B_c^{*+} | 543 | $\eta_{b2}(2D)$ $\Upsilon_{a}(2D)$ | 110555 | Ω_{ccc}^{++} | | | |
| $K_3(2320)^+$ | 9010327 | $B_{c1}(L)^+$ | 10543 | $\Upsilon_2(2D)$ | 120555 | ccc | | | |
| $K_4^*(2045)^0$ | 319 | $B_{c1}(H)^{+}$ | 20543 | $\chi_{b2}(3P)$ | 200555 | | | | |
| $K_4^*(2045)^+$ | 329 | B_{c2}^{*+} | 545 | $\Upsilon_3(1D)$ | 557 | | | | |
| $K_4(2500)^0$ | 9000319 | | | $\Upsilon_3(2D)$ | 100557 | | | | |
| $K_4(2500)^{\circ}$ $K_4(2500)^{+}$ | | | | | | | | | |
| Λ4(2000) | 9000329 | | | | | | | | |

Footnotes to the Tables:

- a) Particulary in the third generation, the left and right sfermion states may mix, as shown. The lighter mixed state is given the smaller number.

 b) The physical $\widetilde{\chi}$ states are admixtures of the pure $\widetilde{\gamma}$, \widetilde{Z}^0 , \widetilde{W}^+ , \widetilde{H}^0_1 , \widetilde{H}^0_2 , and \widetilde{H}^+ states.

 c) Σ^* and Ξ^* are alternate names for $\Sigma(1385)$ and $\Xi(1530)$.

40. CLEBSCH-GORDAN COEFFICIENTS, SPHERICAL HARMONICS, AND d FUNCTIONS

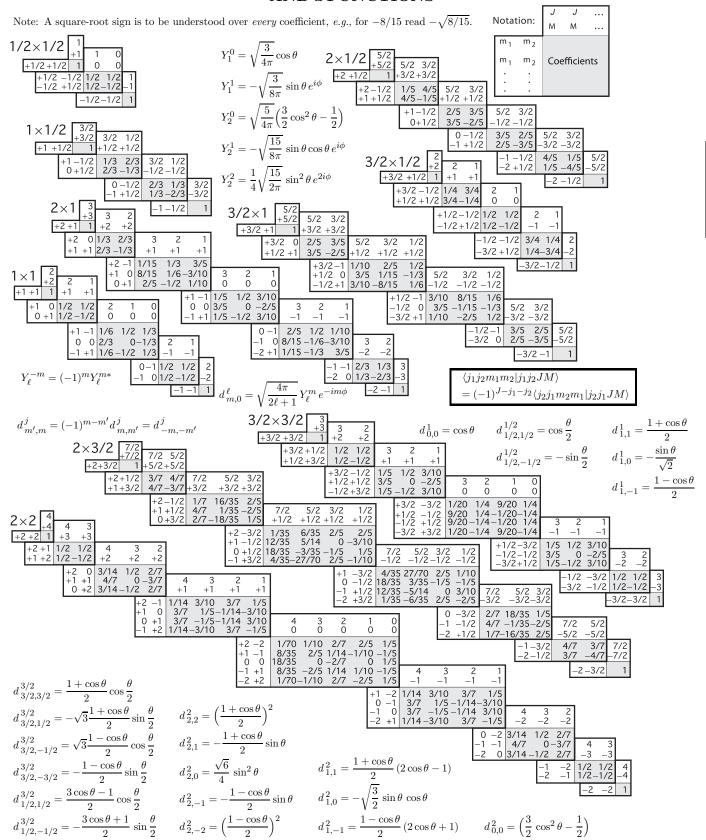


Figure 40.1: The sign convention is that of Wigner (*Group Theory*, Academic Press, New York, 1959), also used by Condon and Shortley (*The Theory of Atomic Spectra*, Cambridge Univ. Press, New York, 1953), Rose (*Elementary Theory of Angular Momentum*, Wiley, New York, 1957), and Cohen (*Tables of the Clebsch-Gordan Coefficients*, North American Rockwell Science Center, Thousand Oaks, Calif., 1974).

41. SU(3) ISOSCALAR FACTORS AND REPRESENTATION MATRICES

Written by R.L. Kelly (LBNL).

The most commonly used SU(3) isoscalar factors, corresponding to the singlet, octet, and decuplet content of $8\otimes 8$ and $10\otimes 8$, are shown at the right. The notation uses particle names to identify the coefficients, so that the pattern of relative couplings may be seen at a glance. We illustrate the use of the coefficients below. See J.J de Swart, Rev. Mod. Phys. **35**, 916 (1963) for detailed explanations and phase conventions.

 $A \sqrt{\ }$ is to be understood over every integer in the matrices; the exponent 1/2 on each matrix is a reminder of this. For example, the $\Xi \to \Omega K$ element of the $10 \to 10 \otimes 8$ matrix is $-\sqrt{6}/\sqrt{24} = -1/2$.

Intramultiplet relative decay strengths may be read directly from the matrices. For example, in decuplet \rightarrow octet + octet decays, the ratio of $\Omega^* \rightarrow \Xi \overline{K}$ and $\Delta \rightarrow N\pi$ partial widths is, from the $10 \rightarrow 8 \times 8$ matrix,

$$\frac{\Gamma\left(\Omega^* \to \Xi \overline{K}\right)}{\Gamma\left(\Delta \to N\pi\right)} = \frac{12}{6} \times \text{ (phase space factors)} . \tag{41.1}$$

Including isospin Clebsch-Gordan coefficients, we obtain, e.g.,

$$\frac{\Gamma(\Omega^{*-} \to \Xi^0 K^-)}{\Gamma(\Delta^+ \to p \, \pi^0)} = \frac{1/2}{2/3} \times \frac{12}{6} \times p.s.f. = \frac{3}{2} \times p.s.f. \tag{41.2}$$

Partial widths for $8 \to 8 \otimes 8$ involve a linear superposition of 8_1 (symmetric) and 8_2 (antisymmetric) couplings. For example,

$$\Gamma(\Xi^* \to \Xi \pi) \sim \left(-\sqrt{\frac{9}{20}} g_1 + \sqrt{\frac{3}{12}} g_2\right)^2$$
 (41.3)

The relations between g_1 and g_2 (with de Swart's normalization) and the standard D and F couplings that appear in the interaction Lagrangian,

$$\mathcal{L} = -\sqrt{2} D \operatorname{Tr}(\{\overline{B}, B\}M) + \sqrt{2} F \operatorname{Tr}([\overline{B}, B]M) , \qquad (41.4)$$

where $[\overline{B}, B] \equiv \overline{B}B - B\overline{B}$ and $\{\overline{B}, B\} \equiv \overline{B}B + B\overline{B}$, are

$$D = \frac{\sqrt{30}}{40} g_1 , \qquad F = \frac{\sqrt{6}}{24} g_2 . \tag{41.5}$$

Thus, for example,

$$\Gamma(\Xi^* \to \Xi \pi) \sim (F - D)^2 \sim (1 - 2\alpha)^2$$
, (41.6)

where $\alpha \equiv F/(D+F)$. (This definition of α is de Swart's. The alternative D/(D+F), due to Gell-Mann, is also used.)

The generators of SU(3) transformations, λ_a (a=1,8), are 3×3 matrices that obey the following commutation and anticommutation relationships:

$$[\lambda_a, \lambda_b] \equiv \lambda_a \lambda_b - \lambda_b \lambda_a = 2i f_{abc} \lambda_c \tag{41.7}$$

$$\{\lambda_a, \lambda_b\} \equiv \lambda_a \lambda_b + \lambda_b \lambda_a = \frac{4}{3} \delta_{ab} I + 2 d_{abc} \lambda_c , \qquad (41.8)$$

where I is the 3×3 identity matrix, and δ_{ab} is the Kronecker delta symbol. The f_{abc} are odd under the permutation of any pair of indices, while the d_{abc} are even. The nonzero values are

$$1 \to 8 \otimes 8$$

$$(\Lambda) \rightarrow (N\overline{K} \Sigma \pi \Lambda \eta \Xi K) = \frac{1}{\sqrt{8}} (2 \ 3 \ -1 \ -2)^{1/2}$$

 $8_1 \to 8 \otimes 8$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix} \rightarrow \begin{pmatrix} N\pi & N\eta & \Sigma K & \Lambda K \\ N\overline{K} & \Sigma\pi & \Lambda\pi & \Sigma\eta & \Xi K \\ N\overline{K} & \Sigma\pi & \Lambda\eta & \Xi K \\ \Sigma\overline{K} & \Lambda\overline{K} & \Xi\pi & \Xi\eta \end{pmatrix} = \frac{1}{\sqrt{20}} \begin{pmatrix} 9 & -1 & -9 & -1 \\ -6 & 0 & 4 & 4 & -6 \\ 2 & -12 & -4 & -2 \\ 9 & -1 & -9 & -1 \end{pmatrix}^{1/2}$$

$$8_2 o 8 \otimes 8$$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix} \rightarrow \begin{pmatrix} N\pi & N\eta & \Sigma K & \Lambda K \\ N\overline{K} & \Sigma\pi & \Lambda\pi & \Sigma\eta & \Xi K \\ N\overline{K} & \Sigma\pi & \Lambda\eta & \Xi K \\ \Sigma\overline{K} & \Lambda\overline{K} & \Xi\pi & \Xi\eta \end{pmatrix} = \frac{1}{\sqrt{12}} \begin{pmatrix} 3 & 3 & 3 & -3 \\ 2 & 8 & 0 & 0 & -2 \\ 6 & 0 & 0 & 6 \\ 3 & 3 & 3 & -3 \end{pmatrix}^{1/2}$$

$$\mathbf{10} \rightarrow \mathbf{8} \otimes \mathbf{8}$$

$$\begin{pmatrix} \Delta \\ \Sigma \\ \Xi \\ \Omega \end{pmatrix} \rightarrow \begin{pmatrix} N\pi & \Sigma K \\ N\overline{K} & \Sigma\pi & \Lambda\pi & \Sigma\eta & \Xi K \\ \Sigma\overline{K} & \Lambda\overline{K} & \Xi\pi & \Xi\eta \\ \Xi\overline{K} \end{pmatrix} = \frac{1}{\sqrt{12}} \begin{pmatrix} -6 & 6 & \\ -2 & 2 & -3 & 3 & 2 \\ 3 & -3 & 3 & 3 & \\ 12 & & & 12 \end{pmatrix}^{1/2}$$

$$8 \rightarrow 10 \otimes 8$$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix} \rightarrow \begin{pmatrix} \Delta\pi & \Sigma K \\ \Sigma\pi & \Sigma\eta & \Xi K \\ \Sigma\pi & \Xi K \\ \Sigma\overline{K} & \Xi\pi & \Xi\eta & \Omega K \end{pmatrix} = \frac{1}{\sqrt{15}} \begin{pmatrix} -12 & 3 \\ 8 & -2 & -3 & 2 \\ -9 & 6 \\ 3 & -3 & -3 & 6 \end{pmatrix}^{1/2}$$

$$10 \rightarrow 10 \otimes 8$$

$$\begin{pmatrix} \Delta \\ \Sigma \\ \Xi \\ \Omega \end{pmatrix} \rightarrow \begin{pmatrix} \Delta \pi & \Delta \eta & \Sigma K \\ \Delta \overline{K} & \Sigma \pi & \Sigma \eta & \Xi K \\ \Sigma \overline{K} & \Xi \pi & \Xi \eta & \Omega K \\ \Xi \overline{K} & \Omega \eta \end{pmatrix} \qquad = \frac{1}{\sqrt{24}} \begin{pmatrix} 15 & 3 & -6 \\ 8 & 8 & 0 & -8 \\ 12 & 3 & -3 & -6 \\ 12 & -12 \end{pmatrix}^{1/2}$$

| abc | f_{abc} | abc | d_{abc} | \underline{abc} | d_{abc} |
|-----|--------------|-----|--------------|-------------------|------------------|
| 123 | 1 | 118 | $1/\sqrt{3}$ | 355 | 1/2 |
| 147 | 1/2 | 146 | 1/2 | 366 | -1/2 |
| 156 | -1/2 | 157 | 1/2 | 377 | -1/2 |
| 246 | 1/2 | 228 | $1/\sqrt{3}$ | 448 | $-1/(2\sqrt{3})$ |
| 257 | 1/2 | 247 | -1/2 | 558 | $-1/(2\sqrt{3})$ |
| 345 | 1/2 | 256 | 1/2 | 668 | $-1/(2\sqrt{3})$ |
| 367 | -1/2 | 338 | $1/\sqrt{3}$ | 778 | $-1/(2\sqrt{3})$ |
| 458 | $\sqrt{3}/2$ | 344 | 1/2 | 888 | $-1/\sqrt{3}$ |
| 678 | $\sqrt{3}/2$ | | | | |

The λ_a 's are

$$\lambda_{1} = \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_{2} = \begin{pmatrix} 0 & -i & 0 \\ i & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \quad \lambda_{3} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

$$\lambda_{4} = \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \quad \lambda_{5} = \begin{pmatrix} 0 & 0 & -i \\ 0 & 0 & 0 \\ i & 0 & 0 \end{pmatrix} \quad \lambda_{6} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$\lambda_{7} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & -i \\ 0 & i & 0 \end{pmatrix} \quad \lambda_{8} = \frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{pmatrix}$$

Equation (41.7) defines the Lie algebra of SU(3). A general d-dimensional representation is given by a set of $d \times d$ matrices satisfying Eq. (41.7) with the f_{abc} given above. Equation (41.8) is specific to the defining 3-dimensional representation.

42. SU(n) MULTIPLETS AND YOUNG DIAGRAMS

Written by C.G. Wohl (LBNL).

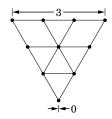
This note tells (1) how SU(n) particle multiplets are identified or labeled, (2) how to find the number of particles in a multiplet from its label, (3) how to draw the Young diagram for a multiplet, and (4) how to use Young diagrams to determine the overall multiplet structure of a composite system, such as a 3-quark or a meson-baryon system.

In much of the literature, the word "representation" is used where we use "multiplet," and "tableau" is used where we use "diagram."

42.1. Multiplet labels

An SU(n) multiplet is uniquely identified by a string of (n-1) nonnegative integers: $(\alpha, \beta, \gamma, \ldots)$. Any such set of integers specifies a multiplet. For an SU(2) multiplet such as an isospin multiplet, the single integer α is the number of *steps* from one end of the multiplet to the other (*i.e.*, it is one fewer than the number of particles in the multiplet). In SU(3), the two integers α and β are the numbers of steps across the top and bottom levels of the multiplet diagram. Thus the labels for the SU(3) octet and decuplet





are (1,1) and (3,0). For larger n, the interpretation of the integers in terms of the geometry of the multiplets, which exist in an (n-1)-dimensional space, is not so readily apparent.

The label for the SU(n) singlet is $(0,0,\ldots,0)$. In a flavor SU(n), the n quarks together form a $(1,0,\ldots,0)$ multiplet, and the n antiquarks belong to a $(0,\ldots,0,1)$ multiplet. These two multiplets are conjugate to one another, which means their labels are related by $(\alpha,\beta,\ldots) \leftrightarrow (\ldots,\beta,\alpha)$.

42.2. Number of particles

The number of particles in a multiplet, $N = N(\alpha, \beta, ...)$, is given as follows (note the pattern of the equations).

In SU(2), $N = N(\alpha)$ is

$$N = \frac{(\alpha + 1)}{1} \ . \tag{42.1}$$

In SU(3), $N = N(\alpha, \beta)$ is

$$N = \frac{(\alpha+1)}{1} \cdot \frac{(\beta+1)}{1} \cdot \frac{(\alpha+\beta+2)}{2} . \tag{42.2}$$

In SU(4), $N = N(\alpha, \beta, \gamma)$ is

$$N = \frac{(\alpha+1)}{1} \cdot \frac{(\beta+1)}{1} \cdot \frac{(\gamma+1)}{1} \cdot \frac{(\gamma+1)}{2} \cdot \frac{(\alpha+\beta+2)}{2} \cdot \frac{(\beta+\gamma+2)}{2} \cdot \frac{(\alpha+\beta+\gamma+3)}{3} \ . \tag{42.3}$$

Note that in Eq. (42.3) there is no factor with $(\alpha + \gamma + 2)$: only a consecutive sequence of the label integers appears in any factor. One more example should make the pattern clear for any SU(n). In SU(5), $N = N(\alpha, \beta, \gamma, \delta)$ is

$$\begin{split} N &= \frac{(\alpha + 1)}{1} \cdot \frac{(\beta + 1)}{1} \cdot \frac{(\gamma + 1)}{1} \cdot \frac{(\delta + 1)}{1} \cdot \frac{(\alpha + \beta + 2)}{2} \cdot \frac{(\beta + \gamma + 2)}{2} \\ &\times \frac{(\gamma + \delta + 2)}{2} \cdot \frac{(\alpha + \beta + \gamma + 3)}{3} \cdot \frac{(\beta + \gamma + \delta + 3)}{3} \cdot \frac{(\alpha + \beta + \gamma + \delta + 4)}{4} (42.4) \end{split}$$

From the symmetry of these equations, it is clear that multiplets that are conjugate to one another have the same number of particles, but so can other multiplets. For example, the SU(4) multiplets (3,0,0) and (1,1,0) each have 20 particles. Try the equations and see.

42.3. Young diagrams

A Young diagram consists of an array of boxes (or some other symbol) arranged in one or more left-justified rows, with each row being at least as long as the row beneath. The correspondence between a diagram and a multiplet label is: The top row juts out α boxes to the right past the end of the second row, the second row juts out β boxes to the right past the end of the third row, etc. A diagram in SU(n) has at most n rows. There can be any number of "completed" columns of n boxes buttressing the left of a diagram; these don't affect the label. Thus in SU(3) the diagrams



represent the multiplets (1,0), (0,1), (0,0), (1,1), and (3,0). In any SU(n), the quark multiplet is represented by a single box, the antiquark multiplet by a column of (n-1) boxes, and a singlet by a completed column of n boxes.

42.4. Coupling multiplets together

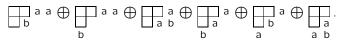
The following recipe tells how to find the multiplets that occur in coupling two multiplets together. To couple together more than two multiplets, first couple two, then couple a third with each of the multiplets obtained from the first two, etc.

First a definition: A sequence of the letters a,b,c,\ldots is admissible if at any point in the sequence at least as many a's have occurred as b's, at least as many b's have occurred as c's, etc. Thus abcd and aabcb are admissible sequences and abb and acb are not. Now the recipe:

- (a) Draw the Young diagrams for the two multiplets, but in one of the diagrams replace the boxes in the first row with a's, the boxes in the second row with b's, etc. Thus, to couple two SU(3) octets (such as the π -meson octet and the baryon octet), we start with \square and
- $^{\sf a}$ $^{\sf a}$ $^{\sf a}$. The unlettered diagram forms the $upper\ left$ -hand corner of all the enlarged diagrams constructed below.
- (b) Add the a's from the lettered diagram to the right-hand ends of the rows of the unlettered diagram to form all possible legitimate Young diagrams that have no more than one a per column. In general, there will be several distinct diagrams, and all the a's appear in each diagram. At this stage, for the coupling of the two SU(3) octets, we have:

- (c) Use the b's to further enlarge the diagrams already obtained, subject to the same rules. Then throw away any diagram in which the full sequence of letters formed by reading right to left in the first row, then the second row, etc., is not admissible.
 - (d) Proceed as in (c) with the c's (if any), etc.

The final result of the coupling of the two SU(3) octets is:



Here only the diagrams with admissible sequences of a's and b's and with fewer than four rows (since n=3) have been kept. In terms of multiplet labels, the above may be written

$$(1,1) \otimes (1,1) = (2,2) \oplus (3,0) \oplus (0,3) \oplus (1,1) \oplus (1,1) \oplus (0,0)$$
.

In terms of numbers of particles, it may be written

$$\mathbf{8} \otimes \mathbf{8} = \mathbf{27} \oplus \mathbf{10} \oplus \overline{\mathbf{10}} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{1} \ .$$

The product of the numbers on the left here is equal to the sum on the right, a useful check. (See also Sec. 14 on the Quark Model.)

43. KINEMATICS

Revised January 2000 by J.D. Jackson (LBNL) and June 2008 by D.R. Tovey (Sheffield).

Throughout this section units are used in which $\hbar=c=1$. The following conversions are useful: $\hbar c=197.3$ MeV fm, $(\hbar c)^2=0.3894$ (GeV)² mb.

43.1. Lorentz transformations

The energy E and 3-momentum p of a particle of mass m form a 4-vector p=(E,p) whose square $p^2\equiv E^2-|p|^2=m^2$. The velocity of the particle is $\beta=p/E$. The energy and momentum (E^*,p^*) viewed from a frame moving with velocity β_f are given by

$$\begin{pmatrix} E^* \\ p_{\parallel}^* \end{pmatrix} = \begin{pmatrix} \gamma_f & -\gamma_f \beta_f \\ -\gamma_f \beta_f & \gamma_f \end{pmatrix} \begin{pmatrix} E \\ p_{\parallel} \end{pmatrix} \;, \quad p_T^* = p_T \;, \tag{43.1}$$

where $\gamma_f = (1-\beta_f^2)^{-1/2}$ and p_T (p_{\parallel}) are the components of p perpendicular (parallel) to β_f . Other 4-vectors, such as the spacetime coordinates of events, of course transform in the same way. The scalar product of two 4-momenta $p_1 \cdot p_2 = E_1 E_2 - p_1 \cdot p_2$ is invariant (frame independent).

43.2. Center-of-mass energy and momentum

In the collision of two particles of masses m_1 and m_2 the total center-of-mass energy can be expressed in the Lorentz-invariant form

$$E_{\rm cm} = \left[(E_1 + E_2)^2 - (\mathbf{p}_1 + \mathbf{p}_2)^2 \right]^{1/2} ,$$

= $\left[m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2\cos\theta) \right]^{1/2} ,$ (43.2)

where θ is the angle between the particles. In the frame where one particle (of mass m_2) is at rest (lab frame),

$$E_{\rm cm} = (m_1^2 + m_2^2 + 2E_{1\,\rm lab}\,m_2)^{1/2} \ . \tag{43.3}$$

The velocity of the center-of-mass in the lab frame is

$$\beta_{\rm cm} = p_{\rm lab}/(E_{1\,\rm lab} + m_2) ,$$
 (43.4)

where $p_{\mathrm{lab}} \equiv p_{\mathrm{1\,lab}}$ and

$$\gamma_{\rm cm} = (E_{1 \, \rm lab} + m_2)/E_{\rm cm} \ .$$
 (43.5)

The c.m. momenta of particles 1 and 2 are of magnitude

$$p_{\rm cm} = p_{\rm lab} \frac{m_2}{E_{\rm cm}} \ .$$
 (43.6)

For example, if a $0.80~{\rm GeV}/c$ kaon beam is incident on a proton target, the center of mass energy is $1.699~{\rm GeV}$ and the center of mass momentum of either particle is $0.442~{\rm GeV}/c$. It is also useful to note that

$$E_{\rm cm} dE_{\rm cm} = m_2 dE_{1 \, \rm lab} = m_2 \, \beta_{1 \, \rm lab} \, dp_{\rm lab} \ .$$
 (43.7)

43.3. Lorentz-invariant amplitudes

The matrix elements for a scattering or decay process are written in terms of an invariant amplitude $-i\mathcal{M}$. As an example, the S-matrix for $2 \to 2$ scattering is related to \mathcal{M} by

$$\langle p_1' p_2' | S | p_1 p_2 \rangle = I - i(2\pi)^4 \, \delta^4(p_1 + p_2 - p_1' - p_2')$$

$$\times \frac{\mathscr{M}(p_1, p_2; p_1', p_2')}{(2E_1)^{1/2} \, (2E_2)^{1/2} \, (2E_1')^{1/2} \, (2E_2')^{1/2}} \, . \quad (43.8)$$

The state normalization is such that

$$\langle p'|p\rangle = (2\pi)^3 \delta^3(\boldsymbol{p} - \boldsymbol{p}') . \tag{43.9}$$

43.4. Particle decays

The partial decay rate of a particle of mass M into n bodies in its rest frame is given in terms of the Lorentz-invariant matrix element $\mathcal M$ by

$$d\Gamma = \frac{(2\pi)^4}{2M} |\mathcal{M}|^2 d\Phi_n (P; p_1, \dots, p_n), \tag{43.10}$$

where $d\Phi_n$ is an element of n-body phase space given by

$$d\Phi_n(P; p_1, \dots, p_n) = \delta^4 \left(P - \sum_{i=1}^n p_i \right) \prod_{i=1}^n \frac{d^3 p_i}{(2\pi)^3 2E_i} . \tag{43.11}$$

This phase space can be generated recursively, viz.

$$d\Phi_n(P; p_1, ..., p_n) = d\Phi_j(q; p_1, ..., p_j)$$

$$\times d\Phi_{n-j+1}(P; q, p_{j+1}, \dots, p_n)(2\pi)^3 dq^2,$$
 (43.12)

where $q^2 = (\sum_{i=1}^j E_i)^2 - \left|\sum_{i=1}^j \mathbf{p}_i\right|^2$. This form is particularly useful in the case where a particle decays into another particle that subsequently decays.

43.4.1. Survival probability: If a particle of mass M has mean proper lifetime τ (= $1/\Gamma$) and has momentum (E, p), then the probability that it lives for a time t_0 or greater before decaying is given by

$$P(t_0) = e^{-t_0 \Gamma/\gamma} = e^{-Mt_0 \Gamma/E}$$
, (43.13)

and the probability that it travels a distance x_0 or greater is

$$P(x_0) = e^{-Mx_0 |\Gamma||p|}. (43.14)$$

43.4.2. Two-body decays:

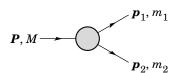


Figure 43.1: Definitions of variables for two-body decays.

In the rest frame of a particle of mass M, decaying into 2 particles labeled 1 and 2,

$$E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M} , (43.15)$$

$$|p_1| = |p_2|$$

$$= \frac{\left[\left(M^2 - (m_1 + m_2)^2\right)\left(M^2 - (m_1 - m_2)^2\right)\right]^{1/2}}{2M}, \quad (43.16)$$

and

$$d\Gamma = \frac{1}{32\pi^2} |\mathcal{M}|^2 \frac{|\mathbf{p}_1|}{M^2} d\Omega$$
, (43.17)

where $d\Omega = d\phi_1 d(\cos \theta_1)$ is the solid angle of particle 1. The invariant mass M can be determined from the energies and momenta using Eq. (43.2) with $M = E_{\rm cm}$.

43.4.3. Three-body decays:

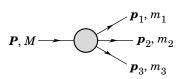


Figure 43.2: Definitions of variables for three-body decays.

Defining $p_{ij}=p_i+p_j$ and $m_{ij}^2=p_{ij}^2$, then $m_{12}^2+m_{23}^2+m_{13}^2=M^2+m_1^2+m_2^2+m_3^2$ and $m_{12}^2=(P-p_3)^2=M^2+m_3^2-2ME_3$, where E_3 is the energy of particle 3 in the rest frame of M. In that frame, the momenta of the three decay particles lie in a plane. The relative orientation of these three momenta is fixed if their energies are known. The momenta can therefore be specified in space by giving three Euler angles (α, β, γ) that specify the orientation of the final system relative to the initial particle [1]. Then

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M} |\mathcal{M}|^2 dE_1 dE_2 d\alpha d(\cos \beta) d\gamma . \tag{43.18}$$

Alternatively

$$d\Gamma = \frac{1}{(2\pi)^5} \frac{1}{16M^2} |\mathcal{M}|^2 |\mathbf{p}_1^*| |\mathbf{p}_3| dm_{12} d\Omega_1^* d\Omega_3 , \qquad (43.19)$$

where $(|p_1^*|, \Omega_1^*)$ is the momentum of particle 1 in the rest frame of 1 and 2, and Ω_3 is the angle of particle 3 in the rest frame of the decaying particle. $|p_1^*|$ and $|p_3|$ are given by

$$|\mathbf{p}_{1}^{*}| = \frac{\left[\left(m_{12}^{2} - (m_{1} + m_{2})^{2}\right)\left(m_{12}^{2} - (m_{1} - m_{2})^{2}\right)\right]^{1/2}}{2m_{12}}, \quad (43.20a)$$

$$|\mathbf{p}_3| = \frac{\left[\left(M^2 - (m_{12} + m_3)^2 \right) \left(M^2 - (m_{12} - m_3)^2 \right) \right]^{1/2}}{2M} \ . \tag{43.20b}$$

[Compare with Eq. (43.16).]

If the decaying particle is a scalar or we average over its spin states, then integration over the angles in Eq. (43.18) gives

$$d\Gamma = \frac{1}{(2\pi)^3} \frac{1}{8M} |\mathcal{M}|^2 dE_1 dE_2$$
$$= \frac{1}{(2\pi)^3} \frac{1}{32M^3} |\mathcal{M}|^2 dm_{12}^2 dm_{23}^2 . \tag{43.21}$$

This is the standard form for the Dalitz plot.

43.4.3.1. Dalitz plot: For a given value of m_{12}^2 , the range of m_{23}^2 is determined by its values when p_2 is parallel or antiparallel to p_3 :

$$(m_{23}^2)_{\rm max} =$$

$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} - \sqrt{E_3^{*2} - m_3^2}\right)^2 , (43.22a)$$

$$(m_{23}^2)_{\min} =$$

$$(m_{23}^2)_{\min} = (E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} + \sqrt{E_3^{*2} - m_3^2}\right)^2 . \tag{43.22b}$$

Here $E_2^* = (m_{12}^2 - m_1^2 + m_2^2)/2m_{12}$ and $E_3^* = (M^2 - m_{12}^2 - m_3^2)/2m_{12}$ are the energies of particles 2 and 3 in the m_{12} rest frame. The scatter plot in m_{12}^2 and m_{23}^2 is called a Dalitz plot. If $|\mathcal{M}|^2$ is constant, the allowed region of the plot will be uniformly populated with events [see Eq. (43.21)]. A nonuniformity in the plot gives immediate information on $|\mathcal{M}|^2$. For example, in the case of $D \to K\pi\pi$, bands appear when $m_{(K\pi)}=m_{K^*(892)}$, reflecting the appearance of the decay chain $D\to K^*(892)\pi\to K\pi\pi$.

43.4.4. Kinematic limits:

43.4.4.1. Three-body decays: In a three-body decay (Fig. 43.2) the maximum of $|p_3|$, [given by Eq. (43.20)], is achieved when $m_{12} = m_1 + m_2$, i.e., particles 1 and 2 have the same vector velocity in the rest frame of the decaying particle. If, in addition, $m_3 > m_1, m_2$, then $|\boldsymbol{p}_3|_{\max} > |\boldsymbol{p}_1|_{\max}$, $|\boldsymbol{p}_2|_{\max}$. The distribution of m_{12} values possesses an end-point or maximum value at $m_{12} = M - m_3$. This can be used to constrain the mass difference of a parent particle and one invisible decay product.

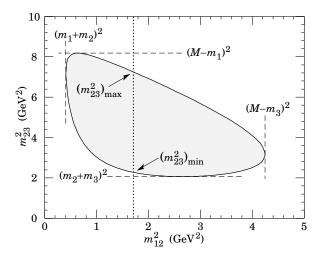


Figure 43.3: Dalitz plot for a three-body final state. In this example, the state is $\pi^+ \overline{K}{}^0 p$ at 3 GeV. Four-momentum conservation restricts events to the shaded region.

43.4.4.2. Sequential two-body decays:

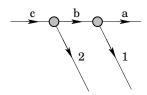


Figure 43.4: Particles participating in sequential two-body decay chain. Particles labeled 1 and 2 are visible while the particle terminating the chain (a) is invisible.

When a heavy particle initiates a sequential chain of two-body decays terminating in an invisible particle, constraints on the masses of the states participating in the chain can be obtained from end-points and thresholds in invariant mass distributions of the aggregated decay products. For the two-step decay chain depicted in Fig. 43.4 the invariant mass distribution of the two visible particles possesses an end-point given by:

$$(m_{12}^{\text{max}})^2 = \frac{(m_{\rm c}^2 - m_{\rm b}^2)(m_{\rm b}^2 - m_{\rm a}^2)}{m_{\rm b}^2} ,$$
 (43.23)

provided particles 1 and 2 are massless. If visible particle 1 has non-zero mass m_1 then Eq. (43.23) is replaced by

$$(m_{12}^{\text{max}})^2 = m_1^2 + \frac{(m_c^2 - m_b^2)}{2m_b^2} \times$$

$$\left(m_1^2 + m_{\rm b}^2 - m_{\rm a}^2 + \sqrt{(-m_1^2 + m_{\rm b}^2 - m_{\rm a}^2)^2 - 4m_1^2 m_{\rm a}^2}\right). \tag{43.24}$$

See Refs. 2 and 3 for other cases.

43.4.5. Multibody decays: The above results may be generalized to final states containing any number of particles by combining some of the particles into "effective particles" and treating the final states as 2 or 3 "effective particle" states. Thus, if $p_{ijk...} = p_i + p_j + p_k + \ldots$,

$$m_{ijk...} = \sqrt{p^2_{ijk...}} , \qquad (43.25)$$

and $m_{ijk...}$ may be used in place of e.g., m_{12} in the relations in Sec. 43.4.3 or Sec. 43.4.4 above.

43.5. Cross sections

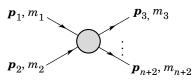


Figure 43.5: Definitions of variables for production of an n-body final state.

The differential cross section is given by

$$d\sigma = \frac{(2\pi)^4 |\mathcal{M}|^2}{4\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2}} \times d\Phi_n(p_1 + p_2; p_3, \dots, p_{n+2}) . \tag{43.26}$$

[See Eq. (43.11).] In the rest frame of $m_2(lab)$,

$$\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2} = m_2 p_{1 \, \text{lab}} ; \qquad (43.27a)$$

while in the center-of-mass frame

$$\sqrt{(p_1 \cdot p_2)^2 - m_1^2 m_2^2} = p_{1\text{cm}} \sqrt{s} \ . \tag{43.27b}$$

43.5.1. Two-body reactions:

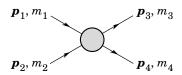


Figure 43.6: Definitions of variables for a two-body final state.

Two particles of momenta p_1 and p_2 and masses m_1 and m_2 scatter to particles of momenta p_3 and p_4 and masses m_3 and m_4 ; the Lorentz-invariant Mandelstam variables are defined by

$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$

= $m_1^2 + 2E_1E_2 - 2\mathbf{p}_1 \cdot \mathbf{p}_2 + m_2^2$, (43.28)
$$t = (p_1 - p_3)^2 = (p_2 - p_4)^2$$

$$t - (p_1 - p_3) - (p_2 - p_4)$$

$$= m_1^2 - 2E_1E_3 + 2\mathbf{p}_1 \cdot \mathbf{p}_3 + m_3^2 , \qquad (43.29)$$

$$u = (p_1 - p_4)^2 = (p_2 - p_3)^2$$

= $m_1^2 - 2E_1E_4 + 2\mathbf{p}_1 \cdot \mathbf{p}_4 + m_4^2$, (43.30)

and they satisfy

$$s + t + u = m_1^2 + m_2^2 + m_3^2 + m_4^2$$
 (43.31)

The two-body cross section may be written as

$$\frac{d\sigma}{dt} = \frac{1}{64\pi s} \frac{1}{|\mathbf{p}_{1cm}|^2} |\mathcal{M}|^2.$$
 (43.32)

In the center-of-mass frame

$$t = (E_{1\text{cm}} - E_{3\text{cm}})^2 - (p_{1\text{cm}} - p_{3\text{cm}})^2 - 4p_{1\text{cm}} p_{3\text{cm}} \sin^2(\theta_{\text{cm}}/2)$$
$$= t_0 - 4p_{1\text{cm}} p_{3\text{cm}} \sin^2(\theta_{\text{cm}}/2) , \qquad (43.33)$$

where $\theta_{\rm cm}$ is the angle between particle 1 and 3. The limiting values t_0 ($\theta_{\rm cm}=0$) and t_1 ($\theta_{\rm cm}=\pi$) for $2\to 2$ scattering are

$$t_0(t_1) = \left[\frac{m_1^2 - m_3^2 - m_2^2 + m_4^2}{2\sqrt{s}}\right]^2 - (p_{1 \text{ cm}} \mp p_{3 \text{ cm}})^2 . \tag{43.34}$$

In the literature the notation t_{\min} (t_{\max}) for t_0 (t_1) is sometimes used, which should be discouraged since $t_0 > t_1$. The center-of-mass energies and momenta of the incoming particles are

$$E_{1{\rm cm}} = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}} \ , \qquad E_{2{\rm cm}} = \frac{s + m_2^2 - m_1^2}{2\sqrt{s}} \ , \eqno(43.35)$$

For $E_{3\mathrm{cm}}$ and $E_{4\mathrm{cm}}$, change m_1 to m_3 and m_2 to m_4 . Then

$$p_{i\,{\rm cm}} = \sqrt{E_{i\,{\rm cm}}^2 - m_i^2}$$
 and $p_{1{\rm cm}} = \frac{p_{1\,{\rm lab}} \, m_2}{\sqrt{s}}$. (43.36)

Here the subscript lab refers to the frame where particle 2 is at rest. [For other relations see Eqs. (43.2)–(43.4).]

43.5.2. *Inclusive reactions*: Choose some direction (usually the beam direction) for the z-axis; then the energy and momentum of a particle can be written as

$$E = m_T \cosh y \; , \; p_x \; , \; p_y \; , \; p_z = m_T \sinh y \; , \eqno(43.37)$$

where m_T , conventionally called the 'transverse mass', is given by

$$m_T^2 = m^2 + p_x^2 + p_y^2 \ . (43.38)$$

and the rapidity y is defined by

$$y = \frac{1}{2} \ln \left(\frac{E + p_z}{E - p_z} \right)$$

$$= \ln \left(\frac{E + p_z}{m_T} \right) = \tanh^{-1} \left(\frac{p_z}{E} \right) . \tag{43.39}$$

Note that the definition of the transverse mass in Eq. (43.38) differs from that used by experimentalists at hadron colliders (see Sec. 43.6.1 below). Under a boost in the z-direction to a frame with velocity β , $y \to y - \tanh^{-1}\beta$. Hence the shape of the rapidity distribution dN/dy is invariant, as are differences in rapidity. The invariant cross section may also be rewritten

$$E \frac{d^3 \sigma}{d^3 p} = \frac{d^3 \sigma}{d \phi \, dy \, p_T dp_T} \Longrightarrow \frac{d^2 \sigma}{\pi \, dy \, d(p_T^2)} \; . \eqno(43.40)$$

The second form is obtained using the identity $dy/dp_z = 1/E$, and the third form represents the average over ϕ .

Feynman's x variable is given by

$$x = \frac{p_z}{p_{z\,\mathrm{max}}} \approx \frac{E + p_z}{(E + p_z)_{\mathrm{max}}} \quad (p_T \ll |p_z|) \ . \tag{43.41} \label{eq:43.41}$$

In the c.m. frame.

$$x \approx \frac{2p_{z\,\mathrm{cm}}}{\sqrt{s}} = \frac{2m_T\,\mathrm{sinh}\,y_\mathrm{cm}}{\sqrt{s}} \tag{43.42}$$

and

$$= (y_{\rm cm})_{\rm max} = \ln(\sqrt{s}/m)$$
 (43.43)

The invariant mass M of the two-particle system described in Sec. 43.4.2 can be written in terms of these variables as

$$M^{2} = m_{1}^{2} + m_{2}^{2} + 2[E_{T}(1)E_{T}(2)\cosh\Delta y - \mathbf{p}_{T}(1)\cdot\mathbf{p}_{T}(2)], \quad (43.44)$$

where

$$E_T(i) = \sqrt{|\mathbf{p}_T(i)|^2 + m_i^2}$$
, (43.45)

and $p_T(i)$ denotes the transverse momentum vector of particle i.

For $p \gg m$, the rapidity [Eq. (43.39)] may be expanded to obtain

$$y = \frac{1}{2} \ln \frac{\cos^2(\theta/2) + m^2/4p^2 + \dots}{\sin^2(\theta/2) + m^2/4p^2 + \dots}$$

$$\approx -\ln \tan(\theta/2) \equiv n$$
 (43.46)

where $\cos\theta=p_z/p$. The pseudorapidity η defined by the second line is approximately equal to the rapidity y for $p\gg m$ and $\theta\gg 1/\gamma$, and in any case can be measured when the mass and momentum of the particle are unknown. From the definition one can obtain the identities

$$\sinh \eta = \cot \theta$$
, $\cosh \eta = 1/\sin \theta$, $\tanh \eta = \cos \theta$. (43.47)

43.5.3. *Partial waves*: The amplitude in the center of mass for elastic scattering of spinless particles may be expanded in Legendre polynomials

$$f(k,\theta) = \frac{1}{k} \sum_{\ell} (2\ell + 1) a_{\ell} P_{\ell}(\cos \theta) ,$$
 (43.48)

where k is the c.m. momentum, θ is the c.m. scattering angle, $a_{\ell} = (\eta_{\ell}e^{2i\delta_{\ell}} - 1)/2i$, $0 \leq \eta_{\ell} \leq 1$, and δ_{ℓ} is the phase shift of the ℓ^{th} partial wave. For purely elastic scattering, $\eta_{\ell} = 1$. The differential cross section is

$$\frac{d\sigma}{d\Omega} = |f(k,\theta)|^2 . \tag{43.49}$$

The optical theorem states that

$$\sigma_{\text{tot}} = \frac{4\pi}{k} \text{Im} f(k, 0) , \qquad (43.50)$$

and the cross section in the ℓ^{th} partial wave is therefore bounded:

$$\sigma_{\ell} = \frac{4\pi}{k^2} (2\ell + 1)|a_{\ell}|^2 \le \frac{4\pi (2\ell + 1)}{k^2} . \tag{43.51}$$

The evolution with energy of a partial-wave amplitude a_{ℓ} can be displayed as a trajectory in an Argand plot, as shown in Fig. 43.7.

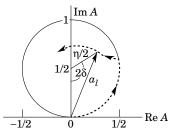


Figure 43.7: Argand plot showing a partial-wave amplitude a_{ℓ} as a function of energy. The amplitude leaves the unitary circle where inelasticity sets in $(\eta_{\ell} < 1)$.

The usual Lorentz-invariant matrix element \mathcal{M} (see Sec. 43.3 above) for the elastic process is related to $f(k, \theta)$ by

$$\mathcal{M} = -8\pi\sqrt{s} f(k,\theta) , \qquad (43.52)$$

so

$$\sigma_{\text{tot}} = -\frac{1}{2p_{\text{lab}} m_2} \text{Im} \mathcal{M}(t=0) ,$$
 (43.53)

where s and t are the center-of-mass energy squared and momentum transfer squared, respectively (see Sec. 43.4.1).

43.5.3.1. Resonances: The Breit-Wigner (nonrelativistic) form for an elastic amplitude a_ℓ with a resonance at c.m. energy E_R , elastic width $\Gamma_{\rm el}$, and total width $\Gamma_{\rm tot}$ is

$$a_{\ell} = \frac{\Gamma_{\rm el}/2}{E_R - E - i\Gamma_{\rm tot}/2} , \qquad (43.54)$$

where E is the c.m. energy. As shown in Fig. 43.8, in the absence of background the elastic amplitude traces a counterclockwise circle with center $ix_{\rm el}/2$ and radius $x_{\rm el}/2$, where the elasticity $x_{\rm el}=\Gamma_{\rm el}/\Gamma_{\rm tot}$. The amplitude has a pole at $E=E_R-i\Gamma_{\rm tot}/2$.

The spin-averaged Breit-Wigner cross section for a spin-J resonance produced in the collision of particles of spin S_1 and S_2 is

$$\sigma_{BW}(E) = \frac{(2J+1)}{(2S_1+1)(2S_2+1)} \frac{\pi}{k^2} \frac{B_{\rm in} B_{\rm out} \Gamma_{\rm tot}^2}{(E-E_R)^2 + \Gamma_{\rm tot}^2/4} , \quad (43.55)$$

where k is the c.m. momentum, E is the c.m. energy, and $B_{\rm in}$ and $B_{\rm out}$ are the branching fractions of the resonance into the entrance and exit channels. The 2S+1 factors are the multiplicities of the incident spin states, and are replaced by 2 for photons. This expression is valid only for an isolated state. If the width is not small, $\Gamma_{\rm tot}$ cannot be treated as a constant independent of E. There are many other forms for σ_{BW} , all of which are equivalent to the one given here in the narrow-width case. Some of these forms may be more appropriate if the resonance is broad.

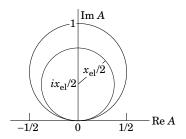


Figure 43.8: Argand plot for a resonance.

The relativistic Breit-Wigner form corresponding to Eq. (43.54) is:

$$a_{\ell} = \frac{-m\Gamma_{\rm el}}{s - m^2 + im\Gamma_{\rm tot}} \ . \tag{43.56}$$

A better form incorporates the known kinematic dependences, replacing $m\Gamma_{\rm tot}$ by $\sqrt{s}\,\Gamma_{\rm tot}(s)$, where $\Gamma_{\rm tot}(s)$ is the width the resonance particle would have if its mass were \sqrt{s} , and correspondingly $m\Gamma_{\rm el}$ by $\sqrt{s}\,\Gamma_{\rm el}(s)$ where $\Gamma_{\rm el}(s)$ is the partial width in the incident channel for a mass \sqrt{s} :

$$a_{\ell} = \frac{-\sqrt{s}\,\Gamma_{\rm el}(s)}{s - m^2 + i\sqrt{s}\,\Gamma_{\rm tot}(s)} \ . \tag{43.57}$$

For the Z boson, all the decays are to particles whose masses are small enough to be ignored, so on dimensional grounds $\Gamma_{\rm tot}(s)=\sqrt{s}\,\Gamma_0/m_Z$, where Γ_0 defines the width of the Z, and $\Gamma_{\rm el}(s)/\Gamma_{\rm tot}(s)$ is constant. A full treatment of the line shape requires consideration of dynamics, not just kinematics. For the Z this is done by calculating the radiative corrections in the Standard Model.

43.6. Transverse variables

At hadron colliders, a significant and unknown proportion of the energy of the incoming hadrons in each event escapes down the beam-pipe. Consequently if invisible particles are created in the final state, their net momentum can only be constrained in the plane transverse to the beam direction. Defining the z-axis as the beam direction, this net momentum is equal to the missing transverse energy vector

$$\boldsymbol{E}_{T}^{\text{miss}} = -\sum_{i} \boldsymbol{p}_{T}(i) , \qquad (43.58)$$

where the sum runs over the transverse momenta of all visible final state particles.

43.6.1. Single production with semi-invisible final state:

Consider a single heavy particle of mass M produced in association with visible particles which decays as in Fig. 43.1 to two particles, of which one (labeled particle 1) is invisible. The mass of the parent particle can be constrained with the quantity M_T defined by

$$\begin{split} M_T^2 &\equiv [E_T(1) + E_T(2)]^2 - [\boldsymbol{p}_T(1) + \boldsymbol{p}_T(2)]^2 \\ &= m_1^2 + m_2^2 + 2[E_T(1)E_T(2) - \boldsymbol{p}_T(1) \cdot \boldsymbol{p}_T(2)] \;, \quad (43.59) \end{split}$$

where

$$\boldsymbol{p}_T(1) = \boldsymbol{E}_T^{\text{miss}} \,. \tag{43.60}$$

This quantity is called the 'transverse mass' by hadron collider experimentalists but it should be noted that it is quite different from that used in the description of inclusive reactions [Eq. (43.38)]. The distribution of event M_T values possesses an end-point at $M_T^{\rm max}=M$. If $m_1=m_2=0$ then

$$M_T^2 = 2|\mathbf{p}_T(1)||\mathbf{p}_T(2)|(1-\cos\phi_{12})$$
, (43.61)

where ϕ_{ij} is defined as the angle between particles i and j in the transverse plane.

${\bf 43.6.2.} \quad Pair\ production\ with\ semi-invisible\ final\ states:$

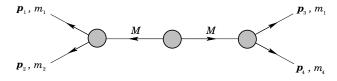


Figure 43.9: Definitions of variables for pair production of semi-invisible final states. Particles 1 and 3 are invisible while particles 2 and 4 are visible.

Consider two identical heavy particles of mass M produced such that their combined center-of-mass is at rest in the transverse plane (Fig. 43.9). Each particle decays to a final state consisting of an invisible particle of fixed mass m_1 together with an additional visible particle. M and m_1 can be constrained with the variables M_{T2} and M_{CT} which are defined in Refs. [4] and [5].

References:

- See, for example, J.J. Sakurai, Modern Quantum Mechnaics, Addison-Wesley (1985), p. 172, or D.M. Brink and G.R. Satchler, Angular Momentum, 2nd ed., Oxford University Press (1968), p. 20.
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44. CROSS-SECTION FORMULAE FOR SPECIFIC PROCESSES

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PART I: STANDARD MODEL PROCESSES

Setting aside leptoproduction (for which, see Sec. 16 of this Review), the cross sections of primary interest are those with light incident particles, e^+e^- , $\gamma\gamma$, $q\overline{q}$, gq, gg, etc., where g and q represent gluons and light quarks. The produced particles include both light particles and heavy ones - t, W, Z, and the Higgs boson H. We provide the production cross sections calculated within the Standard Model for several such processes.

44.1. Resonance Formation

Resonant cross sections are generally described by the Breit-Wigner formula (Sec. 18 of this Review).

$$\sigma(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)} \frac{4\pi}{k^2} \left[\frac{\Gamma^2/4}{(E-E_0)^2 + \Gamma^2/4} \right] B_{in} B_{out}, \quad (44.1)$$

where E is the c.m. energy, J is the spin of the resonance, and the number of polarization states of the two incident particles are $2S_1+1$ and $2S_2+1$. The c.m. momentum in the initial state is k, E_0 is the c.m. energy at the resonance, and Γ is the full width at half maximum height of the resonance. The branching fraction for the resonance into the initial-state channel is B_{in} and into the final-state channel is B_{out} . For a narrow resonance, the factor in square brackets may be replaced by $\pi\Gamma\delta(E-E_0)/2$.

44.2. Production of light particles

The production of point-like, spin-1/2 fermions in e^+e^- annihilation through a virtual photon, $e^+e^- \to \gamma^* \to f\overline{f}$, at c.m. energy squared s is given by

$$\frac{d\sigma}{d\Omega} = N_c \frac{\alpha^2}{4\epsilon} \beta \left[1 + \cos^2 \theta + (1 - \beta^2) \sin^2 \theta \right] Q_f^2 , \qquad (44.2)$$

where β is v/c for the produced fermions in the c.m., θ is the c.m. scattering angle, and Q_f is the charge of the fermion. The factor N_c is 1 for charged leptons and 3 for quarks. In the ultrarelativistic limit, $\beta \to 1$,

$$\sigma = N_c Q_f^2 \frac{4\pi\alpha^2}{3s} = N_c Q_f^2 \frac{86.8 \text{ nb}}{s \text{ (GeV}^2)}.$$
 (44.3)

The cross section for the annihilation of a $q\overline{q}$ pair into a distinct pair $q'\overline{q}'$ through a gluon is completely analogous up to color factors, with the replacement $\alpha \to \alpha_s$. Treating all quarks as massless, averaging over the colors of the initial quarks and defining $t = -s \sin^2(\theta/2)$, $u = -s \cos^2(\theta/2)$, one finds [1]

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to q'\overline{q}') = \frac{\alpha_s^2}{9s} \frac{t^2 + u^2}{s^2} \ . \tag{44.4}$$

Crossing symmetry gives

$$\frac{d\sigma}{d\Omega}(qq' \rightarrow qq') = \frac{\alpha_s^2}{\alpha_s} \frac{s^2 + u^2}{t^2}$$
. (44.5)

If the quarks q and q' are identical, we have

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to q\overline{q}) = \frac{\alpha_s^2}{9s} \left[\frac{t^2 + u^2}{s^2} + \frac{s^2 + u^2}{t^2} - \frac{2u^2}{3st} \right] , \qquad (44.6)$$

and by crossing

$$\frac{d\sigma}{d\Omega}(qq\rightarrow qq) = \frac{\alpha_s^2}{9s} \left[\frac{t^2+s^2}{u^2} + \frac{s^2+u^2}{t^2} - \frac{2s^2}{3ut} \right]. \tag{44.7} \label{eq:44.7}$$

Annihilation of e^+e^- into $\gamma\gamma$ has the cross section

$$\frac{d\sigma}{d\Omega}(e^+e^- \to \gamma\gamma) = \frac{\alpha^2}{2s} \frac{u^2 + t^2}{tu} \ . \tag{44.8}$$

The related QCD process also has a triple-gluon coupling. The cross section is

$$\frac{d\sigma}{d\Omega}(q\overline{q} \to gg) = \frac{8\alpha_s^2}{27s}(t^2 + u^2)\left(\frac{1}{tu} - \frac{9}{4s^2}\right). \tag{44.9}$$

The crossed reactions are

$$\frac{d\sigma}{d\Omega}(qg\rightarrow qg) = \frac{\alpha_s^2}{9s}(s^2+u^2)(-\frac{1}{su}+\frac{9}{4t^2}) \eqno(44.10)$$

and

$$\frac{d\sigma}{d\Omega}(gg\to q\overline{q}) = \frac{\alpha_s^2}{24s}(t^2+u^2)(\frac{1}{tu}-\frac{9}{4s^2})\;. \eqno(44.11)$$

Finally,

$$\frac{d\sigma}{d\Omega}(gg\to gg) = \frac{9\alpha_s^2}{8s}(3-\frac{ut}{s^2}-\frac{su}{t^2}-\frac{st}{u^2})\ . \eqno(44.12)$$

Lepton-quark scattering is analogous (neglecting Z exchange)

$$\frac{d\sigma}{d\Omega}(eq \to eq) = \frac{\alpha^2}{2s}e_q^2 \frac{s^2 + u^2}{t^2} \ . \tag{44.13}$$

where e_q is the charge of the quark. For neutrino scattering with the four-Fermi interaction

$$\frac{d\sigma}{d\Omega}(\nu d \to \ell^- u) = \frac{G_F^2 s}{4\pi^2} , \qquad (44.14)$$

where the Cabibbo angle suppression is ignored. Similarly

$$\frac{d\sigma}{d\Omega}(\nu \overline{u} \to \ell^+ \overline{d}) = \frac{G_F^2 s}{4\pi^2} \frac{(1 + \cos \theta)^2}{4} \ . \tag{44.15}$$

To obtain the formulae for deep inelastic scattering (presented in more detail in Section 16) we consider quarks of type i carrying a fraction $x=Q^2/(2M\nu)$ of the nucleon's energy, where $\nu=E-E'$ is the energy lost by the lepton in the nucleon rest frame. With $y=\nu/E$ we have the correspondences

$$1 + \cos \theta \rightarrow 2(1 - y)$$
,
 $d\Omega_{cm} \rightarrow 4\pi f_i(x) dx dy$, (44.16)

where the latter incorporates the quark distribution, $f_i(x)$. In this way we find

$$\frac{d\sigma}{dx\,dy}(eN \to eX) = \frac{4\pi\alpha^2 xs}{Q^4} \frac{1}{2} \left[1 + (1-y)^2 \right] \times \left[\frac{4}{9} (u(x) + \overline{u}(x) + \ldots) + \frac{1}{9} (d(x) + \overline{d}(x) + \ldots) \right] (44.17)$$

where now s=2ME is the cm energy squared for the electron-nucleon collision and we have suppressed contributions from higher mass quarks.

Similarly,

$$\frac{d\sigma}{dx\,du}(\nu N \to \ell^{-}X) = \frac{G_F^2 x s}{\pi} [(d(x) + \ldots) + (1-y)^2(\overline{u}(x) + \ldots)] \quad (44.18)$$

and

$$\frac{d\sigma}{dx\,dy}(\overline{\nu}N \to \ell^+ X) = \frac{G_F^2 x s}{\pi} [(\overline{d}(x) + \ldots) + (1 - y)^2 (u(x) + \ldots)] . \quad (44.19)$$

Quasi-elastic neutrino scattering $(\nu_{\mu}n \to \mu^{-}p, \overline{\nu}_{\mu}p \to \mu^{+}n)$ is directly related to the crossed reaction, neutron decay. The formula for the differential cross section is presented, for example, in N.J. Baker *et al.*, Phys. Rev. **D23**, 2499 (1981).

44.3. Hadroproduction of heavy quarks

For hadroproduction of heavy quarks $Q=c,\ b,\ t,$ it is important to include mass effects in the formulae. For $q\bar q\to Q\bar Q$, one has

$$\frac{d\sigma}{d\Omega}(q\bar{q}\to Q\bar{Q}) = \frac{\alpha_s^2}{9s^3} \left[(m_Q^2 - t)^2 + (m_Q^2 - u)^2 + 2m_Q^2 s \right], \quad (44.20)$$

while for $gg \to Q\bar{Q}$ one has

$$\begin{split} \frac{d\sigma}{d\Omega}(gg \to Q\bar{Q}) &= \frac{\alpha_s^2}{32s} \left[\frac{6}{s^2} (m_Q^2 - t)(m_Q^2 - u) - \frac{m_Q^2(s - 4m_Q^2)}{3(m_Q^2 - t)(m_Q^2 - u)} + \right. \\ &\qquad \qquad \left. \frac{4}{3} \frac{(m_Q^2 - t)(m_Q^2 - u) - 2m_Q^2(m_Q^2 + t)}{(m_Q^2 - t)^2} \right. \\ &\qquad \qquad \left. + \frac{4}{3} \frac{(m_Q^2 - t)(m_Q^2 - u) - 2m_Q^2(m_Q^2 + u)}{(m_Q^2 - u)^2} \right. \\ &\qquad \qquad \left. - \left[.3 \frac{(m_Q^2 - t)(m_Q^2 - u) + m_Q^2(u - t)}{s(m_Q^2 - t)} \right. \\ &\qquad \qquad \left. - 3 \frac{(m_Q^2 - t)(m_Q^2 - u) + m_Q^2(t - u)}{s(m_Q^2 - u)} \right]. \end{split} \tag{44.21}$$

44.4. Production of Weak Gauge Bosons

44.4.1. W and Z resonant production:

Resonant production of a single W or Z is governed by the partial widths

$$\Gamma(W \to \ell_i \overline{\nu}_i) = \frac{\sqrt{2} G_F m_W^3}{12\pi}$$

$$\Gamma(W \to q_i \overline{q}_j) = 3 \frac{\sqrt{2} G_F |V_{ij}|^2 m_W^3}{12\pi}$$

$$\Gamma(Z \to f \overline{f}) = N_c \frac{\sqrt{2} G_F m_Z^3}{6\pi}$$

$$\times \left[(T_3 - Q_f \sin^2 \theta_W)^2 + (Q_f \sin \theta_W)^2 \right] . (44.24)$$

The weak mixing angle is θ_W . The CKM matrix elements are indicated by V_{ij} and N_c is 3 for $q\overline{q}$ final states and 1 for leptonic final states.

The full differential cross section for $f_i\overline{f}_j\to (W,Z)\to f_{i'}\overline{f}_{j'}$ is given by

$$\frac{d\sigma}{d\Omega} = \frac{N_c^f}{N_c^i} \cdot \frac{1}{256\pi^2 s} \cdot \frac{s^2}{(s - M^2)^2 + s\Gamma^2}
\times \left[(L^2 + R^2)(L'^2 + R'^2)(1 + \cos^2 \theta) \right]
+ (L^2 - R^2)(L'^2 - R'^2)2 \cos \theta$$
(44.25)

where M is the mass of the W or Z. The couplings for the W are $L=(8G_Fm_W^2/\sqrt{2})^{1/2}V_{ij}/\sqrt{2}; R=0$ where V_{ij} is the corresponding CKM matrix element, with an analogous expression for L' and R'. For Z, the couplings are $L=(8G_Fm_Z^2/\sqrt{2})^{1/2}(T_3-\sin^2\theta_WQ); R=-(8G_Fm_Z^2/\sqrt{2})^{1/2}\sin^2\theta_WQ$, where T_3 is the weak isospin of the initial left-handed fermion and Q is the initial fermion's electric charge. The expressions for L' and R' are analogous. The color factors $N_c^{i,f}$ are 3 for initial or final quarks and 1 for initial or final leptons.

44.4.2. Production of pairs of weak gauge bosons:

The cross section for $f\overline{f} \to W^+W^-$ is given in term of the couplings of the left-handed and right-handed fermion $f,\ \ell=2(T_3-Qx_W),\ r=-2Qx_W,$ where T_3 is the third component of weak isospin for the left-handed $f,\ Q$ is its electric charge (in units of the proton charge), and $x_W=\sin^2\theta_W$:

$$\begin{split} \frac{d\sigma}{dt} &= \frac{2\pi\alpha^2}{N_c s^2} \Biggl\{ \Biggl[\Biggl(Q + \frac{\ell + r}{4x_W} \frac{s}{s - m_Z^2} \Biggr)^2 + \Biggl(\frac{\ell - r}{4x_W} \frac{s}{s - m_Z^2} \Biggr)^2 \Biggr] A(s, t, u) \\ &+ \frac{1}{2x_W} \Biggl(Q + \frac{\ell}{2x_W} \frac{s}{s - m_Z^2} \Biggr) \left(\Theta(-Q) I(s, t, u) - \Theta(Q) I(s, u, t) \right) \\ &+ \frac{1}{8x_W^2} \left(\Theta(-Q) E(s, t, u) + \Theta(Q) E(s, u, t) \right) \Biggr\} \,, \end{split}$$
(44.26)

where $\Theta(x)$ is 1 for x > 0 and 0 for x < 0, and where

$$A(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right) \left(\frac{1}{4} - \frac{m_W^2}{s} + 3\frac{m_W^4}{s^2}\right) + \frac{s}{m_W^2} - 4,$$

$$I(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right) \left(\frac{1}{4} - \frac{m_W^2}{2s} - \frac{m_W^4}{st}\right) + \frac{s}{m_W^2} - 2 + 2\frac{m_W^2}{t},$$

$$E(s,t,u) = \left(\frac{tu}{m_W^4} - 1\right) \left(\frac{1}{4} + \frac{m_W^4}{t^2}\right) + \frac{s}{m_W^2},$$

$$(44.27)$$

and s,t,u are the usual Mandelstam variables with $s=(p_f+p_{\overline{f}})^2,t=(p_f-p_{W^-})^2,u=(p_f-p_{W^+})^2$. The factor N_c is 3 for quarks and 1 for leptons.

The analogous cross-section for $q_i\overline{q}_j\to W^\pm Z^0$ is

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2 |V_{ij}|^2}{6s^2 x_W^2} \left\{ \left(\frac{1}{s - m_W^2} \right)^2 \left[\left(\frac{9 - 8x_W}{4} \right) \left(ut - m_W^2 m_Z^2 \right) \right. \right. \\
+ \left. \left(8x_W - 6 \right) s \left(m_W^2 + m_Z^2 \right) \right] \\
+ \left[\frac{ut - m_W^2 m_Z^2 - s(m_W^2 + m_Z^2)}{s - m_W^2} \right] \left[\frac{\ell_j}{t} - \frac{\ell_i}{u} \right] \\
+ \left. \frac{ut - m_W^2 m_Z^2}{4(1 - x_W)} \left[\frac{\ell_j^2}{t^2} + \frac{\ell_i^2}{u^2} \right] + \frac{s(m_W^2 + m_Z^2)}{2(1 - x_W)} \frac{\ell_i \ell_j}{tu} \right\}, \quad (44.28)$$

where ℓ_i and ℓ_j are the couplings of the left-handed q_i and q_j as defined above. The CKM matrix element between q_i and q_j is V_{ij} .

The cross section for $q_i \overline{q}_i \to Z^0 Z^0$ is

$$\frac{d\sigma}{dt} = \frac{\pi\alpha^2}{96} \frac{\ell_i^4 + r_i^4}{x_W^2 (1 - x_W^2)^2 s^2} \left[\frac{t}{u} + \frac{u}{t} + \frac{4m_Z^2 s}{tu} - m_Z^4 \left(\frac{1}{t^2} + \frac{1}{u^2} \right) \right]. \tag{44.29}$$

44.5. Production of Higgs Bosons

44.5.1. Resonant Production:

The Higgs boson of the Standard Model can be produced resonantly in the collisions of quarks, leptons, W or Z bosons, gluons, or photons. The production cross section is thus controlled by the partial width of the Higgs boson into the entrance channel and its total width. The branching fractions for the Standard Model Higgs boson are shown in Fig. 1 of the "Searches for Higgs bosons" review in the Particle Listings section, as a function of the Higgs boson mass. The partial widths are given by the relations

$$\Gamma(H \to f\overline{f}) = \frac{G_F m_f^2 m_H N_c}{4\pi\sqrt{2}} \left(1 - 4m_f^2/m_H^2\right)^{3/2}, (44.30)$$

$$\Gamma(H \to W^+W^-) = \frac{G_F m_H^3 \beta_W}{32\pi\sqrt{2}} \left(4 - 4a_W + 3a_W^2\right), (44.31)$$

$$\Gamma(H \to ZZ) = \frac{G_F m_H^3 \beta_Z}{64\pi\sqrt{2}} \left(4 - 4a_Z + 3a_Z^2 \right),$$
 (44.32)

where N_c is 3 for quarks and 1 for leptons and where $a_W = 1 - \beta_W^2 = 4m_W^2/m_H^2$ and $a_Z = 1 - \beta_Z^2 = 4m_Z^2/m_H^2$. The decay to two gluons proceeds through quark loops, with the t quark dominating [2]. Explicitly,

$$\Gamma(H \to gg) = \frac{\alpha_s^2 G_F m_H^3}{36\pi^3 \sqrt{2}} \left| \sum_q I(m_q^2/m_H^2) \right|^2, \tag{44.33}$$

where I(z) is complex for z < 1/4. For $z < 2 \times 10^{-3}$, |I(z)| is small so the light quarks contribute negligibly. For $m_H < 2m_t$, z > 1/4 and

$$I(z) = 3 \left[2z + 2z(1 - 4z) \left(\sin^{-1} \frac{1}{2\sqrt{z}} \right)^2 \right], \tag{44.34}$$

which has the limit $I(z) \to 1$ as $z \to \infty$.

44.5.2. Higgs Boson Production in W^* and Z^* decay:

The Standard Model Higgs boson can be produced in the decay of a virtual W or Z ("Higgstrahlung") [3,4]: In particular, if k is the c.m. momentum of the Higgs boson,

$$\sigma(q_i \overline{q}_j \to WH) = \frac{\pi \alpha^2 |V_{ij}|^2}{36 \sin^4 \theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_W^2}{(s - m_W^2)^2}$$
(44.35)

$$\sigma(f\overline{f} \to ZH) = \frac{2\pi\alpha^2(\ell_f^2 + r_f^2)}{48N_c \sin^4 \theta_W \cos^4 \theta_W} \frac{2k}{\sqrt{s}} \frac{k^2 + 3m_Z^2}{(s - m_Z^2)^2}, (44.36)$$

where ℓ and r are defined as above.

44.5.3. W and Z Fusion:

Just as high-energy electrons can be regarded as sources of virtual photon beams, at very high energies they are sources of virtual W and Z beams. For Higgs boson production, it is the longitudinal components of the Ws and Zs that are important [5]. The distribution of longitudinal Ws carrying a fraction y of the electron's energy is [6]

$$f(y) = \frac{g^2}{16\pi^2} \frac{1-y}{y},\tag{44.37}$$

where $g=e/\sin\theta_W$. In the limit $s\gg m_H\gg m_W$, the partial decay rate is $\Gamma(H\to W_LW_L)=(g^2/64\pi)(m_H^3/m_W^2)$ and in the equivalent W approximation [7]

$$\sigma(e^+e^- \to \overline{\nu}_e \nu_e H) = \frac{1}{16m_W^2} \left(\frac{\alpha}{\sin^2 \theta_W}\right)^3 \times \left[\left(1 + \frac{m_H^2}{s}\right) \log \frac{s}{m_H^2} - 2 + 2\frac{m_H^2}{s}\right]. (44.38)$$

There are significant corrections to this relation when m_H is not large compared to m_W [8]. For $m_H=150$ GeV, the estimate is too high by 51% for $\sqrt{s}=1000$ GeV, 32% too high at $\sqrt{s}=2000$ GeV, and 22% too high at $\sqrt{s}=4000$ GeV. Fusion of ZZ to make a Higgs boson can be treated similarly. Identical formulae apply for Higgs production in the collisions of quarks whose charges permit the emission of a W^+ and a W^- , except that QCD corrections and CKM matrix elements are required. Even in the absence of QCD corrections, the fine-structure constant ought to be evaluated at the scale of the collision, say m_W . All quarks contribute to the ZZ fusion process.

44.6. Inclusive hadronic reactions

One-particle inclusive cross sections $Ed^3\sigma/d^3p$ for the production of a particle of momentum p are conveniently expressed in terms of rapidity y (see above) and the momentum p_T transverse to the beam direction (in the c.m.):

$$E\frac{d^{3}\sigma}{d^{3}p} = \frac{d^{3}\sigma}{d\phi \, dy \, p_{T} dp_{T}^{2}} \, . \tag{44.39}$$

In appropriate circumstances, the cross section may be decomposed as a partonic cross section multiplied by the probabilities of finding partons of the prescribed momenta:

$$\sigma_{\text{hadronic}} = \sum_{ij} \int dx_1 \ dx_2 \ f_i(x_1) \ f_j(x_2) \ d\widehat{\sigma}_{\text{partonic}} \ , \tag{44.40}$$

The probability that a parton of type i carries a fraction of the incident particle's that lies between x_1 and $x_1 + dx_1$ is $f_i(x_1)dx_1$ and similarly for partons in the other incident particle. The partonic collision is specified by its c.m. energy squared $\hat{s} = x_1x_2s$ and the momentum transfer squared \hat{t} . The final hadronic state is more conveniently specified by the rapidities y_1, y_2 of the two jets resulting from the collision and the transverse momentum p_T . The connection between the differentials is

$$dx_1 dx_2 d\hat{t} = dy_1 dy_2 \frac{\hat{s}}{s} dp_T^2, \tag{44.41}$$

so that

$$\frac{d^{3}\sigma}{dy_{1}dy_{2}dp_{T}^{2}} = \frac{\hat{s}}{s} \left[f_{i}(x_{1})f_{j}(x_{2})\frac{d\hat{\sigma}}{d\hat{t}}(\hat{s},\hat{t},\hat{u}) + f_{i}(x_{2})f_{j}(x_{1})\frac{d\hat{\sigma}}{d\hat{t}}(\hat{s},\hat{u},\hat{t}) \right], \tag{44.42}$$

where we have taken into account the possibility that the incident parton types might arise from either incident particle. The second term should be dropped if the types are identical: i = j.

44.7. Two-photon processes

In the Weizsäcker-Williams picture, a high-energy electron beam is accompanied by a spectrum of virtual photons of energies ω and invariant-mass squared $q^2=-Q^2$, for which the photon number density is

$$dn = \frac{\alpha}{\pi} \left[1 - \frac{\omega}{E} + \frac{\omega^2}{E^2} - \frac{m_e^2 \ \omega^2}{O^2 E^2} \right] \frac{d\omega}{\omega} \frac{dQ^2}{O^2}, \tag{44.43}$$

where E is the energy of the electron beam. The cross section for $e^+e^-\to e^+e^-X$ is then [9]

$$d\sigma_{e^+e^-\to e^+e^-X}(s) = dn_1 dn_2 d\sigma_{\gamma\gamma\to X}(W^2), \tag{44.44}$$

where $W^2=m_X^2$. Integrating from the lower limit $Q^2=m_e^2\frac{\omega_i^2}{E_i(E_i-\omega_i)}$ to a maximum Q^2 gives

$$\begin{split} \sigma_{e^+e^-\to e^+e^-X}(s) &= \frac{\alpha^2}{\pi^2} \int_{z_{th}}^1 \frac{dz}{z} \\ &\times \left[\left(\ln \frac{Q_{max}^2}{z m_e^2} - 1 \right)^2 f(z) + \frac{1}{3} (\ln z)^3 \right] \sigma_{\gamma\gamma\to X}(zs), (44.45) \end{split}$$

where

$$f(z) = \left(1 + \frac{1}{2}z\right)^2 \ln(1/z) - \frac{1}{2}(1-z)(3+z). \tag{44.46}$$

The appropriate value of Q^2_{max} depends on the properties of the produced system X. For production of hadronic systems, $Q^2_{max} \approx m_\rho^2$ while for lepton-pair production, $Q^2 \approx W^2$. For production of a resonance with spin $J \neq 1$, we have

$$\begin{split} \sigma_{e^+e^-\to e^+e^-R}(s) &= (2J+1)\frac{8\alpha^2\Gamma_{R\to\gamma\gamma}}{m_R^3} \\ &\times \Bigg[f(m_R^2/s) \left(\ln\frac{m_V^2s}{m_e^2m_R^2} - 1\right)^2 - \frac{1}{3} \left(\ln\frac{s}{M_R^2}\right)^3 \Bigg], (44.47) \end{split}$$

where m_V is the mass that enters into the form factor for the $\gamma\gamma \to R$ transition, typically m_{ϱ} .

PART II: PROCESSES BEYOND THE STANDARD MODEL

44.8. Production of supersymmetric particles

In supersymmetric (SUSY) theories (see Supersymmetric Particle Searches in this *Review*), every boson has a fermionic superpartner, and every fermion has a bosonic superpartner. The minimal supersymmetric Standard Model (MSSM) is a direct supersymmetrization of the Standard Model (SM), although a second Higgs doublet is needed to avoid triangle anomalies [10]. Under *soft* SUSY breaking, superpartner masses are lifted above the SM particle masses. In weak scale SUSY, the superpartners are invoked to stabilize the weak scale under radiative corrections, so the superpartners are expected to have masses of order the TeV scale.

44.8.1. Gluino and squark production:

The superpartners of gluons are the color octet, spin $-\frac{1}{2}$ gluinos (\tilde{g}) , while each helicity component of quark flavor has a spin-0 squark partner, e.g. \tilde{q}_L and \tilde{q}_R . Third generation left- and right- squarks are expected to have large mixing, resulting in mass eigenstates \tilde{q}_1 and \tilde{q}_2 , with $m_{\tilde{q}_1} < m_{\tilde{q}_2}$ (here, q denotes any of the SM flavors of quarks and \tilde{q}_i the corresponding flavor and type (i=L,R or 1,2) of squark). Gluino pair production $(\tilde{g}\tilde{g})$ takes place via either glue-glue or quark-antiquark annihilation [11].

The subprocess cross sections are usually presented as differential distributions in the Mandelstam variables s, t and u. Note that for a $2 \to 2$ scattering subprocess $ab \to cd$, the Mandelstam variable $s = (p_a + p_b)^2 = (p_c + p_d)^2$, where p_a is the 4-momentum of particle a, and so forth. The variable $t = (p_c - p_a)^2$, where c and a are taken conventionally to be the most similar particles in the subprocess. The variable u would then be equal to $(p_d - p_a)^2$. Note that since s, t and u are squares of 4-vectors, they are invariants in any inertial reference frames

Gluino pair production at hadron colliders is described by:

$$\begin{split} \frac{d\sigma}{dt}(gg \to \tilde{g}\tilde{g}) &= \frac{9\pi\alpha_s^2}{4s^2} \left\{ \frac{2(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u)}{s^2} \right. \\ &\quad + \frac{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u) - 2m_{\tilde{g}}^2(m_{\tilde{g}}^2 + t)}{(m_{\tilde{g}}^2 - t)^2} \\ &\quad + \frac{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u) - 2m_{\tilde{g}}^2(m_{\tilde{g}}^2 + u)}{(m_{\tilde{g}}^2 - u)^2} + \frac{m_{\tilde{g}}^2(s - 4m_{\tilde{g}}^2)}{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u)} \\ &\quad - \frac{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u) + m_{\tilde{g}}^2(u - t)}{s(m_{\tilde{g}}^2 - t)} - \frac{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u) + m_{\tilde{g}}^2(t - u)}{s(m_{\tilde{g}}^2 - u)} \right\}, \end{split}$$

where α_s is the strong fine structure constant. Also

$$\frac{d\sigma}{dt}(q\bar{q}\to\tilde{g}\bar{g}) = \frac{8\pi\alpha_s^2}{9s^2} \left\{ \frac{4}{3} \left(\frac{m_{\tilde{g}}^2 - t}{m_{\tilde{q}}^2 - t} \right)^2 + \frac{4}{3} \left(\frac{m_{\tilde{g}}^2 - u}{m_{\tilde{q}}^2 - u} \right)^2 + \frac{3}{3} \left[(m_{\tilde{g}}^2 - t)^2 + (m_{\tilde{g}}^2 - u)^2 + 2m_{\tilde{g}}^2 s \right] - 3 \frac{\left[(m_{\tilde{g}}^2 - t)^2 + m_{\tilde{g}}^2 s \right]}{s(m_{\tilde{q}}^2 - t)} - 3 \frac{\left[(m_{\tilde{g}}^2 - u)^2 + m_{\tilde{g}}^2 s \right]}{s(m_{\tilde{g}}^2 - u)} + \frac{1}{3} \frac{m_{\tilde{g}}^2 s}{(m_{\tilde{g}}^2 - t)(m_{\tilde{g}}^2 - u)} \right\}.$$
(44.49)

Gluinos can also be produced in association with squarks: $\tilde{g}\tilde{q}_i$ production, where \tilde{q}_i represents any of the various types (left-, right-or mixed) and flavors of squarks. The subprocess cross section is independent of whether the squark is the right-, left- or mixed type:

$$\frac{d\sigma}{dt}(gq \to \tilde{g}\tilde{q}_i) = \frac{\pi\alpha_s^2}{24s^2} \frac{\left[\frac{16}{3}(s^2 + (m_{\tilde{q}_i}^2 - u)^2) + \frac{4}{3}s(m_{\tilde{q}_i}^2 - u)\right]}{s(m_{\tilde{g}}^2 - t)(m_{\tilde{q}_i}^2 - u)^2} \times \left((m_{\tilde{g}}^2 - u)^2 + (m_{\tilde{q}_i}^2 - m_{\tilde{g}}^2)^2 + \frac{2sm_{\tilde{g}}^2(m_{\tilde{q}_i}^2 - m_{\tilde{g}}^2)}{(m_{\tilde{g}}^2 - t)} \right). \tag{44.50}$$

There are many different subprocesses for production of squark pairs. Since left- and right- squarks generally have different masses and different decay patterns, we present the differential cross section for each subprocess of \tilde{q}_i (i=L,~R or 1, 2) separately. (In early literature, the following formulae were often combined into a single equation which didn't differentiate the various squark types.) The result for $qq \to \tilde{q}_i \bar{\tilde{q}}_i$ is:

$$\begin{split} \frac{d\sigma}{dt}(gg \to \tilde{q}_i\bar{\tilde{q}}_i) &= \frac{\pi\alpha_s^2}{4s^2} \left\{ \frac{1}{3} \left(\frac{m_{\tilde{q}}^2 + t}{m_{\tilde{q}}^2 - t} \right)^2 + \frac{1}{3} \left(\frac{m_{\tilde{q}}^2 + u}{m_{\tilde{q}}^2 - u} \right)^2 \right. \\ &\quad + \frac{3}{32s^2} \left(8s(4m_{\tilde{q}}^2 - s) + 4(u - t)^2 \right) + \frac{7}{12} \\ &\quad - \frac{1}{48} \frac{(4m_{\tilde{q}}^2 - s)^2}{(m_{\tilde{q}}^2 - t)(m_{\tilde{q}}^2 - u)} \\ &\quad + \frac{3}{32} \frac{\left[(t - u)(4m_{\tilde{q}}^2 + 4t - s) - 2(m_{\tilde{q}}^2 - u)(6m_{\tilde{q}}^2 + 2t - s) \right]}{s(m_{\tilde{q}}^2 - t)} \\ &\quad + \frac{3}{32} \frac{\left[(u - t)(4m_{\tilde{q}}^2 + 4u - s) - 2(m_{\tilde{q}}^2 - t)(6m_{\tilde{q}}^2 + 2u - s) \right]}{s(m_{\tilde{q}}^2 - u)} \\ &\quad + \frac{7}{96} \frac{\left[4m_{\tilde{q}}^2 + 4t - s \right]}{m_{\tilde{q}}^2 - t} + \frac{7}{96} \frac{\left[4m_{\tilde{q}}^2 + 4u - s \right]}{m_{\tilde{q}}^2 - u} \right\}, \quad (44.51) \end{split}$$

which has an obvious $u \leftrightarrow t$ symmetry.

For $q\bar{q} \to \tilde{q}_i\bar{\tilde{q}}_i$ with the same initial and final state flavors, we have

$$\begin{split} \frac{d\sigma}{dt}(q\bar{q} \to \tilde{q}_i\bar{\tilde{q}}_i) &= \frac{2\pi\alpha_s^2}{9s^2} \left\{ \frac{1}{(t-m_{\tilde{g}}^2)^2} + \frac{2}{s^2} - \frac{2/3}{s(t-m_{\tilde{g}}^2)} \right\} \\ &\times \left[-st - (t-m_{\tilde{q}_i}^2)^2 \right], \end{split} \tag{44.52}$$

while if initial and final state flavors are different $(q\bar{q}\to\tilde{q}_i^{\bar{r}_i^j})$ we instead have

$$\frac{d\sigma}{dt}(q\bar{q} \to \tilde{q}_i'\bar{\tilde{q}}_i') = \frac{4\pi\alpha_s^2}{9s^4} \left[-st - (t - m_{\tilde{q}_i'}^2)^2 \right]. \tag{44.53}$$

If the two initial state quarks are of different flavors, then we have

$$\frac{d\sigma}{dt}(q\bar{q}' \to \tilde{q}_i\bar{q}'_i) = \frac{2\pi\alpha_s^2}{9s^2} \frac{-st - (t - m_{\bar{q}_i}^2)^2}{(t - m_{\bar{q}}^2)^2}.$$
 (44.54)

If the initial quarks are of different flavor and final state squarks are of different type $(i \neq j)$ then

$$\frac{d\sigma}{dt}(q\bar{q}' \to \tilde{q}_i\bar{q}'_j) = \frac{2\pi\alpha_s^2}{9s^2} \frac{m_{\tilde{g}}^2 s}{(t - m_{\tilde{g}}^2)^2}.$$
 (44.55)

For same-flavor initial state quarks, but final state unlike-type squarks, we also have

$$\frac{d\sigma}{dt}(q\bar{q}\to\tilde{q}_i\bar{\tilde{q}}_j) = \frac{2\pi\alpha_s^2}{9s^2} \frac{m_{\tilde{g}}^2s}{(t-m_{\tilde{g}}^2)^2}.$$
 (44.56)

There also exist cross sections for quark-quark annihilation to squark pairs. For same flavor quark-quark annihilation to same flavor/same type final state squarks,

$$\frac{d\sigma}{dt}(qq \to \tilde{q}_i \tilde{q}_i) =$$

$$= \frac{\pi \alpha_s^2}{9s^2} m_{\tilde{g}}^2 s \left\{ \frac{1}{(t - m_{\tilde{g}}^2)^2} + \frac{1}{(u - m_{\tilde{g}}^2)^2} - \frac{2/3}{(t - m_{\tilde{g}}^2)(u - m_{\tilde{g}}^2)} \right\}, (44.57)$$

while if the final type squarks are different $(i \neq j)$, we have

$$\frac{d\sigma}{dt}(qq \rightarrow \tilde{q}_i\tilde{q}_j) =$$

$$\frac{2\pi\alpha_s^2}{9s^2} \left\{ \frac{\left[-st - (t - m_{\tilde{q}_i}^2)(t - m_{\tilde{q}_j}^2) \right]}{(t - m_{\tilde{g}}^2)} + \frac{\left[-su - (u - m_{\tilde{q}_i}^2)(u - m_{\tilde{q}_j}^2) \right]}{(u - m_{\tilde{g}}^2)} \right\}.$$

$$(44.58)$$

If initial/final state flavors are different, but final state squark types are the same, then

$$\frac{d\sigma}{dt}(qq' \to \tilde{q}_i \tilde{q}_i') = \frac{2\pi\alpha_s^2}{9s^2} \frac{m_{\tilde{\varrho}}^2 s}{(t - m_{\tilde{\varrho}}^2)^2}.$$
 (44.59)

If initial quark flavors are different and final squark types are different, then

$$\frac{d\sigma}{dt}(qq' \to \tilde{q}_i \tilde{q}'_j) = \frac{2\pi\alpha_s^2}{9s^2} \frac{-st - (t - m_{\tilde{q}_i}^2)(t - m_{\tilde{q}_j}^2)}{(t - m_{\tilde{\varrho}}^2)^2}.$$
 (44.60)

44.8.2. Gluino and squark associated production:

In the MSSM, the charged spin- $\frac{1}{2}$ winos and higgsinos mix to make chargino states χ_1^\pm and $\chi_2^\pm,$ with $m_{\chi_1^\pm} < m_{\chi_2^\pm}.$ The spin- $\frac{1}{2}$ neutral bino, wino and higgsino fields mix to give four neutralino mass eigenstates $\chi_{1,2,3,4}^0$ ordered according to mass. We sometimes denote the charginos and neutralinos collectively as -inos for notational simplicity

For gluino and squark production in association with charginos and neutralinos [12], the quark-squark-neutralino couplings* are defined by the interaction Lagrangian terms $\mathcal{L}_{\tilde{f}f\tilde{\chi}_{0}^{0}}=$

 $\begin{bmatrix} iA_{\tilde{\chi}_i^0}^f \tilde{f}_L^\dagger \bar{\chi}_i^0 P_L f + iB_{\tilde{\chi}_i^0}^f \tilde{f}_R^\dagger \bar{\chi}_i^0 P_R f + \text{h.c.} \end{bmatrix}, \text{ where } A_{\tilde{\chi}_i^0}^f \text{ and } B_{\tilde{\chi}_i^0}^f \text{ are coupling constants involving gauge couplings, neutralino mixing elements and in the case of third generation fermions, Yukawa couplings. Their form depends on the conventions used for setting up the MSSM Lagrangian, and can be found in various reviews [13] and textbooks [14,15]. <math>P_L$ and P_R are the usual left- and right-spinor projection operators and f denotes any of the SM fermions u, d, e, ν_e, \cdots . The fermion-sfermion- chargino couplings have the form $\mathcal{L} = \left[iA_{\tilde{\chi}_i^-}^d \tilde{u}_L^\dagger \overline{\tilde{\chi}_i^-} P_L d + iA_{\tilde{\chi}_i^-}^u d_L^\dagger \overline{\tilde{\chi}_i^c} P_L u + \text{h.c.}\right]$ for u and d quarks, where the $A_{\tilde{\chi}_i^-}^d$ and $A_{\tilde{\chi}_i^-}^u$ couplings are again convention-dependent, and can be found in textbooks. The superscript c denotes "charge conjugate spinor", defined by $\psi^c \equiv C\bar{\psi}^T$.

The subprocess cross sections for chargino-squark associated production occur via squark exchange and are given by

$$\frac{d\sigma}{dt}(\bar{u}g \rightarrow \tilde{\chi}_{i}^{-}\bar{d}_{L}) = \frac{\alpha_{s}}{24s^{2}}|A_{\tilde{\chi}_{i}^{-}}^{u}|^{2}\psi(m_{\tilde{d}_{L}}, m_{\tilde{\chi}_{i}^{-}}, t), \quad (44.61)$$

$$\frac{d\sigma}{dt}(dg \rightarrow \tilde{\chi}_i^- \tilde{u}_L) = \frac{\alpha_s}{24s^2} |A_{\tilde{\chi}_i^-}^d|^2 \psi(m_{\tilde{u}_L}, m_{\tilde{\chi}_i^-}, t), \tag{44.62} \label{eq:4.62}$$

while neutralino-squark production is given by

$$\frac{d\sigma}{dt}(qg \to \tilde{\chi}^0_i \tilde{q}) = \frac{\alpha_s}{24s^2} \left(|A^q_{\tilde{\chi}^0_i}|^2 + |B^q_{\tilde{\chi}^0_i}|^2 \right) \psi(m_{\tilde{q}}, m_{\tilde{\chi}^0_i}, t), \quad (44.63)$$

where

$$\psi(m_1, m_2, t) = \frac{s + t - m_1^2}{2s} - \frac{m_1^2(m_2^2 - t)}{(m_1^2 - t)^2} + \frac{t(m_2^2 - m_1^2) + m_2^2(s - m_2^2 + m_1^2)}{s(m_1^2 - t)}.$$
 (44.64)

Here, the variable t is given by the square of "squark-minus-quark" four-momentum. The neutralino-gluino associated production cross section also occurs via squark exchange and is given by

$$\frac{d\sigma}{dt}(q\bar{q}\to\tilde{\chi}_{i}^{0}\tilde{g}) = \frac{\alpha_{s}}{18s^{2}} \left(|A_{\tilde{\chi}_{i}^{0}}^{q}|^{2} + |B_{\tilde{\chi}_{i}^{0}}^{q}|^{2} \right) \left[\frac{(m_{\tilde{\chi}_{i}^{0}}^{2} - t)(m_{\tilde{g}}^{2} - t)}{(m_{\tilde{q}}^{2} - t)^{2}} + \frac{(m_{\tilde{\chi}_{i}^{0}}^{2} - u)(m_{\tilde{g}}^{2} - u)}{(m_{\tilde{q}}^{2} - u)^{2}} - \frac{2\eta_{i}\eta_{\tilde{g}}m_{\tilde{g}}m_{\tilde{\chi}_{i}^{0}}s}{(m_{\tilde{q}}^{2} - t)(m_{\tilde{q}}^{2} - u)} \right], (44.65)$$

where η_i is the sign of the neutralino mass eigenvalue and $\eta_{\tilde{g}}$ is the sign of the gluino mass eigenvalue. We also have chargino-gluino associated production:

$$\frac{d\sigma}{dt}(\bar{u}d \to \tilde{\chi}_i^- \tilde{g}) = \frac{\alpha_s}{18s^2} \left[|A_{\tilde{\chi}_i}^u|^2 \frac{(m_{\tilde{\chi}_i^-}^2 - t)(m_{\tilde{g}}^2 - t)}{(m_{\tilde{d}_I}^2 - t)^2} \right]$$

$$+|A_{\tilde{\chi}_{i}^{-}}^{d}|^{2}\frac{(m_{\tilde{\chi}_{i}^{-}}^{2}-u)(m_{\tilde{g}}^{2}-u)}{(m_{\tilde{u}_{L}}^{2}-u)^{2}}+\frac{2\eta_{\tilde{g}}Re(A_{\tilde{\chi}_{i}^{-}}^{u}A_{\tilde{\chi}_{i}^{-}}^{d})m_{\tilde{g}}m_{\tilde{\chi}_{i}}s}{(m_{\tilde{d}_{I}}^{2}-t)(m_{\tilde{u}_{L}}^{2}-u)}\right],~(44.66)$$

where $\hat{t} = (\tilde{g} - d)^2$ and in the third term one must take the real part of the in general complex coupling constant product.

44.8.3. Slepton and sneutrino production:

The subprocess cross section for $\tilde{\ell}_L \tilde{\bar{\nu}}_{\ell_L}$ production $(\ell = e \text{ or } \mu)$ occurs via s-channel W exchange and is given by

$$\frac{d\sigma}{dt}(d\bar{u} \to \tilde{\ell}_L \bar{\tilde{\nu}}_{\ell_L}) = \frac{g^4 |D_W(s)|^2}{192\pi s^2} \left(tu - m_{\tilde{\ell}_L}^2 m_{\tilde{\nu}_{\ell_L}}^2 \right), \tag{44.67}$$

where $D_W(s)=1/(s-M_W^2+iM_W\Gamma_W)$ is the W-boson propagator denominator. The production of $\tilde{\tau}_1\bar{\tilde{\nu}}_{\tau}$ is given as above, but replacing $m_{\tilde{\ell}_L} \to m_{\tilde{\tau}_1}, \ m_{\tilde{\nu}_{\ell}_L} \to m_{\tilde{\nu}_{\tau}}$ and multiplying by an overall factor of $\cos^2\theta_{\tau}$ (where θ_{τ} is the tau-slepton mixing angle). Similar substitutions hold for $\tilde{\tau}_2\bar{\tilde{\nu}}_{\tau}$ production, except the overall factor is $\sin^2\theta_{\tau}$.

Table 44.1: The constants α_f and β_f that appear in in the SM neutral current Lagrangian. Here $t \equiv \tan \theta_W$ and $c \equiv \cot \theta_W$.

| \overline{f} | q_f | α_f | eta_f |
|----------------|----------------|---------------------------------|---------------------|
| ℓ | -1 | $\frac{1}{4}(3t-c)$ | $\frac{1}{4}(t+c)$ |
| ν_ℓ | 0 | $\frac{1}{4}(t+c)$ | $-\frac{1}{4}(t+c)$ |
| u | $\frac{2}{3}$ | $-\frac{5}{12}t + \frac{1}{4}c$ | $-\frac{1}{4}(t+c)$ |
| d | $-\frac{1}{3}$ | $\frac{1}{12}t - \frac{1}{4}c$ | $\frac{1}{4}(t+c)$ |

^{*} The couplings $A_{\tilde{\chi}_{i}^{0}}^{f}$ and $B_{\tilde{\chi}_{i}^{0}}^{f}$ are given explicitly in Ref. 15 in Eq. (8.87). Also, the couplings $A_{\tilde{\chi}_{i}^{-}}^{d}$ and $A_{\tilde{\chi}_{i}^{-}}^{u}$ are given in Eq. (8.93). The couplings X_{i}^{j} and Y_{i}^{j} are given by Eq. (8.103), while the x_{i} and y_{i} couplings are given in Eq. (8.100). Finally, the couplings W_{ij} are given in Eq. (8.101).

The subprocess cross section for $\tilde{\ell}_L\bar{\tilde{\ell}}_L$ production occurs via schannel γ and Z exchange, and depends on the neutral current interaction, with fermion couplings to γ and Z^0 given by $\mathcal{L}_{\text{neutral}} = -eq_f\bar{f}\gamma^\mu fA_\mu + e\bar{f}\gamma^\mu (\alpha_f + \beta_f\gamma_5)fZ_\mu$ (with values of q_f , α_f , and β_f given in Table 44.1.

The subprocess cross section is given by

$$\frac{d\sigma}{dt}(q\bar{q} \to \tilde{\ell}_L \bar{\tilde{\ell}}_L) = \frac{e^4}{24\pi s^2} \left(tu - m_{\tilde{\ell}_L}^4\right) \times \left\{ \frac{q_\ell^2 q_q^2}{s^2} + (\alpha_\ell - \beta_\ell)^2 (\alpha_q^2 + \beta_q^2) |D_Z(s)|^2 + \frac{2q_\ell q_q \alpha_q (\alpha_\ell - \beta_\ell) (s - M_Z^2)}{s} |D_Z(s)|^2 \right\}, \tag{44.68}$$

where $D_Z(s)=1/(s-M_Z^2+iM_Z\Gamma_Z)$. The cross section for sneutrino production is given by the same formula, but with $\alpha_\ell,\,\beta_\ell,\,q_\ell$ and $m_{\tilde\ell_L}$ replaced by $\alpha_\nu,\,\beta_\nu,\,0$ and $m_{\tilde\nu_L}$, respectively. The cross section for $\tilde\tau_1\bar{\tilde\tau}_1$ production is obtained by replacing $m_{\tilde\ell_L}\to m_{\tilde\tau_1}$ and $\beta_\ell\to\beta_\ell\cos2\theta_\tau$. The cross section for $\tilde\ell_R\bar{\tilde\ell}_R$ production is given by substituting $\alpha_\ell-\beta_\ell\to\alpha_\ell+\beta_\ell$ and $m_{\tilde\ell_L}\to m_{\tilde\ell_R}$ in the equation above. The cross section for $\tilde\tau_2\bar{\tilde\tau}_2$ production is obtained from the formula for $\tilde\ell_R\bar{\tilde\ell}_R$ production by replacing $m_{\tilde\ell_R}\to m_{\tilde\tau_2}$ and $\beta_\ell\to\beta_\ell\cos2\theta_\tau$.

Finally, the cross section for $\tilde{\tau}_1\tilde{\tilde{\tau}}_2$ production occurs only via Z exchange, and is given by

$$\frac{d\sigma}{dt}(q\bar{q}\to\tilde{\tau}_1\bar{\tilde{\tau}}_2) = \frac{d\sigma}{dt}(q\bar{q}\to\bar{\tilde{\tau}}_1\tilde{\tau}_2) =$$

$$\frac{e^4}{24\pi s^2} (\alpha_q^2 + \beta_q^2) \beta_\ell^2 \sin^2 2\theta_\tau |D_Z(s)|^2 (ut - m_{\tilde{\tau}_1}^2 m_{\tilde{\tau}_2}^2). \tag{44.69}$$

44.8.4. Chargino and neutralino pair production:

44.8.4.1. $\tilde{\chi}_i^- \tilde{\chi}_i^0$ production:

The subprocess cross section for $d\bar{u}\to \tilde{\chi}_i^-\tilde{\chi}_j^0$ depends on Lagrangian couplings $\mathcal{L}_{W\bar{u}d}=-\frac{g}{\sqrt{2}}\bar{u}\gamma_\mu P_L dW^{+\mu}+\text{h.c.},\,\mathcal{L}_{W\tilde{\chi}_i^-\tilde{\chi}_j^0}=-g(-i)^{\theta j}\overline{\chi}_i^-[X_i^j+Y_i^j\gamma_5]\gamma_\mu\tilde{\chi}_j^0W^{-\mu}+\text{h.c.},\,\mathcal{L}_{q\bar{q}\tilde{\chi}_i^-}=iA_{\tilde{\chi}_i}^d\,\bar{u}_L^\dagger\tilde{\chi}_i^-P_L d+iA_{\tilde{\chi}_i^-}^u\,\bar{d}_L^\dagger\overline{\chi}_i^cP_L u+\text{h.c.}$ and $\mathcal{L}_{q\bar{q}\tilde{\chi}_j^0}=iA_{\tilde{\chi}_j^0}^q\,\bar{d}_L^\dagger\overline{\chi}_j^0\,p_L q+\text{h.c.}$. Contributing diagrams include W exchange and also \tilde{d}_L and \tilde{u}_L squark exchange. The X_i^j and Y_i^j couplings are new, and again convention-dependent: the cross section formulae works if the interaction Lagrangian is written in the above form, so that the couplings can be suitably extracted. The term $\theta_j=0$ (1) if $m_{\tilde{\chi}_j^0}>0$ (<0); it comes about because the neutralino field must be re-defined by a $-i\gamma_5$ transformation if its mass eigenvalue is negative [15]. The subprocess cross section is given in terms of dot products of four momenta, where particle labels are used to denote their four-momenta; note that all mass terms in the cross section formulae are positive definite, so that the signs of mass eigenstates have been absorbed into the Lagrangian couplings, as for instance in Ref. [15]. We then have

$$\begin{split} \frac{d\sigma}{dt}(d\overline{u} \rightarrow \tilde{\chi}_i^- \tilde{\chi}_j^0) &= \frac{1}{192\pi s^2} \\ \\ \left[T_W + T_{\tilde{d}_L} + T_{\tilde{u}_L} + T_{W\tilde{d}_L} + T_{W\tilde{u}_L} + T_{\tilde{d}_L\tilde{u}_L} \right] \end{split} \tag{44.70}$$

where

$$T_{W} = 8g^{4}|D_{W}(s)|^{2} \left\{ [X_{i}^{j2} + Y_{i}^{j2}](\tilde{\chi}_{j}^{0} \cdot d\tilde{\chi}_{i}^{-} \cdot \overline{u} + \tilde{\chi}_{j}^{0} \cdot \overline{u}\tilde{\chi}_{i}^{-} \cdot d) + 2(X_{i}^{j}Y_{i}^{j})(\tilde{\chi}_{j}^{0} \cdot d\tilde{\chi}_{i}^{-} \cdot \overline{u} - \tilde{\chi}_{j}^{0} \cdot \overline{u}\tilde{\chi}_{i}^{-} \cdot d) + [X_{i}^{j2} - Y_{i}^{j2}]m_{\tilde{\chi}_{i}^{-}}m_{\tilde{\chi}_{j}^{0}}d \cdot \overline{u} \right\},$$

$$(44.71)$$

$$T_{\tilde{d}_L} = \frac{4|A^u_{\tilde{\chi}_i^-}|^2|A^d_{\tilde{\chi}_j^0}|^2}{[(\tilde{\chi}_i^- - \overline{u})^2 - m^2_{\tilde{d}_I}]^2} \; d \cdot \tilde{\chi}_j^0 \tilde{\chi}_i^- \cdot \overline{u}, \tag{44.72}$$

$$T_{\tilde{u}_L} = \frac{4|A_{\tilde{\chi}_i}^d|^2|A_{\tilde{\chi}_j^0}^u|^2}{[(\tilde{\chi}_j^0 - \overline{u})^2 - m_{\tilde{u}_L}^2]^2} \, \overline{u} \cdot \tilde{\chi}_j^0 \tilde{\chi}_i^- \cdot d \tag{44.73}$$

$$\begin{split} T_{W\tilde{d}_{L}} &= \frac{-\sqrt{2}g^{2}Re[A_{\tilde{\chi}_{j}^{0}}^{d*}A_{\tilde{\chi}_{i}^{-}}^{u}(-i)^{\theta_{j}}](s-M_{W}^{2})|D_{W}(s)|^{2}}{(\tilde{\chi}_{i}^{-}-\overline{u})^{2}-m_{\tilde{d}_{L}}^{2}} \\ &\times \left\{8(X_{i}^{j}+Y_{i}^{j})\tilde{\chi}_{j}^{0}\cdot d\overline{u}\cdot\tilde{\chi}_{i}^{-}+4(X_{i}^{j}-Y_{i}^{j})m_{\tilde{\chi}_{i}^{-}}m_{\tilde{\chi}_{j}^{0}}d\cdot\overline{u}\right\}(44.74) \end{split}$$

$$\begin{split} T_{W\tilde{u}_{L}} &= \frac{\sqrt{2}g^{2}Re[A^{d*}_{\tilde{\chi}_{i}^{-}}A^{u}_{\tilde{\chi}_{j}^{0}}(-i)^{\theta_{j}}](s-M_{W}^{2})|D_{W}(s)|^{2}}{(\tilde{\chi}_{j}^{0}-\overline{u})^{2}-m_{\tilde{u}_{L}}^{2}} \\ &\times \left\{8(X^{j}_{i}-Y^{j}_{i})\tilde{\chi}_{j}^{0}\cdot\overline{u}d\cdot\tilde{\chi}_{i}^{-}+4(X^{j}_{i}+Y^{j}_{i})m_{\tilde{\chi}_{i}^{-}}m_{\tilde{\chi}_{j}^{0}}d\cdot\overline{u}\right\}(44.75) \end{split}$$

and

$$T_{\tilde{d}_L\tilde{u}_L} = -\frac{4Re[A_{\tilde{\chi}_j}^d A_{\tilde{\chi}_i}^{u*} A_{\tilde{\chi}_i}^{d*} A_{\tilde{\chi}_i}^u] m_{\tilde{\chi}_i} m_{\tilde{\chi}_j}^0 d \cdot \overline{u}}{[(\tilde{\chi}_i^- - \overline{u})^2 - m_{\tilde{d}_L}^2][(\tilde{\chi}_j^0 - \overline{u})^2 - m_{\tilde{u}_L}^2]}. \tag{44.76}$$

44.8.4.2. Chargino pair production:

The subprocess cross section for $d\bar{d} \to \tilde{\chi}_i^- \tilde{\chi}_i^+ \ (i=1,2)$ depends on Lagrangian couplings $\mathcal{L} = e \overline{\tilde{\chi}_i^-} \gamma_\mu \tilde{\chi}_i^- A^\mu - e \cot \theta_W \overline{\tilde{\chi}_i^-} \gamma_\mu (x_i - y_i \gamma_5) \tilde{\chi}_i^- Z^\mu$ and also $\mathcal{L} \ni i A_{\tilde{\chi}_i}^d \tilde{u}_L^\dagger \overline{\tilde{\chi}_i^-} P_L d + i A_{\tilde{\chi}_i}^u \tilde{d}_L^\dagger \overline{\tilde{\chi}_i^-} P_L u + \text{h.c.}$. Contributing diagrams include s-channel γ , Z^0 exchange and t-channel \tilde{u}_L exchange [16,17]. The couplings x_i and y_i are again new and as usual convention-dependent.

The subprocess cross section is given by

$$\frac{d\sigma}{dt}(d\overline{d} \to \tilde{\chi}_i^- \tilde{\chi}_i^+) = \frac{1}{192\pi s^2} \left[T_{\gamma} + T_{Z} + T_{\tilde{u}_L} + T_{\gamma Z} + T_{\gamma \tilde{u}_L} + T_{Z\tilde{u}_L} \right]$$
(44.77)

where

$$T_{\gamma} = \frac{32e^4q_d^2}{s^2} \left[d \cdot \tilde{\chi}_i^+ \overline{d} \cdot \tilde{\chi}_i^- + d \cdot \tilde{\chi}_i^- \overline{d} \cdot \tilde{\chi}_i^+ + m_{\tilde{\chi}_i}^2 d \cdot \overline{d} \right]$$

$$T_Z = 32e^4 \cot^2 \theta_W |D_Z(s)|^2$$

$$(44.78)$$

$$\left\{ (\alpha_d^2 + \beta_d^2)(x_i^2 + y_i^2) \left[d \cdot \tilde{\chi}_i^+ \overline{d} \cdot \tilde{\chi}_i^- + d \cdot \tilde{\chi}_i^- \overline{d} \cdot \tilde{\chi}_i^+ + m_{\tilde{\chi}_i}^2 d \cdot \overline{d} \right] \right\}$$

$$\mp 4\alpha_{d}\beta_{d}x_{i}y_{i}\left[d\cdot\tilde{\chi}_{i}^{+}\overline{d}\cdot\tilde{\chi}_{i}^{-}-d\cdot\tilde{\chi}_{i}^{-}\overline{d}\cdot\tilde{\chi}_{i}^{+}\right]-2y_{i}^{2}(\alpha_{d}^{2}+\beta_{d}^{2})m_{\tilde{\chi}_{i}}^{2}-d\cdot\overline{d}\bigg\},$$

$$(44.79)$$

$$T_{\tilde{u}_L} = \frac{4|A_{\tilde{\chi}_i}^d|^4}{[(d - \tilde{\chi}_i^-)^2 - m_{\tilde{u}_L}^2]^2} d \cdot \tilde{\chi}_i^- \overline{d} \cdot \tilde{\chi}_i^+$$
(44.80)

$$T_{\gamma Z} = \frac{64e^4 \cot \theta_W q_d(s - M_Z^2)|D_Z(s)|^2}{\epsilon} \times$$

$$\left\{ \alpha_{d} x_{i} \left(d \cdot \tilde{\chi}_{i}^{+} \overline{d} \cdot \tilde{\chi}_{i}^{-} + d \cdot \tilde{\chi}_{i}^{-} \overline{d} \cdot \tilde{\chi}_{i}^{+} + m_{\tilde{\chi}_{i}^{-}}^{2} d \cdot \overline{d} \right) \right. \\
\left. \pm \beta_{d} y_{i} \left(d \cdot \tilde{\chi}_{i}^{-} \overline{d} \cdot \tilde{\chi}_{i}^{+} - d \cdot \tilde{\chi}_{i}^{+} \overline{d} \cdot \tilde{\chi}_{i}^{-} \right) \right\} \tag{44.81}$$

$$T_{\gamma \tilde{u}_{L}} = \mp \frac{8e^{2}q_{d}}{s} \frac{|A_{\tilde{\chi}_{i}}^{d}|^{2}}{[(d - \tilde{\chi}_{i}^{-})^{2} - m_{\tilde{u}_{L}}^{2}]} \left\{ 2\overline{d} \cdot \tilde{\chi}_{i}^{+} d \cdot \tilde{\chi}_{i}^{-} + m_{\tilde{\chi}_{i}}^{2} d \cdot \overline{d} \right\}$$

$$(44.82)$$

and

$$T_{Z\bar{u}_L} = \mp 8e^2 \cot \theta_W |D_Z(s)|^2 \frac{|A_{\tilde{\chi}_i}^d|^2 (s - M_Z^2)}{[(d - \tilde{\chi}_i^-)^2 - m_{\tilde{u}_L}^2]} (\alpha_d - \beta_d) \times \left\{ 2(x_i \mp y_i)d \cdot \tilde{\chi}_i^- \overline{d} \cdot \tilde{\chi}_i^+ + m_{\tilde{\chi}_i^-}^2 (x_i \pm y_i)d \cdot \overline{d} \right\}$$
(44.83)

using the upper of the sign choices.

The cross section for $u\overline{u} \to \tilde{\chi}_i^+ \tilde{\chi}_i^-$ can be obtained from the above by replacing $\alpha_d \to \alpha_u$, $\beta_d \to \beta_u$, $q_d \to q_u$, $\tilde{u}_L \to \tilde{d}_L$, $A_{\tilde{\chi}_i^-}^d \to A_{\tilde{\chi}_i^-}^u$, $d \to \overline{u}$, $\overline{d} \to u$ and adopting the lower of the sign choices everywhere.

The cross section for $q\bar{q} \to \tilde{\chi}_1^- \tilde{\chi}_2^+$, $\tilde{\chi}_1^+ \tilde{\chi}_2^-$ can occur via Z and \tilde{q}_L exchange. It is usually much smaller than $\tilde{\chi}_{1,2}^- \tilde{\chi}_{1,2}^+$ production, so the cross section will not be presented here. It can be found in Appendix A of Ref. 15.

44.8.4.3. Neutralino pair production:

Neutralino pair production via $q\bar{q}$ fusion takes place via s-channel Z exchange plus t- and u-channel left- and right- squark exchange (5 diagrams) [17,18]. The Lagrangian couplings (see previous footnote*) needed include terms given above plus terms of the form $\mathcal{L} = W_{ij}\bar{\chi}^{\bar{0}}_{i}\gamma_{\mu}(\gamma_{5})^{\theta_{i}+\theta_{j}+1}\tilde{\chi}^{0}_{j}Z^{\mu}$. The couplings W_{ij} depend only on the higgsino components of the neutralinos i and j. The subprocess cross section is given by:

$$\frac{d\sigma}{dt}(q\bar{q} \to \tilde{\chi}_{i}^{0}\tilde{\chi}_{j}^{0}) = \frac{1}{192\pi s^{2}} \left[T_{Z} + T_{\tilde{q}_{L}} + T_{\tilde{q}_{R}} + T_{Z\tilde{q}_{L}} + T_{Z\tilde{q}_{R}} \right] (44.84)$$

where

$$T_{Z} = 128e^{2}|W_{ij}|^{2}(\alpha_{q}^{2} + \beta_{q}^{2})|D_{Z}(s)|^{2}$$

$$\left[q \cdot \tilde{\chi}_{i}^{0} \bar{q} \cdot \tilde{\chi}_{j}^{0} + q \cdot \tilde{\chi}_{j}^{0} \bar{q} \cdot \tilde{\chi}_{i}^{0} - \eta_{i}\eta_{j}m_{\tilde{\chi}_{i}^{0}}m_{\tilde{\chi}_{j}^{0}}q \cdot \bar{q}\right], \qquad (44.85)$$

$$T_{\tilde{q}_{L}} = 4|A_{\tilde{\chi}_{i}^{0}}^{q}|^{2}|A_{\tilde{\chi}_{j}^{0}}^{q}|^{2} \left\{ \frac{q \cdot \tilde{\chi}_{i}^{0} \bar{q} \cdot \tilde{\chi}_{j}^{0}}{[(\tilde{\chi}_{i}^{0} - q)^{2} - m_{\tilde{q}_{L}}^{2}]^{2}} + \frac{q \cdot \tilde{\chi}_{j}^{0} \bar{q} \cdot \tilde{\chi}_{i}^{0}}{[(\tilde{\chi}_{j}^{0} - q)^{2} - m_{\tilde{q}_{L}}^{2}]^{2}} - \eta_{i} \eta_{j} \frac{m_{\tilde{\chi}_{i}^{0}} m_{\tilde{\chi}_{j}^{0}} q \cdot \bar{q}}{[(\tilde{\chi}_{i}^{0} - q)^{2} - m_{\tilde{q}_{L}}^{2}][(\tilde{\chi}_{j}^{0} - q)^{2} - m_{\tilde{q}_{L}}^{2}]} \right\}$$

$$(44.86)$$

$$\begin{split} T_{\bar{q}_R} &= 4|B_{\tilde{\chi}_i^0}^q|^2|B_{\tilde{\chi}_j^0}^q|^2 \left\{ \frac{q \cdot \tilde{\chi}_i^0 \bar{q} \cdot \tilde{\chi}_j^0}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_R}^2]^2} + \frac{q \cdot \tilde{\chi}_j^0 \bar{q} \cdot \tilde{\chi}_i^0}{[(\tilde{\chi}_j^0 - q)^2 - m_{\tilde{q}_R}^2]^2} \right. \\ &- \eta_i \eta_j \frac{m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q}}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_R}^2][(\tilde{\chi}_j^0 - q)^2 - m_{\tilde{q}_R}^2]} \right\} \\ &- \eta_i \eta_j \frac{m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q}}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_R}^2][(\tilde{\chi}_j^0 - q)^2 - m_{\tilde{q}_R}^2]} \right\} \\ &- \left\{ \frac{Re(W_{ij} A_{\tilde{\chi}_i^0}^{q*} A_{\tilde{\chi}_j^0}^q)}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_L}^2]} \left[2q \cdot \tilde{\chi}_i^0 \bar{q} \cdot \tilde{\chi}_j^0 - \eta_i \eta_j m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q} \right] \right. \\ &+ \eta_i \eta_j \frac{Re(W_{ij} A_{\tilde{\chi}_i^0}^q A_{\tilde{\chi}_j^0}^q)}{[(\tilde{\chi}_j^0 - q)^2 - m_{\tilde{q}_L}^2]} \left[2q \cdot \tilde{\chi}_j^0 \bar{q} \cdot \tilde{\chi}_i^0 - \eta_i \eta_j m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q} \right] \right\} \\ &- \frac{Re(W_{ij} B_{\tilde{\chi}_i^0}^{q*} B_{\tilde{\chi}_j^0}^q)}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_R}^2]} \left[2q \cdot \tilde{\chi}_i^0 \bar{q} \cdot \tilde{\chi}_j^0 - \eta_i \eta_j m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q} \right] \\ &- \frac{Re(W_{ij} B_{\tilde{\chi}_i^0}^q B_{\tilde{\chi}_j^0}^q)}{[(\tilde{\chi}_i^0 - q)^2 - m_{\tilde{q}_R}^2]} \left[2q \cdot \tilde{\chi}_j^0 \bar{q} \cdot \tilde{\chi}_i^0 - \eta_i \eta_j m_{\tilde{\chi}_i^0} m_{\tilde{\chi}_j^0} q \cdot \bar{q} \right] \right\}. \end{aligned} \tag{44.89}$$

As before, $\eta_i=\pm 1$ corresponding to whether the neutralino mass eigenvalue is positive or negative. When i=j in the above formula, one must remember to integrate over just 2π steradians of solid angle to avoid double counting in the total cross section.

44.9. Universal extra dimensions

In the Universal Extra Dimension (UED) model of Ref. [19] (see Ref. [20] for a review of models with extra spacetime dimensions), the Standard Model is embedded in a five dimensional theory, where the fifth dimension is compactified on an S_1/Z_2 orbifold. Each SM chirality state is then the zero mode of an infinite tower of Kaluza-Klein excitations labelled by $n=0-\infty$. A KK parity is usually assumed to hold, where each state is assigned KK-parity $P=(-1)^n$. If the compactification scale is around a TeV, then the n=1 (or even higher) KK modes may be accessible to collider searches.

Of interest for hadron colliders are the production of massive $n \geq 1$ quark or gluon pairs. These production cross sections have been calculated in Ref. [21,22]. We list here results for the n=1 case only with $M_1=1/R$ (R is the compactification radius) and s,t and u are the usual Mandelstam variables; more general formulae can be found in Ref. [22]. The superscript * stands for any KK excited state, while • stands for left chirality states and o stands for right chirality states.

$$\frac{d\sigma}{dt} = \frac{1}{16\pi s^2} T \tag{44.90}$$

where

$$T(q\bar{q} \to g^*g^*) = \frac{2g_s^4}{27} \left[M_1^2 \left(-\frac{4s^3}{t'^2u'^2} + \frac{57s}{t'u'} - \frac{108}{s} \right) + \frac{20s^2}{t'u'} - 93 + \frac{108t'u'}{s^2} \right]$$
(44.91)

and

$$T(gg \to g^*g^*) = \frac{9g_s^4}{27} \left[3M_1^4 \frac{s^2 + t'^2 + u'^2}{t'^2u'^2} - 3M_1^2 \frac{s^2 + t'^2 + u'^2}{st'u'} + 1 + \frac{(s^2 + t'^2 + u'^2)^3}{4s^2t'^2u'^2} - \frac{t'u'}{s^2} \right]$$
(44.92)

where $t' = t - M_1^2$ and $u' = u - M_1^2$.

Alsc

$$\begin{split} T(q\bar{q} \to q_1^{*'}\bar{q}_1^{*'}) &= \frac{4g_s^4}{9} \left[\frac{2M_1^2}{s} + \frac{t'^2 + u'^2}{s^2} \right], \\ T(q\bar{q} \to q_1^*\bar{q}_1^*) &= \frac{g_2^4}{9} \left[2M_1^2 \left(\frac{4}{s} + \frac{s}{t'^2} - \frac{1}{t'} \right) \right. \\ &\quad + \frac{23}{6} + \frac{2s^2}{t'^2} + \frac{8s}{3t'} + \frac{6t'}{s} + \frac{8t'^2}{s^2} \right], \\ T(qq \to q_1^*q_1^*) &= \frac{g_s^4}{27} \left[M_1^2 \left(6\frac{t'}{u'^2} + 6\frac{u'}{t'^2} - \frac{s}{t'u'} \right) \right. \\ &\quad + 2 \left(3\frac{t'^2}{u'^2} + 3\frac{u'^2}{t'^2} + 4\frac{s^2}{t'u'} - 5 \right) \right], \\ T(gg \to q_1^*\bar{q}_1^*) &= g_s^4 \left[M_1^4 \frac{-4}{t'u'} \left(\frac{s^2}{6t'u'} - \frac{3}{8} \right) \right. \\ &\quad + M_1^2 \frac{4}{s} \left(\frac{s^2}{6t'u'} - \frac{3}{8} \right) + \frac{s^2}{6t'u'} - \frac{17}{24} + \frac{3t'u'}{4s^2} \right], \\ T(gq \to g^*q_1^*) &= \frac{-g_s^4}{3} \left[\frac{5s^2}{12t'^2} + \frac{s^3}{t'^2u'} + \frac{11su'}{6t'^2} + \frac{5u'^2}{12t'^2} + \frac{u'^3}{st'^2} \right], \\ T(q\bar{q}' \to q_1^*\bar{q}_1^{*'}) &= \frac{g_s^4}{18} \left[4M_1^4 \frac{s}{t'^2} + 5 + 4\frac{s^2}{t'^2} + 8\frac{s}{t'} \right], \\ T(qq' \to q_1^*q_1^{*'}) &= \frac{2g_s^4}{9} \left[-M_1^2 \frac{s}{t'^2} + \frac{1}{4} + \frac{s^2}{t'^2} \right], \end{split}$$

$$\begin{split} T(qq \to q_1^{\bullet} q_1^{\circ}) &= \frac{g_s^4}{9} \left[M_1^2 \left(\frac{2s^3}{t'^2 u'^2} - \frac{4s}{t' u'} \right) + 2 \frac{s^4}{t'^2 u'^2} - 8 \frac{s^2}{t' u'} + 5 \right], \\ T(q\bar{q}' \to q_1^{\bullet} \bar{q}_1'^{\circ}) &= \frac{g_s^4}{9} \left[2M_1^2 \left(\frac{1}{t'} + \frac{u'}{t'^2} \right) + \frac{5}{2} + \frac{4u'}{t'} + \frac{2u'^2}{t'^2} \right], \end{split}$$

and

$$T(qq' \to q_1^{\bullet} q_1'^{\circ}) = \frac{g_s^4}{9} \left[-2M_1^2 \left(\frac{1}{t'} + \frac{u'}{t'^2} \right) + \frac{1}{2} + \frac{2u'^2}{t'^2} \right].$$

44.10. Large extra dimensions

In the ADD theory [23] with large extra dimensions (LED), the SM particles are confined to a 3-brane, while gravity propagates in the bulk. It is assumed that the n extra dimensions are compactified on an n-dimensional torus of volume $(2\pi r)^n$, so that the fundamental 4+n dimensional Planck scale M_* is related to the usual 4-dimensional Planck scale M_{Pl} by $M_{Pl}^2 = M_*^{n+2}(2\pi r)^n$. If $M_* \sim 1$ TeV, then the $M_W - M_{Pl}$ hierarchy problem is just due to gravity propagating in the large extra dimensions.

In these theories, the KK-excited graviton states $G^n_{\mu\nu}$ for $n=1-\infty$ can be produced at collider experiments. The graviton couplings to matter are suppressed by $1/M_{Pl}$, so that graviton emission cross sections $d\sigma/dt\sim 1/M_{Pl}^2$. However, the mass splittings between the excited graviton states can be tiny, so the graviton eigenstates are usually approximated by a continuum distribution. A summation (integration) over all allowed graviton emissions ends up cancelling the $1/M_{Pl}^2$ factor, so that observable cross section rates can be attained. Some of the fundamental production formulae for a KK graviton (denoted G) of mass m at hadron colliders include the subprocesses

$$\frac{d\sigma_m}{dt}(f\bar{f}\to\gamma G) = \frac{\alpha Q_f^2}{16N_f} \frac{1}{sM_{DI}^2} F_1(\frac{t}{s}, \frac{m^2}{s}), \tag{44.93}$$

where Q_f is the charge of fermion f and N_f is the number of QCD colors of f. Also,

$$\frac{d\sigma_m}{dt}(q\bar{q} \rightarrow gG) = \frac{\alpha_s}{36} \frac{1}{sM_{Pl}^2} F_1(\frac{t}{s}, \frac{m^2}{s}), \tag{44.94}$$

$$\frac{d\sigma_m}{dt}(qg \to qG) = \frac{\alpha_s}{96} \frac{1}{sM_{Pl}^2} F_2(\frac{t}{s}, \frac{m^2}{s}), \tag{44.95}$$

$$\frac{d\sigma_m}{dt}(gg \to gG) = \frac{3\alpha_s}{16} \frac{1}{sM_{Pl}^2} F_3(\frac{t}{s}, \frac{m^2}{s}), \tag{44.96}$$

where

$$\begin{split} F_1(x,y) = & \frac{1}{x(y-1-x)} \left[-4x(1+x)(1+2x+2x^2) + \right. \\ & \left. y(1+6x+18x^2+16x^3) - 6y^2x(1+2x) + y^3(1+4x) \right] (44.97) \end{split}$$

$$F_2(x,y) = -(y-1-x)F_1\left(\frac{x}{y-1-x}, \frac{y}{y-1-x}\right)$$
(44.98)

and

$$\begin{split} F_3(x,y) = & \frac{1}{x(y-1-x)} \left[1 + 2x + 3x^2 + 2x^3 + x^4 \right. \\ & \left. -2y(1+x^3) + 3y^2(1+x^2) - 2y^3(1+x) + y^4 \right]. (44.99) \end{split}$$

These formulae must then be multiplied by the graviton density of states formula $dN=S_{n-1}\frac{M_{Pl}^2}{M_{r}^{n+2}}m^{n-1}dm$ to gain the cross section

$$\frac{d^2\sigma}{dtdm} = S_{n-1} \frac{M_{Pl}^2}{M_*^{n+2}} m^{n-1} \frac{d\sigma_m}{dt}$$
 (44.100)

where $S_n = \frac{(2\pi)^{n/2}}{\Gamma(n/2)}$ is the surface area of an *n*-dimensional sphere of

Virtual graviton processes can also be searched for at colliders. For instance, in Ref. [24] the cross section for Drell-Yan production of lepton pairs via gluon fusion was calculated, where it is found that, in the center-of-mass system

$$\frac{d\sigma}{dz}(gg \to \ell^+\ell^-) = \frac{\lambda^2 s^3}{64\pi M^8} (1 - z^2)(1 + z^2)$$
(44.101)

where $z=\cos\theta$ and λ is a model-dependent coupling constant ~ 1 . Formulae for Drell-Yan production via $q\bar{q}$ fusion can also be found in Ref. [24,25].

44.11. Warped extra dimensions

In the Randall-Sundrum model [26] of warped extra dimensions, the arena for physics is a 5-d anti-deSitter (AdS_5) spacetime, for which a non-factorizable metric exists with a metric warp factor $e^{-2\sigma(\phi)}$. It is assumed that two opposite tension 3-branes exist within AdS_5 at the two ends of an S_1/Z_2 orbifold parametrized by co-ordinate ϕ which runs from $0-\pi$. The 4-D solution of the Einstein equations yields $\sigma(\phi) = kr_c|\phi|$, where r_c is the compactification radius of the extra dimension and $k \sim M_{Pl}$. The 4-D effective action allows one to identify $\overline{M}_{Pl}^2 = \frac{M^3}{k}(1-e^{-2kr_c\pi})$, where M is the 5-D Planck scale. Physical particles on the TeV scale (SM) brane have mass $m = e^{-kr_c\pi}m_0$, where m_0 is a fundamental mass of order the Planck scale. Thus, the weak scale-Planck scale hierarchy occurs due to the existence of the exponential warp factor if $kr_c \sim 12$.

In the simplest versions of the RS model, the TeV-scale brane contains only SM particles plus a tower of KK gravitons. The RS gravitons have mass $m_n=kx_ne^{-kr_c\pi}$, where the x_i are roots of Bessel functions $J_1(x_n)=0$, with $x_1\simeq 3.83,\,x_2\simeq 7.02$ etc. While the RS zero-mode graviton couplings suppressed by $1/\overline{M}_{Pl}$ and are thus inconsequential for collider searches, the n=1 and higher modes have couplings suppressed instead by $\Lambda_\pi=e^{-kr_c\pi}\overline{M}_{Pl}\sim TeV$. The n=1 RS graviton should have width $\Gamma_1=\rho m_1x_1^2(k/\overline{M}_{Pl})^2$, where ρ is a constant depending on how many decay modes are open. The formulae for dilepton production via virtual RS graviton exchange can be gained from the above formulae for the ADD scenario via the replacement [27]

$$\frac{\lambda}{M_*^4} \to \frac{i^2}{8\Lambda_\pi^2} \sum_{n=1}^\infty \frac{1}{s - m_n^2 + i m_n \Gamma_n}.$$
 (44.102)

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45. NEUTRINO CROSS SECTION MEASUREMENTS

Written in April 2012 by G.P. Zeller (Fermilab).

Neutrino interaction cross sections are an essential ingredient in most neutrino experiments. Interest in neutrino scattering has recently increased due to the need for such information in the interpretation of neutrino oscillation data. Scattering results on both charged current (CC) and neutral current (NC) neutrino channels have been collected over many decades using a variety of targets, analysis techniques, and detector technologies. With the advent of intense neutrino sources for oscillation measurements, experiments are remeasuring these cross sections with a renewed appreciation for nuclear effects† and precise knowledge of their incoming neutrino fluxes. This review summarizes accelerator-based neutrino cross section measurements made in the $\sim 0.1-300$ GeV range with an emphasis on inclusive, quasi-elastic, and single pion production processes (areas where we have the most experimental input at present). For a more comprehensive discussion of neutrino interaction cross sections, including neutrino-electron scattering and lower energy measurements, the reader is directed to a recent review of this subject [1].

by NuTeV [2] and at lower energies on argon by ArgoNeuT [3]. At high energy, the inclusive cross section is dominated by deep inelastic scattering (DIS). Several high energy neutrino experiments have measured the DIS cross sections for specific final states, for example opposite-sign dimuon production. The most recent dimuon cross section measurements include those from CHORUS [4], NOMAD [5], and NuTeV [6]. At lower neutrino energies, the inclusive cross section is largely a combination of quasi-elastic scattering and resonance production processes, two areas we will turn to next.

45.2. Quasi-elastic scattering

Historically, neutrino (or antineutrino) quasi-elastic scattering refers to the processes, $\nu_{\mu} n \to \mu^{-} p$ and $\overline{\nu}_{\mu} p \to \mu^{+} n$, where a charged lepton and single nucleon are ejected in the elastic interaction of a neutrino (or antineutrino) with a nucleon in the target material. This is the final state one would strictly observe, for example, in scattering off of a free nucleon target. QE scattering is important as it is the dominant neutrino interaction at energies less than about 1 GeV and is a large signal sample in many neutrino oscillation experiments.

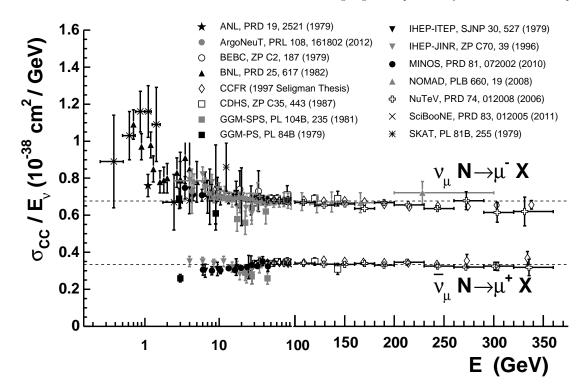


Fig. 45.1: Measurements of ν_{μ} and $\overline{\nu}_{\mu}$ CC inclusive scattering cross sections divided by neutrino energy as a function of neutrino energy. Note the transition between logarithmic and linear scales occurring at 100 GeV. Neutrino-nucleon cross sections are typically twice as large as the corresponding antineutrino cross sections, though this difference can be larger at lower energies. NC cross sections (not shown) are generally smaller (but non-negligible) compared to their CC counterparts.

45.1. Inclusive Scattering

Over the years, many experiments have measured the total cross section for neutrino $(\nu_{\mu} N \to \mu^{-} X)$ and antineutrino $(\overline{\nu}_{\mu} N \to \mu^{+} X)$ scattering off nucleons covering a broad range of energies (Fig. 45.1). As can be seen, the inclusive cross section approaches a linear dependence on neutrino energy. Such behavior is expected for point-like scattering of neutrinos from quarks, an assumption which breaks down at lower energies.

To provide a more complete picture, differential cross sections for such inclusive scattering processes have also been reported on iron

Fig. 45.2 displays the current status of existing measurements of ν_{μ} and $\overline{\nu}_{\mu}$ QE scattering cross sections as a function of neutrino energy. In this plot, and all others in this review, the prediction from a representative neutrino event generator (NUANCE) [7] provides a theoretical comparator. Other generators and more sophisticated calculations exist which can give different predictions [8].

In many of these initial measurements of the neutrino QE cross section, bubble chamber experiments typically employed light targets $(H_2 \text{ or } D_2)$ and required both the detection of the final state muon and single nucleon‡; thus the final state was clear and elastic kinematic conditions could be verified. The situation is more complicated of course for heavier nuclear targets. In this case, nuclear effects can

[†] Kinematic and final state effects which impact neutrino scattering off nuclei. Note that most modern neutrino experiments use nuclear targets to increase their event yields.

 $[\]ddagger$ In the case of D_2 , many experiments additionally observed the spectator proton.

impact the size and shape of the cross section as well as the final state kinematics and topology. Due to intranuclear rescattering and the possible effects of correlations between target nucleons, additional nucleons may be ejected in the final state; hence, a QE interaction on a nuclear target does not always imply the ejection of a single nucleon. Thus, one needs to take some care in defining what one means by neutrino QE scattering when scattering off targets heavier than H_2 or D_2 . Adding to the complexity, recent measurements [9] of the ν_{μ} QE scattering cross section on carbon at low energy have observed a significantly larger than expected cross section, an enhancement believed to be signaling the presence of sizable nuclear effects. Such cross sections have also been reported for the first time in the form of double-differential distributions [9], thus reducing the model-dependence of the data and allowing a much more stringent test of the underlying nuclear theory. The impact of nuclear effects on neutrino QE scattering has been the subject of intense theoretical scrutiny over the past year [19] with potential implications on nucleon ejection [20], neutrino energy reconstruction [21], and the neutrino/antineutrino cross section ratio [22]. The reader is referred to a recent review of the situation in [23]. Additional measurements are clearly needed before a complete understanding is achieved. In addition to such CC investigations, measurements of the NC counterpart of this channel have also been performed. The most recent NC elastic scattering cross section measurements include those from BNL E734 [24] and MiniBooNE [25]. A number of measurements of the Cabibbo-suppressed antineutrino QE hyperon production cross section have additionally been reported [18,26], although none in recent years.

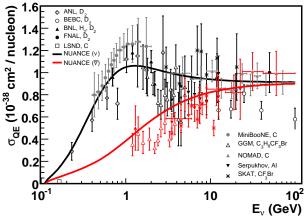


Figure 45.2: Measurements of ν_{μ} (black) and $\overline{\nu}_{\mu}$ (red) quasielastic scattering cross sections (per nucleon) as a function of neutrino energy. Data on a variety of nuclear targets are shown, including measurements from ANL [10], BEBC [11], BNL [12], FNAL [13], Gargamelle [14], LSND [15], MiniBooNE [9], NOMAD [16], Serpukhov [17], and SKAT [18]. Also shown is the QE free nucleon scattering prediction [7] assuming $M_A=1.0$ GeV. This prediction is significantly altered by nuclear corrections in the case of neutrino-nucleus scattering. Care should be taken in interpreting measurements on targets heavier than deuterium.

45.3. Pion Production

In addition to such elastic processes, neutrinos can also inelastically scatter producing a nucleon excited state (Δ , N^*). Such baryonic resonances quickly decay, most often to a nucleon and single pion final state. Fig. 45.3 and Fig. 45.4 show a collection of resonance single pion production cross section data for both CC and NC neutrino scattering. Decades ago, BEBC, FNAL, Gargamelle, and SKAT also performed similar measurements for antineutrinos [27]. Most often these experiments reported measurements of NC/CC single pion cross section ratios [28].

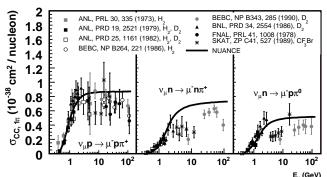


Figure 45.3: Historical measurements of ν_{μ} CC resonant single pion production. The data appear as reported by the experiments; no additional corrections have been applied to account for differing nuclear targets or invariant mass ranges. The free scattering prediction is from [7] with $M_A=1.1$ GeV. Note that other absolute measurements have been made by MiniBooNE [30] but cannot be directly compared with this historical data - the modern measurements are more inclusive and have quantified the production of pions leaving the target nucleus rather than specific $\pi+N$ final states as identified at the neutrino interaction vertex.

It should be noted that baryonic resonances can also decay to multi-pion, other mesonic $(K, \eta, \rho, \text{ etc.})$, and even photon final states. Experimental results for these channels are typically sparse or non-existent [1]; however, photon production processes can be an important background for $\nu_{\mu} \rightarrow \nu_{e}$ appearance searches and thus have become the focus of some recent experimental investigations [29].

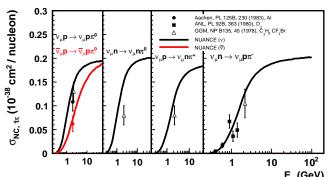


Figure 45.4: Same as Fig. 45.3 but for NC neutrino (black) and antineutrino (red) scattering. The Gargamelle measurements come from a re-analysis of this data [31]. Note that more recent absolute measurements exist [32] but cannot be directly compared with this data for the same reasons as in Fig. 45.3.

In addition to resonance production processes, neutrinos can also coherently scatter off of the entire nucleus and produce a distinctly forward-scattered single pion final state. Both CC ($\nu_{\mu}A \rightarrow \mu^{-}A\pi^{+}$, $\overline{\nu}_{\mu}A \rightarrow \mu^{+}A\pi^{-}$) and NC ($\nu_{\mu}A \rightarrow \nu_{\mu}A\pi^{0}$, $\overline{\nu}_{\mu}A \rightarrow \overline{\nu}_{\mu}A\pi^{0}$) processes are possible in this case. The level of coherent pion production is predicted to be small compared to incoherent processes [33], but observations exist across a broad energy range and on multiple nuclear targets [34–36]. Most of these measurements have been performed at energies above 2 GeV, but several modern experiments have started to search for coherent pion production at lower neutrino energies, including K2K [37], MiniBooNE [38], and SciBooNE [39].

As with QE scattering, a new appreciation for the significance of nuclear effects has surfaced in pion production channels, again due to the use of heavy targets in modern neutrino experiments. Many experiments have been careful to report cross sections for various detected final states, thereby not correcting for large and uncertain nuclear effects (e.g., pion rescattering, charge exchange, and absorption) which can introduce unwanted sources of uncertainty and

model dependence. Recent measurements of single pion cross sections, as published by K2K [40], MiniBooNE [41], and SciBooNE [42], take the form of ratios with respect to QE or CC inclusive scattering samples. Providing the most comprehensive survey of neutrino single pion production to date, MiniBooNE has recently published a total of 16 single- and double-differential cross sections for both the final state muon (in the case of CC scattering) and pion in these interactions; thus, providing the first measurements of these distributions [30,32]. Regardless of the interaction channel, such differential cross section measurements (in terms of observed final state particle kinematics) are now preferred for their reduced model dependence and for the additional kinematic information they provide. Such a new direction has been the focus of modern measurements as opposed to the reporting of (model-dependent) cross sections as a function of neutrino energy. Together with similar results for other interaction channels, a better understanding and modeling of nuclear effects will be possible moving forward.

45.4. Outlook

Coming soon, additional neutrino and antineutrino cross section measurements in the few-GeV energy range are anticipated from ArgoNeuT, MiniBooNE, MINOS, NOMAD, and SciBooNE. In addition, a few new experiments are now collecting data or will soon be commissioning their detectors. Analysis of a broad energy range of data on a variety of targets in the MINER ν A experiment will provide the most detailed analysis yet of nuclear effects in neutrino interactions. Data from ICARUS and MicroBooNE will probe deeper into complex neutrino final states using the superior capabilities of liquid argon time projection chambers, while the T2K and NOvA near detectors will collect high statistics samples in intense neutrino beams. Together, these investigations should significantly advance our understanding of neutrino-nucleus scattering in the years to come.

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46. PLOTS OF CROSS SECTIONS AND RELATED QUANTITIES

(For neutrino plots, see review article "Neutrino Cross Section Measurements" by G.P. Zeller in this edition of RPP)

Jet Production in pp and $\overline{p}p$ Interactions

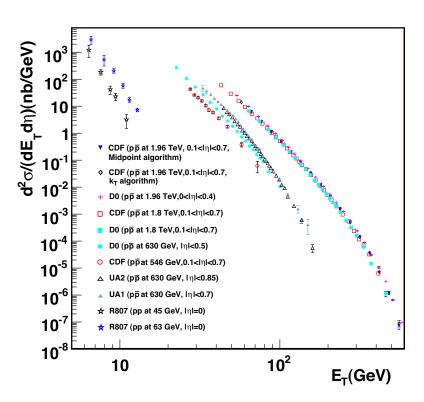


Figure 46.1: Inclusive differential jet cross sections plotted as a function of the jet tranverse energy. The CDF and D0 measurements use a cone algorithm of radius 0.7 for all results shown except for the CDF measurements at 1.96 TeV which also use k_T with a D parameter of 0.7 and midpoint algorithms. The cone/ k_T results should be similar if $R_{cone} = D$. UA1 (UA2) uses a non-iterative cone algorithm with a radius of 1.0 (1.3). Recent NLO QCD predictions (such as CTEQ6M) provide a good description of the CDF and D0 jet cross sections, Rept. on Prog. in Phys. 70, 89 (2007). Comparisons with the older cross sections are more difficult due to the nature of the jet algorithms used. CDF: Phys. Rev. D75, 092006 (2007), Phys. Rev. D64, 032001 (2001), Phys. Rev. Lett. 70, 1376 (1993); **D0**: Phys. Rev. **D64**, 032003 (2001); UA2: Phys. Lett. B257, 232 (1991); UA1: Phys. Lett. **B172**, 461 (1986); **R807**: Phys. Lett. B123, 133 (1983). (Courtesy of J. Huston, Michigan State University, 2010.)

Direct γ Production in $\overline{p}p$ Interactions

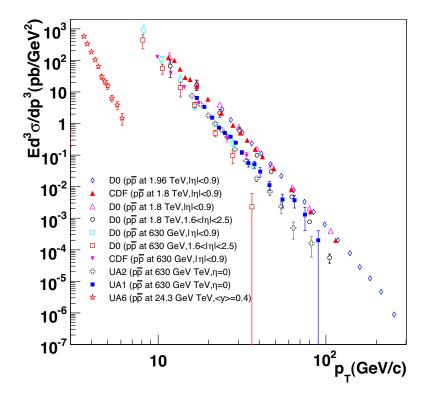


Figure 46.2: Isolated photon cross sections plotted as a function of the photon transverse momentum. The errors are either statistical only (CDF, D0 (1.96 TeV), UA1, UA2, UA6) or uncorrelated (D0 1.8 TeV, 630 GeV). The data are generally in good agreement with NLO QCD predictions, albeit with a tendency for the data to be above (below) the theory for lower (large) transverse momenta, Phys. Rev. D59, 074007 (1999). Do: Phys. Lett. B639, 151 (2006), Phys. Rev. Lett. 87, 251805 (2001); CDF: Phys. Rev. D65, 112003 (2002); UA6: Phys. Lett. B206, 163 (1988); **UA1**: Phys. Lett. **B209**, 385 (1988); **UA2**: Phys. Lett. **B288**, 386 (1992). (Courtesy of J. Huston, Michigan State University, 2007.)

Differential Cross Section for W and Z Boson Production

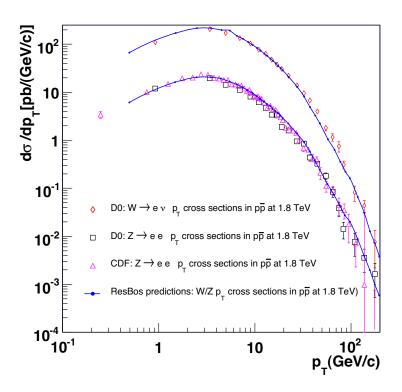


Figure 46.3: Differential cross sections for W and Z production shown as a function of the boson transverse momentum. The D0 results include only the statistical error while the CDF results include all errors except for the 3.9% integrated luminosity error. The results are in good agreement with theoretical predictions that include both the effects of NLO corrections and of q_T resummation, such as the ResBos (Phys. Rev. **D67**, 073016 (2003)) predictions indicated on the plot. D0: Phys. Lett. **B513**, 292 (2001), Phys. Rev. Lett. 84, 2792 (2000). CDF: Phys. Rev. Lett. 84, 845 (2000). (Courtesy of J. Huston, Michigan State University, 2007)

Pseudorapidity Distributions in $\overline{p}p$ Interactions

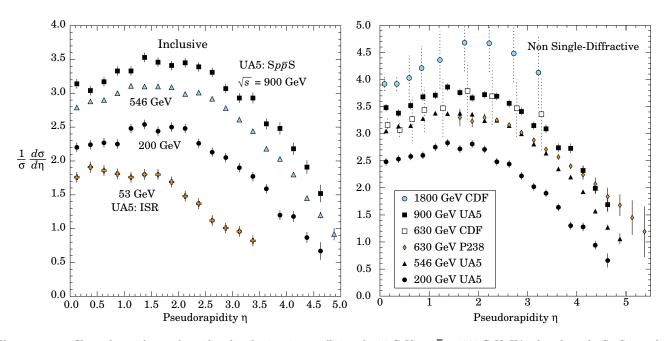


Figure 46.4: Charged particle pseudorapidity distributions in $p\overline{p}$ collisions for 53 GeV $\leq \sqrt{s} \leq$ 1800 GeV. UA5 data from the $Sp\overline{p}S$ are taken from G.J. Alner *et al.*, Z. Phys. **C33**, 1 (1986), and from the ISR from K. Alpgøard *et al.*, Phys. Lett. **112B**, 193 (1982). The UA5 data are shown for both the full inelastic cross section and with singly diffractive events excluded. Additional non single-diffractive measurements are available from CDF at the Tevatron, F. Abe *et al.*, Phys. Rev. **D41**, 2330 (1990) and Experiment P238 at the $Sp\overline{p}S$, R. Harr *et al.*, Phys. Lett. **B401**, 176 (1997). (Courtesy of D.R. Ward, Cambridge Univ., 1999)

Average Hadron Multiplicities in Hadronic e^+e^- Annihilation Events

Table 46.1: Average hadron multiplicities per hadronic e^+e^- annihilation event at $\sqrt{s}\approx 10,\,29-35,\,91,\,$ and 130–200 GeV. The rates given include decay products from resonances with $c\tau<10$ cm, and include the corresponding anti-particle state. Correlations of the systematic uncertainties were considered for the calculation of the averages. (Updated May 2010 by O. Biebel, LMU, Munich)

| Particle | $\sqrt{s} \approx 10 \; \mathrm{GeV}$ | $\sqrt{s}=2935~\mathrm{GeV}$ | $\sqrt{s} = 91 \; \mathrm{GeV}$ | $\sqrt{s}=130200~\mathrm{GeV}$ |
|--------------------------------|----------------------------------------------|------------------------------------|----------------------------------------------------|--------------------------------|
| Pseudoscalar | | | | |
| π^+ | 6.6 ± 0.2 | 10.3 ± 0.4 | 17.02 ± 0.19 | 21.24 ± 0.39 |
| π^0 | 3.2 ± 0.3 | 5.83 ± 0.28 | 9.42 ± 0.32 | |
| K^+ | 0.90 ± 0.04 | 1.48 ± 0.09 | 2.228 ± 0.059 | 2.82 ± 0.19 |
| K^0 | 0.91 ± 0.05 | 1.48 ± 0.07 | 2.049 ± 0.026 | 2.10 ± 0.12 |
| η | 0.20 ± 0.04 | 0.61 ± 0.07 | 1.049 ± 0.080 | |
| $\eta'(958)$ | 0.03 ± 0.01 | 0.26 ± 0.10 | 0.152 ± 0.020 | |
| D^+ | $0.194 \pm 0.019^{(a)}$ | 0.17 ± 0.03 | 0.175 ± 0.016 | |
| D^0 | $0.446 \pm 0.032^{(a)}$ | 0.45 ± 0.07 | 0.454 ± 0.030 | |
| B_s^+ $B^{(c)}$ | $0.063 \pm 0.014^{(a)}$ | $0.45 \pm 0.20^{(b)}$ | 0.131 ± 0.021 | |
| $B^{(c)}$ B^+ | _ | _ | $0.165 \pm 0.026^{(d)} \\ 0.178 \pm 0.006^{(d)}$ | |
| B_s^0 | _ | _ | $0.178 \pm 0.006^{(d)}$ $0.057 \pm 0.013^{(d)}$ | |
| | <u> </u> | | 0.057 ± 0.013 | |
| Scalar meson $f_0(980)$ | 0.024 ± 0.006 | $0.05 \pm 0.02^{(e)}$ | 0.146 ± 0.012 | |
| $a_0(980)^{\pm}$ | 0.024± 0.000 — | 0.00 ± 0.02 | 0.140 ± 0.012 $0.27 \pm 0.11^{(f)}$ | |
| Vector meson | ne• | | 0.21 ± 0.11 | |
| $\rho(770)^0$ | 0.35 ± 0.04 | 0.81 ± 0.08 | 1.231 ± 0.098 | |
| $\rho(770)^{\pm}$ | 0.00 ± 0.04 | 0.01 ± 0.00 | $2.40 \pm 0.43^{(f)}$ | |
| $\omega(782)$ | 0.30 ± 0.08 | _ | 1.016 ± 0.065 | |
| $K^*(892)^+$ | 0.30 ± 0.08 0.27 ± 0.03 | 0.64 ± 0.05 | 0.715 ± 0.059 | |
| $K^*(892)^0$ | 0.27 ± 0.03 0.29 ± 0.03 | 0.56 ± 0.06 | 0.713 ± 0.039 0.738 ± 0.024 | |
| $\phi(1020)$ | 0.29 ± 0.03 0.044 ± 0.003 | 0.085 ± 0.001 | 0.0963 ± 0.0032 | |
| $D^*(2010)^+$ | 0.044 ± 0.003 $0.177 \pm 0.022^{(a)}$ | 0.43 ± 0.07 | 0.0903 ± 0.0032 $0.1937 \pm 0.0057^{(g)}$ | |
| $D^*(2010)^4$ $D^*(2007)^0$ | $0.168 \pm 0.019^{(a)}$ | 0.43 ± 0.07 0.27 ± 0.11 | 0.1337 ± 0.0037 57 | |
| $D_s^*(2112)^+$ | 0.108 ± 0.013 0.048 ± 0.014 0.014 | 0.27 ± 0.11 | $0.101 \pm 0.048^{(h)}$ | |
| B^* (i) | 0.040 ± 0.014 | _ | 0.288 ± 0.026 | |
| $J/\psi(1S)$ | $0.00050 \pm 0.00005^{(a)}$ | _ | $0.0052 \pm 0.0004^{(j)}$ | |
| $\psi(2S)$ | | _ | 0.0002 ± 0.0004 0.0023 ± 0.0004 | |
| $\Upsilon(1S)$ | | _ | 0.0020 ± 0.0004 $0.00014 \pm 0.00007^{(j)}$ | |
| Pseudovecto | r mesons: | | 0.00011± 0.00001 | |
| $f_1(1285)$ | | _ | 0.165 ± 0.051 | |
| $f_1(1420)$ | _ | _ | 0.056 ± 0.012 | |
| $\chi_{c1}(3510)$ | _ | _ | $0.0041 \pm 0.0011^{(j)}$ | |
| Tensor meso | ns: | | | |
| $f_2(1270)$ | 0.09 ± 0.02 | 0.14 ± 0.04 | 0.166 ± 0.020 | |
| $f_2'(1525)$ | _ | _ | 0.012 ± 0.006 | |
| $K_2^*(1430)^+$ | _ | 0.09 ± 0.03 | _ | |
| $K_2^*(1430)^0$ | _ | 0.12 ± 0.06 | 0.084 ± 0.022 | |
| B^{**} (k) | _ | _ | 0.118 ± 0.024 | |
| | _ | _ | $0.0052 \pm 0.0011^{(\ell)}$ | |
| D_{s1}^{\pm} $D_{s2}^{*\pm}$ | _ | _ | $0.0083 \pm 0.0031^{(\ell)}$ | |
| Baryons: | | | | |
| p | 0.253 ± 0.016 | 0.640 ± 0.050 | 1.050 ± 0.032 | 1.41 ± 0.18 |
| Λ | 0.080 ± 0.007 | 0.205 ± 0.010 | 0.3915 ± 0.0065 | 0.39 ± 0.03 |
| Σ^0 | 0.023 ± 0.008 | _ | 0.076 ± 0.011 | |
| Σ^- | _ | _ | 0.081 ± 0.010 | |
| Σ^+ | _ | _ | 0.107 ± 0.011 | |
| Σ^{\pm} | _ | _ | 0.174 ± 0.009 | |
| Ξ^- | 0.0059 ± 0.0007 | 0.0176 ± 0.0027 | 0.0258 ± 0.0010 | |
| $\Delta(1232)^{++}$ | 0.040 ± 0.010 | _ | 0.085 ± 0.014 | |
| $\Sigma(1385)^{-}$ | 0.006 ± 0.002 | 0.017 ± 0.004 | 0.0240 ± 0.0017 | |
| $\Sigma(1385)^{+}$ | 0.005 ± 0.001 | 0.017 ± 0.004 | 0.0239 ± 0.0015 | |
| $\Sigma(1385)^{\pm}$ | 0.0106 ± 0.0020 | 0.033 ± 0.008 | 0.0462 ± 0.0028 | |
| $\Xi(1530)^0$ | 0.0015 ± 0.0006 | _ | 0.0068 ± 0.0006 | |
| Ω_{-} | 0.0007 ± 0.0004 | 0.014 ± 0.007 | 0.0016 ± 0.0003 | |
| Λ_c^+ | $0.074 \pm 0.031^{(m)}$ | 0.110 ± 0.050 | 0.078 ± 0.017 | |
| Λ_b^0 | _ | _ | 0.031 ± 0.016 | |
| $\Sigma_c^{++}, \Sigma_c^0$ | 0.014 ± 0.007 | _ | _ | |
| $\Lambda(1520)$ | 0.008 ± 0.002 | | 0.0222 ± 0.0027 | |

Notes for Table 46.1:

- (a) $\sigma_{\rm had} = 3.33 \pm 0.05 \pm 0.21$ nb (CLEO: Phys. Rev. **D29**, 1254 (1984)) has been used in converting the measured cross sections to average hadron multiplicities.
- (b) $B(D_s \to \eta \pi, \eta' \pi)$ was used (RPP 1994).
- (c) Comprises both charged and neutral B meson states.
- (d) The Standard Model $B(Z \to b\overline{b}) = 0.217$ was used.
- (e) $x_p = p/p_{\text{beam}} > 0.1$ only.
- (f) Both charge states.
- (g) $B(D^*(2010)^+ \to D^0\pi^+) \times B(D^0 \to K^-\pi^+)$ has been used (RPP 2000).
- (h) $B(D_s^* \to D_S^+ \gamma)$, $B(D_s^+ \to \phi \pi^+)$, $B(\phi \to K^+ K^-)$ have been used (RPP 1998).
- (i) Any charge state (i.e., B_d^* , B_u^* , or B_s^*).
- (j) $B(Z \rightarrow hadrons) = 0.699$ was used (RPP 1994).
- (k) Any charge state (i.e., B_d^{**} , B_u^{**} , or B_s^{**}).
- (ℓ) Assumes B($D_{s1}^+ \to D^{*+}K^0 + D^{*0}K +) = 100\%$ and B($D_{s2}^+ \to D^0K^+) = 45\%$.
- (m) The value was derived from the cross section of $\Lambda_c^+ \to p\pi K$ using (a) and assuming the branching fraction to be $(5.0 \pm 1.3)\%$ (RPP 2004).

References for Table 46.1:

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RPP 1994: Phys. Rev. D50, 1173 (1994) and references therein.

RPP 1996: Phys. Rev. D54, 1 (1996) and references therein.

RPP 1998: Eur. Phys. J. C3, 1 (1998) and references therein.

 \mathbf{RPP} 2000: Eur. Phys. J. $\mathbf{C15}$, 1 (2000) and references therein.

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Crystal Ball: Ch. Bieler et al., Z. Phys. C49, 225 (1991).

DELPHI: P. Abreu et al.: Z. Phys. C57, 181 (1993); C59, 533 (1993); C61, 407 (1994); C65, 587 (1995); C67, 543 (1995); C68, 353 (1995); C73, 61 (1996); Nucl. Phys. B444, 3 (1995); Phys. Lett. B341, 109 (1994); B345, 598 (1995); B361, 207 (1995); B372, 172 (1996); B379, 309 (1996); B416, 233 (1998); B449, 364 (1999); B475, 429 (2000); Eur. Phys. J. C6, 19 (1999); C5, 585 (1998); C18, 203 (2000); and J. Abdallah et al., Phys. Lett. B569, 129 (2003); Phys. Lett. B576, 29 (2003); Eur. Phys. J. C44, 299 (2005); and W. Adam et al.: Z. Phys. C69, 561 (1996); C70, 371 (1996).

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Average e^+e^- , pp, and $\overline{p}p$ Multiplicity

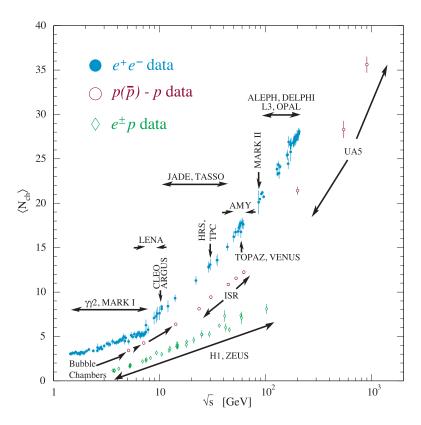


Figure 46.5: Average multiplicity as a function of \sqrt{s} for e^+e^- and $p\overline{p}$ annihilations, and pp and ep collisions. The indicated errors are statistical and systematic errors added in quadrature, except when no systematic errors are given. Files of the data shown in this figure are given in http://pdg.lbl.gov/current/avg-multiplicity/.

 e^+e^- : Most e^+e^- measurements include contributions from K_S^0 and Λ decays. The $\gamma\gamma 2$ and MARK I measurements contain a systematic 5% error. Points at identical energies have been spread horizontally for clarity:

ALEPH: D. Buskulic et al., Z. Phys. C69, 15 (1995); and Z. Phys. C73, 409 (1997);
A. Heister et al., Eur. Phys. J. C35, 457 (2004).

ARGUS: H. Albrecht et al., Z. Phys. C54, 13 (1992).

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L3: M. Acciarri et al., Phys. Lett. B371, 137 (1996); Phys. Lett. B404, 390 (1997); and Phys. Lett. B444, 569 (1998); P. Achard et al., Phys. Reports 339, 71 (2004).

OPAL: G. Abbiendi et al., Eur. Phys. J. C16, 185 (2000); and Eur. Phys. J. C37, 25 (2004);

K. Ackerstaff et al., Z. Phys. C75, 193 (1997);

P.D. Acton et al., Z. Phys. C53, 539 (1992) and references therein;

R. Akers et al., Z. Phys. C68, 203 (1995).

TOPAZ: K. Nakabayashi *et al.*, Phys. Lett. **B413**, 447 (1997).

VENUS: K. Okabe et al., Phys. Lett. B423, 407 (1998).

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H1: C. Adloff et al., Nucl. Phys. B504, 3 (1997); F.D. Aaron et al., Phys. Lett. B654, 148 (2007).

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S. Chekanov et al., Phys. Lett. **B510**, 36 (2001).

 $p(\overline{p})$: The errors of the $p(\overline{p})$ measurements are the quadratically added statistical and systematic errors, except for the bubble chamber measurements for which only statistical errors are given in the references. The values measured by UA5 exclude single diffractive dissociation: bubble chamber: J. Benecke *et al.*, Nucl. Phys. **B76**, 29 (1976); W.M. Morse *et al.*, Phys. Rev. **D15**, 66 (1977).

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(Courtesy of O. Biebel, LMU, Munich, 2010)

σ and R in e^+e^- Collisions

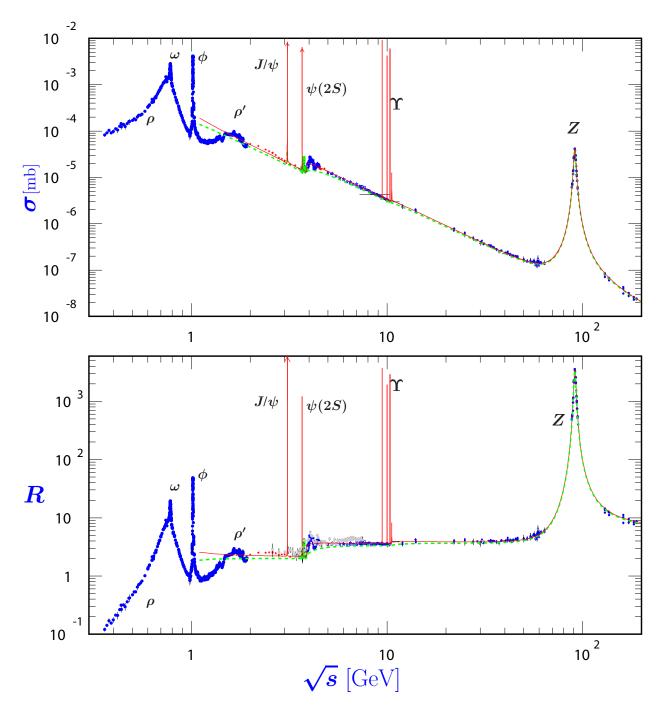


Figure 46.6: World data on the total cross section of $e^+e^- \to hadrons$ and the ratio $R(s) = \sigma(e^+e^- \to hadrons, s)/\sigma(e^+e^- \to \mu^+\mu^-, s)$. $\sigma(e^+e^- \to hadrons, s)$ is the experimental cross section corrected for initial state radiation and electron-positron vertex loops, $\sigma(e^+e^- \to \mu^+\mu^-, s) = 4\pi\alpha^2(s)/3s$. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are an educative guide: the broken one (green) is a naive quark-parton model prediction, and the solid one (red) is 3-loop pQCD prediction (see "Quantum Chromodynamics" section of this *Review*, Eq. (9.7) or, for more details, K. G. Chetyrkin *et al.*, Nucl. Phys. **B586**, 56 (2000) (Erratum *ibid.* **B634**, 413 (2002)). Breit-Wigner parameterizations of J/ψ , $\psi(2S)$, and $\Upsilon(nS)$, n=1,2,3,4 are also shown. The full list of references to the original data and the details of the R ratio extraction from them can be found in [arXiv:hep-ph/0312114]. Corresponding computer-readable data files are available at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS (Protvino) and HEPDATA (Durham) Groups, May 2010.)

R in Light-Flavor, Charm, and Beauty Threshold Regions

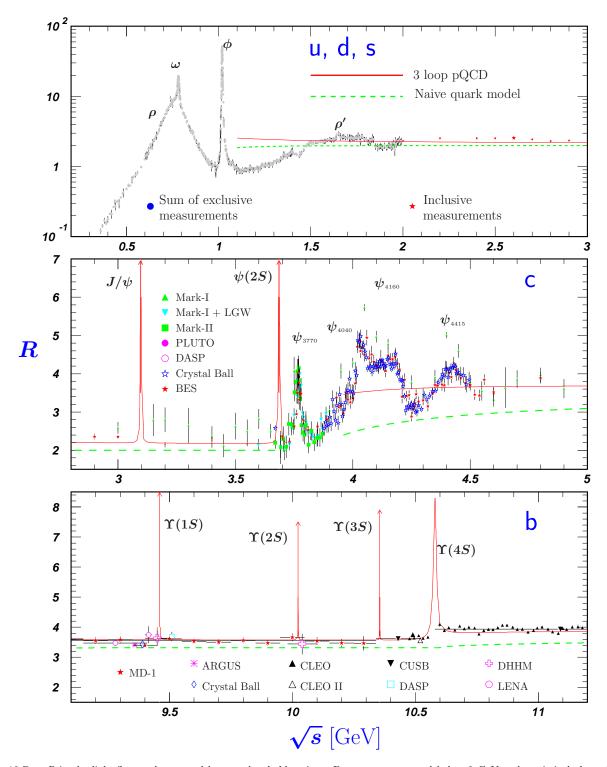


Figure 46.7: R in the light-flavor, charm, and beauty threshold regions. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are the same as in Fig. 46.6. Note: CLEO data above $\Upsilon(4S)$ were not fully corrected for radiative effects, and we retain them on the plot only for illustrative purposes with a normalization factor of 0.8. The full list of references to the original data and the details of the R ratio extraction from them can be found in <code>[arXiv:hep-ph/0312114]</code>. The computer-readable data are available at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS (Protvino) and HEPDATA (Durham) Groups, May 2010.)

Annihilation Cross Section Near M_Z

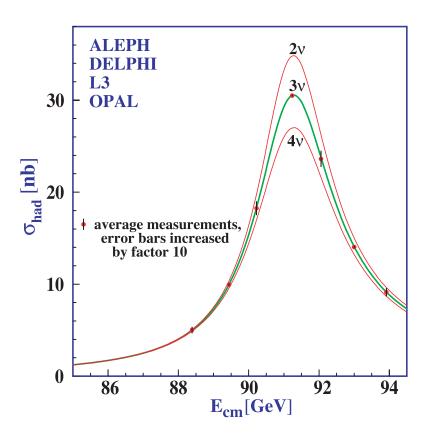


Figure 46.8: Combined data from the ALEPH, DELPHI, L3, and OPAL Collaborations for the cross section in e^+e^- annihilation into hadronic final states as a function of the center-of-mass energy near the Z pole. The curves show the predictions of the Standard Model with two, three, and four species of light neutrinos. The asymmetry of the curve is produced by initial-state radiation. Note that the error bars have been increased by a factor ten for display purposes. References:

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(Courtesy of M. Grünewald and the LEP Electroweak Working Group, 2007)

Table 46.2: Total hadronic cross section. Analytic S-matrix and Regge theory suggest a variety of parameterizations of total cross sections at high energies with different areas of applicability and fits quality.

A ranking procedure, based on measures of different aspects of the quality of the fits to the current evaluated experimental database, allows one to single out the following parameterization of highest rank [1]

$$\sigma^{ab} = Z^{ab} + B^{ab} \log^2(s/s_M) + Y_1^{ab} (s_M/s)^{\eta_1} - Y_2^{ab} (s_M/s)^{\eta_2} \qquad \sigma^{\overline{a}b} = Z^{ab} + B^{ab} \log^2(s/s_M) + Y_1^{ab} (s_M/s)^{\eta_1} + Y_2^{ab} (s_M/s)^{\eta_2} \ ,$$

where Z^{ab} , $B^{a(p,n,\gamma*)} = \pi \frac{(\hbar c)^2}{M^2}$, $B^{ad} = \lambda \pi \frac{(\hbar c)^2}{M^2}$ (dimensionless factor λ introduced to test the universality for nuclei targets), Y_i^{ab} are in mb; s, $s_M = (m_a + m_b + M)^2$ are in GeV²; m_a , m_b , $[m_{\gamma^*} = m_{\rho(770)}]$ are the masses of initial state particles, and M – the mass parameter defining the rate of universal rise of the cross sections are all in GeV. Parameters M, η_1 and η_2 are universal for all collisions considered. Terms $Z^{ab} + B^{ab} \log^2(s/s_M)$ represent the pomerons. The exponents η_1 and η_2 represent lower-lying C-even and C-odd exchanges, respectively. In addition to total cross sections σ , the measured ratios of the real-to-imaginary parts of the forward scattering amplitudes $\rho = Re(T)/Im(T)$ are included in the fits by using s to u crossing symmetry and differential dispersion relations.

Exact factorization hypothesis was used for both Z^{ab} and $B^{ab}\log^2(s/s_M)$ to extend the universal rise of the total hadronic cross sections to the $\gamma p \to hadrons$ and $\gamma \gamma \to hadrons$ collisions. This results in substitutions: $Z^{\gamma p} + \pi \frac{(\hbar c)^2}{M^2}\log^2(s/s_M) \Rightarrow \delta[Z^{pp} + \pi \frac{(\hbar c)^2}{M^2}\log^2(s/s_M)]$, and $Z^{\gamma \gamma} + \pi \frac{(\hbar c)^2}{M^2}\log^2(s/s_M) \Rightarrow \delta^2[Z^{pp} + \pi \frac{(\hbar c)^2}{M^2}\log^2(s/s_M)]$, with the additional parameter δ . Simultaneous fit was made to the 2011-updated data for all collisions listed in the central column of the table. The total number of adjusted parameters is **34**. Asymptotic parameters $(Z, M, \lambda, \delta, \eta_1, \eta_2)$ thus obtained were then fixed and used as inputs to fits by groups to check a stability of the whole situation with description of the high energy data. Results are shown in the right hand part of the table. All fits included data above $\sqrt{s_{\min}} = 5$ GeV with overall $\chi^2/\text{dof} = 0.96$.

| M =2.15(2), η_1 =0.462(2), η_2 =0.550(5) | | | Beam/ | δ =0.00 | $03056(15), \lambda = 1.65$ | 30(35) | χ^2/dof |
|------------------------------------------------------|-------------------------------|----------|---------------------|----------------|-----------------------------|---------|-----------------------|
| Z | Y_1 | Y_2 | Target | Z | Y_1 | Y_2 | by groups |
| 34.71(15) | 12.72(19) | 7.35(8) | $\overline{p}(p)/p$ | 34.71(15) | 12.72(6) | 7.35(7) | |
| 35.00(18) | 12.19(34) | 6.62(16) | $\overline{p}(p)n$ | 35.00(16) | 12.19(45) | 6.6(2) | 1.051 |
| 34.9(1.4) | -55(23) | -57(24) | Σ^-/p | 34.9(1.4) | -55(6) | -57(8) | 0.558 |
| 19.02(13) | 9.22(16) | 1.75(3) | π^{\pm}/p | 19.02(13) | 9.22(3) | 1.75(3) | 1.020 |
| 16.55(9) | 4.02(14) | 3.39(4) | K^{\pm}/p | 16.55(9) | 4.02(3) | 3.39(3) | |
| 16.49(10) | 3.44(19) | 1.82(7) | K^{\pm}/n | 16.49(6) | 3.44(16) | 1.82(7) | 0.737 |
| | 0.0128(12) | | γ/p | | 0.00128(4) | | |
| | $-0.034(0.183){\cdot}10^{-4}$ | | γ/γ | | $-0.034(166)\cdot 10^{-4}$ | | 0.722 |
| 65.02(38) | 29.04(44) | 14.9(2) | $\overline{p}(p)/d$ | 65.02(16) | 29.04(39) | 14.9(2) | 1.524 |
| 37.06(30) | 18.28(41) | 0.34(9) | π^{\pm}/d | 37.06(7) | 18.28(19) | 0.34(9) | 0.747 |
| 32.34(22) | 7.33(34) | 5.59(9) | K^{\pm}/d | 32.34(6) | 7.33(16) | 5.59(7) | 0.819 |

The fitted functions are shown in the following figures, along with one-standard-deviation error bands. Whenever the reduced χ^2 is greater than one, a scale factor has been included to evaluate the parameter values and to draw the error bands. Where appropriate, statistical and systematic errors were combined quadratically in constructing weights for all fits. Only statistical error bars are shown on the plots. Vertical arrows indicate lower limits on the $p_{\rm lab}$ or \sqrt{s} range used in the fits. Database used in the fits now includes pp data from TOTEM experiment [2] and new data in the RHIC energy range from ARGO-YBJ cosmic ray experiment [3]. The modifications of the universal asymptotic term are motivated by ideas, suggestions and results from the old and recent papers [4-13]. Computer-readable data files are available at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS group, IHEP, Protvino, April 2012)

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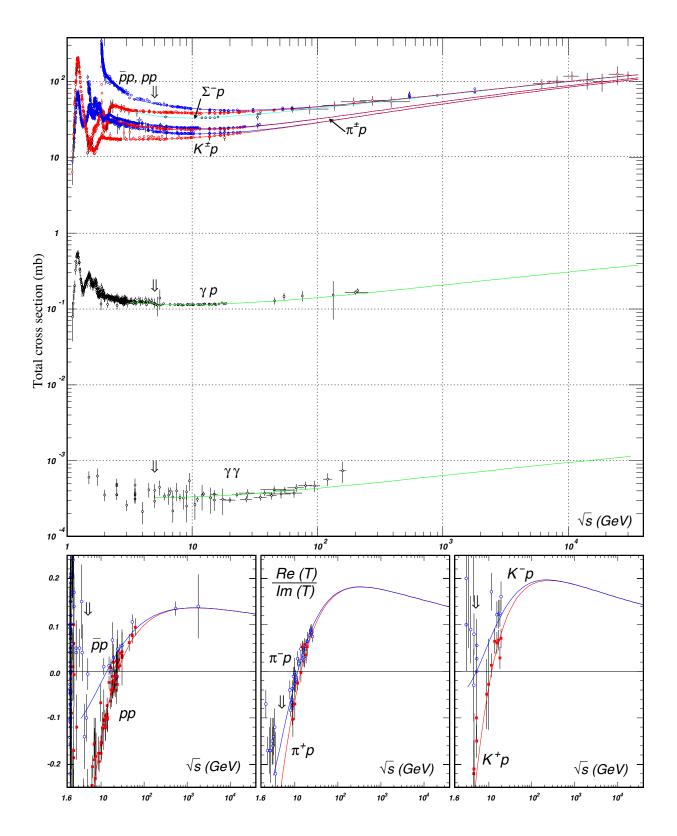


Figure 46.9: Summary of hadronic, γp , and $\gamma \gamma$ total cross sections, and ratio of the real to imaginary parts of the forward hadronic amplitudes. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS group, IHEP, Protvino, April 2012.)

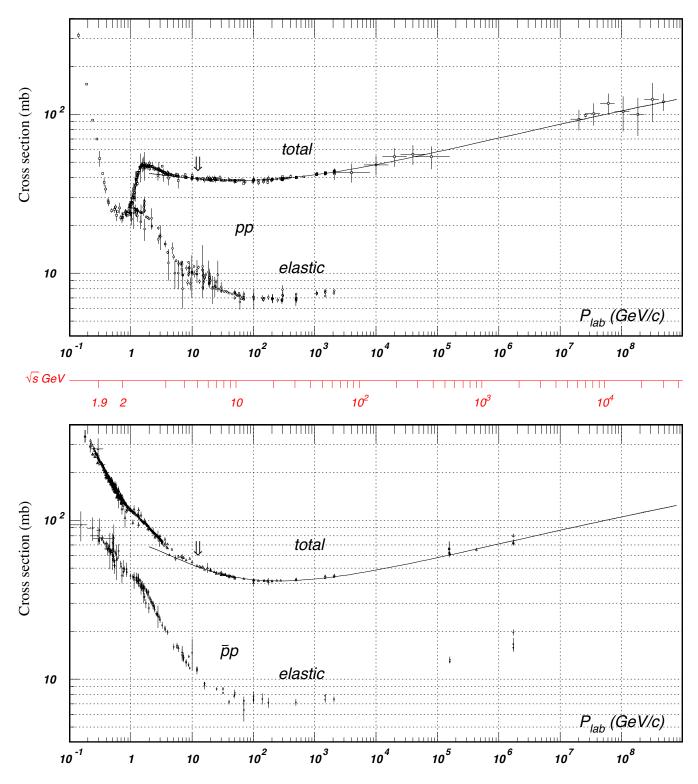


Figure 46.10: Total and elastic cross sections for pp and $\overline{p}p$ collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS group, IHEP, Protvino, April 2012)

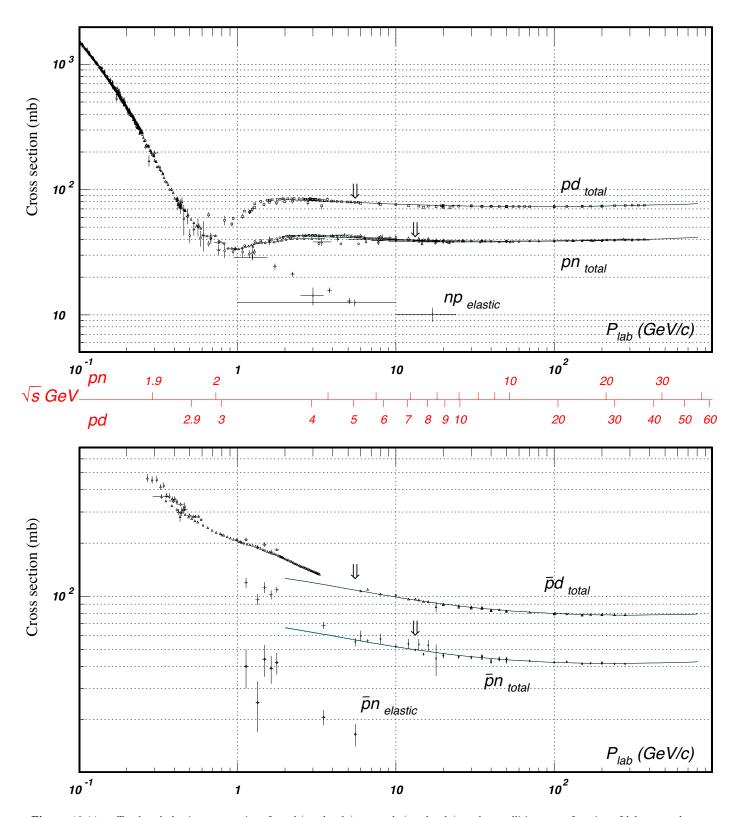


Figure 46.11: Total and elastic cross sections for pd (total only), np, $\overline{p}d$ (total only), and $\overline{p}n$ collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS Group, IHEP, Protvino, April 2012)

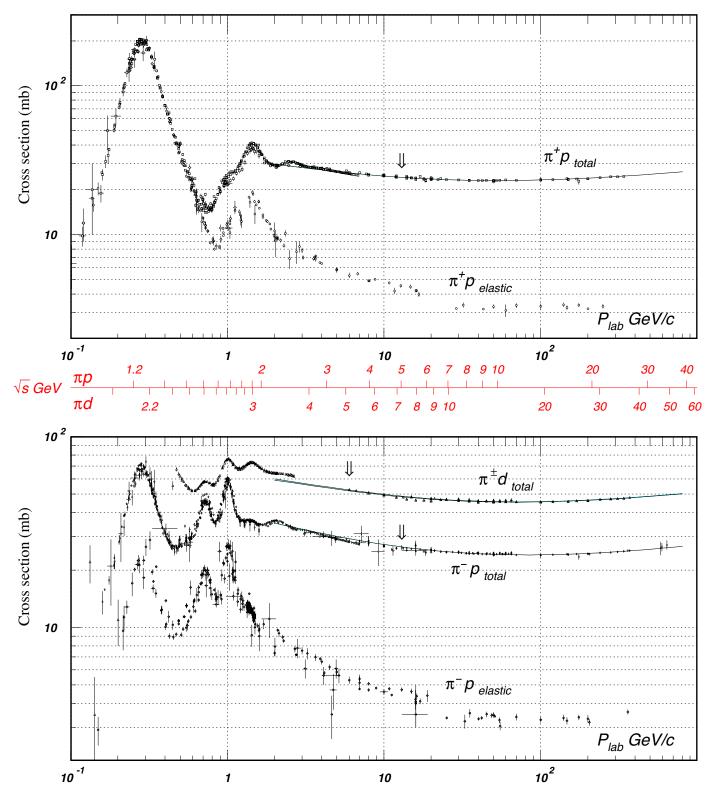


Figure 46.12: Total and elastic cross sections for $\pi^{\pm}p$ and $\pi^{\pm}d$ (total only) collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS Group, IHEP, Protvino, April 2012)

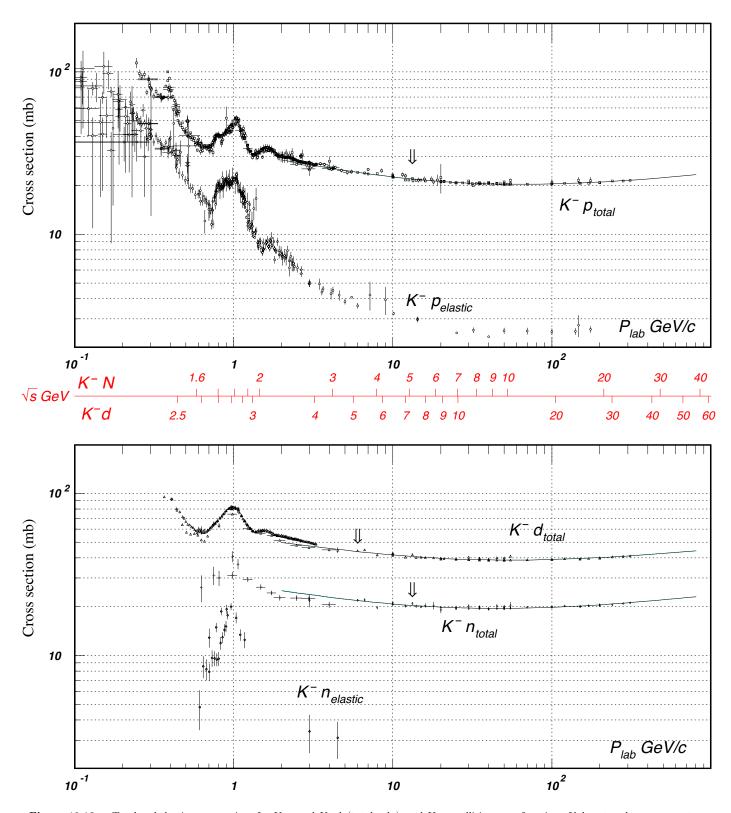


Figure 46.13: Total and elastic cross sections for K^-p and K^-d (total only), and K^-n collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS Group, IHEP, Protvino, April 2012)

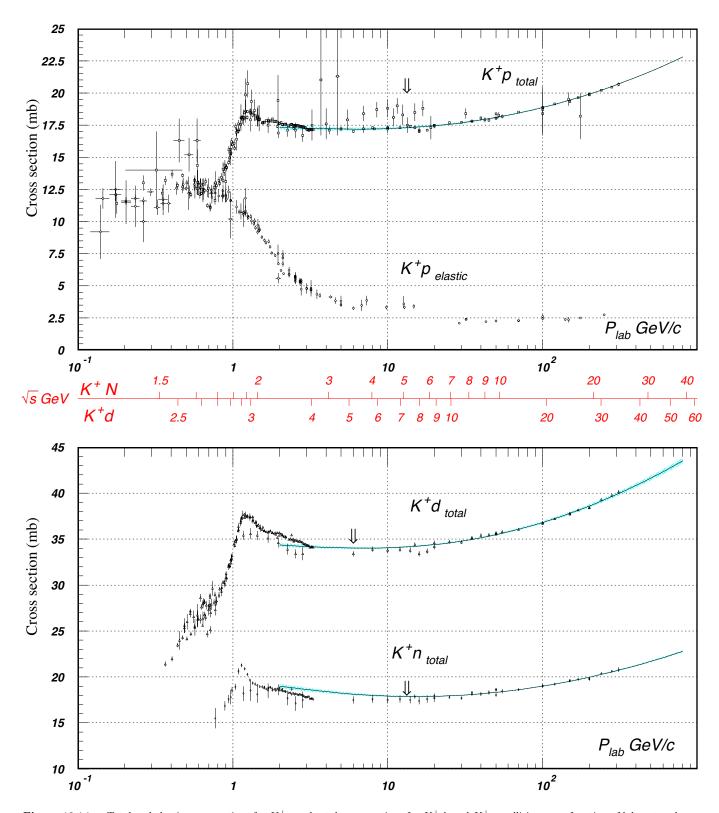


Figure 46.14: Total and elastic cross sections for K^+p and total cross sections for K^+d and K^+n collisions as a function of laboratory beam momentum and total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS Group, IHEP, Protvino, April 2012)

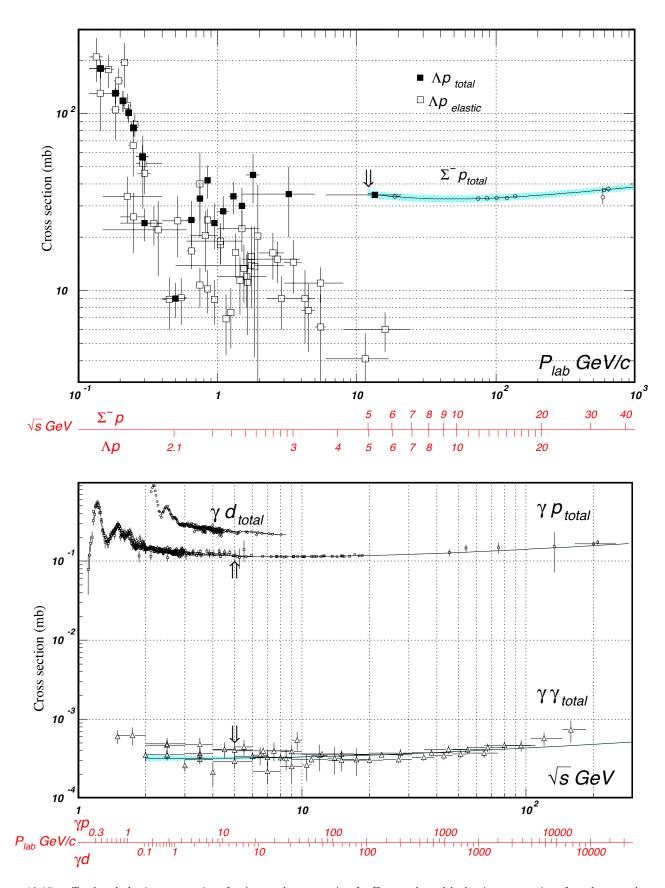


Figure 46.15: Total and elastic cross sections for Λp , total cross section for $\Sigma^- p$, and total hadronic cross sections for γd , γp , and $\gamma \gamma$ collisions as a function of laboratory beam momentum and the total center-of-mass energy. Corresponding computer-readable data files may be found at http://pdg.lbl.gov/current/xsect/. (Courtesy of the COMPAS group, IHEP, Protvino, April 2012)

INTRODUCTION TO THE PARTICLE LISTINGS

| Illustrative key | | | | | | | 457 |
|------------------|--|--|--|--|--|--|-----|
| Abbreviations | | | | | | | 458 |



first author.

this reference.

Quantum number determinations in

Institution(s) of author(s). (See ab-

breviations on next page.)

(SLAC) (FNAL) UP (CLEO COllab.) (SACL, CERN)

Illustrative Key to the Particle Listings

Name of particle. "Old" name used Particle quantum numbers (where $I^{G}(J^{PC}) = 1^{-}(0^{+})$ $a_0(1200)$ before 1986 renaming scheme also known). given if different. See the section Indicates particle omitted from Parti-"Naming Scheme for Hadrons" for de-OMITTED FROM SUMMARY TABLE Evidence not compelling, may be a kinematic effect. cle Physics Summary Table, implying particle's existence is not confirmed. a₀(1200) MASS Quantity tabulated below. DOCUMENT ID TECN CHG COMMENT VALUE (MeV) General comments on particle. Top line gives our best value (and er-1206± 7 OUR AVERAGE ror) of quantity tabulated here, based FENNER 3.5 $\pi^{-}p$ 1210± 8±9 87 MMS 3000 on weighted average of measurements A SP K 1198 + 10PIERCE $2.1 K^{-} p$ 83 used. Could also be from fit, best MERRILL HBC $3.2~K^{-}p$ $1216 \pm 11 \pm 9$ 1500 81 limit, estimate, or other evaluation. "Do cum ent id" for this result; full ref-• • • We do not use the following data for averages, fits, limits, etc. • • • See next page for details. 200 erence given below. LYNCH 81 HBC 1192 + 16 $2.7 \pi^{-} p$ Footnote number linking measure--1Systematic error was added quadratically by us in our 1986 edition Measurement technique. (See abbrement to text of footnote. viations on next page.) $a_0(1200)$ WIDTH Number of events above background. VALUE (MeV) DOCUMENT ID COMMENT 41±11 OUR AVERAGE Error includes scale factor of 1.8. See the ideogram below. Scale factor > 1 indicates possibly in-Measured value used in averages, fits, 50± 8 PIERCE 83 ASPK 2.1 K-p limits, etc. $70 + 30 \\ -20$ Reaction producing particle, or gen-200 LYNCH 81 HBC $2.7 \pi^{-} p$ eral comments. $25 \pm 5 \pm 7$ MERRILL 81 HBC 3.2 K⁻p Error in measured value (often statis-• • We do not use the following data for averages, fits, limits, etc. • tical only; followed by systematic if "Change bar" indicates result added separately known; the two are com-FENNER 87 MMS \Box WEIGHTED AVERAGE or changed since previous edition. bined in quadrature for averaging and fitting.) Charge(s) of particle(s) detected. Measured value not used in averages, Ideogram to display possibly inconsisfits, limits, etc. See the Introductory tent data. Curve is sum of Gaus-Text for explanations. sians, one for each experiment (area Arrow points to weighted average. of Gaussian = 1/error; width of Gaus-Shaded pattern extends $\pm 1\sigma$ (scaled by "scale factor" S) from weighted av $sian = \pm error$). See Introductory Text for discussion. erage. Contribution of experiment to χ^2 (if PIERCE no entry present, experiment not used in calculating χ^2 or scale factor be-LYNCH MERRILL Value and error for each experiment. cause of very large error). a₀ (1200) width (MeV) a₀(1200) DECAY MODES Scale factor/ Mode Fraction (Γ_i/Γ) Confidence level Our best value for branching fraction 3π (65.2±1.3) % S = 1.7Partial decay mode (labeled by Γ_i). KK as determined from data averaging, $(34.8 \pm 1.3) \%$ S = 1.7fitting, evaluating, limit selection, etc. $\eta \pi^{\pm}$ Γ_3 CL=95% This list is basically a compact summary of results in the Branching Ratio a₀(1200) BRANCHING RATIOS section below. $|\Gamma(3\pi)/\Gamma_{\text{total}}|$ Γ_1/Γ Branching ratio. DOCUMENT ID TECN CHG COMMENT 0.652±0.013 OUR FIT Error includes scale factor of 1.7 Our best value (and error) of quantity 0.643±0.010 OUR AVERAGE tabulated, as determined from con-PIERCE A SP K strained fit (using all significant mea- 0.64 ± 0.01 83 $2.1~K^{-}p$ MERRILL 81 HBC 0 3.2 K⁻p sured branching ratios for this parti- 0.74 ± 0.06 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 0.48 ± 0.15 ²LYNCH 81 HBC + Weighted average of measurements of ²Data has questionable background subtraction. this ratio only. $\Gamma(K\overline{K})/\Gamma_{total}$ Branching ratio in terms of partial Footnote (referring to LYNCH 81). decay $mode(s) \Gamma_i$ above. DOCUMENT ID TECN CHG COMMEN 0.348±0.013 OUR FIT Error includes scale factor of 1.7 0.35 ±0.05 PIERCE 83 ASPK + $\Gamma(K\overline{K})/\Gamma(3\pi)$ Γ_2/Γ_1 DOCUMENT ID TECN CHG COMMENT 0.535 ±0.030 OUR FIT Error includes scale factor of 1.7 0.50 ± 0.03 MERRILL 81 нвс Confidence level for measured upper $\Gamma(\eta(\text{neutral decay})\pi^{\pm})/\Gamma_{\text{total}}$ $0.71\Gamma_{3}/\Gamma$ VALUE (units 10-4 DOCUMENT ID TECN CHG COMMENT 95 <3.5 PIERCE 83 ASPK + $2.1~K^-p$ Partial list of author(s) in addition to References, ordered inversely by year, a₀(1200) REFERENCES

then author.

"Document id" used on data entries

Journal, report, preprint, etc. (See

abbreviations on next page.)

FENNER PIERCE

MERRILI

PRL 55 14 PL 123B 230

81 PR D24 610 81 PRL 47 143

H. Fenner et al. J.H. Pierce

G.R. Lynch et al. D.W. Merrill et al

CLAS Jefferson CLAS Collab. CLE2 CLEO II detector at CESR

Abbreviations Used in the Particle Listings

| Abbreviations Used in the Particle Listings | | | | | |
|---------------------------------------------|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|--------------------------------------------------------------------------------------------------------------|--|
| Indica | ator of Proc | edure Used to Obtain Our Result | CLE3 | CLEO III detector at CESR | |
| OHR A | VERAGE | From a weighted average of selected data. | CLEO | Cornell magnetic detector at CESR | |
| OUR F | | From a constrained or overdetermined multipa- | CMB | Cosmic Microwave Background | |
| | | rameter fit of selected data. | CMD CMD2 | Cryogenic magnetic detector at VEPP-2M, Novosibirsk Cryogenic magnetic detector 2 at VEPP-2M, Novosibirsk | |
| OUR E | VALUATION | Not from a direct measurement, but evaluated from measurements of other quantities. | CMS | CMS detector at CERN LHC | |
| OUR E | STIMATE | Based on the observed range of the data. Not | COMP | | |
| | | from a formal statistical procedure. | | COMPASS experiment at the CERN SPS Cosmology and astrophysics | |
| OUR L | IMIT | For special cases where the limit is evaluated by us from measured ratios or other data. Not from | COSY | COSY-TOF Collaboration | |
| | | a direct measurement. | COUP | COUPP (the Chicagoland Observatory for Underground Particle Physics) Collab. | |
| Measi | urement Te | chniques | CPLR | CPLEAR Collaboration | |
| | | and Methods of Analysis) | CRES | CRESST cryogenic detector | |
| ` | , | , | CRYB | Crystal Ball at BNL | |
| | ACCMOR Co | llaboration Matter Experiment | CRYM CSB2 | Crystal Ball detector at Mainz Microtron MAMI Columbia U Stony Brook BGO calorimeter inserted in NaI | |
| | | tive mass spectrometer | CSD2 | array | |
| ALEP | _ | CRN LEP detector | CSME | COSME Collaboration | |
| ALPS | Photon regen | eration experiment | | CUORICINO experiment at Gran Sasso Laboratory. | |
| | | uth Pole neutrino detector | CUSB | , , | |
| AMY ANIT | | r at KEK-TRISTAN oulsive Transient Antenna balloon mission | D0 DAMA | D0 detector at Fermilab Tevatron Collider DAMA, dark matter detector at Gran Sasso National Lab. | |
| APEX | FNAL APEX | | DASP | DESY double-arm spectrometer | |
| ARG | | etor at DORIS | DAYA | Daya Bay Collaboration | |
| ARGD | | cular amplitude path on Argand diagram | DBC | Deuterium bubble chamber | |
| ASP | | ngle-photon detector | | Double Chooz Collaboration | |
| ASPK ASTE | Automatic sp | ark cnambers tector at LEAR | | DELCO detector at SLAC-SPEAR or SLAC-PEP DELPHI detector at LEP | |
| ASTR | Astronomy | tector at LEAR | DM1 | Magnetic detector no. 1 at Orsay DCI collider | |
| ATLS | | tor at CERN LHC | DM2 | Magnetic detector no. 2 at Orsay DCI collider | |
| B787 | BNL experim | ent 787 detector | DMTP | Dark Matter Time Projection Chamber (DMTPC) directional | |
| B791 | | ent 791 detector | DOMI | detection experiment | |
| B845 | _ | ent 845 detector | | DONUT Collab. Energy-dependent partial-wave analysis | |
| $\frac{B852}{B865}$ | BNL E-852 BNL E865 de | tector | E621 | Fermilab E621 detector | |
| B871 | | ent 871 detector | E653 | Fermilab E653 detector | |
| B949 | BNL E949 de | tector at AGS | E665 | Fermilab E665 detector | |
| BABR | BaBar Collab | | E687 E691 | Fermilab E687 detector Fermilab E691 detector | |
| BAKS BC | | ground scintillation telescope | E705 | Fermilab E705 Spectrometer-Calorimeter | |
| | Bubble chaml Beam dump | Ger Ger | E731 | Fermilab E731 Spectrometer-Calorimeter | |
| BEAT | CERN BEAT | RICE Collab. | E756 | Fermilab E756 detector | |
| BEBC | | bubble chamber at CERN | E760 E761 | Fermilab E760 detector Fermilab E761 detector | |
| BELL | Belle Collab. | The second secon | E771 | Fermilab E771 detector | |
| BES BES2 | | Spectrometer at Beijing Electron-Positron Collider Spectrometer at Beijing Electron-Positron Collider | E773 | Fermilab E773 Spectrometer-Calorimeter | |
| BES3 | | Spectrometer at Beijing Electron-Positron Collider | E789 | Fermilab E789 detector | |
| BIS2 | | meter at Serpukhov | E791 E799 | Fermilab E791 detector Fermilab E799 Spectrometer-Calorimeter | |
| BKEI | BENKEI spec | etrometer system at KEK Proton Synchroton | E835 | Fermilab E835 detector | |
| BOLO | | cryogenic thermal detector | EDE2 | EDELWEISS II dark matter search Collaboration | |
| BONA | | nagnetic detector at DORIS | EDEL | EDELWEISS dark matter search Collaboration | |
| | BOREXINO Barrolot zoro | partial-wave analysis | EHS ELEC | Four-pi detector at CERN Electronic combination | |
| CALO | Calorimeter | partial-wave analysis | EMC | European muon collaboration detector at CERN | |
| CAST | | ment at CERN | EMUL | Emulsions | |
| CBAL | Crystal Ball | letector at SLAC-SPEAR or DORIS | FAST | Fiber Active Scintillator Target detector at PSI | |
| CBAR | | l detector at CERN-LEAR | FBC | Freon bubble chamber | |
| CBOX | Crystal Box a | | FENI FIT | FENICE (at the ADONE collider of Frascati) | |
| CBTP | | PS Collaboration | FLAT | Fit to previously existing data Large Area Telescope onboard the Fermi Gamma-Ray Space | |
| CC CCFR | Cloud chamb | er cago-Fermilab-Rochester detector | 1 1111 | Telescope | |
| CDF | | etor at Fermilab | FMPS | Fermilab Multiparticle Spectrometer | |
| CDF2 | CDF-II Colla | | FOCS | FNAL E831 FOCUS Collab. | |
| CDHS | | no detector at CERN | FRAB | ADONE $B\overline{B}$ group detector | |
| CDM2 | ground Lab. | yogenic Dark Matter Search at Soudan Under- | | ADONE $\gamma \gamma$ group detector | |
| CDMS | CDMS Collab |). | FRAM FREJ | ADONE MEA group detector FREJUS Collaboration – modular flash chamber detector | |
| CELL | CELLO detec | | 1.17.17 | (calorimeter) | |
| CGNT | | matter search experiment | FRMI | Fermi large area telescope (Fermi-LAT) | |
| | CHARM II n | | GA24 | Hodoscope Cherenkov γ calorimeter (IHEP GAMS-2000) | |
| CHM2 CHOZ | | eutrino detector (glass) at CERN r Station near Chooz, France | <i></i> | (CERN GAMS-4000) | |
| CHCZ | | crino detector (marble) at CERN | GALX | GALLEX solar neutrino detector in the Gran Sasso Underground Leb | |
| CHRS | | llaboration – CERNS SPS | CAMP | ground Lab. IHEP hodoscope Cherenkov γ calorimeter GAMS-2000 | |
| CIB | | ed Background | | CERN hodoscope Cherenkov γ calorimeter GAMS-2000 | |
| CIBS | CERN-IHEP | boson spectrometer | | IHEP hodoscope Cherenkov γ calorimeter GAMS-4 π | |
| CLAS | Jefferson CLA | AS Collab. | GNO | Gallium Neutrino Observatory in the Gran Sasso Underground | |

GNO

Gallium Neutrino Observatory in the Gran Sasso Underground

| | Abbreviations Used in the Particle Listings | | | | | |
|--------------------|-----------------------------------------------------------------------------------------------------------|--------------|-------------------------------------------------------------------------------------------------------|--|--|--|
| GOLI | CERN Goliath spectrometer | MRKJ | Mark-J detector at DESY | | | |
| GRAL | GRAAL Collaboration | MRS | Magnetic resonance spectrometer | | | |
| H1 | H1 detector at DESY/HERA | MUG2 | MUON(g-2) | | | |
| HBC | Hydrogen bubble chamber | MWPC | Multi-Wire Proportional Chamber | | | |
| | Hydrogen and deuterium bubble chambers | NA14 | CERN NA14 | | | |
| | Heidelberg-Moscow Experiment | NA31 | CERN NA31 Spectrometer-Calorimeter | | | |
| | Heidelberg Dark Matter Search Experiment | NA32 NA48 | CERN NA32 Spectrometer CERN NA48 Collaboration | | | |
| HEBC | Helium bubble chamber Helium proportional tubes | NA49 | CERN NA49 Collaboration | | | |
| | HERA-B detector at DESY/HERA | NA60 | CERN NA60 Collaboration | | | |
| | HERMES detector at DESY/HERA | NA62 | CERN NA62 Experiment | | | |
| HESS HFS | High Energy Stereoscopic System gamma-ray instrument Hyperfine structure | NAGE | NEWAGE, New generation WIMP-search experiment with advanced gaseous tracking | | | |
| $_{\mathrm{HLBC}}$ | Heavy-liquid bubble chamber | NAIA | NAIAD (NaI Advanced Detector) dark matter search experiment | | | |
| | Homestake underground scintillation detector | ND | NaI detector at VEPP-2M, Novosibirsk | | | |
| HPGE HPW | High-purity Germanium detector | NICE | Serpukhov nonmagnetic precision spectrometer | | | |
| HRS | Harvard-Pennsylvania-Wisconsin detector SLAC high-resolution spectrometer | NMR | Nuclear magnetic resonance | | | |
| | Hybrid: bubble chamber + electronics | NOMD | NOMAD Collaboration, CERN SPS | | | |
| HYCP | HyperCP Collab. (FNAL E-871) | NUSX | NuTeV Collab. at Fermilab Mont Blanc NUSEX underground detector | | | |
| ICAR | ICARUS experiment at Gran Sasso Laboratory. | OBLX | 9 | | | |
| ICCB | IceCube neutrino detector at South Pole | OLYA | Detector at VEPP-2M and VEPP-4, Novosibirsk | | | |
| IGEX | IGEX Collab. | OMEG | CERN OMEGA spectrometer | | | |
| IMB | Irvine-Michigan-Brookhaven underground Cherenkov detector | OPAL | OPAL detector at LEP | | | |
| IMB3 | Irvine-Michigan-Brookhaven underground Cherenkov detector | OSPK | Optical spark chamber | | | |
| INDU IPWA | Magnetic induction Energy independent partial ways analysis | PIBE | The PIBETA detector at the Paul Scherrer Institute (PSI), Switzerland. | | | |
| ISTR | Energy-independent partial-wave analysis IHEP ISTRA+ spectrometer-calorimeter | PICA | PICASSO dark matter search experiment | | | |
| JADE | JADE detector at DESY | PLAS | Plastic detector | | | |
| K246 | KEK E246 detector with polarimeter | PLUT | DESY PLUTO detector | | | |
| K2K | KEK to Super-Kamiokande | | The PRIMEX detector in Hall B at TJNAF | | | |
| K391 | KEK E391a detector | PWA REDE | Partial-wave analysis Resonance depolarization | | | |
| K470 | KEK-E470 Stopping K detector | RENO | RENO Collaboration | | | |
| | KAMIOKANDE-II underground Cherenkov detector | RICE | Radio Ice Cherenkov Experiment | | | |
| KAMI KAR2 | KAMIOKANDE underground Cherenkov detector KARMEN2 calorimeter at the ISIS neutron spallation source at | RVUE | Review of previous data | | | |
| IXAI12 | Rutherford | SAGE | US - Russian Gallium Experiment | | | |
| KARM | KARMEN calorimeter at the ISIS neutron spallation source at | SELX | FNAL SELEX Collab. | | | |
| HEDD | Rutherford | SFM | CERN split-field magnet | | | |
| | detector operating at VEPP-4M collider (Novosibirsk) | $_{ m SHF}$ | SLAC Hybrid Facility Photon Collaboration | | | |
| KIMS | Korea Invisible Mass Search experiment at YangYang, Korea KamLand Collab. (Japan) | SILI | Serpukhov CERN-IHEP magnetic spectrometer (SIGMA) Silicon detector | | | |
| | KLOE detector at DAFNE (the Frascati e+e- collider Italy) | SIMP | SIMPLE, dark matter detector at Laboratori Nazionali del Sud | | | |
| | Kolar Gold Field underground detector | SKAM | Super-Kamiokande Collab. | | | |
| KTEV | KTeV Collaboration | SLAX | Solar Axion Experiment in Canfranc Underground Laboratory | | | |
| L3 | L3 detector at LEP | SLD | SLC Large Detector for e^+e^- colliding beams at SLAC | | | |
| LASS | Large-angle superconducting solenoid spectrometer at SLAC | SMPL | SIMPLE, Superheated Instrument for Massive Particle Experi- | | | |
| LATT | Lattice calculations | SND | ments Novosibirisk Spherical neutral detector at VEPP-2M | | | |
| LEBC LEGS | Little European bubble chamber at CERN BNL LEGS Collab. | SNDR | | | | |
| LENA | Nonmagnetic lead-glass NaI detector at DORIS | SNO | SNO Collaboration (Sudbury Neutrino Observatory) | | | |
| LEP | From combination of all 4 LEP experiments: ALEPH, DELPHI, | SOU2 | Soudan 2 underground detector | | | |
| | L3, OPAL | SOUD | Soudan underground detector | | | |
| LEPS | Low-Energy Pion Spectrometer at the Paul Scherrer Institute | SPEC | Spectrometer | | | |
| LGW | Lead Glass Wall collaboration at SPEAR/SLAC | SPED | From maximum of speed plot or resonant amplitude | | | |
| LHCB | LHCb detector at CERN LHC | SPHR | Bonn SAPHIR Collab. | | | |
| LSD LSND | Mont Blanc liquid scintillator detector Liquid Scintillator Neutrino Detector | SPNX SPRK | SPHINX spectrometer at IHEP accelerator Spark chamber | | | |
| MAC | MAC detector at PEP/SLAC | SQID | SQUID device | | | |
| | Fermilab MiniBooNE neutrino experiment | STRC | Streamer chamber | | | |
| MBR | Molecular beam resonance technique | SVD2 | SVD-2 experiment at IHEP, Protvino | | | |
| MCRO | MACRO detector in Gran Sasso | T2K | T2K Collaboration | | | |
| MD1 | Magnetic detector at VEPP-4, Novosibirsk | TASS | DESY TASSO detector | | | |
| | Millikan drop measurement | TEVA TEXO | Combined analysis of CDF and DØ experiments TEXONO Collab., ultra low energy Ge detector at Kuo-Sheng | | | |
| MEG | Muon to electron conversion detector at PSI Underground mice deposits | 1 EAU | Laboratory Laboratory | | | |
| MICA MINS | Underground mica deposits Fermilab MINOS experiment | THEO | Theoretical or heavily model-dependent result | | | |
| MIRA | MIRABELLE Liquid-hydrogen bubble chamber | TNF | TNF-IHEP facility at 70 GeV IHEP accelerator | | | |
| MLEV | Magnetic levitation | TOF | Time-of-flight | | | |
| MMS | Missing mass spectrometer | TOPZ | TOPAZ detector at KEK-TRISTAN | | | |
| MPS | Multiparticle spectrometer at BNL | TPC | TPC detector at PEP/SLAC | | | |
| MPS2 | Multiparticle spectrometer upgrade at BNL | TPS | Tagged photon spectrometer at Fermilab | | | |
| MPSF | Multiparticle spectrometer at Fermilab | TRAP TWST | Penning trap TWIST spectrometer at TRIUMF | | | |
| | Model-dependent partial-wave analysis | UA1 | UA1 detector at CERN | | | |
| MRK1 MRK2 | SLAC Mark-II detector SLAC Mark-II detector | UA2 | UA2 detector at CERN | | | |
| MRK3 | SLAC Mark-III detector | UA5 | UA5 detector at CERN | | | |
| | | | | | | |

| | Abbreviations Used in | the P | article Listings | | | |
|--------------------------------------|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------|---------------------------------------|--|--|
| UCNA | UCNA collaboration using polarizeed ultracold neutrons at | NPBPS | Nuclear Physics B Proceedings | Supplement | | |
| HKDM | LANSCE UK Dark Matter Collab. | PAN | Physics of Atomic Nuclei (form | nerly SJNP) | | |
| VES | Vertex Spectrometer Facility at 70 GeV IHEP accelerator | PD | Physics Doklady (Magazine) | | | |
| VLBI | Very Long Baseline Interferometer | PDAT PL | Physik Daten Physics Letters | | | |
| VNS | VENUS detector at KEK-TRISTAN | PN | Particles and Nuclei | | | |
| WA75 WA82 | CERN WA75 experiment CERN WA82 experiment | PPCF | Plasma Physics and Controlled | | | |
| WA89 | CERN WA89 experiment | PPN Physics of Particles and Nuclei (formerly SJPN) | | | | |
| WARP | Liquid argon detector for CDM searches at Gran Sasso | PPNL PPNP | Physics of Particles and Nuclei Progress in Particles and Nuclei | | | |
| WASA | WASA detector at CELSIUS, Uppsala and at COSY, Juelich | PPSL | Proc. of the Physical Society o | | | |
| WIRE X100 | Wire chamber XENON100 dark matter search experiment at Gran Sasso Na- | PR | Physical Review | | | |
| 11100 | tional Laboratory | | Pramana | | | |
| XE10 | XENON10 experiment at Gran Sasso National Laboratory | $rac{	ext{PRL}}{	ext{PRPL}}$ | Physical Review Letters Physics Reports (Physics Lette | rs C) | | |
| XEBC ZEP2 | Xenon bubble chamber ZEPLIN-II dark matter detector | PRSE | Proc. of the Royal Society of E | · · · · · · · · · · · · · · · · · · · | | |
| ZEP3 | ZEPLIN-III dark matter detector at Palmer Underground Lab. | PRSL | Proc. of the Royal Society of L | 9 | | |
| ZEPL | ZEPLIN-I galactic dark matter detector | PS | Physica Scripta | | | |
| ZEUS | ZEUS detector at DESY/HERA | PTP PTPS | Progress of Theoretical Physics | | | |
| Confo | rences | | Progress of Theoretical Physics Phil. Trans. Royal Society of L | * * | | |
| | | RA | Radiochimica Acta | olidoli | | |
| | nces are generally referred to by the location at which they were g., HAMBURG, TORONTO, CORNELL, BRIGHTON, etc.). | RMP | Reviews of Modern Physics | | | |
| (0. | 5.,, vivo, rover, rover, page 1000. | RNC RPP | La Rivista del Nuovo Cimento Reports on Progress in Physics | | | |
| Journ | als | RRP | Revue Roumaine de Physique | | | |
| AA | Astronomy and Astrophysics | SCI | Science | | | |
| ADVP | Advances in Physics | SJNP | Soviet Journal of Nuclear Phys | | | |
| AFIS | Anales de Fisica | SJPN SPD | Soviet Journal of Particles and Soviet Physics Doklady (Magaz | | | |
| $_{ m AJP}$ | American Journal of Physics Astronomy Letters | SPU | Soviet Physics - Uspekhi | sine) | | |
| ANP | Annals of Physics | UFN | Usp. Fiz. Nauk – Russian versi | on of SPU | | |
| ANPL | Annals of Physics (Leipzig) | YAF | Yadernaya Fizika | | | |
| | Annals of the New York Academy of Sciences | ZETF | Zhurnal Eksperimental'noi i Te | | | |
| AP | Atomic Physics | ZEIFF | Zhurnal Eksperimental'noi i Te Redakts | oreticneskoi Fiziki, Fis ma v | | |
| APAH APJ | Acta Physica Academiae Scientiarum Hungaricae Astrophysical Journal | ZNAT | Zeitschrift fur Naturforschung | | | |
| APJS | Astrophysical Journal Suppl. | ZPHY | Zeitschrift fur Physik | | | |
| APP | Acta Physica Polonica | Institu | utions | | | |
| APS | Acta Physica Slovaca | | | Anchan Carmany | | |
| ARNS | Annual Review of Nuclear and Particle Science Annual Review of Nuclear Science | ААСП | Phys. Inst. der Techn. Hochschule Aachen (His- | Aachen, Germany | | |
| ASP | Astroparticle Physics | | torical, use for general Inst. | | | |
| BAPS | Bulletin of the American Physical Society | A A CITI | der Techn. Hochschule) | Al C | | |
| CJNP | Bulletin of the Academy of Science, USSR (Physics) Chinese Journal of Nuclear Physics | ААСПІ | I Phys. Inst. B, RWTH Aachen | Aachen, Germany | | |
| CJP | Canadian Journal of Physics | AACH3 | III Phys. Inst. A, RWTH | Aachen, Germany | | |
| CNPP | Comments on Nuclear and Particle Physics | AACHT | Aachen Univ. Inst. für Theoretische | Aachen, Germany | | |
| CTP | Communications in Theoretical Physics | 71710171 | Teilchenphysik & Kosmolo- | racien, cermany | | |
| CZJP | Czechoslovak Journal of Physics | | gie, RWTH Aachen | | | |
| DANS EPJ | Doklady Akademii nauk SSSR The European Physical Journal | AARH ABO | Univ. of Aarhus Åbo Akademi Univ. | Aarhus C, Denmark Turku, Finland | | |
| EPL | Europhysics Letters | ADEL | Adelphi Univ. | Garden City, NY, USA | | |
| FECAY | Fizika Elementarnykh Chastits i Atomnogo Yadra | ADLD | The Univ. of Adelaide ; Cen- | Adelaide, SA, Australia | | |
| HADJ | Hadronic Journal | | tre for Subatomic Structure | | | |
| IJMP JAP | International Journal of Modern Physics Journal of Applied Physics | | of Matter (CSSM); Dept. of Physics | | | |
| JCAP | Journal of Cosmology and Astroparticle Physics | AERE | Atomic Energy Research Es- | Didcot, United Kingdom | | |
| JETP | English Translation of Soviet Physics ZETF | 4 EDD | tab. | Dathards MD UCA | | |
| | English Translation of Soviet Physics ZETF Letters | АГКК | Armed Forces Radiobiology Res. Inst. | Bethesda, MD, USA | | |
| JHEP JINR | Joint Inst. for Nuclear Research | | OPhysical Research Lab. | Ahmedabad, Gujarat, India | | |
| | CJINR Rapid Communications | AICH | Akita Univ. of Education | Alchi, Japan | | |
| $_{ m JPA}$ | Journal of Physics, A | AKIT ALAH | Akita Univ. Univ. of Alabama | Akita, Japan Huntsville, AL, USA | | |
| JPB | Journal of Physics, B | | (Huntsville) | ,,,,,, | | |
| JPCRD JPG | Journal of Physical and Chemical Reference Data Journal of Physics, G | ALAT | Univ. of Alabama | Tuscaloosa, AL, USA | | |
| JPSJ | Journal of the Physical Society of Japan | ALBA | (Tuscaloosa) SUNY at Albany | Albany, NY, USA | | |
| LNC | Lettere Nuovo Cimento | ALBA | Univ. of Alberta | Edmonton, AB, Canada | | |
| | Monthly Notices of the Royal Astronomical Society | AMES | Ames Lab. | Ames, IA, USA | | |
| $ \text{MPL} \\ \text{NAT} $ | Modern Physics Letters Nature | AMHT | | Amherst, MA, USA | | |
| NC | Nuovo Cimento | AMST | Univ. van Amsterdam | GL Amsterdam, The Netherlands | | |
| NIM N IP | Nuclear Instruments and Methods New Journal of Physics | ANIK | NIKHEF | Amsterdam, The Netherlands | | |
| NJP NP | New Journal of Physics Nuclear Physics | | | | | |
| | 1 Hyono | | | | | |

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|-----------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------|---------------|----------------------------------------------------------------------------------|--------------------------------------------------|
| ANKA | Middle East Technical Univ.; Dept. of Physics; Ex- | Ankara, Turkey | | Univ. Libre de Bruxelles ; Physique Théorique | Bruxelles, Belgium |
| ANL | perimental HEP Lab Argonne National Lab.; High Energy Physics Division, | Argonne, IL, USA | | Univ. of Bucharest KFKI Research Inst. for Particle & Nuclear Physics | Bucharest-Magurele, Romania Budapest, Hungary |
| | Bldg. 362; Physics Division, Bldg. 203 | | BUFF | SUNY at Buffalo Inst. des Hautes Etudes Scien- | Buffalo, NY, USA Bures-sur-Yvette, France |
| | St. Anselm Coll. | Manchester, NH, USA | | tifiques | , |
| ARIZ | Arecibo Observatory Univ. of Arizona | Arecibo, PR, USA Tucson, AZ, USA | CAEN | Lab. de Physique Corpuscu- laire, ENSICAEN | Caen, France |
| ARZS | Arizona State Univ. | Tempe, AZ, USA | CAGL | Univ. degli Studi di Cagliari | Monserrato (CA), Italy |
| ASCI AST | Russian Academy of Sciences Inst. of Phys. | Moscow, Russian Federation Nankang, Taipei, Taiwan | CAIR CAIW | Cairo University Carnegie Inst. of Washing- | Orman, Giza, Cairo, Egypt Washington, DC, USA |
| ATEN | NCSR "Demokritos" | Aghia Paraskevi , Greece | | ton | , , |
| ATHU AUCK | Univ. of Athens Univ. of Auckland | Athens, Greece Auckland, New Zealand | | Univ. of Calcutta DAMTP | Calcutta, India Cambridge, United Kingdom |
| | Natl. Azerbaijan Academy of Sciences, Inst. of Physics | Baku, Azerbaijan | | Univ. Estadual de Campinas (UNICAMP) | Campinas, SP, Brasil |
| | Indian Inst. of Science | Bangalore, India | | Australian National Univ. | Canberra, ACT, Australia |
| | Bangabasi College Univ. Autónoma de | Calcutta, India Bellaterra (Barcelona), Spain | CANTB | Inst. de Física de Cantabria (CSIC-Univ. Cantabria) | Santander, Spain |
| | Barcelona | // 1 | CAPE | University of Cape Town | Rondebosch, Cape Town, |
| BARI | Univ. e del Politecnico di Bari | Bari, Italy | CARA | Univ. Central de Venezuela | South Africa Caracas, Venezuela |
| BART | Univ. of Delaware ; Bartol Research Inst. | Newark, DE, USA | CARL | | Ottawa, ON, Canada |
| BASL | Inst. für Physik der Univ. | Basel, Switzerland | CARLC CASE | Carleton College Case Western Reserve Univ. | Northfield, MN, USA Cleveland, OH, USA |
| BAYR | Basel Univ. Bayreuth | Bayreuth, Germany | CAST | China Center of Advanced | Beijing, China |
| BCEN | Centre d'Etudes Nucleaires de | Gradignan, France | CATA | Science and Technology Univ. di Catania | Catania, Italy |
| BCIP | Bordeaux-Gradignan Natl. Inst. for Physics & Nu- | Bucharest-Magurele, Romania | CATH | Catholic Univ. of America | Washington, DC, USA |
| ВСП | clear Eng. "Horia Hulubei" | Bucharest-Magurete, Homama | CAVE | Cavendish Lab. | Cambridge, United Kingdom |
| BEIJ | (IFIN-HH) Beijing Univ. | Beijing, China | CBNM CCAC | Allegheny College | Geel, Belgium Meadville, PA, USA |
| | Inst. of Theoretical | Beijing, China | CDEF | Univ. Paris VII, Denis | Paris, France |
| BELG | Physics Inter-University Inst. for High Energies (ULB-VUB) | Brussel, Belgium | CEA | Diderot Cambridge Electron Accelera- tor (Historical in <i>Review</i>) | Cambridge, MA , USA |
| BELL | AT & T Bell Labs | Murray Hill, NJ, USA | CEADE | Center for Apl. Studies for Nuclear Physics | Havana, Cuba |
| BERG BERL | Univ. of Bergen DESY, Deutsches | Bergen, Norway Zeuthen, Germany | CEBAF | Jefferson Lab—Thomas | Newport News, VA, USA |
| | Elektronen-Synchrotron | , | | Jefferson National Accelerator Facility | |
| BERN BGNA | Univ. of Berne Univ. di Bologna, & INFN, | Berne, Switzerland Bologna, Italy | CENG | Centre d'Etudes Nucleaires | Grenoble, France |
| Barris | Sezione di Bologna; Via Irnerio, 46, I-40126 Bologna; Viale | Dologian, Ivaly | CERN CFPA | CERN, European Organization for Nuclear Research Univ. of California, (Berke- | Genève, Switzerland Berkeley, CA, USA |
| ВНАВ | C. Berti Pichat, n. 6/2 Bhabha Atomic Research | Trombay, Bombay, India | | ley) | , |
| | Center | | CHIC CIAE | Univ. of Chicago China Institute of Atomic | Chicago, IL, USA Beijing, China |
| BHEP | Inst. of High Energy Physics | Beijing, China | | Energy | |
| BIEL | Univ. Bielefeld | Bielefeld, Germany | CINC CINV | Univ. of Cincinnati CINVESTAV-IPN, Centro de | Cincinnati, OH, USA México, DF, Mexico |
| BING BIRK | SUNY at Binghamton Birkbeck College, Univ. of London | Binghamton, NY, USA London, United Kingdom | 011.1 | Investigacion y de Estudios Avanzados del IPN | 1101100, 21, 1101100 |
| BIRM | Univ. of Birmingham | Edgbaston, Birmingham, | CIT CLER | California Inst. of Tech. Univ. de Clermont-Ferrand | Pasadena, CA, USA Aubière, France |
| BLSU | Bloomsburg Univ. | United Kingdom Bloomsburg, PA, USA | CLEV | Cleveland State Univ. | Cleveland, OH, USA |
| BNL | Brookhaven National Lab. | Upton, NY, USA | CMNS | Comenius Univ. (FMFI UK) | Bratislava, Slovakia |
| BOCH | Ruhr Univ. Bochum | Bochum, Germany Copenhagen Ø, Denmark | CMU CNEA | Carnegie Mellon Univ. Comisión Nacional de En- | Pittsburgh, PA, USA Buenos Aires, Argentina |
| BOHR BOIS | Niels Bohr Inst. Boise State Univ. | Boise, ID, USA | | ergía Atómica | , 0 |
| | Univ. of Bombay | Bombay, India | CNRC | Centre for Research in Parti- cle Physics | Ottawa, ON, Canada |
| BONN BORD | Univ. of Bonn Univ. de Bordeaux I | Bonn, Germany Gradignan, France | COIM | Univ. de Coimbra | Coimbra, Portugal |
| BOSE | S.N. Bose National Centre | Calcutta, India | COLO | Univ. of Colorado | Boulder, CO, USA |
| BOSK | for Basis Sciences "Rudjer Bošković" Inst. | Zagrah Croatia | COLU CONC | Columbia Univ. Concordia University | New York, NY, USA Montreal, PQ, Canada |
| BOSK BOST | Boston Univ. | Zagreb, Croatia Boston, MA, USA | CORN | Cornell Univ. | Ithaca, NY, USA |
| BRAN | Brandeis Univ. | Waltham, MA, USA | COSU | Colorado State Univ. | Fort Collins, CO, USA |
| BRCO BRIS | Univ. of British Columbia Univ. of Bristol | Vancouver, BC, Canada Bristol, United Kingdom | CPPM | Centre National de la Recherche Scientifique, Lu- | Marseille, France |
| | Brown Univ. | Providence, RI, USA | OF 1 C | miny | TZ 14 DI I |
| BRUN | Brunel Univ. | Uxbridge, Middlesex, United Kingdom | | Henryk Niewodnicza'nski Inst. of Nuclear Physics | Kraków, Poland |
| BRUX | Univ. Libre de Bruxelles ; Service de Physique des Particules Elémentaires | Bruxelles, Belgium | CRNL CSOK | Chalk River Labs. Oklahoma Central State Univ. | Chalk River, ON, Canada Edmond, OK, USA |

| CST | Univ. of Science and Tech- | Hefei, Anhui 230026, China | HAHN | Hahn-Meitner Inst. Berlin GmbH | Berlin, Germany |
|-----------------------|------------------------------------------------------------|-------------------------------------------|-------------------|-------------------------------------------------------------|----------------------------------------|
| | nology of China California State Univ. | Long Beach, CA, USA | HAIF | Technion – Israel Inst. of Tech. | Technion, Haifa, Israel |
| CSUS | California State Univ. | Sacramento, USA | HAMB | Univ. Hamburg | Hamburg, Germany |
| | City College of New York Univ. Pierre et Marie | New York, NY, USA | HANN | Univ. Hannover | Hannover, Germany |
| CURCP | Curie (Paris VI), LCP | Paris, France | HARC | Houston Advanced Re- | The Woodlands, TX, USA |
| CURIN | Univ. Pierre et Marie | Paris, France | TTATOTT | search Ctr. | G 1:1 MA 1794 |
| | Curie (Paris VI), LPNHE | | HARV | Harvard Univ. | Cambridge, MA, USA |
| CURIT | Univ. Pierre et Marie | Paris, France | HEBR | Univ. of Hawai'i Hebrew Univ. | Honolulu, HI, USA Jerusalem, Israel |
| | Curie (Paris VI), LPTHE | | HEID | Univ. Heidelberg ; (unspec- | Heidelberg, Germany |
| | Dalhousie Univ. | Halifax, NS, Canada | IILID | ified division) (Historical in | fielderberg, dermany |
| | Daresbury Lab | Cheshire, United Kingdom | | Review) | |
| | Tech. Hochschule Darmstadt | Darmstadt, Germany | HEIDH | Ruprecht-Karls Univ. Heidel- | Heidelberg, Germany |
| DELA | Univ. of Delaware ; Dept. of Physics & Astronomy | Newark, DE, USA | TIPID D | berg | ****** |
| DELH | Univ. of Delhi | Delhi, India | HEIDP | Univ. Heidelberg ; Physikalisches Inst. | Heidelberg, Germany |
| DESY | DESY, Deutsches | Hamburg, Germany | HEIDT | Univ. Heidelberg ; Inst. für | Heidelberg, Germany |
| | Elektronen-Synchrotron | 3, | | Theoretische Physik | 3, 2 2 3 |
| DFAB | Escuela de Ingenieros | Bilbao, Spain | HELS | Univ. of Helsinki ; Dept. | University of Helsinki, Finland |
| DOE | Department of Energy | Washington, DC, USA | | of Phys., High Energy | |
| DORT | Technische Univ. Dortmund | Dortmund, Germany | | Phys. Div. (SEFO); Dept. of Phys., Theor. Phys. | |
| | Duke Univ. | Durham, NC, USA | | Div. (TFO); Helsinki Insti- | |
| | Univ. of Durham | Durham , United Kingdom | | tute of Physics (HIP) | |
| EDIN | University College Dublin Univ. of Edinburgh | Dublin, Ireland Edinburgh, United Kingdom | HIRO | Hiroshima Univ. | Higashi-Hiroshima, Japan |
| EFI | Univ. of Chicago, The En- | Chicago, IL, USA | HOUS | Univ. of Houston | Houston, TX, USA |
| DFI | rico Fermi Inst. | Cincago, IL, OSA | HPC | Hewlett-Packard Corp. | Cupertino, CA, USA |
| ELMT | Elmhurst College | Elmhurst, IL, USA | HSCA | Harvard-Smithsonian Cen- | Cambridge, MA, USA |
| ENSP | l'Ecole Normale | Paris, France | TAC | ter for Astrophysics | Deinsets NI IICA |
| | Supérieure | | IAS IASD | Inst. for Advanced Study Dublin Inst. for Advanced | Princeton, NJ, USA Dublin, Ireland |
| EOTV | Eötvös University | Budapest, Hungary | IASD | Studies Studies | Dubini, freiand |
| EPOL ERLA | Ecole Polytechnique | Palaiseau, France | IBAR | Ibaraki Univ. | Ibaraki, Japan |
| ETH | Univ. Erlangen-Nurnberg Univ. Zürich | Erlangen, Germany Zürich, Switzerland | $_{\mathrm{IBM}}$ | IBM Corp. | Palo Alto, CA, USA |
| FERR | Univ. di Ferrara | Ferrara, Italy | IBMY | IBM | Yorktown Heights, NY, USA |
| FIRZ | Univ. degli Studi di Firenze | Sesto Fiorentino, Italy | IBS | Inst. for Boson Studies | Pasadena, CA, USA |
| FISK | Fisk Univ. | Nashville, TN, USA | ICEPP | The Univ. of Tokyo | Tokyo, Japan |
| FLOR | Univ. of Florida | Gainesville, FL, USA | ICRR | Univ. of Tokyo | Chiba, Japan |
| FNAL | Fermilab | Batavia, IL, USA | ICTP | Abdus Salam International Centre for Theoretical Physics | Trieste, Italy |
| FOM | FOM, Stichting voor Fundamenteel Onderzoek der Ma- | JP Utrecht , The Netherlands | IFIC | IFIC (Instituto de Física | Valencia, Spain |
| | terie | | | Corpuscular) | |
| FRAN | Frankfurt Inst. for Ad- | Frankfurt am Main, Germany | IFRJ | Univ. Federal do Rio de | Rio de Janeiro, RJ, Brasil |
| | vanced Studies (FIAS) | | IIT | Janeiro Illinois Inst. of Tech. | Chicago, IL, USA |
| FRAS | Lab. Nazionali di Frascati | Frascati (Roma), Italy | ILL | Univ. of Illinois at Urbana- | Urbana, IL, USA |
| FREIR | dell'INFN Albert-Ludwigs Univ. | Freiburg, Germany | | Champaign | , , |
| | Freie Univ. Berlin | Berlin, Germany | ILLC | Univ. of Illinois at Chicago | Chicago, IL, USA |
| | Univ. de Fribourg | Fribourg, Switzerland | ILLG | Inst. Laue-Langevin | Grenoble, France |
| FSU | Florida State Univ.; High | Tallahassee, FL, USA | IND | Indiana Univ. | Bloomington, IN, USA |
| | Energy Physics | | INEL | E G and G Idaho, Inc. | Idaho Falls, ID, USA |
| FSUSC | Florida State Univ.; SCS | Tallahassee, FL, USA | INFN | Ist. Nazionale di Fisica Nu- clear (Generic INFN, un- | Various places, Italy |
| | (School of Computational Science) | | | known location) | |
| FUKI | Fukui Univ. | Fukui, Japan | INNS | Univ. of Innsbruck | Innsbruck, Austria |
| FUKU | Fukushima Univ. | Fukushima, Japan | INPK | Inst. of Nuclear Physics | Kraków, Poland |
| GENO | Univ. di Genova | Genova, Italy | INRM | \mathbf{INR} , Inst. for Nucl. Research | Moscow, Russian Federation |
| | Georgian Academy of Sci- | Tbilisi, Republic of Georgia | INUS | KEK, High Energy Accelera- | Tokyo, Japan |
| GESC | ences General Electric Co. | Schenectady, NY, USA | IOAN | tor Research Organization Univ. of Ioannina | Ioannina, Greece |
| GEVA | Univ. de Genève | Genève, Switzerland | IOFF | A.F. Ioffe Phys. Tech. Inst. | St. Petersburg , Russian Fed- |
| GIES | Univ. Giessen | Giessen, Germany | 1011 | 10110 1 11 to 11 11 11 11 11 11 11 11 11 11 11 11 11 | eration |
| GIFU | Gifu Univ. | Gifu, Japan | IOWA | Univ. of Iowa | Iowa City, IA, USA |
| GLAS | Univ. of Glasgow | Glasgow, United Kingdom | IPN | IPN, Inst. de Phys. Nucl. | Orsay, France |
| GMAS | George Mason Univ. | Fairfax, VA, USA | IPNP | Univ. Pierre et Marie Curie | Paris, France |
| GOET | Univ. Göttingen | Göttingen, Germany | IRAD | (Paris VI) Inst. du Radium (Historical) | Paris Franco |
| GRAN | Univ. de Granada | Granada, Spain | ISNG | Lab. de Physique Sub- | Paris, France Grenoble, France |
| GRAZ | Univ. Graz | Graz, Austria | ISING | atomique et de Cosmologie | Grenobie, France |
| GRON | Univ. of Groningen | Groningen, The Netherlands | | (LPSC) | |
| GSCO | Geological Survey of Canada | Ottawa, ON, Canada | ISU | Iowa State Univ. | Ames, IA, USA |
| GSI | GSI Helmholtzzentrum für | Darmstadt, Germany | ISUT | Isfahan University of Technol- | Isfahan, Iran |
| | Schwerionenforschung GmbH | , | | ogy | |
| GUAN | Univ. de Guanajuato | León, Gto., Mexico | ITEP | ITEP, Inst. of Theor. and | Moscow, Russian Federation |
| GUEL | Univ. of Guelph | Guelph, ON, Canada | ITHA | Exp. Physics Ithaca College | Ithaca, NY, USA |
| GWU | George Washington Univ. | Washington, DC, USA | 11111 | Zumucu Comege | 101000, 111, 0011 |
| | | | | | |

| IUPU | Indiana Univ., Purdue Univ. Indianapolis | Indianapolis, IN, USA | LISBT | Centro de Física Teórica de Partículas (CFTP) | Lisboa, Portugal |
|--------------|-----------------------------------------------------------------------------------------|----------------------------------------------|-------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| JADA JAGL | Jadavpur Univ. Jagiellonian Univ. | Calcutta, India Kraków, Poland | $_{\rm LIVP}_{\rm LLL}$ | Univ. of Liverpool Lawrence Livermore Lab. | Liverpool, United Kingdom Livermore, CA, USA |
| JHU | Johns Hopkins Univ. | Baltimore, MD, USA | LLL | (Old name for LLNL) | Ervermore, Ori, Obri |
| JINR | JINR, Joint Inst. for Nucl. Research | Dubna, Russian Federation | LLNL | Lawrence Livermore National Lab. | Livermore, CA, USA |
| JULI JYV | Forschungszentrum Jülich Univ. of Jyväskylä | Jülich, Germany Jyväskylä, Finland | LOCK | Lockheed Palo Alto Res. Lab | Palo Alto, CA, USA |
| KAGO | Univ. of Kagoshima | Kagoshima-shi, Japan | LOIC | Imperial College of Science Tech. & Medicine | London, United Kingdom |
| KANS KARL | Univ. of Kansas Univ. Karlsruhe (Historical | Lawrence, KS, USA Karlsruhe, Germany | LOQM | Queen Mary, Univ. of London | London, United Kingdom |
| KARLE | in Review) Karlsruhe Inst. of Technology (KIT); Inst. for Experimental Nuclear Physics | Karlsruhe, Germany | LOUV | University College London Univ. Catholique de Louvain Westfield College (Historical, | London, United Kingdom Louvain-la-Neuve, Belgium London, United Kingdom |
| KARLK | Karlsruhe Inst. of Technol- | Eggenstein-Leopoldshafen, Germany | | see LOQM (Queen Mary and Westfield joined)) | |
| KARLT | ogy (KIT) Karlsruhe Inst. of Technol- | Karlsruhe, Germany | LRL | U.C. Lawrence Radiation Lab. (Old name for LBL) | Berkeley, CA, USA |
| | ogy (KIT); Inst. for Theoreti- | | LSU | Louisiana State Univ. | Baton Rouge, LA, USA |
| TZ A 77 A | cal Physics | Al At. Wl.lt | LUND | Fysiska Institutionen | Lund, Sweden |
| AAZA | Kazakh Inst. of High Energy Physics | Alma Ata, Kazakhstan | LUND | Lund Univ. | Lund, Sweden |
| KEK | KEK, High Energy Accelera- tor Research Organization | Ibaraki-ken, Japan | LYON | Institute de Physique Nucléaire de Lyon (IPN) | Villeurbanne, France |
| KENT | Univ. of Kent | Canterbury, United Kingdom | MADE | UAM/CSIC, Inst. de Física Teórica | Madrid, Cantoblanco, Spain |
| KEYN | Open Univ. | Milton Keynes, United King- | MADR | C.I.E.M.A.T | Madrid, Spain |
| KFTI | Kharkov Inst. of Physics and | dom Kharkov, Ukraine | MADU | Univ. Autónoma de Madrid | Cantoblanco, Madrid, Spain |
| 111 11 | Tech. (NSC KIPT) | markov, extance | MANI | Univ. of Manitoba | Winnipeg, MB, Canada |
| KIAE | Kurchatov Inst. | Moscow, Russian Federation | MANZ | Johannes-Gutenberg- | Mainz, Germany |
| KIAM | Keldysh Inst. of Applied | Moscow, Russian Federation | | Univ.; Inst. für Kernphysik, | , |
| KIAM | Math., Acad. Sci., Russia Vinča Inst. of Nuclear Sci- | Belgrade, Serbia | | JJBecher-Weg 45; Inst. für Physik, Staudingerweg 7 | |
| KIEV | ences Institute for Nuclear Re- | Kyiv, Ukraine | MARB MARS | Univ. Marburg Centre de Physique des Par- | Marburg, Germany Marseille, France |
| KINK | search Kinki Univ. | Osaka, Japan | MASA | ticules de Marseille Univ. of Massachusetts | Amherst, MA, USA |
| KNTY | Univ. of Kentucky | Lexington, KY, USA | | Amherst Univ. of Massachusetts | Boston, MA, USA |
| | Kobe Univ. | Kobe, Japan | | Boston | |
| | BUniv. of Tokyo, Komaba N Konan Univ. | Tokyo, Japan Kobe, Japan | MASD | Univ. of Massachusetts Dartmouth | North Dartmouth , MA, USA |
| KOSI | Inst. of Experimental Physics SAS | Košice, Slovakia | MCGI MCHS | | Montreal, QC, Canada |
| КҮОТ | Kyoto Univ.; Dept. of Physics, Graduate School of | Kyoto, Japan | MCMS | McMaster Univ. A Harish-Chandra Research | Manchester, United Kingdom Hamilton, ON, Canada Allahabad, India |
| күотч | Science J Kyoto Univ.; Yukawa Inst. | Kyoto, Japan | MEIS | Inst. Meisei Univ. | Tokyo, Japan |
| KVIIN | for Theor. Physics Kyungpook National Univ. | Daegu, Republic of Korea | MELB | Univ. of Melbourne ; ARC | Victoria, Australia |
| | Kyushu Univ.; Elementary ParticleTheory Group; Exp. Particle Physics Group | Fukuoka, Japan | | Ctr. of Excellence for Part. Phys. at Terascale; Exper. & Theor. Particle Physics | |
| LALO | LAL, Laboratoire de | Orsay, France | MEHID | Research Groups Observatoire de Mondon | Moudon France |
| | l'Accélérateur Linéaire | | MEUD | Observatoire de Meudon | Meudon, France |
| LANC | Lancaster Univ. | Lancaster, United Kingdom | MICH MILA | Univ. of Michigan | Ann Arbor, MI, USA |
| LANL | Los Alamos National Lab. | Los Alamos, NM, USA | | Univ. di Milano INFN, Sez. di Milano | Milano, Italy Milano, Italy |
| LAPP | (LANL) LAPP , Lab. d'Annecy-le- | Annecy-le-Vieux, France | MINN | Univ. of Minnesota | Minneapolis, MN, USA |
| LASL | Vieux de Phys. des Particules U.C. Los Alamos Scientific | Los Alamos, NM, USA | MIPT | Moscow Institute of Physics and Technology | Moscow, Russian Federation |
| | Lab. (Old name for LANL) | • • | MISS | Univ. of Mississippi | University, MS, USA |
| LATV | Latvian State Univ. | Riga, Latvia | MISSR | | Rolla, MO, USA |
| LAUS | EPFL Lausanne | Lausanne, Switzerland | MIT | MIT Massachusetts Inst. | Cambridge, MA, USA |
| LAVL LBL | Univ. Laval Lawrence Berkeley Na- | Quebec, QC, Canada Berkeley, CA, USA | MIU | of Technology Maharishi International | Fairfield, IA, USA |
| LCGT | tional Lab. Univ. di Torino | Turin, Italy | MIYA | Univ. Miyazaki Univ. | Miyazaki-shi, Japan |
| LEBD | Lebedev Physical Inst. | Moscow, Russian Federation | MONP | Univ. de Montpellier II | Montpellier, France |
| LECE | Univ. di Lecce | Lecce, Italy | MONS MONT | Univ. of Mons Univ. de Montréal ; Pavillon | Mons, Belgium Montréal, PQ, Canada |
| LEED LEGN | Univ. of Leeds Lab. Naz. di Legnaro | Leeds, United Kingdom Legnaro, Italy | | René-JALévesque CUniv. de Montréal ; Centre | Montréal, PQ, Canada |
| LEHI LEHM | Lehigh Univ. Lehman College of CUNY | Bethlehem, PA, USA Bronx, NY, USA | | de recherches mathématiques | . • |
| LEID LEMO | Univ. Leiden Le Moyne Coll. | Leiden, The Netherlands Syracuse, NY, USA | MOSU | Skobeltsyn Inst. of Nuclear Physics, Lomonosov Moscow State Univ.; Experimental | Moscow, Russian Federation |
| LEUV | Katholieke Univ. Leuven | Leuven, Belgium | | HEP Division; Theoretical | |
| LINZ | Univ. Linz | Linz, Austria | MDCM | HEP Division May Planck Inst. fur Chemia | Mainz Cormany |
| LISB | T | Lisboa CODEX, Portugal | MPUM | Max Planck Inst. fur Chemie | Mainz, Germany |

| MPEI | Moscow Physical Engi- | Moscow, Russian Federation | ORST | 9 | Corvallis, OR, USA |
|-----------------------|---------------------------------------------------------|------------------------------------------------------------|-------------------|-------------------------------------------------------------------------|-----------------------------------------------|
| MPIA | neering Inst. Max-Planck-Institute für | Garching, Germany | OSAK OSKC | Osaka Univ. Osaka City Univ. | Osaka, Japan Osaka-shi, Japan |
| | Astrophysik | , , | OSLO | Univ. of Oslo | Oslo, Norway |
| MPIH | Max-Planck-Inst. für Kern- physik | Heidelberg, Germany | OSU | Ohio State Univ. | Columbus, OH, USA |
| MPIM | Max-Planck-Inst. für | München, Germany | OTTA OXF | Univ. of Ottawa University of Oxford | Ottawa, ON, Canada Oxford, United Kingdom |
| | Physik | | | Oniversity of Oxford Oniversity of Oxford | Oxford, United Kingdom Oxford, United Kingdom |
| MSU | Michigan State Univ. | East Lansing, MI, USA | PADO | Univ. degli Studi di Padova | Padova, Italy |
| | Mount Holyoke College Centre Univ. du Haut-Rhin | South Hadley, MA, USA Mulhouse, France | | LPNHE , $IN^2P^3/CNRS$ | Paris, France |
| | Ludwig-Maximilians-Univ. | Garching, Germany | | Univ. de Paris (Historical) | Paris, France |
| MINT | München | | | Univ. Paris VII, LPTHE INFN, Gruppo Collegato di | Paris, France Parma, Italy |
| | Tech. Univ. München Midwestern Univ. Research | Garching, Germany Stroughton, WI, USA | FARM | Parma | rarma, mary |
| MUITA | Assoc. (Historical in Review) | Stroughton, WI, USA | PAST | Institut Pasteur | Paris, France |
| MURC | Univ. of Murcia | Murcia, Spain | PATR | Univ. of Patras | Patras, Greece |
| NAAS | North Americal Aviation Sci- | Thousand Oaks, CA, USA | PAVI PAVII | Univ. di Pavia INFN, Sez. di Pavia | Pavia, Italy Pavia, Italy |
| | ence Center (Historical in Review) | | PENN | Univ. of Pennsylvania | Philadelphia, PA, USA |
| NAGO | Nagoya Univ. | Nagoya, Japan | PGIA | INFN, Sezione di Perugia | Perugia, Italy |
| NAPL | Univ. di Napoli "Federico II" | Napoli, Italy | PISA | Univ. di Pisa | Pisa, Italy |
| NASA | NASA | Greenbelt, MD, USA | PISAI | INFN, Sez. di Pisa | Pisa, Italy |
| NBS | U.S National Bureau of | Gaithersburg, MD, USA | PITT PLAT | Univ. of Pittsburgh SUNY at Plattsburgh | Pittsburgh, PA, USA Plattsburgh, NY, USA |
| | Standards (Old name for NIST) | | PLRM | Univ. di Palermo | Palermo, Italy |
| NBSB | National Inst. Standards | Boulder, CO, USA | PNL | Battelle Memorial Inst. | Richland, WA, USA |
| NCAR | Tech. | Boulder, CO, USA | PNPI | Petersburg Nuclear Physics | Gatchina, Russian Federation |
| MACAR | National Center for Atmospheric Research | Boulder, CO, USA | | Inst. of Russian Academy of Sciences | |
| NCSU | North Carolina State Univ. | Raleigh, NC, USA | PPA | Princeton-Penn. Proton Accel- | Princeton, NJ, USA |
| | Univ. of Notre Dame | Notre Dame, IN, USA | | erator (Historical in Review) | _ ~ |
| NEAS | Northeastern Univ. | Boston, MA, USA | PRAG PRIN | Inst. of Physics, ASCR Princeton Univ. | Prague, Czech Republic |
| NEBR NEUC | Univ. of Nebraska Univ. de Neuchâtel | Lincoln, NE, USA Neuchâtel, Switzerland | PSI | Paul Scherrer Inst. | Princeton, NJ, USA Villigen PSI, Switzerland |
| | Univ. de Nice | Nice, France | PSLL | Physical Science Lab | Las Cruces, NM, USA |
| | Observatoire de Nice | Nice, France | $_{\mathrm{PSU}}$ | Penn State Univ. | University Park, PA, USA |
| NIHO | Nihon Univ. | Tokyo, Japan | PUCB | Pontifícia Univ. Católica | Rio de Janeiro, RJ, Brasil |
| NIIG | Niigata Univ. | Niigata, Japan | PUEB | do Rio de Janeiro Univ. Autonoma de Puebla | Puebla, Pue, Mexico |
| NIJM | Radboud Univ. Nijmegen | ED Nijmegen , The Netherlands | PURD | | West Lafayette, IN, USA |
| NIRS | Nat. Inst. Radiological Sci- | Chiba, Japan | QUKI | Queen's Univ. | Kingston, ON, Canada |
| NIST | ences National Institute of Stan- | Gaithersburg, MD, USA | RAL | Rutherford Appleton Lab. | Didcot, Oxfordshire, United Kingdom |
| 11101 | dards & Technology | Gardiersburg, MD, Con | REGE | Univ. Regensburg | Regensburg, Germany |
| NIU | Northern Illinois Univ. | De Kalb, IL, USA | REHO | Weizmann Inst. of Science | Rehovot, Israel |
| NMSU | New Mexico State Univ.; | Las Cruces, NM, USA | REZ | Nuclear Physics Inst. AVČR | Řež, Czech Republic |
| | Dept. of Physics, MSC 3D; Part. & Nucl. Phys. Group, | | RHBL | Royal Holloway, Univ. of | Egham, Surrey, United Kingdom |
| | Box 30001/Dept. | | RHEL | London Rutherford High Energy | Chilton, Didcot, Oxon., United |
| | Nordita | Stockholm, Sweden | | Lab (Old name for RAL) | Kingdom |
| | Univ. of Nottingham | Nottingham, United Kingdom Novosibirsk, Russian Federa- | RICE | Rice Univ. | Houston, TX, USA |
| NOVM | Inst. of Mathematics | tion | RIKEN | Riken Nishina Center for Accelerator-Based Science | Saitama, Japan |
| NOVO | BINP, Budker Inst. of Nu- | Novosibirsk, Russian Federa- | RIKK | Rikkyo Univ. | Tokyo, Japan |
| NPOL | clear Physics Polytechnic of North Lon- | tion London, United Kingdom | RIS | Rowland Inst. for Science | Cambridge, MA, USA |
| M OL | don | London, Omied Kingdom | RISC | Rockwell International | Thousand Oaks, CA, USA |
| NRL | Naval Research Lab | Washington, DC, USA | RISL | Universities Research Reactor | Risley, Warrington, United Kingdom |
| NSF | National Science Founda- tion | Arlington, VA, USA | RISO | Riso National Laboratory | Roskilde, Denmark |
| NTHU | National Tsing Hua Univ. | Hsinchu, Taiwan | RL | Rutherford High Energy | Chilton, Didcot, Oxon., United |
| NTUA | National Tech. Univ. of | Athens, Greece | RMCS | Lab (Old name for RAL) Royal Military Coll. of Sci- | Kingdom Swindon, Wilts., United King- |
| NWES | Athens Northwestern Univ. | Evanston, IL, USA | TUNIOS | ence | dom |
| NYU | New York Univ. | New York, NY, USA | | Univ. of Rochester | Rochester, NY, USA |
| OBER | Oberlin College | Oberlin, OH, USA | | Rockefeller Univ. | New York, NY, USA |
| OCH | Ochanomizu Univ. | Tokyo, Japan | | Univ. di Roma (Historical) 2 Univ. di Roma , "Tor Ver- | Roma, Italy Roma, Italy |
| OHIO | Ohio Univ. | Athens, OH, USA | TOMA. | gata" | roma, mary |
| OKAY OKLA | Okayama Univ. Univ. of Oklahoma | Okayama, Japan Norman, OK, USA | | INFN, Sez. di Roma | Roma, Italy |
| OKLA | Oklahoma State Univ. | Stillwater, OK, USA | ROSE | Rose-Hulman Inst. of Tech- | Terre Haute IN, USA |
| OREG | Univ. of Oregon ; Inst. of | Eugene, OR, USA | RPI | nology Rensselaer Polytechnic | Troy, NY, USA |
| | Theoretical Science; U.O. | | 1(1.1 | Inst. | 110y, 1V1, UDA |
| | Center for High Energy Physics | | RUTG | Rutgers, the State Univ. of | Piscataway, NJ, USA |
| ORNL | Oak Ridge National Labora- | Oak Ridge, TN, USA | SACL | New Jersey CEA Saclay, IRFU | Gif-sur-Yvette, France |
| OBCIT | tory | O GEDEN E | | CEA Saclay, Intro CEA Saclay (Essonne) | Gif-sur-Yvette, France |
| ORSAY | Univ. de Paris Sud | Orsay CEDEX, France | SAGA | - · · | Saga-shi, Japan |
| | | | | | |

| SAHA | Saha Inst. of Nuclear Physics | Bidhan Nagar, Calcutta, India | TEXA | Univ. of Texas at Austin | Austin, TX, USA |
|--------------|------------------------------------------------------------|----------------------------------------------------------|------------|------------------------------------------------------|-----------------------------------------------|
| SANG | Kyoto Sangyo Univ. | Kyoto-shi, Japan | | Tokyo Gakugei Univ. | Tokyo, Japan |
| SANI | Ist. Superiore di Sanità | Roma, Italy | TGU | Tohoku Gakuin Univ. | Miyagi, Japan |
| SASK | Univ. of Saskatchewan Lab. Naz. Gran Sasso | Saskatoon, SK, Canada Assergi (AQ), Italy | THES | Aristotle Univ. of Thessa- loniki (AUTh) | Thessaloniki, Greece |
| SASSO | dell'INFN | Assergi (AQ), Italy | TINT | Tokyo Inst. of Technology | Tokyo, Japan |
| SAVO | Univ. de Savoie | Chambery, France | TISA | Sagamihara Inst. of Space & | Kanagawa, Japan |
| SBER | California State Univ. | San Bernardino, CA, USA | | Astronautical Sci. | , <u>, , , , , , , , , , , , , , , , , , </u> |
| | W.J. Schafer Assoc. | Livermore, DA, USA | | Tomsk Polytechnic Univ. | Tomsk, Russian Federation |
| SCIT | Science Univ. of Tokyo | Tokyo, Japan | TMTC | Tokyo Metropolitan Coll. Tech. | Tokyo, Japan |
| SCOT | Scottish Univ. Research and Reactor Ctr. | Glasgow, United Kingdom | TMU | Tokyo Metropolitan Univ. | Tokyo, Japan |
| SCUC | Univ. of South Carolina | Columbia, SC, USA | TNTO | Univ. of Toronto | Toronto, ON, Canada |
| SEAT | Seattle Pacific Coll. | Seattle, WA, USA | TOHO | Toho Univ. | Chiba, Japan |
| SEIB | Austrian Research Center, | Seibersdorf, Austria | | K Tohoku Univ. | Sendai, Japan |
| SEOU | Seibersdorf LTD. Korea Univ.; Dept. of | Seoul, Republic of Korea | | Tokai Univ. | Shimizu, Japan |
| SECO | Physics; HEP Group | Seoui, Republic of Rolea | | H Tokai Univ. S Univ. of Tokyo; Meson Sci- | Hiratsuka, Japan |
| SEOUL | Seoul National Univ.; Center | Seoul, Republic of Korea | TOKM | ence Laboratory | Tokyo, Japan |
| | for Theoretical Physics; Dept. | | TOKU | Univ. of Tokushima | Tokushima-shi, Japan |
| | of Physics & Astronomy, Coll. | | | Univ. of Tokyo ; High-Energy | Tokyo, Japan |
| SERP | of Natural Sciences IHEP, Inst. for High Energy | Protvino, Russian Federation | | Physics Theory Group | |
| 52101 | Physics | 1 100 mo, 1 dassair 1 odoration | TOKY | CUniv. of Tokyo ; Dept. of | Tokyo, Japan |
| SETO | Seton Hall Univ. | South Orange, NJ, USA | TORI | Chemistry Univ. degli Studi di Torino | Torino Italy |
| SFLA | Univ. of South Florida | Tampa, FL, USA | TPTI | Uzbek Academy of Sciences | Torino, Italy Tashkent, Republic of Uzbek- |
| SFRA | Simon Fraser University | Burnaby, BC, Canada | 11 11 | OZDER Academy of Sciences | istan |
| SFSU | California State Univ. | San Francisco, CA, USA | TRIN | Trinity College Dublin | Dublin, Ireland |
| | Ain Shams University | Abbassia, Cairo, Egypt | TRIU | TRIUMF | Vancouver, BC, Canada |
| SHEF SHMP | Univ. of Sheffield | Sheffield, United Kingdom Southampton, United Kingdom | TRST | Univ. di Trieste | Trieste, Italy |
| SIEG | Univ. of Southampton Univ. Siegen | Siegen, Germany | | INFN, Sez. di Trieste | Trieste, Italy |
| SILES | Univ. of Silesia | Katowice, Poland | | Univ. degli Studi di Trieste | Trieste, Italy |
| SIN | Swiss Inst. of Nuclear Re- | Villigen, Switzerland | TSUK | Univ. of Tsukuba Tamagawa Univ. | Ibaraki-ken, Japan |
| | search (Old name for VILL) | 3 , | TUAT | Tokyo Univ. of Agriculture | Tokyo, Japan Tokyo, Japan |
| SING | National Univ. of Singapore | Kent Ridge, Singapore | IUAI | Tech. | Tokyo, Japan |
| SISSA | Scuola Internazionale Superi- | Trieste, Italy | TUBIN | Univ. Tübingen | Tübingen, Germany |
| SLAC | ore di Studi Avanzati SLAC National Accelera- | Menlo Park, CA, USA | | Tufts Univ. | Medford, MA, USA |
| SLAC | tor Laboratory | Mello Tark, CA, USA | TUW | Technische Univ. Wien | Vienna, Austria |
| SLOV | Inst. of Physics, Slovak Acad. | Bratislava 45, Slovakia | TUZL | Tuzla Univ. | Tuzla, Argentina |
| | of Sciences | | UBA UCB | Univ. de Buenos Aires | Buenos Aires, Argentina |
| SMU | Southern Methodist Univ. | Dallas, TX, USA | ОСБ | Univ. of California (Berkeley) | Berkeley, CA, USA |
| SNSP SOFI | Scuola Normale Superiore Inst. for Nuclear Research and | Pisa, Italy Sofia, Bulgaria | UCD | Univ. of California (Davis) | Davis, CA, USA |
| 5011 | Nuclear Energy | Sona, Bulgaria | UCI | Univ. of California (Irvine) | Irvine, CA, USA |
| SOFU | Univ. of Sofia "St. Kliment | Sofia, Bulgaria | UCLA | Univ. of California (Los | Los Angeles, CA, USA |
| OD LITT | Ohridski" | | | Angeles) | |
| | Univ. de São Paulo | São Paulo, SP, Brasil | UCND | * | Oak Ridge, TN, USA |
| | Inst. de Física Teórica (IFT) | São Paulo, SP, Brasil | UCR | Univ. of California (River- | Riverside, CA, USA |
| SSL | Univ. of California (Berkeley) | Berkeley, CA, USA | UCSB | side) Univ. of California (Santa | Santa Barbara, CA, USA |
| STAN | Stanford Univ. | Stanford, CA, USA | ОСЗБ | Barbara); Physics Dept., | Santa Barbara, CA, USA |
| STEV | Stevens Inst. of Tech. | Hoboken, NJ, USA | | High Energy Physics Experi- | |
| STLO | St. Louis Univ. | St. Louis, MO, USA | TT CODE | ment | G . D . G . TG . |
| STOH | Stockholm Univ. | Stockholm, Sweden | UCSBI | Univ. of California (Santa Barbara); Kavli Inst. for | Santa Barbara, CA, USA |
| STON | SUNY at Stony Brook | Stony Brook, NY, USA | | Theoretical Physics | |
| STRB | Inst. Pluridisciplinaire Hubert | Strasbourg, France | UCSC | Univ. of California (Santa | Santa Cruz, CA, USA |
| CONTRA | Curien (CNRS) | Stuttment Commons | | Cruz) | |
| STUT | Univ. Stuttgart I Max-Planck-Inst. | Stuttgart, Germany | UCSD | Univ. of California (San | La Jolla, CA, USA |
| SUGI | Sugiyama Jogakuen Univ. | Stuttgart, Germany Aichi, Japan | 110.5 | Diego) | 0 |
| SURR | Univ. of Surrey | Guildford, Surrey, United | UGAZ | Univ. of Gaziantep Univ. of Maryland | Gaziantep, Turkey College Park, MD, USA |
| | · · · · · · · · · · · · · · · · · · · | Kingdom | | Univ. Nac. Autónoma de | México, DF, Mexico |
| SUSS | Univ. of Sussex | Brighton, United Kingdom | OLIMINI | México (UNAM) | Lientee, DI, Mentee |
| SVR | Savannah River Labs. | Aiken, SC, USA | UNAM | Univ. Nacional Autónoma de | México, DF, Mexico |
| SYDN | Univ. of Sydney | Sydney, NSW, Australia | | México (\mathbf{UNAM}) | |
| SYRA | Syracuse Univ. | Syracuse, NY, USA Dushanka, Tadahilatan | UNC | Univ. of North Carolina | Greensboro, NC, USA |
| TAJK TAMU | Acad. Sci., Tadzhik SSR Texas A&M Univ. | Dushanbe, Tadzhikstan College Station, TX, USA | UNCCI | Huniv. of North Carolina at | Chapel Hill, NC, USA |
| TATA | Tata Inst. of Fundamental | Bombay, India | UNCS | Chapel Hill Union College | Schonoctady NV IICA |
| 11111 | Research | zomouj, maid | | Union College UNESP | Schenectady, NY, USA Botucatu, Brasil |
| TBIL | Tbilisi State University | Tbilisi, Republic of Georgia | UNH | Univ. of New Hampshire | Durham, NH, USA |
| TELA | Tel-Aviv Univ. | Tel Aviv, Israel | UNM | Univ. of New Mexico | Albuquerque, NM, USA |
| TELE | Teledyne Brown Engineer- | Huntsville, AL, USA | UOEH | Univ. of Occupational and | Kitakyushu, Japan |
| TEMP | ing Temple Univ. | Philadelphia, PA, USA | IIDATI | Environmental Health | , 1 |
| TENN | Univ. of Tennessee | Knoxville, TN, USA | UPNJ | Upsala College | East Orange, NJ, USA |
| T-1111 | Jan. of Lonnobbee | ,,, | UPPS | Uppsala Univ. | Uppsala, Sweden |

| UPR | Univ. of Puerto Rico | Rio Piedras, PR, USA | | Wayne State Univ. | Detroit, MI, USA |
|-----------|---------------------------------------------|----------------------------|--------|-----------------------------|-----------------------------------------|
| URI | Univ. of Rhode Island | Kingston, RI, USA | WESL | Wesleyan Univ. | Middletown, CT, USA |
| USC | Univ. of Southern Califor- | Los Angeles, CA, USA | WIEN | Univ. Wien | Vienna, Austria |
| TIOD | nia | G F : GA HGA | WILL | Coll. of William and Mary | Williamsburg, VA, USA |
| USF | Univ. of San Francisco | San Francisco, CA, USA | WINR | National Centre for Nuclear | Warsaw, Poland |
| UTAH | Univ. of Utah | Salt Lake City, UT, USA | ***** | Research | |
| UTRE | Univ. of Utrecht | Utrecht, The Netherlands | WISC | Univ. of Wisconsin | Madison, WI, USA |
| UTRO | | Trondheim, Norway | | Univ. of the Witwatersrand | Wits, South Africa |
| | ence & Technology | | WMIU | | Kalamazoo, MI, USA |
| UVA | Univ. of Virginia | Charlottesville, VA, USA | WONT | The Univ. of Western On- | London, ON, Canada |
| | Acad. Sci., Ukrainian SSR | Uzhgorod, Ukraine | ***** | tario | *** 1 . 1 . 1 . 1 . 1 . 1 . 1 . 1 . 1 . |
| VALE | Univ. de Valencia ; Dept. | Burjassot, Valencia, Spain | WOOD | Woodstock College (No | Woodstock, MD, USA |
| | Física Teórica, Fac. de Física; | | ****** | longer in existence) | *** |
| | Dept. Ing. Electronica, ETSE | | WUPP | Bergische Univ. Wuppertal | Wuppertal, Germany |
| VALP | Valparaiso Univ. | Valparaiso, IN, USA | | g . | Würzburg, Germany |
| VAND | Vanderbilt Univ. | Nashville, TN, USA | | Washington Univ. | St. Louis, MO, USA |
| VASS | Vassar College | Poughkeepsie, NY, USA | | Univ. of Wyoming | Laramie, WY, USA |
| VICT | Univ. of Victoria | Victoria, BC, Canada | YALE | Yale Univ. | New Haven, CT, USA |
| VIEN | Inst. für Hochenergiephysik | Vienna, Austria | YARO | Yaroslavl State Univ. | Yaroslavl, Russian Federation |
| | (HEPHY) | | YCC | Yokohama Coll. of Com- | Yokohama, Japan |
| VILL | ETH Zürich | Zürich, Switzerland | | merce | |
| VPI | Virginia Tech. | Blacksburg, VA, USA | YERE | Yerevan Physics Inst. | Yerevan, Armenia |
| VRIJ | Vrije Univ. | HV Amsterdam, The Nether- | | Yokohama National Univ. | Yokohama-shi, Japan |
| | | lands | YORKO | York Univ. | Toronto, Canada |
| WABR | NEidgenossisches Amt für Mess- | Waber, Switzerland | ZAGR | Zagreb Univ. | Zagreb, Croatia |
| MADO | wesen | W DII | ZARA | Univ. de Zaragoza | Zaragoza, Spain |
| | Univ. of Warsaw | Warsaw, Poland | ZEEM | Univ. van Amsterdam | TV Amsterdam, The Nether- |
| WASC | R Waseda Univ.; Cosmic Ray | Tokyo, Japan | | | lands |
| XX/A CILI | Division Univ. of Washington ; Elem. | Seattle, WA, USA | ZHZH | Zhengzhou Univ. | Zhengzhou, Henan, China |
| WASH | Particle Experiment (EPE); | Seattle, WA, USA | ZURI | Univ. Zürich | Zürich, Switzerland |
| | Particle Astrophysics (PA) | | | | |
| WASII | Waseda Univ.; Dept. of | Tokyo, Japan | | | |
| WILDO | Physics, High Energy Physics | Tokyo, Japan | | | |
| | Group | | | | |
| | * | | | | |

GAUGE AND HIGGS BOSONS

| γ | | | | | 469 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|----------|------|------|---------------------------------------------------|
| g (gluon) | | | | | 469 |
| graviton | | | | | 470 |
| W | | | | | 470 |
| Z | | | | | 478 |
| Higgs Bosons — H^0 and H^{\pm} | | | | | 501 |
| Heavy Bosons Other than Higgs Bosons | | | | | 543 |
| Axions (A^0) and Other Very Light Bosons . | | | | | 562 |
| | | | | | |
| | | | | | |
| Notes in the Gauge and Higgs Boson Listings | | | | | |
| | | | | | 470 |
| The Mass of the W Boson (rev.) | | | | | 470 474 |
| The Mass of the W Boson (rev.) Triple Gauge Couplings (rev.) | | | | | |
| The Mass of the W Boson (rev.) | | | | | 474 |
| The Mass of the W Boson (rev.) | | | | | 474 477 |
| The Mass of the W Boson (rev.) Triple Gauge Couplings (rev.) | · · · · | | | | 474 477 478 |
| The Mass of the W Boson (rev.) | | | | | 474 477 478 498 |
| The Mass of the W Boson (rev.) | | | | | 474 477 478 498 499 |
| The Mass of the W Boson (rev.) Triple Gauge Couplings (rev.) Anomalous W/Z Quartic Couplings (rev.) The Z Boson Anomalous $ZZ\gamma$, $Z\gamma\gamma$, and ZZV Couplings (rev.) Anomalous W/Z Quartic Couplings Searches for Higgs Bosons (rev.) | | | | | 474 477 478 498 499 501 |
| The Mass of the W Boson (rev.) Triple Gauge Couplings (rev.) Anomalous W/Z Quartic Couplings (rev.) The Z Boson Anomalous $ZZ\gamma$, $Z\gamma\gamma$, and ZZV Couplings (rev.) Anomalous W/Z Quartic Couplings Searches for Higgs Bosons (rev.) The W' Searches (rev.) | | | | | 474 477 478 498 499 501 543 |



GAUGE AND HIGGS BOSONS



$$I(J^{PC}) = 0.1(1^{-})$$

Ī

γ MASS

Results prior to 2008 are critiqued in GOLDHABER 10.

The following conversions are useful: 1 eV = 1.783 \times 10 $^{-33}$ g = 1.957 \times 10 $^{-6}$ m_e ; λ_C = 1.973 \times 10 $^{-7}$ m.

| VALUE (eV) | | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|---------------------|-----------|-------------------------|---------|-----------|-----------------------------------------------|
| < 1 | ×10 ⁻¹⁸ | | ¹ RYUTOV | 07 | | MHD of solar wind |
| ● ● We do n | ot use the | following | | , fits, | limits, e | tc. • • • |
| | | | ² ACCIOLY | 10 | | Anomalous mag. mom. |
| < 1 | ×10 ⁻²⁶ | | ³ ADELBERGER | 07A | | Galactic field existence if Higgs mass |
| < 1.4 | ×10 ⁻⁷ | | ACCIOLY | 04 | | Dispersion of GHz ra- dio waves by sun |
| < 2 | $\times 10^{-16}$ | | FULLEKRUG | 04 | | Speed of 5-50 Hz radi- ation in atmosphere |
| < 7 | $\times 10^{-19}$ | | ⁴ LUO | 03 | | Modulation torsion bal- ance |
| < 1 | $\times 10^{-17}$ | | ⁵ LAKES | 98 | | Torque on toroid bal- ance |
| < 6 | $\times 10^{-17}$ | | ⁶ RYUTOV | 97 | | MHD of solar wind |
| < 9 | $\times 10^{-16}$ | 90 | ⁷ FISCHBACH | 94 | | Earth magnetic field |
| $<$ (4.73 \pm 0.45) | $\times 10^{-12}$ | | 8 CHERNIKOV | 92 | SQID | Ampere-law null test |
| <(9.0 ±8.1) | $\times 10^{-10}$ | | 9 RYAN | 85 | | Coulomb-law null test |
| < 3 | $\times 10^{-27}$ | | ^{L0} CHIBISOV | 76 | | Galactic magnetic field |
| < 6 | $\times 10^{-16}$ | 99.7 | DAVIS | 75 | | Jupiter magnetic field |
| < 7.3 | $\times 10^{-16}$ | | HOLLWEG | 74 | | Alfven waves |
| < 6 | $\times 10^{-17}$ | | ^{l1} FRANKEN | 71 | | Low freq. res. cir. |
| < 1 | $\times 10^{-14}$ | | WILLIAMS | 71 | CNTR | Tests Gauss law |
| < 2.3 | $\times 10^{-15}$ | | GOLDHABER | 68 | | Satellite data |
| < 6 | $\times 10^{-15}$ | | ^{l1} PATEL | 65 | | Satellite data |
| < 6 | × 10 ⁻¹⁵ | | GINTSBURG | 64 | | Satellite data |

 $^{
m 1}$ RYUTOV 07 extends the method of RYUTOV 97 to the radius of Pluto's orbit. ² ACCIOLY 10 limits come from possible alterations of anomalous magnetic moment of electron and gravitational deflection of electromagnetic radiation. Reported limits are not "claimed" by the authors and in any case are not competitive.

not "claimed" by the authors and in any case are not competitive. 3 When trying to measure m one must distinguish between measurements performed on large and small scales. If the photon acquires mass by the Higgs mechanism, the large-scale behavior of the photon might be effectively Maxwellian. If, on the other hand, one postulates the Proca regime for all scales, the very existence of the galactic field implies $m<10^{-26}$ eV, as correctly calculated by YAMAGUCHI 59 and CHIBISOV 76.
4 LUO 03 determine a limit on $\mu^2~A<1.1\times10^{-11}~T~m/m^2$ (with μ^{-1} =characteristic length for photon mass; A=ambient vector potential) — similar to the LAKES 98 technique. Unlike LAKES 98 who used static, the authors used dynamic torsion balance. Assuming A to be $10^{12}~T~m$, they obtain $\mu < 1.2\times10^{-51}~g$, equivalent to $6.7\times10^{-19}~eV$. The rotating modified Cavendish balance removes dependence on the direction of A. GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 GOLDHABER 03 argue that because plasma current effects are neglected, the LUO 03 limit does not provide the best available limit on μ^2 A nor a reliable limit at all on μ .

limit does not provide the best available limit on $\mu^2 A$ nor a reliable limit at all on μ . The reason is that the A associated with cluster magnetic fields could become arbitrarily small in plasma voids, whose existence would be compatible with present knowledge. LUO 03B reply that fields of distant clusters are not accurately mapped, but assert that a zero A is unlikely given what we know about the magnetic field in our galaxy. LAKES 98 reports limits on torque on a toroid Cavendish balance, obtaining a limit on $\mu^2 A < 2 \times 10^{-9} \, \text{Tm/m}^2$ via the Maxwell-Proca equations, where μ^{-1} is the characteristic length associated with the photon mass and A is the ambient vector potential in the Lorentz gauge. Assuming $A \approx 1 \times 10^{12} \, \text{Tm}$ due to cluster fields he obtains $\mu^{-1} > 2 \times 10^{10} \, \text{m}$, corresponding to $\mu < 1 \times 10^{-17} \, \text{eV}$. A more conservative limit, $\mu = 1 \times 10^{12} \, \text{cm}$ has $\mu = 1 \times 10^{12} \, \text{cm}$. using $A\approx (1~\mu{\rm G})\times (600~{\rm pc})$ based on the galactic field, is $\mu^{-1}>1\times 10^9~{\rm m}$ or $\mu<2\times 10^{-16}~{\rm eV}.$

6 RYUTOV 97 uses a magnetohydrodynamics argument concerning survival of the Sun's field to the radius of the Earth's orbit. "To reconcile observations to theory, one has to reduce [the photon mass] by approximately an order of magnitude compared with"

DAVIS 75. 7 FISCHBACH 94 report $<8\times10^{-16}$ with unknown CL. We report Bayesian CL used elsewhere in these Listings and described in the Statistics section.

elsewhere in these Listings and described in the Statistics section.

CHERNIKOV 92 measures the photon mass at 1.24 K, following a theoretical suggestion that electromagnetic gauge invariance might break down at some low critical temperature. See the erratum for a correction, included here, to the published result.

9 RYAN 85 measures the photon mass at 1.36 K (see the footnote to CHERNIKOV 92).

OCHIBISOV 76 depends in critical way on assumptions such as applicability of virial theorem. Some of the arguments given only in unpublished references.

11 See criticism questioning the validity of these results in GOLDHABER 71, PARK 71 and

KROLL 71. See also review GOLDHABER 71B.

γ CHARGE

OKUN 06 has argued that schemes in which all photons are charged are inconsistent. He says that if a neutral photon is also admitted to avoid this problem, then other problems emerge, such as those connected with the emission and absorption of charged photons by charged particles. He concludes that in the absence of a self-consistent phenomenological basis, interpretation of experimental data is at best difficult.

| VALU | E (e) | CHAR GE | DO CUMENT ID | | TECN | COMMENT |
|------|-------------------|---------|-----------------------|-----|------|----------------------|
| | | | | 07в | VLBI | Aharonov-Bohm effect |
| <1 | $\times 10^{-35}$ | single | ¹³ CAPRINI | 05 | CMB | Isotropy constraint |

| • | • | • | We do | o not | use the | following | data 1 | for | averages, | fits, | limits, etc. | • | • | • |
|---|---|---|-------|-------|---------|-----------|--------|-----|-----------|-------|--------------|---|---|---|
|---|---|---|-------|-------|---------|-----------|--------|-----|-----------|-------|--------------|---|---|---|

| $<1 \times 10^{-32}$ | single | ¹² ALTSCHUL | 07в | VLBI | Aharonov-Bohm effect |
|-------------------------|--------|---------------------------|-----|------|------------------------------------------------|
| $<3 \times 10^{-33}$ | mixed | | | | Smear as function of $B \cdot E_{\gamma}$ |
| $< 4 \times 10^{-31}$ | | ¹⁴ KOBYCHEV | 05 | VLBI | Deflection as function of $B \cdot E_{\gamma}$ |
| $< 8.5 \times 10^{-17}$ | | ¹⁵ SEMERTZIDIS | 03 | | Laser light deflection in B-field |
| $< 3 \times 10^{-28}$ | single | ¹⁶ SIVA RA M | 95 | CMB | For $\Omega_M = 0.3$, $h^2 = 0.5$ |
| $<5 \times 10^{-30}$ | | ¹⁷ RAFFELT | 94 | TOF | Pulsar $f_1 - f_2$ |
| $< 2 \times 10^{-28}$ | | ¹⁸ COCCONI | 92 | | VLBA radio telescope resolution |
| $< 2 \times 10^{-32}$ | | COCCONI | 88 | TOF | Pulsar $f_1 - f_2$ TOF |

 $^{12}\mbox{ALTSCHUL}$ 07B looks for Aharonov-Bohm phase shift in addition to geometric phase shift in radio interference fringes (VSOP mission).

 $13\,\mathrm{CAPRINI}$ 05 uses isotropy of the cosmic microwave background to place stringent limits on possible charge asymmetry of the Universe. Charge limits are set on the photon, neutrino, and dark matter particles. Valid if charge asymmetries produced by different particles are not anticorrelated.

14 KOBYCHEV 05 considers a variety of observable effects of photon charge for extragalactic compact radio sources. Best limits if source observed through a foreground cluster of

 15 SEMERTZIDIS 03 reports the first laboratory limit on the photon charge in the last 30 years. Straightforward improvements in the apparatus could attain a sensitivity of 10 $^{-20}$ e.

 $^{16}\,\text{SIVARAM}$ 95 requires that CMB photon charge density not overwhelm gravity. Result scales as $\Omega_M \; \mathrm{h}^2$

17 RAFFELT 94 notes that COCCONI 88 neglects the fact that the time delay due to dispersion by free electrons in the interstellar medium has the same photon energy dependence as that due to bending of a charged photon in the magnetic field. His limit is based on the assumption that the entire observed dispersion is due to photon charge. It is a factor of 200 less stringent than the COCCONI 88 limit.

¹⁸ See COCCONI 92 for less stringent limits in other frequency ranges. Also see RAF-FELT 94 note.

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$$I(J^P) = 0(1^-)$$

SU(3) color octet

Mass m=0. Theoretical value. A mass as large as a few MeV may not be precluded, see YNDURAIN 95.

| VALUE | DO CUMENT ID | TECN | COMMENT | |
|---------------------------------|----------------------|----------------------------------|-----------------------------------------------------------------------|--|
| • • • We do not use the followi | ng data for averages | s, fits, limits, | etc. • • • | |
| | BEHREND BERGER | 91H OPAL 82D CELL 80D PLUT | Spin 1, not 0 | |
| | BRANDELIK | 80c TASS | Spin 1, not 0 | |

gluon REFERENCES

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|-----------|------|--------------|---------------------|------------------|
| ABREU | 92 E | PL B274 498 | P. Abreu et al. | (DELPHI Collab.) |
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| BERGER | 80 D | PL B97 459 | C. Berger et al. | (PLUTO Collab.) |
| BRANDELIK | 80 C | PL B97 453 | R. Brandelik et al. | (TASSO Collab.) |

Gauge & Higgs Boson Particle Listings graviton, W

graviton

J = 2

graviton MASS

All of the following limits are obtained assuming Yukawa potential in weak field limit. VANDAM 70 argue that a massive field cannot approach general relativity in the zero-mass limit; however, see GOLD-HABER 10 and references therein. h_0 is the Hubble constant in units of $100~{\rm km\,s^{-1}\,Mpc^{-1}}.$

The following conversions are useful: 1 eV = 1.783 \times 10 $^{-33}$ g = 1.957 \times 10 $^{-6}$ m_e ; $\lambda_C=1.973\times10^{-7}$ m.

| VALUE (eV) | DO CUMENT ID | | COMMENT |
|----------------------------------------------------------|----------------------|---------|----------------------------|
| <7 × 10 ⁻³² | $^{ m 1}$ CHOUDHURY | 04 | Weak gravitational lensing |
| | data for averages | , fits, | limits, etc. • • • |
| $< 7.6 \times 10^{-20}$ | ² FINN | 02 | Binary Pulsars |
| | ³ DA MOUR | 91 | Binary pulsar PSR 1913+16 |
| $< 2 \times 10^{-29} h_0^{-1} $ $< 7 \times 10^{-28}$ | GOLDHABER | 74 | Rich clusters |
| | HARE | 73 | Galaxy |
| $< 8 \times 10^4$ | HARE | 73 | 2γ decay |
| | | | |

 $^{^{1}\,\}text{CHOUDHURY}$ 04 sets limits based on nonobservation of a distortion in the measured values of the variance of the power spectrum.

graviton REFERENCES

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|------------------------|----------|--------------------------|-----------------------------------------------------|-------------------------------|
| FINN | 02 | PR D65 044022 | L.S. Finn, P.J. Sutton | , , , |
| TAYLOR | 93 | NAT 355 132 | J.N. Taylor et al. | (PRIN, ARCBO, BURE+)J |
| DAMOUR | 91 | APJ 366 501 | T. Damour, J.H. Taylor | (BURE, MEUD, PRIN) |
| GOLDHABER | 74 | PR D9 1119 | A.S. Goldhaber, M.M. Nieto | ` (LANL, STON) |
| HARE | 73 | CJP 51 431 | M.G. Hare | ` (SASK) |
| VANDAM | 70 | NP B22 397 | H. van Dam, M. Veltman | (ÙTRE) |
| | | | | |



tensor [spin 2]-biscalar theories

J = 1

THE MASS AND WIDTH OF THE W BOSON

Revised March 2012 by M.W. Grünewald (U Ghent) and A. Gurtu (King Abdulaziz University).

Precision determination of the W-mass is of great importance in testing the internal consistency of the Standard Model and, together with other electroweak data, in constraining the mass of the undiscovered Higgs boson. From the time of its discovery in 1983, the W-boson has been studied and its mass determined in $p\bar{p}$ and e^+e^- interactions; it is currently studied in pp interactions at the LHC. The W mass and width definition used here corresponds to a Breit-Wigner with mass-dependent width.

Production of on-shell W bosons at hadron colliders is tagged by the high p_T charged lepton from its decay. Owing to the unknown parton-parton effective energy and missing energy in the longitudinal direction, the collider experiments reconstruct the transverse mass of the W, and derive the W mass from comparing the transverse mass distribution with Monte Carlo predictions as a function of M_W . These analyses use the electron and muon decay modes of the W boson.

In the e^+e^- collider (LEP) a precise knowledge of the beam energy enables one to determine the $e^+e^- \rightarrow W^+W^-$ cross section as a function of center of mass energy, as well as

to reconstruct the W mass precisely from its decay products, even if one of them decays leptonically. Close to the W⁺W⁻ threshold (161 GeV), the dependence of the W-pair production cross section on M_W is large, and this was used to determine M_W . At higher energies (172 to 209 GeV) this dependence is much weaker and W-bosons were directly reconstructed and the mass determined as the invariant mass of its decay products, improving the resolution with a kinematic fit.

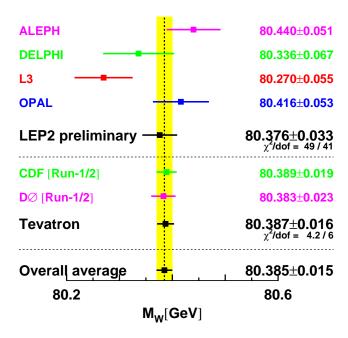


Figure 1: Measurements of the W-boson mass by the LEP and Tevatron experiments.

In order to compute the LEP average W mass, each experiment provided its measured W mass for the $q\overline{q}q\overline{q}$ and $q\overline{q}\ell\overline{\nu_\ell},~\ell=e,\mu,\tau$ channels at each center-of-mass energy, along with a detailed break-up of errors: statistical, uncorrelated, partially correlated and fully correlated systematics [1]. These have been combined to obtain a LEP W mass of $M_W=80.376\pm0.033~{\rm GeV}$. Errors due to uncertainties in LEP energy (9 MeV), and possible effect of color reconnection (CR) and Bose-Einstein correlations (BEC) between quarks from different W's (8 MeV) are included. The mass difference between $q\overline{q}q\overline{q}$ and $q\overline{q}\ell\overline{\nu_\ell}$ final states (due to possible CR and BEC effects) is $-12\pm45~{\rm MeV}$. In a similar manner, the width results obtained at LEP have been combined, resulting in $\Gamma_W=2.196\pm0.083~{\rm GeV}$ [1].

The two Tevatron experiments have also identified common systematic errors. Between the two experiments, uncertainties due to the parton distribution functions, radiative corrections, and choice of mass (width) in the width (mass) measurements are treated as correlated. An average W mass of $M_W=80.420\pm0.031~{\rm GeV}$ [2] and a W width of $\Gamma_W=2.046\pm0.049~{\rm GeV}$ [3] are obtained. Errors of 12 MeV (20 MeV) and 9 MeV (7 MeV) accounting for PDF and radiative correction

²FINN 02 analyze the orbital decay rates of PSR B1913+16 and PSR B1534+12 with a possible graviton mass as a parameter. The combined frequentist mass limit is at 90%CL.

³DAMOUR 91 is an analysis of the orbital period change in binary pulsar PSR 1913+16, and confirms the general relativity prediction to 0.8%. "The theoretical importance of the [rate of orbital period decay] measurement has long been recognized as a direct confirmation that the gravitational interaction propagates with velocity c (which is the immediate cause of the appearance of a damping force in the binary pulsar system) and thereby as a test of the existence of gravitational radiation and of its quadrupolar nature." TAYLOR 93 adds that orbital parameter studies now agree with general relativity to 0.5%, and set limits on the level of scalar contribution in the context of a family of

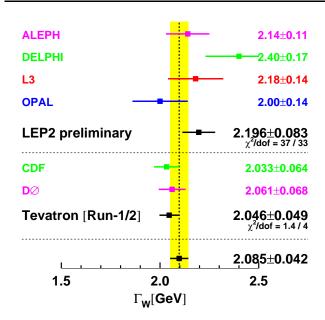


Figure 2: Measurements of the W-boson width by the LEP and Tevatron experiments.

uncertainties in the mass (width) combination dominate the correlated uncertainties.

At the 2012 winter conferences, the CDF and D0 experiments have presented new results for the mass of the W boson based on $2-4~{\rm fb^{-1}}$ of Run-II data, $80.387\pm0.019~{\rm GeV}$ [4] and $80.375\pm0.023~{\rm GeV}$ [5], respectively. The W-mass determination from the Tevatron experiments has thus become very precise. Combining all Tevatron results from Run-I and Run-II using an improved treatment of correlations, a new average of $80.387\pm0.016~{\rm GeV}$ is obtained [6], with common uncertainties of 10 MeV (PDF) and 4 MeV (radiative corrections).

The LEP and Tevatron results on mass and width, which are based on all results available, are compared in Fig. 1 and Fig. 2. Good agreement between the results is observed. Combining these results, assuming no common systematic uncertainties between the LEP and the Tevatron measurements, yields an average W mass of $M_W=80.385\pm0.015$ GeV and a W width of $\Gamma_W=2.085\pm0.042$ GeV.

The Standard Model prediction from the electroweak fit, using Z-pole data plus $m_{\rm top}$ measurement, gives a W-boson mass of $M_W=80.365\pm0.020$ GeV and a W-boson width of $\Gamma_W=2.091\pm0.002$ GeV [7].

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W MASS

The W-mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematic uncertainties between experiments are properly taken into account. The LEP-2 average W mass based on published results is 80.376 ± 0.033 GeV [CERN-PH-EP/2006-042]. The combined Tevatron data yields an average W mass of 80.387 ± 0.016 GeV [FERMILAB-TM-2532-EI.

 $\mbox{OUR}\mbox{ FIT}$ uses these average LEP and Tevatron mass values and combines them assuming no correlations.

| VALUE (GeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|-----------|-------------------------|-------------|---------|-------------------------------------------------------------------------------------------|
| 80.385 ± 0.015 OUR F | Т | | | | _ |
| 80.387 ± 0.019 | 1095k | $^{ m 1}$ aaltonen | 12E | CDF | $E_{\text{CM}}^{\overline{p}} = 1.96 \text{ TeV}$ |
| 80.367 ± 0.026 | 1677k | ² ABAZOV | 12F | D0 | $E_{\text{cm}}^{p\overline{p}} = 1.96 \text{ TeV}$ |
| 80.401 ± 0.043 | 500k | ³ ABAZOV | 09AB | D0 | $E_{cm}^{p\overline{p}} = 1.96 \; TeV$ |
| $80.336 \pm\ 0.055 \pm 0.039$ | 10.3k | ⁴ ABDALLAH | 08A | DLPH | $E_{\rm cm}^{ee} = 161 209 \; {\rm GeV}$ |
| $80.415 \pm\ 0.042 \pm 0.031$ | 11830 | ⁵ ABBIENDI | 06 | OPAL | E ^{ee} _{cm} = 170-209 GeV |
| $80.270 \pm\ 0.046 \pm 0.031$ | 9909 | ⁶ ACHARD | 06 | L3 | E ^{ee} _{cm} = 161-209 GeV |
| $80.440 \pm\ 0.043 \pm 0.027$ | 8692 | ⁷ SCHAEL | 06 | ALEP | E ^{ee} _{cm} = 161-209 GeV |
| 80.483 ± 0.084 | 49247 | ⁸ ABAZOV | 02D | D0 | $E_{ m cm}^{p\overline{p}}$ = 1.8 TeV |
| 80.433 ± 0.079 | 53841 | ⁹ AFFOLDER | 01E | CDF | $E_{ m cm}^{p\overline{p}}$ = 1.8 TeV |
| • • • We do not use the | he follow | ing data for average | s, fits, | limits, | etc. • • • |
| $80.413 \pm \ 0.034 \pm 0.034$ | 115 k | $^{ m 10}$ aaltonen | 07F | CDF | $E_{CM}^{ar{p}\overline{p}}=1.96\;TeV$ |
| 82.87 \pm 1.82 $^{+0.30}_{-0.16}$ | 1500 | ¹¹ AKTAS | 06 | H1 | $e^{\pm} p \rightarrow \overline{\nu}_e(\nu_e) X$, $\sqrt{s} \approx 300 \text{ GeV}$ |
| $80.3 \pm 2.1 \pm 1.2 \pm 1.0$ | 645 | ¹² CHEKA NOV | 02 c | ZEUS | $e^{-\stackrel{\bullet}{p}} \rightarrow \stackrel{\nu_e}{} X, \sqrt{s} =$ 318 GeV |
| $81.4^{+2.7}_{-2.6}\pm2.0^{+3.3}_{-3.0}$ | 1086 | ¹³ BREITWEG | 00D | ZEUS | $e^+p \rightarrow \overline{\nu}_e X, \sqrt{s} \approx 300 \text{ GeV}$ |
| $80.84 \pm 0.22 \pm 0.83$ | 2065 | ¹⁴ ALITTI | 92B | UA2 | See W/Z ratio below |
| $80.79 \ \pm \ 0.31 \ \pm 0.84$ | | ¹⁵ ALITTI | 90B | UA2 | $E_{\mathrm{cm}}^{p\overline{p}}$ = 546,630 GeV |
| $80.0 \pm 3.3 \pm 2.4 $ | 22 | ¹⁶ ABE | 89ı | CDF | $E_{ m cm}^{p\overline{p}}$ = 1.8 TeV |
| 82.7 \pm 1.0 \pm 2.7 | 149 | ¹⁷ ALBAJAR | 89 | UA1 | $E_{\mathrm{cm}}^{p\overline{p}}$ = 546,630 GeV |
| 81.8 $^{+}_{-}$ $^{6.0}_{5.3}$ ± 2.6 | 46 | ¹⁸ ALBAJAR | 89 | UA1 | $E_{\mathrm{cm}}^{p\overline{p}}$ = 546,630 GeV |
| 89 \pm 3 \pm 6 | 32 | ¹⁹ ALBAJAR | 89 | UA1 | $E_{ m cm}^{p\overline{p}}$ = 546,630 GeV |
| 81. ± 5. | 6 | ARNISON | 83 | UA1 | <i>E</i> ^{ee} _{CM} = 546 GeV |
| 80. $ +10. $ $-6. $ | 4 | BANNER | 83в | UA2 | Repl. by ALITTI 90B |

 $^{^1}$ AALTONEN 12E select 470k $W\to e\nu$ decays and 625k $W\to \mu\nu$ decays in 2.2 fb $^{-1}$ of Run-II data. The mass is determined using the transverse mass, transverse lepton momentum and transverse missing energy distributions, accounting for correlations. This results superseeds AALTONEN 07F.

 $^{^2}$ ABAZOV 12F select 1677k $W\to e\nu$ decays in 4.3 fb $^{-1}$ of Run-II data. The mass is determined using the transverse mass and transverse lepton momentum distributions, accounting for correlations.

 $^{^3}$ ABAZOV 09AB study the transverse mass, transverse electron momentum, and transverse missing energy in a sample of 0.5 million $W \to e \nu$ decays selected in Run-II data. The quoted result combines all three methods, accounting for correlations.

 $^{^4}$ ABDALLAH 08a use direct reconstruction of the kinematics of $W^+W^-\to q\overline{q}\ell\nu$ and $W^+W^-\to q\overline{q}q\overline{q}$ events for energies 172 GeV and above. The W mass was also extracted from the dependence of the WW cross section close to the production threshold and combined appropriately to obtain the final result. The systematic error includes ± 0.025 GeV due to final state interactions and ± 0.009 GeV due to LEP energy uncertainty.

⁵ ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\,\ell\nu_\ell$ and $W^+W^- \to q\overline{q}\,q\overline{q}$ events. The result quoted here is obtained combining this mass value with the results using $W^+W^- \to \ell\nu_\ell\ell^\ell\nu_{\ell^\prime}$ events in the energy range 183–207

W

GeV (ABBIENDI 03c) and the dependence of the WW production cross-section on m_W at threshold. The systematic error includes ± 0.009 GeV due to the uncertainty on the LEP beam energy.

- ⁶ ACHARD 06 use direct reconstruction of the kinematics of $W^+W^- \to q \overline{q} \ell \nu_\ell$ and $W^+W^- \to q \overline{q} q \overline{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this mass value with the results obtained from a direct W mass reconstruction at 172 and 183 GeV and with those from the dependence of the WW production cross-section on m_W at 161 and 172 GeV (ACCIARRI 99).
- 7 SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^-\to q\overline{q}\,q\overline{q}$ events in the C.M. energy range 183–209 GeV. The result quoted here is obtained combining this mass value with those obtained from the dependence of the W pair production cross-section on m_V at 161 and 172 GeV (BARATE 97 and BARATE 97s respectively). The systematic error includes ± 0.009 GeV due to possible effects of final state interactions in the $q\overline{q}\,q\overline{q}$ channel and ± 0.009 GeV due to the uncertainty on the LEP beam energy.
- 8 ABAZOV 02D improve the measurement of the W-boson mass including $W \to e \nu_e$ events in which the electron is close to a boundary of a central electromagnetic calorimeter module. Properly combining the results obtained by fitting $m_T(W)$, $p_T(e)$, and $p_T(\nu)$, this sample provides a mass value of 80.574 \pm 0.405 GeV. The value reported here is a combination of this measurement with all previous DØ W-boson mass measurements.
- **Online of this measurement with an provided by the second control of the second contr
- 10 AALTONEN 07F obtain high purity $W\to e\nu_e$ and $W\to \mu\nu_\mu$ candidate samples totaling 63,964 and 51,128 events respectively. The W mass value quoted above is derived by simultaneously fitting the transverse mass and the lepton, and neutrino \mathbf{p}_T distributions.
- $^{11}\text{AKTAS}$ 06 fit the Q^2 dependence (300 $< Q^2 <$ 30,000 GeV 2) of the charged-current differential cross section with a propagator mass. The first error is experimental and the second corresponds to uncertainties due to input parameters and model assumptions.
- 12 CHEKA NOV 02c fit the Q^2 dependence (200< Q^2 <60000 GeV 2) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.
- $^{13}\,\mathrm{BREITWEG}$ 00D fit the Q^2 dependence (200 < Q^2 < 22500 GeV^2) of the charged-current differential cross sections with a propagator mass fit. The last error is due to the uncertainty on the probability density functions.
- 14 ALITTI 92B result has two contributions to the systematic error (\pm 0.83); one (\pm 0.81) cancels in m_W/m_Z and one (\pm 0.17) is noncancelling. These were added in quadrature. We choose the ALITTI 92B value without using the LEP m_Z value, because we perform our own combined fit.
- 15 There are two contributions to the systematic error (± 0.84) : one (± 0.81) which cancels in m_W/m_Z and one (± 0.21) which is non-cancelling. These were added in quadrature.
- $^{16}_{-}$ ABE 891 systematic error dominated by the uncertainty in the absolute energy scale.
- 17 ALBAJAR 89 result is from a total sample of 299 W
 ightarrow e
 u events.
- 18 ALBAJAR 89 result is from a total sample of 67 $W
 ightarrow ~\mu
 u$ events.
- 19 ALBAJAR 89 result is from W
 ightarrow au
 u events.

W/Z MASS RATIO

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|-------|----------------------|------|------|------------------------------------------------|
| 0.8819 ±0.0012 OUR AVER | AGE | | | | |
| $0.8821 \ \pm 0.0011 \ \pm 0.0008$ | 28323 | ²⁰ ABBOTT | 98 N | D0 | $E_{ m cm}^{{ar p}{\overline p}}=1.8~{ m TeV}$ |
| $0.88114 \pm 0.00154 \pm 0.00252$ | 5982 | ²¹ ABBOTT | 98P | D0 | $E_{ m cm}^{{ar p}{\overline p}}=1.8~{ m TeV}$ |
| $0.8813 \pm 0.0036 \pm 0.0019$ | 156 | ²² ALITTI | 92B | UA2 | $E_{\rm cm}^{p\overline{p}} = 630 \text{ GeV}$ |

- 20 ABBOTT 98N obtain this from a study of 28323 $W\to e\nu_e$ and 3294 $Z\to e^+e^-$ decays. Of this latter sample, 2179 events are used to calibrate the electron energy scale.
- ²¹ ABBOTT 98p obtain this from a study of 5 982 $W \rightarrow e \nu_e$ events. The systematic error includes an uncertainty of ± 0.00175 due to the electron energy scale.
- 22 Scale error cancels in this ratio

$m_Z - m_W$

| VALUE (GeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|----------|-----------|-----------------------------------------------|
| 10.4±1.4±0.8 | ALBAJAR | 89 | UA1 | $E_{\rm cm}^{p\overline{p}}$ = 546,630 GeV |
| ullet $ullet$ We do not use the following | data for average | es, fits | , limits, | etc. • • • |
| $11.3 \pm 1.3 \pm 0.9$ | ANSARI | 87 | UA2 | $E_{\text{cm}}^{p\overline{p}}$ = 546,630 GeV |

$m_{W^+} - m_{W^-}$

Test of CPT invariance.

| VALUE (GeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|------|--------------|-----|------|---------------------------------------------------|
| -0.19±0.58 | 1722 | ABE | 90g | CDF | $E_{\text{cm}}^{p\overline{p}} = 1.8 \text{ TeV}$ |

W WIDTH

The W width listed here corresponds to the width parameter in a Breit-Wigner distribution with mass-dependent width. To obtain the world average, common systematic uncertainties between experiments are properly taken into account. The LEP-2 average W width based on published results is 2.196 ± 0.083 GeV [CERN-PH-EP/2006-042]. The combined Tevatron data yields an average W width of 2.046 ± 0.049 GeV [FERMILAB-TM-2460-E].

OUR FIT uses these average LEP and Tevatron width values and combines them assuming no correlations.

| VALUE (GeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|-------------|------------------------|----------|---------|-------------------------------------------------|
| 2.085 ± 0.042 OUR FI | Г | | | | |
| 2.028 ± 0.072 | 5272 | ²³ ABAZOV | 09A F | D0 | $E_{ m cm}^{{ar p}{\overline p}}=1.96~{ m GeV}$ |
| $2.032 \pm 0.045 \pm 0.057$ | 6055 | ²⁴ AALTONEN | 08в | CDF | $E_{ m cm}^{{ar p}{\overline p}}=1.96~{ m TeV}$ |
| $2.404 \pm 0.140 \pm 0.101$ | 10.3k | ²⁵ ABDALLAH | 08A | DLPH | E ^{ee} _{cm} = 183-209 GeV |
| $1.996 \pm 0.096 \pm 0.102$ | 10729 | ²⁶ ABBIENDI | 06 | OPAL | E ^{ee} _{cm} = 170-209 GeV |
| $2.18 \ \pm 0.11 \ \pm 0.09$ | 9795 | ²⁷ ACHARD | 06 | L3 | E ee = 172-209 GeV |
| $2.14 \ \pm 0.09 \ \pm 0.06$ | 8717 | ²⁸ SCHAEL | 06 | ALEP | E ^{ee} _{cm} = 183–209 GeV |
| $2.23 \ ^{+ 0.15}_{- 0.14} \ \pm 0.10$ | 294 | ²⁹ ABAZOV | 02E | D0 | Direct meas. |
| $2.05 \pm 0.10 \pm 0.08$ | 662 | ³⁰ AFFOLDER | 00м | CDF | Direct meas. |
| ● ● We do not use | the followi | ng data for average | s, fits, | limits, | etc. • • • |
| 2.152 ± 0.066 | 79176 | 31 ABBOTT | 00в | D0 | Extracted value |
| $2.064 \pm 0.060 \pm 0.059$ | | ³² ABE | 95 W | CDF | Extracted value |
| $2.10 \ ^{+ 0.14}_{- 0.13} \ \pm 0.09$ | 3559 | ³³ ALITTI | 92 | UA2 | Extracted value |
| $2.18 \ ^{+\ 0.26}_{-\ 0.24} \ \pm 0.04$ | | ³⁴ ALBAJAR | 91 | UA1 | Extracted value |

- 23 ABAZOV 09AK obtain this result fitting the high-end tail (100-200 GeV) of the transverse mass spectrum in $W\to~e\nu$ decays.
- ²⁴ AALTONEN 08e obtain this result fitting the high-end tail (90–200 GeV) of the transverse mass spectrum in semileptonic $W \rightarrow e \nu_e$ and $W \rightarrow \mu \nu_\mu$ decays.
- ²⁵ ABDALLAH 08a use direct reconstruction of the kinematics of $W^+W^-\to q\overline{q}\ell\nu$ and $W^+W^-\to q\overline{q}q\overline{q}$ events. The systematic error includes ± 0.065 GeV due to final state interactions.
- 26 ABBIENDI 06 use direct reconstruction of the kinematics of $W^+W^- \to q\overline{q}\,\ell\nu_\ell$ and $W^+W^- \to q\overline{q}\,q\overline{q}$ events. The systematic error includes ± 0.003 GeV due to the uncertainty on the LEP beam energy.
- 27 ACHARD 06 use direct reconstruction of the kinematics of $W^+W^-\to q\overline{q}\,\ell\nu_\ell$ and $W^+W^-\to q\overline{q}\,q\overline{q}$ events in the C.M. energy range 189–209 GeV. The result quoted here is obtained combining this value of the width with the result obtained from a direct W mass reconstruction at 172 and 183 GeV (ACCIARRI 99).
- 28 SCHAEL 06 use direct reconstruction of the kinematics of $W^+W^-\to q\overline{q}\,\ell\nu_\ell$ and $W^+W^-\to q\overline{q}\,q\overline{q}$ events. The systematic error includes ± 0.05 GeV due to possible effects of final state interactions in the $q\overline{q}\,q\overline{q}$ channel and ± 0.01 GeV due to the uncertainty on the LEP beam energy.
- 29 ABAZOV 02E obtain this result fitting the high-end tail (90–200 GeV) of the transverse-mass spectrum in semileptonic $W \rightarrow e \nu_e$ decays.
- 30 AFFOLDER 00M fit the high transverse mass (100–200 GeV) $W\to e\nu_e$ and $W\to \mu\nu_\mu$ events to obtain $\Gamma(W)=2.04\pm0.11({\rm stat})\pm0.09({\rm syst})$ GeV. This is combined with the earlier CDF measurement (ABE 95c) to obtain the quoted result.
- 31 ABBOTT 00B measure $R=10.43\pm0.27$ for the $W\to e\nu_e$ decay channel. They use the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\Gamma(W\to e\nu_e)$ and the world average for $B(Z\to ee)$. The value quoted here is obtained combining this result (2.169 \pm 0.070 GeV) with that of ABBOTT 99H.
- 32 ABE 95 w measured $R=10.90\pm0.32\pm0.29$. They use $m_{W}=80.23\pm0.18$ GeV, $\sigma(W)/\sigma(Z)=3.35\pm0.03$, $\Gamma(W\to e\nu)=225.9\pm0.9$ MeV, $\Gamma(Z\to e^+e^-)=83.98\pm0.18$ MeV, and $\Gamma(Z)=2.4969\pm0.0038$ GeV. 33 ALITTI 92 measured $R=10.4^{+0.7}_{-0.6}\pm0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from
- 33 ALITTI 92 measured $R=10.4^{+0.7}_{-0.6}\pm0.3$. The values of $\sigma(Z)$ and $\sigma(W)$ come from $O(\alpha_S^2)$ calculations using $m_W=80.14\pm0.27$ GeV, and $m_Z=91.175\pm0.021$ GeV along with the corresponding value of $\sin^2\!\theta_W=0.2274$. They use $\sigma(W)/\sigma(Z)=3.26\pm0.07\pm0.05$ and $\Gamma(Z)=2.487\pm0.010$ GeV.
- 34 ALBAJAR 91 measured $R=9.5^{+}_{-1.0}^{+}$ (stat. + syst.). $\sigma(W)/\sigma(Z)$ is calculated in QCD at the parton level using $m_W=80.18\pm0.28$ GeV and $m_Z=91.172\pm0.031$ GeV along with $\sin^2\theta_W=0.2322\pm0.0014$. They use $\sigma(W)/\sigma(Z)=3.23\pm0.05$ and $\Gamma(Z)=2.498\pm0.020$ GeV. This measurement is obtained combining both the electron and muon channels.

W+ DECAY MODES

 ${\it W}^-$ modes are charge conjugates of the modes below

| | Mode | Fraction (Γ_i/Γ) | Confidence | level |
|-----------------------|----------------|-------------------------------------------------|------------------|-------|
| $\overline{\Gamma_1}$ | $\ell^+ \nu$ | [a] (10.80± 0.09) | % | |
| Γ_2 | $e^+ u$ | (10.75 ± 0.13) | % | |
| Γ_3 | $\mu^+ \nu$ | (10.57± 0.15) | · % | |
| Γ_4 | $\tau^+ \nu$ | (11.25 ± 0.20) | · % | |
| Γ ₅ | hadrons | (67.60± 0.27) | · % | |
| Γ_6 | $\pi^+ \gamma$ | < 8 | $\times 10^{-5}$ | 95% |
| Γ_7 | $D_s^+ \gamma$ | < 1.3 | $\times 10^{-3}$ | 95% |
| Γ ₈ | сX | (33.4 ± 2.6) | · % | |
| Γ9 | c <u>s</u> | $(31 \begin{array}{cc} +13 \\ -11 \end{array}$ |) % | |
| Γ_{10} | invisible | [b] (1.4 \pm 2.9) | 1 % | |

- [a] ℓ indicates each type of lepton (e, μ , and au), not sum over them.
- [b] This represents the width for the decay of the W boson into a charged particle with momentum below detectability, p < 200 MeV.

W PARTIAL WIDTHS

| Γ(ir | visible) | | | | | | | | | Γ ₁₀ |
|------|-----------------|-----------|---------|---------|--------|---------|--------|---------|----------|-----------------|
| • | This represents | the width | for the | e decav | of the | W boson | into a | charged | particle | with |

This represents the width for the decay of the W boson into a charged particle wit momentum below detectability, p< 200 MeV.

 VALUE (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 30-52 + 33
 35 BARATE
 99I
 ALEP
 Eee = 161+172+183 GeV

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

 36 BARATE 99L ALEP $E_{\mathrm{Cm}}^{ee} = 161 + 172 + 183~\mathrm{GeV}$

 35 BARATE 991 measure this quantity using the dependence of the total cross section σ_{WW} upon a change in the total width. The fit is performed to the WW measured cross sections at 161, 172, and 183 GeV. This partial width is < 139 MeV at 95%CL.

 36 BARATE 99L use W-pair production to search for effectively invisible W decays, tagging with the decay of the other W boson to Standard Model particles. The partial width for effectively invisible decay is < 27 MeV at 95%CL.

W BRANCHING RATIOS

Overall fits are performed to determine the branching ratios of the W. LEP averages on $W \to e \nu_e$, $W \to \mu \nu_\mu$, and $W \to \tau \nu_\tau$, and their correlations are first obtained by combining results from the four experiments taking properly into account the common systematics. The procedure is described in the note LEPEWWG/XSEC/2001-02, 30 March 2001, at http://lepewwg.web.cern.ch/LEPEWWG/lepew/4f/PDG01. The LEP average values so obtained, using published data, are given in the note LEPEWWG/SSEC/2005-01 accessible at http://lepewwg.web.cern.ch/LEPEWWG/lepew/4f/PDG05. These results, together with results from the $p\overline{p}$ colliders are then used in fits to obtain the world average W branching ratios. A first fit determines three individual leptonic branching ratios, $B(W \to e \nu_e)$, $B(W \to \mu \mu_\mu)$, and $B(W \to \tau \nu_\tau)$. This fit has a χ^2 =7.9 for 9 degrees of freedom. The correleation coefficients between the branching fractions are 0.08 $(e-\mu)$, -0.21 $(e-\tau)$, -0.14 $(\mu-\tau)$. A second fit assumes lepton universality and determines the leptonic branching ratio $B(W \to \ell \nu_\ell)$ and the hadronic branching ratio is derived as $B(W \to hadrons) = 1$ –3 $B(W \to \ell \nu)$. This fit has a χ^2 =15.5 for 11 degrees of freedom.

The LEP $W \rightarrow \ell \nu$ data are obtained by the Collaborations using individual leptonic channels and are, therefore, not included in the overall fits to avoid double counting

Note: The LEP combination including the new OPAL results, ABBI-ENDI 07A, could not be performed in time for this *Review*. Thus, the OUR FIT values quoted below use the previous OPAL results as in ABBI-ENDI.G 00.

$\Gamma(\ell^+ \nu)/\Gamma_{\text{total}}$ Γ_1/Γ ℓ indicates average over e, μ , and τ modes, not sum over modes.

| = | | | | | |
|---------------------------|-------------|----------------------|---------|-----------|------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TE CN | COMMENT |
| 10.80±0.09 OUR FIT | | | | | |
| $10.86 \pm 0.12 \pm 0.08$ | 16438 | ABBIENDI | 07A | OPAL | $E_{\rm cm}^{ee} = 161-209 \; {\rm GeV}$ |
| $10.85 \pm 0.14 \pm 0.08$ | 13600 | ABDALLAH | 04G | DLPH | $E_{\rm cm}^{ee} = 161-209 \; {\rm GeV}$ |
| $10.83 \pm 0.14 \pm 0.10$ | 11246 | ACHARD | 04J | L3 | $E_{cm}^{ee} = 161-209 \text{ GeV}$ |
| $10.96 \pm 0.12 \pm 0.05$ | 16116 | SCHAEL | 04A | ALEP | $E_{\rm cm}^{ee} = 183-209 \; {\rm GeV}$ |
| • • • We do not use th | e following | data for averages, | fits, l | imits, et | C. • • • |
| $11.02\!\pm\!0.52$ | 11858 | ³⁷ ABBOTT | 99н | D0 | $E_{ m CM}^{{ar p}} = 1.8~{ m TeV}$ |
| 10.4 ± 0.8 | 3642 | ³⁸ ABE | 921 | CDF | $E_{CM}^{p\overline{p}} = 1.8 \; TeV$ |

 $^{^{37}}$ ABBOTT 99H measure $R \equiv [\sigma_W \text{ B}(W \to \ell \nu_\ell)]/[\sigma_Z \text{ B}(Z \to \ell \ell)] = 10.90 \pm 0.52$ combining electron and muon channels. They use $M_W = 80.39 \pm 0.06$ GeV and the SM theoretical predictions for $\sigma(W)/\sigma(Z)$ and $\text{B}(Z \to \ell \ell)$.

 $^{^{38}}$ 1216 \pm 38 $^{+}$ 27 $^{\prime}$ W \rightarrow $\mu\nu$ events from ABE 92I and 2426W \rightarrow $e\nu$ events of ABE 91C. ABE 92I give the inverse quantity as 9.6 \pm 0.7 and we have inverted.

| $\Gamma(e^+ \nu) / \Gamma_{\text{total}}$ | | | | | Γ | 2/[|
|-------------------------------------------|-------------|--------------------|-------------|-----------|--------------------------------------|-----|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 10.75 ± 0.13 OUR FIT | | | | | | |
| $10.71\pm0.25\pm0.11$ | 2374 | ABBIENDI | 07A | OPAL | $E_{\rm cm}^{ee} = 161-209 {\rm G}$ | eV |
| $10.55\pm0.31\pm0.14$ | 1804 | ABDALLAH | 04 G | DLPH | $E_{\rm CM}^{ee} = 161-209 {\rm G}$ | eV |
| $10.78 \pm 0.29 \pm 0.13$ | 1576 | ACHARD | 04J | L3 | $E_{\rm cm}^{ee} = 161-209 {\rm G}$ | eV |
| $10.78 \pm 0.27 \pm 0.10$ | 2142 | SCHAEL | 04A | ALEP | $E_{\rm cm}^{ee} = 183-209 {\rm G}$ | eV |
| • • • We do not use th | e following | data for averages, | fits, I | imits, et | C. • • • | |

39 ABAZOV

 10.61 ± 0.28

 39 ABAZOV 04D take into account all correlations to properly combine the CDF (ABE 95w) and DØ (ABBOTT 00B) measurements of the ratio R in the electron channel. The ratio R is defined as $[\sigma_W \cdot \text{B}(W \rightarrow e \nu_e)] \ / \ [\sigma_Z \cdot \text{B}(Z \rightarrow e e)]$. The combination gives $R^{Tevatron} = 10.59 \pm 0.23. \ \sigma_W \ / \ \sigma_Z$ is calculated at next–to–next–to–leading order (3.360 ± 0.051) . The branching fraction B($Z \rightarrow e e)$ is taken from this Review as $(3.363 \pm 0.004)\%$.

04D TEVA $E_{\rm C}^{p\overline{p}}=1.8~{\rm TeV}$

| $\Gamma(\mu^+ u) / \Gamma_{ m total}$ | | | | | Γ_3/Γ |
|----------------------------------------|------|-------------|-------------|------|----------------------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 10.57±0.15 OUR FIT | | | | | |
| $10.78 \pm 0.24 \pm 0.10$ | 2397 | ABBIENDI | 07A | OPAL | $E_{\rm CM}^{\it ee} = 161 - 209 \; {\rm GeV}$ |
| $10.65 \pm 0.26 \pm 0.08$ | 1998 | ABDALLAH | 04 G | DLPH | $E_{\rm CM}^{\it ee} = 161-209 \; {\rm GeV}$ |
| $10.03 \pm 0.29 \pm 0.12$ | 1423 | ACHARD | 04J | L3 | $E_{\rm cm}^{ee} = 161-209 {\rm GeV}$ |
| $10.87 \pm 0.25 \pm 0.08$ | 2216 | SCHAEL | 04A | ALEP | $E_{cm}^{\mathit{ee}} = 183209 \; GeV$ |
| $\Gamma(\tau^+\nu)/\Gamma_{\rm total}$ | | | | | Γ ₄ /Γ |
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 11.25 ± 0.20 OUR FIT | | | | | |
| $11.14 \pm 0.31 \pm 0.17$ | 2177 | ABBIENDI | 07A | OPAL | $E_{\rm cm}^{\it ee} = 161-209 \; {\rm GeV}$ |
| $11.46 \pm 0.39 \pm 0.19$ | 2034 | ABDALLAH | 04 G | DLPH | $E_{\mathrm{CM}}^{\mathit{ee}} = 161209 \; \mathrm{GeV}$ |
| $11.89 \pm 0.40 \pm 0.20$ | 1375 | ACHARD | 04J | L3 | $E_{\rm cm}^{ee} = 161-209 {\rm GeV}$ |
| $11.25 \pm 0.32 \pm 0.20$ | 2070 | SCHAEL | 04A | ALEP | $E_{\rm cm}^{ee} = 183-209 {\rm GeV}$ |
| $11.89 \pm 0.40 \pm 0.20$ | 1375 | ACHARD | 04J | L3 | $E_{\rm cm}^{ee} = 161-209$ (|
| | | | | | |

 $\frac{\Gamma_b/\Gamma}{\text{OUR FIT value is obtained by a fit to the lepton branching ratio data assuming lepton universality.}}$

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------|--------------|-------------|------|----------------------------------------------------------|
| 67.60±0.27 OUR FIT | | · | | | |
| $67.41 \pm 0.37 \pm 0.23$ | 16438 | ABBIENDI | 07A | OPAL | $E_{cm}^{ee} = 161-209 \text{ GeV}$ |
| $67.45 \pm 0.41 \pm 0.24$ | 13600 | ABDALLAH | 04 G | DLPH | $E_{cm}^{ee} = 161-209 \text{ GeV}$ |
| $67.50 \pm 0.42 \pm 0.30$ | 11246 | ACHARD | 04 J | L3 | $E_{cm}^{ee} = 161-209 \text{ GeV}$ |
| $67.13 \pm 0.37 \pm 0.15$ | 16116 | SCHAEL | 04 A | ALEP | $E_{\mathrm{cm}}^{\mathit{ee}} = 183209 \; \mathrm{GeV}$ |
| $\Gamma(u+v)/\Gamma(e+v)$ | | | | | Га/Га |

| $\Gamma(\mu \cdot \nu) / \Gamma(\epsilon \cdot \nu)$ | | | | | 13/12 |
|------------------------------------------------------|------------|----------------------|-----------|----------|-----------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.983±0.018 OUR FI | Т | | | | |
| 0.89 ± 0.10 | 13k | ⁴⁰ ABACHI | 95D | D0 | $E_{Cm}^{p\overline{p}} = 1.8 \; TeV$ |
| 1.02 ± 0.08 | 1216 | ⁴¹ ABE | | | $E_{ m cm}^{ ho\overline{ ho}}$ = 1.8 TeV |
| $1.00 \ \pm 0.14 \ \pm 0.08$ | 67 | ALBAJAR | 89 | UA1 | $E_{ m cm}^{ ho\overline{ ho}}$ = 546,630 GeV |
| • • • We do not use | the follow | ving data for averag | ges, fits | , limits | , etc. • • • |
| ±0.6 | | | | | |

1.24 $^{+0.6}_{-0.4}$ 14 ARNISON 84D UA1 Repl. by ALBAJAR 89

 40 ABACHI 95D obtain this result from the measured $\sigma_W B(W \to \mu \nu) = 2.09 \pm 0.23 \pm 0.11$ nb and $\sigma_W B(W \to e \nu) = 2.36 \pm 0.07 \pm 0.13$ nb in which the first error is the combined statistical and systematic uncertainty, the second reflects the uncertainty in the luminosity.

41 ABE 921 obtain σ_W B($W \rightarrow \mu \nu$) = $2.21 \pm 0.07 \pm 0.21$ and combine with ABE 91c σ_W B($(W \rightarrow e \nu)$) to give a ratio of the couplings from which we derive this measurement.

| $\Gamma(\tau^+\nu)/\Gamma(e^+\nu)$ | | | | | Γ_4/Γ_2 |
|------------------------------------------------------------------------------------------|-----------|----------------------|------------|------------|--------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1.046±0.023 OUR FIT | | · | | | |
| 0.961 ± 0.061 | 980 | ⁴² ABBOTT | 00D | D0 | $E_{Cm}^{p\overline{p}}$ = 1.8 TeV |
| 0.94 ± 0.14 | 179 | ⁴³ ABE | 92E | CDF | $E_{ m cm}^{ ho\overline{ ho}}$ = 1.8 TeV |
| $1.04 \ \pm 0.08 \ \pm 0.08$ | 754 | ⁴⁴ ALITTI | 92F | UA2 | $E_{ m cm}^{p\overline{p}}=$ 630 GeV |
| $1.02\ \pm0.20\ \pm0.12$ | 32 | ALBAJAR | 89 | UA1 | $E_{ m cm}^{p\overline{p}}$ = 546,630 GeV |
| • • • We do not use th | e follov | ving data for averag | es, fits | , limits | , etc. • • • |
| $\begin{array}{ccc} 0.995 \pm 0.112 \pm 0.083 \\ 1.02 \ \pm 0.20 \ \pm 0.10 \end{array}$ | 198 32 | ALITTI ALBAJAR | 91 ⊂ 87 | UA2 UA1 | Repl. by ALITTI 92F Repl. by ALBAJAR 89 |

 42 ABBOTT 00D measure $\sigma_{W}\times {\rm B}(W\to \tau\nu_{\tau})=2.22\pm0.09\pm0.10\pm0.10$ nb. Using the ABBOTT 00B result $\sigma_{W}\times {\rm B}(W\to e\nu_{e})=2.31\pm0.01\pm0.05\pm0.10$ nb, they quote the ratio of the couplings from which we derive this measurement.

quote the ratio of the couplings from which we derive this measurement. As ABE 92E use two procedures for selecting $W \to \tau \nu_{\tau}$ events. The missing E $_T$ trigger leads to $132\pm 14\pm 8$ events and the τ trigger to $47\pm 9\pm 4$ events. Proper statistical and systematic correlations are taken into account to arrive at σ B($W \to \tau \nu$) = 2.05 \pm 0.27 nb. Combined with ABE 91c result on σ B($W \to e \nu$), ABE 92E quote a ratio of the couplings from which we derive this measurement.

44 This measurement is derived by us from the ratio of the couplings of ALITTI 92F.

| $\Gamma(\pi^+ \gamma)/\Gamma(e^+ \nu)$ | | | | | | Γ_6/Γ_2 |
|----------------------------------------------------------------|--------------------------------|-------------------------------------------|-----|------|---------------------------------------------------|---------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $< 7 \times 10^{-4}$ | 95 | ABE | 98н | CDF | $E_{\rm cm}^{p\overline{p}}=1.8~{\rm TeV}$ | |
| $< 4.9 \times 10^{-3}$ | 95 | ⁴⁵ ALITTI | 92D | UA2 | $E_{\rm cm}^{p\overline{p}}=$ 630 GeV | |
| $< 58 \times 10^{-3}$ | 95 | ⁴⁶ ALBAJAR | 90 | UA1 | $E_{\rm cm}^{p\overline{p}} = 546, 630$ | GeV |
| ⁴⁵ ALITTI 92D limit ⁴⁶ ALBAJAR 90 obt | is $3.8 	imes 10$ ain < 0.04 | 0 ^{—3} at 90%CL. 18 at 90%CL. | | | | |
| $\Gamma(D_s^+ \gamma)/\Gamma(e^+ \nu)$ | | | | | | Γ_7/Γ_2 |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $<1.2 \times 10^{-2}$ | 95 | ABE | 98P | CDF | $E_{\text{cm}}^{p\overline{p}} = 1.8 \text{ TeV}$ | |
| $\Gamma(cX)/\Gamma(hadrons)$ |) | | | | | Γ_8/Γ_5 |

47 ABBIENDI

⁴⁸ BARATE

00v OPAL $E_{cm}^{ee} = 183 + 189 \text{ GeV}$

99м ALEP $E_{cm}^{ee} = 172 + 183 \text{ GeV}$

0.49 ±0.04 OUR AVERAGE

3005

746

 $0.481 \pm 0.042 \pm 0.032$

 $0.51 \pm 0.05 \pm 0.03$

 $^{47} \text{ABBIENDI 00V tag } W \rightarrow c \text{X}$ decays using measured jet properties, lifetime information, and leptons produced in charm decays. From this result, and using the additional measurements of $\Gamma(W)$ and $\text{B}(W \rightarrow \text{hadrons}), |V_{CS}|$ is determined to be 0.969 \pm 0.045 \pm 0.036.

 48 BARATE 99M tag c jets using a neural network algorithm. From this measurement $|V_{CS}|$ is determined to be $1.00\pm0.11\pm0.07$.

| $R_{cs} = \Gamma(c\overline{s})/\Gamma(hadrons)$ | | | | ارو7 |
|--------------------------------------------------|---------------------|-----|------|--------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $0.46^{+0.18}_{-0.14}\pm0.07$ | ⁴⁹ ABREU | 98N | DLPH | E ee = 161+172 GeV |

 49 ABREU 98N tag c and s jets by identifying a charged kaon as the highest momentum particle in a hadronic jet. They also use a lifetime tag to independently identify a c jet, based on the impact parameter distribution of charged particles in a jet. From this measurement $|V_{C\,S}|$ is determined to be $0.94^{+}_{-}0.32^{+}_{-}0.13$.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC W DECAY

Summed over particle and antiparticle, when appropriate

| $\langle N_{\pi^{\pm}} \rangle$ | | | |
|---------------------------------|---------------|---------|---------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 15.70±0.35 | 50 ABREU,P 00 | DF DLPH | Eee = 189 GeV |

 50 ABREU,P 00F measure $\langle N_{\pi^\pm} \rangle = 31.65 \pm 0.48 \pm 0.76$ and 15.51 $\pm 0.38 \pm 0.40$ in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

| $\langle N_{K^{\pm}} \rangle$ | | | | | |
|-------------------------------|--------------|-----|------|---------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 2.20+0.19 | 51 ABREUP | 00F | DIPH | Fee - 189 GeV | |

 51 ABREU,P 00F measure $\langle N_{K^\pm} \rangle = 4.38 \pm 0.42 \pm 0.12$ and 2.23 \pm 0.32 \pm 0.17 in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

| $\langle N_{\rho} \rangle$ | | | |
|----------------------------|----------------|------|---------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 0.92±0.14 | 52 ABREU,P 00F | DLPH | $E_{cm}^{ee} = 189 \text{ GeV}$ |

 52 ABREU,P 00F measure $\left\langle N_p\right\rangle=1.82\pm0.29\pm0.16$ and 0.94 \pm 0.23 \pm 0.06 in the fully hadronic and semileptonic final states respectively. The value quoted is a weighted average without assuming any correlations.

$\langle N_{\rm charged} \rangle$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|------------------------|------------------------|-----|------|---------------------------------------------|
| 19.39±0.08 OUR AVERAGE | | | | |
| $19.38\pm0.05\pm0.08$ | ⁵³ ABBIENDI | 06A | OPAL | E ^{ee} _{cm} = 189-209 GeV |
| 19.44 ± 0.17 | ⁵⁴ ABREU,P | 00F | DLPH | E_{cm}^{ee} = 183+189 GeV |
| $19.3 \pm 0.3 \pm 0.3$ | ⁵⁵ ABBIENDI | 99N | OPAL | $E_{cm}^{ee} = 183 \text{ GeV}$ |
| 19.23 ± 0.74 | ⁵⁶ ABREU | 98c | DLPH | <i>E</i> ^{ee} = 172 GeV |

 $^{53} \text{ABBIENDI 06A measure} \ \langle N_{\text{charged}} \rangle = 38.74 \pm 0.12 \pm 0.26 \ \text{when both} \ W \ \text{bosons}$ decay hadronically and $\langle N_{\text{charged}} \rangle = 19.39 \pm 0.11 \pm 0.09 \ \text{when one} \ W \ \text{boson decays}$ semileptonically. The value quoted here is obtained under the assumption that there is no color reconnection between W bosons; the value is a weighted average taking into account correlations in the systematic uncertainties.

⁵⁴ ABREU,P 00F measure $\langle N_{\rm charged} \rangle = 39.12 \pm 0.33 \pm 0.36$ and $38.11 \pm 0.57 \pm 0.44$ in the fully hadronic final states at 189 and 183 GeV respectively, and $\langle N_{\rm charged} \rangle = 19.49 \pm 0.31 \pm 0.27$ and $19.78 \pm 0.49 \pm 0.43$ in the semileptonic final states. The value quoted is a weighted average without assuming any correlations.

quoted is a weighted average without assuming any correlations. ⁵⁵ ABBIENDI 99N use the final states $W^+W^- o q \overline{q} \ell \overline{\nu}_\ell$ to derive this value.

⁵⁶ ABREU 98c combine results from both the fully hadronic as well semileptonic W W final states after demonstrating that the W decay charged multiplicity is independent of the topology within errors.

TRIPLE GAUGE COUPLINGS (TGC'S)

Revised March 2012 by M.W. Grünewald (U. Ghent) and A. Gurtu (King Abdulaziz University).

Fourteen independent couplings, 7 each for ZWW and γWW , completely describe the VWW vertices within the most general framework of the electroweak Standard Model (SM) consistent with Lorentz invariance and U(1) gauge invariance. Of each of the 7 TGC's, 3 conserve C and P individually, 3 violate CP, and one TGC violates C and P individually while conserving CP. Assumption of C and C conservation and electromagnetic gauge invariance reduces the independent C where C in the Standard Model at the tree level. The parameters C and C are related to the other three due to constraints

of gauge invariance as follows: $\kappa_Z = g_1^Z - (\kappa_\gamma - 1) \tan^2 \theta_W$ and $\lambda_Z = \lambda_\gamma$, where θ_W is the weak mixing angle. The W magnetic dipole moment, μ_W , and the W electric quadrupole moment, q_W , are expressed as $\mu_W = e \ (1 + \kappa_\gamma + \lambda_\gamma)/2M_W$ and $q_W = -e \ (\kappa_\gamma - \lambda_\gamma)/M_W^2$.

Precision measurements of suitable observables at LEP1 has already led to an exploration of much of the TGC parameter space. At LEP2, the VWW coupling arises in W-pair production via s-channel exchange, or in single W production via the radiation of a virtual photon off the incident e^+ or e^- . At the Tevatron and the LHC, hard-photon bremsstrahlung off a produced W or Z signals the presence of a triple-gauge vertex. In order to extract the value of one TGC, the others are generally kept fixed to their SM values.

While most analyses use the above gauge constraints in the extraction of TGCs, one analysis of W-pair events also determines the real and imaginary parts of all 14 couplings using unconstrained single-parameter fits [3]. The results are consistent.

References

- 1. K. Hagiwara et al., Nucl. Phys. **B282**, 253 (1987).
- 2. G. Gounaris et al., CERN 96-01 p. 525.
- S. Schael et al. (ALEPH Collab.), Phys. Lett. B614, 7 (2005).

 g_1^Z

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

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|----------------------------------------------------|------------|------------------------|-------------------|---------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| 0.984 + 0.022 OUR FI | Т | | | |
| $0.975 {}^{+ 0.033}_{- 0.030}$ | 7872 | ⁵⁷ ABDALLAH | 10 DLPH | E ^{ee} _{cm} = 189–209 GeV |
| $1.001 \pm 0.027 \pm 0.013$ | 9310 | ⁵⁸ SCHAEL | 05A ALEP | <i>E</i> ^{ee} cm = 183−209 GeV |
| $0.987 {}^{+ 0.034}_{- 0.033}$ | 9800 | ⁵⁹ ABBIENDI | 04D OPAL | E ^{ee} _{cm} = 183-209 GeV |
| $0.966 + 0.034 \pm 0.015$ | 8325 | ⁶⁰ ACHARD | 04D L3 | <i>E</i> ^{ee} _{cm} = 161−209 GeV |
| • • • We do not use | the follow | ing data for average | es, fits, limits, | etc. • • • |
| | 34 | ⁶¹ ABAZOV | 11 D0 | $E_{ m cm}^{ ho\overline{ ho}}=1.96~{ m TeV}$ |
| | 334 | ⁶² AALTONEN | | $E_{ m cm}^{{ar p}{\overline p}}=1.96$ TeV |
| 1.04 ±0.09 | | ⁶³ ABAZOV | 09AD D0 | $E_{ m cm}^{ ho\overline{ ho}}=1.96~{ m TeV}$ |
| | | ⁶⁴ ABAZOV | 09AJ D0 | $E_{ m cm}^{{ar p}{\overline p}}=1.96~{ m TeV}$ |
| $1.07 \begin{array}{l} +0.08 \\ -0.12 \end{array}$ | 1880 | ⁶⁵ ABDALLAH | 08c DLPH | |
| | 13 | ⁶⁶ ABAZOV | 07z D0 | ${	t LAH \ 10} \ {	t E_{	t CM}^{ ho ar p}} = 1.96 \ {	t TeV}$ |
| | 2.3 | ⁶⁷ ABAZOV | 05s D0 | $E_{ m cm}^{ ho\overline{ ho}}=1.96~{ m TeV}$ |
| $0.98 \pm 0.07 \pm 0.01$ | 2114 | ⁶⁸ ABREU | 01ı DLPH | $E_{\mathrm{cm}}^{\mathit{ee}} = 183 + 189 \; \mathrm{GeV}$ |
| | 331 | ⁶⁹ ABBOTT | 99ı D0 | $E_{ m cm}^{ ho\overline{ ho}}$ = 1.8 TeV |
| | | | | |

⁵⁷ABDALLAH 10 use data on the final states $e^+e^- \rightarrow jj\ell\nu$, jjjj, jjX, ℓX , at center-of-mass energies between 189–209 GeV at LEP2, where j= jet, $\ell=$ lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values.

at their SM values.

SSCHAEL 05A study single-photon, single-W, and WW-pair production from 183 to 209 GeV. The result quoted here is derived from the WW-pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

59 ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.923 < g \frac{7}{1} < 1.054$.

60 ACHARD 04D study WW-pair production, single-W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained from the WW-pair production sample including data from 161 to 183 GeV, ACCIA-RRI 990. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.

 61 ABAZOV 11 study the $p\overline{p}\to 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of 0.944 $<~g_1^Z<1.154$, for a form factor $\Lambda=2$ TeV.

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- 62 AALTONEN 10K study $p\,\overline{p}\to W^+W^-$ with $W\to e/\mu\nu$. The p_T of the leading (second) lepton is required to be > 20 (10) GeV. The final number of events selected is 654 of which 320 \pm 47 are estimated to be background. The 95% C.L. interval is 0.76 $< g_1^Z < 1.34$ for $\Lambda = 1.5$ TeV and 0.78 $< g_1^Z < 1.30$ for $\Lambda = 2$ TeV.
- 63 ABAZOV 09AD study the $p\bar{p} \rightarrow \ell\nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is 0.88 $< g_1^Z < 1.20$.
- 64 ABAZOV 09AJ study the $p\overline{p} \to 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of 0.86 $<~g_1^{\,Z}~<$ 1.3, for a form

65 1 ABDALLAH 08c determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \to W^+W^- \to (q\,q)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values.

- 66 ABAZOV 072 set limits on anomalous TGCs using the measured cross section and $p_T(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting the other couplings to their standard model values, the 95% C.L. limit for a form factor scale $\Lambda=2$ TeV is 0.86 $< g_1^Z < 1.35$.
- ⁶⁷ABAZOV 05s study $\overline{p}p \rightarrow WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell'}$ $(\ell \text{ and } \ell' = e \text{ or } \mu)$. Three events (estimated background 0.71 \pm 0.08 events) with WZdecay characteristics are observed from which they derive limits on the anomalous WWZcouplings. The 95% CL limit for a form factor scale $\Lambda=1.5~{
 m TeV}$ is 0.51 $< g_1^Z <$ 1.66, fixing λ_Z and κ_Z to their Standard Model values.
- 68 ABREU 011 combine results from e^+e^- interactions at 189 GeV leading to W^+W^- and $We\,\nu_e$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is 0.84 $< g_1^Z < 1.13$.
- ⁶⁹ ABBOTT 991 perform a simultaneous fit to the $W\gamma$, $WW\to dilepton$, $WW/WZ\to e\nu jj$, $WW/WZ\to \mu\nu jj$, and $WZ\to trilepton$ data samples. For $\Lambda=2.0$ TeV, the 95%CL limits are $0.63< g_1^Z<1.57$, fixing λ_Z and κ_Z to their Standard Model values, and assuming Standard Model values for the $WW\gamma$ couplings.

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

TECN COMMENT

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VALUE

DO CUMENT ID

EVTS

| MILUL | | DO COMENT ID | | 1 | COMMENT |
|-------------------------------------------------------------|-------------|--------------------------|----------|---------|---------------------------------------------------------------------------------------------------------|
| 0.973 + 0.044 OUR FI | Т | | | | |
| $1.024 + 0.077 \\ -0.081$ | 7872 | ⁷⁰ ABDALLAH | 10 | DLPH | E ^{ee} _{cm} = 189-209 GeV |
| $0.971 \pm 0.055 \pm 0.030$ | 10689 | ⁷¹ SCHAEL | 05 A | ALEP | E ^{ee} _{cm} = 183-209 GeV |
| $0.88 \begin{array}{l} +0.09 \\ -0.08 \end{array}$ | 9800 | ⁷² ABBIENDI | 04D | OPAL | E ^{ee} _{cm} = 183-209 GeV |
| $1.013 {}^{+ 0.067}_{- 0.064} \pm 0.026$ | 10575 | ⁷³ ACHARD | 04D | L3 | Eee = 161-209 GeV |
| ● ● We do not use | the followi | ng data for average | s, fits, | limits, | etc. • • • |
| | | ⁷⁴ ABAZOV | 11AC | D0 | $E_{CM}^{ar{p}\overline{p}}=1.96\;TeV$ |
| | | ⁷⁵ CHATRCHYAI | №11м | CMS | $E_{\rm cm}^{pp}=$ 7 TeV |
| | 334 | ⁷⁶ AALTONEN | 10ĸ | CDF | $E_{ m cm}^{{ar p}{\overline p}}=1.96~{ m TeV}$ |
| | 53 | ⁷⁷ AARON | 09в | H1 | $E_{\mathrm{cm}}^{ep}=0.3\mathrm{TeV}$ |
| $1.07 \begin{array}{c} +0.26 \\ -0.29 \end{array}$ | | ⁷⁸ ABAZOV | 09AE | D0 | $E_{CM}^{p\overline{\overline{p}}} = 1.96 \; TeV$ |
| | | ⁷⁹ ABAZOV | 09AJ | D0 | $E_{ m cm}^{ ho\overline{ ho}}=1.96~{ m TeV}$ |
| | | ⁸⁰ ABAZOV | 08R | D0 | $E_{CM}^{ar{p}\overline{p}}=1.96\;TeV$ |
| $\substack{0.68 \ -0.17 \\ -0.15}$ | 1880 | ⁸¹ ABDALLAH | 080 | DLPH | Superseded by ABDAL- |
| | 1617 | ⁸² AALTONEN | 07L | CDF | $E_{\text{CM}}^{\text{DAH } 10} = 1.96 \text{ GeV}$ |
| | 17 | ⁸³ ABAZOV | 06н | D0 | $E_{ m cm}^{{ar p}{\overline p}}=1.96~{ m TeV}$ |
| | 141 | ⁸⁴ ABAZOV | 05 J | D0 | $E_{CM}^{p\overline{p}} = 1.96 \; TeV$ |
| $1.25 \begin{array}{c} +0.21 \\ -0.20 \end{array} \pm 0.06$ | 2298 | ⁸⁵ ABREU | 011 | DLPH | E ^{ee} _{cm} = 183+189 GeV |
| | | ⁸⁶ BREITWEG | 00 | ZEUS | $e^+ p e^+ W^{\pm} X,$ $\sqrt{s} \approx 300 \text{ GeV}$ $E_{\text{CM}}^{pp} = 1.8 \text{ TeV}$ |
| 0.92 ± 0.34 | 331 | 87 ABBOTT | 991 | D0 | $E_{\text{cm}}^{\frac{\overline{V}}{\overline{P}}} = 1.8 \text{ TeV}$ |
| | | | | | |

- 70 ABDALLAH 10 use data on the final states $e^+e^- o jj\ell\nu$, jjjj, jjX, ℓX , at center-of-mass energies between 189–209 GeV at LEP2, where j= jet, $\ell=$ lepton, and Xrepresents missing momentum. The fit is carried out keeping all other parameters fixed at their SM values
- 71 SCHAEL 05A study single-photon, single-W, and WW-pair production from 183 to 209 GeV. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.
- 72 ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.73 < \kappa_{\gamma} < 1.07$.
- 73 ACHARD 04D study WW-pair production, single—W production and single—photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained including data from 161 to 183 GeV, ACCIARRI 990. Each parameter is determined. from a single-parameter fit in which the other parameters assume their Standard Model
- 74 ABAZOV 11AC study $W\gamma$ production in $p\overline{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: $0.6 < \kappa_\gamma < 1.4$ for a form factor $\Lambda = 2$ TeV.

- 75 CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s}=7$ TeV using 36 pb $^{-1}$ pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^{\gamma}>10~{
 m GeV}$ and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma)>0.7$. The number of candidate (background) events is 452 (228 \pm 21) for the electron channel and 520 (277 \pm 25) for the muon channel. Setting other couplings to their standard model value, they derive a 95% CL limit of $-0.11<\kappa_{\gamma}<2.04$.
- 76 AALTONEN 10K study $p\overline{p}\to W^+W^-$ with $W\to e/\mu\nu$. The p_T of the leading (second) lepton is required to be >20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $0.37 < \kappa_\gamma < 1.72$ for $\Lambda=1.5$ TeV and $0.43 < \kappa_\gamma < 1.65$ for $\Lambda=2$ TeV.
- 77 AARON 09B study single-W production in ep collisions at 0.3 TeV C.M. energy. They select 53 $W\to e/\mu$ events with a standard model expectation of 54.1 \pm 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-3.7 < \kappa_{\gamma} < -1.5$ or $0.3 < \kappa_{\gamma} < 1.5$, where the ambiguity is due to the quadratic dependence of the cross section to the coupling parameter.
- ⁷⁸ABAZOV 09AD study the $p\overline{p} \rightarrow \ell \nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $0.56 < \kappa_\gamma < 1.55$.
- 79 ABAZOV 09AJ study the $\rho\overline{p} \to 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of 0.46 $< \kappa_{\gamma} < 1.83$, for a form factor $\Lambda = 2 \text{ TeV}$.
- factor $\Lambda=2$ TeV. 80 ABAZOV 08R use 0.7 fb $^{-1}$ $p\bar{p}$ data at $\sqrt{s}=1.96$ TeV to select 263 $W\gamma+X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T>9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $0.49<\kappa_{\gamma}<1.51$ with other couplings fixed to their Standard Model values.
- 81 ABDALLAH 08c determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \to W^+W^- \to (q\,q)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values.
- 82 AALTONEN 07L set limits on anomalous TGCs using the $p_T(W)$ distribution in WWand WZ production with the W decaying to an electron or muon and the Z to 2 jets. Setting other couplings to their standard model value, the 95% C.L. limits are 0.54 < 1.39 for a form factor scale $\Lambda = 1.5$ TeV.
- 83 ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow$ $e^{+\nu_e}e^{-\overline{\nu_e}}, WW \rightarrow e^{+\nu_\mu}\mu^{-\overline{\nu}\mu} \text{ or } WW \rightarrow \mu^+\nu_\mu\mu^-\overline{\nu}\mu. \text{ The 95\% C.L. limit for a form factor scale } \Lambda=1 \text{ TeV is }-0.05 < \kappa_\gamma < 2.29, \text{ fixing } \lambda_\gamma = 0. \text{ With the assumption } \lambda_\gamma =$ that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit (Λ = 2 TeV) is $0.68 < \kappa < 1.45$.
- ⁸⁴ ABAZOV 05J perform a likelihood fit to the photon \emph{E}_T spectrum of $\emph{W}\gamma$ + X events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda=2.0$ TeV the 95% CL limits are 0.12 $<\kappa_{\gamma}<1.96$. In the fit λ_{γ} is kept fixed to its Standard Model value.
- 85 ABREU 01I combine results from e^+e^- interactions at 189 GeV leading to $W^+W^-,$ $Wev_e,$ and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $0.87<\kappa_{\gamma}<1.68.$
- 86 BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T>$ 20 GeV, the upper limit on the cross section gives the 95%CL limit 3.7 $<\kappa_{\gamma}<$ 2.5 (for
- 87 $_{
 m ABBOTT}$ 991 perform a simultaneous fit to the $W\gamma$, WW
 ightharpoonup dilepton, WW/WZ
 ightharpoonup e
 ujj, $WW/WZ
 ightharpoonup \mu
 ujj$, and WZ
 ightharpoonup trilepton data samples. For $\Lambda = 2.0$ TeV, the 95%CL limits are $0.75 < \kappa_{\gamma} < 1.39$.

OUR FIT below is obtained by combining the measurements taking into account properly the common systematic errors (see LEPEWWG/TGC/2005-01 at http://lepewwg.web.cern.ch/LEPEWWG/lepww/tgc).

TECN COMMENT

DO CUMENT ID

| VALUE | EVIS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------------|------------|--------------------------|---------|-----------|---------------------------------------------------------------------------|
| -0.028+0.020 OUR F | т | | | | |
| $0.002\!\pm\!0.035$ | 7872 | ⁸⁸ ABDALLAH | 10 | DLPH | Eee = 189-209 GeV |
| $-0.012\pm0.027\pm0.011$ | 10689 | ⁸⁹ SCHAEL | 05 A | ALEP | E ^{ee} _{cm} = 183-209 GeV |
| $-0.060^{+0.034}_{-0.033}$ | 9800 | ⁹⁰ ABBIENDI | 04D | OPAL | E ^{ee} _{CM} = 183-209 GeV |
| $-0.021^{+0.035}_{-0.034}\pm0.017$ | 105 75 | ⁹¹ ACHARD | 04D | L3 | E ^{ee} _{cm} = 161-209 GeV |
| • • • We do not use th | ne followi | ng data for averages | , fits, | limits, e | tc. • • • |
| | | ⁹² ABAZOV | 11AC | D0 | $E_{cm}^{p\overline{p}} = 1.96 \; TeV$ |
| | | ⁹³ CHATRCHYAN | 11м | CMS | $E_{\rm cm}^{pp}=$ 7 TeV |
| | 53 | | 09в | | $E_{\text{cm}}^{ep} = 0.3 \text{ TeV}$ |
| $0.00\ \pm0.06$ | | | | | $E_{cm}^{p\overline{p}} = 1.96 \; TeV$ |
| | | ⁹⁶ ABAZOV | 09AJ | | $E_{CM}^{p\overline{p}} = 1.96 \; TeV$ |
| | | ⁹⁷ ABAZOV | 08R | D0 | $E_{CM}^{p\overline{p}} = 1.96 \; TeV$ |
| $0.16 \begin{array}{l} +0.12 \\ -0.13 \end{array}$ | 1880 | ⁹⁸ ABDALLAH | 08c | DLPH | Superseded by ABDAL- LAH 10 |
| | 1617 | ⁹⁹ AALTONEN | 07L | CDF | $E_{\text{cm}}^{\text{L}} = 1.96 \text{ GeV}$ |
| | 17 | ¹⁰⁰ ABAZOV | 06н | D0 | $E_{cm}^{p\overline{p}} = 1.96 \; TeV$ |
| | 141 | ¹⁰¹ ABAZOV | 05 J | D0 | $E_{cm}^{p\overline{p}} = 1.96 \; TeV$ |
| $0.05\ \pm0.09\ \pm0.01$ | 2298 | ¹⁰² ABREU | 011 | | $E_{cm}^{ee} = 183 + 189 \text{ GeV}$ |
| | | ¹⁰³ BREITWEG | 00 | ZEUS | $e^+ p \rightarrow e^+ W^{\pm} X$, $\sqrt{s} \approx 300 \text{ GeV}$ |
| $0.00 \begin{array}{l} + 0.10 \\ - 0.09 \end{array}$ | 331 | ¹⁰⁴ ABBOTT | 991 | D0 | $E_{\rm cm}^{ ho\overline{p}} = 1.8 \text{ TeV}$ |

W

- 88 ABDALLAH 10 use data on the final states $e^+e^-\to jj\ell\nu,jjjj,jjX,\ell X$, at center-of-mass energies between 189–209 GeV at LEP2, where j= jet, $\ell=$ lepton, and X represents missing momentum. The fit is carried out keeping all other parameters fixed
- at their SM values.

 89 SCHAEL 05A study single-photon, single-W, and WW-pair production from 183 to 209 GeV. Each parameter is determined from a single-parameter fit in which the other
- parameters assume their Standard Model values. 90 ABBIENDI 04D combine results from W^+W^- in all decay channels. Only CP-conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $-0.13 < \lambda_{\gamma} < 0.01$.
- 91 ACHARD 04D study $\stackrel{7}{WW}$ —pair production, single—W production and single—photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained including data from 161 to 183 GeV, ACCIARRI 99Q. Each parameter is determined from a single—parameter fit in which the other parameters assume their Standard Model
- 92 ABAZOV 11AC study $W\gamma$ production in $p\overline{p}$ collisions at 1.96 TeV, with the W decay products containing an electron or a muon. They select 196 (363) events in the electron (muon) mode, with a SM expectation of 190 (372) events. A likelihood fit to the photon E_T spectrum above 15 GeV yields at 95% C.L. the result: - 0.08 $< \, \lambda_{\gamma} \, <$ 0.07 for a formfactor $\Lambda = 2 \text{ TeV}$
- 93 CHATRCHYAN 11M study $W\gamma$ production in pp collisions at $\sqrt{s}=$ 7 TeV using 36 pb $^{-1}$ pp data with the W decaying to electron and muon. The total cross section is measured for photon transverse energy $E_T^\gamma>10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma)>0.7$. The number of candidate (background) events is 452 (228 \pm 21) for the electron channel and 520 (277 \pm 25) for the muon channel. Setting other couplings to their standard model value, the property of the control of the couplings of the couplings of the couplings to the couplings of the coupling of the couplings of the coupling of th they derive a 95% CL limit of $-0.18 < \lambda_{\gamma} < 0.17$.
- 94 AARON 09B study single-W production in $e\,p$ collisions at 0.3 TeV C.M. energy. They select 53 $W o e/\mu$ events with a standard model expectation of 54.1 \pm 7.4 events. Fitting the transverse momentum spectrum of the hadronic recoil system they obtain a 95% C.L. limit of $-2.5 < \lambda_{\gamma} < 2.5$
- 95 ABAZOV 09AD study the $p\overline{p} \rightarrow \ell \nu$ 2jet process arising in WW and WZ production. They select 12,473 (14,392) events in the electron (muon) channel with an expected di-boson signal of 436 (527) events. The results on the anomalous couplings are derived from an analysis of the p_T^{\prime} spectrum of the 2-jet system and quoted at 68% C.L. and for a form factor of 2 TeV. This measurement is not used for obtaining the mean as it is for a specific form factor. The 95% confidence interval is $-0.10 < \stackrel{\circ}{\lambda_{\gamma}} < 0.11$
- 96 ABAZOV 09AJ study the $p\overline{p} \to 2\ell 2\nu$ process arising in WW production. They select 100 events with an expected WW signal of 65 events. An analysis of the p_T spectrum of the two charged leptons leads to 95% C.L. limits of $-0.14 < \lambda_{\gamma} < 0.18$, for a form factor $\Lambda = 2$ TeV.
- 97 actor $\Lambda=2$ TeV. 97 ABAZOV 08R use 0.7 fb $^{-1}$ $p\,\overline{p}$ data at $\sqrt{s}=1.96$ TeV to select 263 $W\gamma+X$ events, of which 187 constitute signal, with the W decaying into an electron or a muon, which is required to be well separated from a photon with $E_T>9$ GeV. A likelihood fit to the photon E_T spectrum yields a 95% CL limit $-0.12 < \lambda_{\gamma} < 0.13$ with other couplings fixed to their Standard Model values.
- 98 ABDALLAH 08c determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \to W^+W^- \to (q\,q)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values.
- of all other couplings are nixed to their standard model values. $P_T(W) \ \text{distribution in } WW \ \text{and } WZ \ \text{production} \ \text{with the } W \ \text{decaying to an electron or muon and the } Z \ \text{to 2} \ \text{jets.} \ \text{Setting other couplings to their standard model value, the 95% C.L. limits are } -0.18 < \lambda_{\gamma} < 0.17 \ \text{for a form factor scale } \Lambda = 1.5 \ \text{TeV}.$
- 100 ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow$ $e^+\nu_e e^-\overline{\nu}_e, \ WW \rightarrow e^+\nu_e \mu^+\nu_\mu \ \text{or} \ WW \rightarrow \mu^+\nu_\mu \mu^-\overline{\nu}_\mu \ \text{The 95\% C.L. limit for a form factor scale } \Lambda = 1 \ \text{TeV} \ \text{is} -0.97 < \lambda_\gamma < 1.04, \ \text{fixing } \kappa_\gamma = 1. \ \text{With the assumption}$ that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit (Λ 2 TeV) is $-0.29 < \lambda < 0.30$.
- 101 ABAZOV 05J perform a likelihood fit to the photon $\it E_{T}$ spectrum of $\it W\gamma + X$ events, where the W decays to an electron or muon which is required to be well separated from the photon. For $\Lambda=2.0$ TeV the 95% CL limits are $-0.20 < \lambda_{\gamma} < 0.20$. In the fit κ_{γ} is kept fixed to its Standard Model value.
- 102 7 ABREU 011 combine results from e $^{+}$ e $^{-}$ interactions at 189 GeV leading to W^{+} W^{-} , $We\nu_{e}$, and $\nu\overline{\nu}\gamma$ final states with results from ABREU 99L at 183 GeV. The 95% confidence interval is $-0.11 < \lambda_{\gamma} < 0.23$.
- $^{'}$ BREITWEG 00 search for W production in events with large hadronic p_T . For $p_T>$ 20 GeV, the upper limit on the cross section gives the 95%CL limit $-3.2<\lambda_{\gamma}<3.2$ for κ_{γ} fixed to its Standard Model value.
- $^{\Lambda}$ BBOTT 99I perform a simultaneous fit to the $W\gamma,WW\to$ dilepton, $WW/WZ\to e\nu jj,\,WW/WZ\to \mu\nu jj$, and $WZ\to$ trilepton data samples. For $\Lambda=2.0$ TeV, the 95%CL limits are $-0.18<\lambda_{\gamma}<0.19$.

This coupling is $\it CP$ -conserving ($\it C$ - and $\it P$ - separately conserving). EVTS DO CUMENT ID

| $0.924^{+0.059}_{-0.056} \pm 0.024$ | 7171 | 105 ACHARD | 04D L3 | E ee = 189-209 GeV |
|-------------------------------------|------|------------|--------|--------------------|
|-------------------------------------|------|------------|--------|--------------------|

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

34 106 ABAZOV $E_{\mathsf{CM}}^{\overline{p}} = 1.96 \; \mathsf{TeV}$ 11 D0 $E_{\text{CM}}^{\overline{p}\overline{p}} = 1.96 \text{ TeV}$ 17 107 ABAZOV 06н D0 2.3 108 ABAZOV 05s D0 $E_{\text{CM}}^{\overline{p}} = 1.96 \text{ TeV}$

- 105 ACHARD 04D study WW-pair production, single-W production and single-photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW-pair production sample. Each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values.
- 106 ABAZOV 11 study the $ho \overline{
 ho}
 ightarrow ~ 3 \ell
 u$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of 0.600 $<\kappa_Z <$ 1.675, for a form factor $\Lambda = 2 \text{ TeV}$.

- 107 ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay WWABACOV oon study $pp \to WW$ posterior with a subsequent decay $WW \to e^+\nu_e\,e^-\overline{\nu}_e$, $WW \to e^\pm\nu_e\,\mu^\mp\nu_\mu$ or $WW \to \mu^+\nu_\mu\mu^-\overline{\nu}_\mu$. The 95% C.L. into a form factor scale $\Lambda=2$ TeV is 0.55 $<\kappa_Z<1.55$, fixing $\lambda_Z=0$. With the assumption that the $WW\gamma$ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda=2$ TeV) is 0.68 $<\kappa<1.45$.
- 108 ABAZOV 05s study $\overline{
 ho}
 ho
 ightarrow \textit{WZ}$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ $(\ell \text{ and } \ell' = e \text{ or } \mu)$. Three events (estimated background 0.71 \pm 0.08 events) with WZdecay characteristics are observed from which they derive limits on the anomalous WWZcouplings. The 95% CL limit for a form factor scale $\Lambda=1$ TeV is $-1.0~<~\kappa_{Z}~<3.4$, fixing λ_Z and g_1^Z to their Standard Model values.

This coupling is CP-conserving (C- and P- separately conserving).

| VALUE | EVTS | <u>DO CUMENT ID</u> | | TECN | COMMENT |
|------------------------------------|------|-----------------------|-----|------|----------------------------------------|
| $-0.088^{+0.060}_{-0.057}\pm0.023$ | 7171 | ¹⁰⁹ ACHARD | 04D | L3 | $E_{CM}^{\mathit{ee}} = 189209 \; GeV$ |

• • We do not use the following data for averages, fits, limits, etc.

- $^{109}\,\mathrm{ACHARD}$ 04p study WW –pair production, single– W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW-pair production sample. Each parameter is determined from a singleparameter fit in which the other parameters assume their Standard Model values.
- parameter fit in which the other parameters assume their standard invocativations.
 110 ABAZOV 11 study the $p\overline{p}\to 3\ell\nu$ process arising in WZ production. They observe 34 WZ candidates with an estimated background of 6 events. An analysis of the p_T spectrum of the Z boson leads to a 95% C.L. limit of $-0.077 < \lambda_Z < 0.093$, for a form factor $\Lambda=2$ TeV.
- form factor $\Lambda=2$ [eV.] 111 AALTONEN 10K study $p\overline{p}\to W^+W^-$ with $W\to e/\mu\nu$. The p_T of the leading (second) lepton is required to be >20 (10) GeV. The final number of events selected is 654 of which 320 ± 47 are estimated to be background. The 95% C.L. interval is $-0.16 < \lambda_Z < 0.16$ for $\Lambda=1.5$ TeV and $-0.14 < \lambda_Z < 0.15$ for $\Lambda=2$ TeV.
- 112 ABAZOV 072 set limits on anomalous TGCs using the measured cross section and $_{PT}(Z)$ distribution in WZ production with both the W and the Z decaying leptonically into electrons and muons. Setting the other couplings to their standard model values, the 95% C.L. limit for a form factor scale $\Lambda=2\,{\rm TeV}$ is $-0.17~<\lambda_Z<0.21.$
- 113 ABAZOV 06H study $\overline{p}p \rightarrow WW$ production with a subsequent decay $WW \rightarrow$ ABACOV USER Study $p p \to WW$ production with a subsequent decay $WW \to e^+ \nu_e \, e^- \overline{\nu}_e$, $WW \to e^\pm \nu_e \, \mu^\mp \nu_\mu$ or $WW \to \mu^+ \nu_\mu \mu^- \overline{\nu}_\mu$. The 95% C.L. limit for a form factor scale $\Lambda = 2$ TeV is $-0.39 < \lambda_Z < 0.39$, fixing $\kappa_Z = 1$. With the assumption that the WW_γ and WWZ couplings are equal the 95% C.L. one-dimensional limit ($\Lambda = 2$ TeV) is $-0.29 < \lambda < 0.30$.
- 114 ABAZOV 05s study $\overline{p}p \to WZ$ production with a subsequent trilepton decay to $\ell\nu\ell'\overline{\ell}'$ (ℓ and $\ell'=e$ or μ). Three events (estimated background 0.71 \pm 0.08 events) with WZdecay characteristics are observed from which they derive limits on the anomalous WWZ couplings. The 95% CL limit for a form factor scale $\Lambda=1.5$ TeV is $-0.48<\lambda_Z<$ 0.48, fixing g_1^Z and κ_Z to their Standard Model values.

This coupling is CD conserving but C and D violating

| i nis coupiing | IS CP-CO | onserving but C- and | P-VIC | nating. | |
|-------------------------------|-----------|-------------------------|--------|------------|-----------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.93±0.09 OUR AV | ERAGE | Error includes scale | e fact | or of 1.1 | |
| $0.96^{+0.13}_{-0.12}$ | 9800 | ¹¹⁵ ABBIENDI | 04D | OPAL | $E_{\rm cm}^{ee} = 183 209 \; {\rm GeV}$ |
| $1.00 \pm 0.13 \pm 0.05$ | 7171 | ¹¹⁶ ACHARD | 04D | L3 | $E_{\rm CM}^{ee} = 189-209 \; {\rm GeV}$ |
| $0.56^{+0.23}_{-0.22}\pm0.12$ | 1154 | ¹¹⁷ ACCIARRI | 99Q | L3 | $E_{\rm CM}^{ee} = 161 + 172 + 183 {\rm GeV}$ |
| • • • We do not us | e the fol | llowing data for aver | ages, | fits, limi | ts, etc. • • • |
| 0.84 ± 0.23 | | ¹¹⁸ EBOLI | 00 | THEO | LEP1, SLC+ Tevatron |
| | | | | | |

- 115 ABBIENDI 04D combine results from W^+W^- in all decay channels. Only $\it CP$ -conserving couplings are considered and each parameter is determined from a single-parameter fit in which the other parameters assume their Standard Model values. The 95% confidence interval is $0.72 < g_5^Z < 1.21$.
- 116 ACHARD 04p study WW –pair production, single–W production and single–photon production with missing energy from 189 to 209 GeV. The result quoted here is obtained using the WW –pair production sample. Each parameter is determined from a single– parameter fit in which the other parameters assume their Standard Model values. 117 ACCIARRI 990 study *W*-pair, single-*W*, and single photon events.
- 118 EBOLI 00 extract this indirect value of the coupling studying the non-universal one-loop contributions to the experimental value of the $Z \to b \bar{b}$ width (Λ =1 TeV is assumed).

ı

This coupling is CP-violating (C-violating and P-conserving).

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|---------|-------------------------|-----|------|----------------------------------------------------|
| -0.30 ± 0.17 OUR | AVERAGE | | | | |
| $-0.39 {}^{+ 0.19}_{- 0.20}$ | 1880 | ¹¹⁹ ABDALLAH | 08c | DLPH | <i>E</i> ^{ee} _{CM} = 189−209 GeV |
| $-0.02^{+0.32}_{-0.33}$ | 1065 | ¹²⁰ ABBIENDI | 01н | OPAL | <i>E</i> ^{ee} = 189 GeV |

- 119 ABDALLAH 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \to W^+W^- \to (qq)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values.
- 120 ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying W. The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W.

This coupling is CP-violating (C-conserving and P-violating)

| i in a coupling | , is cr violat | ing (c conscioning a | 114 1 | nordenig. | l · | |
|------------------------------|----------------|-------------------------|-------|-----------|----------------------------------------------------|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| -0.12 + 0.06 OUR | AVERAGE | | | | | |
| $-0.09 {}^{+ 0.08}_{- 0.05}$ | 1880 | ¹²¹ ABDALLAH | 08c | DLPH | <i>E</i> ^{ee} _{cm} = 189–209 GeV | |
| $-0.20{}^{+0.10}_{-0.07}$ | 1065 | ¹²² ABBIENDI | 01н | OPAL | <i>E</i> ^{ee} _{CM} = 189 GeV | |
| | | | | | | |
| | | 123 BLINOV | 11 | LEP | E ee = 183-207 GeV | |

- $^{121}\mathrm{ABDALLAH}$ 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \rightarrow W^+W^- \rightarrow (qq)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values
- 122 ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying W. The coupling is extracted using information from the W production angle together with decay angles from the leptonically decaying W.
- With decay angles from the leptonicary decaying w. 123 BLINOV 11 use the LEP-average $e^+e^- \rightarrow W^+W^-$ cross section data for $\sqrt{s}=183-207$ GeV to determine an upper limit on the TGC $\widetilde{\kappa}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $\left|\widetilde{\kappa}_{Z}\right| < 0.13$.

This coupling is CP-violating (C-conserving and P-violating)

| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|-----------------|----------|-------------------------|----------|---------|------------------------------------------------|
| -0.09 ± 0.07 | OUR AVEI | RAGE | | | | |
| -0.08 ± 0.07 | | 1880 | ¹²⁴ ABDALLAH | 08c | DLPH | E ^{ee} _{CM} = 189-209 GeV |
| $-0.18 ^{+ 0.24}_{- 0.16}$ | | 1065 | ¹²⁵ ABBIENDI | 01н | OPAL | <i>E</i> ^{ee} _{cm} = 189 GeV |
| • • • We do | not use th | e follow | ing data for average | s, fits, | limits, | etc. • • • |
| | | | 126 BLINOV | 11 | LEP | E ^{ee} _{cm} = 183-207 GeV |

- $^{124}\mathsf{ABDALLAH}$ 08C determine this triple gauge coupling from the measurement of the spin density matrix elements in $e^+e^- \to W^+W^- \to (q\,q)(\ell\nu)$, where $\ell=e$ or μ . Values of all other couplings are fixed to their standard model values.
- 125 ABBIENDI 01H study W-pair events, with one leptonically and one hadronically decaying $\it W$. The coupling is extracted using information from the $\it W$ production angle together with decay angles from the leptonically decaying $\it W$.
- 126 BLINOV 11 use the LEP-average $e^+\,e^ \rightarrow$ $W^+\,W^-$ cross section data for $\sqrt{s}=$ 183–207 GeV to determine an upper limit on the TGC $\widetilde{\lambda}_Z$. The average values of the cross sections as well as their correlation matrix, and standard model expectations of the cross sections are taken from the LEPEWWG note hep-ex/0612034. At 95% confidence level $|\tilde{\lambda}_Z| < 0.31$

W ANOMALOUS MAGNETIC MOMENT

The full magnetic moment is given by $\mu_W=e(1+\kappa+\lambda)/2m_W$. In the Standard Model, at tree level, $\kappa=1$ and $\lambda=0$. Some papers have defined $\Delta \kappa = 1 - \kappa$ and assume that $\lambda = 0$. Note that the electric quadrupole moment is given by $-e(\kappa - \lambda)/m_W^2$. A description of the parameterization of these moments and additional references can be found in HAGIWARA 87 and BAUR 88. The parameter Λ appearing in the theoretical limits below is a regularization cutoff which roughly corresponds to the energy scale where the structure of the W boson becomes manifest.

| VALUE (e/2 m W) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------|--------------------------|---------|-----------|---------------------------------------------|
| 2.22 ⁺ 0.20 -0.19 | 2298 | 127 ABREU | 011 | DLPH | E ^{ee} _{cm} = 183+189 GeV |
| • • • We do not use t | he follow | ing data for average | s, fits | , limits, | etc. • • • |
| | | ¹²⁸ ABE | 95 G | CDF | |
| | | ¹²⁹ ALITTI | 92c | UA2 | |
| | | ¹³⁰ SAMUEL | 92 | THEO | |
| | | ¹³¹ SAMUEL | 91 | THEO | |
| | | ¹³² GRIFOLS | 88 | THEO | |
| | | ¹³³ GROTCH | 87 | THEO | |
| | | ¹³⁴ vanderbij | 87 | THEO | |
| | | ¹³⁵ GRAU | 85 | THEO | |
| | | ¹³⁶ SUZUKI | 85 | THEO | |
| | | ¹³⁷ HERZOG | 84 | THEO | |

- 127 ABREU 011 combine results from $e^+\,e^-$ interactions at 189 GeV leading to $W^+\,W^-$, $We
 u_e$, and $u\overline{
 u}\gamma$ final states with results from ABREU 99L at 183 GeV to determine Δg_1^Z , $\Delta \kappa_\gamma$, and λ_γ . $\Delta \kappa_\gamma$ and λ_γ are simultaneously floated in the fit to determine
- 128 ABE 95G report $-1.3 < \kappa < 3.2$ for $\lambda = 0$ and $-0.7 < \lambda < 0.7$ for $\kappa = 1$ in $\rho \overline{\rho} \rightarrow \ e \ \nu_e \gamma X$ and $\mu \nu_{\mu} \gamma X$ at $\sqrt{s} = 1.8$ TeV.
- 129 ALITTI 92c measure $\kappa=1^{+2.6}_{-2.2}$ and $\lambda=0^{+1.7}_{-1.8}$ in $p\overline{p}\rightarrow e\,\nu\gamma+$ X at $\sqrt{s}=630$ GeV. At 95%CL they report $-3.5<\kappa<5.9$ and $-3.6<\lambda<3.5$.
- 130 SAMUEL 192 use preliminary CDF and UA2 data and find $-2.4 < \kappa < 3.7$ at 96%CL and $-3.1 < \kappa < 4.2$ at 95%CL respectively. They use data for $W\gamma$ production and radiative W decay.
- 131 SAMUEL 91 use preliminary CDF data for $p\overline{p} o W\gamma$ X to obtain $-11.3 \le \Delta \kappa \le$ 10.9. Note that their $\kappa = 1 - \Delta \kappa$.
- 132 GRIFOLS 88 uses deviation from ho parameter to set limit $\Delta\kappa \lesssim$ 65 (M_W^2/Λ^2) .
- 133 GROTCH 87 finds the limit $-37 < \Delta \kappa < 73.5 \ (90\% \ \text{CL})$ from the experimental limits on $e^+\,e^-\to \nu\overline{\nu}\gamma$ assuming three neutrino generations and $-19.5<\Delta\kappa<$ 56 for four generations. Note their $\Delta\kappa$ has the opposite sign as our definition.

- 134 VA NDERBIJ 87 uses existing limits to the photon structure to obtain $|\Delta\kappa|$ (m_W/Λ) . In addition VANDERBIJ 87 discusses problems with using the ρ parameter of the Standard–Model to determine $\Delta\kappa$.
- 135 GRAU 85 uses the muon anomaly to derive a coupled limit on the anomalous magnetic dipole and electric quadrupole (λ) moments $1.05>\Delta\kappa\ln(\Lambda/m_W)+\lambda/2>-2.77$. In he Standard Model $\lambda=0$.
- $136\,\mathrm{SUZUKl}$ 85 uses partial-wave unitarity at high energies to obtain $|\Delta\kappa|\lesssim190$ $(m_W/\Lambda)^2$. From the anomalous magnetic moment of the muon, SUZUKI 85 obtains $|\Delta\kappa|\lesssim 2.2/{\ln(\Lambda/m_W)}$. Finally SUZUKI 85 uses deviations from the ho parameter and obtains a very qualitative, order-of-magnitude limit $|\Delta\kappa|\lesssim 150~(m_W/\Lambda)^4$ if $|\Delta\kappa|\ll 100$
- 137 HERZOG 84 consider the contribution of W-boson to muon magnetic moment including anomalous coupling of $WW\gamma$. Obtain a limit $-1 < \Delta\kappa < 3$ for $\Lambda \gtrsim 1$ TeV.

ANOMALOUS W/Z QUARTIC COUPLINGS

Revised March 2012 by M.W. Grünewald (U. Ghent) and A. Gurtu (King Abdulaziz University).

The Standard Model quartic couplings, WWWW, WWZZ, $WWZ\gamma$, $WW\gamma\gamma$, and $ZZ\gamma\gamma$ lead to negligible effects at LEP energies, while they are important at a TeV Linear Collider. Outside the Standard Model framework, possible quartic couplings, a_0, a_c, a_n , are expressed in terms of the following dimension-6 operators [1,2];

$$\begin{split} L_6^0 &= -\frac{e^2}{16\Lambda^2} \; a_0 \; F^{\mu\nu} \; F_{\mu\nu} \vec{W}^\alpha \cdot \vec{W}_\alpha \\ L_6^c &= -\frac{e^2}{16\Lambda^2} \; a_c \; F^{\mu\alpha} \; F_{\mu\beta} \vec{W}^\beta \cdot \vec{W}_\alpha \\ L_6^n &= -i \frac{e^2}{16\Lambda^2} \; a_n \epsilon_{ijk} \; W^{(i)}_{\mu\alpha} \; W^{(j)}_\nu \; W^{(k)\alpha} F^{\mu\nu} \\ \widetilde{L}_6^0 &= -\frac{e^2}{16\Lambda^2} \; \widetilde{a}_0 \; F^{\mu\nu} \; \widetilde{F}_{\mu\nu} \vec{W}^\alpha \cdot \vec{W}_\alpha \\ \widetilde{L}_6^n &= -i \frac{e^2}{16\Lambda^2} \; \widetilde{a}_n \epsilon_{ijk} \; W^{(i)}_{\mu\alpha} \; W^{(j)}_\nu \; W^{(k)\alpha} \widetilde{F}^{\mu\nu} \end{split}$$

where F, W are photon and W fields, L_6^0 and L_6^c conserve C, P separately $(L_6^0$ conserves only C) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP (\widetilde{L}_6^n violates both C and P) and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately leading to two sets parameterized as a_0^V/Λ^2 and a_c^V/Λ^2 , where V=W or Z.

At LEP the processes studied in search of these quartic couplings are $e^+e^- \to WW\gamma$, $e^+e^- \to \gamma\gamma\nu\overline{\nu}$, and $e^+e^- \to$ $Z\gamma\gamma$ and limits are set on the quantities a_0^W/Λ^2 , a_c^W/Λ^2 , a_n/Λ^2 . The characteristics of the first process depend on all the three couplings whereas those of the latter two depend only on the two CP-conserving couplings. The sensitive measured variables are the cross sections for these processes as well as the energy and angular distributions of the photon and recoil mass to the photon pair.

References

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 - J.W. Stirling and A. Werthenbach, Phys. Lett. **B466**, 369
 - A. Denner et al., Eur. Phys. J. C20, 201 (2001);
 - G. Montagna et al., Phys. Lett. **B515**, 197 (2001).
- 3. G. Belanger et al., Eur. Phys. J. C13, 283 (2000).

W, Z

 a_0/Λ^2 , a_c/Λ^2 , a_n/Λ^2

Using the $WW\gamma$ final state, the LEP combined 95% CL limits on the anomalous contributions to the $WW\gamma\gamma$ and $WWZ\gamma$ vertices (as of summer 2003) are given below:

(See P. Wells, "Experimental Tests of the Standard Model," Int. Europhysics Conference on High-Energy Physics, Aachen, Germany, 17–23 July 2003)

 138
 ABBIENDI
 04B
 OPAL

 139
 ABBIENDI
 04L
 OPAL

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 HEISTER
 04A
 ALEP

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 ABDALLAH
 03I
 DLPH

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 ACHARD
 02F
 L3

 $138\,\mathrm{ABBIENDI}$ 04B select 187 $e^+\,e^-\to W^+\,W^-\gamma$ events in the C.M. energy range 180–209 GeV, where $E_\gamma>2.5$ GeV, the photon has a polar angle $\left|\cos\theta_\gamma\right|<0.975$ and is well isolated from the nearest jet and charged lepton, and the effective masses of both fermion-antifermion systems agree with the W mass within 3 Γ_W . The measured differential cross section as a function of the photon energy and photon polar angle is used to extract the 95% CL limits: $-0.020\,\,\mathrm{GeV}^{-2} < a_0/\Lambda^2 < 0.020\,\,\mathrm{GeV}^{-2}, -0.053\,\,\mathrm{GeV}^{-2} < a_c/\Lambda^2 < 0.037\,\,\mathrm{GeV}^{-2}$ and $-0.16\,\,\mathrm{GeV}^{-2} < a_n/\Lambda^2 < 0.15\,\,\mathrm{GeV}^{-2}$.

139 ABBIENDI 04L select 20 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \to q\,\overline{q}\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $Z\,Z\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma\gamma$ sample of ABBIENDI 04B the following one-parameter 95% CL limits are obtained: -0.007 $< a_d^Z/\Lambda^2 < 0.023~{\rm GeV}^{-2}, -0.029 < a_d^Z/\Lambda^2 < 0.029~{\rm GeV}^{-2}, -0.052 < a_c^W/\Lambda^2 < 0.037~{\rm GeV}^{-2}.$

140 In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+\,e^- \to \nu \overline{\nu} \gamma \gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon-photon acoplanarity is required to be > 5°, $E_\gamma/\sqrt{s}>0.025$ (the more energetic photon having energy > 0.2 \sqrt{s}), $p_{T_\gamma}/E_{\rm beam}>0.05$ and $|\cos\theta_\gamma|<0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one-parameter 95% CL limits: $-0.012 < a_0^Z/\Lambda^2 < 0.019~{\rm GeV}^{-2}, -0.041 < a_C^Z/\Lambda^2 < 0.044~{\rm GeV}^{-2}, -0.060 < a_0^W/\Lambda^2 < 0.055~{\rm GeV}^{-2}, -0.099 < a_C^W/\Lambda^2 < 0.093~{\rm GeV}^{-2}.$

141 ABDALLAH 031 select 122 $e^+e^- \to W^+W^-\gamma$ events in the C.M. energy range 189–209 GeV, where $E_{\gamma} >$ 5 GeV, the photon has a polar angle $|\cos\theta_{\gamma}| < 0.95$ and is well isolated from the nearest charged fermion. A fit to the photon energy spectra yields $a_{c}/\Lambda^{2} = 0.000^{+}_{-0.010}^{+0.019} \text{ GeV}^{-2}$, $a_{0}/\Lambda^{2} = -0.004^{+0.018}_{-0.010} \text{ GeV}^{-2}$, $\bar{a}_{0}/\Lambda^{2} = -0.007^{+0.019}_{-0.010} \text{ GeV}^{-2}$, $a_{0}/\Lambda^{2} = -0.09^{+0.16}_{-0.05} \text{ GeV}^{-2}$, and $\bar{a}_{0}/\Lambda^{2} = +0.05^{+0.07}_{-0.15} \text{ GeV}^{-2}$, keeping the other parameters fixed to their Standard Model values (0). The 95% CL limits are: $-0.063 \text{ GeV}^{-2} < a_{c}/\Lambda^{2} < +0.032 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < a_{0}/\Lambda^{2} < +0.020 \text{ GeV}^{-2}$, $-0.020 \text{ GeV}^{-2} < \bar{a}_{0}/\Lambda^{2} < +0.020 \text{ GeV}^{-2}$, $-0.18 \text{ GeV}^{-2} < a_{n}/\Lambda^{2} < +0.14 \text{ GeV}^{-2}$, $-0.16 \text{ GeV}^{-2} < \bar{a}_{n}/\Lambda^{2} < +0.17 \text{ GeV}^{-2}$.

142 ACHARD 02F select 86 $e^+e^- \to W^+W^-\gamma$ events at 192–207 GeV, where $E_\gamma > 5$ GeV and the photon is well isolated. They also select 43 acoplanar $e^+e^- \to \nu \overline{\nu} \gamma \gamma$ events in this energy range, where the photon energies are >5 GeV and >1 GeV and the photon polar angles are between 14° and 166°. All these 43 events are in the recoil mass region corresponding to the Z (75–110 GeV). Using the shape and normalization of the photon spectra in the $W^+W^-\gamma$ events, and combining with the 42 event sample from 189 GeV data (ACCIARRI 00T), they obtain: $a_0/\Lambda^2 = 0.000 \pm 0.010$ GeV $^{-2}$, $a_c/\Lambda^2 = -0.013 \pm 0.023$ GeV $^{-2}$, and $a_n/\Lambda^2 = -0.002 \pm 0.076$ GeV $^{-2}$. Further combining the analyses of $W^+W^-\gamma$ events with the low recoil mass region of $\nu \overline{\nu} \gamma \gamma$ events (including samples collected at 183 +189 GeV), they obtain the following one-parameter 95% CL limits: -0.015 GeV $^{-2}$ </br> $= -0.013 \pm 0.023$ GeV $^{-2}$ </br> = -0.013 GeV $^{-2}$ </br> = -0.013 GeV $^{-2}$ </br> = -0.013 GeV $^{-2}$ </br> = -0.014 GeV $^{-2}$ </br> = -0.015 GeV $^{-2}$ </br> = -0.015 GeV $^{-2}$ </br> = -0.014 GeV $^{-2}$ </br> = -0.014 GeV $^{-2}$ </br> = -0.015 GeV $^{-2}$ </br> = -0.014 GeV $^{-2}$ </br>

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THE Z BOSON

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Precision measurements at the Z-boson resonance using electron–positron colliding beams began in 1989 at the SLC and at LEP. During 1989–95, the four LEP experiments (ALEPH, DELPHI, L3, OPAL) made high-statistics studies of the production and decay properties of the Z. Although the SLD experiment at the SLC collected much lower statistics, it was able to match the precision of LEP experiments in determining

the effective electroweak mixing angle $\sin^2 \overline{\theta}_W$ and the rates of Z decay to b- and c-quarks, owing to availability of polarized electron beams, small beam size, and stable beam spot.

The Z-boson properties reported in this section may broadly be categorized as:

- The standard 'lineshape' parameters of the Z consisting of its mass, M_Z , its total width, Γ_Z , and its partial decay widths, $\Gamma(\text{hadrons})$, and $\Gamma(\ell \overline{\ell})$ where $\ell = e, \mu, \tau, \nu$;
- Z asymmetries in leptonic decays and extraction of Z couplings to charged and neutral leptons;
- The b- and c-quark-related partial widths and charge asymmetries which require special techniques;
- Determination of Z decay modes and the search for modes that violate known conservation laws;
- \bullet Average particle multiplicities in hadronic Z decay;
- Z anomalous couplings.

The effective vector and axial-vector coupling constants describing the Z-to-fermion coupling are also measured in $p\bar{p}$ and ep collisions at the Tevatron and at HERA. The corresponding cross-section formulae are given in Section 39 (Cross-section formulae for specific processes) and Section 16 (Structure Functions) in this Review. In this minireview, we concentrate on the measurements in e^+e^- collisions at LEP and SLC.

The standard 'lineshape' parameters of the Z are determined from an analysis of the production cross sections of these final states in e^+e^- collisions. The $Z\to \nu\overline{\nu}(\gamma)$ state is identified directly by detecting single photon production and indirectly by subtracting the visible partial widths from the total width. Inclusion in this analysis of the forward-backward asymmetry of charged leptons, $A_{FB}^{(0,\ell)}$, of the τ polarization, $P(\tau)$, and its forward-backward asymmetry, $P(\tau)^{fb}$, enables the separate determination of the effective vector (\overline{g}_V) and axial vector (\overline{g}_A) couplings of the Z to these leptons and the ratio $(\overline{g}_V/\overline{g}_A)$, which is related to the effective electroweak mixing angle $\sin^2 \overline{\theta}_W$ (see the "Electroweak Model and Constraints on New Physics" review).

Determination of the b- and c-quark-related partial widths and charge asymmetries involves tagging the b and c quarks for which various methods are employed: requiring the presence of a high momentum prompt lepton in the event with high transverse momentum with respect to the accompanying jet; impact parameter and lifetime tagging using precision vertex measurement with high-resolution detectors; application of neural-network techniques to classify events as b or non-b on a statistical basis using event—shape variables; and using the presence of a charmed meson (D/D^*) or a kaon as a tag.

Z-parameter determination

LEP was run at energy points on and around the Z mass (88–94 GeV) constituting an energy 'scan.' The shape of the cross-section variation around the Z peak can be described by a Breit-Wigner ansatz with an energy-dependent

total width [1–3]. The **three** main properties of this distribution, viz., the **position** of the peak, the **width** of the distribution, and the **height** of the peak, determine respectively the values of M_Z , Γ_Z , and $\Gamma(e^+e^-) \times \Gamma(f\overline{f})$, where $\Gamma(e^+e^-)$ and $\Gamma(f\overline{f})$ are the electron and fermion partial widths of the Z. The quantitative determination of these parameters is done by writing analytic expressions for these cross sections in terms of the parameters, and fitting the calculated cross sections to the measured ones by varying these parameters, taking properly into account all the errors. Single-photon exchange (σ_{γ}^0) and γ -Z interference $(\sigma_{\gamma Z}^0)$ are included, and the large $(\sim 25~\%)$ initial-state radiation (ISR) effects are taken into account by convoluting the analytic expressions over a 'Radiator Function' [1–5] H(s,s'). Thus for the process $e^+e^- \to f\overline{f}$:

$$\sigma_f(s) = \int H(s, s') \ \sigma_f^0(s') \ ds' \tag{1}$$

$$\sigma_f^0(s) = \sigma_Z^0 + \sigma_\gamma^0 + \sigma_{\gamma Z}^0 \tag{2}$$

$$\sigma_{Z}^{0} = \frac{12\pi}{M_{Z}^{2}} \ \frac{\Gamma(e^{+}e^{-})\Gamma(f\overline{f})}{\Gamma_{Z}^{2}} \ \frac{s \ \Gamma_{Z}^{2}}{(s-M_{Z}^{2})^{2} \ + \ s^{2}\Gamma_{Z}^{2}/M_{Z}^{2}} \ (3)$$

$$\sigma_{\gamma}^0 = \frac{4\pi\alpha^2(s)}{3s} \ Q_f^2 N_c^f \tag{4}$$

$$\sigma_{\gamma Z}^0 = -\; \frac{2\sqrt{2}\alpha(s)}{3} \;\; (Q_f G_F N_c^f \mathcal{G}_V^e \mathcal{G}_V^f)$$

$$\times \frac{(s - M_Z^2)M_Z^2}{(s - M_Z^2)^2 + s^2\Gamma_Z^2/M_Z^2} \tag{5}$$

where Q_f is the charge of the fermion, $N_c^f = 3$ for quarks and 1 for leptons, and \mathcal{G}_V^f is the vector coupling of the Z to the fermion-antifermion pair $f\bar{f}$.

Since $\sigma_{\gamma Z}^0$ is expected to be much less than σ_Z^0 , the LEP Collaborations have generally calculated the interference term in the framework of the Standard Model. This fixing of $\sigma_{\gamma Z}^0$ leads to a tighter constraint on M_Z , and consequently a smaller error on its fitted value. It is possible to relax this constraint and carry out the fit within the S-matrix framework, which is briefly described in the next section.

In the above framework, the QED radiative corrections have been explicitly taken into account by convoluting over the ISR and allowing the electromagnetic coupling constant to run [6]: $\alpha(s) = \alpha/(1 - \Delta \alpha)$. On the other hand, weak radiative corrections that depend upon the assumptions of the electroweak theory and on the values of M_{top} and M_{Higgs} are accounted for by absorbing them into the couplings, which are then called the effective couplings \mathcal{G}_V and \mathcal{G}_A (or alternatively the effective parameters of the \star scheme of Kennedy and Lynn [7].)

 \mathcal{G}_A^V and \mathcal{G}_A^f are complex numbers with small imaginary parts. As experimental data does not allow simultaneous extraction of both real and imaginary parts of the effective couplings, the convention $g_A^f = \operatorname{Re}(\mathcal{G}_A^f)$ and $g_V^f = \operatorname{Re}(\mathcal{G}_V^f)$ is used and the imaginary parts are added in the fitting code [4].

Defining

$$A_f = 2 \frac{g_V^f \cdot g_A^f}{(g_V^f)^2 + (g_A^f)^2} \tag{6}$$

Z

the lowest-order expressions for the various lepton-related asymmetries on the Z pole are [8–10] $A_{FB}^{(0,\ell)}=(3/4)A_eA_f$, $P(\tau)=-A_\tau$, $P(\tau)^{fb}=-(3/4)A_e$, $A_{LR}=A_e$. The full analysis takes into account the energy-dependence of the asymmetries. Experimentally A_{LR} is defined as $(\sigma_L-\sigma_R)/(\sigma_L+\sigma_R)$, where $\sigma_{L(R)}$ are the $e^+e^-\to Z$ production cross sections with left- (right)-handed electrons.

The definition of the partial decay width of the Z to $f\overline{f}$ includes the effects of QED and QCD final-state corrections, as well as the contribution due to the imaginary parts of the couplings:

$$\Gamma(f\overline{f}) = \frac{G_F M_Z^3}{6\sqrt{2}\pi} N_c^f (\left| \mathcal{G}_A^f \right|^2 R_A^f + \left| \mathcal{G}_V^f \right|^2 R_V^f) + \Delta_{ew/QCD} \quad (7)$$

where R_V^f and R_A^f are radiator factors to account for final state QED and QCD corrections, as well as effects due to nonzero fermion masses, and $\Delta_{ew/\text{QCD}}$ represents the non-factorizable electroweak/QCD corrections.

S-matrix approach to the Z

While most experimental analyses of LEP/SLC data have followed the 'Breit-Wigner' approach, an alternative S-matrix-based analysis is also possible. The Z, like all unstable particles, is associated with a complex pole in the S matrix. The pole position is process-independent and gauge-invariant. The mass, \overline{M}_Z , and width, $\overline{\Gamma}_Z$, can be defined in terms of the pole in the energy plane via [11–14]

$$\overline{s} = \overline{M}_Z^2 - i\overline{M}_Z\overline{\Gamma}_Z \tag{8}$$

leading to the relations

$$\overline{M}_Z = M_Z / \sqrt{1 + \Gamma_Z^2 / M_Z^2}$$

$$\approx M_Z - 34.1 \text{ MeV}$$
(9)

$$\overline{\Gamma}_Z = \Gamma_Z / \sqrt{1 + \Gamma_Z^2 / M_Z^2}$$

$$\approx \Gamma_Z - 0.9 \text{ MeV} . \tag{10}$$

The L3 and OPAL Collaborations at LEP (ACCIARRI 00Q and ABBIENDI 04G) have analyzed their data using the S–matrix approach as defined in Eq. (8), in addition to the conventional one. They observe a downward shift in the Z mass as expected.

Handling the large-angle e^+e^- final state

Unlike other $f\overline{f}$ decay final states of the Z, the e^+e^- final state has a contribution not only from the s-channel but also from the t-channel and s-t interference. The full amplitude is not amenable to fast calculation, which is essential if one has to carry out minimization fits within reasonable computer time. The usual procedure is to calculate the non-s channel part of the cross section separately using the Standard Model programs ALIBABA [15] or TOPAZO [16], with the measured value of $M_{\rm top}$, and $M_{\rm Higgs}=150$ GeV, and add it to the s-channel cross section calculated as for other channels. This leads to two additional sources of error in the analysis: firstly,

the theoretical calculation in ALIBABA itself is known to be accurate to $\sim 0.5\%$, and secondly, there is uncertainty due to the error on $M_{\rm top}$ and the unknown value of $M_{\rm Higgs}$ (100–1000 GeV). These errors are propagated into the analysis by including them in the systematic error on the e^+e^- final state. As these errors are common to the four LEP experiments, this is taken into account when performing the LEP average.

Errors due to uncertainty in LEP energy determination [17–22]

The systematic errors related to the LEP energy measurement can be classified as:

- The absolute energy scale error;
- Energy-point-to-energy-point errors due to the nonlinear response of the magnets to the exciting currents;
- Energy-point-to-energy-point errors due to possible higher-order effects in the relationship between the dipole field and beam energy;
- Energy reproducibility errors due to various unknown uncertainties in temperatures, tidal effects, corrector settings, RF status, etc.

Precise energy calibration was done outside normal datataking using the resonant depolarization technique. Run-time energies were determined every 10 minutes by measuring the relevant machine parameters and using a model which takes into account all the known effects, including leakage currents produced by trains in the Geneva area and the tidal effects due to gravitational forces of the Sun and the Moon. The LEP Energy Working Group has provided a covariance matrix from the determination of LEP energies for the different running periods during 1993–1995 [17].

Choice of fit parameters

The LEP Collaborations have chosen the following primary set of parameters for fitting: M_Z , Γ_Z , $\sigma_{\rm hadron}^0$, $R({\rm lepton})$, $A_{FB}^{(0,\ell)}$, where $R({\rm lepton}) = \Gamma({\rm hadrons})/\Gamma({\rm lepton})$, $\sigma_{\rm hadron}^0 = 12\pi\Gamma(e^+e^-)\Gamma({\rm hadrons})/M_Z^2\Gamma_Z^2$. With a knowledge of these fitted parameters and their covariance matrix, any other parameter can be derived. The main advantage of these parameters is that they form a physics motivated set of parameters with much reduced correlations.

Thus, the most general fit carried out to cross section and asymmetry data determines the **nine parameters**: M_Z , Γ_Z , $\sigma^0_{\rm hadron}$, R(e), $R(\mu)$, $R(\tau)$, $A^{(0,e)}_{FB}$, $A^{(0,\mu)}_{FB}$, $A^{(0,\tau)}_{FB}$. Assumption of lepton universality leads to a **five-parameter fit** determining M_Z , Γ_Z , $\sigma^0_{\rm hadron}$, $R({\rm lepton})$, $A^{(0,\ell)}_{FB}$.

$Combining\ results\ from\ LEP\ and\ SLC\ experiments$

With a steady increase in statistics over the years and improved understanding of the common systematic errors between LEP experiments, the procedures for combining results have evolved continuously [23]. The Line Shape Sub-group of the LEP Electroweak Working Group investigated the effects of these common errors, and devised a combination procedure

for the precise determination of the Z parameters from LEP experiments. Using these procedures, this note also gives the results after combining the final parameter sets from the four experiments, and these are the results quoted as the fit results in the Z listings below. Transformation of variables leads to values of derived parameters like partial decay widths and branching ratios to hadrons and leptons. Finally, transforming the LEP combined nine parameter set to $(M_Z, \Gamma_Z, \sigma_{\rm hadron}^{\circ}, g_A^f, g_V^f, f = e, \mu, \tau)$ using the average values of lepton asymmetry parameters (A_e, A_μ, A_τ) as constraints, leads to the best fitted values of the vector and axial-vector couplings (g_V, g_A) of the charged leptons to the Z.

Brief remarks on the handling of common errors and their magnitudes are given below. The identified common errors are those coming from

- (a) LEP energy-calibration uncertainties, and
- (b) the theoretical uncertainties in (i) the luminosity determination using small angle Bhabha scattering, (ii) estimating the non-s channel contribution to large angle Bhabha scattering, (iii) the calculation of QED radiative effects, and (iv) the parametrization of the cross section in terms of the parameter set used.

Common LEP energy errors

All the collaborations incorporate in their fit the full LEP energy error matrix as provided by the LEP energy group for their intersection region [17]. The effect of these errors is separated out from that of other errors by carrying out fits with energy errors scaled up and down by $\sim 10\%$ and redoing the fits. From the observed changes in the overall error matrix, the covariance matrix of the common energy errors is determined. Common LEP energy errors lead to uncertainties on M_Z , Γ_Z , and $\sigma_{\rm hadron}^{\circ}$ of 1.7, 1.2 MeV, and 0.011 nb, respectively.

$Common\ luminosity\ errors$

BHLUMI 4.04 [24] is used by all LEP collaborations for small-angle Bhabha scattering leading to a common uncertainty in their measured cross sections of 0.061% [25]. BHLUMI does not include a correction for production of light fermion pairs. OPAL explicitly corrects for this effect and reduces their luminosity uncertainty to 0.054%, which is taken fully correlated with the other experiments. The other three experiments among themselves have a common uncertainty of 0.061%.

Common non-s channel uncertainties

The same standard model programs ALIBABA [15] and TOPAZ0 [16] are used to calculate the non-s channel contribution to the large angle Bhabha scattering [26]. As this contribution is a function of the Z mass, which itself is a variable in the fit, it is parametrized as a function of M_Z by each collaboration to properly track this contribution as M_Z varies in the fit. The common errors on R_e and $A_{FB}^{(0,e)}$ are 0.024 and 0.0014 respectively, and are correlated between them.

Common theoretical uncertainties: QED

There are large initial-state photon and fermion pair radiation effects near the Z resonance, for which the best currently

available evaluations include contributions up to $\mathcal{O}(\alpha^3)$. To estimate the remaining uncertainties, different schemes are incorporated in the standard model programs ZFITTER [5], TOPAZ0 [16], and MIZA [27]. Comparing the different options leads to error estimates of 0.3 and 0.2 MeV on M_Z and Γ_Z respectively, and of 0.02% on $\sigma_{\rm hadron}^{\circ}$.

Common theoretical uncertainties: parametrization of lineshape and asymmetries

To estimate uncertainties arising from ambiguities in the model-independent parametrization of the differential cross-section near the Z resonance, results from TOPAZ0 and ZFIT-TER were compared by using ZFITTER to fit the cross sections and asymmetries calculated using TOPAZ0. The resulting uncertainties on M_Z , Γ_Z , $\sigma_{\rm hadron}^{\circ}$, $R({\rm lepton})$, and $A_{FB}^{(0,\ell)}$ are 0.1 MeV, 0.1 MeV, 0.001 nb, 0.004, and 0.0001 respectively.

Thus, the overall theoretical errors on M_Z , Γ_Z , $\sigma_{\rm hadron}^{\circ}$ are 0.3 MeV, 0.2 MeV, and 0.008 nb respectively; on each $R({\rm lepton})$ is 0.004 and on each $A_{FB}^{(0,\ell)}$ is 0.0001. Within the set of three $R({\rm lepton})$'s and the set of three $A_{FB}^{(0,\ell)}$'s, the respective errors are fully correlated.

All the theory-related errors mentioned above utilize Standard Model programs which need the Higgs mass and running electromagnetic coupling constant as inputs; uncertainties on these inputs will also lead to common errors. All LEP collaborations used the same set of inputs for Standard Model calculations: $M_Z = 91.187$ GeV, the Fermi constant $G_F = (1.16637 \pm 0.00001) \times 10^{-5} \text{ GeV}^{-2}$ [28], $\alpha^{(5)}(M_Z) = 1/128.877 \pm 0.090 [29], \quad \alpha_s(M_Z) = 0.119 [30],$ $M_{\rm top}=174.3\pm5.1~{\rm GeV}$ [30] and $M_{\rm Higgs}=150~{\rm GeV}$. The only observable effect, on M_Z , is due to the variation of M_{Higgs} between 100–1000 GeV (due to the variation of the γ/Z interference term which is taken from the Standard Model): M_Z changes by +0.23 MeV per unit change in $\log_{10} M_{\rm Higgs}/{\rm GeV}$, which is not an error but a correction to be applied once $M_{\rm Higgs}$ is determined. The effect is much smaller than the error on M_Z (± 2.1 MeV).

$Methodology\ of\ combining\ the\ LEP\ experimental\ results$

The LEP experimental results actually used for combination are slightly modified from those published by the experiments (which are given in the Listings below). This has been done in order to facilitate the procedure by making the inputs more consistent. These modified results are given explicitly in [23]. The main differences compared to the published results are (a) consistent use of ZFITTER 6.23 and TOPAZ0 (the published ALEPH results used ZFITTER 6.10); (b) use of the combined energy-error matrix, which makes a difference of 0.1 MeV on the M_Z and Γ_Z for L3 only as at that intersection the RF modeling uncertainties are the largest.

Thus, nine-parameter sets from all four experiments with their covariance matrices are used together with all the common errors correlations. A grand covariance matrix, V, is constructed and a combined nine-parameter set is obtained by

Z

minimizing $\chi^2 = \Delta^T V^{-1} \Delta$, where Δ is the vector of residuals of the combined parameter set to the results of individual experiments. Imposing lepton universality in the combination results in the combined five parameter set.

Study of $Z \to b\overline{b}$ and $Z \to c\overline{c}$

In the sector of c- and b-physics, the LEP experiments have measured the ratios of partial widths $R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to b\bar{b})$ hadrons), and $R_c = \Gamma(Z \to c\overline{c})/\Gamma(Z \to \text{hadrons})$, and the forward-backward (charge) asymmetries A_{FB}^{bb} and $A_{FB}^{c\bar{c}}$. The SLD experiment at SLC has measured the ratios R_c and R_b and, utilizing the polarization of the electron beam, was able to obtain the final state coupling parameters A_b and A_c from a measurement of the left-right forward-backward asymmetry of b- and c-quarks. The high precision measurement of R_c at SLD was made possible owing to the small beam size and very stable beam spot at SLC, coupled with a highly precise CCD pixel detector. Several of the analyses have also determined other quantities, in particular the semileptonic branching ratios, $B(b \to \ell^-)$, $B(b \to c \to \ell^+)$, and $B(c \to \ell^+)$, the average timeintegrated $B^0\overline{B}^0$ mixing parameter $\overline{\chi}$ and the probabilities for a c-quark to fragment into a D^+ , a D_s , a D^{*+} , or a charmed baryon. The latter measurements do not concern properties of the Z boson, and hence they do not appear in the Listing below. However, for completeness, we will report at the end of this minireview their values as obtained fitting the data contained in the Z section. All these quantities are correlated with the electroweak parameters, and since the mixture of b hadrons is different from the one at the $\Upsilon(4S)$, their values might differ from those measured at the $\Upsilon(4S)$.

All the above quantities are correlated to each other since:

- Several analyses (for example the lepton fits) determine more than one parameter simultaneously;
- Some of the electroweak parameters depend explicitly on the values of other parameters (for example R_b depends on R_c);
- Common tagging and analysis techniques produce common systematic uncertainties.

The LEP Electroweak Heavy Flavour Working Group has developed [31] a procedure for combining the measurements taking into account known sources of correlation. The combining procedure determines fourteen parameters: the six parameters of interest in the electroweak sector, R_b , R_c , $A_{FB}^{b\bar{b}}$, $A_{FB}^{c\bar{c}}$, A_b and A_c and, in addition, $B(b \to \ell^-)$, $B(b \to c \to \ell^+)$, $B(c \to \ell^+)$, $\overline{\chi}$, $f(D^+)$, $f(D_s)$, $f(c_{\text{baryon}})$ and $P(c \to D^{*+}) \times B(D^{*+} \to \pi^+ D^0)$, to take into account their correlations with the electroweak parameters. Before the fit both the peak and off-peak asymmetries are translated to the common energy $\sqrt{s} = 91.26$ GeV using the predicted energy-dependence from ZFITTER [5].

$Summary\ of\ the\ measurements\ and\ of\ the\ various\ kinds$ of analysis

The measurements of R_b and R_c fall into two classes. In the first, named single-tag measurement, a method for selecting b and c events is applied and the number of tagged events is counted. A second technique, named double-tag measurement, has the advantage that the tagging efficiency is directly derived from the data thereby reducing the systematic error on the measurement.

The measurements in the b- and c-sector can be essentially grouped in the following categories:

- Lifetime (and lepton) double-tagging measurements of R_b. These are the most precise measurements of R_b and obviously dominate the combined result. The main sources of systematics come from the charm contamination and from estimating the hemisphere b-tagging efficiency correlation;
- Analyses with $D/D^{*\pm}$ to measure R_c . These measurements make use of several different tagging techniques (inclusive/exclusive double tag, exclusive double tag, reconstruction of all weakly decaying charmed states) and no assumptions are made on the energy-dependence of charm fragmentation;
- A measurement of R_c using single leptons and assuming $B(b \to c \to \ell^+)$;
- Lepton fits which use hadronic events with one or more leptons in the final state to measure the asymmetries $A_{FB}^{b\bar{b}}$ and $A_{FB}^{c\bar{c}}$. Each analysis usually gives several other electroweak parameters. The dominant sources of systematics are due to lepton identification, to other semileptonic branching ratios and to the modeling of the semileptonic decay;
- Measurements of A^{b\bar{b}}_{FB} using lifetime tagged events with a hemisphere charge measurement. These measurements dominate the combined result;
- Analyses with $D/D^{*\pm}$ to measure $A_{FB}^{c\overline{c}}$ or simultaneously $A_{FB}^{b\overline{b}}$ and $A_{FB}^{c\overline{c}}$;
- Measurements of A_b and A_c from SLD, using several tagging methods (lepton, kaon, D/D^* , and vertex mass). These quantities are directly extracted from a measurement of the left–right forward–backward asymmetry in $c\overline{c}$ and $b\overline{b}$ production using a polarized electron beam.

$Averaging\ procedure$

All the measurements are provided by the LEP and SLD Collaborations in the form of tables with a detailed breakdown of the systematic errors of each measurement and its dependence on other electroweak parameters.

The averaging proceeds via the following steps:

• Define and propagate a consistent set of external inputs such as branching ratios, hadron lifetimes, fragmentation models *etc*. All the measurements are checked to ensure that all use a common set of assumptions (for instance, since the QCD corrections for the forward–backward asymmetries are strongly dependent on the experimental conditions, the data are corrected before combining);

Among the non-electroweak observables, the B semileptonic

- Form the full (statistical and systematic) covariance matrix of the measurements. The systematic correlations between different analyses are calculated from the detailed error breakdown in the measurement tables. The correlations relating several measurements made by the same analysis are also used:
- Take into account any explicit dependence of a
 measurement on the other electroweak parameters.
 As an example of this dependence, we illustrate
 the case of the double-tag measurement of R_b,
 where c-quarks constitute the main background.
 The normalization of the charm contribution is not
 usually fixed by the data and the measurement of
 R_b depends on the assumed value of R_c, which can
 be written as:

$$R_b = R_b^{\text{meas}} + a(R_c) \frac{(R_c - R_c^{\text{used}})}{R_c} , \qquad (11)$$

where R_b^{meas} is the result of the analysis which assumed a value of $R_c = R_c^{\text{used}}$ and $a(R_c)$ is the constant which gives the dependence on R_c ;

• Perform a χ^2 minimization with respect to the combined electroweak parameters.

After the fit the average peak asymmetries $A_{FB}^{c\bar{c}}$ and $A_{FB}^{b\bar{b}}$ are corrected for the energy shift from 91.26 GeV to M_Z and for QED (initial state radiation), γ exchange, and γZ interference effects, to obtain the corresponding pole asymmetries $A_{FB}^{0,c}$ and $A_{FB}^{0,c}$.

This averaging procedure, using the fourteen parameters described above, and applied to the data contained in the Z particle listing below, gives the following results (where the last 8 parameters do not depend directly on the Z):

$$R_b^0 = 0.21629 \pm 0.00066$$

$$R_c^0 = 0.1721 \pm 0.0030$$

$$A_{FB}^{0,b} = 0.0992 \pm 0.0016$$

$$A_{FB}^{0,c} = 0.0707 \pm 0.0035$$

$$A_b = 0.923 \pm 0.020$$

$$A_c = 0.670 \pm 0.027$$

$$B(b \to \ell^{-}) = 0.1071 \pm 0.0022$$

$$B(b \to c \to \ell^{+}) = 0.0801 \pm 0.0018$$

$$B(c \to \ell^{+}) = 0.0969 \pm 0.0031$$

$$\overline{\chi} = 0.1250 \pm 0.0039$$

$$f(D^{+}) = 0.235 \pm 0.016$$

$$f(D_{s}) = 0.126 \pm 0.026$$

$$f(c_{\text{baryon}}) = 0.093 \pm 0.022$$

$$P(c \to D^{*+}) \times B(D^{*+} \to \pi^{+}D^{0}) = 0.1622 \pm 0.0048$$

branching fraction $B(b \to \ell^-)$ is of special interest, since the dominant error source on this quantity is the dependence on the semileptonic decay model for $b \to \ell^-$, with $\Delta B(b \to \ell^-)_{b \to \ell^- - \mathrm{model}} = 0.0012$. Extensive studies have been made to understand the size of this error. Among the electroweak quantities, the quark asymmetries with leptons depend also on the semileptonic decay model, while the asymmetries using other methods usually do not. The fit implicitly requires that the different methods give consistent results and this effectively constrains the decay model, and thus reduces in principle the error from this source in the fit result.

To obtain a conservative estimate of the modelling error, the above fit has been repeated removing all asymmetry measurements. The results of the fit on B–decay related observables are [23]: $B(b \to \ell^-) = 0.1069 \pm 0.0022$, with $\Delta B(b \to \ell^-)_{b\to\ell^--\mathrm{model}} = 0.0013$, $B(b \to c \to \ell^+) = 0.0802 \pm 0.0019$ and $\overline{\chi} = 0.1259 \pm 0.0042$.

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Phys. Reports 427, 257 (2006);

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Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). The fit is performed using the Z mass and width, the Z hadronic pole cross section, the ratios of hadronic to leptonic partial widths, and the Z pole forward-backward lepton asymmetries. This set is believed to be most free of correlations.

The Z-boson mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass dependent width. The value is 34 MeV greater than the real part of the position of the pole (in the energysquared plane) in the Z-boson propagator. Also the LEP experiments have generally assumed a fixed value of the $\gamma-Z$ interferences term based on the standard model. Keeping this term as free parameter leads to a somewhat larger error on the fitted Z mass. See ACCIARRI 00Q and ABBIENDI 04G for a detailed investigation of both these issues

| VALUE (GeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------------------------------|-----------|-----------------------------|---------------|------------------------------------------------------------|
| 91.1876 ± 0.0021 OUR FI | T | | | |
| 91.1852 ± 0.0030 | 4.57M | ¹ ABBIENDI 0: | 1A OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 91.1863 ± 0.0028 | 4.08M | ² ABREU 00 | 0F DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 91.1898 ± 0.0031 | 3.96M | ³ ACCIARRI 00 | 0∈ L3 | E ^{ee} _{cm} = 88-94 GeV |
| 91.1885 ± 0.0031 | 4.57M | ⁴ BARATE 00 | 0c ALEP | E ee = 88-94 GeV |
| ullet $ullet$ $ullet$ We do not use the | following | data for averages, fits, | , limits, etc | . • • • |
| 91.1872 ± 0.0033 | | ⁵ ABBIENDI 04 | 4G OPAL | Eee LEP1 + |
| 91.272 ±0.032 ±0.033 | | | 4c L3 | 130–209 GeV E ^{ee} _{cm} = 183–209 GeV |
| 91.1875 ± 0.0039 | 3.97M | ⁷ ACCIARRI 00 | 0Q L3 | Eee = LEP1 + |
| 91.151 ± 0.008 | | ⁸ MIYABAYASHI 95 | 5 TOPZ | |
| $91.74 \pm 0.28 \pm 0.93$ | 156 | ⁹ ALITTI 92 | 2в UA2 | $E_{ m cm}^{p\overline{p}}=$ 630 GeV |
| $90.9 \pm 0.3 \pm 0.2$ | 188 | ¹⁰ ABE 89 | 9c CDF | $E_{CM}^{p\overline{p}} = 1.8 TeV$ |
| 91.14 ± 0.12 | 480 | ¹¹ ABRAMS 89 | 9в MRK2 | E ^{ee} _{cm} = 89-93 GeV |
| 93.1 ± 1.0 ± 3.0 | 24 | 12 ALBAJAR 89 | 9 UA1 | $E_{ m cm}^{ ho\overline{ ho}}=$ 546,630 GeV |

 $^{^{}m 1}$ ABBIENDI 01A error includes approximately 2.3 MeV due to statistics and 1.8 MeV due to LEP energy uncertainty.

⁵ ABBIENDI 04G obtain this result using the S-matrix formalism for a combined fit to their cross section and asymmetry data at the $\it Z$ peak and their data at 130–209 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the

 6 ACHARD 04c select $e^+e^- o Z\gamma$ events with hard initial-state radiation. Z decays to $q\overline{q}$ and muon pairs are considered. The fit results obtained in the two samples are found consistent to each other and combined considering the uncertainty due to ISR modelling as fully correlated.

⁷ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forwardbackward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00ć) as constraints. The 130–189 GeV data constrains the γ/Z interference term. The authors have corrected the measurement for the 34.1 MeV shift with respect to the Breit-Wigner fits. The error contains a contribution of ± 2.3 MeV due to the uncertainty on the γZ interference.

with the ACTON 93D data and perform a fit using an S-matrix formalism. As expected, this result is below the mass values obtained with the standard Breit-Wigner parametriza-

Eithers fit through W/Z mass ratio given in the W Particle Listings. The ALITTI 92B systematic error (± 0.93) has two contributions: one (± 0.92) cancels in m_W/m_Z and one (± 0.12) is noncancelling. These were added in quadrature.

Z WIDTH

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and

| VALUE | (GeV) | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------|--------------------|-----------|------------|------------------------|-------------|-----------|---------------------------------------------------------|
| 2.495 | 2 ± 0.002 | 3 OUR F | iT. | | | | |
| 2.494 | 8 ± 0.004 | 1 | 4.57M | ¹³ ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 2.487 | 6 ± 0.004 | 1 | 4.08M | ¹⁴ ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 2.502 | 4 ± 0.004 | 2 | 3.96M | ¹⁵ ACCIARRI | 00c | L3 | E ee = 88-94 GeV |
| 2.495 | 1 ± 0.004 | 3 | 4.57M | ¹⁶ BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| • • • | • We do | not use t | he followi | ng data for average | s, fits | limits, e | etc. • • • |
| 2.494 | 3 ± 0.004 | 1 | | ¹⁷ ABBIENDI | 04 G | OPAL | Eee LEP1 + |
| 2.502 | 5 ± 0.004 | 1 | 3.97M | ¹⁸ ACCIARRI | 00Q | L3 | 130-209 GeV Eee LEP1 + |
| 2.50 | ±0.21 | ±0.06 | | ¹⁹ ABREU | | | 130-189 GeV E ^{ee} _{Cm} = 91.2 GeV |
| 3.8 | ±0.8 | ± 1.0 | 188 | ABE | 89c | CDF | $E_{\rm cm}^{p\overline{p}}$ = 1.8 TeV |
| 2.42 | $^{+0.45}_{-0.35}$ | | 480 | ²⁰ ABRAMS | 89в | MRK2 | <i>E</i> ^{ee} _{cm} = 89−93 GeV |
| 2.7 | $^{+1.2}_{-1.0}$ | ±1.3 | 24 | ²¹ ALBAJAR | 89 | | $E_{ m cm}^{ ho\overline{p}}=$ 546,630 GeV |
| 2.7 | ±2.0 | ± 1.0 | 25 | ²² ANSARI | 87 | UA2 | $E_{\text{CM}}^{p\overline{p}}$ = 546,630 GeV |
| 13 . | DDIEND | | | | | | 1. 12.12 |

 $^{^{13}}$ ABBIENDI 01A error includes approximately 3.6 MeV due to statistics, 1 MeV due to event selection systematics, and 1.3 MeV due to LEP energy uncertainty, 14 The error includes 1.2 MeV due to LEP energy uncertainty.

²The error includes 1.6 MeV due to LEP energy uncertainty.

³The error includes 1.8 MeV due to LEP energy uncertainty.

⁴BARATE 00c error includes approximately 2.4 MeV due to statistics, 0.2 MeV due to experimental systematics, and 1.7 MeV due to LEP energy uncertainty.

 $^{^{10}}$ First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty

 $^{^{11}\}mathrm{ABRAMS}$ 89B uncertainty includes 35 MeV due to the absolute energy measurement.

 $^{^{12}}$ ALBAJAR 89 result is from a total sample of 33 $Z
ightarrow \ e^+ \, e^-$ events.

 $^{^{15}}$ The error includes 1.3 MeV due to LEP energy uncertainty.

¹⁶ BARATE 00c error includes approximately 3.8 MeV due to statistics, 0.9 MeV due to experimental systematics, and 1.3 MeV due to LEP energy uncertainty.

¹⁷ ABBIENDI 046 obtain, this result using the S-matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130-209 GeV. The authors have corrected the measurement for the 1 MeV shift with respect to the Breit-Wigner fits.

¹⁸ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forwardbackward asymmetries in the framework of the S-matrix formalism. They fit to their

cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00c) as constraints. The 130–189 GeV data constrains the γ/Z interference term. The authors have corrected the measurement for the 0.9 MeV shift with respect to the Breit-Wigner fits.

 $^{19}\mathsf{ABREU}$ 96R obtain this value from a study of the interference between initial and final state radiation in the process $e^+e^- \rightarrow Z \rightarrow \mu^+\mu^-$

20 ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction $21\,\mathrm{ALBA\,JAR}$ 89 result is from a total sample of 33 $Z \to e^+e^-$ events

22 Quoted values of ANSARI 87 are from direct fit. Ratio of Z and W production gives either $\Gamma(Z) < (1.09 \pm 0.07) \times \Gamma(W)$, CL = 90% or $\Gamma(Z) = (0.82 \stackrel{+}{-} 0.14 \pm 0.06) \times \Gamma(W)$. Assuming Standard-Model value $\Gamma(W)=2.65$ GeV then gives $\Gamma(Z)<2.89\pm0.19$ or $=2.17^{+0.50}_{-0.37}\pm0.16$.

Z DECAY MODES

| | Mode | | Fraction (Γ_i/Γ) | | ale factor/ dence level |
|------------------------------------|-------------------------------------------------------------------|-----|------------------------------|----------------------------------------|----------------------------|
| Γ ₁ | e+ e- | | (3.363 ±0.004 | .) % | |
| Γ_2 | $\mu^{+} \mu^{-}$ | | (3.366 ± 0.007 | | |
| Γ ₃ | $\tau^+\tau^-$ | | (3.370 ±0.008 | | |
| Γ ₄ | $\ell^+ \ell^-$ | | [a] (3.3658±0.002 | | |
| Γ_5 | invisible | | (20.00 ±0.06 |) % | |
| Γ ₆ | hadrons | | (69.91 ±0.06 |) % | |
| Γ ₇ | $(u\overline{u} + c\overline{c})/2$ | | (11.6 ± 0.6 |) % | |
| Γ ₈ | $(d\overline{d} + s\overline{s} + b\overline{b})/3$ | | (15.6 ± 0.4) |) % | |
| Г9 | c <u></u> | | $(12.03 \pm 0.21$ |) % | |
| Γ_{10} | b <u>b</u> | | (15.12 ± 0.05) |) % | |
| Γ_{11} | $b \overline{b} b \overline{b}$ | | (3.6 ± 1.3) | $) \times 10^{-4}$ | |
| Γ_{12} | ggg | | < 1.1 | % | CL=95% |
| Γ_{13} | $\pi^0 \gamma$ | | < 5.2 | $\times 10^{-5}$ | CL=95% |
| Γ_{14} | $\eta \gamma$ | | < 5.1 | $\times 10^{-5}$ | CL=95% |
| 15 | $\omega \gamma$ | | < 6.5 | ×10 ⁻⁴ | CL=95% |
| Γ_{16} | $\eta'(958)\gamma$ | | < 4.2 | $\times 10^{-5}$ | CL=95% |
| [₁₇ | $\gamma \gamma$ | | < 5.2 | × 10 ⁻⁵ | CL=95% |
| T ₁₈ | $\gamma \gamma \gamma$ | | < 1.0 | ×10 ⁻⁵ | CL=95% |
| Γ ₁₉ | $\pi^{\pm}W^{\mp}$ | | [b] < 7 | ×10 ⁻⁵ | CL=95% |
| Γ ₂₀ | $ ho^{\pm}W^{\mp}$ | | [b] < 8.3 | ×10 ⁻⁵ | CL=95% |
| Γ ₂₁ | $J/\psi(1S)X$ | | $(3.51 + 0.23 \\ -0.25$ |) × 10 ⁻³ | S=1.1 |
| Γ ₂₂ | $\psi(2S)X$ | | (1.60 ± 0.29) | $) \times 10^{-3}$ | |
| Γ ₂₃ | $\chi_{c1}(1P)X$ | | (2.9 ± 0.7) | $) \times 10^{-3}$ | |
| Γ ₂₄ | $\chi_{c2}(1P)X$ | | < 3.2 | ×10 ⁻³ | CL=90% |
| Γ ₂₅ | $\Upsilon(1S) \times + \Upsilon(2S) \times + \Upsilon(3S) \times$ | | (1.0 ± 0.5) |) × 10 ⁻⁴ | |
| Γ ₂₆ | r(1S)X | | < 4.4 | $\times 10^{-5}$ | CL=95% |
| Γ ₂₇ | $\Upsilon(2S)X$ | | < 1.39 | ×10 ⁻⁴ | CL=95% |
| Γ ₂₈ | r(3S)X | | < 9.4 | ×10 ⁻⁵ | CL=95% |
| Γ ₂₉ | (D^0/\overline{D}^0) X | | (20.7 ± 2.0 |) % | / • |
| Γ ₃₀ | D± X | | (12.2 ±1.7 |) % | |
| Γ ₃₁ | $D^*(2010)^{\pm}X$ | | [b] (11.4 ±1.3 |) % | |
| Γ ₃₂ | $D_{s1}(2536)^{\pm}X$ | | (3.6 ± 0.8 | $) \times 10^{-3}$ | |
| Γ ₃₃ | $D_{s,I}(2573)^{\pm}X$ | | (5.8 ± 2.2 | $) \times 10^{-3}$ | |
| Γ ₃₄ | $D^{*'}(2629)^{\pm}X$ | | searched for | | |
| Γ ₃₅ | BX | | | | |
| Γ ₃₆ | B*X | | | | |
| Γ ₃₇ | <i>B</i> ⁺ X | | [c] (6.08 \pm 0.13 |) % | |
| Γ ₃₈ | $B_s^0 X$ | | [c] (1.59 ± 0.13 |) % | |
| Γ_{39} | $B_c^+ X$ | | searched for | | |
| Γ_{40} | $\Lambda_{c}^{+} X$ | | (1.54 ± 0.33) |) % | |
| Γ_{41} | $\equiv_c^0 X$ | | seen | | |
| Γ_{42} | $\Xi_b^{\circ}X$ | | seen | | |
| Γ_{43} | <i>b</i> -baryon X | | [c] (1.38 \pm 0.22 |) % | |
| Γ_{44} | anomalous $\gamma+$ hadrons | | [d] < 3.2 | $\times 10^{-3}$ | CL=95% |
| Γ_{45} | $e^+e^-\gamma$ | | [d] < 5.2 | $\times 10^{-4}$ | CL=95% |
| Γ ₄₆ | $\mu^+\mu^-\gamma$ | | [d] < 5.6 | $\times 10^{-4}$ | CL=95% |
| Γ ₄₇ | $\tau^+\tau^-\gamma$ | | [d] < 7.3 | ×10 ⁻⁴ | CL=95% |
| Γ ₄₈ | $\ell^+\ell^-\gamma\gamma$ | | [e] < 6.8 | $\times 10^{-6} \times 10^{-6}$ | CL=95% |
| Γ ₄₉ | $q \overline{q} \gamma \gamma$ | | [e] < 5.5 | ×10 ⁻⁶ ×10 ⁻⁶ | CL=95% CL=95% |
| Γ ₅₀ Γ ₅₁ | $ u \overline{ u} \gamma \gamma $ $ e^{\pm} \mu^{\mp} $ | LF | [e] < 3.1 $[b] < 1.7$ | ×10 × 10 -6 | CL=95% CL=95% |
| Γ ₅₂ | $e^{\pm} \tau^{\mp}$ | LF | [b] < 1.7 [b] < 9.8 | ×10 ×10 ⁻⁶ | CL=95% CL=95% |
| Γ ₅₃ | $\mu^{\pm}\tau^{\mp}$ | LF | [b] < 1.2 | ×10 ⁻⁵ | CL=95% |
| Γ ₅₄ | p e | L,B | < 1.8 | $\times 10^{-6}$ | CL=95% |
| Γ ₅₅ | $p\mu$ | L,B | < 1.8 | $\times 10^{-6}$ | CL=95% |

- [a] ℓ indicates each type of lepton $(e, \mu, \text{ and } \tau)$, not sum over them.
- [b] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [c] This value is updated using the product of (i) the $Z
 ightharpoonup b \overline{b}$ fraction from this listing and (ii) the b-hadron fraction in an unbiased sample of weakly decaying b-hadrons produced in Zdecays provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009/#FRACZ).
- [d] See the Particle Listings below for the γ energy range used in this mea-
- [e] For $m_{\gamma\gamma}=$ (60 \pm 5) GeV.

Z PARTIAL WIDTHS

$\Gamma(e^+e^-)$ For the LEP experiments, this parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|--------|---------------------|------|------|-------------------------------------------|
| 83.91±0.12 OUR FIT | | | | | |
| 83.66 ± 0.20 | 137.0K | ABBIENDI | 01A | OPAL | E ee = 88-94 GeV |
| 83.54 ± 0.27 | 117.8k | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 84.16 ± 0.22 | 124.4k | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 83.88 ± 0.19 | | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| $82.89 \pm 1.20 \pm 0.89$ | | ²³ A B E | 95.1 | SLD | $E_{cm}^{ee} = 91.31 \text{ GeV}$ |

 $^{23} \, \text{ABE}$ 95J obtain this measurement from Bhabha events in a restricted fiducial region to improve systematics. They use the values 91.187 and 2.489 GeV for the Z mass and total decay width to extract this partial width.

$\Gamma(\mu^+\mu^-)$ This parameter is not directly used in the overall fit but is derived using the fit results;

see the note "The Z boson" and ref. LEP-SLC 06.

| VALUE (WEV) | LVIJ | DOCUMENTID | | ILCIV | COMMENT |
|--------------------|--------|------------|-----|-------|------------------|
| 83.99±0.18 OUR FIT | | | | | |
| 84.03 ± 0.30 | 182.8K | ABBIENDI | 01A | OPAL | E ee = 88-94 GeV |
| 84.48 ± 0.40 | 157.6k | ABREU | 00F | DLPH | E ee = 88-94 GeV |
| 83.95 ± 0.44 | 113.4k | ACCIARRI | 00c | L3 | E ee = 88-94 GeV |
| 84.02 ± 0.28 | | BARATE | 00c | ALEP | E ee = 88-94 GeV |
| | | | | | |

 $\Gamma(\tau^+\tau^-)$ This parameter is not directly used in the overall fit but is derived using the fit results;

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|--------|--------------|-----|------|-------------------------------------------|
| 84.08±0.22 OUR FIT | | | | | |
| 83.94 ± 0.41 | 151.5K | ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 83.71 ± 0.58 | 104.0k | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 84.23 ± 0.58 | 103.0k | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 84.38 ± 0.31 | | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88–94 GeV |

 $\Gamma(\ell^+\ell^-)$ Γ_4

In our fit $\Gamma(\ell^+\ell^-)$ is defined as the partial Z width for the decay into a pair of massless charged leptons. This parameter is not directly used in the 5-parameter fit assuming lepton universality but is derived using the fit results. See the note "The $\it Z$ boson" and ref. LEP-SLC 06.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------|--------------|-----|------|-------------------------------------------|
| 83.984 ± 0.086 OUR FI | Т | | | | |
| 83.82 ± 0.15 | 471.3K | ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 83.85 ± 0.17 | 379.4k | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 84.14 ± 0.17 | 340.8k | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 84.02 ± 0.15 | 500k | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |

Γ(invisible) We use only direct measurements of the invisible partial width using the single photon channel to obtain the average value quoted below. OUR FIT value is obtained

as a difference between the total and the observed partial widths assuming lepton universality.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|--------------|-----------------------|---------|-----------|-------------------------------------------|
| 499.0± 1.5 OUR FIT | | | | | |
| 503 ±16 OUR AVER | RAGE Erro | r includes scale t | factor | of 1.2. | |
| 498 ± 12 ± 12 | 1791 | ACCIARRI | 98G | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 539 ± 26 ± 17 | 410 | AKERS | 95 c | OPAL | E ^{ee} _{cm} = 88–94 GeV |
| $450 \pm 34 \pm 34$ | 25 8 | BUSKULIC | 93L | ALEP | E ^{ee} _{cm} = 88–94 GeV |
| 540 ± 80 ± 40 | 52 | ADEVA | 92 | L3 | E ^{ee} _{cm} = 88-94 GeV |
| • • • We do not use th | ne following | data for average | s, fits | , limits, | etc. • • • |
| 498.1 ± 2.6 | 2 | ⁴ ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 498.1 ± 3.2 | | | | | E ^{ee} _{cm} = 88-94 GeV |
| 499.1 ± 2.9 | | | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 499.1 ± 2.5 | 2 | ⁴ BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |

 $^{^{24}}$ This is an indirect determination of $\Gamma(\text{invisible})$ from a fit to the visible Z decay modes.

Γ(hadrons)

This parameter is not directly used in the 5-parameter fit assuming lepton universality, but is derived using the fit results. See the note "The Z boson" and ref. LEP-SLC 06.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------|-------|--------------|-----|------|-------------------------------------------|
| 1744.4 ± 2.0 OUR FIT | | | | | |
| 1745.4 ± 3.5 | 4.10M | ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 1738.1 ± 4.0 | 3.70M | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 1751.1 ± 3.8 | 3.54M | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 1744.0 ± 3.4 | 4.07M | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |

Z BRANCHING RATIOS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06).

| $\Gamma(\text{hadrons})/\Gamma(e^+e^-)$ | | | | Γ_6/Γ_1 |
|-----------------------------------------|-----------|------------------------|---------------|---------------------------------------|
| VALUE | EVTS | DO CUMENT ID | TEC | N <u>COMMENT</u> |
| 20.804 ± 0.050 OUR FIT | | | | |
| 20.902 ± 0.084 | 137.0K | ²⁵ ABBIENDI | 01A OPA | L <i>E</i> ^{ee} = 88-94 GeV |
| $20.88~\pm~0.12$ | 117.8k | ABREU | 00F DLF | PH <i>E</i> ^{ee} = 88–94 GeV |
| 20.816 ± 0.089 | 124.4k | ACCIARRI | 00c L3 | <i>E</i> ^{ee} cm = 88-94 GeV |
| 20.677 ± 0.075 | | ²⁶ BARATE | 00c ALE | P <i>E</i> ^{ee} = 88-94 GeV |
| ullet $ullet$ $ullet$ We do not use the | following | lata for averages, fi | ts, limits, e | etc. • • • |
| 27.0 + 11.7 | 12 | 27 ABRAMS | 89D MR | K2 Fee — 89-93 GeV |

 $^{25}\,\mathrm{ABBIENDI}$ 01A error includes approximately 0.067 due to statistics, 0.040 due to event selection systematics, 0.027 due to the theoretical uncertainty in t-channel prediction, and 0.014 due to LEP energy uncertainty.

26 BARATE 00c error includes approximately 0.062 due to statistics, 0.033 due to experimental systematics, and 0.026 due to the theoretical uncertainty in *t*-channel prediction. 27 ABRAMS 89D have included both statistical and systematic uncertainties in their quoted

 $\Gamma(\text{hadrons})/\Gamma(\mu^+\mu^-)$ OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The $\it Z$ boson" and ref. LEP-SLC 06).

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------|------------|------------------------|---------|------------|------------------|
| 20.785 ± 0.033 OUR FIT | | | | | |
| 20.811 ± 0.058 | 182.8K | ²⁸ ABBIENDI | 01A | OPAL | E ee = 88-94 GeV |
| 20.65 ± 0.08 | 157.6k | ABREU | 00F | DLPH | E ee = 88-94 GeV |
| 20.861 ± 0.097 | 113.4k | ACCIARRI | 00c | L3 | E ee = 88-94 GeV |
| 20.799 ± 0.056 | | ²⁹ BARATE | 00c | ALEP | E ee = 88-94 GeV |
| • • • We do not use the f | ollowing d | lata for averages, fi | ts, lin | nits, etc. | • • • |
| $18.9 \begin{array}{c} +7.1 \\ -5.3 \end{array}$ | 13 | ³⁰ ABRAMS | 89D | MRK2 | E ee = 89-93 GeV |

 $^{28}\hspace{0.02cm}\mathsf{ABBIENDI}$ 01A error includes approximately 0.050 due to statistics and 0.027 due to event selection systematics.

²⁹BARATE 00c error includes approximately 0.053 due to statistics and 0.021 due to experimental systematics.

30 ABRAMS 89D have included both statistical and systematic uncertainties in their quoted

 Γ (hadrons)/ Γ ($\tau^+\tau^-$)
OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06).

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------|-------------|------------------------|---------|------------|--------------------------------------------------|
| 20.764 ± 0.045 OUR FIT | | · | | | |
| 20.832 ± 0.091 | 151.5K | ³¹ ABBIENDI | 01A | OPAL | E ee _ 88-94 GeV |
| 20.84 ± 0.13 | 104.0k | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 20.792 ± 0.133 | 103.0k | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 20.707 ± 0.062 | | ³² barate | 00c | ALEP | E ^{ee} _{CM} = 88-94 GeV |
| ullet $ullet$ $ullet$ We do not use the | following o | lata for averages, fi | ts, lin | nits, etc. | • • • |
| $15.2 \begin{array}{c} +4.8 \\ -3.9 \end{array}$ | 21 | ³³ ABRAMS | 89D | MRK2 | <i>E</i> ^{ee} _{cm} = 89−93 GeV |

 $^{31} {\sf ABBIENDI~01A}$ error includes approximately 0.055 due to statistics and 0.071 due to event selection systematics.

32 BARATE 00c error includes approximately 0.054 due to statistics and 0.033 due to experimental systematics.

33 ABRAMS 89D have included both statistical and systematic uncertainties in their quoted

TECN COMMENT

$\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$

 Γ_6/Γ_4

 ℓ indicates each type of lepton $(e,\,\mu,\,{\rm and}\,\, au)$, not sum over them.

Our fit result is obtained requiring lepton universality.

| VALUE | LVIJ | DOCUMENTID | | TLCIV | COMMENT | | |
|--------------------------------------------------|--------|------------------------|-----|-------|--------------------------------------------------|--|--|
| 20.767±0.025 OUR | FIT | · | | | | | |
| 20.823 ± 0.044 | 471.3K | ³⁴ abbiendi | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV | | |
| 20.730 ± 0.060 | 379.4k | ABREU | 00F | DLPH | E ee = 88-94 GeV | | |
| 20.810 ± 0.060 | 340.8k | ACCIARRI | 00c | L3 | E ee = 88-94 GeV | | |
| 20.725 ± 0.039 | 500k | ³⁵ BARATE | 00c | ALEP | E ee = 88-94 GeV | | |
| | | | | | | | |
| $18.9 \begin{array}{c} +3.6 \\ -3.2 \end{array}$ | 46 | ABRAMS | 89B | MRK2 | <i>E</i> ^{ee} _{cm} = 89−93 GeV | | |

 34 ABBIENDI 01A error includes approximately 0.034 due to statistics and 0.027 due to event selection systematics.

35 BARATE 00c error includes approximately 0.033 due to statistics, 0.020 due to experimental systematics, and 0.005 due to the theoretical uncertainty in t-channel prediction.

 $\Gamma \text{(hadrons)/} \Gamma_{\text{total}} \\ \text{This parameter is not directly used in the overall fit but is derived using the fit results;}$ see the note "The $\it Z$ boson" and ref. LEP-SLC 06. DO CUMENT ID

VALUE (%) 69.911 ± 0.056 OUR FIT

 $\Gamma(e^+e^-)/\Gamma_{\text{total}}$

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06. DO CUMENT ID

(3363.2±4.2) × 10⁻³ OUR FIT

 $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$

This parameter is not directly used in the overall fit but is derived using the fit results;

see the note "The Z boson" and ref. LEP-SLC 06. $\underline{DOCUMENT\ ID}$

(3366.2±6.6) × 10⁻³ OUR FIT

 $\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$

 Γ_2/Γ_1

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

1.0009 ± 0.0028 OUR FIT

 $\Gamma(\tau^+\tau^-)/\Gamma_{total}$ This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06. $\underline{DOCUMENT\ ID}$

(3369.6±8.3) × 10⁻³ OUR FIT

 $\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-)$

 Γ_3/Γ_1

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

1.0019±0.0032 OUR FIT

 $\Gamma(\ell^+\ell^-)/\Gamma_{\rm total}$

 Γ_4/Γ

 ℓ indicates each type of lepton $(e, \mu, \text{ and } \tau)$, not sum over them.

Our fit result assumes lepton universality,

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The $\it Z$ boson" and ref. LEP-SLC 06. DO CUMENT ID

VALUE (%) $(3365.8\pm2.3)\times10^{-3}$ OUR FIT

 $\Gamma(\text{invisible})/\Gamma_{\text{total}}$

 Γ_5/Γ

See the data, the note, and the fit result for the partial width, Γ_5 , above.

DO CUMENT ID 20.000 ± 0.055 OUR FIT

 $\Gamma((u\overline{u}+c\overline{c})/2)/\Gamma(\text{hadrons})$

This quantity is the branching ratio of Z o "up-type" quarks to Z o hadrons. Except ACKERSTAFF 97T the values of $Z \to$ "up-type" and $Z \to$ "down-type" branchings are extracted from measurements of $\Gamma({\rm hadrons})$, and $\Gamma(Z \to \gamma + {\rm jets})$ where γ is a highenergy (>5 or 7 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_7 , $\Gamma(\text{hadrons})$ and α_s in their extraction procedures, our average has to be taken with caution.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|--------------------------|-----|------|-------------------------------------------|
| 0.166±0.009 OUR AVERAGE | | | | |
| $0.172 {}^{+ 0.011}_{- 0.010}$ | ³⁶ ABBIENDI | 04E | OPAL | $E_{\text{CM}}^{ee}=91.2\;\text{GeV}$ |
| $0.160 \pm 0.019 \pm 0.019$ | ³⁷ ACKERSTAFF | 97T | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $0.137 + 0.038 \\ -0.054$ | ³⁸ ABREU | 95x | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 0.137 ± 0.033 | ³⁹ ADRIANI | 93 | L3 | <i>E</i> ^{ee} cm = 91.2 GeV |
| 36 - 55 - 51 - 51 - 51 - 51 - 51 - 51 - 5 | | | | |

 36 ABBIENDI 04E select photons with energy > 7 GeV and use $\Gamma({
m hadrons})=1744.4\pm2.0$ MeV and $\alpha_S=0.1172\pm0.002$ to obtain $\Gamma_{\it u}=300^{+19}_{-18}$ MeV.

37 ACKERSTAFF 97T measure $\Gamma_{u\overline{u}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})=0.258\pm0.031\pm0.032$. To obtain this branching ratio authors use $R_{c}+R_{b}=0.380\pm0.010$. This measurement is fully negatively correlated with the measurement of $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})$ given

 38 ABREU 95x use $M_Z=$ 91.187 \pm 0.009 GeV, $\Gamma({\rm hadrons})=$ 1725 \pm 12 MeV and α_s 0.123 ± 0.005 . To obtain this branching ratio we divide their value of $C_{2/3} = 0.91 + 0.25$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

 39 ADRIANI 93 use $M_Z=91.181\pm0.022$ GeV, $\Gamma({\rm hadrons})=1742\pm19$ MeV and $\alpha_S=0.125\pm0.009$. To obtain this branching ratio we divide their value of $C_{2/3}=0.92\pm0.22$ by their value of (3 $C_{1/3}$ + 2 $C_{2/3}$) = 6.720 \pm 0.076.

$\Gamma((d\overline{d} + s\overline{s} + b\overline{b})/3)/\Gamma(\text{hadrons})$

 Γ_8/Γ_6

This quantity is the branching ratio of Z o "down-type" quarks to Z o hadrons Except ACKERSTAFF 97T the values of Z o "up-type" and Z o "down-type" branchings are extracted from measurements of $\Gamma(\text{hadrons})$, and $\Gamma(Z \to \gamma + \text{jets})$ where γ is a high-energy (>5 or 7 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_Z , $\Gamma({\rm hadrons})$ and α_s in their extraction procedures, our average has to be taken with caution.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|--------------------------|-----|------|--------------------------------------------------|
| 0.223±0.006 OUR AVERAGE | | | | |
| 0.218 ± 0.007 | ⁴⁰ ABBIENDI | 04E | OPAL | E ee e 91.2 GeV |
| $0.230 \pm 0.010 \pm 0.010$ | ⁴¹ ACKERSTAFF | 97T | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $0.243 {}^{+ 0.036}_{- 0.026}$ | ⁴² ABREU | 95x | DLPH | <i>E</i> ^{ee} _{Cm} = 88-94 GeV |
| 0.243 ± 0.022 | ⁴³ ADRIANI | 93 | L3 | E ee e 91.2 GeV |

- 40 ABBIENDI 04E select photons with energy >7 GeV and use $\Gamma({\rm hadrons})=1744.4\pm2.0$ MeV and $\alpha_{\rm S}=0.1172\pm0.002$ to obtain $\Gamma_d=381\pm12$ MeV.
- 41 ACKERSTAFF 97T measure $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{w}}+\Gamma_{s\overline{s}})=0.371\pm0.016\pm0.016$. To obtain this branching ratio authors use $R_{C}+R_{b}=0.380\pm0.010$. This measurement is fully negatively correlated with the measurement of $\Gamma_{u\overline{w}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{w}}+\Gamma_{s\overline{s}})$ presented in the previous data block.
- 42 ABREU 95x use $M_Z=91.187\pm0.009$ GeV, $\Gamma({\rm hadrons})=1725\pm12$ MeV and $\alpha_S=0.123\pm0.005$. To obtain this branching ratio we divide their value of $C_{1/3}=1.62^{+0.24}_{-0.17}$ by their value of (3 $C_{1/3}$ + 2 $C_{2/3}$) = 6.66 \pm 0.05.
- 43 ADRIANI 93 use $M_Z=91.81\pm0.022$ GeV, $\Gamma({\rm hadrons})=1742\pm19$ MeV and $\alpha_5=0.125\pm0.009.$ To obtain this branching ratio we divide their value of $C_{1/3}=1.63\pm0.15$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

as explained in the note "The Z boson" and ref. LEP-SLC 06.

The Standard Model predicts $R_{\it C}=$ 0.1723 for $m_{\it t}=$ 174.3 GeV and $M_{\it H}=$ 150 GeV.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------|--------------------------|-------|-----------|-------------------------------------------|
| 0.1721 ± 0.0030 OUR FIT | | | | |
| $0.1744\pm0.0031\pm0.0021$ | ⁴⁴ ABE | | | $E_{\rm cm}^{ee} = 91.28 {\rm GeV}$ |
| $0.1665 \pm 0.0051 \pm 0.0081$ | | | | E ee = 88-94 GeV |
| 0.1698 ± 0.0069 | | | | $E_{\rm cm}^{ee}=88-94~{\rm GeV}$ |
| $0.180\ \pm0.011\ \pm0.013$ | ⁴⁷ ACKERSTAFF | 98E | OPAL | $E_{\rm cm}^{ee}=88-94~{\rm GeV}$ |
| $0.167\ \pm0.011\ \pm0.012$ | ⁴⁸ ALEXANDER | 96R | OPAL | E ee = 88-94 GeV |
| ullet $ullet$ $ullet$ We do not use the | following data for a | verag | es, fits, | limits, etc. • • • |
| $0.1623\pm0.0085\pm0.0209$ | ⁴⁹ ABREU | 95 D | DLPH | E ^{ee} _{cm} = 88-94 GeV |

- 44 ABE 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events using a double tag method. The single c-tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere). A multitag approach is used, defining 4 regions of the output value of the neural network and $R_{\rm c}$ is extracted from a simultaneous fit to the count rates of the 4 different tags. The quoted systematic error includes an uncertainty of ± 0.0006 due to the uncertainty on R_b
- 45 ABREU 00 obtain this result properly combining the measurement from the D^{*+} production rate $(R_C=0.1610\pm0.0104\pm0.0077\pm0.0043~(BR))$ with that from the overall charm counting $(R_C=0.1692\pm0.0047\pm0.0063\pm0.0074~(BR))$ in $c\overline{c}$ events. The systematic error includes an uncertainty of ±0.0054 due to the uncertainty on the charmed hadron branching fractions.
- $^{46}\,\mathrm{BARATE}$ 00B use exclusive decay modes to independently determine the quantities $R_C imes f(c o X), X = D^0, D^+, D_S^+$, and A_C . Estimating $R_C imes f(c o \Xi_C/\Omega_C) = 0.0034$, they simply sum over all the charm decays to obtain $R_C = 0.1738 \pm 0.0047 \pm 0.0088 \pm 0.0075 (BR)$. This is combined with all previous ALEPH measurements (BARATE 98T and BUSKULIC 946, $R_{c}=0.1681\pm0.0054\pm0.0062$) to obtain the quoted value.
- 47 ACKERSTAFF 98E use an inclusive/exclusive double tag. In one jet $D^{*\pm}$ mesons are exclusively reconstructed in several decay channels and in the opposite jet a slow pion copposite charge inclusive $D^{*\pm}$) tag is used. The b content of this sample is measured by the simultaneous detection of a lepton in one jet and an inclusively reconstructed $D^{*\pm}$ meson in the opposite jet. The systematic error includes an uncertainty of ± 0.006 due to the external branching ratios.
- 48 ALEXANDER 96R obtain this value via direct charm counting, summing the partial contributions from ${\it D}^0$, ${\it D}^+$, ${\it D}^+_{\it S}$, and ${\it \Lambda}^+_{\it C}$, and assuming that strange-charmed baryons account for the 15% of the Λ_C^+ production. An uncertainty of ± 0.005 due to the uncertainties in the charm hadron branching ratios is included in the overall systematics.
- 49 ABREU 95D perform a maximum likelihood fit to the combined ρ and ρ_T distributions of single and dilepton samples. The second error includes an uncertainty of ± 0.0124 due to models and branching ratios.

$R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$

OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

The Standard Model predicts R_b =0.21581 for m_t =174.3 GeV and M_H =150 GeV.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------------|------|------|-----------------------------------|
| 0.21629±0.00066 OUR FIT | | | | |
| $0.21594\pm0.00094\pm0.00075$ | ⁵⁰ ABE | 05 F | SLD | $E_{cm}^{ee} = 91.28 \text{ GeV}$ |
| $0.2174 \pm 0.0015 \pm 0.0028$ | ⁵¹ ACCIARRI | 00 | L3 | $E_{cm}^{ee} = 89-93 \text{ GeV}$ |
| $0.2178 \pm 0.0011 \pm 0.0013$ | ⁵² ABBIENDI | 99B | OPAL | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |
| $0.21634 \pm 0.00067 \pm 0.00060$ | ⁵³ ABREU | 99B | DLPH | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |
| $0.2159 \pm 0.0009 \pm 0.0011$ | ⁵⁴ BARATE | 97F | ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $0.2145\ \pm0.0089\ \pm0.0067$ ⁵⁵ ABREU 95 D DLPH $E_{cm}^{ee} = 88-94 \text{ GeV}$ 56 BUSKULIC 94G ALEP $E_{
m cm}^{\it ee}=$ 88-94 GeV 0.219 + 0.006 + 0.005 57 JACOBSEN 91 MRK2 $E_{
m cm}^{\it ee}=$ 91 GeV $0.251 \pm 0.049 \pm 0.030$

- $^{50}\,\mathrm{ABE}$ 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $b\overline{b}$ events using a double tag method. The single b-tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere; the key tag is obtained requiring the secondary vertex corrected mass to be above the D-meson mass). ABE 05F obtain $R_b=0.21604\pm0.00098\pm0.00074$ where the systematic error includes an uncertainty of ±0.00012 due to the uncertainty on $R_c.$ The value reported here is obtained properly combining with ABE 98D. The quoted systematic error includes an uncertainty of ± 0.00012 due to the uncertainty on $R_c.$
- 51 ACCIARRI 00 obtain this result using a double-tagging technique, with a high p_T lepton
- tag and an impact parameter tag in opposite hemispheres. 52 ABBIENDI 998 tag $Z \rightarrow b\overline{b}$ decays using leptons and/or separated decay vertices. The b-tagging efficiency is measured directly from the data using a double-tagging technique.
- 53 ABREU 998 obtain this result combining in a multivariate analysis several tagging meth-ods (impact parameter and secondary vertex reconstruction, complemented by event shape variables). For R_c different from its Standard Model value of 0.172, R_b varies as $-0.024 \times (R_c - 0.172)$.
- ⁵⁴ BARATE 97F combine the lifetime-mass hemisphere tag (BARATE 97E) with event shape information and lepton tag to identify $Z \rightarrow b\overline{b}$ candidates. They further use c- and ud s-selection tags to identify the background. For R_C different from its Standard Model value of 0.172, R_D varies as $-0.019 \times (R_C 0.172)$.
- 55 ABREU 95D perform a maximum likelihood fit to the combined p and p_T distributions of single and dilepton samples. The second error includes an uncertainty of ± 0.0023 due to models and branching ratios.
- 56 BUSKULIC 94G perform a simultaneous fit to the ho and p_T spectra of both single and
- 57 JACOBSEN 91 tagged $b\overline{b}$ events by requiring coincidence of \geq 3 tracks with significant impact parameters using vertex detector. Systematic error includes lifetime and decay uncertainties (± 0.014)

$\Gamma(b\overline{b}b\overline{b})/\Gamma(hadrons)$

 Γ_{11}/Γ_{6}

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|------------------------|-------------|------|------------------|
| 5.2±1.9 OUR AVERAGE | · | | | |
| $3.6 \pm 1.7 \pm 2.7$ | ⁵⁸ ABBIENDI | 01 G | OPAL | E ee = 88-94 GeV |
| $6.0 \pm 1.9 \pm 1.4$ | ⁵⁹ ABREU | 99∪ | DLPH | E ee = 88-94 GeV |

- 58 ABBIENDI 01G use a sample of four-jet events from hadronic $\it Z$ decays. To enhance the $b \, \overline{b} \, b \, \overline{b}$ signal, at least three of the four jets are required to have a significantly detached secondary vertex.
- 59 ABREU $^{\circ}$ 990 force hadronic Z decays into 3 jets to use all the available phase space and require a b tag for every jet. This decay mode includes primary and secondary 4b production, e.g. from gluon splitting to $b\overline{b}$.

$\Gamma(ggg)/\Gamma(hadrons)$ Γ_{12}/Γ_{6} DOCUMENT ID TECN COMMENT 60 ABREU 96s DLPH $E_{ m cm}^{\it ee} = 88-94 \; { m GeV}$ 95

⁶⁰ This branching ratio is slightly dependent on the jet-finder algorithm. The value we quote is obtained using the JADE algorithm, while using the DURHAM algorithm ABREU 96s obtain an upper limit of 1.5 \times 10 $^{-2}.$

| $\Gamma(\pi^0\gamma)/\Gamma_{ m total}$ | | | | | Γ ₁₃ /Γ |
|-----------------------------------------|-----|--------------|-------------|------|-------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $< 5.2 \times 10^{-5}$ | 95 | 61 ACCIARRI | 95 G | L3 | E ^{ee} _{cm} = 88–94 GeV |

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|------------------------|-----|-------------|------|------|-------------------------------------------|
| $< 5.2 \times 10^{-5}$ | 95 | 61 ACCIARRI | 95 G | L3 | E ee = 88-94 GeV |
| $< 5.5 \times 10^{-5}$ | 95 | ABREU | 94B | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| $< 2.1 \times 10^{-4}$ | 95 | DECAMP | 92 | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| $<1.4 \times 10^{-4}$ | 95 | AKRAWY | 91F | OPAL | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

 61 This limit is for both decay modes $Z \to \pi^0 \gamma/\gamma \gamma$ which are indistinguishable in ACCIA-

| $\Gamma(\eta\gamma)/\Gamma_{total}$ | | | | | Γ ₁₄ /Γ |
|-------------------------------------|-----|--------------|------|------|-------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $< 7.6 \times 10^{-5}$ | 95 | ACCIARRI | 95 G | L3 | E ee = 88-94 GeV |
| $< 8.0 \times 10^{-5}$ | 95 | ABREU | 94B | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| $< 5.1 \times 10^{-5}$ | 95 | DECAMP | 92 | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| $< 2.0 \times 10^{-4}$ | 95 | AKRAWY | 91F | OPAL | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

| $\Gamma(\omega\gamma)/\Gamma_{ m total}$ | | | | | Γ ₁₅ /Γ |
|------------------------------------------|-----|--------------|-----|------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $<6.5 \times 10^{-4}$ | 95 | ABREU | 94B | DLPH | E ee = 88-94 GeV |

| $\Gamma(\eta'(958)\gamma)/\Gamma_{\rm total}$ | | | | | Γ ₁₆ | 6/Г |
|-----------------------------------------------|-----|--------------|----|------|-----------------|-----|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <4.2 × 10 ⁻⁵ | 95 | DECAMP | 92 | ALEP | Eee = 88-94 GeV | |

 $\Gamma(\gamma\gamma)/\Gamma_{total}$ This decay would violate the Landau-Yang theorem. Γ_{17}/Γ

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----|--------------|------|------|-------------------------------------------|
| <5.2 × 10 ⁻⁵ | 95 | 62 ACCIARRI | 95 G | L3 | E ee = 88-94 GeV |
| $< 5.5 \times 10^{-5}$ | 95 | ABREU | 94B | DLPH | E ee = 88-94 GeV |
| $< 1.4 \times 10^{-4}$ | 95 | AKRAWY | 91F | OPAL | E ^{ee} _{cm} = 88-94 GeV |

 62 This limit is for both decay modes $Z
ightarrow ~\pi^0 \gamma/\gamma\gamma$ which are indistinguishable in ACCIA-

| $\Gamma(\gamma\gamma\gamma)/\Gamma_{\text{total}}$ | 01 | | | Γ ₁₈ /Γ | $\Gamma(\Upsilon(3S)X)/\Gamma_{total}$ | 04 | | | | Γ ₂₈ /Ι |
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| <1.0 × 10 ⁻⁵ | <u>CL%</u> 95 | 63 ACCIARRI | 95c L3 | <u>COMMENT</u> E ee = 88-94 GeV | <9.4 × 10 ⁻⁵ | <u>CL%_</u> 95 | DOCUMENT ID 76 ACCIARRI | 97R L3 | $\frac{V COMMENT}{E_{cm}^{ee} = 88-9}$ | 1 GeV |
| $<1.7 \times 10^{-5}$ | 95 | ⁶³ ABREU | | H E _{cm} = 88–94 GeV | ⁷⁶ ACCIARRI 97R sear | | | | | |
| $< 6.6 \times 10^{-5}$ | 95 | AKRAWY | 91F OPAI | . <i>E</i> ee = 88–94 GeV | | | (00) timough his do | ouy mico c | ε (ε = ε ε. μ) | |
| ⁶³ Limit derived in t | he context | of composite $\it Z$ mo | del. | | $\Gamma((D^0/\overline{D}^0)X)/\Gamma(h)$ | adrons) | DO CUMENT ID | TEC | COMMENT | Γ_{29}/Γ_{0} |
| $\Gamma(\pi^{\pm}W^{\mp})/\Gamma_{\text{total}}$ | | | | Г19/Г | VALUE 0.296±0.019±0.021 | 369 | DOCUMENT ID 77 ABREU | 931 DLP | <u> СОММЕЛТ</u> Н Ест = 88-9- | 1 GeV |
| The value is fo | the sum o | of the charge states <u>DOCUMENT ID</u> | indicated. <u>TECN</u> | COMMENT | 77 The (D^0/\overline{D}^0) stat | es in AB | REU 931 are detect | ed by the | 0 | |
| <7 × 10 ⁻⁵ | 95 | DECAMP | 92 ALEF | E ^{ee} _{cm} = 88-94 GeV | | | Italii oi ABREO 331 | ,. | | |
| $\Gamma(\rho^{\pm}W^{\mp})/\Gamma_{\text{total}}$ | | | | Г /Г | $\Gamma(D^{\pm}X)/\Gamma(\text{hadrons})$ | 5) | 0.0 50 45 45 40 | T.C. | | Γ_{30}/Γ_{0} |
| | r the sum o | of the charge states | indicated. | Γ ₂₀ /Γ | <u>VALUE</u> 0.174±0.016±0.018 | 539 | DOCUMENT ID 78 ABREU | 93i DLP | <u> СОММЕЛТ</u> Н Е ее = 88-9- | 1 GeV |
| VALUE | <u>CL%</u> | DO CUMENT ID | TECN | | 78 The D^\pm states in A | | | | | |
| $< 8.3 \times 10^{-5}$ | 95 | DECAMP | 92 ALEF | E ee = 88-94 GeV | result (see the errat | um of Al | BREU 93i). | c N n n dec | ay mode. This is | a concete |
| $\Gamma(J/\psi(1S)X)/\Gamma_{to}$ | tal | | | Γ ₂₁ /Γ | $\Gamma(D^*(2010)^{\pm}X)/\Gamma($ | hadron | 5) | | | Γ_{31}/Γ_{0} |
| VALUE (units 10 ⁻³) | | DO CUMENT ID | TECN | COMMENT | The value is for t | he sum o | of the charge states | | | . 31/. (|
| 3.51 + 0.23 OUR AVE | RAGE F | rror includes scale fa | actor of 1.1 | | VALUE 0.163±0.019 OUR AVE | EVTS PAGE | DO CUMENT ID | | N COMMENT | |
| | | | | | $0.155 \pm 0.019 \pm 0.013$ | 35.8 | ⁷⁹ ABREU | | . э. Н <i>Е <mark>ее</mark></i> = 88-9- | 1 GeV |
| $3.21 \pm 0.21 + 0.19 \\ -0.28$ | 553 | 64 ACCIARRI | 99F L3 | E ^{ee} _{cm} = 88–94 GeV | 0.21 ±0.04 | 362 | ⁸⁰ DECAMP | | P E ee = 88-9 | |
| 3.9 ±0.2 ±0.3 | 511 | | | . E ^{ee} _{cm} = 88-94 GeV | $^{79}D^*(2010)^{\pm}$ in ABF | REU 931 a | are reconstructed fr | om $D^0\pi^\pm$, | with $D^0 \rightarrow K$ | $-\pi^+$. Th |
| 3.73±0.39±0.36 | 153 | 66 ABREU | | H E ee = 88–94 GeV | new CLEO II meası | rement o | of B($D^{*\pm} \rightarrow D^0 \pi$ | $^{\pm}) = (68.1)$ | \pm 1.6) % is use | d. This is |
| | | | | annels. The branching ratio | corrected result (see ⁸⁰ DECAMP 91J repo | eine erra rt Β(Ω*/ | $2010)^+ \rightarrow D^0 \pi^+$ |).)B(D ⁰ → | K−π+) г(D* | (2010)±x |
| | | | | $\pm 0.4 ^{+0.4}_{-0.2} ({ m theor.})) 	imes 10^{-4}.$ So ton pairs. $(4.8 \pm 2.4)\%$ of | $/\Gamma(hadrons) = (5$ | .11 ± 0. | $34) 	imes 10^{-3}$ They | obtained t | he above numbe | er assumin |
| this branching rat | io is due to | prompt $J/\psi(1S)$ p | production (A | LEXANDER 96N). | $B(D^0 \rightarrow K^-\pi^+)$ | | | | | |
| ⁶⁶ Combining $\mu^+ \mu^-$ | and e^+e | — channels and taki | ing into acco | unt the common systematic | We have rescaled the II branching ratio B | neir origin (D*(201 | nal result of 0.26 \pm | 0.05 taking (68.1 ± 1.6 | into account the 61% | new CLE |
| errors. $(7.7 + 6.3)$ | % of this b | ranching ratio is du | ie to prompt | $J/\psi(1S)$ production. | | | | (00.1 ± 1.0 | 0) /0. | |
| $\Gamma(\psi(2S)X)/\Gamma_{	ext{total}}$ | | | | Γ ₂₂ /Γ | $\Gamma(D_{s1}(2536)^{\pm}X)/\Gamma$ | | | | | Γ_{32}/Γ |
| /ALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | • | <i>D_{s1}</i> (2536) [±] is a <i>VALUE</i> (%) | | ed orbitally-excited s | | D _S meson. NCOMMENT | |
| .60±0.29 OUR AVE | | | | | 0.52±0.09±0.06 | 92 | 81 HEISTER | | P E cm = 88-9 | 1 GeV |
| $.6 \pm 0.5 \pm 0.3$ | 39 | 67 ACCIARRI | 97J L3 | E ^{ee} _{cm} = 88-94 GeV | 81 HEISTER 02B recor | | | | | |
| $1.6 \pm 0.3 \pm 0.2$ | 46.9 | | 96B OPAI | . E ^{ee} _{Cm} = 88–94 GeV | $D_{s1}(2536)^{\pm} \rightarrow D^{s}$ | *0 K±. 7 | The quoted branchin | g ratio assu | $s1(2330) \rightarrow L$ imes that the dec | avwidth o |
| 1.60±0.73±0.33 | 5.4 | ⁶⁹ ABREU | | H <i>E</i> ^{ee} _{cm} = 88–94 GeV | the D _{s1} (2536) is sa | nturated l | by the two measured | decay mod | des. | , |
| $= \mu$, e). | easure this | branching ratio via | the decay c | hannel $\psi(2S) ightarrow \ell^+\ell^-$ (ℓ | $\Gamma(D_{sJ}(2573)^{\pm}X)/\Gamma$ | (hadroi | ns) | | | Γ_{33}/Γ_{0} |
| 68 ALEXANDER 96 | B measure | this branching ra | atio via the | decay channel $\psi(2S)$ $ ightarrow$ | | | ed orbitally-excited | state of the | D_c meson. | - 33/ - |
| $J/\psi \pi^+ \pi^-$, with | $J/\psi \rightarrow \ell$ | + e- | | | VALUE (%) | EVTS | DO CUMENT ID | | | |
| | | ~ . | | | | | | | <u>COMMENT</u> | |
| | ure this br | anching ratio via dec | cay channel a | $\psi(2S) ightarrow J/\psi \pi^+ \pi^-$, with | | 64 | 82 HEISTER | | | 1 GeV |
| $J/\psi \rightarrow \mu^+ \mu^-$ | ure this br | anching ratio via dec | cay channel व | | $0.83 \pm 0.29 ^{+0.07}_{-0.13}$ | 64 | 82 HEISTER | 02в ALE | P E ee = 88-9 | |
| $J/\psi ightarrow \mu^+ \mu^ \Gamma(\chi_{c1}(1P)X)/\Gamma_{to}$ | ure this br | anching ratio via dec | cay channel व | $\psi(2S) ightarrow \; J/\psi \pi^+ \pi^-$, with $$\Gamma_{23}/\Gamma$$ | 0.83±0.29+0.07 0.13 82 HEISTER 02B recor | 64 nstruct th | 82 HEISTER | 02B ALE | P $E_{\text{cm}}^{ee} = 88-9$ | ⁰ К [±] . Тһ |
| $J/\psi ightarrow \mu^+ \mu^-$. $\Gamma(\chi_{c1}(1P)X)/\Gamma_{to}$ $VALUE (units 10^{-3})$ | tal | onching ratio via dec <u>DOCUMENT ID</u> | | Γ ₂₃ /Γ | $0.83 \pm 0.29 ^{+0.07}_{-0.13}$ | 64 nstruct th | 82 HEISTER | 02B ALE | P $E_{\text{cm}}^{ee} = 88-9$ | ⁰ К [±] . Тһ |
| $J/\psi ightarrow \mu^+ \mu^ \Gamma(\chi_{c1}(1P)X)/\Gamma_{to}$ $\Delta LUE (units 10^{-3})$ $\Delta 2.9 \pm 0.7 \text{ OUR AVER}$ | tal | anching ratio via dec | | Γ ₂₃ /Γ | 0.83±0.29±0.07 0.13 82 HEISTER 02B recor quoted branching ra decay width. | 64 nstruct th | 82 HEISTER his meson in the dec nes that the detected | 02B ALE | P $E_{\text{cm}}^{ee} = 88-9$ | ⁰ K [±] . Th % of the fu |
| $J/\psi \rightarrow \mu^{+}\mu^{-}$ $\Gamma(\chi_{c1}(1P)X)/\Gamma_{to}$ VALUE (units 10^{-3}) 2.9 \pm 0.7 OUR AVER. 2.7 \pm 0.6 \pm 0.5 | tal EVTS AGE 33 | anching ratio via dec <u>DOCUMENT ID</u> | 7ECN | Γ_{23}/Γ _ $COMMENT$ $E_{CM}^{ee}=88-94 \text{ GeV}$ | 0.83±0.29±0.07 0.83±0.29±0.03 82 HEISTER 02B record quoted branching radecay width. Γ(D*/(2629)±X)/Γ D*/(2629)± is a | 64 nstruct th ntio assun | 82 HEISTER als meson in the decines that the detected as) I radial excitation of | 02B ALE ay mode D_3^* d decay mode | P $E_{\text{cm}}^{ee} = 88-9$. $F_{\text{cm}}^{*} = 88-9$. | ⁰ К [±] . Тһ |
| $J/\psi \rightarrow \mu^{+}\mu^{-}$. $\Gamma(\chi_{c1}(1P)X)/\Gamma_{to}$ $VALUE \text{ (units } 10^{-3}\text{)}$ $2.9 \pm 0.7 \text{ OUR AVER}$ $2.7 \pm 0.6 \pm 0.5$ $5.0 \pm 2.1 + 1.5$ $6.0 \pm 2.1 + 0.9$ | talEVTS AGE33 6.4 | DOCUMENT ID 70 ACCIARRI 71 ABREU | 97J L3 | | 0.83±0.29±0.07 82 HEISTER 02B record quoted branching radecay width. Γ(D*/(2629)±X)/Γ D*/(2629)± is a MALUE | 64 nstruct th ntio assun | 82 HEISTER als meson in the decines that the detected is) I radial excitation or DOCUMENT ID | 02B ALE ay mode D_3^* d decay mode f the $D^*(20)$ | P $E_{\text{CM}}^{ee} = 88-9$. $E_{\text{CM}}^{*} = 88-9$. $E_{\text{CM}}^{*} = 88-9$. $E_{\text{CM}}^{*} = 88-9$. $E_{\text{CM}}^{*} = 88-9$. | ⁰ κ [±] . Th % of the fu Γ₃₄/Γ ι |
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| $J/\psi \rightarrow \mu^{+}\mu^{-}$ $(Xc1(1P)X)/\Gamma_{to}$ $(ALUE (units 10^{-3})$ $(2.9\pm0.7 \text{ OUR AVER.})$ $(2.7\pm0.6\pm0.5$ $(3.0\pm2.1^{+}1.5$ $(3.0\pm0.1^{+}1.5)$ $($ | tal $\frac{EVTS}{33}$ 6.4 easure this ℓ^- ($\ell=\mu$ gaussian slitio is meastal $\frac{CL\%}{90}$ erive this lii. The $M(\ell)$ less for χ_{C1} χ_{C1} χ_{C1} χ_{C1} χ_{C2} χ_{C1} χ_{C1} χ_{C2} χ_{C1} χ_{C2} χ_{C1} χ_{C2} χ_{C2} χ_{C1} χ_{C2} χ_{C | pocument idea of the decay of | 97J L3 94P DLPH in the decay of γ)- $M(\ell^+\ell^ \chi_{C2}$. channel χ_{C1} 97J L3 TECN 97J L3 mannel χ_{C2} - mass differe Γ_{25}/Γ_{C2} 96F OPAI | Γ_{23}/Γ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ hannel $\chi_{c1} \rightarrow J/\psi + \gamma$, or mass difference spectrum $F_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow J/\psi + \gamma$, where $J/\psi \rightarrow$ | 0.83±0.29±0.07 82 HEISTER 02B record quoted branching radecay width. $\Gamma(D^{**}(2629)^{\pm} \times)/\Gamma$ $D^{**}(2629)^{\pm} \text{ is a } \Delta LUE$ searched for 83 ABBIENDI 01N searched for 84 ABBIENDI 01N searched for 87 (2629) $\pm \times B(D^*)$ $\Gamma(B^* \times)/[\Gamma(B \times) + AS \text{ the experimen should be taken with } \Delta LUE$ 0.75 ±0.04 OUR AVE 0.76 ±0.036±0.083 0.771±0.026±0.070 0.72 ±0.03 ±0.06 0.76 ±0.08 ±0.06 84 ACKERSTAFF 97M 4.1)% <i>b</i> -baryon con | (hadron predicted arched for and D ⁰ (2629) + F(2629) + F(362) + | 82 HEISTER is meson in the decines that the detected here. 13 ABBIENDI or the decay mode $0 \rightarrow K^-\pi^+$. The properties of the decay mode $0 \rightarrow K^-\pi^+$. The properties of the different values of the many states of the decay mode $0 \rightarrow K^-\pi^+$. The properties of the decay mode $0 \rightarrow K^-\pi^+$. The properties of the decay mode $0 \rightarrow K^-\pi^+$. The properties of the decay mode $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^+$. The decay mode $0 \rightarrow K^-\pi^+$ and $0 \rightarrow K^-\pi^$ | 02B ALE ay mode D d decay mod f the D*(20 | P $E_{cm}^{ee} = 88-9$. $^*_{52}(2573)^{\pm} \rightarrow E$ de represents 45° $^*_{52}(2573)^{\pm} \rightarrow E$ de represents 45° $^*_{52}(2573)^{\pm} \rightarrow E$ | $0 \kappa^{\pm}$. The following of the full formula of the full for |
| $J/\psi \rightarrow \mu^{+} \mu^{-}$ $(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\chi_{c2}(1P)X)/\Gamma_{to}$ $(\chi_{c2}(1P)X)/\Gamma_{c2}(1P)X$ | tal $\frac{EVTS}{33}$ 6.4 easure this ℓ^- ($\ell=\mu$ gaussian slitio is meas tal $\frac{CL\%}{90}$ erive this lii. The $M(\ell)$ less for χ_{C1} $\frac{EVTS}{6.4}$ identify the strict of the strict o | pocument idea of the decay of | 97. L3 94. DLPI 1 the decay of γ)- $M(\ell^+\ell^ \chi_{c2}$. 1 thannel χ_{c1} 97. L3 1 annel χ_{c2} - mass difference 1 25. ℓ 96. OPAI to any of the | Γ_{23}/Γ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ hannel $\chi_{c1} \rightarrow J/\psi + \gamma$, or mass difference spectrum $F_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow J/\psi $ | 0.83 \pm 0.29 $^{+}$ 0.07 82 HEISTER 02b record quoted branching radecay width. $\Gamma(D^{*\prime}(2629)^{\pm} X)/\Gamma$ $D^{*\prime}(2629)^{\pm} \text{ is a }$ MALUE searched for 83 ABBIENDI 01N se $D^{*+} \rightarrow D^{0}\pi^{+},$ $D^{*\prime}(2629)^{\pm} \times B(D^{*\prime})$ $\Gamma(B^{*}X)/[\Gamma(BX) +$ As the experiment should be taken with the experiment of the experime | (hadron predicted arched for and DO to the sassum with caut EVTS ERAGE | 82 HEISTER is meson in the decines that the detecter is) I radial excitation of the decay mode of | 02B ALE ay mode D d decay mod f the D*(20 TECN 01N OPA e D*/(2629 hey quote < 3.1 × 10 1 the D-baryo TECN 97M OPA 96D ALE 95R DLP 95B L3 ruction meta | P $E_{cm}^{ee} = 88-9$. $(2573)^{\pm} \rightarrow E$ de represents $(45)^{0}$ $(2573)^{\pm} \rightarrow E$ de represents $(45)^{0}$ $(2573)^{\pm} \rightarrow E$ $(260)^{\pm} \rightarrow E$ (260) | 10 K^{\pm} . The 10 K^{\pm} of the full 12 13 14 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 15 1 |
| $J/\psi \rightarrow \mu^{+}\mu^{-}$. $(\chi_{c1}(1P)X)/\Gamma_{t0}$ $(\chi_{c1}(1P)X)/\Gamma_{t0}$ $(\chi_{c1}(1P)X)/\Gamma_{t0}$ $(\chi_{c1}(1P)X)/\Gamma_{t0}$ $(\chi_{c2}(1P)X)/\Gamma_{t0}$ | tal $\frac{EVTS}{33}$ 6.4 easure this ℓ^- ($\ell=\mu$ gaussian sl tio is meas tal $\frac{CL\%}{90}$ 9. The $M(\ell)$ ees for χ_{C1} $\frac{EVTS}{6.4}$ is identify it into e^+e^- | pocument identify the decay of | 97. L3 94. DLPI 1 the decay of γ)- $M(\ell^+\ell^ \chi_{c2}$. 1 thannel χ_{c1} 97. L3 1 annel χ_{c2} - mass difference 1 25. ℓ 96. OPAI to any of the | Γ_{23}/Γ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ hannel $\chi_{c1} \rightarrow J/\psi + \gamma$, or mass difference spectrum $F_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow J/\psi + \gamma$, where $J/\psi \rightarrow$ | 0.83±0.29±0.07 82 HEISTER 02B record quoted branching radecay width. $\Gamma(D^{*\prime}(2629)^{\pm} \times)/\Gamma$ $D^{*\prime}(2629)^{\pm} \text{ is a}$ **MALUE** **searched for 83 ABBIENDI 01N seans $D^{*+} \rightarrow D^{0} \pi^{+},$ $D^{*\prime}(2629)^{\pm} \times B(D^{*})$ $\Gamma(B^{*} \times)/\Gamma(B^{*} \times)/\Gamma(B^{*} \times B(D^{*})$ $\Gamma(B^{*} \times B(D^{*})/\Gamma(B^{*} \times B(D^{*}))$ **One of the experiment should be taken with the experiment of the experim | (hadron predicted arched for and D ⁰ (2629) + F(2629) + F(362) + | 82 HEISTER is meson in the decidents that the detected here. 13 ABBIENDI or the decay mode $0 \to K^-\pi^+$. The properties of the decay mode of the decay m | O2B ALE ay mode D d decay mod f the D*(20 TECN O1N OPA c D*/(2629 hey quote < 3.1 × 10 the b-barye TECN F 97M OPA 96D ALE 95B LB ruction met a b-flavore of B hadd | P $E_{cm}^{ee} = 88-9$. $(2573)^{\pm} \rightarrow E_{cm}^{ee}$ de represents 45°. $(310)^{\pm}$ meson. N COMMENT L $E_{cm}^{ee} = 88-9$. $(3)^{\pm} \rightarrow D^{*\pm}\pi$ a 95% CL limit -3. Fab./(on contribution, N) COMMENT L $E_{cm}^{ee} = 88-9$. L $E_{cm}^{ee} = 88-9$. $E_{cm}^{ee} = 88-9$. $E_{cm}^{ee} = 88-9$. And assume the meson mixture trans and assume the constant assume the constant of | $0 \kappa^{\pm}$. The following of the full for K is K in K |
| $J/\psi \rightarrow \mu^+\mu^-$. $(\mathbf{Xc1}(1P)\mathbf{X})/\Gamma_{to}$ $ALUE$ (units 10^{-3}) $.9\pm0.7$ OUR AVER. $.7\pm0.6\pm0.5$ $.0\pm2.1^{+1.5}_{-0.9}$ $.0\pm2.1^{+1.5}_{-0.9}$ ACCIARRI 97J m with $J/\psi \rightarrow \ell^+$ is fitted with two 1 71 This branching ra 1 4 $\mu^+\mu^ .1$ 5 $(\mathbf{Xc2}(1P)\mathbf{X})/\Gamma_{to}$ 1 6 $\ell^+\ell^-$ ($\ell=\mu,e$ two gaussian shall $\ell^+\ell^-$ ($\ell=\mu,e$ two gaussian shall ℓ^-) $.0\pm0.4\pm0.22$ 1 73 ALEXA NDER 96 through its decay of ±0.2 due to ti | tal \underbrace{EVTS}_{AGE} 33 6.4 easure this ℓ^- ($\ell=\mu$ gaussian sitio is meas tal $\underbrace{CL\%_{90}}_{CFIVE}$ this lii. The $M(\ell)$ less for χ_{c1} $\underbrace{EVTS}_{6.4}$ fidentify the into e^+e^- in e producti | pocument identify the decay of | 97. L3 94. DLPI 1 the decay of γ)- $M(\ell^+\ell^ \chi_{c2}$. 1 thannel χ_{c1} 97. L3 1 annel χ_{c2} - mass difference 1 25. ℓ 96. OPAI to any of the | Γ_{23}/Γ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ hannel $\chi_{c1} \rightarrow J/\psi + \gamma$,) mass difference spectrum $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ three lowest bound states) for includes an uncertainty | 0.83 \pm 0.29 $^{\pm}$ 0.07 82 HEISTER 02B record quoted branching radecay width. $\Gamma(D^{*\prime}(2629)^{\pm} X)/\Gamma$ $D^{*\prime}(2629)^{\pm} \text{ is a }$ $MALUE$ searched for 83 ABBIENDI 01N sea $D^{*+} \rightarrow D^0 \pi^+, D^{*\prime}(2629)^{\pm} \times B(D^*)$ $\Gamma(B^*X)/[\Gamma(BX) + AS the experiment should be taken with the experiment of th$ | (hadron predicted arched fram D ⁰ (2629) + F(B*X ts assum with caut EVTS ERAGE | 82 HEISTER is meson in the decidence that the detecter is (a) It radial excitation of the decay mode of the decay mo | 02B ALE ay mode D_0^* d decay mod f the D^* (20 TECN 1N OPA be D^* (2629 bey quote $< 3.1 \times 10$ TECN 7ECN 97M OPA 96D ALE 95R DLP 95B L3 ruction met a b -flavore of B hadio a b -flavo | P $E_{cm}^{ee} = 88-9$. $(2573)^{\pm} \rightarrow E_{cm}^{*}$ de represents 45°. $(2573)^{\pm} \rightarrow E_{cm}^{*}$ de represents 45°. $(2573)^{\pm} \rightarrow E_{cm}^{*}$ $(25$ | $0 K^{\pm}$. The first of the fit for Z - with for Z - F35+F36 our average of B_{u} , B_{d} , and B_{d |
| $J/\psi \rightarrow \mu^{+}\mu^{-}$. $T(\chi_{c1}(1P)X)/\Gamma_{to}$ $(\lambda_{LUE} \text{ (units } 10^{-3})$ $2.9 \pm 0.7 \text{ OUR AVER}$ $2.7 \pm 0.6 \pm 0.5$ $5.0 \pm 2.1 \pm 1.5$ $5.0 \pm 2.1 \pm 1.5$ 6.0 ± 2.1 | tal \underbrace{EVTS}_{AGE} 33 6.4 easure this ℓ^- ($\ell=\mu$ gaussian sitio is meas tal $\underbrace{CL\%_{90}}_{CFIVE}$ this lii. The $M(\ell)$ less for χ_{c1} $\underbrace{EVTS}_{6.4}$ fidentify the into e^+e^- in e producti | pocument identify the decay of | 97J L3 94P DLPI of the decay of γ)- $M(\ell^+\ell^-)$ χ_{C2} . channel χ_{C1} 97J L3 97J L3 nannel χ_{C2} - mass difference F25/ 96F OPAI to any of the systematic e | Γ_{23}/Γ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ hannel $\chi_{c1} \rightarrow J/\psi + \gamma$, or mass difference spectrum $F_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow J/\psi $ | 0.83±0.29±0.07 82 HEISTER 02B record quoted branching radecay width. $\Gamma(D^{**}(2629)^{\pm} \times)/\Gamma$ $D^{**}(2629)^{\pm} \text{ is a }$ MALUE Searched for 83 ABBIENDI 01N SE $D^{*+} \rightarrow D^{0}\pi^{+},$ $D^{**}(2629)^{\pm} \times B(D^{*})$ $\Gamma(B^{*} \times)/[\Gamma(B \times)^{+} + AS the experimens should be taken with the experimens of the experim$ | (hadron predicted arched for and Down (2629) + F(B*X ts assum with caut EVTS 1378 1 use an tribution. e an inclusive | 82 HEISTER is meson in the decidence that the detected has been as that the detected has been as that the detected has been as a substitution of the decay mode $0 \to K - \pi + T + T \to D^* + \pi + T \to D^* + D^* + T \to D^* + D$ | 02B ALE ay mode D_0^* d decay mode if the D^* (262 in OPA is D^* (2629 in OPA if the D^* ALE if the D^* DA if the | P $E_{cm}^{ee} = 88-9$. $E_{cm}^{*} = 88-9$. | $0 K^{\pm}$. The first of the full for K^{\pm} and K^{\pm} are the full for K^{\pm} and K^{\pm} are the full for K^{\pm} and K^{\pm} are the full form of t |

 $^{87}\mathrm{ACCIARRI}$ 958 assume a 9.4% b-baryon contribution. The value refers to a b-flavored mixture of B_u , B_d , and B_S

<13.9 × 10⁻⁵ 95 75 ACCIARRI 97R L3 $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ $^{75}\,\mathrm{ACCIARRI}$ 97R search for $\varUpsilon(2\mathrm{S})$ through its decay into $\ell^+\,\ell^-$ ($\ell=\,e$ or μ).

 74 ACCIARRI 99F search for $\varUpsilon(1S)$ through its decay into $\ell^+\ell^-$ ($\ell=e$ or μ).

 $\Gamma(\Upsilon(2S)X)/\Gamma_{total}$

DOCUMENT ID TECN COMMENT

 Γ_{27}/Γ

$\Gamma(B+X)/\Gamma(hadrons)$

"OUR EVALUATION" is obtained using our current values for ${\bf f}(\overline{b}\to {\it B}^+)$ and ${\bf R}_b$ $=\Gamma(b\,\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(B^+\,X)/\Gamma(\text{hadrons})=R_b\times f(\overline{b}\to B^+)$. The decay fraction $f(\overline{b} \to B^+)$ was provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009/#FRACZ).

DO CUMENT ID TECN COMMENT 0.0869±0.0019 OUR EVALUATION 0.0887 ± 0.0030

 88 ABDALLAH 03K DLPH $E_{
m \, cm}^{\it \, ee}=$ 88–94 GeV

 88 ABDALLAH 03K measure the production fraction of B^+ mesons in hadronic Z decays $f(B^+)=(40.99\pm0.82\pm1.11)\%$. The value quoted here is obtained multiplying this production fraction by our value of $R_b=\Gamma(\overline{b}\,b)/\Gamma(hadrons)$.

 $\Gamma(B_s^0X)/\Gamma(hadrons)$

"OUR EVALUATION" is obtained using our current values for f $(\overline{b} o B^0_S)$ and R $_b$ $= \Gamma(b\,\overline{b})/\Gamma(\text{hadrons}).$ We calculate $\Gamma(B_s^0)/\Gamma(\text{hadrons}) = R_b \times f(\overline{b} \to B_s^0).$ The decay fraction $f(\overline{b} \to B_s^0)$ was provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009/#FRACZ).

| VALUE | - ' | DO CUMENT ID | _ | TECN | COMMENT |
|------------------------------|-----|--------------|-----|------|-----------------------------------|
| 0.0227±0.0019 OUR EVALUATION | NC | | | | |
| seen | 89 | ABREU | 92м | DLPH | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |
| seen | 90 | ACTON | 92N | OPAL | E ee = 88-94 GeV |
| seen | 91 | BUSKULIC | 92E | ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

⁸⁹ ABREU 92M reported value is $\Gamma(B_s^0 X)*B(B_s^0 \to D_s \mu \nu_\mu X)*B(D_s \to \phi \pi)/\Gamma(hadrons)$ $= (18 \pm 8) \times 10^{-5}$

⁹⁰ ACTON 92N find evidence for B_s^0 production using D_s - ℓ correlations, with $D_s^+ o \phi \pi^+$ and $K^*(892) K^+$. Assuming R_b from the Standard Model and averaging over the e and μ channels, authors measure the product branching fraction to be $f(\overline{b} \to B_s^0) \times B(B_s^0 \to B_s^0)$ $D_s^- \ell^+ \nu_\ell X) \times B(D_s^- \to \phi \pi^-) = (3.9 \pm 1.1 \pm 0.8) \times 10^{-4}.$

⁹¹ BUSKULIC 92E find evidence for B_s^0 production using D_s - ℓ correlations, with $D_s^+ \to$ $\phi\pi^+$ and $K^*(892)K^+$. Using B($D_s^+ \to \phi\pi^+$) = (2.7 ± 0.7)% and summing up the e and μ channels, the weighted average product branching fraction is measured to be $B(\overline{b} \to B_s^0) \times B(B_s^0 \to D_s^- \ell^+ \nu_{\ell} X) = 0.040 \pm 0.011 ^{+0.010}_{-0.012}$

 $\Gamma(B_c^+X)/\Gamma(hadrons)$ Γ_{39}/Γ_{6}

| VALUE | DO CUMENT ID | TECN | COMMENT |
|--------------|-------------------------|------|-------------------------------------------|
| searched for | 92 ACKERSTAFF 980 | OPAL | E ee = 88-94 GeV |
| searched for | ⁹³ ABREU 97E | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| searched for | 94 BARATE 97H | ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

 92 ACKERSTAFF 980 searched for the decay modes $B_{C}
ightarrow J/\psi\,\pi^{+}$, $J/\psi\,a_{1}^{+}$, and $J/\psi\ell^+\nu_\ell$, with $J/\psi\to\ell^+\ell^-$, $\ell=e,\mu$. The number of candidates (background) for the three decay modes is 2 $(0.63\pm0.2),\,0\,(1.10\pm0.22),\,$ and $1\,(0.82\pm0.19)$ respectively. Interpreting the $2B_C \to J/\psi \pi^+$ candidates as signal, they report $\Gamma(B_C^+ X) \times B(B_C \to I)$ $J/\psi\pi^+)/\Gamma$ (hadrons) = $(3.8^{+5.0}_{-2.4}\pm0.5)\times10^{-5}$. Interpreted as background, the 90% CL bounds are $\Gamma(B_c^+\,{\rm X})*{\rm B}(B_C^-\to J/\psi\pi^+)/\Gamma({\rm hadrons})<1.06\times10^{-4}$, $\Gamma(B_c^+\,{\rm X})*{\rm B}(B_C^-\to J/\psi\pi^+)/\Gamma({\rm hadrons})$ $J/\psi \, a_1^+)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \ell^+ \,
u_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \mu_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \mu_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m X})*{
m B}(B_C^- o J/\psi \, \mu_\ell)/\Gamma({
m hadrons}) < 5.29 imes 10^{-4}, \ \Gamma(B_C^+ \, {
m A})*{
m B}(B_C^- \, {
m A})*{
m B}(B_C^- \, {
m A})$ 6.96×10^{-5}

93 ABREU 97E searched for the decay modes $B_C \to J/\psi \pi^+$, $J/\psi \ell^+ \nu_\ell$, and $J/\psi (3\pi)^+$, with $J/\psi \to \ell^+\ell^-$, $\ell=e$, μ . The number of candidates (background) for the three decay modes is 1 (1.7), 0 (0.3), and 1 (2.3) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(\text{hadrons}) < (1.05-0.84) \times 10^{-4}, \Gamma(B_c^+ X)*B(B_c \to J/\psi \pi^+)/\Gamma(B_c^+ X)*B(B_c^+ $\textit{J/\psi}\ell\nu_{\ell})/\Gamma(\text{hadrons}) < (5.8-5.0) \times 10^{-5} \text{, } \Gamma(\textit{B}_{\textit{C}}^{+}\,\text{X})*\text{B}(\textit{B}_{\textit{C}}^{-}\rightarrow \textit{J/\psi}(3\pi)^{+})/\Gamma(\text{hadrons})$ < $1.75 imes 10^{-4}$, where the ranges are due to the predicted B_{C} lifetime (0.4–1.4) ps.

⁹⁴BARATE 97H searched for the decay modes $B_C \to J/\psi \pi^+$ and $J/\psi \ell^+ \nu_\ell$ with $J/\psi \to \ell^+\ell^-$, $\ell=e$, μ . The number of candidates (background) for the two decay modes is 0 (0.44) and 2 (0.81) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ \, \mathrm{X}) * \mathrm{B}(B_c \to J/\psi \, \pi^+) / \Gamma(\mathrm{hadrons}) < 3.6 \times 10^{-5}$ and $\Gamma(B_c^+ \, \mathrm{X}) * \mathrm{B}(B_c \to J/\psi \, \pi^+) / \Gamma(\mathrm{hadrons}) < 3.6 \times 10^{-5}$ $J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$.

 $\Gamma(\Lambda_c^+ X)/\Gamma(hadrons)$ Γ_{40}/Γ_{6}

| VALUE | | TECN | COMMENT |
|-----------------------------|-------------------------|----------|-------------------------------------------|
| 0.022±0.005 OUR AVE | RAGE | | |
| $0.024 \pm 0.005 \pm 0.006$ | ⁹⁵ ALEXANDER | 96R OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $0.021 \pm 0.003 \pm 0.005$ | ⁹⁶ BUSKULIC | 96Y ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

⁹⁵ ALEXANDER 96R measure R $_b$ \times f($b \rightarrow \Lambda_c^+ X$) \times B($\Lambda_c^+ \rightarrow p K^- \pi^+$) = (0.122 \pm $0.023 \pm 0.010)\%$ in hadronic Z decays; the value quoted here is obtained using our best value B($\Lambda_c^+ \to p \, K^- \pi^+$) = (5.0 \pm 1.3)%. The first error is the total experiment's error and the second error is the systematic error due to the branching fraction uncertainty.

 96 BUSKULIC 96Y obtain the production fraction of Λ_c^+ baryons in hadronic Z decays f(b \rightarrow $\Lambda_c^+ X) = 0.110 \pm 0.014 \pm 0.006$ using B($\Lambda_c^+ \rightarrow p \ K^- \pi^+$) = (4.4 \pm 0.6)%; we have rescaled using our best value B($\Lambda_C^+ o p \, K^- \, \pi^+$) = (5.0 \pm 1.3)% obtaining f(b o $\Lambda_c^+ X) = 0.097 \pm 0.013 \pm 0.025$ where the first error is their total experiment's error and the second error is the systematic error due to the branching fraction uncertainty. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\overline{b})/\Gamma(hadrons).$

 $\Gamma(\Xi_c^0 X)/\Gamma(hadrons)$

seen

 Γ_{41}/Γ_{6}

DOCUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 97 ABDALLAH 05C DLPH $E_{
m cm}^{\it ee}=$ 88–94 GeV

 97 ABDALLAH 05c searched for the charmed strange baryon Ξ_{c}^{0} in the decay channel $\Xi_c^0 \to \Xi^-\pi^+ \ (\Xi^- \to \Lambda\pi^-)$. The production rate is measured to be $f_{\Xi^0} imes {\sf B}(\Xi_c^0 \to \pi^+)$ $\Xi^-\pi^+) = (4.7 \pm 1.4 \pm 1.1) \times 10^{-4}$ per hadronic Z decay.

$\Gamma(\Xi_b X)/\Gamma(hadrons)$

 Γ_{42}/Γ_{6}

Here Ξ_b is used as a notation for the strange b-baryon states Ξ_b^- and Ξ_b^0 .

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-------------------------------|---------|---------|-------------------------------------------|
| • • • We do not use th | e following data for averages | , fits, | limits, | etc. • • • |
| seen | ⁹⁸ ABDALLAH | 05 C | DLPH | $E_{\rm cm}^{ee} = 88-94 {\rm GeV}$ |
| seen | ⁹⁹ BUSKULIC | 96T | ALEP | E ee = 88-94 GeV |
| seen | 100 ABREU | 95∨ | DLPH | E ^{ee} _{cm} = 88-94 GeV |

 98 ABDALLAH 05c searched for the beauty strange baryon \varXi_b in the inclusive semileptonic decay channel $\Xi_b \to \Xi^- \ell^- \overline{\nu}_\ell X$. Evidence for the Ξ_b production is seen from the observation of $\Xi^{\tilde{\mp}}$ production accompanied by a lepton of the same sign. From the excess of "right-sign" pairs $\Xi^{\mp}\ell^{\mp}$ compared to "wrong-sign" pairs $\Xi^{\mp}\ell^{\pm}$ the production rate is measured to be $B(b \to \Xi_b) \times B(\Xi_b \to \Xi^{-}\ell^{-}X) = (3.0 \pm 1.0 \pm 0.3) \times 10^{-4}$ per lepton species, averaged over electrons and muons.

99 BUSKULIC 96T investigate Ξ -lepton correlations and find a significant excess of "rightsign" pairs $\Xi^\mp\ell^\mp$ compared to "wrong-sign" pairs $\Xi^\mp\ell^\pm$. This excess is interpreted as evidence for Ξ_b semileptonic decay. The measured product branching ratio is B($b\to 0$) $\Xi_b) imes {\sf B}(\Xi_b o X_c X \ell^- \overline{
u}_\ell) imes {\sf B}(X_c o \Xi^- X') = (5.4 \pm 1.1 \pm 0.8) imes 10^{-4}$ per lepton species, averaged over electrons and muons, with X_c a charmed baryon.

 100 ABREU 95v observe an excess of "right-sign" pairs $\varXi^{\mp}\ell^{\bar{\mp}}$ compared to "wrong-sign" pairs $\varXi^\mp\ell^\pm$ in jets: this excess is interpreted as evidence for the beauty strange baryon Ξ_b production, with $\Xi_b \to \Xi^- \ell^- \overline{\nu}_\ell X$. They find that the probability for this signal to because from non b-baryon decays is less than 5×10^{-4} and that Λ_b decays can account for less than 10% of these events. The Ξ_b production rate is then measured to be B($b\to$ $\Xi_b)\times {\rm B}(\Xi_b\to\Xi^-\ell^-X)=(5.9\pm2.1\pm1.0)\times10^{-4}$ per lepton species, averaged over electrons and muons.

 $\Gamma(b ext{-baryon X})/\Gamma(\text{hadrons})$ "OUR EVALUATION" is obtained using our current values for $f(b\to b\text{-baryon})$ and $R_b = \Gamma(b\overline{b})/\Gamma(hadrons)$. We calculate $\Gamma(b$ -baryon X)/ $\Gamma(hadrons) = R_b \times f(b \to b$ -baryon). The decay fraction $f(b \to b$ -baryon) was provided by the Heavy Flavor Averaging Group (HFAG, http://www.slac.stanford.edu/xorg/hfag/osc/PDG_2009). VALUE DOCUMENT ID TECN COMMENT

0.0197±0.0032 OUR EVALUATION

DOCUMENT ID TECN COMMENT

$0.0221 \pm 0.0015 \pm 0.0058$

¹⁰¹ BARATE

98v ALEP $E_{cm}^{ee} = 88-94 \text{ GeV}$

 $^{101}\,\mathrm{BARATE}$ 98V use the overall number of identified protons in \emph{b} -hadron decays to measure f(b \rightarrow b-baryon) = 0.102 \pm 0.007 \pm 0.027. They assume BR(b-baryon \rightarrow pX) = $(58 \pm 6)\%$ and BR($B_s^0 \rightarrow pX$) = $(8.0 \pm 4.0)\%$. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\,\overline{b})/\Gamma(hadrons)$.

$\Gamma(\text{anomalous } \gamma + \text{hadrons})/\Gamma_{\text{total}}$

 Γ_{44}/Γ

Limits on additional sources of prompt photons beyond expectations for final-state

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-----|--------------|-----|------|------------------|
| $< 3.2 \times 10^{-3}$ | 95 | 102 AKRAWY | 90J | OPAL | E ee = 88-94 GeV |

 $102\,{\rm A\,KRAWY}$ 90J report $\Gamma(\gamma{\rm X})<8.2$ MeV at 95%CL. They assume a three-body $\gamma\,q\,\overline{q}$ distribution and use E($\gamma)>10$ GeV.

 103 ACTON 91B looked for isolated photons with E>2% of beam energy (> 0.9 GeV).

 104 ACTON 91B looked for isolated photons with E>2% of beam energy (> 0.9 GeV).

| $\Gamma(\tau^+\tau^-\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₄₇ /Γ |
|------------------------------------------------|-----|--------------|-----|------|--------------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <7.3 × 10 ⁻⁴ | 95 | 105 ACTON | 91B | OPAL | Eee 91.2 GeV | |

105 ACTON 91B looked for isolated photons with E>2% of beam energy (> 0.9 GeV).

| $\Gamma(\ell^+\ell^-\gamma\gamma)/\Gamma_{	ext{tot}}$ The value is t | | $\ell=e,\mu,	au$ | | | Γ ₄₈ /Γ |
|-------------------------------------------------------------------------|----------|------------------|-----|------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $<6.8 \times 10^{-6}$ | 95 | 106 ACTON | 93E | OPAL | E ee = 88-94 GeV |
| 106 For $m_{\gamma\gamma}=$ 60 : | ± 5 GeV. | | | | |

| $\Gamma(q \overline{q} \gamma \gamma) / \Gamma_{\text{total}}$ | | | | | Γ ₄₉ /Γ |
|----------------------------------------------------------------|--------|--------------|-----|------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $<5.5 \times 10^{-6}$ | 95 | 107 ACTON | 93E | OPAL | E ee = 88-94 GeV |
| 107 For $m_{\gamma\gamma}=$ 60 \pm | 5 GeV. | | | | |

| $\Gamma(u\overline{ u}\gamma\gamma)/\Gamma_{ m total}$ | | | | | Γ ₅₀ /Γ |
|---------------------------------------------------------|--------|----------------------|-----|------|-------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $< 3.1 \times 10^{-6}$ | 95 | ¹⁰⁸ ACTON | 93E | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 108 For $m_{\gamma\gamma}=$ 60 \pm | 5 GeV. | | | | |

| States mulcated. | | | | | |
|-------------------------|-----|--------------|------|------|-------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <2.5 × 10 ⁻⁶ | 95 | ABREU | 97c | DLPH | Eee = 88-94 GeV |
| $<1.7 \times 10^{-6}$ | 95 | AKERS | 95 W | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $< 0.6 \times 10^{-5}$ | 95 | ADRIANI | 931 | L3 | E ^{ee} _{CM} = 88-94 GeV |
| $< 2.6 \times 10^{-5}$ | 95 | DECAMP | 92 | ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

 $\Gamma(e^\pm \mu^\mp)/\Gamma(e^+ e^-) \\ \text{Test of lepton family number conservation. The value is for the sum of the charge}$ states indicated. CL%

TECN COMMENT

| <0.07 | 90 | ALBAJAR | 89 | UA1 | $E_{\rm cm}^{PP} = 546,630 \; {\rm GeV}$ | |
|-----------|----|---------|----|-----|------------------------------------------|---|
| c/ + T\/c | | | | | - | , |

DOCUMENT ID

 $\Gamma(e^{\pm} \tau^{\mp})/\Gamma_{total}$ Test of lepton family number conservation. The value is for the sum of the charge

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-----|--------------|------|------|-------------------------------------------|
| $< 2.2 \times 10^{-5}$ | 95 | ABREU | 97c | DLPH | E ee = 88-94 GeV |
| $< 9.8 \times 10^{-6}$ | 95 | AKERS | 95 W | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $< 1.3 \times 10^{-5}$ | 95 | ADRIANI | 931 | L3 | E ^{ee} _{cm} = 88-94 GeV |
| $<1.2 \times 10^{-4}$ | 95 | DECAMP | 92 | ALEP | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

 $\Gamma(\mu^{\pm}\tau^{\mp})/\Gamma_{ ext{total}}$ Test of lepton family number conservation. The value is for the sum of the charge states indicated

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-----|--------------|------|------|-------------------------------------------|
| $<1.2 \times 10^{-5}$ | 95 | ABREU | 97c | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| $< 1.7 \times 10^{-5}$ | 95 | AKERS | 95 W | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| $< 1.9 \times 10^{-5}$ | 95 | ADRIANI | 931 | L3 | E ee = 88-94 GeV |
| $< 1.0 \times 10^{-4}$ | 95 | DECAMP | 92 | ALEP | E ^{ee} _{cm} = 88-94 GeV |

 $\Gamma(pe)/\Gamma_{\text{total}}$ Test of baryon number and lepton number conservations. Charge conjugate states are

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-----|--------------|-----|------|-------------------------------------------|
| $<1.8 \times 10^{-6}$ | 95 | 109 ABBIENDI | 991 | OPAL | E ^{ee} _{cm} = 88-94 GeV |

 109 ABBIENDI 991 give the 95 %CL limit on the partial width $\Gamma(Z^0\to \rho\,e)\!<\!4.6$ KeV and we have transformed it into a branching ratio.

 $\Gamma(\rho\mu)/\Gamma_{total}$ Test of baryon number and lepton number conservations. Charge conjugate states are im plied.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-----|--------------|-----|------|-------------------------------------------|
| $<1.8 \times 10^{-6}$ | 95 | 110 ABBIENDI | 991 | OPAL | E ^{ee} _{cm} = 88-94 GeV |

 110 ABBIENDI 991 give the 95%CL limit on the partial width $\Gamma(Z^0
ightarrow
ho \, \mu) <$ 4.4 KeV and we have transformed it into a branching ratio.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC Z DECAY

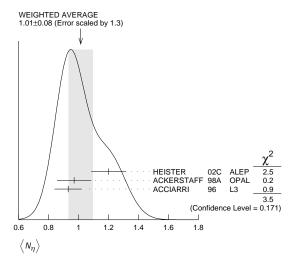
Summed over particle and antiparticle, when appropriate.

 $\langle N_{\sim} \rangle$

| ***\/ | | | | |
|---------------------------------|--------------|-----|------|------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 20.97±0.02±1.15 | ACKERSTAFF | 98A | OPAL | E ^{ee} _{cm} = 91.2 GeV |
| $\langle N_{\pi^{\pm}} \rangle$ | | | | |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 17.03 ±0.16 OUR AVERAGE | | | | |
| 17.007 ± 0.209 | ABE | 04c | SLD | <i>E</i> ^{ee} cm = 91.2 GeV |
| $17.26 \pm 0.10 \pm 0.88$ | ABREU | 98L | DLPH | E ^{ee} _{cm} = 91.2 GeV |
| 17.04 ± 0.31 | BARATE | 98∨ | ALEP | E ^{ee} _{cm} = 91.2 GeV |
| 17.05 ± 0.43 | AKERS | 94P | OPAL | E ^{ee} _{cm} = 91.2 GeV |
| $\langle N_{\pi^0} \rangle$ | | | | |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 9.76±0.26 OUR AVERAGE | | | | |
| $9.55 \pm 0.06 \pm 0.75$ | ACKERSTAFF | 98A | OPAL | E ^{ee} _{cm} = 91.2 GeV |
| $9.63 \pm 0.13 \pm 0.63$ | BARATE | 97J | ALEP | E ^{ee} _{cm} = 91.2 GeV |
| $9.90 \pm 0.02 \pm 0.33$ | ACCIARRI | 96 | L3 | E ^{ee} _{cm} = 91.2 GeV |
| $9.2 \pm 0.2 \pm 1.0$ | ADAM | 96 | DLPH | E ^{ee} _{CM} = 91.2 GeV |

$\langle N_n \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|--------------------------|-------------------------|----------------|------------------------------------------|
| 1.01±0.08 OUR AVERAGE | Error includes scale fa | ctor of 1.3. S | ee the ideogram below. |
| $1.20\pm0.04\pm0.11$ | HEISTER | 02c ALEP | $E_{\rm cm}^{\it ee}=$ 91.2 GeV |
| $0.97 \pm 0.03 \pm 0.11$ | ACKERSTAFF | 98A OPAL | $E_{\rm cm}^{\it ee}=$ 91.2 GeV |
| $0.93 \pm 0.01 \pm 0.09$ | ACCIARRI | 96 L3 | E ^{ee} _{cm} = 91.2 GeV |



$\langle N_{a^{\pm}} \rangle$

| ` <i>P '</i> | | | | |
|--------------------------|------------------------|-----|------|-----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 2.57±0.15 OUR AVER | RAGE | | | |
| $2.59 \pm 0.03 \pm 0.16$ | ¹¹¹ BEDDALL | 09 | | ALEPH archive, $E_{\rm CM}^{\it ee}=91.2~{\rm GeV}$ |
| $2.40\pm0.06\pm0.43$ | ACKERSTAFF | 98A | OPAL | $E_{\text{cm}}^{ee} = 91.2 \text{ GeV}$ |
| | | | | |

¹¹¹ BEDDALL 09 analyse 3.2 million hadronic Z decays as archived by ALEPH collaboration and report a value of $2.59 \pm 0.03 \pm 0.15 \pm 0.04$. The first error is statistical, the second systematic, and the third arises from extrapolation to full phase space. We combine the systematic errors in quadrature.

$\langle N_{\rho 0} \rangle$

| VALUE | DOCUMENT_ID | | TECN | COMMENT |
|-----------------------|-------------------------|-----|------|--------------------------------------------------------|
| 1.24±0.10 OUR AVERAGE | Error includes scale fa | | | |
| 1.19 ± 0.10 | ABREU | ر99 | DLPH | E ee = 91.2 GeV |
| $1.45\pm0.06\pm0.20$ | BUSKULIC | 96н | ALEP | $E_{\mathrm{cm}}^{\mathrm{ee}} = 91.2 \; \mathrm{GeV}$ |
| | | | | |

(N..)

| VALUE | DO CUMENT ID | TECN | COMMENT |
|----------------------------------|--------------|----------|------------------------------------------|
| 1.02±0.06 OUR AVERAGE | | | |
| $1.00 \pm 0.03 \pm 0.06$ | HEISTER | 02c ALEP | $E_{\rm cm}^{\it ee}=91.2~{\rm GeV}$ |
| $1.04 \pm 0.04 \pm 0.14$ | ACKERSTAFF | 98A OPAL | $E_{\rm cm}^{\it ee}=91.2~{\rm GeV}$ |
| $1.17 \!\pm\! 0.09 \!\pm\! 0.15$ | ACCIARRI | 97D L3 | E ^{ee} _{cm} = 91.2 GeV |

$\langle N_{\eta'} \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|----------------------------|----------------|------------------------------------------|
| 0.17 ±0.05 OUR AVERAGE | Error includes scale fac | tor of 2.4. | |
| $0.14 \pm 0.01 \pm 0.02$ | ACKERSTAFF 98 | BA OPAL | E ^{ee} _{cm} = 91.2 GeV |
| 0.25 ±0.04 | ¹¹² ACCIARRI 97 | 7D L3 | E ^{ee} _{CM} = 91.2 GeV |
| | wing data for averages, fi | its, limits, e | etc. • • • |
| $0.068\!\pm\!0.018\!\pm\!0.016$ | ¹¹³ BUSKULIC 92 | D ALEP | <i>E</i> ^{ee} cm = 91.2 GeV |

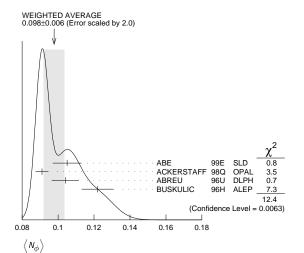
 112 ACCIARRI 97D obtain this value averaging over the two decay channels $\eta' \to ~\pi^+\pi^-\eta$ and $\eta' \to \rho^0 \gamma$. 113 BUSKULIC 92D obtain this value for x>0.1.

$\langle N_{f_0(980)} \rangle$

| VALUE | DOCUMENT ID | TECN | COMMENT |
|--------------------------------------------|----------------|-------------|-------------------------------------------------|
| 0.147±0.011 OUR AVERAGE | | | |
| 0.164 ± 0.021 | ABREU 99J | DLPH | <i>E</i> ^{ee} _{Cm} = 91.2 GeV |
| $0.141 \pm 0.007 \pm 0.011$ | ACKERSTAFF 98Q | OPAL | <i>E</i> ^{ee} _{Cm} = 91.2 GeV |
| $\langle N_{a_0(980)^{\pm}} \rangle$ MALUE | DOCUMENT ID | <u>TECN</u> | COMMENT |
| 0.27±0.04±0.10 | ACKERSTAFF 98A | OPAL | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

$\langle N_{\phi} \rangle$

DOCUMENT ID COMMENT 0.098±0.006 OUR AVERAGE Error includes scale factor of 2.0. See the ideogram below. 0.105 ± 0.008 99E SLD $E_{\rm CM}^{\,ee}=$ 91.2 GeV ABE $0.091 \pm 0.002 \pm 0.003$ ACKERSTAFF 98Q OPAL $E_{
m cm}^{\it ee}=$ 91.2 GeV $0.104 \pm 0.003 \pm 0.007$ ABREU 960 DLPH $E_{
m cm}^{\it ee}=$ 91.2 GeV $0.122 \pm 0.004 \pm 0.008$ BUSKULIC 96н ALEP $E_{
m cm}^{\it ee}=$ 91.2 GeV



$\langle N_{f_2(1270)} \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------------|----------------------|----------------|-----------------|
| 0.169±0.025 OUR AVERAGE | Error includes scale | factor of 1.4. | |
| 0.214 ± 0.038 | ABREU | 99J DLPH | E ee = 91.2 GeV |
| $0.155 \pm 0.011 \pm 0.018$ | ACKERSTAFF | 98Q OPAL | E ee = 91.2 GeV |

$\langle N_{f_1(1285)} \rangle$

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------------|--------------|----------|-----------------|
| 0.165±0.051 | 114 ABDALLAH | 03H DLPH | E ee e 91.2 GeV |

 114 ABDALLAH 03H assume a $K\,\overline{K}\pi$ branching ratio of (9.0 \pm 0.4)%.

$\langle N_{f_1(1420)} \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-------------|----------------|---------|--------------------------------------------------------|
| 0.056±0.012 | 115 ABDALLAH 0 | 3H DLPH | <i>E</i> ^{<i>ee</i>} _{Cm} = 91.2 GeV |

 $^{115}\,\mathrm{ABDALLAH}$ 03H assume a $K\,\overline{K}\pi$ branching ratio of 100%.

$\langle N_{f_2'(1525)} \rangle$

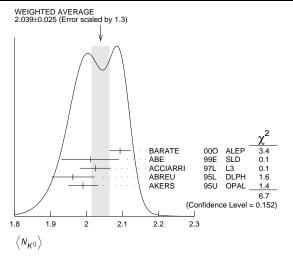
| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-------------|-------------|-----|------|-----------------|
| 0.012±0.006 | ABREU | 99J | DLPH | E ee = 91.2 GeV |

$\langle {\rm N}_{\rm K^\pm} \rangle$

| VALUE | DOCUMENT ID | | ILCIV | COMMENT |
|------------------------|-------------|-----|-------|-------------------------------------------------|
| 2.24 ±0.04 OUR AVERAGE | | | | |
| 2.203 ± 0.071 | ABE | 04c | SLD | <i>E</i> ^{ee} _{cm} = 91.2 GeV |
| 2.21 ±0.05 ±0.05 | ABREU | 98L | DLPH | E ee e 91.2 GeV |
| 2.26 ±0.12 | BARATE | 98∨ | ALEP | E ee = 91.2 GeV |
| 2.42 ±0.13 | AKERS | 94P | OPAL | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

$\langle N_{K^0} \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|--------------------------|---------------|-------------------------------------------------|
| 2.039±0.025 OUR AVERAGE | Error includes scale fac | tor of 1.3 | See the ideogram below. |
| $2.093 \pm 0.004 \pm 0.029$ | BARATE 00 | o ALEP | E ^{ee} _{CM} = 91.2 GeV |
| 2.01 ± 0.08 | ABE 99 | e SLD | E ^{ee} _{CM} = 91.2 GeV |
| $2.024 \pm 0.006 \pm 0.042$ | ACCIARRI 97 | L L3 | E ^{ee} _{CM} = 91.2 GeV |
| $1.962\!\pm\!0.022\!\pm\!0.056$ | ABREU 95 | L DLPH | <i>E</i> ^{ee} _{Cm} = 91.2 GeV |
| $1.99 \ \pm 0.01 \ \pm 0.04$ | AKERS 95 | u OPAL | E ee e 91.2 GeV |



$\langle N_{K^*(892)^{\pm}} \rangle$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------|-------------|------|------|----------------------------------|
| 0.72 ±0.05 OUR AVERAGE | | | | |
| $0.712 \pm 0.031 \pm 0.059$ | ABREU | 95 L | DLPH | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |
| 0.72 ±0.02 ±0.08 | ACTON | 93 | OPAL | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

$\langle N_{K^*(892)^0} \rangle$

| · / (032) / | | | | |
|--------------------------|--------------|-------------|------|-----------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.739±0.022 OUR AVERAGE | | | | |
| 0.707 ± 0.041 | ABE | 99E | SLD | E ee e 91.2 GeV |
| $0.74 \pm 0.02 \pm 0.02$ | ACKERSTAFF | 97s | OPAL | E ee e 91.2 GeV |
| $0.77 \pm 0.02 \pm 0.07$ | ABREU | 96 U | DLPH | E ee = 91.2 GeV |
| $0.83 \pm 0.01 \pm 0.09$ | BUSKULIC | 96н | ALEP | E ee = 91.2 GeV |
| $0.97\ \pm0.18\ \pm0.31$ | ABREU | 93 | DLPH | E ee = 91.2 GeV |

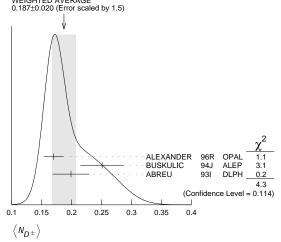
$\langle N_{K_2^*(1430)} \rangle$

| 0.073 ± 0.023 | ABREU | 99」 DLPH <i>E ^{ee}</i> = 91.2 GeV | |
|-------------------------------|----------------------|--------------------------------------------|--|
| • • • We do not use the follo | wing data for averag | es, fits, limits, etc. • • • | |
| $0.19\ \pm0.04\ \pm0.06$ | ¹¹⁶ AKERS | 95x OPAL E_{cm}^{ee} = 91.2 GeV | |
| 116 AKERS 95x obtain this va | ue for $x < 0.3$. | | |

$\langle N_{D^{\pm}} \rangle$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|----------------------|--------|---------|-------------------------|
| 0.187±0.020 OUR AVERAGE | Error includes scale | factor | of 1.5. | See the ideogram below. |
| $0.170 \pm 0.009 \pm 0.014$ | ALEXANDER | 96R | OPAL | E ee = 91.2 GeV |
| $0.251 \pm 0.026 \pm 0.025$ | BUSKULIC | 94J | ALEP | E ee = 91.2 GeV |
| $0.199 \pm 0.019 \pm 0.024$ | ¹¹⁷ ABREU | 93ı | DLPH | E ee = 91.2 GeV |
| ¹¹⁷ See ABREU 95 (erratum). | | | | |

WEIGHTED AVERAGE 0.187±0.020 (Error scaled by 1.5)



Ζ

| $\langle N_{D^0} \rangle$ | | | | WEIGHTED AVERAGE | | | |
|------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|-----------------------------------------------|-------------------------------------------------------------------|-----------------------------------------------------------------------------|-----------------------------|----------------------|-------------------------------------------------|
| ALUE | DO CUMENT ID | TECN | COMMENT | 0.388±0.009 (Error scale | ed by 1.7) | | |
| 462±0.026 OUR AVERAGE | AL EVA NO ED | 06- 0041 | E88 01 0 C V | | | | |
| 465 ± 0.017 ± 0.027 | | | $E_{\rm cm}^{ee} = 91.2 \text{ GeV}$ | | Λ | | |
| 518±0.052±0.035 | BUSKULIC | | E ^{ee} _{cm} = 91.2 GeV | | / \ | | |
| 403±0.038±0.044 | ¹¹⁸ ABREU | 93i DLPH | E ^{ee} _{CM} = 91.2 GeV | | | | |
| ⁸ See ABREU 95 (erratum). | | | | | | | |
| $N_{D_{\epsilon}^{\pm}}\rangle$ | | | | | / \ | | |
| 4LUE | DO CUMENT ID | TECN | COMMENT | / \ | / \ | | |
| .131±0.010±0.018 | ALEXANDER | 96R OPAL | <i>E</i> ^{ee} _{cm} = 91.2 GeV | | / | | χ^2 |
| N _{D*(2010)} ±⟩ | DO CUMENT ID | TECN | COMMENT | | BARAT | 9 | 00 ALEP 4.8 9E SLD 0.1 |
| 183 ±0.008 OUR AVERAG | E | | | | ACCIAI | | 7L L3 1.9 7D OPAL 1.9 |
| $1854 \pm 0.0041 \pm 0.0091$ | ¹¹⁹ ACKERSTAFF | = 98E OPAL | E ^{ee} _{cm} = 91.2 GeV | | · · · · \ · · · · · ABREL | 9 | 3L DLPH <u>3.2</u> |
| 187 ± 0.015 ± 0.013 | BUSKULIC | 94J ALEP | E ee = 91.2 GeV | | \ | (Confi | 11.9 |
| $171 \pm 0.012 \pm 0.016$ | ¹²⁰ ABREU | 93ı DLPH | E ^{ee} _{cm} = 91.2 GeV | | | (Conin | dence Level = 0.018) |
| ¹⁹ ACKERSTAFF 98E system branching ratios B(D^{*+} → 0.0012. ²⁰ See ABREU 95 (erratum). | Tatic error includes $D^0 \pi^+) = 0.683 \pm 0$ | an uncertainty 0.014 and $\mathrm{B}(D)$ | of ± 0.0069 due to the $0 \rightarrow K^-\pi^+) = 0.0383 \pm$ | $\langle N_A \rangle$ 0.35 | 0.4 0.45 | 0.5 | |
| | | | | $\langle N_{A(1520)} \rangle$ | | | |
| $N_{D_{s1}(2536)+}$ | <u></u> | _ | COLUMENT | 0.024 ± 0.027 OUP AVERAGE | DOCUMENT ID | TECN | COMMENT |
| 4LUE (units 10 ⁻³) | DO CUMENT ID | | COMMENT | 0.0224 ± 0.0027 OUR AVERAGE 0.029 ± 0.005 ± 0.005 | ABREU 00 | ь Пірп | <i>E</i> ^{ee} ∈ 91.2 GeV |
| We do not use the follow - | | | | $0.029 \pm 0.005 \pm 0.005$ $0.0213 \pm 0.0021 \pm 0.0019$ | ALEXANDER 97 | | |
| $9^{+0.7}_{-0.6}\pm0.2$ | ¹²¹ ACKERSTAFF | 97w OPAL | E ^{ee} _{cm} = 91.2 GeV | | ALEXANDER 7 | DOIAL | 2 cm = 31.2 GeV |
| 21 ACKERSTAFF 97w obtain width is saturated by the D | | and with the | assumption that its decay | ⟨N _{∑+} ⟩ NALUE | DOCUMENT ID | TECN | COMMENT |
| | Translated. | | | 0.107±0.010 OUR AVERAGE | | | |
| N _{B∗} ⟩ | | | | $0.114 \pm 0.011 \pm 0.009$ | | J L3 | E ee = 91.2 GeV |
| ALUE | DOCUMENT ID | | COMMENT | $0.099 \pm 0.008 \pm 0.013$ | ALEXANDER 97 | E OPAL | E _{cm} = 91.2 GeV |
| .28±0.01±0.03 | ¹²² ABREU | | E ^{ee} _{cm} = 91.2 GeV | $\langle N_{\Sigma^-} angle$ | | | |
| ²² ABREU 95R quote this valu | ue for a flavor-averag | ged excited sta | te. | VALUE | DO CUMENT ID | TECN | COMMENT |
| $\langle N_{J/\psi(1S)} \rangle$ | | | | 0.082±0.007 OUR AVERAGE | | | |
| 3/ψ(13)/ ALUE | DOCUMENT ID | TECN | COMMENT | $0.081 \pm 0.002 \pm 0.010$ | | | $E_{ m cm}^{\it ee}=$ 91.2 GeV |
| .0056±0.0003±0.0004 | 123 ALEXANDER | 96B OPAL | E ee 91.2 GeV | $0.083 \pm 0.006 \pm 0.009$ | ALEXANDER 97 | E OPAL | <i>E</i> _{cm} = 91.2 GeV |
| ²³ ALEXANDER 96B identify | | | · · · · · | /N \ | | | |
| | -,,,(,, | | F | $\langle N_{\Sigma^+ + \Sigma^-} \rangle$ | DOCUMENT ID | TECN | COMMENT |
| $N_{\psi(2S)} angle$ | | | | 0.181 ± 0.018 OUR AVERAGE | DO COMENT ID | 7200 | COMMENT |
| ALUE | DO CUMENT ID | | COMMENT | | ¹²⁴ ALEXANDER 97 | E OPAL | $E_{\rm cm}^{ee} = 91.2 \text{ GeV}$ |
| $.0023 \pm 0.0004 \pm 0.0003$ | ALEXANDER | 96B OPAL | E ^{ee} _{cm} = 91.2 GeV | $0.170 \pm 0.014 \pm 0.061$ | ABREU 95 | o DLPH | E ee = 91.2 GeV |
| A/ \ | | | | $^{124}\mathrm{We}$ have combined the value | | | |
| $ N_p\rangle$ | DO CUMENT ID | TEGN | COMMENT | the statistical and systematic | errors of the two fina | _ / Hom states se | parately in quadratur |
| .046±0.026 OUR AVERAGE | DO CUMENT ID | | COMMENT | isospin symmetry is assumed t | | | |
| 054±0.035 | ABE | 04c SLD | E ee e 91.2 GeV | /N -\ | | | |
| .08 ±0.04 ±0.03 | ABREU | 98L DLPH | E ^{ee} _{cm} = 91.2 GeV | ⟨N _Σ 0⟩ VALUE | DO CUMENT ID | TECN | COMMENT |
| 00 ±0.07 | BARATE | | E ^{ee} _{cm} = 91.2 GeV | 0.076±0.010 OUR AVERAGE | DOCUMENT ID | TECN | COMMENT |
| .92 ±0.11 | AKERS | | E ee = 91.2 GeV | $0.095 \pm 0.015 \pm 0.013$ | ACCIARRI 00 | L3 | <i>E</i> ^{ee} _{Cm} = 91.2 GeV |
| | | · - | 6.II | $0.071 \pm 0.012 \pm 0.013$ | ALEXANDER 97 | | |
| $N_{\Delta(1232)^{++}}\rangle$ | | | | $0.070 \pm 0.010 \pm 0.010$ | ADAM 96 | B DLPH | E ee = 91.2 GeV |
| ALUE | DOCUMENT ID | | COMMENT | 4.04 | | | =::: |
| .087±0.033 OUR AVERAGE | | | E66 010 C V | $\langle \mathit{N}_{(\varSigma^{+}+\varSigma^{-}+\varSigma^{0})/3} angle$ | | | |
| 0.079±0.009±0.011 | ABREU | 95W DLPH | $E_{\rm cm}^{ee} = 91.2 \text{ GeV}$ | VALUE | DOCUMENT ID | TECN | |
| .22 ±0.04 ±0.04 | ALEXA NDER | 95D OPAL | E ^{ee} _{cm} = 91.2 GeV | $0.084 \pm 0.005 \pm 0.008$ | ALEXANDER 97 | e OPAL | E ^{ee} _{cm} = 91.2 GeV |
| (N_A) ALUE | DO CUMENT ID | TECN | COMMENT | $\langle N_{\Sigma(1385)^+} angle$ | | | |
| .388±0.009 OUR AVERAGE | | | | VALUE | DO CUMENT ID | | COMMENT |
| $.404 \pm 0.002 \pm 0.007$ | BARATE | 00o ALEP | <i>E</i> ^{ee} _{cm} = 91.2 GeV | $0.0239 \pm 0.0009 \pm 0.0012$ | ALEXANDER 97 | D OPAL | Ecm = 91.2 GeV |
| $.395 \pm 0.022$ | ABE | | E ee = 91.2 GeV | (N=/> \ | | | |
| $.364 \pm 0.004 \pm 0.017$ | ACCIARRI | 97L L3 | E ee = 91.2 GeV | $\langle N_{\Sigma(1385)^-} \rangle$ | DO CUMENT 12 | TE 011 | COMMENT |
| $.374 \pm 0.002 \pm 0.010$ | | 97D OPAL | E ee = 91.2 GeV | VALUE 0.010 ± 0.0014 | DOCUMENT ID | | COMMENT E CC 01 2 CoV |
| $.357 \pm 0.003 \pm 0.017$ | ABREU | | E ^{ee} _{cm} = 91.2 GeV | $0.0240 \pm 0.0010 \pm 0.0014$ | ALEXANDER 97 | D OPAL | ⊏čm= 91.2 GeV |
| | | | | $\langle N_{\Sigma(1385)^++\Sigma(1385)^-} \rangle$ VALUE | DOCUMENT ID | TECN | <u>COMMENT</u> |
| | | | | 0.046 ±0.004 OUR AVERAGE | Error includes scale f | | |
| | | | | $0.0479 \pm 0.0013 \pm 0.0026$ | ALEXANDER 97 | | |
| | | | | $0.0382 \pm 0.0028 \pm 0.0045$ | | | $E_{\rm cm}^{ee} = 91.2 \text{ GeV}$ |
| | | | | | | | |

 $\langle N_{\Xi^-} \rangle_{\frac{VALUE}{0.0258 \pm 0.0009}}$ OUR AVERAGE

 $\begin{array}{c} 0.0247 \pm 0.0009 \pm 0.0025 \\ 0.0259 \pm 0.0004 \pm 0.0009 \end{array}$

DOCUMENT ID TECN COMMENT

ABDALLAH 06E DLPH $E_{
m Cm}^{\it ee}=91.2~{
m GeV}$ ALEXANDER 97D OPAL $E_{
m Cm}^{\it ee}=91.2~{
m GeV}$

$\langle N_{\Xi(1530)^0} \rangle$

| VALUE | DOCUMENT ID | TECN | COMMENT | | |
|--------------------------------|-------------------------------------|----------|------------------------------------------|--|--|
| 0.0059±0.0011 OUR AVERAGE | Error includes scale factor of 2.3. | | | | |
| $0.0045 \pm 0.0005 \pm 0.0006$ | ABDALLAH | 05c DLPH | $E_{cm}^{ee} = 91.2 \text{ GeV}$ | | |
| $0.0068 \pm 0.0005 \pm 0.0004$ | ALEXA NDER | 97D OPAL | E ^{ee} _{cm} = 91.2 GeV | | |

$\langle N_{\Omega^-} \rangle$

| VALUE | DOCUMENT ID | TECN | COMMENT |
|--------------------------------|-------------|----------|--------------------------------------|
| 0.00164 ± 0.00028 OUR AVERAGE | | | |
| $0.0018 \pm 0.0003 \pm 0.0002$ | ALEXA NDER | 97D OPAL | $E_{\rm cm}^{\it ee}=91.2~{\rm GeV}$ |
| 0.0014 + 0.0002 + 0.0004 | ADAM | 96B DIPH | F ee 91 2 GeV |

$\langle N_{\Lambda^+} \rangle$

| VALUE | DO CUMENT ID | TECN | COMMENT | |
|-------------------|--------------|--------|----------------|--|
| 0.078±0.012±0.012 | ALEXANDER 96 | R OPAL | Eee = 91.2 GeV | |

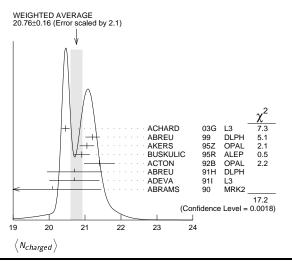
$\langle N_D \rangle$

| VALUE (units 10 ^{-b}) | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|-----------------------------|---------------|----------------------------------|
| • • • We do not use the fo | ollowing data for averages, | fits, limits, | etc. • • • |
| $5.9 \pm 1.8 \pm 0.5$ | 125 SCHAEL (| 06A ALEP | $E_{cm}^{ee} = 91.2 \text{ GeV}$ |

¹²⁵ SCHAEL 06A obtain this anti-deuteron production rate per hadronic $\it Z$ decay in the anti-deuteron momentum range from 0.62 to 1.03 GeV/c.

$\langle N_{charged} \rangle$

| DO CUMENT ID | TECN | COMMENT |
|----------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Error includes scale | factor of 2.1. | See the ideogram below. |
| ACHA RD | 03G L3 | $E_{\rm cm}^{\it ee}=$ 91.2 GeV |
| ABREU | 99 DLPH | E ee = 91.2 GeV |
| AKERS | 95 z OPAL | $E_{\rm cm}^{\it ee}=91.2~{\rm GeV}$ |
| BUSKULIC | 95R ALEP | $E_{\rm cm}^{\it ee}=$ 91.2 GeV |
| ACTON | 92B OPAL | $E_{\rm cm}^{\it ee}=$ 91.2 GeV |
| ABREU | 91H DLPH | <i>E ee</i> = 91.2 GeV |
| ADEVA | 91ı L3 | $E_{ m cm}^{\it ee}=$ 91.2 GeV |
| ABRA MS | 90 MRK | 2 <i>E</i> ^{ee} _{cm} = 91.1 GeV |
| | Error includes scale ACHARD ABREU AKERS BUSKULIC ACTON ABREU ADEVA | ABREU 99 DLPH AKERS 95Z OPAL BUSKULIC 95R ALEP ACTON 92B OPAL ABREU 91H DLPH ADEVA 911 L3 |



Z HADRONIC POLE CROSS SECTION

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The $\it Z$ boson" and ref. LEP-SLC 06). This quantity is defined as

$$\sigma_h^0 = \frac{12\pi}{M_Z^2} \, \frac{\Gamma(e^+e^-) \, \Gamma(\text{hadrons})}{\Gamma_Z^2}$$

It is one of the parameters used in the Z lineshape fit.

| VALUE (nb) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-------------|-------------------------|----------|---------|-------------------------------------------|
| 41.541 ± 0.037 OUR I | FIT | | | | |
| 41.501 ± 0.055 | 4.10M | ¹²⁶ ABBIENDI | 01A | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| 41.578 ± 0.069 | 3.70M | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 41.535 ± 0.055 | 3.54M | ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| 41.559 ± 0.058 | 4.07M | ¹²⁷ BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| ● ● We do not use | the followi | ng data for average | s, fits, | limits, | etc. • • • |
| 42 ±4 | 45 0 | ABRAMS | 89B | MRK2 | Eee = 89.2-93.0 GeV |

 $^{^{126}\}mathsf{ABB}\mathsf{IENDI}$ 01A error includes approximately 0.031 due to statistics, 0.033 due to event selection systematics, $0.029~\mathrm{due}$ to uncertainty in luminosity measurement, and $0.011~\mathrm{due}$ to LEP energy uncertainty.

Z VECTOR COUPLINGS

These quantities are the effective vector couplings of the Z to charged leptons. Their magnitude is derived from a measurement of the Z lineshape and the forward-backward lepton asymmetries as a function of energy around the Z mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the Z asymmetry parameters, $A_e,\,A_\mu,\,{\rm and}\,\,A_\tau.$ By convention the sign of g^e_A is fixed to be negative (and opposite to that of g^{ν_ℓ} obtained using ν_e scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and A_e , A_μ , and A_τ measurements. See the note "The Z boson" and ref. LEP-SLC 06 for details. Where $p\overline{p}$ and ep data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

ge

| οy | | | | | |
|------------------------------------------|--------|-------------------------|------|------|---------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| <u>VALUE</u> -0.03817±0.00047 OUR FIT | - | | | | |
| -0.058 ± 0.016 ± 0.007 | 5026 | ¹²⁸ ACOSTA | 05м | CDF | $E_{\rm cm}^{p\overline{p}}=1.96~{\rm TeV}$ |
| $-0.0346\ \pm0.0023$ | 137.0K | ¹²⁹ ABBIENDI | 010 | OPAL | E ee = 88-94 GeV |
| $-0.0412\ \pm0.0027$ | 124.4k | ¹³⁰ ACCIARRI | 00c | L3 | E ee 88-94 GeV |
| $-0.0400\ \pm0.0037$ | | BARATE | 00c | ALEP | E ee = 88-94 GeV |
| -0.0414 + 0.0020 | | 131 ABF | 95 (| SLD | Fee - 91 31 GeV |

 $^{128} {
m ACOSTA}$ 05M determine the forward–backward asymmetry of $e^+\,e^-$ pairs produced via $ightarrow~Z/\gamma^*
ightarrow~e^+\,e^-$ in 15 M $(e^+\,e^-)$ effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to $e^+\,e^-$, assuming the quark couplings are as predicted by the standard model. Higher

order radiative corrections have not been taken into account. and forward-backward lepton asymmetries. $^{130}\,\mathrm{ACCIARRI}$ 00c use their measurement of the τ polarization in addition to forward-

 $backward\ lepton\ asymmetries.$

131 ABE 93c obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94c. The Bhabha results alone give $-0.0507\pm0.0096\pm0.0020$.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------|-------------------------|---------|-----------|-------------------------------------------|
| -0.0367±0.0023 OUR | | | | | |
| $-0.0388 ^{+0.0060}_{-0.0064}$ | 182.8 K | ¹³² ABBIENDI | 010 | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| -0.0386 ± 0.0073 | 113.4k | ¹³³ ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| -0.0362 ± 0.0061 | | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| • • • We do not use the | he followin | ng data for averages | , fits, | limits, e | etc. • • • |
| -0.0413 ± 0.0060 | 66143 | ¹³⁴ ABBIENDI | 01ĸ | OPAL | E ^{ee} _{cm} = 89-93 GeV |

 132 ABBIENDI 010 use their measurement of the au polarization in addition to the lineshape and forward-backward lepton asymmetries. $^{133} \, {\rm ACCIARRI}$ 00c use their measurement of the τ polarization in addition to forward-

backward lepton asymmetries.

134 ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

\mathbf{g}^{T}

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|--------|-------------------------|-----|------|-------------------------------------------|
| -0.0366±0.0010 OUR | FIT | | | | |
| -0.0365 ± 0.0023 | 151.5K | ¹³⁵ ABBIENDI | 010 | OPAL | E ee = 88-94 GeV |
| -0.0384 ± 0.0026 | 103.0k | ¹³⁶ ACCIARRI | 00c | L3 | E ee = 88-94 GeV |
| -0.0361 ± 0.0068 | | BARATE | 00c | ALEP | E ^{ee} _{cm} = 88-94 GeV |

 135 ABBIENDI 010 use their measurement of the au polarization in addition to the lineshape

and forward-backward lepton asymmetries. $^{136}\,\mathrm{ACCIARRI}$ 00c use their measurement of the τ polarization in addition to forwardbackward lepton asymmetries.

| VALUE | | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------|-------------------------|-----|------|-------------------------------------------|
| -0.03783 ± 0.00041 C | UR FIT | | | | |
| -0.0358 ± 0.0014 | 471.3K | ¹³⁷ ABBIENDI | 010 | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| -0.0397 ± 0.0020 | 379.4k | ¹³⁸ ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| -0.0397 ± 0.0017 | 340.8k | ¹³⁹ ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| -0.0383 ± 0.0018 | 500k | BARATE | 00c | ALEP | E ee = 88-94 GeV |

 137 ABBIENDI 010 use their measurement of the au polarization in addition to the lineshape and forward-backward lepton asymmetries.

 138 Using forward-backward lepton asymmetries. 139 ACCIARRI 00c use their measurement of the au polarization in addition to forwardbackward lepton asymmetries.

| 8 V | | | | | |
|----------------------------------------------------|---------|------------------------|-----|------|-----------------------------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.25 +0.07 OUR | AVERAGE | | | | |
| 0.201 ± 0.112 | 15 6k | ¹⁴⁰ ABAZOV | 11D | D0 | $E_{ m cm}^{ ho\overline{ ho}}=1.97~{ m TeV}$ |
| 0.27 ± 0.13 | 1500 | ¹⁴¹ AKTAS | 06 | H1 | $e^{\pm} p ightarrow \overline{ u}_e(u_e) X$, $\sqrt{s} pprox 300 \; { m GeV}$ |
| $0.24 \begin{array}{c} +0.28 \\ -0.11 \end{array}$ | | ¹⁴² LEP-SLC | 06 | | E ^{ee} _{cm} = 88-94 GeV |
| 0.399 + 0.152 + 0.00 | 66 5026 | 143 ΔΟ Ο ΣΤΔ | 05м | CDE | <i>F</i> p − 1 96 TeV |

¹²⁷ BARATE 00C error includes approximately 0.030 due to statistics, 0.026 due to experimental systematics, and 0.025 due to uncertainty in luminosity measurement.

- 140 ABAZOV 11D study $p\overline{p}\to Z/\gamma^*e^+e^-$ events using 5 fb $^{-1}$ data at $\sqrt{s}=1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T>25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the u- and d- quarks and the value of $\sin^2\theta^\ell_{eff}=0.2309\pm0.0008({\rm stat})\pm0.0006({\rm syst})$.
- $^{141}\,\text{A\,KTAS}$ 06 fit the neutral current (1.5 \leq Q 2 \leq 30,000 GeV $^2)$ and charged current $(1.5 \le Q^2 \le 15,000 \text{ GeV}^2)$ differential cross sections. In the determination of the u-quark couplings the electron and d-quark couplings are fixed to their standard model
- 142 LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.
- 143 ACOSTA 05M determine the forward-backward asymmetry of e^+e^- pairs produced via $q\,\overline{q}\to Z/\gamma^*\to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

| g d V | | | | | |
|-----------------------------------------------------|----------|------------------------|------|------|-----------------------------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| -0.33 + 0.05 OUF | RAVERAGE | | | | |
| -0.351 ± 0.251 | 156k | ¹⁴⁴ ABAZOV | 11D | D0 | $E_{CM}^{p\overline{p}} = 1.97 \; TeV$ |
| -0.33 ± 0.33 | 1500 | ¹⁴⁵ AKTAS | 06 | H1 | $e^{\pm} p ightarrow \overline{ u}_e(u_e) X$, $\sqrt{s} pprox 300 \; { m GeV}$ |
| $-0.33 \begin{array}{l} +0.05 \\ -0.07 \end{array}$ | | ¹⁴⁶ LEP-SLC | 06 | | $E_{\mathrm{cm}}^{ee}=88-94\mathrm{GeV}$ |
| $-0.226^{+0.635}_{-0.290}\pm0.0$ | 90 5026 | ¹⁴⁷ ACOSTA | 05 м | CDF | $E_{ m cm}^{ ho\overline{ ho}}=1.96~{ m TeV}$ |

- 144 ABAZOV 11D study $p\overline{p}\to Z/\gamma^*e^+e^-$ events using 5 fb $^{-1}$ data at $\sqrt{s}=$ 1.96 TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T>25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the u- and d- quarks and the value of $\sin^2\!\theta_{eff}^\ell = 0.2309 \pm 0.0008({\rm stat}) \pm 0.0006({\rm syst})$.
- $^{145}\,\text{AKTAS}$ 06 fit the neutral current (1.5 \leq Q^2 \leq 30,000 GeV²) and charged current $(1.5 \le Q^2 \le 15,000 \text{ GeV}^2)$ differential cross sections. In the determination of the d-quark couplings the electron and u-quark couplings are fixed to their standard model
- 146 LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.
- 147 ACOSTA 05 M determine the forward-backward asymmetry of e^+e^- pairs produced via $q \overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

Z AXIAL-VECTOR COUPLINGS

These quantities are the effective axial-vector couplings of the Z to charged leptons. Their magnitude is derived from a measurement of the Z lineshape and the forward-backward lepton asymmetries as a function of energy around the $\it Z$ mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the Z asymmetry parameters, A_e , A_μ , and A_τ . By convention the sign of g_A^e is fixed to be negative

(and opposite to that of $g^{
u_\ell}$ obtained using u_ℓ scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and , A_{μ} , and A_{τ} measurements. See the note "The Z boson" and ref. LEP-SLC 06 for details. Where $p\overline{p}$ and ep data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

g_A^e

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|--------|-------------------------|------|------|---------------------------------------------------|
| -0.50111±0.00035 OUR FI | T | | | | |
| -0.528 ± 0.123 ± 0.059 | | ¹⁴⁸ ACOSTA | 05 м | CDF | $E_{\text{cm}}^{\overline{p}} = 1.96 \text{ TeV}$ |
| -0.50062 ± 0.00062 | | ¹⁴⁹ ABBIENDI | 010 | OPAL | <i>E</i> ^{ee} _{Cm} = 88−94 GeV |
| -0.5015 ± 0.0007 | 124.4k | ¹⁵⁰ ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| -0.50166 ± 0.00057 | | BARATE | 00c | ALEP | E ee = 88-94 GeV |
| -0.4977 ± 0.0045 | | ¹⁵¹ ABE | 95 J | SLD | E ^{ee} _{cm} = 91.31 GeV |

- 148 ACOSTA 05 M determine the forward–backward asymmetry of $e^+\,e^-$ pairs produced via $q\,\overline{q}
 ightarrow \, Z/\gamma^*
 ightarrow \, e^+\,e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to $e^+\,e^-$, assuming the quark couplings are as predicted by the standard model. Higher order radiative corrections have not been taken into account.
- and forward-backward lepton asymmetries.
- 150 ACCIARRI 00c use their measurement of the au polarization in addition to forwardbackward lepton asymmetries.
- 151 ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94c. The Bhabha results alone give $-0.4968\pm0.0039\pm0.0027$.

| g^µ VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|--------|-------------------------|-----|------|---------------------------------------|
| -0.50120±0.00054 C | UR FIT | | | | |
| -0.50117 ± 0.00099 | 182.8K | ¹⁵² ABBIENDI | 010 | OPAL | E ee = 88-94 GeV |
| -0.5009 ± 0.0014 | 113.4k | ¹⁵³ ACCIARRI | 00c | L3 | E ee = 88-94 GeV |
| -0.50046 ± 0.00093 | | BARATE | 00c | ALEP | $E_{\rm cm}^{ee} = 88-94 \text{ GeV}$ |

66143 154 ABBIENDI 01K OPAL $E_{
m cm}^{\it ee}=$ 89–93 GeV 152 ABBIENDI 010 use their measurement of the au polarization in addition to the lineshape and forward-backward lepton asymmetries.

 153 ACCIARRI 00c use their measurement of the au polarization in addition to forwardbackward lepton asymmetries.

 $^{154} {\sf ABBIENDI~01K}$ obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

-0.50204±0.00064 OUR FIT 151.5K ¹⁵⁵ ABBIENDI -0.50165 ± 0.00124 010 OPAL $E_{\rm cm}^{ee} = 88-94 \; {\rm GeV}$ 103.0k 156 ACCIARRI -0.5023 ± 0.0017 00c L3 E ee = 88-94 GeV -0.50216 ± 0.00100 BARATE 00c ALEP $E_{\mathrm{cm}}^{ee} = 88-94 \; \mathrm{GeV}$

 $155\,\mathrm{ABBIE\,NDI}$ 010 use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

 156 ACCIARRI 00c use their measurement of the au polarization in addition to forwardbackward lepton asymmetries.

 -0.520 ± 0.015

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------|--------|-------------------------|-----|------|-------------------------------------------|
| -0.50123±0.00026 O | | | | | |
| -0.50089 ± 0.00045 | 471.3K | ¹⁵⁷ ABBIENDI | 010 | OPAL | E ^{ee} _{cm} = 88-94 GeV |
| -0.5007 ± 0.0005 | 379.4k | ABREU | 00F | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| -0.50153 ± 0.00053 | 340.8k | ¹⁵⁸ ACCIARRI | 00c | L3 | E ^{ee} _{cm} = 88-94 GeV |
| -0.50150 ± 0.00046 | 500k | BARATE | 00c | ALEP | E ee = 88-94 GeV |

 157 ABBIENDI 010 use their measurement of the au polarization in addition to the lineshape and forward-backward lepton asymmetries.

 158 ACCIARRI 00c use their measurement of the au polarization in addition to forwardbackward lepton asymmetries.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|---------|------------------------|------|------|-----------------------------------------------------------------------------------|
| 0.50 +0.04 OUR | AVERAGE | | | | |
| 0.501 ± 0.110 | 15 6k | ¹⁵⁹ ABAZOV | 11D | D0 | $E_{\text{cm}}^{\overline{p}} = 1.97 \text{ TeV}$ |
| 0.57 ± 0.08 | 1500 | ¹⁶⁰ AKTAS | 06 | H1 | $e^{\pm} p ightarrow \overline{ u}_e(u_e) X$, $\sqrt{s} pprox 300 \; { m GeV}$ |
| $0.47 \begin{array}{l} +0.05 \\ -0.33 \end{array}$ | | ¹⁶¹ LEP-SLC | 06 | | $E_{\mathrm{CM}}^{ee}=88	ext{-}94~\mathrm{GeV}$ |
| $0.441 + 0.207 \pm 0.0$ | 67 5026 | ¹⁶² ACOSTA | 05 м | CDF | $E_{\mathrm{cm}}^{p\overline{p}}$ = 1.96 TeV |

 159 ABAZOV 11D study $\rho\overline{\rho}\to Z/\gamma^*e^+e^-$ events using 5 fb $^{-1}$ data at $\sqrt{s}=1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with The candidate events are selected by requiring two isolated electromagnetic showers with $E_T > 25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the u- and d- quarks and the value of $\sin^2\theta^\ell_{eff} = 0.2309 \pm 0.0008 ({\rm stat}) \pm 0.0006 ({\rm syst})$.

 160 AKTAS 06 fit the neutral current (1.5 \leq Q 2 \leq 30,000 GeV 2) and charged current $(1.5 \le Q^2 \le 15{,}000 \text{ GeV}^2)$ differential cross sections. In the determination of the uquark couplings the electron and d-quark couplings are fixed to their standard model

 161 LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

 162 ACOSTA 05 M determine the forward-backward asymmetry of e^+e^- pairs produced via $q \overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the ${\sf Standard}$ Model. Higher order radiative corrections have not been taken into account.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|--------|------------------------|------|------|-------------------------------------------------------------------------------------|
| -0.523+0.050 OUR A | VERAGI | 1 | | | |
| -0.497 ± 0.165 | 156k | ¹⁶³ ABAZOV | 11D | D0 | $E_{cm}^{\overline{p}}=1.97\;TeV$ |
| -0.80 ± 0.24 | 1500 | ¹⁶⁴ AKTAS | 06 | H1 | $e^{\pm} ho ightarrow \overline{ u}_e(u_e) X$, $\sqrt{s} pprox 300 \; { m GeV}$ |
| $-0.52 \begin{array}{c} +0.05 \\ -0.03 \end{array}$ | | ¹⁶⁵ LEP-SLC | 06 | | $V_s \approx 300 \text{ GeV}$ $E_{\text{cm}}^{ee} = 88-94 \text{ GeV}$ |
| $-0.016^{+0.346}_{-0.536}\pm0.091$ | 5026 | ¹⁶⁶ ACOSTA | 05 м | CDF | $E_{ m cm}^{ m p}=1.96~{ m TeV}$ |

 163 ABAZOV 11D study $\rho\overline{\rho}\to Z/\gamma^*e^+e^-$ events using 5 fb $^{-1}$ data at $\sqrt{s}=1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T>25~{
m GeV}$, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the u- and d- quarks and the value of $\sin^2\!\theta^\ell_{eff}=0.2309\pm0.0008({\rm stat})\pm0.0006({\rm syst})$. $^{164} \text{AKTAS}$ 06 fit the neutral current (1.5 \leq Q^2 \leq 30,000 $\text{GeV}^2)$ and charged current $(1.5 \le Q^2 \le 15,000 \text{ GeV}^2)$ differential cross sections. In the determination of the dquark couplings the electron and u-quark couplings are fixed to their standard model

165 LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

 166 ACOSTA 05 M determine the forward-backward asymmetry of e^+e^- pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the ${\sf Standard}$ Model. Higher order radiative corrections have not been taken into account.

Z COUPLINGS TO NEUTRAL LEPTONS

Averaging over neutrino species, the invisible Z decay width determines the effective neutrino coupling $g^{
u_\ell}$. For $g^{
u_\ell}$ and $g^{
u_\mu}$, $u_e\,e$ and $u_\mu\,e$ scattering results are combined with g_A^e and g_V^e measurements at the Zmass to obtain $g^{
u_{\ell}}$ and $g^{
u\mu}$ following NOVIKOV 93c.

| g ^ν ℓ VALUE | DO CUMENT ID | | COMMENT |
|---------------------------|--------------|----|-------------------------------------------|
| 0.5 0076 ± 0.00076 | 167 LEP-SLC | 06 | E ^{ee} _{cm} = 88-94 GeV |

167 From invisible Z-decay width.

| $g^{ u_e}$ | | | | |
|-------------|--------------|----|------|---------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.528±0.085 | 168 VILAIN | 94 | СНМ2 | From $\nu_{\mu}e$ and $\nu_{e}e$ scattering |

 168 VILAIN 94 derive this value from their value of $g^{
u\mu}$ and their ratio $g^{
u_e}/g^{
u\mu}$ =

| $g^{ u_{\mu}}$ | | | | |
|----------------|--------------|----|------|------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.502±0.017 | 169 VILAIN | 94 | CHM2 | From ν_{ii} e scattering |

 $^{169}\mathrm{VILAIN}$ 94 derive this value from their measurement of the couplings $g_A^{\mathrm{C}\, \nu}$ 0.017 and $g_V^{e\,
u\mu}=-$ 0.035 \pm 0.017 obtained from $u_\mu e$ scattering. We have re-evaluated this value using the current PDG values for g_A^e and g_V^e

Z ASYMMETRY PARAMETERS

For each fermion-antifermion pair coupling to the Z these quantities are

$$A_f = \frac{2g_V^f g_A^f}{(g_V^f)^2 + (g_A^f)^2}$$

where g_V^f and g_A^f are the effective vector and axial-vector couplings. For their relation to the various lepton asymmetries see the note "The Z boson" and ref. LEP-SLC 06.

Using polarized beams, this quantity can also be measured as $(\sigma_L - \sigma_R)/\left(\sigma_L + \sigma_R\right)$, where σ_L and σ_R are the e^+e^- production cross sections for Z bosons produced with left-handed and right-handed electrons respectively.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|---------|-------------------------|------|------|-----------------------------------|
| 0.1515 ± 0.0019 OUR AVERA | | | | | |
| $0.1454 \pm 0.0108 \pm 0.0036$ | 144810 | ¹⁷⁰ ABBIENDI | 010 | OPAL | Eee = 88-94 GeV |
| 0.1516 ± 0.0021 | 559000 | ¹⁷¹ ABE | 01B | SLD | E ee = 91.24 GeV |
| $0.1504 \pm 0.0068 \pm 0.0008$ | | ¹⁷² HEISTER | 01 | ALEP | E ee 88-94 GeV |
| $0.1382 \pm 0.0116 \pm 0.0005$ | 105 000 | ¹⁷³ ABREU | 00E | DLPH | E ee 88-94 GeV |
| $0.1678 \pm 0.0127 \pm 0.0030$ | 137092 | ¹⁷⁴ ACCIARRI | 98н | L3 | E ee 88-94 GeV |
| $0.162\ \pm0.041\ \pm0.014$ | 89838 | ¹⁷⁵ ABE | 97 | SLD | E ee = 91.27 GeV |
| 0.202 + 0.038 + 0.008 | | ¹⁷⁶ ABE | 95.1 | SLD | $E_{cm}^{ee} = 91.31 \text{ GeV}$ |

 $170\,\mathrm{ABBIENDI}$ 010 fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

171 ABE 01B use the left-right production and left-right forward-backward decay asymmetries in leptonic Z decays to obtain a value of 0.1544 ± 0.0060 . This is combined with left-right production asymmetry measurement using hadronic Z decays (ABE 00B) to obtain

172 HEISTER 01 obtain this result fitting the au polarization as a function of the polar production angle of the au.

 173 ABREU 00E obtain this result fitting the au polarization as a function of the polar au production angle. This measurement is a combination of different analyses (exclusive au decay modes, inclusive hadronic 1-prong reconstruction, and a neural network

 174 Derived from the measurement of forward-backward au polarization asymmetry.

 $^{175}\,\mathrm{ABE}$ 97 obtain this result from a measurement of the observed left-right charge asymmetry, $A_Q^{
m obs} = 0.225 \pm 0.056 \pm 0.019$, in hadronic Z decays. If they combine this value of $A_Q^{\rm obs}$ with their earlier measurement of $A_{LR}^{\rm obs}$ they determine A_e to be 0.1574 \pm 0.0197 \pm 0.0067 independent of the beam polarization.

 $176\,\mathrm{ABE}$ 95J obtain this result from polarized Bhabha scattering.

This quantity is directly extracted from a measurement of the left-right forwardbackward asymmetry in $\mu^+\mu^-$ production at SLC using a polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter $_{A_{e}.}$

VALUE EVTS DOCUMENT ID TECN COMMENT 16844 177 ABE 01B SLD $E_{\text{cm}}^{ee} = 91.24 \text{ GeV}$ 0.142 ± 0.015

 $^{177} {\sf ABE}$ 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in $\mu^+\mu^-$ decays of the Z boson obtained with a polarized electron beam.

The LEP Collaborations derive this quantity from the measurement of the au polarization in $Z
ightarrow ~ au^+ ~ au^-$. The SLD Collaboration directly extracts this quantity from its measured left-right forward-backward asymmetry in ${\it Z}
ightarrow ~ au^+ au^-$ produced using a polarized e^- beam. This double asymmetry eliminates the dependence on the Z-e-ecoupling parameter A_{ρ} .

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|--------|------------------------|-----|------|--------------------------------------------------|
| 0.143 ±0.004 OUR AVER | RAGE | | | | |
| $0.1456 \pm 0.0076 \pm 0.0057$ | | | 010 | OPAL | <i>E</i> ^{ee} _{Cm} = 88-94 GeV |
| 0.136 ± 0.015 | 16083 | ¹⁷⁹ ABE | | | <i>E</i> ^{ee} _{CM} = 91.24 GeV |
| $0.1451 \pm 0.0052 \pm 0.0029$ | | ¹⁸⁰ HEISTER | 01 | ALEP | E ee = 88-94 GeV |
| $0.1359 \pm 0.0079 \pm 0.0055$ | 105000 | ¹⁸¹ ABREU | 00E | DLPH | E ee = 88-94 GeV |
| $0.1476 \pm 0.0088 \pm 0.0062$ | 137092 | A CCIA RRI | 98н | L3 | $E_{cm}^{ee} = 88-94 \text{ GeV}$ |

 $178\,\mathrm{ABBIENDI}$ 01o fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

 $179\,\mathrm{ABE}$ 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in $au^+ au^-$ decays of the Z boson obtained with a polarized electron beam.

 180 HEISTER 01 obtain this result fitting the au polarization as a function of the polar production angle of the au.

181 ABREU 00E obtain this result fitting the τ polarization as a function of the polar τ production angle. This measurement is a combination of different analyses (exclusional production angle). sive au decay modes, inclusive hadronic 1-prong reconstruction, and a neural network

The SLD Collaboration directly extracts this quantity by a simultaneous fit to four

0.895 ± 0.066 ± 0.062 2870 182 ABE 00D SLD $E_{\text{Cm}}^{ee} = 91.2 \text{ GeV}$

 182 ABE 00D tag $Z \rightarrow s\overline{s}$ events by an absence of B or D hadrons and the presence in each hemisphere of a high momentum K^{\pm} or K_{S}^{0}

This quantity is directly extracted from a measurement of the left-right forwardbackward asymmetry in $c\overline{c}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

| VALUE | DO CUMENT | DO CUMENT ID | | COMMENT |
|---------------------------------|----------------------|--------------|---------|---------------------------------------|
| 0.670 ±0.027 OUR FIT | | | | |
| $0.6712 \pm 0.0224 \pm 0.0157$ | ¹⁸³ ABE | 05 | SLD | E ee = 91.24 GeV |
| • • • We do not use the fo | llowing data for ave | rages, fits, | limits, | etc. • • • |
| $0.583 \ \pm 0.055 \ \pm 0.055$ | ¹⁸⁴ ABE | 02 G | SLD | $E_{\rm cm}^{\it ee}=91.24~{\rm GeV}$ |
| 0.688 ± 0.041 | 185 ARE | 01.0 | SLD | Fee _ 91 25 GeV |

183 ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The constructed secondary decay vertices. The charge of the underlying c-quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (9970 events) $A_C=0.6747\pm0.0290\pm0.0233$. Taking into account all correlations with earlier results reported in ABE 02g and ABE 01c, they obtain the quoted overall SLD result.

 184 ABE 02G tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_c .

¹⁸⁵ ABE 01c tag $Z \to c \overline{c}$ events using two techniques: exclusive reconstruction of D^{*+} , D^+ and D^0 mesons and the soft pion tag for $D^{*+} \to D^0 \pi^+$. The large background from D mesons produced in $b\bar{b}$ events is separated efficiently from the signal using precision vertex information. When combining the A_C values from these two samples, care is taken to avoid double counting of events common to the two samples, and common systematic errors are properly taken into account.

This quantity is directly extracted from a measurement of the left-right forwardbackward asymmetry in $b\overline{b}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|----------|----------------------|---------|-----------|--------------------------------------------------|
| 0.923 ±0.020 OUR FIT | | | | | |
| $0.9170 \pm 0.0147 \pm 0.0145$ | | ¹⁸⁶ ABE | 05 | SLD | <i>E</i> ^{ee} _{CM} = 91.24 GeV |
| ● ● We do not use the | followin | g data for averages, | fits, l | imits, et | C. • • • |
| $0.907\ \pm0.020\ \pm0.024$ | 48028 | ¹⁸⁷ ABE | 03F | SLD | E ^{ee} _{cm} = 91.24 GeV |
| $0.919 \pm 0.030 \pm 0.024$ | | ¹⁸⁸ ABE | 02G | SLD | $E_{cm}^{ee} = 91.24 \text{ GeV}$ |
| $0.855\ \pm0.088\ \pm0.102$ | 7473 | ¹⁸⁹ ABE | 99L | SLD | E ee = 91.27 GeV |

- 186 ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $^b\bar{b}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying b-quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (25 917 events) $A_b=0.9173\pm0.0184\pm0.0173$. Taking into account all correlations with earlier results reported in ABE 03F, ABE 02G and ABE 991, they obtain the quoted overall SLD results.
- and ABE 99t, they obtain the quoted overlain SED 153m.

 187 ABE 03F obtain an enriched sample of $b\overline{b}$ events tagging on the invariant mass of a 3-dimensional topologically reconstructed secondary decay. The charge of the underlying b quark is obtained using a self-calibrating track-charge method. For the 1996–1998 data sample they measure $A_b = 0.906 \pm 0.022 \pm 0.023$. The value quoted here is obtained combining the above with the result of ABE 98I (1993–1995 data sample).
- 188 ABE 026 tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_C .
- 189 ABE 99L obtain an enriched sample of $b\overline{b}$ events tagging with an inclusive vertex mass cut. For distinguishing b and \overline{b} quarks they use the charge of identified K^\pm .

TRANSVERSE SPIN CORRELATIONS IN $Z \rightarrow \tau^+ \tau^-$

The correlations between the transverse spin components of $\tau^+\tau^-$ produced in Z decays may be expressed in terms of the vector and axial-vector couplings:

$$\begin{split} C_{TT} &= \frac{|g_A^T|^2 - |g_V^T|^2}{|g_A^T|^2 + |g_V^T|^2} \\ C_{TN} &= -2 \frac{|g_A^T||g_V^T|}{|g_A^T|^2 + |g_V^T|^2} \sin(\Phi_{g_V^T} - \Phi_{g_A^T}) \end{split}$$

 C_{TT} refers to the transverse-transverse (within the collision plane) spin correlation and C_{TN} refers to the transverse-normal (to the collision plane) spin correlation.

The longitudinal au polarization $P_{ au} \; (= -A_{ au})$ is given by:

$$P_{\tau} = -2 \frac{|g_{A}^{\tau}||g_{V}^{\tau}|}{|g_{A}^{\tau}|^{2} + |g_{V}^{\tau}|^{2}} \cos(\Phi_{g_{V}^{\tau}} - \Phi_{g_{A}^{\tau}})$$

Here Φ is the phase and the phase difference $\Phi_{\mathcal{G}_V^{\mathcal{T}}}-\Phi_{\mathcal{G}_A^{\mathcal{T}}}$ can be obtained using both the measurements of $C_{\mathcal{TN}}$ and $P_{\mathcal{T}}.$

| C11 | | | | | |
|---------------------------------------|------------|--------------------------|-----------------|-----------|-------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.01±0.12 OUR AVE | RAGE | | | | |
| $0.87 \pm 0.20 {}^{+ 0.10}_{- 0.12}$ | 9.1k | ABREU | 97 _G | DLPH | <i>E</i> ^{ee} _{Cm} = 91.2 GeV |
| $1.06 \pm 0.13 \pm 0.05$ | 120k | BARATE | 97D | ALEP | E ^{ee} _{cm} = 91.2 GeV |
| C _{TN} | | | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $0.08 \pm 0.13 \pm 0.04$ | 120k | ¹⁹⁰ BARATE | 97D | ALEP | <i>E</i> ^{ee} _{CM} = 91.2 GeV |
| 190 BARATE 97D con | hine their | value of C_{+n} with t | he wo | rld avera | $P = -0.140 \pm 0.007$ |

190 BARATE 97D combine their value of C_{TN} with the world average $P_{\tau}=-0.140\pm0.007$ to obtain $\tan(\Phi_{\mathcal{B}_{U}^{T}}-\Phi_{\mathcal{B}_{A}^{T}})=-0.57\pm0.97$.

FORWARD-BACKWARD $e^+e^- \rightarrow f\overline{f}$ CHARGE ASYMMETRIES

These asymmetries are experimentally determined by tagging the respective lepton or quark flavor in $e^+\,e^-$ interactions. Details of heavy flavor (c- or b-quark) tagging at LEP are described in the note on "The Z boson" and ref. LEP-SLC 06. The Standard Model predictions for LEP data have been (re)computed using the ZFITTER package (version 6.36) with input parameters M_Z =91.187 GeV, $M_{\rm top}$ =174.3 GeV, $M_{\rm Higgs}$ =150 GeV, α_S =0.119, $\alpha^{(5)}$ (M_Z)= 1/128.877 and the Fermi constant G_F =1.16637 \times 10 $^{-5}$ GeV $^{-2}$ (see the note on "The Z boson" for references). For non-LEP data the Standard Model predictions are as given by the authors of the respective publications.

– $A_{FB}^{(0,e)}$ CHARGE ASYMMETRY IN $e^+\,e^ightarrow\,e^+\,e^-$ -

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_{\rm e}^2$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| ASYMMETRY (%) | STD. MODEL | √ <u>s</u> (GeV) | DO CUMENT ID | | TECN |
|---------------------|---------------|---------------------|-------------------------|-----|------|
| 1.45 ± 0.25 OUR FIT | | | | | |
| 0.89 ± 0.44 | 1.57 | 91.2 | ¹⁹¹ ABBIENDI | 01A | OPAL |
| 1.71 ± 0.49 | 1.57 | 91.2 | ABREU | 00F | DLPH |
| 1.06 ± 0.58 | 1.57 | 91.2 | ACCIARRI | 00c | L3 |
| 1.88 ± 0.34 | 1.57 | 91.2 | ¹⁹² BARATE | 00c | ALEP |

191 ABBIENDI 01A error includes approximately 0.38 due to statistics, 0.16 due to event selection systematics, and 0.18 due to the theoretical uncertainty in t-channel prediction.
192 BARATE 00c error includes approximately 0.31 due to statistics, 0.06 due to experimental systematics, and 0.13 due to the theoretical uncertainty in t-channel prediction.

- $A_{FB}^{(0,\mu)}$ CHARGE ASYMMETRY IN $e^+\,e^ightarrow\,\mu^+\mu^-$ ——

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_eA_\mu$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| and lepton forward-ba | ackward asym | imetry da | ıta. | | | |
|--------------------------------------------|---------------|-------------|---------|------------------|------|------|
| ASYMMETRY (%) | STD. MODEL | (GeV) | | DO CUMENT ID | | TECN |
| 1.69± 0.13 OUR FIT | | | | | | |
| 1.59± 0.23 | 1.57 | 91.2 | 193 | ABBIENDI | 01A | OPAL |
| 1.65 ± 0.25 | 1.57 | 91.2 | | ABREU | 00F | DLPH |
| 1.88± 0.33 | 1.57 | 91.2 | | ACCIARRI | 00c | L3 |
| 1.71 ± 0.24 | 1.57 | 91.2 | 194 | BARATE | 00c | ALEP |
| • • • We do not use the follo | wing data for | raverages | s, fits | , limits, etc. • | • • | |
| 9 ±30 | -1.3 | 20 | | ABREU | 95 M | DLPH |
| 7 ± 26 | -8.3 | 40 | 1 95 | ABREU | 95 M | DLPH |
| -11 ±33 | -24.1 | 57 | | ABREU | 95 M | DLPH |
| -62 ± 17 | -44.6 | 69 | 1 95 | ABREU | 95 M | DLPH |
| -56 ± 10 | -63.5 | 79 | 1 95 | ABREU | 95 M | DLPH |
| -13 \pm 5 | -34.4 | 87.5 | 1 95 | ABREU | 95 M | DLPH |
| $-29.0 \ ^{+}_{-}\ ^{5.0}_{4.8}\ \pm 0.5$ | -32.1 | 56.9 | 196 | ABE | 90ı | VNS |
| $-$ 9.9 \pm 1.5 \pm 0.5 | -9.2 | 35 | | HEGNER | 90 | JADE |
| 0.05 ± 0.22 | 0.026 | 91.14 | 197 | ABRAMS | 89D | MRK2 |
| -43.4 ± 17.0 | - 24.9 | 52.0 | 198 | BACALA | 89 | AMY |
| -11.0 ± 16.5 | -29.4 | 55.0 | 198 | BACALA | 89 | AMY |
| -30.0 ± 12.4 | -31.2 | 56.0 | 198 | BACALA | 89 | A MY |
| -46.2 ±14.9 | -33.0 | 57.0 | 198 | BACALA | 89 | AMY |
| -29 ±13 | - 25.9 | 53.3 | | ADACHI | 88c | TOPZ |
| $+$ 5.3 \pm 5.0 \pm 0.5 | -1.2 | 14.0 | | ADEVA | 88 | MRKJ |
| $-10.4 \pm 1.3 \pm 0.5$ | -8.6 | 34.8 | | ADEVA | 88 | MRKJ |
| $-12.3 \pm 5.3 \pm 0.5$ | -10.7 | 38.3 | | ADEVA | 88 | MRKJ |
| $-15.6 \pm 3.0 \pm 0.5$ | -14.9 | 43.8 | | ADEVA | 88 | MRKJ |
| -1.0 ± 6.0 | -1.2 | 13.9 | | BRAUNSCH | 88D | TASS |
| $-$ 9.1 \pm 2.3 \pm 0.5 | -8.6 | 34.5 | | BRAUNSCH | 88D | TASS |
| $-10.6 {}^{+}_{-} {}^{2.2}_{2.3} \pm 0.5$ | -8.9 | 35.0 | | BRAUNSCH | 88D | TASS |
| -17.6 | -15.2 | 43.6 | | BRAUNSCH | 88D | TASS |
| $-4.8 \pm 6.5 \pm 1.0$ | -11.5 | 39 | | BEHREND | 87c | CELL |
| $-18.8 \pm 4.5 \pm 1.0$ | -15.5 | 44 | | BEHREND | 87c | |
| + 2.7 ± 4.9 | -1.2 | 13.9 | | BARTEL | 86c | JADE |
| $-11.1 \pm 1.8 \pm 1.0$ | -8.6 | 34.4 | | BARTEL | 86c | JADE |
| $-17.3 \pm 4.8 \pm 1.0$ | -13.7 | 41.5 | | BARTEL | 86c | JADE |
| $-22.8 \pm 5.1 \pm 1.0$ | -16.6 | 44.8 | | BARTEL | 86c | JADE |
| $-6.3 \pm 0.8 \pm 0.2$ | -6.3 | 29 | | ASH | 85 | MAC |
| - 4.9 ± 1.5 ± 0.5 | -5.9 | 29 | | DERRICK | 85 | HRS |
| - 7.1 ± 1.7 | -5.7 | 29 | | LEVI | 83 | MRK2 |
| -16.1 ± 3.2 | -9.2 | 34.2 | | BRANDELIK | 82c | TASS |
| | | | | | | |

- $^{193}\,\mathrm{ABBIENDI}$ 01A error is almost entirely on account of statistics.
- 194 BARATE 00c error is almost entirely on account of statistics.
- 195 ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.
- 196 ABE 901 measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
- 197 ABRAMS 89D asymmetry includes both 9 $\mu^+\mu^-$ and 15 $\tau^+\tau^-$ events.
- 198 BACALA 89 systematic error is about 5%.

 $-10.6 \pm 3.1 \pm 1.5$

- $A_{FB}^{(0, au)}$ CHARGE ASYMMETRY IN $e^+e^ightarrow au^+ au^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_{\rm e}A_{\tau}$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

| ASYMMETRY (%) | STD. MODEL | (GeV) | DO CUMENT ID | | TECN |
|--------------------------------------------------|---------------|------------|-------------------------|-----|------|
| 1.88± 0.17 OUR FIT | | | | | |
| 1.45 ± 0.30 | 1.57 | 91.2 | ¹⁹⁹ ABBIENDI | 01A | OPAL |
| 2.41 ± 0.37 | 1.57 | 91.2 | ABREU | 00F | DLPH |
| 2.60± 0.47 | 1.57 | 91.2 | ACCIARRI | 00c | L3 |
| 1.70± 0.28 | 1.57 | 91.2 | ²⁰⁰ BARATE | 00c | ALEP |
| ● ● We do not use the follow | wing data fo | r average: | s, fits, limits, etc. • | • • | |
| $-32.8 \ ^{+}_{-} \ ^{6.4}_{6.2} \ \pm 1.5$ | -32.1 | 56.9 | ²⁰¹ ABE | 90ı | VNS |
| $-$ 8.1 \pm 2.0 \pm 0.6 | -9.2 | 35 | HEGNER | 90 | JADE |
| -18.4 ± 19.2 | -24.9 | 52.0 | ²⁰² BACALA | 89 | A MY |
| -17.7 ± 26.1 | -29.4 | 55.0 | ²⁰² BACALA | 89 | AMY |
| -45.9 ± 16.6 | -31.2 | 56.0 | ²⁰² BACALA | 89 | AMY |
| -49.5 ± 18.0 | -33.0 | 57.0 | ²⁰² BACALA | 89 | AMY |
| -20 + 14 | -25.9 | 53.3 | A DA CHI | 88c | TOPZ |

34.7

ADEVA

88 MRKJ

| $-$ 8.5 \pm 6.6 \pm 1.5 | -15.4 | 43.8 | ADEVA | 88 | MRKJ |
|-----------------------------|--------|------|-----------|-----|------|
| $-$ 6.0 \pm 2.5 \pm 1.0 | 8.8 | 34.6 | BARTEL | 85F | JADE |
| $-11.8 \pm 4.6 \pm 1.0$ | 14.8 | 43.0 | BARTEL | 85F | JADE |
| $-$ 5.5 \pm 1.2 \pm 0.5 | -0.063 | 29.0 | FERNANDEZ | 85 | MAC |
| $-$ 4.2 \pm 2.0 | 0.057 | 29 | LEVI | 83 | MRK2 |
| -10.3 ± 5.2 | -9.2 | 34.2 | BEHREND | 82 | CELL |
| $-$ 0.4 \pm 6.6 | -9.1 | 34.2 | BRANDELIK | 82c | TASS |

- $^{199} {\sf ABBIENDI}$ 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.
- $^{200}\,\mathrm{BARATE}$ 00c error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics. 201 ABE 901 measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.
- ²⁰²BACALA 89 systematic error is about 5%.

– $A_{FB}^{(0,\ell)}$ CHARGE ASYMMETRY IN $e^+\,e^ightarrow\,\ell^+\ell^-$ –

For the Z peak, we report the pole asymmetry defined by $(3/4)A_{\ell}^2$ as determined by the five-parameter fit to cross-section and lepton forwardbackward asymmetry data assuming lepton universality. For details see the note "The $\it Z$ boson" and ref. LEP-SLC 06.

| ASYMMETRY (%) | STD. MODEL | (GeV) | DO CUMENT ID | | TECN |
|-------------------|---------------|-------|-------------------------|-----|------|
| 1.71±0.10 OUR FIT | | | | | |
| 1.45 ± 0.17 | 1.57 | 91.2 | ²⁰³ ABBIENDI | 01A | OPAL |
| 1.87 ± 0.19 | 1.57 | 91.2 | ABREU | 00F | DLPH |
| 1.92 ± 0.24 | 1.57 | 91.2 | | 00c | L3 |
| 1.73 ± 0.16 | 1.57 | 91.2 | ²⁰⁴ BARATE | 00c | ALEP |

 203 ABBIENDI 01A error includes approximately $^{0.15}$ due to statistics, $^{0.06}$ due to event

selection systematics, and 0.03 due to the theoretical uncertainty in t-channel prediction. 204 BARATE 00c error includes approximately 0.15 due to statistics, 0.04 due to experimental systematics, and 0.02 due to the theoretical uncertainty in t-channel prediction.

- $A^{(0,u)}_{FR}$ CHARGE ASYMMETRY IN $e^+\,e^ightarrow\,u\,\overline{u}$ -

| 40467428 72 | | 205 ACKEDSTAFF 07- | ODAI |
|--------------------------|-------------|--------------------|------|
| ASYMMETRY (%) STD. MODEL | √s (GeV) | DO CUMENT ID | TECN |

 $^{205}\,\mathrm{ACKERSTAFF}$ 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types.

- $A_{FR}^{(0,s)}$ CHARGE ASYMMETRY IN $e^+e^ightarrow s$ \overline{s} ——

The s-quark asymmetry is derived from measurements of the forwardbackward asymmetry of fast hadrons containing an squark

| ASYMMETRY (%) | STD. MODEL | √s (GeV) | DO CUMENT ID | TECN |
|---------------------------|---------------|-------------|------------------------|---------|
| 9.8 ±1.1 OUR AVERAGE | | | · | |
| $10.08 \pm 1.13 \pm 0.40$ | 10.1 | 91.2 | ²⁰⁶ ABREU 0 | 0в DLPН |
| 68 +35 +11 | 10.1 | 91.2 | 207 ACKERSTAFE 9 | 7T OPAL |

 206 ABREU 00B tag the presence of an s quark requiring a high-momentum-identified charged kaon. The s-quark pole asymmetry is extracted from the charged-kaon asymmetry taking the expected d- and u-quark asymmetries from the Standard Model and using the measured values for the c- and b-quark asymmetries.

207 ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types. The value reported here corresponds then to the forward-backward asymmetry for "down-type" quarks.

- $A_{FB}^{(0,c)}$ CHARGE ASYMMETRY IN $e^+\,e^ightarrow\,c\,\overline{c}$ -

OUR FIT, which is obtained by a simultaneous fit to several c- and bquark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06, refers to the Z pole asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

| ASYMMETRY (%) | MODEL | (GeV) | DO CUMENT ID | | TECN |
|--------------------------------|---------------|----------|--------------------------|-----|------|
| 7.07± 0.35 OUR FIT | | | | | |
| $6.31 \pm 0.93 \pm 0.65$ | 6.35 | 91.26 | ²⁰⁸ ABDALLAH | 04F | DLPH |
| $5.68 \pm 0.54 \pm 0.39$ | 6.3 | 91.25 | ²⁰⁹ ABBIENDI | 03P | OPAL |
| $6.45 \pm 0.57 \pm 0.37$ | 6.10 | 91.21 | ²¹⁰ HEISTER | 02н | ALEP |
| $6.59 \pm 0.94 \pm 0.35$ | 6.2 | 91.235 | ²¹¹ ABREU | 99Y | DLPH |
| $6.3 \pm 0.9 \pm 0.3$ | 6.1 | 91.22 | ²¹² BARATE | 980 | ALEP |
| $6.3 \pm 1.2 \pm 0.6$ | 6.1 | 91.22 | ²¹³ ALEXANDER | 97c | OPAL |
| $8.3 \pm 3.8 \pm 2.7$ | 6.2 | 91.24 | ²¹⁴ adriani | 92D | L3 |
| • • • We do not use the follow | ving data for | averages | , fits, limits, etc. • | • • | |
| $3.1 \pm 3.5 \pm 0.5$ | -3.5 | 89.43 | ²⁰⁸ ABDALLAH | 04F | DLPH |
| $11.0 \pm 2.8 \pm 0.7$ | 12.3 | 92.99 | ²⁰⁸ ABDALLAH | 04F | DLPH |
| $-$ 6.8 \pm 2.5 \pm 0.9 | -3.0 | 89.51 | ²⁰⁹ ABBIENDI | 03P | OPAL |
| $14.6 \pm 2.0 \pm 0.8$ | 12.2 | 92.95 | ²⁰⁹ ABBIENDI | 03P | OPAL |
| $-12.4 \pm 15.9 \pm 2.0$ | -9.6 | 88.38 | ²¹⁰ HEISTER | 02н | ALEP |
| $-$ 2.3 \pm 2.6 \pm 0.2 | -3.8 | 89.38 | ²¹⁰ HEISTER | 02н | ALEP |
| $-$ 0.3 \pm 8.3 \pm 0.6 | 0.9 | 90.21 | ²¹⁰ HEISTER | 02H | ALEP |
| $10.6 \pm 7.7 \pm 0.7$ | 9.6 | 92.05 | ²¹⁰ HEISTER | 02н | ALEP |
| $11.9 \pm 2.1 \pm 0.6$ | 12.2 | 92.94 | ²¹⁰ HEISTER | 02н | ALEP |
| $12.1 \pm 11.0 \pm 1.0$ | 14.2 | 93.90 | ²¹⁰ HEISTER | 02н | ALEP |
| | | | | | |

| $-4.96\pm3.68\pm0.53$ | -3.5 | 89.434 | ²¹¹ ABREU | 99Y | DLPH |
|-----------------------------|-------|--------|--------------------------|-----|------|
| $11.80 \pm 3.18 \pm 0.62$ | 12.3 | 92.990 | ²¹¹ ABREU | 99Y | DLPH |
| $-$ 1.0 \pm 4.3 \pm 1.0 | -3.9 | 89.37 | ²¹² BARATE | 980 | ALEP |
| $11.0 \pm 3.3 \pm 0.8$ | 12.3 | 92.96 | ²¹² BARATE | 980 | ALEP |
| $3.9 \pm 5.1 \pm 0.9$ | -3.4 | 89.45 | ²¹³ ALEXANDER | 97c | OPAL |
| $15.8 \pm 4.1 \pm 1.1$ | 12.4 | 93.00 | ²¹³ ALEXANDER | 97c | OPAL |
| $-12.9 \pm 7.8 \pm 5.5$ | -13.6 | 35 | BEHREND | 90D | CELL |
| $7.7 \pm 13.4 \pm 5.0$ | -22.1 | 43 | BEHREND | 90D | CELL |
| $-12.8 \pm 4.4 \pm 4.1$ | -13.6 | 35 | ELSEN | 90 | JADE |
| $-10.9 \pm 12.9 \pm 4.6$ | -23.2 | 44 | ELSEN | 90 | JADE |
| -14.9 ± 6.7 | -13.3 | 35 | OULD-SAADA | 89 | JADE |

- 208 ABDALLAH 04F tag b- and c-quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of c and $b\overline{b}$ events are obtained using lifetime information.
- 209 ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the b and c quark forward-backward asymmetries as well as the average B^0 - \overline{B}^0 mixing.
- 210 HEISTER 02H measure simultaneously $\it b$ and $\it c$ quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating mu<u>lt</u>ivariate analysis.
- 211 ABREU 99Y tag $Z \to b\overline{b}$ and $Z \to c\overline{c}$ events by an exclusive reconstruction of several D meson decay modes $(D^{*+}, D^0, \text{ and } D^+ \text{ with their charge-conjugate states})$.
- 212 BARATE 980 tag $Z \rightarrow c\overline{c}$ events requiring the presence of high-momentum reconstructed $D^{*+}, D^+, \text{ or } D^0$ mesons.
- 213 ALEXANDER 97c identify the b and c events using a D/D^* tag.
- $^{214}\,\mathrm{ADRIA\,NI}$ 92D use both electron and muon semileptonic decays.

– $A_{FB}^{(0,b)}$ CHARGE ASYMMETRY IN $e^+ \, e^- ightarrow \, b \, \overline{b} \,$ —

OUR FIT, which is obtained by a simultaneous fit to several $c ext{-}$ and $b ext{-}$ quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06, refers to the Z pole asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

| ASYMMETRY (%) | STD. MODEL | √s (GeV) | | DO CUMENT ID | | TECN |
|--------------------------------------------------------------------------------------|---------------|------------------|-----|--------------|------------|--------------|
| 9.92± 0.16 OUR FIT | | | | | | |
| 9.58± 0.32± 0.14 | 9.68 | 91.231 | 215 | ABDALLAH | 05 | DLPH |
| 10.04± 0.56± 0.25 | 9.69 | 91.26 | 216 | ABDALLAH | 04F | DLPH |
| 9.72± 0.42± 0.15 | 9.67 | 91.25 | 217 | ABBIENDI | 03P | OPAL |
| 9.77± 0.36± 0.18 | 9.69 | 91.26 | 218 | | 021 | OPAL |
| 9.52± 0.41± 0.17 | 9.59 | 91.21 | 219 | | 02н | ALEP |
| 10.00± 0.27± 0.11 | 9.63 | 91.232 | 220 | HEISTER | 01D | ALEP |
| 7.62± 1.94± 0.85 | 9.64 | 91.235 | 221 | ABREU | 99Y | DLPH |
| 9.60± 0.66± 0.33 | 9.69 | 91.26 | 222 | ACCIARRI | 99D | L3 |
| 9.31 ± 1.01 ± 0.55 | 9.65 | 91.24 | 223 | ACCIARRI | 98u | L3 |
| 9.4 ± 2.7 ± 2.2 | 9.61 | 91.22 | | ALEXANDER | 97c | OPAL |
| • • • We do not use the follow | | averages | | | | |
| | 5.8 | 89.449 | | ABDALLAH | | DIDII |
| 6.37± 1.43± 0.17 | | 92.990 | 215 | ABDALLAH | 05 05 | DLPH |
| $10.41 \pm 1.15 \pm 0.24$ $6.7 \pm 2.2 \pm 0.2$ | 12.1 5.7 | 89.43 | | 'ABDALLAH | 05 04F | DLPH |
| | | 92.99 | 216 | | | DLPH |
| $11.2 \pm 1.8 \pm 0.2$ | 12.1 | | | ABBIENDI | 04F | DLPH |
| $4.7 \pm 1.8 \pm 0.1$ | 5.9 | 89.51 | 217 | ABBIENDI | 03P | OPAL |
| $10.3 \pm 1.5 \pm 0.2$ | 12.0 | 92.95 89.50 | | ABBIENDI | 03P | OPAL OPAL |
| 5.82± 1.53± 0.12 | 5.9 | | 218 | ABBIENDI | 021 | OPAL |
| 12.21 ± 1.23 ± 0.25 | 12.0 3.2 | 92.91 88.38 | | HEISTER | 02ı 02н | |
| $-13.1 \pm 13.5 \pm 1.0$ | | | 219 | | | ALEP |
| 5.5 ± 1.9 ± 0.1 | 5.6 | 89.38 | 219 | TILIDILIN | 02H | ALEP |
| $-0.4 \pm 6.7 \pm 0.8$ | 7.5 | 90.21 | 219 | | 02H | ALEP |
| $11.1 \pm 6.4 \pm 0.5$ | 11.0 | 92.05 | | HEISTER | 02H | ALEP |
| $10.4 \pm 1.5 \pm 0.3$ | 12.0 | 92.94 | | HEISTER | 02H | ALEP |
| $13.8 \pm 9.3 \pm 1.1$ | 12.9 | 93.90 | 220 | HEISTER | 02H | ALEP |
| 4.36± 1.19± 0.11 | 5.8 12.0 | 89.472 92.950 | 220 | HEISTER | 01D 01D | ALEP |
| 11.72± 0.97± 0.11 | | | 221 | ABREU | | ALEP |
| 5.67± 7.56± 1.17 | 5.7 | 89.434 | 221 | ABREU | 99Y | DLPH |
| 8.82± 6.33± 1.22 | 12.1 | 92.990 | 222 | ACCIARRI | 99Y | DLPH |
| 6.11 ± 2.93 ± 0.43 | 5.9 | 89.50 | 222 | ACCIARRI | 99D | L3 L3 |
| 13.71 ± 2.40 ± 0.44 | 12.2 | 93.10 | | ACCIARRI | 99D | |
| 4.95 ± 5.23 ± 0.40 11.37 ± 3.99 ± 0.65 | 5.8 | 89.45 92.99 | 223 | ACCIARRI | 98∪ 98∪ | L3 L3 |
| | 12.1 | | | ALEXANDER | | |
| $-8.6 \pm 10.8 \pm 2.9$ | 5.8 | 89.45 | 224 | ALEXANDER | 97c | OPAL |
| $-2.1 \pm 9.0 \pm 2.6$ | 12.1 | 93.00 | | ALEXANDER | 97c | OPAL |
| -71 ± 34 $^{+}$ 7 8 | -58 | 58.3 | | SHIMONAKA | 91 | TOPZ |
| $-22.2 \pm 7.7 \pm 3.5$ | -26.0 | 35 | | BEHREND | 90D | CELL |
| $-49.1 \pm 16.0 \pm 5.0$ | -39.7 | 43 | | BEHREND | 90D | CELL |
| -28 ± 11 | -23 | 35 | | BRAUNSCH | 90 | TASS |
| $-16.6~\pm~7.7~\pm~4.8$ | -24.3 | 35 | | ELSEN | 90 | JADE |
| $-33.6 \pm 22.2 \pm 5.2$ | -39.9 | 44 | | ELSEN | 90 | JADE |
| $3.4 \pm 7.0 \pm 3.5$ | -16.0 | 29.0 | | BAND | 89 | MAC |
| -72 ± 28 ± 13 | -56 | 55.2 | | SAGAWA | 89 | AMY |
| 215 ARDALLAH 05 obtain an enriched samples of h h events using lifetime information. | | | | | | |

 215 ABDALLAH 05 obtain an enriched samples of $b\overline{b}$ events using lifetime information. The quark (or antiquark) charge is determined with a neural network using the secondary vertex charge, the jet charge and particle identification.

216 ABDALLAH 04F tag b- and c-quarks using semileptonic decays combined with charge

flow information from the hemisphere opposite to the lepton. Enriched samples of $c\overline{c}$ and $b\overline{b}$ events are obtained using lifetime information.

Ζ

- 217 ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the b and c quark forward-backward asymmetries as well as the average B^0 – \overline{B}^0 mixing.
- 218 ABBIENDI 021 tag $Z^0 \to b \, \overline{b}$ decays using a combination of secondary vertex and lepton tags. The sign of the b-quark charge is determined using an inclusive tag based on jet, vertex, and kaon charges.
- 219 HEISTER 02H measure simultaneously b and c quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.
- 220 HEISTER 01D tag $Z \to b\overline{b}$ events using the impact parameters of charged tracks complemented with information from displaced vertices, event shape variables, and lepton identification. The b-quark direction and charge is determined using the hemisphere charge method along with information from fast kaon tagging and charge estimators of primary and secondary vertices. The change in the quoted value due to variation of $A^{\rm C}_{FB}$ and R_b is given as +0.103 ($A^{\rm C}_{FB}-0.0651)-0.440$ ($R_b-0.21585$).
- 221 ABREU 99Y tag $Z \to b \bar{b}$ and $Z \to c \bar{c}$ events by an exclusive reconstruction of several D meson decay modes (D^{*+} , D^0 , and D^+ with their charge-conjugate states).
- 222 ACCIARRI 99D tag $Z \to b\overline{b}$ events using high p and p_T leptons. The analysis determines simultaneously a mixing parameter $\chi_b = 0.1192 \pm 0.0068 \pm 0.0051$ which is used to correct the observed asymmetry.
- 223 ACCIARRI 980 tag $Z \rightarrow b\overline{b}$ events using lifetime and measure the jet charge using the hemisphere charge.
- 224 ALEXANDER 97C identify the b and c events using a D/D^{*} tag.

CHARGE ASYMMETRY IN $e^+e^- \rightarrow q \overline{q}$

Summed over five lighter flavors.

Experimental and Standard Model values are somewhat event-selection dependent. Standard Model expectations contain some assumptions on $B^0 \cdot \overline{B}^0$ mixing and on other electroweak parameters.

| ASYMMETRY (%) | STD. MODEL | √ <u>s</u> (GeV) | DO CUMENT ID | | TECN |
|---------------------------|-----------------|---------------------|-------------------------|-----|------|
| • • • We do not use the f | ollowing data f | or averages | s, fits, limits, etc. • | • • | |
| $-0.76\pm0.12\pm0.15$ | | 91.2 | ²²⁵ ABREU | 921 | DLPH |
| $4.0 \pm 0.4 \pm 0.63$ | 4.0 | 91.3 | ²²⁶ ACTON | 92L | OPAL |
| $9.1 \pm 1.4 \pm 1.6$ | 9.0 | 57.9 | A DA CHI | 91 | TOPZ |
| $-0.84 \pm 0.15 \pm 0.04$ | | 91 | DECAMP | 91B | ALEP |
| $8.3 \pm 2.9 \pm 1.9$ | 8.7 | 56.6 | STUART | 90 | A MY |
| $11.4 \pm 2.2 \pm 2.1$ | 8.7 | 57.6 | ABE | 89L | VNS |
| 6.0 ±1.3 | 5.0 | 34.8 | GREENSHAW | 89 | JADE |
| 8.2 +2.9 | 8.5 | 43.6 | GREENSHAW | 89 | JADE |

225 ABREU 921 has 0.14 systematic error due to uncertainty of quark fragmentation.

226 ACTON 92L use the weight function method on 259k selected $Z \rightarrow hadrons$ events. The systematic error includes a contribution of 0.2 due to B^0 – \overline{B}^0 mixing effect, 0.4 due to Monte Carlo (MC) fragmentation uncertainties and 0.3 due to MC statistics. ACTON 92L derive a value of $\sin^2\theta^{\rm eff}_{MV}$ to be 0.2321 \pm 0.0017 \pm 0.0028.

CHARGE ASYMMETRY IN $p \overline{p} \rightarrow Z \rightarrow e^+ e^-$

| ASYMMETRY (%) | STD. MODEL | √s (GeV) | DO CUMENT II | ס | TECN |
|-------------------------------|---------------|-------------|--------------------|-------|------|
| • • • We do not use the follo | wing data fo | r averages, | fits, limits, etc. | • • • | |
| $5.2 \pm 5.9 \pm 0.4$ | | 91 | ABE | 91E | CDF |

ANOMALOUS $ZZ\gamma$, $Z\gamma\gamma$, AND ZZV COUPLINGS

Revised March 2012 by M.W. Grünewald (U. Ghent) and A. Gurtu (King Abdulaziz University).

In on-shell $Z\gamma$ production, deviations from the Standard Model for the $Z\gamma\gamma^*$ and $Z\gamma Z^*$ couplings may be described in terms of 8 parameters, h_i^V ($i=1,4;\ V=\gamma,Z$) [1]. The parameters h_i^V describe the $Z\gamma\gamma^*$ couplings and the parameters h_i^Z the $Z\gamma Z^*$ couplings. In this formalism h_1^V and h_2^V lead to CP-violating and h_3^V and h_4^V to CP-conserving effects. All these anomalous contributions to the cross section increase rapidly with center-of-mass energy. In order to ensure unitarity, these parameters are usually described by a form-factor representation, $h_i^V(s) = h_{io}^V/(1+s/\Lambda^2)^n$, where Λ is the energy scale for the manifestation of a new phenomenon and n is a sufficiently large power. By convention one uses n=3 for $h_{1,3}^V$ and n=4 for $h_{2,4}^V$. Usually limits on h_i^V 's are put assuming some value of Λ , sometimes ∞ .

In on-shell ZZ production, deviations from the Standard Model for the $ZZ\gamma^*$ and ZZZ^* couplings may be described by

means of four anomalous couplings f_i^V $(i=4,5;V=\gamma,Z)$ [2]. As above, the parameters f_i^γ describe the $ZZ\gamma^*$ couplings and the parameters f_i^Z the ZZZ^* couplings. The anomalous couplings f_5^V lead to violation of C and P symmetries while f_4^V introduces CP violation. Also here, formfactors depending on a scale Λ are used.

All these couplings h_i^V and f_i^V are zero at tree level in the Standard Model; they are measured in e^+e^- , $p\bar{p}$ and pp collisions at LEP, Tevatron and LHC.

References

- 1. U. Baur and E.L. Berger Phys. Rev. **D47**, 4889 (1993).
- 2. K. Hagiwara et al., Nucl. Phys. B282, 253 (1987).

hįV

Combining the LEP results properly taking into account the correlations the following 95% CL limits are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$\begin{array}{lll} -0.13 < h_1^Z < +0.13, & -0.078 < h_2^Z < +0.071, \\ -0.20 < h_3^Z < +0.07, & -0.05 < h_4^Z < +0.12, \\ -0.056 < h_1^\gamma < +0.055, & -0.045 < h_2^\gamma < +0.025, \\ -0.049 < h_3^\gamma < -0.008, & -0.002 < h_4^\gamma < +0.034. \end{array}$$

<u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

• • • We do not use the following data for averages, fits, limits, etc. • • •

231 ABDALLAH 07C DLPH Eee 183-208 GeV
232 ACHARD 04H L3
233 ABBIENDI,G 00C OPAL
234 ABBOTT 98M D0
235 ABREU 98K DLPH

227 AALTONEN 11s study $Z\gamma$ events in $p\overline{p}$ interactions at $\sqrt{s}=1.96$ TeV with integrated luminosity 5.1 fb $^{-1}$ for $Z\to e^+e^-/\mu^+\mu^-$ and 4.9 fb $^{-1}$ for $Z\to \nu\overline{\nu}$. For the charged lepton case, the two leptons must be of the same flavor with the transverse momentum/energy of one >20 GeV and the other >10 GeV. The isolated photon must have $E_T>50$ GeV. They observe 91 events with 87.2 \pm 7.8 events expected from standard model processes. For the $\nu\overline{\nu}$ case they require solitary photons with $E_T>25$ GeV and missing $E_T>25$ GeV and observe 85 events with standard model expectation of 85.9 \pm 5.6 events. Taking the form factor $\Lambda=1.5$ TeV they derive 95% C.L. limits as $|h_3^{\gamma}, z''|<0.022$ and $|h_4^{\gamma}, z''|<0.0009$.

228 CHATRCHYAN 11M study $Z\gamma$ production in $\rho\rho$ collisions at $\sqrt{s}=7$ TeV using 36 pb⁻¹ $\rho\rho$ data, where the Z decays to e^+e^- or $\mu^+\mu^-$. The total cross sections are measured for photon transverse energy $E_T^\gamma>10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma)>0.7$ with the dilepton invariant mass requirement of $M_{\ell\ell}>50$ GeV. The number of $e^+e^-\gamma$ and $\mu^+\mu^-\gamma$ candidates is 81 and 90 with estimated backgrounds of 20.5 ± 2.5 and 27.3 ± 3.2 events respectively. The 95% CL limits for $ZZ\gamma$ couplings are $-0.05< h_3^Z<0.06$ and $-0.0005< h_4^Z<0.0005$, and for $Z\gamma\gamma$ couplings are $-0.07< h_3^\gamma<0.07$ and $-0.0005< h_4^\gamma<0.0006$.

 229 ABAZOV 09L study $Z\gamma,\,Z\to\nu\overline{\nu}$ production in $\rho\overline{\rho}$ collisions at 1.96 TeV C.M. energy. They select 51 events with a photon of transverse energy E_T larger than 90 GeV, with an expected background of 17 events. Based on the photon E_T spectrum and including also Z decays to charged leptons (from ABAZOV 07M), the following 95% CL limits are reported: $|h_{30}^{\gamma}|<0.033,\,|h_{40}^{\gamma}|<0.0017,\,|h_{30}^{\gamma}|<0.0017,\,|h_{30}^{\gamma}|<0.0017$

230 ABAZOV 07M use 968 $p\overline{p}\to e^+e^-/\mu^+\mu^-\gamma X$ candidates, at 1.96 TeV center of mass energy, to tag $p\overline{p}\to Z\gamma$ events by requiring $E_T(\gamma)>7$ GeV, lepton-gamma separation $\Delta R_{\ell\gamma}>0.7$, and di-lepton invariant mass >30 GeV. The cross section is in agreement with the SM prediction. Using these $Z\gamma$ events they obtain 95% C.L. limits on each h_i^V , keeping all others fixed at their SM values. They report: $-0.083 < h_{20}^Z < 0.082, -0.0053 < h_{40}^Z < 0.0054, -0.085 < h_{30}^\gamma < 0.084, -0.0053 < h_{40}^\gamma < 0.0054,$

 $\begin{array}{lll} 0.082, \, -0.0053 < h_{4Q}^{Z} < 0.0054, \, -0.085 < h_{3Q}^{\gamma} < 0.084, \, -0.0053 < h_{4Q}^{\gamma} < 0.0054, \\ \text{for the form factor scale } \Lambda = 1.2 \,\, \text{TeV}. \\ 231 \,\, \text{Using data collected at } \sqrt{s} = 183-208, \,\, \text{ABDALLAH 07c select } 1,877 \,\, e^+ e^- \rightarrow \,\,\, Z\gamma \\ \text{events with } Z \rightarrow q \overline{q} \,\, \text{or } \nu \overline{\nu}, \,\, 171 \,\, e^+ e^- \rightarrow \,\,\, ZZ \,\, \text{events with } Z \rightarrow q \overline{q} \,\, \text{or lepton pair} \\ \text{(except an explicit τ pair), and } 74 \,\, e^+ e^- \rightarrow \,\,\, Z\gamma^* \,\, \text{events with a } q \, \overline{q} \,\, \mu^+ \,\, \mu^- \,\, \text{or } q \, \overline{q} \,\, e^+ \,\, e^- \\ \text{signature, to derive 95% CL limits on } h_1^V. \,\, \text{Each limit is derived with other parameters} \\ \text{set to zero. They report: } -0.23 < h_1^Z < 0.23, \,\, -0.30 < h_3^Z < 0.16, \,\, -0.14 < h_1^{\gamma} < 0.14, \,\, -0.049 < h_3^{\gamma} < 0.044. \end{array}$

232 ACHARD 04H select 3515 $e^+e^- o Z\gamma$ events with $Z o q\overline{q}$ or $\nu\overline{\nu}$ at $\sqrt{s}=189$ –209 GeV to derive 95% CL limits on h_V^V . For deriving each limit the other parameters are fixed at zero. They report: $-0.153 < h_I^Z < 0.141, -0.087 < h_Z^Z < 0.079, -0.220 <$

 $h_3^Z < 0.112, \, -0.068 < h_4^Z < 0.148, \, -0.057 < h_1^{\gamma} < 0.057, \, -0.050 < h_2^{\gamma} < 0.023,$ $-0.059 < h_3^{\gamma} < 0.004, -0.004 < h_4^{\gamma} < 0.042.$

233 ABBIENDI,G 00c study $e^+e^- \rightarrow Z\gamma$ events (with $Z \rightarrow q\overline{q}$ and $Z \rightarrow \nu \overline{\nu}$) at 189 GeV to obtain the central values (and 95% CL limits) of these couplings: $h_1^Z = 0.000 \pm 0.100 \; (-0.190, 0.190), \; h_2^Z = 0.000 \pm 0.068 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.068 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.008 \; (-0.128, 0.128), \; h_3^Z = 0.000 \; \pm 0.000 \; \pm 0.000 \; \pm 0.000 \; + 0.000 \; + 0.000 \; + 0.000 \; + 0.000 \;$ $-0.074^{+0.102}_{-0.103}$ (-0.269, 0.119), $h_4^Z = 0.046 \pm 0.068$ (-0.084, 0.175), $h_1^{\gamma} = 0.000 \pm 0.008$ 0.061 (-0.115, 0.115), $h_2^{\gamma} = 0.000 \pm 0.041$ (-0.077, 0.077), $h_3^{\gamma} = -0.080 + 0.039 - 0.041$ $(-0.164, -0.006), \ h_4^{\gamma} = 0.064 + 0.033 \\ -0.030 \ (+0.007, +0.134). \ \ \text{The results are derived}$ assuming that only one coupling at a time is different from zero.

²³⁴ ABBOTT 98M study $p\overline{p} \rightarrow Z\gamma + X$, with $Z \rightarrow e^+e^-, \, \mu^+\mu^-, \, \overline{\nu}\nu$ at 1.8 TeV, to obtain 95% CL limits at $\Lambda=$ 750 GeV: $|h_{30}^Z|<$ 0.36, $|h_{40}^Z|<$ 0.05 (keeping $h_i^{\gamma}=$ 0), and $|h_{30}^{\gamma}|<0.37, |h_{40}^{\gamma}|<0.05 \text{ (keeping } h_{i}^{\gamma}=0), \text{ and } |h_{30}^{\gamma}|<0.37, |h_{40}^{\gamma}|<0.05 \text{ (keeping } h_{i}^{\gamma}=0). \text{ Limits on the } \textit{CP-violating couplings are } |h_{10}^{\gamma}|<0.36, |h_{20}^{\gamma}|<0.05 \text{ (keeping } h_{i}^{\gamma}=0), \text{ and } |h_{10}^{\gamma}|<0.37, |h_{20}^{\gamma}|<0.05 \text{ (keeping } h_{i}^{\gamma}=0).}$

²³⁵ ABREU 98K determine a 95% CL upper limit on $\sigma(e^+\,e^-\,
ightarrow\,\gamma\,+$ invisible particles) <2.5 pb using 161 and 172 GeV data. This is used to set 95 % CL limits on $|h_{30}^{\gamma}| <$ 0.8 and $|h_{30}^{Z}|<1.3$, derived at a scale $\Lambda=1\,{
m TeV}$ and with n=3 in the form factor representation.

Combining the LEP results properly taking into account the correlations the following 95 % CL limits are derived (CERN-PH-EP/2005-051 or hep-ex/0511027)

$$-0.30 < f_4^Z < +0.30,$$
 $-0.34 < f_5^Z < +0.38,$ $-0.17 < f_4^{\gamma} < +0.19,$ $-0.32 < f_5^{\gamma} < +0.36.$

TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • •

²³⁶ SCHAEL 09 ALEP $E_{\mathrm{C}\underline{\mathrm{m}}}^{\mathit{ee}} = 192\text{--}209~\mathrm{GeV}$ ²³⁷ ABAZOV 08к D0 $E_{\text{CM}}^{\overline{p}\overline{p}} = 1.96 \text{ TeV}$ ²³⁸ ABDALLAH 07c DLPH $E_{
m cm}^{\it ee}=183$ –208 GeV 04c OPAL

239 ABBIENDI 240 ACHARD 03D L3

²³⁶ Using data collected in the center of mass energy range 192–209 GeV, SCHAEL 09 select 318 $e^+\,e^ightarrow~$ $Z\,Z$ events with 319.4 expected from the standard model. Using this data they derive the following 95% CL limits: $-0.321 < f_A^{\gamma} < 0.318$, $-0.534 < f_A^{Z} < 0.534$ $0.534,\, -0.724 < f_{\bf 5}^{\gamma} < 0.733,\, -1.194 < f_{\bf 5}^{Z} < 1.190.$

237 ABAZOV 08k search for ZZ and $Z\gamma^*$ events with $1\,{\rm fb}^{-1}$ $p\overline{p}$ data at $\sqrt{s}=1.96$ TeV in (e e) (e e), $(\mu\mu)(\mu\mu)$, (e e) $(\mu\mu)$ final states requiring the lepton pair masses to be > 30 GeV. They observe 1 event, which is consistent with an expected signal of 1.71 ± 0.15 events and a background of 0.13 ± 0.03 events. From this they derive the following limits, for a form factor (A) value of 1.2 TeV: $-0.28 < f_{40}^Z < 0.28$, $-0.31 < f_{50}^Z < 0.28$ $0.29, \, -0.26 < f_{40}^{\gamma} < 0.26, \, -0.30 < f_{50}^{\gamma} < 0.28.$

 238 Using data collected at $\sqrt{s}=$ 183–208 GeV, ABDALLAH 07c select 171 $e^+\,e^-\to~$ Z Z events with $Z
ightarrow~q\,\overline{q}$ or lepton pair (except an explicit au pair), and 74 e^+e^- – events with a $q\overline{q}\,\mu^+\,\mu^-$ or $q\overline{q}\,e^+\,e^-$ signature, to derive 95% CL limits on f_i^V . Each limit is derived with other parameters set to zero. They report: $-0.40 < f_A^{Z'} < 0.42$, $-0.38 < f_5^Z < 0.62, \, -0.23 < f_4^{\gamma} < 0.25, \, -0.52 < f_5^{\gamma} < 0.48.$

239 ABBIENDI 04c study ZZ production in e⁺e⁻ collisions in the C.M. energy range 190–209 GeV. They select 340 events with an expected background of 180 events. Including the ABBIENDI 00N data at 183 and 189 GeV (118 events with an expected background of 65 events) they report the following 95% CL limits: $-0.45 < f_4^{Z} < 0.58$, $-0.94 < f_5^{Z} < 0.25$, $-0.32 < f_4^{\gamma} < 0.33$, and $-0.71 < f_5^{\gamma} < 0.59$.

 240 ACHARD 03p study Z-boson pair production in e^+e^- collisions in the C.M. energy range 200–209 GeV. They select 549 events with an expected background of 432 events. Including the ACCIARRI 996 and ACCIARRI 990 data (183 and 189 GeV respectively, 286 events with an expected background of 241 events) and the 192–202 GeV ACCIARRI 011 results (656 events, expected background of 512 events), they report the following 95% CL limits: $-0.48 \le f_4^Z \le 0.46, -0.36 \le f_5^Z \le 1.03, -0.28 \le f_4^{\gamma} \le 0.28, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.28, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.28, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48, \text{ and } -0.40 \le 0.48 \le f_4^{\gamma} \le 0.48 \le$ $f_5^{\gamma} \leq 0.47$

ANOMALOUS W/Z QUARTIC COUPLINGS

Revised March 2012 by M.W. Grünewald (U. Ghent) and A. Gurtu (King Abdulaziz University).

The Standard Model quartic couplings, WWZZ, $WWZ\gamma$, $WW\gamma\gamma$, and $ZZ\gamma\gamma$ lead to negligible effects at LEP energies, while they are important at a TeV Linear Collider. Outside the Standard Model framework, possible quartic couplings, a_0, a_c, a_n , are expressed in terms of the following dimension-6 operators [1,2];

$$\begin{split} L_6^0 &= -\frac{e^2}{16\Lambda^2} \; a_0 \; F^{\mu\nu} \; F_{\mu\nu} \vec{W^{\alpha}} \cdot \vec{W_{\alpha}} \\ L_6^c &= -\frac{e^2}{16\Lambda^2} \; a_c \; F^{\mu\alpha} \; F_{\mu\beta} \vec{W^{\beta}} \cdot \vec{W_{\alpha}} \end{split}$$

$$\begin{split} L_6^n &= -i\frac{e^2}{16\Lambda^2} \; a_n \epsilon_{ijk} \; W_{\mu\alpha}^{(i)} \; W_{\nu}^{(j)} \; W^{(k)\alpha} F^{\mu\nu} \\ \widetilde{L}_6^0 &= -\frac{e^2}{16\Lambda^2} \; \widetilde{a}_0 \; F^{\mu\nu} \; \widetilde{F}_{\mu\nu} \vec{W}^\alpha \cdot \vec{W}_\alpha \\ \widetilde{L}_6^n &= -i\frac{e^2}{16\Lambda^2} \; \widetilde{a}_n \epsilon_{ijk} \; W_{\mu\alpha}^{(i)} \; W_{\nu}^{(j)} \; W^{(k)\alpha} \widetilde{F}^{\mu\nu} \end{split}$$

where F,W are photon and W fields, L_6^0 and L_6^c conserve C, P separately (\widetilde{L}_6^0 conserves only C) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP (\widetilde{L}_6^n violates both C and P) and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately leading to two sets parameterized as a_0^V/Λ^2 and a_c^V/Λ^2 , where V=W or Z.

At LEP the processes studied in search of these quartic couplings are $e^+e^- \to WW\gamma$, $e^+e^- \to \gamma\gamma\nu\overline{\nu}$, and $e^+e^- \to$ $Z\gamma\gamma$ and limits are set on the quantities a_0^W/Λ^2 , a_c^W/Λ^2 , a_n/Λ^2 . The characteristics of the first process depend on all the three couplings whereas those of the latter two depend only on the two CP-conserving couplings. The sensitive measured variables are the cross sections for these processes as well as the energy and angular distributions of the photon and recoil mass to the photon pair.

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a_0/Λ^2 , a_c/Λ^2

Combining published and unpublished preliminary LEP results the following 95% CL intervals for the QGCs associated with the $ZZ\gamma\gamma$ vertex are derived (CERN-PH-EP /2005-051 or hep-ex /0511027):

$$\begin{array}{l} -0.008 < a_0^Z/\Lambda^2 < +0.021 \\ -0.029 < a_c^Z/\Lambda^2 < +0.039 \end{array}$$

• • We do not use the following data for averages, fits, limits, etc. • • 241 ABBIENDI ²⁴² HEISTER 04A ALEF ²⁴³ ACHARD 02G L3

²⁴¹ ABBIENDI 04L select 20 $e^+\,e^-
ightarrow \,
u \overline{
u} \gamma \gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+\,e^ightarrow\,q\,\overline{q}\,\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma$ sample of ABBIENDI 04B the following one-parameter 95% CL limits are obtained: $-0.007 < a_0^Z/\Lambda^2 < 0.023 \ {\rm GeV}^{-2}, -0.029 < a_0^Z/\Lambda^2 < 0.020 \ {\rm GeV}^{-2}, -0.052 < 0.020 \ {\rm GeV}^{-2}, -0.$

0.037 GeV $^{-2}$. 242 In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- o \nu \overline{\nu} \gamma \gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon-photon acoplanarity is required to be > 5°, $E_{\gamma}/\sqrt{s}>0.025$ (the more energetic photon having energy > 0.2 \sqrt{s}), p $_{T_{\gamma}}/{\rm E_{beam}}~>$ 0.05 and $|\cos\theta_{\gamma}|~<$ 0.94. A likelihood fit to the photon energy and recoil missing mass yields the following one-parameter 95% CL limits: $-0.012 < a_C^2/\Lambda^2 < 0.019~{\rm GeV}^{-2}, -0.041 < a_C^2/\Lambda^2 < 0.044~{\rm GeV}^{-2}$, $-0.060 < a_0^W/\Lambda^2 < 0.055 \text{ GeV}^{-2}, -0.099 < a_C^W/\Lambda^2 < 0.093 \text{ GeV}^{-2}.$

²⁴³ ACHARD 026 study $e^+e^- \rightarrow Z\gamma\gamma \rightarrow q\overline{q}\gamma\gamma$ events using data at center-of-mass energies from 200 to 209 GeV. The photons are required to be isolated, each with energy

>5 GeV and $|\cos\theta|<0.97$, and the di-jet invariant mass to be compatible with that of the Z boson (74–111 GeV). Cuts on Z velocity ($\beta<0.73$) and on the energy of the most energetic photon reduce the backgrounds due to non-resonant production of the $q\overline{q}\gamma\gamma$ state and due to ISR respectively, yielding a total of 40 candidate events of which 8.6 are expected to be due to background. The energy spectra of the least energetic photon are fitted for all ten center-of-mass energy values from 130 GeV to 209 GeV (as obtained adding to the present analysis 130–202 GeV data of ACCIARRI 01E, for a total of 137 events with an expected background of 34.1 events) to obtain the fitted values $a_0/\Lambda^2=0.00+0.02$ GeV-2 and $a_c/\Lambda^2=0.03+0.02$ GeV-2, where the other parameter is kept fixed to its Standard Model value (0). A simultaneous fit to both parameters yields the 95% CL limits -0.02 GeV $-2< a_o/\Lambda^2<0.03$ GeV-2 and -0.07 GeV $-2< a_o/\Lambda^2<0.05$ GeV-2<0.05 GeV-2<0 ${\rm GeV}^{-\,2} < \! a_{C}/\Lambda^{2} < 0.05~{\rm GeV}^{-\,2}.$

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| ACCIARRI | 97 R | PL B413 167 | M. Acciarri et al. | (L3 Collab.) |
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| ACKERS TAFF | 97 M | ZPHY C74 413 | K. Ackerstaff et al. K. Ackerstaff et al. | (OPAL Collab.) |
| ACKERS TAFF | 97 S | PL B412 210 | | (OPAL Collab.) |
| ACKERS TAFF | 97 T 97 W | ZPHY C76 387 ZPHY C76 425 | K. Ackerstaff et al. | (OPAL Collab.) (OPAL Collab.) |
| ACKERS TAFF ALEXANDER | 97 VV | ZPHY C73 379 | K. Ackerstaff <i>et al.</i> G. Alexander <i>et al.</i> | (OPAL Collab.) |
| ALEXANDER | 97 D | ZPHY C73 569 | G. Alexander <i>et al.</i> | (OPAL Collab.) |
| ALEXANDER | 97 E | ZPHY C73 587 | G. Alexander <i>et al.</i> | |
| BARATE | 97 D | PL B405 191 | R. Barate et al. | (OPAL Collab.) (ALEPH Collab.) |
| BA RATE | 97 E | PL B401 150 | R. Barate et al. | (ALEPH Collab.) |
| BA RATE | 97 F | PL B401 163 | R. Barate et al. | (ALEPH Collab.) |
| BARATE | 97 H | PL B402 213 | R. Barate et al. | (ALEPH Collab.) |
| BARATE | 97 J | ZPHY C74 451 | R. Barate et al. | (ALEPH Collab.) |
| ABREU | 96 R | ZPHY C72 31 | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 96S | PL B389 405 | P Abreu et al | (DELPHI Collab.) |
| ABREU | 96 U | ZPHY C73 61 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| ACCIARRI | 96 | PL B371 126 | M. Acciarri <i>et al.</i> | (L3 Collab.) |
| ADAM | 96 | ZPHY C69 561 | W. Adam et al. | (DELPHI Collab.) |
| ADAM | 96B | ZPHY C70 371 | W. Adam et al. | (DELPHI Collab.) |
| ALEXANDER | 96B | ZPHY C70 197 | G. Alexander et al. | (OPAL Collab.) |
| ALEXANDER | 96 F | PL B370 185 PL B384 343 | G. Alexander <i>et al</i> . | (OPAL Collab.) (OPAL Collab.) |
| ALEXANDER ALEXANDER | 96 N 96 R | ZPHY C72 1 | G. Alexander <i>et al.</i> G. Alexander <i>et al.</i> | (OPAL Collab.) |
| BUS KULIC | 96 D | ZPHY C69 393 | D. Buskulic et al. | (ALEPH Collab.) |
| BUS KULIC | 96 H | ZPHY C69 379 | D. Buskulic et al. | (ALEPH Collab.) |
| BUS KULIC | 96T | PL B384 449 | D. Buskulic et al. | (ALEPH Collab.) |
| BUS KULIC | 96 Y | PL B388 648 | D. Buskulic et al. | (ALEPH Collab.) |
| ABE | 95 J | PRL 74 2880 | K. Abe et al. | (SLD Collab.) |
| ABREU | 95 | ZPHY C65 709 | (erratum)P. Abreu et al. | (DELPHI Collab.) |
| ABREU ABREU | 95 D 95 L | ZPHY C66 323 ZPHY C65 587 ZPHY C65 603 | P. Abreu et al. P. Abreu et al. | (DELPHI Collab.) (DELPHI Collab.) |
| ABREU | 95 M | ZPHY C65 603 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| ABREU | 95 O | ZPHY C67 543 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| ABREU | 95 R | ZPHY C68 353 | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 95 V | ZPHY C68 541 | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 95 W | PL B361 207 | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 95 X | ZPHY C69 1 | P. Abreu et al. | (DELPHI Collab.) |
| ACCIARRI | 95 B | PL B345 589 | M. Acciarri et al. | (L3 Collab.) |
| ACCIARRI | 95 C | PL B345 609 | M. Acciarri et al. | (L3 Collab.) |
| ACCIARRI | 95 G | PL B353 136 | M. Acciarri et al. | (L3 Collab.) |
| AKERS AKERS | 95 C 95 U | ZPHY C65 47 ZPHY C67 389 ZPHY C67 555 | R. Akers et al. R. Akers et al. | (OPAL Collab.) (OPAL Collab.) |
| AKERS | 95 W | ZPHY C67 555 | R. Akers et al. | (OPAL Collab.) |
| AKERS | 95 X | ZPHY C68 1 | R. Akers et al. | (OPAL Collab.) |
| AKERS | 95 Z | ZPHY C68 203 | R. Akers et al. | (OPAL Collab.) |
| ALEXANDER | 95 D | PL B358 162 | G. Alexander et al. | (OPAL Collab.) |
| BUSKULIC | 95 R | ZPHY C69 15 | D. Buskulic et al. | (ALEPH Collab.) |
| MIYABAYASHI | 95 | PL B347 171 | K. Miyabayashi et al. | (TOPAZ Collab.) |
| ABF | 94 C | PRL 73 25 | K. Abe et al. | (SLD Collab.) |
| ABREU | 94 B | PL B327 386 | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 94 P | PL B341 109 | P. Abreu et al. | (DELPHI Collab.) |
| AKERS | 94 P | ZPHY C63 181 | R. Akers et al. | (OPAL Collab.) |
| BUS KULIC | 94 G | ZPHY C62 179 | D. Buskulic et al. | (A`LEPH Collab.) |
| BUS KULIC | 94 J | ZPHY C62 1 | D. Buskulic et al. | (ALEPH Collab.) |
| VILAIN | 94 | PL B320 203 | P. Vilain et al. | (CHARM II Collab.) |
| ABREU | 93 | PL B298 236 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| ABREU | 93 I | ZPHY C59 533 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| Also | 93 L | ZPHY C65 709 | (erratum)P. Abreu et al. | (DELPHI Collab.) |
| ABREU | | PL B318 249 | P. Abreu et al. | (DELPHI Collab.) |
| ACTON | 93 | PL B305 407 | P.D. Acton et al. | (OPAL Collab.) |
| ACT ON | 93 D | ZPHY C58 219 | P.D. Acton et al. | (OPAL Collab.) |
| ACT ON | 93 E | PL B311 391 | P.D. Acton et al. | (OPAL Collab.) |
| ADRIANI | 93 | PL B301 136 | O. Adriani et al. | ` (L3 Collab.) |
| ADRIANI | 931 | PL B316 427 | O. Adriani et al. | (L3 Collab.) |
| BUS KULIC | 93 L | PL B313 520 PL B298 453 | D. Buskulic et al. | (ALEPH Collab.) |
| NOVIKOV | 93 C | PL B298 453 | V.A. Novikov, L.B. Okun, M. | I. Vysotsky` (ITEP) |
| ABREU | 92 I | PL B277 371 | P. Abreu <i>et al</i> . | (DELPHI Collab.) |
| ABREU | 92 M | PL B289 199 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| ACT ON | 92 B | ZPHY C53 539 | D.P. Acton <i>et al.</i> | (OPAL Collab.) |
| ACTON | 92 L | PL B294 436 | P.D. Acton et al. | (OPAL Collab.) |
| ACTON | 92 N | PL B295 357 | P.D. Acton et al. | (OPAL Collab.) |
| ADEVA | 92 | PL B275 209 | B. Adeva et al. | (L3 Collab.) |
| ADRIANI | 92 D | PL B292 454 | O. Adriani et al. | (L3 Collab.) |
| ALITTI | 92 B | PL B276 354 | J. Alitti et al. | (UA2 Collab.) |
| BUS KULIC | 92 D | PL B292 210 | D. Buskulic et al. | (ALEPH Collab.) |
| BUS KULIC | 92 E | PL B294 145 | D. Buskulic et al. | (ALEPH Collab.) |
| DE CAMP | 92 | PRPL 216 253 | D. Decamp et al. | (ALEPH Collab.) |
| ABE | 91 E | PRL 67 1502 | F. Abe et al. | (CDF Collab.) |
| ABREU | 91 H | ZPHY C50 185 | P. Abreu et al. | (DELPHI Collab.) |
| ACTON | 91B | PL B273 338 | D.P. Acton et al. | (OPAL Collab.) |
| ADA CHI | 91 | PL B255 613 | I. Adachi et al. | (L3 Collab.) |
| ADEVA | 911 | PL B259 199 | B. Adeva et al. | |
| AKRAWY | 91 F | PL B257 531 | M.Z. Akrawy et al. | (OPAL Collab.) |
| DECAMP | 91 B | PL B259 377 | D. Decamp et al. | (ALEPH Collab.) |
| DECAMP | 91 J | PL B266 218 | D. Decamp et al. | (ALEPH Collab.) |
| JACOBSEN | 91 | PRL 67 3347 | R.G. Jacobsen <i>et al.</i> | (Mark II Collab.) |
| SHIMONAKA | 91 | PL B268 457 | A. Shimonaka <i>et al.</i> | (TOPAZ Collab.) |
| ABE ABRAMS | 90 I 90 | ZPHY C48 13 PRL 64 1334 | A. Shimonaka et al. K. Abe et al. G.S. Abrams et al. | (VENUS Collab.) (Mark II Collab.) |
| AKRAWY | 90 J | PL B246 285 | M. Z. Akrawy et al. | (OPAL Collab.) |
| BEHREND | | ZPHY C47 333 | H.J. Behrend et al. | (CELLO Collab.) |
| BRAUNSCH | | ZPHY C48 433 | W. Braunschweig et al. | (TASSO Collab.) |
| ELS EN HE GNER | 90 90 | ZPHY C48 433 ZPHY C46 349 ZPHY C46 547 | E. Elsen <i>et al.</i> S. Hegner <i>et al</i> . | `(JADE Collab.) (JADE Collab.) |
| STUART | 90 | PRL 64 983 | D. Stuart et al. | (AMY Collab.) |
| ABE | 89 | PRL 62 613 | F. Abe et al. | (CDF Collab.) |
| ABE | 89 C | PRL 63 720 | F. Abe et al. | (CDF Collab.) |
| ABE | 89L | PL B232 425 | F. Abe et al. K. Abe et al. | (VÈNUS Collab.) (Mark II Collab.) |
| ABRAMS | 89B | PRL 63 2173 | G.S. Abrams et al. | (Mark II Collab.) |
| ABRAMS | 89D | PRL 63 2780 | G.S. Abrams et al. | |
| ALBAJAR | 89 | ZPHY C44 15 | C. Albajar et al. | (UA1 Collab.) |
| BACALA | 89 | PL B218 112 | A. Bacala et al. | (AMY Collab.) |
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| S A G AWA | 89 | PRL 63 2341 | H. Sagawa et al. | (AMY Collab.) |
| A D A C H I | 88 C | PL B208 319 | I. Adachi et al. | (TOPAZ Collab.) |
| ADEVA | 88 | PR D38 2665 | B. Adeva <i>et al.</i> | (Mark-J Collab.) |
| BRAUNSCH | | ZPHY C40 163 | W. Braunschweig <i>et al.</i> | (TASSO Collab.) |
| ANSARI | 87 | PL B186 440 | R. Ansari et al. | (UA2 Collab.) (CELLO Collab.) |
| BEHREND BARTEL | 87 C 86 C | PL B191 209 ZPHY C30 371 | | (JADE Collab.) |
| A Iso | | ZPHY C26 507 | W. Bartel et al. | (JADE Collab.) |
| A Iso | | PL 108B 140 | W. Bartel et al. | (JADE Collab.) |
| AS H | 85 95 E | PRL 55 1831 PL 161B 188 | W.W. Ash et al. | (MAC Collab.) (JADE Collab.) |
| BARTEL DERRICK | 85 F 85 | PR D31 2352 | W. Bartel et al. M. Derrick et al. | (HRS Collab.) |
| FERNANDEZ | 85 | PRL 54 1624 | E. Fernandez <i>et al.</i> | (MAC Collab.) |
| LEVI | 83 | PRL 51 1941 | M.E. Levi et al. | (Mark II Collab.) |
| BEHREND | 82 | PL 114B 282 | H.J. Behrend <i>et al.</i> | (CELLO Collab.) |
| BRANDELIK | 82 C | PL 110B 173 | R. Brandelik <i>et al.</i> | (TASSO Collab.) |
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Gauge & Higgs Boson Particle Listings Higgs Bosons — H^0 and H^{\pm}

Higgs Bosons — H^0 and H^{\pm} , Searches for

HIGGS BOSONS: THEORY AND SEARCHES

Updated May 2012 by G. Bernardi (CNRS/IN2P3, LPNHE/U. of Paris VI & VII), M. Carena (Fermi National Accelerator Laboratory and the University of Chicago), and T. Junk (Fermi National Accelerator Laboratory).

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NOTE: The 4 July 2012 update on the Higgs search from ATLAS and CMS is described in the Addendum at the end of this review.

I. Introduction

Understanding the mechanism that breaks electroweak symmetry and generates the masses of the known elementary particles is one of the most fundamental problems in particle physics. The Higgs mechanism [1] provides a general framework to explain the observed masses of the W^{\pm} and Z gauge bosons by means of charged and neutral Goldstone bosons that are manifested as the longitudinal components of the gauge bosons. These Goldstone bosons are generated by the underlying dynamics of electroweak symmetry breaking (EWSB). However, the fundamental dynamics of the electroweak symmetry breaking are unknown. There are two main classes of

theories proposed in the literature, those with weakly coupled dynamics—such as in the Standard Model (SM) [2]—and those with strongly coupled dynamics; both classes are summarized below

In the SM, the electroweak interactions are described by a gauge field theory based on the $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ symmetry group. The Higgs mechanism posits a self-interacting complex doublet of scalar fields, and renormalizable interactions are arranged such that the neutral component of the scalar doublet acquires a vacuum expectation value $v \approx 246$ GeV, which sets the scale of EWSB. Three massless Goldstone bosons are generated, which are absorbed to give masses to the W^\pm and Z gauge bosons. The remaining component of the complex doublet becomes the Higgs boson—a new fundamental scalar particle. The masses of all fermions are also a consequence of EWSB since the Higgs doublet is postulated to couple to the fermions through Yukawa interactions. If the Higgs boson mass m_H is below ~ 180 GeV, all fields remain weakly interacting up to the Planck scale, $M_{\rm Pl}$.

The validity of the SM as an effective theory describing physics up to the Planck scale is questionable, however, because of the following "naturalness" argument. All fermion masses and dimensionless couplings are logarithmically sensitive to the scale Λ at which new physics becomes relevant. In contrast, scalar squared masses are quadratically sensitive to Λ . Thus, the observable SM Higgs mass has the following form:

$$m_H^2 = m_{H_0}^2 + \frac{kg^2\Lambda^2}{16\pi^2},$$

where m_{H_0} is a fundamental parameter of the theory. The second term is a one-loop correction in which q is an electroweak coupling and k is a constant, presumably of $\mathcal{O}(1)$, that is calculable within the low-energy effective theory. The two contributions arise from independent sources and one would not expect that the observable Higgs boson mass is significantly smaller than either of the two terms. Hence, if the scale of new physics Λ is much larger than the electroweak scale, unnatural cancellations must occur to remove the quadratic dependence of the Higgs boson mass on this large energy scale and to give a Higgs boson mass of order of the electroweak scale, as required from unitarity constraints [3,4], and as preferred by precision measurements of electroweak observables [5]. Most relevantly, recent results from direct Higgs searches at the Tevatron [6] and, in particular, at the LHC [7–10] strongly constrain the SM Higgs boson mass to be in the range 114-129 GeV, in excellent agreement with the indirect predictions from electroweak precision data. Thus, the SM is expected to be embedded in a more fundamental theory which will stabilize the hierarchy between the electroweak scale and the Planck scale in a natural way. A theory of that type would usually predict the onset of new physics at scales of the order of, or just above, the electroweak scale. Theorists strive to construct models of new physics that keep the successful features of the SM while curing its shortcomings, such as the absence of a dark matter candidate or a

¹ In the case of neutrinos, it is possible that the Higgs mechanism plays a role but is not entirely responsible for the generation of their observed masses.

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detailed explanation of the observed baryon asymmetry of the universe.

In the weakly-coupled approach to electroweak symmetry breaking, supersymmetric (SUSY) extensions of the SM provide a possible explanation for the stability of the electroweak energy scale in the presence of quantum corrections [11,12]. These theories predict at least five Higgs particles [13]. The properties of the lightest Higgs scalar often resemble those of the SM Higgs boson, with a mass that is predicted to be less than 135 GeV [14] in the simplest supersymmetric model². Additional neutral and charged Higgs bosons are also predicted. Moreover, low-energy supersymmetry with a supersymmetry breaking scale of order 1 TeV allows for grand unification of the electromagnetic, weak and strong gauge interactions in a consistent way, strongly supported by the prediction of the electroweak mixing angle at low energy scales, with an accuracy at the percent level [22,23].

Alternatively new strong interactions near the TeV scale can induce strong breaking of the electroweak symmetry [24]. "Little Higgs" models have been proposed in which the scale of the new strong interactions is pushed up above 10 TeV [25–27], and the lightest Higgs scalar resembles the weakly-coupled SM Higgs boson.

Another approach to electroweak symmetry breaking has been explored in which extra space dimensions beyond the usual 3+1 dimensional space-time are introduced [28] with characteristic sizes of the fundamental Planck scale of order $(1 \text{ TeV})^{-1}$. In such scenarios, the mechanisms for electroweak symmetry breaking are inherently extra-dimensional and the resulting Higgs phenomenology can depart significantly from SM predictions [27,29].

Both in the framework of supersymmetric theories and in the strongly coupled dynamic approach there have been many studies based on effective theory approaches [18,20,21,30,31] that prove useful in exploring departures from the SM Higgs phenomenology in a more model independent way.

Prior to 1989, when the e^+e^- collider LEP at CERN came into operation, searches were sensitive only to Higgs bosons with masses of a few GeV and below [32]. In the LEP 1 phase, the collider operated at center-of-mass energies close to M_Z . During the LEP 2 phase, the energy was increased in steps, reaching 209 GeV in the year 2000 before the final shutdown. The combined data of the four LEP experiments, ALEPH, DELPHI, L3, and OPAL, were sensitive to neutral

Higgs bosons with masses up to about 115 GeV and to charged Higgs bosons with masses up to about 90 GeV [33,34].

The search for the Higgs boson continued at the Tevatron $p\overline{p}$ collider, which operated at a center-of-mass energy of 1.96 TeV until its shutdown in the Fall of 2011. The two experiments, CDF and DØ, each collected approximately 10 fb⁻¹ of data with the capability to probe a SM Higgs boson mass in the 90-185 GeV range. The combination of the results from CDF and DØ shows an excess of data events with respect to the background estimation in the mass range 115 GeV $< m_H <$ 135 GeV. The global significance for such an excess anywhere in the full mass range is approximately 2.2 standard deviations. The excess is concentrated in the $H \to b\bar{b}$ channel, although the results in the $H \to W^+W^-$ channel are also consistent with the possible presence of a low-mass Higgs boson. Other neutral and charged Higgs particles postulated in most theories beyond the SM are also searched for at the Tevatron. The Tevatron Higgs results are discussed in more detail later in this review. The final results are expected to be available by the end of 2012.

Searches for Higgs bosons are ongoing at the LHC pp collider. These searches have much higher sensitivity than the Tevatron searches and cover masses up to several hundred GeV. At present both LHC experiments, ATLAS and CMS, have searched for a SM Higgs boson produced mainly through gluon fusion, and decaying dominantly into gauge boson pairs. The initial results are compatible with the presence of a SM-like Higgs boson with a mass in the range 114-129 GeV, with most of the remaining mass values up to at least 500 GeV being excluded at the 95% C.L. by both experiments. Both LHC experiments observe small excesses, predominantly in the $\gamma\gamma$ and ZZ modes, which could be compatible with a Higgs boson with a mass near 125 GeV but are not yet conclusive. These results are discussed in more detail later in this review. If a signal is confirmed, the next step is to understand the precise nature of such a particle by scrutinizing the coupling strengths in the different production and decay channels. Searches are also conducted by both LHC collaborations for Higgs bosons produced via vector boson fusion and in association with a W or a Z boson. Decays to $b\bar{b}$ and $\tau^+\tau^-$ are searched for in addition to the more experimentally distinct boson pair signatures. With additional data, these searches will constrain the production rates and decay branching ratios of the Higgs boson. An exciting time lies ahead in the case of the discovery of a Higgs boson since we would need to understand its nature and the underlying new physics that might be related to it. Beyond a discovery, precision measurements will be crucial to completely understand the mechanism of electroweak symmetry breaking.

II. The Standard Model (SM) Higgs Boson

In the SM, the Higgs boson mass is given by $m_H = \sqrt{\lambda/2} v$, where λ is the Higgs self-coupling parameter and v is the vacuum expectation value of the Higgs field, $v = (\sqrt{2}G_F)^{-1/2} \approx$

² Larger values of the mass of the lightest Higgs boson, up to about 250 GeV, can be obtained in non-minimal SUSY extensions of the SM [15–21]. However, if the LHC's indications of a light Higgs boson are confirmed, the main motivation for non-minimal SUSY extensions would be to obtain a Higgs boson mass in the 120–130 GeV mass range without demanding heavy top quark superpartners, and thereby avoid the so-called little hierarchy problem.

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246 GeV, fixed by the Fermi coupling G_F , which is determined with a precision of 0.6 ppm from muon decay measurements [35]. Since λ is presently unknown, the value of the SM Higgs boson mass m_H cannot be predicted. However, besides the upper bound on the Higgs boson mass from unitarity constraints [3,4], additional theoretical arguments place approximate upper and lower bounds on m_H [36]. There is an upper bound based on the perturbativity of the theory up to the scale Λ at which the SM breaks down, and a lower bound derived from the stability of the Higgs potential. If m_H is too large, then the Higgs self-coupling diverges at some scale Λ below the Planck scale. If m_H is too small, then the Higgs potential develops a second (global) minimum at a large value of the magnitude of the scalar field of order Λ . New physics must enter at a scale Λ or below, so that the global minimum of the theory corresponds to the observed $SU(2)_L \times U(1)_Y$ broken vacuum with v = 246 GeV. Given a value of Λ , one can compute the minimum and maximum allowed Higgs boson masses. Conversely, the value of m_H itself can provide an important constraint on the scale up to which the SM remains successful as an effective theory. In particular, a Higgs boson with mass in the range 130 GeV $\lesssim m_H \lesssim 180$ GeV would be consistent with an effective SM description that survives all the way to the Planck scale. For smaller Higgs mass values, the stability of our universe prefers new physics at a lower scale. The lower bound on m_H can be reduced to about 115 GeV [37] if one allows for the electroweak vacuum to be metastable, with a lifetime greater than the age of the universe. The main uncertainties in the stability and perturbativity bounds come from the uncertainties in the value of α_s and the top quark mass. As can be inferred from Fig. 1 [38], taking these uncertainties into account, a Higgs boson mass of about 125 GeV is close to the boundary of a SM that is consistent up to the Planck scale, and a SM that is unstable with a slow tunneling rate.

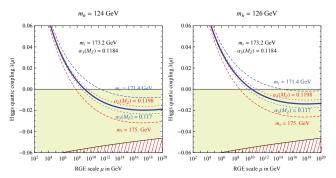


Figure 1: Renormalization group evolution of the Higgs self coupling λ , for $m_H=124~{\rm GeV}$ (left) and $m_H=126~{\rm GeV}$ (right), for the central values of m_t and α_S (solid curves), as well as for variations of m_t (dashed curves) and α_S (dotted curves). For negative values of λ , the lifetime of the SM vacuum due to quantum tunneling at zero temperature is longer than the age of the universe as long as λ remains above the region shaded in red. From Ref. 38.

The SM Higgs couplings to fundamental fermions are proportional to the fermion masses, and the couplings to bosons are proportional to the squares of the boson masses. In particular, the SM Higgs boson is a CP-even scalar, and its couplings to gauge bosons, Higgs bosons and fermions are given by:

$$\begin{split} g_{Hf\bar{f}} &= \frac{m_f}{v}, \quad g_{HVV} = \frac{2m_V^2}{v}, \quad g_{HHVV} = \frac{2m_V^2}{v^2} \\ g_{HHH} &= \frac{3m_H^2}{v} \quad g_{HHHH} = \frac{3m_H^2}{v^2} \end{split}$$

where $V=W^\pm$ or Z. In Higgs boson production and decay processes, the dominant mechanisms involve the coupling of the H to the W^\pm , Z and/or the third generation quarks and leptons. The Higgs boson's coupling to gluons, is induced at leading order by a one-loop graph in which the H couples to a virtual $t\bar{t}$ pair. Likewise, the Higgs boson's coupling to photons is also generated via loops, although in this case the one-loop graph with a virtual W^+W^- pair provides the dominant contribution [13]. Reviews of the SM Higgs boson's properties and phenomenology, with an emphasis on the impact of loop corrections to the Higgs boson decay rates and cross sections, can be found in Refs. [39–45].

The main Higgs boson production cross sections at an e^+e^- collider are the Higgs-strahlung process $e^+e^- \to ZH$ [4,46], and the WW fusion process [47] $e^+e^- \to \bar{\nu}_e\nu_eW^*W^* \to \bar{\nu}_e\nu_eH$. As center-of-mass energy \sqrt{s} is increased, the cross-section for the Higgs-strahlung process decreases as s^{-1} and is dominant at low energies, while the cross-section for the WW fusion process grows as $\ln(s/m_H^2)$ and dominates at high energies [48,49,50]. The ZZ fusion mechanism, $e^+e^- \to e^+e^-Z^*Z^* \to e^+e^-H$, also contributes to Higgs boson production, with a cross-section suppressed by an order of magnitude with respect to that of WW fusion. The process $e^+e^- \to t\bar{t}H$ [51,52] can become relevant for large $\sqrt{s} \simeq 800$ GeV for SM Higgs masses in the experimentally preferred region. For a more detailed discussion of Higgs production properties at lepton colliders see for example Refs. [44] and [45], and references therein.

At high-energy hadron colliders, the Higgs boson production mechanism with the largest cross section is $gg \to H + X$. This process is known at next-to-next-to-leading order (NNLO) in QCD, in the large top-mass limit, and at NLO in QCD for The NLO QCD corrections approxarbitrary top mass [53]. imately double the leading-order prediction, and the NNLO corrections add approximately 50% to the NLO prediction. NLO electroweak corrections range between 0 and 6% of the Mixed QCD-electroweak corrections $O(\alpha \alpha_s)$ LO term [54]. are computed in Ref. [55]. In addition, soft-gluon contributions to the cross sections have been resummed at next-toleading logarithmic (NLL), NNLL and partial NNNLL accuracy Updated predictions for the gluon fusion cross sections at NNLO or through soft-gluon resummation up to next-tonext-to-leading logarithmic accuracy (NNLL), and two-loop electroweak effects can be found in Refs. [55,57].

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perturbative convergence is achieved by resumming the enhanced contributions arising from the analytic continuation of the gluon form factor [58]. Updated predictions to compute the gluon fusion cross sections at NNNLL in renormalization group improved perturbation theory and incorporating two-loop electroweak effects can be found in Ref. [59]. Some search strategies look for Higgs boson production in association with jets. In the heavy top quark mass limit, the Higgs boson production cross section in association with one jet is considered in Refs. [60–63] and in association with two jets in Refs. [64,65].

The other relevant Higgs boson production mechanisms at the Tevatron and the LHC are associated production with W and Z gauge bosons and vector boson fusion, and at a significantly smaller rate, the associated production with top quark pairs. The cross sections for the associated production processes $q\overline{q} \to W^{\pm}H + X$ and $q\overline{q} \to ZH + X$ [66,67,68] are known at NNLO for the QCD corrections and at NLO for the electroweak corrections [69,70]. The residual uncertainty is less than 5%. For the vector boson fusion processes $qq \rightarrow$ qqH+X, corrections to the production cross section are known at NNLO in QCD and at NLO for the electroweak corrections and the remaining theoretical uncertainties in the inclusive cross section are approximately 2% [71], but are larger if jets are required or vetoed [43]. The cross section for the associated production process $t\bar{t}H$ has been calculated at NLO in QCD [72], while the bottom fusion Higgs boson production cross section is known at NNLO in the case of five quark flavors [69,73,74]. The cross sections for the production of SM Higgs bosons are summarized in Fig. 2 for $p\overline{p}$ collisions at the Tevatron, and in Fig. 3 for pp collisions at $\sqrt{s} = 7$ TeV at the LHC [75,76]. Ref. [75] also includes cross sections computed at $\sqrt{s} = 8$ TeV, which are relevant for data collected in 2012.

The branching ratios for the most relevant decay modes of the SM Higgs boson as functions of m_H , including the most recent theoretical uncertainties, are shown in Fig. 4. The total decay width as function of m_H is shown in Fig. 5. Details of these calculations can be found in Refs. [40–44]. boson masses below 135 GeV, decays to fermion pairs dominate; the decay $H \to b\bar{b}$ has the largest branching ratio and the decay $H \to \tau^+ \tau^-$ is about an order of magnitude smaller. For these low masses, the total decay width is less than 10 MeV. For Higgs boson masses above 135 GeV, the W^+W^- decay dominates (below the W^+W^- threshold, one of the W bosons is virtual) with an important contribution from $H \to ZZ$, and the decay width rises rapidly, reaching about 1 GeV at $m_H = 200$ GeV and 100 GeV at $m_H = 500$ GeV. Above the $t\bar{t}$ threshold, the branching ratio into $t\bar{t}$ pairs increases rapidly as a function of the Higgs boson mass, reaching a maximum of about 20% at $m_H \sim 450$ GeV. Higgs boson decays into pairs of gluons, pairs of photons, and $Z\gamma$ are induced at one loop level. Higgs boson decay into a pair of photons is particularly relevant for the discovery potential of the LHC for a low-mass Higgs boson. In

spite of the small expected signal rate, the reconstructed mass resolution provides a way to separate signal from background, a means to calibrate the background rate with a signal-free sample of events, and a precise measurement of m_H once a signal is identified.

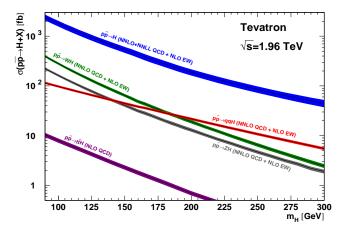


Figure 2: SM Higgs boson production cross sections for $p\overline{p}$ collisions at 1.96 TeV, including theoretical uncertainties [53,70–72].

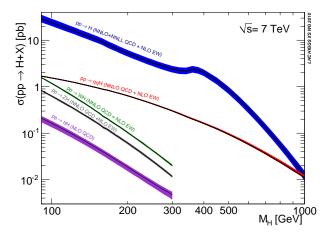


Figure 3: SM Higgs boson production cross sections for *pp* collisions at 7 TeV, including theoretical uncertainties [76].

II.1. Indirect Constraints on the SM Higgs Boson

Indirect experimental bounds for the SM Higgs boson mass are obtained from fits to precision measurements of electroweak observables. The Higgs boson contributes to the W^{\pm} and Z vacuum polarization through loop effects, leading to a logarithmic sensitivity of the ratio of the W^{\pm} and Z gauge boson masses on the Higgs boson mass. A global fit to the precision electroweak data accumulated in the last two decades at LEP, SLC, the Tevatron, and elsewhere, gives $m_H = 94^{+29}_{-24}$ GeV, or

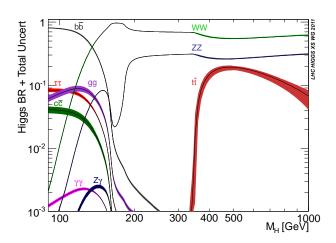


Figure 4: Branching ratios for the main decays of the SM Higgs boson, including theoretical uncertainties [40–44].

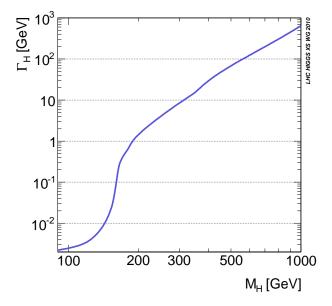


Figure 5: The total decay width of the SM Higgs boson, shown as a function of m_H [76].

 $m_H < 152$ GeV at 95% C.L. [5]. The top quark contributes to the W^\pm boson vacuum polarization through loop effects that depend quadratically on the top mass, which plays an important role in the global fit. A top quark mass of 173.2 ± 0.9 GeV [77] and a W^\pm boson mass of 80.385 ± 0.015 GeV [5] were used.

II.2. Searches for the SM Higgs Boson at LEP

The principal mechanism for producing the SM Higgs boson in e^+e^- collisions at LEP energies is Higgs-strahlung in the schannel, $e^+e^- \to HZ$. The Z boson in the final state is either

virtual (LEP 1), or on mass shell (LEP 2). At LEP energies, SM Higgs boson production via W^+W^- and ZZ fusion in the t-channel has a small cross section. The sensitivity of the LEP searches to the Higgs boson depends on the center-of-mass energy, \sqrt{s} . For $m_H < \sqrt{s} - M_Z$, the cross section is of order 1 pb or more, while for $m_H > \sqrt{s} - M_Z$, the cross section is smaller by at least an order of magnitude.

During the LEP 1 phase, the ALEPH, DELPHI, L3 and OPAL collaborations analyzed over 17 million Z decays and set lower bounds of approximately 65 GeV on the mass of the SM Higgs boson [78]. At LEP 2, substantial data samples were collected at center-of-mass energies up to 209 GeV. Data recorded at each center-of-mass energy were studied independently and the results from the four LEP experiments were then combined. The $\rm CL_s$ method [79] was used to compute the observed and expected limits on the Higgs boson production cross section as functions of the Higgs boson mass considered, and from that a lower bound on m_H was derived.

Higgs bosons with mass above $2m_{\tau}$ were searched for in four final state topologies: The four-jet topology in which $H \to b \overline{b}$ and $Z \to q \overline{q}$; the final states with tau leptons produced in the processes $H \to \tau^+ \tau^-$ where $Z \to q \overline{q}$, together with the mode $H \to b \overline{b}$ with $Z \to \tau^+ \tau^-$; the missing energy topology produced mainly in the process $H \to b \overline{b}$ with $Z \to \nu \overline{\nu}$, and finally the leptonic states $H \to b \overline{b}$ with $Z \to e^+ e^-$, $\mu^+ \mu^-$. At LEP 1, only the modes with $Z \to \ell^+ \ell^-$ and $Z \to \nu \overline{\nu}$ were used because the backgrounds in the other channels were prohibitive. For the data collected at LEP 2, all decay modes were used.

For very light Higgs bosons, with $m_H < 2m_\tau$, the decay modes exploited above are not kinematically allowed, and decays to jets, muon pairs, pion pairs, and lighter particles dominate, depending on m_H . For very low masses, OPAL's decay-mode independent search [80] for the Bjorken process $e^+e^- \to S^0Z$, where S^0 denotes a generic neutral scalar particle, provides sensitivity regardless of the branching fractions of the S^0 . This search is based on studies of the recoil mass spectrum in events with $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ decays, and on the final states $Z \to \nu\overline{\nu}$ and $S^0 \to e^+e^-$ or photons. Upper bounds on the $e^+e^- \to ZH$ cross section are obtained for scalar masses between 1 KeV and 100 GeV, and are below 0.05 times the SM prediction for $m_H < 80$ GeV, constraining the coupling of the Higgs boson to the Z.

The combination of the LEP data yields a 95% C.L. lower bound of 114.4 GeV for the mass of the SM Higgs boson [33]. The median limit one would expect to obtain in a large ensemble of identical experiments with no signal present is 115.3 GeV. An excess of data was seen consistent with a Higgs boson of mass $m_H \approx 115$ GeV. The significance of this excess is low, however. It is quantified by the background-only p-value [79], which is the probability to obtain data at least as signal-like as the observed data, assuming a signal is truly absent; a small p-value indicates data that are inconsistent with the background model but are more consistent with a signal model.

The background-only p-value for the excess in the LEP data is 9%.

II.3. Searches for the SM Higgs Boson at the Tevatron

As shown in Fig. 2, at the Tevatron, the most important SM Higgs boson production processes are gluon fusion $(gg \to H)$ and Higgs boson production in association with a vector boson $(W^{\pm}H \text{ or } ZH)$. Vector boson fusion (VBF) has a smaller cross section, but some search channels are optimized for it. For m_H less than about 135 GeV, the most sensitive analyses search for $W^{\pm}H$ and ZH with $H \to b\bar{b}$. The mode $gg \to H \to b\bar{b}$ is overwhelmed by the background from the inclusive production of $p\bar{p} \to b\bar{b} + X$ via the strong interaction. The associated production modes $W^{\pm}H$ and ZH allow use of the leptonic W and Z decays to purify the signal and reject QCD backgrounds.

The contribution of $H \to W^*W$ or WW is dominant at higher masses, $m_H > 135$ GeV. Using this decay mode, both the direct $(gg \to H)$ and the associated production $(p\overline{p} \to W^{\pm}H)$ or ZH) channels are explored, and the results of both Tevatron experiments, CDF and DØ, are combined to maximize the sensitivity to the Higgs boson.

The signal-to-background ratio is much smaller in the Tevatron searches than in the LEP analyses, and the systematic uncertainties on the estimated background rates are typically larger than the signal rates. In order to estimate the background rates in the selected samples more accurately, auxiliary measurements are made in data samples which are expected to be depleted in Higgs boson signal. These auxiliary samples are chosen to maximize the sensitivity to each specific background in turn. Monte Carlo simulations are used to extrapolate these measurements into the Higgs signal regions. The dominant physics backgrounds such as top-pair, diboson, $W^{\pm}b\overline{b}$, and single top production are estimated by Monte Carlo simulations in this way, i.e., after having been tuned or verified by corresponding measurements in dedicated analyses, thereby reducing the uncertainty on the total background estimate. Nearly all Tevatron analyses use multivariate analysis techniques (MVA's) to further separate signals from backgrounds and to provide the final discriminants whose distributions are used to compute limits, best-fit cross sections and uncertainties, and p-values. Separate MVA's are trained at each m_H in all the different sub-channels.

Both Tevatron experiments have updated their main search analyses to the full analyzable data sample of approximately $10~{\rm fb^{-1}}$. At Higgs boson masses of 150 GeV and below, the searches for associated production, $p\bar{p} \to W^{\pm}H, ZH$, are performed in different channels, as follows. The $WH \to \ell\nu b\bar{b}$ searches [81–85] select events with a charged lepton ($\ell=e$ or μ), large missing transverse energy, and at least two jets, at least one of which must be b-tagged. In order to improve the sensitivity of the searches, events with one b-tag are analyzed separately from those with two, and events with three jets are analyzed separately from those with two jets. Algorithms to identify b jets provide several levels of purity for each jet, and

this serves as another dimension along which to classify events. The quality and the type of the identified lepton also serves to classify events. An event with an isolated, high- p_T track is analyzed as if that track were a lepton, but such events are collected together in different sub-channels. The signals in such categories come from leptons which the detectors failed to reconstruct as leptons, and hadrons from τ lepton decay. The instrumental ("fake-lepton") backgrounds are higher for these selections, and so samples with well-identified leptons are kept separate from the isolated-track samples.

The $ZH \to \nu \bar{\nu} b \bar{b}$ searches [86–89] seek events in which no lepton or high- p_T isolated track is found. These searches also accept signals from $WH \to \ell \nu b \bar{b}$ in which the charged lepton is either not identified or falls outside the detector acceptances. Similar b-tagging categorization is applied to these searches. The $ZH \to \ell^+\ell^-b\bar{b}$ searches [90–93] seek leptonic decays of the Z boson. These events benefit from the absence of neutrinos, and so missing transverse energy can be interpreted as jet energy mismeasurement, and the jet energies are corrected accordingly, improving the dijet mass resolution. CDF searches for associated production and VBF in the all-hadronic mode, in which the W or the Z decays hadronically, and the H decays to $b\bar{b}$ [94,95].

A cross check of the procedures for searching for the SM Higgs boson in the $WH,ZH\to b\bar{b}$ channels, their background estimates, and combination procedures, is provided by measurements of WZ+ZZ production in b-tagged final states [96,97], and their combination [98]. In these analyses, the decay $Z\to b\bar{b}$ mimics the decay $H\to b\bar{b}$, and WW production is considered a background. The measured cross section is consistent with the SM expectations, giving confidence in the Higgs boson search procedures.

Both Tevatron experiments also search for $H \to \tau^+\tau^-$ in events with one or more associated jets [99–102]. As the ditau mass resolution is poor due to the presence of unmeasured neutrinos, the $Z \to \tau^+\tau^-$ background is large in the absence of the requirement of one or more additional jets, which purifies the sample in associated production and VBF. The process $gg \to H$ is considered as well, although the uncertainties on $gg \to H$ +jets are larger than the inclusive uncertainties.

The decay mode $H\to\gamma\gamma$ is searched for by both Tevatron collaborations [103–106]. Prompt diphoton production, $\pi^0\to\gamma\gamma$, and fake photons are the main backgrounds. The backgrounds have a smoothly varying shape as a function of $m_{\gamma\gamma}$, while the signal mass resolution is of order 3%. All Higgs boson production mechanisms are considered, but the signal-to-background ratio at the Tevatron is not sufficient for this channel to contribute significantly to the SM search. Nonetheless, the searches for $H\to\gamma\gamma$ provide powerful tests of models with enhanced BR($H\to\gamma\gamma$), described later.

Another process searched for at the Tevatron is $t\bar{t}H$ production with $H \to b\bar{b}$ [107,108]. The backgrounds in this channel are low and are dominated by $t\bar{t}b\bar{b}$, but the low signal

production rate and combinatoric ambiguity in assigning jets to the Higgs boson decay reduces the sensitivity.

For Higgs boson masses above 130 GeV, the searches for $H\to W^+W^-\to \ell^+\nu\ell^-\bar{\nu}$ [109–114] are the most sensitive. The candidate mass cannot be fully reconstructed in these events due to the presence of two neutrinos, but the lepton angles are correlated due to the scalar nature of the Higgs boson and the V-A $W\ell\nu$ coupling. The process $W^\pm H\to W^\pm W^+W^-$ gives rise to like-sign dilepton and trilepton final states which have very low backgrounds [110,115]. CDF also seeks $H\to ZZ\to \ell^+\ell^-\ell^+\ell^-$ [116] where $\ell=e$ or μ . The excellent mass resolution and low backgrounds help the sensitivity of the search, but low decay branching ratio for $Z\to \ell^+\ell^-$ reduces the sensitivity.

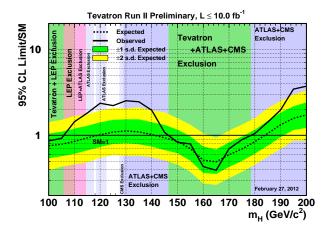


Figure 6: Observed and expected 95% C.L. upper limits on the ratios to the SM cross section, as functions of the Higgs boson mass for the combined CDF and D0 analyses [6]. The limits are expressed as a multiple of the SM prediction. The bands indicate the 68% and 95% probability regions where the limits can fluctuate, in the absence of signal. Also shown are the regions excluded by LEP, ATLAS, and CMS.

All of the searches for the SM Higgs boson at the Tevatron are combined together for maximum sensitivity [6,117,118]. The Tevatron combination excludes two ranges in m_H : between 100 GeV and 106 GeV, and between 147 GeV and 179 GeV. An excess of data is seen in the mass range 115 GeV $< m_H <$ 135 GeV, as shown in Fig. 6. with a maximum local significance of 2.7 standard deviations (sigma), at $m_H = 120$ GeV, where the expected local significance for a SM Higgs signal is 2.0 sigma. When corrected for the look-elsewhere effect (LEE) [119], which accounts for the possibility of selecting the strongest of the several random excess which may happen in the range 115 GeV $< m_H < 200$ GeV, the global significance of the

excess is 2.2 standard deviations³. The majority of the excess is contributed by the searches for $H \to b\bar{b}$. The best-fit cross section for Higgs boson production, normalized to the SM production rate, and assuming SM decay branching ratios and SM ratios between the production mechanisms, is shown in Fig. 7.

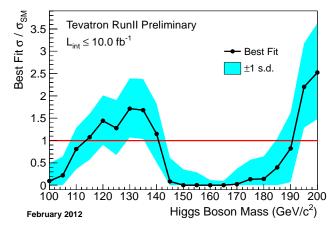


Figure 7: Best-fit cross section for the SM Higgs boson from the combined CDF and DØ searches, normalized to the SM production rates, assuming SM decay branching ratios and the SM ratio between the various production mechanisms [6]. The shaded region shows the 68% C.L. interval, as a function of the mass of the Higgs boson considered. In this fit, negative signal cross sections are not considered.

The channels used at the Tevatron for Higgs boson masses below 130 GeV are different from those dominantly used at the LHC, and thus provide complementary information on the couplings of the Higgs boson to gauge bosons and to b quarks.

II.4. SM Higgs Boson Searches at the LHC

At the LHC, the main production processes are the same as those at the Tevatron, but with a different order of importance: gluon fusion $(gg \to H)$, vector boson fusion (qqH) or $q\overline{q}H$ and Higgs boson production in association with a vector boson $(W^{\pm}H)$ or ZH or with a top-quark pair $(t\overline{t}H)$.

The higher center-of-mass energy of 7 TeV (8 TeV in 2012) and the fact that both beams consist of protons has a strong impact on the parton luminosities. The LHC experiments are sensitive to Higgs bosons with much higher masses than the Tevatron experiments. The gg luminosity is also enhanced at the LHC by the beam energy due to the large gluon PDF at lower parton momentum fraction x compared to that at higher x.

A variety of search channels are pursued by the LHC collaborations, ATLAS and CMS, with the channels' relative importances changing due to the branching ratios of the SM Higgs

³ In this Review, we use the phrase "local significance" to indicate a calculation of the significance not corrected for the LEE.

boson as functions of m_H . At low masses, $m_H < 120$ GeV, searches for $H \to \gamma \gamma$ provide the highest sensitivity, with searches for $H \to b\bar{b}$ and $H \to \tau^+\tau^-$ contributing as well. For higher masses, 120 GeV $< m_H < 200$ GeV, searches for $H \to W^+W^- \to \ell^+\nu\ell^-\nu$ are the most sensitive, with an important contribution from $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$ between 120 GeV and 150 GeV. At even higher masses, up to $m_H = 600$ GeV, the $H \to ZZ$ searches are the most sensitive.

Both LHC collaborations seek $H \to W^+W^- \to \ell^+\nu\ell^-\nu$ production [120–122]. This channel provides high sensitivity for Higgs boson masses for which $\mathrm{BR}(H \to W^+W^-)$ is large, $m_H > 135$ GeV. The main SM background, nonresonant W^+W^- production, is initiated primarily by $q\overline{q}$ and thus the signal to background ratio benefits at the LHC because of the initial state. The first LHC exclusion of Higgs boson masses was obtained in this search mode. CMS also contributes a search in the mode $W^\pm H \to W^\pm W^+W^-$ [123] in the trilepton final state. For ATLAS, the fully leptonic decay mode is supplemented with an $H \to W^+W^- \to \ell\nu jj$ search [124].

At higher masses, $m_H > 180$ GeV, ATLAS and CMS analyses seeking $H \to ZZ$ with $ZZ \to \ell^+\ell^-\ell^+\ell^-$ [125,126], $ZZ \to \ell^+\ell^-\nu\bar{\nu}$ [127,128], $ZZ \to \ell^+\ell^-q\bar{q}$ [129,130], and $ZZ \to \ell^+\ell^-\tau^+\tau^-$ [131] become the most sensitive. A small excess of events in the ATLAS $\ell^+\ell^-\ell^+\ell^-$ channel with reconstructed masses near 125 GeV is seen, with a local significance of ≈ 2 sigma. An excess with similar significance is seen in the CMS $H \to ZZ \to 4$ leptons searches at ~ 119 GeV.

ATLAS and CMS seek the process $H \to \gamma \gamma$ including the four production mechanisms, $gg \to H$, production in association with a W or Z boson, and VBF [132–134]. Events are divided into categories depending on the reconstructed photon type (barrel calorimeter or endcap), and the presence or absence of additional jets. The reconstructed mass resolution of the selected candidates varies between 1% and 3% depending on the event category and detector. ATLAS observes an excess of events with a local significance of 2.8σ which is maximized at m_H =126.5 GeV, while CMS observes an excess of events with a local significance of 2.9σ which is maximized at m_H =124 GeV. ATLAS computes the global significance, accounting for the probability of a background fluctuation anywhere in the range 110 GeV $< m_H < 150$ GeV at least as significant as the observed excess, to be 1.5 σ . CMS's global significance is 1.6σ using the same range of m_H .

ATLAS and CMS seek Higgs bosons produced in association with a leptonically decaying vector boson and which decay into $b\bar{b}$ [135,136]. Although these searches benefit from the higher production cross sections at the LHC as compared to the Tevatron, the background cross sections are relatively larger, as a larger fraction of W and Z bosons at the LHC are produced with accompanying jets, some of which contain heavy hadrons. The sensitivity of the searches is maximized by tagging jets containing B hadrons and using MVAs to separate the expected signals from the backgrounds. The achieved sensitivity, in units of the SM production rate, expressed as the 95% exclusion limit

expected in the absence of a signal, varies in the range 110 GeV $< m_H < 135$ GeV between 2.6 to 5.1 for ATLAS and between 2.7 to 6.7 for CMS. These results are both with 4.7 fb⁻¹ of analyzed data. With more data and improved analyses, the LHC will be able to measure the important decay branching ratio to $b\bar{b}$, where currently the Tevatron contributes the most.

Both ATLAS and CMS seek SM Higgs boson decays to $\tau^+\tau^-$ [137–139]. The selected events in these searches are categorized by the number of associated jets, which differentiates signals produced by $gg \to H$, associated production, and VBF from the backgrounds, which are dominated by $Z \to \tau^+ \tau^-$. The reconstructed di-tau masses are used as the discriminating variables. If the tau pair has a net transverse boost, then the missing transverse energy can be projected unambiguously on the directions of the two tau leptons, and the reconstructed mass resolution is much better than in the case of little transverse boost, in which case the degree to which the neutrino momenta cancel each other is unknown. With 4.7 fb⁻¹ of data, ATLAS's expected 95% C.L. limit varies between 3.2 and 7.9 times the SM rate for Higgs bosons with 100 GeV $< m_H < 150$ GeV, and with 4.6 fb^{-1} of data, CMS's expected limits vary between 3.3and 5.5 times the SM prediction for 110 GeV $< m_H < 145$ GeV. CMS also searches for $WH \to W\tau^+\tau^-$ [140] with a 95% C.L. sensitivity between 5 and 15 times the SM prediction in the range 100 GeV $< m_H < 140$ GeV using 4.7 fb⁻¹ of data.

Both ATLAS and CMS have combined their SM Higgs boson The most recent combination of ATLAS searches [7–10]. includes the full suite of channels mentioned above. As shown in Fig. 8, ATLAS excludes at the 95% C.L. the mass ranges $110.0 \text{ GeV} < m_H < 117.5 \text{ GeV}, 118.5 \text{ GeV} < m_H < 122.5 \text{ GeV},$ and 129 GeV $< m_H < 539$ GeV, and expects to exclude, in the absence of a signal, 120 GeV $< m_H < 555$ GeV. ATLAS's local p-values [79], computed with the likelihood ratio test statistic, are shown as functions of the tested m_H in Fig. 9. The local significance is maximal at $m_H = 126$ GeV, with a value of 2.9σ . The global significance is 1.3σ when the interval considered for the LEE correction is 110 GeV $< m_H < 146$ GeV, and becomes 0.5σ for the interval 110 GeV $< m_H < 600$ GeV. The best-fit production cross section as a multiple of the SM prediction is shown in Fig. 10. The excesses seen in the $H \to \gamma \gamma$ and $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$ searches are somewhat offset by a more background-like outcome in the $H \to W^+W^-$ searches.

The most recent combination of CMS includes the full suite of channels mentioned above. As shown in Fig. 11, CMS excludes at the 95% C.L. the mass range 127.5 GeV $< m_H < 600$ GeV, and expects to exclude 114.5 GeV $< m_H < 525$ GeV in the absence of a signal. CMS's local p-values [79], computed using the likelihood ratio test statistic, are shown as functions of the tested m_H in Fig. 12. The local significance is maximal at $m_H=125$ GeV, with a value of 2.8σ . The global significance becomes 2.1σ (0.8 σ) after correcting for LEE in the range 110 GeV $< m_H < 145$ GeV (110 GeV $< m_H < 600$ GeV). The best-fit production cross section CMS measures as a multiple of the SM prediction is shown in Fig. 13. A signal-like excess

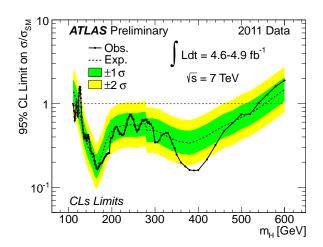


Figure 8: Observed and expected 95% C.L. upper limits on the ratios to the SM cross section, as functions of the Higgs boson mass for the combined ATLAS analyses [8].

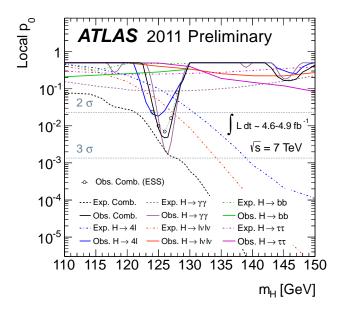


Figure 9: Local p-values for each of AT-LAS's SM Higgs boson search channels and the combination [8]. The observed p-values are shown with solid curves, and the median expected p-values assuming a signal is present at the SM strength are shown with dashed and dot-dashed curves. Dotted lines indicate the 2σ and 3σ thresholds. Hollow circles indicate p-values computed with ensemble tests taking into account energy scale systematic uncertainties (ESS).

is seen in the $H\to\gamma\gamma$ and $H\to W^+W^-$ searches, but the outcome in the $H\to ZZ$ search is less signal-like at $m_H=125~{\rm GeV}.$

In summary, beyond the region excluded by LEP, the region excluded at 95% C.L. by both ATLAS and CMS extends from

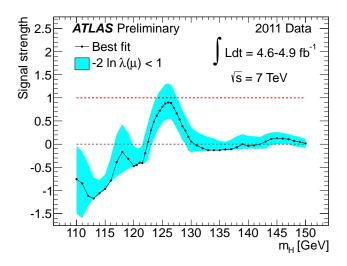


Figure 10: ATLAS SM best-fit cross sections [8].

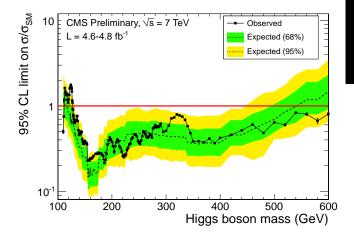


Figure 11: Observed and expected 95% C.L. upper limits on the ratios to the SM cross section, as functions of the Higgs boson mass for the combined CMS analyses [10].

129 GeV to 539 GeV. The observed and expected limits from the two LHC collaborations and the Tevatron are listed in Table 1 for the main channels and the combinations searching for the SM Higgs boson with $m_H=125$ GeV. The best-fit cross section is close to the SM prediction at the m_H corresponding to the most significant p-value for both LHC experiments. The data samples are not yet large enough to make a significant statement about the balance between the individual channels.

If a SM Higgs boson is discovered, its properties will be studied at the LHC. The decay branching ratios, and more generally, the couplings of the Higgs bosons to fermions and gauge bosons will be constrained by the measurements of the cross sections times branching ratios for the processes searched for above.

The mass of the Higgs boson will be measured by each LHC experiment with a precision of $\sim 0.1\%$, limited by the energy

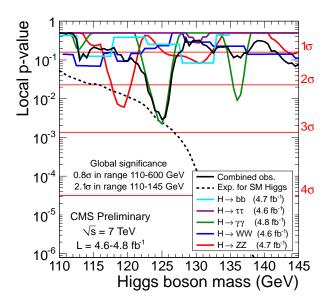


Figure 12: Local p-values for each of CMS's SM Higgs boson search channels and the combination [10]. The observed p-values are shown with solid curves, and the median expected p-value for the combined search assuming a signal is present at the SM strength is shown with a dashed curve. Horizontal lines indicate the 1σ , 2σ , 3σ , and 4σ thresholds.

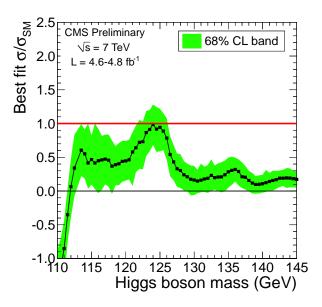


Figure 13: CMS SM best-fit cross sections [10].

scale, in the currently allowed low mass range [141,142]. This projection is based on the invariant mass reconstruction from electromagnetic calorimeter objects, using the decays $H \to \gamma \gamma$ or $H \to ZZ^* \to 4\ell$. The precision would be degraded at higher masses because of the larger decay width, but even at $m_H \sim 700$ GeV a precision of 1% on m_H is expected to be achievable. The width of the SM Higgs boson may be too narrow to be

Table 1: Observed and expected limits at the 95% C.L. normalized to the SM predictions for the main search channels at the Tevatron and the LHC, evaluated for $m_H = 125 \text{ GeV}$

| Channel | Obs | Exp | Lumi $[fb^{-1}]$ | Ref |
|---------------------------------------------|-----|-----|------------------|-------|
| Tevatron | | | | |
| $H \to W^+W^-$ | 2.4 | 2.2 | 9.7 | [6] |
| $H 	o b ar{b}$ | 3.2 | 1.4 | 9.7 | [6] |
| Combined | 2.2 | 1.1 | 10.0 | [6] |
| ATLAS | | | | |
| $H \to \gamma \gamma \text{ (MVA)}$ | 3.5 | 1.6 | 4.9 | [132] |
| $H \to W^+W^- \to \ell^+\nu\ell^-\bar{\nu}$ | 1.4 | 1.2 | 4.7 | [121] |
| $H \to ZZ \to \ell^+ \ell^- \ell^+ \ell^-$ | 4.2 | 2.4 | 4.8 | [125] |
| Combined | 1.5 | 0.8 | 4.9 | [8] |
| CMS | | | | |
| $H \to \gamma \gamma \text{ (MVA)}$ | 2.9 | 1.2 | 4.8 | [134] |
| $H \to W^+W^- \to \ell^+\nu\ell^-\bar\nu$ | 1.5 | 1.1 | 4.6 | [122] |
| $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$ | 2.5 | 1.6 | 4.7 | [126] |
| Combined | 1.6 | 0.7 | 4.8 | [10] |
| | | | | |

measured directly. The width could be constrained indirectly using partial width measurements [143,144]. For $300 < m_H < 700 \text{ GeV}$, a direct measurement of the decay width of an SM-like Higgs boson could be performed with a precision of about 6%.

The possibilities for measuring other properties of the Higgs boson, such as its spin, its CP eigenvalue, its couplings to bosons and fermions, and its self-coupling, have been investigated in numerous studies [141,142,145–148]. Given a sufficiently high integrated luminosity (300 fb⁻¹), most of these properties are expected to be accessible to analysis in the favored mass range 114 GeV < m_H < 129 GeV. The measurement of Higgs self-couplings, however, may suffer from poor sensitivity at the LHC, although a luminosity upgrade, the so-called Super-LHC, could allow for a more precise measurement. The results of these measurements could either establish the presence of a SM-like Higgs boson or point the way to new physics.

II.5 Models with a Fourth Generation of SM-Like Fermions

The SM Higgs boson production processes and branching ratios presented above are limited to the case of three generations of quarks and leptons. The existence of a fourth generation of fermions is compatible with present experimental bounds and would have direct consequences on the SM Higgs boson production and decay branching ratios [149], and hence on Higgs boson searches at LEP, the Tevatron, and the LHC [150,151]. Current experimental searches bound the fourth generation quark masses to be above the top quark mass [152]. These additional heavy quarks lead to new contributions in the loop-induced couplings of the Higgs boson to gluons and to photons.

In particular, they lead to a strong enhancement of the gluon fusion production rate and of the branching ratio of the Higgs boson decay into a pair of gluons. As a result, the branching ratios of Higgs boson decay to $b\bar{b}$, tau pairs, and pairs of W and Z bosons are reduced, although near $m_H \sim 2M_W$, the decay to a pair of W bosons still nearly saturates the decay width, even with the enhanced gluon decay. Due to a cancellation between the W and heavy fermion contributions, the photon decay channels may be further suppressed. The enhancement of the gluon fusion production rate makes the search channels using Higgs boson decays into tau leptons and W and Z bosons promising for a light Higgs boson. In addition, in the case of a fourth generation Majorana neutrino, exotic signals such as Higgs boson decay into same-sign dileptons may be possible. Interpretations of the experimental searches optimized for a minimal fourth-generation model (SM4) are available from the Tevatron [153] and CMS [10]. CMS excludes the Higgs boson in the SM4 model in the mass range 120 GeV $< m_H < 600$ GeV at the 95% C.L.

III. Higgs Bosons in the Minimal Supersymmetric Standard Model (MSSM)

Electroweak symmetry breaking driven by a weakly-coupled elementary scalar sector requires a mechanism to explain the smallness of the breaking scale compared with the Planck scale [154]. In addition, within supersymmetric extensions of the SM, the supersymmetry-breaking effects, whose origins may lie at energy scales much larger than 1 TeV, can induce a radiative breaking of the electroweak symmetry due to the effects of the large Higgs-top quark Yukawa coupling [155]. In this way, the electroweak symmetry breaking scale is intimately tied to the scale of supersymmetry breaking masses. Supersymmetry provides an explanation for the stability of the hierarchy of scales, provided that the supersymmetry-breaking masses, in particular those related to the stop sector, are at most in the TeV range [154].

A fundamental theory of supersymmetry breaking is unknown at this time. Nevertheless, one can parameterize the low-energy theory in terms of the most general set of soft supersymmetry-breaking renormalizable operators [156]. Minimal Supersymmetric extension of the Standard Model (MSSM) [12,157] associates a supersymmetric partner to each gauge boson and chiral fermion of the SM, and provides a realistic model of physics at the weak scale. However, even in this minimal model with the most general set of soft supersymmetry-breaking terms, more than 100 new parameters are introduced [158]. Fortunately, only a subset of these parameters impact the Higgs phenomenology through tree-level and quantum effects. Reviews of the properties and phenomenology of the Higgs bosons of the MSSM can be found for example in Refs. [44] and [159].

The MSSM contains the particle spectrum of a two-Higgs-doublet model (2HDM) extension of the SM and the corresponding supersymmetric partners. Two Higgs doublets, H_u

and H_d , are required to ensure an anomaly-free SUSY extension of the SM and to generate mass for both "up"-type and "down"-type quarks and charged leptons [13]. After the spontaneous breaking of the electroweak symmetry, five physical Higgs particles are left in the spectrum: one charged Higgs pair, H^{\pm} , one CP-odd scalar, A, and two CP-even states, H and h.

The supersymmetric structure of the theory imposes constraints on the Higgs sector of the model. In particular, the parameters of the Higgs self-interaction are given by the gauge coupling constants. As a result, all Higgs sector parameters at tree level are determined by only two free parameters: the ratio of the H_u and H_d vacuum expectation values, $\tan \beta = v_u/v_d$, with $v_u^2 + v_d^2 \approx (246 \text{ GeV})^2$; and one Higgs boson mass, conventionally chosen to be m_A . The other tree-level Higgs boson masses are then given in terms of these parameters

$$m_{H^\pm}^2=m_A^2+M_W^2$$

$$m_{H,h}^2 = \frac{1}{2} \left[m_A^2 + M_Z^2 \pm \sqrt{(m_A^2 + M_Z^2)^2 - 4(M_Z m_A \cos 2\beta)^2} \right]$$

and α is the angle that diagonalizes the CP-even Higgs squaredmass matrix. An important consequence of these mass formulae is that the mass of the lightest CP-even Higgs boson is bounded from above:

$$m_h \leq M_Z |\cos 2\beta|$$
.

This contrasts sharply with the SM, in which the Higgs boson mass is bounded from above only by perturbativity and unitarity considerations. In the large m_A limit, also called the decoupling limit [160], one finds $m_h^2 \simeq (M_Z \cos 2\beta)^2$ and $m_A \simeq m_H \simeq m_{H^\pm}$, up to corrections of $\mathcal{O}(M_Z^2/m_A)$. Below the scale m_A , the Higgs sector of the effective low-energy theory consists only of h, which behaves as the SM Higgs boson.

The phenomenology of the Higgs sector depends on the couplings of the Higgs bosons to gauge bosons, and fermions. The couplings of the two CP-even Higgs bosons to W^\pm and Z bosons are given in terms of the angles α and β by

$$g_{hVV} = g_V m_V \sin(\beta - \alpha)$$
 $g_{HVV} = g_V m_V \cos(\beta - \alpha)$,

where $g_V \equiv 2m_V/v$. There are no tree-level couplings of A or H^{\pm} to VV. The couplings of the Z boson to two neutral Higgs bosons, which must have opposite CP-quantum numbers, are given by

$$g_{hAZ} = g_Z \cos(\beta - \alpha)/2$$
 $g_{HAZ} = -g_Z \sin(\beta - \alpha)/2$.

Charged Higgs-W boson couplings to neutral Higgs bosons and four-point couplings of vector bosons and Higgs bosons can be found in Ref. 13.

The tree-level Higgs couplings to fermions obey the following property: the neutral components of one Higgs doublet couple exclusively to down-type fermion pairs while the neutral components of the other doublet couple exclusively to up-type fermion pairs [13,161]. This Higgs-fermion coupling structure defines the Type-II 2HDM [162], and differs from

Type-I 2HDM [163] in which one Higgs field couples to all fermions while the other field is decoupled from them. In the MSSM, fermion masses are generated when both neutral Higgs components acquire vacuum expectation values, and the relations between Yukawa couplings and fermion masses are (in third-generation notation)

$$h_b = \sqrt{2} m_b / v_d = \sqrt{2} m_b / (v \cos \beta)$$
$$h_t = \sqrt{2} m_t / v_u = \sqrt{2} m_t / (v \sin \beta).$$

Similarly, one can define the Yukawa coupling of the Higgs boson to τ -leptons (the latter is a down-type fermion).

The couplings of the neutral Higgs bosons to $f\bar{f}$ relative to the SM value, $gm_f/2M_W$, are given by

$$\begin{split} hb\bar{b}: & -\sin\alpha/\cos\beta = \sin(\beta-\alpha) - \tan\beta\cos(\beta-\alpha)\,, \\ ht\bar{t}: & \cos\alpha/\sin\beta = \sin(\beta-\alpha) + \cot\beta\cos(\beta-\alpha)\,, \\ Hb\bar{b}: & \cos\alpha/\cos\beta = \cos(\beta-\alpha) + \tan\beta\sin(\beta-\alpha)\,, \\ Ht\bar{t}: & \sin\alpha/\sin\beta = \cos(\beta-\alpha) - \cot\beta\sin(\beta-\alpha)\,, \\ Ab\bar{b}: & \gamma_5\tan\beta\,, \quad At\bar{t}: & \gamma_5\cot\beta\,, \end{split}$$

where the γ_5 indicates a pseudoscalar coupling. In each relation above, the factor listed for $b\bar{b}$ also pertains to $\tau^+\tau^-$. The charged Higgs boson couplings to fermion pairs are given by

$$g_{H^-t\bar{b}} = \frac{g}{\sqrt{2}M_W} \left[m_t \cot \beta P_R + m_b \tan \beta P_L \right] ,$$

$$g_{H^-\tau^+\nu} = \frac{g}{\sqrt{2}M_W} \left[m_\tau \tan \beta P_L \right] ,$$

with
$$P_{L,R} = (1 \mp \gamma_5)/2$$
.

The Higgs couplings to down-type fermions can be significantly enhanced at large $\tan \beta$ in the following two cases: (i) If $m_A \gg M_Z$, then $|\cos(\beta - \alpha)| \ll 1$, $m_H \simeq m_A$, and the $b\bar{b}H$ and $b\bar{b}A$ couplings have equal strength and are significantly enhanced by a factor of $\tan \beta$ relative to the corresponding SM coupling, whereas the VVH coupling is negligibly small. The values of the VVh and $b\bar{b}h$ couplings are equal to the corresponding couplings of the SM Higgs boson. (ii) If $m_A < M_Z$ and $\tan \beta \gg 1$, then $|\cos(\beta - \alpha)| \approx 1$ and $m_h \simeq m_A$. In this case, the $b\bar{b}h$ and $b\bar{b}A$ couplings have equal strength and are significantly enhanced by a factor of $\tan \beta$ relative to the corresponding SM coupling, while the VVh coupling is negligibly small. In addition, the VVH coupling is equal in strength to the corresponding SM VVH coupling and one can refer to Has a SM-like Higgs boson. The value of the $b\bar{b}H$ coupling can differ from the corresponding SM coupling and converges to it only for $m_A \ll M_Z$ for which $\tan \beta \sin(\beta - \alpha) \to 0$. Note that in both cases (i) and (ii) above, only two of the three neutral Higgs bosons have significantly enhanced couplings to $b\bar{b}$.

III.1. Radiatively-Corrected MSSM Higgs Masses and Couplings

Radiative corrections have a significant impact on the values of Higgs boson masses and couplings in the MSSM. Important contributions come from loops of third generation SM particles as well as their supersymmetric partners. The dominant effects to the Higgs mass arise from the incomplete cancellation between top and scalar-top (stop) loops and at large $\tan \beta$ also from sbottom and stau loops. The stop, sbottom and stau masses and mixing angles depend on the supersymmetric Higgsino mass parameter μ and on the soft-supersymmetrybreaking parameters [12,157]: M_Q , M_U , M_D , M_L , M_E , and A_t , A_b A_τ . The first three of these are the left-chiral and the two right-chiral top and bottom scalar quark mass parameters. The next two are the left-chiral stau/sneutrino and the rightchiral stau mass parameters, and the last three are the trilinear parameters that enter in the off-diagonal squark/slepton mixing elements: $X_t \equiv A_t - \mu \cot \beta$ and $X_{b,\tau} \equiv A_{b,\tau} - \mu \tan \beta$. The corrections affecting the Higgs boson masses, production, and decay properties depend on all of these parameters in various ways. At the two-loop level, also the masses of the gluino and the electroweak gaugino enter in the calculations. For simplicity, we shall initially assume that A_t , A_b , A_τ , μ , and the gluino and electroweak gaugino masses are real parameters. The impact of complex phases on MSSM parameters, which will induce *CP*-violation in the Higgs sector, is addressed below.

Radiative corrections to the Higgs boson masses have been computed using a number of techniques, with a variety of approximations; see Refs. [165–176]. They depend strongly on the top quark mass ($\sim m_{\rm t}^4$) and the stop mixing parameter X_t , and there is also a logarithmic dependence on the stop masses. One of the most striking effects is the increase of the upper bound of the light CP-even Higgs boson mass, as first noted in Refs. [165,166]. The value of m_h is maximized for large $m_A \gg M_Z$, when all other MSSM parameters are fixed. Moreover, $\tan \beta \gg 1$ also maximizes m_h , when all other parameters are held fixed. Taking m_A large (the decoupling limit) and $\tan \beta \gg 1$, the value of m_h can be further maximized at one-loop level for $X_t \simeq \sqrt{6}M_{\rm SUSY}$, where $M_{\rm SUSY} \simeq M_Q \simeq M_U \simeq M_D$ is an assumed common value of the soft SUSY-breaking squark mass parameters. This choice of X_t is called the "maximal-mixing scenario" which will be indicated by m_h -max. Instead, for $X_t = 0$, which is called the "no-mixing scenario," the value of m_h has its lowest possible value, for fixed m_A and all other MSSM parameters. The value of m_h also depends on the specific value of $M_{\rm SUSY}$, and, for example, raising $M_{\rm SUSY}$ from 1 TeV to 2 TeV can increase m_h by 2-5 GeV. Variation of the value of m_t by 1 GeV changes the value of m_h by about the same amount. As mentioned above, m_h also depends on μ and more weakly on the electroweak gaugino mass as well as the gluino mass at the two-loop level. For any given scenario defined by a full set of MSSM parameters, we will denote the maximum value of m_h by $m_h^{\max}(\tan \beta)$, for each value of $\tan \beta$. Allowing for the experimental uncertainty on m_t and for the uncertainty inherent in the theoretical analysis, one finds for $M_{SUSY} \lesssim 2$ TeV, large m_A and $\tan \beta \gg 1$, $m_h^{\text{max}} = 135 \text{ GeV}$ in the m_h -max scenario, and $m_h^{\text{max}} = 122 \text{ GeV}$ in the no-mixing scenario [177,178]. In

practice, parameter values leading to maximal mixing are not obtained in most models of supersymmetry breaking, so typical upper limits on m_h will lie between these two extremes [179]. In the large $\tan \beta$ regime light staus and/or sbottoms with sizable mixing, governed by the μ parameter, yield negative radiative corrections to the mass of the lightest Higgs boson, and can lower it by several GeV [173,180]. Hence, if the Higgs boson were to have a mass of about 125 GeV, a sizable mixing in the stop sector would be required [180,181] $(X_t \ge 1.5 M_{SUSY})$ or even larger if $\tan \beta$ is large). The relatively small mass of the lightest neutral scalar boson is a prediction for both the CP-conserving (CPC) and CP-violating (CPV) [182] MSSM scenarios. This is particularly interesting in the light of the intriguing excesses observed at the Tevatron and the LHC and given that masses above 130 GeV are strongly disfavored by LHC data.

Radiative corrections also modify significantly the values of the Higgs boson couplings to fermion pairs and to vector boson pairs. The tree-level Higgs couplings depend strongly on the value of $\cos(\beta - \alpha)$. In a first approximation, when radiative corrections of the Higgs squared-mass matrix are computed, the diagonalizing angle α is shifted from its tree-level value, and hence one may compute a "radiatively-corrected" value for $\cos(\beta - \alpha)$. This shift provides one important source of the radiative corrections to the Higgs couplings. In particular, depending on the sign of μX_t and the magnitude of $X_t/M_{\rm SUSY}$, modifications of α can lead to important variations of the SM-like Higgs boson coupling to bottom quarks and tau leptons [175]. Similar corrections to the mixing angle α can come for large tan beta from the stau/sbottom sector for sizable $A_{b,\tau}$ [180]. Additional contributions from the one-loop vertex corrections to tree-level Higgs couplings These contributions almust also be considered [170–189]. ter significantly the Higgs-fermion Yukawa couplings at large $\tan \beta$, both in the neutral and charged Higgs sector. Moreover, these radiative corrections can modify the basic relationship $g_{h,H,Ab\bar{b}}/g_{h,H,A\tau^+\tau^-} \propto m_b/m_\tau$, and change the main features of MSSM Higgs phenomenology.

III.2. Decay Properties and Production Mechanisms of MSSM Higgs Bosons

In the MSSM, neglecting CP-violating effects, one must consider the decay properties of three neutral Higgs bosons and one charged Higgs pair. In the region of parameter space where $m_A\gg m_Z$ and the masses of supersymmetric particles are large, the decoupling limit applies, and the decay rates of h into SM particles are nearly indistinguishable from those of the SM Higgs boson. Hence, the h boson will decay mainly to fermion pairs, since the mass, less than about 135 GeV, is below the W^+W^- threshold. The SM-like branching ratios of h are modified if decays into supersymmetric particles are kinematically allowed [190]. In addition, if light superpartners exist that can couple to photons and/or gluons, then the effective couplings to qq and $\gamma\gamma$ could deviate from the corresponding

SM predictions [180,191,192]. In the decoupling limit, the heavier Higgs states, H, A and H^{\pm} , are roughly mass degenerate, and their decay branching ratios strongly depend on $\tan \beta$ as discussed below. The AWW and AZZ couplings vanish, and the HWW and HZZ couplings are very small. For values of $m_A \sim \mathcal{O}(M_Z)$, all Higgs boson masses lie below 200 GeV. In this regime, there is a significant area of the parameter space in which none of the neutral Higgs boson decay properties approximates that of the SM Higgs boson. For $\tan \beta \gg 1$, the resulting predictions show marked differences from those for the SM Higgs boson [193]. Significant modifications to the $b\overline{b}$ and/or the $\tau^+\tau^-$ decay rates may occur via radiative effects.

After incorporating the leading radiative corrections to Higgs couplings from both QCD and supersymmetry, the following decay features are relevant in the MSSM. The decay modes $h, H, A \to b\overline{b}, \tau^+\tau^-$ dominate when $\tan \beta$ is large for all values of the Higgs boson masses. For small $\tan \beta$, these modes are significant for neutral Higgs boson masses below $2m_t$ (although there are other competing modes in this mass range), whereas the $t\bar{t}$ decay mode dominates above its kinematic threshold. In contrast to the SM Higgs boson, the vector boson decay modes of H are strongly suppressed at large m_H due to the suppressed HVV couplings in the decoupling limit. For the charged Higgs boson, $H^+ \to \tau^+ \nu_{\tau}$ dominates below the $t\bar{b}$ threshold, while $H^+ \to t\bar{b}$ dominates for large values of $m_{H^{\pm}}$. For low values of $\tan \beta$ ($\lesssim 1$) and low values of the charged Higgs boson mass (\lesssim 120 GeV), the decay mode $H^+ \to c\bar{s}$ becomes relevant.

In addition to the decay modes of the neutral Higgs bosons into fermion and gauge boson final states, additional decay channels may be allowed which involve scalars of the extended Higgs sector, e.g., $h \to AA$. Supersymmetric final states from Higgs boson decays into charginos, neutralinos and third-generation squarks and sleptons can be important if they are kinematically allowed [194]. One interesting possibility is a significant branching ratio for the decay of a neutral Higgs boson to the invisible mode $\tilde{\chi}_1^0 \tilde{\chi}_1^0$ (where the lightest neutralino $\tilde{\chi}_1^0$ is the lightest supersymmetric particle) [195], which poses a challenge at hadron colliders.

The production mechanisms for the SM Higgs boson at e^+e^- and hadron colliders can also be relevant for the production of the MSSM neutral Higgs bosons. However, one must take into account the possibility of enhanced or suppressed couplings with respect to those of the Standard Model, since these can significantly modify the production cross sections of neutral Higgs bosons. The supersymmetric-QCD corrections due to the exchange of virtual squarks and gluinos may modify the cross sections depending on the values of these supersymmetric particle masses. At both lepton and hadron colliders there are new mechanisms that produce two neutral Higgs bosons, as well as processes that produce charged Higgs bosons singly or in pairs. In the following we summarize the main processes

for MSSM Higgs boson production. For a more detailed discussion and consideration of state-of-the-art calculations, see Refs. [44,75,159].

The main production mechanisms for the neutral MSSM Higgs bosons at e^+e^- colliders are Higgs-strahlung $(e^+e^- \to Zh, ZH)$, vector boson fusion $(e^+e^- \to \nu\bar{\nu}h, \nu\bar{\nu}H)$ —with W^+W^- fusion about an order of magnitude larger than ZZ fusion—and s-channel Z boson exchange $(e^+e^- \to Ah, AH)$ [196]. For the Higgs-strahlung process, it is possible to reconstruct the mass and momentum of the Higgs boson recoiling against the particles from the Z boson decay, and hence sensitive searches for Higgs bosons decaying even to invisible final states can be applied.

The main charged Higgs boson production process at e^+e^- colliders is via s-channel γ or Z boson exchange $(e^+e^- \to H^+H^-)$. Charged Higgs bosons can also be produced in top quark decays via $t \to b + H^+$ if $m_H^\pm < m_t - m_b$ or via the one-loop process $e^+e^- \to W^\pm H^\mp$ [197,198], which allows the production of a charged Higgs boson with $m_H^\pm > \sqrt{s}/2$, even when H^+H^- production is kinematically forbidden. Other single charged Higgs production mechanisms include $t\bar{b}H^-/\bar{t}bH^+$ production [51], $\tau^+\nu H^-/\tau^-\bar{\nu}H^+$ production [199], and a variety of processes in which H^\pm is produced in association with a one or two other gauge and/or Higgs bosons [200].

At hadron colliders, the dominant neutral Higgs production mechanism over the majority of the MSSM parameter space is gluon-gluon fusion, mediated by triangle loops containing heavy top and bottom quarks and the corresponding supersymmetric partners [201]. Higgs boson radiation from bottom quarks becomes important for large $\tan \beta$, where at least two of the three neutral Higgs bosons have enhanced couplings to bottom-type fermions [202,203]. A more detailed discussion is presented in Sec. (III.3). The vector boson fusion and Higgsstrahlung production of the CP-even Higgs bosons as well as the associated production of neutral Higgs bosons with top quark pairs have lower production cross sections by least an order of magnitude with respect to the dominant ones, depending on the precise region of MSSM parameter space.

Charged Higgs bosons can be produced in several different modes at hadron colliders. If $m_{H^{\pm}} < m_t - m_b$, the charged Higgs boson can be produced in decays of the top quark via the decay $t \to bH^+$, which would compete with the SM process $t \to bW^+$. Relevant QCD and SUSY-QCD corrections to BR $(t \to H^+ b)$ have been computed [204–207]. For values of $m_{H^{\pm}}$ near m_t , width effects are important. In addition, the full $2 \to 3$ processes $pp/p\bar{p} \to H^+\bar{t}b + X$ and $pp/p\bar{p} \to$ $H^-t\bar{b}+X$ must be considered. If $m_{H^\pm}>m_t-m_b$, then charged Higgs boson production occurs mainly through radiation from a third generation quark. Charged Higgs bosons may also be produced singly in association with a top quark via the $2 \rightarrow 3$ partonic processes $gg, q\bar{q} \rightarrow t\bar{b}H^-$ (and the charge conjugate final states). For charged Higgs boson production cross section predictions for the Tevatron and the LHC, see Refs. [12,43,76,208–214]. Charged Higgs bosons can also be produced via associated production with W^{\pm} bosons through $b\overline{b}$ annihilation and gg-fusion [215]. They can also be produced in pairs via $q\overline{q}$ annihilation [216]. The inclusive H^+H^- cross section is less than the cross section for single charged Higgs associated production [216–218].

III.3. Searches for Neutral Higgs Bosons in the CP-Conserving (CPC) Scenario

Most of the experimental investigations carried out at LEP, the Tevatron, and the LHC, assume *CP*-conservation (*CPC*) in the MSSM Higgs sector. In many cases the search results are interpreted in a number of specific benchmark models where a representative set of the relevant SUSY breaking parameters are specified [177].

III.3.1. Searches for Neutral MSSM Higgs Bosons at LEP

In e^+e^- collisions at LEP energies, the main production mechanisms of the neutral MSSM Higgs bosons are the Higgs-strahlung processes $e^+e^- \to hZ$, HZ and the pair production processes $e^+e^- \to hA$, HA, while the fusion processes play a marginal role. Higgs boson decays to $b\bar{b}$ and $\tau^+\tau^-$ are used in these searches.

The searches and limits from the four LEP experiments are described in Refs. [219–222]. The combined LEP data did not contain any excess of events which would imply the production of a Higgs boson, and combined limits were derived [34]. For $m_A\gg M_Z$ the limit on m_h is nearly that of the SM searches, as $\sin^2(\beta-\alpha)\approx 1$. For high values of $\tan\beta$ and low m_A ($m_A\leq m_h^{max}$) the $e^+e^-\to hA$ searches become the most important, and the lightest Higgs h is non SM-like. In this region, the 95% C.L. mass bounds are $m_h>92.8$ GeV and $m_A>93.4$ GeV. In the m_h -max. scenario, values of $\tan\beta$ from 0.7 to 2.0 are excluded taking $m_t=174.3$ GeV, while a much larger $\tan\beta$ region is excluded for other benchmark scenarios such as the no-mixing one.

Neutral Higgs bosons may also be produced by Yukawa processes $e^+e^- \to f\overline{f}\phi$, where the Higgs particle $\phi \equiv h, H, A$, is radiated off a massive fermion $(f \equiv b \text{ or } \tau^\pm)$. These processes can be dominant at low masses, and whenever the $e^+e^- \to hZ$ and hA processes are suppressed. The corresponding ratios of the $f\overline{f}h$ and $f\overline{f}A$ couplings to the SM coupling are $\sin\alpha/\cos\beta$ and $\tan\beta$, respectively. The LEP data have been used to search for $b\overline{b}b\overline{b}, b\overline{b}\tau^+\tau^-$, and $\tau^+\tau^-\tau^+\tau^-$ final states [223,224]. Regions of low mass and high enhancement factors are excluded by these searches.

III.3.2. Searches for Neutral MSSM Higgs Bosons at Hadron Colliders

Over a large fraction of the MSSM parameter space, one of the CP-even neutral Higgs bosons (h or H) couples to the vector bosons with SM-like strength and has a mass below 135 GeV. Hence, if the current 95% C.L. exclusion limits for a SM Higgs boson from ATLAS and CMS are interpreted in terms of the SM-like supersymmetric Higgs boson, there is a region of SUSY parameter space beyond that excluded by LEP

that is strongly disfavored. In particular, the minimal mixing scenario with $M_{SUSY} \leq 2$ TeV is disfavored considering the LEP and ATLAS data. At the same time, if the excess of events observed in the Higgs boson searches in the diphoton and ZZ channels are confirmed, this could be interpreted as a SM-like MSSM Higgs boson.

Scenarios with enhanced Higgs boson production cross sections are studied at hadron colliders. The best sensitivity is in the regime with low to moderate m_A and with large $\tan \beta$ which enhances the couplings of the Higgs bosons to down-type fermions. The corresponding limits on the Higgs boson production cross section times the branching ratio of the Higgs boson into down-type fermions can be interpreted in MSSM benchmark scenarios [225]. If $\phi = A, H$ for $m_A > m_h^{\text{max}}$, and $\phi = A, h$ for $m_A < m_h^{\rm max}$, the most promising channels at the Tevatron are $b\bar{b}\phi, \phi \to b\bar{b}$ or $\phi \to \tau^+\tau^-$, with three tagged b-jets or $b\tau\tau$ in the final state, respectively, and the inclusive $p\overline{p} \to \phi \to \tau^+\tau^-$ process, with contributions from both $gg \to \phi$ and $b\bar{b}\phi$ production. Although Higgs boson production via gluon fusion has a higher cross section than via associated production, it cannot be used to study the $\phi \to b\bar{b}$ decay mode since the signal is overwhelmed by QCD background.

The CDF and DØ collaborations have searched for neutral Higgs bosons produced in association with bottom quarks and which decay into $b\overline{b}$ [226,227], or into $\tau^+\tau^-$ [228,229]. most recent searches in the $b\bar{b}\phi$ channel with $\phi \to b\bar{b}$ analyze approximately 2.6 fb⁻¹ of data (CDF) and 5.2 fb⁻¹ (DØ), seeking events with at least three b-tagged jets. The cross section is defined such that at least one b quark not from ϕ decay is required to have $p_T > 20$ GeV and $|\eta| < 5$. The decay widths of the Higgs bosons are assumed to be much smaller than the experimental resolution. The invariant mass of the two leading jets as well as b-tagging variables are used to discriminate the signal from the backgrounds. The QCD background rates and shapes are inferred from data control samples, in particular, the sample with two b tagged jets and a third, untagged jet. Separate signal hypotheses are tested and limits are placed on $\sigma(p\bar{p}\to b\bar{b}\phi)\times \mathrm{BR}(\phi\to b\bar{b})$. CDF sees a local excess of approximately 2.5σ significance in the mass range of 130-160 GeV, but DØ's search is more sensitive and sets stronger limits. The DØ result shown in Fig. 14 displays a ≈ 2 sigma local upward fluctuation in the 110 to 125 GeV mass

CDF and DØ have also performed searches for inclusive production of Higgs bosons with subsequent decays to $\tau^+\tau^-$ [230,231,232], although these limits have been superseded by the LHC searches.

In order to interpret the experimental data in terms of MSSM benchmark scenarios, it is necessary to consider carefully the effect of radiative corrections on the production and decay processes. The bounds from the $b\bar{b}\phi,\phi\to b\bar{b}$ channel depend strongly on the radiative corrections affecting the relation between the bottom quark mass and the bottom Yukawa

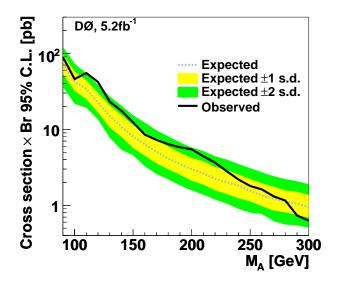


Figure 14: The 95% C.L. limits on $\sigma(p\bar{p}\to b\phi) \times \mathrm{BR}(\phi\to b\bar{b})$ from CDF and DØ. The observed limits are indicated with solid lines, and the expected limits are indicated with dashed lines. The limits are to be compared with the sum of signal predictions for Higgs bosons with similar masses.

coupling. In the channels with $\tau^+\tau^-$ final states, however, compensations occur between large corrections in the Higgs boson production and decay. The total production rates of bottom quarks and τ pairs mediated by the production of a CP-odd Higgs boson in the large $\tan\beta$ regime are approximately given by

$$\sigma_{b\overline{b}A} \times \mathrm{BR}(A \to b\overline{b}) \simeq \sigma_{b\overline{b}A}^{\mathrm{SM}} \ \frac{\tan^2 \beta}{\left(1 + \Delta_b\right)^2} \frac{9}{\left(1 + \Delta_b\right)^2 + 9},$$

and

$$\sigma_{gg \to A, b\overline{b}A} \times \text{BR}(A \to \tau^+ \tau^-) \simeq \sigma_{gg \to A, b\overline{b}A}^{\text{SM}} \ \frac{\tan^2 \beta}{\left(1 + \Delta_b\right)^2 + 9}$$

where $\sigma_{b\bar{b}A}^{\rm SM}$ and $\sigma_{gg\to A,b\bar{b}A}^{\rm SM}$ denote the values of the corresponding SM Higgs boson cross sections for a SM Higgs boson mass equal to m_A . The function Δ_b includes the dominant effects of SUSY radiative corrections for large $\tan\beta$ [170,175,187,188], and it depends strongly on $\tan\beta$ and on the SUSY mass parameters. The $b\bar{b}A$ channel is more sensitive to the value of Δ_b through the factor $1/(1+\Delta_b)^2$ than the inclusive $\tau^+\tau^-$ channel, for which this leading dependence on Δ_b cancels out. As a consequence, the limits derived from the inclusive $\tau^+\tau^-$ channel depend less on the precise MSSM scenario chosen than those of the $b\bar{b}A$ channel.

The production and decay rates of the CP-even Higgs bosons with $\tan \beta$ -enhanced couplings to down-type fermions—H (or h) for m_A larger (or smaller) than m_h^{\max} , respectively—are governed by formulas similar to the ones presented above. At high $\tan \beta$, one of the CP-even Higgs bosons and the CP-odd Higgs boson are nearly degenerate in mass, enhancing the signal

cross section by roughly a factor of two, without complicating the experimental signature except in a small mass region in which the three neutral MSSM Higgs boson masses are close together and each boson contributes to the total production rate. Detailed discussions of the impact of radiative corrections in these search modes are presented in Refs. [225] and [233].

In Fig. 15, the interpretation is shown for DØ's combination of $\phi \to b\bar{b}$ and $\phi \to \tau^+\tau^-$ searches [232] in the $(m_A, \tan\beta)$ plane for the m_h -max benchmark scenario with $\mu=200$ GeV. The neutral Higgs boson searches consider the contribution of both the CP-odd and the CP-even neutral Higgs bosons with enhanced couplings to bottom quarks. As explained above, considering other benchmark scenarios will not relevantly change the region of SUSY parameter space that can be explored via the inclusive di-tau searches, but different regions of SUSY parameter space will be probed in the case of the $b\bar{b}$ searches.

ATLAS and CMS also search for $\phi \to \tau^+\tau^-$ in pp collisions at $\sqrt{s} = 7$ TeV. ATLAS seeks tau pairs in 1.06 fb⁻¹ of data [234,235], and CMS's search uses 4.6 fb^{-1} of The searches are performed in categories data [138,139]. of the decays of the two tau leptons: $e\tau_{\rm had}$, $\mu\tau_{\rm had}$, $e\mu$, and $\mu\mu$, where $\tau_{\rm had}$ denotes a tau lepton which decays to one or more hadrons plus a tau neutrino, e denotes $\tau \to e\nu\nu$, and μ denotes $\tau \to \mu\nu\nu$. The dominant background comes from $Z \to \tau^+\tau^$ decays, although $t\bar{t}$, W+jets and Z+jets events contribute as well. Separating events into categories based on the number of b-tagged jets improves the sensitivity in the MSSM. The $b\bar{b}$ annihilation process and radiation of a Higgs boson from a bquark give rise to events in which the Higgs boson is accompanied by a $b\bar{b}$ pair in the final state, sometimes with only one b within the detector acceptance. Requiring the presence of one or more b jets reduces the background from Z+jets. Data control samples are used to constrain background rates. The rates for jets to be identified as a hadronically decaying tau lepton are measured in dijet samples, and W+jets samples provide a measurement of the rate of events that, with a fake hadronic tau, can pass the signal selection requirements. Lepton fake rates are measured using samples of unisolated lepton candidates and same-sign lepton candidates. Constraints from ATLAS's and CMS's searches for $h \to \tau^+ \tau^-$ are also shown in Fig. 15 in the m_h -max benchmark scenario, with $\mu = 200$ GeV. The neutral Higgs boson searches consider the contributions of both the CP-odd and CP-even neutral Higgs bosons with enhanced couplings to bottom quarks, as they were for the Tevatron results. As explained above, the di-tau inclusive search limits do not significantly change by considering other benchmark scenarios.

In addition to $\phi \to \tau^+ \tau^-$ at the LHC, studies indicate that with about 30 fb⁻¹ of data one can search for the non-standard neutral Higgs bosons of the MSSM in the $b\bar{b}\phi, \phi \to b\bar{b}$ channel with three b's in the final state [233]. Due to the dependence of this production and decay mode on the SUSY radiative corrections there is complementarity between the 3b channel and the inclusive tau pair channel in exploring the supersymmetric parameter space.

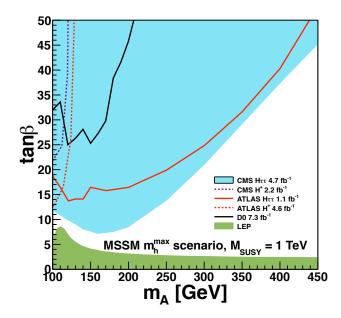


Figure 15: The 95% C.L. MSSM exclusion contours m_h -max benchmark scenario obtained by the ATLAS [234], CMS [138], and DØ [232] collaborations. The LHC collaborations contribute searches for $H \to \tau^+\tau^-$ and $H^\pm \to \tau \nu_\tau$ while DØ combines $H \to \tau^+\tau^-$ with $H \to b\bar{b}$ searches for these results. Also shown is the region excluded by LEP searches [34]. assuming a top quark mass of 174.3 GeV.

The LHC has the potential to explore a broad range of SUSY parameter space through the search for non-SM-like Higgs bosons. Nevertheless, Fig. 15 shows a broad region with intermediate $\tan \beta$ and large values of m_A that is not tested by present neutral or charged Higgs boson searches, and which might be difficult to cover completely via these searches, even with much larger data sets. In this region of parameter space it is possible that only the SM-like Higgs boson can be within the LHC's reach. If a SM-like Higgs boson is discovered, it may be challenging to determine only from the Higgs sector whether there is a supersymmetric extension of the SM in nature.

III.4. Searches for Charged MSSM Higgs Bosons

Searches for the charged Higgs bosons predicted by 2HDMs have been conducted at LEP, the Tevatron, and the LHC, and the results of these searches have been interpreted in terms of the MSSM. Due to the correlations among Higgs boson masses in the MSSM, the experimental results do not yet significantly constrain the MSSM parameter space beyond what is already obtained from the searches for neutral Higgs bosons. In the near future, however, the LHC experiments will be sensitive to charged Higgs boson decays up to ≈ 170 GeV for all values of tan β [236].

At LEP, searches were performed for pair-produced charged Higgs bosons. In the MSSM and in more general Type-II 2HDMs, for masses which are accessible at LEP energies,

the decays $H^+ \to c\overline{s}$ and $\tau^+\nu_{\tau}$ dominate. The final states $H^+H^- \to (c\overline{s})(\overline{c}s)$, $(\tau^+\nu_{\tau})(\tau^-\overline{\nu}_{\tau})$, and $(c\overline{s})(\tau^-\overline{\nu}_{\tau})+(\overline{c}s)(\tau^+\nu_{\tau})$ were considered, and the search results are usually presented as functions of BR $(H^+ \to \tau^+\nu)$. The sensitivity of the LEP searches was limited to $m_{H^\pm} < 90$ GeV, due to the background from $e^+e^- \to W^+W^-$ [237], and the kinematic limitation on the production cross section. The combined LEP data constrain $m_{H^\pm} > 78.6$ GeV independently of BR $(H^+ \to \tau^+\nu_{\tau})$ [238].

At the Tevatron, the CDF and DØ collaborations have searched for charged Higgs bosons in top quark decays with subsequent decays of the charged Higgs boson to $\tau\nu$ or to $c\bar{s}$ [239,240,241]. Assuming BR($H^+ \to c\bar{s}$) = 100%, the limits on BR($t \to H^+b$) from CDF and DØ are \approx 20% in the mass range 90 GeV < m_{H^+} < 160 GeV. Assuming BR($H^+ \to \tau^+\nu_{\tau}$) = 100%, DØ's limits on BR($t \to H^+b$) are also \approx 20% in the same mass range. These limits are valid in general 2HDMs, and they have also been interpreted in terms of the MSSM in the references.

The ATLAS collaboration has also searched for charged Higgs bosons produced in the decay of top quarks in $t\bar{t}$ events. ATLAS has searched for the decay $H^+ \to \tau^+ \nu_{\tau}$ in three final state topologies: 1) lepton+jets: with $t\overline{t} \to \overline{b}WH^+ \to$ $b\overline{b}(q\overline{q}')(\tau_{\rm lep}\nu)$, i.e., the W boson decays hadronically and the tau decays into an electron or a muon, with two neutrinos; 2) τ +lepton: with $t\bar{t} \to \bar{b}WH^+ \to b\bar{b}(l\nu)(\tau_{\rm had}\nu)$ i.e., the W boson decays leptonically (with $\ell=e,\ \mu$) and the tau decays hadronically; 3) τ +jets: $t\bar{t} \to \bar{b}WH^+ \to b\bar{b}(q\bar{q}')(\tau_{\rm had}\nu)$, i.e., both the W boson and the τ decay hadronically [242]. Assuming BR($H^+ \to \tau^+ \nu_{\tau}$) = 100%, ATLAS sets upper limits on BR $(t \to H^+ b)$ between 5% and 1% for charged Higgs boson masses between 90 GeV to 160 GeV, respectively. These limits are shown in Fig. 16. When interpreted in the context of the $m_h^{\rm max}$ scenario of the MSSM, these bounds exclude tan β values above 20 in this range of charged Higgs boson masses, but also provide sensitivity for $\tan \beta < 4$ due to the increasing predicted decay rate for $t \to H^+b$ at low tan β . The high-tan β interpretation of this result is shown in Fig. 15. ATLAS has also searched for charged Higgs bosons in top quark decays assuming BR($H^+ \rightarrow c\bar{s}$) = 100% [243], and sets limits of \approx 20% on ${\rm BR}(t \to H^+ b)$ in the 90 GeV $< m_{H^+} <$ 160 GeV mass range

The CMS collaboration has also searched for the charged Higgs boson in the decay products of top quark pairs: $t\bar{t}\to H^\pm W^\mp b\bar{b}$ and $t\bar{t}\to H^+H^-b\bar{b}$ [244]. Three types of final states with large missing transverse energy and jets originating from b-quark hadronization have been analyzed: the fully-hadronic channel with a hadronically decaying tau in association with jets, the di-lepton channel with a hadronically decaying tau in association with an electron or muon and the di-lepton channel with an electron-muon pair. Combining the results of these three analyses and assuming BR($H^\pm\to \tau\nu$)=1, the upper limits on BR($H^\pm\to H^\pm$) are less than 2% to 3% depending on the charged Higgs boson mass in the interval 80 GeV

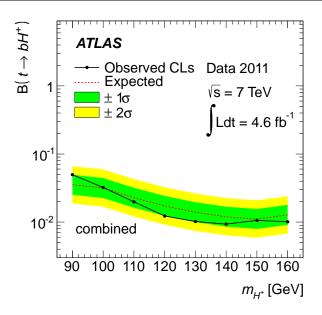


Figure 16: 95% C.L. limit on BR $(t \to H^+ b$ assuming BR $(H^+ \to \tau \nu) = 100\%$ from the AT-LAS collaboration [242].

 $< m_{H^+} < 160$ GeV. The results of this search have been translated into limits in the $(M_A, \tan \beta)$ plane for the m_h -max benchmark scenario and are shown in Fig. 15.

III.5. Effects of CP Violation on the MSSM Higgs Spectrum

In the Standard Model, CP-violation (CPV) is induced by phases in the Yukawa couplings of the quarks to the Higgs field, which results in one non-trivial phase in the CKM mixing matrix. SUSY scenarios with new CPV phases are theoretically appealing, since additional CPV beyond that observed in the K, D, and B meson systems is required to explain the observed cosmic matter-antimatter asymmetry [245,246]. the MSSM, there are additional sources of CPV from phases in the various mass parameters. In particular, the gaugino mass parameters $(M_i, i = 1, 2, 3)$, the Higgsino mass parameter, μ , the bilinear Higgs squared-mass parameter, m_{12}^2 , and the trilinear couplings of the squark and slepton fields to the Higgs fields, A_f , may carry non-trivial phases. The two parameter combinations $\arg[\mu A_f(m_{12}^2)^*]$ and $\arg[\mu M_i(m_{12}^2)^*]$ are invariant under phase redefinitions of the MSSM fields [247,248]. Therefore, if one of these quantities is non-zero, there would be new sources of CP-violation, which affects the MSSM Higgs sector through radiative corrections [182,248–253]. of the neutral CP-odd and CP-even Higgs boson states is no longer forbidden. Hence, m_A is no longer a physical parameter. However, the charged Higgs boson mass $m_{H^{\pm}}$ is still physical and can be used as an input for the computation of the neutral Higgs spectrum of the theory.

For large values of $m_{H^{\pm}}$, corresponding to the decoupling limit, the properties of the lightest neutral Higgs boson state approach those of the SM Higgs boson. That is, for $m_{H^{\pm}} \gg M_W$,

the lightest neutral Higgs boson is approximately a CP-even state, with CPV couplings that are suppressed by terms of $\mathcal{O}(m_W^2/m_{H^\pm}^2)$. In particular, the upper bound on the lightest neutral Higgs boson mass, takes the same value as in the CP-conserving case [248]. Nevertheless, there still can be significant mixing between the two heavier neutral mass eigenstates. For a detailed study of the Higgs boson mass spectrum and parametric dependence of the associated radiative corrections, see Refs. [249,252].

Major variations to the MSSM Higgs phenomenology occur in the presence of explicit CPV phases. In the CPV case, vector boson pairs couple to all three neutral Higgs boson mass eigenstates, H_i (i = 1, 2, 3), with couplings

$$g_{H_iVV} = \cos \beta \mathcal{O}_{1i} + \sin \beta \mathcal{O}_{2i}$$

$$g_{H_iH_jZ} = \mathcal{O}_{3i}(\cos\beta\mathcal{O}_{2j} - \sin\beta\mathcal{O}_{1j}) - \mathcal{O}_{3j}(\cos\beta\mathcal{O}_{2i} - \sin\beta\mathcal{O}_{1i})$$

where the g_{H_iVV} couplings are normalized to the analogous SM coupling and the $g_{H_iH_jZ}$ have been normalized to $g_Z^{\rm SM}/2$. \mathcal{O}_{ij} is the orthogonal matrix relating the weak eigenstates to the mass eigenstates. It has non-zero off-diagonal entries mixing the CP-even and CP-odd components of the weak eigenstates. The above couplings obey the relations

$$\sum_{i=1}^{3} g_{H_iZZ}^2 = 1 \quad \text{ and } \quad g_{H_kZZ} = \varepsilon_{ijk} \, g_{H_iH_jZ}$$

where ε_{ijk} is the Levi-Civita symbol.

Another consequence of CPV effects in the scalar sector is that all neutral Higgs bosons can couple to both scalar and pseudoscalar fermion bilinear densities. The couplings of the mass eigenstates H_i to fermions depend on the loop-corrected fermion Yukawa couplings (similarly to the CPC case), on $\tan \beta$ and on the \mathcal{O}_{ji} . The resulting expressions for the scalar and pseudoscalar components of the neutral Higgs boson mass eigenstates to fermions and the charged Higgs boson to fermions are given in Refs. [249,254].

The prodution processes of neutral MSSM Higgs bosons in the CPV scenario are similar to those in the CPC scenario, except for the fact that in any process, the CP eigenstates h, H, and A can be replaced by any of the three neutral Higgs mass eigenstates H_i . This is the case, since, in the presence of CP violation, the H_i 's do not have well-defined CP quantum numbers. Regarding the decay properties, the lightest mass eigenstate, H_1 , predominantly decays to $b\bar{b}$ if kinematically allowed, with a smaller fraction decaying to $\tau^+\tau^-$, similar to the CPC case. If kinematically allowed, a SM-like neutral Higgs boson, H_2 or H_3 can decay predominantly to H_1H_1 leading to many new interesting signals both at lepton and hadron colliders; otherwise it will decay preferentially to $b\bar{b}$.

III.6. Searches for Neutral Higgs Bosons in CPV Scenarios

At LEP, all three neutral Higgs eigenstates could have been produced by Higgs-strahlung, $e^+e^- \to H_iZ$, and in pairs, $e^+e^- \to Z^* \to H_iH_j$, with $i \neq j$. The production rates depend on the details of the CPV scenario. Possible cascade decays such as H_2 or $H_3 \to H_1H_1$ can lead to interesting experimental signatures in the Higgs-strahlung processes, $e^+e^- \to H_2Z$ or H_3Z , however, the searches in the CPV MSSM scenario are experimentally more difficult. The cross sections for the Higgs-strahlung and pair production processes are given in Refs [182,248,249,253].

The Higgs boson searches at LEP were interpreted [34] in a CPV benchmark scenario [182] for which the parameters were chosen so as to maximize the phenomenological differences with respect to the CPC scenario. Using the most conservative theoretical calculations available at each point in the $(m_{H_1}, \tan \beta)$ plane, parts of the region $m_{H_1} < 60$ GeV and $\tan \beta < 40$ were excluded, and values of $\tan \beta$ lower than 3 were excluded for all values of $m_{H_1} < 114$ GeV. The Tevatron CP-conserving results and projections for MSSM Higgs searches, as well as the existing projections for LHC MSSM CP-conserving searches have been reinterpreted in the framework of CP-violating MSSM Higgs in Ref. 255.

III.7. Indirect Constraints on Supersymmetric Higgs Bosons

Indirect bounds from a global fit to precision measurements of electroweak observables can be derived in terms of MSSM parameters [256] in a way similar to what was done in the SM. Given the MSSM and SM predictions for M_W as a function of m_t , and varying the Higgs boson mass and the SUSY spectrum, one finds that the MSSM overlaps with the SM when SUSY masses are large, of $\mathcal{O}(2 \text{ TeV})$, and the light SM-like Higgs boson has a mass in the experimentally preferred mass range: m_h 114-129 GeV. The MSSM Higgs boson mass expectations are compatible with the constraints provided by the measurements of m_t and M_W [257]. A global fit for m_h in the Constrained MSSM, for example, yields $m_h = 119.1^{+3.4}_{-2.9}$ GeV after including the constraints from LHC data, instead of the pre-LHC value of $m_h = 111.5^{+3.5}_{-1.2}$ GeV, improving the consistency of the model predictions with the LEP exclusion [258] ⁴. These global fit studies show that a SM-like Higgs with mass 125 GeV or larger would start to build up some tension with $g_{\mu}-2$ that may ultimately lead to exclude the CMSSM or other types of constrained SUSY scenarios for which similar results can be obtained.

Improvements in our understanding of B-physics observables put indirect constraints on MSSM scenarios in regions in which Higgs boson searches at the Tevatron and the LHC are sensitive. In particular, $BR(B_s \to \mu^+\mu^-)$, $BR(b \to s\gamma)$, and $BR(B_u \to \tau\nu)$ play an important role within minimal flavor-violating (MFV) models [259], in which flavor effects proportional to the CKM matrix elements are induced, as in the SM. For example, see Refs. [260–263]. The supersymmetric contributions to these observables come both at the tree-and loop-level, and have a different parametric dependence,

⁴ This fit does not include the direct limits on the Higgs boson mass from any collider.

but share the property that they become significant for large values of $\tan \beta$, which is also the regime in which searches for non-standard MSSM Higgs bosons at hadron colliders are the most powerful.

In the SM, the relevant contributions to the rare decay $B_s \to \mu^+\mu^-$ come through the Z-penguin and the W^\pm -box diagrams [264]. In supersymmetry with large $\tan \beta$, there are also significant contributions from Higgs-mediated neutral currents [265–268], which depend on the SUSY spectra, and grow with the sixth power of $\tan \beta$ and decrease with the fourth power of the CP-odd Higgs boson mass m_A . Therefore, the upper limits from the Tevatron and the LHC [269] put strong restrictions on possible flavor-changing neutral currents (FCNC) in the MSSM at large $\tan \beta$ [270].

Further constraints are obtained from the rare decay $b \to s\gamma$. The SM rate is known up to NNLO corrections [271,272] and is in good agreement with measurements [273]. In the Type-II 2HDM and in the absence of other sources of new physics at the electroweak scale, a bound $m_{H^\pm} > 295$ GeV has been derived [271]. Although this indirect bound appears much stronger than the results from direct charged Higgs searches, it can be invalidated by new physics contributions, such as those which can be present in the MSSM. In the minimal flavor-violating MSSM, there are new contributions from charged Higgs as well as chargino-stop and gluino-sbottom diagrams. The charged Higgs boson's contribution is enhanced for small values of its mass and can be partially canceled by the chargino and gluino contributions or by higher-order tan β -enhanced loop effects.

The branching ratio $B_u \to \tau \nu$, measured by the Belle [274,275] and BaBar [276,277] collaborations, also constrains the MSSM. The SM expectation is in slight tension with the latest experimental results [278]. In the MSSM, there is an extra tree-level contribution from the charged Higgs which interferes destructively with the SM contribution, and which increases for small values of the charged Higgs boson mass and large values of $\tan \beta$ [279]. Charged Higgs effects on $B \to D\tau\nu$ decays [280], constrain in an important way the parameter space for small values of the charged Higgs boson mass and large values of $\tan \beta$, and exclude a region that is otherwise allowed by values of $B_u \to \tau\nu$ [278,281,282]. These two observables are only mildly dependent on the SUSY spectra.

Charged Higgs bosons can play a role in explaining the evidence for CP violation in $D^0 \to \pi^+\pi^-$, K^+K^- decays recently presented by LHCb [283] and CDF [284]. In a particular minimal flavor violating 2HDM, tree-level charged Higgs insertions can give large contributions to CP violation in D^0 decays while also being consistent with stringent bounds from $D^0 - \bar{D}^0$ mixing, BR $(b \to s\gamma)$, and BR $(B_u \to \tau\nu)$, as well as direct searches such as $H \to \tau^+\tau^-$ [285].

Several studies [260-263,286,287] have shown that, in extended regions of parameter space, the combined B-physics measurements impose strong constraints on the MSSM models to which Higgs boson searches at the Tevatron and the LHC

are sensitive. Consequently, the observation of a non-SM Higgs boson at the Tevatron or the LHC would point to a rather narrow, well-defined region of MSSM parameter space [260,288] or to something beyond the minimal flavor violation framework.

Another indirect constraint on the Higgs sector comes from the search for dark matter. If dark matter particles are weakly interacting and massive, then particle physics can provide models which predict the correct relic density of the universe. In particular, the lightest supersymmetric particle, typically the lightest neutralino, is an excellent dark matter particle can-Within the MSSM, the measured relic density places constraints in the parameter space, which in turn - for specific SUSY low energy spectra- have implications for Higgs searches at colliders, and also for experiments looking for direct evidence of dark matter particles in elastic scattering with atomic nuclei. Large values of $\tan \beta$ and small m_A are relevant for the $b\overline{b}A/H$ and $A/H \to \tau^+\tau^-$ searches at the Tevatron and the LHC, and also provide a significant contribution from the CP-even Higgs H exchange to the spin-independent cross sections for direct detection experiments such as CDMS or Xenon, for example. Consequently, a signal at colliders would raise prospects for a signal in indirect detection experiments and vice-versa [286,288,290-292]. However, there are theoretical uncertainties in the calculation of dark matter scattering cross sections, and in the precise value of the local dark matter density and velocity distributions, which may dilute these model-dependent correlations.

IV. Other Model Extensions

There are many ways to extend the minimal Higgs sector of the Standard Model. In the preceding sections we have considered the phenomenology of the MSSM Higgs sector⁵, which at tree level is a constrained Type-II 2HDM (with restrictions on the Higgs boson masses and couplings). One can consider general Type-II 2HDMs [13,44,162], with no correlations between masses and couplings, or Type-I 2HDMs [163]. patterns of Higgs-fermion couplings in each case will lead to different phenomenology. It is also possible to consider models with a SM Higgs boson and one or more additional scalar SU(2) doublets that acquire no vacuum expectation value (vev) and hence play no role in the EWSB mechanism. These models are dubbed Inert Higgs Doublet Models [293]. Due to the lack of vev, the inert Higgs bosons cannot decay into a pair of gauge bosons, and imposing a Z_2 symmetry that prevents them from coupling to the fermions it follows that if the lightest inert Higgs boson is neutral it becomes a good dark matter candidate with interesting associated collider signals.

Other extensions of the Higgs sector can include [15,164] multiple copies of $SU(2)_L$ doublets, additional Higgs singlets, triplets or more complicated combinations of Higgs multiplets.

⁵ In the searches for charged Higgs bosons the results are presented for given branching ratio assumptions within a general 2HDM, and then interpreted in the MSSM.

It is also possible to enlarge the gauge symmetry beyond $SU(2)_L \times U(1)_Y$ along with the necessary Higgs structure to generate gauge boson and fermion masses. There are two main experimental constraints that govern these extensions: (i) precision measurements which constrain $\rho = m_W^2/(m_Z^2 \cos^2 \theta_W)$ to be very close to 1 and (ii) flavor changing neutral current (FCNC) effects. In electroweak models based on the SM gauge group, the tree-level value of ρ is determined by the Higgs multiplet structure. By suitable choices for the hypercharges, and in some cases the mass splitting between the charged and neutral Higgs sector or the vacuum expectation values of the Higgs fields, it is possible to obtain a richer combination of singlets, doublets, triplets and higher multiplets compatible with precision measurements [294]. Concerning the constraints coming from FCNC effects, the Glashow-Weinberg theorem [295] states that, in the presence of multiple Higgs doublets the tree-level FCNC's mediated by neutral Higgs bosons will be absent if all fermions of a given electric charge couple to no more than one Higgs doublet. The Higgs doublet models Type-I and Type-II are two different ways of satisfying this theorem. The coupling pattern of these two types can be arranged by imposing either a discrete symmetry or, in the case of Type-II, supersymmetry. The resulting phenomenology of extended Higgs sectors can differ significantly from that of the SM Higgs boson.

In supersymmetry, the most studied extensions of the MSSM have a scalar singlet and its supersymmetric partner [296-298]. These models have an extended Higgs sector with two additional neutral scalar states, one CP-even and one CP-odd, beyond those present in the MSSM. In these models, the tree-level bound on the lightest Higgs boson, considering arguments of perturbativity of the theory up to the GUT scale, is about 100 GeV. The radiative corrections to the masses are similar to those in the MSSM and yield an upper bound of about 145 GeV for the mass of the lightest neutral CP-even scalar, for stop masses in the TeV range [16,299]. plings of the Higgs bosons to the gauge bosons and fermions are weakened somewhat from mixing with the singlet and this can alter significantly the Higgs phenomenology with respect to the MSSM case.

Another extension of the MSSM which can raise the value of the lightest Higgs boson mass to a few hundred GeV is based on gauge extensions of the MSSM [17,18]. The addition of asymptotically-free gauge interactions naturally yields extra contributions to the quartic Higgs couplings. These extended gauge sector models can be combined with the presence of extra singlets or replace the singlet with a pair of triplets [19].

It is also possible that the MSSM is the low energy effective field theory of a more fundamental SUSY theory that includes additional particles with masses at or somewhat above the TeV range, and that couple significantly to the MSSM Higgs sector. A model-independent analysis of the spectrum and couplings of the MSSM Higgs fields, based on an effective theory of the MSSM degrees of freedom has been studied [18,20,21,300]. In these scenarios the tree-level mass of the lightest CP-even state

can easily be above the LEP bound of 114 GeV, thus allowing for a relatively light spectrum of superpartners, restricted only by direct searches. The Higgs spectrum and couplings can be significantly modified compared to the MSSM ones, often allowing for interesting new decay modes. It is also possible to moderately enhance the gluon fusion production cross section of the SM-like Higgs with respect to both the Standard Model and the MSSM.

Many non-SUSY solutions to the problem of electroweak symmetry breaking and the hierarchy problem are being developed. For example, Little Higgs models [25–27] propose additional sets of heavy vector-like quarks, gauge bosons, and scalar particles, with masses in the 100 GeV to a few TeV range. The couplings of the new particles are tuned in such a way that the quadratic divergences induced in the SM by the top, gauge-boson and Higgs loops are canceled at the one-loop level. If the Little Higgs mechanism successfully resolves the hierarchy problem, it should be possible to detect some of these new states at the LHC. For reviews of models and phenomenology, and a more complete list of references, see Refs. [301–303].

In Little Higgs models the production and decays of the Higgs boson are modified. For example, when the dominant production mode of the Higgs is through gluon fusion, the contribution of new fermions in the loop diagrams involved in the effective ϕqq vertex can reduce the production rate. The rate is generally suppressed relative to the SM rate due to the symmetries which protect the Higgs boson mass from quadratic divergences at the one-loop level. As a result, the branching ratio of the Higgs boson to photon pairs can be enhanced in these models [304]. By design, Little Higgs models are valid only up to a scale $\Lambda \sim 5\text{-}10$ TeV. The new physics which would enter above Λ remains unspecified, and will impact the Higgs sector. In general, it can modify Higgs couplings to third-generation fermions and gauge bosons, though these modifications are suppressed by $1/\Lambda$ [305].

Distinctive features in the Higgs phenomenology of Little Higgs models may also stem from the fact that loop-level electroweak precision bounds on models with a tree-level custodial symmetry allows for a Higgs boson heavier than the one permitted by precision electroweak fits in the SM. This looser bound follows from a cancellation of the effects on the ρ parameter of a higher mass Higgs boson and the heavy partner of the top quark. The Higgs boson can have a mass as high as 800-1000 GeV in some Little Higgs models and still be consistent with electroweak precision data [306]. Lastly, the scalar content of a Little Higgs structure is model dependent. There could be two, or even more scalar doublets in a little Higgs model, or even different representations of the electroweak gauge group [26].

Models of extra space dimensions present an alternative way of avoiding the hierarchy problem [28]. New states, known as Kaluza-Klein (KK) excitations, can appear at the TeV scale, where gravity-mediated interactions may become relevant. They share the quantum numbers of the graviton and/or SM particles. In a particular realization of these models, based on

warped extra dimensions, a light Higgs-like particle, the radion, may appear in the spectrum [307]. The mass of the radion, as well as its possible mixing with the light Higgs boson, depends strongly on the mechanism that stabilizes the extra dimension, and on the curvature-Higgs mixing.

The radion couples to the trace of the energy-momentum tensor of the SM particles, leading to effective interactions with quarks, leptons, and weak gauge bosons which are similar to the ones of the Higgs boson, although they are suppressed by the ratio of the weak scale to the characteristic mass of the new excitations. An important characteristic of the radion is its enhanced coupling to gluons. Therefore, if it is light and mixes with the Higgs boson, it may modify the standard Higgs phenomenology at lepton and hadron colliders. A search for the radion conducted by OPAL at LEP gave negative results [308]. Radion masses below 58 GeV are excluded for the mass eigenstate which becomes the Higgs boson in the no-mixing limit, for all parameters of the Randall-Sundrum model. Most recently there has been a study of the effects of radion-Higgs mixing in Higgs boson searches at the LHC [309].

In models of warped extra dimensions in which the SM particles propagate in the extra dimensions, the KK excitations of the vector-like fermions may be pair-produced at colliders and decay into combinations of two Higgs bosons and jets, or one Higgs boson, a gauge boson, and jets. KK excitations may also be singly-produced. Some of these interesting possible new signatures for SM-like Higgs bosons in association with top or bottom quarks have been studied [27,29]. Most interesting, in models with warped extra dimensions the Kaluza-Klein excitations of the quarks and leptons which can be exchanged as virtual particles in the loops, can significantly change the Higgs production via gluon fusion, as well as its decay into diphotons. These results may depend on the precise localization of the SM-like Higgs in the extra dimension as well as on the precise particle content of the models. There are many studies in the literature that address these issues and compute the effects on the Higgs phenomenology [27,310].

Models of flat extra dimensions, in which SM particles propagate in the extra dimensions, are named Universal Extra Dimensions (UED) [311]. In such models the KK particles affect the Higgs couplings at the 1-loop level. In the minimal UED model, for tree-level masses of the lowest KK particles of order 1 TeV the $gg \to h$ production rate is increased by $\approx 20\%$ while the $h \to \gamma\gamma$ decay width is decreased by a factor of $\lesssim 3\%$ [312].

It is also possible to consider a simple description of models in which electroweak symmetry breaking is triggered by a light composite Higgs, which emerges from a strongly-interacting sector as a pseudo-Goldstone boson, by utilizing an effective low-energy Lagrangian approach [31]. Recent studies of the phenomenology relevant for collider searches can be found in Ref. 313.

The Higgs boson can also be a portal to hidden sectors, in particular, the Higgs boson can decay to the particles of a low-mass hidden sector; these models are referred to as hidden valley models [314,315]. Since a light Higgs boson is a particle with a narrow width, even modest couplings to new states can give rise to a significant modification of Higgs phenomenology through exotic decays. Simple hidden valley models exist in which the Higgs boson decays to an invisible fundamental particle, which has a long lifetime to decay back to SM particles through small mixings with the SM Higgs boson; Ref. 315 describes an example. The Higgs boson may also decay to a pair of hidden valley "v-quarks," which subsequently hadronize in the hidden sector, forming "v-mesons." These mesons often prefer to decay to the heaviest state kinematically available, so that a possible signature is $h \to 4b$. Some of the v-mesons may be stable, implying a mixed missing energy plus heavy flavor final state. In other cases, the v-mesons may decay to leptons, implying the presence of low mass lepton resonances in high H_T events [316]. Other scenarios have been studied [317] in which Higgs bosons decay predominantly into light hidden sector particles, either directly, or through light SUSY states, and with subsequent cascades that increase the multiplicity of hidden sector particles. In such scenarios, the high multiplicity hidden sector particles, after decaying back into the Standard Model, appear in the detector as clusters of collimated leptons known as lepton jets.

If Higgs bosons are not discovered at the Tevatron or the LHC, other studies might be able to test alternative theories of dynamical electroweak symmetry breaking which do not involve a Higgs particle [318].

V. Searches for Higgs Bosons Beyond the MSSM

In extensions of the MSSM with one or more additional scalar singlets, limits have been set at e^+e^- and hadron colliders. The ALEPH [319] and DELPHI [320] collaborations place constraints on such models. Precise LEP 2 bounds on the Higgs boson masses depend on the couplings of the Higgs bosons to the gauge bosons and such couplings tend to be weakened somewhat from mixing with the singlet(s). At hadron colliders, searches for a light pseudoscalar boson predicted by the NMSSM have been performed by DØ [321], CDF [322], CMS [323], and ATLAS [324]. No significant excesses have been found and limits have been set on these models.

Most of the searches for the processes $e^+e^- \to hZ$ and hA, which have been discussed in the context of the CPC-MSSM, rely on the assumption that the Higgs bosons have a sizable branching ratio to $b\bar{b}$. However, for specific parameters of the MSSM [325], the general 2HDM case, or composite models [175,177,326], decays to non- $b\bar{b}$ final states may be significantly enhanced. Flavor-independent hadronically-decaying Higgs boson searches have been performed at LEP which do not require the experimental signature of a b-jet [327], and a preliminary combination of LEP data has been performed [34,328]. If Higgs bosons are produced at the SM rate and decay only to jets of hadrons, then the 95% C.L. lower limit on the mass of the Higgs boson is 112.9 GeV, independent of the fractions

of gluons and b, c, s, u and d-quarks in Higgs boson decay. In conjunction with b-flavor sensitive searches, large domains of the general Type-II 2HDM parameter space have been excluded [329].

In the Type-I 2HDM, if the CP-odd neutral Higgs boson A is light (which is not excluded in the general 2HDM case, nor in some extensions of the MSSM), the decay $H^{\pm} \to W^{\pm *}A$ may be dominant for masses accessible at LEP, a possibility that was investigated by DELPHI [330] and OPAL [331]. CDF's search for this decay chain in top quark decays [322] may also be interpreted in this scenario.

The LEP collaborations searched for Higgs bosons produced in pairs, in association with Z bosons, b quarks, and τ leptons. The decays considered are $\phi_{i,j} \to b\bar{b}, \tau^+\tau^-$, and $\phi_j \to \phi_i\phi_i$, when kinematically allowed, yielding four-b, four-b+jets, sixb and four- τ final states as well as mixed modes with bquarks and tau leptons. No evidence for a Higgs boson was found [34,224], and mass-dependent coupling limits on a variety of processes, which apply to a large class of models were, set. The limits on the cross sections of Yukawa production of Higgs bosons are typically more than 100 times larger than the SM predictions [224]. Limits on pair-produced Higgs bosons extend up to $m_{\phi_i} + m_{\phi_i}$ in the range 140- 200 GeV for fullstrength production, assuming $b\bar{b}$ and $\tau^+\tau^-$ decays. Limits on Higgs-strahlung production with subsequent decay of the Higgs into lighter Higgs pairs exclude Higgs masses of the Higgs produced in association with the Z up to 114 GeV, if the lighter Higgs bosons decay to $b\bar{b}$. Weaker limits are set if the lighter Higgs pair decays to four tau leptons, or to a mixture of tau leptons and b quarks [34].

Decays of Higgs bosons into invisible (weakly-interacting and neutral) particles may occur in many models⁶. For example, Higgs bosons might decay into pairs of Goldstone bosons or Majorons [332]. In the process $e^+e^- \to hZ$, the mass of the invisible Higgs boson can be inferred from the kinematics of the reconstructed Z boson by using the beam energy constraint. Results from the LEP experiments can be found in Refs. [219] and [333]. A preliminary combination of LEP data yields a 95% C.L. lower bound of 114.4 GeV for the mass of a Higgs boson, if it is produced with SM production rate, and if it decays exclusively into invisible final states [334].

OPAL's decay-mode independent search for $e^+e^- \to S^0Z$ [80] provides sensitivity to arbitrarily-decaying scalar particles, as only the recoiling Z boson decaying into leptons is required to be reconstructed. The energy and momentum constraints provided by the e^+e^- collisions allow the S^0 's four-vector to be reconstructed and limits placed on its production independent of its decay characteristics, allowing sensitivity for very light scalar masses. The limits obtained in this search are less than one-tenth of the SM Higgs-strahlung production rate for

1 keV< m_{S^0} < 19 GeV, and less than the SM Higgs-strahlung rate for m_{S^0} < 81 GeV.

Hidden-valley models predict a rich phenomenology of new particles, some of which can be long-lived and hadronize with SM particles to form exotic particles which decay at measurable distances in collider experiments. CDF and DØ have searched for pair-produced long-lived particles produced resonantly and which decay to $b\bar{b}$ pairs, and set limits on Higgs boson production in hidden-valley models [335,336]. The Higgs boson can also be the portal to high multiplicity hidden sector particles that may produce multiple charged leptons in the final state. A search for additional leptons in events containing a leptonically decaying W or Z boson by CDF [337] is sensitive to such models and others predicting multi-lepton final states; the results are consistent with SM expectations.

Photonic final states from the processes $e^+e^- \to Z/\gamma^* \to H\gamma$ and from $H \to \gamma\gamma$, could be significantly enhanced, over the SM loop induced effects, in models with anomalous couplings [338]. Searches for the processes $e^+e^- \to (H \to b\bar{b})\gamma$, $(H \to \gamma\gamma)q\bar{q}$, and $(H \to \gamma\gamma)\gamma$ have been used to set limits on such anomalous couplings [339]. These searches also contribute in the combinations of searches for the standard model Higgs boson, although the small predicted signal rates imply that they contribute less than other channels.

Searches with photonic final states are experimentally very appealing and they have been used to constrain fermiophobic Higgs models, in which the Higgs boson has SM-like properties except that its tree-level couplings to fermions are assumed to be absent or very small. Fermiophobic Higgs models are however quite challenging to construct; they are generally strongly fine-tuned and imply new strong dynamics at low energy scales. A Type-I fermiophobic 2HDM could predict an enhanced $h_f \to \gamma \gamma$ branching ratio, where h_f denotes a fermiophobic Higgs boson. The LEP searches are described in Ref. 340. In a preliminary combination of LEP data [341], a fermiophobic Higgs boson with mass less than 108.2 GeV (95%) C.L.) has been excluded. Fermiophobic models would also predict enhanced branching ratios for the decays $h_f \to W^*W$ and Z^*Z , a possibility that has been addressed by L3 [342] and ALEPH [343]. At hadron colliders, the process $gg \to h_f$ has a negligible rate in a fermiophobic Higgs model, but the Wh_f , Zh_f , and VBF production cross sections remain close to their SM predictions and the Higgs boson branching ratios to $\gamma\gamma$, W^+W^- , and ZZ are enhanced. A search for the SM Higgs boson at a hadron collider can not therefore be re-interpreted as a search in a fermiophobic model, even if a limit is set on the total production cross section times a specific decay branching ratio, due to the different kinematic distributions from the different production modes affecting the signal acceptance. CDF and DØ have re-optimized their $h_f \to \gamma \gamma$ searches for the fermiophobic model, and with results based on 9.7 fb⁻¹ of DØ data [344,345] and 10.0 fb^{-1} of CDF data [346,347], combined with $h_f \to W^+W^-$ and $h_f \to ZZ$ searches extend the exclusion in the fermiophobic Higgs model to 119 GeV [110,348]. Other

⁶ As discussed above, in the MSSM the Higgs can decay into pairs of lightest, stable neutralinos.

production of fermiophobic Higgs bosons, leading to a 3-photons final state, has also been searched for by DØ [349].

ATLAS and CMS search for a fermiophobic Higgs boson in $h_f \to \gamma \gamma$ searches optimized for the fermiophobic signature [350,351], and CMS combines these with searches for $h_f \to W^+W^-$ and $h_f \to ZZ$ assuming fermiophobic production and decay [10]. CMS excludes a fermiophobic Higgs boson in the range 110 GeV $< m_H < 188$ GeV at the 95% C.L.

Higgs bosons with double electric charge are predicted, for example, by models with additional triplet scalar fields or left-right symmetric models [352]. It has been emphasized that the see-saw mechanism could lead to doubly-charged Higgs bosons with masses which are accessible to current and fu-Searches were performed at LEP for the ture colliders [353]. pair-production process $e^+e^- \rightarrow H^{++}H^{--}$ with four prompt leptons in the final state [354-356]. Lower mass bounds between 95 GeV and 100 GeV were obtained for left-right symmetric models (the exact limits depend on the lepton flavors). Doubly-charged Higgs bosons were also searched for in single production [357]. Furthermore, such particles would modify the Bhabha scattering cross section and forward-backward asymmetry via t-channel exchange. The absence of a significant deviation from the SM prediction puts constraints on the Yukawa coupling of $H^{\pm\pm}$ to electrons for Higgs boson masses which reach into the TeV range [356,357].

Searches have also been carried out at the Tevatron for the pair production process $p\overline{p}\to H^{++}H^{--}$. The DØ search is performed in the $\mu^+\mu^+\mu^-\mu^-$ final state [358], while CDF also considers $e^+e^+e^-e^-$ and $e^+\mu^+e^-\mu^-$, and final states with τ leptons [359]. A search by CDF for a long-lived $H^{\pm\pm}$ boson, which would decay outside the detector, is described in [360].

CMS has searched for doubly-charged Higgs bosons which are either pair produced, $pp \to H^{++}H^{--}$ or produced in association with a singly-charged Higgs boson via s-channel W^{\pm} exchange, $pp \to H^{++}H^{-}$, assuming decays of the form $\ell^+\ell'^-$, where ℓ , ℓ' are combinations of e, μ , and τ leptons [361]. No significant excess is seen, and limits on the mass of the doubly-charged Higgs boson vary from 165 GeV to 457 GeV, depending on the production and decay mode. ATLAS has searched for doubly charged Higgs bosons in the dimuon decay [362], setting a limit on the mass of 355 GeV assuming a decay branching ratio to dimuons of 100% and coupling to left-handed fermions, and a limit on the mass of 251 GeV assuming coupling to right-handed fermions.

VI. Outlook

The Tevatron has completed its run and is finalizing its Higgs boson search results with up to 10 fb⁻¹ of data analyzed. The combination of the preliminary results from CDF and DØ's searches for the SM Higgs boson shows an excess of data events with respect to the background estimation in the mass range 115 GeV $< m_H < 135$ GeV, dominated by the $H \rightarrow b\bar{b}$ channels. The global significance for such an excess anywhere in the full mass range is 2.2 standard deviations.

In 2011, the LHC delivered approximately 5 fb⁻¹ of pp collision data at $\sqrt{s} = 7$ TeV. A variety of searches targeting the SM Higgs boson in the mass range 100 GeV $< m_H < 600$ GeV have been performed, excluding all masses except the range between 114 GeV and 129 GeV. Most of the region below 123 GeV is also excluded by the ATLAS experiment but not by other experiments. Within the allowed mass range, both ATLAS and CMS observe independent excesses of events consistent with a SM-like Higgs boson with a mass of $\approx 125 \text{ GeV}$, with global significances of 1.3σ and 2.1σ , respectively. Both experiments observe excesses of data over the corresponding background predictions in searches for Higgs bosons decaying into diphotons and Z bosons pairs. More data, at $\sqrt{s} = 8 \text{ TeV}$, being collected in 2012, are required to understand this excess. The LHC will either exclude the SM Higgs boson or confirm the existence of a SM-like Higgs particle. In the latter case, accurate measurements of the properties of the Higgs particle as well as searches for new particles will be of most relevance.

Searches at the LHC for additional Higgs bosons: charged Higgs bosons, doubly charged Higgs bosons, the neutral Higgs bosons of the MSSM, and other exotic Higgs particles, have yielded results consistent with background expectations and strong limits have been placed in significant regions of parameter space. An upgrade of the center of mass energy to 13–14 TeV is planned for the near future. This upgrade will allow the LHC to explore a wide variety of extended Higgs sectors and search for new particles expected in models beyond the SM. This upgrade will also allow for increased precision of measurements of the properties of a SM-like Higgs boson, if one exists.

A high-energy e^+e^- linear collider may be built in the future, allowing ultimate high-precision measurements of the properties of Higgs boson(s) and other particles beyond those of the SM. At a $\mu^+\mu^-$ collider, mass measurements with a precision of a few MeV would be possible, and energy scans may distinguish between signals of Higgs particles nearly degenerate in mass, as predicted in many extended Higgs models.

In the theoretical landscape, numerous models are available with novel approaches to the problem of electroweak symmetry breaking. In the next decade, the LHC's exploration of the multi-TeV energy scale will solidify our understanding of the mechanism of mass generation of the known elementary particles.

VII. Addendum

Updated July 12, 2012.

On July 4, 2012, the ATLAS and CMS collaborations simultaneously announced observation of a new particle produced in pp collision data at high energies [363–366]. The data samples used correspond to between 4.6 and 5.1 fb⁻¹ of collision data collected at $\sqrt{s}=7$ TeV in 2011, and between 5.3 and 5.9 fb⁻¹ of collisions collected at $\sqrt{s}=8$ TeV in 2012. The observed decay modes indicate that the new particle is a boson. The evidence is strong that the new particle decays to $\gamma\gamma$ and ZZ with rates consistent with those predicted for the Standard

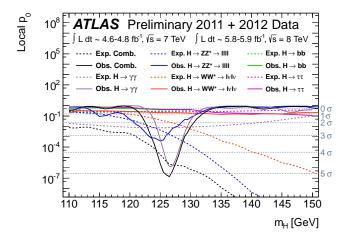
Model (SM) Higgs boson. There are indications that the new particle might also decay to W^+W^- , and decays to $b\bar{b}$ and $\tau^+\tau^-$ are being sought as well.

The ATLAS collaboration has updated its SM Higgs boson searches in the $H \to \gamma \gamma$ and $H \to ZZ \to \ell^+ \ell^- \ell'^+ \ell'^-$ [367] modes with new data collected at $\sqrt{s} = 8$ TeV and improved analysis techniques applied to both the 7 TeV and 8 TeV data. ATLAS has also finalized its $\sqrt{s} = 7$ TeV analyses in the $H \to ZZ \to \ell^+\ell^-\nu\bar{\nu}, H \to ZZ \to \ell^+\ell^-q\bar{q},$ $H \rightarrow W^+W^- \rightarrow \ell^+\nu_\ell\ell'^-\bar{\nu}_{\ell'}, \quad H \rightarrow W^+W^- \rightarrow \ell^+\nu_\ell q\bar{q'},$ $H \to \tau^+ \tau^-$, and $WH, ZH \to Wb\bar{b}, Zb\bar{b}$ channels [368], and includes them in its SM Higgs boson combined results [369,364]. ATLAS's $H \rightarrow \gamma \gamma$ search has been improved with respect to the previous version by separating events with two jets and two photons from other events, which improves the sensitivity for the vector boson fusion (VBF) process, and by improved photon identification and isolation algorithms. AT-LAS's $H \to ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ search has been improved with respect to the previous results by re-optimizing the kinematic cuts, improving electron reconstruction and identification efficiency at low p_T , and improved robustness to pileup events.

The CMS collaboration has updated its SM Higgs boson searches in the $H\to\gamma\gamma$, $H\to ZZ\to\ell^+\ell^-\ell^{\prime+}\ell^{\prime-}$, $H\to ZZ\to\ell^+\ell^-\nu\bar{\nu}$, $H\to W^+W^-\to\ell^+\nu_\ell\ell^{\prime-}\bar{\nu}_{\ell^\prime}$, $H\to b\bar{b}$, and $H\to\tau^+\tau^-$ channels, all of which include 8 TeV data collected in 2012 [370]. The $t\bar{t}H\to t\bar{t}b\bar{b}$ [370] search is new and based on 2011 data. The $H\to W^+W^-\to\ell^+\nu_\ell q\bar{q}'$ [370] search is included for the first time in the combination.

CMS's $H \rightarrow \gamma \gamma$ search has been improved with respect to its earlier version by dividing the diphoton plus two jet category into two, depending on the dijet invariant mass and the jet p_T , and also by removing jets from pileup collisions. The $H \to ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ search has been improved with respect to its previous version, benefiting from improved lepton identification and isolation algorithms, as well as final state radiation recovery. The discriminant variables used now to separate the expected signal from the backgrounds are twodimensional, plotting the invariant mass of the four leptons versus a matrix-element-based likelihood discriminant. CMS's $H \to W^+W^-$ search combines the results from the multivariate analysis (MVA) for the 7 TeV data with the results of a cutbased analysis on the 8 TeV data sample, which is described in Ref. 372. CMS's $VH \rightarrow Vb\bar{b}$ (with V=W or Z) search encompasses five channels: $WH \rightarrow e\nu b\bar{b}$, $WH \rightarrow \mu\nu b\bar{b}$ $ZH \rightarrow$ $e^+e^-b\bar{b}$, $ZH \to \mu^+\mu^-b\bar{b}$, and $ZH \to \nu\bar{\nu}b\bar{b}$. CMS's $H \to \tau^+\tau^$ search divides the candidate events by tau lepton decay type and subdivides the samples based on number of jets (0,1) or on VBF type. The 0 and 1 jet categories are also further subdivided according to low or high p_T of the τ .

Each experiment, ATLAS and CMS, separately combine their data to obtain independent results of their searches, computing the significance of the observation, measuring the production rates times the decay branching fractions for each



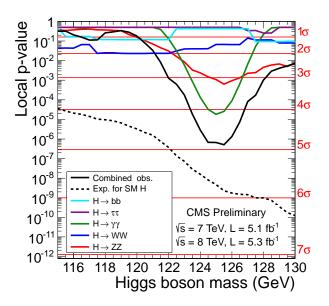


Figure 17: Local p-values for the ATLAS SM Higgs boson search (left), and the CMS SM Higgs boson search (right), separately for each decay mode. The solid lines show the observed p-values and the dashed lines show the median expected p-values, assuming a SM Higgs boson is present, computed at each value of m_H separately.

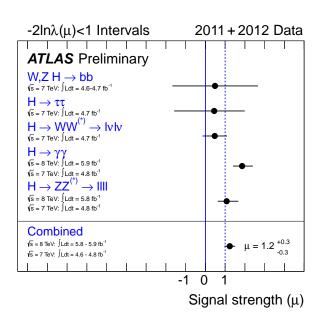
channel analyzed, and updating the mass and rate exclusions [364,366]. The separate results provide independent confirmations of the observation. The significance is quantified by a p-value, which is the probability to observe an upward fluctuation of the background which gives a result at least as signal-like as that observed in the data. A p-value of 2.87×10^{-7} corresponds to a five standard deviation excess over the background prediction. The p-values are shown for the analysis channels separately for ATLAS and CMS in Fig. 17. ATLAS observes an excess with a local significance of 5.0σ at a mass $m_H = 126.5$ GeV, with an expected significance of 4.6σ if a SM Higgs boson were present at such mass value. CMS observes

an excess with a local significance of 4.9σ at a mass $125.5~{\rm GeV}$, with an expected significance of 5.9σ , and measures the mass of the new boson as $m_H=125.3\pm0.6~{\rm GeV}$. Fig. 18 shows the best-fit cross sections times the relevant decay branching fractions for the new particle, normalized to the SM predictions for Higgs boson production and decay, assuming it has a mass of $126.5~{\rm GeV}$ (ATLAS), and $125~{\rm GeV}$ (CMS). ATLAS's combined signal strength fit, assuming SM ratios for the production and decay modes, is $\mu=\sigma/\sigma_{\rm SMH}=1.2\pm0.3$, and CMS's combined fit is $\mu=0.80\pm0.22$. Within the current experimental uncertainties, the measurements are consistent with SM predictions. Both ATLAS and CMS separately exclude SM Higgs bosons with masses outside a narrow range near the local excesses.

The Tevatron collaborations updated their Higgs boson search results on July 2, 2012 [373]. The D0 collaboration has updated its $VH \to Vb\bar{b}$ search results by improving the acceptance of the lepton selection, dividing the events into more categories based on the number an quality of b tags, and improving the MVA treatment [374]. Additional data and analysis improvements also improve the sensitivity of D0's $H \to W^+W^-$ searches by 5-10% with respect to the previous re-The CDF Higgs boson searches were updated with the full Run II data set and improved b-tagging for the Winter 2012 conferences [376]. CDF and D0 combine their results together, and, with the full suite of SM Higgs boson search analyses, see a broad excess in the range 115 GeV $< m_H < 135$ GeV, with a global signal significance of 2.5σ , and a maximum local significance of 3.0σ . Fig. 19 shows the measured cross sections times the relevant decay branching ratios normalized to those expected for a SM Higgs boson at mass $m_H = 125$ GeV for the combined CDF and D0 searches for $H \to W^+W^-, H \to \gamma\gamma$, and $VH \to Vb\bar{b}$ searches. The combined result, assuming SM ratios for the production and decay modes, is $\mu = 1.4 \pm 0.6$. In the dominant decay channel, $VH \to Vb\bar{b}$, the global significance is 2.9σ , with a maximum local significance of 3.2σ . Assuming the existence of a new particle, this provides the first strong indication for its decay into a fermion pair at a rate consistent with the SM prediction for a Higgs boson of such a mass.

In summary, a new particle has been observed at the LHC. Within the experimental uncertainties, it has characteristics consistent with those expected from the Higgs boson predicted by the Standard Model, with a mass near 125 GeV. Tevatron data also are consistent with the production and decay of a SM-like Higgs boson at this mass. However, the present experimental uncertainties still allow for a wide variety of new physics alternatives.

The LHC will continue to run until early 2013, and it is expected to deliver at least 15 fb⁻¹ more data to both ATLAS and CMS, at $\sqrt{s} = 8$ TeV. After this run, a shutdown will occur to improve the accelerator components to allow data taking at higher energies. The much larger dataset to be collected will provide the opportunity to make increasingly precise measurements of the properties of the new particle, and



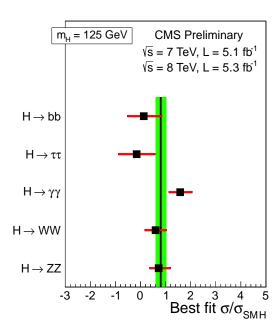


Figure 18: Best-fit production cross sections times branching ratios to $H \to \gamma\gamma$, $H \to ZZ$, $H \to W^+W^-$, $H \to b\bar{b}$, and $H \to \tau^+\tau^-$, normalized to the SM predictions for Higgs boson production and decay, assuming it has a mass of 126.5 GeV (ATLAS, left), and 125 GeV (CMS, right). The combined result, assuming SM ratios for the production and decay modes, is shown as a separate point on the ATLAS graph at $\mu = \sigma/\sigma_{\rm SMH} = 1.2 \pm 0.3$ and is shown with the shaded band on the CMS graph at $\mu = 0.80 \pm 0.22$.

test whether it is the SM Higgs boson or point the way to physics beyond the SM.

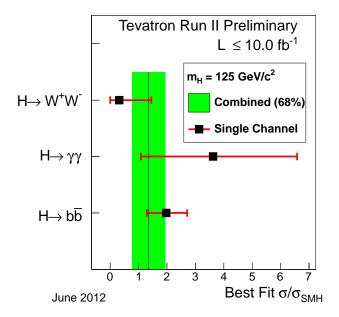


Figure 19: Best-fit cross sections times branching ratios to $H \to W^+W^-$, $H \to \gamma\gamma$ and $H \to b\bar{b}$, normalized to the SM predictions for Higgs boson production and decay, assuming it has a mass of 125 GeV, for the combined CDF and D0 search results. The combined result, assuming SM ratios for the production and decay modes, is shown with a shaded band, at $\mu = \sigma/\sigma_{\rm SMH} = 1.4 \pm 0.6$.

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Gauge & Higgs Boson Particle Listings

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Gauge & Higgs Boson Particle Listings

Higgs Bosons — H^0 and H^\pm

CMS-PAS-HIG-11-024, CMS-PAS-HIG-12-017, CMS-PAS-HIG-12-003, CMS-PAS-HIG-12-021, CMS-PAS-HIG-12-019, CMS-PAS-HIG-12-018, CMS-PAS-HIG-12-012, CMS-PAS-HIG-12-006, CMS-PAS-HIG-12-025 (2011, 2012).

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- Limits for $H^{\pm\pm}$ with $T_3=\pm 1$
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STANDARD MODEL H⁰ (Higgs Boson) MASS LIMITS

These limits apply to the Higgs boson of the three-generation Standard Model with the minimal Higgs sector. For a review and a bibliography, see the above review on "Higgs Bosons: Theory and Searches," where the latest unpublished results are also described.

Note: the addendum to the Higgs boson review describes the latest news reported in July 2012 on the discovery of a boson whose properties are consistent with the Standard Model Higgs boson.

H⁰ Direct Search Limits

All data that have been superseded by newer results are marked as "not used" or have been removed from this compilation, and are documented in previous editions of this Review of Particle Physics.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|----------------------------|----------|--------------------------|-------|------------|--------------------------------------------------------------|
| > 115.5 and no | ne 127 | -600 (CL = 95%) OU | R E | /ALUAT | TON |
| none | 95 | ¹ AAD | 12E | ATLS | $pp \rightarrow H^0 X$ |
| 112.9-115.5, | | | | | |
| 131-238, 251-466 | | | | | |
| none 127-600 | 95 | ² CHATRCHYA N | 12B | CMS | |
| none 162-166 | 95 | | 10F | TEVA | $p\overline{p} \rightarrow H^0 X, H^0 \rightarrow W W^{(*)}$ |
| >114.1 | 95 | ⁴ ABDALLAH | 04 | DLPH | |
| >112.7 | 95 | ⁴ ABBIENDI | 03в | OPAL | |
| >114.4 | 95 | ^{4,5} HEISTER | | LEP | |
| >111.5 | 95 | ^{4,6} HEISTER | | ALEP | |
| >112.0 | 95 | ⁴ ACHARD | 01c | | $e^+ e^- \rightarrow H^0 Z$ |
| • • • We do n | ot use t | the following data for | avera | iges, fits | s, limits, etc. • • • |
| | | ⁷ AAD | 12 | | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ$ |
| none 134-156, | 95 | ⁸ AAD | 12D | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ^{(*)}$ |
| 182-233, 256-265, | | | | | |
| 268-415 | | 0 | | | 0 0 (.) |
| none 145-206 | 95 | | | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow WW^{(*)}$ |
| none 113-115, 134.5-136 | 95 | ¹⁰ AAD | 12G | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow \gamma \gamma$ |
| 134.5-130 | | ¹¹ AALTONEN | 12 | CDF | $H^0 \rightarrow \gamma \gamma$ |
| | | ¹² CHATRCHYAN | 12c | CMS | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ$ |
| | | ¹³ CHATRCHYAN | 12D | CMS | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ^{(*)}$ |
| none 129-270 | 95 | ¹⁴ CHATRCHYAN | 12E | CMS | $pp \rightarrow H^0 X, H^0 \rightarrow W W^{(*)}$ |
| | | ¹⁵ CHATRCHYAN | 12F | CMS | $pp \rightarrow H^0 WX, H^0 ZX$ |
| none 128-132 | 95 | ¹⁶ CHATRCHYAN | 12G | CMS | $pp \rightarrow H^0 X, H^0 \rightarrow \gamma \gamma$ |
| none 134-158, 180-305, | 95 | ¹⁷ CHATRCHYAN | 12н | CMS | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ^{(*)}$ |
| 340-465 none 270-440 | 95 | ¹⁸ CHATRCHYAN | 1.21 | CMS | $pp \rightarrow H^0 X. H^0 \rightarrow ZZ$ |
| 2.0 .40 | | 4.0 | | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow W W$ |
| none 191-197, 199-200, | 95 | | | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow ZZ^{(*)}$ |
| 214-224 | | ²¹ AAD | 110 | ATLS | $pp \rightarrow H^0 X, H^0 \rightarrow \gamma \gamma$ |
| | | | | | |

```
11v ATLS pp \rightarrow H^0 X, H^0 \rightarrow ZZ
                                        ^{22} AAD
none 340-450
                                       23 <sub>AAD</sub>
                                                                     11W ATLS pp \rightarrow H^0 X
                                        <sup>24</sup> AALTONEN
                                                                                          \rho \overline{\rho} \rightarrow H^0 W X, H^0 Z X,
                                                                     11AA CDF

\begin{array}{ccc}
& H^0 & q \overline{q} & X \\
& P \overline{p} \rightarrow & H^0 & W & X, H^0 & Z & X \\
& P \overline{p} \rightarrow & H^0 & X, H^0 \rightarrow & W & W^{(*)}
\end{array}

                                        <sup>25</sup> ABAZOV
                                                                     11AB D0
                                        ^{26}\,\mathrm{ABAZOV}
                                                                     116 D0
                                        ^{27}\,\mathrm{ABAZOV}
                                                                                          p\overline{p} \rightarrow H^0 WX, H^0 \rightarrow b\overline{b}
                                                                     11J D0

\begin{array}{ccc}
\mu^0 \to & H^0 \times X, H^0 \to bb \\
H^0 \to & \gamma \gamma \\
pp \to & H^0 X, H^0 \to WW
\end{array}

                                        <sup>28</sup> ABAZOV
                                                                     11Y D0
                                        <sup>29</sup> CHATRCHYAN 11 J CMS
                                                                                          p\overline{p} \rightarrow H^0 Z X
                                        <sup>30</sup> AALTONEN
                                                                    10AD CDF
                                        <sup>31</sup> AALTONEN
                                                                                          p\overline{p} \rightarrow H^0 X, H^0 \rightarrow WW^{(*)}
                                                                     10g CDF
                                        32 AALTONEN
                                                                                          p\overline{p} \rightarrow H^0 ZX, H^0 WX
                                                                     10J CDF
                                                                                          <sup>33</sup> AALTONEN
                                                                    10M TEVA
                                        34 ABAZOV
                                                                     10B D0
                                        ^{35} ABAZOV
                                                                                          p\overline{p} \rightarrow H^0 Z X, H^0 W X
                                                                     10c D0
                                        ^{36}\,\mathrm{ABAZOV}
                                                                                          p\overline{p} \rightarrow H^0 Z X
                                                                     10T D0
                                                                                          p\overline{p} \rightarrow H^0X, H^0 \rightarrow WW^{(*)}
                                        <sup>37</sup> AALTONEN
                                                                     09A CDF
                                                                                          p\overline{p} \rightarrow H^0 W X
                                        <sup>38</sup> AALTONEN
                                                                     09AG CDF
                                        <sup>39</sup> AALTONEN
                                                                                          p\overline{p} \rightarrow H^0 W X
                                                                     09AL CDE
                                        <sup>40</sup> AALTONEN
                                                                                          p\overline{p} \rightarrow H^0 Z X
                                                                     09A0 CDF
                                        <sup>41</sup> AALTONEN
                                                                                          p\overline{p} \rightarrow H^0 WX, H^0 ZX
                                                                     09AS CDF
                                                                                          p\overline{p} \rightarrow H^0 W X
                                        ^{42}\,\mathrm{ABAZOV}
                                                                     09c D0

\begin{array}{ccc}
H^0 \to & \gamma \gamma \\
H^0 \to & \tau^+ \tau^-
\end{array}

                                        43 ABAZOV
                                                                     09Q D0
                                        44 ABAZOV
                                                                     09H D0
                                                                                          p\overline{p} \rightarrow H^0 Z X, H^0 W X
                                        45 AALTONEN
                                                                     08x CDF
                                                                                          p\overline{p} \rightarrow H^0 ZX, H^0 WX
                                        <sup>46</sup> ABAZOV
                                                                     0840 D0
                                                                                          p\overline{p} \rightarrow H^0 W X
                                        <sup>47</sup> ABAZOV
                                                                     08Y D0
                                        <sup>48</sup> ABAZOV
                                                                                          p\overline{p} \rightarrow H^0 Z X
                                                                     07x D0
                                        <sup>49</sup> ABAZOV
                                                                                          p\overline{p} \rightarrow H^0 X, H^0 \rightarrow W W^*
                                                                     06 D0
                                       ^{50}\,\mathrm{ABAZOV}
                                                                                         p\overline{p} \rightarrow H^0WX, H^0 \rightarrow WW^*
                                                                     060 D0
```

 $^{1}\,\mathrm{AAD}$ 12E combine data from AAD 11v, AAD 11AB, AAD 12, AAD 12D, AAD 12F. AAD 12G. The 99% CL exclusion range is 133-230 and 260-437 GeV. An excess of events over background with a local significance of 3.5 σ is observed at about $m_{H^0}=$ 126 GeV.

The GeV. 2 CHATRCHYAN 12B combine CHATRCHYAN 12E, CHATRCHYAN 12F, CHATRCHYAN 12G, CHATRCHYAN 12H, CHATRCHYAN 12I, CHATRCHYAN 12D, as well as a search in the decay mode $H^0 \to \tau \tau$. The 99% CL exclusion range is 129–525 GeV. An excess of events over background with a local significance of 3.1 σ is observed at about $m_{H^0}=$ 124 GeV.

 3 AALTONEN 10F combine searches for H^0 decaying to W^+W^- in $p\,\overline{p}$ collisions at $E_{\rm cm}$ $= 1.96 \text{ TeV with } 4.8 \text{ fb}^{-1} \text{ (CDF) and } 5.4 \text{ fb}^{-1} \text{ (DØ)}.$

4 Search for $e^+e^- \to H^0 Z$ at $E_{\rm cm} \le 209$ GeV in the final states $H^0 \to b\overline{b}$ with $Z \to \ell \ell$, $\nu \overline{\nu}$, $q\overline{q}$, $\tau^+\tau^-$ and $H^0 \to \tau^+\tau^-$ with $Z \to q\overline{q}$.

Combination of the results of all LEP experiments.

 6 A 3σ excess of candidate events compatible with m_{H^0} near 114 GeV is observed in the combined channels $q \overline{q} q \overline{q}$, $q \overline{q} \ell \overline{\ell}$, $q \overline{q} \tau^+ \tau$

⁷ AAD 12 search for H^0 production with $H \to ZZ \to \ell^+\ell^-q\overline{q}$ in 1.04 fb⁻¹ of pp collisions at $E_{\rm cm}=7$ TeV. A limit on cross section times branching ratio which is (1.7–13) times larger than the expected Standard Model cross section is given for m_{H^0} = 200-600 GeV at 95% CL. The best limit is at $m_{H^0} = 360$ GeV.

⁸ AAD 12D search for H^0 production with $H \to ZZ^{(*)} \to 4\ell$ in 4.8 fb⁻¹ of pp collisions and 12D search for H^0 production with $H \to Z Z^0 \cap A \ell$ in 4.8 ID $^-$ of pp collisions at $E_{\rm cm} = 7$ TeV in the mass range $m_{H^0} = 110$ -600 GeV. An excess of events over background with a local significance of 2.1 σ is observed at 125 GeV. AAD 12F search for H^0 production with $H \to WW^{(*)} \to \ell^+ \nu \ell^- \overline{\nu}$ in 2.05 fb⁻¹ of pp collisions at $E_{\rm cm} = 7$ TeV in the mass range $m_{H^0} = 110$ -300 GeV.

10 AAD 12g search for H^0 production with $H \rightarrow \gamma \gamma$ in 4.9 fb⁻¹ of pp collisions at $E_{\rm Cm}$ = 7 TeV in the mass range $m_{H^0} = 110$ –150 GeV. An excess of events over background with a local significance of 2.8 σ is observed at 126.5 GeV.

11 AALTONEN 12 search for $H^0 \rightarrow \gamma \gamma$ in 7.0 fb⁻¹ of $p\overline{p}$ collisions at $E_{\rm cm} = 1.96$ TeV. A limit on cross section times branching ratio which is (8.5–29) times larger than the expected Standard Model cross section is given for $m_{H^0} = 100$ –150 GeV at 95% CL.

¹²CHATRCHYAN 12C search for H^0 production with $H \to ZZ \to \ell^+\ell^-\tau^+\tau^-$ in 4.7 fb $^{-1}$ of pp collisions at $E_{\rm cm}=$ 7 TeV. A limit on cross section times branching ratio which is (4–12) times larger than the expected Standard Model cross section is given for $m_{H^0}=190$ –600 GeV at 95% CL. The best limit is at $m_{H^0}=200$ GeV.

¹³ CHATRCHYAN 12D search for H^0 production with $H \to ZZ^{(*)} \to \ell^+\ell^-q\overline{q}$ in 4.6 fb⁻¹ of pp collisions at $E_{\rm cm}=7$ TeV. A limit on cross section times branching ratio which corresponds to (1–22) times the expected Standard Model cross section is given for $m_{H^0}=130$ –164 GeV, 200–600 GeV at 95% CL. The best limit is at $m_{H^0}=230$ GeV. In the Standard Model with an additional generation of heavy quarks and leptons which receive their masses via the Higgs mechanism, m_{H^0} values in the ranges m_{H^0}

154–161 GeV and 200–470 GeV are excluded at 95% CL. 14 CHATRCHYAN 12E search for H^0 production with $H \to WW^{(*)} \to \ell^+ \nu \ell^- \overline{\nu}$ in 4.6 fb $^{-1}$ of pp collisions at $E_{\rm cm}=$ 7 TeV in the mass range $m_{H^0}=$ 110–600 GeV.

 15 CHATRCHYAN 12F search for associated H^0 W and H^0 Z production followed by W – CHAIRCH TAIL IZE SEALCH TO ASSOCIATE OF WARM 1.2 PRODUCT A $\ell^+ \ell^-$, ν^- , and $H^0 \rightarrow b \bar{b}$, in 4.7 for $^-$ of pp collisions at $E_{\rm cm} = 7$ TeV. A limit on cross section times branching ratio which is (3.1–9.0) times larger than the expected Standard Model cross section is given for $m_{H^0} = 110$ –135 GeV at 95% CL. The best limit is at $m_{\mbox{$H^0$}}=110$ GeV.

 16 CHATRCHYAN 12G search for H^0 production with $H o \gamma\gamma$ in 4.8 fb $^{-1}$ of pp collisions at $E_{\rm cm}=7$ TeV in the mass range $m_{H^0}=110$ –150 GeV. An excess of events over background with a local significance of 3.1 σ is observed at 124 GeV.

- 17 CHATRCHYAN 12 H search for H^0 production with $H\to ZZ(*)\to 4\ell$ in 4.7 fb $^{-1}$ of pp collisions at $E_{\rm CM}=7$ TeV in the mass range $m_{H^0}=110$ –600 GeV. Excesses of events over background are observed around 11 9, 12 6 and 32 0 GeV. The region $m_{H^0}=114.4$ –134 GeV remains consistent with the expectation for the production of a SM-like \cdots
- 18 CHATRCHYAN 2012I search for H^0 production with $H \to ZZ \to \ell^+\ell^- \nu \overline{\nu}$ in 4.6 fb $^{-1}$ of pp collisions at $E_{
 m cm}=$ 7 TeV in the mass range $m_{H^0}=$ 250–600 GeV.
- 19 AAD 11AB search for 40 production with 4 4 4 4 4 4 4 7 in 1.04 fb $^{-1}$ of 4 4 pcollisions at 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
- = 240-600 GeV at 95% CL. The best limit is at m_{H^0} = 400 GeV. 20 AAD 11T search for H^0 production with $H \rightarrow Z Z^{(*)} \rightarrow 4\ell$ in 2.1 fb⁻¹ of pp collisions AAD IT! Search for n production with $n \to 22$ ~ 3 ~ 3 GeV at 95% CL. Superseded by AAD 12D.
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- at 95% C.L. Superseded by AAD 126. 22 AAD 11v search for H^0 production with $H \to ZZ \to \ell^+\ell^-\nu\overline{\nu}$ in 1.04 fb⁻¹ of pp collisions at $E_{\rm cm}=7$ TeV. A limit on cross section times branching ratio which corresponds to (0.6–6) times the expected Standard Model cross section is given for $m_{H^0}=200$ –600 GeV at 95% CL.
- $m_{H^0} = 200$ -000 dev at 37.8 c.t. 23 AAD 11W search for Higgs boson production in the decay channels $\gamma\gamma$, $ZZ^{(*)} \rightarrow 4\ell$, $ZZ \rightarrow \ell\ell\nu\nu$, $ZZ \rightarrow \ell\ell\mu\nu$, $ZZ \rightarrow \ell\ell\mu\nu$, $ZZ \rightarrow \ell\ell\mu\nu$, $ZZ \rightarrow \ell\ell\nu$, at $ZZ \rightarrow \ell\ell\nu\nu$, $ZZ \rightarrow \ell\nu\nu$, 110-600 GeV at 95% CL. In the Standard Model with an additional generation of heavy quarks and leptons which receive their masses via the Higgs mechanism, m_{H^0} values between 140 and 185 GeV are excluded at 95% CL. The results for the Standard Model Higgs are superseded by AAD 12E.
- ²⁴ AALTONEN 11AA search in 4.0 fb⁻¹ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV for associated H^0 W and H^0 Z production followed by $W/Z \to q \, \overline{q}$, and for $p \, \overline{p} \to H^0 \, q \, \overline{q} \, X$ (vector boson fusion), both with $H^0\to b\overline{b}$. A limit on cross section times branching ratio which is (9–100) times larger than the expected Standard Model cross section is given for $m_{H^0}=100\dot{-}150$ GeV at 95% CL. The best limit is at $m_{H^0}=115$ GeV.
- 25 ABAZOV 11AB search for associated H^0W and H^0Z production followed by $H^0 \rightarrow$ ABACOV ITAB search for associated m and $m \geq p$ consists which is like-sign dilepton final states using 5.3 fb $^{-1}$ of $p\bar{p}$ collisions at $E_{\rm cm}=1.96\,{\rm TeV}$. A limit on cross section times branching ratio which is (6.4–18) times larger than the expected Standard Model cross section is given for $m_{H^0}=115$ –200 GeV at 95% CL. The best limit is for $m_{H^0}=135$ and 165 GeV.
- 26 ABAZOV 11G search for H^0 production in 5.4 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0\to WW^{(*)}\to \ell\nu q\overline{q'}$ (and processes with similar final states). A limit on cross section times branching ratio which is (3.9–37) times larger than the expected Standard Model cross section is given for $m_{H^0}=115$ –200 GeV at 95% CL. The best limit is at $m_{H^0}=160$ GeV.
- The Dest limit is at $m_{H^0}=100$ GeV. 27 ABAZOV 11J search for associated H^0 W production in 5.3 fb $^{-1}$ of $p\bar{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the final state $H^0\to b\bar{b}$, $W\to\ell\nu$. A limit on cross section times branching ratio which is (2.7-30) times larger than the expected Standard Model cross section is given for $m_{H^0}=100\text{-}150$ GeV at 95% C.L. The limit at $m_{H^0}=115$ GeV is 4.5 times larger than the expected Standard Model cross section. 28 ABAZOV 11Y search for $H^0\to\gamma\gamma$ in 8.2 fb $^{-1}$ of $p\bar{p}$ collisions at $E_{\rm cm}=1.96$ TeV. A limit on cross section times branching ratio which is (10-25) times larger than the expected Standard Model cross section is given for $m_{H^0}=100\text{-}150$ GeV at 95% C.L. 29 CHATECHYAN 111 search for H^0 production with $H^0=M^{\prime\prime}$ $W^{\prime\prime}=0.00$ for $W^{\prime\prime}=0.00$.
- 29 CHATRCHYAN 11J search for H^0 production with $\stackrel{\cdots}{H} \to W^+ W^- \to \ell\ell\nu\nu$ in 36 pb $^{-1}$ of pp collisions at $E_{\rm cm}=7$ TeV. See their Fig. 6 for a limit on cross section times branching ratio for $m_{pl0}=120$ –600 GeV at 95% CL. In the Standard Model with an additional generation of heavy quarks and leptons which receive their masses via the Higgs mechanism, m_{H0} values between 144 and 207 GeV are excluded at 95% CL.
- Alt ONEN 10AD search for associated H^0Z production in 4.1 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode H^0Z production in 4.1 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0 \to b\overline{b}, Z \to \ell^+\ell^-$. A limit $\sigma \cdot {\rm B}(H^0 \to b\overline{b}) < (4.5-43) \sigma \cdot {\rm B}({\rm S}({\rm M}))$ (95% CL) is given for $m_{H^0}=100-150$ GeV. The limit for $m_{H^0}=115$ GeV is 5.9 times larger than the expected Standard Model cross section. 31 AALTONEN 10G search for H^0 production in 4.8 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0 \to WW^{(*)}$. A limit on $\sigma(H^0)$ which is (1.3-39) times larger than the expected Standard Model cross section is given for $m_{H^0}=110-200$ GeV at 95% CL. The best limit is obtained for $m_{H^0}=165$ GeV.
- at 95% CL. The best limit is obtained for $m_{H^0}=$ 165 GeV.
- 32 AALTONEN 10J search for associated H^0 W and H^0 Z production in 2.1 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the final state with (b) jets and missing p_T . A limit $\sigma<(5.8\text{--}50)\,\sigma_{\rm SM}$ (95% CL) is given for $m_{H^0}=110\text{--}150$ GeV. The limit for $m_{H^0}=115$ GeV is 6.9 times larger than the expected Standard Model cross section.
- ³³AALTONEN 10M combine searches for H^0 decaying to W^+W^- in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV with 4.8 fb $^{-1}$ (CDF) and 5.4 fb $^{-1}$ (DØ) and derive limits $\sigma(p\overline{p}\to H^0)$ ${\sf B}(H^0 o W^+W^-) < (1.75-0.38)$ pb for $m_H=120$ -165 GeV, where H^0 is produced in gg fusion. In the Standard Model with an additional generation of heavy quarks, $m_{H^0}^{33}$ between 131 and 204 GeV is excluded at 95% CL.
- 34 ABAZOV 10B search for H^0 production in 5.4 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0 \to WW^{(*)}$. A limit on $\sigma(H^0)$ which is (1.6–21) times larger than the expected Standard Model cross section is given for $m_{H^0}=115$ –200 GeV at 95% CL. The best limit is obtained for $m_{H^0}=1$ 65 GeV.
- 35 ABAZOV 10c search for associated H^0Z and H^0W production in 5.2 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the final states $H^0\to b\overline{b}$, $Z\to \nu\overline{\nu}$, and $W\to (\ell)\nu$, where ℓ is not identified. A limit $\sigma \cdot B(H^0 \to b \, \overline{b}) < (3.4-38) \, \sigma \cdot B_{(SM)}$ (95% CL) is given for $m_{H^0}=100$ –150 GeV. The limit for $m_{H^0}=115$ GeV is 3.7 times larger than the expected Standard Model cross section.

- 36 ABAZOV $^{10 au}$ search for associated 40 Z production in 4.2 fb $^{-1}$ of 7 collisions at 2 cm = 1.96 TeV in the decay mode $H^0 \to b\overline{b}$, $Z \to \ell^+ \ell^-$. A limit $\sigma \cdot \mathrm{B}(H^0 \to b\overline{b}) \in (3.0\text{-}49)$ $\sigma \cdot \mathrm{B}_{(\mathrm{SM})}$ (95% CL) is given for $m_{H^0} = 100\text{-}150$ GeV. The limit for $m_{H^0} = 100\text{-}150$ GeV.
- 1.5 GeV is 5 (SM) (95% CL) is given for $m_{H^0} = 100$ –100 GeV. The limit for $m_{H^0} = 115$ GeV is 5 (SM) (95% CL) is given for $m_{H^0} = 100$ –100 GeV. The limit for $m_{H^0} = 10$ TeV in the decay mode $H^0 \rightarrow WW^{(*)} \rightarrow \ell^+\ell^-\nu \overline{\nu}$. A limit on $\sigma(H^0) \rightarrow B(H^0 \rightarrow WW^{(*)})$ between 0.7 and 2.5 pb (95% CL) is given for $m_{H^0} = 110$ –200 GeV, which is 1.7–45 times larger than the expected Standard Model cross section. The best limit is obtained for $m_{H^0} = 160$ GeV.
- ³⁸ AALTONEN 09AG search for associated H^0 W production in 1.9 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV in the decay mode $H^0\to b\overline{b}, W\to \ell\nu$. A limit on $\sigma(H^0W)$ ${\rm B}(H^0\to b\overline{b})$ (95% CL) is given for $m_{H^0}=110$ -150 GeV, which is 7.5-101.9 times $(H^0 \to b \bar{b})$ (95% CL) is given for $m_{H^0} = 110$ –150 GeV, which is 7.5–101.9 times larger than the expected Standard Model cross section. The limit for $m_{H^0} = 115$ GeV is 9.0 times larger than the expected Standard Model cross section. Superseded by AALTONEN 09AL
- 39 AALTONEN 09AI search for associated H^0 W production in 2.7 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\text{CM}}=1.96$ TeV in the decay mode $H^0\to b\overline{b}, W\to \ell\nu$. A limit on $\sigma(H^0W)$ $B(H^0^{0}\to b\overline{b})$ (95% CL) is given for $m_{H^0}=100$ –150 GeV, which is 3.3–75.5 times larger than the expected Standard Model cross section. The limit for $m_{H^0}=115\,$ GeV
- larger than the expected Standard Model cross section. The limit for $m_{H^0}=115$ GeV is 5.6 times larger than the expected Standard Model cross section. 40 AALTONEN 09Ao search for associated H^0 Z production in 2.7 fb⁻¹ of $p\overline{p}$ collisions at $E_{\rm Cm}=1.96$ TeV in the decay mode $H^0\to b\overline{b}$, $Z\to \ell^+\ell^-$. A limit on $\sigma(H^0Z)$. B($H^0\to b\overline{b}$) (95% CL) is given for $m_{H^0}=100$ –150 GeV, which is 7.0–71.3 times larger than the expected Standard Model cross section. The limit for $m_{H^0}=115$ GeV is 8.2 times larger than the expected Standard Model cross section. Superseded by AALTONEN 10.9p. AALTONEN 10AD.
- 41 AALTONEN 09AS search for associated H^0W and H^0Z production in 2.0 fb⁻¹ of $p\overline{p}$
- = 1.96 TeV in the decay mode $H^0 o b\overline{b}$, $W o \ell \nu$. A limit $\sigma(H^0 W) \cdot \mathsf{B}(H^0 W)$
- = 1.96 leV in the decay mode $H^0 \rightarrow DB$, $W \rightarrow \ell \nu$. A limit $\sigma(H^0W)$ · B($H^0 \rightarrow BB$) < (2.1-0.95) pb (95% CL) is given for $m_{H^0} = 100-150$ GeV, which is 9.1-84 times larger than the expected Standard Model cross section. Superseded by ABAZOV 11.
 43 ABAZOV 09Q search for $H^0 \rightarrow \gamma \gamma$ in 2.7 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm} = 1.96$ TeV in the mass range $m_{H^0} = 100-150$ GeV. A limit (95% CL) is given for $m_{H^0} = 115-130$ GeV, which is about 20 times larger than the expected Standard Model cross section. Superseded by ABAZOV 11v Superseded by ABAZOV 11v. 44 ABAZOV 09u search for $H^0 \to \tau^+ \tau^-$ with $\tau \to$ hadrons in 1 fb⁻¹ of $p\overline{p}$ collisions at
- $E_{
 m cm}=1.96$ TeV. The production mechanisms include associated $W/Z+H^0$ production, weak boson fusion, and gluon fusion. A limit (95% CL) is given for $m_{H^0}=105-145$ GeV, which is 20-82 times larger than the expected Standard Model cross section. The limit for $m_{H^0}=115$ GeV is 29 times larger than the expected Standard Model cross
- 45 AALTONEN 08x search for associated H^0Z and H^0W production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0_{-}\to b\overline{b}$, $Z\to \nu\overline{\nu}$ and $W\to (\ell)\nu$, where ℓ is not detected. A limit $\sigma \cdot \mathsf{B}(H^0 \to b \, \overline{b}) < (4.7-3.3) \; \mathsf{pb} \; (95\% \; \mathsf{CL})$ is given for m_{H^0} = 110-140 GeV, which is 18-66 times larger than the expected Standard Model cross
- 47 ABAZOV 08y search for associated H^0 W production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the decay mode $H^0 \rightarrow b\overline{b}$, $W \rightarrow \ell \nu$. A limit $\sigma(H^0W) \cdot B(H^0 \rightarrow b\overline{b}) < (1.9-1.6)$ by (95% CL) is given for $m_{H^0} = 105-145$ GeV, which is 10-93 times larger than the expected Standard Model cross section. These results are combined with ABAZOV 06, ABAZOV 060, ABAZOV 060, and ABAZOV 07x to give cross section limits for m_{H^0}
- = 100–200 GeV which are 6–24 times larger than the Standard Model expectation. ⁴⁸ ABAZOV 07x search for associated H^0Z production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the final state $Z\to e^+e^-$ or $\mu^+\mu^-$; $H^0\to b\overline{b}$. A limit $\sigma(ZH^0)\to B(H^0\to b\overline{b})$ < (4.4–3.1) pb (95%CL) is given for $m_{H^0}=105$ –145 GeV, which is more than 40 times larger than the expected Standard Model cross section. Superseded by ABAZOV 10T.
- 49 ABAZOV 06 search for Higgs boson production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay chain $H^0\to WW^*\to \ell^\pm\nu\ell^{\prime\mp}\overline{\nu}$. A limit $\sigma(H^0)$ -B($H^0\to WW^*$) < (5.6–3.2) pb (95 %CL) is given for $m_{H^0}=$ 120–200 GeV, which far exceeds the expected
- Standard Model cross section. Standard Model cross section associated H^0W production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H^0 \to WW^*$, in the final states $\ell^\pm \ell'^\mp \nu \nu' X$ where $\ell = e$, μ . A limit $\sigma(H^0W)\cdot \mathsf{B}(H^0\to WW^*)<(3.2-2.8)\ \mathsf{pb}\ (95\ \%\mathsf{CL})\ \mathsf{is}\ \mathsf{given}\ \mathsf{for}\ m_{H^0}=$ 115-175 GeV, which far exceeds the expected Standard Model cross section.

H⁰ Indirect Mass Limits from Electroweak Analysis

For limits obtained before the direct measurement of the top quark mass, see the 1996 (Physical Review **D54** 1 (1996)) Edition of this Review. Other studies based on data available prior to 1996 can be found in the 1998 Edition (The European Physical Journal C3 1 (1998)) of this Review. For indirect limits obtained from other considerations of theoretical nature, see the Note on "Searches for Higgs Bosons."

| VALUE (GeV) | DO CUMENT ID | | TECN | |
|-------------------------|----------------------------|-----------|------------------|---|
| $91 + 31 \\ -24$ | ⁵¹ ERLER | 10A | RVUE | |
| • • • We do not use the | following data for average | es, fits, | limits, etc. • • | • |
| $80 + 30 \\ -23$ | ⁵² FLACHER | 09 | RVUE | |

⁵³ LEP-SLC

 $129 + 74 \\ -49$

- 51 ERLER 10A makes Standard Model fits to Z and neutral current parameters, $m_{\,t},\,m_{\,W}$ measurements available in 2009 (using also preliminary data). The quoted result is obtained from a fit that does not include the limits from the direct Higgs searches. With direct search data from LEP2 and Tevatron added to the fit, the 90% CL (99% CL) interval is 115–148 (114–197) GeV.
- ⁵² FLACHER 09 make Standard Model fits to Z and neutral current parameters, m_1 , m_{W} , and r_{W} measurements available in 2008 (using also preliminary data). The 2σ (3σ) interval is 39–155 (26–209) GeV. The quoted results are obtained from a fit that does not include the limit from the direct Higgs searches. Standard Model fits to Z parameters from LEP/SLC and m_t , m_W ,
- and Γ_W measurements available in 2005 with $\Delta\alpha_{\rm had}^{(5)}(m_Z)=0.02758\pm0.00035$. The 95% CL limit is 285 GeV.

MASS LIMITS FOR NEUTRAL HIGGS BOSONS IN SUPERSYMMETRIC MODELS

The minimal supersymmetric model has two complex doublets of Higgs bosons. The resulting physical states are two scalars $[H_1^0]$ and H_2^0 , where we define $m_{H_1^0} < m_{H_2^0}^1$, a pseudoscalar (A^0) , and a charged Higgs pair

 (H^{\pm}) . H_1^0 and H_2^0 are also called h and H in the literature. There are two free parameters in the theory which can be chosen to be $m_{\Delta0}$ and aneta= v_2/v_1 , the ratio of vacuum expectation values of the two Higgs doublets. Tree-level Higgs masses are constrained by the model to be $m_{H^0_*} \leq$

 m_Z , $m_{H_0^0} \geq m_Z$, $m_{A^0} \geq m_{H_1^0}$, and $m_{H^{\pm}} \geq m_W$. However, as described in the review on "Searches for Higgs Bosons" in this Volume these relations are violated by radiative corrections.

Unless otherwise noted, the experiments in e^+e^- collisions search for the processes $e^+e^- \to H_1^0Z^0$ in the channels used for the Standard Model Higgs searches and $e^+e^- \to H_1^0A^0$ in the final states $b\overline{b}b\overline{b}$ and $b \, \overline{b} \, \tau^+ \, \tau^-$. In $p \, \overline{p}$ collisions the experiments search for a variety of processes, as explicitly specified for each entry. Limits on the $A^{\,0}$ mass arise from these direct searches, as well as from the relations valid in the minimal supersymmetric model between m_{A^0} and $m_{H^0_1}$. As discussed in

the review on "Searches for Higgs Bosons" in this Volume, these relations depend, via potentially large radiative corrections, on the mass of the t quark and on the supersymmetric parameters, in particular those of the stop sector. The limits are weaker for larger t and \widetilde{t} masses. To include the radiative corrections to the Higgs masses, unless otherwise stated, the listed papers use theoretical predictions incorporating two-loop corrections and examine the two scenarios of no scalar top mixing and the $m_{\scriptscriptstyle L}^{\sf max}$ benchmark scenario (which gives rise to the most conservative upper bound on the mass of H_1^0 for given values of m_{A^0} and aneta), see CARENA 99B

Limits in the low-mass region of H_1^0 , as well as other by now obsolete limits from different techniques, have been removed from this compilation, and can be found in earlier editions of this Review. Unless otherwise stated, the following results assume no invisible H_1^0 or A^0 decays.

H_1^0 (Higgs Boson) MASS LIMITS in Supersymmetric Models

| VALUE (GeV) | CL% | | DOCUMENT ID | | TECN | COMMENT |
|-----------------|--------|-------|-------------|--------|--------------|----------------------------------------------------------|
| >89.7 | | | ABDALLAH | 08в | DLPH | $E_{\rm cm} \leq 209 \; { m GeV}$ |
| >92.8 | 95 | 55 | SCHAEL | 06в | LEP | $E_{\rm cm} \le 209 \; {\rm GeV}$ |
| >84.5 | 95 | 56,57 | ABBIENDI | 04м | OPAL | $E_{\rm cm} \leq 209 \; {\rm GeV}$ |
| >86.0 | 95 | | ACHARD | 02н | L3 | $E_{ m Cm} \leq$ 209 GeV, $	an\!eta>0.4$ |
| • • • We do not | use th | | | erages | s, fits, lii | |
| | | 59 | ABAZOV | 12 | D0 | $\rho \overline{\rho} \rightarrow H_{1,2}^0/A^0 + X,$ |
| | | | | | | $H_{1,2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| | | 60 | AAD | 11R | ATLS | $pp \to H_{1,2}^0/A^0 + X,$ |
| | | | | | | $H_{1.2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| | | 61 | ABAZOV | 11ĸ | D0 | $p\overline{p} \to H_{1,2}^0/A^0 + b + X, \blacksquare$ |
| | | | ABAZOV | IIK | Du | 1,2 |
| | | | | | | $H_{1,2}^0/A^0 \rightarrow b \overline{b}$ |
| | | 02 | ABAZOV | 11w | D0 | $p\overline{p} \to H_{1,2}^0/A^0 + b + X$, |
| | | | | | | $H_{1,2}^0/A^0 \to \tau^+\tau^-$ |
| | | 63 | CHATRCHYAN | 11н | CMS | $pp \to H_{1,2}^0/A^0 + X,$ |
| | | | | | | $H_{1,2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| | | 64 | ABAZOV | 10D | D0 | $p\overline{p} \to H_{1,2}^0/A^0 + b + X$, |
| | | | | 100 | | |
| | | 65 | | | | $H_{1,2}^0/A^0 \to \tau^+\tau^-$ |
| | | 03 | AALTONEN | 09AR | CDF | $\rho \overline{\rho} \rightarrow H_{1,2}^0/A^0 + X,$ |
| | | | | | | $H_{1,2}^0/A^0 \to \tau^+ \tau^-$ |
| | | 66 | ABAZOV | 09F | D0 | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + b + X$, |
| | | | | | | $H_{1,2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| | | 67 | ABAZOV | 08AJ | D0 | $\rho \overline{\rho} \to H_{1,2}^0/A^0 + b + X,$ |
| | | | ADAZOV | OOMS | Do | |
| | | | | | | $H_{1,2}^0/A^{0} \rightarrow b\overline{b}$ |
| | | 00 | ABAZOV | 08W | D0 | $\rho \overline{\rho} \rightarrow H_{1,2}^0/A^0 + X$, |
| | | | | | | $H_{1,2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| >89.7 | 95 | 56,69 | ABDALLAH | 04 | DLPH | $E_{\rm cm} \le 209$ GeV, $\tan \beta > 0.4$ |
| | | 70 | ABBIENDI | 03G | OPAL | $H_1^0 \rightarrow A^0 A^0$ |
| >89.8 | 95 | 56,71 | HEISTER | 02 | ALEP | $E_{\rm cm}^{\rm T} \le 209$ GeV, $\tan \beta > 0.5$ |
| | | | | | | |

- ⁵⁴ ABDALLAH 08B give limits in eight CP-conserving benchmark scenarios and some CPviolating scenarios. See paper for excluded regions for each scenario. Supersedes AB-DALLAH 04.
- 55 SCHAEL 06B make a combined analysis of the LEP data. The quoted limit is for the $m_h^{\rm max}$ scenario with $m_t=174.3$ GeV. In the *CP*-violating CPX scenario no lower bound on $m_{H_1^0}$ can be set at 95% CL. See paper for excluded regions in various scenarios. See Figs. 2-6 and Tabs. 14–21 for limits on $\sigma(ZH^0)$ · B $(H^0 \to b\overline{b}, \tau^+\tau^-)$ and $\sigma(H^0_1H^0_2)$ ·

 $\mathsf{B}(H_1^0, H_2^0 \to b \, \overline{b}, \tau^+ \, \tau^-).$

- ⁵⁶ Search for $e^+e^- \to H_1^0 A^0$ in the final states $b\overline{b}b\overline{b}$ and $b\overline{b}\tau^+\tau^-$, and $e^+e^- \to$ $H_1^0\,Z.$ Universal scalar mass of 1 TeV, SU(2) gaugino mass of 200 GeV, and $\mu=-200$ GeV are assumed, and two-loop radiative corrections incorporated. The limits hold for $m_t{=}175$ GeV, and for the $m_h^{\rm max}$ scenario.
- 57 ABBIENDI 04M exclude 0.7 < tan/8 < 1.9, assuming $m_t=174.3$ GeV. Limits for other MSSM benchmark scenarios, as well as for CP violating cases, are also given. 58 ACHARD 02H also search for the final state $H_1^0Z \rightarrow 2A^0\,q\,\overline{q},\,A^0 \rightarrow q\,\overline{q}$. In addition, the MSSM parameter set in the "large- μ " and "no-mixing" scenarios are examined. 59 ABAZOV 12 search for production of a Higgs boson followed by the decay $H_{1,2}^0/A^0 \rightarrow$
- $\tau^+\tau^-$ in 5.4 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. See their Fig. 2 for the limit on cross section times branching ratio and Fig. 3 for the excluded region in the MSSM parameter space.
- 60 AAD 11R search for production of a Higgs boson followed by the decay $H_{1.2}^0/A^0
 ightarrow$ $au^+ au^-$ in 36 pb $^{-1}$ of pp collisions at $E_{
 m cm}=$ 7 TeV. See their Fig. 3 for the limit on cross section times branching ratio and for the excluded region in the MSSM parameter
- 61 ABAZOV 11K search for associated production of a Higgs boson and a b quark, followed by the decay $H^0_{1,2}/A^0 \to b\,\overline{b}$, in 5.2 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV. See their Fig. 5/Table 2 for the limit on cross section times branching ratio and Fig. 6 for the excluded region in the MSSM parameter space for $\mu=-200$ GeV.
- 62 ABAZOV 11w search for associated production of a Higgs boson and a *b* quark, followed by the decay $H_{1.2}^0/A^0 \to \tau \tau$, in 7.3 fb $^{-1}$ of $p \overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. See their Fig. 2 for the limit on cross section times branching ratio and for the excluded region in the MSSM parameter space.
- G3 CHATRCHYAN 11H search for production of a Higgs boson followed by the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ in 36 pb $^{-1}$ of pp collisions at $E_{\rm cm}=7$ TeV. See their Fig. 2 the limit on cross section times branching ratio and Fig. 3 for the excluded region in the MSSM parameter space.
- 64 ABAZOV 10D search for associated production of a Higgs boson and a b quark in 2.7 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV, with the decay $H_{1,2}^0/A^0 \to \ \tau^+\,\tau^-$. See their Fig. 1 for the limit on $\sigma \cdot \mathrm{B}(H_{1,2}^0/A^0 \to \tau^+\tau^-)$ (for different Higgs masses) and for the excluded region in the MSSM parameter space for $\mu=-200$ GeV. Superseded
- 65 AALTONEN 09AR search for Higgs bosons decaying to $au^+ au^-$ in two doublet models in 1.8 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{
 m cm}=1.96$ TeV. See their Fig. 2 for the limit on $\sigma \cdot {\sf B}(H_{1,2}^0/{\sf A}^0 \to \ \tau^+\,\tau^-)$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.
- 66 ABAZOV 09F search for associated production of a Higgs boson and a b quark in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H_{1,2}^0/A^0\to \tau^+\tau^-$. See their Fig. 2 for the limit on $\sigma \cdot {\rm B}(H^0_{1,2}/{\it A}^0 \to \ \tau^+\tau^-)$ (for different Higgs masses) and for the excluded
- region in the MSSM parameter space for $\mu=\pm 200$ GeV. Superseded by ABAZOV 10b. 67 ABAZOV 08AJ search for associated production of a Higgs boson and a b quark in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H_{1,2}^0/A^0\to b\overline{b}$. See their Tab. 3 for the limit on $\sigma \cdot {\sf B}(H^0_{1,2}/{\sf A}^0 \to b \, \overline{b})$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space for $\mu=\pm 200$ GeV. Superseded by
- ⁶⁸ ABAZOV 08W search for Higgs boson production in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$. See their Fig. 3 for the limit on $\sigma \cdot {\rm B}(H_{1,2}^0/A^0 \to \tau^+\tau^-)$ $\tau^+\,\tau^-)$ for different Higgs masses, and see their Fig. 4 for the excluded region in the MSSM parameter space. Superseded by ABAZOV 12.
- 69 This limit applies also in the no-mixing scenario. Furthermore, ABDALLAH 04 excludes the range $0.54 < \tan \beta < 2.36$. The limit improves in the region $\tan \beta < 6$ (see Fig. 28). Limits for $\mu = 1$ TeV are given in Fig. 30. 70 ABBIENDI 03G search for $e^+e^- \rightarrow H_1^0Z$ followed by $H_1^0 \rightarrow A^0A^0$, $A^0 \rightarrow c\overline{c}$, gg,
- or $\tau^+\tau^-$. In the no-mixing scenario, the region $m_{H_1^0}=45$ -85 GeV and $m_{A^0}=2$ -9.5 GeV is excluded at 95% CL.
- 71 HEISTER 02 excludes the range 0.7 <tan β < 2.3. A wider range is excluded with different stop mixing assumptions. Updates BARATE 01c.

A⁰ (Pseudoscalar Higgs Boson) MASS LIMITS in Supersymmetric Models

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------|-------------|-------------------------|-----|------|-------------------------------------------------------|
| >90.4 | | ⁷² ABDALLAH | 08в | DLPH | $E_{ m Cm} \leq$ 209 GeV |
| >93.4 | 95 | ⁷³ SCHAEL | | LEP | $E_{\rm cm} \leq 209 {\rm GeV}$ |
| >85.0 | | 74,75 ABBIENDI | 04м | OPAL | $E_{\rm cm} \leq 209 \; {\rm GeV}$ |
| >86.5 | | ^{74,76} ACHARD | 02н | L3 | $E_{\rm cm} \leq 209 \; {\rm GeV, } \tan \beta > 0.4$ |
| >90.1 | 95 | 74,77 HEISTER | 02 | ALEP | $E_{\rm cm} \leq 209$ GeV, $\tan \beta > 0.5$ |
| • • • We do i | not use the | following data for av | | | |
| | | ⁷⁸ ABAZOV | 12 | D0 | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + X$ |

| | | 81 | ABAZOV | 11w | D0 | $ \rho \overline{\rho} \rightarrow H_{1,2}^0/A^0 + b + X, $ |
|-------|----|-----|------------|------|------|----------------------------------------------------------------------------------|
| | | | | | | $H_{1,2}^0/A^0 \rightarrow \tau^+\tau^-$ |
| | | 82 | CHATRCHYAN | 11н | CMS | $pp \to H_{1,2}^0/A^0 + X$, |
| | | 0.0 | | | | $H_{1,2}^{0}/A^{0} \to \tau^{+}\tau^{-}$ |
| | | 83 | ABAZOV | 10D | D0 | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + b + X$ |
| | | 0.4 | | | | $H_{1,2}^{0}/A^{0} \to \tau^{+}\tau^{-}$ |
| | | 04 | AALTONEN | 09AR | CDF | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + X,$ |
| | | 95 | | | | $H_{1,2}^0/A^0 \to \tau^+\tau^-$ |
| | | 03 | ABAZOV | 09F | D0 | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + b + X$ |
| | | 86 | | | ъ. | $H_{1,2}^0/A^0 \to \tau^+\tau^-$ |
| | | 00 | ABAZOV | U8AJ | Du | $p\overline{p} \rightarrow H_{1,2}^0/A^0 + b + X,$ |
| | | 87 | ABAZOV | 0.00 | D0 | $H_{1,2}^0/A^0 \rightarrow b\overline{b}$ |
| | | ٠. | ABAZOV | 08W | DU | $ \rho \overline{\rho} \to H_{1,2}^0/A^0 + X, H_{1,2}^0/A^0 \to \tau^+ \tau^- $ |
| | | 88 | ACOSTA | 05 Q | CDF | $p\overline{p} \to H_{1,2}^0/A^0 \to \tau^+ \tau$ |
| | | | | | | |
| >90.4 | 95 | | ABDALLAH | 04 | | $E_{\rm cm} \leq 209$ GeV, $\tan \beta > 0.4$ |
| | | | ABBIENDI | 03G | OPAL | $H_1^0 \rightarrow A^0 A^0$ |
| | | 91 | AKEROYD | 02 | RVUE | |

- $^{72}\,\mathrm{ABDALLAH}$ 08B give limits in eight $\mathit{CP}\text{-}\mathrm{conserving}$ benchmark scenarios and some $\mathit{CP}\text{-}\mathrm{violating}$ scenarios. See paper for excluded regions for each scenario. Supersedes AB-
- 73 SCHAEL 06B make a combined analysis of the LEP data. The quoted limit is for the $m_h^{
 m m\,ax}$ scenario with $m_{\,t}=$ 174.3 GeV. In the *CP*-violating CPX scenario no lower bound on $m_{H_{\rm s}^0}$ can be set at 95% CL. See paper for excluded regions in various scenarios. See

Figs. 2–6 and Tabs. 14–21 for limits on $\sigma(ZH^0)\cdot B(H^0\to b\,\overline{b},\, \tau^+\,\tau^-)$ and $\sigma(H^0_1H^0_2)\cdot B(H^0\to b\,\overline{b},\, \tau^+\,\tau^-)$ $B(H_1^0, H_2^0 \rightarrow b \overline{b}, \tau^+ \tau^-)$

- 74 Search for $e^+e^- \to H_1^0 A^0$ in the final states $b\overline{b}b\overline{b}$ and $b\overline{b}\tau^+\tau^-$, and $e^+e^- \to$ $H_1^0\,Z$. Universal scalar mass of 1 TeV, SU(2) gaugino mass of 200 GeV, and $\mu{=}-200$ $\vec{\text{GeV}}$ are assumed, and two-loop radiative corrections incorporated. The limits hold for $m_t{=}175$ GeV, and for the m_h^{\max} scenario.
- To ABBIENDI 04M exclude $0.7 < \tan \theta < 1.9$, assuming $m_t = 174.3$ GeV. Limits for other MSSM benchmark scenarios, as well as for CP violating cases, are also given. To ACHARD 02H also search for the final state $H_1^0Z \to 2A^0 q \overline{q}$, $A^0 \to q \overline{q}$. In addition, the MSSM parameter set in the "large- μ " and "no-mixing" scenarios are examined. To HEISTER 02 excludes the range $0.7 < \tan \theta < 2.3$. A wider range is excluded with
- different stop mixing assumptions. Updates BARATE 01c.
- 78 ABAZOV 12 search for production of a Higgs boson followed by the decay $H_{1.2}^0/A^0
 ightarrow$ $\tau^+\,\tau^-$ in 5.4 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV. See their Fig. 2 for the limit on cross section times branching ratio and Fig. 3 for the excluded region in the MSSM
- 79 AAD 11R search for production of a Higgs boson followed by the decay $H_{1.2}^0/A^0
 ightarrow$ $\tau^+\,\tau^-$ in 36 pb $^{-1}$ of pp collisions at $E_{\rm cm}=$ 7 TeV. See their Fig. 3 for the limit on cross section times branching ratio and for the excluded region in the MSSM parameter
- 80 ABAZOV 11K search for associated production of a Higgs boson and a b quark, followed by the decay $H_{1,2}^0/A^0 \to b \, \overline{b}$, in 5.2 fb⁻¹ of $p \, \overline{p}$ collisions at $E_{\rm cm} = 1.96$ TeV. See their Fig. 5/Table 2 for the limit on cross section times branching ratio and Fig. 6 for the excluded region in the MSSM parameter space for $\mu=-200$ GeV.
- ⁸¹ ABAZOV 11W search for associated production of a Higgs boson and a b quark, followed by the decay $H_{1,2}^0/A^0 \to \tau \tau$, in 7.3 fb⁻¹ of $p \overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. See their Fig. 2 for the limit on cross section times branching ratio and for the excluded region in the MSSM parameter space.
- 82 CHATRCHYAN 11H search for production of a Higgs boson followed by the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$ in 36 pb $^{-1}$ of pp collisions at $E_{\rm cm}=7$ TeV. See their Fig. 2 for the limit on cross section times branching ratio and Fig. 3 for the excluded region in
- 83 ABAZOV 10D search for associated production of a Higgs boson and a b quark in $2.7 \, \mathrm{fb}^{-1}$ of $p \overline{p}$ collisions at $E_{\mathrm{Cm}} = 1.96$ TeV, with the decay $H_{1,2}^0/A^0 \to \tau^+ \tau^-$. See their Fig. 1 for the limit on $\sigma \cdot \mathsf{B}(H_{1,2}^0/A^0 \to \tau^+\tau^-)$ (for different Higgs masses) and for the excluded region in the MSSM parameter space for $\mu=-200$ GeV. Superseded
- ⁸⁴ AALTONEN 09AR search for Higgs bosons decaying to $\tau^+\tau^-$ in two doublet models in 1.8 fb⁻¹ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. See their Fig. 2 for the limit on $\sigma \cdot \mathsf{B}(H^0_{1,2}/\mathsf{A}^0 \to \tau^+\tau^-)$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.
- 85 ABAZOV 09F search for associated production of a Higgs boson and a b quark in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H_{1,2}^0/A^0\to \tau^+\tau^-$. See their Fig. 2 for the limit on $\sigma \cdot \mathrm{B}(H_{1,2}^0/\mathrm{A}^0 \to \tau^+ \, \tau^-)$ (for different Higgs masses) and for the excluded region in the MSSM parameter space for $\mu=\pm 200$ GeV. Superseded by ABAZOV 10D.
- ⁸⁶ ABAZOV 08AJ search for associated production of a Higgs boson and a b quark in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with the decay $H_{1,2}^0/A^0\to b\overline{b}$. See their Tab. 3 for the limit on $\sigma \cdot \mathsf{B}(H^0_{1,2}/\mathsf{A}^0 \to b\,\overline{b})$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space for $\mu=\pm 200$ GeV. Superseded by
- 87 ABAZOV 08W search for Higgs boson production in $p\overline{p}$ collisions at $E_{\text{cm}} = 1.96 \text{ TeV}$ with the decay $H_{1,2}^0/A^0 \to \tau^+\tau^-$. See their Fig. 3 for the limit on $\sigma \cdot {\rm B}(H_{1,2}^0/A^0 \to T^+\tau^-)$ $\tau^+\,\tau^-)$ for different Higgs masses, and see their Fig. 4 for the excluded region in the MSSM parameter space. Superseded by ABAZOV 12.

- ⁸⁸ ACOSTA 05Q search for $H_{1,2}^0/A^0$ production in $p\overline{p}$ collisions at $E_{
 m cm}=1.8$ TeV with $H^0_{1,2}/A^0
 ightarrow \ au^+ \, au^-$ At $m_{A^0}=$ 100 GeV, the obtained cross section upper limit is above theoretical expectation.
- 89 This limit applies also in the no-mixing scenario. Furthermore, ABDALLAH 04 excludes the range 0.54 < tan β < 2.36. The limit improves in the region tan β < 6 (see Fig. 28). Limits for μ = 1 TeV are given in Fig. 30.
- 90 ABBIENDI 03G search for $e^+\,e^- \to H_1^0\,Z$ followed by $H_1^0 \to A^0\,A^0$, $A^0 \to c\,\overline{c}$, gg, or $au^+ au^-$. In the no-mixing scenario, the region $m_{H_1^0}=$ 45-85 GeV and $m_{A^0}=$ 2-9.5
- GeV is excluded at 95% CL. 91 AKEROYD 02 examine the possibility of a light A^0 with $\tan\beta$ <1. Electroweak measurements are found to be inconsistent with such a scenario.

H^0 (Higgs Boson) MASS LIMITS in Extended Higgs Models

This Section covers models which do not fit into either the Standard Model or its simplest minimal Supersymmetric extension (MSSM), leading to anomalous production rates, or nonstandard final states and branching ratios. In particular, this Section covers limits which may apply to generic two-Higgs-doublet models (2HDM), or to special regions of the MSSM parameter space where decays to invisible particles or to photon pairs are dominant (see the Note on 'Searches for Higgs Bosons' at the beginning of this Chapter). See the footnotes or the comment lines for details on the nature of the models to which the limits apply.

| VALUE (GeV) | CL% | | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|--------------|------|----------------------|--------------|-----------|---------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not | use the | foll | owing data for a | verag | es, fits, | limits, etc. • • • |
| >114 | 95 | 92 | AALTONEN | 12 | CDF | $H^0 \rightarrow \gamma \gamma$ |
| • | | 93 | AALTONEN | 11p | CDF | $t \rightarrow bH^+, H^+ \rightarrow W^+A^0$ |
| >112.9 | 95 | 94 | ABAZOV | 11Y | D0 | $H^0 \rightarrow \infty$ |
| $< 1.0 \times 10^{-10}$ | 90 | 95 | ABOUZAID | 11A | KTEV | $\kappa_L^0 \rightarrow \pi^0 \pi^0 A^0, A^0 \rightarrow$ |
| | | | | | | μ+ μ- |
| | | 96 | DEL-AMO-SA. | .11J | BABR | $\Upsilon(1S) \rightarrow A^0 \gamma$ |
| | | 97 | LEES | 11H | BABR | $\Upsilon(2S, 3S) \rightarrow A^0 \gamma$ |
| >108.2 | 95 | 98 | ABBIENDI | 10 | OPAL | invisible H ⁰ |
| | | 99 | ABBIENDI | 10 | OPAL | $H^0 \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_2^0$ |
| 0 | | 100 | ANDREAS | 10 | RVUE | 0 0 0 |
| < 2.26 × 10 ⁻⁸ | | 101 | HYUN | 10 | BELL | $B_0^0 \to K^*A^0, A^0 \to \mu^+\mu^-$ |
| $< 1.73 \times 10^{-8}$ | 90 | 101 | HYUN | 10 | BELL | $B^0 \to \rho A^0, A^0 \to \mu^+ \mu^-$ |
| | | 102 | SCHAEL | 10 | ALEP | $H^0 \rightarrow A^0 A^0$ |
| >106 | 95 | 104 | AALTONEN AALTONEN | 09AB 09AR | CDF | $H^0 \rightarrow \gamma \gamma \ p \overline{p} \rightarrow H^0_{1,2}/A^0 + X,$ |
| | | | AALIONEN | USAR | CDF | $pp \rightarrow H_{1,2}/A^2 + X$ |
| | | | | | | $H_{1,2}^{0}/A^{0} \rightarrow \tau^{+}\tau^{-}$ |
| >101 | 95 | 105 | ABAZOV | 09Q | D0 | $H^0 \rightarrow \gamma \gamma$ |
| | | 106 | ABAZOV | 09∨ | D0 | $H^0 \rightarrow A^0 A^0$ |
| | | 107 | AUBERT | 09P | BABR | $\Upsilon(3S) \rightarrow A_0^0 \gamma$ |
| | | 100 | AUBERT | 09z | BABR | $\Upsilon(2S) \rightarrow A_0^0 \gamma$ |
| 7 | | 110 | AUBERT | 09z | BABR | $\Upsilon(3S) \rightarrow A^0 \gamma$ |
| $< 2.4 \times 10^{-7}$ | 90 | | TUNG | 09 | K391 | $\mathcal{K}_{L}^{0} \rightarrow \pi^{0}\pi^{0}A^{0}, A^{0} \rightarrow \gamma\gamma$ |
| | | | ABAZOV | 08∪ | D0 | $H^{0} \rightarrow \gamma \gamma$ |
| | | | LOVE | 80 | CLEO | $\Upsilon(1S) \rightarrow A^0 \gamma$ |
| | | 114 | ABBIENDI | 07 | OPAL | invisible H^0 , large width |
| 5 1 OF O | 95 | 115 | BESSON SCHAEL | 07 07 | CLEO | $\begin{array}{ccc} \varUpsilon(1S) \rightarrow & \eta_b \gamma \\ e^+ e^- \rightarrow & H^0 Z, H^0 \rightarrow \end{array}$ |
| >105.8 | 95 | | SCHAEL | 07 | ALEP | e e → H · Z, H · → |
| none 1-55 | 95 | 116 | ABBIENDI | 05 A | OPAL | W W* H ₁ ⁰ , Type II model |
| none 3-63 | 95 | 116 | ABBIENDI | 05A | OPAL | A ⁰ . Type II model |
| >110.6 | 95 | 117 | ABDALLAH | 05 D | DLPH | $H^0 \rightarrow 2$ jets |
| >112.3 | 95 | 118 | ACHARD | 05 | L3 | invisible H^0 |
| | | 119 | PARK | 05 | HYCP | $\Sigma^+ ightarrow ho A^0$, $A^0 ightarrow \mu^+ \mu^-$ |
| >104 | 95 | 120 | ABBIENDI | 04K | OPAL | $H_{\perp}^{0} \rightarrow 2$ jets |
| | | 121 | ABDALLAH | 04 | DLPH | H ⁰ V V couplings |
| >112.1 | 95 | 118 | ABDALLAH | 04в | DLPH | Invisible H ⁰ |
| >104.1 | 95 122 | 124 | ABDALLAH | 04L | DLPH | $e^+ e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma \gamma$ |
| | | 124 | ABDALLAH | 040 | DLPH | $Z \rightarrow f \overline{f} H$ |
| . 110.0 | 0.5 | 126 | ABDALLAH | 040 | DLPH | $e^{+}e^{-} \rightarrow H^{0}Z, H^{0}A^{0}$ |
| >110.3 | 95 | 127 | ACHARD ACHARD | 04B 04F | L3 L3 | $H^0 \rightarrow 2$ jets Anomalous coupling |
| | | | ABBIENDI | 04F | OPAL | $e^+e^- \rightarrow H^0Z, H^0 \rightarrow \text{any}$ |
| | | | ABBIENDI | 03G | OPAL | $H_1^0 \rightarrow A^0 A^0$ |
| >107 | 95 | 130 | ACHARD | 03c | L3 | $H^0 \rightarrow WW^*, ZZ^*, \gamma\gamma$ |
| >107 | 90 | 131 | ABBIENDI | 02D | OPAL | $e^+e^- \rightarrow b\overline{b}H$ |
| >105.5 | 95 122 | ,132 | ABBIENDI | 02b | OPAL | $H_1^0 \rightarrow \gamma \gamma$ |
| >105.4 | 95 | | ACHARD | 02c | L3 | $H_1^0 \rightarrow \gamma \gamma$ |
| - | 95 | | HEISTER | | | $n_1 \rightarrow \gamma \gamma$ |
| >114.1 | 95 or 122 | .134 | HEISTER | 02 | ALEP | Invisible H^0 , $E_{\rm cm} \leq$ 209 GeV $H_1^0 \rightarrow \gamma \gamma$ |
| >105.4 | | | | 02L | ALEP | |
| >109.1 | 95 oc | | HEISTER ABBIENDI | | ALEP | $H^0 \rightarrow 2$ jets or $\tau^+ \tau^-$ |
| none 1-44 | 95 | | | 01E | OPAL | H ₁ , Type-II model |
| none 12-56 | 95 | | ABBIENDI | 01E | OPAL | A^0 , Type-II model |
| > 98 | 95 | 118 | AFFOLDER BARATE | 01H | CDF | $p\overline{p} \to H^0 W/Z, H^0 \to \gamma\gamma$ |
| >106.4 | 95 | | ACCIARRI | 01c | ALEP | Invisible H^0 , $E_{cm} \le 202 \text{ GeV}$ |
| > 89.2 | 95 | 139 | ACCIARRI | 00m | | Invisible H^0 $e^+e^- \rightarrow H^0\gamma$ and /or $H^0 \rightarrow$ |
| | | | ACCIAKKI | 00R | L3 | $e \cdot e \rightarrow H^- \gamma \text{ and/or } H^0 \rightarrow$ |

Gauge & Higgs Boson Particle Listings

Higgs Bosons — H^0 and H^\pm

| | | ¹⁴⁰ ACCIARRI | 00R | L3 | $e^{+} e^{-} \rightarrow e^{+} e^{-} H^{0}$ |
|--------|----|----------------------------------------------------------------------------|-----------|----------------------|--------------------------------------------------------------------------------------------------------------|
| > 94.9 | 95 | ¹⁴¹ ACCIARRI | 00s | L3 | $e^+ e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma \gamma$ |
| >100.7 | 95 | ¹⁴² BARATE | 00L | ALEP | $e^+e^- \rightarrow H^0Z, H^0 \rightarrow \gamma\gamma$ |
| > 68.0 | 95 | ¹⁴³ ABBIENDI | 99E | OPAL | $	an\!eta>1$ |
| > 96.2 | 95 | ¹⁴⁴ ABBIENDI | 990 | OPAL | $e^+ e^- \rightarrow H^0 Z, H^0 \rightarrow \gamma \gamma$ |
| > 78.5 | 95 | ¹⁴⁵ АВВОТТ | 99B | D0 | $p\overline{p} \rightarrow H^0 W/Z, H^0 \rightarrow \gamma \gamma$ |
| | | ¹⁴⁶ ABREU | 99P | DLPH | $e^+ e^- \rightarrow H^0 \gamma$ and/or $H^0 \rightarrow$ |
| | | 147 GONZALEZ-G. 148 KRAWCZYK 149 ALEXA NDER 150 ABREU 151 PICH | 97 96н | RVUE OPAL DLPH | $\gamma\gamma$ Anomalous coupling $(g-2)_{\mu}$ $Z \to H^0 \gamma$ $Z \to H^0 Z^*, H^0 A^0$ Very light Higgs |
| | | | | _ | , 6 66 |

- 92 AALTONEN 12 search for $H^0\to\gamma\gamma$ in 7.0 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV in the mass range $m_{H^0}=100$ –150 GeV. The limit assumes that all fermion Yukawa couplings vanish.
- 93 AALTONEN 11P search in 2.7 fb $^{-1}$ of $p \overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV for the decay chain $t \rightarrow bH^+$, $H^+ \rightarrow W^+A^0$, $A^0 \rightarrow \tau^+\tau^-$ with m_{A^0} between 4 and 9 GeV. See their Fig. 4 for limits on B($t
 ightarrow b \, H^+$) for 90 < $m_{H^+} <$ 160 GeV.
- 94 ABAZOV 11Y search for $H^0\to\gamma\gamma$ in 8.2 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV in the mass range $m_{H^0}=100$ –150 GeV. The limit assumes that all fermion Yukawa couplings vanish couplings vanish.
- 95 The limit applies at $m_{A^0}=214.3$ MeV, motivated by PARK 05.
- 96 DEL-AMO-SANCHEZ 11J search for the process $\varUpsilon(2S) \to \varUpsilon(1S) \pi^+ \pi^- \to$ $A^0\gamma\gamma^+\pi^-$ with A^0 decaying to invisible final states. They give limits on B($\Upsilon(1S)\to A^0\gamma$)-B($A^0\to$ invisible) in the range $(1.9-4.5)\times 10^{-6}$ (90% CL) for $0\le m_{A^0}\le 10^{-6}$ 8.0 GeV, and (2.7–37) \times 10⁻⁶ for 8.0 $\leq m_{A^0} \leq$ 9.2 GeV.
- 8. GeV, and $(2.7-37) \times 10^{-9}$ for 8.0 $\leq m_{A0} \leq 9.2$ GeV.

 97 LEES 11H search for the process $\Upsilon(2S,3S) \to A^0 \gamma$ with A^0 decaying hadronically and give limits on B($\Upsilon(2S,3S) \to A^0 \gamma$)-B($A^0 \to$ hadrons) in the range $1 \times 10^{-6} 8 \times 10^{-5}$ (90% CL) for $0.3 < m_{A^0} < 7$ GeV. The decay rates for $\Upsilon(2S)$ and $\Upsilon(3S)$ are assumed to be equal up to the phase space factor.

 98 ABBIENDI 10 earch for $e^+e^- \to H^0 Z$ with H^0 decaying invisibly. The limit assumes SM production cross section and B($H^0 \to$ invisible) = 1.

 99 ABBIENDI 10 search for $e^+e^- \to Z^0$ with the decay chain $H^0 \to \widetilde{\chi}_1^0 \widetilde{\chi}_2^0$, $\widetilde{\chi}_2^0 \to 0$
- $\widetilde{\chi}_1^0$ + $(\gamma$ or $Z^*)$, when $\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0$ are nearly degenerate. For a mass difference of 2 (4) GeV, a lower limit on m_{H^0} of 108.4 (107.0) GeV (95% CL) is obtained for SM ZH^0 cross section and B($H^0 \xrightarrow{i} \widetilde{\chi}_1^0 \widetilde{\chi}_2^0$) = 1.
- $100\,\mathrm{A}\,\mathrm{NDREAS}$ 10 analyze various rare decays and find $m_{A0}>210\,\mathrm{MeV}$ or that its couplings to fermions are 4 orders of magnitude below those of the standard Higgs.
- 101 The limit applies at $m_{A0}=214.3$ MeV, motivated by PARK 05. HYUN 10 summarize mass-dependent limits in their Table I.
- 102 SCHAEL 10 search for the process $e^+e^- \rightarrow H^0$ Z followed by the decay chain H^0 A⁰ $A^0 \rightarrow \tau^+ \tau^- \tau^+ \tau^-$ with $Z \rightarrow \ell^+ \ell^-$, $\nu \overline{\nu}$ at $E_{\rm cm}=$ 183–209 GeV. For a H^0 Z Z coupling equal to the SM value, B($H^0 \rightarrow A^0 A^0$) = B($A^0 \rightarrow \tau^+ \tau^-$) = 1, and M_{A^0} = 4–10 GeV, m_{H^0} up to 107 GeV is excluded at 95% CL.
- 103 AALTONEN 09AB search for $H^0 \to \gamma \gamma$ in 3.0 fb $^{-1}$ of $\rho \overline{\rho}$ collisions at $E_{\rm cm}=1.96$ TeV in the mass range $m_{H^0}=70$ -150 GeV. Associated H^0W , H^0Z production and WW, ZZ fusion are considered. The limit assumes that all fermion Yukawa couplings vanish. 104 AALTONEN, 09AR search for Higgs bosons decaying to $\tau^+\tau^-$ in two doublet models
- in 1.8 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=$ 1.96 TeV. See their Fig. 2 for the limit on $\sigma \cdot \mathrm{B}(H_{1,2}^0/A^0 \to \tau^+\tau^-)$ for different Higgs masses, and see their Fig. 3 for the excluded region in the MSSM parameter space.
- 105 ABAZOV 090 search for $H^0 \to \gamma \gamma$ in 2.7 fb $^{-1}$ of $p \overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV in the mass range $m_{H^0}=100$ –150 GeV. The limit assumes that all fermion Yukawa couplings vanish. Superseded by ABAZOV 11Y.
- couplings vanish. Superseded by ABAZOV 11Y. 106 ABAZOV 09V search for H^0 production followed by the decay chain $H^0 \rightarrow A^0 A^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ or $\mu^+ \mu^- + \tau^-$ in 4.2 fb $^{-1}$ of $p \bar{p}$ collisions at $E_{\rm CM}=1.96$ TeV. See their Fig. 3 for limits on $\sigma(H^0)$ -B $(H^0 \rightarrow A^0 A^0)$ for $m_{A^0}=3.6$ -19 GeV. 107 AUBERT 09P search for the process $\Upsilon(3S) \rightarrow A^0 \gamma$ with $A^0 \rightarrow \tau^+ \tau^-$ for $4.03 < m_{A^0} < 9.52$ and $9.61 < m_{A^0} < 10.10$ GeV, and give limits on $B(\Upsilon(3S) \rightarrow A^0 \gamma)$ by $A^0 \rightarrow A^0 \gamma$ with $A^0 \rightarrow A^0 \gamma$ by $A^0 \rightarrow A^0 \gamma$ by
- $A^{0}\gamma$)·B($A^{0} \rightarrow \tau^{+}\tau^{-}$) in the range (1.5–16) \times 10⁻⁵ (90% CL).
- 108 AUBERT 09z search for the process $\Upsilon(2S) \rightarrow A^0 \gamma$ with $A^0 \rightarrow \mu^+ \mu^-$ for 0.212 $< m_{A^0} < 9.3$ GeV and give limits on B($\Upsilon(2S) \rightarrow A^0 \gamma$).B($A^0 \rightarrow \mu^+ \mu^-$) in the range $(0.3-8) \times 10^{-6} (90\% \text{ CL}).$
- 109 AUBERT 09z search for the process $\Upsilon(3S) \rightarrow A^0 \gamma$ with $A^0 \rightarrow \mu^+ \mu^-$ for 0.212 $< m_{A^0} < 9.3$ GeV and give limits on B($\Upsilon(3S) \rightarrow A^0 \gamma$)·B($A^0 \rightarrow \mu^+ \mu^-$) in the range $(0.3-5) \times 10^{-6} (90\% \text{ CL}).$
- 110 The limit applies at $m_{A0}=214.3$ MeV, motivated by PARK 05. TUNG 09 show mass-dependent limits in their Fig. 5.
 111 ABAZOV 08u search for $H^0 \to \gamma \gamma$ in $\rho \overline{\rho}$ collisions at $E_{\rm cm}=1.96$ TeV in the mass
- range $m_{H^0} = 70$ –150 GeV. Associated H^0 W, H^0 Z production and WW, ZZ fusion are considered. See their Tab. 1 for the limit on $\sigma \cdot B(H^0 \to \gamma \gamma)$, and see their Fig. 3 for the excluded region in the m_{H^0} — $\mathrm{B}(H^0 o \gamma \gamma)$ plane.
- $^{112} \text{LOVE 08 search for the process} \stackrel{\prime\prime}{\varUpsilon} (1\text{S}) \rightarrow ~A^0 \gamma \text{ with } A^0 \rightarrow ~\mu^+ \,\mu^- \text{ (for } m_{A^0} < 2m_{\tau})$ and $A^0 \to \tau^+ \tau^-$. Limits on B($\Upsilon(1S) \to A^0 \gamma$) \cdot B($A^0 \to \ell^+ \ell^-$) in the range 10⁻⁶-10⁻⁴ (90% CL) are given.
- ¹¹³ ABBIENDI 07 search for $e^+e^- \rightarrow H^0Z$ with $Z \rightarrow q \overline{q}$ and H^0 decaying to invisible final states. The H^0 width is varied between 1 GeV and 3 TeV. A limit $\sigma \cdot \mathsf{B}(H^0 \to \mathsf{invisible})$ < (0.07–0.57) pb (95%CL) is obtained at $E_{
 m cm}=$ 206 GeV for $m_{H^0}\stackrel{.}{=}$ 60–114 GeV.

- $^{114}\, \rm BESSON$ 07 give a limit B($\Upsilon(1S) \to~\eta_b\, \gamma) \,\cdot\, {\rm B}(\eta_b \to~\tau^+\,\tau^-) <$ 0.27% (95% CL), which constrains a possible A^0 exchange contribution to the η_b decay.
- 115 SCHAEL 07 search for Higgs bosons in association with a fermion pair and decaying to WW*. The limit is from this search and HEISTER 02L for a H⁰ with SM production
- cross section and B($H^0 \to f\overline{f}$) = 0 for all fermions f. 116 ABBIENDI 05A search for $e^+e^- \to H_1^0A^0$ in general Type-II two-doublet models, with
- decays H_1^0 , $A^0 \to q\overline{q}$, gg, $\tau^+\tau^-$, and $H_1^0 \to A^0A^0$. 117 ABDALLAH 050 search for $e^+e^- \to H^0Z$ and H^0A^0 with H^0 , A^0 decaying to two jets of any flavor including gg. The limit is for SM H^0Z production cross section with $B(H^0 \to jj) = 1.$
- 118 Search for $e^+e^- \to H^0\,Z$ with H^0 decaying invisibly. The limit assumes SM production cross section and B $(H^0 \to {\rm invisible})=1$.
- ¹¹⁹PARK 05 found three candidate events for $\Sigma^+ \to p \mu^+ \mu^-$ in the HyperCP experiment. Due to a narrow spread in dimuon mass, they hypothesize the events as a possible signal of a new boson. It can be interpreted as a neutral particle with $m_{A^0}=214.3\pm0.5$ MeV and the branching fraction B($\Sigma^+ \to \ \rho \, A^0) \times$ B($A^0 \to \ \mu^+ \, \mu^-) = (3.1 \, \frac{+ \, 2.4}{-1.9} \, \pm \, 1.5) \times 10^{-8}$.
- ¹²⁰ ABBIENDI 04κ search for $e^+e^- \rightarrow H^0Z$ with H^0 decaying to two jets of any flavor including gg. The limit is for SM production cross section with B($H^0 \rightarrow jj$) = 1.
- 121 ABDALLAH 04 consider the full combined LEP and LEP2 datasets to set limits on the Higgs coupling to W or Z bosons, assuming SM decays of the Higgs. Results in Fig. 26.
- 122 Search for associated production of a $\gamma\gamma$ resonance with a Z boson, followed by Z ightarrow $q\overline{q}$, $\ell^+\ell^-$, or $\nu\overline{\nu}$, at $E_{\rm cm} \leq$ 209 GeV. The limit is for a H^0 with SM production cross section and B($H^0 \rightarrow f\overline{f})=0$ for all fermions f.
- 123 Updates ABREU 01F.
- 124 ABDALLAH 040 search for $Z\to b\overline{b}H^0$, $b\overline{b}A^0$, $\tau^+\tau^-H^0$ and $\tau^+\tau^-A^0$ in the final states 4b, $b\overline{b}\tau^+\tau^-$, and 4 τ . See paper for limits on Yukawa couplings. 125 ABDALLAH 040 search for $e^+e^-\to H^0Z$ and H^0A^0 , with H^0 , A^0 decaying to $b\overline{b}$,
- $au^+ \, au^-$, or $H^0 o A^0 A^0$ at $E_{
 m cm} = 1$ 89–208 GeV. See paper for limits on couplings.
- ¹²⁶ ACHARD 04B search for $e^+e^-\to H^0Z$ with H^0 decaying to $b\,\overline{b},\,c\,\overline{c},\,$ or $g\,g.$ The limit is for SM production cross section with $B(H^0 \rightarrow jj) = 1$.
- 127 ACHARD 04F search for H^0 with anomalous coupling to gauge boson pairs in the processes $e^+e^- o H^0\gamma$, $e^+e^-H^0$, H^0Z with decays $H^0 o f\overline{f}$, $\gamma\gamma$, $Z\gamma$, and W^*W at $E_{\rm cm}=189$ –209 GeV. See paper for limits.
- 128 ABBIENDI 03F search for $H^0 \to \text{anything in } e^+e^- \to H^0 Z$, using the recoil mass spectrum of $Z \to e^+e^-$ or $\mu^+\mu^-$. In addition, it searched for $Z \to \nu\overline{\nu}$ and $H^0 \to e^+e^$ e^+e^- or photons. Scenarios with large width or continuum H^0 mass distribution are considered. See their Figs. 11–14 for the results.
- 129 ABBIENDI 03G search for $e^+e^- \rightarrow H_1^0$ Z followed by $H_1^0 \rightarrow A^0A^0$, $A^0 \rightarrow c\overline{c}$, gg, or $au^+ au^-$ in the region $m_{H_1^0} =$ 45-86 GeV and $m_{A^0} =$ 2-11 GeV. See their Fig. 7 for
- 130 ACHARD 03c search for $e^+e^- \rightarrow ZH^0$ followed by $H^0 \rightarrow WW^*$ or ZZ^* at $E_{cm}=$ 200-209 GeV and combine with the ACHARD 02c result. The limit is for a H^0 with SM production cross section and B($H^0 \to f \bar{f}$) = 0 for all f. For B($H^0 \to WW^*$) + $\mathsf{B}(H^0 \to ZZ^*) = 1$, $\mathsf{m}_{H^0} > 108.1$ GeV is obtained. See fig. 6 for the limits under different BR assumptions.
- 131 ABBIENDI 02D search for $Z \to b\overline{b}H_1^0$ and $b\overline{b}A^0$ with $H_1^0/A^0 \to \tau^+\tau^-$, in the range $4 < m_H < 12$ GeV. See their Fig. 8 for limits on the Yukawa coupling.
- ¹³² For B($H^0 \rightarrow \gamma \gamma$)=1, m_{H^0} >117 GeV is obtained.
- 133 ACHARD 02c search for associated production of a $\gamma\gamma$ resonance with a Z boson, followed by $Z \to q \overline{q}$, $\ell^+ \ell^-$, or $\nu \overline{\nu}$, at $E_{\rm cm} \leq 209$ GeV. The limit is for a H^0 with SM production cross section and B($H^0 \to f \overline{f}$)=0 for all fermions f. For B($H^0 \to \gamma \gamma$)=1, $m_{H^0} > 114 \text{ GeV}$ is obtained.
- $^{134}\,\mathrm{For}\;\mathrm{B}(H^0\,\rightarrow\,\gamma\gamma){=}1,\,m_{H^0}>113.1~\mathrm{GeV}$ is obtained.
- ¹³⁵ HEISTER 02M search for $e^+e^- \rightarrow H^0 Z$, assuming that H^0 decays to $q \overline{q}$, g g, or $^+ au^-$ only. The limit assumes SM production cross section.
- $^{136} ABBIENDI$ 01E search for neutral Higgs bosons in general Type-II two-doublet models, at $E_{\rm cm} \leq$ 189 GeV. In addition to usual final states, the decays H_1^0 , $A^0 \to q \, \overline{q}$, $g \, g$ are searched for. See their Figs. 15,16 for excluded regions.
- AFFOLDER 01H search for associated production of a $\gamma\gamma$ resonance and a W or Z (tagged by two jets, an isolated lepton, or missing E_T). The limit assumes Standard Model values for the production cross section and for the couplings of the H^0 to W and Z bosons. See their Fig. 11 for limits with B($H^0 \to \gamma \gamma$) < 1. ACCIARRI 00M search for $e^+e^- \to ZH^0$ with H^0 decaying invisibly at
- 138 ACCIARRI 00M search for $e^+e^- o ZH^0$ with H^0 decaying invisibly at $E_{\rm cm} = 183-189\,{\rm GeV}$. The limit assumes SM production cross section and ${\rm B}(H^0 o {\rm invisible}) = 1$. See their Fig. 6 for limits for smaller branching ratios.
- 139 ACCIARRI 00R search for $e^+e^- \to H^0\gamma$ with $H^0 \to b \, \overline{b}$, $Z\gamma$, or $\gamma\gamma$. See their Fig. 3 for limits on σ -B. Explicit limits within an effective interaction framework are also given, for which the Standard Model Higgs search results are used in addition.
- Acciarki our search for the two-photon type processes $e^+e^- \to e^+e^-H^0$ with $H^0 \to b\,\overline{b}$ or $\gamma\gamma$. See their Fig. 4 for limits on $\Gamma(H^0 \to \gamma\gamma)\cdot \mathrm{B}(H^0 \to \gamma\gamma$ or $b\,\overline{b})$ for m_{H^0} =70–170 GeV. 140 ACCIARRI 00R search for the two-photon type processes e^+e^-
- 141 ACCIARRI 00s search for associated production of a $\gamma\gamma$ resonance with a $q\overline{q}$, $\nu\overline{\nu}$, or $\ell^+\ell^-$ pair in e^+e^- collisions at $E_{\rm cm}=189$ GeV. The limit is for a H^0 with SM production cross section and B($H^0\to f\bar T$)=0 for all fermions f. For B($H^0\to \gamma\gamma$)=1, $m_{H^0} >$ 98 GeV is obtained. See their Fig. 5 for limits on B($H
 ightarrow \gamma \gamma$) $\cdot \sigma(e^+e^-
 ightarrow$ $Hf\overline{f})/\sigma(e^+e^- \rightarrow Hf\overline{f})$ (SM).
- 142 BARATE 00L search for associated production of a $\gamma\gamma$ resonance with a $q\overline{q}$, $\nu\overline{\nu}$, or $\ell^+\ell^-$ pair in e^+e^- collisions at $E_{\rm cm}=$ 88–202 GeV. The limit is for a H^0 with SM production cross section and B($H^0\to f\overline{t}$)=0 for all fermions f. For B($H^0\to \gamma\gamma$)=1, $m_{H^0} >$ 109 GeV is obtained. See their Fig. 3 for limits on B($H \to \gamma \gamma$) $\sigma(e^+ e^- \to e^-)$ $Hf\overline{f})/\sigma(e^+e^- \rightarrow Hf\overline{f})$ (SM).

- 143 ABBIENDI 99E search for $e^+\,e^-\to H^0\,A^0$ and $H^0\,Z$ at $E_{\rm Cm}=183$ GeV. The limit is with $m_H{=}m_A$ in general two Higgs-doublet models. See their Fig. 18 for the exclusion limit in the $m_H{-}m_A$ plane. Updates the results of ACKERSTAFF 98s.
- 144 ABBIENDI 990 search for associated production of a $\gamma\gamma$ resonance with a $q\overline{q}, \nu\overline{\nu}$, or $\ell^+\ell^-$ pair in e^+e^- collisions at 189 GeV. The limit is for a H^0 with SM production
- $\ell^+\ell^-$ pair in e^+e^- collisions at 189 GeV. The limit is for a H^o with SM production cross section and $B(H^0 \to f\overline{T}) = 0$, for all fermions f. See their Fig. 4 for limits on $\sigma(e^+e^- \to H^0Z^0) \times B(H^0 \to \gamma\gamma) \times B(X^0 \to f\overline{T})$ for various masses. Updates the results of ACKERSTAFF 98Y.

 145 ABBOTT 99s search for associated production of a $\gamma\gamma$ resonance and a dijet pair. The limit assumes Standard Model values for the production cross section and for the couplings of the H^0 to W and Z bosons. Limits in the range of $\sigma(H^0 + Z/W) \cdot B(H^0 \to \gamma\gamma) = 0.80 0.34$ pb are obtained in the mass range $m_{H^0} = 65 150$ GeV.

 146 ABREU 99 search for $e^+e^- \to H^0\gamma$ with $H^0 \to b\overline{b}$ or $\gamma\gamma$, and $e^+e^- \to H^0q\overline{q}$ with $H^0 \to \infty$. See their Fig. A for limits on $\sigma \times B$. Explicit limits within an effective
- with $H^0 \to \gamma \gamma$. See their Fig. 4 for limits on $\sigma \times B$. Explicit limits within an effective interaction framework are also given. 147 GONZALEZ-GARCIA 98b use DØ limit for $\gamma \gamma$ events with missing E_T in $p\overline{p}$ collisions (ABBOTT 98) to constrain possible ZH or WH production followed by unconventional $H \to \gamma \gamma$ decay which is induced by higher-dimensional operators. See their Figs. 1 and 2 for limit on the acceptance of the convention of the second of for limits on the anomalous couplings.
- 148 KRAWCZYK 97 analyse the muon anomalous magnetic moment in a two-doublet Higgs model (with type II Yukawa couplings) assuming no H_1^0 Z Z coupling and obtain $m_{H_1^0}\gtrsim$
 - 5 GeV or $m_{A0}\gtrsim$ 5 GeV for $\tan\beta>$ 50. Other Higgs bosons are assumed to be much
- 149 heavier. ALEXANDER 96H give B(Z \rightarrow H $^0\gamma$)×B(H 0 \rightarrow $q\overline{q}$) < 1-4 × 10 $^{-5}$ (95%CL) and $B(Z \to H^0 \gamma) \times B(H^0 \to b \overline{b}) < 0.7 - 2 \times 10^{-5} \text{ (95 \%CL) in the range 20 } < m_{H^0} < 80$
- $^{150}\,{\rm GeV}.$ See Fig. 4 of ABREU 95H for the excluded region in the $m_{\Breve{H}^0}-m_{\Breve{A}^0}$ plane for general two-doublet models. For $\tan\beta>$ 1, the region $m_{H^0}+m_{A^0}\lesssim$ 87 GeV, $m_{H^0}<$ 47 GeV is
- 151 excluded at 95% CL, with m_{H^0} <2 m_μ in general two-doublet models. Excluded regions in the space of mass-mixing angles from LEP, beam dump, and π^\pm , η rare decays are shown in Figs. 3,4. The considered mass region is not totally excluded.

H[±] (Charged Higgs) MASS LIMITS

Unless otherwise stated, the limits below assume B($H^+ \to \tau^+ \nu$)+B($H^+ \to c \overline{s}$)=1, and hold for all values of B($H^+ o au^+
u_ au$), and assume H^+ weak isospin of T_3 =+1/2. In the following, $tan \beta$ is the ratio of the two vacuum expectation values in two-doublet

The limits are also applicable to point-like technipions. For a discussion of techniparticles, see the Review of Dynamical Electroweak Symmetry Breaking in this Review.

For limits obtained in hadronic collisions before the observation of the top quark, and based on the top mass values inconsistent with the current measurements, see the 1996 (Physical Review D54 1 (1996)) Edition of this Review.

Searches in $e^+\,e^-$ collisions at and above the $\it Z$ pole have conclusively ruled out the existence of a charged Higgs in the region $m_{H^+}\!\lesssim$ 45 GeV, and are now superseded by the most recent searches in higher energy $e^+\,e^-$ collisions at LEP. Results by now obsolete are therefore not included in this compilation, and can be found in the previous Edition (The European Physical Journal C15 1 (2000)) of this Review.

In the following, and unless otherwise stated, results from the LEP experiments (ALEPH, DELPHI, L3, and OPAL) are assumed to derive from the study of the $e^+e^ightarrow~H^+H^-$ process. Limits from $b
ightarrow~s\gamma$ decays are usually stronger in generic 2HDM models than in Supersymmetric models.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
|---------------------------------|---------|-------------------------------|-----------|-------------|------------------------------------------------------------------------------|--|
| > 74.4 | 95 | ABDALLAH | 041 | DLPH | $E_{\rm cm} \le 209 \; {\rm GeV}$ | |
| > 76.5 | 95 | ACHA RD | 03E | L3 | $E_{\rm cm} \leq 209 \; {\rm GeV}$ | |
| > 79.3 | 95 | HEISTER | | | $E_{\rm cm} \leq 209 \; {\rm GeV}$ | |
| ● ● We do not | use the | following data for | averag | es, fits, | | |
| >316 | 95 | 152 AALTONEN 153 DESCHAMPS | 11P 10 | CDF RVUE | $t \rightarrow bH^+, H^+ \rightarrow W^+A^0$ Type II, flavor physics data | |
| | | ¹⁵⁴ AALTONEN | 09a j | CDF | $t \rightarrow bH^+$ | |
| | | ¹⁵⁵ ABAZOV | 09AC | D0 | $t \rightarrow bH^+$ | |
| | | ¹⁵⁶ ABAZOV | 09AG | D0 | $t \rightarrow bH^+$ | |
| | | ¹⁵⁷ ABAZOV | 09A1 | D0 | $t \rightarrow bH^+$ | |
| | | 158 ABAZOV | 09P | D0 | $H^+ \rightarrow t \overline{b}$ | |
| >240 | 95 | 159 FLACHER | 09 | RVUE | Type II, flavor physics data | |
| | | ¹⁶⁰ ABULENCIA | 06E | CDF | $t \rightarrow bH^+$ | |
| > 92.0 | 95 | ABBIENDI | 04 | OPAL | $B(\tau \nu) = 1$ | |
| > 76.7 | 95 | 161 ABDALLAH | 041 | | Type I | |
| | | 162 ABBIENDI | 03 | OPAL | | |
| | | 163 ABAZOV | | D0 | $t \rightarrow bH^+, H \rightarrow \tau \nu$ | |
| | | 164 BORZUMATI | 02 | RVUE | | |
| | | 165 ABBIENDI | | | $B \rightarrow \tau \nu_{\tau} X$ | |
| | | 166 BARATE | 01E | ALEP | | |
| >315 | 99 | 167 GAMBINO | 01 | | $b \rightarrow s \gamma$ | |
| | | ¹⁶⁸ AFFOLDER | 001 | CDF | $t \rightarrow bH^+, H \rightarrow \tau \nu$ | |
| > 59.5 | 95 | ABBIENDI | 99E | OPAL | CIII — | |
| | | 169 ABBOTT | 99E | D0 | $t \rightarrow bH^+$ | |
| | | 170 ACKERSTAFF | | OPAL | | |
| | | 171 ACCIARRI | 97F | L3 | $B \rightarrow \tau \nu_{\tau}$ | |
| | | 172 AMMAR | | | $	au ightarrow \ \mu u u$ | |
| | | 173 COARASA | 97 | | $B \rightarrow \tau \nu_{\tau} X$ | |
| | | 174 GUCHAIT | 97 | | $t \to bH^+, H \to \tau \nu$ | |
| | | 175 MANGANO | 97 | RVUE | $B_{u(c)} \rightarrow \tau \nu_{\tau}$ | |
| | | 176 STAHL | 97 | RVUE | $\tau \rightarrow \mu \nu \nu$ | |
| >244 | 95 | 177 ALAM | 95 | CLE2 | $b \rightarrow s \gamma$ | |
| | | ¹⁷⁸ BUSKULIC | 95 | ALEP | $b \rightarrow \tau \nu_{\tau} X$ | |
| | | | | | | |

- 152 AALTONEN 11P search in 2.7 fb $^{-1}$ of $p\,\overline{p}$ collisions at $E_{\rm cm}=$ 1.96 TeV for the decay chain $t\to b\,H^+$, $H^+\to W^+A^0$, $A^0\to \tau^+\tau^-$ with $m_{A^0}^{--}$ between 4 and 9 GeV. See their Fig. 4 for limits on B($t
 ightarrow b\,H^+)$ for 90 $< m_{H^+}^{} <$ 160 GeV.
- 153 DESCHAMPS 10 make Type II two Higgs doublet model fits to weak leptonic and semileptonic decays, $b \to s \gamma$, B, B_s mixings, and $Z \to b \bar{b}$. The limit holds irrespective
- ¹⁵⁴ AALTONEN 09AJ search for $t \to bH^+$, $H^+ \to c\overline{s}$ in $t\overline{t}$ events in 2.2 fb⁻¹ of $p\overline{p}$ collisions at $E_{
 m cm}=1.96$ TeV. Upper limits on B(t
 ightarrow bH^+) between 0.08 and 0.32 (95% CL) are given for $m_{H^+}=$ 60–150 GeV and B($H^+\to c\, \overline{s})=1.$
- 155 ABAZOV 09AC search for $t \to bH^+$, $H^+ \to \tau^+ \nu$ in $t \overline{t}$ events in 0.9 fb $^{-1}$ of $p \overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. Upper limits on B($t o bH^+$) between 0.19 and 0.25 (95% CL) are given for m_{H^+} = 80–155 GeV and B $(H^+ \to \tau^+ \nu)$ = 1. See their Fig. 4 for an excluded region in a MSSM scenario.
- 156 ABAZOV 09AG measure $t\overline{t}$ cross sections in final states with ℓ + jets (ℓ = e, μ), $\ell\ell$, and $au\ell$ in 1 fb $^{-1}$ of $p\,\overline{p}$ collisions at $E_{
 m cm}=1.96$ TeV, which constrains possible t bH^+ branching fractions. Upper limits (95% CL) on B($t \rightarrow bH^+$) between 0.15 and 0.40 (0.48 and 0.57) are given for B($H^+ \to \tau^+ \nu$) = 1 (B($H^+ \to c \overline{s}$) = 1) for m_{H^+} 80-155 GeV.
- 157 = 80-155 GeV.

 157 ABAZOV 09AI search for $t \to bH^+$ in $t\,\overline{t}$ events in 1 fb $^{-1}$ of $\rho\overline{\rho}$ collisions at $E_{\rm CM}=1.96$ TeV. Final states with $\ell+$ jets ($\ell=e,\mu$), $\ell\ell$, and $\tau\ell$ are examined. Upper limits on B(t ightarrow $b\,H^+$) (95% CL) between 0.15 and 0.19 (0.19 and 0.22) are given for B(H^+ ightarrow $\tau^+ \,
 u) = 1 \, (B(H^+ \to c \, \overline{s}) = 1) \, \text{for} \, m_{H^+} = 80 \text{--} 155 \, \text{GeV. For} \, B(H^+ \to \tau^+ \,
 u) = 1 \, (B(H^+ \to c \, \overline{s}) = 1) \, \text{for} \, m_{H^+} = 80 \text{--} 155 \, \text{GeV.}$ also a simultaneous extraction of B($t \to bH^+$) and the $t\bar{t}$ cross section is performed, yielding a limit on B($t
 ightarrow bH^+$) between 0.12 and 0.26 for $m_{H^+} =$ 80–155 GeV. See
- their Figs. 5–8 for excluded regions in several MSSM scenarios. 158 ABAZOV 09P search for H^+ production by $q \, \overline{q}^\prime$ annihilation followed by $H^+ \to t \, \overline{b}$ ABACOV 697 sealer for $p_{\overline{p}}$ collisions at $E_{\rm cm}=1.96$ TeV. Cross section limits in several two-doublet models are given for $m_{H^+}=180$ –300 GeV. A region with $20\lesssim \tan\beta\lesssim 70$ is excluded (95% CL) for 180 GeV $\lesssim m_{H^+}\lesssim 184$ GeV in type-I models.
- 159 FLACHER 09 make Type II two Higgs doublet model fits to weak leptonic and semileptonic decays, $b\to s\gamma$, and $Z\to b\,\bar{b}$. The limit holds irrespective of $\tan\beta$. 160 ABULENCIA 06E search for associated H^0 W production in $\rho\overline{\rho}$ collisions at $E_{\rm CM}=1.96$
- TeV. A fit is made for $t\overline{t}$ production processes in dilepton, lepton + jets, and lepton + aufinal states, with the decays $t \to W^+ b$ and $t \to H^+ b$ followed by $H^+ \to \tau^+ \nu$, $c \, \overline{s}$, $t^*\overline{b}$, or W^+H^0 . Within the MSSM the search is sensitive to the region $\tan \beta < 1$ or > 30 in the mass range $m_{H^+}=$ 80–160 GeV. See Fig. 2 for the excluded region in a
- certain MSSM scenario. H⁺
 161 ABDALLAH 04I search for $e^+e^- \rightarrow H^+H^-$ with H^\pm decaying to $\tau\nu$, cs, or W^*A^0 in Type-I two-Higgs-doublet models.
- $_{
 m 162\,ABBIENDI~03}$ give a limit $m_{H^+}>1.28{
 m tan}eta$ GeV (95%CL) in Type II two-doublet
- 163 ABAZOV 02B search for a charged Higgs boson in top decays with $H^+
 ightarrow ~ au^+
 u$ at $E_{
 m cm}=$ 1.8 TeV. For $m_{H^+}=$ 75 GeV, the region aneta> 32.0 is excluded at 95%CL. The
- excluded mass region extends to over 140 GeV for $\tan \beta$ values above 100. 164 BORZUMATI 02 point out that the decay modes such as $b\overline{b}$ W, A^0 W, and supersymmetric ones can have substantial branching fractions in the mass range explored at LEP II
- and Tevatron. 165 ABBIENDI 01Q give a limit $\tan\beta/m_{H^+} <$ 0.53 GeV $^{-1}$ (95%CL) in Type II two-doublet
- models. 166 BARATE 01E give a limit $\tan\beta/m_{H^+} <$ 0.40 GeV $^{-1}$ (90% CL) in Type II two-doublet models. An independent measurement of $B o au
 u_ au$ X gives $aneta/m_{H^+} < 0.49~ ext{GeV}^{-1}$ (90% CL)
- 167 GAMBINO 01 use the world average data in the summer of 2001 B($b
 ightarrow s \gamma$)= (3.23 \pm $0.42) \times 10^{-4}$. The limit applies for Type-II two-doublet models.
- 168 AFFOLDER (0) search for a charged Higgs boson in top decays with $H^+ \to \tau^+ \nu$ in $p\overline{p}$ collisions at $E_{\rm cm} = 1.8$ TeV. The excluded mass region extends to over 120 GeV for $\tan eta$ values above 100 and B(au
 u)=1. If B $(t o bH^+) \gtrsim$ 0.6, m_{H^+} up to 160 GeV is excluded. Updates ABE 97L.
- 169 ABBOTT 99E search for a charged Higgs boson in top decays in $\rho \overline{\rho}$ collisions at $E_{\rm CM} = 1.8$ TeV, by comparing the observed $t\overline{t}$ cross section (extracted from the data assuming the dominant decay $t\to b\,W^+)$ with theoretical expectation. The search is sensitive to regions of the domains $\tan\!\beta\!\lesssim\!1$, $50<\!m_{H^+}({\rm GeV})\lesssim\!120$ and $\tan\!\beta\!\lesssim\!40$, $50<\!m_{H^+}$
- (GeV) \lesssim 160. See Fig. 3 for the details of the excluded region. $170~{\sf ACKERSTAFF}$ 99D measure the Michel parameters ρ , ξ , η , and $\xi\delta$ in leptonic τ decays from $Z \to \tau \tau$. Assuming $e - \mu$ universality, the limit $m_{H^+} > 0.97 \, {\rm tan} \beta$ GeV (95%CL) is obtained for two-doublet models in which only one doublet couples to leptons.
- 171 ACCIARRI 97F give a limit $m_{H^+}>2.6$ tan β GeV (90% CL) from their limit on the exclusive $B\to \tau \nu_T$ branching ratio.
- $172\,\mathrm{A\,MMAR}$ 97B measure the Michel parameter ho from au o $e\,
 u\,
 u$ decays and assumes e/μ universality to extract the Michel η parameter from $\tau \to \mu \nu \nu$ decays. The measurement is translated to a lower limit on m_{H^+} in a two-doublet model $m_{H^+} > 0.97$ tan β GeV
- 173 COARASA 97 reanalyzed the constraint on the $(m_{H^\pm}, \tan\beta)$ plane derived from the inclusive $B \to \tau \nu_{\tau} X$ branching ratio in GROSSMAN 95B and BUSKULIC 95. They show that the constraint is quite sensitive to supersymmetric one-loop effects.
- 174 GUCHAIT 97 studies the constraints on m_{H^+} set by Tevatron data on ℓau final states in
- $t\overline{t} o (Wb)(Hb), W o \ell
 u, H o au_{
 u}^{H^+}$. See Fig. 2 for the excluded region. 175 MANGANO 97 reconsiders the limit in ACCIARRI 97F including the effect of the potentially large $B_C o au
 u_{
 u}^{T}$ background to $B_U o au
 u_{
 u}^{T}$ decays. Stronger limits are obtained.
- $^{176}\,\mathrm{STAHL}$ 97 fit τ lifetime, leptonic branching ratios, and the Michel parameters and derive limit $m_{H^+}>1.5~{
 m tan}eta~{
 m GeV}$ (90% CL) for a two-doublet model. See also STAHL 94.
- 177 ALAM 95 measure the inclusive $b o s \gamma$ branching ratio at $\varUpsilon(4S)$ and give B(b $s\gamma$) < 4.2 × 10⁻⁴ (95% CL), which translates to the limit m_{H^+} >[244 + 63/(tan β) $^{1.3}$] GeV in the Type II two-doublet model. Light supersymmetric particles can invalidate this
- 178 BUSKULIC 95 give a limit $m_{H^+}>1.9~{
 m tan}eta$ GeV (90% CL) for Type-II models from $b \to \tau \nu_{\tau} X$ branching ratio, as proposed in GROSSMAN 94.

Gauge & Higgs Boson Particle Listings

Higgs Bosons — H^0 and H^{\pm}

– MASS LIMITS for $H^{\pm\pm}$ (doubly-charged Higgs boson) \cdot

This section covers searches for a doubly-charged Higgs boson with couplings to lepton pairs. Its weak isospin T_3 is thus restricted to two possibilities depending on lepton chiralities: $T_3(H^{\pm\pm})=\pm 1$, with the coupling $g_{\ell\ell}$ to $\ell_L^-\ell_L^{\prime-}$ and $\ell_R^+\ell_R^{\prime+}$ ("left-handed") and $T_3(H^{\pm\pm})=0$, with the coupling to $\ell_R^-\ell_L'^-$ and $\ell_L^+\ell_L'^+$ ("right-handed"). These Higgs bosons appear in some left-right symmetric models based on the gauge group $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R \times \mathrm{U}(1).$ These two cases are listed separately in the following lowing. Unless noted, one of the lepton flavor combinations is assumed to be dominant in the decay.

LIMITS for $H^{\pm\pm}$ with $T_3=\pm1$

| | | · · • —- | | | |
|-----------------------------------|---------|-------------------------|--------|-------------|------------------------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| >128 | 95 | 179 ABAZOV | 12A | D0 | $\tau \tau$ |
| >144 | 95 | ¹⁷⁹ ABAZOV | 12A | D0 | $\mu \tau$ |
| >245 | 95 | ¹⁸⁰ AALTONEN | 11AF | CDF | $\mu\mu$ |
| >210 | 95 | ¹⁸⁰ AALTONEN | 11AF | CDF | $e\mu$ |
| >225 | 95 | ¹⁸⁰ AALTONEN | 11AF | CDF | e e |
| >114 | 95 | ¹⁸¹ AALTONEN | 08AA | CDF | e	au |
| >112 | 95 | ¹⁸¹ AALTONEN | 08AA | CDF | $\mu \tau$ |
| >168 | 95 | ¹⁸² ABAZOV | 08∨ | D0 | $\mu\mu$ |
| > 98.1 | 95 | ¹⁸³ ABDALLAH | 03 | DLPH | au	au |
| > 99.0 | 95 | ¹⁸⁴ ABBIENDI | 02c | OPAL | au	au |
| ● ● We do not | use the | following data for a | verage | es, fits, l | imits, etc. • • • |
| | | ¹⁸⁵ AKTAS | 06A | H1 | single $H^{\pm\pm}$ |
| >133 | 95 | ¹⁸⁶ ACOSTA | 05 L | CDF | stable |
| >118.4 | 95 | ¹⁸⁷ ABAZOV | 04 E | D0 | $\mu\mu$ |
| >136 | 95 | ¹⁸⁸ ACOSTA | 04 G | CDF | $\mu\mu$ |
| | | ¹⁸⁹ ABBIENDI | 03 Q | OPAL | $E_{\rm cm} \leq$ 209 GeV, single $H^{\pm\pm}$ |
| | | ¹⁹⁰ GORDEEV | 97 | SPEC | muonium conversion |
| | | ¹⁹¹ ASAKA | 95 | THEO | |
| > 45.6 | 95 | ¹⁹² ACTON | 92M | OPAL | |
| > 30.4 | 95 | ¹⁹³ ACTON | 92M | OPAL | |
| none 6.5-36.6 | 95 | ¹⁹⁴ SWARTZ | 90 | MRK2 | |
| | | | | | |

- 179 ABAZOV 12A search for $H^{++}H^{--}$ production in 7.0 fb $^{-1}$ of $p\overline{p}$ collisions at $E_{\rm cm}=$
- ¹⁸⁰ AALTONEN 11AF search for $H^{++}H^{--}$ production in 6.1 fb⁻¹ of $p\overline{p}$ collisions at E_{cm}
- 181 AALT ONEN 08AA search for $H^{++}H^{--}$ production in $p\overline{p}$ collisions at $E_{cm}=1.96$ TeV.
- The limit assumes 100% branching ratio to the specified final state. 182 ABAZOV 08v search for $H^{++}H^{--}$ production in $p\overline{p}$ collisions at $E_{\rm Cm}=1.96$ TeV. The limit is for B($H\to\mu\mu$) = 1. The limit is updated in ABAZOV 12A.
- 183 ABDALLAH 03 search for $^{\prime\prime}H^{++}H^{--}$ pair production either followed by $^{\prime\prime}H^{++}$ $^{\prime\prime}$ au^+ , or decaying outside the detector.
- 184 ABBIENDI 02c searches for pair production of $H^{++}H^{--}$, with $H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$ (ℓ,ℓ' $=e,\mu, au$). The limit holds for $\ell{=}\ell'{=} au$, and becomes stronger for other combinations of leptonic final states. To ensure the decay within the detector, the limit only applies for $g(H\ell\ell)\gtrsim 10^{-7}$.
- 185 AKTAS 06 A search for single $H^{\pm\pm}$ production in ep collisions at HERA. Assuming that H^{++} only couples to $e^+\mu^+$ with $g_{e\,\mu}=$ 0.3 (electromagnetic strength), a limit $m_{H^{++}} >$ 141 GeV (95% CL) is derived. For the case where H^{++} couples to e au only the limit is 112 GeV.
- ¹⁸⁶ ACOSTA 05L search for $H^{++}H^{--}$ pair production in $p\overline{p}$ collisions. The limit is valid for $g_{\ell\ell'} < 10^{-8}$ so that the Higgs decays outside the detector.
- 187 ABAZOV 04E search for $H^{++}H^{--}$ pair production in $H^{\pm\pm}\to~\mu^\pm\,\mu^\pm$. The limit is valid for $g_{\mu\mu}\gtrsim 10^{-7}$.
- $^{9\mu\mu}\sim$ 188 ACOSTA 04c search for $H^{++}H^{--}$ pair production in $p\overline{p}$ collisions with muon and electron final states.The limit holds for $\mu\mu$. For $e\,e$ and $e\,\mu$ modes, the limits are 133 and 115 GeV, respectively. The limits are valid for $g_{\ell\ell'}\gtrsim 10^{-5}$. Superseded by AALTONEN 11AF.
- 189 ABBIENDI 03Q searches for single $H^{\pm\pm}$ via direct production in $e^+e^- \rightarrow e^\mp e^\mp H^{\pm\pm}$, ABBIENDI USQ searches for single H^{++} via direct production in $e^+e^- \to e^+e^-$, and via t-channel exchange in $e^+e^- \to e^+e^-$. In the direct case, and assuming $\mathsf{B}(H^{\pm\pm}\to\ell^\pm\ell^\pm)=1$, a 95% CL limit on $h_{ee}<0.071$ is set for $m_{H^{\pm\pm}}<160$ GeV (see Fig. 6). In the second case, indirect limits on h_{ee} are set for $m_{H^{\pm\pm}} <$ 2 TeV (see
- 190 GORDEEV 97 search for muonium-antimuonium conversion and find $G_{M\overline{M}}/G_F < 0.14$ (90% CL), where $G_{M\overline{M}}$ is the lepton-flavor violating effective four-fermion coupling. This limit may be converted to $m_{H^{++}}>$ 210 GeV if the Yukawa couplings of H^{++} to ee and $\mu\mu$ are as large as the weak gauge coupling. For similar limits on muonium-antimuonium conversion, see the muon Particle Listings.
- 191 ASAKA 95 point out that H^{++} decays dominantly to four fermions in a large region of parameter space where the limit of ACTON 92M from the search of dilepton modes does
- 192 ACTON 92M limit assumes $H^{\pm\pm}\to \ell^\pm\ell^\pm$ or $H^{\pm\pm}$ does not decay in the detector. Thus the region $g_{\ell\ell}\approx 10^{-7}$ is not excluded.
- 193 ACTON 92M from $\Delta\Gamma_Z$ <40 MeV. 194 SWARTZ 90 assume $H^{\pm\pm} \to \ell^{\pm}\ell^{\pm}$ (any flavor). The limits are valid for the Higgslepton coupling $g(H\ell\ell) \gtrsim 7.4 \times 10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

LIMITS for $H^{\pm\pm}$ with $T_3=0$

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|-------------------------|------|------|-----------|
| >113 | 95 | 195 ABAZOV | 12A | D0 | $\mu\tau$ |
| >205 | 95 | ¹⁹⁶ AALTONEN | 11AF | CDF | $\mu\mu$ |
| >190 | 95 | ¹⁹⁶ AALTONEN | 11AF | CDF | e μ |
| >205 | 95 | ¹⁹⁶ AALTONEN | 11AF | CDF | e e |
| >145 | 95 | ¹⁹⁷ ABAZOV | 08v | D0 | $\mu\mu$ |
| > 97.3 | 95 | ¹⁹⁸ ABDALLAH | 03 | DLPH | au	au |
| > 97.3 | 95 | ¹⁹⁹ ACHARD | 03F | L3 | au	au |
| > 98.5 | 95 | ²⁰⁰ ABBIENDI | 02c | OPAL | au	au |
| | | | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | ²⁰¹ AKTAS | 06A I | H1 | single $H^{\pm\pm}$ |
|---------------|----|-------------------------|--------|------|------------------------------------------------|
| >109 | 95 | ²⁰² ACOSTA | 05 L (| | stable |
| > 98.2 | 95 | ²⁰³ ABAZOV | 04 E | D0 | $\mu\mu$ |
| >113 | 95 | ²⁰⁴ ACOSTA | 04 G | CDF | $\mu\mu$ |
| | | ²⁰⁵ ABBIENDI | 03Q (| OPAL | $E_{\rm cm} \leq$ 209 GeV, single $H^{\pm\pm}$ |
| | | ²⁰⁶ GORDEEV | 97 5 | SPEC | muonium conversion |
| > 45.6 | 95 | ²⁰⁷ ACTON | 92M (| OPAL | |
| > 25.5 | 95 | ²⁰⁸ ACTON | 92M (| OPAL | |
| none 7.3-34.3 | 95 | ²⁰⁹ SWART Z | 90 | MRK2 | |

- 195 ABAZOV 12A search for $H^{++}H^{--}$ production in 7.0 fb $^{-1}$ of $p\,\overline{p}$ collisions at $E_{\rm cm}=$
- 196 AALTONEN 11AF search for $H^{++}H^{--}$ production in 6.1 fb⁻¹ of $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV.
- 197 a BAZOV 08v search for $H^{++}H^{--}$ production in $\rho\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. The limit is for B($H\to\mu\mu$) = 1. The limit is updated in ABAZOV 12A. 198 ABDALLAH 03 search for $H^{++}H^{--}$ pair production either followed by $H^{++}\to 1.00$
- $au^+ au^+$, or decaying outside the detector.
- 199 ACHARD 03F search for $e^+e^- \to H^{++}H^{--}$ with $H^{\pm\pm} \to \ell^\pm\ell'^\pm$. The limit holds for $\ell=\ell'=\tau$, and slightly different limits apply for other flavor combinations. The limit is valid for $g_{\ell\ell'}\gtrsim 10^{-7}$.
- ²⁰⁰ ABBIENDI 02c searches for pair production of $H^{++}H^{--}$, with $H^{\pm\pm}\to \ell^\pm\ell^\pm$ (ℓ,ℓ' $=e,\mu, au$). the limit holds for $\ell=\ell'= au$, and becomes stronger for other combinations of leptonic final states. To ensure the decay within the detector, the limit only applies for $g(H\ell\ell) \gtrsim 10^{-7}$
- 201 AKTAS 06 A search for single $^{\pm\pm}$ production in ep collisions at HERA. Assuming that H^{++} only couples to $e^+\mu^+$ with $g_{e\,\mu}=$ 0.3 (electromagnetic strength), a limit $m_{H^{++}}~>141$ GeV (95% CL) is derived. For the case where H^{++} couples to $e\tau$ only the limit is 112 GeV.
- 202 ACOSTA 05L search for $H^{++}H^{--}$ pair production in $p\overline{p}$ collisions. The limit is valid for $g_{pp'} < 10^{-8}$ so that the Higgs decays outside the detector.
- 203 ABAZOV 04E search for $H^{++}H^{--}$ pair production in $H^{\pm\pm}\to \mu^{\pm}\mu^{\pm}$. The limit is valid for $g_{\mu\mu}\gtrsim 10^{-7}$
- 204 ACOSTA 04G search for $H^{++}H^{--}$ pair production in $p\bar{p}$ collisions with muon and
- ACOSIA 046 Search for H^+H^- pair production in pp collisions with muon and electron final states. The limit holds for $\mu\mu$. Superseded by AALTONEN 11AF. 205 ABBIENDI 030 searches for single $H^{\pm\pm}$ via direct production in $e^+e^- \rightarrow e^+e^+H^{\pm\pm}$, and via t-channel exchange in $e^+e^- \rightarrow e^+e^-$. In the direct case, and assuming $B(H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}) = 1$, a 95% CL limit on $h_{ee} < 0.071$ is set for $m_{H^{\pm\pm}} < 160$ GeV (see Fig. 6). In the second case, indirect limits on h_{ee} are set for $m_{H^{\pm\pm}}^{~~11}$ < 2 TeV (see
- 206 GORDEEV 97 search for muonium-antimuonium conversion and find $G_{M\overline{M}}/G_F < 0.14$ (90% CL), where $G_{\overline{MM}}$ is the lepton-flavor violating effective four-fermion coupling. This limit may be converted to $m_{H^{++}} > 210$ GeV if the Yukawa couplings of H^{++} to ee and $\mu\mu$ are as large as the weak gauge coupling. For similar limits on muonium-antimuonium conversion, see the muon Particle Listings. 2^{07} ACTON 92M limit assumes $H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$ or $H^{\pm\pm}$ does not decay in the detector.
- Thus the region $g_{\ell\ell} \approx 10^{-7}$ is not excluded.
- 208 ACTON 92M from $\Delta\Gamma_Z$ <40 MeV. 209 SWARTZ 90 assume $H^{\pm\pm}\to \ell^\pm\ell^\pm$ (any flavor). The limits are valid for the Higgslepton coupling $g(H\ell\ell)\gtrsim 7.4\times 10^{-7}/[m_H/\text{GeV}]^{1/2}$. The limits improve somewhat for ee and $\mu\mu$ decay modes.

H⁰ and H[±] REFERENCES

| AAD | 12 | PL B707 27 | G. Aad et al. | (ATLAS | Collab.) |
|------------|------|----------------|---------------------------|---------|----------|
| AAD | 12 D | PL B710 383 | G. Aad et al. | (AT LAS | Collab.) |
| AAD | 12 E | PL B710 49 | G. Aad et al. | (AT LAS | Collab.) |
| AAD | 12 F | PRL 108 111802 | G. Aad et al. | ATLAS | Collab.) |
| AAD | 12 G | PRL 108 111803 | G. Aad et al. | (AT LAS | Collab.) |
| AALTONEN | 12 | PRL 108 011801 | T. Aaltonen et al. | ` (CDF | Collab.) |
| ABAZOV | 12 | PL B707 323 | V.M. Abazov et al. | (D0 | Collab.) |
| ABAZOV | 12A | PRL 108 021801 | V.M. Abazov et al. | (D0 | Collab.) |
| CHATRCHYAN | 12B | PL B710 26 | S. Chatrchyan et al. | (CMS | Collab.) |
| CHATRCHYAN | 12 C | JHEP 1203 081 | S. Chatrchyan et al. | (CMS | Collab.) |
| CHATRCHYAN | 12 D | JHEP 1204 036 | S. Chatrchyan et al. | (CMS | Collab.) |
| CHATRCHYAN | | PL B710 91 | S. Chatrchyan et al. | | Collab.) |
| CHATRCHYAN | 12 F | PL B710 284 | S. Chatrchyan et al. | (CMS | Collab.) |
| CHATRCHYAN | | PL B710 403 | S. Chatrchyan et al. | | Collab.) |
| CHATRCHYAN | 12 H | PRL 108 111804 | S. Chatrchyan et al. | (CMS | Collab.) |
| CHATRCHYAN | 121 | JHEP 1203 040 | S. Chatrchyan et al. | (CMS | Collab.) |
| AAD | 11AB | PRL 107 231801 | G. Aad et al. | (ATLAS | |
| AAD | 11R | PL B705 174 | G. Aad et al. | (ATLAS | Collab.) |
| AAD | 11T | PL B705 435 | G. Aad et al. | (ATLAS | Collab.) |
| AAD | 11 U | PL B705 452 | G. Aad et al. | (ATLAS | |
| AAD | 11V | PRL 107 221802 | G. Aad et al. | (ATLAS | |
| AAD | 11W | EPJ C71 1728 | G. Aad et al. | (ATLAS | |
| AALTONEN | | PR D84 052010 | T. Aaltonen <i>et al.</i> | | Collab.) |
| AALTONEN | | PRL 107 181801 | T. Aaltonen <i>et al.</i> | | Collab.) |
| AALTONEN | 11P | PRL 107 031801 | T. Aaltonen <i>et al.</i> | | Collab.) |
| ABAZOV | | PR D84 092002 | V.M. Abazov et al. | | Collab.) |
| ABAZOV | 11 G | PRL 106 171802 | V.M. Abazov et al. | | Collab.) |
| ABAZOV | 11J | PL B698 6 | V.M. Abazov et al. | | Collab.) |
| ABAZOV | 11K | PL B698 97 | V.M. Abazov et al. | | Collab.) |
| ABAZOV | 11W | PRL 107 121801 | V.M. Abazov et al. | (D0 | Collab.) |

Gauge & Higgs Boson Particle Listings

Higgs Bosons — H^0 and H^{\pm} , Heavy Bosons Other than Higgs Bosons

| ABAZOV 11Y | DDI 107 151901 | V.M. Abazou et al | (D0 Collab.) |
|-------------------------------------------|----------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------|
| ABOUZAID 11A | PRL 107 151801 PRL 107 201803 | V.M. Abazov et al. E. Abouzaid et al. | (D0 Collab.) (KTeV Collab.) |
| CHATRCHYAN 11H CHATRCHYAN 11J | PRL 106 231801 PL B699 25 | S. Chatrohyan et al. S. Chatrohyan et al. | (CMS Collab.) (CMS Collab.) |
| DEL-AMO-SA 11J | PRL 107 021804 | P. del Amó Sanchez et al. J.P. Lees et al. | (BABAR Collb.) |
| AALTONEN 10AD | PRL 107 221803 PRL 105 251802 | T. Aaltonen et al. | (BABAR Collab.) (CDF Collab.) (CDF and DO Collab.) |
| AALTONEN 10F AALTONEN 10G | PRL 104 061802 PRL 104 061803 | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> | (CDF and D0 Collab.) (CDF Collab.) |
| AALT ONEN 10 J | PRL 104 141801 | T. Aaltonen <i>et al</i> . | (CDF Collab.) |
| AALTONEN 10 M ABAZOV 10 B | PR D82 011102R PRL 104 061804 | T. Aaltonen <i>et al.</i> V.M. Abazov <i>et al.</i> | (CDF and D0 Collab.) (D0 Collab.) |
| ABAZOV 10 C | PRL 104 061804 PRL 104 071801 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) (D0 Collab.) |
| ABAZOV 10D ABAZOV 10T | PRL 104 151801 PRL 105 251801 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) |
| ABBIENDI 10 ANDREAS 10 DESCHAMPS 10 | PL B682 381 JHEP 1008 003 | G. Abbiendi et al. S. Andreas et al. | (OPAL Collab.) |
| | PR D82 073012 | O. Deschamps et al. | (DESY) (CLER, ORSAY, LAPP) (UNAM) |
| ERLER 10A HYUN 10 | PR D81 051301 PRL 105 091801 | J. Erler H.J. Hyun <i>et al</i> . | (BELLE Collab.) |
| SCHAEL 10 AALTONEN 09A | JHEP 1005 049 PRL 102 021802 | S. Schael et al. | (ÀLEPH Collab.) (CDF Collab.) |
| AALTONEN 09AB | PRL 103 061803 | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> | (CDF Collab.) |
| AALTONEN 09AG AALTONEN 09AI | PR D80 012002 PRL 103 101802 | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> | (CDF Collab.) (CDF Collab.) (CDF Collab.) |
| AALTONEN 09AJ | PRL 103 101803 | T. Aaltonen <i>et al</i> . | (CDF Collab.) |
| | PR D80 071101R PRL 103 201801 | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> | (CDF Collab.) (CDF Collab.) |
| AALTONEN 09AS | PRL 103 221801 PR D80 051107R | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> V.M. Abazov <i>et al.</i> | (CDF Collab.) (CDF Collab.) (D0 Collab.) |
| ABAZOV 09AG | PR D80 071102R | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 09AI ABAZOV 09C | PL B682 278 PRL 102 051803 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) (D0 Collab.) |
| ABAZOV 09F | PRL 102 051804 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 09P ABAZOV 09Q | PRL 102 051804 PRL 102 191802 PRL 102 231801 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) (D0 Collab.) |
| ABAZOV 09U | PRL 102 251801 | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 09V AUBERT 09P | PRL 103 061801 PRL 103 181801 | V.M. Abazov et al. B. Aubert et al. | (DO Collab.) (BABAR Collab.) |
| AUBERT 09Z FLACHER 09 | PRL 103 181801 PRL 103 081803 EPJ C60 543 | B. Aubert et al. H. Flacher et al. | (BABAR Collab.) |
| TUNG 09 | PRL 102 051802 | Y.C. Tung et al. | (CERN, DESY, HAMB) (KEK E391a Collab.) |
| AALTONEN 08AA AALTONEN 08X | PRL 101 121801 PRL 100 211801 | T. Aaltonen <i>et al.</i> T. Aaltonen <i>et al.</i> | (CDF Collab.) (CDF Collab.) |
| ABAZOV 08AJ | PRL 101 221802 | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 08AC ABAZOV 08U | PRL 101 221802 PRL 101 251802 PRL 101 051801 | V.M. Abazov et al. V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) (D0 Collab.) |
| ABAZOV 08V | PRL 101 071803 | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 08W ABAZOV 08Y | PRL 101 071804 PL B663 26 | V.M. Abazov et al. V.M. Abazov et al. | (D0 Collab.) (D0 Collab.) |
| ABDALLAH 08B Also | EPJ C54 1 EPJ C56 165 (errat) | J. Abdallah <i>et al.</i> J. Abdallah <i>et al.</i> | (DELPHI Collab.) (DELPHI Collab.) |
| LOVE 08 | PRL 101 151802 | W. Love et al. | (CLEO Collab.) |
| ABAZOV 07X ABBIENDI 07 | PL B655 209 EPJ C49 457 | V.M. Abazov et al. G. Abbiendi et al. | (D0 Collab.) (OPAL Collab.) |
| BESS ON 07 | PRL 98 052002 | D. Besson et al. | (CLEO Collab.) |
| SCHAEL 07 ABAZOV 06 | EPJ C49 439 PRL 96 011801 | S. Schael et al. V.M. Abazov et al. | (ALEPH Collab.) (D0 Collab.) |
| ABAZOV 060 | PRL 97 151804 | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV 06Q ABULENCIA 06E | PRL 97 161803 PRL 96 042003 | V.M. Abazov et al. A. Abulencia et al. | (D0 Collab.) (CDF Collab.) |
| AKTAS 06A LEP-SLC 06 | PL B638 432 PRPL 427 257 | A. Aktas et al. ALEPH DELPHI I 3 OPAL | (H1 Collab.) |
| SCHAEL 06B | EPJ C47 547 | ALEPH, DELPHI, L3, OPAL, S. Schael et al. | (LEP Collabs.) |
| ABBIENDI 05A ABDALLAH 05D | EPJ C40 317 EPJ C44 147 | G. Abbiendi et al. J. Abdallah et al. | (ÖPAL Collab.) (DELPHI Collab.) |
| ACHARD 05 | PL B609 35 | P. Achard et al. | (L3 Collab.) (CDF Collab.) (CDF Collab.) |
| ACOSTA 05L ACOSTA 05Q | PRL 95 071801 PR D72 072004 | D. Acosta et al. D. Acosta et al. | (CDF Collab.) |
| PARK 05 ABAZOV 04E | PRL 94 021801 PRL 93 141801 | H.K. Park et al. V.M. Abazov et al. | (FNAL HyperCP Collab.) (D0 Collab.) |
| ABBIENDI 04 | EPJ C32 453 | G. Abbiendi <i>et al.</i> | (OPAL Collab.) |
| ABBIENDI 04K ABBIENDI 04M | PL B597 11 EPJ C37 49 | G. Abbiendi <i>et al.</i> G. Abbiendi <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ABDALLAH 04 | EPJ C32 145 | J. Abdallah et al. | (DELPHI Collab.) |
| ABDALLAH 04B ABDALLAH 04I | EPJ C32 475 EPJ C34 399 | J. Abdallah et al. J. Abdallah et al. | (DELPHI Collab.) (DELPHI Collab.) |
| ABDALLAH 04L ABDALLAH 04O | EPJ C35 313 EPJ C38 1 | J. Abdallah <i>et al.</i> J. Abdallah <i>et al.</i> | (DELPHI Collab.) (DELPHI Collab.) |
| ACHARD 04B | PL B583 14 | P. Achard et al. | ` (L3 Collab.) |
| ACHARD 04F ACOSTA 04G | PL B589 89 PRL 93 221802 | P. Achard et al. D. Acosta et al. | (L3 Collab.) (CDF Collab.) |
| ABBIENDI 03 | PL B551 35 | G. Abbiendi et al. | (ÒPAL Collab.) |
| ABBIENDI 03B ABBIENDI 03F | EPJ C26 479 EPJ C27 311 | G. Abbiendi <i>et al.</i> G. Abbiendi <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ABBIENDI 03 G ABBIENDI 03 Q | EPJ C27 483 PL B577 93 | G. Abbiendi <i>et al.</i> G. Abbiendi <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ABDALLAH 03 | PL B552 127 | J. Abdallah et al. | (DELPHI Collab.) |
| ACHARD 03 C ACHARD 03 E | PL B568 191 PL B575 208 | P. Achard et al. P. Achard et al. | (L3 Collab.) (L3 Collab.) |
| ACHARD 03F | PL B576 18 EPJ C26 601 | P. Achard et al. P. Achard et al. M.S. Garage et al. | (L3 Collab.) |
| HEISTER 03D | PL B565 61 | M.S. Carena et al. A. Heister et al. | (ALEPH, DELPHI, L3+) |
| ALEPH, DELPHI ABAZOV 02B | , L3, OPAL, LEP Higgs \ PRL 88 151803 | Vorking Group V.M. Abazov et al. | (D0 Collab) |
| ABBIENDI 02C | PL B526 221 | G. Abbiendi <i>et al</i> . | (D0 Collab.) (OPAL Collab.) |
| ABBIENDI 02D ABBIENDI 02F | EPJ C23 397 PL B544 44 | G. Abbiendi <i>et al.</i> G. Abbiendi <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ACHARD 02 C ACHARD 02 H | PL B534 28 PL B545 30 | P. Achard et al. P. Achard et al. | ` (L3 Collab.) (L3 Collab.) |
| AKEROYD 02 | PR D66 037702 | A.G. Akeroyd <i>et al.</i> F.M. Borzumati, A. Djouadi | (ES CONAU.) |
| BORZUMATI 02 HEISTER 02 | PL B549 170 PL B526 191 | F.M. Borzumati, A. Djouadi A. Heister <i>et al</i> . | (ALEPH Collab.) |
| HEISTER 02L | PL B544 16 | A. Heister et al. | (ALEPH Collab.) |
| HEISTER 02M HEISTER 02P | PL B544 25 PL B543 1 | A. Heister et al. A. Heister et al. | (ALEPH Collab.) (ALEPH Collab.) |
| ABBIENDI 01E ABBIENDI 01Q | EPJ C18 425 PL B520 1 | G. Abbiendi <i>et al.</i> G. Abbiendi <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ABREU 01F | PL B507 89 | P. Abreu et al. | (DELPHI Collab.) |
| ACHARD 01C AFFOLDER 01H | PL B517 319 PR D64 092002 | P. Achard et al. T. Affolder et al. | (L3 Collab.) (CDF Collab.) |
| BARATE 01C | PL B499 53 EPJ C19 213 | T. Affolder et al. R. Barate et al. R. Barate et al. | (ALEPH Collab.) (ALEPH Collab.) |
| GAMBINO 01 | NP B611 338 | P. Gambino, M. Misiak | |
| ACCIARRI 00 M ACCIARRI 00 R | PL B485 85 PL B489 102 | M. Acciarri <i>et al.</i> M. Acciarri <i>et al.</i> | (L3 Collab.) (L3 Collab.) |
| ACCIARRI 00S | PL B489 115 | M. Acciarri et al. | (L3 Collab.) |
| AFFOLDER 001 BARATE 00L | PR D62 012004 PL B487 241 | T. Affolder et al. R. Barate et al. | (CDF Collab.) (ALEPH Collab.) |
| PDG 00 ABBIENDI 99E | EPJ C15 1 EPJ C7 407 | D.E. Groom et al. G. Abbiendi et al. | (OPAL Collab.) |
| ABBIENDI 990 | PL B464 311 | G. Abbiendi et al. | (OPAL Collab.) |
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| CERN-TH/ ABBOTT ACKERS TAFF ACKERS TAFF GONZALEZ-G PDG | 98 98 S 98 Y | PRL 80 442 EPJ C5 19 PL B437 218 PR D57 7045 EPJ C3 1 | B. Abbott et al. K. Ackerstaff et al. K. Ackerstaff et al. M.C. Gonzalez-Garcia, S.M. Lietti, S.F C. Caso et al. | (D0 Collab.) (OPAL Collab.) (OPAL Collab.) . Novaes |
| ABE ACCIARRI AMMAR COARASA | 97 L 97 F 97 B 97 | PRL 79 357 PL B396 327 PRL 78 4686 PL B406 337 | C. Caso et al. F. Abe et al. M. Acciarri et al. R. Ammar et al. J.A. Coarasa, R.A. Jimenez, J. Sola | (CDF Collab.) (L3 Collab.) (CLEO Collab.) |
| GORDEEV | 97 | PAN 60 1164 Translated from | V.A. Gordeev et al. | (PNPI) |
| GUCHAIT KRAWCZYK MANGANO | 97 97 97 | PR D55 7263 PR D55 6968 PL B410 299 | M. Guchait, D.P. Roy M. Krawczyk, J. Zochowski M. Mangano, S. Slabospitsky | (TATA) (WARS) |
| STAHL ALEXANDER PDG | 97 96 H 96 | ZPHY C74 73 ZPHY C71 1 PR D54 1 | A. Stahl, H. Voss G. Alexander et al. R. M. Barnett et al. | (BONN) (OPAL Collab.) |
| ABREU ALAM ASAKA BUSKULIC GROSSMAN | 95 H 95 95 95 95 95 B | ZPHY C67 69 PRL 74 2885 PL B345 36 PL B343 444 PL B357 630 | P. Abreu <i>et al.</i> M.S. Alam <i>et al.</i> T. Asaka, K.I. Hikasa D. Buskulic <i>et al.</i> Y. Grossman, H. Haber, Y. Nir | (DELPHI Collab.) (CLEO Collab.) (TOHOK) (ALEPH Collab.) |
| GROSSMAN STAHL ACTON PICH SWARTZ | 94 94 92 M 92 90 | PL B332 373 PL B324 121 PL B295 347 NP B388 31 PRL 64 2877 | Y. Grossman, Z. Ligeti A. Stahl P.D. Acton <i>et al.</i> A. Pich, J. Prades, P. Yepes M.L. Swartz <i>et al.</i> | (BONN) (OPAL Collab.) (CERN, CPPM) (Mark II Collab.) |

Heavy Bosons Other Than Higgs Bosons, Searches for

We list here various limits on charged and neutral heavy vector bosons (other than W's and Z's), heavy scalar bosons (other than Higgs bosons), vector or scalar leptoquarks, and axigluons. The latest unpublished results are described in " W^\prime Searches" and " Z^\prime Searches" reviews

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Mass Limits for W' (Heavy Charged Vector Boson Other Than W) in Hadron Collider Experiments

 W_R (Right-Handed W Boson) Mass Limits

Limit on WL-WR Mixing Angle &

Mass Limits for Z' (Heavy Neutral Vector Boson Other Than Z)

- $\begin{array}{l} \text{ Limits for } Z_{\text{SM}}' \\ \text{ Limits for } Z_{LR}' \\ \text{ Limits for } Z_{\chi} \end{array}$

- Limits for Z_{ψ} Limits for Z_{ψ} Limits for Z_{η}
- Limits for other Z'

Indirect Constraints on Kaluza-Klein Gauge Bosons

Mass Limits for Leptoquarks from Pair Production

Mass Limits for Leptoquarks from Single Production Indirect Limits for Leptoquarks

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Mass Limits for a Heavy Neutral Boson Coupling to e^+e^- Search for X^0 Resonance in e^+e^- Collisions Search for X^0 Resonance in e^+e^- Dollisions Search for X^0 Resonance in Two-Photon Process Search for X^0 Resonance in $e^+e^- \to X^0 \gamma$

Search for X^0 Resonance in $e^+e^- o X^0$. Search for X^0 Resonance in $Z o f\overline{7}X^0$ Search for X^0 Resonance in $p\overline{p} o WX^0$ Heavy Particle Production in QHeavy Particle Production in Quarkonium Decays

W'-BOSON SEARCHES

Revised May 2012 by G. Brooijmans (Columbia University), M.-C. Chen (UC Irvine) and B.A. Dobrescu (Fermilab).

The W^\prime boson is a hypothetical massive particle of electric charge ± 1 and spin 1, which is predicted in various extensions of the Standard Model.

W' couplings to quarks and leptons. The Lagrangian terms describing couplings of a W'^+ boson to fermions are given by

$$\frac{W_{\mu}^{\prime+}}{\sqrt{2}}\Big[\overline{u}_{i}\Big(\!C_{q_{ij}}^{\rm R}P_{R}+C_{q_{ij}}^{\rm L}P_{L}\!\Big)\gamma^{\mu}d_{j}+\overline{\nu}_{i}\Big(\!C_{l_{ij}}^{\rm R}P_{R}+C_{l_{ij}}^{\rm L}P_{L}\!\Big)\gamma^{\mu}e_{j}\Big]\;. \eqno(1)$$

Here u, d, ν and e are the Standard Model fermions in the mass eigenstate basis, i, j = 1, 2, 3 label the fermion generation,

and $P_{R,L}=(1\pm\gamma_5)/2$. The coefficients $C^{\mathbf{t}}_{q_{ij}},\ C^{\mathbf{r}}_{q_{ij}},\ C^{\mathbf{t}}_{l_{ij}},\ C^{\mathbf{r}}_{l_{ij}}$ are complex dimensionless parameters. If $C^{\mathbf{r}}_{l_{ij}}\neq 0$, then the ith generation includes a right-handed neutrino. Using this notation, the Standard Model W couplings are $C^{\mathbf{t}}_{q}=gV_{\mathrm{CKM}},$ $C^{\mathbf{t}}_{l}=g$ and $C^{\mathbf{r}}_{q}=C^{\mathbf{r}}_{l}=0$.

Unitarity considerations imply that the W' is a gauge boson associated with a spontaneously-broken gauge symmetry. This is true even when it is a composite particle (e.g., techni- ρ^{\pm} in technicolor theories [1]) if its mass is much smaller than the compositeness scale, or a Kaluza-Klein mode in theories where the W boson propagates in extra dimensions [2]. The simplest extension of the electroweak gauge group that includes a W' boson is $SU(2)_1 \times SU(2)_2 \times U(1)$, but larger groups are encountered in some theories. A generic property of these gauge theories is that they also include a Z' boson; whether the W' boson can be discovered first depends on theoretical details.

The renormalizable photon-W' coupling is fixed by electromagnetic gauge invariance. By contrast, the W'WZ and W'W'Z couplings as well as the W' boson couplings to Z' or Higgs bosons are model-dependent.

A tree-level mass mixing may be induced between the electrically-charged gauge bosons. Upon diagonalization of their mass matrix, the W-Z mass ratio and the couplings of the observed W boson are shifted from the Standard Model values. Given that these are well measured, the W-W' mixing angle must be smaller than about 10^{-2} . Similarly, a Z-Z' mixing is induced in generic theories, leading to even tighter constraints. There are, however, theories in which these mixings are negligible (e.g., due to a new parity [3]), even when the W' and Z' masses are below the electroweak scale.

A popular model [4] is based on the "left-right symmetric" gauge group, $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, with the Standard Model fermions that couple to the W boson transforming as doublets under $SU(2)_L$, and the other ones transforming as doublets under $SU(2)_R$. In this model the W' boson couples primarily to the right-handed fermions, and its coupling to left-handed fermions arises solely due to W-W' mixing. As a result, C_q^t is proportional to the CKM matrix, and its elements are much smaller than the diagonal elements of C_q^R .

There are many other models based on the $SU(2)_1 \times SU(2)_2 \times U(1)$ gauge symmetry. In the "alternate left-right" model [5], all the couplings shown in Eq. (1) vanish, but there are some new fermions such that the W' boson couples to pairs involving a Standard Model fermion and a new fermion. In the "ununified Standard Model" [6], the left-handed quarks are doublets under one SU(2), and the left-handed leptons are doublets under a different SU(2), leading to a mostly leptophobic W' boson: $C^t_{lij} \ll C^t_{qij}$ and $C^R_{qij} = C^R_{lij} = 0$. Fermions of different generations may also transform as doublets under different SU(2) gauge groups [7]. In particular, the couplings to third generation quarks may be enhanced [8].

The W' couplings to Standard Model fermions may be highly suppressed if the quarks and leptons are singlets under one SU(2) [9], or if there are some vectorlike fermions that

mix with the Standard Model ones [10]. Gauge groups that embed the electroweak symmetry, such as $SU(3)_W \times U(1)$ or $SU(4)_W \times U(1)$, also include one or more W' bosons [11].

Collider searches. At LEP-II, W' bosons could have been produced in pairs via their photon and Z couplings. The production cross section depends only on the W' mass, and is large enough to rule out $M_{W'} \leq \sqrt{s}/2 \approx 105$ GeV for most patterns of decay modes.

At hadron colliders, W' bosons can be detected through resonant pair production of fermions or electroweak bosons. Assuming that the W' width is much smaller than its mass, the contribution of the s-channel W' boson exchange to the total rate for $pp \to f\bar{f}'X$, where f and f' are fermions whose electric charges differ by ± 1 , and X is any final state, may be approximated by the branching fraction $B(W' \to f\bar{f}')$ times the production cross section

$$\sigma(pp \to W'X) \simeq \frac{\pi}{48 s} \sum_{i,j} \left[(C_{q_{ij}}^{l})^{2} + (C_{q_{ij}}^{R})^{2} \right] w_{ij} \left(M_{W'}^{2} / s, M_{W'} \right).$$
(2)

The functions w_{ij} include the information about proton structure, and are given to leading order in α_s by

$$w_{ij}(z,\mu) = \int_{z}^{1} \frac{dx}{x} \left[u_{i}(x,\mu) \, \overline{d}_{j}\left(\frac{z}{x},\mu\right) + \overline{u}_{i}(x,\mu) \, d_{j}\left(\frac{z}{x},\mu\right) \right], \quad (3)$$

where $u_i(x,\mu)$ and $d_i(x,\mu)$ are the parton distributions inside the proton at the factorization scale μ for the up- and downtype quark of the *i*th generation, respectively. QCD corrections to W' production are sizable (they also include quark-gluon initial states), but preserve the above factorization of couplings at next-to-leading order [12].

The most commonly studied W' signal consists of a highenergy electron or muon and large missing transverse energy, with the transverse mass distribution forming a Jacobian peak with its endpoint at $M_{W'}$ (see Fig. 1 of Ref. 13) Given that the branching fractions for $W' \to e\nu$ and $W' \to \mu\nu$ could be very different, these channels should be analyzed separately. Searches in these channels often assume that the left-handed couplings vanish (no interference between W and W'), and that the right-handed neutrino of the first generation is light compared to $M_{W'}$ and escapes the detector. However, if a W'boson were discovered and the final state fermions have lefthanded helicity, then the effects of W-W' interference could be observed [14], providing useful information about the W'couplings.

In the $e\nu$ channel, the 95% CL limit set by the ATLAS Collaboration [13] with 1 fb⁻¹ of data on the cross section (at $\sqrt{s}=7$ TeV) times branching fraction is shown in Fig. 1. The CMS limit based on 5 fb⁻¹ of data in this channel [15], for $M_{W'}$ in the 0.5-3 TeV range, varies between 70 and 2.6 fb. For $M_{W'}$ in the 500-600 GeV range, the strongest limits on W' couplings are set by CDF [16] with 5.3 fb⁻¹ (for a comparison, see Fig. 3 of Ref. 13). The limits are much weaker for $M_{W'}$ in the 200-500 GeV range because these were obtained using only

The $t\bar{b}$ channel is particularly important because a W' boson that couples only to right-handed fermions cannot decay to leptons when the right-handed neutrinos are heavier than $M_{W'}$ (additional motivations are provided by a W' boson with enhanced couplings to the third generation [8], and by a leptophobic W' boson). The usual signal consists of a leptonically decaying W boson and two b-jets. The upper limits on the W' couplings to left- and right-handed quarks normalized to the Standard Model W boson couplings, set by DØ with 2.3 fb⁻¹ [21] and by CDF with 1.9 fb⁻¹ [22], respectively, are shown in Fig. 2. LHC searches in this channel have set cross section limits for $M_{W'}$ in the 0.5 – 2.1 TeV range [23].

For $M_{W'}\gg m_t$, one could also use hadronic W boson decays to search for $W'\to t\bar{b}$ with a boosted top quark. If W' couplings to left-handed quarks are large, then interference effects modify the Standard Model s-channel single-top production [24].

Searches for dijet resonances may be used to set limits on $W' \to q\bar{q}'$ [18]. In the 105-200 GeV mass range the limits are rather weak, as they have been set so far only by the UA2 Collaboration; even in the 200-700 GeV range only small data sets from the Tevatron and the LHC have been used so far.

In some theories [3], the W' couplings to Standard Model fermions are suppressed by discrete symmetries. W' production then occurs in pairs, through a photon or Z boson. The decay modes are model-dependent and often involve other new particles. The ensuing collider signals arise from cascade decays and typically include missing transverse energy.

A fermiophobic W' boson which couples to WZ may be produced at hadron colliders in association with a Z boson, or via WZ fusion. This would give rise to (WZ)Z and (WZ)jj final states, where the parentheses represent a resonance [25]. The study of these processes is important for understanding the origin of electroweak symmetry-breaking. The DØ [26] and CDF [27] Collaborations have set limits on $\sigma(p\bar{p}\to W'X)\times B(W'\to WZ)$ for $M_{W'}$ in the 180 – 1000 GeV range, while searches [28] at the 7 TeV LHC have set cross-section limits for $M_{W'}$ in the 200 – 1500 GeV range.

Low-energy constraints. The properties of W' bosons are also constrained by measurements of processes at energies much below $M_{W'}$. The bounds on W-W' mixing [18] are mostly due to the change in the properties of the W boson compared to the Standard Model. Limits on the deviation in the ZWW coupling provide a leading constraint for fermiophobic W' bosons [10].

Constraints arising from low-energy effects of W' exchange are strongly model-dependent. If the W' couplings to quarks are not suppressed, then box diagrams involving a W and a W' boson contribute to neutral meson-mixing. In the case of W' couplings to right-handed quarks as in the left-right symmetric model, the limit from $K_L - K_s$ mixing is severe: $M_{W'} > 2.5 \text{ TeV } [29]$. However, if no correlation between $C_{q_{ij}}^{R}$ and $C_{l_{ij}}^{R}$ is assumed, then the limit on $M_{W'}$ may be significantly relaxed [30].

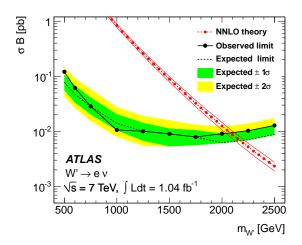


Figure 1: 95% CL limit on $\sigma(pp \to W'X) \times B(W' \to e\nu)$ from ATLAS [13]. The theoretical prediction (dash-dotted line) is for $C_q^{\mathsf{R}} = gV_{\mathrm{CKM}},$ $C_l^{\mathsf{R}} = g, C_q^{\mathsf{L}} = 0.$

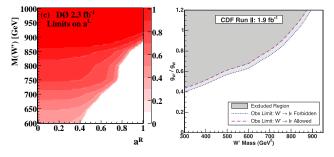


Figure 2: 95% CL upper limits on W' couplings using the $t\bar{b}$ and $\bar{t}b$ final states, assuming that the diagonal couplings are generation independent. Left panel: DØ [21] limit on $C_{q_{11}}^{\ell}/g$ as contours in the $C_{q_{11}}^{R}/g - M_{W'}$ plane. Right panel: CDF [22] limit on $C_{q_{11}}^{R}/g$.

0.2 fb⁻¹ of Tevatron data [17], while the 105 – 200 GeV range

 0.2 fb^{-1} of Tevatron data [17], while the 105 - 200 GeV range has been even less explored (see the UA1 and UA2 references in Ref. 18).

In the $\mu\nu$ channel, the most stringent limit in the 0.5-3 TeV range, set by CMS [15] with 5 fb⁻¹, varies between 39 and 2.7 fb. The ATLAS $\mu\nu$ limit [13] is higher by about 50% compared to that shown in Fig. 1. For $M_{W'}$ in the 200 – 500 GeV range there are only weak limits on the W' couplings from the Tevatron Run I [19]. There are no direct limits on $W' \to \mu\nu$ for $M_{W'}$ in the 105 – 200 GeV range.

Dedicated searches for the $W' \to \tau \nu$ decay have not yet been performed, but limits can be derived from some searches in the $\ell + E_T$ channel as well as from charged-Higgs searches such as $pp \to t\bar{b} \tau \nu X$.

The W' decay into a lepton and a right-handed neutrino, ν_R , may also be followed by the ν_R decay through a virtual W' boson into a lepton and two quark jets. The ATLAS search [20] with 2.1 fb⁻¹ sets cross-section limits in the $\ell^+\ell^-jj$ channel decreasing from 20 fb to 3 fb for $M_{W'}$ in the 1 – 2.7 TeV range.

W' exchange also contributes at tree level to various lowenergy processes. In particular, it would impact the measurement of the Fermi constant G_F in muon decay, which in turn would change the predictions of many other electroweak processes. A recent test of parity violation in polarized muon decay [31] has set limits of about 600 GeV on $M_{W'}$, assuming W' couplings to right-handed leptons as in left-right symmetric models. There are also W' contributions to the neutron electric dipole moment, β decays, and other processes [18].

If right-handed neutrinos have Majorana masses, then there are tree-level contributions to neutrinoless double-beta decay, and a limit on $M_{W'}$ versus the ν_R mass may be derived [32]. For ν_R masses below a few GeV, the W' boson contributes to leptonic and semileptonic B meson decays, so that limits may be placed on various combinations of W' parameters [30]. For ν_R masses below ~ 30 MeV, most stringent constraints on $M_{W'}$ are due to the limits on ν_R emission from supernova.

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MASS LIMITS for W' (Heavy Charged Vector Boson Other Than W) in Hadron Collider Experiments

Couplings of W' to quarks and leptons are taken to be identical with those of W. The following limits are obtained from $\rho \overline{\rho} \to W' X$ with W' decaying to the mode indicated in the comments. New decay channels (e.g., $W' \to WZ$) are assumed to be suppressed. The most recent preliminary results can be found in the "W'-boson searches" review above. $E(gev) \qquad CLS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$

| >2150 | 95 | AAD 11Q ATLS $W' \rightarrow e \nu, \mu \nu$ | |
|--------------------------------------|---------------|-------------------------------------------------------------|--|
| none 180-690 | 95 | 1 ABAZOV 11H D0 $W' 	o WZ$ | |
| > 863 | 95 | ² ABAZOV 11L D0 $W' \rightarrow tb$ | |
| >1510 | 95 | CHATRCHYAN11Y CMS $W' 	o q \overline{q}$ | |
| ● ● We do not us | e the followi | ing data for averages, fits, limits, etc. • • • | |
| >1490 | 95 | AAD 11M ATLS $W' ightarrow e u, \mu u$ | |
| >1120 | 95 | AALTONEN 11c CDF $W' ightarrow e u$ | |
| >1580 | 95 | CHATRCHYAN11K CMS $W' ightarrow e u, \mu u$ | |
| >1400 | 95 | CHATRCHYAN11K CMS $W' ightarrow \mu u$ | |
| >1360 | 95 | KHACHATRY11H CMS $W' ightarrow e u$ | |
| none 285-516 | 95 | ³ AALTONEN 10N CDF $W' \rightarrow WZ$ | |
| none 188-520 | 95 | ⁴ ABAZOV 10A D0 $W' \rightarrow WZ$ | |
| > 800 | 95 | 5 AALTONEN 09AA CDF $W' ightarrow t b$ | |
| none 280-840 | 95 | 6 AALTONEN 09AC CDF $W' 	o q \overline{q}$ | |
| >1000 | 95 | ABAZOV 08c D0 $W' ightarrow e u$ | |
| > 731 | 95 | ⁷ ABAZOV 08P D0 $W' \rightarrow tb$ | |
| > 788 | 95 | ABULENCIA 07K CDF $W' ightarrow e u$ | |
| none 200-610 | 95 | ⁸ ABAZOV 06N D0 $W' \rightarrow tb$ | |
| > 800 | 95 | ABAZOV 04c D0 $W' 	o q \overline{q}$ | |
| 225-536 | 95 | ⁹ ACOSTA 03B CDF $W' \rightarrow tb$ | |
| none 200-480 | 95 | 10 AFFOLDER 02c CDF $W' ightarrow W Z$ | |
| > 786 | 95 | 11 AFFOLDER 011 CDF $W' ightarrow e u, \mu u$ | |
| > 660 | 95 | ^{12}ABE 00 CDF $W'	o \mu u$ | |
| none 300-420 | 95 | 13 ABE 97G CDF $W' 	o q \overline{q}$ | |
| > 720 | 95 | 14 ABACHI 96c D0 $W' ightarrow e u$ | |
| > 610 | 95 | 15 ABACHI 95E D0 $W' ightarrow e u, 	au u$ | |
| > 652 | 95 | 16 ABE 95M CDF $W' \rightarrow e \nu$ | |
| none 260-600 | 95 | ¹⁷ RIZZO 93 RVUE $W' \rightarrow a \overline{a}$ | |

 $^1\,\mathrm{The}$ quoted limit is obtained assuming $\,\mathit{W'}\,\mathit{WZ}$ coupling strength is the same as the ordinary $\,\mathit{W}\,\mathit{WZ}$ coupling strength in the Standard Model.

 2 ABAZOV 11L limit is for W^\prime with SM-like coupling which interferes with the SM W boson. For W^\prime with right-handed coupling, the bound becomes >885 GeV (>890 GeV) if W^\prime decays to both leptons and quarks (only to quarks). If both left- and right-handed couplings present, the limit becomes >916 GeV.

 3 The quoted limit assumes $g_{W'\,W\,Z}/g_{W\,W\,Z}=(\,M_W/\,M_{W'})^2$. See their Fig. 4 for limits in mass-coupling plane.

 4 The quoted limit assumes $g_{W'\,W\,Z}/g_{W\,W\,Z}=(M_W/M_{W'})^2.$ See their Fig. 3 for limits in mass-coupling plane.

- 5 The AALTONEN 09AA quoted limit is for a right-handed W^\prime with SM-like coupling allowing $W' \to \ell \nu$ decays.
- ⁶ AALTONEN 09AC search for new particle decaying to dijets.
- 7 The ABAZOV 08P quoted limit is for W^\prime with SM-like coupling which interferes with the SM W boson. For W' with right-handed coupling, the bound becomes >739 GeV (>768 GeV) if W' decays to both leptons and quarks (only to quarks).
- 8 The ABAZOV 06N quoted limit is for W^\prime with SM-like coupling which interferes with the SM W boson. For W^\prime with right-handed coupling, M_{W^\prime} between 200 and 630 (670) GeV is excluded for ${\it M}_{\nu_R} \ll \ \bar{\it M}_{W'} \ ({\it M}_{\nu_R} \ > {\it M}_{W'}).$
- $^9\,{\rm The}$ ACOSTA 03B quoted limit is for $M_{W'}\gg M_{\nu_R}.$ For $M_{W'}<\! M_{\nu_R}$, $M_{W'}$ between
- 225 and 566 GeV is excluded. 10 The quoted limit is obtained assuming W'WZ coupling strength is the same as the ordinary WWZ coupling strength in the Standard Model. See their Fig. 2 for the limits on the production cross sections as a function of the W^\prime width.
- 11 AFFOLDER 01: combine a new bound on $W'\to e\nu$ of 754 GeV with the bound of ABE 00 on $W'\to \mu\nu$ to obtain quoted bound.
- $^{12}\mathsf{ABE}$ 00 assume that the neutrino from W' decay is stable and has a mass significantly less than $m_{W'}$
- $^{13}\,\mathrm{ABE}$ 97G search for new particle decaying to dijets.
- $^{14}\,\mathrm{For}$ bounds on W_{R} with nonzero right-handed mass, see Fig. 5 from ABACHI 96c.
- 15 ABACHI 95E assume that the decay $W'
 ightarrow \ W \, Z$ is suppressed and that the neutrino from W^\prime decay is stable and has a mass significantly less m_{W^\prime}
- 16 ABE 95M assume that the decay $W'\to WZ$ is suppressed and the (right-handed) neutrino is light, noninteracting, and stable. If $m_{\nu}{=}60$ GeV, for example, the effect on the mass limit is negligible.
- 17 RiZZO 93 analyses CDF limit on possible two-jet resonances. The limit is sensitive to the inclusion of the assumed $\, K$ factor.

WR (Right-Handed W Boson) MASS LIMITS

Assuming a light right-handed neutrino, except for BEALL 82, LANGACKER 89B, and COLANGELO 91. $g_R=g_L$ assumed. [Limits in the section MASS LIMITS for W' below are also valid for W_R if $m_{\nu_R} \ll m_{W_R}$.] Some limits assume manifest left-right symmetry, i.e., the equality of left- and right Cabibbo-Kobayashi-Maskawa matrices. For a comprehensive review, see LA NGACKER 89B. Limits on the W_L - W_R mixing angle ζ are found in the next section. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------------|---------------|--------------------------|--------|-------------|----------------------------------------|
| > 715 | 90 | ¹⁸ CZAKON | 99 | RVUE | Electroweak |
| • • • We do not i | use the follo | owing data for avera | ges, 1 | fits, limit | |
| > 245 | 90 | ¹⁹ WAUTERS | 10 | CNTR | 60 Co eta decay |
| > 180 | 90 | ²⁰ MELCONIAN | 07 | CNTR | 37 K β^+ decay |
| > 290.7 | 90 | ²¹ SCHUMANN | 07 | CNTR | Polarized neutron decay |
| [> 3300] | 95 | ²² CYBURT | 05 | COSM | Nucleosynthesis; light $ u_R$ |
| > 310 | 90 | ²³ THOMAS | 01 | CNTR | β^+ decay |
| > 137 | 95 | ²⁴ ACKERSTAFF | 99D | OPAL | au decay |
| >1400 | 68 | ²⁵ BARENBOIM | 98 | RVUE | Electroweak, $Z-Z'$ mixing |
| > 549 | 68 | ²⁶ BARENBOIM | 97 | RVUE | μ decay |
| > 220 | 95 | ²⁷ STAHL | 97 | RVUE | au decay |
| > 220 | 90 | ²⁸ ALLET | 96 | CNTR | eta^+ decay |
| > 281 | 90 | ²⁹ KUZNETSOV | 95 | CNTR | Polarized neutron decay |
| > 282 | 90 | ³⁰ KUZNETSOV | 94B | CNTR | Polarized neutron decay |
| > 439 | 90 | ³¹ BHATTACH | 93 | RVUE | Z-Z' mixing |
| > 250 | 90 | ³² SEVERIJNS | 93 | CNTR | eta^+ decay |
| | | ³³ IMA ZAT O | 92 | CNTR | K^+ decay |
| > 475 | 90 | ³⁴ POLAK | 92B | RVUE | μ decay |
| > 240 | 90 | ³⁵ AQUINO | 91 | RVUE | Neutron decay |
| > 496 | 90 | 35 AQUINO | 91 | RVUE | Neutron and muon decay |
| > 700 | | ³⁶ COLANGELO | 91 | THEO | ${}^{m}K_{I}^{0} - {}^{m}K_{S}^{0}$ |
| > 477 | 90 | ³⁷ POLAK | 91 | RVUE | μ decay |
| [none 540-23000] | | ³⁸ BARBIERI | 89B | ASTR | SN 1987A; light ν_R |
| > 300 | 90 | ³⁹ LANGACKER | 89B | RVUE | General |
| > 160 | 90 | ⁴⁰ BALKE | 88 | CNTR | $\mu \rightarrow e \nu \overline{\nu}$ |
| > 406 | 90 | ⁴¹ JODIDIO | 86 | ELEC | Any ζ |
| > 482 | 90 | ⁴¹ JODIDIO | 86 | ELEC | $\zeta = 0$ |
| > 800 | | MOHAPATRA | 86 | RVUE | $SU(2)_L \times SU(2)_R \times U(1)$ |
| > 400 | 95 | ⁴² STOKER | 85 | ELEC | Any ζ |
| > 475 | 95 | ⁴² STOKER | 85 | ELEC | ζ < 0.041 |
| | | ⁴³ BERGSMA | 83 | CHRM | $\nu_{\mu} e \rightarrow \mu \nu_{e}$ |
| > 380 | 90 | ⁴⁴ CARR | 83 | ELEC | μ^+ decay |
| >1600 | | ⁴⁵ BEALL | 82 | THEO | $m_{K_{t}^{0}} - m_{K_{c}^{0}}$ |

- 18 CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
- 19 WAUTERS $^{\dot{}}$ 0 limit is from a measurement of the asymmetry parameter of polarized $^{60}{
 m Co}~eta$ decays. The listed limit assumes no mixing.
- 20 MELCONIAN 07 measure the neutrino angular asymmetry in eta^+ -decays of polarized $^{37}\mathrm{K}$, stored in a magneto-optical trap. Result is consistent with SM prediction and does not constrain the $\widetilde{W_L}-W_R$ mixing angle appreciably.
- 21 SCHUMANN 07 limit is from measurements of the asymmetry $\langle \vec{p}_{\nu} \cdot \sigma_{n} \rangle$ in the β decay of polarized neutrons. Zero mixing is assumed.
- 22 CYBURT 05 limit follows by requiring that three light u_R 's decouple when $T_{dec}>140$ MeV. For different T_{dec} , the bound becomes $M_{W_R} >$ 3.3 TeV (T_{dec} / 140 MeV) $^{3/4}$.
- 23 THOMAS 01 limit is from measurement of eta^+ polarization in decay of polarized 12 N. The listed limit assumes no mixing.
- 24 ACKERSTAFF 99D limit is from $ilde{ au}$ decay parameters. Limit increase to 145 GeV for zero

- 25 BARENBOIM 98 assumes minimal left-right model with Higgs of ${\rm SU}(2)_R$ in ${\rm SU}(2)_L$ doublet. For Higgs in ${\rm SU}(2)_L$ triplet, $m_{W_R}>$ 1100 GeV. Bound calculated from effect of corresponding Z_{LR} on electroweak data through Z- Z_{LR} mixing.
- 26 The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L - K_S mass difference.
- $27\,\mbox{STAHL}$ 97 limit is from fit to $\tau\mbox{-decay}$ parameters.
- 28 ALLET 96 measured polarization-asymmetry correlation in 12 N eta^+ decay. The listed limit assumes zero L-R mixing.
- 29 KUZNETSOV 95 limit is from measurements of the asymmetry $\langle \vec{p}_{\mu} \cdot \sigma_{\eta} \rangle$ in the β decay of polarized neutrons. Zero mixing assumed. See also KUZNETSOV 94B.
- ³⁰ KUZNETSOV 94B limit is from measurements of the asymmetry $\langle \vec{p}_{\nu} \cdot \sigma_{n} \rangle$ in the β decay
- of polarized neutrons. Zero mixing assumed. 31 BHATTACHARYYA 93 uses Z-Z' mixing limit from LEP '90 data, assuming a specific Higgs sector of $SU(2)_L \times SU(2)_R \times U(1)$ gauge model. The limit is for m_t =200 GeV and slightly improves for smaller m_t .
- $^{32}\,\mathrm{SEVERIJNS}$ 93 measured polarization-asymmetry correlation in $^{107}\mathrm{ln}~\beta^+$ decay. The listed limit assumes zero L-R mixing. Value quoted here is from SEVERIJNS 94 erratum.
- 33 IMAZATO 92 measure positron asymmetry in $^{K^+}$ ightarrow $\mu^+
 u_\mu$ decay and obtain $\xi P_{\mu} >$ 0.990 (90% CL). If W_{R} couples to $u\overline{s}$ with full weak strength ($V_{n\,s}^{R}\!=\!1$), the result corresponds to $m_{W_R} > 653$ GeV. See their Fig. 4 for m_{W_R} limits for general
- $|V_{us}^R|^2=1-|V_{ud}^R|^2$. 34 POLAK 92B limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming ζ =0. Supersedes POLAK 91.
- 35 AQUINO 91 limits obtained from neutron lifetime and asymmetries together with uni-tarity of the CKM matrix. Manifest left-right symmetry assumed. Stronger of the two limits also includes muon decay results.
- 36 COLANGELO 91 limit uses hadronic matrix elements evaluated by QCD sum rule and is less restrictive than BEALL 82 limit which uses vacuum saturation approximation. Manifest left-right symmetry assumed.
- ³⁷ POLAK 91 limit is from fit to muon decay parameters and is essentially determined by JODIDIO 86 data assuming $\zeta{=}0$. Superseded by POLAK 92B.
- $^{38}\,\mathrm{BARBIERI}$ 89B limit holds for $m_{\nu_R} \leq 10$ MeV.
- 39 LANGACKER 89B limit is for any ν_R mass (either Dirac or Majorana) and for a general class of right-handed quark mixing matrices.
- 40 BALKE 88 limit is for $m_{\nu_e R}=0$ and $m_{\nu_\mu R}\leq 50$ MeV. Limits come from precise measurements of the muon decay asymmetry as a function of the positron energy.
- 41 JODIDIO 86 is the same TRIUMF experiment as STOKER 85 (and CARR 83); however, it uses a different technique. The results given here are combined results of the two techniques. The technique here involves precise measurement of the end-point e^{+} spectrum in the decay of the highly polarized μ^+
- 42 STOKER 85 is same TRIUMF experiment as CARR 83. Here they measure the decay e^+ spectrum asymmetry above 46 MeV/c using a muon-spin-rotation technique. Assumed a light right-handed neutrino. Quoted limits are from combining with CARR 83.
- 43 BERGSMA 83 set limit $m_{W_2}/m_{W_1}~>1.9$ at CL =90%
- 44 CARR 83 is TRIUMF experiment with a highly polarized μ^+ beam. Looked for deviation from V-A at the high momentum end of the decay e^+ energy spectrum. Limit from previous world-average muon polarization parameter is $m_{W_R} >$ 240 GeV. Assumes a light right-handed neutrino.
- ⁴⁵ BEALL 82 limit is obtained assuming that W_R contribution to $K_I^0 K_S^0$ mass difference is smaller than the standard one, neglecting the top quark contributions. Manifest left-right symmetry assumed.

I

Limit on W_L - W_R **Mixing Angle** ζ Lighter mass eigenstate $W_1 = W_L \cos \zeta - W_R \sin \zeta$. Light ν_R assumed unless noted. Values in brackets are from cosmological and astrophysical considerations.

| VALUE | CL% | DOCUMENT ID TECN COMMENT |
|---------------------------------------|-------------|---------------------------------------------------------|
| ullet $ullet$ $ullet$ We do not use t | he followir | ng data for averages, fits, limits, etc. • • • |
| < 0.022 | 90 | MACDONALD 08 TWST $\mu ightarrow e u \overline{ u}$ |
| < 0.12 | 95 | 46 ACKERSTAFF 99D OPAL $	au$ decay |
| < 0.013 | 90 | ⁴⁷ CZAKON 99 RVUE Electroweak |
| < 0.0333 | | 48 BARENBOIM 97 RVUE μ decay |
| < 0.04 | 90 | ⁴⁹ MISHRA 92 CCFR ν N scattering |
| -0.0006 to 0.0028 | 90 | ⁵⁰ AQUINO 91 RVUE |
| [none 0.00001-0.02] | | ⁵¹ BARBIERI 89B ASTR SN 1987A |
| < 0.040 | 90 | 52 JODIDIO 86 ELEC μ decay |
| -0.056 to 0.040 | 90 | 52 JODIDIO 86 ELEC μ decay |
| 46 | | |

- ACKERSTAFF 99D limit is from τ decay parameters.
- 47 CZAKON 99 perform a simultaneous fit to charged and neutral sectors.
- 48 The quoted limit is from μ decay parameters. BARENBOIM 97 also evaluate limit from K_L - K_S mass difference.
- ⁴⁹ MISHRA 92 limit is from the absence of extra large-x, large-y $\overline{
 u}_\mu$ N ightarrow $\overline{
 u}_\mu$ X events at Tevatron, assuming left-handed u and right-handed $\overline{
 u}$ in the neutrino beam. The result gives $\zeta^2(1-2m_{W_1}^2/m_{W_2}^2)$ < 0.0015. The limit is independent of u_R mass
- 50 AQUINO 91 limits obtained from neutron lifetime and asymmetries together with unitarity of the CKM matrix. Manifest left-right asymmetry is assumed.
- $^{51}\,\mathrm{BARBIERI}$ 89B limit holds for $m_{\nu_R} \leq 10\,$ MeV.
- 52 First JODIDIO 86 result assumes $m_{W_R} = \infty$, second is for unconstrained m_{W_R}

Z'-BOSON SEARCHES

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The Z' boson is a hypothetical massive, electrically-neutral and color-singlet particle of spin 1. This particle is predicted

in many extensions of the Standard Model, and has been the object of extensive phenomenological studies [1].

Z' boson couplings to quarks and leptons. The couplings of a Z' boson to the first-generation fermions are given by

$$Z'_{\mu} \left(f_u \overline{u}_L \gamma^{\mu} u_L + f_d \overline{d}_L \gamma^{\mu} d_L + g_u^R \overline{u}_R \gamma^{\mu} u_R + g_d^R \overline{d}_R \gamma^{\mu} d_R \right. \\ + \left. g_{\nu} \overline{\nu}_L \gamma^{\mu} \nu_L + g_e^I \overline{e}_L \gamma^{\mu} e_L + g_e^R \overline{e}_R \gamma^{\mu} e_R \right) , \tag{1}$$

where u,d,ν and e are the quark and lepton fields in the mass eigenstate basis, and the coefficients f_u , f_d , f_u , f_d , f_u , f_d , f_v , f_d ,

These parameters describing the Z' boson interactions with quarks and leptons are subject to some theoretical constraints. Quantum field theories that include a heavy spin-1 particle are well behaved at high energies only if that particle is a gauge boson associated with a spontaneously broken gauge symmetry. Quantum effects preserve the gauge symmetry only if the couplings of the gauge boson to fermions satisfy anomaly cancellation conditions. Furthermore, the fermion charges under the new gauge symmetry are constrained by the requirement that the quarks and leptons get masses from gauge-invariant interactions with Higgs doublets or whatever else breaks the electroweak symmetry.

The relation between the couplings displayed in Eq. (1) and the gauge charges $z_{fi}^{\!\! L}$ and $z_{fi}^{\!\! R}$ of the fermions $f=u,d,\nu,e$ involves the unitary 3×3 matrices V_f^L and V_f^R that transform the gauge eigenstate fermions f_L^i and f_R^i , respectively, into the mass eigenstates. In addition, the Z' couplings are modified if the new gauge boson in the gauge eigenstate basis (\tilde{Z}'_{μ}) has a kinetic mixing $(-\chi/2)B^{\mu\nu}\tilde{Z}'_{\mu\nu}$ with the hypercharge gauge boson B^{μ} (due to a dimension-4 or 6 operator, depending on whether the new gauge symmetry is Abelian or not), or a mass mixing $\delta M^2 \tilde{Z}^{\mu} \tilde{Z}'_{\mu}$ with the linear combination (\tilde{Z}_{μ}) of neutral bosons which has same couplings as the Standard Model Z^0 [2]. Both the kinetic and mass mixings shift the mass and couplings of the Z boson, such that the electroweak measurements impose upper limits on χ and $\delta M^2/(M_{Z'}^2-M_Z^2)$ of the order of 10^{-3} [3]. Keeping only linear terms in these two small quantities, the couplings of the mass-eigenstate Z' boson are given by

$$g_{f\,ij}^L = g_z V_{fii'}^L \, z_{f\,i'}^L \left(V_f^L\right)_{i'j}^\dagger + \frac{e}{c_{\mathrm{W}}} \Bigg(\frac{s_{\mathrm{W}} \chi M_{Z'}^2 + \delta M^2}{2s_{\mathrm{W}} \left(M_{Z'}^2 - M_Z^2\right)} \sigma_f^3 - \epsilon \, Q_f \Bigg) \quad , \label{eq:gfij}$$

$$g_{fij}^{R} = g_z V_{fii'}^{R} z_{fi'}^{R} (V_f^{R})_{i'j}^{\dagger} - \frac{e}{c_W} \epsilon Q_f ,$$
 (2)

where g_z is the new gauge coupling, Q_f is the electric charge of f, e is the electromagnetic gauge coupling, s_W and c_W are the

Table 1: Examples of generation-independent U(1)' charges for quarks and leptons. The parameter x is an arbitrary rational number. Anomaly cancellation requires certain new fermions [4].

| fermion | $U(1)_{B-xL}$ | $U(1)_{10+x\bar{5}}$ | $U(1)_{d-xu}$ | $U(1)_{q+xu}$ |
|----------------|---------------|----------------------|---------------|---------------|
| (u_L, d_L) | 1/3 | 1/3 | 0 | 1/3 |
| u_R | 1/3 | -1/3 | -x/3 | x/3 |
| d_R | 1/3 | -x/3 | 1/3 | (2-x)/3 |
| (ν_L, e_L) | -x | x/3 | (-1+x)/3 | -1 |
| e_R | -x | -1/3 | x/3 | -(2+x)/3 |

sine and cosine of the weak mixing angle, $\sigma_f^3=+1$ for $f=u,\nu$ and $\sigma_f^3=-1$ for f=d,e, and

$$\epsilon = \frac{\chi \left(M_{Z'}^2 - c_W^2 M_Z^2 \right) + s_W \delta M^2}{M_{Z'}^2 - M_Z^2} \ . \tag{3}$$

U(1) gauge groups. A simple origin of a Z' boson is a new U(1)' gauge symmetry. In that case, the matricial equalities $z_u^l = z_d^l$ and $z_\nu^l = z_e^l$ are required by the $SU(2)_W$ gauge symmetry. Given that the U(1)' interaction is not asymptotically free, the theory may be well-behaved at high energies (for example, by embedding U(1)' in a non-Abelian gauge group) only if the Z' couplings are commensurate numbers, i.e. any ratio of couplings is a rational number. Satisfying the anomaly cancellation conditions (which include an equation cubic in charges) with rational numbers is highly nontrivial, and in general new fermions charged under U(1)' are necessary.

Consider first the case where the couplings are generationindependent (the V_f matrices then disappear from Eq. (2)), so that there are five commensurate couplings: g_q^L , g_u^R , g_d^R , g_l^R , g_e^R . Four sets of charges are displayed in Table 1, each of them spanned by one free parameter, x [4]. The first set, labelled B-xL, has charges proportional to the baryon number minus x times the lepton number. These charges allow all Standard Model Yukawa couplings to a Higgs doublet which is neutral under $U(1)_{B-xL}$, so that there is no tree-level $\tilde{Z}-\tilde{Z}'$ mixing. For x=1 one recovers the $U(1)_{B-L}$ group, which is non-anomalous in the presence of one "right-handed neutrino" (a chiral fermion that is a singlet under the Standard Model gauge group) per generation. For $x \neq 1$, it is necessary to include some fermions that are vector-like (i.e. their mass terms are gauge invariant) with respect to the electroweak gauge group and chiral with respect to $U(1)_{B-xL}$. In the particular cases x=0 or $x\gg 1$ the Z' is leptophobic or quark-phobic, respectively.

The second set, $U(1)_{10+x\bar{5}}$, has charges that commute with the representations of the SU(5) grand unified group. Here x is related to the mixing angle between the two U(1) bosons encountered in the $E_6 \to SU(5) \times U(1) \times U(1)$ symmetry breaking patterns of grand unified theories [1,6]. This set leads to $\tilde{Z} - \tilde{Z}'$ mass mixing at tree level, such that for a Z' mass close to the electroweak scale, the measurements at

the Z-pole require some fine tuning between the charges and VEVs of the two Higgs doublets. Vector-like fermions charged under the electroweak gauge group and also carrying color are required (except for x=-3) to make this set anomaly free. The particular cases x=-3,1,-1/2 are usually labelled $U(1)_\chi$, $U(1)_\psi$, and $U(1)_\eta$, respectively. Under the third set, $U(1)_{d-xu}$, the weak-doublet quarks are neutral, and the ratio of u_R and d_R charges is -x. For x=1 this is the "right-handed" group $U(1)_R$. For x=0, the charges are those of the E_6 -inspired $U(1)_I$ group, which requires new quarks and leptons. Other generation-independent sets of U(1)' charges are given in [5].

Table 2: Lepton-flavor dependent charges under various U(1) gauge groups. No new fermions other than right-handed neutrinos are required.

| fermion | $B - xL_e - yL_{\mu}$ | 2+1 leptocratic |
|-----------------------------|-----------------------|-----------------|
| $q_{1_L}, q_{2_L}, q_{3_L}$ | 1/3 | 1/3 |
| u_R, c_R, t_R | 1/3 | x/3 |
| d_R, s_R, b_R | 1/3 | (2-x)/3 |
| (u_L^e, e_L) | -x | -1 - 2y |
| (u^μ_L,μ_L) | -y | -1 + y |
| $(u_L^	au,	au_L)$ | x+y-3 | -1 + y |
| e_R | -x | -(2+x)/3 - 2y |
| μ_R | -y | -(2+x)/3+y |
| $	au_R$ | x+y-3 | -(2+x)/3+y |

In the absence of new fermions charged under the Standard Model group, the most general generation-independent charge assignment is $U(1)_{q+xu}$, which is a linear combination of hypercharge and B-L. Many other anomaly-free solutions exist if generation-dependent charges are allowed. Table 2 shows such solutions that depend on two free parameters, x and y, with generation dependence only in the lepton sector, which includes one right-handed neutrino per generation. The charged-lepton masses may be generated by Yukawa couplings to a single Higgs doublet. These are forced to be flavor diagonal by the generation-dependent U(1)' charges, so that there are no tree-level flavor-changing neutral current (FCNC) processes involving electrically-charged leptons. For the "leptocratic" set, neutrino masses are induced by operators of high dimensionality that may explain their smallness [7].

If the $SU(2)_W$ -doublet quarks have generation-dependent U(1)' charges, then the mass eigenstate quarks have flavor off-diagonal couplings to the Z' boson (see Eq. (1), and note that $V_u^t \left(V_d^t\right)^{\dagger}$ is the CKM matrix). These are severely constrained by measurements of FCNC processes, which in this case are mediated at tree-level by Z' boson exchange [8]. The constraints are relaxed if the first and second generation charges are the same, although they are increasingly tightened by the measurements of B meson properties. If only the $SU(2)_W$ -singlet quarks have generation-dependent U(1)' charges, there is more

freedom in adjusting the flavor off-diagonal couplings because the $V_{n,d}^R$ matrices are not observable in the Standard Model.

The anomaly cancellation conditions for U(1)' could be relaxed only if at scales above $\sim 4\pi M_{Z'}/g_z$ there is an axion which has certain dimension-5 couplings to the gauge bosons. However, such a scenario violates unitarity unless the quantum field theory description breaks down at a scale near $M_{Z'}$ [9].

Other models. Z' bosons may also arise from larger gauge groups. These may be orthogonal to the electroweak group, as in $SU(2)_W \times U(1)_Y \times SU(2)'$, or may embed the electroweak group, as in $SU(3)_W \times U(1)$ [10]. If the larger group is spontaneously broken down to $SU(2)_W \times U(1)_Y \times U(1)'$ at a scale $v_* \gg M_{Z'}/g_z$, then the above discussion applies up to corrections of order $M_{Z'}^2/(g_zv_*)^2$. For $v_* \sim M_{Z'}/g_z$, additional gauge bosons have masses comparable to $M_{Z'}$, including at least a W' boson [10]. If the larger gauge group breaks together with the electroweak symmetry directly to the electromagnetic $U(1)_{\rm em}$, then the left-handed fermion charges are no longer correlated $(z_u^l \neq z_d^l, z_\nu^l \neq z_e^l)$ and a $Z'W^+W^-$ coupling is induced.

If the electroweak gauge bosons propagate in extra dimensions, then their Kaluza-Klein excitations include a series of Z' boson pairs. Each of these pairs can be associated with a different $SU(2) \times U(1)$ gauge group in four dimensions. The properties of the Kaluza-Klein particles depend strongly on the extra-dimensional theory [11]. For example, in universal extra dimensions there is a parity that forces all couplings of Eq. (1) to vanish in the case of the lightest Kaluza-Klein bosons, while allowing couplings to pairs of fermions involving a Standard Model one and a heavy vector-like fermion. There are also 4-dimensional gauge theories (e.g., little Higgs with T parity) with Z' bosons exhibiting similar properties. By contrast, in a warped extra dimension, the couplings of Eq. (1) may be sizable even when Standard Model fields propagate along the extra dimension.

Z' bosons may also be composite particles. For example, in technicolor theories [12], the techni- ρ is a spin-1 boson that may be interpreted as arising from a spontaneously broken gauge symmetry [13].

Resonances versus cascade decays. In the presence of the couplings shown in Eq. (1), the Z' boson may be produced in the s-channel at colliders, and would decay to pairs of fermions. The decay width into a pair of electrons is given by

$$\Gamma\left(Z' \to e^+ e^-\right) \simeq \left[\left(g_e^L\right)^2 + \left(g_e^R\right)^2\right] \frac{M_{Z'}}{24\pi} ,$$
 (4)

where small corrections from electroweak loops are not included. The decay width into $q\bar{q}$ is similar, except for an additional color factor of 3, QCD radiative corrections, and fermion mass corrections. Thus, one may compute the Z' branching fractions in terms of the couplings of Eq. (1). However, other decay channels, such as WW or a pair of new particles, could have large widths and need to be added to the total decay width.

As mentioned above, there are theories in which the Z' couplings are controlled by a discrete symmetry which does not allow its decay into a pair of Standard Model particles. Typically, such theories involve several new particles, which may be produced only in pairs and undergo cascade decays through Z' bosons, leading to signals involving some missing (transverse) energy. Given that the cascade decays depend on the properties of new particles other than Z', this case is not discussed further here.

LEP-II limits. The Z' contribution to the cross sections for $e^+e^- \to f\bar{f}$ proceeds through an s-channel Z' exchange (when f=e, there are also t- and u-channel exchanges). For $M_{Z'} < \sqrt{s}$, the Z' appears as an $f\bar{f}$ resonance in the radiative return process where photon emission tunes the effective center-of-mass energy to $M_{Z'}$. The agreement between the LEP-II measurements and the Standard Model predictions implies that either the Z' couplings are smaller than or of order 10^{-2} , or else $M_{Z'}$ is above 209 GeV, the maximum energy of LEP-II. In the latter case, the Z' effects may be approximated up to corrections of order $s/M_{Z'}^2$ by the contact interactions

$$\frac{g_z^2}{M_{Z'}^2 - s} \left[\bar{e} \gamma_\mu \left(z_e^L P_L + z_e^R P_R \right) e \right] \left[\bar{f} \gamma^\mu \left(z_f^L P_L + z_f^R P_R \right) f \right] , \quad (5)$$

where $P_{L,R}$ are chirality projection operators, and the relation between Z' couplings and charges (see Eq. (2) in the limit where the mass and kinetic mixings are neglected) was used assuming generation-independent charges. The four LEP collaborations have set limits on the coefficients of such operators for all possible chiral structures and for various combinations of fermions [14]. Thus, one may derive bounds on $(M_{Z'}/g_z)|z_e^lz_f^l|^{-1/2}$ and the analogous combinations of LR, RL and RR charges, which are typically on the order of a few TeV. LEP-II limits were derived in Ref. [4] on the four sets of charges shown in Table 1.

Somewhat stronger bounds could be set on $M_{Z'}/g_z$ for specific sets of Z' couplings if the effects of several operators from Eq. (5) are combined. Dedicated analyses by the LEP collaborations have set limits on Z' bosons for particular values of the gauge coupling (see section 3.5.2 of [14]).

Searches at hadron colliders. Z' bosons with couplings to quarks (see Eq. (1)) may be produced at hadron colliders in the s channel, and would show up as resonances in the invariant mass distribution of the decay products. The cross section for producing a Z' boson at the LHC which then decays to some $f\bar{f}$ final state takes the form

$$\sigma\left(pp \to Z'X \to f\bar{f}X\right) \simeq \frac{\pi}{48\,s}\,\sum_{q} c_{q}^{f}\,w_{q}\!\left(s,M_{Z'}^{2}\right) \qquad (6)$$

for flavor-diagonal couplings to quarks. Here we have neglected the interference with the Standard Model contribution to $f\bar{f}$ production, which is a good approximation for a narrow Z' resonance. The coefficients

$$c_q^f = \left[\left(g_q^L \right)^2 + \left(g_q^R \right)^2 \right] B(Z' \to f\bar{f}) \tag{7}$$

contain all the dependence on the Z' couplings, while the functions w_q include all the information about parton distributions and QCD corrections [4,5]. This factorization holds exactly to NLO, and the deviations from it induced at NNLO are very small. Note that the w_u and w_d functions are substantially larger than the w_q functions for the other quarks. Eq. (6) also applies to the Tevatron, except for changing the pp initial state to $p\bar{p}$, which implies that the $w_q(s, M_{Z'}^2)$ functions are replaced by some other functions $\bar{w}_q((1.96 \text{ TeV})^2, M_{Z'}^2)$.

It is common to present results of Z' searches as limits on the cross section versus $M_{Z'}$ (e.g., see Fig. 1). An alternative is to plot exclusion curves for fixed $M_{Z'}$ values in the $c_u^f - c_d^f$ planes, allowing a simple derivation of the mass limit within any Z' model. LHC limits in the $c_u^\ell - c_d^\ell$ plane ($\ell = e$ or μ) for different $M_{Z'}$ are shown in Fig. 2 (for Tevatron limits, see [15]).

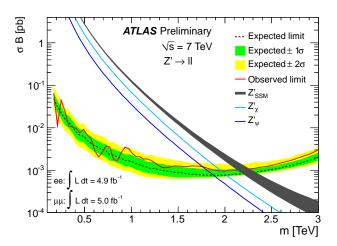


Figure 1: Upper limit on $\sigma(pp \to Z'X \to \ell^+\ell^-X)$ with $\ell = e$ or μ as a function of $M_{Z'}$ [27], assuming equal couplings for electrons and muons. The lines labelled by Z'_{ψ} and Z'_{χ} are theoretical predictions for the $U(1)_{10+x5}$ models in Table 1 with x = -3 and x = +1, respectively, for g_z fixed by an E_6 unification condition. The $Z'_{\rm SSM}$ line corresponds to Z' couplings equal to those of the Z boson.

The observation of a dilepton resonance at the LHC would determine the Z' mass and width. A measurement of the total cross section would define a band in the $c_u^\ell - c_d^\ell$ plane. Angular distributions can be used to measure several combinations of Z' parameters (an example of how angular distributions improve the Tevatron sensitivity is given in [16]). Even though the original quark direction in a pp collider is unknown, the leptonic forward-backward asymmetry $A_{\rm FB}^\ell$ can be extracted from the kinematics of the dilepton system, and is sensitive to parity-violating couplings. A fit to the Z' rapidity distribution can distinguish between the couplings to up and down quarks. These measurements, combined with off-peak observables, have the potential to differentiate among various Z' models [17]. For example, the couplings of a Z' boson with mass below 1.5 TeV

can be well determined with 100 fb⁻¹ of data at $\sqrt{s} = 14$ TeV. With this amount of data, the spin of the Z' boson may be determined for $M_{Z'} \leq 3$ TeV [18], and the expected sensitivity extends to $M_{Z'} \sim 5-6$ TeV for many models [19].

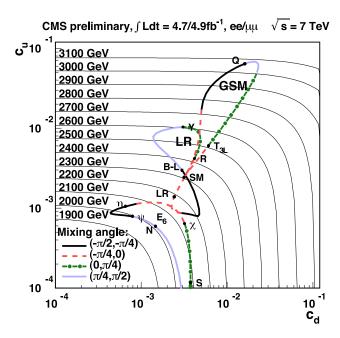


Figure 2: CMS results from Ref. 35. Limits in the $c_u^\ell - c_d^\ell$ plane ($\ell = e$ or μ) are shown as thin lines for certain $M_{Z'}$ values. For specific sets of charges (described in Ref. 5), parametrized by a mixing angle, the mass limit is given by the intersection of the thick and thin lines.

The Z' decays into e^+e^- and $\mu^+\mu^-$ are useful due to relatively good mass resolution and large acceptance. The Z' decays into $e\mu$ and $\tau^+\tau^-$, along with $t\bar{t}$, $b\bar{b}$ and jj which suffer from larger backgrounds, are also important as they probe various combinations of Z' couplings to fermions.

Z' searches at the Tevatron have been performed by the CDF and DØ Collaborations in the e^+e^- [20], $\mu^+\mu^-$ [21], $e\mu$ [22], $\tau^+\tau^-$ [23], $t\bar{t}$ [24], jj [25] and WW [26] final states. At the 7 TeV LHC, the ATLAS and CMS Collaborations have searched for Z' bosons in the e^+e^- and $\mu^+\mu^-$ channels [27,28], as well as in the $e\mu$ [29], $\tau^+\tau^-$ [30], $t\bar{t}$ [31] and jj [32] final states. The $pp \to Z'X \to W^+W^-X$ process may also be explored at the LHC, and is important for disentangling the origin of electroweak symmetry breaking. The Z' boson may be produced in this process through its couplings to either quarks [33] or W bosons [34].

Low-energy constraints. Z' boson properties are also constrained by a variety of low-energy experiments [36]. Polarized electron-nucleon scattering and atomic parity violation are sensitive to electron-quark contact interactions, which get contributions from Z' exchange that can be expressed in terms of the couplings introduced in Eq. (1) and M'_Z . Further corrections to the electron-quark contact interactions are induced in

the presence of $\tilde{Z}-\tilde{Z}'$ mixing because of the shifts in the Z couplings to quarks and leptons [2]. Deep-inelastic neutrinonucleon scattering is similarly affected by Z' bosons. Other low-energy observables are discussed in [3]. Interestingly, due to the $\tilde{Z}-\tilde{Z}'$ mixing, the global fit in Z' models often prefers a higher Higgs mass than in the Standard Model [37]. In some models, the lower limits on $M_{Z'}$ set by the low energy data are above 1 TeV [3].

Although the LHC data are most constraining for many Z' models, one should be careful in assessing the relative reach of various experiments given the freedom in Z' couplings. For example, a Z' associated with the $U(1)_{B-xL_e-yL_\mu}$ model (see Table 2) for x=0 and $y\gg 1$ couples only to leptons of the second and third generations, with implications for the muon g-2, neutrino oscillations or τ decays, and would be hard to see in processes involving first-generation fermions. Moreover, the combination of LHC searches and low-energy measurements could allow a precise determination of the Z' parameters [38].

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MASS LIMITS for Z' (Heavy Neutral Vector Boson Other Than Z)

Limits for Z'_{SM}

 Z'_{SM} is assumed to have couplings with quarks and leptons which are identical to those of Z, and decays only to known fermions. The most recent preliminary results can be found in the "Z'-boson searches" review above.

| VALUE (GeV) | CL% | DO CUMENT ID | 5 rev | TECN_ | COMMENT |
|-----------------|---------|--------------------------|--------|------------|---------------------------------------------------------------|
| >1830 | 95 | ⁵³ AAD | 11AD | ATLS | $pp; Z'_{SM} \rightarrow e^+e^-, \mu^+\mu^-$ |
| >1500 | 95 | ⁵⁴ CHEUNG | 01B | RVUE | Electroweak |
| • • • We do not | use the | following data for | averag | ges, fits, | limits, etc. • • • |
| >1048 | 95 | ⁵⁵ AAD | 11J | ATLS | pp, $Z'_{SM} ightarrow e^+ e^-$, $\mu^+ \mu^-$ |
| >1071 | 95 | ⁵⁶ AALTONEN | 111 | CDF | $p\overline{p}; Z_{SM}^{\prime m} \rightarrow \mu^{+}\mu^{-}$ |
| >1023 | 95 | ⁵⁷ ABAZOV | 11A | D0 | $p\overline{p}, Z_{SM}^{\gamma} \rightarrow e^+e^-$ |
| >1140 | 95 | ⁵⁸ CHATRCHYAN | J 11 | CMS | $pp, Z_{SM}^{jM} \rightarrow e^+e^-, \mu^+\mu^-$ |
| none 247-544 | 95 | ⁵⁹ AALTONEN | 10N | CDF | $Z' \rightarrow WW$ |
| none 320-740 | 95 | ⁶⁰ AALTONEN | 09AC | CDF | $Z' \rightarrow q \overline{q}$ |
| > 963 | 95 | ⁵⁷ AALTONEN | 09T | CDF | $p\overline{p}, Z'_{SM} \rightarrow e^+e^-$ |
| >1030 | 95 | ⁶¹ AALTONEN | 09∨ | CDF | $p\overline{p}; Z_{SM}^{\gamma M} \rightarrow \mu^{+}\mu^{-}$ |
| >1403 | 95 | ⁶² ERLER | 09 | RVUE | Electroweak |
| > 923 | 95 | ⁵⁷ AALTONEN | 07н | CDF | Repl. by AALTONEN 09T |
| >1305 | 95 | ⁶³ ABDALLAH | 06c | DLPH | e^+e^- |
| > 850 | | ⁵⁷ ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| > 825 | 95 | ⁶⁴ ABULENCIA | 05A | CDF | $p\overline{p}; Z'_{SM} \rightarrow e^+e^-, \mu^+\mu^-$ |

| > 399 | 95 | ⁶⁵ ACOSTA | 05R | CDF | $\overline{\rho} \rho : Z'_{SM} \rightarrow \tau^+ \tau^-$ |
|--------------|----|------------------------|------|------|--------------------------------------------------------------------------------------------------------|
| none 400-640 | 95 | ABAZOV | 04€ | D0 | $\overline{p}p: Z'_{SM} \to \tau^+ \tau^ p\overline{p}: Z'_{SM} \to q\overline{q}$ |
| >1018 | 95 | ⁶⁶ ABBIENDI | 04 G | OPAL | e^+e^- |
| > 670 | 95 | ⁶⁷ ABAZOV | 01в | D0 | $p\overline{p}, Z'_{SM} \rightarrow e^+e^-$ |
| > 710 | 95 | ⁶⁸ ABREU | 00s | DLPH | e+ e- |
| > 898 | 95 | ⁶⁹ BARATE | 001 | ALEP | e^+e^- |
| > 809 | 95 | ⁷⁰ ERLER | 99 | RVUE | Electroweak |
| > 690 | 95 | ⁷¹ ABE | 97s | CDF | $p\overline{p}; Z'_{SM} \rightarrow e^+e^-, \mu^+\mu^-$ $p\overline{p}; Z'_{SM} \rightarrow e^+e^-$ |
| > 490 | 95 | ABACHI | 96D | D0 | $p\overline{p}; Z'_{SM} \rightarrow e^+e^-$ |
| > 398 | 95 | ⁷² VILAIN | 94B | | $\nu_{\mu}e ightarrow u_{\mu}e$ and $\overline{ u}_{\mu}e ightarrow\overline{ u}_{\mu}e$ |
| > 237 | 90 | ⁷³ ALITTI | 93 | UA2 | $p\overline{p}; Z'_{SM} \rightarrow q\overline{q}$ |
| none 260-600 | 95 | ⁷⁴ RIZZO | 93 | RVUE | $p\overline{p}; Z'_{SM} \rightarrow q\overline{q}$ |
| > 426 | 90 | ⁷⁵ ABE | 90F | VNS | e^+e^- |
| | | | | | |

- 53 AAD 11AD search for resonances decaying to e^+e^- , $\mu^+\mu^-$ in $p\,p$ collisions at $\sqrt{s}=7$
- 54 CHEUNG 01B limit is derived from bounds on contact interactions in a global electroweak analysis.
- 55 AAD 11J search for resonances decaying to $e^+\,e^-$ or $\mu^+\,\mu^-$ in pp collisions at $\sqrt{s}=7$ TeV.
- 56 AALTONEN 111 search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$
- 57 ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.
- Solvance Caying to e^+e^- im pp consists at $\sqrt{s}=1$ 30 feV. e^+e^- or $\mu^+\mu^-$ in pp collisions at $\sqrt{s}=7$ TeV
- ⁵⁹ The quoted limit assumes $g_{WWZ'}/g_{WWZ} = (M_W/M_{Z'})^2$. See their Fig. 4 for limits in mass-coupling plane.
- 60 AALTONEN 09AC search for new particle decaying to dijets.
- ⁶¹ AALTONEN 09v search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.
- 62 ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0026 < \theta < 0.0006$.
- 63 ABDALLAH 06C use data $\sqrt{s}=130$ –207 GeV.
- ⁶⁴ ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 65 ACOSTA 05R search for resonances decaying to tau lepton pairs in $\overline{\rho}p$ collisions at \sqrt{s} ... = 1.96 TeV.
- 66 ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00422 < \theta < 0.00091$. $\sqrt{s} = 91$ to 207 GeV
- 67 (BAZOV 01B search for resonances in $p\overline{p}\to e^+e^-$ at \sqrt{s} =1.8 TeV. They find σ · B($Z'\to ee$) < 0.06 pb for $M_{Z'}$ > 500 GeV.
- ⁶⁸ ABREU 00s uses LEP data at \sqrt{s} =90 to 189 GeV.
- ⁶⁹ BARATE 00I search for deviations in cross section and asymmetries in $e^+e^- \rightarrow$ fermions at \sqrt{s} =90 to 183 GeV. Assume θ =0. Bounds in the mass-mixing plane are shown in their Figure 18.
- 70 ERLER 99 give 90%CL limit on the Z-Z' mixing $-0.0041 < \theta < 0.0003$. $\rho_0{=}1$ is assumed
- 71 ABE 97s find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) <$ 40 fb for $m_{Z'} >$ 600 GeV at $\sqrt{s} = 1.8$ TeV.
- $^{72}\,\mathrm{VILAIN}$ 94B assume $m_{\,t}=$ 150 GeV.
- 73 ALITTI 93 search for resonances in the two-jet invariant mass. The limit assumes B($Z'
 ightarrow q\overline{q}$)=0.7. See their Fig. 5 for limits in the $m_{Z'}$ -B($q\overline{q}$) plane.
- ⁷⁴ RIZZO 93 analyses CDF limit on possible two-jet resonances.
- 75 ABE 90r use data for R, $R_{\ell\ell}$, and $A_{\ell\ell}$. They fix $m_W=80.49\pm0.43\pm0.24$ GeV and $m_Z=91.13\pm0.03$ GeV.

Limits for Z_{LR}

 Z_{LR} is the extra neutral boson in left-right symmetric models. $g_L = g_R$ is assumed unless noted. Values in parentheses assume stronger constraint on the Higgs sector, usually motivated by specific left-right symmetric models (see the Note on the W'). Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino. Direct search bounds assume decays to Standard Model fermions only, unless noted.

I

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---------------|------------------|------------------|-------|-----------|-------------------------------------------------------------------------------------------------------|
| >1162 9 | ₉₅ 76 | DEL-AGUILA | 10 | | Electroweak |
| > 630 | ₉₅ 77 | ABE | 97s | CDF | $\rho \overline{\rho}; Z'_{LR} \rightarrow e^+ e^-, \mu^+ \mu^-$ |
| | use the foll | owing data for a | verag | es, fits, | limits, etc. • • • |
| > 998 9 | ₉₅ 78 | ERLER | 09 | RVUE | Electroweak |
| > 600 9 | 95 | SCHAEL | 07A | ALEP | e^+e^- |
| > 455 9 | | ABDALLAH | 06c | DLPH | e^+e^- |
| > 518 9 | 95 80 | ABBIENDI | 04 G | OPAL | e^+e^- |
| > 860 9 | | CHEUNG | 01в | RVUE | Electroweak |
| > 380 9 | | ABREU | 00s | DLPH | e^+e^- |
| > 436 9 | | BARATE | 00ı | ALEP | Repl. by SCHAEL 07A |
| > 550 9 | | CHAY | 00 | RVUE | Electroweak |
| | 85 | ERLER | 00 | RVUE | Cs |
| | 86 | CASALBUONI | 99 | RVUE | Cs |
| (> 1205) | 90 87 | CZAKON | 99 | RVUE | Electroweak |
| > 564 9 | 95 88 | ERLER | 99 | RVUE | Electroweak |
| (> 1673) | | ERLER | 99 | RVUE | Electroweak |
| (> 1700) | | BARENBOIM | 98 | RVUE | Electroweak |
| > 244 9 | | CONRAD | 98 | RVUE | $ u_{\mu}$ N scattering |
| > 253 9 | | VILAIN | 94B | CHM2 | $\nu_{\mu}^{r}e \rightarrow \nu_{\mu}e$ and $\overline{\nu}_{\mu}e \rightarrow \overline{\nu}_{\mu}e$ |
| none 200-600 | 95 93 | RIZZO | 93 | | $p\overline{p}; Z_{IR} \rightarrow q\overline{q}$ |
| [> 2000] | | WALKER | 91 | COSM | Nucleosynthesis; light ν_R |
| none 200-500 | 94 | GRIFOLS | 90 | ASTR | SN 1987A; light ν_R |
| none 350-2400 | 95 | BARBIERI | | | SN 1987A; light ν_R |

- $^{76}_{--}$ DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0012 < \theta < 0.0004$
- 77 ABE 97s find $\sigma(Z') \times B(e^+e^-, \mu^+\mu^-) <$ 40 fb for $m_{Z'} >$ 600 GeV at $\sqrt{s} = 1.8$ TeV.
- 78 ERLER 09 give 95% CL limit on the Z-Z' mixing $-0.0013 < \theta < 0.0006$.
- 79 ABDALLAH 06c give 95% CL limit | heta| < 0.0028. See their Fig. 14 for limit contours in the mass-mixing plane.
- 80 ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00098 < \theta < 0.00190$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s} = 91$ to 207 GeV.
- 81 CHEUNG 01 B limit is derived from bounds on contact interactions in a global electroweak
- 82 ABREU 00s give 95% CL limit on Z-Z' mixing $|\theta| < 0.0018$. See their Fig. 6 for the limit contour in the mass-mixing plane. \sqrt{s} =90 to 189 GeV.
- 83 BARATE 001 search for deviations in cross section and asymmetries in $e^+e^-
 ightarrow$ fermions The sum of the various increases section and asymmetries in $e^+e^- \to \text{refmions}$ at $\sqrt{s} = 90$ to 183 GeV. Assume $\theta = 0$. Bounds in the mass-mixing plane are shown in their Figure 18.
- 84 CHAY 00 also find $-0.0003 < \theta <$ 0.0019. For g_R free, $m_{Z^{\prime}} >$ 430 GeV.
- $^{85}\,{\sf ERLER}$ 00 discuss the possibility that a discrepancy between the observed and predicted values of $Q_{W}(\mathsf{Cs})$ is due to the exchange of Z' . The data are better described in a certain class of the Z' models including Z_{LR} and Z_{χ} .
- 86 CASALBUONI 99 discuss the discrepancy between the observed and predicted values of $Q_{W}(\mathrm{Cs}).$ It is shown that the data are better described in a class of models including the Z_{LR} model.
- $87\,\text{CZAKON}$ 99 perform a simultaneous fit to charged and neutral sectors. Assumes manifest left-right symmetric model. Finds $|\theta| < 0.0042$.
- 88 ERLER 99 give 90% CL limit on the Z-Z' mixing -0.0009 < heta < 0.0017.
- 89 ERLER 99 assumes 2 Higgs doublets, transforming as 10 of SO(10), embedded in E_6 .
- 90 BARENBOIM 98 also gives 68% CL limits on the $\it Z-Z'$ mixing $-0.0005 < \theta < 0.0033$. Assumes Higgs sector of minimal left-right model.
- 91 CONRAD 98 limit is from measurements at CCFR, assuming no Z- Z^\prime mixing.
- 92 VILAIN 94 B assume $m_{\,t}\,=\,15\,0$ GeV and $heta{=}0$. See Fig. 2 for limit contours in the mass-mixing plane.
- 93 RIZZO 93 analyses CDF limit on possible two-jet resonances.
- 94 GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim 1$ MeV. A specific Higgs sector is assumed. See also GRIFOLS 90D, RIZZO 91.
- 95 BARBIERI 89B limit holds for $m_{
 u_R} \le 10$ MeV. Bounds depend on assumed supernova core temperature.

Limits for Z_χ Z_χ is the extra neutral boson in SO(10) \to SU(5) \times U(1) χ . $g_\chi = e/\cos\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in parentheses assume stronger constraint on the Higgs sector motivated by superstring models. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino.

| VALUE (CoV) | C10/ | DOCUMENT ID | | TECN | COMMENT |
|--------------------|------------|---------------------------|-------|-------------|--------------------------------------------------------------------------------------------------|
| VALUE (GeV) | <u>CL%</u> | DO CUMENT ID | | TECIV | COMMENT |
| >1640 | 95 | 96 AAD | | | $pp; Z'_{\chi} \rightarrow e^+e^-, \mu^+\mu^-$ |
| >1141 | 95 | ⁹⁷ ERLER | 09 | | Electroweak |
| • • • We do not us | se the f | ollowing data for ave | rages | , fits, lin | nits, etc. • • • |
| > 900 | 95 | ⁹⁸ AAD | 111 | ATLS | pp, $Z_{\chi}' \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| > 930 | 95 | ⁹⁹ AALT ONEN | 111 | CDF | $\rho \overline{\rho}; Z_{\chi}^{\prime} \rightarrow \mu^{+} \mu^{-}$ |
| > 903 | 95 | ¹⁰⁰ ABAZOV | 11A | D0 | $p\overline{p}, Z_{\chi}^{\lambda} \rightarrow e^+e^-$ |
| >1022 | 95 | ¹⁰¹ DEL-AGUILA | 10 | RVUE | Electroweak |
| > 862 | 95 | ¹⁰⁰ AALTONEN | 09т | CDF | $p\overline{p}, Z'_{\gamma} \rightarrow e^+e^-$ |
| > 892 | 95 | ¹⁰² AALTONEN | 09∨ | CDF | $\rho \overline{\rho}; Z_{\chi}^{\prime} \rightarrow \mu^{+} \mu^{-}$ |
| > 822 | 95 | ¹⁰⁰ AALTONEN | 07н | CDF | Repl. by AALTONEN 09T |
| > 680 | 95 | SCHAEL | | ALEP | e+ e- |
| > 545 | 95 | ¹⁰³ ABDALLAH | 06c | | e^+e^- |
| > 740 | | ¹⁰⁰ ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| > 690 | 95 | ¹⁰⁴ ABULENCIA | 05 A | CDF | $p\overline{p}; Z'_{\chi} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 781 | 95 | 105 ABBIENDI | 04 G | OPAL | e+ e- |
| >2100 | | 106 BARGER | 03в | COSM | Nucleosynthesis; light $ u_R$ |
| > 680 | 95 | ¹⁰⁷ CHEUNG | 01в | RVUE | Electroweak |
| > 440 | 95 | ¹⁰⁸ ABREU | 00s | DLPH | e^+e^- |
| > 533 | 95 | 109 BARATE | 001 | ALEP | Repl. by SCHAEL 07A |
| > 554 | 95 | ¹¹⁰ CHO | 00 | RVUE | Electroweak |
| | | ¹¹¹ ERLER | 00 | RVUE | Cs |
| | | 112 ROSNER | 00 | RVUE | Cs |
| > 545 | 95 | ¹¹³ ERLER | 99 | RVUE | Electroweak |
| (>1368) | 95 | 114 ERLER | 99 | RVUE | Electroweak |
| > 215 | 95 | ¹¹⁵ CONRAD | 98 | RVUE | $ u_{\mu}$ N scattering |
| > 5 95 | 95 | ¹¹⁶ ABE | 97s | CDF | $p\overline{p}$; $Z'_{\chi} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 190 | 95 | ¹¹⁷ ARIMA | 97 | VNS | Bhabha scattering |
| > 262 | 95 | ¹¹⁸ VILAIN | 94B | CHM2 | $\nu_{\mu} e \rightarrow \nu_{\mu} e; \overline{\nu}_{\mu} e \rightarrow \overline{\nu}_{\mu} e$ |
| [>1470] | | ¹¹⁹ FARAGGI | 91 | | Nucleosynthesis; light ν_R |
| > 231 | 90 | ¹²⁰ ABE | 90F | | e+ e- |
| [> 1140] | | 121 GONZALEZ-G | | | Nucleosynthesis; light $ u_R$ |
| [> 2100] | | ¹²² GRIFOLS | 90 | ASTR | SN 1987A; light ν_R |
| • | h for re | | | | μ^- in $\rho\rho$ collisions at $\sqrt{s}=7$ |

- 96 AAD 11AD search for resonances decaying to $e^+\,e^-$, $\mu^+\,\mu^-$ in $p\,p$ collisions at $\sqrt{s}=7$
- 97 ERLER 09 give 95% CL limit on the Z-Z' mixing -0.0016 < heta < 0.0006.
- ⁹⁸AAD 11J search for resonances decaying to $e^+\,e^-$ or $\mu^+\,\mu^-$ in $p\,p$ collisions at $\sqrt{s}=$ 99 AALTONEN 111 search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$
- $^{100}\,\mathrm{ABAZOV}$ 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV.

- 101 DEL-AGUILA 10 give 95% CL limit on the Z-Z $^\prime$ mixing 0.0011 < heta < 0.0007. 102 AALTONEN 09v search for resonances decaying to $\mu^+\mu^-$ in $ho \overline{
 ho}$ collisions at $\sqrt{s}=$
- 1.96 TeV. 103 ABDALLAH 06c give 95 % CL limit $|\theta| < 0.0031$. See their Fig. 14 for limit contours in
- 104 ABULENCIA 05 A search for resonances decaying to electron or muon pairs in $^{p}\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV.
- 105 ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00099 < \theta < 0.00194$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s} = 91$ to 207 GeV.
- $^{106}\,\mathrm{BARGER}$ 03B limit is from the nucleosynthesis bound on the effective number of light neutrino δN_{ν} <1. The quark-hadron transition temperature T_c =150 MeV is assumed. The limit with T_c =400 MeV is >4300 GeV.
- $107\,\mathrm{CHEUNG}$ 01B limit is derived from bounds on contact interactions in a global electroweak
- 108 ABREU 00s give 95% CL limit on $\it Z-Z'$ mixing $|\theta| <$ 0.0017. See their Fig. 6 for the limit contour in the mass-mixing plane. \sqrt{s} =90 to 189 GeV.
- 109 BARATE 001 search for deviations in cross section and asymmetries in $e^+e^- \to$ fermions at \sqrt{s} =90 to 183 GeV. Assume θ =0. Bounds in the mass-mixing plane are shown in their Figure 18.
- 110 CHO 00 use various electroweak data to constrain Z^\prime models assuming m_H =100 GeV. See Fig. 3 for limits in the mass-mixing plane.
- $^{111}\mathsf{ERLER}$ 00 discuss the possibility that a discrepancy between the observed and predicted values of $\mathit{Q}_{W}(\mathsf{Cs})$ is due to the exchange of Z' . The data are better described in a certain class of the \mathbf{Z}' models including \mathbf{Z}_{LR} and \mathbf{Z}_{χ}
- $^{112}\mathsf{ROSNER}$ 00 discusses the possibility that a discrepancy between the observed and predicted values of $Q_W(Cs)$ is due to the exchange of Z'. The data are better described in a certain class of the Z' models including Z_{χ} .
- $^{113} {\rm ERLER}$ 99 give 90% CL limit on the $\emph{Z-Z'}$ mixing $-0.0020 < \theta < 0.0015$.
- 114 ERLER 99 assumes 2 Higgs doublets, transforming as 10 of SO(10), embedded in E_6 .
- $^{115}\,\mathrm{CONRAD}$ 98 limit is from measurements at CCFR, assuming no Z-Z' mixing.
- $^{116}\, \rm{ABE}$ 97s find $\sigma(Z') \times \rm{B}(e^+\,e^-, \mu^+\,\mu^-) <$ 40 fb for $m_{Z'} >$ 600 GeV at $\sqrt{\rm s} =$ 1.8 TeV.
- $^{117}_{\cdots}$ Z-Z' mixing is assumed to be zero. $\sqrt{s}=$ 57.77 GeV.
- $^{118}\,\mathrm{VILAIN}$ 94B assume $m_{\,t}\,=\,150$ GeV and $\theta\!=\!0.$ See Fig. 2 for limit contours in the mass-mixing plane.
- $^{119}\,\mathsf{FARAGGI}$ $^{91}\,\mathsf{limit}$ assumes the nucleosynthesis bound on the effective number of neutrinos $\Delta \mathit{N}_{\nu}~<~0.5$ and is valid for $m_{\nu_R}~<1$ MeV.
- 120 ABE 90F use data for $R,\,R_{\ell\ell}$, and $A_{\ell\ell}$. ABE 90F fix $m_W=80.49\pm0.43\pm0.24$ GeV and $m_Z=91.13\pm0.03$ GeV.
- $^{\rm 121}$ Assumes the nucleosynthesis bound on the effective number of light neutrinos $(\delta \textit{N}_{\nu}~<~1)$ and that ν_R is light ($\lesssim 1~{
 m MeV}$).
- $^{122}\,\mathrm{GRIFOLS}$ 90 limit holds for $m_{\nu_R}\,\lesssim$ 1 MeV. See also GRIFOLS 90D, RIZZO 91.

Limits for Z_{ψ} Z_{ψ} is the extra neutral boson in E $_6 \to {\sf SO}(10) \times {\sf U}(1)_{\psi}$. $g_{\psi} = e/{\sf cos}\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in brackets are from cosmological and astrophysical considerations and assume a light right-handed neutrino

| ALUE (GeV) | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
|-------------|------------|----------------------------|------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| >1490 | 95 | 123 AAD | 11AE | ATLS | pp; $Z'_{\psi} ightarrow e^+ e^-$, $\mu^+ \mu^-$ |
| > 476 | 95 | ¹²⁴ DEL-AGUILA | 10 | | Electroweak |
| • • We do n | ot use the | following data for ave | | , fits, lin | nits, etc. • • • |
| > 738 | 95 | ¹²⁵ AAD | 11J | ATLS | pp, $Z'_{\psi} ightarrow e^+ e^-$, $\mu^+ \mu^-$ |
| > 917 | 95 | ¹²⁶ AALTONEN | 11) | CDF | $p\overline{p}; Z_{\eta_j}^{\tau} \rightarrow \mu^+ \mu^-$ |
| > 891 | 95 | ¹²⁷ ABAZOV | 11A | D0 | $p\overline{p}$; $Z_{\psi}^{\prime} \rightarrow \mu^{+}\mu^{-}$ $p\overline{p}$, $Z_{\psi}^{\prime} \rightarrow e^{+}e^{-}$ pp , $Z_{\psi}^{\prime} \rightarrow e^{+}e^{-}$, $\mu^{+}\mu^{-}$ $p\overline{p}$, $Z_{\psi}^{\prime} \rightarrow e^{+}e^{-}$ |
| > 887 | 95 | ¹²⁸ CHATRCHYAN | 111 | CMS | $pp, Z_{\psi}^{\uparrow} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 851 | 95 | ¹²⁷ AALTONEN | 09т | CDF | $p\overline{p}, Z_{\psi}^{T} \rightarrow e^{+}e^{-}$ |
| > 878 | 95 | ¹²⁹ AALTONEN | 09v | CDF | $p\overline{p}; Z_{\psi}^{T} \rightarrow \mu^{+}\mu^{-}$ |
| > 147 | 95 | ¹³⁰ ERLER | 09 | RVUE | Electroweak |
| > 822 | 95 | ¹²⁷ AALTONEN | 07н | CDF | Repl. by AALTONEN 09T |
| > 410 | 95 | SCHAEL | 07A | ALEP | e^+e^- |
| > 475 | 95 | ¹³¹ ABDALLAH | 06c | DLPH | e^+e^- |
| > 725 | | ¹²⁷ ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| > 675 | 95 | ¹³² ABULENCIA | 05 A | CDF | $p\overline{p}$; $Z'_{\psi} \rightarrow e^+e^-$, $\mu^+\mu^-$ |
| > 366 | 95 | 133 ABBIENDI | 04 G | OPAL | e^+e^- |
| > 600 | | ¹³⁴ BARGER | 03в | COSM | Nucleosynthesis; light ν_R |
| > 350 | 95 | ¹³⁵ ABREU | 00s | DLPH | e+e- |
| > 294 | 95 | 136 BARATE | 001 | ALEP | Repl. by SCHAEL 07A |
| > 137 | 95 | ¹³⁷ сно | 00 | RVUE | Electroweak |
| > 146 | 95 | 138 ERLER | 99 | RVUE | Electroweak |
| > 54 | 95 | ¹³⁹ CONRAD | 98 | RVUE | $ u_{\mu}$ N scattering |
| > 590 | 95 | ¹⁴⁰ ABE | 97s | CDF | $p\overline{\overline{p}}; Z'_{\psi} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 135 | 95 | ¹⁴¹ VILAIN | 94B | CHM2 | |
| > 105 | 90 | ¹⁴² ABE | 90F | VNS | e+e- |
| > 160] | | ¹⁴³ GONZALEZ-G. | .90D | COSM | Nucleosynthesis; light $ u_R$ |
| > 2000] | | 144 GRIFOLS | | ASTR | |

- 123 AAD 11AD search for resonances decaying to e^+e^- , $\mu^+\mu^-$ in $ho\, p$ collisions at $\sqrt{s}=7$
- TeV. $124\,\mathrm{DEL}\text{-AGUILA}$ 10 give 95% CL limit on the $\emph{Z-Z'}$ mixing $-0.0019 < \theta < 0.0007$
- $^{125}\,\mathrm{AAD}$ 11J search for resonances decaying to $e^+\,e^-$ or $\mu^+\,\mu^-$ in $p\,p$ collisions at $\sqrt{s}=$ 7 TeV
- 126 AALTONEN 111 search for resonances decaying to $\mu^+\mu^-$ in $\rho\overline{\rho}$ collisions at $\sqrt{s}=1.96$
- 127 ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to e^+e^- in $p\overline{p}$ collisions at $\sqrt{s}=1.96\,\mathrm{TeV}$.

- $^{128}\,\mathrm{CHATRCHYAN}$ 11 search for resonances decaying to $e^+\,e^-$ or $\mu^+\,\mu^-$ in pp collisions
- 129 AALTONEN 09v search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=$
- 130 ERLER 09 give 95% CL limit on the Z-Z' mixing -0.0018 < heta < 0.0009.
- 131 ABDALLAH 06c give 95% CL limit | heta| < 0.0027. See their Fig. 14 for limit contours in the mass-mixing plane.
- 132 ABULENCIA 05A search for resonances decaying to electron or muon pairs in $\rho \overline{\rho}$ collisions at $\sqrt{s}=1.96$ TeV.
- 133 ABBIENDI 04G give 95% CL limit on Z-Z' mixing $-0.00129 < \theta < 0.00258$. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s} = 91$ to 207 GeV. 134 BARGER 03B limit is from the nucleosynthesis bound on the effective number of light
- neutrino δN_{ν} <1. The quark-hadron transition temperature T_C =150 MeV is assumed. The limit with T_C =400 MeV is >1100 GeV.
- 135 ABREU 00s give 95% CL limit on Z-Z' mixing $|\theta| <$ 0.0018. See their Fig. 6 for the limit contour in the mass-mixing plane. \sqrt{s} =90 to 189 GeV.
- 136 BARATE 001 search for deviations in cross section and asymmetries in $e^+e^- \to$ fermions at \sqrt{s} =90 to 183 GeV. Assume θ =0. Bounds in the mass-mixing plane are shown in their Figure 18.
- 137 CHO 00 use various electroweak data to constrain Z^\prime models assuming m_H =100 GeV. See Fig. 3 for limits in the mass-mixing plane.
- 138 ERLER 99 give 90% CL limit on the Z-Z' mixing -0.0013 < heta < 0.0024
- 139 CONRAD 98 limit is from measurements at CCFR, assuming no $Z\text{-}Z^\prime$ mixing.
- $^{140}\,\mathrm{ABE}$ 97s find $\sigma(Z')\times\mathrm{B}(e^+\,e^-,\mu^+\,\mu^-)\!<$ 40fb for $m_{\mbox{$Z'$}}>\bar{600}$ GeV at $\sqrt{s}\!=1.8$ TeV.
- $^{141}\,\mathrm{VILAIN}$ 94B assume $m_{\,t}\,=\,150$ GeV and $\theta{=}0.$ See Fig.2 for limit contours in the mass-mixing plane.
- 142 ABE 90F use data for R, $R_{\ell\ell}$, and $A_{\ell\ell'}$ ABE 90F fix $m_W=80.49\pm0.43\pm0.24$ GeV and $m_Z=91.13\pm0.03$ GeV.
- $^{143} \text{Assumes}$ the nucleosynthesis bound on the effective number of light neutrinos $(\delta \textit{N}_{\nu} \ < \ 1)$ and that ν_R is light ($\lesssim 1$ MeV).
- $^{144}\,\mathrm{GRIFOLS}$ 90D limit holds for $m_{\nu_R} \lesssim 1$ MeV. See also RIZZO 91.

Limits for Z_{η}

 Z_{η} is the extra neutral boson in E $_6$ models, corresponding to $Q_{\eta}=\sqrt{3/8}~Q_{\chi}-\sqrt{5/8}~Q_{\psi}~g_{\eta}=e/{\rm cos}\theta_W$ is assumed unless otherwise stated. We list limits with the assumption $\rho=1$ but with no further constraints on the Higgs sector. Values in parentheses assume stronger constraint on the Higgs sector motivated by superstring models. Values in brackets are from cosmological and astrophysical considerations and

| assume a ligh | t right- | handed neutrino. | | | |
|-------------------------------------|----------|-------------------------|-------------|-------------------|---------------------------------------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| >1540 | 95 | 145 AAD | 11AE | ATLS | $pp; Z'_n \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 619 | 95 | ¹⁴⁶ сно | 00 | RVUE | Electroweak |
| ● ● We do not u | se the 1 | following data for ave | rages | , fits, lin | nits, etc. • • • |
| > 771 | 95 | ¹⁴⁷ AAD | 11J | ATLS | pp, $Z'_{\eta} ightarrow e^+e^-$, $\mu^+\mu^-$ |
| > 938 | 95 | ¹⁴⁸ AALTONEN | 111 | CDF | $p\overline{p}; Z_{\eta}^{\prime} \rightarrow \mu^{+}\mu^{-}$ |
| > 923 | 95 | ¹⁴⁹ ABAZOV | 11A | D0 | $p\overline{p}, Z_n' \rightarrow e^+e^-$ |
| > 488 | 95 | 150 DEL-AGUILA | 10 | RVUE | Electroweak |
| > 877 | 95 | ¹⁴⁹ AALTONEN | 09т | CDF | $p\overline{p}, Z'_{\eta} \rightarrow e^+e^-$ |
| > 904 | 95 | ¹⁵¹ AALTONEN | 09∨ | CDF | $p\overline{p}; Z'_{\eta} \rightarrow \mu^{+}\mu^{-}$ |
| > 427 | 95 | 152 ERLER | 09 | RVUE | Electroweak |
| > 891 | 95 | ¹⁴⁹ AALTONEN | 07н | CDF | Repl. by AALTONEN 09T |
| > 350 | 95 | SCHAEL | 07A | ALEP | e^+e^- |
| > 360 | 95 | 153 ABDALLAH | 06c | DLPH | e^+e^- |
| > 745 | | 149 ABULENCIA | 06L | CDF | Repl. by AALTONEN 07H |
| > 720 | 95 | 154 ABULENCIA | 05 A | CDF | $p\overline{p}; Z'_{\eta} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 515 | 95 | 155 ABBIENDI | 04 G | OPAL | e^+e^- |
| >1600 | | 156 BARGER | 03в | COSM | Nucleosynthesis; light $ u_R$ |
| > 310 | 95 | 157 ABREU | 00s | DLPH | e^+e^- |
| > 329 | 95 | 158 BARATE | 001 | ALEP | Repl. by SCHAEL 07A |
| > 365 | 95 | 159 ERLER | 99 | RVUE | Electroweak |
| > 87 | 95 | ¹⁶⁰ CONRAD | 98 | RVUE | $ u_{\mu}$ N scattering |
| > 620 | 95 | ¹⁶¹ ABE | 97s | CDF | $p\overline{p}; Z'_{\eta} \rightarrow e^+e^-, \mu^+\mu^-$ |
| > 100 | 95 | 162 VILAIN | 94B | CHM2 | μ μ μ μ |
| > 125 | 90 | 163 ABE | 90F | VNS | e ⁺ e ⁻ |
| [> 820] | | 164 GONZALEZ-G | | | Nucleosynthesis; light $ u_R$ |
| [> 3300] | | 165 GRIFOLS | 90 | ASTR | |
| [> 1040] | | ¹⁶⁴ LOPEZ | 90 | COSM | Nucleosynthesis; light $ u_R$ |
| 145 AAD 11AD sear | ch for r | esonances decaying t | o e+ | e^- , μ^+ , | μ^- in pp collisions at $\sqrt{s}=7$ |

- ¹⁴⁶CHO 00 use various electroweak data to constrain Z' models assuming m_H =100 GeV. See Fig. 3 for limits in the mass-mixing plane.
- 147 AAD 11J search for resonances decaying to $e^+\,e^-$ or $\mu^+\,\mu^-$ in $p\,p$ collisions at $\sqrt{s}=$ 7 TeV. 148 AALTONEN 11I search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$
- 149 ABAZOV 11A, AALTONEN 09T, AALTONEN 07H, and ABULENCIA 06L search for resonances decaying to $e^+\,e^-$ in $p\,\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV.
- 150 DEL-AGUILA 10 give 95% CL limit on the Z-Z' mixing $-0.0023 < \theta < 0.0027$.
- 151 AALTONEN 09v search for resonances decaying to $\mu^+\mu^-$ in $p\overline{p}$ collisions at $\sqrt{s}=$
- 152 ERLER 09 give 95% CL limit on the Z-Z' mixing -0.0047 < heta < 0.0021.
- 153 ABDALLAH 06c give 95% CL limit | heta| < 0.0092. See their Fig. 14 for limit contours in the mass-mixing plane.
- 154 ABULENCIA 05 A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions

- 155 ABBIENDI 04G give 95% CL limit on Z-Z' mixing -0.00447 < heta < 0.00331. See their Fig. 20 for the limit contour in the mass-mixing plane. $\sqrt{s}=91$ to 207 GeV.
- $156\,\mathrm{BARGER}$ 03B limit is from the nucleosynthesis bound on the effective number of light neutrino δh_{ν} < 1. The quark-hadron transition temperature T_c =150 MeV is assumed. The limit with T_c =400 MeV is >3300 GeV.
- 157 ABREU 00s give 95% CL limit on Z-Z' mixing $|\theta| <$ 0.0024. See their Fig. 6 for the limit contour in the mass-mixing plane. \sqrt{s} =90 to 189 GeV.
- 158 BARATE 001 search for deviations in cross section and asymmetries in $e^+e^- \to$ fermions at \sqrt{s} =90 to 183 GeV. Assume θ =0. Bounds in the mass-mixing plane are shown in their Figure 18.
- 159 ERLER 99 give 90% CL limit on the Z-Z' mixing $-0.0062 < \theta < 0.0011$
- 160 CONRAD 98 limit is from measurements at CCFR, assuming no Z-Z' mixing. 161 ABE 97s find $\sigma(Z')\times {\rm B(e^+e^-,}\mu^+\mu^-)<40$ fb for $m_{Z'}>600$ GeV at $\sqrt s=1.8$ TeV.
- 162 VILAIN 94B assume $m_t=150$ GeV and $\theta=0$. See Fig. 2 for limit contours in the mass-mixing plane.
- 163 ABE 90F use data for R, $R_{\ell\ell}$, and $A_{\ell\ell}$. ABE 90F fix $m_W=80.49\pm0.43\pm0.24$ GeV and $m_Z=91.13\pm0.03$ GeV.
- 164 These authors claim that the nucleosynthesis bound on the effective number of light neutrinos $(\delta \textit{N}_{\nu}~<~1)$ constrains $\textit{Z'}_{-}$ masses if ν_{R} is light ($\lesssim 1~{\rm MeV}).$
- 165 GRIFOLS 90 limit holds for $m_{\nu_R} \lesssim$ 1 MeV. See also GRIFOLS 90D, RIZZO 91.

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| Limits for other Z' | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------------|--------------|-----------|---------------------------------|
| • • We do not use the follow | wing data for averag | es, fits | , limits, | etc. • • • |
| | ¹⁶⁶ AAD | 11 H | ATLS | $Z' \rightarrow e \mu$ |
| | 167 AAD | 11 z | | $Z' \rightarrow e \mu$ |
| | ¹⁶⁸ AALTONEN | 11AD | CDF | $Z' \rightarrow t \overline{t}$ |
| | ¹⁶⁹ AALTONEN | | | |
| | ¹⁷⁰ CHATRCHYAN | V 110 | CMS | $pp \rightarrow tt$ |
| | ¹⁷¹ AALTONEN | 08D | CDF | $Z' \rightarrow t \overline{t}$ |
| | ¹⁷¹ AALTONEN | 08Y | CDF | $Z' \rightarrow t \overline{t}$ |
| | ¹⁷¹ ABAZOV | AA80 | D0 | $Z' \rightarrow t \overline{t}$ |
| | ¹⁷² ABULENCIA | 06м | CDF | $Z' \rightarrow e \mu$ |
| | ¹⁷³ ABAZOV | 04 A | D0 | Repl. by ABAZOV 08AA |
| | ¹⁷⁴ BARGER | 03B | COSM | Nucleosynthesis; light $ u_R$ |
| | ¹⁷⁵ CHO | 00 | RVUE | E ₆ -motivated |
| | ¹⁷⁶ сно | 98 | RVUE | E ₆ -motivated |
| | ¹⁷⁷ ABE | 97 G | CDF | $Z' \rightarrow \overline{q}q$ |

- $166\,\mathrm{A}\mathrm{\underline{A}D}$ 11H search for new particle with lepton flavor violating decay in pp collisions at $\sqrt{s}=7$ TeV. See their Fig. 3 for exclusion plot on the production cross section.
- 167 AAD 11z search for new particle with lepton flavor violating decay in pp collisions at \sqrt{s} = 7 TeV. See their Fig. 3 for limit on $\sigma \cdot B$.
- 168 Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 4 for limit on $\sigma \cdot \mathrm{B}$.
- 169 Search for narrow resonance decaying to $t\,\overline{t}$. See their Fig. 3 for limit on $\sigma\cdot {\sf B}$.
- 170 CHATRCHYAN 110 search for same-sign top production in pp collisions induced by a hypothetical FCNC Z' at $\sqrt{s}=7$ TeV. See their Fig. 3 for limit in mass-coupling plane. 171 Search for narrow resonance decaying to $t\bar{t}$. See their Fig. 3 for limit on $\sigma \cdot B$.
- 172 ABULENCIA 06M search for new particle with lepton flavor violating decay at \sqrt{s} = 1.96 TeV. See their Fig. 4 for an exclusion plot on a mass-coupling plane
- 173 Search for narrow resonance decaying to $t\overline{t}$. See their Fig. 2 for limit on $\sigma\cdot {\rm B}$.
- 174 BARGER 038 use the nucleosynthesis bound on the effective number of light neutrino δN_{ν} . See their Figs. 4–5 for limits in general E_6 motivated models.
- $^{175}\,\mathrm{CHO}$ 00 use various electroweak data to constrain Z' models assuming m_H =100 GeV. See Fig. 2 for limits in general E_6 -motivated models.
- $176\,\mathrm{CHO}$ 98 study constraints on four-Fermi contact interactions obtained from low-energy electroweak experiments, assuming no Z-Z' mixing.
- 177 Search for Z' decaying to dijets at \sqrt{s} =1.8 TeV. For Z' with electromagnetic strength coupling, no bound is obtained.

Indirect Constraints on Kaluza-Klein Gauge Bosons

Bounds on a Kaluza-Klein excitation of the \overline{Z} boson or photon in d=1 extra dimension. These bounds can also be interpreted as a lower bound on 1/R, the size of the extra dimension. Unless otherwise stated, bounds assume all fermions live on a single brane and all gauge fields occupy the 4+d-dimensional bulk. See also the section on "Extra Dimensions" in the "Searches" Listings in this Review.

| VALUE (TeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------|------------|-------------------------|----------|---------|--------------|
| • • • We do not use | the follow | ing data for average | s, fits, | limits, | etc. • • • |
| > 4.7 | | ¹⁷⁸ MUECK | 02 | RVUE | Electroweak |
| > 3.3 | 95 | 179 CORNET | 00 | RVUE | $e \nu q q'$ |
| >5000 | | ¹⁸⁰ DELGADO | 00 | RVUE | €K |
| > 2.6 | 95 | ¹⁸¹ DELGADO | 00 | RVUE | Electroweak |
| > 3.3 | 95 | ¹⁸² RIZZO | 00 | RVUE | Electroweak |
| > 2.9 | 95 | ¹⁸³ MARCIANO | 99 | RVUE | Electroweak |
| > 2.5 | 95 | ¹⁸⁴ MASIP | 99 | RVUE | Electroweak |
| > 1.6 | 90 | ¹⁸⁵ NATH | 99 | RVUE | Electroweak |
| > 3.4 | 95 | ¹⁸⁶ STRUMIA | 99 | RVUE | Electroweak |

- $^{178}\,\mathrm{MUECK}$ 02 limit is 2σ and is from global electroweak fit ignoring correlations among observables. Higgs is assumed to be confined on the brane and its mass is fixed. For scenarios of bulk Higgs, of brane-SU(2)_L, bulk-U(1)_Y, and of bulk-SU(2)_L, brane-U(1)_Y, the corresponding limits are > 4.6 TeV, > 4.3 TeV and > 3.0 TeV, respectively.
- 179 Bound is derived from limits on $e \, \nu \, q \, q'$ contact interaction, using data from HERA and
- the Tevatron. 180 Bound holds only if first two generations of quarks lives on separate branes. If quark mixing is not complex, then bound lowers to 400 TeV from Δm_K . $^{181}\,\mathrm{See}$ Figs. 1 and 2 of DELGADO 00 for several model variations. Special boundary con-

ditions can be found which permit KK states down to 950 GeV and that agree with the

measurement of $Q_W({\rm Cs})$. Quoted bound assumes all Higgs bosons confined to brane; placing one Higgs doublet in the bulk lowers bound to 2.3 TeV. 182 Bound is derived from global electroweak analysis assuming the Higgs field is trapped on the matter brane. If the Higgs propagates in the bulk, the bound increases to 3.8 TeV. 183 Bound is derived from global electroweak analysis but considering only presence of the KK W bosons.

184 Global electroweak analysis used to obtain bound independent of position of Higgs on brane or in bulk

185 Bounds from effect of KK states on G_F , α , M_W , and M_Z . Hard cutoff at string scale determined using gauge coupling unification. Limits for d=2,3,4 rise to 3.5, 5.7, and 7.8

¹⁸⁶Bound obtained for Higgs confined to the matter brane with m_H =500 GeV. For Higgs in the bulk, the bound increases to 3.5 TeV.

LEPTOQUARKS

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Leptoquarks are hypothetical particles carrying both baryon number (B) and lepton number (L). The possible quantum numbers of leptoquark states can be restricted by assuming that their direct interactions with the ordinary SM fermions are dimensionless and invariant under the standard model (SM) gauge group. Table 1 shows the list of all possible quantum numbers with this assumption [1]. The columns of $SU(3)_C$, $SU(2)_W$, and $U(1)_Y$ in Table 1 indicate the QCD representation, the weak isospin representation, and the weak hypercharge, respectively. The spin of a leptoquark state is taken to be 1 (vector leptoquark) or 0 (scalar leptoquark).

Table 1: Possible leptoquarks and their quantum numbers.

| Spin | 3B + L | $SU(3)_c$ | $SU(2)_W$ | $U(1)_Y$ | Allowed coupling |
|------|--------|-----------|-----------|----------|-----------------------------------------------------------------|
| 0 | -2 | $\bar{3}$ | 1 | 1/3 | $\bar{q}_L^c \ell_L \text{ or } \bar{u}_R^c e_R$ |
| 0 | -2 | $\bar{3}$ | 1 | 4/3 | $ar{d}_R^c e_R$ |
| 0 | -2 | $\bar{3}$ | 3 | 1/3 | $ar{q}^c_L \ell_L$ |
| 1 | -2 | $\bar{3}$ | 2 | 5/6 | $\bar{q}_L^c \gamma^\mu e_R$ or $\bar{d}_R^c \gamma^\mu \ell_L$ |
| 1 | -2 | $\bar{3}$ | 2 | -1/6 | $\bar{u}_R^c \gamma^\mu \ell_L$ |
| 0 | 0 | 3 | 2 | 7/6 | $\bar{q}_L e_R$ or $\bar{u}_R \ell_L$ |
| 0 | 0 | 3 | 2 | 1/6 | $ar{d}_R\ell_L$ |
| 1 | 0 | 3 | 1 | 2/3 | $\bar{q}_L \gamma^\mu \ell_L$ or $\bar{d}_R \gamma^\mu e_R$ |
| 1 | 0 | 3 | 1 | 5/3 | $\bar{u}_R \gamma^\mu e_R$ |
| 1 | 0 | 3 | 3 | 2/3 | $ar{q}_L \gamma^\mu \ell_L$ |

If we do not require leptoquark states to couple directly with SM fermions, different assignments of quantum numbers become possible [2,3].

Leptoquark states are expected to exist in various extensions of SM. The Pati-Salam model [4] is an example predicting the existence of a leptoquark state. Vector leptoquark states also exist in grand unification theories based on SU(5) [5], SO(10) [6], which includes Pati-Salam color SU(4), and larger gauge groups. Scalar quarks in supersymmetric models with R-parity violation may also have leptoquark-type Yukawa couplings. The bounds on the leptoquark states can therefore be applied to constrain R-parity-violating supersymmetric models. Scalar leptoquarks are expected to exist at TeV scale in extended technicolor models [7,8] where leptoquark states appear as the bound states of techni-fermions. Compositeness of quarks

and leptons also provides examples of models which may have light leptoquark states [9].

Bounds on leptoquark states are obtained both directly and indirectly. Direct limits are from their production cross sections at colliders, while indirect limits are calculated from the bounds on the leptoquark-induced four-fermion interactions, which are obtained from low-energy experiments, or from collider experiments below threshold.

If a leptoquark couples to fermions belonging to more than a single generation in the mass eigenbasis of the SM fermions, it can induce four-fermion interactions causing flavor-changing neutral currents and lepton-family-number violations. The quantum number assignment of Table 1 allows several leptoquark states to couple to both left- and right-handed quarks simultaneously. Such leptoquark states are called non-chiral and may cause four-fermion interactions affecting the $(\pi \to e\nu)/(\pi \to \mu\nu)$ ratio [10]. Non-chiral scalar leptoquarks also contribute to the muon anomalous magnetic moment [11,12]. Since indirect limits provide more stringent constraints on these types of leptoquarks, it is often assumed that a leptoquark state couples only to a single generation in a chiral interaction, for which indirect limits become much weaker. Additionally, this assumption gives strong constraints on concrete models of leptoquarks.

Leptoquark states which couple only to left- or righthanded quarks are called chiral leptoquarks. Leptoquark states which couple only to the first (second, third) generation are referred as the first- (second-, third-) generation leptoquarks. Refs. [13,14] give extensive lists of the bounds on the leptoquark-induced four-fermion interactions. For the isoscalar and vector leptoquarks S_0 and V_0 , for example, which couple with the first- (second-) generation left-handed quark, and the first-generation left-handed lepton, the bounds of Ref. 13 read $\lambda^2 < 0.03 \times (M_{LO}/300 \text{ GeV})^2$ for S_0 , and $\lambda^2 < 0.02 \times (M_{\rm LQ}/300~{\rm GeV})^2$ for $V_0~(\lambda^2 < 5 \times (M_{\rm LQ}/300~{\rm GeV})^2$ for S_0 , and $\lambda^2 < 3 \times (M_{LQ}/300 \text{ GeV})^2$ for V_0) with λ being the leptoquark coupling strength. The e^+e^- experiments are sensitive to the indirect effects coming from t- and uchannel exchanges of leptoquarks in the $e^+e^- \rightarrow q\bar{q}$ process. The HERA experiments give bounds on the leptoquark-induced four-fermion interaction. For detailed bounds obtained in this way, see the Boson Particle Listings for "Indirect Limits for Leptoquarks" and its references.

Collider experiments provide direct limits on the leptoquark states through limits on the pair- and single-production cross sections. The leading-order cross sections of the parton processes

$$q + \bar{q} \rightarrow LQ + \overline{LQ}$$

 $g + g \rightarrow LQ + \overline{LQ}$
 $e + q \rightarrow LQ$ (1)

may be written as [15]

$$\begin{split} \hat{\sigma}_{\text{LO}} \left[q \bar{q} \to \text{LQ} + \overline{\text{LQ}} \right] &= \frac{2\alpha_s^2 \pi}{27 \hat{s}} \beta^3, \\ \hat{\sigma}_{\text{LO}} \left[g g \to \text{LQ} + \overline{\text{LQ}} \right] &= \frac{\alpha_s^2 \pi}{96 \hat{s}} \\ &\times \left[\beta (41 - 31 \beta^2) + (18 \beta^2 - \beta^4 - 17) \log \frac{1 + \beta}{1 - \beta} \right], \\ \hat{\sigma}_{\text{LO}} \left[e q \to \text{LQ} \right] &= \frac{\pi \lambda^2}{4} \delta (\hat{s} - M_{\text{LQ}}^2) \end{split} \tag{2}$$

for a scalar leptoquark. Here $\sqrt{\hat{s}}$ is the invariant energy of the parton subprocess, and $\beta \equiv \sqrt{1-4M_{\rm LQ}^2/\hat{s}}$. The leptoquark Yukawa coupling is given by λ . Leptoquarks are also produced singly at hadron colliders through $g+q\to LQ+\ell$ [16], which allows extending to higher masses the collider reach in the leptoquark search [17], depending on the leptoquark Yukawa coupling.

The LHC, Tevatron and LEP experiments search for pair production of the leptoquark states, which arises from the leptoquark gauge interaction. The searches are carried on in signatures including high P_T leptons, E_T jets and large missing transverse energy, due to the typical decay of the leptoquark. The gauge couplings of a scalar leptoquark are determined uniquely according to its quantum numbers in Table 1. Since all of the leptoquark states belong to color-triplet representation, the scalar leptoquark pair-production cross section at the Tevatron and LHC can be determined solely as a function of the leptoquark mass without making further assumptions. This is in contrast to the indirect or single-production limits, which give constraints in the leptoquark mass-coupling plane. For the first- and second-generation scalar leptoquark states with decaying branching fraction $\beta = B(eq) = 1$ and $\beta = B(\mu q) = 1$, the CDF and DØ experiments obtain the lower bounds on the leptoquark mass > 236 GeV (first generation, CDF) [18], > 299 GeV (first generation, DØ) [19], > 226 GeV (second generation, CDF) [20], and > 316 GeV (second generation, DØ) [21] at 95% CL. Third generation leptoquark mass bounds come from the DØ experiment [22] which sets a limit at 247 GeV for a charge -1/3 third generation scalar leptoquark, at 95% C.L.

Recent results from the LHC proton-proton collider, running at a center of mass energy of 7 TeV, extend previous Tevatron mass limits for scalar leptoquarks to > 384 GeV (first generation, CMS, $\beta=1$) [23] and > 339 GeV(first generation, CMS, $\beta=0.5$) [24]; > 660 GeV (first generation, ATLAS, $\beta=1$) and > 607 GeV (first generation, ATLAS, $\beta=1$) and > 523 GeV (second generation, CMS, $\beta=1$) [26] and > 523 GeV (second generation, CMS, $\beta=0.5$) [26] and; > 685 GeV (second generation, ATLAS, $\beta=1$) and > 594 GeV (second generation, ATLAS, $\beta=0.5$) [27]. All limits at 95% C.L. Finally a new measurement performed by the CMS experiment [28] extends the mass limit to 350 GeV for a charge -1/3 third generation scalar leptoquark, at 95% C.L.

The magnetic-dipole-type and the electric-quadrupole-type interactions of a vector leptoquark are not determined even if we fix its gauge quantum numbers as listed in the Table [29]. The production of vector leptoquarks depends in general on additional assumptions that the leptoquark couplings and their pair-production cross sections are enhanced relative to the scalar leptoquark contributions. At the Tevatron for instance, since the acceptance for vector and scalar leptoquark detection is similar, limits on the vector leptoquark mass will be more stringent (see for example [35,19]). The leptoquark pair-production cross sections in e^+e^- collisions depend on the leptoquark $SU(2)\times U(1)$ quantum numbers and Yukawa coupling with electron [30]. The OPAL experiment sets mass bounds on various leptoquark states from the pair-production cross sections [31]. For a second-generation weak-isosinglet weak-hypercharge -4/3scalar-leptoquark state, for example, the OPAL pair-production bound is $M_{\rm LO} > 100~{\rm Ge/c^2V}$ at 95% C.L. The LEP experiments also searched for the single production of the leptoquark states from the process $e\gamma \to LQ + q$.

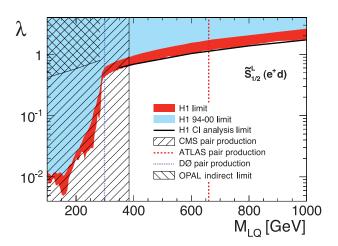
The most stringent searches for the leptoquark single production are performed by the HERA experiments. Since the leptoquark single-production cross section depends on its Yukawa coupling, the leptoquark mass limits from HERA are usually displayed in the mass-coupling plane. For leptoquark Yukawa coupling $\lambda=0.1$, the ZEUS bounds on the first-generation leptoquarks range from 248 to 290 GeV, depending on the leptoquark species [32]. Recently the H1 Collaboration released a comprehensive summary of searches for first generation leptoquarks using the full data sample collected in ep collisions at HERA (446 pb⁻¹). No evidence of production of leptoquarks is observed in final states with a large transverse momentum electron or large missing transverse momentum. For a coupling strength $\lambda=0.3$, first generation leptoquarks with masses up to 800 GeV are excluded at 95% C.L. [34]

Fig. 1 summarizes ATLAS, CMS, DØ, LEP, and H1 limits on two typical first-generation scalar-leptoquark states in the mass-coupling plane [34].

The search for LQ will be continued with more LHC data. Early feasability studies by the LHC experiments ATLAS [36] and CMS [37] indicate that clear signals can be established for masses up to about M(LQ) 1.3 to 1.4 TeV for first- and second-generation scalar LQ, with a likely final reach 1.5 TeV, for collisions at 14 TeV in the center of mass.

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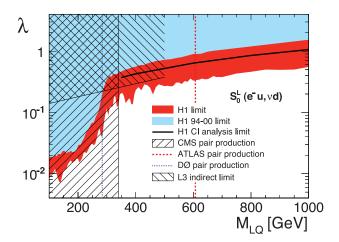


Figure 1: Limits on two typical first-generation scalar leptoquark states in the mass-coupling plane. The upper figure is for a weak-isodoublet, weak-hypercharge 7/6, 3B + L = 0 leptoquark state, while the lower figure for a weak-isosinglet, weak-hypercharge -1/3, 3B + L = 2 state. Figure adopted from Ref. 34.

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MASS LIMITS for Leptoquarks from Pair Production

These limits rely only on the color or electroweak charge of the leptoquark.

| | | | | | = |
|-----------------------------------|---------|---------------------------|--------------|-------------|---------------------------|
| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
| >660 | 95 | 187 AAD | 12H | ATLS | First generation |
| >422 | 95 | ¹⁸⁸ AAD | 11 D | ATLS | Second Generation |
| >247 | 95 | ¹⁸⁹ ABAZOV | 10L | D0 | Third generation |
| ● ● We do not | use the | following data for a | verage | es, fits, l | imits, etc. • • • |
| >376 | 95 | ¹⁹⁰ AAD | 11 D | ATLS | First Generation |
| >326 | 95 | 191 ABAZOV | 11 v | D0 | First generation |
| >339 | 95 | ¹⁹² CHATRCHYAN | J 11N | CMS | First generation |
| >384 | 95 | ¹⁹³ KHACHATRY. | | CMS | First generation |
| >394 | 95 | ¹⁹⁴ KHACHATRY. | .11E | CMS | Second generation |
| >316 | 95 | ¹⁹⁵ ABAZOV | 09 | D0 | Second generation |
| >299 | 95 | ¹⁹⁶ ABAZOV | 09AF | D0 | First generation |
| | | ¹⁹⁷ AALTONEN | 08P | CDF | Third generation |
| >153 | 95 | ¹⁹⁸ AALTONEN | 08 z | CDF | Third generation |
| >205 | 95 | ¹⁹⁹ ABAZOV | 08AD | D0 | All generations |
| >210 | 95 | ¹⁹⁸ ABAZOV | 08AN | D0 | Third generation |
| >229 | 95 | ²⁰⁰ ABAZOV | 07 J | D0 | Third generation |
| >251 | 95 | ²⁰¹ ABAZOV | 06A | D0 | Superseded by ABAZOV 09 |
| >136 | 95 | ²⁰² ABAZOV | 06L | D0 | Superseded by ABAZOV 08AD |
| | | | | | |

Gauge & Higgs Boson Particle Listings

Heavy Bosons Other than Higgs Bosons

| >226 | 95 | 203 | ABULENCIA | 06т | CDF | Second generation |
|----------------|--------|-----|-------------|------|------|----------------------------|
| >256 | 95 | 204 | ABAZOV | 05 н | D0 | First generation |
| >117 | 95 | 199 | ACOSTA | 05 ı | CDF | First generation |
| >236 | 95 | 205 | ACOSTA | 05 P | CDF | First generation |
| > 99 | 95 | 206 | ABBIENDI | 03R | OPAL | First generation |
| >100 | 95 | 206 | ABBIENDI | 03R | OPAL | Second generation |
| > 98 | 95 | 206 | ABBIENDI | 03R | OPAL | Third generation |
| > 98 | 95 | 207 | ABAZOV | 02 | D0 | All generations |
| >225 | 95 | 208 | ABAZOV | 01 D | D0 | First generation |
| > 85.8 | 95 | 209 | ABBIENDI | 00м | OPAL | Superseded by ABBIENDI 03R |
| > 85.5 | 95 | 209 | ABBIENDI | 00м | OPAL | Superseded by ABBIENDI 03R |
| > 82.7 | 95 | 209 | ABBIENDI | 00м | OPAL | Superseded by ABBIENDI 03R |
| >200 | 95 | 210 | ABBOTT | 00 c | D0 | Second generation |
| >123 | 95 | 211 | AFFOLDER | 00K | CDF | Second generation |
| >148 | 95 | 212 | AFFOLDER | 00K | CDF | Third generation |
| >160 | 95 | 213 | ABBOTT | 99 J | D0 | Second generation |
| >225 | 95 | 214 | ABBOTT | 98E | D0 | First generation |
| > 94 | 95 | 215 | ABBOTT | 98J | D0 | Third generation |
| >202 | 95 | | ABE | 98s | CDF | Second generation |
| >242 | 95 | 217 | GROSS-PILCH | 98 | | First generation |
| > 99 | 95 | 218 | ABE | 97 F | CDF | Third generation |
| >213 | 95 | 219 | ABE | 97x | CDF | First generation |
| > 45.5 | 95 220 | | ABREU | 93 J | DLPH | First + second generation |
| > 44.4 | 95 | 222 | ADRIANI | 93 M | L3 | First generation |
| > 44.5 | 95 | 222 | ADRIANI | 93 M | L3 | Second generation |
| > 45 | 95 | 222 | DECAMP | 92 | ALEP | Third generation |
| none 8.9-22.6 | 95 | 223 | KIM | 90 | AMY | First generation |
| none 10.2-23.2 | 95 | 223 | KIM | 90 | AMY | Second generation |
| none 5-20.8 | 95 | 224 | BARTEL | 87B | JADE | |
| none 7-20.5 | 95 | 225 | BEHREND | 86B | CELL | |

- 187 AAD 12H search for scalar leptoquarks using eejj and $e\nu jj$ events in pp collisions at $E_{\rm CM}=7$ TeV. The limit above assumes B(e q)=1. For B(e q)=0.5, the limit becomes 100 GeV.
- 188 AAD 11D search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in pp collisions at $E_{\rm CM}=7$ TeV. The limit above assumes B(μq) = 1. For B(μq) = 0.5, the limit becomes 362 GeV.
- 189 ABAZOV 10L search for pair productions of scalar leptoquark state decaying to νb in $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV. The limit above assumes ${\rm B}(\nu b)=1$.
- 190 AAD 11D search for scalar leptoquarks using eejj and $e\nu jj$ events in pp collisions at $E_{\rm CM}=7$ TeV. The limit above assumes ${\sf B}(eq)=1$. For ${\sf B}(eq)=0.5$, the limit becomes 319 GeV.
- 1913ABAZOV 11v search for scalar leptoquarks using $e\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. The limit above assumes ${\rm B}(eq)=0.5$.
- 192 CHATRCHYAN 11N search for scalar leptoquarks using $e\nu jj$ events in pp collisions at $E_{\rm CM}=7$ TeV. The limit above assumes B(eq)=0.5.
- 193 KHACHATRYAN 11 D search for scalar leptoquarks using eejj events in pp collisions at $E_{\rm cm}=7$ TeV. The limit above assumes B(eq)=1.
- 194 KHACHATRYAN 11E search for scalar leptoquarks using $\mu\mu jj$ events in pp collisions at $E_{cm}=$ 7 TeV. The limit above assumes $B(\mu q)=1$.
- 195 ABAZOV 09 search for scalar leptoquarks using $\mu\mu jj$ and $\mu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV. The limit above assumes ${\rm B}(\mu q)=1$. For ${\rm B}(\mu q)=0.5$, the limit becomes 270 GeV.
- becomes 270 GeV. 196 ABAZOV 09AF search for scalar leptoquarks using eejj and $e\nu jj$ events in $p\overline{p}$ collisions at $E_{cm}=1.96$ TeV. The limit above assumes B(eq)=1. For B(eq)=0.5 the bound becomes 284 GeV. 197 AALTONEN 08P search for vector leptoquarks using $\tau^+\tau^-b\overline{b}$ events in $p\overline{p}$ collisions
- at $E_{\rm CM}=1.96$ TeV. Assuming Yang-Mills (minimal) couplings, the mass limit is >317 GeV (251 GeV) at 95% CL for B(τb) = 1.
- 198 Search for pair production of scalar leptoquark state decaying to τb in $p\overline{p}$ collisions at $E_{\rm cm} = 1.96$ TeV. The limit above assumes $B(\tau b) = 1.06$
- 199 Search for scalar leptoquarks using $\nu\nu jj$ events in $\overline{p}p$ collisions at $E_{\rm cm}=1.96$ TeV. The limit above assumes $B(\nu q) = 1$.
- 200 ABAZOV 07; search for pair productions of scalar leptoquark state decaying to νb in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV. The limit above assumes ${\rm B}(\nu b)=1$.
- 201 ABAZOV 06A search for scalar leptoquarks using $\mu\mu jj$ events in $p\overline{p}$ collisions at $E_{\rm CM}=1.8$ TeV and 1.96 TeV. The limit above assumes $B(\mu q)=1$. For $B(\mu q)=0.5$, the limit becomes 204 GeV. 202 ABAZOV 06L search for scalar leptoquarks using $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}=$
- 1.8 TeV and at 1.96 TeV. The limit above assumes $\tilde{\mathsf{B}}(\nu\,q)=1$.
- 1.8 FeV and at 1.90 FeV. The lithit above assumes $B(\nu q) = 1$. 203 ABULENCIA 06T search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $\rho \overline{\rho}$ collisions at $E_{\rm cm}=1.96$ TeV. The quoted limit assumes $B(\mu q)=1$. For $B(\mu q)=0.5$ or 0.1, the bound becomes 208 GeV or 143 GeV, respectively. See their Fig. 4 for the exclusion limit as a function of $B(\mu q)$.
- 204 ABAZOV 05H search for scalar leptoquarks using eejj and $e \nu j j$ events in $\overline{p} p$ collisions at $E_{\rm CM}=1.8$ TeV and 1.96 TeV. The limit above assumes B(e q) =1. For B(e q) =0.5 the bound becomes 234 GeV.
- 205 ACOSTA 05P search for scalar leptoquarks using eejj, $e\nu jj$ events in $\overline{p}p$ collisions at $E_{\rm CM}=1.96{\rm TeV}$. The limit above assumes ${\rm B}(eq)=1$. For ${\rm B}(eq)=0.5$ and 0.1, the bound becomes 205 GeV and 145 GeV, respectively.
- 206 ABBIENDI 03R search for scalar/vector leptoquarks in e^+e^- collisions at $\sqrt{s}=189$ –209 GeV. The quoted limits are for charge -4/3 isospin 0 scalar-leptoquark with $\mathsf{B}(\ell q)=1$. ee their table 12 for other cases.
- 207 ABAZOV 02 search for scalar leptoquarks using $\nu\nu jj$ events in $\overline{p}p$ collisions at $E_{\rm CM}=1.8$ TeV. The bound holds for all leptoquark generations. Vector leptoquarks are likewise
- constrained to lie above 200 GeV. 208 ABAZOV 01D search for scalar leptoquarks using $e\nu jj$, eejj, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}=1.8$ TeV. The limit above assumes B(eq)=1. For B(eq)=0.5 and 0, the bound becomes 204 and 79 GeV, respectively. Bounds for vector leptoquarks are also
- given. Supersedes ABBOTT 98E. 209 ABBIENDI 00M search for scalar /vector leptoquarks in e^+e^- collisions at \sqrt{s} =183 GeV. The quoted limits are for charge -4/3 isospin 0 scalar-leptoquarks with B(ℓq)=1. See their Table 8 and Figs. 6–9 for other cases.
- ²¹⁰ABBOTT 00c search for scalar leptoquarks using $\mu\mu jj$, $\mu\nu jj$, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm} = 1.8$ TeV. The limit above assumes $B(\mu q) = 1$. For $B(\mu q) = 0.5$ and 0,

- the bound becomes 180 and 79 GeV respectively. Bounds for vector leptoquarks are also
- given. 211 AFFOLDER 00k search for scalar leptoquark using $\nu\nu cc$ events in $\rho \overline{\rho}$ collisions at $E_{\rm cm} = 1.8$ TeV. The quoted limit assumes B(νc)=1. Bounds for vector leptoquarks are also given.
- 212 AFFOLDER 00K search for scalar leptoquark using $\nu\nu bb$ events in $p\overline{p}$ collisions at $E_{\rm Cm} = 1.8$ TeV. The quoted limit assumes B(νb)=1. Bounds for vector leptoquarks are also given.
- 213 ABBOTT 991 search for leptoquarks using $\mu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}=1.8{\rm TeV}$. The quoted limit is for a scalar leptoquark with ${\rm B}(\mu q)={\rm B}(\nu q)=0.5$. Limits on vector leptoquarks range from 240 to 290 GeV.
- 214 ABBOTT 98E search for scalar leptoquarks using $e\nu jj$, eejj, and $\nu\nu jj$ events in $p\overline{p}$ collisions at $E_{\rm cm}=1.8$ TeV. The limit above assumes ${\rm B}(eq)=1$. For ${\rm B}(eq)=0.5$ and 0, the bound becomes 204 and 79 GeV, respectively.
- 215 ABBOTT 98) search for charge -1/3 third generation scalar and vector leptoquarks in $p\overline{p}$ collisions at $E_{\rm cm}=1.8$ TeV. The quoted limit is for scalar leptoquark with B(νb)=1.
- 216 ABE 98s search for scalar leptoquarks using $\mu\mu jj$ events in $p\overline{p}$ collisions at $E_{\rm CM}=1.8\,{\rm TeV}$. The limit is for B(μq)= 1. For B(μq)=B(νq)=0.5, the limit is > 160 GeV. 217 GROSS-PILCHER 98 is the combined limit of the CDF and DØ Collaborations as determined.
- mined by a joint CDF/DØ working group and reported in this FNAL Technical Memo. Original data published in ABE 97x and ABBOTT 98E. ²¹⁸ABE 97F search for third generation scalar and vector leptoquarks in $p\overline{p}$ collisions at
- $E_{\rm cm}=1.8$ TeV. The quoted limit is for scalar leptoquark with B(au b)=1. 219 ABE 97x search for scalar leptoquarks using eejj events in $p\overline{p}$ collisions at $E_{cm}=1.8$ TeV. The limit is for B(eq)=1.
- $220\,\text{Limit}$ is for charge -1/3 isospin-0 leptoquark with $B(\ell \, q)\,=\,2/3$
- $221\,\mathrm{First}$ and second generation leptoquarks are assumed to be degenerate. The limit is slightly lower for each generation.
- 222 Limits are for charge -1/3, isospin-0 scalar leptoquarks decaying to ℓ^-q or νq with any branching ratio. See paper for limits for other charge-isospin assignments of leptoquarks.
- 223 KIM 90 assume pair production of charge 2/3 scalar-leptoquark via photon exchange. The decay of the first (second) generation leptoquark is assumed to be any mixture of $d\,e^+$ and $u\,\overline{
 u}\,(s\,\mu^+$ and $c\,\overline{
 u}).$ See paper for limits for specific branching ratios.
- $^{224}\,\text{BARTEL}$ 87B limit is valid when a pair of charge 2/3 spinless leptoquarks X is produced with point coupling, and when they decay under the constraint $B(X \to c\overline{\nu}_{\mu}) + B(X \to c\overline{\nu}_{\mu})$
- 225 BEHREND 86B assumed that a charge 2/3 spinless leptoquark, χ , decays either into $s\mu^+$ or $c\overline{\nu}$: $\mathrm{B}(\chi \to s\mu^+) + \mathrm{B}(\chi \to c\overline{\nu}) = 1$.

MASS LIMITS for Leptoquarks from Single Production

95

VALUE (GeV)

>298

These limits depend on the $q\text{-}\ell\text{-leptoquark}$ coupling $g_{L\,Q}$. It is often assumed that $g_{LQ}^2/4\pi$ =1/137. Limits shown are for a scalar, weak isoscalar, charge -1/3 leptoguark.

226 CHEKANOV 03B ZEUS First generation

TECN COMMENT

DO CUMENT ID

| > 73 | 95 | ²²⁷ ABREU | 93J DLP | H Second generation |
|-----------------------------------|-------------|------------------------|-----------------|---------------------------|
| ● ● We do not | use the fol | lowing data for avera | ages, fits, lii | mits, etc. • • • |
| | | ²²⁸ AARON | 11A H1 | Lepton-flavor violation |
| >300 | 95 | ²²⁹ AARON | 11B H1 | First generation |
| | | ²³⁰ ABAZOV | 07E D0 | Second generation |
| >295 | 95 | ²³¹ AKTAS | 05B H1 | First generation |
| | | 232 CHEKANOV | 05A ZEU | S Lepton-flavor violation |
| >197 | 95 | 233 ABBIENDI | 02B OPA | L First generation |
| | | 234 CHEKANOV | 02 ZEU | S Repl. by CHEKANOV 05A |
| >290 | 95 | ²³⁵ ADLOFF | 01∈ H1 | First generation |
| >204 | 95 | 236 BREITWEG | 01 ZEU | S First generation |
| | | 237 BREITWEG | 00E ZEU | S First generation |
| >161 | 95 | ²³⁸ ABREU | 99G DLP | H First generation |
| >200 | 95 | ²³⁹ ADLOFF | 99 H1 | First generation |
| | | 240 DERRICK | 97 ZEU | S Lepton-flavor violation |
| >168 | 95 | ²⁴¹ DERRICK | 93 ZEU | S First generation |

- 93 ZEUS First generation $^{226}\,\mathrm{CHEKA\,NOV}$ 03B limit is for a scalar, weak isoscalar, charge -1/3 leptoquark coupled with e_R . See their Figs. 11–12 and Table 5 for limits on states with different quantum numbers.
- 227 Limit from single production in Z decay. The limit is for a leptoquark coupling of electromagnetic strength and assumes $\mathrm{B}(\ell q)=2/3$. The limit is 77 GeV if first and second leptoquarks are degenerate.
- $228\,\mathrm{AARON}\ 11\mathrm{A}$ search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 2–3 and Tables 1–4 for detailed limits.
- The quoted limit is for a scalar, weak isoscalar, charge -1/3 leptoquark coupled with e_R . See their Figs. 3-5 for limits on states with different quantum numbers.
- 230 ABAZOV 07E search for leptoquark single production through qg fusion process in $p\overline{p}$ collisions. See their Fig. 4 for exclusion plot in mass-coupling plane.
- 231 AKTAS 05B limit is for a scalar, weak isoscalar, charge -1/3 leptoquark coupled with e_R . See their Fig. 3 for limits on states with different quantum numbers.
- 232 CHEKANOV 05 search for various leptoquarks with lepton-flavor violating couplings. See their Figs.6–10 and Tables 1–8 for detailed limits.
- 233 For limits on states with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 4 and Fig. 5.
- $^{234}\textsc{CHEKANOV}$ 02 search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 6–7 and Tables 5–6 for detailed limits
- 235 For limits on states with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 3.
- 236 See their Fig. 14 for limits in the mass-coupling plane.
- 237 BREITWEG 00E search for $^{F=0}$ leptoquarks in ^{e+}p collisions. For limits in masscoupling plane, see their Fig. 11.
- 238 ABREU 996 limit obtained from process $e\gamma \to LQ+q$. For limits on vector and scalar states with different quantum numbers and the limits in the coupling-mass plane, see their Fig. 4 and Table 2

- $^{239}\mbox{For limits on states}$ with different quantum numbers and the limits in the mass-coupling plane, see their Fig. 13 and Fig. 14. ADLOFF 99 also search for leptoquarks with lepton-flavor violating couplings. ADLOFF 99 supersedes AID 96B.
- 240 DERRICK 97 search for various leptoquarks with lepton-flavor violating couplings. See
- their Figs. 5–8 and Table 1 for detailed limits.

 241 DERRICK 93 search for single leptoquark production in *ep* collisions with the decay *eq* and νq . The limit is for leptoquark coupling of electromagnetic strength and assumes $B(e\,q)=B(\nu\,q)=1/2$. The limit for $B(e\,q)=1$ is 176 GeV. For limits on states with different quantum numbers, see their Table 3.

Indirect Limits for Leptoquarks

| VAL | JE (TeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----|----------|---------|---------------------------|--------|---------|----------------------------------------------------------------------|
| • • | • We do | not use | e the following data | for av | erages, | fits, limits, etc. • • • |
| > | 2.5 | 95 | ²⁴² AARON | 11c | H1 | First generation |
| | | | ²⁴³ DORSNER | 11 | RVUE | scalar, weak singlet, charge 4/3 |
| | | | ²⁴⁴ AKTAS | 07A | H1 | Lepton-flavor violation |
| > | 0.49 | 95 | 245 SCHAEL | 07A | ALEP | $e^+e^- \rightarrow q\overline{q}$ |
| | | | ²⁴⁶ SMIRNOV | 07 | RVUE | $K \rightarrow e \mu, B \rightarrow e \tau$ |
| | | | 247 CHEKANOV | 05A | ZEUS | Lepton-flavor violation |
| > | 1.7 | 96 | ²⁴⁸ ADLOFF | 03 | H1 | First generation |
| > | 46 | 90 | ²⁴⁹ CHANG | 03 | BELL | Pati-Salam type |
| | | | 250 CHEKANOV | 02 | ZEUS | Repl. by CHEKANOV 05A |
| > | 1.7 | 95 | ²⁵¹ CHEUNG | 01в | RVUE | First generation |
| > | 0.39 | 95 | ²⁵² ACCIARRI | 00P | L3 | $e^+ e^- \rightarrow q q$ |
| > | 1.5 | 95 | ²⁵³ ADLOFF | 00 | H1 | First generation |
| > | 0.2 | 95 | 254 BARATE | 001 | ALEP | Repl. by SCHAEL 07A |
| | | | 255 BARGER | 00 | RVUE | Cs |
| | | | 256 GABRIELLI | 00 | RVUE | Lepton flavor violation |
| > | 0.74 | 95 | 257 ZARNECKI | 00 | RVUE | S_1 leptoquark |
| | | | ²⁵⁸ ABBIENDI | 99 | OPAL | |
| > | 19.3 | 95 | ²⁵⁹ ABE | 98∨ | CDF | $B_S ightarrow e^{\pm} \mu^{\mp}$, Pati-Salam type |
| | | | ²⁶⁰ ACCIARRI | 98J | L3 | $e^+e^- \rightarrow q\overline{q}$ |
| | | | ²⁶¹ ACKERSTAFF | 98v | OPAL | $e^+e^- \rightarrow q\overline{q}, e^+e^- \rightarrow b\overline{b}$ |
| > | 0.76 | 95 | ²⁶² DEANDREA | 97 | RVUE | \widetilde{R}_2 leptoquark |
| | | | ²⁶³ DERRICK | 97 | ZEUS | Lepton-flavor violation |
| | | | ²⁶⁴ GROSSMAN | 97 | RVUE | $B \rightarrow \tau^+ \tau^-(X)$ |
| | | | ²⁶⁵ JADACH | 97 | RVUE | $e^+e^- \rightarrow q\overline{q}$ |
| >12 | 200 | | ²⁶⁶ KUZNETSOV | 95B | RVUE | Pati-Salam type |
| | | | 267 MIZUKOSHI | 95 | RVUE | Third generation scalar leptoquark |
| > | 0.3 | 95 | 268 BHATTACH | 94 | RVUE | Spin-0 leptoquark coupled to $\overline{e}_R t_I$ |
| | | | ²⁶⁹ DAVIDSON | 94 | RVUE | N Z |
| > | 18 | | ²⁷⁰ KUZNETSOV | 94 | RVUE | Pati-Salam type |
| > | 0.43 | 95 | ^{2/1} LEURER | 94 | RVUE | First generation spin-1 leptoquark |
| > | 0.44 | 95 | ²⁷¹ LEURER | 94B | RVUE | First generation spin-0 leptoquark |
| | | | ²⁷² MAHANTA | 94 | RVUE | P and T violation |
| > | 1 | | ²⁷³ SHANKER | 82 | RVUE | Nonchiral spin-0 leptoquark |
| > 3 | l 25 | | ²⁷³ SHANKER | 82 | RVUE | Nonchiral spin-1 leptoquark |
| | | | | | | |

- ²⁴²AARON 11C limit is for weak isotriplet spin-0 leptoquark at strong coupling $\lambda=\sqrt{4\pi}$. For the limits of leptoquarks with different quantum numbers, see their Table 3. Limits are derived from bounds of eq contact intereractions.
- ²⁴³DORSNER 11 give bounds on scalar, weak singlet, charge 4/3 leptoquark from K, B, audecays, meson mixings, LFV, g-2 and $Z \rightarrow b\overline{b}$.
- 244 AKTAS 07A search for lepton-flavor violation in ep collision. See their Tables 4–7 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.
- 245 SCHAEL 07A limit is for the weak-isoscalar spin-0 left-handed leptoquark with the coupling of electromagnetic strength. For the limits of leptoquarks with different quantum numbers, see their Table 35.
- 246 SMIRNOV 07 obtains mass limits for the vector and scalar chiral leptoquark states from $\rightarrow e \mu$, $B \rightarrow e \tau$ decays.
- 247 CHEKA NOV 05 search for various leptoquarks with lepton-flavor violating couplings. See their Figs. 6–10 and Tables 1–8 for detailed limits.
- 248 ADLOFF 03 limit is for the weak isotriplet spin-0 leptoquark at strong coupling $\lambda = \sqrt{4\pi}$. For the limits of leptoquarks with different quantum numbers, see their Table 3. Limits are derived from bounds on $e^\pm q$ contact interactions. 249 The bound is derived from B($B^0 \to e^\pm \mu^\mp$) < 1.7 × 10⁻⁷.
- ²⁵⁰ CHEKA NOV 02 search for lepton-flavor violation in *ep* collisions. See their Tables 1–4 for limits on lepton-flavor violating and four-fermion interactions induced by various eptoquarks
- 251 CHEUNG 018 quoted limit is for a scalar, weak isoscalar, charge -1/3 leptoquark with a coupling of electromagnetic strength. The limit is derived from bounds on contact interactions in a global electroweak analysis. For the limits of leptoquarks with different quantum numbers, see Table 5.
- $^{252}\mathsf{ACCIARRI}$ 00P limit is for the weak isoscalar spin-0 leptoquark with the coupling of electromagnetic strength. For the limits of leptoquarks with different quantum numbers, see their Table 4.
- 253 ADLOFF 00 limit is for the weak isotriplet spin-0 leptoquark at strong coupling, $\lambda = \sqrt{4\pi}$. For the limits of leptoquarks with different quantum numbers, see their Table 2. ADLOFF 00 limits are from the Q^2 spectrum measurement of $e^+ p \rightarrow e^+ X$.
- 254 BARATE 001 search for deviations in cross section and jet-charge asymmetry in $e^+\,e^ \overline{q}q$ due to *t*-channel exchange of a leptoquark at \sqrt{s} =130 to 183 GeV. Limits for other scalar and vector leptoquarks are also given in their Table 22.
- ²⁵⁵ BARGER 00 explain the deviation of atomic parity violation in cesium atoms from prediction is explained by scalar leptoquark exchange.
- 256 GABRIELLI 00 calculate various process with lepton flavor violation in leptoquark models.
- 257 ZARNECKI 00 limit is derived from data of HERA, LEP, and Tevatron and from various low-energy data including atomic parity violation. Leptoquark coupling with electromagnetic strength is assumed.
- ²⁵⁸ABBIENDI 99 limits are from $e^+e^- \rightarrow q\overline{q}$ cross section at 130–136, 161–172, 183 GeV. See their Fig. 8 and Fig. 9 for limits in mass-coupling plane.

- 259 ABE 98v quoted limit is from B($B_S \to e^{\pm} \mu^{\mp}$)< 8.2 imes 10 $^{-6}$. ABE 98v also obtain a similar limit on $\it M_{LQ}$ > 20.4 TeV from B($\it B_d$ ightarrow $e^{\pm}\,\mu^{\mp}$)< 4.5 imes 10 $^{-6}$ Both bounds assume the non-canonical association of the b quark with electrons or muons
- 260 ACCIARRI 98J limit is from $e^+e^-\to q\overline{q}$ cross section at $\sqrt{s}=130$ –172 GeV which can be affected by the t- and u-channel exchanges of leptoquarks. See their Fig. 4 and Fig. 5 for limits in the mass-coupling plane.
- 261 ACKERSTAFF 98V limits are from $e^+\,e^-
 ightarrow$ $q\,\overline{q}$ and $e^+\,e^- o b\,\overline{b}$ cross sections at \sqrt{s} = 130–172 GeV, which can be affected by the t- and u-channel exchanges of leptoquarks. See their Fig. 21 and Fig. 22 for limits of leptoquarks in mass-coupling plane.
- 262 DEANDREA 97 limit is for \bar{R}_2 leptoquark obtained from atomic parity violation (APV). The coupling of leptoquark is assumed to be electromagnetic strength. See Table 2 for limits of the four-fermion interactions induced by various scalar leptoquark exchange. DEANDREA 97 combines APV limit and limits from Tevatron and HERA. See Fig. 1–4 for combined limits of leptoquark in mass-coupling plane
- 263 DERRICK 97 search for lepton-flavor violation in *ep* collision. See their Tables 2–5 for limits on lepton-flavor violating four-fermion interactions induced by various leptoquarks.
- 264 GROSSMAN 97 estimate the upper bounds on the branching fraction $B \to \tau^+\tau^-({\rm X})$ from the absence of the B decay with large missing energy. These bounds can be used to constrain leptoquark induced four-fermion interactions.
- 265 JADACH 97 limit is from $e^+e^- \to q\overline{q}$ cross section at \sqrt{s} =172.3 GeV which can be affected by the t- and u-channel exchanges of leptoquarks. See their Fig. 1 for limits on vector leptoquarks in mass-coupling plane.
- 266 KUZNETSOV 95B use π , K, B, au decays and μe conversion and give a list of bounds on the leptoquark mass and the fermion mixing matrix in the Pati-Salam model. The quoted limit is from $K_L \to \mu e$ decay assuming zero mixing.
- 267 MIZUKOSHI 95 calculate the one-loop radiative correction to the $\it Z$ -physics parameters in various scalar leptoquark models. See their Fig. 4 for the exclusion plot of third generation leptoquark models in mass-coupling plane.
- 268 BHATTACHARYYA 94 limit is from one-loop radiative correction to the leptonic decay width of the Z. m_H =250 GeV, $\alpha_s(m_Z)$ =0.12, m_r =180 GeV, and the electroweak strength of leptoquark coupling are assumed. For leptoquark coupled to \overline{e}_L t_R , $\overline{\mu}t$, and $\overline{\tau}t$, see Fig. 2 in BHATTACHARYYA 94B erratum and Fig. 3.
- 269 DAVIDSON 94 gives an extensive list of the bounds on leptoquark-induced four-fermion interactions from π , K, D, B, μ , τ decays and meson mixings, etc. See Table 15 of DAVIDSON 94 for detail.
- 270 KUZNETSOV 94 gives mixing independent bound of the Pati-Salam leptoquark from the cosmological limit on $\pi^0 o \overline{
 u}
 u$
- 271 LEURER 94, LEURER 94B limits are obtained from atomic parity violation and apply to any chiral leptoquark which couples to the first generation with electromagnetic strength. For a nonchiral leptoquark, universality in $\pi_{\ell 2}$ decay provides a much more stringent bound.
- 272 MAHANTA 94 gives bounds of P- and T-violating scalar-leptoquark couplings from atomic and molecular experiments.
- $273\,{\rm From}~(\pi\to~e\nu)/(\pi\to~\mu\nu)$ ratio. SHANKER 82 assumes the leptoquark induced four-fermion coupling 4g^2/M² (\overline{v}_{eL} u_R) (\overline{d}_L e_R) with g=0.004 for spin-0 leptoquark and g^2/M^2 $(\overline{\nu}_{eL} \ \gamma_{\mu} u_L) \ (\overline{d}_R \ \gamma^{\mu} e_R)$ with $g \simeq 0.6$ for spin-1 leptoquark.

MASS LIMITS for Diquarks

| VALUE (GeV) | CL% | DOCUMENT ID TECN COMMENT |
|--------------------------------|---------|----------------------------------------------------------------|
| >3520 | 95 | 274 CHATRCHYAN11Y CMS E ₆ diquark |
| • • • We do not use the follow | owing d | ata for averages, fits, limits, etc. • • • |
| none 970-1080, 1450-1600 | 95 | ²⁷⁵ KHACHATRY10 CMS <i>E</i> ₆ diquark |
| none 290-630 | 95 | ²⁷⁶ AALTONEN 09AC CDF <i>E</i> ₆ diquark |
| none 290-420 | 95 | 277 ABE 97G CDF E_6 diquark |
| none 15-31.7 | 95 | ²⁷⁸ ABREU 940 DLPH SŬSY E ₆ diquark |
| 074 | | |

- 274 CHATRCHYAN 11Y search for new resonance decaying to dijets in pp collisions at $\sqrt{s} = 7 \text{ TeV}.$
- 275 KHACHATRYAN 10 search for new resonance decaying to dijets in pp collisions at
- 276 AALTONEN 09AC search for new narrow resonance decaying to dijets.
- $277\,\mathrm{ABE}$ 97G search for new particle decaying to dijets.
- $^{278} \text{ABREU 940 limit}$ is from $e^+ \, e^- \to \, \overline{\textit{cs}} \, \textit{cs.}$ Range extends up to 43 GeV if diquarks are degenerate in mass.

MASS LIMITS for g_A (axigluon) and Other Color-Octet Gauge Bosons

Axigluons are massive color-octet gauge bosons in chiral color models and have axialvector coupling to quarks with the same coupling strength as gluons.

| VALUE (GeV) | CL% | DOCUMENT ID TECN COMMENT |
|-----------------------------------|---------------|------------------------------------------------------------------------------------------|
| >2470 | 95 | 279 CHATRCHYAN11Y CMS $pp ightarrow g_A$ X, $g_A ightarrow 2$ jets |
| ● ● We do not | use the follo | wing data for averages, fits, limits, etc. • • • |
| | | ²⁸⁰ AALTONEN 10L CDF $p\overline{p} 	o g_AX$, $g_A 	o t\overline{t}$ |
| none 1470-1520 | 95 | ²⁸¹ KHACHATRY10 CMS $pp \rightarrow g_A X, g_A \rightarrow 2$ jets |
| none 260-1250 | 95 | 282 AALTONEN 09AC CDF $p\overline{p} \rightarrow g_A X, g_A \rightarrow 2$ jets |
| > 910 | 95 | ²⁸³ CHOUDHURY 07 RVUE $p\overline{p} \rightarrow t\overline{t}X$ |
| > 365 | 95 | 284 DONCHESKI 98 RVUE $\Gamma(Z \rightarrow \text{hadron})$ |
| none 200-980 | 95 | 285 ABE 976 CDF $p\overline{p} \rightarrow g_A X, g_A \rightarrow 2 \text{ jets}$ |
| none 200-870 | 95 | 286 ABE 95N CDF $p\overline{p} \rightarrow g_A X, g_A \rightarrow q \overline{q}$ |
| none 240-640 | 95 | 287 ABE 936 CDF $p\overline{p} \rightarrow g_A X, g_A \rightarrow 2$ jets |
| > 50 | 95 | 288 CUYPERS 91 RVUE $\sigma(e^+e^- \rightarrow hadrons)$ |
| none 120-210 | 95 | 289 ABE 90H CDF $p\overline{p} \rightarrow g_A X, g_A \rightarrow 2$ jets |
| > 29 | | ROBINETT 89 THEO Partial-wave unitarity |
| none 150-310 | 95 | ²⁹¹ ALBAJAR 88B UA1 $p\overline{p} \rightarrow g_A X, g_A \rightarrow 2$ jets |
| > 20 | | BERGSTROM 88 RVUE $p\overline{p} ightarrow \varUpsilon X$ via g_Ag |
| > 9 | | 292 CUYPERS 88 RVUE γ decay |
| > 25 | | 293 DONCHESKI 88B RVUE $	au$ decay |

- $^{279}\mathrm{CHATRCHYAN}$ 11Y search for new resonance decaying to dijets in pp collisions at
- 280 AALTONEN 10L search for massive color octet non-chiral vector particle decaying into $t\overline{t}$ pair with mass in the range 400 GeV < M < 800 GeV. See their Fig. 6 for limit in the mass-coupling plane.
- 281 KHACHATRYAN 10 search for new resonance decaying to dijets in pp collisions at
- 282 AALTONEN 09AC search for new narrow resonance decaying to dijets.
- ²⁸³ CHOUDHURY 07 limit is from the $t\overline{t}$ production cross section measured at CDF.
- 284 DONCHESKI 98 compare α_S derived from low-energy data and that from $\Gamma(Z\to {\rm hadrons})/\Gamma(Z\to {\rm leptons})$.
- 285 ABE 97G search for new particle decaying to dijets.
- 286 ABE 95N assume axigluons decaying to quarks in the Standard Model only.
- ²⁸⁷ABE 93G assume $\Gamma(g_A)=N\alpha_S m_{g_A}/6$ with N=10.
- $^{288}\text{CUYPERS}$ 91 compare α_{S} measured in \varUpsilon decay and that from R at PEP/PETRA
- energies. 289 ABE 90H assumes $\Gamma(g_A)=N\alpha_S m_{g_A}/6$ with N=5 ($\Gamma(g_A)=0.09m_{g_A}$). For N=10, the excluded region is reduced to 120–150 GeV.
- 290 ROBINETT 89 result demands partial-wave unitarity of J=0 $t\overline{t} \rightarrow t\overline{t}$ scattering amplitude and derives a limit $m_{g_A} > 0.5 \; m_{\;t}$. Assumes $m_{\;t} > 56$ GeV.
- ²⁹¹ ALBAJAR 88B result is from the nonobservation of a peak in two-jet invariant mass distribution. $\Gamma(g_A) < 0.4~m_{g_A}$ assumed. See also BAGGER 88.
- 292 CUYPERS 88 requires $\Gamma(\varUpsilon \to gg_A) < \Gamma(\varUpsilon \to ggg)$. A similar result is obtained by
- 293 DONCHESKI 88. Pequires $\Gamma(T \to g q \overline{q})/\Gamma(T \to g g g) < 0.25$, where the former decay proceeds via axigluon exchange. A more conservative estimate of < 0.5 leads to

X^0 (Heavy Boson) Searches in Z Decays

Searches for radiative transition of Z to a lighter spin-0 state X^0 decaying to hadrons, a lepton pair, a photon pair, or invisible particles as shown in the comments. The limits are for the product of branching ratios.

CL% DOCUMENT ID TECN COMMENT

| | We do | not | use | the | following | data | for | averages | fits | limits, etc. | | | |
|-------|--------|------|-----|-----|-----------|------|-----|-----------|--------|--------------|---|---|---|
| • | TTC GO | 1100 | usc | unc | TOHOTTHE | autu | 101 | uveruges, | 11100, | minito, etc. | • | • | • |

| | | ²⁹⁴ BARATE | 98U ALE | P $X^0 \rightarrow \ell \overline{\ell}, q \overline{q}, g g, \gamma \gamma, \nu \overline{\nu}$ |
|------------------------|----|-------------------------|---------|--------------------------------------------------------------------------------------------------|
| | | ²⁹⁵ ACCIARRI | 97Q L3 | $X^0 \rightarrow \text{invisible particle(s)}$ |
| | | ²⁹⁶ ACTON | 93E OP/ | AL $X^0 \rightarrow \gamma \gamma$ |
| | | ²⁹⁷ ABREU | 92D DLF | $^{\mathrm{PH}} X^0 \rightarrow ^{\mathrm{hadrons}}$ |
| | | ²⁹⁸ adriani | 92F L3 | $X^0 \rightarrow hadrons$ |
| | | ²⁹⁹ ACTON | 91 OP A | $AL X^0 \rightarrow anything$ |
| $< 1.1 \times 10^{-4}$ | 95 | 300 ACTON | 91B OP/ | $AL X^0 \rightarrow e^+e^-$ |
| $< 9 \times 10^{-5}$ | 95 | ³⁰⁰ ACTON | 91B OP/ | AL $X^0 \rightarrow \mu^+ \mu^-$ |
| $<1.1 \times 10^{-4}$ | 95 | ³⁰⁰ ACTON | 91B OP/ | AL $X^0 \rightarrow \tau^+ \tau^-$ |
| $< 2.8 \times 10^{-4}$ | 95 | ³⁰¹ ADEVA | 91D L3 | $X^0 \rightarrow e^+ e^-$ |
| $< 2.3 \times 10^{-4}$ | 95 | ³⁰¹ ADEVA | 91D L3 | $X^0 \rightarrow \mu^+ \mu^-$ |
| $< 4.7 \times 10^{-4}$ | 95 | ³⁰² ADEVA | 91D L3 | $X^0 \rightarrow hadrons$ |
| $< 8 \times 10^{-4}$ | 95 | ³⁰³ A KRAWY | 90J OP | $AL X^0 \rightarrow hadrons$ |
| | | | | |

- ²⁹⁴BARATE 98U obtain limits on B(Z $\rightarrow \gamma X^0$)B($X^0 \rightarrow \ell \overline{\ell}, \ q \, \overline{q}, \ g \, g, \ \gamma \gamma, \ \nu \overline{\nu}$). See their Fig. 17.
- 295 See Fig. 4 of ACCIARRI 97Q for the upper limit on B(Z $\rightarrow~\gamma X^0;~E_{\gamma}>E_{\rm min})$ as a
- 296 ACTON 93E give $\sigma(e^+\,e^-\to~X^{\,0}\,\gamma)\cdot {\rm B}(X^{\,0}\to~\gamma\gamma)<$ 0.4 pb (95%CL) for $m_{\chi^0}{=}60$ \pm 2.5 GeV. If the process occurs via s-channel γ exchange, the limit translates to
- $\Gamma(X^0)\cdot \mathrm{B}(X^0\to\gamma\gamma)^2<20~\mathrm{MeV}~\mathrm{for}~m_{X^0}=60\pm1~\mathrm{GeV}.$ $^{297}\mathrm{ABREU}~920~\mathrm{give}~\sigma_Z~\cdot~\mathrm{B}(Z\to\gamma X^0)~\cdot~\mathrm{B}(X^0\to\mathrm{hadrons})<(3\text{--}10)~\mathrm{pb}~\mathrm{for}~m_{X^0}=60$ 10–78 GeV. A very similar limit is obtained for spin-1 χ^0
- 298 ADRIANI 92F search for isolated γ in hadronic Z decays. The limit $\sigma_Z \cdot {\sf B}(Z o \gamma X^0)$ \cdot B(X 0 \rightarrow hadrons) <(2–10) pb (95%CL) is given for $m_{X^{0}}$ = 25–85 GeV.
- ²⁹⁹ ACTON 91 searches for $Z \to Z^* X^0$, $Z^* \to e^+ e^-$, $\mu^+ \mu^-$, or $\nu \overline{\nu}$. Excludes any new scalar X^0 with $m_{X^0} <$ 9.5 GeV/c if it has the same coupling to ZZ^* as the MSM Higgs boson.
- 300 ACTON 91B limits are for $m_{\chi^0}=$ 60-85 GeV.
- $^{301}\,\mathrm{ADEVA}$ 91D limits are for $m_{\chi^0}=$ 30–89 GeV.
- 302 ADEVA 91D limits are for $m_{\chi^0}=$ 30–86 GeV.

CL%

VALUE (GeV)

 $^{303}\,\mathrm{A\,KRAWY}$ 90J give $\Gamma(Z\to\stackrel{\curvearrowleft}{\gamma}X^0)\cdot\mathrm{B}(X^0\to\text{ hadrons})<1.9$ MeV (95%CL) for m_{X^0} = 32-80 GeV. We divide by $\Gamma(Z)=2.5$ GeV to get product of branching ratios. For nonresonant transitions, the limit is B($Z\to\gamma q\overline{q}$) < 8.2 MeV assuming three-body phase space distribution.

MASS LIMITS for a Heavy Neutral Boson Coupling to e^+e^- DOCUMENT ID

| • • • We do | not use th | ne following data fo | r avera | ges, fits, | limits, etc. | • • • |
|-------------|------------|----------------------|---------|------------|--------------------------|---------------------|
| none 55-61 | | ³⁰⁴ odaka | 89 | VNS | $\Gamma(X^0 \rightarrow$ | $e^{+}e^{-})$ |
| | | | | | | \rightarrow had.) |
| > 4E | OE. | 305 DEBBICK | 0.6 | LIDC | r/v0 . | a+a-1 |

| | | | | | $B(X^{\circ} \rightarrow nad.) \lesssim 0.2 \text{ MeV}$ |
|----------------|----|------------------------|------|------|----------------------------------------------------------|
| >45 | 95 | ³⁰⁵ DERRICK | 86 | HRS | $\Gamma(X^0 \rightarrow e^+e^-)=6 \text{ MeV}$ |
| >46.6 | 95 | ³⁰⁶ ADEVA | 85 | MRKJ | $\Gamma(X^0 \rightarrow e^+e^-)=10 \text{ keV}$ |
| >48 | 95 | 306 ADEVA | 85 | MRKJ | $\Gamma(X^0 \rightarrow e^+e^-)=4 \text{ MeV}$ |
| | | ³⁰⁷ BERGER | 85 B | PLUT | |
| none 39.8-45.5 | | ³⁰⁸ ADEVA | | | $\Gamma(X^0 \rightarrow e^+e^-)=10 \text{ keV}$ |
| >47.8 | 95 | ³⁰⁸ ADEVA | 84 | MRKJ | $\Gamma(X^0 \rightarrow e^+e^-)=4 \text{ MeV}$ |
| none 39.8-45.2 | | ³⁰⁸ BEHREND | | CELL | |
| >47 | 95 | ³⁰⁸ BEHREND | 84 C | CELL | $\Gamma(X^0 \rightarrow e^+e^-)=4 \text{ MeV}$ |
| | | | | | |

- 304 ODAKA 89 looked for a narrow or wide scalar resonance in $e^+\,e^ightarrow$ hadrons at $E_{
 m cm}$
- $_{
 m 305}$ DERRICK 86 found no deviation from the Standard Model Bhabha scattering at $E_{
 m cm} =$ 29 GeV and set limits on the possible scalar boson e^+e^- coupling. See their figure 4 for excluded region in the $\Gamma(X^0 \to e^+ e^-)$ - m_{X^0} plane. Electronic chiral invariance requires a parity doublet of X^0 , in which case the limit applies for $\Gamma(X^0 \to e^+e^-) =$
- 306 ADEVA 85 first limit is from 2γ , $\mu^+\mu^-$, hadrons assuming X^0 is a scalar. Second limit is from e^+e^- channel. $E_{\rm cm}=40$ –47 GeV. Supersedes ADEVA 84.
- 307 BERGER 85B looked for effect of spin-0 boson exchange in $e^+\,e^ightarrow\,e^+\,e^-$ and $\mu^+\,\mu^$ at $E_{
 m cm}=$ 34.7 GeV. See Fig. 5 for excluded region in the $m_{\chi^0}-\Gamma(\chi^0)$ plane.
- 308 ADEVA 84 and BEHREND 84c have $E_{
 m cm}=39.8$ –45.5 GeV. MARK-J searched 0 in $e^+e^- o$ hadrons, 2γ , $\mu^+\mu^-$, e^+e^- and CELLO in the same channels plus au pair. No narrow or broad X^0 is found in the energy range. They also searched for the effect of X^0 with $m_{X} > E_{
 m cm}$. The second limits are from Bhabha data and for spin-0 singlet. The same limits apply for $\Gamma(X^0 \to e^+e^-) = 2$ MeV if X^0 is a spin-0 doublet. The second limit of BEHREND 84c was read off from their figure 2. The original papers also list limits in other channels.

Search for X^0 Resonance in e^+e^- Collisions

The limit is for $\Gamma(X^0 \to e^+e^-) \cdot \mathsf{B}(X^0 \to f)$, where f is the specified final state. Spin 0 is assumed for X^0 .

| VALUE (keV) | CL% | DO CUMENT ID | | TECN COMMENT |
|------------------------------------------------|---------------|------------------------------|---------|-----------------------------|
| • • • We do not use the | following d | ata for averages | , fits, | limits, etc. • • • |
| $<10^{3}$ | 95 309 | ABE | 93c | VNS $\Gamma(e e)$ |
| <(0.4-10) | 95 310 | | 93c | VNS $f = \gamma \gamma$ |
| <(0.3-5) | 95 311,312 | | 93D | TOPZ $f = \gamma \gamma$ |
| <(2-12) | 95 311,312 | | 93D | TOPZ $f = \text{hadrons}$ |
| <(4-200) | 95 312,313 | | 93D | TOPZ $f = ee$ |
| <(0.1-6) | 95 312,313 | | 93D | TOPZ $f = \mu \mu$ |
| <(0.5-8) | 90 314 | STERNER | 93 | AMY $f = \gamma \gamma$ |
| 309 Limit is for $\Gamma(X^0 \rightarrow$ | $e^+e^-)$ m | $\chi^0 = 56-63.5 \text{ G}$ | eV fo | or $\Gamma(X^0) = 0.5$ GeV. |

- 310 Limit is for $m_{X^0}=$ 56–61.5 GeV and is valid for $\Gamma(X^0)\ll$ 100 MeV. See their Fig. 5 for limits for $\Gamma=1,2$ GeV.
- 311 Limit is for $m_{\chi^0} = 57.2-60$ GeV.
- 312 Limit is valid for $\Gamma(X^0) \ll 100$ MeV. See paper for limits for $\Gamma=1$ GeV and those for J = 2 resonances.313 Limit is for $m_{\chi^0} = 56.6\text{-}60 \text{ GeV.}$
- 314 STERNER 93 limit is for $m_{\chi^0_0}=$ 57–59.6 GeV and is valid for $\Gamma(X^0)<$ 100 MeV. See their Fig. 2 for limits for $\Gamma=$ 1,3 GeV.

Search for X^0 Resonance in ep Collisions

DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • 315 CHEKANOV 02B ZEUS X
ightarrow jj

 315 CHEKANOV 02B search for photoproduction of X decaying into dijets in ep collisions. See their Fig. 5 for the limit on the photoproduction cross section.

TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 316 ACTON < 2.6 95 93E OPAL $m_{\chi^0} = 60 \pm 1 \; \mathrm{GeV}$ BUSKULIC 93F ALEP $m_{\chi^0} \sim$ 60 GeV $^{316}\,\mathrm{ACTON}$ 93E limit for a J=2 resonance is 0.8 MeV.

Search for X^0 Resonance in $e^+e^- \rightarrow X^0 \gamma$

DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • 317 ABBIENDI 03D OPAL $X^0 \rightarrow \gamma \gamma$ 318 ABREU 00z DLPH X^0 decaying invisibly ³¹⁹ ADAM 96c DLPH X^0 decaying invisibly

- 317 ABBIENDI 03D measure the $e^+e^-\to\gamma\gamma\gamma$ cross section at \sqrt{s} =181–209 GeV. The upper bound on the production cross section, $\sigma(e^+e^-\to X^0\gamma)$ times the branching ratio for $X^0\to\gamma\gamma$, is less than 0.03 pb at 95%CL for X^0 masses between 20 and 180 GeV. See their Fig. 9b for the limits in the mass-cross section plane.
- 318 ABREU 00Z is from the single photon cross section at \sqrt{s} =183, 189 GeV. The production cross section upper limit is less than 0.3 pb for X^0 mass between 40 and 160 GeV. See their Fig. 4 for the limit in mass-cross section plane.
- 319 ADAM 96c is from the single photon production cross at √5=130, 136 GeV. The upper bound is less than 3 pb for X⁰ masses between 60 and 130 GeV. See their Fig. 5 for the exact bound on the cross section $\sigma(e^+e^- \rightarrow \gamma X^0)$.

Search for X^0 Resonance in $Z \to f\overline{f}X^0$ The limit is for $B(Z \to f\overline{f}X^0) \cdot B(X^0 \to F)$ where f is a fermion and F is the specified final state. Spin 0 is assumed for \boldsymbol{X}^0 .

CL% DO CUMENT ID TECN COMMENT

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

| $ <3.7\times 10^{-6} \\ <6.8\times 10^{-6} \\ <5.5\times 10^{-6} \\ <3.1\times 10^{-6} \\ <6.5\times 10^{-6} \\ <7.1\times 10^{-6} $ | 95 95 95 95 95 95 | 320 ABREU 321 ABREU 322 ABREU 321 ACTON 321 ACTON 321 ACTON 321 ACTON 321 BUSKULIC 323 ADRIANI | 96T 96T 93E 93E 93E 93E | DLPH DLPH OPAL OPAL OPAL OPAL ALEP | $\begin{split} &f{=}e,\mu,\tau;F{=}\gamma\gamma\\ &f{=}\nu;F{=}\gamma\gamma\\ &f{=}q;F{=}\gamma\gamma\\ &f{=}e,\mu,\tau;F{=}\gamma\gamma\\ &f{=}q;F{=}\gamma\gamma\\ &f{=}\nu;F{=}\gamma\gamma\\ &f{=}e,\mu;F{=}\ell^{\dagger},q\overline{q},\nu\overline{\nu}\\ &f{=}e,\mu;F{=}\ell^{\dagger},q\overline{q},\nu\overline{\nu}\\ &f{=}e,\mu;F{=}\ell^{\dagger},q\overline{q},\nu\overline{\nu}\\ &f{=}e,\mu;F{=}\ell^{\dagger},q\overline{q},\nu\overline{\nu} \end{split}$ |
|--------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------------|----------------------------------------|------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 220 | | 323 ADRIANI | | | $f=q$; $F=\gamma\gamma$ |

 $^{320}\,\mathrm{ABREU}$ 96T obtain limit as a function of $m_{X^0}.$ See their Fig. 6.

Search for X^0 Resonance in $p\overline{p} \rightarrow WX^0$

| VALUE (MeV) | DO CUMENT IL | TECN | COMMENT | |
|-----------------------------|------------------------|--------------------|----------------------------------|--|
| • • • We do not use the fol | lowing data for averag | ges, fits, limits, | etc. • • • | |
| | ³²⁴ ABAZOV | 11ı D0 | $X^0 \rightarrow jj$ | |
| | ³²⁵ ABE | 97w CDF | $X^0 \rightarrow b \overline{b}$ | |

324 ABAZOV 111 search for X^0 production associated with W in $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV. The 95% CL upper limit on the cross section ranges from 2.57 to 1.28 pb for X^0 mass between 110 and 170 GeV. 325 ABE 97% search for X^0 production associated with W in $p\overline{p}$ collisions at $E_{\rm CM}=1.8$ TeV. The 95% CL upper limit on the production cross section times the branching ratio for $X^0 \to b\overline{b}$ ranges from 14 to 19 pb for X^0 mass between 70 and 120 GeV. See their Fig. 3 for upper limits of the production cross section as a function of m_{X^0} .

Heavy Particle Production in Quarkonium Decays

Limits are for branching ratios to modes shown.

| VAL | .UE | CL76 | DOCUMENTID | | TECN | COMMENT |
|-----|---------------------------------------|---------|----------------------|--------|---------|------------------------------------------------------------------------------------------------------|
| • • | • We do not use the | followi | ng data for averages | , fits | limits, | etc. • • • |
| <1 | $.5 \times 10^{-5}$ | 90 | 326 BALEST | 95 | CLE2 | $\Upsilon(1S) \to X^0 \gamma$ |
| < 3 | $3 \times 10^{-5} - 6 \times 10^{-3}$ | | 327 BALEST | 95 | CLE2 | $m_{X^0} < 5 \text{ GeV}$ $\Upsilon(1S) \rightarrow X^0 \overline{X}^0 \gamma$, |
| <5 | 6.6×10^{-5} | 90 | 328 ANTREASYAN | 90c | CBAL | $m_{X^0}^{'} < 3.9 \text{ GeV}^{'}$ $r(1S) \rightarrow X^0 \gamma$, $m_{X^0}^{'} < 7.2 \text{ GeV}$ |
| | | | 329 ALBRECHT | 89 | ARG | χ., . |

 $^{326}\,\mathrm{BALEST}$ 95 two-body limit is for pseudoscalar $\mathrm{\textit{X}}^{\,0}$. The limit becomes $< 10^{-4}$ for m_{χ^0} < 7.7 GeV

327 BALEST 95 three-body limit is for phase-space photon energy distribution and angular distribution same as for $\mathcal{T} \to gg\gamma$.

328 ANTREASYAN 90c assume that X^0 does not decay in the detector.

329 ALBRECHT 89 give limits for $B(\mathcal{T}(1S),\mathcal{T}(2S)\to X^0\gamma)$ - $B(X^0\to \pi^+\pi^-,K^+K^-,p\overline{p})$ for $m_{X^0}<3.5$ GeV.

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| | 99 99 | PL B458 355 PL B456 68 PR D60 093006 | M. Czakon, J. Gluza, M. Zralek | |
| | 99 99 | PR D60 096005 | J. Erler, P. Langacker W. Marciano M. Masip, A. Pomarol | |
| STRUMIA 9 | 99 99 | PR D60 116004 PL B466 107 | P. Nath, M. Yamaguchi A. Strumia | |
| | 98 E 98 J | PRL 80 2051 PRL 81 38 | B. Abbott et al. B. Abbott et al. | (D0 Collab.) (D0 Collab.) |
| ABE 9 | 98S 98V | PRL 81 4806 PRL 81 5742 | F. Abe et al. F. Abe et al. | (CDF Collab.) (CDF Collab.) |
| ACKERSTAFF 9 | 98 J 98 V | EPJ C2 441 | M. Acciarri et al. K. Ackerstaff et al. | (L3 Collab.) (OPAL Collab.) |
| BARENBOIM 9 | 98 U 98 | EPJ C4 571 EPJ C1 369 | R. Barate <i>et al.</i> G. Barenboim | (ALEPH Collab.) |
| CONRAD 9 | 98 98 | EPJ C5 155 RMP 70 1341 | G. Cho, K. Hagiwara, S. Matsum J.M. Conrad, M.H. Shaevitz, T. E | oto Bolton |
| GROSS-PILCH9 | | PR D58 097702 hep-ex/9810015 | M.A. Doncheski, R.W. Robinett C. Grosso-Pilcher, G. Landsberg, I F. Abe <i>et al.</i> | vI. Paterno |
| ABE 9 | 97 F 97 G 97 S | PRL 78 2906 PR D55 R5263 PRL 79 2192 | F. Abe et al. F. Abe et al. F. Abe et al. | (CDF Collab.) (CDF Collab.) (CDF Collab.) |
| ABE 9 | 97W 97X | PRL 79 3819 | F. Abe et al. | (CDF Collab.) |
| ACCIARRI 9 | 97 Q 97 Q 97 | PRL 79 4327 PL B412 201 PR D55 19 | F. Abe et al. M. Acciarri et al. T. Arima et al. | (CDF Collab.) (L3 Collab.) (VENUS Collab.) |
| BARENBOIM 9 | 97 97 | PR D55 4213 PL B409 277 | G. Barenboim et al. A. Deandrea | (VALE, IFIC) (MARS) |
| DERRICK 9 | 97 97 | ZPHY C73 613 PR D55 2768 | M. Derrick et al. | (ZEUS Collab.) (REHO, CIT) |
| JADACH 9 | 97 97 | PL B408 281 ZPHY C74 73 | Y. Grossman, Z. Ligeti, E. Nardi S. Jadach, B.F.L. Ward, Z. Was A. Stahl, H. Voss | (CERN, INPK+) (BONN) |
| ABACHI 9 | 96 C 96 D | PRL 76 3271 PL B385 471 | S. Abachi et al. S. Abachi et al. | (D0 Collab.) (D0 Collab.) |
| ABREU 9 | 96T 96C | | P. Abreu et al. W. Adam et al. | (DELPHI Collab.) (DELPHI Collab.) |
| AID 9 | 96B 96 | PL B369 173 | S. Aid et al. M. Allet et al. (VILL | (H1 Collab.) , LEUV, LOUV, WISC) |
| | 95 E | PL B358 405 | S. Abachi et al. | (D0 Collab.) |

 $^{^{321}\,\}mathrm{Limit}$ is for m_{χ^0} around 60 GeV.

 $^{^{322}\,\}mathrm{ABREU}$ 96T obtain limit as a function of $m_{X^0}.$ See their Fig. 15.

³²³ ADRIANI 92F give $\sigma_Z \cdot {\sf B}(Z \to q\overline{q}\,X^0) \cdot {\sf B}(X^0 \to \gamma\gamma) < (0.75-1.5)$ pb (95%CL) for $m_{X^0} = 10$ -70 GeV. The limit is 1 pb at 60 GeV.

Gauge & Higgs Boson Particle Listings

Heavy Bosons Other than Higgs Bosons, Axions (A^0) and Other Very Light Bosons

| ABE ABE | 95 M 95 N | PRL 74 2900 PRL 74 3538 | F. Abe et al. F. Abe et al. | (CDF Collab.) (CDF Collab.) |
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| BALEST | 95 | PR D51 2053 | R. Balest et al. | (CLEO Collab.) |
| KUZNETSOV | 95 | PRL 75 794 | I.A. Kuznetsov et al. | (PNPI, KIAE, HARV+) |
| KUZNETSOV | 95 B | PAN 58 2113 | A.V. Kuznetsov, N.V. Mikheev | (YARO) |
| MIZUKOSHI | 95 | NP R443 20 | 2228. J.K. Mizukoshi, O.J.P. Eboli, M | C Gonzalez-Garcia |
| ABREU | 94 O | ZPHY C64 183 | P Abreu et al | (DELPHI Collab) |
| BHATTACH | 94 | PL B336 100 | G. Bhattacharyya, J. Ellis, K. S G. Bhattacharyya, J. Ellis, K. S | ridhar `(CERN) |
| Also BHATTACH | 94 B | PL B338 522 (erratum) | G. Bhattacharyya, J. Ellis, K. S. | ridhar (CERN) ridhar (CERN) |
| DAVIDS ON | 94 D | ZPHY C61 613 | G. Bhattacharyya, J. Ellis, K. S S. Davidson, D. Bailey, B.A. Ca | mpbell (CFPA+) |
| KUZNETSOV | 94 | PL B329 295 | A.V. Kuznetsov, N.V. Mikheev | (YARO) |
| KUZNETSOV | 94 B | JETPL 60 315 | I.A. Kuznetsov et al. | (PNPI, KIAE, HARV+) |
| LEURER | 94 | Translated from ZETFP PR D50 536 | M. Leurer | (REHO) |
| LEURER | 94 B | PR D49 333 | M. Leurer | (REHO) |
| A Iso | | PRL 71 1324 | M. Leurer | (REHO) |
| MAHANTA SEVERIJNS | 94 94 | PL B337 128 PRL 73 611 (erratum) | U. Mahanta | (MEHTA) |
| VILAIN | 94 B | PL B332 465 | N. Severijns et al. P. Vilain et al. | (CHARM II Collab.) |
| ABE | 93 C | PL B302 119 | K. Abe et al. | (VENUS Collab.) |
| ABE | 93 D | PL B304 373 | T. Abe et al. F. Abe et al. | (TOPAZ Collab.) (CDF Collab.) |
| ABE ABREU | 93 G 93 J | PRL 71 2542 PL B316 620 | F. Abe et al. P. Abreu et al. | (CDF Collab.) (DELPHI Collab.) |
| ACTON | 93 E | PL B311 391 | P.D. Acton et al. | (OPAL Collab.) |
| ADRIANI | 93 M | PRPL 236 1 | O. Adriani et al. | (L3 Collab.) |
| ALITTI | 93 93 | NP B400 3 | J. Alitti et al. | (UA2 Collab.) |
| BHATTACH BUSKULIC | 93 93 F | PR D47 R3693 PL B308 425 | G. Bhattacharyya et al. D. Buskulic et al. | (CALC, JADA, ICTP+) (ALEPH Collab.) |
| DERRICK | 93 | PL B306 173 | M. Derrick et al. | (ZEUS Collab.) |
| RIZZO | 93 | PR D48 4470 | T.G. Rizzo | (ANL) |
| SEVERIJNS | 93 | PRL 70 4047 | N. Severijns et al. | (LOUV, WISC, LEUV+) (LOUV, WISC, LEUV+) (AMY Collab.) |
| Also STERNER | 93 | PRL 73 611 (erratum) PL B303 385 | N. Severijns <i>et al.</i> K.L. Sterner <i>et al.</i> | (LOUV, WISC, LEUV+) |
| ABREU | 92 D | ZPHY C53 555 | P. Abreu et al. | (DELPHI Collab.) |
| ADRIANI | 92 F | PL B292 472 | O. Adriani et al. | ` (L3 Collab.) |
| DECAMP | 92 | PRPL 216 253 | D. Decamp et al. | (ALEPH Collab.) |
| IMA ZATO MIS HRA | 92 92 | PRL 69 877 PRL 68 3499 | J. Imazato <i>et al.</i> S.R. Mishra <i>et al.</i> | (KEK, INUS, TOKY+) (COLU, CHIC, FNAL+) |
| POLAK | 92 B | PR D46 3871 | J. Polak, M. Zralek | (SILES) |
| ACTON | 91 | PL B268 122 | D.P. Acton et al. | (SILES) (OPAL Collab.) |
| ACTON | 91 B | PL B273 338 | D.P. Acton et al. | (OPAL Collab.) |
| | 0.1 E | | D. Adous at al. | (L3 Collab.) |
| ADEVA | 91 D 91 | PL B262 155 | B. Adeva et al. | (L3 Collab.) |
| | 91 D 91 91 | | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli | (L3 Collab.) arcia (CINV, PUEB) (BARI) |
| ADEVA AQUINO COLANGELO CUYPERS | 91 91 91 | PL B262 155 PL B261 280 PL B253 154 PL B259 173 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuvpers, A.F. Falk, P.H. Fra | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI | 91 91 91 91 | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuvpers, A.F. Falk, P.H. Fra | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK | 91 91 91 91 91 | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Fral A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI | 91 91 91 91 91 91 91 | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Fra A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE | 91 91 91 91 91 91 91 90 F | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. | (L3 Collab.) arcia (CINV, PUEB) (BAR1) npton (DURH, HÄRV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ABE | 91 91 91 91 91 91 91 90 F 90 H | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuppers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. | (L3 Collab.) arcia (CINV, PUEB) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (COF Collab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ABE | 91 91 91 91 91 91 90 F 90 H | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zrakk T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. M.Z. Akrawy et al. M.Z. Akrawy et al. | (L3 Collab.) arcia (CINV, PUEB) (BAR1) mpton (DURH, HARV+) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE AKRAWY ANTREAS YAN GONZALEZ-G. | 91 91 91 91 91 91 90 F 90 H 90 J 90 C | PL B262 155 PL B261 280 PL B253 154 PL B253 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 295 PL B246 295 PL B246 163 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.P. Walker et al. K. Abe et al. F. Abe et al. F. Abe et al. D. Antreasyan et al. D. Antreasyan d. M.C. Gonzalez-Garcia, J.W.F. V | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (YALE) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE AKRAWY ANTREAS YAN GONZALEZ-G. GRIFOLES | 91 91 91 91 91 91 90 F 90 H 90 J 90 C 90 D | PL B262 155 PL B261 280 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 285 PL B251 204 PL B240 163 NP B331 244 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.P. Walker et al. K. Abe et al. F. Abe et al. F. Abe et al. D. Antreasyan et al. D. Antreasyan d. M.C. Gonzalez-Garcia, J.W.F. V | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (COPAL Collab.) (YALE) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE AKRAWY ANTREAS YAN GONZALEZ-G. | 91 91 91 91 91 91 90 F 90 H 90 J 90 C 90 D | PL B262 155 PL B261 280 PL B253 154 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 265 PL B251 204 PL B240 163 NP B331 244 PR D42 3293 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. D. Antreasyan et al. D. Antreasyan et al. M.C. Gonzalez-Garcia, J.W.F. V J.A. Grifols, E. Masso, T.G. Riz A. Grifols, E. Masso, T.G. Riz | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) (COPAL Collab.) (COPAL Collab.) (SILES) (ADPAL COllab.) (BARC, CERN+) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ARRAWY ANTREAS YAN GONZALE Z-G. GRIFOLS KIM LOPEZ | 91 91 91 91 91 91 90 F 90 H 90 C 90 D 90 D 90 D | PL B262 155 PL B261 280 PL B253 154 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 285 PL B251 204 PL B240 163 NP B331 244 PR D42 3293 PL B240 243 PL B240 243 PL B240 243 PL B240 1392 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. D. Antreasyan et al. M.C. Gonzalez-Garcia, J.W.F. V J.A. Grifols, E. Masso J.A. Grifols, E. Masso J.A. Grifols, E. Masso T.G. Riz G.N. Kim et al. J.L. Lopez, D.V. Nanopoulos | (L3 Collab.) arcia (CiNV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) (COPF Collab.) (Crystal Ball Collab.) alle (CALE) (BARC, CERN+) (AMY Collab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE AKRAWY ANTREASYAN GONZALEZ-G. GRIFOLS KIM LOPEZ ALBRECHT | 91 91 91 91 91 91 90 F 90 H 90 J 90 C 90 D 90 D 90 D 90 B9 | PL B262 155 PL B261 280 PL B253 154 PL B253 157 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 297 PR D51 1722 PL B246 295 PL B261 204 PL B201 163 NP B331 244 PR D42 3293 PL B240 243 PL B241 392 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A. F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zrake T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. M.Z. Akrawy et al. D. Antreasyan et al. D. Antreasyan et al. M.C. Gonzalez-Garcia, J.W.F. V J.A. Grifols, E. Masso J. G | (L3 Collab.) arcia (CiNV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENUS Collab.) (CDF Collab.) (COPAL Collab.) (Crystal Ball Collab.) alle (WALE) (BARC, CERN+) (AMY Collab.) (TAMU) (ARGUS COllab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ABE AKRAWY ANTREAS YAN GONZALE Z- G. GRIFOLS KIM LOPE Z ALBRECHT BARBIERI | 91 91 91 91 91 91 90 F 90 H 90 J 90 C 90 D 90 90 D 90 90 S 89 B | PL B262 155 PL B261 280 PL B253 154 PL B253 154 PL B253 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 265 PL B251 204 PL B240 163 NP B331 244 PR D42 3293 PL B240 243 PP B34 294 PP D54 2349 PR D59 1229 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. D. Antrasyan et al. M.C. Gonzalez-Garcia, J.W.F. V J.A. Grifols, E. Masso, T.G. Riz G.N. Kim et al. J.L. Lopez, D.V. Nanopoulos H. Albrecht et al. B. Barbieri, R.N. Mohapatra | (L3 Collab.) arcia (CINV, PUEB) (MARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (WISC, ISU) (WISC, ISU) (COF Collab.) (COF Collab.) (COPAL Collab.) (COPAL Collab.) (COSTAL COLLAB.) (COSTAL COLLAB.) (MAL COLLAB.) (ANY COLLAB.) (ANY COLLAB.) (ARGUS COLLAB.) (ARGUS COLLAB.) (PISA. UMD) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ARRAWY ANT REAS YAN GONZALEZ-G. GRIFOLS KIM LOPEZ ALBRECHT BARBIERI LANGACKER ODAKA | 91 91 91 91 91 91 90 F 90 H 90 J 90 D 90 D 90 D 90 B9 89 B8 89 B | PL B262 155 PL B261 280 PL B253 154 PL B253 154 PL B259 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 285 PL B240 163 NP B331 244 PR D42 3293 PL B240 243 PR D42 349 PR D39 1229 PR D40 1569 JPSJ 58 3037 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zralek T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. M. Z. Akrawy et al. M. Z. Akrawy et al. M. C. González-García, J.W.F. V J.A. Grífols, E. Masso, T. G. Riz G.N. Kim et al. J.L. Lopez, D.V. Nanopoulos H. Albrecht et al. R. Barbieri, R.N. Mohapatra P. Langacker, S. Uma Sankar S. Odaka et R.N. Mohapatra | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (SILES) (WISC, ISU) (WISC, ISU) (WISC, ISU) (COROLLA) (COPAL Collab.) (ARY Collab.) (ARY Collab.) (ARY Collab.) (PISA, UMD) (PENN) (VENUS Collab.) |
| ADEVA AQUINO COLANGELO CUYPERS FARAGGI POLAK RIZZO WALKER ABE ABE ARRAWY ANTREAS YAN GONZALEZ-G. GRIFOLS KIM LOPEZ ALBRECHT BARBIERI LANGACKER ODAKA ROBINETT | 91 91 91 91 91 91 90 F 90 H 90 J 90 C 90 D 90 90 90 89 89 B 89 B 89 | PL B262 155 PL B261 280 PL B261 280 PL B263 154 PL B269 173 MPL A6 61 NP B363 385 PR D44 202 APJ 376 51 PL B246 297 PR D41 1722 PL B246 297 PR D41 1722 PL B246 295 PL B261 204 PR D42 3293 PL B240 243 PL B240 243 PL B240 243 PR D42 3293 PL B240 243 PR D42 3293 PL B240 243 PR D42 3293 PL B240 1659 PR D539 1229 PR D40 1569 JPSJ 58 3037 PR D39 834 | B. Adeva et al. M. Aquino, A. Fernandez, A. G. P. Colangelo, G. Nardulli F. Cuypers, A.F. Falk, P.H. Frat A.E. Faraggi, D.V. Nanopoulos J. Polak, M. Zrakk T.G. Rizzo T.P. Walker et al. K. Abe et al. F. Abe et al. F. Abe et al. D. Antreasyan et al. D. Antreasyan et al. D. Antreasyan et al. D. Antreasyan et al. J. L. Lopez, D.V. Nanopoulos J.A. Grifols, E. Masso, T.G. Riz G.N. Kim et al. J.L. Lopez, D.V. Nanopoulos H. Albrecht et al. R. Barbieri, R.N. Mohapatra P. Langacker, S. Uma Sankar S. Odaka et al. R.W. Robinett | (L3 Collab.) arcia (CINV, PUEB) (BARI) mpton (DURH, HARV+) (TAMU) (SILES) (WISC, ISU) (HSCA, OSU, CHIC+) (VENNS Collab.) (COPT Collab.) (COPAL Collab.) (COPAL Collab.) (CAPAL COllab.) (CAMY COllab.) (FIAMU) (ARGUS COllab.) (PENN) (VENUS Collab.) (PESA, UMD) (PENN) (VENUS Collab.) |
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Axions (A^0) and Other Very Light Bosons, Searches for

AXIONS AND OTHER SIMILAR PARTICLES

Revised March 2012 by G.G. Raffelt (MPI Physics, Munich) and L.J. Rosenberg (U. of Washington).

Introduction

In this section, we list coupling-strength and mass limits for light neutral scalar or pseudoscalar bosons that couple weakly to normal matter and radiation. Such bosons may arise from a global spontaneously broken U(1) symmetry, resulting in a massless Nambu-Goldstone (NG) boson. If there is a small explicit symmetry breaking, either already in the Lagrangian or

due to quantum effects such as anomalies, the boson acquires a mass and is called a pseudo-NG boson. Typical examples are axions (A^0) [1,2], familons [3] and Majorons [4], associated, respectively, with a spontaneously broken Peccei-Quinn, family and lepton-number symmetry.

A common characteristic among these light bosons ϕ is that their coupling to Standard-Model particles is suppressed by the energy scale that characterizes the symmetry breaking, *i.e.*, the decay constant f. The interaction Lagrangian is

$$\mathcal{L} = f^{-1}J^{\mu}\partial_{\mu}\phi\,,\tag{1}$$

where J^{μ} is the Noether current of the spontaneously broken global symmetry. If f is very large, these new particles interact very weakly. Detecting them would provide a window to physics far beyond what can be probed at accelerators.

Axions remain of particular interest because the Peccei-Quinn (PQ) mechanism remains perhaps the most credible scheme to preserve CP in QCD. Moreover, the cold dark matter of the universe may well consist of axions and they are searched for in dedicated experiments with a realistic chance of discovery.

Originally it was assumed that the PQ scale f_A was related to the electroweak symmetry-breaking scale $v_{\rm weak} = (\sqrt{2}G_{\rm F})^{-1/2} = 247$ GeV. However, the associated "standard" and "variant" axions were quickly excluded—we refer to the Listings for detailed limits. Here we focus on "invisible axions" with $f_A \gg v_{\rm weak}$ as the main possibility.

Axions have a characteristic two-photon vertex, inherited from their mixing with π^0 and η . It allows for the main search strategy based on axion-photon conversion in external magnetic fields [5], an effect that also can be of astrophysical interest. While for axions the product " $A\gamma\gamma$ interaction strength × mass" is essentially fixed by the corresponding π^0 properties, one may consider more general axion-like particles (ALPs) where the two parameters are independent. Several experiments have recently explored this more general parameter space.

I. THEORY

I.1 Peccei-Quinn mechanism and axions

The QCD Lagrangian includes a CP-violating term $\mathcal{L}_{\Theta} = \bar{\Theta} (\alpha_s/8\pi) \, G^{\mu\nu a} \tilde{G}^a_{\mu\nu}$, where $-\pi \leq \bar{\Theta} \leq +\pi$ is the effective Θ parameter after diagonalizing quark masses, G is the color field strength tensor, and \tilde{G} its dual. Limits on the neutron electric dipole moment [6] imply $|\bar{\Theta}| \lesssim 10^{-10}$ even though $\bar{\Theta} = \mathcal{O}(1)$ is otherwise completely satisfactory. The spontaneously broken global Peccei-Quinn symmetry $\mathrm{U}(1)_{\mathrm{PQ}}$ was introduced to solve this "strong CP problem" [1], an axion being the pseudo-NG boson of $\mathrm{U}(1)_{\mathrm{PQ}}$ [2]. This symmetry is broken due to the axion's anomalous triangle coupling to gluons,

$$\mathcal{L} = \left(\bar{\Theta} - \frac{\phi_A}{f_A}\right) \frac{\alpha_s}{8\pi} G^{\mu\nu a} \tilde{G}^a_{\mu\nu} \,, \tag{2}$$

where ϕ_A is the axion field and f_A the axion decay constant. Color anomaly factors have been absorbed in the normalization of f_A which is defined by this Lagrangian. Thus normalized, f_A

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is the quantity that enters all low-energy phenomena [7]. Non-perturbative effects induce a potential for ϕ_A whose minimum is at $\phi_A = \bar{\Theta} f_A$, thereby canceling the $\bar{\Theta}$ term in the QCD Lagrangian and thus restoring CP symmetry.

The resulting axion mass is given by $m_A f_A \approx m_\pi f_\pi$ where $m_\pi = 135$ MeV and $f_\pi \approx 92$ MeV. In more detail one finds

$$m_A = \frac{z^{1/2}}{1+z} \frac{f_\pi m_\pi}{f_A} = \frac{0.60 \text{ meV}}{f_A/10^{10} \text{ GeV}},$$
 (3)

where $z = m_u/m_d$. We have used the canonical value z = 0.56 [8], although the range z = 0.35-0.60 is plausible [9].

Originally one assumed $f_A \sim v_{\rm weak}$ [1,2]. Tree-level flavor conservation fixes the axion properties in terms of a single parameter $\tan \beta$, the ratio of the vacuum expectation values of two Higgs fields that appear as a minimal ingredient. This "standard axion" is excluded after extensive searches [10]. A narrow peak structure observed in positron spectra from heavy ion collisions [11] suggested an axion-like particle of mass 1.8 MeV that decays into e^+e^- , but extensive follow-up searches were negative. "Variant axion models" were proposed which keep $f_A \sim v_{\rm weak}$ while dropping the constraint of tree-level flavor conservation [12], but these models are also excluded [13].

Axions with $f_A \gg v_{\rm weak}$ evade all current experimental limits. One generic class of models invokes "hadronic axions" where new heavy quarks carry U(1)_{PQ} charges, leaving ordinary quarks and leptons without tree-level axion couplings. The prototype is the KSVZ model [14], where in addition the heavy quarks are electrically neutral. Another generic class requires at least two Higgs doublets and ordinary quarks and leptons carry PQ charges, the prototype being the DFSZ model [15]. All of these models contain at least one electroweak singlet scalar that acquires a vacuum expectation value and thereby breaks the PQ symmetry. The KSVZ and DFSZ models are frequently used as generic examples, but other models exist where both heavy quarks and Higgs doublets carry PQ charges.

I.2 Model-dependent axion couplings

Although the generic axion interactions scale approximately with f_{π}/f_A from the corresponding π^0 couplings, there are non-negligible model-dependent factors and uncertainties. The axion's two-photon interaction plays a key role for many searches,

$$\mathcal{L}_{A\gamma\gamma} = \frac{G_{A\gamma\gamma}}{4} F_{\mu\nu} \tilde{F}^{\mu\nu} \phi_A = -G_{A\gamma\gamma} \mathbf{E} \cdot \mathbf{B} \phi_A, \qquad (4)$$

where F is the electromagnetic field-strength tensor and \tilde{F} its dual. The coupling constant is

$$G_{A\gamma\gamma} = \frac{\alpha}{2\pi f_A} \left(\frac{E}{N} - \frac{2}{3} \frac{4+z}{1+z} \right)$$

$$= \frac{\alpha}{2\pi} \left(\frac{E}{N} - \frac{2}{3} \frac{4+z}{1+z} \right) \frac{1+z}{z^{1/2}} \frac{m_A}{m_\pi f_\pi},$$
(5)

where E and N are the electromagnetic and color anomalies of the axial current associated with the axion. In grand unified models, and notably for DFSZ [15], E/N=8/3, whereas for KSVZ [14] E/N=0 if the electric charge of the new heavy

quark is taken to vanish. In general, a broad range of E/N values is possible [16]. The two-photon decay width is

$$\Gamma_{A \to \gamma \gamma} = \frac{G_{A \gamma \gamma}^2 m_A^3}{64 \, \pi} = 1.1 \times 10^{-24} \text{ s}^{-1} \left(\frac{m_A}{\text{eV}}\right)^5.$$
(6)

The second expression uses Eq. (5) with z = 0.56 and E/N = 0. Axions decay faster than the age of the universe if $m_A \gtrsim 20\,$ eV.

The interaction with fermions f has derivative form and is invariant under a shift $\phi_A \rightarrow \phi_A + \phi_0$ as behooves a NG boson,

$$\mathcal{L}_{Aff} = \frac{C_f}{2f_A} \bar{\Psi}_f \gamma^\mu \gamma_5 \Psi_f \partial_\mu \phi_A . \tag{7}$$

Here, Ψ_f is the fermion field, m_f its mass, and C_f a model-dependent coefficient. The dimensionless combination $g_{Aff} \equiv C_f m_f/f_A$ plays the role of a Yukawa coupling and $\alpha_{Aff} \equiv g_{Aff}^2/4\pi$ of a "fine-structure constant." The oftenused pseudoscalar form $\mathcal{L}_{Aff} = -\mathrm{i} \left(C_f m_f/f_A \right) \bar{\Psi}_f \gamma_5 \Psi_f \phi_A$ need not be equivalent to the appropriate derivative structure, for example when two NG bosons are attached to one fermion line as in axion emission by nucleon bremsstrahlung [17].

In the DFSZ model [15], the tree-level coupling coefficient to electrons is

$$C_e = \frac{\cos^2 \beta}{3},\tag{8}$$

where $\tan\beta$ is the ratio of two Higgs vacuum expectation values that are generic to this and similar models.

For nucleons, $C_{n,p}$ are related to axial-vector current matrix elements by generalized Goldberger-Treiman relations,

$$C_p = (C_u - \eta)\Delta u + (C_d - \eta z)\Delta d + (C_s - \eta w)\Delta s,$$

$$C_n = (C_u - \eta)\Delta d + (C_d - \eta z)\Delta u + (C_s - \eta w)\Delta s.$$
(9)

Here, $\eta = (1+z+w)^{-1}$ with $z = m_u/m_d$ and $w = m_u/m_s \ll z$ and the Δq are given by the axial vector current matrix element $\Delta q S_{\mu} = \langle p | \bar{q} \gamma_{\mu} \gamma_5 q | p \rangle$ with S_{μ} the proton spin.

Neutron beta decay and strong isospin symmetry considerations imply $\Delta u - \Delta d = F + D = 1.269 \pm 0.003$, whereas hyperon decays and flavor SU(3) symmetry imply $\Delta u + \Delta d - 2\Delta s = 3F - D = 0.586 \pm 0.031$ [19]. The strange-quark contribution is $\Delta s = -0.08 \pm 0.01_{\rm stat} \pm 0.05_{\rm syst}$ from the COMPASS experiment [18], and $\Delta s = -0.085 \pm 0.008_{\rm exp} \pm 0.013_{\rm theor} \pm 0.009_{\rm evol}$ from HERMES [19], in agreement with each other and with an early estimate of $\Delta s = -0.11 \pm 0.03$ [20]. We thus adopt $\Delta u = 0.84 \pm 0.02$, $\Delta d = -0.43 \pm 0.02$ and $\Delta s = -0.09 \pm 0.02$, very similar to what was used in the axion literature.

The uncertainty of the axion-nucleon couplings is dominated by the uncertainty $z=m_u/m_d=0.35$ –0.60 that we mentioned earlier. For hadronic axions $C_{u,d,s}=0$ so that $-0.51 < C_p < -0.36$ and $0.10 > C_n > -0.05$. Therefore it is well possible that $C_n=0$ whereas C_p does not vanish within the plausible z range. In the DFSZ model, $C_u=\frac{1}{3}\sin^2\beta$ and $C_d=\frac{1}{3}\cos^2\beta$ and C_n and C_p as functions of β and z do not vanish simultaneously.

The axion-pion interaction is given by the Lagrangian [21]

$$\mathcal{L}_{A\pi} = \frac{C_{A\pi}}{f_{\pi}f_{A}} \left(\pi^{0}\pi^{+}\partial_{\mu}\pi^{-} + \pi^{0}\pi^{-}\partial_{\mu}\pi^{+} - 2\pi^{+}\pi^{-}\partial_{\mu}\pi^{0} \right) \partial_{\mu}\phi_{A},$$
(10)

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where $C_{A\pi} = (1-z)/[3(1+z)]$ in hadronic models. The chiral symmetry-breaking Lagrangian provides an additional term $\mathcal{L}'_{A\pi} \propto (m_{\pi}^2/f_{\pi}f_A) (\pi^0\pi^0 + 2\pi^-\pi^+) \pi^0\phi_A$. For hadronic axions it vanishes identically, in contrast to the DFSZ model (Roberto Peccei, private communication).

II. LABORATORY SEARCHES

II.1 Photon regeneration

Searching for "invisible axions" is extremely challenging. The most promising approaches rely on the axion-two-photon vertex, allowing for axion-photon conversion in external electric or magnetic fields [5]. For the Coulomb field of a charged particle, the conversion is best viewed as a scattering process, $\gamma + Ze \leftrightarrow Ze + A$, called Primakoff effect [22]. In the other extreme of a macroscopic field, usually a large-scale B-field, the momentum transfer is small, the interaction coherent over a large distance, and the conversion is best viewed as an axion-photon oscillation phenomenon in analogy to neutrino flavor oscillations [23].

Photons propagating through a transverse magnetic field, with incident \mathbf{E}_{γ} and magnet \mathbf{B} parallel, may convert into axions. For $m_A^2 L/2\omega \ll 2\pi$, where L is the length of the B field region and ω the photon energy, the resultant axion beam is coherent with the incident photon beam and the conversion probability is $\Pi \sim (1/4)(G_{A\gamma\gamma}BL)^2$. A practical realization uses a laser beam propagating down the bore of a superconducting dipole magnet (like the bending magnets in high-energy accelerators). If another magnet is in line with the first, but shielded by an optical barrier, then photons may be regenerated from the pure axion beam [24]. The overall probability $P(\gamma \to A \to \gamma) = \Pi^2$.

The first such experiment utilized two magnets of length $L=4.4~\mathrm{m}$ and $B=3.7~\mathrm{T}$ and found $G_{A\gamma\gamma}<6.7\times10^{-7}~\mathrm{GeV}^{-1}$ at 95% CL for $m_A<1~\mathrm{meV}$ [25]. More recently, several such experiments were performed (see Listings), improving the limit to $G_{A\gamma\gamma}<0.7\times10^{-7}~\mathrm{GeV}^{-1}$ at 95% CL for $m_A\lesssim0.5~\mathrm{meV}$ [26]. Some of these experiments have also reported limits for scalar bosons where the photon \mathbf{E}_{γ} must be chosen perpendicular to the magnet \mathbf{B} .

The concept of resonantly enhanced photon regeneration may open unexplored regions of coupling strength [27]. In this scheme, both the production and detection magnets are within Fabry-Perot optical cavities and actively locked in frequency. The $\gamma \to A \to \gamma$ rate is enhanced by a factor $2\mathcal{F}\mathcal{F}'/\pi^2$ relative to a single-pass experiment, where \mathcal{F} and \mathcal{F}' are the finesses of the two cavities. The resonant enhancement could be of order $10^{(10-12)}$, improving the $G_{A\gamma\gamma}$ sensitivity by $10^{(2.5-3)}$.

Another new concept involves axion absorption and emission between electromagnetic fields within a high finesse optical cavity [28]. A signal appears as resonant sidebands on the carrier. This technique could be sensitive in the mass range 10^{-6} – 10^{-4} eV and reach the KSVZ line after one year of operation.

II.2 Photon polarization

An alternative to regenerating the lost photons is to use the beam itself to detect conversion: the polarization of light propagating through a transverse B field suffers dichroism and birefrigence [29]. Dichroism: The E_{\parallel} component, but not E_{\perp} , is depleted by axion production, causing a small rotation of linearly polarized light. For $m_A^2 L/2\omega \ll 2\pi$ the effect is independent of m_A , for heavier axions it oscillates and diminishes as m_A increases, and it vanishes for $m_A > \omega$. Birefringence: This rotation occurs because there is mixing of virtual axions in the E_{\parallel} state, but not for E_{\perp} . Hence, linearly polarized light will develop elliptical polarization. Higher-order QED also induces vacuum birefringence. A search for these effects was performed on the same dipole magnets in the early experiment above [30]. The dichroic rotation gave a stronger limit than the ellipticity rotation: $G_{A\gamma\gamma} < 3.6 \times 10^{-7} \text{ GeV}^{-1}$ at 95% CL for $m_A < 5 \times 10^{-4}$ eV. The ellipticity limits are better at higher masses, as they fall off smoothly and do not terminate at m_A .

In 2006 the PVLAS collaboration reported a signature of magnetically induced vacuum dichroism that could be interpreted as the effect of a pseudoscalar with $m_A = 1$ –1.5 meV and $G_{A\gamma\gamma} = (1.6-5) \times 10^{-6}~{\rm GeV}^{-1}$ [31]. Since then, these findings are attributed to instrumental artifacts [32]. This particle interpretation is also excluded by the above photon regeneration searches that were perhaps inspired by the original PVLAS result.

II.3 Long-range forces

New bosons would mediate long-range forces, which are severely constrained by "fifth force" experiments [33]. Those looking for new mass-spin couplings provide significant constraints on pseudoscalar bosons [34]. However, they do not yet cover realistic parameters for invisible axion models because they are only sensitive for small m_A . The corresponding coupling strengths scale with $f_A^{-1} \approx m_A/m_\pi f_\pi$ and are too small to be detected. Still, these efforts provide constraints on more general low-mass bosons.

III. AXIONS FROM ASTROPHYSICAL SOURCES

III.1 Stellar energy-loss limits:

Low-mass weakly-interacting particles (neutrinos, gravitons, axions, baryonic or leptonic gauge bosons, etc.) are produced in hot astrophysical plasmas, and can thus transport energy out of stars. The coupling strength of these particles with normal matter and radiation is bounded by the constraint that stellar lifetimes or energy-loss rates not conflict with observation [35–37].

We begin this discussion with our Sun and concentrate on hadronic axions. They are produced predominantly by the Primakoff process $\gamma + Ze \rightarrow Ze + A$. Integrating over a standard solar model yields the axion luminosity [51]

$$L_A = G_{10}^2 \, 1.85 \times 10^{-3} \, L_{\odot} \,, \tag{11}$$

where $G_{10} = G_{A\gamma\gamma} \times 10^{10}$ GeV. The maximum of the spectrum is at 3.0 keV, the average at 4.2 keV, and the number flux at Earth is G_{10}^2 3.75 × 10¹¹ cm⁻² s⁻¹. The solar photon luminosity is fixed, so axion losses require enhanced nuclear energy production and thus enhanced neutrino fluxes. The all-flavor measurements by SNO together with a standard solar model imply $L_A \lesssim 0.10 L_{\odot}$, corresponding to $G_{10} \lesssim 7$ [38], mildly superseding a similar limit from helioseismology [39].

A more restrictive limit derives from globular-cluster (GC) stars that allow for detailed tests of stellar-evolution theory. The stars on the horizontal branch (HB) in the color-magnitude diagram have reached helium burning with a core-averaged energy release of about 80 erg g⁻¹ s⁻¹, compared to Primakoff axion losses of G_{10}^2 30 erg g⁻¹ s⁻¹. The accelerated consumption of helium reduces the HB lifetime by about $80/(80+30\,G_{10}^2)$. Number counts of HB stars in 15 GCs compared with the number of red giants (that are not much affected by Primakoff losses) reveal agreement with expectations within 20–40% in any one GC and overall on the 10% level [36]. Therefore, a reasonably conservative limit is

$$G_{A\gamma\gamma} \lesssim 1 \times 10^{-10} \text{ GeV}^{-1},$$
 (12)

although a detailed error budget is not available.

We translate this constraint on $G_{A\gamma\gamma}$ to $f_A > 2.3 \times 10^7~{\rm GeV}$ ($m_A < 0.3~{\rm eV}$), using z = 0.56 and E/N = 0 as in the KSVZ model, and show the excluded range in Figure 1. For the DFSZ model with E/N = 8/3, the corresponding limits are slightly less restrictive, $f_A > 0.8 \times 10^7~{\rm GeV}$ ($m_A < 0.7~{\rm eV}$). The exact high-mass end of the exclusion range has not been determined. The relevant temperature is around 10 keV and the average photon energy is therefore around 30 keV. The excluded m_A range thus certainly extends beyond the shown 100 keV.

If axions couple directly to electrons, the dominant emission processes are $\gamma + e^- \rightarrow e^- + A$ and $e^- + Ze \rightarrow Ze + e^- + A$. Moreover, bremsstrahlung is efficient in white dwarfs (WDs), where the Primakoff and Compton processes are suppressed by the large plasma frequency. The enhanced energy losses would delay helium ignition in GC stars, implying $\alpha_{Aee} \lesssim 0.5 \times 10^{-26}$ [40]. Enhanced WD cooling led to a similar limit from the WD luminosity function [41]. Based on much better data and detailed WD cooling treatment, today it appears that the WD luminosity function fits better with a new energy-loss channel that can be interpreted in terms of axion losses corresponding to $\alpha_{Aee} \sim 10^{-27}$ [42]. For pulsationally unstable WDs (ZZ Ceti stars), the period decrease \dot{P}/P is a measure of the cooling speed. A well-studied case is the star G117-B15A, where the measured P/P also implies additional cooling that can be interpreted in terms of similar axion losses [43]. moment we prefer to interpret these results as an upper limit $\alpha_{Aee} \lesssim 10^{-27}$ shown in Figure 1.

Similar constraints derive from the measured duration of the neutrino signal of the supernova SN 1987A. Numerical simulations for a variety of cases, including axions and Kaluza-Klein gravitons, reveal that the energy-loss rate of a nuclear medium

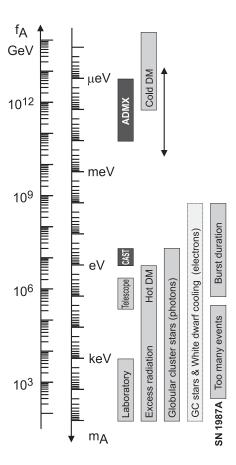


Figure 1: Exclusion ranges as described in the text. The dark intervals are the approximate CAST and ADMX search ranges. Limits on coupling strengths are translated into limits on m_A and f_A using z=0.56 and the KSVZ values for the coupling strengths. The "Laboratory" bar is a rough representation of the exclusion range for standard or variant axions. The "GC stars and white-dwarf cooling" range uses the DFSZ model with an axion-electron coupling corresponding to $\cos^2\beta=1/2$. The Cold Dark Matter exclusion range is particularly uncertain. We show the benchmark case from the misalignment mechanism.

at the density $3 \times 10^{14}\,$ g cm⁻³ and temperature 30 MeV should not exceed about $1 \times 10^{19}\,$ erg g⁻¹ s⁻¹ [36]. The energy-loss rate from nucleon bremsstrahlung, $N+N\to N+N+A$, is $(C_N/2f_A)^2(T^4/\pi^2m_N)\,F$. Here F is a numerical factor that represents an integral over the dynamical spin-density structure function because axions couple to the nucleon spin. For realistic conditions, even after considerable effort, one is limited to a heuristic estimate leading to $F\approx 1$ [37].

The SN 1987A limits are of particular interest for hadronic axions where the bounds on α_{Aee} are moot. Within uncertainties of $z=m_u/m_d$ a reasonable choice for the coupling constants is then $C_p=-0.4$ and $C_n=0$. Using a proton fraction of 0.3, F=1, and T=30 MeV one finds [37]

$$f_A \gtrsim 4 \times 10^8 \text{ GeV}$$
 and $m_A \lesssim 16 \text{ meV}$. (13)

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If axions interact sufficiently strongly they are trapped. Only about three orders of magnitude in g_{ANN} or m_A are excluded, a range shown somewhat schematically in Figure 1. For even larger couplings, the axion flux would have been negligible, yet it would have triggered additional events in the detectors, excluding a further range [44]. A possible gap between these two SN 1987A arguments was discussed as the "hadronic axion window" under the assumption that $G_{A\gamma\gamma}$ was anomalously small [45]. This range is now excluded by hot dark matter bounds (see below).

The very tentative indication for additional WD cooling by axion emission described above is not in conflict with SN 1987A bounds. Still, if the WD interpretation were correct, SNe would lose a large fraction of their energy as axions. This would lead to a diffuse SN axion background (DSAB) in the universe with an energy density comparable to the extra-galactic background light [46]. However, there is no apparent way of detecting it or the axion burst from the next nearby SN.

III.2 Searches for solar axions

Instead of using stellar energy losses to derive axion limits, one can also search directly for these fluxes, notably from the Sun. The main focus has been on axion-like particles with a two-photon vertex. They are produced by the Primakoff process with a flux given by Equation 11 and can be detected at Earth with the reverse process in a macroscopic B-field ("axion helioscope") [5]. The average energy of solar axions of 4.2 keV implies a photon-axion oscillation length in vacuum of $2\pi \left(2\omega/m_A^2\right) \sim \mathcal{O}(1 \text{ mm})$, precluding the vacuum mixing from achieving its theoretical maximum in any practical magnet. However, one can endow the photon with an effective mass in a gas, $m_{\gamma} = \omega_{\text{plas}}$, thus matching the axion and photon dispersion relations [47].

An early implementation of these ideas used a conventional dipole magnet, with a conversion volume of variable-pressure gas with a xenon proportional chamber as x-ray detector [48]. The conversion magnet was fixed in orientation and collected data for about 1000 s/day. Axions were excluded for $G_{A\gamma\gamma} < 3.6 \times 10^{-9} \text{ GeV}^{-1}$ for $m_A < 0.03 \text{ eV}$, and $G_{A\gamma\gamma} < 7.7 \times 10^{-9} \text{ GeV}^{-1}$ for $0.03 < m_A < 0.11 \text{ eV}$ at 95% CL.

Later, the Tokyo axion helioscope used a superconducting magnet on a tracking mount, viewing the Sun continuously. They reported $G_{A\gamma\gamma} < 6 \times 10^{-10} \text{ GeV}^{-1}$ for $m_A < 0.3 \text{ eV}$ [49]. Recently this experiment was recommissioned and a similar limit for masses around 1 eV was reported [50]. These exclusion ranges are shown in Figure 2.

The most recent helioscope CAST (CERN Axion Solar Telescope) uses a decommissioned LHC dipole magnet on a tracking mount. The hardware includes grazing-incidence x-ray optics with solid-state x-ray detectors, as well as a novel x-ray Micromegas position-sensitive gaseous detector. CAST has established a 95% CL limit $G_{A\gamma\gamma} < 8.8 \times 10^{-11}~{\rm GeV}^{-1}$ for $m_A < 0.02~{\rm eV}$ [51]. To cover larger masses, the magnet bores are filled with a gas at varying pressure. The runs with

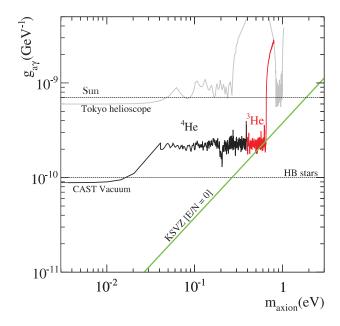


Figure 2: Solar exclusion plot for axion-like particles (adapted from [53]). The green solid line corresponds to KSVZ axions.

⁴He cover masses up to about 0.4 eV [52], providing the ⁴He limits shown in Figure 2. To cover yet larger masses to about 1.15 eV, ³He was used to achieve a larger pressure at cryogenic temperatures. First limits up to 0.64 eV were recently published [53], allowing CAST to "cross the axion line" for the KSVZ model (Figure 2).

Going to yet larger masses in a helioscope search is not well motivated because of the cosmic hot dark matter bound of $m_A \lesssim 0.7 \text{ eV}$ (see below). Sensitivity to significantly smaller values of $G_{A\gamma\gamma}$ can be achieved with a next-generation axion helioscope with a much larger magnetic-field cross section. Realistic design options for this "International Axion Observatory" (IAXO) have been studied in some detail [54].

Other Primakoff searches for solar axions have been carried out using crystal detectors, exploiting the coherent conversion of axions into photons when the axion angle of incidence satisfies a Bragg condition with a crystal plane [55]. However, none of these limits is more restrictive than the one derived from solar neutrinos that was discussed earlier.

Another idea is to look at the Sun with an x-ray satellite when the Earth is in between. Solar axions would convert in the Earth magnetic field on the far side and could be detected [56]. The sensitivity to $G_{A\gamma\gamma}$ could be comparable to CAST, but only for much smaller m_A . Deep solar x-ray measurements with existing satellites, using the solar magnetosphere as conversion region, have reported preliminary limits on $G_{A\gamma\gamma}$ [57].

III.3 Conversion of astrophysical photon fluxes

Large-scale B fields exist in astrophysics that can induce axion-photon oscillations. In practical cases, B is much smaller than in the laboratory, whereas the conversion region L is much

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larger. Therefore, while the product BL can be large, realistic sensitivities are usually restricted to very low-mass particles, far away from the "axion line" in a plot like Figure 2.

One example is SN 1987A, which would have emitted a burst of axion-like particles due to the Primakoff production in its core. They would have partially converted into γ -rays in the galactic B-field. The absence of a γ -ray burst in coincidence with SN 1987A neutrinos provides a limit $G_{A\gamma\gamma} \lesssim 1 \times 10^{-11} \text{ GeV}^{-1}$ for $m_A \lesssim 10^{-9} \text{ eV}$ [58], the most restrictive limit for very small m_A . Axion-like particles from other stars (e.g. magnetic white dwarfs or neutron stars) can be converted to photons, but no tangible new limits or signatures seem to have appeared, except perhaps from solar x-ray observations (see above).

Magnetically induced oscillations between photons and axion-like particles (ALPs) can modify the photon fluxes from distant sources in various ways: (i) Frequency-dependent dimming. (ii) Modified polarization. (iii) Avoiding absorption by propagation in the form of axions. For example, dimming of SNe Ia could influence the interpretation in terms of cosmic acceleration [59], although it has become clear that photon-ALP conversion could only be a subdominant effect [60]. More recently, it appears that the universe could be too transparent to TeV γ -rays that should be absorbed by pair production on the extra-galactic background light [61]. The situation is not conclusive at present, but the possible role of photon-ALP oscillations in TeV γ -ray astronomy is tantalizing [62].

IV. COSMIC AXIONS

IV.1 Cosmic axion populations

In the early universe, axions are produced by processes involving quarks and gluons [63]. After color confinement, the dominant thermalization process is $\pi + \pi \leftrightarrow \pi + A$ [21]. The resulting axion population would contribute a hot dark matter component in analogy to massive neutrinos. Cosmological precision data provide restrictive constraints on a possible hot dark-matter fraction that translate into $m_A < 0.7$ eV at the 95% statistical CL [64], but in detail depend on the used data set and assumed cosmological model.

For $m_A \gtrsim 20$ eV, axions decay fast on a cosmic time scale, removing the axion population while injecting photons. This excess radiation provides additional limits up to very large axion masses [65]. An anomalously small $G_{A\gamma\gamma}$ provides no loophole because suppressing decays leads to thermal axions overdominating the mass density of the universe.

The main cosmological interest in axions derives from their possible role as cold dark matter (CDM). In addition to thermal processes, axions are abundantly produced by the "misalignment mechanism" [66]. After the breakdown of the PQ symmetry, the axion field relaxes somewhere in the "bottom of the wine bottle" potential. Near the QCD epoch, instanton effects explicitly break the PQ symmetry, the very effect that causes dynamical PQ symmetry restoration. This "tilting of the wine

bottle" drives the axion field toward the CP-conserving minimum, thereby exciting coherent oscillations of the axion field that ultimately represent a condensate of CDM. The cosmic mass density in this homogeneous field mode is [67]

$$\Omega_A h^2 \approx 0.7 \left(\frac{f_A}{10^{12} \text{ GeV}}\right)^{7/6} \left(\frac{\bar{\Theta}_i}{\pi}\right)^2,$$
 (14)

where h is the present-day Hubble expansion parameter in units of 100 km s⁻¹ Mpc⁻¹, and $-\pi \leq \bar{\Theta}_{\rm i} \leq \pi$ is the initial "misalignment angle" relative to the CP-conserving position. If the PQ symmetry breakdown takes place after inflation, $\bar{\Theta}_{\rm i}$ will take on different values in different patches of the universe. The average contribution is [67]

$$\Omega_A h^2 \approx 0.3 \left(\frac{f_A}{10^{12} \text{ GeV}}\right)^{7/6}$$
 (15)

Comparing with the measured CDM density of $\Omega_{\rm CDM}h^2 \approx 0.13$ implies that axions with $m_A \approx 10~\mu {\rm eV}$ provide the dark matter, whereas smaller masses are excluded (Figure 1).

This density sets only a rough scale for the expected m_A . The mass of CDM axions could be significantly smaller or larger than 10 μ eV. Apart from the overall particle physics uncertainties, the cosmological sequence of events is crucial. Assuming axions make up CDM, much smaller masses are possible if inflation took place after the PQ transition and the initial value $\bar{\Theta}_i$ was small ("anthropic axion window" [68]). The oscillating galactic dark matter axion field induces extremely small oscillating nuclear electric dipole moments. Conceivably, these could be measured by extremely tiny energy shifts in cold molecules [69].

Conversely, if the PQ transition took place after inflation, there are additional sources for nonthermal axions, notably the decay of cosmic strings and domain walls. According to Sikivie and collaborators, these populations are comparable to the misalignment contribution [67]. Other groups find a significantly enhanced axion density [70] or rather, a larger m_A value for axions providing CDM. Moreover, the spatial axion density variations are large at the QCD transition and they are not erased by free streaming. When matter begins to dominate the universe, gravitationally bound "axion miniculsters" form promptly [71]. A significant fraction of CDM axions can reside in these bound objects.

If the reheat temperature after inflation is too small to restore PQ symmetry, the axion field is present during inflation. It is subject to quantum fluctuations, leading to isocurvature fluctuations that are severely constrained [72].

IV.2 Telescope searches

The two-photon decay is extremely slow for axions with masses in the CDM regime, but could be detectable for eV masses. The signature would be a quasi-monochromatic emission line from galaxies and galaxy clusters. The expected optical line intensity for DFSZ axions is similar to the continuum night emission. An early search in three rich Abell clusters [73],

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and a recent search in two rich Abell clusters [74], exclude the "Telescope" range in Figure 1 unless the axion-photon coupling is strongly suppressed. Of course, axions in this mass range would anyway provide an excessive hot DM contribution.

Very low-mass axions in halos produce a weak quasi-monochromatic radio line. Virial velocities in undisrupted dwarf galaxies are very low, and the axion decay line would therefore be extremely narrow. A search with the Haystack radio telescope on three nearby dwarf galaxies provided a limit $G_{A\gamma\gamma} < 1.0 \times 10^{-9} \ {\rm GeV}^{-1}$ at 96% CL for $298 < m_A < 363 \ \mu {\rm eV}$ [75]. However, this combination of m_A and $G_{A\gamma\gamma}$ does not exclude plausible axion models.

IV.3 Microwave cavity experiments

The limits of Figure 1 suggest that axions, if they exist, provide a significant fraction or even perhaps all of the cosmic CDM. In a broad range of the plausible m_A range for CDM, galactic halo axions may be detected by their resonant conversion into a quasi-monochromatic microwave signal in a high-Q electromagnetic cavity permeated by a strong static B field [5,76]. The cavity frequency is tunable, and the signal is maximized when the frequency is the total axion energy, rest mass plus kinetic energy, of $\nu = (m_A/2\pi) \left[1 + \mathcal{O}(10^{-6})\right]$, the width above the rest mass representing the virial distribution in the galaxy. The frequency spectrum may also contain finer structure from axions more recently fallen into the galactic potential and not yet completely virialized [77].

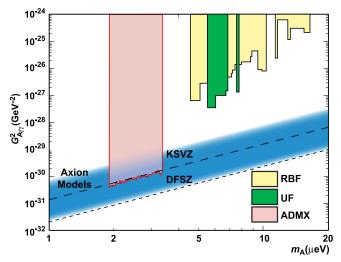


Figure 3: Exclusion region reported from the microwave cavity experiments RBF and UF [78] and ADMX [79]. A local dark-matter density of 450 MeV cm⁻³ is assumed.

The feasibility of this technique was established in early experiments of relatively small sensitive volume, $\mathcal{O}(1 \text{ liter})$, with HFET-based amplifiers, setting limits in the range $4.5 < m_A < 16.3 \ \mu\text{eV}$ [78], but lacking by 2–3 orders of magnitude the sensitivity required to detect realistic axions.

Later, ADMX ($B \sim 8$ T, $V \sim 200$ liters) has achieved sensitivity to KSVZ axions, assuming they saturate the local dark matter density and are well virialized, over the mass range 1.9–3.3 μ eV [79]. Should halo axions have a component not yet virialized, ADMX is sensitive to DFSZ axions [80]. responding 90% CL exclusion regions shown in Figure 3 are normalized to an assumed local CDM density of 7.5×10^{-25} g cm⁻³ $(450 \text{ MeV cm}^{-3})$. More recently the ADMX experiment commissioned an upgrade [81] that replaces the microwave HFET amplifiers by near quantum-limited low-noise dc SQUID microwave amplifiers [82], allowing for a significantly improved sensitivity [83]. This apparatus is also sensitive to other hypothetical light bosons over a limited parameter space [84]. Alternatively, a Rydberg atom single-photon detector [85] can in principle evade the standard quantum limit for coherent photon detection.

Conclusions

Experimental, astrophysical, and cosmological limits have been refined and indicate that axions, if they exist, very likely have very low mass, $m_A \lesssim 10$ meV, suggesting that axions are a non-negligible fraction of the cosmic CDM. The upgraded versions of the ADMX experiment will ultimately cover the range 1–100 μ eV with a sensitivity allowing one to detect such axions, unless the local DM density is unexpectedly small or the axion-photon coupling anomalously weak. Other experimental techniques remain of interest to search for axion-like particles, although at present no method besides the DM search is known that could detect realistic axions obeying the astrophysical and cosmological limits, and fulfilling the QCD-implied relationship between mass and coupling strength.

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A⁰ (Axion) MASS LIMITS from Astrophysics and Cosmology

These bounds depend on model-dependent assumptions (i.e. — on a combination of

VALUE (MeV) DO CUMENT ID • • • We do not use the following data for averages, fits, limits, etc. • • •

- >0.2 BARROSO ASTR Standard Axion 82 ¹ RAFFELT >0.25 82 ASTR Standard Axion 2 DICUS >0.2 ASTR Standard Axion 78C MIKAELIAN ASTR ² SATO >0.3 ASTR Standard Axion > 0.2VYSOTSKII 78 ASTR Standard Axion
- $^1\,\mathrm{Lower}$ bound from 5.5 MeV $\gamma\text{-ray}$ line from the sun.
- 2 Lower bound from requiring the red giants' stellar evolution not be disrupted by axion

A^0 (Axion) and Other Light Boson (X^0) Searches in Hadron Decays

Limits are for branching ratios. CL% DO CUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $< 7 \times 10^{-10}$ ³ ADLER 04 B787 $K^+ \rightarrow \pi^+ X^0$ $< 7.3 \times 10^{-11}$ ⁴ A NI SIMOVSK...04 B949 $<\!\!4.5\times 10^{-11}$ ⁵ ADLER 02c B787 $^{<4}\times10^{-5}$ ⁶ ADLER B787 01 $< 4.9 \times 10^{-5}$ 01B CLEO $B^{\pm} \rightarrow \pi^{\pm}(K^{\pm})X^{0}$ AMMAR $<\!\!5.3\times 10^{-5}$ 01B CLEO $B^0 \rightarrow \kappa_S^0 X^0$ AMMAR $< 3.3 \times 10^{-5}$ 98 NOMD $\pi^0 \rightarrow \gamma \overset{\smile}{\chi^0}$, $m_{\chi^0} <$ 120 MeV $^{7}\,\mathrm{ALTEGOER}$ 90 $< 5.0 \times 10^{-8}$ B787 $K^+ \rightarrow \pi^+ X^0 (X^0 \rightarrow \gamma \gamma)$ ⁸ KIT CHING 97 $< 5.2 \times 10^{-10}$ $K^+ \rightarrow \pi^+ X^0$ ⁹ ADLER 96 B787 96B CBAR $\pi^0 \rightarrow \gamma X^0$, $m_{X^0} < 65$ MeV $<\!2.8\times10^{-4}$ $^{10}\,\mathrm{AMSLER}$ 90 96B CBAR $\eta \rightarrow \gamma X^0$, $m_{\chi^0} = 50-200 \text{ MeV}$ $< \! 3 \times 10^{-4}$ $^{10}\,\mathrm{AMSLER}$ 96B CBAR $\eta' \to \gamma X^0$, $m_{X^0} = 50-925$ MeV $\times 10^{-5}$ 90 ¹⁰ AMSLER <4 94B CBAR $\pi^0
ightarrow \gamma X^0$, $m_{X^0} = 65 - 125$ MeV $\times 10^{-5}$ ¹⁰ AMSLER 94B CBAR $\eta \rightarrow \gamma X^0$, $m_{X^0} = 200-525$ MeV $\times 10^{-5}$ $^{10}\,\mathrm{AMSLER}$ <6 90 CNTR $\eta \rightarrow \gamma X$, $m_{X^0} = 25$ MeV $< 7 \quad \times \, 10^{-3}$ ¹¹ MEIJERDREES 94 CNTR $\pi^0 \rightarrow \gamma X^0$, $m_{X^0}^2 = 100 \text{ MeV}$ $<\!\!2 \times 10^{-3}$ ¹¹ MEIJERDREES 94 90 $\times 10^{-7}$ 12 ATIYA 93B B787 Sup. by ADLER 04 <2 $< 3 \times 10^{-13}$ ¹³ NG COSM $\pi^0 \rightarrow \gamma X^0$ $< 1.1 \times 10^{-8}$ ¹⁴ ALLIEGRO SPEC $K^+ \rightarrow \pi^+ X^0 (X^0 \rightarrow e^+ e^-)$ 92 $< 5 \quad \times \, 10^{-4}$ 15 ATIYA B787 $\pi^0 \rightarrow \gamma X^0$ 92 SPEC $\pi^0 \rightarrow \gamma X^0, X^0 \rightarrow e^+e^-,$ $<\!\!4\times10^{-6}$ ¹⁶ MEIJERDREES 92 $m_{\chi^0}=100~{\rm MeV}$ Sup. by KITCHING 97 <1 $\times 10^{-7}$ ¹⁷ ATIYA 90B B787 $< 1.3 \times 10^{-8}$ ¹⁸ KORENCHE... 87 SPEC $\pi^+ \rightarrow e^+ \nu A^0 (A^0$ $<1 \times 10^{-9}$ ¹⁹ EICHLER Stopped $\pi^+ \rightarrow e^+ \nu A^0$ 86 SPEC $< 2 \times 10^{-5}$ ²⁰ YA MA ZA KI For 160<m<260 MeV 84 SPEC $<(1.5-4)\times10^{-6}$ 90 $^{20}\,\mathrm{YA\,MA\,ZA\,KI}$ 84 $^{21}\,\mathrm{ASANO}$ 82 81B CNTR Stopped $K^+ \rightarrow \pi^+ X^0$ ²² ASANO ²³ ZHITNITSKII 79 Heavy axion

 3 This limit applies for a mass near 180 MeV. For other masses in the range $m_{_{\mathbf{V}0}}=$ 150-250 MeV the limit is less restrictive, but still improves ADLER 02c and ATIYA 93B. $^4\,\mathrm{A\,NISIM\,OVSKY}$ 04 bound is for $m_{\chi^0}\!=\!0.$

 5 ADLER 02C bound is for $m_{\chi^{0}}$ <60 MeV. See Fig. 2 for limits at higher masses.

⁶ The quoted limit is for $m_{X^0} = 0$ -80 MeV. See their Fig. 5 for the limit at higher mass. The branching fraction limit assumes pure phase space decay distributions. ⁷ ALTEGOER 98 looked for X^0 from π^0 decay which penetrate the shielding and convert

to π^0 in the external Coulomb field of a nucleus. 8 KITCHING 97 limit is for B($K^+\to \pi^+ X^0$)·B($X^0\to \gamma\gamma$) and applies for $m_{X^0}\simeq$ 50

MeV, $au_{X^0} < 10^{-10}\,\mathrm{s}$. Limits are provided for $0 < m_{X^0} < 100$ MeV, $au_{X^0} < 10^{-8}\,\mathrm{s}$.

⁹ ADLER 96 looked for a peak in missing-mass distribution. This work is an update of ATIYA 93. The limit is for massless stable χ^0 particles and extends to $m_{\chi 0} = 80$ MeV at the same level. See paper for dependence on finite lifetime.

 $^{
m 10}$ AMSLER 94B and AMSLER 96B looked for a peak in missing-mass distribution

 11 The MEIJERDREES 94 limit is based on inclusive photon spectrum and is independent of X^0 decay modes. It applies to $\tau(X^0)\!>\!10^{-23}\,{\rm sec}.$

 $^{12}\mathrm{ATIYA}$ 93B looked for a peak in missing mass distribution. The bound applies for stable X^0 of m_{X^0} = 150 - 250 MeV, and the limit becomes stronger (10⁻⁸) for m_{X^0} = 180 - 240

13 NG 93 studied the production of X^0 via $\gamma\gamma\to\pi^0\to\gamma X^0$ in the early universe at $T\simeq 1$ MeV. The bound on extra neutrinos from nucleosynthesis $\Delta N_{\nu} < 0.3$ (WALKER 91) is employed. It applies to $m_{\chi 0} \ll 1$ MeV in order to be relativistic down to nucleosynthesis temperature. See paper for heavier X^0 .

 14 ALLIEGRO 92 limit applies for $m_{\chi^0} = 150$ –340 MeV and is the branching ratio times the decay probability. Limit is $<1.5\stackrel{\frown}{\times}10^{-8}$ at 99%CL.

The limit applies to $m_{\chi^0} = 0$ -130 MeV in the narrow resonance limit. See paper for the dependence on

If MEI JERDREES 92 limit applies for $\tau_{X0}=10^{-23}$ - 10^{-11} sec. Limits between 2×10^{-4} and 4 imes 10 $^{-6}$ are obtained for $m_{\chi^0}=$ 25–120 MeV. Angular momentum conservation requires that X^0 has spin ≥ 1 .

17 ATIYA 90B limit is for B($K^+ \to \pi^+ X^0$)·B($X^0 \to \gamma \gamma$) and applies for $m_{X^0} =$ 50 MeV, $au_{\chi 0}~<~10^{-10}$ s. Limits are also provided for 0 < $m_{\chi 0}~<$ 100 MeV, $au_{\chi 0}^{++}~<~10^{-8}$ s. 18 KORENCHENKO 87 limit assumes $m_{A^0}=1.7$ MeV, $\tau_{A^0}\lesssim 10^{-12}$ s, and ${\rm B}(A^0\to$ $e^+e^-)=1.$

07 CNTR $A^0 \rightarrow e^+e^-$

Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

37 JAIN

- 19 EICHLER 86 looked for $\pi^+ \rightarrow e^+ \nu A^0$ followed by $A^0 \rightarrow$ e^+e^- . Limits on the branching fraction depend on the mass and and lifetime of A^0 . The quoted limits are valid when $au(A^0) \gtrsim 3. imes 10^{-10} ext{s}$ if the decays are kinematically allowed.
- ²⁰ YAMAZAKI 84 looked for a discrete line in $K^+ \to \pi^+ X$. Sensitive to wide mass range (5–300 MeV), independent of whether X decays promptly or not.
- ²¹ ASANO 82 at KEK set limits for B($K^+
 ightarrow \pi^+ X^0$) for m_{X^0} <100 MeV as BR ASANO 81B is KEK experiment. Set B(K' > X') is $m \chi_0$
 1. × 10⁻⁹ s, BR < 1.4 × 10⁻⁶ for τ < 1. × 10⁻⁹s.
 22 ASANO 81B is KEK experiment. Set B(K' $\rightarrow \pi^+ X^0$) < 3.8 × 10⁻⁸ at CL = 90%.
- 23 ZHIT NITSKII 79 argue that a heavy axion predicted by YANG 78 (3 < m <40 MeV) contradicts experimental muon anomalous magnetic moments.

A⁰ (Axion) Searches in Quarkonium Decays

Decay or transition of quarkonium. Limits are for branching ratio.

CL% DOCUMENT ID TECN COMMENT

| • • • | • We do | not use | the following data | for | averages, | fits, limits, etc. • • • |
|-------|--------------------|---------|-------------------------|-----|-----------|----------------------------------------------------------------|
| | $\times10^{-5}$ | | ²⁴ DRUZHININ | 87 | ND | $\phi \rightarrow A^0 \gamma (A^0 \rightarrow e^+ e^-)$ |
| | $\times 10^{-3}$ | | ²⁵ DRUZHININ | | | $\phi \rightarrow A^0 \gamma (A^0 \rightarrow \gamma \gamma)$ |
| | $\times 10^{-6}$ | | ²⁶ DRUZHININ | | | $\phi \rightarrow A^0 \gamma (A^0 \rightarrow \text{missing})$ |
| <1 A | × 10 ⁻⁵ | 90 | 27 FDWARDS | 82 | CRAI | $I/2/2 \rightarrow \Delta^0 \gamma$ |

- 24 The first DRUZHININ 87 limit is valid when $au_{A^0}/m_{A^0}~<~3 imes 10^{-13}~{
 m s/MeV}$ and $m_{A^0}~<$ 20 MeV.
- ²⁵ The second DRUZHININ 87 limit is valid when $au_{A^0}/m_{A^0}~<~5 imes 10^{-13}$ s/MeV and $m_{A^0}~<$ 20 MeV.
- ²⁶ The third DRUZHININ 87 limit is valid when $au_{A^0}/m_{A^0} > 7 imes 10^{-12}$ s/MeV and m_{Δ^0} < 200 MeV.
- 27 EDWARDS 82 looked for $J/\psi \to \gamma A^0$ decays by looking for events with a single γ [of energy $\sim 1/2$ the $J/\psi(1S)$ mass], plus nothing else in the detector. The limit is inconsistent with the axion interpretation of the FAISSNER 81B result.

A⁰ (Axion) Searches in Positronium Decays

Decay or transition of positronium. Limits are for branching ratio.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------|-----|-----------------------|----|------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| | | | | | fits, limits, etc. • • • |
| $<\!\!4.4\times10^{-5}$ | 90 | ²⁸ BADERT | 02 | CNTR | o-Ps $\rightarrow \gamma X_1 X_2$, $m_{X_1} + m_{X_2} \le$ |
| $<\!2\times10^{-4}$ | 90 | MAENO | 95 | CNTR | $o\text{-Ps} \to A^0 \gamma m_{A^0} = 850\text{-}1013 \text{ keV}$ |
| $< 3.0 \times 10^{-3}$ | 90 | ²⁹ A SA I | 94 | CNTR | $o-Ps \rightarrow A^0 \gamma m_{A0} = 30-500 \text{ keV}$ |
| $< 2.8 \times 10^{-5}$ | 90 | ³⁰ AKOPYAN | 91 | CNTR | $ \begin{array}{ccc} o\text{-Ps} & \rightarrow & A^0 \gamma \ (A^0 \rightarrow & \gamma \gamma), \\ m_{\Delta^0} & < 30 \text{ keV} \end{array} $ |
| $< 1.1 \times 10^{-6}$ | 90 | 31 ASAI | 91 | CNTR | o-Ps $\stackrel{A^{\circ}}{\rightarrow} A^{0} \gamma$, $m_{A^{0}} < 800 \text{ keV}$ |
| $< 3.8 \times 10^{-4}$ | 90 | GNINENKO | 90 | CNTR | o -Ps $\rightarrow A^0 \gamma$, $m_{A^0} < 30 \text{ keV}$ |
| $<$ (1-5) \times 10 ⁻⁴ | 95 | 32 TSUCHIAKI | 90 | | $o\text{-Ps} \to A^0 \gamma$, $m_{A^0} = 300900 \text{ keV}$ |
| $<$ 6.4 \times 10 ⁻⁵ | 90 | ³³ ORITO | 89 | | o -Ps $\rightarrow A^0 \gamma$, $m_{A0}^{\gamma} < 30 \text{ keV}$ |
| | | 34 AMALDI | 85 | | Ortho-positronium |
| | | ³⁵ CARBONI | 83 | CNTR | Ortho-positronium |

- 28 BADERTSCHER 02 looked for a three-body decay of ortho-positronium into a photon and two penetrating (neutral or milli-charged) particles.
- $^{
 m 29}$ The ASAI 94 limit is based on inclusive photon spectrum and is independent of A^0 decay
- 30 The AKOPYAN 91 limit applies for a short-lived 40 with $\tau_{A^0}<10^{-13}~m_{A^0}$ [keV] s. 31 ASAI 91 limit translates to $g_{A^0~e^+e^-}^2/4\pi<~1.1\times10^{-11}$ (90% CL) for $m_{A^0}<800$
- $^{-A^0}\rm e^{-\epsilon}e^{-\epsilon}$... $^{32}\rm The$ TSUCHIAKI 90 limit is based on inclusive photon spectrum and is independent of A⁰ decay modes.
- $^{A^0}$ decay modes. 33 ORITO 89 limit translates to $g_{A^0~ee}^2/4\pi < 6.2\times 10^{-10}.$ Somewhat more sensitive limits are obtained for larger m_{A^0} : $B<7.6\times 10^{-6}$ at 100 keV. 34 AMALDI 85 set limits ${\rm B}(A^0\gamma)$ / ${\rm B}(\gamma\gamma\gamma)<(1\text{--}5)\times 10^{-6}$ for $m_{A^0}=900\text{--}100$ keV
- which are about 1/10 of the CARBONI 83 limits.
- 35 CARBONI 83 looked for orthopositronium $\rightarrow A^0 \gamma$. Set limit for A^0 electron coupling squared, $g(eeA^0)^2/(4\pi) < 6. \times 10^{-10}$ –7. $\times 10^{-9}$ for m_{A^0} from 150–900 keV (CL = 99.7%). This is about 1/10 of the bound from g-2 experiments.

A⁰ (Axion) Search in Photoproduction

- ³⁶ BASSOMPIE... 95 $m_{A^0} = 1.8 \pm 0.2 \text{ MeV}$
- 36 BASSOMPIERRE 95 is an extension of BASSOMPIERRE 93. They looked for a peak in the invariant mass of e^+e^- pairs in the region $m_{e^+e^-}=1.8\pm0.2$ MeV. They obtained bounds on the production rate A^0 for $\tau(A^0)=10^{-1}8-10^{-9}$ sec. They also found an excess of events in the range $m_{e^+e^-}=2.1$ –3.5 MeV.

A⁰ (Axion) Production in Hadron Collisions

Limits are for $\sigma(A^0)$ / $\sigma(\pi^0)$.

CL% ÉVTS DO CUMENT ID TECN COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • • •

| VALUE | DO CUMENT ID | COMMENT |
|--------------------------------|-------------------------------|--------------------|
| • • • We do not use the follow | wing data for averages, fits, | limits, etc. • • • |
| | 36 DA CCOLADIE OF | 10 100111 |

| | | | ³⁸ ahmad | 97 | SPEC | e^+ production |
|--------------------------|----|----|--------------------------|------|-------|------------------------------------------------------------|
| | | | ³⁹ LEINBERGER | 97 | SPEC | $A^0 \rightarrow e^+e^-$ |
| | | | ⁴⁰ GANZ | 96 | SPEC | $A^0 \rightarrow e^+e^-$ |
| | | | ⁴¹ KAMEL | 96 | EMUL | 32 S emulsion, $A^0 \rightarrow$ |
| | | | | | | a+ a- |
| | | | ⁴² BLUEMLEIN | 92 | BDMP | $A^0 N_Z \rightarrow \ell^+ \ell^- N_Z$ |
| | | | 43 MEIJERDREES | 5 92 | SPEC | $\pi^- p \rightarrow nA^0, A^0 \rightarrow$ |
| | | | 44 | | | $A^0 \stackrel{e^+e^-}{\rightarrow e^+e^-}, 2\gamma$ |
| | | | 44 BLUEMLEIN | 91 | BDMP | |
| | | | ⁴⁵ FAISSNER | 89 | OSP K | Beam dump, |
| | | | ⁴⁶ DEBOER | 88 | RVUE | $A^0 \xrightarrow{A^0} \stackrel{e^+e^-}{\rightarrow} e^-$ |
| | | | 47 EL-NADI | 88 | EMUL | $A^0 \rightarrow e^+e^-$ |
| | | | 48 FAISSNER | 88 | OSPK | Beam dump, $A^0 \rightarrow 2\gamma$ |
| | | | 49 BADIER | 86 | | $A^0 \rightarrow e^+e^-$ |
| $<$ 2. $\times 10^{-11}$ | 90 | 0 | ⁵⁰ BERGSMA | 85 | | CERN beam dump |
| <1. × 10 ⁻¹³ | 90 | 0 | 50 BERGSMA | 85 | | CERN beam dump |
| (1. A 10 | 50 | 24 | ⁵¹ FAISSNER | 83 | OSPK | |
| | | | 52 FAISSNER | 83B | RVUE | LAMPF beam dump |
| | | | ⁵³ FRANK | 83B | RVUE | LAMPF beam dump |
| | | | ⁵⁴ HOFF MAN | 83 | CNTR | $\pi p \rightarrow nA^0$ |
| | | | | | | $(A^0 \rightarrow e^+e^-)$ |
| | | | ⁵⁵ FETSCHER | 82 | RVUE | See FAISSNER 81B |
| | | 12 | ⁵⁶ FAISSNER | 81 | OSPK | CERN PS $ u$ wideband |
| | | 15 | ⁵⁷ FAISSNER | 81B | OSP K | Beam dump, $A^0 \rightarrow 2\gamma$ |
| | | 8 | ⁵⁸ KIM | 81 | OSP K | 26 GeV $p N \rightarrow A^0 X$ |
| | | 0 | ⁵⁹ FAISSNER | 80 | OSP K | Beam dump, $A^0 \rightarrow e^+e^-$ |
| $<1. \times 10^{-8}$ | 90 | | ⁶⁰ JACQUES | 80 | HLBC | 28 GeV protons |
| <1. × 10 ⁻¹⁴ | 90 | | ⁶⁰ JACQUES | 80 | HLBC | Beam dump |
| • | | | ⁶¹ SOUKAS | 80 | CALO | 28 GeV p beam dump |
| | | | ⁶² BECHIS | 79 | CNTR | |
| $<1. \times 10^{-8}$ | 90 | | ⁶³ COTEUS | 79 | OSP K | Beam dump |
| $<1. \times 10^{-3}$ | 95 | | ⁶⁴ DISHAW | 79 | CALO | 400 GeV pp |
| $<1. \times 10^{-8}$ | 90 | | ALIBRAN | 78 | HYBR | Beam dump |
| $<6. \times 10^{-9}$ | 95 | | ASRATYAN | 78B | CALO | Beam dump |
| $<1.5 \times 10^{-8}$ | 90 | | 65 BELLOTTI | 78 | HLBC | Beam dump |
| $< 5.4 \times 10^{-14}$ | 90 | | 65 BELLOTTI | 78 | HLBC | $m_{A^0} = 1.5 \text{ MeV}$ |
| $< 4.1 \times 10^{-9}$ | 90 | | ⁶⁵ BELLOTTI | 78 | HLBC | $m_{A0}=1$ MeV |
| $<1. \times 10^{-8}$ | 90 | | ⁶⁶ BOSETTI | 78B | HYBR | Beam dump |
| | | | ⁶⁷ DONNELLY | 78 | | • |
| $< 0.5 \times 10^{-8}$ | 90 | | HA NSL | 78D | WIRE | Beam dump |
| | | | 68 14 65 1446 | | | • |

⁶⁸ MICELMAC... 78 69 VYSOTSKII 78 37 JAIN 07 claims evidence for $A^0 \rightarrow e^+ e^-$ produced in 207 Pb collision on nuclear emulsion (Ag/Br) for $\mathit{m}(A^0) = 7 \pm 1$ or 19 ± 1 MeV and $\tau(A^0) \leq 10^{-13}$ s.

38 AHMAD 97 reports a result of APEX Collaboration which studied positron production in $^{238}\mathrm{U} + ^{232}\mathrm{Ta}$ and $^{238}\mathrm{U} + ^{181}\mathrm{Ta}$ collisions, without requiring a coincident electron. No narrow lines were found for $250 < E_{
ho+} < 750 \ {\rm keV}.$

 39 LEINBERGER 97 (ORANGE Collaboration) at GSI looked for a narrow sum-energy e^+e^- -line at ~ 635 keV in 238 U $_+^{181}$ Ta collision. Limits on the production probability for a narrow sum-energy e^+e^- line are set. See their Table 2.

 40 GANZ 96 (EPos II Collaboration) has placed upper bounds on the production cross section of e^+e^- pairs from 238 U+ 181 Ta and 238 U+ 232 Th collisions at GSI. See Table 2 for limits both for back-to-back and isotropic configurations of $e^+\,e^-$ pairs. These limits rule out the existence of peaks in the $e^+\,e^-$ sum-energy distribution, reported by an

 41 KAMEL 96 looked for $^{e+}e^-$ pairs from the collision of 32 S (200 GeV/nucleon) and emulsion. No evidence of mass peaks is found in the region of sensitivity $m_{e\,e} > 2$ MeV.

emulsion. No evidence of mass peaks is round in the region of sensitivity $m_{ee} > 2$ knev. 42 BLUEMLEIN 92 is a proton beam dump experiment at Serpukhov with a secondary target to induce Bethe-Heitler production of e^+e^- or $\mu^+\mu^-$ from the produce A^0 . See Fig. 5 for the excluded region in m_{A^0} -x plane. For the standard axion, 0.3 < x < 25 is excluded at 95 % C.L. If combined with BLUEMLEIN 91, 0.008 < x < 32 is excluded. 43 MEIJERDREES 92 give $\Gamma(\pi^-p \to nA^0)$ -B($A^0 \to e^+e^-$)/ $\Gamma(\pi^-p \to all) < 10^-5$ (90% CL) for $m_{A^0} = 100$ MeV, $\tau_{A^0} = 10^{-11}$ - 10^{-23} sec. Limits ranging from 2.5×10^{-3} to 10^{-7} are given for $m_{A^0} = 25$ -136 MeV. 44 BLITEMIFIN 91 is a proton beam dump experiment at Serpukhov. No candidate event

44 BLUEMLEIN 91 is a proton beam dump experiment at Serpukhov. No candidate event for $A^0
ightarrow e^+e^-$, 2γ are found. Fig. 6 gives the excluded region in m_{A^0} -x plane (x = $aneta = v_2/v_1$). Standard axion is excluded for 0.2 $< m_{A^0} < 3.2\,{\rm MeV}$ for most

x>1, 0.2–11 MeV for most x<1. 45 FAISSNER 89 searched for $A^0\to e^+e^-$ in a proton beam dump experiment at SIN. No excess of events was observed over the background. A standard axion with mass $2m_e$ –20 MeV is excluded. Lower limit on f_{A^0} of $\simeq \bar{1}\,^{04}$ GeV is given for $m_{A^0}=2m_e$ -20 MeV.

 46 DEBOER 88 reanalyze EL-NADI 88 data and claim evidence for three distinct states with mass $\sim 1.1,\,\sim 2.1,\,$ and $\sim 9\,$ MeV, lifetimes $10^{-1}6^{-}10^{-15}\,$ s decaying to e^+e^- and note the similarity of the data with those of a cosmic-ray experiment by Bristol group (B.M. Anand, Proc. of the Royal Society of London, Section A A22 183 (1953)). For a criticism see PERKINS 89, who suggests that the events are compatible with π^0 Dalitz decay. DEBOER 89B is a reply which contests the criticism.

 47 EL-NADI 88 claim the existence of a neutral particle decaying into e^+e^- with mass 1.60 \pm 0.59 MeV, lifetime (0.15 \pm 0.01) \times 10⁻¹⁴s, which is produced in heavy ion interactions with emulsion nuclei at \sim 4 GeV/c/nucleon.

 $^{
m 48}$ FAISSNER 88 is a proton beam dump experiment at SIN. They found no candidate event for $A^0 \to \gamma \gamma$. A standard axion decaying to 2γ is excluded except for a region $x{\simeq}$ 1. Lower limit on f_{A^0} of 10^2 – 10^3 GeV is given for $m_{A^0}=0.1$ –1 MeV.

Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

- 49 BADIER 86 did not find long-lived A^0 in 300 GeV π^- Beam Dump Experiment that decays into e^+e^- in the mass range $m_{A^0}=(20$ –200) MeV, which excludes the A^0 decay constant $f(A^0)$ in the interval (60–600) GeV. See their figure 6 for excluded region on $f(A^0)$ - m_{A^0} plane.
- 50 BERGSMA 85 look for $A^0\to 2\gamma,\,e^+e^-,\,\mu^+\mu^-.$ First limit above is for $m_{A^0}=1$ MeV; second is for 200 MeV. See their figure 4 for excluded region on $f_{A^0} - m_{A^0}$ plane, where t_{A0} is A^0 decay constant. For Peccei-Quinn PECCEI 77 A^0 , m_{A0} <180 keV and au >0.037 s. (CL = 90%). For the axion of FAISSNER 81B at 250 keV, BERGSMA 85 expect 15 events but observe zero.
- 51 FAISSNER 83 observed 19 1- γ and 12 2- γ events where a background of 4.8 and 2.3 respectively is expected. A small-angle peak is observed even if iron wall is set in front of the decay region.
- 52 FAISSNER 838 extrapolate SIN γ signal to LAMPF ν experimental condition. Resulting 370 γ 's are not at variance with LAMPF upper limit of 450 γ 's. Derived from LAMPF limit that $\left[d\sigma(A^0)/\omega$ at $90^\circ\right]m_{A^0}/\tau_{A^0}<14\times10^{-35}$ cm² sr $^{-1}$ MeV ms $^{-1}$. See comment on FRANK 83B.
- 55 FRANK 838 stress the importance of LAMPF data bins with negative net signal. By statistical analysis say that LAMPF and SIN-AO are at variance when extrapolation by phase-space model is done. They find LAMPF upper limit is 248 not 450 γ 's. See comment on FAISSNER 83B.
- 54 HOFFMAN 83 set CL = 90% limit $d\sigma/dt$ B(e^+e^-) $< 3.5 \times 10^{-32}$ cm 2 /GeV 2 for 140 $< m_{A^0}$ <160 MeV. Limit assumes $\tau(A^0)$ $< 10^{-9}$ s.
- 55 FETSCHER 82 reanalyzes SIN beam-dump data of FAISSNER 81. Claims no evidence for axion since 2γ peak rate remarkably decreases if iron wall is set in front of the decay
- 56 FAISSNER 81 see excess μe events. Suggest axion interactions.
- 57 FAISSNER 81 B is SIN 590 MeV proton beam dump. Observed $^{14.5}$ \pm $^{5.0}$ events of $^{2}\gamma$ decay of long-lived neutral penetrating particle with $m_{2\gamma} \lesssim$ 1 MeV. Axion interpretation with η -A 0 mixing gives $m_{A^0}=250\pm25$ keV, $au_{(2\gamma)}=(7.3\pm3.7)\times10^{-3}\,\mathrm{s}$ from above rate. See critical remarks below in comments of FETSCHER 82, FAISSNER 83, FAISSNER 83B, FRANK 83B, and BERGSMA 85. Also see in the next subsection ALEK-
- SEEV 82B, CAVAIGNAC 83, and ANANEV 85. 58 KIM 81 analyzed 8 candidates for $A^0\to~2\gamma$ obtained by Aachen-Padova experiment at CERN with 26 GeV protons on Be. Estimated axion mass is about 300 keV and lifetime is $(0.86 \sim 5.6) \times 10^{-3} \, \mathrm{s}$ depending on models. Faissner (private communication), says axion production underestimated and mass overestimated. Correct value around 200
- 59 FAIS-SNER 80 is SIN beam dump experiment with 590 MeV protons looking for 40 \rightarrow $e^+\,e^-$ decay. Assuming $A^0/\pi^0=5.5\times 10^{-7}$, obtained decay rate limit $20/(A^0$ mass) MeV/s (CL = 90%), which is about 10^{-7} below theory and interpreted as upper limit to $m_{\Delta^0} < 2m_{\rho^-}$
- 60 JACQUES 80 is a BNL beam dump experiment. First limit above comes from nonobservation of excess neutral-current-type events $[\sigma(\text{production})\sigma(\text{interaction}) < 7. \times 10^{-68}]$ cm 4 , CL = 90%]. Second limit is from nonobservation of axion decays into 2γ 's or $e^+\,e^-$, and for axion mass a few MeV.
- 61 SOUKAS 80 at BNL observed no excess of neutral-current-type events in beam dump.
- $^{62}\mathrm{BECHIS}$ 79 looked for the axion production in low energy electron Bremsstrahlung and the subsequent decay into either 2γ or e^+e^- . No signal found. CL = 90% limits for model parameter(s) are given.
- ⁶³COTEUS 79 is a beam dump experiment at BNL.
- 64 DISHAW 79 is a calorimetric experiment and looks for low energy tail of energy distributions due to energy lost to weakly interacting particles.
- 65 BELLOTTI 78 first value comes from search for $A^0 \to e^+e^-$. Second value comes from search for $A^0 \to 2\gamma$, assuming mass $<\!2m_{e^-}$. For any mass satisfying this, limit is above value $\times ({\rm mass}^{-4})$. Third value uses data of PL 60B 401 and quotes $\sigma({\rm production})\sigma({\rm interaction}) < 10^{-67}~{\rm cm}^4$.
- $^{66}_{-}$ BOSETTI 78B quotes $\sigma({
 m production})\sigma({
 m interaction}) < 2. imes 10^{-67}~{
 m cm}^4$.
- 67 DONNELLY 78 examines data from reactor neutrino experiments of REINES 76 and GURR 74 as well as SLAC beam dump experiment. Evidence is negative.
- 68 MICELMACHER 78 finds no evidence of axion existence in reactor experiments of REINES 76 and GURR 74. (See reference under DONNELLY 78 below)
- 69 YYSOTSKII 78 derived lower limit for the axion mass 25 keV from luminosity of the sun and 200 keV from red supergiants.

A⁰ (Axion) Searches in Reactor Experiments

| VALUE | DO CUMENT ID | | I E CN | COMMENT |
|-------------------------------|--------------------------|----------|-----------|------------------------------------------|
| • • • We do not use the follo | owing data for averag | es, fits | , limits, | etc. • • • |
| | ⁷⁰ CHANG | 07 | | Primakoff or Compton |
| | | | | Reactor; $A^0 \rightarrow e^+ e^-$ |
| | ⁷² KETOV | | | Reactor, $A^0 	o \gamma \gamma$ |
| | ⁷³ косн | 86 | SPEC | Reactor; $A^0 \rightarrow \gamma \gamma$ |
| | ⁷⁴ DATAR | | | Light water reactor |
| | ⁷⁵ VUILLEUMIE | R 81 | CNTR | Reactor, $A^0 	o 2\gamma$ |

- $^{70}\,\mathrm{CHANG}$ 07 looked for monochromatic photons from Primakoff or Compton conversion of axions from the Kuo-Sheng reactor due to axion coupling to photon or electron, respectively. The search places model-independent limits on the products ${\it G_{A\gamma\gamma}G_{ANN}}$ and $G_{A\,e\,e}\,G_{A\,N\,N}$ for $m(A^0)$ less than the MeV range.
- 71 ALTMANN 95 looked for A0 decaying into $e^+\,e^-$ from the Bugey 5 nuclear reactor. They obtain an upper limit on the A^0 production rate of $\omega(A^{\bar{0}})/\omega(\gamma) \times B(A^0 \to 0)$ $e^+\,e^-)$ < 10^{-16} for $m_{A^0}=1.5$ MeV at 90% CL. The limit is weaker for heavier A^0 . In the case of a standard axion, this limit excludes a mass in the range $2m_e < m_{A^0} < 4.8$ MeV at 90% CL. See Fig. 5 of their paper for exclusion limits of axion-like resonances Z^0 in the (m_{X^0}, f_{X^0}) plane.
- 72 KETOV 86 searched for A^0 at the Rovno nuclear power plant. They found an upper limit on the A^0 production probability of 0.8 $[100~{
 m keV}/m_{A^0}]^6~ imes 10^{-6}$ per fission. In

- the standard axion model, this corresponds to $m_{A^0} >$ 150 keV. Not valid for $m_{A^0} \gtrsim$
- 1 MeV. 73 KOCH 86 searched for $A^0 \to \gamma \gamma$ at nuclear power reactor Biblis A. They found an upper limit on the A^0 production rate of $\omega(A^0)/\omega(\gamma(M1)) < 1.5 \times 10^{-10}$ (CL=95%). Standard axion with $m_{A^0} = 250$ keV gives 10^{-5} for the ratio. Not valid for $m_{A^0} > 1022$
- 74 DATAR 82 looked for $A^0 \rightarrow 2\gamma$ in neutron capture $(np \rightarrow dA^0)$ at Tarapur 500 MW reactor. Sensitive to sum of I=0 and I=1 amplitudes. With ZEHNDER 81 [(I=0)]- (I = 1)] result, assert nonexistence of standard A^0 .
- 75 VUILLEUMIER 81 is at Grenoble reactor. Set limit $m_{A^0}~<$ 280 keV.

A^0 (Axion) and Other Light Boson (X^0) Searches in Nuclear Transitions Limits are for branching ratio

| VALUE VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----|-------------------------|-------|------|--------------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not us | | | verag | | |
| $< 8.5 \times 10^{-6}$ | 90 | ⁷⁶ DERBIN | 02 | | 125mTe decay |
| < 0.5 × 10 | 50 | 77 DEBOER | 97 c | RVUE | M1 transitions |
| $< 5.5 \times 10^{-10}$ | 95 | ⁷⁸ TSUNODA | 95 | CNTR | 252 Cf fission, $A^0 \rightarrow e e$ |
| $< 1.2 \times 10^{-6}$ | 95 | ⁷⁹ MINOWA | 93 | CNTR | 139 _{La* →} 139 _{La A} 0 |
| $< 2 \times 10^{-4}$ | 90 | ⁸⁰ HICKS | 92 | CNTR | 35 S decay, $A^0 \rightarrow \gamma \gamma$ |
| $< 1.5 \times 10^{-9}$ | 95 | ⁸¹ ASANUMA | 90 | CNTR | ²⁴¹ Am decay |
| $<(0.4-10)\times10^{-3}$ | 95 | ⁸² DEBOER | 90 | CNTR | 8 Be $^{*} \rightarrow {}^{8}$ Be A^{0} . |
| $<$ (0.2–1) \times 10 ⁻³ | 90 | 83 BINI | 89 | CNTR | $16_{O^*}^{A^0} \rightarrow f_{OX}^{+e^-}$ |
| | | ⁸⁴ AVIGNONE | 88 | CNTR | $X^0 \rightarrow e^+e^-,$ $Cu^* \rightarrow CuA^0 (A^0 \rightarrow 2\gamma,$ $A^0e \rightarrow \gamma e, A^0Z \rightarrow \gamma Z)$ |
| $<1.5\times10^{-4}$ | 90 | ⁸⁵ DATAR | 88 | CNTR | ¹² C* → ¹² CA ⁰ , |
| $<$ 5 $\times 10^{-3}$ | 90 | ⁸⁶ DEB OER | 88c | CNTR | $16_{O^*} 16_{OX} 0$, |
| $< 3.4 \times 10^{-5}$ | 95 | ⁸⁷ DOEHNER | 88 | SPEC | ${}^{X^0}_{H^*, A^0} \xrightarrow{e^+ e^-} {}^{e^+ e^-}$ |
| $< 4 \times 10^{-4}$ | 95 | ⁸⁸ SAVAGE | 88 | CNTR | Nuclear decay (isovector) |
| $< 3 \times 10^{-3}$ | 95 | ⁸⁸ SAVAGE | 88 | CNTR | Nuclear decay (isoscalar) |
| $< 10.6 \times 10^{-2}$ | 90 | 89 HALLIN | 86 | SPEC | ⁶ Li isovector decay |
| <10.8 | 90 | 89 HALLIN | 86 | SPEC | ¹⁰ B isoscalar decays |
| < 2.2 | 90 | 89 HALLIN | 86 | SPEC | ¹⁴ N isoscalar decays |
| $<$ 4 \times 10 ⁻⁴ | 90 | 90 SAVAGE | 86B | CNTR | 14 _{N*} |
| | | 91 A NA NEV | 85 | CNTR | Li*, deut* $A^0 \rightarrow 2\gamma$ |
| | | ⁹² CAVAIGNAC | 83 | CNTR | 97 Nb*, deut* transition $A^0 \rightarrow 2\gamma$ |
| | | ⁹³ ALEKSEEV | 82B | CNTR | Li*, deut* transition $A^0 \rightarrow 2\gamma$ |
| | | ⁹⁴ LEHMANN | 82 | CNTR | $Cu^* \rightarrow CuA^0 (A^0 \rightarrow 2\gamma)$ |
| | | ⁹⁵ ZEHNDER | 82 | CNTR | Li*, Nb* decay, n-capt. |
| | | ⁹⁶ ZEHNDER | 81 | CNTR | $Ba^* \rightarrow BaA^0 (A^0 \rightarrow 2\gamma)$ |
| | | ⁹⁷ CALAPRICE | 79 | | Carbon |
| 76 | | | | | 1.05 |

- 76 DERBIN 02 looked for the axion emission in an M1 transition in ^{125}m Te decay. They looked for a possible presence of a shifted energy spectrum in gamma rays due to the undetected axion.
- $^{77}\mathsf{DEBOER}$ 97c reanalyzed the existent data on Nuclear M1 transitions and find that a 9 MeV boson decaying into e^+e^- would explain the excess of events with large opening angles. See also DEBOER 01 for follow-up experiments.
- ⁷⁸TSUNODA 95 looked for axion emission when ²⁵²Cf undergoes a spontaneous fission, with the axion decaying into $e^+\,e^-$. The bound is for $m_{A^0} =$ 40 MeV. It improves to 2.5×10^{-5} for $m_{\ensuremath{A^0}}\!=\!200$ MeV.
- 79 MINOWA 93 studied chain process, 139 Ce \rightarrow 139 La* by electron capture and M1 transition of 139 La* to the ground state. It does not assume decay modes of A^0 . The bound applies for m_{A^0} < 166 keV.
- $^{80}\,\mathrm{HICKS}$ 92 bound is applicable for $\tau_{X^0}~<\mathrm{4}\times\mathrm{10}^{-11}~\mathrm{sec.}$
- 81 The ASANUMA 90 limit is for the branching fraction of X^0 emission per $^{241}{\rm Am}\,\alpha$ decay and valid for $\tau_{X^0}~<~3\times 10^{-11}~{\rm s}.$
- ⁸² The DEBOER 90 limit is for the branching ratio $^8\mathrm{Be}^*$ (18.15 MeV, $^{1+}$) \to $^8\mathrm{Be}A^0$, $A^0
 ightarrow e^+ \, e^-$ for the mass range $m_{A^0} =$ 4–15 MeV.
- ⁸³ The BINI 89 limit is for the branching fraction of 16 O*(6.05 MeV, 0⁺) \rightarrow 16 O X^0 , $X^0
 ightarrow e^+e^-$ for $m_{X}=1.5$ –3.1 MeV. $au_{X^0}\lesssim 10^{-11}$ s is assumed. The spin-parity
- of X is restricted to 0^+ or 1^- .

 84 AVIGNONE 88 looked for the 1115 keV transition $C^* \rightarrow CuA^0$, either from $A^0 \rightarrow CuA^0$. 2γ in-flight decay or from the secondary A^0 interactions by Compton and by Primakoff processes. Limits for axion parameters are obtained for $m_{A^0} < 1.1$ MeV.
- 85 DATAR 88 rule out light pseudoscalar particle emission through its decay $A^0 \rightarrow e^+e^-$ in the mass range 1.02–2.5 MeV and lifetime range 10^{-13} – 10^{-8} s. The above limit is for $\tau=5\times10^{-13}$ s and m=1.7 MeV; see the paper for the τ -m dependence of the
- ⁸⁶The limit is for the branching fraction of $^{16}{\rm O}^*(6.05~{\rm MeV},\,0^+) \rightarrow ^{16}{\rm O}\,X^0$, $X^0 \rightarrow$ $e^+\,e^-$ against internal pair conversion for $m_{\chi^0}=1.7$ MeV and $au_{\chi^0}~<~10^{-11}\,\mathrm{s}.$ Similar limits are obtained for $m_{\chi^0}=1.3$ –3.2 MeV. The spin parity of χ^0 must be either 0+ or 1-. The limit at 1.7 MeV is translated into a limit for the X^0 -nucleon coupling constant: $g_{X^0NN}^2/4\pi < 2.3 \times 10^{-9}$.
- 87 The DOEHNER 88 limit is for $m_{A^0}=1.7\,$ MeV, $au(A^0)<10^{-10}\,$ s. Limits less than
- 10^{-4} are obtained for $m_{A^0}=1.2^{-2}.2$ MeV. 88 SAVAGE 88 looked for A^0 that decays into $e^+\,e^-$ in the decay of the 9.17 MeV J^P 2^+ state in 14 N, 17.64 MeV state $J^P=1^+$ in $^8{\rm Be},$ and the 18.15 MeV state J^P

Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

- 1^+ in $^8{
 m Be}$. This experiment constrains the isovector coupling of A^0 to hadrons, if m_{A^0} = (1.1 $\,\rightarrow\,$ 2.2) MeV and the isoscalar coupling of ${\it A}^{\,0}$ to hadrons, if ${\it m}_{{\it A}^{\,0}}$ = (1.1 $\,\rightarrow\,$ 2.6) MeV. Both limits are valid only if $au(A^0) \lesssim 1 imes 10^{-11}\,$ s.
- 89 Limits are for $\Gamma(A^0(1.8~{
 m MeV}))/\Gamma(\pi{
 m M1});$ i.e., for 1.8 MeV axion emission normalized to the rate for internal emission of $e^+\,e^-$ pairs. Valid for $au_{A^0}~<~2 imes 10^{-11} {
 m s.}~^{6}{
 m Li}$ isovector decay data strongly disfavor PECCEI 86 model I, whereas the $^{10}\mathrm{B}$ and $^{14}\mathrm{N}$
- isoscalar decay data strongly reject PECCEI 86 model II and III. 90 SAVAGE 86B looked for A^0 that decays into $e^+\,e^-$ in the decay of the 9.17 MeV $J^P=$ 2^+ state in 14 N. Limit on the branching fraction is valid if $\tau_{A^0}\lesssim 1.\times 10^{-11}{\rm s}$ for m_{A^0} = (1.1-1.7) MeV. This experiment constrains the iso-vector coupling of A^0 to hadrons.
- 91 A NA NEV 85 with IBR-2 pulsed reactor exclude standard 40 at CL = 95% masses below 470 keV (Li* decay) and below $2m_{\it e}$ for deuteron* decay.
- 92 CAVAIGNAC 83 at Bugey reactor exclude axion at any $m_{^{97}}{
 m Nb^*decay}$ and axion with m_{A^0} between 275 and 288 keV (deuteron* decay).
- 93 ALEKSEEV 82 with IBR-2 pulsed reactor exclude standard 0 at CL = 95% mass-ranges m_{A^0} <400 keV (Li* decay) and 330 keV < m_{A^0} <2.2 MeV. (deuteron* decay).
- ⁹⁴ LEHMANN 82 obtained $A^0 \rightarrow 2\gamma$ rate $< 6.2 \times 10^{-5} / \text{s}$ (CL = 95%) excluding m_{A^0}
- 95 between 100 and 1000 keV. 95 ZEHNDER 82 used Gosgen 2.8GW light-water reactor to check A^0 production. No 2γ peak in Li*, Nb* decay (both single p transition) nor in n capture (combined with previous Ba* negative result) rules out standard A^0 . Set limit $m_{\Delta 0} <$ 60 keV for any
- 96 ZEHNDER 81 looked for Ba* \rightarrow A^0 Ba transition with A^0 \rightarrow 2γ . Obtained 2γ coincidence rate $<2.2\times10^{-5}/\mathrm{s}$ (CL = 95%) excluding m_{A^0} >160 keV (or 200 keV in the constant of the depending on Higgs mixing). However, see BARROSO 81.
- 97 CALAPRICE 79 saw no axion emission from excited states of carbon. Sensitive to axion mass between 1 and 15 MeV.

A⁰ (Axion) Limits from Its Electron Coupling

| Limits are for $\tau(A^0 \rightarrow$ | $e^{+}e^{-}$) | | | | |
|------------------------------------------------|----------------|------------------------|--------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (s) | CL% | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the follow | wing da | ta for averages, fits, | limits | s, etc. • | • • |
| none $4 \times 10^{-16} - 4.5 \times 10^{-12}$ | 90 | ⁹⁸ BROSS | 91 | BDMP | $e \stackrel{N}{\longrightarrow} e \stackrel{A}{\longrightarrow} N $ $(\stackrel{A}{A}^0 \rightarrow e e)$ |
| | | ⁹⁹ GUO | 90 | BDMP | $e \stackrel{N}{\longrightarrow} e \stackrel{A}{\longrightarrow} N $ $(\stackrel{A}{\longrightarrow} e \stackrel{e}{\rightarrow} e)$ |
| | | ¹⁰⁰ BJORKEN | 88 | | $A \rightarrow e^+e^-$ or |
| | | 101 BLINOV | 88 | MD1 | $e \stackrel{2}{\leftarrow} \stackrel{7}{\rightarrow} e \stackrel{2}{\rightarrow} A^{0}$ $(\stackrel{1}{A^{0}} \stackrel{2}{\rightarrow} e \stackrel{2}{\rightarrow} e)$ |
| none $1\times10^{-14}1\times10^{-10}$ | 90 | ¹⁰² RIORDAN | 87 | BDMP | $e \stackrel{(A \rightarrow e e)}{\longrightarrow} e \stackrel{A}{\longrightarrow} N $ $(\stackrel{(A^0 \rightarrow e e)}{\longrightarrow} e e)$ |
| none $1\times10^{-14}1\times10^{-11}$ | 90 | ¹⁰³ BROWN | 86 | BDMP | $e \stackrel{(A \rightarrow e e)}{\longrightarrow} e \stackrel{A}{\longrightarrow} N $ $(\stackrel{(A^0 \rightarrow e e)}{\longrightarrow} e e)$ |
| none $6\times10^{-14}9\times10^{-11}$ | 95 | ¹⁰⁴ DAVIER | 86 | | $e \stackrel{(A^{1} \rightarrow e e)}{\rightarrow} e \stackrel{A^{0}}{\rightarrow} N $ $\stackrel{(A^{0} \rightarrow e e)}{\rightarrow} e e)$ |
| none $3\times10^{-13}1\times10^{-7}$ | 90 | ¹⁰⁵ KONAKA | 86 | BDMP | $e N \rightarrow e A^0 N$ |

- $(A^0 \rightarrow e e)$ 98 The listed BROSS 91 limit is for $m_{A^0}\,=\,1.14$ MeV. B($A^0\,\rightarrow\,\,e^+\,e^-)\,=1$ assumed. Excluded domain in the au_{A^0} - m_{A^0} plane extends up to $m_{A^0} \approx$ 7 MeV (see Fig. 5). Combining with electron g-2 constraint, axions coupling only to e^+e^- ruled out for $m_{A^0} <$ 4.8 MeV (90% CL).
- $^{99}\,{}^{60}{}^{00}$ 90 use the same apparatus as BROWN 86 and improve the previous limit in the shorter lifetime region. Combined with g-2 constraint, axions coupling only to e^+e^- are ruled out for m_{A^0} < 2.7 MeV (90% CL).
- $^{A^{-}}$ BJORKEN 88 reports limits on axion parameters ($f_{A},\,m_{A},\,\tau_{A}$) for $m_{A^{0}}\,<$ 200 MeV from electron beam-dump experiment with production via Primakoff photoproduction, bremsstrahlung from electrons, and resonant annihilation of positrons on atomic elec-
- $101\,\mathrm{BLINOV}$ 88 assume zero spin, $m=1.8\,\mathrm{MeV}$ and lifetime $<~5\times10^{-12}\,\mathrm{s}$ and find
- $\Gamma(A^0\to\gamma\gamma) {\rm B}(A^0\to e^+e^-) < 2~{\rm eV}~({\rm CL=90\%}).$ 102 Assumes $A^0\gamma\gamma$ coupling is small and hence Primakoff production is small. Their figure 2 shows limits on axions for $m_{A^0}<15~{\rm MeV}.$
- $^{103}\mathrm{Uses}$ electrons in hadronic showers from an incident 800 GeV proton beam. Limits for $m_{A^0} <$ 15 MeV are shown in their figure 3.
- $^{104}\,m_{A^0}^{A}=1.8$ MeV assumed. The excluded domain in the $\tau_{A^0}-m_{A^0}$ plane extends up to $m_{A^0}^{\prime\prime} \approx$ 14 MeV, see their figure 4.
- 105 The limits are obtained from their figure 3. Also given is the limit on the ${\it A^0}\,\gamma\gamma - {\it A^0}\,e^+\,e^-$ coupling plane by assuming Primakoff production.

Search for A⁰ (Axion) Resonance in Bhabha Scattering

The limit is for $\Gamma(A^0)[B(A^0 \rightarrow e^+e^-)]^2$

| <i>VALUE</i> (10 ⁻³ eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|-----------|--------------------------|----------|---------|------------------------------------------|
| • • • We do not use | he follow | ing data for average | s, fits, | limits, | etc. • • • |
| < 1.3 | 97 | ¹⁰⁶ HALLIN | 92 | CNTR | $m_{A^0} = 1.75 - 1.88 \text{ MeV}$ |
| none 0.0016-0.47 | 90 | ¹⁰⁷ HENDERSON | 92c | CNTR | $m_{\Delta^0} = 1.5 - 1.86 \text{ MeV}$ |
| < 2.0 | 90 | ¹⁰⁸ WU | 92 | CNTR | $m_{\Delta 0} = 1.56 - 1.86 \text{ MeV}$ |
| < 0.013 | 95 | TSERTOS | 91 | CNTR | $m_{\Delta^0} = 1.832 \text{ MeV}$ |
| none 0.19-3.3 | 95 | ¹⁰⁹ WIDMANN | 91 | CNTR | $m_{A^0} = 1.78 - 1.92 \text{ MeV}$ |
| < 5 | 97 | BAUER | | | $m_{A^0} = 1.832 \text{ MeV}$ |
| none 0.09-1.5 | 95 | ¹¹⁰ JUDGE | 90 | CNTR | $m_{A^0} = 1.832 \text{ MeV},$ |
| | | | | | elastic |

| | | | 111 | | | |
|------|------|----|------------------------|----|------|------------------------------------------|
| < | 1.9 | 97 | ¹¹¹ TSERTOS | 89 | CNTR | $m_{\Delta 0} = 1.82 \text{ MeV}$ |
| <(10 | -40) | 97 | ¹¹¹ TSERTOS | 89 | CNTR | $m_{\Delta^0} = 1.51 - 1.65 \text{ MeV}$ |
| <(1- | 2.5) | 97 | ¹¹¹ TSERTOS | 89 | CNTR | $m_{A^0} = 1.80 - 1.86 \text{ MeV}$ |
| < : | 31 | 95 | LORENZ | 88 | CNTR | $m_{A^0} = 1.646 \text{ MeV}$ |
| < | 94 | 95 | LORENZ | 88 | CNTR | $m_{A^0} = 1.726 \text{ MeV}$ |
| < : | 23 | 95 | LORENZ | 88 | CNTR | $m_{A^0} = 1.782 \text{ MeV}$ |
| < | 19 | 95 | LORENZ | 88 | CNTR | $m_{A^0} = 1.837 \text{ MeV}$ |
| < | 3.8 | 97 | ¹¹² TSERTOS | 88 | CNTR | $m_{A^0} = 1.832 \text{ MeV}$ |
| | | | 113 VANKLINKEN | 88 | CNTR | |
| | | | ¹¹⁴ MAIER | 87 | CNTR | |
| <25 | 00 | 90 | MILLS | 87 | CNTR | $m_{\Delta^0}=1.8~{ m MeV}$ |
| | | | 115 VONWIMMER | 87 | CNTR | ,, |

 106 HALLIN 92 quote limits on lifetime, 8×10^{-14} – 5×10^{-13} sec depending on mass, assuming B(A $^0
ightarrow e^+e^-) = 100\%$. They say that TSERTOS 91 overstated their sensitivity by a factor of 3.

 107 HENDERSON 92c exclude axion with lifetime $\tau_{A^0}{=}1.4\times10^{-12}$ – 4.0 $\times10^{-10}$ s, assuming $B(A^0)$ \rightarrow $e^+e^-)=100\%$. HENDERSON 92c also exclude a vector boson with $r = 1.4 \times 10^{-12} - 6.0 \times 10^{-10} \text{ s.}$

 108 WU 92 quote limits on lifetime $> 3.3 \times 10^{-13}$ s assuming B(A⁰ $\rightarrow e^+e^-$)=100%. They say that TSERTOS 89 overestimate the limit by a factor of $\pi/2$. WU 92 also quote a bound for vector boson, $\tau > 8.2 \times 10^{-13} \, \mathrm{s}$.

 109 WIDMANN 91 bound applies exclusively to the case B($A^0
ightarrow e^+ \, e^-$)=1, since the detection efficiency varies substantially as $\Gamma(A^0)_{total}$ changes. See their Fig. 6.

 110 JUDGE 90 excludes an elastic pseudoscalar $e^+\,e^-$ resonance for 4.5 $imes 10^{-13}$ s $<~ au(A^0)$ $<~7.5 imes10^{-12}\,\mathrm{s}$ (95% CL) at $m_{A^0}=1.832$ MeV. Comparable limits can be set for $m_{A^0} = 1.776 - 1.856 \text{ MeV}.$

- 111 See also TSERTOS 88B in references
- 112 The upper limit listed in TSERTOS 88 is too large by a factor of 4. See TSERTOS 88B,
- 113 VA NKLINKEN 88 looked for relatively long-lived resonance ($au=10^{-10}$ – 10^{-12} s). The
- sensitivity is not sufficient to exclude such a narrow resonance. 114 MAIER 87 obtained limits $R\Gamma\lesssim 60$ eV (100 eV) at $m_{A^0}\simeq 1.64$ MeV (1.83 MeV) for energy resolution $\Delta E_{\rm CM}\simeq 3$ keV, where R is the resonance cross section normalized to that of Bhabha scattering, and $\Gamma=\Gamma_{e\,e}^2/\Gamma_{total}.$ For a discussion implying that $\Delta E_{
 m cm} \simeq 10$ keV, see TSERTOS 89.
- 115 VONWIMMERSPERG 87 measured Bhabha scattering for $E_{\rm CM}=1.37$ –1.86 MeV and found a possible peak at 1.73 with $\int \sigma dE_{\rm CM}=14.5\pm6.8$ keV-b. For a comment and a reply, see VANKLINKEN 88B and VONWIMMERSPERG 88. Also see CONNELL 88.

Search for A^0 (Axion) Resonance in $e^+e^- \rightarrow \gamma\gamma$

The limit is for $\Gamma(A^0 \rightarrow e^+ e^-) \cdot \Gamma(A^0 \rightarrow \gamma \gamma) / \Gamma_{\text{total}}$

| | | | | ora. | |
|-----------------------------|------------|------------------------|----------|-----------|------------------------------------------|
| VALUE (10 ⁻³ eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use | the follow | ing data for averag | es, fits | , limits, | etc. • • • |
| < 0.18 | 95 | VO | 94 | CNTR | $m_{\Delta0}\!=\!1.1~{\rm MeV}$ |
| < 1.5 | 95 | VO | 94 | CNTR | $m_{\Delta^0} = 1.4 \text{ MeV}$ |
| <12 | 95 | VO | 94 | CNTR | $m_{\Delta^0} = 1.7 \text{ MeV}$ |
| < 6.6 | 95 | ¹¹⁶ TRZASKA | 91 | CNTR | $m_{A^0} = 1.8 \text{ MeV}$ |
| < 4.4 | 95 | WIDMANN | 91 | CNTR | $m_{\Delta 0} = 1.78 - 1.92 \text{ MeV}$ |
| | | ¹¹⁷ FOX | 89 | CNTR | /· |
| < 0.11 | 95 | ¹¹⁸ MINOWA | 89 | CNTR | $m_{A^0} = 1.062 \text{ MeV}$ |
| <33 | 97 | CONNELL | 88 | CNTR | $m_{A^0} = 1.580 \text{ MeV}$ |
| <42 | 97 | CONNELL | 88 | CNTR | $m_{A^0} = 1.642 \text{ MeV}$ |
| <73 | 97 | CONNELL | 88 | CNTR | $m_{A^0} = 1.782 \text{ MeV}$ |
| < 79 | 97 | CONNELL | 88 | CNTR | $m_{A^0} = 1.832 \text{ MeV}$ |
| 116 | | | | | |

- 116 TRZASKA 91 also give limits in the range $(6.6-30) \times 10^{-3}$ eV (95%CL) for $m_{A0} =$
- 1.6-2.0 MeV. 117 FOX 89 measured positron annihilation with an electron in the source material into two photons and found no signal at 1.062 MeV ($< 9 \times 10^{-5}$ of two-photon annihilation at
- $^{118}\,\mathrm{Similar}$ limits are obtained for $m_{A^0}=1.045\text{--}1.085\,$ MeV.

Search for X^0 (Light Boson) Resonance in $e^+e^- \rightarrow \gamma\gamma\gamma$

The limit is for $\Gamma(X^0 \to e^+ e^-) \cdot \Gamma(X^0 \to \gamma \gamma \gamma) / \Gamma_{total}$. C invariance forbids spin-0 X^0 coupling to both $e^+\,e^-$ and $\gamma\gamma\gamma$.

| VALUE (10 ⁻³ eV) | CL% | DO CUMENT IE |) | TECN | COMMENT |
|-----------------------------|-----------------|------------------------|------------|---------|------------------------------------------|
| • • • We do not u | ise the followi | ng data for averag | ges, fits, | limits, | etc. • • • |
| < 0.2 | 95 | ¹¹⁹ VO | 94 | CNTR | $m_{\chi 0} = 1.1 - 1.9 \text{ MeV}$ |
| < 1.0 | 95 | 120 VO | | | $m_{X^0}^{\lambda^2} = 1.1 \text{ MeV}$ |
| < 2.5 | 95 | ¹²⁰ VO | | | $m_{\chi^0}^{\Lambda} = 1.4 \text{ MeV}$ |
| <120 | 95 | ¹²⁰ VO | | | $m_{X^0}^{\Lambda} = 1.7 \text{ MeV}$ |
| < 3.8 | 95 | ¹²¹ SKALSEY | | | $m_{\chi^0}^{\Lambda} = 1.5 \text{ MeV}$ |

 $^{119}{
m VO}$ 94 looked for ${\it X}^0
ightarrow \gamma \gamma \gamma$ decaying at rest. The precise limits depend on ${\it m}_{{\it X}^0}$. See

- $120\,\mathrm{VO}$ 94 looked for $X^0 \to \gamma\gamma\gamma$ decaying in flight.
- $^{121}\,\mathrm{SKALSEY}$ 92 also give limits 4.3 for $m_{\chi^0}=1.54$ and 7.5 for 1.64 MeV. The spin of $\mathrm{\it X}^0$ is assumed to be one.

Gauge & Higgs Boson Particle Listings

Axions (A^0) and Other Very Light Bosons

Light Boson (X^0) Search in Nonresonant e^+e^- Annihilation at Rest Limits are for the ratio of $n_{\alpha} + x_{\alpha}^{0}$ production relative to

| Elinits are for the ratio of high X production relative to 11. | | | | | | |
|----------------------------------------------------------------|------------|------------------------|-----------|---------------------------------------------------------|--|--|
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN COMMENT | | |
| • • • We do not use | the follow | ving data for averag | es, fits, | , limits, etc. • • • | | |
| < 4.2 | 90 | ¹²² MITSUI | 96 | CNTR γX^0 | | |
| < 4 | 68 | ¹²³ SKALSEY | 95 | CNTR γX^0 | | |
| <40 | 68 | ¹²⁴ SKALSEY | 95 | RVUE γX^0 | | |
| < 0.18 | 90 | ¹²⁵ ADACHI | | CNTR $\gamma \gamma X^0, X^0 \rightarrow \gamma \gamma$ | | |
| < 0.26 | 90 | ¹²⁶ ADACHI | 94 | CNTR $\gamma \gamma X^0, X^0 \rightarrow \gamma \gamma$ | | |
| < 0.33 | 90 | ¹²⁷ ADACHI | 94 | CNTR $\gamma X^0, X^0 \rightarrow \gamma \gamma \gamma$ | | |

- $^{122}\,\mathrm{MITSUI}$ 96 looked for a monochromatic $\gamma.$ The bound applies for a vector X^0 with C=-1 and m_{χ^0} <200 keV. They derive an upper bound on eeX 0 coupling and hence on the branching ratio B(o-Ps $\rightarrow \gamma \gamma X^0$) < 6.2 × 10⁻⁶. The bounds weaken for heavier
- χ^0 . 123 SKALSEY 95 looked for a monochromatic γ without an accompanying γ in e^+e^- annihilation. The bound applies for scalar and vector χ^0 with ${\it C}=-1$ and $m_{\chi^0}=$
- 124 SKALSEY 95 reinterpreted the bound on γA^0 decay of o-Ps by ASAI 91 where 3% of delayed annihilations are not from 3S_1 states. The bound applies for scalar and vector X^0 with C=-1 and $m_{X^0}=0$ -800 keV.
- 125 ADACHI 94 looked for a peak in the $\gamma\gamma$ invariant mass distribution in $\gamma\gamma\gamma\gamma$ production from $e^+\,e^-$ annihilation. The bound applies for $m_{\chi^0}=$ 70–800 keV.
- 126 ADACHI 94 looked for a peak in the missing-mass mass distribution in $\gamma\gamma$ channel, using $\gamma\gamma\gamma\gamma$ production from e^+e^- annihilation. The bound applies for $m_{\chi0}^{}$ $\,$ <800 keV.
- 127 ADACHI 94 looked for a peak in the missing mass distribution in $\gamma\gamma\gamma$ channel, using $\gamma\gamma\gamma\gamma$ production from $e^+\,e^-$ annihilation. The bound applies for $m_{\chi0}=$ 200–900

Searches for Goldstone Bosons (X^0)

(Including Horizontal Bosons and Majorons.) Limits are for branching ratios. DO CUMENT ID TECN COMMENT

| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | | |
|-------------------------------------------------------------------------------|----|----------------------------|-----|------|---------------------------------------------------------------------|--|--|--|
| | | ¹²⁸ LESSA | 07 | RVUE | Meson, ℓ decays to Majoron | | | |
| | | ¹²⁹ DIAZ | 98 | THEO | $H^0 \rightarrow X^0 X^0$, $A^0 \rightarrow X^0 X^0 X^0$, Majoron | | | |
| | | ¹³⁰ BOBRAKOV | 91 | | Electron quasi-magnetic in- | | | |
| $< 3.3 \times 10^{-2}$ | 95 | ¹³¹ ALBRECHT | 90E | ARG | teraction $\tau \to \mu X^0$. Familion | | | |
| $<1.8 \times 10^{-2}$ | 95 | ¹³¹ ALBRECHT | 90E | ARG | $	au ightarrow e X^0$. Familon | | | |
| $< 6.4 \times 10^{-9}$ | 90 | ¹³² ATIYA | 90 | B787 | $K^+ ightarrow \pi^+ X^0$. Familon | | | |
| $<1.1 \times 10^{-9}$ | 90 | 133 BOLT ON | 88 | CBOX | $\mu^+ \rightarrow e^+ \gamma X^0$. Familon | | | |
| | | ¹³⁴ CHANDA | 88 | ASTR | Sun, Majoron | | | |
| | | ¹³⁵ СНОІ | 88 | ASTR | Majoron, SN 1987A | | | |
| $< 5 \times 10^{-6}$ | 90 | ¹³⁶ PICCIOTTO | 88 | CNTR | $\pi \to e \nu X^0$, Majoron | | | |
| $< 1.3 \times 10^{-9}$ | 90 | ¹³⁷ GOLDMAN | 87 | CNTR | $\mu \rightarrow e \gamma X^0$. Familon | | | |
| $< 3 \times 10^{-4}$ | 90 | ¹³⁸ BRYMAN | 86B | RVUE | $\mu \rightarrow e X^0$. Familon | | | |
| $< 1 \times 10^{-10}$ | 90 | ¹³⁹ EICHLER | 86 | SPEC | $\mu^+ ightarrow e^+ X^0$. Familon | | | |
| $< 2.6 \times 10^{-6}$ | 90 | ¹⁴⁰ JODIDIO | 86 | SPEC | $\mu^+ ightarrow e^+ X^0$. Familon | | | |
| | | ¹⁴¹ BALTRUSAIT. | 85 | MRK3 | $\tau \to \ell X^0$. Familon | | | |
| | | ¹⁴² DICUS | 83 | COSM | $\nu(hvy) \rightarrow \nu(light) X^0$ | | | |
| | | | | | | | | |

- ¹²⁸LESSA 07 consider decays of the form Meson $\rightarrow \ell \nu$ Majoron and $\ell \rightarrow \ell' \nu \overline{\nu}$ Majoron and use existing data to derive limits on the neutrino-Majoron Yukawa couplings $g_{lphaeta}$ $(\alpha,\beta\!=\!e,\mu, au)$. Their best limits are $|g_{e\,\alpha}|^2<5.5 imes10^{-6}$, $|g_{\mu\,\alpha}|^2<4.5 imes10^{-5}$, $|g_{\tau\alpha}|^2 < 5.5 \times 10^{-2}$ at CL = 90%
- 129 DIAZ 98 studied models of spontaneously broken lepton number with both singlet and triplet Higgses. They obtain limits on the parameter space from invisible decay $Z \rightarrow H^0A^0 \rightarrow X^0X^0X^0X^0X^0$ and $e^+e^- \rightarrow ZH^0$ with $H^0 \rightarrow X^0X^0$.
- 130 BOBRAKOV 91 searched for anomalous magnetic interactions between polarized electrons expected from the exchange of a massless pseudoscalar boson (arion). A limit $x_e^2 < 2 imes 10^{-4}$ (95%CL) is found for the effective anomalous magneton parametrized as $x_e (G_F / 8\pi \sqrt{2})^{1/2}$.
- 131 ALBRECHT 90E limits are for B($au o \ell X^0$)/B($au o \ell
 u \overline{
 u}$). Valid for $m_{\chi^0} < 100$
- MeV. The limits rise to 7.1% (for μ), 5.0% (for e) for $m_{\chi^0}=$ 500 MeV. 132 ATIYA 90 limit is for $m_{\chi^0}=$ 0. The limit B $<1\times10^{-8}$ holds for $m_{\chi^0}<$ 95 MeV. For the reduction of the limit due to finite lifetime of X^0 , see their Fig. 3
- $133\,\mathrm{BOLTON}$ 88 limit corresponds to $F>3.1 imes10^9$ GeV, which does not depend on the chirality property of the coupling.
- 134 CHANDA 88 find v_T < 10 MeV for the weak-triplet Higgs vacuum expectation value in Gelmini-Roncadelli model, and $\nu_S~>~5.8\times 10^6$ GeV in the singlet Majoron model.
- 135 CHOI 88 used the observed neutrino flux from the supernova SN1987A to exclude the neutrino Majoron Yukawa coupling h in the range 2×10^{-5} $< h < 3\times 10^{-4}$ for the interaction $L_{
 m int}=rac{1}{2}i\hbar\overline{\psi}^c_
 u\gamma_5\psi_
 u\phi_{
 m X}$. For several families of neutrinos, the limit applies for
- $^{136}\,\mathrm{PIC}\dot{\mathrm{CIOTTO}}$ 88 limit applies when $m_{\chi^0}~<$ 55 MeV and $\tau_{\chi^0}~>$ 2ns, and it decreases to 4 $\times\,10^{-7}$ at $m_{\chi\,0}\,=\,125\,$ MeV, beyond which no limit is obtained.
- 137 GOLD MAN 87 limit corresponds to $F > 2.9 \times 10^9$ GeV for the family symmetry breaking scale from the Lagrangian $L_{\rm int}=(1/F)\overline{\psi}_{\mu}\gamma^{\mu}~(a+b\gamma_5)~\psi_e\partial_{\mu}\phi_{X^0}$ with $a^2+b^2=1$. This is not as sensitive as the limit $F>9.9 imes10^9$ GeV derived from the search for $\mu^+ o$ $e^+\,X^0$ by JODIDIO 86, but does not depend on the chirality property of the coupling.

- 138 Limits are for $\Gamma(\mu \to e X^0)/\Gamma(\mu \to e \nu \overline{\nu})$. Valid when $m_{X^0}=$ 0-93.4, 98.1-103.5
- MeV. 139 EICHLER 86 looked for $\mu^+ \to e^+ X^0$ followed by $X^0 \to e^+ e^-$. Limits on the branching fraction depend on the mass and and lifetime of X^0 . The quoted limits are valid when $\tau_{X^0} \lesssim 3. \times 10^{-10} \, \mathrm{s}$ if the decays are kinematically allowed.
- 140 JODIDIO 86 corresponds to $F>9.9\times10^9$ GeV for the family symmetry breaking scale with the parity-conserving effective Lagrangian $L_{\rm int}=(1/{\it F})~\overline{\psi}_{\mu}\gamma^{\mu}\psi_{e}\partial^{\mu}\phi_{X^0}$
- 141 BALTRUSAITIS 85 search for light Goldstone boson(X^0) of broken U(1). CL = 95% limits are B($au o \mu^+ X^0$)/B($au o \mu^+ \nu
 u$) <0.125 and B($au o e^+ X^0$)/B($au o e^+ \nu
 u$) <0.04. Inferred limit for the symmetry breaking scale is $m ext{>} 3000$ TeV.
- 142 The primordial heavy neutrino must decay into ν and familon, f_A , early so that the red-shifted decay products are below critical density, see their table. In addition, $K \rightarrow 5$ πf_A and $\mu
 ightarrow e f_A$ are unseen. Combining these excludes $m_{
 m heavy}
 u$ between 5 imes 10 $^{-5}$ and 5 \times 10 $^{-4}$ MeV (μ decay) and $m_{
 m heavy}
 u$ between 5 \times 10 $^{-5}$ and 0.1 MeV (K-decay).

Majoron Searches in Neutrinoless Double β Decay

Limits are for the half-life of neutrinoless $\beta\beta$ decay with a Majoron emission. No experiment currently claims any such evidence. Only the best or comparable limits for each isotope are reported. Also see the reviews ZUBER 98 and FAESSLER 98B.

| $t_{1/2}(10^{21} \text{ yr})$ | CL% | ISOTOPE | TRANSITION | METHOD | DOCUMENT ID | |
|-------------------------------|----------|-------------------|----------------|------------------------------------------|---------------------------|------|
| >7200 | 90 | 128 Te | | CNTR | 143 BERNATOW | . 92 |
| • • • We do no | t use th | he following | data for avera | ges, fits, limits, etc | | |
| > 16 | 90 | 130 Te | $0\nu\chi$ | NEMO-3 | ¹⁴⁴ ARNOLD | 11 |
| > 1.9 | 90 | ⁹⁶ Zr | $2\nu 1\chi$ | NEMO-3 | 145 ARGYRIADES | 10 |
| > 1.52 | 90 | 150 Nd | $0\nu1\chi$ | NEMO-3 | ¹⁴⁶ ARGYRIADES | 09 |
| > 27 | 90 | 100 Mo | $0\nu1\chi$ | NEMO-3 | ¹⁴⁷ ARNOLD | 06 |
| > 15 | 90 | 82 Se | $0\nu1\chi$ | NEMO-3 | ¹⁴⁸ ARNOLD | 06 |
| > 14 | 90 | ¹⁰⁰ Mo | $0\nu1\chi$ | NEMO-3 | ¹⁴⁹ ARNOLD | 04 |
| > 12 | 90 | ⁸² Se | $0\nu1\chi$ | NEMO-3 | ¹⁵⁰ ARNOLD | 04 |
| > 2.2 | 90 | 130 Te | $0\nu1\chi$ | Cryog. det. | ¹⁵¹ ARNABOLDI | 03 |
| > 0.9 | 90 | 130 Te | $0\nu2\chi$ | Cryog. det. | ¹⁵² arnaboldi | 03 |
| > 8 | 90 | 116 _{Cd} | $0\nu1\chi$ | CdWO₄ scint. | ¹⁵³ DANEVICH | 03 |
| > 0.8 | 90 | 116 _{Cd} | $0\nu2\chi$ | CdWO₄ scint. | ¹⁵⁴ DANEVICH | 03 |
| > 500 | 90 | 136 Xe | $0\nu\chi$ | Liquid Xe Scint. | ¹⁵⁵ BERNABEI | 02D |
| > 5.8 | 90 | $100 M_{\odot}$ | $0\nu\chi$ | ELEGANT V | ¹⁵⁶ FUSHIMI | 02 |
| > 0.32 | 90 | 100 Mo | $0\nu\chi$ | Liq. Ar ioniz. | ¹⁵⁷ A SHITKOV | 01 |
| > 0.0035 | 90 | ¹⁶⁰ Gd | $0\nu\chi$ | 160 Gd 2 SiO5: Ce | ¹⁵⁸ DANEVICH | 01 |
| > 0.013 | 90 | 160 _{Gd} | $0\nu 2\chi$ | 160 Gd ₂ SiO ₅ :Ce | ¹⁵⁹ DANEVICH | 01 |
| > 2.3 | 90 | 82 Se | $0\nu\chi$ | NEMO 2 | ¹⁶⁰ ARNOLD | 00 |
| > 0.31 | 90 | ⁹⁶ Zr | $0\nu\chi$ | NEMO 2 | ¹⁶¹ ARNOLD | 00 |
| > 0.63 | 90 | 82 Se | $0\nu 2\chi$ | NEMO 2 | ¹⁶² ARNOLD | 00 |
| > 0.063 | 90 | ⁹⁶ Zr | $0\nu 2\chi$ | NEMO 2 | ¹⁶² ARNOLD | 00 |
| > 0.16 | 90 | 100 _{Mo} | $0\nu 2\chi$ | NEMO 2 | ¹⁶² ARNOLD | 00 |
| > 2.4 | 90 | 82 Se | $0\nu\chi$ | NEMO 2 | ¹⁶³ ARNOLD | 98 |
| > 7.2 | 90 | 136 Xe | $0\nu 2\chi$ | TPC | ¹⁶⁴ LUESCHER | 98 |
| > 7.91 | 90 | 76 Ge | 70 | SPEC | ¹⁶⁵ GUENTHER | 96 |
| > 17 | 90 | ⁷⁶ Ge | | CNTR | BECK | 93 |
| 1/3 | | | | . 128 130- | | |

- 143 BERNATOWICZ 92 studied double-eta decays of 128 Te and 130 Te, and found the ratio $au(^{130}{
 m Te})/ au(^{128}{
 m Te}) = (3.52\,\pm\,0.11) imes 10^{-4}$ in agreement with relatively stable theoretical predictions. The bound is based on the requirement that Majoron-emitting decay cannot be larger than the observed double-beta rate of $^{128}{\rm Te}$ of $(7.7\pm0.4)\times10^{24}$ year. We calculated 90% CL limit as $(7.7\text{--}1.28 \times 0.4\text{=-}7.2) \times 10^{24}$
- $^{144}\,\mathrm{AR}\,\mathrm{NOLD}\,11$ use the NEMO-3 detector to obtain the reported limit on Majoron emission. $< 0.6-1.6 \times 10^{-4}$ depending on the nuclear It implies that the coupling constant $g_{\nu\chi} < 0.6$ –1 matrix element used. Supercedes ARNABOLDI 03.
- $^{145}\,\mathrm{ARGYRIADES}$ 10 use the NEMO-3 tracking detector and $^{96}\mathrm{Zr}$ to derive the reported
- limit. No limit for the Majoron electron coupling is given. $^{146} \, \text{ARGYRIADES} \,\, 09 \,\, \text{use} \,\, ^{150} \, \text{Nd} \,\, \text{data} \,\, \text{taken} \,\, \text{with} \,\, \text{the NEMO-3 tracking detector.} \quad \text{The}$ reported limit corresponds to $\langle g_{\nu\chi} \rangle < 1.7^{-3.0} \times 10^{-4}$ using a range of nuclear matrix elements that include the effect of nuclear deformation. 147 ARNOLD 06 use 100 Mo data taken with the NEMO-3 tracking detector. The reported
- limit corresponds to $\langle g_{\nu\,\chi} \rangle < (0.4$ –1.8) $\times\,10^{-4}$ using a range of matrix element calculations. Supersedes ARNOLD 04.
- 148 NEMO-3 tracking calorimeter is used in ARNOLD 06 . Reported half-life limit for 82 Se corresponds to $\langle g_{\nu\gamma} \rangle < (0.66-1.9) \times 10^{-4}$ using a range of matrix element calculations. Supersedes ARNOLD 04.
- $^{149} \rm ARNOLD$ 04 use the NEMO-3 tracking detector. The limit corresponds to $\langle g_{\nu\chi} \rangle~<$ (0.5-0.9)10-4 using the matrix elements of SIMKOVIC 99, STOICA 01 and CIV-ÎTARESÉ 03
- 150 ARNOLD 04 use the NEMO-3 tracking detector. The limit corresponds to $\langle g_{\nu\chi} \rangle~<$ $(0.7 - 1.6)10^{-4}$ using the matrix elements of SIMKOVIC 99, STOICA 01 and CIV-ITARESE 03.
- 151 Supersedes ALESSANDRELLO 00. Array of TeO $_2$ crystals in high resolution cryogenic calorimeter. Some enriched in 130 Te. Derive $\langle g_{\nu\chi} \rangle~<~17$ –33 $\times~10^{-5}$ depending on
- matrix element.

 152 Supersedes ALESSANDRELLO 00. Cryogenic calorimeter search.
- 153 Limit for the $0
 u\chi$ decay with Majoron emission of 116 Cd using enriched CdWO $_4$ scintillators. $\langle g_{\nu\chi} \rangle <$ 4.6–8.1 \times 10⁻⁵ depending on the matrix element. Supersedes DANEVICH 00.
- 154 Limit for the $0\nu2\chi$ decay of 116 Cd. Supersedes DANEVICH 00.
- 155 BERNABEI 02D obtain limit for 0 $u\chi$ decay with Majoron emission of 136 Xe using liquid Xe scintillation detector. They derive $\langle g_{
 u\chi}
 angle <$ 2.0–3.0 imes 10⁻⁵ with several nuclear

Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

- 156 Replaces TANAKA 93. FUSHIMI 02 derive half-life limit for the $0 \nu \chi$ decay by means of tracking calorimeter ELEGANT V. Considering various matrix element calculations, a range of limits for the Majoron-neutrino coupling is given: $\langle g_{\nu\chi} \rangle < (6.3-360) \times 10^{-5}$.
- 157 ASHITKOV 01 result for 0 $u\chi$ of 100 Mo is less stringent than ARNOLD 00.
- 158 DANEVICH 01 obtain limit for the $0
 u\chi$ decay with Majoron emission of 160 Gd using Gd₂SiO₅:Ce crystal scintillators.
- 159 DANEVICH 01 obtain limit for the 0ν 2χ decay with 2 Majoron emission of 160 Gd.
- 160 ARNOLD 00 reports limit for the $0
 u\chi$ decay with Majoron emission derived from tracking calorimeter NEMO 2. Using $^{82}{\rm Se}$ source: $\langle g_{\nu\chi}\rangle < 1.6\times 10^{-4}$. Matrix element from GUENTHER 96. 161 Using $^{96}{\rm Zr}$ source: $\langle g_{\nu\chi} \rangle < 2.6 \times 10^{-4}$. Matrix element from ARNOLD 99.
- 162 ARNOLD 00 reports limit for the $0\nu2\chi$ decay with two Majoron emission derived from tracking calorimeter NEMO 2.
- $^{163} \text{ARNOLD}$ 98 determine the limit for $0 \nu_{\chi}$ decay with Majoron emission of $^{82} \text{Se}$ using the NEMO-2 tracking detector. They derive $\langle g_{\nu_\chi} \rangle <$ 2.3–4.3 \times 10⁻⁴ with several nuclear
- matrix elements. 164 LUESCHER 98 report a limit for the 0ν decay with Majoron emission of 136 Xe using Xe TPC. This result is more stringent than BARABASH 89. Using the matrix elements of ENGEL 88, they obtain a limit on $\langle g_{\nu\chi} \rangle$ of 2.0×10^{-4} .
- $^{165}\,\mathrm{See}$ Table 1 in GUENTHER 96 for limits on the Majoron coupling in different models.

Invisible A⁰ (Axion) MASS LIMITS from Astrophysics and Cosmology

 $v_1=v_2$ is usually assumed ($v_i=v_1$ vacuum expectation values). For a review of these limits, see RAFFELT 91 and TURNER 90. In the comment lines below, D and K refer

to DFSZ and KSVZ axion types, discussed in the above minireview. VALUE (eV) CL% DOCUMENT ID TECN COMMENT

| VALUE (eV) | CL% | | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|---------------|------|------------------|---------|-----------------------------------------|-----------------------------------------------------------|
| • • • We do not us | e the followi | ng d | ata for averages | , fits, | limits, e | etc. • • • |
| none 0.73×10^5 | | 166 | CADAMURO | 11 | COSM | D abundance |
| <105 | 90 | 167 | DERBIN | 11A | CNTR | D, solar axion |
| • | | 168 | | .10 | CAST | K, solar axions |
| < 0.72 | 95 | 169 | HANNESTAD | 10 | COSM | K, hot dark matter |
| | | 170 | ANDRIAMON | .09 | CAST | K, solar axions |
| <191 | 90 | 171 | DERBIN | 09A | CNTR | K, solar axions |
| <334 | 95 | 172 | KEKEZ | 09 | HPGE | K, solar axions |
| < 1.02 | 95 | 173 | HANNESTAD | 80 | COSM | K, hot dark matter |
| < 1.2 | 95 | 174 | HANNESTAD | 07 | COSM | K, hot dark matter |
| < 0.42 | 95 | 175 | MELCHIORRI | 07A | COSM | K, hot dark matter |
| < 1.05 | 95 | 176 | HANNESTAD | 05 A | COSM | K, hot dark matter |
| 3 to 20 | | 1// | MOROI | 98 | COSM | K, hot dark matter |
| < 0.007 | | 178 | BORISOV | 97 | ASTR | D, neutron star |
| < 4 | | 179 | KACHELRIESS | 97 | ASTR | D, neutron star cooling |
| $<(0.5-6)\times10^{-3}$ | | 180 | KEIL | 97 | ASTR | SN 1987A |
| < 0.018 | | 181 | RAFFELT | 95 | ASTR | D, red giant |
| < 0.010 | | 182 | ALTHERR | 94 | ASTR | D, red giants, white |
| | | 183 | CHANG | 93 | ASTR | dwarfs K, SN 1987A |
| < 0.01 | | | WANG | 92 | ASTR | D, white dwarf |
| < 0.03 | | | WANG | 92c | ASTR | D, C-O burning |
| none 3-8 | | 184 | | 91 | ASTR | D, K, |
| | | | | | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | intergalactic light |
| < 10 | | 185 | KIM | 91∈ | COSM | D, K, mass density of the universe, super- symmetry |
| | | 186 | RAFFELT | 91B | ASTR | D,K, SN 1987A |
| $< 1 \times 10^{-3}$ | | 187 | RESSELL | 91 | ASTR | K, intergalactic light |
| none 10 ⁻³ -3 | | | BURROWS | 90 | ASTR | D,K, SN 1987A |
| | | 188 | ENGEL | 90 | ASTR | D,K, SN 1987A |
| < 0.02 | | 189 | RAFFELT | 90D | ASTR | D, red giant |
| $< 1 \times 10^{-3}$ | | 190 | BURROWS | 89 | ASTR | D,K, SN 1987A |
| $<(1.4-10)\times10^{-3}$ | | 191 | ERICSON | 89 | ASTR | D,K, SN 1987A |
| $< 3.6 \times 10^{-4}$ | | 192 | MAYLE | 89 | ASTR | D,K, SN 1987A |
| < 12 | | | CHANDA | 88 | ASTR | D, Sun |
| $< 1 \times 10^{-3}$ | | | RAFFELT | 88 | ASTR | D,K, SN 1987A |
| * | | 193 | RAFFELT | 88B | ASTR | red giant |
| < 0.07 | | | FRIEMAN | 87 | ASTR | D, red giant |
| < 0.7 | | 194 | RAFFELT | 87 | ASTR | K, red giant |
| < 2-5 | | | TURNER | 87 | COSM | K, thermal production |
| < 0.01 | | 195 | DEARBORN | 86 | ASTR | D, red giant |
| < 0.06 | | | RAFFELT | 86 | ASTR | D, red giant |
| < 0.7 | | 196 | RAFFELT | 86 | ASTR | K, red giant |
| < 0.03 | | | RAFFELT | 86в | ASTR | D, white dwarf |
| < 1 | | 197 | KAPLAN | 85 | ASTR | K, red giant |
| < 0.003-0.02 | | | IWAMOTO | 84 | ASTR | D, K, neutron star |
| $> 1 \times 10^{-5}$ | | | ABBOTT | 83 | COSM | D,K, mass density of |
| > 1 ×10 ⁻⁵ | | | DINE | 83 | COSM | the universe D,K, mass density of the universe |
| < 0.04 | | | ELLIS | 83B | ASTR | D, red giant |
| > 1 × 10 ⁻⁵ | | | PRESKILL | 83 | COSM | D,K, mass density of the universe |
| < 0.1 | | 100 | BARROSO | 82 | ASTR | D, red giant |
| < 1 | | 1 20 | FUKUGITA | 82 | ASTR | D, stellar cooling |
| < 0.07 | | | FUKUGITA | 82в | ASTR | D, red giant |

- 166 CADAMURO 11 use the deuterium abundance to show that the $\,m_{A^0}\,$ range 0.7 eV -300 keV is excluded for axions, complementing HANNESTAD 10.
- 167 DERBIN 11A look for solar axions produced by Compton and bremsstrahlung processes, in the resonant excitation of ¹⁶⁹Tm, constraining the axion-electron × axion nucleon
- 168 A NDRIA MONJE 10 search for solar axions produced from 7 Li (478 keV) and D $(p,\gamma)^{3}$ He (5.5 MeV) nuclear transitions. They show limits on the axion-photon coupling for two reference values of the axion-nucleon coupling for $m_A < 100$ eV.
- 169 This is an update of HANNESTAD 08 including 7 years of WMAP data.
- 170 ANDRIAMONJE 09 look for solar axions produced from the thermally excited 14.4 keV level of 57 Fe. They show limits on the axion-nucleon imes axion-photon coupling assuming $m_A < 0.03 \text{ eV}$
- $171\,\mathrm{DERBIN}$ 09A look for Primakoff-produced solar axions in the resonant excitation of $^{169}\text{Tm}\text{,}$ constraining the axion-photon \times axion-nucleon couplings.
- $^{172}\,\mathrm{KEKEZ}$ 09 look at axio-electric effect of solar axions in HPGe detectors. The one-loop axion-electron coupling for hadronic axions is used.
- 173 This is an update of HANNESTAD 07 including 5 years of WMAP data.
- 174 This is an update of HANNESTAD 05A with new cosmological data, notably WMAP (3 years) and baryon acoustic oscillations (BAO). Lyman-lpha data are left out, in contrast to HANNESTAD 05A and MELCHIORRI 07A, because it is argued that systematic errors are large. It uses Bayesian statistics and marginalizes over a possible neutrino hot dark matter component.
- 175 MELCHIORRI 07A is analogous to HANNESTAD 05A, with updated cosmological data, notably WMAP (3 years). Uses Bayesian statistics and marginalizes over a possible neutrino hot dark matter component. Leaving out Lyman-α data, a conservative limit is
- 176 HANNESTAD 05A puts an upper limit on the mass of hadronic axion because in this mass range it would have been thermalized and contribute to the hot dark matter component of the universe. The limit is based on the CMB anisotropy from WMAP, SDSS large scale structure, Lyman lpha, and the prior Hubble parameter from HST Key Project. A χ^2
- statistic is used. Neutrinos are assumed not to contribute to hot dark matter.

 177 MOROI 98 points out that a KSVZ axion of this mass range (see CHANG 93) can be a viable hot dark matter of Universe, as long as the model-dependent $g_{A\gamma}$ is accidentally small enough as originally emphasized by KAPLAN 85; see Fig. 1.
- small enough as originally emphasized by KAPLAN 85; see Fig. 1. $178\, {\rm BORISOV}\,97\, {\rm bound}\, {\rm is}\, {\rm on}\, {\rm the}\, {\rm axion-electron}\, {\rm coupling}\, g_{ae} < 1\times 10^{-13}\, {\rm from}\, {\rm the}\, {\rm photoproduction}\, {\rm of}\, {\rm axions}\, {\rm off}\, {\rm magnetic}\, {\rm fields}\, {\rm in}\, {\rm the}\, {\rm outer}\, {\rm layers}\, {\rm of}\, {\rm neutron}\, {\rm stars}.$ $179\, {\rm KACHELRIESS}\, 97\, {\rm bound}\, {\rm is}\, {\rm on}\, {\rm the}\, {\rm axion-electron}\, {\rm coupling}\, g_{ae}^2 < 1\times 10^{-10}\, {\rm from}\, {\rm the}\, {\rm production}\, {\rm of}\, {\rm axions}\, {\rm in}\, {\rm strongly}\, {\rm magnetic}\, {\rm deutron}\, {\rm stars}\, .$
 The authors also quote a stronger limit, $g_{ae}^2 < 9\times 10^{-13}\, {\rm which}\, {\rm is}\, {\rm strongly}\, {\rm dependent}\, {\rm on}\, {\rm the}\, {\rm strength}\, {\rm of}\, {\rm nucleons}\, {\rm axiongly}\, {\rm strongly}\, {\rm otherwise}\, {\rm otherwise}\, {\rm axiongly}\, {\rm otherwise}\,
- $180\,\mathrm{KEIL}$ 97 uses new measurements of the axial-vector coupling strength of nucleons, as well as a reanalysis of many-body effects and pion-emission processes in the core of the neutron star, to update limits on the invisible-axion mass.
- $^{181}\,\mathrm{RAFFELT}$ 95 reexamined the constraints on axion emission from red giants due to the axion-electron coupling. They improve on DEARBORN 86 by taking into proper account degeneracy effects in the bremsstrahlung rate. The limit comes from requiring the red giant core mass at helium ignition not to exceed its standard value by more than 5% (0.025 solar masses).
- $^{182}\text{ALTHERR}$ 94 bound is on the axion-electron coupling $\textit{g}_{\textit{ae}} < 1.5 \times 10^{-13}$, from energy
- loss via axion emission.

 183 CHANG 93 updates ENGEL 90 bound with the Kaplan-Manohar ambiguity in $z=m_u/m_d$ (see the Note on the Quark Masses in the Quark Particle Listings). It leaves the window $f_{A} = 3 \times 10^{5} - 3 \times 10^{6}$ GeV open. The constraint from Big-Bang Nucleosynthesis is satisfied this window as well.
- $^{184}\, \mathrm{BERSHADY}$ 91 searched for a line at wave length from 3100–8300 Å expected from 2γ decays of relic thermal axions in intergalactic light of three rich clusters of galaxies.
- 185 KIM 91c argues that the bound from the mass density of the universe will change drastically for the supersymmetric models due to the entropy production of saxion (scalar component in the axionic chiral multiplet) decay. Note that it is an upperbound rather han a lowerbound.
- 186 RAFFELT 91B argue that previous SN 1987A bounds must be relaxed due to corrections to nucleon bremsstrahlung processes.
- 188 ENGEL 90 rule out $10^{-10} \lesssim g_{AN} \lesssim 10^{-3}$, which for a hadronic axion with EMC motivated axion-nucleon couplings corresponds to $2.5 \times 10^{-3} \, {\rm eV} \lesssim m_{A^0} \lesssim 2.5 \times 10^{-3} \, {\rm eV}$ 10^4 eV. The constraint is loose in the middle of the range, i.e. for $g_{AN} \sim 10^{-6}$.
- 189 RAFFELT 90D is a re-analysis of DEARBORN 86. 190 The region $m_{A^0}\gtrsim 2$ eV is also allowed.
- 191 ERICSON 89 considered various nuclear corrections to axion emission in a supernova core, and found a reduction of the previous limit (MAYLE 88) by a large factor.
- 192 MAYLE 89 limit based on naive quark model couplings of axion to nucleons. Limit based on couplings motivated by EMC measurements is 2–4 times weaker. The limit from axion-electron coupling is weak: see HATSUDA 88B.
- $^{193}\,\mathrm{RAFFELT}$ 88B derives a limit for the energy generation rate by exotic processes in heliumburning stars $\epsilon <$ 100 erg g $^{-1}$ s $^{-1}$, which gives a firmer basis for the axion limits based on red giant cooling.
- $^{194}\,\mathrm{RAFFELT}$ 87 also gives a limit $g_{A\gamma}~<~1\times10^{-10}~\mathrm{GeV}^{-1}$
- 195 DEARBORN 86 also gives a limit $g_{A\gamma} < 1.4 imes 10^{-11}~{
 m GeV}^{-1}$.
- 196 RAFFELT 86 gives a limit $g_{A\gamma} < 1.1 \times 10^{-10}~{\rm GeV}^{-1}$ from red giants and $< 2.4 \times 10^{-9}$ ${
 m GeV}^{-1}$ from the sun.
- 197 KAPLAN 85 says $m_{A^0} <$ 23 eV is allowed for a special choice of model parameters.
- $^{198}\,\mathrm{FU\,KUGITA}$ 82 gives a limit $g_{A\gamma}~<~2.3\times10^{-10}~\mathrm{GeV}^{-1}$

Search for Relic Invisible Axions

Limits are for $[G_{A\gamma\gamma}/m_{A^0}]^2
ho_A$ where $G_{A\gamma\gamma}$ denotes the axion two-photon coupling, $L_{\rm int}=rac{G_{A\gamma\gamma}}{4}\phi_AF_{\mu
u}\widetilde{F}^{\mu
u}=G_{A\gamma\gamma}\phi_A{f E}\cdot{f B},$ and ho_A is the axion energy density near the earth.

<u>CL%</u> DO CUMENT ID TECN COMMENT \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

Gauge & Higgs Boson Particle Listings

Axions (A^0) and Other Very Light Bosons

| $< 3.5 \times 10^{-43}$ | | ¹⁹⁹ HOSKINS | 11 | ADMX $m_{A^0} = 3.3-3.69 \times 10^{-6} \text{ eV}$ |
|-------------------------|------|-------------------------|----|-----------------------------------------------------------------|
| $< 2.9 \times 10^{-43}$ | 90 | ²⁰⁰ ASZTALOS | | ADMX $m_{\Delta 0}^{7} = 3.34 - 3.53 \times 10^{-6} \text{ eV}$ |
| $< 1.9 \times 10^{-43}$ | 97.7 | ²⁰¹ DUFFY | | ADMX $m_{\Delta 0}^{7} = 1.98-2.17 \times 10^{-6} \text{ eV}$ |
| $< 5.5 \times 10^{-43}$ | 90 | ²⁰² ASZTALOS | 04 | ADMX $m_{\Delta^0} = 1.9 - 3.3 \times 10^{-6} \text{ eV}$ |
| | | ²⁰³ KIM | 98 | THEO |
| $< 2 \times 10^{-41}$ | | ²⁰⁴ hagmann | 90 | CNTR $m_{A^0} = (5.4-5.9)10^{-6} \text{ eV}$ |
| $< 1.3 \times 10^{-42}$ | 95 | ²⁰⁵ WUENSCH | 89 | CNTR $m_{A^0} = (4.5-10.2)10^{-6} \text{ eV}$ |
| $< 2 \times 10^{-41}$ | 95 | ²⁰⁵ WUENSCH | 89 | CNTR $m_{A^0} = (11.3-16.3)10^{-6} \text{ eV}$ |

- $^{199} \mathrm{HOSKINS} \ 11$ is analogous to DUFFY 06. See Fig. 4 for the mass-dependent limit in terms of the local density.
- $200\,\mathrm{ASZTALOS}$ 10 used the upgraded detector of ASZTALOS 04 to search for halo axions. See their Fig. 5 for the $m_{\ensuremath{A^0}}$ dependence of the limit.
- 201 DUFFY 06 used the upgraded detector of ASZTALOS 04, while assuming a smaller velocity dispersion than the isothermal model as in Eq. (8) of their paper. See Fig. 10 of their paper on the axion mass dependence of the limit.
- $^{202} \text{ASZTALOS}$ 04 looked for a conversion of halo axions to microwave photons in magnetic field. At 90% CL, the KSVZ axion cannot have a local halo density more than 0.45 $\,$ GeV/cm 3 in the quoted mass range. See Fig. 7 of their paper on the axion mass dependence of the limit.
- 203 KIM 98 calculated the axion-to-photon couplings for various axion models and compared them to the HAGMANN 90 bounds. This analysis demonstrates a strong model dependence of ${\it G}_{A\,\gamma\gamma}$ and hence the bound from relic axion search.
- 204 HAGMANN 90 experiment is based on the proposal of SIKIVIE 83.
- 205 WUENSCH 89 looks for condensed axions near the earth that could be converted to photons in the presence of an intense electromagnetic field via the Primakoff effect, following the proposal of SIKIVIE 83. The theoretical prediction with $[G_{A\gamma\gamma}/m_{\Delta0}]^2=$ $2\times 10^{-14}~{\rm MeV^{-4}}$ (the three generation DFSZ model) and $\rho_A=300~{\rm MeV/cm^3}$ that makes up galactic halos gives $(G_A\gamma\gamma/m_{A^0})^2~\rho_A=4\times 10^{-44}$. Note that our definition of $G_A\gamma\gamma$ is $(1/4\pi)$ smaller than that of WUENSCH 89.

Invisible A⁰ (Axion) Limits from Photon Coupling

Limits are for the axion-two-photon coupling $G_{A\gamma\gamma}$ defined by $L=G_{A\gamma\gamma}\phi_A {f E}{\cdot}{f B}$. For scalars S^0 the limit is on the coupling constant in $L = G_{S\gamma\gamma}\phi_S(\mathbf{E}^2 - \mathbf{B}^2)$.

| | CL% | DO CUMENT ID | | | COMMENT |
|--------------------------------|------|----------------------------|-----|------|-------------------------------------------------------|
| • • • We do not use the | | | | | |
| $< 2.3 \times 10^{-10}$ | 95 | ²⁰⁶ ARIK | 11 | CAST | $m_{A^0} = 0.39 - 0.64 \text{ eV}$ |
| $<6.5 \times 10^{-8}$ | 95 | ²⁰⁷ EHRET | 10 | ALPS | $m_{A^0}^{A^2} < 0.7 \text{ meV}$ |
| $< 2.4 \times 10^{-9}$ | 95 | ²⁰⁸ AHMED | 09A | CDMS | |
| $< 1.2 - 2.8 \times 10^{-10}$ | 95 | ²⁰⁹ ARIK | 09 | CAST | $m_{A^0}^A = 0.02 - 0.39 \text{ eV}$ |
| | | ²¹⁰ CHOU | 09 | | Chameleons |
| $< 7 \times 10^{-10}$ | | 211 GONDOLO | 09 | ASTR | $m_{A^0} < {\sf few keV}$ |
| $<1.3 \times 10^{-6}$ | 95 | ²¹² A FA NA SEV | 80 | | $m_{S^0} < 1 \text{ meV}$ |
| <3.5 × 10 ⁻⁷ | 99.7 | ²¹³ CHOU | 80 | | $m_{A^0} < 0.5 \text{ meV}$ |
| $<1.1 \times 10^{-6}$ | 99.7 | 214 FOUCHE | 80 | | $m_{A^0} < 1 \text{ meV}$ |
| $< 5.6 - 13.4 \times 10^{-10}$ | 95 | ²¹⁵ INOUE | 80 | | $m_{A^0} = 0.84-1.00 \text{ eV}$ |
| <5 × 10 ⁻⁷ | | 216 ZAVATTINI | 80 | | $m_{A^0} < 1 \text{ meV}$ |
| <8.8 × 10 ⁻¹¹ | 95 | ²¹⁷ ANDRIAMON | .07 | CAST | $m_{A^0}^{\prime\prime} < 0.02 \text{ eV}$ |
| $< 1.25 \times 10^{-6}$ | 95 | ²¹⁸ ROBILLIARD | 07 | | $m_{A^0} < 1 \text{ meV}$ |
| $2-5 \times 10^{-6}$ | | ²¹⁹ ZAVATTINI | 06 | | $m_{A^0} = 1-1.5 \text{ meV}$ |
| $<1.1 \times 10^{-9}$ | 95 | ²²⁰ INOUE | 02 | | $m_{A^0} = 0.05 - 0.27 \text{ eV}$ |
| $< 2.78 \times 10^{-9}$ | 95 | ²²¹ MORALES | 02в | | $m_{A^0} < 1 \text{ keV}$ |
| $< 1.7 \times 10^{-9}$ | 90 | ²²² BERNABEI | 01в | | $m_{A^0}^{7} < 100 \text{ eV}$ |
| $< 1.5 \times 10^{-4}$ | 90 | ²²³ ASTIER | 00в | NOMD | $m_{A^0}^{\prime\prime} < 40 \text{ eV}$ |
| | | 224 MASSO | 00 | | induced γ coupling |
| $< 2.7 \times 10^{-9}$ | 95 | ²²⁵ AVIGNONE | 98 | SLAX | $m_{A^0} < 1 \text{ keV}$ |
| $<6.0 \times 10^{-10}$ | 95 | ²²⁶ MORIYAMA | 98 | | $m_{A^0} < 0.03 \text{eV}$ |
| $< 3.6 \times 10^{-7}$ | 95 | ²²⁷ CAMERON | 93 | | $m_{A^0}^A < 10^{-3} \text{ eV},$ |
| <6.7 × 10 ⁻⁷ | 95 | ²²⁸ CAMERON | 93 | | optical rotation $m_{\Delta^0} < 10^{-3} \text{ eV},$ |
| <0.7 × 10 | 90 | CAMERON | 93 | | photon regeneration |
| $< 3.6 \times 10^{-9}$ | 99.7 | ²²⁹ LAZARUS | 92 | | $m_{A^0} < 0.03 \text{ eV}$ |
| $< 7.7 \times 10^{-9}$ | 99.7 | ²²⁹ LAZARUS | 92 | | $m_{A^0}^{A^0} = 0.03 - 0.11 \text{ eV}$ |
| $< 7.7 \times 10^{-7}$ | 99 | ²³⁰ RUOSO | 92 | | $m_{A^0}^{A^0} < 10^{-3} \text{ eV}$ |
| $< 2.5 \times 10^{-6}$ | | ²³¹ SEMERTZIDIS | 90 | | $m_{A^0}^{A^0} < 7 \times 10^{-4} \text{ eV}$ |
| | | | | | A- |

- $^{206}\,\text{ARIK}$ 11 search for solar axions using ^{3}He buffer gas in CAST, continuing from the ^{4}He version of ARIK 09. See Fig. 2 for the exact mass-dependent limits.
- 207 ALPS is a photon regeneration experiment. See their Fig. 4 for mass-dependent limits on scalar and pseudoscalar bosons.
- $^{208}\,\mathrm{AH\,MED}$ 09A is analogous to AVIGNONE 98.
- 209 ARIK 09 is the ⁴He filling version of the CAST axion helioscope in analogy to INOUE 02 and INOUE 08. See their Fig. 7 for mass-dependent limits.
- 210 CHOU 09 use the GammeV apparatus in the afterglow mode to search for chameleons, (pseudo)scalar bosons with a mass depending on the environment. For pseudoscalars they exclude at 3σ the range $2.6\times 10^{-7}~{\rm GeV}^{-1}< G_{A\gamma\gamma}<4.2\times 10^{-6}~{\rm GeV}^{-1}$ for vacuum m_{A^0} roughly below 6 meV for density scaling index exceeding 0.8.
- $^{211}\,\mathrm{GONDOLO}$ 09 use the all-flavor measured solar neutrino flux to constrain solar interior temperature and thus energy losses

- 212 LIPSS photon regeneration experiment, assuming scalar particle S^0 . See Fig. 4 for mass-
- 213 CHOU 08 perform a variable-baseline photon regeneration experiment. See their Fig. 3 for mass-dependent limits. Excludes the PVLAS result of ZAVATTINI 06.
- 214 FOUCHE 08 is an update of ROBILLIARD 07. See their Fig. 12 for mass-dependent
- 215 | NOUE 08 is an extension of INOUE 02 to larger axion masses, using the Tokyo axion
- helioscope. See their Fig. 4 for mass-dependent limits.

 216 ZAVATTINI 08 is an upgrade of ZAVATTINI 06, see their Fig. 8 for mass-dependent limits. They now exclude the parameter range where ZAVATTINI 06 had seen a positive ignature.
- 217 ANDRIAMONJE 07 looked for Primakoff conversion of solar axions in 9T superconducting magnet into X-rays. Supersedes ZIOUTAS 05.
- 218 ROBILLIARD 07 perform a photon regeneration experiment with a pulsed laser and pulsed magnetic field. See their Fig. 4 for mass-dependent limits. Excludes the PVLAS result of ZAVATTINI 06 with a CL exceeding 99.9%.
- 219 ZAVATTINI 06 propagate a laser beam in a magnetic field and observe dichroism and birefringence effects that could be attributed to an axion-like particle. This result is now excluded by ROBILLIARD 07, ZAVATTINI 08, and CHOU 08.
- 220 I NOUE 02 looked for Primakoff conversion of solar axions in 4T superconducting magnet
- 221 MORALES 02B looked for the coherent conversion of solar axions to photons via the Primakoff effect in Germanium detector.
- 222 BERNABEI 01B looked for Primakoff coherent conversion of solar axions into photons via Bragg scattering in Nal crystal in DAMA dark matter detector.
- 223 ASTIER 00B looked for production of axions from the interaction of high-energy photons with the horn magnetic field and their subsequent re-conversion to photons via the interaction with the NOMAD dipole magnetic field.
- 224 MASSO 00 studied limits on axion-proton coupling using the induced axion-photon coupling through the proton loop and CAMERON 93 bound on the axion-photon coupling using optical rotation. They obtained the bound $s_p^2/4\pi < 1.7 \times 10^{-9}$ for the coupling $g_p \overline{p} \gamma_5 p \phi_A$
- 225 AVIGNONE 98 result is based on the coherent conversion of solar axions to photons via the Primakoff effect in a single crystal germanium detector.
- $\frac{226}{1-2}$ Based on the conversion of solar axions to X-rays in a strong laboratory magnetic field.
- 227 Experiment based on proposal by MAIANI 86.
- 228 Experiment based on proposal by VANBIBBER 87.
- $^{229} \, \mathsf{LAZARUS} \,\, \mathsf{92} \,\, \mathsf{experiment}$ is based on proposal found in VANBIBBER 89.
- $^{230}\,\text{RUOSO}$ 92 experiment is based on the proposal by VANBIBBER 87.
- $231\, \text{SEMERTZIDIS}$ 90 experiment is based on the proposal of MAIANI 86. The limit is obtained by taking the noise amplitude as the upper limit. Limits extend to $m_{A0}=$ $4 imes 10^{-3}$ where $\textit{G}_{A \, \gamma \, \gamma} \, < \, 1 imes 10^{-4} \, \, \mathrm{GeV}^{-1}$.

Limit on Invisible A^0 (Axion) Electron Coupling

The limit is for ${\it G_{Aee}}\partial_{\mu}\phi_{A}\overline{e}\gamma^{\mu}\gamma_{5}e$ in ${\it GeV}^{-1}$, or equivalently, the dipole-dipole potential $\frac{G_{Aee}^2}{4\pi} ((\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) - 3(\boldsymbol{\sigma}_1 \cdot \boldsymbol{n}) (\boldsymbol{\sigma}_2 \cdot \boldsymbol{n}))/r^3$ where $\boldsymbol{n} = \boldsymbol{r}/r$.

| $VALUE (GeV^{-1})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------------------|----------------------------|----------|-----------|----------------------------------|
| • • • We do no | t use the follow | ing data for average | s, fits, | limits, e | etc. • • • |
| $< 0.02 - 1 \times 10^{-1}$ | 7 90 | ²³² AALSETH | 11 | CNTR | $m_{\Delta 0} = 0.3$ -8 keV |
| $< 1.4 \times 10^{-9}$ | 90 | ²³³ AHMED | | | $m_{\Delta 0} = 2.5 \text{ keV}$ |
| $< 3 \times 10^{-6}$ | | ²³⁴ DAVOUDIA SL | 09 | ASTR | Earth cooling |
| $< 5.3 \times 10^{-5}$ | 66 | ²³⁵ NI | 94 | | Induced magnetism |
| $< 6.7 \times 10^{-5}$ | 66 | ²³⁵ CHUI | 93 | | Induced magnetism |
| $< 3.6 \times 10^{-4}$ | 66 | 236 PAN | 92 | | Torsion pendulum |
| $< 2.7 \times 10^{-5}$ | 95 | ²³⁵ BOBRAKOV | 91 | | Induced magnetism |
| $< 1.9 \times 10^{-3}$ | 66 | ²³⁷ WINELAND | 91 | NMR | · · |
| $< 8.9 \times 10^{-4}$ | 66 | ²³⁶ RITTER | 90 | | Torsion pendulum |
| $< 6.6 \times 10^{-5}$ | 95 | ²³⁵ VOROBYOV | 88 | | Induced magnetism |

- 232 AALSETH 11 assume keV-mass pseudoscalars are the local dark matter and constrain the axio-electric effect in the CoGeNT detector. See their Fig. 4 for mass-dependent
- 233 AHMED 09A is analogous to AALSETH 08, using the CDMS detector. See their Fig. 5 for mass-dependent limits.
- $^{234}_{--}$ DAVOUDIASL 09 use geophysical constraints on Earth cooling by axion emission.
- 235 These experiments measured induced magnetization of a bulk material by the spin-dependent potential generated from other bulk material with aligned electron spins, where the magnetic field is shielded with superconductor.
- $236\,\mathrm{These}$ experiments used a torsion pendulum to measure the potential between two bulk matter objects where the spins are polarized but without a net magnetic field in either
- 237 WINELAND 91 looked for an effect of bulk matter with aligned electron spins on atomic hyperfine splitting using nuclear magnetic resonance

Invisible A⁰ (Axion) Limits from Nucleon Coupling

Limits are for the axion mass in eV

| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|------------|--------------------------|----------|-----------|----------------------|
| • • • We do not use | the follow | ing data for averag | es, fits | , limits, | etc. • • • |
| <145 | 95 | ²³⁸ DERBIN | 11 | CNTR | Solar axion |
| $< 1.39 \times 10^4$ | 90 | ²³⁹ BELLI | 08A | CNTR | Solar axion |
| | | ²⁴⁰ BELLINI | | CNTR | Solar axion |
| | | ²⁴¹ ADELBERGE | R 07 | | Test of Newton's law |
| $< 1.6 \times 10^{4}$ | 90 | ²⁴² DERBIN | 05 | CNTR | Solar axion |
| <400 | 95 | ²⁴³ LJUBICIC | 04 | CNTR | Solar axion |
| $< 3.2 \times 10^4$ | 95 | ²⁴⁴ KRCMAR | 01 | CNTR | Solar axion |

Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

- ²³⁸ DERBIN 11 looked for solar axions emitted by the M1 transition of thermally excited 57 Fe nuclei in the Sun, using their possible resonant capture on 57 Fe in the laboratory. The mass bound assumes $m_u/m_d=0.56$ and the flavor-singlet axial vector matrix element $S=3F-D\simeq0.5$.
- 239 BELLI 08A is analogous to KRCMAR 01 and DERBIN 05.
- 240 BELLINI 08 consider solar axions emitted in the M1 transition of 7 Li* (478 keV) and bellin to consider solar axions entire in the wint transition of $El^{-}(476 \text{ keV})$ and look for a peak at 478 keV in the energy spectra of the Counting Test Facility (CTF), a Borexino prototype. For $m_{A^0} < 450$ keV they find mass-dependent limits on products of axion couplings to photons, electrons, and nucleons.
- ²⁴¹ ADELBERGER 07 use precision tests of Newton's law to constrain a force contribution from the exchange of two pseudoscalars. See their Fig. 5 for limits on the pseudoscalar coupling to nucleons, relevant for m_{A^0} below about 1 meV.
- $^{242}\,\mathrm{DERBIN}$ 05 bound is based on the same principle as KRCMAR 01.
- ²⁴³LJUBICIC 04 looked for ejection of K-shell electrons by the axioelectric effect of 14.4 keV solar axions in a Germanium detector. The limit assumes the hadronic axion model and the same solar axion flux as in KRCMAR 98 and KRCMAR 01. 244 KRCMAR 01 looked for solar axions emitted by the M1 transition of ⁷Li after the electron
- capture by ${}^{7}\mathrm{Be}$ and the emission of 384 keV line neutrino, using their resonant capture on $^7\mathrm{Li}$ in the laboratory. The mass bound assumes $m_u/m_d =$ 0.56 and the flavor-singlet axial-vector matrix element S=0.4.

Axion Limits from T-violating Medium-Range Forces

V

The limit is for the coupling $g=g_{
m p}\,\,g_{
m S}$ in a $ar{T}$ -violating potential between nucleons or nucleon and electron of the form $V=rac{g\hbar^2}{8\pi m_p}(\pmb{\sigma}\cdot \pmb{\hat{r}})~(rac{1}{r^2}+rac{1}{\lambda r})~e^{-r/\lambda}$, where $g_{\rm p}$ and $g_{\rm S}$ are dimensionless scalar and pseudoscalar coupling constants and $\lambda=\hbar/(m_Ac)$ is the range of the force.

| ALUE | DO CUMENT ID | TECN | COMMENT |
|------|--------------|------|---------|
|------|--------------|------|---------|

| • • • We do not use t | the following data f | or ave | rages, fi | ts, limits, etc. • • • |
|-----------------------|---------------------------|--------|-----------|-------------------------------------|
| | ²⁴⁵ HOEDL | 11 | | torsion pendulum |
| | ²⁴⁶ PETUKHOV | 10 | | polarized ³ He |
| | | 10 | | ultracold neutrons |
| | ²⁴⁸ IGNATOVICH | 09 | RVUE | ultracold neutrons |
| | ²⁴⁹ SEREBROV | 09 | RVUE | ultracold neutrons |
| | ²⁵⁰ BAESSLER | 07 | | ultracold neutrons |
| | ²⁵¹ HECKEL | 06 | | torsion pendulum |
| | 252 _{NI} | 99 | | paramagnetic Tb F ₃ |
| | 253 POSPELOV | 98 | THEO | neutron EDM |
| | 254 YOUDIN | 96 | | |
| | 255 RITTER | 93 | | torsion pendulum |
| | 256 VENEMA | 92 | | nuclear spin-precession frequencies |
| | 257 WINELAND | 91 | NMR | |

- $^{245}\,\mathrm{HOEDL}$ 11 use a novel torsion pendulum to study the force by the polarized electrons of an external magnet. In their Fig. 3 they show restrictive limits on g in the approximate m_{A^0} range 0.03–10 meV.
- 246 PETUKHOV 10 use spin relaxation of polarized 3 He and find $g<3\times10^{-23}~(\text{cm}/\lambda)^2$ at 95% CL for the force range $\lambda=10^{-4}$ -1 cm. 247 SEREBROV 10 use spin precession of ultracold neutrons close to bulk matter and find $g<2\times10^{-21}~(\text{cm}/\lambda)^2$ at 95% CL for the force range $\lambda=10^{-4}$ -1 cm.
- 248 IGNATOVICH 09 use data on depolarization of ultracold neutrons in material traps. They show λ -dependent limits in their Fig. 1.
- 249 SEREBROV 09 uses data on depolarization of ultracold neutrons stored in material traps and finds $g < 2.96 \times 10^{-21} \ (\text{cm}/\lambda)^2$ for the force range $\lambda = 10^{-3} 1$ cm and $g < 3.9 \times 10^{-22} \ (\text{cm}/\lambda)^2$ for $\lambda = 10^{-4} 10^{-3}$ cm, each time at 95% CL, significantly improving on BAESSLER 07.
- $250\,\mathrm{BAESSLER}$ 07 use the observation of quantum states of ultracold neutrons in the Earth's gravitational field to constrain g for an interaction range 1 μ m-a few mm. See their Fig. 3
- 251 HECKEL 06 studied the influence of unpolarized bulk matter, including the laboratory's surroundings or the Sun, on a torsion pendulum containing about 9×10^{22} polarized electrons. See their Fig. 4 for limits on g as a function of interaction range.
- $^{252}\,\mathrm{Nl}$ 99 searched for a T-violating medium-range force acting on paramagnetic Tb F $_3$ salt. See their Fig. 1 for the result.
- 253 POSPELOV 98 studied the possible contribution of *T*-violating Medium-Range Force to the neutron electric dipole moment, which is possible when axion interactions violate *CP*. The size of the force among nucleons must be smaller than gravity by a factor of $2 imes 10^{-10}~(1~{
 m cm}/\lambda_A)$, where $\lambda_A = \hbar/m_A c$.
- 254 YOUDIN 96 compared the precession frequencies of atomic ¹⁹⁹Hg and Cs when a large mass is positioned near the cells, relative to an applied magnetic field. See Fig. 3 for
- 255 RITTER 93 studied the influence of bulk mass with polarized electrons on an unpolarized torsion pendulum, providing limits in the interaction range from 1 to 100 cm
- 256 VENEMA 92 looked for an effect of Earth's gravity on nuclear spin-precession frequencies of $^{199}\mathrm{Hg}$ and $^{201}\mathrm{Hg}$ atoms.
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Gauge & Higgs Boson Particle Listings Axions (A^0) and Other Very Light Bosons

| AT IYA A Iso AT IYA | 93 93 B | PRL 70 2521 PRL 71 305 (erratum) PR D48 R1 | M.S. Atiya et al. M.S. Atiya et al. M.S. Atiya et al. | (BNL E787 Coll (BNL E787 Coll (BNL E787 Coll | ab.) ab.) | VONWIMMER. VOROBYOV DRUZHININ | 88 87 | PRL 60 2443 PL B208 146 ZPHY C37 1 | U. von Wimmersperg (BNL) P.V. Vorobiev, Y.I. Gitarts (NOVO) V.P. Druzhinin et al. (NOVO) |
|----------------------------------|--------------------|--------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------|--------------------|-------------------------------------|--------------------|---------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| BASSOMPIE BECK CAMERON | 93 93 93 | EPL 22 239 PRL 70 2853 PR D47 3707 | R.E. Cameron et al. | (LÁPP, TORI, LYC (MPIH, KIAE, SAS: (ROCH, BNL, FNA | S O) | FRIEMAN GOLDMAN KORENCHE | | PR D36 2201 PR D36 1543 SJNP 46 192 Translated from YAF 46 | J.A. Frieman, S. Dimopoulos, M.S. Turner (SLAC+) T. Goldman et al. (LANL, CHIC, STAN+) S.M. Korenchenko et al. (JINR) 313. |
| CHANG CHUI MINOWA | 93 93 93 | PL B316 51 PRL 71 3247 PRL 71 4120 | S. Chang, K. Choi T.C.P. Chui, W.T. Ni M. Minowa <i>et al.</i> | (NTI (TO | KY) | MAIER MILLS RAFFELT | 87 87 87 | ZPHY A326 527 PR D36 707 PR D36 2211 | K. Maier <i>et al.</i> (STUT, GSI) A.P. Mills, J. Levy (BELL) G.G. Raffelt, D.S.P. Dearborn (LLL, UCB) |
| NG RITTER TANAKA | 93 93 93 | PR D48 2941 PRL 70 701 PR D48 5412 | K.W. Ng R.C. Ritter <i>et al.</i> J. Tanaka, H. Ejiri | (OS. | | RIORDAN TURNER | 87 87 | PRL 59 755 PRL 59 2489 | E.M. Riord an et al. (ROCH, CIT+) M.S. Turner (FNAL, EFI) |
| ALLIEGRO ATIYA BERNATOW | 92 92 92 | PRL 68 278 PRL 69 733 PRL 69 2341 | C. Alliegro <i>et al.</i> M.S. Atiya <i>et al.</i> T. Bernatowicz <i>et al.</i> | (BNL, FNAL, PS (BNL, LANL, PRII (WUSL, TA | N +) | VANBIBBER VONWIMMER. BADIER | 86 | PRL 59 759 PRL 59 266 ZPHY C31 21 | K. van Bibber et al. (LLL, CIT, MIT+) U. von Wimmersperg et al. (WITW) J. Badier et al. (NA3 Collab.) |
| BLUEMLEIN HALLIN HENDERSON | 92 92 92 C | IJMP A7 3835 PR D45 3955 PRL 69 1733 | J. Blumlein et al. A.L. Hallin et al. S.D. Henderson et al. | BERL, BUDA, JINF PF YALE, B | RIN) | BROWN BRYMAN DAVIER | 86 86B 86 | PRL 57 2101 PRL 57 2787 PL B180 295 | C.N. Brown <i>et al.</i> (FNAL, WASH, KYOT+) D.A. Bryman, E.T.H. Clifford (TRIU) M. Davier, J. Jeanjean, H. Nguyen Ngoc (LALO) |
| HICKS LAZARUS MEIJERDREES | 92 92 | PL B276 423 PRL 69 2333 PRL 68 3845 | K.H. Hicks, D.E. Alburger D.M. Lazarus <i>et al.</i> | OHIO, B (BNL, ROCH, FN | NL) AL) | DEARBORN EICHLER HALLIN | 86 86 86 | PRL 56 26 PL B175 101 PRL 57 2105 | D.S.P. Dearborn, D.N. Schramm, G. Steigman (LLL+) R.A. Eichler et al. (SINDRUM Collab.) A.L. Hallin et al. (PRIN) |
| PAN RUOSO | 92 92 | MPL A7 1287 ZPHY C56 505 | | SINDRUM I Coll) NTI) H, BNL, FNAL, TR | HU) ST) | JODIDIO Also KETOV | 86 86 | PR D34 1967 PR D37 237 (erratum) JETPL 44 146 | A. Jodidio et al. (LBL, NWES, TRIU) A. Jodidio et al. (LBL, NWES, TRIU) |
| SKALSEY VENEMA WANG | 92 92 92 | | M. Skalsey, J.J. Kolata B.J. Venema <i>et al.</i> J. Wang | | ILL) | KOCH KONAKA | 86 86 | Translated from ZETFP 4 NC 96A 182 PRL 57 659 | H.R. Koch, O.W.B. Schult (JULI) |
| WANG WU AKOPYAN | 92 C 92 91 | PL B291 97 PRL 69 1729 PL B272 443 | J. Wang X.Y. Wu <i>et al.</i> M.V. Akopyan <i>et al.</i> | (I BNL, YALE, CUI) (INF | | MAIANI PECCEI | 86 86 | PL B175 359 PL B172 435 | L. Maiani, R. Petronzio, E. Zavattini (CERN) R.D. Peccei, T.T. Wu, T. Yanagida (DESY) |
| ASAI BERSHADY BLUEMLEIN | 91 91 91 | PRL 66 2440 PRL 66 1398 ZPHY C51 341 | S. Asai et al. M.A. Bershady, M.T. Ressell, M.S | (ÌCE Turner (CHIC) BERL, BUDA, JINF | C+) | RAFFELT RAFFELT SAVAGE | 86 86B 86B | PR D33 897 PL 166B 402 PRL 57 178 | G.G. Raffelt (MPIM) G.G. Raffelt (MPIM) M.J. Savage <i>et al.</i> (CIT) |
| BOBRAKOV BROSS | 91 91 | JETPL 53 294 Translated from ZETFP 5 PRL 67 2942 | V.F. Bobrakov et al. | (PN (FNAL, I | NPI) | AMALDI ANANEV | 85 85 | | U. Amaldi [*] et al. (CÈRN) V.D. Ananev et al. (JINR) 912. |
| KIM RAFFELT RAFFELT | 91 C 91 91 B | PRL 67 3465 PRPL 198 1 PRL 67 2605 | J.E. Kim G.G. Raffelt G. Raffelt, D. Seckel | (SEO (MP (MPIM, BA | iUL) PIM) | BALTRUSAIT BERGSMA KAPLAN | . 85 85 85 | PRL 55 1842 PL 157B 458 NP B260 215 | R.M. Baltrusaitis et al. (Mark III Collab.) F. Bergsma et al. (CHARM Collab.) D.B. Kaplan (HARV) |
| RESSELL TRZASKA TSERTOS | 91 91 | PR D44 3001 PL B269 54 | M.T. Ressell W.H. Trzaska et al. | `(CHIC, FN (TAI | AL) MU) | IWAMOTO YAMAZAKI ABBOTT | 84 84 83 | PRL 53 1198 PRL 52 1089 PL 120B 133 | N. Iwamoto (UCSB, WUSL) T. Yamazaki et al. (INUS, KEK) L.F. Abbott, P. Sikivie (BRAN, FLOR) |
| WALKER WIDMANN | 91 91 91 | PL B266 259 APJ 376 51 ZPHY A340 209 | H. Tsertos et al. T.P. Walker et al. E. Widmann et al. | (ILLG, C HSCA, OSU, CHIC STUT, GSI, STUT | С+)́ ГМ) | CARBONI CAVAIGNAC DICUS | 83 83 83 | PL 123B 349 PL 121B 193 PR D28 1778 | G. Carboni, W. Dahme (CERN, MUNI) J.F. Cavaignac et al. (ISNG, LAPP) D.A. Dicus, V.L. Teplitz (TEXA, UMD) |
| WINELAND ALBRECHT ASANUMA | 91 90 E 90 | PRL 67 1735 PL B246 278 PL B237 588 | D.J. Wineland <i>et al.</i> H. Albrecht <i>et al.</i> T. Asanuma <i>et al.</i> | (NB (ARGUS Coll (TO | ab.) KY) | DINE ELLIS | 83 83 B | PL 120B 137 NP B223 252 | M. Dine, W. Fischler (IAS, PENN) J. Ellis, K.A. Olive (CERN) |
| ATIYA ATIYA BAUER | 90 90 B 90 | PRL 64 21 PRL 65 1188 NIM B50 300 | M.S. Atiya et al. M.S. Atiya et al. W. Bauer et al. | (BNL E787 Coll (BNL E787 Coll (STUT, VILL, (| ab.) | FAISS NER FAISS NER FRANK | 83 83 B 83 B | PR D28 1198 PR D28 1787 PR D28 1790 | H. Faissner et al. (AACH) H. Faissner et al. (AACH3) J.S. Frank et al. (LANL, YALE, LBL+) |
| BURROWS DEBOER ENGEL | 90 90 90 | PR D42 3297 JPG 16 L1 PRL 65 960 | A. Burrows, M.T. Ressell, M.S. Tr F.W.N. de Boer, J. Lehmann, J. S J. Engel, D. Seckel, A.C. Hayes | urner (ARI: | Z+) UV) | HOFFMAN PRESKILL SIKIVIE | 83 83 83 | PR D28 660 PL 120B 127 PRL 51 1415 | C.M. Hoffman et al. (LANL, ARZS) J. Preskill, M.B. Wise, F. Wilczek (HARV, UCSBT) P. Sikivie (FLOR) |
| GNINENKO GUO HAGMANN | 90 90 90 | PL B237 287 PR D41 2924 PR D42 1297 | S.N. Gninenko et al. | (INF LANL, FNAL, CASI (FL) | RM) E+) | Also ALEKSEEV | | PRL 52 695 (erratum) JETP 55 591 Translated from ZETF 82 | |
| JUDGE RAFFELT RITTER | 90 90 D 90 | PRL 65 972 PR D41 1324 PR D42 977 | G.M. Judge et al. G.G. Raffelt R.C. Ritter et al. | (ILLĠ, ((MP | GSI) | ALEKSEEV AS ANO | 82 | PL 113B 195 | G.D. Alekseev et al. (MOSU, JINR) 36 94. Y. Asano et al. (KEK, TOKY, INUS, OSAK) |
| SEMERT ZIDIS TS UCHIAKI | 90 90 | PRL 64 2988 PL B236 81 | Y.K. Semertzidis et al. M. Tsuchiaki et al. | (ROCH, BNL, FNA) (ICE) | L+) PP) | BARROSO DATAR EDWARDS | 82 82 82 | PL 116B 247 PL 114B 63 PRL 48 903 | A. Barroso, G.C. Branco (LISB) V.M. Datar et al. (BHAB) C. Edwards et al. (Crystal Ball Collab.) |
| TURNER BARABASH BINI | 90 89 89 | PRPL 197 67 PL B223 273 PL B221 99 | M.S. Turner A.S. Barabash et al. M. Bini et al. | (FN (ITEP, INF (FIRZ, CERN, AA | RM) RH) | FETSCHER FUKUGITA FUKUGITA | 82 82 82 B | JPG 8 L147 PRL 48 1522 PR D26 1840 | W. Fetscher (ETH) M. Fukugita, S. Watamura, M. Yoshimura (KEK) M. Fukugita, S. Watamura, M. Yoshimura (KEK) |
| BURROWS Also DEBOER | 89 89B | PR D39 1020 PRL 60 1797 PRL 62 2639 | A. Burrows, M.S. Turner, R.P. Br M.S. Turner F.W.N. de Boer, R. van Dantzig | (FNÀL, E (AN | EFI) IIK) | LEHMANN RAFFELT ZEHNDER | 82 82 82 | PL 115B 270 PL 119B 323 PL 110B 419 | P. Lehmann <i>et al.</i> (\$ACL) G. Raffelt, L. Stodolsky (MPIM) A. Zehnder, K. Gabathuler, J.L. Vuilleumier (ETH+) |
| ERICS ON FAISS NER FOX | 89 89 89 | PL B219 507 ZPHY C44 557 PR C39 288 | T.E.O. Ericson, J.F. Mathiot H. Faissner <i>et al.</i> J.D. Fox <i>et al.</i> | (CERN, II (AACH3, BERL, I (F | PN) PSI) SU) | AS AN O BARROS O FAISS NER | 81B 81 81 | PL 107B 159 PL 106B 91 ZPHY C10 95 | Y. Asano et al. (KEK, TOKY, INUS, OSAK) A. Barroso, N.C. Mukhopadhyay (SIN) H. Faissner et al. (AACH3) |
| MAYLE Also MINOWA | 89 89 | PL B219 515 PL B203 188 PRL 62 1091 | R. Mayle et al. (LLL, C R. Mayle et al. (LLL, C H. Minowa et al. | SERN, MINN, FNA SERN, MINN, FNA (ICE | L+) | FAISS NER KIM VUILLEUMIER | 81B 81 | PL 103B 234 PL 105B 55 PL 101B 341 | H. Faissner et al. (AACH3) B.R. Kim, C. Stamm (AACH3) J.L. Vuilleumier et al. (CIT, MUNI) |
| ORITO PERKINS TSERTOS | 89 89 89 | PRL 63 597 PRL 62 2638 PR D40 1397 | S. Orito et al. D.H. Perkins H. Tsertos et al. | (ICE (O (GSI, IL | XF) | ZEHNDER FAISSNER JACQUES | 81 80 80 | PL 104B 494 PL 96B 201 PR D21 1206 | A. Zehnder (ETH) H. Faissner et al. (AACH3) P.F. Jacques et al. (RUTG, STEV, COLU) |
| VANBIBBER WUENSCH Also | 89 89 | PR D39 2089 PR D40 3153 PRL 59 839 | K. van Bibber et al. W.U. Wuensch et al. S. de Panfilis et al. | (LLL, TÀMU, L (ROCH, BNL, FN (ROCH, BNL, FN | BL) AL) | SOUKAS BECHIS | 80 79 | PRL 44 564 PRL 42 1511 | A. Soukas et al. (BNL, HARV, ORNL, PENN) D.J. Bechis et al. (UMD, COLU, AFRR) |
| AVIGNONE BJORKEN BLINOV | 88 88 88 | PR D37 618 PR D38 3375 SJNP 47 563 | | PŘIN, SCUC, ORN (FNAL, SLAC, V (NO | L+) /PI) | CALAPRICE COTEUS DISHAW | 79 79 79 | PR D20 2708 PRL 42 1438 PL 85B 142 | F.P. Calaprice et al. (PRIN) P. Coteus et al. (COLU, ILL, BNL) J.P. Dishaw et al. (SLAC, CIT) |
| BOLT ON Also | 88 | | B89. R.D. Bolton <i>et al.</i> (| LANL, STAN, CHIC LANL, STAN, CHIC | C+) | ZHITNITSKII ALIBRAN ASRATYAN | 78 | SJNP 29 517 Translated from YAF 29 PL 74B 134 PL 79B 497 | P. Alibran et al. (Gargamelle Collab.) |
| Also CHANDA CHOI | 88 88 | PRL 57 3241 PR D37 2714 PR D37 3225 | | CHIC, LANL, STAI UMD, UPF | N+) | BELLOTTI BOSETTI | 78 78 B | PL 76B 223 PL 74B 143 | A.E. Asratyan et al. (ITEP, SERP) E. Bellotti, E. Fiorini, L. Zanotti P.C. Bosetti et al. (BEBC Collab.) D.A. Dicus et al. (TEXA. VPI. STAN) |
| CONNELL DATAR DEBOER | 88 88 88 | PRL 60 2242 PR C37 250 PRL 61 1274 | V.M. Connell et al. V.M. Datar et al. F.W.N. de Boer, R. van Dantzig | TIŴ) I) | | DICUS DONNELLY Also | 78 C 78 | PR D18 1829 PR D18 1607 PRL 37 315 | T.W. Donnelly et al. (STAN) F. Reines, H.S. Gurr, H.W. Sobel (UCI) |
| A Iso A Iso | 00 | PRL 62 2644 (erratum) PRL 62 2638 | F.W.N. de Boer, R. van Dantzig D.H. Perkins F.W.N. de Boer, R. van Dantzig | (AN (O | IIK) XF) | Also HANSL MICELMAC | 78 | PRL 33 179 PL 74B 139 LNC 21 441 | H.S. Gurr, F. Reines, H.W. Sobel T. Hansl et al. G.V. Mitselmakher, B. Pontecorvo (CDHS Collab.) (JINR) |
| Also DEBOER DOEHNER | 88 C 88 | PRL 62 2639 JPG 14 L131 PR D38 2722 | F.W.N. de Boer et al. J. Dohner et al. | (LO (HEIDP, ANL, IL | .LG) | MIKAELIAN SATO VYSOTSKII | 78 78 78 | PR D18 3605 PTP 60 1942 JETPL 27 502 | K.O. Mikaelian (FNAL, NWES) K. Sato (KYOT) M.I. Vysotsky et al. (ASCI) |
| EL-NADI ENGEL FAISSNER | 88 88 88 | PRL 61 1271 PR C37 731 ZPHY C37 231 | M. el Nadi, O.E. Badawy J. Engel, P. Vogel, M.R. Zirnbaue H. Faissner et al. | r (AACH3, BERL, S | | YANG PECCEI | 78 77 | PRL 41 523 PR D16 1791 | 27 533. T.C. Yang (MASA) R.D. Peccei, H.R. Quinn (STAN, SLAC) |
| HATSUDA LORENZ MAYLE | 88 B 88 | PL B203 469 PL B214 10 PL B203 188 | | (MPIM), F SERN, MINN, FNA | L+) | Also REINES GURR | 76 74 | PRL 38 1440 PRL 37 315 PRL 33 179 | R.D. Peccei, H.R. Quinn (STAN, SLAC) F. Reines, H.S. Gurr, H.W. Sobel H.S. Gurr, F. Reines, H.W. Sobel (UCI) |
| PICCIOTTO RAFFELT RAFFELT | 88 88 88 B | PR D37 1131 PRL 60 1793 PR D37 549 | C.E. Picciotto <i>et al.</i> G. Raffelt, D. Seckel G.G. Raffelt, D.S.P. Dearborn | (TRIU, CN (UCB, LLL, UC (UCB, L | SC) LLL) | ANAND | 53 | PRSL A22 183 | RELATED PAPERS ——— |
| SAVAGE TSERTOS TSERTOS | 88 88 88 B | PR D37 1134 PL B207 273 ZPHY A331 103 | M.J. Savage, B.W. Filippone, L.W A. Tsertos <i>et al.</i> A. Tsertos <i>et al.</i> | (GSI, IL (GSI, IL | .LG) | SREDNICKI | 85 | NP B260 689 | M. Srednicki (UCSB) |
| | 88 88 B | PL B205 223 PRL 60 2442 | J. van Klinken <i>et al.</i> J. van Klinken | (GRON, G (GR | on) | BARDEEN | 78 | PL 74B 229 | W.A. Bardeen, SH.H. Tye (FNAL) |

LEPTONS

| e | | | | | | | | | | | | 581 |
|-------------------------------------------|-------|------|-----|----|-----|-----|-----|-----|--|--|--|-----|
| μ | | | | | | | | | | | | 582 |
| au | | | | | | | | | | | | 592 |
| Heavy Charged Lepton Searches | | | | | | | | | | | | 621 |
| Neutrino Properties | | | | | | | | | | | | 622 |
| Number of Neutrino Types | | | | | | | | | | | | |
| Double- β Decay | | | | | | | | | | | | |
| Neutrino Mixing | | | | | | | | | | | | 636 |
| Heavy Neutral Leptons, Searches | for | | | | | | | | | | | 647 |
| Notes in the Lenten Linking | | | | | | | | | | | | |
| Notes in the Lepton Listings | | | | | | | | | | | | |
| Muon Anomalous Magnetic Moment | (rev. | .) | | | | | | | | | | 583 |
| Muon Decay Parameters (rev.) | | | | | | | | | | | | 587 |
| au Branching Fractions (rev.) | | | | | | | | | | | | 596 |
| au-Lepton Decay Parameters | | | | | | | | | | | | 617 |
| Number of Light Neutrino Types from | n Co | llic | ler | Ex | pei | rin | ıer | nts | | | | 629 |
| Neutrinoless Double- β Decay (rev.) | | | | | | | | | | | | 631 |



LEPTONS



 $J = \frac{1}{2}$

e MASS (atomic mass units u)

The primary determination of an electron's mass comes from measuring the ratio of the mass to that of a nucleus, so that the result is obtained in u (atomic mass units). The conversion factor to MeV is more uncertain than the mass of the electron in u; indeed, the recent improvements in the mass determination are not evident when the result is given in MeV. In this datablock we give the result in u, and in the following datablock in MeV.

| VALUE (10 ⁻⁶ u) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|----------------------|----------|-------------|-------------------|
| $548.57990946 \pm 0.00000022$ | MOHR | 12 | RVUE | 2010 CODATA value |
| ullet $ullet$ We do not use the following | data for averages | s, fits, | , limits, e | etc. • • • |
| $548.57990943 \pm 0.00000023$ | MOHR | 80 | RVUE | 2006 CODATA value |
| $548.57990945 \pm 0.00000024$ | MOHR | 05 | RVUE | 2002 CODATA value |
| 548.5799092 ±0.0000004 | ^L BEIER | 02 | CNTR | Penning trap |
| 548.5799110 ±0.0000012 | MOHR | 99 | RVUE | 1998 CODATA value |
| 548.5799111 ±0.0000012 | ² FARNHAM | 95 | CNTR | Penning trap |
| 548.579903 ± 0.000013 | COHEN | 87 | RVUE | 1986 CODATA value |

 $^{^1}$ BEIER 02 compares Larmor frequency of the electron bound in a $^{12}{\rm C}^{5+}$ ion with the cyclotron frequency of a single trapped $^{12}{\rm C}^{5+}$ ion.

e MASS

2010 CODATA (MOHR 12) gives the conversion factor from u (atomic mass units, see the above datablock) to MeV as 931.494 061 (21). Earlier values use the then-current conversion factor. The conversion error dominates the uncertainty of the masses given below.

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|------------------------|---------|-------------|-------------------|
| $0.510998928 \pm 0.000000011$ | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • We do not use the follow | owing data for aver | ages, f | fits, limit | s, etc. • • • |
| $0.510998910 \pm 0.000000013$ | MOHR | 08 | RVUE | 2006 CODATA value |
| $0.510998918 \pm 0.000000044$ | MOHR | 05 | RVUE | 2002 CODATA value |
| $0.510998901\pm0.000000020$ | ^{3,4} BEIER | 02 | CNTR | Penning trap |
| $0.510998902 \pm 0.000000021$ | MOHR | 99 | RVUE | 1998 CODATA value |
| $0.510998903 \pm 0.000000020$ | ^{3,5} FARNHAM | 95 | CNTR | Penning trap |
| $0.510998895 \pm 0.0000000024$ | ³ COHEN | 87 | RVUE | 1986 CODATA value |
| 0.5110034 ± 0.0000014 | COHEN | 73 | RVUE | 1973 CODATA value |

 $^{^3}$ Converted to MeV using the 1998 CODATA value of the conversion constant, 931.494013 \pm 0.000037 MeV/u.

$$(m_{e^+} - m_{e^-}) / m_{average}$$

A test of CPT invariance.

| VALUE | CL% | DO CUMEN | T ID | TECN | COMMENT |
|----------------------|---------------|---------------|--------------|------------|--------------------------|
| $< 8 \times 10^{-9}$ | 90 | 6 FEE | 93 | CNTR | Positronium spectroscopy |
| • • • We do not u | se the follow | wing data for | averages, fi | ts, limits | , etc. • • • |
| <4 × 10-8 | 9.0 | CHII | 84 | CNTR | Positronium spectroscopy |

 $^{^6\,\}text{FEE}$ 93 value is obtained under the assumption that the positronium Rydberg constant is exactly half the hydrogen one.

$$|q_{e^+} + q_{e^-}|/e$$

A test of $\ensuremath{\mathit{CPT}}$ invariance. See also similar tests involving the proton.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|----------|-----------|---------------------|
| <4 × 10 ⁻⁸ | 7 HUGHES | 92 | RVUE | |
| • • • We do not use the follow | ving data for average | es, fits | , limits, | etc. • • • |
| $< 2 \times 10^{-18}$ | ⁸ SCHAEFER | 95 | THEO | Vacuum polarization |
| $<1 \times 10^{-18}$ | 9 MUELLER | 92 | THEO | Vacuum polarization |

⁷HUGHES 92 uses recent measurements of Rydberg-energy and cyclotron-frequency ra-

e MAGNETIC MOMENT ANOMALY

$\mu_e/\mu_B - 1 = (g-2)/2$

| VALUE (units 10 ⁻⁶) | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------|--------------------|--------|-----------|----------|-------------------|
| 1159.65218076±0.00000027 | MOHR | 12 | RVUE | | 2010 CODATA value |
| • • • We do not use the following | owing data for ave | rages, | fits, lim | its, etc | i. • • • |
| $1159.65218073{\pm}0.00000028$ | HANNEKE | 08 | MRS | | Single electron |
| $1159.65218111\pm0.00000074$ | ¹⁰ MOHR | 80 | RVUE | | 2006 CODATA value |
| $1159.65218085\pm0.00000076$ | ¹¹ ором | 06 | MRS | _ | Single electron |
| $1159.6521859 \pm 0.0000038$ | MOHR | 05 | RVUE | | 2002 CODATA value |
| $1159.6521869 \pm 0.0000041$ | MOHR | 99 | RVUE | | 1998 CODATA value |
| 1159.652193 ± 0.000010 | COHEN | 87 | RVUE | | 1986 CODATA value |
| $1159.6521884 \pm 0.0000043$ | VANDYCK | 87 | MRS | _ | Single electron |
| $1159.6521879 \pm 0.0000043$ | VANDYCK | 87 | MRS | + | Single positron |
| 1.0 | | | | | |

¹⁰ MOHR 08 average is dominated by ODOM 06.

$(g_{e^+} - g_{e^-}) / g_{average}$

A test of CPT invariance.

| VALUE (units 10 ⁻¹²) | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------|---------------|--------------------------|----------|-----------|-----------------------------|
| -0.5 ± 2.1 | | ¹² VANDYCK | 87 | MRS | Penning trap |
| ● ● We do not us | e the followi | ng data for averag | es, fits | , limits, | etc. • • • |
| < 12 | 95 | ¹³ VASSERMAN | 87 | CNTR | Assumes $m_{e^+} = m_{e^-}$ |
| 22 ±64 | | SCHWINBER | G 81 | MRS | Penning trap |
| ¹² VA NDYCK 87 n | neasured (g_ | $/g_{\perp})-1$ and we c | onvert | ed it. | |
| 13.4.66=5.44.4 | | , | | | |

 $^{^{13}\,\}rm VA\,SSER\,MA\,N$ 87 measured $(g_+-g_-)/(g-2).$ We multiplied by $(g-2)/g=1.2\times 10^{-3}.$

e ELECTRIC DIPOLE MOMENT (d)

A nonzero value is forbidden by both T invariance and P invariance.

| VALUE (10 ⁻²⁸ ecm) | CL% | DO CUMENT ID | TEC | N COMMENT |
|-------------------------------|-----------|------------------------|-------------|---------------------------|
| < 10.5 | 90 | ¹⁴ HUDSON | 11 NM | IR YbF molecules |
| • • • We do not use the | following | data for averages, fi | ts, limits, | etc. • • • |
| 6.9± 7.4 | | REGAN | 02 MR | S ²⁰⁵ Tl beams |
| 18 \pm 12 \pm | 10 | ¹⁵ COMMINS | 94 MR | S ²⁰⁵ Tl beams |
| $-$ 27 \pm 83 | | ¹⁵ ABDULLAH | 90 MR | S ²⁰⁵ Tl beams |
| $-$ 1400 \pm 2400 | | CHO | 89 NM | IR TI F molecules |
| $-$ 150 \pm 550 \pm | 150 | MURTHY | 89 | Cesium, no B field |
| -5000 ± 11000 | | LAMOREAUX | 87 NM | IR ¹⁹⁹ Hg |
| 19000 ± 34000 | 90 | SANDARS | 75 MR | S Thallium |
| 7000 ± 22000 | 90 | PLAYER | 70 MR | S Xenon |
| < 30000 | 90 | WEISSKOPF | 68 MR | S Cesium |

 $^{^{14}}$ HUDSON 11 gives a measurement corresponding to this limit as $(-2.4\pm5.7\pm1.5)\times$._ 10^{-28} ecm.

e- MEAN LIFE / BRANCHING FRACTION

A test of charge conservation. See the "Note on Testing Charge Conservation and the Pauli Exclusion Principle" following this section in our 1992 edition (Physical Review **D45** S1 (1992), p. VI.10).

Most of these experiments are one of three kinds: Attempts to observe (a) the 255.5 keV gamma ray produced in $e^- \to \nu_e \gamma$, (b) the (K) shell x ray produced when an electron decays without additional energy deposit, e.g., $e^- \to \nu_e \overline{\nu}_e \nu_e$ ("disappearance" experiments), and (c) nuclear deexcitation gamma rays after the electron disappears from an atomic shell and the nucleus is left in an excited state. The last can include both weak boson and photon mediating processes. We use the best $e^- \to \nu_e \gamma$ limit for the Summary Tables.

Note that we use the mean life rather than the half life, which is often reported. $% \left(1\right) =\left(1\right) \left(1\right$

$e ightarrow u_e \gamma$ and astrophysical limits

| VALUE (yr) | CL% | DO CUMENT ID | TECN | COMMENT |
|------------------------------------|--------------|----------------------------|--------------|---------------------------------------------------|
| >4.6 × 10 ²⁶ | 90 | BACK 02 | BORX | $e^- \rightarrow \nu \gamma$ |
| ● ● We do not | use the foll | owing data for averages | , fits, limi | ts, etc. • • • |
| $> 1.22 \times 10^{26}$ | 68 | ¹⁶ KLAPDOR-K 07 | CNTR | $e^- \rightarrow \nu \gamma$ |
| $> 3.4 \times 10^{26}$ | 68 | BELLI 00 | B DAMA | $e^- ightarrow u \gamma$, liquid Xe |
| $> 3.7 \times 10^{25}$ | 68 | AHARONOV 95 | 3 CNTR | $e^- ightarrow u \gamma$ |
| $>$ 2.35 \times 10 ²⁵ | 68 | BALYSH 93 | CNTR | $e^- ightarrow u \gamma$, 76 Ge detector |
| $>1.5 \times 10^{25}$ | 68 | | CNTR | $e^- ightarrow u \gamma$ |
| >1 $\times 10^{39}$ | | ¹⁷ ORITO 85 | ASTR | Astrophysical argument |
| $>3 \times 10^{23}$ | 68 | BELLOTTI 83 | 3 CNTR | $e^- \rightarrow \nu \gamma$ |

¹⁶ The authors of A. Derbin et al, arXiv:0704.2047v1 argue that this limit is overestimated by at least a factor of 5.

 $^{^2}$ FARNHAM 95 compares cyclotron frequency of trapped electrons with that of a single trapped 12 C $^{6+}$ ion.

 $^{^4}$ BEIER 02 compares Larmor frequency of the electron bound in a $^{12}\mathrm{C}^{5+}$ ion with the cyclotron frequency of a single trapped $^{12}\mathrm{C}^{5+}$ ion.

 $^{^{5}\,\}text{FARNHAM}$ 95 compares cyclotron frequency of trapped electrons with that of a single trapped $^{12}\text{C}^{6+}$ ion.

⁸ SCHAEFER 95 removes model dependency of MUELLER 92.

⁹ MUELLER 92 argues that an inequality of the charge magnitudes would, through higherorder vacuum polarization, contribute to the net charge of atoms.

¹¹ Superseded by HANNEKE 08 per private communication with Gerald Gabrielse.

¹⁵ ABDULLAH 90, COMMINS 94, and REGAN 02 use the relativistic enhancement of a valence electron's electric dipole moment in a high-Z atom.

 $^{^{17}}$ ORITO 85 assumes that electromagnetic forces extend out to large enough distances and that the age of our galaxy is 10^{10} years.

e, μ

Disappearance and nuclear-de-excitation experiments

| VALUE (yr) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------|-----------------------|--------|--------------|--------------------------------------------|
| >6.4 × 10 ²⁴ | 68 | 18 BELLI | | | De-excitation of ¹²⁹ Xe |
| ● ● We do not | use the 1 | following data for av | rerage | s, fits, lii | mits, etc. • • • |
| $>$ 4.2 \times 10 ²⁴ | 68 | BELLI | 99 | | lodine L-shell disappearance |
| $>$ 2.4 \times 10 ²³ | 90 | ¹⁹ BELLI | 99D | DA MA | De-excitation of ¹²⁷ I (in NaI) |
| $>$ 4.3 \times 10 ²³ | 68 | AHARONOV | 95B | CNTR | Ge K-shell disappearance |
| $>$ 2.7 \times 10 ²³ | 68 | REUSSER | 91 | CNTR | Ge K-shell disappearance |
| $>2 \times 10^{22}$ | 68 | BELLOTTI | 83B | CNTR | Ge K-shell disappearance |

 $^{^{18}}$ BELLI 998 limit on charge nonconserving e $^-$ capture involving excitation of the 236.1 keV nuclear state of 129 Xe; the 90% CL limit is 3.7 \times 10^{24} yr. Less stringent limits for other states are also given.

LIMITS ON LEPTON-FLAVOR VIOLATION IN PRODUCTION

Forbidden by lepton family number conservation.

This section was added for the 2008 edition of this *Review* and is not complete. For a list of further measurements see references in the papers listed below.

$\sigma(e^+e^- \rightarrow e^{\pm}\tau^{\mp}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$

| - 1 | . ,, - | (<i>F</i> - | - , | | |
|------------------------|------------|--------------------|---------|--------------|-----------------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
| $< 8.9 \times 10^{-6}$ | 95 | AUBERT | 07P | BABR | e^+e^- at $E_{\rm cm}=10.58~{ m GeV}$ |
| | ise the fo | llowing data for a | verages | s, fits, lin | nits, etc. • • • |
| $< 1.8 \times 10^{-3}$ | 95 | GOMEZ-CAD | 91 | MRK2 | e^+e^- at $E_{ m cm}=$ 29 GeV |

$\sigma(e^+e^- \rightarrow \mu^{\pm}\tau^{\mp}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------|------------|-------------------|--------|-----------|----------------------------------------|
| $<4.0 \times 10^{-6}$ | 95 | AUBERT | 07p | BABR | e^+e^- at $E_{ m cm}=10.58~{ m GeV}$ |
| ● ● We do not use | the follow | wing data for ave | rages, | fits, lim | its, etc. • • • |
| $<\!6.1\times10^{-3}$ | 95 | GOMEZ-CAD | 91 | MRK2 | e^+e^- at $E_{ m cm}=$ 29 GeV |

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 $J = \frac{1}{2}$

μ MASS (atomic mass units u)

The muon's mass is obtained from the muon-electron mass ratio as determined from the measurement of Zeeman transition frequencies in muonium $(\mu^+e^-$ atom). Since the electron's mass is most accurately known in u, the muon's mass is also most accurately known in u. The conversion factor to MeV has approximately the same relative uncertainty as the mass of the muon in u. In this datablock we give the result in u, and in the following datablock in MeV.

| VALUE (u) | DO CUMENT I | D | TECN | COMMENT | _ |
|---------------------------------|--------------------|------------|---------|-------------------|---|
| $0.1134289267 \pm 0.0000000029$ | MOHR | 12 | RVUE | 2010 CODATA value | |
| • • • We do not use the followi | ng data for avera | ges, fits, | limits, | etc. • • • | |
| $0.1134289256 \pm 0.0000000029$ | MOHR | 08 | RVUE | 2006 CODATA value | |
| $0.1134289264 \pm 0.0000000030$ | MOHR | 05 | RVUE | 2002 CODATA value | |
| $0.1134289168 \pm 0.0000000034$ | 1 MOHR | 99 | RVUE | 1998 CODATA value | |
| $0.113428913 \pm 0.000000017$ | ² COHEN | 87 | RVUE | 1986 CODATA value | |

 $[\]frac{1}{2}$ MOHR 99 make use of other 1998 CODATA entries below.

μ MASS

2010 CODATA (MOHR 12) gives the conversion factor from u (atomic mass units, see the above datablock) to MeV as 931.494.061 (21). Earlier values use the then-current conversion factor. The conversion error contributes significantly to the uncertainty of the masses given below.

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|---------------------------------|-----------------------|---------|-----------|----------|-------------------|
| $105.6583715 \pm 0.0000035$ | MOHR | 12 | RVUE | | 2010 CODATA value |
| ullet $ullet$ We do not use the | following data for av | erages, | fits, lim | its, etc | i. • • • |
| $105.6583668 \pm 0.0000038$ | MOHR | 80 | RVUE | | 2006 CODATA value |
| $105.6583692 \pm 0.0000094$ | MOHR | 05 | RVUE | | 2002 CODATA value |
| $105.6583568 \pm 0.0000052$ | MOHR | 99 | RVUE | | 1998 CODATA value |
| 105.658353 ± 0.000016 | ³ COHEN | 87 | RVUE | | 1986 CODATA value |
| 105.658386 ± 0.000044 | ⁴ MARIAM | 82 | CNTR | + | |
| 105.65836 ±0.00026 | ⁵ CROWE | 72 | CNTR | | |
| 105.65865 ± 0.00044 | ⁶ CRANE | 71 | CNTR | | |

 $^{^3}$ Converted to MeV using the 1998 CODATA value of the conversion constant, 931.494013 \pm 0.000037 MeV/u.

μ MEAN LIFE au

Measurements with an error $>~0.001\times10^{-6}\,\text{s}$ have been omitted.

| VALUE (10 ⁻⁶ s) | DO CUMENT ID | | TECN | CHC | COMMENT |
|--------------------------------------|--------------|----|------|-----|-------------------------------------|
| 2.1969811 ± 0.0000022 OUR AVER/ | AGE | | | | |
| 2.1969803 ± 0.0000022 | WEBBER | 11 | CNTR | + | Surface μ^+ at PSI |
| $2.197083 \pm 0.000032 \pm 0.000015$ | BARCZYK | 80 | CNTR | + | Muons from π^+ decay at rest |
| $2.197013 \pm 0.000021 \pm 0.000011$ | CHITWOOD | 07 | CNTR | + | Surface μ^+ at PSI |
| 2.197078 ± 0.000073 | BARDIN | 84 | CNTR | + | |
| 2.197025 ± 0.000155 | BARDIN | 84 | CNTR | _ | |
| 2.19695 ± 0.00006 | GIOVA NETTI | 84 | CNTR | + | |
| 2.19711 ± 0.00008 | BALANDIN | 74 | CNTR | + | |
| 2.1973 ± 0.0003 | DUCLOS | 73 | CNTR | + | |

au_{μ^+}/ au_{μ^-} MEAN LIFE RATIO

A test of CPT invariance.

| VALUE | | DOCUMENT ID | | TECN | COMMENT |
|---------|-----------------------------|-------------------|----------|---------|--------------------------|
| 1.00002 | 4±0.000078 | BARDIN | 84 | CNTR | |
| • • • V | Ve do not use the following | data for averages | s, fits, | limits, | etc. • • • |
| 1.0008 | ±0.0010 | BAILEY | | | Storage ring |
| 1.000 | ±0.001 | MEYER | 63 | CNTR | Mean life $\mu^+/~\mu^-$ |

$$(\tau_{\mu^+} - \tau_{\mu^-}) / \tau_{\text{average}}$$

A test of *CPT* invariance. Calculated from the mean-life ratio, above.

 $\frac{\text{VALUE}}{(2\pm8)\times10^{-5} \text{ OUR EVALUATION}} \frac{\text{DO CUMENT ID}}{}$

 $^{^{19}}$ BELLI 99D limit on charge nonconserving e^- capture involving excitation of the 57.6 keV nuclear state of 127 I. Less stringent limits for the other states and for the state of 23 Na are also given.

² COHEN 87 make use of other 1986 CODATA entries below.

⁴ MARIAM 82 give $m_{\mu}/m_e = 206.768259(62)$.

⁵ CROWE 72 give $m_{\mu}/m_{e} = 206.7682(5)$.

⁶ CRANE 71 give $m_{\mu}/m_e = 206.76878(85)$.

μ/p MAGNETIC MOMENT RATIO

This ratio is used to obtain a precise value of the muon mass and to reduce experimental muon Larmor frequency measurements to the muon magnetic moment anomaly. Measurements with an error > 0.00001 have been omitted. By convention, the minus sign on this ratio is omitted. CODATA values were fitted using their selection of data, plus other data from multiparameter fits.

| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------------------------|-------------------|--------|-------------|---------|-------------------|
| $3.183345137 \pm 0.000000085$ | MOHR | 80 | RVUE | | 2006 CODATA value |
| | ving data for ave | rages, | fits, limit | ts, etc | . • • • |
| $3.183345118 \pm 0.000000089$ | MOHR | 05 | RVUE | | 2002 CODATA value |
| $3.18334513 \pm 0.00000039$ | LIU | 99 | CNTR | + | HFS in muonium |
| $3.18334539 \pm 0.00000010$ | MOHR | 99 | RVUE | | 1998 CODATA value |
| $3.18334547 \pm 0.00000047$ | COHEN | 87 | RVUE | | 1986 CODATA value |
| 3.1833441 ± 0.0000017 | KLEMPT | 82 | CNTR | + | Precession strob |
| 3.1833461 ± 0.0000011 | MARIAM | 82 | CNTR | + | HFS splitting |
| 3.1833448 ± 0.0000029 | CA MA NI | 78 | CNTR | + | See KLEMPT 82 |
| 3.1833403 ± 0.0000044 | CASPERSON | 77 | CNTR | + | HFS splitting |
| 3.1833402 ± 0.0000072 | COHEN | 73 | RVUE | | 1973 CODATA value |
| 3.1833467 ± 0.0000082 | CROWE | 72 | CNTR | + | Precession phase |

THE MUON ANOMALOUS MAGNETIC MOMENT

Updated July 2011 by A. Hoecker (CERN), and W.J. Marciano (BNL).

The Dirac equation predicts a muon magnetic moment, $\vec{M} = g_{\mu} \frac{e}{2m_{\mu}} \vec{S}$, with gyromagnetic ratio $g_{\mu} = 2$. Quantum loop effects lead to a small calculable deviation from $g_{\mu} = 2$, parameterized by the anomalous magnetic moment

$$a_{\mu} \equiv \frac{g_{\mu} - 2}{2} \ . \tag{1}$$

That quantity can be accurately measured and, within the Standard Model (SM) framework, precisely predicted. Hence, comparison of experiment and theory tests the SM at its quantum loop level. A deviation in $a_{\mu}^{\rm exp}$ from the SM expectation would signal effects of new physics, with current sensitivity reaching up to mass scales of $\mathcal{O}(\text{TeV})$ [1,2]. For recent and very thorough muon g-2 reviews, see Refs. [3,4].

The E821 experiment at Brookhaven National Lab (BNL) studied the precession of μ^+ and μ^- in a constant external magnetic field as they circulated in a confining storage ring. It found [6] ¹

$$\begin{split} a_{\mu+}^{\rm exp} &= 11\,659\,204(6)(5)\times 10^{-10}\,,\\ a_{\mu-}^{\rm exp} &= 11\,659\,215(8)(3)\times 10^{-10}\,, \end{split} \tag{2}$$

where the first errors are statistical and the second systematic. Assuming CPT invariance and taking into account correlations between systematic errors, one finds for their average [6]

$$a_{\mu}^{\text{exp}} = 11659208.9(5.4)(3.3) \times 10^{-10}$$
 . (3)

These results represent about a factor of 14 improvement over the classic CERN experiments of the 1970's [7]. Improvement of the measurement in Eq. (3) by a factor of four by moving the E821 storage ring to Fermilab, and utilizing a cleaner and more intense muon beam has been proposed.

The SM prediction for a_{μ}^{SM} is generally divided into three parts (see Fig. 1 for representative Feynman diagrams)

$$a_{\mu}^{\text{SM}} = a_{\mu}^{\text{QED}} + a_{\mu}^{\text{EW}} + a_{\mu}^{\text{Had}} . \tag{4}$$

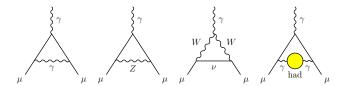


Figure 1: Representative diagrams contributing to $a_{\mu}^{\rm SM}$. From left to right: first order QED (Schwinger term), lowest-order weak, lowest-order hadronic.

The QED part includes all photonic and leptonic (e, μ, τ) loops starting with the classic $\alpha/2\pi$ Schwinger contribution. It has been computed through 4 loops and estimated at the 5-loop level [8]

$$a_{\mu}^{\text{QED}} = \frac{\alpha}{2\pi} + 0.765857410(27) \left(\frac{\alpha}{\pi}\right)^2 + 24.05050964(43) \left(\frac{\alpha}{\pi}\right)^3 + 130.8055(80) \left(\frac{\alpha}{\pi}\right)^4 + 663(20) \left(\frac{\alpha}{\pi}\right)^5 + \cdots$$
 (5

Employing $\alpha^{-1} = 137.035999084(51)$, determined [8,9] from the electron a_e measurement, leads to

$$a_{\mu}^{\rm QED} = 116\,584\,718.09(0.15) \times 10^{-11}\,,$$
 (6)

where the error results from uncertainties in the coefficients of Eq. (5) and in α .

Loop contributions involving heavy W^{\pm}, Z or Higgs particles are collectively labeled as a_{μ}^{EW} . They are suppressed by at

least a factor of
$$\frac{\alpha}{\pi} \frac{m_{\mu}^2}{m_W^2} \simeq 4 \times 10^{-9}$$
. At 1-loop order [10]

$$a_{\mu}^{\text{EW}}[1\text{-loop}] = \frac{G_{\mu}m_{\mu}^{2}}{8\sqrt{2}\pi^{2}} \left[\frac{5}{3} + \frac{1}{3} \left(1 - 4\sin^{2}\theta_{\text{W}} \right)^{2} + \mathcal{O}\left(\frac{m_{\mu}^{2}}{M_{W}^{2}} \right) + \mathcal{O}\left(\frac{m_{\mu}^{2}}{m_{H}^{2}} \right) \right],$$

$$= 194.8 \times 10^{-11}, \tag{7}$$

for $\sin^2\theta_{\rm W} \equiv 1-M_W^2/M_Z^2 \simeq 0.223$, and where $G_{\mu} \simeq 1.166 \times 10^{-5} \ {\rm GeV^{-2}}$ is the Fermi coupling constant. Two-loop corrections are relatively large and negative [11]

$$a_{\mu}^{\text{EW}}[2\text{-loop}] = -40.7(1.0)(1.8) \times 10^{-11},$$
 (8)

where the errors stem from quark triangle loops and the assumed Higgs mass range between 100 and 500 GeV. The 3-loop leading logarithms are negligible [11,12], $\mathcal{O}(10^{-12})$, implying in total

$$a_{\mu}^{\text{EW}} = 154(1)(2) \times 10^{-11} \ . \tag{9}$$

Hadronic (quark and gluon) loop contributions to $a_{\mu}^{\rm SM}$ give rise to its main theoretical uncertainties. At present, those effects

¹ The original results reported by the experiment have been updated in Eqs. (2) and (3) to the newest value for the absolute muon-to-proton magnetic ratio $\lambda = 3.183345137(85)$ [5]. The change induced in $a_{\mu}^{\rm exp}$ with respect to the value of $\lambda = 3.18334539(10)$ used in Ref. 6 amounts to $+0.92 \times 10^{-10}$.

are not calculable from first principles, but such an approach, at least partially, may become possible as lattice QCD matures. Instead, one currently relies on a dispersion relation approach to evaluate the lowest-order (i.e., $\mathcal{O}(\alpha^2)$) hadronic vacuum polarization contribution $a_{\mu}^{\mathrm{Had}}[\mathrm{LO}]$ from corresponding cross section measurements [13]

$$a_{\mu}^{\text{Had}}[\text{LO}] = \frac{1}{3} \left(\frac{\alpha}{\pi}\right)^{2} \int_{m^{2}}^{\infty} ds \, \frac{K(s)}{s} R^{(0)}(s) \,,$$
 (10)

where K(s) is a QED kernel function [14], and where $R^{(0)}(s)$ denotes the ratio of the bare² cross section for e^+e^- annihilation into hadrons to the pointlike muon-pair cross section at center-of-mass energy \sqrt{s} . The function $K(s) \sim 1/s$ in Eq. (10) gives a strong weight to the low-energy part of the integral. Hence, $a_{\mu}^{\text{Had}}[\text{LO}]$ is dominated by the $\rho(770)$ resonance.

Currently, the available $\sigma(e^+e^- \to \text{hadrons})$ data give a leading-order hadronic vacuum polarization (representative) contribution of [15]

$$a_{\mu}^{\text{Had}}[\text{LO}] = 6\,923(42)(3) \times 10^{-11},$$
 (11)

where the first error is experimental (dominated by systematic uncertainties), and the second due to perturbative QCD, which is used at intermediate and large energies to predict the contribution from the quark-antiquark continuum. New multi-hadron data from the BABAR experiment have increased the constraints on unmeasured exclusive final states and led to a small reduction in the hadronic contribution compared to the 2009 PDG value.

Alternatively, one can use precise vector spectral functions from $\tau \to \nu_{\tau}$ + hadrons decays [16] that can be related to isovector $e^+e^- \to \text{hadrons}$ cross sections by isospin symmetry. Replacing e^+e^- data in the two-pion and four-pion channels by the corresponding isospin-transformed τ data, and applying isospin-violating corrections (from QED and $m_d - m_u \neq 0$), one finds [15]

$$a_{\mu}^{\text{Had}}[\text{LO}] = 7015(42)(19)(3) \times 10^{-11} (\tau),$$
 (12)

where the first error is experimental, the second estimates the uncertainty in the isospin-breaking corrections applied to the τ data, and the third error is due to perturbative QCD. The current discrepancy between the e^+e^- and τ -based determinations of $a_{\mu}^{\rm Had}[{\rm LO}]$ has been reduced to 1.8 σ with respect to earlier evaluations. New e^+e^- and τ data from the *B*-factory experiments BABAR and Belle have increased the experimental information. Reevaluated isospin-breaking corrections have also contributed to this improvement [17]. BABAR recently

reported good agreement with the τ data in the most important two-pion channel [18]. The remaining discrepancy with the older e^+e^- and τ datasets may be indicative of problems with one or both data sets. It may also suggest the need for additional isospin-violating corrections to the τ data.

Higher order, $\mathcal{O}(\alpha^3)$, hadronic contributions are obtained from dispersion relations using the same $e^+e^- \to \text{hadrons}$ data [16,19,22], giving $a_\mu^{\text{Had,Disp}}[\text{NLO}] = (-98.4 \pm 0.6) \times 10^{-11}$, along with model-dependent estimates of the hadronic light-by-light scattering contribution, $a_\mu^{\text{Had,LBL}}[\text{NLO}]$, motivated by large- N_C QCD [23–29]. § Following [27], one finds for the sum of the two terms

$$a_{\mu}^{\text{Had}}[\text{NLO}] = 7(26) \times 10^{-11},$$
 (13)

where the error is dominated by hadronic light-by-light uncertainties.

Adding Eqs. (6), (9), (11) and (13) gives the representative e^+e^- data based SM prediction

$$a_{\mu}^{\text{SM}} = 116591802(2)(42)(26) \times 10^{-11},$$
 (14)

where the errors are due to the electroweak, lowest-order hadronic, and higher-order hadronic contributions, respectively. The difference between experiment and theory

$$\Delta a_{\mu} = a_{\mu}^{\text{exp}} - a_{\mu}^{\text{SM}} = 287(63)(49) \times 10^{-11},$$
 (15)

(with all errors combined in quadrature) represents an interesting but not yet conclusive discrepancy of 3.6 times the estimated 1σ error. All the recent estimates for the hadronic contribution compiled in Fig. 2 exhibit similar discrepancies. Switching to τ data reduces the discrepancy to 2.4σ , assuming the isospin-violating corrections are under control within the estimated uncertainties.

An alternate interpretation is that Δa_{μ} may be a new physics signal with supersymmetric particle loops as the leading candidate explanation. Such a scenario is quite natural, since generically, supersymmetric models predict [1] an additional contribution to $a_{\nu}^{\rm SM}$

$$a_{\mu}^{\rm SUSY} \simeq \pm 130 \times 10^{-11} \cdot \left(\frac{100 \text{ GeV}}{m_{\rm SUSY}}\right)^2 \tan\beta,$$
 (16)

where $m_{\rm SUSY}$ is a representative supersymmetric mass scale, and $\tan\beta \simeq 3\text{--}40$ is a potential enhancement factor. Supersymmetric particles in the mass range 100–500 GeV could be the source of the deviation Δa_{μ} . If so, those particles could be directly observed at the next generation of high energy colliders.

New physics effects [1] other than supersymmetry could also explain a non-vanishing Δa_{μ} . A recent popular scenario involves the "dark photon", a relatively light hypothetical vector boson from the dark matter sector that couples to our world of particle

² The bare cross section is defined as the measured cross section corrected for initial-state radiation, electron-vertex loop contributions and vacuum-polarization effects in the photon propagator. However, QED effects in the hadron vertex and final state, as photon radiation, are included.

³ Some representative recent estimates of the hadronic light-by-light scattering contribution, $a_{\mu}^{\rm Had,LBL}[\rm NLO]$, that followed after the sign correction of [25], are: $105(26) \times 10^{-11}$ [27], $110(40) \times 10^{-11}$ [23], $136(25) \times 10^{-11}$ [24].

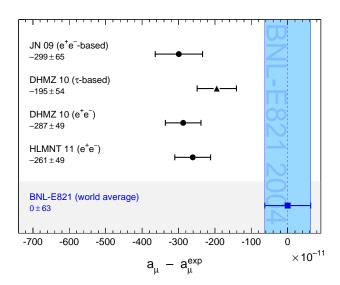


Figure 2: Compilation of recently published results for a_{μ} (in units of 10^{-11}), subtracted by the central value of the experimental average (3). The shaded band indicates the experimental error. The SM predictions are taken from: JN [4], DHMZ [15], and HMNT [19]. Note that the quoted errors do not include the uncertainty on the subtracted experimental value. To obtain for each theory calculation a result equivalent to Eq. (15), the errors from theory and experiment must be added in quadrature.

physics through mixing with the ordinary photon [30,31]. As a result, it couples to ordinary charged particles with strength $\varepsilon \cdot e$ and gives rise to an additional muon anomalous magnetic moment contribution

$$a_{\mu}^{\mathrm{dark \ photon}} = \frac{\alpha}{2\pi} \varepsilon^2 F(m_V/m_{\mu}) \,,$$
 (17)

where $F(x) = \int_0^1 2z(1-z)^2/[(1-z)^2+x^2z]\,dz$. For values of $\varepsilon \sim 1$ –2·10⁻³ and $m_V \sim 10$ –100 MeV, the dark photon, which was originally motivated by cosmology, can provide a viable solution to the muon g-2 discrepancy. Searches for the dark photon in that mass range are currently underway at Jefferson Lab, USA, and MAMI in Mainz, Germany.

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 μ

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μ MAGNETIC MOMENT ANOMALY

The parity-violating decay of muons in a storage ring is observed. The difference frequency ω_a between the muon spin precision and the orbital angular frequency $(e/m_\mu c)\langle B\rangle$ is measured, as is the free proton NMR frequency ω_p , thus determining the ratio $R\!=\!\omega_a/\omega_p$. Given the magnetic moment ratio $\lambda\!=\!\mu_\mu/\mu_p$ (from hyperfine structure in muonium), $(g\!-\!2)/2=R/(\lambda\!-\!R)$.

$\mu_{\mu}/(e\hbar/2m_{\mu})-1=(g_{\mu}-2)/2$

| VALUE (units 10^{-10}) | | DOCUMENT ID | | TECN | CHG | COMMENT |
|---------------------------|--------------|----------------------|--------|------------|---------|-----------------------------|
| 11659208.9± 5 | .4 ± 3.3 | ⁷ BENNETT | 06 | MUG2 | | Average μ^+ and μ^- |
| • • • We do not | use the foll | owing data for ave | rages, | fits, limi | ts, etc | . • • • |
| 11659208 ± 6 | | BENNETT | 04 | MUG2 | | Average μ^+ and μ^- |
| 11659214 ± 8 | ± 3 | BENNETT | 04 | MUG2 | _ | Storage ring |
| 11659203 ± 6 | ±5 | BENNETT | 04 | MUG2 | + | Storage ring |
| 11659204 ± 7 | ± 5 | BENNETT | 02 | MUG2 | + | Storage ring |
| 11659202 ± 14 | ±6 | BROWN | 01 | MUG2 | + | Storage ring |
| 11659191 ± 59 | | BROWN | 00 | MUG2 | + | |
| 11659100 ± 110 | | ⁸ BAILEY | 79 | CNTR | + | Storage ring |
| 11659360 ± 120 | | ⁸ BAILEY | 79 | CNTR | - | Storage ring |
| 11659230 ± 85 | | ⁸ BAILEY | 79 | CNTR | \pm | Storage ring |
| 11620000 ±5000 | | CHARPAK | 62 | CNTR | + | |

 7 BENNETT 06 reports $(g_\mu-2)/2=(1165\,9208.0\,\pm\,5.4\,\pm\,3.3)\,\times\,10^{-10}$. We rescaled this value using μ/p magnetic moment ratio of 3.183345137(85) from MOHR 08.

 8 BAILEY 79 values recalculated by HUGHES 99 using the COHEN 87 μ/p magnetic moment. The improved MOHR 99 value does not change the result.

$(g_{\mu^+} - g_{\mu^-}) / g_{\text{average}}$

A test of CPT invariance.

| VALUE (units 10 ⁻⁸) | DO CUMENT ID | | TECN |
|-------------------------------------|-------------------|---------|------------------------------|
| -0.11 ± 0.12 | BENNETT | 04 | MUG2 |
| • • • We do not use the following d | lata for averages | , fits, | limits, etc. $ullet$ $ullet$ |
| -2.6 ± 1.6 | BAILEY | 79 | CNTR |

μ ELECTRIC DIPOLE MOMENT (d)

A nonzero value is forbidden by both T invariance and P invariance.

| <u>VALUE (10⁻¹⁹ ecm)</u> | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------------------------------------|-----------------------|---------|-------------|-------|--------------|
| -0.1±0.9 | 9 BENNETT | 09 | MUG2 | ± | Storage ring |
| | wing data for average | s, fits | , limits, e | tc. • | • • |
| -0.1 ± 1.0 | BENNETT | 09 | MUG2 | + | Storage ring |
| -0.1 ± 0.7 | BENNETT | 09 | MUG2 | _ | Storage ring |
| -3.7 ± 3.4 | ¹⁰ BAILEY | 78 | CNTR | \pm | Storage ring |
| 8.6 ± 4.5 | BAILEY | 78 | CNTR | + | Storage ring |
| 0.8 ± 4.3 | BAILEY | 78 | CNTR | _ | Storage ring |

 9 This is the combination of the two BENNETT 09 results quoted here separately for μ^+ and $\mu^-.$ BENNETT 09 uses the convention d = 1/2 \cdot (d $_{\mu^-}$ – d $_{\mu^+}$).

 10 This is the combination of the two BAILEY 78 results quoted here separately for μ^+ and μ^- . BAILEY 78 uses the convention d = $1/2 \cdot (d_{\mu^+} - d_{\mu^-})$ and reports 3.7 \pm 3.4. We convert their result to use the same convention as BENNETT 09.

MUON-ELECTRON CHARGE RATIO ANOMALY $q_{\mu^+}/q_{e^-}+1$

| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------------------|--------------|----|------|-----|---------------|
| $(1.1\pm2.1)\times10^{-9}$ | 11 MEYER | 00 | CNTR | + | 1s-2s muonium |

 11 MEYER 00 measure the 1s–2s muonium interval, and then interpret the result in terms of muon-electron charge ratio q_{μ^+}/q_{e^-} .

μ^- DECAY MODES

 μ^+ modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ _i /Γ) | Confidence level |
|-----------------------|-----------------------------------------|------------------------------------|------------------|
| $\overline{\Gamma_1}$ | $e^- \overline{\nu}_e \nu_\mu$ | ≈ 100% | |
| Γ_2 | $e^-\overline{ u}_e^{} u_\mu\gamma$ | [a] (1.4 ± 0.4) % | |
| Γ_3 | $e^- \overline{ u}_e u_\mu e^+ e^-$ | [b] $(3.4 \pm 0.4) \times 10^{-5}$ | |

Lepton Family number (LF) violating modes

| Γ_4 | $e^- \nu_e \overline{\nu}_\mu$ | LF | [c] < 1.2 | % | 90% |
|------------|--------------------------------|----|-----------|-------------------|-----|
| Γ_5 | $e^-\gamma$ | LF | < 2.4 | $\times 10^{-12}$ | 90% |
| Γ_6 | $e^-e^+e^-$ | LF | < 1.0 | $\times 10^{-12}$ | 90% |
| Γ_7 | $e^-2\gamma$ | LF | < 7.2 | $\times 10^{-11}$ | 90% |

- [a] This only includes events with the γ energy > 10 MeV. Since the $e^-\overline{\nu}_e\,\nu_\mu$ and $e^-\overline{\nu}_e\,\nu_\mu\gamma$ modes cannot be clearly separated, we regard the latter mode as a subset of the former.
- [b] See the Particle Listings below for the energy limits used in this measurement.
- $\left[c\right]$ A test of additive vs. multiplicative lepton family number conservation.

μ^- BRANCHING RATIOS

| $\Gamma(e^-\overline{ u}_e u_\mu\gamma)/\Gamma_{ m tota}$ | ıl | | Γ ₂ /Γ |
|-----------------------------------------------------------|--------------|--------------------------|-------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN COMMENT |
| 0.014 ± 0.004 | | CRITTENDEN 61 | CNTR γ KE > 10 MeV |
| • • • We do not use | the followin | g data for averages, fit | s, limits, etc. • • • |
| | 862 | BOGART 67 | CNTR γ KE > 14.5 MeV |
| 0.0033 ± 0.0013 | | CRITTENDEN 61 | CNTR γ KE $>$ 20 MeV |
| | 27 | ASHKIN 59 | CNTR |

| $\Gamma(e^-\overline{\nu}_e\nu_\mue^+e^-$ | ⁻)/「 _{total} | | | | | | Г3/Г |
|-------------------------------------------|-----------------------|------------------------|----------|-----------|---------|---------------|--------|
| VALUE (units 10^{-5}) | EVTS | DOCUMENT | ID | TECN | CHG | COMMENT | |
| $3.4 \pm 0.2 \pm 0.3$ | 7443 | ¹² BERTL | 85 | SPEC | + | SINDRUM | |
| ● ● We do not | use the fol | lowing data for a | verages, | fits, lim | ts, etc | | |
| 2.2 ± 1.5 | 7 | ¹³ CRITTEND | EN 61 | HLBC | + | $E(e^+e^-) >$ | 10 MeV |

 12 BERTL 85 has transverse momentum cut $p_T > 17~{\rm MeV/}c.~$ Systematic error was increased by us. 13 CRITTENDEN 61 count only those decays where total energy of either (e^+, e^-) com-

bination is >10 MeV. 14 GUREVICH 60 interpret their event as either virtual or real photon conversion. $\rm e^+$ and $\rm e^-$ energies not measured.

15 in the three LEE 59 events, the sum of energies $E(e^+) + E(e^-) + E(e^+)$ was 51 MeV, 55 MeV, and 33 MeV.

 $\Gamma(e^-\nu_e\overline{\nu}_\mu)/\Gamma_{total}$ Forbidden by the additive conservation law for lepton family number. A multiplicative law predicts this branching ratio to be 1/2. For a review see NEMETHY 81.

| VALUE | CL% | DO CUMENT ID | | TECN CHG | COMMENT |
|-------------------------------------|--------------|------------------------|---------|------------------|-----------------------------------------------------------------|
| < 0.012 | 90 | ¹⁶ FREEDMAN | 93 | CNTR + | u oscillation search |
| ● ● We do not u | se the follo | wing data for averag | ges, fi | ts, limits, etc. | • • • |
| < 0.018 | 90 | KRAKAUER | 91B | CALO + | |
| < 0.05 | 90 | ¹⁷ BERGSMA | 83 | CALO | $\overline{\nu}_{\mu} e \rightarrow \mu^{-} \overline{\nu}_{e}$ |
| < 0.09 | 90 | JONKER | 80 | CALO | See BERGSMA 83 |
| -0.001 ± 0.061 | | WILLIS | 80 | CNTR + | |
| 0.13 ± 0.15 | | BLIETSCHAU | 78 | HLBC \pm | Avg. of 4 values |
| < 0.25 | 90 | EICHTEN | 73 | HLBC + | |
| | | | | | |

 16 FREEDMAN 93 limit on $\overline{
u}_e$ observation is here interpreted as a limit on lepton family

number violation. The BERGSMA 83 gives a limit on the inverse muon decay cross-section ratio $\sigma(\overline{\nu}_{\mu}e^{-}\rightarrow \mu^{-}\overline{\nu}_{e})/\sigma(\nu_{\mu}e^{-}\rightarrow \mu^{-}\nu_{e})$, which is essentially equivalent to $\Gamma(e^{-}\nu_{e}\overline{\nu}_{\mu})/\Gamma_{\rm total}$ for small values like that quoted.

 $\Gamma(e^-\gamma)/\Gamma_{total}$ Forbidden by lepton family number conservation.

| VAL | UE (units 10^{-11}) | CL% | DO CUMENT ID | | TECN CHG | COMMENT |
|-----|------------------------|--------------|--------------------|---------|------------------|------------|
| < | 0.24 | 90 | A DA M | 11 | SPEC + | MEG at PSI |
| • • | • We do not use | the followin | g data for average | s, fits | , limits, etc. • | • • |
| < | 2.8 | 90 | ADAM | 10 | SPEC + | MEG at PSI |
| < | 1.2 | 90 | AHMED | 02 | SPEC + | MEGA |
| < | 1.2 | 90 | BROOKS | 99 | SPEC + | LAMPF |
| < | 4.9 | 90 | BOLTON | 88 | CBOX + | LAMPF |
| <1 | 00 | 90 | AZUELOS | 83 | CNTR + | TRIUMF |
| < | 17 | 90 | KINNISON | 82 | SPEC + | LAMPF |
| <1 | 00 | 90 | SCHAAF | 80 | ELEC + | SIN |

 $\Gamma(e^-e^+e^-)/\Gamma_{total}$ Forbidden by lepton family number conservation.

| VALUE (units 10 ⁻¹²) | CL% | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------------------------|-----------|-------------------------|---------|-----------|-------|---------|
| < 1.0 | 90 1 | ^{.8} BELLGARDT | 88 | SPEC | + | SINDRUM |
| • • • We do not use the | following | data for averages | , fits, | limits, e | tc. • | • • |
| < 36 | 90 | BARANOV | 91 | SPEC | + | ARES |
| < 35 | 90 | BOLTON | 88 | CBOX | + | LAMPF |
| < 2.4 | 90 1 | .8 BERTL | 85 | SPEC | + | SINDRUM |
| <160 | 90 1 | .8 BERTL | 84 | SPEC | + | SINDRUM |
| <130 | 90 1 | .8 BOLTON | 84 | CNTR | | LAMPF |

¹⁸These experiments assume a constant matrix element.

$\Gamma(e^-2\gamma)/\Gamma_{total}$ Forbidden by lepton family number conservation.

 VALUE (units 10^{-11})
 CL%
 DOCUMENT ID
 TECN
 CHG
 COMMENT

 < 7.2</td>
 90
 BOLTON
 88
 CBOX
 +
 LAMPF

• • • We do not use the following data for averages, fits, limits, etc. • • •
 < 840
 90
 19 AZUELOS
 83 CNTR + TRIUMF
 <5000
 90
 20 BOWMAN
 78 CNTR DEPOMMIER 77 data

 $^{19} {\sf AZUELOS}$ 83 uses the phase space distribution of BOWMAN 78.

 20 BOWMAN 78 assumes an interaction Lagrangian local on the scale of the inverse μ mass.

LIMIT ON $\mu^- \rightarrow e^-$ CONVERSION

Forbidden by lepton family number conservation

 $<7 \times 10^{-11}$ 90 BADERT... 80 STRC SIN •• We do not use the following data for averages, fits, limits, etc. ••• $<4 \times 10^{-10}$ 90 BADERT... 77 STRC SIN

 $\sigma(\mu^- \, \mathsf{Cu} \, o \, e^- \, \mathsf{Cu}) \, / \, \sigma(\mu^- \, \mathsf{Cu} \, o \, \mathsf{capture})$

$\sigma(\mu^- \text{Ti} \rightarrow e^- \text{Ti}) / \sigma(\mu^- \text{Ti} \rightarrow \text{capture})$

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|-------------------|---------|-----------|------------|
| $<4.3 \times 10^{-12}$ | 90 2 | 1 DOHMEN | 93 | SPEC | SINDRUMII |
| • • • We do not use the | following | data for averages | , fits, | limits, e | etc. • • • |
| $<4.6 \times 10^{-12}$ | 90 | AHMAD | 88 | TPC | TRIUMF |
| $< 1.6 \times 10^{-11}$ | 90 | BRYMAN | 85 | TPC | TRIUMF |

 $^{21}\,\mathrm{DOHMEN}$ 93 assumes $\mu^-\to e^-$ conversion leaves the nucleus in its ground state, a process enhanced by coherence and expected to dominate.

$\sigma(\mu^-\,{\rm Pb}\,\to\,\,e^-\,{\rm Pb})$ / $\sigma(\mu^-\,{\rm Pb}\,\to\,\,{\rm capture})$

VALUE CL% DOCUMENT ID TECN COMMENT

<4.6 × 10⁻¹¹
90 HONECKER 96 SPEC SINDRUM II

• • • We do not use the following data for averages, fits, limits, etc. • • •

<4.9 × 10⁻¹⁰
90 AHMAD 88 TPC TRIUMF

 $\sigma(\mu^- Au \rightarrow e^- Au) / \sigma(\mu^- Au \rightarrow capture)$

 VALUE
 CL%
 DOCUMENT ID
 TECN
 CHG
 COMMENT

 <7 × 10⁻¹³
 90
 BERTL
 06
 SPEC
 —
 SINDRUM II

LIMIT ON $\mu^- \rightarrow e^+$ CONVERSION

Forbidden by total lepton number conservation

$\sigma(\mu^{-\,32}\text{S}\,\rightarrow\,\,e^{+\,32}\text{Si*})\,\,/\,\,\sigma(\mu^{-\,32}\text{S}\,\rightarrow\,\,\nu_{\mu}^{\,\,32}\text{P*})$

 VALUE
 CL%
 DOCUMENT ID
 TECN
 COMMENT

 $<9 \times 10^{-10}$ 90
 BADERT...
 80
 STRC
 SIN

 • • • We do not use the following data for averages, fits, limits, etc.
 • • •

 $<1.5 \times 10^{-9}$ 90
 BADERT...
 78
 STRC
 SIN

$\sigma(\mu^{-127}| \rightarrow e^{+127} \text{Sb*}) / \sigma(\mu^{-127}| \rightarrow \text{anything})$

<u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> **<3 × 10^{−10}** 90 22 ABELA 80 CNTR Radiochemical tech.

 22 ABELA 80 is upper limit for $\mu^-\,e^+$ conversion leading to particle-stable states of 127 Sb. Limit for total conversion rate is higher by a factor less than 4 (G. Backenstoss, private communication).

$\sigma(\mu^- Cu \rightarrow e^+ Co) / \sigma(\mu^- Cu \rightarrow \nu_\mu Ni)$

$\sigma(\mu^- \, {\sf Ti} \, o \, e^+ \, {\sf Ca}) \, / \, \sigma(\mu^- \, {\sf Ti} \, o \, {\sf capture})$

| VALUE | CL% EV | <u> 15</u> | UCUMENT ID | | IECN | CHG | COMMENT |
|-------------------------|------------|-----------------|-----------------|-------|-----------|---------|------------|
| $<3.6 \times 10^{-11}$ | 90 | 1 23,24 K | AULARD | 98 | SPEC | _ | SINDRUM II |
| ullet $ullet$ We do not | use the fo | llowing dat | a for averages, | fits, | limits, e | tc. • • | • • |
| $< 1.7 \times 10^{-12}$ | 90 | 1 24,25 K | | 98 | SPEC | _ | SINDRUM II |
| $< 4.3 \times 10^{-12}$ | 90 | | | 93 | SPEC | | SINDRUM II |
| $< 8.9 \times 10^{-11}$ | 90 | | | 93 | SPEC | | SINDRUM II |
| $< 1.7 \times 10^{-10}$ | 90 | 26 _A | HMAD | 88 | TPC | | TRIUMF |
| | | | | | | | |

 23 This limit assumes a giant resonance excitation of the daughter Ca nucleus (mean energy and width both 20 MeV).

 24 KAULARD 98 obtained these same limits using the unified classical analysis of FELD- $_{\rm nS}$ MAN 98.

25 This limit assumes the daughter Ca nucleus is left in the ground state. However, the probability of this is unknown.

²⁶ Assuming a giant-resonance-excitation model.

LIMIT ON MUONIUM -> ANTIMUONIUM CONVERSION

Forbidden by lepton family number conservation.

$R_{g} = G_{C} / G_{F}$

 Γ_7/Γ

The effective Lagrangian for the $\mu^+e^-
ightarrow \mu^-e^+$ conversion is assumed to be

$$\mathcal{L} = 2^{-1/2} \ \textit{G}_{\textit{C}} \ [\overline{\psi}_{\mu} \gamma_{\lambda} \left(1 - \gamma_{5} \right) \, \psi_{e}] \, [\overline{\psi}_{\mu} \gamma_{\lambda} \left(1 - \gamma_{5} \right) \, \psi_{e}] \, + \, \text{h.c.}$$

The experimental result is then an upper limit on G_C/G_F , where G_F is the Fermi coupling constant

| VALUE | CL% E | VTS | DO CUMENT ID | | TECN CHG | COMMENT |
|-----------------|-----------|----------|------------------------|---------|------------------|------------------------|
| < 0.0030 | 90 | 1 2 | ²⁷ WILLMANN | 99 | SPEC + | μ^+ at 26 GeV/ c |
| • • • We do not | use the 1 | ollowing | data for average | s, fits | , limits, etc. • | • • |
| < 0.14 | 90 | | ²⁸ GORDEEV | 97 | SPEC + | JINR phasotron |
| < 0.018 | 90 | 0 2 | ²⁹ ABELA | 96 | SPEC + | μ^+ at 24 MeV |
| < 6.9 | 90 | | NI | 93 | CBOX | LAMPF |
| < 0.16 | 90 | | MATTHIAS | 91 | SPEC | LAMPF |
| < 0.29 | 90 | | HUBER | 90B | CNTR | TRIUMF |
| <20 | 95 | | BEER | 86 | CNTR | TRIUMF |
| < 42 | 95 | | MARSHALL | 82 | CNTR | |
| | | | | | | |

 27 WILLMANN 99 quote both probability $P_{M\,\overline{M}} < 8.3\times 10^{-11}$ at 90%CL in a 0.1 T field and $R_{\rm g} = G_{\rm C}/G_{\rm F}.$

²⁸ GORDEEV 97 quote limits on both $f=G_{MM}/GF$ and the probability $W_{MM}<4.7\times10^{-7}$ (90% CL).

 $^{29}\,\mathrm{ABELA}$ 96 quote both probability $P_{M\overline{M}}$ $<8\times10^{-9}$ at 90% CL and R_g = G_C/G_F .

MUON DECAY PARAMETERS

Revised January 2012 by W. Fetscher and H.-J. Gerber (ETH Zürich).

Introduction: All measurements in direct muon decay, $\mu^- \to e^- + 2$ neutrals, and its inverse, $\nu_\mu + e^- \to \mu^- + \text{neutral}$, are successfully described by the "V-A interaction," which is a particular case of a local, derivative-free, lepton-number-conserving, four-fermion interaction [1]. As shown below, within this framework, the Standard Model assumptions, such as the V-A form and the nature of the neutrals $(\nu_\mu \text{ and } \bar{\nu}_e)$, and hence the doublet assignments $(\nu_e \ e^-)_L$ and $(\nu_\mu \ \mu^-)_L$, have been determined from experiments [2,3]. All considerations on muon decay are valid for the leptonic tau decays $\tau \to \ell + \nu_\tau + \bar{\nu}_e$ with the replacements $m_\mu \to m_\tau$, $m_e \to m_\ell$.

Parameters: The differential decay probability to obtain an e^{\pm} with (reduced) energy between x and x + dx, emitted in the direction \hat{x}_3 at an angle between ϑ and $\vartheta + d\vartheta$ with respect to the muon polarization vector \mathbf{P}_{μ} , and with its spin parallel to the arbitrary direction $\hat{\zeta}$, neglecting radiative corrections, is given by

$$\begin{split} \frac{\mathrm{d}^{2}\Gamma}{\mathrm{d}x \, \mathrm{d}\cos\vartheta} &= \frac{m_{\mu}}{4\pi^{3}} \, W_{e\mu}^{4} \, G_{\mathrm{F}}^{2} \, \sqrt{x^{2} - x_{0}^{2}} \\ &\times (F_{\mathrm{IS}}(x) \pm P_{\mu}\cos\vartheta \, F_{\mathrm{AS}}(x)) \\ &\times \left[1 + \hat{\boldsymbol{\zeta}} \cdot \boldsymbol{P}_{e}(x,\vartheta) \right] \, . \end{split} \tag{1}$$

Here, $W_{e\mu} = \max(E_e) = (m_{\mu}^2 + m_e^2)/2m_{\mu}$ is the maximum e^{\pm} energy, $x = E_e/W_{e\mu}$ is the reduced energy, $x_0 = m_e/W_{e\mu} = 9.67 \times 10^{-3}$, and $P_{\mu} = |\mathbf{P}_{\mu}|$ is the degree of muon polarization. $\hat{\boldsymbol{\zeta}}$ is the direction in which a perfect polarization-sensitive electron detector is most sensitive. The isotropic part of the spectrum, $F_{\rm IS}(x)$, the anisotropic part $F_{\rm AS}(x)$, and the electron polarization, $\mathbf{P}_e(x,\vartheta)$, may be parametrized by the Michel parameter ρ [1], by η [4], by ξ and δ [5,6], etc. These are bilinear combinations of the coupling constants $g_{\varepsilon\mu}^{\gamma}$, which occur in the matrix element (given below).

 μ

If the masses of the neutrinos as well as x_0^2 are neglected, the energy and angular distribution of the electron in the rest frame of a muon (μ^{\pm}) measured by a polarization insensitive detector, is given by

$$\frac{\mathrm{d}^2 \Gamma}{\mathrm{d}x \, \mathrm{d} \cos \vartheta} \sim x^2 \cdot \left\{ 3(1-x) + \frac{2\rho}{3} (4x-3) + 3\eta \, x_0 (1-x) / x \right.$$

$$\pm P_\mu \cdot \xi \cdot \cos \vartheta \left[1 - x + \frac{2\delta}{3} (4x-3) \right] \right\} . \tag{2}$$

Here, ϑ is the angle between the electron momentum and the muon spin, and $x \equiv 2E_e/m_\mu$. For the Standard Model coupling, we obtain $\rho = \xi \delta = 3/4$, $\xi = 1$, $\eta = 0$ and the differential decay rate is

$$\frac{\mathrm{d}^2 \Gamma}{\mathrm{d}x \, \mathrm{d} \cos \vartheta} = \frac{G_{\mathrm{F}}^2 m_{\mu}^5}{192\pi^3} \left[3 - 2x \pm P_{\mu} \cos \vartheta (2x - 1) \right] x^2 \quad . \quad (3)$$

The coefficient in front of the square bracket is the total decay rate.

If only the neutrino masses are neglected, and if the e^{\pm} polarization is detected, then the functions in Eq. (1) become

$$F_{\rm IS}(x) = x(1-x) + \frac{2}{9} \rho(4x^2 - 3x - x_0^2) + \eta \cdot x_0(1-x)$$

$$F_{\rm AS}(x) = \frac{1}{3}\xi \sqrt{x^2 - x_0^2}$$

$$\times \left[1 - x + \frac{2}{3}\delta(4x - 3 + (\sqrt{1 - x_0^2} - 1))\right]$$

$$\mathbf{P}_e(x, \vartheta) = P_{\rm T_1} \cdot \hat{\mathbf{x}}_1 + P_{\rm T_2} \cdot \hat{\mathbf{x}}_2 + P_L \cdot \hat{\mathbf{x}}_3 . \tag{4}$$

Here $\hat{\boldsymbol{x}}_1,~\hat{\boldsymbol{x}}_2,$ and $\hat{\boldsymbol{x}}_3$ are orthogonal unit vectors defined as follows:

$$\begin{split} \widehat{\boldsymbol{x}}_3 & \text{ is along the } e \text{ momentum } \boldsymbol{p}_e \\ \frac{\widehat{\boldsymbol{x}}_3 \times \boldsymbol{P}_{\mu}}{|\widehat{\boldsymbol{x}}_2 \times \boldsymbol{P}_{\mu}|} = \widehat{\boldsymbol{x}}_2 & \text{ is transverse to } \boldsymbol{p}_e \text{ and perpendicular} \\ & \text{ to the "decay plane"} \\ \widehat{\boldsymbol{x}}_2 \times \widehat{\boldsymbol{x}}_3 = \widehat{\boldsymbol{x}}_1 & \text{ is transverse to the } \boldsymbol{p}_e \text{ and in the} \\ & \text{"decay plane."} \end{split}$$

The components of P_e then are given by

$$\begin{split} P_{\mathrm{T}_{1}}(x,\vartheta) &= P_{\mu}\sin\vartheta \cdot F_{\mathrm{T}_{1}}(x)/\left(F_{\mathrm{IS}}(x) \pm P_{\mu}\cos\vartheta \cdot F_{\mathrm{AS}}(x)\right) \\ P_{\mathrm{T}_{2}}(x,\vartheta) &= P_{\mu}\sin\vartheta \cdot F_{\mathrm{T}_{2}}(x)/\left(F_{\mathrm{IS}}(x) \pm P_{\mu}\cos\vartheta \cdot F_{\mathrm{AS}}(x)\right) \\ P_{L}(x,\vartheta) &= \left(\pm F_{\mathrm{IP}}(x) + P_{\mu}\cos\vartheta \\ &\quad \times F_{\mathrm{AP}}(x)\right)/\left(F_{\mathrm{IS}}(x) \pm P_{\mu}\cos\vartheta \cdot F_{\mathrm{AS}}(x)\right) \;, \end{split}$$

where

$$F_{\text{T}_{1}}(x) = \frac{1}{12} \left\{ -2 \left[\xi'' + 12(\rho - \frac{3}{4}) \right] (1 - x) x_{0} -3\eta(x^{2} - x_{0}^{2}) + \eta''(-3x^{2} + 4x - x_{0}^{2}) \right\}$$

$$F_{\text{T}_{2}}(x) = \frac{1}{3} \sqrt{x^{2} - x_{0}^{2}} \left\{ 3 \frac{\alpha'}{A} (1 - x) + 2 \frac{\beta'}{A} \sqrt{1 - x_{0}^{2}} \right\}$$

$$F_{\text{IP}}(x) = \frac{1}{54} \sqrt{x^{2} - x_{0}^{2}} \left\{ 9 \xi' \left(-2x + 2 + \sqrt{1 - x_{0}^{2}} \right) + 4 \xi (\delta - \frac{3}{4}) (4x - 4 + \sqrt{1 - x_{0}^{2}}) \right\}$$

$$F_{\text{AP}}(x) = \frac{1}{6} \left\{ \xi''(2x^{2} - x - x_{0}^{2}) + 4(\rho - \frac{3}{4}) (4x^{2} - 3x - x_{0}^{2}) + 2\eta''(1 - x) x_{0} \right\} . \tag{5}$$

For the experimental values of the parameters ρ , ξ , ξ' , ξ'' , δ , η , η'' , α/A , β/A , α'/A , β'/A , which are not all independent, see the Data Listings below. Experiments in the past have also been analyzed using the parameters a, b, c, a', b', c', α/A , β/A , α'/A , β'/A (and $\eta = (\alpha - 2\beta)/2A$), as defined by Kinoshita and Sirlin [5,6]. They serve as a model-independent summary of all possible measurements on the decay electron (see Listings below). The relations between the two sets of parameters are

$$\begin{split} \rho - \frac{3}{4} &= \frac{3}{4}(-a+2c)/A \;, \\ \eta &= (\alpha - 2\beta)/A \;, \\ \eta'' &= (3\alpha + 2\beta)/A \;, \\ \delta - \frac{3}{4} &= \frac{9}{4} \; \cdot \; \frac{(a'-2c')/A}{1 - [a+3a'+4(b+b')+6c-14c']/A} \;, \\ 1 - \xi \frac{\delta}{\rho} &= 4 \; \frac{[(b+b')+2(c-c')]/A}{1 - (a-2c)/A} \;, \\ 1 - \xi' &= \; [(a+a')+4(b+b')+6(c+c')]/A \;, \\ 1 - \xi'' &= \; (-2a+20c)/A \;, \end{split}$$

where

$$A = a + 4b + 6c. (6)$$

The differential decay probability to obtain a left-handed ν_e with (reduced) energy between y and y+dy, neglecting radiative corrections as well as the masses of the electron and of the neutrinos, is given by [7]

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}y} = \frac{m_{\mu}^5 G_F^2}{16\pi^3} \cdot Q_L^{\nu_e} \cdot y^2 \left\{ (1-y) - \omega_L \cdot (y - \frac{3}{4}) \right\}. \tag{7}$$

Here, y=2 E_{ν_e}/m_{μ} . $Q_L^{\nu_e}$ and ω_L are parameters. ω_L is the neutrino analog of the spectral shape parameter ρ of Michel. Since in the Standard Model, $Q_L^{\nu_e}=1$, $\omega_L=0$, the measurement of $d\Gamma/dy$ has allowed a null-test of the Standard Model (see Listings below).

Matrix element: All results in direct muon decay (energy spectra of the electron and of the neutrinos, polarizations, and angular distributions), and in inverse muon decay (the reaction cross section) at energies well below $m_W c^2$, may be parametrized in terms of amplitudes $g_{\varepsilon\mu}^{\gamma}$ and the Fermi coupling constant G_F , using the matrix element

$$\frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma = S, V, T \\ \varepsilon \mid \mu = R, L}} g_{\varepsilon\mu}^{\gamma} \langle \bar{e}_{\varepsilon} | \Gamma^{\gamma} | (\nu_e)_n \rangle \langle (\bar{\nu}_{\mu})_m | \Gamma_{\gamma} | \mu_{\mu} \rangle. \tag{8}$$

We use the notation of Fetscher et al. [2], who in turn use the sign conventions and definitions of Scheck [8]. Here, $\gamma = S, V, T$ indicates a scalar, vector, or tensor interaction; and $\varepsilon, \mu = R, L$ indicate a right- or left-handed chirality of the electron or muon. The chiralities n and m of the ν_e and $\bar{\nu}_{\mu}$ are then determined by the values of γ, ε , and μ . The particles are represented by fields of definite chirality [9].

As shown by Langacker and London [10], explicit leptonnumber nonconservation still leads to a matrix element equivalent to Eq. (8). They conclude that it is not possible, even in principle, to test lepton-number conservation in (leptonic) muon decay if the final neutrinos are massless and are not observed.

The ten complex amplitudes $g_{\varepsilon\mu}^{\gamma}$ (g_{RR}^{T} and g_{LL}^{T} are identically zero) and G_{F} constitute 19 independent (real) parameters to be determined by experiment. The Standard Model interaction corresponds to one single amplitude g_{LL}^{V} being unity and all the others being zero.

The (direct) muon decay experiments are compatible with an arbitrary mix of the scalar and vector amplitudes g_{LL}^S and g_{LL}^V – in the extreme even with purely scalar $g_{LL}^S = 2$, $g_{LL}^V = 0$. The decision in favour of the Standard Model comes from the quantitative observation of inverse muon decay, which would be forbidden for pure g_{LL}^S [2].

Experimental determination of V-A: In order to determine the amplitudes $g_{\varepsilon\mu}^{\gamma}$ uniquely from experiment, the following set of equations, where the left-hand sides represent experimental results, has to be solved.

 $a = 16(|g_{RL}^V|^2 + |g_{LR}^V|^2) + |g_{RL}^S + 6g_{RL}^T|^2 + |g_{LR}^S + 6g_{LR}^T|^2$

 $a' = 16(|g_{RL}^V|^2 - |g_{LR}^V|^2) + |g_{RL}^S + 6g_{RL}^T|^2 - |g_{LR}^S + 6g_{LR}^T|^2$

$$\begin{split} \alpha &= 8 \mathrm{Re} \left\{ g_{RL}^V(g_{LR}^{S*} + 6g_{LR}^{T*}) + g_{LR}^V(g_{RL}^{S*} + 6g_{RL}^{T*}) \right\} \\ \alpha' &= 8 \mathrm{Im} \left\{ g_{LR}^V(g_{RL}^{S*} + 6g_{RL}^{T*}) - g_{RL}^V(g_{LR}^{S*} + 6g_{LR}^{T*}) \right\} \\ b &= 4 (|g_{RR}^V|^2 + |g_{LL}^V|^2) + |g_{RR}^S|^2 + |g_{LL}^S|^2 \\ b' &= 4 (|g_{RR}^V|^2 - |g_{LL}^V|^2) + |g_{RR}^S|^2 - |g_{LL}^S|^2 \\ \beta &= -4 \mathrm{Re} \left\{ g_{RR}^V g_{LL}^{S*} + g_{LL}^V g_{RR}^{S*} \right\} \\ \beta' &= 4 \mathrm{Im} \left\{ g_{RR}^V g_{LL}^{S*} + g_{LL}^V g_{RR}^{S*} \right\} \\ c &= \frac{1}{2} \left\{ |g_{RL}^S - 2g_{RL}^T|^2 + |g_{LR}^S - 2g_{LR}^T|^2 \right\} \\ c' &= \frac{1}{2} \left\{ |g_{RL}^S - 2g_{RL}^T|^2 - |g_{LR}^S - 2g_{LR}^T|^2 \right\} \\ \mathrm{nd} \\ Q_L^{\nu_e} &= 1 - \left\{ \frac{1}{4} |g_{LR}^S|^2 + \frac{1}{4} |g_{LL}^S|^2 + |g_{RR}^V|^2 + |g_{RL}^V|^2 + 3|g_{LR}^T|^2 \right\} \\ \omega_L &= \frac{3}{4} \frac{\left\{ |g_{RR}^S|^2 + 4|g_{LR}^V|^2 + |g_{RL}^S|^2 + 12|g_{RL}^T|^2 \right\}}{|g_{RR}^S|^2 + |g_{RR}^S|^2 + 4|g_{LL}^V|^2 + 4|g_{LR}^V|^2 + 12|g_{RL}^T|^2} \,. \end{split}$$

It has been noted earlier by C. Jarlskog [11], that certain experiments observing the decay electron are especially informative if they yield the V-A values. The complete solution is now found as follows. Fetscher et al. [2] introduced four probabilities $Q_{\varepsilon\mu}(\varepsilon,\mu=R,L)$ for the decay of a μ -handed muon into an ε -handed electron, and showed that there exist upper bounds on Q_{RR} , Q_{LR} , and Q_{RL} , and a lower bound on Q_{LL} . These probabilities are given in terms of the $g_{\varepsilon\mu}^{\gamma}$'s by

$$Q_{\varepsilon\mu} = \frac{1}{4} |g_{\varepsilon\mu}^S|^2 + |g_{\varepsilon\mu}^V|^2 + 3(1 - \delta_{\varepsilon\mu})|g_{\varepsilon\mu}^T|^2 , \qquad (9)$$

where $\delta_{\varepsilon\mu} = 1$ for $\varepsilon = \mu$, and $\delta_{\varepsilon\mu} = 0$ for $\varepsilon \neq \mu$. They are related to the parameters a, b, c, a', b', and c' by

$$Q_{RR} = 2(b+b')/A ,$$

$$Q_{LR} = [(a-a') + 6(c-c')]/2A ,$$

$$Q_{RL} = [(a+a') + 6(c+c')]/2A ,$$

$$Q_{LL} = 2(b-b')/A ,$$
(10)

with A = 16. In the Standard Model, $Q_{LL} = 1$ and the others are zero.

Since the upper bounds on Q_{RR} , Q_{LR} , and Q_{RL} are found to be small, and since the helicity of the ν_{μ} in pion decay is known from experiment [12,13] to very high precision to be -1 [14], the cross section S of *inverse* muon decay, normalized to the V-A value, yields [2]

$$|g_{LL}^S|^2 \le 4(1-S) \tag{11}$$

and

$$|g_{LL}^V|^2 = S. (12)$$

Thus the Standard Model assumption of a pure V-A leptonic charged weak interaction of e and μ is derived (within errors) from experiments at energies far below mass of the W^{\pm} : Eq. (12) gives a lower limit for V-A, and Eqs. (9) and (11) give upper limits for the other four-fermion interactions. The existence of such upper limits may also be seen from $Q_{RR}+Q_{RL}=(1-\xi')/2$ and $Q_{RR}+Q_{LR}=\frac{1}{2}(1+\xi/3-16\ \xi\delta/9)$. Table 1 gives the current experimental limits on the magnitudes of the $g_{E\mu}^{\gamma}$'s. More stringent limits on the six coupling constants g_{LR}^{S} , g_{LR}^{V} , g_{LR}^{T} , g_{RL}^{S} , g_{RL}^{V} , and g_{RL}^{T} have been derived from upper limits on the neutrino mass [18]. Limits on the "charge retention" coordinates, as used in the older literature (e.g., Ref. 19), are given by Burkard et al. [20].

Table 1. Coupling constants $g_{\varepsilon\mu}^{\gamma}$ and some combinations of them. Ninety-percent confidence level experimental limits. The limits on $|g_{LL}^S|$ and $|g_{LL}^V|$ are from Ref. 15, and the others from a general analysis of muon decay measurements. Top two rows: Ref. 22, next two rows: Ref. 16, bottom three rows: Ref. 17, last row: Ref. 21. The experimental uncertainty on the muon polarization in pion decay is included. Note that, by definition, $|g_{\varepsilon\mu}^S| \leq 2$, $|g_{\varepsilon\mu}^V| \leq 1$ and $|g_{\varepsilon\mu}^S| \leq 1/\sqrt{3}$.

| $ g_{RR}^S < 0.035$ | $ g_{RR}^V < 0.017$ | $ g_{RR}^T \equiv 0$ |
|-----------------------------------|----------------------------------|-----------------------|
| $ g_{LR}^S < 0.050$ | $ g_{LR}^V < 0.023$ | $ g_{LR}^T < 0.015$ |
| $ g_{RL}^S < 0.412$ | $ g_{RL}^{V} < 0.104$ | $ g_{RL}^T < 0.103$ |
| $ g_{LL}^S < 0.550$ | $ g_{LL}^{V} > 0.960$ | $ g_{LL}^T \equiv 0$ |
| $ g_{LR}^S + 6g_{LR}^T < 0.143$ | $ g_{RL}^S + 6g_{RL}^T < 0.418$ | |
| $ g_{LR}^S + 2g_{LR}^T < 0.108$ | $ g_{RL}^S + 2g_{RL}^T < 0.417$ | |
| $ g_{LR}^S - 2g_{LR}^T < 0.070$ | $ g_{RL}^S - 2g_{RL}^T < 0.418$ | |
| $Q_{RR} + Q_{LR} < 8.2 \times 10$ | -4 | |

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μ DECAY PARAMETERS

ρ PARAMETER

($V{-}A)$ theory predicts ho= 0.75.

| VALUE | EVTS | DOCUMENT ID | TECN | CHG | COMMENT |
|-------------------------------------|----------|-------------------------|---------------|-----|-----------------|
| 0.74979 ± 0.00026 OUR AVE | RAGE | | | | |
| $0.74977 \pm 0.00012 \pm 0.00023$ | | ³⁰ BAYES | 11 TWST | + | Surface μ^+ |
| 0.7518 ± 0.0026 | | DERENZO | 69 RVUE | | |
| ullet $ullet$ We do not use the fol | lowing d | ata for averages, fits | , limits, etc | • • | • |
| $0.75014\pm0.00017\pm0.00045$ | | 31 MACDONALD | 08 TWST | + | Surface μ^+ |
| $0.75080 \pm 0.00032 \pm 0.00100$ | 6 G | ³² MUSSER | 05 TWST | + | Surface μ^+ |
| 0.72 ± 0.06 ± 0.08 | | AMORUSO | 04 ICAR | | Liquid Ar TPC |
| 0.762 ±0.008 | 170k | ³³ FRYBERGER | 68 ASPK | + | 25-53 MeV e+ |
| 0.760 ±0.009 | 280k | ³³ SHERWOOD | 67 ASPK | + | 25–53 MeV e^+ |
| 0.7503 ± 0.0026 | 800k | ³³ PEOPLES | 66 ASPK | + | 20–53 MeV e^+ |

 30 The quoted systematic error includes a contribution of 0.00013 (added in quadrature) from uncertainties on radiative corrections and on the Michel parameter $\eta.$

 31 The quoted systematic error includes a contribution of 0.00011 (added in quadrature) from the dependence on the Michel parameter η .

32 The quoted systematic error includes a contribution of 0.00023 (added in quadrature) from the dependence on the Michel parameter η .

 η constrained = 0. These values incorporated into a two parameter fit to ρ and η by DERENZO 69.

η PARAMETER

($V{-}A$) theory predicts $\eta=$ 0.

| VALUE | EVTS | DOCUMENT ID | TECN | CHG COMMENT |
|----------------------------------------|-------------|-------------------------|----------------|----------------------------|
| 0.057 ±0.034 OUR AVE | RAGE | | | |
| $0.071 \pm 0.037 \pm 0.005$ | 30M | DANNEBERG | 05 CNTR | $+$ 7–53 MeV e^+ |
| $0.011 \pm 0.081 \pm 0.026$ | 5.3M | ³⁴ BURKARD | 85BCNTR | $+$ 9–53 MeV e^+ |
| -0.12 ± 0.21 | 6346 | DERENZO | 69 HBC | $+$ 1.6-6.8 MeV e^+ |
| • • • We do not use the fo | llowing d | lata for averages, fits | s, limits, etc | . • • • |
| $-0.0021 \pm 0.0070 \pm 0.0010$ | 30M | ³⁵ DANNEBERG | 05 CNTR | $_{+}$ 7–53 MeV e^{+} |
| $-0.012 \pm 0.015 \pm 0.003$ | 5.3M | ³⁵ BURKARD | 85BCNTR | $+~$ 9–53 MeV e^{+} |
| -0.007 ± 0.013 | 5.3M | ³⁶ BURKARD | 85BFIT | $+$ 9–53 MeV e^{+} |
| -0.7 ± 0.5 | 170k | ³⁷ FRYBERGER | 68 ASPK | $+$ 25–53 MeV e^{+} |
| -0.7 ± 0.6 | 280k | ³⁷ SHERWOOD | 67 ASPK | $+$ 25-53 MeV e^{+} |
| 0.05 ±0.5 | 800k | ³⁷ PEOPLES | 66 ASPK | + 20-53 MeV e ⁺ |
| -2.0 ± 0.9 | 9213 | ³⁸ PLANO | 60 HBC | + Whole spectrum |
| ³⁴ Previously we used the g | lobal fit i | esult from BURKAR | D 85B in O | UR AVERAGE, we now |

only include their actual measurement.

 $\alpha=\alpha'=0$ assumed.

 36 Global fit to all measured parameters. The fit correlation coefficients are given in BURKARD 85B

 ρ constrained = 0.75 ³⁸Two parameter fit to ho and η ; PLANO 60 discounts value for η .

δ PARAMETER

($V{-}A$) theory predicts $\delta=$ 0.75.

| VALUE EVTS | DOCUMENT ID | TECN | CHG COMMENT |
|--------------------------------|------------------------|------|---------------------|
| 0.75047±0.00034 OUR AVERAGE | | | |
| $0.75049\pm0.00021\pm0.00027$ | ³⁹ BAYES 11 | TWST | $+$ Surface μ^+ |
| $0.7486 \pm 0.0026 \pm 0.0028$ | ⁴⁰ BALKE 88 | SPEC | $+$ Surface μ^+ |

| • • • | VVe do not use the fol | lowing da | ta for averages, fits | i, limits, etc. | • • | • |
|---------|-----------------------------|-----------|-----------------------|-----------------|-----|-----------------|
| 0.75067 | $7 \pm 0.00030 \pm 0.00067$ | | MACDONALD | 08 TWST | + | Surface μ^+ |
| 0.74964 | $1 \pm 0.00066 \pm 0.00112$ | 6G | GAPONENKO | 05 TWST | + | Surface μ^+ |
| | | | ⁴¹ VOSSLER | 69 | | |
| 0.752 | +0.009 | 4906 | ERVRERGER | 68 ASPK | 1 | 25_53 MeV e+ |

 0.782 ± 0.031 KRUGER 61 60 HBC + Whole spectrum 0.78 ± 0.05 8354 PLANO

 39 The quoted systematic error includes a contribution of 0.00006 (added in quadrature) from uncertainties on radiative corrections and on the Michel parameter $\eta.$ $^{40}\,\mathrm{BALKE}$ 88 uses ho= 0.752 \pm 0.003.

⁴¹ VOSSLER 69 has measured the asymmetry below 10 MeV. See comments about radiative corrections in VOSSLER 69.

$|(\xi \text{ PARAMETER}) \times (\mu \text{ LONGITUDINAL POLARIZATION})|$

(V-A) theory predicts $\xi=1$, longitudinal polarization =1 . DOCUMENT ID TECN CHO TECN CHG COMMENT

1.0009 + 0.0016 OUR AVERAGE

| 1.00084 | 1±0.00029 | $9 + 0.00165 \\ -0.00063$ | BUENO | 11 | TWST | Surface μ^+ beam |
|---------|-------------|---------------------------|------------------------|--------|-----------------|-----------------------------------|
| 1.0027 | ±0.0079 | ±0.0030 | BELTRAMI | 87 | CNTR | SIN, π decay in flight |
| • • • | We do not | use the follo | owing data for ave | rages, | fits, limits, e | tc. • • • |
| 1.0003 | ±0.0006 | ± 0.0038 | JAMIESON | 06 | TWST + | surface μ^+ beam |
| 1.0013 | ±0.0030 | ±0.0053 | ⁴² IMAZATO | 92 | SPEC + | $K^+ \rightarrow \mu^+ \nu_{\mu}$ |
| 0.975 | ±0.015 | | AKHMANOV | 68 | EMUL | 140 kG |
| 0.975 | ± 0.030 | | GUREVICH | 64 | EMUL | See AKHMANOV 68 |
| 0.903 | ± 0.027 | | ⁴³ ALI-ZADE | 61 | EMUL + | 27 kG |
| 0.93 | ± 0.06 | | PLANO | 60 | HBC + | 8.8 kG |
| 0.97 | ± 0.05 | | BARDON | 59 | CNTR | Bromoform target |
| | | | | | | |

 42 The corresponding 90% confidence limit from IMAZATO 92 is $|\xi P_{\mu}| >$ 0.990. This measurement is of K^+ decay, not π^+ decay, so we do not include it in an average, nor do we yet set up a separate data block for K results.

43 Depolarization by medium not known sufficiently well

$\xi \times (\mu \text{ LONGITUDINAL POLARIZATION}) \times \delta / \rho$

| VALUE | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
|--------------------------------------|-----------|-----------------------|----------|-----------|--------|----------------------|
| $1.00179 {}^{+ 0.00156}_{- 0.00071}$ | 4 | ¹⁴ BAYES | 11 | TWST | + | Surface μ^+ beam |
| • • • We do not use the | following | data for averages | s, fits, | limits, e | etc. • | • • |
| >0.99682 | 90 4 | ^{I5} JODIDIO | 86 | SPEC | + | TRIUMF |
| >0.9966 | 90 4 | ^{l6} STOKER | 85 | SPEC | + | μ -spin rotation |
| × 0.00E0 | 0.0 | CARR | 00 | CDEC | | 11 1.0 |

ı

⁴⁴BAYES 11 obtains the limit > 0.99909 (90% CL) with the constraint that $\xi imes (\mu$ LON-GITUDINAL POLARIZATION) $\times \delta/\rho \leq 1.0$.

45 JODIDIO 86 includes data from CARR 83 and STOKER 85. The value here is from the

 $_{
m 46}^{
m effatum.}$ STOKER 85 find $(\xi {
m P}_{\mu} \delta/
ho) >$ 0.9955 and > 0.9966, where the first limit is from new μ spin-rotation data and the second is from combination with CARR 83 data. In $V\!-\!A$ theory, $(\delta/\rho)=1.0$

$\xi' = LONGITUDINAL POLARIZATION OF e^+$

(V-A) theory predicts the longitudinal polarization $=\pm 1$ for e^\pm , respectively. We have flipped the sign for e^- so our programs can average.

| VALUE | <u>EVTS</u> | DO CUMENT ID | | TECN C | HG COMMENT | |
|-------------------|-------------|--------------|----|--------|---------------------------------------|--|
| 1.00 ± 0.04 | OUR AVERAGE | | | | | |
| 0.998 ± 0.045 | 1 M | BURKARD | 85 | CNTR + | - Bhabha + annihil | |
| 0.89 ± 0.28 | 29k | SCHWARTZ | 67 | OSPK - | Moller scattering | |
| 0.94 ± 0.38 | | BLOOM | 64 | CNTR + | - Brems transmiss. | |
| 1.04 ± 0.18 | | DUCLOS | 64 | CNTR + | Bhabha scattering | |
| 1.05 ± 0.30 | | BUHLER | 63 | CNTR + | - Annihilation | |

ξ'' PARAMETER

FVTS DOCUMENT ID TECN CHG COMMENT 85 CNTR + 47 BURKARD 0.65 ± 0.36 326k Bhabha + annihil ⁴⁷BURKARD 85 measure $(\xi'' - \xi \xi')/\xi$ and ξ' and set $\xi = 1$.

TRANSVERSE e^+ POLARIZATION IN PLANE OF μ SPIN, e^+ MOMEN-TUM

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|---------------------------------|-------|--------------|------|------|-----|------------------|
| 7 ± 8 OUR AV | ERAGE | | | | | |
| $6.3 \pm 7.7 \pm 3.4$ | 30 M | DANNEBERG | 05 | CNTR | + | 7–53 MeV e^+ |
| $16 \pm 21 \pm 10$ | 5.3M | BURKARD | 85 B | CNTR | + | Annihil 9-53 MeV |

TRANSVERSE e^+ POLARIZATION NORMAL TO PLANE OF μ SPIN, e^+ MOMENTUM

Zero if T invariance holds.

5.3M

| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|--------------------------|------|--------------|------|------|-----|------------------|
| -2 ± 8 OUR AVE | RAGE | | | | | |
| $-3.7\pm\ 7.7\pm3.4$ | 30 M | DA NNEBERG | 05 | CNTR | + | 7–53 MeV e^+ |
| $7 \pm 22 \pm 7$ | 5.3M | BURKARD | 85 B | CNTR | + | Annihil 9-53 MeV |

α/A

15 + 50 + 14

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|---------------------------------|---------------|-----------------------|---------|---------|--------|---------|
| 0.4± 4.3 | | ¹⁸ BURKARD | 85B | FIT | | |
| • • • We do not use | the following | data for averages | , fits, | limits, | etc. • | • • |

BURKARD 85B CNTR + $^{\rm 48}\,{\rm Global}$ fit to all measured parameters. Correlation coefficients are given in BURKARD 85B.

9-53 MeV e+

Zero if T invariance holds. <u>VALUE (units 10^{-3}) EVTS</u>

30M

5.3M

-10 ±20 OUR AVERAGE

 $-~3.4\pm 21.3\pm~4.9$

-47 ± 50 ± 14

| - 0.2 ± 4.3 49 Previously we used: | | | 85B FIT |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------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| | | ⁵⁰ BURKARD t result from BU | JRKARD 85B in OUR AVERAGE, we now |
| only include their a | ctual measu | rement. BURK | ARD 85B measure e^+ polarizations P $_T$ |
| and P $_{T_2}$ versus e^+ | | | - |
| ⁵⁰ Global fit to all m | | rameters. The | fit correlation coefficients are given in |
| BURKARD 85B. | | | - |
| β/A | | | |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT IE | TECN CHG COMMENT |
| 3.9± 6.2 | į | BURKARD | 85B FIT |
| • • • We do not use t | he following | data for averag | ges, fits, limits, etc. • • • |
| 2 ±17 ±6 | 5.3M | BURKARD | 85B CNTR $+$ 9–53 MeV e^+ |
| ⁵¹ Global fit to all m BURKARD 85B. | neasured pai | ameters. The | fit correlation coefficients are given in |
| β'/A Zero if <i>T</i> invariar | nce holds | | |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN CHG COMMENT |
| 2 ± 7 OUR AVE | RAGE | | |
| - 0.5 ± 7.8 ± 1.8 | 30M | DANNEBER: | · · · · · · · · · · · · · · · · · · · |
| 17 ±17 ±6 | | ⁵² BURKARD | 85B CNTR $+$ 9–53 MeV e^+ ges, fits, limits, etc. \bullet \bullet |
| - 1.3 ± 3.5 ± 0.6 | _ | 3 DANNEBER | |
| 1.5 ± 6.3 | į | ⁵⁴ BURKARD | 85B FIT |
| Previously we used | the global fi | t result from BU | JRKARD 85B in OUR AVERAGE, we now ARD 85B measure e^\pm polarizations P $_{T^\pm}$ |
| | | rement. BUKK | AND obstitle asure e - polarizations P_{T_1} |
| and P_{T_2} versus e^+ | | | |
| $^{53}\alpha = \alpha' = 0$ assume 54 Global fit to all m BURKARD 85B. | ed. neasured par | ameters. The | fit correlation coefficients are given in |
| | | | |
| a/A This comes from | an alternat | ive narameteriz | ation to that used in the Summary Table |
| (see the "Note or | | | |
| VALUE (units 10 ⁻³) | CL%_ | DO CUMENT ID | TECN_ |
| • • • We do not use t | he following | data for averag | ges, fits, limits, etc. • • • |
| <15.9 | 90 5 | 55 BURKARD | 85B FIT |
| ⁵⁵ Global fit to all | measured | parameters. | Correlation coefficients are given in |
| | | | |
| BURKARD 85B. | | | |
| a'/A | | | |
| a'/A This comes from | | | ation to that used in the Summary Table |
| This comes from (see the "Note of | | ay Parameters" | above). |
| This comes from (see the "Note or WALUE (units 10 ⁻³) | n Muon Dec | ay Parameters" DOCUMENT ID | above). <u>TECN</u> |
| This comes from (see the "Note or NALUE (units 10 ⁻³) • • • We do not use t | n Muon Dec he following | ay Parameters" <u>DOCUMENT ID</u> data for averag | above). TECN ges, fits, limits, etc. • • • |
| This comes from (see the "Note of MALUE (units 10 ⁻³) • • • We do not use t 5.3 ± 4.1 | n Muon Ded he following | ay Parameters" <u>DOCUMENT ID</u> data for averag ⁵⁶ BURKARD | above). |
| This comes from (see the "Note or WALUE (units 10 ⁻³) | n Muon Ded he following | ay Parameters" <u>DOCUMENT ID</u> data for averag ⁵⁶ BURKARD | above). TECN ges, fits, limits, etc. • • • |
| a'/A This comes from (see the "Note or NALUE (units 10 ⁻³) • • • • We do not use t 5.3±4.1 56 Global fit to all BURKARD 85B. (b'+b)/A | n Muon Ded he following t measured | ay Parameters" <u>DOCUMENT ID</u> data for average 66 BURKARD parameters. | above). TECN res, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in |
| This comes from (see the "Note or (see the "Note or MALUE (units 10 ⁻³) • • • We do not use t 5.3 ± 4.1 56 Global fit to all BURKARD 85B. (b'+b)/A This comes from | n Muon Ded he following t measured an alternat | ay Parameters" <u>DOCUMENT ID</u> data for averag 66 BURKARD parameters. | above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in action to that used in the Summary Table |
| This comes from (see the "Note or (see the "Note or (see the "Note or NALUE (units 10 ⁻³) • • • We do not use t 5.3 ± 4.1 56 Global fit to all BURKARD 85B. (b'+b)/A This comes from (see the "Note or (see the "Note or "Note | n Muon Dec he following t measured an alternat n Muon Dec | ay Parameters" <u>DOCUMENT ID</u> data for average 6 BURKARD parameters. ive parameters" ay Parameters" | above). TECN (imits, etc. • • • 85B FIT Correlation coefficients are given in the summary Table above). |
| This comes from (see the "Note or (see the "Note | n Muon Decompose the following measured an alternat n Muon Decompose CL% | ay Parameters" <u>DOCUMENT ID</u> data for averag 66 BURKARD parameters. ive parameteriz. ay Parameters" <u>DOCUMENT ID</u> | above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in a standard to that used in the Summary Table above). TECN |
| This comes from (see the "Note or (see the "Note | n Muon Dec he following t measured an alternat n Muon Dec CL% he following | ay Parameters" <u>DOCUMENT ID</u> data for averag 66 BURKARD parameters. ve parameteriz. ay Parameters" <u>DOCUMENT ID</u> data for averag | above). TECN (es, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN (es, fits, limits, etc. • • • |
| This comes from (see the "Note or (see the "Note or (see the "Note or (wature (units 10 ⁻³)) • • • We do not use t 5.3 ± 4.1 56 Global fit to all BURKARD 85B. (b'+b)/A This comes from (see the "Note or (se | n Muon Dec he following measured an alternat n Muon Dec <u>CL%</u> he following | ay Parameters" <u>DOCUMENT ID</u> data for averag 66 BURKARD parameters. ive parameters" <u>DOCUMENT ID</u> data for averag data for averag 77 BURKARD | above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN ges, fits, limits, etc. • • • 85B FIT |
| This comes from (see the "Note or (see the "Note | n Muon Dec he following measured an alternat n Muon Dec <u>CL%</u> he following | ay Parameters" <u>DOCUMENT ID</u> data for averag 66 BURKARD parameters. ive parameters" <u>DOCUMENT ID</u> data for averag data for averag 77 BURKARD | above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN ges, fits, limits, etc. • • • 85B FIT |
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| This comes from (see the "Note or (see the "Note | he following to measured an alternat n Muon Dec CL% he following 90 to measured an alternat an alternat an alternat an alternat an alternat an alternat | ay Parameters" <u>DOCUMENT ID</u> data for average 66 BURKARD parameters. Eve parameters. <u>DOCUMENT ID</u> data for average 67 BURKARD parameters. | above). TECN |
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| This comes from (see the "Note or (see the "Note | n Muon Dec measured an alternat n Muon Dec CL% he following 90 measured an alternat n Muon Dec cL% he following 90 measured | ay Parameters" <u>DOCUMENT IC</u> data for average 66 BURKARD parameters. ive parameters" <u>DOCUMENT IC</u> data for average 67 BURKARD parameters. ive parameters. ive parameters. ive parameters" <u>DOCUMENT IC</u> data for average 70 BURKARD parameters" <u>DOCUMENT IC</u> data for average 88 BURKARD | above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above. 85B FIT Correlation coefficients are given in above. TECN ges, fits, limits, etc. • • • |
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| a'/A This comes from (see the "Note or (see th | an alternat n Muon Dec measured an alternat n Muon Dec CL% he following 90 measured an alternat n Muon Dec CL% he following 90 measured an alternat n Muon Dec he following 10 measured an alternat n Muon Dec he following 10 he following | ay Parameters" <u>DOCUMENT ID</u> data for average 66 BURKARD parameters. ive parameters" <u>DOCUMENT ID</u> data for average 67 BURKARD parameters. ive parameteriz. ive parameteriz. ive parameters" <u>DOCUMENT ID</u> data for average 88 BURKARD parameters. ive parameters. ive parameters. ive parameteriz. above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above. TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above. TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above. TECN ges, fits, limits, etc. • • • 85B FIT Correlation coefficients are given in above). TECN ges, fits, limits, etc. • • • |

DO CUMENT ID

⁴⁹ BURKARD

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

DANNEBERG 05 CNTR +

85B CNTR +

TECN CHG COMMENT

7-53 MeV e+

9-53 MeV e+

MOHR arX iv:1203 5425 P.J. Mohr. B.N. Taylor, D.B. Newell arXiv:1203.5425 PRL 107 171801 PRL 106 041804 PR D84 032005 PRL 106 041803 PRL 106 079901 NP B834 1 PR D80 052008 P.J. Mohr, B.N. Tay J. Adam et al. R. Bayes et al. J.F. Bueno et al. D.M. Webber et al. D.M. Webber et al. J. Adam et al. G.W. Bennett et al. A. Barrayk et al. (NIST (MEG Collab. (TWIST Collab. (TWIST Collab. (MuLan Collab. (MuLan Collab. (MEG Collab. (MUG-2 Collab. (FAST Collab. ADAM BAYES BUENO WEBBER 11 11 11 11 A. Barczyk et al. R.P. MacDonald et al. P.J. Mohr, B.N. Taylor, D.B. Newell D.B. Chitwood et al. BARCZYK MACDONALD PL B663 172 PR D78 032010 (FAST Collab (TWIST Collab MOHR CHITWOOD RMP 80 633 PRL 99 032001 (NIST (MULAN Collab. (MULAN Collab.) (MUG-2 Collab.) (SINDRUM II Collab.) (TWIST Collab.) (ETH, JAGL, PSI+) (TWIST Collab.) (INST) (INST) (INST) (INST) (ICARUS Collab.) (Muon(g-2) Collab.) (Muon(g-2) Collab.) (Muon(g-2) Collab.) (BUN) (B PRL 99 032001 PR D73 072003 EPJ C47 337 PR D74 072007 PRL 94 021802 PR D71 071101R RMP 77 1 PRL 94 101805 EPJ C33 233 PRL 92 161802 PR D55 112002 PRL 89 101804 PRL 86 2227 PR D65 091101R D.B. Chitwood et al. G.W. Bennett et al. W. Bertl et al. B. Jamieson et al. N. Danneberg et al. A. Gaponenko et al. P.J. Mohr, B.N. Taylor J.R. Musser et al. G.W. Bennett et al. M. Ahmed et al. G.W. Bennett et al. H.N. Brown et al. H.N. Brown et al. H.N. Brown et al. V. Meyer et al. BENNETT BERTL JAMIESON JAMIESON DANNEBERG GAPONENKO MOHR MUSSER AMORUSO BENNETT AHMED BENNETT BROWN BROWN 05 05 05 04 04 02 01 00 00 PR D62 091101R BROWN MEYER PRL 84 1136 PRL 83 1521 RMP 71 S133 V. Mever et al. V. Meyer et al. M.L. Brooks et al. V.W. Hughes, T. Kinoshita W. Liu et al. P.J. Mohr, B.N. Taylor P.J. Mohr, B.N. Taylor L. Willmann et al. (MEGA/LAMPE Collab.) BROOKS HUGHES (LAMPF Collab.) PRL 82 711 MOHR JPCRD 28 1713 RMP 72 351 PRL 82 49 Also WILLMANN RMP 72 351 P.J. Mohr, B.N. Taylor P.RL 82 49 L. Williman et al. PR D57 3873 G.J. Feldman, R.D. Cousins PL B422 334 J. Kaulard et al. V.A. Gordeev et al. Translated from YAF 60 1291. PRL 77 1950 PRL 76 200 W. Honecker et al. C. Dohmen et al. PR D48 1976 B. Ni et al. PR D48 1976 B. Ni et al. PR D48 1976 J. Imazato et al. PR D48 1976 YAF 53 1302. PL B263 534 PRL 66 2716 B.E. Matthias et al. PRL 67 392 (erratum) B.E. Matthias et al. PR D41 2709 T.M. Huber et al. PR D38 2102 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 59 970 S. Ahmad et al. (9 RR L 50 PR L FELDMAN KAULARD GORDEEV (SINDRUM-II Collab.) (PNPI) (PSI, ZURI, HEIDH, TBIL+) (SINDRUM II Collab.) (PSI SINDRUM-II Collab.) (LAMPF E645 Collab.) (LAMPF Crystal-Box Collab.) (KEK, INUS, TOKY+) (JINR) ABELA HONECKER DOHMEN FREEDMAN B. Ni et al. V.A. Baranov et al. 1302. D.A. Krakauer et al. B.E. Matthias et al. B.E. Matthias et al. Y.A. Baranov et al. 150. B.E. Matthias et al. Y.A.E. Helipp. Will.+ Y.A. KRAKAUER MATTHIAS Also HUBER AHMAD PRL 59 970 PR D37 587 BELLGARDT BOLT ON NP B299 1 PR D38 2077 PRL 56 2461 PRL 57 3241 PRL 57 3241 PL B194 326 RMP 59 1121 PRL 57 671 PR D34 1967 PR D37 237 (erratum) NP B260 1 PRL 55 465 PL 150B 242 PL 160B 343 PR D24 2004 BELTRAMI COHEN COHEN BEER JODIDIO Also BERTL BRYMAN BURKARD BURKARD 85 85 85 85 B PR D24 2004 PL 129B 260 STOKER PRL 54 1887 BARDIN PL 137B 135 PL 140B 299 BERTI PL 140B 299 PRL 53 1415 NP A412 523 PR D29 343 PRL 51 164 PRL 39 1113 PL 122B 465 PRL 51 627 PR D25 2846 PRL 42 556 PR D25 652 PRL 49 993 PR D25 1174 CNPP 10 147 CNPP 10 147 PI 958 318 FICHENBER GIOVANETTI AZUELOS A ISO BERGS MA CARR KINNISON Also KLEMPT MARIAM 82 82 82 81 MARSHALL NEMETHY PL 95B 318 LNC 28 401 NP A377 406 ABELA BADERT.. 80 80 NP A377 406 PL 93B 203 NP A340 249 PL 72B 183 PRL 44 522 PRL 45 1370 NP B150 1 PL 79B 371 JPG 4 345 NP B150 1 NP B133 205 PRL 41 442 PL 77B 326 JONKER SCHAAF Also WILLIS Also BAILEY BADERT... 80 79 78 78 BAILEY Also BLIETS CHAU BOWMAN PL 77B 326 PRL 39 1385 PRL 38 956 PRL 39 1113 CAMANI BADERT. CASPERSON DEPOMMIER BALANDIN JETP 40 811 M.P. Balandin et al. Translated from ZETF 67 1631.

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| DUCLOS | 64 | PL 9 62 | J. Duclos et al. | (CERN) |
| GUREVICH | 64 | PL 11 185 | I.I. Gurevich et al. | (KIAE) |
| BUHLER | 63 | PL 7 368 | A. Buhler-Broglin et al. | (ČERN) |
| MEYER | 63 | PR 132 2693 | S.L. Meyer et al. | (COLU) |
| CHARPAK | 62 | PL 1 16 | G. Charpak et al. | (CERN) |
| CONFORTO | 62 | NC 26 261 | G. Conforto et al. | (INFN, ROMA, CERN) |
| A LI-ZA DE | 61 | JETP 13 313 | S.A. Ali-Zade, I.I. Gurevich, B.A. | Nikolsky |
| | | Translated from ZETF 40 | | |
| CRITTENDEN | 61 | PR 121 1823 | R.R. Crittenden, W.D. Walker, J. | |
| KRUGER | 61 | UCRL 9322 unpub. | H. Kruger | (LRL) |
| GUREVICH | 60 | JETP 10 225 | I.I. Gurevich, B.A. Nikolsky, L.V. | Surkova (ITEP) |
| PLANO | 60 | Translated from ZETF 37 PR 119 1400 | '318. R.I. Plano | (COLU) |
| ASHKIN | | NC 14 1266 | J. Ashkin et al. | |
| BARDON | 59 | PRL 2 56 | | (CERN) rman (COLU) |
| LEE | 59 59 | PRL 2 56 | M. Bardon, D. Berley, L.M. Lede J. Lee. N.P. Samios | (COLU) |
| LCC | 59 | FRE 3 33 | J. Lee, N.F. Saililos | (COLO) |
| | | | | |



au discovery paper was PERL 75. $e^+e^-
ightarrow au^+ au^-$ cross-section threshold behavior and magnitude are consistent with pointlike spin-1/2 Dirac particle. BRANDELIK 78 ruled out pointlike spin-0 or spin-1 particle. FELDMAN 78 ruled out J = 3/2. KIRKBY 79 also ruled out J=integer, J=3/2.

τ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------|------------|-----------------------|-------|-----------|--------------------------------------------------------------------------|
| 1776.82 ± 0.16 OUR A | WERAGE | | | | |
| $1776.68 \pm 0.12 \pm 0.41$ | 682k | ¹ AUBERT | 09AK | BABR | 423 fb $^{-1}$, $E_{\rm cm}^{ee}$ =10.6 GeV |
| $1776.81 {}^{+\ 0.25}_{-\ 0.23} \pm 0.15$ | 81 | ANASHIN | | | 6.7 pb ⁻¹ , $E_{\rm cm}^{ee} =$ |
| $1776.61 \pm 0.13 \pm 0.35$ | | ¹ BELOUS | 07 | BELL | 3.54-3.78 GeV 414 fb $^{-1}$ $E^{ee}_{\text{cm}} = 10.6 \text{ GeV}$ |
| $1775.1 \ \pm 1.6 \ \pm 1.0$ | 13.3k | ² ABBIENDI | 00A | OPAL | 1990-1995 LEP runs |
| $1778.2 \ \pm 0.8 \ \pm 1.2$ | | ANASTASSOV | 97 | CLEO | $E_{\mathrm{CM}}^{\mathit{ee}} = 10.6 \; \mathrm{GeV}$ |
| $1776.96 {}^{+\ 0.18}_{-\ 0.21} {}^{+\ 0.25}_{-\ 0.17}$ | 65 | ³ BAI | 96 | BES | $E_{\rm cm}^{\it ee} = 3.54 - 3.57 \; {\rm GeV}$ |
| $1776.3 \ \pm 2.4 \ \pm 1.4$ | 11 k | ⁴ ALBRECHT | 92M | ARG | $E_{cm}^{ee} = 9.4-10.6 \text{ GeV}$ |
| $1783 \begin{array}{c} +3 \\ -4 \end{array}$ | 692 | ⁵ BACINO | 78B | DLCO | $E_{cm}^{ee} = 3.1-7.4 \text{ GeV}$ |
| • • • We do not use | the follow | wing data for aver | ages, | fits, lim | its, etc. • • • |
| $1777.8 \ \pm 0.7 \ \pm 1.7$ | 35 k | ⁶ BALEST | 93 | CLEO | Repl. by ANASTASSOV 97 |

1776.9 $^{+\ 0.4}_{-\ 0.5}$ ± 0.2 14 ⁷ BAI 92 BES Repl. by BAI 96

$(m_{\tau^+} - m_{\tau^-})/m_{\text{average}}$

TECN

COMMENT

DOCUMENT ID

A test of CPT invariance.

C1 %

VALUE

| $< 2.8 \times 10^{-4}$ | 90 | BELOUS | 07 | BELL | 414 fb $^{-1}$, $E_{ m cm}^{\it ee}$ =10.6 GeV | | | |
|--------------------------------------------------------------------------------------------------|--------------------------|--------------------|--------|------------|-------------------------------------------------|--|--|--|
| • • • We do not | use the follo | owing data for ave | rages, | fits, limi | ts, etc. • • • | | | |
| $< 5.5 \times 10^{-4}$ | 90 | $^{ m 1}$ AUBERT | 09A H | BABR | 423 fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6$ GeV | | | |
| $< 3.0 \times 10^{-3}$ | 90 | ABBIENDI | 0 0 A | OPAL | 1990-1995 LEP runs | | | |
| 1 AUBERT 09AK quote both the listed upper limit and $(m_{_{T}^+}-m_{_{T}^-})/m_{ m average}=$ | | | | | | | | |
| $(-3.4 \pm 1.3 \pm$ | = 0.3) × 10 ⁻ | -4 | | | | | | |

au MEAN LIFE

| VALUE (10 ⁻¹⁵ s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------------------------------|----------------|-------------------|---------|-----------|------------------------------------------------|
| 290.6± 1.0 OUR A | VERAGE | | | | |
| $290.9 \pm 1.4 \pm 1.0$ | | ABDALLAH | 04 T | DLPH | 1991-1995 LEP runs |
| $293.2 \pm 2.0 \pm 1.5$ | | ACCIARRI | 00B | L3 | 1991-1995 LEP runs |
| $290.1 \pm 1.5 \pm 1.1$ | | BARATE | 97R | ALEP | 1989-1994 LEP runs |
| $289.2 \pm 1.7 \pm 1.2$ | | ALEXANDER | 96E | OPAL | 1990-1994 LEP runs |
| $289.0 \pm 2.8 \pm 4.0$ | 57.4k | BALEST | 96 | CLEO | $E_{\mathrm{cm}}^{ee} = 10.6 \; \mathrm{GeV}$ |
| | e the followin | g data for averag | es, fit | s, limits | , etc. • • • |
| $291.2 \pm 2.0 \pm 1.2$ | | BARATE | 97ı | ALEP | Repl. by BARATE 97R |
| 291.4 ± 3.0 | | ABREU | 96B | DLPH | Repl. by ABDAL- |
| 290.1 ± 4.0 | 34k | ACCIARRI | 96ĸ | 1.3 | LAH 04T Repl. by ACCIARRI 00B |
| 297 ± 9 ± 5 | 1671 | ABE | | SLD | 1992–1993 SLC runs |
| | | BATTLE | 92 | | |
| | 4100 | | | | $E_{\rm cm}^{\it ee}=10.6~{\rm GeV}$ |
| 301 ± 29 | 3780 | KLEINWORT | 89 | JADE | E ee = 35-46 GeV |
| 288 \pm 16 \pm 17 | 807 | AMIDEI | 88 | MRK2 | $E_{\rm cm}^{\it ee}$ = 29 GeV |
| $306~\pm~20~\pm14$ | 695 | BRAUNSCH | 88 C | TASS | $E_{\rm cm}^{\it ee}=36~{\rm GeV}$ |
| $299~\pm~15~\pm10$ | 1311 | ABACHI | 87 c | HRS | $E_{\rm cm}^{\it ee}$ = 29 GeV |
| $295 \hspace{0.1cm} \pm \hspace{0.1cm} 14 \hspace{0.1cm} \pm \hspace{0.1cm} 11$ | 5696 | ALBRECHT | 87P | ARG | $E_{\rm cm}^{ee} = 9.3 - 10.6 {\rm GeV}$ |
| $309 ~\pm~ 17 ~\pm~ 7$ | 3788 | BAND | 87B | MAC | $E_{\rm cm}^{\it ee}=$ 29 GeV |
| $325 \ \pm \ 14 \ \pm 18$ | 8470 | BEBEK | 87c | CLEO | $E_{\rm cm}^{\it ee}=10.5~{\rm GeV}$ |
| 460 ±190 | 102 | FELDMAN | 82 | MRK2 | $E_{\text{cm}}^{\textit{ee}} = 29 \text{ GeV}$ |

au MAGNETIC MOMENT ANOMALY

The q^2 dependence is expected to be small providing no thresholds are nearby.

$\mu_{\tau}/(e\hbar/2m_{\tau})-1=(g_{\tau}-2)/2$

For a theoretical calculation [$(g_{\tau}-2)/2=117~721(5)\times 10^{-8}$], see EIDELMAN 07. <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u>
> − 0.052 and < 0.013 (CL = 95%) OUR LIMIT DOCUMENT ID TECN COMMENT

| >-0.052 and <0.013 | 95 | ¹ ABDALLAH | 04K | DLPH | $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ |
|------------------------------------------------|----------|--------------------------|--------|------------|----------------------------------------------------|
| • • • We do not use th | e follow | ing data for avera | ges, f | its, limit | at LEP2 s, etc. • • • |
| < 0.107 | 95 | • | _ | | $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ |
| 0.107 | ,,, | | | | |
| > -0.007 and < 0.005 | 95 | ³ GONZALEZ-S. | 00 | RVUE | $e^+e^- \rightarrow \tau^+\tau^-$ and |
| > -0.052 and < 0.058 | OE | 4 ACCIARRI | 00- | 1.2 | $W \rightarrow 	au u_{	au}$ 1991-1995 LEP runs |
| > - 0.052 and < 0.056 > - 0.068 and < 0.065 | | | | | 1990-1995 LEP runs |
| | | | | | |
| > -0.004 and < 0.006 | 95 | ⁶ ESCRIBANO | 97 | RVUE | $Z \rightarrow \ 	au^+ \ 	au^-$ at LEP |
| < 0.01 | 95 | ⁷ ESCRIBANO | 93 | RVUE | $Z ightarrow ~	au^+ ~	au^-$ at LEP |
| < 0.12 | 90 | GRIFOLS | 91 | RVUE | $Z \rightarrow \tau \tau \gamma$ at LEP |

 $^{^{8}}$ SILVERMAN 83 RVUE $e^{+}e^{-} \rightarrow \tau^{+}\tau^{-}$ at PETRA \$\$^{1}\$ ABDALLAH 04K limit is derived from \$e^+e^- \rightarrow e^+e^- \tau^+ \tau^-\$ total cross-section measurements at \$\sqrt{s}\$ between 183 and 208 GeV. In addition to the limits, the authors also quote a value of \$-0.018 \pm 0.017\$.

au ELECTRIC DIPOLE MOMENT $(d_{ au})$

A nonzero value is forbidden by both T invariance and P invariance.

The q^2 dependence is expected to be small providing no thresholds are nearby.

$Re(d_{\tau})$

< 0.023

| · '' | | | | | |
|--------------------------|------------|-----------------------|---------|------------|---------------------------------------------------------------|
| $VALUE\ (10^{-16}\ ecm)$ | CL% | DO CUMENT ID | | TECN | COMMENT |
| - 0.22 to 0.45 | 95 | 1 NA MI | 03 | BELL | E _{cm} = 10.6 GeV |
| | the follow | ving data for avera | ges, fi | ts, limits | s, etc. • • • |
| < 2.3 | 90 | ² grozin | 09A | RVUE | From e EDM limit |
| < 3.7 | 95 | ³ ABDALLAH | | | $e^+e^- ightarrow \ e^+e^- 	au^+ 	au^-$ |
| < 11.4 | 95 | ⁴ ACHARD | 04G | L3 | at LEP2 $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ at LEP2 |
| < 4.6 | 95 | ⁵ ALBRECHT | 00 | ARG | $E_{\rm cm}^{ee} = 10.4 \text{ GeV}$ |
| >-3.1 and <3.1 | 95 | ACCIARRI | 98E | L3 | 1991-1995 LEP runs |

 $^{^1\,{\}rm AUBERT}\,$ 09AK and BELOUS 07 fit τ pseudomass spectrum in $\tau\to\,\pi\pi^+\,\pi^-\,\nu_\tau$ decays. Result assumes $m_{\nu_{\tau}}=0$.

 $^{^2}$ ABBIENDI 00A fit au pseudomass spectrum in $au
ightarrow \pi^\pm \leq 2\,\pi^0\,
u_ au$ and $au
ightarrow \pi^{\pm}\pi^{+}\pi^{-} \leq 1\pi^{0}\nu_{\tau}$ decays. Result assumes $m_{\nu_{\tau}}=0$.

 $^{^3}$ BAI 96 fit $\sigma(e^+e^- \to \tau^+\tau^-)$ at different energies near threshold.

 $^{^4}$ ALBRECHT 92M fit τ pseudomass spectrum in $\tau^- \to ~2\pi^-\pi^+\,\nu_\tau$ decays. Result assumes $m_{
u_{ au}} = 0$.

 $^{^5}$ BACINO 78B value comes from $e^\pm X^\mp$ threshold. Published mass 1782 MeV increased by 1 MeV using the high precision $\psi(2S)$ mass measurement of ZHOLENTZ 80 to eliminate the absolute SPEAR energy calibration uncertainty.

⁶ BALEST 93 fit spectra of minimum kinematically allowed τ mass in events of the type $e^+e^- \rightarrow \tau^+\tau^- \rightarrow (\pi^+ n\pi^0 \nu_\tau)(\pi^- m\pi^0 \nu_\tau)$ $n \leq 2, \ m \leq 2, \ 1 \leq n+m \leq 3$. If $m_{\nu_{T}}\neq$ 0, result increases by $(m_{\nu_{T}}^{2}/1100~{\rm MeV}).$

⁷BAI 92 fit $\sigma(e^+e^- \rightarrow \tau^+\tau^-)$ near threshold using $e\mu$ events.

² ACHARD 04G limit is derived from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ total cross-section measurements at \sqrt{s} between 189 and 206 GeV, and is on the absolute value of the magnetic moment anomaly.

³ GONZALEZ-SPRINBERG 00 use data on tau lepton production at LEP1, SLC, and

LEP2, and data from colliders and LEP2 to determine limits. Assume imaginary component is zero. 4 ACCIARRI 98E use $Z \rightarrow ~\tau^+\tau^-\gamma$ events. In addition to the limits, the authors also quote a value of $0.004\pm0.027\pm0.023$.

⁵ ACKERSTAFF 98n use $Z \to \tau^+ \tau^- \gamma$ events. The limit applies to an average of the form factor for off-shell τ 's having ρ^2 ranging from m_τ^2 to $(M_Z - m_\tau)^2$.

⁶ ESCRIBANO 97 use preliminary experimental results.

 $^{^7}$ ESCRIBANO 93 limit derived from $\Gamma(Z
ightarrow~ au^+ au^-)$, and is on the absolute value of the magnetic moment anomaly.

SILVERMAN 83 limit is derived from $e^+e^- \to \tau^+\tau^-$ total cross-section measurements for g^2 up to $(37~{\rm GeV})^2$.

| >-3.8 and <3.6 | 95 | ⁶ ACKERSTAFF | 98N | OPAL | 1990-1995 LEP runs |
|------------------|----|--------------------------|-----|------|---------------------------------------------|
| < 0.11 | 95 | ^{7,8} ESCRIBANO | 97 | RVUE | $Z \rightarrow ~ 	au^+ 	au^-$ at LEP |
| < 0.5 | 95 | ⁹ ESCRIBANO | 93 | RVUE | $Z \rightarrow ~ 	au^+ 	au^-$ at LEP |
| < 7 | 90 | GRIFOLS | 91 | RVUE | $Z \rightarrow \ 	au 	au 	au \gamma$ at LEP |
| < 1.6 | 90 | DELAGUILA | 90 | RVUE | $e^+ e^- \rightarrow \tau^+ \tau^-$ |
| | | | | | $E_{\rm cm}^{ee} = 35 \text{ GeV}$ |

 1 INAMI 03 use $e^+\,e^-\to\,\tau^+\tau^-$ events. 2 GROZIN 09A calculate the contribution to the electron electric dipole moment from the τ electric dipole moment appearing in loops, which is $\Delta d_e=6.9\times 10^{-12}~d_\tau.$ Dividing the REGAN 02 upper limit $\left|d_e\right|\leq 1.6\times 10^{-27}~e$ cm at CL=90% by $6.9\times 10^{-12}~g$ gives the limit

the REGAL 2 appendix |e| = 200000 this limit. 3 ABDALLAH 04K limit is derived from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ total cross-section measurements at \sqrt{s} between 183 and 208 GeV and is on the absolute value of d_τ . 4 ACHARD 04G limit is derived from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ total cross-section measurements. The section of 200 GeV, and is on the absolute value of d_τ .

surements at \sqrt{s} between 189 and 206 GeV, and is on the absolute value of d_{τ} .

 5 ALBRECHT 00 use $e^+\,e^-\to \tau^+\tau^-$ events. Limit is on the absolute value of Re(d_τ). 6 ACKERSTAFF 98N use $Z\to \tau^+\tau^-\gamma$ events. The limit applies to an average of the form factor for off-shell au's having p^2 ranging from $m_{ au}^2$ to $(M_Z - m_{ au})^2$.

 7 ESCRIBANO 97 derive the relationship $|d_{\tau}|=\cot\theta_W\,|d_{\tau}^W|$ using effective Lagrangian methods, and use a conference result $|d_{\tau}^{W}|<5.8\times10^{-18}$ e cm at 95% CL (L. Silvestris, ICHEP96) to obtain this result.

⁸ ESCRIBANO 97 use preliminary experimental results.

$|\mathsf{m}(d_{ au})$

| VALUE (10 ⁻¹⁰ ecm) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------|--------------------------------------------------------------------|--------------------------------------------|---------|-----------|-------------------------------------------------|
| -0.25 to 0.008 | 95 | ¹ INAMI | 03 | BELL | $E_{ m cm}^{\it ee}$ = 10.6 GeV |
| • • • We do not use th | e followin | g data for average | s, fits | , limits, | etc. • • • |
| < 1.8 | | | | | $E_{ m cm}^{\it ee}$ = 10.4 GeV |
| 1 INAMI 03 use $\it e^{+}$ $\it e^{-}$ ALBRECHT 00 use | $\stackrel{-}{e^+}\stackrel{-}{e^-}\stackrel{\tau^+}{\rightarrow}$ | $	au^-$ events. $	au^+ 	au^-$ events. L | imit is | s on the | absolute value of $\operatorname{Im}(d_{	au}).$ |

τ WEAK DIPOLE MOMENT (d_{-}^{w})

A nonzero value is forbidden by CP invariance

The q^2 dependence is expected to be small providing no thresholds are ne ar by.

Re(dw)

| ····(- T) | | | | | |
|------------------------|-----------|-----------------------|-------|-----------|--------------------------------------|
| $VALUE (10^{-17} ecm)$ | CL% | DOCUMENT ID | | TECN | COMMENT |
| < 0.50 | 95 | ¹ HEISTER | 03F | ALEP | 1990-1995 LEP runs |
| • • • We do not use | the follo | wing data for aver | ages, | fits, lim | its, etc. • • • |
| < 3.0 | 90 | ¹ ACCIARRI | 98 c | L3 | 1991-1995 LEP runs |
| < 0.56 | 95 | | 97L | OPAL | 1991-1995 LEP runs |
| < 0.78 | 95 | ² AKERS | 95 F | OPAL | Repl. by ACKERSTAFF 97L |
| <1.5 | 95 | ² BUSKULIC | 95 c | ALEP | Repl. by HEISTER 03F |
| < 7.0 | 95 | ² ACTON | 92F | OPAL | $Z \rightarrow \tau^+ \tau^-$ at LEP |
| < 3.7 | 95 | ² BUSKULIC | 92J | ALEP | Repl. by BUSKULIC 95c |

 $^1\,\mathrm{Limit}$ is on the absolute value of the real part of the weak dipole moment. $^2\,\mathrm{Limit}$ is on the absolute value of the real part of the weak dipole moment, and applies for $q^2 = m_Z^2$.

$\operatorname{Im}(d_{\tau}^{\mathbf{W}})$

| $VALUE (10^{-17} ecm)$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|-------------|---------------------|--------|-----------|-------------------------------|
| <1.1 | 95 | $^{ m 1}$ HEISTER | 03F | ALEP | 1990-1995 LEP runs |
| ullet $ullet$ We do not | use the fol | lowing data for ave | rages, | fits, lim | its, etc. • • • |
| <1.5 | 95 | | 97L | OPAL | 1991-1995 LEP runs |
| < 4.5 | 95 | ² AKERS | 95 F | OPAL | Repl. by ACKERSTAFF 97L |
| ¹ HEISTER 03F | limit is on | the absolute valu | e of t | he imag | inary part of the weak dipole |

moment. 2 Limit is on the absolute value of the imaginary part of the weak dipole moment, and

applies for $q^2 = m_Z^2$.

τ WEAK ANOMALOUS MAGNETIC DIPOLE MOMENT (α_{τ}^{W})

Electroweak radiative corrections are expected to contribute at the 10^{-6} level. See BERNABEU 95.

The q^2 dependence is expected to be small providing no thresholds are nearby

$Re(\alpha_{\tau}^{W})$

| VALUE | CL% | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|----------|---------------------------|-------------|-------------------------------------------------------|
| $<1.1 \times 10^{-3}$ | 95 | ¹ HEISTER 03 | F ALEP | 1990-1995 LEP runs |
| • • • We do not use the f | ollowing | data for averages, fits, | limits, etc | . • • • |
| $>-0.0024 \ {\rm and} < 0.0025$ | 95 | ² GONZALEZ-S00 | RVUE | |
| $<4.5 \times 10^{-3}$ | 90 | ¹ ACCIARRI 98 | c L3 | and $W ightarrow 	au u_{	au}$ 1991-1995 LEP runs |

 $^{
m 1}$ Limit is on the absolute value of the real part of the weak anomalous magnetic dipole

$\operatorname{Im}(\alpha_{\tau}^{W})$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|-----------------------|---------|-----------|--------------------|
| <2.7 × 10 ⁻³ | 95 | 1 HEISTER | 03F | ALEP | 1990-1995 LEP runs |
| • • • We do not use the | following | data for averages | , fits, | limits, e | tc. • • • |
| $< 9.9 \times 10^{-3}$ | 90 | ¹ ACCIARRI | 98c | L3 | 1991-1995 LEP runs |

¹Limit is on the absolute value of the imaginary part of the weak anomalous magnetic

au^- DECAY MODES

 τ^+ modes are charge conjugates of the modes below. " h^\pm " stands for π^\pm or K^\pm . " ℓ " stands for e or μ . "Neutrals" stands for γ 's and/or π^0 's.

| | Mode | | Fraction (Γ_i/Γ) | | cale factor/ dence level |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|------------------------------------------|------------------------------------------|-----------------------------|
| | Modes with one o | hare | ed particle | | |
| Γ_1 | particle $^- \ge 0$ neutrals $\ge 0 K^0 \nu_{	au}$ ("1-prong") | | (85.35 ±0.07 |) % | S=1.3 |
| Γ_2 | particle ≥ 0 neutrals $\geq 0 K_L^0 \nu_{\tau}$ | | (84.71 ±0.08 |) % | S=1.3 |
| Γ ₃ | $\mu^-\overline{ u}_\mu u_	au$ | [a] | (17.41 ± 0.04) | | S=1.1 |
| Γ ₄ | $\mu^{-}\overline{ u}_{\mu} u_{	au}\gamma$ | [b] | | $) \times 10^{-3}$ | |
| Γ ₅ | $e^{-\frac{\mu}{\nu}e}\nu_{\tau}$ | [a] | (17.83 ±0.04 | | |
| Γ ₆ | $e^{-}\overline{ u}_{e}^{\prime} u_{	au}\gamma$ | [b] | (1.75 ± 0.18 | | |
| Γ ₇ | $h^- \geq 0 K_L^0 \nu_{	au}$ | | (12.06 ± 0.06) |) % | S=1.2 |
| Γ ₈ | $h^- u_	au$ | | (11.53 ± 0.06) |) % | S=1.2 |
| Г9 | $\pi^- u_{	au}$ | [a] | $(10.83 \pm 0.06$ | | S=1.2 |
| Γ_{10} | $\mathcal{K}^- u_	au$ | [a] | $(7.00 \pm 0.10$ | | S=1.1 |
| ₁₁ | $h^- \geq 1$ neutrals ν_{τ} | | (37.10 ±0.10 | | S=1.2 |
| Γ ₁₂ | $h^- \geq 1\pi^0 u_	au (ext{ex.} \mathcal{K}^0) onumber \ h^- \pi^0 u_	au$ | | (36.57 ±0.10 | | S=1.2 |
| Г ₁₃ | $\frac{\pi}{\pi}$ $\frac{\pi}{\pi}$ $\frac{\nu_{\tau}}{\nu_{\tau}}$ | [-] | (25.95 ± 0.09) (25.52 ± 0.09) | | S=1.1 S=1.1 |
| Γ ₁₄ Γ ₁₅ | $\pi^-\pi^0$ non- ρ (770) $\nu_	au$ | [a] | | $) \times 10^{-3}$ | 3-1.1 |
| Γ ₁₆ | $K^-\pi^0 \nu_{\tau}$ | [a] | (4.29 ±0.15 | | |
| Γ ₁₇ | $h^- \geq 2\pi^0 \nu_{\tau}$ | | (10.87 ± 0.11) | | S=1.2 |
| Γ ₁₈ | $h^- 2\pi^0 u_	au$ | | (9.52 ± 0.11) |) % | S=1.1 |
| Γ_{19} | $h^{-} 2\pi^{0} \nu_{\pi} (\text{ex.} K^{0})$ | | (9.36 ± 0.11 | | S=1.2 |
| Γ_{20} | $\pi^{-} 2\pi^{0} \nu_{\tau} (\text{ex.} K^{0})$ | [a] | | , _ | S=1.2 |
| Γ ₂₁ | $\pi^{-} 2\pi^{0} \nu_{\tau} (\text{ex.} K^{0}),$ | | < 9 | $\times 10^{-3}$ | CL=95% |
| Γ_{22} | scalar $\pi^{-2}\pi^{0}\nu_{\tau}(\text{ex.}K^{0}),$ | | < 7 | $\times10^{-3}$ | CL=95% |
| Γ ₂₃ | κ^{-} vector κ^{-} $2\pi^{0}$ $\nu_{	au}$ (ex. κ^{0}) | [a] | (6.5 ± 2.3 | $) \times 10^{-4}$ | |
| Γ ₂₄ | $h^- \geq 3\pi^0 u_	au$ | | (1.35 ± 0.07 | | S=1.1 |
| Γ_{25} | $h^- \geq 3\pi^0 u_{	au}({ m ex.} K^0)$ | | (1.26 ± 0.07) |) % | S=1.1 |
| Γ ₂₆ | $h^{-}3\pi^{0}\nu_{\tau}$ | | (1.19 ± 0.07) | * | |
| Γ ₂₇ | $\pi^{-} 3\pi^{0} \nu_{\tau} (\text{ex.} K^{0})$ | [a] | (1.05 ± 0.07) | | |
| F ₂₈ | $K^{-}3\pi^{0}\nu_{\tau}(ex.K^{0},\eta)$ | [a] | | $) \times 10^{-4}$ | |
| Γ ₂₉ | $h^- 4\pi^0 u_{	au}({\sf ex}.{\cal K}^0) h^- 4\pi^0 u_{	au}({\sf ex}.{\cal K}^0,\eta)$ | [a] | | $) \times 10^{-3}$ $) \times 10^{-3}$ | |
| Γ ₃₀ Γ ₃₁ | $K^- \ge 0\pi^0 \ge 0K^0 \ge 0\gamma \nu_{\tau}$ | [a] | (1.1 ±0.4 (1.572±0.033 | | S=1.1 |
| Γ ₃₂ | $K^- \geq 1 \; (\pi^0 \text{ or } K^0 \text{ or } \gamma) \; \nu_{\tau}$ | | (8.72 ± 0.32 | | S=1.1 |
| . 32 | Modes wit | <i>v</i> | _ | , | |
| Γ ₃₃ | K_S^0 (particles) $^- u_	au$ | LIIA | | $) \times 10^{-3}$ | S=1.5 |
| Γ ₃₄ | $h^-\overline{K}^0\nu_{\tau}$ | | (1.00 ±0.05 | | S=1.8 |
| Γ ₃₅ | $\pi^- \overline{K}{}^0 u_	au$ | [a] | | $) \times 10^{-3}$ | S = 2.1 |
| Γ_{36} | $\pi^-\overline{K}^0$ (non- K^* (892) $^-$) $ u_	au$ | | |) × 10 ⁻⁴ | |
| Γ ₃₇ | $K^-K^0 u_	au$ | [a] | $(\ 1.59\ \pm 0.16$ | | |
| L ₃₈ | $\stackrel{\displaystyle \mathcal{K}^-}{h^-}\stackrel{\displaystyle \mathcal{K}^0}{\overline{\mathcal{K}^0}}\stackrel{\displaystyle 0}{\pi^0} \stackrel{\displaystyle 0}{ u_{	au}}$ | | (3.18 ±0.23 | $) \times 10^{-3}$ | |
| Г ₃₉ | $\frac{h^- K^0 \pi^0 \nu_{\tau}}{\pi^- K^0 \pi^0 \nu_{\tau}}$ | r 1 | (5.5 ± 0.4 | $) \times 10^{-3}$ | |
| Г ₄₀ | $\frac{\pi}{K^0} \rho^- \nu_{\tau}$ | [a] | (4.0 ± 0.4) (2.2 ± 0.5) | $) \times 10^{-3}$ $) \times 10^{-3}$ | |
| Γ ₄₁ Γ ₄₂ | $K^{-} K^{0} \pi^{0} \nu_{	au}$ | [a] | (2.2 ± 0.5) (1.59 ± 0.20) |) × 10) × 10-3 | |
| Γ ₄₃ | $\pi^{-}\overline{K}^{0} \geq 1\pi^{0}\nu_{	au}$ | [6] | (3.2 ±1.0 | $) \times 10^{-3}$ | |
| Γ_{44} | $\pi^{-} \overline{K}{}^{0} \pi^{0} \pi^{0} \nu_{\tau}$ | | (2.6 ± 2.4 | $) \times 10^{-4}$ | |
| Γ ₄₅ | $K^- K^0 \pi^0 \pi^0 u_	au$ | | < 1.6 | $\times 10^{-4}$ | CL=95% |
| Γ_{46} | $\pi^- K^0 \overline{K}{}^0 u_{	au}$ | | $(1.7\pm0.4$ | $) \times 10^{-3}$ | S=1.7 |
| Γ_{47} | $\pi^- K^0_{\c S} K^{\dot 0}_{\c S} u_	au$ | [a] | (2.4 ± 0.5) | $) \times 10^{-4}$ | |
| Γ ₄₈ | $\pi^{-}K_{S}^{0}K_{L}^{0}\nu_{\tau}$ | [a] | | $) \times 10^{-3}$ | S=1.7 |
| Γ ₄₉ | $\pi^{-} K^{0} \overline{K}^{0} \pi^{0} \nu_{\tau}$ | | |) × 10 ⁻⁴ | |
| Γ ₅₀ | $\pi^{-} K_{S}^{0} K_{S}^{0} \pi^{0} \nu_{\tau}$ | | < 2.0 | × 10 ⁻⁴ | CL=95% |
| Γ ₅₁ | $\pi^- K_S^{0} K_L^{0} \pi^0 \nu_{\tau}$ | | | $) \times 10^{-4}$ | |
| Г ₅₂ | $K^0 h^+ h^- h^- \ge 0$ neutrals ν_{τ} | | < 1.7 | $\times 10^{-3}$ | CL=95% |

(2.3 ± 2.0) $\times\,10^{-4}$

 $\overset{\cdot \cdot \cdot}{K^0}\,h^+\,h^-\,h^-\,
u_ au$

 Γ_{53}

 $^{^{\}rm 2}\,{\rm moment.}$ $^{\rm 2}\,{\rm GONZALEZ\text{-}SPRINBERG}$ 00 use data on tau lepton production at LEP1, SLC, and LEP2, and data from colliders and LEP2 to determine limits. Assume imaginary component is zero.

 τ

| | Modes with three o | harge | d part | icles | | | Miscellaneous oth | er allowed modes | | |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------|--------|--------|------------------------------------------------------------|-----------------|-------------------|-----------------------------------------------------------------------|----------------------------|---------------------------------|------------------|
| Γ_{54} | $h^- h^- h^+ \geq 0$ neutrals $\geq 0 K_I^0 \nu_{\tau}$ | | | ±0.08)% | S=1.3 | Γ ₁₀₅ | $(5\pi)^-\nu_{\tau}$ | (7.7 ± 0.5 | $5) \times 10^{-3}$ | |
| Γ ₅₅ | $h^- h^- h^+ \geq 0$ neutrals $ u_{	au}$ | | (14.57 | ±0.07)% | S=1.3 | Γ ₁₀₆ | 4 h^- 3 $h^+\geq$ 0 neutrals $ u_{	au}$ | < 3.0 | $\times 10^{-7}$ | CL=90% |
| ••• | (ex. $K_S^{\overline{0}} ightarrow \pi^+ \pi^-$) | | | | | _ | ("7-prong") | | - | |
| | ("3-prong") | | | | | [₁₀₇ | $4h^{-}3h^{+}\nu_{\tau}$ | < 4.3 | × 10 ⁻⁷ | CL=90% |
| Γ ₅₆ | $h^-h^-h^+ u_	au$ | | • | ±0.07) % | S=1.2 | Γ ₁₀₈ | $4h^{-}3h^{+}\pi^{0}\nu_{\tau}$ | < 2.5 | × 10 ⁻⁷ | CL=90% |
| Γ ₅₇ | $h^- h^- h^+ \nu_{\tau} (\text{ex.} K^0)$ | | • | ±0.06)% | S=1.2 | | $X^-(S=-1) u_	au$ $K^*(892)^- \ge 0$ neutrals \ge | (2.87 ±0.0 (1.42 ±0.1 | | S=1.3 S=1.4 |
| Γ ₅₈ | $h^- h^- h^+ \nu_{\tau} (\text{ex.} K^0, \omega)$ | | • | ±0.06)% | S=1.2 | '110 | $0K_I^0 u_{	au}$ | (1.42 ±0 | 10 / /0 | 3-1.4 |
| Γ ₅₉ | $\pi^-\pi^+\pi^- u_	au \ \pi^-\pi^+\pi^- u_	au$ (ex. K^0) | | | ±0.06)% ±0.06)% | S=1.2 S=1.1 | Γ ₁₁₁ | | (1.20 ±0.0 | n7 \% | S=1.8 |
| Г ₆₀ Г ₆₁ | $\pi^-\pi^+\pi^-\nu_{\tau}$ (ex.K ⁰), | | 2.4 | ±0.06)% | S=1.1 CL=95% | Γ ₁₁₁ | 770 | | $5) \times 10^{-3}$ | 3_1.0 |
| ' 61 | non-axial vector | | 2.4 | /0 | CL _ 33 /0 | Γ ₁₁₃ | $K^*(892)^0 K^- \geq 0$ neutrals ν_{τ} | (3.2 ±1.4 | | |
| Γ_{62} | $\pi^-\pi^+\pi^-\nu_{	au}(\operatorname{ex}.K^0,\omega)$ | [a] | (8.99 | ±0.06) % | S=1.1 | Γ ₁₁₄ | | (2.1 ± 0.4 | 4)×10 ⁻³ | |
| Γ_{63} | $\mathit{h^-h^-h^+} \geq 1$ neutrals $ u_{	au}$ | | | ±0.07) % | S=1.2 | Γ ₁₁₅ | \overline{K}^* (892) $^0\pi^- \geq$ 0 neutrals $ u_	au$ | (3.8 ± 1.5) | | |
| Γ ₆₄ | $h^- h^- h^+ \ge 1 \pi^0 \nu_{\tau} (\text{ex. } K^0)$ | | | ±0.06) % | S=1.2 | Γ ₁₁₆ | $K^*(892)^0 \pi^- \nu_{\tau}$ | (2.2 ± 0.5) | | |
| Γ ₆₅ | $h^- h^- h^+ \pi^0 \nu_{\tau}$ | | • | ± 0.06) % | S=1.2 | Γ ₁₁₇ | $(\overline{K}^*(892)\pi)^-\nu_{\tau} \rightarrow$ | (1.0 ± 0.4) | 4) $\times 10^{-3}$ | |
| Γ ₆₆ | $h^- h^- h^+ \pi^0 \nu_{\tau} (ex.K^0)$ | | | ±0.06)% | S=1.2 | _ | $\pi^-\overline{K}{}^0\pi^0\nu_{\tau}$ | | | |
| Γ ₆₇ | $h^- h^- h^+ \pi^0 u_{	au} (ext{ex. } K^0, \omega) \pi^- \pi^+ \pi^- \pi^0 u_{	au}$ | | • | ±0.08)% | S=1.2 | | $K_1(1270)^- \nu_{\tau}$ | (4.7 ±1.1 | | |
| Г ₆₈ | $\pi^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{	au}(\text{ex.}K^{0})$ | | • | ±0.06)% ±0.06)% | S=1.2 S=1.2 | | $K_1(1400)^-\nu_{\tau}$ | (1.7 ± 2.0 | | S=1.7 |
| Γ ₆₉ Γ ₇₀ | $\pi^-\pi^+\pi^-\pi^0\nu_{\tau}(\mathrm{ex}.K^0,\omega)$ | | | ±0.08) % | S=1.2 | Γ ₁₂₀ | $K^*(1410)^- u_	au$ | (1.5 + 1.4) | $(0.01) \times 10^{-3}$ | |
| Γ ₇₁ | $h^-\rho\pi^0\nu_{\tau}$ | [a] | (2.70 | ±0.00) /6 | 3-1.2 | Γ ₁₂₁ | $K_0^*(1430)^- \nu_{\tau}$ | < 5 | $\times 10^{-4}$ | CL=95% |
| Γ ₇₂ | $h^-\rho^+h^-\nu_{\tau}$ | | | | | Γ ₁₂₂ | $K_2^*(1430)^-\nu_{	au}$ | < 3 | $\times 10^{-3}$ | CL=95% |
| Γ ₇₃ | $h^-\rho^-h^+\nu_{\tau}$ | | | | | Γ ₁₂₃ | $a_0(980)^- \geq 0$ neutrals $ u_	au$ | | | |
| Γ ₇₄ | $h^- h^- h^+ \geq 2 \pi^0 u_{	au}$ (ex. | | (5.21 | $\pm 0.32~)\times 10^{-3}$ | | Γ ₁₂₄ | $\eta \pi^- \nu_{\tau}$ | < 9.9 | × 10 ⁻⁵ | CL=95% |
| | K^0) | | | _ | | [₁₂₅ | $\eta \pi^{-} \pi^{0} \nu_{\tau}$ | [a] (1.39 ±0.3 | | S=1.4 |
| Γ ₇₅ | $h^- h^- h^+ 2\pi^0 \nu_{\tau}$ | | | $\pm 0.32) \times 10^{-3}$ | | l 126 | $\eta \pi^- \pi^0 \pi^0 \nu_\tau$ | (1.5 ± 0.5 | | |
| Γ ₇₆ | $h^- h^- h^+ 2\pi^0 \nu_{\tau} (\text{ex.} K^0)$ | | | $\pm 0.32) \times 10^{-3}$ | | 1127 | $\eta K^- \nu_{\tau} \\ \eta K^* (892)^- \nu_{\tau}$ | [a] (1.52 ±0.0 | | |
| Γ ₇₇ | $h^- h^- h^+ 2\pi^0 \nu_{\tau} (\text{ex.} K^0, \omega, \eta)$ | | | | | 1 128 | $\eta K^{-} (092) \nu_{\tau}$ $\eta K^{-} \pi^{0} \nu_{\tau}$ | (1.38 ±0.1 | $(2) \times 10^{-5}$ | |
| Γ ₇₈ | $h^-h^-h^+3\pi^0 u_	au$ $K^-h^+h^-\geq 0$ neutrals $ u_	au$ | | | ± 0.6) $\times 10^{-4}$ ± 0.24) $\times 10^{-3}$ | S=1.2 S=1.5 | 129 F120 | $\eta K^{-} \pi^{0} (\text{non-} K^{*}(892)) \nu_{\tau}$ | < 3.5 | × 10 ⁻⁵ | CL=90% |
| Γ ₇₉ Γ ₈₀ | $K^-h^+\pi^-\nu_{\tau}(\mathrm{ex}.K^0)$ | | | ± 0.24) $\times 10^{-3}$ | 5=1.5 S=2.7 | Γ131 | $n\overline{K}^0\pi^-\nu_{\tau}$ | (9.3 ±1.5 | | 02-3070 |
| Γ ₈₁ | $K^{-}h^{+}\pi^{-}\pi^{0}\nu_{\tau}(ex.K^{0})$ | | | ± 1.2) × 10 ⁻⁴ | S=1.1 | Γ ₁₃₂ | $\eta \overline{K}{}^0 \pi^- \pi^0 \nu_{\tau}$ | < 5.0 | × 10 ⁻⁵ | CL=90% |
| Γ ₈₂ | $K^-\pi^+\pi^- \geq 0$ neutrals $ u_{	au}$ | | | ± 0.21) $\times 10^{-3}$ | S=1.4 | Γ ₁₃₃ | $\etaK^-K^0 u_	au$ | < 9.0 | $\times 10^{-6}$ | CL=90% |
| Γ ₈₃ | $K^-\pi^+\pi^- \stackrel{-}{\geq} 0\pi^0 \nu_{\tau} (\text{ex.} K^0)$ | | | ± 0.19) $\times 10^{-3}$ | S=1.5 | Γ ₁₃₄ | $\eta \pi^+ \pi^- \pi^- \geq$ 0 neutrals $ u_	au$ | < 3 | $\times 10^{-3}$ | CL=90% |
| Γ ₈₄ | $K^-\pi^+\pi^- u_	au$ | | 3.49 | ± 0.16) $\times 10^{-3}$ | S=1.9 | Γ ₁₃₅ | $\eta \pi^- \pi^+ \pi^- u_{	au} ({ m ex} {\cal K}^0)$ | (1.64 ± 0.3 | | |
| Γ ₈₅ | $K^-\pi^+\pi^- u_{	au}({ m ex.}K^0)$ | | | ± 0.15) $\times 10^{-3}$ | S=2.2 | <u>Γ</u> 136 | | < 3.9 | $\times 10^{-4}$ | CL=90% |
| Γ ₈₆ | $K^- ho^0 u_	au$ $ ightarrow$ | | (1.4 | ± 0.5) $\times 10^{-3}$ | | [₁₃₇ | $\eta \eta \pi^{-} \nu_{\tau}$ | < 7.4 | × 10 ⁻⁶ | CL=90% |
| _ | $K^-\pi^+\pi^-\nu_{	au}$ | | | . 3 | | I 138 | $\eta \eta \pi^- \pi^0 \nu_{\tau}$ | < 2.0 | $\times 10^{-4} \times 10^{-6}$ | CL=95% |
| Γ ₈₇ | $K^-\pi^+\pi^-\pi^0\nu_{\tau}$ | | | ± 0.14) $\times 10^{-3}$ | | 139 F | $\eta \eta K^- \nu_{\tau} $ $\eta'(958) \pi^- \nu_{\tau}$ | < 3.0 < 7.2 | × 10 ° × 10 −6 | CL=90% CL=90% |
| Γ ₈₈ | $K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}$ (ex. K^{0}) $K^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau}$ (ex. K^{0} , η) | f -1 | (8.1 | ± 1.2) $\times 10^{-4}$ | | ' 140 | $\eta'(958)\pi^{-}\pi^{0}\nu_{\tau}$ | < 8.0 | × 10 × 10 ⁻⁵ | CL=90% CL=90% |
| Г ₈₉ Г ₉₀ | $K = \pi^+ \pi^- \pi^0 \nu_\tau (ex. K^0, \omega)$ | [a] | (1.0 | ± 1.2) × 10 · ± 0.9) × 10 ⁻⁴ | | | $\phi \pi^- \nu_{\tau}$ | (3.4 ±0.6 | | CL=3070 |
| Γ ₉₁ | $K^-\pi^+K^- \geq 0$ neut. $ u_{	au}$ | | 9 | × 10 ⁻⁴ | CL=95% | Γ ₁₄₃ | $\phi K^- \nu_{\tau}$ | (3.70 ±0.3 | | S=1.3 |
| Γ ₉₂ | $K^-K^+\pi^- \geq 0$ neut. $ u_{	au}$ | | | ± 0.06) $\times 10^{-3}$ | S=1.8 | | $f_1(1285)\pi^-\nu_{\tau}$ | (3.6 ± 0.5 | | |
| Γ ₉₃ | $K^-K^+\pi^-\nu_{\tau}$ | | | ± 0.05) $\times 10^{-3}$ | S=1.9 | Γ ₁₄₅ | $f_1(1285) \pi^- \nu_{\tau} \rightarrow$ | $(1.11 \pm 0.0$ | | |
| Γ ₉₄ | $\mathcal{K}^-\mathcal{K}^+\pi^-\pi^{0} u_{	au}$ | | | ± 2.5) $\times 10^{-5}$ | S=1.4 | | $\eta\pi^-\pi^+\pi^- u_	au$ | | | |
| Γ ₉₅ | $K^-K^+K^- u_	au$ | | (2.1 | ±0.8) $\times10^{-5}$ | S=5.4 | Γ ₁₄₆ | $\pi(1300)^-\nu_{\tau} \rightarrow (\rho\pi)^-\nu_{\tau} \rightarrow$ | < 1.0 | $\times 10^{-4}$ | CL=90% |
| Γ_{96} | $K^{-}K^{+}K^{-}\nu_{\tau}(\text{ex. }\phi)$ | < | 2.5 | $\times 10^{-6}$ | CL=90% | F | $(3\pi)^- \nu_{\tau}$ | | 4 | |
| Γ_{97} | $\mathcal{K}^- \mathcal{K}^+ \mathcal{K}^- \pi^0 \nu_	au$ | | 4.8 | $\times 10^{-6}$ | CL=90% | 147 | $\pi(1300)^-\nu_{\tau} \rightarrow$ | < 1.9 | $\times 10^{-4}$ | CL=90% |
| Γ ₉₈ | $\pi^-K^+\pi^- \geq 0$ neut. ν_{τ} | | 2.5 | × 10 ⁻³ | CL=95% | | $((\pi\pi)_{S-\text{wave}} \pi)^- \nu_{\tau} \rightarrow$ | | | |
| | $e^-e^-e^+\overline{\nu}_e\nu_{	au}$ | | | ± 1.5) $\times 10^{-5}$ | CI 000/ | Г | $(3\pi)^- u_	au$ $h^- \omega \geq 0$ neutrals $ u_	au$ | (2.41 ±0.0 | ng \ % | S=1.2 |
| 100 | $\mu^-e^-e^+\overline{ u}_\mu u_	au$ | < | 3.6 | × 10 ⁻⁵ | CL=90% | Γ ₁₄₉ | $h^-\omega \geq 0$ fled trais $\nu_{	au}$ | [a] (2.00 ±0.0 | | S=1.2 |
| | Modes with five c | harged | parti | des | | Γ ₁₅₀ | • | (4.1 ±0.9 | | |
| Γ_{101} | $3h^-2h^+ \geq 0$ neutrals $ u_{	au}$ | | (1.02 | ±0.04) $\times10^{-3}$ | S=1.1 | Γ ₁₅₁ | 0 ' | [a] (4.1 ± 0.4 | | |
| | (ex. $K_S^0 \rightarrow \pi^-\pi^+$) | | | | | Γ _{15 2} | 0 | (1.4 ± 0.5 | | |
| - | ("5-prong") | _ | | | | Γ _{15 3} | $h^- 2\omega u_	au$ | < 5.4 | $\times 10^{-7}$ | CL=90% |
| Γ ₁₀₂ | $3h^{-}2h^{+}\nu_{\tau}(ex.K^{0})$ | | | ± 0.35) $\times 10^{-4}$ | S=1.1 | Γ ₁₅₄ | $2h^-h^+\omega u_	au$ | (1.20 ± 0.2 | 22) $\times 10^{-4}$ | |
| Γ ₁₀₃ | | | | ± 0.27) $\times 10^{-4}$ | CI 222 | | | | | |
| Γ_{104} | $3h^-2h^+2\pi^0\nu_{	au}$ | < | 3.4 | $\times 10^{-6}$ | CL=90% | | | | | |

Lepton Family number (LF), Lepton number (L), or Baryon number (B) violating modes

L means lepton number violation (e.g. $\tau^- \to e^+ \pi^- \pi^-$). Following common usage, LF means lepton family violation and not lepton number violation (e.g. $\tau^- \to e^- \pi^+ \pi^-$). B means baryon number violation.

| | violation (e.g. $	au^- ightarrow e^- \pi^+$ | π^-). | B means baryon numbe | r violation. | |
|-------------------|-------------------------------------------------|------------|----------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Γ ₁₅₅ | $e^-\gamma$ | LF | < 3.3 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₅₆ | $\mu^-\gamma$ | LF | < 4.4 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₅₇ | $e^{-\frac{1}{\pi}0}$ | LF | < 8.0 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₅₈ | $\mu^-\pi^0$ | LF | < 1.1 | $\times 10^{-7}$ | CL=90% |
| Γ _{15 9} | $e^{-}K_{S}^{0}$ | LF | < 2.6 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₆₀ | $\mu^- K_S^0$ | LF | < 2.3 | × 10 ⁻⁸ | CL=90% |
| | $e^{-\eta}$ | LF | | × 10 ⁻⁸ | CL=90% |
| Γ ₁₆₁ | | LF | | × 10 × 10 -8 | CL=90% CL=90% |
| Γ ₁₆₂ | $\mu^- \eta$ $e^- \rho^0$ | | | × 10 ⁻⁸ | CL=90% |
| Γ ₁₆₃ | e ρ ο0 | LF | < 1.8 | × 10 -8 | CL=90% CL=90% |
| 164 | $\mu^-\rho^0$ | LF | < 1.2 | × 10 -8 | CL=90% CL=90% |
| Γ ₁₆₅ | e ⁻ ω | LF | < 4.8 | × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × 10 ° × | CL=90% CL=90% |
| 166 | $\mu^-\omega$ | LF | < 4.7 | × 10 ° × 10 −8 | |
| Γ ₁₆₇ | $e^{-}K^{*}(892)^{0}$ | LF | < 3.2 | × 10 ° | CL=90% |
| Γ ₁₆₈ | $\mu^{-} \frac{K^{*}(892)^{0}}{K^{*}(892)^{0}}$ | LF | < 5.9 | × 10 ⁻⁸ | CL=90% |
| Γ ₁₆₉ | $e^{-\frac{1}{K^*}(892)^0}$ | LF | < 3.4 | × 10 ⁻⁸ | CL=90% |
| Γ ₁₇₀ | $\mu^{-}\overline{K}^{*}(892)^{0}$ | LF | < 7.0 | × 10 ⁻⁸ | CL=90% |
| Γ_{171} | $e^{-}\eta'(958)$ | LF | < 1.6 | × 10 ⁻⁷ | CL=90% |
| Γ_{172} | $\mu^- \eta'(958)$ | LF | < 1.3 | $\times 10^{-7}$ | CL=90% |
| Γ_{173} | $e^- f_0(980) \rightarrow e^- \pi^+ \pi^-$ | LF | < 3.2 | $\times 10^{-8}$ | CL=90% |
| Γ_{174} | $\mu^- f_0(980) \rightarrow \mu^- \pi^+ \pi^-$ | LF | < 3.4 | × 10 ⁻⁸ | CL=90% |
| Γ_{175} | $e^-\phi$ | LF | < 3.1 | $\times 10^{-8}$ | CL=90% |
| Γ_{176} | $\mu^-\phi$ | LF | < 8.4 | $\times 10^{-8}$ | CL=90% |
| Γ_{177} | $e^{-}e^{+}e^{-}$ | LF | < 2.7 | $\times 10^{-8}$ | CL=90% |
| Γ_{178} | $e^-\mu^+\mu^-$ | LF | < 2.7 | $\times 10^{-8}$ | CL=90% |
| Γ_{179} | $e^{+}\mu^{-}\mu^{-}$ | LF | < 1.7 | $\times 10^{-8}$ | CL=90% |
| Γ_{180} | $\mu^- e^+ e^-$ | LF | < 1.8 | $\times 10^{-8}$ | CL=90% |
| Γ_{181} | $\mu^{+} e^{-} e^{-}$ | LF | < 1.5 | $\times 10^{-8}$ | CL=90% |
| Γ_{182} | $\mu^-\mu^+\mu^-$ | LF | < 2.1 | $\times 10^{-8}$ | CL=90% |
| Γ_{183} | $e^-\pi^+\pi^-$ | LF | < 4.4 | $\times 10^{-8}$ | CL=90% |
| Γ_{184} | $e^{+} \pi^{-} \pi^{-}$ | L | < 8.8 | $\times 10^{-8}$ | CL=90% |
| Γ_{185} | $\mu^-\pi^+\pi^-$ | LF | < 3.3 | $\times 10^{-8}$ | CL=90% |
| Γ_{186} | $\mu^{+} \pi^{-} \pi^{-}$ | L | < 3.7 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₈₇ | $e^{-}\pi^{+}K^{-}$ | LF | < 5.8 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₈₈ | $e^{-}\pi^{-}K^{+}$ | LF | < 5.2 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₈₉ | $e^{+} \pi^{-} K^{-}$ | L | < 6.7 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₉₀ | $e^{-}K_{S}^{0}K_{S}^{0}$ | LF | < 7.1 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₉₁ | $e^{-}K^{+}K^{-}$ | LF | < 5.4 | $\times 10^{-8}$ | CL=90% |
| Γ ₁₉₂ | e ⁺ K ⁻ K ⁻ | L | < 6.0 | × 10 ⁻⁸ | CL=90% |
| Γ ₁₉₃ | $\mu^-\pi^+K^-$ | LF | < 1.6 | × 10 ⁻⁷ | CL=90% |
| Γ ₁₉₄ | $\mu^-\pi^-K^+$ | LF | < 1.0 | × 10 ⁻⁷ | CL=90% |
| Γ ₁₉₅ | $\mu^+\pi^-K^-$ | L | < 9.4 | × 10 ⁻⁸ | CL=90% |
| Γ ₁₉₆ | $\mu^- K_S^0 K_S^0$ | LF | < 8.0 | × 10 ⁻⁸ | CL=90% |
| | $\mu^- K^+ K^-$ | LF | < 6.8 | × 10 ⁻⁸ | CL=90% |
| Γ ₁₉₇ | $\mu^+ K^- K^-$ | | | × 10 -8 | CL=90% CL=90% |
| 「198 | $e^{-\frac{\pi}{\pi^0}\pi^0}$ | L | < 9.6 | × 10 ° × 10 −6 | CL=90% CL=90% |
| [₁₉₉ | $\mu^{-}\pi^{0}\pi^{0}$ | LF | < 6.5 | × 10 ° × 10 −5 | |
| Γ ₂₀₀ | $\mu \pi^- \pi^-$ | LF | < 1.4 | | CL=90% |
| Γ ₂₀₁ | $e^-\eta\eta$ | LF | < 3.5 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₀₂ | $ \mu^- \eta \eta $ $ e^- \pi^0 \eta $ | LF | < 6.0 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₀₃ | $e \pi^{\circ} \eta$ | LF | < 2.4 | × 10 ⁻⁵ | CL=90% |
| | $\mu^-\pi^0\eta$ | LF | < 2.2 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₀₅ | \overline{p}_{0} | L,B | < 3.5 | × 10 ⁻⁶ | CL=90% |
| [₂₀₆ | $\frac{\overline{p}}{\overline{p}} \pi^0$ | L,B | < 1.5 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₀₇ | $\frac{\overline{p}}{\underline{p}}2\pi^0$ | L,B | < 3.3 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₀₈ | $\overline{p}\eta_0$ | L,B | < 8.9 | × 10 ⁻⁶ | CL=90% |
| Γ ₂₀₉ | $\frac{1}{p} \dot{\pi}^0 \eta$ | L,B | < 2.7 | × 10 ⁻⁵ | CL=90% |
| [210 | $\frac{\Lambda \pi^{-}}{\Lambda}$ | L,B | < 7.2 | × 10 ⁻⁸ | CL=90% |
| Γ ₂₁₁ | $\overline{\Lambda}\pi^-$ | L,B | < 1.4 | × 10 ⁻⁷ | CL=90% |
| Γ _{21 2} | e−light boson | LF | < 2.7 | × 10 ⁻³ | CL=95% |
| F ₂₁₃ | μ^- light boson | LF | < 5 | $\times 10^{-3}$ | CL=95% |
| | | | | | |

- [a] Basis mode for the au.
- [b] See the Particle Listings below for the energy limits used in this measurement

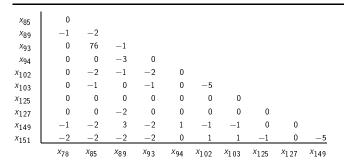
CONSTRAINED FIT INFORMATION

An overall fit to 66 branching ratios uses 138 measurements and one constraint to determine 31 parameters. The overall fit has a $\chi^2=128.9$ for 108 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}.$ The fit constrains the x_i whose labels appear in this array to sum to one

| <i>X</i> ₅ | 13 | | | | | | | | | |
|------------------------|-----------------------|-----------------------|------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|
| <i>X</i> 9 | -13 | 8 | | | | | | | | |
| <i>X</i> ₁₀ | 11 | 0 | -5 | | | | | | | |
| <i>x</i> ₁₄ | -15 | -18 | -15 | -3 | | | | | | |
| <i>x</i> ₁₆ | 0 | 0 | -1 | -1 | -7 | | | | | |
| <i>x</i> ₂₀ | -1 | -8 | -15 | -3 | -48 | -2 | | | | |
| <i>x</i> ₂₃ | -1 | 0 | 0 | -1 | -1 | -11 | -10 | | | |
| <i>x</i> ₂₇ | -1 | -4 | -11 | -1 | 1 | 0 | -28 | -1 | | |
| <i>x</i> ₂₈ | -1 | 0 | 1 | -1 | 1 | -10 | -6 | -18 | -11 | |
| <i>x</i> ₃₀ | -1 | -4 | -12 | 0 | -10 | 0 | 10 | -2 | -41 | 1 |
| X35 | -9 | -7 | -5 | -2 | -2 | 0 | -12 | 0 | -4 | 0 |
| <i>X</i> 37 | -2 | -2 | -1 | -1 | 0 | -6 | -1 | -10 | 1 | -10 |
| x_{40} | -7 | -6 | -4 | -1 | -2 | 1 | -9 | 2 | -6 | 2 |
| x_{42} | -1 | -1 | -1 | -1 | 1 | -8 | 1 | -13 | 1 | -13 |
| X47 | -1 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 |
| <i>x</i> ₄₈ | -7 | -6 | -4 | -2 | -2 | 1 | -10 | 1 | -3 | 1 |
| x ₆₂ | -10 | -8 | 3 | -2 | 0 | 0 | -22 | 1 | -12 | 1 |
| <i>x</i> ₇₀ | -4 | -5 | -5 | 0 | -7 | 1 | -2 | 1 | -3 | 0 |
| <i>x</i> ₇₇ | 2 | 0 | -4 | 0 | -2 | 0 | 3 | -1 | 3 | -1 |
| <i>x</i> ₇₈ | 0 | 0 | 0 | 0 | 1 | 0 | -2 | 0 | -1 | 0 |
| <i>x</i> ₈₅ | -3 | -2 | -1 | -1 | 1 | 0 | -10 | 0 | -4 | 0 |
| <i>x</i> ₈₉ | -1 | 0 | 1 | 0 | 2 | 0 | -4 | 0 | -2 | 0 |
| <i>X</i> 93 | -3 | -2 | 0 | -1 | 1 | 0 | -9 | 0 | -4 | 0 |
| X94 | 0 | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 |
| x ₁₀₂ | 1 | 1 | 0 | 0 | -1 | -1 | 2 | -1 | 2 | -1 |
| ^X 103 | 0 | 0 | -1 | 0 | -2 | 0 | 2 | 0 | 1 | 0 |
| ^X 125 | -1 | -1 | 0 | 0 | 0 | 0 | -3 | 0 | 0 | 0 |
| ^X 127 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ^X 149 | -4 | -4 | -4 | 0 | -4 | 0 | -5 | 0 | -3 | 0 |
| ^X 151 | 0 | -2 | -5 | -1 | -3 | 0 | 1 | -1 | 3 | -2 |
| | <i>x</i> ₃ | <i>x</i> ₅ | <i>X</i> 9 | <i>x</i> ₁₀ | <i>x</i> ₁₄ | <i>x</i> ₁₆ | <i>x</i> ₂₀ | <i>x</i> ₂₃ | <i>x</i> ₂₇ | x ₂₈ |
| | | | | | | | | | | |

 τ



au BRANCHING FRACTIONS

Revised April 2012 by K.G. Hayes (Hillsdale College).

Since the previous edition of this Review, there have been 7 published papers that have contributed to the τ Listings: 4 by the BaBar collaboration and 3 by the Belle collaboration. Four of these papers have provided new upper limits on the branching fractions for neutrinoless τ -decay modes. Of the 59 neutrinoless τ -decay modes in the τ Listings, 17 have had improved limits set. The upper limits have been reduced by factors that range between 1.3 and 43 with the median reduction being a factor of 1.5.

There are now 30 measurements and 13 upper limits from Belle and BaBar on branching fractions of conventional τ -decay modes, up from 1 measurement and 3 upper limits in the 2006 edition of this Review. Sixteen of these measurements are used in the constrained fit to τ branching fractions, and 20 are for τ -decay modes for which older non-B-factory measurements exist. For those 20 measurements, the new B-factory measurements have on average about sixty times the number of events as the most precise earlier measurements, and the statistical uncertainties on the B-factory measurements are on average about eight times smaller. However, the systematic uncertainties now greatly exceed the statistical uncertainties of all B-factory branching fraction measurements of major τ -decay modes. For example, the average ratio of systematic to statistical uncertainty of the B-factory measurements of τ branching fractions larger than 10^{-3} is 17.6, while the average ratio for branching fractions smaller than 10^{-4} is 0.8. Thus, the total uncertainty on the branching fraction measurements from Bfactories is on average only about 3.4 times smaller than the previous most precise non-B-factory measurements.

The constrained fit to τ branching fractions: The Lepton Summary Table and the List of τ -Decay Modes contain branching fractions for 119 conventional τ -decay modes and upper limits on the branching fractions for 31 other conventional τ -decay modes. Of the 119 modes with branching fractions, 82 are derived from a constrained fit to τ branching fraction data. The goal of the constrained fit is to make optimal use of the experimental data to determine τ branching fractions. For example, the branching fractions for the decay mode $\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_{\tau}$ is determined mostly from experimental measurements of the branching fraction for $\tau^- \to h^- h^- h^+ \pi^0 \nu_{\tau}$ and measurements

of exclusive branching fractions for 3-prong modes containing charged kaons and 1 π^0 .

Branching fractions from the constrained fit are derived from a set of basis modes. The basis modes form an exclusive set whose branching fractions are constrained to sum exactly to one. The set of selected basis modes expands as branching fraction measurements for new τ -decay modes are published. The number of basis modes has expanded from 12 in the year 1994 fit to 31 in the 2002 through 2012 fits. The 31 basis modes selected for the 2012 fit are listed in Table 1. See the 1996 edition of this Review [1] for a complete description of our notation for naming τ -decay modes and the selection of the basis modes. For each edition since the 1996 edition, the changes in the selected basis modes from the previous edition are described in the τ Branching Fractions Review. Figure 1 illustrates the basis mode branching fractions from the 2012 fit.

Table 1: Basis modes and fit values (%) for the 2012 fit to τ branching fraction data.

| $e^{-}\overline{ u}_{e} u_{	au}$ | 17.83 ± 0.04 |
|----------------------------------------------------------------------|---------------------|
| $\mu^-\overline{ u}_\mu u_	au$ | 17.41 ± 0.04 |
| $\pi^- u_	au$ | 10.83 ± 0.06 |
| $\pi^-\pi^0 u_	au$ | 25.52 ± 0.09 |
| $\pi^{-}2\pi^{0}\nu_{\tau} \text{ (ex. } K^{0})$ | 9.30 ± 0.11 |
| $\pi^{-}3\pi^{0}\nu_{\tau} \text{ (ex. } K^{0})$ | 1.05 ± 0.07 |
| $h^{-}4\pi^{0}\nu_{\tau} \ (\text{ex. } K^{0}, \eta)$ | 0.11 ± 0.04 |
| $K^- u_{	au}$ | 0.700 ± 0.010 |
| $K^-\pi^0 u_	au$ | 0.429 ± 0.015 |
| $K^{-}2\pi^{0}\nu_{\tau} \ (\text{ex. } K^{0})$ | 0.065 ± 0.023 |
| $K^{-}3\pi^{0}\nu_{\tau} \text{ (ex. } K^{0}, \eta)$ | 0.048 ± 0.022 |
| $\pi^{-}\overline{K}^{0} u_{	au}$ | 0.84 ± 0.04 |
| $\pi^-\overline{K}^0\pi^0 u_	au$ | 0.40 ± 0.04 |
| $\pi^-K^0_SK^0_S u_	au$ | 0.024 ± 0.005 |
| $\pi^-K^0_SK^0_L u_	au$ | 0.12 ± 0.04 |
| $K^-K^0 u_	au$ | 0.159 ± 0.016 |
| $K^-K^0\pi^0 u_	au$ | 0.159 ± 0.020 |
| $\pi^{-}\pi^{+}\pi^{-}\nu_{\tau} \ (\text{ex. } K^{0}, \omega)$ | 8.99 ± 0.06 |
| $\pi^{-}\pi^{+}\pi^{-}\pi^{0}\nu_{\tau} \text{ (ex. } K^{0},\omega)$ | 2.70 ± 0.08 |
| $K^-\pi^+\pi^-\nu_{\tau} \ (\text{ex. } K^0)$ | 0.294 ± 0.015 |
| $K^-\pi^+\pi^-\pi^0\nu_{\tau} \ (\text{ex. } K^0, \eta)$ | 0.078 ± 0.012 |
| $K^-K^+\pi^- u_	au$ | 0.144 ± 0.005 |
| $K^-K^+\pi^-\pi^0 u_	au$ | 0.0061 ± 0.0025 |
| $h^- h^- h^+ 2\pi^0 \nu_{\tau} \text{ (ex. } K^0, \omega, \eta)$ | 0.10 ± 0.04 |
| $h^{-}h^{-}h^{+}3\pi^{0}\nu_{\tau}$ | 0.023 ± 0.006 |
| $3h^-2h^+\nu_{\tau} \ (\text{ex. } K^0)$ | 0.0839 ± 0.0035 |
| $3h^-2h^+\pi^0\nu_{\tau} \ (\text{ex. } K^0)$ | 0.0178 ± 0.0027 |
| $h^-\omega u_	au$ | 2.00 ± 0.08 |
| $h^-\omega\pi^0 u_	au$ | 0.41 ± 0.04 |
| $\eta\pi^-\pi^0 u_	au$ | 0.139 ± 0.010 |
| $\eta K^- u_{	au}$ | 0.0152 ± 0.0008 |

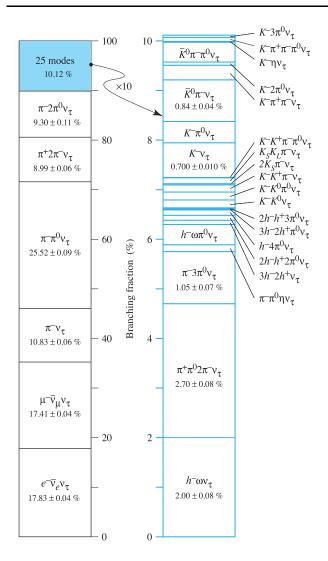


Figure 1: Basis mode branching fractions of the τ . Six modes account for 90% of the decays, 25 modes account for the last 10%. The list of excluded intermediate states for each basis mode has been suppressed.

In selecting the basis modes, assumptions and choices must be made. For example, we assume the decays $\tau^- \to \pi^- K^+ \pi^- >$ $0\pi^0\nu_{\tau}$ and $\tau^-\to\pi^+K^-K^-\geq 0\pi^0\nu\tau$ have negligible branching fractions. This is consistent with standard model predictions for τ decay, although the experimental limits for these branching fractions are not very stringent. The 95% confidence level upper limits for these branching fractions in the current Listings are B($\tau^- \to \pi^- K^+ \pi^- \ge 0 \pi^0 \nu_{\tau}$) < 0.25% and $B(\tau^- \to \pi^+ K^- K^- > 0\pi^0 \nu_{\tau}) < 0.09\%$, values not so different from measured branching fractions for allowed 3-prong modes containing charged kaons. Although our usual goal is to impose as few theoretical constraints as possible so that the world averages and fit results can be used to test the theoretical constraints (i.e., we do not make use of the theoretical constraint from lepton universality on the ratio of the τ -leptonic branching fractions $B(\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau)/B(\tau^- \to e^- \overline{\nu}_e \nu_\tau) = 0.9726)$, the experimental challenge to identify charged prongs in 3-prong τ decays is sufficiently difficult that experimenters have been forced to make these assumptions when measuring the branching fractions of the allowed decays. We are constrained by the assumptions made by the experimenters.

There are several τ -decay modes with small but well-measured (> 2.5 sigma from zero) branching fractions [2] which cannot be expressed in terms of the selected basis modes and are therefore left out of the fit:

$$\begin{array}{ll} {\rm B}(\tau^-\to\pi^-K_S^0K_L^0\pi^0\nu_\tau) &= (3.1\pm1.2)\times 10^{-4} \\ {\rm B}(\tau^-\to 2K^-K^+\nu_\tau) &= (0.21\pm0.08)\times 10^{-4} \\ {\rm B}(\tau^-\to\eta K^-\pi^0\nu_\tau) &= (0.48\pm0.12)\times 10^{-4} \\ {\rm B}(\tau^-\to\eta \overline{K}^0\pi^-\nu_\tau) &= (0.93\pm0.15)\times 10^{-4}. \end{array}$$

Certain components of other small but well-measured τ -decay modes cannot be expressed in terms of the selected basis modes and therefore are also left out of the fit:

$$\begin{split} & B(\tau^- \to \eta \pi^- \pi^0 \pi^0 \nu_\tau) \times \\ & B(\eta \to \gamma \gamma \text{ or } \eta \to \pi^+ \pi^- \gamma \text{ or } \eta \to 3\pi^0) = (1.1 \pm 0.4) \times 10^{-4}, \\ & B(\tau^- \to \eta \pi^- \pi^+ \pi^- \nu_\tau) \times \\ & B(\eta \to \gamma \gamma \text{ or } \eta \to \pi^+ \pi^- \gamma) \\ & B(\eta \to \gamma \gamma \text{ or } \eta \to \pi^+ \pi^- \gamma) \\ & B(\tau^- \to \phi K^- \nu_\tau) \times \\ & B(\phi \to K_S^0 K_L^0 \text{ or } \phi \to \eta \gamma) \\ & B(\tau^- \to f_1(1285) \pi^- \nu_\tau) B(f_1(1285) \to \rho^0 \gamma) = (0.20 \pm 0.06) \times 10^{-4}, \\ & B(\tau^- \to h^- \omega \pi^0 \pi^0 \nu_\tau) B(\omega \to \pi^0 \gamma) \\ & B(\tau^- \to 2h^- h^+ \omega \nu_\tau) B(\omega \to \pi^0 \gamma) \\ & = (0.12 \pm 0.04) \times 10^{-4}, \\ & B(\tau^- \to 2h^- h^+ \omega \nu_\tau) B(\omega \to \pi^0 \gamma) \\ & = (0.10 \pm 0.02) \times 10^{-4}. \end{split}$$

The sum of these excluded branching fractions is $(0.07 \pm 0.01)\%$. This is near our goal of 0.1% for the internal consistency of the τ Listings for this edition, and thus for simplicity we do not include these small branching fraction decay modes in the basis set.

Beginning with the 2002 edition, the fit algorithm has been improved to allow for correlations between branching fraction measurements used in the fit. If only a few measurements are correlated, the correlation coefficients are listed in the footnote for each measurement. If a large number of measurements are correlated, then the full correlation matrix is listed in the footnote to the measurement that first appears in the τ Listings. Footnotes to the other measurements refer to the first measurement. For example, the large correlation matrices for the branching fraction measurements contained in Refs. [3,4] are listed in Footnotes to the $\Gamma(e^{-}\overline{\nu}_{e}\nu_{\tau})/\Gamma_{\text{total}}$ and $\Gamma(h^-\nu_{\tau})/\Gamma_{\rm total}$ measurements respectively. Sometimes experimental papers contain correlation coefficients between measurements using only statistical errors without including systematic errors. We usually cannot make use of these correlation coefficients.

The 2012 constrained fit has a χ^2 of 128.9 for 108 degrees of freedom, up from 102.9 for 103 degrees of freedom in the 2010 fit. Two basis-mode branching fractions changed by more than 1.0 σ from their 2010 values, $B(\mu^-\overline{\nu}_\mu\nu_\tau)$ and $B(\pi^-\nu_\tau)$, due to new measurements by the BaBar Collaboration [5] of τ -decay

modes containing one charged prong and no neutral particles other than neutrinos.

Inconsistencies in the τ -lepton Branching Fraction Data: Several inconsistencies are known to exist in the branching fraction measurements that are used to determine the τ -lepton branching fractions. The sources of the inconsistencies are unknown. The treatment of discrepant data used for fits and averages is described in the introduction of this Review. Of the 82 branching fractions that are derived from the constrained fit, 12 (15%) have scale factors that are 1.5 or larger, and the largest is 2.7. Of the 37 branching fractions that are not derived from the constrained fit, 20 make use of only one measurement. Of the 17 averages that make use of more than one measurement, 3 (18%) have scale factors that are 1.5 or larger, and the largest is 5.4. Ideograms for 8 branching fractions are currently displayed in the τ Listings.

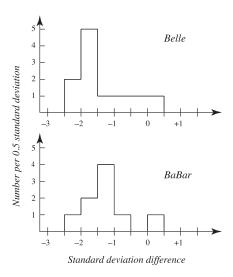


Figure 2: Distribution of the normalized difference between the 20 B-factory measurements of conventional τ -decay branching fractions and non-B-factory measurements. The Belle and BaBar collaborations have published 11 and 9 measurements respectively.

The τ branching fraction measurements by BaBar and Belle tend to be smaller than the non-B-factory measurements. There are 20 B-factory branching fraction measurements of τ -decay modes for which older non-B-factory measurements exist. Comparing the B-factory branching fraction measurements to the earlier non-B-factory measurements reveals a systematic discrepancy between the two sets of measurements. Figure 2 shows a histogram of the normalized difference ((B-factory value minus non-B-factory value)/estimated uncertainty in the difference) for the 20 measurements. The value used for the non-B-factory measurement is the value listed in the latest edition of this Review prior to the first B-factory measurement for that decay mode. Eighteen of the 20 B-factory branching

fraction measurements are smaller than the non-B-factory values. The average normalized difference between the two sets of measurements is -1.30 (-1.41 for the 11 Belle measurements and -1.24 for the 9 BaBar measurements). The Heavy Flavor Averaging Group (HFAG) analysis of τ branching fractions includes a similar comparison of the B-factory and non-B-factory measurements [6].

Belle and BaBar have each published branching fraction measurements for the six τ -decay modes listed in Table 2. The normalized difference between the two measured values is calculated by subtracting the Belle value from the BaBar value and dividing this difference by the quadratic sum of the statistical and systematic errors for each measurement. When a measurement has asymmetric errors, the larger of the two values is used in the quadratic sum. It is apparent from the values in Table 2 that the Belle and BaBar values differ significantly for several of the τ -decay modes.

Table 2: Comparison of the Belle and Babar branching fraction measurements for the six τ -decay modes that both experiments have measured. The normalized difference is the difference between the Belle and BaBar branching fraction values divided by the quadratic sum of the statistical and systematic errors for both measurements.

| Mode | BaBar - Belle |
|------------------------------------------------------|------------------------------------|
| | Normalized Difference $(\#\sigma)$ |
| $\pi^- \pi^+ \pi^- \nu_\tau \text{ (ex. } K^0)$ | +1.4 |
| $K^{-}\pi^{+}\pi^{-}\nu_{\tau} \text{ (ex. } K^{0})$ | -2.9 |
| $K^-K^+\pi^-\nu_	au$ | -2.9 |
| $K^-K^+K^-\nu_{	au}$ | -5.4 |
| $\eta~K^-\nu_{	au}$ | -1.0 |
| $\phi K^- \nu_{\tau}$ | -1.3 |

Overconsistency of Leptonic Branching Fraction Measurements: To minimize the effects of older experiments which often have larger systematic errors and sometimes make assumptions that have later been shown to be invalid, we exclude old measurements in decay modes which contain at least several newer data of much higher precision. As a rule, we exclude those experiments with large errors which together would contribute no more than 5% of the weight in the average. This procedure leaves five measurements for $B_e \equiv B(\tau^- \to e^- \overline{\nu}_e \nu_\tau)$ and five measurements for $B_{\mu} \equiv B(\tau^{-} \to \mu^{-} \overline{\nu}_{\mu} \nu_{\tau})$. For both B_e and B_{μ} , the selected measurements are considerably more consistent with each other than should be expected from the quoted errors on the individual measurements. The χ^2 from the calculation of the average of the selected measurements is 0.34 for B_e and 0.08 for B_{μ} . Assuming normal errors, the probability of a smaller χ^2 is 1.3% for B_e and 0.08% for B_{μ} .

References

- 1. R.M. Barnett et al. (Particle Data Group), Review of Particle Physics, Phys. Rev. **D54**, 1 (1996).
- See the τ Listings for references.
- S. Schael et al. (ALEPH Collab.), Phys. Rep. 421, 191 (2005).
- J. Abdallah et al. (DELPHI Collab.), Eur. Phys. J. C46, 1
- B. Aubert et al. (BaBar Collab.), Phys. Rev. Lett. 105, 051602 (2010).
- S. Banerjee et al. (HFAG), http://arxiv.org/pdf/1101.5138v1.pdf.

au^- BRANCHING RATIOS

 $\begin{array}{l} \Gamma\left(\text{particle}^{-} \geq 0 \text{ neutrals } \geq 0 K^0 \nu_{\tau} (\text{"1-prong"})) / \Gamma_{\text{total}} \right. \\ \Gamma_1 / \Gamma = (\Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma_{35} + \Gamma_{37} + \Gamma_{40} + \Gamma_{42} + 2\Gamma_{47} + \Gamma_{48} + 0.708\Gamma_{125} + 0.715\Gamma_{127} + 0.09\Gamma_{149} + 0.09\Gamma_{151}) / \Gamma \end{array}$ Γ_1/Γ

The charged particle here can be $e,\ \mu,$ or hadron. In many analyses, the sum of the topological branching fractions (1, 3, and 5 prongs) is constrained to be unity. Since the 5-prong fraction is very small, the measured 1-prong and 3-prong fractions are highly correlated and cannot be treated as independent quantities in our overall fit. We arbitrarily choose to use the 3-prong fraction in our fit, and leave the 1-prong fraction out. We do, however, use these 1-prong measurements in our average below. The measurements used only for the average are marked "avg," whereas "f&a" marks a result used for the fit and the average

| VALUE (%) | EVTS | DO CUMENT ID | TECN | COMMENT |
|----------------------------------|-------------|----------------------------|--------------|------------------|
| _ | | r includes scale factor of | | • |
| 85.26 ± 0.13 below | OUR AVERAGE | Error includes scale fa | ctor of 1.6. | See the ideogram |

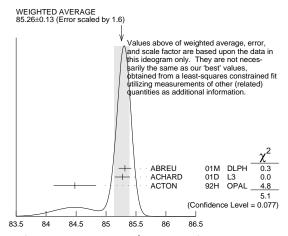
• • • We use the following data for averages but not for fits. • • •

| $85.316 \pm 0.093 \pm 0.049$ | 78k | ¹ ABREU | 01м | DLPH | 1992-1995 LEP runs |
|------------------------------|-----|---------------------|-----|------|--------------------|
| $85.274 \pm 0.105 \pm 0.073$ | | ² ACHARD | 01D | L3 | 1992-1995 LEP runs |
| $84.48 \pm 0.27 \pm 0.23$ | | ACTON | 92H | OPAL | 1990-1991 LEP runs |

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $\begin{array}{cc} 85.45 & ^{+}0.69 \\ ^{-}0.73 & \pm 0.65 \end{array}$ DECAMP 92c ALEP Repl. by SCHAEL 05c

 1 The correlation coefficients between this measurement and the ABREU 01M measurements of B($\tau\to 3$ -prong) and B($\tau\to 5$ -prong) are -0.98 and -0.08 respectively.

 $^{2}\,\mathrm{The}$ correlation coefficients between this measurement and the ACHARD 01D measurements of B(au
ightarrow "3-prong") and B(au
ightarrow "5-prong") are - 0.978 and - 0.082 respectively.



 $\Gamma(\text{particle}^- \ge 0 \text{ neutrals } \ge 0K^0\nu_{\tau}(\text{"1-prong"}))/\Gamma_{\text{total}}(\%)$

| 311131 127 31331 | 149 10.03 | . 151//. | | | |
|-------------------------|------------|--------------------------|------------|---------|--|
| VALUE (%) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 84.71 ± 0.08 OUR FIT | Error incl | ludes scale factor of 1. | 3. | | |
| 85.1 ±0.4 OUR AVER | RAGE | | | | |
| • • • We use the follow | ving data | for averages but not fo | or fits. • | • • | |
| | - | 1 | | | |

| 85.6 ± 0.6 ± 0.3 | 3300 | $^{ m 1}$ ADEVA | 91F L3 | E ^{ee} _{cm} = 88.3-94.3 GeV |
|--------------------------|------|---------------------|----------|-----------------------------------------------|
| $84.9 \pm 0.4 \pm 0.3$ | | BEHREND | 89B CELL | $E_{cm}^{ee} = 14-47 \text{ GeV}$ |
| $84.7 \pm 0.8 \pm 0.6$ | | ² AIHARA | 87B TPC | $E_{cm}^{ee} = 29 \text{ GeV}$ |

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

| 86.4 ± 0.3 ± 0.3 | | ABACHI | 89в | HRS | $E_{\rm cm}^{\it ee}=$ 29 GeV |
|----------------------------------|-----|----------------------|------|------|--------------------------------------------|
| 87.1 ± 1.0 ± 0.7 | | ³ BURCHAT | 87 | MRK2 | E ee 29 GeV |
| $87.2 \pm 0.5 \pm 0.8$ | | SCHMIDKE | 86 | MRK2 | $E_{ m cm}^{\it ee}=$ 29 GeV |
| 84.7 $\pm 1.1 ^{+ 1.6}_{- 1.3}$ | 169 | ⁴ ALTHOFF | 85 | TASS | $E_{\mathrm{cm}}^{\mathit{ee}} =$ 34.5 GeV |
| 86.1 ± 0.5 ± 0.9 | | BARTEL | 85 F | JADE | $E_{cm}^{ee} = 34.6 \text{ GeV}$ |
| 87.8 ± 1.3 ± 3.9 | | ⁵ BERGER | 85 | PLUT | $E_{cm}^{ee} = 34.6 \text{ GeV}$ |
| 86.7 ± 0.3 ± 0.6 | | FERNANDEZ | 85 | MAC | $E_{\rm cm}^{\it ee}=$ 29 GeV |

- 1 Not independent of ADEVA 91F $\Gamma(h^-\,h^-\,h^+ \ge 0$ neutrals $\ge 0K_I^0\,
 u_{ au})/\Gamma_{ ext{total}}$ value.
- $^2\,\mathrm{Not}$ independent of AIHARA 87B $\Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma_{\mathrm{total}}$, $\Gamma(e^-\overline{\nu}_e\,\nu_\tau)/\Gamma_{\mathrm{total}}$, and $\Gamma(h^- \geq 0 \text{ neutrals } \geq 0 \kappa_I^0 \nu_\tau) / \Gamma_{\text{total}}$ values.
- ³ Not independent of SCHMIDKE 86 value (also not independent of BURCHAT 87 value for $\Gamma \left(h^- \, h^- \, h^+ \, \geq \, 0 \, \, {
 m neutrals} \, \, \geq \, 0 \, K_L^0 \,
 u_{ au} \, \right) / \Gamma_{
 m total}$
- 4 Not independent of ALTHOFF 85 $\Gamma(\mu^-\overline{\nu}_\mu\nu_ au)/\Gamma_{
 m total}$, $\Gamma(e^-\overline{
 u}_e\nu_ au)/\Gamma_{
 m total}$, $\Gamma(h^-\geq 0)$ neutrals $\geq 0 K_L^0 \ \nu_ au)/\Gamma_{ ext{total}}$, and $\Gamma(h^- h^- h^+ \geq 0 \text{ neutrals } \geq 0 K_L^0 \ \nu_ au)/\Gamma_{ ext{total}}$ values. 5 Not independent of (1-prong + $0\pi^0)$ and (1-prong + $\geq 1\pi^0)$ values.

 $\Gamma(\mu^-\overline{
u}_\mu
u_ au)/\Gamma_{
m total}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

To minimize the effect of experiments with large systematic errors, we exclude experiments which together would contribute 5% of the weight in the average.

| VALUE | | | EVTS | | DO CUMENT ID | | TECN | COMMENT |
|-------|-----------|----------------------|-------------|------|-------------------|---------|-----------|-------------------------------------------------|
| | | | | nclu | ıdes scale factor | of 1. | 1. | |
| | _ | OUR AV | | 4 | | | | |
| | | ± 0.032 | 54k | 1 | SCHAEL | | | 1991-1995 LEP runs |
| | | ± 0.06 | | _ | ABBIENDI | 03 | OPAL | 1990-1995 LEP runs |
| | | ± 0.067 | | | ACCIARRI | 01F | L3 | 1991-1995 LEP runs |
| | | ± 0.077 | | | ABREU | | | 1991-1995 LEP runs |
| • • • | We use | the follow | wing data | for | averages but no | t for | fits. • • | • |
| 17.37 | ±0.08 | ±0.18 | | 3 | ANASTASSOV | 97 | CLEO | $E_{cm}^{ee} = 10.6 \text{ GeV}$ |
| • • • | We do | not use t | he followin | ng d | ata for averages | , fits, | limits, | etc. • • • |
| 17.31 | ±0.11 | ± 0.05 | 20.7k | | BUSKULIC | 96c | ALEP | Repl. by SCHAEL 05c |
| 17.02 | ±0.19 | ± 0.24 | 6586 | | ABREU | 95T | DLPH | Repl. by ABREU 99x |
| 17.36 | ±0.27 | | 7941 | | AKERS | 951 | OPAL | Repl. by ABBIENDI 03 |
| 17.6 | ±0.4 | ± 0.4 | 2148 | | ADRIANI | 93м | L3 | Repl. by ACCIARRI 01F |
| 17.4 | ±0.3 | ±0.5 | | 4 | ALBRECHT | 93G | ARG | E ee = 9.4-10.6 GeV |
| 17.35 | ±0.41 | ± 0.37 | | | DECAMP | 92c | ALEP | 1989-1990 LEP runs |
| 17.7 | ±0.8 | ± 0.4 | 568 | | BEHREND | 90 | CELL | $E_{cm}^{ee} = 35 \text{ GeV}$ |
| 17.4 | ±1.0 | | 2197 | | ADEVA | 88 | MRKJ | E ee = 14-16 GeV |
| 17.7 | ± 1.2 | ±0.7 | | | AIHARA | 87в | TPC | E ^{ee} _{cm} = 29 GeV |
| 18.3 | ±0.9 | ±0.8 | | | BURCHAT | 87 | MRK2 | E ^{ee} _{cm} = 29 GeV |
| 18.6 | ±0.8 | ±0.7 | 558 | 5 | BARTEL | 86D | JA DE | E ^{ee} _{cm} = 34.6 GeV |
| 12.9 | ±1.7 | $^{+\ 0.7}_{-\ 0.5}$ | | | ALTHOFF | 85 | TASS | <i>E</i> ^{ee} _{Cm} = 34.5 GeV |
| 18.0 | ±0.9 | ±0.5 | 473 | 5 | ASH | 85B | MAC | E ^{ee} _{cm} = 29 GeV |
| 18.0 | ±1.0 | ±0.6 | | 6 | BALTRUSAIT | .85 | MRK3 | E ^{ee} _{CM} = 3.77 GeV |
| 19.4 | ± 1.6 | ± 1.7 | 15.3 | | BERGER | 85 | PLUT | $E_{cm}^{ee} = 34.6 \text{ GeV}$ |

 $17.8\pm2.0\pm1.8$ 81B PLUT $E_{\rm cm}^{\it ee}=$ 9-32 GeV 1 See footnote to SCHAEL 05c $\Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\rm total}$ measurement for correlations with other measurements.

BEHREND

BERGER

83c CELL $E_{
m cm}^{\it ee}=$ 34 GeV

²The correlation coefficient between this measurement and the ACCIARRI 01F measurement of B($\tau^- \to \ e^- \, \overline{\nu}_e \, \nu_\tau)$ is 0.08.

3 The correlation coefficients between this measurement and the ANASTASSOV 97 measurements of $B(e\overline{\nu}_e\nu_\tau),~B(\mu\overline{\nu}_\mu\nu_\tau)/B(e\overline{\nu}_e\nu_\tau),~B(h^-\nu_\tau),~and~B(h^-\nu_\tau)/B(e\overline{\nu}_e\nu_\tau)$ are 0.50, 0.58, 0.50, and 0.08 respectively.

 4 Not independent of ALBRECHT 92D $\Gamma(\mu^-\overline{\nu}_{\mu}\nu_{\tau})/\Gamma(e^-\overline{\nu}_{\rm e}\nu_{\tau})$ and ALBRECHT 93G $\Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)\times\Gamma(e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\rm total}^2 \ \ {\rm values}.$

 5 Modified using B(e^- $\overline{\nu}_e \, \nu_\tau)/$ B("1 prong") and B("1 prong") ,= 0.855.

 6 Error correlated with BALTRUSAITIS 85 $e
u \overline{
u}$ value.

47

 $17.6 \pm 2.6 \pm 2.1$

| $\Gamma(\mu^-\overline{ u}_\mu u_	au\gamma)/\Gamma_{ m total}$ | | | | | Γ_4/Γ |
|--------------------------------------------------------------------------------|-------------|-------------------------------------------|---------|-----------|-------------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $0.361 \pm 0.016 \pm 0.035$ | | ¹ BERGFELD | 00 | CLEO | $E_{\rm cm}^{\it ee}$ = 10.6 GeV |
| • • • We do not use th | ne followin | g data for average | s, fits | , limits, | etc. • • • |
| $\begin{array}{ccc} 0.30 & \pm 0.04 & \pm 0.05 \\ 0.23 & \pm 0.10 \end{array}$ | 116 10 | ² ALEXANDER ³ WU | | | 1991-1994 LEP runs $E_{ m cm}^{\it ee}=$ 29 GeV |

- 1 BERGFELD 00 impose requirements on detected γ 's corresponding to a au-rest-frame energy cutoff $E_{\gamma}^* >$ 10 MeV. For $E_{\gamma}^* >$ 20 MeV, they quote $(3.04 \pm 0.14 \pm 0.30) \times 10^{-3}$
- 2 ALEXANDER 96s impose requirements on detected γ 's corresponding to a $\tau\text{-rest-frame}$ energy cutoff $E_{\gamma} > 20$ MeV.
- 3 WU 90 reports $\Gamma(\mu^-\overline{
 u}_\mu
 u_ au\gamma)/\Gamma(\mu^-\overline{
 u}_\mu
 u_ au) = 0.013 \pm 0.006$, which is converted to $\Gamma(\mu^-\overline{\nu}_\mu\nu_\tau\gamma)/\Gamma_{\rm total} \ {\rm using} \ \Gamma(\mu^-\overline{\nu}_\mu\nu_\tau\gamma)/\Gamma_{\rm total} = 17.35\%. \ {\rm Requirements} \ {\rm on} \ {\rm detected} \ \gamma'{\rm s} \ {\rm correspond} \ {\rm to} \ {\rm a} \ \tau \ {\rm rest} \ {\rm frame} \ {\rm energy} \ {\rm cutoff} \ E_\gamma > 37 \ {\rm MeV}.$

24.7k

33.1k

23.3k

25.3k

20.6k

5059

2892

3970

2960

1.7k

60

459

(3) $\Gamma(\tau^- \to \pi^- \nu_\tau)/\Gamma_{\text{total}}$ (4) $\Gamma(\tau^- \to \pi^- \pi^0 \nu_\tau)/\Gamma_{\text{total}}$ (5) $\Gamma(\tau^- \to \pi^- 2\pi^0 \nu_\tau (\text{s. } \kappa^0))/\Gamma_{\text{total}}$

(6) $\Gamma(\tau^- \to \pi^- 3\pi^0 \nu_\tau (\text{ex.} K^0)) / \Gamma_{\text{total}}$

(1) $\Gamma(\tau^- \rightarrow e^- \overline{\nu}_e \nu_\tau) / \Gamma_{total}$

(2) $\Gamma(\tau^- \to \mu^- \overline{\nu}_{\mu} \nu_{\tau}) / \Gamma_{\text{total}}$

DO CUMENT ID

 $^{
m 1}$ SCHAEL

² ACCIARRI

ABREU

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

ABBIENDI

BUSKULIC

ABREU

ADRIANI

AKERIB

⁵ AMMAR

DECAMP

ABACHI

BEHREND

JANSSEN

BURCHAT

BEHREND

⁷ BACINO

 ${\bf 1}$ Correlation matrix for SCHAEL 05c branching fractions, in percent:

⁶ BALTRUSAIT...85

AIHARA

⁵ BARTEL

⁴ ALBRECHT

TECN COMMENT

99H OPAL 1991-1995 LEP runs

99x DLPH 1991-1995 LEP runs

1991-1995 LEP runs

1991-1995 LEP runs

ENDI 99H Repl. by SCHAEL 05c

Repl.. by ABREU 99x

Eee = 9.4-10.6 GeV

 $E_{\rm cm}^{\it ee} = 10.5 - 10.9 \; {\rm GeV}$

Repl. by SCHAEL 05c

Repl. by ANAS-TASSOV 97

 $E_{\rm cm}^{\it ee}=$ 29 GeV

 $E_{cm}^{ee} = 35 \text{ GeV}$

CBAL $E_{\text{cm}}^{ee} = 9.4\text{--}10.6 \text{ GeV}$

MRK2 E_{cm}^{ee} = 29 GeV

86D JADE $E_{\rm cm}^{\,ee}=34.6~{\rm GeV}$

 $E_{\rm cm}^{\it ee}=$ 29 GeV

 $E_{\rm cm}^{ee} = 34.5 \text{ GeV}$

 $E_{\rm cm}^{\it ee}$ = 29 GeV

MRK3 $E_{cm}^{ee} = 3.77 \text{ GeV}$

PLUT $E_{cm}^{ee} = 34.6 \text{ GeV}$

78B DLCO $E_{cm}^{ee} = 3.1-7.4 \text{ GeV}$

83c CELL $E_{\mathrm{CM}}^{\mathit{ee}} =$ 34 GeV

Repl. by ACCIARRI 01F

05c ALEP

 3 ANASTASSOV 97 CLEO $E_{
m cm}^{\it ee}=$ 10.6 GeV

ALEXANDER 96D OPAL Repl. by ABBI-

96c ALEP

95T DLPH

93M L3

92

90 HRS

90 CELL

89

87B TPC

87

85

936 ARG

92 CLEO

92c ALEP

CLEO

01F L3

VALUE (%) EVTS

17.82 ±0.05 OUR AVERAGE

 $17.837 \pm 0.072 \pm 0.036$

 $17.806 \pm 0.104 \pm 0.076$

 $17.877 \pm 0.109 \pm 0.110$

 $17.81 \pm 0.09 \pm 0.06$

 $17.76 \pm 0.06 \pm 0.17$

 $17.78 \ \pm 0.10 \ \pm 0.09$

17.79 + 0.12 + 0.06

 $17.51 \pm 0.23 \pm 0.31$

17.9 ± 0.4 ± 0.4

17.5 + 0.3 + 0.5

 $17.97 \pm 0.14 \pm 0.23$

19.1 + 0.4 + 0.6

 $18.09 \pm 0.45 \pm 0.45$

 $17.0 \pm 0.5 \pm 0.6$

 $18.4 \pm 0.8 \pm 0.4$

16.3 + 0.3 + 3.2

19.1 ± 0.8 ± 1.1

 $16.8 \pm 0.7 \pm 0.9$

 $20.4 \pm 3.0 \begin{array}{c} +1.4 \\ -0.9 \end{array}$

17.8 ± 0.9 ± 0.6

18.2 + 0.7 + 0.5

18.3 + 2.4 + 1.9

 13.0 ± 1.9

 ± 1.0

 18.4 ± 1.2

```
(6) \Gamma(\tau \to \pi^- 3\pi^- \nu_{\tau} (\text{ex. n.}))/\tau \text{total}

(7) \Gamma(\tau^- \to h^- 4\pi^0 \nu_{\tau} (\text{ex. k}^0, \eta))/\Gamma \text{total}

(8) \Gamma(\tau^- \to \pi^- \pi^+ \pi^- \nu_{\tau} (\text{ex. k}^0, \omega))/\Gamma \text{total}

(9) \Gamma(\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_{\tau} (\text{ex. k}^0))/\Gamma \text{total}
            (10) \Gamma(\tau^- \rightarrow h^- h^- h^+ 2\pi^0 \nu_{\tau} (\text{ex.} K^0))/\Gamma_{\text{total}}
            (11) \Gamma(\tau^- \rightarrow h^- h^- h^+ 3\pi^0 \nu_\tau) / \Gamma_{\text{total}}
           (12) \Gamma(\tau^- \to 3h^- 2h^+ \nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}

(13) \Gamma(\tau^- \to 3h^- 2h^+ \pi^0 \nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}
                            (1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12)
              (2)
                           -20
              (3)
                             _9
                                       -6
              (4)
                           -16 -12
                                                  2
              (5)
                             -5
                                      -5 -17 -37
                              0
                                       -4 -15
                                                            2
                                                                    -27
               (7)
                             -2
                                       -4 -24
                                                        -15
                                                                    20 -47
                                       -9
                                              15
                                                          -5
                                                                   -17 -14
                            -13 -12
                                              -25
                                                        -30
                                                                                -2
                                                                                         16
                                                                                                  -15
            (10)
                                     -2 -23 -14
                                                                                         13
                                         0
                                                  -5
                                                                      4
                                                                                6
                                                                                            0
                                                                                                    -9
                                                                                                              -2 -11
                                                                                         -6
                                                                                                              -5
            (12)
                                                  -3
                                                            -5
                                                                      3
                                                                                                     -3
                                                                                                              -1
    ^2 The correlation coefficient between this measurement and the ACCIARRI 01F measurement of B(\tau^-\to\mu^-\overline{\nu}_\mu\nu_\tau) is 0.08.
    ^3 The correlation coefficients between this measurement and the ANASTASSOV 97 measurements of B(\mu\overline{\nu}_{\mu}\nu_{\tau}), B(\mu\overline{\nu}_{\mu}\nu_{\tau})/B(e\overline{\nu}_{e}\nu_{\tau}), B(h^-\nu_{\tau}), and B(h^-\nu_{\tau})/B(e\overline{\nu}_{e}\nu_{\tau}) are 0.50, -0.42, 0.48, and -0.39 respectively.
    ^4 Not independent of ALBRECHT 92D \Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma(e^-\overline{\nu}_e\,\nu_\tau) and ALBRECHT 93G
    \Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)\times\Gamma(e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\rm total}^2 \ \ {\rm values}.  5 Modified using B(e^-\overline{\nu}_e\nu_\tau)/B("1 prong") and B("1 prong") ,= 0.855. 6 Error correlated with BALTRUSAITIS 85 \Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma_{\rm total}
     ^7BACINO 78B value comes from fit to events with e^{\pm} and one other nonelectron charged
\Gamma(\mu^-\overline{
u}_\mu
u_	au)/\Gamma(e^-\overline{
u}_e
u_	au)
Standard Model prediction including mass effects is 0.9726
                                                                                                                                                            \Gamma_3/\Gamma_5
VALUE EVTS DOCUMENT ID TECN 0.9764 ± 0.0030 OUR FIT Error includes scale factor of 1.1.
                                                                                                       TECN COMMENT
0.979 ±0.004 OUR AVERAGE
0.9796 \pm 0.0016 \pm 0.0036 731k <sup>1</sup> AUBERT
                                                                                             10F BABR 467 fb^{-1} E_{cm}^{ee} = 10.6 GeV
                                                            ^2 anastassov 97 CLEO E_{
m cm}^{\it ee} = 10.6~{
m GeV}
0.9777 \pm 0.0063 \pm 0.0087
0.997 \pm 0.035 \pm 0.040
                                                                ALBRECHT 92D ARG E_{cm}^{ee} = 9.4-10.6 \text{ GeV}
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<sup>1</sup> Correlation matrix for AUBERT 10F branching fractions:
           (1) \Gamma(\tau^- \rightarrow \mu^- \overline{\nu}_{\mu} \nu_{\tau}) / \Gamma(\tau^- \rightarrow e^- \overline{\nu}_e \nu_{\tau})
           (2) \Gamma(\tau^- \rightarrow \pi^- \nu_\tau) / \Gamma(\tau^- \rightarrow e^- \overline{\nu}_e \nu_\tau)
          (3) \Gamma(\tau^- \rightarrow K^- \nu_\tau) / \Gamma(\tau^- \rightarrow e^- \overline{\nu}_e \nu_\tau)
                     (1)
                                (2)
                    0.25
           (2)
           (3)
                   0.12
   <sup>2</sup>The correlation coefficients between this measurement and the ANASTASSOV 97 mea-
     surements of B(\mu\overline{\nu}_{\mu}\nu_{\tau}), B(e\overline{\nu}_{e}\nu_{\tau}), B(h^{-}\nu_{\tau}), and B(h^{-}\nu_{\tau})/B(e\overline{\nu}_{e}\nu_{\tau}) are 0.58, - 0.42, 0.07, and 0.45 respectively.
                                                                                                                    \Gamma_6/\Gamma
\Gamma(e^-\overline{\nu}_e\nu_{\tau}\gamma)/\Gamma_{\text{total}}
                                                   DO CUMENT ID
                                                 <sup>1</sup> BERGFELD
1.75 \pm 0.06 \pm 0.17
                                                                        00 CLEO E_{cm}^{ee} = 10.6 \text{ GeV}
   ^1BERGFELD 00 impose requirements on detected \gamma's corresponding to a 	au-rest-frame
     energy cutoff E_{\sim}^* > 10~{
m MeV}
\Gamma(h^- \geq 0K_L^0 \nu_{\tau})/\Gamma_{\text{total}}
                                                                                                                     \Gamma_7/\Gamma
        \Gamma_7/\Gamma = (\Gamma_9 + \Gamma_{10} + \frac{1}{2}\Gamma_{35} + \frac{1}{2}\Gamma_{37} + \Gamma_{47})/\Gamma
         Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
         and are therefore used for the average given below but not in the overall fits. "f&a"
         marks results used for the fit and the average.
                                  EVTS
                                                   DO CUMENT ID
                                                                                 TECN COMMENT
12.06±0.06 OUR FIT Error includes scale factor of 1.2.
12.2 ±0.4 OUR AVERAGE
12.47 \pm 0.26 \pm 0.43
                                                <sup>1</sup> ACCIARRI
                                                <sup>2</sup> ABREU
12.4 \pm 0.7 \pm 0.7
                                                                         92N DLPH 1990 LEP run
                                    283
                                                   ALEXANDER 91D OPAL 1990 LEP run
12.1 \pm 0.7 \pm 0.5
                                    309
• • • We use the following data for averages but not for fits. • • •
                                                <sup>3</sup> FORD
                                                                        87 MAC E_{\rm cm}^{\it ee}= 29 GeV
11.3 \pm 0.5 \pm 0.8
                                    798
\bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
                                                <sup>4</sup> BUSKULIC
12.44 \pm 0.11 \pm 0.11
                                                                        96 ALEP Repl. by SCHAEL 05c
                                                 <sup>5</sup> ALBRECHT
11.7 \pm 0.6 \pm 0.8
                                                                        92D ARG E_{cm}^{ee} = 9.4-10.6 \text{ GeV}
                                                 <sup>6</sup> DECAMP
12.98 \pm 0.44 \pm 0.33
                                                                         92c ALEP Repl. by SCHAEL 05c
12.3 \pm 0.9 \pm 0.5
                                                   BEHREND
                                                                                CELL E_{cm}^{ee} = 35 \text{ GeV}
                                                 <sup>7</sup> BURCHAT
11.1 + 1.1 + 1.4
                                                                        87 MRK2 E_{cm}^{ee} = 29 \text{ GeV}
                                                <sup>8</sup> BARTEL
12.3\ \pm0.6\ \pm1.1
                                                                         86D JADE E_{\rm cm}^{\it ee}= 34.6 GeV
13.0 \pm 2.0 \pm 4.0
                                                   BERGER
                                                                         85 PLUT E_{\rm CM}^{\it ee}= 34.6 GeV
                                                <sup>9</sup> BEHREND
11.2 \pm 1.7 \pm 1.2
                                      34
                                                                        83c CELL E_{cm}^{ee} = 34 \text{ GeV}
   ^{1} ACCIARRI 95 with 0.65% added to remove their correction for \pi^{-} K_{I}^{0} backgrounds.
   ^2ABREU 92N with 0.5% added to remove their correction for K^*(892)^- backgrounds.
   ^3 FORD 87 result for B(\pi^-\nu_\tau) with 0.67% added to remove their K^- correction and adjusted for 1992 B("1 prong").
   ^4 BUSKULIC 96 quote 11.78\pm0.11\pm0.13 We add 0.66 to undo their correction for
     unseen K_I^0 and modify the systematic error accordingly.
   ^5 Not independent of ALBRECHT 92D \Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma(e^-\overline{\nu}_e\nu_\tau),~\Gamma(\mu^-\overline{\nu}_\mu\nu_\tau) \times
     \Gamma(e^-\overline{\nu}_e\,\nu_{	au}), and \Gamma(h^-\geq 0\,K_L^0\,\nu_{	au})/\Gamma(e^-\overline{\nu}_e\,\nu_{	au}) values.
   ^{6}\,{\rm DECA\,MP\,\,92c\,\,quote\,\,B}(h^{-}\,\geq\,\,0\,\,K_{L}^{0}\,\geq\,\,0\,\,(\,K_{S}^{0}\,\rightarrow\,\,\pi^{+}\,\pi^{-})\,\,\nu_{\tau}) = 13.32\,\pm\,0.44\,\pm\,0.33.
     We subtract 0.35 to correct for their inclusion of the K_S^0 decays.
   ^7 BURCHAT 87 with 1.1% added to remove their correction for \,{\it K}^- and \,{\it K}^*(892)^- back-
   ^8BARTEL 86D result for B(\pi^-
u_	au) with 0.59% added to remove their K^- correction and
     adjusted for 1992 B("1 prong")
   ^9 BEHREND 83C quote B( \pi^-\nu_{\tau})=9.9\pm1.7\pm1.3 after subtracting 1.3\pm0.5 to correct
     for B(K^-\nu_{\tau})
\Gamma(h^-\nu_{	au})/\Gamma_{	ext{total}} Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
         and are therefore used for the average given below but not in the overall fits. "f&a'
         marks results used for the fit and the average.
11.53 ±0.06 OUR FIT Error includes scale factor of 1.2.

11.63 +0.12 OUR PAGE 7
11.63 \pm0.12 OUR AVERAGE Error includes scale factor of 1.4. See the ideogram
                                                   <sup>1</sup> ABDALLAH 06A DLPH 1992-1995 LEP runs
11.571 \pm 0.120 \pm 0.114 \;\; \text{f\&a} \;\; 19 \text{k}
11.98 ±0.13 ±0.16 f&a
                                                     ACKERSTAFF 98M OPAL 1991-1995 LEP runs
                                                   ^2 ANASTASSOV 97 CLEO E_{
m cm}^{\it ee} = 10.6~{
m GeV}
11.52 \pm 0.05 \pm 0.12 f&a
   <sup>1</sup> Correlation matrix for ABDALLAH 06A branching fractions, in percent:
          (1) \Gamma(\tau^- \to h^- \nu_\tau)/\Gamma_{\text{total}}

(2) \Gamma(\tau^- \to h^- \pi^0 \nu_\tau)/\Gamma_{\text{total}}

(3) \Gamma(\tau^- \to h^- \pi^0 \nu_\tau)/\Gamma_{\text{total}}
          (4) \Gamma(\tau^- \to h^- 2\pi^0 \nu_\tau (\text{ex. } K^0))/\Gamma_{\text{total}}

(5) \Gamma(\tau^- \to h^- 2\pi^0 \nu_\tau (\text{ex. } K^0))/\Gamma_{\text{total}}
          (6) \Gamma(\tau^- \to h^- h^+ h^+ \nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}

(7) \Gamma(\tau^- \to h^- h^- h^+ \pi^0 \nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}
```

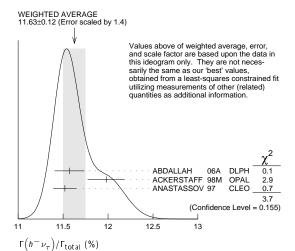
(8) $\Gamma(\tau^{-} \to h^{-}h^{-}h^{+} \geq 1\pi^{0}\nu_{\tau}(\text{ex. }K^{0}))/\Gamma_{\text{total}}$

(9) $\Gamma(\tau^- \rightarrow h^- h^- h^+ \ge 2\pi^0 \nu_{\tau} (\text{ex. } K^0)) / \Gamma_{\text{total}}$ (10) $\Gamma(\tau^- \rightarrow 3h^- 2h^+ \nu_{\tau}(\text{ex.} K^0))/\Gamma_{\text{total}}$

(11) $\Gamma(\tau^- \rightarrow 3h^- 2h^+ \pi^0 \nu_{\tau}(\text{ex.} K^0))/\Gamma_{\text{total}}$

```
(1) (2) (3) (4) (5) (6) (7) (8) (9) (10)
(2)
(3)
      -47
          -66
(4)
       6
               15
          38
               11 -86
(5)
       -6
       -7
           -8
                        -2
(6)
               15
                    0
(7)
       -2
          -1
               -5
                   -3
                        3 -53
                       -2 -56 75
           -4 -13
                   -4
(8)
(9)
       -1
           -1
               -4
                    3
                       -6
                           26 -78 -16
(10)
           -1
               1
                    0
                        0
                           -2 -3 -1
(11)
                0
                    0
                        0
                            1
                                0 -5
                                        5 -57
```

² The correlation coefficients between this measurement and the ANASTASSOV 97 measurements of B($\mu\overline{\nu}_{\mu}\nu_{\tau}$), B($e\overline{\nu}_{e}\nu_{\tau}$), B($\mu\overline{\nu}_{\mu}\nu_{\tau}$)/B($e\overline{\nu}_{e}\nu_{\tau}$), and B($h^{-}\nu_{\tau}$)/B($e\overline{\nu}_{e}\nu_{\tau}$) are 0.50, 0.48, 0.07, and 0.63 respectively.



$\Gamma(h^-\nu_{\tau})/\Gamma(e^-\overline{\nu}_e\nu_{\tau})$ $\Gamma_8/\Gamma_5 = (\Gamma_9 + \Gamma_{10})/\Gamma_5$

Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

VALUE EVTS DOCUMENT ID TECN

0.647 ±0.004 OUR FIT Error includes scale factor of 1.1. $\textbf{0.640} \ \, \textbf{\pm 0.007} \ \ \, \textbf{OUR AVERAGE} \quad \text{Error includes scale factor of } 1.6.$ \bullet \bullet We use the following data for averages but not for fits. \bullet \bullet 0.6333 ± 0.0014 ± 0.0061 394k ¹ AUBERT 10F BABR 467 fb $^{-1}$ E_{cm}^{ee} =10.6 GeV

 $0.6484 \pm 0.0041 \pm 0.0060$

 2 anastassov 97 CLEO $E_{
m CM}^{\it ee}=$ 10.6 GeV 1 Not independent of AUBERT 10F $\Gamma(au^- o \pi^-
u_ au)/\Gamma(au^- o e^- \overline{
u}_e
u_ au)$ and $\Gamma(au^- o$ $K^-\nu_\tau)/\Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)$

²The correlation coefficients between this measurement and the ANASTASSOV 97 measurements of $B(\mu\overline{\nu}_{\mu}\nu_{\tau})$, $B(e\overline{\nu}_{e}\nu_{\tau})$, $B(\mu\overline{\nu}_{\mu}\nu_{\tau})/B(e\overline{\nu}_{e}\nu_{\tau})$, and $B(h^{-}\nu_{\tau})$ are 0.08, - 0.39, 0.45, and 0.63 respectively.

 $\Gamma(\pi^-\nu_{\tau})/\Gamma_{\rm total}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

DOCUMENT ID TECN COMMENT EVTS 10.83 ±0.06 OUR FIT Error includes scale factor of 1.2. 10.828±0.070±0.078 f&a 38k ¹ SCHAEL 05c 05 C ALEP 1991-1995 LEP runs ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet² BUSKULIC 96 ALEP Repl. by SCHAEL 05 c $11.06 \pm 0.11 \pm 0.14$ 1138 BLOCKER 82D MRK2 $E_{cm}^{ee} = 3.5-6.7 \text{ GeV}$ $11.7 \pm 0.4 \pm 1.8$

 1 See footnote to SCHAEL 05c $\Gamma(\tau^-\to~e^-\overline{\nu}_e\,\nu_\tau)/\Gamma_{\rm total}$ measurement for correlations

2 with other measurements. 2 Not independent of BUSKULIC 96 B($h^-\nu_{\tau})$ and B($K^-\nu_{\tau})$ values.

 $\Gamma(\pi^-\nu_{\tau})/\Gamma(e^-\overline{\nu}_e\,\nu_{\tau})$ Γ_9/Γ_5

 1 See footnote to AUBERT 10F $\Gamma(\tau^-\to~\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)$ for correlations

| $\Gamma(K^- u_	au)/\Gamma_{ m total}$ | | | | | Γ ₁₀ /Γ |
|---------------------------------------|-------|-----------------------|--------|------|--------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.700±0.010 OUR FIT | Error | includes scale factor | of 1.1 | | |
| 0.685 ± 0.023 OUR AVE | RAGE | | | | |
| $0.658 \pm 0.027 \pm 0.029$ | | ¹ abbiendi | 01J | OPAL | 1990-1995 LEP runs |
| $0.696 \pm 0.025 \pm 0.014$ | 2032 | BARATE | 99K | ALEP | 1991-1995 LEP runs |
| 0.85 ± 0.18 | 27 | ABREU | 94K | DLPH | LEP 1992 Z data |
| $0.66 \pm 0.07 \pm 0.09$ | 99 | BATTLE | 94 | CLEO | $E_{\rm cm}^{ee} \approx 10.6 \text{ GeV}$ |

```
• • • We do not use the following data for averages, fits, limits, etc. • • •
0.72 \pm 0.04 \pm 0.04
                         728
                                     BUSKULIC
                                                    96 ALEP Repl. by BARATE 99к
                                                     84 DLCO E_{\rm cm}^{\it ee}= 29 GeV
0.59 \pm 0.18
                           16
                                     MILLS
                                                     82B MRK2 E_{\rm cm}^{\it ee} = 3.9-6.7 GeV
1.3 \pm 0.5
                           15
                                     BLOCKER
```

 1 The correlation coefficient between this measurement and the ABBIENDI 01J B($au^-
ightarrow$ $\kappa^- \geq 0\pi^0 \geq 0 \, \kappa^0 \geq 0 \gamma \, \nu_{\scriptscriptstyle \mathcal{T}}$) is 0.60.

 $\Gamma(K^-\nu_{\tau})/\Gamma(e^-\overline{\nu}_e\,\nu_{\tau})$ Γ_{10}/Γ_{5} DO CUMENT ID TECN COMMENT **3.93** ± 0.06 **OUR FIT** Error includes scale factor of 1.1.

3.882±0.032±0.057 25k ¹ AUBERT 10F BABR 467 fb $^{-1}$ $E_{
m cm}^{ee}$ = 10.6 GeV 1 See footnote to AUBERT 10F $\Gamma(\tau^-\to~\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)$ for correlations with other measurements.

 $\Gamma(K^-\nu_{\tau})/\Gamma(\pi^-\nu_{\tau})$ Γ_{10}/Γ_{9} VALUE (units 10-2) DOCUMENT ID TECN COMMENT

6.46 ±0.10 OUR FIT Error includes scale factor of 1.1. \bullet \bullet $\,\bullet$ We use the following data for averages but not for fits. \bullet $\,\bullet$

¹ AUBERT 10F BABR 467 fb $^{-1}$ $E_{
m cm}^{\it ee}$ = 10.6 GeV

 1 Not independent of AUBERT 10F $\Gamma(\tau^-\to~\pi^-\nu_\tau)/\Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)$ and $\Gamma(\tau^-\to\pi^-\nu_\tau)$ $K^-\nu_{ au})/\Gamma(\tau^- \rightarrow e^-\overline{\nu}_e\nu_{ au}).$

 $\Gamma(h^- \geq 1 ext{ neutrals }
u_ au)/\Gamma_{ ext{total}}$ $\begin{matrix} \Gamma_{11}/\Gamma = (\Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + 0.157\Gamma_{35} + 0.157\Gamma_{37} + 0.157\Gamma_{40} + 0.157\Gamma_{42} + 0.0985\Gamma_{47} + 0.708\Gamma_{125} + 0.715\Gamma_{127} + 0.09\Gamma_{149} + 0.09\Gamma_{151})/\Gamma \end{matrix}$

DOCUMENT ID 37.10±0.10 OUR FIT Error includes scale factor of 1.2. • • • We do not use the following data for averages, fits, limits, etc. • • • ¹ AKERS 94E OPAL 1991-1992 LEP runs ² BURCHAT $38.4 \pm 1.2 \pm 1.0$ 87 MRK2 $E_{cm}^{ee} = 29 \text{ GeV}$ 42.7 ±2.0 ±2.9 85 PLUT *E* ^{ee}_{cm} = 34.6 GeV BERGER

 1 Not independent of ACKERSTAFF 98m B($h^-\,\pi^0\,\nu_{\tau})$ and B($h^-\,\geq 2\,\pi^0\,\nu_{\tau})$ values.

 $^2\,{\rm BURCHAT}$ 87 quote for ${\rm B}(\pi^\pm \ge 1~{\rm neutral}\,\nu_\tau) = 0.378 \pm 0.012 \pm 0.010.$ We add 0.006 to account for contribution from $(K^{*-}\nu_{\tau})$ which they fixed at BR = 0.013.

 $\Gamma(h^- \geq 1\pi^0 \nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}}$ $\Gamma_{12}/\Gamma = (\Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + 0.325\Gamma_{125} + 0.325\Gamma_{127})/\Gamma$ DOCUMENT ID EVTS TECN COMMENT

36.57 ±0.10 OUR FIT Error includes scale factor of 1.2.

• • • We use the following data for averages but not for fits. • • •

¹ ABDALLAH 06A DLPH 1992-1995 LEP runs 36.641 ± 0.155 ± 0.127 45k

 1 See footnote to ABDALLAH 06A $\Gamma(\tau^-\to~h^-\nu_\tau)/\Gamma_{\mbox{total}}$ measurement for correlations with other measurements.

 $\Gamma(h^-\pi^0\nu_ au)/\Gamma_{
m total}$ $\Gamma_{13}/\Gamma = (\Gamma_{14} + \Gamma_{16})/\Gamma$ EVTS DOCUMENT ID TO TO THE PROPERTY OF THE PRO 25.73 ± 0.16 OUR AVERAGE BELL 72 fb $^{-1}$ $E_{\mathrm{CM}}^{ee} = 10.6 \mathrm{GeV}$ $25.67 \ \pm 0.01 \ \pm 0.39 \quad \ 5.4 M$ **FUJIKAWA** 08 $25.740 \pm 0.201 \pm 0.138$ ¹ ABDALLAH 06A DLPH 1992-1995 LEP runs ACKERSTAFF 98M OPAL 1991-1995 LEP runs $25.89 \pm 0.17 \pm 0.29$ 6613 $25.05\ \pm0.35\ \pm0.50$ ACCIARRI 95 L3 1992 LEP run $25.87\ \pm0.12\ \pm0.42$ ² ARTUSO 94 CLEO $E_{\rm cm}^{\it ee} = 10.6 \; {\rm GeV}$ 51 k ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $25.76 \ \pm 0.15 \ \pm 0.13$ BUSKULIC 96 ALEP Repl. by SCHAEL 05c 94E OPAL Repl. by ACKER-STAFF 98M 92N DLPH $E_{\rm cm}^{\rm ee}=88.2$ –94.2 GeV ³ A KERS $25.98 \ \pm 0.36 \ \pm 0.52$ ⁴ ABREU 22.9 + 0.8 + 1.3283 $E_{
m cm}^{\it ee} = 10 \; {
m GeV}$ $23.1\pm0.4\pm0.9$ ⁵ ALBRECHT 92Q ARG 1249 25.02 ± 0.64 ± 0.88 DECAMP 92c ALEP 1989-1990 LEP runs ANTREASYAN 91 CBAL $E_{
m cm}^{\it ee}=$ 9.4–10.6 GeV $22.0 \pm 0.8 \pm 1.9$ 779 $22.6 \pm 1.5 \pm 0.7$ 1101 BEHREND 90 CELL $E_{cm}^{ee} = 35 \text{ GeV}$ 23.1 ± 1.9 ± 1.6 BEHREND 84 CELL $E_{cm}^{ee} = 14,22 \text{ GeV}$

 $^1\,\mathrm{See}$ footnote to ABDALLAH 06A $\Gamma(\tau^-\to~h^-\nu_\tau)/\Gamma_{\mbox{total}}$ measurement for correlations with other measurements. ARTUSO 94 reports the combined result from three independent methods, one of which

(23% of the $\tau^- \to h^- \pi^0 \nu_{\tau}$) is normalized to the inclusive one-prong branching fraction, Taken as 0.854 ± 0.004 . Renormalization to the present value causes negligible change. ³ AKERS 94E quote $(26.25\pm0.36\pm0.52)\times10^{-2}$; we subtract 0.27% from their number to correct for $\tau^- \to h^- K_I^0 \nu_{\tau}$.

 4 ABREU 92N with 0.5% added to remove their correction for $K^*(892)^-$ backgrounds.

 5 ALBRECHT 92Q with 0.5% added to remove their correction for $\tau^{-} \rightarrow~$ $\textit{K*}(892)^{-}\nu_{\tau}$ background

 τ

```
\Gamma(\pi^-\pi^0\nu_{\tau})/\Gamma_{\rm total}
                                                                                                                                                                   \Gamma(h^- 2\pi^0 \nu_{\tau} (\text{ex.} K^0)) / \Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                        \Gamma_{19}/\Gamma
         Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
                                                                                                                                                                            \Gamma_{19}/\Gamma = (\Gamma_{20} + \Gamma_{23})/\Gamma
         and are therefore used for the average given below but not in the overall fits. "f&a"
                                                                                                                                                                             Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
         marks results used for the fit and the average.
                                                                                                                                                                             and are therefore used for the average given below but not in the overall fits. f&a marks
VALUE (%)EVTSDO CUMENT IDT25.52±0.09OUR FITError includes scale factor of 1.1.
                                                                                             TECN COMMENT
                                                                                                                                                                             results used for the fit and the average.
                                                                                                                                                                     ### ALUE (%) EVTS DOCUMENT ID T

9.36 ±0.11 OUR FIT Error includes scale factor of 1.2.
                                                                                                                                                                                                                                                                TECN COMMENT
25.46 ±0.12 OUR AVERAGE
                                                        ^{\mathrm{1}} SCHAEL
25.471 \pm 0.097 \pm 0.085
                                       81 k
                                                                                    05c ALEP 1991-1995 LEP runs
                                                                                                                                                                     9.17 ±0.27 OUR AVERAGE
\bullet \bullet \bullet We use the following data for averages but not for fits. 
 \bullet \bullet
                                                                                                                                                                     9.498 \pm 0.320 \pm 0.275
                                                                                                                                                                                                                           <sup>1</sup> ABDALLAH
                                                                                                                                                                                                           9.5k
                                                                                                                                                                                                                                                       06A DLPH 1992-1995 LEP runs
                                                        <sup>2</sup> ARTUSO
                                                                                    94 CLEO E_{\mathrm{CM}}^{ee} = 10.6 \; \mathrm{GeV}
25.36 \pm 0.44
                                                                                                                                                                     8.88 \ \pm 0.37 \ \pm 0.42
                                                                                                                                                                                                                              ACCIARRI
                                                                                                                                                                                                                                                       95 L3 1992 LEP run
• • • We do not use the following data for averages, fits, limits, etc. • •
                                                                                                                                                                    • • • We use the following data for averages but not for fits. • • •
                                                        <sup>3</sup> BUSKULIC
25.30 \pm 0.15 \pm 0.13
                                                                                   96 ALEP Repl. by SCHAEL 05c
                                                                                                                                                                                                                           ^2 PROCARIO 93 CLEO E_{
m cm}^{\it ee} pprox 10.6 GeV
                                                                                                                                                                     8.96 \pm 0.16 \pm 0.44
                                                     ^{4,5} ALBRECHT
21.5 \pm 0.4 \pm 1.9
                                        4400
                                                                                    88L ARG E_{\rm cm}^{\it ee}=10~{\rm GeV}
                                                                                                                                                                   \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
23.0 \pm 1.3 \pm 1.7
                                         582
                                                          ADLER
                                                                                    87B MRK3 E_{\mathrm{cm}}^{ee}=3.77~\mathrm{GeV}
                                                                                                                                                                                                                           <sup>3</sup> DECAMP
                                                                                                                                                                   10.38 \ \pm 0.66 \ \pm 0.82
                                                                                                                                                                                                             809
                                                                                                                                                                                                                                                       92c ALEP Repl. by SCHAEL 05c
                                                         6 BURCHAT
25.8 \pm 1.7 \pm 2.5
                                                                                    87 MRK2 E_{\text{cm}}^{ee} = 29 GeV
                                                                                                                                                                     5.7 \pm 0.5 \begin{array}{c} +1.7 \\ -1.0 \end{array}
                                                                                                                                                                                                                           <sup>4</sup> ANTREASYAN 91 CBAL E_{\text{CM}}^{ee} = 9.4-10.6 \text{ GeV}
                                                       <sup>5</sup> YELTON
                                         629
                                                                                    86 MRK2 E_{cm}^{ee} = 29 \text{ GeV}
                                                                                                                                                                    10.0 ±1.5 ±1.1
                                                                                                                                                                                                                                                    90 CELL E <sup>ee</sup><sub>CM</sub> = 35 GeV
                                                                                                                                                                                                                           <sup>5</sup> BEHREND
    ^1 See footnote to SCHAEL 05c \Gamma(\tau^-\to~e^-\overline{\nu}_e\,\nu_\tau)/\Gamma_{\rm total} measurement for correlations
                                                                                                                                                                                                                            6 BAND
                                                                                                                                                                                                                                                       87 MAC E_{\mathrm{CM}}^{ee} = 29 \; \mathrm{GeV}
                                                                                                                                                                     8.7 \pm 0.4 \pm 1.1
   with other measurements. 2 Not independent of ARTUSO 94 B(h^-\pi^0\nu_{\tau}) and BATTLE 94 B(K^-\pi^0\nu_{\tau}) values. 3 Not independent of BUSKULIC 96 B(h^-\pi^0\nu_{\tau}) and B(K^-\pi^0\nu_{\tau}) values.
                                                                                                                                                                                                                            <sup>7</sup> GAN
                                                                                                                                                                                                                                                               MRK2 E_{cm}^{ee} = 29 GeV
                                                                                                                                                                     6.2 \pm 0.6 \pm 1.2
                                                                                                                                                                                                                                                       87
                                                                                                                                                                     6.0 + 3.0 + 1.8
                                                                                                                                                                                                                              BEHREND 84 CELL E_{\mathrm{CM}}^{ee} = 14,22 \; \mathrm{GeV}
    ^4 The authors divide by ( \Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} )/\Gamma = 0.467 to obtain this result
                                                                                                                                                                      ^1 See footnote to ABDALLAH 06A \Gamma(\tau^-\to~h^-\nu_\tau)/\Gamma_{\mbox{total}} measurement for correlations
    <sup>5</sup> Experiment had no hadron identification. Kaon corrections were made, but insufficient
                                                                                                                                                                       <sup>2</sup> PROCARIO 93 entry is obtained from B(h^-2\pi^0\nu_{	au})/B(h^-\pi^0\nu_{	au}) using ARTUSO 94
       information is given to permit their removal.
    <sup>6</sup>BURCHAT 87 value is not independent of YELTON 86 value. Nonresonant decays
                                                                                                                                                                          result for B(h^-\pi^0\nu_{\tau}).
                                                                                                                                                                       ^3\, {\rm We~subtract} 0.0015 to account for \tau^- \to \ {\rm K^*(892)^-} \, \nu_\tau contribution.
                                                                                                                                                                       ^4 A NTREASYA N 91 subtract 0.001 to account for the \tau^-\to~K^*(892)^-\nu_\tau contribution.
\Gamma(\pi^-\pi^0\, {
m non-}
ho(770)
u_	au)/\Gamma_{
m total}
                                                                                                                                     \Gamma_{15}/\Gamma
                                                                                                                                                                       ^5 BEHREND 90 subtract 0.002 to account for the 	au^- 
ightarrow \ K^*(892)^- 
u_	au contribution.
VALUE (%)
                                                     DOCUMENT ID
                                                                                  TECN COMMENT
                                                                                                                                                                       ^6\,{\rm BA\,ND} 87 assume {\rm B}(\pi^-\,3\pi^0\,\nu_T)= 0.01 and {\rm B}(\pi^-\,\pi^0\,\eta\,\nu_T)= 0.005.
                                                 <sup>1</sup> BEHREND 84 CELL E_{cm}^{ee} = 14,22 \text{ GeV}
                                                                                                                                                                       <sup>7</sup> GAN 87 analysis use photon multiplicity distribution.
    <sup>1</sup>BEHREND 84 assume a flat nonresonant mass distribution down to the \rho(770) mass,
       using events with mass above 1300 to set the level.
                                                                                                                                                                   \Gamma(h^-2\pi^0\nu_\tau(\text{ex}.K^0))/\Gamma(h^-\pi^0\nu_\tau)
                                                                                                                                                                                                                                                                                                    \Gamma_{19}/\Gamma_{13}
                                                                                                                                                                            \Gamma_{19}/\Gamma_{13} = (\Gamma_{20} + \Gamma_{23})/(\Gamma_{14} + \Gamma_{16})
\Gamma(K^-\pi^0
u_	au)/\Gamma_{
m total}
                                                                                                                                     \Gamma_{16}/\Gamma
VALUE (%)
                                                     DOCUMENT ID TECN COMMENT
                                                                                                                                                                                                                 DO CUMENT ID
                                      EVTS
                                                                                                                                                                                                                                                   TECN COMMENT
                                                                                                                                                                   0.361±0.005 OUR FIT Error includes scale factor of 1.1.
0.429±0.015 OUR FIT
                                                                                                                                                                                                             ^{1} PROCARIO 93 CLEO E_{
m cm}^{ee} pprox 10.6 GeV
                                                                                                                                                                   0.342 \pm 0.006 \pm 0.016
0.426 ± 0.016 OUR AVERAGE
0.416 \pm 0.003 \pm 0.018
                                        78k
                                                     AUBERT
                                                                              07AP BABR 230 fb^{-1} E_{\rm CM}^{\it ee} = 10.6 GeV
                                                                                                                                                                      ^{1} PROCARIO 93 quote 0.345 \pm 0.006 \pm 0.016 after correction for 2 kaon backgrounds
                                                                                                                                                                         assuming B (K^*-\nu_T)=1.42 \pm 0.18% and B (K^*-\kappa^0\pi^0\nu_T)=0.48 \pm 0.48%. We multiply by 0.990 \pm 0.010 to remove these corrections to B (K^*-\kappa^0\nu_T).
0.471 \pm 0.059 \pm 0.023
                                                     ABBIENDI
                                                                              04 | OPAL 1991-1995 | EP runs
                                        360
                                                     BARATE
                                                                              99K ALEP 1991-1995 LEP runs
0.444 \pm 0.026 \pm 0.024
                                        923
                                                                              94 CLEO E_{\mathrm{C}\,\mathrm{m}}^{ee} \approx 10.6~\mathrm{GeV}
0.51 \pm 0.10 \pm 0.07
                                         37
                                                     BATTLE
                                                                                                                                                                   \Gamma(\pi^- 2\pi^0 \, \nu_{	au}({
m ex.} K^0))/\Gamma_{
m total}
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                            Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
                                        395
                                                    BUSKULIC 96 ALEP Repl. by BARATE 99K
0.52 \pm 0.04 \pm 0.05
                                                                                                                                                                             and are therefore used for the average given below but not in the overall fits. "f&a"
 \Gamma \left( h^{-} \geq 2\pi^{0} \nu_{\tau} \right) / \Gamma_{\text{total}} 
 \Gamma_{17} / \Gamma = \left( \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + 0.157\Gamma_{35} + 0.157\Gamma_{37} + 0.157\Gamma_{40} + 0.157\Gamma_{42} + 0.157\Gamma_{42} + 0.157\Gamma_{40} + 0.
                                                                                                                                                                             marks results used for the fit and the average.
                                                                                                                                                                                                                                DOCUMENT ID
                                                                                                                                                                                                                 EVTS
                                                                                                                                                                                                                                                                  TECN COMMENT
                                                                                                                                                                   9.30 ±0.11 OUR FIT Error includes scale factor of 1.2.
         0.0985\Gamma_{47} + 0.319\Gamma_{125} + 0.322\Gamma_{127})/\Gamma
                                                                                                                                                                   9.239±0.086±0.090 f&a 31k <sup>1</sup> SCHAEL
                                                                                                                                                                                                                                                    05c ALEP 1991-1995 LEP runs
         Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
                                                                                                                                                                   \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
         and are therefore used for the average given below but not in the overall fits. "f&a"
                                                                                                                                                                   9.21 \pm 0.13 \pm 0.11
                                                                                                                                                                                                                              <sup>2</sup> BUSKULIC 96 ALEP Repl. by SCHAEL 05c
         marks results used for the fit and the average.
                                                                                                                                                                       ^1 See footnote to SCHAEL 05c \Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\rm total} measurement for correlations
                                        EVTS
                                                                                             TECN COMMENT
                                                            DO CUMENT ID
10.87±0.11 OUR FIT Error includes scale factor of 1.2.
                                                                                                                                                                      with other measurements. 
 ^2 Not independent of BUSKULIC 96 B(h^-2\pi^0\nu_{\tau}({\rm ex.}\ K^0)) and B(K^-2\pi^0\nu_{\tau}({\rm ex.}\ K^0))
 9.91±0.31±0.27 f&a
                                                            ACKERSTAFF 98M OPAL 1991-1995 LEP runs
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                         <sup>1</sup> AKERS
                                                                                     94E OPAL Repl. by ACKER-STAFF 98M 90 CELL E_{\rm cm}^{\it ee}= 35 GeV
                                                                                                                                                                   \Gamma\big(\pi^-\,2\pi^0\,\nu_\tau\,(\text{ex}.K^0),\text{scalar}\big)/\Gamma\big(\pi^-\,2\pi^0\,\nu_\tau\,(\text{ex}.K^0)\big)
  9.89 \pm 0.34 \pm 0.55
                                                          <sup>2</sup> BEHREND
                                                                                                                                                                                                                         DOCUMENT ID TECN COMMENT
14.0\ \pm 1.2\ \pm 0.6
                                                                                                                                                                     < 0.094
                                                                                                                                                                                                                      ^{1} BROWDER 00 CLEO 4.7 fb^{-1} E_{\mathrm{CM}}^{\mathit{ee}} = 10.6 GeV
                                                          <sup>3</sup> BURCHAT
                                                                                     87 MRK2 E_{\rm cm}^{\it ee}= 29 GeV
12.0 \pm 1.4 \pm 2.5
                                                                                                                                                                      ^1 Model-independent limit from structure function analysis on contribution to B(	au^- 
ightarrow
13.9 \pm 2.0 \stackrel{+}{-} \stackrel{1.9}{-} \stackrel{2.2}{2}
                                                          <sup>4</sup> AIHARA
                                                                                     86E TPC E_{\rm cm}^{ee} = 29 \text{ GeV}
                                                                                                                                                                          \pi^- 2\pi^0 \nu_{\tau} (ex. K^0)) from scalars.
    ^1 AKERS 94E not independent of AKERS 94E B(h^- \geq 1\,\pi^0\,
u_	au) and B(h^-\,\pi^0\,
u_	au) mea-
   surements. ^{2} No independent of BEHREND 90 \Gamma(h^{-}2\pi^{0}\nu_{\tau}(\exp.~K^{0})) and \Gamma(h^{-}\geq3\pi^{0}\nu_{\tau}).
                                                                                                                                                                   \Gamma(\pi^- 2\pi^0 \nu_{\tau} (\text{ex.} K^0), \text{vector}) / \Gamma(\pi^- 2\pi^0 \nu_{\tau} (\text{ex.} K^0))
                                                                                                                                                                                                                                                                                                    \Gamma_{22}/\Gamma_{20}
                                                                                                                                                                                                                        DO CUMENT ID
                                                                                                                                                                                                                                                          TECN COMMENT
    ^3\,\mathrm{Error} correlated with BURCHAT 87 \Gamma(\rho^-\,\nu_e)/\Gamma(\mathrm{total}) value.
                                                                                                                                                                                                                      ^{1} BROWDER 00 CLEO 4.7 fb^{-1} E_{\rm cm}^{ee} = 10.6 GeV
    <sup>4</sup> AIHARA 86E (TPC) quote B(2\pi^0\pi^-\nu_{\tau}) + 1.6B(3\pi^0\pi^-\nu_{\tau}) + 1.1B(\pi^0\eta\pi^-\nu_{\tau}).
                                                                                                                                                                      ^1 Model-independent limit from structure function analysis on contribution to B(	au^- 
ightarrow
\Gamma(h^-2\pi^0\nu_{	au})/\Gamma_{
m total}
                                                                                                                                                                          \pi^- 2\pi^0 \nu_{\tau} (ex. K^0)) from vectors.
                                                                                                                                     \Gamma_{18}/\Gamma
         \Gamma_{18}/\Gamma = (\Gamma_{20} + \Gamma_{23} + 0.157\Gamma_{35} + 0.157\Gamma_{37})/\Gamma
                                                                                                                                                                   \Gamma(K^-2\pi^0\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                        \Gamma_{23}/\Gamma
                                       EVTS
                                                         DO CUMENT ID
                                                                                            TECN COMMENT
                                                                                                                                                                   VALUE (units 10^{-4})
                                                                                                                                                                                                                              DO CUMENT ID
                                                                                                                                                                                                                                                            TECN COMMENT
9.52±0.11 OUR FIT Error includes scale factor of 1.1.
                                                                                                                                                                   6.5 + 2.3 OUR FIT
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                   5.8 ± 2.4 OUR AVERAGE
                                                      <sup>1</sup> BUSKULIC 96 ALEP Repl. by SCHAEL 05c
                                       12k
                                                                                                                                                                                                            131
                                                                                                                                                                                                                              BARATE
                                                                                                                                                                                                                                                       99K ALEP 1991-1995 LEP runs
                                                                                                                                                                   5.6\pm\ 2.0\pm1.5
    ^{1}\,\mathrm{BUSKULIC} 96 quote 9.29 \pm 0.13 \pm 0.10. We add 0.19 to undo their correction for
                                                                                                                                                                                                                           <sup>1</sup> BATTLE
                                                                                                                                                                                                                                                       94 CLEO E_{
m cm}^{\it ee} \approx \, 10.6 GeV
                                                                                                                                                                                                               3
                                                                                                                                                                   9 \pm 10 \pm 3
      	au^- 
ightarrow h^- K^0 
u_	au
                                                                                                                                                                   \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                                                                         BUSKULIC 96 ALEP Repl. by BARATE 99K
                                                                                                                                                                                                            59
                                                                                                                                                                      ^1 BATTLE 94 quote (14 \pm 10 \pm 3) \times 10 ^{-4} or < 30 \times 10 ^{-4} at 90% CL. We subtract (5 \pm 2) \times 10 ^{-4} to account for \tau^- \rightarrow K^- (K ^0 \rightarrow \pi^0 \pi^0) \nu_\tau background.
```

assume B($h^- \geq$ 5 $~\pi^0 \, \nu_{\tau})$ is small and do not correct for it.

 2 BUSKULIC 96 quote result for $\tau^-\to~h^-\geq 4\pi^0\,\nu_\tau.$ We assume B($h^-\geq 5\pi^0\,\nu_\tau$) is

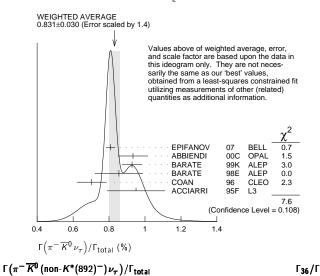
| $ \Gamma(h^- \ge 3\pi^0 \nu_\tau) / \Gamma_{\text{total}} $ $ \Gamma_{24} / \Gamma = (\Gamma_{27} + \Gamma_{28} + \Gamma_{30} + 0.157\Gamma_{40} + 0.157\Gamma_{42} + 0.0985\Gamma_{47} + 0.319\Gamma_{125} + 0.0985\Gamma_{47} + 0.319\Gamma_{125} + 0.0985\Gamma_{47} + 0.$ | $\Gamma(h^-4\pi^0 u_	au(ex.K^0.\eta))/\Gamma_{total}$ $VALUE~(\%)$ V |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.322F ₁₂₇)/F | 0.11 ±0.04 OUR FIT 0.112±0.037±0.035 957 ¹ SCHAEL 05c ALEP 1991-1995 LEP runs |
| <u>NALUE (%)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> ■ • • We do not use the following data for averages, fits, limits, etc. • • • | 1 See footnote to SCHAEL 05c $\Gamma(\tau^{-}\to e^{-}\overline{\nu}_{e}\nu_{\tau})/\Gamma_{\rm total}$ measurement for correlations with other measurements. |
| $1.53 \pm 0.40 \pm 0.46$ 186 DECAMP 92c ALEP Repl. by SCHAEL 05c 3.2 ± 1.0 ± 1.0 BEHREND 90 CELL $E_{\rm cm}^{\it ee}=35$ GeV | $ \Gamma(K^{-} \ge 0\pi^{0} \ge 0K^{0} \ge 0\gamma \nu_{\tau})/\Gamma_{\text{total}} \qquad \Gamma_{31}/\Gamma = (\Gamma_{10} + \Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{37} + \Gamma_{42} + 0.715\Gamma_{127})/\Gamma $ |
| | Data marked "avg" are highly correlated with data appearing elsewhere in the Listings and are therefore used for the average given below but not in the overall fits. "f&a' marks results used for the fit and the average. VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| 1.26 ±0.07 OUR FIT Error includes scale factor of 1.1. 1.403±0.214±0.224 1.1k | 1.572±0.033 OUR FIT Error includes scale factor of 1.1. |
| 1 See footnote to ABDALLAH 06A $\Gamma(\tau^-\to h^-\nu_\tau)/\Gamma_{\mbox{total}}$ measurement for correlations with other measurements. | 1.53 ±0.04 OUR AVERAGE 1.528±0.039±0.040 |
| $\Gamma(h^-3\pi^0\nu_{\tau})/\Gamma_{\text{total}}$ Γ_{26}/Γ | 1.70 $\pm 0.12 \pm 0.19$ 202 ² BATTLE 94 CLEO $E_{\text{CM}}^{\text{ee}} \approx 10.6 \text{ GeV}$ • • • We use the following data for averages but not for fits. • • • |
| $\Gamma_{26}/\Gamma = (\Gamma_{27} + \Gamma_{28} + 0.157\Gamma_{40} + 0.157\Gamma_{42} + 0.322\Gamma_{127})/\Gamma$ | 1.520±0.040±0.041 4006 ³ BARATE 99K ALEP 1991-1995 LEP runs |
| Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average. | ullet $ullet$ $$ |
| VALUE (%) EVTS DOCUMENT ID TECN COMMENT | 1.6 ± 0.4 ± 0.2 35 AIHARA 87B TPC $E_{\text{CM}}^{ee} = 29 \text{ GeV}$ |
| 1.19±0.07 OUR FIT 1.21±0.17 OUR AVERAGE Error includes scale factor of 1.2. | 1.71 ± 0.29 53 MILLS 84 DLCO $E_{\rm em}^{\rm em} = 29 {\rm GeV}$ |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | ¹ The correlation coefficient between this measurement and the ABBIENDI 01J B($\tau^- \to K^- \nu_\tau$) is 0.60. ² BATTLE 94 quote 1.60 \pm 0.12 \pm 0.19. We add 0.10 \pm 0.02 to correct for their rejection |
| $1.15\pm0.08\pm0.13$ PROCARIO 93 CLEO $E_{\rm cm}^{\it ee}\approx 10.6~{\rm GeV}$ | of $K_S^0 	o \pi^+\pi^-$ decays. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 1.24±0.09±0.11 2.3k ² BUSKULIC 96 ALEP Repl. by SCHAEL 05c | 3 Not independent of BARATE 99K B(K $^-\nu_{\tau}$), B(K $^-\pi^0\nu_{\tau}$), B(K $^-2\pi^0\nu_{\tau}$ (ex. K 0)), B(K $^-3\pi^0\nu_{\tau}$ (ex. K 0)), B(K $^-\kappa^0\nu_{\tau}$), and B(K $^-\kappa^0\pi^0\nu_{\tau}$) values. |
| 0.0 | ⁴ Not independent of BUSKULIC 96 B($K^-\nu_{	au}$), B($K^-\pi^0\nu_{	au}$), B($K^-\pi^0\nu_{	au}$), B($K^-\pi^0\nu_{	au}$), and B($K^-K^0\pi^0\nu_{	au}$) values. |
| 1 PROCARIO 93 entry is obtained from B(h^- $3\pi^0\nu_{\tau})/{\rm B}(h^-\pi^0\nu_{\tau})$ using ARTUSO 94 result for B(h^- $\pi^0\nu_{\tau}).$ | |
| result for B($n = \pi^0 \nu_T$). 2 BUSKULIC 96 quote B($h^- 3\pi^0 \nu_T$ (ex. K^0)) = 1.17 \pm 0.09 \pm 0.11. We add 0.07 to | $ \Gamma(K^- \ge 1 (\pi^0 \text{ or } K^0 \text{ or } \gamma) \nu_\tau) / \Gamma_{\text{total}} $ $ \Gamma_{32} / \Gamma = (\Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{37} + \Gamma_{42} + 0.715\Gamma_{127}) / \Gamma $ |
| remove their correction for K^0 backgrounds. 3 Highly correlated with GAN 87 $\Gamma(\eta\pi^-\pi^0\nu_{	au})/\Gamma_{ m total}$ value. Authors quote ${\rm B}(\pi^\pm 3\pi^0\nu_{	au}) + 0.67 {\rm B}(\pi^\pm \eta\pi^0\nu_{	au}) = 0.047 \pm 0.010 \pm 0.011.$ | Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average. |
| $ \begin{array}{c} \Gamma \big(h^{-} 3 \pi^{0} \nu_{\tau} \big) / \Gamma \big(h^{-} \pi^{0} \nu_{\tau} \big) \\ \Gamma_{26} / \Gamma_{13} = (\Gamma_{27} + \Gamma_{28} + 0.157 \Gamma_{40} + 0.157 \Gamma_{42} + 0.322 \Gamma_{127}) / (\Gamma_{14} + \Gamma_{16}) \end{array} $ | VALUE (%) 0.872±0.032 OUR FIT Error includes scale factor of 1.1. 0.86 ±0.05 OUR AVERAGE |
| <u>VALUE</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | • • We use the following data for averages but not for fits. • • • APPLIEND AND ADDITION ADDITION AND ADDITION ADDITION AND ADDITION AND ADDITION AND ADDITION AND ADDITION AND ADDITION ADDITION AND ADDITION AND ADDITION ADDITION AND ADDITION ADDITION AND ADDITION ADDI |
| 0.044 ±0.003 ±0.005 1 PROCARIO 93 CLEO $E_{\rm CM}^{ee} \approx 10.6 \; {\rm GeV}$ | 0.869±0.031±0.034 |
| 1 PROCARIO 93 quote 0.041 \pm 0.003 \pm 0.005 after correction for 2 kaon backgrounds assuming B($K^{*-}\nu_{\tau}$)=1.42 \pm 0.18% and B($h^ K^0$ π^0 ν_{τ})=0.48 \pm 0.48%. We add 0.003 \pm 0.003 and multiply the sum by 0.990 \pm 0.010 to remove these corrections. | 1.2 $\pm 0.5 {}^{+ 0.2}_{- 0.4}$ 9 AIHARA 87B TPC $E^{ee}_{ m CM} = 29~{ m GeV}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Not independent of ABBIENDI 01J B($\tau^-\to K^-\nu_\tau$) and B($\tau^-\to K^-\geq 0\pi^0\geq 0K^0\geq 0\gamma~\nu_\tau$) values. 2 Not independent of ABREU 94K B($K^-\nu_\tau$) and B($K^-\geq 0$ neutrals ν_τ) measurements. |
| 0.977±0.069±0.058 6.1k 1 SCHAEL 05c ALEP 1991-1995 LEP runs 1 See footnote to SCHAEL 05c $\Gamma(\tau^- \to e^- \overline{ u}_e \nu_	au)/\Gamma_{\rm total}$ measurement for correlations | $ \begin{array}{ll} \Gamma \big(\mathcal{K}_{\mathbf{S}}^{0} (particles)^{-} \nu_{\boldsymbol{\tau}} \big) / \Gamma_{\mathbf{total}} & \Gamma_{33} / \Gamma \\ \Gamma_{33} / \Gamma & = (\frac{1}{2} \Gamma_{35} + \frac{1}{2} \Gamma_{37} + \frac{1}{2} \Gamma_{40} + \frac{1}{2} \Gamma_{42} + \Gamma_{47} + \Gamma_{48}) / \Gamma \end{array} $ |
| with other measurements. | VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma(K^{-}3\pi^{0}\nu_{\tau}(\text{ex}.K^{0},\eta))/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ $VALUE (units 10^{-$ | 0.92 ±0.04 OUR FIT Error includes scale factor of 1.5. 0.97 ±0.07 OUR AVERAGE |
| 4.8± 2.2 OUR FIT 3.7± 2.1±1.1 22 BARATE 99K ALEP 1991–1995 LEP runs • • • We do not use the following data for averages, fits, limits, etc. • • • | 0.970±0.058±0.062 929 BARATE 98E ALEP 1991-1995 LEP runs 0.97 ±0.09 ±0.06 141 AKERS 94G OPAL $E_{ m cm}^{\it ee}=88$ -94 GeV |
| 5 ± 13 BUSKULIC 94E ALEP Repl. by BARATE 99K 1 BUSKULIC 94E quote B($K^{-}>0\pi^{0}>0K^{0}\nu_{-})$ - [B($K^{-}\nu_{-}$) + B($K^{-}\pi^{0}\nu_{-}$) + | $\Gamma(h^-\overline{K}^0\nu_{\tau})/\Gamma_{	ext{total}}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings. |
| ${\sf B}(K^-K^0 u_{	au})+{\sf B}(K^-\pi^0\pi^0 u_{	au})+{\sf B}(K^-\pi^0K^0 u_{	au})]=(5\pm13)\times10^{-4}$ accounting for common systematic errors in BUSKULIC 94E and BUSKULIC 94F measurements of these modes. We assume ${\sf B}(K^-\geq2K^0 u_{	au})$ and ${\sf B}(K^-\geq4\pi^0 u_{	au})$ are negligible. | and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average. VALUE (%) |
| $ \Gamma(h^{-}4\pi^{0}\nu_{\tau}(\text{ex}.K^{0}))/\Gamma_{\text{total}} $ $ \Gamma_{29}/\Gamma = (\Gamma_{30} + 0.319\Gamma_{125})/\Gamma $ | 0.90 \pm0.07 OUR AVERAGE $0.855 \pm 0.036 \pm 0.073$ 1242 COAN 96 CLEO $E_{ m CM}^{\it ee} \approx 10.6 \; { m GeV}$ |
| VALUE (%) EVTS DO CUMENT ID TECN COMMENT | • • • We use the following data for averages but not for fits. • • • 1.01 ±0.11 ±0.07 555 BARATE 98E ALEP 1991–1995 LEP runs |
| 0.16±0.04 OUR FIT | 1.01 \pm 0.11 \pm 0.07 555 ¹ BARATE 98E ALEP 1991–1995 LEP runs ¹ Not independent of BARATE 98E B($\tau^- \to \pi^- \overline{K}^0 \nu_{\tau}$) and B($\tau^- \to K^- K^0 \nu_{\tau}$) values. |
| 0.16 \pm 0.05 \pm 0.05 \pm 0.06 GeV | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.16 \pm 0.04 \pm 0.09$ 232 ² BUSKULIC 96 ALEP Repl. by SCHAEL 05c | |
| ¹ PROCARIO 93 quotes B($h^- 4\pi^0 \nu_{\pi}$)/B($h^- \pi^0 \nu_{\pi}$) = 0.006 ± 0.002 ± 0.002. We multiply | |
| by the ARTUSO 94 result for $B(h^-\pi^0\nu_{\tau})$ to obtain $B(h^-4\pi^0\nu_{\tau})$. PROCARIO 93 assume $B(h^->5,\pi^0\nu_{\tau})$ is small and do not correct for it. | |

 $\Gamma(\pi^-\overline{K^0}\nu_{\tau})/\Gamma_{\text{total}}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, marks results used for the fit and the average.

| VALUE (%) | EVIS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|-----------|-----------------------|---------|-----------|-------------------------------------------------|
| 0.84 ±0.04 OUR FIT | Error | includes scale fact | or of 2 | 2.1. | |
| 0.831 ± 0.030 OUR AV | ERAGE | Error includes sca | le fact | or of 1.4 | See the ideogram below |
| $0.808 \pm 0.004 \pm 0.026$ | 5 3k | EPIFANOV | 07 | BELL | 351 fb $^{-1}$ E_{cm}^{ee} =10.6 GeV |
| $0.933 \pm 0.068 \pm 0.049$ | 377 | ABBIENDI | | | 1991-1995 LEP runs |
| $0.928 \pm 0.045 \pm 0.034$ | 937 | | 99K | ALEP | 1991-1995 LEP runs |
| $0.95\ \pm0.15\ \pm0.06$ | | ² ACCIARRI | 95 F | L3 | 1991-1993 LEP runs |
| ullet $ullet$ We use the following | wing data | a for averages but | not fo | orfits. • | • • |
| $0.855 \pm 0.117 \pm 0.066$ | 5 0 9 | ³ BARATE | 98E | ALEP | 1991-1995 LEP runs |
| $0.704 \pm 0.041 \pm 0.072$ | | ⁴ COAN | 96 | CLEO | $E_{\rm cm}^{\it ee} \approx 10.6 \; {\rm GeV}$ |
| | | | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • • 0.79 ± 0.10 ± 0.09 98 ⁵ BUSKULIC 96 ALEP Repl. by BARATE 99 κ

- 1 BARATE 99K measure K^0 's by detecting K^0_I 's in their hadron calorimeter.
- 2 ACCIARRI 95F do not identify π^-/K^- and assume B($K^-\,K^{\,0}\nu_{\tau})=(0.29\pm0.12)\%.$
- ³BARATE 98E reconstruct κ^0 's using $\kappa^0_S \to \pi^+\pi^-$ decays. Not independent of BARATE 98E B(κ^0 particles $-\nu_{ au}$) value.
- 4 Not independent of COAN 96 B(h^- K 0 $\nu_{\tau})$ and B(K^- K 0 $\nu_{\tau})$ measurements.
- 5 BUSKULIC 96 measure $\it K^{\,0}$'s by detecting $\it K^{\,0}_{\,L}$'s in their hadron calorimeter.



| VALUE (units 10 ⁻⁴) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------------|-----------------------|------------------|------------------------|------------------------------------------------------------|
| 5.4 ± 2.1 | | ¹ EPIFANOV | 07 | BELL | 351 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6 \; {\rm GeV}$ |
| | the follow | ing data for aver | ages, | fits, limi | ts, etc. • • • |
| <17 | 95 | ACCIARRI | 95 F | L3 | 1991-1993 LEP runs |
| ¹ EPIFANOV 07 q | uote B($	au^-$ | → K*(892)-ı | _τ) Β | (K*(892 | $)^- \rightarrow \kappa_S^0 \pi^-) / B(\tau^- \rightarrow$ |
| $K_S^0 \pi^- \nu_{\tau}) = 0.9$ | 933 ± 0.02 | 7. We multiply t | heir E | $3(\tau^- \rightarrow$ | $\overline{K}{}^0\pi^-\nu_{	au}$ by [1-(0.933 \pm |
| 0.027)] to obtain | this result. | | | | ,,, |

| $\Gamma(K^-K^0 u_	au)/\Gamma_{ m tota}$ | I | | | | Γ ₃₇ / |
|-----------------------------------------|--------------------|----------------------------------|--------------|------------|--------------------------------------|
| VALUE (%) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.159±0.016 OUR FIT | Γ | | | | |
| 0.158±0.017 OUR AV | ERAGE | | | | |
| $0.162 \pm 0.021 \pm 0.011$ | 150 | ¹ BARATE | 99K | ALEP | 1991-1995 LEP runs |
| $0.158 \pm 0.042 \pm 0.017$ | 46 | ² BARATE | 98E | ALEP | 1991-1995 LEP runs |
| $0.151 \pm 0.021 \pm 0.022$ | 111 | COAN | 96 | CLEO | $E_{ m cm}^{ee} pprox 10.6~{ m GeV}$ |
| • • • We do not use | the follow | ing data for avera | ges, fits | s, limits, | etc. • • • |
| $0.26\ \pm0.09\ \pm0.02$ | 13 | ³ BUSKULIC | 96 | ALEP | Repl. by BARATE 99к |
| ¹ BARATE 99к mea | sure κ^0 's | by detecting K_I^0 , | s in the | eir hadro | n calorimeter. |
| ² BARATE 98E reco | nstruct <i>K</i> | 0 's using $K_S^0 \rightarrow$ | $\pi^+\pi^-$ | decays. | |
| ³ BUSKULIC 96 me | asure κ^0 , | s by detecting κ_L^0 | 's in th | eir hadr | on calorimeter. |

| $\Gamma(K^-K^0 \geq 0\pi^0\nu_{	au})$ | $/\Gamma_{total}$ | | | | $\Gamma_{38}/\Gamma = (\Gamma_{37} + \Gamma_{42})/\Gamma$ |
|---------------------------------------|-------------------|--------------|-----|------|-----------------------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.318±0.023 OUR FIT | | | | | |
| $0.330 \pm 0.055 \pm 0.039$ | 124 | ABBIENDI | 00c | OPAL | 1991-1995 LEP runs |

 $\Gamma(h^-\overline{K^0}\pi^0\nu_\tau)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{\text{39/I}} = (140 \pm 142) I.$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

| iliaiks iesuits useu | TOT THE I | it allu tile averag | c. | | |
|-----------------------------------|-----------|-----------------------|------------------------------|----------------|------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT IE | | TECN | COMMENT |
| 0.55 ±0.04 OUR FIT | | | | | |
| 0.50 ±0.06 OUR AVE | RAGE E | rror includes sca | le factor | of 1.2. | |
| $0.562 \pm 0.050 \pm 0.048$ | 264 | COAN | 96 | CLEO | $E_{cm}^{ee} \approx 10.6 \text{ GeV}$ |
| • • • We use the follow | ing data | for averages but | not for | fits. • • | • |
| $0.446 \pm 0.052 \pm 0.046$ | 157 | ¹ BARATE | 98E | ALEP | 1991-1995 LEP runs |
| ¹ Not independent of E | BARATE | 98E B($	au^- 	o \pi$ | $-\frac{\kappa^0}{\kappa^0}$ | $^{0}	au)$ and | ${\rm B}(\tau^-\to~K^-K^0\pi^0\nu_\tau)$ |

 $\Gamma(\pi^-\overline{K}^0\pi^0\nu_{ au})/\Gamma_{ ext{total}}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------------------|------------------------------|---------|-----------------------|-------------------------------------------------|
| 0.40 ±0.04 OUR FIT | | | | | |
| 0.36 ±0.04 OUR AVE | RAGE | | | | |
| $0.347 \pm 0.053 \pm 0.037$ | 299 | ¹ BARATE | 99K | ALEP | 1991-1995 LEP runs |
| $0.294 \pm 0.073 \pm 0.037$ | 142 | ² BARATE | | | 1991-1995 LEP runs |
| $0.41 \ \pm 0.12 \ \pm 0.03$ | | ³ ACCIARRI | 95 F | L3 | 1991-1993 LEP runs |
| • • • We use the follow | ving data | for averages but no | ot for | fits. • • | • • |
| $0.417 \pm 0.058 \pm 0.044$ | | ⁴ COAN | 96 | CLEO | $E_{\rm cm}^{\it ee} \approx 10.6 \; {\rm GeV}$ |
| • • • We do not use the | ne followii | ng data for average | s, fits | , limits, | etc. • • • |
| $0.32 \ \pm 0.11 \ \pm 0.05$ | 23 | ⁵ BUSKULIC | 96 | ALEP | Repl. by BARATE 99к |
| ¹ BARATE 99к measi | ıre K ⁰ 's | by detecting K_I^0 's | n thei | r hadron | ı calorimeter. |
| ² BARATE 98E recons | | | | | |
| 3 ACCIARRI 95 F do n | ot identify | π^-/K^- and assu | me B(| $\kappa^-\kappa^0$ | $\pi^0 \nu_{\tau}$) = (0.05 ± 0.05)%. |
| ⁴ Not independent of | COAN 9 | $B(h^- K^0 \pi^0 \nu_{\pi})$ | nd B | $(\kappa - \kappa^0)$ | $\pi^0 u_{	au}$) measurements. |
| ⁵ BUSKULIC 96 meas | sure <i>K</i> 0's | by detecting K_I^{0} 's | in the | ir hadro | n calorimeter. |

| $\Gamma(\overline{K^0} ho^- u_	au)/\Gamma_{ m total}$ | | | | | Γ_{41}/Γ |
|-------------------------------------------------------|---------------------|-----|------|---------------|----------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 0.22 ±0.05 OUR AVERAGE | · | | | <u> </u> | |
| $0.250 \pm 0.057 \pm 0.044$ | ¹ BARATE | 99K | ALEP | 1991-1995 LEP | runs |
| $0.188 \pm 0.054 \pm 0.038$ | 2 βαβατε | 98F | ΔIFP | 1991-1995 LEP | runs |

 1 BARATE 99K measure K^0 's by detecting K^0_L 's in hadron calorimeter. They determine the $\overline{K}{}^0 \rho^-$ fraction in $\tau^- \to \pi^- \overline{K}{}^0 \pi^0 \nu_\tau$ decays to be (0.72 \pm 0.12 \pm 0.10) and multiply their B($\pi^-\overline{K}^0\pi^0\nu_{\tau}$) measurement by this fraction to obtain the quoted result. ² BARATE 98E reconstruct K^0 's using $K^0_S\to\pi^+\pi^-$ decays. They determine the $\overline{K}^0\rho^$ fraction in $\tau^- \to ~\pi^- \overline{K}{}^0 \, \pi^0 \, \nu_\tau$ decays to be (0.64 \pm 0.09 \pm 0.10) and multiply their ${\rm B}(\pi^-\overline{\rm K}^0\,\pi^0\,
u_{ au})$ measurement by this fraction to obtain the quoted result.

| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------|-----------------------|-----------------------------------|-------------------|-----------|----------------------------------|---------|
| 0.159±0.020 OUR FIT | | | | | | |
| 0.144 ± 0.023 OUR AVE | RAGE | | | | | |
| $0.143 \pm 0.025 \pm 0.015$ | 78 | ¹ BARATE | 99K | ALEP | 1991-1995 LE | Pruns |
| $0.152 \pm 0.076 \pm 0.021$ | 15 | ² BARATE | 98E | ALEP | 1991-1995 LE | Pruns |
| $0.145 \pm 0.036 \pm 0.020$ | 32 | COAN | 96 | CLEO | $E_{\rm cm}^{ee} \approx 10.6$ G | GeV |
| • • • We do not use ti | ne followi | ng data for averag | es, fits, | limits, | etc. • • • | |
| $0.10 \pm 0.05 \pm 0.03$ | 5 | ³ BUSKULIC | 96 | ALEP | Repl. by BAR | ATE 99K |
| ¹ BARATE 99к meas | ure <i>K</i> 0's | by detecting K_I^0 's | in thei | r hadroi | n calorimeter. | |
| ² BARATE 98E recon | struct K ⁰ | 's using $K_s^0 \rightarrow \tau$ | $_{r}^{+}\pi^{-}$ | decays. | | |
| ³ BUSKULIC 96 mea | sure K^{0} 's | by detecting K_0^0 , | s in the | eir hadro | n calorimeter. | |

| $\Gamma(\pi^-\overline{K}^0 \ge 1\pi^0\nu_{\tau})$ VALUE (%) | EVTS | DO CUMENT ID | | TECN | $\Gamma_{43}/\Gamma = (\Gamma_{40} + \Gamma_{44})/\Gamma$ COMMENT |
|------------------------------------------------------------------------|--------------------|---------------------|-----------|-----------|-------------------------------------------------------------------|
| 0.324±0.074±0.066 | 148 | ABBIENDI | 00c | OPAL | 1991-1995 LEP runs |
| $\Gamma(\pi^-\overline{K}{}^0\pi^0\pi^0 u_	au)/$ | Γ _{total} | | | | Γ ₄₄ /Γ |
| VALUE (units 10^{-3}) | L% EVTS | DO CUMENT | ID | TECI | NCOMMENT |
| 0.26 ± 0.24 | | 1 BARATE | 99 | 9R ALE | P 1991-1995 LEP runs |
| • • • We do not use t | he following | data for averag | es, fits, | , limits, | etc. • • • |
| < 0.66 9 | 5 17 | ² BARATE | 99 | 9ĸ ALE | P 1991-1995 LEP runs |
| $0.58 \pm 0.33 \pm 0.14$ | 5 | ³ BARATE | 98 | BE ALE | P 1991-1995 LEP runs |
| ¹ BARATE 99R comb value. ² BARATE 99K meas | | | | | easurements to obtain this n calorimeter. |

| $\Gamma(K^-K^0\pi^0\pi^0)$ | $ u_{	au})/\Gamma_{ m total}$ | | | | | Γ ₄₅ /Γ |
|-----------------------------------------------------------------|------------------------------------------|-----------------------------------------|-----------------|---------|-----------------------------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $< 0.16 \times 10^{-3}$ | 95 | 1 BARATE | 99R | ALEP | 1991-1995 L | EP runs |
| ● ● We do not | use the followin | g data for averag | es, fits, | limits, | etc. • • • | |
| $< 0.18 \times 10^{-3}$ | 95 | ² BARATE | 99K | ALEP | 1991-1995 L | EP runs |
| $< 0.39 \times 10^{-3}$ | 95 | ³ BARATE | 98E | ALEP | 1991-1995 L | EP runs |
| ¹ BARATE 99R ¹ ² BARATE 99K | combine the BA measure <i>K</i> 0's b | RATE 98E and B. by detecting K_I^0 's | ARATE in had | 99K bo | ounds to obtai orimeter. | n this value. |

³BARATE 98E reconstruct K^0 's using $K^0_S \rightarrow \pi^+\pi^-$ decays.

³BARATE 98E reconstruct K^0 's by using $K_S^{0^-} \rightarrow \pi^+\pi^-$ decays.

See key on page 457 $\Gamma(\pi^- K^0 \overline{K}^0 \nu_\tau) / \Gamma_{total}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings and are therefore used for the average given below but not in the overall fits. "f&a" $\Gamma_{46}/\Gamma = (2\Gamma_{47} + \Gamma_{48})/\Gamma$ marks results used for the fit and the average. DO CUMENT ID EVTS TECN COMMENT 0.17 ±0.04 OUR FIT Error includes scale factor of 1.7. \bullet \bullet \bullet We use the following data for averages but not for fits. \bullet \bullet **0.153±0.030±0.016** 74 ¹ BARATE 98E ALEP 1991-1995 LEP runs ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet² ACCIARRI 95F L3 1991-1993 LEP runs $0.31 \pm 0.12 \pm 0.04$ $^1\, {\rm BARATE}$ 98E obtain this value by adding twice their ${\rm B}(\pi^-\, K^0_S\, K^0_S\, \nu_\tau)$ value to their ${\rm B}(\pi^-\, K^0_{\,\rm S}\, K^0_I\, \nu_\tau)$ value. ${}^2\text{ACCIARRI 95F assume B}(\pi^- \ \textit{K}^0_S \ \textit{K}^0_S \ \nu) = \ \text{B}(\pi^- \ \textit{K}^0_S \ \textit{K}^0_L \ \nu) = \ 1/2 \text{B}(\pi^- \ \textit{K}^0_S \ \textit{K}^0_L \ \nu).$ $\Gamma(\pi^-K_S^0K_S^0\nu_{ au})/\Gamma_{total}$ Bose-Einstein correlations might make the mixing fraction different than 1/4. VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT 2.4 ± 0.5 OUR FIT 2.4 ± 0.5 OUR AVERAGE $2.6 \pm 1.0 \pm 0.5$ BARATE 98E ALEP 1991-1995 LEP runs 96 CLEO $E_{\mathrm{cm}}^{ee} \approx 10.6 \ \mathrm{GeV}$ COAN $\Gamma(\pi^- K_S^0 K_L^0 \nu_{\tau})/\Gamma_{\text{total}}$ Γ_{48}/Γ TECN COMMENT $10.1 \pm 2.3 \pm 1.3$ BARATE 98E ALEP 1991-1995 LEP runs $\Gamma(\pi^- K^0 \overline{K}{}^0 \pi^0 \nu_{ au}) / \Gamma_{ m total}$ Γ_{49}/Γ DOCUMENT ID TECN COMMENT $(0.31\pm0.23) \times 10^{-3}$ ¹ BARATE 99R ALEP 1991-1995 LEP runs BARATE 98E $\Gamma(\pi^- \kappa_S^0 \kappa_S^0 \pi^0 \nu_{\tau})/\Gamma_{ m total}$ ¹BARATE 99R combine $\Gamma(\pi^- \kappa_S^0 \kappa_I^0 \pi^0 \nu_T)/\Gamma_{total}$ measurements to obtain this value. $\Gamma(\pi^- K_S^0 K_S^0 \pi^0 \nu_{\tau})/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT < 2.0 BARATE 98E ALEP 1991-1995 LEP runs

| $\Gamma(\pi^- K_S^0 K_L^0 \pi^0 \nu_s)$ | $_{	au})/\Gamma_{ m total}$ | | | | | Γ ₅₁ /Γ |
|-----------------------------------------|-----------------------------|-------------------------------|-----------|---------|------------------------------------|--------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT II |) | TECN | COMMENT | |
| 3.1 ± 1.1 ± 0.5 | 11 | BARATE | 98E | ALEP | 1991-1995 LEF | runs |
| $\Gamma(K^0 h^+ h^- h^- \ge$ | ≥ 0 neutrals | $ u_{	au})/\Gamma_{ m total}$ | | | | Г ₅₂ /Г |
| VALUE (%) | CL% | DOCUMENT | ID | TECN | COMMENT | |
| <0.17 | 95 | TSCHIRHA | RT 88 | HRS | $E_{\rm cm}^{ee} = 29 {\rm Ge}^4$ | V |
| ● ● We do not us | se the followin | g data for avera | ges, fits | limits, | etc. • • • | |
| ∠0.27 | 90 | BELTRAMI | 85 | HRS | Fee _ 20 GeV | ./ |

| V.21 | ,,, | BEETTOTIM | 00 | 11113 | - CIII - 23 G | |
|------------------------------------|---------------------|-------------------------|----------|---------|---------------|--------------------|
| $\Gamma(K^0 h^+ h^- h^- u_{	au})$ | /Γ _{total} | | | | | Γ ₅₃ /Γ |
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $2.3 \pm 1.9 \pm 0.7$ | 6 | ¹ BARATE | 98E | ALEP | 1991-1995 LE | EP runs |
| ¹ BARATE 98E reco | nstruct κ^0 | 's using $K_S^0 	o \pi$ | $+\pi^-$ | decays. | | |

$$\begin{split} & \Gamma\left(h^-h^-h^+ \geq 0 \text{ neutrals } \geq 0 \frac{K_0^0}{\nu_\tau} \nu_\tau\right) / \Gamma_{\text{total}} \\ & \Gamma_{54}/\Gamma = (0.3431\Gamma_{35} + 0.3431\Gamma_{37} + 0.3431\Gamma_{40} + 0.3431\Gamma_{42} + 0.4307\Gamma_{47} + 0.6861\Gamma_{48} + \\ & \Gamma_{62} + \Gamma_{70} + \Gamma_{77} + \Gamma_{78} + \Gamma_{85} + \Gamma_{89} + \Gamma_{93} + \Gamma_{94} + 0.285\Gamma_{125} + 0.285\Gamma_{127} + 0.9101\Gamma_{149} + \\ & 0.9101\Gamma_{151})/\Gamma \end{split}$$

| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|-----------------|-------------------------|---------|-------------|------------------------------------------------------|
| 15.20± 0.08 OUR F | | cludes scale factor | of 1.3 | 3. | |
| 14.8 ± 0.4 OUR A | VERAGE | | | | -00 |
| $14.4 \pm 0.6 \pm 0.3$ | | ADEVA | 91F | L3 | E ^{ee} _{cm} = 88.3-94.3 GeV |
| $15.0 \pm 0.4 \pm 0.3$ | | BEHREND | 89B | CELL | E ee = 14–47 GeV |
| $15.1 \ \pm \ 0.8 \ \pm 0.6$ | | AIHARA | 87в | TPC | E ee ≥9 GeV |
| | e the following | g data for average | s, fits | , limits, e | etc. • • • |
| $13.5 \ \pm \ 0.3 \ \pm 0.3$ | | ABACHI | 89B | HRS | <i>E</i> ^{<i>ee</i>} _{cm} = 29 GeV |
| $12.8 \pm 1.0 \pm 0.7$ | | $^{ m 1}$ BURCHAT | 87 | MRK2 | E ee ≥ 29 GeV |
| $12.1 \pm 0.5 \pm 1.2$ | | RUCKSTUHL | 86 | DLCO | E ee ≥ 29 GeV |
| $12.8 \ \pm \ 0.5 \ \pm 0.8$ | 1420 | SCHMIDKE | 86 | MRK2 | E ^{ee} _{cm} = 29 GeV |
| $15.3 \pm 1.1 {}^{+1.3}_{-1.6}$ | 367 | ALTHOFF | 85 | TASS | E ^{ee} _{CM} = 34.5 GeV |
| $13.6 \pm 0.5 \pm 0.8$ | | BARTEL | 85 F | JADE | <i>E</i> ^{ee} _{cm} = 34.6 GeV |
| $12.2 \pm 1.3 \pm 3.9$ | | ² BERGER | 85 | PLUT | E ^{ee} _{cm} = 34.6 GeV |
| $13.3 \ \pm \ 0.3 \ \pm 0.6$ | | FERNANDEZ | 85 | MAC | E ee ≥ 29 GeV |
| 24 ± 6 | 35 | BRA NDELIK | 80 | TASS | E ^{ee} cm = 30 GeV |
| 32 ± 5 | 692 | ³ BACINO | 78B | DLCO | $E_{cm}^{ee} = 3.1-7.4 \text{ GeV}$ |
| 35 ±11 | | ³ BRA NDELIK | 78 | DASP | Assumes V-A decay |
| 18 ± 6.5 | 33 | ³ JAROS | 78 | LGW | E ^{ee} _{cm} > 6 GeV |

BURCHAT 87 value is not independent of SCHMIDKE 86 value.

```
\Gamma(h^-h^-h^+ \ge 0 \text{ neutrals } \nu_{\tau}(\text{ex. } K_{\mathbf{5}}^0 \to \pi^+\pi^-)(\text{"3-prong"}))/\Gamma_{\text{total}} \Gamma_{55}/\Gamma = (\Gamma_{62} + \Gamma_{70} + \Gamma_{77} + \Gamma_{78} + \Gamma_{85} + \Gamma_{89} + \Gamma_{93} + \Gamma_{94} + 0.285\Gamma_{125} + 0.285\Gamma_{127} + 0.285\Gamma_
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  \Gamma_{55}/\Gamma
                                                                                                                                                 0.9101\Gamma_{149} + 0.9101\Gamma_{151})/\Gamma
```

Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a"

| | | | in the Overan ints. Toca |
|----------------------------------------------|-----------------------------------------|------------------------------|-----------------------------------------------------|
| marks results used | for the fit and the avera | | |
| VALUE (%) | EVTS DOCUMENT I | D TECN | COMMENT |
| 14.57 ±0.07 OUR FIT | Error includes scale fac | ctor of 1.3. | |
| 14.61 ±0.06 OUR AVE | RAGE | | |
| $14.556 \pm 0.105 \pm 0.076$ | ¹ ACHARD | 01D L3 | 1992-1995 LEP runs |
| $14.96 \pm 0.09 \pm 0.22$ | 0.4k AKERS | 95Y OPAL | 1991-1994 LEP runs |
| ● ● We use the following | ng data for averages but | not for fits. • • | • |
| $14.652 \pm 0.067 \pm 0.086$ | SCHAEL | 05c ALEP | 1991-1995 LEP runs |
| $14.569 \pm 0.093 \pm 0.048$ | 23k ² ABREU | 01M DLPH | 1992-1995 LEP runs |
| $14.22 \pm 0.10 \pm 0.37$ | ³ BALEST | 95∈ CLEO | $E_{\rm cm}^{ee} \approx 10.6 \text{ GeV}$ |
| • • • We do not use the | following data for avera | ges, fits, limits, | etc. • • • |
| $15.26 \pm 0.26 \pm 0.22$ | ACTON | 92H OPAL | Repl. by AKERS 95Y |
| $13.3 \pm 0.3 \pm 0.8$ | ⁴ ALBRECHT | 92D ARG | E ee e 9.4-10.6 GeV |
| $14.35 \ ^{+\ 0.40}_{-\ 0.45} \ \pm 0.24$ | DECAMP | 92c ALEP | 1989-1990 LEP runs |
| ¹ The correlation coefficient | cients between this meas | surement and the | ACHARD 01D measure- |
| ments of B($	au ightarrow$ "1-p | rong") and B($	au ightarrow$ "5-p | rong") are -0.97 | 78 and $-$ 0.19 respectively. |
| ² The correlation coeffi | cients between this mea | surement and ti | ne ABREU 01M measure- |
| | rong) and $B(\tau \rightarrow 5$ -pro | | |
| ³ Not independent of B | ALEST 95 C B(h-h-h-h- | $^+\nu_{	au}$) and B(h^- | $\mathit{h}^-\mathit{h}^+\pi^0 u_	au$) values, and |
| | $(h^- h^- h^+ 2\pi^0 \nu_{\tau})/B(h^+$ | | |
| | · · · · · · · · · · · · · · · · · · · | | T' |

⁴ This ALBRECHT 92D value is not independent of their $\Gamma(\mu^-\overline{
u}_\mu\nu_ au)\Gamma(e^-\overline{
u}_e\nu_ au)/\Gamma_{
m total}^2$

 $\frac{\Gamma \left(h^-h^-h^+\nu_{\tau}\right)/\Gamma_{total}}{\Gamma_{56}/\Gamma = (0.3431\Gamma_{35}+0.3431\Gamma_{37}+\Gamma_{62}+\Gamma_{85}+\Gamma_{93}+0.017\Gamma_{149})/\Gamma_{149}}$

Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

E(%) EVTS DOCUMENT ID

| VALUE (70) | LVIJ | DOCUMENTID | | ILCN | COMMENT |
|---------------------------------------|----------------|------------------------|----------|-----------|-----------------------------------------------|
| 9.80±0.07 OUR FIT | Error inclu | des scale factor of | 1.2. | | |
| ● ● We use the fo | llowing data | for averages but no | ot for | fits. • • | • |
| 7.6 ±0.1 ±0.5 | 7.5k | $^{ m 1}$ ALBRECHT | 96E | ARG | E ^{ee} _{cm} = 9.4-10.6 GeV |
| • • • We do not use | e the followin | g data for averages | s, fits, | limits, e | etc. • • • |
| $9.92 \pm 0.10 \pm 0.09$ | 11.2k | ² BUSKULIC | 96 | ALEP | Repl. by SCHAEL 05c |
| $9.49 \pm 0.36 \pm 0.63$ | | | | | Repl. by SCHAEL 05c |
| $3.7 \pm 0.7 \pm 0.3$ | 694 | ³ BEHREND | 90 | CELL | <i>E</i> ^{ee} _{Cm} = 35 GeV |
| $7.0 \pm 0.3 \pm 0.7$ | 1566 | ⁴ BAND | | | |
| $5.7 \pm 0.8 \pm 0.9$ | | ⁵ BURCHAT | 87 | MRK2 | E ^{ee} _{cm} = 29 GeV |
| 6.4 ±0.4 ±0.9 | | ⁶ RUCKSTUHL | 86 | DLCO | $E_{\rm cm}^{\it ee}=$ 29 GeV |
| $7.8 \pm 0.5 \pm 0.8$ | 890 | SCHMIDKE | 86 | MRK2 | E ee 29 GeV |
| 8.4 ±0.4 ±0.7 | 1255 | ⁶ FERNANDEZ | 85 | MAC | E ^{ee} _{cm} = 29 GeV |
| $9.7 \pm 2.0 \pm 1.3$ | | BEHREND | 84 | CELL | $E_{ m cm}^{\it ee}$ = 14,22 GeV |
| | | | | | |

 1 ALBRECHT 96E not independent of ALBRECHT 93c $\Gamma(h^-\,h^-\,h^+\,
u_{ au}({
m ex.}~~{
m K}^0)$ imes $\Gamma({
m particle}^- \geq 0 \ {
m neutrals} \ \geq 0 \ {
m K}_L^0 \,
u_{ au})/\Gamma_{
m total}^2 \ {
m value}.$

²BUSKULIC 96 quote B($h^-h^-h^+\nu_{ au}({\rm ex.}\ K^0))=9.50\pm0.10\pm0.11.$ We add 0.42 to remove their κ^0 correction and reduce the systematic error accordingly.

 3 BEHREND 90 subtract 0.3% to account for the $au^-
ightarrow \ extbf{K*} (892)^-
u_{ au}$ contribution to

measured events.

4 BAND 87 subtract for charged kaon modes; not independent of FERNANDEZ 85 value. ⁵ BURCHAT 87 value is not independent of SCHMIDKE 86 value.

 $^6 \, {\rm Value}$ obtained by multiplying paper's $R = {\rm B} (h^- \, h^+ \, \nu_\tau) / {\rm B} (3{\rm -prong})$ by B(3-prong) = 0.143 and subtracting 0.3% for $K^*(892)$ background.

$$\begin{array}{l} \Gamma \big(h^- \, h^- \, h^+ \, \nu_\tau \, (ex. K^0) \big) / \Gamma_{total} \\ \Gamma_{57} / \Gamma = (\Gamma_{62} + \Gamma_{85} + \Gamma_{93} + 0.017 \Gamma_{149}) / \Gamma \end{array} \hspace{3cm} \Gamma_{57} / \Gamma$$

Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

VALUE (%)

EVTS

DOCUMENT ID

| VALUE (%) | EVIS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|----------|------------------------|----------|-----------|-------------------------------------------------|
| 9.46 ±0.06 OUR FIT | Error | includes scale factor | of 1.2 | | |
| 9.44 ±0.14 OUR AVE | RAGE | Error includes scale | factor | of 1.4. | See the ideogram below. |
| $9.317 \pm 0.090 \pm 0.082$ | 12.2k | ¹ ABDALLAH | 06A | DLPH | 1992-1995 LEP runs |
| $9.51 \ \pm 0.07 \ \pm 0.20$ | 37.7k | BALEST | 95 c | CLEO | $E_{\rm cm}^{\it ee} \approx 10.6 \; {\rm GeV}$ |
| ullet $ullet$ We use the follow | ing da | ta for averages but no | ot for | fits. • • | • |
| $9.87 \pm 0.10 \pm 0.24$ | | ² AKERS | 95Y | OPAL | 1991-1994 LEP runs |
| ullet $ullet$ We do not use th | e follov | wing data for average | s, fits, | limits, | etc. • • • |
| $9.50 \ \pm 0.10 \ \pm 0.11$ | 11.2k | ³ BUSKULIC | 96 | ALEP | Repl. by SCHAEL 05c |

 $^{^2}$ Not independent of BERGER 85 $\Gamma(\mu^-\overline{\nu}_\mu\nu_\tau)/\Gamma_{\mbox{total}},$ $\Gamma(e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\mbox{total}},$ $\Gamma(h^-\geq 1)$ neutrals $\nu_{ au}$)/ $\Gamma_{ ext{total}}$, and $\Gamma(h^- \geq 0\,K_I^0\,\,\nu_{ au})/\Gamma_{ ext{total}}$, and therefore not used in the fit.

³ Low energy experiments are not in average or fit because the systematic errors in background subtraction are judged to be large.

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^1 See footnote to ABDALLAH 06A \Gamma(	au^- 	o h^- 
u_	au)/\Gamma_{	ext{total}} measurement for correlations
    2 With other measurements. Not independent of AKERS 95Y B( h^-\,h^-\,h^+ \ge 0 neutrals \nu_{\tau}({\rm ex.}~K_S^0 \to~\pi^+\,\pi^-)) and
        B(h^-h^-h^+\nu_{\tau}(ex.\ K^0))/B(h^-h^-h^+\geq 0\ neutrals \nu_{\tau}(ex.\ K^0_S \to \pi^+\pi^-)) values.
     ^3 Not independent of BUSKULIC 96 B(h^-h^-h^+\nu_{	au}) value.
                     WEIGHTED AVERAGE
9.44±0.14 (Error scaled by 1.4)
                                                                                        Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values,
                                                                                        obtained from a least-squares constrained fit
utilizing measurements of other (related)
quantities as additional information.
                                                                                                      ABDALLAH
                                                                                                                                        06A DLPH
                                                                                                      BALEST
                                                                                                                                        95C CLEO
                                                                                                                                                                        0.1
                                                                                                                             (Confidence Level = 0.145)
                  8.5
                                                                                    10
                                                             9.5
                     \Gamma(h^-h^-h^+
u_{	au}(\text{ex.}K^0))/\Gamma_{	ext{total}} (%)
\Gamma\big(h^-\,h^-\,h^+\,\nu_\tau\,(\text{ex}.K^0)\big)/\Gamma\big(\,h^-\,h^-\,h^+\,\geq\,0\;\text{neutrals}\;\nu_\tau\,(\text{ex}.~K^0_S\to\,\pi^+\,\pi^-)
             (57)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)^{-1} (58)
AKERS
                                                                                                                 95Y OPAL 1991-1994 LEP runs
 \Gamma(h^-h^-h^+\nu_{\tau}(\text{ex.}K^0,\omega))/\Gamma_{\text{total}}
                                                                                                                             \Gamma_{58}/\Gamma = (\Gamma_{62} + \Gamma_{85} + \Gamma_{93})/\Gamma
                                                                               DOCUMENT ID
9.42±0.06 OUR FIT Error includes scale factor of 1.2.
\Gamma(\pi^-\pi^+\pi^-\nu_	au)/\Gamma_{
m total}
                                                                                            \Gamma_{59}/\Gamma = (0.3431\Gamma_{35} + \Gamma_{62} + 0.017\Gamma_{149})/\Gamma
                                                                               DOCUMENT ID
9.31±0.06 OUR FIT Error includes scale factor of 1.2.
\Gamma(\pi^-\pi^+\pi^-\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}}
                                                                                                                          \Gamma_{60}/\Gamma = (\Gamma_{62} + 0.017\Gamma_{149})/\Gamma
                                                                       DOCUMENT ID
<u>VALUE (%)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TE</u>

9.02±0.06 OUR FIT Error includes scale factor of 1.1.
                                                                                                                     TECN COMMENT
8.77±0.13 OUR AVERAGE Error includes scale factor of 1.1.
                                                                                                        10 BELL 666 fb^{-1} E_{
m cm}^{\it ee}= 10.6 GeV
8.42 \pm 0.00 + 0.26 \\ -0.25
                                           8.9M
8.83 \pm 0.01 \pm 0.13
                                                                    <sup>2</sup> AUBERT
                                                                                                         08 BABR 342 fb^{-1} E_{cm}^{ee} = 10.6 \text{ GeV}
                                          1.6M
                                                                   <sup>3</sup> BRIERE
9.13 \pm 0.05 \pm 0.46
                                             43k
                                                                                                        03 CLE3 E_{cm}^{ee} = 10.6 \text{ GeV}
      ^{
m 1} Quoted statistical error is 0.003%. Correlation matrix for LEE 10 branching fractions:
                 (1) \Gamma(\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_{\tau} (\text{ex.} K^0)) / \Gamma_{\text{total}}
                 (2) \Gamma(\tau^- \to \kappa^- \pi^+ \pi^- \nu_\tau (\text{ex } \kappa^0)) / \Gamma_{\text{total}}
                (3) \Gamma(\tau^- \to K^- K^+ \pi^- \nu_\tau)/\Gamma_{\text{total}}

(4) \Gamma(\tau^- \to K^- K^+ K^- \nu_\tau)/\Gamma_{\text{total}}
                               (1)
                                                (2)
                                                                (3)
                (2) 0.175
                 (3) 0.049 0.080
                          -0.053 0.035 -0.008
     <sup>2</sup> Correlation matrix for AUBERT 08 branching fractions:
                 (1) \Gamma(\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_{\tau} (ex. K^0)) / \Gamma_{total}
                 (2) \Gamma(\tau^- \rightarrow K^- \pi^+ \pi^- \nu_{\tau} (\text{ex.} K^0)) / \Gamma_{\text{total}}
                 (3) \Gamma(\tau^- \rightarrow K^- K^+ \pi^- \nu_{\tau})/\Gamma_{\text{total}}
                 (4) \Gamma(\tau^- \rightarrow K^- K^+ K^- \nu_\tau)/\Gamma_{\text{total}}
                               (1)
                                                (2)
                          0.544
                 (2)
                 (3)
                          0.390 0.177
                 (4) 0.031 0.093 0.087
     ^3 47% correlated with BRIERE 03 	au^- 
ightarrow ~K^- \pi^+ \pi^- 
u_	au and 71% correlated with 	au^- 
ightarrow
         {\it K}^- \, {\it K}^+ \, \pi^- \, \nu_\tau because of a common 5% normalization error.
```

 $\Gamma(\pi^-\pi^+\pi^-\nu_{\tau}(\text{ex}.K^0), \text{non-axial vector})/\Gamma(\pi^-\pi^+\pi^-\nu_{\tau}(\text{ex}.K^0))$

 $\pi^-\pi^+\pi^-\nu_{\tau}$ (ex. K^0)) from non-axial vectors.

DOCUMENT ID

 1 Model-independent limit from structure function analysis on contribution to B($au^-
ightarrow$

<u>VAL</u>UE

< 0.261

 $\Gamma_{61}/\Gamma_{60} = \Gamma_{61}/(\Gamma_{62}+0.017\Gamma_{149})$

TECN COMMENT 1 ACKERSTAFF 97R OPAL 1992-1994 LEP runs

```
\Gamma(\pi^-\pi^+\pi^-\nu_{\tau}(\text{ex.}K^0,\omega))/\Gamma_{\text{total}}
                                                                                                                                                                           \Gamma_{62}/\Gamma
                                                                           DOCUMENT ID
                                                                                                                       TECN COMMENT
 8.99 ±0.06 OUR FIT Error includes scale factor of 1.1.
                                                                       <sup>1</sup> SCHAEL 05C ALEP 1991-1995 LEP runs
                                                  29k
     ^1 See footnote to SCHAEL 05c \Gamma(\tau^-\to~e^-\overline{\nu}_e\nu_\tau)/\Gamma_{\rm total} measurement for correlations
        with other measurements.
\begin{split} &\Gamma \big( h^- h^- h^+ \geq 1 \text{ neutrals } \nu_{T} \big) / \Gamma_{\text{total}} &\Gamma_{63} / \Gamma = (0.3431 \Gamma_{40} + 0.3431 \Gamma_{42} + 0.4307 \Gamma_{47} + 0.6861 \Gamma_{48} + \Gamma_{70} + \Gamma_{77} + \Gamma_{78} + \Gamma_{89} + \Gamma_{94} + 0.285 \Gamma_{125} + 0.285 \Gamma_{127} + 0.888 \Gamma_{149} + 0.9101 \Gamma_{151} \big) / \Gamma \end{split}
5.39±0.07 OUR FIT Error includes scale factor of 1.2.
 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
5.6 \ \pm 0.7 \ \pm 0.3
                                                                             <sup>1</sup> BEHREND
                                                                                                                 90 CELL E_{cm}^{ee} = 35 \text{ GeV}
                                                                              <sup>2</sup> ALBRECHT
                                                                                                              87L ARG E_{
m cm}^{\it ee}=10~{
m GeV}
4.2 \pm 0.5 \pm 0.9
                                                                              <sup>3</sup> BURCHAT
6.1 \ \pm 0.8 \ \pm 0.9
                                                                                                                  87
                                                                                                                             MRK2 E_{cm}^{ee} = 29 GeV
7.6 \pm 0.4 \pm 0.9
                                                                           <sup>4,5</sup> RUCKSTUHL 86
                                                                                                                         DLCO E_{cm}^{ee} = 29 GeV
                                                                              <sup>6</sup> SCHMIDKE 86
                                                                                                                             MRK2 E_{\mathrm{cm}}^{\mathit{ee}} = 29 \; \mathrm{GeV}
4.7 \pm 0.5 \pm 0.8
                                                           530
                                                                              <sup>5</sup> FERNANDEZ 85
5.6 \pm 0.4 \pm 0.7
                                                                                                                             MAC E_{cm}^{ee} = 29 \text{ GeV}
                                                                                 BEHREND 84 CELL E_{
m cm}^{\it ee}= 14,22 GeV
6.2 + 2.3 + 1.7
     ^{1}BEHREND 90 value is not independent of BEHREND 90 B(3h
u_{	au} \, \geq \, 1 neutrals) +
        B(5-prong).
                                                                                                                                     of
                                                                                                                                                  branching
                                                             measure
                                                                                        the
                                                                                                           product
        ALEACTI to B(3\pi^{\pm}\pi^{0}\,\nu_{\tau}) B((e\,\overline{\nu}\sigma)\,\mu\overline{\nu}\sigma \pi or K or \rho) \nu_{\tau}) = 0.029 and use the PDG 86 values for the second branching ratio which sum to 0.69 \pm 0.03 to get the quoted value.
     <sup>3</sup>BURCHAT 87 value is not independent of SCH MIDKE 86 value.
     ^4 Contributions from kaons and from > 1\pi^0 are subtracted. Not independent of (3-prong
         + 0\pi^0) and (3\text{-prong} + \geq 0\pi^0) values.
     ^5 Value obtained using paper's R= B(h^-\,h^-\,h^+\,
u_{_T})/B(3-prong) and current B(3-prong)
     6 Not independent of SCHMIDKE 86 h^-h^-h^+\nu_{_T} and h^-h^-h^+(~\geq 0\pi^0)\nu_{_T} values.
 \begin{array}{l} \Gamma \left( h^- h^- h^+ \geq 1 \, \pi^0 \, \nu_\tau \left( {\rm ex.} \; \; K^0 \right) \right) / \Gamma_{\rm total} \\ \Gamma_{64} / \Gamma = (\Gamma_{70} + \Gamma_{77} + \Gamma_{78} + \Gamma_{89} + \Gamma_{94} + 0.226 \Gamma_{125} + 0.226 \Gamma_{127} + 0.888 \Gamma_{149} + 0.9101 \Gamma_{151} \right) / \Gamma \end{array} 
            Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
             and are therefore used for the average given below but not in the overall fits. "f&a'
             marks results used for the fit and the average.
                                                    EVTS
                                                                            DO CUMENT ID
                                                                                                                        TECN COMMENT
5.09 ±0.06 OUR FIT Error includes scale factor of 1.2.
5.10 ±0.12 OUR AVERAGE
\bullet \bullet We use the following data for averages but not for fits. 
 \bullet \bullet
5.106 \pm 0.083 \pm 0.103 10.1k
                                                                       ABDALLAH 06A DLPH 1992-1995 LEP runs
5.09 \pm 0.10 \pm 0.23
                                                                       <sup>2</sup> AKERS
                                                                                                            95Y OPAL 1991-1994 LEP runs
• • • We do not use the following data for averages, fits, limits, etc. • • •
4.95 \pm 0.29 \pm 0.65
                                                  570
                                                                         DECAMP
                                                                                                           92c ALEP Repl. by SCHAEL 05c
     ^1 See footnote to ABDALLAH 06A \Gamma(	au^- 	o h^- 
u_	au)/\Gamma_{
m total} measurement for correlations
     ^2 Not independent of AKERS 95Y B( h^-\,h^-\,h^+\,\geq\,0\, neutrals \nu_{\tau}\,({\rm ex.}~~{\it K}_{~\rm S}^{~0}~\rightarrow~\pi^+\pi^-))
        and B(h^-h^-h^+ \ge 0 neutrals \nu_{\tau} (ex. K^0))/B(h^-h^-h^+ \ge 0 neutrals \nu_{\tau} (ex. K^0_S \to 0
         \pi^+\pi^-)) values.
 \Gamma \left( h^- h^- h^+ \pi^0 \nu_\tau \right) / \Gamma_{\text{total}} 
 \Gamma_{65} / \Gamma = (0.3431 \Gamma_{40} + 0.3431 \Gamma_{42} + \Gamma_{70} + \Gamma_{89} + \Gamma_{94} + 0.226 \Gamma_{127} + 0.888 \Gamma_{149} + 0.000 \Gamma_{127} + 0.0
                                                                                                                                                                           \Gamma_{65}/\Gamma
4.76±0.06 OUR FIT Error includes scale factor of 1.2.
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                   6.1k
                                                                     <sup>1</sup> BUSKULIC 96 ALEP Repl. by SCHAEL 05c
     ^{1} BUSKULIC 96 quote B(h^{-} h^{-} h^{+} \pi^{0} \nu_{\tau} (ex. K^{0})) = 4.30 \pm 0.09 \pm 0.09. We add 0.15
        to remove their K^0 correction and reduce the systematic error accordingly.
\Gamma(h^-h^-h^+\pi^0\nu_{\tau}(ex.K^0))/\Gamma_{total}
                                                                                                                                                                           \Gamma_{66}/\Gamma
            \Gamma_{66}/\Gamma = (\Gamma_{70} + \Gamma_{89} + \Gamma_{94} + 0.226\Gamma_{127} + 0.888\Gamma_{149} + 0.017\Gamma_{151})/\Gamma
                                                   EVTS
                                                                            DO CUMENT ID
                                                                                                                       TECN COMMENT
 4.57 ±0.06 OUR FIT Error includes scale factor of 1.2.
4.45 ±0.14 OUR AVERAGE Error includes scale factor of 1.2.
                                                                        ^{1} ABDALLAH 06A DLPH 1992-1995 LEP runs BALEST 95C CLEO E_{\mathrm{CM}}^{ee} pprox 10.6 GeV
4.545\pm0.106\pm0.103
                                                  8.9k
4.23 \pm 0.06 \pm 0.22
                                                    7.2k
     ^1\,\mathrm{See} footnote to ABDALLAH 06a \Gamma(\tau^-\to~h^-\nu_{\tau})/\Gamma_{\mathrm{total}} measurement for correlations
 \Gamma \big( h^- \, h^- \, h^+ \, \pi^0 \, \nu_\tau \, (\text{ex. } K^0, \omega) \big) / \Gamma_{\text{total}} \quad \Gamma_{67} / \Gamma = (\Gamma_{70} + \Gamma_{89} + \Gamma_{94} + 0.226 \Gamma_{127}) / \Gamma_{\text{total}} 
                                                                            DOCUMENT ID
2.79±0.08 OUR FIT Error includes scale factor of 1.2.
\Gamma(\pi^-\pi^+\pi^-\pi^0\nu_{\tau})/\Gamma_{\text{total}}
                                     \Gamma_{68}/\Gamma = (0.3431\Gamma_{40} + \Gamma_{70} + 0.888\Gamma_{149} + 0.017\Gamma_{151})/\Gamma
```

DOCUMENT ID

4.62±0.06 OUR FIT Error includes scale factor of 1.2.

```
\Gamma(\pi^-\pi^+\pi^-\pi^0\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}} \Gamma_{69}/\Gamma = (\Gamma_{70} + 0.888\Gamma_{149} + 0.017\Gamma_{151})/\Gamma
VALUE (%) EVTS DOCUMENT ID TECN
4.48 ±0.06 OUR FIT Error includes scale factor of 1.2.
                                                                       TECN COMMENT
05 C ALEP 1991-1995 LEP runs
                                         <sup>2</sup> EDWARDS 00A CLEO 4.7 fb^{-1} E_{\rm cm}^{ee}= 10.6 GeV
   ^{1} SCHAEL 05c quote (4.590 \pm 0.057 \pm 0.064)%. We add 0.008% to remove their correction
     for \tau^- \to \pi^- \pi^0 \omega \nu_{	au} \to \pi^- \pi^0 \pi^+ \pi^- \nu_{	au} decays. See footnote to SCHAEL 05c
     \Gamma(	au^- 
ightarrow e^- \overline{
u}_e \, 
u_	au) / \Gamma_{	ext{total}} measurement for correlations with other measurements.
   ^2 EDWARDS 00A quote (4.19 \pm 0.10) 	imes 10^{-2} with a 5% systematic error.
\Gamma(\pi^-\pi^+\pi^-\pi^0\nu_{\tau}(\text{ex}.K^0,\omega))/\Gamma_{\text{total}}
                                                                                                                  \Gamma_{70}/\Gamma
                                                  DO CUMENT ID
2.70±0.08 OUR FIT Error includes scale factor of 1.2.
\Gamma(h^-\rho\pi^0\nu_{\tau})/\Gamma(h^-h^-h^+\pi^0\nu_{\tau})
                                                                                                              \Gamma_{71}/\Gamma_{65}
                             <u>EVTS DOCUMENT ID TECN COMMENT</u>
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
0.30 \pm 0.04 \pm 0.02
                                                  ALBRECHT 91D ARG E_{\text{CM}}^{ee} = 9.4-10.6 \text{ GeV}
                                  393
\Gamma(h^-\rho^+h^-\nu_\tau)/\Gamma(h^-h^-h^+\pi^0\nu_\tau)
                                                                                                              \Gamma_{72}/\Gamma_{65}
                    EVTS
                                              DOCUMENT ID
                                                                            TECN COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •
0.10 \pm 0.03 \pm 0.04
                                 142
                                                  ALBRECHT 91D ARG E_{\text{CM}}^{ee} = 9.4-10.6 \text{ GeV}
\Gamma(h^-\rho^-h^+\nu_\tau)/\Gamma(h^-h^-h^+\pi^0\nu_\tau)
                               <u>EVTS</u>
                                                 DOCUMENT ID
                                                                              TECN COMMENT
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                               ALBRECHT 91D ARG E_{
m cm}^{\it ee}= 9.4–10.6 GeV
0.26 \pm 0.05 \pm 0.01
                                 370
\Gamma(h^-h^-h^+ \geq 2\pi^0 \nu_{\tau}(\text{ex. } K^0))/\Gamma_{\text{total}}
                               \Gamma_{74}/\Gamma = (\Gamma_{77} + \Gamma_{78} + 0.226\Gamma_{125} + 0.888\Gamma_{151})/\Gamma
                                                   DOCUMENT ID TECN COMMENT
0.521±0.032 OUR FIT
                                                ^{1}\, {\tt ABDALLAH} \quad \  \, {\tt 06A} \quad {\tt DLPH} \quad {\tt 1992-1995} \ {\tt LEP} \ {\tt runs}
0.561 \pm 0.068 \pm 0.095
                                  1 3k
   ^1\,\mathrm{See} footnote to ABDALLAH 06A \Gamma(\tau^-\to~h^-\nu_\tau)/\Gamma_{\mathrm{total}} measurement for correlations
\Gamma(h^-h^-h^+2\pi^0\nu_{\tau})/\Gamma_{\text{total}}
                                                                                                                  \Gamma_{75}/\Gamma
        \Gamma_{75}/\Gamma = (0.4307\Gamma_{47} + \Gamma_{77} + 0.226\Gamma_{125} + 0.888\Gamma_{151})/\Gamma
                                                  DO CUMENT ID
0.509±0.032 OUR FIT
\begin{array}{c} \Gamma\left(h^-\,h^-\,h^+\,2\pi^0\,\nu_{\tau}\,(\text{ex.}K^0)\right)/\Gamma_{\text{total}} \\ \Gamma_{76}/\Gamma = (\Gamma_{77}+0.226\Gamma_{125}+0.888\Gamma_{151})/\Gamma \end{array}
                                                                                                                  \Gamma_{76}/\Gamma
                                                  DO CUMENT ID
                                                                            TECN COMMENT
0.498 ± 0.032 OUR FIT
                                               ^{
m 1} SCHAEL
0.435 \pm 0.030 \pm 0.035
                                                                        05c ALEP 1991-1995 LEP runs
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                 BUSKULIC 96 ALEP Repl. by SCHAEL 05c
0.50 \pm 0.07 \pm 0.07
                                1.8k
   ^{1} SCHAEL 05c quote (0.392 \pm 0.030 \pm 0.035)%. We add 0.043% to remove their cor-
      rection for \tau^- \rightarrow ~\pi^-\,\eta\pi^0\,\nu_{\tau} \rightarrow ~\pi^-\,\pi^+\,\pi^-\,2\pi^0\,\nu_{\tau} and \tau^- \rightarrow ~K^*(892)^-\,\eta\nu_{\tau} \rightarrow
     \begin{array}{l} \Gamma\big(h^-h^-h^+2\pi^0\nu_{\tau}(ex.K^0)\big)/\Gamma\big(h^-h^-h^+\geq 0 \text{ neutrals } \geq 0\,K_1^0\nu_{\tau}\big) & \Gamma_{76}/\Gamma_{54} \\ \Gamma_{76}/\Gamma_{54} = (\Gamma_{77}+0.226\Gamma_{125}+0.888\Gamma_{151})/(0.3431\Gamma_{35}+0.3431\Gamma_{37}+0.3431\Gamma_{40}+\\ 0.3431\Gamma_{42}+0.4307\Gamma_{47}+0.6861\Gamma_{48}+\Gamma_{62}+\Gamma_{70}+\Gamma_{77}+\Gamma_{78}+\Gamma_{85}+\Gamma_{89}+\Gamma_{93}+\Gamma_{94}+\\ 0.285\Gamma_{125}+0.285\Gamma_{127}+0.9101\Gamma_{149}+0.9101\Gamma_{151}) \end{array}
                                                   DO CUMENT ID
                                                                           TECN COMMENT
0.0328±0.0021 OUR FIT
0.034 ±0.002 ±0.003 668
                                                   BORTOLETTO93 CLEO E_{cm}^{ee} \approx 10.6 \text{ GeV}
\Gamma(h^- h^- h^+ 2\pi^0 
u_{	au} (\mathrm{ex}.K^0 \omega.\eta))/\Gamma_{\mathrm{total}}
                                                                                                                  \Gamma_{77}/\Gamma
                                                   DOCUMENT ID
10±4 OUR FIT
\Gamma(h^-h^-h^+3\pi^0\nu_{\tau})/\Gamma_{\rm total}
                                                                                                                  \Gamma_{78}/\Gamma
                                                    DOCUMENT ID
 VALUE (units 10<sup>-4</sup>) <u>CLW</u> <u>EVTS</u> <u>DOCUMENT ID</u>

2.3 ±0.6 OUR FIT Error includes scale factor of 1.2.
                                                                               TECN COMMENT
 2.2 \pm 0.3 \pm 0.4
                                                    ANASTASSOV 01 CLEO E_{
m cm}^{\it ee} = 10.6 \; {
m GeV}
                                    139
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                       05 C ALEP 1991-1995 LEP runs
                                                    SCHAEL
                                                ANDERSON 97 CLEO Repl. by ANAS-
TASSOV 01
1 BUSKULIC 96 ALEP Repl. by SCHAEL 05 c
 2.85 \pm 0.56 \pm 0.51
                                      5.7
11 ±4 ±5
                                     440
   ^{1} BUSKULIC 96 state their measurement is for B(h^- h^- h^+ \geq 3\pi^0 
u_	au). We assume that
     B(h^-h^-h^+ \geq 4\pi^0\nu_{\tau}) is very small.
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```
\Gamma(K^-h^+h^- \ge 0 \text{ neutrals } \nu_{\tau})/\Gamma_{\text{total}}
        \Gamma_{79}/\Gamma = (0.3431\Gamma_{37} + 0.3431\Gamma_{42} + \Gamma_{85} + \Gamma_{89} + \Gamma_{93} + \Gamma_{94} + 0.285\Gamma_{127})/\Gamma_{79}/\Gamma_{127}
  ALUE (%) CL% DOCUMENT ID TECN COMMENT

0.635±0.024 OUR FIT Error includes scale factor of 1.5.
                                    90
                                                   AIHARA
                                                                        84c TPC E_{cm}^{ee} = 29 \text{ GeV}
\Gamma(K^-h^+\pi^-\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}}
                                                                                       \Gamma_{80}/\Gamma = (\Gamma_{85} + \Gamma_{93})/\Gamma
                                                 DO CUMENT ID
0.438±0.019 OUR FIT Error includes scale factor of 2.7.
\Gamma(K^-h^+\pi^-\nu_{\tau}(\text{ex}.K^0))/\Gamma(\pi^-\pi^+\pi^-\nu_{\tau}(\text{ex}.K^0))
                                                          \Gamma_{80}/\Gamma_{60} = (\Gamma_{85} + \Gamma_{93})/(\Gamma_{62} + 0.017\Gamma_{149})
4.85 ± 0.22 OUR FIT Error includes scale factor of 2.7.
                                                 RICHICHI
                                                                      99 CLEO E_{\rm cm}^{\it ee} = 10.6 GeV
5.44 \pm 0.21 \pm 0.53
                                  7.9k
\Gamma(K^-h^+\pi^-\pi^0\nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}
                                                                    \Gamma_{81}/\Gamma = (\Gamma_{89} + \Gamma_{94} + 0.226\Gamma_{127})/\Gamma
                                                 DO CUMENT ID
8.7±1.2 OUR FIT Error includes scale factor of 1.1.
\Gamma(K^-h^+\pi^-\pi^0\nu_{\tau}(ex.K^0))/\Gamma(\pi^-\pi^+\pi^-\pi^0\nu_{\tau}(ex.K^0))
            \Gamma_{81}/\Gamma_{69} = (\Gamma_{89} + \Gamma_{94} + 0.226\Gamma_{127})/(\Gamma_{70} + 0.888\Gamma_{149} + 0.017\Gamma_{151})
                                                                            TECN COMMENT
                                 EVTS
                                                 DOCUMENT ID
1.94±0.27 OUR FIT
2.61 \pm 0.45 \pm 0.42
                                                 RICHICHI
                                                                       99 CLEO E_{\text{cm}}^{ee} = 10.6 \text{ GeV}
\Gamma(K^-\pi^+\pi^- \geq 0 \text{ neutrals } \nu_{\tau})/\Gamma_{\text{total}}
                  \Gamma_{82}/\Gamma = (0.3431\hat{\Gamma}_{37} + 0.3431\Gamma_{42} + \Gamma_{85} + \Gamma_{89} + 0.285\Gamma_{127})/\Gamma_{42}
<u>VALUE (%)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

0.485 ± 0.021 OUR FIT Error includes scale factor of 1.4.
0.58 \begin{array}{c} +0.15 \\ -0.13 \end{array} \pm 0.12
                                        20
                                                 <sup>1</sup> BAUER
                                                                          94 TPC E_{\mathrm{cm}}^{\,ee}= 29 GeV
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
0.22 \ ^{+\, 0.1\, 6}_{-\, 0.1\, 3}\ \pm 0.05
                                                <sup>2</sup> MILLS
                                                                         85 DLCO E_{\rm cm}^{\it ee} = 29 GeV
   ^{
m 1} We multiply 0.58% by 0.20, the relative systematic error quoted by BAUER 94, to obtain
     the systematic error
   ^2 Error correlated with MILLS 85 (KK\pi\nu) value. We multiply 0.22% by 0.23, the relative
     systematic error quoted by MILLS 85, to obtain the systematic error
\Gamma(K^-\pi^+\pi^- \ge 0\pi^0\nu_{\tau}(\text{ex}.K^0))/\Gamma_{\text{total}}
                                                                    \Gamma_{83}/\Gamma = (\Gamma_{85} + \Gamma_{89} + 0.226\Gamma_{127})/\Gamma
        Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a"
        marks results used for the fit and the average.
                                                 DO CUMENT ID
                                                                              TECN COMMENT
0.375 ± 0.019 OUR FIT Error includes scale factor of 1.5.
0.30 ±0.05 OUR AVERAGE
• • • We use the following data for averages but not for fits. • • •
0.343 \pm 0.073 \pm 0.031
                                                 ABBIENDI
                                                                    00D OPAL 1990-1995 LEP runs
                                               <sup>1</sup> BARATE
0.275 \pm 0.064
                                                                       98 ALEP 1991-1995 LEP runs
   ^1 Not independent of BARATE 98 \Gamma(\tau^- \ \to \ K^- \, \pi^+ \, \pi^- \nu_{\mathcal{T}})/\Gamma_{\rm total} and \Gamma(\tau^- \ \to \ K^- \, \pi^+ \, \pi^- \nu_{\mathcal{T}})
     K^-\pi^+\pi^-\pi^0\nu_{\tau})/\Gamma_{\text{total}} values.
\Gamma(K^-\pi^+\pi^-\nu_	au)/\Gamma_{
m total}
                                                                             \Gamma_{84}/\Gamma = (0.3431\Gamma_{37} + \Gamma_{85})/\Gamma
0.349±0.016 OUR FIT Error includes scale factor of 1.9.
\Gamma(K^-\pi^+\pi^-\nu_{	au}(\text{ex.}K^0))/\Gamma_{	ext{total}}
        Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a"
        marks results used for the fit and the average.
                               EVTS
                                               DO CUMENT ID
                                                                          TECN COMMENT
0.294 ± 0.015 OUR FIT Error includes scale factor of 2.2.
0.290±0.018 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below.
0.330 \pm 0.001 + 0.016 - 794k
                                                                   10 BELL 666 fb<sup>-1</sup> E_{\rm Cm}^{ee}=10.6 GeV
                                            <sup>2</sup> AUBERT
                                                                   08 BABR 342 fb^{-1} E_{\rm cm}^{ee} = 10.6 GeV
0.273 \pm 0.002 \pm 0.009
                              70k
                                               ABBIENDI 04J OPAL 1991-1995 LEP runs
0.415 \pm 0.053 \pm 0.040 269
                                             <sup>3</sup> BRIERE
0.384 \pm 0.014 \pm 0.038 \phantom{00}3.5 \, k
                                                                   03 CLE3 E_{\text{CM}}^{ee} = 10.6 \text{ GeV}
                                               BARATE
                                                                   98 ALEP 1991-1995 LEP runs
0.214 \pm 0.037 \pm 0.029
• • • We use the following data for averages but not for fits. • • •
                                          <sup>4</sup> RICHICHI 99 CLEO E_{
m cm}^{ee}=10.6~{
m GeV}
0.346 \pm 0.023 \pm 0.056 158
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                              ABBIENDI 00D OPAL 1990-1995 LEP runs
   ^1 See footnote to LEE 10 \Gamma(\tau^- \ \to \ \pi^- \, \pi^+ \, \pi^- \, \nu_\tau \, ({\rm ex.} \, {\it K}^0))/\Gamma_{\rm total} measurement for
    correlations with other measurements. Not independent of LEE 10 \Gamma(	au^- 
ightarrow
     {\it K}^-\pi^+\pi^-\nu_{\tau}({\rm ex.}{\it K}^0))/\Gamma(\tau^-\to\pi^-\pi^+\pi^-\nu_{\tau}({\rm ex.}{\it K}^0)) \ \ {\rm value}
   ^2 See footnote to AUBERT 08 \Gamma(\tau^-\to\pi^-\pi^+\pi^-\nu_\tau({\rm ex}.{\it K}^0))/\Gamma_{\rm total} measurement for
   correlations with other measurements. 3 47% correlated with BRIERE 03 \tau^- \to \pi^- \pi^+ \pi^- \nu_\tau and 34% correlated with \tau^- \to \pi^- \pi^+ \pi^- \nu_\tau
     {\it K}^- \, {\it K}^+ \, \pi^- \, \nu_\tau because of a common 5% normalization error.
```

 $\Gamma(\tau^- \rightarrow K^- h^+ \pi^- \nu_{\tau}(\text{ex.} K^0))/\Gamma(\tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_{\tau}(\text{ex.} K^0)), \Gamma(\tau^- \rightarrow K^- h^+ \pi^- \nu_{\tau}(\text{ex.} K^0))$

⁴ Not independent of RICHICHI 99

```
{\it K}^-{\it K}^+\pi^-\nu_{	au})/\Gamma(	au^- 	o \pi^-\pi^+\pi^-\nu_{	au}({\rm ex}.{\it K}^0)) and BALEST 95c \Gamma(	au^- 	o
     h^-h^-h^+\nu_{	au}({\rm ex}.K^0))/\Gamma_{
m total} values.
              WEIGHTED AVERAGE 0.290±0.018 (Error scaled by 2.4)
                                                               Values above of weighted average, error,
                                                              and scale factor are based upon the data in
                                                              and scale factor are based upon the data in
this ideogram only. They are not neces-
sarily the same as our 'best' values,
obtained from a least-squares constrained fit
utilizing measurements of other (related)
quantities as additional information.
                                                                       LEE
                                                                                               10
                                                                        AUBERT
                                                                                               08
                                                                                                        BABR
                                                                                                        OPAL
CLE3
                                                                        ABBIENDI
                                                                        BRIFRF
                                                                                               03
                                                                                                                      5.4
                                                                       BARATE
                                                                                               98
                                                                                                        ALEP
                                                                                                                     16.9
                                                                                      (Confidence Level = 0.0007)
            0.1
                                                                                        0.6
                           0.2
                                           0.3
                                                          0.4
                                                                          0.5
               \Gamma \left( {\it K}^- \pi^+ \pi^- \nu_\tau ({\rm ex.} {\it K}^0) \right) / \Gamma_{\rm total} \left( \% \right)
\Gamma\left(K^-\pi^+\pi^-\nu_\tau\left(\mathrm{ex}.K^0\right)\right)/\Gamma\left(\pi^-\pi^+\pi^-\nu_\tau\left(\mathrm{ex}.K^0\right)\right)
                                                                              \Gamma_{85}/\Gamma_{60} = \Gamma_{85}/(\Gamma_{62} + 0.017\Gamma_{149})
\frac{VALUE \text{ (units } 10^{-2})}{3.26 \pm 0.17 \text{ OUR FIT}} EVTS DOCUMENT ID TO \frac{7.3}{2.3} Error includes scale factor of 2.3.
                                                                                TECN COMMENT
• • • We use the following data for averages but not for fits. • • •
3.92 \pm 0.02 + 0.15
                                                                         10 BELL 666 fb<sup>-1</sup> E_{\rm cm}^{ee} = 10.6 \, {\rm GeV}
   ^1\,\mathrm{Not} independent of LEE 10 \Gamma(\tau^- \rightarrow ~\mathrm{\it K}^-\pi^+\pi^-\nu_\tau(\mathrm{ex}.\mathrm{\it K}^0))/\Gamma_{\mathrm{total}} and \Gamma(\tau^- \rightarrow
     \pi^-\pi^+\pi^-\nu_{	au}({\rm ex.}\,{\it K}^0))/\Gamma_{
m total} values.
\Gamma(K^-\rho^0\nu_{\tau}\to K^-\pi^+\pi^-\nu_{\tau})/\Gamma(K^-\pi^+\pi^-\nu_{\tau}(\text{ex}.K^0))
                                                                                                                        \Gamma_{86}/\Gamma_{85}
                                                       DOCUMENT ID
                                                                                    TECN COMMENT
                                                    <sup>1</sup> ASNER
0.48 \pm 0.14 \pm 0.10
                                                                               00B CLEO E_{\rm cm}^{\it ee}=10.6~{\rm GeV}
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. 
 \bullet \bullet
                                                    <sup>2</sup> BARATE
                                                                            99R ALEP 1991-1995 LEP runs
   ^1\,{\rm A\,SNER} 00B assume \tau^-\to~{\it K}^-\,\pi^+\,\pi^-\,\nu_\tau (ex. {\it K}^0) decays proceed only through {\it K}\,\rho and
      K^*\pi intermediate states. They assume the resonance structure of 	au^- 	o K^-\pi^+\pi^-\nu_	au
      (ex. K^0) decays is dominated by K_1(1270)^- and K_1(1400)^- resonances, and assume
     {\sf B}({\it K}_1(1270)\to {\it K}^*(892)\pi)=(16\pm5)\%, \ {\sf B}({\it K}_1(1270)\to {\it K}\rho)=(42\pm6)\%, \ {\sf and} \ {\sf B}({\it K}_1(1400)\to {\it K}\rho)=0.
   <sup>2</sup>BARATE 99R assume 	au^- 	o K^- \pi^+ \pi^- 
u_	au (ex. K^0) decays proceed only through K 
ho
      and K^*\pi intermediate states. The quoted error is statistical only.
\Gamma(K^-\pi^+\pi^-\pi^0\nu_{\tau})/\Gamma_{\text{total}}
                                                                 \Gamma_{87}/\Gamma = (0.3431\Gamma_{42} + \Gamma_{89} + 0.226\Gamma_{127})/\Gamma
VALUE (units 10-4)
                                                       DOCUMENT ID
13.5 ± 1.4 OUR FIT
 \Gamma(K^-\pi^+\pi^-\pi^0\nu_\tau({\rm ex}.K^0))/\Gamma_{\rm total} \\ {\rm Data\ marked\ "avg"\ are\ highly\ correlated\ with\ data\ appearing\ elsewhere\ in\ the\ Listings,} 
         and are therefore used for the average given below but not in the overall fits. "f&a"
         marks results used for the fit and the average.
VALUE (units 10<sup>-4</sup>)
8.1 ± 1.2 OUR FIT
                                                   DOCUMENT ID
                                                                              TECN COMMENT
7.3±1.2 OUR AVERAGE
                                                ^{\mathrm{1}} ARMS
7.4 \pm 0.8 \pm 1.1
                                                                          05 CLE3 7.6 fb<sup>-1</sup>, E_{\text{CM}}^{ee} = 10.6 \text{ GeV}
                                                                         98 ALEP 1991-1995 LEP runs
                                                 BARATE
6.1 \pm 3.9 \pm 1.8
\bullet \bullet We use the following data for averages but not for fits. 
 \bullet \bullet
7.5 \pm 2.6 \pm 1.8
                                               <sup>2</sup> RICHICHI
                                                                      99 CLEO E<sub>cm</sub><sup>ee</sup> 10.6 GeV
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
```

ABBIENDI 00D OPAL 1990-1995 LEP runs

TECN COMMENT 05 CLE3 7.6 fb $^{-1}$, $E_{\mathrm{cm}}^{ee}=$ 10.6 GeV

 Γ_{89}/Γ

 Γ_{90}/Γ

 1 Not independent of ARMS 05 $\Gamma(\tau^- \ \to \ K^- \, \pi^+ \, \pi^- \, \pi^0 \, \nu_\tau({\rm ex.} \, K^0, \omega)) \ / \ \Gamma_{\rm total}$ and

 $\Gamma(\tau^- \ \rightarrow \ K^- \, h^+ \, \pi^- \, \nu_\tau (\text{ex.} \, K^0)) / \Gamma(\tau^- \ \rightarrow \ \pi^- \, \pi^+ \, \pi^- \, \nu_\tau (\text{ex.} \, K^0)), \ \Gamma(\tau^- \ \rightarrow \ \pi^- \, \pi^+ \, \pi^- \, \nu_\tau (\text{ex.} \, K^0))$ $K^-K^+\pi^-\nu_{ au})/\Gamma(au^- o \pi^-\pi^+\pi^-\nu_{ au}({\rm ex}.K^0))$ and BALEST 95c $\Gamma(au^- o$

DOCUMENT ID

DOCUMENT ID

ARMS

95

 $\Gamma(\tau^- \to \ {\it K}^- \, \omega \, \nu_\tau) \ / \ \Gamma_{\rm total}$ values. ² Not independent of RICHICHI 99

 $h^-h^-h^+\nu_{ au}({\rm ex}.K^0))/\Gamma_{
m total}$ values. $\Gamma(K^-\pi^+\pi^-\pi^0\nu_{\tau}(\text{ex}.K^0,\eta))/\Gamma_{\text{total}}$

 $\Gamma(K^-\pi^+\pi^-\pi^0
u_{ au}({
m ex.}K^0\omega))/\Gamma_{
m total}$

VALUE (units 10⁻⁴)
7.8±1.2 OUR FIT

 $3.7 \pm 0.5 \pm 0.8$

VALUE (units 10^{-4}) EVTS

| | arked "avg" are h therefore used fo esults used for th | | | a appear ow but n | F93/ ing elsewhere in the Listing ot in the overall fits. "f& |
|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 | OUR FIT Error | <u>DOCUMENT</u> includes scale fa | | | COMMENT |
| | OUR AVERAGE | Error includes | scale fa | ctor of 2 | .4. See the ideogram belo |
| 1.55 ±0.01 | +0.06 -0.05 108k | 1 LEE | 10 | BELL | CIII |
| 1.346 ± 0.010 | | ² AUBERT | 80 | | 342 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6 {\rm Ge}$ |
| 1.55 ±0.06 : 1.63 ±0.21 : | ± 0.17 | ³ BRIERE BARATE | 03 98 | CLE3 ALEP | 1991-1995 LEP runs |
| 0.87 ±0.56 | e the following da +040 | ABBIENDI | | | 1990-1995 LEP runs |
| 1.45 ±0.13 | | ⁴ RICHICHI | 99 | CLEO | $E_{\mathrm{cm}}^{ee} = 10.6 \; \mathrm{GeV}$ |
| . 1 7 | ±0.5 9 | ⁵ MILLS | 85 | | E ee = 29 GeV |
| | ata ta LEE 10 | F/ | _+ | |)))/F _{total} measurement f |
| 3 correlation 71% corre $K^-\pi^+\pi^-$ 4 Not inde $\pi^-\pi^+\pi^-$ ues. 5 Error corr | is with other mea- elated with BRIEI $^-\nu_{	au}$ because of a ependent of R $^-\nu_{	au}$ (ex. K^0)) and elated with MILI | as remembers. RE 03 $	au^- 	o \pi$ as common 5% no ICHICHI 99 FI BALEST 95 CFL S 85 $(K\pi\pi\pi^0)$ | $\tau^-\pi^+\pi^-$ prmaliza $\tau(\tau^- \to \tau)$ $\tau(\tau^- \to \tau)$ $\tau(\tau^- \to \tau)$ | $t^- u_{\mathcal{T}}$ and the strong error of t^- and t^- | 0))/ $\Gamma_{\rm total}$ measurement to d 34% correlated with τ or. |
| WEI | IGHTED AVERAG 3±0.07 (Error scale | SE . | 55, 10 01 | DLAIN LIN | systematic error. |
| | 1 | | | | |
| | | and s this id sarily obtair utilizir | cale fact leogram the samed from ng meas | tor are ba only. The ne as our a least- surement | nted average, error, assed upon the data in ney are not neces- 'best' values, squares constrained fit s of other (related) al information. |
| ~ | | | LEE AUBEI BRIER ABBIE RICHIO BARA | RE INDI CHI | 10 BELL 5.7 08 BABR 4.9 03 CLE3 1.3 00D OPAL 99 CLEO 98 ALEP 11.8 |
| | | | | | idence Level = 0.0027) |
| 1 | 1.2 1.4 | 1.6 1.8 | 2 | 2.2 | |
| Г(А | $K^- K^+ \pi^- \nu_{\tau}$ | Γ _{total} (units 10 |)-3) | | |
| and are | $(-\nu_{	au})/\Gamma(\pi^-\pi^-)$ arked "avg" are h therefore used fo esults used for th | or the average gi | ven belo | 93/Γ ₆₀ a appear ow but n | = $\Gamma_{93}/(\Gamma_{62}+0.017\Gamma_{14})$ ing elsewhere in the Listing ot in the overall fits. "f& |
| marks r | | DOCUMENT ID | _ | <u>TECN</u> | COMMENT |
| marks r <u>VALUE (%)</u> 1.60±0.06 O I | <u>EVTS</u> UR FIT Error in | icludes scale fact | 01 01 1. | 9. | |
| VALUE (%) 1.60±0.06 OI 1.83±0.05 OI 1.60±0.15±0 | UR AVERAGE | RICHICHI | 99 | CLEO | $E_{	extsf{CM}}^{ee} = 10.6 \; 	extsf{GeV}$ |

 $\Gamma(K^-\pi^+K^- \ge 0 \text{ neut. } \nu_{\tau})/\Gamma_{\text{total}}$

0.203±0.031 OUR AVERAGE

 $0.159 \pm 0.053 \pm 0.020$

 $0.15 \ ^{+\, 0.09}_{-\, 0.07} \ \pm 0.03$

 0.238 ± 0.042

CL%

marks results used for the fit and the average.

<u>VALUE (%)</u> <u>EVTS</u> <u>DO CUMENT ID</u> **0.150±0.006 OUR FIT** Error includes scale factor of 1.8.

VALUE (%)

DOCUMENT ID

 $\Gamma \big(K^- \, K^+ \, \pi^- \geq 0 \text{ neut. } \nu_T \big) / \Gamma_{total}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,

ABBIENDI

¹ BAUER

² BARATE

 $^{1}\,\mathrm{We}$ multiply 0.15 % by 0.20, the relative systematic error quoted by BAUER 94, to obtain the systematic error. ² Not independent of BARATE 98 $\Gamma(\tau^- \to K^- K^+ \pi^- \nu_\tau)/\Gamma_{\rm total}$ and $\Gamma(\tau^- \to K^- K^+ \pi^- \nu_\tau)/\Gamma_{\rm total}$

 \bullet \bullet \bullet We use the following data for averages but not for fits. \bullet \bullet

and are therefore used for the average given below but not in the overall fits. "f&a"

BAUER

 Γ_{91}/Γ

TECN COMMENT

94 TPC $E_{\text{cm}}^{ee} = 29 \text{ GeV}$

00D OPAL 1990-1995 LEP runs

98 ALEP 1991-1995 LEP runs

94 TPC $E_{\mathrm{CM}}^{\mathit{ee}} = 29 \; \mathrm{GeV}$

 $0.170 \pm 0.022 \pm 0.026$

 $0.097 \pm 0.005 \pm 0.011$

 0.102 ± 0.029

¹ ACHARD

GIBAUT

BYLSMA

13

01D L3

1992-1995 LEP runs

94B CLEO $E_{\mathrm{CM}}^{ee} = 10.6 \; \mathrm{GeV}$

87 HRS $E_{\rm cm}^{ee} = 29 \, {\rm GeV}$

```
^1\,{\rm Not} independent of LEE 10 \Gamma(\tau^- \to -{\it K}^+\,\pi^-\,\nu_\tau)/\Gamma_{\rm total} and \Gamma(\tau^- \to -{\it K}^+\,\pi^-\,\nu_\tau)/\Gamma_{\rm total}
                                                                                                                                                                               ullet ullet We use the following data for averages but not for fits. ullet ullet
       \pi^-\pi^+\pi^-\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}} values.
                                                                                                                                                                              0.093 \pm 0.009 \pm 0.012
                                                                                                                                                                                                                                           SCHAEL
                                                                                                                                                                                                                                                                      05 C ALEP 1991-1995 LEP runs
                                                                                                                                                                                                                                         <sup>2</sup> ABREU
                                                                                                                                                                              0.115 \pm 0.013 \pm 0.006
                                                                                                                                                                                                                         112
                                                                                                                                                                                                                                                                      01M DLPH 1992-1995 LEP runs
\Gamma(K^-K^+\pi^-\pi^0\nu_{\tau})/\Gamma_{\text{total}}
                                                                                                                                                                                                                                        <sup>3</sup>ACKERSTAFF 99E OPAL 1991-1995 LEP runs
                                                                                                                                                                              0.119 \pm 0.013 \pm 0.008
                                                                                                                                                                                                                       119
          Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a"
                                                                                                                                                                              ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                              0.26 \pm 0.06 \pm 0.05
                                                                                                                                                                                                                                                                      92н OPAL E_{\rm CM}^{ee} = 88.2–94.2 GeV
                                                                                                                                                                                                                                           ACTON
          marks results used for the fit and the average.
                                                                                                                                                                              0.10 \ ^{+\, 0.05}_{-\, 0.04} \ \pm 0.03
0.61±0.25 OUR FIT Error includes scale factor of 1.4.
                                                                                                                                                                                                                                            DECAMP
                                                                                                                                                                                                                                                                      92C ALEP 1989-1990 LEP runs
                                                                                                                                                                              0.16 \ \pm 0.13 \ \pm 0.04
                                                                                                                                                                                                                                            BEHREND
                                                                                                                                                                                                                                                                      89B CELL E_{\mathrm{CM}}^{ee} = 14\text{--}47~\mathrm{GeV}
0.60±0.18 OUR AVERAGE
                                                                                                                                                                              0.3\phantom{0}\pm0.1\phantom{0}\pm0.2\phantom{0}
                                                                                                                                                                                                                                            BARTEL
                                                                                                                                                                                                                                                                      85F JADE E_{\rm cm}^{ee}=34.6~{\rm GeV}
                                                                                       05 CLE3 7.6 fb^{-1},E_{\mathrm{cm}}^{ee}=10.6 GeV
0.55 \pm 0.14 \pm 0.12
                                                            ARMS
                                                                                                                                                                                                                                                                      85 HRS Repl. by BYLSMA 87
                                                                                                                                                                              0.13 \pm 0.04
                                                                                                                                                                                                                                            BELTRAMI
                                                                                                                                                                                                                           10
7.5 \pm 2.9 \pm 1.5
                                                           BARATE
                                                                                       98 ALEP 1991-1995 LEP runs
                                                                                                                                                                                                                                                                               MRK2 E_{\rm cm}^{ee}= 29 GeV
                                                                                                                                                                              0.16 \pm 0.08 \pm 0.04
                                                                                                                                                                                                                                            BURCHAT
                                                                                                                                                                                                                                                                      85
• • • We use the following data for averages but not for fits. • • •
                                                                                                                                                                              1.0 \pm 0.4
                                                                                                                                                                                                                           10
                                                                                                                                                                                                                                           BEHREND
                                                                                                                                                                                                                                                                      82 CELL Repl. by BEHREND 89B
                                 158 ^{1} RICHICHI 99 CLEO E_{
m cm}^{\it ee}=10.6 GeV
                                                                                                                                                                                  ^1 The correlation coefficients between this measurement and the ACHARD 01D measurements of B(\tau \to \text{ "1-prong"}) and B(\tau \to \text{ "3-prong"}) are -0.082 and -0.19 respectively.
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                                  ^2 The correlation coefficients between this measurement and the ABREU 01M measurements of B(\tau \to 1-prong) and B(\tau \to 3-prong) are -0.08 and -0.08 respectively. ^3 Not independent of ACKERSTAFF 99E B(\tau^- \to 3h^-2h^+\nu_{\tau}({\rm ex.}~K^0)) and B(\tau^- \to 3h^-2h^+\nu_{\tau}({\rm ex.}~K^0)) and B(\tau^- \to 3h^-2h^+\nu_{\tau}({\rm ex.}~K^0))
                                                           ABBIENDI
                                                                                   00D OPAL 1990-1995 LEP runs
                           95
   ^{
m 1} Not independent of RICHICHI 99
      \Gamma(\tau^- \to K^- K^+ \pi^- \nu_\tau) / \Gamma(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0)) \text{ and BALEST 95c } \Gamma(\tau^- \to \pi^- \pi^+ \pi^- \nu_\tau (\text{ex.} K^0))
                                                                                                                                                                                     3h^- 2h^+ \pi^0 \nu_{\tau} ({\rm ex.} \ K^0)) measurements.
       h^-h^-h^+\nu_{	au}({\rm ex}.K^0))/\Gamma_{
m total} values.
                                                                                                                                                                              \Gamma(3h^-2h^+
u_{	au}(\text{ex}.K^0))/\Gamma_{	ext{total}}
                                                                                                                                                                                                                                                                                                                          \Gamma_{102}/\Gamma
\Gamma \left( K^- \, K^+ \, \pi^- \, \pi^0 \, \nu_\tau \right) / \Gamma \left( \pi^- \, \pi^+ \, \pi^- \, \pi^0 \, \nu_\tau \, (\text{ex.} K^0) \right)
                                                                                                                                                                               VALUE (units 10<sup>-4</sup>) EVTS DOCUMENT ID TE 8.39±0.35 OUR FIT Error includes scale factor of 1.1.
                                                                                                                                                                                                                                                                         TECN COMMENT
                                                                 \Gamma_{94}/\Gamma_{69} = \Gamma_{94}/(\Gamma_{70} + 0.888\Gamma_{149} + 0.017\Gamma_{151})

        VALUE (%)
        EVTS
        DOCUMENT ID
        TECN
        COMMENT

        0.14±0.05 OUR FIT
        Error includes scale factor of 1.4.

                                                                                                                                                                               8.32±0.35 OUR AVERAGE
                                                                                                                                                                                                                                   <sup>1</sup> ABDALLAH 06A DLPH 1992-1995 LEP runs
                                                                                                                                                                               9.7 \pm 1.5 \pm 0.5
                                                          ^{1} RICHICHI 99 CLEO E_{
m cm}^{\it ee}=10.6 GeV
0.79 \pm 0.44 \pm 0.16
                                           158
                                                                                                                                                                                                                                                                05 w BABR 232 fb^{-1}, E_{\rm cm}^{ee} = 10.6 \, {\rm GeV}
                                                                                                                                                                               8.56 \pm 0.05 \pm 0.42
                                                                                                                                                                                                                                     AUBERT,B
    ^{1}\,\mathrm{RICHICHI} 99 also quote a 95%CL upper limit of 0.0157 for this measurement.
                                                                                                                                                                                                                                   <sup>2</sup> SCHAEL
                                                                                                                                                                              7.2 + 0.9 + 1.2
                                                                                                                                                                                                                    165
                                                                                                                                                                                                                                                                05 C ALEP 1991-1995 LEP runs
                                                                                                                                                                                                                                     ACKERSTAFF 99E OPAL 1991-1995 LEP runs
                                                                                                                                                                              9.1 \pm 1.4 \pm 0.6
                                                                                                                                                                                                                     97
\Gamma \big( K^- \, K^+ \, K^- \, \nu_\tau \big) / \Gamma_{\mathsf{total}}
                                                                                                                                              \Gamma_{95}/\Gamma
                                                                                                                                                                                                                                                                94B CLEO E_{\mathrm{cm}}^{ee} = 10.6 \; \mathrm{GeV}
                                                                                                                                                                              7.7 \pm 0.5 \pm 0.9
                                                                                                                                                                                                                    295
                                                                                                                                                                                                                                     GIBAUT
VALUE (units 10^{-5}) CL% EVTS
                                                          DO CUMENT ID
                                                                                       TECN COMMENT
                                                                                                                                                                              6.4 \pm 2.3 \pm 1.0
                                                                                                                                                                                                                    12
                                                                                                                                                                                                                                     ALBRECHT 88B ARG E_{
m cm}^{\,ee}= 10 GeV
2.1 ±0.8 OUR AVERAGE Error includes scale factor of 5.4.
                                                                                                                                                                              5.1 \pm 2.0
                                                                                                                                                                                                                     7
                                                                                                                                                                                                                                     BYLSMA
                                                                                                                                                                                                                                                                87 HRS E_{\rm CM}^{ee} = 29 \, {\rm GeV}
                                                                             10 BELL 666 fb^{-1} E_{
m CM}^{\it ee}= 10.6 GeV
                                    3.2k ^1 LEE
                                                                                                                                                                              • • • We do not use the following data for averages, fits, limits, etc. • •
                                         275 <sup>2</sup> AUBERT 08 BABR 342 fb<sup>-1</sup> E_{cm}^{ee} = 10.6 \text{ GeV}
                                                                                                                                                                              8.0 \pm 1.1 \pm 1.3
                                                                                                                                                                                                                    58
                                                                                                                                                                                                                                     BUSKULIC
                                                                                                                                                                                                                                                               96 ALEP Repl. by SCHAEL 05 c
                                                                                                                                                                                                                                   <sup>3</sup> BELTRAMI 85 HRS Repl. by BYLSMA 87
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                                                   ^1 See footnote to ABDALLAH 06A \Gamma(	au^- 	o \ h^- 
u_	au)/\Gamma_{
m total} measurement for correlations
                                                         BRIERE
                                                                               03 CLE3 E_{cm}^{ee} = 10.6 \text{ GeV}
                                                                                                                                                                                     with other measurements
                                                                               98 ALEP 1991-1995 LEP runs
                                                          BARATE
                                                                                                                                                                                  2 See footnote to SCHAEL 05c \Gamma(\tau^- \to e^- \overline{\nu}_e \nu_\tau)/\Gamma_{\rm total} measurement for correlations
   ^1 See footnote to LEE 10 \Gamma(\tau^-\to\pi^-\pi^+\pi^-\nu_\tau({\rm ex.} K^0))/\Gamma_{\rm total} measurement for correlations with other measurements. Not independent of LEE 10 \Gamma(\tau^-\to\pi^-\pi^+\pi^-\nu_\tau)
                                                                                                                                                                                      with other measurements
                                                                                                                                                                                  <sup>3</sup> The error quoted is statistical only.
       {\it K}^-\,{\it K}^+\,{\it K}^-\,\nu_\tau)/\Gamma(\tau^-\,\to\,\pi^-\,\pi^+\,\pi^-\,\nu_\tau({\rm ex.}\,{\it K}^{\,0})) value.
                                                                                                                                                                               \Gamma(3h^-2h^+\pi^0\nu_{\tau}(\text{ex.}K^0))/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                           \Gamma_{103}/\Gamma
    ^2 See footnote to AUBERT 08 \Gamma(\tau^-\to~\pi^-\pi^+\pi^-\nu_\tau({\rm ex}.{\it K}^0))/\Gamma_{\rm total} measurement for
                                                                                                                                                                                                                                       DOCUMENT ID
                                                                                                                                                                                                                                                                          TECN COMMENT
      correlations with other measurements.
                                                                                                                                                                               1.78±0.27 OUR FIT
\Gamma(K^-K^+K^-\nu_\tau)/\Gamma(\pi^-\pi^+\pi^-\nu_\tau(\text{ex}.K^0))
                                                                                                                                         \Gamma_{95}/\Gamma_{60}
                                                                                                                                                                              1.74±0.27 OUR AVERAGE
                                                                                                                                                                                                                                     <sup>1</sup> ABDALLAH 06A DLPH 1992-1995 LEP runs
                                                                                                                                                                               1.6 \pm 1.2 \pm 0.6
VALUE (units 10<sup>-4</sup>) EVTS
                                                   DOCUMENT ID
                                                                                          TECN COMMENT
                                                                                                                                                                                                                                    <sup>2</sup> SCHAEL
                                                                                                                                                                              2.1 \pm 0.7 \pm 0.9
                                                                                                                                                                                                                       95
                                                                                                                                                                                                                                                                 05c ALEP 1991-1995 LEP runs
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                                                                                       ANASTASSOV 01 CLEO E_{
m cm}^{ee} = 10.6~{
m GeV}
                                                                                                                                                                              1.7 \pm 0.2 \pm 0.2
                                                                                                                                                                                                                    231
                                                 ^{1} LEE
                                                                                  10 BELL 666 fb^{-1} E_{\rm CM}^{ee} = 10.6 GeV
3.90 \pm 0.02 + 0.22 \atop -0.23 3.2k
                                                                                                                                                                                                                                       ACKERSTAFF 99E OPAL 1991-1995 LEP runs
                                                                                                                                                                              2.7 \pm 1.8 \pm 0.9
                                                                                                                                                                                                                      23
                                                                                                                                                                              \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
    ^1\,\mathrm{Not} independent of LEE 10 \Gamma(\tau^- \ \to \ K^-\,K^+\,K^-\,\nu_\tau)/\Gamma_{\mathrm{total}} and \Gamma(\tau^- \ \to \ K^-\,K^+\,K^-\,\nu_\tau)
                                                                                                                                                                                                                                       BUSKULIC
                                                                                                                                                                                                                                                                 96 ALEP Repl. by SCHAEL 05c
                                                                                                                                                                              1.8 \pm 0.7 \pm 1.2
                                                                                                                                                                                                                      18
       \pi^-\pi^+\pi^-\nu_{	au}({\rm ex.}\,{\it K}^0))/\Gamma_{
m total} values.
                                                                                                                                                                                                                                       GIBAUT
                                                                                                                                                                                                                                                                  94B CLEO Repl. by ANASTASSOV 01
                                                                                                                                                                              1.9 + 0.4 + 0.4
                                                                                                                                                                                                                      31
                                                                                                                                                                                                                                       BYLSMA
                                                                                                                                                                                                                                                                  87 HRS E_{\rm cm}^{ee} = 29 \, {\rm GeV}
                                                                                                                                                                              5.1\ \pm2.2
                                                                                                                                                                                                                        6
\Gamma(K^-K^+K^-\nu_{\tau}(\text{ex. }\phi))/\Gamma_{\text{total}}
                                                                                                                                              \Gamma_{96}/\Gamma
                                                                                                                                                                                                                                    <sup>3</sup> BELTRAMI 85 HRS Repl. by BYLSMA 87
                                                        DOCUMENT ID
                                                                                           TECN COMMENT
                                                                                                                                                                                   ^1 See footnote to ABDALLAH 06A \Gamma(\tau^-\to~h^-\nu_{\tau})/\Gamma_{\rm total} measurement for correlations
                                                                                   08 BABR 342 fb<sup>-1</sup> E_{cm}^{ee} = 10.6 \text{ GeV}
                                                         AUBERT
                                                                                                                                                                                      with other measurements.
                                                                                                                                                                                   ^2 SCHAEL 05c quote (1.4\pm0.7\pm0.9)\times10^{-4} . We add 0.7\times10^{-4} to remove their
\Gamma(K^-K^+K^-\pi^0
u_	au)/\Gamma_{
m total}
                                                                                                                                              \Gamma_{97}/\Gamma
                                                                                                                                                                                    correction for \tau^- \to \eta \pi^- \pi^+ \pi^- \nu_\tau \to 3\pi^- 2\pi^+ \pi^0 \nu_\tau and \tau^- \to K^*(892)^- \eta \nu_\tau
                                                          DOCUMENT ID
                                                                                          TECN COMMENT
                                                                                                                                                                                     3\pi^-\,2\pi^+\,\pi^0\,
u_	au decays. See footnote to SCHAEL 05c \Gamma(	au^-	o e^-\overline{
u}_e\,
u_	au)/\Gamma_{
m total} mea-
 <4.8 × 10<sup>-6</sup>
                                                                                    05 CLE3 7.6 fb<sup>-1</sup>, E_{cm}^{ee} = 10.6 \text{ GeV}
                                                                                                                                                                                     surement for correlations with other measurements.
                                                                                                                                                                                   <sup>3</sup> The error quoted is statistical only.
\Gamma(\pi^- K^+ \pi^- \ge 0 \text{ neut. } \nu_{\tau})/\Gamma_{\text{total}}
                                                                                                                                              \Gamma_{98}/\Gamma
                                                                                                                                                                              \Gamma(3h^-2h^+2\pi^0\nu_{\tau})/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                          \Gamma_{104}/\Gamma
                                                               DOCUMENT ID
                                                                                                  TECN COMMENT
                                                                                                                                                                                                                                      DOCUMENT ID TECN COMMENT
                                                               BAUER
                                                                                          94 TPC E_{\text{cm}}^{ee} = 29 \text{ GeV}
                                                                                                                                                                                                                                      AUBERT,B 06 BABR 232 fb<sup>-1</sup> E_{cm}^{ee} = 10.6 \,\text{GeV}
                                                                                                                                                                                                                   90
                                                                                                                                                                               \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
\Gamma(e^-e^-e^+\overline{\nu}_e\,\nu_{\tau})/\Gamma_{\rm total}
                                                                                                                                              Г99/Г
                                                                                                                                                                                < 1.1 \times 10^{-4}
                                                                                                                                                                                                                   90
                                                                                                                                                                                                                                     GIBAUT
                                                                                                                                                                                                                                                                 94B CLEO E_{\rm CM}^{\it ee}=10.6~{\rm GeV}
VALUE (units 10<sup>-5</sup>) EVTS
                                                               DOCUMENT ID
                                                                                                  TECN COMMENT
2.8 \pm 1.4 \pm 0.4
                                                               ALAM
                                                                                          96 CLEO E_{\mathrm{cm}}^{ee} = 10.6 \; \mathrm{GeV}
                                                                                                                                                                               \begin{array}{c} \Gamma \big( (5\pi)^- \nu_\tau \big) / \Gamma_{total} \\ \Gamma_{105} / \Gamma = (\Gamma_{30} + \Gamma_{47} + \Gamma_{77} + \Gamma_{102} + 0.553 \Gamma_{125} + 0.888 \Gamma_{151}) / \Gamma_{total} \end{array} 
                                                                                                                                                                                                                                                                                                                           \Gamma_{105}/\Gamma
\Gamma(\mu^- e^- e^+ \overline{\nu}_\mu \nu_\tau) / \Gamma_{\text{total}}
                                                                                                                                            \Gamma_{100}/\Gamma
                                                                                                                                                                                        Data marked "avg" are highly correlated with data appearing elsewhere in the Listings,
                                                               DOCUMENT ID
                                                                                             TECN COMMENT
                                                                                                                                                                                        and are therefore used for the average given below but not in the overall fits. "f&a"
                                                                                          96 CLEO E_{
m cm}^{\it ee}= 10.6 GeV
                                                               ALAM
                                                                                                                                                                                         marks results used for the fit and the average.
                                                                                                                                                                                                                                            DO CUMENT ID
 \Gamma \big( 3h^- 2h^+ \geq 0 \text{ neutrals } \nu_\tau (\text{ex. } K_S^0 \to \pi^- \pi^+) \big( \text{`$5$-prong"} \big) \big) / \Gamma_{\text{total}} \quad \Gamma_{101} / \Gamma_{\text{botal marked "avg"}} \quad \Gamma_{101} / \Gamma_{\text{total marked "avg"}} \quad \Gamma
                                                                                                                                                                              0.77±0.05 OUR FIT
                                                                                                                                                                               • • • We use the following data for averages but not for fits. • • •
          and are therefore used for the average given below but not in the overall fix. "f&a" marks results used for the fit and the average. \Gamma_{101}/\Gamma = (\Gamma_{102} + \Gamma_{103})/\Gamma
                                                                                                                                                                                                                                         ^{1} GIBAUT 94B CLEO E_{
m cm}^{\it ee}= 10.6 GeV
                                                                                                                                                                                   ^1 Not independent of GIBAUT 94B B(3h^-2h^+ \nu_{\tau}), PROCARIO 93 B(h^-4\pi^0 \nu_{\tau}), and
VALUE (%) EVTS DOCUMENT ID T

0.102±0.004 OUR FIT Error includes scale factor of 1.1.
                                                                                                  TECN COMMENT
                                                                                                                                                                                     BORTOLETTO 93 B(2 h^- h^+ 2\pi^0 \nu_{\tau})/{\rm B}(\,{\rm ``aprong"}) measurements. Result is corrected
0.107±0.007 OUR AVERAGE Error includes scale factor of 1.1.
```

| • | | ν _τ ("7-prong")), | | | Γ ₁₀₆ /Γ |
|---------------------------------|-----------------------------|------------------------------|-------|-----------|-------------------------------------------------------|
| VALUE | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT |
| $< 3.0 \times 10^{-7}$ | 90 | AUBERT,B | 05 F | BABR | 232 fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6 \ {\rm GeV}$ |
| ullet $ullet$ We do not | use the follo | owing data for aver | ages, | fits, lim | its, etc. • • • |
| $< 1.8 \times 10^{-5}$ | 95 | ACKERSTAFF | 97 J | OPAL | 1990-1995 LEP runs |
| $< 2.4 \times 10^{-6}$ | 90 | EDWARDS | 97B | CLEO | $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ |
| $< 2.9 \times 10^{-4}$ | 90 | BYLSMA | 87 | HRS | $E_{cm}^{ee} = 29 \text{ GeV}$ |
| $\Gamma(4h^-3h^+\nu_{\tau})$ | /Γ _{total} | | | | Γ ₁₀₇ /Γ |
| VALUE | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT |
| $<4.3 \times 10^{-7}$ | 90 | AUBERT,B | 05F | BABR | 232 fb $^{-1}$, $E_{ m cm}^{\it ee} = 10.6$ |
| | | | | | GeV |
| $\Gamma(4h^{-}3h^{+}\pi^{0}\nu$ | $(\tau)/\Gamma_{\rm total}$ | | | | Γ ₁₀₈ /Γ |
| VALUE | CLOV | DO CUMENT ID | | TECN | COMMENT |

DOCUMENT ID TECN COMMENT AUBERT,B 05F BABR 232 fb $^{-1}$, $E_{\mathrm{CM}}^{ee} = 10.6 \; \mathrm{GeV}$

 $\Gamma(X^{-}(S=-1)\nu_{\tau})/\Gamma_{\text{total}}$ $\Gamma_{109}/\Gamma = (\Gamma_{10} + \Gamma_{16} + \Gamma_{23} + \Gamma_{28} + \Gamma_{35} + \Gamma_{40} + \Gamma_{85} + \Gamma_{89} + \Gamma_{127})/\Gamma_{109}$

Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average.

2.87±0.07 OUR FIT Error includes scale factor of 1.3.

• • • We use the following data of the following data o

• • • We use the following data for averages but not for fits. • • •

¹ BARATE

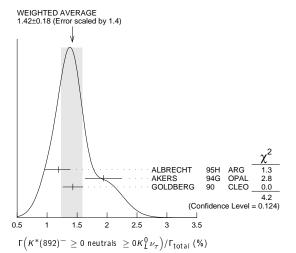
99R ALEP 1991-1995 LEP runs

 1 BARATE 99R perform a combined analysis of all ALEPH LEP 1 data on au branching fraction measurements for decay modes having total strangeness equal to -1.

| $\Gamma(K^*(892)^- \ge 0 \text{ new}$ | trals ≥ 0 | $K_L^0 u_{	au})/\Gamma_{ m total}$ | | | Γ ₁₁₀ /Γ |
|---------------------------------------|-----------------|-------------------------------------|---------|-------|----------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.42±0.18 OUR AVERA | GE Error | includes scale fact | or of 1 | 4 See | the ideogram below. |
| $1.19 \pm 0.15 {}^{+ 0.13}_{- 0.18}$ | 104 | ALBRECHT | 95 H | ARG | E ^{ee} _{cm} = 9.4-10.6 GeV |
| $1.94 \pm 0.27 \pm 0.15$ | 74 | ¹ AKERS | 94 G | OPAL | E ee = 88-94 GeV |
| $1.43 \pm 0.11 \pm 0.13$ | 475 | ² GOLDBERG | 90 | CLEO | E ^{ee} _{CM} = 9.4–10.9 GeV |
| | | _ | | | |

 $^{^1}$ AKERS 94G reject events in which a K_S^0 accompanies the $K^*(892)^-$. We do not correct

for them. 2 GOLDBERG 90 estimates that 10% of observed $\mathit{K}^*(892)$ are accompanied by a $\pi^0.$



| $\Gamma(K^*(892)^-\nu_{\tau})/\Gamma$ | total | | | | Γ ₁₁₁ /Γ |
|---------------------------------------|------------|-------------------------|---------|------------|-------------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.20 ±0.07 OUR AV | /ERAGE | Error includes sca | | | 8. See the ideogram below. |
| $1.131 \pm 0.006 \pm 0.051$ | 49k | ¹ EPIFANOV | 07 | BELL | 351 fb $^{-1}$ $E_{\rm cm}^{ee}$ =10.6 GeV |
| 1.326 ± 0.063 | | BARATE | 99R | ALEP | 1991-1995 LEP runs |
| 1.11 ± 0.12 | | ² COAN | 96 | CLEO | $E_{\rm cm}^{\it ee} \approx 10.6 \; {\rm GeV}$ |
| $1.42 \ \pm 0.22 \ \pm 0.09$ | | ³ ACCIARRI | 95 F | L3 | 1991-1993 LEP runs |
| ● ● We do not use | the follow | ving data for averag | ges, fi | ts, limits | , etc. • • • |
| $1.39 \pm 0.09 \pm 0.10$ | | ⁴ BUSKULIC | 96 | ALEP | Repl. by BARATE 99R |
| $1.45 \ \pm 0.13 \ \pm 0.11$ | 273 | ⁵ BUSKULIC | 94F | ALEP | Repl. by BUSKULIC 96 |
| $1.23 \pm 0.21 ^{+ 0.11}_{- 0.21}$ | 54 | ⁶ ALBRECHT | 88L | ARG | $E_{ m cm}^{\it ee}$ = 10 GeV |
| $1.9\pm0.3\pm0.4$ | 44 | ⁷ TSCHIRHART | 88 | HRS | E ^{ee} _{CM} = 29 GeV |
| $1.5\pm0.4\pm0.4$ | 15 | ⁸ AIHARA | 87c | TPC | E ^{ee} _{cm} = 29 GeV |
| $1.3\pm0.3\pm0.3$ | 31 | YELTON | 86 | MRK2 | E ^{ee} _{cm} = 29 GeV |
| 1.7 ± 0.7 | 11 | DORFAN | 81 | MRK2 | $E_{cm}^{ee} = 4.2-6.7 \text{ GeV}$ |

¹ EPIFANOV 07 quote B($\tau^- \to K^*(892)^- \nu_{\tau}$) B($K^*(892)^- \to K_5^0 \pi^-$) = (3.77 \pm 0.02(stat) \pm 0.12(syst) \pm 0.12(mod)) \times 10⁻³. We add the systematic and model uncertainties in quadrature and divide by B($K^*(892)^- \rightarrow K_S^0 \pi^-$) = 0.3333.

 $^2\,{\rm Not}$ independent of COAN 96 ${\rm B}(\pi^-\,\overline{K}^0\,\nu_\tau)$ and BATTLE 94 ${\rm B}(K^-\,\pi^0\,\nu_\tau)$ measurements. $K\pi$ final states are consistent with and assumed to originate from $K^*(892)^-$

 3 This result is obtained from their B $(\pi^-\overline{K}^0\nu_{\pi})$ assuming all those decays originate in K*(892) - decays.

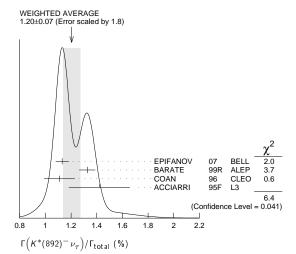
⁴ Not independent of BUSKULIC 96 B $(\pi^-\overline{K}^0\nu_{\tau})$ and B $(K^-\pi^0\nu_{\tau})$ measurements.

 5 BUSKULIC 94F obtain this result from BUSKULIC 94F B($\overline{K}^0\pi^-\nu_{\tau})$ and BUSKULIC 94E $B(K^-\pi^0\nu_{\tau})$ assuming all of those decays originate in $K^*(892)^-$ decays.

 $^6\,\text{The}$ authors divide by $\Gamma_2/\Gamma=$ 0.865 to obtain this result.

⁷ Not independent of TSCHIRHART 88 $\Gamma(\tau^- \to h^- \overline{K}^0 \ge 0 \text{ neutrals } \ge 0 K_L^0 \nu_{\tau}) / \Gamma$.

 $^{8}\,\mathrm{Decay}\;\pi^{-}$ identified in this experiment, is assumed in the others.



| $\Gamma(K^*(892)^-\nu_{\tau})/\Gamma(\pi^-\pi^0\nu_{\tau})$ | .) | | | Γ ₁₁₁ | _ι /Γ ₁₄ |
|-------------------------------------------------------------|--------------------|-----|------|------------------|-------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.075 ± 0.027 | ¹ ABREU | 94ĸ | DLPH | LEP 1992 Z data | |
| • | | | | | |

 1 ABREU 94K quote B($au^- o K^*(892)^-
u_ au$)B($K^*(892)^- o K^- \pi^0$)/B($au^- o
ho^-
u_ au$) = 0.025 \pm 0.009. We divide by B($K^*(892)^- \rightarrow K^- \pi^0$) = 0.333 to obtain this result.

 $\Gamma\big(K^*(892)^-\nu_\tau\to\pi^-\overline{K}{}^0\nu_\tau\big)/\Gamma\big(\pi^-\overline{K}{}^0\nu_\tau\big)$ Γ_{112}/Γ_{35} EVTS DOCUMENT ID TECN COMMENT 0.933±0.027 EPIFANOV 07 BELL 351 fb $^{-1}$ $E_{\rm cm}^{ee}=10.6$ GeV

 $\Gamma(K^*(892)^0 K^- \ge 0 \text{ neutrals } \nu_{\tau})/\Gamma_{\text{total}}$ Γ_{113}/Γ EVTS DOCUMENT ID TECN COMMENT 0.32±0.08±0.12 GOLDBERG 90 CLEO $E_{
m cm}^{\it ee}=$ 9.4–10.9 GeV 119

 $\Gamma(K^*(892)^0 K^- \nu_{\tau})/\Gamma_{\text{total}}$ Γ_{114}/Γ DOCUMENT ID TECN COMMENT 0.21 ±0.04 OUR AVERAGE 98 ALEP 1991-1995 LEP runs $0.20 \ \pm 0.05 \ \pm 0.04$ ALBRECHT 95H ARG $E_{\text{CM}}^{ee} = 9.4-10.6 \text{ GeV}$

 $^1\,{\rm BARATE}$ 98 measure the $K^ (\rho^0$ \to $~\pi^+\,\pi^-)$ fraction in $\tau^ \to$ $~K^-\,\pi^+\,\pi^-\,\nu_\tau$ decays to be (35 \pm 11)% and derive this result from their measurement of $\Gamma(au^2)$ $\kappa^-\pi^+\pi^-\nu_ au)/\Gamma_{
m total}$ assuming the intermediate states are all κ^ho and $\kappa^-\kappa^*(892)^0$

| $\Gamma(\overline{K}^*(892)^0\pi^- \ge 0$ | neutrals (| $ u_{	au})/\Gamma_{ m total}$ | | | Γ ₁₁₅ /Γ |
|------------------------------------------------|---------------------|-------------------------------|------|------------|----------------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $0.38 \pm 0.11 \pm 0.13$ | 1 05 | GOLDBERG | 90 | CLEO | E ^{ee} _{cm} = 9.4–10.9 GeV |
| $\Gamma(\overline{K}^*(892)^0\pi^-\nu_{\tau})$ | /Γ _{total} | | | | Γ ₁₁₆ /Γ |
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.22 ±0.05 OUR AV | ERAGE | · | | | |
| 0.209 ± 0.058 | | ¹ BARATE | 98 | ALEP | 1991-1995 LEP runs |
| $0.25\ \pm0.10\ \pm0.05$ | 27 | ALBRECHT | 95 H | ARG | E ee = 9.4-10.6 GeV |
| ¹ BARATE 98 mea | sure the | $K^- K^* (892)^0$ frac | tion | in $	au^-$ | \rightarrow $K^- K^+ \pi^- \nu_{	au}$ de- |
| | | | _ | | |

cays to be (87 \pm 13)% and derive this result from their measurement of $\Gamma(au^-
ightarrow$ $K^- K^+ \pi^- \nu_{ au})/\Gamma_{ ext{total}}$ F//77*/000\ \-- 770 O \ / c

| $I((K^+(892)\pi)^-\nu_{\tau} \rightarrow \pi^-K^0\pi^0\nu_{\tau})/I_{\text{total}}$ | | | | | |
|-------------------------------------------------------------------------------------|---------------------|-----|------|--------------|-------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 0.10 ±0.04 OUR AVERAGE | · | | | | |
| $0.097 \pm 0.044 \pm 0.036$ | ¹ BARATE | 99K | ALEP | 1991-1995 LE | Pruns |
| $0.106 \pm 0.037 \pm 0.032$ | ² BARATE | 98E | ALEP | 1991-1995 LE | Pruns |

| 1 BARATE 99к me termine the $\overline{K}^0 ho^-$ and multiply their the quoted result. | fraction in $B(\pi^-\overline{K}^0)$ | by detecting K_L^0 's $\pi^- \to \pi^- \overline{K}^0 \pi$ $\pi^0 u_{	au}$) measurement | in the $^0 u_{	au}$ denotes the denotes t | eir hadr ecays to one min | on calorimeter be $(0.72\pm0$ us this fractio | . They de- $.12\pm0.10)$ n to obtain |
|----------------------------------------------------------------------------------------------|-------------------------------------------------|---------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| 2 BARATE 98E reco | onstruct K^0 , $\pi^- \overline{K}{}^0 \pi^0$ | 's using $K^0_S	o\pi^+$ $ u_{\mathcal T}$ decays to be (t by one minus thi | 0.64 ± | 0.09 ± | 0.10) and m | ultiply their |
| $(K_1(1270)^- \nu_{\tau})/$ | Γ _{total} | 0.0000000000000000000000000000000000000 | | T | 50444547 | Γ ₁₁₈ /Γ |
| VALUE (%) D.47±0.11 OUR AVE | RAGE | DO CUMENT ID | | TECN | COMMENT | |
| 0.48±0.11 | | BARATE | | ALEP | 1991-1995 L | |
| $.41^{+0.41}_{-0.35} \pm 0.10$ | 5 | ¹ BAUER | 94 | TPC | $E_{\rm cm}^{ee} = 29 \text{ Ge}$ | |
| We multiply 0.41% the systematic err | | ne relative systema | ic erro | or quote | by BAUER 9 | 4, to obtain |
| $(K_1(1400)^- \nu_{\tau})/$ | | | | | | Γ ₁₁₉ /Γ |
| ALUE (%) .17±0.26 OUR AVE | <u>EVTS</u> RAGE Err | DOCUMENT ID or includes scale fa | actor o | TECN f 1.7. | COMMENT | |
| 0.05 ± 0.17 | | BARATE | | ALEP | 1991-1995 L | |
| $.76^{+0.40}_{-0.33} \pm 0.20$ | 11 | ¹ BAUER | 94 | TPC | E ee 29 Ge | |
| ¹ We multiply 0.76% the systematic err | % by 0.25, th or. | ne relative systema | ic erro | or quote | by BAUER 9 | 4, to obtain |
| Γ(K ₁ (1270) ⁻ ν _τ) | + Γ(<i>K</i> ₁ (1 | 400) ⁻ ν _τ)]/Γ _{to} | | TECN | (Γ ₁₁₈ | +Γ ₁₁₉)/Γ |
| $.17^{+0.41}_{-0.37} \pm 0.29$ | 16 | ¹ BAUER | 94 | TPC | E ee 29 Ge | ٠V |
| $B(\mathit{K}_{1}(1400)^{-}\nu_{\tau})$ | or. Not inde measureme | ependent of BAUE ents. | R 94 E | 3(K ₁ (12 | 70) $^- u_	au$) and | BAUER 94 |
| $(K_1(1270)^- u_{	au})/U$ | [Γ(<i>K</i> ₁ (12 | 70) ⁻ ν _τ) + Γ(<i>K</i>) <u>DO CUMENT ID</u> | | | | .18+F ₁₁₉) |
| 0.69±0.15 OUR AVE 0.71±0.16±0.11 | RAGE | 1 ABBIENDI | | | 1990–1995 L | ED runs |
| $.66 \pm 0.19 \pm 0.13$ | | ² ASNER | 00В | CLEO | $E_{\rm cm}^{ee} = 10.6$ | GeV |
| -(K*(1410)ν_τ)/ ALUE (units 10 ⁻³) | _ | and $K_1(1400)^-$ re | | TECN | COMMENT | Γ ₁₂₀ /Γ |
| .5 + 1.4 | | BARATE | 99R | ALEP | 1991–1995 L | EP runs |
| $(K_0^*(1430)^-\nu_{\tau})/$ | /Γ _{total} | | | | | Γ ₁₂₁ /Γ |
| ALUE (units 10 ⁻³) | <u>CL%</u> 95 | <u>DOCUMENT ID</u> BARATE | 99R | TECN ALEP | <u>СОММЕНТ</u> 1991–1995 L | EP runs |
| $(K_2^*(1430)^-\nu_{\tau})/$ | /F _{total} | | | | | Γ ₁₂₂ /Γ |
| /ALUE (%) | CL% EVTS | | | TECI | | CoV |
| <0.3 • • • We do not use | 95 the followin | TSCHIRHA ng data for average | | | 0 | Gev |
| <0.33 <0.9 | 95 95 0 | ¹ ACCIARRI DORFAN | 95 81 | F L3 | | 3 LEP runs 2–6.7 GeV |
| ¹ ACCIARRI 95F qu | | | → π ⁻ | $\overline{K}^0 \nu_{\tau})$ | | |
| $(a_0(980)^- \ge 0 \text{ n})$ | | | | | к-) г _: | ₁₂₃ /Г×В |
| /ALUE (units 10 ⁻⁴) | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| <2.8 | 90 | GOLDBERG | 90 | CLEO | $E_{\rm cm}^{ee} = 9.4-1$ | 0.9 GeV |
| $(\eta \pi^- \nu_{\tau})/\Gamma_{\text{total}}$ | CL% EVTS | <u>DO CUMENT</u> | ID | TECI | N COMMENT | Γ ₁₂₄ /Γ |
| < 0.99 | 95 | 1 DEL-AMO- | | | | Eee = |
| • • We do not use | the followin | | | | 10.6 G | |
| < 6.2 | 95 | BUSKULIC | | c ALE | P 1991-1994 | 4 LEP runs |
| < 1.4 | 95 0 | BARTELT | 96 | CLE | O $E_{\rm cm}^{ee} \approx 1$ | 0.6 GeV |
| < 3.4 | 95 95 | ARTUSO | 92 F 88 | | CIII | |
| < 90 <140 | 90 | ALBRECHT BEHREND | 88 | 3m ARO 3 CEL | 0 | -46.8 GeV |
| <180 | 95 | BARINGER | | | | |
| <250 | 90 0 | COFFMAN | | | $E_{cm}^{ee} = 3.7$ | |
| 510 ±100±120 | 65 os | DERRICK | 87 | | CIII | |
| 100 1051 AMO SANG | 95 | GAN | 87 | ו NIKI פי | $\begin{array}{ccc} \text{(2)} & E_{\text{cm}}^{\text{ge}} = 29 \\ \text{(2)} & \text{(3)} & \text{(4)} & \text{(5)} \end{array}$ | 1) 10-5 |

 1 DEL-A MO-SA NCHEZ 11E also quote B($\tau^- \to ~\eta \, \pi^- \, \nu_\tau) = (3.4 \pm 3.4 \pm 2.1) \times 10^{-5}$.

```
\Gamma(\eta\pi^-\pi^0\nu_	au)/\Gamma_{
m total}
                                                                                                     \Gamma_{125}/\Gamma
 MALUE (units 10<sup>-3</sup>) CL% EVTS DOCUMENT ID TEC

1.39± 0.10 OUR FIT Error includes scale factor of 1.4.
 1.38± 0.09 OUR AVERAGE Error includes scale factor of 1.2.
                                 6.0k INAMI 09 BELL 490 fb<sup>-1</sup> E_{cm}^{ee} = 10.6
 1.35 \pm 0.03 \pm 0.07
1.8 ± 0.4 ± 0.2 BUSKULIC 97c ALEP 1991–1994 LEP runs 1.7 ± 0.2 ± 0.2 125 ARTUSO 92 CLEO E_{\rm cm}^{\rm ee} \approx 10.6~{\rm GeV}
• • • We do not use the following data for averages, fits, limits, etc. • • •
            95
                                          ALBRECHT 88M ARG E_{
m cm}^{\it ee} \approx 10~{
m GeV}
                                            BARINGER 87 CLEO E_{\text{cm}}^{ee} = 10.5 \text{ GeV}
< 21.0
                          95
42.0 ^{+}_{-12.0} ^{+}_{2.0} ^{+}_{16.0}
                                          ^{1}\,\mathrm{GA\,N}
                                                              87 MRK2 E ee = 29 GeV
  ^1\,\mathrm{Highly} correlated with GAN 87 \Gamma(\pi^-\,3\pi^0\,\nu_{_T})/\Gamma(\mathrm{total}) value.
\Gamma(\eta\pi^-\pi^0\pi^0\nu_	au)/\Gamma_{
m total}
                                                                                                    \Gamma_{126}/\Gamma
                                   • • • We do not use the following data for averages, fits, limits, etc. • • •
    1.4\pm0.6\pm0.3 15 ^2 BERGFELD 97 CLEO Repl. by ANASTASSOV 01 4.3 95 ARTUSO 92 CLEO \frac{E_{\rm cm}^{\rm ex}}{E_{\rm cm}^{\rm ex}} \approx 10.6 GeV
< 4.3
                                                  ALBRECHT 88M ARG E_{
m CM}^{\it ee} \, \approx \, 10 \; {
m GeV}
 <120
                            95
  ^1\,\text{Weighted} average of BERGFELD 97 and ANASTASSOV 01 value of (1.5\pm0.6\pm0.3)\,\times
    10^{-4} obtained using \eta's reconstructed from \eta \to \pi^+\pi^-\pi^0 decays.
  <sup>2</sup>BERGFELD 97 reconstruct \eta's using \eta \to \gamma \gamma decays.
\Gamma(\eta K^- \nu_{\tau})/\Gamma_{\text{total}}
                                                                                                     \Gamma_{127}/\Gamma
VALUE (units 10<sup>-4</sup>) CL% EVTS
                                        DOCUMENT ID TECN COMMENT
1.52±0.08 OUR FIT
1.52±0.08 OUR AVERAGE
1.42 \pm 0.11 \pm 0.07 690
                                        DEL-AMO-SA..11E BABR 470 fb^{-1} E_{\rm cm}^{ee}=10.6 GeV
                            1.6k INAMI 09 BELL 490 fb<sup>-1</sup> E_{cm}^{ee} = 10.6 \text{ GeV}
1.58 \pm 0.05 \pm 0.09
\bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
2.9 \ ^{+1.3}_{-1.2} \ \pm 0.7
                                        BUSKULIC 97c ALEP 1991-1994 LEP runs
                                                           96 CLEO E_{
m cm}^{\it ee} \approx 10.6~{
m GeV}
                                        BARTELT
2.6 \pm 0.5 \pm 0.5
< 4.7
                                        ARTUSO
                                                            92 CLEO E_{\mathrm{cm}}^{ee} \approx 10.6 \ \mathrm{GeV}
\Gamma(\eta K^*(892)^-\nu_{\tau})/\Gamma_{\text{total}}
                                                                                                     \Gamma_{128}/\Gamma
VALUE (units 10^{-4})
                                          DOCUMENT ID
                                                                    TECN COMMENT
1.38±0.15 OUR AVERAGE
                                       <sup>1</sup> INAMI
                                                             09 BELL 490 fb<sup>-1</sup> E_{\rm cm}^{ee} = 10.6
1.34 \pm 0.12 \pm 0.09
                                                             _{
m GeV}^{
m GeV} 99 CLEO E_{
m cm}^{\it ee}= 10.6 GeV
2.90 \pm 0.80 \pm 0.42
                                          BISHAI
  ^1 Not independent of INA MI 09 B( \tau^-\to~\eta~K^-~\pi^0~\nu_{\tau}) and B( \tau^-\to~\eta~\overline{K}^0~\pi^-~\nu_{\tau}) values.
\Gamma(\eta K^-\pi^0 \nu_{\tau})/\Gamma_{\text{total}}
                                         DOCUMENT ID TECN COMMENT
0.48±0.12 OUR AVERAGE
                                                            09 BELL 490 fb^{-1} E_{\rm CM}^{ee} = 10.6 GeV
0.46 \pm 0.11 \pm 0.04
                                         INAMI
1.77 \pm 0.56 \pm 0.71
                                         BISHAI
                                                            99 CLEO E_{cm}^{ee} = 10.6 \text{ GeV}
\Gamma(\eta K^-\pi^0 (\text{non-}K^*(892))\nu_{\tau})/\Gamma_{	ext{total}}
                                         DOCUMENT ID
                                                                 TECN COMMENT
                                         INAMI
                                                            09 BELL 490 fb^{-1} E_{\rm CM}^{ee} = 10.6 GeV
\Gamma(\eta \overline{K}{}^0 \pi^- \nu_{	au}) / \Gamma_{	ext{total}}
                                          DOCUMENT ID TECN COMMENT
0.93±0.15 OUR AVERAGE
                                       ^{1} INAMI
                                                             09 BELL 490 fb^{-1} E_{\rm CM}^{ee} = 10.6
0.88 \pm 0.14 \pm 0.06
                                                             GeV
99 CLEO E_{Cm}^{ee} = 10.6 GeV
                                       <sup>2</sup> BISHAI
2.20 \pm 0.70 \pm 0.22
                         15
  ^1\,{\rm We} multiply the INAMI 09 measurement B( \tau^-\,\rightarrow\,\,\eta\,K_S^0\,\pi^-\,\nu_\tau)\,=\,(0.44\,\pm\,0.07\,\pm\,0.07
    0.03) \times\,10^{\,\textbf{--4}} by 2 to obtain the listed value.
  ^2 We multiply the BISHAI 99 measurement B(	au^- 
ightarrow \eta \, K_S^0 \, \pi^- 
u_	au) = (1.10 \pm 0.35 \pm
    0.11) \times\,10^{\,-4} by 2 to obtain the listed value.
\Gamma(\eta \overline{K}{}^0\pi^-\pi^0\nu_{	au})/\Gamma_{
m total}
                                      VALUE
 <5.0 × 10<sup>-5</sup>
                          90
  ^1\, {\rm We} multiply the INAMI 09 measurement B( \tau^- \to ~\eta\, K_S^0\, \pi^-\, \pi^0 \nu_{\tau}) <~2.5 \times 10^{-5} by
    2 to obtain the listed value.
\Gamma(\eta K^- K^0 
u_	au)/\Gamma_{
m total}
<u>VALUE</u> <u>CL%</u>
<9.0 × 10<sup>-6</sup> 90
                                         DOCUMENT ID TECN COMMENT
                                      1 \text{ INAMI} 09 BELL 490 fb^{-1} E_{\text{CM}}^{\text{ee}} = 10.6 \text{ GeV}
  ^1\, {\rm We} multiply the INAMI 09 measurement B( \tau^- \to ~\eta\, {\it K}^-\, {\it K}^0_S\, \nu_{\tau}) < ~4.5 \times 10^{-6} by 2
    to obtain the listed value.
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 τ

| $\Gamma(\eta\pi^+\pi^-\pi^-\geq 0 \text{ neutrals } \nu_	au)/\Gamma_{	ext{total}}$ Γ_{134}/Γ | $\Gamma(f_1(1285)\pi^-\nu_{	au} 	o \eta\pi^-\pi^+\pi^-\nu_{	au})/\Gamma_{	ext{total}}$ Γ_{145}/Γ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (%)CL%DOCUMENT IDTECNCOMMENT<0.390ABACHI87BHRS $E_{cm}^{ee} = 29$ GeV | <u>VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT</u> 1.11±0.06±0.05 1.3 k AUBERT 08AE BABR 384 fb ⁻¹ , E ^{en} _{cm} = 10.6 GeV |
| $\Gamma(\eta \pi^- \pi^+ \pi^- \nu_{\tau} (\text{ex.} K^0)) / \Gamma_{\text{total}}$ Γ_{135} / Γ | $\Gamma(f_1(1285)\pi^-\nu_{	au} 	o \eta\pi^-\pi^+\pi^-\nu_{	au})/\Gamma(\eta\pi^-\pi^+\pi^-\nu_{	au}(\text{ex.}K^0))$ $\Gamma_{145}/\Gamma_{135}$ |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT 1.64±0.12 OUR AVERAGE | VALUE DO CUMENT ID TECN COMMENT 0.69±0.01±0.05 ¹ AUBERT 08AE BABR 384 fb⁻¹, Ecm = 10.6 GeV |
| $-1.60\pm0.05\pm0.11$ 1.8 k AUBERT 08AE BABR 384 fb $^{-1}$, $E_{\rm cm}^{\it ee}=10.6$ GeV | • • We do not use the following data for averages, fits, limits, etc. |
| 2.3 \pm 0.5 170 ¹ ANASTASSOV 01 CLEO $E_{\rm CM}^{\rm ee}$ = 10.6 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • | 0.55 ± 0.14 BERGFELD 97 CLEO $E_{\text{cm}}^{\text{ee}} = 10.6 \text{ GeV}$ |
| $3.4 \begin{array}{c} +0.6 \\ -0.5 \end{array} \pm 0.6$ 89 ² BERGFELD 97 CLEO Repl. by ANASTASSOV 01 | 1 Not independent of AUBERT 08AE B($\tau^-\to f_1(1285)\pi^-\nu_\tau\to \eta\pi^-\pi^+\pi^-\nu_\tau)$ and B($\tau^-\to \eta\pi^-\pi^+\pi^-\nu_\tau$ (ex.K 0)) values. |
| ¹ Weighted average of BERGFELD 97 and ANASTASSOV 01 measurements using η 's reconstructed from $\eta \to \pi^+\pi^-\pi^0$ and $\eta \to 3\pi^0$ decays. | $ \Gamma(\pi(1300)^{-}\nu_{\tau} \to (\rho\pi)^{-}\nu_{\tau} \to (3\pi)^{-}\nu_{\tau})/\Gamma_{\text{total}} \qquad \qquad \Gamma_{146}/\Gamma_{\text{VALUE}} $ VALUE CL% DOCUMENT ID TECN COMMENT |
| 2 BERGFELD 97 reconstruct η 's using $\eta \to \gamma \gamma$ and $\eta \to 3\pi^0$ decays. $\Gamma(\eta a_1(1260)^-\nu_\tau \to \eta \pi^-\rho^0\nu_\tau)/\Gamma_{\rm total}$ Γ_{136}/Γ | VALUECL%DOCUMENT IDTECNCOMMENT<1.0 \times 10-490ASNER00CLEO $E_{\rm CM}^{ee}=10.6$ GeV |
| VALUECL%DOCUMENT IDTECNCOMMENT | $\Gamma(\pi(1300)^{-}\nu_{\tau} \to ((\pi\pi)_{S-wave} \pi)^{-}\nu_{\tau} \to (3\pi)^{-}\nu_{\tau})/\Gamma_{total} $ |
| <3.9 × 10⁻⁴ 90 BERGFELD 97 CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | VALUECL%DOCUMENT IDTECNCOMMENT $<1.9 \times 10^{-4}$ 90ASNER00CLEO $E_{\rm cm}^{ee} = 10.6$ GeV |
| $\Gamma(\eta\eta\pi^- u_	au)/\Gamma_{	ext{total}}$ VALUE CL% DOCUMENT ID TECN COMMENT | $\Gamma(h^-\omega \ge 0 \text{ neutrals } \nu_{\tau})/\Gamma_{\text{total}}$ Γ_{148}/Γ |
| VALUE CL% DOCUMENT ID TECN COMMENT <7.4 × 10 ⁻⁶ 90 INAMI 09 BELL 490 fb ⁻¹ E_{cm}^{ee} = 10.6 GeV | $\Gamma_{148}/\Gamma = (\Gamma_{149} + \Gamma_{151})/\Gamma^{-11}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" |
| $<1.1 \times 10^{-4}$ 95 ARTUSO 92 CLEO $E_{\rm cm}^{\rm ee} \approx 10.6~{\rm GeV}$ $<8.3 \times 10^{-3}$ 95 ALBRECHT 88M ARG $E_{\rm cm}^{\rm ee} \approx 10~{\rm GeV}$ | marks results used for the fit and the average. <u>VALUE (%)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| $\Gamma(\eta\eta\pi^{-}\pi^{0}\nu_{	au})/\Gamma_{	ext{total}}$ | 2.41±0.09 OUR FIT Error includes scale factor of 1.2. • • • We use the following data for averages but not for fits. • • • |
| VALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT | 1.65\pm0.3 \pm0.2 1513 ALBRECHT 88M ARG $E_{\text{CM}}^{\text{ee}} \approx 10 \text{ GeV}$ |
| < 2.095ARTUSO92CLEO $E_{\rm Cm}^{ee} \approx 10.6 \; {\rm GeV}$ • • • We do not use the following data for averages, fits, limits, etc.• • •<90 | $\Gamma(h^-\omega\nu_{\tau})/\Gamma_{	ext{total}}$ Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average. |
| $\Gamma(\eta\eta K^- u_{	au})/\Gamma_{	ext{total}}$ $\Gamma_{	ext{139}}/\Gamma$ | VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| VALUE CL% DOCUMENT ID TECN COMMENT <3.0 × 10 ⁻⁶ 90 INA MI 09 BELL 490 fb ⁻¹ $E_{CD}^{ee} = 10.6 \text{ GeV}$ | 2.00±0.08 OUR FIT Error includes scale factor of 1.3. 1.92±0.07 OUR AVERAGE |
| CIII | $1.91\pm0.07\pm0.06$ 5803 BUSKULIC 97c ALEP 1991-1994 LEP runs $1.60\pm0.27\pm0.41$ 139 BARINGER 87 CLEO $E_{\text{CM}}^{\text{ep}}=10.5$ GeV |
| $\Gamma(\eta'(958)\pi^- u_{	au})/\Gamma_{	ext{total}}$ VALUE CL% DOCUMENT ID TECN COMMENT | |
| <7.2 × 10 ⁻⁶ 90 AUBERT 08AE BABR 384 fb ⁻¹ , $E_{cm}^{ee} = 10.6$ GeV | $1.95\pm0.07\pm0.11$ 2223 1 BALEST 95c CLEO $E_{\rm CM}^{\rm ecm}\approx 10.6$ GeV 1 Not independent of BALEST 95c B($\tau^- \to h^- \omega u_	au$)/B($\tau^- \to h^- h^- h^+ \pi^0 u_	au$) value. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $<7.4 \times 10^{-5}$ 90 BERGFELD 97 CLEO $E_{\rm CM}^{\rm ee}=10.6$ GeV | · |
| $\Gamma(\eta'(958)\pi^-\pi^0\nu_	au)/\Gamma_{	ext{total}}$ Γ_{141}/Γ | $\Gamma_{149}/\Gamma_{66} = \Gamma_{149}/(\Gamma_{70} + \Gamma_{89} + \Gamma_{94} + 0.226\Gamma_{127} + 0.888\Gamma_{149} + 0.017\Gamma_{151})$ |
| VALUE CL% DOCUMENT ID TECN COMMENT | <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.437±0.017 OUR FIT Error includes scale factor of 1.2. |
| <8.0 × 10⁻⁵ 90 BERGFELD 97 CLEO $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ | 0.453±0.019 OUR AVERAGE 0.431±0.033 2350 ¹ BUSKULIC 96 ALEP LEP 1991−1993 data |
| $\Gamma(\phi\pi^- u_	au)/\Gamma_{	ext{total}}$ VALUE (units 10^{-5}) CL% EVTS DOCUMENT ID TECN COMMENT | $0.464\pm0.016\pm0.017$ 2223 ² BALEST 95c CLEO $E_{\rm ce}^{\rm en}\approx 10.6~{\rm GeV}$ ••• We do not use the following data for averages, fits, limits, etc. ••• |
| VALUE (units 10^{-5}) CL% EVTS DOCUMENT ID TECN COMMENT 3.42 ±0.55 ± 0.25 344 AUBERT 08 BABR 342 fb ⁻¹ $E_{CM}^{ee} = 10.6 \text{ GeV}$ | 0.37 ± 0.05 ± 0.02 458 ³ ALBRECHT 91D ARG $E_{\text{CM}}^{ee} = 9.4$ –10.6 GeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | ¹ BUSKULIC 96 quote the fraction of $\tau \to h^-h^-h^+\pi^0\nu_{\tau}(ex.~K^0)$ decays which |
| $<$ 20 90 1 AVERY 97 CLEO $E_{\rm cm}^{\rm ee} = 10.6$ GeV $<$ 35 90 ALBRECHT 95H ARG $E_{\rm cm}^{\rm ee} = 9.4$ -10.6 GeV | originate in a $h^-\omega$ final state $=0.383\pm0.029$. We divide this by the $\omega(782)\to\pi^+\pi^-\pi^0$ branching fraction (0.888). |
| 1 AVERY 97 limit varies from $(1.22.0) 	imes 10^{-4}$ depending on decay model assumptions. | 2 BALEST 95c quote the fraction of $	au^- 	o h^- h^- h^+ \pi^0 u_{	au}$ (ex. K^0) decays which originate in a $h^- \omega$ final state equals 0.412 \pm 0.014 \pm 0.015. We divide this by the |
| $\Gamma(\phi K^- u_{	au})/\Gamma_{	ext{total}}$ Γ_{143}/Γ | ω (782) $\to \pi^+\pi^-\pi^0$ branching fraction (0.888). ³ ALBRECHT 91D quote the fraction of $\tau^-\to h^-h^-h^+\pi^0\nu_{\tau}$ decays which originate in |
| VALUE (units 10 ⁻⁵) CL% EVTS DOCUMENT ID TECN COMMENT 3.70±0.33 OUR AVERAGE Error includes scale factor of 1.3. | a $\pi^-\omega$ final state equals $0.33\pm0.04\pm0.02$. We divide this by the $\omega(782) ightarrow \pi^+\pi^-\pi^0$ |
| $3.39 \pm 0.20 \pm 0.28$ 274 AUBERT 08 BABR 342 fb ⁻¹ $E_{\text{cm}}^{\text{ee}} = 10.6 \text{ GeV}$ | branching fraction (0.888). |
| $4.05\pm0.25\pm0.26$ 551 INAMI 06 BELL 401 fb $^{-1}$ E_{CM}^{ee} = 10.6 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(K^-\omega u_	au)/\Gamma_{	ext{total}}$ Γ ₁₅₀ /Γ VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT |
| <6.7 90 $\frac{1}{4}$ AVERY 97 CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | 4.1±0.6±0.7 500 ARMS 05 CLE3 7.6 fb ⁻¹ , E_{cm}^{ee} = 10.6 GeV |
| 1 AVERY 97 limit varies from (5.4–6.7) $	imes$ 10 $^{-5}$ depending on decay model assumptions. | $\Gamma(h^-\omega\pi^0 u_{	au})/\Gamma_{	ext{total}}$ |
| $\Gamma(f_1(1285)\pi^- u_{	au})/\Gamma_{	ext{total}}$ | VALUE (%) EVTS DOCUMENT ID TECN COMMENT 0.41±0.04 OUR FIT |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT 3.6 ±0.7 OUR AVERAGE | 0.43±0.06±0.05 7283 BUSKULIC 97c ALEP 1991-1994 LEP runs |
| $3.19\pm0.18\pm1.00$ 1.3 k 1 AUBERT 08AE BABR 384 fb $^{-1}$, $E_{\text{Cm}}^{\text{ee}}=10.6$ GeV $3.9\pm0.7\pm0.5$ 1.4 k 2 AUBERT,B 05W BABR 232 fb $^{-1}$, $E_{\text{cm}}^{\text{ee}}=10.6$ GeV \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | $ \begin{array}{l} \Gamma(h^-\omega\pi^0\nu_\tau)/\Gamma(h^-h^-h^+\geq 0 \text{ neutrals } \geq 0K_0^0\nu_\tau) & \Gamma_{151}/\Gamma_{54} \\ \Gamma_{151}/\Gamma_{54} = \Gamma_{151}/(0.3431\Gamma_{35}+0.3431\Gamma_{37}+0.3431\Gamma_{40}+0.3431\Gamma_{42}+0.4307\Gamma_{47}+\\ 0.6861\Gamma_{48}+\Gamma_{62}+\Gamma_{70}+\Gamma_{77}+\Gamma_{78}+\Gamma_{85}+\Gamma_{89}+\Gamma_{93}+\Gamma_{94}+0.285\Gamma_{125}+0.285\Gamma_{127}+\\ 0.9101\Gamma_{149}+0.9101\Gamma_{151}) \end{array} $ |
| 5.8 $^{+1.4}_{-1.3}$ ±1.8 54 3 BERGFELD 97 CLEO E^{ee}_{cm} = 10.6 GeV | Data marked "avg" are highly correlated with data appearing elsewhere in the Listings, |
| ¹ AUBERT 08AE obtain this value by dividing their B($\tau^- \to f_1(1285)\pi^-\nu_{\tau} \to \eta\pi^-\pi^+\pi^-\nu_{\tau})$ measurement by the PDG 06 value of B($f_1(1285) \to \eta\pi^-\pi^+) = 0.35 \pm 0.11$. The quote (3.19 \pm 0.18 \pm 0.16 \pm 0.99) \times 10 ⁻⁴ where the final error is due to the uncertainty on B($f_1(1285) \to \eta\pi^-\pi^+)$. We combine the two systematic errors | and are therefore used for the average given below but not in the overall fits. "f&a" marks results used for the fit and the average. VALUE |
| to the uncertainty on B($f_1(1285) \rightarrow \eta \pi^- \pi^+$). We combine the two systematic errors in quadrature. | • • We use the following data for averages but not for fits. |
| ² AUBERT,B 05w use the $f_1(1285) \to 2\pi^+ 2\pi^-$ decay mode and the PDG 04 value of B($f_1(1285) \to 2\pi^+ 2\pi^-$) = $0.110^{+0.007}_{-0.006}$. | 0.028 \pm 0.003 \pm 0.003 430 1 BORTOLETTO 93 CLEO $E_{ m CM}^{ee} \approx 10.6$ GeV 1 Not independent of BORTOLETTO 93 $\Gamma(au^- 	o h^- \omega \pi^0 u_	au)/\Gamma(au^- 	o h^- \omega \pi^0 u_	au)/\Gamma(au^- 	o h^- \omega \pi^0 u_	au)$ |
| $^{-0.006}$ BERGFELD 97 use the $f_1(1285) ightarrow \eta \pi^+ \pi^-$ decay mode. | $h^-h^-h^+2\pi^0\nu_{\tau}({\rm ex}.K^0))$ value. |

| $ \begin{array}{ll} (h^{-}\omega\pi^{0}\nu_{\tau})/\Gamma(h^{-}h^{-}h^{+}2\pi^{0}\nu_{\tau}(\text{ex.}K^{0})) & \Gamma_{151}/\Gamma_{76} \\ \Gamma_{151}/\Gamma_{76} = \Gamma_{151}/(\Gamma_{77} + 0.226\Gamma_{125} + 0.888\Gamma_{151}) & \end{array} $ | | ton family num | nber conservati | | | Г ₁₅₉ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|----------------------|---------------------------------------|----------|-----------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LUE <u>DOCUMENT ID</u> <u>TECN_COMMENT</u> | <u>∨ALUE</u> <2.6 × 10 ^{−8} | <u>CL%</u> 90 | DOCUMENT ID | | | $\frac{COMMENT}{671 \text{ fb}^{-1} E_{\text{cm}}^{ee}} = 10.6 \text{ Ge}$ |
| 83±0.08 OUR FIT | • • • We do not | | MIYAZAKI ing data for av | | | |
| $11\pm0.06\pm0.06$ BORTOLETTO93 CLEO $E_{\text{CM}}^{ee} \approx 10.6 \text{ GeV}$ | <3.3 × 10 ⁻⁸ | 90 | AUBERT | | | 469 fb $^{-1}$ $E_{\rm CM}^{ee} = 10.6$ Ge |
| $(h^-\omega 2\pi^0 u_	au)/\Gamma_{total}$ Γ_{152}/Γ | <5.6 × 10 ⁻⁸ | 90 | MIYAZAKI | 064 | BFII | $E_{\rm cm} = 10.0 {\rm Ge}^{-1}$ 281 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6 {\rm Ge}^{-1}$ |
| LUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | <9.1 × 10 ⁻⁷ | 90 | CHEN | 02c | CLEO | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| $1 \pm 0.4 \pm 0.3$ 53 ANASTASSOV 01 CLEO $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ | $< 1.3 \times 10^{-3}$ | 90 | HAYES | | | E ee = 3.8-6.8 GeV |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(\mu^- K_S^0)/\Gamma_{\rm tot}$ | 4-1 | | | | Г ₁₆₀ |
| $89^{+0.74}_{-0.67}\pm$ 0.40 19 ANDERSON 97 CLEO Repl. by ANASTASSOV 01 | | | nber conservati <u>DOCUMENT ID</u> | | TECN | COMMENT |
| $(h^- 2\omega u_	au)/\Gamma_{	ext{total}}$ Γ_{153}/Γ | <2.3 × 10 ⁻⁸ | 90 | MIYAZAKI | | | $671 \text{ fb}^{-1} E_{\text{cm}}^{ee} = 10.6 \text{ Ge}$ |
| LUE CL% DOCUMENT ID TECN COMMENT 5.4 × 10 ⁻⁷ 90 AUBERT,B 06 BABR 232 fb ⁻¹ $E_{Cm}^{ee} = 10.6 \text{ GeV}$ | • • • We do not $<4.0 \times 10^{-8}$ | | | | | nits, etc. $ullet$ |
| | <4.9 × 10 ⁻⁸ | 90 90 | AUBERT MIYAZAKI | 090 | DELL | $281 \text{ fb}^{-1} E_{\text{cm}}^{ee} = 10.6 \text{ Ge}^{-1}$ |
| $(2h^-h^+\omega\nu_{\tau})/\Gamma_{\text{total}}$ Γ_{154}/Γ | $<9.5 \times 10^{-7}$ | 90 | CHEN | | | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| LUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | $<1.0 \times 10^{-3}$ | 90 | HAYES | | | $E_{\rm cm}^{ee} = 3.8-6.8 \text{ GeV}$ |
| \pm 0.2±0.1 110 A NASTASSOV 01 CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | | | | | | |
| $e^-\gamma)/\Gamma_{ m total}$ Γ_{155}/Γ | $\Gamma(e^-η)/\Gamma_{total}$ Test of lept | on family num | nber conservati | ion. | | Г161 |
| Test of lepton family number conservation. LUECL%DOCUMENT IDCOMMENT | VALUE | <u>CL%</u> | DO CUMENT IE | | | COMMENT 1 22 |
| 3.3 × 10 ⁻⁸ 90 AUBERT 10B BABR 516 fb ⁻¹ , E_{CM}^{ee} =10.6 GeV | < 9.2 × 10 ⁻⁸ | 90 | MIYAZAKI | 07 | | 401 fb $^{-1}$, $E_{ m cm}^{\it ee}$ $=$ 10.6 Ge |
| • We do not use the following data for averages, fits, limits, etc. • • • | • • • We do not | | | | | |
| 1.2×10^{-7} 90 HAYASAKA 08 BELL 535 fb ⁻¹ , $E_{\rm Cm}^{ee} = 10.6 {\rm GeV}$ | $< 1.6 \times 10^{-7}$ $< 2.4 \times 10^{-7}$ | 90 90 | AUBERT | | | 339 fb ⁻¹ , E_{cm}^{ee} = 10.6 Ge |
| 1.1×10^{-7} 90 AUBERT 06c BABR 232 fb ⁻¹ , $E_{\rm cm}^{ee} = 10.6$ GeV | $< 2.4 \times 10^{-7}$ $< 8.2 \times 10^{-6}$ | 90 90 | ENARI BONVICINI | | | 154 fb ⁻¹ , $E_{\rm cm}^{ee}$ = 10.6 Ge $E_{\rm cm}^{ee}$ = 10.6 GeV |
| 3.9×10^{-7} 90 HAYASAKA 05 BELL 86.7 fb ⁻¹ , $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ | < 6.3 × 10 ⁻⁵ | 90 | ALBRECHT | | | $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ $E_{\text{cm}}^{ee} = 10 \text{ GeV}$ |
| $2.7 	imes 10^{-6}$ 90 EDWARDS 97 CLEO | $< 0.3 \times 10$ $< 24 \times 10^{-5}$ | 90 | KEH | | | $E_{\rm cm}^{ee} = 10 \text{ GeV}$ |
| 1.1 × 10 ⁻⁴ 90 ABREU 95 U DLPH 1990–1993 LEP runs | | | | | 2 | |
| 1.2×10^{-4} 90 ALBRECHT 92K ARG $E_{ m cm}^{ee} = 10~{ m GeV}$ 2.0×10^{-4} 90 KEH 88 CBAL $E_{ m cm}^{ee} = 10~{ m GeV}$ | $\Gamma(\mu^-\eta)/\Gamma_{\rm total}$ | | | | | Γ ₁₆₂ |
| 5.4×10^{-4} 90 HAYES 82 MRK2 $E_{\rm cm}^{\rm ee} = 3.8 - 6.8 {\rm GeV}$ | Test of lept <u>VALUE</u> | ton family num | nber conservati DOCUMENT IE | | TECN | COMMENT |
| 1.4 × 10 | <6.5 × 10 ⁻⁸ | 90 | MIYAZAKI | 07 | | 401 fb ⁻¹ , E ^{ee} _{cm} =10.6 Ge |
| $(μ^- γ)/Γ_{total}$ Γ ₁₅₆ /Γ | • • • We do not | use the follow | | | | |
| Test of lepton family number conservation. <u>UE CL% DOCUMENT ID TECN COMMENT</u> | $< 1.5 \times 10^{-7}$ | 90 | AUBERT | | | 339 fb $^{-1}$, $E_{ m cm}^{\it ee}$ $=$ 10.6 Ge |
| UE CL% DOCUMENT ID TECN COMMENT 4.4 × 10 ⁻⁸ 90 AUBERT 10B BABR 516 fb ⁻¹ , E_{CIII}^{ee} =10.6 GeV | $< 1.5 \times 10^{-7}$ | 90 | ENARI | 05 | | 154 fb ⁻¹ , $E_{\rm cm}^{ee} = 10.6 {\rm G}$ |
| • We do not use the following data for averages, fits, limits, etc. • • • | $< 3.4 \times 10^{-7}$ | 90 | ENARI | 04 | | 84.3 fb ⁻¹ , E ^{ee} _{cm} =10.6 G |
| 0 1 | $< 9.6 \times 10^{-6}$ | 90 | BONVICINI | 97 | CLEO | $E_{\text{cm}}^{\textit{ee}} = 10.6 \text{ GeV}$ |
| 4.5×10^{-6} 90 HAYASAKA 08 BELL 535 fb ⁻¹ , $E_{cm}^{em} = 10.6$ GeV 6.8×10^{-8} 90 AUBERT,B 05A BABR 232 fb ⁻¹ , $E_{cm}^{em} = 10.6$ GeV | $< 7.3 \times 10^{-5}$ | 90 | ALBRECHT | | ARG | $E_{\rm cm}^{\it ee}=10~{\rm GeV}$ |
| 3.1×10^{-7} 90 ABE 04B BELL 86.3 fb ⁻¹ , $E_{\text{cm}}^{\text{ee}} = 10.6 \text{ GeV}$ | E(- 0) /E | | | | | - |
| 1.1×10^{-6} 90 AHMED 00 CLEO $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | $\Gamma(e^-\rho^0)/\Gamma_{\text{tota}}$ | | nber conservati | ion | | Γ ₁₆₃ |
| 3.0×10^{-6} 90 EDWARDS 97 CLEO | VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| 6.2 × 10 ⁻⁵ 90 ABREU 950 DLPH 1990-1993 LEP runs | $< 1.8 \times 10^{-8}$ | 90 | MIYAZAKI | 11 | BELL | 854 fb $^{-1}$ $E_{\rm CM}^{ee}=10.6$ Ge |
| 0.42×10^{-5} 90 BEAN 93 CLEO $E_{\rm CM}^{ee} = 10.6 \; {\rm GeV}$ | ● ● We do not | use the follow | ing data for a | verages, | fits, lin | nits, etc. • • • |
| 3.4×10^{-5} 90 ALBRECHT 92K ARG $E_{\text{CM}}^{ee} = 10 \text{ GeV}$ | $< 4.6 \times 10^{-8}$ | 90 | AUBERT | 09W | BABR | 451 fb $^{-1}$ $E_{\rm cm}^{ee}=10.6$ Ge |
| 55×10^{-5} 90 HAYES 82 MRK2 $E_{\rm cm}^{ee} = 3.8-6.8 {\rm GeV}$ | $< 6.3 \times 10^{-8}$ | 90 | NISHIO | | | 543 fb $^{-1}$ $E_{\rm CM}^{ee} = 10.6$ Ge |
| $(e^-\pi^0)/\Gamma_{\rm total}$ Γ_{157}/Γ | $< 6.5 \times 10^{-7}$ | 90 | YUSA | | | 158 fb $^{-1}$ $E_{\rm CM}^{ee} = 10.6$ Ge |
| Test of lepton family number conservation. | $< 2.0 \times 10^{-6}$ | 90 | BLISS | | | $E_{ m cm}^{\it ee} = 10.6 \; { m GeV}$ |
| UE CL% DOCUMENT ID TECN COMMENT | $< 4.2 \times 10^{-6}$ | | BARTELT | | | Repl. by BLISS 98 |
| 8.0 × 10⁻⁸ 90 MIYAZAKI 07 BELL 401 fb ⁻¹ , E_{cm}^{ee} =10.6 GeV | $< 1.9 \times 10^{-5}$ $< 37 \times 10^{-5}$ | 90 90 | ALBRECHT | 92K | | $E_{\text{cm}}^{ee} = 10 \text{ GeV}$ |
| • We do not use the following data for averages, fits, limits, etc. • • • | | | HAYES | | WKK2 | E ee = 3.8-6.8 GeV |
| 1.3 × 10 ⁻⁷ 90 AUBERT 071 BABR 339 fb ⁻¹ , E_{Cm}^{ee} =10.6 GeV | ¹ BARTELT 94 | · | space decays. | | | |
| 1.9×10^{-7} 90 ENARI 05 BELL 154 fb ⁻¹ , $E_{\text{CM}}^{\text{ee}} = 10.6 \text{ GeV}$ | $\Gamma(\mu^-\rho^0)/\Gamma_{ m tota}$ | al | | | | Γ ₁₆₄ |
| 3.7×10^{-6} 90 BONVICINI 97 CLEO $E_{\rm cm}^{ee} = 10.6$ GeV 17 $\times 10^{-5}$ 90 ALBRECHT 92K ARG $E_{\rm cm}^{ee} = 10$ GeV | Test of lept | ton family num | nber conservati | | | |
| CIII | < 1.2 × 10 ⁻⁸ | <u>CL%</u> | DOCUMENT ID | | | COMMENT |
| 14×10^{-5} 90 KEH 88 CBAL $E_{\rm cm}^{\rm ce} = 10~{\rm GeV}$ 210×10^{-5} 90 HAYES 82 MRK2 $E_{\rm cm}^{\rm ce} = 3.8$ –6.8 GeV | < 1.2 × 10 ⁻⁵ • • • We do not | 90 use the follow | MIYAZAKI Jing data for av | | | 854 fb $^{-1}$ $E_{ m Cm}^{ee}=10.6$ Ge |
| CIII | $< 2.6 \times 10^{-8}$ | 90 | AUBERT | | | 451 fb $^{-1}$ $E_{ m cm}^{ee}=$ 10.6 Ge |
| $(\mu^-\pi^0)/\Gamma_{	ext{total}}$ Γ_{158}/Γ | < 2.6 × 10 ° < 6.8 × 10 ⁻⁸ | 90 90 | NISHIO | 0500 | DARK | $^{451 \text{ fb}}$ 1 $E_{\text{cm}}^{ee} = 10.6 \text{ Ge}$ 543 fb^{-1} $E_{\text{cm}}^{ee} = 10.6 \text{ Ge}$ |
| Test of lepton family number conservation. | < 2.0 × 10 ⁻⁷ | 90 | YUSA | 08 06 | BELL | $158 \text{ fb}^{-1} E_{\text{Cm}}^{ee} = 10.6 \text{ Ge}^{\circ}$ |
| UE CL% DOCUMENT ID TECN COMMENT 1.1×10^{-7} 90 AUBERT 071 BABR 339 fb ⁻¹ , E_{cm}^{ee} =10.6 GeV | < 6.3 × 10 ⁻⁶ | 90 | BLISS | 98 | CLEO | $E_{\rm cm}^{ee} = 10.6 \text{GeV}$ |
| • We do not use the following data for averages, fits, limits, etc. • • • | $< 5.7 \times 10^{-6}$ | | BARTELT | | | Repl. by BLISS 98 |
| | $< 2.9 \times 10^{-5}$ | 90 | ALBRECHT | | ARG | $E_{\rm cm}^{ee} = 10 \text{ GeV}$ |
| 1.2×10^{-7} 90 MIYAZAKI 07 BELL 401 fb $^{-1}$, $E_{\rm m}^{\rm ee}$ =10.6 GeV 4.1×10^{-7} 90 ENARI 05 BELL 154 fb $^{-1}$, $E_{\rm m}^{\rm ee}$ = 10.6 GeV | $<$ 44 $\times 10^{-5}$ | 90 | HAYES | | | E ^{ee} _{cm} = 3.8-6.8 GeV |
| 4.1×10^{-7} 90 ENARI 05 BELL 154 fb $^{-1}$, $E_{\rm CM}^{ee} = 10.6$ GeV 4.0×10^{-6} 90 BONVICINI 97 CLEO $E_{\rm CM}^{ee} = 10.6$ GeV | ¹ BARTELT 94 | assume nhase | space decays | | | ** |
| 4.0×10^{-5} 90 BONVICINI 97 CLEO $E_{\text{CM}}^{\text{em}} = 10.6 \text{ GeV}$ 4.4×10^{-5} 90 ALBRECHT 92K ARG $E_{\text{CM}}^{\text{em}} = 10 \text{ GeV}$ | | • | F | | | _ |
| TIT ALD NO ALDRECHT FER AND ECM = 10 GeV | $\Gamma(e^-\omega)/\Gamma_{\rm total}$ | | | _ | _ | Γ ₁₆₅ |
| | <u>VALUE</u> | CL% | DO CUMENT IL | <u>J</u> | | COMMENT |
| | | 0.0 | MIVAZARI | 11 | DELL | 954 fb-1 ree 1010 |
| | <4.8 × 10 ⁻⁸ | 90 | MIYAZAKI | | | 854 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6 {\rm G}_{\rm cm}^{ee}$ |
| | | | | verages, | fits, lin | |

 τ

| (μ¯ω)/Γ _{total} | CL% | DO CUMENT II | D | TECN | COMMENT | Γ ₁₆₆ /Γ | | $\Gamma(e^-\phi)/\Gamma_{\text{tota}}$ Test of lep | | ımber conservatio | n. | | Γ ₁₇ |
|------------------------------------------|----------------------------------|--------------------------------------------|---------|------|------------------------------------------------------|-----------------------|---|----------------------------------------------------|--------------------|-----------------------------------|------------|-------------|---------------------------------------------------------------------------|
| 4.7 × 10 ⁻⁸ | 90 | MIYAZAKI | 11 | | 854 fb ⁻¹ E ee cm | = 10.6 GeV | Ī | VALUE | | DO CUMENT ID | | | COMMENT |
| • • We do not u | | | | | | | • | $< 3.1 \times 10^{-8}$ | 90 | MIYAZAKI | 11 | BELL | 854 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ G |
| 1.0×10^{-7} | 90 | AUBERT | | | 384 fb ⁻¹ E ee cm | - 10 6 GeV | | $< 3.1 \times 10^{-8}$ | 90 | AUBERT | 09W | BABR | 451 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ G |
| 3.9 × 10 ⁻⁸ | 90 | NISHIO | 08 | BELL | 543 fb ⁻¹ E ee cm | = 10.6 GeV | | | t use the foll | owing data for av | erages | , fits, lin | nits, etc. • • • |
| J.J A 10 | 50 | MISTITO | 00 | DELL | 343 10 L CM | = 10.0 GCV | | $< 7.3 \times 10^{-8}$ | 90 | NISHIO | 08 | BELL | $543 \text{ fb}^{-1} E_{\text{Cm}}^{ee} = 10.6 \text{ G}$ |
| e ⁻ K*(892) ⁰) | /F _{total} | | | | | Γ_{167}/Γ | | $< 7.3 \times 10^{-7}$ | 90 | YUSA | 06 | BELL | $158 \text{ fb}^{-1} E_{\text{Cm}}^{ee} = 10.6 \text{ G}$ |
| Test of lepto | | mber conservati | ion. | | | , | | $< 6.9 \times 10^{-6}$ | 90 | BLISS | 98 | | $E_{\rm cm}^{\it ee}$ = 10.6 GeV |
| LUE | <u>CL%</u> | DO CUMENT ID | | | COMMENT 1 00 | | i | -4 34- | | | | | |
| 3.2×10^{-8} | 90 | MIYAZAKI | 11 | | 854 fb $^{-1}$ $E_{\rm cm}^{ee}$ | = 10.6 GeV | | $\Gamma(\mu^-\phi)/\Gamma_{\rm tota}$ | | | | | Γ ₁₇ |
| • • We do not ι | ise the follo | wing data for a | | | | | | | | ımber conservatio | n. | TECN | COMMENT |
| 5.9×10^{-8} | 90 | AUBERT | 09w | BABR | 451 fb ⁻¹ E _{CM} | = 10.6 GeV | | <8.4 × 10 ⁻⁸ | <u>CL%</u> 90 | <u>DO CUMENT ID</u> MIYA ZA KI | 11 | DELL | $\frac{COMMENT}{854 \text{ fb}^{-1} E_{\text{Cm}}^{ee}} = 10.6 \text{ G}$ |
| 7.8×10^{-8} | 90 | NISHIO | 80 | BELL | 543 fb ⁻¹ E ^{ee} _{Cm} | = 10.6 GeV | | | | | | | |
| 1.0×10^{-7} | 90 | YUSA | 06 | BELL | 158 fb $^{-1}$ $E_{\rm cm}^{ee}$ | = 10.6 GeV | | | | owing data for av | | | |
| $.1 \times 10^{-6}$ | 90 | BLISS | 98 | CLEO | $E_{\rm cm}^{\it ee}=10.6$ GeV | / | | $<1.9 \times 10^{-7}$ | 90 | AUBERT | 09W | BABR | 451 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ G |
| $.3 \times 10^{-6}$ | 90 | ¹ BARTELT | 94 | CLEO | Repl. by BLISS | 98 | | $<1.3 \times 10^{-7}$ | 90 | NISHIO | | BELL | $543 \text{ fb}^{-1} E_{\text{Cm}}^{ee} = 10.6 \text{ G}$ |
| $.8 \times 10^{-5}$ | 90 | ALBRECHT | 92ĸ | ARG | $E_{ m cm}^{\it ee}=10~{ m GeV}$ | | | $< 7.7 \times 10^{-7}$ | 90 | YUSA | 06 | BELL | 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ G |
| BARTELT 94 a | assume pha | se space decays. | | | | | | $< 7.0 \times 10^{-6}$ | 90 | BLISS | 98 | CLEO | $E_{ m cm}^{\it ee}=$ 10.6 GeV |
| - K*(000)0) | <i></i> | | | | | E /E | | Γ(e ⁻ e ⁺ e ⁻)/ | _ | | | | Γ |
| ı− K*(892) ⁰) | // total | mber conservati | ion | | | Г ₁₆₈ /Г | | | | ımber conservatio | n | | Γ ₁₇ |
| UE UE | <u>CL%</u> | DO CUMENT ID | ion. | TECN | COMMENT | | | VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| .9 × 10 ⁻⁸ | 90 | NISHIO | 08 | | 543 fb ⁻¹ Eee | | | $< 2.7 \times 10^{-8}$ | 90 | HAYASAKA | 10 | | 782 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ (|
| | | wing data for a | | | 0 | | | ● ● • We do no | t use the follo | owing data for av | | | |
| 2 × 10 ⁻⁸ | 90 | MIYAZAKI | 11 | | 854 fb ⁻¹ E ^{ee} _{cm} | - 10 6 GaV | Ī | < 2.9 ×10 ⁻⁸ | 90 | LEES | | | 468 fb ⁻¹ $E_{\rm cm}^{ee}$ = 10.6 G |
| 7×10^{-7} | 90 | AUBERT | | DVDD | AE1 fb-1 ree | _ 10.0 GeV | • | < 3.6 × 10 ⁻⁸ | 90 | MIYAZAKI | 104 | BELL | $E_{\rm cm} = 10.00$ 535 fb ⁻¹ $E_{\rm cm}^{ee} = 10.60$ |
| 7×10^{-7} 9×10^{-7} | | | | DARK | 451 fb ⁻¹ E ^{ee} _{cm} | _ 10.0 GeV | | < 4.3 × 10 ⁻⁸ | 90 | AUBERT | 00 | RBYDD | 376 fb ⁻¹ $E_{cm}^{ee} = 10.6$ (|
| _ | 90 | YUSA | 06 | BELL | 158 fb ⁻¹ E ^{ee} _{cm} | = 10.6 GeV | | < 4.3 × 10 ° < 2.0 × 10 ⁻⁷ | | | 0/B | N DABK | 01 E fb = 1 Cee 10.6 (|
| 5 × 10 ⁻⁶ | 90 | BLISS | 98 | | E ee = 10.6 GeV | | | | 90 | AUBERT | | DARK | 91.5 fb ⁻¹ $E_{cm}^{ee} = 10.6$ |
| 4×10^{-6} | 90 90 | 1 BARTELT | 94 | | Repl. by BLISS | שע | | < 3.5 × 10 ⁻⁷ | 90 | YUSA | 04 | BELL | 87.1 fb ⁻¹ $E_{cm}^{ee} = 10.6$ |
| 5 × 10 ⁻⁵ | | ALBRECHT | | ARG | $E_{\text{cm}}^{ee} = 10 \text{ GeV}$ | | | < 2.9 × 10 ⁻⁶ | 90 | BLISS | 98 | CLEO | E ee cm = 10.6 GeV |
| BARTELT 94 a | assume pha | se space decays. | | | | | | $< 0.33 \times 10^{-5}$ | 90 | 1 BARTELT | 94 | | Repl. by BLISS 98 |
| - ₹*(892) ⁰) | /F4-4-1 | | | | | Γ ₁₆₉ /Γ | | < 1.3 × 10 ⁻⁵ | 90 | ALBRECHT | 92K | | E ee |
| | | mber conservati | ion. | | | . 109/. | | < 2.7 × 10 ⁻⁵ | 90 | BOWCOCK | 90 | | $E_{\rm cm}^{ee} = 10.4-10.9$ |
| / <u>E</u> | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | | | $< 40 \times 10^{-5}$ | 90 | HAYES | 82 | MRK2 | $E_{\rm cm}^{ee} = 3.8-6.8 {\rm GeV}$ |
| 4×10^{-8} | 90 | MIYAZAKI | 11 | BELL | 854 fb $^{-1}$ $E_{ m cm}^{ee}$ | = 10.6 GeV | | ¹ BARTELT 9 | 4 assume pha | ise space decays. | | | |
| | ise the follo | wing data for a | verages | | | | | $\Gamma(e^-\mu^+\mu^-)/$ | г | | | | Γ |
| $.6 \times 10^{-8}$ | 90 | AUBERT | 09w | BABR | 451 ${\rm fb^{-1}}~E_{\rm CM}^{ee}$ | = 10.6 GeV | | | | ımber conservatio | ın | | Γ ₁₇ |
| 7×10^{-8} | 90 | NISHIO | 08 | BELL | 543 fb ⁻¹ E ^{ee} _{cm} | = 10.6 GeV | | VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| 0×10^{-7} | 90 | YUSA | 06 | BELL | 158 fb ⁻¹ E _{cm} | - 10 6 GeV | | $< 2.7 \times 10^{-8}$ | 90 | HAYASAKA | 10 | | 782 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ (|
| 4×10^{-6} | 90 | BLISS | 98 | CLEO | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ | _ 10.0 GeV | | | | owing data for av | | | |
| 1×10^{-5} | 90 | ¹ BARTELT | 94 | | Repl. by BLISS | | | $< 3.2 \times 10^{-8}$ | 90 | LEES | | | 468 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ G |
| | | se space decays. | | CLLO | Repl. by BE133 | 30 | | < 4.1 × 10 ⁻⁸ | 90 | MIYAZAKI | 08 | BELL | $535 \text{ fb}^{-1} E_{\text{cm}}^{\text{ee}} = 10.6 \text{ G}$ |
| | | sc space decays. | • | | | | | < 3.7 × 10 ⁻⁸ | 90 | AUBERT | 07 p | K BARR | $376 \text{ fb}^{-1} E_{\text{cm}}^{\text{ee}} = 10.6 \text{ G}$ |
| ı [−] K*(892) ⁰) | $/\Gamma_{total}$ | | | | | Γ_{170}/Γ | | < 3.3 × 10 ⁻⁷ | 90 | AUBERT | 07.6 | BABB | 91.5 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ |
| Test of lepto | n family nu | mber conservati | ion. | | | | | < 2.0 × 10 ⁻⁷ | 90 | YUSA | 04 | DELL | 87.1 fb ⁻¹ $E_{\text{cm}}^{\text{ee}} = 10.6$ |
| UE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | | | < 1.8 × 10 ⁻⁶ | 90 | BLISS | | | |
| .0 × 10 ⁻⁸ | 90 | MIYAZAKI | 11 | | 854 fb $^{-1}$ $E_{\rm cm}^{ee}$ | = 10.6 GeV | | < 0.36 × 10 ⁻⁵ | 90 | | 98 | | E ee = 10.6 GeV |
| | | wing data for a | _ | | | | | < 1.9 × 10 ⁻⁵ | 90 90 | ^I BARTELT ALBRECHT | 94 92 k | | Repl. by BLISS 98 <i>E^{ee}</i> _{cm} = 10 GeV |
| $.3 \times 10^{-8}$ | 90 | AUBERT | 09W | BABR | 451 fb ⁻¹ E _{cm} | = 10.6 GeV | | < 2.7 × 10 ⁻⁵ | 90 | BOWCOCK | | | $E_{\rm cm}^{ee} = 10.4-10.9$ |
| $.0 \times 10^{-7}$ | 90 | NISHIO | 80 | BELL | 543 fb ⁻¹ E _{cm} | = 10.6 GeV | | <33 ×10 ⁻⁵ | 90 | HAYES | | | $E_{cm}^{e} = 10.4-10.9$! $E_{cm}^{ee} = 3.8-6.8 \text{ GeV}$ |
| 0×10^{-7} | 90 | YUSA | 06 | BELL | 158 fb ⁻¹ E ^{ee} _{cm} : | = 10.6 GeV | | | | | 02 | IVIT\ I\ Z | - cm - 3.0-0.0 GeV |
| 5×10^{-6} | 90 | BLISS | 98 | CLEO | $E_{\rm CM}^{\it ee}=10.6$ GeV | / | | BARTELT 9 | 4 assume pha | ise space decays. | | | |
| 7×10^{-6} | 90 | ¹ BARTELT | 94 | | ${\sf Repl.\ by\ BLISS}$ | | | $\Gamma(e^+ \mu^- \mu^-)$ | [total | | | | Γ ₁₇ |
| BARTELT 94 a | assume pha | se space decays. | | | | | | Test of lep | ton family nu | ımber conservatio | n. | | ' 14 |
| | | | | | | F /F | | VALUE | <u>CL%</u> | DO CUMENT ID | | | COMMENT |
| _η'(958))/Γ | total | DO CUMENT " | n | TECN | COMMENT | Γ ₁₇₁ /Γ | | <1.7 × 10 ⁻⁸ | 90 | | | | 782 fb $^{-1}$ $E_{\rm cm}^{ee}$ = 10.6 (|
|) <u>E</u> 1.6 × 10 ⁻⁷ | 90 | <u>DO CUMENT II</u> MIYA ZA KI | 07 | | 401 fb ⁻¹ , E _{cm} | -10.6.GoV | | | t use the foll | owing data for av | | | |
| | | | | | | 1-10.0 060 | | $< 2.6 \times 10^{-8}$ | 90 | LEES | 10A | BABR | 468 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ G |
| | | wing data for a | | | | 10 1 5 | | $< 2.3 \times 10^{-8}$ | 90 | MIYAZAKI | 08 | BELL | 535 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ (|
| 2.4×10^{-7} | 90 | AUBERT | | | 339 fb ⁻¹ , E _{cm} | | | $< 5.6 \times 10^{-8}$ | 90 | AUBERT | 07в | k BABR | 376 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ (|
| $0. \times 10^{-7}$ | 90 | ENARI | 05 | BELL | $154~{ m fb}^{-1}$, $E^{ee}_{ m CM}$ | = 10.6 GeV | | <1.3 × 10 ⁻⁷ | 90 | AUBERT | 04 J | BABR | 91.5 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ |
| - ~/(0EO)/ /F | _ | | | | | F /F | | $< 2.0 \times 10^{-7}$ | 90 | YUSA | 04 | BELL | 87.1 fb ⁻¹ $E_{\rm cm}^{ee} = 10.6$ |
| - η'(958))/Γ | | DO 51114-11- | | TE C | courter- | Γ ₁₇₂ /Γ | | $<1.5 \times 10^{-6}$ | 90 | BLISS | | CLEO | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| ^{JE} | <u>CL%</u> | DO CUMENT II | | TECN | | 10 (C) (| | <0.35 × 10 ⁻⁵ | 90 | ¹ BARTELT | 94 | | Repl. by BLISS 98 |
| 3 × 10 ⁻⁷ | 90 | MIYAZAKI | 07 | | 401 fb $^{-1}$, $E_{\rm cm}^{ee}$ | 1=10.6 GeV | | $<1.8 \times 10^{-5}$ | 90 | ALBRECHT | | ARG | $E_{\rm cm}^{\it ee} = 10 {\rm GeV}$ |
| | | wing data for a | | | | | | <1.6 × 10 ⁻⁵ | 90 | BOWCOCK | | | $E_{\rm cm}^{ee} = 10.4-10.9$ |
| 4×10^{-7} | 90 | AUBERT | 071 | | 339 fb $^{-1}$, $E_{\rm cm}^{ee}$ | | | | | | ,,, | CLLO | - CIII - 10.4 10.7 |
| $.7 \times 10^{-7}$ | 90 | ENARI | 05 | | $154~{ m fb}^{-1}$, $E_{ m CM}^{ee}$ | | | +BARTELT 9 | assume pha | ise space decays. | | | |
| - £ (000) | | -> /= | | | | - /- | | $\Gamma(\mu^- e^+ e^-)$ | Γ _{total} | | | | Γ ₁₈ |
| $-f_0(980) \rightarrow$ | | | | _ | | Γ ₁₇₃ /Γ | | Test of lep | ton family nu | ımber conservatio | n. | | |
| <u>JE</u> | <u>CL%</u> | DOCUMENT I | | | COMMENT 1 = 00 | | | VALUE | CL% | DO CUMENT ID | | TECN | |
| 2 × 10 ⁻⁸ | 90 | MIYAZAKI | 09 | BELL | 671 fb ⁻¹ <i>E</i> cm | = 10.6 GeV | | $< 1.8 \times 10^{-8}$ | 90 | HAYASAKA | 10 | BELL | 782 fb $^{-1}$ $E_{\rm cm}^{ee}$ = 10.6 G |
| | | · | | | | E /E | | | | | | | |
| - f (000) · | ,,- + | - \ / E | | | | | | | | | | | |
| $f_0(980) \rightarrow$ | μ ⁻ π ⁺ π' | ¯)/「 _{total} <u>DOCUMENT I</u> | ID | TECN | COMMENT | Γ ₁₇₄ /Γ | | | | | | | |

| Γ ₁₈₅ / | | | n | or concernatio | otal | $\Gamma(\mu^-\pi^+\pi^-)/$ | _ | | | lowing data for ave | use the fol | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|----------------------------|--------------------------------------------------------|----------------------------------------------------------|---------------------------------------------------------------------------------------|------------------------------------------------------------------------|-----------|--------|----------------------|------------------------------|----------------------------|
| | COMMENT | TECN | n. | er conservatio OCUMENT ID | | lest of lept <u>VALUE</u> | 68 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ GeV | BABR | 10A | LEES | 90 | 2×10^{-8} |
| -10 6 GeV | 671 fb ⁻¹ , $E_{cm}^{ee} = 1$ | | 10 | IIYAZAKI | | <3.3 × 10 ⁻⁸ | 35 fb $^{-1}$ $E_{\rm cm}^{{ee}} = 10.6$ GeV | BELL | 80 | MIYAZAKI | 90 | 7×10^{-8} |
| _ 10.0 GCV | | | | | | • • • We do not | 76 fb $^{-1}$ $E_{ m cm}^{\it ee}$ $=$ 10.6 GeV | BABR | 07вк | AUBERT | 90 | 0×10^{-8} |
| | | | | | | | 1.5 fb $^{-1}$ $E_{ m cm}^{\it ee}$ = 10.6 GeV | BABR | 04 J | AUBERT | 90 | 7×10^{-7} |
| = 10.6 GeV | 158 fb ⁻¹ $E_{\rm cm}^{ee} = 1$ | RELL | 06 | USA | | $<4.8 \times 10^{-7}$ | 7.1 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ GeV | BELL | 04 | YUSA | 90 | 9×10^{-7} |
| | 221 fb ⁻¹ , $E_{cm}^{ee} = 1$ | | | | | $<2.9 \times 10^{-7}$ | ee = 10.6 GeV | CLEO | 98 | BLISS | 90 | 7×10^{-6} |
| V | $E_{ m cm}^{\it ee}$ = 10.6 GeV | CLEO | 98 | LISS | _ | $< 8.2 \times 10^{-6}$ | epl. by BLISS 98 | | 94 | ¹ BARTELT | 90 | 34×10^{-5} |
| 98 | Repl. by BLISS 98 | CLEO | 94 | ARTELT | 90 1 | $< 7.4 \times 10^{-6}$ | ee = 10 GeV | | | ALBRECHT | 90 | 4×10^{-5} |
| | $E_{ m cm}^{\it ee}$ $=$ 10 GeV | ARG | 92K | LBRECHT | 90 | $< 3.6 \times 10^{-5}$ | | | | BOWCOCK | 90 | 7 × 10 ⁻⁵ |
| .9 | $E_{cm}^{ee} = 10.4-10.9$ | CLEO | 90 | OWCOCK | 90 | $< 3.9 \times 10^{-5}$ | ee cm = 10.4-10.9 em = 3.8-6.8 GeV | MDKO | | | 90 | × 10 ⁻⁵ |
| | | | | nace decays | ssume nhase | ¹ BARTELT 94 | 5m = 3.8-6.8 GeV | WKK2 | 82 | HAYES | | |
| | | | | , | | | | | | ase space decays. | assume ph | ARTELT 94 a |
| Γ186/ | | | | | otal | $\Gamma(\mu^+\pi^-\pi^-)/$ | Γ ₁₈₁ /Γ | | | | | - e - e -)/Γ _t |
| | COMMENT | TECN | | ervation. | n number cor | Test of lept | ' 1817' | | n . | umber conservatio | | |
| 404614 | $\frac{COMMENT}{671 \text{ fb}^{-1}, E_{\text{cm}}^{ee} = 1}$ | <u>TECN</u> | | OCUMENT ID | | VALUE | OMMENT | TECN | **** | DO CUMENT ID | CL% | Test of lepto |
| =10.6 GeV | | | | IIYAZAKI | | <3.7 × 10 ⁻⁸ | $E_{\rm cm}^{-1} = 10.6 {\rm GeV}$ | BELL | 10 | HAYASAKA | 90 | × 10 ⁻⁸ |
| | | | | | | • • • We do not | | | | lowing data for ave | | |
| = 10.6 GeV | $158 \text{fb}^{-1} E_{\text{cm}}^{ee} = 1$ | BELL | 06 | USA | 90 | $< 3.4 \times 10^{-7}$ | | | | | | × 10 ⁻⁸ |
| = 10.6 GeV | 221 fb $^{-1}$, $E_{cm}^{ee} = 1$ | BABR | 05 D | UBERT,BE | 90 | $< 7 \times 10^{-8}$ | $E_{\rm cm}^{-1} = 10.6 \text{GeV}$ | DADK | 10A | LEES | 90 | |
| V | $E_{\rm cm}^{\it ee}=10.6~{\rm GeV}$ | CLEO | 98 | LISS | 90 | $< 3.4 \times 10^{-6}$ | 35 fb ⁻¹ $E_{\text{cm}}^{\text{ee}} = 10.6 \text{ GeV}$ | RELL | 08 | MIYAZAKI | 90 | × 10 ⁻⁸ |
| | Repl. by BLISS 98 | | | ARTELT | 90 1 | $< 6.9 \times 10^{-6}$ | 76 fb $^{-1}E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | BABR | 07вк | AUBERT | 90 | $\times 10^{-8}$ |
| | $E_{\rm cm}^{ee} = 10 \text{GeV}$ | | 92K | LBRECHT | | $<6.3 \times 10^{-5}$ | 1.5 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ GeV | BABR | ر 04 | AUBERT | 90 | × 10 ⁻⁷ |
| .9 | $E_{\rm cm}^{ee} = 10.4-10.9$ | | | owcock | | $< 3.9 \times 10^{-5}$ | 7.1 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ GeV | BELL | 04 | YUSA | 90 | $\times 10^{-7}$ |
| | CIII 2017 | | - | | | | ee cm = 10.6 GeV | | | BLISS | 90 | $\times 10^{-6}$ |
| | | | | pace decays. | issume phase | ¹ BARTELT 94 | epl. by BLISS 98 | | 94 | ¹ BARTELT | 90 | 1×10^{-5} |
| Γ ₁₈₇ / | | | | | total | $\Gamma(e^-\pi^+K^-)/$ | $\stackrel{ee}{\rm cm}=10$ GeV | | 92K | ALBRECHT | 90 | $\times 10^{-5}$ |
| 1017 | | | n. | er conservatio | n family num | Test of lept | ee = 10.4–10.9 | | | BOWCOCK | 90 | $\times 10^{-5}$ |
| | COMMENT | TECN | | OCUMENT ID | CL% | VALUE | 3111 | | | | | |
| =10.6 GeV | 671 fb ⁻¹ , $E_{cm}^{ee} = 1$ | BELL | 10 | 1IYA ZA KI | 90 | $< 5.8 \times 10^{-8}$ | | | | ase space decays. | assume pn | ARTELI 94 a |
| | nits, etc. • • • | fits, lim | erages, | g data for ave | se the follow | • • • We do not | Γ ₁₈₂ /Γ | | | | total | $-\mu^+\mu^-)/\Gamma_1$ |
| - 10 6 GeV | 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 1$ | | | USA | | $< 7.2 \times 10^{-7}$ | | | n. | umber conservatio | n family n | Test of lepto |
| _ 10.0 GeV | 221 fb ⁻¹ , $E_{cm}^{ee} = 1$ | DADD | 00 | UDEDT DE | 90 | $< 3.2 \times 10^{-7}$ | OMMENT | TECN | | DO CUMENT ID | CL% | |
| = 10.6 GeV | 221 TD -, E cm = 1 | BABK | 050 | | | | DMMENT 32 fb ⁻¹ E ^{ee} _{Cm} = 10.6 GeV | BELL | 10 | HAYASAKA | 90 | 1 × 10 ⁻⁸ |
| | $E_{ m cm}^{\it ee} = 10.6 \; { m GeV}$ | | | LISS | _ | $<6.4 \times 10^{-6}$ | etc • • | fits limi | erages | lowing data for ave | | |
| 5 98 | Repl. by BLISS 98 | | | ARTELT | | $< 7.7 \times 10^{-6}$ | | | | | | |
| | $E_{\rm cm}^{\it ee}=10~{\rm GeV}$ | | | LBRECHT | | $<2.9 \times 10^{-5}$ | $E_{\text{Cm}}^{ee} = 10.6 \text{ GeV}$ | | | LEES | 90 | 3 × 10 ⁻⁸ |
| .9 | $E_{\rm cm}^{ee} = 10.4-10.9$ | CLEO | 90 | owcock | 90 | $< 5.8 \times 10^{-5}$ | $E_{\rm cm}^{-1} = 10.6 \; {\rm GeV}$ | | | MIYAZAKI | 90 | 2×10^{-8} |
| | | | | pace decays. | ssume phase | ¹ BARTELT 94 | 76 fb $^{-1}$ $E_{ m cm}^{\it ee}$ = 10.6 GeV | BABR | 07BK | AUBERT | 90 | 3×10^{-8} |
| | | | | , | | | 1.5 fb $^{-1}$ $E_{ m cm}^{ee} = 10.6$ GeV | BABR | 04 J | AUBERT | 90 | 9×10^{-7} |
| Г188/ | | | | | | $\Gamma(e^-\pi^-K^+)/$ | 7.1 fb $^{-1}$ $E_{ m cm}^{\it ee}$ $=$ 10.6 GeV | BELL | 04 | YUSA | 90 | 0×10^{-7} |
| | | | n. | er conservatio | | | <i>ee</i> cm = 10.6 GeV | CLEO | 98 | BLISS | 90 | 9×10^{-6} |
| 10.6.6.16 | COMMENT | | 10 | OCUMENT ID | | VALUE | epl. by BLISS 98 | | 94 | ¹ BARTELT | 90 | 43×10^{-5} |
| =10.6 GeV | 671 fb $^{-1}$, $E_{\rm cm}^{ee} = 1$ | | | IIYA ZA KI | | <5.2 × 10 ⁻⁸ | $_{ m cm}^{ee}=10$ GeV | ARG | 92K | ALBRECHT | 90 | 9×10^{-5} |
| | | | | g data for ave | ise the follow | • • • We do not | ee cm = 10.4–10.9 | | 90 | BOWCOCK | 90 | 7×10^{-5} |
| | 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 1$ | | | USA | 90 | $<1.6 \times 10^{-7}$ | ee cm = 3.8-6.8 GeV | | 82 | HAYES | 90 | $\times 10^{-5}$ |
| | 221 fb $^{-1}$, $E_{\rm cm}^{ee} = 1$ | | | UBERT,BE | 90 | $< 1.7 \times 10^{-7}$ | .m = 515 515 551 | | | | | |
| V | $E_{ m cm}^{\it ee}$ = 10.6 GeV | CLEO | 98 | LISS | 90 | $< 3.8 \times 10^{-6}$ | | | | ase space decays. | assume ph | ARTELI 94 a |
| | Repl. by BLISS 98 | | | ARTELT | 90 1 | $< 4.6 \times 10^{-6}$ | Γ ₁₈₃ /Γ | | | | 4-4-1 | $\pi^+\pi^-)/\Gamma_t$ |
| | $E_{\rm cm}^{ee} = 10.4-10.9$ | | | owcock | | $< 5.8 \times 10^{-5}$ | 1 103/1 | | n. | umber conservatio | tota l on family n | Test of lepto |
| | CIII | | | naco docave | scumo phaco | ¹ BARTELT 94 | MMENT | TECN | | DO CUMENT ID | CL% | |
| | | | | pace decays. | | | I fb ⁻¹ , <i>E</i> ^{ee} _{CM} =10.6 GeV | | | MIYAZAKI | 90 | ×10 ⁻⁸ |
| Γ ₁₈₉ / | | | | | total | $\Gamma(e^+\pi^-K^-)/$ | | | | lowing data for ave | | |
| 107/ | | | | ervation. | n numbercor | | | | | | | |
| | COMMENT | | | OCUMENT ID | CL% | VALUE | $6 \text{fb}^{-1} E_{\text{CM}}^{ee} = 10.6 \text{GeV}$ | | | YUSA | 90 | × 10 ⁻⁷ |
| =10.6 GeV | 671 fb $^{-1}$, $E_{\rm cm}^{ee} = 1$ | BELL | 10 | 1IYA ZA KI | 90 | $< 6.7 \times 10^{-8}$ | I fb $^{-1}$, $E_{ m cm}^{\it ee} = 10.6 \; { m GeV}$ | | | | 90 | × 10 ⁻⁷ |
| | | | | | | • • • We do not | e m= 10.6 GeV | CLEO | 98 | BLISS | 90 | $\times 10^{-6}$ |
| - 10 6 GeV | $158 \text{fb}^{-1} E_{\text{cm}}^{ee} = 1$ | | | USA | | $< 1.9 \times 10^{-7}$ | pl. by BLISS 98 | CLEO I | | ¹ BARTELT | 90 | $\times 10^{-6}$ |
| | | | | | | | e m= 10 GeV | ARG A | 92ĸ | ALBRECHT | 90 | $\times 10^{-5}$ |
| | 221 fb ⁻¹ , $E_{\rm cm}^{ee} = 1$ | | | | | $<1.8 \times 10^{-7}$ | e m = 10.4–10.9 | CLEO / | | BOWCOCK | 90 | $\times 10^{-5}$ |
| | E ^{ee} _{cm} = 10.6 GeV | | | LISS | _ | $<2.1 \times 10^{-6}$ | *** | - | | | | |
| 98 | Repl. by BLISS 98 | | | ARTELT | | $<4.5 \times 10^{-6}$ | | | | ase space decays. | assume ph | AKIELI 94 a |
| | $E_{ m cm}^{\it ee}=$ 10 GeV | | 92K | LBRECHT | | $<2.0 \times 10^{-5}$ | Γ ₁₈₄ /Γ | | | | tota! | $\pi^-\pi^-)/\Gamma_t$ |
| .9 | $E_{\rm cm}^{ee} = 10.4-10.9$ | CLEO | 90 | owcock | 90 | $< 4.9 \times 10^{-5}$ | - 104/ - | | | conservation. | on number | Test of lepto |
| | | | | pace decays. | issume phase | ¹ BARTELT 94 | MMENT | TECN | | DO CUMENT ID | CL% | |
| _ | | | | , | | | I fb $^{-1}$, $E_{ m cm}^{\it ee}$ $=$ 10.6 GeV | | | MIYAZAKI | 90 | ×10 ⁻⁸ |
| Г190/ | | | | | | $\Gamma(e^-K_S^0K_S^0)/$ | | | | lowing data for ave | use the fol | |
| | | | | er conservatio | | | $E_{\rm cm}^{-1} = 10.6 {\rm GeV}$ | | - | YUSA | 90 | × 10 ⁻⁷ |
| | COMMENT | | | DO CUMENT ID | <u>CL %</u> | VALUE | | | | | | |
| 5 = 10.6 Ge | . 671 fb $^{-1} E_{ m cm}^{ee} =$ | | | MIYAZAKI | 90 | $< 7.1 \times 10^{-8}$ | I fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | | | AUBERT,BE | 90 | × 10 ⁻⁷ |
| | mits etc | fits, lim | erages, | g data for ave | se the follow | • • • We do not | $ m ^{\it e}_{m} = 10.6 \; GeV$ | | | BLISS | 90 | $\times 10^{-6}$ |
| | into, etc. • • • | | | CHEN | 90 | $< 2.2 \times 10^{-6}$ | pl. by BLISS 98 | | | ¹ BARTELT | 90 | $\times 10^{-6}$ |
| | | | | | | | e _m = 10 GeV | ARG I | 92K | ALBRECHT | 90 | $\times 10^{-5}$ |
| | D $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ | CLLO | | | | $\Gamma(e^-K^+K^-)$ | m = 10.4-10.9 | | 90 | BOWCOCK | 90 | $\times 10^{-5}$ |
| GeV | | CLLO | | | total | | ** | | | | | |
| GeV | O <i>E</i> ^{ee} _{cm} = 10.6 GeV | | n. | er conservatio | total n family num | Test of lept | | | | see ensee decess | accilmo of | |
| _{БеV} Г ₁₉₁ / | D $E_{ m cm}^{ee} = 10.6~{ m GeV}$ | <u>TECN</u> | | er conservatio OCUMENT ID | n family num | Test of lept | | | | ase space decays. | assume ph | ARTELI 94 a |
| _{Г191} / | D $E_{ m cm}^{ee} = 10.6~{ m GeV}$ | <u>TECN</u> | | | n family num <u>CL%_</u> | Test of lept | | | | ase space decays. | assume ph | ARTELI 94 a |
| _{Г191} / | $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ $\frac{COMMENT}{671 \text{ fb}^{-1}, E_{\text{CM}}^{ee}} = 1$ | <u>TECN</u> BELL | 10 | OCUMENT ID 11 YA ZA KI | n family num <u>CL%</u> 90 | Test of lept VALUE <5.4 × 10 ⁻⁸ | | | | ase space decays. | assume ph | ARTELI 94 a |
| F191/ _=10.6 GeV | $D E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ $\frac{COMMENT}{671 \text{ fb}^{-1}, E_{\text{cm}}^{ee} = 1}$ nits, etc. • • | <u>TECN</u> BELL fits, lim | 10 erages, | <i>OCUMENT ID</i> ¶YAZAKI g data for ave | n family num <u>CL%</u> 90 use the follow | Test of lept VALUE $<5.4 \times 10^{-8}$ • • • We do not | | | | ase space decays. | assume ph | ARTELT 94 a |
| F191/ =10.6 GeV = 10.6 GeV | $\begin{array}{c} C & E_{\rm CM}^{ee} = 10.6 \; {\rm GeV} \\ \\ & \frac{COMMENT}{671 \; {\rm fb}^{-1}, \; E_{\rm CM}^{ee}} = 1 \\ \\ {\rm mits, \; etc. \bullet \bullet} \\ & 158 \; {\rm fb}^{-1} \; E_{\rm CM}^{ee} = 1 \end{array}$ | TECN BELL fits, lim BELL | 10 erages, 06 | <u>OCUMENT ID</u> IIYAZAKI g data for ave USA | n family num <u>CL%</u> 90 use the follow 90 | Test of lept VALUE $ < 5.4 \times 10^{-8} $ • • • We do not $ < 3.0 \times 10^{-7} $ | | | | ase space decays. | assume ph | ARTELT 94 6 |
| Fig. 7 Fi | $D E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ $\frac{COMMENT}{671 \text{ fb}^{-1}, E_{\text{cm}}^{ee} = 1}$ nits, etc. • • | TECN BELL fits, lim BELL BABR | 10 erages, 06 05D | <u>OCUMENT ID</u> IIYAZAKI g data for ave USA | n family num <u>CL%</u> 90 use the follow 90 | Test of lept VALUE $<5.4 \times 10^{-8}$ • • • We do not | | | | ase space decays. | assume ph | ARTELI 94 a |

 τ

| Γ(e ⁺ K ⁻ K ⁻)/ | /F _{total} | conservation. | | Γ ₁₉₂ /Γ | $\Gamma(e^-\eta\eta)/\Gamma_{\text{total}}$ | I on family numbe | r conservation | | | Γ ₂₀₁ /Γ |
|-------------------------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|-------------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------------------------------|---------------------------------------|-------------------|------------------------------|---------------------------------------------------------------------------------------|
| VALUE | | DO CUMENT ID | | CN COMMENT | VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
| $<6.0 \times 10^{-8}$ | 90 | MIYAZAKI | 10 BE | LL $671~{ m fb}^{-1}$, $E^{ee}_{ m CM}$ $=$ $10.6~{ m GeV}$ | $< 35 \times 10^{-6}$ | 90 | BONVICINI | 97 | CLEO | $E_{\rm cm}^{\it ee}$ = 10.6 GeV |
| ullet $ullet$ We do not | use the foll | owing data for av | | , limits, etc. • • • | Γ(=) /Γ | | | | | F /F |
| $< 3.1 \times 10^{-7}$ | 90 | YUSA | 06 BE | LL $158 \text{ fb}^{-1} E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ | $\Gamma(\mu^-\eta\eta)/\Gamma_{ m tota}$ | ı l on family numbe | r conservation. | | | Γ ₂₀₂ /Γ |
| $<1.5 \times 10^{-7}$ | 90 | AUBERT,BE | | BR 221 fb $^{-1}$, $E_{\rm CM}^{ee} = 10.6 {\rm GeV}$ | VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
| $< 3.8 \times 10^{-6}$ | 90 | BLISS | 98 CL | EO $E_{ m CM}^{\it ee}=10.6$ GeV | $<60 \times 10^{-6}$ | 90 | BONVICINI | 97 | CLEO | $E_{\mathrm{cm}}^{\mathit{ee}} = 10.6 \; \mathrm{GeV}$ |
| Γ(μ ⁻ π ⁺ K ⁻)/ Test of lept | | umber conservatio | on. | Γ ₁₉₃ /Γ | $\Gamma(e^-\pi^0\eta)/\Gamma_{ m tot}$ Test of lepto | t al on family numbe | r conservation. | | | Γ ₂₀₃ /Γ |
| VALUE | <u>CL%</u> | DO CUMENT ID | | N COMMENT | VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $< 1.6 \times 10^{-7}$ | 90 | MIYAZAKI | | L 671 fb $^{-1}$, $E_{ m cm}^{\it ee}$ $=$ 10.6 GeV | $<24 \times 10^{-6}$ | 90 | BONVICINI | 97 | CLEO | $E_{ m cm}^{\it ee}=10.6~{ m GeV}$ |
| _ | use the foll | | | , limits, etc. • • • | $\Gamma(\mu^-\pi^0\eta)/\Gamma_{\rm tot}$ | . | | | | Γ ₂₀₄ /Γ |
| $< 2.7 \times 10^{-7}$ | 90 | YUSA | | L 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | Test of lepto | ta l on family numbe | r conservation. | | | ' 204/ ' |
| $< 2.6 \times 10^{-7}$ | 90 | AUBERT,BE | | BR 221 fb ⁻¹ , $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | VALUE | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT |
| $< 7.5 \times 10^{-6}$ $< 8.7 \times 10^{-6}$ | 90 | BLISS ¹ BARTELT | | O E cm = 10.6 GeV | $<22 \times 10^{-6}$ | 90 | BONVICINI | 97 | CLEO | $E_{\rm cm}^{\it ee}=10.6~{\rm GeV}$ |
| $< 8.7 \times 10^{-5}$ | 90 90 | ALBRECHT | 94 CLE 92K ARG | O Repl. by BLISS 98 G E ^{ee} _{CM} = 10 GeV | $\Gamma(\overline{p}\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂₀₅ /Γ |
| $< 7.7 \times 10^{-5}$ | 90 | BOWCOCK | | O $E_{cm}^{ee} = 10.4-10.9$ | Test of lepto | on number and b | aryon number co | onserva | tion. | . 2057 - |
| _ | | ase space decays. | 70 CLL | C Lcm = 10.4 10.5 | VALUE | <u>CL%_</u> | DOCUMENT ID | | TECN | COMMENT |
| | · | ise space decays. | | | < 3.5 × 10 ⁻⁶ | 90 | GODANG | | | <i>E</i> ^{ee} _{cm} = 10.6 GeV |
| $\Gamma(\mu^-\pi^-K^+)/$ | Γ _{total} | | | Γ ₁₉₄ /Γ | • • • We do not | _ | _ | | | |
| Test of lept | on family no | umber conservation of the | | NCOMMENT | $< 29 \times 10^{-5}$ | 90 | ALBRECHT | 92K | ARG | E ^{ee} _{cm} = 10 GeV |
| <1.0 × 10 ⁻⁷ | 90 | MIYAZAKI | | L 671 fb ⁻¹ , $E_{\rm cm}^{ee}$ =10.6 GeV | $\Gamma(\overline{p}\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₂₀₆ /Γ |
| | | | | , limits, etc. • • • | Test of lepto | on number and b | | onserva | | • |
| $< 7.3 \times 10^{-7}$ | 90 | YUSA | | L 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | <u>∨ALUE</u> <15 × 10 ⁻⁶ | <u>CL%_</u> | DO CUMENT ID | | TECN | COMMENT |
| $< 3.2 \times 10^{-7}$ | 90 | | 05 D BAF | $E_{\rm cm} = 10.6 {\rm GeV}$ BR 221 fb ⁻¹ , $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | | 90 | GODANG | | | E ee = 10.6 GeV |
| $< 7.4 \times 10^{-6}$ | 90 | BLISS | | O $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ | • • • We do not $<66 \times 10^{-5}$ | 90 | | | ARG | |
| $<1.5 \times 10^{-5}$ | 90 | ¹ BARTELT | | O Repl. by BLISS 98 | <00 × 10 - | 90 | ALBRECHT | 92K | ARG | E ^{ee} _{cm} = 10 GeV |
| $< 7.7 \times 10^{-5}$ | 90 | BOWCOCK | | O $E_{cm}^{ee} = 10.4-10.9$ | $\Gamma(\overline{p}2\pi^0)/\Gamma_{\text{total}}$ | | | | | Γ ₂₀₇ /Γ |
| ¹ BARTELT 94 | assume pha | ase space decays. | | | Test of lepto | on number and b | | onserva | | |
| | | | | - /- | <33 × 10 ⁻⁶ | <u>CL%</u> 90 | DOCUMENT ID | | TECN | COMMENT |
| $\Gamma(\mu^+\pi^-K^-)/$ | total | conservation. | | Γ ₁₉₅ / Γ | ₹33 X 10 - | 90 | GODANG | 99 | CLEO | E ^{ee} _{cm} = 10.6 GeV |
| VALUE | CL% | DO CUMENT ID | TEC | N <u>COMMENT</u> | $\Gamma(\overline{p}\eta)/\Gamma_{total}$ | | | | | Γ ₂₀₈ /Γ |
| $< 9.4 \times 10^{-8}$ | 90 | MIYAZAKI | 10 BEL | L 671 fb $^{-1}$, $E_{\rm cm}^{\it ee}$ =10.6 GeV | Test of lepto | on number and b | | | | COLUMENT |
| ullet $ullet$ We do not | use the foll | owing data for av | verages, fits | , limits, etc. • • • | < 8.9 × 10 ⁻⁶ | <u>CL%</u> 90 | CODANG | | | COMMENT Eee 10.6 CoV |
| $< 2.9 \times 10^{-7}$ | 90 | YUSA | 06 BEL | L 158 fb $^{-1}$ $E_{\rm cm}^{ee} = 10.6$ GeV | • • • We do not | | GODANG | | | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| $< 2.2 \times 10^{-7}$ | 90 | AUBERT,BE | 05D BAE | 3R 221 fb $^{-1}$, $E_{\rm cm}^{ee}$ = 10.6 GeV | <130 × 10 ⁻⁵ | 90 | ALBRECHT | | ARG | Eem = 10 GeV |
| $< 7.0 \times 10^{-6}$ | 90 | BLISS | 98 CLE | O $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | | | ALBRECHT | 72N | AING | -cm = 10 dcv |
| $< 2.0 \times 10^{-5}$ | 90 | ¹ BARTELT | | O Repl. by BLISS 98 | $\Gamma(\overline{ ho}\pi^0\eta)/\Gamma_{ m total}$ | 1 | | | | Γ ₂₀₉ /Γ |
| $< 5.8 \times 10^{-5}$ | 90 | ALBRECHT | 92K ARG | CIII | Test of lepto <u>VALUE</u> | on number and b | aryon number co DOCUMENT ID | onserva | tion. TECN | COMMENT |
| $<4.0 \times 10^{-5}$ | 90 | BOWCOCK | 90 CLE | O $E_{\text{cm}}^{ee} = 10.4-10.9$ | <27 × 10 ⁻⁶ | <u>CL%_</u> 90 | GODANG | 99 | | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| ¹ BARTELT 94 | assume pha | ase space decays. | | | | ,,, | 005/1110 | • | 0220 | 2 CM - 10:0 001 |
| $\Gamma(\mu^{-}K_{S}^{0}K_{S}^{0})/$ | r _{total} | | | Γ ₁₉₆ /Γ | $\Gamma(\Lambda\pi_{-}^{-})/\Gamma_{ m total}$ | | | | | Γ ₂₁₀ /Γ |
| VALUE | <u>CL%</u> | DOCUMENT I | ID TE | COMMENT | _ VALUE | on number and b CL% D | aryon number co OCUMENT ID | | tion. <u>:N</u> <u>CO</u> | MMENT |
| $< 8.0 \times 10^{-8}$ | 90 | MIYAZAKI | 10A B | ELL 671 fb $^{-1}$ $E_{ m cm}^{\it ee}$ = 10.6 GeV | $<0.72 \times 10^{-7}$ | | | | | 4 fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6$ GeV |
| | use the foll | owing data for av | verages, fits | , limits, etc. • • • | | | | | | , CIII |
| $< 3.4 \times 10^{-6}$ | 90 | CHEN | 02c CI | EO <i>E</i> ^{ee} _{Cm} = 10.6 GeV | $\Gamma(\overline{\Lambda}\pi^-)/\Gamma_{ m total}$ | | | | | Γ ₂₁₁ /Γ |
| F(- 12± 12=) | | | | | lest of lepto VALUE | on number and b | aryon number co OCUMENT ID | onserva TF1 | tion. <u>CO</u> | MMENT |
| $\Gamma(\mu^- K^+ K^-)$ | /I total | umber conservatio | on | Γ ₁₉₇ /Γ | <1.4 × 10 ⁻⁷ | | | | | 4 fb ⁻¹ , $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ |
| VALUE | CL%_ | DOCUMENT ID | | N COMMENT | | | | | | , - CIII |
| $< 6.8 \times 10^{-8}$ | 90 | MIYAZAKI | | L 671 fb ⁻¹ , $E_{\rm cm}^{ee} = 10.6 {\rm GeV}$ | Γ(e [—] light boso | n)/ $\Gamma(e^-\overline{ u}_e u_	au)$ |) | | | Γ ₂₁₂ /Γ ₅ |
| • • • We do not | use the foll | owing data for av | | limits, etc. • • • | VALUE | on family numbe CL% | r conservation. <u>DOCUMENT ID</u> | | TECN | COMMENT |
| $< 8.0 \times 10^{-7}$ | 90 | YUSA | 06 BEL | L 158 fb $^{-1}$ $E_{ m cm}^{ee}=10.6$ GeV | < 0.015 | 95 | 1 ALBRECHT | 95 G | ARG | $E_{\rm cm}^{ee} = 9.4-10.6 \text{ GeV}$ |
| $< 2.5 \times 10^{-7}$ | 90 | AUBERT,BE | | 3R 221 fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6$ GeV | • • • We do not | | | | | |
| $< 15 \times 10^{-6}$ | 90 | BLISS | | O <i>E</i> ^{ee} _{CM} = 10.6 GeV | < 0.018 | 95 | ² ALBRECHT | 90E | ARG | E ee e 9.4-10.6 GeV |
| = (Lu- u- \ | | | | | < 0.040 | 95 | 3 BALTRUSAIT | Г85 | MRK3 | E ee = 3.77 GeV |
| $\Gamma(\mu^+ K^- K^-)$ | /I total | conservation | | Γ ₁₉₈ /Γ | | 95.6 limit holds fo | | | | The limit rises to 0.036 |
| VALUE | .on number | conservation. <u>DOCUMENT ID</u> |) TE | CN COMMENT | for a mass of 1 | 1.0 GeV. then fal | Is to 0.006 at th | е прре | r mass l | imit of 1.6 GeV. |
| <9.6 × 10 ⁻⁸ | 90 | MIYAZAKI | | LL 671 fb ⁻¹ , E ^{ee} _{CM} =10.6 GeV | ALBRECHT 9 0.050 for mass | OE limit applies | for spinless bose | on with | mass - | < 100 MeV, and rises to |
| • • • We do not | use the foll | owing data for av | | limits, etc. • • • | ³ BALTRUSAIT | IS 85 limit applie | s for spinless bo | son wit | h mass | < 100 MeV. |
| $< 4.4 \times 10^{-7}$ | 90 | YUSA | 06 BE | LL 158 fb $^{-1}$ $E_{ m cm}^{\it ee}=10.6$ GeV | $\Gamma(\mu^-)$ light boso | n)/Γ(e= ν ν |) | | | Γ ₂₁₃ /Γ ₅ |
| $< 4.8 \times 10^{-7}$ | 90 | AUBERT,BE | 05 D BA | BR 221 fb $^{-1}$, $E_{\rm cm}^{ee} = 10.6$ GeV | | on family numbe | | | | ' 213/ ' 5 |
| $< 6.0 \times 10^{-6}$ | 90 | BLISS | | EO <i>E</i> ee = 10.6 GeV | VALUE | <u>CL%</u> | DO CUMENT ID | | | COMMENT |
| E(0 0) (- | | | | - 1- | <0.026 | 95 | ¹ ALBRECHT | 95 G | ARG | $E_{\rm cm}^{\it ee} = 9.4 10.6 \; {\rm GeV}$ |
| $\Gamma(e^-\pi^0\pi^0)/\Gamma_1$ | total | umber conservatio | on | Γ ₁₉₉ /Γ | ◆ ◆ We do not | use the following | data for averag | es, fits, | limits, | etc. • • • |
| VALUE | .OII Tallilly III | | | TECN COMMENT | < 0.033 | 95 | ² ALBRECHT | 90E | ARG | $E_{\text{cm}}^{ee} = 9.410.6 \text{ GeV}$ $E_{\text{cm}}^{ee} = 3.77 \text{ GeV}$ |
| <6.5 × 10 ⁻⁶ | 90 | BONVIC | | CLEO $E_{\text{cm}}^{\text{ee}} = 10.6 \text{ GeV}$ | < 0.125 | | | | | |
| E/ = 0 0\ - | | | | | | | | | | The limit rises to 0.034 |
| $\Gamma(\mu^-\pi^0\pi^0)/\Gamma$ Test of lept | total | umbor construct | on | Γ ₂₀₀ /Γ | ² ALBRECHT 9 | 1.4 GeV, then fal 90E limit applies | for spinless bose | c uppe on with | mass i mass - | imit of 1.6 GeV. < 100 MeV, and rises to |
| rest of lept VALUE | on family ni | | | TECN COMMENT | _ U.U/1 for mass | s = 500 MeV. | | | | |
| <14 × 10 ⁻⁶ | 90 | BONVIC | | CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ | - RALI RUSAIT | IS 85 limit applie | s for spinless bo | son Wil | ıı mass | < 100 IVIEV. |
| | | 20 | | CIII | | | | | | |

τ-DECAY PARAMETERS

au-LEPTON DECAY PARAMETERS

Updated August 2011 by A. Stahl (RWTH Aachen).

The purpose of the measurements of the decay parameters (*i.e.*, Michel parameters) of the τ is to determine the structure (spin and chirality) of the current mediating its decays.

Leptonic Decays: The Michel parameters are extracted from the energy spectrum of the charged daughter lepton $\ell=e,\mu$ in the decays $\tau \to \ell \nu_\ell \nu_\tau$. Ignoring radiative corrections, neglecting terms of order $(m_\ell/m_\tau)^2$ and $(m_\tau/\sqrt{s})^2$, and setting the neutrino masses to zero, the spectrum in the laboratory frame reads

$$\begin{split} \frac{d\Gamma}{dx} &= \frac{G_{\tau\ell}^2 \ m_{\tau}^5}{192 \ \pi^3} \ \times \\ &\left\{ f_0\left(x\right) + \rho f_1\left(x\right) + \eta \frac{m_{\ell}}{m_{\tau}} f_2\left(x\right) - P_{\tau} \left[\xi g_1\left(x\right) + \xi \delta g_2\left(x\right)\right] \right\} \ , \ (1) \end{split}$$

with

$$\begin{split} f_0\left(x\right) &= 2 - 6\,x^2 + 4\,x^3 \\ f_1\left(x\right) &= -\frac{4}{9} + 4\,x^2 - \frac{32}{9}\,x^3 & g_1\left(x\right) &= -\frac{2}{3} + 4\,x - 6\,x^2 + \frac{8}{3}\,x^3 \\ f_2\left(x\right) &= 12\left(1 - x\right)^2 & g_2\left(x\right) &= \frac{4}{9} - \frac{16}{3}\,x + 12\,x^2 - \frac{64}{9}\,x^3 \;. \end{split}$$

The quantity x is the fractional energy of the daughter lepton ℓ , i.e., $x=E_{\ell}/E_{\ell,max}\approx E_{\ell}/(\sqrt{s}/2)$ and P_{τ} is the polarization of the tau leptons. The integrated decay width is given by

$$\Gamma = \frac{G_{\tau\ell}^2 \ m_{\tau}^5}{192 \ \pi^3} \left(1 + 4 \eta \ \frac{m_{\ell}}{m_{\tau}} \right) \ . \tag{2}$$

The situation is similar to muon decays $\mu \to e\nu_e\nu_\mu$. The generalized matrix element with the couplings $g_{\varepsilon\mu}^{\gamma}$ and their relations to the Michel parameters ρ , η , ξ , and δ have been described in the "Note on Muon Decay Parameters." The Standard Model expectations are 3/4, 0, 1, and 3/4, respectively. For more details, see Ref. 1.

Hadronic Decays: In the case of hadronic decays $\tau \to h\nu_{\tau}$, with $h = \pi$, ρ , or a_1 , the ansatz is restricted to purely vectorial currents. The matrix element is

$$\frac{G_{\tau h}}{\sqrt{2}} \sum_{\lambda = R, L} g_{\lambda} \langle \overline{\Psi}_{\omega}(\nu_{\tau}) \mid \gamma^{\mu} \mid \Psi_{\lambda}(\tau) \rangle J_{\mu}^{h}$$
 (3)

with the hadronic current J_{μ}^{h} . The neutrino chirality ω is uniquely determined from λ . The spectrum depends only on a single parameter ξ_{h}

$$\frac{d^{n}\Gamma}{dx_{1}dx_{2}\dots dx_{n}} = f\left(\vec{x}\right) + \xi_{h}P_{\tau}g\left(\vec{x}\right) , \qquad (4)$$

with f and g being channel-dependent functions of the n observables $\vec{x} = (x_1, x_2, \dots, x_n)$ (see Ref. 2). The parameter ξ_h is related to the couplings through

$$\xi_h = |g_L|^2 - |g_R|^2 \ . \tag{5}$$

 ξ_h is the negative of the chirality of the τ neutrino in these decays. In the Standard Model, $\xi_h=1$. Also included in the Data Listings for ξ_h are measurements of the neutrino helicity which coincide with ξ_h , if the neutrino is massless (ASNER 00, ACKERSTAFF 97R, AKERS 95P, ALBRECHT 93C, and ALBRECHT 90I).

Combination of Measurements: The individual measurements are combined, taking into account the correlations between the parameters. In a first fit, universality between the two leptonic decays, and between all hadronic decays, is assumed. A second fit is made without these assumptions. The results of the two fits are provided as OUR FIT in the Data Listings below in the tables whose title includes "(e or mu)" or "(all hadronic modes)," and "(e)," "(mu)" etc., respectively. The measurements show good agreement with the Standard Model. The χ^2 values with respect to the Standard model predictions are 24.1 for 41 degrees of freedom and 26.8 for 56 degrees of freedom, respectively. The correlations are reduced through this combination to less than 20%, with the exception of ρ and η which are correlated by +23%, for the fit with universality and by +70% for $\tau \to \mu \nu_{\mu} \nu_{\tau}$.

Table 1: Coupling constants $g_{\varepsilon\mu}^{\gamma}$. 95% confidence level experimental limits. The limits include the quoted values of A_e , A_{μ} , and A_{π} and assume $A_{\rho}=A_{a_1}=1$.

| $	au 	o e \nu_e \nu_	au$ | | |
|--------------------------------|--------------------------------------|----------------------------------|
| $ g_{RR}^S <0.70$ | $\left g_{RR}^{V}\right <0.17$ | $ g_{RR}^T \equiv 0$ |
| $ g_{LR}^S <0.99$ | $ g_{\scriptscriptstyle LR}^V <0.13$ | $ g_{LR}^T < 0.082$ |
| $ g_{\rm RL}^S < 2.01$ | $ g_{RL}^V < 0.52$ | $ g_{RL}^T < 0.51$ |
| $ g_{LL}^S < 2.01$ | $ g_{LL}^V < 1.005$ | $ g_{LL}^T \equiv 0$ |
| $	au 	o \mu u_{\mu} u_{	au}$ | | |
| $ g_{RR}^S < 0.72$ | $ g_{RR}^V < 0.18$ | $ g_{RR}^T \equiv 0$ |
| $\left g_{LR}^S\right <0.95$ | $ g_{LR}^V <0.12$ | $ g_{LR}^{T} < 0.079$ |
| $ g_{\rm RL}^S <2.01$ | $ g_{RL}^V <0.52$ | $\left g_{\rm RL}^T\right <0.51$ |
| $ g_{LL}^S < 2.01$ | $ g_{LL}^V < 1.005$ | $ g_{LL}^T \equiv 0$ |
| $\tau \to \pi \nu_{\tau}$ | | |
| $ g_R^V < 0.15$ | $ g_L^V > 0.992$ | |
| $	au 	o ho u_{	au}$ | | |
| $ g_R^V < 0.10$ | $ g_L^V > 0.995$ | |
| $	au 	o a_1 \nu_{	au}$ | | |
| $ g_R^V < 0.16$ | $ g_L^V > 0.987$ | |

Model-independent Analysis: From the Michel parameters, limits can be derived on the couplings $g_{\varepsilon\lambda}^{\kappa}$ without further model assumptions. In the Standard model $g_{LL}^V = 1$ (leptonic decays), and $g_L = 1$ (hadronic decays) and all other couplings vanish. First, the partial decay widths have to be compared to the Standard Model predictions to derive limits on the normalization of the couplings $A_x = G_{\tau x}^2/G_F^2$ with Fermi's constant G_F :

$$A_e = 1.0029 \pm 0.0046$$
 ,
$$A_{\mu} = 0.981 \pm 0.018$$
 ,
$$A_{\pi} = 1.0020 \pm 0.0073$$
 . (6)

Then limits on the couplings (95% CL) can be extracted (see Ref. 3 and Ref. 4). Without the assumption of universality, the limits given in Table 1 are derived.

Model-dependent Interpretation: More stringent limits can be derived assuming specific models. For example, in the framework of a two Higgs doublet model, the measurements correspond to a limit of $m_{H^{\pm}} > 1.9 \text{ GeV} \times \tan \beta$ on the mass of the charged Higgs boson, or a limit of 253 GeV on the mass of the second W boson in left-right symmetric models for arbitrary mixing (both 95% CL). See Ref. 4 and Ref. 5.

Footnotes and References

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| $\rho(e \text{ or } \mu) \text{ PARAM}$ | ETER | | | | |
|-----------------------------------------|------------|-----------------------|---------|-----------|--------------------------------------|
| $(V-A)$ theory μ | predicts , | o = 0.75. | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.745 ± 0.008 OUR FI | Т | | | | |
| 0.749±0.008 OUR AV | /ERAGE | | | | |
| $0.742 \pm 0.014 \pm 0.006$ | 81k | HEISTER | 01 E | ALEP | 1991-1995 LEP runs |
| $0.775 \pm 0.023 \pm 0.020$ | 36k | ABREU | 00L | DLPH | 1992-1995 runs |
| $0.781 \pm 0.028 \pm 0.018$ | 46k | ACKERSTAFF | 99D | OPAL | 1990-1995 LEP runs |
| 0.762 ± 0.035 | 54k | ACCIARRI | 98R | L3 | 1991-1995 LEP runs |
| 0.731 ± 0.031 | | ¹ ALBRECHT | 98 | ARG | E ee = 9.5-10.6 GeV |
| $0.72 \pm 0.09 \pm 0.03$ | | ² ABE | 970 | SLD | 1993-1995 SLC runs |
| $0.747 \pm 0.010 \pm 0.006$ | 55k | ALEXANDER | 97F | CLEO | $E_{cm}^{ee} = 10.6 \text{ GeV}$ |
| $0.79 \ \pm 0.10 \ \pm 0.10$ | 3732 | FORD | 87в | MAC | $E_{cm}^{ee} = 29 \text{ GeV}$ |
| $0.71 \ \pm 0.09 \ \pm 0.03$ | 1426 | BEHRENDS | 85 | CLEO | e^+e^- near \varUpsilon (45) |
| ullet $ullet$ $ullet$ We do not use | the follo | wing data for averag | es, fit | s, limits | , etc. • • • |
| $0.735\pm0.013\pm0.008$ | 31k | AMMAR | 97в | CLEO | Repl. by ALEXAN- DER 97F |
| $0.794 \pm 0.039 \pm 0.031$ | 18k | ACCIARRI | 96н | L3 | Repl. by ACCIARRI 98R |
| $0.732 \pm 0.034 \pm 0.020$ | 8.2k | ³ ALBRECHT | 95 | ARG | $E_{cm}^{ee} = 9.5-10.6 \text{ GeV}$ |
| 0.738 ± 0.038 | | ⁴ ALBRECHT | 95 c | ARG | Repl. by ALBRECHT 98 |
| $0.751 \pm 0.039 \pm 0.022$ | | BUSKULIC | 95 D | ALEP | Repl. by HEISTER 01E |
| $0.742 \pm 0.035 \pm 0.020$ | 8000 | ALBRECHT | 90E | ARG | Eee 9.4-10.6 GeV |

 $^{
m 1}$ Combined fit to ARGUS tau decay parameter measurements in ALBRECHT 98, AL-BRECHT 95c, ALBRECHT 93G, and ALBRECHT 94E. ALBRECHT 98 use tau pair events of the type $\tau^-\tau^+ \to (\ell^-\overline{\nu}_\ell\nu_\tau)(\pi^+\pi^0\overline{\nu}_\tau)$, and their charged conjugates.

 2 ABE 970 assume $\eta=$ 0 in their fit. Letting η vary in the fit gives a ρ value of 0.69 \pm

3 Value is from a simultaneous fit for the ρ and η decay parameters to the lepton energy spectrum. Not independent of ALBRECHT 9Bc ρ (e or μ) value which assumes $\eta=0$. Result is strongly correlated with ALBRECHT 95c.

A Combined fit to ARGUS tau decay parameter measurements in ALBRECHT 95c, ALBRECHT 93c, and ALBRECHT 94e.

$\rho(e)$ PARAMETER

V-A) theory predicts $\rho = 0.75$

| VALUE | <u>EVTS</u> | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------|-------------------------|-----------------------|---------------|-----------|----------------------------------------------------------------------------|
| 0.747±0.010 OUR FI | Т | | | | |
| 0.744 ± 0.010 OUR AV | /ERAGE | | | | |
| $0.747 \pm 0.019 \pm 0.014$ | 44k | HEISTER | 01 E | ALEP | 1991-1995 LEP runs |
| $0.744 \pm 0.036 \pm 0.037$ | 17k | ABREU | 00L | DLPH | 1992-1995 runs |
| $0.779 \pm 0.047 \pm 0.029$ | 25 k | ACKERSTAFF | 99D | OPAL | 1990-1995 LEP runs |
| $0.68 \pm 0.04 \pm 0.07$ | | ¹ ALBRECHT | 98 | ARG | $E_{\rm cm}^{\it ee} = 9.5 - 10.6 \; {\rm GeV}$ |
| $0.71 \pm 0.14 \pm 0.05$ | | ABE | 97 0 | SLD | 1993-1995 SLC runs |
| $0.747 \pm 0.012 \pm 0.004$ | 34k | ALEXANDER | 97F | CLEO | $E_{\mathrm{CM}}^{ee} = 10.6 \; \mathrm{GeV}$ |
| $0.735 \pm 0.036 \pm 0.020$ | 4.7k | ² ALBRECHT | 95 | ARG | $E_{\rm cm}^{\it ee} = 9.5 - 10.6 \; {\rm GeV}$ |
| $0.79 \ \pm 0.08 \ \pm 0.06$ | 3230 | ³ ALBRECHT | 93 G | ARG | $E_{\rm cm}^{ee} = 9.4 - 10.6 {\rm GeV}$ |
| $0.64 \ \pm 0.06 \ \pm 0.07$ | 2753 | JANSSEN | 89 | CBAL | $E_{\rm cm}^{ee} = 9.4 - 10.6 {\rm GeV}$ |
| $0.62\ \pm0.17\ \pm0.14$ | 1823 | FORD | 87B | MAC | $E_{\rm cm}^{\it ee}=$ 29 GeV |
| 0.60 ± 0.13 | 699 | BEHRENDS | 85 | CLEO | e^+e^- near \varUpsilon (45) |
| $0.72 \ \pm 0.10 \ \pm 0.11$ | 594 | BACINO | 79B | DLCO | $E_{\rm cm}^{ee} = 3.5 - 7.4 {\rm GeV}$ |
| ullet $ullet$ $ullet$ We do not use | the following | ng data for averag | es, fit | s, limits | , etc. • • • |
| $0.732 \pm 0.014 \pm 0.009$ | 19k | AMMAR | 97в | CLEO | Repl. by ALEXAN- DER 97F |
| $0.793 \pm 0.050 \pm 0.025$ | | BUSKULIC | 95 D | ALEP | Repl. by HEISTER 01E |
| $0.747 \pm 0.045 \pm 0.028$ | 5106 | ALBRECHT | 90E | ARG | Repl. by ALBRECHT 95 |
| their charged coni | ugates. | | | | $(\ell^-\overline{ u}_\ell u_	au)(\pi^+ \pi^0 \overline{ u}_	au)$, and |
| ² ALBRECHT 95 | use tau | pair events of | the | type | $\tau^- \tau^+ \rightarrow (\ell^- \overline{\nu}_{\ell} \nu_{\tau})$ |
| $(h^+ h^- h^+ (\pi^0) \overline{\nu})$ | $ar{r}_{	au}$) and the | eir charged conjug | ates. | | |
| ³ ALBRECHT 93G u | ise tau pair | events of the type | $\tau^- \tau$ | + → (| $\mu^- \overline{ u}_\mu u_	au$) ($e^+ u_e \overline{ u}_	au$) and |
| | | | | | , |

their charged conjugates

$\rho(\mu)$ PARAMETER

| (V−A) theory pi | edicts $ ho =$ | 0.75. | | |
|-----------------------------------------|----------------|-----------------------|-------------|--------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | TE | ECN COMMENT |
| 0.763±0.020 OUR FIT | - | | | |
| 0.770±0.022 OUR AV | ERAGE | | | |
| $0.776 \pm 0.045 \pm 0.019$ | 46k | HEISTER | 01E AI | LEP 1991-1995 LEP runs |
| $0.999 \pm 0.098 \pm 0.045$ | 22k | ABREU | 00L DI | LPH 1992-1995 runs |
| $0.777 \pm 0.044 \pm 0.016$ | 27k | ACKERSTAFF | 99D O | PAL 1990-1995 LEP runs |
| $0.69 \ \pm 0.06 \ \pm 0.06$ | | ¹ ALBRECHT | 98 AI | RG E ^{ee} _{cm} = 9.5-10.6 GeV |
| $0.54 \ \pm 0.28 \ \pm 0.14$ | | ABE | 970 SL | _D 1993-1995 SLC runs |
| $0.750 \pm 0.017 \pm 0.045$ | 22k | ALEXANDER | 97F CL | LEO $E_{ m cm}^{\it ee}=10.6~{ m GeV}$ |
| $0.76\ \pm0.07\ \pm0.08$ | 3230 | ALBRECHT | 93G A | RG <i>E</i> ^{ee} _{cm} = 9.4–10.6 GeV |
| $0.734 \pm 0.055 \pm 0.027$ | 3041 | ALBRECHT | 90E A | RG <i>E</i> ^{ee} _{cm} = 9.4–10.6 GeV |
| $0.89 \ \pm 0.14 \ \pm 0.08$ | 1909 | FORD | 87B M | IAC $E_{ m cm}^{\it ee}=$ 29 GeV |
| 0.81 ± 0.13 | 727 | BEHRENDS | | LEO e^+e^- near \varUpsilon (4 S) |
| ● ● We do not use t | he followin | g data for averages | , fits, lin | nits, etc. • • • |
| $0.747 \pm 0.048 \pm 0.044$ | 13k | AMMAR | 97B CL | LEO Repl. by ALEXAN- DER 97F |
| $0.693 \pm 0.057 \pm 0.028$ | | BUSKULIC | 95D AI | LEP Repl. by HEISTER 01s |
| 1 | | | _ 1 | (c)(± 0-) |

¹ ALBRECHT 98 use tau pair events of the type $\tau^-\tau^+ \to (\ell^-\overline{\nu}_\ell\nu_\tau)(\pi^+\pi^0\overline{\nu}_\tau)$, and their charged conjugates

$\xi(e \text{ or } \mu) \text{ PARAMETER}$

| (• 7.1) thicony p | icaicio Ç — | | | | |
|---------------------------------------|--------------|-----------------------|--------|------------|-----------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.985 ± 0.030 OUR FI | Г | | | | |
| 0.981 ± 0.031 OUR AV | ERAGE | | | | |
| $0.986 \pm 0.068 \pm 0.031$ | 81k | HEISTER | 01 E | ALEP | 1991-1995 LEP runs |
| $0.929 \pm 0.070 \pm 0.030$ | 36k | ABREU | 00L | DLPH | 1992-1995 runs |
| $0.98 \pm 0.22 \pm 0.10$ | 46k | ACKERSTAFF | 99D | OPAL | 1990-1995 LEP runs |
| 0.70 ± 0.16 | 54k | A CCIA RRI | 98R | L3 | 1991-1995 LEP runs |
| 1.03 ± 0.11 | | ¹ ALBRECHT | 98 | ARG | $E_{\rm cm}^{\it ee} = 9.5 - 10.6 {\rm GeV}$ |
| $1.05 \pm 0.35 \pm 0.04$ | | ² ABE | 970 | SLD | 1993-1995 SLC runs |
| $1.007 \pm 0.040 \pm 0.015$ | 55k | ALEXANDER | 97 F | CLEO | $E_{cm}^{ee} = 10.6 \text{ GeV}$ |
| ● ● We do not use | the followin | g data for averag | es, fi | ts, limits | , etc. • • • |
| $0.94 \pm 0.21 \pm 0.07$ | 18k | ACCIARRI | 96н | L3 | Repl. by ACCIARRI 98R |
| 0.97 ± 0.14 | | ³ ALBRECHT | 95 C | ARG | Repl. by ALBRECHT 98 |
| $1.18 \ \pm 0.15 \ \pm 0.16$ | | BUSKULIC | 95 D | ALEP | Repl. by HEISTER 01E |
| $0.90\ \pm0.15\ \pm0.10$ | 3230 | ⁴ ALBRECHT | 93 G | ARG | $E_{cm}^{ee} = 9.4-10.6 \text{ GeV}$ |

¹ Combined fit to ARGUS tau decay parameter measurements in ALBRECHT 98, AL-BRECHT 95c, ALBRECHT 93c, and ALBRECHT 94e. ALBRECHT 98 use tau pair events of the type $\tau^-\tau^+ \to (\ell^-\overline{\nu}_\ell\nu_\tau)(\pi^+\pi^0\overline{\nu}_\tau)$, and their charged conjugates. ²ABE 970 assume $\eta=0$ in their fit. Letting η vary in the fit gives a ξ value of 1.02 \pm

3 0.36 \pm 0.05. 3 Combined fit to ARGUS tau decay parameter measurements in ALBRECHT 95c, AL-BRECHT 93G, and ALBRECHT 94E. ALBRECHT 95C uses events of the type $au^- au^+$ $(\ell^- \overline{\nu}_\ell \nu_\tau) (h^+ h^- h^+ \overline{\nu}_\tau)$ and their charged conjugates.

ALBRECHT 93G measurement determines $|\xi|$ for the case $\xi(e)=\xi(\mu)$, but the authors point out that other LEP experiments determine the sign to be positive

$\xi(e)$ PARAMETER ($V{-}A)$ theory predicts $\xi=1.$ 0.994±0.040 OUR FIT DO CUMENT ID TECN COMMENT 1.00 ±0.04 OUR AVERAGE $1.011 \pm 0.094 \pm 0.038$ HEISTER 01E ALEP 1991-1995 LEP runs $1.01\ \pm0.12\ \pm0.05$ 00L DLPH 1992-1995 runs $1.13 \pm 0.39 \pm 0.14$ ACKERSTAFF 99D OPAL 1990-1995 LEP runs $^{ m 1}$ ALBRECHT $1.11 \ \pm 0.20 \ \pm 0.08$ 98 ARG *E* ee e 9.5-10.6 GeV $1.16 \pm 0.52 \pm 0.06$ 970 SLD 1993-1995 SLC runs $0.979 \pm 0.048 \pm 0.016$ ALEXANDER 97F CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $1.03 \pm 0.23 \pm 0.09$ BUSKULIC 95D ALEP Repl. by HEISTER 01E ¹ ALBRECHT 98 use tau pair events of the type $\tau^-\tau^+ \to (\ell^-\overline{\nu}_\ell\nu_\tau)(\pi^+\pi^0\overline{\nu}_\tau)$, and their charged conjugates. $\xi(\mu)$ PARAMETER (V-A) theory predicts $\xi=1$. DO CUMENT ID TECN COMMENT 1.030±0.059 OUR FIT 1.06 ±0.06 OUR AVERAGE $1.030 \pm 0.120 \pm 0.050$ HEISTER 01E ALEP 1991-1995 LEP runs $1.16\ \pm0.19\ \pm0.06$ 00L DLPH 1992-1995 runs $0.79 \pm 0.41 \pm 0.09$ 27k ACKERSTAFF 99D OPAL 1990-1995 LEP runs ¹ ALBRECHT $1.26\ \pm0.27\ \pm0.14$ 98 ARG $E_{\text{cm}}^{ee} = 9.5 - 10.6 \text{ GeV}$ $0.75 \pm 0.50 \pm 0.14$ 970 SLD 1993-1995 SLC runs ALEXANDER 97F CLEO $E_{\text{CM}}^{ee} = 10.6 \text{ GeV}$ $1.054 \pm 0.069 \pm 0.047$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $1.23 \pm 0.22 \pm 0.10$ BUSKULIC 95D ALEP Repl. by HEISTER 01E ¹ ALBRECHT 98 use tau pair events of the type $\tau^-\tau^+ \to (\ell^-\overline{\nu}_\ell\nu_\tau)(\pi^+\pi^0\overline{\nu}_\tau)$, and their charged conjugates. $\eta(e \text{ or } \mu) \text{ PARAMETER}$ (V-A) theory predicts $\eta=0$. 0.013±0.020 OUR FIT DOCUMENT ID TECN COMMENT 0.015 ± 0.021 OUR AVERAGE $0.012 \pm 0.026 \pm 0.004$ 81 k HEISTER 01E ALEP 1991-1995 LEP runs $-0.005 \pm 0.036 \pm 0.037$ ABREU 00L DLPH 1992-1995 runs $0.027 \pm 0.055 \pm 0.005$ ACKERSTAFF 99D OPAL 1990-1995 LEP runs 0.27 ± 0.14 54 k ACCIARRI 98R L3 1991-1995 LEP runs $-0.13 \pm 0.47 \pm 0.15$ ABE 970 SLD 1993-1995 SLC runs 97B CLEO $E_{\mathrm{cm}}^{ee} = 10.6 \,\mathrm{GeV}$ $-0.015 \pm 0.061 \pm 0.062$ 31 k AMMAR $0.03 \pm 0.18 \pm 0.12$ 8.2k ALBRECHT 95 ARG $E_{\rm cm}^{ee} = 9.5 - 10.6 \, {\rm GeV}$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $0.25\ \pm 0.17\ \pm 0.11$ 18k ACCIARRI 96H L3 Repl. by ACCIARRI 98R $-0.04 \pm 0.15 \pm 0.11$ BUSKULIC 95D ALEP Repl. by HEISTER 01E $\eta(\mu)$ PARAMETER ($V{-}A$) theory predicts $\eta=$ 0. VALUE EVTS DO CUMENT ID TECN COMMENT 0.094 ± 0.073 OUR FIT 0.17 ±0.15 OUR AVERAGE Error includes scale factor of 1.2. $0.160 \pm 0.150 \pm 0.060$ HEISTER 01E ALEP 1991-1995 LEP runs 46k $0.72 \pm 0.32 \pm 0.15$ ABREU 00L DLPH 1992-1995 runs $-0.59 \pm 0.82 \pm 0.45$ ¹ ABE 970 SLD 1993-1995 SLC runs ² AMMAR $0.010 \pm 0.149 \pm 0.171$ 13k 97B CLEO $E_{\rm cm}^{\it ee}=10.6~{\rm GeV}$ ³ ACKERSTAFF 99D OPAL 1990-1995 LEP runs BUSKULIC 95D ALEP Repl. by HEISTER 01E $^{1}\,\mathrm{Highly}$ correlated (corr. = 0.92) with ABE 970 $\rho(\mu)$ measurement. $^2_{\rm c}{\rm Highly}$ correlated (corr. = 0.949) with AMMAR 97B $\rho(\mu)$ value. 3 ACKERSTAFF 99D result is dominated by a constraint on η from the OPAL measurements of the au lifetime and B($au^- o \mu^- \overline{ u}_\mu u_ au$) assuming lepton universality for the total coupling strength. $(\delta \xi)(e \text{ or } \mu) \text{ PARAMETER}$ (V-A) theory predicts $(\delta \xi)=0.75.$ 0.744 ± 0.021 OUR FIT DO CUMENT ID TECN COMMENT 0.744 ± 0.022 OUR AVERAGE $0.776 \pm 0.045 \pm 0.024$ HEISTER 01E ALEP 1991-1995 LEP runs $0.779 \pm 0.070 \pm 0.028$ 36k ABREU 00L DLPH 1992-1995 runs $0.65\ \pm0.14\ \pm0.07$ ACKERSTAFF 99D OPAL 1990-1995 LEP runs 0.70 ± 0.11 54k ACCIARRI 98R L3 1991-1995 LEP runs $^{ m 1}$ ALBRECHT 0.63 ± 0.09 98 ARG $E_{cm}^{ee} = 9.5-10.6 \text{ GeV}$

 $0.88 \pm 0.27 \pm 0.04$

 $0.745 \pm 0.026 \pm 0.009$

 $0.81 \ \pm 0.14 \ \pm 0.06$

 $0.88 \pm 0.11 \pm 0.07$

 0.65 ± 0.12

² ABE

• • • We do not use the following data for averages, fits, limits, etc. • • •

ACCIARRI

³ ALBRECHT

BUSKULIC

55k

970 SLD

96H L3

ALEXANDER 97F CLEO $E_{
m cm}^{\it ee}=10.6~{
m GeV}$

1993-1995 SLC runs

Repl. by ACCIARRI 98R

95 c ARG Repl. by ALBRECHT 98

95D ALEP Repl. by HEISTER 01E

 $0.85 \begin{array}{c} +0.15 \\ -0.17 \end{array} \pm 0.05$

 $1.08 \begin{array}{c} +0.46 \\ -0.41 \end{array} \begin{array}{c} +0.14 \\ -0.25 \end{array}$

 $0.937 \pm 0.116 \pm 0.064$

| | | • | | | J |
|---------------------------------------------------------|-----------------------------|-------------------------------------------------------------------------|------------------------------|-------------------|---------------------------------------------------------------------------------------------------|
| | | | | | au |
| 1 | | | | | |
| * Combined fit to Al BRECHT 95c. ALF | ∢GUS tau c BRECHT 93 | lecay parameter BG. and ALBREC | measu :HT 9 | rements 4F.ALF | s in ALBRECHT 98, AL- BRECHT 98 use tau pair |
| events of the type τ | $-\tau^+ \rightarrow (\ell$ | $(-\frac{\overline{\nu}_{\ell}\nu_{\tau}}{\nu_{\ell}})(\pi^{+}\pi^{0})$ | $\overline{\nu}_{\tau}$), a | nd their | charged conjugates. |
| ² ABE 970 assume r | $_{7} = 0$ in th | eir fit. Letting | η vary | in the | fit gives a $(\delta \xi)$ value of |
| 0.87 ± 0.27 ± 0.04 | PCHS tou d | ocay parameter r | moacu | romonto | in ALBRECHT 95c, AL- |
| | | | | | ents of the type $	au^-	au^+$ $	o$ |
| $(\ell^- \overline{\nu}_{\ell} \nu_{\tau}) (h^+ h^-)$ | | | | | ents of the type 7 7 |
| | • | _ | | | |
| $(\delta \xi)(e)$ PARAMETE (V-A) theory pre | | = 0.75. | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.734±0.028 OUR FIT 0.731±0.029 OUR AVE | | | | | |
| 0.778±0.066±0.024 | 44k | HEISTER | 01 F | ALEP | 1991-1995 LEP runs |
| 0.85 ±0.12 ±0.04 | 17k | ABREU | 00L | | 1992-1995 runs |
| $0.72 \pm 0.31 \pm 0.14$ | 25 k | ACKERSTAFF | | | 1990-1995 LEP runs |
| 0.56 ±0.14 ±0.06 | | 1 ALBRECHT | 98 | ARG | E ee = 9.5-10.6 GeV |
| 0.85 ±0.43 ±0.08 | 34 k | ABE | 97o 97f | SLD CLEO | 1993–1995 SLC runs |
| 0.720±0.032±0.010 • • • We do not use ti | | ALEXANDER | | | $E_{\rm cm}^{ee} = 10.6 \text{ GeV}$ |
| 11 ± 0.17 ± 0.07 | ile iollowing | BUSKULIC | | ALEP | |
| . – – | | | | | Repl. by HEISTER 01E $\ell^- \overline{ u}_\ell u_	au) (\pi^+ \pi^0 \overline{ u}_	au)$, and |
| their charged conjug | | vents of the type | ττ | · · · (| $\ell = \nu_\ell \nu_\tau$) $(\pi \cdot \pi \cdot \nu_\tau)$, and |
| | | | | | |
| $(\delta oldsymbol{\xi})(oldsymbol{\mu})$ $PARAMETI$ | | - 0.75 | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| .778±0.037 OUR FIT | | | | | |
|).79 ±0.04 OUR AVE).786±0.066±0.028 | ERAGE 46k | HEICTED | 015 | ALED | 1991-1995 LEP runs |
| $0.786 \pm 0.036 \pm 0.028$ $0.86 \pm 0.13 \pm 0.04$ | 46k 22k | HEISTER ABREU | 001 | ALEP DLPH | 1991-1995 LEP runs 1992-1995 runs |
| $0.63 \pm 0.23 \pm 0.05$ | 27k | ACKERSTAFF | 99D | | 1990-1995 LEP runs |
| $0.73 \pm 0.18 \pm 0.10$ | | ¹ ALBRECHT | 98 | ARG | E ^{ee} _{cm} = 9.5-10.6 GeV |
| $.82 \pm 0.32 \pm 0.07$ | | ABE | 970 | SLD | 1993-1995 SLC runs |
| $.786 \pm 0.041 \pm 0.032$ | 22k | ALEXANDER | 97F | CLEO | E ^{ee} _{cm} = 10.6 GeV |
| • • We do not use the | he following | _ | | | |
| 0.71 ±0.14 ±0.06 | | BUSKULIC | | ALEP | |
| ¹ ALBRECHT 98 use their charged conjug | | vents of the type | $\tau^- \tau$ | + → (| $\ell^-\overline{ u}_\ell u_	au)(\pi^+\pi^0\overline{ u}_	au)$, and |
| _ | - | | | | |
| $\xi(\pi)$ PARAMETER $(V{-}A)$ theory pro | edicts ε(π) | = 1 | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.993 ± 0.022 OUR FIT | | | | | |
|).994±0.023 OUR AVE).994±0.020±0.014 | 27k | HEISTER | 01E | ALEP | 1991-1995 LEP runs |
| $0.81 \pm 0.17 \pm 0.02$ | 211 | ABE | 970 | | 1993-1995 SLC runs |
| $.03 \pm 0.06 \pm 0.04$ | 2.0k | COAN | 97 | CLEO | $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ |
| • • We do not use ti | he following | data for average | s, fits | limits, | |
| $0.987 \pm 0.057 \pm 0.027$ | | BUSKULIC | 95 D | ALEP | Repl. by HEISTER 01E |
| $0.95 \pm 0.11 \pm 0.05$ | | $^{ m 1}$ BUSKULIC | 94D | ALEP | 1990+1991 LEP run |
| ¹ Superseded by BUS | KULIC 95D | | | | |
| (ρ) PARAMETER | | | | | |
| (V-A) theory pre | edicts $\xi(\rho)$ | = 1. | | | |
| ALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|).994±0.008 OUR FIT).994±0.009 OUR AVE | RAGE | | | | |
| $0.987 \pm 0.012 \pm 0.011$ | 59k | HEISTER | 01E | ALEP | 1991-1995 LEP runs |
| $0.99 \pm 0.12 \pm 0.04$ | | ABE | | SLD | 1993-1995 SLC runs |
| $0.995 \pm 0.010 \pm 0.003$ | 66k | ALEXANDER | 97F | CLEO | $E_{\mathrm{cm}}^{ee} = 10.6 \; \mathrm{GeV}$ |
| $.022 \pm 0.028 \pm 0.030$ | 1.7k | ¹ ALBRECHT | 94E | ARG | E ^{ee} _{cm} = 9.4–10.6 GeV |
| • • • We do not use t | he following | data for average | s, fits | limits, | etc. • • • |
| $.045 \pm 0.058 \pm 0.032$ | | BUSKULIC | | ALEP | Repl. by HEISTER 01E |
| .03 ±0.11 ±0.05 | | ² BUSKULIC | | ALEP | 1990+1991 LEP run |
| ALBRECHT 94E m ALBRECHT 90I to Superseded by BUS | obtain the o | quoted result. | iantity | and us | se the sign determined by |
| ξ(a ₁) PARAMETER | | | | | |
| (V-A) theory pro- | | = 1. | | | |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.001±0.027 OUR FIT | DAGE | | | | |
| l.002±0.028 OUR AVE l.000±0.016±0.024 | 35 k | ¹ HEISTER | 01E | ALEP | 1991-1995 LEP runs |
| $1.02 \pm 0.13 \pm 0.03$ | 17.2k | ASNER | 00 | CLEO | |
| | | 2 | 075 | | 1992-1994 LEP runs |
| 1.29 ±0.26 ±0.11 | 7.4k | ² ACKERSTAFF | 91K | OIAL | 1772 1774 EEI TUIIS |

ALBRECHT

ALBRECHT

BUSKULIC

• • • We do not use the following data for averages, fits, limits, etc. • • •

³ AKERS

95c ARG E^{ee}_{cm} = 9.5-10.6 GeV

93c ARG E^{ee}_{cm}= 9.4-10.6 GeV

95P OPAL Repl. by ACKER-STAFF 97R

95D ALEP Repl. by HEISTER 01E

| HEISTER 01E quote $1.000\pm0.016\pm0.013\pm0.020$ where | ere the errors are statistical, |
|------------------------------------------------------------|---------------------------------|
| ystematic, and an uncertainty due to the final state model | |
| rror and model uncertainty. | |

 2 ACKERSTAFF 97R obtain this result with a model independent fit to the hadronic structure functions. Fitting with the model of Kuhn and Santamaria (ZPHY **C48**, 445 (1990)) gives $0.87\pm0.16\pm0.04$, and with the model of of Isgur et al. (PR **D39**,1357 (1989)) they obtain $1.20\pm0.21\pm0.14$.

 3 AKERS 95P obtain this result with a model independent fit to the hadronic structure functions. Fitting with the model of Kuhn and Santamaria (ZPHY **C48**, 445 (1990)) gives $0.87 \pm 0.27 + 0.05$, and with the model of of Isgur *et al.* (PR **D39**,1357 (1989)) they obtain $1.10 \pm 0.31 ^{+0.13}_{-0.14}$

ξ (all hadronic modes) PARAMETER

| (V-A) theory p | redicts ξ | = 1. | | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------------------|---------|-------------------|-----------------------------------------------------|--|--|--|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | | | |
| 0.995 ± 0.007 OUR FI | | | | | | | | |
| 0.997±0.007 OUR AV | | 4 | | | | | | |
| $0.992 \pm 0.007 \pm 0.008$ | 102k | 1 HEISTER | 01E | ALEP | 1991-1995 LEP runs | | | |
| $0.997 \pm 0.027 \pm 0.011$ | 39k | ² ABREU | 00L | DLPH | 1992-1995 runs | | | |
| $1.02 \pm 0.13 \pm 0.03$ | 17.2k | ³ ASNER | 00 | CLEO | $E_{\rm cm}^{ee}$ = 10.6 GeV | | | |
| 1.032 ± 0.031 | 37k | ⁴ ACCIARRI | 98R | L3 | 1991-1995 LEP runs | | | |
| $0.93 \pm 0.10 \pm 0.04$ | | ABE | 970 | SLD | 1993-1995 SLC runs | | | |
| $1.29 \pm 0.26 \pm 0.11$ | 7.4k | 5 ACKERSTAFF | | OPAL | 1992-1994 LEP runs | | | |
| $0.995 \pm 0.010 \pm 0.003$ | 66k | ⁶ ALEXANDER | 97F | CLEO | $E_{\rm cm}^{ee}$ = 10.6 GeV | | | |
| $1.03 \pm 0.06 \pm 0.04$ | 2.0k | ⁷ COAN | 97 | CLEO | $E_{cm}^{ee} = 10.6 \text{ GeV}$ | | | |
| 1.017 ± 0.039 | | ⁸ ALBRECHT | 95c | ARG | Eee = 9.5-10.6 GeV | | | |
| $1.25 \pm 0.23 ^{+ 0.15}_{- 0.08}$ | 7.5 k | ⁹ ALBRECHT | 93c | ARG | <i>E</i> ^{ee} _{cm} = 9.4–10.6 GeV | | | |
| • • • We do not use | the follow | ing data for average | s, fits | s, limits, | etc. • • • | | | |
| $0.970 \pm 0.053 \pm 0.011$ | 14k | ¹⁰ ACCIARRI | 96н | L3 | Repl. by ACCIARRI 98R | | | |
| $1.08 \begin{array}{c} +0.46 \\ -0.41 \end{array} \begin{array}{c} +0.14 \\ -0.25 \end{array}$ | 2.6k | ¹¹ AKERS | 95P | OPAL | Repl. by ACKER- STAFF 97R | | | |
| $1.006 \pm 0.032 \pm 0.019$ | | ¹² BUSKULIC | 95D | ALEP | Repl. by HEISTER 01E | | | |
| $1.022 \pm 0.028 \pm 0.030$ | 1.7k | ¹³ ALBRECHT | 94E | ARG | $E_{cm}^{ee} = 9.4-10.6 \text{ GeV}$ | | | |
| $0.99 \pm 0.07 \pm 0.04$ | | ¹⁴ BUSKULIC | 94D | ALEP | 1990+1991 LEP run | | | |
| 1 HEISTER 01E quote $0.992\pm0.007\pm0.006\pm0.005$ where the errors are statistical, systematic, and an uncertainty due to the final state model. We combine the systematic error and model uncertainty. They use $\tau\to~\pi\nu_{\tau},~\tau\to~K\nu_{\tau},~\tau\to~\rho\nu_{\tau}$, and $\tau\to$ | | | | | | | | |
| $a_1 \nu_{\tau}$ decays. | | 0 | | | | | | |
| 2 ABREU 00L use $	au$ | | | | | | | | |
| 3 A SNER 00 use $	au^-$ | | | | | | | | |
| ⁴ ACCIARRI 98R use | | | au $	o$ | $ ho u_{	au}$ de | ecays. | | | |
| 5 ACKERSTAFF 97R use $	au ightarrow a_{1} u_{	au}$ decays. | | | | | | | | |

- $^{6}\,\mathrm{ALEXA\,NDER}$ 97F use $\tau \to \ \rho \bar{\nu_{\tau}}$ decays.
- 7 COAN 97 use h^+h^- energy correlations.
- 8 Combined fit to ARGUS tau decay parameter measurements in ALBRECHT 95 c, ALBRECHT 93c, and ALBRECHT 94e. 9 Uses $au \to a_1
 u_{ au}$ decays. Replaced by ALBRECHT 95 c. 10 ACCIARRI 96H use $au \to \pi
 u_{ au}$, $au \to K
 u_{ au}$, and $au \to \rho
 u_{ au}$ decays.

- 11 AKERS 95p use $\tau \rightarrow a_1 \nu_\tau$ decays. $^{12} \text{BUSKULIC 95D use } \tau \rightarrow \pi \nu_\tau, \tau \rightarrow \rho \nu_\tau, \text{ and } \tau \rightarrow a_1 \nu_\tau \text{ decays.}$
- Table Buskulic 93D use $\tau \to \pi \nu_{\tau}$, $\tau \to \rho \nu_{\tau}$, and $\tau \to a_1 \nu_{\tau}$ decays. 13 ALBRECHT 94E measure the square of this quantity and use the sign determined by ALBRECHT 90: to obtain the quoted result. Uses $\tau \to a_1 \nu_{\tau}$ decays. Replaced by ALBRECHT 95c. 14 BUSKULIC 94D use $\tau \to \pi \nu_{\tau}$ and $\tau \to \rho \nu_{\tau}$ decays. Superseded by BUSKULIC 95D.

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| BRIERE | 03 | PRL 90 181802 | R. A. Briere et al. | |
| HEISTER INAMI | 03 F 03 | EPJ C30 291 PL B551 16 | A. Heister et al. K. Inami et al. | (CLEO Collab.) (ALEPH Collab.) (BELLE Collab.) |
| CHEN REGAN | 02 C 02 | PR D66 071101R | S. Chen et al. | (CLEO Collab.) |
| ABBIENDI | 01 J | EPJ C19 653 EPJ C20 617 | B.C. Regan et al. G. Abbiendi et al. P. Abreu et al. | (OPAL Collab.) |
| ABREU ACCIARRI | 01 M 01 F | PL B507 47 | M. Acciarri et al. | (DÈLPHI Collab.) (L3 Collab.) |
| ACHARD | 01 D | PL B519 189 | P. Achard et al. | (L3 Collab.) |
| ANASTASSOV | 01 | PRL 86 4467 | A. Anastassov et al. | (CLEO Collab.) |
| HEISTER | 01E | EPJ C22 217 | A. Heister et al. | (ÀLEPH Collab.) |
| ABBIENDI | 00A | PL B492 23 | G. Abbiendi et al. | (OPAL Collab.) |
| ABBIENDI | 00 C | EPJ C13 213 | G. Abbiendi <i>et al.</i> | (OPAL Collab.) |
| ABBIENDI | 00 D | EPJ C13 197 | G. Abbiendi <i>et al.</i> | (OPAL Collab.) |
| ABREU | 00 L | EPJ C16 229 | P. Abreu et al. | (DELPHI Collab.) |
| ACCIARRI | 00 B | | M. Acciarri et al. | (L3 Collab.) |
| AHMED | 00 | PR D61 071101R | S. Ahmed et al. | (CLEO Collab.) (ARGUS Collab.) |
| ALBRECHT | 00 | PL B485 37 | H. Albrecht et al. | (CLEO Collab.) |
| AS NER | 00 | PR D61 012002 | D.M. Asner et al. | |
| AS NER BERGFELD | 00 B 00 | PRL 84 830 | D.M. Asner et al. T. Bergfeld et al. | (CLEO Collab.) (CLEO Collab.) |
| BROWDER | 00 | PR D61 052004 | T.E. Browder et al. | (CLEO Collab.) |
| EDWARDS | 00 A | PR D61 072003 | K.W. Edwards et al. | (CLEO Collab.) |
| GONZALEZ-S. | 00 | NP B582 3 | G.A. Gonzalez-Sprinberg et al. | (OPAL Collab.) |
| ABBIENDI | 99 H | PL B447 134 | G. Abbiendi et al. | |
| ABREU | 99X | EPJ C10 201 | P. Abreu et al. | (DELPHI Collab.) |
| ACKERSTAFF | | EPJ C8 3 | K. Ackerstaff et al. | (OPAL Collab.) |
| ACKERSTAFF | 99E | EPJ C8 183 | K. Ackerstaff et al. | (OPAL Collab.) |
| BARATE | 99 K | EPJ C10 1 | R. Barate et al. | (ÀLEPH Collab.) |
| BARATE | 99 R | EPJ C11 599 | R. Barate et al. | (ALEPH Collab.) |
| BISHAI | 99 | PRL 82 281 | M. Bishai et al. | (CLEO Collab.) |
| GODANG | 99 | PR D59 091303 | R. Godang et al. | (CLEO Collab.) |
| RICHICHI | 99 | PR D60 112002 | S.J. Richichi et al. | (CLEO Collab.) |
| ACCIARRI | 98 C | PL B426 207 | M. Acciarri et al. | (L3 Collab.) |
| ACCIARRI | 98 E | PL B434 169 | M. Acciarri et al. | (L3 Collab.) |
| ACCIARRI | 98 R | PL B438 405 | M. Acciarri et al. | (L3 Collab.) |
| ACKERS TAFF | | EPJ C4 193 | K. Ackerstaff et al. | (OPAL Collab.) |
| ACKERS TAFF | | PL B431 188 | K. Ackerstaff et al. | (OPAL Collab.) |
| ALBRECHT | 98 | PL B431 179 | H. Albrecht et al. | (ARGUS Collab.) |
| BARATE | 98 | EPJ C1 65 | R. Barate et al. | (ALEPH Collab.) |
| BARATE | 98 E | EPJ C4 29 | R. Barate et al. | (ALEPH Collab.) |
| BLISS | 98 | PR D57 5903 | D.W. Bliss et al. | (CLEO Collab.) |
| ABE | 97 O | PRL 78 4691 | K. Abe et al. | (SLD Collab.) |
| ACKERS TAFF ACKERS TAFF | 97 J 97 L | PL B404 213 ZPHY C74 403 ZPHY C75 593 | K. Ackerstaff <i>et al.</i> K. Ackerstaff <i>et al.</i> K. Ackerstaff <i>et al.</i> | (OPAL Collab.) (OPAL Collab.) |
| ACKERSTAFF ALEXANDER | 97 R 97 F | ZPHY C75 593 PR D56 5320 | K. Ackerstaff et al. J.P. Alexander et al. | (OPAL Collab.) (OPAL Collab.) (CLEO Collab.) |
| AMMAR | 97 B | PRL 78 4686 | R. Ammar et al. | (CLEO Collab.) |
| ANASTASSOV | | PR D55 2559 | A. Anastassov et al. | (CLEO Collab.) |
| Also ANDERSON | 97 | PR D58 119903 (erratum | n)A. Anastassov et al. | (CLEO Collab.) |
| AVERY | 97 | PRL 79 3814 PR D55 R1119 | S. Anderson et al. P. Avery et al. | (CLEO Collab.) |
| BARATE | 97 I | ZPHY C74 387 | R. Barate et al. | (ALEPH Collab.) |
| BARATE | 97 R | PL B414 362 | R. Barate et al. | (ALEPH Collab.) |
| BERGFELD | 97 | PRL 79 2406 | T. Bergfeld et al. | (CLEO Collab.) |
| BONVICINI | 97 | PRL 79 1221 | G. Bonvicini et al. | (CLEO Collab.) |
| BUS KULIC | 97 C | ZPHY C74 263 | D. Buskulic et al. | (ALEPH Collab.) |
| COAN | 97 | PR D55 7291 | T.E. Coan et al. | (CLEO Collab.) |
| EDWARDS | 97 | PR D55 R3919 | K.W. Edwards et al. | (CLEO Collab.) |
| EDWARDS | 97 B | PR D56 R5297 | K.W. Edwards et al. | (CLEO Collab.) |
| ES CRIBANO ABREU | 97 96 B | PL B395 369 | R. Escribano, E. Masso | (BARC, PARIT) (DELPHI Collab.) |
| ACCIARRI ACCIARRI | 96 H 96 K | PL B365 448 PL B377 313 PL B389 187 | P. Abreu et al. M. Acciarri et al. M. Acciarri et al. | (L3 Collab.) (L3 Collab.) |
| ALAM | 96 | PRL 76 2637 | M.S. Alam et al. | (CLEO Collab.) |
| ALBRECHT | 96 E | PRPL 276 223 | H. Albrecht <i>et al.</i> | (ARGUS Collab.) |
| ALEXANDER | 96 D | PL B369 163 | G. Alexander <i>et al.</i> | (OPAL Collab.) |
| ALEXANDER | 96 E | PL B374 341 | G. Alexander et al. | (OPAL Collab.) |
| ALEXANDER | 96 S | PL B388 437 | G. Alexander et al. | (OPAL Collab.) |
| BAI | 96 | PR D53 20 | J.Z. Bai et al. | (BES Collab.) |
| BALEST | 96 | PL B388 402 | R. Balest et al. | (CLEO Collab.) |
| BARTELT | 96 | PRL 76 4119 | J.E. Bartelt <i>et al.</i> | (CLEO Collab.) |
| BUS KULIC | 96 | ZPHY C70 579 | D. Buskulic <i>et al.</i> | (ALEPH Collab.) |
| BUS KULIC | 96 C | ZPHY C70 561 | D. Buskulic et al. | (ALEPH Collab.) |
| COAN | 96 | PR D53 6037 | T.E. Coan et al. | (CLEO Collab.) |
| ABE | 95 Y | | K. Abe et al. | (SLD Collab.) |
| ABREU | 95 T | | P. Abreu et al. | (DELPHI Collab.) |
| ABREU | 95 U | PL B359 411 | P. Abreu et al. | (DELPHI Collab.) |
| ACCIARRI | 95 | PL B345 93 | M. Acciarri et al. | (L3 Collab.) |
| ACCIARRI | 95 F | PL B352 487 | M. Acciarri et al. | (L3 Collab.) |
| AKERS | 95 F | ZPHY C66 31 | R. Akers et al. | (OPAL Collab.) |
| AKERS | 95 I | ZPHY C66 543 | R. Akers et al. | (OPAL Collab.) |
| AKERS | 95 P | ZPHY C67 45 | R. Akers et al. | (OPAL Collab.) |
| AKERS | 95 Y | ZPHY C68 555 | R. Akers et al. | (OPAL Collab.) |
| ALBRECHT ALBRECHT | | PL B341 441 | H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECHT ALBRECHT | 95 95 C | PL B349 576 | H. Albrecht et al. | (ARGUS Collab.) |
| | | PL B349 576 ZPHY C68 25 ZPHY C68 215 | H. Albrecht <i>et al.</i> H. Albrecht <i>et al.</i> H. Albrecht <i>et al.</i> | (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) |
| BALEST | 95 C 95 G 95 H 95 C | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. | (ARGUS Collab.) |
| BALEST BERNABEU BUS KULIC | 95 C 95 G 95 H 95 C 95 C | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP B436 474 PL B346 371 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (ALEPH Collab.) |
| BALEST BERNABEU BUS KULIC BUS KULIC Also | 95 C 95 H 95 C 95 C 95 C 95 D | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP B436 474 PL B346 371 PL B346 379 PL B363 265 (erratum) | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. | (ARGUS COIIab.) (ARGUS COIIab.) (CLEO COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) |
| BALEST BERNABEU BUS KULIC BUS KULIC Also ABREU AKERS | 95 C 95 G 95 H 95 C 95 C 95 D 94 K 94 E | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP B436 474 PL B346 371 PL B363 265 (erratum) PL B334 435 PL B338 207 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. P. Abreu et al. R. Akers et al. | (ARGUS COIIab.) (ARGUS COIIab.) (CLEO COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) (DELPHI COIIab.) (OPAL COIIab.) |
| BALEST BERNABEU BUS KULIC BUS KULIC AISO ABREU AKERS AKERS ALBRECHT | 95 C 95 H 95 C 95 C 95 C 95 D 94 K 94 E 94 G 94 E | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP 8436 474 PL 8346 371 PL 8346 379 PL 8334 255 (erratum) PL 8328 207 PL 8339 278 PL 8339 278 PL 8339 378 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. D. Buskulic et al. P. Abreu et al. R. Akers et al. R. Akers et al. H. Albrecht et al. | (ARGUS COIIab.) (ARGUS COIIab.) (CLEO COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) (ALEPH COIIab.) (DELPHI COIIab.) (OPAL COIIab.) (OPAL COIIab.) (ARGUS COIIab.) |
| BALEST BERNABEU BUS KULIC BUS KULIC Also ABREU AKERS AKERS ALBRECHT ARTUSO BARTELT | 95 C 95 G 95 H 95 C 95 C 95 D 94 K 94 E 94 G 94 E 94 | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP 8436 474 PL 8346 371 PL 8346 371 PL 8333 265 (erratum) PL 8333 435 PL 8339 278 PL 8339 278 PL 8337 383 PRL 72 3762 PRL 73 1890 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. P. Abreu et al. R. Akers et al. R. Akers et al. H. Albrecht et al. M. Artuso et al. J.E. Barfelt et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (DELPHI Collab.) (OPAL Collab.) (OPAL Collab.) (ARGUS Collab.) (CLEO Collab.) (CLEO Collab.) |
| BALEST BERNABEU BUS KULIC AISO ABREU AKERS AKERS ALBRECHT ARTUSO BARTELT BATTLE BAUER | 95 C 95 G 95 H 95 C 95 C 95 D 94 K 94 E 94 G 94 E 94 94 | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP 8436 474 PL 8346 371 PL 8363 265 (erratum) PL 8333 435 PL 8339 278 PL 8339 278 PL 8339 278 PR 173 3762 PRL 73 1079 PRL 73 1079 PR D50 R13 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. P. Albreu et al. R. Akers et al. R. Akers et al. H. Albrecht et al. M. Artuso et al. J.E. Barfelt et al. M. Battle et al. D. B. Battle et al. D. A. Bauer et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO COllab.) (ALEPH COllab.) (ALEPH COllab.) (ALEPH COllab.) (ALEPH COllab.) (OPAL Collab.) (OPAL COllab.) (ARGUS COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) |
| BALEST BERNABEU BUS KULIC ALSO ABREU AKERS AKERS AKERS AKERS BATTLE BAUER BUS KULIC BUS KULIC BUS KULIC BUS KULIC BUS KULIC BUS KULIC | 95 C 95 G 95 H 95 C 95 C 95 D 94 K 94 E 94 G 94 E 94 94 94 D 94 E | ZPHY C68 25 ZPHY C68 215 PRL 75 3809 NP 8436 474 PL 8346 371 PL 8363 265 (erratum) PL 8363 265 (erratum) PL 8328 207 PL 8339 278 PL 8339 278 PRL 73 362 PRL 73 1079 PRL 73 1079 PR D50 R13 PL 8321 168 PL 8321 168 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bernabeu et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. P. Abreu et al. R. Akers et al. R. Akers et al. H. Albrecht et al. M. Artuso et al. JE. Bardelt et al. M. Battle et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. | (ARGUS Collab.) (ARGUS Collab.) (ALEPH COllab.) (ALEPH COllab.) (ALEPH COllab.) (ALEPH COllab.) (ALEPH COllab.) (OPAL Collab.) (OPAL Collab.) (OPAL Collab.) (CLEO Collab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (ALEPH COllab.) (ALEPH COllab.) |
| BALEST BERNABEU BUS KULIC ALSO ABREU AKERS AKERS ALBRECHT ARTUSO BARTELT BATTLE BAUER BUS KULIC | 95 C 95 G 95 H 95 C 95 C 95 D 94 K 94 E 94 G 94 E 94 94 94 D | ZPHY C68 25 ZPHY C68 25 PRL 75 3809 NP B436 474 PL B346 371 PL B346 379 PL B332 255 (erratum) PL B333 275 PL B328 207 PL B339 278 PL B339 278 PL B339 78 PRL 72 3762 PRL 73 1890 PRL 73 1079 PR D50 R13 PRL B321 168 | H. Albrecht et al. H. Albrecht et al. R. Balest et al. J. Bermabeu et al. D. Buskulic et al. D. Buskulic et al. D. Buskulic et al. P. Albreu et al. R. Akers et al. R. Akers et al. H. Albrecht et al. M. Artuso et al. J.E. Bartelt et al. M. Battle et al. D.A. Bauer et al. D.A. Bauer et al. D.B. Buskulic et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (DELPHI Collab.) (OPAL Collab.) (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (TPC/2gamma Collab.) (ALEPH Collab.) |

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| ALBRECHT 93 C ALBRECHT 93 G BALEST 93 | ZPHY C58 61 PL B316 608 PR D47 R3671 PRL 70 138 PRL 71 1791 PL B301 419 PRL 70 1207 ZPHY C55 555 PL B288 373 PRL 69 3610 PRL 71 3395 (erratum) | H. Albrecht et al. H. Albrecht et al. R. Balest et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) |
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| BEAN 93 BORTOLETTO 93 | PRL 70 138 PRL 71 1791 | A. Bean et al. D. Bortoletto et al. R. Escribano, E. Masso M. Procario et al. | (CLEO Collab.) (CLEO Collab.) (BARC) |
| PROCARIO 93 | PRL 70 1207 | M. Procario et al. P. Abreu et al. | (CLEO Collab.) |
| ABREU 92N | ZPHY C55 555 | | (DELPHI Collab.) |
| ACTON 92F | PL B281 405 | D.P. Acton et al. | (OPAL Collab.) |
| ACTON 92H | PL B288 373 | P.D. Acton et al. | (OPAL Collab.) |
| AKERIB 92 Also | PRL 69 3610 PRL 71 3395 (erratum) ZPHY C53 367 | D.S. Akerib et al. D.S. Akerib et al. | (CLEO Collab.) (CLEO Collab.) (ARGUS Collab.) |
| ALBRECHT 92D ALBRECHT 92K | ZPHY C53 367 ZPHY C55 179 | H. Albrecht et al. H. Albrecht et al. | (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) |
| ALBRECHT 92 Q AMMAR 92 | ZPHY C56 339 PR D45 3976 | H. Albrecht et al. R. Ammar et al. | (ARGUS CONIAL.) (ARGUS CONIAL.) (CLEO CONIAL.) |
| ARTUSO 92 | PRL 69 3610 PRL 71 3395 (erratum) ZPHY CS3 367 ZPHY CS5 179 PL B292 221 ZPHY CS6 339 PR D45 3976 PRL 69 3278 PRL 69 3278 PRL 69 3278 PRL 8291 488 PL B297 459 ZPHY CS4 211 PL B265 451 PL B260 259 PL B260 259 PL B260 259 | M. Artuso et al. | (CLEO Collab.) |
| BAI 92 | | J.Z. Bai et al. | (BES Collab.) |
| BATTLE 92 | PL B291 488 | M. Battle et al. | (CLEO Collab.) |
| BUSKULIC 92J | PL B297 459 | D. Buskulic et al. | (ALEPH Collab.) |
| ADEVA 91F | PL B265 451 | B. Adeva et al. H. Albrecht et al. | (ALEPH Collab.) (L3 Collab.) (ARGUS Collab.) |
| ANTREAS YAN 91 | PL B259 216 | G. Alexander et al. D. Antreasyan et al. | (OPAL Collab.) (Crystal Ball Collab.) |
| GRIFOLS 91 ABACHI 90 ALBRECHT 90E ALBRECHT 90I BEHREND 90 BOWCOCK 90 DELAGUILA 90 GOLDBERG 90 WU 90 ABACHI 898 | PL B265 451 PL B260 259 PL B266 201 PL B259 216 PL B255 611 PR D41 1414 PL B246 278 | J.A. Grifols, A. Mendez S. Abachi <i>et al.</i> | (BARC) (HRS Collab.) (ARGUS Collab.) |
| ALBRECHT 90E | PL B246 278 | H. Albrecht <i>et al.</i> H. Albrecht <i>et al.</i> H.J. Behrend <i>et al.</i> | (ARGUS CONIAD.) |
| ALBRECHT 90I | PL B250 164 | | (ARGUS CONIAD.) |
| BEHREND 90 | 7PHY C46 537 | | (CELLO CONIAD.) |
| BOWCOCK 90 | PR D41 805 | T.J.V. Bowcock et al. | (CLEO Collab.) |
| DELAGUILA 90 | PL B252 116 | F. del Aguila, M. Sher | (BARC, WILL) |
| GOLDBERG 90 | PL B251 223 | M. Goldberg et al. | (CLEO Collab.) |
| WU 90 | PR D41 2339 | D.Y. Wu et al. | (Mark II Collab.) |
| DELIDEND COD | DI DOGG 440 | T.J.V. Bowcock et al. F. del Aguila, M. Sher M. Goldberg et al. D.Y. Wu et al. S. Abachi et al. H.J. Behrend et al. H. Janssen et al. C. Kleinwort et al. | ` (HRS Collab.) (CELLO Collab.) (Crystal Ball Collab.) |
| WU 90 ABACHI 89B BEHREND 89B JANSSEN 89 KLEINWORT 89 ADEVA 88 ALBRECHT 88B | ZPHY C42 7 | C. Kleinwort et al. | (JADE Collab.) |
| | PR D38 2665 | B. Adeva et al. | (Mark-J Collab.) |
| ALBRECHT 88B | PL B202 149 | H. Albrecht et al. | (ÀRGUS Collab.) |
| | ZPHY C41 1 | H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECHI 88M | PR D37 1750 PI B200 226 | H. Albrecht et al. D. Amidei et al. H.I. Behrend et al. | (ARGUS Collab.) (Mark II Collab.) (CELLO Collab.) |
| BRAUNSCH 88 C | ZPHY C39 331 | W. Braunschweig et al. | (TASSO Collab.) |
| KEH 88 | PL B212 123 | S. Keh et al. | (Crystal Ball Collab.) |
| TS CHIRHART 88 ABACHI 87B | PL B205 407 | R. Tschirhart et al. | (HRS Collab.) |
| | PL B197 291 | S. Abachi et al. | (HRS Collab.) |
| ADLER 87B | PRL 59 2519 PRL 59 1527 PR D35 1553 | J. Adler et al. H. Aihara et al. | (HRS Collab.) (Mark III Collab.) (TPC Collab.) |
| AIHARA 87 C | PRL 59 751 | H. Aihara <i>et al.</i> | (TPC Collab.) |
| ALBRECHT 87 L | PL B185 223 | H. Albrecht <i>et al.</i> | |
| ALBRECHT 87P BAND 87 | PL B199 580 PL B198 297 | H. Albrecht et al. H.R. Band et al. | (ARGUS Collab.) (MAC Collab.) (MAC Collab.) |
| BARINGER 87 BEBEK 87C | PRL 59 415 PRL 59 1993 PR D36 690 | P. Baringer et al. C. Bebek et al. | (CLEO Collab.) (CLEO Collab.) |
| BURCHAT 87 | PL B222 133 PL B222 137 ZPHY C42 7 PR D38 2665 PL B202 149 ZPHY C41 1 ZPHY C41 1405 PR D37 1750 PL B200 226 ZPHY C39 331 PL B212 123 PL B212 123 PL B212 123 PL B215 407 PR D37 1551 PR D36 1553 PR D36 1553 PR D36 690 PR D35 2569 PR D36 2185 PL B199 260 PR D35 269 PR D36 2185 PL B199 540 PR D36 2185 PL B199 541 PR D36 2185 PL B199 551 PR D36 2185 PL B189 260 PR D36 2185 PL B189 261 PR D36 2182 | P.R. Burchat et al. | (Mark II Collab.) |
| BYLSMA 87 | | B.G. Bylsma et al. | (HRS Collab.) |
| COFFMAN 87 DERRICK 87 | PR D36 2185 PL B189 260 PP D25 400 | D.M. Coffman et al. M. Derrick et al. W.T. Ford et al. | (Mark III Collab.) (HRS Collab.) (MAC Collab.) |
| FORD 87B GAN 87 | PR D36 1971 PRL 59 411 | W.T. Ford et al. K.K. Gan et al. | (MAC Collab.) (MAC Collab.) (Mark II Collab.) |
| GAN 87B | PL B197 561 | K.K. Gan et al. | (Mark II Collab.) |
| AIHARA 86E | PRL 57 1836 | H. Aihara et al. | (TPC Collab.) |
| BARTEL 86D PDG 86 RUCKSTUHL 86 SCHMIDKE 86 YELTON 86 ALTHOFF 85 ASH 85B BALTRUSAIT 85 | PL B182 216 PL 170B 1 | W. Bartel et al. M. Aguilar-Benitez et al. W. Ruckstuhl et al. | (ĴADE Collab.) (CERN, CIT+) (DELCO Collab.) |
| SCHMIDKE 86 | PRL 57 527 | J.M. Yelton et al. | (Mark II Collab.) |
| YELTON 86 | PRL 56 812 | | (Mark II Collab.) |
| ALTHOFF 85 | ZPHY C26 521 | M. Althoff et al. | (TASSO Collab.) |
| ASH 85B | PRL 55 2118 | | (MAC Collab.) |
| BALTRUSAIT 85 BARTEL 85F BEHRENDS 85 | PRL 55 1842 PL 161B 188 PR D32 2468 PRL 54 1775 | R.M. Baltrusaitis et al. W. Bartel et al. S. Behrends et al. | (JADE Collab.) |
| BERGER 85 | ZPHY C28 1 | S. Behrends <i>et al.</i> I. Beltrami <i>et al.</i> C. Berger <i>et al.</i> | (CLEO Collab.) (HRS Collab.) (PLUTO Collab.) |
| FERNANDEZ 85 | PRL 54 2489 | P.R. Burchat et al. | (Mark II Collab.) |
| | PRL 54 1624 | E. Fernandez et al. | (MAC Collab.) |
| MILLS 85 | PRL 54 624 | G.B. Mills et al. | (DÉLCO Collab.) |
| AIHARA 84 C | PR D30 2436 | H. Aihara et al. | (TPC Collab.) |
| BEHREND 84 | ZPHY C23 103 | H.J. Behrend et al. | (CELLO Collab.) |
| MILLS 84 | PRL 52 1944 | G.B. Mills et al. | (DELCO COllab.) |
| BEHREND 83 C | PL 127B 270 | H.J. Behrend et al. | (CELLO COllab.) |
| SILVERMAN 83 BEHREND 82 | PR D27 1196 PL 114B 282 | D.J. Silverman, G.L. Shaw H.J. Behrend <i>et al.</i> C.A. Blocker <i>et al.</i> | (UCI) (CELLO Collab.) |
| BLOCKER 82B | PRL 48 1586 | C.A. Blocker et al. C.A. Blocker et al. G.J. Feldman et al. | (Mark II Collab.) |
| BLOCKER 82D | PL 109B 119 | | (Mark II Collab.) J |
| FELDMAN 82 | PRL 48 66 | | (Mark II Collab.) |
| HAYES 82 | PR D25 2869 | K.G. Hayes et al. | (Mark II Collab.) |
| BERGER 81B | PL 99B 489 | C. Berger et al. | (PLUTO Collab.) |
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| DAVIER | 06 | RMP 78 1043 | M. Davier, A. Hocker, Z. Zhang | (LALO, PARIN+) |
|-----------|----|--------------|--------------------------------|----------------|
| RAHAL-CAL | 98 | IJMP A13 695 | G. Rahal-Callot | (ETH |
| GENTILE | 96 | PRPL 274 287 | S. Gentile, M. Pohl | (ROMAI, ETH) |
| WEINSTEIN | 93 | ARNPS 43 457 | A.J. Weinstein, R. Stroynowski | ` (CIT, SMU) |
| PERL | 92 | RPP 55 653 | M.L. Perl | ` (SLAC |

A. Pich B.C. Barish, R. Stroynowski K.K. Gan, M.L. Perl K.G. Hayes, M.L. Perl M.L. Perl GAN HAYES PERL 88 88 80 Heavy Charged Lepton Searches

Charged Heavy Lepton MASS LIMITS

Sequential Charged Heavy Lepton (L±) MASS LIMITS

MPL A5 1995 PRPL 157 1 IJMP A3 531 PR D38 3351

ARNPS 30 299

PICH BARISH

These experiments assumed that a fourth generation L^\pm decayed to a fourth generation ν_L (or L^0) where ν_L was stable, or that L^\pm decays to a light ν_ℓ via mixing.

See the "Quark and Lepton Compositeness, Searches for" Listings for limits on radiatively decaying excited leptons, i.e. $\ell^* \to \ell \gamma$. See the "WIMPs and other Particle Searches" section for heavy charged particle search limits in which the charged particle could be a lepton.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------------|-----------|-----------------------|-------|------------|-------------------------------------------------------------------------|
| >100.8 | 95 | ACHARD | 01в | L3 | Decay to ν W |
| >101.9 | 95 | ACHARD | 01B | L3 | $m_L - m_{I0} > 15 \text{ GeV}$ |
| • • • We do no | t use the | following data for | avera | ages, fits | , limits, etc. • • • |
| > 81.5 | 95 | ACKERSTAFF | 98c | OPAL | Assumed $m_{L^{\pm}} - m_{L^{0}} > 8.4$ |
| > 80.2 | 95 | ACKERSTAFF | 98c | OPAL | $m_{L^0}^{\text{GeV}} > m_{L^\pm}^{\text{and } L^\pm} ightarrow \nu W$ |
| < 48 or > 61 | 95 | ¹ ACCIARRI | 96G | L3 | |
| > 63.9 | 95 | ALEXA NDER | 96P | OPAL | Decay to massless $ u$'s |
| > 63.5 | 95 | BUSKULIC | 96s | ALEP | $m_L - m_{I0} > 7 \text{ GeV}$ |
| > 65 | 95 | BUSKULIC | 96s | ALEP | Decay to massless ν 's |
| none 10-225 | | ² AHMED | 94 | CNTR | H1 Collab. at HERA |
| none 12.6-29.6 | 95 | KIM | 91B | A MY | Massless $ u$ assumed |
| > 44.3 | 95 | AKRAWY | 90G | OPAL | |
| none 0.5-10 | 95 | ³ RILES | 90 | MRK2 | For $(m_{10} - m_{10}) > 0.25 - 0.4 \text{GeV}$ |
| > 8 | | ⁴ STOKER | 89 | MRK2 | For $(m_{I+} - m_{I0}) = 0.4 \text{ GeV}$ |
| > 12 | | ⁴ STOKER | 89 | | For $m_{10} = 0.9$ GeV |
| none 18.4-27.6 | 95 | ⁵ ABE | 88 | VNS | L |
| > 25.5 | 95 | ⁶ ADACHI | 88B | TOPZ | |
| none 1.5-22.0 | 95 | BEHREND | 88c | CELL | |
| > 41 | 90 | ⁷ ALBAJAR | 87B | UA1 | |
| > 22.5 | 95 | ⁸ ADEVA | 85 | MRKJ | |
| > 18.0 | 95 | 9 BARTEL | 83 | JADE | |
| none 4-14.5 | 95 | ¹⁰ BERGER | 81B | PLUT | |
| > 15.5 | 95 | 11 BRANDELIK | 81 | TASS | |
| > 13. | | 12 AZIMOV | 80 | | |
| > 16. | 95 | 13 BARBER | 80B | CNTR | |
| > 0.490 | | ¹⁴ ROTHE | 69 | RVUE | |

 $^{1}\,\text{ACCIARRI}$ 96G assumes LEP result that the associated neutral heavy lepton mass > 40

GeV. ² The AHMED 94 limits are from a search for neutral and charged sequential heavy leptons at HERA via the decay channels $L^- \to e \gamma$, $L^- \to \nu W^-$, $L^- \to e Z$; and $L^{0} \to \nu \gamma$, $L^0 \to e^- W^+$, $L^- \to \nu Z$, where the W decays to $\ell \nu_\ell$, or to jets, and Z decays to $\ell^+\ell^-$ or jets.

³ RILES 90 limits were the result of a special analysis of the data in the case where the mass difference $m_{L^-}-m_{L^0}$ was allowed to be quite small, where L^0 denotes the neutrino into which the sequential charged lepton decays. With a slightly reduced m_{I^\pm} range,

the mass difference extends to about 4 GeV.

4 STOKER 89 (Mark II at PEP) gives bounds on charged heavy lepton (L+) mass for the generalized case in which the corresponding neutral heavy lepton (L^0) in the $\mathrm{SU}(2)$

doublet is not of negligible mass. 5 ABE 88 search for L^+ and $L^- \to \,$ hadrons looking for acoplanar jets. The bound is valid for $m_{\nu} < 10$ GeV.

⁶ ADACHI 88B search for hadronic decays giving acoplanar events with large missing energy. $E_{cm}^{ee} = 52 \text{ GeV}.$

Assumes associated neutrino is approximately massless.

Assumes associated neutrino is approximately massicess. 8 ADEVA 85 analyze one-isolated-muon data and sensitive to τ <10 nanosec. Assume B(lepton) = 0.30. $E_{\rm cm}$ = 40-47 GeV. 9 BARTEL 83 limit is from PETRA \pm^+e^- experiment with average $E_{\rm cm}$ = 34.2 GeV.

 10 BERGER 81B is DESY DORIS and PETRA experiment. Looking for $e^+e^- \rightarrow L^+L^-$. 11 BRANDELIK 81 is DESY-PETRA experiment. Looking for $e^+e^- \rightarrow L^+L^-$. 12 AZIMOV 80 estimated probabilities for M+N type events in $e^+e^- \rightarrow L^+L^-$ deducing semi-hadronic decay multiplicities of L from e^+e^- annihilation data at $E_{\rm cm}=(2/3)m_L$.

Obtained above limit comparing these with $e^+\,e^-$ data (BRANDELIK 80). 13 BARBER 80B looked for $e^+\,e^-
ightarrow \, {\it L}^+\,{\it L}^-$, ${\it L}
ightarrow \, {\it \nu}_{\it L}^+$ X with MARK-J at DESY-PETRA.

 $^{14}\,\mathrm{ROTHE}$ 69 examines previous data on μ pair production and π and K decays.

Stable Charged Heavy Lepton (L±) MASS LIMITS

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN |
|-------------------------|-------------|-------------------|--------------|--------------------|
| >102.6 | 95 | ACHARD | 01в | L3 |
| • • • We do not use the | e following | data for averages | , fits, | limits, etc. • • • |
| > 28.2 | 95 15 | ADACHI | 90c | TOPZ |
| none 18.5-42.8 | 95 | AKRAWY | 90 o | OPAL |
| > 26.5 | 95 | DECAMP | 90F | ALEP |
| none m_{μ} -36.3 | 95 | SODERSTROM | / 190 | MRK2 |

 $^{^{\}prime\prime}$ ADACHI 90c put lower limits on the mass of stable charged particles with electric charge Q satisfying 2/3 < Q/e < 4/3 and with spin 0 or 1/2. We list here the special case for a stable charged heavy lepton.

Heavy Charged Lepton Searches, Neutrino Properties

Charged Long-Lived Heavy Lepton MASS LIMITS

| VALUE (GeV) | CL% EVTS | DO CUMENT ID | | TECN CHG | COMMENT |
|-----------------------------------------------------------|----------------|--------------------------------------------------|-----------------------|-------------------------------------|---------------------------------------------------------------------------|
| • • • We do not | use the follow | ing data for averag | es, fits, | limits, etc. • | • • |
| >102.0 | 95 | ABBIENDI | 03L | OPAL | pair produced in |
| > 0.1 none 0.55-4.5 none 0.2-0.92 none 0.97-1.03 | 0 | 16 ANSORGE 17 BUSHNIN 18 BARNA 18 BARNA | 73B 73 68 68 | HBC – CNTR – CNTR – CNTR – | e ⁺ e− Long-lived Long-lived Long-lived Long-lived |

 $^{16}\mathsf{ANSORGE}$ 73B looks for electron pair production and electron-like Bremsstrahlung. $^{17} \text{BUSHNIN}$ 73 is SERPUKHOV 70 GeV p experiment. Masses assume mean life above 7×10^{-10} and 3×10^{-8} respectively. Calculated from cross section (see "Charged Quasi-Stable Lepton Production Differential Cross Section" below) and 30 GeV muon pair production data.

¹⁸BARNA 68 is SLAC photoproduction experiment.

Doubly-Charged Heavy Lepton MASS LIMITS

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | CHG | | |
|---------------------------------|-----------|---------------------|-------|---------|--------|---|---|
| ullet $ullet$ We do not use the | following | data for averages, | fits, | limits, | etc. • | • | • |
| none 1-9 GeV | 90 1 | ¹⁹ CLARK | 81 | SPEC | ++ | | |

 19 CLARK 81 is FNAL experiment with 209 GeV muons. Bounds apply to μ_P which couples with full weak strength to muon. See also section on "Doubly-Charged Lepton Production Cross Section.

Doubly-Charged Lepton Production Cross Section (μN Scattering)

| VALUE (cm ²) | EVTS | DO CUMENT | ID | TECN | <u>CHG</u> | |
|--------------------------------|------------|---------------------|-------------|---------|---------------------|---------------|
| • • • We do not use the | e followin | g data for avera | ages, fits, | limits, | etc. • • • | |
| $<6. \times 10^{-38}$ | 0 | ²⁰ CLARK | 81 | SPEC | ++ | |
| ²⁰ CLARK 81 is FNAL | experime | nt with 209 GeV | / muon. | Looked | for μ^+ nucleon | \rightarrow |
| | | | | | | |

 $\overline{\mu}^0_P \to \mu^+ \mu^- \overline{\nu}_\mu$ and $\mu^+ n \to \mu^+_P + X$, $\mu^+_P + \to 2\mu^+ \nu_\mu$. Above limits are for $\sigma \times BR$ taken from their mass-dependence plot figure 2.

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| ALEXANDER | 96 P | PL B385 433 | G. Alexander et al. | (OPAL Collab.) |
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| ADACHI | 88 B | PR D37 1339 | I. Adachi et al. | (TOPAZ Collab.) |
| BEHREND | 88 C | ZPHY C41 7 | H.J. Behrend et al. | (CELLO Collab.) |
| ALBAJAR | 87 B | PL B185 241 | C. Albajar et al. | `(UA1 Collab.) |
| ADEVA | 85 | PL 152B 439 | B. Adeva et al. | (Mark-J Collab.) |
| Also | | PRPL 109 131 | B. Adeva et al. | (Mark-J Collab.) |
| BARTEL | 83 | PL 123B 353 | W. Bartel et al. | (JADE Collab.) |
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| | | Translated from ZET | | , , |
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OTHER RELATED PAPERS -

M.L. Perl

(SLAC)

PERL 81 SLAC-PUB-2752 Physics in Collision Conference.

Neutrino Properties

INTRODUCTION TO THE NEUTRINO PROPERTIES LISTINGS

Revised August 2011 by P. Vogel (Caltech) and A. Piepke (University of Alabama).

The following Listings concern measurements of various properties of neutrinos. Nearly all of the measurements, all of which so far are limits, actually concern superpositions of the mass eigenstates ν_i , which are in turn related to the weak eigenstates ν_{ℓ} , via the neutrino mixing matrix

$$|\nu_{\ell}\rangle = \sum_{i} U_{\ell i} |\nu_{i}\rangle$$
.

In the analogous case of quark mixing via the CKM matrix, the smallness of the off-diagonal terms (small mixing angles) permits a "dominant eigenstate" approximation. However, the present results of neutrino oscillation searches show that the mixing matrix contains two large mixing angles. We cannot, therefore, associate any particular state $|\nu_i\rangle$ with any particular lepton label e, μ or τ . Nevertheless, neutrinos are produced in weak decays with a definite lepton flavor, and are typically detected by the charged current weak interaction again associated with a specific lepton flavor. Hence, the listings for the neutrino mass that follow are separated into the three associated charged-lepton categories. Other properties (mean lifetime, magnetic moment, charge, and charge radius) are no longer separated this way. If needed, the associated lepton flavor is reported in the footnotes.

Measured quantities (mass-squared, magnetic moments, mean lifetimes, etc.) all depend upon the mixing parameters $|U_{\ell i}|^2$, but to some extent also on experimental conditions (e.g., on energy resolution). Most of these observables, in particular mass-squared, cannot distinguish between Dirac and Majorana neutrinos, and are unaffected by CP phases.

Direct neutrino mass measurements are usually based on the analysis of the kinematics of charged particles (leptons, pions) emitted together with neutrinos (flavor states) in various weak decays. The most sensitive neutrino mass measurement to date, involving electron type antineutrinos, is based on fitting the shape of the beta spectrum. The quantity $\langle m_{\beta}^2 \rangle =$ $\sum_{i} |U_{ei}|^2 m_{\nu_i}^2$ is determined or constrained, where the sum is over all mass eigenvalues m_{ν_i} that are too close together to be resolved experimentally. If the energy resolution is better than $\Delta m_{ij}^2 \equiv m_{\nu_i}^2 - m_{\nu_j}^2$, the corresponding heavier m_{ν_i} and mixing parameter could be determined by fitting the resulting spectral anomaly (step or kink).

A limit on $\langle m_{\beta}^2 \rangle$ implies an upper limit on the minimum value m_{min}^2 of $m_{\nu_i}^2$, independent of the mixing parameters U_{ei} : $m_{min}^2 \leq \langle m_{\beta}^2 \rangle$. However, if and when the value of $\langle m_{\beta}^2 \rangle$ is determined and the study of neutrino oscillations provides us with the values of all neutrino mass-squared differences $\Delta m_{ij}^2 \equiv m_i^2 - m_i^2$ and the mixing parameters $|U_{ei}|^2$, then the individual neutrino mass squares $m_{\nu_i}^2 = \langle m_{\beta}^2 \rangle - \sum_i |U_{ei}|^2 \Delta m_{ij}^2$ can be determined.

So far solar, reactor, atmospheric and accelerator neutrino oscillation experiments can be consistently described using three active neutrino flavors, i.e. two mass splittings and three mixing angles. However, several experiments with radioactive sources, reactors, and accelerators imply the possible existence of one or more non-interacting neutrino species.

Lepton Particle Listings Neutrino Properties

Combined three neutrino analyses determine the squared mass differences and two of the mixing angles to within reasonable accuracy. For given $|\Delta m_{ij}^2|$, a limit on $\langle m_{\beta}^2 \rangle$ from beta decay defines an upper limit on the maximum value m_{max} of m_{ν_i} : $m_{max}^2 \leq \langle m_{\beta}^2 \rangle + \sum_{i < j} |\Delta m_{ij}^2|$. The analysis of the low energy beta decay of tritium, combined with the oscillation results, thus limits all active neutrino masses. Traditionally experimental neutrino mass limits obtained from pion decay $\pi^+ \to \mu^+ + \nu_\mu$, or the shape of the spectrum of decay products of the τ lepton, did not distinguish between flavor and mass eigenstates. These results are reported as limits of the μ and τ based neutrino mass. After the determination of the $|\Delta m_{ij}^2|$'s, the corresponding neutrino mass limits are no longer competitive with those derived from low energy beta decays, with the proviso, however, that the oscillation searches, reported below, can be regarded as a reliable source of all $|\Delta m_{ij}^2|$ values.

The spread of arrival times of the neutrinos from SN1987A, coupled with the measured neutrino energies, provided a time-of-flight limit on a quantity similar to $\langle m_{\beta} \rangle \equiv \sqrt{\langle m_{\beta}^2 \rangle}$. This statement, clothed in various degrees of sophistication, has been the basis for a very large number of papers. The resulting limits, however, are no longer comparable with the limits from tritium beta decay.

Constraint on the sum of the neutrino masses can be obtained from the analysis of the cosmic microwave background anisotropy, combined with the galaxy redshift surveys and other data. These limits are reported in a separate table (Sum of Neutrino Masses, m_{tot}). Discussion concerning the model dependence of this limit is continuing.

▽ MASS (electron based)

Those limits given below are for the square root of $m_{\nu_e}^{2({\rm eff})} \equiv \sum_i |{\rm U}_{ei}|^2 m_{\nu_i}^2$. Limits that come from the kinematics of ${}^3{\rm H}\,\beta^-\overline{\nu}$ decay are the square roots of the limits for $m_{\nu_e}^{2({\rm eff})}$. Obtained from the measurements reported in the Listings for " $\overline{\nu}$ Mass Squared," below.

| VALUE (eV) | CL% | DOCUMENT ID TECN COMMENT |
|-------------------------------------------------|----------|-----------------------------------------------------------|
| < 2 OUR EVALUAT | ON | |
| < 2.05 | 95 | 1 ASEEV 11 SPEC 3 H eta decay |
| • • • We do not use the | followin | g data for averages, fits, limits, etc. ● ● |
| < 5.8 | 95 | ² PAGLIAROLI 10 ASTR SN1987A |
| < 2.3 | 95 | 3 KRAUS 05 SPEC 3 H β decay |
| <21.7 | 90 | ⁴ ARNABOLDI 03A BOLO ¹⁸⁷ Re β-decay |
| < 5.7 | 95 | ⁵ LOREDO 02 ASTR SN1987A |
| < 2.5 | 95 | ⁶ LOBASHEV 99 SPEC ³ H β decay |
| < 2.8 | 95 | 7 WEINHEIMER 99 SPEC 3 H β decay |
| < 4.35 | 95 | 8 BELESEV 95 SPEC 3 H $_{eta}$ decay |
| <12.4 | 95 | 9 CHING 95 SPEC 3 H β decay |
| <92 | 95 | 10 HIDDEMANN 95 SPEC 3 H $_{eta}$ decay |
| $\begin{array}{cc} 15 & +32 \\ -15 \end{array}$ | | HIDDEMANN 95 SPEC 3 H eta decay |
| <19.6 | 95 | KERNAN 95 ASTR SN 1987A |
| < 7.0 | 95 | 11 STOEFFL 95 SPEC 3 H β decay |
| < 7.2 | 95 | 12 WEINHEIMER 93 SPEC 3 H β decay |
| <11.7 | 95 | 13 HOLZSCHUH 92B SPEC 3 H 3 decay |
| <13.1 | 95 | 14 KAWAKAMI 91 SPEC 3 H β decay |
| < 9.3 | 95 | 15 ROBERTSON 91 SPEC 3 H β decay |
| <14 | 95 | AVIGNONE 90 ASTR SN 1987A |
| <16 | | SPERGEL 88 ASTR SN 1987A |
| 17 to 40 | | 16 BORIS 87 SPEC ³ H β decay |

- 1 ASEEV 11 report the analysis of the entire beta endpoint data, taken with the Troitsk integrating electrostatic spectrometer between 1997 and 2002 (some of the earlier runs were rejected), using a windowless gaseous tritium source. The fitted value of m_{ν} , based on the method of Feldman and Cousins, is obtained from the upper limit of the fit for m_{ν}^2 . Previous analysis problems were resolved by careful monitoring of the tritium gas column density. Supersedes LOBASHEV 99 and BELESEV 95.
- ²PAGLIAROLI 10 is critical of the likelihood method used by LOREDO 02.
- ³ KRAUS 05 is a continuation of the work reported in WEINHEIMER 99. This result represents the final analysis of data taken from 1997 to 2001. Various sources of systematic uncertainties have been identified and quantified. The background has been reduced compared to the initial running period. A spectral anomaly at the endpoint, reported in LOBASHEV 99, was not observed.
- 4 ARNABOLDI 03A *et al.* report kinematical neutrino mass limit using β-decay of 187 Re. Bolometric AgReO $_4$ micro-calorimeters are used. Mass bound is substantially weaker than those derived from tritium β-decays but has different systematic uncertainties.
- ⁵ LOREDO 02 updates LOREDO 89.
- 6 LOBASHEV 99 report a new measurement which continues the work reported in BELESEV 95. This limit depends on phenomenological fit parameters used to derive their best fit to m_{ν}^2 , making unambiguous interpretation difficult. See the footnote under " $\overline{\nu}$ Mass Squared."
- 7 WEINHEIMER 99 presents two analyses which exclude the spectral anomaly and result in an acceptable m_{ν}^2 . We report the most conservative limit, but the other is nearly the same. See the footnote under "\$\overline{n}\$ Mass Squared."
- 8 BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. A fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly) plus a monochromatic line 7–15 eV below the endpoint yields $m_{\nu}^2=-4.1\pm10.9~{\rm eV}^2,$ leading to this Bayesian limit.
- 9 CHING 95 quotes results previously given by SUN 93; no experimental details are given A possible explanation for consistently negative values of m_H^2 is given.
- 10 HIDDEMANN 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. Bayesian limit calculated from the weighted mean $m_{\nu}^2=$ 221 \pm 4244 eV 2 from the two runs listed below.
- 11 STOEFFL 95 (LLNL) result is the Bayesian limit obtained from the m_{ν}^2 errors given below but with m_{ν}^2 set equal to 0. The anomalous endpoint accumulation leads to a value of m_{ν}^2 which is negative by more than 5 standard deviations.
- 12 WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.
- 13 HOLZSCHUH 92B (Zurich) result is obtained from the measurement $m_{\nu}^2=-24\pm48\pm61$ (1σ errors), in eV², using the PDG prescription for conversion to a limit in m_{ν} .
- 14 KAWAKAMI 91 (Tokyo) experiment uses tritium-labeled arachidic acid. This result is the Bayesian limit obtained from the $m^2_{\ \nu}$ limit with the errors combined in quadrature. This was also done in ROBERTSON 91, although the authors report a different procedure.
- 15 ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_{ν} lies between 17 and 40 eV. However, the probability of a positive m^2 is only 3% if statistical and systematic error are combined in quadrature.
- $^{16}\,\mbox{See}$ also comment in BORIS 87B and erratum in BORIS 88.

CL%

▽ MASS SQUARED (electron based)

Given troubling systematics which result in improbably negative estimators of $m^{2({\rm eff})}_{
u_e} \equiv \sum_i |{\rm U}_{ei}|^2 \ m^2_{\nu_i}$, in many experiments, we use only KRAUS 05 and LOBASHEV 99 for our average.

DOCUMENT ID

TECN COMMENT

| _ | 0.6 | ± | 1.9 | OUR A | VERAGE | | | | |
|-----|------|----------|------|-----------|----------|--------------------------|---------|-----------|-----------------------|
| _ | 0.67 | '± | 2.53 | 3 | | ¹⁷ A SEEV | 11 | SPEC | 3 H β decay |
| _ | 0.6 | \pm | 2.2 | \pm 2.1 | | ¹⁸ KRAUS | 05 | SPEC | 3 H β decay |
| • • | • V | Ve do | not | use the f | ollowing | data for averages, f | its, li | mits, etc | . • • • |
| _ | 1.9 | ± | 3.4 | ± 2.2 | | ¹⁹ LOBASHEV | 99 | SPEC | 3 H $_{eta}$ decay |
| _ | 3.7 | \pm | 5.3 | \pm 2.1 | | ²⁰ WEINHEIMER | 99 | SPEC | 3 H β decay |
| - 3 | 22 | \pm | 4.8 | | | ²¹ BELESEV | 95 | SPEC | 3 H β decay |
| 13 | 29 | ± 60 | 10 | | | ²² HIDDEMANN | 95 | SPEC | 3 H β decay |
| 3 | 13 | ±59 | 94 | | | ²² HIDDEMANN | 95 | SPEC | 3 H β decay |
| -1 | 30 | \pm | 20 | ± 15 | 95 | ²³ STOEFFL | 95 | SPEC | 3 H β decay |
| _ : | 31 | \pm | 75 | ± 48 | | ²⁴ SUN | 93 | SPEC | 3 H $_\beta$ decay |
| _ : | 39 | \pm | 34 | ± 15 | | ²⁵ WEINHEIMER | 93 | SPEC | 3 H β decay |
| _ : | 24 | \pm | 48 | ±61 | | ²⁶ HOLZSCHUH | 92B | SPEC | 3 H β decay |
| _ | 65 | \pm | 85 | ± 65 | | ²⁷ KAWA KA MI | 91 | SPEC | 3 H β decay |
| -14 | 47 | \pm | 68 | ± 41 | | ²⁸ ROBERTSON | 91 | SPEC | 3 H β decay |

- 17 ASEEV 11 report the analysis of the entire beta endpoint data, taken with the Troitsk integrating electrostatic spectrometer between 1997 and 2002, using a windowless gaseous tritium source. The analysis does not use the two additional fit parameters (see LOBASHEV 99) for a step-like structure near the endpoint. Using only the runs where the tritium gas column density was carefully monitored the need for such parameters was eliminated. Supersedes LOBASHEV 99 and BELESEV 95.
- ¹⁸ KRAUS 05 is a continuation of the work reported in WEINHEIMER 99. This result represents the final analysis of data taken from 1997 to 2001. Problems with significantly negative squared neutrino masses, observed in some earlier experiments, have been resolved in this work.

Neutrino Properties

- $^{19}\text{LOBASHEV}$ 99 report a new measurement which continues the work reported in BELE-SEV 95. The data were corrected for electron trapping effects in the source, eliminating the dependence of the fitted neutrino mass on the fit interval. The analysis assuming a pure beta spectrum yields significantly negative fitted $m_\nu^2 \approx -(20\text{-}10) \text{ eV}^2$. This problem is attributed to a discrete spectral anomaly of about 6×10^{-11} intensity with a time-dependent energy of 5–15 eV below the endpoint. The data analysis accounts for this anomaly by introducing two extra phenomenological fit parameters resulting in a best fit of $m_\nu^2 = -1.9 \pm 3.4 \pm 2.2 \text{ eV}^2$ which is used to derive a neutrino mass limit. However, the introduction of phenomenological fit parameters which are correlated with the derived m_ν^2 limit makes unambiguous interpretation of this result difficult.
- 20 WEINHEIMER 99 is a continuation of the work reported in WEINHEIMER 93 . Using a lower temperature of the frozen tritium source eliminated the dewetting of the T_2 film, which introduced a dependence of the fitted neutrino mass on the fit interval in the earlier work. An indication for a spectral anomaly reported in LOBASHEV 99 has been seen, but its time dependence does not agree with LOBASHEV 99. Two analyses, which exclude the spectral anomaly either by choice of the analysis interval or by using a particular data set which does not exhibit the anomaly, result in acceptable m_{ν}^2 fits and are used to derive the neutrino mass limit published by the authors. We list the most conservative of the two.
- 21 BELESEV 95 (Moscow) use an integral electrostatic spectrometer with adiabatic magnetic collimation and a gaseous tritium sources. This value comes from a fit to a normal Kurie plot above 18300–18350 eV (to avoid a low-energy anomaly), including the effects of an apparent peak 7-15 eV below the endpoint.
- $^{22}\,\text{HIDDEMANN}$ 95 (Munich) experiment uses atomic tritium embedded in a metal-dioxide lattice. They quote measurements from two data sets.
- 23 STOEFFL 95 (LLNL) uses a gaseous source of molecular tritium. An anomalous pileup of events at the endpoint leads to the negative value for m_{ν}^2 . The authors acknowledge that "the negative value for the best fit of m_{ν}^2 has no physical meaning" and discuss possible explanations for this effect.
- $^{\rm 24}\,{\rm SUN}$ 93 uses a tritiated hydrocarbon source. See also CHING 95.
- 25 WEINHEIMER 93 (Mainz) is a measurement of the endpoint of the tritium β spectrum using an electrostatic spectrometer with a magnetic guiding field. The source is molecular tritium frozen onto an aluminum substrate.
- $^{26}\,\mathrm{H\,OLZSCHUH}$ 92B (Zurich) source is a monolayer of tritiated hydrocarbon.
- $^{\rm 27}\,{\rm KAWA\,KA\,MI}$ 91 (Tokyo) experiment uses tritium-labeled arachidic acid.
- 28 ROBERTSON 91 (LANL) experiment uses gaseous molecular tritium. The result is in strong disagreement with the earlier claims by the ITEP group [LUBIMOV 80, BORIS 87 (+ BORIS 88 erratum)] that m_{ν} lies between 17 and 40 eV. However, the probability of a positive m_{ν}^2 is only 3% if statistical and systematic error are combined in quadrature.

ν MASS (electron based)

These are measurement of m_{ν} (in contrast to $m_{\overline{\nu}}$, given above). The masses can be different for a Dirac neutrino in the absence of CPT invariance. The possible distinction between ν and $\overline{\nu}$ properties is usually ignored elsewhere in these Listings.

| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------|-----|--------------|----|------|-------------------------|
| <460 | 68 | YA SU MI | | | 163 Ho decay |
| <225 | 95 | SPRINGER | 87 | CNTR | ¹⁶³ Ho decay |

ν MASS (muon based)

Limits given below are for the square root of $\mathit{m}_{\nu_{\mu}}^{2(\mathrm{eff})} \equiv \sum_{i} |\mathsf{U}_{\mu i}|^2 \; \mathit{m}_{\nu_{i}}^2$

In some of the COSM papers listed below, the authors did not distinguish between weak and mass eigenstates.

OUR EVALUATION is based on OUR AVERAGE for the π^\pm mass and the ASSAMAGAN 96 value for the muon momentum for the π^+ decay at rest. The limit is calculated using the unified classical analysis of FELDMAN 98 for a Gaussian distribution near a physical boundary. WARNING: since $m_{\mu}^2(\text{eff})$ is calculated from the differences of large numbers, it and the corresponding limits are extraordinarily sensitive to small changes in the pion mass, the decay muon momentum, and their errors. For example, the limits obtained using JECKELMANN 94, LENZ 98, and the weighted averages are 0.15, 0.29, and 0.19 MeV, respectively.

| VALUE (MeV) | CL% | DO CUMENT ID | TECN | COMMENT |
|------------------|----------|----------------------------|------|------------------------------|
| <0.19 (CL = 90%) | OUR EVAL | UATION | | |
| < 0.17 | 90 | ²⁹ ASSAMAGAN 96 | SPEC | $m_{y}^2 = -0.016 \pm 0.023$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| < 0.15 | | ³⁰ DOLGOV | 95 | COSM | Nucleosynthesis |
|--------|----|------------------------|----|------|------------------------------|
| < 0.48 | | 31 ENQVIST | 93 | COSM | Nucleosynthesis |
| < 0.3 | | 32 FULLER | 91 | COSM | Nucleosynthesis |
| < 0.42 | | ³² LAM | 91 | | Nucleosynthesis |
| < 0.50 | 90 | ³³ ANDERHUB | 82 | SPEC | $m_{\nu}^2 = -0.14 \pm 0.20$ |
| < 0.65 | 90 | CLARK | 74 | ASPK | $\kappa_{\mu 3}$ decay |

 29 ASSAMAGAN 96 measurement of p_μ from $\pi^+\to \mu^+\nu$ at rest combined with JECK-ELMANN 94 Solution B pion mass yields $m_\nu^2=-0.016\pm0.023$ with corresponding Bayesian limit listed above. If Solution A is used, $m_\nu^2=-0.143\pm0.024~{\rm MeV}^2.$ Replaces ASSAMAGAN 94.

- 30 DOLGOV 95 removes earlier assumptions (DOLGOV 93) about thermal equilibrium below $T_{\rm QCD}$ for wrong-helicity Dirac neutrinos (ENQVIST 93, FULLER 91) to set more stringent limits.
- 31 ENQVIST 93 bases limit on the fact that thermalized wrong-helicity Dirac neutrinos would speed up expansion of early universe, thus reducing the primordial abundance. FULLER 91 exploits the same mechanism but in the older calculation obtains a larger production rate for these states, and hence a lower limit. Neutrino lifetime assumed to exceed nucleosynthesis time, ~1s.
- 32 Assumes neutrino lifetime >1 s. For Dirac neutrinos only. See also ENQVIST 93.
- $^{
 m 33}\,{\rm A\,NDERHUB}$ 82 kinematics is insensitive to the pion mass.

ν MASS (tau based)

The limits given below are the square roots of limits for $m_{\nu_{\tau}}^{2({\rm eff})} \equiv \sum_i |{\rm U}_{\tau i}|^2 \ m_{\nu_i}^2.$

In some of the ASTR and COSM papers listed below, the authors did not distinguish between weak and mass eigenstates.

| VALUE (| VleV) | CL% | EVTS | | DO CUMENT ID | | TECN | COMMENT |
|---------|-----------|---------|----------|-----|------------------|---------|-----------|-----------------------------------------------------|
| < 18.2 | 2 | 95 | | 34 | BARATE | 98F | ALEP | 1991-1995 LEP runs |
| • • • \ | Ne do not | use the | followin | g d | ata for averages | , fits, | limits, e | etc. • • • |
| < 28 | | 95 | | 35 | ATHANAS | 00 | CLEO | Eee = 10.6 GeV |
| < 27.6 | 5 | 95 | | 36 | ACKERSTAFF | 98T | OPAL | 1990-1995 LEP runs |
| < 30 | | 95 | 473 | 37 | AMMAR | 98 | CLEO | $E_{\text{cm}}^{ee} = 10.6 \text{ GeV}$ |
| < 60 | | 95 | | | ANASTASSOV | 97 | CLEO | $E_{\rm cm}^{\it ee}=10.6~{\rm GeV}$ |
| < 0.37 | or >22 | | | | FIELDS | 97 | COSM | Nucleosynthesis |
| < 68 | | 95 | | 40 | SWAIN | 97 | THEO | $m_{	au}, 	au_{	au}, 	au$ partial widths |
| < 29.9 |) | 95 | | | ALEXANDER | 96м | OPAL | 1990-1994 LEP runs |
| <149 | | | | | BOTTINO | 96 | THEO | π , μ , $	au$ leptonic decays |
| <1 or > | >25 | | | | HA NNESTAD | 96c | COSM | Nucleosynthesis |
| < 71 | | 95 | | 44 | SOBIE | 96 | THEO | m_{τ} , τ_{τ} , $B(\tau^- \rightarrow$ |
| | | | | | | | | $e^{-}\overline{\nu}_{e}\nu_{\tau})$ |
| < 24 | | 95 | 25 | 45 | BUSKULIC | 95 H | ALEP | 1991-1993 LEP runs |
| < 0.1 | .9 | | | 46 | DOLGOV | 95 | COSM | Nucleosynthesis |
| < 3 | | | | 47 | SIGL | 95 | ASTR | SN 1987A |
| < 0.4 o | | | | 48 | DODELSON | 94 | COSM | Nucleosynthesis |
| < 0.1 o | | | | 49 | KAWA SA KI | 94 | COSM | , |
| 155-22 | 5 | | | | PERES | 94 | THEO | |
| < 32.6 | j | 95 | 113 | 51 | CINABRO | 93 | CLEO | $E_{\rm cm}^{\it ee} \approx 10.6 \; {\rm GeV}$ |
| < 0.3 | or > 35 | | | 52 | DOLGOV | 93 | COSM | Nucleosynthesis |
| < 0.7 | '4 | | | 53 | ENQVIST | 93 | COSM | Nucleosynthesis |
| < 31 | | 95 | 19 | | ALBRECHT | 92м | ARG | $E_{\rm cm}^{\it ee} = 9.4 10.6 \; {\rm GeV}$ |
| < 0.3 | 3 | | | 55 | FULLER | 91 | COSM | , |
| < 0.5 | | | | 56 | KOLB | 91 | COSM | Nucleosynthesis |
| < 0.4 | 12 | | | 55 | LAM | 91 | COSM | Nucleosynthesis |

- 34 BARATE 98F result based on kinematics of 2939 $\tau^-\to 2\pi^-\pi^+\nu_\tau$ and 52 $\tau^-\to 3\pi^-2\pi^+(\pi^0)\nu_\tau$ decays. If possible 2.5% excited a_1 decay is included in 3-prong sample analysis, limit increases to 19.2 MeV.
- ³⁵ ATHANAS 00 bound comes from analysis of $\tau^- \to \pi^- \pi^+ \pi^- \pi^0 \nu_{\pi}$ decays.
- 36 ACKERSTAFF 98T use $\tau\to 5\pi^\pm\nu_\tau$ decays to obtain a limit of 43.2 MeV (95%CL). They combine this with ALEXANDER 96M value using $\tau\to 3\hbar^\pm\nu_\tau$ decays to obtain quoted limit.
- 37 A MMAR 98 limit comes from analysis of $\tau^-\to 3\pi^-\,2\pi^+\,\nu_\tau$ and $\tau^-\to 2\pi^-\,\pi^+\,2\pi^0\,\nu_\tau$ decay modes.
- 38 ANASTASSOV 97 derive limit by comparing their m_{τ} measurement (which depends on $m_{\nu_{\tau}})$ to BAI 96 m_{τ} threshold measurement.
- 39 FIELDS 97 limit for a Dirac neutrino. For a Majorana neutrino the mass region <0.93 or $>\!31$ MeV is excluded. These bounds assume $N_{\nu}<\!4$ from nucleosynthesis; a wider excluded region occurs with a smaller N_{ν} upper limit.
- 40 SWAIN 97 derive their limit from the Standard Model relationships between the tau mass, lifetime, branching fractions for $\tau^- \to e^- \overline{\nu}_e \nu_\tau, \tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau, \tau^- \to \pi^- \nu_\tau$, and $\tau^- \to K^- \nu_\tau$, and the muon mass and lifetime by assuming lepton universality and using world average values. Limit is reduced to 48 MeV when the CLEO τ mass measurement (BALEST 93) is included; see CLEO's more recent m_{ν_τ} limit (ANASTASSOV 97). Consideration of mixing with a fourth generation heavy neutrino yields $\sin^2\!\theta_L < 0.016$ (95 %CL).
- 41 ALEXANDER 96M bound comes from analyses of $\tau^-\to 3\pi^-2\pi^+\nu_\tau$ and $\tau^-\to h^-h^-h^+\nu_\tau$ decays.
- 42 BOTTINO 96 assumes three generations of neutrinos with mixing, finds consistency with massless neutrinos with no mixing based on 1995 data for masses, lifetimes, and leptonic nartial widths
- $^{43}\,\mathrm{HANNESTAD}$ 96C limit is on the mass of a Majorana neutrino. This bound assumes $N_{\nu}<4$ from nucleosynthesis. A wider excluded region occurs with a smaller N_{ν} upper limit. This paper is the corrected version of HANNESTAD 96; see the erratum: HANNESTAD 96B.
- 44 SOBIE 96 derive their limit from the Standard Model relationship between the tau mass, lifetime, and leptonic branching fraction, and the muon mass and lifetime, by assuming lepton universality and using world average values.

- $^{
 m 45}$ BUSKULIC 95H bound comes from a two-dimensional fit of the visible energy and invariant mass distribution of $au o 5\pi(\pi^0)
 u_{ au}$ decays. Replaced by BARATE 98F
- $^{
 m 46}$ DOLGOV 95 removes earlier assumptions (DOLGOV 93) about thermal equilibrium below $T_{
 m QCD}$ for wrong-helicity Dirac neutrinos (ENQVIST 93, FULLER 91) to set more stringent limits. DOLGOV 96 argues that a possible window near 20 MeV is excluded.
- $^{
 m 47}$ SIGL 95 exclude massive Dirac or Majorana neutrinos with lifetimes between 10^{-3} and 10^8 seconds if the decay products are predominantly γ or $e^+\,e^-$
- $^{48}\, {\tt DODELSON}$ 94 calculate constraints on ν_{τ} mass and lifetime from nucleosynthesis for 4 generic decay modes. Limits depend strongly on decay mode. Quoted limit is valid for all decay modes of Majorana neutrinos with lifetime greater than about 300s. For Dirac neutrinos limits change to < 0.3 or > 33.
- 49 KAWASAKI 94 excluded region is for Majorana neutrino with lifetime >1000 s. Other limits are given as a function of ν_{τ} lifetime for decays of the type $\nu_{\tau} \rightarrow \ \nu_{\mu} \phi$ where ϕ is a Nambu-Goldstone boson.
- ⁵⁰ PERES 94 used PDG 92 values for parameters to obtain a value consistent with mixing. Reexamination by BOTTINO 96 which included radiative corrections and 1995 PDG parameters resulted in two allowed regions, $m_3 < 70\,$ MeV and $140\,$ MeV $m_3 < 149\,$
- 51 CINABRO 93 bound comes from analysis of au^- ightarrow $3\pi^ 2\pi^+$ $u_ au$ and au^- ightarrow $2\pi^-\pi^+2\pi^0\nu_{\tau}$ decay modes.
- 52 DOLGOV 93 assumes neutrino lifetime >100s. For Majorana neutrinos, the low mass limit is 0.5 MeV. KAWANO 92 points out that these bounds can be overcome for a Dirac neutrino if it possesses a magnetic moment. See also DOLGOV 96.
- $^{53}\mathsf{ENQVIST}$ 93 bases limit on the fact that thermalized wrong-helicity Dirac neutrinos would speed up expansion of early universe, thus reducing the primordial abundance. FULLER 91 exploits the same mechanism but in the older calculation obtains a larger production rate for these states, and hence a lower limit. Neutrino lifetime assumed to exceed nucleosynthesis time, ~ 1 s.
- 54 ALBRECHT 92M reports measurement of a slightly lower au mass, which has the effect of reducing the $\nu_{ au}$ mass reported in ALBRECHT 88B. Bound is from analysis of $au^-
 ightarrow$ $3\pi^-\,2\pi^+\,\nu_{\tau}$ mode
- $^{55}\,\mathrm{Assumes}$ neutrino lifetime $>\!1\,\mathrm{s}$. For Dirac neutrinos. See also ENQVIST 93.
- 56 KOLB 91 exclusion region is for Dirac neutrino with lifetime $>\!\!1\,\mathrm{s};$ other limits are given.

Revised August 2009 by K.A. Olive (University of Minnesota).

The limits on low mass $(m_{\nu} \lesssim 1 \text{ MeV})$ neutrinos apply to $m_{\rm tot}$ given by

$$m_{\rm tot} = \sum_{\nu} (g_{\nu}/2) m_{\nu} ,$$

where g_{ν} is the number of spin degrees of freedom for ν plus $\overline{\nu}$: $g_{\nu} = 4$ for neutrinos with Dirac masses; $g_{\nu} = 2$ for Majorana neutrinos. Stable neutrinos in this mass range make a contribution to the total energy density of the Universe which is given by

$$\rho_{\nu} = m_{\text{tot}} n_{\nu} = m_{\text{tot}} (3/11) n_{\gamma}$$
,

where the factor 3/11 is the ratio of (light) neutrinos to photons. Writing $\Omega_{\nu} = \rho_{\nu}/\rho_c$, where ρ_c is the critical energy density of the Universe, and using $n_{\gamma} = 412 \text{ cm}^{-3}$, we have

$$\Omega_{\nu}h^2 = m_{\rm tot}/(94 \text{ eV})$$
.

While an upper limit to the matter density of $\Omega_m h^2 < 0.12$ would constrain $m_{\rm tot} < 11$ eV, much stronger constraints are obtained from a combination of observations of the CMB and the amplitude of density fluctuations on smaller scales from the clustering of galaxies and the Lyman- α forest. These combine to give an upper limit around 0.5 eV.

SUM OF THE NEUTRINO MASSES, mtot

(Defined in the above note), of effectively stable neutrinos (i.e., those with mean lives greater than or equal to the age of the universe). These papers assumed Dirac neutrinos. When necessary, we have generalized the results reported so they apply to $m_{
m tot}$. For other limits, see SZALAY 76, VYSOTSKY 77, BERNSTEIN 81, FREESE 84, SCHRAMM 84, and COWSIK 85

I

VALUE (eV) DOCUMENT ID TECN COMMENT CL%

• • • We do not use the following data for averages, fits, limits, etc. • • •

| < 0.4 | 1 95 | ⁵⁸ HANNESTAD | 10 | COSM | |
|---------|------|---------------------------|----|------|------------------------|
| < 0.6 | 95 | ⁵⁹ SEKIGUCHI | 10 | COSM | |
| < 0.2 | 3 95 | ⁶⁰ THOMAS | 10 | COSM | |
| < 1.1 | | ⁶¹ іСНІКІ | 09 | COSM | |
| < 1.3 | 95 | ⁶² KOMATSU | 09 | COSM | WMAP |
| < 1.2 | | ⁶³ TERENO | 09 | COSM | |
| < 0.3 | 3 | ⁶⁴ VIKHLININ | 09 | COSM | |
| < 0.2 | 3 | ⁶⁵ BERNARDIS | 08 | COSM | |
| < 0.17- | -2.3 | ⁶⁶ FOGLI | 07 | COSM | |
| < 0.43 | 2 95 | ⁶⁷ KRISTIANSEN | 07 | COSM | |
| < 0.63- | -2.2 | ⁶⁸ ZUNCKEL | 07 | COSM | |
| < 0.24 | 1 95 | ⁶⁹ CIRELLI | 06 | COSM | |
| < 0.63 | 2 95 | ⁷⁰ HANNESTAD | 06 | COSM | |
| < 1.2 | | ⁷¹ SANCHEZ | 06 | COSM | |
| < 0.1 | 7 95 | ⁶⁹ SELJAK | 06 | COSM | |
| < 2.0 | 95 | ⁷² ICHIKAWA | 05 | COSM | |
| < 0.79 | 5 | ⁷³ BARGER | 04 | COSM | |
| < 1.0 | | ⁷⁴ CROTTY | 04 | COSM | |
| < 0.7 | | ⁷⁵ SPERGEL | 03 | COSM | WMAP |
| < 0.9 | | ⁷⁶ LEWIS | 02 | COSM | |
| < 4.2 | | ⁷⁷ WA NG | 02 | COSM | CMB |
| < 2.7 | | ⁷⁸ FUKUGITA | 00 | COSM | |
| < 5.5 | | ⁷⁹ CROFT | 99 | ASTR | Ly α power spec |
| <180 | | SZALAY | 74 | COSM | |
| <132 | | COWSIK | 72 | COSM | |
| <280 | | MARX | 72 | COSM | |
| <400 | | GERSHTEIN | 66 | COSM | |

- 57 Constrains the total mass of neutrinos from the Sloan Digital Sky Survey and the five-year
- WMAP data. 58 Constrains the total mass of neutrinos from the 7-year WMAP data including SDSS and HST data. Limit relaxes to 1.19 eV when CMB data is used alone. Supersedes
- ⁵⁹ Constrains the total mass of neutrinos from a combination of CMB data, a recent measurement of H_0 (SHOES), and baryon acoustic oscillation data from SDSS.
- ⁶⁰ Constrains the total mass of neutrinos from SDSS MegaZ LRG DR7 galaxy clustering data combined with CMB, HST, supernovae and baryon acoustic oscillation data. Limit relaxes to 0.47 eV when the equation of state parameter, $w~\neq~1.$
- 61 Constrains the total mass of neutrinos from weak lensing measurements when combined with CMB. Limit improves to 0.54 eV when supernovae and baryon acoustic oscillation observations are included. Assumes ACDM model.
- 62 Constrains the total mass of neutrinos from five-year WMAP data. Limit improves to 0.67eV when supernovae and baryon acoustic oscillation observations are included. Limits quoted assume the Λ CDM model. Supersedes SPERGEL 07.
- 63 Constrains the total mass of neutrinos from weak lensing measurements when combined with CMB. Limit improves to 0.03 $< \Sigma m_{\nu} <$ 0.54 eV when supernovae and baryon acoustic oscillation observations are included. The slight preference for massive neutrinos at the two-sigma level disappears when systematic errors are taken into account. Assumes ACDM model.
- 64 Constrains the total mass of neutrinos from recent Chandra X-ray observations of galaxy clusters when combined with CMB, supernovae, and baryon acoustic oscillation measurements. Assumes flat universe and constant dark-energy equation of state, w.
- 65 Constraints the total mass of neutrinos from recent CMB and SOSS LRG power spectrum data along with bias mass relations from SDSS, DEEP2, and Lyman-Break Galaxies. It assumes ACDM model. Limit degrades to 0.59 eV in a more general wCDM model.
- 66 Constrains the total mass of neutrinos from neutrino oscillation experiments and cosmological data. The most conservative limit uses only WMAP three-year data, while the most stringent limit includes CMB, large-scale structure, supernova, and Lyman-alpha
- 67 Constrains the total mass of neutrinos from recent CMB, large scale structure, SN1a, and baryon acoustic oscillation data. The limit relaxes to 1.75 when WMAP data alone is used with no prior. Paper shows results with several combinations of data sets. Supersedes KRISTIANSEN 06.
- 68 Constrains the total mass of neutrinos from the CMB and the large scale structure data. The most conservative limit is obtained when generic initial conditions are allowed
- 69 Constrains the total mass of neutrinos from recent CMB, large scale structure, Lymanalpha forest, and SN1a data.
- 70 Constrains the total mass of neutrinos from recent CMB and large scale structure data. See also GOOBAR 06. Superseded by HANNESTAD 10.
- 71 Constrains the total mass of neutrinos from the CMB and the final 2dF Galaxy Redshift
- 72 Constrains the total mass of neutrinos from the CMB experiments alone, assuming ΛCDM Universe. FUKUGITA 06 show that this result is unchanged by the 3-year WMAP data.
- 73 Constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the Sloan Digital Sky Survey and the 2dF galaxy redshift survey, WMAP and 27 other CMB experiments and measurements by the HST Key project.
- 74 Constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the Sloan Digital Sky Survey, the 2dF galaxy redshift survey, WMAP and ACBAR. The limit is strengthened to 0.6 eV when measurements by the HST Key project and
- 75 Constrains the fractional contribution of neutrinos to the total matter density in the Universe from WMAP data combined with other CMB measurements, the 2dfGRS data, and Lyman lpha data. The limit does not noticeably change if the Lyman lpha data are not
- derived from the CMB, HST Key project, 2dF galaxy redshift survey, supernovae type Ia, and BBN. ⁷⁶ LEWIS 02 constrains the total mass of neutrinos from the power spectrum of fluctuations

Neutrino Properties

- 77 WA NG 02 constrains the total mass of neutrinos from the power spectrum of fluctuations derived from the CMB and other cosmological data sets such as galaxy clustering and the Lyman α forest.
- 78 FUKUGITA 00 is a limit on neutrino masses from structure formation. The constraint is based on the clustering scale σ_8 and the COBE normalization and leads to a conservative limit of 0.9 eV assuming 3 nearly degenerate neutrinos. The quoted limit is on the sum of the light neutrino masses.
- 79 CROFT 99 result based on the power spectrum of the Ly α forest. If $\Omega_{\rm matter}<$ 0.5, the limit is improved to $m_{\nu}<$ 2.4 ($\Omega_{\rm matter}/0.17\text{--}1)$ eV.

Limits on MASSES of Light Stable Right-Handed ν (with necessarily suppressed interaction strengths)

| VALUE (eV) | DO CUMENT I | _ | TECN | COMMENT |
|-------------------------|-----------------------------|-----------|-----------|---------------|
| • • • We do not use the | ne following data for avera | ges, fits | , limits, | etc. • • • |
| <100-200 | ⁸⁰ OLIVE | 82 | COSM | Dirac $ u$ |
| <200-2000 | ⁸⁰ OLIVE | 82 | COSM | Majorana $ u$ |

⁸⁰ Depending on interaction strength G_R where $G_R < G_F$.

Limits on MASSES of Heavy Stable Right-Handed ν (with necessarily suppressed interaction strengths)

| VALUE (GeV) | DO CUMENT I | <u> </u> | TECN | COMMENT |
|-------------------------|----------------------------|-----------|-------------|--------------------|
| • • • We do not use the | e following data for avera | ges, fits | , limits, e | etc. • • • |
| > 10 | ⁸¹ OLIVE | 82 | COSM | $G_R / G_F < 0.1$ |
| >100 | ⁸¹ OLIVE | 82 | COSM | $G_R / G_F < 0.01$ |

 $^{^{81}}$ These results apply to heavy Majorana neutrinos and are summarized by the equation: $m_{\nu}>$ 1.2 GeV (G_F/G_R) . The bound saturates, and if G_R is too small no mass range is allowed.

ν CHARGE DO CUMENT ID

TECN COMMENT

| • • • We | do not use th | e following | g data for averages | , fits, | , limits, e | etc. • • • |
|-------------------|------------------|-------------|---------------------------|---------|-------------|-----------------------------|
| $< 3.7 \times 10$ | -12 | | | 07 | | Nuclear reactor |
| <2 × 10 | -14 | | ⁸³ RAFFELT | 99 | ASTR | Red giant luminosity |
| <6 × 10 | -14 | | ⁸⁴ RAFFELT | | | Solar cooling |
| <4 × 10 | -4 | | ⁸⁵ BABU | | | BEBC beam dump |
| <3 × 10 | -4 | | ⁸⁶ DAVIDSON | 91 | RVUE | ${\sf SLAC}\;e^-$ beam dump |
| <2 × 10 | ₁ —15 | | ⁸⁷ BARBIELLINI | | | |
| <1 × 10 | ₁ —13 | | ⁸⁸ BERNSTEIN | 63 | ASTR | Solar energy losses |

- 82 GNINENKO 07 use limit on $\overline{\nu}_e$ magnetic moment from LI 03B to derive this result. The limit is considerably weaker than the limits on the charge of ν_e and $\overline{\nu}_e$ from various astrophysics considerations.
- 83 This RAFFELT 99 limit applies to all neutrino flavors which are light enough (<5 keV) to be emitted from globular-cluster red giants.
- 84 This RAFFELT 99 limit is derived from the helioseismological limit on a new energy-loss channel of the Sun, and applies to all neutrino flavors which are light enough (<1 keV) to be emitted from the sun.</p>
- 85 BABU 94 use COOPER-SARKAR 92 limit on ν magnetic moment to derive quoted result. It applies to $\nu_{\mathcal{T}}.$
- 86 DAVIDSON 91 use data from early SLAC electron beam dump experiment to derive charge limit as a function of neutrino mass. It applies to $\nu_{\mathcal{T}}.$
- 87 Exact BARBIELLINI 87 limit depends on assumptions about the intergalactic or galactic magnetic fields and about the direct distance and time through the field. It applies to ν_e .
- ⁸⁸The limit applies to all flavors.

VALUE (units: electron charge) CL%

u (MEAN LIFE) / MASS

Measures $\left[\sum |U_{\ell j}|^2 \; \Gamma_j \; m_j\right]^{-1}$, where the sum is over mass eigenstates which cannot be resolved experimentally. Some of the limits constrain the radiative decay and are based on the limit of the corresponding photon flux. Other apply to the decay of a heavier neutrino into the lighter one and a Majoron or other invisible particle. Many of these limits apply to any ν within the indicated mass range.

Limits on the radiative decay are either directly based on the limits of the corresponding photon flux, or are derived from the limits on the neutrino magnetic moments. In the later case the transition rate for $\nu_i \to \nu_j + \gamma$

is constrained by $\Gamma_{ij}=rac{1}{ au_{ij}}=rac{(m_i^2-m_j^2)^3}{m_j^3}~\mu_{ij}^2$ where μ_{ij} is the neutrino transition moment in the mass eigenstates basis. Typically, the limits on

transition moment in the mass eigenstates basis. Typically, the limits on lifetime based on the magnetic moments are many orders of magnitude more restrictive than limits based on the nonobservation of photons.

| VALUE (s/eV) | CL% | DO CUMENT ID | TECN | COMMENT |
|-----------------------|-----|------------------------|--------|-----------------------------------------------|
| > 15.4 | 90 | 89 KRAKAUER 9 | 1 CNTR | ν_{μ} , $\overline{\nu}_{\mu}$ at LAMPF |
| > 7 × 10 ⁹ | | 90 RAFFELT 8 | 5 ASTR | r. r. |
| > 300 | 90 | ⁹¹ REINES 7 | 4 CNTR | $\overline{\nu}_{\rho}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 5 10 | | 00 | | | - |
|------------------------------------------|-----|---------------------------|----------|------|-----------------------------------------------------------------------|
| $> 10^5 - 10^{10}$ | 95 | 92 CECCHINI | 11 | ASTR | $ u_2 \! ightarrow u_1$ radiative decay |
| | 90 | 93 MIRIZZI | 07 | CMB | radiative decay |
| | 90 | 94 MIRIZZI | 07 | CIB | radiative decay |
| | | 95 WONG | 07 | CNTR | Reactor $\overline{ u}_e$ |
| > 0.11 | 90 | ⁹⁶ XIN | 05 | CNTR | Reactor ν_e |
| | | ⁹⁷ XIN | 05 | CNTR | Reactor ν_e |
| > 0.004 | 90 | ⁹⁸ AHARMIM | 04 | SNO | quasidegen. ν masses |
| $>$ 4.4 $\times 10^{-5}$ | 90 | ⁹⁸ AHARMIM | 04 | SNO | hierarchical $ u$ masses |
| | 95 | 99 CECCHINI | 04 | ASTR | Radiative decay for ν mass > 0.01 eV |
| > 0.067 | 90 | ¹⁰⁰ EGUCHI | 04 | KLND | quasidegen. ν masses |
| $> 1.1 \times 10^{-3}$ | 90 | ¹⁰⁰ EGUCHI | 04 | KLND | hierarchical $ u$ masses |
| $>$ 8.7 $\times 10^{-5}$ | 99 | 101 BANDYOPA | 03 | FIT | nonradiative decay |
| ≥ 4200 | 90 | ¹⁰² DERBIN | 02в | CNTR | Solar pp and Be ν |
| > 2.8 × 10 ⁻⁵ | 99 | ¹⁰³ JOSHIPURA | 02в | FIT | nonradiative decay |
| | | ¹⁰⁴ DOLGOV | 99 | COSM | , and the second second |
| | | ¹⁰⁵ BILLER | 98 | ASTR | $m_{\nu} = 0.05-1 \text{ eV}$ |
| $>$ 2.8 $\times 10^{15}$ | 106 | ,107 BLUDMAN | 92 | ASTR | $m_{\nu}^{\nu} < 50 \text{ eV}$ |
| none $10^{-12} - 5 \times 10^4$ | | 108 DODELSON | 92 | ASTR | $m_{\nu} = 1 - 300 \text{ keV}$ |
| $< 10^{-12} \text{ or } > 5 \times 10^4$ | | ¹⁰⁸ DODELSON | 92 | ASTR | m, =1-300 keV |
| (10 0.) 0 / 10 | | ¹⁰⁹ GRANEK | 91 | COSM | Decaying L^0 |
| > 6.4 | 90 | 110 KRAKAUER | 91 | CNTR | ν _e at LAMPF |
| > 1.1 × 10 ¹⁵ | 70 | 111 WALKER | 90 | ASTR | $m_{\nu} = 0.03 - \sim 2 \text{ MeV}$ |
| > 6.3 × 10 ¹⁵ | 107 | ,112 CHUPP | 89 | ASTR | $m_{\nu} = 0.03 - \infty 2 \text{ N/eV}$ $m_{\nu} < 20 \text{ eV}$ |
| 1 0 | | 107 KOLB | | ASTR | |
| $> 1.7 \times 10^{15}$ | | 113 RAFFELT | 89 89 | | $m_{\nu} < 20 \text{ eV}$ |
| | | 114 RAFFELT | | RVUE | $\overline{ u}$ (Dirac, Majorana) |
| $>$ 8.3 $\times 10^{14}$ | | 115 VONFEILIT | 89B | ASTR | |
| | 68 | 116 OBERAUER | 88 87 | ASTR | = (Disas) |
| • | | 116 OBERAUER | | | $\overline{\nu}_R$ (Dirac) |
| > 38 | 68 | 116 OBERAUER | 87 | | v (Majorana) |
| > 59 | 68 | 116 OBERAUER | 87 | | $\overline{\nu}_L$ (Dirac) |
| > 30 | 68 | KETOV | 86 | CNTR | v (Dirac) |
| > 20 | 68 | KETOV | 86 | CNTR | $\overline{\nu}$ (Majorana) |
| 0.44 | | 117 BINETRUY | 84 | COSM | $m_{\nu} \sim 1 \text{ MeV}$ |
| > 0.11 | 90 | 118 FRANK | 81 | CNTR | $\nu \overline{\nu}$ LAMPF |
| $> 2 \times 10^{21}$ | | 119 STECKER | 80 | ASTR | m_{ν} = 10–100 eV |
| > 1.0 × 10 ⁻² | 90 | 118 BLIETSCHAU | 78 | HLBC | $ u_{\mu}$, cern ggm |
| $> 1.7 \times 10^{-2}$ | 90 | ¹¹⁸ BLIETSCHAU | 78 | HLBC | $\overline{ u}_{\mu}$, CERN GGM |
| $<$ 3 $\times 10^{-11}$ | | ¹²⁰ FALK | 78 | ASTR | m, <10 MeV |
| $>$ 2.2 $\times 10^{-3}$ | 90 | ¹¹⁸ BARNES | 77 | DBC | ν, A NL 12-ft |
| | | ¹²¹ COWSIK | 77 | ASTR | |
| $>$ 3. $\times 10^{-3}$ | 90 | 118 BELLOTTI | 76 | HLBC | ν , CERN GGM |
| > 1.3 × 10 ⁻² | 90 | ¹¹⁸ BELLOTTI | 76 | HLBC | $\overline{\nu}$, CERN GGM |
| | - | | | | , |

- 89 KRAKAUER 91 quotes the limit $\tau/m_{\nu_1}>(0.75\,a^2+21.65\,a+26.3)\,\mathrm{s/eV},$ where a is a parameter describing the asymmetry in the neutrino decay defined as $dN_{\gamma}/d\cos\theta=(1/2)(1+a\cos\theta)$ The parameter a=0 for a Majorana neutrino, but can vary from -1 to 1 for a Dirac neutrino. The bound given by the authors is the most conservative (which applies for a=-1).
- 90 RAFFELT 85 limit on the radiative decay is from solar x- and γ -ray fluxes. Limit depends on ν flux from pp, now established from GALLEX and SAGE to be > 0.5 of expectation.
- 91 REINES 74 looked for ν of nonzero mass decaying radiatively to a neutral of lesser mass + $\gamma.$ Used liquid scintillator detector near fission reactor. Finds lab lifetime 6×10^7 s or more. Above value of (mean life)/mass assumes average effective neutrino energy of 0.2 MeV. To obtain the limit 6×10^7 s REINES 74 assumed that the full $\overline{\nu}_e$ reactor flux could be responsible for yielding decays with photon energies in the interval 0.1 MeV 0.5 MeV. This represents some overestimates of their lower limit is an over-estimate of the lab lifetime (VOGEL 84). If so, OBERAUER 87 may be comparable or better.
- 92 CECCHINI 11 search for radiative decays of solar neutrinos into visible photons during the 2006 total solar eclipse. The range of (mean life)/mass values corresponds to a range of ν_1 masses between 10^{-4} and 0.1 eV.
- 93 MIRIZZI 07 determine a limit on the neutrino radiative decay from analysis of the maximum allowed distortion of the CMB spectrum as measured by the COBE/FIRAS. For the decay $\nu_2 \rightarrow \nu_1$ the lifetime limit is $\lesssim 4 \times 10^{20}$ s for $m_{min} \lesssim 0.14$ eV. For transition with the $|\Delta m_{31}|$ mass difference the lifetime limit is $\sim 2 \times 10^{19}$ s for $m_{min} \lesssim 0.14$ eV and $\sim 5 \times 10^{20}$ s for $m_{min} \gtrsim 0.14$ eV.
- 94 MIRIZZI 07 determine a limit on the neutrino radiative decay from analysis of the cosmic infrared background (CIB) using the Spitzer Observatory data. For transition with the $|\Delta m_{31}|$ mass difference they obtain the lifetime limit $\sim 10^{20}$ s for $m_{min} \lesssim 0.14$ eV.
- 95 WONG 07 use their limit on the neutrino magnetic moment together with the assumed experimental value of $\Delta m_{13}^2 \sim 2 \times 10^{-3} \; \text{eV}^2$ to obtain $\tau_{13}/m_1^3 > 3.2 \times 10^{27} \; \text{s/eV}^3$ for the radiative decay in the case of the inverted mass hierarchy. Similarly to RAFFELT 89 this limit can be violated if electric and magnetic moments are equal to each other. Analogous, but numerically somewhat different limits are obtained for τ_{23} and τ_{21} .
- 96 XIN 05 search for the γ from radiative decay of ν_e produced by the electron capture on 51 Cr. No events were seen and the limit on τ/m_{ν} was derived. This is a weaker limit on the decay of ν_e than KRAKAUER 91.
- 97 XIN 05 use their limit on the neutrino magnetic moment of ν_e together with the assumed experimental value of $\Delta m_{1,3}^2 \sim 2 \times 10^{-3} \, \mathrm{eV}^2$ to obtain $\tau_{13}/m_1^3 > 1 \times 10^{23} \, \mathrm{s/eV}^3$ for the radiative decay in the case of the inverted mass hierarchy. Similarly to RAFFELT 89 this limit can be violated if electric and magnetic moments are equal to each other. Analogous, but numerically somewhat different limits are obtained for τ_{23} and τ_{21} . Again, this limit is specific for ν_e .

Lepton Particle Listings Neutrino Properties

- 98 AHARMIM 04 obtained these results from the solar $\overline{\nu}_e$ flux limit set by the SNO measurement assuming ν_2 decay through nonradiative process $\nu_2 \to \overline{\nu}_1 X$, where X is a Majoron or other invisible particle. Limits are given for the cases of quasidegenerate and hierarchical neutrino masses.
- 99 CECCHINI 04 obtained this bound through the observations performed on the occasion of the 21 June 2001 total solar eclipse, looking for visible photons from radiative decays of solar neutrinos. Limit is a τ/m_{ν_2} in $\nu_2 \rightarrow \nu_1 \gamma$. Limit ranges from ~ 100 to 10^7 s/eV for $0.01 < m_{\nu_1} < 0.1$ eV.
- $100\,\text{EGUCHI}$ 04 obtained these results from the solar \overline{v}_e flux limit set by the KamLAND measurement assuming ν_2 decay through nonradiative process $\nu_2 \to \overline{v}_1 X$, where X is a Majoron or other invisible particle. Limits are given for the cases of quasidegenerate and hierarchical neutrino masses.
- of the right of the lifetime over the mass derived by BANDYOPADHYAY 03 is for ν_2 . They obtained this result using the following solar-neutrino data: total rates measured in CI and Ga experiments, the Super-Kamiokande's zenith-angle spectra, and SNO's day and night spectra. They assumed that ν_1 is the lowest mass, stable or nearly stable neutrino state and ν_2 decays through nonradiative Majoron emission process, $\nu_2 \rightarrow \mathcal{P}_1 + J$, or through nonradiative process with all the final state particles being sterile. The best fit is obtained in the region of the LMA solution.
- 102 DERBIN 02B (also BACK 03B) obtained this bound for the radiative decay from the results of background measurements with Counting Test Facility (the prototype of the Borexino detector). The laboratory gamma spectrum is given as $dN_{\gamma}/d\cos\theta = (1/2)(1+\alpha\cos\theta)$ with α =0 for a Majorana neutrino, and α varying to -1 to 1 for a Dirac neutrino. The listed bound is for the case of α =0. The most conservative bound 1.5×10^3 s eV $^{-1}$ is obtained for the case of α =-1.
- 103 The ratio of the lifetime over the mass derived by JOSHIPURA 02B is for ν_2 . They obtained this result from the total rates measured in all solar neutrino experiments. They assumed that ν_1 is the lowest mass, stable or nearly stable neutrino state and ν_2 decays through nonradiative process like Majoron emission decay, $\nu_2 \rightarrow \nu_1' + J$ where ν_1' state is sterile. The exact limit depends on the specific solution of the solar neutrino problem. The quoted limit is for the LMA solution.
- $104\,{\rm DOLGOV}$ 99 places limits in the (Majorana) τ -associated ν mass-lifetime plane based on nucleosynthesis. Results would be considerably modified if neutrino oscillations exist.
- 105 BILLER 98 use the observed TeV $\gamma\text{-ray}$ spectra to set limits on the mean life of any radiatively decaying neutrino between 0.05 and 1 eV. Curve shows $\tau_{\nu}/\text{B}_{\gamma}>0.15\times10^{21}\,\text{s}$ at 0.05 eV, $>1.2\times10^{21}\,\text{s}$ at 0.17 eV, $>3\times10^{21}\,\text{s}$ at 1 eV, where B $_{\gamma}$ is the branching ratio to photons.
- 106 BLUD MAN 92 sets additional limits by this method for higher mass ranges. Cosmological limits are also obtained.
- 107 Limit on the radiative decay based on nonobservation of γ 's in coincidence with ν 's from SN 1987A
- 108 DODELSON 92 range is for wrong-helicity keV mass Dirac ν 's from the core of neutron star in SN 1987A decaying to ν 's that would have interacted in KAM2 or IMB detectors.
- 109 GRANEK 91 considers heavy neutrino decays to $\gamma\nu_L$ and $3\nu_L$, where m_{ν_L} <100 keV. Lifetime is calculated as a function of heavy neutrino mass, branching ratio into $\gamma\nu_L$, and m_{ee} .
- 110 KRAKAUER 91 quotes the limit for $\nu_e, \tau/m_\nu > (0.3a^2 + 9.8a + 15.9)\,\text{s/eV},$ where a is a parameter describing the asymmetry in the radiative neutrino decay defined as $dN_\gamma/d\cos\theta = (1/2)(1+a\cos\theta)~a=0$ for a Majorana neutrino, but can vary from -1 to 1 for a Dirac neutrino. The bound given by the authors is the most conservative (which applies for a=-1).
- $^{111}\,\mathrm{WALKER}$ 90 uses SN 1987A γ flux limits after 289 days.
- $112\,\text{CHUPP}$ 89 should be multiplied by a branching ratio (about 1) and a detection efficiency (about 1/4), and pertains to radiative decay of any neutrino to a lighter or sterile neutrino.
- 113 RAFFELT 89 uses KYULDJIEV 84 to obtain $\tau m^3>3\times 10^{18}\,\mathrm{s}$ eV 3 (based on $\overline{\nu}_e\,e^-$ cross sections). The bound for the radiative decay is not valid if electric and magnetic transition moments are equal for Dirac neutrinos.
- $^{114}\, \rm RAFFELT$ 89B analyze stellar evolution and exclude the region 3 \times 10 $^{12}~<~\tau m^3$ $<~3\times 10^{21}\, \rm s\, eV^3.$
- 115 Model-dependent theoretical analysis of SN 1987A neutrinos. Quoted limit is for $\left[\sum_j |U_{\ell j}|^2 \; \Gamma_j \; m_j\right]^{-1}$, where $\ell = \mu, \; \tau$. Limit is 3.3 \times 10¹⁴ s/eV for $\ell = e$.
- 116 OBERAUER 87 looks for photons and $e^+\,e^-$ pairs from radiative decays of reactor neutrinos.
- 117 BINETRUY 84 finds $au < 10^8$ s for neutrinos in a radiation-dominated universe.
- $^{118}\, {\rm These}$ experiments look for $\nu_{\pmb k} \ \to \ \nu_{\pmb j} \, \gamma$ or $\overline{\nu}_{\pmb k} \ \to \ \overline{\nu}_{\pmb j} \, \gamma.$
- 119 STECKER 80 limit based on UV background; result given is $\tau > 4 \times 10^{22}$ s at $m_{\nu} = 20$ eV.
- $^{120}\,\mathrm{FALK}$ 78 finds lifetime constraints based on supernova energetics.
- 121 COWSIK 77 considers variety of scenarios. For neutrinos produced in the big bang, present limits on optical photon flux require $\tau>10^{23}\,\mathrm{s}$ for $m_{\nu}\sim 1$ eV. See also COWSIK 79 and GOLDMAN 79.

ν MAGNETIC MOMENT

The coupling of neutrinos to an electromagnetic field is a characterized by a 3×3 matrix λ of the magnetic (μ) and electric (d) dipole moments $(\lambda=\mu$ - id). For Majorana neutrinos the matrix λ is antisymmetric and only transition moments are allowed, while for Dirac neutrinos λ is a general 3×3 matrix. In the standard electroweak theory extended to include neutrino masses (see FUJIKAWA 80) $\mu_{\nu}=3eG_{F}m_{\nu}/(8\pi^{2}\sqrt{2})=3.2\times10^{-19}(m_{\nu}/\mathrm{eV})\mu_{B}$, i.e. it is unobservably small given the known small neutrino masses. In more general models there is no longer a proportionality between neutrino mass and its magnetic moment, even though

only massive neutrinos have nonvanishing magnetic moments without fine tuning.

Laboratory bounds on λ are obtained via elastic $\nu\text{-}e$ scattering, where the scattered neutrino is not observed. The combinations of matrix elements of λ that are constrained by various experiments depend on the initial neutrino flavor and on its propagation between source and detector (e.g., solar ν_e and reactor $\overline{\nu}_e$ do not constrain the same combinations). The listings below therefore identify the initial neutrino flavor.

Other limits, e.g. from various stellar cooling processes, apply to all neutrino flavors. Analogous flavor independent, but weaker, limits are obtained from the analysis of $e^+e^-\to \nu\overline{\nu}\gamma$ collider experiments.

| VALUE | $(10^{-10} \mu_B)$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------|--------------------|-----|--------------------------|----|------|---------------------------------------------|
| < | 0.32 | 90 | 122 BEDA | 10 | CNTR | Reactor $\overline{\nu}_{\rho}$ |
| < | 6.8 | 90 | ¹²³ AUERBACH | 01 | LSND | $ u_e e, u_\mu e \text{scattering}$ |
| < 3 | 900 | 90 | ¹²⁴ SCHWIENHO | 01 | DONU | $\nu_{\tau} e^- \rightarrow \nu_{\tau} e^-$ |

• • • We do not use the following data for averages, fits, limits, etc. • •

| | | 105 | | |
|---------------|-----|-----------------------------|-----------|-------------------------------------------------------------|
| < 2.2 | 90 | 125 DENIZ 1 | .0 TEXO | Reactor $\overline{ u}_e$ |
| < 0.011-0.027 | | | 9 ASTR | $ u_L ightarrow u_R$ in SN1987A |
| < 0.54 | 90 | | 08A BORX | Solar $ u$ spectrum shape |
| < 0.58 | 90 | | 7 CNTR | Reactor $\overline{\nu}_e$ |
| < 0.74 | 90 | | 7 CNTR | Reactor $\overline{\nu}_e$ |
| < 0.9 | 90 | |)5 | Reactor $\overline{\nu}_e$ |
| < 130 | 90 | | 5 CNTR | Reactor ν_e |
| < 37 | 95 | 132 GRIFOLS 0 | 04 FIT | Solar ⁸ B ν (SNO NC) |
| < 3.6 | 90 | | 04 SKAM | Solar ν spectrum shape |
| < 1.1 | 90 | 1 2 4 | 04 SKAM | Solar ν spectrum shape |
| 1.1 | ,,, | LIO 0 |)+ 3101W | (LMA region) |
| < 5.5 | 90 | 135 BACK 0 | 3B CNTR | Solar pp and Be ν |
| < 1.0 | 90 | 136 DARAKTCH 0 |)3 | Reactor $\overline{\nu}_e$ |
| < 1.3 | 90 | | 3B CNTR | Reactor $\overline{\nu}_e$ |
| < 2 | 90 | 100 |)2 FIT | solar + reactor (Majo- |
| ` - | ,,, | GITTIMOS 0 | ,_ ,,, | rana ν) |
| <80000 | 90 | 139 TANIMOTO 0 | 00 RVUE | $e^+e^- \rightarrow \nu \overline{\nu} \gamma$ |
| < 0.01-0.04 | | 140 AYALA 9 | 9 ASTR | $\nu_I \rightarrow \nu_R$ in SN 1987A |
| < 1.5 | 90 | | 99 SKAM | ν spectrum shape |
| < 0.03 | | | 99 ASTR | Red giant luminosity |
| < 4 | | | 99 ASTR | Solar cooling |
| <44000 | 90 | | 7J DLPH | $e^+e^- ightarrow u \overline{ u} \gamma$ at LEP |
| <33000 | 90 | | 970 L3 | $e^+e^- \rightarrow \nu \overline{\nu} \gamma$ at LEP |
| | ,,, | 1.40 | 7 COSM | |
| < 0.62 | | ELIVIFORS 9 | or COSINI | Depolarization in early universe plasma |
| <27000 | 95 | 146 ESCRIBANO 9 | 7 RVUE | $\Gamma(Z \rightarrow \nu \nu)$ at LEP |
| < 30 | 90 | | 95в СНМ2 | $\nu_{\mu} e \rightarrow \nu_{\mu} e$ |
| < 55000 | 90 | GOULD 9 | 4 RVUE | $e^{+}e^{-} \rightarrow \nu \overline{\nu} \gamma$ at LEP |
| < 1.9 | 95 | 1.47 | 3 CNTR | Reactor $\overline{\nu}e \rightarrow \overline{\nu}e$ |
| < 5400 | 90 | | DEBC | |
| | 90 | | | $\nu_{\tau} e^{-} \rightarrow \nu_{\tau} e^{-}$ |
| < 2.4 | | | | Reactor $\overline{\nu}e \rightarrow \overline{\nu}e$ |
| < 5 6 0 0 0 | 90 | | 1 RVUE | $e^+e^- \rightarrow \nu \overline{\nu} \gamma$ |
| < 100 | 95 | | | $\nu_{\mu} e \rightarrow \nu_{\mu} e$ |
| < 8.5 | 90 | | 00 CNTR | $\nu_{\mu} e \rightarrow \nu_{\mu} e$ |
| < 10.8 | 90 | | 0 CNTR | LAMPF $\nu e \rightarrow \nu e$ |
| < 7.4 | 90 | ¹⁵¹ KRAKAUER 9 | 0 CNTR | LAMPF $(\nu_{\mu}, \overline{\nu}_{\mu}) e$ |
| | | 100 | | elast. |
| < 0.02 | | | 00 ASTR | Red giant luminosity |
| < 0.1 | | | 39в ASTR | Cooling helium stars |
| | | | 38 COSM | Primordial magn. fields |
| <40000 | 90 | | 88 RVUE | $e^+e^- \rightarrow \nu \overline{\nu} \gamma$ |
| ≤ .3 | | 153 RAFFELT 8 | 88B ASTR | He burning stars |
| < 0.11 | | 153 FUKUGITA 8 | 37 ASTR | Cooling helium stars |
| < 0.0006 | | | 37 ASTR | Cosmic EM back- |
| | | | | grounds |
| < 0.1-0.2 | | MORGAN 8 | 31 COSM | ⁴ He abundance |
| < 0.85 | | 157 | 78 ASTR | Stellar plasmons |
| < 0.6 | | ¹⁵⁷ SUTHERLAND 7 | 6 ASTR | Red giants + degener- |
| < 81 | | ¹⁵⁸ KIM 7 | 4 RVUE | ate dwarfs |
| | | | | $\overline{\nu}_{\mu} e \rightarrow \overline{\nu}_{\mu} e$ |
| < 1 | | | 3 ASTR | Solar cooling |
| < 14 | | COWAN 5 | 7 CNTR | Reactor $\overline{\nu}$ |
| | | | | |

- $122\,\mathrm{BEDA}$ 10 report $\overline{\nu}_e\,\mathrm{e}^-$ scattering results, using the Kalinin Nuclear Power Plant and a shielded Ge detector. The recoil electron spectrum is analyzed between 2.9 and 45 keV. Supersedes BEDA 07. This is the most stringent limit on the magnetic moment of reactor $\overline{\nu}_e$.
- 123 AUERBACH 01 limit is based on the LSND ν_e and ν_μ electron scattering measurements. The limit is slightly more stringent than KRAKAUER 90.
- $^{124}\,\text{SCHWIENHORST}$ 01 quote an experimental sensitivity of 4.9×10^{-7}
- 125 DENIZ 10 observe reactor $\overline{v}_e e$ scattering with recoil kinetic energies 3–8 MeV using Csl(Tl) detectors. The observed rate and spectral shape are consistent with the Standard Model prediction, leading to the reported constraint on \overline{v}_e magnetic moment.
- 126 KUZNETSOV 09 obtain a limit on the flavor averaged magnetic moment of Dirac neutrinos from the time averaged neutrino signal of SN1987A. Improves and supersedes the analysis of BARBIERI 88 and AYALA 99.
- 127 ARPESELLA 08A obtained this limit using the shape of the recoil electron energy spectrum from the Borexino 192 live days of solar neutrino data.

Neutrino Properties

- $^{128}\, \text{BEDA}$ 07 performed search for electromagnetic $\overline{\nu}_{e}\text{-}e$ scattering at Kalininskaya nuclear reactor. A Ge detector with active and passive shield was used and the electron recoil spectrum between 3.0 and 61.3 keV analyzed. Superseded by BEDA 10.
- 129 WONG 07 performed search for non-standard $\overline{\nu}_{e^-}$ e scattering at the Kuo-Sheng nuclear reactor. Ge detector equipped with active anti-Compton shield is used. Most stringent laboratory limit on magnetic moment of reactor $\overline{
 u}_e$. Supersedes LI 03B.
- 130 DARAKTCHIEVA 05 present the final analysis of the search for non-standard $\overline{\nu}_e$ -e scattering component at Bugey nuclear reactor. Full kinematical event reconstruction of both the kinetic energy above 700 keV and scattering angle of the recoil electron, by use of TPC. Most stringent laboratory limit on magnetic moment. Supersedes DARAKTERING 020 TCHIEVA 03.
- 131 XIN 05 evaluated the $u_{
 m p}$ flux at the Kuo-Sheng nuclear reactor and searched for nonstandard ν_e -e scattering. Ge detector equipped with active anti-Compton shield was used. This laboratory limit on magnetic moment is considerably less stringent than the limits for reactor $\overline{
 u}_e$, but is specific to u_e .
- $^{132}\,\mathrm{GRIFOLS}$ 04 obtained this bound using the SNO data of the solar $^{8}\mathrm{B}$ neutrino flux measured with deuteron breakup. This bound applies to $\mu_{
 m eff}=(\mu_{21}^2+\mu_{22}^2+\mu_{23}^2)^{1/2}.$
- 133 LIU 04 obtained this limit using the shape of the recoil electron energy spectrum from the Super-Kamiokande-I 1496 days of solar neutrino data. Neutrinos are assumed to have only diagonal magnetic moments, $\mu_{\nu 1}=\mu_{\nu 2}$. This limit corresponds to the oscillation parameters in the vacuum oscillation region.
- 134 LIU 04 obtained this limit using the shape of the recoil electron energy spectrum from the Super-Kamiokande-1 1496 live-day solar neutrino data, by limiting the oscillation parameter region in the L MA region allowed by solar neutrino experiments plus KamLAND. $\mu_{\nu 1}=\mu_{\nu 2}$ is assumed. In the LMA region, the same limit would be obtained even if neutrinos have off-diagonal magnetic moments.
- $^{135}\,\mathrm{BACK}$ 03B obtained this bound from the results of background measurements with Counting Test Facility (the prototype of the Borexino detector). Standard Solar Model flux was assumed. This μ_{ν} can be different from the reactor μ_{ν} in certain oscillation scenarios (see BEACOM 99).
- $136\,\mathrm{DARAKTCHIEVA}$ 03 searched for non-standard $\overline{\nu}_e\text{-e}$ scattering component at Bugey nuclear reactor. Full kinematical event reconstruction by use of TPC. Superseded by DARAKTCHIEVA 05.
- 137 LI 03B used Ge detector in active shield near nuclear reactor to test for nonstandard $\overline{\nu}_{e}$ -e
- 138 GRIMUS 02 obtain stringent bounds on all Majorana neutrino transition moments from a simultaneous fit of LMA-MSW oscillation parameters and transition moments to global solar neutrino data , reactor data. Using only solar neutrino data, a 90% CL bound of $6.3 \times 10^{-10} \mu_B$ is obtained.
- 139 TANIMOTO 00 combined $e^+\,e^ightarrow\,
 u\,\overline{
 u}\gamma$ data from VENUS, TOPAZ, and AMY.
- $^{140}\,\mathrm{AYALA}$ 99 improves the limit of BARBIERI 88.
- 141 BEACOM 99 obtain the limit using the shape, but not the absolute magnitude which is affected by oscillations, of the solar neutrino spectrum obtained by Superkamiokande (825 days). This $\mu_{
 u}$ can be different from the reactor $\mu_{
 u}$ in certain oscillation scenarios.
- 142 RAFFELT 99 is an update of RAFFELT 90. This limit applies to all neutrino flavors which are light enough (< 5 keV) to be emitted from globular-cluster red giants. This limit pertains equally to electric dipole moments and magnetic transition moments, and it applies to both Dirac and Majorana neutrinos.
- 143 RAFFELT 99 is essentially an update of BERNSTEIN 63, but is derived from the helioseismological limit on a new energy-loss channel of the Sun. This limit applies to all neutrino flavors which are light enough $(<1~{\rm keV})$ to be emitted from the Sun. This limit pertains equally to electric dipole and magnetic transition moments, and it applies to both Dirac and Majorana neutrinos.
- $^{144}\,\mathrm{ACCIARRI}$ 97Q result applies to both direct and transition magnetic moments and for $a^2 = 0$
- $^{145}\, {\sf ELMFORS}$ 97 calculate the rate of depolarization in a plasma for neutrinos with a magnetic moment and use the constraints from a big-bang nucleosynthesis on additional degrees of freedom.
- $^{\rm 146}\,{\rm Applies}$ to absolute value of magnetic moment.
- $147\,\text{DERBIN}$ 93 determine the cross section for 0.6–2.0 MeV electron energy as $(1.28\pm0.63)\times\sigma_{\text{Weak}}.$ However, the (reactor on reactor off)/(reactor off) is only $\sim1/100.$
- 148 COOPER-SARKAR 92 assume $f_{\overline{D}_S}/f_{\pi}$ = 2 and D_S , \overline{D}_S production cross section = 2.6 μb to calculate ν flux.
- $^{149}\,\text{ViDYAKIN}$ 92 limit is from a $e\overline{\nu}_e$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2 heta_W = 0.23$ as input.
- 150 DORENBOSCH 91 corrects an incorrect statement in DORENBOSCH 89 that the ν magnetic moment is < 1 \times 10 $^{-9}$ at the 95%CL. DORENBOSCH 89 measures both $u_{\mu}\overset{ extbf{G}}{e}$ and $\overline{
 u}e$ elastic scattering and assume $\mu(
 u)=\mu(\overline{
 u})$.
- $^{151}\,\mathrm{KRAKAUER}$ 90 experiment fully reported in ALLEN 93.
- $^{152}\,\mathrm{RAFFELT}$ 90 limit applies for a diagonal magnetic moment of a Dirac neutrino, or for a transition magnetic moment of a Majorana neutrino. In the latter case, the same analysis gives $<1.4\times10^{-12}$. Limit at 95%CL obtained from δM_C .
- $153\,\mathrm{Significant}$ dependence on details of stellar models.
- 154 FUKUGITA 88 find magnetic dipole moments of any two neutrino species are bounded by $_{\mu}~<~10^{-16}~[10^{-9}~G/B_{0}]$ where B_{0} is the present-day intergalactic field strength.
- 155 GROTCH 88 combined data from MAC, ASP, CELLO, and Mark J.
- $^{156}\,\mathrm{For}~m_{\nu}=$ 8–200 eV. NUSSINOV 87 examines transition magnetic moments for $\nu_{\mu}\to$ ν_e and obtain $< 3 \times 10^{-15}$ for $m_{\nu} > 16$ eV and $< 6 \times 10^{-14}$ for $m_{\nu} > 4$ eV.
- $^{157}\mathrm{We}$ obtain above limit from SUTHERLAND 76 using their limit f < 1/3.
- $^{158}\, ext{KIM}$ 74 is a theoretical analysis of $\overline{
 u}_{\mu}$ reaction data.

NEUTRINO CHARGE RADIUS SQUARED

We report limits on the so-called neutrino charge radius squared. While the straight-forward definition of a neutrino charge radius has been proven to be gauge-dependent and, hence, unphysical (LEE 77C), there have been attempts to define a physically observable neutrino charge radius (BERNABEU 00, BERNABEU 02). The issue is still controversial (FU-JIKAWA 03, BERNABEU 03). A more general interpretation of the experimental results is that they are limits on certain nonstandard contributions to neutrino scattering

| VALUE (10 ⁻³² cm ²) | CL % | DO CUMENT | DO CUMENT ID | | COMMENT |
|--------------------------------------------|----------|--------------------|--------------|------------|-------------------------------|
| -2.1 to 3.3 | 90 | 159 DENIZ | 10 | TEXO | Reactor $\overline{ u}_e$ e |
| • • • We do not us | e the fo | llowing data for a | verage . | fite limit | s etc |

| -0.53 to 0.68 | 90 | ¹⁶⁰ HIRSCH | 03 | | $\nu_{\mu}e$ scat. |
|-----------------|----|-------------------------|-----|------|----------------------------------------------------------|
| -8.2 to 9.9 | 90 | ¹⁶¹ HIRSCH | 03 | | anomalous $e^+e^- \rightarrow \nu \overline{\nu} \gamma$ |
| -2.97 to 4.14 | 90 | ¹⁶² AUERBACH | 01 | LSND | $\nu_e e \rightarrow \nu_e e$ |
| -0.6 to 0.6 | 90 | VILAIN | 95B | CHM2 | $ u_{\mu}e$ elastic scat. |
| 0.9 ± 2.7 | | ALLEN | 93 | CNTR | LAMPF $\nu e \rightarrow \nu e$ |
| < 2.3 | 95 | MOURAO | 92 | ASTR | HOME/KAM2 ν rates |
| < 7.3 | 90 | ¹⁶³ VIDYAKIN | 92 | CNTR | Reactor $\overline{\nu}e \rightarrow \overline{\nu}e$ |
| 1.1 ± 2.3 | | ALLEN | 91 | CNTR | Repl. by ALLEN 93 |
| -1.1 ± 1.0 | | ¹⁶⁴ AHRENS | | | $ u_{\mu}e$ elastic scat. |
| $-0.3\ \pm1.5$ | | ¹⁶⁴ DORENBOS | 89 | CHRM | $ u_{\mu}^{\prime}e$ elastic scat. |
| | | ¹⁶⁵ GRIFOLS | | | SN 1987A |

- 159 DENIZ 10 observe reactor $\overline{\nu}_e\,e$ scattering with recoil kinetic energies 3–8 MeV using CsI((TI)) detectors. The observed rate and spectral shape are consistent with the Standard Model prediction, leading to the reported constraint on $\overline{
 u}_e$ charge radius.
- 160 Based on analysis of CCFR 98 results. Limit is on $\langle r_V^2 \rangle + \langle r_A^2 \rangle$. The CHARM II and E734 at BNL results are reanalyzed, and weaker bounds on the charge radius squared than previously published are obtained. The NuTeV result is discussed; when tentatively interpreted as ν_μ charge radius it implies $\langle r_V^2 \rangle + \langle r_A^2 \rangle = (4.20 \pm 1.64) \times 10^{-33}$ cm².
- 161 Results of LEP-2 are interpreted as limits on the axial-vector charge radius squared of a Majorana $\nu_{ au}$. Slightly weaker limits for both vector and axial-vector charge radius squared are obtained for the Dirac case, and somewhat weaker limits are obtained from the analysis of lower energy data (LEP-1.5 and TRISTAN)
- 162 AUERBACH 01 measure $\nu_e \, e$ elastic scattering with LSND detector. The cross section agrees with the Standard Model expectation, including the charge and neutral current interference. The 90% CL applies to the range shown.
- $^{163}\,\mathrm{VIDYA\,KIN}$ 92 limit is from a $ear{
 u}$ elastic scattering experiment. No experimental details are given except for the cross section from which this limit is derived. Signal/noise was 1/10. The limit uses $\sin^2\!\theta_{\,W}=$ 0.23 as input.
- 164 Result is obtained from reanalysis given in ALLEN 91, followed by our reduction to obtain
- ¹⁶⁵ GRIFOLS 89B sets a limit of $\langle r^2 \rangle < 0.2 \times 10^{-32} \, \mathrm{cm}^2$ for right-handed neutrinos.

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| LAM | 91 | PR D44 3345 | W.P. Lam, K.W. Ng (AST) |
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| | 63 57 | PR 132 1227 PR 107 528 | | | tein, M. Rude van, F. Reines | | einberg | (NYU+) (LANL) |

Number of Neutrino Types

The neutrinos referred to in this section are those of the Standard SU(2)×U(1) Electroweak Model possibly extended to allow nonzero neutrino masses. Light neutrinos are those with $m < m_Z/2$. The limits are on the number of neutrino mass eigenstates, including ν_1 , ν_2 , and ν_3 .

THE NUMBER OF LIGHT NEUTRINO TYPES FROM COLLIDER EXPERIMENTS

Revised March 2008 by D. Karlen (University of Victoria and TRIUMF).

The most precise measurements of the number of light neutrino types, N_{ν} , come from studies of Z production in e^+e^- collisions. The invisible partial width, $\Gamma_{\rm inv}$, is determined by subtracting the measured visible partial widths, corresponding to Z decays into quarks and charged leptons, from the total Z width. The invisible width is assumed to be due to N_{ν} light neutrino species each contributing the neutrino partial width Γ_{ν} as given by the Standard Model. In order to reduce the model dependence, the Standard Model value for the ratio of the neutrino to charged leptonic partial widths, $(\Gamma_{\nu}/\Gamma_{\ell})_{\rm SM}=1.991\pm0.001$, is used instead of $(\Gamma_{\nu})_{\rm SM}$ to determine the number of light neutrino types:

$$N_{\nu} = \frac{\Gamma_{\rm inv}}{\Gamma_{\ell}} \left(\frac{\Gamma_{\ell}}{\Gamma_{\nu}} \right)_{\rm SM} . \tag{1}$$

The combined result from the four LEP experiments is $N_{\nu} = 2.984 \pm 0.008$ [1].

In the past, when only small samples of Z decays had been recorded by the LEP experiments and by the Mark II at SLC, the uncertainty in N_{ν} was reduced by using Standard Model fits to the measured hadronic cross sections at several center-of-mass energies near the Z resonance. Since this method is

Number of Neutrino Types

much more dependent on the Standard Model, the approach described above is favored.

Before the advent of the SLC and LEP, limits on the number of neutrino generations were placed by experiments at lower-energy e^+e^- colliders by measuring the cross section of the process $e^+e^- \to \nu \overline{\nu} \gamma$. The ASP, CELLO, MAC, MARK J, and VENUS experiments observed a total of 3.9 events above background [2], leading to a 95% CL limit of $N_{\nu} < 4.8$. This process has a much larger cross section at center-of-mass energies near the Z mass and has been measured at LEP by the ALEPH, DELPHI, L3, and OPAL experiments [3]. These experiments have observed several thousand such events, and the combined result is $N_{\nu} = 3.00 \pm 0.08$. The same process has also been measured by the LEP experiments at much higher center-of-mass energies, between 130 and 208 GeV, in searches for new physics [4]. Combined with the lower energy data, the result is $N_{\nu} = 2.92 \pm 0.05$.

Experiments at $p\overline{p}$ colliders also placed limits on N_{ν} by determining the total Z width from the observed ratio of $W^{\pm} \to \ell^{\pm} \nu$ to $Z \to \ell^{+} \ell^{-}$ events [5]. This involved a calculation that assumed Standard Model values for the total W width and the ratio of W and Z leptonic partial widths, and used an estimate of the ratio of Z to W production cross sections. Now that the Z width is very precisely known from the LEP experiments, the approach is now one of those used to determine the W width.

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Number from e^+e^- Colliders

Number of Light ν Types

| VALUE | DO CUMENT IL | TECN | | |
|--------------------------------|----------------------|----------|----------------|-----|
| 2.9840 ± 0.0082 | $^{ m 1}$ LEP-SLC | 06 | RVUE | |
| • • • We do not use the follow | wing data for averag | es, fits | , limits, etc. | • • |
| 3.00 ±0.05 | ² LEP | 92 | RVUE | |

 $^{^{\}rm 1}\,{\rm Combined}$ fit from ALEPH, DELPHI, L3 and OPAL Experiments.

Number of Light u Types from Direct Measurement of Invisible Z Width

In the following, the invisible Z width is obtained from studies of single-photon events from the reaction $e^+e^- \rightarrow \nu \overline{\nu} \gamma$. All are obtained from LEP runs in the $E_{\rm Em}^{\rm em}$ range e^+e^-

| 88–209 GeV. VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------|-------------------------|----------|---------|-----------------------------------|
| 2.92±0.05 OUR AVERAGE | Error includes scale fa | ctor of | 1.2. | |
| $2.84 \pm 0.10 \pm 0.14$ | ABDALLAH | 05B | DLPH | $\sqrt{s} = 180 209 \text{ GeV}$ |
| $2.98 \pm 0.05 \pm 0.04$ | ACHARD | 04E | L3 | 1990-2000 LEP runs |
| 2.86 ± 0.09 | HEISTER | 03c | ALEP | $\sqrt{s} = 189 209 \text{ GeV}$ |
| $2.69 \pm 0.13 \pm 0.11$ | ABBIENDI,G | 00D | OPAL | 1998 LEP run |
| $2.89 \pm 0.32 \pm 0.19$ | ABREU | 97J | DLPH | 1993-1994 LEP runs |
| $3.23 \pm 0.16 \pm 0.10$ | AKERS | 95 c | OPAL | 1990-1992 LEP runs |
| $2.68 \pm 0.20 \pm 0.20$ | BUSKULIC | 93L | ALEP | 1990-1991 LEP runs |
| ullet $ullet$ We do not use the fol | lowing data for average | s, fits, | limits, | etc. • • • |
| $2.84 \pm 0.15 \pm 0.14$ | ABREU | 00z | DLPH | 1997-1998 LEP runs |
| 3.01 ± 0.08 | ACCIARRI | 99R | L3 | 1991-1998 LEP runs |
| $3.1 \pm 0.6 \pm 0.1$ | ADAM | 96c | DLPH | $\sqrt{s}=1$ 30, 136 GeV |

Limits from Astrophysics and Cosmology

Number of Light ν Types

("light" means < about 1 MeV). See also OLIVE 81. For a review of limits based on Nucleosynthesis, Supernovae, and also on terrestial experiments, see DENEGRI 90. Also see "Big-Bang Nucleosynthesis" in this *Review*.

| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-------------|-------------------------|---------|-----------|-----------------------------------------------|
| • • • We do not use | the followi | ng data for average | s, fits | , limits, | etc. • • • |
| < 4.08 | 95 | MANGANO | 11 | | BBN |
| $0.9 < N_{\nu} < 8.2$ | | ³ ICHIKAWA | 07 | COSM | |
| $3 < N_{y} < 7$ | 95 | ⁴ CIRELLI | 06 | COSM | |
| $2.7 < N_{y} < 4.6$ | 95 | ⁵ HA NNESTAD | 06 | COSM | |
| $3.6 < N_{\nu} < 7.4$ | 95 | ⁴ SELJA K | 06 | COSM | |
| < 4.4 | | ⁶ CYBURT | 05 | COSM | |
| < 3.3 | | ⁷ BARGER | 03c | COSM | |
| $1.4 < N_{\nu} < 6.8$ | | ⁸ CROTTY | 03 | COSM | |
| $1.9 < N_{\nu} < 6.6$ | | ⁸ PIERPAOLI | 03 | COSM | |
| $2 < N_{\nu} < 4$ | | LISI | 99 | | BBN |
| < 4.3 | | OLIVE | 99 | | BBN |
| < 4.9 | | COPI | 97 | | Cosmology |
| < 3.6 | | HATA | 97B | | High D/H quasar abs. |
| < 4.0 | | OLIVE | 97 | | BBN; high ⁴ He and ⁷ Li |
| < 4.7 | | CARDALL | 96B | COSM | High D/H quasar abs. |
| < 3.9 | | FIELDS | 96 | COSM | BBN; high ⁴ He and ⁷ Li |
| < 4.5 | | KERNAN | 96 | COSM | High D/H quasar abs. |
| < 3.6 | | OLIVE | 95 | | BBN; \geq 3 massless ν |
| < 3.3 | | WALKER | 91 | | Cosmology |
| < 3.4 | | OLIVE | 90 | | Cosmology |
| < 4 | | YANG | 84 | | Cosmology |
| < 4 | | YANG | 79 | | Cosmology |
| < 7 | | STEIGMAN | 77 | | Cosmology |
| | | PEEBLES | 71 | | Cosmology |
| <16 | | ⁹ SHVARTSMAI | V 69 | | Cosmology |
| | | HOYLE | 64 | | Cosmology |

 $^{^3}$ Constrains the number of neutrino types from recent CMB and large scale structure data. No priors on other cosmological parameters are used.

Number Counting with Less Than Full Weak Strength

| VALUE COUPING | <u>DOCUMENT ID</u> TECN |
|---------------------------------|----------------------------------------------------------------|
| • • • We do not use | the following data for averages, fits, limits, etc. • • • |
| <20 <20 | ¹⁰ OLIVE 81c COSM ¹⁰ STEIGMAN 79 COSM |
| ¹⁰ Limit varies with | strength of coupling. See also WALKER 91. |

 $^{^{2}\,\}mathrm{Simultaneous}$ fits to all measured cross section data from all four LEP experiments.

 $^{^4}$ Constrains the number of neutrino types from recent CMB, large scale structure, Lymanalpha forest, and SNIa data. The slight preference for $N_\nu > 3$ comes mostly from the Lyman-alpha forest data.

 $^{^{5}}$ Constrains the number of neutrino types from recent CMB and large scale structure data. See also HAMANN 07.

 $^{^6}$ Limit on the number of neutrino types based on 4 He and D/H abundance assuming a baryon density fixed to the WMAP data. Limit relaxes to 4.6 if D/H is not used or to 5.8 if only D/H and the CMB are used. See also CYBURT 01 and CYBURT 03.

⁷Limit on the number of neutrino types based on combination of WMAP data and bigbang nucleosynthesis. The limit from WMAP data alone is 8.3. See also KNELLER 01. $N_{yz} \ge 3$ is assumed to compute the limit.

^{8 95%} confidence level range on the number of neutrino flavors from WMAP data combined with other CMB measurements, the 2dfGRS data, and HST data.

⁹ SHVARTSMAN 69 limit inferred from his equations

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Double- β Decay

OMITTED FROM SUMMARY TABLE

NEUTRINOLESS DOUBLE- β DECAY

Revised August 2011 by P. Vogel (Caltech) and A. Piepke (University of Alabama).

Neutrinoless double-beta $(0\nu\beta\beta)$ decay would signal violation of total lepton number conservation. The process can be mediated by an exchange of a light Majorana neutrino, or by an exchange of other particles. However, the existence of $0\nu\beta\beta$ -decay requires Majorana neutrino mass, no matter what the actual mechanism is. As long as only a limit on the lifetime is available, limits on the effective Majorana neutrino mass, on the lepton-number violating right-handed current or other possible mechanisms mediating $0\nu\beta\beta$ -decay can be obtained, independently of the actual mechanism. These limits are listed in the next three tables, together with a claimed $0\nu\beta\beta$ -decay signal reported by part of the Heidelberg-Moscow collaboration. A 6σ excess of counts at the decay energy is used for a determination of the Majorana neutrino mass. This signal has not yet been independently confirmed. In the following we assume that the exchange of light Majorana neutrinos $(m_{\nu_i} \leq 10 \text{ MeV})$ contributes dominantly to the decay rate.

Besides a dependence on the phase space $(G^{0\nu})$ and the nuclear matrix element $(M^{0\nu})$, the observable $0\nu\beta\beta$ -decay rate is proportional to the square of the effective Majorana mass $\langle m_{\beta\beta} \rangle$, $(T_{1/2}^{0\nu})^{-1} = G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$, with $\langle m_{\beta\beta} \rangle^2 = |\sum_i U_{ei}^2 m_{\nu_i}|^2$. The sum contains, in general, complex *CP*-phases in U_{ei}^2 , *i.e.*, cancellations may occur. For three neutrino flavors, there are

three physical phases for Majorana neutrinos and one for Dirac neutrinos. The two additional Majorana phase differences affect only processes to which lepton-number-changing amplitudes contribute. Given the general 3×3 mixing matrix for Majorana neutrinos, one can construct other analogous lepton number violating quantities, $\langle m_{\ell\ell'} \rangle = \sum_i U_{\ell i} U_{\ell' i} m_{\nu_i}$. However, these are currently much less constrained than $\langle m_{\beta\beta} \rangle$.

Nuclear structure calculations are needed to deduce $\langle m_{\beta\beta} \rangle$ from the decay rate. While $G^{0\nu}$ can be calculated reliably, the computation of $M^{0\nu}$ is subject to uncertainty. Comparing different nuclear model evaluations indicates a factor ~ 2 spread in the calculated nuclear matrix elements. The particle physics quantities to be determined are thus nuclear model-dependent, so the half-life measurements are listed first. Where possible, we reference the nuclear matrix elements used in the subsequent analysis. Since rates for the more conventional $2\nu\beta\beta$ decay serve to calibrate the nuclear theory, results for this process are also given.

Oscillation experiments utilizing atmospheric-, accelerator-, solar-, and reactor-produced neutrinos and anti-neutrinos yield strong evidence that at least some neutrinos are massive. However, these findings shed no light on the mass hierarchy (i.e., on the sign of Δm^2_{atm}), the absolute neutrino mass values or the properties of neutrinos under CPT-conjugation (Dirac or Majorana).

All confirmed oscillation experiments can be consistently described using three interacting neutrino species with two mass splittings and three mixing angles. Full three flavor analyses such as e.g. [2] yield: $|\Delta m_{atm}^2| \equiv |m_3^2 - (m_2^2 + m_1^2)/2| = (2.39_{-0.20}^{+0.27}) \times 10^{-3} \text{ eV}^2$ and $\sin^2\theta_{atm} \equiv \sin^2\theta_{23} = 0.466_{-0.100}^{+0.136}$ for the parameters observed in atmospheric and accelerator experiments. Oscillations of solar ν_e and reactor $\bar{\nu}_e$ lead to $\Delta m_\odot^2 \equiv m_2^2 - m_1^2 = (7.67_{-0.36}^{+0.34}) \times 10^{-5} \text{ eV}^2$ and $\sin^2\theta_\odot \equiv \sin^2\theta_{12} = 0.312_{-0.034}^{+0.040}$. (All errors correspond to 95% CL) The investigation of reactor $\bar{\nu}_e$ at \sim 1 km baseline, combined with solar neutrino and long baseline reactor experiments, indicates that electron type neutrinos couple only weakly to the third mass eigenstate with $\sin^2\theta_{13} < 0.036$.

Based on the 3-neutrino analysis: $\langle m_{\beta\beta} \rangle^2 \approx |\cos^2\theta_{\odot}m_1 + e^{i\Delta\alpha_{21}}\sin^2\theta_{\odot}m_2 + e^{i\Delta\alpha_{31}}\sin^2\theta_{13}m_3|^2$, with $\Delta\alpha_{21}$, $\Delta\alpha_{31}$ denoting the physically relevant Majorana CP-phase differences (possible Dirac phase δ is absorbed in these $\Delta\alpha$). Given the present knowledge of the neutrino oscillation parameters one can derive the relation between the effective Majorana mass and the mass of the lightest neutrino, as illustrated in the left panel of Fig. 1. The three mass hierarchies allowed by the oscillation data: normal $(m_1 < m_2 < m_3)$, inverted $(m_3 < m_1 < m_2)$, and degenerate $(m_1 \approx m_2 \approx m_3)$, result in different projections. The width of the innermost hatched bands reflects the uncertainty introduced by the oscillation parameters are taken into account, then the allowed areas are widened as shown by the outer bands of Fig. 1. Because of the overlap of the

Double- β Decay

different mass scenarios a measurement of $\langle m_{\beta\beta} \rangle$ in the degenerate or inversely hierarchical ranges would not determine the hierarchy. The middle panel of Fig. 1 depicts the relation of $\langle m_{\beta\beta} \rangle$ with the summed neutrino mass $M=m_1+m_2+m_3$, constrained by observational cosmology. The oscillation data thus allow to test whether observed values of $\langle m_{\beta\beta} \rangle$ and M are consistent within the 3 neutrino framework. The right hand panel of Fig. 1, finally, shows $\langle m_{\beta\beta} \rangle$ as a function of the average mass $\langle m_{\beta} \rangle = [\Sigma |U_{ei}|^2 m_{\nu_i}^2]^{1/2}$ determined through the analysis of low energy beta decays. The rather large intrinsic width of the $\beta\beta$ -decay constraint essentially does not allow to positively identify the inverted hierarchy, and thus the sign of Δm_{atm}^2 , even in combination with these other observables. Naturally, if the value of $\langle m_{\beta\beta} \rangle \leq 0.01$ eV is ever established then normal hierarchy becomes the only possible scenario.

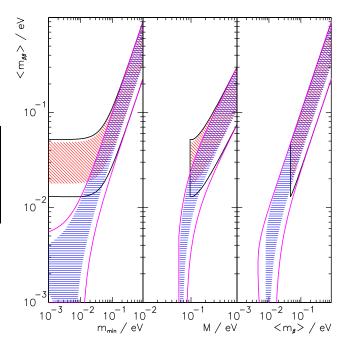


Figure 1: The left panel shows the dependence of $\langle m_{\beta\beta} \rangle$ on the absolute mass of the lightest neutrino m_{min} . The middle panel shows $\langle m_{\beta\beta} \rangle$ as a function of the summed neutrino mass M, while the right panel depicts $\langle m_{\beta\beta} \rangle$ as a function of the mass $\langle m_{\beta} \rangle$. In all panels, the width of the hatched areas is due to the unknown Majorana phases and thus irreducible. The allowed areas given by the solid lines are obtained by taking into account the errors of the oscillation parameters. The two sets of solid lines correspond to the normal and inverted hierarchies. These sets merge into each other for $\langle m_{\beta\beta} \rangle \geq 0.1 \text{ eV}$, which corresponds to the degenerate mass pattern.

It should be noted that systematic uncertainties of the nuclear matrix elements are not folded into the mass limits reported by $\beta\beta$ -decay experiments. Taking this additional uncertainty into account would further widen the projections. The uncertainties in oscillation parameterers affect the width of the allowed bands in an asymmetric manner, as shown in Fig. 1. For example, for the degenerate mass pattern $(\langle m_{\beta\beta} \rangle \geq 0.1 \text{ eV})$ the upper edge is simply $\langle m_{\beta\beta} \rangle \sim m$, where m is the common mass of the degenerate multiplet, independent of the oscillation parameters, while the lower edge is $m \cos(2\theta_{\odot})$. Similar arguments explain the other features of Fig. 1.

If the neutrinoless double-beta decay is observed, it will be possible to fix a range of absolute values of the masses m_{ν_i} . Unlike the direct neutrino mass measurements, however, a limit on $\langle m_{\beta\beta} \rangle$ does not allow one to constrain the individual mass values m_{ν_i} even when the mass differences Δm^2 are known.

Neutrino oscillation data imply, for the first time, the existence of a lower limit ~ 0.013 eV for the Majorana neutrino mass for the inverted hierarchy mass pattern while $\langle m_{\beta\beta} \rangle$ could, by fine tuning, vanish in the case of the normal mass hierarchy. Several new double-beta searches have been proposed to probe the interesting $\langle m_{\beta\beta} \rangle$ mass range.

If lepton-number-violating right-handed current weak interactions exist, their strength can be characterized by the phenomenological coupling constants η and λ (η describes the coupling between the right-handed lepton current and lefthanded quark current while λ describes the coupling when both currents are right-handed). The $0\nu\beta\beta$ decay rate then depends on $\langle \eta \rangle = \eta \sum_{i} U_{ei} V_{ei}$ and $\langle \lambda \rangle = \lambda \sum_{i} U_{ei} V_{ei}$ that vanish for massless or unmixed neutrinos ($V_{\ell j}$ is a matrix analogous to $U_{\ell j}$ but describing the mixing with the hypothetical right-handed neutrinos). This mechanism of the $0\nu\beta\beta$ decay could be, in principle, distinguished from the light Majorana neutrino exchange by the observation of the single electron spectra. The limits on $\langle \eta \rangle$ and $\langle \lambda \rangle$ are listed in a separate table. The reader is cautioned that a number of earlier experiments did not distinguish between η and λ . In addition, see the section on Majoron searches for additional limits set by these experiments.

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Half-life Measurements and Limits for Double- β Decay

In most cases the transitions (Z,A) \rightarrow (Z+2,A) +2e^- + (0 or 2) $\overline{\nu}_e$ to the 0+ ground state of the final nucleus are listed. However, we also list transitions that increase the nuclear charge (2e+, e+/EC and ECEC) and transitions to excited states of the final nuclei (0 $_i^+$, 2+, and 2 $_i^+$). In the following Listings, only best or comparable limits or lifetimes for each isotope are reported and only those with $T_{1/2} > 10^{20}$ years that are relevant for particle physics. For 2ν decay, which is well established, only measured half-lives are reported.

| t _{1/2} (10 ²¹ yr) | CL% ISOTOPE | TRANSITION | METHOD | DOCUMENT ID | |
|------------------------------------------------------|----------------|---------------------|----------------------|----------------------------------------------|----------|
| • • • We do not us | e the followir | ng data for average | es, fits, limits, | , etc. • • • | |
| $2.11 \pm 0.04 \pm 0.21$ 0 $0.7 \pm 0.09 \pm 0.11$ 0 | | | EX O-200 NE M O-3 | ¹ ACKERMAN ² ARNOLD | 11 11 |

Lepton Particle Listings Double- β Decay

| > 130 | 90 | $^{130}\mathrm{Te}$ | 0ν | | NEMO-3 | 3 | ARNOLD | 11 |
|-----------------------------------------------------------------------------------------------------------------------------|-----------|----------------------------------------|-------------------------|---------------------------------------|--------------------------------------------------------------------------------|-----|------------------------|------------|
| > 1.3 | 90 | $^{112}\mathrm{Sn}$ | 0ν | $0^+ \rightarrow 0_3^+$ | γ Ge det. | 4 | BARABASH | 11 |
| > 0.69 | 90 | $112\mathrm{Sn}$ | 0ν | $0^+ \rightarrow 0^+_2$ | γ Ge det. | 5 | BARABASH | 11 |
| > 1.3 | 90 | $^{112}\mathrm{Sn}$ | 0ν | $0^+ \rightarrow 0_1^+$ | γ Ge det. | 6 | BARABASH | 11 |
| > 1.06 | 90 | 112 _{Sn} | 0ν | 1 | γ Ge det. | 7 | BARABASH | 11 |
| $(2.8 \pm 0.1 \pm 0.3)$ E | -2 | $^{116}\mathrm{Cd}$ | 2ν | | NEMO-3 | 8 | BARABASH | 11A |
| $(4.4^{+0.5}_{-0.4}\pm0.4)$ E- | 2 | ⁴⁸ Ca | 2ν | | NEMO-3 9 | ,10 | BARABASH | 11A |
| (69 ± 9 ± 10)E-2 | | $^{130}\mathrm{Te}$ | 2ν | | NEMO-3 10 | ,11 | BARABASH | 11A |
| >1100 | 90 | $^{100}\mathrm{Mo}$ | 0ν | | NEMO-3 10 | ,12 | BARABASH | 11A |
| >360 | 90 | ⁸² Se | 0ν | | NEMO-3 ¹⁰ | ,13 | BARABASH | 11A |
| >100 | 90 | ¹³⁰ Te | 0ν | | | | BARABASH | 11a |
| >16 | 90 | 116 _{Cd} | 0ν | | | | BARABASH | 11A |
| >13 | 90 | ⁴⁸ Ca | 0ν | | | | BARABASH | 11A |
| > 0.32 | 90 | ⁶⁴ Zn ⁶⁴ Zn | 0ν | ECEC,g.s. | ZnWO ₄ scint. | | BELLI | 110 |
| > 0.85 | 90 | 106 _{Cd} | 0ν | β LC,g.s. $0^+ \rightarrow 4^+$ | ZnWO ₄ scint. | | BELLI RUKHADZE | 110 |
| > 0.11 (2.35 \pm 0.14 \pm 0.1 | 90 6)E | | 0ν 2ν | 0 ' → 4 ' | TGV2 det. NEMO-3 | | ARGYRIADES | 11 |
| $(2.35 \pm 0.14 \pm 0.1$ > 9.2 | 90 90 | ² Zr | 2ν 0ν | | NEMO-3 | | ARGYRIADES | |
| > 0.22 | 90 | 96 Zr | 0ν | $0^+ \rightarrow 0_1^+$ | NEMO-3 | | ARGYRIADES | |
| $0.69^{+0.10}_{-0.08} \pm 0.07$ | | 100 Mo | | $0^{+} \rightarrow 0_{1}^{+}$ | Ge coinc. | | BELLI | 10 |
| > 18.0 | 90 | 150 Nd | 0ν | $0 \cdot \rightarrow 0_1$ | NEMO-3 | | ARGYRIADES | |
| $(9.11^{+0.25}_{-0.22} \pm 0.63)$ | | 150 Nd | 2ν | | NEMO-3 | | ARGYRIADES | |
| > 0.43 | 90 | ⁶⁴ Zn | 0ν | β^+ EC | ZnW0 ₄ scint. | | BELLI | 09A |
| > 0.11 | 90 | 64 Zn 100 Ma | 0ν $2\nu+0\nu$ | ECEC | ZnW0 ₄ scint. Ge coincidence | | BELLI KIDD | 09A 09 |
| $0.55 + 0.12 \\ -0.09 \\ > 3000$ | 90 | 130 Te | 0ν | $0^+ \to 0_1^+$ | TeO ₂ bolometer | | ARNABOLDI | 08 |
| > 0.22 | 90 | 64 Zn | 0ν | | ZnWO ₄ scint. | 29 | BELLI | 08 |
| > 1.1 | 90 | ¹¹⁴ Cd ⁴⁸ Ca | 0ν | $\beta\beta$ | CdWO ₄ scint | 30 | BELLI | 08B |
| $>$ 58 $0.57^{+0.13}_{-0.09}\pm0.08$ | 90 68 | 100 Mo | 0ν | $0^+ \rightarrow 0_1^+$ | CaF ₂ scint. NEMO-3 | | UMEHARA ARNOLD | 08 07 |
| > 89 | 90 | 100 Mo | 0ν | $0^{+} \rightarrow 0_{1}^{+}$ | NEMO-3 | | ARNOLD | 07 |
| > 160 | 90 | 100 _{Mo} | 0ν | $0^+ \rightarrow 2^+$ | NEMO-3 | 34 | ARNOLD | 07 |
| > 0.0019 | 90 | ⁷⁴ Se | $0\nu+2\nu$ | | γ in $Ge \ det$ | 35 | BARABASH | 07 |
| > 0.0055 $22300 + 4400$ -3100 | 90 68 | ⁷⁴ Se ⁷⁶ Ge | $0\nu+2\nu$ 0ν | $0^+ \rightarrow 2_2^+$ | γ in Ge det. Enriched HPGe | | BARABASH KLAPDOR-K | 07 .06a |
| > 1800 | 90 | 130 _{Te} | 01/ | | Cryog. det. | 38 | ARNABOLDI | . 0 0 A |
| > 460 | 90 | 100 Mo | 0ν | | NEMO-3 | 39 | ARNOLD | 05A |
| > 100 (7.11 \pm 0.02 \pm 0.5 | 90 4)E | 82Se 2100 Ma | 0ν | | NEMO-3 NEMO-3 | 41 | ARNOLD ARNOLD | 05A 05A |
| $(9.6 \pm 0.3 \pm 1.0)$ E | | ⁸² Se | 2ν | | NEMO-3 | | ARNOLD | 05A |
| > 140 | 90 | 82 _{Se} | 0ν | | NEMO-3 | 43 | ARNOLD | 04 |
| $\begin{array}{l} (7.68 \pm 0.02 \pm 0.5 \\ 0.14 {}^{+ 0.04}_{- 0.02} \pm 0.03 \end{array}$ | 4)E-: | 150 Mo | 2ν | $0^+ \rightarrow 0_1^+$ | NEMO-3 γ in Ge det. | | ARNOLD BARABASH | 04 04 |
| > 31 | 90 | 130 _{Te} | 0ν 2ν | $0^+ \rightarrow 2^+$ | Cryog. det. | | ARNABOLDI | 03 |
| $0.61 \pm 0.14 ^{+\ 0.29}_{-\ 0.35}$ | 90 | ¹³⁰ Te | 2ν | | Cryog. det. | 47 | ARNABOLDI | 03 |
| > 110 | 90 | 128 Te | 0ν | | Cryog det. | | ARNABOLDI | 03 |
| $(0.029^{+0.004}_{-0.003})$ > 170 | 90 | ¹¹⁶ Cd ¹¹⁶ Cd | 2ν 0ν | | 116 _{CdWO₄} scint 116 _{CdWO₄} scint | 50 | DANEVICH | 03 03 |
| > 170 > 29 | 90 | 116 Cd | 0ν | $0^+ \rightarrow 2^+$ | 116 CdWO ₄ scint | 51 | DANEVICH | 03 |
| > 14 | 90 | 116 _{Cd} | 0ν | $0^+ \rightarrow 0_1^+$ | 116CdWO ₄ scint | | | 03 |
| > 6 | 90 | 116 Cd | 0ν | $0^+ \rightarrow 0_2^+$ | 116CdWO ₄ scint | | | 03 |
| > 1.1 > 1.1 | 90 90 | 186 _W | 0ν 0ν | $0^{+} \rightarrow 2^{+}$ | CdWO ₄ scint. CdWO ₄ scint. | | DANEVICH DANEVICH | 03 03 |
| $1.74 \pm 0.01 + 0.18 \\ -0.16$ | 50 | 76 Ge | 2ν | 0 2 | Enriched HPGe | | DOERR | 03 |
| >15700 | 90 | ⁷⁶ Ge | 0ν | | Enriched HPGe | | AALSETH | 02в |
| > 58 | 90 90 | ¹³⁴ Xe ¹³⁶ Xe | 0ν 0ν | | Liquid Xe Scint. | | BERNABEI BERNABEI | 02D |
| > 1200 > 4.9 | 90 | 100 Mo | 0ν | | Liquid Xe Scint. Liq. Ar ioniz. | | ASHITKOV | 01 |
| > 1.3 | 90 | $^{160}\mathrm{Gd}$ | 0ν | | Gd ₂ SiO ₅ ∶Ce | 61 | DANEVICH | 01 |
| > 1.3 | 90 | 160 Gd | 0ν $0\nu+2\nu$ | $0^{+} \rightarrow 2^{+}$ | Gd ₂ SiO ₅ :Ce | | DANEVICH DEBRAECKEL | 01 |
| $0.59^{+0.17}_{-0.11} \pm 0.06$ >19000 | 90 | 76 _{Ge} | $0\nu + 2\nu$ 0ν | $0^+ \rightarrow 0_1^+$ | Ge coinc. Enriched HPGe | | KLAPDOR-K | |
| (9.4 + 3.2)F-3 | 90 | ⁹⁶ Zr | $0\nu + 2\nu$ | | Geochem | 65 | WIESER | 01 |
| $0.042 \begin{array}{c} + 0.033 \\ - 0.013 \\ - 0.003 \end{array}$ | | ⁴⁸ Ca | 2ν | | Ge spectrometer | | BRUDANIN | 00 |
| $\begin{array}{c} 0.042 \begin{array}{c} -0.013 \\ 0.021 \begin{array}{c} +0.008 \\ -0.004 \end{array} \pm 0.0 \end{array}$ | 002 | ⁹⁶ Zr ⁸² Se | 2ν | | NEMO-2 | | ARNOLD | 99 |
| $(8.3 \pm 1.0 \pm 0.7)$ E > 2.8 | 90 | 82 _{Se} | 2ν 0ν | $0^{+} \rightarrow 2^{+}$ | NEMO-2 NEMO-2 | 69 | ARNOLD ARNOLD | 98 98 |
| $(7.6^{+2.2}_{-1.4})$ E-3 $(6.82^{+0.38}_{-0.53} \pm 0.68$ | | 100 Mo | 2ν | | Si(Li) | 70 | ALSTON | 97 |
| $(6.82 + 0.38 \pm 0.68)$ |)E-3 | 100 Mo | 2ν | | TPC | | DESILVA | 97 |
| $(6.75 + 0.37 \pm 0.68) $ $(6.75 + 0.37 \pm 0.68)$ |)E-3 | 150 Nd | 2ν | | TPC | 72 | DESILVA | 97 |
| $(3.75 \pm 0.35 \pm 0.2)$ | 1)E- | 2 _{11ρ} Cd | 2ν | $0^+ \rightarrow 0^+$ | NEMO 2 | 13 | ARNOLD | 96 |

| $0.043^{+0.024}_{-0.011}\pm0.014$ | ⁴⁸ Ca | 2ν | | TPC | ⁷⁴ BALYSH | 96 |
|-----------------------------------|---------------------|-----------------|-----------------------|------------------|-------------------------|-----|
| 0.79 ± 0.10 | ¹³⁰ Te | $0\nu+2\nu$ | | Geochem | ⁷⁵ TAKAOKA | 96 |
| $0.61 + 0.18 \\ -0.11$ | ¹⁰⁰ Mo | $0\nu\!+\!2\nu$ | $0^+ \to 0_1^+$ | γ in HPGe | ⁷⁶ BARABASH | 95 |
| 0.026 + 0.009 | $^{116}\mathrm{Cd}$ | 2ν | | ELEGANT IV | EJIRI | 95 |
| $0.017 + 0.010 \pm 0.0035$ | $^{150}\mathrm{Nd}$ | 2ν | $0^+ \rightarrow 0^+$ | TPC | ARTEMEV | 93 |
| 0.039 ± 0.009 | ⁹⁶ Zr | $0\nu+2\nu$ | | Geochem | KAWASHIMA | 93 |
| 2.7 ± 0.1 | ¹³⁰ Те | $0\nu+2\nu$ | | Geochem | BERNAT OW | 92 |
| 7200 ± 400 | ¹²⁸ Te | $0\nu+2\nu$ | | Geochem | 77 BERNATOW | 92 |
| $0.108 + 0.026 \\ -0.006$ | ⁸² Se | 2ν | $0^+ \rightarrow 0^+$ | TPC | ELLIOTT | 92 |
| 2.0 ± 0.6 | 238 _U | $0\nu+2\nu$ | | Radiochem | ⁷⁸ TURKEVICH | 91 |
| $0.12\pm0.01\pm0.0468$ | ⁸² Se | $_{0\nu+2\nu}$ | | Geochem. | ⁷⁹ LIN | 88 |
| $0.75\pm0.03\pm0.2368$ | 130 Te | $0\nu+2\nu$ | | Geochem. | ⁸⁰ LIN | 88 |
| 1800 ± 700 68 | ¹²⁸ Te | $0\nu+2\nu$ | | Geochem. | ⁸¹ LIN | 88B |
| 2.60 ± 0.28 | ¹³⁰ Te | $0\nu+2\nu$ | | Geochem | ⁸² KIRSTEN | 83 |
| 1.000 | = | | | | 136 | |

- 1 ACKERMAN 11 use the EXO-200 liquid Xe TPC filled with \sim 175 kg of enriched 136 Xe to determine the 2ν halflife of 136 Xe. 2 ARNOLD 11 use enriched 130 Te in the NEMO-3 detector to measure the 2ν $\beta\beta$ decay rate. This result is in agreement with, but more accurate than ARNABOLDI 03.
- 3 ARNOLD 11 use the NEMO-3 detector to obtain a limit for the 0 ν $\beta\beta$ decay.This result is less significant than ARNABOLDI 05.
- 4 BARABASH 11 use 100 g of enriched 112 Sn to determine a limit for the ECEC 0
 u decay to the 0 $^+_2$ state of $^{112}{
 m Cd}$ by searching for the de-excitation γ with a Ge detector. This decay mode is a candidate for resonant rate enhancement.
- 5 BARABASH 11 use 100 g of enriched 112 Sn to determine a limit for the ECEC 0
 u decay to the 0 $_2^+$ state of $^{112}{\rm Cd}$ by searching for the de-excitation γ with a Ge detector.
- 6 BARABASH 11 use 100 g of enriched 112 Sn to determine a limit for the ECEC 0ν decay to the 0 $^+_{\rm 1}$ state of $^{112}{\rm Cd}$ by searching for the de-excitation γ with a Ge detector.
- 7 BARABASH 11 use 100 g of enriched $^{112}{\rm Sn}$ to determine a limit for the ECEC 0 ν decay to the ground state of $^{112}{\rm Cd}$ by searching for the de-excitation γ with a Ge detector. § Supersedes DANEVICH 03 and ARNOLD 96.
- ⁹ Supersedes BRUDANIN 00 and BALYSH 96.
- 10 BARABASH 11A use the NEMO-3 detector to measure etaeta 2u rates and place limits on etaeta 0
 u half lives for various nuclides.
- 11 Supersedes ARNABOLDI 03.
- 12 Supersedes ARNOLD 05A, ARNOLD 04, ASHITKOV 01, EJIRI 01, and DASSIE 95.
- 13 Supersedes ARNOLD 05A, ARNOLD 04, ARNOLD 98, and ELLIOTT 92.
- 14 Less restrictive than ARNABOLDI 08. 15 Less restrictive than DANEVICH 03.
- 16 Less restrictive than UMEHARA 08 and OGAWA 04. 17 BELLI 11D use ZnWO $_4$ scintillator calorimeters to search for various $\beta\beta$ decay modes of 64 Zn, 70 Zn, 180 W, and 186 W.
- 18 RUKHADZE 11 uses 13.6 g of enriched ¹⁰⁶Cd to search for the neutrinoless ECEC decay into an excited state of ^{106}Pd and its characteristic $\gamma\text{-radiation}$ using the TGV2 detector. This decay mode is a candidate for resonant rate enhancement, however, hindered by the large spin difference.
- the large spin ourseence. 19 ARGYRIADES 10 use 9.4 \pm 0.2 g of 96 Zr in NEMO-3 detector and identify its $2\nu\beta\beta$ decay. The result is in agreement and supersedes ARNOLD 99. 20 ARGYRIADES 10 use 9.4 \pm 0.2 g of 96 Zr in NEMO-3 detector and obtain a limit of the $0\nu\beta\beta$ decay. The result is in agreement and supersedes ARNOLD 99.
- $^{21}\text{ARGYRIADES}\,10$ use 9.4 $\pm\,0.2$ g of ^{96}Zr in NEMO-3 detector and obtain a limit of the 0
 uetaeta decay into the first excited 0^+_1 state in $^{96}\,\mathrm{Mo}.$
- 22 BELLI 10 use enriched 100 Mo with 4 HP Ge detectors to record the 590.8 and 539.5 keV γ rays from the decay of the 0_1^+ state in 100 Ru both in singles and coincidences. This result confirms the measurement of KIDD 09 and ARNOLD 07 and supersedes them.
- 23 ARGYRIADES 09 use the NEMO-3 tracking calorimeter containing 36.5 g of 150 Nd, a total exposure of 924.7 days, to derive a limit for the $0\nu\beta\beta$ half-life. Supersedes DESILVA 97.
- 24 ARGYRIADES 09 use the NEMO-3 tracking calorimeter containing 36.5 g of 150 Nd, a total exposure of 924.7 days, to determine the value of the $2\nu\beta\beta$ half-life. This result is in marginal agreement, but has somewhat smaller error bars, than DESILVA 97.
- 25 BELLI 09A use ZnWO₄ scintillating crystals to search for various modes of $\beta\beta$ decay. This work improves the limits for different modes of 64 Zn decay into the ground state of 64 Ni, in this case for the 0ν β^+ EC mode. Supersedes BELLI 08.
- 26 BELLI 09A use ZnWO $_4$ scintillating crystals to search for various modes of etaeta decay. This work improves the limits for different modes of ⁶⁴ Zn decay into the ground state of 64 Ni, in this case for the 0ν ECEC mode. Supersedes BELLI 08.
- $^{27}\,\mathrm{KIDD}$ 09 combine past and new data with an improved coincidence detection efficiency determination. The result agrees with ARNOLD 95. Supersedes DEBRAECKELEER 01 and BARABASH 95.
- $^{28} \mathrm{ARNABOLDI}$ 08 use high resolution TeO_2 bolometer calorimeter to search for double beta decay of ¹³⁰Te. Supersedes ARNABOLDI 05.
- 29 BELLI 08 use ZnWO $_4$ scintillation calorimeter to search for neutrinoless eta^+ plus electron capture decay of 64 Zn. The halflife limit for the 2ν mode is 2.1×10^{20} years.
- 30 BELLI 08B use CdWO $_4$ scintillation calorimeter to search for 0u etaeta decay of 114 Cd.
- $^{31}\,\mathrm{UMEHARA}$ 08 use CaF_2 scintillation calorimeter to search for double beta decay of 48 Ca. Limit is significantly more stringent than quoted sensitivity: 18×10^{21} years.
- 32 First exclusive measurement of 2ν -decay to the first excited 0^+_1 -state of daughter nucleus. ARNOLD 07 use the NEMO-3 tracking calorimeter to detect all particles emitted in decay. Result agrees with the inclusive $(0\nu+2\nu)$ measurement of DEBRAECKELEER 01.
- 33 Limit on 0ν -decay to the first excited 0_1^+ -state of daughter nucleus using NEMO-3 tracking calorimeter. Supersedes DASSIE 95.

Double- β Decay

- 34 Limit on 0
 u-decay to the first excited 2^+ -state of daughter nucleus using NEMO-3 tracking calorimeter.
- 35 BARABASH 07 use Ge calorimeter to search for γ -radiation following double electron capture or β^+ plus electron capture decays of 74 Se to the ground state of 74 Ge. This limit is based on the search for the 511 keV annihilation radiation. Various other limits, for the capture from different atomic shells and also to the excited states, are reported
- 36 BARABASH 07 use Ge calorimeter to search for $\gamma-$ radiation following double electron capture decay of 74 Se into the second excited 2+-state of 74 Ge. That transition has been considered due to a possible resonance enhancement. The 2ν mode would be suppressed for this decay by its extremely small phase space factor.
- 37 KLAPDOR-KLEINGROTHAUS 06A present re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim improved 6σ statistical evidence for observation of 0ν -decay, compared to 4.2 σ in KLAPDOR-KLEINGROTHAUS 04A. Analysis of the systematic uncertainty is not presented. Supersedes KLAPDOR-KLEINGROTHAUS 04A.
- 38 Supersedes ARNABOLDI 04. Bolometric TeO $_2$ detector array CUORICINO is used for high resolution search for $0\nu\beta\beta$ decay. The half-life limit is derived from 3.09 kg yr ¹³⁰Te exposure.
- 39 NEMO-3 tracking calorimeter containing 6.9 kg of enriched 100 Mo is used in ARNOLD 05A. A limit for $0\nu\beta\beta$ half-life of 100 Mo is reported. Supersedes ARNOLD 04.
- 40 NEMO-3 tracking calorimeter is used in ARNOLD 05A to place limit on 0
 uetaeta half-life of 82 Se. Detector contains 0.93 kg of enriched 82 Se. Supersedes ARNOLD 04.
- 41 ARNOLD 05A use the NEMO-3 tracking calorimeter to determine the 2
 uetaeta half-life of $100\,\mathrm{Mo}$ with high statistics and low background (389 days of data taking). Supersedes
- $^{42} \, \mathrm{AR} \, \mathrm{NOLD}$ 05A use the NEMO-3 tracking detector to determine the $2 \nu \, \beta \, \beta$ half-life of ⁸²Se with high statistics and low background (389 days of data taking). Supersedes ARNOLD 04
- 43 ARNOLD 04 use the NEMO-3 tracking detector to determine the limit for 0
 uetaeta halflife of 82 Se. This represents an improvement, by a factor of \sim 10, when compared with ELLIOTT 92. It supersedes the limit of ARNOLD 98 for this decay using NEMO-2.
- 44 ARNOLD 04 use the NEMO-3 tracking detector to determine the $2\nu\beta\beta$ halfilfe of 100 Mo with high statistics and low background. The halfilfe is determined assuming the Single State Dominance. It is in agreement with, and more accurate than, previous determinations. Supersedes DASSIE 95 determination of this quantity with NEMO-2.
- 45 BARABASH 04 perform an inclusive measurement of the etaeta decay of 150 Nd into the first excited (0^+_1) state of 150 Sm. Gamma radiation emitted in decay of the excited state is detected.
- $^{
 m 46}\,{\rm Decay}$ into first excited state of daughter nucleus.
- $^{
 m 47}$ Two neutrino decay into ground state. Relatively large error mainly due to uncertainties in background determination. Reported value is shorter than the geochemical measurements of KIRSTEN 83 and BERNATOWICZ 92 but in agreement with LIN 88 and
- 48 Supersedes ALESSANDRELLO 00. Array of TeO $_2$ crystals in high resolution cryogenic calorimeter. Some enriched in 128 Te. Ground state to ground state decay.
- 49 Calorimetric measurement of 2ν ground state decay of 116 Cd using enriched CdWO $_4$ scintillators. Agrees with EJIRI 95 and ARNOLD 96. Supersedes DA NEVICH 00.
- 50 Limit on 0
 u decay of 116 Cd using enriched CdWO $_{A}$ scintillators. DANEVICH 00.
- 51 Limit on 0x decay of 116 Cd into first excited 2^+ state of daughter nucleus using enriched CdWO $_4$ scintillators. Supersedes DANEVICH 00.
- 52 Limit on 0 ν decay of 116 Cd into first excited 0 $^+$ state of daughter nucleus using enriched CdWO $_4$ scintillators. Supersedes DANEVICH 00.
- 53 Limit on 0
 u decay of 116 Cd into second excited 0^+ state of daughter nucleus using enriched CdWO₄ scintillators. Supersedes DANEVICH 00. 54 Limit on the 0ν ground state decay of 186 W using enriched CdWO₄ scintillators.
- 55 Limit on the 0ν decay of 186 W to the first excited 2^+ state of the daughter nucleus using enriched CdWO4 scintillators.
- $^{56}\,\text{Results}$ of the Heidelberg-Moscow experiment (KLAPDOR-KLEINGROTHAUS 01 and GUENTHER 97) are reanalyzed using a new simulation of the complete background spectrum. The $\beta\beta 2\nu$ -decay rate is deduced from a 41.57 kg-y exposure. The result is in agreement and supersedes the above referenced halflives with similar statistical and
- 57 AALSETH 02B limit is based on 117 mol-yr of data using enriched Ge detectors. Background reduction by means of pulse shape analysis is applied to part of the data set. Reported limit is slightly less restrictive than that in KLAPDOR-KLEINGROTHAUS 01 However, it excludes part of the allowed half-life range reported in KLAPDOR-KLEINGROTHAUS 01B for the same nuclide. The analysis has been criticized in KLAPDOR-KLEINGROTHAUS 04B. The criticism was addressed and disputed in ΔAI SETH 04. in AALSETH 04
- 58 BERNABEI 02D report a limit for the 0 ν , 0 $^+$ $\;\to$ 0 $^+$ decay of 134 Xe, present in the source at 17%, by considering the maximum number of events for this mode compatible with the fitted smooth background.
- 59 BERNABEI 02D report a limit for the 0 ν , 0+ \rightarrow 0+ decay of 136 Xe, by considering the maximum number of events for this mode compatible with the fitted smooth background. The quoted sensitivity is 450 \times 10 21 yr. The Feldman and Cousins method is used to obtain the quoted limit.
- 60 ASHITKOV 01 result for 0
 u of 100 Mo is less stringent than EJIRI 01.
- $^{61}\,\mathrm{DA\,NEVICH}$ 01 place limit on 0ν decay of $^{160}\,\mathrm{Gd}$ using $\mathrm{Gd}_2\mathrm{SiO}_5$:Ce crystal scintillators. The limit is more stringent than KOBAYASHI 95
- 62 DANEVICH 01 place limits on 0u decay of 160 Gd into excited 2^+ state of daughter nucleus using $\operatorname{Gd}_2\operatorname{SiO}_5$: Ce crystal scintillators.

- 63 DEBRAECKELEER 01 performed an inclusive measurement of the etaeta decay into the second excited state of the daughter nucleus. A novel coincidence technique counting the de-excitation photons is employed. The result agrees with BARABASH 95.
- 64 KLAPDOR-KLEINGROTHAUS 01 is a continuation of the work published in BAUDIS 99. Isotopically enriched Ge detectors are used in calorimetric measurement. The most stringent bound is derived from the data set in which pulse-shape analysis has been used to reduce background. Exposure time is 35.5 kg y. Supersedes BAUDIS 99 as most stringent
- 65 WIESER 01 reports an inclusive geochemical measurement of 96 Zr $\beta\beta$ half life. Their result agrees within 2σ with ARNOLD 99 but only marginally, within 3σ , with KAWASHIMA 93.
- 66 BRUDANIN 00 determine the 2
 u halflife of 48 Ca. Their value is less accurate than
- 67 ARNOLD 99 measure directly the 2ν decay of Zr for the first time, using the NEMO-2 tracking detector and an isotopically enriched source. The lifetime is more accurate than the geochemical result of KAWASHIMA 93.
- 68 ARNOLD 98 measure the 2ν decay of 82 Se by comparing the spectra in an enriched and natural selenium source using the NEMO-2 tracking detector. The measured half-life is in agreement, perhaps slightly shorter, than ELLIOTT 92.
- 69 ARNOLD 98 determine the limit for 0
 u decay to the excited 2^+ state of 82 Se using the NEMO-2 tracking detector.
- 70 ALSTON-GARNJOST 97 report evidence for 2
 u decay of 100 Mo. This decay has been also observed by EJIRI 91, DASSIE 95, and DESILVA 97.
- 71 DESILVA 97 result for 2ν decay of 100 Mo is in agreement with ALSTON-GARNJOST 97 and DASSIE 95. This measurement has the smallest errors.
- 72 DESILVA 97 result for 2ν decay of 150 Nd is in marginal agreement with ARTEMEV 93. It has smaller errors.
- 73 ARNOLD 96 measure the 2ν decay of 116 Cd. This result is in agreement with EJIRI 95, but has smaller errors. Supersedes ARNOLD 95.
- 74 BALYSH 96 measure the 2ν decay of 48 Ca, using a passive source of enriched 48 Ca in
- 75 TAKAOKA 96 measure the geochemical half-life of 130 Te. Their value is in disagreement with the quoted values of BERNATOWICZ 92 and KIRSTEN 83; but agrees with several other unquoted determinations, e.g., MANUEL 91.
- 76 BARABASH 95 cannot distinguish 0ν and 2ν , but it is inferred indirectly that the 0ν mode accounts for less than 0.026% of their event sample. They also note that their result disagrees with the previous experiment by the NEMO group (BLUM 92).
- $^{77}\,\mathrm{BERNATOWICZ}$ 92 finds $^{128}\mathrm{Te}/^{130}\mathrm{Te}$ activity ratio from slope of $^{128}\mathrm{Xe}/^{132}\mathrm{Xe}$ vs $130\, {\rm Xe}/132\, {\rm Xe}$ ratios during extraction, and normalizes to lead-dated ages for the $130\, {\rm Te}$ lifetime. The authors state that their results imply that "(a) the double beta decay of $^{128}\mathrm{Te}$ has been firmly established and its half-life has been determined ... without any ambiguity due to trapped Xe interferences... (b) Theoretical calculations ... underany ambiguity use to trapped xe interleades... (i) Theoretical calculations... undersection to the property of the property o reevaluated cosmic-ray ¹²⁸Xe production corrections.
- 78 TURKEVICH 91 observes activity in old U sample. The authors compare their results with theoretical calculations. They state "Using the phase-space factors of Boehm and Vogel (BOEHM 87) leads to matrix element values for the 238 U transition in the same range as deduced for 130 Te and 76 Ge. On the other hand, the latest theoretical estimates (STAUDT 90) give an upper limit that is 10 times lower. This large discrepancy implies either a defect in the calculations or the presence of a faster path than the standard two-neutrino mode in this case." See BOEHM 87 and STAUDT 90.
- 79 Result agrees with direct determination of ELLIOTT 92.
- 80 Inclusive half life inferred from mass spectroscopic determination of abundance of etaeta-Inclusive half life inferred from mass spectroscopic determination of abundance of $\beta\beta$ -decay product 130 Te in mineral kitkaite (NiTeSe). Systematic uncertainty reflects variations in U-Xe gas-retention-age derived from different uranite samples. Agrees with geochemical determination of TAKAOKA 96 and direct measurement of ARNABOLDI 03. Inconsistent with results of KIRSTEN 83 and BERNATOWICZ 92.
- Inconsistent with results of KIRSTEN 83 and BERNATOWICZ 92. 81 Ratio of inclusive double beta half lives of 128 Te and 130 Te determined from minerals melonite (NiTe₂) and altaite (PbTe) by means of mass spectroscopic measurement of abundance of $\beta\beta$ -decay products. As gas-retention-age could not be determined the authors use half life of 130 Te (LIN 88) to infer the half life of 128 Te. No estimate of the systematic uncertainty of this method is given. The directly determined half life ratio agrees with BERNATOWICZ 92. However, the inferred 128 Te half life disagrees with RISTEN 83 and REPNATOWICZ 92. KIRSTEN 83 and BERNATOWICZ 92.
- 82 KIRSTEN 83 reports " 2σ " error. References are given to earlier determinations of the 130 Te lifetime

$\langle m_{ u} angle$, The Effective Weighted Sum of Majorana Neutrino Masses Contributing to Neutrinoless Double- $oldsymbol{eta}$ Decay

 $\langle m_{
u}
angle = |\Sigma| U_{1\, i}^2 m_{
u_i}^{}|$, where the sum goes from 1 to n and where n= number of neutrino generations, and u_j is a Majorana neutrino. Note that $U_{e\,j}^2$, not $|U_{e\,j}|^2$, occurs in the sum. The possibility of cancellations has been stressed. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

CL% ISOTOPE TRANSITION METHOD DO CUMENT ID • • • We do not use the following data for averages, fits, limits, etc. • • •

 $90~^{100} Mo~^{0}\nu$ 83 BARABASH 11A < 0.45 - 0.93NEMO-3 90 82 Se 84 BARABASH 11A < 0.89 - 2.43NEMO-3

Lepton Particle Listings Double- β Decay

| < 7.2-19.5 | 90 | ⁹⁶ Zr | 0ν | NEMO-3 | ⁸⁵ ARGYRIADES | 10 |
|-----------------------------|------|--------------------|---------------------------|------------------------------|--------------------------|------|
| < 4.0-6.8 | 90 | 150 Nd | 0ν | NEMO-3 | ⁸⁶ ARGYRIADES | 09 |
| < 0.19-0.68 | 90 | ¹³⁰ Te | 0ν | TeO ₂ bolometer | ⁸⁷ ARNABOLDI | 80 |
| < 3.5-22 | 90 | 48 Ca | 0ν | CaF ₂ scint. | ⁸⁸ UMEHARA | 80 |
| < 9.3-60 | 90 | ¹⁰⁰ Мо | $0^+ \rightarrow 0_1^+$ | NEMO-3 | ⁸⁹ ARNOLD | 07 |
| < 6500 | 90 | ¹⁰⁰ Мо | $0^{+} \rightarrow 2^{+}$ | NEMO-3 | ⁹⁰ ARNOLD | 07 |
| 0.32 ± 0.03 | 68 | ⁷⁶ Ge | 0ν | Enriched HPGe | ⁹¹ KLAPDOR-K | 06A |
| < 0.2-1.1 | 90 | 130Te | | Cryog. det. | ⁹² ARNABOLDI | 05 |
| < 0.7-2.8 | 90 | 100 Mo | 0ν | NEMO-3 | ⁹³ ARNOLD | 05 A |
| < 1.7-4.9 | 90 | 82 Se | 0ν | NEMO-3 | ⁹⁴ ARNOLD | 05 A |
| < 0.37-1.9 | 90 | 130Te | | Cryog. det. | ⁹⁵ ARNABOLDI | 04 |
| < 0.8-1.2 | 90 | ¹⁰⁰ Mo | 0ν | NEMO-3 | ⁹⁶ ARNOLD | 04 |
| < 1.5-3.1 | 90 | 82 Se | 0ν | NEMO-3 | ⁹⁶ ARNOLD | 04 |
| 0.1-0.9 | 99. | 7 ⁷⁶ Ge | | Enriched HP Ge | ⁹⁷ KLAPDOR-K | 04A |
| < 7.2-44.7 | 90 | ⁴⁸ Ca | | CaF ₂ scint. | ⁹⁸ O GAWA | 04 |
| < 1.1-2.6 | 90 | 130 _{Te} | | Cryog. det. | ⁹⁹ ARNABOLDI | 03 |
| < 1.5-1.7 | 90 | 116 _{Cd} | 0ν | $^{116}\text{CdWO}_4$ scint. | ¹⁰⁰ DANEVICH | 03 |
| < 0.33-1.35 | 90 | | | Enriched HPGe | ¹⁰¹ AALSETH | 02в |
| < 2.9 | 90 | ¹³⁶ Xe | 0ν | Liquid Xe Scint. | ¹⁰² BERNABEI | 02D |
| $0.39 {}^{+ 0.17}_{- 0.28}$ | | ⁷⁶ Ge | 0ν | Enriched HPGe | ¹⁰³ KLAPDOR-K | 02D |
| < 2.1-4.8 | 90 | 100 Mo | 0ν | ELEGANT V | ¹⁰⁴ EJIRI | 01 |
| < 0.35 | 90 | ⁷⁶ Ge | | Enriched HPGe | ¹⁰⁵ KLAPDOR-K | 01 |
| <23 | 90 | ⁹⁶ Zr | | NEMO-2 | ¹⁰⁶ ARNOLD | 99 |
| < 1.1-1.5 | | 128 _{Te} | | Geochem | 107 BERNATOW | 92 |
| <5 | 68 | ⁸² Se | | TPC | ¹⁰⁸ ELLIOTT | 92 |
| <8.3 | 76 | ⁴⁸ Ca | 0ν | CaF ₂ scint. | YOU | 91 |
| 83 DADADACII : | 11.1 | | -4 NEMO | 2 4 - 4 - 6 - 100 4 | h | |

- 83 BARABASH 11A limit is based on NEMO-3 data for 100 Mo. The reported range reflects different nuclear matrix elements. Supersedes ARNOLD 05A and ARNOLD 04
- ⁸⁴BARABASH 11A limit is based on NEMO-3 data for ⁸²Se. The reported range reflects
- different nuclear matrix elements. Supersedes ARNOLD 05A and ARNOLD 04. 85 ARGYRIADES 10 use 96 Zr and the NEMO-3 tracking detector to obtain the reported mass limit. The range reflects the fluctuation of the nuclear matrix elements considered.
- 86 ARGYRIADES 09 limit is based on data taken with the NEMO-3 detector and $^{15\,0}$ Nd. A range of nuclear matrix elements that include the effect of nuclear deformation have
- 87 Limit was obtained using high resolution ${
 m TeO_2}$ bolometer calorimeter to search for double beta decay of ¹³⁰Te. Reported range of limits reflects spread of matrix element calculations used. Supersedes ARNABOLDI 05.
- 88 Limit was obtained using CaF $_2$ scintillation calorimeter to search for double beta decay of ⁴⁸Ca. Reported range of limits reflects spread of QRPA and SM matrix element calculations used. Supersedes OGAWA 04.
- 89 ARNOLD 07 use NEMO-3 half life limit for 0ν -decay of 100 Mo to the first excited 0^+_1 state of daughter nucleus to obtain neutrino mass limit. The spread reflects the choice of two different nuclear matrix elements. This limit is not competitive when compared to the decay to the ground state.
- 90 ARNOLD 07 use NEMO-3 half life limit for 0 ν -decay of 100 Mo to the first excited 2 $^+$ -state of daughter nucleus to obtain neutrino mass limit. This limit is not competitive when compared to the decay to the ground state.
- 91 Re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim 6σ statistical evidence for observation of 0
 u-decay. Authors use matrix element of STAUDT 90. Uncertainty of nuclear matrix element is not reflected in stated error. Supersedes KLAPDOR-KLEINGROTHAUS 04A.
- 92 Supersedes ARNABOLDI 04. Reported range of limits due to use of different nuclear matrix element calculations
- 93 Mass limits reported in ARNOLD 05A are derived from 100 Mo data, obtained by the NEMO-3 collaboration. The range reflects the spread of matrix element calculations considered in this work. Supersedes ARNOLD 04.
- 94 Neutrino mass limits based on 82 Se data utilizing the NEMO-3 detector. The range reported in ARNOLD 05A reflects the spread of matrix element calculations considered in this work. Supersedes ARNOLD 04.
- 95 Supersedes ARNABOLDI 03. Reported range of limits due to use of different nuclear matrix element calculations.
- 96 ARNOLD 04 limit is based on the nuclear matrix elements of SIMKOVIC 99, STOICA 01 and CIVITARESE 03.
- 97 Supersedes KLAPDOR-KLEINGROTHAUS 02D. Event excess at ββ-decay energy is used to derive Majorana neutrino mass using the nuclear matrix elements of STAUDT 90. The mass range shown is based on the authors evaluation of the uncertainties of the decay of the state of the st STAUDT 90 matrix element calculation. If this uncertainty is neglected, and only statistical errors are considered, the range in $\langle m \rangle$ becomes (0.2–0.6) eV at the 3 σ level.
- 98 Calorimetric CaF $_2$ scintillator. Range of limits reflects authors' estimate of the uncertainty of the nuclear matrix elements. Replaces YOU 91 as the most stringest limit based
- 99 Supersedes ALESSANDRELLO 00. Cryogenic calorimeter search. Reported a range reflecting uncertainty in nuclear matrix element calculations.
- 100 Limit for $\langle m_p \rangle$ is based on the nuclear matrix elements of STAUDT 90 and ARNOLD 96. Supersedes DANEVICH 00.
- 101 AALSETH 02B reported range of limits on $\langle m_{\nu} \rangle$ reflects the spread of theoretical nuclear matrix elements. Excludes part of allowed mass range reported in KLAPDOR-KLEINGROTHAUS 01B.
- $102\, {\rm BERNABEI}$ 020 limit is based on the matrix elements of SIMKOVIC 02. The range of neutrino masses based on a variety of matrix elements is 1.1–2.9 eV.

- $^{103}\,\text{KLAPDOR-KLEINGROTHAUS}$ 02D is a detailed description of the analysis of the data collected by the Heidelberg-Moscow experiment, previously presented in KLAPDOR-KLEINGROTHAUS 01B. Matrix elements in STAUDT 90 have been used. See the footnote in the preceding table for further details. See also KLAPDOR-KLEINGROTHAUS 02B.
- 104 The range of the reported $\langle m_{
 u} \rangle$ values reflects the spread of the nuclear matrix elements. On axis value assuming $\langle \lambda \rangle = \langle \eta \rangle = 0$.
- $105~{\rm KLAPDOR\text{-}KLEINGROTHAUS}$ 01 uses the calculation by STAUDT 90. Using several other models in the literature could worsen the limit up to 1.2eV. This is the most stringent experimental bound on m_{ν^+} It supersedes BAUDIS 99B.
- $^{106} \, \mathrm{AR} \, \mathrm{NOLD}$ 99 limit based on the nuclear matrix elements of STAUDT 90.
- $^{107} \mbox{BERNATOWICZ}$ 92 finds these majorana neutrino mass limits assuming that the measured geochemical decay width is a limit on the 0ν decay width. The range is the range found using matrix elements from HAXTON 84, TOMODA 87, and SUHONEN 91. Further details of the experiment are given in BERNATOWICZ 93.
- $^{108}\, extsf{ELLIOTT}$ 92 uses the matrix elements of HAXTON 84.

Limits on Lepton-Number Violating (V+A) Current Admixture

For reasons given in the discussion at the beginning of this section, we list only results from 1989 and later. $\langle \lambda \rangle = \lambda \sum U_{ej} V_{ej}$ and $\langle \eta \rangle = \eta \sum U_{ej} V_{ej}$, where the sum is over the number of neutrino generations. This sum vanishes for massless or unmixed neutrinos. In the following Listings, only best or comparable limits or lifetimes for each isotope are reported.

| $\langle \lambda \rangle (10^{-6})$ | CL% | $\langle \eta \rangle (10^{-8})$ | CL% | <i>ISOTOPE</i> | METHOD | DOCUMENT ID |
|-------------------------------------|-----|----------------------------------|-----|----------------|--------|-------------|

• • • We do not use the following data for averages, fits, limits, etc. • • •

| $\begin{array}{c} <120 & 90 \\ 0.692 + 0.058 & 68 \\ < 2.5 & 90 \\ < 3.8 & 90 \\ < 1.5 - 2.0 & 90 \\ < 3.2 - 3.8 & 90 \\ < 1.6 - 2.4 & 90 \\ < 2.2 & 90 \\ < 3.2 - 4.7 & 90 \\ < 1.1 & 90 \end{array}$ | 0.305 + 0.026 $< 0.9-5.3$ < 2.5 $< 2.4-2.7$ < 0.64 | 90 90 90 90 | 100 Mo 76 Ge 100 Mo 82 Se 100 Mo 82 Se 130 Te 116 Cd 100 Mo 76 Ge | $0^+ \rightarrow 2^+$ Enriched HPGe 0_{ν} , NEMO-3 0_{ν} , NEMO-3 0_{ν} , NEMO-3 0_{ν} , NEMO-3 Cryog. det. $116_{\rm CdWO_4}$ scin ELEGANT V Enriched HPGe | | 07 06A 05A 05A 04 04 03 03 01 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|----------------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-------------------------------------------------------|
| - | - | | | | | |
| < 4.4 90 | <2.3 <5.3 | 90 | 136 _{Xe} 128 _{Te} | TPC Geochem | 119 VUILLEUMIER 120 BERNATOW | 93 |

- 109 ARNOLD 07 use NEMO-3 half life limit for 0
 u-decay of 100 Mo to the first excited $^{2+}$ state of daughter nucleus to limit the right-right handed admixture of weak currents $\langle \lambda \rangle$. This limit is not competitive when compared to the decay to the ground state
- 110 Re-analysis of data originally published in KLAPDOR-KLEINGROTHAUS 04A. Modified pulse shape analysis leads the authors to claim 6σ statistical evidence for observation of 0ν -decay. Authors use matrix element of MUTO 89 to determine $\langle\lambda\rangle$ and $\langle\eta\rangle$. Uncertainty of nuclear matrix element is not reflected in stated errors.
- 111 AR NOLD 05A derive limit for $\langle\lambda
 angle$ based on 100 Mo data collected with NEMO-3 detector. No limit for $\langle \eta \rangle$ is given. Supersedes ARNOLD 04.
- 112 ARNOLD 05A derive limit for $\langle\lambda
 angle$ based on 82 Se data collected with NEMO-3 detector. No limit for $\langle \eta \rangle$ is given. Supersedes ARNOLD 04.
- 113 ARNOLD 04 use the matrix elements of SUHONEN 94 to obtain a limit for $\langle \lambda
 angle$, no limit for $\langle \eta \rangle$ is given. This limit is more stringent than the limit in EJIRI 01 for the same nucleus.
- 114 ARNOLD 04 use the matrix elements of TOMODA 91 and SUHONEN 91 to obtain a limit for $\langle\lambda\rangle$, no limit for $\langle\eta\rangle$ is given.
- $^{115}\,\mathrm{Supersedes}$ ALESSANDRELLO 00. Cryogenic calorimeter search. Reported a range reflecting uncertainty in nuclear matrix element calculations
- 116 Limits for $\langle\lambda\rangle$ and $\langle\eta\rangle$ are based on nuclear matrix elements of STAUDT 90. Supersedes DANEVICH 00.
- 117 The range of the reported $\langle\lambda\rangle$ and $\langle\eta\rangle$ values reflects the spread of the nuclear matrix elements. On axis value assuming $\langle m_{
 u} \rangle = 0$ and $\langle \lambda \rangle = \langle \eta \rangle = 0$, respectively.
- $^{118}\,\mathrm{GUENTHER}$ 97 limits use the matrix elements of STAUDT 90. Supersedes BALYSH 95 and BALYSH 92.
- 119 VUILLEUMIER 93 uses the matrix elements of MUTO 89. Based on a half-life limit 2.6×10^{23} y at 90%CL.
- 120 BERNATOWICZ 92 takes the measured geochemical decay width as a limit on the 0
 uwidth, and uses the SUHONEN 91 coefficients to obtain the least restrictive limit on η . Further details of the experiment are given in BERNATOWICZ 93.

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| RUKHADZE | 11 | NP A852 197 | N.I. Rukhadze et al. | ` (TGV-2 Collab.) |
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| BELLI | 08 | PL B658 193 | P. Belli et al. | (DAMA-INR Collab.) |
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Double- β Decay, Neutrino Mixing

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|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BARABASH 04 KLAPDOR-K 04A KLAPDOR-K 04B OGAWA 04 ARNABOLDI 03 CIVITARESE 03 DANEVICH 03 DOERR 03 | Translated from ZETFP JETPL 79 10 PL B586 198 PR D70 078301 NP A730 215 PL B557 167 NP A729 867 PR C68 035501 NIM A513 596 | |
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| | | |

Neutrino Mixing

With the exception of a few possible anomalies such as LSND, current neutrino data can be described within the framework of a 3×3 mixing matrix between the flavor eigenstates ν_e , ν_μ , and ν_τ and the mass eigenstates ν_1 , ν_2 , and ν_3 . (See Eq. (13.79) of the review "Neutrino Mass, Mixing, and Oscillations" by K. Nakamura and S.T. Petcov.) The Listings are divided into the following sections:

- (A) Neutrino fluxes and event ratios: shows measurements which correspond to various oscillation tests for Accelerator, Reactor, Atmospheric, and Solar neutrino experiments. Typically ratios involve a measurement in a realm sensitive to oscillations compared to one for which no oscillation effect is expected.
- (B) Three neutrino mixing parameters: shows measurements of $\sin^2(2\theta_{12})$, $\sin^2(2\theta_{23})$, Δm_{21}^2 , Δm_{32}^2 , and $\sin^2(2\theta_{13})$

which are all interpretations of data based on the three neutrino mixing scheme described in the review "Neutrino Mass, Mixing, and Oscillations." by K. Nakamura and S.T. Petcov. Many parameters have been calculated in the two-neutrino approximation.

(C) Other neutrino mixing results: shows measurements and limits for the probability of oscillation for experiments which might be relevant to the LSND oscillation claim. Included are experiments which are sensitive to $\nu_{\mu} \rightarrow \nu_{e}$, $\bar{\nu}_{\mu} \rightarrow \bar{\nu}_{e}$, sterile neutrinos, and CPT tests.

(A) Neutrino fluxes and event ratios

Events (observed/expected) from accelerator u_{μ} experiments.

Some neutrino oscillation experiments compare the flux in two or more detectors. This is usually quoted as the ratio of the event rate in the far detector to the expected rate based on an extrapolation from the near detector in the absence of oscillations.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|------------------------|---------------------------|----------------------------------------------------------------------------------|
| • • • We do not use the following | owing data for ave | rages, | fits, lin | nits, etc. • • • |
| $\begin{array}{c} 0.71 \pm 0.08 \\ 0.64 \pm 0.05 \\ 0.71 \stackrel{+}{-} 0.08 \\ 0.70 \stackrel{+}{-} 0.10 \\ 0.70 \stackrel{-}{-} 0.11 \end{array}$ | 1 AHN 2 MICHAEL 3 ALIU 4 AHN | 06 A 06 05 03 | K2K MINS K2K K2K | K2K to Super-K All charged current events KEK to Super-K KEK to Super-K |

- 1 Based on the observation of 112 events when $158.1^{+}_{-8.6}^{9.2}$ were expected without oscillations. Including not only the number of events but also the shape of the energy distribution, the evidence for oscillation is at the level of about 4.3 σ . Supersedes ALIU 05.
- $^2\,\text{This}$ ratio is based on the observation of 215 events compared to an expectation of 336 \pm 14 without oscillations. See also ADAMSON 08.
- $^3{\rm This}$ ratio is based on the observation of 107 events at the far detector 250 km away from KEK, and an expectation of 151 $^{+12}_{-10}$

Events (observed/expected) from reactor $\overline{\nu}_e$ experiments.

The quoted values are the ratios of the measured reactor $\overline{\nu}_e$ event rate at the quoted distances, and the rate expected without oscillations. The expected rate is based on the experimental data for the most significant reactor fuels (235 U, 239 Pu, 241 Pu) and on calculations for 238 U.

A recent re-evaluation of the spectral conversion of electron to $\overline{\nu}_e$ in MUELLER 11 results in an upward shift of the reactor $\overline{\nu}_e$ spectrum by 3% and, thus, might require revisions to the ratios listed in this table.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------------------------|-------|------------|----------------------------------------|
| • • • We do not use the | e following data for | avera | ges, fits, | limits, etc. • • • |
| $0.944 \pm 0.016 \pm 0.040$ | ¹ ABE | 12 | DCHZ | Chooz reactors |
| $0.920 \pm 0.009 \pm 0.014$ | ² AHN | 12 | RENO | Yonggwang reactors |
| $0.940 \pm 0.011 \pm 0.004$ | ³ AN | 12 | DAYA | Daya Bay, Ling Ao, Ling Ao-II reactors |
| $1.08 \pm 0.21 \pm 0.16$ | ⁴ DENIZ | 10 | TEXO | Kuo-Sheng reactor, 28 m |
| $0.658 \pm 0.044 \pm 0.047$ | ⁵ ARAKI | 05 | KLND | Japanese react. ∼ 180 km |
| $0.611 \pm 0.085 \pm 0.041$ | ⁶ EGUCHI | 03 | KLND | Japanese react. ~ 180 km |
| $1.01\ \pm0.024\pm0.053$ | ⁷ ВОЕНМ | 01 | | Palo Verde react. 0.75-0.89 km |
| $1.01 \pm 0.028 \pm 0.027$ | ⁸ APOLLONIO | 99 | CHOZ | Chooz reactors 1 km |
| $0.987 \pm 0.006 \pm 0.037$ | ⁹ GREENWOOD | 96 | | Savannah River, 18.2 m |
| $0.988 \pm 0.004 \pm 0.05$ | ACHKAR | 95 | CNTR | Bugey reactor, 15 m |
| $0.994 \pm 0.010 \pm 0.05$ | ACHKAR | 95 | CNTR | Bugey reactor, 40 m |
| $0.915 \pm 0.132 \pm 0.05$ | ACHKAR | 95 | CNTR | Bugey reactor, 95 m |
| $0.987 \pm 0.014 \pm 0.027$ | ¹⁰ DECLAIS | 94 | CNTR | Bugey reactor, 15 m |
| $0.985 \pm 0.018 \pm 0.034$ | KUVSHINN | 91 | CNTR | Rovno reactor |
| $1.05 \pm 0.02 \pm 0.05$ | VUILLEUMIER | 82 | | Gösgen reactor |
| $0.955 \pm 0.035 \pm 0.110$ | ¹¹ KWON | 81 | | $\overline{\nu}_e p \rightarrow e^+ n$ |
| $0.89\ \pm0.15$ | ¹¹ ВОЕНМ | 80 | | $\overline{\nu}_e p \rightarrow e^+ n$ |

- 1 ABE 12 determine the $\overline{\nu}_e$ interaction rate in a single detector, located 1050 m from the cores of two reactors. The rate normalization is fixed by the results of the Bugey4 reactor experiment, thus avoiding any dependence on possible very short baseline oscillations.
- ² AHN 12 use two identical detectors, placed at flux weighted distances of 408.56 m and 1433.99m from six reactor cores, to determine the $\overline{\nu}_e$ interaction rate ratio.
- 3 AN 12 use six identical detectors with three placed near the reactor cores (flux-weighted baselines of 470 m and 576 m) and the remaining three at the far hall (at the flux averaged distance of 1648 m from all six reactor cores) to determine the $\overline{\nu}_e$ interaction rate ratios.

⁴ This ratio is based on the observation of 56 events with an expectation of $80.1^{+6.2}_{-5.4}$

Lepton Particle Listings Neutrino Mixing

- 4 DENIZ 10 observe reactor $\overline{\nu}_e\,e$ scattering with recoil kinetic energies 3–8 MeV using CsI(TI) detectors. The observed rate is consistent with the Standard Model prediction, leading to a constraint on $\sin^2\!\theta_{W}=0.251\pm0.031 ({\rm stat})\pm0.024 ({\rm sys})$.
- ⁵ Updated result of KamLAND, including the data used in EGUCHI 03. Note that the survival probabilities for different periods are not directly comparable because the effective baseline varies with power output of the reactor sources involved, and there were large variations in the reactor power production in Japan in 2003.
- $^6\,{\sf EGUCHI}$ 03 observe reactor neutrino disappearance at \sim 180 km baseline to various Japanese nuclear power reactors.
- $^{7}\,\mathrm{BOEHM}$ 01 search for neutrino oscillations at 0.75 and 0.89 km distance from the Palo Verde reactors.
- 8 APOLLONIO 99, APOLLONIO 98 search for neutrino oscillations at 1.1 km fixed dis-APOLLONIO 99, APOLLONIO 98 search for heatring oscillations at 1.1 km liked ulstrance from Chooz reactors. They use $\overline{\sigma}_e p - e^+ n$ in Gd-loaded scintillator taget APOLLONIO 99 supersedes APOLLONIO 98. See also APOLLONIO 03 for detailed description.
- $^{9}\, {\sf GREENWOOD}$ 96 search for neutrino oscillations at 18 m and 24 m from the reactor at Savannah River.
- 10 DECLAIS 94 result based on integral measurement of neutrons only. Result is ratio of measured cross section to that expected in standard $\it V\!-\!A$ theory. Replaced by ACHKAR 95.
- $^{
 m 11}\,{
 m KWON}$ 81 represents an analysis of a larger set of data from the same experiment as BOEHM 80.

– Atmospheric neutrinos –

Neutrinos and antineutrinos produced in the atmosphere induce μ -like and e-like events in underground detectors. The ratio of the numbers of the two kinds of events is defined as μ/e . It has the advantage that systematic effects, such as flux uncertainty, tend to cancel, for both experimental and theoretical values of the ratio. The "ratio of the ratios" of experimental to theoretical μ/e , $R(\mu/e)$, or that of experimental to theoretical μ/total , $R(\mu/{
m total})$ with ${
m total}=\mu+e$, is reported below. If the actual value is not unity, the value obtained in a given experiment may depend on the experimental conditions. In addition, the measured "up-down asymmetry" for μ $(N_{up}(\mu)/N_{down}(\mu))$ or e $(N_{up}(e)/N_{down}(e))$ is reported. The expected "up-down asymmetry" is nearly unity if there is no neutrino

$R(\mu/e) = (Measured Ratio <math>\mu/e) / (Expected Ratio <math>\mu/e)$

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------------------|---------------------------------------------|-----------|-----------|-----------------------------------------|--|
| • • • We do not use the follow | ving data for average | s, fits | , limits, | etc. • • • | |
| $0.658 \pm 0.016 \pm 0.035$ | ¹ ASHIE | 05 | SKAM | sub-GeV | |
| $0.702 + 0.032 \pm 0.101$ | ² ASHIE | 05 | SKAM | multi-GeV | |
| $0.69 \pm 0.10 \pm 0.06$ | ³ SANCHEZ ⁴ FUKUDA | 03 96в | | Calorimeter raw data Water Cherenkov | |
| $1.00 \pm 0.15 \pm 0.08$ | ⁵ DAUM | 95 | FREJ | Calorimeter | |
| $0.60 \ ^{+ 0.06}_{- 0.05} \ \pm 0.05$ | ⁶ FUKUDA | 94 | KAMI | sub-GeV | |
| $0.57 {}^{+ 0.08}_{- 0.07} \pm 0.07$ | ⁷ FUKUDA | 94 | KAMI | multi-Gev | |
| | 8 BECKER-S7 | 92B | LMB | Water Cherenkov | |

- $^{
 m 1}$ ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring e-like events with 0.1 GeV/c < p_e and μ -like events 0.2 GeV/c < p_{μ} . both having a visible energy < 1.33 GeV. These criteria match the definition used by FUKUDA 94.
- 2 ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring events with visible energy >1.33 GeV and partially-contained events. All partially-contained events are classified as $\mu\text{-like}.$
- $^3\, {\sf SANCHEZ}$ 03 result is based on an exposure of 5.9 kton yr, and updates ALLISON 99 result. The analyzed data sample consists of fully-contained e-flavor and μ -flavor events having lepton momentum > 0.3 GeV/c.
- $^4\,{\sf FUKUDA}$ 96B studied neutron background in the atmospheric neutrino sample observed in the Kamiokande detector. No evidence for the background contamination was found.
- 5 DAUM 95 results are based on an exposure of 2.0 kton yr which includes the data used by BERGER 90B. This ratio is for the contained and semicontained events. DAUM 95 also report $R(\mu/e)=0.99\pm0.13\pm0.08$ for the total neutrino induced data sample which includes upward going stopping muons and horizontal muons in addition to the contained and semicontained events.
- $^6\,\text{FUKUDA}$ 94 result is based on an exposure of 7.7 kton yr and updates the HIRATA 92 result. The analyzed data sample consists of fully-contained e-like events with 0.1 < $ho_e <$ 1.33 GeV/c and fully-contained μ -like events with 0.2 < $ho_{\mu} <$ 1.5 GeV/c.
- 7 FUKUDA 94 analyzed the data sample consisting of fully contained events with visible energy > 1.33 GeV and partially contained μ -like events.
- 8 BECKER-SZENDY 92B reports the fraction of nonshowering events (mostly muons from atmospheric neutrinos) as $0.36\pm0.02\pm0.02$, as compared with expected fraction $0.51\pm0.01\pm0.05$. After cutting the energy range to the Kamiokande limits, BEIER 92 finds $R(\mu/e)$ very close to the Kamiokande value.

$R(\nu_{\mu}) = (Measured Flux of \nu_{\mu}) / (Expected Flux of \nu_{\mu})$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|-----------------------|-------|------------|-----------------------------------------------------|
| • • • We do not use the | following data for | avera | ges, fits, | limits, etc. • • • |
| 0.84 ± 0.12 | ¹ ADA MSON | 06 | MINS | MINOS atmospheric |
| $0.72 \pm 0.026 \pm 0.13$ | ² ambrosio | 01 | MCRO | upward through-going |
| $0.57 \pm 0.05 \pm 0.15$ | ³ AMBROSIO | 00 | MCRO | upgoing partially contained |
| $0.71 \pm 0.05 \pm 0.19$ | ⁴ AMBROSIO | 00 | MCRO | downgoing partially contained + upgoing stopping |
| $0.74 \pm 0.036 \pm 0.046$ | ⁵ AMBROSIO | 98 | MCRO | Streamer tubes |
| | ⁶ CASPER | 91 | IMB | Water Cherenkov |
| | ⁷ AGLIETTA | 89 | NUSX | |
| 0.95 ± 0.22 | ⁸ BOLIEV | 81 | | Baksan |
| 0.62 ± 0.17 | CROUCH | 78 | | Case Western/UCI |

- $^1\,\text{ADAMSON}$ 06 uses a measurement of 107 total neutrinos compared to an expected rate of 127 \pm 13 without oscillations.
- 2 AMBROSIO 01 result is based on the upward through-going muon tracks with $E_{\mu}>1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration, is 6.17 years. The first error is the statistical error, the second is the systematic error, dominated by the theoretical error in the predicted flux.
- ³ AMBROSIO 00 result is based on the upgoing partially contained event sample. It came from 4.1 live years of data taking with the full detector, from April 1994 to February 1999. The average energy of atmospheric muon neutrinos corresponding to this sample is 4 GeV. The first error is statistical, the second is the systematic error, dominated by the 25% theoretical error in the rate (20% in the flux and 15% in the cross section, added in the control of the control in quadrature). Within statistics, the observed deficit is uniform over the zenith angle.
- A MBROSIO 00 result is based on the combined samples of downgoing partially contained events and upgoing stopping events. These two subsamples could not be distinguished due to the lack of timing information. The result came from 4.1 live years of data taking with the full detector, from April 1994 to February 1999. The average energy of atmospheric muon neutrinos corresponding to this sample is 4 GeV. The first error is statistical, the second is the systematic error, dominated by the 25% theoretical error in the rate (20% in the flux and 15% in the cross section, added in quadrature). Within statistics, the observed deficit is uniform over the zenith angle.
- $^{5}\,\mathrm{AMBROSIO}$ 98 result is for all nadir angles and updates AHLEN 95 result. The lower AMBROSIO 98 result is for all hadir angles and updates AHLEN 95 result. The lower cutoff on the muon energy is 1 GeV. In addition to the statistical and systematic errors, there is a Monte Carlo flux error (theoretical error) of ± 0.13 . With a neutrino oscillation hypothesis, the fit either to the flux or zenith distribution independently yields $\sin^2 2\theta = 1.0$ and $\Delta(m^2) \sim a$ few times 10^{-3} eV². However, the fit to the observed zenith distribution gives a maximum probability for χ^2 of only 5% for the best oscillation
- 6 CASPER 91 correlates showering/nonshowering signature of single-ring events with parent atmospheric-neutrino flavor. They find nonshowering ($\approx \nu_\mu$ induced) fraction is $0.41\pm0.03\pm0.02$, as compared with expected 0.51 ± 0.05 (syst).
- 7 AGLIETTA 89 finds no evidence for any anomaly in the neutrino flux. They define $\rho=(\text{measured number of }\nu_{\mu}\text{'s}).$ They report $\rho(\text{measured}) = \rho(\text{expected}) = 0.96 + 0.32$
- 8 From this data BOLIEV 81 obtain the limit $\Delta(m^2)~\leq~6 imes 10^{-3}~{\rm eV}^2$ for maximal mixing, $u_{\mu}
 eq
 u_{\mu}$ type oscillation.

DOCUMENT ID

TECN COMMENT

$R(\mu/total) = (Measured Ratio \mu/total) / (Expected Ratio \mu/total)$

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

 $1.1^{+0.07}_{-0.12} \pm 0.11$ 1 CLARK 97 IMB

 $^{
m 1}$ CLARK 97 obtained this result by an analysis of fully contained and partially contained events in the IMB water-Cherenkov detector with visible energy > 0.95 GeV.

 $N_{\rm up}(\mu)/N_{\rm down}(\mu)$ DOCUMENT ID TECN COMMENT ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $0.551^{\,+\,0.035}_{\,-\,0.033}\,\pm\,0.004$ ¹ ASHIE 05 SKAM multi-GeV

 1 ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring μ -like events with visible energy >1.33 GeV and partially-contained events. All partially-contained events are classified as μ -like. Upward-going events are those with $-1 < \cos(z\mathrm{enith}$ angle) < -0.2 and downward-going events are those with $0.2 < \cos(z\mathrm{enith}$ angle) <1. The μ -like up-down ratio for the multi-GeV data deviates from 1 (the expectation for no atmospheric ν_μ oscillations) by more than 12 standard deviations.

$N_{\rm up}(e)/N_{\rm down}(e)$

DOCUMENT ID TECN COMMENT ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

 $0.961^{\,+\,0.086}_{\,-\,0.079}\pm0.016$ ¹ ASHIE 05 SKAM multi-GeV

 $^{^1}$ ASHIE 05 results are based on an exposure of 92 kton yr during the complete Super-Kamiokande I running period. The analyzed data sample consists of fully-contained single-ring e-like events with visible energy > 1.33 GeV. Upward-going events are those with $-1 < \cos(zenith\ angle) < -0.2\ and\ downward-going\ events\ are\ those\ with 0.2 < \cos(zenith\ angle) < 1.$ The e-like up-down ratio for the multi-GeV data is consistent with 1 (the expectation for no atmospheric ν_{ρ} oscillations).

Neutrino Mixing

$R(up/down; \mu) = (Measured up/down; \mu) / (Expected up/down; \mu)$

DOCUMENT ID

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $0.62^{+0.19}_{-0.14} \pm 0.02$ 1 ADAMSON 06 MINS atmospheric ν with far detector

$R(\mu^+/\mu^-) = (Measured N(\mu^+)/N(\mu^-)) / (Expected N(\mu^+)/N(\mu^-))$

| • • • We do not use | the following data for | avera | ges, fits, | limits, etc. • • • |
|---------------------------------------------|------------------------|-------|------------|------------------------------------|
| $1.39 { + 0.35 + 0.08 \atop -0.46 - 0.14 }$ | ¹ ADAMSON | 07 | MINS | Upward and horizontal μ with |
| $0.96^{+0.38}_{-0.27}\pm0.15$ | ² ADAMSON | 06 | MINS | atmospheric $ u$ with far detector |

- $^{
 m 1}$ ADAMSON 07 result is obtained with the MINOS far detector in 854.24 live days, based on neutrino-induced upward-going and horizontal muons. This result is consistent with
- ²ADAMSON 06 result is obtained with the MINOS far detector with an exposure of 4.54 kton yr, based on contained events. The expected ratio is calculated by assuming the same oscillation parameters for neutrinos and antineutrinos.

Solar neutrinos

Solar neutrinos are produced by thermonuclear fusion reactions in the Sun. Radiochemical experiments measure particular combinations of fluxes from various neutrino-producing reactions, whereas water-Cherenkov experiments mainly measure a flux of neutrinos from decay of ⁸B. Solar neutrino fluxes are composed of all active neutrino species, u_e , u_μ , and $u_{ au}$. In addition, some other mechanisms may cause antineutrino components in solar neutrino fluxes. Each measurement method is sensitive to a particular component or a combination of components of solar neutrino fluxes. For details, see Section 13.4 of Reviews, Tables, and Plots

u_e Capture Rates from Radiochemical Experiments

1 SNU (Solar Neutrino Unit) = 10^{-36} captures per atom per second.

| VALUE (SNU) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------------------------|-------------------------|--------|------------|-----------------------------------------------|
| • • • We do not use the | e following data fo | or ave | rages, fit | s, limits, etc. • • • |
| $\begin{array}{cccc} 73.4 & +6.1 & +3.7 \\ -6.0 & -4.1 \end{array}$ | $^{\mathrm{1}}$ KAETHER | 10 | | GALX reanalysis |
| 67.6 $\pm 4.0 \pm 3.2$ | ² KAETHER | 10 | | GNO+GALX reanalysis combined |
| $65.4 \begin{array}{c} +3.1 \\ -3.0 \end{array} \begin{array}{c} +2.6 \\ -2.8 \end{array}$ | ³ ABDURASHI | . 09 | SAGE | $^{71}\text{Ga}\rightarrow^{71}\text{Ge}$ |
| 62.9 $^{+5.5}_{-5.3}$ ± 2.5 | ⁴ ALT MANN | 05 | GNO | $^{71}\mathrm{Ga} ightarrow^{71}\mathrm{Ge}$ |
| 69.3 $\pm 4.1 \pm 3.6$ | ⁵ ALT MANN | 05 | GNO | GNO + GALX combined |
| 77.5 $\pm 6.2 \begin{array}{c} +4.3 \\ -4.7 \end{array}$ | ⁶ HAMPEL | 99 | GALX | $^{71}\mathrm{Ga}\rightarrow^{71}\mathrm{Ge}$ |
| $2.56 \pm 0.16 \pm 0.16$ | ⁷ CLEVELAND | 98 | HOME | $^{37}CI \rightarrow ^{37}Ar$ |

- 1 KAETHER 10 reports the reanalysis results of a complete GALLEX data (GALLEX I+II+III+IV, reported in HAMPEL 99) based on the event selection with a new pulse shape analysis, which provides a better background reduction than the rise time analysis adopted in HAMPEL 99.
- ${}^{2}\,Combined\,\,result\,\,of\,\,GALLEX\,\,I+II+III+IV\,\,reanalysis\,\,and\,\,GNO\,\,I+II+III\,\,(ALTMANN\,\,05).$
- 3 ABDURASHITOV 09 reports a combined analysis of 168 extractions of the SAGE solar neutrino experiment during the period January 1990 through December 2007, and updates the ABDURASHITOV 02 result. The data are consistent with the assumption that the solar neutrino production rate is constant in time. Note that a ~ 15% systematic uncertainty in the overall normalization may be added to the ABDURASHITOV 09 result, because calibration experiments for gallium solar neutrino measurements using intense 51c. ^{51}Cr (twice by GALLEX and once by SAGE) and ^{37}Ar (by SAGE) result in an average ratio of 0.87 \pm 0.05 of the observed to calculated rates.
- ⁴ ALT MANN 05 reports the complete result from the GNO solar neutrino experiment (GNO 1+11+111), which is the successor project of GALLEX. Experimental technique of GNO is essentially the same as that of GALLEX. The run data cover the period 20 May 1998 through 9 April 2003.
- ⁵ Combined result of GALLEX I+II+III+IV (HAMPEL 99) and GNO I+II+III.
- ⁶ HAMPEL 99 report the combined result for GALLEX I+II+III+IV (65 runs in total), which update the HAMPEL 96 result. The GALLEX V result (12 runs) is $118.4\pm17.8\pm6.6$ SNU. (HAMPEL 99 discuss the consistency of partial results with the mean.) The GALLEX experimental program has been completed with these runs. The total run where Δ experimental program has been completed with these runs. The total run data cover the period 14 May 1991 through 23 January 1997. A total of 300 71 Ge events were observed. Note that a \sim 15% systematic uncertainty in the overall normalization may be added to the HAMPEL 99 result, because calibration experiments for gallium solar neutrino measurements using intense 51 Cr (twice by GALLEX and once by SAGE) 37 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 43 and $^{37}\text{Ar}\,(\text{by SAGE})$ result in an average ratio of 0.87 ± 0.05 of the observed to calculated
- 7 CLEVELAND 98 is a detailed report of the ^{37}Cl experiment at the Homestake Mine. The average solar neutrino-induced ^{37}Ar production rate from 108 runs between 1970 and 1994 updates the DAVIS 89 result.

ϕ_{ES} (8B)

 $^8 ext{B}$ solar-neutrino flux measured via u e elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to u_{μ} , $u_{ au}$ due to the crosssection difference, $\sigma(\nu_{\mu,\tau}e)\sim 0.16\sigma(\nu_ee)$. If the $^{\hat{0}}B$ solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is ~ 0.16 times of

| $VALUE (10^6 \text{ cm}^{-2} \text{s}^{-1})$ | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------------|--------|------------|-------------------------------------------------------------------|
| • • • We do not us | e the following data fo | r avei | rages, fit | s, limits, etc. • • • |
| $2.32 \pm 0.04 \pm 0.05$ | ¹ ABE | 11 | SKAM | SK-III average flux |
| $2.41 \pm 0.05 {}^{+\; 0.16}_{-\; 0.15}$ | ² ABE | 11 | SKAM | SK-II average flux |
| $2.38 \pm 0.02 \pm 0.08$ | ³ ABE | 11 | SKAM | SK-I average flux |
| $2.77 \pm 0.26 \pm 0.32$ | ⁴ ABE | 11B | KLND | average flux |
| $2.4 \ \pm 0.4 \ \pm 0.1$ | ⁵ BELLINI | 10A | BORX | average flux |
| $1.77 { + 0.24 + 0.09 \atop - 0.21 - 0.10 }$ | ⁶ AHARMIM | 80 | SNO | Phase III |
| $2.38 \pm 0.05 {}^{+ 0.16}_{- 0.15}$ | ⁷ CRAVENS | 80 | SKAM | average flux |
| $2.35 \pm 0.02 \pm 0.08$ | ⁸ HOSAKA | 06 | SKAM | average flux |
| $2.35 \pm 0.22 \pm 0.15$ | ⁹ AHARMIM | 05 A | SNO | Salty D ₂ O; ⁸ B shape not con- strained |
| $2.34 \pm 0.23 {}^{+\; 0.15}_{-\; 0.14}$ | ⁹ AHARMIM | 05 A | SNO | Salty D_2O ; 8B shape constrained |
| $2.39^{+0.24}_{-0.23}\pm0.12$ | ¹⁰ AHMAD | 02 | SNO | average flux |
| $2.39 \pm 0.34 {}^{+\ 0.16}_{-\ 0.14}$ | ¹¹ AHMAD | 01 | SNO | average flux |
| $2.80 \pm 0.19 \pm 0.33$ | ¹² FUKUDA | 96 | KAMI | average flux |
| 2.70 ± 0.27 | ¹² FU KUDA | 96 | KAMI | day flux |
| $2.87 + 0.27 \\ -0.26$ | ¹² FU KUDA | 96 | KAMI | night flux |

- $^{
 m 1}$ ABE 11 reports the Super-Kamiokande-III results for 548 live days from August 4, 2006 to August 18, 2008. The analysis threshold is 5.0 MeV, but the event sample in the 5.0-6.5 MeV total electron range has a total live time of 298 days.
- 2 ABE 11 recalculated the Super-Kamiokande-II results using 8 B spectrum of WIN-
- TER 06A.

 3 ABE 11 recalculated the Super-Kamiokande-I results using 8B spectrum of WINTER 06A. 4 ABE 11B use a 123 kton-day exposure of the KamLAND liquid scintillation detector to measure the 8 B solar neutrino flux. They utilize $\nu-e$ elastic scattering above a reconstructed-energy threshold of 5.5 MeV, corresponding to 5 MeV electron recoil energy. 299 electron recoil candidate events are reported, of which 157 \pm 23.6 are assigned
- to background. 5 BELLINI 10A reports the Borexino result with 3 MeV energy threshold for scattered electrons. The data correspond to 345.3 live days with a target mass of 100 t, between July 15, 2007 and August 23, 2009.
- $^6\mathrm{AHARMIM}$ 08 reports the results from SNO Phase III measurement using an array of ³He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the ⁸B
- $^7\,\mathrm{CRAVENS}$ 08 reports the Super-Kamiokande-II results for 791 live days from December 2002 to October 2005. The photocathode coverage of the detector is 19% (reduced from 40% of that of Super-Kamiokande-I due to an accident in 2001). The analysis threshold for the average flux is 7 MeV.
- $^8\, {\rm HOSAKA}$ 06 reports the final results for 1496 live days with Super-Kamiokande-I between May 31, 1996 and July 15, 2001, and replace FUKUDA 02 results. The analysis threshold is 5 MeV except for the first 280 live days (6.5 MeV).
- ⁹ AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The CC, ES, and NC events were statistically separated. In one method, the ⁸B energy spectrum was not constrained. In the other method, the constraint of an undistorted ⁸B energy spectrum was added for comparison with AHMAD 02 results.
- 10 AHMAD 02 reports the 8 B solar-neutrino flux measured via u e elastic scattering above the kinetic energy threshold of 5 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001, and updates AHMAD 01 results.
- 11 AH MAD 01 reports the 8 B solar-neutrino flux measured via νe elastic scattering above the kinetic energy threshold of 6.75 MeV. The data correspond to 241 live days with SNO between November 2, 1999 and January 15, 2001.
- 12 FUKUDA 96 results are for a total of 2079 live days with Kamiokande II and III from January 1987 through February 1995, covering the entire solar cycle 22, with threshold $\mathrm{E}_e >$ 9.3 MeV (first 449 days), > 7.5 MeV (middle 794 days), and > 7.0 MeV (last 836 days). These results update the HIRATA 90 result for the average ⁸B solar-neutrino flux and HIRATA 91 result for the day-night variation in the $^8\mathrm{B}$ solar-neutrino flux. The total data sample was also analyzed for short-term variations: within experimental errors, no strong correlation of the solar-neutrino flux with the sunspot numbers was found.

 $^{^{}m 1}$ ADAMSON 06 result is obtained with the MINOS far detector with an exposure of 4.54 kton yr. The expected ratio is calculated with no neutrino oscillation

Lepton Particle Listings Neutrino Mixing

ϕ_{CC} (8B)

 $^8{\rm B}$ solar-neutrino flux measured with charged-current reaction which is sensitive exclusively to $\nu_{\rm e}.$

| VALUE (106 cm-2s-1) | DO CUMENT ID | TEC | N COMMENT |
|-----------------------------------------------|----------------------|----------------|-----------------------------------------------------------------------------|
| • • • We do not use the follow | ing data for averag | es, fits, limi | ts, etc. • • • |
| $1.67 ^{+ 0.05}_{- 0.04} ^{+ 0.07}_{- 0.08}$ | ¹ AHARMIM | 08 SN | D Phase III |
| $1.68 \pm 0.06 {}^{+\; 0.08}_{-\; 0.09}$ | ² AHARMIM | 05A SN | |
| $1.72 \pm 0.05 \pm 0.11$ | ² AHARMIM | 05A SN | not const. O Salty D ₂ O; ⁸ B shape constrained |
| $1.76^{+0.06}_{-0.05}\pm 0.09$ | ³ AHMAD | 02 SN | |
| $1.75 \pm 0.07 ^{+\ 0.12}_{-\ 0.11} \pm 0.05$ | ⁴ AHMAD | 01 SN | O average flux |

- 1 AHARMIM 08 reports the results from SNO Phase III measurement using an array of 3 He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the $^8\mathrm{B}$ shape.
- 2 AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The $CC,\,ES,$ and NC events were statistically separated. In one method, the 8B energy spectrum was not constrained. In the other with AHMAD 02 results.
- 3 AHMAD 02 reports the SNO result of the 8 B solar-neutrino flux measured with charged-current reaction on deuterium, $\nu_e\,d\,\rightarrow\,p\,p\,e^-$, above the kinetic energy threshold of 5 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001, and updates AHMAD 01 results. The complete description of the SNO Phase I data set is given in AHARMIM 07.
- 4 AH MAD 01 reports the first SNO result of the 8 B solar-neutrino flux measured with the charged-current reaction on deuterium, $\nu_e\,d\,\rightarrow\,p\,p\,e^-$, above the kinetic energy threshold of 6.75 MeV. The data correspond to 241 live days with SNO between November 2, 1999 and January 15, 2001.

ϕ_{NC} (8B)

 $^8{\rm B}$ solar neutrino flux measured with neutral-current reaction, which is equally sensitive to ν_e , ν_μ , and ν_τ

| VALUE (10 ⁶ cm ⁻² s ⁻¹) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------|------------------------|--------|-----------|----------------------------------------------------------|
| • • • We do not use the | e following data fo | or ave | rages, fi | ts, limits, etc. • • • |
| $5.140 {}^{+ 0.160}_{- 0.158} {}^{+ 0.132}_{- 0.117}$ | ¹ AHARMIM | 10 | SNO | Phase I+II, low threshold |
| $5.54 \begin{array}{c} +0.33 \\ -0.31 \end{array} \begin{array}{c} +0.36 \\ -0.34 \end{array}$ | ² A HAR MIM | 80 | SNO | Phase III, prop. counter $+$ PMT |
| $4.94\ \pm0.21\ ^{+0.38}_{-0.34}$ | ³ A HAR MIM | 05 A | SNO | Salty D ₂ O; ⁸ B shape not const. |
| $\begin{array}{cccc} 4.81 & \pm 0.19 & ^{+ 0.28}_{- 0.27} \end{array}$ | ³ A HAR MIM | 05 A | SNO | Salty D ₂ O; ⁸ B shape constrained |
| $5.09 \begin{array}{c} +0.44 & +0.46 \\ -0.43 & -0.43 \end{array}$ | ⁴ AHMAD | 02 | SNO | average flux; ⁸ B shape const. |
| $6.42 \pm 1.57 ^{+ 0.55}_{- 0.58}$ | ⁴ AHMAD | 02 | SNO | average flux; ⁸ B shape not const. |

- 1 AHARMIM 10 reports this result from a joint analysis of SNO Phase I+II data with the "effective electron kinetic energy" threshold of 3.5 MeV. This result is obtained with a "binned-histogram unconstrained fit" where binned probability distribution functions of the neutrino signal observables were used without any model constraints on the shape of the neutrino spectrum.
- 2 AHARMIM 08 reports the results from SNO Phase III measurement using an array of 3 He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the $^8\mathrm{B}$ shape.
- ³ AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The *CC*, *ES*, and *NC* events were statistically separated. In one method, the ⁸B energy spectrum was not constrained. In the other method, the constraint of an undistorted ⁸B energy spectrum was added for comparison with AHMAD 02 results.
- 4 AHMAD 02 reports the first SNO result of the 8B solar-neutrino flux measured with the neutral-current reaction on deuterium, $\nu_\ell d \to n \rho \nu_{\ell'}$ above the neutral-current reaction threshold of 2.2 MeV. The data correspond to 306.4 live days with SNO between November 2, 1999 and May 28, 2001. The complete description of the SNO Phase I data set is given in AHARMIM 07.

$\phi_{\nu_{\boldsymbol{\mu}}+\nu_{\boldsymbol{\tau}}}~(^{8}\mathrm{B})$

Nonelectron-flavor active neutrino component (ν_{μ} and $\nu_{ au}$) in the ⁸B solar-neutrino flux.

| VALUE (106 cm - 2s - 1) | DO CUMENT ID | TECN | COMMENT |
|-------------------------|--------------|------|---------|
| | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| $3.26 \pm 0.25 {}^{+ 0.40}_{- 0.35}$ | ¹ AHARMIM | 05A SNO | From ϕ_{NC} , ϕ_{CC} , and ϕ_{ES} ; $^8{ m B}$ shape not const. |
|---------------------------------------|----------------------|---------|-------------------------------------------------------------------------------------|
| $3.09 \pm 0.22 ^{+ 0.30}_{- 0.27}$ | ¹ AHARMIM | 05A SNO | From ϕ_{NC} , ϕ_{CC} , and ϕ_{ES} ; ⁸ B shape constrained |
| $3.41 \pm 0.45 + 0.48 \\ -0.45$ | ² AHMAD | 02 SNO | From ϕ_{NC} , ϕ_{CC} , and ϕ_{ES} |
| $3.69\!\pm\!1.13$ | ³ AHMAD | 01 | Derived from SNO+SuperKam, water Cherenkov |

- 1 AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The CC, ES, and NC events were statistically separated. In one method, the $^8\mathrm{B}$ energy spectrum was not constrained. In the other method, the constraint of an undistorted $^8\mathrm{B}$ energy spectrum was added for comparison with AHMAD 02 results.
- 2 AHMAD 02 deduced the nonelectron-flavor active neutrino component $(\nu_{\mu}$ and $\nu_{\tau})$ in the 8 B solar-neutrino flux, by combining the charged-current result, the νe elastic-scattering result and the neutral-current result. The complete description of the SNO Phase I data set is given in AHARMIM 07.
- 3 AHMAD 01 deduced the nonelectron-flavor active neutrino component $(\nu_{\mu}$ and $\nu_{\tau})$ in the 8 B solar-neutrino flux, by combining the SNO charged-current result (AHMAD 01) and the Super-Kamiokande $\nu\,e$ elastic-scattering result (FUKUDA 01).

Total Flux of Active ⁸B Solar Neutrinos

Total flux of active neutrinos $(\nu_{\it e},\,\nu_{\mu},\,{\rm and}\,\,\nu_{\tau}).$

| VALUE (10 ⁶ cm ⁻² s ⁻¹) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------|----------------------|-------|----------|-----------------------------------------------------|
| ullet $ullet$ We do not use the | following data fo | r ave | ages, fi | its, limits, etc. • • • |
| $5.046 { + 0.159 + 0.107 \atop - 0.152 - 0.123 }$ | ¹ AHARMIM | 10 | SNO | From ϕ_{NC} in Phase III |
| $\substack{5.54 & +0.33 & +0.36 \\ -0.31 & -0.34}$ | ² AHARMIM | 80 | SNO | ϕ_{NC} in Phase III |
| $4.94 \ \pm 0.21 \ ^{+ 0.38}_{- 0.34}$ | ³ AHARMIM | 05 A | SNO | From ϕ_{NC} ; $^8{ m B}$ shape not const. |
| 4.81 $\pm 0.19 ^{+ 0.28}_{- 0.27}$ | ³ AHARMIM | 05 A | SNO | From ϕ_{NC} ; ⁸ B shape constrained |
| $5.09 \begin{array}{c} +0.44 & +0.46 \\ -0.43 & -0.43 \end{array}$ | ⁴ AHMAD | 02 | SNO | Direct measurement from $\phi_{\it NC}$ |
| 5.44 ±0.99 | ⁵ AHMAD | 01 | | Derived from SNO+SuperKam, water Cherenkov |

- 1 AHARMIM 10 reports this result from a joint analysis of SNO Phase I+II data with the "effective electron kinetic energy" threshold of 3.5 MeV. This result is obtained with the assumption of unitarity, which relates the NC, CC, and ES rates. The data were fit with the free parameters directly describing the total 8 B neutrino flux and the energy-dependent ν_e survival probability.
- 2 AHARMIM 08 reports the results from SNO Phase III measurement using an array of 3 He proportional counters to measure the rate of NC interactions in heavy water, over the period between November 27, 2004 and November 28, 2006, corresponding to 385.17 live days. A simultaneous fit was made for the number of NC events detected by the proportional counters and the numbers of NC, CC, and ES events detected by the PMTs, where the spectral distributions of the ES and CC events were not constrained to the $^8\mathrm{B}$ shape.
- 3 AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, corresponding to 391.4 live days, and update AHMED 04A. The CC, ES, and NC events were statistically separted. In one method, the $^8\mathrm{B}$ energy spectrum was not constrained. In the other method, the constraint of an undistorted $^8\mathrm{B}$ energy spectrum was added for comparison with AHMAD 02 results.
- 4 AHMAD 02 determined the total flux of active 8 B solar neutrinos by directly measuring the neutral-current reaction, $\nu_\ell \, d \to n \rho \nu_\ell$, which is equally sensitive to ν_e, ν_μ , and ν_τ . The complete description of the SNO Phase I data set is given in AHARMIM 07.
- ⁵ AHMAD 01 deduced the total flux of active ⁸B solar neutrinos by combining the SNO charged-current result (AHMAD 01) and the Super-Kamiokande νe elastic-scattering result (FUKUDA 01).

Day-Night Asymmetry (8B)

 $A = (\phi_{\mathsf{night}} - \phi_{\mathsf{day}}) / \phi_{\mathsf{average}}$

| VALUE | DO CUMENT ID | | TECN | COMMENT | | | | | |
|---------------------------------------------------------------------------------------------------------------------|----------------------|------|------|-----------------------------------------------------------------|--|--|--|--|--|
| \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | | | | | | | | | |
| $0.063 \pm 0.042 \pm 0.037$ | $^{ m 1}$ CRAVENS | 08 | SKAM | Based on ϕ_{ES} | | | | | |
| $0.021 \pm 0.020 {}^{+\ 0.012}_{-\ 0.013}$ | ² HOSAKA | 06 | SKAM | Based on ϕ_{ES} | | | | | |
| $0.017 \pm 0.016 {}^{+\; 0.012}_{-\; 0.013}$ | ³ HOSAKA | 06 | SKAM | Fitted in the LMA region | | | | | |
| $-0.056\pm0.074\pm0.053$ | ⁴ AHARMIM | 05 A | SNO | From salty SNO ϕ_{CC} | | | | | |
| $-0.037 \pm 0.063 \pm 0.032$ | ⁴ AHARMIM | 05 A | SNO | From salty SNO ϕ_{CC} ; const. of no ϕ_{NC} asymmetry | | | | | |
| $0.14 \ \pm 0.063 { + 0.015 \atop - 0.014 }$ | ⁵ AHMAD | 02в | SNO | Derived from SNO $\phi_{\it CC}$ | | | | | |
| $0.07 \pm 0.049 + 0.013 \\ -0.012$ | ⁶ AHMAD | 02в | SNO | Const. of no ϕ_{NC} asymmetry | | | | | |

¹ CRAVENS 08 reports the Super-Kamiokande-II results for 791 live days from December 2002 to October 2005. The photocathode coverage of the detector is 19% (reduced from 40% of that of Super-Kamiokande-I due to an accident in 2001). The analysis threshold for the day and night fluxes is 7.5 MeV.

Neutrino Mixing

- ² HOSAKA 06 reports the final results for 1496 live days with Super-Kamiokande-I between May 31, 1996 and July 15, 2001, and replace FUKUDA 02 results. The analysis threshold is 5 MeV except for the first 280 live days (6.5 MeV).
- 3 This result with reduced statistical uncertainty is obtained by assuming two-neutrino oscillations within the LMA (large mixing angle) region and by fitting the time variation of the solar neutrino flux measured via ν_e elastic scattering to the variations expected from neutrino oscillations. For details, see SMY 04. There is an additional small systematic error of ± 0.0004 coming from uncertainty of oscillation parameters.
- 4 AHARMIM 05A measurements were made with dissolved NaCl (0.195% by weight) in heavy water over the period between July 26, 2001 and August 28, 2003, with 176.5 days of the live time recorded during the day and 214.9 days during the night. This result is obtained with the spectral distribution of the CC events not constrained to the $^8\mathrm{B}$ shape.
- 5 AH MAD 02B results are based on the charged-current interactions recorded between November 2, 1999 and May 28, 2001, with the day and night live times of 128.5 and 177.9 days, respectively. The complete description of the SNO Phase I data set is given in AHARMIM 07.
- 6 AHMAD 02B results are derived from the charged-current interactions, neutral-current interactions, and νe elastic scattering, with the total flux of active neutrinos constrained to have no asymmetry. The data were recorded between November 2, 1999 and May 28, 2001, with the day and night live times of 128.5 and 177.9 days, respectively. The complete description of the SNO Phase I data set is given in AHARMIM 07.

ϕ_{ES} (⁷Be)

 ^7Be solar-neutrino flux measured via ν_e elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_μ, ν_τ due to the cross-section difference, $\sigma(\nu_{\mu,\tau} e) \sim 0.2~\sigma(\nu_e \, e).$ If the ^7Be solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is ~ 0.2 times that of ν_μ .

 $\begin{array}{c|cccc} \textit{VALUE} \ (10^9 \ \text{cm}^{-2} \ \text{s}^{-1}) & \textit{DOCUMENT ID} & \textit{TECN} & \textit{COMMENT} \end{array}$

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

 3.10 ± 0.15 BELLINI 11A BORX average flux

 1 BELLINI 11A reports the 7 Be solar neutrino flux measured via $\nu-e$ elastic scattering. The data correspond to 740.7 live days between May 16, 2007 and May 8, 2010, and also correspond to 153.6 ton-year fiducial exposure. BELLINI 11A measured the 862 keV 7 Be solar neutrino flux, which is an 89.6% branch of the 7 Be solar neutrino flux, to be $(2.78\pm0.13)\times10^9~{\rm cm}^{-2}~{\rm s}^{-1}$. Supercedes ARPESELLA 08A.

$\phi_{CC}(pp)$

pp solar-neutrino flux measured with charged-current reaction which is sensitive exclusively to $\nu_{e}.$

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 1.38 ± 0.47 ABDURASHI... 09 FIT Fit existing solar- ν data

 1 ABDURASHITOV 09 reports the pp solar-neutrino flux derived from the Ga solar neutrino capture rate by subtracting contributions from 8 B, 7 Be, $\rho e \rho$ and CNO solar neutrino fluxes determined by other solar neutrino experiments as well as neutrino oscillation parameters determined from available world neutrino oscillation data.

ϕ_{ES} (hep)

hep solar-neutrino flux measured via νe elastic scattering. This process is sensitive to all active neutrino flavors, but with reduced sensitivity to ν_{μ}, ν_{τ} due to the cross-section difference, $\sigma(\nu_{\mu,\tau}e)\sim 0.16\sigma(\nu_e\,e)$. If the hep solar-neutrino flux involves nonelectron flavor active neutrinos, their contribution to the flux is ~ 0.16 times of ν_e .

VALUE (10³ cm⁻²s⁻¹) CL% DOCUMENT ID TECN

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

<73 90 1 HOSAKA 06 SKAM

 $^{1}\,\text{HOSAKA}$ 06 result is obtained from the recoil electron energy window of 18–21 MeV, and updates FUKUDA 01 result.

ϕ_{77} . (8B)

Searches are made for electron antineutrino flux from the Sun. Flux limits listed here are derived relative to the BS05(OP) Standard Solar Model 8B solar neutrino flux (5.69 \times 10 6 cm $^{-2}$ s $^{-1}$), with an assumption that solar \mathcal{P}_e s follow an unoscillated 8B neutrino spectrum.

| VALUE (70) | | | | | | CL 70 | 00 | COW | LNIID | | ILCIV | | IVIIV | $I \subseteq I$ | v i | | | | |
|------------|---|---|---|----|----|-------|-----|-----|-----------|------|-------|-----------|-------|-----------------|------|---|---|---|--|
| | • | • | • | We | do | not | use | the | following | data | for | averages, | fits, | limits, | etc. | • | • | • | |

| < 0.013 | 90 | BELLINI | 11 | BORX | $E_{\overline{\nu}_a} > 1.8 \text{ MeV}$ |
|---------|----|---------------------|----|------|-------------------------------------------------|
| <1.9 | 90 | ¹ BALATA | 06 | CNTR | $1.8 < E_{\overline{ u}_a} < 20.0 \; MeV$ |
| < 0.72 | 90 | AHARMIM | 04 | SNO | $4.0 < E_{\overline{\nu}_a} < 14.8 \text{ MeV}$ |
| < 0.022 | 90 | EGUCHI | 04 | KLND | $8.3 < E_{\overline{\nu}_a} < 14.8 \text{ MeV}$ |
| < 0.7 | 90 | GANDO | 03 | SKAM | $8.0 < E_{\overline{ u}_a} < 20.0 \text{ MeV}$ |
| <1.7 | 90 | AGLIETTA | 96 | LSD | 7< E _{77.} < 17 MeV |

(B) Three-neutrino mixing parameters

INTRODUCTION TO THREE-NEUTRINO MIXING PARAMETERS LISTINGS

Updated April 2012 by M. Goodman (ANL).

Introduction and Notation: With the exception of the LSND anomaly, current accelerator, reactor, solar and atmospheric neutrino data can be described within the framework of a 3×3 mixing matrix between the flavor eigenstates ν_e , ν_μ and ν_τ and mass eigenstates ν_1 , ν_2 and ν_3 . (See equation 13.79 of the review "Neutrino Mass, Mixing and Oscillations" by K. Nakamura and S.T. Petcov.) Whether or not this is the ultimately correct framework, it is currently widely used to parametrize neutrino mixing data and to plan new experiments.

The mass differences are called $\Delta m^2_{21} \equiv m^2_2 - m^2_1$ and $\Delta m^2_{32} \equiv m^2_3 - m^2_2$. In these listings, we assume

$$\Delta m_{32}^2 \sim \Delta m_{31}^2 \tag{1}$$

although in the future, experiments may be precise enough to measure these separately. The angle are labeled θ_{12} , θ_{23} and θ_{13} . The CP violating phase is called δ , but that does not yet appear in the listings. The familiar two neutrino form for oscillations is

$$P(\nu_a \to \nu_b) = \sin^2(2\theta) \sin^2(\Delta m^2 L/4E). \tag{2}$$

Despite the fact that the mixing angles have been measured to be much larger than in the quark sector, the two neutrino form is often a very good approximation and is used in many situations.

The angles appear in the equations below in many forms. They most often appear as $\sin^2(2\theta)$. The listings currently use this convention.

Accelerator neutrino experiments: Ignoring the small Δm_{21}^2 scale, CP violation, and matter effects, the equations for the probability of appearance in an accelerator oscillation experiment are:

$$P(\nu_{\mu} \to \nu_{\tau}) = \sin^2(2\theta_{23})\cos^4(\theta_{13})\sin^2(\Delta m_{32}^2 L/4E)$$
 (3)

$$P(\nu_{\mu} \to \nu_{e}) = \sin^{2}(2\theta_{13})\sin^{2}(\theta_{23})\sin^{2}(\Delta m_{32}^{2}L/4E)$$
 (4)

$$P(\nu_e \to \nu_\mu) = \sin^2(2\theta_{13}) \sin^2(\theta_{23}) \sin^2(\Delta m_{32}^2 L/4E)$$
 (5)

$$P(\nu_e \to \nu_\tau) = \sin^2(2\theta_{13})\cos^2(\theta_{23})\sin^2(\Delta m_{32}^2 L/4E)$$
. (6)

For the case of negligible θ_{13} , these probabilities vanish except for $P(\nu_{\mu} \rightarrow \nu_{\tau})$, which then takes the familiar two-neutrino form.

Current and future long-baseline accelerator experiments are studying non-zero θ_{13} through $P(\nu_{\mu} \rightarrow \nu_{e})$. Including the CP terms and low mass scale, the equation for neutrino oscillation in vacuum is:

$$P(\nu_{\mu} \to \nu_{e}) = P1 + P2 + P3 + P4$$

$$P1 = \sin^{2}(\theta_{23}) \sin^{2}(2\theta_{13}) \sin^{2}(\Delta m_{32}^{2} L/4E)$$

$$P2 = \cos^{2}(\theta_{23}) \sin^{2}(2\theta_{13}) \sin^{2}(\Delta m_{21}^{2} L/4E)$$

$$P3 = -/+ J \sin(\delta) \sin(\Delta m_{32}^{2} L/4E)$$

$$P4 = J \cos(\delta) \cos(\Delta m_{32}^{2} L/4E)$$
(7)

 $^{^1}$ BALATA 06 obtained this result from the search for $\overline{\nu}_e$ interactions with Counting Test Facility (the prototype of the Borexino detector).

where

$$J = \cos(\theta_{13})\sin(2\theta_{12})\sin(2\theta_{13})\sin(2\theta_{23}) \times \sin(\Delta m_{32}^2 L/4E)\sin(\Delta m_{21}^2 L/4E)$$
(8)

and the sign in P3 is negative for neutrinos and positive for antineutrinos respectively. For most new long-baseline accelerator experiments, P2 can safely be neglected but the other three terms could be comparable. Also, depending on the distance and the mass hierarchy, matter effects will need to be included.

Reactor neutrino experiments: Nuclear reactors are prolific sources of $\bar{\nu}_e$ with an energy near 4 MeV. The oscillation probability can be expressed

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta m_{21}^2 L/4E) - \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta m_{31}^2 L/4E) - \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta m_{32}^2 L/4E)$$
 (9)

not using the approximation in Eq. (1). For short distances (L<5 km) we can ignore the second term on the right and can reimpose approximation Eq. (1). This takes the familiar two neutrino form with θ_{13} and Δm_{32}^2 :

$$P(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2(2\theta_{13})\sin^2(\Delta m_{32}^2 L/4E).$$
 (10)

For long distances and small θ_{13} , the last two terms in Eq. (9) oscillate rapidly and average to zero for an experiment with finite energy resolution, leading to the familiar two neutrino form but with θ_{12} and Δm_{21}^2 .

Solar and Atmospheric neutrino experiments: Solar neutrino experiments are sensitive to ν_e disappearance and have allowed the measurement of θ_{12} and Δm_{21}^2 . They are also sensitive to θ_{13} . We identify $\Delta m_{\odot}^2 = \Delta m_{21}^2$ and $\theta_{\odot} = \theta_{12}$.

Atmospheric neutrino experiments are primarily sensitive to ν_{μ} disappearance through $\nu_{\mu} \to \nu_{\tau}$ oscillations, and have allowed the measurement of θ_{23} and Δm_{32}^2 . We identify $\Delta m_A^2 = \Delta m_{32}^2$ and $\theta_A = \theta_{23}$. Despite the large ν_e component of the atmospheric neutrino flux, it is difficult to measure Δm_{21}^2 effects. This is because of a cancellation between $\nu_{\mu} \to \nu_e$ and $\nu_e \to \nu_{\mu}$ together with the fact that the ratio of ν_{μ} and ν_e atmospheric fluxes, which arise from sequential π and μ decay, is near 2.

Oscillation Parameter Listings: In Section (B) we encode the three mixing angles θ_{12} , θ_{23} , θ_{13} and two mass squared differences Δm_{21}^2 and Δm_{32}^2 . Our knowledge of θ_{12} and Δm_{21}^2 comes from the KamLAND reactor neutrino experiment together with solar neutrino experiments. Our knowledge of θ_{23} and Δm_{32}^2 comes from atmospheric neutrino experiments and long-baseline accelerator experiments. Results on θ_{13} come from reactor antineutrino disappearance experiments. There are also results from long-baseline accelerator experiments looking for ν_e appearance. The interpretation of both kinds of results depends on Δm_{32}^2 , and the accelerator results also depend on the mass hierarchy, θ_{23} and the CP violating phase δ .

| $\sin^2(2	heta_{12})$ | | | | | |
|-------------------------------------------------------|---------------------------|--------|-----------|-----------------------------------------------|--|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| $0.857 ^{f +0.023}_{-0.025}$ | ¹ GANDO | 11 | FIT | KamLAND $+$ solar: $3 u$ | |
| • • • We do not u | se the following data for | averag | es, fits, | limits, etc. • • • | |
| 0.85 ± 0.02 | ² ABE | 11 | FIT | KamLAND + global solar: 2ν | |
| $\begin{array}{cc} 0.84 & +0.03 \\ -0.02 \end{array}$ | ³ ABE | 11 | FIT | global solar: $2 u$ | |
| $0.85 \begin{array}{l} +0.04 \\ -0.03 \end{array}$ | ⁴ ABE | 11 | FIT | KamLAND + global solar: 3 ν | |
| $\begin{array}{cc} 0.85 & +0.04 \\ -0.05 \end{array}$ | ⁵ ABE | 11 | FIT | global solar: $3 u$ | |
| $0.861 {}^{+ 0.022}_{- 0.018}$ | ⁶ BELLINI | 11 A | FIT | KamLAND + global solar: 2 ν | |
| $0.869 {}^{+ 0.024}_{- 0.022}$ | ⁷ BELLINI | 11 A | FIT | global solar: $2 u$ | |
| $0.846 {}^{+ 0.064}_{- 0.073}$ | ⁸ GANDO | 11 | FIT | KamLAND: 3ν | |
| $0.861 {}^{+ 0.026}_{- 0.022}$ | 9,10 AHARMIM | 10 | FIT | KamLAND + global solar: 2 ν | |
| $0.861 {}^{+ 0.024}_{- 0.031}$ | 9,11 AHARMIM | 10 | FIT | global solar: $2 u$ | |
| $0.869 {}^{+ 0.026}_{- 0.024}$ | 9,12 AHARMIM | 10 | FIT | KamLAND + global solar: 3 ν | |
| $0.869 {}^{+ 0.031}_{- 0.037}$ | 9,13 AHARMIM | 10 | FIT | global solar: $3 u$ | |
| 0.92 ± 0.05 | ¹⁴ ABE | 08A | FIT | KamLAND | |
| 0.87 ± 0.04 | ¹⁵ ABE | 08A | FIT | KamLAND + global fit | |
| 0.87 ± 0.03 | ¹⁶ AHARMIM | 80 | FIT | KamLAND + global solar | |
| $0.85 \begin{array}{l} +0.04 \\ -0.06 \end{array}$ | ¹⁷ HOSAKA | 06 | FIT | KamLAND + global solar | |
| $\begin{array}{cc} 0.85 & +0.06 \\ -0.05 \end{array}$ | ¹⁸ HOSAKA | 06 | FIT | SKAM+SNO+KamLA ND | |
| $0.86 \begin{array}{l} +0.05 \\ -0.07 \end{array}$ | ¹⁹ HOSAKA | 06 | FIT | SKAM+SNO | |
| $0.86 \begin{array}{l} +0.03 \\ -0.04 \end{array}$ | ²⁰ AHARMIM | 05 A | FIT | ${\sf KamLAND} + {\sf global} {\sf solar}$ | |
| 0.75-0.95 | ²¹ AHARMIM | 05 A | FIT | global solar | |
| 0.82 ± 0.05 | ²² ARAKI | 05 | FIT | KamLAND + global solar | |
| 0.82 ± 0.04 | ²³ AHMED | 04 A | FIT | KamLAND + global solar | |
| 0.71-0.93 | ²⁴ AHMED | 04 A | FIT | global solar | |
| $\begin{array}{cc} 0.85 & +0.05 \\ -0.07 \end{array}$ | ²⁵ SMY | 04 | FIT | KamLAND + global solar | |
| $0.83 \ ^{+ 0.06}_{- 0.08}$ | ²⁶ SMY | 04 | FIT | global solar | |
| $0.87 \ ^{+ 0.07}_{- 0.08}$ | 27 SMY | 04 | FIT | SKAM + SNO | |
| 0.62-0.88 | ²⁸ AHMAD | 02B | FIT | global solar | |
| 0.62-0.95 | ²⁹ FUKUDA | 02 | FIT | global solar | |

 $^{1}\,\mbox{GANDO}\,11$ obtain this result with three-neutrino fit using the KamLAND + solar data. Supersedes ABE 08A.

² ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. CPT invariance is assumed.

³ ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, and SAGE data.

 4 ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{32}^2 fixed to $2.4\times 10^{-3}~\rm eV^2$, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. The normal neutrino mass hierarchy and CPT invariance are assumed.

 5 ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{32}^2 fixed to $2.4\times 10^{-3}~\rm eV^2$, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.

6 BELLINI 11A obtained this result by a two-neutrino oscillation analysis using KamLAND, Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal 743 24 (2011)) with the exception that the ⁸B flux was left free. CPT invariance is assumed.

⁷BELLINI 11A obtained this result by a two-neutrino oscillation analysis using Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENBELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ⁸B flux was left free.

8 GANDO 11 obtain this result with three-neutrino fit using the KamLAND data only.
Supersedes ABE 08A.

⁹ AHARMIM 10 global solar neutrino data include SNO's low-energy-threshold analysis survival probability day/night curves, SNO Phase III integral rates (AHARMIM 08), CI (CLEVELAND 98), SAGE (ABDURASHITOV 09), Gallex/GNO (HAMPEL 99, ALT-MANN 05), Borexino (ARPESELLA 08A), SK-I zenith (HOSAKA 06), and SK-II day/night spectra (CRAVENS 08).

10 AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data and KamLAND data (ABE 08A). CPT invariance is assumed.

11 AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data.
12 AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value

 $^{12} \rm AHARMIM\,10$ obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to $2.3\times 10^{-3}~\rm eV^2$, using global solar neutrino data and KamLAND data (ABE 08A). CPT invariance is assumed.

 13 AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to $^{2.3}\times 10^{-3}$ eV², using global solar neutrino data.

Neutrino Mixing

- 14 ABE 08A obtained this result by a rate + shape + time combined geoneutrino and reactor two-neutrino fit for Δm_{21}^2 and $\tan^2\theta_{12}$, using KamLAND data only.
- 15 ABE 08A obtained this result by means of a two-neutrino fit using KamLAND, Homestake, SAGE, GALLEX, GNO, SK (zenith angle and E-spectrum), the SNO χ^2 -map, and solar flux data. CPT invariance is assumed.
- 16 The result given by AHARMIM 08 is $\theta=(34.4^{+1.3}_{-1.2})^{\circ}$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino data including those of Borexino (ARPESELLA 08A) and Super-Kamiokande-I (HOSAKA 06), and KamLAND data (ABE 08A). CPT invariance is assumed.
- $^{17}\,\text{HOSAKA}$ 06 obtained this result by a two-neutrino oscillation analysis using SK ν_e data, CC data from other solar neutrino experiments, and KamLAND data (ARAKI 05). CPT invariance is assumed.
- ¹⁸ HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the data from Super-Kamiokande, SNO (AHMAD 02 and AHMAD 02B), and KamLAND (ARAKI 05) experiments. CPT invariance is assumed.
- $^{19}\mathrm{HOSAKA}$ 06 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data.
- 20 The result given by AHARMIM 05A is $\theta=(33.9\pm1.6)^\circ$. This result is obtained by a two-neutrino oscillation analysis using SNO pure deuteron and salt phase data, SK ν_e data, Cl and Ga CC data, and KamLAND data (ARAKI 05). CPT invariance is assumed. AHARMIM 05A also quotes $\theta=(33.9^{+2.4}_{-2.2})^\circ$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2 2 \;\theta=0.86^{+0.05}_{-0.06}$.
- 21 AHARMIM 05A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in figure 35a of AHARMIM 05A. AHARMIM 05A also quotes $\tan^2\theta=0.45 {+0.09 \atop 0.08}$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2\theta=0.86 {+0.05 \atop 0.07}$.
- 22 ARAKI 05 obtained this result by a two-neutrino oscillation analysis using KamLAND and solar neutrino data. CPT invariance is assumed. The 1σ error shown here is translated from the number provided by the KamLAND collaboration, $\tan^2\theta=0.40^{+0.07}_{-0.05}$. The corresponding number quoted in ARAKI 05 is $\tan^2\theta=0.40^{+0.10}_{-0.07}$ ($\sin^2\theta=0.82\pm0.07$), which envelops the 68% CL two-dimensional region.
- 23 The result given by AHMED 04A is $\theta=(32.5^{+1.7}_{-1.6})^{\circ}$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (EGUCHI 03). CPT invariance is assumed. AHMED 04A also quotes $\theta=(32.5^{+2.4}_{-2.3})^{\circ}$ as the error enveloping the 68% CL two-dimensional region. This translates into $\sin^2 2~\theta=0.82\pm0.06$.
- 24 AHMED 04A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 5(a) of AHMED 04A. The best-fit point is $\Delta(m^2)=6.5\times 10^{-5}~{\rm eV}^2, \tan^2\theta=0.40~(\sin^22~\theta=0.82).$
- 25 The result given by SMY 04 is $\tan^2\theta=0.44\pm0.08$. This result is obtained by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (IANNI 03). *CPT* invariance is assumed.
- 26 SMY 04 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The 1σ errors are read from Fig. 6(a) of SMY 04.
- 27 SMY 04 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data. The 1σ errors are read from Fig. 6(a) of SMY 04.
- 28 AHMAD 02B obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4(b) of AHMAD 02B. The best fit point is $\Delta(m^2)=5.0\times 10^{-5}~{\rm eV}^2$ and $\tan\theta=0.34~(\sin^2\!2~\theta=0.76).$
- 29 FUKUDA 02 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4 of FUKUDA 02. The best fit point is $\Delta(m^2) = 6.9 \times 10^{-5} \ \text{eV}^2$ and $\tan^2\theta = 0.38 \ (\sin^22 \ \theta = 0.80)$.

Δm_{21}^2

| VALUE (10 ⁻⁵ eV ²) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|-----------------------|-------|----------|---------------------------------------------|
| $7.50 {}^{+ 0.19}_{- 0.20}$ | $^{ m 1}$ gando | 11 | FIT | KamLAND $+$ solar: $3 u$ |
| • • • We do not u | se the following data | for a | verages, | fits, limits, etc. • • • |
| $7.6\ \pm0.2$ | ² ABE | 11 | FIT | KamLAND $+$ global solar: $2 u$ |
| $6.2 \begin{array}{c} +1.1 \\ -1.9 \end{array}$ | ³ ABE | 11 | FIT | global solar: $2 u$ |
| $7.7\ \pm0.3$ | ⁴ ABE | 11 | FIT | KamLAND $+$ global solar: $3 u$ |
| $6.0 \begin{array}{c} +2.2 \\ -2.5 \end{array}$ | ⁵ ABE | 11 | FIT | global solar: $3 u$ |
| $7.50 {}^{+ 0.16}_{- 0.24}$ | ⁶ BELLINI | 11A | FIT | $KamLAND + global \; solar \colon \; 2 u$ |
| $5.2 \begin{array}{c} +1.5 \\ -0.9 \end{array}$ | ⁷ BELLINI | 11A | FIT | global solar: $2 u$ |
| 7.49 ± 0.20 | ⁸ gando | 11 | FIT | KamLAND: $3 u$ |
| $7.59 {}^{+ 0.20}_{- 0.21}$ | 9,10 AHARMIM | 10 | FIT | $KamLAND + global \; solar \colon \; 2 \nu$ |
| $5.89 {}^{+ 2.13}_{- 2.16}$ | 9,11 AHARMIM | 10 | FIT | global solar: $2 u$ |
| 7.59 ± 0.21 | 9,12 AHARMIM | 10 | FIT | KamLAND $+$ global solar: $3 u$ |

| $6.31 {}^{+ 2.49}_{- 2.58}$ | ^{9,13} AHARMIM | 10 | FIT | global solar: $3 u$ |
|-------------------------------------------------|-----------------------------------------------|-----------|------------|----------------------------------------------------------------|
| $7.58^{+0.14}_{-0.13}\pm0.15$ | ¹⁴ ABE | 08A | FIT | KamLAND |
| 7.59 ± 0.21 | ¹⁵ ABE | 08A | FIT | KamLAND + global solar |
| $7.59 + 0.19 \\ -0.21$ | ¹⁶ AHARMIM | 08 | FIT | KamLAND + global solar |
| 8.0 ±0.3 8.0 ±0.3 | ¹⁷ HOSAKA ¹⁸ HOSAKA | 06 06 | FIT FIT | ${\sf KamLAND} + {\sf global solar} \\ {\sf SKAM+SNO+KamLAND}$ |
| $6.3 \begin{array}{c} +3.7 \\ -1.5 \end{array}$ | ¹⁹ HOSAKA | 06 | FIT | SKAM+SNO |
| 5-12 | ²⁰ HOSAKA | 06 | FIT | SKAM day/night in the LMA region |
| $8.0 \begin{array}{c} +0.4 \\ -0.3 \end{array}$ | ²¹ AHARMIM | 05 A | FIT | KamLAND + global solar LMA |
| 3.3-14.4 | ²² AHARMIM | 05 A | FIT | global solar |
| $7.9 \begin{array}{c} +0.4 \\ -0.3 \end{array}$ | ²³ ARAKI | 05 | FIT | KamLAND + global solar |
| $7.1 \begin{array}{c} +1.0 \\ -0.3 \end{array}$ | ²⁴ AHMED | 04 A | FIT | KamLAND + global solar |
| 3.2-13.7 | ²⁵ AHMED | 04 A | FIT | global solar |
| $7.1 \begin{array}{c} +0.6 \\ -0.5 \end{array}$ | ²⁶ SMY | 04 | FIT | KamLAND + global solar |
| $6.0 \begin{array}{c} +1.7 \\ -1.6 \end{array}$ | ²⁷ SMY | 04 | FIT | global solar |
| $6.0 \begin{array}{c} +2.5 \\ -1.6 \end{array}$ | ²⁸ SMY | 04 | FIT | SKAM + SNO |
| 2.8-12.0 3.2-19.1 | ²⁹ AH MAD ³⁰ FU KUDA | 02в 02 | FIT FIT | global solar global solar |
| | | | | |

- $^1\,\mbox{GANDO}\,11$ obtain this result with three-neutrino fit using the KamLAND + solar data. Supersedes ABE 08A.
- ²ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. CPT invariance is assumed.
- ³ ABE 11 obtained this result by a two-neutrino oscillation analysis using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, and SAGE data.
- 4 ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{32}^2 fixed to $2.4\times 10^{-3}~\rm eV^2$, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. The normal neutrino mass hierarchy and CPT invariance are assumed.
- 5 ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{32}^2 fixed to $2.4\times 10^{-3}~\rm eV^2$, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.
- ⁶ BELLINI 11A obtained this result by a two-neutrino oscillation analysis using KamLAND, Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal 743 24 (2011)) with the exception that the ⁸B flux was left free. CPT invariance is assumed.
- 7 assumed.
 7 BELLINI 11A obtained this result by a two-neutrino oscillation analysis using Homestake, SAGE, Gallex, GNO, Kamiokande, Super-Kamiokande, SNO, and Borexino (BELLINI 11A) data and the SSM flux prediction in SERENELLI 11 (Astrophysical Journal **743** 24 (2011)) with the exception that the ⁸B flux was left free.
- 8 GANDO 11 obtain this result with three-neutrino fit using the KamLAND data only. Supersedes ABE 08A.
- Supersedes ABE USA.

 9 AHARMIM 10 global solar neutrino data include SNO's low-energy-threshold analysis survival probability day/night curves, SNO Phase III integral rates (AHARMIM 08), CI (CLEVELAND 98), SAGE (ABDURASHITOV 09), Gallex/GNO (HAMPEL 99, ALT-MANN 05), Borexino (ARPESELLA 08A), SK-I zenith (HOSAKA 06), and SK-II day/night spectra (CRAVENS 08).
- 10 AHARMIM 10 obtained this result by a two-neutrino oscillation analysis using global solar neutrino data and KamLAND data (ABE 08A). CPT invariance is assumed.
- $^{11} \rm AHARMIM~10$ obtained this result by a two-neutrino oscillation analysis using global solar neutrino data. $^{12} \rm AHARMIM~10$ obtained this result by a three-neutrino oscillation analysis with the value
- 12 AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to 2.3×10^{-3} eV², using global solar neutrino data and KamLAND data (ABE 08A). *CPT* invariance is assumed.
- 13 AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to $^{2.3} \times 10^{-3}$ eV², using global solar neutrino data.
- 14 ABE 08A obtained this result by a rate + shape + time combined geoneutrino and reactor two-neutrino fit for Δm_{21}^2 and $\tan^2\theta_{12}$, using KamLAND data only.
- 15 ABE 08A obtained this result by means of a two-neutrino fit using KamLAND, Homestake, SAGE, GALLEX, GNO, SK (zenith angle and E-spectrum), the SNO χ^2 -map, and solar flux data. $\it CPT$ invariance is assumed.
- 16 AHARMIM 08 obtained this result by a two-neutrino oscillation analysis using all solar neutrino data including those of Borexino (ARPESELLA 08A) and Super-Kamiokande-I (HOSAKA 06), and KamLAND data (ABE 08A). CPT invariance is assumed.
- $^{17}\,\mathrm{HOSAKA}$ 06 obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLA ND data (ARAKI 05). CPT invariance is assumed.
- ¹⁸ HOSAKA 06 obtained this result by a two-neutrino oscillation analysis using the data from Super-Kamiokande, SNO (AHMAD 02 and AHMAD 02B), and KamLAND (ARAKI 05) experiments. CPT invariance is assumed.
- $^{19}\,\mathrm{HOSAKA}$ 06 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data.
- 20 HOSAKA 06 obtained this result from the consistency between the observed and expected day-night flux asymmetry amplitude. The listed 68% CL range is derived from the 1σ boundary of the amplitude fit to the data. Oscillation parameters are constrained to be in the LMA region. The mixing angle is fixed at $\tan^2\theta=0.44$ because the fit depends only very weekly on it.

Lepton Particle Listings Neutrino Mixing

- 21 AHARMIM 05a obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (ARAKI 05). $\it CPT$ invariance is assumed. AHARMIM 05a also quotes $\Delta(m^2)=(8.0^{+0.6}_{-0.4})\times 10^{-5}~eV^2$ as the error enveloping the 68% CL two-
- 22 AHARMIM 05A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in figure 35a of AHARMIM 05A. AHARMIM 05A also quotes $\Delta(m^2)=(6.5 \stackrel{+}{-} \frac{4.4}{2.3}) \times 10^{-5} \text{ eV}^2$ as the error enveloping the 68% CL two-...
- 23 ARAKI 05 obtained this result by a two-neutrino oscillation analysis using KamLAND and solar neutrino data. CPT invariance is assumed. The 1σ error shown here is provided by the KamLAND collaboration. The error quoted in ARAKI 05, $\Delta(m^2)=(7.9^+0.6)$ × 10^{-5} , envelops the 68% CL two-dimensional region.
- ²⁴ AHMED 04A obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (EGUCHI 03). CPT invariance is assumed. AHMED 04A also quotes $\Delta(\mathit{m}^2) = (7.1 ^{+}_{-0.6}^{+1.2}) \times 10^{-5} \ \text{eV}^2$ as the error enveloping the 68% CL twodimensional region.
- 25 AHMED 04A obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 5(a) of AHMED 04A. The best-fit point is $\Delta(m^2)=6.5\times 10^{-5}~{\rm eV}^2, \tan^2\theta=0.40~(\sin^22~\theta=0.82).$
- 26 SMY 04 obtained this result by a two-neutrino oscillation analysis using solar neutrino and KamLAND data (IANNI 03). CPT invariance is assumed.
- $27\,\text{SMY}$ 04 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The 1σ errors are read from Fig. 6(a) of SMY 04.
- 28 SMY 04 obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande and SNO (AHMAD 02 and AHMAD 02B) solar neutrino data. The 1σ errors are read from Fig. 6(a) of SMY 04.
- ²⁹AHMAD 02B obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4(b) of AHMAD 02B. The best fit point is $\Delta(m^2) = 5.0 \times 10^{-5} \ \text{eV}^2 \ \text{and} \ \tan \theta = 0.34 \ (\sin^2 \! 2 \ \theta = 0.76).$
- 30 FUKUDA 02 obtained this result by a two-neutrino oscillation analysis using the data from all solar neutrino experiments. The listed range of the parameter envelops the 95% CL two-dimensional region shown in Fig. 4 of FUKUDA 02. The best fit point is $\Delta(m^2)$ $= 6.9 \times 10^{-5} \text{ eV}^2 \text{ and } \tan^2 \theta = 0.38 \text{ (sin}^2 2 \theta = 0.80).$

$\sin^{2}(2\theta_{23})$

The ranges below correspond to the projection onto the $\sin^2(2\theta_{23})$ axis of the 90% CL contours in the $\sin^2(2\theta_{23}) - \Delta m_{32}^2$ plane presented by the authors. The values are reported with one standard deviation uncertainty.

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------------|---------------------------------|-----------|---------------------------------|
| >0.95 | ¹ ABE 11c | SKAM | Super-Kamiokande |
| • • • We do | o not use the following data fo | r average | s, fits, limits, etc. • • • |
| >0.90 | ADAMSON 11 | MINS | 2 u oscillation; maximal mixing |

| | · · | | | |
|-------------------------------------------------------|--------------------------|-----------|--------------|------------------------------------------------------|
| >0.90 | ADAMSON | 11 | MINS | 2 u oscillation; maximal mixing |
| $\begin{array}{cc} 0.86 & +0.11 \\ -0.12 \end{array}$ | ² ADAMSON | 11в | MINS | $\overline{ u}$ beam |
| >0.965 | ³ WENDELL | 10 | SKAM | $3 u$ oscillation with solar terms; $	heta_{13}{=}0$ |
| >0.95 | ⁴ WENDELL | 10 | SKAM | 3 u oscillation; normal mass hierarchy |
| >0.93 >0.85 | 5 WENDELL ADAMSON | 10 08A | SKAM MINS | 3 u oscillation; inverted mass hierarchy MINOS |
| >0.85 | ⁶ ADAMSON | 06A | MINS | atmospheric ν with far detector |
| >0.59 | ⁷ AHN | 06A | K2K | KEK to Super-K |
| >0.7 | ⁸ MICHAEL | 06 | MINS | MINOS |
| >0.58 | ⁹ ALIU | 05 | K2K | KEK to Super-K |
| >0.6 | ¹⁰ ALLISON | 05 | SOU2 | |
| >0.92 | 11 ASHIE | 05 | SKAM | Super-Kamiokande |
| >0.80 | ¹² AMBROSIO | 04 | MCRO | MACRO |
| >0.90 | 13 A SHIE | 04 | SKAM | L/E distribution |
| >0.30 | ¹⁴ AHN | 03 | K2K | KEK to Super-K |
| >0.45 | ¹⁵ AMBROSIO | 03 | MCRO | MACRO |
| >0.77 | ¹⁶ AMBROSIO | 03 | MCRO | MACRO |
| >0.50 | ¹⁷ SANCHEZ | 03 | SOU2 | Soudan-2 Atmospheric |
| >0.80 | ¹⁸ AMBROSIO | 01 | MCRO | upward μ |
| >0.82 | ¹⁹ AMBROSIO | 01 | MCRO | upward μ |
| >0.45 | ²⁰ FUKUDA | 99c | SKAM | upward μ |
| >0.70 | ²¹ FUKUDA | 99D | SKAM | upward μ |
| >0.30 | ²² FUKUDA | 99D | SKAM | stop μ / through |
| >0.82 | ²³ FUKUDA | 98c | SKAM | Super-Kamiokande |
| >0.30 | ²⁴ HATAKEYAMA | | KAMI | Kamiokande |
| >0.73 | ²⁵ HATAKEYAMA | 198 | KAMI | Kamiokande |
| >0.65 | ²⁶ FUKUDA | 94 | KAMI | Kamiokande |
| | | | | |

- $^1\,\text{ABE}$ 11c obtained this result by a two-neutrino oscillation analysis using the Super-Kamiokande-I+II+III atmospheric neutrino data. ABE 11c also reported results under
- Kamiokande-|+||+||| atmospheric neutrino data. ABE 11c also reported results under a two-neutrino disappearance model with separate mixing parameters between ν and $\overline{\nu}$, and obtained $\sin^2 2\theta > 0.93$ for ν and $\sin^2 2\theta > 0.83$ for $\overline{\nu}$ at 90% C.L. ² ADAMSON 118 obtained this result by a two-neutrino oscillation analysis of antineutrinos in an antineutrino enhanced beam with 1.71×10^{20} protons on target. This results is consistent with the neutrino measurements of ADAMSON 11 at 2% C.L. ³ WENDELL 10 obtained this result ($\sin^2 \theta_{23} = 0.407-0.583$) by a three-neutrino oscillation analysis using the Super-Kamiokande-|+||+||| atmospheric neutrino data, assuming
- $heta_{13}=0$ but including the solar oscillation parameters Δm_{21}^2 and $\sin^2 heta_{12}$ in the fit.

- 4 WENDELL 10 obtained this result ($\sin^2 \theta_{23} = 0.43$ –0.61) by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m_{21}^2=0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.
- 5 WENDELL 10 obtained this result (sin $^2\theta_{23} =$ 0.44–0.63) by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m_{21}^2=0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.
- 6 ADAMSON 06 obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 4.54 kton yr atmospheric neutrino data with the MINOS far detector.
- ⁷ Supercedes ALIU 05.
- 8 MICHAEL 06 best fit is for maximal mixing. See also ADAMSON 08.
- ⁹The best fit is for maximal mixing.
- $^{
 m 10}$ ALLISON 05 result is based upon atmospheric neutrino interactions including upwardstopping muons, with an exposure of 5.9 kton yr. From a two-flavor oscillation analysis the best-fit point is $\Delta m^2=0.0017~{\rm eV}^2$ and $\sin^2(2\theta)=0.97$.
- $^{11}{\rm ASHIE}$ 05 obtained this result by a two-neutrino oscillation analysis using 92 kton yr atmospheric neutrino data from the complete Super-Kamiokande I running period.
- 12 AMBROSIO 04 obtained this result, without using the absolute normalization of the neutrino flux, by combining the angular distribution of upward through-going muon tracks with ${\it E}_{\mu} > 1$ GeV, ${\rm N}_{low}$ and ${\rm N}_{high}$, and the numbers of inDown + UpStop and inUp events. Here, N_{low} and N_{high} are the number of events with reconstructed neutrino energies < 30 GeV and > 130 GeV, respectively. InDown and InUp represent events with downward and upward-going tracks starting inside the detector due to neutrino interactions, while Up stop represents entering upward-going tracks which stop in the detector. The best fit is for maximal mixing.
- 13 ASHIE 04 obtained this result from the L(flight length)/E(estimated neutrino energy) distribution of ν_{μ} disappearance probability, using the Super-Kamiokande-I 1489 live-day atmospheric neutrino data.
- $^{14}\,\mathrm{There}$ are several islands of allowed region from this K2K analysis, extending to high values of Δm^2 . We only include the one that overlaps atmospheric neutrino analyses. The best fit is for maximal mixing.
- $^{15}\,\mathrm{A\,MB\,ROSIO}$ 03 obtained this result on the basis of the ratio R $=\,\mathrm{N}_{low}/\mathrm{N}_{high}$, where N_{low} and N_{high} are the number of upward through-going muon event reconstructed neutrino energy < 30 GeV and > 130 GeV, respectively. The data came from the full detector run started in 1994. The method of FELDMAN 98 is used to obtain
- 16 AMBROSIO 03 obtained this result by using the ratio R and the angular distribution of the upward through-going muons. R is given in the previous note and the angular distribution is reported in AMBROSIO 01. The method of FELDMAN 98 is used to obtain the limits. The best fit is to maximal mixing.
- 17 SANCHEZ 03 is based on an exposure of 5.9 kton yr. The result is obtained using a likelihood analysis of the neutrino L/E distribution for a selection μ flavor sample while the e-flavor sample provides flux normalization. The method of FELDMAN 98 is used to obtain the allowed region. The best fit is $\sin^2(2\theta)=0.97$.
- 18 A MB ROSIO 01 result is based on the angular distribution of upward through-going muon tracks with $E_{\mu} > 1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration is 6.17 years. The best fit is obtained outside the physical region. The method of FELDMAN 98 is used to obtain the limits. The best fit is for maximal mixing.
- $^{
 m 19}$ AMBROSIO 01 result is based on the angular distribution and normalization of upward through-going muon tracks with $E_{\mu}~>1$ GeV. See the previous footnote
- ²⁰ FU KUDA 99c obtained this result from a total of 537 live days of upward through-going muon data in Super-Kamiokande between April 1996 to January 1998. With a threshold of E $_{\mu}$ > 1.6 GeV, the observed flux is $(1.74\pm0.07\pm0.02)\times10^{-13}$ cm $^{-2}$ s $^{-1}$ sr $^{-1}$ The best fit is $\sin^2(2\theta) = 0.95$.
- 21 FU KUDA 990 obtained this result from a simultaneous fitting to zenith angle distributions of upward-stopping and through-going muons. The flux of upward-stopping muons of minimum energy of 1.6 GeV measured between April 1996 and January 1998 is (0.39 \pm $0.04\pm0.02)\times10^{-13}$ cm $^{-2}$ s $^{-1}$ sr $^{-1}$. This is compared to the expected flux of (0.73 \pm 0.16 (theoretical error)) $\times 10^{-13}$ cm $^{-2}$ s $^{-1}$ sr $^{-1}$. The best fit is to maximal mixing.
- $^{22}{\rm FU\,KUDA}$ 990 obtained this result from the zenith dependence of the upward-stopping/through-going flux ratio. The best fit is to maximal mixing.
- $^{23}\,\mathrm{FU\,KUDA}$ 98c obtained this result by an analysis of 33.0 kton yr atmospheric neutrino data. The best fit is for maximal mixing.
- 24 HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_{\mu} > 1.6$ GeV, the observed flux of upward through-going muons is $(1.94 \pm 0.10 + 0.07) \times (1.94 \pm 0.07) \times (1.$ 10^{-13} cm $^{-2}$ s $^{-1}$ sr $^{-1}$. This is compared to the expected flux of (2.46 \pm 0.54 (theoretical error)) $\times 10^{-13}~\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$. The best fit is for maximal mixing.
- $^{25}\,\mathrm{HATAKEYAMA}$ 98 obtained this result from a combined analysis of Kamiokande contained events (FUKUDA 94) and upward going muon events. The best fit is $\sin^2(2\theta) =$
- 26 FU KUDA 94 obtained the result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande. The best fit is for maximal mixing.

Δm_{32}^2

The sign of Δm_{32}^2 is not known at this time. Only the absolute value is quoted below. Unless otherwise specified, the ranges below correspond to the projection onto the Δm_{32}^2 axis of the 90% CL contours in the $\sin^2(2\theta_{23}) - \Delta m_{32}^2$ plane presented by the authors. The values are reported with one standard deviation uncertainty.

VALUE (10-3 eV2) $2.32 + 0.12 \\ -0.08$

DOCUMENT ID TECN COMMENT

Neutrino Mixing

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

| | 1.3 - 4.0 | ¹ ABE | 110 | SKAM | atmospheric $\overline{ u}$ |
|---|-----------------------------|---------------------------|-----|------|------------------------------------|
| | $3.36 {}^{+ 0.46}_{- 0.40}$ | ² ADAMSON | 11в | MINS | $\overline{ u}$ beam |
| < | <3.37 | ³ ADAMSON | 11∈ | MINS | MINOS |
| | 1.9 - 2.6 | ⁴ WENDELL | 10 | SKAM | 3 u osc.; normal mass hierarchy |
| | 1.7 - 2.7 | ⁴ WENDELL | 10 | SKAM | 3 u osc.; inverted mass hierarchy |
| | 2.43 ± 0.13 | ADAMSON | 08A | MINS | MINOS |
| | 0.07-50 | ⁵ ADAMSON | 06 | MINS | atmospheric $ u$ with far detector |
| | 1.9-4.0 | 6,7 AHN | 06A | K2K | KEK to Super-K |
| | 2.2-3.8 | ⁸ MICHAEL | 06 | MINS | MINOS |
| | 1.9-3.6 | ⁶ ALIU | 05 | K2K | KEK to Super-K |
| 0 | .3-12 | ⁹ ALLISON | 05 | SOU2 | |
| | 1.5-3.4 | ¹⁰ ASHIE | 05 | SKAM | atmospheric neutrino |
| | 0.6-8.0 | ¹¹ AMBROSIO | 04 | MCRO | MACRO |
| | 1.9 to 3.0 | 12 ASHIE | 04 | SKAM | L/E distribution |
| | 1.5-3.9 | ¹³ AHN | 03 | K2K | KEK to Super-K |
| | 0.25-9.0 | ¹⁴ AMBROSIO | 03 | MCRO | MACRO |
| | 0.6-7.0 | ¹⁵ AMBROSIO | 03 | MCRO | MACRO |
| | 0.15-15 | 16 SANCHEZ | 03 | SOU2 | Soudan-2 Atmospheric |
| | 0.6-15 | ¹⁷ AMBROSIO | 01 | MCRO | upward μ |
| | 1.0-6.0 | ¹⁸ AMBROSIO | 01 | MCRO | upward μ |
| | 1.0-50 | ¹⁹ FUKUDA | 99c | SKAM | upward μ |
| | 1.5-15.0 | ²⁰ FUKUDA | 99D | SKAM | upward μ |
| | 0.7-18 | ²¹ FUKUDA | 99D | SKAM | stop μ / through |
| | 0.5-6.0 | ²² FUKUDA | | SKAM | Super-Kamiokande |
| | 0.55-50 | ²³ HATAKEYAMA | 98 | KAMI | Kamiokande |
| | 4-23 | ²⁴ HATAKEYA MA | 98 | KAMI | Kamiokande |
| | 5-25 | ²⁵ FUKUDA | 94 | KAMI | Kamiokande |
| | | | | | |

- 1 ABE 11c obtained this result by a two-neutrino oscillation analysis with separate mixing parameters between neutrinos and antineutrinos, using the Super-Kamiokande-I+II+III atmospheric neutrino data. The corresponding 90% CL neutrino oscillation parameter range obtained from this analysis is $\Delta m^2=1.7-3.0\times 10^{-3}~{\rm eV}^2$.
- 2 ADAMSON 118 obtained this result by a two-neutrino oscillation analysis of antineutrinos in an antineutrino enhanced beam with 1.71×10^{20} protons on target. This results is consistent with the neutrino measurements of ADAMSON 11 at 2% C.L.
- 3 ADAMSON 11c obtains this result based on a study of antineutrinos in a neutrino beam and assumes maximal mixing in the two-flavor approximation.
- 4 WENDELL 10 obtained this result by a three-neutrino oscillation analysis with one mass scale dominance ($\Delta m_{21}^2=0$) using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.
- 5 ADAMSON 06 obtained this result by a two-neutrino oscillation analysis of the L/E distribution using 4.54 kton yr atmospheric neutrino data with the MINOS far detector.
- ⁶ The best fit in the physical region is for $\Delta m^2 = 2.8 \times 10^{-3} \text{ eV}^2$.
- Supercedes ALIU 05
- 8 MICHAEL 06 best fit is $2.74\times 10^{-3}~\text{eV}^2.$ See also ADAMSON 08.
- ⁹ALLISON 05 result is based on an atmospheric neutrino observation with an exposure of 5.9 kton yr. From a two-flavor oscillation analysis the best-fit point is $\Delta m^2 = 0.0017$ eV² and $\sin^2 2 \theta = 0.97$.
- 10 ASHIE 05 obtained this result by a two-neutrino oscillation analysis using 92 kton yr atmospheric neutrino data from the complete Super-Kamiokande I running period. The best fit is for $\Delta m^2 = 2.1 \times 10^{-3} \ eV^2$.
- 11 AMBROSIO 04 obtained this result, without using the absolute normalization of the neutrino flux, by combining the angular distribution of upward through-going muon tracks with $E_{\mu} > 1$ GeV, N_{low} and N_{high} , and the numbers of InDown + UpStop and InUp events. Here, N_{low} and N_{high} are the number of events with reconstructed neutrino energies < 30 GeV and > 130 GeV, respectively. InDown and InUp represent events with downward and upward-going tracks starting inside the detector due to neutrino interactions, while UpStop represents entering upward-going tracks which stop in the detector. The best fit is for $\Delta m^2 = 2.3 \times 10^{-3} \ {\rm eV}^2$.
- $^{12}\text{ASHIE}$ 04 obtained this result from the L(flight length)/E(estimated neutrino energy) distribution of ν_{μ} disappearance probability, using the Super-Kamiokande-I 1489 live-day atmospheric neutrino data. The best fit is for $\Delta m^2=2.4\times 10^{-3}~\text{eV}^2.$
- 13 There are several islands of allowed region from this K2K analysis, extending to high values of Δm^2 . We only include the one that overlaps atmospheric neutrino analyses. The best fit is for $\Delta m^2=2.8\times 10^{-3}~\text{eV}^2.$
- 14 AMBROSIO 03 obtained this result on the basis of the ratio R = N_{low}/N_{high}, where N_{low} and N_{high} are the number of upward through-going muon events with reconstructed neutrino energy < 30 GeV and > 130 GeV, respectively. The data came from the full detector run started in 1994. The method of FELDMAN 98 is used to obtain the limits. The best fit is for $\Delta m^2 = 2.5 \times 10^{-3} \ \mbox{eV}^2$.
- 15 AMBROSIO 03 obtained this result by using the ratio R and the angular distribution of the upward through-going muons. R is given in the previous note and the angular distribution is reported in AMBROSIO 01. The method of FELDMAN 98 is used to obtain the limits. The best fit is for $\Delta m^2=2.5\times 10^{-3}~\text{eV}^2.$
- 16 SANCHEZ 03 is based on an exposure of 5.9 kton yr. The result is obtained using a likelihood analysis of the neutrino L/E distribution for a selection μ flavor sample while the e-flavor sample provides flux normalization. The method of FELDMAN 98 is used to obtain the allowed region. The best fit is for $\Delta m^2 = 5.2 \times 10^{-3} \ eV^2$.
- 17 AMBROSIO 01 result is based on the angular distribution of upward through-going muon tracks with $E_{\mu}>1$ GeV. The data came from three different detector configurations, but the statistics is largely dominated by the full detector run, from May 1994 to December 2000. The total live time, normalized to the full detector configuration is 6.17 years. The best fit is obtained outside the physical region. The method of FELDMAN 98 is used to obtain the limits.

- 18 AMBROSIO 01 result is based on the angular distribution and normalization of upward through-going muon tracks with $E_{\mu}~>1$ GeV. See the previous footnote.
- 19 FUKUDA 99c obtained this result from a total of 537 live days of upward through-going muon data in Super-Kamiokande between April 1996 to January 1998. With a threshold of $E_{\mu} > 1.6$ GeV, the observed flux is $(1.74 \pm 0.07 \pm 0.02) \times 10^{-13}$ cm $^{-2}$ s $^{-1}$ sr $^{-1}$. The best fit is for $\Delta m^2 = 5.9 \times 10^{-3}$ eV 2 .
- 20 FUKUDA 990 obtained this result from a simultaneous fitting to zenith angle distributions of upward-stopping and through-going muons. The flux of upward-stopping muons of minimum energy of 1.6 GeV measured between April 1996 and January 1998 is $(0.39\pm0.04\pm0.02)\times10^{-13}$ cm $^{-2}s^{-1}sr^{-1}$. This is compared to the expected flux of (0.73 ± 0.16) (theoretical error)) $\times10^{-13}$ cm $^{-2}s^{-1}sr^{-1}$. The best fit is for $\Delta m^2=3.9\times10^{-3}$ eV².
- $^{21}\text{FUKUDA}$ 99D obtained this result from the zenith dependence of the upward-stopping/through-going flux ratio. The best fit is for $\Delta m^2=3.1\times 10^{-3}~\text{eV}^2$.
- 22 FUKUDA 98c obtained this result by an analysis of 33.0 kton yr atmospheric neutrino data. The best fit is for $\Delta m^2=2.2\times 10^{-3}$ eV 2 .
- ²³ HATAKEYAMA 98 obtained this result from a total of 2456 live days of upward-going muon data in Kamiokande between December 1985 and May 1995. With a threshold of $E_{\mu}>1.6$ GeV, the observed flux of upward through-going muons is $(1.94\pm0.10^{+0.07}_{-0.06})\times10^{-13}$ cm $^{-2}{\rm s}^{-1}{\rm s}^{-1}$. This is compared to the expected flux of $(2.46\pm0.54$ (theoretical error)) $\times10^{-13}$ cm $^{-2}{\rm s}^{-1}{\rm s}^{-1}$. The best fit is for $\Delta m^2=2.2\times10^{-3}$ eV².
- 24 HATAKEYAMA 98 obtained this result from a combined analysis of Kamiokande contained events (FUKUDA 94) and upward going muon events. The best fit is for $\Delta m^2=13\times 10^{-3}~\text{eV}^2.$
- 25 FUKUDA 94 obtained the result by a combined analysis of sub- and multi-GeV atmospheric neutrino events in Kamiokande. The best fit is for $\Delta m^2=16\times 10^{-3}~{\rm eV}^2$.

$\sin^2(2\theta_{13})$

At present time direct measurements of $\sin^2(2\,\theta_{13})$ are derived from the reactor $\overline{\nu}_e$ disappearance at distances corresponding to the Δm_{32}^2 value, i.e. L $\sim \,$ 1km. Alternatively, limits can also be obtained from the analysis of the solar neutrino data and accelerator-based $\nu_\mu \to \, \nu_e$ experiments.

| VALUE | CL % | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|--------|------------------|----|------|-------------------------------|
| 0.098±0.013 OUR A | /ERAGE | . | | | |
| $0.086 \pm 0.041 \pm 0.030$ | 1 | ABE | 12 | DCHZ | Chooz reactors |
| $0.113 \pm 0.013 \pm 0.019$ | 2 | ² AHN | 12 | RENO | Yonggwang reactors |
| $0.092\!\pm\!0.016\!\pm\!0.005$ | 3 | ³ A N | 12 | DAYA | Daya Bay, Ling Ao, Ling Ao-II |

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| | | = | _ | | |
|----------------------------------------------------------|----------|--------------------------------------------|----------|------|---------------------------------------------|
| $0.098 \! \begin{array}{l} +0.067 \\ -0.062 \end{array}$ | 68 | ⁴ ABE | 11 | FIT | KamLAND + global solar |
| < 0.23 | 95 | ⁵ ABE | 11 | FIT | Global solar |
| 0.05 - 0.21 | 68 | ⁶ ABE | 11A | T2K | Normal mass hierarchy |
| 0.06 - 0.25 | 68 | ⁷ ABE | 11A | T2K | Inverted mass hierarchy |
| 0.01 - 0.09 | 68 | ⁸ ADAMSON | 11 D | MINS | Normal mass hierarchy |
| 0.03 - 0.15 | 68 | ⁹ ADAMSON | 11 D | MINS | Inverted mass hierarchy |
| $0.08\ \pm0.03$ | 68 | ¹⁰ FOGLI | 11 | FIT | Global neutrino data |
| 0.078 ± 0.062 | 68 | ¹¹ GANDO | 11 | FIT | KamLAND $+$ solar: $3 u$ |
| 0.124 ± 0.133 | 68 | ¹² gando | 11 | FIT | KamLAND: $3 u$ |
| $0.03 \ ^{+ 0.09}_{- 0.07}$ | 90 | ¹³ ADAMSON | 10A | MINS | Normal mass hierarchy |
| $0.06 \ ^{+ 0.14}_{- 0.06}$ | 90 | ¹⁴ ADAMSON | 10A | MINS | Inverted mass hierarchy |
| $0.08 \begin{array}{l} +0.08 \\ -0.07 \end{array}$ | 15 | ^{,16} AHARMIM | 10 | FIT | $KamLAND + global \; solar \colon \; 3 \nu$ |
| < 0.30 | 9515 | ^{,17} AHARMIM | 10 | FIT | global solar: $3 u$ |
| < 0.15 | 90 | ¹⁸ WENDELL | 10 | SKAM | $3 u$ osc.; normal \emph{m} hierarchy |
| < 0.33 | 90 | ¹⁸ WENDELL | 10 | SKAM | $3 u$ osc.; inverted \emph{m} hierarchy |
| $0.11 \begin{array}{c} +0.11 \\ -0.08 \end{array}$ | | ¹⁹ ADAMSON | 09 | MINS | Normal mass hierarchy |
| $0.18 \begin{array}{l} +0.15 \\ -0.11 \end{array}$ | | ²⁰ ADAMSON | 09 | MINS | Inverted mass hierarchy |
| $0.06\ \pm0.04$ | | ²¹ FOGLI | 80 | FIT | Global neutrino data |
| 0.08 ± 0.07 | | ²² FOGLI | 80 | FIT | Solar + KamLAND data |
| 0.05 ±0.05 | | ²³ FOGLI | 80 | FIT | Atmospheric+LBL+CHOOZ |
| < 0.36 | 90 | 24 YA MA MOTO | 06 | K2K | Accelerator experiment |
| < 0.48 | 90 | 25 AHN 26 DOELLA | 04 | K2K | Accelerator experiment |
| < 0.36 | 90 90 | ²⁶ ВОЕНМ ²⁷ ВОЕНМ | 01 | | Palo Verde react. |
| < 0.45 < 0.15 | 90 | 28 APOLLONIO | 00 99 | CHOZ | Palo Verde react. Reactor Experiment |
| V 0.13 | 50 | AF OLLOWIO | 22 | CHOZ | Reactor Experiment |

- 1 ABE 12 determine the $\overline{\nu}_e$ interaction rate in a single detector, located 1050 m from the cores of two reactors. The rate normalization is fixed by the results of the Bugey4 reactor experiment, thus avoiding any dependence on possible very short baseline oscillations. The value of $\Delta m_{31}^2=2.4\times 10^{-3}~\text{eV}^2$ is used in the analysis.
- 2 AHN 12 use two identical detectors, placed at flux weighted distances of 408.56 m and 1433.99 m from six reactor cores, to determine the mixing angle θ_{13} . This rate-only analysis excludes the no-oscillation hypothesis at 4.9 standard deviations. The value of $\Delta m_{31}^2 = (2.32 \pm 0.12^{+0.12}_{-0.08}) \times 10^{-3} \ \text{eV}^2$ was assumed in the analysis.

- $^3\,\mathrm{A\,N}$ 12 use six identical detectors with three placed near the reactor cores (flux-weighted baselines of 470 m and 576 m) and the remaining three at the far hall (at the flux averaged distance of 1648 m from all six reactor cores) to determine the mixing angle θ_{13} using the \overline{v}_e observed interaction rate ratios. This rate-only analysis excludes the no-oscillation hypothesis at 5.2 standard deviations. The value of $\Delta m^2_{31}=(2.32^{+0.12}_{-0.08})\times 10^{-3}~{\rm eV}^2$ was assumed in the analysis.
- ⁴ ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{32}^2 fixed to 2.4×10^{-3} eV², using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, GALLEX/GNO, SAGE, and KamLAND data. This result implies an upper bound of $\sin^2\!\theta_{13} < 0.059$ (95% CL) or $\sin^2\!2\theta_{13} < 0.22$ (95% CL). The normal neutrino mass hierarchy and CPT invariance are assumed.
- 5 ABE 11 obtained this result by a three-neutrino oscillation analysis with the value of Δm^2_{32} fixed to $2.4\times 10^{-3}~{\rm eV}^2$, using solar neutrino data including Super-Kamiokande, SNO, Borexino (ARPESELLA 08A), Homestake, and GALLEX/GNO data. The normal neutrino mass hierarchy is assumed.
- 6 The quoted limit is for $\Delta m^2_{32}=2.4\times 10^{-3}$ eV 2 , $\theta_{23}=\pi/2$, $\delta=$ 0, and the normal mass hierarchy. For other values of δ , the 68% region spans from 0.03 to 0.25, and the 90% region from 0.02 to 0.32.
- 7 The quoted limit is for $\Delta m_{32}^2=2.4\times 10^{-3}$ eV², $\theta_{23}=\pi/2$, $\delta=$ 0, and the inverted mass hierarchy. For other values of δ , the 68% region spans from 0.04 to 0.30, and the 90% region from 0.02 to 0.39.
- 8 The quoted limit is for $\Delta m_{32}^{2}=2.32\times10^{-3}~\rm{eV^{2}},~\theta_{23}=\pi/2,~\delta=0,$ and the normal mass hierarchy. For other values of δ , the 68% region spans from 0.02 to 0.12, and the 90% region from 0 to 0.16.
- 9 The quoted limit is for $\Delta m_{32}^2=2.32\times 10^{-3}~{\rm eV^2},\, \theta_{23}=\pi/2,\, \delta=0,$ and the inverted mass hierarchy. For other values of δ , the 68% region spans from 0.02 to 0.16, and the 90% region from 0 to 0.21.
- $^{
 m 10}$ FOGLI 11 obtained this result from an analysis using the atmospheric, accelerator long baseline, CHOOZ, solar, and KamLAND data. Recently, MUELLER 11 suggested an average increase of about 3.5% in normalization of the reactor v_e fluxess, and using these fluxes, the fitted result becomes 0.10 ± 0.03 . 11 GANDO 11 report $\sin^2\theta_{13}=0.020\pm0.016$. This result was obtained with three-neutrino fit using the KamLAND + solar data.
- 12 GANDO 11 report $\sin^2\theta_{13}=0.032\pm0.037$. This result was obtained with three-neutrino fit using the KamLAND data only.
- 13 This result corresponds to the limit of <0.12 at 90% CL for $\Delta m_{32}^2=2.43\times 10^{-3}~{\rm eV}^2,$ $\theta_{23}=\pi/2,$ and $\delta=0.$ For other values of δ , the 90% CL region spans from 0.16.
- ¹⁴This result corresponds to the limit of <0.20 at 90% CL for $\Delta m_{32}^2=2.43\times 10^{-3}$ eV², $heta_{23}=\pi/2$, and $\delta=0$. For other values of δ , the 90% CL region spans from 0 to 0.21.
- 32 A M/2, and 6 B of North Mark and 6 B, and
- ¹⁶ AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to 2.3×10^{-3} eV², using global solar neutrino data and KamLAND data (ABE 08A). CPT invariance is assumed. This result implies an upper bound of $\sin^2 \theta_{13} < \cos^2 \theta_{13}$ 0.057 (95% CL) or $\sin^2 2\theta_{13} <$ 0.22 (95% CL).
- 17 AHARMIM 10 obtained this result by a three-neutrino oscillation analysis with the value of Δm_{31}^2 fixed to $2.3\times 10^{-3}~\text{eV}^2$, using global solar neutrino data.
- 18 WENDELL 10 obtained this result by a three-neutrino oscillation analysis with one mass scale dominance $(\Delta m_{21}^2=0)$ using the Super-Kamiokande-I+II+III atmospheric neutrino data, and updates the HOSAKA 06A result.
- 19 The quoted limit is for $\Delta m^2_{32}=2.43\times 10^{-3}~\rm eV^2,~\theta_{23}=\pi/2,$ and $\delta=0.$ For other values of $\delta,$ the 68% CL region spans from 0.02 to 0.26.
- 20 The quoted limit is for $\Delta m_{32}^2=2.43\times 10^{-3}~\rm eV^2,~\theta_{23}=\pi/2$, and $\delta=0.$ For other values of δ , the 68% CL region spans from 0.04 to 0.34.
- $^{21}\,\text{FOGLI}$ 08 obtained this result from a global analysis of all neutrino oscillation data, that is, solar + KamLAND + atmospheric + accelerator long baseline + CHOOZ.
- $^{22}\mathsf{FOGLI}$ 08 obtained this result from an analysis using the solar and KamLAND neutrino
- ²³FOGLI 08 obtained this result from an analysis using the atmospheric, accelerator long baseline, and CHOOZ neutrino oscillation data.
- 24 YAMAMOTO 06 searched for $u_{\mu}
 ightarrow
 u_{e}$ appearance. Assumes $2 \sin^{2}(2 heta_{\mu\,e}) =$ $\sin^2(2\theta_{13})$. The quoted limit is for $\Delta m_{32}^2 = 1.9 \times 10^{-3} \text{ eV}^2$. That value of Δm_{32}^2 is the one- σ low value for AHN 06A. For the AHN 06A best fit value of $2.8\times10^{-3}~{\rm eV}^2$, the $\sin^2(2\theta_{13})$ limit is < 0.26. Supersedes AHN 04.
- 25 AHN 04 searched for $u_{\mu}
 ightarrow \;
 u_e$ appearance. Assuming 2 $\sin^2(2\; heta_{\mu_e}) = \sin^2(2\; heta_{13})$, a limit on sin² $(2 \ \theta_{\mu_2})$ is converted to a limit on sin² $(2 \ \theta_{13})$. The quoted limit is for $\Delta m_{32}^2 = 1.9 \times 10^{-3} \ \text{eV}^2$. That value of Δm_{32}^2 is the one- σ low value for ALIU 05. For the ALIU 05 best fit value of $2.8 \times 10^{-3} \ \text{eV}^2$, the $\sin^2(2 \ \theta_{13})$ limit is < 0.30.
- ²⁶The quoted limit is for $\Delta m_{32}^2=1.9\times 10^{-3}~{\rm eV}^2$. That value of Δm_{32}^2 is the 1- σ low value for ALIU 05. For the ALIU 05 best fit value of 2.8 \times 10 $^{-3}$ eV 2 , the $\sin^2 2 \, \theta_{13}$ limit is < 0.19. In this range, the θ_{13} limit is larger for lower values of Δm_{32}^2 , and smaller for higher values of Δm_{32}^2 .
- 27 The quoted limit is for $\Delta m^2_{32}=1.9\times 10^{-3}~\text{eV}^2.$ That value of Δm^2_{32} is the 1- σ low value for ALIU 05. For the ALIU 05 best fit value of $2.8 \times 10^{-3} \text{ eV}^{2}$, the $\sin^2 2 \theta_{13}$
- 28 The quoted limit is for $\Delta m^2_{32}=$ 2.43 $\times\,10^{-3}$ eV 2 . That value of Δm^2_{32} is the central the $\sin^2 2\,\theta_{13}$ limit is < 0.16. See also APOLLONIO 03 for a detailed description of the experiment.

(C) Other neutrino mixing results

The LSND collaboration reported in AGUILAR 01 a signal which is consistent with $\overline{
u}_{\mu}
ightarrow \overline{
u}_e$ oscillations. In a three neutrino framework, this would be a measurement of θ_{12} and Δm_{21}^2 . This does not appear to be consistent with the interpretation of other neutrino data. The MiniBooNE expersions iment, reported in AGUILAR-AREVALO 07, does a two-neutrino analysis which, assuming $\it CPT$ conservation, rules out AGUILAR 01. The following listings include results which might be relevant towards understanding these observations. They include searches for $\nu_{\mu} o \; \nu_e, \overline{\nu}_{\mu} o \; \overline{\nu}_e$, sterile neutrino oscillations, and $\ensuremath{\mathit{CPT}}$ violation.

$\Delta(m^2)$ for $\sin^2(2\theta)=1~(u_{\mu} ightarrow~ u_e)$

| • • • We do not us | se the followin | g data for averages, fits, limits, etc. • • • |
|--------------------|-----------------|------------------------------------------------------------------------|
| < 0.034 | 90 | AGUILAR-AR07 MBOO MiniBooNE |
| < 0.0008 | 90 | AHN 04 K2K Water Cherenkov |
| < 0.4 | 90 | ASTIER 03 NOMD CERN SPS |
| < 2.4 | 90 | AVVAKUMOV 02 NTEV NUTEV FNAL |
| | | ¹ AGUILAR 01 LSND $\nu\mu \rightarrow \nu_{\rho}$ osc.prob. |
| 0.03 to 0.3 | 95 | 2 ATHANASSO98 LSND $ u_{\mu} ightarrow u_{e}$ |
| <2.3 | 90 | ³ LOVERRE 96 CHARM/CDHS |
| < 0.9 | 90 | VILAIN 94c CHM2 CERN SPS |
| ∠0.09 | 9.0 | ANGELINI 86 HIRC BERCCERNIPS |

- $^{
 m 1}$ AGUILAR 01 is the final analysis of the LSND full data set. Search is made for the $u_{\mu}
 ightarrow \
 u_{e}$ oscillations using u_{μ} from π^{+} decay in flight by observing beam-on electron events from $\nu_{\rm e}{\rm C} \to e^- X$. Present analysis results in 8.1 \pm 12.2 \pm 1.7 excess events in the $60{<}E_{\rm e}^{}<200$ MeV energy range, corresponding to oscillation probability of 0.10 \pm 0.16 \pm 0.04%. This is consistent, though less significant, with the previous result of ATHANASSOPOULOS 98, which it supersedes. The present analysis uses selection criteria developed for the decay at rest region, and is less effective in removing the background above 60 MeV than ATHANASSOPOULOS 98.
- 2 ATHANASSOPOULOS 98 is a search for the $\nu_{\mu} \rightarrow \ \nu_{e}$ oscillations using ν_{μ} from π^+ decay in flight. The 40 observed beam-on electron events are consistent with ν_{e} C \rightarrow e^- X; the expected background is 21.9 ± 2.1 . Authors interpret this excess as evidence for an oscillation signal corresponding to oscillations with probability (0.26 \pm 0.10 \pm 0.05)%. Although the significance is only 2.3 σ , this measurement is an important and consistent cross check of ATHANASSOPOULOS 96 who reported evidence for $\overline{
 u}_{\mu}
 ightarrow \overline{
 u}_e$ oscillations from μ^+ decay at rest. See also ATHANASSOPOULOS 98B.
- ³LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $(\nu_{\mu} \rightarrow \nu_{e})$

| VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | TECN COMMENT |
|---------------------------------|-------------|--------------------------|-------------------------------------------|
| • • • We do not use th | e following | data for averages, fits | , limits, etc. • • • |
| < 1.8 | 90 | | MBOO MiniBooNE |
| <110 | 90 | ² AHN 04 | K2K Water Cherenkov |
| < 1.4 | 90 | ASTIER 03 | NOMD CERN SPS |
| < 1.6 | 90 | AVVAKUMOV 02 | NTEV NUTEV FNAL |
| | | ³ AGUILAR 01 | LSND $\nu\mu \rightarrow \nu_e$ osc.prob. |
| 0.5 to 30 | 95 | ⁴ ATHANASSO98 | LSND $\nu_{\mu} ightarrow \nu_{e}$ |
| < 3.0 | 90 | ⁵ LOVERRE 96 | CHARM/CDHS |
| < 9.4 | 90 | VILAIN 94c | CHM2 CERN SPS |
| < 5.6 | 90 | ⁶ VILAIN 94c | CHM2 CERN SPS |

- 1 The limit is $\sin^22\theta < 0.9 \times 10^{-3}$ at $\Delta m^2 = 2~\text{eV}^2.$ That value of Δm^2 corresponds to the smallest mixing angle consistent with the reported signal from LSND in AGUILAR 01.
- 2 The limit becomes $\sin^2 2 heta < 0.15$ at $\Delta m^2 = 2.8 imes 10^{-3}$ eV 2 , the bets-fit value of the u_{μ} disappearance analysis in K2K.
- 3 AGUILAR 01 is the final analysis of the LSND full data set of the search for the u_{μ} ightarrow $\nu_{\rm P}$ oscillations. See footnote in preceding table for further details.
- $^4\,\text{ATHANASSOPOULOS}$ 98 report (0.26 \pm 0.10 \pm 0.05)% for the oscillation probability; the value of $\sin^2 2\theta$ for large Δm^2 is deduced from this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions. If effect is due to oscillation, it is most likely to be intermediate $\sin^2 2\theta$ and Δm^2 . See also ATHANASSOPOULOS 98B.
- ⁵ LOVERRE 96 uses the charged-current to neutral-current ratio from the combined CHARM (ALLABY 86) and CDHS (ABRAMOWICZ 86) data from 1986.
- 6 VILAIN 94c limit derived by combining the u_μ and $\overline{
 u}_\mu$ data assuming *CP* conservation.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $(\overline{\nu}_{\mu} \rightarrow \overline{\nu}_{e})$

<2.6

0.03 - 0.05

| VALUE (eV2) | CL% | DOCUMENT ID | TECN | COMMENT |
|-------------------|-------------------|---------------------------|-----------|---------------------------|
| • • • We do not u | use the following | g data for averages, fits | , limits, | etc. • • • |
| 0.03-0.09 | 90 | ¹ AGUILAR-AR10 | мвос | Ε _ν > 475 MeV |
| 0.03-0.07 | 90 | ² AGUILAR-AR10 | МВОС | E ₁₁ > 200 MeV |
| < 0.06 | 90 | | | MiniBooNE |
| < 0.055 | 90 | ³ ARMBRUSTER02 | KAR2 | Liquid Sci. calor. |

AVVAKUMOV 02

01

⁴ AGUILAR

NTEV NUTEV FNAL

LSND LAMPF

Neutrino Mixing

| 0.05-0.08 | 90 | ⁵ ATHANASSO. | 96 | LSND | LAMPF |
|-------------|----|-------------------------|------|------|----------|
| 0.048-0.090 | 80 | ⁶ ATHANASSO. | 95 | | |
| < 0.07 | 90 | ⁷ HILL | 95 | | |
| < 0.9 | 90 | VILAIN | 94 c | CHM2 | CERN SPS |
| < 0.14 | 90 | ⁸ FREEDMAN | 93 | CNTR | LAMPF |

- 1 This value is for a two neutrino oscillation analysis for excess antineutrino events with E $_{\nu}>$ 475 MeV. The best fit is at 0.07. The allowed region is consistent with LSND reported by AGUILAR 01. Supercedes AGUILAR-AREVALO 09B.
- $^2\,\mathrm{This}$ value is for a two neutrino oscillation analysis for excess antineutrino events with ${\sf E}_{
 u} >$ 200 MeV with subtraction of the expected 12 events low energy excess seen in the neutrino component of the beam. The best fit value is 0.007 for $\Delta(m^2)=4.4~{\rm eV}^2.$
- 3 ARMBRUSTER 02 is the final analysis of the KARMEN 2 data for 17.7 m distance from the ISIS stopped pion and muon neutrino source. It is a search for $\overline{
 u}_e$, detected by the inverse β -decay reaction on protons and ^{12}C . 15 candidate events are observed, and 15.8 ± 0.5 background events are expected, hence no oscillation signal is detected. The results exclude large regions of the parameter area favored by the LSND experiment.
- 4 AGUILAR 01 is the final analysis of the LSND full data set. It is a search for $\overline{
 u}_e$ 30 m from LAMPF beam stop. Neutrinos originate mainly for π^+ decay at rest. $\overline{\nu}_e$ are detected through $\overline{v}_e p \to e^+ n$ ($20 < E_{e^+} < 60$ MeV) in delayed coincidence with $np \to d\gamma$. Authors observe $87.9 \pm 22.4 \pm 6.0$ total excess events. The observation is attributed to $\overline{v}_\mu \to \overline{v}_e$ oscillations with the oscillation probability of $0.264 \pm 0.067 \pm 0.045\%$, consistent with the previously published result. Taking into account all constraints, the most favored allowed region of oscillation parameters is a band of $\Delta(m^2)$ from C.2–2.0 eV². Supersedes ATHANASSOPOULOS 95, ATHANASSOPOULOS 96, and ATHANASSOPOULOS 98.
- 5 ATHANASSOPOULOS 96 is a search for $\overline{
 u}_{e}$ 30 m from LAMPF beam stop. Neutrinos originate mainly from π^+ decay at rest. $\overline{
 u}_e$ could come from either $\overline{
 u}_\mu \to \overline{
 u}_e$ or $u_e
 ightarrow \overline{
 u}_e$; our entry assumes the first interpretation. They are detected through $\overline{
 u}_e p
 ightarrow$ e⁺ n (20 MeV < E_{e^+} < 60 MeV) in delayed coincidence with $np \rightarrow d\gamma$. Authors observe 51 \pm 20 \pm 8 total excess events over an estimated background 12.5 \pm 2.9. ATHANASSOPOULOS 96B is a shorter version of this paper.
- 6 ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 ± 0.4 events. Corresponds to an oscillation probability of $(0.34^{+0.20}_{-0.18}\pm0.07)\%$. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.
- ⁷ HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{
 u}_{\mu}
 ightarrow \ \overline{
 u}_{e}$ and obtains only upper limits.
- 8 FREEDMAN 93 is a search at LAMPF for $\overline{\nu}_e$ generated from any of the three neutrino types $\nu_{\mu},\,\overline{\nu}_{\mu},\,$ and ν_e which come from the beam stop. The $\overline{\nu}_e$'s would be detected by the reaction $\overline{
 u}_e \, p \,
 ightarrow \, e^+ \, n$. FREEDMAN 93 replaces DURKIN 88.

$(\overline{\nu}_{\mu} \rightarrow \overline{\nu}_{e})$ $\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ CI %

| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | TECN | COMMENT |
|--------------------------|-----|--------------|------|---------|
| | | | | |

| • • | • | We do not | use the | following | data fo | averages, | fits, | limits, | etc. | • | • | • |
|-----|---|-----------|---------|-----------|---------|-----------|-------|---------|------|---|---|---|
|-----|---|-----------|---------|-----------|---------|-----------|-------|---------|------|---|---|---|

| 2.000.00 | , |
|---------------------------------------------------------------------------|-----|
| 0.4-9.0 99 2 AGUILAR-AR10 MBOO E _{ν} > 200 MeV | |
| <3.3 90 ³ AGUILAR-AR 09B MBOO MiniBooNE | |
| <1.7 90 4 ARMBRUSTER02 KAR2 Liquid Sci. cal | or. |
| <1.1 90 AVVA KUMOV 02 NTEV NUTEV FNAL | |
| 5.3±1.3±9.0 ⁵ AGUILAR 01 LSND LAMPF | |
| $6.2\pm2.4\pm1.0$ 6 ATHANASSO96 LSND LAMPF | |
| 3–12 80 ⁷ ATHA NA SSO 95 | |
| <6 90 ⁸ HILL 95 | |

- $^{
 m 1}$ This value is for a two neutrino oscillation analysis for excess antineutrino events with $\rm E_{\nu}>475$ MeV. At 90% CL there is no solution at high $\Delta(m^2).$ The best fit is at maximal mixing. The allowed region is consistent with LSND reported by AGUILAR 01. Supercedes AGUILAR-AREVALO 09B.
- ²This value is for a two neutrino oscillation analysis for excess antineutrino events with ${\rm E}_{
 u} >$ 200 MeV with subtraction of the expected 12 events low energy excess seen in the neutrino component of the beam. At 90% CL there is no solution at high $\Delta(m^2)$. The best fit value is 0.007 for $\Delta(m^2) = 4.4 \text{ eV}^2$.
- $^3\,\text{This}$ result is inconclusive with respect to small amplitude mixing suggested by LSND.
- ⁴ ARMBRUSTER 02 is the final analysis of the KARMEN2 data. See footnote in the preceding table for further details, and the paper for the exclusion plot.
- 5 AGUILAR 01 is the final analysis of the LSND full data set. The deduced oscillation probability is 0.264 \pm 0.067 \pm 0.045%; the value of $\sin^2 2\theta$ for large $\Delta(m^2)$ is twice this probability (although these values are excluded by other constraints). See footnote in preceding table for further details, and the paper for a plot showing allowed regions. Supersedes ATHANASSOPOULOS 95, ATHANASSOPOULOS 96, and ATHANASSOPOULOS 98.
- 6 ATHANASSOPOULOS 96 reports $(0.31\pm0.12\pm0.05)\%$ for the oscillation probability; the value of $\sin^2 2\theta$ for large $\Delta(m^2)$ should be twice this probability. See footnote in preceding table for further details, and see the paper for a plot showing allowed regions.
- 7 ATHANASSOPOULOS 95 error corresponds to the 1.6σ band in the plot. The expected background is 2.7 \pm 0.4 events. Corresponds to an oscillation probability of $(0.34 \stackrel{+}{-} 0.18 \pm 0.07)\%$. For a different interpretation, see HILL 95. Replaced by ATHANASSOPOULOS 96.
- 8 HILL 95 is a report by one member of the LSND Collaboration, reporting a different conclusion from the analysis of the data of this experiment (see ATHANASSOPOULOS 95). Contrary to the rest of the LSND Collaboration, Hill finds no evidence for the neutrino oscillation $\overline{
 u}_{\mu}
 ightarrow \overline{
 u}_{e}$ and obtains only upper limits.

$\Delta(m^2)$ for $\sin^2(2\theta) = 1$ $(\nu_{\mu}(\overline{\nu}_{\mu}) \rightarrow \nu_{e}(\overline{\nu}_{e}))$

| | | <i>p</i> . <i>p</i> | | | | |
|--------------------------|-----------------|----------------------|----------|-----------|------------|--|
| VALUE (eV ²) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.075 | 90 | BORODOV | 92 | CNTR | BNL E776 | |
| • • • We do not u | se the followin | g data for average | es, fits | , limits, | etc. • • • | |
| <1.6 | 90 | ¹ ROMOSAN | 97 | CCFR | FNAL | |

 $^{1}\,\text{ROMOSAN}$ 97 uses wideband beam with a 0.5 km decay region.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $(\nu_{\mu}(\overline{\nu}_{\mu}) \rightarrow \nu_{e}(\overline{\nu}_{e}))$

| ` ' | ٠, | · ~ · ~ · | ٠. | -,, | |
|---------------------------------|------------|------------------------|---------|-----------|------------|
| VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | | TECN | COMMENT |
| <1.8 | 90 | 1 ROMOSAN | 97 | CCFR | FNAL |
| • • • We do not use th | e followin | g data for average | s, fits | , limits, | etc. • • • |
| <3.8 | 90 | ² MCFARLAND | 95 | CCFR | FNAL |

¹ROMOSAN 97 uses wideband beam with a 0.5 km decay region

 2 MCFARLAND 95 state that "This result is the most stringent to date for 250< $\Delta(m^2)$ <450 eV 2 and also excludes at 90%CL much of the high $\Delta(m^2)$ region favored by the recent LSND observation." See ATHANASSOPOULOS 95 and ATHANASSOPOU-

BORODOV... 92 CNTR BNL E776

$\Delta(m^2)$ for $\sin^2(2\theta) = 1 \; (\overline{\nu}_e \not\rightarrow \; \overline{\nu}_e)$

<3

CL% DOCUMENT ID TECN COMMENT ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $^{
m 1}$ ACHKAR 95 CNTR Bugey reactor

 1 ACHKAR 95 bound is for L=15, 40, and 95 m.

$\sin^2(2\theta)$ for "Large" $\Delta(m^2)$ $(\overline{\nu}_e \not\rightarrow \overline{\nu}_e)$

DOCUMENT ID CL% TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ¹ ACHKAR 95 CNTR For $\Delta(m^2) = 0.6 \text{ eV}^2$ 90

 1 ACHKAR 95 bound is from data for L=15, 40, and 95 m distance from the Bugey reactor.

Sterile neutrino limits from atmospheric neutrino studies –

$\Delta(m^2)$ for $\sin^2(2\theta) = 1 \ (\nu_{\mu} \rightarrow \nu_{s})$

 $\nu_{\it S}$ means $\nu_{\it T}$ or any sterile (noninteracting) $\nu.$

VALUE (10⁻⁵ eV²) CL% DO CUMENT_ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ¹ OYA MA <3000 (or <550) 90 89 KAMI Water Cherenkov 88 IMB Flux has ν_{μ} , $\overline{
u}_{\mu}$, ν_{e} , and $\overline{
u}_{e}$ BIONTA < 4.2 or > 54.

 1 OYAMA 89 gives a range of limits, depending on assumptions in their analysis. They argue that the region $\Delta(m^2)=(100\text{--}1000)\times 10^{-5}~\text{eV}^2$ is not ruled out by any data for large mixing.

Search for $\nu_{\mu} \rightarrow \nu_{s}$

DOCUMENT ID TECN COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • • •

AMBROSIO 01 MCRO matter effects ² FUKUDA 0.0 SKAM neutral currents + matter effects

- 1 AMBROSIO 01 tested the pure 2-flavor $\nu_{\mu} \to \nu_{\rm S}$ hypothesis using matter effects which change the shape of the zenith-angle distribution of upward through-going muons. With maximum mixing and $\Delta(m^2)$ around 0.0024 eV 2 , the $\nu_{\mu} \to \nu_{\rm S}$ oscillation is disfavored with 99% confidence level with respect to the $\nu_{\mu} \to \nu_{\tau}$ hypothesis.
- 2 FUKUDA 00 tested the pure 2-flavor $\nu_{\mu} \rightarrow \nu_{s}$ hypothesis using three complementary atmospheric-neutrino data samples. With this hypothesis, zenith-angle distributions are expected to show characteristic behavior due to neutral currents and matter effects. In the $\Delta(m^2)$ and $\sin^2 2 heta$ region preferred by the Super-Kamiokande data, the u_{μ} - $\nu_{\rm S}$ hypothesis is rejected at the 99% confidence level, while the $\nu_{\mu}
 ightarrow \nu_{ au}$ hypothesis consistently fits all of the data sample.

- CPT tests -

$\langle \Delta m_{21}^2 - \Delta \overline{m}_{21}^2 \rangle$

DOCUMENT ID CL% TECN COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • • •

¹ DEGOUVEA 05 FIT solar vs. reactor

 1 DEGOUVEA 05 obtained this bound at the 3σ CL from the KamLAND (ARAKI 05) and

Neutrino Mixing, Heavy Neutral Leptons, Searches for

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| HATA KEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO ATHANASSO. | 98 C 98 97 97 96 96 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 19 PR C54 2665 PRL 77 3082 PRL 77 1683 PL B388 397 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 53 753. C. Athanassopoulos et al. C. Athanassopoulos et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUL, SVR, |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL | 98 C 98 97 97 96 96 96 B 96 B 96 B | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PL B388 397 PR D53 6054 PL B388 384 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hample let al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSD Collab.) (LSND Collab.) (LSND Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE | 98 C 98 97 97 96 96 96 B 96 B 96 B 96 96 B | PRL 81 2016 PRL 79 345 PRL 76 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PR 53 6054 PL 8388 307 PR D53 6054 PL B388 344 PL B388 349 PL B388 349 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Lovere | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC.) (GALLEX Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR | 98 C 98 97 97 96 96 96 B 96 96 B 96 96 96 | PRL 81 2016 PRL 79 345 PRL 77 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP PR C54 2685 PRL 77 3082 PRL 77 1683 PL B388 397 PR D53 6054 PL B388 384 PL B370 156 NP B434 503 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (LSND Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC) (GALLEX Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA AT HANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN | 98 C 98 97 97 96 96 96 B 96 96 96 96 95 | PRL 81 2016 PRL 79 345 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP PR C54 2685 PRL 77 3082 PRL 77 1683 PR D53 6054 PL B388 384 PL B388 384 PL B389 156 NP B434 503 PR B434 503 PR B434 503 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. S.P. Ahlen et al. (SINC | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC) (GALLEX Collab.) 5, SACLD, CPPM, CDEF+) (MACRO Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO DAUM | 98 C 98 97 97 96 96 B 96 96 96 96 95 95 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PR D53 6054 PL B388 384 PL B380 384 PL B370 156 NP B434 503 PR D53 6954 PL B370 491 PR D53 6954 PL B370 491 PR D5 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. Sa 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. C. Athanassopoulos et al. K. Daum et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC) (GALLEX Collab.) 5, SACLD, CPPM, CDEF+, (MACRO Collab.) (LSND Collab.) (FREUS Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLETTA ATHANASSO ATHANASSO FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO DAUM HILL | 98 C 98 97 97 96 96 B 96 96 96 95 95 95 | PRL 81 2016 PRL 79 345 PRL 77 345 PRL 76 2912 FFTPL 63 791 Translated from ZETFP PR C54 2685 PRL 77 3082 PRL 77 1683 PRL 53 397 PR D53 6054 PL B388 334 PL B387 316 NP B434 503 PL B367 481 PRL 75 2650 ZPHY C66 417 PRL 75 2654 | S. Hatakeyam a et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. J. D. Summer al. J. D. S.P. Ahlen et al. J. D. Athanassopoulos et al. K. Daum et al. J. E. Hill | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (KSMIOKANDE COllab.) (KAMIOKANDE COLIAB.) (UCI, SVR, SCUC.) (GALLEX Collab.) (LSND COllab.) (LSND COllab.) (LSND COllab.) (FREJUS COllab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO DAUM HILL MCFARLAND | 98 C 98 97 97 96 96 B 96 B 96 96 95 95 95 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PL 8388 397 PR D53 6054 PL 838 384 PL 8370 156 NP B434 503 PL 8357 481 PRL 75 2650 ZPHY C66 417 PRL 75 2654 PRL 75 2654 PRL 75 2654 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 53 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. J.E. Hill J.E. Hill L.S. McFarland et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSD Collab.) (LSD Collab.) (LSD Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC) (GALLEX Collab.) 5, SACLD, CPPM, CDEF+, (MACRO Collab.) (LSND Collab.) (FREUS Collab.) |
| HATAKEYAMA CLARK ROMOSAN AGLETTA ATHANASSO ATHANASSO FUKUDA FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO BALLAN HILL MCFARLAND BCLLAIS | 98 C 98 97 97 96 96 96 B 96 96 95 95 95 95 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 3082 PRL 77 1683 PL B388 384 PL B370 156 NP B434 503 PRL B370 357 PR D53 6054 PRL 75 2650 ZPHY C66 417 PRL 75 2959 PRL 75 3993 PRL 75 3993 PL B338 383 | S. Hatakeyam a et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Lovere B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. J.E. Hill K.S. McFarland et al. Y. Declais et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (KSMIOKANDE COllab.) (KAMIOKANDE COllab.) (UCI, SVR, SCUC) (GALLEX Collab.) (MARON COllab.) (LSND Collab.) (LSND Collab.) (ESLUS COllab.) (ESLUS COllab.) (CSND Collab.) (CSND COllab.) (CSND COllab.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO FUKUDA FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO DAUM HILL MCFARLAND | 98 C 98 97 97 96 96 B 96 B 96 96 95 95 95 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PL 8388 397 PR D53 6054 PL 838 384 PL 8370 156 NP B434 503 PL 8357 481 PRL 75 2650 ZPHY C66 417 PRL 75 2654 PRL 75 2654 PRL 75 2654 | S. Hatakeyam a et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 33 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Lovere B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. J.E. Hill K.S. McFarland et al. Y. Declais et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (LSND Collab.) (Kamiokande Collab.) (Kamiokande Collab.) (UCI, SVR, SCUC.) (GALLEX Collab.) (LSND Collab.) (LSND Collab.) (FREJUS Collab.) (FREJUS Collab.) (FOR COLLAB.) (KAMIOKANDE COLLAB.) (KAMIOKANDE COLLAB.) |
| HATAKEYAMA CLARK ROMOSAN AGLIETTA ATHANASSO ATHANASSO FUKUDA GREENWOOD HAMPEL LOVERRE ACHKAR AHLEN ATHANASSO DAUM HILL MCFARLAND DECLAIS FUKUDA | 98 C 98 97 97 96 96 B 96 96 96 95 95 95 95 95 | PRL 81 2016 PRL 79 345 PRL 78 2912 JETPL 63 791 Translated from ZETFP 1 PR C54 2685 PRL 77 3082 PRL 77 1683 PL 838 397 PR D53 6054 PL 838 384 PL 8370 156 NP 8434 503 PL 836 7 481 PRL 75 2650 ZPHY C66 417 PRL 75 2654 PRL 75 2654 PRL 75 2654 PRL 75 3993 PL 8338 383 | S. Hatakeyama et al. R. Clark et al. A. Romosan et al. M. Aglietta et al. 53 753. C. Athanassopoulos et al. C. Athanassopoulos et al. Y. Fukuda et al. Z.D. Greenwood et al. W. Hampel et al. P.F. Loverre B. Achkar et al. S.P. Ahlen et al. C. Athanassopoulos et al. K. Daum et al. J.E. Hill J.E. Hill L.S. McFarland et al. | (Kamiokande Collab.) (IMB Collab.) (CCFR Collab.) (LSND Collab.) (LSND Collab.) (KSMIOKANDE COllab.) (KAMIOKANDE COllab.) (UCI, SVR, SCUC) (GALLEX Collab.) (MARON COllab.) (LSND Collab.) (LSND Collab.) (ESLUS COllab.) (ESLUS COllab.) (CSND Collab.) (CSND COllab.) (CSND COllab.) |

| BECKER-SZ | 92B | PR D46 3720 | R.A. Becker-Szendy et al. | |
|-------------|------|------------------------|---------------------------|--------------------------|
| BEIER | 92 | PL B283 446 | E.W. Beier et al. | (KAM2 Collab.) |
| A Iso | | PTRSL A346 63 | E.W. Beier, E.D. Frank | (PENN) |
| BORODOV | 92 | PRL 68 274 | L. Borodovsky et al. | (COLU, JHÙ, ILL) |
| HIRATA | 92 | PL B280 146 | K.S. Hirata et al. | (Kamiokande II Collab.) |
| CASPER | 91 | PRL 66 2561 | D. Casper et al. | ` (IMB Collab.) |
| HIRATA | 91 | PRL 66 9 | K.S. Hirata et al. | (Kamiokande II Collab.) |
| KUVSHINN | 91 | JETPL 54 253 | A.A. Kuvshinnikov et al. | (KIAE) |
| BERGER | 90 B | PL B245 305 | C. Berger et al. | (FREJUS Collab.) |
| HIRATA | 90 | PRL 65 1297 | K.S. Hirata et al. | (Kamiòkande II Collab.) |
| AGLIETTA | 89 | EPL 8 611 | M. Aglietta et al. | ` (FREJUS Collab.) |
| DAVIS | 89 | ARNPS 39 467 | R. Davis, A.K. Mann, L. | Wolfenstein (BNL, PENN+) |
| OYAMA | 89 | PR D39 1481 | Y. Oyama et al. | (Kamiokande II Collab.) |
| BIONTA | 88 | PR D38 768 | R.M. Bionta et al. | (IMB Collab.) |
| DURKIN | 88 | PRL 61 1811 | L.S. Durkin et al. | (OSU, ANL, CIT+) |
| ABRAMOWICZ | 86 | PRL 57 298 | H. Abramowicz et al. | (CDHS Collab.) |
| ALLABY | 86 | PL B177 446 | J.V. Allaby et al. | (CHARM Collab.) |
| ANGELINI | 86 | PL B179 307 | C. Angelini et al. | (PISA, `ATHU, PADO+) |
| VUILLEUMIER | 82 | PL 114B 298 | J.L. Vuilleumier et al. | (CIT, SIN, MUNI) |
| BOLIEV | 81 | SJNP 34 787 | M.M. Boliev et al. | (INRM) |
| | | Translated from YAF 34 | 1418. | |
| KWON | 81 | PR D24 1097 | H. Kwon et al. | (CIT, ISNG, MUNI) |
| BOEHM | 80 | PL 97B 310 | F. Boehm et al. | (ILLG, CIT, ISNG, MUNI) |
| CROUCH | 78 | PR D18 2239 | M.F. Crouch et al. | (CASE, UCI, WITW) |
| | | | | |

Heavy Neutral Leptons, Searches for

(A) Heavy Neutral Leptons

- Stable Neutral Heavy Lepton MASS LIMITS ----

Note that LEP results in combination with REUSSER 91 exclude a fourth stable neutrino with $\it m < 2400$ GeV.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|--------------------|-----|------|---------------|
| >45.0 | 95 | ABREU | 92B | DLPH | Dirac |
| >39.5 | 95 | ABREU | 92B | DLPH | Majorana |
| >44.1 | 95 | ALEXANDER | 91F | OPAL | Dirac |
| >37.2 | 95 | ALEXANDER | 91F | OPAL | Majorana |
| none 3-100 | 90 | SATO | 91 | KAM2 | Kamiokande II |
| >42.8 | 95 | ¹ ADEVA | 90s | L3 | Dirac |
| >34.8 | 95 | ¹ ADEVA | 90s | L3 | Majorana |
| >42.7 | 95 | DECAMP | 90F | ALEP | Dirac |

 $^{^1}$ ADEVA 90s limits for the heavy neutrino apply if the mixing with the charged leptons satisfies $|u_{1\,j}|^2+|u_{2\,j}|^2+|u_{3\,j}|^2>6.2\times 10^{-8}$ at $m_{L^0}=$ 20 GeV and $>5.1\times 10^{-10}$ for $m_{L^0}=$ 40 GeV.

— Heavy Neutral Lepton MASS LIMITS —

Limits apply only to heavy lepton type given in comment at right of data Listings.

See the "Quark and Lepton Compositeness, Searches for" Listings for limits on radiatively decaying excited neutral leptons, i.e. $\nu^* \to \nu \gamma$.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|----------------|-------------------------|----------|-----------|-----------------------------|
| >101.3 | 95 | ACHARD | 01B | L3 | Dirac coupling to e |
| >101.5 | 95 | ACHARD | 01B | L3 | Dirac coupling to μ |
| > 90.3 | 95 | ACHARD | 01B | L3 | Dirac coupling to $	au$ |
| > 89.5 | 95 | ACHARD | 01B | L3 | Majorana coupling to e |
| > 90.7 | 95 | ACHARD | 01B | L3 | Majorana coupling to μ |
| > 80.5 | 95 | ACHARD | 01B | L3 | Majorana coupling to $	au$ |
| ullet $ullet$ We do not | use the follow | ing data for averag | es, fits | , limits, | etc. • • • |
| > 76.0 | 95 | ABBIENDI | 001 | OPAL | Majorana, coupling to e |
| > 88.0 | 95 | ABBIENDI | 001 | OPAL | Dirac, coupling to e |
| > 76.0 | 95 | ABBIENDI | 001 | OPAL | Majorana, coupling to μ |
| > 88.1 | 95 | ABBIENDI | 001 | OPAL | Dirac, coupling to μ |
| > 53.8 | 95 | ABBIENDI | 001 | OPAL | Majorana, coupling to $	au$ |
| > 71.1 | 95 | ABBIENDI | 001 | OPAL | Dirac, coupling to $	au$ |
| > 76.5 | 95 | ABREU | 990 | DLPH | Dirac coupling to e |
| > 79.5 | 95 | ABREU | 990 | DLPH | Dirac coupling to μ |
| > 60.5 | 95 | ABREU | 990 | DLPH | Dirac coupling to $	au$ |
| > 63 | 95 | ^{2,3} BUSKULIC | 96s | ALEP | Dirac |
| > 54.3 | 95 | ^{2,4} BUSKULIC | 96s | ALEP | Majorana |
| 2 DUCKILLE 06 | | | | | to be < 1 cm. limiting the |

 $^{^2}$ BUSKULIC 96s requires the decay length of the heavy lepton to be < 1 cm, limiting the square of the mixing angle $|\nu_{\ell j}|^2$ to $10^{-10}.$

- Astrophysical Limits on Neutrino MASS for $m_{ u}~>$ 1 GeV $-\!\!\!\!-$

VALUE (GeV) CL% DOCUMENT ID TECN COMMENT

 $^{^3\, {\}rm BUSKULIC}$ 96s limit for mixing with $\tau.$ Mass is > 63.6 GeV for mixing with e or $\mu.$

 $^{^4\,{\}rm BUSKULIC}$ 96s limit for mixing with $\tau.\,$ Mass is > 55.2 GeV for mixing with e or $\mu.\,$

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

Heavy Neutral Leptons, Searches for

| (0 115 | | 5 | FARGION | 95 | A CTD | Diver |
|--------------------|----|-----|-----------|-----|-------|-------------------|
| none 60-115 | | | TANGION | | ASTR | Dirac |
| none 9.2-2000 | | 6 | GARCIA | 95 | COSM | Nucleosynthesis |
| none 26-4700 | | | BECK | 94 | COSM | Dirac |
| none 6 - hundreds | | | MORI | 92B | KAM2 | Dirac neutrino |
| none 24 - hundreds | | 7,8 | MORI | 92B | KAM2 | Majorana neutrino |
| none 10-2400 | 90 | 9 | REUSSER | 91 | CNTR | HPGe search |
| none 3-100 | 90 | | SATO | 91 | KAM2 | Kamiokande II |
| | | 10 | LINGVISI | 89 | COSM | |
| none 12-1400 | | - 6 | CALDVVLLL | 88 | COSM | Dirac $ u$ |
| none 4-16 | 90 | 6,7 | OLIVE | 88 | COSM | Dirac ν |
| none 4-35 | 90 | | OLIVE | 88 | COSM | Majorana $ u$ |
| >4.2 to 4.7 | | | SREDNICKI | 88 | COSM | Dirac ν |
| >5.3 to 7.4 | | | SREDNICKI | 88 | COSM | Majorana $ u$ |
| none 20-1000 | 95 | 6 | AHLEN | 87 | COSM | Dirac $ u$ |
| >4.1 | | | GRIEST | 87 | COSM | Dirac ν |
| | | | | | | |

 $^{^{5}}$ FARGION 95 bound is sensitive to assumed u concentration in the Galaxy. See also KONOPLICH 94.

(B) Other Bounds from Nuclear and Particle Decays

— Limits on $|U_{e_X}|^2$ as Function of $m_{ u_{ u}}$ —

TECN COMMENT

80 THEO $m_{\nu_{\nu}} = 160 \text{ MeV}$

DOCUMENT ID

Peak and kink search tests

<u>VALUE</u> <u>CL%</u> **<1** × 10⁻⁷ 90

Limits on $|U_{e_X}|^2$ as function of $m_{
u_i}$

| VALU | <u> </u> | CL% | DOCUMENT ID | | I E CN | COMMENI |
|------|--------------------|----------|-----------------------|-------|-----------|-------------------------------------|
| <1 | ×10 ⁻⁷ | 90 | ¹¹ BRITTON | 92B | CNTR | 50 MeV $< m_{ u_\chi} $ < 130 MeV |
| • • | • We do not use | the foll | owing data for aver | ages, | fits, lim | |
| <5 | $\times 10^{-6}$ | 90 | DELEENER | 91 | | $m_{\nu_{\nu}} = 20 \text{ MeV}$ |
| <5 | $\times 10^{-7}$ | 90 | DELEENER | 91 | | $m_{\nu_{\chi}} = 40 \text{ MeV}$ |
| <3 | $\times 10^{-7}$ | 90 | DELEENER | 91 | | $m_{\nu_{x}} = 60 \text{ MeV}$ |
| <1 | $\times 10^{-6}$ | 90 | DELEENER | 91 | | $m_{\nu_{\nu}} = 80 \text{ MeV}$ |
| <1 | $\times 10^{-6}$ | 90 | DELEENER | 91 | | $m_{\nu_{\nu}} = 100 \text{ MeV}$ |
| < 5 | $\times 10^{-7}$ | 90 | AZUELOS | 86 | CNTR | $m_{\nu_{\rm v}} = 60 \text{ MeV}$ |
| <2 | $\times 10^{-7}$ | 90 | AZUELOS | 86 | CNTR | $m_{\nu_{\nu}} = 80 \text{ MeV}$ |
| <3 | $\times 10^{-7}$ | 90 | AZUELOS | 86 | CNTR | $m_{\nu_{\nu}} = 100 \text{ MeV}$ |
| <1 | $\times 10^{-6}$ | 90 | AZUELOS | 86 | CNTR | $m_{\nu_{\nu}} = 120 \text{ MeV}$ |
| <2 | $\times 10^{-7}$ | 90 | AZUELOS | 86 | CNTR | $m_{\nu_{\nu}}^{2}=130 \text{ MeV}$ |
| <1 | $\times 10^{-4}$ | 90 | ¹² BRYMAN | 83B | CNTR | $m_{\nu_{\nu}} = 5 \text{ MeV}$ |
| <1.5 | 5×10^{-6} | 90 | BRYMAN | 83B | CNTR | $m_{\nu_{\nu}} = 53 \text{ MeV}$ |
| <1 | $\times 10^{-5}$ | 90 | BRYMAN | 83B | CNTR | $m_{\nu_{x}} = 70 \text{ MeV}$ |
| <1 | $\times 10^{-4}$ | 90 | BRYMAN | 83B | CNTR | $m_{\nu_{\nu}} = 130 \text{ MeV}$ |
| <1 | $\times 10^{-4}$ | 68 | ¹³ SHROCK | 81 | THEO | $m_{\nu_{x}} = 10 \text{ MeV}$ |
| <5 | $\times 10^{-6}$ | 68 | ¹³ SHROCK | 81 | THEO | $m_{\nu_{x}}^{2}=60 \text{ MeV}$ |
| <1 | $\times 10^{-5}$ | 68 | ¹⁴ SHROCK | 80 | | $m_{\nu_{\nu}} = 80 \text{ MeV}$ |
| | , | | 1.4 | | | ^ |

 $^{^{11}}$ BRITTON 92B is from a search for additional peaks in the e^+ spectrum from $\pi^+
ightarrow$ $e^+ \nu_e$ decay at TRIUMF. See also BRITTON 92.

¹⁴ SHROCK

68

Kink search in nuclear β decay

 $< \! 3 \times 10^{-6}$

High-sensitivity follow-up experiments show that indications for a neutrino with mass $17\ keV$ (Simpson, Hime, and others) were not valid. Accordingly, we no longer list the experiments by these authors and some others which made positive claims of 17 keV neutrino emission. Complete listings are given in the 1994 edition (Physical Review D50 1173 (1994)) and in the 1998 edition (The European Physical Journal C3 1 (1998)). We list below only the best limits on $|U_{ex}|^2$ for each $m_{\nu_{\nu}}$. See WIETFELDT 96 for a comprehensive review.

| VALUE | | | | | |
|--------------------|-----|-------------------|---------|--------|-------------|
| (units 10^{-3}) | CL% | m_{ν_i} (keV) | ISOTOPE | METHOD | DOCUMENT ID |

^{• • •} We do not use the following data for averages, fits, limits, etc. • • •

| < 10 95 < 6 95 < 2 95 < 0.7 99 < 2 95 < 0.73 95 | 13-40 17 | ³ H ³⁵ S ⁶³ Ni | Prop chamber Si(Li) Mag spect | 22 KALBFLEISCH23 MORTARAOHSHIMA | 93 93 93 |
|----------------------------------------------------------------|-------------|-------------------------------------------------------|-------------------------------------|---------------------------------------------------------------------|----------------|
| - | | | | | |

 $^{^{15}}$ TRINCZEK 03 is a search for admixture of heavy neutrino to u_e , in contrast to $\overline{
u}_e$ used in many other searches. Full kinematic reconstruction of the neutrino momentum by use of a magneto optical trap.

Searches for Decays of Massive ν

Limits on 111 |2 as function of m

| Limits on $ u_e $ | x = as funct | ion of $m_{ u_{\chi}}$ | | | |
|---------------------------------|----------------|------------------------|----------|---------|-------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not us | e the followi | ng data for average | s, fits, | limits, | etc. • • • |
| $< 1.6 \times 10^{-4}$ | 90 | ²⁹ BACK | 03A | CNTR | $m_{\nu_{\nu}} = 4 \text{ MeV}$ |
| $< 4.5 \times 10^{-5}$ | 90 | ²⁹ BACK | 03A | CNTR | $m_{\nu_x} = 7 \text{ MeV}$ |
| $< 3.8 \times 10^{-5}$ | 90 | ²⁹ BACK | 03A | CNTR | $m_{\nu_{\chi}} = 10 \text{ MeV}$ |
| $< 1.5 \times 10^{-3}$ | 95 | ACHARD | 01 | L3 | $m_{\nu} = 80 \text{ GeV}$ |
| $< 2 \times 10^{-2}$ | 95 | ACHARD | 01 | L3 | $m_{\nu_{\chi}}$ =175 GeV |
| < 0.3 | 95 | ACHARD | 01 | L3 | $m_{\nu_{x}} = 200 \text{ GeV}$ |
| $< 4 \times 10^{-3}$ | 95 | ACCIARRI | 99K | L3 | $m_{\nu_x} = 80 \text{ GeV}$ |
| $< 5 \times 10^{-2}$ | 95 | ACCIARRI | 99ĸ | L3 | $m_{\nu_{\rm v}} = 175 \text{ GeV}$ |
| $<$ 2 \times 10 ⁻⁵ | 95 | ³⁰ ABREU | 971 | DLPH | $m_{\nu_{\chi}}^{2}=6 \text{ GeV}$ |

⁶ These results assume that neutrinos make up dark matter in the galactic halo.

⁷Limits based on annihilations in the sun and are due to an absence of high energy neutrinos detected in underground experiments.

 $^{^{8}\,\}mathrm{MORI}$ 92B results assume that neutrinos make up dark matter in the galactic halo. Limits based on annihilations in earth are also given.

 $^{^9\,\}mathrm{REUSSER}$ 91 uses existing $\beta\beta$ detector (see FISHER 89) to search for CDM Dirac

 $^{^{\}rm 10}\,{\rm ENQVIST}$ 89 argue that there is no cosmological upper bound on heavy neutrinos.

 $^{^{12}}$ BRYMAN 83B obtain upper limits from both direct peak search and analysis of B($\pi
ightarrow$ $e\nu)/B(\pi \to \mu \nu)$. Latter limits are not listed, except for this entry (i.e. — we list the most stringent limits for given mass).

 $^{^{13}}$ Analysis of $(\pi^+ \to~e^+\,\nu_e)/(\pi^+ \to~\mu^+\,\nu_\mu)$ and $(K^+ \to~e^+\,\nu_e)/(K^+ \to~\mu^+\,\nu_\mu)$ decay ratios.

 $^{^{14}}$ Analysis of $(K^+ \rightarrow e^+ \nu_e)$ spectrum.

 $^{^{16}\,\}mathrm{GALEAZZI}$ 01 use an cryogenic microcalorimeter to search for mass 50–1000 eV neutrino admixtures using the 187 Re beta spectrum with 2.4 keV endpoint. They derive limits for the admixture of heavy neutrinos, ranging from 9×10^{-3} for mass 1 keV to 0.116 for mass 100 eV. This is a significant improvement with respect to HIDDEMANN 95, especially for masses below \sim 500 MeV, where the limit is about a factor of \sim 2 higher.

 $^{^{17}}$ HOLZSCHUH 00 use an iron-free eta spectrometer to measure the 35 S eta decay spectrum. An analysis of the spectrum in the energy range 56–173 keV is used to derive limits for the admixture of heavy neutrinos. This extends the range of neutrino masses explored in HOLZSCHUH 99.

 $^{^{18}}$ DRAGOUN 99 analyze the eta decay spectrum of 241 Pu in the energy range 0.2–9.2 keV to derive limits for the admixture of heavy neutrinos. It is not competitive with

 $^{^{19}}$ HOLZSCHUH 99 use an iron-free eta spectrometer to measure the 63 Nieta decay spectrum. An analysis of the spectrum in the energy rage 33–67.8 keV is used to derive limits for the admixture of heavy neutrinos.

 $^{^{20}}$ HINDI 98 obtain a limit on heavy neutrino admixture from EC decay of 37 Ar by measuring the time-of-flight distribution of the recoiling ions in coincidence with x-rays or Auger electrons. The authors report upper limit for $|U_{\rm ex}|^2$ of $\approx 3\%$ for $m_{\nu_{\chi}} = 500$ keV, 1% for $m_{\nu_{
m v}}$ =550 keV, 2% for $m_{\nu_{
m v}}$ =600 keV, and 4% for m_{χ} =650 keV. Their reported limits for $m_{\nu_{\nu}} \leq 450$ keV are inferior to the limits of SCHRECKENBACH 83.

 $^{^{21}}$ In the beta spectrum from tritium eta decay nonvanishing or mixed $m_{\overline{
u}_1}$ state in the mass region 0.01-4 keV. For $m_{\nu_{\nu}}$ <1 keV, their upper limit on $|U_{\rm ex}|^2$ becomes less

²² KALBFLEISCH 93 extends the 17 keV neutrino search of BAHRAN 92, using an improved proportional chamber to which a small amount of $^3{\rm H}$ is added. Systematics are significantly reduced, allowing for an improved upper limit. The authors give a 99% confidence limit on $|U_{e\, X}|^2$ as a function of m_{ν_X} in the range from 13.5 keV to 17.5 keV. See also the related papers BAHRAN 93, BAHRAN 93B, and BAHRAN 95 on theoretical aspects of beta spectra and fitting methods for heavy neutrinos.

²³ MORTARA 93 limit is from study using a high-resolution solid-state detector with a superconducting solenoid. The authors note that "The sensitivity to neutrino mass is verified by measurement with a mixed source of 35 S and 14 C, which artificially produces a distortion in the beta spectrum similar to that expected from the massive neutrino."

 $^{^{24}\,\}mathrm{DEUTSCH}$ 90 search for emission of heavy $\overline{\nu}_e$ in super-allowed beta decay of $^{20}\mathrm{F}$ by spectral analysis of the electrons.

 $^{^{25}}$ This limit was taken from the figure 3 of APALIKOV 85; the text gives a more restrictive limit of 1.7 $\times 10^{-3}$ at CL $\,=\,90\%$

 $^{^{26}}$ SCHRECKENBACH 83 is a combined measurement of the β^+ and β^- spectrum.

 $^{^{27}}$ SHROCK 80 was a retroactive analysis of data on several superallowed eta decays to search for kinks in the Kurie plot.

 $^{^{28}\,\}mathrm{Application}$ of test to search for kinks in β decay Kurie plots.

Lepton Particle Listings Heavy Neutral Leptons, Searches for

| $< 3 \times 10^{-5}$ | 95 | 30 | ABREU | 971 | DLPH | $m_{ u_\chi} =$ 50 GeV |
|-------------------------|----|----|----------|-----|------|---------------------------------------------------|
| $< 1.8 \times 10^{-3}$ | 90 | | HAGNER | 95 | MWPC | $m_{\nu_h}^{\nu_\chi} = 1.5 \text{ MeV}$ |
| $< 2.5 \times 10^{-4}$ | 90 | | HAGNER | 95 | MWPC | $m_{\nu_h}^{\nu_n} = 4 \text{ MeV}$ |
| $< 4.2 \times 10^{-3}$ | 90 | | HAGNER | 95 | | $m_{\nu_h} = 9 \text{ MeV}$ |
| $< 1 \times 10^{-5}$ | 90 | | BARANOV | 93 | | $m_{\nu_{\chi}}^{\nu_{\eta}}$ =100 MeV |
| $< 1 \times 10^{-6}$ | 90 | | BARANOV | 93 | | $m_{\nu_{\chi}}^{\nu_{\chi}}$ = 200 MeV |
| $< 3 \times 10^{-7}$ | 90 | | BARANOV | 93 | | $m_{\nu_{\chi}}^{\nu_{\chi}}$ = 300 MeV |
| $< 2 \times 10^{-7}$ | 90 | 32 | BARANOV | 93 | | $m_{\nu_{\chi}}^{\nu_{\chi}}$ =400 MeV |
| $<6.2 \times 10^{-8}$ | 95 | | ADEVA | 90s | L3 | $m_{\nu_{\chi}}^{-}$ =20 GeV |
| $< 5.1 \times 10^{-10}$ | 95 | | ADEVA | 90s | L3 | $m_{\nu} = 40 \text{ GeV}$ |
| all values ruled out | 95 | 33 | BURCHAT | 90 | MRK2 | $m_{ u_\chi}^{ u_\chi} < 19.6 \mathrm{GeV}$ |
| $< 1 \times 10^{-10}$ | 95 | | BURCHAT | 90 | MRK2 | $m_{\nu_{\chi}}^{-\chi}$ = 22 GeV |
| $< 1 \times 10^{-11}$ | 95 | 33 | BURCHAT | 90 | MRK2 | $m_{\nu_x}^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{$ |
| all values ruled out | 95 | | DECAMP | 90F | ALEP | $m_{\nu_x}^{\ \ \ } = 25.0-42.7 \text{ GeV}$ |
| $< 1 \times 10^{-13}$ | 95 | | DECAMP | 90F | ALEP | $m_{\nu_x} = 42.7-45.7 \text{ GeV}$ |
| $< 5 \times 10^{-3}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu_x} = 1.8 \text{ GeV}$ |
| $< 2 \times 10^{-5}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu_{\chi}} = 4 \text{ GeV}$ |
| $< 3 \times 10^{-6}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu} = 6 \text{ GeV}$ |
| $<1.2 \times 10^{-7}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{\nu}} = 100 \text{ MeV}$ |
| $<1 \times 10^{-8}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{x}} = 200 \text{ MeV}$ |
| $< 2.4 \times 10^{-9}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{\chi}} = 300 \text{ MeV}$ |
| $< 2.1 \times 10^{-9}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{\chi}}$ =400 MeV |
| $< 2 \times 10^{-2}$ | 68 | | OBERAUER | 87 | | $m_{\nu_{\rm y}} = 1.5 \text{ MeV}$ |
| $< 8 \times 10^{-4}$ | 68 | 34 | OBERAUER | 87 | | $m_{\nu_{\nu}} = 4.0 \text{ MeV}$ |
| $< 8 \times 10^{-3}$ | 90 | | BADIER | 86 | CNTR | $m_{\nu_{\nu}}$ =400 MeV |
| <8 × 10 ⁻⁵ | 90 | | BADIER | 86 | CNTR | $m_{\nu_{\rm y}} = 1.7 \text{ GeV}$ |
| $< 8 \times 10^{-8}$ | 90 | | BERNARDI | 86 | CNTR | $m_{ u_{\chi}} = 100 \; \mathrm{MeV}$ |
| <4 × 10 ⁻⁸ | 90 | | BERNARDI | 86 | CNTR | $m_{\nu_{x}} = 200 \text{ MeV}$ |
| $< 6 \times 10^{-9}$ | 90 | | BERNARDI | 86 | CNTR | $m_{\nu_{\chi}} = 400 \text{ MeV}$ |
| <3 × 10 ⁻⁵ | 90 | | DORENBOS | 86 | CNTR | $m_{\nu_{\chi}} = 150 \text{ MeV}$ |
| $<1 \times 10^{-6}$ | 90 | | DORENBOS | 86 | CNTR | $m_{\nu_{\chi}} = 500 \text{ MeV}$ |
| <1 × 10 ⁻⁷ | 90 | | DORENBOS | 86 | CNTR | $m_{\nu_{\chi}}$ =1.6 GeV |
| $< 7 \times 10^{-7}$ | 90 | | COOPER | 85 | HLBC | $m_{\nu_{\chi}} = 0.4 \text{ GeV}$ |
| <8 × 10 ⁻⁸ | 90 | | COOPER | 85 | HLBC | $m_{\nu_{\chi}}$ =1.5 GeV |
| <1 × 10 ⁻² | 90 | | BERGSMA | 83B | CNTR | $m_{\nu_{\chi}} = 10 \text{ MeV}$ |
| $<1 \times 10^{-5}$ | 90 | | BERGSMA | 83B | CNTR | $m_{\nu_{\chi}}$ =110 MeV |
| <6 × 10 ⁻⁷ | 90 | 36 | BERGSMA | 83B | CNTR | $m_{\nu_{\chi}}$ =410 MeV |
| $<1 \times 10^{-5}$ | 90 | | GRONAU | 83 | | $m_{\nu_{\chi}}$ =160 MeV |
| $<1 \times 10^{-6}$ | 90 | | GRONAU | 83 | | $m_{\nu_{\chi}}$ =480 MeV |

- 29 BACK 03A searched for heavy neutrinos emitted from 8 B decay in the Sun using the decay $\nu_{h} o \nu_{e} \, e^{+} \, e^{-}$ in the Counting Test Facility (the prototype of the Borexino detector) and obtained limits on heavy neutrino admixture for the ν_{h} mass range 1.1–12
- 30 ABREU 97I long-lived $\nu_{\rm X}$ analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity except at 3.5 GeV, where the limit is the same as at 6 GeV.
- 31 HAGNER 95 obtain limits on heavy neutrino admixture from the decay $u_h
 ightarrow \,
 u_e \, e^+ \, e^$ at a nuclear reactor for the ν_h mass range 2–9 MeV.
- 32 BARANOV 93 is a search for neutrino decays into $e^+e^-\nu_e$ using a beam dump experiment at the 70 GeV Serpukhov proton synchrotron. The limits are not as good as those achieved earlier by BERGSMA 83 and BERNARDI 86, BERNARDI 88.
- $^{
 m 33}\,{
 m BURCHAT}$ 90 includes the analyses reported in JUNG 90, ABRAMS 89c, and WENDT 87.
- 34 OBERAUER 87 bounds from search for u
 ightarrow
 u'ee decay mode using reactor (anti)neutrinos.
- 35 COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_{τ} flux. We do not list these. Note that for this bound to be nontrivial, x is not equal to 3, i.e. ν_{χ} cannot be the dominant mass eigenstate in ν_{τ} since $m_{\nu_{3}}$ <70 MeV (ALBRECHT 85). Also, of course, x is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.
- 36 BERGSMA 83B also quote limits on $\lfloor U_{e3} \rfloor^2$ where the index 3 refers to the mass eigenstate dominantly coupled to the τ . Those limits were based on assumptions about the D_S mass and $D_S \rightarrow ~\tau \nu_{\tau}$ branching ratio which are no longer valid. See COOPER-SARKAR 85.

– Limits on Coupling of μ to $u_{_{m{X}}}$ as Function of $m_{ u_{_{m{v}}}}$ –

| Peak search test | ; | | | | |
|---------------------------------------------|-----------------|----------------------------|--------|--------------|------------------------------------------|
| Limits on B(| π (or K) | $\rightarrow \mu \nu_X$). | | | |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not u | ise the fo | llowing data for ave | erages | s, fits, lin | nits, etc. • • • |
| | | 37 ASTIER | 02 | NOMD | $\pi \to \mu X$ for $m_X = 33.9$ |
| $<\!6.0.0000000000000000000000000000000000$ | 95 | ³⁸ DAUM | 00 | CNTR | $\pi \rightarrow \mu X$ for $m_X = 33.9$ |
| | | ³⁹ FOR MAGGIO | 00 | CNTR | $\pi \to \mu X$ for $m_X = 33.9$ |
| < 0.22 | 90 | 40 ASSAMAGAN | 98 | SILI | MeV m — 0.53 MeV |

| < 0.029 |) | 90 | ⁴⁰ ASSAMAGAN | 98 | SILI | $m_{\nu_{\chi}} = 0.75 \text{ MeV}$ |
|-------------------|------------------|----|--------------------------|------|------|-------------------------------------------------------|
| < 0.016 | 5 | 90 | ⁴⁰ ASSAMAGAN | 98 | SILI | $m_{\nu_{\nu}} = 1.0 \text{ MeV}$ |
| < 4-6 > | $\times 10^{-5}$ | | ⁴¹ BRYMAN | 96 | CNTR | $m_{\nu_x} = 30-33.91 \text{ MeV}$ |
| $\sim 1 \times 1$ | 10 | | ⁴² ARMBRUSTER | R 95 | KARM | |
| <4 | $\times 10^{-7}$ | 95 | ⁴³ BILGER | 95 | LEPS | $m_{\overline{\nu}_{x}}^{\lambda} = 33.9 \text{ MeV}$ |
| <7 | $\times 10^{-8}$ | 95 | ⁴³ BILGER | 95 | LEPS | $m_{\nu_{x}}^{2} = 33.9 \text{ MeV}$ |
| < 2.6 | $\times 10^{-8}$ | 95 | ⁴³ DAUM | 95B | TOF | $m_{\nu_{-}}^{2} = 33.9 \text{ MeV}$ |
| <2 | $\times 10^{-2}$ | 90 | DAUM | 87 | | $m_{\nu_{x}}^{x}=1$ MeV |
| <1 | $\times 10^{-3}$ | 90 | DAUM | 87 | | $m_{\nu_{x}}^{2}=2 \text{ MeV}$ |
| <6 | $\times 10^{-5}$ | 90 | DAUM | 87 | | $3~{ m MeV} < m_{ u_{ m Y}} < 19.5~{ m MeV}$ |
| <3 | $\times 10^{-2}$ | 90 | 44 MINEHART | 84 | | $m_{\nu_{\nu}} = 2 \text{ MeV}^{\chi}$ |
| <1 | $\times 10^{-3}$ | 90 | 44 MINEHART | 84 | | $m_{\nu_{\nu}}^{2}$ =4 MeV |
| <3 | $\times 10^{-4}$ | 90 | ⁴⁴ MINEHART | 84 | | $m_{\nu_{\nu}} = 10 \text{ GeV}$ |
| <5 | $\times 10^{-6}$ | 90 | ⁴⁵ HAYANO | 82 | | $m_{\nu_{\chi}}^{\chi}$ =330 MeV |
| <1 | $\times 10^{-4}$ | 90 | ⁴⁵ HAYANO | 82 | | $m_{\nu_{\nu}}^{2} = 70 \text{ MeV}$ |
| <9 | $\times 10^{-7}$ | 90 | ⁴⁵ HAYANO | 82 | | $m_{\nu_{_{_{Y}}}}^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{^{$ |
| <1 | $\times 10^{-1}$ | 90 | ⁴⁴ ABELA | 81 | | $m_{\nu_{x}}^{2}$ =4 MeV |
| <7 | $\times 10^{-5}$ | 90 | ⁴⁴ ABELA | 81 | | $m_{\nu_{\nu}}^{2} = 10.5 \text{ MeV}$ |
| <2 | $\times10^{-4}$ | 90 | ⁴⁴ ABELA | 81 | | $m_{\nu_{\rm y}}^{\nu_{\rm x}}$ =11.5 MeV |
| <2 | $\times10^{-5}$ | 90 | ⁴⁴ ABELA | 81 | | $m_{\nu_{\nu}}^{2} = 16-30 \text{ MeV}$ |
| | | | | | | |

- $37\,\mathrm{ASTIER}$ 02 search for anomalous pion decay into a 33.9 MeV neutral particle. No evidence was found and the sensitivity to the branching ratio $\mathrm{B}(\pi\to\mu X)\cdot\mathrm{B}(X\to\nu e^+e^-)$ is as low as 3.7×10^{-15} , depending on the X lifetime.
- 38 DAUM 00 search for anomalous pion decay into a 33.9 MeV neutral particle that might be responsible for the time-distribution anomaly observed by the KARMEN Collaboration.
- 39 FORMAGGIO 00 search for anomalous pion decay into a 33.9 MeV neutral particle $\it Q^{0}$ That might be responsible for the time-distribution anomaly observed by the KARMEN Collaboration. In the E815 (NuTeV) experiment at Fermilab no evidence was found, with sensitivity for the pion branching ratio B($\pi \to \mu Q^0$)·B($Q^0 \to \text{visible}$) as low as
- 40 ASSAMAGAN 98 obtain a limit on heavy neutrino admixture from π^+ decay essentially at rest, by measuring with good resolution the momentum distribution of the muons. However, the search uses an ad hoc shape correction. The authors report upper limit for $|U_{\mu\chi}|^2$ of 0.22 for $m_{\nu}=0.53\,$ MeV, 0.029 for $m_{\nu}=0.75\,$ MeV, and 0.016 for $m_{\nu}=0.05\,$ MeV, and 0.018 for $m_{\nu}=0.05\,$ MeV, 0.018 for $m_{\nu}=0.05\,$ 1.0 MeV at 90%CL.
- $^{41}\,\mathrm{BRYMAN}$ 96 search for massive unconventional neutrinos of mass $m_{
 u_\chi}$ in π^+ decay.
- $^{42}\rm{ARMBRUSTER}$ 95 study the reactions $^{12}\rm{C}(\nu_e,e^-)$ $^{12}\rm{N}$ and $^{12}\rm{C}(\nu,\nu')$ $^{12}\rm{C}^*$ induced by neutrinos from π^+ and μ^+ decay at the ISIS neutron spallation source at the Rutherford-Appleton laboratory. An anomaly in the time distribution can be interpreted as the decay $\pi^+\to~\mu^+\nu_X$, where ν_X is a neutral weakly interacting particle with mass ≈ 33.9 MeV and spin 1/2. The lower limit to the branching ratio is a function of the lifetime of the new massive neutral particle, and reaches a minimum of a few $\times\,10^{-16}$ for $\tau_X\sim 5\,\mathrm{s}$.
- 43 From experiments of π^+ and π^- decay in flight at PSI, to check the claim of the KARMEN Collaboration quoted above (ARMBRUSTER 95).
- ⁴⁴ $\pi^+ \rightarrow \ \mu^+ \, \nu_{\mu}$ peak search experiment.
- 45 K $^+$ ightarrow $\mu^+\,
 u_\mu$ peak search experiment.

Peak search test

I**K SEATCH** LOSE

Limits on $|U_{\mu_X}|^2$ as function of m_{ν_X}

| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|-------------------------|---------|-------------|--------------------------------------------|
| • • • We do not us | e the follow | ing data for average | s, fits | , limits, e | etc. • • • |
| $< 1 10 \times 10^{-4}$ | | ⁴⁶ BRYMAN | 96 | CNTR | $m_{\nu_{\nu}} = 30-33.91 \text{ MeV}$ |
| $< 2 \times 10^{-5}$ | 95 | ⁴⁷ ASANO | 81 | | $m_{\nu} = 70 \text{ MeV}$ |
| $< 3 \times 10^{-6}$ | 95 | ⁴⁷ ASANO | 81 | | $m_{\nu} = 210 \text{ MeV}$ |
| $< 3 \times 10^{-6}$ | 95 | ⁴⁷ ASANO | 81 | | $m_{\nu_{\nu}}^{2} = 230 \text{ MeV}$ |
| $<6 \times 10^{-6}$ | 95 | ⁴⁸ ASANO | 81 | | $m_{\nu_{\nu}}^{2} = 240 \text{ MeV}$ |
| $<5 \times 10^{-7}$ | 95 | ⁴⁸ ASANO | 81 | | $m_{\nu_{x}}^{2} = 280 \text{ MeV}$ |
| $< 6 \times 10^{-6}$ | 95 | ⁴⁸ ASANO | 81 | | $m_{\nu_{\nu}}^{2}$ = 300 MeV |
| $<1 \times 10^{-2}$ | 95 | CALAPRICE | 81 | | $m_{\nu} = 7 \text{ MeV}$ |
| $< 3 \times 10^{-3}$ | 95 | ⁴⁹ CALAPRICE | 81 | | $m_{\nu} = 33 \text{ MeV}$ |
| $< 1 \times 10^{-4}$ | 68 | ⁵⁰ SHROCK | 81 | THEO | $m_{\nu_{\nu}}^{\nu_{\nu}}=13 \text{ MeV}$ |
| $< 3 \times 10^{-5}$ | 68 | ⁵⁰ SHROCK | 81 | | $m_{\nu_{\nu}}^{2}$ = 33 MeV |
| $< 6 \times 10^{-3}$ | 68 | ⁵¹ SHROCK | 81 | | $m_{\nu_{\nu}}^{2}$ = 80 MeV |
| $< 5 \times 10^{-3}$ | 68 | ⁵¹ SHROCK | 81 | | $m_{\nu} = 120 \text{ MeV}$ |

- $^{46}\,\mathrm{BRYMA\,N}$ 96 search for massive unconventional neutrinos of mass $m_{\nu_{\mathrm{v}}}$ in π^+ decay. They interpret the result as an upper limit for the admixture of a heavy sterile or otherwise
- $^{47}\,\mathrm{K^+}\,
 ightarrow\, \mu^+\,
 u_{\mu}$ peak search experiment.
- ⁴⁸ Analysis of experiment on $K^+
 ightarrow \ \mu^+
 u_\mu
 u_\chi \overline{
 u}_\chi$ decay.
- $^{49}\,\pi^+\,
 ightarrow\, \mu^+\,
 u_\mu$ peak search experiment.
- $^{50}\,\mathrm{Analysis}$ of magnetic spectrometer experiment, bubble chamber experiment, and emulsion experiment on $\pi^+
 ightarrow \, \mu^+ \,
 u_\mu$ decay.

Lepton Particle Listings

Heavy Neutral Leptons, Searches for

 51 Analysis of magnetic spectrometer experiment on $~{\it K}
ightarrow ~\mu$, $~{\it \nu}_{\mu}$ decay.

Peak Search in Muon Capture

Limits on $|\mathit{U}_{\mu_{X}}|^{2}$ as function of $\mathit{m}_{\nu_{x}}$

| | $\nu_{\nu_{\chi}}$ | | | |
|--------------------------------|----------------------|----------|-----------------------------------|--|
| VALUE | DO CUMENT ID | | COMMENT | |
| • • • We do not use the follow | ving data for averag | es, fits | , limits, etc. • • • | |
| $<1 \times 10^{-1}$ | DEUTSCH | 83 | $m_{\nu_{\nu}} = 45 \text{ MeV}$ | |
| $< 7 \times 10^{-3}$ | DEUTSCH | 83 | $m_{\nu_{\nu}}^{}=70 \text{ MeV}$ | |
| $<1 \times 10^{-1}$ | DEUTSCH | 83 | $m_{\nu_{\nu}} = 85 \text{ MeV}$ | |

Searches for Decays of Massive u

Limits on $|U_{\mu,\nu}|^2$ as function of $m_{\nu,\nu}$

| Limits on $ U_{\mu X} ^2$ | as functi | on | of $m_{ u_{\chi}}$ | | | |
|---------------------------|-----------|------|--------------------|---------|-----------|--------------------------------------------------|
| VALUE | CL% | | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the | followin | ng d | ata for averages | , fits, | limits, e | etc. • • • |
| $< 5 \times 10^{-7}$ | 90 | 52 | VAITAITIS | 99 | CCFR | $m_{\nu_x} = 0.28 \text{ GeV}$ |
| $< 8 \times 10^{-8}$ | 90 | 52 | VAITAITIS | 99 | CCFR | $m_{\nu_{\chi}}^{\nu_{\chi}} = 0.37 \text{ GeV}$ |
| $< 5 \times 10^{-7}$ | 90 | 52 | VAITAITIS | 99 | CCFR | $m_{\nu_{\chi}}^{\nu_{\chi}} = 0.50 \text{ GeV}$ |
| $< 6 \times 10^{-8}$ | 90 | 52 | VAITAITIS | 99 | CCFR | $m_{\nu_{\chi}} = 1.50 \text{ GeV}$ |
| $< 2 \times 10^{-5}$ | 95 | 53 | ABREU | 97ı | DLPH | $m_{\nu_{\chi}}^{2}=6 \text{ GeV}$ |
| $< 3 \times 10^{-5}$ | 95 | 53 | ABREU | 971 | DLPH | $m_{\nu_{\chi}}^{-\chi}$ =50 GeV |
| $< 3 \times 10^{-6}$ | 90 | | GALLAS | 95 | CNTR | $m_{ u_{\chi}} = 1 \; GeV$ |
| $< 3 \times 10^{-5}$ | 90 | 54 | VILAIN | 95 c | CHM2 | $m_{ u_{\chi}}^{^{^{\prime}}}=2\;\mathrm{GeV}$ |
| $<6.2 \times 10^{-8}$ | 95 | | ADEVA | 90s | L3 | $m_{\nu_{\chi}}^{2}$ = 20 GeV |
| $< 5.1 \times 10^{-10}$ | 95 | | ADEVA | 90s | L3 | m_{ν} =40 GeV |
| all values ruled out | 95 | 55 | BURCHAT | 90 | MRK2 | $m_{ u_\chi}^{ u_\chi} < 19.6 \mathrm{GeV}$ |
| $< 1 \times 10^{-10}$ | 95 | 55 | BURCHAT | 90 | MRK2 | $m_{ u_{\chi}} = 22 \text{ GeV}$ |
| $< 1 \times 10^{-11}$ | 95 | 55 | BURCHAT | 90 | MRK2 | $m_{ u_{\chi}} = 41 \text{ GeV}$ |
| all values ruled out | 95 | | DECAMP | 90F | ALEP | $m_{\nu_{x}} = 25.0-42.7 \text{ GeV}$ |
| $< 1 \times 10^{-13}$ | 95 | | DECAMP | 90F | ALEP | $m_{\nu_{\nu}} = 42.7-45.7 \text{ GeV}$ |
| $< 5 \times 10^{-3}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu_{\chi}}$ =1.8 GeV |
| $< 2 \times 10^{-5}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu_{\chi}} = 4 \text{ GeV}$ |
| $< 3 \times 10^{-6}$ | 90 | | AKERLOF | 88 | HRS | $m_{\nu_{\nu}} = 6 \text{ GeV}$ |
| $<1 \times 10^{-7}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{\chi}} = 200 \text{ MeV}$ |
| $< 3 \times 10^{-9}$ | 90 | | BERNARDI | 88 | CNTR | $m_{\nu_{x}} = 300 \text{ MeV}$ |
| $< 4 \times 10^{-4}$ | 90 | 56 | MISHRA | 87 | CNTR | $m_{\nu_{x}} = 1.5 \text{ GeV}$ |
| $<4 \times 10^{-3}$ | 90 | 56 | MISHRA | 87 | CNTR | $m_{\nu_{\chi}} = 2.5 \text{ GeV}$ |
| $< 0.9 \times 10^{-2}$ | 90 | 56 | MISHRA | 87 | CNTR | $m_{\nu_{\chi}} = 5 \text{ GeV}$ |
| < 0.1 | 90 | 56 | MISHRA | 87 | CNTR | $m_{\nu_{\nu}} = 10 \text{ GeV}$ |
| $< 8 \times 10^{-4}$ | 90 | | BADIER | 86 | CNTR | $m_{\nu_{\chi}} = 600 \text{ MeV}$ |
| $< 1.2 \times 10^{-5}$ | 90 | | BADIER | 86 | CNTR | $m_{\nu_{\nu}} = 1.7 \text{ GeV}$ |
| $< 3 \times 10^{-8}$ | 90 | | BERNARDI | 86 | CNTR | $m_{\nu_x} = 200 \text{ MeV}$ |
| $< 6 \times 10^{-9}$ | 90 | | BERNARDI | 86 | CNTR | $m_{\nu_x} = 350 \text{ MeV}$ |
| $<1 \times 10^{-6}$ | 90 | | DORENBOS | 86 | CNTR | $m_{\nu_{\nu}} = 500 \text{ MeV}$ |
| $<1 \times 10^{-7}$ | 90 | | DORENBOS | 86 | CNTR | $m_{\nu_{\chi}}$ =1600 MeV |
| $< 0.8 \times 10^{-5}$ | 90 | 57 | COOPER | 85 | HLBC | $m_{\nu_x} = 0.4 \text{ GeV}$ |
| $<1.0 \times 10^{-7}$ | 90 | 57 | COOPER | 85 | HLBC | $m_{\nu_{\nu}} = 1.5 \text{ GeV}$ |

 $^{^{52}}$ VAITAITIS 99 search for $L_{\mu}^{0}
ightarrow \mu$ X . See paper for rather complicated limit as function of m .

Limits on $|U_{ au_X}|^2$ as a Function of $m_{ u_X}$

| VALUE | CL% | DO CUMENT IE |) | TECN COMMENT |
|------------------------|---------------|----------------------|-----------|----------------------------------------|
| • • • We do not use | the following | ng data for averag | ges, fits | , limits, etc. • • • |
| <1 $\times 10^{-2}$ | 90 | ⁵⁸ ORLOFF | 02 | CHRM $m_{\nu_{\nu}} = 45 \text{ MeV}$ |
| $< 1.4 \times 10^{-4}$ | 90 | ⁵⁸ ORLOFF | 02 | CHRM $m_{\nu_{\nu}} = 180 \text{ MeV}$ |
| < 0.025 | 90 | ASTIER | 01 | $m_{\nu_{\chi}} = 45 \text{ MeV}$ |
| < 0.002 | 90 | ASTIER | 01 | $m_{\nu_x} = 140 \text{ MeV}$ |
| $< 2 \times 10^{-5}$ | 95 | ⁵⁹ ABREU | 97ı | DLPH $m_{\nu_{\chi}} = 6 \text{ GeV}$ |
| <3 $\times 10^{-5}$ | 95 | ⁵⁹ ABREU | 971 | DLPH $m_{\nu_x} = 50 \text{ GeV}$ |

| | $\times 10^{-8}$ | 95 | ADEVA | 90s | L3 | $m_{\nu_{\rm v}} = 20 \text{ GeV}$ |
|----------|-------------------|----|-----------------------|-----|------|-----------------------------------------|
| <5.1 | $\times 10^{-10}$ | 95 | ADEVA | 90s | L3 | $m_{\nu_{\chi}} = 40 \text{ GeV}$ |
| | es ruled out | 95 | ⁶⁰ BURCHAT | 90 | MRK2 | $m_{ u_{ m v}}$ < 19.6 GeV |
| <1 | $\times 10^{-10}$ | 95 | ⁶⁰ BURCHAT | 90 | MRK2 | $m_{\nu} = 22 \text{ GeV}$ |
| <1 | $\times 10^{-11}$ | 95 | ⁶⁰ BURCHAT | 90 | MRK2 | $m_{\nu_{\nu}}^{x} = 41 \text{ GeV}$ |
| all valu | es ruled out | 95 | DECAMP | 90F | ALEP | $m_{\nu_{x}} = 25.0-42.7 \text{ GeV}$ |
| <1 | $\times 10^{-13}$ | 95 | DECAMP | 90F | ALEP | $m_{\nu_{\nu}} = 42.7-45.7 \text{ GeV}$ |
| <5 | $\times 10^{-2}$ | 80 | AKERLOF | 88 | HRS | $m_{\nu_{\nu}}^{2}=2.5 \text{ GeV}$ |
| <9 | $\times 10^{-5}$ | 80 | AKERLOF | 88 | HRS | $m_{\nu} = 4.5 \text{ GeV}$ |

 $^{^{58}}$ ORLOFF 02 use the negative result of a search for neutral particles decaying into two electrons performed by CHARM to get these limits for a mostly isosinglet heavy neutrino.

Limits on $|U_{ax}|^2$

Where a=e, μ from ho parameter in μ decay.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-------------|-------------------|---------|-----------|----------------------------------|
| • • • We do not use the | following d | lata for averages | , fits, | limits, e | etc. • • • |
| $<1 \times 10^{-2}$ | 68 | SHROCK | 81B | THEO | $m_{\nu_{\nu}} = 10 \text{ GeV}$ |
| $<2 \times 10^{-3}$ | 68 | SHROCK | 81в | THEO | $m_{\nu_{x}}$ =40 MeV |
| $<4 \times 10^{-2}$ | 68 | SHROCK | 81B | THEO | $m_{ij} = 70 \text{ MeV}$ |

Limits on $|U_{1j} \times U_{2j}|$ as Function of m_{ν_j}

| VALUE | | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------|------------------|----------------|-----------------------|---------|---------|----------------------------------|
| • • • | • We do not us | e the followin | g data for average | s, fits | limits, | etc. • • • |
| <3 | $\times10^{-5}$ | 90 | ⁶¹ BARANOV | 93 | | $m_{ u_i} = 80 \; \mathrm{MeV}$ |
| <3 | $\times 10^{-6}$ | 90 | ⁶¹ BARANOV | 93 | | $m_{\nu_i} = 160 \text{ MeV}$ |
| <6 | $\times 10^{-7}$ | 90 | ⁶¹ BARANOV | 93 | | $m_{\nu_i} = 240 \text{ MeV}$ |
| <2 | $\times 10^{-7}$ | 90 | ⁶¹ BARANOV | 93 | | $m_{\nu_i} = 320 \text{ MeV}$ |
| <9 | $\times10^{-5}$ | 90 | BERNARDI | 86 | CNTR | $m_{\nu_i}^{J}$ =25 MeV |
| < 3.6 | $\times 10^{-7}$ | 90 | BERNARDI | 86 | CNTR | $m_{\nu_i}^{J}$ =100 MeV |
| <3 | $\times 10^{-8}$ | 90 | BERNARDI | 86 | CNTR | $m_{\nu_i}^{J}$ =200 MeV |
| <6 | $\times 10^{-9}$ | 90 | BERNARDI | 86 | CNTR | $m_{\nu_i}^{J}$ =350 MeV |
| <1 | $\times 10^{-2}$ | 90 | BERGSMA | 83B | CNTR | $m_{\nu_i}^{J} = 10 \text{ MeV}$ |
| <1 | $\times 10^{-5}$ | 90 | BERGSMA | 83B | CNTR | $m_{\nu_i}^{J}$ =140 MeV |
| <7 | $\times 10^{-7}$ | 90 | BERGSMA | 83B | | $m_{\nu_j}^{J}$ =370 MeV |

 $^{^{61}}$ BARANOV 93 is a search for neutrino decays into $e^+\,e^-\,\nu_e$ using a beam dump experiment at the 70 GeV Serpukhov proton synchrotron.

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 $^{^{53} \}text{ABREU 97} \text{l long-lived } \nu_{\text{X}}$ analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity except at 3.5 GeV, where the limit is the same as at 6 GeV.

⁵⁴ VILAIN 95c is a search for the decays of heavy isosinglet neutrinos produced by neutral current neutrino interactions. Limits were quoted for masses in the range from 0.3 to 24 GeV. The best limit is listed above.

⁵⁵ BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89c, and WENDT 87.

 $^{^{56}\,\}mathrm{See}$ also limits on $|\mathit{U}_{3x}|$ from WENDT 87.

 $^{^{57}}$ COOPER-SARKAR 85 also give limits based on model-dependent assumptions for ν_{τ} flux. We do not list these. Note that for this bound to be nontrivial, x is not equal to 3, i.e. ν_{X} cannot be the dominant mass eigenstate in ν_{τ} since $m_{\nu_{3}}~<$ 70 MeV (ALBRECHT 851). Also, of course, x is not equal to 1 or 2, so a fourth generation would be required for this bound to be nontrivial.

 $^{^{59}}$ ABREU 971 long-lived $\nu_{\rm X}$ analysis. Short-lived analysis extends limit to lower masses with decreasing sensitivity.

⁶⁰BURCHAT 90 includes the analyses reported in JUNG 90, ABRAMS 89c, and WENDT 87.

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QUARKS

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Quark Particle Listings Quarks

QUARKS

QUARK MASSES

Updated Jan 2012 by A.V. Manohar (University of California, San Diego) and C.T. Sachrajda (University of Southampton).

A. Introduction

This note discusses some of the theoretical issues relevant for the determination of quark masses, which are fundamental parameters of the Standard Model of particle physics. Unlike the leptons, quarks are confined inside hadrons and are not observed as physical particles. Quark masses therefore cannot be measured directly, but must be determined indirectly through their influence on hadronic properties. Although one often speaks loosely of quark masses as one would of the mass of the electron or muon, any quantitative statement about the value of a quark mass must make careful reference to the particular theoretical framework that is used to define it. It is important to keep this scheme dependence in mind when using the quark mass values tabulated in the data listings.

Historically, the first determinations of quark masses were performed using quark models. The resulting masses only make sense in the limited context of a particular quark model, and cannot be related to the quark mass parameters of the Standard Model. In order to discuss quark masses at a fundamental level, definitions based on quantum field theory be used, and the purpose of this note is to discuss these definitions and the corresponding determinations of the values of the masses.

B. Mass parameters and the QCD Lagrangian

The QCD [1] Lagrangian for N_F quark flavors is

$$\mathcal{L} = \sum_{k=1}^{N_F} \overline{q}_k (i \not\!\!D - m_k) q_k - \frac{1}{4} G_{\mu\nu} G^{\mu\nu} , \qquad (1)$$

where $\not{\!\! D} = (\partial_{\mu} - igA_{\mu}) \gamma^{\mu}$ is the gauge covariant derivative, A_{μ} is the gluon field, $G_{\mu\nu}$ is the gluon field strength, m_k is the mass parameter of the $k^{\rm th}$ quark, and q_k is the quark Dirac field. After renormalization, the QCD Lagrangian Eq. (1) gives finite values for physical quantities, such as scattering amplitudes. Renormalization is a procedure that invokes a subtraction scheme to render the amplitudes finite, and requires the introduction of a dimensionful scale parameter μ . The mass parameters in the QCD Lagrangian Eq. (1) depend on the renormalization scheme used to define the theory, and also on the scale parameter μ . The most commonly used renormalization scheme for QCD perturbation theory is the $\overline{\rm MS}$ scheme.

The QCD Lagrangian has a chiral symmetry in the limit that the quark masses vanish. This symmetry is spontaneously broken by dynamical chiral symmetry breaking, and explicitly broken by the quark masses. The nonperturbative scale of dynamical chiral symmetry breaking, Λ_{χ} , is around 1 GeV [2]. It is conventional to call quarks heavy if $m > \Lambda_{\chi}$, so that explicit

chiral symmetry breaking dominates (c, b, and t quarks are heavy), and light if $m < \Lambda_{\chi}$, so that spontaneous chiral symmetry breaking dominates (u, d and s quarks are light). The determination of light- and heavy-quark masses is considered separately in sections D and E below.

At high energies or short distances, nonperturbative effects, such as chiral symmetry breaking, become small and one can, in principle, determine quark masses by analyzing mass-dependent effects using QCD perturbation theory. Such computations are conventionally performed using the $\overline{\rm MS}$ scheme at a scale $\mu\gg\Lambda_\chi$, and give the $\overline{\rm MS}$ "running" mass $\overline{m}(\mu)$. We use the $\overline{\rm MS}$ scheme when reporting quark masses; one can readily convert these values into other schemes using perturbation theory.

The μ dependence of $\overline{m}(\mu)$ at short distances can be calculated using the renormalization group equation,

$$\mu^{2} \frac{\mathrm{d}\overline{m}(\mu)}{\mathrm{d}\mu^{2}} = -\gamma(\overline{\alpha}_{s}(\mu)) \,\overline{m}(\mu), \qquad (2)$$

where γ is the anomalous dimension which is now known to four-loop order in perturbation theory [3,4]. $\overline{\alpha}_s$ is the coupling constant in the $\overline{\rm MS}$ scheme. Defining the expansion coefficients γ_r by

$$\gamma\left(\overline{\alpha}_{s}\right) \equiv \sum_{r=1}^{\infty} \gamma_{r} \left(\frac{\overline{\alpha}_{s}}{4\pi}\right)^{r},$$

the first four coefficients are given by

$$\begin{split} \gamma_1 &= 4, \\ \gamma_2 &= \frac{202}{3} - \frac{20N_L}{9}, \\ \gamma_3 &= 1249 + \left(-\frac{2216}{27} - \frac{160}{3}\zeta\left(3\right)\right)N_L - \frac{140}{81}N_L^2, \\ \gamma_4 &= \frac{4603055}{162} + \frac{135680}{27}\zeta\left(3\right) - 8800\zeta\left(5\right) \\ &+ \left(-\frac{91723}{27} - \frac{34192}{9}\zeta\left(3\right) + 880\zeta\left(4\right) + \frac{18400}{9}\zeta\left(5\right)\right)N_L \\ &+ \left(\frac{5242}{243} + \frac{800}{9}\zeta\left(3\right) - \frac{160}{3}\zeta\left(4\right)\right)N_L^2 \\ &+ \left(-\frac{332}{243} + \frac{64}{27}\zeta\left(3\right)\right)N_L^3, \end{split}$$

where N_L is the number of active light quark flavors at the scale μ , i.e. flavors with masses $< \mu$, and ζ is the Riemann zeta function ($\zeta(3) \simeq 1.2020569$, $\zeta(4) \simeq 1.0823232$, and $\zeta(5) \simeq 1.0369278$). In addition, as the renormalization scale crosses quark mass thresholds one needs to match the scale dependence of m below and above the threshold. There are finite threshold corrections; the necessary formulae can be found in Ref. [5].

The quark masses for light quarks discussed so far are often referred to as current quark masses. Nonrelativistic quark models use constituent quark masses, which are of order $350\,\mathrm{MeV}$ for the u and d quarks. Constituent quark masses

Quarks

model the effects of dynamical chiral symmetry breaking, and are not related to the quark mass parameters m_k of the QCD Lagrangian Eq. (1). Constituent masses are only defined in the context of a particular hadronic model.

C. Lattice Gauge Theory

The use of the lattice simulations for ab initio determinations of the fundamental parameters of QCD, including the coupling constant and quark masses (except for the top-quark mass) is a very active area of research (see the review on Lattice Quantum Chromodynamics in this Review). Here we only briefly recall those features which are required for the determination of quark masses. In order to determine the lattice spacing (a, i.e. the distance between neighboring points of the lattice) and quark masses, one computes a convenient and appropriate set of physical quantities (frequently chosen to be a set of hadronic masses) for a variety of input values of the quark masses. The true (physical) values of the quark masses are those which correctly reproduce the set of physical quantities being used for the calibration.

The values of the quark masses obtained directly in lattice simulations are bare quark masses, corresponding to a particular discretization of QCD and with the lattice spacing as the ultraviolet cut-off. In order for these results to be useful in phenomenological applications, it is necessary to relate them to renormalized masses defined in some standard renormalization scheme such as \overline{MS} . Provided that both the ultraviolet cut-off a^{-1} and the renormalization scale are much greater than $\Lambda_{\rm OCD}$, the bare and renormalized masses can be related in perturbation theory. However, in order to avoid uncertainties due to the unknown higher-order coefficients in lattice perturbation theory, most results obtained recently use non-perturbative renormalization to relate the bare masses to those defined in renormalization schemes which can be simulated directly in lattice QCD (e.g. those obtained from quark and gluon Green functions at specified momenta in the Landau gauge [50] or those defined using finite-volume techniques and the Schrödinger functional [51]). The conversation to the $\overline{\rm MS}$ scheme (which cannot be simulated) is then performed using continuum perturbation theory.

The determination of quark masses using lattice simulations is well established and the current emphasis is on the reduction and control of the systematic uncertainties. With improved algorithms and access to more powerful computing resources, the precision of the results has improved immensely in recent years. Particularly pleasing is the observation that results obtained using different formulations of lattice QCD, with different systematic uncertainties, give results which are largely consistent with each other. This gives us broad confidence in the estimates of the systematic errors. As the precision of the results approaches the percent level, more attention will now have to be given to sources of systematic uncertainty which have only been studied in a limited way up to now. In particular most current simulations are performed with degenerate u

and d quarks and without including electromagnetic effects. Vacuum polarisation effects are included with $N_f=2+1$ or $N_f=2$ flavors of sea quarks, although simulations with charm sea quarks are now beginning. In earlier reviews, results were presented from simulations in which vacuum polarization effects were completely neglected (this is the so-called quenched approximation), leading to systematic uncertainties which could not be estimated reliably. It is no longer necessary to include quenched results in compilations of quark masses.

D. Light quarks

In this section we review the determination of the masses of the light quarks u, d and s from lattice simulations and then discuss the consequences of the approximate chiral symmetry.

Lattice Gauge Theory: The most reliable determinations of the strange quark mass m_s and of the average of the up and down quark masses $m_{ud} = (m_u + m_d)/2$ are obtained from lattice simulations. As explained in section C above, the simulations are performed with degenerate up and down quarks $(m_u = m_d)$ and so it is the average which is obtained directly from the computations. Below we discuss attempts to derive m_u and m_d separately using lattice results in combination with other techniques, but here we briefly present our estimate of the current status of the latest lattice results. Based largely on references [19–26], which have among the most reliable estimates of the systematic errors, our summary is

$$\overline{m}_s = (93.5 \pm 2.5) \,\text{MeV}, \quad \overline{m}_{ud} = (3.40 \pm 0.25) \,\text{MeV}$$
 (3)

and

$$\frac{\overline{m}_s}{\overline{m}_{ud}} = 27.5 \pm 0.3. \tag{4}$$

The masses are given in the $\overline{\rm MS}$ scheme at a renormalization scale of 2 GeV. Because the errors are dominated by systematics, these results are not simply the combinations of all the results in quadrature, but include a judgement of the remaining uncertainties. Since the different collaborations use different formulations of lattice QCD, the (relatively small) variations of the results between the groups provides important information about the reliability of the estimates.

Current lattice simulations are performed in the isospin symmetry limit, i.e. with the masses of the up and down quarks equal, $m_u = m_d \equiv m_{ud}$ and, apart from Refs. [31,32], electromagnetic effects are not included in the simulation. It is the average of the physical up and down quark masses which is determined directly. In order to estimate m_u and m_d separately, further experimental and theoretical inputs have to be included. Recent studies which combine lattice data with studies of isospin breaking effects using chiral perturbation theory and phenomenology include those by the MILC [20,27] and BMW [22,23] collaborations and by the Flavianet Lattice Averaging Group [32]. Based on these results we summarise the current status as

$$\frac{\overline{m}_u}{\overline{m}_d} = 0.46(5)$$
, $\overline{m}_u = 2.15(15) \,\text{MeV}$, $\overline{m}_d = 4.70(20) \,\text{MeV}$. (5)

Again the masses are given in the $\overline{\rm MS}$ scheme at a renormalization scale of 2 GeV. Of particular importance is the fact that $m_u \neq 0$ since there would have been no strong CP problem had m_u been equal to zero.

The quark mass ranges for the light quarks given in the listings combine the lattice and continuum values and use the PDG method for determining errors given in the introductory notes.

Chiral Perturbation Theory: For light quarks, one can use the techniques of chiral perturbation theory [6–8] to extract quark mass ratios. The mass term for light quarks in the QCD Lagrangian is

$$\overline{\Psi}M\Psi = \overline{\Psi}_L M\Psi_R + \overline{\Psi}_R M^{\dagger} \Psi_L, \tag{6}$$

where M is the light quark mass matrix,

$$M = \begin{pmatrix} m_u & 0 & 0\\ 0 & m_d & 0\\ 0 & 0 & m_s \end{pmatrix}, \tag{7}$$

 $\Psi=(u,d,s)$, and L and R are the left- and right-chiral components of Ψ given by $\Psi_{L,R}=P_{L,R}\Psi,\ P_L=(1-\gamma_5)/2,$ $P_R=(1+\gamma_5)/2$. The mass term is the only term in the QCD Lagrangian that mixes left- and right-handed quarks. In the limit $M\to 0$, there is an independent $SU(3)\times U(1)$ flavor symmetry for the left- and right-handed quarks. The vector U(1) symmetry is baryon number; the axial U(1) symmetry of the classical theory is broken in the quantum theory due to the anomaly. The remaining $G_\chi=\mathrm{SU}(3)_L\times\mathrm{SU}(3)_R$ chiral symmetry of the QCD Lagrangian is spontaneously broken to $SU(3)_V$, which, in the limit $M\to 0$, leads to eight massless Goldstone bosons, the π 's, K's, and η .

The symmetry G_χ is only an approximate symmetry, since it is explicitly broken by the quark mass matrix M. The Goldstone bosons acquire masses which can be computed in a systematic expansion in M, in terms of low-energy constants, which are unknown nonperturbative parameters of the effective theory, and are not fixed by the symmetries. One treats the quark mass matrix M as an external field that transforms under G_χ as $M \to LMR^\dagger$, where $\Psi_L \to L\Psi_L$ and $\Psi_R \to R\Psi_R$ are the $SU(3)_L$ and $SU(3)_R$ transformations, and writes down the most general Lagrangian invariant under G_χ . Then one sets M to its given constant value Eq. (7), which implements the symmetry breaking. To first order in M one finds that [9]

$$m_{\pi^0}^2 = B (m_u + m_d) ,$$

$$m_{\pi^{\pm}}^2 = B (m_u + m_d) + \Delta_{em} ,$$

$$m_{K^0}^2 = m_{\overline{K}^0}^2 = B (m_d + m_s) ,$$

$$m_{K^{\pm}}^2 = B (m_u + m_s) + \Delta_{em} ,$$

$$m_{\eta}^2 = \frac{1}{3} B (m_u + m_d + 4m_s) ,$$
(8)

with two unknown constants B and $\Delta_{\rm em}$, the electromagnetic mass difference. From Eq. (8), one can determine the quark mass ratios [9]

$$\begin{split} \frac{m_u}{m_d} &= \frac{2m_{\pi^0}^2 - m_{\pi^+}^2 + m_{K^+}^2 - m_{K^0}^2}{m_{K^0}^2 - m_{K^+}^2 + m_{\pi^+}^2} = 0.56 , \\ \frac{m_s}{m_d} &= \frac{m_{K^0}^2 + m_{K^+}^2 - m_{\pi^+}^2}{m_{K^0}^2 + m_{\pi^+}^2 - m_{K^+}^2} = 20.2 , \end{split} \tag{9}$$

to lowest order in chiral perturbation theory, with an error which will be estimated below. Since the mass ratios extracted using chiral perturbation theory use the symmetry transformation property of M under the chiral symmetry G_{χ} , it is important to use a renormalization scheme for QCD that does not change this transformation law. Any mass independent subtraction scheme such as $\overline{\rm MS}$ is suitable. The ratios of quark masses are scale independent in such a scheme, and Eq. (9) can be taken to be the ratio of $\overline{\rm MS}$ masses. Chiral perturbation theory cannot determine the overall scale of the quark masses, since it uses only the symmetry properties of M, and any multiple of M has the same G_{χ} transformation law as M.

Chiral perturbation theory is a systematic expansion in powers of the light quark masses. The typical expansion parameter is $m_K^2/\Lambda_\chi^2 \sim 0.25$ if one uses SU(3) chiral symmetry, and $m_\pi^2/\Lambda_\chi^2 \sim 0.02$ if instead one uses SU(2) chiral symmetry. Electromagnetic effects at the few percent level also break SU(2) and SU(3) symmetry. The mass formulæ Eq. (8) were derived using SU(3) chiral symmetry, and are expected to have approximately a 25% uncertainty due to second order corrections. This estimate of the uncertainty is consistent with the lattice results found in Eq. (3) and Eq. (4).

There is a subtlety which arises when one tries to determine quark mass ratios at second order in chiral perturbation theory. The second order quark mass term [10]

$$\left(M^{\dagger}\right)^{-1} \det M^{\dagger} \tag{10}$$

(which can be generated by instantons) transforms in the same way under G_{χ} as M. Chiral perturbation theory cannot distinguish between M and $\left(M^{\dagger}\right)^{-1} \det M^{\dagger}$; one can make the replacement $M \to M(\lambda) = M + \lambda M \left(M^{\dagger}M\right)^{-1} \det M^{\dagger}$ in the chiral Lagrangian,

$$M(\lambda) = \operatorname{diag}(m_u(\lambda), m_d(\lambda), m_s(\lambda))$$

$$= \operatorname{diag} (m_u + \lambda m_d m_s, \ m_d + \lambda m_u m_s, \ m_s + \lambda m_u m_d), (11)$$

and leave all observables unchanged.

The combination

$$\left(\frac{m_u}{m_d}\right)^2 + \frac{1}{Q^2} \left(\frac{m_s}{m_d}\right)^2 = 1 \tag{12}$$

where

$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}, \qquad \hat{m} = \frac{1}{2} (m_u + m_d),$$

Quarks

is insensitive to the transformation in Eq. (11). Eq. (12) gives an ellipse in the $m_u/m_d-m_s/m_d$ plane. The ellipse is well-determined by chiral perturbation theory, but the exact location on the ellipse, and the absolute normalization of the quark masses, has larger uncertainties. Q is determined to be in the range 21–25 from $\eta \to 3\pi$ decay and the electromagnetic contribution to the K^+-K^0 and $\pi^+-\pi^0$ mass differences [11].

The absolute normalization of the quark masses cannot be determined using chiral perturbation theory. Other methods, such as lattice simulations discussed above or spectral function sum rules [12,13] for hadronic correlation functions, which we review next are necessary.

Sum Rules: Sum rule methods have been used extensively to determine quark masses and for illustration we briefly discuss here their application to hadronic τ decays [14]. Other applications involve very similar techniques.

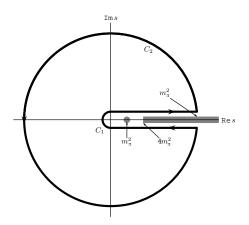


Figure 1: The analytic structure of $\Pi(s)$ in the complex s-plane. The contours C_1 and C_2 are the integration contours discussed in the text.

The experimentally measured quantity is R_{τ} ,

$$\frac{\mathrm{d}R_{\tau}}{\mathrm{d}s} = \frac{\mathrm{d}\Gamma/\mathrm{d}s \left(\tau^{-} \to \text{hadrons} + \nu_{\tau}(\gamma)\right)}{\Gamma\left(\tau^{-} \to e^{-}\overline{\nu}_{e}\nu_{\tau}(\gamma)\right)}$$
(13)

the hadronic invariant mass spectrum in semihadronic τ decay, normalized to the leptonic τ decay rate. It is useful to define q as the total momentum of the hadronic final state, so $s=q^2$ is the hadronic invariant mass. The total hadronic τ decay rate R_{τ} is then given by integrating $\mathrm{d}R_{\tau}/\mathrm{d}s$ over the kinematically allowed range $0 \le s \le M_{\tau}^2$.

 R_{τ} can be written as

$$R_{\tau} = 12\pi \int_{0}^{M_{\tau}^{2}} \frac{\mathrm{d}s}{M_{\tau}^{2}} \left(1 - \frac{s}{M_{\tau}^{2}}\right)^{2} \times \left[\left(1 + 2\frac{s}{M_{\tau}^{2}}\right) \operatorname{Im}\Pi^{T}(s) + \operatorname{Im}\Pi^{L}(s)\right]$$
(14)

where $s=q^2$, and the hadronic spectral functions $\Pi^{L,T}$ are defined from the time-ordered correlation function of two weak

currents is the time-ordered correlator of the weak interaction current $(j^{\mu}(x))$ and $j^{\nu}(0)$ by

$$\Pi^{\mu\nu}(q) = i \int \mathrm{d}^4 x \; e^{iq \cdot x} \left\langle 0 \right| T \left(j^{\mu}(x) j^{\nu}(0)^{\dagger} \right) \left| 0 \right\rangle, \tag{15}$$

$$\Pi^{\mu\nu}(q) = (-g^{\mu\nu} + q^{\mu}q^{\nu})\Pi^{T}(s) + q^{\mu}q^{\nu}\Pi^{L}(s), \tag{16}$$

and the decomposition Eq. (16) is the most general possible structure consistent with Lorentz invariance.

By the optical theorem, the imaginary part of $\Pi^{\mu\nu}$ is proportional to the total cross-section for the current to produce all possible states. A detailed analysis including the phase space factors leads to Eq. (14). The spectral functions $\Pi^{L,T}(s)$ are analytic in the complex s plane, with singularities along the real axis. There is an isolated pole at $s=m_{\pi}^2$, and single- and multi-particle singularities for $s \geq 4m_{\pi}^2$, the twoparticle threshold. The discontinuity along the real axis is $\Pi^{L,T}(s+i0^+) - \Pi^{L,T}(s-i0^+) = 2i \text{Im } \Pi^{L,T}(s)$. As a result, Eq. (14) can be rewritten with the replacement Im $\Pi^{L,T}(s) \rightarrow$ $-i\Pi^{L,T}(s)/2$, and the integration being over the contour C_1 . Finally, the contour C_1 can be deformed to C_2 without crossing any singularities, and so leaving the integral unchanged. One can derive a series of sum rules analogous to Eq. (14) by weighting the differential τ hadronic decay rate by different powers of the hadronic invariant mass,

$$R_{\tau}^{kl} = \int_0^{M_{\tau}^2} \mathrm{d}s \, \left(1 - \frac{s}{M_{\tau}^2}\right)^k \left(\frac{s}{M_{\tau}^2}\right)^l \frac{\mathrm{d}R_{\tau}}{\mathrm{d}s} \tag{17}$$

where dR_{τ}/ds is the hadronic invariant mass distribution in τ decay normalized to the leptonic decay rate. This leads to the final form of the sum rule(s),

$$R_{\tau}^{kl} = -6\pi i \int_{C_2} \frac{\mathrm{d}s}{M_{\tau}^2} \left(1 - \frac{s}{M_{\tau}^2} \right)^{2+k} \left(\frac{s}{M_{\tau}^2} \right)^l \times \left[\left(1 + 2 \frac{s}{M_{\tau}^2} \right) \Pi^T(s) + \Pi^L(s) \right]. \tag{18}$$

The manipulations so far are completely rigorous and exact, relying only on the general analytic structure of quantum field theory. The left-hand side of the sum rule Eq. (18) is obtained from experiment. The right hand-side can be computed for s far away from any physical cuts using the operator product expansion (OPE) for the time-ordered product of currents in Eq. (15), and QCD perturbation theory. The OPE is an expansion for the time-ordered product Eq. (15) in a series of local operators, and is an expansion about the $q \to \infty$ limit. It gives $\Pi(s)$ as an expansion in powers of $\alpha_s(s)$ and $\Lambda_{\rm QCD}^2/s$, and is valid when s is far (in units of $\Lambda_{\rm QCD}^2$) from any singularities in the complex s-plane.

The OPE gives $\Pi(s)$ as a series in α_s , quark masses, and various non-perturbative vacuum matrix element. By computing $\Pi(s)$ theoretically, and comparing with the experimental values of R_{τ}^{kl} , one determines various parameters such as α_s and the quark masses. The theoretical uncertainties in using Eq. (18) arise from neglected higher order corrections (both

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perturbative and non-perturbative), and because the OPE is no longer valid near the real axis, where Π has singularities. The contribution of neglected higher order corrections can be estimated as for any other perturbative computation. The error due to the failure of the OPE is more difficult to estimate. In Eq. (18), the OPE fails on the endpoints of C_2 that touch the real axis at $s=M_\tau^2$. The weight factor $(1-s/M_\tau^2)$ in Eq. (18) vanishes at this point, so the importance of the endpoint can be reduced by choosing larger values of k.

E. Heavy quarks

For heavy-quark physics one can exploit the fact that $m_Q \gg \Lambda_{\rm QCD}$ to construct effective theories (m_Q) is the mass of the heavy quark Q). The masses and decay rates of hadrons containing a single heavy quark, such as the B and D mesons can be determined using the heavy quark effective theory (HQET) [33]. The theoretical calculations involve radiative corrections computed in perturbation theory with an expansion in $\alpha_s(m_Q)$ and non-perturbative corrections with an expansion in powers of $\Lambda_{\rm QCD}/m_Q$. Due to the asymptotic nature of the QCD perturbation series, the two kinds of corrections are intimately related; an example of this are renormalon effects in the perturbative expansion which are associated with non-perturbative corrections.

Systems containing two heavy quarks such as the Υ or J/Ψ are treated using non-relativistic QCD (NRQCD) [34]. The typical momentum and energy transfers in these systems are $\alpha_s m_Q$, and $\alpha_s^2 m_Q$, respectively, so these bound states are sensitive to scales much smaller than m_Q . However, smeared observables, such as the cross-section for $e^+e^- \to \bar{b}b$ averaged over some range of s that includes several bound state energy levels, are better behaved and only sensitive to scales near m_Q . For this reason, most determinations of the c,b quark masses using perturbative calculations compare smeared observables with experiment [35–37].

There are many continuum extractions of the c and b quark masses, some with quoted errors of 10 MeV or smaller. There are systematic effects of comparable size, which are typically not included in these error estimates. Reference [30], for example, shows that even though the error estimate of m_c using the rapid convergence of the α_s perturbation series is only a few MeV, the central value of m_c can differ by a much larger amount depending on which algorithm (all of which are formally equally good) is used to determine m_c from the data. This leads to a systematic error from perturbation theory of around 20 MeV for the c quark and 25 MeV for the b quark. Electromagnetic effects, which also are important at this precision, are often not included. For this reason, we inflate the errors on the continuum extractions of m_c and m_b . The average values of m_c and m_b from continuum determinations are (see Sec. G for the 1S scheme)

$$\overline{m}_c(\overline{m}_c) = (1.275 \pm 0.025) \,\mathrm{GeV}$$

$$\overline{m}_b(\overline{m}_b) = (4.18 \pm 0.03) \,\mathrm{GeV} \,, \quad m_b^{1\mathrm{S}} = (4.65 \pm 0.03) \,\mathrm{GeV} \,.$$

Lattice simulations of QCD lead to discretization errors which are powers of $m_Q a$ (modulated by logarithms); the power depends on the formulation of lattice QCD being used and in most cases is quadratic. Clearly these errors can be reduced by performing simulations at smaller lattice spacings, but also by using *improved* discretizations of the theory. Recently, with more powerful computing resources, better algorithms and techniques, it has become possible to perform simulations in the charm quark region and beyond, also decreasing the extrapolation which has to be performed to reach the b-quark. A novel approach proposed in [52] has been to compare the lattice results for moments of correlation functions of $c\overline{c}$ quark-bilinear operators to perturbative calculations of the same quantities at 4-loop order. In this way both the strong coupling constant and the charm quark mass can be determined with remarkably small errors; in particular $\overline{m}_c(\overline{m}_c) = 1.273(6) \,\text{GeV}$ [26]. This lattice determination also uses the perturbative expression for the current-current correlator, and so has the perturbation theory systematic error discussed above.

Traditionally, the main approach to controlling the discretization errors in lattice studies of heavy quark physics is to perform simulations of the effective theories such as HQET and NRQCD. This remains an important technique, both in its own right and in providing additional information for extrapolations from lower masses to the bottom region. Using effective theories, m_b is obtained from what is essentially a computation of the difference of $M_{H_b}-m_b$, where M_{H_b} is the mass of a hadron H_b containing a b-quark. The relative error on m_b is therefore much smaller than that for $M_{H_b} - m_b$, and this is the reason for the small errors quoted in section G. The principal systematic errors are the matching of the effective theories to QCD and the presence of power divergences in a^{-1} in the $1/m_b$ corrections which have to be subtracted numerically. The use of HQET or NRQCD is less precise for the charm quark, but in this case, as mentioned above, direct QCD simulations have recently become possible.

F. Pole Mass

For an observable particle such as the electron, the position of the pole in the propagator is the definition of its mass. In QCD this definition of the quark mass is known as the pole mass. It is known that the on-shell quark propagator has no infrared divergences in perturbation theory [40,41], so this provides a perturbative definition of the quark mass. The pole mass cannot be used to arbitrarily high accuracy because of nonperturbative infrared effects in QCD. The full quark propagator has no pole because the quarks are confined, so that the pole mass cannot be defined outside of perturbation theory. The relation between the pole mass m_Q and the $\overline{\rm MS}$ mass \overline{m}_Q is known to three loops [42,43,44,45]

$$\begin{split} m_Q &= \overline{m}_Q(\overline{m}_Q) \bigg\{ 1 + \frac{4\overline{\alpha}_s(\overline{m}_Q)}{3\pi} \\ &+ \left[-1.0414 \sum_k \left(1 - \frac{4}{3} \frac{\overline{m}_{Q_k}}{\overline{m}_Q} \right) + 13.4434 \right] \left[\frac{\overline{\alpha}_s(\overline{m}_Q)}{\pi} \right]^2 \end{split}$$

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+
$$\left[0.6527N_L^2 - 26.655N_L + 190.595\right] \left[\frac{\overline{\alpha}_s(\overline{m}_Q)}{\pi}\right]^3$$
, (19)

where $\overline{\alpha}_s(\mu)$ is the strong interaction coupling constants in the $\overline{\text{MS}}$ scheme, and the sum over k extends over the N_L flavors Q_k lighter than Q. The complete mass dependence of the α_s^2 term can be found in [42]; the mass dependence of the α_s^3 term is not known. For the b-quark, Eq. (19) reads

$$m_b = \overline{m}_b (\overline{m}_b) [1 + 0.09 + 0.05 + 0.03],$$
 (20)

where the contributions from the different orders in α_s are shown explicitly. The two and three loop corrections are comparable in size and have the same sign as the one loop term. This is a signal of the asymptotic nature of the perturbation series [there is a renormalon in the pole mass]. Such a badly behaved perturbation expansion can be avoided by directly extracting the $\overline{\rm MS}$ mass from data without extracting the pole mass as an intermediate step.

G. Numerical values and caveats

The quark masses in the particle data listings have been obtained by using a wide variety of methods. Each method involves its own set of approximations and uncertainties. In most cases, the errors are an estimate of the size of neglected higher-order corrections or other uncertainties. The expansion parameters for some of the approximations are not very small (for example, they are $m_K^2/\Lambda_\chi^2 \sim 0.25$ for the chiral expansion and $\Lambda_{\rm QCD}/m_b \sim 0.1$ for the heavy-quark expansion), so an unexpectedly large coefficient in a neglected higher-order term could significantly alter the results. It is also important to note that the quark mass values can be significantly different in the different schemes.

The heavy quark masses obtained using HQET, QCD sum rules, or lattice gauge theory are consistent with each other if they are all converted into the same scheme and scale. We have specified all masses in the $\overline{\rm MS}$ scheme. For light quarks, the renormalization scale has been chosen to be $\mu = 2 \,\text{GeV}$. The light quark masses at 1 GeV are significantly different from those at $2 \, \text{GeV}$, $\overline{m}(1 \, \text{GeV})/\overline{m}(2 \, \text{GeV}) \sim 1.35$. It is conventional to choose the renormalization scale equal to the quark mass for a heavy quark, so we have quoted $\overline{m}_Q(\mu)$ at $\mu = \overline{m}_Q$ for the c and b quarks. Recent analyses of inclusive B meson decays have shown that recently proposed mass definitions lead to a better behaved perturbation series than for the $\overline{\rm MS}$ mass, and hence to more accurate mass values. We have chosen to also give values for one of these, the b quark mass in the 1S-scheme [46,47]. Other schemes that have been proposed are the PS-scheme [48] and the kinetic scheme [49].

If necessary, we have converted values in the original papers to our chosen scheme using two-loop formulæ. It is important to realized that our conversions introduce significant additional errors. In converting to the $\overline{\rm MS}$ b-quark mass, for example, the three-loop conversions from the 1S and pole masses give values about 40 MeV and 135 MeV lower than the two-loop

conversions. The uncertainty in $\alpha_s(M_Z)=0.1187(20)$ gives an uncertainty of ± 20 MeV and ± 35 MeV respectively in the same conversions. We have not added these additional errors when we do our conversions. The α_s value in the conversion is correlated with the α_s value used in determining the quark mass, so the conversion error is not a simple additional error on the quark mass.

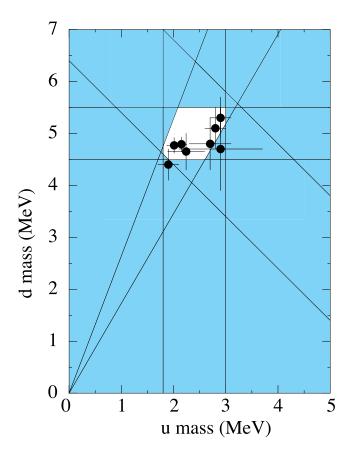


Figure 2: The allowed region (shown in white) for up quark and down quark masses. This region was determined in part from papers reporting values for m_u and m_d (data points shown) and in part from analysis of the allowed ranges of other mass parameters (see Fig. 3). The parameter $(m_u + m_d)/2$ yields the two downward-sloping lines, while m_u/m_d yields the two rising lines originating at (0,0).

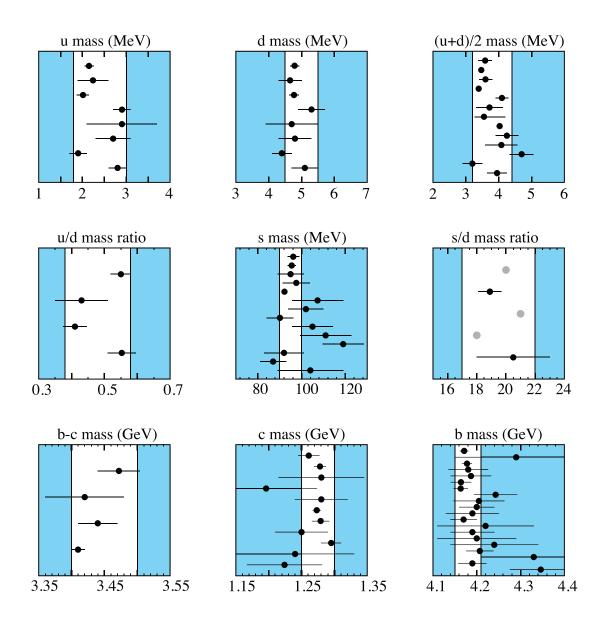


Figure 3. The values of each quark mass parameter taken from the Data Listings. The points are in chronological order with the more recent measurements at the top. Points from papers reporting no error bars are colored grey. The shaded regions indicate values excluded by our evaluations; some regions were determined in part through examination of Fig. 2.

Quarks, u, d, s, Light Quarks (u, d, s)

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$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Mass $m=4.8^{+0.7}_{-0.3}$ MeV Charge $=-\frac{1}{3}$ e $I_Z=-\frac{1}{2}$ $m_S/m_d=17-22$ $\overline{m}=(m_U+m_d)/2=3.2-4.4$ MeV

 $I(J^P) = 0(\frac{1}{2}^+)$ Mass $m=95\pm 5$ MeV Charge $=-\frac{1}{3}e$ Strangeness =-1 $(m_s-(m_u+m_d)/2)/(m_d-m_u)=27\pm 1$

LIGHT QUARKS (u, d, s)

OMITTED FROM SUMMARY TABLE

u-QUARK MASS

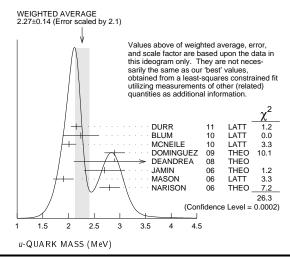
The u-, d-, and s-quark masses are estimates of so-called "current-quark masses," in a mass- independent subtraction scheme such as $\overline{\rm MS}$. The ratios m_u/m_d and m_s/m_d are extracted from pion and kaon masses using chiral symmetry. The estimates of d and u masses are not without controversy and remain under active investigation. Within the literature there are even suggestions that the u-quark could be essentially massless. The s-quark mass is estimated from ${\rm SU}(3)$ splittings in hadron masses.

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu=2$ GeV. Results quoted in the literature at $\mu=1$ GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

VALUE (MeV) DO CUMENT ID TECN COMMENT 2.3 ± 0.7 OUR EVALUATION See the ideogram below. $2.15 \pm 0.03 \pm 0.10$ ¹ DURR LATT MS scheme ² BLUM $2.24 \pm 0.10 \pm 0.34$ 3 MCNEILE 2.01 ± 0.14 10 LATT MS scheme ⁴ DOMINGUEZ MS scheme 2.9 ± 0.2 09 THEO ⁵ DEANDREA 2.9 ± 0.8 08 THEO MS scheme MS scheme 2.7 ± 0.4 6 JA MIN THEO $1.9\ \pm0.2$ 7 MASON LATT MS scheme ⁸ NARISON THEO MS scheme

Quark Particle Listings Light Quarks (u, d, s)

- • We do not use the following data for averages, fits, limits, etc. • 3 DAVIES 10 LATT MS scheme
- ⁹ BLUM 07 LATT MS scheme 3.02 ± 0.33 $^{10}\,\mathrm{AUBIN}$ 04A LATT MS scheme $1.7\ \pm0.3$
- $^1\,{\rm DURR}$ 11 determine quark mass from a lattice computation of the meson spectrum using $N_f=2+1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual m_{u} , m_{d} values are obtained using the lattice determination of the average mass m_{ud} and isospin
- ${}^2\text{BLUM I) determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use$ 2+1 dynamical quark flavors.
- 3 DAVIES 10 and MCNEILE 10 determine $\overline{m}_{\mathcal{C}}(\mu)/\overline{m}_{\mathcal{S}}(\mu)=11.85\pm0.16$ using a lattice computation with $N_f=2+1$ dynamical fermions of the pseudoscalar meson masses. Mass m_U is obtained from this using the value of m_C from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratios, m_S/\overline{m} and m_U/m_d .
- ⁴ DOMINGUEZ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order $lpha_{
 m s}^4$
- 5 DEANDREA 08 determine m_U-m_d from $\eta\to 3\pi^0$, and combine with the PDG 06 lattice average value of $m_U+m_d=7.6\pm1.6$ to determine m_U and m_d .
- 6 JAMIN 06 determine $m_U(^2$ GeV) by combining the value of m_S obtained from the spectral function for the scalar $K\pi$ form factor with other determinations of the quark
- 7 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order. The quark masses $m_{\it u}$ and $m_{\it d}$ were determined from their $(m_{\it u}+m_{\it d})/2$ measurement and AUBIN 04A m_{u}/m_{d} value.
- ⁸ NARISON 06 uses sum rules for $e^+e^- \rightarrow \text{hadrons to order } \alpha_s^3$ to determine m_s combined with other determinations of the quark mass ratios.
- ⁹BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors
- $^{
 m 10}$ AUBIN 04A employ a partially quenched lattice calculation of the pseudoscalar meson



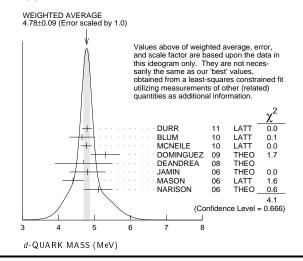
d-QUARK MASS

See the comment for the u quark above

We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu=2$ GeV. Results quoted in the literature at $\mu=1$ GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------|-------------------------|---------|-----------|------------|
| 4.8 $^{+0.7}_{-0.3}$ OUR EVALUATION | See the ideogram | below | r. | |
| $4.79 \pm 0.07 \pm 0.12$ | ¹¹ DURR | 11 | LATT | MS scheme |
| $4.65 \pm 0.15 \pm 0.32$ | ¹² BLUM | 10 | LATT | MS scheme |
| 4.77 ± 0.15 | ¹³ MCNEILE | 10 | LATT | MS scheme |
| 5.3 ±0.4 | ¹⁴ DOMINGUEZ | 09 | THEO | MS scheme |
| 4.7 ±0.8 | ¹⁵ DEA NDREA | 80 | THEO | MS scheme |
| 4.8 ±0.5 | ¹⁶ JAMIN | 06 | THEO | MS scheme |
| 4.4 ±0.3 | ¹⁷ MASON | 06 | LATT | MS scheme |
| 5.1 ±0.4 | ¹⁸ NARISON | 06 | THEO | MS scheme |
| • • • We do not use the following | ng data for averages | , fits, | limits, e | etc. • • • |
| 4.79 ± 0.16 | ¹³ DAVIES | 10 | LATT | MS scheme |
| 5.49 ± 0.39 | ¹⁹ BLUM | 07 | LATT | MS scheme |
| 3.9 +0.5 | ²⁰ AUBIN | 04A | LATT | MS scheme |

- 11 DURR 11 determine quark mass from a lattice computation of the meson spectrum using $N_f=2+1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed. The individual m_{u}, m_{d} values are obtained using the lattice determination of the average mass m_{ud} , and isospin
- 12 BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors
- 2+1 dynamical quark mavors. $^{13} \, {\rm DAVIES} \, \, 10 \, {\rm and} \, \, {\rm MCNEILE} \, 10 \, {\rm determine} \, \, \overline{m}_C(\mu)/\overline{m}_S(\mu) = 11.85 \pm 0.16 \, {\rm using} \, {\rm a} \, {\rm lattice} \, {\rm computation} \, {\rm with} \, N_f = 2 + 1 \, {\rm dynamical} \, {\rm fermions} \, {\rm of} \, {\rm the} \, {\rm pseudoscalar} \, {\rm meson} \, {\rm masses}. \, {\rm Mass} \, m_d \, {\rm is} \, {\rm obtained} \, {\rm from} \, {\rm this} \, {\rm using} \, {\rm the} \, {\rm value} \, {\rm of} \, m_C \, {\rm from} \, {\rm ALLISON} \, 08 \, {\rm or} \, \, {\rm MCNEILE} \, 10 \, {\rm mod} \, {\rm the} \, {\rm BAZAVOV} \, 10 \, {\rm values} \, {\rm for} \, {\rm the} \, {\rm light} \, {\rm quark} \, {\rm mass} \, {\rm ratios}, \, m_S/\overline{m} \, {\rm and} \, m_u/m_d.$
- $^{14}\hspace{-.05cm}\mathsf{DOMINGUEZ}$ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order α_s^4
- 15 DEANDREA 08 determine $m_u m_d$ from $\eta \to 3\pi^0$, and combine with the PDG 06 lattice average value of $m_u + m_d = 7.6 \pm 1.6$ to determine m_u and m_d . 16 JAMIN 06 determine m_d (2 GeV) by combining the value of m_s obtained from the spectral function for the scalar $K\pi$ form factor with other determinations of the quark
- 17 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order. The quark masses m_{u} and m_{d} were determined from their $(m_{u}+m_{d})/2$ measurement and AUBIN 04A m_{II}/m_{d} value.
- ¹⁸ NARISON 06 uses sum rules for $e^+e^- \rightarrow$ hadrons to order $lpha_{\rm S}^3$ to determine $m_{\rm S}$ combined with other determinations of the quark mass ratios.
- 19 BLUM O'N determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.
- 20 AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses, and one-loop perturbative renormalization constant.



$\overline{m} = (m_u + m_d)/2$

See the comments for the u quark above.

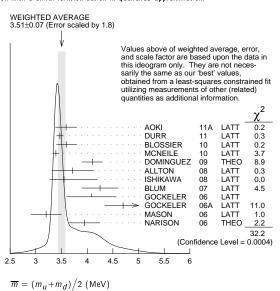
We have normalized the $\overline{\text{MS}}$ masses at a renormalization scale of $\mu=2$ GeV. Results quoted in the literature at $\mu=1$ GeV have been rescaled by dividing by 1.35. The values of "Our Evaluation" were determined in part via Figures 1 and 2.

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|--------------------------------------------------------|--------------------------|-----------------|------------|
| 3.2–4.4 OUR EVALUATION | See the ideogram belo | w. | |
| 3.59 ±0.21 | ²¹ AOKI | 11A LATT | MS scheme |
| $3.469 \pm 0.047 \pm 0.048$ | ²² DURR | 11 LATT | MS scheme |
| 3.6 ±0.2 | 23 BLOSSIER | 10 LATT | MS scheme |
| 3.39 ±0.06 | 24 MCNEILE | 10 LATT | MS scheme |
| 4.1 ± 0.2 | ²⁵ DOMINGUEZ | 09 THEO | MS scheme |
| 3.72 ±0.41 | ²⁶ ALLTON | 08 LATT | MS scheme |
| $\begin{array}{ccc} 3.55 & +0.65 \\ -0.28 \end{array}$ | ²⁷ ISHIKAWA | 08 LATT | MS scheme |
| 4.25 ±0.35 | ²⁸ BLUM | 07 LATT | MS scheme |
| $4.08 \pm 0.25 \pm 0.42$ | ²⁹ GOCKELER | 06 LATT | MS scheme |
| $4.7 \pm 0.2 \pm 0.3$ | 30 GOCKELER | 06A LATT | MS scheme |
| 3.2 ±0.3 | 31 MASON | 06 LATT | MS scheme |
| 3.95 ±0.3 | ³² NARISON | 06 THEO | MS scheme |
| ● We do not use the follo | wing data for averages | , fits, limits, | etc. • • • |
| 3.40 ±0.07 | ²⁴ DAVIES | 10 LATT | MS scheme |
| $3.85 \pm 0.12 \pm 0.4$ | ³³ BLOSSIER | 08 LATT | MS scheme |
| > 4.85 ±0.20 | 34 DOMINGUEZ | .08B THEO | MS scheme |
| 4.026±0.048 | ³⁵ NA KA MURA | 08 LATT | MS scheme |
| 2.8 ±0.3 | ³⁶ AUBIN | 04 LATT | MS scheme |
| $4.29 \pm 0.14 \pm 0.65$ | ³⁷ AOKI | 03 LATT | MS scheme |
| 3.223 ± 0.3 | ³⁸ aoki | 03B LATT | MS scheme |
| $4.4 \pm 0.1 \pm 0.4$ | ³⁹ BECIREVIC | 03 LATT | MS scheme |
| | ⁴⁰ CHIU | 03 LATT | MS scheme |

Light Quarks (u, d, s)

- $^{21}\mathrm{AOKI}$ 11A determine quark masses from a lattice computation of the hadron spectrum using $N_f=2+1$ dynamical flavors of domain wall fermions
- 22 DURR $^{'}$ 11 determine quark mass from a lattice computation of the meson spectrum using $N_f = 2 + 1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.

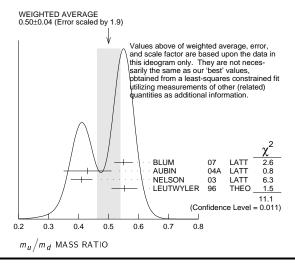
 23 BLOSSIER 10 determines quark masses from a computation of the hadron spectrum
- using N_f =2 dynamical twisted-mass Wilson fermions.
- 24 DAVIES 10 and MCNEILE 10 determine $\overline{m}_C(\mu)/\overline{m}_S(\mu)=11.85\pm0.16$ using a lattice computation with $N_f=2+1$ dynamical fermions of the pseudoscalar meson masses. Mass \overline{m} is obtained from this using the value of m_C from ALLISON 08 or MCNEILE 10 and the BAZAVOV 10 values for the light quark mass ratio, m_S/\overline{m} .
- $^{25}\, \mathsf{DOMINGUEZ}$ 09 use QCD finite energy sum rules for the two-point function of the divergence of the axial vector current computed to order α_c^4 .
- 26 ALLTON 08 use a lattice computation of the π , K, and Ω masses with $2{+}1$ dynamical flavors of domain wall quarks, and non-perturbative renormalization.
- Have 50 domain wan quants, and non-personal recommendation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.
- 28 BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.
- plus QCD lattice computation with two dynamical quark navors. 29 GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f=2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\overline{m}(2\,\text{GeV})=4.08\pm0.25\pm0.19\pm0.23\,\text{MeV}$, where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly.
- 30 GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f=2$ dynamical light quark flavors, and non-perturbative renormalization.
- 31 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order.
- ³² NARISON 06 uses sum rules for $e^+e^- \rightarrow \text{hadrons}$ to order α_s^3 to determine m_s combined with other determinations of the quark mass ratios.
- 33 BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization
- ³⁴DOMINGUEZ-CLARIMON 08B obtain an inequality from sum rules for the scalar two-
- 35 NAKAMURA 08 do a lattice computation using quenched domain wall fermions and
- non-perturbative renormalization. 36 AUBIN 04 perform three flavor dynamical lattice calculation of pseudoscalar meson
- masses, with one-loop perturbative renormalization constant. 37 AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation
- The errors given in AOKI 03B were $^{+0.046}_{-0.069}$. We changed them to ± 0.3 for calculating the overall best values. AOKI 03B uses lattice simulation of the meson and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved
- Wilson action. 39 BECIREVIC 03 perform quenched lattice computation using the vector and axial Ward identities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization.
- 40 CHIU 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.



mu/md MASS RATIO

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|-------------------------|-------|------|-------------|
| 0.38-0.58 OUR EVALUATION | See the ideogram b | elow. | | |
| 0.550 ± 0.031 | ⁴¹ BLUM | 07 | LATT | |
| 0.43 ±0.08 | ⁴² AUBIN | 04A | LATT | |
| 0.410 ± 0.036 | ⁴³ NELSON | 03 | LATT | |
| 0.553 ± 0.043 | ⁴⁴ LEUTWYLER | 96 | THEO | Compilation |

- $^{
 m 41}\,{
 m BLUM}$ 07 determine quark masses from the pseudoscalar meson masses using a QED
- PELOWI Of determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.
 42 AUBIN 04A perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with continuum estimate of electromagnetic effects in the kaon masses.
 43 NELSON 03 computes coefficients in the order ρ⁴ chiral Lagrangian using a lattice
- calculation with three dynamical flavors. The ratio $m_{\it u}/m_{\it d}$ is obtained by combining this with the chiral perturbation theory computation of the meson masses to order p^4 .
- 44 LEUTWYLER 96 uses a combined fit to $\eta \to 3\pi$ and $\psi' \to J/\psi \ (\pi,\eta)$ decay rates, and the electromagnetic mass differences of the π and K.



s-QUARK MASS

See the comment for the u quark above

VALUE (MeV.)

We have normalized the $\overline{\sf MS}$ masses at a renormalization scale of $\mu=2$ GeV. Results quoted in the literature at $\mu=1$ GeV have been rescaled by dividing by 1.35.

DOCUMENT ID

TECN COMMENT

| VALUE (MeV) | DO CUMENT ID | | I E CN | COMMENT |
|-----------------------------------------------------------------|--------------------------|---------|-------------|--------------------|
| 95 ± 5 OUR EVALUATION | | belo | w. | |
| 96.2± 2.7 | ⁴⁵ AOKI | 11A | LATT | MS scheme |
| 95.5 ± 1.1 ± 1.5 | ⁴⁶ DURR | 11 | LATT | MS scheme |
| 95 ± 6 | ⁴⁷ BLOSSIER | 10 | LATT | MS scheme |
| 97.6± 2.9± 5.5 | ⁴⁸ BLUM | 10 | LATT | MS scheme |
| 92.2± 1.3 | ⁴⁹ MCNEILE | 10 | LATT | MS scheme |
| 107.3 ± 11.7 | ⁵⁰ ALLTON | 80 | LATT | MS scheme |
| 102 ± 8 | ⁵¹ DOMINGUEZ | 08A | THEO | MS scheme |
| $90.1 {}^{+ 1 7.2}_{- 6.1}$ | ⁵² ISHIKAWA | 08 | LATT | MS scheme |
| $105 \pm 6 \pm 7$ | ⁵³ CHETYRKIN | 06 | THEO | MS scheme |
| $111 \pm 6 \pm 10$ | ⁵⁴ GOCKELER | 06 | LATT | MS scheme |
| $119 \pm 5 \pm 8$ | ⁵⁵ GOCKELER | 06A | LATT | MS scheme |
| 92 ± 9 | ⁵⁶ JA MIN | 06 | THEO | MS scheme |
| 87 ± 6 | ⁵⁷ MASON | 06 | LATT | MS scheme |
| 104 ±15 | ⁵⁸ NARISON | 06 | | MS scheme |
| • • We do not use the following | ng data for averages | s, fits | , limits, e | etc. • • • |
| 92.4± 1.5 | ⁴⁹ DAVIES | 10 | LATT | MS scheme |
| $105 \pm 3 \pm 9$ | ⁵⁹ BLOSSIER | 80 | LATT | MS scheme |
| 105.6± 1.2 | ⁶⁰ NA KA MURA | 80 | LATT | MS scheme |
| 119.5 ± 9.3 | 61 BLUM | 07 | LATT | MS scheme |
| \geq 71 \pm 4, \leq 151 \pm 14 | ⁶² NARISON | 06 | THEO | MS scheme |
| $96 \begin{array}{cccc} + & 5 & +16 \\ - & 3 & -18 \end{array}$ | ⁶³ BAIKOV | 05 | THEO | MS scheme |
| 81 ±22 | 64 GAMIZ | 05 | THEO | MS scheme |
| 125 ±28 | 65 GORBUNOV | 05 | THEO | MS scheme |
| 93 ±32 | 66 NARISON | 05 | | MS scheme |
| 76 ± 8 | 67 AUBIN | 04 | LATT | |
| $116 \pm 6 \pm 0.65$ | ⁶⁸ AOKI | 03 | LATT | MS scheme |
| $84.5 {}^{+ 1 2}_{- 1.7}$ | ⁶⁹ AOKI | 03в | LATT | MS scheme |
| $106 \pm 2 \pm 8$ | 70 BECIREVIC | 03 | LATT | MS scheme |
| 92 \pm 9 \pm 16 | ⁷¹ CHIU | 03 | | MS scheme |
| 117 ±17 | 72 GAMIZ | 03 | | MS scheme |
| 103 ±17 | ⁷³ GAMIZ | 03 | THEO | MS scheme |
| 45 AOKI 11A determine quark m | nasses from a lattic | e con | putation | of the hadron spec |

- using $N_f = 2 + 1$ dynamical flavors of domain wall fermions.
- 46 DURR 11 determine quark mass from a lattice computation of the meson spectrum using $N_f=2+1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.
- $^{
 m 47}$ BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using $N_f = 2$ dynamical twisted-mass Wilson fermions
- 48 BLUM 10 determines light quark masses using a QCD plus QED lattice computation of the electromagnetic mass splittings of the low-lying hadrons. The lattice simulations use 2+1 dynamical quark flavors.

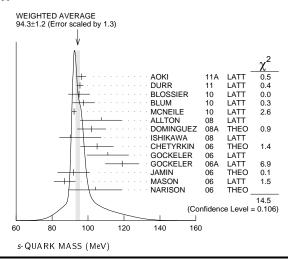
- 49 DAVIES 10 and MCNEILE 10 determine $\overline{m}_{\mathcal{C}}(\mu)/\overline{m}_{\mathcal{S}}(\mu)=11.85\pm0.16$ using a lattice computation with $N_f=2+1$ dynamical fermions of the pseudoscalar meson masses. Mass $m_{\mathcal{S}}$ is obtained from this using the value of $m_{\mathcal{C}}$ from ALLISON 08 or MCNEILE 10.
- 50 ALLTON 08 use a lattice computation of the $\pi,\,K,$ and Ω masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.
- $^{51}\, {\sf DOMINGUEZ}$ 08A make determination from QCD finite energy sum rules for the pseudoscalar two-point function computed to order α_s^4 .
- 52 ISHIKAWA 08 use a lattice computation of the light meson spectrum with 2+1 dynamical flavors of $\mathcal{O}(a)$ improved Wilson quarks, and one-loop perturbative renormalization.
- 53 CHETYRKIN 06 use QCD sum rules in the pseudoscalar channel to order $lpha_c^4$
- 54 GOCKELER 06 use an unquenched lattice computation of the axial Ward Identity with $N_f=2$ dynamical light quark flavors, and non-perturbative renormalization, to obtain $\overline{m}_S(2~{\rm GeV})=111\pm6\pm4\pm6~{\rm MeV},$ where the first error is statistical, the second and third are systematic due to the fit range and force scale uncertainties, respectively. We have combined the systematic errors linearly.
- 55 GOCKELER 06A use an unquenched lattice computation of the pseudoscalar meson masses with $N_f=2$ dynamical light quark flavors, and non-perturbative renormalization.
- 56 JAMIN 06 determine $\overline{m}_{\rm S}({
 m 2~GeV})$ from the spectral function for the scalar $K\pi$ form
- factor.

 57 MASON 06 extract light quark masses from a lattice simulation using staggered fermions with an improved action, and three dynamical light quark flavors with degenerate u and d quarks. Perturbative corrections were included at NNLO order.
- ⁵⁸ NARISON 06 uses sum rules for $e^+e^- \rightarrow$ hadrons to order α_s^3
- $^{59}\,\mathrm{BLOSSIER}$ 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization
- 60 NAKAMURA 08 do a lattice computation using quenched domain wall fermions and
- non-perturbative renormalization.
- non-perturbative renormalization.

 61 BLUM 07 determine quark masses from the pseudoscalar meson masses using a QED plus QCD lattice computation with two dynamical quark flavors.

 62 NARISON 06 obtains the quoted range from positivity of the spectral functions.

 63 BAIKOV 05 determines $\overline{m}_S(M_T) = 100 \frac{5}{3} + \frac{11}{17}$ from sum rules using the strange spectral function in τ decay. The computations were done to order α_c^3 , with an estimate of the $lpha_{s}^{4}$ terms. We have converted the result to $\mu=2$ GeV.
- 64 GAMIZ 05 determines $\overline{m}_{_{\rm S}}({\rm 2~GeV})$ from sum rules using the strange spectral function in au decay. The computations were done to order $lpha_s^2$, with an estimate of the $lpha_s^3$ terms.
- 65 GORBUNOV 05 use hadronic tau decays to N³LO, including power corrections.
- 66 NARISON 05 determines $\overline{m}_{\rm S}({\rm 2~GeV})$ from sum rules using the strange spectral function in au decay. The computations were done to order $lpha_s^3$.
- $^{67}\mathrm{AUBIN}$ 04 perform three flavor dynamical lattice calculation of pseudoscalar meson masses, with one-loop perturbative renormalization constant.
- 68 AOKI 03 uses quenched lattice simulation of the meson and baryon masses with degenerate light quarks. The extrapolations are done using quenched chiral perturbation theory. Determines $m_s=113.8\pm2.3^{+5.8}_{-2.9}$ using K mass as input and $m_s=142.3\pm5.8^{+22}_{-2.9}$ using K ϕ mass as input. We have performed a weighted average of these values.
- 69 Midss as liptur. We have performed a meganic and baryon masses with two dynamical light quarks. Simulations are performed using the $\mathcal{O}(a)$ improved Wilson action.
- $^{70}\,\mathrm{BECIREVIC}$ 03 perform quenched lattice computation using the vector and axial Ward dientities. Uses $\mathcal{O}(a)$ improved Wilson action and nonperturbative renormalization. They also quote \overline{m}/m_s =24.3 \pm 0.2 \pm 0.6.
- $^{71}\,\text{CHIU}$ 03 determines quark masses from the pion and kaon masses using a lattice simulation with a chiral fermion action in quenched approximation.
- 72 GAMIZ 03 determines m_s from SU(3) breaking in the τ hadronic width. The value of $V_{u\,s}$ is chosen to satisfy CKM unitarity.
- 73 GAMIZ 03 determines m_S from SU(3) breaking in the τ hadronic width. The value of V_{US} is taken from the PDG.



OTHER LIGHT QUARK MASS RATIOS

m_s/m_d MASS RATIO

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-----------------------------|--------|-------------|-------------|
| 17-22 OUR EVALUATION | | | | |
| • • • We do not use the f | following data for averages | , fits | , limits, e | etc. • • • |
| 20.0 | ⁷⁴ GAO | 97 | THEO | |
| 18.9 ± 0.8 | ⁷⁵ LEUTWYLER | | | Compilation |
| 21 | ⁷⁶ DONOGHUE | | | |
| 18 | ⁷⁷ GERARD | | | |
| 18 to 23 | ⁷⁸ LEUTWYLER | 90B | THEO | |
| | | | | |

 $^{74}\,\mathrm{GAO}$ 97 uses electromagnetic mass splittings of light mesons.

 75 LEUTWYLER 96 uses a combined fit to $\eta\to 3\pi$ and $\psi'\to J/\psi~(\pi,\eta)$ decay rates, and the electromagnetic mass differences of the π and K.

 76 DONOGHUE 92 result is from a combined analysis of meson masses, $\eta
ightarrow 3\pi$ using second-order chiral perturbation theory including nonanalytic terms, and $(\psi(2S) \to J/\psi(1S) \pi)/(\psi(2S) \to J/\psi(1S) \eta)$.

 77 GERARD 90 uses large N and η - η' mixing.

78 LEUTWYLER 908 determines quark mass ratios using second-order chiral perturbation theory for the meson and baryon masses, including nonanalytic corrections. Also uses Weinberg sum rules to determine L_7 .

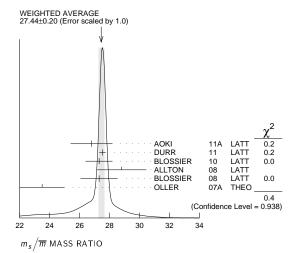
m_s/\overline{m} MASS RATIO

 $\overline{m} \equiv (m_u + m_d)/2$

| VALUE | | DO CUMENT ID | | TECN |
|--------|----------------------------|------------------------|---------|----------------|
| 27 Ⅎ | E1 OUR EVALUATION | See the ideogram | belov | v. |
| 26.8 ± | ±1.4 | ⁷⁹ AOKI | 11A | LATT |
| 27.53∃ | $\pm 0.20 \pm 0.08$ | | 11 | LATT |
| 27.3 ± | ±0.9 | ⁸¹ BLOSSIER | 10 | LATT |
| 28.8 ± | ±1.65 | | 80 | LATT |
| 27.3 ± | ±0.3 ±1.2 | | 80 | LATT |
| 23.5 ± | ±1.5 | ⁸⁴ OLLER | 07A | THEO |
| • • • | We do not use the followin | g data for averages | , fits, | limits, etc. • |
| 27.4 ± | ±0.4 | ⁸⁵ AUBIN | 04 | LATT |

 $^{79}\mathrm{AOKI}$ 11A determine quark masses from a lattice computation of the hadron spectrum using $N_f=2+1$ dynamical flavors of domain wall fermions.

- $^{80}\,{\sf DURR}$ 11 determine quark mass from a lattice computation of the meson spectrum using $N_f=2+1$ dynamical flavors. The lattice simulations were done at the physical quark mass, so that extrapolation in the quark mass was not needed.
- 81 BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using N_f =2 dynamical twisted-mass Wilson fermions.
- 82 ALLTON 08 use a lattice computation of the $\pi,\,K,$ and Ω masses with 2+1 dynamical flavors of domain wall quarks, and non-perturbative renormalization.
- 83 BLOSSIER 08 use a lattice computation of pseudoscalar meson masses and decay constants with 2 dynamical flavors and non-perturbative renormalization
- 84 OLLER 07A use unitarized chiral perturbation theory to order ho^4
- 85 Three flavor dynamical lattice calculation of pseudoscalar meson masses.



Q MASS RATIO

 86 MARTEMYANOV 05 determine Q from $\eta\to 3\pi$ decay. 87 ANISOVICH 96 find Q from $\eta\to \pi^+\pi^-\pi^0$ decay using dispersion relations and chiral

Light Quarks (u, d, s), c

LIGHT QUARKS (u, d, s) REFERENCES

| A OKI DURR BA ZAVOV BLOSSIER BLUM | 11A 11 10 10 10 | PR D83 074508 PL B701 265 RMP 82 1349 PR D82 114513 PR D82 094508 | Y. Aoki et al. S. Durr et al. A. Bazavov et al. B. Blossier et al. T. Blum et al. | (MILC | Collab.) Collab.) Collab.) Collab.) |
|-------------------------------------------------------------------------------------------------|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|----------------------------------------------|
| DAVIES MCNEILE DOMINGUEZ | 10 10 09 | PRL 104 132003 PR D82 034512 PR D79 014009 | C.T.H. Davies et al. C. McNeile et al. C.A. Dominguez et al. | (HPQCD (HPQCD | |
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| GAMIZ GORBUNOV MARTEMYA NARISON | 05 05 | PRL 94 012003 PR D71 013002 PR D71 017501 PL B626 101 | E. Gamiz et al. D.S. Gorbunov, A.A. Pivov B.V. Martemyanov, V.S. S S. Narison | arov | |
| AUBIN AUBIN AOKI BECIREVIC CHIU GAMIZ NELSON GAO ANISOVICH LEUTWYLER | 04 A 03 A 03 B 03 B 03 C 03 C 03 C 03 C 03 C 03 C | PR D70 031504R PR D70 114501 PR D67 034503 PR D68 054502 PL B558 69 NP B673 217 JHEP 0301 060 PRL 90 021601 PR D56 4115 PL B375 335 PL B378 313 | C. Aubin et al. (HP C. Aubin et al. S. Aoki et al. S. Aoki et al. S. Aoki et al. D. Becirevic, V. Lubicz, C TW. Chiu, TH. Hsieh E. Gamiz et al. D. Nelson, G.T. Fleming, DN. Gao, B.A. Li, ML. A.V. Anisovich, H. Leutwy H. Leutwyler | (CP-PACS (CP-PACS . Tarantino G.W. Kilcup Yan ler | Collab.) Collab.) Collab.) |
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| ı |
|---|
| |
| |

$$I(J^P) = 0(\frac{1}{2}^+)$$

Charge = $\frac{2}{3}e$

 $\mathsf{Ch}\,\mathsf{arm}\,=\,+1$

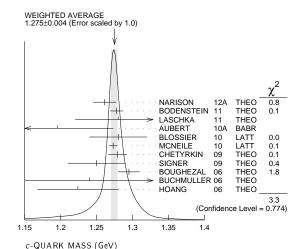
c-QUARK MASS

The c-quark mass corresponds to the "running" mass $m_{\, C} \, \left(\mu \, = \, m_{\, C} \right)$ in the $\overline{\text{MS}}$ scheme. We have converted masses in other schemes to the $\overline{\text{MS}}$ scheme using two-loop QCD perturbation theory with $\alpha_s(\mu=m_c)=$ 0.38 \pm 0.03. The value 1.275 \pm 0.025 GeV for the $\overline{\text{MS}}$ mass corresponds to 1.67 ± 0.07 GeV for the pole mass (see the "Note on Quark Masses").

| VALUE (GeV) | DO CUMENT ID | TECN COMMENT | |
|----------------------------------------------------|-----------------------------|----------------------|--|
| 1.275 ± 0.025 OUR EVALUATIO | N See the ideogram bel | ow. | |
| 1.261 ± 0.016 | | THEO MS scheme | |
| 1.278 ± 0.009 | ² BODENSTEIN 11 | THEO MS scheme | |
| $1.28 \begin{array}{c} +0.07 \\ -0.06 \end{array}$ | ³ LASCHKA 11 | THEO MS scheme | |
| $1.196 \pm 0.059 \pm 0.050$ | ⁴ AUBERT 10A | BABR MS scheme | |
| 1.28 ± 0.04 | ⁵ BLOSSIER 10 | LATT MS scheme | |
| 1.273 ± 0.006 | 6 MCNEILE 10 | LATT MS scheme | |
| 1.279 ± 0.013 | CHETYRKIN 09 | THEO MS scheme | |
| 1.25 ± 0.04 | ⁸ SIGNER 09 | THEO MS scheme | |
| 1.295 ± 0.015 | ⁹ BOUGHEZAL 06 | THEO MS scheme | |
| 1.24 ±0.09 | ¹⁰ BUCHMULLER 06 | THEO MS scheme | |
| $1.224 \pm 0.017 \pm 0.054$ | ¹¹ HOANG 06 | THEO MS scheme | |
| | | , limits, etc. • • • | |
| 1.299 ± 0.026 | 12 BODENSTEIN 10 | THEO MS scheme | |
| 1.261 ± 0.018 | ¹³ NARISON 10 | THEO MS scheme | |
| 1.268 ± 0.009 | ¹⁴ ALLISON 08 | LATT MS scheme | |
| 1.286 ± 0.013 | ¹⁵ KUHN 07 | THEO MS scheme | |
| 1.33 ±0.10 | ¹⁶ AUBERT 04x | THEO MS scheme | |
| 1.29 ±0.07 | ¹⁷ HOANG 04 | THEO MS scheme | |
| 1.319 ± 0.028 | 18 DEDIVITIIS 03 | LATT MS scheme | |
| 1.19 ±0.11 | ¹⁹ EIDEMULLER 03 | THEO MS scheme | |
| 1.289 ± 0.043 | ²⁰ ERLER 03 | THEO MS scheme | |
| 1.26 ± 0.02 | ²¹ ZYABLYUK 03 | THEO MS scheme | |

- $^{\rm 1}$ NARISON 12A determines m_{C} using sum rules for the vector current correlator to order α_s^3 , including the effect of gluon condensates up to dimension eight.
- 2 BODENSTEIN 11 determine $\overline{m}_{\rm C}(3~{\rm GeV})=0.987\pm0.009$ GeV and $\overline{m}_{\rm C}(\overline{m}_{\rm C})=1.278\pm0.009$ GeV using QCD sum rules for the charm quark vector current correlator.
- 3 LASCHKA 11 determine the c mass from the charmonium spectrum. The theoretical computation uses the heavy $Q\overline{Q}$ potential to order $1/m_Q$ obtained by matching the short-distance perturbative result onto lattice QCD result at larger scales.
- ⁴ AUBERT 10A determine the b- and c-quark masses from a fit to the inclusive decay spectra in semileptonic B decays in the kinetic scheme (and convert it to the $\overline{\text{MS}}$ scheme)
- BLOSSIER 10 determines quark masses from a computation of the hadron spectrum using $N_f{=}2$ dynamical twisted-mass Wilson fermions.
- 6 MCNEILE 10 determines $m_{\cal C}$ by comparing four-loop perturbative results for the pseudoscalar current to lattice simulations with $N_f=2+1$ sea-quarks by the HPQCD collaboscalar current $^{\circ}$

- 7 CHETYRKIN 09 determine m_C and m_D from the $e^+\,e^-\to Q\,\overline{Q}$ cross-section and sum rules, using a four-loop computation of the heavy quark vacuum polarization. They also determine $m_{C}(3~{\rm GeV}) = 0.986 \pm 0.013 {\rm GeV}$
- $^{8}\,\mathrm{SIGNER}$ 09 determines the c-quark mass using non-relativistic sum rules to analyze the ightarrow $c\,\overline{c}$ cross-section near threshold. Also determine the PS mass $m_{PS}(\mu_F = 0.7)$ $GeV) = 1.50 \pm 0.04 \text{ GeV}.$
- $^9\,\text{BOUGHEZAL}$ 06 result comes from the first moment of the hadronic production crosssection to order α_s^3
- $^{10}\,\mathrm{BUCH\,MULLER}$ 06 determine m_b and m_c by a global fit to inclusive B decay spectra.
- 11 HOANG 06 determines $\overline{m}_{\mathcal{C}}(\overline{m}_{\mathcal{C}})$ from a global fit to inclusive B decay data. The Bdecay distributions were computed to order $\alpha_s^2 \beta_0$, and the conversion between different m_C mass schemes to order α_s^3
- S 2B BODENSTEIN 10 determines $\overline{m}_{C}(3~{\rm GeV})=1.008\pm0.026~{\rm GeV}$ using finite energy sum rules for the vector current correlator. The authors have converted this to $\overline{m}_{C}(\overline{m}_{C})$ using $\alpha_{S}(M_{Z})=0.1189\pm0.0020.$
- 13 NARISON 10 determines m_c from ratios of moments of vector current correlators computed to order α_s^3 and including the dimension-six gluon condensate.
- 14 ALLISON 08 determine $m_{\it C}$ by comparing four-loop perturbative results for the pseudoscalar current correlator to lattice simulations by the HPQCD collaboration. The result has been updated in MCNEILE 10.
- 15 KUHN 07 determine $\overline{m}_{\mathcal{C}}(\mu=$ 3 GeV $)=0.986\pm0.013$ GeV and $\overline{m}_{\mathcal{C}}(\overline{m}_{\mathcal{C}})$ from a four-loop sum-rule computation of the cross-section for $e^+e^ightarrow$ hadrons in the charm threshold
- 16 AUBERT 04x obtain m_c from a fit to the hadron mass and lepton energy distributions in semileptonic B decay. The paper quotes values in the kinetic scheme. The $\overline{\text{MS}}$ value has been provided by the BABAR collaboration.
- $^{17}\,\mathrm{HOANG}$ 04 determines $\overline{m}_{\mathcal{C}}(\overline{m}_{\mathcal{C}})$ from moments at order $\alpha_{\mathcal{S}}^2$ of the charm production cross-section in e^+e^- annihilation.
- 18 DEDIVITIIS 03 use a quenched lattice computation of heavy-heavy and heavy-light me-
- son masses. $^{19}\,\mathrm{EIDEMULLER}$ 03 determines m_b and m_c using QCD sum rules. $^{20}\,\mathrm{ERLER}$ 03 determines m_b and m_c using QCD sum rules. Includes recent BES data.
- $^{21}\,{\rm ZYABLYUK}$ 0.3 determines m $_c$ by using QCD sum rules in the pseudoscalar channel and comparing with the η_c mass.



mb-mc QUARK MASS DIFFERENCE

| 3.45 ±0.05 | OUR EVALUATION | | |
|-------------|----------------|-------------|------|
| VALUE (GeV) | | DOCUMENT ID | TECN |
| | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | ²² AUBERT | 10A | BABR |
|------------|------------------------|-----|------|
| 3.42 ±0.06 | ²³ ABDALLAH | 06в | DLPH |
| 3.44 ±0.03 | ²⁴ AUBERT | 04x | BABR |
| 3.41 ±0.01 | ²⁴ BAUER | 04 | THEO |

- 22 AUBERT 10A determine the $\emph{b}-$ and $\emph{c}-$ quark masses from a fit to the inclusive decay spectra in semileptonic B decays in the kinetic scheme.
- 23 ABDALLAH 06B determine $m_b m_c$ from moments of the hadron invariant mass and lepton energy spectra in semileptonic inclusive B decays.
- 24 Determine $m_b m_c$ from a global fit to inclusive B decay spectra.

c-QUARK REFERENCES

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|------------|------|----------------------|-------------------------------------|-----------------|
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| LAS CHKA | 11 | PR D83 094002 | A. Laschka, N. Kaiser, W. Weise | |
| AUBERT | 10 A | PR D81 032003 | B. Aubert et al. | (BABAR Collab.) |
| BLOSSIER | 10 | PR D82 114513 | B. Blossier et al. | (ETM Collab.) |
| BODENSTEIN | 10 | PR D82 114013 | S. Bodenstein et al. | |
| MCNEILE | 10 | PR D82 034512 | C. McNeile et al. | (HPQCD Collab.) |
| NARIS ON | 10 | PL B693 559 | S. Narison | (MONP) |
| A Iso | | PL B705 544 (errat.) | S. Narison | (MONP) |
| CHETYRKIN | 09 | PR D80 074010 | K.G. Chetyrkin et al. | (KARĹ, BNL) |
| SIGNER | 09 | PL B672 333 | A. Signer | ` (DURH) |
| ALLISON | 08 | PR D78 054513 | I. Allison et al. | (HPQCD Collab.) |
| KUHN | 07 | NP B778 192 | J.H. Kuhn, M. Steinhauser, C. Sturm | |

| ABDALLAH | 06B | EPJ C45 35 | J. Abdallah et al. | (DELPHI | Collab.) |
|------------|------|---------------|--------------------------------------|---------|----------|
| BOUGHEZAL | 06 | PR D74 074006 | R. Boughezal, M. Czakon, T. Schutzme | ier | |
| BUCHMULLER | 06 | PR D73 073008 | O.L. Buchmuller, H.U. Flacher | | |
| HOANG | 06 | PL B633 526 | A.H. Hoang, A.V. Manohar | | |
| AUBERT | 04 X | PRL 93 011803 | B. Aubert et al. | (BABAR | Collab.) |
| BAUER | 04 | PR D70 094017 | C. Bauer et al. | , | , |
| HOANG | 04 | PL B594 127 | A.H. Hoang, M. Jamin | | |
| DEDIVITIIS | 03 | NP B675 309 | G.M. de Divitiis et al. | | |
| EIDEMULLER | 03 | PR D67 113002 | M. Eidemuller | | |
| ERLER | 03 | PL B558 125 | J. Erler, M. Luo | | |
| ZYABLYUK | 03 | JHEP 0301 081 | K.N. Zyablyuk | | (ITEP) |
| | | | | | |



$$I(J^P) = 0(\frac{1}{2}^+)$$

 $Bottom\,=\,-1$

b-QUARK MASS

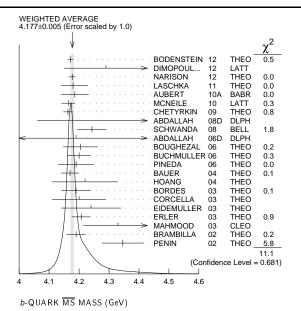
The first value is the "running mass" $\overline{m}_b(\mu=\overline{m}_b)$ in the $\overline{\text{MS}}$ scheme, and the second value is the 1S mass, which is half the mass of the $\varUpsilon(1S)$ in perturbation theory. For a review of different quark mass definitions and their properties, see EL-KHADRA 02. The $15\,\mathrm{mass}$ is better suited for use in analyzing B decays than the $\overline{\mathrm{MS}}$ mass because it gives a stable perturbative expansion. We have converted masses in other schemes to the $\overline{\rm MS}$ mass and 15 mass using two-loop QCD perturbation theory with $\alpha_S(\mu=\overline{m}_b)=0.223\pm0.008.$ The values 4.18 \pm 0.03 GeV for the $\overline{\rm MS}$ mass and 4.65 \pm 0.03 GeV for the 15 mass correspond to 4.78 \pm 0.06 GeV for the pole mass, using the two-loop conversion formula. A discussion of masses in different schemes can be found in the "Note on Quark Masses."

| MS MASS (GeV) | 1S MASS (GeV) | DO CUMENT ID | | TECN |
|-----------------------------------------------|--------------------------|-------------------------|------|------|
| 4.18 ±0.03 OUR EVAL | | See the ideogram belo | w. | |
| 4.65 ±0.03 OUR EVAL | | | | |
| 4.171 ± 0.009 | 4.642 ± 0.010 | ¹ BODENSTEIN | 12 | THEO |
| 4.29 ± 0.14 | 4.77 ± 0.16 | ² DIMOP OUL | 12 | LATT |
| 4.177 ± 0.011 | 4.649 ± 0.012 | ³ NARISON | 12 | THEO |
| $\begin{array}{c} -0.05 \\ -0.04 \end{array}$ | $4.65 + 0.06 \\ -0.04$ | ⁴ LASCHKA | 11 | THEO |
| $4.186 \pm 0.044 \pm 0.015$ | $4.659\pm0.050\pm0.017$ | | 10A | BABR |
| 4.164 ± 0.023 | 4.635 ± 0.026 | | 10 | LATT |
| 4.163 ± 0.016 | 4.633 ± 0.018 | | 09 | THEO |
| 5.26 ±1.2 | 5.85 ± 1.3 | | 08D | DLPH |
| 4.243 ± 0.049 | 4.723 ± 0.055 | | 80 | BELL |
| 4.19 ± 0.40 | 4.66 ± 0.45 | | 06D | DLPH |
| 4.205 ± 0.058 | 4.68 ± 0.06 | ¹¹ BOUGHEZAL | 06 | THEO |
| 4.20 ±0.04 | 4.67 ± 0.04 | 12 BUCHMULLER | 06 | THEO |
| 4.19 ±0.06 | 4.66 ± 0.07 | 13 PINEDA | 06 | THEO |
| 4.17 ±0.03 | 4.68 ± 0.03 | 14 BAUER | 04 | THEO |
| 4.22 ± 0.11 | 4.72 ± 0.12 | ^{15,16} HOANG | 04 | THEO |
| 4.19 ±0.05 | 4.66 ± 0.05 | ¹⁷ BORDES | 03 | THEO |
| 4.20 ± 0.09 | 4.67 ± 0.10 | | 03 | THEO |
| 4.24 ±0.10 | 4.72 ± 0.11 | | 03 | THEO |
| 4.207 ± 0.031 | 4.682 ± 0.035 | ²⁰ ERLER | 03 | THEO |
| $4.33 \pm 0.06 \pm 0.10$ | $4.82\pm0.07\pm0.11$ | ²¹ MAHMOOD | 03 | CLEO |
| 4.190 ± 0.032 | 4.663 ± 0.036 | 22 BRAMBILLA | 02 | THEO |
| 4.346 ± 0.070 | 4.837 ± 0.078 | 23 PENIN | 02 | THEO |
| • • • We do not use the | following data for avera | • | • • | |
| 4.212 ± 0.032 | 4.688 ± 0.036 | | 12 | THEO |
| 4.171 ± 0.014 | 4.642 ± 0.016 | | 12A | THEO |
| 4.173 ± 0.010 | 4.645 ± 0.011 | ²⁶ NARISON | 10 | THEO |
| $4.42 \pm 0.06 \pm 0.08$ | $4.92\pm0.07\pm0.09$ | ²⁷ GUAZZINI | 80 | LATT |
| $4.347 \pm 0.048 \pm 0.08$ | $4.838\pm0.053\pm0.09$ | ²⁸ DELLA-MOR | 07 | LATT |
| 4.164 ± 0.025 | 4.635 ± 0.028 | | 07 | THEO |
| 4.4 ± 0.3 | 4.9 ± 0.3 | ^{15,30} GRAY | 05 | LATT |
| 4.22 ± 0.06 | 4.72 ± 0.07 | 31 AUBERT | 04 x | THEO |
| 4.25 ± 0.11 | 4.76 ± 0.12 | 15,32 MCNEILE | 04 | LATT |
| 4.22 ± 0.09 | 4.74 ± 0.10 | ³³ BAUER | 03 | THEO |
| 4.33 ±0.10 | 4.84 ± 0.11 | 15,34 DEDIVITIIS | 03 | LATT |

- $^{
 m 1}$ BODENSTEIN 12 determine m_b using sum rules for the vector current correlator and the $e^+e^- o Q\,\overline{Q}$ total cross-section. We have converted $\overline{m}_b(\overline{m}_b)$ to the 1S scheme.
- 2 DIMOPOULOS 12 determine quark masses from a lattice computation using N_f = dynamical flavors of twisted mass fermions. We have converted $\overline{m}_b(\overline{m}_b)$ to the 1S
- 3 Determines m_b to order α_5^3 , including the effect of gluon condensates up to dimension eight combining the methods of NARISON 12 and NARISON 12A. We have converted $\overline{m}_b(\overline{m}_b)$ to the 1S scheme.
- ^4 LASCHKA 11 determine the b mass from the charmonium spectrum. The theoretical computation uses the heavy $Q\overline{Q}$ potential to order $1/m_Q$ obtained by matching the short-distance perturbative result onto lattice QCD result at larger scales. We have converted $\overline{m}_b(\overline{m}_b)$ to the 1S scheme.
- ⁵ AUBERT 10A determine the *b* and *c*-quark masses from a fit to the inclusive decay spectra in semileptonic B decays in the kinetic scheme (and convert it to the $\overline{\text{MS}}$ scheme). We have converted this to the 1S scheme.
- 6 MCNEILE 10 determines m_b by comparing four-loop perturbative results for the pseudoscalar current to lattice simulations with $N_f=2+1$ sea-quarks by the HPQCD collaboration. We have converted \overline{m}_b (\overline{m}_b) to the 1S scheme.
- 7 CHETYRKIN 09 determine m_{C} and m_{D} from the $e^+\,e^-\to Q\,\overline{Q}$ cross-section and sum rules, using a four-loop computation of the heavy quark vacuum polarization. We have converted their m_{D} to the 1S scheme.

- 8 ABDALLAH 08D determine $\overline{m}_b(M_Z)=3.76\pm1.0$ GeV from a leading order study of four-jet rates at LEP. We have converted this to $\overline{m}_b(\overline{m}_b)$ and m_b^{1S}
- 9 SCHWANDA 08 measure moments of the inclusive photon spectrum in $B
 ightarrow X_S \, \gamma$ decay to determine m_h^{1S} . We have converted this to $\overline{\rm MS}$ scheme.
- 10 ABDALLAH 06D determine $m_b(M_Z)=2.85\pm0.32$ GeV from Z-decay three-jet events containing a b-quark. We have converted this to $\overline{m}_b(\overline{m}_b)$ and $m_b^{1S}.$
- $^{11} \mbox{BOUGHEZAL 06 $\overline{\mbox{MS}}$}$ scheme result comes from the first moment of the hadronic production cross-section to order α_s^3 . We have converted it to the 1S scheme.
- 12 BUCH MULLER 06 determine m_b and m_c by a global fit to inclusive $\it B$ decay spectra. We have converted this to the 1S scheme.
- NNLO) of sum rules of the bottom production cross-section in $e^+\,e^-$ annihilation. We
- have converted it to the 1S scheme. 14 BAUER 04 determine $m_b,\,m_c$ and m_b-m_c by a global fit to inclusive B decay spectra.
- $^{15}\,\mathrm{We}$ have converted $\,m_b^{}$ to the 1S scheme
- 16 HOANG 04 determines $\overline{m}_b(\overline{m}_b)$ from moments at order $lpha_S^2$ of the bottom production cross-section in e^+e^- annihilation.
- 17 BORDES 03 determines m_b using QCD finite energy sum rules to order α_s^2
- 18 CORCELLA 03 determines \overline{m}_b using sum rules computed to order α_s^2 . Includes charm quark mass effects.
- 19 EIDEMULLER 03 determines \overline{m}_b and \overline{m}_c using QCD sum rules.
- 20 ERLER 03 determines \overline{m}_b and \overline{m}_c using QCD sum rules. Includes recent BES data. 21 MAHMOOD 03 determines m_b^{LS} by a fit to the lepton energy moments in $B\to X_c\ell\nu_\ell$ decay. The theoretical expressions used are of order $1/m^3$ and $\alpha_s^2\beta_0$. We have converted
- their result to the $\overline{\rm MS}$ scheme. 22 BRAMBILLA 02 determine $\overline{m}_b(\overline{m}_b)$ from a computation of the $\Upsilon(1S)$ mass to order α_s^4 , including finite m_c corrections. We have converted this to the 1S scheme.
- ²³ PENIN 02 determines \overline{m}_b from the spectrum of the \varUpsilon system.
- $^{24}\,\mathrm{NARISO\,N}\,12$ determines $m_{\,b}$ using exponential sum rules for the vector current correlator to order α_c^3 , including the effect of gluon condensates up to dimension eight. We have converted $\frac{s}{m}_{b}(\overline{m}_{b})$ to the 1S scheme.
- 25 NARISON $^{-1}$ determines m_b using sum rules for the vector current correlator to order $lpha_c^3$, including the effect of gluon condensates up to dimension eight. We have converted $\overline{m}_b(\overline{m}_b)$ to the 1S scheme.
- 26 NARISON 10 determines m_b from ratios of moments of vector current correlators computed to order α_c^3 and including the dimension-six gluon condensate. These values are
- taken from the erratum to that reference. 27 GUAZZINI 08 determine $m_b(\overline{m}_b)$ from a quenched lattice simulation of heavy meson masses. The ± 0.08 is an estimate of the quenching error. We have converted these values to the 15 scheme.
- 28 DELLA-MORTE O7 determine $\overline{m}_b(\overline{m}_b)$ from a computation of the spin-averaged B meson mass using quenched lattice HQET at order 1/m. The ± 0.08 is an estimate of the quenching error
- ²⁹ KUHN 07 determine $\overline{m}_b(\mu=$ 10 GeV) $=3.609\pm0.025$ GeV and $\overline{m}_b(\overline{m}_b)$ from a fourloop sum-rule computation of the cross-section for $e^+e^ightarrow$ hadrons in the bottom
- threshold region. We have converted this to the 1S scheme. 30 GRAY 05 determines $\overline{m}_b(\overline{m}_b)$ from a lattice computation of the \varUpsilon spectrum. The simulations have 2+1 dynamical light flavors. The b quark is implemented using NRQCD.
- 31 AUBERT 04x obtain m_b from a fit to the hadron mass and lepton energy distributions in semileptonic B decay. The paper quotes values in the kinetic scheme. The $\overline{\text{MS}}$ value has been provided by the BABAR collaboration, and we have converted this to the 1S
- 32 MCNEILE 04 use lattice QCD with dynamical light quarks and a static heavy quark to compute the masses of heavy-light mesons.
- 33 BAUER 03 determine the b quark mass by a global fit to B decay observables. The experimental data includes lepton energy and hadron invariant mass moments in semileptonic $B \to X_c \ell \nu_\ell$ decay, and the inclusive photon spectrum in $B \to X_s \gamma$ decay. The theoretical expressions used are of order $1/m^3$, and $\alpha_s^2\beta_0$.
- $^{34}\,\mathrm{DEDIVITIIS}$ 03 use a quenched lattice computation of heavy-heavy and heavy-light me-

b. 1



b-QUARK REFERENCES

| BODENSTEIN | 12 | PR D85 034003 | S. Bodenstein et al. | |
|------------|------|----------------------|----------------------------------------|-------------------|
| DIM OP OUL | 12 | JHEP 1201 046 | P. Dimopoulos et al. | (ETM Collab.) |
| NARIS ON | 12 | PL B707 259 | S Narison | (MONP) |
| NARIS ON | 12A | PL B706 412 | S. Narison | (MONP) |
| LAS CHKA | 11 | PR D83 094002 | A. Laschka, N. Kaiser, W. Weise | (/ |
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| NARIS ON | 10 | PL B693 559 | S. Narison | ` (MONP) |
| Also | | PL B705 544 (errat.) | S. Narison | (MONP) |
| CHETYRKIN | 09 | PR D80 074010 | K.G. Chetyrkin et al. | (KARL, BNL) |
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| GUAZZINI | 08 | JHEP 0801 076 | D. Guazzini, R. Sommer, N. Tantalo | , |
| SCHWANDA | 08 | PR D78 032016 | C. Schwanda et al. | (BELLE Collab.) |
| DELLA-MOR | 07 | JHEP 0701 007 | M. Della Morte et al. | , |
| KUHN | 07 | NP B778 192 | J.H. Kuhn, M. Steinhauser, C. Sturm | |
| ABDALLAH | 06 D | EPJ C46 569 | J. Abdallah et al. | (DELPHI Collab.) |
| BOUGHEZAL | 06 | PR D74 074006 | R. Boughezal, M. Czakon, T. Schutzm | eier |
| BUCHMULLER | 06 | PR D73 073008 | O.L. Buchmuller, H.U. Flacher | |
| PINEDA | 06 | PR D73 111501R | A. Pineda, A. Signer | |
| GRAY | 05 | PR D72 094507 | A. Gray et al. (HPQCE |), UKQCD Collab.) |
| AUBERT | 04 X | PRL 93 011803 | B. Aubert et al. | (BABAR Collab.) |
| BAUER | 04 | PR D70 094017 | C. Bauer et al. | |
| HOANG | 04 | PL B594 127 | A.H. Hoang, M. Jamin | |
| MCNEILE | 04 | PL B600 77 | C. McNeile, C. Michael, G. Thompson | (UKQCD Collab.) |
| BAUER | 03 | PR D67 054012 | C.W. Bauer et al. | |
| BORDES | 03 | PL B562 81 | J. Bordes, J. Penarrocha, K. Schilcher | |
| CORCELLA | 03 | PL B554 133 | G. Corcella, A.H. Hoang | |
| DEDIVITIIS | 03 | NP B675 309 | G.M. de Divitiis et al. | |
| EIDEMULLER | 03 | PR D67 113002 | M. Eidemuller | |
| ERLER | 03 | PL B558 125 | J. Erler, M. Luo | |
| MAHMOOD | 03 | PR D67 072001 | A.H. Mahmood et al. | (CLEO Collab.) |
| BRAMBILLA | 02 | PR D65 034001 | N. Brambilla, Y. Sumino, A. Vairo | |
| EL-KHADRA | 02 | ARNPS 52 201 | A.X. El-Khadra, M. Luke | |
| PENIN | 02 | PL B538 335 | A. Penin, M. Steinhauser | |



$$I(J^P) = O(\frac{1}{2}^+)$$

Charge $= \frac{2}{3} e$ Top $= +1$

THE TOP QUARK

Updated December 2011 by T.M. Liss (Univ. Illinois) and A. Quadt (Univ. Göttingen).

A. Introduction: The top quark is the Q = 2/3, $T_3 = +1/2$ member of the weak-isospin doublet containing the bottom quark (see the review on the "Electroweak Model and Constraints on New Physics" for more information). This note summarizes the properties of the top quark (mass, production cross section, decay branching ratios, etc.), and provides a discussion of the experimental and theoretical issues involved in their determination

B. Top quark production at the Tevatron and LHC: In hadron collisions, top quarks are produced dominantly in pairs through the QCD processes $q\overline{q} \to t\overline{t}$ and $gg \to t\overline{t}$. In $p\overline{p}$ collisions at the Tevatron with $\sqrt{s} = 1.96$ TeV the most recent calculations are at NLO with next-to-leading-log soft gluon resummation [1], and at approximate next-to-next-to-leading order (NNLO) [2]. Cacciari et al. give a production cross section of 7.93 pb for $m_t = 172.5 \text{ GeV/c}^2$ with MRST2006nnlo PDFs. Over the range 150 GeV/ $c^2 \le m_t \le 190 \text{ GeV}/c^2$ the calculated cross section changes by approximately $0.24 \text{ pb/(GeV/c}^2)$ for m_t greater or less than 172.5 GeV/c². An approximate NNLO calculation by Kidonakis and Vogt yields a production cross section of 7.68 pb for $m_t = 172.5 \text{ GeV/c}^2 \text{ using MRST2006nnlo}$, with nearly the same mass-dependence. The difference in the central value obtained using different PDFs is typically a few tenths of a pb or less. Langenfeld et al. [3], in an approximate NNLO calculation find 7.04 pb for $m_t = 173 \text{ GeV/c}^2 \text{ using}$ MSTW2008nnlo. The uncertainties on these calculations, due to the choice of scale, which is set at $\mu = m_t$, are typically 0.5 pb or less. In pp collisions at the LHC with $\sqrt{s} = 7$ TeV, Langenfeld et al. calculate an approximate NNLO production cross section of 161 pb for $m_t = 172.5 \text{ GeV/c}^2$ using CTEQ6.6 with an uncertainty of less than 10%. Approximately 85% of the production cross section at the Tevatron is from $q\bar{q}$ annihilation, with the remainder from gluon-gluon fusion [4], while at LHC energies about 90% of the production is from the latter process at $\sqrt{s} = 14 \text{ TeV} \ (\approx 80\% \text{ at } \sqrt{s} = 7 \text{ TeV})$. The resulting theoretical prediction of the top quark cross-section at the LHC is $\sigma_{t\bar{t}} = 165^{+11}_{-16}$ pb, assuming a top quark mass of 172.5 GeV/c^2 [5].

Somewhat smaller cross sections are expected from electroweak single top production mechanisms, namely from $q\overline{q}' \to t\overline{b}$ [6] and $qb \to q't$ [7], mediated by virtual s-channel and t-channel W bosons, respectively. At the Tevatron, the production cross sections of top and antitop are identical, while at the LHC they are not. Approximate NNLO cross sections for t-channel single top quark production are calculated for $m_t = 173 \text{ GeV/c}^2$ to be 1.04 pb in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV and 41.7 pb in pp collisions at $\sqrt{s} = 7$ TeV [8]. For the s-channel, these calculations yield 0.52 pb for the Tevatron, and 3.2 pb for $\sqrt{s} = 7$ TeV LHC [9]. The corresponding single anti-top-quark cross sections at the LHC are 22.5 pb and 1.4 pb for t- and s-channel, respectively, at $\sqrt{s} = 7$ TeV. At LHC energies, the production of a single top quark in association with a W⁻ boson, through $bg \to W^- t$, becomes relevant. At $\sqrt{s} = 7$ TeV, an approximate NNLO calculation using the MSTW2008 PDF gives 8.1 pb [10]. The production cross section for single anti-top quarks in this channel $(W^{+}\bar{t})$ is the same as for single top quarks.

The cross sections for single top production are proportional to $|V_{tb}|^2$, and no assumption is needed on the number of quark families or on the unitarity of the CKM matrix in extracting $|V_{tb}|$. Separate measurements of the s- and t-channel processes provide sensitivity to physics beyond the Standard Model (SM) [11].

The identification of top quarks in the electroweak singletop channel is much more difficult than in the QCD $t\bar{t}$ channel, due to a less distinctive signature and significantly larger backgrounds.

In top decay, the Ws and Wd final states are expected to be suppressed relative to Wb by the square of the CKM matrix elements V_{ts} and V_{td} . Assuming unitarity of the three-generation CKM matrix, these matrix element values are estimated to be less than 0.043 and 0.014, respectively, implying a value of $V_{tb} > 0.999$ (see the review "The CKM Quark-Mixing Matrix" for more information). With a mass above the Wb threshold, and V_{tb} close to unity, the decay width of the top quark is expected to be dominated by the two-body channel $t \to Wb$. Neglecting terms of order m_b^2/m_t^2 , α_s^2 , and $(\alpha_s/\pi)M_W^2/m_t^2$, the width predicted in the Standard Model (SM) at NLO is [12]:

$$\Gamma_{t} = \frac{G_{F} m_{t}^{3}}{8\pi\sqrt{2}} \left(1 - \frac{M_{W}^{2}}{m_{t}^{2}}\right)^{2} \left(1 + 2\frac{M_{W}^{2}}{m_{t}^{2}}\right) \left[1 - \frac{2\alpha_{s}}{3\pi} \left(\frac{2\pi^{2}}{3} - \frac{5}{2}\right)\right],\tag{1}$$

where m_t refers to the top quark pole mass. The width for a value of $m_t = 171 \text{ GeV/c}^2$, close to the world average, is 1.29 GeV/c^2 (we use $\alpha_s(M_Z) = 0.118$) and increases with mass. With its correspondingly short lifetime of $\approx 0.5 \times 10^{-24}$ s, the top quark is expected to decay before top-flavored hadrons or $t\bar{t}$ -quarkonium-bound states can form [13]. The order α_s^2 QCD corrections to Γ_t are also available [14], thereby improving the overall theoretical accuracy to better than 1%.

The final states for the leading pair-production process can be divided into three classes:

A.
$$t\overline{t} \to W^+ b W^- \overline{b} \to q \overline{q}' b q'' \overline{q}''' \overline{b},$$
 (45.7%)
B. $t\overline{t} \to W^+ b W^- \overline{b} \to q \overline{q}' b \ell^- \overline{\nu}_\ell \overline{b} + \ell^+ \nu_\ell b q'' \overline{q}''' \overline{b},$ (43.8%)

C.
$$t\overline{t} \to W^+ b W^- \overline{b} \to \hat{\overline{\ell}} \nu_{\ell} b \ell' \overline{\nu}_{\ell'} \overline{b}$$
. (10.5%)

The quarks in the final state evolve into jets of hadrons. A, B, and C are referred to as the all-jets, lepton+jets (ℓ +jets), and dilepton ($\ell\ell$) channels, respectively. Their relative contribu-

and dilepton ($\ell\ell$) channels, respectively. Their relative contributions, including hadronic corrections, are given in parentheses assuming lepton universality. While ℓ in the above processes refers to e, μ , or τ , most of the results to date rely on the e and μ channels. Therefore, in what follows, we will use ℓ to refer to e or μ , unless otherwise noted.

The initial and final-state quarks can radiate gluons that can be detected as additional jets. The number of jets reconstructed in the detectors depends on the decay kinematics, as well as on the algorithm for reconstructing jets used by the analysis. The transverse momenta of neutrinos are reconstructed from the imbalance in transverse momentum measured in each event (missing p_T , which is here also missing E_T).

NLO Monte Carlo programs are available for the $t\bar{t}$ production processes [15]. Theoretical estimates of the background processes (W or Z bosons+jets and dibosons+jets) using leading order (LO) calculations have large uncertainties. While this limitation affects estimates of the overall production rates, it is believed that the LO determination of event kinematics, and of the fraction of W+multi-jet events that contain b- or c-quarks, are relatively accurate [16]. Comparison to CDF and DØ data,

however, indicates the *b*- and *c*-quark fractions to be underestimated by the LO generators and hence does not seem to support the theoretical expectations.

C. Top quark measurements: Since the discovery of the top quark, direct measurements of $t\bar{t}$ production have been made at three center-of-mass energies, providing stringent tests of QCD. The first measurements were made in Run I at the Tevatron at $\sqrt{s}=1.8$ TeV. In Run II at the Tevatron relatively precise measurements were made at $\sqrt{s}=1.96$ TeV. Finally, beginning in 2010 measurements have been made at the LHC at $\sqrt{s}=7$ TeV.

Production of single top quarks through electroweak production mechanisms has now been measured with good precision at the Tevatron at $\sqrt{s} = 1.96$ TeV, and at the LHC at $\sqrt{s} = 7$ TeV. Recent measurements are beginning to separate the s- and t-channel production cross sections, and at the LHC, the Wt mechanism as well, though only t-channel is well measured to date. The measurements allow an extraction of the CKM matrix element V_{tb} .

The top quark mass is now measured at the 0.6% level, by far the most precisely measured quark mass. Together with the W boson mass measurement, this places strong constraints on the mass of the Standard Model Higgs boson.

With more than 5 fb⁻¹ of Tevatron data analyzed as of this writing, and 1-2 fb⁻¹ of LHC data, many properties of the top quark are now being measured with precision. These include properties related to the production mechanism, such as $t\bar{t}$ spin correlations, forward-backward or charge asymmetries, and differential production cross sections, as well as properties related to the t-W-b decay vertex, such as the helicity of the W bosons from the top decay. In addition, many searches for physics beyond the Standard Model are being performed with increasing reach in both production and decay channels.

In the following sections we review the current status of measurements of the characteristics of the top quark.

C.1 Top quark production

 $C.1.1 \ t\overline{t}$ production Fig. 1 summarizes the $t\overline{t}$ production cross-section measurements from both the Tevatron and LHC. The most recent measurement from D0 [17], combining the measurements from the dilepton and lepton plus jets final states in $5.4~{\rm fb^{-1}}$, is $7.56^{+0.63}_{-0.56}~{\rm pb}$. From CDF the most precise measurement made recently [18] is in 4.6 fb^{-1} and is a combination of dilepton, lepton plus jets, and all-hadronic final-state measurements, yielding 7.50 ± 0.48 pb. Both of these measurements assume a top mass of 172.5 GeV/c². The dependence of the cross section measurements on the value chosen for the mass is less than that of the theory calculations because it only affects the determination of the acceptance. In some analyses also the shape of topological variables might be modified. At LHC energies, ATLAS [19] combines measurements in the lepton plus jets and dilepton final states with $0.7 \, \mathrm{fb^{-1}}$ to find $176 \pm 14 \, \mathrm{pb}$, whereas a more recent analysis of that dataset in the lepton plus jets channel without b-tagging yields the most precise result of 179 ± 12 pb [20] and a measurement in the all-jets channels using 1.02 fb⁻¹ yields 167 ± 80 pb [21]. CMS [22] uses 0.8 - 1.1 fb⁻¹ in the lepton plus jets channel and measures 164 ± 14 pb. In the all-hadronic channel they use 1.1 fb⁻¹ for a cut-based event selection combined with a kinematic fit and obtain 136 ± 45 pb [23]. These should be compared to the theoretical calculations that yield 7.9 - 6.7 pb for top masses from 170 to 175 GeV/c² respectively [1] at $\sqrt{s} = 1.96$ TeV and $\sigma_{t\bar{t}} = 165^{+11}_{-16}$ pb, assuming $m_t = 172.5$ GeV/c² at $\sqrt{s} = 7$ TeV at the LHC [5](see Listings).

Most of these measurements assume a $t \to Wb$ branching ratio of 100%. CDF and DØ have made direct measurements of the $t \to Wb$ branching ratio [24]. Comparing the number of events with 0, 1 and 2 tagged b jets in the lepton+jets channel, and also in the dilepton channel, using the known b-tagging efficiency, the ratio $R = B(t \to Wb)/\sum_{q=d,s,b} B(t \to Wq)$ can be extracted. In 5.4 fb⁻¹ of data, DØ measures $R = 0.90 \pm 0.04$, 2.5 σ from unity. A significant deviation of R from unity would imply either non-SM top decay (for example a flavor-changing neutral-current decay), or a fourth generation of quarks.

CDF also performs measurements of the $t\bar{t}$ production cross section normalized to the Z production cross section in order to reduce the impact of the luminosity uncertainty.

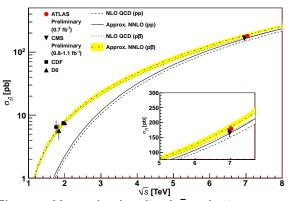


Figure 1: Measured and predicted $t\bar{t}$ production cross sections from Tevatron energies in $p\bar{p}$ collisions to LHC energies in pp collisions. Tevatron data points at $\sqrt{s}=1.8$ TeV are from Refs. [25] and [26]. Those at $\sqrt{s}=1.96$ TeV are from Refs. [17] and [18]. The ATLAS and CMS data points are from Refs. [20] and [22], respectively. Theory curves are generated using HATHOR [5] with input from Ref. [27] for the NLO curves and Ref. [2] for the approximate NNLO curves. Figure adapted from Ref. [19].

In Fig. 1, one sees the importance of $p\overline{p}$ at Tevatron energies where the valence antiquarks in the antiprotons contribute to the dominant $q\overline{q}$ production mechanism. At LHC energies the dominant production mode is gluon-gluon fusion and the $pp-p\overline{p}$ difference nearly disappears. The excellent agreement of these measurements with the theory calculations is a strong validation of QCD and the soft-gluon resummation techniques employed in

the calculations. The measurements are not yet precise enough to distinguish between the NLO and approximate NNLO calculations including their respective PDF uncertainties.

C.1.2 Single-top production Single-top quark production was first observed in 2009 by $D\emptyset$ [28] and CDF [29,30] at the Tevatron. The production cross section at the Tevatron is roughly half that of the $t\bar{t}$ cross section, but the final state with a single W-boson and typically two jets is less distinct than that for $t\bar{t}$ and much more difficult to distinguish from the background of W+jets and other sources. A recent review of the first observation and the techniques used to extract the signal from the backgrounds can be found in [31].

The dominant production at the Tevatron is through schannel and t-channel W-boson exchange. Associated production with a W-boson (Wt production) has a cross section that is too small to observe at the Tevatron. The t-channel process includes $qb \rightarrow q't$ and $qg \rightarrow q't\overline{b}$, while the s-channel process is $q\overline{q'} \to t\overline{b}$. The s- and t-channel productions can be separated kinematically. This is of particular interest because potential physics beyond the Standard Model, such as fourth-generation quarks, heavy W and Z bosons, or flavor-changing-neutralcurrents [11], would affect the s- and t-channels differently. However, the separation is difficult and initial observations and measurements at the Tevatron by both experiments were of combined s + t-channel production. The two experiments combined their measurements for maximum precision with a resulting s+t channel production cross section of $2.76^{+0.58}_{-0.47}$ pb [32]. The measured value assumes a top quark mass of 170 GeV/c^2 . The mass dependence of the result comes both from the acceptance dependence and from the $t\bar{t}$ background evaluation. Also the shape of discriminating topological variables is sensitive to m_t . It is therefore not necessarily a simple linear dependence but amounts to only a few tenths of picobarns over the range $170 - 175 \text{ GeV/c}^2$. The measured value agrees well with the theoretical calculation at $m_t = 173 \text{ GeV/c}^2 \text{ of } \sigma_{s+t} = 3.12 \text{ pb}$ (including both top and anti-top production) [8,9].

Both experiments have done separate measurements of the s- and t-channel cross sections by reoptimizing the analysis for one or both of the channels separately. In a simultaneous measurement of s- and t-channel cross sections, CDF measures $\sigma_s=1.8^{+0.7}_{-0.5}$ pb and $\sigma_t=0.8^{+0.4}_{-0.4}$ pb, respectively, in 3.2 fb⁻¹ of data [30], while DØ measures $2.7^{+0.7}_{-0.6}$ pb and $0.7^{+0.4}_{-0.4}$ pb, respectively in 5.4 fb⁻¹ of integrated luminosity [33]. In a separate analysis, optimized for the s-channel alone, CDF measures $1.49^{+0.92}_{-0.75}$ pb in 3.2 fb⁻¹ of data [34].

Recently, DØ has measured the t-channel production cross section separately in 5.4 fb⁻¹ of data [35] using a variety of advanced analysis techniques similar to those described in [31]. These take advantage of kinematic differences in such things as the leading b-tagged jet p_T , centrality of jets, lepton charge times η of the jets, and the scalar sum of the energy of the final state objects. The s-channel production is considered a background and integrated over the full measured s-channel

plane. The $p\overline{p}\to tqb+X$ cross section is measured to be 2.90±0.59 pb, assuming a top quark mass of 172.5 GeV/c². This is in good agreement with the theoretical value at this mass of 2.08±0.13 pb [8]. It should be noted that the theory citations here list cross sections for t or \overline{t} alone, whereas the experiments measure the sum. At the Tevatron these cross sections are equal. The theory values quoted here already include this factor of two.

At the LHC the t-channel cross section is expected to be more than three times as large as s-channel and Wt production, combined. Both ATLAS and CMS have measured single top production cross sections at $\sqrt{s} = 7$ TeV in pp collisions. In the measurement of the t-channel cross section, both experiments treat s-channel and Wt production as backgrounds. ATLAS uses a counting experiment in 0.7 fb^{-1} and combines W+2 and 3 jet data to measure $\sigma_t = 90^{+32}_{-22}$ pb [36]. In 36 pb⁻¹ of data, CMS uses a boosted decision tree and kinematic observables to separate signal from background, and combines the two measurements to find $\sigma_t = 83.6 \pm 30.0$ pb [37]. The experimental uncertainties are still too large for a precision test, but the measurements are consistent with the theoretical expectation of 64.2 $^{+1.8}_{-1.1}$ pb at $m_t = 173 \text{ GeV/c}^2$ [8]. This theoretical value is the sum of the t and \overline{t} production cross sections, which individually are 41.7 pb and 22.5 pb, respectively, at $\sqrt{s} = 7 \text{ TeV}.$

The s-channel production cross section is expected to be only 4.6 ± 0.3 pb for $m_t = 173 \text{ GeV/c}^2$ at $\sqrt{s} = 7 \text{ TeV } [9]$, and has not yet been observed at LHC. The Wt process has also not yet been observed, but appears a bit closer and has a theoretical cross section of 15.6 ± 1.2 pb [10]. This is of interest because it probes the W-t-b vertex in a different kinematic region than s- and t-channel production, and because of its similarity to the associated production of a charged-Higgs boson and a top quark. The signal is difficult to extract because of its similarity to the $t\bar{t}$ signature. Similarly, it is difficult to uniquely define because at NLO a subset of diagrams have the same final state as $t\bar{t}$ and the two interfere [38]. The cross section is calculated using the diagram removal technique [39] to define the signal process. In the diagram removal technique the interfering diagrams are removed, at the amplitude level, from the signal definition (an alternate technique, diagram subtraction removes these diagrams at the cross-section level and yields similar results). These techniques work provided the selection cuts are defined such that the interference effects are small, which is usually the case.

At ATLAS, a search is performed in 0.7 fb^{-1} using dilepton decays of the two putative W bosons in the final state and selecting events with exactly one high- p_T jet and large missing E_T [40]. No significant signal is observed yet, and the background-only hypothesis is rejected at only the 1.2σ level. Interpreted as a signal, the measured cross section is 14 ± 11 pb. At CMS a recent result has been released using 2.7 fb^{-1} of data. CMS also uses the dilepton channel and selects events with at least one high- p_T jet and large missing E_T [41]. The

CMS analysis requires exactly one b-tagged jet, which helps to distinguish the signal from non-top backgrounds and from $t\bar{t}$ production. The observed data are inconsistent with the background-only hypothesis at the 2.7σ level. If interpreted as a signal, the measured cross section is 22^{+9}_{-7} pb, consistent with the theoretical expectation.

The CKM matrix element V_{tb} is extracted from the measured cross sections using the ratio to the theoretical values, which assume $V_{tb} = 1.0$. The extracted value therefore depends on the theoretical cross section. The results, including limits at the 95% C.L., are summarized in Table 1.

Table 1: Measurements and 95% C.L. limits of $|V_{tb}|$ from single-top results.

| $ V_{tb} $ | Source | $\int \mathcal{L} dt \ (fb^{-1})$ | Ref. |
|-----------------------------------|---------------|-----------------------------------|------|
| $ V_{tb} = 0.88 \pm 0.07$ | DØ+CDF Run II | 2.3-3.2 | [32] |
| $ V_{tb} > 0.77$ | DØ+CDF Run II | 2.3-3.2 | [32] |
| $ V_{tb} = 1.02^{+0.10}_{-0.11}$ | DØ | 5.4 | [33] |
| $ V_{tb} = 1.14 \pm 0.22$ | CMS | 0.036 | [37] |
| $ V_{tb} > 0.62$ | CMS | 0.036 | [37] |

C.1.3 Top Quark Forward-Backward & Charge Asymmetry:

NLO calculations predict a small forward-backward asymmetry in $t\bar{t}$ production at the Tevatron of ($\approx 5.0 \pm 1.5$)% [42]. The asymmetry arises from an interference between the Born and box diagrams for $t\bar{t}$ production and between diagrams with initial- and final-state gluon radiation. Both CDF and DØ have measured asymmetry values in excess of the SM prediction, fueling speculation about exotic production mechanisms (see, for example, [43] and references therein). The first measurement of this asymmetry by DØ in 0.9 fb⁻¹ [44] found an asymmetry at the detector level of $(12 \pm 8)\%$. The first CDF measurement in 1.9 fb⁻¹ [45] yielded $(24 \pm 14)\%$ at parton level. Both values were higher, though statistically consistent with the small SM expectation. With the addition of more data, the uncertainties have been reduced, but the measured asymmetries remain in excess of the SM expectation. The most recent measurement from DØ in 5.4 fb⁻¹ finds an asymmetry, corrected for detector acceptance and resolution, of $(19.6 \pm 6.5)\%$ [46]. From CDF, the most recent measurement combines results in the lepton+jets and dilepton channels, using up to 5.3 fb^{-1} , and finds $(20.1 \pm 6.7)\%$ [47]. CDF has recently reported a massdependent asymmetry [48], with a larger asymmetry at large $t\bar{t}$ invariant mass. DØ does not see any significant increase at large mass [46].

At LHC, where the dominant $t\bar{t}$ production mechanism is the charge-symmetric gluon-gluon fusion, the measurement is more difficult. For the sub-dominant $q\bar{q}$ production mechanism, the symmetric pp collision does not define a forward and backward direction. Instead, the charge asymmetry is defined

t

in terms of a positive versus a negative $t - \overline{t}$ rapidity difference. Both CMS [49] and ATLAS [50] have made preliminary measurements of the charge asymmetry in almost 1 fb⁻¹. The uncertainties are still too large for a precision test, but both measurements are consistent with the very small asymmetry expected at the LHC while also not being inconsistent with the larger asymmetry observed at the Tevatron.

C.2 Top Quark Properties

C.2.1 Top Quark Mass Measurements: The most precisely studied property of the top quark is its mass. The top mass has been measured in the lepton+jets, the dilepton, and the all-jets channel by both CDF and DØ. At the LHC, both CMS and ATLAS have made measurements in the lepton+jets channel, CMS also in the dilepton channel. The latest results are summarized in Table 2. The lepton+jets channel yields the most precise single measurements because of good signal to background (in particular after b-tagging) and the presence of only a single neutrino in the final state. The momentum of a single neutrino can be reconstructed (up to a quadratic ambiguity) via the missing E_T measurement and the constraint that the lepton and neutrino momenta reconstruct to the known W boson mass.

A large number of techniques have now been applied to measuring the top mass. The original 'template method' [51], in which Monte Carlo templates of reconstructed mass distributions are fit to data, has evolved into a precision tool in the lepton+jets channel, where the systematic uncertainty due to the jet energy scale uncertainty is controlled by a simultaneous, in situ, fit to the $W \to jj$ hypothesis [52]. The latest measurements with this technique, which is now also used in the all-jets channel, are from ATLAS and CDF. In 0.7 fb⁻¹ of data in the lepton+jets channel, ATLAS already achieves a total uncertainty of better than 2%, with a statistical component of close to 0.5% [53]. The measurement from CDF with 5.6 fb⁻¹ [54] achieves a precision of better than 1% in the lepton+jets channel and is combined with a measurement in the dilepton channel yielding a precision of about 0.8%.

The template method is complemented by the 'matrix element' method. This method was first applied by the DØ Collaboration [55], and is similar to a technique originally suggested by Kondo et al. [56] and Dalitz and Goldstein [57]. In the matrix element method a probability for each event is calculated as a function of the top mass, using a LO matrix element for the production and decay of $t\bar{t}$ pairs. The in situ calibration of dijet pairs to the $W \to jj$ hypothesis is now also used with the matrix element technique to constrain the jet energy scale uncertainty. The latest measurement with this technique is from DØ in the lepton+jets channel with 3.6 fb⁻¹ yielding an uncertainty of about 0.9% [58].

CMS has measured the top mass at LHC using an 'ideogram' method, first used by DØ [59], in which a constrained fit is performed and an event-by-event likelihood for signal or background is calculated taking into account all jet-parton assignments. In the lepton+jets channel at CMS, the measurement has a precision of 2% in just $0.036~{\rm fb^{-1}}$. The precision is slightly improved by a combination with a measurement in the dilepton channel.

In the dilepton channel, the signal to background is typically very good, but reconstruction of the mass is non-trivial because there are two neutrinos in the final state, yielding a kinematically unconstrained system. A variety of techniques have been developed to handle this. Recently, an analytic solution to the problem has been proposed [60], but this has not yet been used in the mass measurement. The most precise measurements in the dilepton channel come from the application of the matrix element technique, in which an integration is performed over the unmeasured neutrino energies. A detailed description of the use of the matrix element technique in the dilepton channel is given in [61]. The most recent measurement in the dilepton channel by DØ uses 5.4 fb⁻¹ of data and has a precision of better than 2% [62].

Several other techniques also yield precise measurements in the dilepton channel. In the neutrino weighting technique a weight is assigned by assuming a top mass value and applying energy-momentum conservation to the top decay, resulting in up to four possible pairs of solutions for the neutrino and anti-neutrino momenta. The missing E_T calculated in this way is then compared to the observed missing E_T to assign a weight [63]. Another recent measurement in the dilepton channel uses the Dalitz and Goldstein technique [64]. The precision of these techniques approaches that of the matrix element technique, but the measurements to date have used only 2 fb^{-1} of data.

In the all-jets channel there is no ambiguity due to neutrino momenta, but the signal to background is significantly poorer due to the severe QCD multijets background. The emphasis therefore has been on background modeling, and reduction through event selection. The most recent measurement in the all-jets channel, by CDF in 5.8 fb⁻¹ [65], uses a template method for reconstruction and achieves a precision of almost 1%

A recent measurement from CDF in 5.7 fb⁻¹ uses a neural net to select events with a missing E_T plus jets signature [66]. A modified template method is used to extract the top mass, and a precision of about 1.5% is achieved.

The dominant systematic uncertainty in these methods is the understanding of the jet energy scale, and so several techniques have been developed that have little sensitivity to the jet energy scale uncertainty. These include the measurement of the top mass using the following techniques: Fitting of the lepton p_T spectrum of candidate events [67]; Fitting of the transverse decay length of the b-jet (L_{xy}) [68]; Fitting the invariant mass of a lepton from the W-decay and a muon from the semileptonic b decay [69].

Several measurements have now been made in which the top mass is extracted from the measured cross section using the theoretical relationship between the mass and the production cross section. This allows an extraction of both the pole and $\overline{\rm MS}$ mass [70]. The direct measurements of the top mass, such as those shown in Table 2, are generally assumed to be measurements of the pole mass. Strictly speaking, the mass measured in these direct measurements is the mass used in the Monte Carlo generators, but the relation between the Monte Carlo generator mass and the pole mass is uncertain at the level of 1 GeV [71], which is now comparable to the measurement uncertainty.

Table 2: Measurements of top quark mass from Tevatron and LHC. $\int \mathcal{L} dt$ is given in fb⁻¹. The results shown are mostly preliminary (not yet submitted for publication as of December 2011); for a complete set of published results see the Listings. Statistical uncertainties are listed first, followed by systematic uncertainties.

| $m_t \; (\mathrm{GeV}/c^2)$ | Source | $\int \mathcal{L} dt$ | Ref. Channel |
|-----------------------------|----------------|-----------------------|--------------------------------|
| $175.1 \pm 0.8 \pm 1.3$ | DØ Run I+II | \leq 5.4 | [72] ℓ +jets + $\ell\ell$ |
| $172.5 \pm 1.4 \pm 1.5$ | CDF Run II | 5.8 | [65] All jets |
| $172.3 \pm 2.4 \pm 1.0$ | CDF Run II | 5.7 | [66] Missing E_T +jets |
| $172.3 \pm 3.4 \pm 2.1$ | CDF Run II | 2.0 | $[64] \ell\ell$ |
| $172.7 \pm 9.3 \pm 3.7$ | CDF Run II | 2.2 | [73] τ +jets |
| $172.7 \pm 0.6 \pm 0.9$ | CDF Run I+II | \leq 5.8 | [74] Multiple channels |
| $173.4 \pm 1.9 \pm 2.7$ | CMS | 0.036 | [75] ℓ +jets + $\ell\ell$ |
| $175.9 \pm 0.9 \pm 2.7$ | ATLAS | 0.70 | [53] ℓ +jets |
| $173.5 \pm 0.6 \pm 0.8$ * | CDF,DØ CMS | | publ. results, PDG best |
| $173.2 \pm 0.6 \pm 0.8$ * | *CDF,DØ (I+II) | $) \le 5.8$ | [76] publ. or prelim. results |

^{*} PDG uses this result as its best value. It is a combination of published measurements. See Listings for more details.

Current global fits performed within the SM or its minimal supersymmetric extension, in which the top-mass measurements play a crucial role, provide indications for a relatively light Higgs (see " H^0 Indirect Mass Limits" in the Particle Listings of this Review for more information). Such fits, including Z-pole data [77] and direct measurements of the mass and width of the W-boson, yield a pole top mass $m_t = 179^{+12}_{-9} \text{ GeV/c}^2$ [78]. A fit including additional electroweak precision data (see the review "Electroweak Model and Constraints on New Physics" in this Review) yields $m_t = 177.5^{+9.4}_{-7.8} \text{ GeV/c}^2$. Both indirect evaluations are in good agreement with the direct top quark mass measurements. A review of top quark mass measurements can be found in reference [79].

C.2.2 Top Quark Spin Correlations and Width: One of the unique features of the top quark is that it typically decays before its spin can be depolarized by the strong interaction. Thus the top quark polarisation is directly observable via the angular distribution of its decay products. Hence, it is possible to define and measure observables sensitive to the top quark spin and its production mechanism. Although the top and antitop quarks are produced in strong interactions essentially unpolarized in hadron collisions, the spins of t and \bar{t} are correlated. For QCD processes, the $t\bar{t}$ system is dominantly produced in a 3S_1 state with parallel spins for $q\bar{q}$ annihilation or in a 1S_0 state with antiparallel spins for gluon-gluon fusion. Hence, the situation at the Tevatron and at the LHC are complementary. The sensitivity to top spin is greatest when the top quark daughters are down-type fermions (charged leptons or d-type quarks), in which case the joint angular distribution is [80–82]

$$\frac{1}{\sigma} \frac{d^2 \sigma}{d(\cos \theta_+) d(\cos \theta_-)} = \frac{1 + \kappa \cdot \cos \theta_+ \cdot \cos \theta_-}{4}, \tag{2}$$

where θ_+ and θ_- are the angles of the daughters in the top rest frames with respect to a particular spin quantization axis. The maximum value for κ , 0.782 at NLO at the Tevatron [83], is found in the off-diagonal basis [80] while at the LHC the value at NLO is 0.326 in the helicity basis [83]. The spin correlation could be modified by a new production mechanism such as Z' bosons, Kaluza-Klein gluons or the Higgs boson.

CDF uses 5.1 fb⁻¹ in the dilepton channel to measure the correlation coefficient in the beam axis [84]. They use the expected distributions of $(\cos\theta_+,\cos\theta_-)$ and $(\cos\theta_b,\cos\theta_{\bar{b}})$ of the charged leptons or the *b*-quarks in the $t\bar{t}$ signal and background templates to calculate a likelihood of observed reconstructed distributions as a function of assumed κ . They determine the 68% confidence interval for the correlation coefficient κ as $-0.52 < \kappa < 0.61$ or $\kappa = 0.04 \pm 0.56$ assuming $m_t = 172.5 \ {\rm GeV/c^2}$.

CDF also analyzes lepton+jets events in 5.3 fb⁻¹ [85] assuming $m_t = 172.5 \text{ GeV/c}^2$. They form three separate templates - the same-spin template, the opposite-spin template, and the background template for the 2-dimensional distributions in $\cos(\theta_l)\cos(\theta_d)$ vs. $\cos(\theta_l)\cos(\theta_b)$. The fit to the data in the helicity basis returns an opposite helicity fraction of $F_{OH} = 0.74 \pm 0.24(stat) \pm 0.11(syst)$. Converting this to the spin correlation coefficient yields $\kappa_{helicity} = 0.48 \pm 0.48(stat) \pm 0.22(syst)$. In the beamline basis, they find an opposite spin fraction of $F_{OS} = 0.86 \pm 0.32(stat) \pm 0.13(syst)$ which can be converted into a correlation coefficient of $\kappa_{beam} = 0.72 \pm 0.64(stat) \pm 0.26(syst)$.

DØ performs a measurement of the ratio f of events with correlated t and \bar{t} spins to the total number of $t\bar{t}$ events in 5.3 fb⁻¹ in the l+jets channel using a matrix element technique [86]. From 729 events they obtain $f_{meas}=1.15^{+0.42}_{-0.43}$ (stat + syst) and can exclude values of f<0.420 at the 95% C.L. In the dilepton channel [87], they also use a matrix element method and can exclude the hypothesis that the spins of the $t\bar{t}$ are uncorrelated at the 97.7% C.L.. The combination [86] yields $f_{meas}=0.85\pm0.29$ (stat + syst) and a $t\bar{t}$ production cross section which is in good agreement with the SM prediction

^{**}The TEVEWWG world average is a combination of published Run 1 and preliminary or pub. Run-II meas., yielding a χ^2 of 8.3 for 11 deg. of freedom.

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and previous measurements. For an expected fraction of f=1, they can exclude f<0.481 at the 95% C.L. For the observed value of $f_{meas}=0.85$, they can exclude f<0.344(0.052) at the 95(99.7)% C.L. The observed fraction f_{meas} translates to a measured asymmetry value of $A_{meas}=0.66\pm0.23$ (stat + syst). They therefore obtain first evidence of SM spin correlation at 3.1 standard deviations.

Using 5.4 fb⁻¹ of data, DØ measures the correlation in the dilepton channel also from the angles of the two leptons in the t and \bar{t} rest frames, yielding a correlation strength $C=0.10\pm0.45$ [88], in agreement with the NLO QCD prediction, but also in agreement with the no correlation hypothesis.

The ATLAS collaboration has performed a study of spin correlation in $t\bar{t}$ production at $\sqrt{s}=7$ TeV using 0.70 fb⁻¹ of data. Candidate events are selected in the dilepton topology with large missing transverse energy and at least two jets. The difference in azimuthal angle between the two charged leptons is compared to the expected distributions in the Standard Model, and to the case where the top quarks are produced with uncorrelated spin. Using the helicity basis as the quantisation axis, the strength of the spin correlation between the top and antitop quark is measured to be $A_{helicity} = 0.34^{+0.15}_{-0.11}$ [89], which is in agreement with the NLO Standard Model prediction.

Related to the measurement of top-spin correlations, which requires a top lifetime less than the hadronization timescale, is the measurement of the top width. The top width is expected to be of order 1 $\rm GeV/c^2$ (Eq. 1). The sensitivity of current experiments does not approach this level in direct measurements.

CDF presents a measurement of the top quark width in the lepton+jets decay channel of $t\bar{t}$ events from a data sample corresponding to 4.3 fb⁻¹ of integrated luminosity, yielding 756 events. The top quark mass and the mass of the hadronically decaying W boson that comes from the top quark decay are reconstructed for each event and compared with templates of different top quark widths (Γ_t) and deviations from nominal jet energy scale (ΔJES) to perform a simultaneous fit for both parameters, where ΔJES is used for the in situ calibration of the jet energy scale. By applying a Feldman-Cousins approach, they establish an upper limit at 95% C.L. of $\Gamma_t < 7.6$ GeV and a two-sided 68% C.L. interval of 0.3 GeV $< \Gamma_t < 4.4$ GeV [90], consistent with the Standard Model prediction.

DØ extracts the total width of the top quark from the partial decay width $\Gamma(t \to Wb)$ and the branching fraction $B(t \to Wb)$. $\Gamma(t \to Wb)$ is obtained from the measured t-channel cross section for single top quark production in 2.3 fb⁻¹, and $B(t \to Wb)$ is extracted from a measurement of the ratio $R = B(t \to Wb)/B(t \to Wq)$ in $\bar{t}t$ events in lepton+jets channels with 0, 1 and 2 b-tags in 1 fb⁻¹ of integrated luminosity. Assuming $B(t \to Wq) = 1$, where q includes any kinematically accessible quark, the result is: $\Gamma_t = 1.99^{+0.69}_{-0.55}$ GeV which translates to a top quark lifetime of $\tau_t = (3.3^{+1.3}_{-0.9}) \times 10^{-25}$ s. Assuming a high mass fourth generation b' quark and unitarity of the fourgeneration quark-mixing matrix, they set the first upper limit on $|V_{tb'}| < 0.63$ at 95% C.L. [91].

C.2.3 W Boson Helicity in Top Quark Decay: The Standard Model dictates that the top quark has the same vector-minus-axial-vector (V-A) charged-current weak interactions $\left(-i\frac{g}{\sqrt{2}}V_{tb}\gamma^{\mu}\frac{1}{2}(1-\gamma_{5})\right)$ as all the other fermions. In the SM, the fraction of top quark decays to longitudinally polarized W bosons is similar to its Yukawa coupling and hence enhanced with respect to the weak coupling. It is expected to be [92] $\mathcal{F}_{0}^{\text{SM}} \approx x/(1+x)$, $x=m_{t}^{2}/2M_{W}^{2}$ ($\mathcal{F}_{0}^{\text{SM}} \sim 70\%$ for $m_{t}=175~\text{GeV}/c^{2}$). Fractions of left-handed, right-handed, or longitudinal W bosons are denoted as \mathcal{F}_{-} , \mathcal{F}_{+} , and \mathcal{F}_{0} respectively. In the SM, \mathcal{F}_{-} is expected to be $\approx 30\%$ and $\mathcal{F}_{+} \approx 0\%$.

The Tevatron and the LHC experiments use various techniques to measure the helicity of the W boson in top quark decays, in both the lepton+jets events and dilepton channels.

The first method uses a kinematic fit, similar to that used in the lepton+jets mass analyses, but with the top quark mass constrained to a fixed value, to improve the reconstruction of final-state observables, and render the under-constrained dilepton channel solvable. The distribution of the helicity angle $(\cos \theta^*)$ between the lepton and the b quark in the W rest frame provides the most direct measure of the W helicity. In a simplified version of this approach, the $\cos \theta^*$ distribution is reduced to a forward-backward asymmetry.

The second method (p_T^{ℓ}) uses the different lepton p_T spectra from longitudinally or transversely polarized W-decays to determine the relative contributions.

A third method uses the invariant mass of the lepton and the *b*-quark in top decays $(M_{\ell b}^2)$ as an observable, which is directly related to $\cos \theta^*$.

At the LHC, top quark pairs in the dilepton channels are reconstructed by solving a set of six independent kinematic equations on the missing transverse energy in x- and in y-direction, two W-masses, and the two top/antitop quark masses. In addition, the two jets with the largest p_T in the event are interpreted as b-jets. The pairing of the jets to the charged leptons is based on the minimisation of the sum of invariant masses m_{min} . Simulations show that this criterion gives the correct pairing in 68% of the events.

Finally, the Matrix Element method (ME) has also been used, in which a likelihood is formed from a product of event probabilities calculated from the ME for a given set of measured kinematic variables and assumed W-helicity fractions. The results of recent CDF, DØ and ATLAS analyses are summarized in Table 3.

The datasets are now large enough to allow for a simultaneous fit of \mathcal{F}_0 and \mathcal{F}_+ , which we denote by '2-param' in the table. Results with either \mathcal{F}_0 or \mathcal{F}_+ fixed at its SM value are denoted '1-param'. For the simultaneous fits the correlation coefficient between the two values is about -0.8 for both experiments. A complete set of published results can be found in the Listings. All results are in agreement with the SM expectation.

Table 3: Measurement and 95% C.L. upper limits of the W helicity in top quark decays. Most results listed are preliminary and not yet submitted for publication, as of December 2011. A full set of published results is given in the Listings.

| W Helicity | Source | ∫£dt | Ref. | Method |
|------------------------------------|---------------|-------------|------|--------------------------------|
| | | (fb^{-1}) | | |
| $\mathcal{F}_0 = 0.71 \pm 0.20$ | CDF Run II | 5.3 | [93] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_0 = 0.59 \pm 0.11$ | CDF Run II | 5.3 | [93] | $\cos\theta^*$ 1-param |
| $\mathcal{F}_0 = 0.65 \pm 0.19$ | CDF Run II | 1.9 | [94] | $\cos\theta^*$ 2-param |
| $\mathcal{F}_0 = 0.59 \pm 0.12$ | CDF Run II | 1.9 | [94] | $\cos\theta^*$ 1-param |
| $\mathcal{F}_0 = 0.67 \pm 0.13$ | DØ Run II | 5.4 | [95] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_0 = 0.73 \pm 0.08$ | CDF+DØ Run II | 5.4 | [96] | $\cos\theta^*$ 2-param |
| $\mathcal{F}_0 = 0.69 \pm 0.06$ | CDF+DØ Run II | 5.4 | [96] | $\cos \theta^*$ 1-param |
| $\mathcal{F}_0 = 0.57 \pm 0.11$ | ATLAS | 0.7 | [97] | $\cos \theta^*$ 3-param |
| $\mathcal{F}_0 = 0.75 \pm 0.08$ | ATLAS | 0.7 | [97] | $\cos \theta^*, m_{min}$ 2-par |
| $\mathcal{F}_{+} = -0.07 \pm 0.10$ | CDF Run II | 5.3 | [93] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_{+} = -0.07 \pm 0.05$ | CDF Run II | 5.3 | [93] | $\cos \theta^*$ 1-param |
| $\mathcal{F}_{+} = -0.03 \pm 0.08$ | CDF Run II | 1.9 | [94] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_{+} = -0.04 \pm 0.05$ | CDF Run II | 1.9 | [94] | $\cos \theta^*$ 1-param |
| $\mathcal{F}_{+} = 0.02 \pm 0.05$ | DØ Run II | 5.4 | [95] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_{+} = -0.04 \pm 0.05$ | CDF+DØ Run II | 5.4 | [96] | $\cos \theta^*$ 2-param |
| $\mathcal{F}_{+} = -0.01 \pm 0.04$ | CDF+DØ Run II | 5.4 | [96] | $\cos \theta^*$ 1-param |
| $\mathcal{F}_{+} = 0.09 \pm 0.09$ | ATLAS | 0.7 | [97] | $\cos \theta^*$ 3-param |

C.2.4 Top Quark Electric Charge: The top quark is the only quark whose electric charge has not been measured through production at threshold in e^+e^- collisions. Furthermore, it is the only quark whose electromagnetic coupling has not been observed and studied until recently. Since the CDF and DØ analyses on top quark production did not associate the b, \bar{b} , and W^\pm uniquely to the top or antitop, decays such as $t \to W^+ \bar{b}, \bar{t} \to W^- b$ were not excluded. A charge 4/3 quark of this kind is consistent with current electroweak precision data. The $Z \to \ell^+ \ell^-$ and $Z \to b\bar{b}$ data, in particular the discrepancy between A_{LR} from SLC at SLAC and $A_{FB}^{0,b}$ of b-quarks and $A_{FB}^{0,\ell}$ of leptons from LEP at CERN, can be fitted with a top quark of mass $m_t = 270 \text{ GeV/c}^2$, provided that the right-handed b quark mixes with the isospin +1/2 component of an exotic doublet of charge -1/3 and -4/3 quarks, $(Q_1, Q_4)_R$ [98,99].

DØ studies the top quark charge in double-tagged lepton+jets events, CDF does it in single-tagged lepton+jets and dilepton events. Assuming the top and antitop quarks have equal but opposite electric charge, then reconstructing the charge of the b-quark through jet charge discrimination techniques, the $|Q_{top}| = 4/3$ and $|Q_{top}| = 2/3$ scenarios can be differentiated. For the exotic model of Chang et al. [99] with a top quark charge $|Q_{top}| = 4/3$, DØ excludes the exotic model at 91.2% C.L.% [100] using 370 pb⁻¹, while CDF excludes the model at 99% C.L. [101] in 5.6 fb⁻¹. Both results indicate that the observed particle is indeed consistent with being a SM $|Q_{top}| = 2/3$ quark. In 0.70 fb⁻¹, ATLAS performed a similar

analysis, reconstructing the *b*-quark charge either via a jetcharge technique or via the lepton charge in soft muon decays in combination with a kinematic likelihood fit. They exclude the exotic scenario at more than 5 σ [102].

The electromagnetic or the weak coupling of the top quark can be probed directly by investigating $t\bar{t}$ events with an additional gauge boson, like $t\bar{t}\gamma$ and $t\bar{t}Z$ events. Top quark pair events with additional photons in the final state are directly sensitive to the $t\bar{t}\gamma$ vertex.

CDF performs a search for events containing a lepton, a photon, significant missing transverse momentum, and a jet identified as containing a b-quark and at least three jets and large total transverse energy in 1.9 fb⁻¹. They find 16 $t\bar{t}\gamma$ events with an expectation from SM sources of $11.2^{+2.3}_{-2.1}$ events which they translate into a measurement of the $t\bar{t}\gamma$ cross section measurement of 0.15 ± 0.08 pb [103]. Recently, CDF repeated this measurement with 6.0 fb⁻¹ and reported evidence for the observation of $t\bar{t}\gamma$ production with a cross section $\sigma_{t\bar{t}\gamma}=0.18\pm0.08$ pb and a ratio of $\sigma_{t\bar{t}\gamma}/\sigma_{t\bar{t}}=0.024\pm0.009$ [104].

ATLAS performed a first measurement of the $t\bar{t}\gamma$ cross section in pp collisions at $\sqrt{s}=7$ TeV using 1.04 fb⁻¹ of data. Events are selected that contain a large transverse momentum electron or muon and a large transverse momentum photon, yielding 52 and 70 events in the electron and muon samples, respectively. The resulting cross section times branching ratio into the single lepton and dilepton channels for $t\bar{t}\gamma$ production with a photon with transverse momentum above 8 GeV is $\sigma(t\bar{t}\gamma)=2.0\pm0.5(stat.)\pm0.7(syst.)\pm0.1(lumi.)$ pb [105], which is consistent with theoretical calculations. A real test, however, of the vector and axial vector couplings in $t\bar{t}\gamma$ events or searches for possible tensor couplings of top quarks to photons will only be feasible with an integrated luminosity of several fb⁻¹ in the future.

C.3 Searches for Non-Standard Model Top Quark Production & Decay:

Motivated by the large mass of the top quark, several models suggest that the top quark plays a role in the dynamics of electroweak symmetry breaking. One example is topcolor [106], where a large top quark mass can be generated through the formation of a dynamic $t\bar{t}$ condensate, X, which is formed by a new strong gauge force coupling preferentially to the third generation. Another example is topcolor-assisted technicolor [107], predicting a heavy Z' boson that couples preferentially to the third generation of quarks with cross sections expected to be visible at the Tevatron and the LHC. CDF, DØ ATLAS, and CMS have searched for $t\bar{t}$ production via intermediate, narrowwidth, heavy-vector bosons X in the lepton+jets, the dilepton or the all-jets channels.

CDF has searched for resonant production of $t\bar{t}$ pairs in 4.8 fb⁻¹ of data in the lepton+jets channel. A matrix element reconstruction technique is used; for each event a probability density function (pdf) of the $t\bar{t}$ candidate invariant mass is sampled. These pdfs are used to construct a likelihood function, whereby the cross section for resonant $t\bar{t}$ production is

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estimated, given a hypothetical resonance mass and width. The data indicate no evidence of resonant production of $t\bar{t}$ pairs. A benchmark model of leptophobic $Z\to t\bar{t}$ is excluded with $m_{Z'}<900$ GeV at 95% C.L. [108]. A similar analysis has been performed in the all-jets channel using 2.8 fb⁻¹ of data [109]. In the absence of any evidence for top-antitop quark resonant production upper limits on the production cross section times branching ratio for a specific topcolor assisted technicolor model with width of $\Gamma_{Z'}=0.012M_{Z'}$ are set. Within this model, they exclude Z' bosons with masses below 805 GeV at the 95% C.L.

DØ has searched for narrow $t\bar{t}$ resonances that decay into a lepton+jets final state based on 5.3 fb⁻¹. They place upper limits on the production cross section times branching fraction to $t\bar{t}$ in comparison to the prediction for a leptophobic topcolor Z' boson. They exclude such a resonance at the 95% C.L. for masses below 835 GeV at width $\Gamma_{Z'}=0.012M_{Z'}$ [110]. This limit turns out to be independent of couplings of the $t\bar{t}$ resonance (pure vector, pure axial-vector, or Standard Model Z-like) and is valid for any narrow resonance decaying 100% to a $t\bar{t}$ final state.

ATLAS has performed a search for $t\bar{t}$ resonances in the lepton+jets final states using 0.2 fb⁻¹ of data at $\sqrt{s} = 7$ TeV. No evidence for a resonance is found. Using the reconstructed $t\bar{t}$ mass spectrum, limits are set on the production crosssection times branching ratio to $t\bar{t}$ for narrow and wide resonances. For narrow Z' models, the observed 95% C.L. limits range from approximately 38 pb to 3.2 pb for masses going from $m_{Z'} = 500 \text{ GeV}$ to $m_{Z'} = 1300 \text{ GeV}$ [111]. In Randall-Sundrum models, Kaluza-Klein gluons with masses below 650 GeV are excluded at 95% C.L. Using 1.04 fb⁻¹ of data in the dilepton channel, they have not observed any significant excess and place upper limits at the 95% C.L. on the cross section times branching ratio of the resonance decaying to $t\bar{t}$ pairs as a function of the resonance pole mass. A lower mass limit of 0.84 TeV is set for the case of a Kaluza Klein gluon resonance in the Randall-Sundrum Model [112].

CMS performs a search for massive neutral bosons decaying via a top-antitop quark pair. The analysis is based on 36 pb⁻¹ of data. From a combined analysis of the muon plus jets and electron plus jets decay modes no significant signal is observed, and upper limits on the production cross section as a function of the boson mass are reported [113]. They also perform a search for narrow heavy resonances decaying to top quark pairs in the μ +jets channel using 1.1 fb⁻¹ and set sub-picobarn limits at 95% C.L. on $\sigma(pp \to Z' \to t\bar{t})$ for invariant Z' masses above 1.35 TeV/c² [114]. Using 0.9 fb⁻¹, they search in the all-hadronic channel for sufficiently heavy resonances with decay products partially or fully merged into one jet. They set sub-picobarn limits on $\sigma_{Z'} \times B(Z' \to t\bar{t})$ at 95% C.L. for Z' heavier than 1.1 TeV/c² [115]

Both CDF and DØ have searched for non-SM top decays [116–121], particularly those expected in supersymmetric models, such as $t \to H^+b$, followed by $H^+ \to \tau^+\bar{\nu}$ or $c\bar{s}$. The $t \to H^+b$ branching ratio has a minimum at

 $\tan \beta = \sqrt{m_t/m_b} \simeq 6$, and is large in the region of either $\tan \beta \ll 6$ or $\tan \beta \gg 6$. In the former range, $H^+ \to c\overline{s}$ is dominant, while $H^+ \to \tau^+ \bar{\nu}$ dominates in the latter range. These studies are based either on direct searches for these final states, or on top "disappearance." In the standard lepton+jets or dilepton cross-section analyses, any charged-Higgs decays are not detected as efficiently as $t \to W^\pm b$, primarily because the selection criteria are optimized for the standard decays, and because of the absence of energetic isolated leptons in Higgs decays. A significant $t \to H^+ b$ contribution would give rise to measured $t\overline{t}$ cross sections that would be lower than the prediction from the SM (assuming that non-SM contributions to $t\overline{t}$ production are negligible), and the measured cross-section ratio $\sigma_{t\overline{t}}^{\ell+jets}/\sigma_{t\overline{t}}^{\ell\ell}$ would differ from unity.

In Run II, CDF has searched for charged-Higgs production in dilepton, lepton+jets, and lepton+hadronic tau final states, considering possible H^+ decays to $c\bar{s}$, $\tau\bar{\nu}$, t^*b , or W^+h^0 , in addition to the SM decay $t \to W^+ b$ [118,119]. Depending on the top and Higgs-decay branching ratios, which are scanned in a particular 2-Higgs doublet benchmark model, the number of expected events in these decay channels can show an excess or deficit when compared to SM expectations. A modelindependent interpretation yields a limit of $B(t \to H^{\pm}b) < 0.91$ at 95% C.L. for $m_{H^{\pm}} \approx 100$ GeV, and $B(t \to H^{\pm}b) < 0.4$ in the tauonic model with $B(H^{\pm} \to \tau \nu) = 100\%$. In a more recent search, the dijet invariant mass in lepton+jets events has been used in 2.2 fb⁻¹ to search for a charged Higgs decaying to $c\bar{s}$ with mass above the W boson mass. The absence of a signal leads to a 95% C.L. limit of $B(t \to H^{\pm}b) \times B(H^{\pm} \to c\bar{s}) < 0.1$ to 0.3 for masses between 90 and 150 GeV/c^2 [119].

In 1 fb⁻¹ of integrated luminosity, the DØ collaboration has used the $t\bar{t}$ dilepton and lepton+jets events, including τ lepton channels, to search for evidence of charged-Higgs decays into τ leptons via the ratio of events with τ leptons to those with e and μ [120], global fits [121] and topological searches [122]. They exclude regions of $B(t \to H^{\pm}b)$ as a function of Higgs mass, ranging from $B(t \to H^{\pm}b) > 0.12$ at low mass to $B(t \to H^{\pm}b) > 0.2$ at high mass. In a companion analysis they look for evidence of leptophobic charged Higgs production in top decays in which the Higgs decays purely hadronically, leading to a suppression of the measured $t\bar{t}$ rate in all leptonic channels. They exclude $B(t \to H^{\pm}b) > 0.2$ for charged-Higgs masses between 80 and 155 GeV/c².

DØ combines measurements of the top quark pair production cross section in the ℓ +jets, $\ell\ell$, and $\tau\ell$ final states (where ℓ is an electron or muon) in 1 fb⁻¹ of data, yielding $\sigma_{t\bar{t}}=8.18^{+0.98}_{-0.87}$ pb for $m_t=170$ GeV, or based on QCD predictions extract a top quark mass consistent with the world average. In addition, they measure the cross section ratios to be $\sigma_{ll}/\sigma_{lj}=0.86^{+0.19}_{-0.17}(stat+syst)$ and $\sigma_{\tau l}/\sigma_{ll+lj}=0.97^{+0.32}_{-0.29}(stat+syst)$. Based on this, they set upper limits on the branching fractions $B(t\to H^+b\to \tau^+\nu b)$ and $B(t\to H^+b\to c\bar{s}b)$ as a function of the charged Higgs boson mass [123].

In 35 pb⁻¹, ATLAS searches for the decay $H^+ \to c\bar{s}$ in the lepton+jets channel by investigation of the invariant jj-mass spectrum. The observed limits are within one standard deviation of the expected limits and range from B=0.25 to 0.14 for $m_{H^\pm}=90$ to 130 GeV/c² [124]. In 1.03 fb⁻¹ ATLAS searches for $t\bar{t}\to\tau(\to hadrons)+jets$. They set a 95% C.L. limit on the production of branching ratios $B(t\to bH^\pm)\times B(H^\pm\to\tau\nu)$ of 0.03 to 0.10 for H^\pm masses in the range 90 GeV/c² < $m_{H^\pm}<160$ GeV/c² [125]. A similar analysis with τ decaying to leptons in 1.03 fb⁻¹, assuming $B(H^\pm\to\tau\nu)=1$, this leads to 95% C.L. upper limits on the branching fraction $B(t\to bH^\pm)$ between 5.2% and 14.1% for H^\pm masses in the range 90 GeV/c² < $m_H^\pm<160$ GeV/c² [126].

The ATLAS collaboration has also searched for FCNC processes in $0.7~{\rm fb}^{-1}$ of $t\bar{t}$ events with one top quark decaying through FCNC $(t \to qZ)$ and the other through the Standard Model dominant mode $(t \to bW)$. Only the decays of the Z boson to charged leptons and leptonic W boson decays were considered as signal, leading to a final state topology characterised by the presence of three isolated leptons, at least two jets and missing transverse energy from the undetected neutrino. No evidence for an FCNC signal was found. An upper limit on the $t \to qZ$ branching ratio of $B(t \to qZ) < 1.1\%$ is set at the 95% confidence level, compatible with the expected limit, assuming no FCNC decay, of $B(t \to qZ) < 1.3\%$ [127].

More details, and the results of these studies for the exclusion in the m_{H^\pm} , $\tan\beta$ plane, can be found in the review "Higgs Bosons: Theory and Searches" and in the " H^+ Mass Limits" section of the Higgs Particle Listings of the current edition.

Using up to 2.7 fb⁻¹ of data, DØ has measured the Wtb coupling form factors by combining information from the W boson helicity in top quark decays in $t\bar{t}$ events and single-top quark production, allowing to place limits on the left-handed and right-handed vector and tensor couplings [128–130].

In 2.3 fb⁻¹, DØ excludes the production of W' bosons with masses below 863 GeV/c² for a W' boson with Standard Model-like couplings, below 885 GeV/c² for a W' boson with right-handed couplings that is allowed to decay to both leptons and quarks, and below 890 GeV/c² for a W' boson with right-handed couplings that is only allowed to decay to quarks [131]. CDF has recently released W' limits also using the single-top analysis [132]. In 1.9 fb⁻¹ of Run-II data, a W' with Standard Model couplings is searched for in the $t\bar{b}$ decay mode. Masses below 800 GeV/c² are excluded, assuming that any right-handed neutrino is lighter than the W', and below 825 GeV/c² if the right-handed neutrino is heavier than the W'.

CDF reported a search for flavor-changing neutral-current (FCNC) decays of the top quark $t \to q\gamma$ and $t \to qZ$ in the Run-I data [133], and recently with enhanced sensitivity in Run II [134]. The SM predicts such small rates that any observation would be a sign of new physics. CDF assumes that one top decays via FCNC, while the other decays via Wb. The Run-I analysis included a $t \to q\gamma$ search in which two signatures are examined, depending on whether the W decays leptonically

or hadronically. For leptonic W decay, the signature is $\gamma\ell$ and missing E_T and two or more jets, while for hadronic W decay, it is $\gamma+\geq 4$ jets. In either case, one of the jets must have a secondary vertex b tag. One event is observed $(\mu\gamma)$ with an expected background of less than half an event, giving an upper limit on the top branching ratio of $B(t\to q\gamma)<3.2\%$ at 95% C.L. In the search for $t\to qZ$, CDF considers $Z\to \mu\mu$ or ee and $W\to qq'$, giving a Z+ four jets signature. A Run-II dataset of 1.9 fb⁻¹ is found consistent with background expectations and a 95% C.L. on the $t\to qZ$ branching fraction of <3.7% (for $m_t=175~{\rm GeV/c^2}$) is set [134]. By comparison to the number expected from the theoretical production cross section, CDF has used the observed number of double b-tagged lepton+jets candidate events to place limits on a variety of decay modes, ranging from $B(t\to Zc)<13\%$ to $B(t\to invisible)<9\%$ [135].

In 4.1 fb⁻¹, DØ performs a search for events with $t\bar{t} \to \ell' \nu \ell \bar{\ell} + {\rm jets}$ $(\ell,\ell'=e,\mu)$ and extracts limits on the branching ratio $B(t\to Zq)(q=u,c$ quarks) < 3.2%) at 95% C.L. [136]. DØ performs also in single-top event candidates with an additional jet searches for flavor changing neutral currents via quark-gluon couplings, using 2.3 fb⁻¹. They find consistency between background expectation and observed data and set cross section limits at the 95% C.L. of $\sigma_{tgu} < 0.20$ pb and $\sigma_{tgc} < 0.27$ pb which corresponds to limits on the top quark decay branching fractions of $B(t\to gu) < 2.0 \cdot 10^{-4}$ and $B(t\to gc) < 3.9 \cdot 10^{-3}$ [137].

Constraints on FCNC couplings of the top quark can also be obtained from searches for anomalous single-top production in e^+e^- collisions, via the process $e^+e^- \to \gamma, Z^* \to t\overline{q}$ and its charge-conjugate (q = u, c), or in $e^{\pm}p$ collisions, via the process $e^{\pm}u \rightarrow e^{\pm}t$. For a leptonic W decay, the topology is at least a high- p_T lepton, a high- p_T jet and missing E_T , while for a hadronic W-decay, the topology is three high- p_T jets. Limits on the cross section for this reaction have been obtained by the LEP collaborations [138] in e^+e^- collisions, and by H1 [139] and ZEUS [140] in $e^{\pm}p$ collisions. When interpreted in terms of branching ratios in top decay [141,142], the LEP limits lead to typical 95% C.L. upper bounds of $B(t \to qZ) < 0.137$. Assuming no coupling to the Z boson, the 95% C.L. limits on the anomalous FCNC coupling $\kappa_{\gamma} < 0.13$ and < 0.27 by ZEUS and H1, respectively, are stronger than the CDF limit of $\kappa_{\gamma} < 0.42$, and improve over LEP sensitivity in that domain. The H1 limit is slightly weaker than the ZEUS limit due to an observed excess of five-candidate events over an expected background of 3.2 ± 0.4 . If this excess is attributed to FCNC top quark production, this leads to a total cross section of $\sigma(ep \to e + t + X, \sqrt{s} = 319 \text{ GeV}) < 0.25 \text{ pb } [139,143].$

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t-QUARK MASS

We first list the direct measurements of the top quark mass which employ the event kinematics and then list the measurements which extract a top quark mass from the measured $t\overline{t}$ cross-section using theory calculations. A discussion of the definition of the top quark mass in these measurements can be found in the review "The Top Quark."

OUR EVALUATION of 173.5 \pm 0.6 \pm 0.8 GeV is an average of published top mass measurements from Tevatron Run-I (1992–1996) and Run-II (2001–present) and of the LHC. The Tevatron average (173.4 \pm 0.6 \pm 0.8 GeV) was provided by the Tevatron Electroweak Working Group (TEVEWWG). It takes correlated uncertainties into account and has a χ^2 of 8.5 for 11 degrees of freedom. We include in OUR EVALUATION the measurement from CHATRCHYAN 11F assuming uncorrelated systematic uncertainties. The average would be 173.4 \pm 0.6 \pm 0.8 GeV if we assumed fully correlated systematics between the Tevatron average and CHATRCHYAN 11F.

For earlier search limits see PDG 96, Physical Review **D54** 1 (1996). We no longer include a compilation of indirect top mass determinations from Standard Model Electroweak fits in the Listings (our last compilation can be found in the Listings of the 2007 partial update). For a discussion of current results see the reviews "The Top Quark" and "Electroweak Model and Constraints on New Physics."

t-Quark Mass (Direct Measurements)

The following measurements extract a t-quark mass from the kinematics of $t\overline{t}$ events. They are sensitive to the top quark mass used in the MC generator that is usually interpreted as the pole mass, but the theoretical uncertainty in this interpretation is hard to quantify. See the review "The Top Quark" and references therein for more information

| VALUE | | | , | | | DO CUMENT ID | | | COMMENT |
|--------|----------------|------------|---------|------------|-------|--------------|-------------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 173.5 | | | | | | EVALUATION | | | ts in the header above. |
| 172.3 | | | | | | AALTONEN | 11ak | | $ ot\!\!\!E_T + \geq$ 4 jets (\geq 1 \emph{b} -tag) |
| 172.1 | | | | | | AALTONEN | 11E | CDF | ℓ + jets and dilepton |
| 174.94 | | | | | J | ABAZOV | 11P | D0 | $\ell+ ot\!\!\!E_T+4$ jets $(\ge 1$ <i>b</i> -tag) |
| 174.0 | | | | | | ABAZOV | 11R | D0 | dilepton $+ \not\!\!E_T + \geq 2$ jets |
| 175.5 | | | ± | 4.6 | | CHATRCHYAN | | CMS | dilepton $+ \not\!\!E_T + jets$ |
| 73.0 | ± | 1.2 | | | v | AALTONEN | 10AE | CDF | $\ell + E_T + 4 \; { m jets} \; (\; \geq 1 \; b{ m -tag}), \ { m ME} \; { m method}$ |
| 170.7 | \pm | 6.3 | \pm | 2.6 | 7 | AALTONEN | 10D | CDF | $\ell + \not\!\!E_T + 4 \text{ jets } (b\text{-tag})$ |
| 174.8 | ± | 2.4 | + | 1.2 | _ | AALTONEN | 10E | CDF | ≥ 6 jets, vtx <i>b</i> -tag |
| 180.1 | | | + | 1.0 3.9 | | ABAZOV | 04G | D0 | lepton + jets |
| 176.1 | | | | | 11 | AFFOLDER | 01 | CDF | lepton + jets |
| 167.4 | | | | | 12,13 | ABE | 99B | CDF | dilepton |
| 168.4 | | | | | 10 | ABBOTT | 98D | D0 | dilepton |
| 186 | ±1 | | | 5.7 | 12,14 | ABE | 97R | CDF | 6 or more jets |
| • • • | | | | | | | | | limits, etc. • • • |
| 172.4 | | | | | | AALTONEN | 11AC | | |
| 176.9 | | | | | 16 | AALTONEN | 11T | CDF | $\begin{array}{l} \ell + E_T + \text{4 jets (} \geq 1 b\text{-tag)} \\ \ell + E_T + \text{4 jets (} \geq 1 b\text{-tag)}, \\ p_T(\ell) \text{ shape} \end{array}$ |
| 169.3 | \pm | 2.7 | \pm | 3.2 | 17 | AALTONEN | 10c | CDF | dilepton + b-tag (MT2+NWA) |
| 180.5 | ± 1 | 2.0 | \pm | 3.6 | 18 | AALTONEN | 09AK | CDF | $\ell + \not\!\!E_T + jets (soft \; \mu \; b-tag)$ |
| 172.7 | \pm | 1.8 | \pm | 1.2 | 19 | AALTONEN | 09J | CDF | $\ell + \cancel{E}_T + 4 \text{ jets } (b\text{-tag})$ |
| 171.1 | | | | 2.1 | 20 | AALTONEN | | CDF | 6 jets, vtx b-tag |
| 171.9 | \pm | 1.7 | \pm | 1.1 | 21 | AALTONEN | 09L | CDF | ℓ + jets, $\ell\ell$ + jets |
| 171.2 | \pm | 2.7 | \pm | 2.9 | 22 | AALTONEN | 09 o | CDF | dilepton |
| 165.5 | + | 3.4 3.3 | ± | 3.1 | | AALTONEN | 09x | CDF | $\ell\ell+{\not\!\!E_T} \ (u\phi \ {\sf weighting})$ |
| 174.7 | ± | 4.4 | ± | 2.0 | | ABAZOV | 09ан | D0 | dilepton + b-tag (ν WT+MWT |
| 170.7 | + | 4.2 3.9 | ± | 3.5 | | AALTONEN | | CDF | dilepton, $\sigma_{t\overline{t}}$ constrained |
| 171.5 | | 1.8 | | | | ABAZOV | 08AH | | $\ell + \not\!\!E_T + 4$ jets |
| | | 4.9 | | | 28,29 | AALTONEN | 07 | CDF | 6 jets with ≥ 1 b vtx |
| 172.3 | +1 | 0.8 | +1 | 10.8 | | AALTONEN | 07в | CDF | > 4 jets (b-tag) |
| 174.0 | | | | | | AALTONEN | 07D | CDF | |
| 170.8 | | | | 1.4 | 32,33 | AALTONEN | 07b | CDF | ≥ 6 jets, vtx b-tag lepton + jets (b-tag) |
| | | | + | 21 | | ABAZOV | | | · =: |
| 173.7 | ± | 4.4 | - | 2.0 | | | 07F | D0 | lepton + jets |
| 176.2 | | | | 3.9 | 32 | ABAZOV | | | dilepton (MWT) |
| 179.5 | | | | 5.6 | 33 36 | ABAZOV | 07w | | dilepton (vWT) |
| 164.5 | | 3.9 | ± | 3.9 | | ABULENCIA | 07D | CDF | dilepton |
| 180.7 | -1 | 5.5 3.4 | ± | 8.6 | 37 | ABULENCIA | ر07 | CDF | lepton + jets |
| 170.3 | + | 4.1 4.5 | + | 1.2 1.8 | | ABAZOV | 06 U | D0 | lepton + jets (b-tag) |
| 173.2 | + | 2.6 2.4 | ± | 3.2 | 39,40 | ABULENCIA | 06D | CDF | lepton + jets |
| 173.5 | + | 3.7 3.6 | | 1.3 | | ABULENCIA | 06D | CDF | lepton + jets |
| 165.2 | | | | 3.4 | 35,41 | ABULENCIA | 06G | CDF | dilepton |
| | | 6.0 | | 4.1 | 26,42 | ABULENCIA | 06∨ | CDF | dilepton |
| 178.5 | | | \pm | 7.7 | 43,44 | ABAZOV | 05 | D0 | 6 or more jets |
| 176.1 | | | | | 45 | AFFOLDER | 01 | CDF | dilepton, lepton+jets, all-jets |
| 172.1 | | | \pm | 4.9 | 12.47 | ABBOTT | 99G | D0 | di-lepton, lepton+jets |
| 176.0 | | | | | 13,47 | ABE | 99B | CDF | dilepton, lepton+jets, all-jets |
| 173.3 | | | | | 10,48 | ABBOTT | 98F | D0 | lepton + jets |
| 175.9 | | | | 5.3 | 12,49 | ABE | 98E | CDF | lepton + jets |
| 161 | ± 1 | | ± 1 | | 12 | ABE | 98F | CDF | dilepton |
| | | | \pm | 4.9 | 50 | BHAT | 98B | RVUE | dilepton and lepton+jets |
| 173.8 | | | | | 51 | BHAT | 98B | RVUE | dilepton, lepton+jets, all-jets |
| 173.3 | | | ± | 6.2 | 10 | ABACHI | 97E | D0 | lepton + jets |
| 199 | $+\frac{1}{2}$ | 19 21 | ± 2 | 22 | | ABACHI | 95 | D0 | lepton + jets |
| 176 | ± | 8 | ± 1 | | | ABE | 95 F | CDF | lepton + b-jet |
| 174 | ± 1 | | + 1 | 3 | | ABE | 94E | CDF | lepton + b-jet |
| | | - | - 1 | .2 | | | | | P 1 = y=- |

t-Quark MS Mass from Cross-Section Measurements

The top quark $\overline{\rm MS}$ or pole mass can be extracted from a measurement of $\sigma(t\bar{t})$ by using theory calculations. We quote below the $\overline{\rm MS}$ mass. See the review "The Top Quark" and references therein for more information.

| VALUE (GeV) | DO CUMENT ID | DO CUMENT ID | | COMMENT | |
|---------------------------|----------------------------------------------|--------------|-----------|-------------------------------------|--|
| 160.0 + 4.8 - 4.3 | ⁵² ABAZOV | 11s | D0 | $\sigma(t\overline{t})+{ m theory}$ | |
| • • • We do not use the f | ollowing data for ave | erages, f | fits, lim | ts, etc. • • • | |
| | ⁵³ ABAZOV ⁵⁴ ABAZOV | 09AG | | cross sects, theory + exp | |
| | . ABAZOV | 09R | DU | cross sects, theory + exp | |

- 1 Based on 5.7 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. Events with an identified charged lepton or small E_T are rejected from the event sample, so that the measurement is statistically independent from those in the $\ell+$ jets and all hadronic channels while being sensitive to those events with a τ lepton in the final state. Supersedes AALTONEN 07B.
- 2 Based on 5.6 fb $^{-1}$ in $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV. Employs a multi-dimensional template likelihood technique where the lepton plus jets (one or two b-tags) channel gives $172.2\pm1.2\pm0.9$ GeV while the dilepton channel yields $170.3\pm2.0\pm3.1$ GeV. The results are combined. OUR EVALUATION includes the measurement in the dilepton
- 3 Based on 3.6 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV. ABAZOV 11P reports 174.94 $0.83\pm0.78\pm0.96$ GeV, where the first uncertainty is from statistics, the second from JES, and the last from other systematic uncertainties. We combine the JES and systematic uncertainties. A matrix-element method is used where the JES uncertainty is constrained by the W mass. ABAZOV 11P describes a measurement based on 2.6 fb $^{-1}$ that is combined with ABAZOV 08AH, which employs an independent $1~{
 m fb}^{-1}$ of data.
- 4 Based on a matrix-element method which employs 5.4 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=$

- 1.96 TeV. 5 Based on 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV. A Kinematic Method using b-tagging and an analytical Matrix Weighting Technique give consistent results and are combined. 6 Based on 5.6 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. The likelihood calculated using a matrix element method gives $m_t=173.0\pm0.7(\mathrm{stat})\pm0.6(\mathrm{JES})\pm0.9(\mathrm{syst})$ GeV, for a total uncertainty of 1.2 GeV. 7 Based on 1.9 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. The result is from the measurement using the transverse decay length of b-hadrons and that using the transverse momentum of the W decay muons, which are both insensitive to the JES (jet energy scale) uncertainty. OUR EVALUATION uses only the measurement exploiting the decay length significance which yields $166.9^{+9.5}_{-8.5}(\mathrm{stat})\pm2.9$ (syst) GeV. The measurement that uses the lepton transverse momentum is excluded from the average because of a statistical correlation with other samples. 8 Based on 2.9 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. The first error is from statistics
- 8 Based on 2.9 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV. The first error is from statistics and JES uncertainty, and the latter is from the other systematics. Neural-network-based kinematical selection of 6 highest ${\it E_T}$ jets with a vtx $\it b$ -tag is used to distinguish signal from background.
- $\begin{array}{l} \text{Obtain detaglorism.} \\ \text{Obtain detaglorism.} \\ \text{It is based upon the maximum likelihood method which makes use of the leading order} \end{array}$ matrix elements.
- 10 Based on 125 ± 7 pb $^{-1}$ of data at $\sqrt{s}=1.8$ TeV. 11 Based on ~ 106 pb $^{-1}$ of data at $\sqrt{s}=1.8$ TeV. 12 Based on 109 ± 7 pb $^{-1}$ of data at $\sqrt{s}=1.8$ TeV.
- 13 See AFFOLDER 01 for details of systematic error re-evaluation.
- The Based on the first observation of all hadronic decays of $t\bar{t}$ pairs. Single b-quark tagging with jet-shape variable constraints was used to select signal enriched multi-jet events. The updated systematic error is listed. See AFFOLDER 01, appendix C.

 15 Based on 3.2 fb⁻¹ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. The first error is from statistics and JES combined, and the latter is from the other systematic uncertainties. The result is obtained using a published may be updated where the top quark mass.
- is obtained using an unbinned maximum likelihood method where the top quark mass and the JES are measured simultaneously, with $\Delta_{JES}=0.3\pm0.3 ({\rm stat}).$
- 16 Uses a likelihood fit of the lepton p_T distribution based on 2.7 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}.$
- $\sqrt{s}=1.96$ TeV. 17 Based on 3.4 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. The result is obtained by combining the MT2 variable method and the NWA (Neutrino Weighting Algorithm). The MT2 method alone gives $m_t=168.0^{+4.8}_{-4.0}({\rm stat})\pm 2.9({\rm syst})$ GeV with smaller systematic error due to small JES uncertainty.
- 18 Based on 2 fb^{-1} of data at $\sqrt{s} = 1.96$ TeV. The top mass is obtained from the measurement of the invariant mass of the lepton (e or μ) from W decays and the soft μ in b-jet. The result is insensitive to jet energy scaling.

 19 Based on 1.9 fb^{-1} of data at $\sqrt{s} = 1.96 \text{ TeV}$. The first error is from statistics and jet
- ^-Based on 1.7 b ^- of data at $\sqrt{s}=1.96$ TeV. The first error is from statistics and jet energy scale uncertainty, and the latter is from the other systematics. Matrix element method with effective propagators. 20 Based on 943 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. The first error is from statistical and jet-energy-scale uncertainties, and the latter is from other systematics. AALTONEN 09k selected 6 jet events with one or more vertex b-tags and used the tree-level matrix element to construct tompolate for fixed and between
- selected of the ventes with older models of signal and background. $^{21} \text{Based on } 1.9 \text{ fb}^{-1} \text{ of data at } \sqrt{s} = 1.96 \text{ TeV}. \text{ The first error is from statistical and jet-energy-scale (JES) uncertainties, and the second is from other systematics. Events with lepton + jets and those with dilepton + jets were simultaneously fit to constrain <math>m_t$ and JES. Lepton + jets data only give $m_t = 171.8 \pm 2.2 \text{ GeV}$, and dilepton data $m_t = 171.8 \pm 1.2 \text{ GeV}$. only give $m_t = 171.2^{+5.3}_{-5.1} \text{ GeV}$.
- 22 Based on 2 fb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV. Matrix Element method. Optimal selection criteria for candidate events with two high p_T leptons, high E_T , and two or more jets with and without b-tag are obtained by neural network with neuroevolution technique to
- minimize the statistical error of m_t . 23 Based on 2.9 fb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. Mass m_t is estimated from the likelihood for the eight-fold kinematical solutions in the plane of the azimuthal angles of the two
- neutrino momenta. 2^4 Based on 1 fb⁻¹ of data at $\sqrt{s}=1.96$ TeV. Events with two identified leptons, and those with one lepton plus one isolated track and a b-tag were used to constrain m_t . The result is a combination of the ν WT (ν Weighting Technique) result of 176.2 \pm 4.8 \pm 2.1 GeV and the MWT (Matrix-element Weighting Technique) result of 173.2 \pm 4.9 \pm 2.0 GeV
- 25 Reports measurement of $170.7 + \frac{4.2}{3.9} \pm 2.6 \pm 2.4$ GeV based on $1.2 \, \mathrm{fb^{-1}}$ of data at $\sqrt{s} = 1.96$ TeV. The last error is due to the theoretical uncertainty on $\sigma_{t\overline{t}}$. Without the cross-section constraint a top mass of $169.7^{+5.2}_{-4.9} \pm 3.1$ GeV is obtained.
- ²⁶ Template method.
- 27 Result is based on 1 fb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. The first error is from statistics and jet energy scale uncertainty, and the latter is from the other systematics.
 28 Based on 310 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV.
- ²⁹ Ideogram method.
- To determine the signal acceptance is from $\tau \nu + 4$ jets. Events with 4 or more jets with $E_T > 15$ GeV, significant missing E_T , and secondary vertex b-tag are used in the fit. About 44% of the signal acceptance is from $\tau \nu + 4$ jets. Events with identified e or μ are vetoed to provide a statistically independent measurement.
- 31 Based on $1.02~{
 m fb}^{-1}$ of data at $\sqrt{s}=1.96~{
 m TeV}.$

- 32 Based on 955 pb $^{-1}$ of data $\sqrt{s}=$ 1.96 TeV. m_t and JES (Jet Energy Scale) are fitted simultaneously, and the first error contains the JES contribution of 1.5 GeV.
- 33 Matrix element method. 34 Based on 425 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. The first error is a combination of statistics gives $\frac{1}{2} = \frac{1}{2} = \frac$ and JES (Jet Energy Scale) uncertainty, which has been measured simultaneously to give JES $=0.989\pm0.029(\text{stat})$.
- 35 Based on 370 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. Combined result of MWT (Matrix-element Weighting Technique) and ν WT (ν Weighting Technique) analyses is 178.1 \pm 6.7 ± 4.8 GeV
- $6.7\pm4.8\,\mathrm{GeV}$. $36\,\mathrm{Based}$ on $1.0\,\mathrm{fb}^{-1}$ of data at $\sqrt{s}=1.96\,\mathrm{TeV}$. ABULENCIA 07D improves the matrix element description by including the effects of initial-state radiation. $37\,\mathrm{Based}$ on $695\,\mathrm{pb}^{-1}$ of data at $\sqrt{s}=1.96\,\mathrm{TeV}$. The transverse decay length of the b hadron is used to determine m_t , and the result is free from the JES (jet energy scale) in the second of the se uncertainty.
- 38 Based on \sim 400 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. The first error includes statistical and systematic jet energy scale uncertainties, the second error is from the other systematics. The result is obtained with the b-tagging information. The result without b-tagging is $169.2 \substack{+5.0 + 1.5 \\ -7.4 - 1.4}$ GeV. Superseded by ABAZOV 08AH.
- 39 Based on 318 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV
- ⁴⁰ Dynamical likelihood method.
- 41 Based on 340 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV.
- 42 Based on 360 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV.
- 43 Based on $110.2 \pm 5.8~{
 m pb}^{-1}$ at $\sqrt{s} = 1.8~{
 m TeV}$.
- ⁴⁴ Based on the all hadronic decays of $t\bar{t}$ pairs. Single b-quark tagging via the decay chain $b\to c\to \mu$ was used to select signal enriched multijet events. The result was obtained by the maximum likelihood method after bias correction.
- $^{
 m 45}$ Obtained by combining the measurements in the lepton + jets [AFFOLDER 01], all-jets [ABE 97R, ABE 99B], and dilepton [ABE 99B] decay topologies.
- 46 Obtained by combining the D0 result m_t (GeV) = $168.4\pm12.3\pm3.6$ from 6 di-lepton events (see also ABBOTT 98D) and m_t (GeV) = $173.3\pm5.6\pm5.5$ from lepton+jet events (ABBOTT 98F).
- events (ABBUT For). 47 Obtained by combining the CDF results of m_t (GeV)=167.4 \pm 10.3 \pm 4.8 from 8 dilepton events, m_t (GeV)=175.9 \pm 4.8 \pm 5.3 from lepton+jet events (ABE 98E), and m_t (GeV)=186.0 \pm 10.0 \pm 5.7 from all-jet events (ABE 97R). The systematic errors in the latter two measurements are changed in this paper.
- 48 See ABAZOV 04 G.
- ⁴⁹ The updated systematic error is listed. See AFFOLDER 01, appendix C.
- 50 Obtained by combining the DØ results of $m_t ({\rm GeV}) = \!\! 168.4 \pm 12.3 \pm 3.6$ from 6 dilepton events and $m_t ({\rm GeV}) = \!\! 173.3 \pm 5.6 \pm 5.5$ from 77 lepton+jet events.
- 51 Obtained by combining the DØ results from dilepton and lepton+jet events, and the CDF results (ABE 99B) from dilepton, lepton+jet events, and all-jet events.
- ⁵² Based on 5.3 fb⁻¹ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. ABAZOV 11s uses the measured $t\overline{t}$ production cross section of $8.13^{+1.02}_{-0.90}$ pb [ABAZOV 11E] in the lepton plus jets channel to obtain the top quark $\overline{\text{MS}}$ mass by using an approximate NNLO computation (MOCH 08, LANGENFELD 09). The corresponding top quark pole mass is $167.5^{+5.4}_{-4.9}$ GeV. A different theory calculation (AHRENS 10, AHRENS 10A) is also used and yields
- m $_{\ell}^{\overline{\rm MS}}$ = 154.5 $_{-4.3}^{+5.0}$ GeV. Sasked on 1 fb¹ of data at \sqrt{s} = 1.96 TeV. Uses the ℓ + jets, $\ell\ell$, and $\ell\tau$ + jets channels. ABAZOV 09AG extract the pole mass of the top quark using two different calculations that yield 169.1 $_{-5.2}^{+5.9}$ GeV (MOCH 08, LANGENFELD 09) and 168.2 $_{-5.4}^{+5.9}$
- 54 Based on 1 fb¹ of data at $\sqrt{s}=1.96$ TeV. Uses the $\ell\ell$ and $\ell\tau$ + jets channels. ABAZOV 09R extract the pole mass of the top quark using two different calculations that yield $173.3^{+9.8}_{-8.6}$ GeV (MOCH 08, LANGENFELD 09) and $171.5^{+9.9}_{-8.8}$ GeV (CAC-CIARI 08).

$m_t - m_{\overline{t}}$

Test of CPT conservation. OUR AVERAGE assumes that the systematic uncertainties are uncorrelated

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------------|---------|----------------------------------------------------------------------------------------------------------------------------------------|--|--|--|
| -1.4±2.0 OUR AVERAGE | Error includes so | | | | | | |
| $-3.3\pm1.4\pm1.0$ | $^{ m 1}$ aaltonen | 11ĸ | CDF | $\ell + ot\!\!\!E_T + 4$ jets | | | |
| $0.8 \pm 1.8 \pm 0.5$ | ² ABAZOV | 11T | D0 | $\begin{array}{l} \ell + \not\!\!E_T + \text{4 jets} \\ \ell + \not\!\!E_T + \text{4 jets} \; (\; \geq 1 \; b\text{-tag}) \end{array}$ | | | |
| ullet $ullet$ $ullet$ We do not use the fo | | | | | | | |
| $3.8 \pm 3.4 \pm 1.2$ | ³ ABAZOV | 09aa | D0 | $\ell + \not\!\!E_T + \text{4 jets (} \geq \text{1 b-tag)}$ | | | |
| 1 Based on a template likelihood technique which employs 5.6 fb $^{-1}$ in $p\overline{p}$ collisions at \sqrt{s} $_\circ=1.96$ TeV. | | | | | | | |
| | ent method which | empl | oys 3.6 | fb $^{-1}$ in $ ho \overline{ ho}$ collisions at $\sqrt{s}=$ | | | |
| $^{1.96}$ TeV. 3 Based on 1 fb $^{-1}$ of data | in n a collicione | a+ /= | 1.06 | ToV | | | |
| Daseu on 1 in Ordata | ill pp collisions | at \sqrt{s} | = 1.90 | iev. | | | |

t-quark DECAY WIDTH

| VALUE (GeV) | CL% | DO CUMENT ID | TE | COMMENT | |
|------------------------|-------------|-----------------------|---------------|------------------------------|-----------------------|
| $1.99 + 0.69 \\ -0.55$ | | $^{ m 1}$ abazov | 11B D0 | $\Gamma(t \rightarrow Wb)/E$ | $B(t \rightarrow Wb)$ |
| • • • We do not | use the fol | lowing data for ave | erages, fits, | limits, etc. • • • | |
| > 1.21 | 95 | $^{ m 1}$ ABAZOV | 11B D0 | $\Gamma(t \rightarrow Wb)$ | |
| < 7.6 | 95 | ² AALTONEN | 10AC CD | $F = \ell + jets$, direct | |
| <13.1 | 95 | ³ AALTONEN | 09м CD | F m t(rec) distrib | ution |

†

- 1 Based on 2.3 fb $^{-1}$ in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. ABAZOV 118 extracted \varGamma_t from the partial width $\varGamma(t\to Wb)=1.92^{+0.58}_{-0.51}$ GeV measured using the t-channel single top production cross section, and the branching fraction br $t\to Wb=0.962^{+0.066}_{-0.065}(\text{stat})^{+0.064}_{-0.052}(\text{syst}).$ The $\varGamma(t\to Wb)$ measurement gives the 95% CL lowerbound of $\varGamma(t\to Wb)$ and hence that of \varGamma_t .
- Results are based on 4.3 fb⁻¹ of data in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. The top quark mass and the hadronically decaying W boson mass are reconstructed for each candidate events and compared with templates of different top quark width. The two sided 68% CL interval is 0.3 GeV< $\Gamma_t <$ 4.4 GeV for $m_t = 172.5$ GeV.

 3 Based on 955 pb⁻¹ of $p\overline{p}$ collision data at $\sqrt{s}=1.96$ TeV. AALTONEN 09M selected
- 3 Based on 955 pb $^{-1}$ of $p\overline{p}$ collision data at $\sqrt{s}=1.96$ TeV. AALTONEN 09M selected $t\overline{t}$ candidate events for the $\ell+\cancel{E}_T+$ jets channel with one or two b-tags, and examine the decay width dependence of the reconstructed m_t distribution. The result is for $m_t=175$ GeV, whereas the upper limit is lower for smaller m_t .

t DECAY MODES

| | Mode | Fraction (Γ _i /Γ) | Confidence level |
|----------------------------------|--------------------------|-----------------------------------|------------------|
| Γ ₁ | W q(q = b, s, d) | | _ |
| Γ_2 | W b | | |
| Γ_3 | ℓu_ℓ a nything | $[a,b]$ (9.4 ± 2.4) % | |
| Γ ₄ Γ ₅ | $	au u_{	au} b$ | | |
| Γ_5 | $\gamma q (q=u,c)$ | $[c] < 5.9 \qquad \times 10^{-3}$ | 95% |

$\Delta T = 1$ weak neutral current (T1) modes

95%

 Γ_2/Γ_1

$$\Gamma_6$$
 $Zq(q=u,c)$ $T1$ $[d] < 3.2$ %

- [a] ℓ means e or μ decay mode, not the sum over them.
- [b] Assumes lepton universality and W-decay acceptance.
- [c] This limit is for $\Gamma(t \to \gamma q)/\Gamma(t \to W b)$.
- [d] This limit is for $\Gamma(t \to Zq)/\Gamma(t \to Wb)$.

t BRANCHING RATIOS

$\Gamma(W b)/\Gamma(W q(q = b, s, d))$

OUR AVERAGE assumes that the systematic uncertainties are uncorrelated.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|-----------------------|-------|-------------|------------------------------------------|
| 0.91±0.04 OUR AVERAGE | | | | |
| 0.90 ± 0.04 | $^{ m 1}$ ABAZOV | 11x | D0 | |
| $1.12^{+0.21+0.17}_{-0.19-0.13}$ | ² ACOSTA | 05A | CDF | |
| • • • We do not use the follow | ving data for avera | ages, | fits, limit | s, etc. • • • |
| $0.97 + 0.09 \\ -0.08$ | ³ ABAZOV | 08м | D0 | ℓ + n jets with 0,1,2 <i>b</i> -tag |
| $1.03 + 0.19 \\ -0.17$ | ⁴ ABAZOV | 06K | D0 | |
| $0.94 + 0.26 + 0.17 \\ -0.21 - 0.12$ | ⁵ AFFOLDER | 010 | CDF | |

- 1 Based on 5.4 fb $^{-1}$ of data. The error is statistical and systematic combined. The result is a combination of 0.95 \pm 0.07 from ℓ + jets channel and 0.86 \pm 0.05 from $\ell\ell$ channel. $|\mathsf{V}^{tb}|=0.95\pm0.02$ follows from the result by assuming unitarity of the 3x3 CKM matrix.
- 2 ACOSTA 05A result is from the analysis of lepton + jets and di-lepton + jets final states of $t\bar{t}$ candidate events with $\sim 162~{\rm pb}^{-1}$ of data at $\sqrt{s}=1.96~{\rm TeV}$. The first error is statistical and the second systematic. It gives R > 0.61, or $|V_{th}| > 0.78$ at 95% CL.
- 3 Result is based on 0.9 fb $^{-1}$ of data. The 95% CL lower bound R > 0.79 gives $|V_{tb}|>$ 0.89 (95% CL).
- 4 ABAZOV 06K result is from the analysis of $t\,\overline{t}\to\ell\nu+\geq3$ jets with 230 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. It gives R > 0.61 and $\left|V_{tb}\right|>0.78$ at 95% CL. Superseded by ABAZOV 08M. 5 AFFOLDER 01C measures the top-quark decay width ratio $R=\Gamma(Wb)/\Gamma(Wq)$, where
- ⁵ AFFOLDER 01c measures the top-quark decay width ratio $R = \Gamma(Wb)/\Gamma(Wq)$, where q is a d, s, or b quark, by using the number of events with multiple b tags. The first error is statistical and the second systematic. A numerical integration of the likelihood function gives R > 0.61 (0.56) at 90% (95%) CL. By assuming three generation unitarity, $|V_{t\,b}| = 0.97^{+0.16}_{-0.12}$ or $|V_{t\,b}| > 0.78$ (0.75) at 90% (95%) CL is obtained. The result is based on 109 pb $^{-1}$ of data at $\sqrt{s} = 1.8$ TeV.

$\Gamma(\ell\nu_{\ell}$ anything)/ Γ_{total} ν_{ALUE} 0.094±0.024 ν_{L} $\nu_$

 $1\,\ell$ means e or μ decay mode, not the sum. Assumes lepton universality and W-decay acceptance.

| $\Gamma(au u_{	au}b)/\Gamma_{	ext{total}}$ | | | | Γ_4/Γ |
|---------------------------------------------|-----------------------------|--------|---------|-------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the follo | wing data for averages fits | limite | etc | |

- 1 ABULENCIA 06R looked for $t\overline{t} \to (\ell\nu_\ell)\,(\tau\nu_\tau)\,b\overline{b}$ events in $194\,{\rm pb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. 2 events are found where 1.00 ± 0.17 signal and 1.29 ± 0.25 background events are expected, giving a 95% CL upper bound for the partial width ratio $\Gamma(t\to\tau\nu\eta)/\Gamma_{SM}(t\to\tau\nu\eta)<5.2$.
- ² ABE 97v searched for $t\overline{t} \rightarrow (\ell\nu_\ell) (\tau\nu_\tau) b\overline{b}$ events in 109 pb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV. They observed 4 candidate events where one expects ~ 1 signal and ~ 2 background events. Three of the four observed events have jets identified as b candidates.

| $\Gamma(\gamma q(q=u,c))$ | $)/\Gamma_{total}$ | | | | Γ ₅ /Γ |
|---------------------------|--------------------|------------------------|---------|------------|--------------------------------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| < 0.0064 | 95 | $^{ m 1}$ aaron | 09A | | $t \rightarrow \gamma u$ |
| < 0.0059 | 95 | ² CHEKA NOV | 03 | ZEUS | $B(t \rightarrow \gamma u)$ |
| • • • We do no | t use the follow | wing data for avera | ges, fi | its, limit | s, etc. • • • |
| < 0.0465 | 95 | ³ ABDALLAH | 04c | DLPH | $B(\gamma c \text{ or } \gamma u)$ |
| < 0.0132 | 95 | ⁴ AKTAS | 04 | H1 | $B(t \rightarrow \gamma u)$ |
| < 0.041 | 95 | ⁵ ACHARD | 02J | L3 | $B(t \rightarrow \gamma c \text{ or } \gamma u)$ |
| < 0.032 | 95 | ⁶ ABE | 98G | CDF | $t \overline{t} \rightarrow (W b) (\gamma c \text{ or } \gamma u)$ |

- 1 AARON 09A looked for single top production via FCNC in $e^\pm p$ collisions at HERA with 474 pb $^{-1}$. The upper bound of the cross section gives the bound on the FCNC coupling $\kappa_{t\,u\,\gamma}/\Lambda < 1.03~{\rm TeV}^{-1}$, which corresponds to the result for $m_t=175~{\rm GeV}.$
- 2 CHEKANOV 03 looked for single top production via FCNC in the reaction $e^\pm p \to e^\pm$ (t or \overline{t}) X in 130.1 pb $^{-1}$ of data at \sqrt{s} =300–318 GeV. No evidence for top production and its decay into b W was found. The result is obtained for m_t =175 GeV when B(γc)=B(Z q)=0, where q is a u or c quark. Bounds on the effective t-u- γ and t-u-Z couplings are found in their Fig. 4. The conversion to the constraint listed is from private communication, E. Gallo, January 2004.
- 3 ABDALLAH 04c looked for single top production via FCNC in the reaction $e^+e^-\to \overline{t}c$ or $\overline{t}u$ in S41 pb $^{-1}$ of data at $\sqrt{s}{=}189{+}208$ GeV. No deviation from the SM is found, which leads to the bound on B($t\to\gamma q$), where q is a u or a c quark, for $m_t=175$ GeV when B($t\to Zq){=}0$ is assumed. The conversion to the listed bound is from private communication, O. Yushchenko, April 2005. The bounds on the effective $t{-}q{-}\gamma$ and $t{-}q{-}Z$ couplings are given in their Fig. 7 and Table 4, for $m_t=170{-}180$ GeV, where most conservative bounds are found by choosing the chiral couplings to maximize the negative interference between the virtual γ and Z exchange amplitudes.
- AKTAS 04 looked for single top production via FCNC in e^\pm collisions at HERA with 118.3 pb⁻¹, and found 5 events in the e or μ channels. By assuming that they are due to statistical fluctuation, the upper bound on the $tu\gamma$ coupling $\kappa_t u\gamma < 0.27$ (95% CL) is obtained. The conversion to the partial width limit, when $B(\gamma c) = B(Zu) = B(Zc) = 0$, is from private communication, E. Perez, May 2005.
- 5 ACHARD 021 looked for single top production via FCNC in the reaction $e^+\,e^-\to \overline{t}\,c$ or $\overline{t}\,u$ in 634 pb $^-1$ of data at $\sqrt{s}=189$ –209 GeV. No deviation from the SM is found, which leads to a bound on the top-quark decay branching fraction $B(\gamma\,q)$, where q is a u or c quark. The bound assumes $B(Z\,q)=0$ and is for $m_{\,t}=175$ GeV; bounds for $m_{\,t}=170$ GeV and 180 GeV and $B(Z\,q)\neq 0$ are given in Fig. 5 and Table 7.
- 6 ABE 98G looked for $t\bar{t}$ events where one t decays into $q\gamma$ while the other decays into b W. The quoted bound is for $\Gamma(\gamma\,q)/\Gamma(W\,b).$

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---------------|------------|-----------------------|-----------------|----------------------------------------------------------|
| < 0.032 | 95 | $^{ m 1}$ ABAZOV | 11M D0 | $t \rightarrow Zq (q = u, c)$ |
| < 0.037 | 95 | ² AALTONEN | 08AD CDF | $t \rightarrow Zq (q = u, c)$ |
| < 0.159 | 95 | ³ ABDALLAH | 04c DLPH | $e^+e^- ightarrow \overline{t}c$ or $\overline{t}u$ |
| < 0.137 | 95 | ⁴ ACHARD | 02」 L3 | $e^+e^- ightarrow \overline{t}c$ or $\overline{t}u$ |
| < 0.14 | 95 | ⁵ HEISTER | 02Q ALEP | $e^+e^- \rightarrow \overline{t}c$ or $\overline{t}u$ |
| < 0.137 | 95 | ⁶ ABBIENDI | 01T OPAL | $e^+e^- ightarrow \overline{t}c$ or $\overline{t}u$ |
| • • • We do n | ot use the | following data for a | averages, fits, | limits, etc. • • • |
| < 0.083 | 95 | ⁷ AALTONEN | 09AL CDF | $t \rightarrow Zq (q=c)$ |
| < 0.17 | 95 | ⁸ BARATE | 00s ALEP | $e^+e^- \rightarrow \overline{t}c$ or $\overline{t}u$ |
| < 0.33 | 95 | ⁹ ABE | 98G CDF | $t \overline{t} \rightarrow (W b) (Z c \text{ or } Z u)$ |

- 1 Based on 4.1 fb $^{-1}$ of data. ABAZOV 11M searched for FCNC decays of the top quark in $t\overline{t}\to\ell^+\ell^-\ell'^\pm\nu$ + jets $(\ell,\ell'=e,\mu)$ final states, and absence of the signal gives the head
- The bound. 2 Result is based on 1.9 fb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. $t\overline{t}\to WbZq$ or ZqZq processes have been looked for in $Z+\geq 4$ jet events with and without b-tag. No signal leads to the bound B($t\to Zq$) <0.037 (0.041) for $m_{t}=175$ (170) GeV.
- ³ ABDALLAH 04c looked for single top production via FCNC in the reaction $e^+e^- \to \overline{\iota} c$ or $\overline{\iota} u$ in 541 pb⁻¹ of data at $\sqrt{s}{=}$ 189-208 GeV. No deviation from the SM is found, which leads to the bound on $B(t \to Zq)$, where q is a u or a c quark, for $m_t = 175$ GeV when $B(t \to \gamma q) = 0$ is assumed. The conversion to the listed bound is from private communication, O. Yushchenko, April 2005. The bounds on the effective t-q- γ and t-q-Z-couplings are given in their Fig. 7 and Table 4, for $m_t = 170$ -180 GeV, where most conservative bounds are found by choosing the chiral couplings to maximize the negative interference between the virtual γ and Z exchange amplitudes.
- 4 ACHARD 02J looked for single top production via FCNC in the reaction $e^+e^-\to \overline{t}\,c$ or $\overline{t}\,u$ in 634 pb $^{-1}$ of data at \sqrt{s} = 189–209 GeV. No deviation from the SM is found, which leads to a bound on the top-quark decay branching fraction B(Zq), where q is a u or c quark. The bound assumes B(γq)=0 and is for m_t = 175 GeV; bounds for m_t =170 GeV and 180 GeV and B(γq) $\neq 0$ are given in Fig. 5 and Table 7. Table 6 gives constraints on t-c-e-e four-fermi contact interactions.
- constraints on t-c-e-e four-termi contact interactions. HEISTER 02Q looked for single top production via FCNC in the reaction $e^+e^- \to \overline{t}c$ or $\overline{t}u$ in 214 pb $^{-1}$ of data at \sqrt{s} = 204-209 GeV. No deviation from the SM is found, which leads to a bound on the branching fraction B(Zq), where q is a u or c quark. The bound assumes B(γq)=0 and is for m_t = 174 GeV. Bounds on the effective t- (c or u)- γ and t- (c or u)-Z couplings are given in their Fig. 2.
- γ and t- (c of u) Z couplings are given in their Fig. 2. 6 ABBIENDI 01T looked for single top production via FCNC in the reaction $e^+e^- \to \overline{t}c$ or $\overline{t}u$ in 600 pb⁻¹ of data at \sqrt{s} = 189-209 GeV. No deviation from the SM is found, which leads to bounds on the branching fractions B(Zq) and $B(\gamma q)$, where q is a u or c quark. The result is obtained for m_t = 174 GeV. The upper bound becomes 9.7% (20.6%) for m_t = 169 (179) GeV. Bounds on the effective t- (c or u)- γ and t- (c or u)-Z couplings are given in their Fig. 4.
- 7 Based on $p\overline{p}$ data of $1.52\,{\rm fb}^{-1}$. AALTONEN 09AL compared $t\overline{t}\to WbWb\to\ell\nu bjjb$ and $t\overline{t}\to Zc\,Wb\to\ell\nu\ell jjb$ decay chains, and absence of the latter signal gives the bound. The result is for 100% longitudinally polarized Z boson and the theoretical $t\overline{t}$ production cross section The results for different Z polarizations and those without the cross section assumption are given in their Table XII.
- 8 BARATE 00s looked for single top production via FCNC in the reaction $e^+\,e^-\to \overline{t}\,c$ or $\overline{t}u$ in 411 pb $^{-1}$ of data at c.m. energies between 189 and 202 GeV. No deviation from

the SM is found, which leads to a bound on the branching fraction. The bound assumes B(γq)=0. Bounds on the effective t- (c or u)- γ and t- (c or u)-Z couplings are given in their Fig. 4.

ABE 986 looked for $t\overline{t}$ events where one t decays into three jets and the other decays into qZ with $Z\to\ell\ell$. The quoted bound is for $\Gamma(Zq)/\Gamma(Wb)$.

t-quark EW Couplings

W helicity fractions in top decays. F_0 is the fraction of longitudinal and F_+ the fraction of right-handed W bosons. F_{V+A} is the fraction of $V\!+\!A$ current in top decays. The effective Lagrangian (cited by ABAZOV 08AI) has terms \mathfrak{f}_1^L and \mathfrak{f}_1^R for V-A and V+A couplings, f_2^L and f_2^R for tensor couplings with \mathbf{b}_R and \mathbf{b}_L respectively.

| VALUE | CL% | | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------|--------|------|-----------------|---------|-----------|--------------------------------------------------------------------------------|
| ullet $ullet$ $ullet$ We do not use the | follow | /ing | data for averag | es, fit | s, limits | , etc. • • • |
| $(V_{tb} f_2^L)^2 < 0.13$ | 95 | 1 | ABAZOV | 12E | D0 | Single-top |
| $(V_{tb} f_1^R)^2 < 0.93$ | 95 | 1 | ABAZOV | 12E | D0 | Single-top |
| $(V_{tb} f_2^R)^2 < 0.06$ | 95 | | ABAZOV | 12E | D0 | Single-top |
| $0.\overline{669} \pm 0.078 \pm 0.065$ | | | ABAZOV | 11 c | D0 | $F_0 = B(t \rightarrow W_0 b)$ |
| $0.023 \pm 0.041 \pm 0.034$ | | | ABAZOV | 11 C | D0 | $F_+ = B(t \rightarrow W_+ b)$ |
| $0.70 \pm 0.07 \pm 0.04$ | | | AALTONEN | 10Q | CDF | $F_0 = B(t \rightarrow W_0 b)$ |
| $-0.01 \pm 0.02 \pm 0.05$ | | | AALTONEN | 10Q | CDF | $F_+ = B(t \rightarrow W_+ b)$ |
| $0.62 \pm 0.10 \pm 0.05$ | | | AALTONEN | 09Q | | $F_0 = B(t \rightarrow W_0 b)$ |
| $-0.04 \pm 0.04 \pm 0.03$ | | | AALTONEN | 09Q | CDF | $F_{\pm} = B(t \rightarrow W_{\pm} b)$ |
| $ \mathbf{f}_1^R ^2 < 1.01$ | 95 | 5 | ABAZOV | ر99 | D0 | $ \mathbf{f}_{1}^{L} = 1$, $ \mathbf{f}_{2}^{L} = \mathbf{f}_{2}^{R} = 0$ |
| $ f_2^L ^2 < 0.28$ | 95 | 5 | ABAZOV | 09J | D0 | $ f_1^L = 1$, $ f_1^R = f_2^R = 0$ |
| $ f_2^R ^2 < 0.23$ | 95 | 5 | ABAZOV | 09J | D0 | $ \mathbf{f}_{1}^{L} = 1, \mathbf{f}_{1}^{R} = \mathbf{f}_{2}^{L} = 0$ |
| $ f_1^R ^2 < 2.5$ | 95 | 6 | ABAZOV | 08AI | D0 | $ _{\mathbf{f}}L _{2} = _{1} \circ + 1.0$ |
| $ f_2^L ^2 < 0.5$ | 95 | 6 | ABAZOV | 08AI | D0 | $ f_1^L ^2 = 1.4 + 0.6$ |
| $ f_2^R ^2 < 0.3$ | 95 | 6 | ABAZOV | 08AI | D0 | $ f_1^L ^2 = 1.4 + 0.9 \\ -0.8$ |
| $0.425 \pm 0.166 \pm 0.102$ | | 7 | ABAZOV | 08в | D0 | $F_0 = B(t \rightarrow W_0 b)$ |
| $0.119 \pm 0.090 \pm 0.053$ | | 7 | ABAZOV | 08в | D0 | $F_{+} = B(t \rightarrow W_{+} b)$ |
| $0.056 \pm 0.080 \pm 0.057$ | | 8 | ABAZOV | 07D | D0 | $F_{+} = B(t \rightarrow W_{+} b)$ |
| $-0.06 \pm 0.22 \pm 0.12$ | | 9 | ABULENCIA | 07 G | CDF | $F_{V+A} = B(t \rightarrow Wb_R)$ |
| < 0.29 | 95 | 9 | ABULENCIA | 07 G | CDF | $F_{V+A} = B(t \rightarrow Wb_R)$ |
| $0.85 \ ^{+ 0.15}_{- 0.22} \ \pm 0.06$ | | 10 | ABULENCIA | 071 | CDF | $F_0 = B(t \rightarrow W_0 b)$ |
| $0.05 \begin{array}{c} +0.11 \\ -0.05 \end{array} \pm 0.03$ | | 10 | ABULENCIA | 07ı | CDF | $F_+ = B(t \rightarrow W_+ b)$ |
| < 0.26 | 95 | 10 | ABULENCIA | 07ı | CDF | $F_+ = B(t \rightarrow W_+ b)$ |
| $0.74 \begin{array}{l} +0.22 \\ -0.34 \end{array}$ | | 11 | ABULENCIA | 06U | CDF | $F_0 = B(t \rightarrow W_0 b)$ |
| < 0.27 | 95 | 11 | ABULENCIA | 06U | CDF | $F_{+} = B(t \rightarrow W_{+} b)$ |
| 0.56 ± 0.31 | | 12 | ABAZOV | 05 G | D0 | $F_0 = B(t \rightarrow W_0 b)$ |
| $0.00 \pm 0.13 \pm 0.07$ | | 13 | ABAZOV | 05 L | D0 | $F_{+} = B(t \rightarrow W_{+} b)$ |
| < 0.25 | 95 | 13 | ABAZOV | 05 L | D0 | $F_{+} = B(t \rightarrow W_{+} b)$ |
| < 0.80 | 95 | | ACOSTA | 05 D | CDF | $F_{V+A}^{\top} = B(t \to W b_R)$ |
| < 0.24 | 95 | 14 | ACOSTA | 05 D | CDF | $F_{+} = B(t \rightarrow W_{+} b)$ |
| $0.91 \pm 0.37 \pm 0.13$ | | 15 | AFFOLDER | 00в | CDF | $F_0^{\top} = B(t \rightarrow W_0 b)$ |
| 0.11 ± 0.15 | | 15 | AFFOLDER | 00в | CDF | $F_+ = B(t \rightarrow W_+ b)$ |
| | | | | | | |

- $^1\,\mathrm{Based}$ on 5.4 fb $^{-1}$ of data. For each value of the form factor quoted the other two are assumed to have their SM value. Their Fig. 4 shows two-dimensional posterior probability density distributions for the anomalous couplings.
- 2 Results are based on 5.4 fb $^{-1}$ of data in $p\overline{p}$ collisions at 1.96 TeV, including those of ABAZOV 08B. Under the SM constraint of $f_0=0.698$ (for $m_t=173.3$ GeV, $m_W=80.399$ GeV), $f_+=0.010\pm0.022\pm0.030$ is obtained.
- ³ Results are based on 2.7 fb⁻¹ of data in $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV. F_0 result is obtained by assuming $F_+=0$, while F_+ result is obtained for $F_0=0.70$, the SM value. Model independent fits for the two fractions give $F_0=0.88\pm0.11\pm0.06$ and $F_+=-0.15\pm0.07\pm0.06$ with correlation coefficient of -0.59. The results are for $m_t=175$ GeV.
- 4 Results are based on 1.9 fb $^{-1}$ of data in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. F_0 result is obtained assuming $F_+=0$, while F_+ result is obtained for $F_0=0.70$, the SM values. Model independent fits for the two fractions give $F_0=0.66\pm0.16\pm0.05$ and $F_+=0.00$
- $-0.03\pm0.06\pm0.03$. 5 Based on 1 fb $^{-1}$ of data at $p\overline{p}$ collisions $\sqrt{s}=1.96$ TeV. Combined result of the W helicity measurement in $t\overline{t}$ events (ABAZOV 08B) and the search for anomalous tb Wcouplings in the single top production (ABAZOV 08AI). Constraints when ${
 m f}_{1}^{L}$ and one of the anomalous couplings are simultaneously allowed to vary are given in their Fig. 1 and
- 1301e 1. 6 Result is based on $0.9~{\rm fb}^{-1}$ of data at $\sqrt{s}=1.96~{\rm TeV}$. Single top quark production events are used to measure the Lorentz structure of the tb W coupling. The upper bounds on the non-standard couplings are obtained when only one non-standard coupling is allowed to be present together with the SM one, $\mathbf{f}_1^L = \mathbf{V}_{t\,b}^*$
- 7 Based on 1 fb $^{-1}$ at $\sqrt{s}=1.96$ TeV.
- ⁸ Based on 370 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV, using the ℓ + jets and dilepton decay channels. The result assumes $F_0=0.70$, and it gives $F_+<0.23$ at 95% CL.
- 9 Based on 700 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV.
- $^{10}\,\mathrm{Based}$ on 318 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV.
- 11 Based on 200 pb $^{-1}$ of data at $\sqrt{s}=$ 1.96 TeV. $t \to ~Wb \to ~\ell \nu b~(\ell = {\rm e~or}~\mu)$. The errors are stat + syst.
- 12 ABAZOV 05G studied the angular distribution of leptonic decays of W bosons in $t\bar{t}$ candidate events with lepton + jets final states, and obtained the fraction of Posette 135 polarized W under the constraint of no right-handed current, $F_+=0$. Based on 125 pb $^{-1}$ of data at $\sqrt{s}=$ 1.8 TeV.
- 13 ABAZOV 05L studied the angular distribution of leptonic decays of W bosons in $t\bar{t}$ events, where one of the W's from t or \bar{t} decays into e or μ and the other decays

- hadronically. The fraction of the "+" helicity W boson is obtained by assuming F_0 = 0.7, which is the generic prediction for any linear combination of V and A currents. Based on 230 \pm 15 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV.
- Based on 230 \pm 13 pb of data at \sqrt{s} = 1.78 fc. 14 ACOSTA 05D measures the m_ℓ^2 $\pm b$ distribution in tT production events where one or both W's decay leptonically to ℓ = e or μ , and finds a bound on the V+A coupling of the tbW vertex. By assuming the SM value of the longitudinal W fraction $F_0 = B(t \rightarrow W_0 b) = 0.70$, the bound on F_+ is obtained. If the results are combined with those of AFFOLDER 00B, the bounds become $F_{V+A}<0.61$ (95% CL) and $F_+<0.18$ (95% CL), respectively. Based on 109 \pm 7 pb $^{-1}$ of data at $\sqrt{s}=1.8$ TeV (run I).
- 15 AFFOLDER 00B studied the angular distribution of leptonic decays of $\it W$ bosons in $\it t$ Wb events. The ratio F_0 is the fraction of the helicity zero (longitudinal) W bosons in the decaying top quark rest frame. B($t \rightarrow W_+ b$) is the fraction of positive helicity (right-handed) positive charge W bosons in the top quark decays. It is obtained by assuming the Standard Model value of F_0 .

Spin Correlation in $t\bar{t}$ Production

C is the correlation strength parameter, f is the ratio of events with correlated t and \overline{t} spins (SM prediction: f=1), and κ is the spin correlation coefficient. See "The Top iew for more informatio

| DO CUMENT ID | TECN | COMMENT |
|------------------------|--------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| the following data for | averages, fits, | limits, etc. • • • |
| ¹ ABAZOV | 12B D0 | f ($\ell\ell$ + \geq 2 jets, ℓ + \geq 4 jets) |
| ² ABAZOV | 12B D0 | f $(\ell + ot \!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| ³ AALTONEN | 11AR CDF | $\kappa \; (\ell + ot \!\!\!E_T \; + \; \geq$ 4 jets) |
| ⁴ ABAZOV | 11AE D0 | f $(\ell\ell+\cancel{E}_T + \ge 2 \text{ jets})$ |
| ⁵ ABAZOV | 11AF D0 | C $(\ell\ell+ ot\!\!\!/T+2$ jets) |
| | the following data for 1 ABAZOV 2 ABAZOV 3 AALTONEN 4 ABAZOV | the following data for averages, fits, 1 ABAZOV 12B D0 2 ABAZOV 12B D0 3 AALTONEN 11AR CDF 4 ABAZOV 11AE D0 |

- 1 This is a combination of the lepton + jets analysis presented in ABAZOV 12B and the dilepton measurement of ABAZOV 11AE. It provides a 3.1 σ evidence for the $t\overline{t}$ spin
- $^2\text{Based}$ on 5.3 fb^{-1} of data. The error is statistical and systematic combined. A matrix element method is used.

 Based on 4.3 fb⁻¹ of data. The measurement is based on the angular study of the top
- quark decay products in the helicity basis. The theory prediction is $\kappa \approx 0.40$
- 4 Based on 5.4 fb $^{-1}$ of data using a matrix element method. The error is statistical and
- systematic combined. The no-correlation hypothesis is excluded at the 97.7% CL. 5 Based on 5.4 fb $^{-1}$ of data. The error is statistical and systematic combined. The NLO QCD prediction is C = 0.78 \pm 0.03. The neutrino weighting method is used for reconstruction of kinematics.

t-quark FCNC couplings κ^{utg}/Λ and κ^{ctg}/Λ

| VALUE (TeV ⁻¹) | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|-----------------|------------------------|-----------|---------|---------------------------------------------|
| • • • We do not u | se the followir | ng data for average | es, fits, | limits, | etc. • • • |
| < 0.013 | 95 | $^{ m 1}$ ABAZOV | 10ĸ | D0 | κ^{tug}/Λ |
| < 0.057 | 95 | $^{ m 1}$ ABAZOV | 10K | D0 | κ^{tcg}/Λ |
| < 0.018 | 95 | ² AALT ONEN | 09N | CDF | $\kappa^{tug}/\Lambda \ (\kappa^{tcg} = 0)$ |
| < 0.069 | 95 | ² AALTONEN | 09N | CDF | $\kappa^{tcg}/\Lambda \ (\kappa^{tug} = 0)$ |
| < 0.037 | 95 | ³ ABAZOV | 07∨ | D0 | κ^{utg}/Λ |
| < 0.15 | 95 | ³ ABAZOV | 07∨ | D0 | κ^{ctg}/Λ |

- Based on 2.3 fb⁻¹ of data in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. Upper limit of single top quark production cross section 0.20 pb and 0.27 pb via FCNC t-u-g and t-c-g couplings, respectively, lead to the bounds without assuming the absence of the other coupling. B($t \rightarrow u + g$) < 2.0×10^{-4} and B($t \rightarrow c + g$) < 3.9×10^{-3} follow. 2 Based on 2.2 fb⁻¹ of data in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. Upper limit of single top quark production cross section $\sigma(u(c)+g \rightarrow t) < 1.8$ pb (95% CL) via FCNC t-u-g
- and t-c-g couplings lead to the bounds. B(t \rightarrow u + g) < 3.9 \times 10⁻⁴ and B(t \rightarrow $(c + g) < 5.7 \times 10^{-3}$ follow.
- ³ Result is based on 230 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV. Absence of single top quark production events via FCNC t-u-g and t-c-g couplings lead to the upper bounds on the dimensioned couplings, κ^{utg}/Λ and κ^{ctg}/Λ , respectively.

Single t-Quark Production Cross Section in $p\overline{p}$ Collisions at $\sqrt{s}=1.8$ TeV

Direct probe of the tb W coupling and possible new physics at $\sqrt{s} = 1.8$ TeV.

| VALUE (pb) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------|----------------|---------------------|---------|------------|---------------------------------------------|
| • • • We do n | ot use the fol | owing data for a | verages | , fits, li | mits, etc. • • • |
| <24 | 95 | ¹ ACOSTA | 04н | CDF | $p\overline{p} \rightarrow tb + X, tqb + X$ |
| <18 | 95 | ² ACOSTA | 02 | CDF | $p\overline{p} \rightarrow tb + X$ |
| <13 | 95 | ³ ACOSTA | 02 | CDF | $p\overline{p} \rightarrow tqb + X$ |

- $^{
 m 1}$ ACOSTA 04H bounds single top-quark production from the s-channel W-exchange process, $q'\overline{q}\to t\overline{b}$, and the t-channel W-exchange process, $q'g\to qt\overline{b}$. Based on $\sim 106\,{\rm pb}^{-1}$ of data.
- ² ACOSTA 02 bounds the cross section for single top-quark production via the s-channel W-exchange process, $q' \overline{q} \rightarrow t \overline{b}$. Based on $\sim 106 \, \mathrm{pb}^{-1}$ of data.
- 3ACOSTA 02 bounds the cross section for single top-quark production via the t-channel W-exchange process, $q'g \rightarrow qt\overline{b}$. Based on $\sim 106\,\mathrm{pb}^{-1}$ of data.

Single t-Quark Production Cross Section in $p\overline{p}$ Collisions at $\sqrt{s}=1.96$ TeV

Direct probes of the $t\,b\,W$ coupling and possible new physics at $\sqrt{s}=1.96$ TeV $\label{eq:our average} \mbox{OUR AVERAGE assumes that the systematic uncertainties are uncorrelated}.$

| VALUE (pb) CL% | | DO CUMENT ID | TECN | COMMENT | |
|-------------------------|------------|-----------------------|----------------|-----------------|--|
| 2.7 ^{+ 0.6} OU | IR AVERAGE | Error includes | scale factor o | f 1.2. | |
| $3.43 + 0.73 \\ -0.74$ | | ¹ ABAZOV | 11AD D0 | s- + t-channels | |
| 2.3 + 0.6 | | ² AALTONEN | 09AT CDF | s- + t-channel | |

†

| • • • We do not us | e the foll | owing data for aver | ages, | fits, limi | ts, etc. • • • |
|-----------------------------------------------------|------------|-----------------------|-------|------------|----------------------------------------------|
| 0.98 ± 0.63 | | ³ ABAZOV | 11 AA | D0 | s-channel |
| 2.90 ± 0.59 | | ³ ABAZOV | 11 AA | D0 | t-channel |
| $1.8 \begin{array}{l} +0.7 \\ -0.5 \end{array}$ | | ⁴ AALTONEN | 10AB | CDF | s-channel |
| 0.8 ± 0.4 | | ⁴ AALTONEN | 10AB | CDF | t-channel |
| $\begin{array}{cc} 4.9 & +2.5 \\ -2.2 \end{array}$ | | ⁵ AALTONEN | 10∪ | CDF | $ ot\!\!\!E_T$ + jets decay |
| $3.14 + 0.94 \\ -0.80$ | | ⁶ ABAZOV | 10 | D0 | t-channel |
| $\boldsymbol{1.05\pm0.81}$ | | ⁶ ABAZOV | 10 | D0 | s-channel |
| < 7.3 | 95 | ⁷ ABAZOV | 10J | D0 | au+ jets decay |
| 3.94 ± 0.88 | | ⁸ ABAZOV | 09 Z | D0 | s- + t-channel |
| $\begin{array}{ccc} 2.2 & +0.7 \\ -0.6 \end{array}$ | | ⁹ AALTONEN | 08ан | CDF | s- + t-channel |
| 4.7 ± 1.3 | | ¹⁰ ABAZOV | 180 | D0 | s- + t-channel |
| 4.9 ±1.4 | | 11 ABAZOV | 07н | D0 | s- $+$ t -channel |
| < 6.4 | 95 | 12 ABAZOV | 05 P | D0 | $p \overline{p} \rightarrow t b + X$ |
| < 5.0 | 95 | ¹² ABAZOV | 05 P | D0 | $\rho \overline{\rho} \rightarrow t q b + X$ |
| <10.1 | 95 | 13 A COSTA | | | $p\overline{p} \rightarrow tqb + X$ |
| <13.6 | 95 | 13 A COSTA | | | $\rho \overline{\rho} \rightarrow tb + X$ |
| <17.8 | 95 | ¹³ ACOSTA | 05 N | CDF | $p\overline{p} \rightarrow tb + X, tqb + X$ |

- 1 Based on 5.4 fb $^{-1}$ of data and for $m_t=172.5$ GeV. The error is statistical + systematic combined. Results for other m_t values are given in Table III of ABAZOV 11AD. The result is obtained by assuming the SM ratio between tb (s-channel) and $t\,q\,b$ (t-channel) productions, and gives $|\mathsf{V}_{tb}|\,f^L|=1.02^{+}_{-0.11}$, or $|\mathsf{V}_{tb}|\,>0.79$ at 95% CL for a flat prior within $0<|\mathsf{V}_{vb}|^2<1$
- prior within $0 < |V_{tb}|^2 < 1$.
 ² Based on 3.2 fb⁻¹ of data. Events with isolated $\ell + \not\!\!\! E_T$ + jets with at least one b-tag are analyzed and s- and t-channel single top events are selected by using the likelihood function, matrix element, neural-network, boosted decision tree, likelihood function optimized for s-channel process, and neural-networked based analysis of events with $\not\!\!\! E_T$ that has sensitivity for $W \to \tau \nu$ decays. The result is for $m_t = 175$ GeV, and the mean value decreases by 0.02 pb/GeV for smaller m_t . The signal has 5.0 sigma significance. The result gives $|V_{tb}| = 0.91 \pm 0.11$ (stat+syst) ± 0.07 (theory), or $|V_{tb}| > 0.71$ at 95% CL.
- 3 Based on 5.4 fb $^{-1}$ of data. The error is statistical + systematic combined. The results are for $m_t=172.5$ GeV. Results for other m_t values are given in Table 2 of ABAZOV 11AA.
- ABAZOV 11AA. 4 Based on 3.2 fb $^{-1}$ of data. For combined s- + t-channel result see AALTONEN 09AT. 5 Result is based on 2.1 fb $^{-1}$ of data. Events with large missing E_T and jets with at least one b-jet without identified electron or muon are selected. Result is obtained when observed 2.1 σ excess over the background originates from the signal for $m_t = 175$ GeV, giving $|V_{t+1}| = 1.24 \pm 0.34 \pm 0.07$ (theory).
- giving $|V_{tb}|=1.24^{+0.34}_{-0.29}\pm0.07$ (theory). ⁶ Result is based on 2.3 fb $^{-1}$ of data. Events with isolated $\ell+E_T+2$,3,4 jets with one or two b-tags are selected. The analysis assumes $m_t=170$ GeV.
- 7 Result is based on 4.8 fb $^{-1}$ of data. Events with an isolated reconstructed tau lepton, missing E_T + 2, 3 jets with one or two b-tags are selected. When combined with ABAZOV 09z result for e+ μ channels, the s- and t-channels combined cross section is 3.84 $^{+0.89}_{-0.83}$ pb.
- ⁸ Based on 2.3 fb⁻¹ of data. Events with isolated $\ell+E_T+\geq 2$ jets with 1 or 2 b-tags are analyzed and s- and t-channel single top events are selected by using boosted decision tree, Bayesian neural networks and the matrix element method. The signal has 5.0 sigma significance. The result gives $|V_{tb}|=1.07\pm0.12$, or $|V_{tb}|>0.78$ at 95% CL. The analysis assumes $m_t=170$ GeV.
- 9 Result is based on $^2.2~{\rm fb^{-1}}$ of data. Events with isolated $\ell+\not\!\!E_T+2$, 3 jets with at least one b-tag are selected, and s- and r-channel single top events are selected by using likelihood, matrix element, and neural network discriminants. The result can be interpreted as $|V_{tb}|=0.88^{+0.13}_{-0.12}({\rm stat+syst})\pm 0.07({\rm theory}),$ and $|V_{tb}|>0.66~(95\%$ CL) under the $|V_{tb}|<1$ constraint.
- 10 Result is based on $0.9~{\rm fb^{-1}}$ of data. Events with isolated $\ell+E_T+2$, 3, 4 jets with one or two b-vertex-tag are selected, and contributions from W+ jets, $t\overline{t}$, s- and t-channel single top events are identified by using boosted decision trees, Bayesian neural networks, and matrix element analysis. The result can be interpreted as the measurement of the CKM matrix element $|V_{tb}|=1.31^{+0.25}_{-0.21},$ or $|V_{tb}|>0.68~(95\%~{\rm CL})$ under the $|V_{tb}|<1$ constraint.
- 11 Result is based on 0.9 fb $^{-1}$ of data. This result constrains V_{tb} to 0.68 $<|V_{tb}|\le 1$ at 95% CL.
- 12 ÅBAZOV 05P bounds single top-quark production from either the s-channel W-exchange process, $q'\overline{q} \to t\overline{b}$, or the t-channel W-exchange process, $q'g \to qt\overline{b}$, based on $\sim 230~{\rm pb}^{-1}$ of data.
- $^{13}\text{ACOSTA}$ 05N bounds single top-quark production from the t-channel W-exchange process ($q'g\to qt\bar{b}$), the s-channel W-exchange process ($q'\overline{q}\to t\overline{b}$), and from the combined cross section of t- and s-channel. Based on $\sim 162~\text{pb}^{-1}$ of data.

Single t-Quark Production Cross Section in pp Collisions at $\sqrt{s} = 7$ TeV

| 83 6 + 20 8 + 3 3 | 1 CHATRCHVANIIB | CMS | t channol | |
|--------------------------|-----------------------------|---------|--------------------|----|
| VALUE (pb) | DO CUMENT ID | TECN | COMMENT | |
| Direct probe of the tb W | coupling and possible new / | physics | at $\sqrt{s}=7$ Te | ٧. |

 1 Based on 36 pb $^{-1}$ of data. The first error is statistical + systematic combined, the second is luminosity. The result gives $|\mathsf{V}_{tb}|=1.114\pm0.22(\text{exp})\pm0.02(\text{th})$ from the ratio $\sigma(\text{exp})/\sigma(\text{th})$, where $\sigma(\text{th})$ is the SM prediction for $|\mathsf{V}_{tb}|=1$. The 95% CL lower bound of $|\mathsf{V}_{tb}|>0.62$ (0.68) is found from the 2D (BDT) analysis under the constraint $0<|\mathsf{V}_{tb}|^2<1$.

Single t-Quark Production Cross Section in ep Collisions

| VALUE (pb) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|------------------------|---------|---------|-------------------------------------|
| • • • We do not use the | following | data for averages | , fits, | limits, | etc. • • • |
| < 0.25 | 95 | ¹ AARON | 09A | | $e^{\pm} p \rightarrow e^{\pm} t X$ |
| < 0.55 | 95 | ² AKTAS | 04 | H1 | $e^{\pm} p \rightarrow e^{\pm} t X$ |
| < 0.225 | 95 | ³ CHEKA NOV | 03 | ZEUS | $e^{\pm} p \rightarrow e^{\pm} t X$ |
| | | | | | |

- 1 AARON 09A looked for single top production via FCNC in $e^\pm p$ collisions at HERA with 474 pb $^{-1}$ of data at $\sqrt{s}=301$ –319 GeV. The result supersedes that of AKTAS 04.
- 2 AKTAS 04 looked for single top production via FCNC in e^\pm collisions at HERA with $118.3~{\rm pb}^{-1}$, and found 5 events in the e or μ channels while 1.31 ± 0.22 events are expected from the Standard Model background. No excess was found for the hadronic channel. The observed cross section of $\sigma(e\,p\,\rightarrow\,e\,t\,X)=0.29^{+0.15}_{-0.14}$ pb at $\sqrt{s}=319$ GeV gives the quoted upper bound if the observed events are due to statistical fluctuation.
- THUCTURATION: 3 CHEKANOV 03 looked in 130.1 pb $^{-1}$ of data at $\sqrt{s}=$ 301 and 318 GeV. The limit is for $\sqrt{s}=$ 318 GeV and assumes $m_t=$ 175 GeV.

$t\,\overline{t}$ production cross section in $p\,\overline{p}$ collisions at $\sqrt{s}=$ 1.8 TeV

Only the final combined $t\overline{t}$ production cross sections obtained from Tevatron Run I by the CDF and D0 experiments are quoted below.

| VALUE (pb) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|-----------------------|-----------|---------|-------------------|
| • • • We do not use the follow | ring data for average | es, fits, | limits, | etc. • • • |
| $5.69\!\pm\!1.21\!\pm\!1.04$ | $^{ m 1}$ ABAZOV | 03A | D0 | Combined Runldata |
| $\begin{array}{ccc} 6.5 & +1.7 \\ -1.4 \end{array}$ | ² AFFOLDER | 01A | CDF | Combined Runldata |

- 1 Combined result from 110 pb $^{-1}$ of Tevatron Run I data. Assume $m_{t}=$ 172.1 GeV.
- ² Combined result from 105 pb⁻¹ of Tevatron Run I data. Assume $m_t = 172.1$ GeV.

$t\,\overline{t}$ production cross section in $ho\,\overline{ ho}$ collisions at $\sqrt{s}=$ 1.96 TeV

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

| tematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties. | | | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-------------|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|
| VALUE (pb) | DOCUMENT ID | | | COMMENT | | |
| • • • We do not use the f | | | | | | |
| 8.5 \pm 0.6 \pm 0.7 7.64 \pm 0.57 \pm 0.45 7.99 \pm 0.55 \pm 0.76 \pm 0.46 | ¹ AALTONEN ² AALTONEN ³ AALTONEN | 11W | CDF | $\begin{array}{l} \ell + \not\!\!E_T + jets \; (\geq 1 b -tag) \\ \ell + \not\!\!E_T + jets \; (\geq 1 b -tag) \\ \not\!\!E_T + \geq 4 jets \; (0,1,2 \; b -tag) \end{array}$ | | |
| $7.78 + 0.77 \\ -0.64$ | ⁴ ABAZOV | 11 E | D0 | $\ell + ot\!\!\!E_T + \ \ge 2$ jets | | |
| $7.56 {}^{+ 0.63}_{- 0.56}$ | ⁵ ABAZOV | 11 z | D0 | Combination | | |
| $ 6.27 \pm 0.73 \pm 0.63 \pm 0.39 $ $ 7.2 \pm 0.5 \pm 1.0 \pm 0.4 $ $ 7.8 \pm 2.4 \pm 1.6 \pm 0.5 $ $ 7.70 \pm 0.52 $ | ⁶ AALTONEN ⁷ AALTONEN ⁸ AALTONEN ⁹ AALTONEN | 10E 10V | CDF CDF | $\begin{array}{l} \ell\ell+\not\!\!E_T+\geq 2 \text{ jets} \\ \geq 6 \text{ jets, vtx } b\text{-tag} \\ \ell+\geq 3 \text{ jets, soft-} e \ b\text{-tag} \\ \ell+\not\!\!E_T+\geq 3 \text{ jets} + b\text{-tag,} \\ \text{norm. to } \sigma(Z\to\ell\ell)_{TH} \end{array}$ | | |
| 6.9 ±2.0 | ¹⁰ ABAZOV | 101 | D0 | ≥ 6 jets with 2 <i>b</i> -tags | | |
| 6.9 $\pm 1.2 ^{+\ 0.8}_{-\ 0.7} \pm 0.4$ | ¹¹ ABAZOV | 10Q | D0 | $	au_{h}$ + jets | | |
| $9.6 \pm 1.2 ^{+\ 0.6}_{-\ 0.5} \pm 0.6$ | ¹² AALTONEN | 09ad | CDF | $\ell\ell+{E_T}$ / vtx <i>b</i> -tag | | |
| $9.1 \pm 1.1 \stackrel{+}{-} \stackrel{1.0}{0.9} \pm 0.6$ | ¹³ AALTONEN | 09н | CDF | $\ell + \ \geq \ \mathrm{3\ jets} + E_T/\mathrm{soft}\ \mu\ b$ -tag | | |
| $8.18 ^{+\ 0.98}_{-\ 0.87}$ | ¹⁴ ABAZOV | 09AG | D0 | ℓ + jets, $\ell\ell$ and $\ell\tau$ + jets | | |
| 7.5 $\pm 1.0 ^{+ 0.7}_{- 0.6} ^{+ 0.6}_{- 0.5}$ | ¹⁵ ABAZOV | 09R | D0 | $\ell\ell$ and $\ell	au$ + jets | | |
| $8.18^{+0.90}_{-0.84}\pm0.50$ | 16 ABAZOV | м80 | D0 | ℓ + n jets with 0,1,2 <i>b</i> -tag | | |
| 7.62 ± 0.85 | ¹⁷ ABAZOV | 08N | D0 | ℓ + n jets + <i>b</i> -tag or kinematics | | |
| $8.5 \begin{array}{c} +2.7 \\ -2.2 \end{array}$ | ¹⁸ ABULENCIA | 80 | CDF | $\ell^+\ell^-\;(\ell=e,\mu)$ | | |
| $8.3 \pm 1.0 \stackrel{+}{-} \stackrel{2.0}{1.5} \pm 0.5$ | ¹⁹ AALTONEN | 07D | CDF | ≥ 6 jets, vtx <i>b-</i> tag | | |
| $7.4 \pm 1.4 \pm 1.0$ | ²⁰ ABAZOV | 070 | D0 | $\ell\ell$ + jets, vtx <i>b</i> -tag | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ²¹ ABAZOV | 07P | D0 | ≥ 6 jets, vtx <i>b</i> -tag | | |
| 6.4 $^{+1.3}_{-1.2}$ ± 0.7 ± 0.4 | ²² ABAZOV | 07R | D0 | $\ell + \geq 4 \ \text{jets}$ | | |
| $6.6 \pm 0.9 \pm 0.4$ | ²³ ABAZOV | 06x | D0 | ℓ + jets, vtx <i>b</i> -tag | | |
| $8.7 \pm 0.9 \stackrel{+}{-} \stackrel{1.1}{0.9}$ | ²⁴ ABULENCIA | 06 Z | CDF | ℓ + jets, vtx \emph{b} -tag | | |
| $5.8 \pm 1.2 ^{+ 0.9}_{- 0.7}$ | ²⁵ ABULENCIA,A | 06c | CDF | missing ${\it E}_T$ + jets, vtx ${\it b}$ -tag | | |
| $7.5 \pm 2.1 \begin{array}{c} +3.3 & +0.5 \\ -2.2 & -0.4 \end{array}$ | ²⁶ ABULENCIA ,A | 06E | CDF | 6–8 jets, <i>b</i> -tag | | |
| $8.9 \pm 1.0 \stackrel{+}{-} \stackrel{1.1}{1.0}$ | ²⁷ ABULENCIA,A | 06F | CDF | $\ell + \geq 3$ jets, $\emph{b}\text{-tag}$ | | |
| $8.6 \begin{array}{c} +1.6 \\ -1.5 \end{array} \pm 0.6$ | ²⁸ ABAZOV | 05 Q | D0 | $\ell+n jets$ | | |
| $8.6^{+3.2}_{-2.7} \pm 1.1 \pm 0.6$ | ²⁹ ABAZOV | 05 R | D0 | di-lepton + n jets | | |
| $6.7 \ ^{+ 1.4}_{- 1.3} \ ^{+ 1.6}_{- 1.1} \ \pm 0.4$ | ³⁰ ABAZOV | 05 X | D0 | ℓ + jets / kinematics | | |
| $5.3 \pm 3.3 \stackrel{+}{-} \stackrel{1.3}{-} \stackrel{1}{0}$ | ³¹ ACOSTA | 05 s | CDF | ℓ + jets / soft μ <i>b</i> -tag | | |
| 6.6 ±1.1 ±1.5 | ³² ACOSTA | 05 T | CDF | $\ell + {\sf jets} \ / \ {\sf kinematics}$ | | |
| $6.0 \begin{array}{c} +1.5 \\ -1.6 \end{array} \begin{array}{c} +1.2 \\ -1.3 \end{array}$ | ³³ ACOSTA | 05∪ | CDF | $\ell + {\sf jets/kinematics} + {\sf vtx} \ \textit{b}{\sf -tag}$ | | |
| $5.6 \begin{array}{c} +1.2 \\ -1.1 \\ -0.6 \end{array}$ | ³⁴ ACOSTA | 05 V | CDF | $\ell + n$ jets | | |

 $7.0 \begin{array}{c} +2.4 & +1.6 \\ -2.1 & -1.1 \end{array} \pm 0.4$

³⁵ ACOSTA

041 CDF di-lepton + jets + missing ET

- 1 Based on 1.12 fb $^{-1}$ and assumes $m_{\,t}\,=\,$ 175 GeV, where the cross section changes by ± 0.1 pb for every ∓ 1 GeV shift in $m_{\tilde{t}}.$ AALTONEN 11D fits simultaneously the $t\,\overline{t}$ production cross section and the b-tagging efficiency and find improvements in both measurements.
- Based on 2.7 fb $^{-1}$. The first error is from statistics and systematics, the second is from luminosity. The result is for $m_t=175\,$ GeV. AALTONEN 11w fits simultaneously a jet flavor discriminator between b-, c-, and light-quarks, and find significant reduction in the systematic error.
- 3 Based on 2.2 fb $^{-1}$. The result is for $m_t=172.5$ GeV. AALTONEN 11Y selects multi-jet events with large $\not\!\!E_T$, and vetoes identified electrons and muons. 4 Based on 5.3 fb $^{-1}$. The error is statistical + systematic + luminosity combined. The
- = 172.5 GeV. The results for other $m_{ extbf{\emph{t}}}$ values are given in Table XII and result is for $m_t = 172.5 \text{ G}$ eq.(10) of ABAZOV 11E.
- ⁵ Combination of a dilepton measurement presented in ABAZOV 11z (based on 5.4 fb⁻¹), which yields $7.36^{+0.90}_{-0.79}$ (stat+syst) pb, and the lepton + jets measurement of ABAZOV 11E. The result is for $m_t=172.5$ GeV. The results for other m_t values is given by eq.(5) of ABAZOV 11A.
- $^6\mathrm{Based}$ on 2.8 fb $^{-1}$. The result is for $m_t=175$ GeV.
- $^7\,\mathrm{Based}$ on 2.9 fb $^{-1}.$ Result is obtained from the fraction of signal events in the top quark mass measurement in the all hadronic decay channel.
- 8 Based on 1.7 fb $^{-1}$. The result is for $m_t=175$ GeV. AALTONEN 10v uses soft electrons from b-hadron decays to suppress W+jets background events.
- g Based on 4.6 fb $^{-1}$. The result is for $m_t=$ 172.5 GeV. The ratio $\sigma(t\,\overline{t}\to\ell+{
 m jets})$ / $\sigma(Z/\gamma^* o \ \ell\ell)$ is measured and then multiplied by the theoretical $Z/\gamma^* o \ \ell\ell$ cross
- section of $\sigma(Z/\gamma^* \to \ell\ell)=251.3\pm5.0$ pb, which is free from the luminosity error. 10 Based on 1 fb $^{-1}$. The result is for $m_t=175$ GeV. 7.9 ± 2.3 pb is found for $m_t=170$ GeV. ABAZOV 10i uses a likelihood discriminant to separate signal from background,
- where the background model was created from lower jet-multiplicity data. 11 Based on 1 fb $^{-1}$. The result is for $m_t=$ 170 GeV. For $m_t=$ 175 GeV, the result is $6.3^{+1.2}_{-1.1}(\text{stat}) \pm 0.7(\text{syst}) \pm 0.4(\text{lumi})$ pb. Cross section of $t\overline{t}$ production has been measured in the $t\,\overline{t} o au_h + ext{ jets topology, where } au_h ext{ denotes hadronically decaying } au$ leptons. The result for the cross section times the branching ratio is $\sigma(t\,\overline{t})\cdot \mathsf{B}(t\,\overline{t} \to t)$ au_h + jets) = 0.60 $^+$ 0.23 $^+$ 0.15 $^+$ 0.04 pb for m_t = 170 GeV.
- 12 Based on 1.1 fb $^{-1}$. The result is for B(W $\rightarrow \ell \nu)=10.8\%$ and $m_t=175$ GeV; the mean value is 9.8 for $m_t=172.5$ GeV and 10.1 for $m_t=170$ GeV. AALTONEN 09AD used high p_T e or μ with an isolated track to select t7 decays into dileptons including ℓ
- = τ . The result is based on the candidate event samples with and without vertex b-tag. 13 Based on 2 fb $^{-1}$. The result is for $m_t=175$ GeV; the mean value is 3% higher for m_t = 170 GeV and 4% lower for $m_{ extit{t}} = 180$ GeV.
- 14 Result is based on 1 fb $^{-1}$ of data. The result is for $m_t=170$ GeV, and the mean value decreases with increasing m_t ; see their Fig. 2. The result is obtained after combining ℓ + jets, $\ell\ell_{\rm c}$ and $\ell\tau$ final states, and the ratios of the extracted cross sections are R $^{\ell\ell/\ell j}=0.86^{+}_{-0.17}^{+0.19}$ and R $^{\ell\tau/\ell\ell-\ell j}=0.97^{+0.32}_{-0.29}$, consistent with the SM expectation of R = 1. This leads to the upper bound of B($t o bH^+$) as a function of m_{H^+} . Results are shown in their Fig. 1 for B($H^+ \to \tau \nu$) = 1 and B($H^+ \to c\bar{s}$) = 1 cases. Comparison of the m_t dependence of the extracted cross section and a partial NNLO prediction gives $m_t = 169.1 {+} 5.9_{-5.2} \text{ GeV}.$
- 15 Result is based on 1 fb $^{-1}$ of data. The result is for $m_t=170$ GeV, and the mean value changes by $-0.07\ [m_t({\rm GeV})-170]$ pb near the reference m_t value. Comparison of the m_t dependence of the extracted cross section and a partial NNLO QCD prediction gives $m_t=171.5^{+9.9}_{-8.8}$ GeV. The ℓau channel alone gives $7.6^{+4.9}_{-4.3}+\frac{3.5}{3.4}+\frac{1.4}{0.9}$ pb and the $\ell\ell$
- than el gives 7.5 + 1.2 + 0.7 + 0.7 pb. 16 Result is based on 0.9 fb-1 of data. The first error is from stat + syst, while the latter error is from luminosity. The result is for m_t =175 GeV, and the mean value changes by
- -0.09 pb[m_t (GeV)-175]. 17 Result is based on 0.9 fb $^{-1}$ of data. The cross section is obtained from the $\ell+\geq 3$ jet event rates with 1 or 2 b-tag, and also from the kinematical likelihood analysis of the $\ell+3$, 4 jet events. The result is for $m_t=172.6$ GeV, and its m_t dependence shown in Fig. 3 leads to the constraint $m_t=170\pm7$ GeV when compared to the SM prediction.
- $^{18}\,\mathrm{Result}$ is based on 360 pb $^{-1}$ of data. Events with high p_T oppositely charged dileptons $\ell^+\ell^-$ ($\ell=e,\mu$) are used to obtain cross sections for $t\bar{t}$, W^+W^- , and $Z\to\tau^+\tau^-$ production processes simultaneously. The other cross sections are given in Table IV. 19 Based on 1.02 fb $^{-1}$ of data. Result is for $m_t=175$ GeV. Secondary vertex b-tag and neural network selections are used to achieve a signal-to-background ratio of about 1/2.
- 20 Based on 425 pb $^{-1}$ of data. Result is for $m_{t}=175$ GeV. For $m_{t}=170.9$ GeV,
- 7.8 \pm 1.8(stat + syst) pb is obtained. ²¹ Based on 405 \pm 25 pb $^{-1}$ of data. Result is for $m_t=175\,$ GeV. The last error is for luminosity. Secondary vertex b-tag and neural network are used to separate the signal
- events from the background. 22 Based on 425 pb $^{-1}$ of data. Assumes $m_{\,t}=$ 175 GeV.
- ²³ Based on ⁴²⁵ pb ⁻¹ of data. Assumes $m_t = 1/5$ GeV. The first error is combined statistical and systematic, the second one is luminosity. ²⁴ Based on ~ 318 pb ⁻¹. Assuming $m_t = 178$ GeV. The cross section changes by ± 0.08 pb for each ∓ 1 GeV change in the assumed m_t . Result is for at least one b-tags per jets of significance greater than 5σ is found, and the cross section is $10.1 \pm 1.6 \pm 2.0$ pb for $m_t = 178$ GeV. For $m_t = 175$ GeV, the result is $6.0 \pm 1.2 \pm 0.9$ This is the first CDE massurement without lepton identification, and
- $6.0\pm1.2^{+0.9}_{-0.7}$. This is the first CDF measurement without lepton identification, and hence it has sensitivity to the $W \rightarrow \tau \nu$ mode.
- 26 ABULENCIA,A 06E measures the $t\overline{t}$ production cross section in the all hadronic decay mode by selecting events with 6 to 8 jets and at least one b-jet. $S/B\,=\,1/5$ has been achieved. Based on 311 pb $^{-1}$. Assuming $m_{\,t}=$ 178 GeV.
- 27 Based on \sim 318 pb $^{-1}$. Assuming $m_t=$ 178 GeV. Result is for at least one b-tag. For at least two *b*-tagged jets, the cross section is 11.1 + 2.3 + 2.5 pb.
- 28 ABAZOV 05Q measures the top-quark pair production cross section with \sim 230 pb $^{-1}$ of data, based on the analysis of W plus n-jet events where W decays into e or μ

- plus neutrino, and at least one of the jets is b-jet like. The first error is statistical and systematic, and the second accounts for the luminosity uncertainty. The result assumes $m_t=175\,$ GeV; the mean value changes by $(175-m_t({\rm GeV}))\times 0.06\,$ pb in the mass range 160 to 190 GeV
- 29 ABAZOV 05R measures the top-quark pair production cross section with 224–243 pb $^{-1}$ of data, based on the analysis of events with two charged leptons in the final state. The result assumes $m_t=175$ GeV; the mean value changes by $(175-m_t({\rm GeV}))\times 0.08$ pb in the mass range 160 to 190 GeV. 30 Based on 230 pb $^{-1}$. Assuming $m_t=175$ GeV.
- $^{31}\,\mathrm{Based}$ on 194 pb^{-1} . Assuming $m_{\,t}=$ 175 GeV.
- $^{32}\,\mathrm{Based}$ on 194 \pm 11 pb $^{-1}$. Assuming $m_t=$ 175 GeV.
- $^{33}\,\mathrm{Based}$ on $162\pm10~\mathrm{pb}^{-1}$. Assuming $m_{\,t}^{\,}=175~\mathrm{GeV}.$
- 34 ACOSTA 05v measures the top-quark pair production cross section with \sim 162 pb $^{-1}$ data, based on the analysis of W plus n-jet events where W decays into e or μ plus neutrino, and at least one of the jets is b-jet like. Assumes $m_t=175$ GeV.
- 35 ACOSTA $\,$ 041 measures the top-quark pair production cross section with 197 ± 12 pb $^{-1}$ data, based on the analysis of events with two charged leptons in the final state. Assumes $m_t = 175 \text{ GeV}.$

Ratio of the production cross sections of $t\bar{t}\gamma$ to $t\bar{t}$ at $\sqrt{s}=1.96$ TeV

DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • $^{1}\,\mathrm{AALTONEN}$ $\,$ 11z CDF $\,$ $\,$ $E_{\,T}(\gamma) >$ 10 GeV, $\left|\eta(\gamma)\right| <$ 1.0 $\,$ $\left|$ 0.024 ± 0.009 1 Based on 6.0 fb $^{-1}$ of data. The error is statistical and systematic combined. Events with lepton + E_T + \geq 3 jets(\geq 1b) with and without central, high E_T photon are measured. The result is consistent with the SM prediction of 0.024 \pm 0.005. The absolute production cross section is measured to be 0.18 \pm 0.08 fb. The statistical significance is 2.2 the statistical significance is

$t\bar{t}$ production cross section in pp collisions at $\sqrt{s}=7$ TeV

3.0 standard deviations.

Unless otherwise noted the first quoted error is from statistics, the second from systematic uncertainties, and the third from luminosity. If only two errors are quoted the luminosity is included in the systematic uncertainties.

| VALUE (pb) | DO CUMENT ID | TECN | COMMENT |
|-----------------------------------------------|-----------------------------|-------------|----------------------------------------------------------------------------------------|
| • • • We do not use t | he following data for avera | iges, fits, | limits, etc. • • • |
| $177 \pm 20 \pm 14 \pm 7$ | ¹ AAD 1: | 2B ATLS | $\ell\ell + E_T + \geq 2j$ |
| $145 \pm 31 {}^{+42}_{-27}$ | ² AAD 1: | LA ATLS | $\ell + \not\!\! E_T + \geq$ 4j, $\ell \ell + \not\!\! E_T + \geq$ 2j |
| $173^{+39}_{-32} \pm 7$ | ³ CHATRCHYAN1 | LAA CMS | $\ell + ot\!\!E_T + \geq 3$ jets |
| 168±18±14± 7 | 4 CHATRCHYAN1 | LF CMS | $\ell\ell+{\not\!\!E_T}+{ m jets}$ |
| 154±17± 6 | 5 CHATRCHYAN1: | Lz CMS | Combination |
| $194 \pm 72 \pm 24 \pm 21$ | 6 KHACHATRY1 | LA CMS | $\ell\ell+ ot\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| $^{1}\mathrm{Based}$ on 35 pb^{-1} | of data for an assumed to | p quark m | ass of $m_t = 172.5$ GeV. |
| 2 | | | |

- 2 Based on 2.9 pb $^{-1}$ of data. The result for single lepton channels is 142 \pm 34 $^{+50}_{-31}$ pb, while for the dilepton channels is 151 + 78 + 37 pb.
- 3 Result is based on 3 6 pb $^{-1}$ of data. The first uncertainty corresponds to the statistical and systematic uncertainties, and the second corresponds to the luminosity.
- ⁴ Based on 36 pb⁻¹ of data. The ratio of $t\bar{t}$ and Z/γ^* cross sections is measured as $\sigma(pp\to t\bar{t})/\sigma(pp\to Z/\gamma^*\to e^+e^-/\mu^+\mu^-)=0.175\pm0.018(\text{stat})\pm0.015(\text{syst})$ for 60 $< m_{\ell\ell} < 120$ GeV, for which they use an NNLO prediction for the denominator cross section of 972 \pm 42 pb.
- ⁵ Result is based on $\overset{\frown}{36}$ pb $\overset{\frown}{-1}$ of data. The first error is from statistical and systematic uncertainties, and the second from luminosity. This is a combination of a measurement in the dilepton channel (CHATRCHYAN 11F) and the measurement in the $\ell+$ jets channel (CHATRCHYAN 11z) which yields $150 \pm 9 \pm 17 \pm 6$ pb.
- 6 Result is based on 3.1 \pm 0.3 pb $^{-1}$ of data.

$gg \rightarrow t\bar{t}$ fraction in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

DO CUMENT ID TECN COMMENT 1 AALTONEN 08AG CDF low p_{T} number of tracks $0.07 \pm 0.14 \pm 0.07$ • • We do not use the following data for averages, fits, limits, etc. 2 AALTONEN 09F CDF $t\,\overline{t}$ correlations 68

- 1 Result is based on 0.96 fb $^{-1}$ of data. The contribution of the subprocesses $gg\to t\,\overline{t}$ and $q\,\overline{q}\to t\,\overline{t}$ is distinguished by using the difference between quark and gluon initiated jets in the number of small p_T (0.3 GeV < $\,p_T$ < 3 GeV) charged particles in the
- central region ($|\eta|<1.1$). ² Based on 955 pb $^{-1}$. AALTONEN 09F used differences in the $t\overline{t}$ production angular distribution and polarization correlation to descriminate between $gg\to t\overline{t}$ and $q\overline{q}\to t\overline{t}$ $t\,\overline{t}$ subprocesses. The combination with the result of AALTONEN 08AG gives 0.07 + 0.15

A_{EP} of $t\bar{t}$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

| VALUE (%) | DO CUMENT ID | TECN | COMMENT |
|------------------|------------------------|----------|-----------------------------------------------------|
| | the following data for | | |
| -11.6 ± 15.3 | $^{ m 1}$ AALTONEN | 11F CDF | $m_{t\overline{t}}$ < 450 GeV |
| 47.5 ± 11.4 | $^{ m 1}$ aaltonen | 11F CDF | $m_{t\overline{t}} > 450 \text{ GeV}$ |
| 19.6 ± 6.5 | ² ABAZOV | 11AH D0 | $\ell + \not\!\!E_T + \geq$ 4 jets($\geq 1b$ -tag) |
| 17 ± 8 | ³ AALTONEN | 08AB CDF | $p\overline{p}$ frame |
| 24 ± 14 | ³ AALTONEN | 08AB CDF | $t \overline{t} $ frame |
| $12 \pm 8 \pm 1$ | ⁴ ABAZOV | 08L D0 | $\ell + ot\!\!\!E_T + \geq$ 4 jets |

Quark Particle Listings

†

 1 Based on 5.3 fb $^{-1}$ of data. The error is statistical and systematic combined. Events with lepton $+\not\!\!E_T + \ge 4 \mathrm{jets}(\ge 1b)$ are used. AALTONEN 11F also measures the asymmetry as a function of the rapidity difference $|\mathsf{y}_t - \mathsf{y}_{\overline{t}}|.$ The NLO QCD predictions [MCFM] are $(4.0\pm 0.6)\%$ and $(8.8\pm 1.3)\%$ for $m_{t\overline{t}} < 450$ and > 450 GeV, respectively.

[MCFM] are (4.0 \pm 0.0)% and (0.0 \pm 1.0)% for $m_{t\bar{t}}$ and systematic combined. The quoted asymmetry is obtained after unfolding to be compared with the MC@NLO prediction of (5.0 \pm 0.1)%. No significant difference between the $m_{t\bar{t}}$ < 450 and > 450 GeV data samples is found. A corrected asymmetry based on the lepton from a top quark decay of (15.2 \pm 4.0)% is measured to be compared to the MC@NLO prediction of (2.1 \pm 0.1)%.

 3 Result is based on 1.9 fb $^{-1}$ of data. The FB asymmetry in the $t\overline{t}$ events has been measured in the $\ell+$ jets mode, where the lepton charge is used as the flavor tag. The asymmetry in the $p\overline{p}$ frame is defined in terms of $\cos(\theta)$ of hadronically decaying t-quark momentum, whereas that in the $t\overline{t}$ frame is defined in terms of the t and \overline{t} rapidity difference. The results are consistent ($\leq 2~\sigma$) with the SM predictions.

 4 Result is based on 0.9 fb $^{-1}$ of data. The asymmetry in the number of $t\overline{t}$ events with $y_t>y_{\overline{t}}$ and those with $y_t<y_{\overline{t}}$ has been measured in the lepton + jets final state. The observed value is consistent with the SM prediction of 0.8% by MC@NLO, and an upper bound on the $Z'\to t\overline{t}$ contribution for the SM Z-like couplings is given in in Fig. 2 for 350 GeV $< m_{Z'}<1$ TeV.

t-Quark Electric Charge

VALUE <u>DOCUMENT ID</u> TECN COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $\begin{array}{cccc} \frac{1}{2}\,\mathsf{AALTONEN} & \mathsf{10s} & \mathsf{CDF} \\ 2\,\mathsf{ABAZOV} & \mathsf{07c} & \mathsf{D0} & \mathsf{fraction} \ \mathsf{of} \ |\mathsf{q}| \!\!=\! \! \mathsf{4e/3} \ \mathsf{pair} \end{array}$

 1 AALTONEN 10s excludes the charge -4/3 assignment for the top quark [CHANG 99] at 95%CL, using $2.7~{\rm fb}^{-1}$ of data in $\rho\overline{\rho}$ collisions at $\sqrt{s}=1.96$ TeV. Result is obtained by reconstructing $t\overline{t}$ events in the lepton + jets final state, where b-jet charges are tagged by the SLT (soft lepton tag) algorithm.

2ABAZOV 07C reports an upper limit $\rho<0.80$ (90% CL) on the fraction ρ of exotic quark pairs $Q\overline{Q}$ with electric charge $|{\bf q}|=4{\bf e}/3$ in $t\overline{t}$ candidate events with high p_T lepton, missing E_T and ≥ 4 jets. The result is obtained by measuring the fraction of events in which the quark pair decays into W^-+b and $W^++\overline{b}$, where b and \overline{b} jets are discriminated by using the charge and momenta of tracks within the jet cones. The maximum CL at which the model of CHANG 99 can be excluded is 92%. Based on 370 pb $^{-1}$ of data at $\sqrt{s}=1.96$ TeV.

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(4th Generation) Quark, Searches for

b'-quark/hadron mass limits in $p\overline{p}$ and pp collisions

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|----------------|----------|----------------------------|-------|------------|---------------------------------------------|
| >372 | 95 | $^{ m 1}$ aaltonen | | | |
| >361 | 95 | ² CHATRCHYA N | 11L | CMS | $b' \rightarrow t W$ |
| >190 | 95 | ³ ABAZOV | 08x | D0 | $c\tau$ = 200mm |
| >268 | 95 | ^{4,5} AALTONEN | 07c | CDF | $B(b' \rightarrow bZ) = 1 \text{ assumed}$ |
| >190 | 95 | ⁶ A C O S T A | 03 | CDF | quasi-stable b' |
| >128 | 95 | ⁷ ABACHI | 95F | D0 | $\ell\ell$ + jets, ℓ + jets |
| • • • We do no | t use th | e following data for | avera | iges, fits | , limits, etc. • • • |
| >338 | 95 | ⁸ A A LT O NE N | 10н | CDF | $b' \rightarrow t W$ |
| > 380-430 | 95 | ⁹ FLACCO | 10 | RVUE | $m_{b'} > m_{t'}$ |
| >199 | 95 | ¹⁰ AFFOLDER | 00 | CDF | $NC: b' \rightarrow bZ$ |
| >148 | 95 | ¹¹ ABE | 98N | CDF | NC: $b' \rightarrow bZ + decay vertex$ |
| > 96 | 95 | ¹² АВАСНІ | 97D | D0 | NC: $b' \rightarrow b\gamma$ |
| > 75 | 95 | ¹³ MUKHOPAD | 93 | RVUE | NC: $b' \rightarrow b\ell\ell$ |
| > 85 | 95 | ¹⁴ ABE | 92 | CDF | CC: <i>ℓℓ</i> |
| > 72 | 95 | 15 ABE | 90B | CDF | CC: $e + \mu$ |
| > 54 | 95 | ¹⁶ A KESSON | 90 | UA2 | CC: $e + \text{jets} + \text{missing } E_T$ |
| > 43 | 95 | ¹⁷ ALBAJAR | 90B | UA1 | CC: μ + jets |
| > 34 | 95 | ¹⁸ A LB A JA R | 88 | UA1 | CC: e or μ + jets |

- 1 Based on 4.8 fb $^{-1}$ of data in $p\overline{p}$ collisions at 1.96 TeV. AALTONEN 11J looked for events with $\ell+\not\!\!E_T+\ \geq$ 5j (≥ 1 b or c). No signal is observed and the bound $\sigma(b'\overline{b}')$
- < 30 fb for $m_{b'}>$ 375 GeV is found for B($b'\to t\,W)=1.$ 2 Based on 34 pb $^{-1}$ of data in pp collisions at 7 TeV. CHATRCHYAN 11L looked for multijet events with trileptons or same-sign dileptons. No excess above the SM background excludes $m_{b'}$ between 255 and 361 GeV at 95% CL for B($b' \rightarrow t W$) = 1.
- 3 Result is based on 1.1 fb $^{-1}$ of data. No signal is found for the search of long-lived particles which decay into final states with two electrons or photons, and upper bound on the cross section times branching fraction is obtained for $2 < c\tau < 7000$ mm; see Fig.
- 3. 95% CL excluded region of b' lifetime and mass is shown in Fig. 4. ⁴ Result is based on 1.06 fb⁻¹ of data. No excess from the SM Z+jet events is found when Z decays into ee or $\mu\mu$. The $m_{b'}$ bound is found by comparing the resulting upper bound on $\sigma(b'b')$ [1-(1-B($b' \to bZ$))²] and the LO estimate of the b' pair production cross section shown in Fig. 38 of the article.

 5 HUANG 08 reexamined the b' mass lower bound of 268 GeV obtained in AALTONEN 07c that assumes B($b' \to bZ$) = 1, which does not hold for $m_{b'} > 255$ GeV. The lower
- mass bound is given in the plane of $\sin^2(\theta_{t\,b'})$ and $m_{b'}$
- ⁶ACOSTA 03 looked for long-lived fourth generation quarks in the data sample of 90 pb⁻¹ of \sqrt{s} =1.8 TeV $p\bar{p}$ collisions by using the muon-like penetration and anomalously high ionization energy loss signature. The corresponding lower mass bound for the charge (2/3)e quark (t') is 220 GeV. The t' bound is higher than the b' bound because t' is more likely to produce charged hadrons than b^\prime . The 95% CL upper bounds for the production cross sections are given in their Fig. 3. ⁷ ABACHI 95F bound on the top-quark also applies to b^\prime and t^\prime quarks that decay pre-
- dominantly into W. See FROGGATT 97. 8 Based on 2.7 fb $^{-1}$ of data in $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV. AALTONEN 10H looked for pair production of heavy quarks which decay into $t\,W^-$ or $t\,W^+$, in events with same sign dileptons (e or μ), several jets and large missing E_T . The result is obtained for b' which decays into tW^- . For the charge 5/3 quark ($T_{5/3}$) which decays into $t\,W^+$, $m_{T_5/3}>365$ GeV (95% CL) is found when it has the charge -1/3 partner B of the same mass.
- 9 FLACCO 10 result is obtained from AALTONEN 10H result of $m_{\,b'} >$ 338 GeV, by relaxing the condition B(b'
 ightarrow t W) = 100% when $m_{b'} > m_{t'}$.
- 10 AFFOLDER 00 looked for b' that decays in to b+Z. The signal searched for is $b\,b\,Z\,Z$ events where one Z decays into $e^+\,e^-$ or $\mu^+\,\mu^-$ and the other Z decays hadronically. The bound assumes B(b' o b Z)= 100%. Between 100 GeV and 199 GeV, the 95%CL upper bound on $\sigma(b' \to \overline{b'}) \times B^2(b' \to bZ)$ is also given (see their Fig. 2).
- 11 ABE 98N looked for $Z
 ightarrow e^+e^-$ decays with displaced vertices. Quoted limit assumes B($b'
 ightarrow b\,Z)\!=\!1$ and $c\, au_{b'}\!=\!1\,\mathrm{cm}$. The limit is lower than $m_{Z}\!+\!m_{b}$ (\sim 96 GeV) if $c\, au>$ 22 cm or $c\, au<$ 0.009 cm. See their Fig. 4.
- 12 ABACHI 97D searched for b^\prime that decays mainly via FCNC. They obtained 95%CL upper bounds on B($b'\overline{b'} \to \gamma + 3$ jets) and B($b'\overline{b'} \to 2\gamma + 2$ jets), which can be interpreted as the lower mass bound $m_{b'} > m_Z + m_b$.
- 13 MUKHOPADHYAYA 93 analyze CDF dilepton data of ABE 92g in terms of a new quark decaying via flavor-changing neutral current. The above limit assumes $\mathsf{B}(b'$ – $b\,\ell^+\,\ell^-)\!=\!1\%.$ For an exotic quark decaying only via virtual Z [B($\!b\,\ell^+\,\ell^-)=3\%$], the limit is 85 GeV.
- 14 Imit is 85 GeV.

 14 Imit is 85 GeV.

 15 ABE 92 dilepton analysis limit of >85 GeV at CL=95% also applies to b' quarks, as discussed in ABE 908. ABE 908 exclude the region 28–72 GeV.

 15 ABE 908 exclude the region 28–72 GeV.
- 16 AKESSON 90 searched for events having an electron with $p_{T}~>12$ GeV, missing momentum > 15 GeV, and a jet with $E_{T}>$ 10 GeV, $\left|\eta\right|$ < 2.2, and excluded $m_{B'}$ between 30 and 69 GeV.

- 15 between 30 and 69 GeV.

 17 For the reduction of the limit due to non-charged-current decay modes, see Fig. 19 of ALBAJAR 908.

 18 ALBAJAR 80 study events at $E_{\rm cm} = 546$ and 630 GeV with a muon or isolated electron, accompanied by one or more jets and find agreement with Monte Carlo predictions for the production of charm and bottom, without the need for a new quark. The lower mass limit is obtained by using a conservative estimate for the $b^{\prime}\overline{b^{\prime}}$ production cross section and by assuming that it cannot be produced in W decays. The value quoted here is revised using the full $O(\alpha_s^3)$ cross section of ALTARELLI 88.

b' mass limits from single production in $p\overline{p}$ and pp collisions

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|----------------------|-----|------|------------------------------------------------------------------------------------------------------------|
| >693 | 95 | 19 ABAZOV | 11F | D0 | $qu \rightarrow q'b' \rightarrow q'(Wu)$ |
| >430 | 95 | ¹⁹ ABAZOV | 11F | D0 | $\widetilde{\kappa}_{u b'} = 1$, B($b' \rightarrow W u$)=1 $q d \rightarrow q b' \rightarrow q(Z d)$ |
| - | | | | | $\tilde{\kappa}_{d,b'} = \sqrt{2}$, B($b' \rightarrow Zd$)=1 |

 19 Based on 5.4 fb $^{-1}$ of data in ppbar collisions at 1.96 TeV. ABAZOV 11F looked for single production of b' via the W or Z coupling to the first generation up or down quarks, respectively. Model independent cross section limits for the single production processes $p\overline{p} \to b'q \to Wuq$, and $p\overline{p} \to b'q \to Zdq$ are given in Figs. 3 and 4, respectively, and the mass limits are obtained for the model of ATRE 09 with degenerate bi-doublets of vector-like quarks.

MASS LIMITS for b' (4th Generation) Quark or Hadron in e^+e^- Collisions

Search for hadrons containing a fourth-generation -1/3 quark denoted b'.

The last column specifies the assumption for the decay mode (CC denotes the conventional charged-current decay) and the event signature which is looked for.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------|------------|-------------------------------------------------|-----------|------------|------------------------------------------------------------------|
| >46.0 | 95 | ²⁰ DECAMP | 90F | ALEP | any decay |
| • • • We do not use | the follow | ing data for average | es, fits | , limits, | etc. • • • |
| none 96-103 | 95 | ²¹ ABDALLAH ²² ADRIANI | 07 93G | DLPH L3 | $b' \rightarrow b Z, c W$ Quarkonium |
| >44.7 | 95 | ADRIANI | 93м | L3 | Γ(Z) |
| >45 | 95 | ABREU | 91F | DLPH | $\Gamma(Z)$ |
| one 19.4-28.2 | 95 | ABE | 90D | VNS | Any decay; event shape |
| >45.0 | 95 | ABREU | 90D | DLPH | B(C C) = 1; event shape |
| >44.5 | 95 | ²³ ABREU | 90D | DLPH | $b' \rightarrow cH^-, H^- \rightarrow \overline{c}s, \tau^- \nu$ |
| >40.5 | 95 | ²⁴ ABREU | 90D | DLPH | $\Gamma(Z \to hadrons)$ |
| >28.3 | 95 | A DA CHI | 90 | TOPZ | B(FCNC)=100%; isol. γ or 4 jets |
| >41.4 | 95 | ²⁵ AKRAWY | 90B | OPAL | Any decay; acoplanarit |
| >45.2 | 95 | ²⁵ AKRAWY | 90в | OPAL | B(C C) = 1; acoplanarity |
| >46 | 95 | ²⁶ AKRAWY | 90J | OPAL | $b' 	o \gamma + any$ |
| >27.5 | 95 | ²⁷ ABE | 89E | VNS | $B(C C) = 1; \mu, e$ |
| one 11.4-27.3 | 95 | ²⁸ ABE | 89G | VNS | $B(b' \rightarrow b\gamma) > 10\%;$ isolated γ |
| >44.7 | 95 | ²⁹ ABRAMS | 89c | MRK2 | B(C C) = 100%; isol. |
| >42.7 | 95 | ²⁹ ABRAMS | 89c | | B(bg) = 100%; event shape |
| >42.0 | 95 | 29 ABRAMS | 89c | MRK2 | Any decay; event shape |
| >28.4 | 95 | ^{30,31} ADACHI | 89c | TOPZ | $B(CC) = 1; \mu$ |
| >28.8 | 95 | ³² ENO | 89 | AMY | $B(C C) \gtrsim 90\%$; μ , e |
| >27.2 | 95 | ^{32,33} ENO | 89 | AMY | any decay; event shape |
| >29.0 | 95 | ³² ENO | 89 | AMY | $B(b' \rightarrow bg) \gtrsim 85\%$ event shape |
| >24.4 | 95 | ³⁴ IGARASHI | 88 | AMY | μ , e |
| >23.8 | 95 | ³⁵ SAGAWA | 88 | AMY | event shape |
| >22.7 | 95 | ³⁶ ADEVA | 86 | MRKJ | μ |
| >21 | | 37 ALTHOFF | 84 C | TASS | R, event shape |
| >19 | | ³⁸ ALTHOFF | 841 | TASS | Aplanarity |

- $^{20}\,\mathrm{DECAMP}$ 90F looked for isolated charged particles, for isolated photons, and for four-jet final states. The modes $b'\to bg$ for B($b'\to bg$) >65% $b'\to b\gamma$ for B($b'\to b\gamma$) >5% are excluded. Charged Higgs decay were not discussed.
- ²¹ABDALLAH 07 searched for b' pair production at $E_{
 m cm} = 196$ –209 GeV, with 420 pb $^{-1}$. No signal leads to the 95% CL upper limits on B(b' o bZ) and B(b' o cW) for $m_{b'}$
- = 96 to 103 GeV. 22 ADRIANI 93G search for vector quarkonium states near Z and give limit on quarkonium-Z mixing parameter $\delta m^2 < (10{\text -}30) \; {\rm GeV}^2$ (95%CL) for the mass 88–94.5 GeV. Using Richardson potential, a 1S $(b'\overline{b'})$ state is excluded for the mass range 87.7–94.7 GeV. This range depends on the potential choice
- $^{23}\,\mathrm{ABREU}$ 90D assumed $m_{\ensuremath{H^-}} < m_{\ensuremath{b^\prime}} 3$ GeV.
- 24 Superseded by ABREU 91F.
- $_{25}^{25}$ AKRAWY 90B search was restricted to data near the Z peak at $E_{
 m cm}=91.26$ GeV at LEP. The excluded region is between 23.6 and 41.4 GeV if no H^+ decays exist. For charged Higgs decays the excluded regions are between $(m_{H^+}\ +\ 1.5\ {\rm GeV})$ and 45.5
- 26 AKRAWY 90J search for isolated photons in hadronic Z decay and derive $B(Z \to b' \overline{b}') \cdot B(b' \to \gamma X)/B(Z \to hadrons) < 2.2 \times 10^{-3}$. Mass limit assumes $B(b' \rightarrow \gamma X) > 10\%$
- $27\,\text{ABE 895}$ search at $E_{Cm}=56\text{--}57$ GeV at TRISTAN for multihadron events with a spherical shape (using thrust and acoplanarity) or containing isolated leptons.
- $^{28}\,\mathrm{ABE}$ 89G search was at $E_\mathrm{cm} = 55\text{--}60.8$ GeV at TRISTAN.
- ²⁹ If the photonic decay mode is large (B($b' \to b \gamma$) > 25%), the ABRAMS 89c limit is 45.4 GeV. The limit for for Higgs decay ($b' \to cH^-, H^- \to \overline{c}s$) is 45.2 GeV.
- 30 ADACHI 89c search was at $E_{
 m cm}=56.5$ –60.8 GeV at TRISTAN using multi-hadron events accompanying muons.
- 31 ADACHI 89c also gives limits for any mixture of $\it CC$ and $\it bg$ decays.
- 32 ENO 89 search at $E_{\rm cm} = 50$ –60.8 at TRISTAN.
- 33 ENO 89 considers arbitrary mixture of the charged current, bg, and $b\gamma$ decays.
- 34 IGARASHI 88 searches for leptons in low-thrust events and gives $\Delta R(b') < 0.26$ (95% CL) assuming charged current decay, which translates to $m_{h'} > 24.4~{\rm GeV}$.

Quark Particle Listings

b' (Fourth Generation) Quark, t' (Fourth Generation) Quark, Free Quark Searches

- 35 SAGAWA 88 set limit $\sigma(top) < 6.1$ pb at CL=95% for top-flavored hadron production from event shape analyses at $E_{\rm cm} = 52$ GeV. By using the quark parton model cross-section formula near threshold, the above limit leads to lower mass bounds of 23.8 GeV for charge -1/3 quarks.
- 36 ADEVA 86 give 95%CL upper bound on an excess of the normalized cross section, ΔR , as a function of the minimum c.m. energy (see their figure 3). Production of a pair of 1/3 charge quarks is excluded up to $E_{
 m CM}=45.4$ GeV.
- 37 ALTHOFF 84C narrow state search sets limit $\Gamma(e^+e^-)$ B(hadrons) <2.4 keV CL = 95% and heavy charge 1/3 quark pair production m > 21 GeV, CL = 95%.
- $^{36} \rm ALTHOFF$ 84! exclude heavy quark pair production for 7 $<\!m<\!19$ GeV (1/3 charge) using aplanarity distributions (CL = 95%).

REFERENCES FOR Searches for (Fourth Generation) b' Quark

(4th Generation) Quark, Searches for

t'-quark/hadron mass limits in $p\overline{p}$ and pp collisions CL% DOCUMENT ID TECN COMMENT

 1 AAD

VALUE (GeV)

| >420 | 95 | ¹ AAD | 12c ATLS | $t' \rightarrow tX (m_X < 140 \text{ GeV})$ |
|-------------|-----------------|-----------------------|-------------------|-----------------------------------------------|
| >358 | 95 | ² AALTONEN | 11AL CDF | $t' \rightarrow Wb$ |
| >340 | 95 | ² AALTONEN | 11AL CDF | $t' \rightarrow Wq (q=d,s,b)$ |
| • • • We do | not use the fol | llowing data for ave | erages, fits, lir | mits, etc. • • • |
| >400 | 95 | ³ AALTONEN | 11AH CDF | $t' \rightarrow tX (m_X < 70 \text{ GeV})$ |
| >360 | 95 | ⁴ AALTONEN | 110 CDF | $t' \rightarrow tX \ (m_X < 100 \text{ GeV})$ |
| >285 | 95 | ⁵ ABAZOV | 11Q D0 | |
| >256 | 95 | 6,7 AALTONEN | 08H CDF | $t' \rightarrow Wq$ |

- 1 Based on 1.04 fb $^{-1}$ of data in pp collisions at 7 TeV. AAD 12c looked for $t'\bar{t}'$ production followed by t^\prime decaying into a top quark and X, an invisible particle, in a final state with an isolated high-P $_T$ lepton, four or more jets, and a large missing transverse energy. No excess over the SM ttbar production gives the upper limit on $t' \bar t'$ production cross section as a function of $m_{\,t'}$ and $m_{\,X}$. The result is obtained for B($t'
 ightarrow t \, W$) = 1.
- 2 Based on 5.6 fb $^{-1}$ of data in ppbar collisions at 1.96 TeV. AALTONEN 11AL looked for $\ell + \geq$ 4j events and set upper limits on $\sigma(\,t'\,\overline{t}')$ as functions of $m_{_{t'}}$
- 3 Based on 5.7 fb $^{-1}$ of data in $p\overline{p}$ collisions at 1.96 TeV. AALTONEN 11AH looked for $t'\overline{t'}$ production followed by t' decaying into a top quark and X, an invisible particle, in the all hadronic decay mode of $t\overline{t}$. No excess over the SM tibar production gives the upper limit on $t'\overline{t}'$ production cross section as a function of $m_{t'}$ and $m_{X'}$. The result is obtained for $B(t' \rightarrow tX) = 1$.
- ⁴ Based on 4.8 fb⁻¹ of data in $p\overline{p}$ collisions at 1.96 TeV. AALTONEN 110 looked for $t'\overline{t}'$ production signal when t' decays into a top quark and X, an invisible particle, in ℓ $+
 ot\!\!\!E_T + ext{jets channel}$. No excess over the SM ttbar production gives the upper limit on $t'\overline{t}'$ production cross section as a function of $m_{t'}$ and m_X . The result is obtained for $B(t' \rightarrow tX) = 1$
- 5 Based on 5.3 fb $^{-1}$ of data in $p\overline{p}$ collisions at 1.96 TeV. ABAZOV 11Q looked for ℓ +
- 6 Searches for pair production of a new heavy top-like quark t^\prime decaying to a W boson and another quark by fitting the observed spectrum of total transverse energy and reconstructed t' mass in the lepton + jets events.

 7 HUANG 08 reexamined the t' mass lower bound of 256 GeV obtained in AALTONEN 08H that assumes B($b' \rightarrow qZ$) = 1 for q = u, c which does not hold when $m_{b'} < m_{t'} - m_W$ or the mixing $\sin^2(\theta_{h\,t'})$ is so tiny that the decay occurs outside of the vertex detector. Fig. 1 gives that lower bound on $m_{t'}$ in the plane of $\sin^2(\theta_{h\,t'})$ and $m_{h'}$.

t' mass limits from single production in $p\overline{p}$ and pp collisions

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|---------------------|-----|------|---------------------------------------------------------|
| >403 | 95 | ⁸ ABAZOV | 11F | D0 | $qd \rightarrow q't' \rightarrow q'(Wd)$ |
| | | ۰ | | | $\tilde{\kappa}_{dt'}=1$, $B(t' \rightarrow Wd)=1$ |
| >551 | 95 | ⁸ ABAZOV | 11F | D0 | $qu \rightarrow qt' \rightarrow q(Zu)$ |
| | | | | | $\tilde{\kappa}_{u t'} = \sqrt{2}, B(t' \to Z u) = 1$ |

 $^8\mathrm{\,Based}$ on 5.4 fb $^{-1}$ of data in ppbar collisions at 1.96 TeV. ABAZOV 11F looked for single production of t^\prime via the Z or E coupling to the first generation up or down quarks, respectively. Model independent cross section limits for the single production processes $p\overline{p} \to t'q \to (Wd)q$, and $p\overline{p} \to t'q \to (Zd)q$ are given in Figs. 3 and 4, respectively, and the mass limits are obtained for the model of ATRE 09 with degenerate bi-doublets of vector-like quarks.

REFERENCES FOR Searches for (Fourth Generation) t' Quark

| AALTONEN | 11AH | PRL 107 191803 | G. Aad et al. T. Aaltonen et al. | (ATLAS Collab.) (CDF Collab.) |
|----------|------|----------------|-------------------------------------|----------------------------------|
| AALTONEN | 11AL | PRL 107 261801 | T. Aaltonen <i>et al</i> . | (CDF Collab.) |
| AALTONEN | 110 | PRL 106 191801 | T. Aaltonen et al. | (CDF Collab.) |
| ABAZOV | 11 F | PRL 106 081801 | V.M. Abazov et al. | (D0 Collab.) |
| ABAZOV | 11 Q | PRL 107 082001 | V.M. Abazov et al. | (D0 Collab.) |
| ATRE | 09 | PR D79 054018 | A. Atre et al. | |
| AALTONEN | 08 H | PRL 100 161803 | T. Aaltonen et al. | (CDF Collab.) |
| HUANG | 08 | PR D77 037302 | P.Q. Hung, M. Sher | (UVA, WILL) |

Free Quark Searches

FREE QUARK SEARCHES

The basis for much of the theory of particle scattering and hadron spectroscopy is the construction of the hadrons from a set of fractionally charged constituents (quarks). A central but unproven hypothesis of this theory, Quantum Chromodynamics, is that quarks cannot be observed as free particles but are confined to mesons and baryons.

Experiments show that it is at best difficult to "unglue" quarks. Accelerator searches at increasing energies have produced no evidence for free quarks, while only a few cosmic-ray and matter searches have produced uncorroborated events.

This compilation is only a guide to the literature, since the quoted experimental limits are often only indicative. Reviews can be found in Refs. 1–4.

References

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- 2. P.F. Smith, Ann. Rev. Nucl. and Part. Sci. 39, 73 (1989).
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Quark Production Cross Section — Accelerator Searches

| <u>(cm²)</u> | (e/3) | (GeV) | (GeV) | BEAM E | VTS | DO CUMENT ID | | TECN |
|--------------|-----------|---------|--------|--------------------------|-----|----------------------------|-----|------|
| < 1.3E - 36 | ± 2 | 45-84 1 | 30-172 | e^+e^- | 0 | ABREU | 97D | DLPH |
| < 2.E - 35 | + 2 | 250 | 1800 | $p\overline{p}$ | 0 | $^{ m 1}$ abe | 92J | CDF |
| < 1.E - 35 | +4 | 250 | 1800 | $p\overline{p}$ | 0 | ¹ ABE | 92J | CDF |
| < 3.8E - 28 | | | 14.5A | ²⁸ Si–P b | | ² HE | 91 | PLAS |
| < 3.2E - 28 | | | 14.5A | ²⁸ Si–Cu | 0 | ² HE | 91 | PLAS |
| < 1.E - 40 | $\pm 1,2$ | <10 | | $p, \nu, \overline{\nu}$ | 0 | BERGSMA | 84B | CHRM |
| < 1.E - 36 | $\pm 1,2$ | < 9 | 200 | μ | 0 | AUBERT | 83c | SPEC |
| < 2.E - 10 | $\pm 2,4$ | 1-3 | 200 | p | 0 | ³ BUSSIERE | 80 | CNTR |
| < 5.E - 38 | +1,2 | >5 | 300 | p | 0 | ^{4,5} STEVENSON | 79 | CNTR |
| < 1.E - 33 | ± 1 | <20 | 52 | pр | 0 | BASILE | 78 | SPEC |
| < 9.E - 39 | $\pm 1,2$ | <6 | 400 | p | 0 | ⁴ A NTREA SYA N | 177 | SPEC |
| < 8.E - 35 | +1,2 | < 20 | 52 | pр | 0 | ⁶ FABJAN | 75 | CNTR |
| < 5.E - 38 | -1,2 | 4-9 | 200 | p | 0 | NASH | 74 | CNTR |
| < 1.E - 32 | +2,4 | 4-24 | 52 | pр | 0 | ALPER | 73 | SPEC |

| <5.E $-$ 31 | +1,2,4 | <12 | 300 | р | 0 | LEIPUNER | 73 | CNTR |
|-------------|-----------|---------|-----|----|---|-------------------------|-----|------|
| < 6.E - 34 | $\pm 1,2$ | <13 | 52 | рр | 0 | BOTT | 72 | CNTR |
| < 1.E - 36 | -4 | 4 | 70 | р | 0 | ANTIPOV | 71 | CNTR |
| < 1.E - 35 | $\pm 1,2$ | 2 | 28 | р | 0 | ⁷ ALLABY | 69B | CNTR |
| < 4.E - 37 | -2 | < 5 | 70 | р | 0 | ³ A NT IP OV | 69 | CNTR |
| < 3.E - 37 | -1,2 | 2-5 | 70 | р | 0 | ⁷ A NT IP OV | 69B | CNTR |
| < 1.E - 35 | +1,2 | < 7 | 30 | р | 0 | DORFAN | 65 | CNTR |
| < 2.E - 35 | -2 | < 2.5-5 | 30 | р | 0 | ⁸ FRANZINI | 65B | CNTR |
| <5.E $-$ 35 | +1,2 | < 2.2 | 21 | р | 0 | BINGHAM | 64 | HLBC |
| < 1.E - 32 | +1,2 | < 4.0 | 28 | р | 0 | BLUM | 64 | HBC |
| < 1.E - 35 | +1,2 | < 2.5 | 31 | р | 0 | ⁸ HAGOPIA N | 64 | HBC |
| < 1.E - 34 | +1 | <2 | 28 | р | 0 | LEIPUNER | 64 | CNTR |
| < 1.E - 33 | +1,2 | < 2.4 | 24 | р | 0 | MORRISON | 64 | HBC |
| | | | | | | | | |

- The production of the state of the form $N\pm 1/3$ from 23/3 to 38/3. The production of the state of the form $N\pm 1/3$ from 23/3 to 38/3. Hadronic or leptonic quarks. Cross section cm²/GeV². The production of the state of the form $N\pm 1/3$ from 23/3 to 38/3. Hadronic or leptonic quarks. The production of the produ

- ⁸ Cross section inferred from flux.

Quark Differential Production Cross Section — Accelerator Searches

| X-SECT | CHG | MA SS | ENERGY | | | | | |
|---------------------------------------|------------|------------------------|-----------|-------------|------|--------------------|-----|-------|
| (cm ² sr ⁻¹ GeV | -1) e/3 | (GeV) | (GeV) | <u>BEAM</u> | EVTS | DOCUMENT ID | | TE CN |
| < 4.E - 36 | -2,4 | 1.5-6 | 70 | p | 0 | BALDIN | 76 | CNTR |
| < 2.E - 33 | ± 4 | 5-20 | 52 | pр | 0 | ALBROW | 75 | SPEC |
| <5.E $-$ 34 | < 7 | 7-15 | 44 | pр | 0 | JOVA NOV | 75 | CNTR |
| <5.E $-$ 35 | | | 20 | γ | 0 | ⁹ GALIK | 74 | CNTR |
| < 9.E - 35 | -1,2 | | 200 | p | 0 | NASH | 74 | CNTR |
| < 4.E - 36 | -4 | 2.3 - 2.7 | 70 | р | 0 | ANTIPOV | 71 | CNTR |
| < 3.E - 35 | $\pm 1,2$ | < 2.7 | 27 | p | 0 | ALLABY | 69B | CNTR |
| < 7.E - 38 | -1,2 | < 2.5 | 70 | p | 0 | ANTIPOV | 69B | CNTR |
| ⁹ Cross se | ction in c | m ² /sr/equ | ivalent q | uanta. | | | | |

Quark Flux — Accelerator Searches

The definition of FLUX depends on the experiment

- (a) is the ratio of measured free quarks to predicted free quarks if there is no "con-
- (b) is the probability of fractional charge on nuclear fragments. Energy is in GeV/nucleon.
- (c) is the 90%CL upper limit on fractionally-charged particles produced per interaction.
- (d) is quarks per collision.
- (e) is inclusive quark-production cross-section ratio to $\sigma(e^+e^- \to \mu^+\mu^-)$.
- (f) is quark flux per charged particle.
- (g) is the flux per ν -event.
- (h) is quark yield per π^- yield.
- (i) is 2-body exclusive quark-production cross-section ratio to $\sigma(e^+\,e^-
 ightarrow$ 2-bou, $\mu^+\mu^-$).

| | | $\mu \cdot \mu$). | | | | | | | |
|-------------|---|--------------------|---------------|----------------|--------------------|-----|------------------------|-----|------|
| FLUX | | CHG (e/3) | MASS (GeV) | ENRGY (GeV) | BEAM E | /TS | DOCUMENT ID | | TECN |
| <1.6E-3 | b | see note | | 200 | ³² S-Pb | 0 | ¹⁰ HUENTRUP | 96 | PLA: |
| <6.2E-4 | b | see note | | 10.6 | ³² S–Pb | 0 | ¹⁰ HUENTRUP | 96 | PLA: |
| < 0.94E - 4 | e | ± 2 | 2-30 | 88-94 | e^+e^- | 0 | AKERS | 95R | OPA |
| < 1.7E - 4 | е | ± 2 | 30-40 | 88-94 | e^+e^- | 0 | AKERS | 95R | OPA |
| < 3.6E - 4 | е | ± 4 | 5-30 | 88-94 | e^+e^- | 0 | AKERS | 95R | OPA |
| < 1.9E - 4 | e | ± 4 | 30-45 | 88-94 | e^+e^- | 0 | AKERS | 95R | OPA |
| < 2.E - 3 | e | +1 | 5-40 | 88-94 | e^+e^- | 0 | ¹¹ BUSKULIC | 93c | ALEF |
| < 6.E - 4 | е | + 2 | 5-30 | 88-94 | e^+e^- | 0 | ¹¹ BUSKULIC | 93c | ALEF |
| < 1.2E - 3 | e | +4 | 15-40 | 88-94 | e^+e^- | 0 | ¹¹ BUSKULIC | 93c | ALEF |
| < 3.6E - 4 | i | +4 | 5.0-10.2 | 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEF |
| < 3.6E - 4 | i | +4 | 16.5-26.0 | 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEF |
| < 6.9E - 4 | i | +4 | 26.0-33.3 | 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEF |
| < 9.1E - 4 | i | +4 | 33.3-38.6 | 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEF |
| < 1.1E - 3 | i | +4 | 38.6-44.9 | 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEF |
| < 1.6E - 4 | b | see note | Se | e note | | 0 | 12 CECCHINI | 93 | PLA: |

| < 6.E - 4 | e | + 2 | 5-30 88-94 | e^+e^- | 0 | 11 BUSKULIC | 93c | ALEP |
|-------------|---|-------------|-----------------|----------------------|-------|------------------------|-----|------|
| < 1.2E - 3 | e | +4 | 15-40 88-94 | e^+e^- | 0 | ¹¹ BUSKULIC | 93c | ALEP |
| < 3.6E - 4 | i | +4 | 5.0-10.2 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEP |
| < 3.6E - 4 | i | +4 | 16.5-26.0 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEP |
| < 6.9E - 4 | i | +4 | 26.0-33.3 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEP |
| < 9.1E - 4 | i | +4 | 33.3-38.6 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEP |
| < 1.1E - 3 | i | +4 | 38.6-44.9 88-94 | e^+e^- | 0 | BUSKULIC | 93c | ALEP |
| < 1.6E - 4 | b | see note | see note | | 0 | ¹² CECCHINI | 93 | PLAS |
| | b | 4,5,7,8 | 2.1A | 16 O 0,2 | 2,0,6 | ¹³ GHOSH | 92 | EMUL |
| < 6.4E - 5 | g | 1 | | $\nu,\overline{\nu}$ | 1 | 14 BASILE | 91 | CNTR |
| < 3.7E - 5 | g | 2 | | $\nu,\overline{\nu}$ | 0 | 14 BASILE | 91 | CNTR |
| < 3.9E - 5 | g | 1 | | $\nu,\overline{\nu}$ | 1 | 15 BASILE | 91 | CNTR |
| < 2.8E - 5 | g | 2 | | $\nu,\overline{\nu}$ | 0 | ¹⁵ BASILE | 91 | CNTR |
| < 1.9E - 4 | C | | 14.5A | ²⁸ Si–P b | 0 | ¹⁶ HE | 91 | PLAS |
| < 3.9E - 4 | С | | 14.5A | ²⁸ Si–Cu | 0 | ¹⁶ HE | 91 | PLAS |
| < 1.E - 9 | С | $\pm 1,2,4$ | 14.5A | ¹⁶ O–A r | 0 | MATIS | 91 | MDRP |
| < 5.1E - 10 | c | $\pm 1,2,4$ | 14.5A | ¹⁶ O-Hg | 0 | MATIS | 91 | MDRP |
| < 8.1E - 9 | C | $\pm 1,2,4$ | 14.5A | Si-Hg | 0 | MATIS | 91 | MDRP |
| < 1.7E - 6 | C | $\pm 1,2,4$ | 60A | ¹⁶ O-Hg | 0 | MATIS | 91 | MDRP |
| < 3.5 E - 7 | С | $\pm 1,2,4$ | 200A | ¹⁶ O-Hg | 0 | MATIS | 91 | MDRP |
| < 1.3E - 6 | C | $\pm 1,2,4$ | 200A | S-Hg | 0 | MATIS | 91 | MDRP |
| < 5E - 2 | e | 2 | 19-27 52-60 | e^+e^- | 0 | ADACHI | 90c | TOPZ |
| < 5E - 2 | e | 4 | <24 52-60 | e^+e^- | 0 | ADACHI | 90c | TOPZ |
| < 1.E - 4 | e | + 2 | < 3.5 10 | e^+e^- | 0 | BOWCOCK | 89B | CLEO |
| < 1.E - 6 | d | $\pm 1,2$ | 60 | ¹⁶ O-Hg | 0 | CALLOWAY | 89 | MDRP |
| | | | | | | | | |
| | | | | | | | | |

| $< 3.5 \mathrm{E} - 7$ | d | $\pm 1,2$ | | 200 | ¹⁶ О-Нg | 0 | CALLOWAY | 89 | MDRP |
|------------------------|----|---------------|------------|--------------|-------------------------|----|-------------------------|---------|--------|
| < 1.3E - 6 | d | $\pm 1,2$ | | 200 | S-Hg | 0 | CALLOWAY | 89 | MDRP |
| < 1.2E - 10 | d | ± 1 | 1 | 800 | p−Hg | 0 | MATIS | 89 | MDRP |
| <1.1E-10 | d | ± 2 | 1 | 800 | <i>p</i> −Hg | 0 | MATIS | 89 | MDRP |
| < 1.2E - 10 | d | ± 1 | 1 | 800 | $p-N_2$ | 0 | MATIS | 89 | MDRP |
| < 7.7E - 11 | d | ± 2 | 1 | 800 | $p-N_2$ | 0 | MATIS | 89 | MDRP |
| < 6.E - 9 | h | -5 | 0.9 - 2.3 | 12 | p | 0 | NA KA MURA | 89 | SPEC |
| < 5.E - 5 | g | 1,2 | < 0.5 | | $\nu, \overline{\nu} d$ | 0 | _ ALLASIA | 88 | BEBC |
| < 3.E - 4 | b | See note | | 14.5 | 16 O-Pb | 0 | ¹⁷ HOFFMANN | 88 | PLAS |
| < 2.E - 4 | b | See note | | 200 | ¹⁶ O-P b | 0 | ¹⁸ HOFFMANN | 88 | PLAS |
| < 8E - 5 | b | 19,20,22,23 | | 200 <i>A</i> | | | GERBIER | 87 | PLAS |
| < 2.E - 4 | а | ± 1.2 | < 300 | 320 | $\overline{p}p$ | 0 | LYONS | 87 | MLEV |
| < 1.E - 9 | c | $\pm 1,2,4,5$ | | 14.5 | ¹⁶ O-Hg | 0 | SHAW | 87 | MDRP |
| < 3.E - 3 | d | -1,2,3,4,6 | <5 | 2 | Si-Si | 0 | ¹⁹ АВАСНІ | 86c | CNTR |
| < 1.E - 4 | е | $\pm 1,2,4$ | <4 | 10 | e^+e^- | 0 | ALBRECHT | 85 G | ARG |
| $<\!6.E\!-\!5$ | b | $\pm 1,2$ | 1 | 540 | $p\overline{p}$ | 0 | BANNER | 85 | UA2 |
| < 5.E - 3 | е | -4 | 1-8 | 29 | e^+e^- | 0 | AIHARA | 84 | TPC |
| < 1.E - 2 | e | $\pm 1,2$ | 1-13 | 29 | e^+e^- | 0 | AIHARA | 84B | TPC |
| < 2.E - 4 | b | ± 1 | | 72 | ⁴⁰ Ar | 0 | ²⁰ BARWICK | 84 | CNTR |
| < 1.E - 4 | е | ± 2 | < 0.4 | 1.4 | e^+e^- | 0 | BONDAR | 84 | OLYA |
| < 5.E - 1 | e | $\pm 1,2$ | <13 | 29 | e^+e^- | 0 | GURYN | 84 | CNTR |
| < 3.E - 3 | b | $\pm 1,2$ | <2 | 540 | $p\overline{p}$ | 0 | BANNER | 83 | CNTR |
| < 1.E - 4 | b | $\pm 1,2$ | | 106 | ⁵⁶ Fe | 0 | LINDGREN | 83 | CNTR |
| < 3.E - 3 | b | $> \pm 0.1 $ | | 74 | ⁴⁰ Ar | 0 | ²⁰ PRICE | 83 | PLAS |
| < 1.E - 2 | е | ±1,2 | <14 | 29 | e^+e^- | 0 | MARINI | 82B | CNTR |
| < 8.E - 2 | е | $\pm 1,2$ | <12 | 29 | e^+e^- | 0 | ROSS | 82 | CNTR |
| < 3.E - 4 | е | ±2 | 1.8-2 | 7 | e^+e^- | 0 | WEISS | 81 | MRK2 |
| < 5.E - 2 | е | +1,2,4,5 | 2-12 | 27 | e^+e^- | 0 | BARTEL | 80 | JADE |
| <2.E-5 | g | 1,2 | | | ν | 0 | ^{14,15} BASILE | 80 | CNTR |
| < 3.E - 10 | f | $\pm 2,4$ | 1-3 | 200 | p | 0 | ²¹ BOZZOLI | 79 | CNTR |
| < 6.E - 11 | f | ± 1 | <21 | 52 | p p | 0 | BASILE | 78 | SPEC |
| < 5.E - 3 | g | | | | ν_{μ} | 0 | BASILE | 78B | CNTR |
| < 2.E - 9 | f | ± 1 | <26 | 62 | p p | 0 | BASILE | 77 | SPEC |
| < 7.E - 10 | f | +1,2 | <20 | 52 | p | 0 | ²² FAB JAN | 75 | CNTR |
| | | +1,2 | >4.5 | | γ | 0 | 14,15 GALIK | 74 | CNTR |
| | | +1,2 | >1.5 | 12 | | 0 | 14,15 BELLAMY | 68 | CNTR |
| | | +1,2 | >0.9 | | γ | 0 | ¹⁵ BATHOW | 67 | CNTR |
| | | +1,2 | >0.9 | 6 | γ | 0 | ¹⁵ FOSS | 67 | CNTR |
| 10 HHEN | TR | IIP 96 quote | 95% CL lin | nits for | production | of | fragments with char | σe diff | erin o |

- 10 HUENTRUP 96 quote 95% CL limits for production of fragments with charge differing by as much as $\pm 1/3$ (in units of e) for charge $6 \le Z \le 10$.
- 11 BUSKULIC 93c limits for inclusive quark production are more conservative if the ALEPH hadronic fragmentation function is assumed.
- nadronic fragmentation function is assumed. 21 CECCHNI) 93 limit at 90%CL for 23/3 \leq Z \leq 40/3, for 16A GeV O, 14.5A Si, and 200A S incident on Cu target. Other limits are 2.3×10^{-4} for $17/3\leq$ Z \leq 20/3 and 1.2×10^{-4} for $20/3\leq$ Z \leq 23/3.
- 13 GHOSH 92 reports measurement of spallation fragment charge based on ionization in emulsion. Out of 650 measured tracks, 2 were consistent with charge 5e/3, and 4 with 7e/3.
- 14 Hadronic quark.
- ¹⁵ Leptonic quark.
- 16 HE 91 limits are for charges of the form $N\pm 1/3$ from 23/3 to 38/3, and correspond to cross-section limits of $380\mu b$ (Pb) and $320\mu b$ (Cu).

 17 The limits apply to projectile fragment charges of 17, 19, 20, 22, 23 in units of e/3.
- The limits apply to projectile fragment charges of 16, 17, 19, 20, 22, 23 in units of e/3.
- 19 Flux limits and mass range depend on charge.
- 20 Bound to nuclei. 21 Quark lifetimes $> 1 \times 10^{-8}$ s.
- 22 One candidate m < 0.17 GeV.

Quark Flux — Cosmic Ray Searches

Shielding values followed with an asterisk indicate altitude in km. Shielding values not followed with an asterisk indicate sea level in kg/cm².

| FLUX | CHG | MASS | | ٠. | | | |
|---------------------|-------------|-------|--------------|------|---------------------------|-----|------|
| (cm-2sr-1s-1 |) (e/3) | (GeV) | SHIELDING | EVTS | DOCUMENT ID | | TECN |
| < 9.2E - 15 | ± 1 | | 3800 | 0 | ²³ ambrosio | 00c | MCRO |
| $< 2.1{\sf E} - 15$ | ± 1 | | | 0 | MORI | 91 | KAM2 |
| < 2.3E - 15 | ± 2 | | | 0 | MORI | 91 | KAM2 |
| < 2.E - 10 | $\pm 1, 2$ | | 0.3 | 0 | WADA | 88 | CNTR |
| | ± 4 | | 0.3 | 12 | ²⁴ WADA | 88 | CNTR |
| | ± 4 | | 0.3 | 9 | ²⁵ WADA | 86 | CNTR |
| < 1.E - 12 | $\pm 2,3/2$ | | −70 . | 0 | ²⁶ KAWAGOE | 84B | PLAS |
| < 9.E - 10 | $\pm 1,2$ | | 0.3 | 0 | WADA | 84B | CNTR |
| < 4.E - 9 | ± 4 | | 0.3 | 7 | WADA | 84B | CNTR |
| < 2.E - 12 | $\pm 1,2,3$ | | - 0.3 * | 0 | MASHIMO | 83 | CNTR |
| < 3.E - 10 | $\pm 1,2$ | | 0.3 | 0 | MARINI | 82 | CNTR |
| < 2.E - 11 | $\pm 1,2$ | | | 0 | MASHIMO | 82 | CNTR |
| < 8.E - 10 | $\pm 1,2$ | | 0.3 | 0 | ²⁶ NAPOLITA NO | 82 | CNTR |
| | | | | 3 | ²⁷ YOCK | 78 | CNTR |
| < 1.E - 9 | | | | 0 | 28 BRIATORE | 76 | ELEC |
| < 2.E - 11 | +1 | | | 0 | ²⁹ HAZEN | 75 | CC |
| < 2.E - 10 | +1,2 | | | 0 | KRISOR | 75 | CNTR |
| < 1.E - 7 | +1,2 | | | 0 | 29,30 CLARK | 74B | CC |
| < 3.E - 10 | +1 | >20 | | 0 | KIFUNE | 74 | CNTR |
| < 8.E - 11 | +1 | | | 0 | ²⁹ ASHTON | 73 | CNTR |
| < 2.E - 8 | +1,2 | | | 0 | HICKS | 73B | CNTR |
| < 5.E - 10 | +4 | | 2.8 * | 0 | BEAUCHAMP | 72 | CNTR |
| < 1.E - 10 | +1,2 | | | 0 | ²⁹ вонм | 72B | CNTR |

Quark Particle Listings

Free Quark Searches

| < 1.E - 10 | +1,2 | | 2.8 * | 0 | COX | 72 | ELEC |
|------------|-------------|-------|-------------|------|---------------------------|-----|------|
| < 3.E - 10 | + 2 | | | 0 | CROUCH | 72 | CNTR |
| < 3.E - 8 | | | 7 | 0 | ²⁸ DARDO | 72 | CNTR |
| < 4.E - 9 | +1 | | | 0 | ²⁹ EVANS | 72 | CC |
| < 2.E - 9 | | >10 | | 0 | ²⁸ TONWAR | 72 | CNTR |
| < 2.E - 10 | +1 | | 2.8 * | 0 | CHIN | 71 | CNTR |
| < 3.E - 10 | +1,2 | | | 0 | ²⁹ CLARK | 71B | CC |
| < 1.E - 10 | +1,2 | | | 0 | ²⁹ HAZEN | 71 | CC |
| <5.E -10 | +1,2 | | 3.5 * | 0 | BOSIA | 70 | CNTR |
| | +1,2 | < 6.5 | | 1 | ²⁹ СНИ | 70 | HLBC |
| < 2.E - 9 | +1 | | | 0 | FAISSNER | 70B | CNTR |
| < 2.E - 10 | +1,2 | | * 8.0 | 0 | KRIDER | 70 | CNTR |
| <5.E -11 | + 2 | | | 4 | CAIRNS | 69 | CC |
| < 8.E - 10 | +1,2 | <10 | | 0 | FUKUSHIMA | 69 | CNTR |
| | + 2 | | | 1 | ^{29,31} MCCUSKER | 69 | CC |
| < 1.E - 10 | | >5 | 1.7,3.6 | 0 | ²⁸ BJORNBOE | 68 | CNTR |
| < 1.E - 8 | $\pm 1,2,4$ | | 6.3,.2 * | 0 | ²⁶ BRIAT ORE | 68 | CNTR |
| < 3.E - 8 | | >2 | | 0 | FRA NZINI | 68 | CNTR |
| < 9.E - 11 | $\pm 1,2$ | | | 0 | GARMIRE | 68 | CNTR |
| < 4.E - 10 | ± 1 | | | 0 | H A NAYA MA | 68 | CNTR |
| < 3.E - 8 | | >15 | | 0 | KASHA | 68 | OSPK |
| < 2.E - 10 | + 2 | | | 0 | KASHA | 68B | CNTR |
| < 2.E - 10 | +4 | | | 0 | KASHA | 68c | CNTR |
| < 2.E - 10 | + 2 | | 6 | 0 | BARTON | 67 | CNTR |
| < 2.E - 7 | +4 | | 0.008,0.5 * | 0 | BUHLER | 67 | CNTR |
| < 5.E - 10 | 1,2 | | 0.008,0.5 * | 0 | BUHLER | 67B | CNTR |
| < 4.E - 10 | +1,2 | | | 0 | GOMEZ | 67 | CNTR |
| < 2.E - 9 | + 2 | | | 0 | KASHA | 67 | CNTR |
| < 2.E - 10 | + 2 | | 220 | 0 | BARTON | 66 | CNTR |
| < 2.E - 9 | +1,2 | | 0.5 * | 0 | BUHLER | 66 | CNTR |
| < 3.E - 9 | +1,2 | | | 0 | KASHA | 66 | CNTR |
| < 2.E - 9 | +1,2 | | | 0 | LAMB | 66 | CNTR |
| < 2.E - 8 | +1,2 | >7 | 2.8 * | 0 | DELISE | 65 | CNTR |
| < 5.E - 8 | + 2 | >2.5 | 0.5 * | 0 | MASSAM | 65 | CNTR |
| < 2.E - 8 | +1 | | 2.5 * | 0 | BOWEN | 64 | CNTR |
| < 2.E - 7 | +1 | | 0.8 | 0 | SUNYAR | 64 | CNTR |
| 23 4 4000 | CIO 00-11 1 | | 11 10-15 | 0.05 | . / . 0 = 11 1 | | 2.00 |

 $^{^{23}}$ AMBROSIO 00c limit is below 11×10^{-15} for 0.25 $<\!q/\mathrm{e}<$ 0.5, and is changing rapidly near $q/\mathrm{e}{=}2/3$, where it is 2×10^{-14} . 24 Distribution in celestial sphere was described as anisotropic.

³¹ No events in subsequent experiments.

| Quark Dens | sity — Mat | ter Sea | rches |
|------------|------------|---------|-------|
| QUARKS/ | CHG | MA SS | |
| NUCLEÓN | (a/2) | (CoV) | MAATE |

| Qualk DCII | | | i Gi Gi | | | | |
|--------------------|--------------|---------------|----------------------------|-----|----|-------------|-----|
| QUARKS/ NUCLEON | CHG (e/3) | MASS (GeV) | MATERIAL/METHOD E | VTS | | DOCUMENT ID | |
| < 1.17E - 22 | | | silicone oil drops | 0 | | LEE | 02 |
| < 4.71E - 22 | | | silicone oil drops | 1 | 33 | HALYO | 00 |
| < 4.7E - 21 | $\pm 1,2$ | | silicone oil drops | 0 | | MAR | 96 |
| < 8.E - 22 | + 2 | | Si/infrared photoionizatio | n 0 | | PERERA | 93 |
| < 5.E - 27 | $\pm 1,2$ | | sea water/levitation | 0 | | HOMER | 92 |
| < 4.E - 20 | $\pm 1,2$ | | meteorites/mag. levitatio | n 0 | | JONES | 89 |
| < 1.E - 19 | $\pm 1,2$ | | various/spectrometer | 0 | | MILNER | 87 |
| < 5.E - 22 | $\pm 1,2$ | | W/levitation | 0 | | SMITH | 87 |
| < 3.E - 20 | +1,2 | | org liq/droplet tower | 0 | | VANPOLEN | 87 |
| < 6.E - 20 | -1,2 | | org liq/droplet tower | 0 | | VANPOLEN | 87 |
| < 3.E - 21 | ± 1 | | Hg drops-untreated | 0 | | SAVAGE | 86 |
| < 3.E - 22 | $\pm 1,2$ | | levitated niobium | 0 | | SMITH | 86 |
| < 2.E - 26 | $\pm 1,2$ | | ⁴ He/levitation | 0 | | SMITH | 86в |
| < 2.E - 20 | $> \pm 1$ | 0.2 - 250 | niobium+tungs/ion | 0 | | MILNER | 85 |
| < 1.E - 21 | ± 1 | | levitated niobium | 0 | | SMITH | 85 |
| | +1,2 | < 100 | niobium/mass spec | 0 | | KUTSCHERA | 84 |
| < 5.E - 22 | | | levitated steel | 0 | | MARINELLI | 84 |
| < 9.E - 20 | $\pm < 13$ | | water/oil drop | 0 | | JOYCE | 83 |
| <2.E-21> | $ \pm 1/2 $ | | levitated steel | 0 | | LIEBOWITZ | 83 |
| < 1.E - 19 | $\pm 1,2$ | | photo ion spec | 0 | | VANDESTEEG | |
| < 2.E - 20 | | | mercury/oil drop | 0 | | HODGES | 81 |
| 1.E - 20 | +1 | | levitated niobium | 4 | | LARUE | 81 |
| 1.E - 20 | -1 | | levitated niobium | 4 | 35 | LARUE | 81 |
| < 1.E - 21 | | | levitated steel | 0 | | MARINELLI | 80B |
| < 6.E - 16 | | | helium/mass spec | 0 | 25 | BOYD | 79 |
| 1.E — 20 | +1 | | levitated niobium | 2 | 35 | LARUE | 79 |
| < 4.E - 28 | | | earth+/ion beam | 0 | | OGOROD | 79 |
| <5.E -15 | +1 | | tungs./mass spec | 0 | | BOYD | 78 |
| < 5.E - 16 | + 3 | <1.7 | hydrogen/mass spec | 0 | | BOYD | 78B |
| < 1.E - 21 | $\pm 2,4$ | | water/ion beam | 0 | | LUND | 78 |
| < 6.E - 15 | >1/2 | | levitated tungsten | 0 | | PUTT | 78 |
| < 1.E - 22 | | | metals/mass spec | 0 | | SCHIFFER | 78 |
| < 5.E - 15 | | | levitated tungsten ox | 0 | | BLAND | 77 |
| < 3.E - 21 | | | levitated iron | 0 | эг | GALLINARO | 77 |
| 2.E — 21 | -1 | | levitated niobium | 1 | 33 | LARUE | 77 |

| 4.E-21 | +1 | | levitated niobium | 2 | ³⁵ LARUE | 77 |
|-------------|-------------|------|----------------------|---|-----------------------|----|
| | | | | _ | | |
| < 1.E - 13 | | <7.7 | , , , | 0 | MULLER | 77 |
| < 5.E - 2 | 7 | | water+/ion beam | 0 | OGOROD | 77 |
| < 1.E - 2 | Į. | | lunar+/ion spec | 0 | STEVENS | 76 |
| < 1.E - 15 | +1 | < 60 | oxygen+/ion spec | 0 | ELBERT | 70 |
| < 5.E - 19 | 9 | | levitated graphite | 0 | MORPURGO | 70 |
| < 5.E - 23 | 3 | | water+/atom beam | 0 | COOK | 69 |
| < 1.E - 1.7 | $7 \pm 1,2$ | | levitated graphite | 0 | BRAGINSK | 68 |
| < 1.E - 1.7 | 7 | | water+/uv spec | 0 | RANK | 68 |
| < 3.E - 19 | 9 ±1 | | levitated iron | 0 | STOVER | 67 |
| < 1.E - 10 |) | | sun/uv spec | 0 | ³⁶ BENNETT | 66 |
| < 1.E - 1. | 7 +1,2 | | meteorites+/ion beam | 0 | CHUPKA | 66 |
| < 1.E - 16 | 5 ±1 | | levitated graphite | 0 | GALLINARO | 66 |
| <1.E-22 | 2 | | argon/electrometer | 0 | HILLAS | 59 |
| | -2 | | levitated oil | 0 | MILLIKAN | 10 |
| | | | | | | |

 $^{^{32}}$ 95% CL limit for fractional charge particles with 0.18 $e \leq |\mathsf{Q}_{residual}| \leq 0.82 e$ in total of 70.1 mg of silicone oil. 33 95% CL limit for particles with fractional charge $|\mathsf{Q}_{residual}| > 0.16 e$ in total of 17.4 mg of silicone oil. 34 Also set limits for $Q=\pm e/6$.

LEE

02 PR D66 012002

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|-----------------------|------------|------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------|
| HALYO | 00 | PRL 84 2576 | V. Halyo et al. | (MACKO CONS.) |
| ABREU | 97 D | PL B396 315 | P. Abreu et al. | (DELPHI Collab.) |
| HUENTRUP | 96 | PR C53 358 | G. Huentrup et al. | (SIEG) |
| MAR AKERS | 96 95 R | PR D53 6017 ZPHY C67 203 | N.M. Mar et al. R. Akers et al. | (SLAC, SCHAF, LANL, UCI) (OPAL Collab.) |
| BUS KULIC | 93 C | | D. Buskulic et al. | (ALEPH Collab.) |
| CECCHINI | 93 | ASP 1 369 | S. Cecchini et al. | ` ' |
| PERERA | 93 | PRL 70 1053 | A.G.U. Perera et al. | (PITT) |
| ABE | 92 J | PR D46 R1889 | F. Abe et al. | (CDF Collab.) |
| GHOSH HOMER | 92 92 | NC 105A 99 ZPHY C55 549 | D. Ghosh et al. G.J. Homer et al. | (JADA, BANGB) |
| BASILE | 91 | NC 104A 405 | M. Basile et al. | (RAL, SHMP, LOQM) (BGNA, INFN, CERN, PLRM+) |
| HE | 91 | PR C44 1672 | Y.B. He, P.B. Price | (UCB) |
| MATIS | 91 | NP A525 513c | H.S. Matis et al. | (LBL, SFSU, ÙCI+) |
| MORI ADACHI | 91 90 C | PR D43 2843 PL B244 352 | M. Mori et al. | (Kamiokande II Collab.) (TOPAZ Collab.) |
| BOWCOCK | 89B | PR D40 263 | I. Adachi et al. T.J.V. Bowcock et al. | (CLEO Collab.) |
| CALLOWAY | 89 | | D. Calloway et al. | (SFSU, UCI, LBL+) |
| JONES | 89 | ZPHY C43 349 | W.G. Jones et al. | (LOIC, RAL) |
| MATIS | 89 | PR D39 1851 | H.S. Matis et al. | (LBL, SFSU, UCI+) (KYOT, TMTC) |
| NAKAMURA ALLASIA | 89 88 | PR D39 1261 PR D37 219 | T.T. Nakamura et al. | (KYOI, IMIC) |
| HOFFMANN | 88 | | D. Allasia et al. A. Hofmann et al. | (WA25 Collab.) |
| PHILLIPS | 88 | NIM A264 125 | J.D. Phillips, W.M. Fairb | (SIEG, USF) ank, J. Navarro (STAN) |
| WADA | 88 | NC 11C 229 | T. Wada, Y. Yamashita, | I. Yamamoto (OKAY) |
| GERBIER | 87 | PRL 59 2535 | G. Gerbier et al. | (UCB, CERN) |
| LYONS MILNER | 87 87 | ZPHY C36 363 PR D36 37 | L. Lyons et al. R.E. Milner et al. | (OXF, RAL, LOIC) (CIT) |
| SHAW | 87 | PR D36 3533 | G.L. Shaw et al. | (UCI, LBL, LANL, SFSU) |
| SMITH | 87 | PL B197 447 | P.F. Smith et al. | (RAL, LOIC) |
| VANPOLEN | 87 | PR D36 1983 | J. van Polen, R.T. Hagst | rom, G. Hirsch (ANL+) |
| ABACHI | 86 C | PR D33 2733 | S. Abachi et al. | (UCLA, LBL, UCD) |
| SAVAGE SMITH | 86 86 | PL 167B 481 PL B171 129 | M.L. Savage et al. | (SFSU) |
| SMITH | 86B | PL B181 407 | P.F. Smith et al. P.F. Smith et al. | (RAL, LOIC) (RAL, LOIC) |
| WADA | 86 | NC 9C 358 | T. Wada | (OKAY) (ARGUS Collab.) |
| ALBRECHT | 85 G | PL 156B 134 | H. Albrecht et al. | (ARGUS Collab.) |
| BANNER | 85 85 | PL 156B 129 PRL 54 1472 | M. Banner et al. R.E. Milner et al. | (UA2 Collab.) |
| MILNER SMITH | 85 | PL 153B 188 | P.F. Smith et al. | (CIT) (RAL, LOIC) |
| AIHARA | 84 | | H. Aihara et al. | (ŤPC Collab.) |
| AIHARA | 84 B | PRL 52 2332 | H. Aihara et al. | (TPC Collab.) |
| BARWICK | 84 | PR D30 691 | S.W. Barwick, J.A. Musse | er, J.D. Stevenson (UCB) |
| BERGS MA BONDAR | 84 B 84 | ZPHY C24 217 | F. Bergsma et al. | (CHARM Collab.) (NOVO) |
| | | JETPL 40 1265 Translated from ZETFP 4 | 0 440. | ` ' |
| GURYN | 84 | PL 139B 313 LNC 41 604 | W. Guryn et al. | (FRAS, LBL, NWES, STAN+) |
| KAWAGOE KUTS CHERA | 84 B 84 | PR D29 791 | K. Kawagoe et al. | (TOKÝ) (ANL, FNAL) |
| MARINELLI | 84 | PL 137B 439 | W. Kutschera et al. M. Marinelli, G. Morpurgo | (GENO) |
| WADA | 84 B | LNC 40 329 | T. Wada, Y. Yamashita, | I. Yamamoto (OKAY) |
| AUBERT | 83 C | PL 133B 461 | J.J. Aubert et al. | (EMC Collab.) |
| BANNER | 83 | PL 121B 187 | M. Banner et al. | (UA2 Collab.) |
| JOYCE LIEBOWITZ | 83 83 | PRL 51 731 PRL 50 1640 | D.C. Joyce et al. D. Liebowitz, M. Binder, | K.O.H. Ziock (SFSU) |
| LINDGREN | 83 | PRL 51 1621 | M.A. Lindgren et al. | (SFSU, UCR, ÜCI+) |
| MASHIMO | 83 | PL 128B 327 | T. Mashimo et al. | (ICEPP) |
| PRICE | 83 | PRL 50 566 | P.B. Price et al. | (UCB) |
| VANDESTEEG MARINI | 83 82 | PRL 50 1234 PR D26 1777 | M.J.H. van de Steeg, H.V. | W.H.M. Jongbloets, P. Wyder ((FRAS, LBL, NWES, STAN+) |
| MARINI | 82 B | PRL 48 1649 | A. Marini et al. A. Marini et al. | (FRAS IBL NWES STAN+) |
| MASHIMO | 82 | JPSJ 51 3067 | T. Mashimo, K. Kawagoe | (STAN, FRAS, LBL+) (FRAS, LBL, NWES, STAN+) |
| NAPOLITANO | | PR D25 2837 | J. Napolitano et al. | (STAN, FRAS, LBL+) |
| ROSS | 82 | PL 118B 199 | M.C. Ross et al. | (FRAS, LBL, NWES, STAN+) |
| HODGES LARUE | 81 81 | PRL 47 1651 PRL 46 967 | C.L. Hodges et al. G.S. Larue, J.D. Phillips, | (UCR, SFSU) W.M. Fairbank (STAN) |
| WEISS | 81 | PL 101B 439 | J.M. Weiss et al. | (SLAC, LBL, UCB) (JADE Collab.) |
| BARTEL | 80 | ZPHY C6 295 | W. Bartel et al. | ` (JADE Collab.) |
| BASILE | 80 | LNC 29 251 | | BGNA, CERN, FRAS, ROMA+) |
| BUSSIERE MARINELLI | 80 80 B | NP B174 1 PL 94B 433 | A. Bussiere et al. M. Marinelli, G. Morpurgo | (BGNA, SACL, LAPP) (GENO) |
| Also | 000 | PL 94B 427 | M. Marinelli, G. Morpurgo | (GENO) |
| BOYD | 79 | PRL 43 1288 | R.N. Boyd et al. | (OSU) |
| BOZZOLI | 79 | NP B159 363 | W. Bozzoli et al. | (BGNA, LAPP, SACL+) |
| LARUE Also | 79 | PRL 42 142 PRL 42 1019 | G.S. Larue, W.M. Fairban G.S. Larue, W.M. Fairban | nk, J.D. Phillips (STAN) |
| OGOROD | 79 | JETP 49 953 | G.S. Larue, W.M. Fairbar D.D. Ogorodnikov, I.M. S 1881. M.L. Stevenson | amoilov, A.M. Solntsev |
| | | Translated from ZETF 76 | 1881. | |
| STEVENSON BASILE | 79 78 | PR D20 82 NC 45A 171 | M.L. Stevenson M. Basile et al. | |
| BASILE | 78 B | NC 45A 171 NC 45A 281 | M. Basile et al. | (CERN, BGNA) (CERN, BGNA) |
| BOYD | 78 | PRL 40 216 | R.N. Boyd et al. | (ROCH) |
| D OL CD | 78 B | DI 70D 101 | D. N. D. T. | |
| BOYD | | PL 72B 484 | R.N. Boyd et al. | (ROCH) |
| LUND PUTT | 78 78 | RA 25 75 PR D17 1466 | T. Lund, R. Brandt, Y. F G.D. Putt, P.C.M. Yock | |

²⁵ With telescope axis at zenith angle 40° to the south.

²⁶ Leptonic quarks.

27 Lifetime > 10⁻⁸ s; charge ±0.70, 0.68, 0.42; and mass >4.4, 4.8, and 20 GeV, respectively.

28 Time delayed air shower search.

²⁹ Prompt air shower search. 30 Also e/4 and e/6 charges.

³⁵ Note that in PHILLIPS 88 these authors report a subtle magnetic effect which could account for the apparent fractional charges.
36 Limit inferred by JONES 77B.

Quark Particle Listings Free Quark Searches

| SCHIFFER | 70 | PR D17 2241 | LD Cabiffra at all | (CIUC ANIL) | CHIZHCHIAA | 69 | PR 178 2058 | W. E. B. M. Land | (TOKY) |
|------------|------|-------------------------|------------------------------------------|-----------------|------------|------|-------------------------|-------------------------------------------|--------------|
| | 78 | | J.P. Schiffer et al. | (CHIC, ANL) | FUKUSHIMA | | | Y. Fukushima et al. | |
| YOCK | 78 | PR D18 641 | P.C.M. Yock | (AUCK) | MCCUS KER | 69 | PRL 23 658 | C.B.A. McCusker, I. Cairns | (SYDN) |
| ANTREASYAN | | PRL 39 513 | D. Antreasyan et al. | (EFI, PRIN) | BELLAMY | 68 | PR 166 1391 | | (STAN, SLAC) |
| | 77 | NC 40A 41 | | CERN, BGNA) | BJORNBOE | 68 | NC B53 241 | | ATA, BERN+) |
| BLAND | 77 | PRL 39 369 | R.W. Bland et al. | (SFSU) | BRAGINSK | 68 | JETP 27 51 | V.B. Braginsky et al. | (MOSU) |
| | 77 | PRL 38 1255 | G. Gallinaro, M. Marinelli, G. Morpurgo | (GENO) | | | Translated from ZETF 54 | | |
| JONES | 77 B | RMP 49 717 | L.W. Jones | | BRIATORE | 68 | NC 57A 850 | | CERN, BGNA) |
| LARUE | 77 | PRL 38 1011 | G.S. Larue, W.M. Fairbank, A.F. Hebard | (STAN) | FRANZINI | 68 | PRL 21 1013 | P. Franzini, S. Shulman | (COLU) |
| MULLER | 77 | SCI 196 521 | R.A. Muller et al. | `(LBL) | GARMIRE | 68 | PR 166 1280 | G. Garmire, C. Leong, V. Sreekantan | (MIT) |
| OGOROD | 77 | JETP 45 857 | D.D. Ogorodnikov, I.M. Samoilov, A.M. So | | HANAYAMA | 68 | CJP 46 S734 | Y. Hanayama et al. | (OSAK) |
| 0001100 | | Translated from ZETF 72 | | | KASHA | 68 | PR 172 1297 | H. Kasha, R.J. Stefanski | (BNL. YALE) |
| BALDIN | 76 | SJNP 22 264 | B.Y. Baldin et al. | (JINR) | KAS HA | 68 B | PRL 20 217 | H. Kasha et al. | BNL, YALE |
| | | Translated from YAF 22 | 512. | · / | KAS HA | 68 C | CJP 46 S730 | H. Kasha et al. | (BNL, YALE) |
| BRIATORE | 76 | NC 31A 553 | L. Briatore et al. (LCGT, | FRAS, FREIB) | RANK | 68 | PR 176 1635 | D. Rank | (MICH) |
| STEVENS | 76 | PR D14 716 | C.M. Stevens, J.P. Schiffer, W. Chupka | (ANL) | BARTON | 67 | PRSL 90 87 | J.C. Barton | (NPOL) |
| ALBROW | 75 | NP B97 189 | | DARE, FÒM+) | BATHOW | 67 | PL 25B 163 | G. Bathow et al. | (DESY) |
| FABJAN | 75 | NP B101 349 | | CERN. MPIMÍ | BUHLER | 67 | NC 49A 209 | | CERN. BGNA |
| | 75 | NP B95 189 | | (MICH, LEED) | | | | | |
| | 75 | PL 56B 105 | | ACH. CERN+) | BUHLER | 67 B | NC 51A 837 | | ERN, BGNA+) |
| KRIS OR | 75 | NC 27A 132 | K. Krisor | (AACH3) | FOSS | 67 | PL 25B 166 | J. Foss et al. | (MIT) |
| | | | | | GOMEZ | 67 | PRL 18 1022 | R. Gomez et al. | (CIT) |
| | | PR D10 2721 | A.F. Clark et al. | (LLL) | KAS HA | 67 | PR 154 1263 | H. Kasha et al. | (BNL, YALE) |
| | 74 | PR D9 1856 | | (SLAC, FNAL) | STOVER | 67 | PR 164 1599 | R.W. Stover, T.I. Moran, J.W. Trischka | (SYRA) |
| | 74 | JPSJ 36 629 | | (TOKY, KEK) | BARTON | 66 | PL 21 360 | J.C. Barton, C.T. Stockel | (NPOL) |
| | 74 | PRL 32 858 | | CORN, NYU) | BENNETT | 66 | PRL 17 1196 | W.R. Bennett | (YALE) |
| ALPER | 73 | PL 46B 265 | B. Alper et al. (CERN, LÎVP, LU | | BUHLER | 66 | NC 45A 520 | A. Buhler-Broglin et al. (C | ERN, BĠNA+ĺ |
| ASHTON | 73 | JPA 6 577 | F. Ashton et al. | (DURH) | CHUPKA | 66 | PRL 17 60 | W.A. Chupka, J.P. Schiffer, C.M. Stevens | (ANL) |
| HICKS | 73 B | NC 14A 65 | R.B. Hicks, R.W. Flint, S. Standil | (MANI) | GALLINARO | 66 | PL 23 609 | G. Gallinaro, G. Morpurgo | (GENO) |
| LEIPUNER | 73 | PRL 31 1226 | L.B. Leipuner et al. | (BNL, YALE) | KASHA | 66 | PR 150 1140 | H. Kasha, L.B. Leipuner, R.K. Adair | (BNL. YALE) |
| BEAUCHAMP | 72 | PR D6 1211 | W.T. Beauchamp et al. | (ARIZ) | LAMB | 66 | PRL 17 1068 | R.C. Lamb et al. | (ANL) |
| BOHM | 72 B | PRL 28 326 | A. Bohm et al. | (ÀA CHÍ | DELISE | 65 | PR 140B 458 | D.A. de Lise, T. Bowen | (ARIZ) |
| BOTT | 72 | PL 40B 693 | M. Bott-Bodenhausen et al. (| CERN. M PIM S | DORFAN | 65 | PRL 14 999 | D.E. Dorfan et al. | (COLU) |
| COX | 72 | PR D6 1203 | A.J. Cox et al. | (ARIZ) | FRANZINI | 65 B | PRL 14 196 | P. Franzini et al. | (BNL. COLU) |
| | 72 | PR D5 2667 | M.F. Crouch, K. Mori, G.R. Smith | (CASE) | MASSAM | 65 | NC 40A 589 | T. Massam, T. Muller, A. Zichichi | (CERN) |
| DARDO | 72 | NC 9A 319 | M. Dardo et al. | (TORI) | | | | | |
| | 72 | PRSE A70 143 | | (EDIN, LEED) | BINGHAM | 64 | PL 9 201 | | (CERN, EPOL) |
| | 72 | JPA 5 569 | S.C. Tonwar, S. Naranan, B.V. Sreekantan | | BLUM | 64 | PRL 13 353A | W. Blum et al. | (CERN) |
| | | | | | BOWEN | 64 | PRL 13 728 | T. Bowen et al. | (ARIZ) |
| | 71 | NP B29 374 | Y.M. Antipov et al. | (SERP) | HAGOPIAN | 64 | PRL 13 280 | V. Hagopian et al. | (PENN, BNL) |
| | 71_ | NC 2A 419 | S. Chin et al. | (OSAK) | LEIPUNER | 64 | PRL 12 423 | L.B. Leipuner et al. | (BNL, YALE) |
| | 71B | PRL 27 51 | A.F. Clark et al. | (LLL, LBL) | MORRISON | 64 | PL 9 199 | D.R.O. Morrison | (CERN) |
| | 71 | PRL 26 582 | W.E. Hazen | (MICH) | SUNYAR | 64 | PR 136 B1157 | A.W. Sunyar, A.Z. Schwarzschild, P.I. Con | nors (BNL) |
| BOSIA | 70 | NC 66A 167 | G.F. Bosia, L. Briatore | (TORI) | HILLAS | 59 | NAT 184 B92 | A.M. Hillas, T.E. Cranshaw | (ÀERE) |
| CHU | 70 | PRL 24 917 | W.T. Chu et al. (OSU, | ROSE, KANS) | MILLIKAN | 10 | Phil Mag 19 209 | R.A. Millikan | (CHIC) |
| A Iso | | PRL 25 550 | W.W.M. Allison et al. | (ANL) | | | | | \ / |
| ELBERT | 70 | NP B20 217 | J.W. Elbert et al. | (WIS C) | | | OTHER | DELATED DADEDO | |
| FAISSNER | 70 B | PRL 24 1357 | H. Faissner et al. | (A`ACH3`) | | | UTHER | RELATED PAPERS ——— | |
| KRIDER | 70 | PR D1 835 | E.P. Krider, T. Bowen, R.M. Kalbach | `(ARIZ) | | | | | |
| | 70 | NIM 79 95 | G. Morpurgo, G. Gallinaro, G. Palmieri | (ĠENO) | LYONS | 85 | PRPL C129 225 | L. Lyons | (OXF) |
| ALLABY | | NC 64A 75 | J.V. Allaby et al. | CERN | Review | | | * | () |
| ANTIPOV | 69 | PL 29B 245 | Y.M. Antipov et al. | (SERP) | MARINELLI | 82 | PRPL 85 161 | M. Marinelli, G. Morpurgo | (GENO) |
| ANTIPOV | | PL 30B 576 | Y.M. Antipov et al. | SERP | Review | | | | (=) |
| CAIRNS | 69 | PR 186 1394 | I. Cairns et al. | (SERF) | | | | | |
| COOK | 69 | PR 188 2092 | D.D. Cook et al. | (SYDN) (ILL) | | | | | |
| COOK | 0.9 | FK 100 2072 | D.D. COOK Et al. | (ILL) | | | | | |
| | | | | | | | | | |

| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | LIGHT UNFLAVORED MESONS ($S =$ | C = B = 0 | • $f_2(2010)$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------|--------------------------------------------|
| $\begin{array}{c} \bullet \\ \bullet \\ \neg \\$ | • | • | * = } (|
| $\begin{array}{c} \bullet, \eta \\ \bullet, h(500) \\ \bullet, h(500) \\ \rho(770) \\ \rho$ | | | 30() |
| $\begin{array}{c} \mathbf{i}_{0}(500) \\ \rho(770) \\ \rho(770) \\ \sigma(782) \\ \sigma(798) \\ \sigma(798) \\ \sigma(998) \\ \sigma(1980) \\ \sigma(1170) \\ \sigma(1170) \\ \sigma(11235) \\ \sigma(11235) \\ \sigma(11235) \\ \sigma(11235) \\ \sigma(11235) \\ \sigma(11235) \\ \sigma(11236) \\ \sigma(11235) \\ \sigma(11236) \\ \sigma(11285) \\ \sigma(11300) \\ \sigma(11300) \\ \sigma(11300) \\ \sigma(11300) \\ \sigma(11300) \\ \sigma(11300) \\ \sigma(11420) \\ \sigma(11430) \\ \sigma(11450) \\ $ | | | |
| $\begin{array}{c} \rho (770) \\ \omega (782) \\ \omega (782) \\ \gamma (1958) \\ \gamma (1020) \\ \gamma (1170) \\ \gamma (1120) \\ \gamma (1120$ | • | | |
| $\begin{array}{c} \bullet (782) \\ \bullet (782) \\ \bullet (7638) \\ \bullet (7638) \\ \bullet (1690) \\ \bullet (1690) \\ \bullet (1020) \\ \bullet (11235) \\ \bullet (11235) \\ \bullet (1235) \\ \bullet (1235) \\ \bullet (1240) \\ \bullet (1220) \\ \bullet (1230) \\ \bullet (1370) \\ \bullet (1$ | | | |
| $ \begin{array}{c} \bullet f/9(88) \\ \bullet f_0(880) \\ \bullet f_0(980) \\ \bullet f_0(980) \\ \bullet f_0(980) \\ \bullet f_0(120) \\ \bullet f_0(1235) \\ \bullet f_0(1220) \\ \bullet f_0(1235) \\ \bullet f_0(1235) \\ \bullet f_0(1285) \\ \bullet f_0(1285) \\ \bullet f_0(1285) \\ \bullet f_0(1295) \\ \bullet f_0(1295) \\ \bullet f_0(1295) \\ \bullet f_0(1295) \\ \bullet f_0(1330) \\ \bullet f_0(1295) \\ \bullet f_0(1300) \\ \bullet f_0(1320) \\ \bullet f_0(1370) \\ \bullet f_0(1370) \\ \bullet f_0(1380) \\ \bullet f_0(1370) \\ \bullet f_0(1380) \\ \bullet f_0(1450) \\ \bullet f_0(1500) \\ $ | | | |
| $\begin{array}{c} b_0(980) \\ a_0(980) \\ a_0(980) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0) \\ (0$ | | | * \ / |
| $\begin{array}{c} \bullet_{0}(980) \\ \bullet_{0}(1020) \\ \bullet_{0}(1020) \\ \bullet_{1}(1170) \\ \bullet_{1}(1170) \\ \bullet_{1}(1235) \\ \bullet_{2}(1200) \\ \bullet_{3}(1200) \\ \bullet_{1}(1235) \\ \bullet_{1}(1270) \\ \bullet_{1}(1285) \\ \bullet_{1}(1295) \\ \bullet_{1}(1295) \\ \bullet_{1}(1300) \\ \bullet_{1}(1300) \\ \bullet_{1}(1295) \\ \bullet_{1}(1300) \\ \bullet_{1}(1300) \\ \bullet_{1}(1300) \\ \bullet_{1}(1300) \\ \bullet_{1}(1300) \\ \bullet_{2}(1320) \\ \bullet_{2}(1320) \\ \bullet_{2}(1320) \\ \bullet_{3}(1370) \\ \bullet_{1}(1380) \\ \bullet_{3}(1380) \\ \bullet_{3}(1400) \\ \bullet_{3}(1400) \\ \bullet_{3}(1400) \\ \bullet_{3}(1420) \\ \bullet_{3}(1420) \\ \bullet_{3}(1420) \\ \bullet_{4}(1420) \\ \bullet_{2}(1420) \\ \bullet_{3}(1420) \\ \bullet_{3}(1420) \\ \bullet_{3}(1420) \\ \bullet_{4}(1420) \\ \bullet_{5}(1430) \\ \bullet_{1}(1430) \\ \bullet_{1}(1450) \\ \bullet_{1}(1450) \\ \bullet_{2}(1430) \\ \bullet_{3}(1450) \\ \bullet_{3}(1450) \\ \bullet_{3}(1450) \\ \bullet_{3}(1450) \\ \bullet_{3}(1450) \\ \bullet_{3}(1450) \\ \bullet_{4}(1450) \\ \bullet_{5}(1500) \\ \bullet_{5}(1500) \\ \bullet_{5}(1500) \\ \bullet_{5}(1650) \\ \bullet_{7}(1650) \\ \bullet_{7}(1650$ | | | • ` ' |
| $ \begin{array}{c} \bullet \phi(1020) \\ \bullet h_1(170) \\ \bullet h_1(170) \\ \bullet h_1(135) \\ \bullet h_1(235) \\ \bullet h_1(235) \\ \bullet h_1(235) \\ \bullet h_1(236) \\ \bullet h_1(270) \\ \bullet h_1(270) \\ \bullet h_1(270) \\ \bullet h_1(285) \\ \bullet h_1(2870) \\ \bullet h_1(287$ | | | |
| $\begin{array}{c} \bullet_{1}(1170) \\ \bullet_{5}(1235) \\ \bullet_{5}(12260) \\ \bullet_{6}(12260) \\ \bullet_{5}(1270) \\ \bullet_{5}(1270) \\ \bullet_{5}(1270) \\ \bullet_{7}(1295) \\ \bullet_{7}(1300) \\ \bullet_{7}(1400) \\ \bullet_{7}(1400) \\ \bullet_{7}(1400) \\ \bullet_{7}(1420) \\ \bullet_{7}(1$ | | | |
| $\begin{array}{c} \bullet_{1}(1235) & 742 & \rho_{3}(2250) \\ \bullet_{4}(1260) & 743 & \bullet_{5}(2300) \\ \bullet_{5}(1270) & 745 & \bullet_{5}(2300) \\ \bullet_{5}(1285) & 748 & \bullet_{5}(2330) \\ \bullet_{7}(1285) & 751 & \bullet_{5}(2340) \\ \bullet_{7}(1300) & 751 & \rho_{5}(2350) \\ \bullet_{2}(320) & 752 & \bullet_{6}(2450) \\ \bullet_{5}(1370) & 755 & \bullet_{5}(2510) \\ \bullet_{1}(1380) & 755 & \bullet_{5}(2510) \\ \bullet_{1}(1380) & 755 & \bullet_{5}(2510) \\ \bullet_{1}(1400) & 755 & \bullet_{5}(2510) \\ \bullet_{1}(1405) & 758 & \bullet_{7}(1420) \\ \bullet_{1}(1405) & 758 & \bullet_{7}(1420) \\ \bullet_{1}(1420) & 763 & \bullet_{7}(1420) \\ \bullet_{1}(1420) & 765 & \bullet_{8}(1420) \\ \bullet_{1}(1450) & 766 & \bullet_{8}(1420) \\ \bullet_{1}(1450) & 767 & \bullet_{8}(1420) \\ \bullet_{1}(1475) & 769 & \bullet_{8}(800) \\ \bullet_{1}(1475) & 769 & \bullet_{8}(800) \\ \bullet_{1}(1475) & 769 & \bullet_{8}(800) \\ \bullet_{1}(1500) & 770 & \bullet_{8}(822) \\ \bullet_{1}(1510) & 777 & \bullet_{8}(11400) \\ \bullet_{1}(1500) & 778 & \bullet_{1}(1400) \\ \bullet_{1}(1500) & 778 & \bullet_{1}(1400) \\ \bullet_{1}(1500) & 778 & \bullet_{1}(1400) \\ \bullet_{1}(1595) & 778 & \bullet_{1}(1400) \\ \bullet_{1}(1640) & 779 & \bullet_{1}(1600) \\ \bullet_{1}(1640) & 779 & \bullet_{1}(1650) \\ \bullet_{1}(1640) & 779 & \bullet_{1}(1650) \\ \bullet_{1}(1650) & 780 & \bullet_{1}(1650) \\ \bullet_{1}(1650) & 781 & \bullet_{2}(180) \\ \bullet_{1}(1600) & 781 & \bullet_{2}(180) \\ \bullet_{1}(1600) & 781 & \bullet_{2}(180) \\ \bullet_{1}(1600) & 782 & \bullet_{2}(180) \\ \bullet_{1}(1600) & 793 & \bullet_{1}(2520) \\ \bullet_{1}(1710) & 793 & \bullet_{1}(200) \\ \bullet_{1}(180) & 795 & \bullet_{1}(230) \\ \bullet_{2}(180) & 795 & \bullet_{2}(230) \\ \bullet_{2}(180) & 795 & \bullet_{2}(230) \\ \bullet_{2}(180)$ | ' ' | | |
| $ \begin{array}{c} \bullet_{1}(1260) & 743 & - f_{2}(3300) \\ \bullet_{2}(1270) & 745 & f_{2}(3300) \\ \bullet_{3}(1285) & 748 & f_{2}(330) \\ \bullet_{3}(1295) & 751 & - f_{2}(2350) \\ \bullet_{2}(1320) & 751 & - f_{2}(2350) \\ \bullet_{2}(1320) & 752 & - f_{2}(2550) \\ \bullet_{3}(1370) & 755 & f_{6}(2510) \\ \bullet_{1}(1380) & 758 & OTHER LIGHT UNFLAVORED (S = C = B = Further States) \\ \bullet_{1}(1400) & 758 & OTHER LIGHT UNFLAVORED (S = C = B = Further States) \\ \bullet_{1}(1400) & 759 & STRANGE MESONS (S = \pm 1, C = B = 0) \\ \bullet_{1}(1420) & 763 & K^{\pm} \\ \bullet_{1}(1420) & 765 & K^{0} \\ \bullet_{2}(1430) & 766 & K^{0} \\ \bullet_{2}(1430) & 766 & K^{0} \\ \bullet_{2}(1430) & 766 & K^{0} \\ \bullet_{3}(1450) & 767 & K^{0} \\ \bullet_{1}(1475) & 769 & K^{0}_{3}(800) \\ \bullet_{1}(1510) & 773 & K_{1}(1270) \\ \bullet_{1}(1510) & 773 & K_{1}(1200) \\ \bullet_{1}(1510) & 773 & K_{1}(1400) \\ \bullet_{2}(1555) & 774 & K_{1}(1400) \\ \bullet_{2}(1565) & 776 & K^{0}_{3}(1400) \\ \bullet_{1}(1595) & 778 & K^{0}_{3}(130) \\ \bullet_{1}(1640) & 779 & K_{2}(180) \\ \bullet_{2}(1640) & 779 & K_{2}(180) \\ \bullet_{2}(1640) & 779 & K_{2}(180) \\ \bullet_{2}(1670) & 781 & K_{2}(1770) \\ \bullet_{2}(1670) & 781 & K_{2}(1770) \\ \bullet_{2}(1680) & 783 & K_{2}(1820) \\ \bullet_{2}(1670) & 784 & K_{2}(180) \\ \bullet_{2}(1670) & 785 & K_{3}(180) \\ \bullet_{2}(1670) & 781 & K_{2}(170) \\ \bullet_{2}(1700) & 782 & K_{3}(180) \\ \bullet_{2}(1700) & 792 & K_{3}(180) \\ \bullet_{2}(1700) & 793 & K_{3}(230) \\ \bullet_{2}(1700) & 794 & K_{3}(230) \\ \bullet_{2}(1700) & 795 & K_{3}(230) \\ \bullet_{2}(1810) & 797 & K_{3}(230) \\ \bullet_{2}(1810) & 799 & K_{3}(230) \\ \bullet_{2}(1810) & 799 & K_{3}(230) \\ \bullet_{2}(1810) & 799 & K_{3}(230) \\ \bullet_{2}(1870) & 799 & K_{3}(230) \\ \bullet_{2}(1880) & 799 & K_{3}(200) \\ \bullet_{2}(1800) & 90 & 90 & 90 \\ \bullet_{2}(1800) & 90 & 90 & 90 \\ \bullet_{2}(1800) & 90 & 90$ | = \ / | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | V=\ / |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | V=\ / | | |
| $\begin{array}{c} \bullet \pi(1300) & 751 & \rho_5(2350) \\ \bullet o_2(1320) & 752 & o_6(2450) \\ \bullet f_0(1370) & 755 & f_6(2510) \\ \bullet f_1(1380) & 758 & OTHER LIGHT UNFLAVORED (S = C = B = Further States) \\ \bullet \pi(1400) & 758 & STRANGE MESONS (S = \pm 1, C = B = 0) \\ \bullet f_1(1420) & 763 & K^{\pm} \\ \bullet f_1(1420) & 766 & K^0 \\ \bullet f_1(1420) & 766 & K^0 \\ \bullet f_2(1430) & 766 & K^0 \\ \bullet o_2(1450) & 766 & K^0 \\ \bullet o_2(1450) & 766 & K^0 \\ \bullet f_1(1450) & 767 & K^0 \\ \bullet f_1(1450) & 767 & K^0 \\ \bullet f_1(1450) & 767 & K^0 \\ \bullet f_1(150) & 770 & K^0 \\ \bullet f_1(1510) & 773 & K_1(1270) \\ \bullet f_1(1510) & 773 & K_1(1270) \\ \bullet f_2(1555) & 774 & K_1(1400) \\ \bullet f_1(150) & 777 & K^0 \\ \bullet f_1(150) & 778 & K_1(1430) \\ \bullet f_1(1640) & 779 & K_2(1580) \\ \bullet f_1(1640) & 779 & K_2(1580) \\ \bullet f_1(1640) & 779 & K_2(1580) \\ \bullet f_2(1640) & 780 & K^1(1650) \\ \bullet o_2(1670) & 781 & K^0 \\ \bullet f_2(1670) & 781 & K^0 \\ \bullet f_2(160) & 782 & K^0 \\ \bullet f_1(160) & 783 & K_2(1820) \\ \bullet f_2(1670) & 784 & K^0 \\ \bullet f_1(180) & 792 & K^0 \\ \bullet f_2(180) & 784 & K^0 \\ \bullet f_1(180) & 794 & K^0 \\ \bullet f_2(180) & 795 & K^0 \\ \bullet f_2(180) & 796 & K^0 \\ \bullet f_2(180) & 798 & K^0 \\ \bullet f_2(180) & 798 & K^0 \\ \bullet f_2(180) & 799 & CHARMED MESONS (C = \pm 1) \\ \bullet f_1(1900) & f_1(1900) \\ \bullet f_2(1910) & 800 & D^0 \\ \bullet f_1(1900) & f_1(1900) \\ \bullet f_1(1900) & 799 & D^1 \\ \bullet f_1(1900) & f_1(1900) \\ \bullet f_1(1900) & f_1$ | V-1 () | | |
| $ \begin{array}{c} \bullet g_2(1320) \\ \bullet f_0(1370) \\ \bullet f_0(1370) \\ \bullet f_0(1380) \\ \bullet f_0(1380) \\ \bullet f_0(1400) \\ \bullet f_0(1400) \\ \bullet f_0(1400) \\ \bullet f_0(1400) \\ \bullet f_0(1420) \\ \bullet f_0(1420) \\ \bullet g_0(1420) \\ \bullet g_0(1420) \\ \bullet g_0(1450) \\ \bullet g_0(1500) \\ \bullet g_0(15$ | • ` ' | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | ` ' | | 10(|
| $\begin{array}{c} h_1(1380) & 758 \\ \pi_1(1400) & 758 \\ \pi_1(1400) & 758 \\ \hline \\ f_1(1420) & 763 \\ \hline \\ f_1(1420) & 763 \\ \hline \\ f_1(1420) & 763 \\ \hline \\ f_1(1430) & 766 \\ \hline \\ f_1(1430) & 766 \\ \hline \\ f_2(1430) & 766 \\ \hline \\ f_2(1430) & 766 \\ \hline \\ f_2(1430) & 766 \\ \hline \\ f_2(1450) & 766 \\ \hline \\ f_2(1450) & 766 \\ \hline \\ f_2(1450) & 767 \\ \hline \\ f_1(1510) & 767 \\ \hline \\ f_2(1505) & 774 \\ \hline \\ f_1(1510) & 773 \\ \hline \\ f_2(1525) & 774 \\ \hline \\ f_1(1510) & 777 \\ \hline \\ f_2(1550) & 776 \\ \hline \\ f_1(1500) & 777 \\ \hline \\ f_2(1550) & 776 \\ \hline \\ f_2(1640) & 778 \\ \hline \\ f_2(1640) & 779 \\ \hline \\ f_2(1650) & 780 \\ \hline \\ f_2(1640) & 779 \\ \hline \\ f_2(1640) & 779 \\ \hline \\ f_2(1640) & 781 \\ \hline \\ f_2(1670) & 781 \\ \hline \\ f_2(1680) & 780 \\ \hline \\ f_2(1670) & 781 \\ \hline \\ f_2(1680) & 780 \\ \hline \\ f_2(1680) & 780 \\ \hline \\ f_2(1680) & 781 \\ \hline \\ f_2(1680) & 782 \\ \hline \\ f_2(1680) & 783 \\ \hline \\ f_2(1680) & 784 \\ \hline \\ f_2(1680) & 784 \\ \hline \\ f_2(1680) & 784 \\ \hline \\ f_2(1810) & 795 \\ \hline \\ f_2(1810) & 795 \\ \hline \\ f_2(1810) & 797 \\ \hline \\ f_2(1880) & 798 \\ \hline \\ f_2(1880) & 799 \\ \hline \\ f_2(1910) & 800 \\ \hline \\ f_2(1910) & 801 \\ \hline \end{array}$ | = \ / | | |
| $ \begin{array}{c} \bullet \pi_1(1400) \\ \bullet \eta(1405) \\ \bullet \eta(1420) \\ \bullet \tilde{h}(1420) \\ \bullet \omega(1420) \\ \bullet \omega(1420) \\ \bullet z_1(1450) \\ \bullet z_2(1430) \\ \bullet z_3(1450) \\ \bullet z_4(1450) \\ \bullet z_5(1450) \\ \bullet z_5(1500) \\ \bullet$ | *** | | |
| $ \begin{array}{c} \bullet & \eta(1405) \\ \bullet & f_1(1420) \\ \bullet & f_1(1420) \\ \bullet & f_2(1430) \\ \bullet & g_0(1450) \\ \bullet & g_0(1450) \\ \bullet & f_0(1450) \\ \bullet & f_0(1500) \\ \bullet & f_0(1500) \\ \bullet & f_0(1500) \\ \bullet & f_0(1500) \\ \bullet & f_0(1510) \\ \bullet & f_0(1510) \\ \bullet & f_0(1510) \\ \bullet & f_0(1500) \\ \bullet & f_0($ | | | OTHER LIGHT UNFLAVORED ($S = C = B = 0$) |
| $\begin{array}{c} \bullet \hat{h}(1420) & 763 \\ \bullet \ \ \ \ \ \ \ \ \ \ \ \ \$ | | | Further States |
| $\begin{array}{c} \bullet, 1/(1420) \\ \omega/(1420) \\ \omega/(1420) \\ -\omega/(1420) \\ -\omega/(1420) \\ -\omega/(1450) \\$ | | | STRANGE MESONS $(S = \pm 1, C = B = 0)$ |
| $\begin{array}{c} \kappa(1430) \\ \bar{k}_2(1430) \\ = a_0(1450) \\ = a_0(1450) \\ = \rho(1450) \\ = \rho(14$ | | | |
| $\begin{array}{c} p_{2}(1450) & 766 & K_{0}^{S} \\ \bullet \ a_{0}(1450) & 766 & K_{0}^{S} \\ \bullet \ \rho(1450) & 767 & K_{0}^{S}(800) \\ \bullet \ \rho(1450) & 767 & K_{0}^{S}(800) \\ \bullet \ \rho(1475) & 769 & K_{0}^{S}(800) \\ \bullet \ \rho(1500) & 770 & K^{*}(892) \\ \bullet \ \rho(1510) & 773 & K_{1}(1270) \\ \bullet \ f_{2}(1525) & 774 & K_{1}(1400) \\ \bullet \ f_{2}(1525) & 774 & K_{1}(1400) \\ \bullet \ \rho(1570) & 777 & K_{0}^{*}(1430) \\ \bullet \ \rho(1570) & 777 & K_{0}^{*}(1430) \\ \bullet \ h_{1}(1595) & 778 & K_{1}^{*}(1430) \\ \bullet \ h_{1}(1600) & 778 & K_{1}(1460) \\ \bullet \ a_{1}(1640) & 779 & K_{2}(1580) \\ \bullet \ f_{2}(1640) & 779 & K_{1}(1630) \\ \bullet \ \mu_{2}(1645) & 780 & K_{1}(1650) \\ \bullet \ \omega(1650) & 780 & K_{1}(1650) \\ \bullet \ \omega(1650) & 780 & K_{1}(1650) \\ \bullet \ \omega_{3}(1670) & 781 & K_{2}(1770) \\ \bullet \ \pi_{2}(1670) & 781 & K_{2}(1830) \\ \bullet \ \rho_{1}(1680) & 783 & K_{2}(1820) \\ \bullet \ \rho_{3}(1690) & 784 & K_{1}(1830) \\ \bullet \ \rho_{1}(1700) & 792 & K_{2}^{*}(1980) \\ \bullet \ \rho_{1}(1700) & 793 & K_{2}^{*}(2045) \\ \bullet \ \rho_{1}(1700) & 795 & K_{2}(2250) \\ \bullet \ \pi_{1}(1800) & 797 & K_{2}^{*}(2380) \\ \bullet \ \rho_{1}(1870) & 798 & K_{4}(2500) \\ \bullet \ \rho_{2}(1870) & 798 & K_{4}(2500) \\ \bullet \ \rho_{2}(1870) & 799 & CHARMED MESONS (C = \pm 1) \\ \bullet \ \rho_{1}(1900) & 799 & \rho_{1}(1900) \\ \bullet \ f_{2}(1910) & 800 & \rho_{2}(2007)^{0} \\ \bullet \ f_{2}(1910) & 801 & \rho_{2}(1910) \\ \bullet \ f_{2}(1910) & 80$ | | | • K ⁰ |
| $\begin{array}{c} \bullet_{0}(1450) & 767 & K_{0}^{T} \\ \bullet_{1}(1475) & 769 & K_{0}^{*}(800) \\ \bullet_{0}(1500) & 770 & K^{*}(892) \\ \bullet_{1}(1510) & 773 & K_{1}(1270) \\ \bullet_{2}(1525) & 774 & K_{1}(1400) \\ \bullet_{2}(1565) & 776 & K^{*}(1410) \\ \bullet_{1}(570) & 777 & K_{0}^{*}(1430) \\ \bullet_{1}(1595) & 778 & K_{0}^{*}(1430) \\ \bullet_{1}(1595) & 778 & K_{0}^{*}(1430) \\ \bullet_{1}(1600) & 778 & K_{0}^{*}(1430) \\ \bullet_{1}(1640) & 779 & K_{2}(1580) \\ \bullet_{2}(1640) & 779 & K_{1}(1630) \\ \bullet_{2}(1640) & 779 & K_{1}(1630) \\ \bullet_{2}(1645) & 780 & K_{1}(1650) \\ \bullet_{2}(1650) & 780 & K_{1}(1650) \\ \bullet_{2}(1670) & 781 & K_{2}(1770) \\ \bullet_{2}(1670) & 781 & K_{2}(1770) \\ \bullet_{2}(1670) & 781 & K_{1}(1830) \\ \bullet_{2}(1600) & 783 & K_{2}(1820) \\ \bullet_{2}(1600) & 784 & K_{1}(1830) \\ \bullet_{2}(1700) & 788 & K_{0}^{*}(1950) \\ \bullet_{2}(1700) & 792 & K_{2}^{*}(1980) \\ \bullet_{2}(1700) & 793 & K_{4}^{*}(2045) \\ \bullet_{1}(1800) & 795 & K_{3}(2320) \\ \bullet_{2}(1810) & 797 & K_{5}^{*}(2380) \\ \bullet_{2}(1870) & 798 & K_{4}(2500) \\ \bullet_{2}(1870) & 798 & K_{4}(2500) \\ \bullet_{2}(1870) & 799 & K_{1}(1800) \\ \bullet_{2}(1870) & 799 & K_{1}(1800) \\ \bullet_{2}(1870) & 799 & K_{1}(2500) \\ \bullet_{2}(1880) & 799 & K_{1}(2500) \\ \bullet_{2}(1880) & 799 & K_{1}(2500) \\ \bullet_{2}(1870) & 799 & K_{1}(2100) \\ \bullet_{2}(1990) & 799 & K_{1}(2100) \\ \bullet_{2}(1990) & 799 & K_{1}(2100) \\ \bullet_{2}(1990) & 799 & K_{1}(2100) \\ \bullet_{2}(1870) & 799 & K_{2}(2100) \\ \bullet_$ | | | |
| $\begin{array}{c} \bullet & \eta(1475) & 769 & K_0^*(800) \\ \bullet & f_0(1500) & 770 & \bullet & K^*(892) \\ f_1(1510) & 773 & \bullet & K_1(1270) \\ \bullet & f_2'(1525) & 774 & \bullet & K_1(1400) \\ f_2(1565) & 776 & \bullet & K^*(1410) \\ \bullet & f_2(1565) & 776 & \bullet & K^*(1410) \\ \bullet & f_2(1570) & 777 & \bullet & K_0^*(1430) \\ \bullet & f_1(1595) & 778 & \bullet & K_2^*(1430) \\ \bullet & f_1(1600) & 778 & \bullet & K_2^*(1430) \\ \bullet & f_1(1600) & 779 & \bullet & K_1(1400) \\ \bullet & f_1(1640) & 779 & K_1(1630) \\ \bullet & f_2(1640) & 779 & K_1(1630) \\ \bullet & f_2(1640) & 779 & K_1(1630) \\ \bullet & f_2(1650) & 780 & K^*(1680) \\ \bullet & f_2(1650) & 780 & \bullet & K^*(1680) \\ \bullet & f_2(1670) & 781 & \bullet & K_2^*(1770) \\ \bullet & f_2(1670) & 781 & \bullet & K_3^*(1780) \\ \bullet & f_2(1690) & 784 & K_1(1830) \\ \bullet & f_2(1690) & 784 & K_1(1830) \\ \bullet & f_2(1700) & 788 & K_0^*(1950) \\ \bullet & f_2(1700) & 792 & K_2^*(1980) \\ \bullet & f_2(1700) & 793 & \bullet & K_2(2250) \\ \bullet & f_1(1800) & 795 & K_2(2250) \\ \bullet & f_1(1800) & 795 & K_2(2250) \\ \bullet & f_2(1810) & 797 & K_5^*(2380) \\ & f_2(1810) & 797 & K_5^*(2380) \\ & f_2(1870) & 798 & K_4(2500) \\ \bullet & f_2(1880) & 799 & K_4(2500) \\ \bullet & f_2(1880) & 799 & K_4(2010) \\ \bullet & f_2(1950) & 801 & D^*(2007)^0 \\ \bullet & f_2(1950) & 801 & D^$ | 5. | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • \ / | | <u> </u> |
| $\begin{array}{c} \widehat{h}_1(1510) & 773 & *K_1(1270) \\ \bullet f_2'(1525) & 774 & *K_1(1400) \\ f_2(1565) & 776 & *K^*(1410) \\ \rho(1570) & 777 & *K_0^*(1430) \\ h_1(1595) & 778 & *K_3(1430) \\ \bullet \pi_1(1600) & 778 & K(1460) \\ a_1(1640) & 779 & K_2(1580) \\ f_2(1640) & 779 & K_2(1580) \\ \bullet \eta_2(1645) & 780 & K_1(1650) \\ \bullet \omega(1650) & 780 & *K^*(1680) \\ \bullet \omega_3(1670) & 781 & *K_2(1770) \\ \bullet \pi_2(1670) & 781 & *K_3(1780) \\ \bullet \phi(1680) & 783 & *K_2(1820) \\ \bullet \rho_3(1690) & 784 & K(1830) \\ \bullet \rho(1700) & 788 & K_0^*(1950) \\ \bullet \sigma_2(1700) & 792 & K_3^*(1980) \\ \bullet f_0(1710) & 793 & *K_4(2045) \\ \eta(1760) & 795 & K_2(2250) \\ \bullet \pi(1800) & 795 & K_3(2320) \\ f_2(1810) & 797 & K_5^*(2380) \\ \bullet \phi_3(1850) & 798 & K_4(2500) \\ \bullet \phi_2(1880) & 799 & K_3(1980) \\ \bullet \phi_2(1880) & 799 & K_4(2500) \\ \bullet \phi_2(1880) & 799 & K_4(2500) \\ \bullet \phi_1(1910) & 799 & CHARMED MESONS (C = ±1) \\ \bullet \rho_1(1910) & 800 & \rho^{*}(2010) \pm \\ \bullet f_2(1910) & 801 & \rho^{*}(2010) \pm \\ \bullet f_2(1910) & 801 & \rho^{*}(2010) \pm \\ \end{array}$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | ` ' |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | - / |
| $\begin{array}{c} h_1(1595) \\ \hline h_1(1600) \\ \hline \pi_1(1600) \\ \hline \pi_1(1600) \\ \hline a_1(1640) \\ \hline f_2(1640) \\ \hline f_2(1640) \\ \hline \hline f_2(1645) \\ \hline \hline f_2(1645) \\ \hline \hline f_2(1650) \\ \hline \hline f_2(1650) \\ \hline \hline f_2(1670) \\ \hline \hline f_2(1670) \\ \hline \hline f_2(1680) \\ \hline \hline f_2(1680) \\ \hline \hline f_2(1680) \\ \hline \hline f_2(1670) \\ \hline \hline f_2(1700) \\ \hline $ | $f_2(1565)$ | 776 | · , |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\rho(1570)$ | 777 | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $h_1(1595)$ | 778 | • $K_2^*(1430)$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\pi_1(1600)$ | 778 | K(1460) |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $a_1(1640)$ | 779 | $K_2(1580)$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 779 | K(1630) |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\eta_2(1645)$ | 780 | $K_1(1650)$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\omega(1650)$ | 780 | • $K^*(1680)$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\omega_3(1670)$ | 781 | • $K_2(1770)$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\pi_2(1670)$ | 781 | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 783 | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • $\rho_3(1690)$ | 784 | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | ` ' |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | <u> </u> |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • • • • | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | · , | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | · = \ / | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ` ' | | |
| • $\pi_2(1880)$ | , - \ | | |
| $\rho(1900)$ | ·= \ / | | |
| $f_2(1910)$ | ` ' | | |
| • $f_2(1950)$ | | | • D^0 |
| 12(1950) | | | • $D^*(2007)^0$ |
| | | | |
| $p_3(1990)$ | | | |
| • Indicates the particle is in the Meson Summary Table (continued on the next page) | • Indicates the particle is in the Meson Summ | nary Table | |

| $D_0^*(2400)^{\pm}$ | $X(4050)^{\pm}$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|
| • $D_1(2420)^0$ | X(4140) |
| $D_1(2420)^{\pm}$ | • $\psi(4160)$ |
| $D_1(2430)^0$ | X(4160) |
| | $X(4250)^{\pm}$ |
| 2() | • X(4260) |
| • $D_2^*(2460)^{\pm}$ | |
| $D(2550)^0$ | X(4350) |
| D(2600) | X(4360) |
| $D^{*}(2640)^{\pm}$ | • $\psi(4415)$ |
| D(2750) | $X(4430)^{\pm}$ |
| | X(4660) |
| CHARMED, STRANGE MESONS $(C = S = \pm 1)$ | $b\overline{b}$ MESONS |
| • D_s^{\pm} | |
| $\bullet D_{\circ}^{s\pm} \qquad \dots \qquad \dots \qquad \dots \qquad 957$ | Bottomonium system |
| D* (2217)± | $\eta_b(1S)$ |
| • $D_{s0}^{s}(2317)^{\pm}$ | • $\Upsilon(1S)$ |
| • $D_{s1}(2460)^{\pm}$ | • $\chi_{b0}(1P)$ |
| • $D_{s1}(2536)^{\pm}$ | • $\chi_{b1}(1P)$ |
| • $D_{c2}(2573)$ | • $h_b(1P)$ |
| $D_{s1}^{*}(2700)^{\pm}$ | • $\chi_{b2}(1P)$ |
| $D_{sJ}^{*}(2860)^{\pm}$ | |
| $D_{sJ}(2000)$ | • $\Upsilon(2S)$ |
| $D_{sJ}(3040)^{\pm}$ | $\Upsilon(1D)$ |
| BOTTOM MESONS $(B = \pm 1)$ | • $\chi_{b0}(2P)$ |
| B-particle organization | • $\chi_{b1}(2P)$ |
| • B [±] | $h_b(2P)$ |
| | • $\chi_{b2}(2P)$ |
| • B^0 | • $\Upsilon(3S)$ |
| • B^{\pm}/B^0 ADMIXTURE | $\chi_b(3P)$ |
| • $B^{\pm}/B^0/B_s^0/b$ -baryon ADMIXTURE 1104 | • $\Upsilon(4S)$ |
| V_{cb} and V_{ub} CKM Matrix Elements | |
| • B^* | $X(10610)^{\pm}$ |
| | |
| $B_{\tau}^{*}(5732)$ | $X(10650)^{\pm}$ |
| $B_J^*(5732)$ | • $\Upsilon(10860)$ |
| • $B_1(5721)^0$ | |
| • $B_1(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{"}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{"}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{"}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |
| $ \bullet \ B_1^{\circ}(5721)^0 \qquad \qquad \qquad 1126 \\ \bullet \ B_2^{*}(5747)^0 \qquad \qquad \qquad 1127 \\ \textbf{BOTTOM, STRANGE MESONS} \ (B=\pm 1, S=\mp 1) \\ \bullet \ B_s^0 \qquad \qquad \qquad 1128 \\ \bullet \ B_s^{*} \qquad \qquad \qquad 1138 \\ \bullet \ B_{s1}(5830)^0 \qquad \qquad \qquad 1138 \\ \bullet \ B_{s2}^{*}(5840)^0 \qquad \qquad \qquad 1138 \\ B_{sJ}^{*}(5850) \qquad \qquad \qquad 1138 \\ \end{pmatrix} $ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{0}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{''}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{'}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1(5721)^0$ | • $\Upsilon(10860)$ |
| • $B_1^{\circ}(5721)^0$ | • $\Upsilon(10860)$ |

LIGHT UNFLAVORED MESONS (S=C=B=0)

For I = 1 (π, b, ρ, a) : $u\overline{d}$, $(u\overline{u} - d\overline{d})/\sqrt{2}$, $d\overline{u}$; for I = 0 $(\eta, \eta', h, h', \omega, \phi, f, f')$: $c_1(u\overline{u} + d\overline{d}) + c_2(s\overline{s})$



$$I^{G}(J^{P}) = 1^{-}(0^{-})$$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters **B204** 1 (1988).

π^{\pm} MASS

The most accurate charged pion mass measurements are based upon xray wavelength measurements for transitions in π^- -mesonic atoms. The observed line is the blend of three components, corresponding to different K-shell occupancies. JECKELMANN 94 revisits the occupancy question, with the conclusion that two sets of occupancy ratios, resulting in two different pion masses (Solutions A and B), are equally probable. We choose the higher Solution B since only this solution is consistent with a positive mass-squared for the muon neutrino, given the precise muon momentum measurements now available (DAUM 91, ASSAMAGAN 94, and ASSAM-AGAN 96) for the decay of pions at rest. Earlier mass determinations with pi-mesonic atoms may have used incorrect K-shell screening corrections.

Measurements with an error of $> 0.005\,$ MeV have been omitted from this Listing

| VALUE (MeV) | DOCUMENT ID | TECN CHG | COMMENT |
|-----------------------------|-----------------------------|------------------|-------------------------------------|
| 139.57018±0.00035 O | UR FIT Error includes | scale factor of | 1.2. |
| 139.57018±0.00035 O | UR AVERAGE Error in | cludes scale fac | ctor of 1.2. |
| 139.57071 ± 0.00053 | ¹ LENZ 98 | CNTR - | pionic N2-atoms gas target |
| 139.56995 ± 0.00035 | ² JECKELMANN 94 | CNTR - | π^- atom, Soln. B |
| • • • We do not use t | he following data for ave | rages, fits, lim | ts, etc. • • • |
| $139.57022 \!\pm\! 0.00014$ | ³ ASSAMAGAN 96 | SPEC + | $\pi^+ \rightarrow \mu^+ \nu_{\mu}$ |
| 139.56782 ± 0.00037 | ⁴ JECKELMANN 94 | CNTR - | π^- atom, Soln. A |
| 139.56996 ± 0.00067 | ⁵ DAUM 91 | SPEC + | $\pi^+ \rightarrow \mu^+ \nu$ |
| 139.56752 ± 0.00037 | ⁶ JECKELMANN 86B | CNTR - | Mesonic atoms |
| 139.5704 ± 0.0011 | ⁵ ABELA 84 | SPEC + | See DAUM 91 |
| 139.5664 ± 0.0009 | ⁷ LU 80 | CNTR - | Mesonic atoms |
| 139.5686 ± 0.0020 | CARTER 76 | CNTR - | Mesonic atoms |
| 139.5660 ± 0.0024 | ^{7,8} MARUSHEN 76 | CNTR - | Mesonic atoms |

- 1 LENZ 98 result does not suffer K-electron configuration uncertainties as does JECKEL-
- ² JECKELMANN 94 Solution B (dominant 2-electron K-shell occupancy), chosen for consistency with positive $m_{
 u_{\mu}}^2$
- $^3 \, {\rm ASSAMAGAN}$ 96 measures the μ^+ momentum p_μ in $\pi^+ \to \ \mu^+ \, \nu_\mu$ decay at rest to be 29.79200 \pm 0.00011 MeV/c. Combined with the μ^+ mass and the assumption $m_{
 u_{\mu}}$
- = 0, this gives the π^+ mass above; if $\textit{m}_{\nu_{\mu}}>$ 0, \textit{m}_{π^+} given above is a lower limit.
- Combined instead with m_{μ} and (assuming $^{'}\mathit{CPT})$ the π^- mass of JECKELMANN 94,
- p_{μ} gives an upper limit on $m_{\nu_{\mu}}$ (see the ν_{μ}). 4 JECKELMANN 94 Solution A (small 2-electron K-shell occupancy) in combination with either the DAUM 91 or ASSAMAGAN 94 pion decay muon momentum measurement yields a significantly negative $m_{
 u_{\mu}}^2$. It is accordingly not used in our fits.
- 5 The DAUM 91 value includes the ABELA 84 result. The value is based on a measurement of the μ^+ momentum for π^+ decay at rest, $\rho_\mu=$ 29.79179 \pm 0.00053 MeV, uses $m_\mu=$ 105.658389 \pm 0.000034 MeV, and assumes that $m_{\nu_\mu}=$ 0. The last assumption means that in fact the value is a lower limit.
- that in fact the value is a lower limit. 6 JECKELMANN 868 gives $m_{e}/m_{e}=273.12677(71)$. We use $m_{e}=0.51099906(15)$ MeV from COHEN 87. The authors note that two solutions for the probability distribution of K-shell occupancy fit equally well, and use other data to choose the lower of the two
- possible π^\pm masses. 7 These values are scaled with a new wavelength-energy conversion factor $\textit{V}\lambda =$ $1.23984244(37) imes 10^{-6}$ eV m from COHEN 87. The LU 80 screening correction relies upon a theoretical calculation of inner-shell refilling rates.
- 8 This MARUSHENKO 76 value used at the authors' request to use the accepted set of calibration γ energies. Error increased from 0.0017 MeV to include QED calculation error of 0.0017 MeV (12 ppm).

$$m_{\pi^+} - m_{\mu^+}$$

Measurements with an error >~0.05~MeV have been omitted from this

| VALUE (MeV) | EVTS | DO CUMENT | ID | TECN | CHG | COMMENT |
|------------------------|--------------|-----------------|-------------|---------|--------|-------------------------------|
| • • • We do not use t | he following | g data for aver | ages, fits, | limits, | etc. • | • • |
| 33.91157 ± 0.00067 | | 9 DAUM | 91 | SPEC | + | $\pi^+ \rightarrow \mu^+ \nu$ |
| 33.9111 ± 0.0011 | | ABELA | 84 | SPEC | | See DAUM 91 |
| 33.925 ± 0.025 | | воотн | 70 | CNTR | + | Magnetic spect. |
| 33.881 ± 0.035 | 145 | HYMAN | 67 | HEBC | + | K− He |

 9 The DAUM 91 value assumes that $m_{
u_{\mu}}=$ 0 and uses our $m_{\mu}=$ 105.658389 \pm 0.000034

$$(m_{\pi^+} - m_{\pi^-}) / m_{\text{average}}$$

A test of CPT invariance

VALUE (units 10^{-4}) DOCUMENT ID TECN 71 CNTR 2±5 AYRES

π± MEAN LIFE

Measurements with an error $> 0.02 \times 10^{-8}$ s have been omitted.

| VALUE (10 ⁻⁸ s) | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------|-------------------|---------|-------------|--------|--------------------|
| 2.6033 ± 0.0005 OUR AVERAGE | Error includes s | cale 1 | factor of | 1.2. | |
| 2.60361 ± 0.00052 |) KOPTEV | 95 | SPEC | + | Surface μ^+ 's |
| $2.60231 \pm 0.00050 \pm 0.00084$ | NUMAO | 95 | SPEC | + | Surface μ^+ 's |
| 2.609 ±0.008 | DUNAITSEV | 73 | CNTR | + | |
| 2.602 ± 0.004 | AYRES | 71 | CNTR | ± | |
| 2.604 ± 0.005 | NORDBERG | 67 | CNTR | + | |
| 2.602 ± 0.004 | ECKHAUSE | 65 | CNTR | + | |
| | data for averages | , fits, | , limits, e | etc. • | • • |
| 2.640 ±0.008 | KINSEY | 66 | CNTR | + | |

 $^{10}\, extsf{KOPTEV}$ 95 combines the statistical and systematic errors; the statistical error domi-

nates. 11 Systematic errors in the calibration of this experiment are discussed by NORDBERG 67.

$$(\tau_{\pi^+} - \tau_{\pi^-}) / \tau_{\text{average}}$$

A test of CPT invariance.

| VALUE (units 10^{-4}) | DO CUMENT ID | | TECN | | | | |
|--------------------------------------------------------------------|-------------------------|----------|----------------------|--|--|--|--|
| 5.5 ± 7.1 | AYRES | 71 | CNTR | | | | |
| • • • We do not use the follow | ring data for averages | s, fits, | , limits, etc. • • • | | | | |
| -14 ± 29 | PETRUKHIN | 68 | CNTR | | | | |
| 40 ±70 | BARDON | | | | | | |
| 23 ±40 | ¹² LOBKOWICZ | 66 | CNTR | | | | |
| 12 This is the most conservative value given by LOBKOWICZ 66. | | | | | | | |

π^+ DECAY MODES

 π^- modes are charge conjugates of the modes below.

For decay limits to particles which are not established, see the section on Searches for Axions and Other Very Light Bosons.

| | Mode | Fraction (Γ_i/Γ) | | | | e level |
|-----------------------|-----------------------------------|------------------------------|----------|------------|--------------------|---------|
| $\overline{\Gamma_1}$ | $\mu^+ u_{\mu}$ | [a] | (99.9877 | 0 ± 0.0000 | 04) % | |
| Γ_2 | $\mu^{\dot{+}} u_{\mu} \gamma$ | [b] | (2.00 | ±0.25 | $) \times 10^{-4}$ | |
| Γ_3 | $e^+ u_e$ | [a] | (1.230 | ±0.004 | $) \times 10^{-4}$ | |
| Γ_4 | $e^+ u_e \gamma$ | [b] | (7.39 | ±0.05 | $) \times 10^{-7}$ | |
| Γ ₅ | $e^+ u_e \pi^0$ | | (1.036 | ±0.006 | $) \times 10^{-8}$ | |
| Γ_6 | $e^+ u_e e^+ e^-$ | | (3.2 | ±0.5 | $) \times 10^{-9}$ | |
| Г¬ | $e^+ \nu_a \nu \overline{\nu}$ | | < 5 | | $\times 10^{-6}$ | 90% |

Lepton Family number (LF) or Lepton number (L) violating modes

- [a] Measurements of $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ always include decays with γ 's, and measurements of $\Gamma(e^+\nu_e\,\gamma)$ and $\Gamma(\mu^+\nu_\mu\,\gamma)$ never include low-energy γ 's. Therefore, since no clean separation is possible, we consider the modes with γ 's to be subreactions of the modes without them, and let $[\Gamma(e^+
 u_e)$ + $\Gamma(\mu^+ \nu_\mu)]/\Gamma_{\text{total}} = 100\%$.
- [b] See the Particle Listings below for the energy limits used in this measurement; low-energy γ 's are not included.
- [c] Derived from an analysis of neutrino-oscillation experiments.

π^+ BRANCHING RATIOS

 $\Gamma(e^+\nu_e)/\Gamma_{\rm total}$

See note [a] in the list of π^+ decay modes just above, and see also the next block of data. See also the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_s^+ Listings.

 $\underline{\mathit{VALUE}}$ (units 10^{-4}) 1.230±0.004 OUR EVALUATION

DO CUMENT ID

$\left[\Gamma(e^+\nu_e) + \Gamma(e^+\nu_e\gamma)\right] / \left[\Gamma(\mu^+\nu_\mu) + \Gamma(\mu^+\nu_\mu\gamma)\right]$ $(\Gamma_3+\Gamma_4)/(\Gamma_1+\Gamma_2)$

See note [a] in the list of π^+ decay modes above. See NUMAO 92 for a discussion of $e^-\mu$ universality. See also the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_S^+ Listings.

| - | | | | | |
|---------------------------------|-----------|-----------------------|-------|-----------|------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.230 ±0.004 OUR AV | ERAGE | | | | |
| $1.2346 \pm 0.0035 \pm 0.0036$ | 120k | CZAPEK | 93 | | Stopping π^+ |
| $1.2265 \pm 0.0034 \pm 0.0044$ | 190k | BRITTON | 92 | CNTR | Stopping π^+ |
| 1.218 ± 0.014 | 32k | BRYMAN | 86 | CNTR | Stopping π^+ |
| • • • We do not use the | following | data for averages, | fits, | limits, e | tc. • • • |
| 1.273 ± 0.028 | 11k | ¹³ DICAPUA | 64 | CNTR | |
| 1.21 ± 0.07 | | ANDERSON | 60 | SPEC | |
| ¹³ DICAPUA 64 has be | en update | d using the current | mea | n life. | |

 $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ Note that measurements here do not cover the full kinematic range

VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN CHG COMMENT 14 BRESSI 98 CALO + $2.0 \pm 0.24 \pm 0.08$ Stopping π^+ • • • We do not use the following data for averages, fits, limits, etc. • • • 1.24 ± 0.25 26 CASTAGNOLI 58 EMUL $KE_{\mu} < 3.38 \text{ MeV}$

 Γ_2/Γ

 Γ_5/Γ

 $^{14}\,\mathrm{BRESSI}$ 98 result is given for $E_{\,\gamma}>1\,$ MeV only. Result agrees with QED expectation, 2.283×10^{-4} and does not confirm discrepancy of earlier experiment CASTAGNOLI 58.

 $\Gamma(e^+\nu_e\gamma)/\Gamma_{\rm total}$

The very different values reflect the very different kinematic ranges covered (bigger range, bigger value). And none of them covers the whole kinematic range.

| VALUE (units 10 ⁻⁸) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|------------|-----------------------|----------|---------|--------------------------------------------------------------------------------------------------------|
| 73.86±0.54 | 65 k | 15 BYCHKOV | 09 | PIBE | $e^+ \nu \gamma$ at rest |
| • • • We do not use the | e followi | ng data for average | s, fits, | limits, | etc. • • • |
| $16.1\ \pm2.3$ | | ¹⁶ BOLOTOV | 90в | SPEC | |
| 5.6 ±0.7 3.0 | 226 143 | 17 STETZ | | | $e^{-}\overline{\nu}_{e}\gamma$ $P_{e} > 56 \text{ MeV}/c$ $(KE)_{e^{+}\gamma} > 48 \text{ MeV}$ |
| 3.0 | 143 | DEPONIMIER | 038 | CNIK | (NE) _{e+~} > 40 IVIEV |

 $^{15}\,\mathrm{This}\;\mathrm{BYCH}\,\mathrm{KOV}$ 09 value is for $E_{\gamma}>10\;\mathrm{MeV}$ and $\Theta_{\,e^+\,\gamma}>40^\circ.$

 16 BOLOTOV 90B is for $E_{\gamma}~>21$ MeV, $E_{e}~>~70~-~0.8\,E_{\gamma}$

 17 STETZ 78 is for an $e^-\gamma$ opening angle $>132^\circ.$ Obtains 3.7 when using same cutoffs as DEPOMMIER 63B.

 $\Gamma(e^+\nu_e\pi^0)/\Gamma_{\rm total}$

| VALUE (units 10^{-8}) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|---------------------------|---------------|-------------------------|-------|-------------|---------|---------------------|
| 1.036±0.006 OUR | | | | | | |
| 1.036 ± 0.006 | | ¹⁹ POCANIC | 04 | | + | π decay at rest |
| 1.026 ± 0.039 | 1224 | ²⁰ MCFARLANE | 85 | CNTR | + | Decay in flight |
| $^{1.00}^{+0.08}_{-0.10}$ | 332 | DEPOMMIER | 68 | CNTR | + | |
| 1.07 ± 0.21 | | ²¹ BACASTOW | 65 | OSPK | + | |
| 1.10 ± 0.26 | | ²¹ BERTRAM | 65 | OSPK | + | |
| 1.1 ± 0.2 | 43 | ²¹ DUNAITSEV | 65 | CNTR | + | |
| 0.97 ± 0.20 | 36 | ²¹ BARTLETT | 64 | OSPK | + | |
| • • • We do not | use the follo | owing data for ave | rages | , fits, lim | its, et | . • • • |
| 1 150 22 | E 2 | 21 DEPOMMIER | 63 | CNTD | | Soo DEDOMMIED 60 |

¹⁸ POCANIC 04 normalizes to $e^+\nu_{\rho}$ decays, using the PDG 2004 value B($\pi^+\to e^+\nu_{\rho}$) = $(1.230 \pm 0.004) \times 10^{-4}$. We add their statistical (0.004×10^{-8}) , systematic (0.004×10^{-8}) 10^8) and systematic error due to the uncertainty of B($\pi^+
ightarrow e^+
u_e$) (0.003 imes 10^8)

¹⁹This result can be used to calculate V_{ud} from pion beta decay: $V_{ud}^{PIBETA} = 0.9728 \pm 0.000$

0.0030. $\frac{100}{20}$ MCFARLANE 85 combines a measured rate (0.394 \pm 0.015)/s with 1982 PDG mean

21 DEPOMMIER 68 says the result of DEPOMMIER 63 is at least 10% too large because of a systematic error in the π^0 detection efficiency, and that this may be true of all the previous measurements (also V. Soergel, private communication, 1972).

 $\Gamma(e^+\nu_e\,e^+\,e^-)/\Gamma(\mu^+\nu_\mu)$ Γ_6/Γ_1

| VALUE (units 10 ⁻⁹) | CL% EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|----------|-------------|----|------|----------------------------------------|
| 3.2 ±0.5 ±0.2 | 98 | EGLI | 89 | SPEC | Uses R _{PCAC} = 0.068 ± 0.004 |

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

7 22 BARANOV 92 SPEC Stopped π^+ $0.46 \pm 0.16 \pm 0.07$ 90 KORENCHE... 76B SPEC 90 KORENCHE... 71 OSPK

22 This measurement by BARANOV 92 is of the structure-dependent part of the decay. The value depends on values assumed for ratios of form factors

 $\Gamma(\mu^+ \overline{\nu}_e) / \Gamma_{\text{total}}$ Γ_8/Γ Forbidden by total lepton number conservation. See the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_s^+ Listings.

CL% DO CUMENT ID TECN COMMENT 90 ²³ COOPER 82 HLBC Wideband ν beam

 23 COOPER 82 limit on $\overline{
u}_e$ observation is here interpreted as a limit on lepton number

 Γ_9/Γ $\Gamma(\mu^+\nu_e)/\Gamma_{\rm total}$ Forbidden by lepton family number conservation

VALUE (units 10⁻³) CL% DO CUMENT ID TECN COMMENT 24 COOPER 90 82 HLBC Wideband ν beam

 24 COOPER 82 limit on ν_e observation is here interpreted as a limit on lepton family number

 $\Gamma(\mu^- e^+ e^+ \nu)/\Gamma_{\text{total}}$ Γ_{10}/Γ Forbidden by lepton family number conservation VALUE (units 10⁻⁶) CL% DO CUMENT ID <1.6 BARANOV 91B SPEC + • • • We do not use the following data for averages, fits, limits, etc. • • • <7.7 90 KORENCHE... 87 SPEC +

π^+ — POLARIZATION OF EMITTED μ^+

 $\pi^+ \to ~\mu^+ \nu$ Tests the Lorentz structure of leptonic charged weak interactions. TECN CHG COMMENT CL% DO CUMENT ID \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$ ²⁵ FETSCHER 84 RVUE + $^{26}\,\mathrm{ABELA}$ -0.99 ± 0.16 83 SPEC $^{\mbox{\scriptsize 25}}$ FETSCHER 84 uses only the measurement of CARR 83. 26 Sign of measurement reversed in ABELA 83 to compare with μ^+ measurements.

FORM FACTORS FOR RADIATIVE PION AND KAON DECAYS

Updated August 2009 by W. Bertl (Paul Scherrer Inst.)

The radiative decays, $\pi^{\pm} \to l^{\pm} \nu \gamma$ and $K^{\pm} \to l^{\pm} \nu \gamma$, with l standing for an e or a μ , and γ for a real or virtual photon (e^+e^-) pair), provide a powerful tool to investigate the hadronic structure of pions and kaons. The structure-dependent part SD_i of the amplitude describes the emission of photons from virtual hadronic states, and is parametrized in terms of form factors F_i , with i = V, A (vector, axial vector), in the standard description [1,2]. Exotic, non-standard contributions like i = T, S (tensor, scalar) have also been considered, and we shall discuss them below. Apart from the SD terms, the decay amplitude depends also on Inner Bremsstrahlung IB from the weak decay $\pi^{\pm}(K^{\pm}) \to l^{\pm}\nu$ accompanied by the photon radiated from the external charged particles. Naturally, experiments try to optimize their kinematics so as to minimize the "trivial" IB part of the amplitude.

The SD amplitude in its standard form is given as

$$M(SD_V) = \frac{-eG_F V_{qq'}}{\sqrt{2}m_P} \epsilon^{\mu} l^{\nu} F_V^P \epsilon_{\mu\nu\sigma\tau} k^{\sigma} q^{\tau}$$
 (1)

$$M(SD_A) = \frac{-ieG_F V_{qq'}}{\sqrt{2}m_P} \epsilon^{\mu} l^{\nu} \{ F_A^P [(qk - k^2)g_{\mu\nu} - q_{\mu}k_{\nu}] + R^P k^2 g_{\mu\nu} \},$$
 (2)

which contains an additional axial form factor \mathbb{R}^P which only can be accessed if the photon remains virtual. $V_{qq'}$ is the Cabibbo-Kobayashi-Maskawa mixing-matrix element; ϵ^{μ} is the polarization vector of the photon (or the effective vertex, ϵ^{μ} $(e/k^2)\overline{u}(p_-)\gamma^{\mu}v(p_+)$, of the e^+e^- pair); $\ell^{\nu}=\overline{u}(p_{\nu})\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}(1-e^+k^2)\overline{u}(p_-)\gamma^{\nu}$ $\gamma_5)v(p_\ell)$ is the lepton-neutrino current; q and k are the meson

and photon four-momenta ($k = p_+ + p_-$ for virtual photons); and P stands for π or K.

The pion vector form factor, F_V^π , is related via CVC (Conserved Vector Current) to the $\pi^0 \to \gamma \gamma$ decay width by $|F_V^\pi| = (1/\alpha) \sqrt{2\Gamma_{\pi^0 \to \gamma \gamma}/\pi m_{\pi^0}}$ [3]. The resulting value, $F_V^\pi(0) = 0.0259(9)$, has been confirmed by calculations based on chiral perturbation theory (χPT) [4], and by two experiments given in the Listings below. A recent experiment by the PIBETA collaboration [5] obtained an F_V that is in excellent agreement with the CVC hypothesis. It also measured the slope parameter a in $F_V^\pi(s) = F_V^\pi(0)(1+a\cdot s)$, where $s = (1-2E_\gamma/m_\pi)$, and E_γ is the gamma energy in the pion rest frame: $a = 0.095 \pm 0.058$. A functional dependence on s is expected for all form factors. It becomes non-negligible in the case of $F_V^\pi(s)$ when a wide range of photon momenta is recorded; proper treatment in the analysis of K decays is mandatory.

The form factor, R^P , can be related to the electromagnetic radius, r_P , of the meson [2]: $R^P = \frac{1}{3} m_P f_P \langle r_P^2 \rangle$ using PCAC (Partial Conserved Axial vector Current; f_P is the meson decay constant). In lowest order χPT , the ratio F_A/F_V is related to the pion electric polarizability $\alpha_E = [\alpha/(8\pi^2 m_\pi f_\pi^2)] \times F_A/F_V$ [6]. The calculation of the other form factors, F_A^π, F_V^K , and F_A^K , is model-dependent [1,2,4].

For decay processes where the photon is real, the partial decay width can be written in analytical form as a sum of IB, SD, and IB/SD interference terms INT [1,4]:

$$\frac{d^{2}\Gamma_{P\to\ell\nu\gamma}}{dxdy} = \frac{d^{2}\left(\Gamma_{\rm IB} + \Gamma_{\rm SD} + \Gamma_{\rm INT}\right)}{dxdy}
= \frac{\alpha}{2\pi}\Gamma_{P\to\ell\nu}\frac{1}{(1-r)^{2}} \left\{ IB(x,y) + \frac{1}{r}\left(\frac{m_{P}}{2f_{P}}\right)^{2} \left[(F_{V} + F_{A})^{2}SD^{+}(x,y) + (F_{V} - F_{A})^{2}SD^{-}(x,y) \right] + \frac{m_{P}}{f_{P}} \left[(F_{V} + F_{A})S_{\rm INT}^{+}(x,y) + (F_{V} - F_{A})S_{\rm INT}^{-}(x,y) \right] \right\}.$$
(3)

Here

$$IB(x,y) = \left[\frac{1-y+r}{x^2(x+y-1-r)}\right]$$

$$\left[x^2 + 2(1-x)(1-r) - \frac{2xr(1-r)}{x+y-1-r}\right]$$

$$SD^+(x,y) = (x+y-1-r)\left[(x+y-1)(1-x) - r\right]$$

$$SD^-(x,y) = (1-y+r)\left[(1-x)(1-y) + r\right]$$

$$S_{INT}^+(x,y) = \left[\frac{1-y+r}{x(x+y-1-r)}\right]\left[(1-x)(1-x-y) + r\right]$$

$$S_{INT}^-(x,y) = \left[\frac{1-y+r}{x(x+y-1-r)}\right]\left[x^2 - (1-x)(1-x-y) - r\right]$$

$$(4)$$

where $x = 2E_{\gamma}/m_P$, $y = 2E_{\ell}/m_P$, and $r = (m_{\ell}/m_P)^2$. Recently, formulas (3) and (4) have been extended to describe polarized distributions in radiative meson and muon decays [7].

The "helicity" factor r is responsible for the enhancement of the SD over the IB amplitude in the decays $\pi^{\pm} \to e^{\pm}\nu\gamma$, while $\pi^{\pm} \to \mu^{\pm}\nu\gamma$ is dominated by IB. Interference terms are important for the decay $K^{\pm} \to \mu^{\pm}\nu\gamma$ [8], but contribute only a few percent correction to pion decays. However, they provide the basis for determining the signs of F_V and F_A . Radiative corrections to the decay $\pi^+ \to e^+\nu\gamma$ have to be taken into account in the analysis of the precision experiments. They make up to 4% corrections in the total decay rate [9]. In $\pi^{\pm} \to e^{\pm}\nu e^+e^-$ and $K^{\pm} \to \ell^{\pm}\nu e^+e^-$ decays, all three form factors, F_V^P , F_A^P , and R^P , can be determined [10,11].

We give the experimental π^{\pm} form factors F_V^{π} , F_A^{π} , and R^{π} in the Listings below. In the K^{\pm} Listings, we give the extracted sum $F_A^K + F_V^K$ and difference $F_A^K - F_V^K$, as well as F_V^K , F_A^K and R^K .

Several searches for the exotic form factors F_T^{π} , F_T^K (tensor), and F_S^K (scalar) have been pursued in the past, some of them claiming non-zero results [12,13]. In particular, F_T^{π} has been brought into focus by experimental as well as theoretical work. It was shown that a tensor contribution could destructively interfere with the inner bremsstrahlung amplitude, leading to a substantial reduction of the branching ratio as compared with standard V-A calculations [14]. In addition, a tensor contribution as large as $F_T = -(5.6\pm1.7)\times10^{-3}$ could not be completely ruled out by constraints from other measurements [15]. New high-statistics data from the PIBETA collaboration have been re-analyzed together with an additional data set optimized for low backgrounds in the radiative pion decay. In particular, lower beam rates have been used in order to reduce the accidental background, thereby making the treatment of systematic uncertainties easier and more reliable. The PIBETA analysis now restricts F_T to the range $-5.2 \times 10^{-4} < F_T < 4.0 \times 10^{-4}$ at a 90% confidence limit [5]. This result is in excellent agreement with the most recent theoretical work [4].

Precision measurements of radiative pion and kaon decays are effective tools to study QCD in the non-perturbative region. The structure-dependent form factors have direct relations to (renormalized) coupling constants of chiral perturbation theories. Therefore, they are of interest beyond the scope of radiative decays. On the other hand, the interest in searching for new physics manifesting in exotic form factors F_T or F_S has weakened over the last years mainly for two reasons: (i) on the experimental side, the lack of results confirming the non-zero findings; (ii) on the theoretical side, numerical uncertainties are still too large to allow a clear distinction of exotic and standard contributions at the currently required level. Likely this will change in the future, but meanwhile other processes such as $\pi^+ \to e^+ \nu$ seem to be better suited to search for new physics at the precision frontier, because of the very accurate and reliable theoretical predictions and the more straightforward experimental analysis.

 π^{\pm}

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π^{\pm} FORM FACTORS

F_V , VECTOR FORM FACTOR

| VALUE | EVTS | | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------|--------|----|--------------|-----|------|--------------------------------------------------------|
| 0.0254±0.0017 OUR AV | /ERAGE | | | | | |
| 0.0258 ± 0.0017 | 65 k | | | 09 | PIBE | $e^+ u\gamma$ at rest |
| $0.014\ \pm0.009$ | | 28 | BOLOTOV | 90в | SPEC | 17 GeV $\pi^- \rightarrow e^- \overline{\nu}_a \gamma$ |
| $0.023 \begin{array}{l} + 0.015 \\ - 0.013 \end{array}$ | 98 | | EGLI | 89 | SPEC | $\pi^+ \rightarrow e^+ \nu_e e^+ e^-$ |

 27 The BYCHKOV 09 ${\it F_A}$ and ${\it F_V}$ results are highly (anti-)correlated: ${\it F_A}$ + 1.0286 ${\it F_V}$ = 0.03853 \pm 0.00014.

F_A , AXIAL-VECTOR FORM FACTOR

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------|----------------------|------------------------|-----|------|-------------------------------------------|
| 0.0119 ± 0.0001 | 65 k ²⁹ , | ³⁰ BYCHKOV | 09 | PIBE | $e^+ u\gamma$ at rest |
| | | | | | |
| 0.0115 ± 0.0004 | | | | | $\pi^+ ightarrow e^+ u \gamma$ at rest |
| 0.0106 ± 0.0060 | 29, | ³² BOLOTOV | 90B | SPEC | 17 GeV $\pi^- \rightarrow$ |
| | | | | | $e^{-}\overline{\nu}_{e}\gamma$ |
| $0.021 \begin{array}{c} +0.011 \\ -0.013 \end{array}$ | 98 | EGLI | 89 | SPEC | $\pi^+ \to \ e^+ \nu_e e^+ e^-$ |
| 0.0135 ± 0.0016 | | ³² BAY | 86 | | $\pi^+ \rightarrow e^+ \nu \gamma$ |
| 0.006 ± 0.003 | 29, | ³² PIILONEN | 86 | SPEC | $\pi^+ \rightarrow e^+ \nu \gamma$ |
| 0.011 ± 0.003 | 29,32, | 33 STETZ | 78 | SPEC | $\pi^+ \rightarrow e^+ \nu \gamma$ |

- 29 These values come from fixing the vector form factor at the CVC prediction, F_V =
- 0.0259 \pm 0.0005. 30 When F_V is released, the BYCHKOV 09 F_A is 0.0117 \pm 0.0017, and F_A and F_V results are highly (anti-)correlated: F_A + 1.0286 F_V = 0.03853 \pm 0.00014.
- $^{31}\,\mathrm{The}$ sign of $\gamma=\mathit{F_A}\ /\mathit{F_V}$ is determined to be positive.
- 32 Only the absolute value of F_A is determined.
- 33 The result of STETZ 78 has a two-fold ambiguity. We take the solution compatible with later determinations

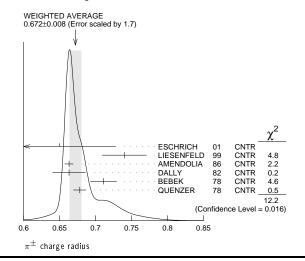
VECTOR FORM FACTOR SLOPE PARAMETER a

| This is a in | $F_V(q^2) = F_V(q^2)$ | 0) $(1 + a q^2)$ | | | | | | |
|-----------------|------------------------------------|------------------|----|------|--------------------------------------------|--|--|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
| 0.10 ± 0.06 | 65k | BYCHKOV | 09 | PIBE | $e^+ u\gamma$ at rest | | | |
| R, SECOND A | R. SECOND AXIAL-VECTOR FORM FACTOR | | | | | | | |
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | | | |
| 0.059+0.009 | 98 | EGLI | 89 | SPEC | $\pi^+ \rightarrow e^+ \nu_{\rho} e^+ e^-$ | | | |

π± CHARGE RADIUS

| VALUE (fm) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|------------------------|---------|---------|---------------------------------|
| 0.672±0.008 OUR AVERAGE | Error includes scale | factor | of 1.7. | See the ideogram below. |
| $0.65 \pm 0.05 \pm 0.06$ | ESCHRICH | 01 | CNTR | $\pi e ightarrow \pi e$ |
| 0.740 ± 0.031 | LIESENFELD | 99 | CNTR | $e p \rightarrow e \pi^+ n$ |
| 0.663 ± 0.006 | AMENDOLIA | 86 | CNTR | $\pi e \rightarrow \pi e$ |
| 0.663 ± 0.023 | DALLY | 82 | CNTR | $\pi e \rightarrow \pi e$ |
| $0.711 \pm 0.009 \pm 0.016$ | BEBEK | 78 | CNTR | $e N \rightarrow e \pi N$ |
| $0.678 \pm 0.004 \pm 0.008$ | QUENZER | 78 | CNTR | $e^+e^- \rightarrow \pi^+\pi^-$ |
| • • • We do not use the follow | ving data for averages | , fits, | limits, | etc. • • • |
| 0.661 ± 0.012 | ³⁴ BIJNENS | 98 | CNTR | χ PT extraction |
| 0.660 ± 0.024 | AMENDOLIA | 84 | CNTR | $\pi e \rightarrow \pi e$ |
| $0.78 \begin{array}{l} +0.09 \\ -0.10 \end{array}$ | ADYLOV | 77 | CNTR | $\pie\to\pie$ |
| $0.74 \begin{array}{c} +0.11 \\ -0.13 \end{array}$ | BARDIN | 77 | CNTR | $e p \rightarrow e \pi^+ n$ |
| 0.56 ± 0.04 | DALLY | 77 | CNTR | $\pie\rightarrow\pie$ |

34 BIJNENS 98 fits existing data



π[±] REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1988 edition Physics Letters B204 1 (1988).

| BYCHKOV | 09 | PRL 103 051802 | M. Bychkov et al. | (PSTPIBETA Collab.) |
|------------|-----|---------------------------|-----------------------------------|----------------------|
| FRLEZ | 04 | PRL 93 181804 | E. Friez et al. | (PSTPIBETA Collab.) |
| POCANIC | 04 | PRL 93 181803 | D. Pocanic et al. | (PSTPIBETA Collab.) |
| ES CHRICH | 01 | PL B522 233 | I. Eschrich et al. | (FNAL SELEX Collab.) |
| LIESENFELD | 99 | PL B468 20 | A. Liesenfeld et al. | |
| BIJNENS | 98 | JHEP 9805 014 | J. Bijnens et al. | |
| BRESSI | 98 | NP B513 555 | G. Bressi et al. | |
| LENZ | 98 | PL B416 50 | S. Lenz et al. | |
| ASSAMAGAN | 96 | PR D53 6065 | K.A. Assamagan et al. | (PSI, ZURI, VILL+) |
| KOPTEV | 95 | JETPL 61 877 | V.P. Koptev et al. | (PNPI) |
| | | Translated from ZETFP 6: | | |
| NUMAO | 95 | PR D52 4855 | T. Numao et al. | (TRIU, BRCO) |
| ASSAMAGAN | 94 | PL B335 231 | K.A. Assam ag an et al. | (PSI, ZURI, VILL+) |
| JECKELMANN | 94 | PL B335 326 | B. Jeckelmann, P.F.A. Goudsmit, F | I.J. Lèisi (WABRN+) |
| CZAPEK | 93 | PRL 70 17 | G. Czapek et al. | (BERN, VILL) |
| BARANOV | 92 | SJNP 55 1644 | V.A. Baranov et al. | ` (JINR) |
| | | Translated from YAF 55 2 | | |
| BRITTON | 92 | PRL 68 3000 | D.I. Britton et al. | (TRIU, CARL) |
| A Iso | | PR D4 9 28 | D.I. Britton et al. | (TRIU, CARL) |
| NUMAO | 92 | MPL A7 3357 | T. Numao | (TRIU) |
| BARANOV | 91B | SJNP 54 790 | V.A. Baranov et al. | (JINR) |
| | | Translated from YAF 54 12 | 298. | , , |

| DAIIM | 0.1 | DL DOGE 405 | M. Daum et al | (1/11.1.) |
|------------------------|------------|-----------------------------------------|---------------------------------------------|----------------------------|
| DAUM BOLOTOV | 91 90 B | PL B265 425 PL B243 308 | M. Daum et al. V.N. Bolotov et al. | (VILL) (INRM) |
| EGLI | 89 | PL B222 533 | S. Egli et al. | (SINDRUM Collab.) |
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| PDG | 88 | PL B204 1 | G.P. Yost et al. | (LBL+) |
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| COHEN | 87 | RMP 59 1121 | E.R. Cohen, B.N. Taylor | `(RISC, NBS) |
| KORENCHE | 87 | SJNP 46 192 | S.M. Korenchenko et al. | (JINR) |
| AMENDOLIA | 86 | Translated from YAF 46 3 NP B277 168 | 13. S.R. Amendolia <i>et al.</i> | (CERN NA7 Collab.) |
| BAY | 86 | PL B174 445 | A. Bay et al. | (LAUS, ZURI) |
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| JECKELMANN | 86B | NP A457 709 | B. Jeckelmann et al. | (ETH, FRIB) |
| A Iso | | PRL 56 1444 | B. Jeckelmann et al. | (ETH, FRIB) |
| PIILONEN | 86 | PRL 57 1402 | L.E. Piilonen et al. | (LANL, TEMP, CHIC) |
| MCFARLANE | 85 | PR D32 547 | W.K. McFarlane et al. | (TEMP, LANL) |
| ABELA Also | 84 | PL 146B 431 PL 74B 126 | R. Abela et al. M. Daum et al. | (SIN) (SIN) |
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| ADYLOV | 77 | NP B128 461 | G.T. Adylov et al. | (===, = ===,) |
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| KORENCHE | 76B | JETP 44 35 | S.M. Korenchenko et al. | (JINR) |
| MARUSHEN | 76 | Translated from ZETF 71 JETPL 23 72 | V.I. Marushenko <i>et al.</i> | (PNPI) |
| | | Translated from ZETFP 2 | | () |
| A Iso | | Private Comm. | R.E. Shafer | (FNAL) |
| A Iso | | Private Comm. | A. S mirnov | (PNPI) |
| DUNAITSEV | 73 | SJNP 16 292 | A.F. Dunaitsev et al. | (S ERP) |
| AYRES | 71 | Translated from YAF 16 5 PR D3 1051 | D.S. Ayres et al. | (LRL, UCSB) |
| Also | | PR 157 1288 | D.S. Ayres et al. | (LRL) |
| Also | | PRL 21 261 | D.S. Ayres et al. | (LRL, UCSB) |
| A Iso | | Thesis UCRL 18369 | D.S. Ayres | ` (LRL) |
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| KORENCHE | 71 | SJNP 13 189 Translated from YAF 13 3 | S.M. Korenchenko et al. | (JINR) |
| воотн | 70 | PL 32B 723 | P.S.L. Booth et al. | (LIVP) |
| DEPOMMIER | 68 | NP B4 189 | P. Depommier et al. | (CERN) |
| PETRUKHIN | 68 | JINR P1 3862 | V.I. Petrukhin et al. | (JINR) |
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| BARDON | 66 | PRL 16 775 | M. Bardon et al. | (COLU) |
| KINSEY | 66 | PR 144 1132 | K.F. Kinsey, F. Lobkowicz, M.E | |
| L OBKOWICZ BACASTOW | 66 65 | PRL 17 548 PR 139 B407 | F. Lobkowicz et al. R.B. Bacastow et al. | (ROCĤ, BNL) (LRL, SLAC) |
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| DUNAITSEV | 65 | JETP 20 58 | A.F. Dunaitsev et al. | (JINR) |
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| BARTLETT | 64 | PR 136 B1452 | D. Bartlett et al. | (COLU) |
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| ANDERSON | 60 | PR 119 2050 | H.L. Anderson et al. | `(EFI) |
| CAS TA GN OLI | 58 | PR 112 1779 | C. Castagnoli, M. Muchnik | (RÔMA) |
| | | | | |

$$I^{G}(J^{PC}) = 1^{-}(0^{-}+)$$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters **B204** 1 (1988).

π^0 MASS

The value is calculated from m_{π^\pm} and $(m_{\pi^\pm}-m_{\pi^0}).$ See also the notes under the π^{\pm} Mass Listings.

DOCUMENT ID

134.9766±0.0006 OUR FIT Error includes scale factor of 1.1.

$m_{\pi^{\pm}}-m_{\pi^0}$

Measurements with an error > 0.01 MeV have been omitted.

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|------------------|---------|-----------|-------------------------------------------------|
| 4.5936 ±0.0005 OUR FIT | | | | |
| 4.5936 ±0.0005 OUR AVERAGE | | | | |
| 4.59364 ± 0.00048 | | | | $\pi^- p \rightarrow \pi^0 n$, $n \text{ TOF}$ |
| 4.5930 ±0.0013 | CRAWFORD | 86 | CNTR | $\pi^- p \rightarrow \pi^0 n$, n TOF |
| | data for average | s, fits | , limits, | etc. • • • |
| 4.59366 ± 0.00048 | CRAWFORD | 88B | CNTR | See CRAWFORD 91 |
| 4.6034 ±0.0052 | VASILEVSKY | 66 | CNTR | |
| 4.6056 ±0.0055 | CZIRR | 63 | CNTR | |
| | | | | |

π^0 MEAN LIFE

Most experiments measure the π^0 width which we convert to a lifetime. ATHERTON 85 is the only direct measurement of the π^0 lifetime. Our average based only on indirect measurement yields $(8.30\pm0.19)\times10^{-17}\,\mathrm{s}$. The two Primakoff measurements from 1970 have been excluded from our average because they suffered model-related systematics unknown at the time. More information on the π^0 lifetime can be found in BERN-

| VALUE (10 ⁻¹⁷ s) | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
|--------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|--------|------------|--------------------------------------------|--|--|
| 8.52±0.18 OUR A | /ERAGE | Error includes scal | e fact | or of 1.2 | | | |
| $8.32 \pm 0.15 \pm 0.18$ | | ¹ LARIN | 11 | | Primakoff effect | | |
| 8.5 ±1.1 | | ² BYCHKOV | 09 | PIBE | $\pi^+ ightarrow e^+ \nu \gamma$ at rest | | |
| $8.4 \pm 0.5 \pm 0.5$ | 1182 | | | | $e^+e^- \rightarrow e^+e^-\pi^0$ | | |
| $8.97 \pm 0.22 \pm 0.17$ | | ATHERTON | 85 | CNTR | Direct measurement | | |
| 8.2 ± 0.4 | | ⁴ BROWMAN | 74 | CNTR | Primakoff effect | | |
| ● ● We do not u | se the foll | owing data for aver | ages, | fits, limi | ts, etc. • • • | | |
| 5.6 ±0.6 | | BELLETTINI | 70 | CNTR | Primakoff effect | | |
| 9 ± 0.68 | | KRYSHKIN | 70 | CNTR | Primakoff effect | | |
| 7.3 ± 1.1 | | BELLETTINI | 65 B | CNTR | Primakoff effect | | |
| life $\tau = \hbar/\Gamma$ (to | ¹ LARIN 11 reported $\Gamma(\pi^0 \to \gamma\gamma) = 7.82 \pm 0.14 \pm 0.17$ eV which we converted to mean life $\tau = \hbar/\Gamma$ (total). | | | | | | |
| ² BYCHKOV 09 c | btains this | using the conserve | d-vect | or-curre | nt relation between the vector | | |
| form factor F_{V} and the π^{0} lifetime. | | | | | | | |
| | 3 WILLIAMS 88 gives $\Gamma(\gamma\gamma)=$ 7.7 \pm 0.5 \pm 0.5 eV. We give here $	au=\hbar/\Gamma({ m total})$. | | | | | | |
| 4 BROWMAN 74 gives a π^0 width $\Gamma=8.02\pm0.42$ eV. The mean life is \hbar/Γ . | | | | | | | |

π^0 DECAY MODES

For decay limits to particles which are not established, see the appropriate Search sections (A^0 (axion) and Other Light Boson (X^0) Searches, etc.).

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-----------------------|------------------------------------|------------------------------|-----------------------------------|
| $\overline{\Gamma_1}$ | 2γ | (98.823±0.034) | % S=1.5 |
| Γ_2 | $e^+ e^- \gamma$ | (1.174 ± 0.035) | % S=1.5 |
| Γ_3 | γ positronium | (1.82 ± 0.29) | $\times 10^{-9}$ |
| Γ_4 | $e^{+} e^{+} e^{-} e^{-}$ | (3.34 ± 0.16) | $\times 10^{-5}$ |
| Γ ₅ | $e^+ e^-$ | (6.46 ± 0.33) | $\times 10^{-8}$ |
| Γ ₆ | 4γ | < 2 | $\times10^{-8}$ CL=90% |
| Γ_7 | $ u \overline{ u}$ | [a] < 2.7 | $\times10^{-7}$ CL=90% |
| Γ ₈ | $\nu_e \overline{\nu}_e$ | < 1.7 | $\times10^{-6}$ CL=90% |
| Г9 | $ u_{\mu}\overline{ u}_{\mu}$ | < 1.6 | $\times10^{-6}\text{CL}\!=\!90\%$ |
| Γ_{10} | $\nu_{\tau} \overline{\nu}_{\tau}$ | < 2.1 | $\times10^{-6}$ CL=90% |
| Γ11 | $\gamma \nu \overline{\nu}$ | < 6 | $\times10^{-4}$ CL=90% |

Charge conjugation (C) or Lepton Family number (LF) violating modes

| Γ_{12} | 3γ | С | < 3.1 | $\times 10^{-8}$ CL=90% |
|---------------|---------------------------------|----|-------|--------------------------|
| Γ_{13} | μ^+ e^- | LF | < 3.8 | $\times 10^{-10}$ CL=90% |
| Γ_{14} | $\mu^- e^+$ | LF | < 3.4 | $\times 10^{-9}$ CL=90% |
| Γ15 | $\mu^{+} e^{-} + \mu^{-} e^{+}$ | LF | < 3.6 | $\times 10^{-10}$ CL=90% |

[a] Astrophysical and cosmological arguments give limits of order 10^{-13} ; see the Particle Listings below.

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 6 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 =$ 4.6 for 4 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\mathrm{total}}$. The fit constrains the x_i whose labels appear in this array to sum to

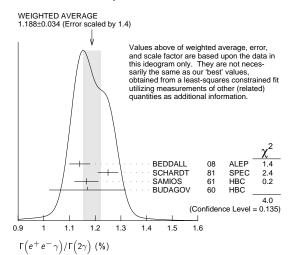
$$\begin{array}{c|cccc}
x_2 & -100 & \\
x_4 & 0 & -1 \\
\hline
& x_1 & x_2
\end{array}$$

π^0 BRANCHING RATIOS

| $\Gamma(e^+ e^- \gamma)/\Gamma(2\gamma)$ | | | | | Γ_2/Γ_1 | |
|-------------------------------------------------------------------------------|-------|---------------------|---------|-----------|-----------------------------------------|--|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 1.188±0.035 OUR FIT | Error | includes scale fact | or of | 1.5. | | |
| 1.188±0.034 OUR AV | ERAGE | Error includes sc | ale fac | tor of 1. | 4. See the ideogram below. | |
| $1.140 \pm 0.024 \pm 0.033$ | 12.5k | | | | $e^+e^- ightarrow~Z ightarrow~$ hadrons | |
| 1.25 ± 0.04 | | SCHARDT | 81 | SPEC | $\pi^- \rho \rightarrow n \pi^0$ | |
| 1.166 ± 0.047 | 3071 | ⁶ SAMIOS | 61 | HBC | $\pi^- p \rightarrow n \pi^0$ | |
| 1.17 ± 0.15 | 27 | BUDAGOV | 60 | HBC | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| 1.196 | | JOSEPH | 60 | THEO | QED calculation | |

 π

 5 This BEDDALL 08 value is obtained from ALEPH archived data. 6 SAMIOS 61 value uses a Panofsky ratio $=\,1.62.$



| $\Gamma(\gamma p o sitronium)$ | $1)/\Gamma(2\gamma)$ | | | | | Γ_3/Γ_1 |
|-----------------------------------------------------------------|----------------------|-----------------------|-----|------|--------------------------------------|---------------------|
| VALUE (units 10 ⁻⁹) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 1.84 ± 0.29 | 277 | A FA NA SYEV | 90 | CNTR | <i>p</i> C 70 GeV | |
| Γ(e ⁺ e ⁺ e ⁻ e ⁻) | $/\Gamma(2\gamma)$ | | | | | Γ_4/Γ_1 |
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 3.38±0.16 OUR F | IT | | | | | |
| 3.38±0.16 OUR A | WERAGE | | | | | |
| 3.46 ± 0.19 | 30.5k | ⁷ ABOUZAID | 08D | KTEV | $\kappa_I^0 \rightarrow \pi^0 \pi^0$ | π_{DD}^0 |
| 3.18 ± 0.30 | 146 | 8 SAMIOS | 62B | нвс | L | DD |

 7 This ABOUZAID 08D value includes all radiative final states. The error includes both statistical and systematic errors. The correlation between the Dalitz-pair planes gives a direct measurement of the π^0 parity. The π^0 $2\gamma^*$ form factor is measured and limits are placed on a scalar contribution to the decay.

8 SAMIOS 62B value uses a Panofsky ratio = 1.62

 $\Gamma(e^+e^-)/\Gamma_{total}$ Experimental results are listed; branching ratios corrected for radiative effects are given in the footnotes. BERMAN 60 found $B(\pi^0 \to e^+e^-) \ge 4.69 \times 10^{-8}$ via an exact OFD calculation.

| VALUE (units 10 ⁻⁸) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|---------------------------------------------------------|-------|-----------------------------|----|------|-----|-----------------------------------------------|
| 6.46±0.33 OUR AV | /ERAG | E | | | | |
| $6.44 \pm 0.25 \pm 0.22$ | 794 | ⁹ ABOUZAID | 07 | KTEV | | $K_I^0 \rightarrow 3\pi^0$ in flight |
| $6.9 \ \pm 2.3 \ \pm 0.6$ | 21 | ¹⁰ DESHPANDE | 93 | SPEC | | $\kappa^+ \rightarrow \pi^+ \pi^0$ |
| $7.6 \begin{array}{c} +2.9 \\ -2.8 \end{array} \pm 0.5$ | 8 | $^{11}\;\mathrm{MCFARLAND}$ | 93 | SPEC | | $\mathcal{K}_L^0 ightarrow 3\pi^0$ in flight |

 \bullet • • We do not use the following data for averages, fits, limits, etc. • • • $6.09\pm0.40\pm0.24$ 275 12 ALAVI-HARATI99C SPEC 0 Repl. by ABOUZAID 07

 9 ABOUZAID 07 result is for $m_{e^+\,e^-}/m_{\pi^0}>$ 0.95. With radiative corrections the result becomes (7.48 \pm 0.29 \pm 0.25) \times 10 $^{-8}$.

 10 The DESHPANDE 93 result with bremsstrahlung radiative corrections is (8.0 \pm 2.6 \pm 0.6) \times 10–8.

11 The MCFARLAND 93 result is for B[$\pi^0 \rightarrow e^+e^-$, $(m_{e^+e^-}/m_{\pi^0})^2 > 0.95$]. With radiative corrections it becomes $(8.8^{+4.5}_{-3.2} \pm 0.6) \times 10^{-8}$.

 12 ALAVI-HARATI 99c quote result for B| $_{170}^{0} \rightarrow e^{+}e^{-}$, ($m_{e^{+}e^{-}}/m_{\pi^{0}})^{2} > 0.95$] to minimize radiative contributions from $\pi^{0} \rightarrow e^{+}e^{-}\gamma$. After radiative corrections they obtain (7.04 \pm 0.46 \pm 0.28) \times 10 $^{-8}$.

| $\Gamma(e^+e^-)/\Gamma(2\gamma)$ | | | | | | Г ₅ /Г |
|----------------------------------|----------|------------|------------------|-----------|------------|-----------------------------------------------------------|
| VALUE (units 10 ⁻⁷) | CL% | EVTS | DO CUMENT ID | ı | TECN | COMMENT |
| • • • We do not us | e the fo | llowing da | ta for averages, | fits, lin | nits, etc. | • • • |
| <1.3 | 90 | | NIEBUHR | | | $\pi^- p \rightarrow \pi^0 n$ at |
| <5.3 | 90 | | ZEPHAT | | | $\pi^{-} \stackrel{\text{rest}}{p \to \pi^0} n$ 0.3 GeV/c |
| $1.7 \pm 0.6 \pm 0.3$ | | 59 | FRANK | 83 | SPEC | $\pi^- p \rightarrow n \pi^0$ |
| 1.8 ± 0.6 | | 58 | MISCHKE | 82 | SPEC | See FRANK 83 |
| $2.23 + 2.40 \\ -1.10$ | 90 | 8 | FISCHER | 78B | SPRK | $K^+ \rightarrow \pi^+ \pi^0$ |

| Γ(4 | γ)/Γ _{total} | | | | | | Γ_6/Γ |
|----------------|-----------------------------------------|-----------------|------------------------------------------|----------------|-------------------------|-------------------|-------------------|
| VALU | E (units 10 ⁻⁸) <u>CL</u> % | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| < | 2 90 | | MCDONOUGH | 1 88 h | CBOX | $\pi^- p$ at rest | |
| • • | We do not use | the following (| data for average | s, fits | limits, | etc. • • • | |
| <16 | 0 90 | | BOLOTOV | 86c | CALO | | |
| <44 | 0 90 | 0 | AUERBACH | 80 | CNTR | | |
| < • • • <16 | 90 We do not use 0 90 | the following (| MCDONOUGH data for average BOLOTOV | s, fits 86c | CBOX limits, CALO | $\pi^- p$ at rest | |

| $\Gamma(\nu\overline{\nu})/\Gamma_{total}$ | Γ_7/Γ |
|---------------------------------------------------------------------------------|-------------------|
| The astrophysical and cosmological limits are many orders of magnitude lower, I | but we |
| use the best laboratory limit for the Summary Tables | |

| ase the best laboratory mine for the barning rables | | | | | | | | | |
|-----------------------------------------------------|------------|--------|--------------------------|--------|-----------|-----------------------------------------------|--|--|--|
| VALUE (units 10 ⁻⁶) | CL% EV | TS | DOCUMENT ID | | TECN | COMMENT | | | |
| < 0.27 | 90 | | ¹³ ARTA MONOV | 05A | B949 | $K^+ \rightarrow \pi^+ \pi^0$ | | | |
| ● ● We do not use | the follow | ing da | ta for averages, fit | s, lim | its, etc. | • • • | | | |
| < 0.83 | 90 | | | 91 | B787 | $K^+ \rightarrow \pi^+ \nu \nu'$ | | | |
| $< 2.9 \times 10^{-7}$ | | | | 91 | | Cosmological limit | | | |
| $< 3.2 \times 10^{-7}$ | | | ¹⁵ NATALE | 91 | | SN 1987A | | | |
| < 6.5 | 90 | | DORENBOS | 88 | CHRM | Beam dump, | | | |
| <24 | 90 | 0 | ¹³ HERCZEG | 81 | RVUE | prompt ν $K^+ \rightarrow \pi^+ \nu \nu'$ | | | |
| 1.2 | | | | | | | | | |

 13 This limit applies to all possible $\nu\nu'$ states as well as to other massless, weakly interacting states.

states. 14 LAM 91 considers the production of right-handed neutrinos produced from the cosmic thermal background at the temperature of about the pion mass through the reaction $\gamma\gamma \rightarrow \pi^0 \rightarrow \nu\overline{\nu}.$

15 NATALE 91 considers the excess energy-loss rate from SN1987A if the process $\gamma\gamma \to \pi^0 \to \nu\overline{\nu}$ occurs, permitted if the neutrinos have a right-handed component. As pointed out in LAM 91 (and confirmed by Natale), there is a factor 4 error in the NATALE 91 published result (0.8×10^{-7}) .

| $\Gamma(u_e \overline{ u}_e)/\Gamma_{ m total}$ | | | | | | Г ₈ /Г |
|--------------------------------------------------|-------------------|-----------------------|-----------|-------------|---------------|-------------------|
| VALUE (units 10 ⁻⁶) | CL% | DOCUMENT ID | | TECN | COMMENT | |
| <1.7 | 90 | DORENBOS. | . 88 | CHRM | Beam dump, | prompt $ u$ |
| ● ● We do not | use the followin | g data for average | es, fits, | , limits, e | etc. • • • | |
| < 3.1 | 90 | ¹⁶ HOFFMAN | 88 | RVUE | Beam dump, | prompt $ u$ |
| ¹⁶ HOFFMAN 88 | 3 analyzes data 1 | from a 400-GeV E | BEBC I | beam-dui | mp experiment | i. |

| $\Gamma(u_{\mu}\overline{ u}_{\mu})$ |)/F _{total} | | | | | | Γ9/Γ |
|---------------------------------------|----------------------------------|----------|------------------------|---------|---------|------------------------|----------|
| VALUE (uni | ts 10 ⁻⁶) <u>CL%</u> | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| <1.6 | 90 | 8.7 | AUERBACH | 04 | LSND | 800 MeV <i>p</i> on Cu | |
| < 3.1 | 90 | | ¹⁷ HOFF MAN | 88 | RVUE | Beam dump, prom | pt ν |
| • • • We | e do not use th | e follow | ing data for averages | , fits, | limits, | etc. • • • | |
| <7.8 | 90 | | DORENBOS | 88 | CHRM | Beam dump, prom | pt ν |

 17 HOFFMAN 88 analyzes data from a 400-GeV BEBC beam-dump experiment. $\Gamma(
u_{ au}
u_{ au})/\Gamma_{ ext{total}}$ Γ_{10}/Γ

| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|-------------------|---------|-----------|-------------------------|
| <2.1 | 90 1 | 8 HOFFMAN | 88 | RVUE | Beam dump, prompt $ u$ |
| • • • We do not use the | e following | data for averages | , fits, | limits, e | etc. • • • |
| <4.1 | 90 | DORENBOS | 88 | CHRM | Beam dump, prompt ν |

 18 HOFFMAN 88 analyzes data from a 400-GeV BEBC beam-dump experiment. $\Gamma(\gamma \nu \overline{\nu})/\Gamma_{\text{total}}$ Γ_{11}/Γ

| ENT |
|-----------------------------------------------|
| |
| $\rightarrow \gamma \nu \overline{\nu} \pi^+$ |
| Γ ₁₂ /Γ |
| ENT |
| at rest |
| • • |
| |
| |
| |
| |
| |

$\Gamma(\mu^+ e^-)/\Gamma_{\text{total}}$ Γ_{13}/Γ

 19 These experiments give B(3 $\gamma/2\gamma$) $<~5.0 imes 10^{-6}$

| Forbidden by lepton family number conservation. | | | | | | | | | |
|-------------------------------------------------|------------|----------|--------------------|---------|-----------|-----------------------------------|--|--|--|
| VALUE (units 10 ⁻⁹ |) CL% | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
| < 0.38 | 90 | 0 | APPEL | 00 | SPEC | $K^+ \rightarrow \pi^+ \mu^+ e^-$ | | | |
| • • • We do n | ot use the | followin | g data for average | s, fits | , limits, | etc. • • • | | | |
| <16 | 90 | | LEE | 90 | SPEC | $K^+ \rightarrow \pi^+ \mu^+ e^-$ | | | |
| <78 | 90 | | CA MPA GNA R | 88 | SPEC | See LEE 90 | | | |

| Γ(μ [—] e ⁺)/Γ _{to} Forbidden | otal by lepto | on family | number conservati | on. | | Γ ₁₄ /Γ |
|----------------------------------------------------------------|-------------------------|-----------|-------------------|-----|------|-----------------------------------|
| VALUE (units 10 ⁻⁹ |)CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| <3.4 | 90 | 0 | APPEL | 00в | B865 | $K^+ \rightarrow \pi^+ e^+ \mu^-$ |

| $\left[\Gamma(\mu^+ e^-) + \Gamma(\mu^-)\right]$ Forbidden by le | · e+)]/Γ _{to} pton family | otal number conservation. | | | Γ ₁₅ /Γ |
|------------------------------------------------------------------|---------------------------------------|-------------------------------------|------|---------|--------------------|
| 141115 (3 10 - 9) | C1.0/ | DO CUMENT ID | TECN | COMMENT | |

| VALUE (units 10 ⁻⁹) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|---------------------|---------|-----------|---------------------------------------------------|
| < 0.36 | 90 | ABOUZAID | 08c | KTEV | $\kappa_I^0 \rightarrow 2\pi^0 \mu^{\pm} e^{\mp}$ |
| • • • We do not use | he followin | ng data for average | s, fits | , limits, | etc. • • • |
| < 17.2 | 90 | KROLAK | 94 | E799 | In $K_I^0 	o 3\pi^0$ |
| <140 | | HERCZEG | 84 | RVUE | $K^+ \rightarrow \pi^+ \mu e$ |
| $< 2 \times 10^{-6}$ | | HERCZEG | | | $\mu^- \rightarrow e^-$ conversion |
| < 70 | 90 | BRYMAN | 82 | RVUE | $K^+ \rightarrow \pi^+ \mu e$ |

π^0 ELECTROMAGNETIC FORM FACTOR

The amplitude for the process $\pi^0\to e^+e^-\gamma$ contains a form factor ${\sf F}(x)$ at the $\pi^0\,\gamma\gamma$ vertex, where $x=[m_{e^+e^-}/m_{\pi^0}]^2$. The parameter a in the linear expansion ${\sf F}(x)=1+ax$ is listed below.

All the measurements except that of BEHREND 91 are in the time-like region of momentum transfer.

LINEAR COEFFICIENT OF π^0 ELECTROMAGNETIC FORM FACTOR

| VALUE | EVIS | DOCUMENT ID | TECN | COMMENT |
|----------------------------------------------------|----------------|-----------------------|-----------------|--------------------------------------------------------------|
| 0.032 ±0.004 OUR | AVERAGE | | | |
| $+0.026 \pm 0.024 \pm 0.04$ | 18 7548 | | | $\pi^- \rho \rightarrow \pi^0 n$ at |
| $+0.025$ ± 0.014 ± 0.02 | 26 54k | MEIJERDREES | 92B SPEC | $\pi^{-}\stackrel{rest}{\rho} \to \pi^0 n$ at |
| $+0.0326\pm0.0026\pm0.00$ | 026 127 | ²⁰ BEHREND | 91 CELL | $e^{+}\stackrel{\text{lest}}{e^{-}} \xrightarrow{\pi^{+}} 0$ |
| -0.11 ± 0.03 ± 0.08 | 32k | FONVIEILLE | 89 SPEC | Radiation corr. |
| • • • We do not use the | he following d | ata for averages, fit | s, limits, etc. | • • • |
| $0.12 \begin{array}{c} +0.05 \\ -0.04 \end{array}$ | | | | FISCHER 78 data |
| $+ 0.10 \pm 0.03$ | 31k | ²² FISCHER | 78 SPEC | Radiation corr. |
| . 0.01 0.11 | 22.00 | DEVONC | CO OCDIC | Maria distribution and a |

their statistical error, and so we have included a systematic error of this magnitude. The value of a is obtained by extrapolation from the region of large space-like momentum transfer assuming vector dominance.

 $21\, \text{TUPPER}$ 83 is a theoretical analysis of FISCHER 78 including 2-photon exchange in the corrections.

 22 The FISCHER 78 error is statistical only. The result without radiation corrections i $+0.05\,\pm\,0.03$.

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| ABOUZAID | 08 C | PRL 100 131803 | E. Abouzaid et al. | (FNAL KTeV Collab.) |
| ABOUZAID | 08 D | PRL 100 182001 | E. Abouzaid et al. | (FNAL KTeV Collab.) |
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$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

We have omitted some results that have been superseded by later experiments. The omitted results may be found in our 1988 edition Physics Letters **B204** (1988).

η MASS

The new measurements from CLEO-c and KLOE seem to resolve the obvious inconsistency of the previously available high-precision η mass measurements by NA48 (LAI 02) and GEM (ABDEL-BARY 05) in favor of the higher η mass from NA48. Therefore we now use only the results from LAI 02, MILLER 07, and AMBROSINO 07B for our η mass average.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|-------------|-------------------------|---------|-----------|---------------------------------------------------|
| 547.853±0.024 OUR A | /ERAGE | | | | |
| $547.874 \pm 0.007 \pm 0.029$ | | AMBROSINO | 07в | KLOE | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |
| $547.785 \pm 0.017 \pm 0.057$ | 16k | MILLER | 07 | CLEO | $\psi(2S) \rightarrow J/\psi \eta$ |
| $547.843 \pm 0.030 \pm 0.041$ | 1134 | LAI | 02 | NA48 | $\eta \rightarrow 3\pi^0$ |
| • • • We do not use th | e following | data for averages | s, fits | , limits, | etc. • • • |
| $547.311 \pm 0.028 \pm 0.032$ | | ¹ ABDEL-BARY | 05 | SPEC | $dp \rightarrow {}^{3}\text{He }X$ |
| $547.12 \pm 0.06 \pm 0.25$ | | KRUSCHE | 95 D | SPEC | $\gamma p \rightarrow \eta p$, threshold |
| 547.30 ±0.15 | | PLOUIN | 92 | SPEC | $d p \rightarrow \eta^3 He$ |
| 547.45 ±0.25 | | DUANE | 74 | SPEC | $\pi^- p ightarrow n$ neutrals |
| 548.2 ±0.65 | | FOSTER | 65 C | HBC | |
| 549.0 ±0.7 | 148 | FOELSCHE | 64 | HB C | |
| 548.0 ±1.0 | 91 | ALFF | 62 | нвс | |
| 549.0 ±1.2 | 53 | BASTIEN | 62 | HB C | |

 $^{1}\,\mathrm{ABDEL}\text{-}BARY$ 05 disagrees significantly with the measurements of similar precision by LAI 02, MILLER 07, and AMBROSINO 07B. See comment in the header.

η WIDTH

This is the partial decay rate $\Gamma(\eta \to \gamma \gamma)$ divided by the fitted branching fraction for that mode. See the note at the start of the $\Gamma(2\gamma)$ data block, next below.

 η DECAY MODES

<u>VALUE (keV)</u> <u>DO CUMENT ID</u> 1.30±0.07 OUR FIT

0±0.07 00K111

| | Mode | Fraction (Γ_j/Γ) Co | Scale factor/ onfidence level |
|-----------------|------------------------------------|---------------------------------|----------------------------------|
| | | Neutral modes | |
| Γ_1 | neutral modes | (71.91 ± 0.34) % | S=1.2 |
| Γ_2 | 2γ | (39.31 ± 0.20) % | S=1.1 |
| Γ3 | $3\pi^{0}$ | (32.57±0.23) % | S=1.1 |
| Γ_4 | $\pi^0 2\gamma$ | $(2.7 \pm 0.5) \times 10^{-4}$ | |
| Γ_5 | $2\pi^{0} 2\gamma$ | $< 1.2 \times 10^{-3}$ | CL=90% |
| Γ_6 | 4 γ | $< 2.8 \times 10^{-4}$ | CL=90% |
| Γ_7 | invisible | < 6 × 10 ⁻⁴ | CL=90% |
| | | Charged modes | |
| Γ ₈ | charged modes | (28.10±0.34) % | S=1.2 |
| Г9 | $\pi^{+} \pi^{-} \pi^{0}$ | (22.74±0.28) % | S=1.2 |
| Γ_{10} | $\pi^+\pi^-\gamma$ | (4.60±0.16) % | S=2.0 |
| Γ_{11} | $e^+ e^- \gamma$ | $(6.9 \pm 0.4) \times 10^{-3}$ | S=1.2 |
| Γ_{12} | $\mu^+\mu^-\gamma$ | $(3.1 \pm 0.4) \times 10^{-4}$ | |
| Γ_{13} | $e^+ e^-$ | $< 5.6 \times 10^{-6}$ | CL=90% |
| Γ_{14} | $\mu^+\mu^-$ | $(5.8 \pm 0.8) \times 10^{-6}$ | |
| Γ_{15} | 2e ⁺ 2e ⁻ | $(2.40\pm0.22)\times10^{-5}$ | |
| Γ_{16} | $\pi^{+}\pi^{-}e^{+}e^{-}(\gamma)$ | $(2.68\pm0.11)\times10^{-4}$ | |
| Γ_{17} | $e^{+}\;e^{-}\mu^{+}\mu^{-}$ | $< 1.6 \times 10^{-4}$ | CL=90% |
| Γ_{18} | $2\mu^{+}2\mu^{-}$ | $< 3.6 \times 10^{-4}$ | CL=90% |
| Γ_{19} | $\mu^{+}\mu^{-}\pi^{+}\pi^{-}$ | $< 3.6 \times 10^{-4}$ | CL=90% |
| Γ_{20} | $\pi^+\pi^-2\gamma$ | $< 2.0 \times 10^{-3}$ | |
| Γ_{21} | $\pi^+\pi^-\pi^0\gamma$ | < 5 × 10 ⁻⁴ | CL=90% |
| Γ ₂₂ | $\pi^0\mu^+\mu^-\gamma$ | $<$ 3 $\times 10^{-6}$ | CL=90% |

Charge conjugation (C), Parity (P), Charge conjugation \times Parity (CP), or Lepton Family number (LF) violating modes

| Γ ₂₃ | $\pi^0 \gamma$ | C | < 9 | $\times 10^{-5}$ | CL=90% |
|-----------------|---------------------------------|------|--------|------------------|--------|
| Γ_{24} | $\pi^+\pi^-$ | P,CP | < 1.3 | $\times 10^{-5}$ | CL=90% |
| Γ_{25} | $2\pi^{0}$ | P,CP | < 3.5 | $\times 10^{-4}$ | CL=90% |
| Γ_{26} | $2\pi^0\gamma$ | С | < 5 | $\times 10^{-4}$ | CL=90% |
| Γ_{27} | $3\pi^0\gamma$ | С | < 6 | $\times 10^{-5}$ | CL=90% |
| Γ ₂₈ | 3γ | С | < 1.6 | $\times 10^{-5}$ | CL=90% |
| Γ_{29} | $4\pi^0$ | P,CP | < 6.9 | $\times 10^{-7}$ | CL=90% |
| 30 | $\pi^{0} e^{+} e^{-}$ | C [a | o] < 4 | $\times 10^{-5}$ | CL=90% |
| Γ ₃₁ | $\pi^{0}\mu^{+}\mu^{-}$ | C [a |] < 5 | $\times 10^{-6}$ | CL=90% |
| Γ_{32} | $\mu^{+} e^{-} + \mu^{-} e^{+}$ | LF | < 6 | $\times 10^{-6}$ | CL=90% |
| | | | | | |

[a] C parity forbids this to occur as a single-photon process.

CONSTRAINED FIT INFORMATION

An overall fit to a decay rate and 19 branching ratios uses 49 measurements and one constraint to determine 9 parameters. The overall fit has a $\chi^2=$ 56.4 for 41 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle/(\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.

| <i>x</i> ₃ | 26 | | | | | | | |
|------------------------|-------|-----------------------|-------|------------|------------------------|------------------------|------------------------|------------------------|
| x_4 | -1 | -1 | | | | | | |
| <i>X</i> 9 | -66 | -73 | -1 | | | | | |
| <i>x</i> ₁₀ | -44 | -46 | 0 | 12 | | | | |
| x_{11} | -5 | -5 | 0 | -6 | -3 | | | |
| <i>x</i> ₁₂ | 0 | 0 | 0 | -1 | 0 | 0 | | |
| <i>X</i> 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Γ | -10 | -2 | 0 | 6 | 4 | 1 | 0 | 0 |
| | x_2 | <i>x</i> ₃ | x_4 | <i>X</i> 9 | <i>x</i> ₁₀ | <i>x</i> ₁₁ | <i>x</i> ₁₂ | <i>x</i> ₁₆ |

| | Mode | Rate (keV) | Scale factor |
|-----------------|----------------------------------------|----------------------------------|--------------|
| Γ2 | 2γ | 0.510 ± 0.026 | |
| Γ_3 | $3\pi^0$ | 0.423 ± 0.022 | |
| Γ_4 | $\pi^0 2\gamma$ | $(3.5 \pm 0.7) \times 10^{-4}$ | |
| Г9 | $\pi^+\pi^-\pi^0$ | 0.295 ± 0.016 | |
| Γ_{10} | $\pi^+\pi^-\gamma$ | 0.060 ± 0.004 | 1.2 |
| Γ ₁₁ | $e^+ e^- \gamma$ | 0.0089 ± 0.0007 | 1.1 |
| Γ_{12} | $\mu^+\mu^-\gamma$ | $(4.0 \pm 0.6) \times 10^{-4}$ | |
| Γ_{16} | $\pi^{+} \pi^{-} e^{+} e^{-} (\gamma)$ | $(3.48 \pm 0.23) \times 10^{-4}$ | |

η DECAY RATES

| VALUE (keV) | EVTS | DOCUMENT ID | | TECN | COMMENT | | | | |
|------------------------------|---------------|------------------------|----------|------------|------------------------------------|--|--|--|--|
| 0.510±0.026 OUR FIT | | | | | | | | | |
| 0.510±0.026 OUR AV | /ERAGE | | | | | | | | |
| $0.51 \pm 0.12 \pm 0.05$ | 36 | BARU | 90 | MD1 | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| $0.490\pm0.010\pm0.048$ | 2287 | ROE | 90 | ASP | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| $0.514\pm0.017\pm0.035$ | 1 2 9 5 | WILLIAMS | 88 | CBAL | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| $0.53 \pm 0.04 \pm 0.04$ | | BARTEL | 85 E | JADE | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| • • • We do not use | the following | ng data for average | es, fits | s, limits, | etc. • • • | | | | |
| 0.476 ± 0.062 | | ² RODRIGUES | 08 | CNTR | Reanalysis | | | | |
| $0.64 \ \pm 0.14 \ \pm 0.13$ | | AIHARA | 86 | TPC | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| 0.56 ± 0.16 | 56 | WEINSTEIN | 83 | CBAL | $e^+ e^- \rightarrow e^+ e^- \eta$ | | | | |
| 0.324 ± 0.046 | | BROWMAN | 74B | CNTR | Primakoff effect | | | | |
| 1.00 ± 0.22 | | ³ BEMPORAD | 67 | CNTR | Primakoff effect | | | | |

²RODRIGUES 08 uses a more sophisticated calculation for the inelastic background due to incoherent photoproduction to reanalyze the η photoproduction data on Be and Cu at 9 GeV from BROWMAN 74B. This brings the value of $\Gamma(\eta \to 2\gamma)$ in line with direct measurements of the width. The error here is only statistical.

³BEMPORAD 67 gives $\Gamma(2\gamma) = 1.21 \pm 0.26$ keV assuming $\Gamma(2\gamma)/\Gamma(\text{total}) = 0.314$.

 3 BEMPORAD 67 gives $\Gamma(2\gamma)=1.21\pm0.26$ keV assuming $\Gamma(2\gamma)/\Gamma(\text{total})=0.314$. Bemporad private communication gives $\Gamma(2\gamma)^2/\Gamma(\text{total})=0.380\pm0.083$. We evaluate this using $\Gamma(2\gamma)/\Gamma(\text{total})=0.38\pm0.01$. Not included in average because the uncertainty resulting from the separation of the coulomb and nuclear amplitudes has apparently been underestimated.

η BRANCHING RATIOS

| — N | eutral | modes | - |
|-----|--------|-------|---|

| Γ(neutral modes)/I | total | | | ſ | $\Gamma_1/\Gamma = (\Gamma_2 + \Gamma_3 + \Gamma_4)/\Gamma_1$ |
|---------------------------------------|----------------------|------------------------|-----------|-----------|---------------------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT I | D | TECN | COMMENT |
| 0.7191 ± 0.0034 OUR | FIT Error | includes scale fa | ctor of | 1.2. | |
| 0.705 ±0.008 | 16k | BASILE | 71D | CNTR | MM spectrometer |
| ● ● We do not use | the followir | ng data for avera | ges, fits | , limits, | etc. • • • |
| 0.79 ± 0.08 | | BUNIATOV | 67 | OSP K | |
| $\Gamma(2\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂ /Γ |
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 39.31 ± 0.20 OUR FIT | Error inc | ludes scale facto | r of 1.1 | , | |
| $39.49 \pm 0.17 \pm 0.30$ | 65 k | ABEGG | 96 | SPEC | $pd \rightarrow {}^{3}He\eta$ |
| • • • We do not use | the followin | ng data for avera | ges, fits | , limits, | etc. • • • |
| $38.45 \pm 0.40 \pm 0.36$ | 14k | ⁴ LOPEZ | 07 | CLEO | $\psi(2S) \rightarrow J/\psi \eta$ |
| | $^+\pi^-\gamma$, ar | nd $e^+e^-\gamma$ acco | | | ming decays of $\eta ightarrow \gamma \gamma$ cays within a contribution |

| $\Gamma(2\gamma)/\Gamma(\text{neutr}$ | al modes) | | Гэ/ | $\Gamma_1 = \Gamma_2/(\Gamma_2 + \Gamma_3 + \Gamma_3)$ | ٦) |
|---------------------------------------|-------------|-------------|------|--------------------------------------------------------|----|
| 1 (2 /)/1 (Head | ui illouca) | | . 2/ | .12/(.2 | 4) |
| VALUE | FVTS | DOCUMENT ID | TECN | COMMENT | |

| 1 (27 |)/ i (ileu | urai ilioues) | | | 12/11 = 12/(12+13+14) |
|--------|----------------|----------------------|--------------------|--------|-----------------------|
| VALUE | | EVTS | DO CUMENT ID | | TECN COMMENT |
| 0.5467 | 7 ± 0.0019 | OUR FIT | | | |
| 0.548 | ± 0.023 | OUR AVERAGE | Error includes sca | le fac | ctor of 1.5. |
| 0.535 | ±0.018 | | BUTTRAM | 70 | OSP K |
| 0.59 | ±0.033 | | BUNIATOV | 67 | OSP K |
| • • • | We do n | ot use the following | data for averages | , fits | , limits, etc. • • • |
| 0.52 | ± 0.09 | 88 | ABROSIMOV | 80 | HLBC |
| 0.60 | ±0.14 | 113 | KENDALL | 74 | OSP K |
| 0.57 | ±0.09 | | STRUGALSKI | 71 | HLBC |
| 0.579 | ±0.052 | | FELD MA N | 67 | OSP K |
| 0.416 | ±0.044 | | DIGIUGNO | 66 | CNTR Error doubled |
| 0.44 | ± 0.07 | | GRUNHAUS | 66 | OSP K |
| 0.39 | ± 0.06 | | ⁵ JONES | 66 | CNTR |

⁵ This result from combining cross sections from two different experiments.

| $\Gamma(3\pi^0)/\Gamma_{ m total}$ | | | | | | Гз/Г |
|------------------------------------------------------------------------------------|--------------------------------|-------------------------|------------------|---------------------|--------------------------------------|----------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT IL |) | TECN | COMMENT | |
| 32.57±0.23 OUR FIT | Error inc | ludes scale factor | of 1.1 | | | |
| ● ● We do not use | the followin | ng data for averag | ges, fits | , limits, | etc. • • • | |
| $34.03 \pm 0.56 \pm 0.49$ | 1821 | ⁶ LOPEZ | 07 | CLEO | $\psi(2S) \rightarrow J/\psi$ | $^{\flat}\eta$ |
| 6 Not independent $_{3\pi^0,\ \pi^+\pi^-\pi^0,\ \sigma}^{6}$ of 0.3% to the sys | $_{	au}^{+}\pi^{-}\gamma$, an | nd $e^+e^-\gamma$ accou | PEZ 0 int for | 7. Assur η dec | ming decays of s cays within a co | $\eta ightarrow \gamma \gamma$, ntribution |

| $\Gamma(3\pi^0)/\Gamma(\text{neutra})$ | al modes) | | | Γ3/ | $\Gamma_1 = \Gamma_3/(\Gamma_2 + \Gamma_3 + \Gamma_4)$ |
|----------------------------------------|------------------|--------------------|---------|-----------|--------------------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.4529 ± 0.0019 OU | R FIT | | | | · |
| 0.439 ± 0.024 | | BUTTRAM | 70 | OSPK | |
| • • • We do not u | se the following | g data for average | s, fits | , limits, | etc. • • • |
| 0.44 ± 0.08 | 75 | ABROSIMOV | 80 | HLBC | |
| 0.32 ± 0.09 | | STRUGALSKI | 71 | HLBC | |
| 0.41 ± 0.033 | | BUNIATOV | 67 | OSP K | Not indep. of $\Gamma(2\gamma)$ |
| | | | | | Γ(neutral modes) |
| 0.177 ± 0.035 | | FELD MA N | 67 | OSP K | , |
| 0.209 ± 0.054 | | DIGIUGNO | 66 | CNTR | Error doubled |
| 0.29 ± 0.10 | | GRUNHAUS | 66 | OSP K | |
| | | | | | |

| 0.209 ± 0.054 | | DIGIUGNO | 66 | | Error doubled |
|----------------------------------|--------------------|------------------|---------|-----------|----------------------------------------------------|
| 0.29 ± 0.10 | | GRUNHAUS | 66 | OSPK | |
| $\Gamma(3\pi^0)/\Gamma(2\gamma)$ | | | | | Γ_3/Γ_2 |
| VALUE | <u>EVTS</u> | DOCUMENT ID | | TECN | COMMENT |
| 0.829±0.006 OUR FIT | | | | | |
| 0.829±0.007 OUR AVE | RAGE | | | | |
| $0.884 \pm 0.022 \pm 0.019$ | 1821 | LOPEZ | 07 | | $\psi(2S) \rightarrow J/\psi \eta$ |
| $0.817 \pm 0.012 \pm 0.032$ | 17.4k ⁷ | AKHMETSHIN | 05 | CMD2 | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |
| 0.826 ± 0.024 | | ACHASOV | 00D | SND | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |
| $0.832 \pm 0.005 \pm 0.012$ | | KRUSCHE | 95 D | SPEC | $\gamma p ightarrow \eta p$, threshold |
| 0.841 ± 0.034 | | AMSLER | 93 | CBAR | $\overline{p}p \rightarrow \pi^+\pi^-\eta$ at rest |
| 0.822 ± 0.009 | | ALDE | 84 | GAM2 | |
| • • • We do not use th | e following d | ata for averages | , fits, | limits, e | etc. • • • |
| $0.796 \pm 0.016 \pm 0.016$ | | ACHASOV | 00 | SND | See ACHASOV 00D |
| 0.91 ± 0.14 | | COX | 70B | HB C | |
| 0.75 ± 0.09 | | DEVONS | 70 | OSPK | |
| 0.88 ± 0.16 | | BALTAY | 67D | DBC | |
| 1.1 ± 0.2 | | CENCE | 67 | OSP K | |
| 1.25 ± 0.39 | | BACCI | 63 | CNTR | Inverse BR reported |
| | | | | | |

⁷ Uses result from AKHMETSHIN 01B.

| -/ 00 \/- | | | | | | |
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| $\lceil (\pi^0 2\gamma) / \Gamma_{	ext{total}} ceil$ Early results an | e summarize | d in the review by | LANE | SBERG | 85. | Γ ₄ /Γ |
| ALUE (units 10 ⁻⁴) CL9 | % EVTS | DO CUMENT ID | | | COMMENT | |
| .7 ±0.5 OUR FIT | | des scale factor of | | | _ | |
| .21±0.24±0.47 | | | | | $\pi^- p \rightarrow \eta n \approx$ | threshold |
| We do not use | | - | | | | |
| .5 ±0.7 ±0.6 (8.4 90 | 1.6K ³ ,± | | 05 C | | See PRAKHOV $e^+e^- ightarrow \phi$ - | |
| 30 90 | 0 | | | | $\pi^- p \rightarrow \eta n$ | → η·γ |
| ⁸ PRAKHOV 08 is | | | | | | rst time the |
| invariant-mass sp | ectrum of th | e two photons. | | , 05, u | ang for the h | ist time the |
| ⁹ Normalized using | $\Gamma(\eta \rightarrow 2\gamma)$ | $/\Gamma = 0.3943 \pm 0.0$ | 0026. | | | |
| ¹⁰ This measuremen | t and the inc | lependent analysis | of the | e same d | ata by KNEC | HT 04 both |
| imply a lower valu | e of I $(\pi^{\circ} 2\gamma)$ |) than the one obta | ained t | by ALDE | 84 from I (π ^o | $2\gamma)/\Gamma(2\gamma)$. |
| $(\pi^0 2\gamma)/\Gamma(2\gamma)$ | | | | | | Γ_4/Γ_2 |
| ALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | CHG COMM | ENT - |
| 69±0.13 OUR FIT | | des scale factor of | | | | |
| 8 ±0.4 | | ALDE | 84 | GA M2 | | |
| • • We do not use | the followin | g data for average | s, fits, | , limits, | etc. • • • | |
| 5 ±0.6 | 70 | BINON | 82 | GA M2 | See Al | LDE 84 |
| $(\pi^0 2\gamma)/\Gamma(3\pi^0)$ | | | | | | г /г. |
| . , , , | | | | | | Γ ₄ /Γ ₃ |
| NLUE (units 10 ⁻⁴) 3±1.6 OUR FIT | Error include | DOCUMENT ID | 1 | TECN | COMMENT | |
| • • We do not use | | | | . limits | etc. • • • | |
| | the followin | 11 KNECHT | 04 | | $\pi^- p \rightarrow nn$ | |
| 3±2.8±1.4 | | | | CRYB | π $p \rightarrow n\eta$ | |
| $^{ m 1}$ independent analy | ysis of same | data as PRAKHO | V 05. | | | |
| $(2\pi^0 2\gamma)/\Gamma_{ m total}$ | | | | | | Γ_5/Γ |
| NLUE | CL% | DOCUMENT ID | | ECN C | COMMENT | |
| (1.2×10^{-3}) | 90 1 | NEFKENS (| 05 A C | RYB p | (720 MeV/c) | $\pi^- \rightarrow n\eta$ |
| • • We do not use | the followin | g data for average | s, fits | , limits, | etc. • • • | |
| (4.0×10^{-3}) | 90 | BLIK (| 07 G | iAM4 π | $r^- p \rightarrow \eta n$ | |
| ^{L2} Measurement is d | one in limite | ed $\gamma\gamma$ energy range | e. | | | |
| | | 77 63 6 | | | | |
| $(4\gamma)/\Gamma_{\rm total}$ | | | | | | Γ ₆ /Γ |
| ALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| <2.8 × 10 ⁻⁴ | 90 | BLIK | 07 | GA M4 | $\pi^- p \rightarrow \eta n$ | |
| $(invisible)/\Gamma(2\gamma)$ |) | | | | | Γ_7/Γ_2 |
| ALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | , |
| <1.65 × 10 ⁻³ | 90 | 13 ABLIKIM | | BES2 | $J/\psi \rightarrow \phi \eta$ | |
| 13 Based on 58M $J_{/}$ | /ψ decavs. | | | | | |
| , | | | | | | |
| | | Charged mod | ies – | | į. | |
| | | | | | | Γ9/Γ |
| $(\pi^+\pi^-\pi^0)/\Gamma_{\rm tot}$ | | | | | | |
| • | ai | DOCUMENT ID | | TECN | COMMENT | 19/1 |
| LUE (units 10 ⁻²) | al EVTS | <u>DOCUMENT ID</u> udes scale factor o | | | COMMENT | 19/1 |
| ALUE (units 10 ⁻²) 2.74±0.28 OUR FIT | al <u>EVTS</u> Error incl | udes scale factor o | of 1.2. | | | |
| ALUE (units 10 ⁻²) 2.74±0.28 OUR FIT • • We do not use | EVTS Error incles the followin | udes scale factor o g data for average | of 1.2. es, fits, | , limits, | etc. • • • | |
| ALUE (units 10^{-2}) 2.74 ± 0.28 OUR FI • • We do not use $2.60 \pm 0.35 \pm 0.29$ | EVTS Ferror includes the followin | udes scale factor o g data for average ¹⁴ LOPEZ | of 1.2. es, fits, 07 | , limits, CLEO | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J$ | /ψη |
| 2.74 \pm 0.28 OUR FIT • • We do not use 2.60 \pm 0.35 \pm 0.29 | EVTS Ferror includes the following 3915 of other residents | udes scale factor of g data for average ¹⁴ LOPEZ ults listed for LOP | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{j}$ ming decays o | $/\psi\eta$ f $\eta \to \gamma\gamma$, |
| ALUE (units 10^{-2}) 2.74 \pm 0.28 OUR FIT • • We do not use 2.60 \pm 0.35 \pm 0.29 | $EVTS$ F Error includes the followin 3915 of other results: $\pi^+\pi^-\gamma$, and | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $_{e}^{+}$ $_{e}^{-}$ $_{\gamma}$ account | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{j}$ ming decays o | $/\psi\eta$ f $\eta \to \gamma\gamma$, |
| NLUE (units 10^{-2}) 2.74 ± 0.28 OUR FIT • • We do not use 2.60 ± 0.35 ± 0.29 14 Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy | $\frac{EVTS}{Error}$ Error inclinates the followin 3915 of other resing $\pi^+\pi^-\gamma$, an externatic error er | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $^{e^+e^-\gamma}$ accounds. | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur all η dec | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 1. LUE (units 10^{-2}) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 1.4 Not independent 3 π^{0} , $\pi^{+}\pi^{-}\pi^{0}$, of 0.3% to the sy (neutral modes)/ | EVTS Error includes the following 3915 of other residuals the matter $\pi^+\pi^-\gamma$, and stematic error $\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | udes scale factor of g data for average $14~\text{LOPEZ}$ ults listed for LOP d $e^+e^-\gamma$ accounds. | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur all η dec | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{j}$ ming decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| NLUE (units 10^{-2}) 2.74±0.28 OUR FIT • We do not use 2.60±0.35±0.29 ¹⁴ Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ | EVTS EVTS Ferror inclination in the followin 3915 of other restrained in the followin in the following stematic error in the following in t | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $_{\rm e}^+$ e $^ _{\rm \gamma}$ account. | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur all η dec | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| | EVTS EVTS Error includes the following a $\pi^+\pi^-\gamma$, and stematic error $T(\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $_{\rm e}^+$ e $^ _{\rm \gamma}$ account. | of 1.2. es, fits, 07 PEZ 07 | , limits, CLEO 7. Assur all η dec | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 1.0 LUE (units 10 $^{-2}$) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 1.4 Not independent 3 π^0 , $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ LUE 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.89 | Γ EVTS Γ Error include the followin 3915 of other rest $\pi^+\pi^-\gamma$, and stematic error Γ ($\pi^+\pi^-\pi$ EVTS Error inclusives 74 | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $e^+e^-\gamma$ accounds. 10 DOCUMENT ID des scale factor of KENDALL | of 1.2. of 7.2 PEZ 07 of 1.2. f 1.2. | , limits, CLEO 7. Assur all η dec $\Gamma_1/$ | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| $\frac{AUUE \text{ (units } 10^{-2})}{2.74 \pm 0.28 \text{ OUR FIT}}$ • • We do not use 2.60 ± 0.35 ± 0.29 ¹⁴ Not independent $\frac{3\pi^0}{3\pi^0}, \frac{\pi^+\pi^-\pi^0}{\pi^0}, \text{ of } 0.3\% \text{ to the sy}$ (neutral modes)/ $\frac{MUE}{26 \pm 0.30 \text{ OUR FIT}}$ 26 ± 0.30 OUR AVE 54 ± 1.89 4 ± 1.1 | EVTS F Error inclusion and the followin and the followin and the followin and the followin and the following and the f | udes scale factor of g data for average 14 LOPEZ ults listed for LOP d $e^+e^-\gamma$ accounds. DOCUMENT ID des scale factor of KENDALL AGUILAR | of 1.2. 07 PEZ 07 nt for : 74 72B | , limits, CLEO 7. Assurall η dec $\Gamma_1/$ TECN OSP K HBC | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 1.0 LUE (units 10 ⁻²) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 4.4 Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.0 LUE 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.1.89 4±1.1 83±0.80 | EVTS EVTS F Error includes the following 3915 of other residuals are $\pi^+\pi^-\gamma$, and so the following are $\pi^+\pi^-\gamma$, and so the following EVTS EVTS EVTS EVTS EVTS EVTS 29 70 | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d e e e o account. Document ID des scale factor of KENDALL AGUILAR BLOODWO | of 1.2. 07 PEZ 07 at for a f 1.2. 74 72B 72B | , limits, CLEO 7. Assur η dec $\Gamma_1/TECN$ OSP K HBC HBC | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 2.4 LUE (units 10^{-2}) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 1.4 Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.6 LUE 1.6 ±0.05 OUR FIT 2.6 ±0.30 OUR AVE 5.4±1.89 4 ±1.1 83±0.80 6 ±0.6 | EVTS F Error inclusion and the followin and the followin and the followin and the followin and the following and the f | udes scale factor of g data for average 14 LOPEZ lits listed for LOP d $e^+e^-\gamma$ account. DOCUMENT ID des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE | of 1.2. 07 PEZ 07 at for a f 1.2. 74 72B 72B 67B | , limits, CLEO 7. Assur all η dec Γ1/ TECN OSP K HBC HBC HBC | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| LUE (units 10^{-2}) L74 ± 0.28 OUR FIT • • We do not use the solution of 0.3% to the sy (neutral modes) / LUE (16±0.05 OUR FIT 26±0.05 OUR AVE 34±1.89 4 ±1.1 33±0.80 6 ±0.6 6 39±0.56 | The following states of the following space of the rest $\pi^+\pi^-\gamma$, and stematic error inclustrates of the following space of the followi | udes scale factor of g data for average 14 LOPEZ lits listed for LOP d $e^+e^-\gamma$ accounds. 190 DOCUMENT ID des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF | of 1.2. 07 PEZ 07 at for 3 f 1.2. 74 72B 72B 67B 66 | , limits, CLEO 7. Assurall η dec F ₁ / TECN OSP K HBC HBC HBC HBC | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 1.1 UE (units 10^{-2}) 2.74 ± 0.28 OUR FIT • • We do not use 2.60 ± 0.35 ± 0.29 4 Not independent 3 π^0 , $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.1 UE 16 ± 0.05 OUR FIT 26 ± 0.30 OUR AVE 54 ± 1.1 33 ± 0.80 6 ± 0.6 89 ± 0.56 6 ± 0.8 | EVTS EVTS F Error includes the following 3915 of other residuals are $\pi^+\pi^-\gamma$, and so the following are $\pi^+\pi^-\gamma$, and so the following EVTS EVTS EVTS EVTS EVTS EVTS 29 70 | udes scale factor of g data for average 14 LOPEZ lits listed for LOP d $e^+e^-\gamma$ account. DOCUMENT ID des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE | of 1.2. 07 PEZ 07 at for a f 1.2. 74 72B 72B 67B | , limits, CLEO 7. Assur all η dec Γ1/ TECN OSP K HBC HBC HBC | etc. $ullet$ $ullet$ $\psi(2S) ightarrow J_{ m in}$ ning decays o | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution |
| 1.1 UE (units 10^{-2}) 2.74 ± 0.28 OUR FIT • • We do not use 2.60 ± 0.35 ± 0.29 4 Not independent 3 π^0 , $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.1 UE 16 ± 0.05 OUR FIT 26 ± 0.30 OUR AVE 54 ± 1.1 83 ± 0.80 6 ± 0.6 89 ± 0.56 6 ± 0.8 8 ± 1.1 | EVTS EVTS F Error includes the following 3915 of other residuals are $\pi^+\pi^-\gamma$, and so the following are $\pi^+\pi^-\gamma$, and so the following are $\pi^+\pi^-\gamma$. EVTS EVTS EVTS EVTS 29 70 244 50 | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d $e^+e^-\gamma$ accound 10 des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI | of 1.2. es, fits, 07 PEZ 07 at for : f 1.2. 74 72B 72B 67B 66 64 64 | CLEO 7. Assurable for the control of the control o | etc. $\bullet \bullet \bullet$ $\psi(2S) \to J$ ming decays of says within a of $\Gamma_9 = \{\Gamma_2 + \Gamma\}$ | $/\psi\eta$ If $\eta 	o \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ |
| 1.0 LUE (units 10 $^{-2}$) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 4. Not independent 3π0, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.18 33±0.80 6±0.6 89±0.56 6±0.8 8±1.1 15 Error increased fr | The following states of the following space of the rest $\pi^+\pi^-\gamma$, and stematic error inclustrates of the following space of the followi | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d $e^+e^-\gamma$ accound 10 des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI | of 1.2. es, fits, 07 PEZ 07 at for : f 1.2. 74 72B 72B 67B 66 64 64 | CLEO 7. Assurable for the control of the control o | etc. $\bullet \bullet \bullet$ $\psi(2S) \to J$ ming decays of says within a of $\Gamma_9 = \{\Gamma_2 + \Gamma\}$ | $/\psi\eta$ If $\eta 	o \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ |
| 1.0 LUE (units 10 $^{-2}$) 2.74 ± 0.28 OUR FIT • • We do not use 2.60 ± 0.35 ± 0.29 4. Not independent 3π0, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.89 4 ±1.1 83±0.80 6 ±0.6 89±0.56 6 ±0.8 8 ±1.1 1.5 Error increased fr (2γ)/ $\Gamma(\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | The following states of the following space of the rest $\pi^+\pi^-\gamma$, and stematic error inclustrates of the following space of the followi | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d $e^+e^-\gamma$ accound 10 des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI | of 1.2. es, fits, 07 PEZ 07 at for : f 1.2. 74 72B 72B 67B 66 64 64 | CLEO 7. Assurable for the control of the control o | etc. $\bullet \bullet \bullet$ $\psi(2S) \to J$ ming decays of says within a of $\Gamma_9 = \{\Gamma_2 + \Gamma\}$ | $/\psi\eta$ If $\eta 	o \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ |
| $\frac{NLUE \text{ (units 10}^{-2})}{2.74 \pm 0.28 \text{ OUR FIT}}$ • • We do not use 2.60 ± 0.35 ± 0.29 14 Not independent 3π0, π+π−π0, of 0.3% to the sy (neutral modes)/NLUE 16±0.05 OUR FIT 22±0.30 OUR AVE 54±1.89 4 ±1.1 83±0.80 6 ±0.6 89±0.56 6 ±0.8 8 ±1.1 15 Error increased fr (2γ)/Γ (π+π−π) MLUE | $\begin{array}{c} \textbf{al} \\ \textbf{F} \\ \textbf{Error} \\ \textbf{Error} \\ \textbf{In Error} \\ \textbf{Error} \\ \textbf{In Error} \\ I$ | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d et e = γ account or. DOCUMENT ID AGUILAR SHOODWO FLATTE ALFF KRAEMER PAULI I value 0.5 by Blood | 74 72B 72B 66 64 64 64 64 64 64 64 64 64 64 64 64 | CLEO 7. Assurable for the following series of the fol | etc. $\bullet \bullet \bullet$ $\psi(2S) \to J$ ming decays of says within a of $\Gamma_9 = \{\Gamma_2 + \Gamma\}$ | $/\psi\eta$ f $\eta \rightarrow \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). |
| 1.0 LUE (units 10^{-2}) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 1.4 Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.4 LUE 1.6±0.05 OUR FIT 2.6±0.30 OUR AVE 3.4±1.1 1.83±0.80 6.±0.6 1.89±0.56 6.±0.8 1.9±0.56 6.±0.8 1.11 1.5 Error increased fr (2 γ)/ $\Gamma(\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | $\begin{array}{c} \mathbf{r} \\ $ | udes scale factor of g data for average 14 LOPEZ uits listed for LOP d e+e-γ account. DOCUMENT ID des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI I value 0.5 by Blood | 74 72B 72B 66 64 64 64 64 64 64 64 64 64 64 64 64 | CLEO 7. Assurable for the following series of the fol | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays of any within a of $\Gamma_9 = (\Gamma_2 + \Gamma_2)$ | $/\psi\eta$ f $\eta \rightarrow \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). |
| 1. LUE (units 10^{-2}) 2. 74 ± 0.28 OUR FIT • • We do not use 10^{-2} 2. 60 ± 0.35 ± 0.29 2. 60 ± 0.35 ± 0.29 2. 60 ± 0.38 to the sy (neutral modes) / 1. LUE 16 ± 0.05 OUR FIT 26 ± 0.30 OUR AVE 4 ± 1.1 83 ± 0.80 6 ± 0.6 89 ± 0.56 6 ± 0.8 8 ± 1.1 5 Error increased fr (2 γ) / Γ (π + π - π) 1. LUE 1. 228 ± 0.028 OUR F 70 ± 0.04 OUR AVE | $ \begin{array}{c c} \textbf{FUTS} \\ \hline \textbf{F} & \textbf{EvTS} \\ \hline \textbf{F} & \textbf{Error} & \textbf{incl} \\ \textbf{the followin} \\ \textbf{3915} \\ \textbf{of other resi} \\ \textbf{\pi}^{+} & \textbf{\pi}^{-} & \textbf{\gamma}, \textbf{an} \\ \textbf{stematic error} \\ \textbf{FUTS} \\ \hline \textbf{Error} & \textbf{including and particles} \\ \textbf{29} \\ \textbf{70} \\ \textbf{244} \\ \textbf{50} \\ \textbf{om published} \\ \textbf{0} \\ \textbf{0} \\ \textbf{IT} & \textbf{EVTS} \\ \hline \textbf{Error} & \textbf{including and particles} \\ \textbf{EVTS} \\ \hline \textbf{ETTS} & \textbf{Error} & \textbf{including and particles} \\ \textbf{VERAGE} \\ \textbf{VERAGE} \\ \end{array} $ | udes scale factor of g data for average 14 LOPEZ uits listed for LOP d e+e-γ account. DOCUMENT ID des scale factor of KENDALL AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAUL! It value 0.5 by Bloodudes scale factor | of 1.2. 07 PEZ 07 It for : 74 72B 72B 66 64 64 64 odwort | , limits, CLEO 7. Assur Medical Processing CLEO 7. Assur Medical Processing CLEO CLEO CLEO CLEO CLEO CLEO CLEO CLEO | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays or ays within a \bullet $\Gamma_9 = (\Gamma_2 + \Gamma)$ te communica | $/\psi\eta$ f $\eta \rightarrow \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). |
| 1.0 LUE (units 10^{-2}) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 1.4 Not independent 3π0, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.5 LUE 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.89 4 ±1.1 83±0.80 6 ±0.6 6 ±0.6 83±0.56 6 ±0.8 8 ±1.1 1.5 Error increased fr (2γ)/Γ($\pi^+\pi^-\pi^-\pi^0$ 1.0 LUE 728±0.028 OUR F 70 ±0.04 OUR A 704±0.032±0.026 | $\begin{array}{c} \mathbf{r} \\ $ | udes scale factor of g data for average 14 LOPEZ uits listed for LOP d e+e-γ account of the factor | of 1.2. 07 EZ 07 It for : 74 72B 72B 66 64 64 64 07 | , limits, CLEO 7. Assurd 7. Assurd 7. Assurd 7. Assurd 8. Assurd 8 | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays or any within a of $\Gamma_9 = (\Gamma_2 + \Gamma_2)$ te communica $\frac{COMMENT}{\psi(2S) \rightarrow J}$ | $/\psi\eta$ f $\eta	o \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). Γ_2/Γ_9 |
| 10.00 (units 10 ⁻²) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 4.4 Not independent 3π ⁰ , $π + π - π^0$, of 0.3% to the sy (neutral modes)/ 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.89 4.±1.1 33±0.80 6.±0.6 39±0.56 6.±0.8 8.±1.1 1.5 Error increased fr (2γ)/Γ($π + π - π^0$ 1.00 (1.00 OUR AVE 1.00 OUR AVE 1.00 (1.00 OUR AVE 1.00 OUR AVE 1.00 (1.00 OUR AVE 1.00 OUR | $\begin{array}{c c} \textbf{EVTS} \\ \hline \textbf{F} & \text{Error inclusion} \\ \textbf{Solution} \\ Solutio$ | udes scale factor of g data for average 14 LOPEZ 11ts listed for LOP d e + e - γ account or. PO DOCUMENT ID AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI II value 0.5 by Bloodudes scale factor 16 LOPEZ ABLIKIM | of 1.2. 07 PEZ 07 tt for : 74 72B 72B 66 64 64 64 07 06E | CLEO T. Assurd TECN OSPK HBC HBC DBC DBC CLEO CLEO BES2 | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays of says within a of | $\psi\eta$ f $\eta \to \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). Γ_2/Γ_9 |
| 1. LUE (units 10^{-2}) 2. 74 ± 0.28 OUR FIT • • We do not use 10^{-2} 2. 60 ± 0.35 ± 0.29 2. 60 ± 0.35 ± 0.29 2. 60 ± 0.38 to the sy (neutral modes) / 1. LUE 16 ± 0.05 OUR FIT 26 ± 0.30 OUR AVE 4 ± 1.1 83 ± 0.80 6 ± 0.6 89 ± 0.56 6 ± 0.8 8 ± 1.1 5 Error increased fr (2 γ) / Γ (π + π - π) 1. LUE 1. 228 ± 0.028 OUR F 70 ± 0.04 OUR AVE | $\begin{array}{c c} \textbf{EVTS} \\ \hline \textbf{F} & \textbf{Error} \textbf{incl} \\ \textbf{the followin} \\ 3915 \\ \textbf{of other resi} \\ \pi^+\pi^-\gamma, \textbf{ anstematic error} \\ \hline \textbf{/'} \textbf{(}\pi^+\pi^-\pi^-\pi^-) \\ \hline \textbf{EVTS} \\ \textbf{Error} \textbf{ inclu} \\ \textbf{ERAGE} \\ 74 \\ 29 \\ 70 \\ 244 \\ 50 \\ \textbf{om published} \\ \textbf{om published} \\ \textbf{O} \\ \textbf{IT} & \textbf{Error} \textbf{ inclu} \\ \hline \textbf{Error} \textbf{ inclu} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} \textbf{ includes a specific error} \\ \textbf{ST} & \textbf{Error} includes a specif$ | udes scale factor of g data for average 14 LOPEZ JITS listed for LOP d e+ e - γ account or. DOCUMENT ID des scale factor of KENDALL AGUILAR BLOODWO FLATTE ALFF KRAEMER PAULI I value 0.5 by Blood DOCUMENT ID cludes scale factor 16 LOPEZ ABLIKIM AMSLER | of 1.2. 07 EZ 07 It for : 74 72B 72B 66 64 64 64 07 | CLEO T. Assurd TECN OSPK HBC HBC DBC DBC CLEO CLEO BES2 | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays or any within a of $\Gamma_9 = (\Gamma_2 + \Gamma_2)$ te communica $\frac{COMMENT}{\psi(2S) \rightarrow J}$ | $\psi\eta$ f $\eta \to \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). Γ_2/Γ_9 $\psi\eta$ $\psi\eta \to \eta\gamma$ |
| 1.0 LUE (units 10^{-2}) 2.74±0.28 OUR FIT • • We do not use 2.60±0.35±0.29 4.4 Not independent $3\pi^0$, $\pi^+\pi^-\pi^0$, of 0.3% to the sy (neutral modes)/ 1.0 LUE 16±0.05 OUR FIT 26±0.30 OUR AVE 54±1.1 83±0.80 6±0.6 89±0.56 6±0.8 8±1.1 1.5 Error increased fr (2 γ)/ Γ ($\pi^+\pi^-\pi^0$ 1.0 LUE 70±0.03 OUR FIT 70±0.04 OUR A | $\begin{array}{c c} \textbf{EVTS} \\ \hline \textbf{F} & \text{Error inclusion} \\ \textbf{Solution} \\ Solutio$ | udes scale factor of g data for average 14 LOPEZ 11ts listed for LOP d e + e - γ account or. PO DOCUMENT ID AGUILAR 15 BLOODWO FLATTE ALFF KRAEMER PAULI II value 0.5 by Bloodudes scale factor 16 LOPEZ ABLIKIM | of 1.2. 07 PEZ 07 It for: 74 72B 66 64 64 64 07 06E 95 | , limits, CLEO 7. Assuru fee MBC HBC HBC DBC DBC CLEO BES2 CBAR | etc. $\bullet \bullet \bullet$ $\psi(2S) \rightarrow J$ ming decays of says within a of | $\psi\eta$ f $\eta \to \gamma\gamma$, contribution $3+\Gamma_4)/\Gamma_9$ tion). Γ_2/Γ_9 |

| $\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ | | | | | | Г3/Г |
|----------------------------------------------------------------------------|-----------------------|------------------------------------|------------|---------------------|-------------------------------------|------------------------------|
| VALUE | EVTS | DOCUMENT ID | -610 | TECN | COMMENT | |
| 1.432±0.026 OUR FIT 1.48 ±0.05 OUR AVEI | | des scale factor o | OI 1.2 | • | | |
| 1.46 ±0.03 ±0.09 | | ACHASOV | 06A | SND | $e^+e^ \rightarrow$ | $\eta \gamma$ |
| 1.52 ±0.04 ±0.08 | 23k 17 | AKHMETSHIN | | | $e^+e^- \rightarrow$ | |
| $1.44 \pm 0.09 \pm 0.10$ | 1627 | AMSLER | 95 | CBAR | $\overline{p}p \rightarrow \pi^{+}$ | $^{\vdash}\pi^{-}\eta$ at re |
| +0.15 | 199 | BAGLIN | 69 | HLBC | | |
| -0.29 -0.20 | | | | | | |
| $.47 \begin{array}{c} +0.20 \\ -0.17 \end{array}$ | | BULLOCK | 68 | HLBC | | |
| • • We do not use the | e following o | lata for averages | , fits, | limits, | etc. • • • | |
| .3 ±0.4 | | BAGLIN | 67B | HLBC | | |
| 0.90 ±0.24 | | FOSTER | 65 | HBC | | |
| 2.0 ±1.0 0.83 ±0.32 | | FOELSCHE CRAWFORD | 64 63 | HB C HB C | | |
| | 11 | | | | | |
| ¹⁷ AKHMETSHIN 01B | uses results | from AKHMETS | SHIN | 99F. | | |
| $(\pi^{+}\pi^{-}\pi^{0})/[\Gamma(2\gamma)$ | $+\Gamma(3\pi^{0})$ | 1 | | | | ۲+۲)/و۲ |
| ALUE | | DOCUMENT ID | | TECN | | -, , - |
| .316 ±0.005 OUR FI | Γ Error in o | | | | _ | |
| .304 ±0.012 | 6.11 | ACHASOV | | SND | $e^+e^- \rightarrow$ | $\phi \to ~\eta \gamma$ |
| • We do not use the | e following o | • | | | | |
| $.3141 \pm 0.0081 \pm 0.0058$ | | ACHASOV | 00B | SND | See ACHA | SOV 00D |
| $(\pi^+\pi^-\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₁₀ / |
| ` ' | 51/7.0 | 00.000.000 | | TE 644 | | 110/ |
| | EVTS rror includes | DOCUMENT ID | | TECN | COMMENT | |
| • We do not use the | | | | limits. | etc. • • • | |
| .96±0.14±0.14 | _ | LOPEZ | | | $\psi(2S) \rightarrow$ | 1/4/20 |
| | | | | | | |
| 18 Not independent of $_{3\pi^0}$, $_{\pi^+\pi^-\pi^0}$, $_{\pi^+}$ | other results | + a - a account | = Z U/ | . Assur | ning decays | or $\eta \to \gamma$ |
| of 0.3% to the syster | matic error. | c y account | . 101 6 | iii ij dee | ays within | a continuati |
| -/ + - \/ - / + - | - 0\ | | | | | - /- |
| $(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-$ | , | | | | | Γ ₁₀ /Γ |
| 0.202±0.007 OUR FIT | EVTS Error inclu | DOCUMENT ID des scale factor of | | | COMMENT | |
| 0.202±0.007 OUR AVE | | or includes scale | | | See the ide | eogram belo |
| .175 ± 0.007 ± 0.006 | 85 9 | LOPEZ | 07 | | $\psi(2S) \rightarrow$ | • |
| 0.209 ± 0.004 | 18k | THALER | 73 | ASPK | | |
| $.201 \pm 0.006$ | 725 0 | GORMLEY | 70 | ASPK | | |
| • We do not use the | e following o | lata for averages | , fits, | limits, | etc. • • • | |
| .28 ±0.04 | | BALTAY | | DBC | | |
| 1.25 ±0.035 | | LITCHFIELD | 67 | DBC | | |
| .30 ±0.06 .196±0.041 | | CRAWFORD FOSTER | 66 65.c | HB C HB C | | |
| .170 ± 0.041 | | IJJIEK | 050 | TIDC | | |
| WEIGHTED AV | /ERAGE | | | | | |
| 0.203±0.008 (E | rror scaled b | y 2.4) | | | | |
| | | ↓ | | | | |
| | | | | | d average, e | |
| | | | | | ed upon the are not ned | |
| | | sarily the sa | ame a | s our 'be | est' values, | |
| | | obtained fro | om a l | east-squ ments o | uares constr f other (rela | ained fit |
| | | quantities a | | | | iou) |
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| | / | | | | | ₂ 2 |
| | / | | | _ | 7 0150 | X |
| | | + LOP | | 0° 73 | | 9.2 2.3 |
| | _ / | | RMLE | | | 0.1 |
| | \searrow | \ | | | | 11.6 |
| | | | . ' | (Confide | ence Level = | 0.0031) |
| 244 242 | 0.18 0.2 | 2 0.22 0. | 24 | 0.26 | | |
| 0.14 0.16 | | | | | | |
| 0.14 0.16 | | | | | | |
| 0.14 0.16 $\Gamma(\pi^+\pi^-\gamma)/$ | | | | | | |
| | | | | | | Γ ₁₁ / |

 $\Gamma(e^+e^-\gamma)/\Gamma_{\text{total}}$ Γ_{11}/Γ
 VALUE (units $10^{-3})$ EVTS
 DOCUMENT ID
 1 LECN
 COMMENT

 6.9 ± 0.4
 OUR AVERAGE
 Error includes scale factor of 1.2.

 6.6 ± 0.4
 ± 0.4
 1345
 BERGHAUSER 11
 SPEC
 $\gamma p \rightarrow p \eta$

 7.8 ± 0.5 ± 0.8
 435 ± 31
 BERLOWSKI
 08
 WASA
 $pd \rightarrow {}^{3}He \eta$

 5.15 ± 0.62 ± 0.74
 283
 ACHASOV
 01B
 SND
 $e^{+}e^{-} \rightarrow \phi \rightarrow \eta \gamma$

 7.10 ± 0.64 ± 0.46
 323
 AKHMETSHIN 01
 CMD2
 $e^{+}e^{-} \rightarrow \phi \rightarrow \eta \gamma$ EVTS DOCUMENT ID \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 172 19 LOPEZ 07 CLEO $\psi(2S)
ightarrow J/\psi \eta$ $9.4 \pm 0.7 \pm 0.5$

 19 Not independent of other results listed for LOPEZ 07. Assuming decays of $\eta \to \gamma \gamma$, $3\pi^0,~\pi^+\pi^-\pi^0,~\pi^+\pi^-\gamma,$ and $e^+e^-\gamma$ account for all η decays within a contribution of 0.3% to the systematic error.

 η

| $\Gamma(e^+e^-\gamma)/\Gamma(\pi^+\pi^-\gamma)$ | Γ ₁₁ /Γ ₁₀ | $\Gamma(e^+e^-\mu^+\mu^-)/\Gamma_{ m total}$ | Γ_1 | 17/T |
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| VALUE EVTS | DOCUMENT ID TECN COMMENT | VALUE CL% | DO CUMENT ID TECN COMMENT | |
| 0.150±0.011 OUR FIT Error in 0.237±0.021±0.015 172 | cludes scale factor of 1.3. LOPEZ 07 CLEO $\psi(2S) 	o J/\psi \eta$ | <1.6 × 10 ⁻⁴ 90 | BERLOWSKI 08 WASA $pd ightarrow {}^3	ext{He }\eta$ | /- |
| $\Gamma(e^+e^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ | Г ₁₁ /Г ₉ | $\Gamma(2\mu^+2\mu^-)/\Gamma_{\text{total}}$ | DOCUMENT ID TECN COMMENT | 18/F |
| 3.02±0.19 OUR FIT Error inclu | | <3.6 × 10 ⁻⁴ 90 | BERLOWSKI 08 WASA $pd ightarrow {}^3	ext{He }\eta$ | |
| 2.1 ±0.5 80 | JANE 75B OSPK See the erratum | $\Gamma(\mu^+\mu^-\pi^+\pi^-)/\Gamma_{	ext{total}}$ | DOCUMENT ID TECN COMMENT | 19/Γ |
| | π^{0}) + $\Gamma(\pi^{+}\pi^{-}\gamma)$ + $\Gamma(e^{+}e^{-}\gamma)$] $_{1}/(\Gamma_{9}+\Gamma_{10}+\Gamma_{11}) = (\Gamma_{2}+\Gamma_{3}+\Gamma_{4})/(\Gamma_{9}+\Gamma_{10}+\Gamma_{11})$ | <3.6 × 10 ⁻⁴ 90 | BERLOWSKI 08 WASA $pd \rightarrow {}^{3}\text{He }\eta$ | |
| <u>VALUE</u> <u>EVTS</u> 2.57±0.04 OUR FIT Error inclu | DOCUMENT ID TECN | $\Gamma(\pi^+\pi^-2\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ | | 0/Γ9 |
| 2.64±0.23 | BALTAY 67B DBC | <u>VALUE</u> <u>CL%</u> < 9 × 10 ^{−3} | DOCUMENT ID TECN PRICE 67 HBC | |
| • • We do not use the followin 4.5 ± 1.0 280 | g data for averages, fits, limits, etc. • • • • 20 JAMES 66 HBC | • • • We do not use the follow | ring data for averages, fits, limits, etc. • • • | |
| 3.20 ± 1.26 53 | 20 BASTIEN 62 HBC | $<16 \times 10^{-3}$ 95 | BALTAY 67B DBC | |
| 2.5 ± 1.0 10 | 20 PICKUP 62 HBC sed in the averages as they do not separate clearly $\eta ightharpoonup$ | $\Gamma(\pi^+\pi^-\pi^0\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ | • | 1/Γ9 |
| $\pi^+\pi^-\pi^0$ and $\eta 	o \pi^+\pi^-$ | γ from each other. The reported values thus probably | VALUE CL% EVTS <0.24 × 10 ⁻² 90 0 | <u>DOCUMENT ID</u> <u>TECN</u> THALER 73 ASPK | |
| contain some unknown fraction | · | | ring data for averages, fits, limits, etc. • • • | |
| $\Gamma(2\gamma)/[\Gamma(\pi^+\pi^-\pi^0) + \Gamma(\pi^-)]$ | $(\Gamma_{\sigma}^{+} - \gamma) + \Gamma(e^{+} e^{-} \gamma)$ $\Gamma_{2}/(\Gamma_{9} + \Gamma_{10} + \Gamma_{11})$ DOCUMENT ID TECN | $<1.7 \times 10^{-2}$ 90 $<1.6 \times 10^{-2}$ 95 | ARNOLD 68 HLBC BALTAY 67B DBC | |
| 1.402±0.023 OUR FIT Error in | | $< 7.0 \times 10^{-2}$ | FLATTE 67 HBC | |
| 1.1 ±0.4 OUR AVERAGE 1.51 ±0.93 75 | KENDALL 74 OSPK | <0.9 × 10 ⁻² | PRICE 67 HBC | |
| 0.99 ±0.48 | CRAWFORD 63 HBC | $\Gamma(\pi^0\mu^+\mu^-\gamma)/\Gamma_{	ext{total}}$ | | ₂₂ /Γ |
| $\Gamma(\mu^+\mu^-\gamma)/\Gamma_{ m total}$ | Γ ₁₂ /Γ | <u>VALUE</u> <u>CL%</u> <3 × 10 ^{−6} 90 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | |
| <u>VALUE (units 10⁻⁴)</u> <u>EVTS</u> 3.1 ± 0.4 OUR FIT | DOCUMENT ID TECN COMMENT | | — Forbidden modes ——— | |
| 3.1±0.4 600 | DZHELYADIN 80 SPEC $\pi^- p 	o \eta n$ | $\Gamma(\pi^0\gamma)/\Gamma_{ m total}$ | Γ: | 23/Г |
| • • • We do not use the followin 1.5 ± 0.75 100 | g data for averages, fits, limits, etc. • • • BUSHNIN 78 SPEC See DZHELYADIN 80 | Forbidden by angular mor <u>VALUE</u> <u>CL%</u> | | , |
| | | <9 × 10 ⁻⁵ 90 | NEFKENS 05A CRYB p(720 MeV/c) π^- | <i>η</i> |
| Γ(e ⁺ e ⁻)/Γ _{total} | Γ ₁₃ /Γ <u>DOCUMENT ID TECN COMMENT</u> | $\Gamma(\pi^+\pi^-)/\Gamma_{ m total}$ | Γ | 24/Γ |
| <5.6 × 10 ⁻⁶ 90 | 21 AGAKISHIEV 12A SPEC $pp ightarrow \eta + X$ | Forbidden by P and CP in | nvariance. | 24/ |
| _ | g data for averages, fits, limits, etc. • • • | <u>VALUE</u> <u>CL%</u> <u>EVTS</u> < 0.13 × 10^{−4} 90 16M | AMBROSINO 05A KLOE $e^+e^- 	o \phi 	o \eta$ | 17 |
| $<2.7 \times 10^{-5}$ 90 $<0.77 \times 10^{-4}$ 90 | BERLOWSKI 08 WASA $pd ightarrow {}^3	ext{He}\eta$ BROWDER 97B CLE2 $e^+e^-\simeq 10.5$ GeV | | ring data for averages, fits, limits, etc. • • • | |
| $\begin{array}{cccc} <2 & \times 10^{-4} & 90 \\ <3 & \times 10^{-4} & 90 \end{array}$ | WHITE 96 SPEC $pd \rightarrow \eta^3$ He DAVIES 74 RVUE Uses ESTEN 67 | $< 3.9 \times 10^{-4} 90 225 \mathrm{M}$ $< 3.3 \times 10^{-4} 90$ | ABLIKIM 11G BES3 $e^+e^- \rightarrow J/\psi \rightarrow$ AKHMETSHIN 99B CMD2 $e^+e^- \rightarrow \phi \rightarrow \eta$ | |
| | a sample of 3.5 GeV proton beam collisions on liquid hy- | | AKHMETSHIN 97c CMD2 See AKHMETSHIN THALER 73 ASPK | |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ | HADES detector. | | | N 99B |
| | _ | $\Gamma(2\pi^0)/\Gamma_{ m total}$ | | ч 99в 25 / Г |
| VALUE (units 10 ⁻⁶) CL% EVTS | Γ ₁₄ /Γ DOCUMENT ID TECN COMMENT | Forbidden by P and CP in | nvariance. | |
| <u>VALUE (units 10⁻⁶)</u> <u>CL% EVTS</u> 5.8±0.8 OUR AVERAGE | DOCUMENT ID TECN COMMENT | Forbidden by P and CP in $VALUE$ $CL\%$ $EVTS$ $CL\%$ CL | nvariance. $\frac{DOCUMENT\ ID}{\text{BLIK}} \qquad 07 \qquad \frac{TECN}{\text{GAM4}} \qquad \frac{COMMENT}{\pi^- \rho \rightarrow \eta n}$ | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in $VALUE$ $CL\%$ $EVTS$ $<$ 3.5 \times 10 ⁻⁴ 90 \cdot • • We do not use the follow | nvariance. $\frac{DOCUMENT\ ID}{\text{BLIK}} \qquad \frac{TECN}{\text{GAM4}} \frac{COMMENT}{\pi^- p \to \eta n}$ ring data for averages, fits, limits, etc. \bullet \bullet | ₂₅ /Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in VALUE $CL\%$ EVTS <3.5 × 10 ⁻⁴ 90 • • We do not use the follow <6.9 × 10 ⁻⁴ 90 225 M <4.3 × 10 ⁻⁴ 90 | Nariance. $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 25 /Γ |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in $VALUE$ $CL\%$ $EVTS$ $ <3.5 \times 10^{-4}$ 90 $ \bullet$ \bullet We do not use the follow $ <6.9 \times 10^{-4}$ 90 $225 \mathrm{M}$ $ <4.3 \times 10^{-4}$ 90 $<6 \times 10^{-4}$ 90 | Nariance. $\frac{DOCUMENT ID}{DOCUMENT ID} \qquad \frac{TECN}{GAM4} \frac{COMMENT}{\pi^- p \rightarrow \eta n}$ ring data for averages, fits, limits, etc. \bullet • • • ABLIKIM 116 BES3 $e^+e^- \rightarrow J/\psi \rightarrow AKHMETSHIN$ 99c CMD2 $e^+e^- \rightarrow \phi \rightarrow \eta$ 24 ACHASOV 98 SND $e^+e^- \rightarrow \phi \rightarrow \eta$ | 25 /Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in VALUE $C1\%$ $EVTS$ <3.5 × 10⁻⁴ 90 • • We do not use the follow $<6.9 \times 10^{-4}$ 90 $225 \mathrm{M}$ $<4.3 \times 10^{-4}$ 90 $<6 $ | Nariance. $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 25 /Γ |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in VALUE $\frac{CL\%}{2.5 \times 10^{-4}}$ $\frac{CL\%}{90}$ $\frac{EVTS}{90}$ $\frac{CL\%}{90}$ $\frac{EVTS}{90}$ $\frac{CL\%}{90}$ $\frac{CL\%}{$ | Nation Nation Nation 1 Nation 1 Nation 1 Nation 1 Nation 1 Nation 1 Nation 2 Nation 1 Nation 2 Nation 1 Nation 2 Nation | $\eta \gamma$ $\eta \gamma$ $\eta \gamma$ $\eta \gamma$ $\eta \gamma$ $\eta \gamma$ Monte or one |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Forbidden by P and CP in VALUE $C1\%$ $EVTS$ <3.5 × 10⁻⁴ 90 • • We do not use the follow $<6.9 \times 10^{-4}$ 90 $225 \mathrm{M}$ $<4.3 \times 10^{-4}$ 90 $<6 $ | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} \qquad \frac{TECN}{GAM4} \qquad \frac{COMMENT}{\pi^-p \to \eta n}$ ring data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN\ 99c} \qquad \frac{116}{CMD2} \qquad \frac{e^+e^- \to J/\psi \to \eta n}{e^+e^- \to \phi \to \eta}$ event in a $\pm 3\sigma$ region around the η mass, while a Normal events. The limit here is the Poisson upper limit for ground. | 25 /Γ |
| $\frac{VALUE (units 10^{-6})}{5.8 \pm 0.8} \frac{CL\%}{5.8 \pm 0.8} \frac{EVTS}{5.8 \pm 0.7 \pm 0.5}$ 5.7 ± 0.7 ± 0.5 ± 114 6.5 ± 2.1 27 • • • We do not use the followin 5.6 $\frac{+}{0.7}$ ± 0.5 100 < 20 95 0 Γ (μ+μ−)/Γ (2γ) VALUE (units 10 ⁻⁵) | T14/ Γ DOCUMENT ID TECN OMMENT ABEGG 94 SPEC $pd \rightarrow \eta^3$ He DZHELYADIN 808 SPEC $\pi^-p \rightarrow \eta n$ g data for averages, fits, limits, etc. • • KESSLER 93 SPEC See ABEGG 94 WEHMANN 68 OSPK T14/ Γ_2 | Forbidden by P and CP in VALUE ALUE CL% $EVTS$ EVTS <a href="</td"><td>Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} \qquad \frac{TECN}{A} \qquad \frac{COMMENT}{TEOM}$ Fing data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN} \qquad \frac{116}{990} \qquad \frac{BES3}{6} \qquad \frac{e^+e^- \to J/\psi \to \eta}{e^+e^- \to \phi \to \eta}$ $\frac{24}{4} \qquad ACHASOV \qquad 98 \qquad SND \qquad e^+e^- \to \phi \to \eta$ event in a $\pm 3\sigma$ region around the η mass, while a N_0 so events. The limit here is the Poisson upper limit for ground.</td><td>ηγ γγ γγ Monte or one</td> | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} \qquad \frac{TECN}{A} \qquad \frac{COMMENT}{TEOM}$ Fing data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN} \qquad \frac{116}{990} \qquad \frac{BES3}{6} \qquad \frac{e^+e^- \to J/\psi \to \eta}{e^+e^- \to \phi \to \eta}$ $\frac{24}{4} \qquad ACHASOV \qquad 98 \qquad SND \qquad e^+e^- \to \phi \to \eta$ event in a $\pm 3\sigma$ region around the η mass, while a N_0 so events. The limit here is the Poisson upper limit for ground. | ηγ γγ γγ Monte or one |
| VALUE (units 10 ⁻⁶) CL% EVTS 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • • We do not use the followin 5.6 $^{+0.6}_{-0.7}$ ±0.5 100 < 20 95 0 Γ (μ+μ-)/Γ (2γ) VALUE (units 10 ⁻⁵) • • • We do not use the followin the followin states the followin | T14/ Γ DOCUMENT ID TECN TECN COMMENT ABEGG 94 SPEC $pd \rightarrow \eta^3$ He DZHELYADIN 808 SPEC $\pi^-p \rightarrow \eta n$ g data for averages, fits, limits, etc. • • • KESSLER 93 SPEC See ABEGG 94 WEHMANN 68 OSPK T14/ Γ_2 DOCUMENT ID TECN g data for averages, fits, limits, etc. • • • | Forbidden by P and CP in $VALUE$ $<3.5 \times 10^{-4}$ $<0.5 \times 10^{-4}$ | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} \qquad \frac{TECN}{GAM4} \qquad \frac{COMMENT}{\pi^-p \to \eta n}$ ring data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN} \qquad \frac{11}{9} \qquad \frac{BES3}{6} \qquad \frac{e^+e^- \to J/\psi \to \eta}{e^+e^- \to \phi \to \eta}$ avent in a $\pm 3\sigma$ region around the η mass, while a N c so events. The limit here is the Poisson upper limit for ground. | ηγ γγ γγ Monte or one |
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| VALUE (units 10 ⁻⁶) CL% EVTS 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • • We do not use the followin 5.6 $^+$ 0.6 ±0.5 100 < 20 | The pocument idea of the property of the prop | Forbidden by P and CP in VALUE AALUE CL% $EVTS$ EVTS EVTS CL% $EVTS$ EVTS < | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{GAM4} \times \frac{COMMENT}{p \rightarrow \eta n}$ ring data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{11}{90} \times \frac{BES3}{ND} \times \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{e^+e^- \rightarrow \phi \rightarrow \eta}$ event in a $\pm 3\sigma$ region around the η mass, while a New to sevents. The limit here is the Poisson upper limit for ground. $\frac{CUMENT\ ID}{IECN} = \frac{TECN}{IEK} \times \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ fing data for averages, fits, limits, etc. • • • $\frac{CUMENT\ ID}{IECN} = \frac{TECN}{IEK} \times \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow \frac{CHG}{IEK} \times \frac{COMMENT}{IEK}$ | $\eta \gamma$ γ γ γ γ γ γ γ γ γ |
| $\frac{\text{VALUE (units 10}^{-6})}{\text{5.8 \pm 0.8}} \frac{\text{CL \%}}{\text{EVTS}}$ 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • • We do not use the followin 5.6 $^{+0.6}_{-0.7}$ ±0.5 20 95 0 $\frac{\Gamma(\mu^{+}\mu^{-})/\Gamma(2\gamma)}{\text{VALUE (units 10}^{-5})}$ • • • We do not use the followin 5.9±2.2 $\frac{\text{VALUE (units 10}^{-5})}{\text{2.4 \pm 0.2 \pm 0.1}} \frac{\text{CL \%}}{\text{362}} \frac{\text{EVTS}}{\text{2.4 \pm 0.2 \pm 0.1}}$ 29.7 90 22 This measurement is fully incl $\frac{(\pi^{+}\pi^{-}e^{+}e^{-}(\gamma))}{\Gamma_{\text{total}}}$ | T14/ Γ DOCUMENT ID TECN COMMENT ABEGG 94 SPEC $pd \rightarrow \eta^3$ He DZHELYADIN 808 SPEC $\pi^-p \rightarrow \eta n$ g data for averages, fits, limits, etc. • • • KESSLER 93 SPEC See ABEGG 94 WEH MANN 68 OSP K F14/ Γ_2 DOCUMENT ID g data for averages, fits, limits, etc. • • • HYAMS 69 OSP K F15/ Γ DOCUMENT ID 22 AMBROSINO 11B KLOE $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ g data for averages, fits, limits, etc. • • • BERLOWSKI 08 WASA $pd \rightarrow {}^3$ He η AKH METSHIN 01 CMD2 $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ usive (includes " $2e^+2e^-\gamma$ " channel). | Forbidden by P and CP in $VALUE$ $<3.5 \times 10^{-4}$ 90 • • We do not use the follow $<6.9 \times 10^{-4}$ $<9.0 \times 10^{-4}$ $<4.3 \times 10^{-4}$ $<9.0 \times 10^{-4}$ $<5.0 \times 10^{-5}$ | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{AMA} = \frac{COMMENT}{p \to \eta n}$ ring data for averages, fits, limits, etc. • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{99} = \frac{BES3}{ACHASOV} = \frac{e^+e^- \to J/\psi \to \eta n}{8 \text{ NND}} = \frac{e^+e^- \to \psi \to \eta}{e^+e^- \to \psi \to \eta}$ event in a $\pm 3\sigma$ region around the η mass, while a Nest events. The limit here is the Poisson upper limit for ground. $\frac{CUMENT\ ID}{FKENS} = \frac{CHG}{SCMENT} = \frac{CMMENT}{SCMENT} = \frac{CMMENT}{SCMENT} = \frac{CMMENT}{SCMENT} = \frac{CMMENT}{SCMENT} = \frac{CMMENT}{SCMENT} = \frac{CMMENT\ ID}{SCMENT\ ID} = \frac{CHG}{SCMENT\ ID} = \frac{CHG}{SCMENT\ ID} = \frac{CHG}{SCMENT\ ID} = \frac{CHG}{SCMMENT} = \frac{CMMENT}{SCMENT\ ID} = \frac{CHG}{SCMENT\ ID} = \frac{CHG}{SC$ | $\eta \gamma$ γ γ γ Monte or one $26/\Gamma$ $\rightarrow n\eta$ |
| VALUE (units 10 ⁻⁶) CL% EVTS 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • We do not use the followin 5.6−0.7±0.5 100 < 20 | T14/ Γ DOCUMENT ID TECN COMMENT ABEGG 94 SPEC $pd \rightarrow \eta^3$ He DZHELYADIN 80B SPEC $\pi^-p \rightarrow \eta n$ g data for averages, fits, limits, etc. • • • KESSLER 93 SPEC See ABEGG 94 WEHMANN 68 OSPK F14/ Γ_2 DOCUMENT ID TECN g data for averages, fits, limits, etc. • • • HYAMS 69 OSPK F15/ Γ DOCUMENT ID TECN QUMENT ID TECN E COMMENT 22 AMBROSINO 11B KLOE BERLOWSKI 08 WASA $pd \rightarrow 3$ He η AKHMETSHIN 01 CMD2 $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ usive (includes " $2e^+2e^-\gamma$ " channel). | Forbidden by P and CP in VALUE AALUE CL% $EVTS$ EVTS EVTS CL% $EVTS$ EVTS < | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{A} = \frac{COMMENT}{A}$ ring data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{CMENT} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{CMD2} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{e^+e^- \rightarrow \psi \rightarrow \eta}$ event in a $\pm 3\sigma$ region around the η mass, while a $\frac{N}{2}$ so events. The limit here is the Poisson upper limit for ground. Fig. 2. $\frac{CUMENT\ ID}{E} = \frac{TECN}{A} = \frac{CHG}{CMMENT} = \frac{COMMENT}{E}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow 0$ ring data for averages, fits, limits, etc. • • • • $\frac{F_2}{E} = \frac{CUMENT\ ID}{E} = \frac{TECN}{A} = \frac{CHG}{A} = \frac{COMMENT}{A}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow 0$ ring data for averages, fits, limits, etc. • • • • $\frac{F_2}{E} = \frac{CUMENT\ ID}{E} = \frac{TECN}{A} = \frac{CHG}{A} = \frac{COMMENT}{A}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow 0$ ring data for averages, fits, limits, etc. • • • • $\frac{F_2}{E} = \frac{CMENT\ ID}{A} = \frac{TECN}{A} = \frac{CHG}{A} = \frac{COMMENT}{A}$ FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow 0$ ring data for averages, fits, limits, etc. • • • • $\frac{F_2}{E} = \frac{CMENT\ ID}{A} = \frac{F_2}{A} | $\eta \gamma$ γ γ γ γ γ γ γ γ γ |
| VALUE (units 10 ⁻⁶) CL% EVTS 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • • We do not use the followin 5.6 ^{+0.6} _{-0.7} ±0.5 100 < 20 | The pocument idea of the pocu | Forbidden by P and CP in VALUE <3.5 × 10 ⁻⁴ 90 • • We do not use the follow <6.9 × 10 ⁻⁴ 90 <6.9 × 10 ⁻⁴ 90 <6 × 10 ⁻⁴ 90 24 ACHASOV 98 observes one Carlo calculation gives 10 ± 0 observed event and no back $\Gamma(2\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 5 × 10 ⁻⁴ 90 NE $(17 \times 10^{-4} = 90)$ BL $\Gamma(3\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 6 × 10 ⁻⁵ 90 NE • • We do not use the follow <17 × 10 ⁻⁴ 90 BL $\Gamma(3\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 6 × 10 ⁻⁵ 90 BL $\Gamma(3\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE Forbidden by C invariance VALUE $C(1\%)$ So NE Forbidden by C invariance VALUE $C(1\%)$ So NE Forbidden by C invariance VALUE $C(1\%)$ Co NE | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{ABLIK}$ Fing data for averages, fits, limits, etc. • • • ABLIKIM 116 BES3 $e^+e^- \rightarrow J/\psi \rightarrow AKHMETSHIN 99c$ CMD2 $e^+e^- \rightarrow \phi \rightarrow \eta$ 24 ACHASOV 98 SND $e^+e^- \rightarrow \phi \rightarrow \eta$ event in a $\pm 3\sigma$ region around the η mass, while a Merotropic state of the poisson upper limit for ground. FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow KKHMETSHIN 99c$ CMB4 $\pi^- p \rightarrow \eta n$ 18 O7 GAM4 $\pi^- p \rightarrow \eta n$ 19 COMMENT ID TECN CHG COMMENT FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow KKHMETSHIN 99c$ CMB4 $\pi^- p \rightarrow \eta n$ 19 COMMENT ID TECN CHG COMMENT FKENS 05 CRYB 0 p(720 MeV/c) $\pi^- \rightarrow KKHMETSHIN 99c$ CMB4 $\pi^- p \rightarrow \eta n$ 19 COMMENT ID TECN CHG COMMENT FOR GAM4 $\pi^- p \rightarrow \eta n$ | $\eta \gamma$ γ γ γ Monte or one $26/\Gamma$ $\rightarrow n\eta$ |
| $\frac{VALUE (units 10^{-6})}{5.8 \pm 0.8}$ OUR AVERAGE 5.7 ± 0.7 ± 0.5 5.6 ± 0.6 6.5 ± 2.1 27 • • • We do not use the followin 5.6 $^{+0.6}_{-0.7}$ ± 0.5 20 95 0 $\frac{VALUE (units 10^{-5})}{2.4 \pm 0.2 \pm 0.1}$ 20 • • We do not use the followin 5.9 ± 2.2 $\frac{VALUE (units 10^{-5})}{2.4 \pm 0.2 \pm 0.1}$ 362 • • • We do not use the followin 6.9 90 22 This measurement is fully incl $\frac{VALUE (units 10^{-4})}{2.68 \pm 0.11}$ 2.68 ± 0.10 OUR FIT 2.68 ± 0.10 OUR FIT 2.68 ± 0.09 ± 0.07 1555 ± 52 • • • We do not use the followin | The pocument idea of the pocu | Forbidden by P and CP in VALUE <3.5 × 10 ⁻⁴ 90 • • We do not use the follow <6.9 × 10 ⁻⁴ 90 <6.9 × 10 ⁻⁴ 90 <6 × 10 ⁻⁴ 90 24 ACHASOV 98 observes one Carlo calculation gives 10 ± 0 observed event and no back $\Gamma(2\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 5 × 10 ⁻⁴ 90 NE $(17 \times 10^{-4} = 90)$ BL $\Gamma(3\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 6 × 10 ⁻⁵ 90 NE • • We do not use the follow <17 × 10 ⁻⁴ 90 BL $\Gamma(3\pi^{0}\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE < 6 × 10 ⁻⁵ 90 BL $\Gamma(3\gamma)/\Gamma_{total}$ Forbidden by C invariance VALUE Forbidden by C invariance VALUE $C(1\%)$ So NE Forbidden by C invariance VALUE $C(1\%)$ So NE Forbidden by C invariance VALUE $C(1\%)$ Co NE | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{ABLIK}$ Fing data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{24} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AK$ | $\eta \gamma$ γ γ γ Monte or one $26/\Gamma$ $\rightarrow n\eta$ |
| VALUE (units 10 ⁻⁶) CL% EVTS 5.8 ± 0.8 OUR AVERAGE 5.7 ± 0.7 ± 0.5 114 6.5 ± 2.1 27 • • • We do not use the following 5.6 $^{+}_{-0.7}$ ± 0.5 100 < 20 | The pocument idea of the pocu | Forbidden by P and CP in $VALUE$ ALUE AC 18 $VALUE$ EVTS <a< td=""><td>Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{ABLIK}$ Fing data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{24} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AK$</td><td>$\eta\gamma$ $\gamma\gamma$ $\gamma\gamma$ Monte or one 226/Γ $\rightarrow n\eta$</td></a<> | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{ABLIK}$ Fing data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{24} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{24} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AKHMETSHIN} = \frac{e^+e^- \rightarrow \psi \rightarrow \eta}{AK$ | $\eta\gamma$ $\gamma\gamma$ $\gamma\gamma$ Monte or one 226/ Γ $\rightarrow n\eta$ |
| VALUE (units 10 ⁻⁶) CL% EVTS 5.8±0.8 OUR AVERAGE 5.7±0.7±0.5 114 6.5±2.1 27 • • • We do not use the followin 5.6+0.6 − 0.7±0.5 100 < 20 95 0 $\Gamma (\mu^+\mu^-)/\Gamma (2\gamma)$ VALUE (units 10 ⁻⁵) • • We do not use the followin 5.9±2.2 $\Gamma (2e^+2e^-)/\Gamma_{total}$ VALUE (units 10 ⁻⁵) CL% EVTS 2.4±0.2±0.1 362 • • We do not use the followin 6.9 90 22 This measurement is fully incl $\Gamma (\pi^+\pi^-e^+e^-(\gamma))/\Gamma_{total}$ VALUE (units 10 ⁻⁴) EVTS 2.68±0.11 OUR FIT 2.68±0.11 OUR FIT 2.68±0.09±0.07 1555±52 • • We do not use the followin 6.3 ±2.6 ±0.14 16 ±0.14 16 ±0.14 16 | The pocument idea of the property of the prop | Forbidden by P and CP in the second value P in | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{A} = \frac{COMMENT}{A}$ Fing data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{AKHMETSHIN} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{90}$ $\frac{AKHMETSHIN}{AKHMETSHIN} = \frac{16}{90} = \frac{AKHMETSHIN}{90} = \frac{AKHMETSHIN}{90$ | $\eta\gamma$ $\gamma\gamma$ $\gamma\gamma$ Monte or one 226/ Γ $\rightarrow n\eta$ |
| $\frac{VALUE (units 10^{-6})}{5.8 \pm 0.8}$ OUR AVERAGE 5.7 ± 0.7 ± 0.5 5.6 ± 0.6 5.6 ± 0.7 5.6 ± 0.6 5.6 ± 0.7 5.6 ± 0.5 5.6 ± 0.6 5.6 ± 0.7 5.6 ± 0.5 5.9 5.9 5.9 5.9 6.9 6.9 6.9 6.9 6.9 6.9 6.9 6.9 6.9 6 | The pocument idea of the polynomial of the pocument idea of the pocumen | Forbidden by P and CP in VALUE <3.5 × 10 ⁻⁴ 90 • • We do not use the follow <6.9 × 10 ⁻⁴ 90 <6 × 10 ⁻⁴ 90 24 ACHASOV 98 observes one Carlo calculation gives $10 \pm$ observed event and no back $\Gamma(2\pi^{0}\gamma)/\Gamma_{\text{total}}$ Forbidden by C invariance $\frac{VALUE}{\sqrt{15}} = \frac{CL\%}{\sqrt{15}} = \frac{DO}{\sqrt{15}}$ • • We do not use the follow <17 × 10 ⁻⁴ 90 BL $\Gamma(3\pi^{0}\gamma)/\Gamma_{\text{total}}$ Forbidden by C invariance $\frac{VALUE}{\sqrt{15}} = \frac{CL\%}{\sqrt{15}} = \frac{DO}{\sqrt{15}}$ • • We do not use the follow <24 × 10 ⁻⁵ 90 BL $\Gamma(3\gamma)/\Gamma_{\text{total}}$ Forbidden by C invariance $\frac{VALUE}{\sqrt{15}} = \frac{CL\%}{\sqrt{15}} = \frac{DO}{\sqrt{15}}$ • • We do not use the follow <24 × 10 ⁻⁵ 90 BL $\Gamma(3\gamma)/\Gamma_{\text{total}}$ Forbidden by C invariance $\frac{VALUE}{\sqrt{15}} = \frac{CL\%}{\sqrt{15}}$ • • We do not use the follow <16 × 10 ⁻⁵ 90 <4 × 10 ⁻⁵ 90 | Nariance. $\frac{DOCUMENT\ ID}{DOCUMENT\ ID} = \frac{TECN}{ABLIK} = \frac{COMMENT}{A} = \frac{COMMENT}{A}$ Fing data for averages, fits, limits, etc. • • • • $\frac{ABLIKIM}{AKHMETSHIN} = \frac{116}{90} = \frac{BES3}{AKHMETSHIN} = \frac{e^+e^- \rightarrow J/\psi \rightarrow \eta}{90}$ $\frac{AKHMETSHIN}{AKHMETSHIN} = \frac{16}{90} = \frac{AKHMETSHIN}{90} = \frac{AKHMETSHIN}{90$ | $\frac{\eta \gamma}{\gamma \gamma}$ Monte or one $\frac{226}{\Gamma}$ $\frac{\pi \eta}{\tau}$ $\frac{\pi \eta}{\tau}$ $\frac{\pi \eta}{\tau}$ $\frac{\pi \eta}{\tau}$ |

VALUE (units 10^{-2})

 $1.2\ \pm0.6$

 $0.5\ \pm0.6$

 1.22 ± 1.56

0.9 ±0.4 OUR AVERAGE

EVTS

36k

7257

35 k

DO CUMENT ID TECN

74B OSPK

72 ASPK

70 ASPK

IA NE

THALER

GORMLEY

| $\Gamma(3\gamma)/\Gamma(3\pi^0)$ | | | | | | Γ ₂₈ /Γ ₃ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| <4.9 × 10 ⁻⁵ | <u>CL%</u> 90 | <u>DOCUMENT ID</u> ALOISIO | 04 | TECN KLOE | $\phi \rightarrow \eta \gamma$ | |
| | | | | | 7 77 | F /r |
| $(4\pi^0)/\Gamma_{total}$ Forbidden by | P and CP inv | ariance. | | | | Γ ₂₉ /Ι |
| | <u>CL%</u> | | | | COMMENT | |
| < 6.9 × 10 ⁻⁷ • • We do not u | 90 se the followin | PRAKHOV (ng data for average | | | | , 720 MeV/ <i>c</i> |
| <200 × 10 ⁻⁷ | 90 | | | | $\tau^- p \rightarrow \eta n$ | |
| $(\pi^0 e^+ e^-)/\Gamma_{to}$ | 4-1 | | | | | Γ ₃₀ /Ι |
| C parity forbi | ds this to occi | ur as a single-photo | | | | 1 30 / 1 |
| | <u>CL%</u> se the followin | <u>DOCUMENT ID</u> ng data for average | | | etc | |
| $< 1.6 \times 10^{-4}$ | 90 | MARTYNOV | 76 | HLBC | cic. • • • | |
| $< 8.4 \times 10^{-4}$ | 90 | BAZIN | 68 | DBC | | |
| <70 × 10 ⁻⁴ | | RITTENBERG | 65 | НВС | | |
| $(\pi^0 e^+ e^-)/\Gamma(r$ | | | | | | Γ_{30}/Γ_{9} |
| | ds this to occi <i>CL%_ <u>EVTS</u></i> | ur as a single-photo <u>DOCUMENT ID</u> | | cess. <u>TECN</u> | | |
| | 90 | JA NE | 75 | OSPK | | |
| | | ng data for average | | | etc. • • • | |
| | 90 90 0 | BAGLIN BILLING | 67 67 | HLBC HLBC | | |
| $< 77 \times 10^{-4}$ | 0 | FOSTER | 65B | НВС | | |
| <110 × 10 ⁻⁴ | | PRICE | 65 | НВС | | |
| $(\pi^0 \mu^+ \mu^-)/\Gamma_{to}$ | | | | | | Γ ₃₁ /Ι |
| | ds this to occi | ur as a single-photo <u>DOCUMENT ID</u> | | | COMMENT | |
| < 5×10 ⁻⁶ | 90 | DZHELYADIN | 81 | SPEC | $\pi^- p \rightarrow r$ | n |
| • • We do not u <500 × 10 ⁻⁶ | se the followin | ng data for average | | | etc. • • • | |
| | | WEHMANN | 68 | OSP K | | |
| | | | | | | |
| $\Gamma(\mu^+e^-)+\Gamma(\mu^+e^-)$ | $μ^- e^+)]/\Gamma_{to}$ | otal | | | | Γ ₃₂ /Ι |
| $\Gamma(\mu^+e^-)+\Gamma(\mu^+e^-)$ | $\mu^-e^+)]/\Gamma_{ m to}$ lepton family | | | TECN | COMMENT | Γ ₃₂ /Ι |
| $\Gamma(\mu^+e^-)+\Gamma(\mu^+e^-)$ | lepton family | otal number conservati | | <u>TECN</u> SPEC | $\frac{\textit{COMMENT}}{\textit{pd} \rightarrow \eta^{3}}$ | Г₃₂/Г Не |
| $\Gamma(\mu^+ e^-) + \Gamma(\mu^+ e^-) + \Gamma(\mu$ | epton family CL% 90 C-NONCON | number conservati <u>DO CUMENT ID</u> WHITE | 96 AY P | SPEC ARAM | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^$ | c-NONCON | otal number conservati <u>DOCUMENT ID</u> WHITE | 96 AY P | SPEC ARAM ETER | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^$ | C-NONCON RIGHT ASY s with an erro | number conservati <u>DOCUMENT ID</u> WHITE USERVING DEC | 96 AY P | SPEC ARAM ETER | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^$ | C-NONCON RIGHT ASY s with an erro | DOTAL NUMBER CONSERVATION WHITE ISERVING DEC /MMETRY PAF or > 1.0 × 10 ⁻² h | 96 AY P | SPEC ARAM ETER een omit | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^$ | G-NONCON RIGHT AS) s with an erro EVTS AVERAGE | DOTAL NUMBER CONSERVATION WHITE ISERVING DEC /MMETRY PAF or > 1.0 × 10 ⁻² h | 96 AY P RAME | SPEC ARAM ETER een omit TECN | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^$ | G-NONCON RIGHT AS) s with an erro EVTS AVERAGE | DOCUMENT ID WHITE ISERVING DEC /MMETRY PAF or > 1.0 × 10 - 2 h DOCUMENT ID | 96 AY P RAME | SPEC ARAM ETER een omit TECN KLOE OSPK | $pd \rightarrow \eta^3$ | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-)$ $\sim 10^{-6}$ $\sim 10^{-$ | C-NONCON RIGHT AS) s with an erro EVTS AVERAGE 1.34M 165 k 220 k | INTERPORT OF THE PROPERTY OF T | 96 AY P RAME ave be 08D 74 72 | SPEC ARAM ETER een omit TECN KLOE OSPK ASPK | $pd \rightarrow \eta^{3}$ ETERS | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-)$ $\sim 10^{-6}$ $\sim 10^{-$ | C-NONCON RIGHT AS) s with an erro EVTS AVERAGE 1.34M 165 k 220 k | INTERPOLATION OF THE PROPERTY | 96 AY P RAME ave be 08D 74 72 s, fits, | SPEC ARAM ETER een omit TECN KLOE OSPK ASPK | $pd \rightarrow \eta^{3}$ ETERS | |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | C-NONCON RIGHT ASY s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followin 37 k 68 c asymmet | DOTAL NUMBER CONSERVATION WHITE ISERVING DEC /MMETRY PAF of > 1.0 × 10 ⁻² h DOCUMENT ID A MBROSINO JANE LAYTER ng data for average 25 GORMLEY try is probably due | 96 AY P RAME ave be 08D 74 72 s, fits, 68c to uni | TER the | $pd \rightarrow \eta^{2}$ ETERS etc. • • • • d (E × B) s | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | c-NONCON RIGHT AS) s with an erro EVTS AVERAGE 1.34M 165 k 220k se the followin 37k ′ 68C asymmet periments with | DOCUMENT ID AMBROSINO JANE LAYTER ag data for average 25 GORMLEY try is probably due (E × B) controls | 96 AY P RAME 08D 74 72 58c 68c to unidon't | ARAM ETER een omit TECN KLOE OSP K ASP K , limits, , asp K measure observed | $pd \rightarrow \eta^{2}$ ETERS etc. • • • • d (E × B) s | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | C-NONCON RIGHT ASY s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followir 37 k 68 c asymmet periments witl | DOCUMENT ID WHITE ISERVING DEC /MMETRY PAF IN | 96 AY P RAME 08D 74 72 68c to unidon't | ARAM ETER een omit TECN KLOE OSP K ASP K , limits, , asp K measure observe | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) se an asymmetric asymmetric and the second and | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | C-NONCON RIGHT ASY s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followir 37 k 68 c asymmet periments witl | DOCUMENT ID AMBROSINO JANE LAYTER ag data for average 25 GORMLEY try is probably due (E × B) controls | 96 AY P RAME 08D 74 72 68c to unidon't | ARAM ETER een omit TECN KLOE OSP K ASP K , limits, , asp K measure observe | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) se an asymmetric asymmetric and the second and | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | C-NONCON RIGHT ASY S with an erro EVTS AVERAGE 1.34M 165k 220k se the followin 37k 68c asymmet periments with ANT ASYM s with an erro EVTS | INTERPOLATION OF THE PARAMETRY PARAMETRY PARAMETRY BANGED TO AMBROSINO JANE LAYTER BY data for average 25 GORMLEY THE STORM OF THE STOR | 96 AY P RAME 08D 74 72 68c to unidon't | KLOE OSPK ASPK , limits, ASPK measure : observe ER een omit | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) se an asymmetric asymmetric and the second and | ³ He park chambe |
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| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | Lepton family C-NONCON RIGHT AS) S with an erro EVTS AVERAGE 1.34M 165 k 220k See the followin 37k 68c asymmet periments with ANT ASYM S with an erro EVTS AVERAGE 1.34M 165 k | DOCUMENT ID AMBROSINO JANE LAYTER 125 GORMLEY 17 S 1.0 × 10 - 2 h DOCUMENT ID AMBROSINO JANE LAYTER 18 g data for average 25 GORMLEY 17 try is probably due 16 (E × B) controls METRY PARAI 17 S 2.0 × 10 - 2 h DOCUMENT ID AMBROSINO JANE AMBROSINO JANE | 96 AY P RAME ave be 08D 74 72 68c tto unit don't METI ave be 08D 74 72 | SPEC ARAMM ETER een omin TECN KLOE OSPK ASPK Ilimits, ASPK measure observer KLOE OSPK KLOE OSPK KLOE | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) se an asymmetric asymmetric and the second symmetric and the second symm | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | Lepton family C-NONCON RIGHT AS) S with an erro EVTS AVERAGE 1.34M 165 k 220k se the followin 37k 68c asymmet periments with ANT ASYM s with an erro EVTS AVERAGE 1.34M 165 k 220k 37k | DATE TO STANDARD STONE TO STAN | 96 AY P RAME ave be 08D 74 72 to unidon't METI ave be 08D 74 72 68c | SPEC ARAMM ETER een omit TECN KLOE OSPK ASPK Ilimits, ASPK measurer observer KLOE OSPK ASPK WIRE | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) se an asymmetric asymmetric and the second symmetric and the second symm | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | Lepton family GL% 90 C-NONCON RIGHT ASY s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followin 37 k 68 c asymmet periments with ANT ASYM s with an erro EVTS AVERAGE 1.34M 165 k 220 k 37 k ORANT ASY EVTS | DOCUMENT ID AMBROSINO JANE LAYTER TO SOUMENT ID METRY PARAI TO SOUMENT ID AMBROSINO JANE LAYTER TO SOUMENT ID AMBROSINO JANE LAYTER TO SOUMENT ID AMBROSINO JANE LAYTER DOCUMENT ID AMBROSINO JANE LAYTER GORMLEY | 96 AY P RAME 08D 74 72 s, fits, 68c to uni don't METI ave be 08D 74 72 68c AME | SPEC ARAM ETER een omit TECN KLOE OSPK ASPK Ilimits, ASPK Ilimits, ASPK Measurer observer KLOE OSPK ASPK WIRE KLOE OSPK ASPK WIRE | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) s e an asymmetric and the second sec | ³ He park chambe |
| $(\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu^+e^-)$ Forbidden by ALUE (and the provided of the provided | C-NONCON RIGHT AS) s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followin 37k 68C asymmet periments with ANT ASYM 165 k 220 k 37k ORANT ASY EVTS AVERAGE 1.34M 165 k 220 k 37k | METRY PARAIN AMBROSINO JANE LAYTER TO SERVING DEC METRY PARAIN AMBROSINO JANE LAYTER TO SERVING DEC METRY PARAIN TO SERVING AMBROSINO JANE LAYTER AMBROSINO JANE LAYTER AMBROSINO JANE LAYTER AMBROSINO METRY PARAIN AMBROSINO JANE LAYTER GORMLEY METRY PARAIN AMBROSINO JANE LAYTER GORMLEY METRY PARAIN AMBROSINO JANE LAYTER GORMLEY | 96 AY P RAME 08D 74 72 68c 08D 74 72 68c AME | SPEC ARAM ETER KLOE OSPK ASPK , limits, ASPK KLOE Observe ER KLOE OSPK ASPK WIRE TECN | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) s e an asymmetric and the second sec | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | Lepton family 90 C-NONCON RIGHT ASY s with an erro EVTS AVERAGE 1.34M 165 k 220k se the followin 37k 68C asymmet periments with ANT ASYM s with an erro EVTS AVERAGE 1.34M 165 k 220k 37k ORANT ASY EVTS AVERAGE 1.34M | INTERPOLATION OF THE PART OF T | 96 AY P RAME 08D 74 72 68c 08D 74 72 68c AME | SPEC ARAM ETER KLOE OSPK ASPK , limits, ASPK KLOE OSPK ASPK WIRE KLOE KLOE KLOE KLOE KLOE KLOE KLOE KL | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) s e an asymmetric and the second sec | ³ He park chambe |
| $\Gamma(\mu^+e^-) + \Gamma(\mu^+e^-) + \Gamma(\mu$ | C-NONCON RIGHT AS) s with an erro EVTS AVERAGE 1.34M 165 k 220 k se the followin 37k 68C asymmet periments with ANT ASYM 165 k 220 k 37k ORANT ASY EVTS AVERAGE 1.34M 165 k 220 k 37k | METRY PARAIN AMBROSINO JANE LAYTER TO SERVING DEC METRY PARAIN AMBROSINO JANE LAYTER TO SERVING DEC METRY PARAIN TO SERVING AMBROSINO JANE LAYTER AMBROSINO JANE LAYTER AMBROSINO JANE LAYTER AMBROSINO METRY PARAIN AMBROSINO JANE LAYTER GORMLEY METRY PARAIN AMBROSINO JANE LAYTER GORMLEY METRY PARAIN AMBROSINO JANE LAYTER GORMLEY | 96 AY P RAME 08D 74 72 68c 08D 74 72 68c AME | SPEC ARAM ETER KLOE OSPK ASPK , limits, ASPK KLOE Observe ER KLOE OSPK ASPK WIRE TECN | $pd \rightarrow \eta^{3}$ ETERS etc. • • • • d (E × B) s e an asymmetric and the second sec | ³ He park chambe |

$\pi^+\pi^-\gamma$ PARAMETER β (*D*-wave)

Sensitive to a *D*-wave contribution: $dN/d\cos\theta = \sin^2\theta \ (1 + \beta \cos^2\theta)$.

| VALUE | EVTS | DO CUMENT ID | | TECN | |
|---------------------|---------------|----------------------|-----------|--------------|-------|
| -0.02 ±0.07 OUR | AVERAGE | Error includes sc | ale fac | tor of 1.3. | |
| 0.11 ± 0.11 | 35k | JA NE | 74B | OSP K | |
| -0.060 ± 0.065 | 7250 | GORMLEY | 70 | WIRE | |
| • • • We do not use | the following | ng data for averag | es, fits, | limits, etc. | • • • |
| 0.12 ± 0.06 | | ²⁶ THALER | 72 | A SP K | |

 $^{^{26}\,\}mathrm{The}$ authors don't believe this indicates D-wave because the dependence of β on the γ energy is inconsistent with the theoretical prediction. A $\cos^2 \theta$ dependence can also come from P- and F-wave interference.

η CP-NONCONSERVING DECAY PARAMETER

$\pi^+\pi^-e^+e^-$ DECAY-PLANE ASYMMETRY PARAMETER A_ϕ

In the η rest frame, the total momentum of the e^+e^- pair is equal and opposite to that of the $\pi^+\pi^-$ pair. Let \hat{z} be the unit vector along the momentum of the e^+e^- pair; let \hat{n}_{ee} and $\hat{n}_{\pi\pi}$ be the unit vectors normal to the e^+e^- and $\pi^+\pi^-$ planes; and let ϕ be the angle between the two normals. Then

$$\sin\!\phi\,\cos\!\phi = [(\,\hat{n}_{ee}\times\hat{n}_{\pi\,\pi})\,\cdot\hat{z}\,]\,(\,\hat{n}_{ee}\cdot\hat{n}_{\pi\,\pi})$$
 ,

$$A_{\phi} \equiv \frac{\textit{N}_{\sin\phi\cos\phi>0} - \textit{N}_{\sin\phi\cos\phi<0}}{\textit{N}_{\sin\phi\cos\phi>0} + \textit{N}_{\sin\phi\cos\phi<0}}$$

| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | TECN | COMMENT |
|--------------------------|-----------|---------------|------|---------------------------------------------------|
| -0.6±2.5±1.8 | 1555 ± 52 | AMBROSINO 09B | KLOE | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |

ENERGY DEPENDENCE OF $\eta \to 3\pi$ DALITZ PLOTS

PARAMETERS FOR $\eta \to \pi^+\pi^-\pi^0$

See the "Note on η Decay Parameters" in our 1994 edition, Phys. Rev. **D50**, 1 August 1994, Part I, p. 1454. The following experiments fit to one or more of the coefficients a, b, c, d, or e for $|matrix\ element|^2 = 1 + <math>ay + by^2 + cx + dx^2 + exy$.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|-------------------|----------------------|----------|---------|----------------------------------------------------|
| • • • We do no | t use the followi | ng data for average | s, fits, | limits, | etc. • • • |
| | 1.34M | AMBROSINO | 08D | KLOE | |
| | 3230 | ²⁷ ABELE | 98D | | $\overline{p}p \rightarrow \pi^0\pi^0\eta$ at rest |
| | 1077 | ²⁸ AMSLER | 95 | CBAR | $\overline{p}p \rightarrow \pi^+\pi^-\eta$ at rest |
| | 81k | LAYTER | 73 | ASPK | |
| | 220k | LAYTER | 72 | ASPK | |
| | 1138 | CARPENTER | 70 | HB C | |
| | 349 | DANBURG | 70 | DBC | |
| | 725 0 | GORMLEY | 70 | WIRE | |
| | 5 2 6 | BAGLIN | 69 | HLBC | |
| | 7170 | CNOPS | 68 | OSP K | |
| | 37k | GORMLEY | 68c | WIRE | |
| | 1300 | CLPWY | 66 | HB C | |
| | 705 | LARRIBE | 66 | HB C | |
| | | | | | |

 $^{27\,\}mathrm{ABELE}$ 98D obtains $a=-1.22\pm0.07$ and $b=0.22\pm0.11$ when c (our \emph{d}) is fixed at

α PARAMETER FOR $\eta \to 3\pi^0$

See the "Note on η Decay Parameters" in our 1994 edition, Phys. Rev. **D50**, 1 August 1994. Part I in 1454. The value here is of α in [matrix element] $\frac{1}{2} = 1 + 2\alpha z$

| 1994, Part I, p. 1454. | The va | ilue here is of $lpha$ in | matrix elen | $ 1ent ^2 = 1 + 2\alpha z$. |
|----------------------------------------------|-----------|---------------------------|---------------|---------------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
| -0.0315 ±0.0015 OUR AV | ERAGE | | | |
| $-0.0301\pm 0.0035{}^{+0.0022}_{-0.0035}$ | 512k | | 10A KLOE | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |
| $-0.027 \pm 0.008 \pm 0.005$ | 120k | ²⁹ ADOLPH | 09 WASA | $\lambda pp \rightarrow pp\eta$ |
| $-0.0322 \pm 0.0012 \pm 0.0022$ | 3 M | ³⁰ PRAKHOV | 09 CRYE | $\gamma p \rightarrow p \eta$ |
| $-0.032 \pm 0.002 \pm 0.002$ | 1.8 M | ³⁰ UNVERZAGT | 09 CRYE | $\gamma p \rightarrow p \eta$ |
| $-0.026 \pm 0.010 \pm 0.010$ | 75 k | BASHKANOV | 07 WASA | $\lambda \rho \rho \rightarrow \rho \rho \eta$ |
| $-0.010 \pm 0.021 \pm 0.010$ | 12k | ACHASOV | 01c SND | $e^+e^- \rightarrow \phi \rightarrow \eta \gamma$ |
| -0.031 ± 0.004 | 1 M | TIPPENS | 01 CRYE | $\pi^- p \rightarrow n \eta$, 720 MeV |
| $-0.052 \pm 0.017 \pm 0.010$ | 98k | ABELE | 98c CBAF | $R \overline{p} p \rightarrow 5\pi^0$ |
| -0.022 ± 0.023 | 50k | ALDE | 84 GAM: | 2 |
| • • • We do not use the f | ollowing | data for averages, | fits, limits, | etc. • • • |
| $- 0.038 \pm 0.003 {}^{+ 0.012}_{- 0.008}$ | 1.34M | ³¹ AMBROSINO | 08D KLOE | |
| -0.32 ± 0.37 | 192 | BAGLIN | 70 HLBC | |
| ²⁹ This ADOLPH 09 resul | t is inde | pendent of the BA | SHKANOV | 07 result. |
| 30 The PRAKHOV 09 and | UNVE | RZAGT 09 results | are independ | dent. |
| 21 | | | | |

 $^{^{31}}$ This AMBROSINO 08D value is an indirect result using $\eta\to\pi^+\pi^0\pi^-$ events and a rescattering matrix that mixes isospin decay amplitudes.

 $^{^{28}{\}rm A\,MSLER}$ 95 fits to $(1+ {\it ay+by^2})$ and obtains $\it a=-$ 0.94 \pm 0.15 and $\it b=0.11$ \pm 0.27.

 η , $f_0(500)$

| η REFERENCE | 5 |
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| THALER BASILE STRUGALSKI BAGLIN BUTTRAM CARPENTER | 72 71 D 71 70 70 70 | PRL 29 313 NC 3A 796 NP B27 429 NP B22 66 PRL 25 1358 PR D1 1303 | M. Basile et al. Z.S. Strugalski et al. C. Baglin et al. M.T. Buttram, M.N. Kre D.W. Carpenter et al. | (CERN, BGNA, STRB) (JINR) (EPOL, MADR, STRB) isler, R.E. Mischke (PRIN) (DUKE) |
| THALER BASILE STRUGALSKI BAGLIN BUTTRAM CARPENTER COX | 72 71 D 71 70 70 70 70 70 B | PRL 29 313 NC 3A 796 NP B27 429 NP B22 66 PRL 25 1358 PR D1 1303 PRL 24 534 | M. Basile et al. Z.S. Strugalski et al. C. Baglin et al. M.T. Buttram, M.N. Kre D.W. Carpenter et al. B. Cox, L. Fortney, J.P. | (CERN, BGNA, STRB) (JINR) (EPOL, MADR, STRB) isler, R.E. Mischke (PRIN) (DUKE) Golson (DUKE) |
| THALER BASILE STRUGALSKI BAGLIN BUTTRAM CARPENTER COX DANBURG DEVONS | 72 71 D 71 70 70 70 70 70 70 B 70 | PRL 29 313 NC 3A 796 NP B27 429 NP B22 66 PRL 25 1358 PR D1 1303 PRL 24 534 PR D2 2564 PR D1 1936 | M. Basile et al. Z.S. Strugalski et al. C. Baglin et al. M.T. Buttram, M.N. Kre D.W. Carpenter et al. B. Cox, L. Forntey, J.P. J.S. Danburg et al. S. Devons et al. | (CERN, BGNA, STRB) (JINR) (EPOL, MADR, STRB) (isler, R.E. Mischke (PRIN) (Golson (DUKE) (LRL) (COLU, SYRA) |
| THALER BASILE STRUGALSKI BAGLIN BUTTRAM CARPENTER COX DANBURG | 72 71 D 71 70 70 70 70 B 70 B | PRL 29 313 NC 3A 796 NP B27 429 NP B22 66 PRL 25 1358 PR D1 1303 PRL 24 534 PR D2 2564 PR D1 1936 PR D2 501 | M. Basile et al. Z.S. Strugalski et al. C. Baglin et al. M.T. Buttram, M.N. Kre D.W. Carpenter et al. B. Cox, L. Fortney, J.P. J.S. Danburg et al. S. Devons et al. M. Gormley et al. | (CERN, BGNA, STRB) (IJNR) (EPOL, MADR, STRB) (Isler, R.E. Mischke (PRIN) (DUKE) Golson (DUKE) (LIRL) (COLU, SYRA) (COLU, BNL) |
| THALER BASILE STRUGALSKI BAGLIN BUTTRAM CARPENTER COX DANBURG DEVONS GORMLEY | 72 71 D 71 70 70 70 70 70 70 B 70 | PRL 29 313 NC 3A 796 NP B27 429 NP B22 66 PRL 25 1358 PR D1 1303 PRL 24 534 PR D2 2564 PR D1 1936 | M. Basile et al. Z.S. Strugalski et al. C. Baglin et al. M.T. Buttram, M.N. Kre D.W. Carpenter et al. B. Cox, L. Forntey, J.P. J.S. Danburg et al. S. Devons et al. | (CERN, BGNA, STRB) (JINR) (EPOL, MADR, STRB) (isler, R.E. Mischke (PRIN) (Golson (DUKE) (LRL) (COLU, SYRA) |

| HYAMS ARNOLD BAZIN BULLOCK CNOPS GORMLEY WEHMANN BAGLIN BAGLIN BALTAY BALTAY BEMPORAD | 69 68 68 68 68 C 68 67 67 B 67 B 67 D | PL 29B 128 PL 27B 466 PRL 20 895 PL 27B 402 PRL 21 1609 PRL 21 1609 PRL 21 402 PRL 20 748 PL 24B 637 PRL 19 1498 PRL 19 1495 PRL 19 1495 PRL 19 1495 PRL 25B 380 | B.D. Hyams et al. R.G. Arnold et al. M.J. Bazin et al. F.W. Bullock et al. A.M. Cnops et al. M. Gormley et al. A.W. Wehmann et al. C. Baglin et al. C. Baglin et al. C. Bathay et al. C. Bathay et al. C. Bathay et al. C. Barbay et al. C. Barbay et al. C. Barbay et al. C. Barbay et al. | (CERN, MPIM) (STRB, MADR, EPOL+) (PRIN, QUK) (PRIN, QUK) (LOUC) (BNL, ORNL, UCND+) (COLU, BNL) (HARV CASS, SLAC+) (EPOL, UCB) (EPOL, UCB) (COLU, STON) (COLU, BRAN) (PSA, BONN) |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Also BILLING BUNIATOV CENCE ESTEN FELDMAN FELDMAN FLATTE LITCHFIELD PRICE ALFF CLPWY CRAWFORD DIGIUGNO GRUNHAUS JAMES JONES LARRIBE FOSTER FOSTER FOSTER FOSTER FOSTER FOSTER FOSTER RITTENBERG FOELSCHE KRAEMER PAULI BACCI CRAWFORD Also ALFF | 67 67 67 67 67 67 67 66 66 66 66 66 66 6 | Private Comm. PL 25B 435 PL 25B 560 PRL 19 1393 PL 24B 115 PRL 18 868 PRL 18 976 PR 163 1441 PL 24B 15 PR 145 1072 PR 149 1044 PRL 16 333 PRL 16 767 Thesis PR 142 896 PL 23 597 PL 23 600 PR 138 B652 Athens Conf. Thesis PRL 15 556 PR 14 15 556 PR 13 B138 PR 13 B496 PRL 11 37 PRL 11 576 PRL 19 546 PRL 16 907 PRL 19 322 | I. Ion K.D. Billing et al. S.A. Bunyatov et al. R.J. Cence et al. M.J. Esten et al. M.J. Esten et al. M.Feldman et al. S.M. Flatte, C.G. Wohl P.J. Litchfield et al. L.R. Price, F.S. Crawford C. Allfi-Steinberger et al. C. Baitay F.S. Crawford, L.R. Price G. di Giugno et al. J. Grunhaus F.E. James, H.L. Kraybill W.G. Jones et al. M. Foster et al. M. Foster et al. M. Foster, M. Good, M. Meer M. Foster, M. Good, M. Meer M. Foster, B. Kabhielsch L.W.J. Foelsche, H.L. Kraybill R.W. Kraemer et al. R.W. Kraemer et al. R.W. Kraemer et al. F.S. Pauli, A. Muller C. Bacci et al. F.S.J. Crawford, L.J. Lloyd, E.S. F.S.J. Crawford, L.J. Lloyd, E.S. C. Alff-Steinberger et al. | (WISC) (LRL) (LRL, BNL) (YALE) (JHU, NWES, WOOD) (SACL) (ROMA, FRAS)C. Fowler (LRL+) |
| BASTIEN PICKUP | 62 62 | PRL 8 114 PRL 8 329 | P.L. Bastien <i>et al.</i> E. Pickup, D.K. Robinson, E.O | (LRL) . Salant (CNRC+) |

 $f_0(500)$ or σ was $f_0(600)$

 $I^{G}(J^{PC}) = 0^{+}(0^{+})$

NOTE ON SCALAR MESONS BELOW 2 GEV

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I. Introduction: In contrast to the vector and tensor mesons, the identification of the scalar mesons is a long-standing puzzle. Scalar resonances are difficult to resolve because some of them have large decay widths which cause a strong overlap between resonances and background. In addition, several decay channels sometimes open up within a short mass interval (e.g. at the $K\bar{K}$ and $\eta\eta$ thresholds), producing cusps in the line shapes of the near-by resonances. Furthermore, one expects non- $q\bar{q}$ scalar objects, such as glueballs and multiquark states in the mass range below 2 GeV (for reviews see, e.g., Refs. [1–4]) .

Scalars are produced, for example, in πN scattering on polarized/unpolarized targets, $p\bar{p}$ annihilation, central hadronic production, J/Ψ , B-, D- and K-meson decays, $\gamma\gamma$ formation, and ϕ radiative decays. Especially for the lightest scalar mesons simple parameterizations fail and more advanced theory tools are necessary to extract the resonance parameters from data. In the analyses available in the literature fundamental properties of the amplitudes such as unitarity, analyticity, Lorentz invariance, chiral and flavor symmetry are implemented at different levels of rigor. Especially, chiral symmetry implies the appearance of zeros close to the threshold in elastic S-wave scattering amplitudes involving soft pions [5,6], which may be shifted or removed in associated production processes [7]. The methods employed are the K-matrix formalism, the N/D-method, the

Meson Particle Listings $f_0(500)$

Dalitz Tuan ansatz, unitarized quark models with coupled channels, effective chiral field theories and the linear sigma model, etc. Dynamics near the lowest two-body thresholds in some analyses are described by crossed channel (t, u) meson exchange or with an effective range parameterization instead of, or in addition to, resonant features in the s-channel. Recent dispersion theoretical approaches made it possible to accurately pin down the location of resonance poles for the low lying states [8–11].

The mass and width of a resonance are found from the position of the nearest pole in the process amplitude (T-matrix or S-matrix) at an unphysical sheet of the complex energy plane, traditionally labeled as

$$\sqrt{s_{\text{Pole}}} = M - i \Gamma/2$$
.

It is important to note that the Breit-Wigner parameterization agrees with this pole position only for narrow and well–separated resonances, far away from the opening of decay channels.

In this note, we discuss the light scalars below 2 GeV organized in the listings under the entries $(I=1/2)~K_0^*(800)$ (or κ , currently omitted from the summary table), $K_0^*(1430)$, $(I=1)~a_0(980),~a_0(1450)$, and $(I=0)~f_0(500)$ (or σ), $f_0(980)$, $f_0(1370),~f_0(1500)$, and $f_0(1710)$. This list is minimal and does not necessarily exhaust the list of actual resonances. The $(I=2)~\pi\pi$ and $(I=3/2)~K\pi$ phase shifts do not exhibit any resonant behavior. See also our notes in previous issues for further comments on, e.g., scattering lengths and older papers.

II. The I=1/2 States: The $K_0^*(1430)$ [12] is perhaps the least controversial of the light scalar mesons. The $K\pi$ S-wave scattering has two possible isospin channels, I = 1/2and I = 3/2. The I = 3/2 wave is elastic and repulsive up to 1.7 GeV [13] and contains no known resonances. The $I = 1/2 K\pi$ phase shift, measured from about 100 MeV above threshold in Kp production, rises smoothly, passes 90° at 1350 MeV, and continues to rise to about 170° at 1600 MeV. The first important inelastic threshold is $K\eta'(958)$. In the inelastic region the continuation of the amplitude is uncertain since the partial-wave decomposition has several solutions. The data are extrapolated towards the $K\pi$ threshold using effective range type formulas [12,14] or chiral perturbation predictions [15,16]. From analyses using unitarized amplitudes there is agreement on the presence of a resonance pole around 1410 MeV having a width of about 300 MeV. With reduced model dependence, Ref. 17 finds a larger width of 500 MeV.

Similar to the situation for the $f_0(500)$, discussed in the next section, the presence and properties of the light $K_0^*(800)$ (or κ) meson in the 700-900 MeV region are difficult to establish since it appears to have a very large width ($\Gamma \approx 500$ MeV) and resides close to the $K\pi$ threshold. Hadronic *D*-meson decays provide additional data points in the vicinity of the $K\pi$ threshold - experimental results from E791, e.g., Ref. [18,19], FOCUS [17,20], CLEO [21], and BaBar [22] are discussed in the Review of Charm Dalitz Plot Analyses. Precision information

from semileptonic D decays avoiding theoretically ambiguous three-body final state interactions is not available. BES II [23] (re-analyzed in [24]) finds a $K_0^*(800)$ -like structure in J/ψ decays to $\bar{K}^{*0}(892)K^+\pi^-$ where $K_0^*(800)$ recoils against the $K^*(892)$. Also clean with respect to final state interaction is the decay $\tau^- \to K_S^0\pi^-\nu_\tau$ studied by Belle [25], with $K_0^*(800)$ parameters fixed to Ref. 23.

Some authors find a $K_0^*(800)$ pole in their phenomenological analysis (see, e.g., [21,26–36]), while others do not need to include it in their fits (see, e.g., [16,22,37–39]). Similarly to the case of the $f_0(500)$ discussed below, all works including constraints from chiral symmetry at low energies naturally seem to find a light $K_0^*(800)$ below 800 MeV, see, e.g., [40-44]. In these works the $K_0^*(800)$, $f_0(500)$, $f_0(980)$ and $a_0(980)$ appear to form a nonet [41,42]. Additional evidence for this assignment is presented in Ref. 11, where the couplings of the nine states to $\bar{q}q$ sources were compared. The same low lying scalar nonet was also found earlier in the unitarized quark model of Ref. 43. The analysis of Ref. 45 is based on the Roy-Steiner equations, which include analyticity and crossing symmetry. It establishes the existence of a light $K_0^*(800)$ pole in the $K\pi \to K\pi$ amplitude on the second sheet.

III. The I=1 States: Two isovector states are known, the established $a_0(980)$ and the $a_0(1450)$. Independent of any model, the KK component in the $a_0(980)$ wave function must be large: it lies just below the opening of the $K\bar{K}$ channel to which it strongly couples [14,46]. This generates an important cusp-like behavior in the resonant amplitude. Hence, its mass and width parameters are strongly distorted. To reveal its true coupling constants, a coupled channel model with energy-dependent widths and mass shift contributions is necessary. All listed $a_0(980)$ measurements agree on a mass position value near 980 MeV, but the width takes values between 50 and 100 MeV, mostly due to the different models. For example, the analysis of the $p\bar{p}$ -annihilation data [14] using a unitary K-matrix description finds a width as determined from the T-matrix pole of 92 ± 8 MeV, while the observed width of the peak in the $\pi\eta$ mass spectrum is about 45 MeV.

The relative coupling $K\bar{K}/\pi\eta$ is determined indirectly from $f_1(1285)$ [47–49] or $\eta(1410)$ decays [50–52], from the line shape observed in the $\pi\eta$ decay mode [54–57], or from the coupled-channel analysis of the $\pi\pi\eta$ and $K\bar{K}\pi$ final states of $p\bar{p}$ annihilation at rest [14].

The $a_0(1450)$ is seen in $p\bar{p}$ annihilation experiments with stopped and higher momenta antiprotons, with a mass of about 1450 MeV or close to the $a_2(1320)$ meson which is typically a dominant feature. A contribution from $a_0(1450)$ is also found in the analysis of the $D^\pm \to K^+K^-\pi^\pm$ decay [58]. The broad structure at about 1300 MeV observed in $\pi N \to K\bar{K}N$ reactions [59] needs still further confirmation in its existence and isospin assignment.

IV. The I = 0 States: The I = 0, $J^{PC} = 0^{++}$ sector is the most complex one, both experimentally and theoretically. The

 $f_0(500)$

data have been obtained from $\pi\pi$, $K\bar{K}$, $\eta\eta$, 4π , and $\eta\eta'$ (958) systems produced in S-wave. Analyses based on several different production processes conclude that probably four poles are needed in the mass range from $\pi\pi$ threshold to about 1600 MeV. The claimed isoscalar resonances are found under separate entries $f_0(500)$ (or σ), $f_0(980)$, $f_0(1370)$, and $f_0(1500)$.

For discussions of the $\pi\pi$ S wave below the $K\bar{K}$ threshold and on the long history of the $f_0(500)$, which was suggested in linear sigma models more than 50 years ago, see our reviews in previous editions and the conference proceedings [60].

Information on the $\pi\pi$ S-wave phase shift $\delta_I^I = \delta_0^0$ was already extracted many years ago from πN scattering [61–63], and near threshold from the K_{e4} -decay [64]. The kaon decays were later revisited leading to consistent data, however, with very much improved statistics [65,66]. The reported $\pi\pi \to K\bar{K}$ cross sections [67–70] have large uncertainties. The πN data have been analyzed in combination with highstatistics data (see entries labeled as RVUE for re-analyses of the data). The $2\pi^0$ invariant mass spectra of the $p\bar{p}$ annihilation at rest [71-73] and the central collision [74] do not show a distinct resonance structure below 900 MeV, but these data are consistently described with the standard solution for πN data [62,75], which allows for the existence of the broad $f_0(500)$. An enhancement is observed in the $\pi^+\pi^-$ invariant mass near threshold in the decays $D^+ \to \pi^+\pi^-\pi^+$ [76–103] and $J/\psi \to \omega \pi^+ \pi^-$ [79,100], and in $\psi(2S) \to J/\psi \pi^+ \pi^-$ with very limited phase space [81,82].

The precise $f_0(500)$ (or σ) pole is difficult to establish because of its large width, and because it can certainly not be modeled by a naive Breit-Wigner resonance. For the same reason a splitting in background and resonance contributions is not possible in a model-independent way. The $\pi\pi$ scattering amplitude shows an unusual energy dependence due to the presence of a zero in the unphysical regime close to the threshold [5–6], required by chiral symmetry, and possibly due to crossed channel exchanges, the $f_0(1370)$, and other dynamical features. However, most of the analyses listed under $f_0(500)$ agree on a pole position near (500 - i 250 MeV). In particular, analyses of $\pi\pi$ data that include unitarity, $\pi\pi$ threshold behavior, strongly constrained by the K_{e4} data, and the chiral symmetry constraints from Adler zeroes and/or scattering lengths find a light $f_0(500)$, see, e.g., [83,84].

Precise pole positions with an uncertainty of less than 20 MeV (see our table for T-matrix pole) were extracted by use of Roy equations, which are twice subtracted dispersion relations derived from crossing symmetry and analyticity. In Ref. [9] the subtraction constants were fixed to the S-wave scattering lengths a_0^0 and a_0^2 derived from matching Roy equations and two-loop chiral perturbation theory [8]. The only additional relevant input to fix the $f_0(500)$ pole turned out to be the $\pi\pi$ -wave phase shifts at 800 MeV. The analysis was improved further in Ref. 11. Alternatively, in Ref. 10 only data was used as input inside Roy equations. In that reference also once-subtracted Roy-like equations, called GKPY equations,

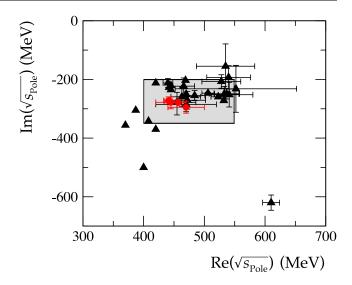


Figure 1: Location of the $f_0(500)$ (or σ) poles in the complex energy plane. Circles denote the recent analyses based on Roy(-like) dispersion relations [8–11], while all other analyses are denoted by triangles. The corresponding references are given in the listing.

were used, since the extrapolation into the complex plane based on the twice subtracted equations leads to larger uncertainties mainly due to the limited experimental information on the isospin 2 $\pi\pi$ scattering length. All these extractions find consistent results. Using analyticity and unitarity only to describe data from $K_{2\pi}$ and K_{e4} decays, Ref. 85 finds consistent values for pole position and scattering length a_0^0 . The importance of the $\pi\pi$ scattering data for fixing the $f_0(500)$ pole is nicely illustrated by comparing analyses of $\bar{p}p \to 3\pi^0$ omitting [71,86] or including [72,87] information on $\pi\pi$ scattering: while the former analyses find an extremely broad structure above 1 GeV, the latter find $f_0(500)$ masses of the order of 400 MeV.

As a result of the sensitivity of the extracted $f_0(500)$ pole position on the high accuracy low energy $\pi\pi$ scattering data [65,66], the currently quoted range of pole positions for the $f_0(500)$, namely

$$\sqrt{s_{\text{Pole}}^{\sigma}} = (400 - 550) - i(200 - 350) \text{ MeV}$$
,

in the listing was fixed including only those analyses consistent with these data, Refs. [29,32,41,43,44,53,56,72], [81–85] and [88–103] as well as the advanced dispersion analyses [8–11]. The pole positions from those references are compared to the range of poles positions quoted above in Fig. 1. Note that this range is labeled as 'our estimate' — it is not an average over the quoted analyses but is chosen to include the bulk of the analyses consistent with the mentioned criteria. An averaging procedure is not justified, since the analyses use overlapping or identical data sets.

One might also take the more radical point of view and just average the most advanced dispersive analyses, Refs. [8–11],

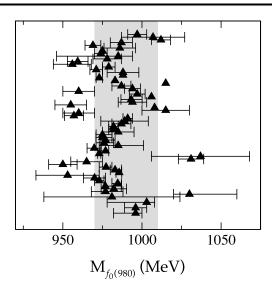


Figure 2: Values of the $f_0(980)$ masses as they appear in the listing compared to the currently quoted mass estimate. The newest references appear at the bottom, the oldest on the top. The corresponding references are given in the listing.

shown as solid dots in Fig. 1, for they provide a determination of the pole positions with minimal bias. This procedure leads to the much more restricted range of $f_0(500)$ parameters

$$\sqrt{s_{\text{Pole}}^{\sigma}} = (446 \pm 6) - i(276 \pm 5) \text{ MeV}$$
.

Due to the large strong width of the $f_0(500)$ an extraction of its two-photon width directly from data is not possible. Thus, the values for $\Gamma(\gamma\gamma)$ quoted in the literature as well as the listing are based on the expression in the narrow width approximation [104] $\Gamma(\gamma\gamma) \simeq \alpha^2 |g_{\gamma}|^2/(4\text{Re}(\sqrt{s_{\text{Pole}}^{\sigma}}))$ where g_{γ} is derived from the residue at the $f_0(500)$ pole to two photons and α denotes the electromagnetic fine structure constant. The explicit form of the expression may vary between different authors due to different definitions of the coupling constant, however, the expression given for $\Gamma(\gamma\gamma)$ is free of ambiguities. According to Refs. [105,106], the data for $f_0(500) \rightarrow \gamma \gamma$ are consistent with what is expected for a two-step process of $\gamma\gamma \to \pi^+\pi^-$ via pion exchange in the t- and u-channel, followed by a final state interaction $\pi^+\pi^- \to \pi^0\pi^0$. The same conclusion is drawn in Ref. 107 where the bulk part of the $f_0(500) \rightarrow \gamma \gamma$ decay width is dominated by re-scattering. Therefore, it might be difficult to learn anything new about the nature of the $f_0(500)$ from its $\gamma\gamma$ coupling. For the most recent work on $\gamma\gamma \to \pi\pi$, see Refs. [108,109]. There are theoretical indications (e.g., [110–113]) that the $f_0(500)$ pole behaves differently from a $q\bar{q}$ -state – see next section for details.

The $f_0(980)$ overlaps strongly with the background represented mainly by the $f_0(500)$ and the $f_0(1370)$. This can lead to a dip in the $\pi\pi$ spectrum at the $K\bar{K}$ threshold. It changes from a dip into a peak structure in the $\pi^0\pi^0$ invariant mass

spectrum of the reaction $\pi^-p \to \pi^0\pi^0n$ [114], with increasing four-momentum transfer to the $\pi^0\pi^0$ system, which means increasing the a_1 -exchange contribution in the amplitude, while the π -exchange decreases. The $f_0(500)$ and the $f_0(980)$ are also observed in data for radiative decays ($\phi \to f_0\gamma$) from SND [115,116], CMD2 [117], and KLOE [118,119]. Recently a dispersive analysis was used to simultaneously pin down the pole parameters of both the $f_0(500)$ and the $f_0(980)$ [10]; the uncertainty in the pole position quoted for the latter state is of the order of 10 MeV, only (see lowest point in Fig. 2). Compared to the 2010 issue of the Review of Particle Physics, in this issue we extended the allowed range of $f_0(980)$ masses to include the mass value derived in Ref. 10. We now quote for the mass

$$M_{f_0(980)} = 990 \pm 20 \text{ MeV}$$
.

As in case of the $f_0(500)$ (or σ), this range is not an average, but is labeled as 'our estimate'. A comparison of the mass values in the listing and the allocated range is shown in Fig. 2.

Analyses of $\gamma\gamma \to \pi\pi$ data [120–122] underline the importance of the $K\bar{K}$ coupling of $f_0(980)$, while the resulting two-photon width of the $f_0(980)$ cannot be determined precisely [123].

The f_0 's above 1 GeV. A meson resonance that is very well studied experimentally, is the $f_0(1500)$ seen by the Crystal Barrel experiment in five decay modes: $\pi\pi$, $K\bar{K}$, $\eta\eta$, $\eta\eta'(958)$, and 4π [14,72,73]. Due to its interference with the $f_0(1370)$ (and $f_0(1710)$), the peak attributed to $f_0(1500)$ can appear shifted in invariant mass spectra. Therefore, the application of simple Breit-Wigner forms arrive at slightly different resonance masses for $f_0(1500)$. Analyses of central-production data of the likewise five decay modes Refs. [124,125] agree on the description of the S-wave with the one above. The $p\bar{p}$, $p\bar{n}/n\bar{p}$ measurements [126–128,73] show a single enhancement at 1400 MeV in the invariant 4π mass spectra, which is resolved into $f_0(1370)$ and $f_0(1500)$ [129,130]. The data on 4π from central production [131] require both resonances, too, but disagree on the relative content of $\rho\rho$ and $f_0(500)f_0(500)$ in 4π . All investigations agree that the 4π decay mode represents about half of the $f_0(1500)$ decay width and is dominant for $f_0(1370)$.

The determination of the $\pi\pi$ coupling of $f_0(1370)$ is aggravated by the strong overlap with the broad $f_0(500)$ and $f_0(1500)$. Since it does not show up prominently in the 2π spectra, its mass and width are difficult to determine. Multichannel analyses of hadronically produced two- and three-body final states agree on a mass between 1300 MeV and 1400 MeV and a narrow $f_0(1500)$, but arrive at a somewhat smaller width for $f_0(1370)$.

Both Belle and BaBar have observed scalars in B and D meson decays. They observe broad or narrow structures between 1 and 1.6 GeV in K^+K^- and $\pi^+\pi^-$ decays [132–136] (see also [137]). It could be a result of interference of several resonances in this mass range, but lack of statistics prevents an

 $f_0(500)$

unambiguous identification of this effect. In $\gamma\gamma$ collisions the observation of scalars was reported in Refs. [121,138–196].

V. Interpretation of the scalars below 1 GeV: In the literature, many suggestions are discussed, such as conventional $q\bar{q}$ mesons, $q\bar{q}q\bar{q}$ or meson-meson bound states. In addition one expects a scalar glueball in this mass range. In reality, there can be superpositions of these components, and one often depends on models to determine the dominant one. Although we have seen progress in recent years, this question remains open. Here, we mention some of the present conclusions.

The $f_0(980)$ and $a_0(980)$ are often interpreted as multiquark states [140–144] or $K\bar{K}$ bound states [145]. The insight into their internal structure using two-photon widths [116,146–152] is not conclusive. The $f_0(980)$ appears as a peak structure in $J/\psi \to \phi \pi^+ \pi^-$ and in D_s decays without $f_0(500)$ background, while being nearly invisible in $J/\psi \to \omega \pi^+ \pi^-$. Based on that observation it is suggested that $f_0(980)$ has a large $s\bar{s}$ component, which according to Ref. 153 is surrounded by a virtual KKcloud (see also Ref. 154). Data on radiative decays ($\phi \to f_0 \gamma$ and $\phi \to a_0 \gamma$) from SND, CMD2, and KLOE (see above) are consistent with a prominent role of kaon loops. This observation is interpreted as evidence for a compact four-quark [155] or a molecular [160,156] nature of these states. Details of this controversy are given in the comments [157,158]; Ref. 159. It remains quite possible that the states $f_0(980)$ and $a_0(980)$, together with the $f_0(500)$ and the $K_0^*(800)$, form a new low-mass state nonet of predominantly four-quark states, where at larger distances the quarks recombine into a pair of pseudoscalar mesons creating a meson cloud (see e.g., Ref. 161). Different QCD sum rule studies [162–166] do not agree on a tetraquark configuration for the same particle group.

Models that start directly from chiral Lagrangians, either in non-linear [44,28,83,160] or in linear [167–172] realization, predict the existence of the $f_0(500)$ meson near 500 MeV. Here the $f_0(500)$, $a_0(980)$, $f_0(980)$, and $K_0^*(800)$ (in some models the $K_0^*(1430)$) would form a nonet (not necessarily $q\bar{q}$). In the linear sigma models the lightest pseudoscalars appear as their chiral partners. In these models the light $f_0(500)$ is often referred to as the "Higgs boson of strong interactions", since here the $f_0(500)$ plays a role similar to the Higgs particle in electro-weak symmetry breaking: within the linear sigma models it is important for the mechanism of chiral symmetry breaking, which generates most of the proton mass, and what is referred to as the constituent quark mass.

In the non–linear approaches of Ref. 28 [83], the above resonances together with the low lying vector states are generated starting from chiral perturbation theory predictions near the first open channel, and then by extending the predictions to the resonance regions using unitarity and analyticity.

Ref. 167 uses a framework with explicit resonances that are unitarized and coupled to the light pseudo-scalars in a chirally invariant way. Evidence for a non- $\bar{q}q$ nature of the lightest scalar resonances is derived from their mixing scheme. To

identify the nature of the resonances generated from scattering equations, in Ref. 175 the large N_c behavior of the poles was studied, with the conclusion that, while the light vector states behave consistent with what is predicted for $\bar{q}q$ states, the light scalars behave very differently. This finding provides strong support for a non- $\bar{q}q$ nature of the light scalar resonances. Note, the more refined study of Ref. 110 found, in case of the $f_0(500)$, in addition to a dominant non- $\bar{q}q$ nature, indications for a subdominant $\bar{q}q$ component located around 1 GeV. A model-independent method to identify hadronic molecules goes back to a proposal by Weinberg [176], shown to be equivalent to the pole counting arguments of Ref. 177 [178] in Ref. 179. The formalism allows one to extract the amount of molecular component in the wave function from the effective coupling constant of a physical state to a nearby continuum channel. It can be applied to near threshold states only and provided strong evidence that the $f_0(980)$ is a $\bar{K}K$ molecule, while the situation turned out to be less clear for the $a_0(980)$ (see also Refs. [152,150]). Further insights into $a_0(980)$ and $f_0(980)$ are expected from their mixing [180]. The corresponding signal predicted in Refs. [181,182] was recently observed at BES III [183].

In the unitarized quark model with coupled $q\bar{q}$ and meson-meson channels, the light scalars can be understood as additional manifestations of bare $q\bar{q}$ confinement states, strongly mass shifted from the 1.3 - 1.5 GeV region and very distorted due to the strong 3P_0 coupling to S-wave two-meson decay channels [173–184]. Thus, in these models the light scalar nonet comprising the $f_0(500)$, $f_0(980)$, $K_0^*(800)$, and $a_0(980)$, as well as the nonet consisting of the $f_0(1370)$, $f_0(1500)$ (or $f_0(1710)$), $K_0^*(1430)$, and $a_0(1450)$, respectively, are two manifestations of the same bare input states (see also Ref. 185).

Other models with different groupings of the observed resonances exist and may, e.g., be found in earlier versions of this review.

VI. Interpretation of the f_0 's above 1 GeV: The $f_0(1370)$ and $f_0(1500)$ decay mostly into pions $(2\pi$ and $4\pi)$ while the $f_0(1710)$ decays mainly into $K\bar{K}$ final states. The $K\bar{K}$ decay branching ratio of the $f_0(1500)$ is small [124,186].

If one uses the naive quark model, it is natural to assume that the $f_0(1370)$, $a_0(1450)$, and the $K_0^*(1430)$ are in the same SU(3) flavor nonet, being the $(u\bar{u}+d\bar{d})$, $u\bar{d}$ and $u\bar{s}$ states, probably mixing with the light scalars [187], while the $f_0(1710)$ is the $s\bar{s}$ state. Indeed, the production of $f_0(1710)$ (and $f_2'(1525)$) is observed in $p\bar{p}$ annihilation [188] but the rate is suppressed compared to $f_0(1500)$ (respectively, $f_2(1270)$), as would be expected from the OZI rule for $s\bar{s}$ states. The $f_0(1500)$ would also qualify as $(u\bar{u}+d\bar{d})$ state, although it is very narrow compared to the other states and too light to be the first radial excitation.

However, in $\gamma\gamma$ collisions leading to $K_S^0K_S^0$ [189] a spin 0 signal is observed at the $f_0(1710)$ mass (together with a dominant spin 2 component), while the $f_0(1500)$ is not observed

Meson Particle Listings $f_0(500)$

in $\gamma\gamma \to K\bar{K}$ nor $\pi^+\pi^-$ [190]. In $\gamma\gamma$ collisions leading to $\pi^0\pi^0$ Ref. 138 reports the observation of a scalar around 1470 MeV albeit with large uncertainties on the mass and $\gamma\gamma$ couplings. This state could be the $f_0(1370)$ or the $f_0(1500)$. The upper limit from $\pi^+\pi^-$ [190] excludes a large $n\bar{n}$ (here n stands for the two lightest quarks) content for the $f_0(1500)$ and hence points to a mainly $s\bar{s}$ state [191]. This appears to contradict the small $K\bar{K}$ decay branching ratio of the $f_0(1500)$ and makes a $q\bar{q}$ assignment difficult for this state. Hence the $f_0(1500)$ could be mainly glue due the absence of a 2γ -coupling, while the $f_0(1710)$ coupling to 2γ would be compatible with an $s\bar{s}$ state. However, the 2γ -couplings are sensitive to glue mixing with $q\bar{q}$ [192].

Note that an isovector scalar, possibly the $a_0(1450)$ (albeit at a lower mass of 1317 MeV) is observed in $\gamma\gamma$ collisions leading to $\eta \pi^0$ [193]. The state interferes destructively with the non-resonant background, but its $\gamma\gamma$ coupling is comparable to that of the $a_2(1320)$, in accord with simple predictions (see, e.g., Ref. 191).

The small width of $f_0(1500)$, and its enhanced production at low transverse momentum transfer in central collisions [197–199] also favor $f_0(1500)$ to be non- $q\bar{q}$. In the mixing scheme of Ref. 192, which uses central production data from WA102 and the recent hadronic J/ψ decay data from BES [200,201], glue is shared between $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$. The $f_0(1370)$ is mainly $n\bar{n}$, the $f_0(1500)$ mainly glue and the $f_0(1710)$ dominantly $s\bar{s}$. This agrees with previous analyses [202,203].

However, alternative schemes have been proposed (e.g., inRef. 204 [205]; for a review see, e.g., Ref. 1). In particular, for a scalar glueball, the two-gluon coupling to $n\bar{n}$ appears to be suppressed by chiral symmetry [206] and therefore the $K\bar{K}$ decay could be enhanced. This mechanism would imply that the $f_0(1710)$ can possibly be interpreted as an unmixed glueball [207]. In Ref. 208, a large K^+K^- scalar signal reported by Belle in B decays into $KK\bar{K}$ [209], compatible with the $f_0(1500)$, is explained as due to constructive interference with a broad glueball background. However, the Belle data are inconsistent with the BaBar measurements which show instead a broad scalar at this mass for B decays into both $K^{\pm}K^{\pm}K^{\mp}$ [135] and $K^{+}K^{-}\pi^{0}$ [210].

Whether the $f_0(1500)$ is observed in 'gluon rich' radiative J/ψ decays is debatable [211] because of the limited amount of data - more data for this and the $\gamma\gamma$ mode are needed.

In Ref. 212 $f_0(1370)$ and $f_0(1710)$ (together with $f_2(1270)$ and $f_2'(1525)$) were interpreted as bound systems of two vector mesons. This picture could be tested in radiative J/ψ decays [213] as well as radiative decays of the states themselves [214].

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$f_0(500)$ T-MATRIX POLE \sqrt{s}

Note that $\Gamma \approx 2 \text{ Im}(\sqrt{s_{pole}})$

VALUE (MeV DOCUMENT ID TECN COMMENT (400-550)-i(200-350) OUR ESTIMATE • • • We do not use the following data for averages, fits, limits, etc. • • • $^{1,2}\,{\sf GARCIA\text{-}MAR...11}$ RVUE Compilation $(445 \pm 25) - i(278 + \frac{22}{18})$ $\begin{array}{c} (457 + 14 \\ -13) - i(279 + 11 \\ (442 + 5 \\ -8) - i(274 + 6 \\ -5) \end{array}$ 1,3 GARCIA-MAR..11 RVUE Compilation 4 MOUSSALLAM11 RVUE ⁵ MENNESSIER 10 $(452 \pm 13) - i(259 \pm 16)$ RVUE Compilation $\begin{array}{c} (448 \pm 43) - i(266 \pm 43) \\ (455 \pm 6 + \frac{31}{13}) - i(278 \pm 6 + \frac{34}{43}) \\ (463 \pm 6 + \frac{31}{17}) - i(259 \pm 6 + \frac{33}{34}) \\ \end{array}$ ⁶ MENNESSIER 10 RVUE Compilation ⁷ CAPRINI 08 RVUE Compilation ⁸ CAPRINI RVUE 08 Compilation $(552 + 84 \atop -106) - i(232 + 81 \atop -72)$ ⁹ ABLIKIM $\psi(2S) \rightarrow \pi^{+}\pi^{-}J/\psi$ 07A BES2 ¹⁰ BONVICINI $(466 \pm 18) - i(223 \pm 28)$ 07 CLEO $D^+ \rightarrow \pi^- \pi^+ \pi$ $^{11}\,\mathrm{BUGG}$ (472 + 30) - i(271 + 30)07A RVUE Compilation GARCIA-MAR..07 $(484 \pm 17) - i(255 \pm 10)$ RVUE Compilation $^{12}\,\mathrm{A\,NISOVICH}$ (430)-i(325)06 **RVUE** Compilation $(441 + 16 \atop - 8) - i(272 + 9 \atop - 12.5)$ 13 CAPRINI RVUE 06 ¹⁴ ZHOU $(470 \pm 50) - i(285 \pm 25)$ 05 RVUE ¹⁵ ABLIKIM $(541 \pm 39) - i(252 \pm 42)$ BES2 $J/\psi \rightarrow \omega \pi^+ \pi^-$ ¹⁶ GALLEGOS $(528 \pm 32) - i(207 \pm 23)$ 04 RVUE Compilation ¹⁷PELAEZ $(440 \pm 8) - i(212 \pm 15)$ 04 A RVUE $^{18}\,\mathrm{BUGG}$ $(533 \pm 25) - i(249 \pm 25)$ 03 RVUE BLACK $\pi^0\pi^0 \rightarrow \pi^0\pi^0$ 517 - i24001 RVUE $^{13}\,\mathrm{COLANGELO}$ $(470 \pm 30) - i(295 \pm 20)$ 01 RVUE $(535 + 48 \atop -36) - i(155 + 76 \atop -53)$ 19 ISHIDA $\Upsilon(3S) \rightarrow \Upsilon \pi \pi$ 01 $610 \pm 14 - i620 \pm 26$ (540 + 36- 29) - i(193 + 32- 40)²⁰ SUROVTSEV 01 **RVUE** ISHIDA $p \overline{p} \rightarrow \pi^0 \pi^0 \pi^0$ 00B 445 - i235HANNAH 99 RVUE π scalar form factor

$f_0(500)$

| $(523 \pm 12) - i(259 \pm 7)$ | KAMINSKI 99 RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$, $\sigma\sigma$ |
|------------------------------------------|----------------------------------------------------------------------------------------|
| $442 - i \ 227$ | OLLER 99 RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 469 - i203 | OLLER 99B RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 445 - i221 | OLLER 99C RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$, $\eta\eta$ |
| $(1530 + 90 \atop -250) - i(560 \pm 40)$ | ANISOVICH 98B RVUE Compilation |
| $420 - i \ 212$ | LOCHER 98 RVUE $\pi\pi \to \pi\pi$. $K\overline{K}$ |
| 420 - i 212 440 - i245 | 21 DOBADO 97 RVUE Compilation |
| | |
| $(602 \pm 26) - i(196 \pm 27)$ | |
| $(537 \pm 20) - i(250 \pm 17)$ | ²³ KAMINSKI 97B RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$, 4π |
| 470 - i250 | 24,25 TORNQVIST 96 RVUE $\pi\pi\to\pi\pi$, K \overline{K} , K π , |
| | 25.26 ηπ |
| 387 - i305 | 25,26 JANSSEN 95 RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 420 - i370 | 27 ACHASOV 94 RVUE $\pi\pi ightarrow \pi\pi$ |
| $(506 \pm 10) - i(247 \pm 3)$ | KAMINSKI 94 RVUE $\pi\pi	o\pi\pi$, K \overline{K} |
| 370 - i356 | ²⁸ ZOU 94B RVUE $\pi\pi \to \pi\pi$, K \overline{K} |
| 408 - i342 | 25,28 ZOU 93 RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 470 - i208 | ²⁹ VANBEVEREN 86 RVUE $\pi\pi \to \pi\pi$, K \overline{K} , $\eta\eta$, |
| $(750 \pm 50) - i(450 \pm 50)$ | ³⁰ ESTABROOKS 79 RVUE $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| $(660 \pm 100) - i(320 \pm 70)$ | PROTOPOP 73 HBC $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| | 21 |
| 650 - i370 | |
| Illege the K data of | BATLEY 10c and the $\pi N \rightarrow \pi \pi N$ data of HVAMS 73 |

- Uses the $K_{\rm e4}$ data of BATLEY 10c and the $\pi N \to \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73.
- $^2\,\mbox{\sc Analytic}$ continuation using Roy equations.
- ³Analytic continuation using GKPY equations.
- ⁴ Using Roy equations.
- S Average of three variants of the analytic K-matrix model. Uses the κ_{e4} data of BAT-
- LEY 08A and the $\pi N \to \pi \pi N$ data of HYAMS 73 and GRAYER 74. ⁶ Average of the analyses of three data sets in the K-matrix model. Uses the data of
- BATLEY 08A, HYAMS 73, and GRAYER 74, partially of COHEN 80 or ETKIN 82B 7 From the K_{e4} data of BATLEY 08A and $\pi\,N\,\to\,\pi\pi\,N$ data of HYAMS 73.
- 8 From the $K_{\rm e4}$ data of BATLEY 08A and $\pi\,N\to\pi\pi\,N$ data of PROTOPOPESCU 73, GRAYER 74, and ESTABROOKS 74.
- From a mean of three different $f_0(500)$ parametrizations. Uses 40k events.
- $^{10}\,\mathrm{From}$ an isobar model using 2.6k events.
- 11 Reanalysis of ABLIKIM 04A, PISLAK 01, and HYAMS 73 data.
- 12 Using the N/D method.
- 13 From the solution of the Roy equation (ROY 71) for the isoscalar S-wave and using a phase-shift analysis of HYAMS 73 and PROTOPOPESCU 73 data.

 14 Reanalysis of the data from PROTOPOPESCU 73, ESTABROOKS 74, GRAYER 74, ROSSELET 77, PISLAK 03, and AKHMETSHIN 04.
- 15 From a mean of six different analyses and $\emph{f}_{0}(500)$ parameterizations.
- 16 Using data on $\psi(2S) \to J/\psi \pi \pi$ from BAI 00E and on $\Upsilon(nS) \to \Upsilon(mS)\pi \pi$ from BUTLER 94B and ALEXANDER 98.

 17 Reanalysis of data from PROTOPOPESCU 73, ESTABROOKS 74, GRAYER 74, and COHEN 80 in the unitarized ChPT model.

 19 A similar analysis (KOMADA 01) finds $(580 + \frac{7}{30}) i(190 + \frac{107}{49})$ MeV.

- ²⁰ Coupled channel reanalysis of BATON 70, BENSINGER 71, BAILLON 72, HYAMS 73, HYAMS 75, ROSSELET 77, COHEN 80, and ETKIN 82B using the uniformizing variable.
- 21 Using the inverse amplitude method and data of ESTABROOKS 73, GRAYER 74, and PROTOPOPESCU 73.
- 22 Reanalysis of data from HYAMS 73, GRAYER 74, SRINIVASAN 75, and ROSSELET 77
- vising the interfering amplitude method.

 23 Average and spread of 4 variants ("up" and "down") of KAMINSKI 978 3-channel model.

 24 Uses data from BEIER 728, OCHS 73, HYAMS 73, GRAYER 74, ROSSELET 77, CASON 83, ASTON 88, and ARMSTRONG 918. Coupled channel analysis with flavor
- symmetry and all light two-pseudoscalars systems. 25 Demonstrates explicitly that $f_0(500)$ and $f_0(1370)$ are two different poles.
- ²⁶ Analysis of data from FALVARD 88.
- 27 Analysis of data from OCHS 73, ESTABROOKS 75, ROSSELET 77, and MUKHIN 80.
- 29 Coupled-channel analysis using data from PROTOPOPESCU 73, HYAMS 73, HYAMS 75, GRAYER 74, ESTABROOKS 74, ESTABROOKS 75, FROGGATT 77, CORDEN 79, BISWAS 81.
- ³⁰ Analysis of data from APEL 73, GRAYER 74, CASON 76, PAWLICKI 77. Includes spread and errors of 4 solutions
- 31 Analysis of data from BATON 70, BENSINGER 71, COLTON 71, BAILLON 72,PRO-TOPOPESCU 73, and WALKER 67.

f₀(500) BREIT-WIGNER MASS OR K-MATRIX POLE PARAMETERS

| VALUE (IVIEV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------------|--------|---------|--------------------------------------------------|
| (400-550) OUR ESTI | MATE | | | |
| • • • We do not use | the following data | for av | ærages, | fits, limits, etc. • • • |
| $513\!\pm\!32$ | ³² MURA MAT SU | 02 | CLEO | e^+e^-pprox 10 GeV |
| $478 + \frac{24}{23} \pm 17$ | AITALA | 01в | E791 | $D^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| $563 + 58 \\ -29$ | ³³ ISHIDA | 01 | | $\Upsilon(3S) \rightarrow \Upsilon \pi \pi$ |
| 555 | ³⁴ ASNER | 00 | CLE2 | $	au^- ightarrow ~\pi^- \pi^0 \pi^0 u_{	au}$ |
| 540 ± 36 | ISHIDA | 00B | | $p\overline{p} \rightarrow \pi^0 \pi^0 \pi^0$ |
| 750± 4 | ALEKSEEV | 99 | SPEC | 1.78 $\pi^ p_{polar} \rightarrow \pi^- \pi^+ n$ |
| 744± 5 | ALEKSEEV | 98 | SPEC | 1.78 $\pi^- p_{polar} \rightarrow \pi^- \pi^+ n$ |
| 759 ± 5 | 35 TROYAN | | | $5.2 np \rightarrow np\pi^+\pi^-$ |

| 780 ± 30 | _ ALDE | 97 | GA M2 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
|---------------|------------------------|----|-------|----------------------------------------------------------------------|
| 585 ± 20 | ³⁶ ISHIDA | 97 | | $\pi\pi \rightarrow \pi\pi$ |
| 761 ± 12 | ³⁷ SVEC | 96 | RVUE | 6-17 π N polar $\rightarrow \pi^+\pi^-$ N |
| ~ 860 | | | RVUE | $\pi\pi \rightarrow \pi\pi$, $K\overline{K}$, $K\pi$, $\eta\pi$ |
| 1165 ± 50 | 40,41 anisovich | 95 | RVUE | |
| | | | | $\overline{p}p \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \pi^0 \eta$, |
| | | | | $\pi^0 \eta \eta$ |
| ~ 1000 | ⁴² ACHASOV | 94 | RVUE | $\pi\pi \to \pi\pi$ |
| 414 ± 20 | ³⁷ AUGUSTIN | 89 | DM2 | |

- 32 Statistical uncertainty only.
- 33 A similar analysis (KOMADA 01) finds $526 + \frac{48}{37}$ MeV.
- $^{34}\,\mathrm{From}$ the best fit of the Dalitz plot.
- 35 $_{6\sigma}$ effect, no PWA.

I

- 36 Reanalysis of data from HYAMS 73, GRAYER 74, SRINIVASAN 75, and ROSSELET 77 using the interfering amplitude method.
- 37 Breit-Wigner fit to S-wave intensity measured in $\pi N \to \pi^- \pi^+ N$ on polarized targets. The fit does not include $f_0(980)$.
- ³⁸ Uses data from ASTON 88, OCHS 73, HYAMS 73, ARMSTRONG 91B, GRAYER 74, CASON 83, ROSSELET 77, and BEIER 72B. Coupled channel analysis with flavor symmetry and all light two-pseudoscalars systems. 39 Also observed by ASNER 00 in $\tau^-\to\pi^-\pi^0\,\pi^0\,\nu_\tau$ decays.
- 40 Uses $\pi^0\pi^0$ data from ANISOVICH 94, AMSLER 94D, and ALDE 95B, $\pi^+\pi^-$ data from OCHS 73, GRAYER 74 and ROSSELET 77, and $\eta\eta$ data from ANISOVICH 94.
- 41 The pole is on Sheet III. Demonstrates explicitly that $f_0(500)$ and $f_0(1370)$ are two
- 42 Analysis of data from OCHS 73, ESTABROOKS 75, ROSSELET 77, and MUKHIN 80.

f₀(500) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID |) | TECN | COMMENT |
|---------------------|-----------------------------|----------|---------|-----------------------------------------------------------------------------------------------------|
| (400-700) OUR E | STIMATE | | | |
| • • • We do not | use the following dat | a for av | erages, | fits, limits, etc. • • • |
| 335 ± 67 | ⁴³ MURA MATS | U 02 | CLEO | e^+e^-pprox 10 GeV |
| $324 + 42 \pm 21$ | AITALA | 01в | E791 | $D^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| $372 + 229 \\ - 95$ | ⁴⁴ ISHIDA | 01 | | $\Upsilon(3S) \rightarrow \Upsilon \pi \pi$ |
| 540 | ⁴⁵ ASNER | 00 | CLE2 | $	au^- ightarrow ~\pi^- \pi^0 \pi^0 u_	au$ |
| 372± 80 | ISHIDA | 00в | | $p\overline{p} \rightarrow \pi^0 \pi^0 \pi^0$ |
| $119\pm~13$ | ALEKSEEV | 99 | SPEC | 1.78 $\pi^- p_{polar} \rightarrow \pi^- \pi^+ n$ |
| 77± 22 | ALEKSEEV | 98 | | 1.78 $\pi^- \rho_{polar} \rightarrow \pi^- \pi^+ n$ |
| $35\pm~12$ | ⁴⁶ TROYAN | 98 | | $5.2 np \rightarrow np \pi^+ \pi^-$ |
| 780± 60 | ALDE | 97 | GAM2 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| 385 ± 70 | ⁴⁷ ISHIDA | 97 | | $\pi\pi \to \pi\pi$ |
| 290 ± 54 | ⁴⁸ SVEC | 96 | RVUE | $6-17 \pi N_{polar} \rightarrow \pi^+ \pi^- N$ |
| ~ 880 | 49,50 TORNQVIST | 96 | | $\pi \pi \rightarrow \pi \pi, K \overline{K}, K \pi, \eta \pi$ |
| 460 ± 40 | ^{51,52} A NISOVICH | 95 | RVUE | $\pi^- p \rightarrow \pi^0 \pi^0 n$ |
| | | | | $ \frac{\overline{\rho}}{\overline{\rho}} {\rho} \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \pi^0 \eta, $ |
| ~ 3200 | ⁵³ ACHASOV | 94 | RVUE | $\pi^- \eta \eta$ $\pi \pi \rightarrow \pi \pi$ |
| 494± 58 | ⁴⁸ AUGUSTIN | 89 | DM2 | |
| 43 - | | | | |

- ⁴³ Statistical uncertainty only.
- ⁴⁴ A similar analysis (KOMADA 01) finds $301 + 145 \\ -100$ MeV.
- $^{
 m 45}$ From the best fit of the Dalitz plot.
- 46 6σ effect, no PWA.
- 47 Reanalysis of data from HYAMS 73, GRAYER 74, SRINIVASAN 75, and ROSSELET 77 using the interfering amplitude method.
- 48 Breit-Wigner fit to S-wave intensity measured in $\pi N \to \pi^- \pi^+ N$ on polarized targets. The fit does not include $f_0(980)$.
- 49 Uses data from ASTON 88, OCHS 73, HYAMS 73, ARMSTRONG 91B, GRAYER 74, CASON 83, ROSSELET 77, and BEIER 728. Coupled channel analysis with flavor symmetry and all light two-pseudoscalars systems. 50 Also observed by ASNER 00 in $\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$ decays.
- 51 Uses $\pi^0\pi^0$ data from ANISOVICH 94, AMSLER 94b, and ALDE 95B, $\pi^+\pi^-$ data from OCHS 73, GRAYER 74 and ROSSELET 77, and $\eta\eta$ data from ANISOVICH 94.
- 52 The pole is on Sheet III. Demonstrates explicitly that $f_0(500)$ and $f_0(1370)$ are two different poles.
- ⁵³ Analysis of data from OCHS 73, ESTABROOKS 75, ROSSELET 77, and MUKHIN 80.

ሐ(500) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------|------------------------------|
| $\overline{\Gamma_1}$ | $\pi\pi$ | dominant |
| Γ_2 | $\gamma\gamma$ | seen |

| - %(500) PARTIAL WIDTHS | | | | | | | |
|-----------------------------------------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------------------------------------|---------------------------|--|--|--|--|
| $\Gamma(\gamma\gamma)$ | | | Γ2 | | | | |
| VALUE (keV) | DOCUMENT ID | TECN COMMENT | | | | | |
| • • • We do not use the follo | wing data for averages, fi | ts, limits, etc. • • • | | | | | |
| 1.7 ±0.4 | ⁵⁴ HOFERICHTER11 | RVUE Compilation | I | | | | |
| 3.08±0.82 | ⁵⁵ MENNESSIER 11 | RVUE Compilation | | | | | |
| $2.08 \pm 0.2 \begin{array}{l} + 0.07 \\ - 0.04 \end{array}$ | ⁵⁶ MOUSSALLAM11 | RVUE Compilation | ı | | | | |
| 2.08 | ⁵⁷ MAO 09 | RVUE Compilation | Ī | | | | |
| 1.2 ±0.4 | ⁵⁸ BERNABEU 08 | RVUE | - | | | | |
| 3.9 ±0.6 | ⁵⁵ MENNESSIER 08 | RVUE $\gamma \gamma \rightarrow \pi^+ \pi^-$ | $\pi^0 \pi^0$ | | | | |
| 1.8 ±0.4 | ⁵⁹ OLLER 08 | RVUE Compilation | | | | | |
| 1.68±0.15 | | RVUE Compilation | | | | | |
| 3.1 ±0.5 | 1,62 PENNINGTON 08 | RVUE Compilation | | | | | |
| | ^{2,63} PENNINGTON 08 | RVUE Compilation | | | | | |
| 4.1 ±0.3 | 64 PENNINGTON 06 | RVUE $\gamma \gamma \rightarrow \pi^0 \pi^0$ | 0 0 | | | | |
| | 5,66 BOGLIONE 99 | RVUE $\gamma \gamma \rightarrow \pi^+ \pi^-$ | | | | | |
| 5.4 ±2.3 | 65 MORGAN 90 | RVUE $\gamma \gamma \rightarrow \pi^+ \pi^-$ DM1 $e^+ e^- \rightarrow \pi^+$ | | | | | |
| 10 ±6 | COURAU 86 | | | | | | |
| ⁵⁴ Using Roy-Steiner equation and from GARCIA-MARTI | N 11A (PR D83 074004) | | ANGELO 01 | | | | |
| ⁵⁵ Using an analytic K-matrix ⁵⁶ Using dispersion integral v SISKE 90, BOYER 90, BE | vith phase input from R | oy equations and data | from MAR- | | | | |
| ⁵⁷ Used dispersion theory. Th | e value quoted used the | $f_0(500)$ pole position of | 457 — <i>i</i> 276 | | | | |
| MeV. 58 Using p , n polarizabilities f MARTIN 07 and σ -poles f | rom PDG 06 and fitting | to $\pi\pi$ phase motion fro | m GARCIA- | | | | |
| 59 Using twice-subtracted disp | | 7 and CAPRINI 06. | I | | | | |
| 60 Supersedes OLLER 08. | reision integrals. | | ŧ | | | | |
| 61 Solution A (preferred solut | ion based on $\sqrt{2}$ -analysis | 1 | Ī | | | | |
| 62 Dispersion theory based am | | | HREND 92. | | | | |
| and MORI 07. | | | | | | | |
| 63 Solution B (worse than so included). | lution A; still acceptable | when systematic unce | rtainties are | | | | |
| 64 Using unitarity and the σ μ | oole position from CAPRI | NI 06. | _ | | | | |
| 65 This width could equally we | ell be assigned to the $f_0(1$ | 370). The authors analy | se data from | | | | |
| BOYER 90 and MARSISKI | E 90 and report strong co | rrelation with $\gamma\gamma$ width | of f ₂ (1270). | | | | |
| ⁶⁶ Supersedes MORGAN 90. | | | | | | | |
| | | | | | | | |

| fol | (500) | \ RF | FFF | ₽FN | CES |
|-----|-------|-------|------|------|-----|
| 701 | 300 | , ,,_ | 1 -1 | /LIV | CLJ |

R Garcia-Martin et al

(MADR CRAC)

GARCIA-MAR 11 PRI 107 072001

| GARCIA-MAR11 | PRL 107 072001 | R. Garcia-Martin <i>et al</i> . | (MADR, CRAC) |
|----------------|-------------------------|----------------------------------------|--------------------|
| HOFERICHTER 11 | EPJ C71 1743 | M. Hoferichter, D.R. Phillips, C. Scha | |
| MENNESSIER 11 | PL B696 40 | G. Mennessier, S. Narison, XG. Wan | g |
| MOUSSALLAM 11 | EPJ C71 1814 | B. Moussallam | |
| BATLEY 10 C | EPJ C70 635 | | N NA48/2 Collab.) |
| MENNESSIER 10 | PL B688 59 | G. Mennessier, S. Narison, XG. Wan | g |
| MAO 09 | PR D79 116008 | Y. Mao et al. | - |
| BATLEY 08A | EPJ C54 411 | J.R. Batley et al. (CER | N NA48/2 Collab.) |
| BERNABEU 08 | PRL 100 241804 | J. Bernabeu, J. Prades | (IFÍC, GRAN) |
| CAPRINI 08 | PR D77 114019 | I. Caprini | |
| MENNESSIER 08 | PL B665 205 | G. Mennessier, S. Narison, W. Ochs | |
| OLLER 08 | PL B659 201 | J.A. Oller, L. Roca, C. Schat | (MURC, UBA) |
| OLLER 08A | EPJ A37 15 | J.A. Oller, L. Roca | ` (MURC) |
| PENNINGTON 08 | EPJ C56 1 | M.R. Pennington et al. | \ / |
| UEHARA 08A | PR D78 052004 | S. Uehara et al. | (BELLE Collab.) |
| ABLIKIM 07A | PL B645 19 | M. Ablikim et al. | (BES Collab.) |
| BONVICINI 07 | PR D76 012001 | G. Bonvicini et al. | (CLEO Collab.) |
| BUGG 07A | JPG 34 151 | D.V. Bugg et al. | (CLEO COMBD.) |
| GARCIA-MAR07 | PR D76 074034 | R. Garcia-Martin, J.R. Pelaez, F.J. Yn | durain |
| MORI 07 | PR D75 051101R | T. Mori et al. | (BELLE Collab.) |
| ANISOVICH 06 | UMP A21 3615 | V.V. Anisovich | (BEEEE COMBD.) |
| CAPRINI 06 | PRL 96 132001 | | (D CID .) |
| | | I. Caprini, G. Colangelo, H. Leutwyler | (BCIP+) |
| | JPG 33 1 | WM. Yao et al. | (PDG`Collab.) |
| PENNINGTON 06 | PRL 97 011601 | M.R. Pennington | |
| ZH OU 05 | JHEP 0502 043 | Z.Y. Zhou et al. | |
| ABLIKIM 04A | PL B598 149 | M. Ablikim et al. | (BES Collab.) |
| AKHMETSHIN 04 | PL B578 285 | | rsk CMD-2 Collab.) |
| GALLEGOS 04 | PR D69 074033 | A. Gallegos et al. | |
| PELAEZ 04A | MPL A19 2879 | J.R. Pelaez | |
| BUGG 03 | PL B572 1 | D.V. Bugg | |
| PIS LAK 03 | PR D67 072004 | | BNL E865 Collab.) |
| A Iso | PR D81 119903E | | BNL E865 Collab.) |
| MURAMATSU 02 | PRL 89 251802 | H. Muramatsu et al. | (CLEO Collab.) |
| A Iso | PRL 90 059901 (erratum | | (CLEO Collab.) |
| AITALA 01B | PRL 86 770 | E.M. Aitala et al. (F | NAL E791 Collab.) |
| BLACK 01 | PR D64 014031 | D. Black et al. | |
| COLANGELO 01 | NP B603 125 | G. Colangelo, J. Gasser, H. Leytwyler | |
| ISHIDA 01 | PL B518 47 | M. Ishida et al. | |
| KOMADA 01 | PL B508 31 | T. Komada et al. | |
| PIS LAK 01 | PRL 87 221801 | S. Pislak et al. (| BNL E865 Collab.) |
| Also | PR D67 072004 | | BNL E865 Collab. |
| Also | PRL 105 019901E | S. Pislak et al. | BNL E865 Collab. |
| SUROVTSEV 01 | PR D63 054024 | Y.S. Surovtsev, D. Krupa, M. Nagy | |
| ASNER 00 | PR D61 012002 | D.M. Asner et al. | (CLEO Collab.) |
| BAI 00E | PR D62 032002 | J. Bai et al. | (BES Collab.) |
| ISHIDA 00B | PTP 104 203 | M. Ishida et al. | () |
| ALEKSEEV 99 | NP B541 3 | I.G. Alekseev et al. | |
| BOGLIONE 99 | EPJ C9 11 | M. Boglione, M.R. Pennington | |
| HANNAH 99 | PR D60 017502 | T. Hannah | |
| KAMINSKI 99 | EPJ C9 141 | R. Kaminski, L. Lesniak, B. Loiseau | (CRAC, PARIN) |
| OLLER 99 | PR D60 099906 (erratur | | (ciore, raidit) |
| OLLER 99B | NP A652 407 (erratum) | | |
| OLLER 99C | PR D60 074023 | J.A. Oller, E. Oset | |
| ALEKSEEV 98 | PAN 61 174 | I.G. Alekseev et al. | |
| | | | (CLEO Collab.) |
| | PR D58 052004 | J.P. Alexander et al. | (CLEO Collab.) |
| ANISOVICH 98B | SPU 41 419 | V.V. Anisovich et al. | |
| | Translated from UFN 168 | 401. | |

| LOCHER | 98 | EPJ C4 317 | | M.P. Locher et al. | | | | (PSI |) |
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| TROYAN | 98 | JINRRC 5-91 33 | | Yu. Troyan et al. | | | | | |
| ALDE | 97 | PL B397 350 | | D.M. Alde et al. | | | (GAMS | Collab. |) |
| DOBADO | 97 | PR D56 3057 | | A. Dobado, J.R. Pelaez | | | | | |
| ISHIDA | 97 97 B | PTP 98 1005 | | S. Ishida et al. | D 1-1- | | | A, KEK | |
| KAMINSKI Also | 97 B | PL B413 130 PTP 95 745 | | R. Kaminski, L. Lesniak, S. Ishida <i>et al.</i> | B. Lois | | | AC, IPN | |
| SVEC | 96 | PR D53 2343 | | M. Svec | | (106 | ct, Will | A, KEK (MCGI) | |
| TORNQVIST | 96 | PRL 76 1575 | | N.A. Tornqvist, M. Roos | | | | (HELS | |
| ALDE | 95 B | ZPHY C66 375 | | D.M. Alde et al. | | | (GAMS | Collab. | |
| ANISOVICH | 95 | PL B355 363 | | V.V. Anisovich et al. | | | | I, SERP | |
| JANSSEN | 95 | PR D52 2690 | | G. Janssen et al. | | (STO | | Ď, JULI | |
| ACHASOV | 94 | PR D49 5779 | | N.N. Achasov, G.N. Shes | takov | | | (NOVM) | |
| AMSLER | 94 D | PL B333 277 | | C. Amsler et al. | | (Crysta | al Barre | l`Collab. |) |
| ANISOVICH | 94 | PL B323 233 | | V.V. Anisovich et al. | | (Crysta | al Barre | l Collab. |) |
| BUTLER | 94 B | PR D49 40 | | F. Butler et al. | | | | Collab. | |
| KAMINSKI | 94 | PR D50 3145 | | R. Kaminski, L. Lesniak, | J.P. Mi | a ille t | | (CRAC+ | |
| ZOU | 94 B | PR D50 591 | | B.S. Zou, D.V. Bugg | | | | (LOQM) | |
| ZOU | 93 | PR D48 R3948 | | B.S. Zou, D.V. Bugg | | | (6511.0 | (LOQM) | |
| BEHREND | 92 01 D | ZPHY C56 381 ZPHY C52 389 | | H.J. Behrend | | | | Collab. | |
| ARMSTRONG BOYER | 91 B 90 | PR D42 1350 | | T.A. Armstrong et al. J. Boyer et al. | | | | BIRM+ Collab. | |
| MARSISKE | 90 | PR D41 3324 | | H. Marsiske et al. | | | | l Collab. | |
| MORGAN | 90 | ZPHY C48 623 | | D. Morgan, M.R. Pennin | gton | (Ciy | | , DURH | |
| AUGUSTIN | 89 | NP B320 1 | | J.E. Augustin, G. Cosme | 6.0 | | | Collab. | |
| ASTON | 88 | NP B296 493 | | D. Aston et al. | (SLA | C NAG | | c. INUS | |
| FALVARD | 88 | PR D38 2706 | | A. Falvard et al. | (| | | LALO+ | |
| COURAU | 86 | NP B271 1 | | A. Courau et al. | | | | R, LALO | |
| VANBEVEREN | 86 | ZPHY C30 615 | | E. van Beveren et al. | | | LLIN) | VI, BIEL | j . |
| CASON | 83 | PR D28 1586 | | N.M. Cason et al. | | | | M, ANL | |
| ETKIN | 82 B | PR D25 1786 | | A. Etkin et al. | (BNL, | CUNY, | | , VAND | |
| BISWAS | 81 | PRL 47 1378 | | N.N. Biswas et al. | | | (NDA | M, ANL | |
| COHEN | 80 | PR D22 2595 | | D. Cohen et al. | | | | (ANL) | |
| MUKHIN | 80 | JETPL 32 601 Translated from ZETI | ED. | K.N. Mukhin et al. | | | | (KIAE) |) |
| CORDEN | 79 | NP B157 250 | rr . | M.J. Corden et al. | | (BIRM | RHEL | TELA+ | ۱IP |
| ESTABROOKS | | PR D19 2678 | | P. Estabrooks | | (5, | | (CARL | |
| FROGGATT | 77 | NP B129 89 | | C.D. Froggatt, J.L. Peter | sen | | (GLAS | , NORD | |
| PAWLICKI | 77 | PR D15 3196 | | A.J. Pawlicki et al. | | | (| (ANL | |
| ROSSELET | 77 | PR D15 574 | | L. Rosselet et al. | | | (GEV | A, ŠACL | j |
| CASON | 76 | PRL 36 1485 | | N.M. Cason et al. | | | (NDA | M, ANL |) IJ |
| ESTABROOKS | | NP B95 322 | | P.G. Estabrooks, A.D. M | artin | | | (DURH) | |
| HYAMS | 75 | NP B100 205 | | B.D. Hyams et al. | | | | , MPIM | |
| SRINIVASAN | 75 | PR D12 681 | | V. Srinivasan <i>et al.</i> | | | (NDA | M, ANL | |
| ESTABROOKS | | NP B79 301 | | P.G. Estabrooks, A.D. M | artin | | | (DURH) | |
| GRAYER | 74 | NP B75 189 | | G. Grayer et al. | | | | MPIM | |
| APEL | 73 | PL 41B 542 Tallahassee | | W.D. Apel et al. | | | | L, PISA | |
| ES TABROOKS HYAMS | 73 | NP B64 134 | | P.G. Estabrooks et al. B.D. Hyams et al. | | | | , MPIM , MPIM | |
| OCHS | 73 | Thesis | | W. Ochs | | | | , MUNI | |
| PROTOPOP | | PR D7 1279 | | S.D. Protopopescu et al. | | | form no | (LBL | |
| BAILLON | 72 | PL 38B 555 | | P.H. Baillon et al. | | | | (SLAC | |
| BASDEVANT | 72 | PL 41B 178 | | J.L. Basdevant, C.D. Fro | ggatt, J | .L. Pete | rse n | (CERN | |
| BEIER | 72B | PRL 29 511 | | E.W. Beier et al. | | | | (PENN' | |
| BENSINGER | 71 | PL 36B 134 | | J.R. Bensinger et al. | | | | (WISC |) |
| COLTON | 71 | PR D3 2028 | | E.P. Colton et al. | | (LBL, | FNAL, | UCLA+ |) |
| ROY | 71 | PL 36B 353 | | S.M. Roy | | | | | |
| BATON | 70 | PL 33B 528 | | J.P. Baton, G. Laurens, . | J. Reign | i ie r | | (SACL | |
| WALKER | 67 | RMP 39 695 | | W.D. Walker | | | | (WISC |) |

 $\rho(770)$

 $I^G(J^{PC}) \ = \ 1^+(1^{\, - \, -})$

THE $\rho(770)$

Updated May 2012 by S. Eidelman (Novosibirsk) and G. Venanzoni (Frascati).

The determination of the parameters of the $\rho(770)$ is beset with many difficulties because of its large width. In physical region fits, the line shape does not correspond to a relativistic Breit-Wigner function with a P-wave width, but requires some additional shape parameter. This dependence on parameterization was demonstrated long ago [1]. Bose-Einstein correlations are another source of shifts in the $\rho(770)$ line shape, particularly in multiparticle final state systems [2].

The same model-dependence afflicts any other source of resonance parameters, such as the energy-dependence of the phase shift δ_1^1 , or the pole position. It is, therefore, not surprising that a study of $\rho(770)$ dominance in the decays of the η and η' reveals the need for specific dynamical effects, in addition to the $\rho(770)$ pole [3,4].

The cleanest determination of the $\rho(770)$ mass and width comes from e^+e^- annihilation and τ -lepton decays. Analysis of ALEPH [5] showed that the charged $\rho(770)$ parameters measured from τ -lepton decays are consistent with those of the neutral one determined from e^+e^- data [6]. This conclusion is qualitatively supported by the later studies of CLEO [7] and Belle [8]. However, model-independent comparison of the

$\rho(770)$

two-pion mass spectrum in τ decays, and the $e^+e^- \to \pi^+\pi^-$ cross section, gave indications of discrepancies between the overall normalization: τ data are about 3% higher than e^+e^- data [7,9]. A detailed analysis using such two-pion mass spectra from τ decays measured by OPAL [10], CLEO [7], and ALEPH [11,12], as well as recent pion form factor measurements in e^+e^- annihilation by CMD-2 [13,14], showed that the discrepancy can be as high as 10% above the ρ meson [15,16]. This discrepancy remains after recent measurements of the two-pion cross section in e^+e^- annihilation at KLOE [17,18] and SND [19,20]. This effect is not accounted for by isospin breaking [21–24], but the accuracy of its calculation may be overestimated [25,26].

This problem seems to be solved after a recent analysis in [27] which showed that after correcting the τ data for the missing ρ - γ mixing contribution, besides the other known isospin symmetry violating corrections, the $\pi\pi$ I=1 part of the hadronic vacuum polarization contribution to the muon g - 2 is fully compatible between τ based and e^+e^- based evaluations including more recent BaBar [28] and KLOE [29] data. Further proof of the consistency of the data on τ decays to two pions and e^+e^- annihilation is given by the global fit of the whole set of the ρ , ω , and ϕ decays, taking into account mixing effects in the hidden local symmetry model [30].

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ρ(770) MASS

We no longer list S-wave Breit-Wigner fits, or data with high combinatorial background.

| MELLE | TDA I | ONLY | / _+ | |
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| NEU I KAL UNLI, | C. C | | | | |
|---------------------------------------|------------|-------------------------|----------|---------|-------------------------------------------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 775.49 ± 0.34 OUR AV | /ERAGE | | | | |
| $775.97 \pm 0.46 \pm 0.70$ | 900k | ¹ AKHMETSHIN | l 07 | | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 774.6 $\pm 0.4 \pm 0.5$ | 800k | ^{2,3} ACHASOV | 06 | SND | $e^+e^- \rightarrow \pi^+\pi^-$ |
| $775.65 \pm 0.64 \pm 0.50$ | 114k | 4,5 AKHMETSHIN | l 04 | CMD2 | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 775.9 ± 0.5 ± 0.5 | 1.98M | ⁶ ALOISIO | 03 | KLOE | $1.02 e^{+} e^{-}_{\pi^{+} \pi^{-} \pi^{0}}$ |
| 775.8 ±0.9 ±2.0 | 500k | ⁶ ACHASOV | 02 | SND | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 775.9 ±1.1 | | ⁷ BARKOV | 85 | OLYA | $e^{+\stackrel{\pi}{e}^{-}\stackrel{\pi}{\longrightarrow}\stackrel{\pi}{\pi}^{+}\pi^{-}}$ |
| ● ● We do not use | the follow | ing data for average: | s, fits, | limits, | etc. • • • |
| 775.8 ± 0.5 ± 0.3 | 1.98M | ⁸ ALOISIO | 03 | KLOE | $1.02 e^{+}_{\pi^{+}\pi^{-}\pi^{0}} \rightarrow$ |
| 775.9 ±0.6 ±0.5 | 1.98M | ⁹ ALOISIO | 03 | KLOE | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 775.0 ± 0.6 ± 1.1 | 500k | ¹⁰ ACHASOV | 02 | SND | $1.02 \begin{array}{c} r + \pi & \pi \\ e^{+} e^{-} & 0 \end{array}$ |
| 775.1 ±0.7 ±5.3 | | ¹¹ BENAYOUN | 98 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$, |
| 770.5 ±1.9 ±5.1 | | ¹² GARDNER | 98 | RVUE | $ \mu^{+} \mu^{-} $ 0.28-0.92 $e^{+} e^{-} \rightarrow$ |
| 764.1 ±0.7 | | ¹³ O'CONNELL | 97 | RVUE | $e^{+}e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ |
| 757.5 ± 1.5 | | ¹⁴ BERNICHA | 94 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 768 ±1 | | ¹⁵ GESHKEN | 89 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$ |

CHARGED ONLY, τ DECAYS and e^+e^-

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------|-------------------|---------------------------|--------|-------------|---------|-------------------------------------------------------------------------------------------|
| 775.11 ± 0.34 OUR | | | | | | |
| 774.6 $\pm 0.2 \pm 0.5$ | | | 80 | BELL | \pm | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| 775.5 ± 0.7 | 17 | ^{7,18} SCHAEL | 05 C | ALEP | | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| 775.5 $\pm 0.5 \pm 0.4$ | 1.98M | ⁶ ALOISIO | 03 | KLOE | | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 775.1 ± 1.1 ± 0.5 | 87k ¹⁹ | ^{9,20} ANDERSON | 00A | CLE2 | | τ^{-} \rightarrow π^{-} π^{0} ν_{τ} |
| • • • We do not ι | ise the fol | lowing data for ave | rages, | , fits, lim | its, et | C. • • • |
| 774.8 $\pm 0.6 \pm 0.4$ | 1.98 M | ⁹ ALOISIO | 03 | KLOE | - | $^{1.02}_{00000000000000000000000000000000000$ |
| 776.3 $\pm 0.6 \pm 0.7$ | 1.98 M | ⁹ ALOISIO | 03 | KLOE | + | $1.02 e^{+} e^{-} \longrightarrow \pi^{+} \pi^{-} \pi^{0}$ |
| 773.9 $\pm 2.0 ^{+ 0.3}_{- 1.0}$ | | ²¹ SANZ-CILLER | O03 | RVUE | | $\tau^- \to \ \pi^- \pi^0 \nu_\tau$ |
| $774.5\ \pm0.7\ \pm1.5$ | 5 00k | ⁶ ACHASOV | 02 | SND | \pm | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $775.1\ \pm0.5$ | | ²² PICH | 01 | RVUE | | $\tau^{-} \stackrel{\pi^{+}\pi^{-}\pi^{-}\pi^{0}}{\rightarrow} \pi^{-}\pi^{0} \nu_{\tau}$ |

MIXED CHARGES, OTHER REACTIONS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|---------------|------|---------------------|-----|------|-----|----------------------------------------------------------------------------------------------|
| 763.0±0.3±1.2 | 600k | ²³ ABELE | 99E | CBAR | 0± | $ \begin{array}{c} 0.0 \ \overline{p} p \rightarrow \\ \pi^{+} \pi^{-} \pi^{0} \end{array} $ |

CHARGED ONLY, HADROPRODUCED

| VALUE (MEV) | EVIS | DOCUMENT ID | | TECN | CHG | COMMENT | | | |
|------------------------|-------|-----------------------|----|------|-----|-------------------------------------------------------------------------------|--|--|--|
| 766.5 ±1.1 OUR AVERAGE | | | | | | | | | |
| 763.7 ± 3.2 | | ABELE | 97 | CBAR | | $\overline{p} n \rightarrow \pi^- \pi^0 \pi^0$ | | | |
| 768 ±9 | | AGUILAR | 91 | EHS | | 400 pp | | | |
| 767 ±3 | 2935 | ²⁴ CAPRARO | 87 | SPEC | _ | 200 π^- Cu \rightarrow | | | |
| 761 ±5 | 967 | ²⁴ CAPRARO | 87 | SPEC | - | $\pi^-\pi^0$ Cu $200 \pi^-$ Pb \rightarrow $\pi^-\pi^0$ Pb | | | |
| 771 ± 4 | | HUSTON | 86 | SPEC | + | $\begin{array}{c} 202 \pi^{+} A \rightarrow \\ \pi^{+} \pi^{0} A \end{array}$ | | | |
| 766 ±7 | 65 00 | 25 BYERLY | 73 | OSPK | _ | $5 \pi^{-} p$ | | | |
| 766.8 ± 1.5 | 9650 | ²⁶ PISUT | 68 | RVUE | _ | 1.7-3.2 $\pi^- p$, $t < 10$ | | | |
| 767 ±6 | 900 | ²⁴ EISNER | 67 | HBC | _ | 4.2 $\pi^- p$, $t < 10$ | | | |

NEUTRAL ONLY, PHOTOPRODUCED

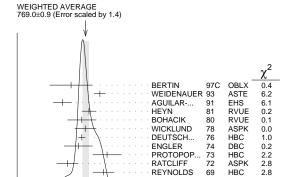
| VALUE (MeV) | EVIS | DO CUMENT ID | | IECN | CHG | COMMENT |
|---------------------|---------|------------------------|-----|------|-----|--------------------------------|
| 768.5 ± 1.1 OUR | AVERAGE | | | | | |
| 770 \pm 2 \pm 1 | 79k | ²⁷ BREITWEG | 98B | ZEUS | 0 | 50-100 γp |
| 767.6± 2.7 | | BARTALUCCI | 78 | CNTR | 0 | $\gamma p \rightarrow e^+e^-p$ |
| 775 ± 5 | | GLADDING | 73 | CNTR | 0 | 2.9-4.7 γp |
| 767 ± 4 | 1930 | BALLAM | 72 | HBC | 0 | 2.8 γp |
| | | | | | | |

| 7 | 70 | ± 4 | 2430 | BALLAM | 72 | HBC | 0 | $4.7 \gamma p$ |
|---|------|-------------------------|--------------------|-----------------------|--------|-----------|-------|----------------------------------|
| 7 | 65 | ± 10 | | ALVENSLEB | 70 | CNTR | 0 | γA , $t < 0.01$ |
| 7 | 67.7 | 7 ± 1.9 | 140k | BIGGS | 70 | CNTR | 0 | $<$ 4.1 γ C \rightarrow |
| | | | | | | | | $\pi^{+}\pi^{-}C$ |
| 7 | 65 | \pm 5 | 4000 | ASBURY | 67B | CNTR | 0 | γ + Pb |
| • | • | We do | not use the follow | wing data for ave | rages, | fits, lim | iits, | etc. • • • |
| 7 | 71 | ± 2 | 79k 2 | ⁸ BREITWEG | 98B | ZEUS | 0 | 50-100 γp |

NEUTRAL ONLY, OTHER REACTIONS

| VALUE (MeV) | EVIS | | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------|---------------|-----|-------------------|--------|-----------|----------|-----------------------------------------------------|
| 769.0±0.9 OUR A | VERAGE | Er | ror includes scal | e fact | or of 1.4 | . See | the ideogram below. |
| 765 ±6 | | | BERTIN | 97c | OBLX | | $0.0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0$ |
| 773 ±1.6 | | | WEIDENAUER | 93 | ASTE | | $\overline{p}p \rightarrow \pi^{+}\pi^{-}\omega$ |
| 762.6 ± 2.6 | | | | 91 | EHS | | 400 pp |
| 770 ±2 | | 29 | HEYN | 81 | RVUE | | Pion form factor |
| 768 ±4 | 30, | ,31 | | 80 | RVUE | 0 | |
| 769 ±3 | | 25 | WICKLUND | 78 | A SP K | 0 | 3,4,6 π^{\pm} N |
| 768 ±1 | 76000 | | DEUTSCH | 76 | HBC | 0 | 16 $\pi^+ p$ |
| 767 ±4 | 4100 | | | 74 | DBC | 0 | $6 \pi^+ n \rightarrow \pi^+ \pi^- p$ |
| 775 ±4 | 32000 | 30 | PROTOP OP | 73 | HBC | 0 | 7.1 $\pi^+ p$, $t < 0.4$ |
| 764 ±3 | 6800 | | RATCLIFF | 72 | A SP K | 0 | 15 $\pi^- p$, $t < 0.3$ |
| 774 ±3 | 1700 | | | 69 | HBC | 0 | 2.26 π ⁻ p |
| $769.2\!\pm\!1.5$ | 13300 | 32 | PISUT | 68 | RVUE | 0 | $1.7-3.2 \pi^- p$, $t < 10$ |
| ● ● We do not | use the follo | owi | ng data for aver | ages, | fits, lim | its, etc | . • • • |
| 773.5 ± 2.5 | | 33 | COLANGELO | 01 | RVUE | | $\pi\pi \to \pi\pi$ |
| $762.3 \pm 0.5 \pm 1.2$ | | | | 99E | CBAR | 0 | $0.0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0$ |
| 777 ±2 | | | | 97 | E665 | | 470 $\mu p \rightarrow \mu XB$ |
| 770 ±2 | | | BOGOLYUB | 97 | MIRA | | $32 \overline{p}p \rightarrow \pi^+ \pi^- X$ |
| 768 ±8 | | 36 | BOGOLYUB | 97 | MIRA | | 32 $pp \rightarrow \pi^+\pi^-X$ |
| 761.1 ± 2.9 | | | | 89 | RVUE | | π form factor |
| 777.4 ± 2.0 | | 37 | CHABAUD | 83 | ASPK | 0 | $17 \pi^- p$ polarized |
| $\textbf{769.5} \pm \textbf{0.7}$ | | | | 79 | RVUE | 0 | |
| 770 ±9 | | 31 | ESTABROOKS | 74 | RVUE | 0 | 17 $\pi^- p \to \pi^+ \pi^- n$ |
| 773.5 ± 1.7 | 11200 | 24 | JACOBS | 72 | HBC | 0 | 2.8 π ⁻ p |
| 775 ±3 | 2250 | | HYAMS | 68 | OSPK | 0 | 11.2 $\pi^- p$ |

COMMENT



PISUT

790

800

RVUE

(Confidence Level = 0.023)

0.0 22 1

760 ho(770) 0 mass (MeV)

¹ A combined fit of AKHMETSHIN 07, AULCHENKO 06, and AULCHENKO 05.

780

750

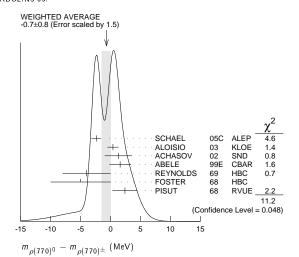
- 3 A fit of the SND data from 400 to 1000 MeV using parameters of the $\rho(1450)$ and $\rho(1700)$ from a fit of the data of BARKOV 85, BISELLO 89 and ANDERSON 00A. 4 Using the GOUNARIS 68 parametrization with the complex phase of the $\rho\text{-}\omega$ interference.
- ⁵ Update of A KH MET SHIN 02.
- 6 Assuming $m_{\rho^+}=m_{\rho^-}$, $\Gamma_{\rho^+}=\Gamma_{\rho^-}$. 7 From the GOUNARIS 68 parametrization of the pion form factor.
- ⁸ Assuming $m_{\rho^+}=m_{\rho^-}=m_{\rho^0}$, $\Gamma_{\rho^+}=\Gamma_{\rho^-}=\Gamma_{\rho^0}$.
- Without limitations on masses and widths.
- 10 Assuming $m_{\rho^0}=m_{\rho^\pm}$, $g_{\rho^0\,\pi\,\pi}=g_{\rho^\pm\,\pi\,\pi}$
- 11 Using the data of BARKOV 85 in the hidden local symmetry model. 12 From the fit to $e^+e^- \rightarrow \pi^+\pi^-$ data from the compilations of HEYN 81 and BARKOV 85, including the GOUNARIS 68 parametrization of the pion form factor. 13 A fit of BARKOV 85 data assuming the direct $\omega \pi \pi$ coupling.
- 14 Applying the S-matrix formalism to the BARKOV 85 data.
- 15 Includes BARKOV 85 data. Model-dependent width definition.
- $^{16}|F_{\pi}(0)|^2$ fixed to 1.
- $17 \frac{1}{\text{From the GOUNARIS}}$ 68 parametrization of the pion form factor.
- $^{18}\, ext{The}$ error combines statistical and systematic uncertainties. Supersedes BARATE 97M.
- $^{19}
 ho(1700)$ mass and width fixed at 1700 MeV and 235 MeV respectively.
- 20 From the GOUNARIS 68 parametrization of the pion form factor. The second error is a model error taking into account different parametrizations of the pion form factor.
- 21 Using the data of <code>BARATE</code> 97M and the effective chiral Lagrangian.
- $^{22}\mathrm{From}$ a fit of the model-independent parameterization of the pion form factor to the data of BARATE 97M.

- 23 Assuming the equality of ρ^+ and ρ^- masses and widths. 24 Mass errors enlarged by us to $\Gamma/\sqrt{N};$ see the note with the $K^*(892)$ mass.
- 25 Phase shift analysis. Systematic errors added corresponding to spread of different fits.
- 26 From fit of 3-parameter relativistic P-wave Breit-Wigner to total mass distribution. Includes BATON 68, MILLER 67B, ALFF-STEINBERGER 66, HAGOPIAN 66, HAGOPIAN 66B, JACOBS 66B, JAMES 66, WEST 66, BLIEDEN 65 and CARMONY 64.
- 27 From the parametrization according to SOEDING 66.
- $^{\mbox{\footnotesize 28}}\,\mbox{From the parametrization according to ROSS 66}.$
- $^{29}\,\mathrm{HEYN}$ 81 includes all spacelike and timelike F_π values until 1978.
- $^{30}\,\mathrm{From}$ pole extrapolation.
- 32 From poise extrapolation.
 32 From phase shift analysis of GRAYER 74 data.
 32 Includes MALAMUD 69, ARMENISE 68, BACON 67, HUWE 67, MILLER 67B, ALFF-STEINBERGER 66, HAGOPIAN 66, HAGOPIAN 66B, JACOBS 66B, JAMES 66, WEST 66, GOLDHABER 64, ABOLINS 63.
- 33 Breit-Wigner mass from a phase-shift analysis of HYAMS 73 and PROTOPOPESCU 73
- data. 34 Using relativistic Breit-Wigner and taking into account $\rho ext{-}\omega$ interference.
- 35 Systematic errors not evaluated.
- 36 Systematic effects not studied.
- 37 Systematic enects not study during.
 37 From fit of 3-parameter relativistic Breit-Wigner to helicity-zero part of P-wave intensity.
 CHABAUD 83 includes data of GRAYER 74.

$m_{\rho(770)^0} - m_{\rho(770)^{\pm}}$

| | | | - | | |
|-----------------------|---------|------------------------|--------|----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN CHG | COMMENT |
| -0.7±0.8 OUR AVER | AGE Err | or includes scale fac | ctor o | f 1.5. See the | ideogram below. |
| -2.4 ± 0.8 | | ³⁸ SCHAEL | 05 C | ALEP | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| $0.4 \pm 0.7 \pm 0.6$ | 1.98M | ³⁹ ALOISIO | 03 | KLOE | $1.02 e^{+} e^{-} \rightarrow$ |
| $1.3 \pm 1.1 \pm 2.0$ | 500k | ³⁹ ACHASOV | 02 | SND | $ \begin{array}{c} 1.02 \ e^{+} e^{-} \longrightarrow \\ \pi^{+} \pi^{-} \pi^{0} \end{array} $ $ \begin{array}{c} 1.02 \ e^{+} e^{-} \longrightarrow \\ \pi^{+} \pi^{-} \pi^{0} \end{array} $ |
| $1.6 \pm 0.6 \pm 1.7$ | 600k | ABELE | 99E | CBAR $0\pm$ | $0.0 \overline{\rho} \rho \rightarrow$ |
| -4 ±4 | 3000 | ⁴⁰ REYNOLDS | 69 | HB C −0 | $_{\pi^{+}\pi^{-}\pi^{0}}^{+\pi^{-}\pi^{0}}$ 2.26 $_{\pi^{-}p}$ |
| -5 ± 5 | 3600 | ⁴⁰ FOSTER | 68 | HBC ± 0 | 0.0 p p |
| 2.4 ± 2.1 | 22950 | ⁴¹ PISUT | 68 | RVUE | $\pi N \rightarrow \rho N$ |
| | | | | | |

- 38 From the combined fit of the au^- data from ANDERSON 00A and SCHAEL 05C and $e^+\,e^-$ data from the compilation of BARKOV 85, AKHMETSHIN 04, and ALOISIO 05. Supersedes BARATE 97M.
- Superseues particles m_{ρ} , m_{ρ} ,
- ATION quotee masses of chaged and neutral modes.
 AI Includes MALAMUD 69, ARMENISE 68, BATON 68, BACON 67, HUWE 67, MILLER 67B, ALFF-STEINBERGER 66, HAGOPIAN 66, HAGOPIAN 66B, JACOBS 66B, JAMES 66, WEST 66, BLIEDEN 65, CARMONY 64, GOLDHABER 64, ABOLINS 63.



$m_{\rho(770)^+} - m_{\rho(770)^-}$

| VALUE (MeV) | EVTS | DO CUMENT I | D | TECN | COMMENT | |
|---------------------------------|---------------|-----------------------|-----------|-------------|--------------------------|----------------------------|
| ullet $ullet$ $ullet$ We do not | use the follo | wing data for av | erages, 1 | fits, limit | s, etc. • • • | |
| $1.5 \pm 0.8 \pm 0.7$ | 1.98M | ⁴² ALOISIO | 03 | KLOE | 1.02 $e^+e^ \rightarrow$ | $_{\pi^{+}\pi^{-}\pi^{0}}$ |
| 42 Without limita | tions on ma | sses and widths. | | | | |

ρ (770) RANGE PARAMETER

The range parameter R enters an energy-dependent correction to the width, of the form $(1+q_r^2\ R^2)\ /\ (1+q^2\ R^2)$, where q is the momentum of one of the pions in the $\pi\pi$ rest system. At resonance, q

| VALUE (GeV ⁻¹) | DO CUMENT ID | TECN | CHG | COMMENT | |
|----------------------------|--------------|------|------|---------|----------------------------|
| 5.3+0.9 5.7 | CHABAUD | 83 | ASPK | 0 | 17 π ⁻ p polar- |

 $\rho(770)$

ρ(770) WIDTH

We no longer list S-wave Breit-Wigner fits, or data with high combinatorial

NEUTRAL ONLY, e+e-

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN CHO | COMMENT | | | | |
|------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------|-----|----------|-------------------------------------------------------------------------------------|--|--|--|--|
| 146.2 ±0.7 OUR AVERAGE Error includes scale factor of 1.1. | | | | | | | | | |
| $145.98 \pm 0.75 \pm 0.50$ | 900k | 43 AKHMETSHIN | 07 | | $e^+e^- \rightarrow \pi^+\pi^-$ | | | | |
| $146.1 \ \pm 0.8 \ \pm 1.5$ | 800k ⁴⁴ | ^{,45} ACHASOV | 06 | SND | $e^+e^- \rightarrow \pi^+\pi^-$ | | | | |
| $143.85\pm1.33\pm0.80$ | | ^{,47} AKHMETSHIN | 04 | CMD2 | $e^+e^- \rightarrow \pi^+\pi^-$ | | | | |
| $147.3 \ \pm 1.5 \ \pm 0.7$ | 1.98M | ⁴⁸ ALOISIO | 03 | KLOE | $1.02 e^{+}e^{-}_{\pi^{+}\pi^{-}\pi^{0}}$ | | | | |
| $151.1 \ \pm 2.6 \ \pm 3.0$ | 500k | ⁴⁸ ACHASOV | 02 | SND 0 | $1.02 e^{+}_{\pi} e^{-}_{\pi} 0^{-}$ | | | | |
| 150.5 ± 3.0 | | ⁴⁹ BARKOV | 85 | OLYA 0 | $e^{+\stackrel{\pi}{e}^-\stackrel{\pi}{\longrightarrow}\stackrel{\pi}{\pi}^+\pi^-}$ | | | | |
| • • • We do not use | • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | | |
| $143.9 \ \pm 1.3 \ \pm 1.1$ | 1.98M | ⁵⁰ ALOISIO | 03 | KLOE | $^{1.02}_{\pi^{+}\pi^{-}\pi^{0}}$ | | | | |
| $147.4 \ \pm 1.5 \ \pm 0.7$ | 1.98M | ⁵¹ ALOISIO | 03 | KLOE | $1.02 \stackrel{\pi}{e} + \stackrel{\pi}{e} - \stackrel{\pi}{\pi} 0$ | | | | |
| $149.8 \ \pm 2.2 \ \pm 2.0$ | 500k | ⁵² ACHASOV | 02 | SND | $1.02 e^+e^- \rightarrow$ | | | | |
| $147.9 \ \pm 1.5 \ \pm 7.5$ | | ⁵³ BENAYOUN | 98 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$, | | | | |
| 153.5 ± 1.3 ± 4.6 | | ⁵⁴ GARDNER | 98 | RVUE | $\mu^{+} \mu^{-}$ 0.28-0.92 $e^{+} e^{-} \rightarrow$ | | | | |
| 145.0 ±1.7 | | ⁵⁵ O'CONNELL | 97 | RVUE | $e^{+}e^{+}e^{-} \xrightarrow{\pi^{+}\pi^{-}} \pi^{+}\pi^{-}$ | | | | |
| 142.5 ± 3.5 | | ⁵⁶ BERNICHA | 94 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$ | | | | |
| 120 11 | | 57 сеением | 9.0 | DV/HE | a+a | | | | |

CHARGED ONLY, τ DECAYS and e^+e^-

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|------------------------------------|---------------------|-----------------------|--------|-------------|---------|-------------------------------------------------------------------------------------------|
| 149.1±0.8 OUR F | IT | | | | | |
| 149.1±0.8 OUR A | VERAGE | | | | | |
| $148.1 \pm 0.4 \pm 1.7$ | | ⁹ FUJIKAWA | 80 | BELL | \pm | $	au^- ightarrow ~\pi^- \pi^0 u_	au$ |
| 149.0 ± 1.2 | | ⁰ SCHAEL | 05 C | ALEP | | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| $149.9\!\pm\!2.3\!\pm\!2.0$ | 500k ⁴ | ¹⁸ ACHASOV | 02 | SND | \pm | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $150.4 \pm 1.4 \pm 1.4$ | 87k ^{61,6} | ² ANDERSON | 00A | CLE2 | | $\tau^{-} \xrightarrow{\pi^{+}} \pi^{-} \pi^{0} \nu_{\tau}$ |
| | use the follow | wing data for ave | rages, | , fits, lim | its, et | C. • • • |
| $143.7 \pm 1.3 \pm 1.2$ | 1.98M ⁴ | ¹⁸ ALOISIO | 03 | KLOE | \pm | $1.02 \stackrel{e^+e^-}{_{-}} \stackrel{\longrightarrow}{_{0}}$ |
| $142.9\!\pm\!1.3\!\pm\!1.4$ | 1.98M ⁵ | ¹ ALOISIO | 03 | KLOE | _ | $ \frac{1.02 e^{+} e^{-}}{\pi^{+} \pi^{-} \pi^{0}} $ $ 1.02 e^{+} e^{-} \xrightarrow{0} $ |
| $144.7\!\pm\!1.4\!\pm\!1.2$ | 1.98M ⁵ | ¹ ALOISIO | 03 | KLOE | + | $1.02 \stackrel{\pi}{e} + \stackrel{\pi}{e} - \stackrel{\pi}{\pi}^{0}$ |
| $150.2 \pm 2.0 {}^{+ 0.7}_{- 1.6}$ | 6 | 3 SANZ-CILLER | O03 | RVUE | | $\tau^- \to \ \pi^- \pi^0 \nu_\tau$ |
| $150.9\!\pm\!2.2\!\pm\!2.0$ | 500k ⁵ | ² ACHASOV | 02 | SND | | $1.02 e^{+}e^{-}_{\pi^{+}\pi^{-}\pi^{0}}$ |

MIXED CHARGES, OTHER REACTIONS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------------|------|--------------|-----|------|-----|----------------------------------|
| 149.5 ±1.3 | 600k | 64 ABELE | 99E | CBAR | 0± | $0.0 \overline{p} p \rightarrow$ |
| | | | | | | $_{\pi}+_{\pi}{\pi}0$ |

CHARGED ONLY, HADROPRODUCED

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN CH | G COMMENT |
|-----------------|--------|-----------------------|----|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| 150.2± 2.4 OUR | FIT | · | | | |
| 150.2± 2.4 OUR | AVERAG | E | | | |
| 152.8 ± 4.3 | | ABELE | 97 | CBAR | $\overline{p}n \rightarrow \pi^- \pi^0 \pi^0$ |
| 155 ±11 | 2935 | ⁶⁵ CAPRARO | 87 | SPEC - | $^{200}_{\pi^-\pi^0}C_{\text{U}}^{\text{U}} \rightarrow$ |
| $154\ \pm20$ | 967 | ⁶⁵ CAPRARO | 87 | SPEC - | $200 \frac{\pi^{-}}{\pi^{-}} \frac{Pb}{\pi^{0}} \rightarrow \frac{1}{\pi^{0}} \frac{Pb}{Pb}$ |
| $150\ \pm\ 5$ | | HUSTON | 86 | SPEC + | $202 \frac{\pi}{\pi^+} \stackrel{\pi}{A} \stackrel{\Gamma}{A} \stackrel{\Gamma}{\rightarrow} \stackrel{\Gamma}{\rightarrow$ |
| 146 ±12 | 6500 | ⁶⁶ BYERLY | 73 | OSPK - | 5 π ⁻ ρ |
| 148.2 ± 4.1 | 9650 | ⁶⁷ PISUT | 68 | RVUE - | 1.7-3.2 $\pi^- p$, $t < 10$ |
| 146 ± 13 | 900 | EISNER | 67 | нвс – | 4.2 $\pi^- p$, $t < 10$ |

NEUTRAL ONLY. PHOTOPRODUCED

| | , | | | | | |
|---------------------------------|---------------|------------------------|--------|-----------|---------|----------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
| 150.7± 2.9 OUR | | | | | | |
| $146 \ \pm \ 3 \ \pm 13$ | 79k | ⁶⁸ BREITWEG | 98B | ZEUS | 0 | 50-100 γp |
| 150.9 ± 3.0 | | BARTALUCCI | 78 | CNTR | 0 | $\gamma p \rightarrow e^+e^-p$ |
| ullet $ullet$ $ullet$ We do not | use the follo | wing data for ave | rages, | fits, lim | its, et | S. • • • |
| 138 ± 3 | 79k | ⁶⁹ BREITWEG | 98B | ZEUS | 0 | 50-100 γp |
| 147 ± 11 | | GLADDING | 73 | CNTR | 0 | 2.9-4.7 γp |
| 155 ± 12 | 2430 | BALLAM | 72 | HBC | 0 | 4.7 γp |
| 145 ±13 | 1930 | BALLAM | 72 | HBC | 0 | 2.8 γp |
| 140 ± 5 | | ALVENSLEB | 70 | CNTR | 0 | γ A, $t < 0.01$ |
| 146.1 ± 2.9 | 140k | BIGGS | 70 | CNTR | 0 | $<$ 4.1 γ C \rightarrow |
| | | | | | | $\pi^{+}\pi^{-}C$ |
| 160 ± 10 | | LANZEROTTI | 68 | CNTR | 0 | γp |
| 130 ± 5 | 4000 | ASBURY | 67B | CNTR | 0 | γ + Pb |

NEUTRAL ONLY, OTHER REACTIONS

| VALUE | (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------|----------------|------------|--------------------------|--------|-----------|----------|-----------------------------------------------------|
| 150.9 | ± 1.7 OUR A | WERAGE | Error includes sca | ile fa | ctor of 1 | .1. | |
| 122 | ± 20 | | BERTIN | 97 c | OBLX | | $0.0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0$ |
| 145.7 | ± 5.3 | | WEIDENAUER | 93 | ASTE | | $\overline{p}p \rightarrow \pi^{+}\pi^{-}\omega$ |
| 144.9 | ± 3.7 | | DUBNICKA | 89 | RVUE | | π form factor |
| 148 | ± 6 | 70 | | 80 | RVUE | 0 | |
| 152 | ± 9 | | ⁶⁶ WICKLUND | 78 | ASPK | 0 | 3,4,6 $\pi^{\pm} p N$ |
| 154 | ± 2 | 76000 | DEUTSCH | 76 | HBC | 0 | 16 $\pi^+ p$ |
| 157 | ± 8 | 6800 | RATCLIFF | 72 | ASPK | 0 | 15 $\pi^- p$, $t < 0.3$ |
| 143 | ± 8 | 1700 | REYNOLDS | 69 | HBC | 0 | 2.26 π ⁻ p |
| • • • | • We do not u | se the fol | lowing data for aver | ages, | fits, lim | its, etc | . • • • |
| 147.0 | ± 2.5 | 600k | ⁷² ABELE | 99E | CBAR | 0 | $0.0 \overline{p}p \rightarrow \pi^+ \pi^- \pi^0$ |
| 146 | ± 3 | 4943 | ⁷³ ADAMS | 97 | E665 | | 470 $\mu p \rightarrow \mu XB$ |
| 160.0 | + 4.1 - 4.0 | | ⁷⁴ CHABAUD | 83 | ASPK | 0 | $17~\pi^- p$ polarized |
| 155 | ± 1 | | | 81 | RVUE | 0 | π form factor |
| 148.0 | ± 1.3 | 70 | ^{),71} LANG | 79 | RVUE | 0 | |
| 146 | ± 14 | 4100 | ENGLER | 74 | DBC | 0 | $6 \pi^+ n \rightarrow \pi^+ \pi^- \rho$ |
| 143 | ± 13 | | ⁷¹ ESTABROOKS | 74 | RVUE | 0 | $17 \pi^- \rho \rightarrow \pi^+ \pi^- n$ |
| 160 | ± 10 | 32000 | ⁷⁰ PROTOPOP | 73 | HBC | 0 | 7.1 $\pi^+ p$, $t < 0.4$ |
| 145 | ± 12 | 2250 | ⁶⁵ HYAMS | 68 | OSPK | 0 | 11.2 π ⁻ p |
| 163 | ± 15 | 13300 | ⁷⁶ PISUT | 68 | RVUE | 0 | 1.7-3.2 $\pi^- p$, $t < 10$ |
| 42 | | | | | | | |

⁴³ A combined fit of AKHMETSHIN 07, AULCHENKO 06, and AULCHENKO 05.

50 Assuming
$$m_{\rho^+}=m_{\rho^-}=m_{\rho^0}$$
 , $\Gamma_{\rho^+}=\Gamma_{\rho^-}=\Gamma_{\rho^0}$.

$\Gamma_{\rho(770)^0} - \Gamma_{\rho(770)^{\pm}}$

| VALUE | EVTS | <u>DO CUMENT II</u> | <u>D</u> | TECN | COMMENT |
|-----------------------|-----------|-----------------------|-----------|------|---------------------------------------------|
| 0.3±1.3 OUR AVE | RAGE Erro | or includes scale | factor of | 1.4. | |
| -0.2 ± 1.0 | | ⁷⁷ SCHAEL | 05 c | ALEP | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| $3.6 \pm 1.8 \pm 1.7$ | 1.98M | ⁷⁸ ALOISIO | 03 | KLOE | $1.02 e^{+}e^{-}_{\pi^{+}\pi^{-}\pi^{0}}$ |
| | | | | | $_{\pi^{+}\pi^{-}\pi^{0}}$ |

$\Gamma_{c/770)+} - \Gamma_{c/770)-}$

| $\rho(II0)$. | <i>P</i> (110) | | | | | |
|-----------------|----------------|--------------|----|------|--------------------------------------|--|
| VALUE | EVTS | DO CUMENT I | ID | TECN | COMMENT | |
| 1.8 ± 2.0 ± 0.5 | 1.98N | 1 79 ALOISIO | 03 | KLOE | 1.02 e ⁺ e [−] → | |

 $^{^{77}}$ From the combined fit of the τ^- data from ANDERSON 00A and SCHAEL 05c and e^+e^- data from the compilation of BARKOV 85, AKH METSHIN 04, and ALOISIO 05. Supersedes BARATE 97M.

⁴⁴ Supersedes ACHASOV 05A.

⁴⁵ A fit of the SND data from 400 to 1000 MeV using parameters of the $\rho(1450)$ and $\rho(1700)$ from a fit of the data of BARKOV 85, BISELLO 89 and ANDERSON 00A.

 $^{^{46}}$ Using the GOUNARIS 68 parametrization with the complex phase of the ho- ω interference.

⁴⁷ From a fit in the energy range 0.61 to 0.96 GeV. Update of AKHMETSHIN 02.

⁴⁸ Assuming $m_{\rho^+}=m_{\rho^-}$, $\Gamma_{\rho^+}=\Gamma_{\rho^-}$.

⁴⁹ From the GOUNARIS 68 parametrization of the pion form factor.

⁵¹ Without limitations on masses and widths.

⁵² Assuming $m_{\rho^0}=m_{\rho^\pm}$, $g_{\rho^0\,\pi\pi}=g_{\rho^\pm\pi\pi}$

 $^{^{53}}$ Using the data of BARKOV 85 in the hidden local symmetry model. 54 From the fit to $e^+e^- \rightarrow \pi^+\pi^-$ data from the compilations of HEYN 81 and BARKOV 85, including the GOUNARIS 68 parametrization of the pion form factor.

 $^{^{55}}$ A fit of BARKOV 85 data assuming the direct $\omega\pi\pi$ coupling.

 $^{^{56}\,\}mathrm{Applying}$ the S-matrix formalism to the BARKOV 85 data.

⁵⁷ Includes BARKOV 85 data. Model-dependent width definition. $^{58}|F_\pi(0)|^2 \text{ fixed to } 1.$

⁵⁹ From the GOUNARIS 68 parametrization of the pion form factor.

 $^{^{60}}$ The error combines statistical and systematic uncertainties. Supersedes BARATE 97M.

 $^{^{61}\,}ho(1700)$ mass and width fixed at 1700 MeV and 235 MeV respectively.

⁶² From the GOUNARIS 68 parametrization of the pion form factor. The second error is a model error taking into account different parametrizations of the pion form factor.

 $^{^{63}\,\}text{Using}$ the data of BARATE 97M and the effective chiral Lagrangian.

⁶⁴ Assuming the equality of ρ^+ and ρ^- masses and widths.

⁶⁵ Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.

⁶⁶ Phase shift analysis. Systematic errors added corresponding to spread of different fits.

⁶⁷ From fit of 3-parameter relativistic P-wave Breit-Wigner to total mass distribution. Includes BATON 68, MILLER 67B, ALFF-STEINBERGER 66, HAGOPIAN 66, HAGOPIAN 66B, JACOBS 66B, JAMES 66, WEST 66, BLIEDEN 65 and CARMONY 64.

⁶⁸ From the parametrization according to SOEDING 66.

⁶⁹ From the parametrization according to ROSS 66.

⁷⁰ From pole extrapolation.

⁷¹ From phase shift analysis of GRAYER 74 data. 72 Using relativistic Breit-Wigner and taking into account ρ - ω interference.

⁷³ Systematic errors not evaluated.

⁷⁴ From fit of 3-parameter relativistic Breit-Wigner to helicity-zero part of P-wave intensity.

CHABAUD 83 includes data of GRAYER 74. 75 HEYN 81 includes all spacelike and timelike F_π values until 1978.

⁷⁶ Includes MALAMUD 69, ARMENISE 68, BACON 67, HUWE 67, MILLER 67B, ALFF-STEINBERGER 66, HAGOPIAN 66, HAGOPIAN 66B, JACOBS 66B, JAMES 66, WEST 66, GOLDHABER 64, ABOLINS 63.

 $^{^{78} \}operatorname{Assuming} \ m_{\rho^+} = m_{\rho^-}, \ \Gamma_{\rho^+} = \Gamma_{\rho^-}.$

⁷⁹ Without limitations on masses and widths.

| | | ho(770) DECAY MODES | | |
|----------------|---------------------------------------------------------|------------------------------|------------------------|----------------------------|
| | Mode | Fraction (Γ_j/Γ) | | ale factor/ dence level |
| Γ ₁ | $\pi\pi$ | ~ 100 | % | |
| | | $ ho$ (770) $^{\pm}$ decays | | |
| Γ_2 | $\pi^{\pm}\pi^{0}$ | ~ 100 | % | |
| Γ3 | $\pi^{\pm} \pi^{0}$ $\pi^{\pm} \gamma$ $\pi^{\pm} \eta$ | (4.5 ± 0.5 | $) \times 10^{-4}$ | S=2.2 |
| Γ ₄ | $\pi^{\pm}\eta$ | < 6 | $\times 10^{-3}$ | CL=84% |
| Γ_5 | $\pi^{\pm}\pi^{+}\pi^{-}\pi^{0}$ | < 2.0 | $\times 10^{-3}$ | CL=84% |
| | | $ ho(770)^0$ decays | | |
| Γ_6 | $\pi^+\pi^-$ | ~ 100 | % | |
| Γ_7 | $\pi^+\pi^-\gamma$ | (9.9 ±1.6 | $) \times 10^{-3}$ | |
| | $\pi^0 \gamma$ | (6.0 ± 0.8 | $) \times 10^{-4}$ | |
| Г9 | $^{\eta\gamma}_{\pi^0\pi^0\gamma}$ | $(3.00 \pm 0.20$ | $) \times 10^{-4}$ | |
| | | (4.5 ± 0.8 | | |
| | $\mu^+\mu^-$ | [a] (4.55 ± 0.28) | | |
| Γ_{12} | $e^+ e^-$ | [a] (4.72 ± 0.05) | $) \times 10^{-5}$ | |
| Γ_{13} | $\pi^+\pi^-\pi^0$ | $(1.01^{+0.54}_{-0.36}\pm 0$ | $(.34) \times 10^{-4}$ | |
| Γ_{14} | $\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ | (1.8 ±0.9 | $) \times 10^{-5}$ | |
| Γ_{15} | $\pi^{+} \pi^{-} \pi^{0} \pi^{0}$ | (1.6 ±0.8 | $) \times 10^{-5}$ | |
| Γ_{16} | $\pi^{0} e^{+} e^{-}$ | < 1.2 | $\times 10^{-5}$ | CL=90% |
| Γ_{17} | $\eta e^+ e^-$ | | | |

[a] The $\omega \rho$ interference is then due to $\omega \rho$ mixing only, and is expected to be small. If $e\mu$ universality holds, $\Gamma(\rho^0 \to \mu^+ \mu^-) = \Gamma(\rho^0 \to e^+ e^-)$

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 10 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 = 10.7$ for 8 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta p_i \delta p_j \right>/(\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$x_3 = \begin{bmatrix} -100 \\ \Gamma & 15 & -15 \\ \hline x_2 & x_3 \end{bmatrix}$$

| | Mode | Rate (MeV) | Scale factor |
|----------------|--------------------|-------------------|--------------|
| Γ ₂ | $\pi^{\pm}\pi^{0}$ | 150.2 ± 2.4 | |
| Γ_3 | $\pi^{\pm}\gamma$ | 0.068 ± 0.007 | 2.3 |

CONSTRAINED FIT INFORMATION

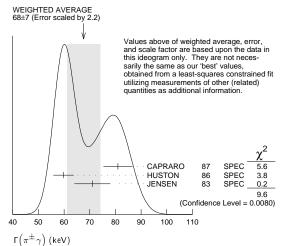
An overall fit to the total width, a partial width, and 7 branching ratios uses 21 measurements and one constraint to determine 9 parameters. The overall fit has a $\chi^2=$ 6.0 for 13 degrees of

The following off-diagonal array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (MeV) |
|----------------|-----------------------------------|---------------------------|
| Γ ₆ | $\pi^+\pi^-$ | 147.5 ±0.9 |
| Γ_7 | $\pi^+\pi^-\gamma$ | 1.48 ± 0.24 |
| Γ ₈ | $\pi^0 \gamma$ | 0.089 ± 0.012 |
| Г9 | $\eta\gamma$ | 0.0447 ± 0.0031 |
| Γ_{10} | $\pi^0 \pi^0 \gamma$ | 0.0066 ± 0.0012 |
| Γ_{11} | $\mu^+\mu^-$ | [a] 0.0068 ± 0.0004 |
| Γ_{12} | e^+e^- | [a] 0.00704 ± 0.00006 |
| Γ_{14} | $\pi^{+} \pi^{-} \pi^{+} \pi^{-}$ | 0.0027 ± 0.0014 |

ρ (770) PARTIAL WIDTHS

| $\Gamma(\pi^{\perp}\gamma)$ | | | | | 13 |
|-----------------------------|--------------------|---------|-----------|--------|-----------------------------------------------|
| VALUE (keV) | DO CUMENT ID | | TECN | CHG | COMMENT |
| 68 ±7 OUR FIT | Error includes sca | le fact | or of 2.3 | i. | |
| 68 ±7 OUR AVE | RAGE Error inclu | des sc | ale facto | of 2.2 | See the ideogram below. |
| 81 ±4 ±4 | CAPRARO | 87 | SPEC | _ | |
| 59.8 ± 4.0 | HUSTON | 86 | SPEC | + | 202 π^+ A $\rightarrow \pi^+ \pi^0$ A |
| 71 \pm 7 | JE NSE N | 83 | SPEC | _ | $156-260 \ \pi^- A \rightarrow \pi^- \pi^0 A$ |
| | | | | | |



| Γ(e ⁺ e ⁻) | | | | | | Γ ₁₂ |
|-----------------------------------|---------|--------------------------|-----------|----------|---------------------------------|-----------------|
| VALUE (keV) | EVTS | DO CUMENT ID | TE | ECN | COMMENT | |
| 7.04 ±0.06 OUR FIT | | | | | | |
| 7.04 ±0.06 OUR AVE | RAGE | | | | | |
| $7.048 \pm 0.057 \pm 0.050$ | 900k | ⁸⁰ AKHMETSHIN | | | | |
| $7.06 \pm 0.11 \pm 0.05$ | 114k | 81,82 AKHMETSHIN | 04 CI | MD2 | $e^+e^- \rightarrow \pi^+\pi^-$ | |
| $6.77 \pm 0.10 \pm 0.30$ | | BARKOV | 85 O | LYA | $e^+e^- \rightarrow \pi^+\pi^-$ | |
| • • • We do not use th | e follo | wing data for averages, | fits, lin | nits, et | C. • • • | |
| $7.12 \pm 0.02 \pm 0.11$ | 800k | 83 ACHASOV | 06 SI | ND . | $e^+e^- \rightarrow \pi^+\pi^-$ | |
| 6.3 ±0.1 | | 84 BENAYOUN | 98 R' | VUE | $e^+e^- \rightarrow \pi^+\pi^-$ | |
| | | | | | $\mu^+\mu^-$ | |

| $I(\pi^{\circ}\gamma)$ | | | | | I | | |
|-----------------------------------------------------------------------------|--------|-----------------------|----|------|--------------------------------------------------------------------|--|--|
| VALUE (keV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • | | | | | | | |
| $77 \pm 17 \pm 11$ | 365 00 | ⁸⁵ ACHASOV | 03 | SND | $0.60^{-}_{0}0.97 \ e^{+} \ e^{-} \rightarrow$ | | |
| 121 ± 31 | | DOLINSKY | 89 | ND | $e^{+\stackrel{\pi^{0}}{e^{-}} \gamma} \rightarrow \pi^{0} \gamma$ | | |

| $\Gamma(\eta\gamma)$ | | | | |
|-----------------------------|------------------------------|-------------|------------------------------|--|
| VALUE (keV) | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the fol | lowing data for averages, fi | ts, limits, | , etc. • • • | |
| 62±17 | 86 DOLINSKY 89 | ND | $e^+e^- \rightarrow n\gamma$ | |

| $\Gamma(\pi^+\pi^-\pi^+\pi^-)$ | | | | | Γ ₁₄ |
|--------------------------------|----------------|-----------------------|------------|---------|-----------------|
| VALUE (keV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not us | a the followin | m data for averages f | ite limite | etc | |

 $2.8 \pm 1.4 \pm 0.5$ 153 AKHMETSHIN 00 CMD2 0.6-0.97 $e^+e^ \pi^+\pi^-\pi^+$

80 A combined fit of AKHMETSHIN 07, AULCHENKO 06, and AULCHENKO 05.

 81 Using the GOUNARIS 68 parametrization with the complex phase of the ho- ω interference.

 $^{82}\mbox{From a fit in the energy range 0.61 to 0.96 GeV. Update of AKHMETSHIN 02.$ 83 Supersedes ACHASOV 05A.

 84 Using the data of BARKOV 85 in the hidden local symmetry model. 85 Using $\Gamma_{total}=$ 147.9 \pm 1.3 MeV and $B(\rho\to\pi^0\gamma)$ from ACHASOV 03.

86 Solution corresponding to constructive ω - ρ interference.

 $\rho(770)$

```
\rho(770) \Gamma(e^+e^-)\Gamma(i)/\Gamma^2(total)
                                                                                                                                                     \Gamma(e^+e^-)/\Gamma(\pi\pi)
                                                                                                                                                                                                                                                                             \Gamma_{12}/\Gamma_{1}
                                                                                                                                                     VALUE (units 10^{-4})
                                                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                                                      TECN COMMENT
\Gamma(e^+e^-)/\Gamma_{
m total} \, 	imes \, \Gamma(\pi^+\pi^-)/\Gamma_{
m total}
                                                                                                            \Gamma_{12}/\Gamma \times \Gamma_6/\Gamma
                                                                                                                                                     • • • We do not use the following data for averages, fits, limits, etc. • •
VALUE (units 10<sup>-5</sup>) EVTS
                                                     DOCUMENT ID TECN COMMENT
                                                                                                                                                                                                    104 BENAKSAS 72 OSPK e^+e^- \rightarrow \pi^+\pi^-
4.876±0.023±0.064 800k 87,88 ACHASOV 06 SND e^+e^- \rightarrow \pi^+\pi^-
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                                                                                                                                \Gamma_9/\Gamma
                                                                                                                                                     \Gamma(\eta\gamma)/\Gamma_{\rm total}
                                                 ^{89} BENAYOUN 10 RVUE 0.4-1.05 e^{+}\,e^{-}
                                                                                                                                                     VALUE (units 10^{-4}) EVTS
                                                                                                                                                                                                   DO CUMENT ID TECN CHG COMMENT
  87 Supersedes ACHASOV 05A.
                                                                                                                                                     3.00 ± 0.21 OUR FIT
  88 A fit of the SND data from 400 to 1000 MeV using parameters of the \rho(1450) and \rho(1700) from a fit of the data of BARKOV 85, BISELLO 89 and ANDERSON 00A.
                                                                                                                                                     2.90±0.32 OUR AVERAGE

    2.90±0.32 OUR AVEKAGE

    2.79±0.34±0.03
    33k
    105 ACHASOV
    07B
    SND
    0.6-1.38 e<sup>+</sup>

    3.6 +0.9
    106 ANDREWS
    77
    CNTR
    0
    6.7-10 7 Cu

                                                                                                                                                                                                                                                    0.6-1.38 e^+e^- \rightarrow \eta \gamma
  <sup>89</sup> A simultaneous fit of e^+e^- \rightarrow \pi^+\pi^-, \pi^+\pi^-\pi^0, \pi^0\gamma, \eta\gamma data.
                                                                                                                                                     \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
\Gamma(e^+e^-)/\Gamma_{\text{total}} \times \Gamma(\eta\gamma)/\Gamma_{\text{total}}
                                                                                                           \Gamma_{12}/\Gamma \times \Gamma_{9}/\Gamma
                                                                                                                                                     3.21\pm1.39\pm0.20 17.4k^{07,108} AKHMETSHIN 05 CMD2
                                                                                                                                                                                                                                                    0.60-1.38 e^+\,e^-\,\rightarrow\,\,\eta\gamma
VALUE (units 10<sup>-8</sup>)
1.42±0.10 OUR FIT
                                                                                                                                                     3.39 \pm 0.42 \pm 0.23 106,109,110 AKHMETSHIN 01B CMD2
                                                  DOCUMENT ID TECN COMMENT
                                                                                                                                                                                                                                                    e^+\,e^- \to ~\eta\gamma
                                                                                                                                                                                            111 BENAYOUN 96 RVUE
                                                                                                                                                                                                                                                     0.54-1.04 e^+e^- \rightarrow \eta \gamma
1.45 ± 0.12 OUR AVERAGE
                                                                                                                                                                                       106,108 DOLINSKY
                                              ^{90} ACHASOV 07B SND 0.6–1.38 e^+ e^- 
ightarrow \eta \gamma
                                                                                                                                                                                                                         89
                                                                                                                                                                                                                                ND
                                                                                                                                                     4.0 \pm 1.1
1.32 \pm 0.14 \pm 0.08
                                  33k
                                              ^{91} AKHMETSHIN 05 CMD2 0.60-1.38 e^+e^- 
ightarrow \eta \gamma
1.5\,0\pm0.65\pm0.09
                                 17.4k
                                                                                                                                                     \Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                               \Gamma_{14}/\Gamma
                                  23k ^{92,93} AKHMETSHIN 01B CMD2 e^+e^- 
ightarrow \eta\gamma
1.61 \pm 0.20 \pm 0.11
                                              ^{94} DOLINSKY 89 ND e^+e^- 
ightarrow \eta\gamma
                                                                                                                                                     VALUE (units 10^{-5}) CL% EVTS
                                                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                                                      TECN COMMENT
                                                                                                                                                          1.8±0.9 OUR FIT
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                                                           AKHMETSHIN 00 CMD2 0.6-0.97 e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-
                                                                                                                                                          1.8 \pm 0.9 \pm 0.3
                                                                                                                                                                                           153
                                              ^{95} BENAYOUN 10 RVUE 0.4–1.05 e^+\,e^-
  ^{90} From a combined fit of \sigma(e^+e^-\to\eta\gamma) with \eta\to3\pi^0 and \eta\to\pi^+\pi^-\pi^0, and fixing B(\eta\to3\pi^0)/ B(\eta\to\pi^+\pi^-\pi^0)=1.44\pm0.04. Recalculated by us from the cross section at the peak. Supersedes ACHASOV 00D and ACHASOV 06A.
                                                                                                                                                     • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                                                                           KURDADZE 88 OLYA e^+e^-_{\pi^+\pi^-\pi^+\pi^-}
                                                                                                                                                                                90
  or Sos section at the peak. Superseus ACTMASOV VOD and ACTMASOV VOD ACTMASOV VOD and ACTMASOV VOD and ACTMASOV VOD and ACTMASOV VOD ACTMASOV VOD and ACTMASOV VOD and ACTMASOV VOD and ACTMASOV VOD 
                                                                                                                                                     \Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma(\pi\pi)
                                                                                                                                                                                                                                                                             \Gamma_{14}/\Gamma_{1}
  93 The combined fit from 600 to 1380 MeV taking into account \rho(770), \omega(782), \phi(1020),
                                                                                                                                                     VALUE (units 10^{-4})
                                                                                                                                                                                       CL%
                                                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                                                    TECN CHG COMMENT
      and \rho(1450) (mass and width fixed at 1450 MeV and 310 MeV respectively).
                                                                                                                                                     ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
  98 A simultaneous fit of e^+e^-\to \pi^+\pi^-, \pi^+\pi^-\pi^0, \pi^0\gamma, \eta\gamma data.
                                                                                                                                                                                                           ERBE
                                                                                                                                                                                                                                  69 HBC 0
                                                                                                                                                      <15
                                                                                                                                                                                          90
                                                                                                                                                                                                                                                              3.2,4.2 \pi^{-}p
                                                                                                                                                      <20
                                                                                                                                                                                                           CHUNG
                                                                                                                                                                                                                                  68 HBC 0
\Gamma(e^+e^-)/\Gamma_{\rm total} \times \Gamma(\pi^0\gamma)/\Gamma_{\rm total}
                                                                                                                                                      < 20
                                                                                                                                                                                          90
                                                                                                                                                                                                           HUSON
                                                                                                                                                                                                                                  68
                                                                                                                                                                                                                                         HLBC 0
                                                                                                                                                                                                                                                              16.0 \pi^{-} D
                                                                                                            \Gamma_{12}/\Gamma \times \Gamma_8/\Gamma
                                                                                                                                                      <80
                                                                                                                                                                                                           JA MES
                                                                                                                                                                                                                                  66
                                                                                                                                                                                                                                       HBC 0
                                                                                                                                                                                                                                                              2.1 \pi^{+} p
VALUE (units 10^{-8})
                                   EVTS
                                                   DO CUMENT ID
                                                                                    TECN COMMENT
2.8 ±0.4 OUR FIT
                                                                                                                                                     \Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\rm total}
                                                                                                                                                                                                                                                                               \Gamma_{13}/\Gamma
2.8 ±0.4 OUR AVERAGE
                                                                                                                                                     VALUE (units 10<sup>-4</sup>) CL% EVTS
                                                                                                                                                                                                                DOCUMENT ID
                                                                                                                                                                                                                                              TECN COMMENT
2.90 \, ^{+\, 0.60}_{-\, 0.55} \, \pm 0.18 18680
                                                     AKHMETSHIN 05 CMD2 0.60-1.38 e^+e^- \rightarrow 0.000
                                                                                                                                                     ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                 <sup>96</sup> ACHASOV
2.37 ±0.53 ±0.33 36500
                                                                                             0.60^{-0.97}_{\pi^0} e^+ e^- \rightarrow
                                                                                                                                                        1.01 + 0.54 \pm 0.34
                                                                                                                                                                                               1.2M 112 ACHASOV
                                                                                                                                                                                                                                        03D RVUE 0.44-2.00
3.61 \pm 0.74 \pm 0.49 10625 97 DOLINSKY 89 ND
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                                                                  VASSERMAN 88B ND
                                                 ^{98} BENAYOUN 10 RVUE 0.4-1.05 e^+\,e^-
                                                                                                                                                     \Gamma(\pi^+\pi^-\pi^0)/\Gamma(\pi\pi)
  ^{96}\, {\rm Using}~\sigma_{\phi~\to\pi^{0}\,\gamma} from ACHASOV 00 and m_{\rho}{=} 775.97 MeV in the model with the
                                                                                                                                                                                                                                                                             \Gamma_{13}/\Gamma_{1}
                                                                                                                                                                                       CL%
                                                                                                                                                                                                          DOCUMENT ID TECN CHG COMMENT
     energy-independent phase of \rho-\omega interference equal to (-10.2 \pm 7.0)^{\circ}.
  97 Recalculated by us from the cross section in the peak. 98 A simultaneous fit of e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, \pi^0\gamma, \eta\gamma data.
                                                                                                                                                     • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                      I
                                                                                                                                                                                                           BRAMON
                                                                                                                                                                                                                               86 RVUE 0 J/\psi \rightarrow \omega \pi^0
                                                                                                                                                                                                    113 ABRAMS
                                                                                                                                                                                                                                 71 HBC 0 3.7 \pi^+ p
\Gamma(e^+e^-)/\Gamma_{\text{total}} \times \Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}
                                                                                                          \Gamma_{12}/\Gamma \times \Gamma_{13}/\Gamma
                                                                                                                                                     \Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{\text{total}}
VALUE (units 10<sup>-9</sup>) EVTS DOCUMENT ID
                                                                                  TECN COMMENT
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                     VALUE (units 10^{-5}) CL%
                                                                                                                                                                                                        DOCUMENT ID TECN COMMENT
                                                                                                                                                                                               114 ACHASOV 09A SND e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0
0.903 \pm 0.076
                                                ^{99} BENAYOUN 10 RVUE 0.4-1.05 e^{+}\,e^{-}
                                                                                                                                                          1.60 \pm 0.74 \pm 0.18
4.58 ^{+2.46}_{-1.64} \pm 1.56 1.2M ^{100} ACHASOV 03D RVUE 0.44-2.00 ^{+} ^{+} ^{-} ^{-}
                                                                                                                                                      • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                                                                        AULCHENKO 870 ND e^+e^- 
ightarrow \, \pi^+\,\pi^-\,\pi^0\,\pi^0
                                                                                                                                                                                       90
  ^{99}A simultaneous fit of e^+\,e^-\,\to\,\,\pi^+\,\pi^-, \pi^+\,\pi^-\,\pi^0, \pi^0\,\gamma, \eta\,\gamma data.
                                                                                                                                                                                                        KURDADZE 86 OLYA e^+e^- 
ightarrow \pi^+\pi^-\pi^0\pi^0
                                                                                                                                                      <20
                                                                                                                                                                                       90
^{100}\,\mathrm{Statistical} significance is less than 3 \sigma.
                                                                                                                                                     \Gamma(\pi^+\pi^-\gamma)/\Gamma_{\rm total}
                                                                                                                                                                                                                                                                                \Gamma_7/\Gamma
                                        \rho(770) BRANCHING RATIOS
                                                                                                                                                                                                           DOCUMENT ID TECN COMMENT
                                                                                                                                                     0.0099±0.0016 OUR FIT
                                                                                                                                                         0.0099±0.0016
                                                                                                                                                                                                     115 DOLINSKY 91 ND
\Gamma(\pi^{\pm}\eta)/\Gamma(\pi\pi)
                                                                                                                         \Gamma_4/\Gamma_1
                                                                                                                                                      • • • We do not use the following data for averages, fits, limits, etc. • • •
VALUE (units 10^{-4})
                                                      DOCUMENT ID
                                                                              TECN CHG COMMENT
                                                                                                                                                        0.0111 \pm 0.0014
                                                                                                                                                                                                     ^{116} VASSERMAN 88 ND e^+e^- 
ightarrow \pi^+\pi^-\gamma
                                                                             66 HBC
                                                                                                        \pi^{\pm} p above 2.5
                                                                                                                                                                                                     117 VASSERMAN 88 ND
                                                                                                                                                      < 0.005
\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})/\Gamma(\pi\pi)
                                                                                                                          \Gamma_5/\Gamma_1
                                                                                                                                                     \Gamma(\pi^0 \gamma)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                \Gamma_8/\Gamma
                                                      DOCUMENT ID
                                                                              TECN CHG COMMENT
                                                                                                                                                     VALUE (units 10^{-4})
                                                                                                                                                                                      EVTS
                                                                                                                                                                                                         DOCUMENT ID TECN COMMENT
                                                                            66 HBC \pm \pi^{\pm}p above 2.5
                                                      FERBEL
                                                                                                                                                     \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                     6.21^{\,+\,1.28}_{\,-\,1.18}\,\pm\,0.39
                                                                                                                                                                                        1868^{018,119}_{01} AKHMETSHIN 05 CMD2 0.60-1.38 e^+e^- \rightarrow
                                                      JAMES
                                                                            66 HBC + 2.1 \pi^+ p
                                                                                                                                                                                         365 00 9,120 ACHASOV
                                                                                                                                                     5.22 \pm 1.17 \pm 0.75
\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-)
                                                                                                                                                                                                                                 03 SND
                                                                                                                       \Gamma_{11}/\Gamma_{6}
VALUE (units 10-5)
                                                      DOCUMENT ID
                                                                                    TECN COMMENT
                                                                                                                                                                                                     121 BENAYOUN 96
                                                                                                                                                     6.8 +1.7
                                                                                                                                                                                                                                         RVUE 0.54-1.04 e^+e^- \rightarrow
4.60±0.28 OUR FIT
                                                      A NTIP OV
                                                                                                                                                                                                     119 DOLINSKY 89 ND
4.6 \pm 0.2 \pm 0.2
                                                                             89 SIGM \pi^- Cu \rightarrow
                                                                                                                                                     7.9 \pm 2.0
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                     \Gamma(\pi^0 e^+ e^-)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                               \Gamma_{16}/\Gamma
                                               ^{101} ROTHWELL 69 CNTR Photoproduction
                                                                                                                                                     VALUE (units 10^{-5}) CL%
                                                                                                                                                                                                DOCUMENT ID TECN COMMENT
                                                                                                                                                                                                ACHASOV 08 SND 0.36-0.97 e^+e^- \rightarrow \pi^0 e^+e^-
                                                                                                                                                                               90
                                                ^{102} WEHMANN 69 OSPK 12 \pi^- C, Fe
5.6 ±1.5
                                                                                                                                                     • • • We do not use the following data for averages, fits, limits, etc. • •
                                               <sup>103</sup> HYAMS
9.7 \begin{array}{l} +3.1 \\ -3.3 \end{array}
                                                                             67 OSPK 11 \pi^-Li, H
                                                                                                                                                                                               AKHMETSHIN 05A CMD2 0.72-0.84 e+e-
                                                                                                                                                      <1.6
```

Meson Particle Listings $\rho(770), \omega(782)$

| $\Gamma(\eta e^+ e^-)/\Gamma_{\text{total}}$ | | | | | | Γ ₁₇ /Γ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10^{-5}) | | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do not use | the follow | ring data for average | s, fits | , limits, | etc. • • • | |
| < 0.7 | | AKHMETSHII | N 05A | CMD2 | 0.72-0.84 e | + e- |
| $\Gamma(\pi^0\pi^0\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₁₀ /Γ |
| VALUE (units 10 ⁻⁵) 4.5 ± 0.8 OUR FIT | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 4.5 ± 0.9 OUR AVERA | GE | | | | | |
| $5.2^{+1.5}_{-1.3} \pm 0.6$ | 190 | 122 AKHMETSHII | N 04B | CMD2 | 0.6-0.97 e | $^+e^ ^-$ |
| $4.1 + 1.0 \pm 0.3$ | 295 | ¹²³ ACHASOV | 02F | SND | 0.36-0.97 e | |
| • • • We do not use | the follow | ring data for average | s, fits, | , limits, | | |
| $4.8 + 3.4 \pm 0.5$ | 63 | 124 ACHASOV | 00g | SND | $e^+ e^- \rightarrow$ | $\pi^0\pi^0\gamma$ |
| -1.8 $^{-1.8}$ Possibly large $ ho$ - ω | | | | | | |
| = (4.72 ± 0.05) error is the system ACHASOV 06A. 106 Solution correspon 107 Using B($\rho \rightarrow e^+$ 108 Not independent of 109 The combined fit and ρ (1450) (mas: 110 Using B($\rho \rightarrow e^+$ 3 π^0) = $(32.24\pm111$ Reanalysis of DRU | n is not t eports [Γ 08) \times 10 ⁻⁵ \times 10 ⁻⁵ atic error ding to co e^-) = (4 of the corr from 600 s and wid: e^-) = (0.0.29) \times 10 ZHININ 3 | aken into account. $(\rho(770) \rightarrow \eta \gamma)/-8$ which we divide Our first error is t from using our best constructive ω - ρ inter. $67 \pm 0.09) \times 10^{-5}$ esponding $\Gamma(e^+e^-$ to 1380 MeV taking th fixed at 1450 MeV $4.75 \pm 0.10) \times 10^{-}$ 0^{-2} . | Ftotal by our heir ex value ference and less of the second | $ \times [B($ best va xperimer Supers e. $ B(\eta \rightarrow \eta \gamma)/\Gamma_{	ext{to}}^2 $ account 310 Me $^{\circ}$ in AKHM | ho(770) ightarrow ho(770) it's error and sedes ACHA: $ ho(770)$, $ ho(780)$, $ ho(770)$, $ ho(780)$, $ ho(780)$ W respectivel METSHIN 02 | $0 \rightarrow e^+e^-)$ d our second SOV 00D and $3 \pm 0.26\%$. $3 \pm 0.26\%$. $3 \pm 0.26\%$. $3 \pm 0.26\%$. |
| 112 Statistical significa 113 Model dependent, 114 Assuming no inter 115 Bremsstrahlung fro 116 Superseded by DC 117 Structure radiatior | nce is les assumes ference be om a deca LINSKY due to q | is than 3σ . $I=1$, 2, or 3 for the etween the $ ho$ and ω by pion and for photo 91. $I=1$ | e 3π s contrib on ene in the | ystem. outions. rgy abo | | |
| 118 Using B($ ho ightarrowe^+$ 119 Not independent c | f the corr | esponding $\Gamma(e^+e^-$ |) × Γ(: | $\pi^0 \gamma)/\Gamma_{ m t}^2$ | otal' | |
| 120 Using B($ ho ightarrow e^+$ 121 Reanalysis of DRU a triangle anomaly | ZHININ : | 84, DOLINSKY 89, ion. | and D | | | |
| ¹²² This branching rat and the new deca $(2.0^{+1}.0 \pm 0.3)$ | y mode ρ | s the conventional V $ ho ightarrow f_0(500)\gamma$, $f_0($ ffering from zero by | 500) - | $\rightarrow \pi^0 \pi$ | .0 with a bra | $0,\omega ightarrow\pi^0\gamma$ anching ratio |
| 123 This branching rat and the new deca | io include y mode $ ho$ $	imes$ 10^{-5} c | s the conventional $\gamma ightarrow f_0(500) \gamma$, $f_0(500) \gamma$ for zero by | /MD n 500) - | $_{ ightarrow}^{ m nechanis}$ | m $ ho ightarrow \omega \pi^0$ With a bra | anching ratio |

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| | | | | | |

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 ω (782)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

ω (782) MASS

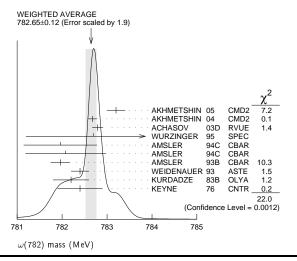
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|--------|-------------------------|-------|---------|-------------------------------------------------------------|
| 782.65 ± 0.12 OUR A | VERAGE | Error includes scale | facto | of 1.9. | See the ideogram below. |
| $783.20 \pm 0.13 \pm 0.16$ | 18680 | AKHMETSHIN | 05 | CMD2 | $0.60 \text{-} 1.38 \ e^+ \ e^- \rightarrow \pi^0 \ \gamma$ |
| $782.68 \pm 0.09 \pm 0.04$ | 11200 | ¹ AKHMETSHIN | 04 | CMD2 | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| $782.79 \pm 0.08 \pm 0.09$ | 1.2 M | ² ACHASOV | 03D | | $0.44-2.00 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 782.7 ± 0.1 ± 1.5 | 19500 | WURZINGER | 95 | SPEC | $1.33 \ pd \rightarrow {}^{3}\text{He}\omega$ |
| $781.96 \pm 0.17 \pm 0.80$ | 11 k | ³ AMSLER | 94c | CBAR | $0.0 \overline{p}p \rightarrow \omega \eta \pi^0$ |
| $782.08 \pm 0.36 \pm 0.82$ | 3463 | ⁴ AMSLER | 94c | CBAR | $0.0 \overline{p}p \rightarrow \omega \eta \pi^0$ |
| $781.96 \pm 0.13 \pm 0.17$ | 15 k | AMSLER | 93B | CBAR | $0.0 \overline{p}p \rightarrow \omega \pi^0 \pi^0$ |
| 782.4 ± 0.2 | 270k | WEIDENAUER | 93 | ASTE | $\overline{p}p \rightarrow 2\pi^+ 2\pi^- \pi^0$ |
| 782.2 ± 0.4 | 1488 | KURDADZE | 83B | OLYA | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| $782.4\ \pm0.5$ | 7000 | ⁵ KEYNE | 76 | CNTR | $\pi^- p \rightarrow \omega n$ |

$\omega(782)$

| • • • We do not u | ise the following | data for averages | , fits, | , limits, e | etc. • • • |
|-------------------|-------------------|---------------------|---------|-------------|--------------------------------------------------------|
| 781.78 ± 0.10 | | ⁶ BARKOV | 87 | | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| 783.3 ± 0.4 | 433 | CORDIER | 80 | DM1 | $e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$ |
| 782.5 ± 0.8 | 33260 | ROOS | 80 | | 0.0−3.6 p p |
| 782.6 ± 0.8 | 3000 | BENKHEIRI | 79 | OMEG | 9-12 π [±] p |
| 781.8 ± 0.6 | 1430 | COOPER | 78B | HBC | $0.7-0.8 \overline{p}p \rightarrow 5\pi$ |
| 782.7 ± 0.9 | 535 | VA NA PEL | 78 | HBC | $7.2 \overline{p} p \rightarrow \overline{p} p \omega$ |
| 783.5 ± 0.8 | 2100 | GESSAROLI | 77 | HBC | $11 \pi^- p \rightarrow \omega n$ |
| 782.5 ± 0.8 | 418 | AGUILAR | 72B | HBC | 3.9,4.6 K ⁻ p |
| 783.4 ± 1.0 | 248 | BIZZARRI | 71 | HBC | $0.0 p \overline{p} \rightarrow K^+ K^- \omega$ |
| 781.0 ± 0.6 | 510 | BIZZARRI | 71 | HBC | $0.0 p\overline{p} \rightarrow K_1 K_1 \omega$ |
| 783.7 ± 1.0 | 3583 | ⁷ COYNE | 71 | HBC | $3.7 \pi^+ p \rightarrow$ |
| | | | | | $\rho \pi^{+} \pi^{+} \pi^{-} \pi^{0}$ |
| 784.1 ± 1.2 | 75 0 | ABRAMOVI | 70 | HBC | 3.9 π ⁻ p |
| 783.2 ± 1.6 | | ⁸ BIGGS | 70B | CNTR | $<$ 4.1 γ C \rightarrow $\pi^+\pi^-$ C |
| $782.4\ \pm0.5$ | 2400 | BIZZARRI | 69 | HBC | 0.0 p p |

¹ Update of A KH MET SHIN 00c.

 $^{^{8}\,\}mathrm{From}~\omega\text{-}\rho$ interference in the $\pi^{+}\,\pi^{-}$ mass spectrum assuming ω width 12.6 MeV.



ω (782) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID TECN COMMENT | |
|--------------------------|---------------|--------------------------------------------------------------------------|---|
| 8.49±0.08 OUR AV | ERAGE | | |
| $8.68 \pm 0.23 \pm 0.10$ | 11200 | 9 AKHMETSHIN 04 CMD2 $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{-}$ | 0 |
| $8.68 \pm 0.04 \pm 0.15$ | 1.2M | 10 ACHASOV 03D RVUE 0.44-2.00 $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | |
| 8.2 ± 0.3 | 19500 | WURZINGER 95 SPEC $1.33 pd \rightarrow {}^{3}\text{He}\omega$ | |
| 8.4 ±0.1 | | 11 AULCHENKO 87 ND $e^+e^- ightarrow \pi^+\pi^-\pi^0$ | 0 |
| 8.30 ± 0.40 | | BARKOV 87 CMD $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 0 |
| 9.8 ±0.9 | 1488 | KURDADZE 83B OLYA $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 0 |
| 9.0 ±0.8 | 433 | CORDIER 80 DM1 $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 0 |
| 9.1 ±0.8 | 451 | BENAKSAS 72B OSPK $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 0 |
| | the following | g data for averages, fits, limits, etc. • • • | |
| 12 ±2 | 1430 | COOPER 78B HBC 0.7 – $0.8 \overline{p} p \rightarrow 5 \pi$ | |
| 9.4 ±2.5 | 2100 | GESSAROLI 77 HBC $11~\pi^- p ightarrow \omega n$ | |
| 10.22 ± 0.43 | 20000 | ¹² KEYNE 76 CNTR $\pi^- p \rightarrow \omega n$ | |
| 13.3 ± 2 | 418 | AGUILAR 72B HBC 3.9,4.6 K - p | |
| 10.5 ± 1.5 | | BORENSTEIN 72 HBC 2.18 K ⁻ p | |
| $7.70 \pm 0.9 \pm 1.15$ | 940 | BROWN 72 MMS 2.5 $\pi^- p \rightarrow nMM$ | |
| 10.3 ±1.4 | 510 | BIZZARRI 71 HBC $0.0 p\overline{p} \rightarrow K_1 K_1 \omega$ | |
| 12.8 ± 3.0 | 248 | BIZZARRI 71 HBC $0.0 p\overline{p} \rightarrow K^{+} K^{-} \omega$ | υ |
| 9.5 ±1.0 | 3583 | COYNE 71 HBC $3.7 \pi^+ p \rightarrow + + - 0$ | |

⁹Update of AKHMETSHIN 00c.

ω (782) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-----------------|--------------------------------------|---------------------------------------------------------------|-----------------------------------|
| Г1 | $\pi^{+} \pi^{-} \pi^{0}$ | (89.2 ±0.7) % | |
| | $\pi^0 \gamma$ | (8.28±0.28) % | S=2.1 |
| Γ_3 | $\pi^+\pi^-$ | $(1.53^{+0.11}_{-0.13})$ % | S=1.2 |
| Γ_4 | neutrals (excluding $\pi^0\gamma$) | $(8 \ \ \begin{array}{cc} +8 \\ -5 \end{array}) \times 10$ | o-3 S=1.1 |
| Γ_5 | $\eta\gamma$ | $(4.6 \pm 0.4) \times 10$ |) ⁻⁴ S=1.1 |
| | $\frac{\eta \gamma}{\pi^0} e^+ e^-$ | (7.7 ± 0.6) $\times 10$ |)-4 |
| | $\pi^0\mu^+\mu^-$ | (1.3 ± 0.4) $\times 10$ | S=2.1 |
| | $\eta e^+ e^-$ | | |
| | $e^+ e^-$ | $(7.28 \pm 0.14) \times 10$ | S=1.3 |
| Γ_{10} | $\pi^{+} \pi^{-} \pi^{0} \pi^{0}$ | < 2 × 10 | $^{-4}$ CL=90% |
| Γ_{11} | $\pi^+\pi^-\gamma$ | < 3.6 × 10 | $^{-3}$ CL=95% |
| Γ_{12} | $\pi^{+} \pi^{-} \pi^{+} \pi^{-}$ | < 1 ×10 | $^{-3}$ CL=90% |
| | $\pi^0 \pi^0 \gamma$ | $(6.6 \pm 1.1) \times 10$ | ₎ —5 |
| Γ_{14} | $\eta\pi^0\gamma$ | < 3.3 × 10 |) ⁻⁵ CL=90% |
| Γ_{15} | $\mu^+\mu^-$ | $(9.0 \pm 3.1) \times 10$ |) ⁻⁵ |
| Γ ₁₆ | 3γ | < 1.9 × 10 |)-4 CL=95% |
| | | (C) violating modes | |
| Γ_{17} | $\eta\pi^0$ | C < 2.1 × 10 |) ⁻⁴ CL=90% |
| Γ ₁₈ | $2\pi^0$ | C < 2.1 × 10 | |
| Γ ₁₉ | $3\pi^{0}$ | C < 2.3 × 10 | |

CONSTRAINED FIT INFORMATION

An overall fit to 15 branching ratios uses 51 measurements and one constraint to determine 10 parameters. The overall fit has a $\chi^2 = 51.8$ for 42 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to

ω (782) PARTIAL WIDTHS

| | $\omega(10)$ | Z) FARTIAL V | נחוטוו | • | |
|-----------------------------------------------|-------------------|-------------------------------------------|--------------|---------------------------------------------------|----------------|
| $\Gamma(\pi^0\gamma)$ | | | | | Γ2 |
| VALUE (keV) | EVTS I | DOCUMENT ID | TECN | COMMENT | |
| • • • We do not use | the following | data for averages | , fits, lim | nits, etc. • • • | |
| $788 \pm 12 \pm 27$ | | | | 0.60-0.97 $e^+e^ \rightarrow$ | $\pi^0\gamma$ |
| 764 ± 51 | 10625 | OOLINSKY 89 |) ND | $e^+e^- \rightarrow \pi^0 \gamma$ | |
| 13 Using $\Gamma_{\omega}=$ 8.44 | \pm 0.09 MeV a | and B($\omega ightarrow \pi^0 \gamma$ |) from A | CHASOV 03. | |
| $\Gamma(\eta\gamma)$ | | | | | Γ ₅ |
| VALUE (keV) | | DO CUMENT ID | TE | CN_COMMENT | |
| • • • We do not use | the following | data for averages | s, fits, lim | nits, etc. • • • | |
| 6.1 ± 2.5 | 1 | ⁴ DOLINSKY | 89 NE | $e^+e^- \rightarrow \eta \gamma$ | |
| 14 Using $ \Gamma_{\omega} = $ 8.4 \pm | 0.1 MeV and | d B $(\omega ightarrow \eta \gamma)$ fro | om DOLI | NSKY 89. | |
| Γ(e+ e ⁻) | | | | | Г9 |
| VALUE (keV) | EVTS | DO CUMENT ID | TE | CN COMMENT | |
| 0.60 ±0.02 OUR E | VALUATION | | | | |
| • • • We do not use | | | | | |
| $0.591{\pm}0.015$ | $11200^{\ 15,1}$ | ⁶ AKHMETSHIN | 104 CN | MD2 $e^+e^- \rightarrow \pi^+\pi^-$ | $-\pi^0$ |
| $0.653 \pm 0.003 \pm 0.021$ | 1.2M ¹ | ⁷ ACHASOV | 03D R\ | /UE $0.44-2.00 e^+e^-$ | \rightarrow |
| 0.600 ± 0.031 | 10625 | DOLINSKY | 89 NE | $e^{+}e^{-} \xrightarrow{\pi^{-}} \pi^{0} \gamma$ | |

 $^{^{15}\,} Using~B(\omega \rightarrow~\pi^+\pi^-\pi^0) =$ 0.891 \pm 0.007 and $\Gamma_{\mbox{total}}$ = 8.44 \pm 0.09 MeV.

² From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.

 $^{^3}$ From the $\eta\to\gamma\gamma$ decay. 4 From the $\eta\to3\pi^0$ decay.

 $^{^{5}}$ Observed by threshold-crossing technique. Mass resolution = 4.8 MeV FWHM.

⁶ Systematic uncertainties underestimated.

⁷ From best-resolution sample of COYNE 71.

Option the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.

¹¹ Relativistic Breit-Wigner includes radiative corrections.

 $^{^{12}\,\}mathrm{Observed}$ by threshold-crossing technique. Mass resolution = 4.8 MeV FWHM.

¹⁶ Update of AKHMETSHIN 00c.

 $^{^{17}}$ Using ACHASOV 03, ACHASOV 03D and B($\omega \rightarrow ~\pi^+\pi^-) = (1.70 \pm 0.28)\%$

 Γ_2/Γ

 $\Gamma(\pi^0\gamma)/\Gamma_{
m total}$

| | ω (7 | 82) Γ(e ⁺ e ⁻)Γ | (i)/I | ⁻² (total |) |
|-----------------------------------------------------------------------------------------------|----------------------------------------|---------------------------------------------------|-----------------------|----------------------------------------|----------------------------------------------------------------------------------|
| Γ (e⁺ e⁻)/Γ_{total} : VALUE (units 10 ⁻⁵) | × Γ(π+ π | -π ⁰)/Γ _{total} | | TECN | $\Gamma_9/\Gamma 	imes \Gamma_1/\Gamma$ |
| 5.49±0.11 OUR FIT | Error inc | ludes scale facto | | . 3. | |
| .38±0.10 OUR AV | | rror includes scal | | | |
| $5.24 \pm 0.11 \pm 0.08$ $5.70 \pm 0.06 \pm 0.27$ | 11.2k | ^{.8} AKHMETSHIN AUBERT,B | | CMD2 BABR | $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 0.70±0.06±0.27 | | AUBERT,B | 04N | вавк | $10.6 e^{+}e^{-}_{\pi^{+}\pi^{-}\pi^{0}\gamma}$ |
| $6.74 \pm 0.04 \pm 0.24$ | | ²⁰ ACHASOV | 03D | RVUE | $0.44-2.00 e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| $.37 \pm 0.35$ | | ⁹ DOLINSKY | 89 | ND | $e \mid e \rightarrow \pi \mid \pi \pi^{\circ}$ |
| .45 ± 0.24 | | 9 BARKOV | 87 | | $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| .79±0.42 .89±0.54 | | .9 KURDADZE .9 CORDIER | 83B 80 | OLYA DM1 | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| .54±0.84 | | 9 BENAKSAS | | OSPK | • |
| • • We do not use | | | | | |
| 5.20±0.13 | 2 | ²¹ BENAYOUN | 10 | RVUE | 0.4-1.05 e ⁺ e ⁻ |
| ¹⁸ Update of AKHN | | | | | |
| ACHASOV 03D d | ined fit of lata on the ASOV 99E | ANTONELLI 9 $\pi^+\pi^-\pi^0$ and A and ACHASOV 0 | 2, A0 NTOI 02e. | CHASOV NELLI 92 | 01E, ACHASOV 02E, and conthe $\omega\pi^+\pi^-$ final states. $\eta\gamma$ data. |
| $(e^+e^-)/\Gamma_{\text{total}}$ | × Γ(π ⁰ γ |)/F _{total} | | | $\Gamma_9/\Gamma \times \Gamma_2/\Gamma$ |
| ALUE (units 10 ⁻⁶) | EVTS | DO CUMENT IE |) | TECN | COMMENT |
| 6.02±0.20 OUR FIT | Error inc | ludes scale facto | | | - |
| .45 ± 0.17 OUR AV | | | | _ | |
| $6.47 \pm 0.14 \pm 0.39$ | 18680 | A KH METSH | | | 2 0.60-1.38 $e^+e^- \rightarrow \pi^0 \gamma$ |
| $6.50 \pm 0.11 \pm 0.20$ | 36500 | ²² ACHASOV | 03 | SND | $0.60^{-0.97}_{\pi^0} e^+ e^- \rightarrow$ |
| $6.34 \pm 0.21 \pm 0.21$ | 10625 | ²³ DOLINSKY | 89 | ND | $e^+e^- \rightarrow \pi^0\gamma$ |
| • • We do not use | e the follow | | | fits, limi | ts, etc. • • • |
| 5.80 ± 0.13 | | ²⁴ BENAYOUN | 10 | RVUE | 0.4-1.05 e ⁺ e ⁻ |
| ²² Using σ_{\perp} 0 | from ACI | HASOV 00 and | m,,= | 782.57 | MeV in the model with the |
| energy-independe | nt phase o | f ρ - ω interference | equa | nl to (— 1 | 10.2 ± 7.0)°. |
| ²³ Recalculated by | us from the | cross section in | the p | eak. | _ , |
| ²⁴ A simultaneous f | it of e^+e^- | \rightarrow $\pi^+\pi^-$, π^+ | $\pi^-\pi$ | 0 , $\pi^{0}\gamma$, | $\eta\gamma$ data. |
| Γ(a+ a-)/Γ | . г/_+ - | -\/г | | | F /F v F /F |
| -(e+ e ⁻)/Γ _{total} : | | • | | | $\Gamma_9/\Gamma \times \Gamma_3/\Gamma$ |
| VALUE (units 10 ⁻⁶) | | DO CUMENT | | | N COMMENT |
| 1.225 ± 0.05 8 ± 0.041 • • • We do not use | | ²⁵ ACHASOV | | 06 SNI | |
| | tile lollow | | - | | |
| 1.146 ± 0.05 7 | | ²⁶ BENAYOU | N. | LO RVI | JE 0.4-1.05 e ⁺ e ⁻ |
| 25 Supersedes ACH, 26 A simultaneous f | | | _ | 0 0 | 4.4 |
| - A simultaneous t | it or e · e | \rightarrow π ' π ', π ' | ππ | τ° , $\pi^{\circ}\gamma$, | $\eta\gamma$ data. |
| $\Gamma(e^+e^-)/\Gamma_{\rm total}$: | $\times \Gamma(\eta \gamma)$ | /Γ _{total} | | | $\Gamma_9/\Gamma \times \Gamma_5/\Gamma$ |
| VALUE (units 10 ⁻⁸) | <u>EVTS</u> | DO CUMENT IE |) | TECN | COMMENT |
| 3.32±0.28 OUR FIT | Error inc | | | | |
| 3.18±0.28 OUR AV | ERAGE | 0.7 | | | |
| $3.10 \pm 0.31 \pm 0.11$ | 33k | ²⁷ ACHASOV | | в SND | , , |
| $3.17^{+1.85}_{-1.31} \pm 0.21$ | 17.4k | ²⁸ AKHMETSH | IN 05 | CMD | 2 0.60-1.38 $e^+e^- \rightarrow \eta \gamma$ |
| $3.41 \pm 0.52 \pm 0.21$ | 23k ²⁹ | | | | $e^+e^- \rightarrow \eta \gamma$ |
| • • We do not use | e the follow | ing data for aver | ages, | fits, limi | ts, etc. • • • |
| 1.50±0.10 | | 31 BENAYOUN | 10 | RVUE | 0.4-1.05 e ⁺ e ⁻ |
| 27 From a combine | d fit of σ(e | $e^+e^- \rightarrow n\gamma) v$ | vith ~ | $a \rightarrow 3\pi$ | 0 and $\eta \rightarrow \pi^+\pi^-\pi^0$, and |
| fixing B($n \rightarrow 3\tau$ | r^0) / B(n | $\rightarrow \pi^{+}\pi^{-}\pi^{0}) =$ | 1.44 | ± 0.04 | Recalculated by us from the |
| cross section at t | he beak. S | upersedes ACHA | SOV | UUD and | ACHASOV U6A. |
| 28 From the $\eta \rightarrow ^{29}$ | $^2\gamma$ decay an | d using $B(\eta ightarrow 0.001)$ | $\gamma \gamma) =$ | 39.43 ± | 0.26%. |
| 29 From the $\eta \rightarrow 3$ | βπ ^o decay a | and using $B(\eta \rightarrow 1300)$ | $3\pi^0$ |)= (32.2 | $(4 \pm 0.29) \times 10^{-2}$ |
| | | | | | int $ ho(770)$, $\omega(782)$, $\phi(1020)$, MeV respectively). |
| 31 A simultaneous f | it of e + e - | $\rightarrow \pi^{+}\pi^{-}, \pi^{+}$ | $\pi^-\pi$ | $0, \pi^0\gamma$ | $\eta \gamma$ data. |
| | | | | | |
| | • | 82) BRANCH | NG | RATIOS | 5 |
| $(\pi^+\pi^-\pi^0)/\Gamma_{\rm tot}$ | al | | | | Γ_1/Γ |
| ALUE | EVTS | | | | CN COMMENT |
| • • We do not use | e the follow | ring data for aver | ages. | tits, limi | ts. etc. • • • |

| | EVTS | DO CUMENT ID | | | COMMENT |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | use the f | ollowing data for a | - | | |
| 8.09 ± 0.14 | | ³⁶ AMBROSINO | | | $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}2\pi^{0}, 2\pi^{0}$ |
| | | 7,38 AKHMETSHII | | | $0.60-1.38 \ e^{+} \ e^{-} \rightarrow \pi^{0} \gamma$ |
| $9.34 \pm 0.15 \pm 0.31$ $8.65 \pm 0.16 \pm 0.42$ | | 38 ACHASOV | 03 | SND | $0.60-0.97 \ e^{+} \ e^{-} \rightarrow \pi^{0} \gamma$ |
| 8.65 ± 0.16 ± 0.42 | 1.2IVI | ACHASOV | 03D | RVUE | $0.44-2.00 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 8.39 ± 0.24 | 9975 | 41 BENAYOUN | 96 | RVUE | $e^+e^- \rightarrow \pi^0 \gamma$ |
| 8.88 ± 0.62 | 10625 | 38 DOLINSKY | 89 | ND | $e^+ e^- \rightarrow \pi^0 \gamma$ |
| | | $\Gamma^0 \gamma) \ / \ \Gamma(\pi^+ \pi^- \pi^0)$ | | | ROSINO 08G. |
| ³⁷ Using B($\omega \rightarrow$ | e+ e-): | = (7.14 ± 0.13) × | 10-5 | 0 | 1=2 |
| 39 a sun a | ent of the | corresponding $\Gamma(e)$ | ' e . |) × I (π° | $\gamma_{\rm I}/{\rm I}_{\rm total}$ |
| 40 Not independs | OV U3, A | corresponding Γ(<i>e</i> | + ω – · | $\rightarrow \pi \cdot \pi$ | $(\pi^{-}) = (1.70 \pm 0.28)\%.$ |
| 41 Reanalysis of triangle anom | DRUZHII | NIN 84, DOLINSK | Y 89, | DOLINS | 5KY 91 taking into account 1 |
| $\Gamma(\pi^0\gamma)/\Gamma(\pi^+\gamma)$ | | | | | Γ ₂ / |
| VALUE (units 10 ⁻²) | , | DOCUMENT ID | 7 | ECN C | • 27 COMMENT |
| 9.28±0.31 OUR | FIT Er | ror includes scale fa | | | OMMENT |
| 9.05 ± 0.27 OUR | | | | | 1.8. |
| 8.97 ± 0.16 | | | | | $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}2\pi^{0}, 2\pi^{0}\gamma$ |
| $9.94 \pm 0.36 \pm 0.38$ | 3 4 | | | | $e^+e^- \rightarrow \pi^+\pi^-2\pi^0$, $2\pi^0\gamma$ |
| 8.4 ±1.3 | | | | | $e^- p \rightarrow \omega n$ $e^+ e^- \rightarrow \pi^0 \gamma$ |
| 10.9 ±2.5 8.1 ±2.0 | | | | | $e \cdot e \rightarrow \pi^{\circ} \gamma$ 2.9 $\pi^{+} p$ |
| 13 ±4 | | | | | $2.05 \pi^+ p \rightarrow \pi^+ p \omega$ |
| | use the f | ollowing data for a | | | |
| 9.7 ±0.2 ±0.5 | 43,4 | ⁴ ACHASOV (| 3D R | VUE 0 | $0.44-2.00 \ e^{+} \ e^{-} \rightarrow \pi^{+} \pi^{-}$ |
| 9.9 ± 0.7 | 4 | ¹³ DOLINSKY 8 | 39 N | ID e | $e^+e^- \rightarrow \pi^0\gamma$ |
| 42 From _ωπ ⁰ - | $\rightarrow \pi^0 \pi^0 \gamma_I$ | $m = 1/2\omega \pi^0 \rightarrow \pi^+$ | $\pi^{-} \pi^{0}$ | π^0 (m) | with a phase-space correct |
| factor of $1/1$. | ((| $m_{\phi}^{\prime\prime}/\sigma_{0}^{\prime\prime}$ | | (m_{ϕ}) | with a phase-space correct |
| 43 Not ind | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | E. | 1 . | | 1=2 |
| - ivot independe | ent of the | corresponding 11 <i>e</i> | $^+e^-$ | $) \times \Gamma(\pi^{\circ}$ | 'γ)/[' |
| | | corresponding $\Gamma(e)$ | |) × Γ(π ⁰ | 'γ)/Γ ² total |
| ⁴⁴ Using ACHAS | OV 03. E | corresponding I (e Based on 1.2M ever | |) × Γ(π ^υ | |
| 44 Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{tot}$ | OV 03. B | Based on 1.2M ever | |) × Γ(π ^υ | (^/)/ total |
| ⁴⁴ Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{tot}$ See also Γ(: | OV 03. E $\pi^+\pi^-)/0$ | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. | nts. | | Гз |
| ⁴⁴ Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{tot}$ See also Γ($\frac{VALUE}{T}$ (units 10^{-2}) | OV 03. E al $\pi^+ \pi^-)/1$ EVTS | Sased on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. | its. | <u>TECN</u> | Гз |
| ⁴⁴ Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{tot}$ See also Γ(: | OV 03. E al $\pi^+ \pi^-)/1$ EVTS | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID or includes scale fac | otor of | <u>TECN</u> f 1.2. | Γ ₃ |
| ⁴⁴ Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{tot}$ See also Γ($\frac{VALUE}{T}$ (units 10^{-2}) | OV 03. E al $\pi^+ \pi^-)/l$ EVTS FIT Error | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID or includes scale factorized includes scale factorized includes so the scale factorized includes includes include includes so the scale factorized includes so the scale factorized includes include includes include includes include includes include include includes include include includes include include include include includes include includ | etor of | <u>TECN</u> f 1.2. | COMMENT 1.3. See the ideogram below. |
| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\frac{1}{2})$ 1.53 $^{+}$ 0.11 OUR 1.49 $^{\pm}$ 0.12 OUR 1.46 $^{\pm}$ 0.12 $^{\pm}$ 0.02 | OV 03. E al π ⁺ π ⁻)/! <u>EVTS</u> FIT Erro AVERAGE 900k | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID or includes scale factor includes scal | ctor of cale fa N 07 | <u>TECN</u> f 1.2. ector of 1 | Γ_3 |
| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\frac{1}{2})$ $^{1.53}$ $^{+0.11}$ OUR 1 $^{1.49}$ $^{+0.13}$ OUR 1 $^{1.46}$ $^{+0.12}$ $^{+0.02}$ $^{1.30}$ $^{+0.12}$ | OV 03. E al π + π -) / I <u>EVTS</u> FIT Erro AVERAGE 900k 11.2k | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID or includes scale factor of the scale of the s | ctor of cale fa N 07 | <u>TECN</u> f 1.2. ector of 1 | COMMENT |
| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\frac{1}{2})$ 1.53 $^{+}$ 0.11 OUR 1.49 $^{\pm}$ 0.12 OUR 1.46 $^{\pm}$ 0.12 $^{\pm}$ 0.02 | OV 03. E al π + π -) / I <u>EVTS</u> FIT Erro AVERAGE 900k 11.2k | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID or includes scale factor includes scal | ctor of cale fa N 07 | <u>TECN</u> f 1.2. ector of 1 | COMMENT 1.3. See the ideogram below. $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ 1.1-1.38 e ⁺ e ⁻ \rightarrow |
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| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\cdot)$ $\times ALUE (units 10^{-2})$ 1.53 $^{+}0.11$ 0.11 0.11 1.49 $^{+}0.13$ 0.13 0.18 1.46 $^{+}0.12$ 0.02 1.30 $^{+}0.24$ 0.05 2.38 $^{+}1.77$ 3.6 $^{+}0.9$ 3.6 $^{+}0.9$ 3.6 $^{+}0.9$ 4.9 4.0 5.0 6.0 7.0 7.0 7.0 7.0 7.0 7.0 7.0 7.0 7.0 7 | OV 03. E al $\pi^+\pi^-)/l$ EVTS FIT Error AVERAGE 900k 11.2k 5.4k use the for 4.5 M | The state of the s | ctor of cale fa N 07 N 04 02E 85 78 72 everage 05A 78 78 78 78 77 C 71 70B | TECN f 1.2. ctor of : CMD2 SND OLYA DM1 OSPK ss, fits, li SND RVUE RVUE RVUE ASPK CNTR HBC CNTR | COMMENT 1.3. See the ideogram below. $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $1.1-1.38 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $1.1-1.38 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ imits, etc. \bullet \bullet $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}$ |
| 44 Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{\rm tot}$ See also $\Gamma(\frac{1}{2})$ $\Gamma(\pi^+\pi^-)/\Gamma_{\rm tot}$ See also $\Gamma(\frac{1}{2})$ 1.53 $\stackrel{+}{=}0.13$ OUR I 1.49 $\stackrel{+}{=}0.13$ OUR I 1.49 $\stackrel{+}{=}0.13$ OUR I 1.46 $\stackrel{+}{=}0.12 \pm 0.02$ 1.30 $\stackrel{+}{=}0.24 \pm 0.05$ 2.38 $\stackrel{+}{=}1.77 \pm 0.18$ 2.3 $\stackrel{+}{=}0.5$ 1.6 $\stackrel{+}{=}0.9$ 3.6 $\stackrel{+}{=}1.9$ • • • We do not 1.75 $\stackrel{+}{=}0.11$ 2.01 $\stackrel{+}{=}0.29$ 1.9 $\stackrel{+}{=}0.3$ 2.3 $\stackrel{+}{=}0.4$ 1.0 $\stackrel{+}{=}0.11$ 1.02 $\stackrel{+}{=}0.3$ 1.3 $\stackrel{+}{=}0.2$ 45 A combined fi 46 Update of AK 47 From the m_π | OV 03. E al $\pi^+\pi^-)/l$ $EVTS$ FIT Error AVERAGE 900k 11.2k 5.4k use the fr 4.5 M | Based on 1.2M ever F (\pi + \pi - \pi^0). \textit{DOCUMENT ID} Or includes scale fact E rror includes scale fact 45 AKH MET SHII 46 AKH MET SHII 47 ACHA SOV BARKOV QUENZER BENAKSAS Ollowing data for according data for according data for according to the scale of the | ottor of cale factor | TECN f 1.2. ctor of 1 CMD2 SND OLYA DM1 OSPK ss, fits, li SND RVUE RVUE RVUE RVUE ASPK CNTR HBC CNTR | 1.3. See the ideogram below: $e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}$ $1.1.3. See the ideogram below: e^{+}e^{-}\rightarrow\pi^{+}\pi^{-} 1.1.1.38 e^{+}e^{-}\rightarrow\pi^{+}\pi^{-} e^{+}e^{-}\rightarrow\pi^{+}\pi^{-} e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{+}e^{-}\rightarrow\pi^{+}\pi^{-}e^{-}e^{-}e^{-}e^{-}e^{-}e^{-}e^{-}e$ |
| 44 Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{\rm tot}$ See also $\Gamma(\frac{1}{2})$ 1.53 $^+$ 0.11 OUR 1 1.49 $^+$ 0.13 OUR 1 1.49 $^+$ 0.13 OUR 1 1.49 $^+$ 0.15 0UR 1 1.40 $^+$ 0.15 0.18 2.3 $^+$ 1.77 0.18 2.3 $^+$ 1.77 0.18 2.3 $^+$ 1.77 0.18 2.3 $^+$ 1.77 0.7 3.6 $^+$ 1.9 • • • We do not 1.75 $^+$ 0.11 2.01 $^+$ 0.29 1.0 $^+$ 0.11 1.22 $^+$ 0.3 1.3 $^+$ 1.2 1.0 $^+$ 0.11 1.22 $^+$ 0.3 1.3 $^+$ 1.2 0.80 $^+$ 0.28 0.80 $^+$ 0.28 0.20 45 A combined fi 46 Update of AK From the m amplitudes. | OV 03. E al $\pi^{+}\pi^{-})/l$ EVTS FIT Error AVERAGE 900k 11.2k 5.4k 4.5M t of AKH HMETSH $+\pi^{-}$ spe | Based on 1.2M ever $\Gamma(\pi^+\pi^-\pi^0)$. DOCUMENT ID. or includes scale factor includes sca | ctor of cale fa N 07 N 04 02E 85 78 72 verage 05A 71 70B LCHE account | TECN f 1.2. ctor of 3 CMD2 SND OLYA DM1 OSPK s, fits, li SND RVUE RVUE RVUE ASPK CNTR HBC CNTR NKO 06, nt the i | COMMENT 1.3. See the ideogram below. $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^-$ wints, etc. \bullet |
| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\frac{1}{2})$ $1.53 + 0.11 - 0.11 \text{ OUR } 1$ $1.49 + 0.13 \text{ OUR } 1$ $1.46 + 0.12 + 0.02$ $1.30 + 0.24 + 0.05$ $2.38 + 1.77 + 0.18$ $2.3 + 0.5$ $1.6 + 0.9 - 0.7$ $3.6 + 1.9 - 0.7$ $3.6 + 1.9$ • • • We do not $1.75 + 0.11$ $2.01 + 0.29$ $1.9 + 0.3$ $2.3 + 0.4$ $1.0 + 0.11$ $1.22 + 0.30$ $1.3 + 1.2$ -0.9 $0.80 + 0.28$ -0.20 45 A combined fi 46 Update of AK $47 \text{ From the } m_{\pi}$ amplitudes. $48 \text{ Using } \Gamma(\omega \rightarrow \omega)$ | OV 03. E al $\pi^+\pi^-)/l$ EVTS FIT Error AVERAGE 900k 11.2k 5.4k 4.5 M t of AKH H METSH $+\pi^-$ spe $e^+e^-)$ | Based on 1.2M ever F (\pi + \pi - \pi 0). \[\textit{DOCUMENT ID.} \] Or includes scale fact F (\pi + \pi \text{AKMMETSHII} F (\pi \text{AKMMETSHIII} F (\pi AKMMETSHIIII) F (\pi \text{AKMMETS | tor of cale fa N 07 N 04 02E 85 78 72 verage 05A 78 71 70B LCHE accountion of | TECN f 1.2. ctor of 1 CMD2 SND OLYA DM1 OSPK ss, fits, lit SND RVUE RVUE ASPK CNTR HBC CNTR NKO 06, nt the i | COMMENT 1.3. See the ideogram below. $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^-$ 1.1-1.38 $e^+e^- \rightarrow \pi^+\pi^-$ 1.1-1.38 $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^-$ inits, etc. \bullet \bullet $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^- \rightarrow \pi^ e^- \rightarrow \pi$ |
| 44 Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{\rm tot}$ See also $\Gamma(\frac{1}{2})$ 1.53 $\stackrel{+}{=}0.13$ OUR 1 1.49 $\stackrel{+}{=}0.13$ OUR 1 1.46 $\stackrel{+}{=}0.13$ OUR 1 1.46 $\stackrel{+}{=}0.13$ OUR 1 1.46 $\stackrel{+}{=}0.12 \stackrel{+}{=}0.02$ 1.30 $\stackrel{+}{=}0.24 \stackrel{+}{=}0.05$ 2.38 $\stackrel{+}{=}0.90 \stackrel{+}{=}0.18$ 2.3 $\stackrel{+}{=}0.5$ 1.6 $\stackrel{+}{=}0.9$ 2.8 $\stackrel{+}{=}0.90$ 2.9 $\stackrel{+}{=}0.90$ 2.9 $\stackrel{+}{=}0.90$ 2.10 $\stackrel{+}{=}0.90$ 2.11 $\stackrel{+}{=}0.90$ 2.3 $\stackrel{+}{=}0.11$ 2.01 $\stackrel{+}{=}0.29$ 2.3 $\stackrel{+}{=}0.4$ 2.3 $\stackrel{+}{=}0.4$ 2.3 $\stackrel{+}{=}0.4$ 2.4 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 | OV 03. E al $\pi^+\pi^-)/l$ EVTS FIT Error 900k 11.2k 5.4k use the fr 4.5 M t of AKH HMETSH $+\pi^-$ spe $e^+e^-)$ a of AKH | Based on 1.2M ever F (\pi + \pi - \pi^0). \textit{DOCUMENT ID} Or includes scale fact E rror includes scale fact 45 AKHMETSHII 46 AKHMETSHII 47 ACHASOV BARKOV QUENZER BENAKSAS Ollowing data for act 48 ACHASOV 49 BENAYOUN 50 GARDNER 51 BENAYOUN 52 WICKLUND ALVENSLEB MOFFEIT 53 BIGGS METSHIN 07, AUI III 02. ctrum taking into from the 2004 Edit METSHIN 02 in the MET | tor of cale fa N 07 N 04 02E 85 78 72 verage 05A 78 71 70B LCHE accountion of | TECN f 1.2. ctor of 1 CMD2 SND OLYA DM1 OSPK ss, fits, lit SND RVUE RVUE ASPK CNTR HBC CNTR NKO 06, nt the i | COMMENT 1.3. See the ideogram below. $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^-$ 1.1-1.38 $e^+e^- \rightarrow \pi^+\pi^-$ 1.1-1.38 $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^-$ inits, etc. \bullet \bullet $e^+e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^- \rightarrow \pi^+\pi^ e^+e^- \rightarrow \pi^+\pi^ e^- \rightarrow \pi^ e^- \rightarrow \pi$ |
| 44 Using ACHAS $\Gamma(\pi^+\pi^-)/\Gamma_{\rm tot}$ See also $\Gamma(\frac{1}{2})$ 1.53 $^+$ 0.11 OUR 1.49 $^+$ 0.13 OUR 1.49 $^+$ 0.13 OUR 1.40 $^+$ 0.15 $^+$ 0.16 $^+$ 0.17 $^-$ 0.18 2.3 $^+$ 1.77 $^+$ 0.18 2.3 $^+$ 1.77 $^+$ 0.19 $^+$ 0.18 2.3 $^+$ 1.77 $^+$ 0.19 $^+$ 0.18 2.3 $^+$ 1.77 $^+$ 0.7 3.6 $^+$ 1.9 $^+$ 0.9 • • • We do not 1.75 $^+$ 0.11 2.01 $^+$ 0.29 1.19 $^+$ 0.3 2.3 $^+$ 0.4 1.0 $^+$ 0.11 1.22 $^+$ 0.30 1.3 $^+$ 1.2 $^+$ 0.9 0.80 $^+$ 0.28 $^+$ 0.20 45 A combined fi 46 Update of AK 47 From the m_π amplitudes. 48 Using $\Gamma(\omega \rightarrow 49)$ Using the dation of the second of the | OV 03. E al $\pi^+\pi^-)/I$ EVTS FIT Error 900k 11.2k 5.4k 4.5M t of AKH HMETSH $+\pi^-$ spe $e^+e^-)$ a of AKH a of BAR | Transport of the state of the s | ctor of cale far N 07 N 04 02E 85 78 72 verage 05A 78 78 77 C 71 70B LCHE accountion of e hiddelen local den local d | TECN f 1.2. ctor of 3 CMD2 SND OLYA DM1 OSPK s, fits, li SND RVUE RVUE RVUE RVUE ASPK CNTR HBC CNTR NKO 06, nt the i this Red | COMMENT 1.3. See the ideogram below. $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $1.1-1.38 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ wints, etc. • • $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ e^{+} |
| 44 Using ACHAS $\Gamma(\pi^{+}\pi^{-})/\Gamma_{\text{tot}}$ See also $\Gamma(\frac{1}{2})$ $1.53 + 0.11 \text{OUR} O$ | OV 03. E al $\pi^+\pi^-)/l$ EVTS FIT Error 900k 11.2k 5.4k 4.5 M t of AKH H MET SH $+\pi^-$ spe $e^+e^-)$ a of AKH dependen | Based on 1.2M ever $(\pi^+\pi^-\pi^0)$. DOCUMENT ID. TO includes scale factor includes scal | ctor of cale far N 07 N 04 O2E 85 72 Verage 05A 03 99 8 78 . 71C 71 70B LCHE accountion of e hide | TECN f 1.2. cctor of 1 CMD2 SND OLYA DM1 OSPK ss, fits, li SND RVUE RVUE RVUE ASPK CNTR HBC CNTR NKO 06, nt the i f this Reden local | COMMENT 1.3. See the ideogram below. $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $1.1-1.38 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ wints, etc. • • $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}$ e^{+} |

| $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{ m total}$ | | | | | Γ_1 | /I |
|---------------------------------------------------------------|--------------------|--------------------------------|---------|-----------|-------------------------------------------------------------|--------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use the | following | g data for averages | , fits, | limits, e | tc. • • • | |
| 0.9024 ± 0.0019 | | ³² A MBROSINO | 08 G | KLOE | $^{1.0-1.03}_{\pi^+\pi^-2\pi^0, 2\pi^0}e^+e^{2\pi^0}$ | \sim |
| $0.8965 \pm 0.0016 \pm 0.0048$ $0.880 \pm 0.020 \pm 0.032$ | 1.2M ³³ | ^{3,34} ACHASOV | 03D | RVUE | $0.44-2.00 e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} \pi^{0}$ | |
| $0.880 \ \pm 0.020 \ \pm 0.032$ | 11200 34 | ^{1,35} AKHMETSHII | 100c | CMD2 | $e^+e^- \rightarrow \pi^+\pi^-\pi$ | .0 |
| 0.8942 ± 0.0062 | | ³⁴ DOLINSKY | 89 | ND | $e^+e^- \rightarrow \pi^+\pi^-\pi$ | .0 |
| 32 Not independent of Γ | $(\pi^0 \gamma)$ / | $\Gamma(\pi^+\pi^-\pi^0)$ from | AME | ROSING | O 08G. | |

³³ Using ACHASOV 03, ACHASOV 03D and B($\omega \to \pi^+\pi^-$) = (1.70 ± 0.28)%. 34 Not independent of the corresponding $\Gamma(e^+e^-) \times \Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\rm total}^2$.

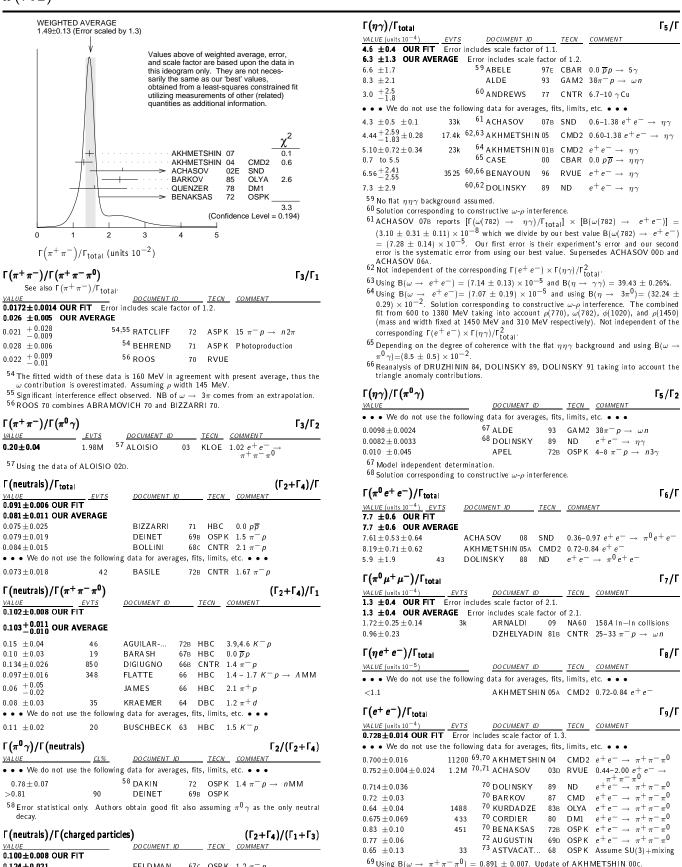
 $^{^{35}\,{}m Using}\,\,\Gamma(e^+\,e^-){=}0.60\,\pm\,0.02\,\,{
m keV}.$

 $\omega(782)$

 0.124 ± 0.021

FELDMAN

67c OSPK 1.2 π⁻ p



70 Not independent of the corresponding $\Gamma(e^+\,e^-) \times \Gamma(\pi^+\,\pi^-\,\pi^0)/\Gamma_{
m total}^2$ 71 Using ACHASOV 03, ACHASOV 03D and B($\omega \to \pi^+\pi^-$) = (1.70 \pm 0.28)%. 72 Rescaled by us to correspond to ω width 8.4 MeV. Systematic errors underestimated.

 $^{73}\,\mathrm{Not}$ resolved from ρ decay. Error statistical only.

Meson Particle Listings ω (782)

| $\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ | $\Gamma(\pi^0 \mu^+ \mu^-)/\Gamma(\mu^+ \mu^-)$ Γ_7/Γ_{15} |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT | <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> • • • • We do not use the following data for averages, fits, limits, etc. • • • |
| < 2 90 ACHASOV 09A SND $e^+e^- \rightarrow \pi^+\pi^-\pi^0\pi^0$ • • • We do not use the following data for averages, fits, limits, etc. • • • | 1.2 \pm 0.6 30 ⁷⁸ DZHELYADIN 79 CNTR 25–33 π^-p |
| <200 90 KURDADZE 86 OLYA $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}\pi^{0}$ | 78 Superseded by DZHELYADIN 81B result above. |
| $\Gamma(\pi^+\pi^-\gamma)/\Gamma_{	ext{total}}$ Γ_{11}/Γ | $\Gamma(3\gamma)/\Gamma_{total}$ Γ_{16}/Γ |
| VALUE CL% DOCUMENT ID TECN COMMENT <0.0036 95 WEIDENAUER 90 ASTE $p\overline{p} \rightarrow \pi^+\pi^-\pi^+\pi^-\gamma$ | $\frac{VALUE \text{ (units }10^{-4})}{4.9}$ $\frac{CL\%}{95}$ $\frac{DOCUMENT \ ID}{79 \text{ ABELE}}$ $\frac{TECN}{97E}$ $\frac{COMMENT}{DD \rightarrow 5\gamma}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • | • • • We do not use the following data for averages, fits, limits, etc. • • |
| <0.004 95 BITYUKOV 88B SPEC 32 $\pi^- ho ightarrow \pi^+ \pi^- \gamma {\sf X}$ | $<$ 2 90 ⁷⁹ PROKOSHKIN 95 GAM2 38 $\pi^- p ightarrow ~3 \gamma n$ |
| $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{11}/Γ_1 | 79 From direct 3γ decay search. |
| VALUECL%DOCUMENT IDTECNCOMMENT | $\Gamma(\eta\pi^0)/\Gamma_{ m total}$ Γ_{17}/Γ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | `Violates C conservation. <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> |
| <0.066 90 KALBFLEISCH 75 HBC $2.18~K^-p \rightarrow \Lambda\pi^+\pi^-\gamma$ <0.05 90 FLATTE 66 HBC $1.2-1.7~K^-p \rightarrow \Lambda\pi^+\pi^-\gamma$ | • • • We do not use the following data for averages, fits, limits, etc. • • • < 0.001 90 ALDE 94B GAM2 $38\pi^- p \to \eta \pi^0 n$ |
| $\Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{12}/Γ | $\left[\Gamma(\eta\gamma) + \Gamma(\eta\pi^{0})\right]/\Gamma(\pi^{+}\pi^{-}\pi^{0}) \tag{\Gamma_{5}+\Gamma_{17}}/\Gamma_{1}$ |
| VALUE CL% DOCUMENT ID TECN COMMENT | VALUE CL% DOCUMENT ID TECN COMMENT |
| <1 × 10⁻³ 90 KURDADZE 88 OLYA $e^+e^{\pi^+\pi^-\pi^+\pi^-}$ | <0.016 90 ⁸⁰ FLATTE 66 HBC 1.2 − 1.7 $K^-p \to \Lambda \pi^+ \pi^-$ MM |
| | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $\Gamma(\pi^{0}\pi^{0}\gamma)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECH COMMENT | <0.045 95 JACQUET 69B HLBC $2.05~\pi^+p ightarrow~\pi^+p\omega$ |
| 6.6±1.1 OUR FIT | 80 Restated by us using B($\eta ightarrow$ charged modes) = 29.2%. |
| 6.5±1.2 OUR AVERAGE $6.4^{+}2.04_{0}\pm0.8$ 190 ⁷⁴ AKHMETSHIN 04B CMD2 0.6-0.97 $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\gamma$ | $\Gamma(\eta\pi^0)/\Gamma(\pi^0\gamma)$ Γ_{17}/Γ_2 Violates C conservation. |
| -2.0 | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| $6.6^{+1.4}_{-1.3}\pm 0.6$ 295 ACHASOV 02F SND $0.36^{+0.97}_{-0.07} e^+ e^- ightarrow 0.36^{+0.97}_{-0.07} \gamma$ | <2.6 90 ⁸¹ STAROSTIN 09 CRYM $\gamma p \rightarrow \eta \pi^0 p$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | ⁸¹ STAROSTIN 09 reports $\left[\Gamma\left(\omega(782)\to\eta\pi^0\right)/\Gamma\left(\omega(782)\to\pi^0\gamma\right)\right]\times\left[B(\eta\to2\gamma)\right]$ < 1.01 × 10 ⁻³ which we divide by our best value $B(\eta\to2\gamma)=39.31\times10^{-2}$. |
| 11.8 $^{+2.1}_{-1.9}\pm$ 1.4 190 75 AKHMETSHIN 04B CMD2 0.6 $-$ 0.97 $e^+e^-\to\pi^0\pi^0\gamma$ | |
| 7.8 \pm 2.7 \pm 2.0 63 ⁷⁴ ,7 ⁶ ACHASOV 00G SND $e^+e^- \to \pi^0\pi^0\gamma$ 12.7 \pm 2.3 \pm 2.5 63 ⁷⁵ ,7 ⁶ ACHASOV 00G SND $e^+e^- \to \pi^0\pi^0\gamma$ | $\Gamma(2\pi^0)/\Gamma(\pi^0\gamma)$ Γ_{18}/Γ_2 Violates C conservation and Bose-Einstein statistics. |
| 74 In the model assuming the $ ho 	o 	au^0 \pi^0 \gamma$ decay via the $\omega \pi$ and $f_0(500) \gamma$ mechanisms. | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| 75 In the model assuming the $ ho 	o \pi^0 \pi^0 \gamma$ decay via the $\omega\pi$ mechanism only. 76 Superseded by ACHASOV 02F. | <2.59 90 STAROSTIN 09 CRYM $\gamma p \rightarrow 2\pi^0 p$ |
| | $\Gamma(3\pi^0)/\Gamma_{\text{total}}$ Γ_{19}/Γ Violates C conservation. |
| $\Gamma(\pi^0\pi^0\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{13}/Γ_1 VALUE CL% DOCUMENT ID TECN COMMENT | <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> • • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <0.00045 90 DOLINSKY 89 ND $e^+e^- ightarrow \pi^0\pi^0\gamma$ | $<3 \times 10^{-4}$ 90 PROKOSHKIN 95 GAM2 38 $\pi^- p \rightarrow 3 \pi^0 n$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <0.08 95 JACQUET 69B HLBC $2.05~\pi^+p \to \pi^+p\omega$ | $\Gamma(3\pi^0)/\Gamma(\pi^0\gamma)$ Γ_{19}/Γ_2 |
| $\Gamma(\pi^0\pi^0\gamma)/\Gamma(\pi^0\gamma)$ Γ_{13}/Γ_2 | Violates C conservation. VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT | <2.72 90 STAROSTIN 09 CRYM $\gamma p \rightarrow 3\pi^0 p$ |
| 8.0±1.3 OUR FIT | $\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{19}/Γ_1 |
| 8.5 ± 2.9 40 ± 14 ALDE 94B GAM2 $38\pi^- p \rightarrow \pi^0 \pi^0 \gamma n$ • • • We do not use the following data for averages, fits, limits, etc. • • • | Violates C conservation. |
| $<$ 50 90 DOLINSKY 89 ND $e^+e^- ightarrow~\pi^0\pi^0\gamma$ | <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>COMMENT</u> • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <1800 95 KEYNE 76 CNTR $\pi^- p \rightarrow \omega n$ <1500 90 BENAKSAS 72C OSPK $e^+ e^-$ | < 0.009 90 BARBERIS 01 450 $\rho p \to \rho_f 3\pi^0 \rho_S$ |
| <1500 90 BENAKSAS 72C OSPK e^+e^- <1400 BALDIN 71 HLBC $2.9 \pi^+ \rho$ | |
| <1000 90 BARMIN 64 HLBC 1.3-2.8 $\pi^- p$ | PARAMETER A IN $\omega ightarrow \ \pi^0 \mu^+ \mu^-$ DECAY |
| $\Gamma(\pi^0\pi^0\gamma)/\Gamma(\text{neutrals})$ $\Gamma_{13}/(\Gamma_2+\Gamma_4)$ | In the pole approximation the electromagnetic transition form factor for a resonance of mass M is given by the expression: |
| <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> • • • We do not use the following data for averages, fits, limits, etc. • • • | $ F ^2 = (1 - M^2/\Lambda^2)^{-2}$ |
| 0.22 \pm 0.07 77 DAKIN 72 OSPK 1.4 $\pi^- p \rightarrow n$ MM | where for the parameter Λ vector dominance predicts $\Lambda=M_p\approx 0.770$ GeV. The ARNALDI 09 measurement is in obvious conflict with this expectation. Note that |
| <0.19 90 DEINET 69B OSPK | for $\eta \to \mu^+\mu^-\gamma$ decay ARNALDI 09 and DZHELYADIN 80 obtain the value of Λ consistent with vector dominance. |
| ⁷⁷ See $\Gamma(\pi^0 \gamma)/\Gamma$ (neutrals). | Consistent with vector dominance. <u>VALUE (GeV)EVTSDOCUMENT IDTECNCOMMENT</u> |
| $\Gamma(\eta\pi^0\gamma)/\Gamma_{	ext{total}}$ Γ_{14}/Γ | 0.668±0.009±0.003 3k ARNALDI 09 NA 60 158 <i>A</i> In−In collisions |
| VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • • 0.65 ±0.03 DZHELYADIN 81s CNTR 25-33 = 0 → 00s |
| <3.3 90 AKHMETSHIN 04B CMD2 0.6 – $0.97~e^+~e^- ightarrow \eta \pi^0 \gamma$ | 0.65 \pm 0.03 DZHELYADIN 81B CNTR 25-33 $\pi^- \rho \rightarrow \omega n$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{	ext{total}}$ Γ_{15}/Γ | ω (782) REFERENCES |
| <u>VALUE (units 10⁻⁵) </u> | BENAYOUN 10 EPJ C65 211 M. Benayoun et al. ACHASOV 09A JETP 109 379 M.N. Achasov et al. (SND Collab.) Translated from ZETF 136 442. |
| 9.0 ± 2.9 ± 1.1 18 HEISTER 02c ALEP $Z \to \mu^+ \mu^- + X$ | ARNALDI 09 PL B677 260 R. Arnaldi <i>et al.</i> (NA60 Collab.) STAROSTIN 09 PR C79 065201 A. Starostin <i>et al.</i> (Crystal Ball Collab. at MAMI) |
| $\Gamma(\mu^+\mu^-)/\Gamma(\pi^+\pi^-\pi^0)$ Γ_{15}/Γ_1 | ACHASOV 08 JETP 107 61 M.N. Achasov et al. (SND Collab.) Translated from ZETF 134 80. |
| VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT | AMBROSINO 08 GPL B669 223 F. Ambrosino et al. (KLOE Collab.) ACHASOV 07B PR D76 077101 M.N. Achasov et al. (SND Collab.) AVENUETS UN 07 PR D P609 29 A Abbrosibility et al. (NDC collab.) |
| <0.2 90 WILSON 69 OSPK $12 \pi^- C \rightarrow Fe$ • • • We do not use the following data for averages, fits, limits, etc. • • • | AKHMETSHIN 07 PL B648 28 R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) ACHASOV 06 JETP 103 380 M.N. Achasov et al. (Novosibirsk SND Collab.) Translated from ZETF 130 437. |
| <1.7 74 FLATTE 66 HBC 1.2 – 1.7 $K^- \rho \rightarrow$ | ACHASOV 06A PR D74 014016 M.N. Achasov et al. (SND Collab.) AULCHENKO 06 JETPL 84 413 V.M. Aulchenko et al. (Novosibirsk CMD-2 Collab.) |
| $\Lambda \mu^+ \mu^-$ | Translated from ZETFP 84 491. ACHASOV 05A JETP 101 1053 M.N. Achasov et al. (Novosibirsk SND Collab.) |
| <1.2 BARBARO 65 HBC 2.7 K ⁻ p | Translated from ZETF 128 1201. |

 ω (782), η' (958)

| AKHMETSHIN AKHMETSHIN | 05 A | PL B605 26 R.R. Akhmetshin et al. PL B613 29 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) |
|-----------------------------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AULCHENKO AKHMETSHIN | 05 04 | JETPL 82 743 V.M. Aulchenko et al. (Novosibirsk CMD-2 Collab.) Translated from ZETFP 82 841. PL B578 285 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) |
| AKHMETSHIN AUBERT,B | 04 B 04 N | PL B580 119 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) PR D70 072004 B. Aubert et al. (BABAR Collab.) |
| PDG ACHASOV | 04 03 | PL B592 1 S. Eidelman et al. (PDG Collab.) PL B559 171 M.N. Achasov et al. (Novosibirsk SND Collab.) |
| A CHASOV A LOISIO BENAYOUN | 03 D 03 03 | PR D68 052006 M.N. Achasov et al. (Novosibirsk SND Collab.) PL B561 55 A. Aloisio et al. (KLOE Collab.) EPJ C29 397 M. Benayoun et al. |
| A CHASOV ACHASOV | 02 E 02 F | PR D66 032001 M.N. Achasov et al. (Novosibirsk SND Collab.) PL B537 201 M.N. Achasov et al. (Novosibirsk SND Collab.) |
| AKHMETSHIN ALOISIO | 02 02 D | PL B527 161 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) PL B537 21 A. Aloisio et al. (KLOE Collab.) |
| HEISTER ACHASOV AKHMETSHIN | 02 C 01 E 01 B | PL B528 19 A. Heister et al. (ALEPH Collab.) PR D63 072002 M.N. Achasov et al. (Novosibirsk SND Collab.) PL B509 217 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) |
| BARBERIS A CHAS OV | 01 00 | PL B507 14 D. Barberis et al. EPJ C12 25 M.N. Achasov et al. (Novosibirsk SND Collab.) |
| A CHASOV A CHASOV | 00 D 00 G | JETPL 72 282 M.N. Achasov et al. (Novosibirsk SND Collab.) Translated from ZETFP 72 411. |
| AKHMETSHIN | 00 C | JETPL 71 355 M.N. Achasov et al. (Novosibirsk SND Collab.) Translated from ZETFP 71 519. PL B476 33 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) |
| AULCHENKO | 00 A | JETP 90 927 V.M. Aulchenko et al. (Novosibirsk SND Collab.) Translated from ZETF 117 1067. |
| CASE A CHASOV GARDNER | 00 99E 99 | PR D61 032002 T. Case <i>et al.</i> (Crystal Barrel Collab.) PL B462 365 M.N. Achasov <i>et al.</i> (Novosibirsk SND Collab.) PR D59 076002 S. Gardner, H.B. O'Connell |
| BENAYOUN ABELE | 98 97 E | EPJ C2 269 M. Benayoun et al. (IPNP, NOVO, ADLD+) PL B411 361 A. Abele et al. (Crystal Barrel Collab.) |
| BENAYOUN PROKOSHKIN | 96 95 | ZPHY C72 221 M. Benayoun et al. (IPNP, NOVO) SPD 40 273 Y.D. Prokoshkin, V.D. Samoilenko (SERP) |
| WURZINGER ALDE | 95 94 B | Translated from DANS 342 610. PR C51 443 R. Wurzinger et al. (BONN, ORSAY, SACL+) PL B340 122 D.M. Alde et al. (SERP, BELG, LANL, LAPP+) |
| AMS LER ALDE | 94 C 93 | PL B327 425 C. Amsler et al. (Crystal Barrel Collab.) PAN 56 1229 D.M. Alde et al. (SERP, LAPP, LANL, BELG+) |
| Also | 02 D | Translated from YAF 56 137. ZPHY C61 35 D.M. Alde et al. (SERP, LAPP, LANL, BELG+) |
| AMSLER WEIDENAUER ANTONELLI | 93 B 93 92 | PL B311 362 C. Amsler <i>et al.</i> (Crystal Barrel Collab.) ZPHY C59 387 P. Weidenauer <i>et al.</i> (ASTERIX Collab.) ZPHY C56 15 A. Antonelli <i>et al.</i> (DM2 Collab.) |
| DOLINS KY WEIDENAUER | 91 90 | PRPL 202 99 S.I. Dolinsky et al. (NOVO) ZPHY C47 353 P. Weidenauer et al. (ASTERIX Collab.) |
| DOLINS KY BITYUKOV | 89 88 B | ZPHY C42 511 S.I. Dolinsky et al. (NOVO) SJNP 47 800 S.I. Bityukov et al. (SERP) |
| DOLINS KY | 88 | Translated from YAF 47 1258. SJNP 48 277 S.I. Dolinsky et al. (NOVO) Translated from YAF 48 442. |
| KUR DAD ZE | 88 | JETPL 47 512 L.M. Kurdadze et al. (NOVO) Translated from ZETFP 47 432. |
| AULCHENKO BARKOV | 87 87 | PL B186 432 V.M. Aulchenko <i>et al.</i> (NOVO) JETPL 46 164 L.M. Barkov <i>et al.</i> (NOVO) Translated from ZETFP 46 132. |
| KUR DAD ZE | 86 | JETPL 43 643 L.M. Kurdadze et al. (NOVO) Translated from ZETFP 43 497. |
| BARKOV DRUZHININ | 85 84 83 B | NP B256 365 LM. Barkov et al. (NOVO) PL 144B 136 V.P. Druzhinin et al. (NOVO) JETPL 36 274 A.M. Kurd adze et al. (NOVO) |
| DZHELYADIN | 81B | JETPL 36 274 A.M. Kurdadze et al. (NOVO) Translated from ZETFP 36 221. PL 102B 296 R.I. Dzhelyadin et al. (SERP) |
| CORDIER DZHELYADIN | 80 80 | NP B172 13 A. Cordier et al. (LALO) PL 94B 548 R.I. Dzhelyadin et al. (SERP) |
| ROOS BENKHEIRI | 80 79 79 | LNC 27 321 M. Roos, A. Pellinen (HELS) NP B150 268 P. Benkheiri et al. (EPOL, CERN, CDEF+) PL 84B 143 R.I. Dzhelyadin et al. (SERP) |
| DZHELYADIN COOPER QUENZER | 78 B 78 | PL 84B 143 R.I. Dzhelyadin et al. (SERP) NP B146 1 A.M. Cooper et al. (TATA, CERN, CDEF+) PL 76B 512 A. Quenzer et al. (LALO) |
| VANAPEL WICKLUND | 78 78 | NP B133 245 G.W. van Apeldoorn et al. (ZEEM) PR D17 1197 A.B. Wicklund et al. (ANL) |
| ANDREWS GESSAROLI | 77 77 | PRL 38 198 D.E. Andrews et al. (ROCH) NP B126 382 R. Gessaroli et al. (BGNA, FIRZ, GENO+) PR D14 28 J. Keyne et al. (LOIC, SHMP) |
| KEYNE Also KALBFLEISCH | 76 75 | PR D14 28 |
| AGUILAR APEL | 72B 72B | PR D6 29 M. Aguilar-Benitez et al. (BNL+) PL 41B 234 W.D. Apel et al. (KARLK, KARLE, PISA) |
| BASILE BENAKSAS | 72B 72 | Phil. Conf. 153 M. Basile et al. (CERN) PL 39B 289 D. Benaksas et al. (ORSAY) |
| BENAKSAS BENAKSAS | 72 B 72 C | PL 42B 507 D. Benaksas et al. (ORSAY) PL 42B 511 D. Benaksas et al. (ORSAY) |
| BORENSTEIN BROWN DAKIN | 72 72 72 | PR D5 1559 S.R. Borenstein <i>et al.</i> (BNL, MICH) PL 42B 117 R.M. Brown <i>et al.</i> (ILL, ILLC) PR D6 2321 J.T. Dakin <i>et al.</i> (PRIN) |
| RAT CLIFF ALVENS LEB | 72 | PR D6 2321 J.T. Dakin et al. (PRIN) PL 38B 345 B.N. Ratcliff et al. (SLAC) PRL 27 888 H. Alvensleben et al. (DESY) |
| BALDIN | 71 | SJNP 13 758 A.B. Baldin et al. (ITEP) Translated from YAF 13 1318. |
| BEHREND BIZZARRI COYNE | 71 71 | PRL 27 61 H.J. Behrend et al. (ROCH, CORN, FNAL) NP B27 140 R. Bizzarri et al. (CERN, CDEF) NP B32 333 D.G. Coyne et al. (LRL) |
| M OFFEIT ABRAMOVI | 71 71 70 | NP B29 349 K.C. Moffeit et al. (LRL, UCB, SLAC+) |
| BIGGS BIZZARRI | 70 B 70 | NP B20 209 M. Abramovich et al. (CERN) PRL 24 1201 P.J. Biggs et al. (DARE) PRL 25 1385 R. Bizzarri et al. (ROMA, SYRA) |
| ROOS Proc. Dan | 70 esbury | DNPL/R7 173 M. Roos (CERN) Study Weekend No. 1. |
| AUGUSTIN BIZZARRI DEINET | 69 D 69 69 B | PL 28B 513 J.E. Augustin et al. (ORSAY) NP B14 169 R. Bizzarri et al. (CERN, CDEF) PL 30B 426 W. Deinet et al. (KARL, CERN) |
| JACQUET WILS ON | 69B 69 | NC 63A 743 F. Jacquet et al. (EPOL, BERG) Private Comm. R. Wilson (HARV) |
| Also ASTVACAT | 68 | PR 178 2095 A.A. Wehmann et al. (HARV, CASE, ŠLAC+) PL 27B 45 R.G. Astvatsaturov et al. (JINR, MOSU) |
| BOLLINI BARASH | 68 C 67 B | NC 56A 531 D. Bollini et al. (CERN, BGNA, STRB) PR 156 1399 N. Barash et al. (COLU) |
| FELDMAN DIGIUGNO FLATTE | 67 C 66 B 66 | PR 159 1219 M. Feldman et al. (PENN) NC 44A 1272 G. Di Giugno et al. (NAPL, FRAS, TRST) PR 145 1050 S.M. Flatte et al. (LRL) |
| JAMES BARBARO | 66 65 | PR 142 896 F.E. James, H.L. Kraybill (YALE, BNL) PRL 14 279 A. Barbaro-Galtieri, R.D. Tripp (LRL) |
| BARMIN | 64 | JETP 18 1289 V.V. Barmin et al. (ÎTEP) Translated from ZETF 45 1879. |
| KRAEMER BUSCHBECK | 64 63 | PR 136 B496 R.W. Kraemer et al. (JHU, NWES, WOOD) Siena Conf. 1 166 B. Buschbeck et al. (VIEN, CERN, ANIK) |

 $\eta'(958)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

| | | | | η'(958) MA | SS | | |
|----------|------------|------------|------------|------------------------|---------|-----------|----------------------------------------------------|
| VALUE (I | | OUR AV | EVTS | DOCUMENT ID | | TECN | COMMENT |
| | | ± 0.036 | 3.9k | LIBBY | 00 | CLEO | 1/1 / |
| | | | | | 80 | CLEO | |
| 957.9 | ± 0.2 | ± 0.6 | 4800 | WURZINGER | 96 | | $1.68 pd \rightarrow {}^{3}\text{He}\eta'$ |
| 957.46 | ± 0.33 | | | DUANE | 74 | MMS | $\pi^- p \rightarrow nMM$ |
| 958.2 | ± 0.5 | | 1414 | DANBURG | 73 | HBC | $2.2 K^- p \rightarrow \Lambda \eta'$ |
| 958 | ± 1 | | 400 | JACOBS | 73 | HBC | $2.9 K^- p \rightarrow \Lambda \eta'$ |
| 956.1 | ± 1.1 | | 3415 | ¹ BASILE | 71 | CNTR | $1.6 \pi^- p \rightarrow n \eta'$ |
| • • • ١ | Ne do n | ot use the | e followin | g data for average | s, fits | , limits, | etc. • • • |
| 957.5 | ± 0.2 | | | BAI | 04J | BES2 | $J/\psi \rightarrow \gamma \gamma \pi^+ \pi^-$ |
| 959 | ± 1 | | 630 | ² BELADIDZE | 92c | VES | 36 π^- Be $\rightarrow \pi^- \eta' \eta$ Be |
| 958 | ± 1 | | 340 | ² ARMSTRONG | 91B | OMEG | 300 $pp \rightarrow pp \eta \pi^+ \pi^-$ |
| 958.2 | ± 0.4 | | 622 | ² AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 957.8 | ± 0.2 | | 2420 | ² AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma \gamma \pi^{+} \pi^{-}$ |
| 956.3 | ± 1.0 | | 143 | ² GIDAL | 87 | MRK2 | $e^+e^{e^+e^-\eta\pi^+\pi^-}$ |
| 957.4 | ±1.4 | | 5 35 | ³ BASILE | 71 | CNTR | $1.6 \pi^- p \rightarrow n \eta'$ |
| 957 | ± 1 | | | RITTENBERG | 69 | нвс | 1.7-2.7 K ⁻ p |

η' (958) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------------------------------|---------------|-------------------|--------|------------|--------|-----------------------------------------------------------------|
| 0.199±0.009 OUR FI 0.230±0.021 OUR AV | | | | | | |
| $0.226 \pm 0.017 \pm 0.014$ | 2300 | CZERWINSKI | 10 | MMS | | $pp \rightarrow pp \eta'$ |
| 0.40 ± 0.22 | 4800 | WURZINGER | 96 | SPEC | | $pp \rightarrow pp\eta'$ 1.68 $pd \rightarrow {}^{3}He\eta'$ |
| 0.28 ± 0.10 | 1000 | BINNIE | 79 | MMS | 0 | $\pi^- p \rightarrow nMM$ |
| ● ● We do not use | the following | g data for averag | es, fi | ts, limits | , etc. | • • • |
| 0.20 ± 0.04 | | BAI | 04 J | BES2 | | $J/\psi \rightarrow \gamma \gamma \pi^{+} \pi^{-}$ |

I

$\eta'(958)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence | level |
|-----------------|---------------------------------------------------------------------------------|---------------------------------------------------|-------------------|-------|
| Γ ₁ | $\pi^+\pi^-\eta$ | (43.4 ±0.7) | % | |
| | $ ho^0 \gamma$ (including non-resonant | (29.3 ±0.6) | % | |
| | π^+ $\pi^ \gamma)$ | | | |
| Γ_3 | $\pi^0 \pi^0 \eta$ | (21.6 ± 0.8) | % | |
| Γ_4 | $\omega \gamma$ | (2.75 ± 0.22) | % | |
| | $\gamma \gamma$ | (2.18 ± 0.08) | _ | |
| | $3\pi^0$ | (1.68 ± 0.22) | | |
| | $\mu_{\perp}^{+}\mu_{-}^{-}\gamma_{\perp}$ | (1.07 ± 0.26) | | |
| | $\pi^{+} \pi^{-} \mu^{+} \mu^{-}$ | < 2.2 | | 90% |
| Γ9 | $\pi^+ \pi^- \pi^0$ | $(3.6 \begin{array}{c} +1.1 \\ -0.9 \end{array})$ | $\times 10^{-3}$ | |
| Γ_{10} | $\pi^{0} \rho^{0}$ | < 4 | % | 90% |
| Γ_{11} | $2(\pi^{+}\pi^{-})$ | < 2.4 | ×10 ⁻⁴ | 90% |
| Γ_{12} | $\pi^{+}\pi^{-}2\pi^{0}$ | < 2.6 | $\times 10^{-3}$ | 90% |
| Γ_{13} | $2(\pi^+\pi^-)$ neutrals | < 1 | % | 95% |
| Γ_{14} | $2(\pi^{+}\pi^{-})\pi^{0}$ | < 1.9 | $\times 10^{-3}$ | 90% |
| Γ_{15} | $2(\pi^{+}\pi^{-})2\pi^{0}$ | | % | 95% |
| Γ_{16} | $3(\pi^{+}\pi^{-})$ | < 5 | $\times 10^{-4}$ | 90% |
| Γ_{17} | $\pi^+\pi^-e^+e^-$ | $(2.4 \begin{array}{c} +1.3 \\ -1.0 \end{array})$ | $\times 10^{-3}$ | |
| $\Gamma_{1.8}$ | $\gamma e^+ e^-$ | < 9 | ×10 ⁻⁴ | 90% |
| Γ ₁₉ | $\begin{array}{c} \stackrel{'}{\pi}^{0} \gamma \gamma \\ 4 \pi^{0} \end{array}$ | < 8 | $\times 10^{-4}$ | 90% |
| Γ ₂₀ | $4\pi^0$ | | $\times 10^{-4}$ | 90% |
| Γ ₂₁ | $e^+ e^-$ | < 2.1 | $\times 10^{-7}$ | 90% |
| | invisible | < 9 | $\times 10^{-4}$ | 90% |
| | Charge conjugati | on (<i>C</i>), Parity (<i>P</i>), | | |
| | Lepton family number | | les | |
| Γ_{23} | $\pi^+\pi^-$ | | $\times 10^{-5}$ | 90% |
| | π ⁰ π ⁰ | | × 10-4 | 90% |

| | $\pi^+\pi^-$ | P,CP | < | 6 | $\times 10^{-5}$ | 90% |
|-----------------|-------------------------|------|-------|-----|------------------|-----|
| Γ_{24} | $\pi^{0} \pi^{0}$ | P,CP | < | 4 | $\times 10^{-4}$ | 90% |
| Γ ₂₅ | $\pi^0 e^+ e^-$ | C | [a] < | 1.4 | $\times 10^{-3}$ | 90% |
| Γ_{26} | ηe^+e^- | С | [a] < | 2.4 | $\times 10^{-3}$ | 90% |
| Γ_{27} | 3γ | C | < | 1.0 | $\times 10^{-4}$ | 90% |
| Γ ₂₈ | $\mu^{+}\mu^{-}\pi^{0}$ | С | [a] < | 6.0 | $\times 10^{-5}$ | 90% |
| Γ_{29} | $\mu^+\mu^-\eta$ | C | [a] < | 1.5 | $\times 10^{-5}$ | 90% |
| Γ_{30} | $e\mu$ | LF | < | 4.7 | $\times 10^{-4}$ | 90% |

 $[[]a]\ C$ parity forbids this to occur as a single-photon process.

 $^{^1}$ Using all η' decays. 2 Systematic uncertainty not estimated. 3 Using η' decays into neutrals. Not independent of the other listed BASILE 71 η' mass measurement.

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, 2 combinations of partial widths obtained from integrated cross section, and $13\,$ branching ratios uses 40 measurements and one constraint to determine 9 parameters. The overall fit has a $\chi^2=31.5$ for 32 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| <i>x</i> ₂ | 1 | | | | | | | |
|------------------------|------------|-------|-------|-------|-------|-----------------------|------------|------------------------|
| <i>x</i> ₃ | -76 | -57 | | | | | | |
| x_4 | -20 | -24 | 6 | | | | | |
| <i>X</i> ₅ | -31 | -26 | 35 | 0 | | | | |
| <i>x</i> ₆ | -23 | -17 | 28 | 1 | 10 | | | |
| <i>X</i> 9 | -1 | -5 | -7 | -3 | -4 | -2 | | |
| <i>x</i> ₁₇ | -4 | -6 | -5 | -2 | -3 | -2 | -1 | |
| Γ | 26 | 5 | -21 | 4 | -72 | -6 | 4 | 3 |
| | x_1 | x_2 | x_3 | x_4 | x_5 | <i>x</i> ₆ | <i>X</i> 9 | <i>x</i> ₁₇ |

| | Mode | Rate (MeV) |
|----------------------------------------------------------------------|-----------------------------------------|-------------------------------------------------------------------|
| Γ ₁ | $\pi^+\pi^-\eta$ | 0.086 ±0.004 |
| Γ_2 | $ ho^0 \gamma$ (including non-resonant | 0.0583 ± 0.0028 |
| | π^+ $\pi^ \gamma)$ | |
| Γ_3 | $\pi^0 \pi^0 \eta$ | 0.0430 ± 0.0022 |
| Γ_4 | $\omega \gamma$ | 0.0055 ± 0.0005 |
| Γ_5 | $\frac{\gamma \gamma}{3\pi^0}$ | 0.00434 ± 0.00013 |
| Γ ₃ Γ ₄ Γ ₅ Γ ₆ | $3\pi^{0}$ | $(3.3 \pm 0.5) \times 10^{-4}$ |
| | $\pi^+\pi^-\pi^0$ | $(7.2 \begin{array}{c} +2.2 \\ -1.9 \end{array}) \times 10^{-4}$ |
| Γ_{17} | $\pi^{+}\pi^{-}e^{+}e^{-}$ | $(4.8 {}^{+ 2.6}_{- 1.9}) \times 10^{-4}$ |

η'(958) PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | | | | | | Г ₅ |
|------------------------------------------------------------|--------------------------------------------------|-----------------------|---------------|------------|----------------------|----------------------------------|
| VALUE (keV) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 4.34±0.14 OUR FI | Т | | | | | |
| 4.28±0.19 OUR AV | /ERAGE | | | | | |
| $4.17 \pm 0.10 \pm 0.27$ | 2000 | ⁴ ACCIARRI | 98 Q | L3 | $e^+e^- \rightarrow$ | $e^{+}e^{-}\pi^{+}\pi^{-}\gamma$ |
| $4.53\pm0.29\pm0.51$ | 266 | KARCH | 92 | CBAL | e^+e^- | $e^{+}e^{-}\eta\pi^{0}\pi^{0}$ |
| $3.61 \pm 0.13 \pm 0.48$ | | ⁵ BEHREND | 91 | CELL | $e^+e^- \rightarrow$ | $e^+e^-\eta'(958)$ |
| $4.6 \pm 1.1 \pm 0.6$ | 23 | BARU | 90 | MD1 | $e^+e^- \rightarrow$ | $e^{+}e^{-}\pi^{+}\pi^{-}\gamma$ |
| $4.57\pm0.25\pm0.44$ | | BUTLER | 90 | MRK2 | e^+e^- | $e^+e^-\eta'(958)$ |
| $5.08 \pm 0.24 \pm 0.71$ | 547 | ⁶ ROE | 90 | ASP | $e^+e^- \rightarrow$ | $e^+e^-2\gamma$ |
| $3.8 \pm 0.7 \pm 0.6$ | 34 | AIHARA | 88 c | TPC | $e^+e^- \rightarrow$ | $e^{+}e^{-}\eta\pi^{+}\pi^{-}$ |
| $4.9 \pm 0.5 \pm 0.5$ | 136 | ⁷ WILLIAMS | 88 | CBAL | $e^+e^- \rightarrow$ | $e^+e^-2\gamma$ |
| • • • We do not u | se the foll | owing data for ave | rages, | fits, limi | ts, etc. 🔸 🔸 | • |
| $4.7 \pm 0.6 \pm 0.9$ | 143 | ⁸ GIDAL | 87 | MRK2 | e^+e^- | $e^{+}e^{-}\eta\pi^{+}\pi^{-}$ |
| 4.0 ±0.9 | | ⁹ BARTEL | 85 E | JADE | $e^+e^- \rightarrow$ | $e^+e^-2\gamma$ |
| ⁵ Reevaluated by ⁶ Reevaluated by | us using l us using l us using l BUTLER | | = (30 11 ± | 0.13)%. |)%. | |

$\eta'(958) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

This combination of a partial width with the partial width into $\gamma\gamma$ and with the total width is obtained from the integrated cross section into channel(i) in the $\gamma\gamma$ annihilation.

| $\Gamma(\gamma\gamma) \times \Gamma(\rho^0\gamma)$ | (includi | ng non-resonant | π+ 1 | $(-\gamma)$ | Γ _{total} | $\Gamma_5\Gamma_2/\Gamma$ |
|----------------------------------------------------|------------|---------------------|---------|-------------|----------------------|---------------------------------|
| VALUE (keV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 1.27±0.04 OUR FI | т | | | | | |
| 1.26±0.07 OUR A | /ERAGE | Error includes sca | ale fac | tor of 1. | 2. | |
| $1.09 \pm 0.04 \pm 0.13$ | | BEHREND | 91 | CELL | $e^+e^- \rightarrow$ | $e^{+}e^{-}\rho(770)^{0}\gamma$ |
| $1.35 \pm 0.09 \pm 0.21$ | | AIHARA | 87 | TPC | $e^+e^- \rightarrow$ | $e^+e^- ho\gamma$ |
| $1.13 \pm 0.04 \pm 0.13$ | 867 | ALBRECHT | 87B | ARG | $e^+e^- \rightarrow$ | $e^+e^- ho\gamma$ |
| $1.53\pm0.09\pm0.21$ | | ALTHOFF | 84E | TASS | $e^+e^- \rightarrow$ | $e^+e^- ho\gamma$ |
| $1.14 \pm 0.08 \pm 0.11$ | 243 | BERGER | 84B | | $e^+e^- \rightarrow$ | |
| $1.73 \pm 0.34 \pm 0.35$ | 95 | JENNI | 83 | MRK2 | $e^+e^- \rightarrow$ | $e^+e^- ho\gamma$ |
| $1.49 \pm 0.13 \pm 0.027$ | 213 | BARTEL | 82B | JADE | $e^+e^- \rightarrow$ | $e^+e^- ho\gamma$ |
| • • • We do not u | se the fol | lowing data for ave | erages | , fits, lin | nits, etc. • • | • • |
| $1.85 \pm 0.31 \pm 0.24$ | 43 | BEHREND | 83B | CELL | $e^+e^- \to$ | $e^+e^- ho\gamma$ |

| $\Gamma(\gamma\gamma) \times \Gamma(\pi^0\pi^0\eta)$ | /Γ _{total} | | | | Г ₅ Г ₃ /Г |
|------------------------------------------------------|---------------------------------------------------|--------|------------|-----------------------|----------------------------------|
| VALUE (keV) | | | TECN | COMMENT | |
| 0.94±0.05 OUR FIT | | | | | |
| $0.92 \pm 0.06 \pm 0.11$ | ¹⁰ KARCH | 92 | CBAL | $e^+ e^- \rightarrow$ | $e^{+}e^{-}\eta\pi^{0}\pi^{0}$ |
| • • • We do not use th | e following data for ave | rages, | fits, limi | ts, etc. • • | • |
| $0.95 \pm 0.05 \pm 0.08$ | ¹¹ KARCH | 90 | CBAL | $e^+e^- \rightarrow$ | $e^{+}e^{-}\eta\pi^{0}\pi^{0}$ |
| $1.00 \pm 0.08 \pm 0.10$ | ^{11,12} ANTREASYA | N 87 | CBAL | $e^+e^ \rightarrow$ | $e^{+}e^{-}\eta\pi^{0}\pi^{0}$ |
| and KARCH 90. | sing B $(\eta ightarrow \gamma \gamma) = (39.2)$ | 21 ± 0 | .34)%. S | upersedes A | NTREASYAN 87 |
| ¹¹ Superseded by KAR | | | | | |
| ¹² Using BR($\eta \rightarrow 2\gamma$) | $=(38.9 \pm 0.5)\%$. | | | | |
| | | | | | |

$\eta'(958) \rightarrow \eta \pi \pi$ DECAY PARAMETERS

$|MATRIX ELEMENT|^2 = |1 + \alpha Y|^2 + CX + DX^2$

X and Y are Dalitz variables; α is complex and C, and D are real-valued. Parameters C and D are not necessarily equal to c and d, respectively, in the generalized parameterization following this one. May be different for $\eta'(958) \to \eta \pi^+ \pi^-$ and $\eta'(958) \to \eta \pi^0 \pi^0$ decays. Because of different initial assumptions and strong correlations of the parameters we do not average the parameters in the section below.

$Re(\alpha)$ decay parameter

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------|------------------|------------------------------------------|----------|-----------|---------------------------------------------------------------------------------------|
| • • • We do not use th | e follow | ing data for average | es, fits | , limits, | etc. • • • |
| $-0.033 \pm 0.005 \pm 0.003$ | 44 k | ¹³ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $-0.072\pm0.012\pm0.006$ | 7k | ¹⁴ AMELIN | 05 A | VES | 28 $\pi^- A \rightarrow$ |
| $-0.021 \pm 0.018 \pm 0.017$ | 6.7k | ¹⁵ BRIERE | | | $\eta \pi^{+} \pi^{-} \pi^{-} A^{*}$ 10.6 $e^{+} e^{-} \rightarrow \pi^{+} \pi^{-} X$ |
| $-0.058\pm0.013\pm0.003$ | | ¹⁶ ALDE | 86 | GAM2 | $\eta \pi^{+} \pi^{-} X$ 38 $\pi^{-} \rho \rightarrow n \eta \pi^{0} \pi^{0}$ |
| -0.08 ± 0.03 | 1 | ^{l6,17} KALBFLEISCI | H 74 | RVUE | $\eta' \rightarrow \eta \pi^+ \pi^-$ |
| 13 See ABLIKIM 11 for 14 Superseded by DOR | the ful OFEEV | correlation matrix. 07, which found t | his pa | rameteriz | zation unacceptable. See |

15 below. Assuming $\operatorname{Im}(\alpha)=0$, C=0, and D=0.

 16 Assuming C = 0.

ASSUMING C = 0.

17 From the data of DAUBER 64, RITTENBERG 69, AGUILAR-BENITEZ 72B, JACOBS 73, and DANBURG 73.

$Im(\alpha)$ decay parameter

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------------------------------|---------------------|----------------------------------------------------|---------|----------|----------------------------------------------|
| • • • We do not use t | he follow | ving data for averages | , fits, | limits, | etc. • • • |
| $0.000 \pm 0.049 \pm 0.001$ | 44 k | ¹⁸ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $0.0\pm0.1\pm0.0$ | 7k | ¹⁹ AMELIN | 05A | VES | 28 $\pi^- A \rightarrow$ |
| $\begin{array}{ccccc} -0.00 & \pm 0.13 & \pm 0.00 \\ 0.0 & \pm 0.3 & \end{array}$ | | ²⁰ ALDE ^{20,21} KALBFLEISCH | | | |
| below. | or the fu ROFEEN | ll correlation matrix. / 07, which found th | is par | ameteriz | ration unacceptable. See |
| 20 Assuming $C=0$. 21 From the data of COBS 73, and DA | DAUBI NBURG | ER 64, RITTENBER 73. | G 69 | , AGUIL | AR-BENITEZ 72B, JA- |

C decay parameter

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------------|-----------------------|-----------|-----------|----------------------------------------------|
| • • • We do not use th | ne followi | ng data for averag | es, fits, | , limits, | etc. • • • |
| $+0.018\pm0.009\pm0.003$ | 44 k | ²² ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $0.020 \pm 0.018 \pm 0.004$ | 7k | ²³ AMELIN | OE v | VEC | $28 \pi^- A \rightarrow$ |

23 Superseded by DOROFEEV 07, which found this parameterization unacceptable. See

${\it D}$ decay parameter

| VALUE | EVIS | DO CUMENT ID | | IECN | COMMENT |
|-----------------------------------------|----------------------|---------------------|----------|--------------|------------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not use th | e following o | data for averages | , fits, | limits, | etc. • • • |
| $-0.059\pm0.012\pm0.004$ | | | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $-0.066\pm0.030\pm0.015$ | 7k 25 | AMELIN | 05 A | VES | 28 $\pi^- A \rightarrow$ |
| $0.00 \pm 0.03 \pm 0.00$ | 5.4k 26,27 | ALDE KALBFLEISCH | 86 74 | GAM2 RVUE | $ \eta \pi^{+} \pi^{-} \pi^{-} A^{*} $ $ 38 \pi^{-} p \rightarrow n \eta \pi^{0} \pi^{0} $ $ \eta' \rightarrow n \pi^{+} \pi^{-} $ |
| = | | | | | zation unacceptable. See |
| 27 From the data of COBS 73, and DAN | DAUBER 6 BURG 73. | 4, RITTENBER | G 69 | , AGUII | AR-BENITEZ 72B, JA- |

 $\eta'(958)$

$\eta'(958) \rightarrow \eta \pi \pi$ DECAY PARAMETERS

$|MATRIX ELEMENT|^2 \propto 1 + a Y + b Y^2 + c X + d X^2$

X and Y are Dalitz variables and a, b, c, and d are real-valued parameters. May be different for $\eta'(958) \to \eta \pi^+ \pi^-$ and $\eta'(958) \to \eta \pi^0 \pi^0$ decays. We do not average measurements in the section below because parameter values from each experiment are strongly correlated.

a decay parameter

| a accay parameta | | | | | | |
|----------------------------------------------------------------------------------------------------------------------------|------------------------------|------------------------|-----------|---------|----------------------------------------------|---|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use th | e followi | ng data for average | es, fits, | limits, | etc. • • • | |
| $-0.047\pm0.011\pm0.003$ | 44 k | ²⁸ ABLIKIM | | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ | I |
| $-0.066\pm0.016\pm0.003$ | 15 k | ²⁹ BLIK | | | $32.5 \pi^- p \rightarrow \eta' n$ | |
| $-0.127\pm0.016\pm0.008$ | 20k | ³⁰ DOROFEEV | 07 | VES | $27 \pi^- p \rightarrow \eta' n$ | |
| | | | | | $\pi^- A \rightarrow \eta' \pi^- A^*$ | |
| ²⁸ See ABLIKIM 11 for 29 From $\eta' \rightarrow \eta \pi^0 \pi^0$ 30 From $\eta' \rightarrow \eta \pi^+ \pi^-$ | the full decay. decay. | correlation matrix. | | | | I |

b decay parameter

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------|------------------------|----------|-----------|----------------------------------------------|
| ullet $ullet$ We do not use th | e followi | ng data for average | es, fits | , limits, | etc. • • • |
| $-0.069 \pm 0.019 \pm 0.009$ | 44 k | ³¹ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $-0.063\pm0.028\pm0.004$ | 15 k | ³² BLIK | 09 | GA M4 | 32.5 $\pi^- p \rightarrow \eta' n$ |
| $-0.106\pm0.028\pm0.014$ | 20k | ³³ DOROFEEV | 07 | VES | 27 $\pi^- p \rightarrow \eta' n$, |
| | | | | | $\pi^- A \rightarrow \eta' \pi^- A^*$ |
| 31 See ARLIKIM 11 for | the full | correlation matrix | | | |

- 31 See ABLIKIM 11 for the full correlation matrix. 32 From $\eta' \to ~\eta \pi^0 \, \pi^0$ decay. 33 From $\eta' \to ~\eta \pi^+ \pi^-$ decay.

c decay parameter

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|------------|------------------------|---------|-----------|----------------------------------------------|
| ● ● We do not use th | e followii | ng data for average | s, fits | , limits, | etc. • • • |
| $+0.019\pm0.011\pm0.003$ | 44 k | ³⁴ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $-0.107 \pm 0.096 \pm 0.003$ | 15 k | ³⁵ BLIK | | | 32.5 $\pi^- p \rightarrow \eta' n$ |
| $0.015 \pm 0.011 \pm 0.014$ | 20k | ³⁶ DOROFEEV | 07 | VES | 27 $\pi^- p \rightarrow \eta' n$, |
| | | | | | $\pi^- A \rightarrow \eta' \pi^- A^*$ |
| 34.6 ADLIKINA 11.6 | | 1.00 | | | |

- 34 See ABLIKIM 11 for the full correlation matrix. 35 From $\eta' \to ~\eta \pi^0 \, \pi^0$ decay. 36 From $\eta' \to ~\eta \pi^+ \, \pi^-$ decay.

d decay parameter

| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|---------|----------|------------------------|---------|-----------|----------------------------------------------|
| • • • We do not | use the | followin | ng data for average | s, fits | , limits, | etc. • • • |
| $-0.073 \pm 0.012 \pm 0$ | 0.003 | 44 k | ³⁷ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $0.018 \pm 0.078 \pm 0$ | 0.006 | 15 k | ³⁸ BLIK | | | 32.5 $\pi^- p \rightarrow \eta' n$ |
| $-0.082 \pm 0.017 \pm 0$ | 0.008 | 20k | ³⁹ DOROFEEV | 07 | VES | 27 $\pi^- p \rightarrow \eta' n$, |
| | | | | | | $\pi^- A \rightarrow \eta' \pi^- A^*$ |

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 Γ_1/Γ

 $0.25\ \pm0.14$

- . 37 See ABLIKIM 11 for the full correlation matrix. 38 From $\eta' \to \eta \pi^0 \pi^0$ decay. If $c \equiv 0$ from Bose-Einstein symmetry, $d=-0.067\pm0.003$. 39 From $\eta' \to \eta \pi^+ \pi^-$ decay.

$\eta'(958) \beta$ PARAMETER $|MATRIX ELEMENT|^2 = (1 + 2\beta Z)$

See the "Note on η Decay Parameters" in our 1994 edition Physical Review $\bf D50$ 1173 (1994), p. 1454.

β decay parameter

 $\Gamma(\pi^+\pi^-\eta)/\Gamma_{\text{total}}$

| VALUE EVTS | DO CUMENT ID | TECN | COMMENT |
|------------------------|-----------------------------|---------|--------------------------------------|
| -0.46±0.22 OUR AVERAGE | Error includes scale factor | of 1.4. | |
| -0.59 ± 0.18 235 | | | $32 \pi^- p \rightarrow \eta' n$ |
| -0.1 ± 0.3 | ALDE 87B | GAM2 | $38 \pi^- \rho \rightarrow n 3\pi^0$ |

η'(958) BRANCHING RATIOS

| | EVTS | <u>DO CUMEN</u> | VI ID | TECN COMM | IENI |
|----------------------------------------------------------|-----------------------------------------|-------------------------------------------|-------------|-----------------------------------------------------------------------|----------------------------|
| 0.434±0.007 OL | R FIT | | | | |
| • • • We do no | use the follo | owing data for av | verages, fi | ts, limits, etc. • | • • |
| $0.424\pm0.011\pm0$ | .004 1.2k | 40 PEDLAR | 09 | CLEO J/ψ - | $\rightarrow \gamma \eta'$ |
| ⁴⁰ Not independ | ent of other | η' branching fra | ctions and | ratios in PEDLA | AR 09. |
| $\Gamma(\pi^+\pi^-\eta)$ (character) | arged decay |))/Γ _{total} | | | 0.286Γ1/Γ |
| | | | | | |
| VALUE | | DOCUMENT ID | TEC | N COMMENT | |
| • | EVTS | , | TEC | COMMENT | |
| VALUE | <u>EVTS</u> DUR FIT | DOCUMENT ID | , | | •• |
| VALUE 0.1240±0.0020 | <u>EVTS</u> DUR FIT | DOCUMENT ID wing data for av RITTENBERG | verages, fi | ts, limits, etc. • C 1.7-2.7 K | p |
| 0.1240±0.0020 (• • • We do no | <u>EVTS</u> DUR FIT use the follo | DOCUMENT ID wing data for av RITTENBERG | verages, fi | ts, limits, etc. • C 1.7-2.7 K | |
| VALUE 0.1240 ± 0.0020 0 • • • We do not 0.123 ± 0.014 | DUR FIT t use the follo | DOCUMENT ID wing data for av RITTENBERG | verages, fi | ts, limits, etc. • C 1.7-2.7 K ⁻ C 2.24 K ⁻ p - | p |

| $\Gamma(\pi^+\pi^-\eta)$ (neutr | al decay))/ | Γ _{total} | | | | 0.714Γ ₁ / |
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| VALUE 0.310±0.005 OUR | EVTS | DO CUMENT IE |) | TECN | COMMENT | |
| • • • We do not us | | ng data for averag | ges, fits | s, limits, | etc. • • • | |
| 0.314 ± 0.026 | 281 | RITTENBER | G 69 | HBC | 1.7-2.7 K | ⁻ p |
| $\Gamma(ho^0\gamma)$ (including | | nt π^+ $\pi^ \gamma))/i$ | total | | | Γ2/ |
| VALUE 0.293±0.006 OUR | <u>EVTS</u> FIT | DO CUMENT ID | | TECN C | OMMENT | |
| • • • We do not us | | ng data for averag | ges, fits | s, limits, | etc. • • • | |
| 0.287 ± 0.007 ± 0.004 | | 1 PEDLAR | | | $/\psi \rightarrow \gamma \eta'$ | |
| 0.329±0.033 0.2 ±0.1 | 298 20 | RITTENBERG LONDON | | | .7-2.7 K ⁻ p .24 K ⁻ p | |
| 0.34 ±0.09 | 35 | BADIER | 65в I | | $\kappa^- \rho$ | |
| ⁴¹ Not independent | t of other η' | branching fraction | ns and | ratios in | PEDLAR 09 | Э. |
| $\Gamma(ho^0\gamma)$ (including | non-resona | | | | | Γ_2/Γ |
| 0.676±0.017 OUR | FIT | DO CUMENT IE |) | TECN | COMMENT | |
| 0.683±0.020 OUR | AVERAGE | | | | | |
| $0.677 \pm 0.024 \pm 0.013$ 0.69 ± 0.03 | 1 | PEDLAR ABLIKIM | 09 065 | | $J/\psi \rightarrow \eta'$ $J/\psi \rightarrow \eta'$ | |
| | | | | | | , |
| $\Gamma(ho^0\gamma)$ (including | non-resona | $\operatorname{nt} \pi^+ \pi^- \gamma))/1$ | (π^{\top}) | $\pi^-\eta$ (ne | | y)) Γ ₂ /0.714Γ |
| VALUE | EVTS | DOCUMENT ID | | <u>TECN</u> | | - 21 2 +1 |
| 0.947±0.024 OUR 0.97 ±0.09 OUR | | | | | | |
| 0.70 ±0.22 | | AMSLER | | | $0 \ \overline{\rho} \rho \rightarrow \pi$ | |
| 1.07 ±0.17 0.92 ±0.14 | 473 | BELADIDZE DANBURG | 92c 73 | VES HBC | 36 π ⁻ Be - 2.2 K ⁻ p - | |
| 1.11 ±0.18 | 192 | JACOBS | 73 | НВС | 2.9 K - p - | |
| $\Gamma(\pi^0\pi^0\eta)/\Gamma_{\text{total}}$ | | | | | | Γ ₃ / |
| | | DO CUMENT IE |) | TECN | COMMENT | . 3/ |
| <u>VALUE</u> 0.216±0.008 OUR I • • • We do not us | FIT se the followi | ng data for averag | rac fits | limite | etc • • • | |
| $0.235 \pm 0.013 \pm 0.004$ | | - | | | $J/\psi \rightarrow \gamma$ | n' |
| | | | | | | ., |
| 42 Not independent | t of other η' | branching fraction | ns and | ratios in | | 9. |
| | | branching fraction | ns and | ratios in | | _ |
| $\Gamma(\pi^0\pi^0\eta(3\pi^0$ de | cay))/Γ _{tota} | | | | PEDLAR 09 | 0.321Γ ₃ / |
| $\Gamma(\pi^0\pi^0\eta)(3\pi^0$ de $\frac{VALUE}{0.0694 \pm 0.0026}$ OUI | cay))/Γ _{tota} R FIT | II <u>DOCUMENT IE</u> |) | TECN | PEDLAR 09 | 0.321Γ ₃ / |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de}$ $\frac{VALUE}{0.0694 \pm 0.0026 \text{ OU}}$ • • • We do not us | e cay))/F_{tota} | II <u>DOCUMENT IC</u> ng data for averag | ges, fits | <u>TECN</u> | PEDLAR 09 COMMENT etc. • • • | 0.321Γ ₃ / |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de})$ $0.0694 \pm 0.0026 \text{ OUI}$ • • • We do not us 0.11 ± 0.06 | ECAY))/F _{tota} EVTS R FIT se the followi | II <u>DOCUMENT IE</u> | ges, fits | <u>TECN</u> | PEDLAR 09 | 0.321Γ ₃ / |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de}$ $\frac{VALUE}{0.0694 \pm 0.0026 \text{ OU}}$ • • • We do not us | ECAY))/F _{tota} EVTS R FIT se the followi | ng data for averag BENSINGER | ges, fits 70 | TECN 5, limits, DBC | PEDLAR 09 <u>COMMENT</u> etc. • • • 2.2 π + d | 0.321Γ ₃ / |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de} \frac{VALUE}{0.0694 \pm 0.0026 \text{ OUI}}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0 \pi^0 \eta) / \Gamma(\pi^+ \frac{VALUE}{0.498 \pm 0.025 \text{ OUR}}$ | $\frac{EVTS}{FIT}$ R FIT 4 $\pi^-\eta$ | DOCUMENT IL BENSINGER DOCUMENT IL | 70 | TECN 5, limits, DBC TECN | PEDLAR 09 COMMENT etc. • • • 2.2 $\pi^+ d$ COMMENT | 0.321Γ ₃ / |
| $\Gamma(\pi^0\pi^0\eta)(3\pi^0 \text{ de}$ $\frac{VALUE}{0.0694\pm0.0026 \text{ OUI}}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+)$ $\frac{VALUE}{VALUE}$ | $\frac{EVTS}{FIT}$ R FIT 4 $\pi^-\eta$ | ng data for averag BENSINGER | 70 | TECN 5, limits, DBC TECN | PEDLAR 09 <u>COMMENT</u> etc. • • • 2.2 π + d | 0.321Γ ₃ / |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de} \frac{VALUE}{0.0694 \pm 0.0026 \text{ OUI}}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0 \pi^0 \eta) / \Gamma(\pi^+ \frac{VALUE}{0.498 \pm 0.025 \text{ OUR}}$ | $\frac{ECay)}{\Gamma \text{ FiT}}$ se the followi $\frac{\pi^{-}\eta}{\Gamma \text{FiT}}$ FIT | DOCUMENT IL BENSINGER DOCUMENT IL PEDLAR nt π+ π- γ))/I | ges, fits 70 09 (ππ1 | TECN 5, limits, DBC TECN CLE3 | PEDLAR 09 <u>COMMENT</u> etc. • • • 2.2 $\pi^+ d$ <u>COMMENT</u> $J/\psi \rightarrow \eta'$ | 0.321Γ ₃ / Γ ₃ /Γ |
| $\Gamma(\pi^0 \pi^0 \eta) (3\pi^0 \text{ de} \frac{NALUE}{0.0694 \pm 0.0026 \text{ OUI}}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0 \pi^0 \eta) / \Gamma(\pi^+ \frac{NALUE}{0.498 \pm 0.025 \text{ OUR}}$ $0.555 \pm 0.043 \pm 0.01$ $\Gamma(\rho^0 \gamma) (\text{including})$ $NALUE$ | ecay))/ Γ_{tota} $EVTS$ R FIT se the followi Γ Γ FIT 3 | DOCUMENT IL BENSINGER DOCUMENT IL PEDLAR | ges, fits 70 09 (ππ1 | TECN 5, limits, DBC TECN CLE3 | PEDLAR 09 <u>COMMENT</u> etc. • • • 2.2 $\pi^+ d$ <u>COMMENT</u> $J/\psi \rightarrow \eta'$ | 0.321Γ ₃ / Γ ₃ /Γ |
| $\Gamma(\pi^0\pi^0\eta)(3\pi^0 \text{ de } \frac{VALUE}{0.0694\pm0.0026 \text{ OUI}}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+\frac{VALUE}{0.555\pm0.043\pm0.015}$ $\Gamma(\rho^0\gamma)(\text{including } \frac{VALUE}{0.451\pm0.012 \text{ OUR }}$ $0.451\pm0.012 \text{ OUR }$ $0.451\pm0.012 \text{ OUR }$ $0.431\pm0.012 \text{ OUR }$ | cay))/ Γ_{tota} $\frac{EVTS}{R \text{ FIT}}$ se the followi $\frac{4}{\pi} - \eta$ FIT 3 non-resona | DOCUMENT IL DOCUMENT IL DOCUMENT IL PEDLAR INT ## # - \(\chi) / I DOCUMENT IL BARBERIS | ges, fits 70 09 (ππ1) | TECN S, limits, DBC TECN CLE3 TECN OMEG | PEDLAR 09 $ \begin{array}{c} \hline COMMENT \\ \hline etc. \bullet \bullet \bullet \\ 2.2 \pi^+ d \\ \hline COMMENT \\ \hline J/\psi \rightarrow \eta' \\ \hline COMMENT \\ \hline 450 pp \rightarrow \\ \hline $ | 0.321Γ ₃ / Γ ₃ /Γ Γ ₂ /(Γ ₁ +Γ ₃ |
| $\Gamma(\pi^0\pi^0\eta)(3\pi^0 \text{ de } \frac{VALUE}{0.0694\pm0.0026} \text{ OUI}$ • • • We do not us 0.11 ± 0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+ \frac{VALUE}{0.555\pm0.043\pm0.015}$ $\Gamma(\rho^0\gamma)(\text{including} \frac{VALUE}{0.491\pm0.012} \text{ OUR} \frac{1}{0}$ $0.451\pm0.012 \text{ OUR} \frac{1}{0}$ $0.431\pm0.012 \text{ OUR} \frac{1}{0}$ $0.431\pm0.012 \text{ OUR} \frac{1}{0}$ $0.4411\pm0.012 \text{ OUR} \frac{1}{0}$ | cay))/ Γ_{tota} $\frac{EVTS}{R \text{ FIT}}$ se the followi $\frac{4}{\pi} - \eta$ FIT 3 non-resona | DOCUMENT IL DOCUMENT IL PEDLAR INT π+ π- γ))/I DOCUMENT IL BARBERIS ng data for average | ges, fits 70 09 (ππ1) 980 ges, fits | TECN 5, limits, DBC TECN CLE3 7) TECN OMEG 5, limits, | PEDLAR 09 $ \begin{array}{c} \hline comment \\ \hline comment \\ \hline deta \\ \hline comment \\ \hline J/\psi \rightarrow \eta' \end{array} $ $ \begin{array}{c} \hline comment \\ \hline comment \\ \hline deta \\ \hline comment \\ \hline deta \\ \hline comment \\ comment \\ \hline comment \\ com$ | 0.321Γ ₃ / Γ ₃ /Γ Γ ₂ /(Γ ₁ +Γ ₃ |
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| $\Gamma(\pi^0\pi^0\eta)(3\pi^0$ de NALUE 0.0694±0.0026 OUI • • • We do not us 0.11 ±0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+$ NALUE 0.499±0.025 OUR I 0.555±0.043±0.01: $\Gamma(\rho^0\gamma) \text{ (including }$ NALUE 0.43 ±0.02 ±0.02 • • We do not us 0.31 ±0.15 $\Gamma(\omega\gamma)/\Gamma \text{ total }$ NALUE 0.0275±0.0022 OUI • • • We do not us 0.0234±0.030±0.14 3 Not independent $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-$ NALUE 0.063±0.005 OUR I 0.063±0.005 OUR I 0.063±0.005 OUR I 0.055±0.007±0.00 • • We do not us 0.068±0.013 $\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ NALUE | $\frac{EVTS}{RFIT}$ se the following the following set $\frac{EVTS}{4}$ $\pi^-\eta$) FIT 3 non-resona FIT See the following the following set $\frac{EVTS}{4}$ EVT | DOCUMENT IL PEDLAR BARBERIS BARBERIS DOCUMENT IL BARBERIS DAVIS DOCUMENT May be a data for average | 98cc (fits 0') 98cs, fits 0') 98cs, fits 77 | TECN S, limits, DBC TECN CLE3 TECN OMEG S, limits, HBC TECN TECN TECN CLE3 S, limits, ASPK | PEDLAR 09 $\frac{COMMENT}{2.2 \pi^{+} d}$ etc. • • • $2.2 \pi^{+} d$ $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ $\frac{COMMENT}{3.450 pp \rightarrow 0}$ etc. • • $5.5 K^{-} p$ $\frac{COMMENT}{4.50 pp \rightarrow 0}$ etc. • • $0 J/\psi \rightarrow 0$ PEDLAR 09 $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ etc. • • • $8.4 \pi^{-} p$ | 0.321Γ ₃ /Γ Γ ₃ /Γ Γ ₇ Γ ₂ /(Γ ₁ +Γ ₃ Γ ₄ /Γ Γ ₇ Γ ₄ /Γ |
| $\Gamma(\pi^0\pi^0\eta)(3\pi^0 \text{ de } \frac{NALUE}{0.0694 \pm 0.0026} \text{ OUI}$ • • • We do not us 0.11 ±0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+ \frac{NALUE}{0.498 \pm 0.025} \text{ OUR}$ 0.555 ±0.043 ±0.01: $\Gamma(\rho^0\gamma)(\text{including } \frac{NALUE}{0.451 \pm 0.012} \text{ OUR}$ 0.451 ±0.012 OUR is 0.43 ±0.02 ±0.02 • • • We do not us 0.0275 ±0.0022 OUI • • • We do not us 0.0275 ±0.0020 OUI • • We do not us 0.0234 ±0.0030 ±0.1 43 Not independent $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^- \frac{NALUE}{0.063 \pm 0.007 \pm 0.00}$ • • • We do not us 0.068 ±0.013 $\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ | $\frac{EVTS}{RFIT}$ se the following the following set $\frac{EVTS}{4}$ $\pi^-\eta$) FIT 3 non-resona FIT See the following the following set $\frac{EVTS}{4}$ EVT | DOCUMENT IL BENSINGER DOCUMENT IL PEDLAR THE TOTAL TO THE TOTAL THE T | 98cges, fits 0 98cges, fits 68 0 09 ges, fits 0 77 | TECN TECN CLE3 TECN OMEG TIMES, HIMITS, HBC TECN CLE3 | PEDLAR 09 $\frac{COMMENT}{2.2 \pi^{+} d}$ etc. • • • $2.2 \pi^{+} d$ $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ $\frac{COMMENT}{3.450 pp \rightarrow 0}$ etc. • • $5.5 K^{-} p$ $\frac{COMMENT}{4.50 pp \rightarrow 0}$ etc. • • $0 J/\psi \rightarrow 0$ PEDLAR 09 $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ etc. • • • $8.4 \pi^{-} p$ | 0.321Γ ₃ /Γ Γ ₃ /Γ Γ ₇ Γ ₂ /(Γ ₁ +Γ ₃ Γ ₄ /Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ |
| $\Gamma(\pi^0\pi^0\eta(3\pi^0\text{ det}))$ ΔLUE 0.0694±0.0026 OUI • • • We do not us 0.11 ±0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+)$ 0.498±0.025 OUR 0.555±0.043±0.01: $\Gamma(\rho^0\gamma(\text{including}))$ ΔLUE 0.43 ±0.02 ±0.02 • • • We do not us 0.31 ±0.15 $\Gamma(\omega\gamma)/\Gamma_{\text{total}}$ ΔLUE 0.0275±0.0022 OUI • • • We do not us 0.0234±0.0030±0.043 ±0.0034±0.0030±0.07 $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-)$ $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-)$ $\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ $\Gamma(\omega\gamma)/\Gamma(\omega\gamma)$ | $\frac{EVTS}{RFIT}$ se the following the following set $\frac{EVTS}{4}$ $\pi^-\eta$) FIT 3 non-resona FIT $\frac{EVTS}{8}$ se the following set the following set $\frac{EVTS}{4}$ $\frac{EVTS}{4}$ set the following set $\frac{EVTS}{4}$ | DOCUMENT IL PEDLAR MR π+ π- γ))/I DOCUMENT IL BARBERIS IN DAVIS DOCUMENT IL AND PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PARENT IL PEDLAR AND PEDLAR AND PEDLAR PEDLAR PEDLAR ALDE | 98ces, fits 0 98ces, fits 0 09 oges, fits 0 07 oges, fits 0 oges, fits 0 oges, fits | TECN TECN CLE3 TECN OMEG TECN OMEG TECN TECN TECN CLE3 PEDLAR 09 $\frac{COMMENT}{COMMENT}$ etc. • • • $2.2 \pi^{+} d$ $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ $450 pp \rightarrow \text{etc.} • • • 5.5 K^{-} p \frac{COMMENT}{J/\psi \rightarrow \eta'} etc. • • • 8.4 \pi^{-} p \frac{COMMENT}{38 \pi^{-} p \rightarrow 0}$ | 0.321Γ ₃ /Γ Γ ₃ /Γ Γ ₇ Γ ₂ /(Γ ₁ +Γ ₃ ρ _f η' ρ _s Γ ₄ /Γ γ η' γ Γ ₄ /Γ γ η ₄ /Γ |
| $\Gamma(\pi^0\pi^0\eta(3\pi^0\text{ det}))$ ΔLUE 0.0694±0.0026 OUI • • • We do not us 0.11 ±0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+)$ 0.498±0.025 OUR 0.555±0.043±0.013 $\Gamma(\rho^0\gamma(\text{including}))$ 0.431±0.012 OUR 0.431±0.012 OUR 0.431±0.015 $\Gamma(\omega\gamma)/\Gamma_{\text{total}}$ 0.0275±0.0022 OUI • • • We do not us 0.0234±0.0030±0.043 And independent $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-)$ 0.063±0.005 OUR 0.063±0.005 OUR 0.063±0.0013 $\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ 0.147±0.0016 $\Gamma(\rho^0\gamma(\text{including})$ $\Gamma(\rho^0\gamma(\text{including})$ | $\frac{EVTS}{RFIT}$ se the following the following set $\frac{EVTS}{4}$ $\pi^-\eta$) FIT 3 non-resona FIT $\frac{EVTS}{8}$ se the following set the following set $\frac{EVTS}{4}$ $\frac{EVTS}{4}$ set the following set $\frac{EVTS}{4}$ | DOCUMENT IL PEDLAR MR π+ π- γ))/I DOCUMENT IL BARBERIS IN DAVIS DOCUMENT IL AND PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PARENT IL PEDLAR AND PEDLAR AND PEDLAR PEDLAR PEDLAR ALDE | 98ces, fits 0 98ces, fits 0 09 oges, fits 0 07 oges, fits 0 oges, fits 0 oges, fits | TECN TECN CLE3 TECN OMEG TECN OMEG TECN TECN TECN CLE3 PEDLAR 09 $\frac{COMMENT}{COMMENT}$ etc. • • • 2.2 $\pi^+ d$ $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ if 450 $pp \rightarrow$ etc. • • • 5.5 K^-p $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ etc. • • • • 0 $J/\psi \rightarrow$ PEDLAR 09 $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ etc. • • • 8.4 π^-p $\frac{COMMENT}{38 \pi^-p \rightarrow + \Gamma(\pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 $ | 0.321Γ ₃ /Γ Γ ₃ /Γ Γ ₂ /(Γ ₁ +Γ ₃ ρ _f η' ρ _s Γ ₄ /Γ |
| $\Gamma(\pi^0\pi^0\eta(3\pi^0\text{ det}))$ ΔLUE 0.0694±0.0026 OUI • • • We do not us 0.11 ±0.06 $\Gamma(\pi^0\pi^0\eta)/\Gamma(\pi^+)$ 0.498±0.025 OUR 0.555±0.043±0.01: $\Gamma(\rho^0\gamma(\text{including}))$ ΔLUE 0.43 ±0.02 ±0.02 • • • We do not us 0.31 ±0.15 $\Gamma(\omega\gamma)/\Gamma_{\text{total}}$ ΔLUE 0.0275±0.0022 OUI • • • We do not us 0.0234±0.0030±0.043 ±0.0034±0.0030±0.07 $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-)$ $\Gamma(\omega\gamma)/\Gamma(\pi^+\pi^-)$ $\Gamma(\omega\gamma)/\Gamma(\pi^0\pi^0\eta)$ $\Gamma(\omega\gamma)/\Gamma(\omega\gamma)$ | $\frac{EVTS}{RFIT}$ se the following the following set $\frac{EVTS}{4}$ $\pi^-\eta$) FIT 3 non-resona FIT $\frac{EVTS}{8}$ se the following set the following set $\frac{EVTS}{4}$ $\frac{EVTS}{4}$ set the following set $\frac{EVTS}{4}$ | DOCUMENT IL PEDLAR MR π+ π- γ))/I DOCUMENT IL BARBERIS IN DAVIS DOCUMENT IL AND PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PEDLAR PARENT IL PEDLAR AND PEDLAR AND PEDLAR PEDLAR PEDLAR ALDE | 980 99 980 99 99 99 99 99 99 99 99 99 99 99 99 99 | TECN S, limits, DBC TECN CLE3 OMEG S, limits, HBC TECN CLE3 S, limits, S CLE6 ratios in TECN CLE3 S, limits, ASPK TECN GAM2 | PEDLAR 09 $\frac{COMMENT}{COMMENT}$ etc. • • • 2.2 $\pi^+ d$ $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ if 450 $pp \rightarrow$ etc. • • • 5.5 $K^- p$ etc. • • • • 0 $J/\psi \rightarrow$ PEDLAR 09 $\frac{COMMENT}{J/\psi \rightarrow \eta'}$ etc. • • • 8.4 $\pi^- p$ $\frac{COMMENT}{38 \pi^- p \rightarrow}$ + $\Gamma(\pi^0 \pi^0 1 \Gamma_2)$ | 0.321Γ ₃ /Γ Γ ₃ /Γ Γ ₂ /(Γ ₁ +Γ ₃ Γ ₄ /Γ |

DAUBER

64 HBC 1.95 K-p

 $^{48}\,\mathrm{Not}$ independent of measured value of Γ_8/Γ_1 from NAIK 09.

Meson Particle Listings $\eta'(958)$

| [(| $ay)) + \Gamma(\omega)$ | :harged dec | $ay)\gamma)]/Г$ | |) | $\Gamma(\pi^+\pi^-\mu^+\mu^-)/\Gamma($ | | , | | | Г8/Г |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|----------------------------------|--------------------------|-----------------------------------------------------------------------|--------------------------------|--------------------------------------------------------------------------|-------------------------------|---------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------|---------------------------|
| ALUE EN | /TS DOCL | UMENT ID | TECN | (0.286Γ ₃ +0.89 | 114)/1 | VALUE (units 10 ⁻³) <0.5 | <u>CL%</u> 90 | 49 NAIK 09 | TECN | $\frac{\textit{COMMENT}}{J/\psi \rightarrow \gamma \eta'}$ | |
| .0863 ± 0.0032 OUR FIT • • We do not use the fo | allowing data f | or averages f | ite limite | etc | | ⁴⁹ NAIK 09 reports [Γ | | | | | / [B(η - |
| | _ | - | | 1.7-2.7 K ⁻ p | | $2\gamma)] < 1.3 \times 10^{-3}$ | which we | multiply by our best | value $B(\eta$ | \rightarrow 2 γ) = 39.3 | 31 × 10 ⁻ |
| | | | | · |) | $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\rm total}$ | | | | | Г9/ |
| (π+π ⁻ neutrals)/Γ _{tot} | al <u>DOCUMENT ID</u> | | (U.7141 <u>]</u> | +0.286Γ3+0.89 ^{ΝΤ} | 114)/1 | VALUE (units 10^{-2}) | CL% | DOCUMENT ID | TECN | COMMENT | |
| .396±0.004 OUR FIT | -11 | (| 14- 1114- | | | 0.36 + 0.11 OUR FIT | | | | | |
| • • We do not use the form ± 0.1 39 | LONDON | or averages, r 66 HBC | | ${p} \rightarrow \Lambda \pi^{+} \pi^{-}$ n | eutrals | • • • We do not use th | he followin | g data for averages, f | ts, limits, | etc. • • • | |
| .35 ±0.06 33 | BADIER | 65B HBC | | | | $0.37 + 0.11 \pm 0.04$ | | ⁵⁰ NAIK 09 | CLEO | $J/\psi \rightarrow \gamma \eta'$ | |
| $(\gamma\gamma)/\Gamma_{\rm total}$ | | | | | Γ ₅ /Γ | < 9 | 95 | DANBURG 73 | | 2.2 K ⁻ p → | |
| ALUE (units 10^{-2}) EVTS | DOCUME | NT ID | TECN CO | MMENT | | <5 ⁵⁰ Not independent of | 90 measured | RITTENBERG 69 | | 1.7-2.7 K ⁻ p | |
| .18±0.08 OUR FIT .00±0.15 OUR AVERAGE | : | | | | | | | value of Fig/Fig Hom | 1471111 05. | | - /- |
| $98^{+0.31}_{-0.27} \pm 0.07$ 114 | 44 WICHT | 08 | BELL B | $^{\pm} \rightarrow \kappa^{\pm} \gamma \gamma$ | | $\Gamma(\pi^+\pi^-\pi^0)/\Gamma(\pi^+\pi^0)$ VALUE (units 10^{-3}) | ٠, | DO CUMENT ID | TECN | COMMENT | ا/و۲ |
| -0.27 $.00 \pm 0.18$ | ⁴⁵ STANTO | ON 80 | SPEC 8.4 | 15 $\pi^- p \rightarrow n \pi^+ \pi$ | $\pi^- 2\gamma$ | 8.3 +2.5 OUR FIT | LVIS | DO COMENT ID | TECN | COMMENT | |
| We do not use the form | _ | = | | | | | | E1 | | | |
| 0.3k $0.3k$ $0.3k$ $0.3k$ $0.3k$ $0.3k$ | ⁴⁶ PEDLAF ⁴⁷ APEL | | CLEO J/ NICE 15 | $\psi \rightarrow \gamma \eta'$ -40 $\pi^- p \rightarrow n2\gamma$ | | $8.26 + 2.12 \pm 0.04$ | | | | $J/\psi \rightarrow \gamma \eta'$ | |
| .5 ±0.7 | DUANE | 74 | MMS π^- | - p → nMM | | ⁵¹ NAIK 09 reports [Γ(| (η'(958) – | $\rightarrow \pi^+\pi^-\pi^0)/\Gamma(\eta'(95)$ multiply by our best v | 8) → π ⁺ | $\pi^- \eta$)] / [B(η | $\rightarrow 2\gamma)$ |
| $.71 \pm 0.33$ 68 $.0 \begin{array}{c} +0.8 \\ -0.6 \end{array}$ 31 | DALPIA HARVE | | | $5 \pi^- p \rightarrow nX^0$ $5 \pi^- p \rightarrow nX^0$ | | | | experiment's error an | | | |
| | | | | | ± v1 | error from using our | | | a ou. 5000 | | 5,500 |
| 44 WICHT 08 reports $(1.40 {+} 0.16 {+} 0.15 {-} 0.12) 	imes 1$ | $1(\eta(936) \rightarrow 0.0^{-6} \text{ which we}$ | tot'/ <i>ורך</i> divide by o≘ | :all × [□ ur best val | ue B($B^+ 	o \eta'$) | ·)] = K+) = | $\Gamma(\pi^0 ho^0)/\Gamma_{ m total}$ | | | | | Γ ₁₀ / |
| $(7.06 \pm 0.25) \times 10^{-5}$ | Our first error | is their exper | iment's err | or and our second | error is | <u>∨ALUE</u> <0.04 | <u>CL%</u> 90 | DOCUMENT ID RITTENBERG 65 | TECN HBC | 2.7 K ⁻ p | |
| the systematic error fro ¹⁵ Includes APEL 79 resul | t. | | | | | | 90 | KITTENBERG 03 | пвс | 2.1 K P | _ |
| ¹⁶ Not independent of oth ¹⁷ Data is included in STA | er η' branching | | d ratios in | PEDLAR 09. | | $\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ | | | | | Γ ₁₁ , |
| | INT ON OU EVAL | u at ion. | | | | VALUE (units 10 ⁻⁴) • • • We do not use the | <u>CL%</u> he followin | DOCUMENT ID | ts limits | | |
| $(\gamma\gamma)/\Gamma(\pi^+\pi^-\eta)$ | DOC | IMENT ID | TECN | COMMENT | Γ ₅ /Γ ₁ | < 2.4 | 90 | | | $J/\psi \rightarrow \gamma \eta'$ | |
| .0503±0.0022 OUR FIT | | | | | | <100 | 90 | RITTENBERG 69 | НВС | 1.7-2.7 K ⁻ p | |
| .053 ±0.004 ±0.001 | PED | LAR 09 | 9 CLE3 | $J/\psi \rightarrow \eta' \gamma$ | | ⁵² Not independent of | measured | value of Γ_{11}/Γ_1 from | NAIK 09 | | |
| $\Gamma(\gamma\gamma)/\Gamma(ho^0\gamma)$ (including | | |)) | | Γ_5/Γ_2 | $\Gamma(2(\pi^+\pi^-))/\Gamma(\pi^+\pi^-)$ | $\pi^-\eta)$ | | | | Γ_{11}/I |
| ALUE 0.0744 ± 0.0033 OUR FIT | | JMENT ID | TECN | COMMENT | | VALUE (units 10 ⁻³) | CL% | DOCUMENT ID | | COMMENT | |
| 0.080 ±0.008 | ABL | IKIM 06 | SE BES2 | $J/\psi \rightarrow \eta' \gamma$ | | <0.6 ⁵³ NAIK 09 reports [Fi | 90 | | | $J/\psi \rightarrow \gamma \eta'$ | |
| $\Gamma(\gamma\gamma)/\Gamma(\pi^0\pi^0\eta)$ | | | | | Γ ₅ /Γ ₃ | | | \rightarrow 2(π ' π))/I(η '(Σ | | | |
| ALUE | <u>DO CL</u> | JMENT ID | TECN | COMMENT | <u> </u> | $\Gamma(\pi^+\pi^-2\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₁₂ / |
| .105 ±0.010 OUR AVERA | GE Error incl | udes scale fac | tor of 1.9. | | | VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | TECN | COMMENT | .12/ |
| .091±0.009 .112±0.002±0.006 | A MS ALD | | B CBAR | $0.0 \overline{p}p$ $38 \pi^- p \rightarrow n2\gamma$ | | • • • We do not use th | he followin | g data for averages, f | ts, limits, | etc. • • • | |
| | | _ 0, | IB GAME | | | <27 | 90 | | | $J/\psi \rightarrow \gamma \eta'$ | |
| $(\gamma\gamma)/\Gamma(\pi^0\pi^0\eta)$ (neutr | | UMENT ID | TECN | I ₅ /0. | .714Γ ₃ | ⁵⁴ Not independent of | | value of Γ_{12}/Γ_1 from | NAIK 09 | | |
| .141±0.006 OUR FIT | | | | • | | $\Gamma(\pi^+\pi^-2\pi^0)/\Gamma(\pi^+$ | $\pi^-\eta)$ | | | | Γ_{12}/Γ_{12} |
| • We do not use the following. 188±0.058 | ollowing data fo 16 APEI | - | | etc. • • • 3.8 π [−] p → nX | 0 | VALUE (units 10 ⁻³) | <u>CL%</u> | DO CUMENT ID 55 NA IK 09 | | COMMENT | |
| | 10 APE | L 12 | | | | <6 ⁵⁵ NAIK 09 reports [Γ(| 90 (n/(958) - | | | $J/\psi \rightarrow \gamma \eta'$ $\pi^{+}\pi^{-}\eta 1 / [B/V]$ | (n → 2 |
| '(neutrals)/Γ _{total} 'ALUE EN | /TS DOCL | JMENT ID | • | 14Γ₃+0.09Γ₄+ <i>COMMENT</i> | Г5)/Г | | | iply by our best value | | | |
| .179±0.006 OUR FIT | <u>13 DOCC</u> | INTENT ID | IECN | COMMENT | | $\Gamma(2(π^+π^-)$ neutrals |)/F _{total} | | | | Γ ₁₃ , |
| • We do not use the form | _ | _ | | | n. | VALUE | <u>CL%</u> | DOCUMENT ID | TECN | COMMENT | . 13/ |
| | 35 BASI .23 RITT | ILE 71 FENBERG 69 | | $1.6 \pi^{-} p \rightarrow nX$ $1.7-2.7 K^{-} p$ | U | <0.01 | 95 | DANBURG 73 | | | ΛX^0 |
| $\Gamma(3\pi^0)/\Gamma(\pi^0\pi^0\eta)$ | | | | • | F /F | • • • We do not use th <0.01 | ne followir 90 | g data for averages, fi RITTENBERG 69 | | | |
| 1.57 × 1/1 (7 × 7 × 10) | /TS 00.0 | UMENT ID | TECN | COMMENT | Γ_6/Γ_3 | | | MITTENDENG 0 | 1100 | 1.1 2.1 K P | |
| ` '' ` '' | <u>13</u> <u>DOCC</u> | IMENT ID | | COMMENT | | $\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma_{to}$ | tal CL% | DOCUMENT ID | TECN | COMMENT | Γ ₁₄ / |
| ALUE (units 10 ⁻⁴)E\ | 12E DIII | . 0 | CAME | 22 == n = -/ n | | • • • We do not use th | | | | | |
| #LUE (units 10 ⁻⁴) EN 8±10 OUR FIT 8±10 OUR AVERAGE | 35 BLIK | | 7в GAM2 | $32 \pi^- p \rightarrow \eta' n$ $38 \pi^- p \rightarrow n6\gamma$ | | < 0.002 | 90 | ⁵⁶ NAIK 09 | CLEO | $J/\psi \rightarrow \gamma \eta'$ | |
| ###################################### | ALD | | 4 GAM2 | $30-40 \pi^- p \rightarrow$ | $n6\gamma$ | <0.01 | 90 | RITTENBERG 69 | | | |
| ### ALUE (units 10 ⁻⁴) E1 8 ± 10 OUR FIT 8 ± 10 OUR AVERAGE 6 ± 19 4 ± 15 | ALD BING | ON 84 | | | F /F | ⁵⁶ Not independent of | | | NAIK 09 | | |
| ### ALUE (units 10 ⁻⁴) E1 ### 10 OUR FIT ### 10 OUR AVERAGE ### 16 ± 19 ## 15 ## 15 ## 15 | | ON 8 | | | Γ_7/Γ_5 | | | | | | |
| $\frac{ALUE (units 10^{-4})}{(8\pm 10 \text{ OUR FIT})}$ E1 $\frac{1}{8\pm 10 \text{ OUR AVERAGE}}$ 16±19 2 $\frac{1}{24\pm 15}$ 25±18 2 $\frac{1}{24\pm 15}$ $\frac{1}{25\pm 18}$ $\frac{1}{24\pm 15}$ $\frac{1}{25\pm 18}$ $\frac{1}{24\pm 15}$ $\frac{1}{24\pm $ | BING | ON 84 UMENT ID | <u>TECN</u> | COMMENT | <u> </u> | $\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma(\tau$ | $\pi^+\pi^-\eta)$ | | | | Γ_{14}/Γ |
| $\frac{ALUE (units 10^{-4})}{(8\pm 10 \text{ OUR FIT})}$ E1 $\frac{1}{8\pm 10 \text{ OUR AVERAGE}}$ 16±19 2 $\frac{1}{4\pm 15}$ 2 $\frac{1}{5\pm 18}$ 2 $\frac{1}{(μ^+μ^-γ)/Γ(γγ)}$ ΔLUE (units 10^{-3}) E1 | BINC | | | | <u> </u> | VALUE (units 10 ⁻³) | <u>CL%</u> | DO CUMENT ID | | COMMENT | Γ ₁₄ /Γ |
| ALUE (units 10^{-4}) 8±10 OUR FIT 8±10 OUR AVERAGE 6±19 24±15 5±18 $(\mu^{+}\mu^{-}\gamma)/\Gamma(\gamma\gamma)$ ALUE (units 10^{-3}) EV | ### BING #################################### | UMENT ID | | COMMENT | <u> </u> | VALUE (units 10 ⁻³) | <u>CL%</u> 90 | 57 <u>DOCUMENT ID</u> NAIK 09 | CLEO | $J/\psi \rightarrow \gamma \eta'$ | Γ ₁₄ /Γ |
| ALUE (units 10^{-4}) B±10 OUR FIT B±10 OUR AVERAGE 6±19 2 4±15 5±18 $(\mu^{+}\mu^{-}\gamma)/\Gamma(\gamma\gamma)$ ALUE (units 10^{-3}) 9±1.2 $(\pi^{+}\pi^{-}\mu^{+}\mu^{-})/\Gamma_{\text{total}}$ | BING <u>/TS </u> | UMENT ID FOROV 80 | CNTR | $COMMENT$ 25,33 $\pi^- p \rightarrow 2$ | $\mu\gamma$ | <u>VALUE (units 10⁻³)</u> <4 57 NAIK 09 reports [Γ(| <u>CL%</u> 90 η'(958) – | 57 <u>DOCUMENT ID</u> NAIK 09 | CLEO (958) → | $\frac{J/\psi \to \gamma \eta'}{\pi^+ \pi^- \eta)] / [B$ | $(\eta \rightarrow 2$ |

 $\eta'(958)$

| $(2(\pi^+\pi^-)2\pi^0)/\Gamma_{\text{total}}$ | DOCUMENT ID TEG | CN COMMENT | Γ ₁₅ /Γ | $\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ | 0/ | | _ | | Γ ₂₃ / |
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| <0.01 95 | KALBFLEISCH 64B HB | | $\pi^-)+MM$ | VALUE (units 10 ⁻⁴) < 0.6 | <u>CL%</u> 90 | 64 ABLIKIM | | ES3 $J/\psi \rightarrow \gamma$ | π+π- |
| • We do not use the follow | = = | | | • • • We do not use t | | ing data for average | | | |
| <0.01 90 | LONDON 66 HB | C Compilation | | < 29 | 90 | 65 MORI | | ELL $\gamma \gamma \rightarrow \pi^{+}$ | |
| $(3(\pi^+\pi^-))/\Gamma_{\text{total}}$ | | | Γ ₁₆ /Γ | < 3.3 <800 | 90 95 | ⁶⁶ MORI DANBURG | | ELL $\gamma \gamma \rightarrow \pi^{+}$ BC 2.2 $K^{-}p$ | |
| LUE (units 10 ⁻³) CL% | DO CUMENT ID | TECN COMMENT | | <800 <200 | 95 90 | | | BC 2.2 K p · BC 1.7-2.7 K | |
| • • We do not use the follow | | , limits, etc. • • • | | ⁶⁴ ABLIKIM 11G repo | rts $[\Gamma(\eta')]$ | 958) $\rightarrow \pi^{+} \pi^{-})/\Gamma$ | total] × | $[B(J/\psi(1S) \rightarrow$ | $\gamma \eta'(958))]$ |
| 0.53 90 | | CLEO $J/\psi \rightarrow \gamma \eta'$ | | 2.84×10^{-7} which | we divide | by our best value B | $(J/\psi(1S)$ | $) \rightarrow \gamma \eta'(958)) =$ | 5.16×10 ⁻ |
| 5 95 | | HBC $K^-p \rightarrow \Lambda 2$ | $(\pi^{+}\pi^{-})$ | ⁶⁵ Taking into accoun ⁶⁶ Without interferenc | | | | | |
| ⁵⁸ Not independent of measur | ed value of I 16/I 1 from N | NAIK U9. | | | e with th | $e \gamma \gamma \rightarrow \pi \cdot \pi cc$ |) L u u | • | |
| $(3(\pi^+\pi^-))/\Gamma(\pi^+\pi^-\eta)$ | | | Γ_{16}/Γ_{1} | $\Gamma(\pi^0\pi^0)/\Gamma_{total}$ | | | _ | | Γ ₂₄ / |
| ALUE (units 10 ⁻³) <u>CL%</u> | | TECN COMMENT | | <u>VALUE</u> <4 × 10 ⁻⁴ | <u>CL%</u> 90 | 67 ABLIKIM | | ES3 $J/\psi \rightarrow \gamma$ | _0 _0 |
| 1.2 90 | | CLEO $J/\psi \rightarrow \gamma \eta'$ | | 67 ABLIKIM 11G repo | | | | , , , | |
| ⁹ NAIK 09 reports $[\Gamma(\eta')(958)]$ | $\rightarrow 3(\pi^+\pi^-))/\Gamma(\eta'(958))$ | $B) \rightarrow \pi^{+}\pi^{-}\eta)] / [B($ | $\eta \rightarrow 2\gamma)$] | 2.84×10 ⁻⁷ which | we divide | by our best value B | totall $^{\circ}$ $(J/\psi(1S)$ | $(B(3/\psi(13)) \rightarrow \gamma \eta'(958)) =$ | 5.16×10 |
| $< 3.0 \times 10^{-3}$ which we m | nuitiply by our best value B | $5(\eta \rightarrow 2\gamma) = 39.31 \times 1$ | 10 | | | | | | |
| $(\pi^+\pi^-e^+e^-)/\Gamma_{ m total}$ | | | Γ ₁₇ /Γ | $\Gamma(\pi^0\pi^0)/\Gamma(\pi^0\pi^0\eta)$ | , | | _ | | Γ ₂₄ /Γ |
| LUE (units 10 ⁻³) <u>CL%</u> | DO CUMENT ID | TECN COMMENT | | <u>VALUE (units 10⁻⁴)</u> <45 | <u>CL%</u> 90 | <u>DO CUMENT ID</u> ALDE | | <u>COMMENT</u> A M2 38 π ⁻ p – | n 4a: |
| 2.4 ^{+ 1.3} OUR FIT | | | | - | 30 | ALDL | 016 0 | A1012 30 % p = | , |
| • • We do not use the follow | wing data for averages, fits, | , limits, etc. • • • | | $\Gamma(\pi^0e^+e^-)/\Gamma_{ m total}$ | | | | | Γ ₂₅ / |
| $2.5 + 1.2 \pm 0.5$ | ⁶⁰ NAIK 09 | CLEO $J/\psi \rightarrow \gamma \eta'$ | | VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | | ECN COMMENT | |
| _ 0.9 (6 90 | RITTENBERG 65 | HBC 2.7 K ⁻ p | | < 1.4 • • • We do not use t | 90 he follow | BRIERE | | LEO 10.6 e ⁺ e ⁻ | _ |
| ⁰ Not independent of measur | | | | <13 | 90 | | | BC 2.7 K ⁻ p | |
| $(\pi^+\pi^-e^+e^-)/\Gamma(\pi^+\pi^-$ | | | F /F | | ,, | NII TENBERG | , 05 11 | DC 2.7 K p | _ |
| , ,, , | •, | T5011 001111511T | Γ_{17}/Γ_1 | $\Gamma(\eta e^+ e^-)/\Gamma_{\text{total}}$ | | | | | Γ ₂₆ / |
| LUE (units 10 ⁻³) EVTS | DO CUMENT ID | TECN COMMENT | | VALUE (units 10 ⁻³) | <u>CL%</u> | DO CUMENT ID | | ECN COMMENT | |
| 6 +3.0 OUR FIT | | | | < 2.4 • • • We do not use t | 90 he follow | BRIERE ing data for average | | LEO 106 e ⁺ e− mits.etc. • • • | |
| 50+2.99 ± 0.03 8 | ⁶¹ NAIK 09 | CLEO $J/\psi \rightarrow \gamma \eta'$ | | <11 | 90 | | | BC 2.7 K ⁻ p | |
| 51 NAIK 09 reports [$\Gamma(\eta'(958))$ | 3) $\rightarrow \pi^+\pi^-e^+e^-)/\Gamma(\eta$ | $\eta'(958) \rightarrow \pi^{+}\pi^{-}\eta)$ | / [B(η → | E(a) /E(0 0) | | | | | - /- |
| | ′ • ′′ ′′ | , , , , , , , , , , , , , , , , , , , , | , | $\Gamma(3\gamma)/\Gamma(\pi^0\pi^0\eta)$ | | | | | Γ_{27}/Γ |
| $[2\gamma)] = (14^{+7}_{-5} \pm 3) \times 10$ | $^{-3}$ which we multiply by | our best value $B(\eta$ - | \rightarrow 2 γ) = | · · / · · · / | | | _ | | |
| $[2\gamma]$] = $(14 + \frac{7}{5} \pm 3) \times 10$ $(39.31 \pm 0.20) \times 10^{-2}$. O | ur first error is their experi | our best value $B(\eta$ -ment's error and our se | $ ightarrow$ $2\gamma) =$ econd error | VALUE (units 10^{-4}) | <u>CL%</u> | DOCUMENT ID | | AM2 38 = n = | n 3ov |
| $[2\gamma] = (14^{+7}_{-5} \pm 3) \times 10$ | ur first error is their experi | our best value $B(\eta$ -ment's error and our se | $ ightarrow$ $2\gamma) =$ econd error | VALUE (units 10 ⁻⁴) <4.6 | 90 | DOCUMENT ID | | <u>COMMENT</u> A M2 38 π ⁻ p – | , |
| 2γ] = $(14^{+7}_{-5} \pm 3) \times 10$ (39.31 ± 0.20) × 10^{-2} . Of is the systematic error from | ur first error is their experi | our best value $\mathrm{B}(\eta$ -ment's error and our se | $ ightarrow 2\gamma) =$ econd error $ ho_{18}/\Gamma$ | $\frac{\text{VALUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ | | | | AM2 38 π ⁻ p - | , |
| $2\gamma)] = (14^{+7}_{-5} \pm 3) \times 10^{-2}$. Of $(39.31 \pm 0.20) \times 10^{-2}$. Of is the systematic error from $(\gamma e^+ e^-)/\Gamma_{total}$. | ur first error is their experi n using our best value. <u>DOCUMENT ID</u> | ment's error and our se | econd error | VALUE (units 10^{-4}) <4.6 $\Gamma(\mu^+\mu^-\pi^0)/\Gamma_{\text{total}}$ VALUE (units 10^{-5}) | 90 CL% | ALDE | 87B G | A M2 38 π ⁻ ρ - | Γ ₂₈ / |
| $2\gamma)] = (14^{+7}_{-5} \pm 3) \times 10^{-2}$ $(39.31 \pm 0.20) \times 10^{-2}$. Of is the systematic error from $(\gamma e^+e^-)/\Gamma_{total}$ LUE (units 10^{-3}) CL% | ur first error is their experi n using our best value. | ment's error and our se | econd error | $\frac{\text{VALUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{VALUE (units }10^{-5})}{<6.0}$ | 90 | ALDE | 87B G | AM2 38 π ⁻ p - | Γ ₂₈ / |
| (2γ)] = $(14^{+7}_{-5} \pm 3) \times 10^{-2}$. (39.31 ± 0.20) × 10^{-2} . O is the systematic error from $(\gamma e^+ e^-)/\Gamma_{\text{total}}$. (4.40E (units 10^{-3}) (2.69) 90 | ur first error is their experi n using our best value. <u>DOCUMENT ID</u> | ment's error and our se | econd error | VALUE (units 10^{-4}) <4.6 $\Gamma(\mu^+\mu^-\pi^0)/\Gamma_{\text{total}}$ VALUE (units 10^{-5}) | 90 CL% | ALDE | 87B G | A M2 38 π ⁻ ρ - | Γ ₂₈ / |
| 2γ] = $(14^{+7}_{-5} \pm 3) \times 10^{-2}$. (39.31 ± 0.20) × 10^{-2} . O is the systematic error from $(\gamma e^+ e^-)/\Gamma_{total}$. (40.9) $\frac{CL\%}{90}$. (70.9) $\frac{CL\%}{90}$. | ur first error is their experi n using our best value. <u>DOCUMENT ID</u> | ment's error and our se | Γ ₁₈ /Γ | $\frac{\text{VALUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{VALUE (units }10^{-5})}{<6.0}$ | 90 CL% | DOCUMENT ID DZHELYADIN DOCUMENT ID | 87B G | AM2 $38 \pi^- p - \frac{COMMENT}{1}$ NTR $30 \pi^- p - \frac{COMMENT}{1}$ | Γ ₂₈ / → η' n Γ ₂₉ / |
| 2γ] = $(14^{+7}_{-5} \pm 3) \times 10^{-2}$. (39.31 ± 0.20) × 10^{-2} . O is the systematic error from $(\gamma e^+ e^-)/\Gamma_{total}$. (40.9) $\frac{CL\%}{90}$. (70.9) $\frac{CL\%}{90}$. | ur first error is their experi n using our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID | ment's error and our se $\frac{\textit{TECN}}{\textit{CLEO}} = \frac{\textit{COMMENT}}{10.6~e^{+}~e^{-}}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ | $\frac{\text{MLUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<6.0}$ $\Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}}$ | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID | 87B G | AM2 38 π ⁻ p - <u>ECN COMMENT</u> NTR 30 π ⁻ p - | Γ ₂₈ / → η' n Γ ₂₉ / |
| $\begin{array}{lll} 2\gamma)] &= (14\frac{+7}{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2}. & \text{O} \\ \text{is the systematic error from} \\ & (\gamma e^{+}e^{-})/\Gamma_{\text{total}} \\ & \frac{ALUE (\text{units }10^{-3})}{90} & \frac{CL\%}{37} \\ & \frac{ALUE (\text{units }10^{-4})}{90} & \frac{CL\%}{37} \\ & \frac{CL\%}{37} & \frac{CL\%}{90} \end{array}$ | ur first error is their experi n using our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID | ment's error and our se $\frac{\textit{TECN}}{\textit{CLEO}} = \frac{\textit{COMMENT}}{\textit{10.6 e}^+ e^-}$ $\frac{\textit{TECN}}{\textit{COMMENT}} = \frac{\textit{COMMENT}}{\textit{COMMENT}}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ | $\frac{\text{MLUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<6.0}$ $\Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<1.5}$ | 90 <u>CL%</u> 90 <u>CL%</u> | DOCUMENT ID DZHELYADIN DOCUMENT ID | 87B G | AM2 $38 \pi^- p - \frac{COMMENT}{1}$ NTR $30 \pi^- p - \frac{COMMENT}{1}$ | Γ ₂₈ / → η' n Γ ₂₉ / → η' n |
| $\begin{array}{lll} 2\gamma)] &= (14^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2} & \text{O} \\ \text{is the systematic error from} \\ (\boldsymbol{\gamma} \boldsymbol{e^+} \boldsymbol{e^-}) / \Gamma_{\text{total}} \\ &\frac{1.0 \text{UE} (\text{units } 10^{-3})}{90} & \frac{\text{CL\%}}{90} \\ &(\boldsymbol{\pi^0} \boldsymbol{\gamma} \boldsymbol{\gamma}) / \Gamma \left(\boldsymbol{\pi^0} \boldsymbol{\pi^0} \boldsymbol{\eta}\right) \\ &\frac{1.0 \text{UE} (\text{units } 10^{-4})}{37} & \frac{\text{CL\%}}{90} \\ &(4\boldsymbol{\pi^0}) / \Gamma \left(\boldsymbol{\pi^0} \boldsymbol{\pi^0} \boldsymbol{\eta}\right) \end{array}$ | ur first error is their experi n using our best value. <u>DOCUMENT ID</u> BRIERE 00 <u>DOCUMENT ID</u> | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ \ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- \ p \rightarrow \ r}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ | $\frac{\text{VALUE (units }10^{-4})}{\text{<4.6}}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{VALUE (units }10^{-5})}{\text{<6.0}}$ $\Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}}$ $\frac{\text{VALUE (units }10^{-5})}{\text{VALUE (units }10^{-5})}$ | 90 <u>CL%</u> 90 <u>CL%</u> | DOCUMENT ID DZHELYADIN DOCUMENT ID | 87B G | AM2 $38 \pi^- p - \frac{COMMENT}{1}$ NTR $30 \pi^- p - \frac{COMMENT}{1}$ | Γ ₂₈ / → η' n Γ ₂₉ / |
| $\begin{array}{lll} 2\gamma)] &= (14^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2}_{-2} & \text{O} \\ \text{is the systematic error from} \\ & (\gamma e^+ e^-)/\Gamma_{\text{total}} \\ & \underline{UUE \text{ (units } 10^{-3})} & \underline{CL\%} \\ 0.9 & 90 \\ & (\pi^0 \gamma \gamma)/\Gamma (\pi^0 \pi^0 \eta) \\ & \underline{UUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & 37 & 90 \\ & (4\pi^0)/\Gamma (\pi^0 \pi^0 \eta) \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{CL\%} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-4})} \\ & \underline{LUE \text{ (units } 10^{-4})} & \underline{LUE \text{ (units } 10^{-$ | ur first error is their experi nusing our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID ALDE 87B | ment's error and our se $\frac{\textit{TECN}}{\textit{CLEO}} = \frac{\textit{COMMENT}}{\textit{10.6 e}^+ e^-}$ $\frac{\textit{TECN}}{\textit{COMMENT}} = \frac{\textit{COMMENT}}{\textit{COMMENT}}$ | Γ_{18}/Γ Γ_{19}/Γ_{3} Γ_{20}/Γ_{3} | $ \frac{\text{VALUE (units } 10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+} \mu^{-} \pi^{0}) / \Gamma_{\text{total}} $ $ \frac{\text{VALUE (units } 10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+} \mu^{-} \eta) / \Gamma_{\text{total}} $ $ \frac{\text{VALUE (units } 10^{-5})}{\text{<1.5}} $ $ \frac{\text{<1.5}}{\Gamma(e \mu)} / \Gamma_{\text{total}} $ | 90 <u>CL%</u> 90 <u>CL%</u> 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN | 87B G | AM2 $38 \pi^- p$ — ECN COMMENT NTR $30 \pi^- p$ — ECN COMMENT NTR $30 \pi^- p$ — | Γ ₂₈ / → η' n Γ ₂₉ / → η' n Γ ₃₀ / |
| $\begin{array}{lll} 2\gamma)] &= (14^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2}_{-5} & \text{o} \\ \text{is the systematic error from} \\ (\boldsymbol{\gamma} \boldsymbol{e^+} \boldsymbol{e^-}) / \Gamma_{\text{total}} \\ \frac{LUE (\text{units } 10^{-3})}{90} & \frac{CL\%}{90} \\ (\boldsymbol{\pi^0} \boldsymbol{\gamma} \boldsymbol{\gamma}) / \Gamma \left(\boldsymbol{\pi^0} \boldsymbol{\pi^0} \boldsymbol{\eta}\right) \\ \frac{LUE (\text{units } 10^{-4})}{37} & \frac{CL\%}{90} \\ (4\boldsymbol{\pi^0}) / \Gamma \left(\boldsymbol{\pi^0} \boldsymbol{\pi^0} \boldsymbol{\eta}\right) \\ \frac{LUE (\text{units } 10^{-4})}{90} & \frac{CL\%}{90} \\ \end{array}$ | ur first error is their experi nusing our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID ALDE 87B | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow r}$ $\frac{TECN}{TECN} = \frac{COMMENT}{r}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ Γ ₂₀ /Γ ₃ | $ \frac{\text{MLUE (units } 10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-5})}{\text{<1.5}} $ $ \Gamma(e\mu)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-4})}{\text{<4.7}} $ | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE | 87B G 7 1 81 C 1 81 C | AM2 $38 \pi^- p - \frac{COMMENT}{30 \pi^- p - COM$ | Γ ₂₈ / → η' n Γ ₂₉ / → η' n Γ ₃₀ / |
| $\begin{array}{lll} (2\gamma)] &= (14^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2}_{-0.00} & \text{old} \\ \text{is the systematic error from} \\ (\gamma e^+ e^-)/\Gamma_{\text{total}} & & \text{CL\%} \\ (0.9) & 90 & & 90 \\ (\pi^0 \gamma \gamma)/\Gamma(\pi^0 \pi^0 \eta) & & \text{CL\%} \\ \text{237} & & 90 & & \text{CL\%} \\ (4\pi^0)/\Gamma(\pi^0 \pi^0 \eta) & & & \text{CL\%} \\ \text{247} & & & \text{CL\%} \\ \text{250} & & & \text{CL\%} \\ \text{260} & & & \text{CL\%} \\ \text{270} & & & \text{CL\%} \\ \text{281} & & & \text{CL\%} \\ \text{290} & & & \text{CL\%} \\ \text{291} & & & \text{CL\%} \\ \text{291} & & & \text{CL\%} \\ \text{292} & & & \text{90} & & \text{CL\%} \\ \text{293} & & & \text{90} & & \text{CL\%} \\ \text{294} & & & \text{CL\%} \\ \text{295} & & & \text{CL\%} \\ \text{296} & & & \text{CL\%} \\ \text{297} & & & \text{CL\%} \\ \text{297} & & & \text{CL\%} \\ \text{298} & & & \text{CL\%} \\ \text{299} & & & \text{CL\%} \\ \text{290} & & & & \text{CL\%} \\ \text{290} & & & & \text{CL\%} \\ \text{291} & & & & \text{CL\%} \\ \text{292} & & & & \text{CL\%} \\ \text{293} & & & & \text{CL\%} \\ \text{294} & & & & \text{CL\%} \\ \text{294} & & & & \text{CL\%} \\ \text{295} & & & & \text{CL\%} \\ \text{296} & & & & \text{CL\%} \\ \text{297} & & & & \text{CL\%} \\ \text{297} & & & & \text{CL\%} \\ \text{298} & & & & \text{CL\%} \\ \text{299} & & & & \text{CL\%} \\ \text{290} & & & & & & \text{CL\%} \\ \text{290} & & & & & & & \text{CL\%} \\ \text{290} & & & & & & & & & & & & & & & & & & &$ | ur first error is their experi nusing our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID ALDE 87B DOCUMENT ID ALDE 87B | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow \ r}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow \ r}$ | Γ_{18}/Γ Γ_{19}/Γ_{3} Γ_{20}/Γ_{3} | $ \frac{\text{MLUE (units } 10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-5})}{\text{<1.5}} $ $ \Gamma(e\mu)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units } 10^{-4})}{\text{<4.7}} $ | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID | 87B G 7 1 81 C 1 81 C | AM2 $38 \pi^- p - \frac{COMMENT}{30 \pi^- p - COM$ | Γ ₂₈ / → η' n Γ ₂₉ / → η' n Γ ₃₀ / |
| $\begin{array}{lll} (2\gamma)] &= (14 {}^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2} & \text{O} \\ \text{is the systematic error from} \\ (\gamma e^+ e^-)/\Gamma_{\text{total}} \\ &= (1.09) & 90 \\ (\pi^0 \gamma \gamma)/\Gamma (\pi^0 \pi^0 \eta) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &= (1.02) & (1.02) & (1.02) \\ &$ | ur first error is their experi nusing our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID ALDE 87B | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow r}$ $\frac{TECN}{TECN} = \frac{COMMENT}{r}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ Γ ₂₀ /Γ ₃ Γ ₂₁ /Γ | $ \frac{\text{MLUE (units }10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-5})}{\text{<1.5}} $ $ \Gamma(e\mu)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-4})}{\text{<4.7}} $ $ \frac{\eta'(958)}{\text{See the note of }} $ | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I | 87B G 7 1 81 C 1 81 C 00 T DECAY | AM2 $38 \pi^- p - \frac{COMMENT}{NTR}$ NTR $30 \pi^- p - \frac{COMMENT}{NTR}$ NTR $30 \pi^- p - \frac{COMMENT}{NTR}$ LEO $10.6 e^+ e^-$ PARAMETER | Γ ₂₈ / Γ ₂₉ / Γ ₃₀ / |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | Ur first error is their expering our best value. DOCUMENT ID BRIERE 00 DOCUMENT ID ALDE 87B DOCUMENT ID ALDE 87B | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ \ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- \ p \rightarrow \ r}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- \ p \rightarrow \ r}$ $\frac{TECN}{TECN} = \frac{COMMENT}{38 \ \pi^- \ p \rightarrow \ r}$ | Fig./Fa Γ_{18}/Γ Γ_{19}/Γ_{3} Γ_{20}/Γ_{3} Γ_{3}/Γ_{4} Γ_{21}/Γ $\Gamma_{3}/\Gamma_{4}/\Gamma_{5}$ | $ \frac{\text{VALUE (units }10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+} \mu^{-} \pi^{0}) / \Gamma_{\text{total}} $ $ \frac{\text{VALUE (units }10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+} \mu^{-} \eta) / \Gamma_{\text{total}} $ $ \frac{\text{VALUE (units }10^{-5})}{\text{<1.5}} $ $ \Gamma(e\mu) / \Gamma_{\text{total}} $ $ \frac{\text{VALUE (units }10^{-4})}{\text{<4.7}} $ | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I | 87B G 7 1 81 C 1 81 C 00 T DECAY | AM2 $38 \pi^- p - \frac{COMMENT}{NTR}$ NTR $30 \pi^- p - \frac{COMMENT}{NTR}$ NTR $30 \pi^- p - \frac{COMMENT}{NTR}$ LEO $10.6 e^+ e^-$ PARAMETER | Γ ₂₈ / Γ ₂₉ / Γ ₃₀ / |
| $\begin{array}{lll} 2\gamma)] &= (14^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2}_{-2} & \text{O} \\ \text{is the systematic error from} \\ & (\gamma e^+ e^-)/\Gamma_{\text{total}} \\ & \underline{LUE (\text{units } 10^{-3})} & \underline{CL\%} \\ \text{10.9} & 90 \\ & (\pi^0 \gamma \gamma)/\Gamma (\pi^0 \pi^0 \eta) \\ & \underline{LUE (\text{units } 10^{-4})} & \underline{CL\%} \\ \text{37} & 90 \\ & (4\pi^0)/\Gamma (\pi^0 \pi^0 \eta) \\ & \underline{LUE (\text{units } 10^{-4})} & \underline{CL\%} \\ \text{23} & 90 \\ & (e^+ e^-)/\Gamma_{\text{total}} \\ & \underline{LUE (\text{units } 10^{-7})} & \underline{CL\%} \\ \text{2.1} & 90 \\ & (\text{invisible})/\Gamma_{\text{total}} \\ & (\text{invisible})/\Gamma_{\text{total}} \\ \end{array}$ | UT first error is their expering our best value. DOCUMENT ID BRIERE | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow \ r}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow \ r}$ $\frac{TECN}{ND} = \frac{COMMENT}{e^+ e^- \rightarrow \ \pi^-}$ | Γ ₁₈ /Γ Γ ₁₉ /Γ ₃ Γ ₂₀ /Γ ₃ Γ ₂₁ /Γ | $\frac{\text{MLUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<6.0}$ $\Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<1.5}$ <1.5 $\Gamma(e\mu)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-4})}{<4.7}$ $9/(958)$ See the note of for definition of DECAY ASYMMET | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I / parameters in the rameter. RAMETER FOR | 87B \overline{G} 87B \overline{G} 1 81 \overline{C} 1 81 \overline{C} 00 \overline{C} DECAY Stable Pa | AM2 $38 \pi^- p - \frac{ECN}{NTR}$ $\frac{COMMENT}{30 \pi^- p} - \frac{ECN}{30 \pi^- p} - \frac{ECN}{10.6 e^+ e^-}$ PARAMETER article Particle List | Γ ₂₈ / Γ ₂₉ / Γ ₃₀ / |
| $2\gamma)] = (14^{+7}_{-5} \pm 3) \times 10^{-2}$. (39.31 ± 0.20) × 10^{-2} . O is the systematic error from $(\gamma e^+ e^-)/\Gamma_{\text{total}}$ (10.9 90 $(\pi^0 \gamma \gamma)/\Gamma(\pi^0 \pi^0 \eta)$ (137 90 $(\pi^0 \gamma)/\Gamma(\pi^0 \pi^0 \eta)$ (140E (units 10^{-4}) (1523 90 $(\pi^0 \gamma)/\Gamma(\pi^0 \pi^0 \eta)$ (1523 90 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1524 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1525 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1615 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1616 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1617 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1617 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1617 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ (1618 $(\pi^0 \gamma)/\Gamma_{\text{total}}$ | UR FIRST ERROR IS THEIR ERROR IN USING OUT BERLEN TO US BRIERE OUT TO US B | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ \ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- \ p \rightarrow \ r}$ $\frac{TECN}{ND} = \frac{COMMENT}{e^+ \ e^- \rightarrow \ \pi^-}$ $\frac{TECN}{TECN} = \frac{COMMENT}{r}$ $\frac{TECN}{R} = \frac{COMMENT}{R}$ | Fig./Fa Γ_{18}/Γ Γ_{19}/Γ_{3} Γ_{20}/Γ_{3} Γ_{3}/Γ_{4} Γ_{21}/Γ $\Gamma_{3}/\Gamma_{4}/\Gamma_{5}$ | $ \frac{\text{MLUE (units }10^{-4})}{\text{<4.6}} $ $ \Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-5})}{\text{<6.0}} $ $ \Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-5})}{\text{<1.5}} $ $ \Gamma(e\mu)/\Gamma_{\text{total}} $ $ \frac{\text{MLUE (units }10^{-4})}{\text{<4.7}} $ $ \frac{\text{MLUE (units }10^{-4})}{\text{<4.7}} $ $ \frac{\pi}{\sqrt{958}} $ See the note of or definition of the definiti | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I parameters in the rameter. RAMETER FOR DOCUMENT ID | 87B G 7 1 81 C 1 81 C 00 T DECAY Stable Pa | AM2 $38 \pi^- p - \frac{ECN}{NTR}$ $\frac{COMMENT}{30 \pi^- p} - \frac{ECN}{30 \pi^- p} - \frac{ECN}{10.6 e^+ e^-}$ PARAMETER article Particle List | Γ ₂₈ / Γ ₂₉ / Γ ₃₀ / |
| $\begin{array}{lll} (2\gamma)] &= (14 {}^{+7}_{-5} \pm 3) \times 10 \\ (39.31 \pm 0.20) \times 10^{-2} & \text{O} \\ \text{is the systematic error from} \\ (\gamma e^+ e^-)/\Gamma_{\text{total}} \\ \frac{LUE \text{ (units } 10^{-3})}{(0.9)} & \frac{CL\%}{90} \\ (0.9) & 90 \\ \frac{(\pi^0 \gamma \gamma)/\Gamma(\pi^0 \pi^0 \eta)}{(37)} & \frac{CL\%}{(37)} \\ \frac{LUE \text{ (units } 10^{-4})}{90} & \frac{CL\%}{(37)} \\ \frac{(LUE \text{ (units } 10^{-4})}{90} & \frac{CL\%}{(23)} \\ \frac{(e^+ e^-)/\Gamma_{\text{total}}}{(221)} & \frac{CL\%}{(221)} \\ \frac{(\text{invisible})/\Gamma_{\text{total}}}{(1000 \text{ (units } 10^{-4})} & \frac{CL\%}{(200 \text{ (units } 10^{-4})} \\ \text{ • • We do not use the follows} \end{array}$ | ur first error is their experinusing our best value. DOCUMENT ID | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ $\frac{TECN}{GAM2} = \frac{COMMENT}{38 \ \pi^- p \rightarrow r}$ $\frac{TECN}{ND} = \frac{COMMENT}{e^+ e^- \rightarrow \pi^-}$ $\frac{TECN}{r} = \frac{COMMENT}{r}$, limits, etc. • • • | Fig./Fa Γ_{18}/Γ Γ_{19}/Γ_{3} Γ_{20}/Γ_{3} Γ_{3}/Γ_{4} Γ_{21}/Γ $\Gamma_{3}/\Gamma_{4}/\Gamma_{5}$ | $\frac{\text{MLUE (units }10^{-4})}{<4.6}$ $\Gamma(\mu^{+}\mu^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<6.0}$ $\Gamma(\mu^{+}\mu^{-}\eta)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-5})}{<1.5}$ <1.5 $\Gamma(e\mu)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-4})}{<4.7}$ $9/(958)$ See the note of for definition of DECAY ASYMMET | 90 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I parameters in the rameter. RAMETER FOR DOCUMENT ID | 87B G 87B G 7 1 81 C 7 00 C DECAY Stable Pa 7 ECN | AM2 $38 \pi^- p - \frac{ECN}{NTR}$ $\frac{COMMENT}{30 \pi^- p} - \frac{ECN}{30 \pi^- p} - \frac{ECN}{10.6 e^+ e^-}$ PARAMETER article Particle List | Γ ₂₈ / |
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YAF 71 ZH. | 87B G 87B G 7 T 881 C 7 TPC STRG 6 HBC STRG | AM2 $38 \pi^- p - \frac{ECN}{30 \pi^- p} - \frac{COMMENT}{30 \pi^- p} - \frac{ECN}{30 \pi$ | $\Gamma_{28}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/\Gamma_{29}/$ |
| $2\gamma)] = (14^{+7}_{-5} \pm 3) \times 10^{-2}$ $(39.31 \pm 0.20) \times 10^{-2}$. O is the systematic error from $(\gamma e^+ e^-)/\Gamma_{\text{total}}$ $\frac{ALUE (\text{units }10^{-3})}{20.9}$ (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) (0.9) | ur first error is their experinusing our best value. $\frac{DOCUMENT\ ID}{BRIERE} 00$ $\frac{DOCUMENT\ ID}{ALDE} 87B$ $\frac{DOCUMENT\ ID}{ALDE} 87B$ $\frac{DOCUMENT\ ID}{VOROBYEV} 88$ $\frac{DOCUMENT\ ID}{VOROBYEV} 88$ wing data for averages, fits, 62 NAIK 09 ed value of Γ_{22}/Γ_1 from Normal Maliking data for averages, fits, ABLIKIM 06Q $\frac{DOCUMENT\ ID}{63\ NAIK} 09$ on invisible) $\Gamma(\eta'(958)$ | ment's error and our set $\frac{TECN}{CLEO} = \frac{COMMENT}{10.6 \ e^+ e^-}$ TECN $\frac{COMMENT}{38 \ \pi^- p \rightarrow t}$ TECN $\frac{COMMENT}{38 \ \pi^- p \rightarrow t}$ TECN $\frac{COMMENT}{38 \ \pi^- p \rightarrow t}$ TECN $\frac{COMMENT}{4000000000000000000000000000000000000$ | Fig. (Fig. 1) F | $VALUE$ (units 10^{-4}) <4.6 Γ (μ+μ-π0)/Γ total $VALUE$ (units 10^{-5}) <6.0 Γ (μ+μ-η)/Γ total $VALUE$ (units 10^{-5}) <1.5 Γ (eμ)/Γ total $VALUE$ (units 10^{-4}) <4.7 P(958) See the note of for definition of definiti | 90 CL% 90 CL% 90 C-NON π η decay of this pa RY PA VTS VERAGE 295 103 he follow 152 83 012003 84 032006 105 122007 72 231 atted from 102 061800 77 9 111101 71 2124 atted from 101 182006 662 323 | DOCUMENT ID DZHELYADIN DOCUMENT ID DZHELYADIN DOCUMENT ID BRIERE CONSERVING I A parameters in the rameter. RAMETER FOR DOCUMENT ID AIHARA 87 GRIGORIAN 75 KALBFLEISCH 75 ing data for average RITTENBERG 65 M. Ablikim et M. Ablikim et E. Czerwinski A.M. Blik et al. T.K. Pedlar et A. Blik et al. T.K. Pedlar et J. Uichy et al. J. Liby et al. J. Wicht et a | 87B G 87B G 7 T C 1 81 C DECAY Stable Pa 7 TPC 6 HBC ENCES 6 HBC it al. al. al. | AM2 $38 \pi^- p - \frac{ECN}{NTR}$ $30 \pi^- p - \frac{ECN}{30 \pi^- p} - \frac{COMMENT}{30 \pi^- p}$ HECO $\frac{COMMENT}{10.6 e^+ e^-}$ PARAMETER article Particle List γ $\frac{COMMENT}{27 \rightarrow \pi^+ \pi^-}$ $\frac{C}{2.11 \pi^- p}$ $\frac{2.18 K^- p}{2.18 K^- p}$ mits, etc. • • • 2.1–2.7 $K^- p$ (BES (BSS (COSY) (IHEP) (CL (GAMS-COS) (CL (BEL (GAMS-COS) (CL (BEL (C)) (CL (GAMS-COS) (CL (BEL (C)) (CL | $\Gamma_{28}/$ $\rightarrow \eta' n$ $\Gamma_{29}/$ $\rightarrow \eta' n$ $\Gamma_{30}/$ - III Collab.) -III Collab.) -III Collab. (Protvino)) EO Collab. (Protvino) EO Collab.) EO Collab. (EO Collab.) |

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| BARBERIS 96 | | | | | |
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| BELADIDZE SLNP 55 1535 | | | | | |
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| ALDE 87B ZPHY C36 603 D.M. Alde et al. (LANL, BELG, SERP, LAPP) ANTREASYAN 87 PR D36 2633 D. Antreasyan et al. (CPStal Ball Collab.) GIDAL 86 PL B177 115 D.M. Alde et al. (LERL, SLAC, HARV) ALDE 86 PL B177 115 D.M. Alde et al. (SERP, BELG, LANL, LAPP) BARTEL 85E PL 1608 421 W. Bartel et al. (SERP, BELG, LANL, LAPP) BARTEL 85E PL 147B 487 M. Althoff et al. (JADE Collab.) BERGER 84B PL 142B 125 C. Berger (PUTO Collab.) BINON 84 PL 1408 264 F.G. Binon et al. (SERP, BELG, LANL, LAPP) BEHREND 83B PL 1258 518 (erratum) H.J. Behrend et al. (SERP, BELG, LANL, LAPP) BEHREND 83 PR D27 1031 P. Jenni et al. (SERP, BELG, LAPP) BARTEL 82B PL 113B 190 W. Bartel et al. (CELLO Collab.) JENNI 83 PR D27 1031 P. Jenni et al. (SERP, BELG, LAPP) BARTEL 82B PL 113B 190 W. Bartel et al. (CELLO Collab.) JENNI 83 PR D27 1031 P. Jenni et al. (SLAC, LBL) DZHELYADIN 81 PL 105B 239 R.I. Dzhelyadin et al. (JADE Collab.) VIKTOROV 80 SINP 32 520 V.A. Viktorov et al. (SERP) TTANSIATED TARREST STANTON 77 PR 138 1930 C. Zanfino et al. (CARL, MCGI+) VIKTOROV 79 PL 33B 141 D.M. Binnie et al. (CARL, MCGI+) VIKTOROV 79 PR 138 1930 C. Zanfino et al. (CARL, MCGI, HOLD) ANBURG 73 PR D31 987 G.R. Kalbfleisch, R.C. Strand, J.W. Chapman (BNL+) VIANLE 74 PR D10 916 G.R. Kalbfleisch, R.C. Strand, J.W. Chapman (BNL+) ANBURG 73 PR D8 18 S.M. Jacobs et al. (BNL, MICH) JACOBS 73 PR D8 18 S.M. Jacobs et al. (BNL, MICH) ANBURG 74 PR 124 837 P. PF. Daliquer et al. (MINN), MICH) JACOBS 75 PR D9 3744 J.S. Danburg et al. (MINN), MICH) JACOBS 76 PR 128 337 G.R. Kalbfleisch, R.C. Strand, J.W. Chapman (BNL+) JACOBS 77 PR 138 1505 J.R. Bensinger et al. (MINN), MICH) JACOBS 78 PR D8 18 S.M. Jacobs et al. (BNL, MICH) ANBURG 79 PL 278 535 G.R. Nabiger et al. (MINN), MICH) JACOBS 79 PR 143 1034 G.W. London et al. (CARL, MCGI, OHO) ANBURG 70 PR 143 1034 G.W. London et al. (CARL, MICH) ANBURG 70 PR 143 1034 G.W. London et al. (CARL, MICH) ANDLER 66 PL 173 377 J. J. Badier et al. (MINN), MICH) ANDLER 66 PL 178 134 G.W. London et al. (CARL, MINN) ANDLER 66 PL 178 134 G.W. London | | | | | |
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| ALTHOFF BERGER 84B PL 147B 487 M. Althoff et al. (TASSO Collab.) BINON 84 PL 140B 125 C. Begger (PLUTO Collab.) FIG. Binon et al. SERP, BELG, LAPP+) BEHREND Also PL 114B 379 PL 112B 518 (erratum) PL 114B 379 PL 105B 239 R. R. Dzhelyadin et al. (SERC) SCERC) SCERCH SCERC | ALDE | 86 | PL B177 115 | D.M. Alde et al. | (SERP, BELG, LANL, LAPP) |
| BERGER 848 | BARTEL | 85 E | PL 160B 421 | W. Bartel et al. | (JADE Collab.) |
| BINON 84 | ALTHOFF | 84 E | PL 147B 487 | M. Althoff et al. | (TASSO Collab.) |
| BEHREND | BERGER | 84 B | PL 142B 125 | C. Berger | (PLUTO Collab.) |
| BEHREND | BINON | 84 | PL 140B 264 | F.G. Binon et al. | (SERP, BELG, LAPP+) |
| Asion | | 83 B | PL 125B 518 (erratum) | | |
| JENNI | Also | | | | |
| BARTEL 828 | JENNI | 83 | PR D27 1031 | P. Jenni et al. | |
| DZHELYADIN 81 | BARTEL | 82 B | | | |
| STANTON | | | | | |
| VILTOROV 80 SJNP 32 520 | | | | | |
| Translated from YAF 32 1005. APEL 79 PL 83B 131 W.D. Apel, K.H. Augenstein, E. Bertolucci (KARLK+) D.M. Binnie et al. (LOIC) C. Zafinio et al. (CARL, MCGI, OHO+) C. Zafinio et al. (LOIC, SHMP) C. Zafinio et | | | | | |
| APEL 79 PL 83B 131 W.D. Apel, K.H. Augenstein, E. Bertolucci (KARLK+) BINNIE 79 PL 83B 141 D.M. Binnie et al. (CARL, MCGI, OHIO+) CANFINO 77 PRL 38 930 C. Zanfino et al. (CARL, MCGI, OHIO+) CRIGORIAN 75 PR D11 987 A. Grigorian et al. (LOC, SIMP) KALBFLEISCH 74 PR D12 916 G.R. Kalbfleisch, R.C. Strand, J.W. Chapman (BNL+) DANBURG 73 PR D3 3744 J.S. Danburg et al. (ENL, MICH) JP JACOBS 73 PR D8 18 S.M. Jacobs et al. (BNL) AGUILAR 72B PB D6 29 M. Aguilar-Benitez et al. (BRAN, UMD, SYRA+) JP APEL 72 PL 42B 377 PF. Dalpiaz et al. (KARLK, KARLE, PISA) ALEPIAZ 72 PL 42B 3371 M. Basile et al. (CERN, BGNA, STRB) BENSINGER 70 PL 33B 505 J.R. Bensinger et al. (WISC) AVISTORIA 88 PL 27B 552 R. Davis et al. (NUES, ANL) LONDON 68 PL 27B 552 R. Davis et al. </td <td>***********</td> <td>-</td> <td></td> <td></td> <td>(0 Em.)</td> | *********** | - | | | (0 Em.) |
| BINNIE 79 | APEL | 79 | | | . E. Bertolucci (KARLK+) |
| ZANFINO | BINNIE | 79 | PL 83B 141 | | |
| GRIGORIAN 75 NP B91 232 A. Grigorian et al. KALBFLEISCH 75 PR D11 987 G.R. Kabfleisch, R.C. Strand, J.W. Chapman (BNL+) DUANE 74 PRL 32 425 A. Duane et al. KALBFLEISCH 74 PR D10 916 G.R. Kabfleisch, R.C. Strand, J.W. Chapman (BNL+) DANBURG 73 PR D8 3744 J. Duane et al. J.S. Danburg et al. J.S. Danburg et al. J.S. Danburg et al. J.S. Danburg et al. GRAN, UMD, SYRA+JJP AGUILAR 72B PR D6 29 M. Aguilar-Benitez et al. APEL 72 PL 40B 660 W.D. Apel et al. DALPIAZ 72 PL 42B 377 M. Basile et al. GERN, MICH JP BASILE 71 NC 3A 371 M. Basile et al. HARVEY 71 PR L27 885 E.H. Harvey et al. GERN, BGNA, STRB BENINGER 70 PL 33B 505 E.H. Harvey et al. GERN, BGNA, STRB DAVIS 68 PL 27B 532 R. Davis et al. LONDON 66 PR 143 1034 G.W. London et al. GW. London et al. GW. London et al. GW. London et al. GEPOL, SACC, AMST) RITTENBERG 64 PR L13 3449 P.M. Dauber et al. GEPOL, SACC, AMST) GRANGER 64 PR L13 3449 P.M. Dauber et al. GEPOL, SACC, AMST) CLR, BNL) DAUBER 64 PR L13 3449 P.M. Dauber et al. GUCLA) JP | | | | | |
| RALBFLEISCH 75 | | 75 | | | |
| DANNE | | 75 | | | |
| RALBFLEISCH 74 | | | | | |
| DANBURG 73 | | | | | |
| JACOBS 73 | | | | | |
| AGULAR 72B PR D6 29 M. Aguilar-Benitez et al. (BNL) APEL 72 PL 40B 680 WD. Apel et al. (KARLK, KARLE, PISA) DALPIAZ 72 PL 42B 377 P.F. Dalplaz et al. (CERN) BASILE 71 NC 3A 371 M. Basile et al. (CERN, BGNA, STRB) HARVEY 71 PRL 27 885 E.H. Harvey et al. (MINN, MICH) BENSINGER 70 PL 33B 505 E.H. Harvey et al. (MINN, MICH) BENSINGER 69 Theis UCRL 1863 A. Rittenberg (IRL) DAVIS 68 PL 27B 532 R. Davis et al. (NWES, ANL) LONDON 66 PR 143 1034 GW. London et al. (BNL, SYRA) IJP BADIER 65B PL 17 337 J. Bødler et al. (EPOL, SACL, AMST) RITTENBERG 64 PRL 13 449 P.M. Dauber et al. (UCLA) JP | | | | | |
| APEL 72 | | | | | |
| DALPIAZ 72 | | | | | |
| BASILE 71 | | | | | |
| HARVEY | | | | | |
| BENSINGER 70 PL 33B 505 J.R. Bensinger et al. (WISC) RITTENBERG 69 Thesis UCRL 18863 A. Rittenberg (LRL) DAVIS 68 PL 27B 532 R. Davis et al. (NWES, ANL) LONDON 66 PR 143 1034 G.W. London et al. (BNL, SYRA) IJP BADIER 65 PR L17 337 J. Badier et al. (EPOL, SACL, AMST) ARITENBERG 64 PRL 15 556 A. Rittenberg, G.R. Kalbfleisch (LRL, BNL) DAUBER 64 PRL 13 449 P.M. Dauber et al. (UCLA) JP | | | | | |
| RITTENBERG 69 Theis UCRL 18863 A. Rittenberg (LRL) | | | | | |
| DAVIS 68 | | | | | |
| LONDON 66 PR 143 1034 G.W. London et al. (BNL, SYRA) IJP BADIER 65B PL 17 337 J. Badier et al. (EPOL, SACL, AMST) RITTENBERG 65 PRL 15 556 A. Rittenberg, G.R. Kalbfleisch (LRL, BNL) DAUBER 64 PRL 13 449 P.M. Dauber et al. (UCLA) JP | | | | | |
| BADIER 65B PL 17 337 J. Badier et al. (EPOL, ŚACL, AMST) RITTENBERG 65 PRL 15 556 A. Rittenberg, G.R. Kalbfleisch (LRL, BNL) DAUBER 64 PRL 13 449 P.M. Dauber et al. (UCLA) JP | | | | | |
| RITTENBERG 65 PRL 15-556 A. Rittenberg, G.R. Kalbfleisch (LRL, BNL) DAUBER 64 PRL 13-449 P.M. Dauber et al. (UCLA) JP | | | | | |
| DAUBER 64 PRL 13 449 P.M. Dauber et al. (UCLA) JP | | | | | |
| | | | | | |
| KALBFLEISCH 64B PKL 13 349 G.R. Kalbfleisch, O.I. Dahl, A. Rittenberg (LRL)JP | | | | | |
| | KALBFLEISCH | 64 B | PKL 13 349 | G.K. Kalbfleisch, O.I. Dahl, | A. KITTENDERG (LRL) JP |

$f_0(980)$

VALUE (MeV)

EVTS

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

DOCUMENT ID TECN COMMENT

See also the minireview on scalar mesons under $f_0(500)$. (See the index for the page number.)

f₀(980) MASS

| 990 | ± | 20 | ΟU | R ES | STIM | IATE | | | | | |
|-------|---------|------------|---------------|----------|-------|---------|-----|------------------|---------|-----------|-------------------------------------------------------------------------------------------------------------------------------|
| • • • | W | e do | not | use | the | followi | ngo | data for average | s, fits | , limits, | etc. • • • |
| 1003 | + | 5 | | | | | 1,2 | GARCIA-MAR. | .11 | RVUE | Compilation |
| 996 | \pm | 7 | | | | | 1,3 | GARCIA-MAR. | .11 | RVUE | Compilation |
| 996 | + | 4 | | | | | 4 | MOUSSALLAN | 111 | RVUE | Compilation |
| 981 | | | | | | | 5 | MENNESSIER | 10 | RVUE | Compilation |
| 1030 | + 3 | 30 L0 | | | | | 6 | ANISOVICH | 09 | RVUE | 0.0 p ρ, πN |
| 977 | + 3 | 9 | ± 1 | | | 44 | 7 | ECKLUND | 09 | CLEO | $4.17 e^{+} e^{-} \rightarrow D_{S}^{-} D_{S}^{*+} + c.c.$ |
| 982.2 | 2± | 1.0 | + 8 - 8 | .0 | | | 8 | UEHARA | 08A | BELL | $^{10.6}_{e^{+}e^{-}\pi^{0}\pi^{0}} \xrightarrow{\pi^{0}}$ |
| 976.8 | 8 ± | 0.3 | $^{+10}_{-0}$ | .1 .6 | | 64 k | 9 | AMBROSINO | 07 | KLOE | $1.02~e^{+}~e^{-}~\rightarrow~\pi^{0}~\pi^{0}~\gamma$ |
| 984. | 7 ± | 0.4 | + 2 | .4 | | 64 k | 10 | AMBROSINO | 07 | KLOE | $1.02~e^+~e^-~\rightarrow~\pi^0\pi^0\gamma$ |
| 973 | \pm | 3 | | 2 | 262 ± | 30 | 11 | AUBERT | 07A | BABR | 10.6 $e^+_+e^ \rightarrow$ |
| 970 | ± | 7 | | | 54 : | ± 9 | 11 | AUBERT | 07A | BABR | $ \begin{array}{c} \phi \pi^{+} \pi^{-} \gamma \\ 10.6 \ e^{+} e^{-} \rightarrow \\ \phi \pi^{0} \pi^{0} \gamma \end{array} $ |
| 953 | ± 2 | 20 | | | 2 | .6k | 12 | BONVICINI | 07 | CLEO | $D^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| 985.6 | 6+ | 1.2 1.5 | + 1 - 1 | .1 .6 | | | 13 | MORI | 07 | BELL | $10.6 e^{+}e^{-} \rightarrow e^{+}e^{-}\pi^{+}\pi^{-}$ |
| 983.0 | 0 ± | 0.6 | + 4 - 3 | .0 | | | 14 | AMBROSINO | 06в | KLOE | $\begin{array}{c} 1.02 \ e^+ e^- \rightarrow \\ \pi^+ \pi^- \gamma \end{array}$ |
| 977.3 | 3 ± | 0.9 | + 3 - 4 | .7 | | | 15 | AMBROSINO | 06в | KLOE | $1.02 e^+ e^- \rightarrow \pi^+ \pi^- \gamma$ |
| 950 | \pm | 9 | | | 4 | 286 | | GARMASH | 06 | BELL | $B^+ \xrightarrow{\pi^+ \pi^- \gamma} K^+ \pi^+ \pi^-$ |
| 965 | ± 1 | 10 | | | | | 17 | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$, |
| 1031 | ± | 8 | | | | | 18 | ANISOVICH | 03 | RVUE | $\phi K^+ K^-$ |

| 1037 ±31 | | TIKHOMIROV | 03 SPEC | $^{40.0}$ $\pi^ \stackrel{C}{\kappa}^{\circ}_{6}$ $\stackrel{\rightarrow}{\kappa}^{\circ}_{6}$ $\stackrel{\leftarrow}{\kappa}^{\circ}_{1}$ $\stackrel{\rightarrow}{\chi}^{\circ}_{1}$ |
|-----------------------------------------------|--------|-----------------------------------------------|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | | 10 | | |
| 973 ± 1 | 2438 | | 02D KLOE | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| $977 \pm 3 \pm 2$ | 848 | | 01A E791 | $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| 969.8± 4.5 | 419 | | 00н SND | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\gamma$ |
| $985 \begin{array}{c} +16 \\ -12 \end{array}$ | 419 22 | ^{2,23} ACHASOV | 00н SND | $e^+e^- ightarrow ~\pi^0\pi^0\gamma$ |
| 976 ± 5 ± 6 | | ²⁴ A KH METSHIN | 99B CMD2 | $e^+ e^- \rightarrow \pi^+ \pi^- \gamma$ |
| 977 \pm 3 \pm 6 | 268 | ²⁴ A KH METSHIN | 99c CMD2 | $e^+ e^- \rightarrow \pi^0 \pi^0 \gamma$ |
| 975 \pm 4 \pm 6 | | ²⁵ A KH METSHIN | 99c CMD2 | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| 975 \pm 4 \pm 6 | | ²⁶ A KH METSHIN | 99c CMD2 | $e^+e^- \rightarrow \pi^+\pi^-\gamma$, |
| 985 ±10 | | BARBERIS | 99 OMEG | $\pi^0\pi^0\gamma$ |
| 985 ±10 | | BARBERIS | 99 UNEG | $\begin{array}{c} 450 \ pp \rightarrow \\ p_S p_f K^+ K^- \end{array}$ |
| 982 ± 3 | | BARBERIS | 99B OMEG | $450 pp \rightarrow p_S p_f \pi^+ \pi^-$ |
| 982 ± 3 | | | | $450 pp \rightarrow p_S p_f \pi^0 \pi^0$ |
| 987 ± 6 ± 6 | | ²⁷ BARBERIS | 99D OMEG | $450 pp \rightarrow K^+K^-,$ |
| | | | | $\pi^+\pi^-$ |
| 989 ±15 | | | 99 GAM4 | $450 pp \rightarrow pp\pi^0\pi^0$ |
| 991 ± 3 | | ²⁸ KAMINSKI ²⁸ OLLER | 99 RVUE 99 RVUE | $\pi\pi \to \pi\pi, K\overline{K}, \sigma\sigma$ |
| ~ 980 ~ 993.5 | | | 99 RVUE 99B RVUE | $\pi\pi \to \pi\pi, K\overline{K}$ $\pi\pi \to \pi\pi, K\overline{K}$ |
| ~ 987 | | ²⁸ OLLER | 99c RVUE | $\pi \pi \rightarrow \pi \pi, K \overline{K}, \eta \eta$ |
| 957 ± 6 | | ²⁹ ACKERSTAFF | | $Z \rightarrow f_0 X$ |
| 960 ±10 | | ALDE | 98 GAM4 | v |
| 1015 ± 15 | | ²⁸ A NISOVICH | 98B RVUE | Compilation |
| 1008 | | | 98 RVUE | $\pi\pi \rightarrow \pi\pi$, $K\overline{K}$ |
| 955 ±10 | | | 97 GAM2 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| 994 ± 9 993.2± 6.5± 6.9 | | ³¹ BERTIN ³² ISHIDA | 97c OBLX 96 RVUE | $\begin{array}{ccc} 0.0 \overline{\rho} \rho \to & \pi^+ \pi^- \pi^0 \\ \pi \pi \to & \pi \pi , K \overline{K} \end{array}$ |
| 1006 | | TORNOVIST | 96 RVUE | $\pi \pi \to \pi \pi$, $K \overline{K}$, $K \pi$, $K \pi \to \pi \pi$, $K \overline{K}$, $K \pi$, |
| | | • | | n m |
| 997 \pm 5 | 3k | 33 ALDE | 95B GAM2 | $38 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ |
| 960 ±10 | 10k | ³⁴ ALDE | 95B GAM2 | $38 \pi^- p \to \pi^0 \pi^0 n$ |
| 994 \pm 5 \sim 996 | | AMSLER ³⁵ AMSLER | 95B CBAR | $\begin{array}{ccc} 0.0 \ \overline{p}p \rightarrow & 3\pi^{0} \\ 0.0 \ \overline{p}p \rightarrow & \pi^{0} \pi^{0} \pi^{0}, \end{array}$ |
| ~ 990 | | SS AWSLER | 95D CBAR | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 987 ± 6 | | ³⁶ A NISOVICH | 95 RVUE | х дд, х х д |
| 1015 | | _ JANSSEN | 95 RVUE | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 983 | | 37 BUGG | 94 RVUE | $\overline{p}p \rightarrow \eta 2\pi^0$ |
| 973 ± 2 | | | 94 RVUE | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 988 988 ±10 | | ³⁹ ZOU ⁴⁰ MORGAN | 94B RVUE 93 RVUE | $\pi\pi(K\overline{K}) \rightarrow \pi\pi(K\overline{K}),$ |
| 900 ±10 | | "- WORGAN | 93 KVUE | $J/\psi \rightarrow \phi \pi \pi (K \overline{K}),$ |
| | | | | $D_S \rightarrow \pi(\pi\pi)$ |
| 971.1 ± 4.0 | | | 91 EHS | 400 <i>p p</i> |
| 979 ± 4 | | ⁴¹ ARMSTRONG | 91 OMEG | $300 pp \rightarrow pp \pi\pi$, |
| 956 ±12 | | BREAKSTONE | 90 SFM | $pp K \overline{K}$ $pp \rightarrow pp \pi^+ \pi^-$ |
| 959.4± 6.5 | | | 89 DM2 | $J/\psi \rightarrow \omega \pi^+ \pi^-$ |
| 978 ± 9 | | | 86B HRS | $e^+e^- \rightarrow \pi^+\pi^-X$ |
| $985.0 + 9.0 \\ -39.0$ | | | 82B MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| - 39.0 974 ± 4 | | | 81 MRK2 | $J/\psi \rightarrow \pi^{+}\pi^{-}X$ |
| 975 | | | 80 RVUE | $J/\psi \rightarrow \pi \cdot \pi \cdot \Lambda$ |
| 986 ±10 | | | 78 HBC | $0.7 \overline{p} p \rightarrow \kappa_S^0 \kappa_S^0$ |
| 969 ± 5 | | | 77 ASPK | $2-2.4 \pi^- p \rightarrow$ |
| | | | | $\pi^{+}\pi^{-}n$, $K^{+}K^{-}n$ |
| 987 ± 7 | | | 73 CNTR | $\pi^- p \rightarrow nMM$ |
| 1012 ± 6 | | | 73 ASPK | $17 \pi^- \rho \to \pi^+ \pi^- n$ |
| 1007 ± 20 | | | 73 ASPK | 17 $\pi^- p \to \pi^+ \pi^- n$ |
| 997 ± 6 | | ⁴³ PROTOPOP | 73 HBC | $7 \pi^+ \rho \rightarrow \pi^+ \rho \pi^+ \pi^-$ |

¹ Quoted number refers to real part of pole position.

¹ Quoted number refers to real part of pole position.

² Analytic continuation using Roy equations. Uses the K_{e4} data of BATLEY 10c and the $\pi N \rightarrow \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73.

³ Analytic continuation using GKPY equations. Uses the K_{e4} data of BATLEY 10c and the $\pi N \rightarrow \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73.

⁴ Pole position. Used Roy equations.

⁵ Average of the analyses of three data sets in the K-matrix model. Uses the data of BATLEY 08A, HYAMS 73, and GRAYER 74, partially of COHEN 80 or ETKIN 82B.

⁶ On sheet H in a 2 pole solution. The other pole is found on sheet H in 4 (850–100) MeV

 6 On sheet II in a 2-pole solution. The other pole is found on sheet III at (850-100i) MeV $^7\,{\rm Using}$ a relativistic Breit-Wigner function and taking into account the finite D_S mass.

 8 Breit-Wigner mass. Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio $g_{f_0\ K\ K}^2/g_{f_0\ \pi\pi}^2=0.$

⁹In the kaon-loop fit.

To the kaon-loop in: 10 in the no-structure fit. 11 Systematic errors not estimated. 12 FLATTE 76 parameterization. $gf_0\pi\pi=329\pm96~{\rm MeV/c^2}$ assuming $gf_0KK/gf_0\pi\pi=2$.

 13 Breit-Wigner mass. Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio $g_{f_0\ K\ K}^2/g_{f_0\ \pi\pi}^2=4.21\pm0.25\pm0.21$ from ABLIKIM 05.

 $^{14}\ln$ the kaon-loop fit following formalism of ACHASOV 89.

 16 FLATTE 76 parameterization. Supersedes GARMASH 05. 17 FLATTE 76 parameterization, $g_{f_0}^2$ K $\overline{K}/g_{f_0}^2$ π π = 4.21 \pm 0.25 \pm 0.21.

$f_0(980)$

| ¹⁸ K-matrix pole from combined analysis of $\pi^- p \rightarrow \pi^0 \pi^0 n$, $\pi^- p \rightarrow K \overline{K}$ | ζn, |
|----------------------------------------------------------------------------------------------------------------------------------|-----|
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | π0, |
| $K^+ K^0_S \pi^-$ at rest, $\overline{p} n \to \pi^- \pi^- \pi^+$, $K^0_S K^- \pi^0$, $K^0_S K^0_S \pi^-$ at rest. | |

- ¹⁹ From the negative interference with the $f_0(500)$ meson of AITALA 01B using the ACHASOV 89 parameterization for the $f_0(980)$, a Breit-Wigner for the $f_0(500)$, and ACHASOV 01F for the $ho\pi$ contribution.
- 20 Coupled-channel Breit-Wigner, couplings $g_\pi=0.09\pm0.01\pm0.01, g_{\mbox{\it K}}=0.02\pm0.04\pm0.03.$
- $^{21}\,\mathrm{Supersedes}$ ACHASOV 981. Using the model of ACHASOV 89.
- ²² Supersedes ACHASOV 981.
- 23 In the "narrow resonance" approximation.
- 24 Assuming $\Gamma(f_0) = 40$ MeV.
- 25 From a narrow pole fit taking into account $\mathit{f}_{0}(980)$ and $\mathit{f}_{0}(1200)$ intermediate mecha-
- ²⁶ From the combined fit of the photon spectra in the reactions $e^+e^-
 ightarrow \pi^+\pi^-\gamma$,
- ²⁷ Supersedes BARBERIS 99 and BARBERIS 99B
- 28 T-matrix pole.
- ²⁹ From invariant mass fit.
- 30 On sheet II in a 2 pole solution. The other pole is found on sheet III at (1039–93*i*) MeV.
- 31 On sheet II in a 2 pole solution. The other pole is found on sheet III at (963-29i) MeV.
- 32 Reanalysis of data from HYAMS 73, GRAYER 74, SRINIVASAN 75, and ROSSELET 77 using the interfering amplitude method.
- ³³ At high |t|.
- 34 At low |t|.
- 35 On sheet II in a 4-pole solution, the other poles are found on sheet III at (953–55*i*) MeV and on sheet IV at (938–35*i*) MeV.
- ³⁶ Combined fit of ALDE 95B, ANISOVICH 94, AMSLER 94D.
- 37 On sheet II in a 2 pole solution. The other pole is found on sheet III at (996–103*i*) MeV.
- ³⁸ From sheet II pole position. 39 On sheet II in a 2 pole solution. The other pole is found on sheet III at (797–185*i*) MeV and can be interpreted as a shadow pole.
- 40 On sheet II in a 2 pole solution. The other pole is found on sheet III at (978-28i) MeV.
- $^{41}\,\mathrm{From}$ coupled channel analysis.
- 42 Coupled channel analysis with finite width corrections.
- 43 Included in AGUILAR-BENITEZ 78 fit.

f₀(980) WIDTH

Width determination very model dependent. Peak width in $\pi\pi$ is about 50 MeV, but decay width can be much larger.

| VALU | E (N | leV) | | | EVTS | | DO CUMENT ID | | TECN | COMMENT |
|-----------|-------|------------|-------|--------------|------------|---------|-------------------|------------|-----------|---------------------------------------------------------------------------------------------------|
| 40 | | | | | STIMATE | | | | | |
| • • | | | o no | ot use | the follow | /ing da | ta for averages, | fits, I | imits, et | C. • • • |
| 42 | | 20 16 | | | | 44,45 | GARCIA-MAR. | .11 | RVUE | Compilation |
| 50 | - | 20 12 | | | | 45,46 | GARCIA-MAR. | .11 | RVUE | Compilation |
| 48 | + | 22 6 | | | | 47 | MOUSSALLAN | 111 | RVUE | Compilation |
| 36 | | 22 | | | | 48 | MENNESSIER | 10 | RVUE | Compilation |
| 70 | + | 20 32 | | | | 49 | ANISOVICH | 09 | RVUE | $0.0 \ \overline{p} p, \ \pi N$ |
| 91 | + | 30 22 | ± | 3 | 44 | 50 | ECKLUND | 09 | CLEO | 4.17 $e^+e^- \to D_s^- D_s^{*+} + c.c.$ |
| 66. | 9± | 2. | 2+ | 17.6 12.5 | | 51 | UEHARA | A80 | BELL | $^{10.6}_{e^{+}e^{-}\pi^{0}\pi^{0}} \xrightarrow{_{\pi^{0}}}$ |
| 65 | ± | 13 | | | 262 ± 30 | 52 | AUBERT | 07AK | BABR | $ \begin{array}{ccc} 10.6 & e^+ e^- \rightarrow \\ \phi \pi^+ \pi^- \gamma \end{array} $ |
| 81 | | 21 | | | 54 ± 9 | 52 | AUBERT | 07ak | BABR | $10.6 \begin{array}{c} e^{+}e^{-} \\ \phi \pi^{0} \pi^{0} \gamma \end{array}$ |
| 51. | 3+ | 20. 17. | | 13.2 3.8 | | 53 | MORI | 07 | BELL | $^{10.6}_{e^{+}e^{-}\pi^{+}\pi^{-}}$ |
| 61 | \pm | 9 | +3 | 14 8 | 25 84 | | GAR MA SH | 05 | BELL | $B^+ \rightarrow K^+ \pi^+ \pi^-$ |
| 64 | \pm | 16 | | | | 55 | ANISOVICH | 03 | RVUE | |
| 121 | ± | 23 | | | | | TIKHOMIROV | 03 | SPEC | $\kappa_S^0 \kappa_S^0 \kappa_L^0 X$ |
| ~ 70 | ı | | | | | 56 | BRAMON | 02 | RVUE | $1.02 e^{+}e^{-} \rightarrow$ |
| 44 | \pm | 2 | \pm | 2 | 848 | 57 | AITALA | 01 A | E791 | $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| 201 | \pm | 28 | | | 419 | | ACHASOV | 00н | SND | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| 122 | \pm | 13 | | | 419 | 59,60 | ACHASOV | 00н | SND | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| 56 | | 20 | | | | 61 | AKHMETSHIN | | CMD2 | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| 65 | ± | 20 | | | | | BARBERIS | 99 | OMEG | $\begin{array}{c} 450 \ pp \rightarrow \\ p_S p_f \ K^+ \ K^- \end{array}$ |
| 80 | ± | 10 | | | | | BARBERIS | 99в | OMEG | 450 <i>pp</i> → |
| 80 | ± | 10 | | | | | BARBERIS | 99c | OMEG | $ \begin{array}{c} p_S p_f \pi^+ \pi^- \\ 450 pp \rightarrow \\ p_S p_f \pi^0 \pi^0 \end{array} $ |
| 48 | ± | 12 | ± | 8 | | 62 | BARBERIS | 99D | OMEG | $ 450 pp \rightarrow K^+ K^-, \pi^+ \pi^- $ |
| 65 | \pm | 25 | | | | | BELLAZZINI | 99 | GAM4 | |
| 71 | | 14 | | | | 63 | KAMINSKI | 99 | RVUE | $\pi\pi \to \pi\pi$, K \overline{K} , $\sigma\sigma$ |
| ~ 28 | | | | | | 63 | OLLER | 99 | RVUE | |
| ~ 25 | | | | | | 63 | OLLER | | RVUE | |
| ~ 14 | | 20 | | | | 03 | OLLER | 99c | | $\pi\pi \to \pi\pi$, $K\overline{K}$, $\eta\eta$ |
| 70 86 | | 20 16 | | | | 63 | ALDE ANISOVICH | 98 98 p | GAM4 | Compilation |
| 00 | Τ | 10 | | | | | AMBOVICH | 30B | NVUE | Compilation |

| | ± ± 0 | | | | 65 66 67 | BERTIN ISHIDA | 98 97 97 c 96 96 | OBLX | $\begin{array}{ccc} 450 \; pp \rightarrow & pp\pi^0\pi^0 \\ 0.0 \; \overline{p}p \rightarrow & \pi^+\pi^-\pi^0 \\ \pi\pi \rightarrow & \pi\pi, \; K\overline{K} \end{array}$ |
|-----------|-------------|------|----------|-----|----------------|------------------|------------------------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 48 | \pm | 10 | | 3k | 68 | ALDE | 95 B | GAM2 | $38 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ |
| 95 | \pm | 20 | | 10k | 69 | ALDE | 95 B | GAM2 | $38 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ |
| 26 | \pm | 10 | | | | AMSLER | 95 B | CBAR | |
| ~ 11 | 2 | | | | 70 | AMSLER | 95 D | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \pi^0,$ $\pi^0 nn, \pi^0 \pi^0 n$ |
| 80 | \pm | 12 | | | 71 | ANISOVICH | 95 | RVUE | π - $\eta\eta$, π - π - η |
| 30 | _ | | | | | JANSSEN | 95 | RVUE | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 74 | | | | | 72 | | 94 | | $\overline{p}p \rightarrow \eta 2\pi^0$ |
| 29 | \pm | 2 | | | 73 | | 94 | RVUE | $\pi\pi \rightarrow \pi\pi, K\overline{K}$ |
| 46 | | | | | | | 94B | RVUE | |
| 48 | \pm | 12 | | | 75 | MORGAN | 93 | RVUE | |
| | | | | | | | | | $ \begin{array}{ccc} \pi\pi(\overline{K}, \overline{K}), & J/\psi \to \\ \phi\pi\pi(\overline{K}, \overline{K}), & D_S \to \\ \pi(\pi\pi) \end{array} $ |
| 37.4 | ŧ± | 10.6 | 5 | | 65 | AGUILAR | 91 | EHS | 400 pp |
| 72 | ± | 8 | | | 76 | ARMSTRONG | 91 | OMEG | 300 $pp \rightarrow pp\pi\pi$, $ppK\overline{K}$ |
| 110 | \pm | 30 | | | | BREAKSTONE | 90 | SFM | $pp \rightarrow pp\pi^{+}\pi^{-}$ |
| 29 | \pm | 13 | | | 65 | ABACHI | 86B | HRS | $e^+e^- \rightarrow \pi^+\pi^- X$ |
| 120 | ± 2 | 81 | ± 20 | | | ETKIN | 82B | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| 28 | \pm | 10 | | | 76 | GIDAL | 81 | MRK2 | $J/\psi \rightarrow \pi^+\pi^-X$ |
| 70 | to | 300 | | | 77 | ACHASOV | 80 | RVUE | , , |
| 100 | \pm | 80 | | | 78 | AGUILAR | 78 | HBC | $0.7 \overline{p}p \rightarrow K_S^0 K_S^0$ |
| 30 | \pm | 8 | | | 76 | LEEPER | 77 | ASPK | 2-2.4 $\pi^- p \rightarrow$ |
| | | | | | ٦. | | | | $\pi^{+}\pi^{-}$ n, $K^{+}K^{-}$ n |
| 48 | \pm | | | | | BINNIE | 73 | | $\pi^- \rho \rightarrow n MM$ |
| 32 | \pm | | | | | | 73 | ASPK | |
| 30 | \pm | | | | | HYA MS | | ASPK | $17 \pi^- p \rightarrow \pi^+ \pi^- n$ |
| 54 | \pm | 16 | | | 79 | PROTOP OP | 73 | HBC | $7 \pi^+ p \rightarrow$ |
| | | | | | | | | | $\pi^+ \rho \pi^+ \pi^-$ |

- 44 Analytic continuation using Roy equations. Uses the $K_{\rm e4}$ data of BATLEY 10c and the $\pi\,N\,\to\,\pi\pi\,N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73.
- 46 Quoted number refers to twice imaginary part of pole position. When 46 Analytic continuation using GKPY equations. Uses the $K_{\rm e4}$ data of BATLEY 10c and the $\pi N \to \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73. 47 Pole position. Used Roy equations.
- 48 Average of the analyses of three data sets in the K-matrix model. Uses the data of BATLEY 08A, HYAMS 73, and GRAYER 74, partially of COHEN 80 or ETKIN 82B.
- 49 On sheet II in a 2-pole solution. The other pole is found on sheet III at (850-100i) MeV
- 50 Using a relativistic Breit-Wigner function and taking into account the finite D_s mass.
- 51 Breit-Wigner $\pi\pi$ width. Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio $g_{f_0 KK}^2/g_{f_0 \pi\pi}^2=0$.
- 52 Systematic errors not estimated.
- 53 Breit-Wigner $\pi\pi$ width. Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio $g_{f_0\ K\ K}^2/g_{f_0\ \pi\ \pi}^2=4.21\pm0.25\pm0.21$ from ABLIKIM 05.
- ⁵⁴ Breit-Wigner, solution 1, PWA ambiguous.
- 55 K-matrix pole from combined analysis of $\pi^-p \to \pi^0\pi^0$ n, $\pi^-p \to K\overline{K}$ n, $\pi^+\pi^- \to \pi^+\pi^-$, $\overline{p}p \to \pi^0\pi^0\pi^0$, $\pi^0\eta\eta$, $\pi^0\pi^0\eta$, $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, K^0_S K^0_S π^0 , ${\cal K}^+ \; {\cal K}^0_S \; \pi^- \; \text{at rest, } \overline{\rho} \, n \to \; \pi^- \pi^- \pi^+ \text{, } \; {\cal K}^0_S \; {\cal K}^- \pi^0 \text{, } \; {\cal K}^0_S \; {\cal K}^0_S \; \pi^- \; \text{at rest.}$
- ⁵⁶ Using the data of AKHMETSHIN 99c, ACHASOV 00H, and ALOISIO 02D.
- 57 Breit-Wigner width.
 58 Supersedes ACHASOV 98I. Using the model of ACHASOV 89.
- ⁵⁹ Supersedes ACHASOV 981.
- 60 In the "narrow resonance" approximation.
- 61 From the combined fit of the photon spectra in the reactions $e^+\,e^- \to \pi^+\pi^-\gamma$,
- 62 Supersedes BARBERIS 99 and BARBERIS 99B
- 63 T-matrix pole.
- 64 On sheet II in a 2 pole solution. The other pole is found on sheet III at (1039-93i) MeV.
- 65 From invariant mass fit.
 66 On sheet II in a 2 pole solution. The other pole is found on sheet III at (963-29i) MeV. 67 Reanalysis of data from HYAMS 73, GRAYER 74, SRINIVASAN 75, and ROSSELET 77
- using the interfering amplitude method. 68 At high |t|
- ⁶⁹ At low |t|.
- 70 On sheet II in a 4-pole solution, the other poles are found on sheet III at (953-55i) MeV 71 Combined fit of ALDE 95B, ANISOVICH 94,
- 72 On sheet II in a 2 pole solution. The other pole is found on sheet III at (996-103i) MeV.
- ⁷³ From sheet II pole position.
- 74 On sheet II in a 2 pole solution. The other pole is found on sheet III at (797–185i) MeV and can be interpreted as a shadow pole.
- 75 On sheet II in a 2 pole solution. The other pole is found on sheet III at (978–28i) MeV.
- $^{76}\,\mathrm{From}$ coupled channel analysis.
- 77 Coupled channel analysis with finite width corrections.
- 78 From coupled channel fit to the HYAMS 73 and PROTOPOPESCU 73 data. With a simultaneous fit to the $\pi\pi$ phase-shifts, inelasticity and to the K^0_S K^0_S invariant mass.
- ⁷⁹Included in AGUILAR-BENITEZ 78 fit.

f₀(980) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------|----------------------|------------------------------|
| Γ1 | ππ Κ Κ | dominant |
| I ₂ Гз | KK | seen seen |
| Γ ₄ | $e^{+}e^{-}$ | |

fo (980) PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | | | | Гз |
|-------------------------------------------------------|---------------------------|-------------|-----------|------------------------------------------------------------|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT |
| 0.29 +0.07 OUR AV | ERAGE | | | |
| $0.286 \pm 0.017 ^{+ 0.211}_{- 0.070}$ | ⁸⁰ UEHARA | 08A | BELL | $10.6~e^{+}e^{-}\rightarrowe^{+}e^{-}\pi^{0}\pi^{0}$ |
| $0.205 {}^{+ 0.095}_{- 0.083} {}^{+ 0.147}_{- 0.117}$ | ⁸¹ MORI | 07 | BELL | 10.6 $e^+e^-\rightarrowe^+e^-\pi^+\pi^-$ |
| $0.28 \begin{array}{l} +0.09 \\ -0.13 \end{array}$ | 82 BOGLIONE | 99 | RVUE | $\gamma \gamma ightarrow \ \pi^+ \pi^-$, $\pi^0 \pi^0$ |
| $0.42 \pm 0.06 \pm 0.18$ | ⁸³ OEST | 90 | JADE | $e^{+}e^{-} ightarrow \; e^{+}e^{-}\pi^{0}\pi^{0}$ |
| • • • We do not use | the following data for a | verag | es, fits, | limits, etc. • • • |
| 0.16 ±0.01 | ⁸⁴ MENNESSIER | 11 | RVUE | |
| $0.29 \pm 0.21 ^{+ 0.02}_{- 0.07}$ | ⁸⁵ MOUSSALLAN | Л 11 | RVUE | Compilation |
| 0.42 | 86,87 PENNINGTON | 1 08 | RVUE | Compilation |
| 0.10 | 87,88 PENNINGTON | 1 08 | RVUE | Compilation |
| $0.29 \pm 0.07 \pm 0.12$ | ^{89,90} BOYER | 90 | | $e^{+}e^{-} \rightarrow e^{+}e^{-}\pi^{+}\pi^{-}$ |
| $0.31 \pm 0.14 \pm 0.09$ | ^{89,90} MARSISKE | 90 | CBAL | $e^{+}e^{-} \rightarrow e^{+}e^{-}\pi^{0}\pi^{0}$ |
| 0.63 ± 0.14 | ⁹¹ MORGAN | 90 | RVUE | $\gamma \gamma ightarrow \ \pi^+ \pi^-$, $\pi^0 \pi^0$ |
| 80 Hain or finite width | arractions asserding to | . г. л- | TTE 70 | and ACHACOV OF and the ratio |

- ⁸⁰ Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio
- 81 Using finite width corrections according to FLATTE 76 and ACHASOV 05, and the ratio $g_{f_0 \ K \ K}^2/g_{f_0 \ \pi \pi}^2 = 4.21 \pm 0.25 \pm 0.21$ from ABLIKIM 05.
- 82 Supersedes MORGAN 90.
- 83 OEST 90 quote systematic errors $^{+0.08}_{-0.18}.$ We use $\pm 0.18.$ Observed 60 events.
- $^{84}_{\hbox{\scriptsize ---}}$ Uses an analytic K-matrix model. Compilation.
- So Ses an analytic Remarks model: explosions and data from MAR-SISKE 90, BOYER 90, BEHREND 92, UEHARA 08A, and MORI 07.
- ⁸⁶ Solution A (preferred solution based on χ^2 -analysis).
- 87 Dispersion theory based amplitude analysis of BOYER 90, MARSISKE 90, BEHREND 92, and MORI 07. 88 Solution B (worse than solution A; still acceptable when systematic uncertainties are
- included).

- included). 89 From analysis allowing arbitrary background unconstrained by unitarity. 90 Data included in MORGAN 90, BOGLIONE 99 analyses. 91 From amplitude analysis of BOYER 90 and MARSISKE 90, data corresponds to resonance parameters $m=989\,$ MeV, $\Gamma=61\,$ MeV.

| Γ(e ⁺ e ⁻) | | | | | Γ4 |
|-----------------------------------|-----|--------------|-------|---------------------------------|----|
| VALUE (eV) | CL% | DO CUMENT ID | TECN | COMMENT | |
| <8.4 | 90 | VOROBYEV 8 | 38 ND | $e^+e^- \rightarrow \pi^0\pi^0$ | |

fo (980) BRANCHING RATIOS

| $\Gamma(\pi\pi)/[\Gamma(\pi\pi)$ - | +Γ(<i>κҠ</i>)] | | | | $\Gamma_1/(\Gamma_1+\Gamma_2)$ |
|------------------------------------|------------------|--------------------------|-----------|---------|-------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not us | se the following | ng data for average | es, fits, | limits, | etc. • • • |
| 0.52 ± 0.12 | 9.9k | ⁹² AUBERT | 060 | BABR | $B^{\pm} \rightarrow K^{\pm}\pi^{\pm}\pi^{\mp}$ |
| $0.75 {}^{+ 0.11}_{- 0.13}$ | | ⁹³ ABLIKIM | 05 Q | BES2 | $\chi_{c0} \rightarrow 2\pi^+ 2\pi^-$, |
| $\textbf{0.84} \pm \textbf{0.02}$ | | ⁹⁴ A NISOVICH | 02D | | $\pi^+\pi^-K^+K^-$ Combined fit |
| ~ 0.68 | | OLLER | | | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| $\boldsymbol{0.67 \pm 0.09}$ | | ⁹⁵ LOVERRE | 80 | HBC | $4 \pi^- p \rightarrow n2K_S^0$ |
| $0.81 {}^{+ 0.09}_{- 0.04}$ | | ⁹⁵ CASON | 78 | STRC | $7 \pi^- p \rightarrow n2K_S^0$ |
| $\boldsymbol{0.78 \pm 0.03}$ | | ⁹⁵ WETZEL | 76 | OSP K | $8.9 \pi^- p \rightarrow n2K_S^0$ |

- 92 Recalculated by us using $\Gamma(K^+K^-)$ / $\Gamma(\pi^+\pi^-)=0.69\pm0.32$ from AUBERT 060 and isospin relations.
- 93 Using data from ABLIKIM 04G.
- 94 From a combined K-matrix analysis of Crystal Barrel (0. $p\overline{p} \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, $\pi^0 \eta^0 \eta$), GAMS ($\pi p \rightarrow \pi^0 \pi^0 n$, $\eta \eta n$, $\eta \eta' n$), and BNL ($\pi p \rightarrow K \overline{K} n$) data.
- 95 Measure $\pi\pi$ elasticity assuming two resonances coupled to the $\pi\pi$ and $K\overline{K}$ channels

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| | f ₀ (98 | 0) REFERENCES | |
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 $a_0(980)$

 $a_0(980)$

$$I^{G}(J^{PC}) = 1^{-}(0^{+})$$

See our minireview on scalar mesons under f_0 (500). (See the index for the page number.)

a₀(980) MASS

DOCUMENT ID

980±20 OUR ESTIMATE Mass determination very model dependent

$\eta\pi$ FINAL STATE ONLY

| • | (May) | | DO CUMENT ID | | TECN CUC | COMMENT |
|------------|----------------------------------|-------|---------------------------------------|-----------|--------------|-------------------------------------------------------------------------------------|
| VALUE | | EVTS | DOCUMENT ID | | TECN CHG | |
| | | | owing data for aver | • | | |
| | \pm 1.6 \pm 1.1 | 16.9k | ¹ AMBROSINO | 09F | | 1.02 $e^+e^- \rightarrow \eta \pi^0 \gamma$ |
| 986 | ± 4 | | ANISOVICH | 09 | RVUE | $0.0 \overline{p} p$, πN |
| 982.3 | $^{+ 0.6 +\ 3.1}_{- 0.7 -\ 4.7}$ | | ² UEHARA | 09A | BELL | $\gamma \gamma \rightarrow \pi^0 \eta$ |
| 987.4 | $\pm~1.0~\pm3.0$ | | ^{3,4} BUGG | 08A | RVUE 0 | $\overline{\rho}\rho \rightarrow \pi^0\pi^0\eta$ |
| 989.1 | $\pm~1.0~\pm3.0$ | | ^{4,5} BUGG | 08A | RVUE 0 | $\overline{p}p \rightarrow \pi^0 \pi^0 \eta$ |
| 985 | \pm 4 \pm 6 | 318 | ACHARD | 02в | L3 | $^{183-209}_{e^{+}e^{-}\eta\pi^{+}\pi^{-}}$ |
| 995 | $^{+52}_{-10}$ | 36 | ⁶ A CHA SOV | 00F | SND | $e^+e^- ightarrow \eta\pi^0\gamma$ |
| 994 | + 33 - 8 | 36 | ⁷ ACHASOV | 00F | SND | $e^+ e^- \rightarrow ~ \eta \pi^0 \gamma$ |
| 975 | ± 7 | | BARBERIS | 00н | | 450 $pp \rightarrow p_f \eta \pi^0 p_S$ |
| 988 | ± 8 | | BARBERIS | 00н | | 450 <i>p p</i> → |
| | | | | | | $\Delta_f^{++}\eta\pi^-\rho_S^-$ |
| ~ 105 | 5 | | ⁸ OLLER | 99 | RVUE | $\eta \pi$, $\dot{K} \overline{K}$ |
| ~ 100 | 9.2 | | ⁸ OLLER | 99B | RVUE | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| 993.1 | ± 2.1 | | ⁹ TEIGE | 99 | B 85 2 | 18.3 $\pi^- p \rightarrow$ |
| | | | 8 | | 51.015 | $\eta \pi^+ \pi^- n$ |
| 988 987 | ± 6 | | ⁸ A NISOVICH TOR NQVIST | 98в 96 | RVUE RVUE | Compilation $\pi\pi \to \pi\pi$, $K\overline{K}$, $K\pi$, |
| 901 | | | TORNQVIST | 90 | RVUE | $\pi\pi \to \pi\pi$, κ κ , κ π , $\eta\pi$ |
| 991 | | | JANSSEN | 95 | RVUE | $\eta \pi \xrightarrow{\eta} \eta \pi$, $K \overline{K}$, $K \pi$, |
| 984.45 | 5 ± 1.23 ± 0.34 | | AMSLER | 94 c | CBAR | $0.0 \frac{\eta \pi}{\overline{p}} p \rightarrow \omega \eta \pi^0$ |
| 982 | ± 2 | | ¹⁰ AMSLER | 92 | CBAR | $0.0 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 984 | ± 4 | 1040 | ¹⁰ ARMSTRONG | 91 B | $OMEG\pm$ | 300 pp → |
| | | | | | | $\rho \rho \eta \pi^+ \pi^-$ |
| 976 | ± 6 | | ATKINSON | 84 E | $OMEG\pm$ | 25-55 $\gamma p \rightarrow \eta \pi n$ |
| 986 | ± 3 | 500 | ¹¹ EVA NGELIS | 81 | $OMEG\pm$ | 12 $\pi^- p \rightarrow$ |
| 990 | ± 7 | 145 | ¹¹ GURTU | 79 | НВС ± | $\eta \pi^{+} \pi^{-} \pi^{-} p$ |
| 980 | ± 11 | 47 | CONFORTO | 79 78 | OSPK - | 4.2 $K^- p \rightarrow \Lambda \eta 2\pi$ 4.5 $\pi^- p \rightarrow p X^-$ |
| 978 | ±16 | 50 | CORDEN | 78 | OMEG ± | $12-15 \pi^- p \rightarrow n\eta 2\pi$ |
| 977 | ± 7 | 50 | GRASSLER | 77 | HBC - | $12^{-15} \pi p \rightarrow n\eta 2\pi$ $16 \pi^{\mp} p \rightarrow p\eta 3\pi$ |
| 989 | ± 4 | 70 | WELLS | 75 | HBC - | $3.1-6 \ K^- p \rightarrow \Lambda \eta 2\pi$ |
| 972 | ±10 | 150 | DEFOIX | 72 | HBC ± | $0.7 \overline{p}p \rightarrow 7\pi$ |
| 970 | ±15 | 20 | BARNES | 69c | HBC - | $4-5 K^- p \rightarrow \Lambda \eta 2\pi$ |
| 980 | ±10 | _, | CAMPBELL | 69 | DBC ± | $2.7 \pi^{+} d$ |
| 980 | ±10 | 15 | MILLER | 69B | HBC - | 4.5 $K^- N \rightarrow \eta \pi \Lambda$ |
| 980 | ±10 | 30 | AMMAR | 68 | HBC ± | 5.5 $K^- p \rightarrow \Lambda \eta 2\pi$ |
| - | | | | | | |

- $\frac{1}{2}$ Using the model of ACHASOV 89 and ACHASOV 03B.
- ² From a fit with the S-wave amplitude including two interfering Breit-Wigners plus a
- ³ Parameterizes couplings to $\overline{K}K$, $\pi\eta$, and $\pi\eta'$.
- ⁴Using AMSLER 94D and ABELE 98.

- 9 Breit-Wigner fit, average between a_0^\pm and a_0^0 . The fit favors a slightly heavier a_0^\pm
- ¹⁰ From a single Breit-Wigner fit.
- 11 From $f_1(1285)$ decay.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------|-----------|-------------------------|--------|-----------|---------|-----------------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not | t use the | following data for | averag | es, fits, | limits, | etc. • • • |
| ~ 1053 | | ¹² OLLER | 99c | RVUE | | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| $982\ \pm\ 3$ | | ¹³ ABELE | 98 | CBAR | | $\begin{array}{ccc} 0.0 \overline{p} p \to & K_L^0 K^{\pm} \pi^{\mp} \\ 0.0 \overline{p} p \to & K^{\pm} K_S \pi^{\mp} \end{array}$ |
| 975 ± 15 | | BERTIN | 98B | OBLX | \pm | $0.0 \overline{p}p \rightarrow K^{\pm}K_S \pi^{\mp}$ |
| 976 ± 6 | 316 | DEBILLY | 80 | HBC | \pm | 1.2-2 $\overline{p}p \rightarrow f_1(1285) \omega$ |
| 1016 ± 10 | 100 | ¹⁴ ASTIER | 67 | HBC | \pm | 0.0 p p |
| 1003.3 ± 7.0 | 143 | ¹⁵ ROSENFELD | 65 | RVUE | \pm | |
| 12 T-matrix pole | e. | | | | | |

¹³T-matrix pole on sheet II, the pole on sheet III is at 1006-i49 MeV.

14 ASTIER 67 includes data of BARLOW 67, CONFORTO 67, ARMENTEROS 65.

15 Plus systematic errors.

a₀(980) WIDTH

| VALUE | (MeV) | | EVI | 5 | DOCUN | 1ENIID | IECN | CHG | COMMENT | |
|-------|--------|-----|-------|-----|-------|---------------|-------|-------|------------|------------|
| 50 | to 100 | OUR | ESTIM | ATE | Width | determination | veryn | nodel | dependent. | Peak width |
| | | | | | | can be much | | | • | |
| | | | _ | | | _ | | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | | data ioi atoia | 800, | , | |
|-------------------------|-----------------------------------------------------------|------|--------------------------|------------|--------------|-------------------------------------------------------------------------|
| 75.6 | $\pm \ 1.6 \ \begin{array}{l} +17.4 \\ -10.0 \end{array}$ | | ¹⁶ UEHARA | 09A | BELL | $\gamma\gamma \to \ \pi^0\eta$ |
| 80.2 | \pm 3.8 \pm 5.4 | | ¹⁷ BUGG | 08A | RVUE 0 | $\overline{p} p \rightarrow \pi^0 \pi^0 \eta$ |
| 50 | ± 13 \pm 4 | 318 | ACHARD | 02в | L3 | 183-209 $e^+e^ ightarrow$ |
| | | | D. D. D. D. D. L. C. | | | $e^{+}e^{-}\eta\pi^{+}\pi^{-}$ |
| 72 61 | ±16 | | BARBERIS BARBERIS | 00н 00н | | $450 pp \rightarrow p_f \eta \pi^0 p_S$ |
| 01 | ± 19 | | BARBERIS | UUH | | $450 pp \rightarrow$ |
| | | | ¹⁸ OLLER | 99 | D) (IIIE | $\Delta_f^{++} \eta \pi^- \rho_S$ |
| ~ 42 ~ 112 | | | 18 OLLER | 99 99B | RVUE RVUE | $\eta \pi$, $K \overline{K}$ $\pi \pi \to \eta \pi$, $K \overline{K}$ |
| ~ 112 71 | ± 7 | | TEIGE | 99 | B852 | $18.3 \pi^- p \rightarrow$ |
| 11 | ± ' | | TEIGE | ,, | D032 | $\eta \pi^+ \pi^- \eta$ |
| 92 | ± 20 | | ¹⁸ A NISOVICH | 98B | RVUE | Compilation |
| 65 | ± 10 | | ¹⁹ BERTIN | 98B | OBLX \pm | $0.0 \overline{p}p \rightarrow K^{\pm} K_{s} \pi^{\mp}$ |
| ~ 100 | | | TORNQVIST | 96 | RVUE | $\pi\pi \to \pi\pi$, $K\overline{K}$, $K\pi$, |
| 202 | | | JANSSEN | οr | RVUE | $\eta \pi$ |
| 202 | | | JANSSEN | 95 | RVUE | $\eta \pi \eta \pi$, $K \overline{K}$, $K \pi$, |
| 54.12 | 2± 0.34± 0.12 | | AMSLER | 94c | CBAR | $0.0 \overline{p} p \rightarrow \omega \eta \pi^0$ |
| 54 | ± 10 | | ²⁰ AMSLER | 92 | CBAR | $0.0 \ \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 95 | ± 14 | 1040 | ²⁰ ARMSTRONG | 91B | $OMEG \pm$ | 300 $pp \rightarrow$ |
| | | | 21 | | | $ ho ho \eta \pi^+ \pi^-$ |
| 62 | ± 15 | 500 | ²¹ EVANGELIS | 81 | OMEG \pm | 12 $\pi^- p \rightarrow$ |
| 60 | ± 20 | 145 | ²¹ GURTU | 79 | HBC ± | $\eta \pi^+ \pi^- \pi^- p$ 4.2 $K^- p \rightarrow \Lambda \eta 2\pi$ |
| | ± 20 + 50 | | | | | |
| 60 | - 30 | 47 | CONFORTO | 78 | OSPK — | $4.5 \pi^- p \rightarrow pX^-$ |
| 86.0 | $^{+\ 60.0}_{-\ 50.0}$ | 50 | CORDEN | 78 | OMEG \pm | $12-15 \pi^{-} p \rightarrow n\eta 2\pi$ |
| 44 | ± 22 | | GRASSLER | 77 | HBC - | $16 \pi^{\mp} p \rightarrow p \eta 3\pi$ |
| 80 | to 300 | | 22 FLATTE | 76 | RVUE - | $4.2 K^{-} p \rightarrow \Lambda \eta 2\pi$ |
| | | | | | | |
| 16.0 | $^{+ 25.0}_{- 16.0}$ | 70 | WELLS | 75 | HBC - | $3.1-6 K^- p \rightarrow \Lambda \eta 2\pi$ |
| 30 | ± 5 | 150 | DEFOIX | 72 | HBC ± | $0.7 \overline{p}p \rightarrow 7\pi$ |
| 40 | ±15 | | CAMPBELL | 69 | DBC ± | $2.7 \pi^{+} d$ |
| 60 | ±30 | 15 | MILLER | 69B | HBC - | 4.5 $K^- N \rightarrow \eta \pi \Lambda$ |
| 80 | ± 30 | 30 | AMMAR | 68 | HBC ± | $5.5 K^- p \rightarrow \Lambda \eta 2\pi$ |
| | | | | | | |

 16 From a fit with the S-wave amplitude including two interfering Breit-Wigners plus a background term.

17 From the T-matrix pole on sheet II, using AMSLER 94D and ABELE 98.

¹⁸ T-matrix pole.

 $^{19}\,\mathrm{The}\;\eta\pi$ width.

²⁰ From a single Breit-Wigner fit.

 21 From $f_1(1285)$ decay.

22 Using a two-channel resonance parametrization of GAY 76B data.

KK ONLY

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|----------------|-------------|-------------------------|--------|-------------|--------|------------------------------------------------------------|
| 92± 8 | | ²³ ABELE | 98 | CBAR | | $0.0 \overline{p} p \rightarrow K_L^0 K^{\pm} \pi^{\mp}$ |
| • • • We do no | t use the 1 | following data for a | verage | es, fits, l | imits, | etc. • • • |
| ~ 24 | | | | RVUE | | $\pi\pi \to \pi\pi$, $K\overline{K}$ |
| ~ 25 | 100 | | 67 | | \pm | |
| 57 ± 13 | 143 | ²⁶ ROSENFELD | 65 | RVUE | \pm | |
| 23 | | | | | | |

- ²³ T-matrix pole on sheet II, the pole on sheet III is at 1006-i49 MeV.
- 24 T-matrix pole.
- 25 ASTIER 67 includes data of BARLOW 67, CONFORTO 67, ARMENTEROS 65.
- 26 Plus systematic errors.

a₀(980) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------|------------------------------|
| Γ ₁ | $\eta\pi$ | dominant |
| Γ_2 | $K\overline{K}$ | seen |
| Γ_3 | $ ho\pi$ | |
| Γ_4 | $\gamma\gamma$ | seen |
| Γ_5 | $e^+ e^-$ | |

a₀(980) PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | | | Γ4 |
|-------------------------------|---------------------------|--------------------------|----|
| VALUE (keV) | DO CUMENT ID | TECN | |
| • • • We do not use the follo | wing data for averages, 1 | fits, limits, etc. • • • | |

²⁷ AMSLER 27 Using $\Gamma_{\gamma\gamma} B(a0(980) \rightarrow \eta\pi) = 0.24 \pm 0.08 \text{ keV}.$

| F F /F | ϕ (102 |
|--------|-------------|
| Γ1Γ4/Γ | |

| ϕ (1020) | |
|---------------|--|
| | |

$I^{G}(J^{PC}) = 0^{-}(1^{-})$

 ϕ (1020) MASS

| VALUE (N | | | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------|---------------|-------------|-----------|--------------------------|---------|-----------|-------------------------------------------------------------------|
| 1019.455 | ± 0.020 | OUR AV | ERAGE | Error includes scal | e facto | or of 1.1 | |
| 1019.30 | ± 0.02 | ±0.10 | 105k | AKHMETSHIN | 06 | CMD2 | $0.98-1.06 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 1019.52 | ±0.05 | ±0.05 | 17.4k | AKHMETSHIN | 05 | CMD2 | $0.60-1.38 \ e^{+} \ e^{-} \rightarrow \eta \gamma$ |
| 1019.483 | 3 ± 0.011 | ± 0.025 | 272k | ¹ AKHMETSHIN | 04 | CMD2 | $e^+e^- \rightarrow \kappa_L^0 \kappa_S^0$ |
| 1019.42 | | | 1900k | ² ACHASOV | 01E | SND | a+ a K+ K- |
| 1019.42 | ±0.03 | | 1900K | ACHASOV | OIE | SIND | $K_S K_L, \pi^+\pi^-\pi^0$ |
| 1019.40 | ± 0.04 | ± 0.05 | 23k | AKHMETSHIN | 01в | CMD2 | $e^+ e^- \rightarrow \eta \gamma$ |
| 1019.36 | ± 0.12 | | | ³ A CHA S O V | 00в | SND | $e^+e^- \rightarrow \eta \gamma$ |
| 1019.38 | ±0.07 | ±0.08 | 2200 | ⁴ AKHMETSHIN | 199F | CMD2 | $e^+e^- \rightarrow \pi^+\pi^- \ge 2\gamma$ |
| 1019.51 | ± 0.07 | ± 0.10 | 11169 | AKHMETSHIN | 98 | CMD2 | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| 1019.5 | ±0.4 | | | BARBERIS | 98 | OMEG | |
| | | | | | | | pp2K+2K- |
| 1019.42 | ± 0.06 | | 55600 | AKHMETSHIN | 95 | CMD2 | $e^+e^- \rightarrow hadrons$ |
| 1019.7 | ± 0.3 | | 2012 | DAVENPORT | 86 | MPSF | 400 pA → 4KX |
| 1019.7 | ± 0.1 | ± 0.1 | 5 0 7 9 | ALBRECHT | 85 D | ARG | 10 e ⁺ e [−] → |
| 1019.3 | ±0.1 | | 1500 | ARENTON | 82 | AEMS | $K^+ K^- X$ 11.8 polar. $pp \rightarrow$ |
| | | | 05.000 | 5 | | 5 | KK |
| 1019.67 | | | 25 08 0 | ⁵ PELLINEN | 82 | RVUE | |
| 1019.52 | | | 3681 | BUKIN | 78C | OLYA | $e^+e^- 	o hadrons$ |
| • • • W | /e do no | t use the | following | data for averages, | | mits, etc | |
| 1019.441 | ±0.008 | ± 0.080 | 542k | ⁶ AKHMETSHIN | 80 | CMD2 | $1.02 e^+ e^- \rightarrow K^+ K^-$ |
| 1019.63 | ± 0.07 | | 12540 | ⁷ AUBERT,B | 05 J | BABR | $D^{0} \rightarrow \overline{K}^{0} K + K -$ |
| 1019.8 | ± 0.7 | | | ARMSTRONG | 86 | OMEG | 85 $\pi^+/pp \rightarrow$ |
| | | | | | | | π^+/p 4 Kp |
| 1020.1 | ± 0.11 | | 5526 | ⁷ ATKINSON | 86 | OMEG | 20-70 γp |
| 1019.7 | ± 1.0 | | | BEBEK | 86 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 1019.411 | ± 0.008 | 1 | 642k | ⁸ DIJKSTRA | 86 | SPEC | 100-200 π^{\pm} , \overline{p} , p , K^{\pm} , on Be |
| 1020.9 | ± 0.2 | | | ⁷ FRAME | 86 | OMEG | 13 $K^+p \rightarrow \phi K^+p$ |
| 1021.0 | ±0.2 | | | ⁷ ARMSTRONG | | | 18.5 $K^-p \rightarrow$ |
| 1020.0 | ±0.5 | | | ⁷ ARMSTRONG | | | $K^- K^+ \Lambda$ 18.5 $K^- p \rightarrow$ |
| | | | | | | | $\kappa^- \kappa^+ \Lambda$ |
| 1019.7 | ± 0.3 | | | ⁷ BARATE | 83 | GOLI | 190 π^- Be → 2μ X |
| 1019.8 | ± 0.2 | ± 0.5 | 766 | IVANOV | 81 | OLYA | 1-1.4 e+ e− → |
| 1019.4 | ±0.5 | | 337 | COOPER | 78B | нвс | $K^+ K^-$ $0.7-0.8 \overline{p}p \rightarrow$ $K^0 K^0 + -$ |
| | | | | 7 | | | $\kappa_S^0 \kappa_L^0 \pi^+ \pi^-$ |
| 1020 | ± 1 | | 383 | ⁷ BALDI | 77 | CNTR | $10 \pi^- \rho \rightarrow \pi^- \phi \rho$ |
| 1018.9 | ± 0.6 | | 800 | COHEN | 77 | ASPK | $6 \pi^{\pm} N \rightarrow K^{+} K^{-} N$ |
| 1019.7 | ± 0.5 | | 454 | KALBFLEISCH | 76 | нвс | $2.18 \text{ K}^- p \rightarrow \Lambda \text{ K}^{-} \text{K}$ |
| 1019.4 | ±0.8 | | 984 | BESCH | 74 | CNTR | $2 \gamma p \rightarrow p K^+ K^-$ |
| 1020.3 | ±0.4 | | 100 | BALLAM | 73 | HBC | $2.8-9.3 \gamma p$ |
| 1019.4 | ±0.7 | | 100 | BINNIE | 73B | CNTR | $\pi^- p \rightarrow \phi n$ |
| 1019.4 | ±0.7 | | 120 | 9 AGUILAR | 72B | HBC | $3.9,4.6 \ K^- p \rightarrow$ |
| 1019.0 | ±0.5 | | 120 | AGUILAR | 1 2B | пьс | $\Lambda K^+ K^-$ |
| 1019.9 | ±0.5 | | 100 | ⁹ AGUILAR | 72B | НВС | $3.9,4.6 \ K^- p \rightarrow K^- p K^+ K^-$ |
| 1020.4 | ± 0.5 | | 131 | COLLEY | 72 | нвс | $10 K^+ p \rightarrow K^+ p \phi$ |
| 1019.9 | ±0.3 | | 410 | STOTTLE | 71 | нвс | 2.9 K ⁻ p → |
| | | | | | | | $\Sigma/\Lambda K \overline{K}$ |
| 1 | | | | | | | |

¹ Update of AKHMETSHIN 99D

 9 Mass errors enlarged by us to $\Gamma/\sqrt{\textit{N}};$ see the note with the $\textit{K}^*(892)$ mass.

ϕ (1020) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------|-------|--------------------------|----|---------------|--------------------------------------------------------|
| 4.26 ±0.04 OUR A | | | | $\overline{}$ | See the ideogram below. |
| 4.30 ±0.06 ±0.17 | 105k | AKHMETSHIN | 06 | CMD2 | $0.98-1.06 e^{+}_{0} e^{-} \rightarrow$ |
| 4.280±0.033±0.025 | 272k | ¹⁰ AKHMETSHIN | 04 | CMD2 | $e^{+}e^{-} \rightarrow \kappa_{I}^{0} \kappa_{S}^{0}$ |
| 4.21 ±0.04 | 1900k | | | | $e^+e^- \rightarrow K^+K^-$, |
| | | | | | $\kappa_S^{} \kappa_L^{}, \pi^+ \pi^- \pi^0$ |
| 4.44 ±0.09 | 55600 | AKHMETSHIN | 95 | CMD2 | $e^+e^- \rightarrow hadrons$ |
| 4.5 ±0.7 | 1500 | ARENTON | 82 | AEMS | 11.8 polar. $pp \rightarrow KK$ |
| 42 +06 | 766 | 12 IVA NOV | 81 | OIVA | $1-14e^+e^- \rightarrow K^+K^-$ |

$a_0(980) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\eta\pi) \times \Gamma(\gamma\gamma)/\Gamma$ | total | | | | $\Gamma_1\Gamma_4/\Gamma$ |
|-------------------------------------------------------|-------|----------------------|------|------|----------------------------------------|
| VALUE (keV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.21 +0.08 OUR AV | ERAGE | | | | |
| $0.128 {}^{+ 0.003}_{- 0.002} {}^{+ 0.502}_{- 0.043}$ | | ²⁸ UEHARA | 09A | BELL | $\gamma \gamma \rightarrow \pi^0 \eta$ |
| $0.28 \ \pm 0.04 \ \pm 0.10$ | 44 | OEST | 90 | JADE | $e^+e^- ightarrowe^+e^-\pi^0\eta$ |
| $0.19 \ \pm 0.07 \ ^{+ \ 0.10}_{- \ 0.07}$ | | ANTREASYAI | N 86 | CBAL | $e^+e^- \rightarrow \ e^+e^-\pi^0\eta$ |
| 29 | _ | | | | |

²⁸ From a fit with the S-wave amplitude including two interfering Breit-Wigners plus a background term.

| $\Gamma(\eta\pi) \times \Gamma(e^+e^-)$ | -)/Γ _{tota⊢} | | | | | $\Gamma_1\Gamma_5/\Gamma$ |
|-----------------------------------------|-----------------------|--------------|----|------|-----------------------------|---------------------------|
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.5 | 90 | VOROBYEV | 88 | ND | $e^+ e^- \rightarrow \pi^0$ | η |

a₀(980) BRANCHING RATIOS

| $\Gamma(K\overline{K})/\Gamma(\eta\pi)$ | | | | | Γ_2/Γ_1 |
|-----------------------------------------|--------------------------|------|------------|---------|----------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT |
| 0.183±0.024 OUR AVE | | | | r of 1. | 2. |
| 0.57 ± 0.16 | ²⁹ BARGIOTTI | 03 | OBLX | | $\overline{p}p$ |
| 0.23 ± 0.05 | ³⁰ ABELE | 98 | CBAR | | $0.0 \overline{p} p \rightarrow K_L^0 K^{\pm} \pi^{\mp}$ |
| $0.166 \pm 0.01 \pm 0.02$ | ³¹ BARBERIS | 98c | OMEG | | $450 pp \rightarrow p_f f_1(1285) p_s$ |
| • • • We do not use th | e following data fo | aver | ages, fits | , limit | s, etc. • • • |
| 1.20 ± 0.15 | ³² A NISOVICH | 09 | RVUE | | $0.0 \overline{p} \rho$, πN |
| $1.05 \pm 0.07 \pm 0.05$ | ³³ BUGG | 08A | RVUE | 0 | $\overline{\rho}\rho \rightarrow \pi^0 \pi^0 \eta$ |
| ~ 0.60 | OLLER | 99B | RVUE | | $\pi\pi \rightarrow \eta\pi, K\overline{K}$ |
| 0.7 ±0.3 | ³¹ CORDEN | 78 | OMEG | | $12-15 \pi^- p \rightarrow n\eta 2\pi$ |
| 0.25 ±0.08 | ³¹ DEFOIX | 72 | HBC | \pm | $0.7 \overline{p} \rightarrow 7\pi$ |

 $\Gamma(\rho\pi)/\Gamma(\eta\pi)$ Γ_3/Γ_1

| • • • | We do | not | use the | following | data fo | or averages | , fits, | limits, | etc. • • | • | |
|--------|-------|-----|---------|-----------|---------|-------------|---------|---------|----------|--------------------|---------------------|
| < 0.25 | | | 70 | AM | IMAR | 70 | нвс | \pm | 4.1,5.5 | $K^-p \rightarrow$ | $\Lambda \eta 2\pi$ |
| 20 | | | | | | 1 | ٥ | | 0 - | | |

²⁹ Coupled channel analysis of $\pi^+\pi^-\pi^0$, $\kappa^+\kappa^-\pi^0$, and $\kappa^\pm\kappa^0_5\pi^\mp$.

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| ANTREASYAN | 86 | PR D33 1847 | D. Antreasyan et al. | (Crystal Ball Collab.) |
| ATKINSON | 84 E | PL 138B 459 | M. Atkinson et al. | (BONN, CERN, GLAS+) |
| | 81 | NP B178 197 | | |
| EVAN GELIS | | | C. Evangelista et al. | (BARI, BONN, CERN+) |
| DEBILLY | 80 | NP B176 1 | L. de Billy et al. | (CURIN, LAUS, NEUC+) |
| GURTU | 79 | NP B151 181 | A. Gurtu et al. | (CERN, ZEEM, NIJM, OXF) |
| CONFORTO | 78 | LNC 23 419 | B. Conforto et al. | (RHEL, TNTO, CHIC+) |
| CORDEN | 78 | NP B144 253 | M.J. Corden et al. | (BIRM, RHEL, TELA+) |
| GRASSLER | 77 | NP B121 189 | H. Grassler et al. | (AACH3, BERL, BONN+) |
| JAFFE | 77 | PR D15 267,281 | R. Jaffe | (MIT) |
| FLATTE | 76 | PL 63B 224 | S.M. Flatte | (CERN) |
| GAY | 76B | PL 63B 220 | J.B. Gay et al. | (CERN, AMST, NIJM)JP |
| WELLS | 75 | NP B101 333 | J. Wells et al. | (OXF) |
| DEFOIX | 72 | NP B44 125 | C. Defoix et al. | (CDEF, CERN) |
| AMMAR | 70 | PR D2 430 | | (KANS, NWES, ANL, WISC) |
| BARNES | 69 C | PRL 23 610 | V.E. Barnes et al. | |
| | | | | (BNL, SYRA) |
| CAMPBELL | 69 | PRL 22 1204 | J.H. Campbell et al. | (PURD) |
| MILLER | 69B | PL 29B 255 | D.H. Miller et al. | (PURD) |
| A Iso | | PR 188 2011 | W.L. Yen et al. | (PURD) |
| AMMAR | 68 | PRL 21 1832 | R. Ammar et al. | (NWES, ANL) |
| ASTIER | 67 | PL 25B 294 | A. Astier et al. | (CDEF, CERN, IRAD) |
| Includes d | ata of | | 0 67, and ARMENTEROS 65 | |
| BARLOW | 67 | NC 50A 701 | J. Barlow et al. | (CERN, CDEF, IRAD, LIVP) |
| | | | | |
| CONFORTO | 67 | NP B3 469 | G. Conforto et al. | |
| CONFORTO ARMENTEROS | 67 | | G. Conforto et al. R. Armenteros et al. | (CERN, CDEF, IPNP+) (CERN, CDEF) |
| | 67 | NP B3 469 | | (CERN, CDEF, IPNP+) |

From the combined fit assuming that the total $\phi(1020)$ production cross section is saturated by those of K^+K^- , K_SK_L , $\pi^+\pi^-\pi^0$, and $\eta\gamma$ decays modes and using ACHASOV 00B for the $\eta\gamma$ decay mode.

 $^{^3}$ Using a total width of 4.43 \pm 0.05 MeV. Systematic uncertainty included.

 $^{^4}$ Using a total width of 4.43 \pm 0.05 MeV.

⁵ PELLINEN 82 review includes AKERLOF 77, DAUM 81, BALDI 77, AYRES 74, DE-GROOT 74. 5 Strongly correlated with AKHMETSHIN 04.

⁷ Systematic errors not evaluated.

⁸ Weighted and scaled average of 12 measurements of DIJKSTRA 86.

 $^{^{30}}_{21}$ Using $\pi^0\,\pi^0\,\eta$ from AMSLER 94D.

 $^{^{31}}$ From the decay of $f_1(1285)$.

³² This is a ratio of couplings.

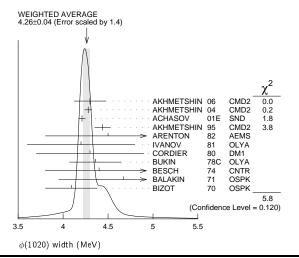
³³ A ratio of couplings, using AMSLER 94D and ABELE 98. Supersedes BUGG 94.

$\phi(1020)$

| | ±0.6 | | 12 CORDIER | 80 | | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
|------|-----------------------------------|------------|-------------------------|---------|-----------|-----------------------------------------------------------------|
| 4.36 | ± 0.29 | 3681 | ¹² BUKIN | 78 C | OLYA | $e^+e^- \rightarrow hadrons$ |
| 4.4 | ± 0.6 | 984 | ¹² BESCH | 74 | CNTR | $2 \gamma p \rightarrow p K^+ K^-$ |
| 4.67 | ± 0.72 | 681 | ¹² BALAKIN | 71 | OSPK | $e^+e^- ightarrow hadrons$ |
| 4.09 | ± 0.29 | | BIZOT | 70 | OSPK | $e^+e^- ightarrow hadrons$ |
| • • | We do not use | the follow | ving data for averag | es, fit | s, limits | , etc. • • • |
| 4.24 | $\pm 0.02 \pm 0.03$ | 542k | 13 AKHMETSHIN | 08 | CMD2 | 1.02 $e^+e^- \rightarrow K^+K^-$ |
| 4.28 | ± 0.13 | 12540 | ¹⁴ AUBERT,B | 05 J | BABR | $D^0 \rightarrow \overline{K}^0 K^+ K^-$ |
| 4.45 | ± 0.06 | 271k | DIJKSTRA | 86 | SPEC | 100 π ⁻ Be |
| 3.6 | ± 0.8 | 337 | ¹² COOPER | 78B | HBC | $0.7-0.8 \overline{p}p \rightarrow$ |
| | | | | | | $\kappa_{S}^{0} \kappa_{I}^{0} \pi^{+} \pi^{-}$ |
| 4.5 | ± 0.50 | 1300 12 | ^{2,14} AKERLOF | 77 | SPEC | $400 pA \rightarrow K^+ K^- X$ |
| 4.5 | ± 0.8 | 500 12 | ^{2,14} AYRES | 74 | ASPK | $3-6 \pi^- p \rightarrow$ |
| | | | | | | K^+K^-n , $K^-p \rightarrow$ |
| | | | | | | $\kappa^+ \kappa^- \Lambda / \Sigma^0$ |
| 3.81 | ± 0.37 | | COSME | 74B | OSP K | $e^+e^- \rightarrow K_I^0 K_S^0$ |
| 3.8 | ± 0.7 | 454 | 12 BORENSTEIN | 72 | | $2.18 \text{ K}^- p \rightarrow \text{K} \overline{\text{K}} n$ |
| | | | | | | • |

¹⁰ Update of AKHMETSHIN 99D

¹⁴ Systematic errors not evaluated.



ϕ (1020) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-----------------|---------------------------------------|------------------------------------------------------------|-----------------------------------|
| Г | K ⁺ K ⁻ | (48.9 ±0.5)% | S=1.1 |
| Γ_2 | $K_I^0 K_S^0$ | (34.2 ±0.4) % | S=1.1 |
| Γ_3 | $\rho \pi + \pi^{+} \pi^{-} \pi^{0}$ | $(15.32 \pm 0.32)\%$ | S=1.1 |
| Γ ₄ | $\rho\pi$ | | |
| Γ_5 | $\pi^+\pi^-\pi^0$ | | |
| Γ_6 | $\eta \gamma$ | $(1.309\pm0.024)\%$ | S=1.2 |
| Γ ₇ | $\pi^0_{\cdot} \gamma$ | (1.27 ± 0.06) $\times 10$ | _3 |
| 0 | $\ell^+\ell^-$ | _ | |
| Γ9 | e^+e^- | $(2.954 \pm 0.030) \times 10$ | _ |
| | $\mu^+\mu^-$ | (2.87 ±0.19) × 10 | |
| Γ ₁₁ | $\eta e^+ e^-$ | $(1.15 \pm 0.10) \times 10$ | |
| | $\pi^{+}\pi^{-}$ | $(7.4 \pm 1.3) \times 10$ | |
| | $\omega \pi^0$ | (4.7 ±0.5) × 10 | |
| Γ ₁₄ | $\omega\gamma$ | < 5 % | CL=84% |
| Γ ₁₅ | $ ho \gamma \\ \pi^+ \pi^- \gamma$ | < 1.2 × 10 | |
| 10 | $f_0(980)\gamma$ | $(4.1 \pm 1.3) \times 10$ $(3.22 \pm 0.19) \times 10$ | |
| | $\pi^0 \pi^0 \gamma$ | $(3.22 \pm 0.19) \times 10$ $(1.13 \pm 0.06) \times 10$ | |
| | ' | | |
| | $\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ | $(4.0 {}^{+2.8}_{-2.2}) \times 10$ | 9-0 |
| Γ_{20} | $\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0}$ | < 4.6 × 10 | ^{−6} CL=90% |
| | $\pi^{0}_{0} e^{+} e^{-}$ | $(1.12 \pm 0.28) \times 10$ | _5 |
| | $\pi^0 \eta \gamma$ | $(7.27 \pm 0.30) \times 10$ | |
| Γ_{23} | $a_0(980)\gamma$ | $(7.6 \pm 0.6) \times 10$ | |
| Γ ₂₄ | $K^0 \overline{K}^0 \gamma$ | < 1.9 × 10 | |
| | $\eta'(958)\gamma$ | (6.25 ± 0.21) \times 10 | |
| Γ ₂₆ | $\eta \pi^0 \pi^0 \gamma$ | < 2 × 10 | ^{−5} CL=90% |
| | | | |

| Γ_{27} | $\mu^+\mu^-\gamma$ | | | | (| 1.4 | ±0.5 | $) \times 10^{-5}$ | |
|---------------|----------------------|---|---|--|----|-----|----------|--------------------|--------|
| Γ_{28} | $\rho \gamma \gamma$ | | | | < | 1.2 | | $\times 10^{-4}$ | CL=90% |
| Γ_{29} | $\eta \pi^+ \pi^-$ | | | | < | 1.8 | | $\times 10^{-5}$ | CL=90% |
| Γ_{30} | $\eta \mu^+ \mu^-$ | | | | < | 9.4 | | $\times 10^{-6}$ | CL=90% |
| | | _ | _ | | =\ | | | | |

Lepton Faminly number (LF) violating modes

| $\Gamma_{31} e^{\pm} \mu^{\mp}$ | LF | < 2 | $\times 10^{-6}$ | CL=90% |
|----------------------------------|----|-----|------------------|--------|
|----------------------------------|----|-----|------------------|--------|

CONSTRAINED FIT INFORMATION

An overall fit to 30 branching ratios uses 79 measurements and one constraint to determine 14 parameters. The overall fit has a $\chi^2 =$ 57.4 for 66 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta x_i \delta x_j\right>/(\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{ ext{total}}$. The fit constrains the x_i whose labels appear in this array to sum to

| <i>x</i> ₂ | -72 | | | | | | | | | |
|------------------------|------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|------------------------|------------------------|------------------------|
| <i>x</i> ₃ | -53 | -21 | | | | | | | | |
| <i>x</i> ₆ | -13 | 7 | 2 | | | | | | | |
| <i>x</i> ₇ | -5 | 3 | 1 | 5 | | | | | | |
| <i>X</i> 9 | 30 | -25 | -10 | -32 | -15 | | | | | |
| <i>x</i> ₁₀ | -4 | 3 | 1 | 3 | 2 | -11 | | | | |
| x_{12} | -2 | 1 | 0 | 2 | 1 | -5 | 1 | | | |
| <i>x</i> ₁₃ | -2 | 2 | 1 | 2 | 1 | -7 | 1 | 0 | | |
| <i>x</i> ₁₇ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| <i>x</i> ₁₈ | -6 | 4 | 2 | 17 | 3 | -17 | 2 | 1 | 1 | 0 |
| <i>x</i> ₁₉ | 0 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 0 | 0 |
| x ₂₃ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| x ₂₅ | -4 | 2 | 1 | 32 | 2 | -10 | 1 | 1 | 1 | 0 |
| | x_1 | <i>x</i> ₂ | <i>x</i> ₃ | <i>x</i> ₆ | <i>x</i> ₇ | <i>x</i> ₉ | <i>x</i> ₁₀ | <i>x</i> ₁₂ | <i>x</i> ₁₃ | <i>x</i> ₁₇ |
| <i>x</i> ₁₉ | 0 | | | | | | | | | |
| <i>x</i> ₂₃ | 0 | 0 | | | | | | | | |
| x ₂₅ | 5 | 0 | 0 | | | | | | | |
| | <i>x</i> ₁₈ | <i>X</i> 19 | <i>X</i> 23 | | | | | | | |

ϕ (1020) PARTIAL WIDTHS

| , , | | | |
|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DOCUMENT I | D TECN | COMMENT | Γ ₆ |
| | | | |
| ACHASOV | 00 SND | $e^+e^- \rightarrow r$ | $\eta \gamma$ |
| | | | Γ ₇ |
| DOCUMENT I | D TECN | COMMENT | |
| lowing data for avera | ges, fits, limits | , etc. • • • | |
| ACHASOV | 00 SND | $e^+e^- \rightarrow \tau$ | $\pi^0 \gamma$ |
| | | | Га |
| DO CUMENT I | D TECN | COMMENT | |
| lowing data for avera | ges, fits, limits | , etc. • • • | |
| ¹⁵ AMBROSIN | O 05 KLOE | 1.02 e ⁺ e ⁻ | $\rightarrow \ \mu^+ \mu^-$ |
| | | | Г9 |
| DO CUMENT I | D TECN | COMMENT | |
| TION | | | |
| | | | |
| | | | |
| | | | |
| AKHMETSH | IIN 95 CMD | 2 1.02 e ⁺ e ⁻ | $\rightarrow \phi$ |
| 1/2 | | | (Γ ₉ Γ ₁₀) ^{1/2} |
| DO CUMENT I | D TECN | COMMENT | |
| AMBROSIN | O 05 KLOE | 1.02 e ⁺ e ⁻ | $\rightarrow \ \mu^+ \mu^-$ |
| and \(\bigcup_{} \Gamma\) from | m AMBROSIN | O 05 assuming | r lenton uni- |
| • | DOCUMENT IN DOCUMENT IN DOCUMENT IN DOCUMENT IN DOCUMENT IN DOCUMENT IN TION E Error includes sca 16 AKH METSI- 17 A MBROSIN AKH METSI- AKH METSI- DOCUMENT IN DOCUMENT IN AKH METSI- AMBROSIN DOCUMENT IN AKH METSI- AMBROSIN | DOCUMENT ID TECN TON E Error includes scale factor of 1.: 16 AKHMETSHIN 11 AKHMETSHIN 11 AKHMETSHIN 95 CMD MBROSINO 05 KLOB LOB AKHMETSHIN 95 CMD LOB AKHMETSHIN 95 CMD LOB AKHMETSHIN 05 AKHMETSHIN 95 CMD LOB AKHMETSHIN 95 CMD | lowing data for averages, fits, limits, etc. • • • • ACHASOV 00 SND $e^+e^- \rightarrow e^-$ DOCUMENT ID TECN COMMENT DOCUMENT ID TECN COMMENT SAMBROSINO 05 KLOE 1.02 e^+e^- TION E Fror includes scale factor of 1.1. e^{-16} AKHMETSHIN 11 CMD2 1.02 e^+e^- AKHMETSHIN 95 CMD2 1.02 e^+e^- AKHMETSHIN 95 CMD2 1.02 e^+e^- |

Weighted average of Γ_{ee} and $\sqrt{\Gamma_{e\,e}\Gamma_{\mu\mu}}$ from AMBROSINO 05 assuming lepton universality.

The combined fit assuming that the total $\phi(1020)$ production cross section is saturated by those of K^+K^- , K_SK_L , $\pi^+\pi^-\pi^0$, and $\eta\gamma$ decays modes and using ACHASOV 008 for the $\eta\gamma$ decay mode.

¹² Width errors enlarged by us to $4T/\sqrt{N}$; see the note with the $K^*(892)$ mass. 13 Strongly correlated with AKHMETSHIN 04.

versally. 16 Combined analysis of the CMD-2 data on $\phi \to K^+K^-$, $K^0_S K^0_L$, $\pi^+\pi^-\pi^0$, $\eta\gamma$ assuming that the sum of their branching fractions is 0.99741 ± 0.00007 .

 $^{^{17}}$ From forward-backward asymmetry and using $\Gamma_{total}=4.26\pm0.05$ MeV from the 2004 edition of this Review

 $\phi(1020)$

| $\phi(1020) \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$ | $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ VALUE (units 10^{-8}) DOCUMENT ID TECH COMMENT |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(K^+K^-)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_1/\Gamma \times \Gamma_9/\Gamma$ | 8.5 + 0.5 OUR FIT |
| ###################################### | 8.8 ±0.9 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below. |
| 4.24±0.30 OUR AVERAGE | 8.36 \pm 0.59 \pm 0.37 ACHASOV 01G SND $e^+e^- ightarrow \mu^+\mu^-$ |
| $4.27 \pm 0.05 \pm 0.31$ 542k AKHMETSHIN 08 CMD2 $1.02~e^+e^- \rightarrow K^+K^-$ 3.93 $\pm 0.14 \pm 0.99$ 1000k 18 ACHASOV 01E SND $e^+e^- \rightarrow K^+K^-$, $K_S~K_{I,I}~\pi^+\pi^-\pi^0$ | 9.9 \pm 1.4 \pm 0.9 |
| $(K_L^0 K_S^0)/\Gamma_{\text{total}} \times \Gamma(e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_2/\Gamma \times \Gamma_9/\Gamma$ | WEIGHTED AVERAGE |
| ALUE (units 10 ^{−5})EVTSDOCUMENT_IDTECNCOMMENT | 8.8±0.9 (Error scaled by 1.5) |
| 0.06±0.16 OUR AVERAGE | √ Values above of weighted average, error, |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained fit |
| $[\Gamma(\rho\pi) + \Gamma(\pi^+\pi^-\pi^0)]/\Gamma_{\rm total} \times \Gamma(e^+e^-)/\Gamma_{\rm total}$ $\Gamma_3/\Gamma \times \Gamma_9/\Gamma$ | utilizing measurements of other (related) quantities as additional information. |
| ALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | |
| 1.53 ±0.10 OUR FIT Error includes scale factor of 1.1. | |
| .46 ±0.12 OUR AVERAGE .51 ±0.16 ±0.11 105k AKHMETSHIN 06 CMD2 0.98-1.06 $e^+e^$ → | 2 |
| $\pi^+\pi^-\pi^0$ 1.30 ± 0.08 ± 0.21 AUBERT,B 04N BABR 10.6 $e^+e^ \longrightarrow$ | $\frac{\chi^2}{2\pi}$ |
| $\pi^+\pi^-\pi^0\gamma$ | ACHASOV 01G SND 0.5 ACHASOV 99C SND 0.4 |
| 18 ACHASOV 01E SND $e^+e^- ightarrow K^+K^-, K_SK_L,\pi^+\pi^-\pi^0$ | VASSERMAN 81 OLYA 3.4 AUGUSTIN 73 OSPK |
| .35 $\pm 0.27 \pm 0.08$ 11169 ²⁰ AKHMETSHIN 98 CMD2 $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 4.3 |
| • • We do not use the following data for averages, fits, limits, etc. • • • | (Confidence Level = 0.116) |
| .38 ± 0.12 BENAYOUN 10 RVUE 0.4-1.05 e^+e^- | 0 5 10 15 20 25 |
| $(\eta\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_6/\Gamma \times \Gamma_9/\Gamma$ | $\Gamma(\mu^+\mu^-)/\Gamma_{	ext{total}} 	imes \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{10}/\Gamma 	imes \Gamma_{9}/\Gamma$ |
| ALUE (units 10 ⁻⁶) EVTS DOCUMENT ID TECN COMMENT 87 ±0.07 OUR FIT Error includes scale factor of 1.2. | [(a+a-1)/[\ \ [(a+a-1)/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ \ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[\ []/[|
| .87 ±0.07 OUR FIT Error includes scale factor of 1.293 ±0.09 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below. | $\Gamma(\pi^+\pi^-)/\Gamma_{	ext{total}} \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ VALUE (units 10^{-8}) DOCUMENT ID TECH COMMENT |
| .050 \pm 0.067 \pm 0.118 33k 21 ACHASOV 07B SND 0.6-1.38 $e^+e^- ightarrow\eta\gamma$ | <u>VALUE (units 10⁻⁸)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.2 ±0.4 OUR FIT |
| $.093^{+0.040}_{-0.043}\pm0.247$ 17.4k 22 A KH METSHIN 05 CMD2 0.60-1.38 $e^+e^- ightarrow\eta\gamma$ | 2.2 ±0.4 OUR AVERAGE |
| $0.850\pm0.041\pm0.159$ 23k 23,24 AKHMETSHIN $01\mathrm{B}$ CMD2 $e^+e^- ightarrow$ | 2.1 \pm 0.3 \pm 0.3 |
| $1.00 \pm 0.04 \pm 0.11$ $\frac{25}{26}$ ACHASOV 00 SND $e^+e^- 	o \eta \gamma$ | $1.95 ^{+1.15}_{-0.87}$ 20 GOLUBEV 86 ND $e^+e^- ightarrow \pi^+\pi^-$ |
| $1.53 \pm 0.08 \pm 0.17$ 2200 26,27 AKHMETSHIN 99F CMD2 $e^+e^- \to \eta \gamma$ | $6.01^{+3.19}_{-2.51}$ 20 VASSERMAN 81 OLYA $e^+e^- ightarrow\pi^+\pi^-$ |
| .19 ± 0.06 28 BENAYOUN 10 RVUE 0.4–1.05 e^+e^- | |
| DENATOON 10 KVOE 0.4 1.03 C C | $\Gamma(\omega \pi^0)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{13}/\Gamma \times \Gamma_9/\Gamma_{13}$ |
| WEIGHTED AVERAGE 3.93±0.09 (Error scaled by 1.3) | <u>VALUE (units 10⁻⁸)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 1.40±0.15 OUR FIT |
| J. | 1.37 \pm 0.17 \pm 0.01 30,31 AMBROSINO 08G KLOE $e^+e^- \to \pi^+\pi^-2\pi^0$, $2\pi^0\gamma$ |
| Values above of weighted average, error, | $\Gamma(\pi^0\pi^0\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{18}/\Gamma \times \Gamma_9/\Gamma$ |
| and scale factor are based upon the data in this ideogram only. They are not neces- | VALUE (units 10 ⁻⁸) DO CUMENT ID TECH COMMENT |
| sarily the same as our 'best' values, obtained from a least-squares constrained fit | 3.34±0.17 OUR FIT |
| utilizing measurements of other (related) quantities as additional information. | 3.33 $^{+0.04}_{-0.09}$ $^{+0.19}_{-0.20}$ 32 AMBROSINO 07 KLOE $e^+e^- ightarrow \pi^0 \pi^0 \gamma$ |
| qualitate de dedicina membro. | $\Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma_{	ext{total}} \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{19}/\Gamma \times \Gamma_{9}/\Gamma$ |
| | VALUE (units 10 ⁻⁹) EVTS DOCUMENT ID TECN COMMENT |
| y ² | 1.2 +0.8 OUR FIT |
| / ······ ACHASOV 07B SND | |
| / — + · · · · · · AKHMETSHIN 05 CMD2 0.4 | 1.17±0.52±0.64 3285 ²⁶ AKHMETSHIN 00E CMD2 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ |
| AKHMETSHIN 01B CMD2 0.2 | ¹⁸ From the combined fit assuming that the total $\phi(1020)$ production cross section is |
| AKHMETSHIN 99F CMD2 4.5 | saturated by those of K^+K^- , K_S , K_L , $\pi^+\pi^-\pi^0$, and $\eta\gamma$ decays modes and using ACHASOV 00B for the $\eta\gamma$ decay mode. |
| 6.3 (Confidence Level = 0.176) | ¹⁹ Update of AKHMETSHIN 99D |
| | 20 Recalculated by us from the cross section in the peak. 21 From a combined fit of $\sigma(e^+e^-	o\eta\gamma)$ with $\eta	o3\pi^0$ and $\eta	o\pi^+\pi^-\pi^0$, and |
| 3 3.5 4 4.5 5 5.5 | fixing $B(\eta\to\pi^0\pi^0)$ / $B(\eta\to\pi^+\pi^-\pi^0)$ = 1.44 ± 0.04. Recalculated by us from the cross section at the peak. Supersedes ACHASOV 00D and ACHASOV 06A. |
| $\Gamma(\eta\gamma)/\Gamma_{total} 	imes \Gamma\!\left(e^+e^-\right)/\Gamma_{total}$ $\Gamma_{6}/\Gamma 	imes \Gamma_{9}/\Gamma$ | cross section at the peak. Supersedes ACHASOV 00D and ACHASOV 06A. |
| | ²² From the $\eta\to 2\gamma$ decay and using B($\eta\to\gamma\gamma$) = 39.43 \pm 0.26%. ²³ From the $\eta\to 3\pi^0$ decay and using B($\eta\to 3\pi^0$) = (32.24 \pm 0.29) \times 10 ⁻² . |
| $-(\pi^0\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_7/\Gamma \times \Gamma_9/\Gamma$ | 24 The combined fit from 600 to 1380 MeV taking into account $\rho(770),\omega(782),\phi(1020)$ and $\rho(1450)$ (mass and width fixed at 1450 MeV and 310 MeV respectively). |
| | and $\rho(1450)$ (mass and width fixed at 1450 MeV and 310 MeV respectively). |
| ALUE (units 10 ⁻⁷) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | From the $\eta \to 2\gamma$ decay and using $B(\eta \to 2\gamma) = (39.21 \pm 0.34) \times 10^{-2}$. |
| .74±0.18 OUR FIT .71±0.21 OUR AVERAGE | ²⁶ Recalculated by the authors from the cross section in the peak. |
| 1.74 \pm 0.18 OUR FIT 1.71 \pm 0.21 OUR AVERAGE 1.75 \pm 0.11 \pm 0.29 18680 AKHMETSHIN 05 CMD2 0.60-1.38 $e^+e^- \to \pi^0\gamma$ | 25 From the $\eta \to 2\gamma$ decay and using B($\eta \to 2\gamma$) =(39.21 \pm 0.34) \times 10 ⁻² . 26 Recalculated by the authors from the cross section in the peak. 27 From the $\eta \to \pi^+\pi^-\pi^0$ decay and using B($\eta \to \pi^+\pi^-\pi^0$) =(23.1 \pm 0.5) \times 10 ⁻² |
| .74±0.18 OUR FIT .71±0.21 OUR AVERAGE .75±0.11±0.29 | ²⁷ From the $n \to \pi^+ \pi^- \pi^0$ decay and using B($n \to \pi^+ \pi^- \pi^0$) = $(23.1 \pm 0.5) \times 10^{-2}$ |
| 1.74±0.18 OUR FIT 1.71±0.21 OUR AVERAGE 1.75±0.11±0.29 18680 A KH METSHIN 05 CMD2 0.60-1.38 $e^+e^- \rightarrow \pi^0 \gamma$ 1.67±0.10 $^+_{-0.25}$ 29 A CHASOV 00 SND $e^+e^- \rightarrow \pi^0 \gamma$ 0.00 • Wed on not use the following data for averages, fits, limits, etc. • • • | ²⁷ From the $\eta \to \pi^+\pi^-\pi^0$ decay and using $B(\eta \to \pi^+\pi^-\pi^0) = (23.1 \pm 0.5) \times 10^{-2}$ 28 A simultaneous fit of $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\eta^0$, $\pi^0\gamma$, $\eta\gamma$ data. ²⁹ From the $\pi^0 \to 2\gamma$ decay and using $B(\pi^0 \to 2\gamma) = (98.798 \pm 0.032) \times 10^{-2}$. ³⁰ Recalculated by the authors from the cross section at the peak. |
| 3.74 \pm 0.18 OUR FIT 3.71 \pm 0.21 OUR AVERAGE 3.75 \pm 0.11 \pm 0.29 18680 AKHMETSHIN 05 CMD2 0.60-1.38 $e^+e^- ightarrow \pi^0\gamma$ | 27 From the $\eta \to \pi^+\pi^-\pi^0$ decay and using $B(\eta \to \pi^+\pi^-\pi^0) = (23.1 \pm 0.5) \times 10^{-2}$. 28 A simultaneous fit of $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $\pi^0\gamma$, $\eta\gamma$ data. 29 From the $\pi^0 \to 2\gamma$ decay and using $B(\pi^0 \to 2\gamma) = (98.798 \pm 0.032) \times 10^{-2}$. 30 Recalculated by the authors from the cross section at the peak. 31 AMBROSINO 08G reports $[\Gamma(\phi(1020) \to \omega\pi^0)/\Gamma_{\text{total}} \times \Gamma(\phi(1020) \to e^+e^-)/\Gamma_{\text{total}} \times \Gamma(\phi(1020) \to e^+e^-)/\Gamma_{$ |
| .74±0.18 OUR FIT .71±0.21 OUR AVERAGE .75±0.11±0.29 | 27 From the $\eta \to \pi^+\pi^-\pi^0$ decay and using $B(\eta \to \pi^+\pi^-\pi^0) = (23.1 \pm 0.5) \times 10^{-2}$ 28 A simultaneous fit of $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $\pi^0\gamma$, $\eta\gamma$ data. 29 From the $\pi^0 \to 2\gamma$ decay and using $B(\pi^0 \to 2\gamma) = (98.798 \pm 0.032) \times 10^{-2}$. 30 Recalculated by the authors from the cross section at the peak. 31 AMBROSINO 08c reports $[\Gamma(\phi(1020) \to \omega\pi^0)/\Gamma_{\text{total}} \times \Gamma(\phi(1020) \to e^+e^-), \Gamma_{\text{total}} \times B(\omega/R^2) \to \pi^+\pi^-\pi^0] = (1.22 \pm 0.13 \pm 0.08) \times 10^{-8}$ which we divide |
| 1.74±0.18 OUR FIT 1.71±0.21 OUR AVERAGE 1.75±0.11±0.29 18680 A KH METSHIN 05 CMD2 0.60-1.38 $e^+e^- \rightarrow \pi^0 \gamma$ 1.67±0.10 $^+_{-0.25}$ 29 A CHASOV 00 SND $e^+e^- \rightarrow \pi^0 \gamma$ 0.00 • Wed on not use the following data for averages, fits, limits, etc. • • • | 27 From the $\eta \to \pi^+\pi^-\pi^0$ decay and using $B(\eta \to \pi^+\pi^-\pi^0) = (23.1 \pm 0.5) \times 10^{-2}$ 28 A simultaneous fit of $e^+e^- \to \pi^+\pi^-$, $\pi^+\pi^-\pi^0$, $\pi^0\gamma$, $\eta\gamma$ data. 29 From the $\pi^0 \to 2\gamma$ decay and using $B(\pi^0 \to 2\gamma) = (98.798 \pm 0.032) \times 10^{-2}$. 30 Recalculated by the authors from the cross section at the peak. 31 AMBROSINO 08G reports $[\Gamma(\phi(1020) \to \omega\pi^0)/\Gamma_{\rm total} \times \Gamma(\phi(1020) \to e^+e^-)/\Gamma_{\rm total} \times \Gamma(\phi(1020) \to \pi^+\pi^-\pi^0)] = (1.22 \pm 0.13 \pm 0.08) \times 10^{-8}$ which we divide |
| 1.74±0.18 OUR FIT 1.71±0.21 OUR AVERAGE 1.75±0.11±0.29 18680 A KH METSHIN 05 CMD2 0.60-1.38 $e^+e^- \rightarrow \pi^0 \gamma$ 1.67±0.10 $^+_{-0.25}$ 29 A CHASOV 00 SND $e^+e^- \rightarrow \pi^0 \gamma$ 0.00 • Wed on not use the following data for averages, fits, limits, etc. • • • | ²⁷ From the $\eta \to \pi^+\pi^-\pi^0$ decay and using $B(\eta \to \pi^+\pi^-\pi^0) = (23.1 \pm 0.5) \times 10^{-2}$ ²⁸ A simultaneous fit of $e^+e^- \to \pi^+\pi^-, \pi^+\pi^-\pi^0, \pi^0\gamma, \eta\gamma$ data. ²⁹ From the $\pi^0 \to 2\gamma$ decay and using $B(\pi^0 \to 2\gamma) = (98.798 \pm 0.032) \times 10^{-2}$. |

 ϕ (1020)

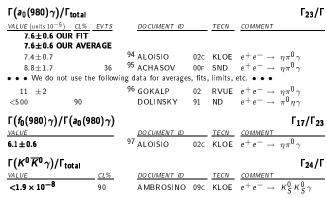
| ϕ (1020) BRANCHING RATIOS | $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{	ext{total}}$ Γ_5/Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ Γ_1/Γ | <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> |
| $\Gamma(K^+K^-)/\Gamma_{	ext{total}}$ Γ_1/Γ | • • We do not use the following data for averages, fits, limits, etc. |
| 0.489±0.005 OUR FIT Error includes scale factor of 1.1. | $\simeq 0.0087$ 1.98M 38,39 ALOISIO 03 KLOE 1.02 $e^+e^- \to \pi^+\pi^-\pi^0$ |
| 0.493±0.010 OUR AVERAGE | <0.0006 90 40 ACHASOV 02 SND $1.02 e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| 0.492 ± 0.012 2913 AKHMETSHIN 95 CMD2 $e^+e^- ightarrow$ K^+K^- | < 0.23 90 40 CORDIER 80 DM1 $e^+e^- 	oup \pi^+\pi^-\pi^0$ < 0.20 90 40 PARROUR 76B OSPK $e^+e^- 	oup \pi^+\pi^-\pi^0$ |
| 0.44 \pm 0.05 321 KALBFLEISCH 76 HBC 2.18 $K^-p \rightarrow \Lambda K^+ K^-$ | <0.20 90 40 PARROUR 76B OSPK $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |
| 0.49 \pm 0.06 270 DEGROOT 74 HBC 4.2 $K^-p \rightarrow \Lambda \phi$ | $\Gamma(\eta\gamma)/\Gamma_{\text{total}}$ Γ_6/Γ |
| 0.540 ± 0.034 565 BALAKIN 71 OSPK $e^+e^- \rightarrow K^+K^-$ 0.48 ± 0.04 252 LINDSEY 66 HBC 2.1-2.7 $K^-p \rightarrow \Lambda K^+K^-$ | VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT |
| 0.48 ± 0.04 252 LINDSEY 66 HBC 2.1–2.7 $K^-p \rightarrow \Lambda K^+K^-$ • • • We do not use the following data for averages, fits, limits, etc. • • • | 1.309±0.024 OUR FIT Error includes scale factor of 1.2. |
| $0.493\pm0.003\pm0.007$ 33 AKHMETSHIN11 CMD2 $1.02~e^+e^- \rightarrow K^+K^-$ | 1.26 ±0.04 OUR AVERAGE |
| 0.476 ± 0.007 1000k 34 ACHASOV 01E SND $e^+e^- \rightarrow K^+K^-$, K_SK_I , | $1.246\pm0.025\pm0.057$ 10k $\frac{41}{40}$ ACHASOV 98F SND $e^+e^- ightarrow 7\gamma$ |
| $\frac{100000}{\pi^{+}\pi^{-}\pi^{0}}$ | 1.18 \pm 0.11 279 42 AKHMETSHIN 95 CMD2 $e^+e^- \rightarrow \pi^+\pi^- 3\gamma$ |
| | 1.30 ± 0.06 43 DRUZHININ 84 ND $e^+e^- \rightarrow 3\gamma$ |
| $\Gamma(K_L^0 K_S^0)/\Gamma_{\text{total}}$ Γ_2/Γ | 1.4 \pm 0.2 |
| VALUE EVTS DOCUMENT ID TECN COMMENT | 1.35 ± 0.29 ANDREWS 77 CNTR 6.7–10 γ Cu |
| 0.342±0.004 OUR FIT Error includes scale factor of 1.1. 0.331±0.009 OUR AVERAGE | 1.5 ± 0.4 54 43 COSME 76 OSPK e^+e^- |
| 0.335 ± 0.010 40644 AKHMETSHIN 95 CMD2 $e^+e^- \rightarrow K_I^0 K_C^0$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.326 ± 0.035 DOLINSKY 91 ND $e^+e^- \rightarrow K_0^0 K_0^0$ | 1.38 ± 0.02 ± 0.02 33 AKHMETSHIN11 CMD2 1.02 $e^+e^- ightarrow \eta \gamma$ |
| 0.310 ± 0.024 DRUZHININ 84 ND $e^+e^- \rightarrow K_0^0 K_0^0$ | 1.37 ± 0.05 ± 0.01 33k ⁴⁵ ACHASOV 07B SND 0.6-1.38 $e^+e^- ightarrow \eta\gamma$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • | $1.373\pm0.014\pm0.085$ 17.4 k 46,47 AKH METSHIN 05 CMD2 0.60-1.38 $e^+e^- ightarrow\eta\gamma$ |
| $0.336\pm0.002\pm0.006$ 33 AKHMETSHIN11 CMD2 $1.02~e^+e^- \rightarrow K_c^0~K_I^0$ | $1.287\pm0.013\pm0.063$ 48,49 AKHMETSHIN 01B CMD2 $e^+e^- ightarrow\eta\gamma$ |
| $0.356\pm0.002\pm0.006$ ARTIMETSHINTT CIMD2 $1.02e^+e^- \rightarrow K_S^-K_L$ 0.351±0.013 500k ³⁴ ACHASOV 01E SND $e^+e^- \rightarrow K^+K^-$. | $1.338\pm0.012\pm0.052$ ${50 \atop 51 \atop $ |
| $\kappa_{\rm S} \kappa_{\rm L}, \pi^+ \pi^- \pi^0$ | 1.18 \pm 0.03 \pm 0.06 2200 ⁵¹ AKHMETSHIN 99F CMD2 $e^+e^- \rightarrow \eta \gamma$ 1.21 \pm 0.07 ⁵² BENAYOUN 96 RVUE 0.54-1.04 $e^+e^- \rightarrow \eta \gamma$ |
| 0.27 ± 0.03 133 KALBFLEISCH 76 HBC $2.18 K^- p \rightarrow \Lambda K_L^0 K_S^0$ | 1.21 ± 0.07 |
| 0.257 ± 0.030 95 BALAKIN 71 OSPK $e^+e^- \rightarrow \kappa_L^0 \kappa_S^0$ | $\Gamma(\pi^0\gamma)/\Gamma_{total}$ Γ_7/Γ |
| 0.40 ± 0.04 167 LINDSEY 66 HBC 2.1-2.7 $K^{-}_{p} \xrightarrow{L}^{3} \Lambda K_{0}^{0} K_{c}^{0}$ | VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT |
| (0 0) (() | 1.27 ±0.06 OUR FIT |
| $\Gamma(K_L^0 K_S^0)/\Gamma(K^+ K^-)$ Γ_2/Γ_1 | 1.31 ±0.13 OUR AVERAGE |
| VALUEEVTS DOCUMENT ID TECN COMMENT | 1.30 \pm 0.13 DRUZHININ 84 ND $e^+e^- \rightarrow 3\gamma$ |
| 0.740±0.031 OUR AVERAGE | 1.4 \pm 0.5 32 COSME 76 OSPK e^+e^- • • • We do not use the following data for averages, fits, limits, etc. • • |
| 0.70 \pm 0.06 2732 BUKIN 78C OLYA $e^+e^- \rightarrow K_L^0 K_S^0$ | |
| 0.82 ± 0.08 LOSTY 78 HBC $4.2 \ K^- p \rightarrow \phi$ hyperon | |
| 0.71 \pm 0.05 LAVEN 77 HBC 10 $K^-p \rightarrow K^+K^-\Lambda$ | $1.226 \pm 0.036 ^{+0.096}_{-0.089}$ 55 ACHASOV 00 SND $e^+e^- \to \pi^0 \gamma$ |
| 0.71 \pm 0.08 LYONS 77 HBC 3-4 $K^-p \rightarrow \Lambda \phi$ | 1.26 \pm 0.17 |
| 0.89 ± 0.10 144 AGUILAR 72B HBC 3.9,4.6 K $^-$ p | $\Gamma(\eta\gamma)/\Gamma(\pi^0\gamma)$ Γ_6/Γ_7 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | '(////'(" 1) VALUE DOCUMENT IDTECNCOMMENT |
| 0.68 \pm 0.03 35 AKHMETSHIN 95 CMD2 $e^+e^- \rightarrow \kappa_L^0 \kappa_S^0, \kappa^+ \kappa^-$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $\Gamma(K_L^0 K_S^0) / \Gamma(K\overline{K})$ $\Gamma_2 / (\Gamma_1 + \Gamma_2)$ | .07 |
| VALUE EVTS DOCUMENT ID TECN COMMENT | $10.9 \pm 0.3 ^{+0.7}_{-0.8}$ ACHASOV 00 SND $e^+e^- ightarrow \eta \gamma$, $\pi^0 \gamma$ |
| 0.411±0.005 OUR FIT Error includes scale factor of 1.1. | $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ Γ_9/Γ |
| 0.45 ±0.04 OUR AVERAGE | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 0.44 \pm 0.07 LONDON 66 HBC 2.24 $K^-p \rightarrow \Lambda K \overline{K}$ | 2.954±0.030 OUR FIT Error includes scale factor of 1.1. |
| 0.48 ± 0.07 52 BADIER 65B HBC 3 $K^- \rho$ 0.40 ± 0.10 34 SCHLEIN 63 HBC 1.95 $K^- \rho \rightarrow \Lambda K \overline{K}$ | 2.98 ±0.07 OUR AVERAGE Error includes scale factor of 1.1. |
| · | 2.93 ± 0.14 1900k ⁵⁶ ACHASOV 01E SND $e^+e^- \rightarrow K^+K^-$, |
| $\left[\Gamma(\rho\pi) + \Gamma(\pi^+\pi^-\pi^0)\right]/\Gamma_{\text{total}}$ Γ_3/Γ | $\kappa_{S} \kappa_{L}, \pi^{+} \pi^{-} \pi^{0}$ |
| VALUE EVTS DOCUMENT ID TECN COMMENT | 2.88 ± 0.09 55600 AKHMETSHIN 95 CMD2 $e^+e^- \rightarrow \text{hadrons}$ 3.00 ± 0.21 3681 BUKIN 78c OLYA $e^+e^- \rightarrow \text{hadrons}$ |
| 0.1532±0.0032 OUR FIT Error includes scale factor of 1.1. | 3.10 ± 0.14 57 PARROUR 76 OSP K e^+e^- |
| 0.151 \pm 0.009 OUR AVERAGE Error includes scale factor of 1.7. 0.161 \pm 0.008 11761 AKHMETSHIN 95 CMD2 $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 3.3 ± 0.3 COSME 74 OSPK $e^+e^- \rightarrow \text{hadrons}$ |
| 0.143 ± 0.007 DOLINSKY 91 ND $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | $2.81~\pm0.25$ 681 BALAKIN 71 OSPK $e^+e^- ightarrow$ hadrons |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 3.50 ± 0.27 CHATELUS 71 OSPK e^+e^- |
| 0.155 $\pm 0.002 \pm 0.005$ 33 AKHMETSHIN11 CMD2 1.02 $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | $\Gamma(\mu^+\mu^-)/\Gamma_{ m total}$ $\Gamma_{ m 10}/\Gamma$ |
| 0.159 ± 0.008 400k 34 ACHASOV 01E SND $e^+e^- \rightarrow K^+K^-$, | · · · |
| $\kappa_{S} \kappa_{L}$, $\pi^{+} \pi^{-} \pi^{0}$ | <u>VALUE (units 10⁻⁴)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.87±0.19 OUR FIT |
| $0.145 \pm 0.009 \pm 0.003 \ 11169 \ \frac{36}{37} \text{AKHMETSHIN 98} \text{ CMD2 } e^+e^- \rightarrow \pi^+\pi^-\pi^0$ | 2.5 ±0.4 OUR AVERAGE |
| 0.139 ± 0.007 37 PARROUR 76B OSPK $e^{+}e^{-}$ | $-$ 2.69 \pm 0.46 $-$ 58 HAYES 71 CNTR 8.3,9.8 γ C $\to \mu^+ \mu^-$ X |
| $[\Gamma(\rho\pi) + \Gamma(\pi^{+}\pi^{-}\pi^{0})]/\Gamma(K^{+}K^{-})$ Γ_{3}/Γ_{1} | 2.17 ± 0.60 58 EARLES 70 CNTR $6.0~\gamma$ C $ ightarrow~\mu^+\mu^-$ X |
| VALUE EVTS DOCUMENT ID TECN COMMENT | • • We do not use the following data for averages, fits, limits, etc. |
| 0.313±0.009 OUR FIT Error includes scale factor of 1.1. | $2.87\pm0.20\pm0.14$ SOV 01G SND $e^+e^- ightarrow \mu^+\mu^-$ |
| 0.28 ±0.09 34 AGUILAR 72B HBC 3.9,4.6 K [−] p | $3.30 \pm 0.45 \pm 0.32$ |
| $[r(\cdot), r(+-0)] / r / r $ | 4.83 \pm 1.02 |
| $\left[\Gamma(\rho\pi) + \Gamma(\pi^{+}\pi^{-}\pi^{0})\right]/\Gamma(K\overline{K}) \qquad \qquad \Gamma_{3}/(\Gamma_{1}+\Gamma_{2})$ | 2.87 ± 1.98 60 AUGUSTIN 73 OSPK $e^+e^- ightarrow \mu^+\mu^-$ |
| VALUE DOCUMENT ID TECN COMMENT 0.184±0.005 OUR FIT Error includes scale factor of 1.1. | $\Gamma(\eta e^+ e^-)/\Gamma_{\text{total}}$ Γ_{11}/Γ |
| 0.24 ±0.04 OUR AVERAGE | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 0.237 \pm 0.039 CERRADA 77B HBC 4.2 K $^-p ightarrow \Lambda3\pi$ | 1.15±0.10 OUR AVERAGE |
| 0.30 ± 0.15 LONDON 66 HBC 2.24 $K^- p \to \Lambda \pi^+ \pi^- \pi^0$ | $1.19\pm0.19\pm0.12$ 213 61 ACHASOV 01B SND $e^+e^- 	o \gamma\gamma e^+e^-$ |
| [[() + [(-+0)] /[(\nu \nu \nu \nu \nu \nu \nu \nu \nu \nu | $1.14\pm0.10\pm0.06$ 355 ⁶² AKHMETSHIN 01 CMD2 $e^+e^- ightarrow \eta e^+e^-$ |
| $ [\Gamma(\rho\pi) + \Gamma(\pi^+\pi^-\pi^0)]/\Gamma(K_0^0K_0^0) $ $ \Gamma_3/\Gamma_2 $ | 1.3 $^{+0.8}_{-0.6}$ 7 GOLUBEV 85 ND $e^+e^- ightarrow\gamma\gamma e^+e^-$ |
| <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.448±0.012 OUR FIT Error includes scale factor of 1.1. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.51 ±0.05 OUR AVERAGE | $1.13\pm0.14\pm0.07$ 183 ⁶³ AKHMETSHIN 01 CMD2 $e^+e^- ightarrow\eta e^+e^-$ |
| 0.56 ± 0.07 3681 BUKIN 78C OLYA $e^+e^- ightarrow~\kappa_L^0~\kappa_S^0$, $\pi^+\pi^-\pi^0$ | $1.21\pm0.14\pm0.09$ 130 ⁶⁴ AKHMETSHIN 01 CMD2 $e^+e^- ightarrow \eta e^+e^-$ |
| 0.47 ± 0.06 516 COSME 74 OSPK $e^+e^- \to \pi^+\pi^-\pi^0$ | $1.04\pm0.20\pm0.08$ 42 ⁶⁵ AKHMETSHIN 01 CMD2 $e^+e^- ightarrow \eta e^+e^-$ |
| | |

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 $\phi(1020)$

| $\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ | Γ ₁₂ /Γ |
|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) | e the following data for averages, fits, limits, etc. • • |
| $0.71 \pm 0.11 \pm 0.09$ | 36 ACHASOV 00c SND $e^+e^- ightarrow\pi^+\pi^-$ |
| $0.65 + 0.38 \\ -0.29$ | 36 GOLUBEV 86 ND $e^+e^- \rightarrow \pi^+\pi^-$ |
| | |
| $2.01 {}^{+ 1.07}_{- 0.84}$ | 36 VASSERMAN 81 OLYA $e^+e^- ightarrow\pi^+\pi^-$ |
| < 6.6 | 95 BUKIN 78B OLYA $e^+e^- ightarrow\pi^+\pi^-$ |
| <2.7 | 95 ALVENSLEB 72 CNTR 6.7 γ C \rightarrow C $\pi^+\pi^-$ |
| $\Gamma(\omega\pi^0)/\Gamma_{	ext{total}}$ VALUE (units 10 $^{-5}$) | Γ ₁₃ /Γ |
| 4.7±0.5 OUR FIT | |
| $5.2^{+1.3}_{-1.1}$ | 66,67 AULCHENKO 00A SND $^{e^+e^-} ightarrow \pi^+\pi^-\pi^0\pi^0$ |
| | e the following data for averages, fits, limits, etc. • • |
| 4.4 ± 0.6 | 68 AMBROSINO 086 KLOE $e^+e^- \rightarrow \pi^+\pi^- 2\pi^0$, $2\pi^0\gamma$ |
| √5.4 ±16 | 69 ACHASOV 00E SND $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| $5.5 + 1.6 \pm 0.3$ | 67,70 AULCHENKO 00A SND $e^+e^- ightarrow\pi^+\pi^-\pi^0\pi^0$ |
| $4.8 {}^{+ 1.9}_{- 1.7} \pm 0.8$ | 69 ACHASOV 99 SND $^{}e^{+}e^{-} ightarrow \pi^{+}\pi^{-}\pi^{0}\pi^{0}$ |
| $\Gamma(\omega\gamma)/\Gamma_{ m total}$ | Γ ₁₄ /Γ |
| /ALUE CL% | DOCUMENT ID TECN COMMENT |
| <0.05 84 | LINDSEY 66 HBC 2.1-2.7 $K^-p \rightarrow \Lambda \pi^+ \pi^-$ neutrals |
| $\Gamma(ho\gamma)/\Gamma_{ m total}$ | Γ ₁₅ /Γ |
| VALUE (units CL% 10 ⁻⁴) | DOCUMENT ID TECN COMMENT |
| < 0.12 90 | $71 \overline{\text{AKHMETSHIN 99B}} \ \overline{\text{CMD2}} \ \overline{e^+ e^- ightarrow \pi^+ \pi^- \gamma}$ |
| | e the following data for averages, fits, limits, etc. \bullet \bullet \bullet AKHMETSHIN 97c CMD2 $e^+e^- 	o \pi^+\pi^-\gamma$ |
| < 7 90 <200 84 | LINDSEY 66 HBC 2.1-2.7 $K^-p \rightarrow \Lambda \pi^+ \pi^-$ neutrals |
| $(\pi^+\pi^-\gamma)/\Gamma_{\text{tota}}$ (ALUE (units 10^{-4}) | II CL% EVTS DOCUMENT ID TECN COMMENT |
| 0.41±0.12±0.0 | |
| | e the following data for averages, fits, limits, etc. • • • |
| < 0.3 <600 | 90 73 AKHMETSHIN 97c CMD2 $e^+e^- ightarrow \pi^+\pi^- \gamma$ 90 KALBFLEISCH 75 HBC 2.18 $K^-p ightarrow$ |
| < 70 | 90 COSME 74 OSPK $e^+e^- \rightarrow \pi^+\pi^-\gamma$ |
| <400 | 90 LINDSEY 65 HBC 2.1–2.7 K $^- p \rightarrow \Lambda \pi^+ \pi^-$ neutrals |
| $\Gamma(f_0(980)\gamma)/\Gamma_{\rm tot}$ | _{al} Γ ₁₇ /Γ |
| VALUE (units 10 ⁻⁴) | CL% EVTS DOCUMENT ID TECN COMMENT |
| 3.22±0.19 OUR FIT | |
| 3.21±0.19 OUR AV | |
| $3.21^{+0.03}_{-0.09} \pm 0.18$ | 74 AMBROSINO 07 KLOE $e^+e^- ightarrow\pi^0\pi^0\gamma$ |
| $2.90 \pm 0.21 \pm 1.54$ | 75 AKHMETSHIN 99c CMD2 $e^+e^- ightarrow\pi^+\pi^-\gamma$, $\pi^0\pi^0\gamma$ |
| | e the following data for averages, fits, limits, etc. • • • |
| 1.47±0.21 | 2438 76 ALOISIO 02D KLOE $e^+e^- ightarrow \pi^0\pi^0\gamma$ |
| $3.5 \pm 0.3 \begin{array}{c} +1.3 \\ -0.5 \end{array}$ | 419 77,78 ACHASOV 00H SND $e^+e^- ightarrow\pi^0\pi^0\gamma$ |
| 1.93±0.46±0.50 | 27188 79 AKHMETSHIN 99B CMD2 $e^+e^- \rightarrow \pi^+\pi^-\gamma$ |
| 3.05 ± 0.25 ± 0.72 1.5 ± 0.5 | 268 80 AKHMETSHIN 99C CMD2 $e^+e^- ightarrow \pi^0\pi^0\gamma$ 268 81 AKHMETSHIN 99C CMD2 $e^+e^- ightarrow \pi^0\pi^0\gamma$ |
| 3.42±0.30±0.36 | 164 77 ACHASOV 981 SND $e^+e^- \rightarrow 5\gamma$ |
| < 1 | 90 82 AKHMETSHIN 97C CMD2 $e^+e^- \rightarrow \pi^+\pi^-\gamma$ |
| < 7 | 90 83 AKHMETSHIN 97C CMD2 $e^+e^- \rightarrow \pi^+\pi^-\gamma$ |
| < 20 | 90 DRUZHININ 87 ND $e^+e^- 	oup \pi^0\pi^0\gamma$ |
| $\Gammaig(f_0(980)\gammaig)/\Gammaig(\eta$ | $\gamma)$ Γ_{17}/Γ_{6} |
| VALUE (units 10 ⁻²) | EVTS DOCUMENT ID TECN COMMENT |
| 2.46±0.15 OUR FIT 2.6 ±0.2 +0.8 -0.3 | Ferror includes scale factor of 1.1. 419 77 ACHASOV 00H SND $e^+e^- ightarrow\pi^0\pi^0\gamma$ |
| $^{-0.3}$ $\Gamma(\pi^0\pi^0\gamma)/\Gamma_{ m total}$ | Γ ₁₈ /Γ |
| | CL% EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻⁴) | AVERAGE |
| VALUE (units 10 ⁻⁴) 1.07 ±0.06 OUR A | |
| VALUE (units 10 ⁻⁴) | 84 ambrosino 07 kloe $e^+e^- ightarrow~\pi^0\pi^0\gamma$ |
| VALUE (units 10 ⁻⁴) 1.07 ±0.06 OUR A 1.07 +0.01 +0.06 -0.03 -0.06 1.08 ±0.17 ±0.09 | AMBROSINO 07 KLOE $e^+e^-	o \pi^0\pi^0\gamma$ 268 AKHMETSHIN 99C CMD2 $e^+e^-	o \pi^0\pi^0\gamma$ |
| VALUE (units 10 ⁻⁴) 1.07 ±0.06 OUR A 1.07 +0.01 +0.06 1.07 -0.03 -0.06 1.08 ±0.17 ±0.09 • • • We do not us | 84 AMBROSINO 07 KLOE $e^+e^-\to~\pi^0\pi^0\gamma$ 268 AKHMETSHIN 99c CMD2 $e^+e^-\to~\pi^0\pi^0\gamma$ e the following data for averages, fits, limits, etc. • • • |
| VALUE (units 10 ⁻⁴) 1.07 ±0.06 OUR A 1.07 +0.01 +0.06 -0.03 -0.06 1.08 ±0.17 ±0.09 | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |

```
\Gamma(\pi^0\pi^0\gamma)/\Gamma(\eta\gamma)
                                                                                               \Gamma_{18}/\Gamma_{6}
VALUE (units 10^{-2})
                                                                   TECN COMMENT
                             EVTS
0.86 ±0.04 OUR FIT
                                       ^{85}\, {\rm ACHASOV} \qquad {\rm 00H} \ {\rm SND} \qquad e^{+}\,e^{-} \rightarrow \ \pi^{0}\,\pi^{0}\,\gamma
0.865 ±0.070 ±0.017 419
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                          ACHASOV 981 SND e^+e^- 
ightarrow 5\gamma
0.90\ \pm0.08\ \pm0.07
                           164
\Gamma(\pi^+\pi^-\pi^+\pi^-)/\Gamma_{\text{total}}
                                                                                                 \Gamma_{19}/\Gamma
VALUE (units 10^{-6}) CL% EVTS
                                       DO CUMENT ID
                                                               TECN COMMENT
\bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                      AKHMETSHIN 00E CMD2 e^+e^- 
ightarrow \pi^+\pi^-\pi^+\pi^-
3.93\!\pm\!1.74\!\pm\!2.14
                           3285
                                                        79 WIRE e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{+}\pi^{-}
                                        CORDIER
\Gamma(\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma_{\text{total}}
                                                                                                 \Gamma_{20}/\Gamma
VALUE (units 10^{-6}) CL%
                                   DOCUMENT ID
                                                        TECN COMMENT
                                   AKHMETSHIN 00E CMD2 e^+\,e^-
ightarrow\,\pi^+\pi^-
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                     95
                                BARKOV 88 CMD e^{+}e^{-} \to \pi^{+}\pi^{-}\pi^{+}\pi^{-}\pi^{0}
\Gamma(\pi^0 e^+ e^-)/\Gamma_{\rm total}
                                             DOCUMENT ID
                                                                    TECN COMMENT
    1.12±0.28 OUR AVERAGE
                                          86 ACHASOV 02D SND e^+e^- \rightarrow \pi^0 e^+e^-
    1.01\pm0.28\pm0.29
                                          ^{87} AKHMETSHIN 01c CMD2 e^+e^- 
ightarrow ~\pi^0\,e^+\,e^-
                                  46
• • • We do not use the following data for averages, fits, limits, etc. • • •
                       90
                                             DOLINSKY 88 ND e^+e^- 
ightarrow \pi^0 \, e^+ \, e^-
\Gamma(\pi^0\eta\gamma)/\Gamma_{\rm total}
                     CL% EVTS
                                           DOCUMENT ID
                                                                    TECN
                                                                             COMMENT
7.27±0.30 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below.
                            16.9k 88 AMBROSINO 09F KLOE 1.02 e^+e^- \to \eta \pi^0 \gamma
607 89 ALOISIO 02C KLOE e^+e^- \to \eta \pi^0 \gamma
7.06 \pm 0.22
8.51 \pm 0.51 \pm 0.57
                                        <sup>90</sup> ALOISIO
                                                              02C KLOE e^+e^- 
ightarrow \eta \pi^0 \gamma
7.96 \pm 0.60 \pm 0.40
                               197
                                        <sup>91</sup> ACHASOV 00F SND e^+e^- \rightarrow \eta \pi^0 \gamma
8.8 + 1.4 + 0.9
                               36
                                         AKHMETSHIN 99c CMD2 e^+e^- 
ightarrow \eta \pi^0 \gamma
                                80
9.0 \pm 2.4 \pm 1.0
• • • We do not use the following data for averages, fits, limits, etc. • • •
                             13.3k ^{89,92} AMBROSINO 09F KLOE 1.02 e^+e^- 
ightarrow \eta \pi^0 \gamma
                              3.6k ^{90,93} AMBROSINO 09F KLOE 1.02 e^+e^- \rightarrow \eta \pi^0 \gamma
7.12 \!\pm\! 0.13 \!\pm\! 0.22
                                           ACHASOV 98B SND e^+e^- 
ightarrow 5\gamma
8.3 \pm 2.3 \pm 1.2
                                            DOLINSKY 91 ND e^+e^- 
ightarrow \pi^{\c0} \eta \gamma
< 250
           WEIGHTED AVERAGE 7.27±0.30 (Error scaled by 1.5)
                                                                                           χ
0.9
                                                        AMBROSINO 09F
                                                                                KLOE
                                                                         02C
02C
                                                                                 KLOE
                                                       ACHASOV 00F SND
AKHMETSHIN 99C CMD2
                                                                    (Confidence Level = 0.108)
           \Gamma(\pi^0 \eta \gamma)/\Gamma_{\text{total}} \text{ (units } 10^{-5})
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 $\phi(1020)$

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\Gamma(\eta'(958)\gamma)/\Gamma_{\text{total}}
                                                                                                                                                            \Gamma_{25}/\Gamma
                                                                                                                                                                                                   <sup>42</sup> From \pi^+\pi^-\pi^0 decay mode of \eta.
                                                                                                                                                                                                  ^{43} From ^{2}\gamma decay mode of ^{\eta}. ^{44} From ^{3}\pi^0 decay mode of ^{\eta}.
                                                                                                          TECN COMMENT
  6.25 ± 0.21 OUR FIT
                                                                                                                                                                                                   45 ACHASOV 07B reports [\Gamma(\phi(1020) \rightarrow \eta \gamma)/\Gamma_{\mathsf{total}}] \times [B(\phi(1020) \rightarrow e^+e^-)] =
  6.25 ± 0.30 OUR AVERAGE
                                                                                                                                                                                                       (4.050\pm0.067\pm0.118)\times10^{-6} which we divide by our best value B(\phi(1020)\to e^+e^-)=(2.954\pm0.030)\times10^{-4}. Our first error is their experiment's error and our second error is the systematic error from using our best value. Supersedes ACHASOV 00D and
                                                            ^{98} AMBROSINO 07A KLOE 1.02 e^{+}e^{-} \rightarrow \pi^{+}\pi^{-} _{7\gamma}
   6.25 \pm 0.28 \pm 0.11
  6.7 \begin{array}{c} +2.8 \\ -2.4 \end{array} \pm 0.8
                                                  12 ^{99} AULCHENKO 03B SND e^+e^- 
ightarrow \eta' \gamma
                                                                                                                                                                                                  ACHASOV 06A. 46 Using B(\phi \rightarrow e^+e^-) = (2.98 \pm 0.04) \times 10<sup>-4</sup> and B(\eta \rightarrow \gamma \gamma) = 39.43 \pm 0.26%.
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                                                  40 Using B(\phi \to e^+e^-) = (2.98 ± 0.04) × 10<sup>-4</sup> and B(\eta \to \gamma \gamma \gamma) = 39.43 ± 0.20%. 47 Not independent of the corresponding \Gamma(e^+e^-) × \Gamma(\eta \gamma)/\Gamma_{\text{total}}^2. 48 Using B(\phi \to e^+e^-) = (2.99±0.08)×10<sup>-4</sup> and B(\eta \to 3\pi^0)=(32.24±0.29)×10<sup>-2</sup>. 49 The combined fit from 600 to 1380 MeV taking into account \rho(770), \omega(782), \phi(1020), and \rho(1450) (mass and width fixed at 1450 MeV and 310 MeV respectively). 50 From the \eta \to 2\gamma decay and using B(\phi \to e^+e^-) =(2.99±0.08)×10<sup>-4</sup>. 51 From \pi^+\pi^-\pi^0 decay mode of \eta and using B(\phi \to e^+e^-) = (2.99±0.08)×10<sup>-4</sup>. 52 Power for the PULINSKY 90, and POLINSKY 91 taking into account
  6.7 \begin{array}{c} +5.0 \\ -4.2 \end{array} \pm 1.5
                                                                 AULCHENKO 03B SND e^+e^- \rightarrow 7\gamma
                                               120 ^{100} ALOISIO 02E KLOE 1.02 e^{+}e^{-} \rightarrow \pi^{+} \pi^{-} 3\gamma
  6.10 \pm 0.61 \pm 0.43
                                                 21 ^{101} AKHMETSHIN 00B CMD2 e^+e^- 
ightarrow ~\pi^+\pi^- \, 3\gamma
  8.2 \begin{array}{c} +2.1 \\ -1.9 \end{array} \pm 1.1
                                                 9 ^{102} AKHMETSHIN 00F CMD2 ^{e^+e^-}_{\pi^+\pi^-\pi^+\pi^-} \geq 2\gamma 30 ^{103} AKHMETSHIN 00F CMD2 ^{e^+e^-}_{} \rightarrow \eta'(958)\gamma
  4.9 \begin{array}{c} +2.2 \\ -1.8 \end{array} \pm 0.6
                                                                                                                                                                                                   <sup>52</sup>Reanalysis of DRUZHININ 84, DOLINSKY 89, and DOLINSKY 91 taking into account
                                                                                                                                                                                                        a triangle anomaly contribution.
  6.4 ±1.6
                                                                                                                                                                                                   53 Using B(\phi \rightarrow e^+e^-) = (2.98 ± 0.04) × 10<sup>-4</sup>.
                                                   5 ^{104} AULCHENKO 99 SND ^{e^+e^-} 
ightarrow \pi^+\pi^- \, 3\gamma
  6.7 \begin{array}{c} +3.4 \\ -2.9 \end{array} \pm 1.0
                                                                                                                                                                                                   54 Not independent of the corresponding \Gamma(e^+e^-) \times \Gamma(\pi^0\gamma)/\Gamma_{\text{total}}^2
                                                                  AULCHENKO 98 SND e^+e^- \rightarrow 7\gamma
<11
                                                                                                                                                                                                   ^{55} From the \pi^0 	o 2\gamma decay and using B(\phi 	o e^+e^-) = (2.99 \pm 0.08) 	imes 10^{-4}
                                                                                                                                                                                                  For the \pi^+ \rightarrow 2\gamma decay and using S(\psi \rightarrow e^+ e^-) = (2.99 \pm 0.00) \times 10^-. See From the combined fit assuming that the total \phi(1020) production cross section is saturated by those of K^+K^-, K_SK_L, \pi^+\pi^-\pi^0, and \eta\gamma decays modes and using ACHASOV 00B for the \eta\gamma decay mode. They detect 3\pi mode and observe significant interference
                                                    6 ^{101} AKHMETSHIN 97B CMD2 e^+e^- 
ightarrow ~\pi^+\pi^- 3\gamma
\begin{array}{cc} 12 & +7 \\ -5 \end{array}
                    +2
                                                                                                                     e^+e^- \rightarrow \gamma \eta \pi^+ \pi^-
<41
                                                                  DRUZHININ 87 ND
\Gamma(\eta'(958)\gamma)/\Gamma(K_L^0K_S^0)
                                                                                                                                                                                                        with \omega tail. This is accounted for in the result quoted above.
                                                                                                                                                                                                  58 Neglecting interference between resonance and continuum. 59 Using B(\phi \rightarrow e^+e^-) = (2.91 ± 0.07) × 10<sup>-4</sup>.
                                                              DOCUMENT ID TECN COMMENT
1.83±0.06 OUR FIT
                                                                                                                                                                                                   Recalculated by us using B(\phi \rightarrow e^+e^-)= (2.99 \pm 0.08) \times 10<sup>-4</sup>.
1.46 + 0.64 \pm 0.18
                                                   ^{105} AKHMETSHIN 00F CMD2 e^{+}e^{-}\rightarrow \ \pi^{+}\pi^{-}\pi^{+}\pi^{-} \geq ^{2}\gamma
                                                                                                                                                                                                  61 Using B(\eta\to\gamma\gamma) = (39.25 ± 0.32)%, B(\phi\to\eta\gamma) = (1.26 ± 0.06)%, and B(\phi\toe^+e^-) = (3.00 ± 0.06) × 10<sup>-4</sup>.
\Gamma(\eta'(958)\gamma)/\Gamma(\eta\gamma)
                                                                                                                                                                                                   ^{62}The average of the branching ratios separately obtained from the \eta \to \gamma \gamma, 3\pi^0,
                                                                                                                                                          \Gamma_{25}/\Gamma_{6}
VALUE (units 10<sup>-3</sup>)
4.77±0.15 OUR FIT
                                                                                                                                                                                                         \pi^+\pi^-\pi^0 decays.
                                                                 DOCUMENT ID
                                                                                                                                                                                                  \begin{array}{l} \pi^+\pi^-\pi^0 \ \text{decays}. \\ 63 \ \text{From} \ \eta \to \gamma \gamma \ \text{decays} \ \text{and} \ \text{using} \ B(\eta \to \gamma \gamma) = (39.33\pm 0.25)\times 10^{-2}, \ B(\eta \to \pi^+\pi^-\gamma) \\ = (4.75\pm11)\times 10^{-2}, \ \text{and} \ B(\phi \to \eta \gamma) = (1.297\pm 0.033)\times 10^{-2}. \\ 64 \ \text{From} \ \eta \to 3\pi^0 \ \text{decays} \ \text{and} \ \text{using} \ B(\pi^0 \to \gamma \gamma) = (98.798\pm 0.033)\times 10^{-2}, \ B(\eta \to 3\pi^0) = (32.24\pm 0.29)\times 10^{-2}, \ B(\eta \to \pi^+\pi^-\gamma) = (4.75\pm 0.11)\times 10^{-2}, \ \text{and} \ B(\phi \to \eta \gamma) = (1.297\pm 0.033)\times 10^{-2}. \\ 65 \ \text{From} \ \eta \to \pi^+\pi^-\pi^0 \ \text{decays} \ \text{and} \ \text{using} \ B(\pi^0 \to \gamma \gamma) = (98.798\pm 0.033)\times 10^{-2}, \ B(\pi^0 \to e^+e^-\gamma) = (1.198\pm 0.032)\times 10^{-2}, \ B(\eta \to \pi^+\pi^-\pi^0) = (23.0\pm 0.4)\times 10^{-2}, \ B(\phi \to \pi^+\pi^-\pi^0) = (15.5\pm 0.6)\times 10^{-2}, \ \text{and} \ B(\phi \to \eta \gamma) = (1.297\pm 0.033)\times 10^{-2}. \\ 66 \ \text{Using} \ \text{the} \ 1996 \ \text{and} \ 1998 \ \text{data}. \end{array}
                                                                                                    TECN COMMENT
4.78±0.20 OUR AVERAGE
                                                                AMBROSINO 07A KLOE 1.02 e^+\,e^-
ightarrow~\pi^+\pi^-7\gamma
4.77 \pm 0.09 \pm 0.19
                                                       106 ALOISIO 02E KLOE 1.02 e^+e^- 
ightarrow \pi^+\pi^- 3\gamma
4.70 \pm 0.47 \pm 0.31
6.5 \  \, ^{+\, 1.7}_{-\, 1.5} \  \, \pm \, 0.8
                                              21
                                                                AKHMETSHIN 00B CMD2 e^+e^- \rightarrow \pi^+\pi^- 3\gamma
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                6 ^{107} AKHMETSHIN 97B CMD2 e^+\,e^-
ightarrow~\pi^+\pi^- 3\gamma
                                                                                                                                                                                                    66 Using the 1996 and 1998 data.
                                                                                                                                                                                                   67 (2.3\pm0.3)\% correction for other decay modes of the \omega(782) applied.
\Gamma(\eta \pi^0 \pi^0 \gamma) / \Gamma_{\text{total}}
                                                                                                                                                             \Gamma_{26}/\Gamma
                                                                                                                                                                                                   68 Not independent of the corresponding \Gamma(\omega\pi^0) \times \Gamma(e^+\,e^-) \ / \ \Gamma^2({
m total}).
                                                                                                          TECN COMMENT
VALUE (units 10^{-5})
                                                CL%
                                                                      DO CUMENT ID
                                                                                                                                                                                                   <sup>69</sup> Using the 1996 data.
                                                                                                                                                                                                   70 Using the 1998 data.
                                                                      AULCHENKO 98 SND e^+\,e^-
ightarrow 7\gamma
                                                                                                                                                                                                   71 Supersedes AKHMETSHIN 97c.
\Gamma(\mu^+\mu^-\gamma)/\Gamma_{\text{total}}
                                                                                                                                                                                                   72 For E_{\gamma} > 20 MeV and assuming that B(\phi(1020) \rightarrow f_0(980) \gamma) is negligible. Supersedes
                                                                                                                                                            \Gamma_{27}/\Gamma
VALUE (units 10^{-5})
                                                                     DO CUMENT ID TECN COMMENT
                                                                                                                                                                                                   73 For E_{\gamma} > 20 MeV and assuming that B(\phi(1020) \rightarrow f_0(980) \gamma) is negligible.
                                                                ^{79}\overline{
m_{AKHMETSHIN\,99B}} CMD2 e^+\,e^-
ightarrow\,\mu^+\,\mu^-\,\gamma
1.43±0.45±0.14
                                             27188
                                                                                                                                                                                                   ^{74} Obtained by the authors taking into account the \pi^+\pi^- decay mode. Includes a com-
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                                                                        ponent due to \pi\pi production via the f_0(500) meson. Supersedes ALOISIO 02D.
2.3 ±1.0
                                             824 \pm 108 AKHMETSHIN 97c CMD2 e^+e^- \rightarrow \mu^+\mu^-\gamma
                                                                                                                                                                                                   75 From the combined fit of the photon spectra in the reactions e<sup>+</sup> e<sup>-</sup> \to \pi^+\pi^-\gamma, \pi^0\pi^0\gamma.
                                                                                                                                                                                                  \pi^0\pi^0\gamma. To From the negative interference with the f_0(500) meson of AITALA 01B using the ACHASOV 89 parameterization for the f_0(980), a Breit-Wigner for the f_0(500), and ACHASOV 01F for the \rho\pi contribution. Superseded by AMBROSINO 07. Assuming that the \pi^0\pi^0\gamma final state is completely determined by the f_0\gamma mechanism,
\Gamma(\rho\gamma\gamma)/\Gamma_{\rm total}
                                                                                                                                                             \Gamma_{28}/\Gamma
VALUE (units 10^{-4})
                                                                     \begin{array}{cccc} \underline{\textit{DOCUMENT ID}} & \underline{\textit{TECN}} & \underline{\textit{COMMENT}} \\ \text{AULCHENKO 08} & \text{CMD2} & \phi \rightarrow \pi^+\pi^-\gamma\gamma \end{array}
                                                CL%
 <1.2
                                                90
                                                                                                                                                                                                   neglecting the decay B(\phi \to K \overline{K} \gamma) and using B(f_0 \to \pi^+\pi^-)= 2B(f_0 \to \pi^0\pi^0). 78 Using the value B(\phi \to \eta \gamma)=(1.338 \pm 0.053) \times 10<sup>-2</sup>.
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                     AKHMETSHIN 98 CMD2 e^+e^- \rightarrow \pi^+\pi^-\gamma\gamma
                                                90
                                                                                                                                                                                                   ^{79} For E_{\gamma} > 20\, MeV. Supersedes AKHMETSHIN 97c.
\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}
                                                                                                                                                            \Gamma_{29}/\Gamma
                                                                                                                                                                                                   ^{80} Neglecting other intermediate mechanisms (\rho\pi,\,\sigma\gamma)
                                                                                                                                                                                                   ^{81} A narrow pole fit taking into account f_0(980) and f_0(1200) intermediate mechanisms.
VALUE (units 10^{-5}) CL%
                                                            DOCUMENT ID
                                                                                                  TECN COMMENT
                                                                                                                                                                                                   ^{82} \, \text{For destructive interference} with the Bremsstrahlung process
                                                            AKHMETSHIN 00E CMD2 e^+\,e^- 
ightarrow \, \pi^+\,\pi^-\,\pi^+\,\pi^-\,\pi^0
                                      90
                                                                                                                                                                                                   83 For constructive interference with the Bremsstrahlung process

    • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                                                                   84 Supersedes ALOISIO 02D.
                                                            AULCHENKO 08 CMD2 \phi \rightarrow \eta \pi^+ \pi^-
 < 6.1
                                       90
                                                                                                                                                                                                   ^{85} Supersedes ACHASOV 981. Excluding \omega\,\pi^0
                                                            AKHMETSHIN 98 CMD2 e^+e^- \rightarrow \pi^+\pi^-\gamma\gamma
 < 30
                                       90
                                                                                                                                                                                                   <sup>86</sup> Using various branching ratios from the 2000 Edition of this Review (PDG 00).
                                                                                                                                                                                                  87 Using B(\pi^0 \to \gamma\gamma) = 0.98798 \pm 0.00032, B(\phi \to \eta\gamma) = (1.297 \pm 0.033) \times 10<sup>-2</sup>, and B(\eta \to \pi^+\pi^-\gamma) = (4.75 \pm 0.11) \times 10<sup>-2</sup>.
\Gamma(\eta \mu^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                                                                             \Gamma_{30}/\Gamma
                                                                                                                                                                                                  88 Combined results of \eta \to \gamma \gamma and \eta \to \pi^+\pi^-\pi^0 decay modes measurements. 89 From the decay mode \eta \to \gamma \gamma. 90 From the decay mode \eta \to \pi^+\pi^-\pi^0.
VALUE (units 10^{-6})
                                                                     DOCUMENT ID TECN COMMENT
                                               90
                                                                 AKHMETSHIN 01 CMD2 e^+\,e^-
ightarrow\,\eta\,e^+\,e^-
  ^{33} Combined analysis of the CMD-2 data on \phi\to~K^+K^-,~K^0_S~K^0_I,~\pi^+\pi^-\pi^0,~\eta\gamma assuming that the sum of their branching fractions is 0.99741 \pm~\tilde{S} .00007.
                                                                                                                                                                                                   91 Supersedes ACHASOV 98B.
                                                                                                                                                                                                  92 Using B(\phi \to \eta \gamma) = (1.304 ± 0.025)%, B(\eta \to 3\pi^0) = (32.56 ± 0.23)%, and B(\eta \to \gamma \gamma) = (39.31 ± 0.20)%.
   34 Using B(\phi \rightarrow e^+e^-)= (2.93 \pm 0.14) \times 10<sup>-4</sup>.
   35 Theoretical analysis of BRAMON 00 taking into account phase-space difference, elec-
                                                                                                                                                                                                  93 ^{\prime\prime} (1) = (3.256 ± 0.23)%, and B(^{\prime\prime} ^{\prime\prime} ^{\prime\prime} = (1.304 ± 0.025)%, B(^{\prime\prime} ^{\prime\prime} ^{\prime\prime} 3\pi^0) = (32.56 ± 0.23)%, and B(^{\prime\prime} ^{\prime\prime} ^{\prime\prime} ^{\prime\prime} ^{\prime\prime} (22.73 ± 0.28)%. 94 Using M_{a_0(980)} =984.8 MeV and assuming a_0(980) ^{\prime\prime} dominance.
  Theoretical analysis of BKAMON UU taking into account phase-space difference, electromagnetic radiative corrections, as well as isospin breaking, predicts 0.62. FLOREZ-BAEZ 08 predicts 0.63 considering also structure-dependent radiative corrections. FIS-CHBACH 02 calculates additional corrections caused by the close threshold and predicts 0.68. See also BENAYOUN 01 and DUBYNSKIY 07. 36 Using B(\phi \to e^+e^-)=(2.99\pm0.08)\times10^{-4}. 37 Using \Gamma(\phi)=4.1 MeV. If interference between the \rho\pi and 3\pi modes is neglected, the fraction of the \rho\pi is more than 80% at the 90% confidence level.
                                                                                                                                                                                                   ^{95} Assuming a_0(980)\,\gamma dominance in the \eta\,\pi^0\,\gamma final state.
                                                                                                                                                                                                   96 Using data of ACHASOV 00F.
                                                                                                                                                                                                  97 Using results of ALOISIO 02D and assuming that f_0(980) decays into \pi\pi only and a_0(980) into \eta\pi only.
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98 AMBROSINO 07A reports $\left[\Gamma\left(\phi(1020)\rightarrow \eta'(958)\gamma\right)/\Gamma_{\mathsf{total}}\right]/\left[B(\phi(1020)\rightarrow \eta\gamma)\right]=$ $(4.77\pm0.09\pm0.19) imes10^{-3}$ which we multiply by our best value B $(\phi(1020) o\eta\gamma)=$ $(1.309 \pm 0.024) \times 10^{-2}$. Our first error is their experiment's error and our second error

is the systematic error from using our best value.

39 Adding the direct and $\omega\pi$ contributions and considering the interference between the $\rho\pi$ and $\pi^+\pi^-\pi^0$. 41 Using B($\phi \to e^+ e^-$) = (2.99 \pm 0.08) \times 10⁻⁴ and B($\eta \to 3\pi^0$) = (32.2 \pm 0.4) \times 10⁻².

 38 From a fit without limitations on charged and neutral ho masses and widths.

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99 Averaging AULCHENKO 03B with AULCHENKO 99. 100 Using B(\phi \to \eta \gamma) = (1.297 \pm 0.033)%. 101 Using the value B(\phi \to \eta \gamma) = (1.26 \pm 0.06) \times 10<sup>-2</sup>. 102 Using B(\phi \to K_L^0 K_S^0) = (33.8 \pm 0.6)%. 103 Averaging AKHMETSHIN 00B with AKHMETSHIN 00F. 104 Using the value B(\eta' \to \eta \pi^+ \pi^-) = (43.7 \pm 1.5) \times 10<sup>-2</sup> and B(\eta \to \gamma \gamma) = (39.25 \pm 0.31) \times 10<sup>-2</sup>
0.31) \times 10<sup>-2</sup>. 
105 Using various branching ratios of K_S^0, K_S^0, \eta, \eta' from the 2000 edition (The European Physical Journal C15 1 (2000)) of this Review. 
106 From the decay mode \eta' \to \eta \pi^+ \pi^-, \eta \to \gamma \gamma. 
107 Superseded by AKHMETSHIN 00B.
^{108} For E_{\gamma}~> 20 MeV.

    Lepton Faminly number (LF) violating modes -

 \Gamma(e^{\pm}\mu^{\mp})/\Gamma_{\rm total}
                                                                                                                                                                                          \Gamma_{31}/\Gamma
                                                           CL%
                                                                                   DOCUMENT ID
                                                                                                                                  TECN COMMENT
 <2 \times 10^{-6}
                                                                                                                    10A SND e^+\,e^-
ightarrow\,e^\pm\,\mu^\mp
                                                         90
                                                                                   ACHASOV
         \pi^+\pi^-\pi^0 / 
ho\pi AMPLITUDE RATIO a_1 IN DECAY OF \phi 	o \pi^+\pi^-\pi^0
```

| $10.1 \pm 4.4 \pm 1.7$ | 80k ¹⁰⁹ AKHMETS | SHIN 06 CMD2 $1.017 - 1.021 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$ | ÷ | | | | |
|-------------------------------------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| $9.0\!\pm\!1.1\!\pm\!0.6$ | 1.98M ^{110,111} ALOISIO | 03 KLOE $1.02 \stackrel{\pi}{e^+} \stackrel{\pi}{e^-} \stackrel{\pi^0}{\rightarrow} \stackrel$ | | | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| $-6 < a_1 < 6$ | | 02 SND $e^+e^- \to \pi^+\pi^-\pi^0$ | | | | | |
| $-16 < a_1 < 11$ 90 |) 9.8k ^{109,112} AKHMETS | SHIN 98 CMD2 $e^+e^- \rightarrow \pi^+\pi^-\gamma\gamma$ | | | | | |
| 109 | | | | | | | |

DOCUMENT ID TECN COMMENT

- 109 Dalitz plot analysis taking into account interference between the contact and $ho\pi$ amplitudes. 110 From a fit without limitations on charged and neutral ρ masses and widths. 111 Recalculated by us to match the notations of AKHMETSHIN 98.

- $^{112}\ensuremath{\mathsf{Assuming}}$ zero phase for the contact term.

AKHMETSHIN 11 PL B695 412

 $\frac{\textit{VALUE (units }10^{-2})}{\textbf{9.1} \!\pm\! \textbf{1.2 OUR AVERAGE}} \, \frac{\textit{CL\%}}{}$

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 $h_1(1170)$

$$I^{G}(J^{PC}) = 0^{-}(1^{+})$$

h1(1170) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN CHG | COMMENT |
|------------------------------------------------------------------------|---------------------------------|---------|------------------|------------------------------------------------------------------------------------------------------------|
| 1170±20 OUR ESTIMATE | | | | |
| | ving data for averages | s, fits | , limits, etc. • | • • |
| 1168± 4 | ANDO | 92 | SPEC | 8 $\pi^- p \rightarrow$ |
| $1166 \pm 5 \pm 3$ | ¹ ANDO | 92 | SPEC | $ \begin{array}{c} \pi^{+}\pi^{-}\pi^{0}n\\ 8\pi^{-}\rho\rightarrow\\ \pi^{+}\pi^{-}\pi^{0}n \end{array} $ |
| 1190 ± 60 | ² DA NKOWY | 81 | SPEC 0 | $8 \pi p \rightarrow 3\pi n$ |
| $^{ m 1}$ Average and spread of valu $^{ m 2}$ Uses the model of BOWLE | es using 2 variants of R 75. | the | model of BOW | /LER 75. |

h₁ (1170) WIDTH

VALUE (MeV) DOCUMENT ID TECN CHG COMMENT

360±40 OUR ESTIMATE

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

$h_1(1170), b_1(1235)$

| 345 ± 6 | ANDO | 92 | SPEC | | $8 \pi^- p \rightarrow$ |
|--------------------|----------------------|----|------|---|-------------------------------------------------------------------------------------|
| $375 \pm 6 \pm 34$ | ³ ANDO | 92 | SPEC | | $8 \pi^{+} p \rightarrow 0$ |
| 320±50 | ⁴ DANKOWY | 81 | SPEC | 0 | $ \begin{array}{c} \pi^{+}\pi^{-}\pi^{0}n\\ 8\pi\rho\rightarrow3\pi n \end{array} $ |

 $^{^3}$ Average and spread of values using 2 variants of the model of BOWLER 75. 4 Uses the model of BOWLER 75.

h1(1170) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|----------|------------------------------|
| Γ ₁ | $ ho\pi$ | seen |

h1(1170) BRANCHING RATIOS

| $\Gamma(ho\pi)/\Gamma_{ m total}$ | | | | Г1/Г |
|------------------------------------|-----------------------|---------|-----------|---------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the follow | wing data for average | s, fits | , limits, | etc. • • • |
| seen | ANDO | 92 | SPEC | $8 \pi^- p \rightarrow \pi^+ \pi^- \pi^0 n$ |
| seen | ATKINSON | 84 | OMEG | |
| | | | | $_{\pi^+\pi^-\pi^0 ho}$ |
| seen | DA NKOWY | 81 | SPEC | $8 \pi p \rightarrow 3\pi n$ |
| seen | DANKOWY | 81 | SPEC | $8 \pi p \rightarrow 3\pi n$ |

h₁(1170) REFERENCES

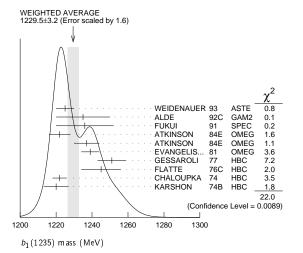
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|----------|----|-------------|------------------------------|--------------------------|
| ATKINSON | 84 | NP B231 15 | M. Atkinson et al. | (BONN, CERN, GLAS+) |
| DANKOWY | 81 | PRL 46 580 | J.A. Dankowych <i>et al.</i> | (TNTO, BNL, CARL+) |
| BOWLER | 75 | NP B97 227 | M.G. Bowler et al. | ` (OXFTP, DARE) |

$b_1(1235)$

$$I^{G}(J^{PC}) = 1^{+}(1^{+})$$

b1(1235) MASS

| VALUE | (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|--------|----------|-----------------|------------------|-------|-------------|---------|---------------------------------------------------|
| 1229.5 | ± 3.2 Ol | JR AVERAGE | Error includes | scale | factor o | of 1.6. | See the ideogram below. |
| 1225 | \pm 5 | | WEIDENAUER | 93 | ASTE | | $\overline{p}p \rightarrow 2\pi^+ 2\pi^- \pi^0$ |
| 1235 | ± 15 | | ALDE | 92 c | GAM2 | | 38,100 $\pi^- p \to \omega \pi^0 n$ |
| 1236 | ± 16 | | FUKUI | 91 | SPEC | | 8.95 $\pi^- p \rightarrow \omega \pi^0 n$ |
| 1222 | ± 6 | | ATKINSON | 84 E | OMEG | \pm | 25-55 $\gamma p \rightarrow \omega \pi X$ |
| 1237 | ± 7 | | ATKINSON | 84 E | OMEG | 0 | 25-55 $\gamma p \rightarrow \omega \pi X$ |
| 1239 | ± 5 | | EVA NGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow \omega \pi p$ |
| 1251 | ± 8 | 450 | GESSAROLI | 77 | HBC | _ | $11 \pi^- p \rightarrow \pi^- \omega p$ |
| 1245 | ± 11 | 890 | FLATTE | 76 C | HBC | _ | 4.2 K $^- \rho \rightarrow \pi^- \omega \Sigma^+$ |
| 1222 | ± 4 | 1400 | CHALOUPKA | 74 | HBC | _ | 3.9 $\pi^- p$ |
| 1220 | ± 7 | 600 | KARSHON | 74B | нвс | + | 4.9 $\pi^+ p$ |
| • • • | We do no | t use the follo | wing data for av | erage | s, fits, li | mits, e | etc. • • • |
| 1190 | ± 10 | | AUGUSTIN | 89 | DM2 | \pm | $e^+e^- ightarrow~5\pi$ |
| 1213 | ± 5 | | ATKINSON | 84 c | OMEG | 0 | 20-70 γp |
| 1271 | ± 11 | | COLLICK | 84 | SPEC | + | 200 $\pi^+ Z \rightarrow Z \pi \omega$ |
| | | | | | | | |



b_1 (1235) WIDTH

| VALUE (MeV) EVTS | DOCUMENT ID | TECN CHG | COMMENT |
|--------------------|-------------------------|-------------|-----------------------------------------------------|
| 142± 9 OUR AVERAGE | Error includes scale fa | tor of 1.2. | • |
| 113±12 | WEIDENAUER 93 | ASTE | $\overline{\rho} p \rightarrow 2\pi^+ 2\pi^- \pi^0$ |
| 160±30 | ALDE 920 | GAM2 | $38,100 \ \pi^- p \rightarrow \omega \pi^0 n$ |
| 151 ± 31 | FUKUI 91 | SPEC | 8.95 $\pi^- p \rightarrow \omega \pi^0 n$ |
| 170 ± 15 | EVANGELIS 81 | OMEG - | $12 \pi^- p \rightarrow \omega \pi p$ |

| 170 ± 50 | 225 | BALTAY | 78B | HBC | + | 15 $\pi^+ p \rightarrow p 4\pi$ |
|-------------------------|---------------|------------------|--------|-------------|----------|---------------------------------------------|
| 155 ± 32 | 450 | GESSAROLI | 77 | HBC | _ | $11 \pi^- p \rightarrow \pi^- \omega p$ |
| 182 ± 45 | 890 | FLATTE | 76C | HBC | _ | 4.2 $K^-p \rightarrow \pi^-\omega \Sigma^+$ |
| 135 ± 20 | 1400 | CHALOUPKA | 74 | HBC | _ | 3.9 $\pi^- p$ |
| 156 ± 22 | 600 | KARSHON | 74B | HBC | + | 4.9 $\pi^+ p$ |
| ullet $ullet$ We do not | use the follo | owing data for a | /erage | es, fits, l | imits, e | etc. • • • |
| 210 ± 19 | | AUGUSTIN | 89 | DM2 | \pm | $e^+e^- ightarrow 5\pi$ |
| 231 ± 14 | | ATKINSON | 84c | OMEG | 0 | 20-70 γp |
| 232 ± 29 | | COLLICK | 84 | SPEC | + | 200 $\pi^+ Z \rightarrow Z \pi \omega$ |
| | | | | | | |

b1(1235) DECAY MODES

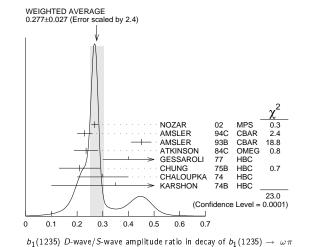
| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|------------------------------------------------|--------------------------------|------------------|
| $\overline{\Gamma_1}$ | $\omega\pi$ [D/S amplitude ratio = 0.277 \pm | dominant 0.027] | |
| Γ_2 | $\pi^{\pm}\gamma$ | $(1.6 \pm 0.4) \times 10^{-1}$ | -3 |
| Γ_3 | $\eta \rho$ | seen | |
| | $\pi^{+} \pi^{+} \pi^{-} \pi^{0}$ | < 50 % | 84% |
| Γ ₅ | $K^*(892)^{\pm} K^{\mp}$ | seen | |
| Γ_6 | $(K\overline{K})^{\pm}\pi^{0}$ | < 8 % | 90% |
| Γ ₇ | $K_S^0 K_L^0 \pi^\pm$ | < 6 % | 90% |
| Γ8 | $K_S^{reve{0}}K_S^{ar{0}}\pi^{\pm}$ | < 2 % | 90% |
| Γ_9 | $\phi\pi$ | < 1.5 % | 84% |

b1(1235) PARTIAL WIDTHS

| $\Gamma(\pi^{\pm}\gamma)$ | | | | | | Γ_2 |
|---------------------------|--------------|----|------|-----|------------------------|------------|
| VALUE (keV) | DO CUMENT IE |) | TECN | CHG | COMMENT | |
| 230±60 | COLLICK | 84 | SPEC | + | 200 π ⁺ Z → | |

b₁(1235) D-wave/S-wave AMPLITUDE RATIO IN DECAY OF $b_1(1235) \rightarrow \omega \pi$

| <u>VALUEEVTS</u> 0.277±0.027 OUR AVERAGE | <u>DOCUMENT ID</u> Error includes sca | | | _ | COMMENT the ideogram below. |
|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------|------------------------|-----------------------------|------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\begin{array}{c} 0.269 \pm 0.009 \pm 0.010 \\ 0.23 \ \pm 0.03 \\ 0.45 \ \pm 0.04 \\ 0.235 \pm 0.047 \end{array}$ | NOZAR AMSLER AMSLER ATKINSON | 93в | MPS CBAR CBAR OMEG | - | $\begin{array}{ccc} 18 \; \pi^- p \to \; \omega \pi^- p \\ 0.0 \; \overline{p} p \to \; \omega \eta \pi^0 \\ 0.0 \; \overline{p} p \to \; \omega \pi^0 \pi^0 \\ 20 - 70 \; \gamma p \end{array}$ |
| $\begin{array}{ccc} 0.4 & +0.1 \\ -0.1 & \\ 0.21 & \pm 0.08 \\ 0.3 & \pm 0.1 \\ 0.35 & \pm 0.25 & 600 \end{array}$ | GESSAROLI CHUNG CHALOUPKA KARSHON | 77 75B 74 74B | HBC HBC HBC HBC | - + - + | 11 $\pi^- p \rightarrow \pi^- \omega p$ 7.1 $\pi^+ p$ 3.9-7.5 $\pi^- p$ 4.9 $\pi^+ p$ |



b1(1235) D-wave/S-wave AMPLITUDE PHASE DIFFERENCE IN DECAY OF $b_1(1235) \rightarrow \omega \pi$

| VALUE (°) | DO CUMENT I | D | TECN | CHG | COMMENT |
|------------------|-------------|----|------|-----|-----------------------------------------------|
| 10.5 ± 2.4 ± 3.9 | NOZAR | 02 | MPS | _ | $18 \pi^- \rho \rightarrow \omega \pi^- \rho$ |

b1(1235) BRANCHING RATIOS

| $\Gamma(\eta ho)/\Gamma(\omega\pi)$ | | | | Γ_3/Γ_1 |
|-------------------------------------|--------------|--------|-----------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| <0.10 | ATKINSON 84 | D OMEG | 20-70 γ p | |

| $\Gamma(\pi^{+}\pi^{+}\pi^{-}\pi^{0})/$ | $\Gamma(\omega\pi)$ | | | | | | Γ_4/Γ_1 |
|------------------------------------------------------|---------------------|----------------------|-------|---------|----------|-------------------------------------------|---------------------|
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT | |
| <0.5 | | ABOLINS | 63 | нвс | + | 3.5 $\pi^{+} p$ | |
| Γ(K*(892)± K [∓]) | /Γ _{total} | | | | | | Γ_5/Γ |
| VALUE | | DO CUMENT ID | | TECN | COMI | MENT | |
| seen | | ¹ ABLIKIM | 10E | BES2 | J/ψ | $\rightarrow \kappa^{\pm} \kappa_{S}^{0}$ | $\pi^{\mp}\pi^{0}$ |
| 1 From a fit included width. | ding ten add | itional resonance | s and | energy- | indepe | ndent Breit | -Wigner |
| $\Gamma((K\overline{K})^{\pm}\pi^{0})/\Gamma(c$ | $\omega\pi)$ | | | | | | Γ_6/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | CHG | COMMENT | |
| <0.08 | 90 | BALTAY | 67 | HBC | \pm | 0.0 p p | |
| $\Gamma(K_S^0 K_L^0 \pi^{\pm})/\Gamma(\sigma^{\pm})$ | $_{\upsilon}\pi)$ | | | | | | Γ_7/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | CHG | COMMENT | |
| <0.06 | 90 | BALTAY | 67 | НВС | ± | 0.0 p p | |
| $\Gamma(K_S^0K_S^0\pi^{\pm})/\Gamma(\sigma^{\pm})$ | $\omega\pi)$ | | | | | | Γ_8/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | CHG | COMMENT | |
| <0.02 | 90 | BALTAY | 67 | HBC | ± | 0.0 p p | |
| $\Gamma(\phi\pi)/\Gamma(\omega\pi)$ | | | | | | _ | Γ_9/Γ_1 |
| VALUE CL | | | | CHG CO | | | 0 |
| <0.004 95 • • • We do not use | | | EC (| | | $p \rightarrow K^+ K$ | $-\pi^0 n$ |
| | | | | | | •• | |
| < 0.04 95 | BIZZA | | | ± 0.0 | | _ | |
| < 0.015 | DAHL | 67 HE | s C | 1.6 | 5-4.2 τ | r — p | |
| - | | (1005) DEEED | ENG | | | | |

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| Translated from YAF 59 1239. | ` ′ |
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$a_1(1260)$

VALUE (MeV) EVTS
1230±40 OUR ESTIMATE

$$I^G(J^{PC}) = 1^-(1^{++})$$

See also our review under the $a_1(1260)$ in PDG 06, Journal of Physics, G 33 1 (2006).

a₁(1260) MASS

DOCUMENT ID TECN COMMENT

| 1100 1 40 0011 10 | | | | | Ē |
|----------------------------------------------------------------------------------|--------------|----------------------------------------------|----------------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $1255 \pm 6 ^{+}_{-17}^{7}$ | 420k | ALEKSEEV | 10 | COMP | 190 $\pi^- Pb \to \pi^- \pi^- \pi^+ Pb'$ |
| ullet $ullet$ We do not | use the foll | owing data for av | erage | s, fits, li | mits, etc. • • • |
| $\begin{array}{c} 1243 \pm 12 \pm 20 \\ 1230 - 1270 \\ 1203 \pm \ 3 \end{array}$ | 6360 | ² LINK ³ GOMEZ-DUM. | 07A .04 | FOCS RVUE | $\begin{array}{l} 10.6 \ e^{+} e^{-} \to \rho^{0} \rho^{\pm} \pi^{\mp} \gamma \\ D^{0} \to \pi^{-} \pi^{+} \pi^{-} \pi^{+} \\ \tau^{+} \to \pi^{+} \pi^{+} \pi^{-} \nu_{\tau} \end{array}$ |
| 1330 ± 24 | 90k | SALVINI | 04 | | $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| $1331 \pm 10 \pm 3$ | 37k | ⁴ ASNER | 00 | CLE2 | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $1255 \pm 7 \pm 6$ | 5 9 0 4 | ⁵ ABREU | 98 G | DLPH | e+ e- |
| $1207\pm~5\pm~8$ | 5 9 0 4 | ⁶ ABREU | 98 G | DLPH | e^+e^- |
| $1196 \pm \ 4 \pm \ 5$ | 5 9 0 4 7, | ⁸ ABREU | 98 G | DLPH | e^+e^- |
| 1240 ± 10 | | BARBERIS | 98B | | 450 $pp \rightarrow p_f \pi^+ \pi^- \pi^0 p_S$ |
| $1262\pm~9\pm~7$ | 5, | ⁹ ACKERSTAFF | 97R | OPAL | $E_{\rm cm}^{ee} = 88-94, \tau \rightarrow 3\pi\nu$ |
| $1210\pm~7\pm~2$ | 6, | ⁹ ACKERSTAFF | 97R | OPAL | $E_{\mathrm{CM}}^{ee}=$ 88-94, $	au	o$ 3 $\pi	au$ |
| $1211 \pm 7^{+50}_{-0}$ | | ⁶ ALBRECHT | 93 c | ARG | $\tau^+ \rightarrow \ \pi^+ \pi^+ \pi^- \nu$ |
| 1121 ± 8 1242 ± 37 1260 ± 14 1250 ± 9 | 1 1 | O ANDO I IVANOV VIVANOV IVANOV | 92 91 91 91 | RVUE RVUE | $ 8 \pi^{-} p \rightarrow \pi^{+} \pi^{-} \pi^{0} n \tau \rightarrow \pi^{+} \pi^{+} \pi^{-} \nu \tau \rightarrow \pi^{+} \pi^{+} \pi^{-} \nu \tau \rightarrow \pi^{+} \pi^{+} \pi^{-} \nu $ |
| | | | | | |

| 1208 ± 15 | | ARMSTRONG | 90 | OMEG | $300.0pp \rightarrow pp\pi^{+}\pi^{-}\pi^{0}$ |
|----------------------|----|-----------|-----|------|-----------------------------------------------|
| 1220 ± 15 | | ISGUR | 89 | RVUE | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| 1260 ± 25 | 15 | BOWLER | 88 | RVUE | |
| $1166 \pm 18 \pm 11$ | | BAND | 87 | MAC | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| $1164 \pm 41 \pm 23$ | | BAND | 87 | MAC | $\tau^+ \rightarrow \pi^+ \pi^0 \pi^0 \nu$ |
| 1250 ± 40 | 14 | TORNQVIST | 87 | RVUE | |
| 1046 ± 11 | | ALBRECHT | 86B | ARG | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| $1056 \pm 20 \pm 15$ | | RUCKSTUHL | 86 | DLCO | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| $1194 \pm 14 \pm 10$ | | SCHMIDKE | 86 | MRK2 | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| 1255 ± 23 | | BELLINI | 85 | SPEC | 40 $\pi^- A \rightarrow \pi^- \pi^+ \pi^- A$ |
| 1240 ± 80 | 16 | DANKOWY | 81 | SPEC | $8.45 \pi^- p \rightarrow n3\pi$ |
| 1280 ± 30 | 16 | DAUM | 81B | CNTR | 63,94 $\pi^- p \rightarrow p 3\pi$ |
| 1041 ± 13 | 17 | GAVILLET | 77 | нвс | $4.2 K^- p \rightarrow \Sigma 3\pi$ |
| | | | | | • |

- ¹ The $\rho^{\pm}\pi^{\mp}$ state can be also due to the $\pi(1300)$.
- ²Using the Breit-Wigner parameterization; strong correlation between mass and width.
- ³Using the data of BARATE 98R.
- 4 From a fit to the 3π mass spectrum including the $K\overline{K}^*(892)$ threshold.

- 5 Uses the model of ISGUR 89.
 7 Includes the effect of a possible a_1' state.
- 8 Uses the model of FEINDT 90. 9 Supersedes AKERS 95P.
- 10 Average and spread of values using 2 variants of the model of BOWLER 75.
- 11 Reanalysis of RUCKSTUHL 86.
- 12 Reanalysis of SCHMIDKE 86.
- 13 Reanalysis of ALBRECHT 86B.

 14 From a combined reanalysis of ALBRECHT 86B, SCHMIDKE 86, and RUCKSTUHL 86.
- 15 From a combined reanalysis of ALBRECHT 86B and DAUM 81B.
- 16 Uses the model of BOWLER 75. 17 Produced in K^- backward scattering.

a₁(1260) WIDTH

| | | | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|--------------------|------------------|----------|---------|--------|-------------------------|--------|--------------|-------------------------------------------------------------------|
| | | | ESTIM | ATE | | | | |
| 367± | 9+ | 25 25 | 420k | | ALEKSEEV | 10 | COMP | 190 $\pi^- Pb \to \pi^- \pi^- \pi^+ Pb$ |
| • • • | We do | o not | use th | e foll | owing data for av | /erage | es, fits, li | mits, etc. • • • |
| 410± | $31\pm$ | 30 | | | BAUBERT | 07AU | BABR | |
| 520-68 | 30 | | 6360 | |) LINK | | FOCS | |
| 480± | 20 | | | 20 | ⁾ GOMEZ-DUM. | .04 | RVUE | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu_{\tau}$ |
| 580± | 41 | | 90k | | SALVINI | 04 | OBLX | |
| 460± | 85 | | 205 | | DRUTSKOY | 02 | BELL | |
| 814± | $36\pm$ | 13 | 37k | | ² ASNER | 00 | CLE2 | $	au^- \rightarrow \pi^- \pi^0 \pi^0 \nu_{	au}$ |
| 450± | 50 | | 22k | 23 | ³ AKHMETSHIN | 99E | CMD2 | $1.05-1.38 e^{+}e^{-}_{\pi^{+}\pi^{-}\pi^{0}\pi^{0}} \rightarrow$ |
| 570± | 10 | | | 24 | ¹ BONDAR | 99 | RVUE | $e^+e^- \rightarrow 4\pi, \tau \rightarrow 3\pi\nu_{\tau}$ |
| 587± | $27\pm$ | 21 | 5 9 0 4 | | ABREU | 98G | DLPH | e+ e- |
| 478± | $3\pm$ | 15 | 5 9 0 4 | | ABREU | 98G | DLPH | e^+e^- |
| 425 ± | $14\pm$ | 8 | 5 9 0 4 | 27,28 | ³ ABREU | 98G | DLPH | e^+e^- |
| 400± | 35 | | | | BARBERIS | 98B | | 450 $pp \to p_f \pi^+ \pi^- \pi^0 p_s$ |
| $621 \pm$ | $32\pm$ | 58 | | 25,29 | ACKERSTAFF | 97R | OPAL | $E_{\rm cm}^{ee} = 88-94, \tau \rightarrow 3\pi\nu$ |
| 457± | $15\pm$ | 17 | | 26,29 | ACKERSTAFF | 97R | OPAL | $E_{\mathrm{cm}}^{ee} =$ 88-94, $	au ightarrow 3\pi 	au$ |
| 446± | 21 + 1 | 40 0 | | 26 | ALBRECHT | 93c | ARG | $\tau^+ \rightarrow \ \pi^+ \pi^+ \pi^- \nu$ |
| 239± | 11 | | | | ANDO | 92 | SPEC | $8 \pi^- p \rightarrow \pi^+ \pi^- \pi^0 n$ |
| 266± | | 4 | | 30 | O ANDO | 92 | SPEC | $8 \pi^- p \rightarrow \pi^+ \pi^- \pi^0 n$ |
| $^{465}_{-1}^{+2}$ | 28 43 | | | 3: | I IVA NOV | 91 | RVUE | $\tau \to ~\pi^+ \pi^+ \pi^- \nu$ |
| 298+ | | | | 32 | ² IVA NOV | 91 | RVUE | $	au ightarrow ~\pi^+\pi^+\pi^- u$ |
| 488± | | | | 33 | 3 IVA NOV | 91 | RVUE | $\tau \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| 430± | 50 | | | | ARMSTRONG | 90 | OMEG | $300.0pp \rightarrow pp\pi^{+}\pi^{-}\pi^{0}$ |
| 420± | 40 | | | | ¹ ISGUR | 89 | | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| 396± | 43 | | | 35 | BOWLER | 88 | RVUE | |
| 405 ± | 75 \pm | 25 | | | BAND | 87 | MAC | |
| 419±1 | \pm 80. | 57 | | | BAND | 87 | MAC | |
| $521\pm$ | 27 | | | | ALBRECHT | 86B | ARG | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |
| 476 + 10 - 10 | $^{32}_{20} \pm$ | 54 | | | RUCKSTUHL | 86 | | $\tau^+ \rightarrow \ \pi^+ \pi^+ \pi^- \nu$ |
| 462± | $56\pm$ | 30 | | | SCHMIDKE | 86 | | $\tau^+ \rightarrow \ \pi^+ \pi^+ \pi^- \nu$ |
| 292± | 40 | | | | BELLINI | 85 | SPEC | |
| 380 ± 1 | | | | | DANKOWY | | SPEC | |
| $300\pm$ | | | | 36 | DAUM | 81в | | 63,94 $\pi^- p \rightarrow p 3\pi$ |
| 230± | 50 | | | 3 | ⁷ GAVILLET | 77 | HBC | $4.2 K^- p \rightarrow \Sigma 3\pi$ |

- 19 Using the Breit-Wigner parameterization; strong correlation between mass and width.
- 20 Using the data of BARATE 98R.
- $^{21}\,\mathrm{From}$ a fit of the $\,\mathrm{K}^-\,\mathrm{K}^{*0}$ distribution assuming $m_{a_1}^{} = 1230$ MeV and purely resonant production of the K^-K^{*0} system. 22 From a fit to the 3π mass spectrum including the $K\overline{K}^*(892)$ threshold.
- $^{23}\,\mathrm{Using}$ the $a_1(1260)$ mass of 1230 MeV.
- 24 From AKHMETSHIN 99E and ASNER 00 data using the $a_1(1260)$ mass of 1230 MeV.
- $^{25}_{\rm 26}$ Uses the model of KUHN 90. $^{26}_{\rm Uses}$ the model of ISGUR 89.

$a_1(1260)$

| 27 Includes the effect of a possible a_1' state | ²⁷ Includes | the | effect | of a | possible | a_1' | state |
|--------------------------------------------------------|------------------------|-----|--------|------|----------|--------|-------|
|--------------------------------------------------------|------------------------|-----|--------|------|----------|--------|-------|

- 28 Uses the model of FEINDT 90.
 29 Supersedes AKERS 95P.
 30 Average and spread of values using 2 variants of the model of BOWLER 75.
 31 Reanalysis of RUCKSTUHL 86.
 32 Reanalysis of SCHMIDKE 86.

- 33 Reanalysis of ALBRECHT 86B.
- 34 From a combined reanalysis of ALBRECHT 86B, SCHMIDKE 86, and RUCKSTUHL 86.
- 35 From a combined reanalysis of ALBRECHT 86B and DAUM 81B.
- 36 Uses the model of BOWLER 75. 37 Produced in K⁻ backward scattering.

$a_1(1260)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-------------------------------|------------------------------|
| Γ ₁ | $\pi^{+} \pi^{-} \pi^{0}$ | |
| Γ_2^- | $\pi^0 \pi^0 \pi^0$ | |
| | $(\rho\pi)_{S-wave}$ | seen |
| | $(ho\pi)_{D-wave}$ | seen |
| Γ_5 | $(\rho(1450)\pi)_{S-wave}$ | seen |
| Γ_6 | $(ho(1450)\pi)_{D-wave}$ | seen |
| Γ ₇ | $\sigma\pi$ | seen |
| | $f_0(980)\pi$ | not seen |
| | $f_0(1370)\pi$ | seen |
| Γ_{10} | $f_2(1270)\pi$ | seen |
| Γ_{11} | $K\overline{K}^*(892) + c.c.$ | seen |
| Γ_{12} | $\pi\gamma$ | seen |

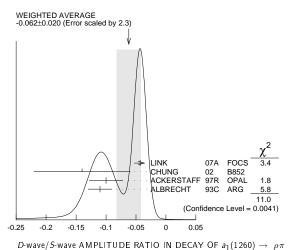
a₁ (1260) PARTIAL WIDTHS

| $\Gamma(\pi\gamma)$ | | | | | Γ ₁₂ |
|---------------------|--------------|-----|------|----------------------------------|-----------------|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| 640±246 | ZIELINSKI | 84c | SPEC | $200 \pi^+ Z \rightarrow Z 3\pi$ | |

D-wave/S-wave AMPLITUDE RATIO IN DECAY OF $a_1(1260) ightarrow ho\pi$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------------|-------|----------|------------------------------------------------|
| -0.062 ± 0.020 OUR AVERA | GE Error includes | scale | factor o | of 2.3. See the ideogram |
| below. | | | | _ |
| $-0.043 \pm 0.009 \pm 0.005$ | | | | $D^0 \rightarrow \pi^-\pi^+\pi^-\pi^+$ |
| $-0.14 \pm 0.04 \pm 0.07$ | ³⁸ CHUNG | 02 | B 85 2 | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |
| $-0.10 \pm 0.02 \pm 0.02$ 39 | ^{,40} ACKERSTAFF | 97R | OPAL | $E_{\mathrm{cm}}^{ee}=88$ –94, $	au	o	3\pi	au$ |
| -0.11 ± 0.02 | ³⁹ ALBRECHT | 93c . | ARG | $\tau^+ \rightarrow \pi^+ \pi^+ \pi^- \nu$ |

 $^{^{38}}$ Deck-type background not subtracted. 39 Uses the model of ISGUR 89. 40 Supersedes AKERS 95P.



a₁(1260) BRANCHING RATIOS

| $\Gamma((ho\pi)_{S-wave})/\Gamma$ | total | | | | | Гз/Г |
|------------------------------------|--------------|---------------------|-----------|-----------|----------------------------|--------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT I | ס | TECN | COMMENT | |
| • • • We do not use | the followin | g data for avera | ges, fits | , limits, | etc. • • • | |
| 60.19 | 37k | ⁴¹ ASNER | 00 | CLE2 | 10.6 $e^+e^ \rightarrow$ | $\tau^+\tau^-$ |
| | | | | | $\tau^- \rightarrow \pi^-$ | $\pi^0 \pi^0 \nu_{\tau}$ |

| $\Gamma((\rho\pi)_{D-\text{wave}})/\Gamma_{to}$ | otal | | | | | | Γ4. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| VALUE (units 10 ⁻²) | | | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use t | the followi | ng d | ata for averages | s, fits, | limits, | etc. • • • | |
| $1.30 \pm 0.60 \pm 0.22$ | 37k | 41 | ASNER | 00 | CLE2 | | $\tau^+\tau$ |
| | | | | | | $\tau^- \rightarrow \pi^-$ | $\pi^{0}\pi^{0}_{1}$ |
| $\Gamma((\rho(1450)\pi)_{S-wa}$ | ١/г | | | | | | Γ_5 |
| VALUE (units 10 ⁻²) | | | DOCUMENT ID | | TECN | COMMENT | . 5 |
| | | | | | | | |
| | | - | _ | | | 10.6 e ⁺ e [−] → | π+ π |
| 0.30 ± 0.04 ± 0.32 | 31 K | | NONER | 00 | CLLZ | $\tau^- \rightarrow \pi^-$ | |
| E// (4450)) | \ | | | | | | _ |
| $\Gamma((\rho(1450)\pi)_{D-wa}$ | | | | | | | Γ ₆ |
| VALUE (units 10 ⁻²) • • • We do not use t | | | DOCUMENT ID | | | | |
| | | - | _ | | | | |
| $2.04 \pm 1.20 \pm 0.28$ | 37k 4 | 1,42 | ASNER | 00 | CLE2 | $10.6 e^+e^- \rightarrow \pi^-$ | $_{\pi^0\pi^0}^{\tau^{\mp}\tau}$ |
| | | | | | | 7 → K | n n i |
| $\Gamma(\sigma\pi)/\Gamma_{total}$ | | | | | | | Γ _{7,} |
| VALUE (units 10 ⁻²) | EVTS | | DOCUMENT ID | | TECN | COMMENT | |
| ● ● We do not use t | the followi | ng d | ata for averages | s, fits, | limits, | etc. • • • | |
| seen | | | CHUNG | 02 | B852 | 18.3 $\pi^- p \rightarrow$ | |
| 10 76 14 20 11 42 | 271. 1 | 1,43 | ASNER | 00 | CLE2 | $\pi^{+}\pi^{-}\pi^{-}\mu$ | -+ |
| 18.76±4.29±1.48 | 3/K · | 1, | ASNER | 00 | CLEZ | $\begin{array}{ccc} 10.6 & e^+ & e^- \rightarrow \\ \tau^- \rightarrow & \pi^- \end{array}$ | $\pi^0\pi^0_{\iota}$ |
| | | | | | | | |
| $\Gamma(f_0(980)\pi)/\Gamma_{\text{total}}$ | | | | | | | Γ8, |
| VALUE (units 10 ⁻²) | | | DOCUMENT ID | | | | |
| ● ● We do not use t | he followi | ng d | ata for averages | | | | |
| not seen | 37k | | ASNER | 00 | CLE2 | 10.6 $e^+e^- \rightarrow$ | $\tau^+\tau$ |
| | | | | | | $\tau^- \rightarrow \pi^-$ | $\pi^{0}\pi^{0}i$ |
| $\Gamma(f_0(1370)\pi)/\Gamma_{\text{tota}}$ | ri | | | | | | Го |
| VALUE (units 10 ⁻²) | | | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do not use t | | | | | | | |
| | | | ASNER | | CLE2 | | $\tau^+\tau$ |
| | | | | | | $\tau^- \rightarrow \pi^-$ | $\pi^{0}\pi^{0}_{i}$ |
| F/&(1270)=\/F | | | | | | | Γ ₁₀ |
| $\Gamma(f_2(1270)\pi)/\Gamma_{\text{tota}}$ | | | DO 6004507 10 | | T. C | | 110, |
| $VALUE$ (units 10^{-2}) • • • We do not use t | | | | | | | |
| 1.19±0.49±0.17 | | - | ASNER | | | 10.6 $e^+e^- \rightarrow$ | _+ _ |
| 1.19 ± 0.49 ± 0.17 | 311 | | ASNER | 00 | CLLZ | $\tau^- \rightarrow \pi^-$ | $\pi^{0}\pi^{0}_{i}$ |
| = (| \ | | | | | | _ |
| $\Gamma(K\overline{K}^*(892) + \text{c.c.})$ | | | | | | | Γ ₁₁ , |
| VALUE (units 10 ⁻²) • • • We do not use t | | | DOCUMENT ID | | | | |
| | 2255 | - | COAN | 04 | | $\tau^- \rightarrow K^- \pi^-$ | - v+ |
| 2.2±0.5 8 to 15 | 2255 | | DRUTSKOY | | BELL | | κ·ν. -κ∗0 |
| 3.3±0.5±0.1 | 37k | | ASNER | 00 | CLE2 | 10.6 $e^+e^- \rightarrow$ | $\tau^+\tau$ |
| | | | | | | $\tau^- \rightarrow \pi^-$ | $\pi^0\pi^0\iota$ |
| | | | D + D + T F | 99R | ALEP | $\tau \to K \overline{K} \pi \nu_{\tau}$ | |
| | | 49 | BARATE | 3310 | | | |
| 2.6±0.3 |) | 49 | BAKAIE | 3311 | | | Γ - /! |
| 2.6 ± 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)_{S-W})$ VALUE | ave) | 49 | | | <u>TE</u> CN | <u>COM</u> MENT | Γ ₇ / |
| 2.6±0.3 Γ(σπ)/Γ((ρπ)_{S-w} | EVTS | | DO CUMENT ID | | | | Γ ₇ / |
| 2.6±0.3 Γ(σπ)/Γ((ρπ)_{S−w:} VALUE | EVTS | | DO CUMENT ID | | limits, | | |
| 2.6 ± 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)_{S-W})$ VALUE • • • We do not use to 0.06 ± 0.05 | <u>EVTS</u> the followi | | <u>DOCUMENT ID</u> ata for averages | s, fits, 04 | limits, | etc. • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi$ $1.05-1.38 e^{+}e^{-}$ | .– .– → |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)_{S-W})$ $\underbrace{\text{WALUE}}_{0.06} \bullet \bullet \text{ We do not use t}$ 0.06 ± 0.05 ~ 0.3 | <u>EVTS</u> the followi 90k | ng d | <u>DOCUMENT ID</u> ata for averages SALVINI AKHMETSHIN | s, fits, 04 I 99E | OBLX CMD2 | etc. • • • $\overline{p}p \rightarrow 2\pi^+ 2\pi$ | .– .– → |
| 2.6 ± 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ • • We do not use to 0.06 ± 0.05 ~ 0.3 0.003 ± 0.003 | <u>EVTS</u> the followi 90k 28k | ng d | <u>DOCUMENT ID</u> ata for averages SALVINI | s, fits, 04 | limits, | etc. • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi$ $1.05-1.38 e^{+}e^{-}$ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)_{S-W})$ $\underbrace{\text{WALUE}}_{0.06} \bullet \bullet \text{ We do not use t}$ 0.06 ± 0.05 ~ 0.3 | the following 90k 28k $\pi^-\pi^0$ | ng d | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE | 5, fits, 04 J 99E 82 | OBLX CMD2 RVUE | etc. • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi$ $1.05-1.38 e^{+}\epsilon$ $\pi^{+}\pi^{-}\pi^{+}\tau$ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ VALUE • • • We do not use t 0.06 \pm 0.05 ~ 0.3 0.003 \pm 0.003 $\Gamma(\pi^{0}\pi^{0}\pi^{0})/\Gamma(\pi^{+}\tau)$ VALUE | <u>EVTS</u> the following 90k 28k π - π 0 1 CL% | ng d 50 | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE | s, fits, 04 1 99E 82 | OBLX CMD2 RVUE | etc. • • • • $ \overline{p}p \rightarrow 2\pi^{+}2\pi $ $1.05-1.38 e^{+}\epsilon $ $\pi^{+}\pi^{-}\pi^{+}\tau $ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ $VALUE$ • • We do not use to 0.06 \pm 0.05 ~ 0.3 0.003 ± 0.003 $\Gamma(\pi^{0}\pi^{0}\pi^{0})/\Gamma(\pi^{+}\tau)$ $VALUE$ • • • We do not use to 0.05 | the following polymers $\frac{EVTS}{90k}$ the following $\frac{90k}{28k}$ and $\frac{\pi}{6k}$ the following $\frac{EVTS}{6k}$ | ng d 50 ng d | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages | s, fits, 04 1 99E 82 s, fits, | OBLX CMD2 RVUE | etc. • • • • $ \overline{p}p \rightarrow 2\pi^{+}2\pi $ $1.05-1.38 e^{+}\epsilon $ $\pi^{+}\pi^{-}\pi^{+}\tau $ etc. • • • | - - - |
| 2.6 ± 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ • • • We do not use to 0.06 ± 0.05 ~ 0.3 0.003 ± 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau_{VALUE})$ • • • We do not use to <0.008 | the following polymers $\frac{EVTS}{90k}$ the following polymers $\frac{90k}{28k}$ the following polymers $\frac{CL\%}{90}$ | ng d 50 ng d 51 | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE | s, fits, 04 1 99E 82 | OBLX CMD2 RVUE | etc. • • • • $ \overline{p}p \rightarrow 2\pi^{+}2\pi $ $1.05-1.38 e^{+}\epsilon $ $\pi^{+}\pi^{-}\pi^{+}\tau $ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w_0)$ • • • We do not use to 0.06 \pm 0.05 ~ 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^0\pi^0)$ **MALUE** • • • We do not use to 0.008 41 From a fit to the D | the following $90k$ $28k$ $\pi^{-}\pi^{0})$ $CL\%$ $CL\%$ the following 90 $Dalitz plot.$ | ng d 50 ng d 51 | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS | s, fits, 04 1 99E 82 s, fits, | OBLX CMD2 RVUE COMME limits, 4 450 pp | etc. • • • $ \overline{p}p \rightarrow 2\pi^{+}2\pi \\ 1.05-1.38 \ e^{+}\epsilon \\ \pi^{+}\pi^{-}\pi^{+}\tau $ etc. • • • $ \rightarrow p_{f}3\pi^{0}p_{S} $ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w)$ • • • We do not use to 0.06 \pm 0.05 \sim 0.3 0.003 \pm 0.003 $\Gamma(\pi^{0}\pi^{0}\pi^{0})/\Gamma(\pi^{+}\pi^{+}m)$ VALUE • • • We do not use to 0.008 41 From a fit to the Education of ρ (145) | the following $\frac{EVTS}{90k}$ the following $\frac{\pi}{28k}$ the following $\frac{CL\%}{90}$ the following $\frac{\pi}{90}$ Dalitz plot. $\frac{\pi}{500}$ mass a | 50 ng d 51 | DOCUMENT ID ata for averages SALVINI AKH MET SHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a | s, fits, 04 1 99E 82 s, fits, 01 | OBLX CMD2 RVUE COMME limits, 450 pp | etc. • • • $pp \rightarrow 2\pi^+ 2\pi^ 1.05 - 1.38 \stackrel{e}{}_{\pi} $ | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w)$ $VALUE$ • • We do not use to 0.06 \pm 0.05 \sim 0.3 0.003 ± 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | the following polystem $\frac{EVTS}{90k}$ the following $\frac{CL\%}{90}$ the follo | ng d 50 ng d 51 | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 | s, fits, 04 1 99E 82 s, fits, 01 nd 38 MeV | OBLX CMD2 RVUE COMME limits, 450 pp | etc. • • • • $\overline{p}p \rightarrow 2\pi^+ 2\pi^ 1.05 - 1.38 \stackrel{e^+e^-}{\pi^+ \pi^-} \frac{e^+e^-}{\pi^+ \tau^-}$ NT etc. • • • $p_f 3\pi^0 p_S$ espectively. | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ WALUE • • • We do not use to 0.06 \pm 0.05 ~ 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau)$ WALUE • • • We do not use to <0.008 41 From a fit to the E 42 Assuming for σ mad 44 Assuming for f_0 (145 43 Assuming for f_0 (150 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 45 147 47 47 47 47 47 47 47 47 47 47 47 47 4 | the following $\frac{EVTS}{90k}$ $\frac{T}{28k}$ $\frac{T}{28k}$ $\frac{T}{28k}$ $\frac{T}{28k}$ $\frac{CL\%}{90}$ Obalitz plot. 500 mass a sand with $\frac{T}{28k}$ | ng d 50 square of the square o | DOCUMENT ID ata for averages SALVINI AKHMET SHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a | 82 82 81 82 82 83 84 85 85 86 86 87 87 88 88 | OBLX CMD2 RVUE COMME limits, 450 pp 6 MeV respective 50 MeV | etc. • • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ $1.05-1.38 \stackrel{+}{\sigma} \stackrel{+}{\pi} \stackrel{-}{\pi} \stackrel{+}{\pi} \stackrel{-}{\pi} \stackrel{+}{\pi}$ etc. • • • $\rightarrow p_f 3\pi^{0} p_S$ espectively. respectively. | - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s_{-W})$ • • • We do not use to 0.06 \pm 0.05 \sim 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^{+}\tau_{-W})$ We do not use to 0.008 41 From a fit to the Equation 42 Assuming for ρ [144 43 Assuming for σ ma 44 Assuming for σ for 43 45 Assuming for σ [2.12 | EVTS the followi 90k 28k π-π0)CL% the followi 90 20alitz plot. 50) mass a 370) mass 270) mass 270) mass | 50 51 th cand and | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a width of 1275 a | s, fits, 04 1 99E 82 82 01 nd 38 MeV MeV | Ilimits, of OBLX CMD2 RVUE COMME Ilimits, of MeV respective of MeV respective of MeV | etc. • • • • $pp \rightarrow 2\pi^+ 2\pi$ $1.05 - 1.38 \stackrel{+}{\pi} \stackrel{+}{\pi} \stackrel{-}{\pi} \stackrel{+}{\pi} \stackrel{+}{\pi}$ etc. • • • $pf 3\pi^0 p_S$ espectively. respectively. respectively. | - - - - - - - - - - |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w)$ $VALUE$ • • We do not use to 0.06 \pm 0.05 \sim 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ $VALUE$ • • We do not use to 42 Assuming for ρ (144 43 Assuming for ρ (145 46 Using structure of ρ (146 Using structure of ρ (147 46 Using structure of ρ (147 46 Using structure of ρ (148 191 49 Using structure of ρ (149 Using structure of ρ | the following poly $28k$ $\pi^-\pi^0)$ $CL\%$ the following poly 200 the | ng d 50 51 and ward and from 0.00 | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a width of 1275 a n KUHN 92 6 ± 0.009)% for | 55, fits, 04 1 99E 82 82 01 86V 97 and 18 98 and 18 | OBLX CMD2 RVUE COMME limits, 4 450 pp 6 MeV respective 60 MeV DECKE | etc. • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi$ $1.05-1.38 \stackrel{+}{e^{+}}e^{-}$ $\pi^{+}\pi^{-}\pi^{+}\tau$ wr etc. • • • $\rightarrow p_{f}3\pi^{0}p_{s}$ espectively. respectively. | Γ_2 |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w)$ VALUE • • We do not use to 0.06 \pm 0.05 \sim 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau^-\tau$ | the following poly $28k$ $\pi^-\pi^0)$ $CL\%$ the following poly 200 the | ng d 50 51 and v and from | DOCUMENT ID ata for averages SALVINI AKHMETSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a width of 1275 a n KUHN 92 6 ± 0.009)% for | 55, fits, 04 1 99E 82 82 01 86V 97 and 18 98 and 18 | OBLX CMD2 RVUE COMME limits, 4 450 pp 6 MeV respective 60 MeV DECKE RIERE 0 | etc. • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi$ $1.05-1.38 \stackrel{+}{e^{+}}e^{-}$ $\pi^{+}\pi^{-}\pi^{+}\tau$ wr etc. • • • $\rightarrow p_{f}3\pi^{0}p_{s}$ espectively. respectively. | Γ_2 |
| 2.6 \pm 0.3 $ \Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w) $ WALUE • • • We do not use to 0.06 \pm 0.05 $ \sim 0.3 $ 0.003 \pm 0.003 $ \Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau^0\pi^0\pi^0)/\Gamma(\pi^+\tau^0\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^$ | the following polystem \mathbf{x}^{-} \mathbf{x}^{0}) \mathbf{c}_{L} % the following polystem \mathbf{y}^{0} 0 ability plot. \mathbf{y}^{0} 0 mass and wide \mathbf{y}^{0} 0 mass functions \mathbf{y}^{0} 0 mass functions \mathbf{y}^{0} 0 mass \mathbf{y} | ng d 50 fond to and from 0.00 194 | DOCUMENT ID ata for averages SALVINI AKHMET SHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a width of 1275 a n KUHN 92 6 ± 0.009)% fr assuming pure | s, fits, 04 1 99E 82 82 01 and 38 MeV and 31 and om B | OBLX CMD2 RVUE COMME limits, 450 pp 6 MeV respective 50 MeV DECKE RIERE 0 Donant pr | etc. • • • • • $\overline{p}p \to 2\pi^+ 2\pi^ 1.05 - 1.38 \stackrel{+}{=} \stackrel{+}{=} \frac{\pi^+ \pi^-}{\pi^+ \pi^-} \pi^+ \tau^-$ etc. • • • $\to p_f 3\pi^0 p_S$ espectively. respectively. respectively. R 93A and E 3. oduction of the | Γ_2 |
| 2.6 \pm 0.3 $\Gamma(\sigma\pi)/\Gamma((\rho\pi)s-w)$ WALUE • • We do not use to 0.06 \pm 0.05 ~ 0.3 0.003 \pm 0.003 $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\tau)$ WALUE • • We do not use to 0.008 41 From a fit to the Equation of 24 Assuming for ρ (145) 43 Assuming for ρ (145) 43 Assuming for ρ (145) 44 Assuming for ρ (146) 45 Assuming for ρ (147) 46 Using structure of ρ (149) 47 From a comparison | PEVTS the following 90k 28k π π π 0) CL% the following 90 Dalitz plot. 500) mass and wick 370) mass functions (0.155 ± n to ALAN m mass sp | ng d 50 fond to and from 0.00 M 94 ectri | DOCUMENT ID ata for averages SALVINI AKH METSHIN LONGACRE DOCUMENT ID ata for averages BARBERIS width of 1370 a of 860 and 880 width of 1186 a width of 1186 a of KUHN 92 6 ± 0.009)% for assuming pure | 5, fits, 04 199E 82 82 01 88 80 80 80 80 80 80 80 80 80 80 80 80 | Ilimits, of OBLX CMD2 RVUE COMME Ilimits, of 450 pp 6 MeV respective to MeV DECKERIERE Openant pr | etc. • • • • $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}1.05^{-}1.38 \stackrel{e}{\leftarrow} \stackrel{e}{\pi^{+}}\pi^{-}\pi^{+}\tau^{-}$ NT etc. • • • $\rightarrow p_{f}3\pi^{0}p_{s}$ espectively. respectively. respectively. R 93A and E 3. oduction of the threshold. | Γ_2/Γ Γ_2/Γ Γ_2/Γ Γ_2/Γ |

50 Uses multichannel Aitchison-Bowler model (BOWLER 75). Uses data from GAVILLET 77, DAUM 80, and DANKOWYCH 81. 51 Inconsistent with observations of $\sigma\pi$, $f_0(1370)\pi$, and $f_2(1270)\pi$ decay modes.

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| | | | | | |

$f_2(\overline{1270})$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

f2(1270) MASS

| VALUE | | EVTS | | DOCUMENT ID | | | COMMENT |
|--------|-----------------------------|---------------|---|------------------|---------|-------------|--------------------------------------------------------------------|
| 1275. | L± 1.2 OUR | AVERAGE | | Error includes | scale : | factor of | 1.1. |
| 1262 | $^{+}_{-}\ ^{1}_{2}\ \pm 8$ | | | ABLIKIM | 06∨ | BES2 | $e^+ e^- \rightarrow \ J/\psi \rightarrow \ \gamma \pi^+ \pi^-$ |
| 1275 | ± 15 | | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$ |
| 1283 | ± 5 | | | ALDE | 98 | GA M4 | |
| 1278 | ± 5 | | 1 | BERTIN | 97c | OBLX | |
| 1272 | ± 8 | 200k | | PROKOSHKIN | 94 | GAM2 | $38 \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| 1269.7 | 7± 5.2 | 5730 | | AUGUSTIN | 89 | DM2 | $e^+e^- \rightarrow 5\pi$ |
| 1283 | ± 8 | 400 | | ALDE | 87 | GA M4 | $100 \ \pi^- \rho \rightarrow 4\pi^0 n$ |
| 1274 | ± 5 | | | AUGUSTIN | 87 | DM2 | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 1283 | ± 6 | | 3 | LONGACRE | 86 | MPS | $22 \pi^- p \rightarrow n2K_S^0$ |
| 1276 | ± 7 | | | COURAU | 84 | DLCO | $e^+ e^- \rightarrow e^+ e^- \pi^+ \pi^-$ |
| 1273.3 | 3 ± 2.3 | | | CHABAUD | 83 | ASPK | |
| 1280 | ± 4 | | 5 | CASON | 82 | STRC | $8 \pi^+ \rho \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| 1281 | ± 7 | 11600 | | GIDAL | 81 | MRK2 | J/ψ decay |
| 1282 | ± 5 | | 6 | CORDEN | 79 | OMEG | |
| 1269 | ± 4 | 10k | | APEL | 75 | NICE | $40 \pi^- p \rightarrow n2\pi^0$ |
| 1272 | ± 4 | 4600 | | ENGLER | 74 | DBC | $6 \pi^+ n \rightarrow \pi^+ \pi^- p$ |
| 1277 | ± 4 | 5300 | _ | FLATTE | 71 | HBC | 7.0 π ⁺ p |
| 1273 | ± 8 | | 2 | STUNTEBECK | | нвс | $8 \pi^- p$, 5.4 $\pi^+ d$ |
| 1265 | ± 8 | | | BOESEBECK | 68 | нвс | 8 π ⁺ p |
| • • • | We do not u | use the follo | W | ing data for ave | rages | , fits, lin | nits, etc. • • • |
| 1270 | ± 8 | | | ANISOVICH | 09 | RVUE | 0.0 p p, π N |
| 1277 | ± 6 | 870 | 8 | SCHEGELSKY | 06A | RVUE | $\gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ |
| 1251 | ± 10 | | | TIKHOMIROV | 03 | SPEC | 40.0 π^- C \rightarrow $K_S^0 K_S^0 K_L^0 X$ |
| 1260 | ± 10 | | 9 | ALDE | 97 | GAM2 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| 1278 | ± 6 | | 9 | GRYGOREV | 96 | SPEC | 40 $\pi^- N \rightarrow K_S^0 K_S^0 X$ |
| 1262 | ± 11 | | | AGUILAR | 91 | EHS | 400 pp |
| 1275 | ± 10 | | | AKER | 91 | CBAR | $0.0 \overline{p}p \rightarrow 3\pi^0$ |
| 1220 | ±10 | | | BREAKSTONE | 90 | SFM | $pp \rightarrow pp\pi^{+}\pi^{-}$ |
| 1288 | ± 12 | | | ABACHI | 86в | HRS | $e^+e^- \rightarrow \pi^+\pi^-X$ |
| 1284 | ± 30 | 3k | | BINON | 83 | GAM2 | 38 $\pi^- p \rightarrow n2\eta$ |
| 1280 | ± 20 | 3k | | APEL | 82 | CNTR | $25 \pi^{-} p \rightarrow n2\pi^{0}$ |
| 1284 | ± 10 | 16000 | | DEUTSCH | 76 | нвс | 16 π ⁺ p |
| 1258 | ± 10 | 600 | | TAKAHASHI | 72 | нвс | $8 \pi^- p \rightarrow n2\pi$ |
| 1275 | ± 13 | | | ARMENISE | 70 | нвс | $9 \pi^+ n \rightarrow p \pi^+ \pi^-$ |
| 1261 | ± 5 | 1960 | 2 | ARMENISE | 68 | DBC | $5.1 \pi^+ n \rightarrow p \pi^+ MM^-$ |
| 1270 | ± 10 | 360 | | ARMENISE | 68 | DBC | $5.1 \pi^+ n \rightarrow p \pi^0 MM$ |
| 1268 | \pm 6 | 1 | 0 | JOHNSON | 68 | нвс | 3.7-4.2 $\pi^- p$ |

- ¹ T-matrix pole.
- ² Mass errors enlarged by us to Γ/\sqrt{N} ; see the note with the $K^*(892)$ mass.
- ** Mass errors enlarged by us to 1/V M, see the note with the π (022) mass.

 ** From a partial-wave analysis of data using a K-matrix formalism with 5 poles.

 ** From an energy-independent partial-wave analysis.

 ** From an amplitude analysis of the reaction $\pi^+\pi^- \to 2\pi^0$.

 ** From an amplitude analysis of $\pi^+\pi^- \to \pi^+\pi^-$ scattering data.

- 7 4-poles, 5-channel K matrix fit.
 8 From analysis of L3 data at 91 and 183–209 GeV.
 9 Systematic uncertainties not estimated.
- 10 JOHNSON 68 includes BONDAR 63, LEE 64, DERADO 65, EISNER 67.

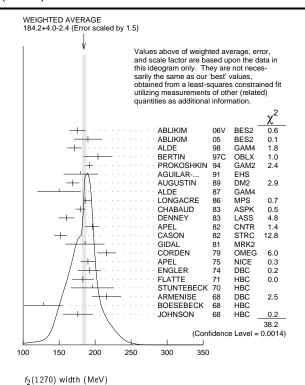
f2(1270) WIDTH

| 7FRAGE 11 200k 7730 12 400 12 13 14 3k 15 | ABLIKIM ABLIKIM ALDE BERTIN PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 06v 05 98 97c | BES2 BES2 GAM4 OBLX GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | 1.5. See the ideogram below. $e^{+}e^{-} \rightarrow J/\psi \rightarrow \gamma \pi^{+}\pi^{-}$ $J/\psi \rightarrow \phi \pi^{+}\pi^{-}$ $100 \pi^{-}p \rightarrow \pi^{0}\pi^{0}n$ $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $38 \pi^{-}p \rightarrow \pi^{0}\pi^{0}n$ $400 pp$ $e^{+}e^{-} \rightarrow 5\pi$ $100 \pi^{-}p \rightarrow 4\pi^{0}n$ $22 \pi^{-}p \rightarrow n2K_{S}^{0}$ $17 \pi^{-}p \text{ polarized}$ $10 \pi^{+}N$ $25 \pi^{-}p \rightarrow n2\pi^{0}$ $8 \pi^{+}p \rightarrow \Delta^{+}\pi^{0}\pi^{0}$ $J/\psi \text{ decay}$ |
|-----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11 200k 1730 12 400 12 13 14 3k 15 1600 16 | ABLIKIM ABLIKIM ALDE BERTIN PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 06v 05 98 97c 94 91 89 87 86 83 83 82 82 | BES2 BES2 GAM4 OBLX GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $\begin{array}{lll} e^{+}e^{-} &\rightarrow& J/\psi \rightarrow& \gamma \pi^{+}\pi^{-} \\ J/\psi \rightarrow& \phi \pi^{+}\pi^{-} \\ 100 \pi^{-}\rho \rightarrow& \pi^{0}\pi^{0}n \\ 0.0\overline{\rho}p &\rightarrow& \pi^{+}\pi^{-}\pi^{0} \\ 38\pi^{-}\rho &\rightarrow& \pi^{0}\pi^{0}n \\ 400\rhop \\ e^{+}e^{-} &\rightarrow& 5\pi \\ 100\pi^{-}\rho &\rightarrow& 4\pi^{0}n \\ 22\pi^{-}\rho &\rightarrow& n2K^{0}_{S} \\ 17\pi^{-}\rho \text{polarized} \\ 10\pi^{+}N \\ 25\pi^{-}\rho &\rightarrow& n2\pi^{0} \\ 8\pi^{+}\rho &\rightarrow& \Delta^{+}\pi^{0}\pi^{0} \end{array}$ |
| 200k 1730 12 400 12 13 14 3k 15 1600 16 | ABLIKIM ALDE BERTIN PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 05 98 97c 94 91 89 87 86 83 83 82 82 | BES2 GAM4 OBLX GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $J/\psi \to \phi \pi^{+} \pi^{-} \\ 100 \pi^{-} p \to \pi^{0} \pi^{0} n \\ 0.0 \overline{p} p \to \pi^{+} \pi^{-} \pi^{0} \\ 38 \pi^{-} p \to \pi^{0} \pi^{0} n \\ 400 pp \\ e^{+} e^{-} \to 5\pi \\ 100 \pi^{-} p \to 4\pi^{0} n \\ 22 \pi^{-} p \to n2K_{S}^{0} \\ 17 \pi^{-} p \text{ polarized} \\ 10 \pi^{+} N \\ 25 \pi^{-} p \to n2\pi^{0} \\ 8 \pi^{+} p \to \Delta^{+} \pi^{0} \pi^{0}$ |
| 200k 1730 12 400 12 13 14 3k 15 1600 16 | ALDE BERTIN PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 98 97c 94 91 89 87 86 83 83 82 82 | GAM4 OBLX GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $\begin{array}{l} 100 \ \pi^{-} p \rightarrow \pi^{0} \pi^{0} n \\ 0.0 \ \overline{p} p \rightarrow \pi^{+} \pi^{-} \pi^{0} \\ 38 \ \pi^{-} p \rightarrow \pi^{0} \pi^{0} n \\ 400 \ pp \\ e^{+} e^{-} \rightarrow 5\pi \\ 100 \ \pi^{-} p \rightarrow 4\pi^{0} n \\ 22 \ \pi^{-} p \rightarrow n2K_{S}^{0} \\ 17 \ \pi^{-} p \ \text{polarized} \\ 10 \ \pi^{+} N \\ 25 \ \pi^{-} p \rightarrow n2\pi^{0} \\ 8 \ \pi^{+} p \rightarrow \Delta^{+} \pi^{0} \pi^{0} \end{array}$ |
| 200k 1730 12 400 12 13 14 3k 15 1600 16 | BERTIN PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 97c 94 91 89 87 86 83 83 82 82 | OBLX GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $\begin{array}{c} 100 \ \pi^{-} p \rightarrow \pi^{0} \pi^{0} n \\ 0.0 \ \overline{p} p \rightarrow \pi^{+} \pi^{-} \pi^{0} \\ 38 \ \pi^{-} p \rightarrow \pi^{0} \pi^{0} n \\ 400 \ pp \\ e^{+} e^{-} \rightarrow 5\pi \\ 100 \ \pi^{-} p \rightarrow 4\pi^{0} n \\ 22 \ \pi^{-} p \rightarrow n2K_{S}^{0} \\ 17 \ \pi^{-} p \ \text{polarized} \\ 10 \ \pi^{+} N \\ 25 \ \pi^{-} p \rightarrow n2\pi^{0} \\ 8 \ \pi^{+} p \rightarrow \Delta^{+} \pi^{0} \pi^{0} \end{array}$ |
| 200k 1730 12 400 12 13 14 3k 15 1600 16 | PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 94 91 89 87 86 83 83 82 82 | GAM2 EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $38 \frac{\pi^{-} p}{n^{-}} \rightarrow \pi^{0} \pi^{0} n$ $400 pp$ $e^{+} e^{-} \rightarrow 5\pi$ $100 \pi^{-} p \rightarrow 4\pi^{0} n$ $22 \pi^{-} p \rightarrow n2K_{S}^{0}$ $17 \pi^{-} p \text{ polarized}$ $10 \pi^{+} N$ $25 \pi^{-} p \rightarrow n2\pi^{0}$ $8 \pi^{+} p \rightarrow \Delta^{+} \pi^{0} \pi^{0}$ |
| 200k 1730 12 400 12 13 14 3k 15 1600 16 | PROKOSHKIN AGUILAR AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 91 89 87 86 83 83 82 82 | EHS DM2 GAM4 MPS ASPK LASS CNTR STRC | $\begin{array}{l} 400 \ p \ p \\ e^{+} \ e^{-} \ \rightarrow \ 5\pi \\ 100 \ \pi^{-} \ p \ \rightarrow \ 4\pi^{0} \ n \\ 22 \ \pi^{-} \ p \ \rightarrow \ n \ 2K_{S}^{C} \\ 17 \ \pi^{-} \ p \ polarized \\ 10 \ \pi^{+} \ N \\ 25 \ \pi^{-} \ p \ \rightarrow \ n \ 2\pi^{0} \\ 8 \ \pi^{+} \ p \ \rightarrow \ \Delta^{++} \ \pi^{0} \ \pi^{0} \end{array}$ |
| 3k 15 | AUGUSTIN ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 89 87 86 83 83 82 82 | DM2 GAM4 MPS ASPK LASS CNTR STRC | $\begin{array}{l} e^{+}e^{-} \longrightarrow 5\pi \\ 100 \ \pi^{-}p \longrightarrow 4\pi^{0} \ n \\ 22 \ \pi^{-}p \longrightarrow n2K_{S}^{0} \\ 17 \ \pi^{-}p \ \text{polarized} \\ 10 \ \pi^{+} \ N \\ 25 \ \pi^{-}p \longrightarrow n2\pi^{0} \\ 8 \ \pi^{+}p \longrightarrow \Delta^{+} + \pi^{0} \ \pi^{0} \end{array}$ |
| 3k 15 | ALDE LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 87 86 83 83 82 82 | GAM4 MPS ASPK LASS CNTR STRC | $100 \pi^{-} p \rightarrow 4\pi^{0} n$ $22 \pi^{-} p \rightarrow n 2K_{S}^{0}$ $17 \pi^{-} p \text{ polarized}$ $10 \pi^{+} N$ $25 \pi^{-} p \rightarrow n 2\pi^{0}$ $8 \pi^{+} p \rightarrow \Delta^{++} \pi^{0} \pi^{0}$ |
| 13 14 3k 15 1600 | LONGACRE CHABAUD DENNEY APEL CASON GIDAL CORDEN | 86 83 83 82 82 | MPS ASPK LASS CNTR STRC | $22 \pi^{-} p \rightarrow n 2K_{S}^{0}$ $17 \pi^{-} p \text{ polarized}$ $10 \pi^{+} N$ $25 \pi^{-} p \rightarrow n 2\pi^{0}$ $8 \pi^{+} p \rightarrow \Delta^{++} \pi^{0} \pi^{0}$ |
| 14 3k 15 1600 | CHABAUD DENNEY APEL CASON GIDAL CORDEN | 83 83 82 82 | ASPK LASS CNTR STRC | 17 $\pi^- p$ polarized 10 $\pi^+ N$ 25 $\pi^- p \rightarrow n 2\pi^0$ 8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| 3k 15 1600 | DENNEY APEL CASON GIDAL CORDEN | 83 82 82 | LASS CNTR STRC | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 15 1600 16 | APEL CASON GIDAL CORDEN | 82 82 | CNTR STRC | $25 \pi^- p \rightarrow n 2\pi^0$ $8 \pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| 15 1600 16 | APEL CASON GIDAL CORDEN | 82 82 | CNTR STRC | 25 $\pi^- p \to n 2\pi^0$ 8 $\pi^+ p \to \Delta^{++} \pi^0 \pi^0$ |
| 15 1600 16 | CASON GIDAL CORDEN | 82 | STRC | $8 \pi^{+} \rho \rightarrow \Delta^{++} \pi^{0} \pi^{0}$ |
| 1600 16 | GIDAL CORDEN | 81 | MRK2 | |
| | | | | |
| 10k | | 79 | OMEG | $12\text{-}15 \ \pi^- p \rightarrow n2\pi$ |
| | APEL | 75 | NICE | $40 \pi^{-} p \rightarrow n 2\pi^{0}$ |
| 600 | ENGLER | 74 | DBC | $6 \pi^+ n \rightarrow \pi^+ \pi^- p$ |
| 300 | FLATTE | 71 | нвс | $7 \pi^+ p \rightarrow \Delta^{++} f_2$ |
| 12 | STUNTEBECK | 70 | нвс | $8 \pi^{-} p$, 5.4 $\pi^{+} d^{-}$ |
| .960 12 | ARMENISE | 68 | DBC | $5.1 \pi^+ n \rightarrow p \pi^+ MM^-$ |
| | BOESEBECK | 68 | HBC | 8 π ⁺ p |
| 12,17 | JOHNSON | 68 | HBC | 3.7-4.2 π ⁻ p |
| | ving data for ave | • | , fits, lin | nits, etc. • • • |
| | ANISOVICH | 09 | RVUE | 0.0 p ρ, π N |
| 870 19 | SCHEGELSKY | 06A | RVUE | '' 3 3 |
| | TIKHOMIROV | | SPEC | $40.0 \pi^- C \rightarrow K_S^0 K_S^0 K_I^0 X$ |
| | | 97 | | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| 20 | GRYGOREV | 96 | SPEC | $40 \pi^- N \rightarrow K_S^0 K_S^0 X$ |
| | AKER | 91 | CBAR | $0.0 \overline{p}p \rightarrow 3\pi^0$ |
| 3k | BINON | 83 | GAM2 | 38 $\pi^- p \rightarrow n2\eta$ |
| 650 12 | A NTIP OV | 77 | CIBS | $25 \pi^- p \rightarrow p 3\pi$ |
| | DEUTSCH | 76 | нвс | 16 $\pi^{+} p$ |
| 6000 | TAKAHACHI | 72 | нвс | $8 \pi^- p \rightarrow n2\pi$ |
| 600 12 | | | HBC | $9 \pi^+ n \rightarrow p \pi^+ \pi^-$ |
| 600 12 | | 70 | | |
| | 3k 65 0 12 | 3k BINON 650 ¹² ANTIPOV 5000 DEUTSCH 600 ¹² TAKAHASHI | 20 GRYGOREV 96 AKER 91 3k BINON 83 650 ¹² ANTIPOV 77 5000 DEUTSCH 76 | 20 GRYGOREV 96 SPEC AKER 91 CBAR 3k BINON 83 GAM2 650 ¹² ANTIPOV 77 CIBS 5000 DEUTSCH 76 HBC 600 ¹² TAKAHASHI 72 HBC |

- 12 Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.
- 13 From a partial-wave analysis of data using a K-matrix formalism with 5 poles.

- 13 From a partial-wave analysis of data using a K-matrix formalism with 5 pc 14 From an energy-independent partial-wave analysis. 15 From an amplitude analysis of the reaction $\pi^+\pi^- \to 2\pi^0$. 16 From an amplitude analysis of $\pi^+\pi^- \to \pi^+\pi^-$ scattering data. 17 JOHNSON 68 includes BONDAR 63, LEE 64, DERADO 65, EISNER 67. 18 4-poles, 5-channel K matrix fit.
- ¹⁹ From analysis of L3 data at 91 and 183–209 GeV.
- ²⁰ Systematic uncertainties not estimated.

$f_2(1270)$



f₂(1270) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|----------------|-------------------------------|-------------------------------------------------------|-----------------------------------|
| Γ ₁ | $\pi\pi$ | $(84.8 \begin{array}{c} +2.4 \\ -1.2 \end{array}) \%$ | S=1.2 |
| Γ_2 | $\pi^{+} \pi^{-} 2\pi^{0}$ | $(7.1 \begin{array}{c} +1.4 \\ -2.7 \end{array}) \%$ | S=1.3 |
| Γ_3 | $K\overline{K}$ | $(4.6 \pm 0.4)\%$ | S=2.8 |
| Γ_4 | $2\pi^{+}2\pi^{-}$ | (2.8 ± 0.4) % | S=1.2 |
| Γ_5 | $\eta\eta_{\perp}$ | (4.0 \pm 0.8) \times 1 | 0^{-3} S=2.1 |
| Γ ₆ | $4\pi^0$ | (3.0 ± 1.0) $\times 1$ | 0-3 |
| Γ_7 | $\gamma\gamma$ | $(1.64 \pm 0.19) \times 1$ | 0^{-5} S=1.9 |
| Γ8 | $\eta \pi \pi$ | < 8 ×1 | 0^{-3} CL=95% |
| Γ9 | $K^0 K^- \pi^+ + \text{c.c.}$ | < 3.4 × 1 | 0 ⁻³ CL=95% |
| Γ_{10} | $e^+ e^-$ | < 6 ×1 | 0 ⁻¹⁰ CL=90% |

CONSTRAINED FIT INFORMATION

An overall fit to the total width, 4 partial widths, a combination of partial widths obtained from integrated cross sections, and 6 branching ratios uses 44 measurements and one constraint to determine 8 parameters. The overall fit has a $\chi^2 =$ 81.8 for 37 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta \rho_i \delta \rho_j \right\rangle / (\delta \rho_i \cdot \delta \rho_j)$, in percent, from the fit to parameters ρ_i , including the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| <i>x</i> ₂ | -91 | | | | | | |
|-----------------------|------------|-----|-----|----|----|----|-----|
| <i>x</i> ₃ | 11 | -39 | | | | | |
| x_4 | 10 | -37 | 1 | | | | |
| x_5 | 1 | -6 | 0 | 0 | | | |
| <i>x</i> ₆ | 0 | -7 | 0 | 0 | 0 | | |
| <i>x</i> ₇ | 8 | -5 | -6 | 1 | 0 | 0 | |
| Γ | -78 | 71 | -11 | -8 | -1 | 0 | -11 |
| | V- | Yo | V. | ν. | v_ | V. | v_ |

| | Mode | Rate (M | leV) | Scale factor |
|----------------|---------------------------------|---------|--------------------|--------------|
| Γ ₁ | $\pi\pi$ | 156.9 | $^{+4.0}_{-1.2}$ | |
| - | $\pi^{+} \pi^{-} 2 \pi^{0}$ | 13.2 | $^{+ 2.8}_{- 5.0}$ | 1.3 |
| Гз | $K\overline{K} \ 2\pi^+ 2\pi^-$ | 8.5 | ± 0.8 | 2.9 |
| Γ_4 | $2\pi^{+}2\pi^{-}$ | 5.2 | ± 0.7 | 1.2 |

| $\Gamma_6 = 4\pi^0$ | | | 0.5 | | 0.14 0.18 | 2.1 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------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-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma_7 \gamma \gamma$ | | | | | 0.00035 | 1.9 |
| | fal | (1270) PARTIA | WID | THS | | |
| $\Gamma(\pi\pi)$ | .21 | (2210) 171111 | | | | Гι |
| ALUE (MeV) | EVTS | DO CUMENT I | D | TECN | COMMENT | . 1 |
| 56.9 ^{+4.0} OUR FI | т | | | | | |
| 57.0 + 6.0 -1.0 | | ²¹ LONGACRE | 86 | MPS | $22 \pi^- p \rightarrow n2K_S^0$ | |
| | se the follow | ving data for avera | | | | |
| 52 ±8 | 870 | ²² SCHEGELS | KY 06A | RVU | $\exists \gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ | |
| Γ(<i>K</i> K) | | | | | | Гз |
| / <u>ALUE (MeV)</u> 3.5 ± 0.8 OUR FIT | Error inclu | DOCUMENT II. | | TECN | COMMENT | |
| 9.0 + 0.7 - 0.3 | Elloi ilicia | 21 LONGACRE | | MPS | $22 \pi^- p \rightarrow n2K_S^0$ | |
| | se the follow | ving data for avera | | | | |
| 7.5 ± 2.0 | 870 | ²² SCHEGELS | KY 06A | RVU | $\exists \gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ | |
| $(\eta \eta)$ | | | | | | Γ ₅ |
| VALUE (MeV) | EVTS | DO CUMENT I | | TECN | COMMENT | |
| 0.74±0.14 OUR FI 1.0 ±0.1 | ■ ELLOL INC | cludes scale factor ²¹ LONGACRE | | MPS | $22 \pi^- p \rightarrow n2K_S^0$ | |
| | | ving data for avera | ges, fits | | , etc. • • • | |
| 1.8 ±0.4 | 870 | ²² SCHEGELS | KY 06A | RVUE | $\exists \gamma \gamma \to \kappa_S^0 \kappa_S^0$ | |
| with scalars around 2.6 ke ically around | typically (w :V; without a 3 keV). | ith exception of P an S-wave contribu | ENNIN | IGTON Ilues are | l used. Unitary approa 08) give values clust esystematically higher | ering |
| /ALUE (keV) 3.03±0.35 OUR FI | | DOCUMENT ID cludes scale factor | | TECN | COMMENT | |
| 3.14±0.20 • • • We do not u | 23 se the follow | 3,24 PENNINGTOI | N 08 oes fits | RVUE | | |
| 3.82±0.30 | 24 | ^{1,25} PENNINGTOI | N 08 | RVUE | Compilation | |
| 2.55 ± 0.15 | 870 | 22 SCHEGELSKY | | RVUE | $\gamma \gamma \rightarrow K_S^0 K_S^0$ | n |
| 2.84 ± 0.35 2.93 ± 0.23 ± 0.32 | | BOGLIONE ²⁶ YABUKI | 99 95 | RVUE VNS | $\gamma \gamma \rightarrow \pi^+ \pi^-, \pi^0 \pi$ | U |
| $2.58 \pm 0.13 + 0.36 \\ -0.27$ | | ²⁷ BEHREND | 92 | CELL | $e^+e^- \rightarrow e^+e^-\pi^+$ | π^{-} |
| $3.10 \pm 0.35 \pm 0.35$ | | ²⁸ BLINOV | 92 | MD1 | $e^+e^- ightarrow e^+e^-\pi^+$ | π^{-} |
| $2.27 \pm 0.47 \pm 0.11$ | | ADACHI | 90 D 90 | TOPZ MRK2 | | |
| $3.15 \pm 0.04 \pm 0.39$ | | BOYER | 90 | CBAL | $e^+e^- \rightarrow e^+e^-\pi^0$ | |
| 1 1 9 ± 0 1 h 1 21 = 2 | | MARSISKE | | | | |
| | | MARSISKE ²⁹ MORGAN | | | $\gamma \gamma \rightarrow \pi^{+} \pi^{-} . \pi^{0} \pi$ | .0 |
| 2.35 ± 0.65 | 2177 | 29 MORGAN OEST | 90 90 | RVUE JADE | $\gamma \gamma \rightarrow \pi^+ \pi^-, \pi^0 \pi^0 \pi^0 e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0 \pi^0$ | |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22 - 0.38$ | 2177 | ²⁹ MORGAN | 90 90 | RVUE | | π^0 |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22$ -0.38 $3.2 \pm 0.1 \pm 0.4$ $2.5 \pm 0.1 \pm 0.5$ | 2177 | ²⁹ MORGAN OEST ³⁰ AIHARA BEHREND | 90 90 86B 84B | RVUE JADE TPC CELL | $\begin{array}{ccc} e^+e^- \rightarrow & e^+e^-\pi^0 \\ e^+e^- \rightarrow & e^+e^-\pi^+ \\ e^+e^- \rightarrow & e^+e^-\pi^+ \end{array}$ | π ⁰ |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22$ -0.38 $3.2 \pm 0.1 \pm 0.4$ $2.5 \pm 0.1 \pm 0.5$ $2.85 \pm 0.25 \pm 0.5$ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU | 90 90 86в | RVUE JADE TPC | $\begin{array}{ccc} e^+e^- &\rightarrow& e^+e^-\pi^0\\ e^+e^- &\rightarrow& e^+e^-\pi^+\\ e^+e^- &\rightarrow& e^+e^-\pi^+\\ e^+e^- &\rightarrow& e^+e^-2\pi \end{array}$ | π^0 $\pi^ \pi^-$ |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22 - 0.38$ $3.2 \pm 0.1 \pm 0.4$ $2.5 \pm 0.1 \pm 0.5$ $2.85 \pm 0.25 \pm 0.5$ $2.70 \pm 0.05 \pm 0.20$ $2.52 \pm 0.13 \pm 0.38$ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH | 90 90 86B 84B 84 84 | RVUE JADE TPC CELL PLUT DLCO MRK2 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | π^0 $\pi^ \pi^ \pi^ \pi^-$ |
| $\begin{array}{c} 2.35 \pm 0.65 \\ 3.19 \pm 0.09 \stackrel{+}{-} 0.22 \\ -0.38 \\ 3.2 \pm 0.1 \pm 0.4 \\ 2.5 \pm 0.1 \pm 0.5 \\ 2.85 \pm 0.25 \pm 0.5 \\ .70 \pm 0.05 \pm 0.20 \\ 2.52 \pm 0.13 \pm 0.38 \\ 2.7 \pm 0.2 \pm 0.6 \\ -0.05 \pm 0.6 \\$ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS | 90 90 86B 84B 84 84 84 | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL | $\begin{array}{l} e^{+}e^{-}\rightarrow e^{+}e^{-}\pi^{0} \\ e^{+}e^{-}\rightarrow e^{+}e^{-}\pi^{+} \\ e^{+}e^{-}\rightarrow e^{+}e^{-}\pi^{+} \\ e^{+}e^{-}\rightarrow e^{+}e^{-}2\pi \\ e^{+}e^{-}\rightarrow e^{+}e^{-}\pi^{+} \\ e^{+}e^{-}\rightarrow e^{+}e^{-}\pi^{+} \\ e^{+}e^{-}\rightarrow e^{+}e^{-}2\pi \end{array}$ | π^0 $\pi^ \pi^ \pi^ \pi^ 0$ |
| $\begin{array}{c} 2.35 \pm 0.65 \\ 3.19 \pm 0.09 + 0.22 \\ 3.22 \pm 0.1 \pm 0.4 \\ 2.5 \pm 0.1 \pm 0.5 \\ 2.85 \pm 0.25 \pm 0.5 \\ 2.70 \pm 0.05 \pm 0.20 \\ 2.52 \pm 0.13 \pm 0.38 \\ 2.7 \pm 0.2 \pm 0.6 \\ 2.9 + 0.6 \pm 0.6 \end{array}$ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS | 90 90 86B 84B 84 84 84C 82F | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL | $\begin{array}{l} e^{+}e^{-} \rightarrow e^{+}e^{-}\pi^{0} \\ e^{+}e^{-} \rightarrow e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} \rightarrow e^{+}e^{-}2\pi \\ e^{+}e^{-} \rightarrow e^{+}e^{-}2\pi \end{array}$ | π^{0} π^{-} π^{-} π^{-} π^{-} π^{-} 0 |
| $\begin{array}{c} 2.35 \pm 0.65 \\ 3.19 \pm 0.09 \stackrel{+}{-} 0.32 \\ 3.2 \pm 0.1 \pm 0.4 \\ 2.5 \pm 0.1 \pm 0.5 \\ 8.85 \pm 0.25 \pm 0.5 \\ 2.70 \pm 0.05 \pm 0.20 \\ 3.52 \pm 0.13 \pm 0.38 \\ 3.7 \pm 0.2 \pm 0.6 \\ 2.9 \stackrel{+}{-} 0.6 \\ 2.9 \stackrel{+}{-} 0.6 \\ 3.2 \pm 0.3 \pm 0.5 \\ 3.6 \pm 0.3 \pm 0.5 \\ 3.6 \pm 0.3 \pm 0.5 \\ 3.6 \pm 0.3 \pm 0.5 \\ 3.7 \pm 0.2 \pm 0.6 \\ 3.7 \pm 0.2 \pm 0.6 \\ 3.8 \pm 0.6 \pm 0.3 \pm 0.5 \\ 3.8 \pm 0.5 \\ 3.8 \pm 0.6 \\ 3.9 \pm 0.6 \\ 3.0 \pm 0.6 $ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE | 90 90 86B 84B 84 84 82F 82F 81B 81 | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 | $\begin{array}{lll} e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{0} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}2\pi \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \end{array}$ | π^0 $\pi^ \pi^ \pi^ 0$ 0 |
| $\begin{array}{c} 2.35 \pm 0.65 \\ 3.19 \pm 0.09 \stackrel{+}{-} 0.38 \\ 3.2 \pm 0.1 \pm 0.4 \\ 2.5 \pm 0.1 \pm 0.5 \\ 3.85 \pm 0.25 \pm 0.5 \\ 2.70 \pm 0.05 \pm 0.20 \\ 3.22 \pm 0.13 \pm 0.38 \\ 2.7 \pm 0.22 \pm 0.6 \\ 2.9 \stackrel{+}{-} 0.6 \pm 0.6 \\ 3.2 \pm 0.2 \pm 0.6 \\ 3.2 \pm 0.3 \pm 0.5 \\ 3.3 \pm 0.8 \\ \end{array}$ | 2177 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK | 90 90 86B 84B 84 84 82F 82F 81B 81 | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS | $\begin{array}{lll} e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{0} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}2\pi \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \end{array}$ | π^0 $\pi^ \pi^ \pi^ 0$ 0 |
| $\begin{array}{c} 2.35 \pm 0.65 \\ 3.19 \pm 0.09 \stackrel{+}{-} 0.38 \\ 3.2 \pm 0.1 \pm 0.4 \\ 2.5 \pm 0.1 \pm 0.5 \\ 2.85 \pm 0.25 \pm 0.5 \\ 2.70 \pm 0.05 \pm 0.20 \\ 2.52 \pm 0.13 \pm 0.38 \\ 2.7 \pm 0.2 \pm 0.6 \\ 2.9 \stackrel{+}{-} 0.4 \pm 0.6 \\ 3.2 \pm 0.2 \pm 0.6 \\ 2.9 \pm 0.6 \pm 0.3 \pm 0.5 \\ 2.3 \pm 0.8 \\ \hline (e^+e^-) \end{array}$ | | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER | 90 90 86B 84B 84 84 82F 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT | $\begin{array}{lll} e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{0} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}2\pi \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}2\pi \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}2\pi \\ e^{+}e^{-} & \rightarrow & e^{+}e^{-}\pi^{+} \end{array}$ | π^0 $\pi^ \pi^ \pi^ 0$ 0 |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22$ $3.19 \pm 0.09 + 0.38$ $3.2 \pm 0.1 \pm 0.4$ $2.5 \pm 0.1 \pm 0.5$ $2.85 \pm 0.25 \pm 0.5$ $2.70 \pm 0.05 \pm 0.20$ $2.52 \pm 0.13 \pm 0.38$ $2.7 \pm 0.2 \pm 0.6$ $2.9 + 0.6$ $3.2 \pm 0.2 \pm 0.6$ $3.2 \pm 0.2 \pm 0.6$ $3.2 \pm 0.2 \pm 0.6$ $3.2 \pm 0.3 \pm 0.5$ 2.3 ± 0.8 $\Gamma(e^+e^-)_{VALUE (eV)}$ | <u>CL%</u> | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER | 90 90 86B 84B 84 84 82F 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow e^+e^-2\pi \\ e^+e^- \rightarrow e^+e^-\pi^+ \end{array}$ | π^{0} π^{-} π^{-} π^{-} 0 0 |
| 2.35 ± 0.65 $3.19 \pm 0.09 + 0.22$ $3.19 \pm 0.09 + 0.38$ $3.2 \pm 0.1 \pm 0.4$ $2.5 \pm 0.1 \pm 0.5$ $2.85 \pm 0.25 \pm 0.5$ $2.70 \pm 0.05 \pm 0.20$ $2.52 \pm 0.13 \pm 0.38$ $2.7 \pm 0.2 \pm 0.6$ $2.9 + 0.6 \pm 0.6$ $3.2 \pm 0.2 \pm 0.6$ $3.2 \pm 0.2 \pm 0.6$ $3.6 \pm 0.3 \pm 0.5$ 2.3 ± 0.8 | <u>CL%</u> 90 se the follow | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV ving data for avera | 90 90 86B 84B 84 84 C 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow e^+e^-2\pi \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ \end{array}$ | π^{0} π^{-} π^{-} π^{-} 0 0 |
| 2.35 ± 0.65 3.19 ± 0.09 ± 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 2.9 ± 0.4 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.4 ± 0.5 3.5 ± 0.13 ± 0.38 4.7 ± 0.2 ± 0.6 4.6 ± 0.3 ± 0.5 4.7 ± 0.2 ± 0.6 5.8 ± 0.2 ± 0.6 5.9 ± 0.6 5.0 ± 0.6 5.0 ± 0.6 5.0 ± 0.8 4.7 ± 0.9 5.3 ± 0.8 4.7 ± 0.9 5.3 ± 0.9 5.3 ± 0.9 5.4 ± 0.9 5.5 ± 0.9 5.6 ± 0.9 5.7 ± 0.9 5.8 ± 0.9 5.9 ± 0.9 5.9 ± 0.9 5.9 ± 0.9 5.9 ± 0.9 5.9 ± 0.9 5.9 ± 0.9 5.0 ± | <u>CL%</u> 90 se the follow 90 | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS BRANDELIK ROUSSARIE 34 BERGER DO CUMENT IN ACHASOV ving data for avera VOROBYEN | 90 90 86B 84B 84 84C 82F 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT TECN : SND s, limits | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \end{array}$ | π^{0} π^{-} π^{-} π^{-} 0 0 |
| 2.35 \pm 0.65 3.19 \pm 0.09 $^{+}$ 0.22 3.2 \pm 0.1 \pm 0.4 2.5 \pm 0.1 \pm 0.5 2.85 \pm 0.25 \pm 0.5 2.70 \pm 0.05 \pm 0.20 2.52 \pm 0.13 \pm 0.38 2.7 \pm 0.2 \pm 0.6 2.9 \pm 0.6 3.2 \pm 0.6 3.2 \pm 0.6 3.2 \pm 0.5 3.3 \pm 0.8 $\Gamma(e^{+}e^{-})$ MLUE (eV) <1.7 21 From a partial-4 22 From analysis o | <u>CL%</u> 90 se the follow 90 wave analysis f L3 data at | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV ving data for avera VOROBYES s of data using a k 91 and 183-209 of | 90 90 86B 84B 84 84 82F 82F 81B 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT TECN SND ND X formad d using | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \end{array}$ | π^{0} π^{-} π^{-} π^{-} 0 0 |
| 2.35 ± 0.65 3.19 ± 0.09 $^+$ 0.22 3.19 ± 0.09 $^+$ 0.38 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 3.9 $^+$ 0.6 3.9 $^+$ 0.6 4.6 ± 0.3 ± 0.5 2.3 ± 0.8 | <u>CL%</u> 90 se the follow 90 wave analysis f L3 data at ferred solutic | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV ving data for avera VOROBYEV. | 90 90 86B 84B 84 84 c 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL TASS MRK2 PLUT TECN TECN ND x forma d using | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ , \text{ etc. } \bullet \bullet \bullet \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \text{Isim with 5 poles.} \\ \text{SU(3) relations.} \end{array}$ | π ⁰ - π π π - 0 0 - π π π π π π π π π π π π π π π π π π π π π π π π π π π π π π π |
| 2.35 \pm 0.65 3.19 \pm 0.09 $^{+}$ 0.22 3.2 \pm 0.1 \pm 0.4 2.5 \pm 0.1 \pm 0.4 2.5 \pm 0.1 \pm 0.5 2.85 \pm 0.25 \pm 0.5 2.70 \pm 0.05 \pm 0.20 2.52 \pm 0.13 \pm 0.38 2.7 \pm 0.2 \pm 0.6 2.9 \pm 0.6 3.2 \pm 0.6 3.2 \pm 0.6 3.2 \pm 0.5 3.3 \pm 0.8 T(e+e) ALUE (eV) Vol.11 •• We do not u <1.7 21 From a partial-1 22 From analysis of 23 Solution A (pre 24 Dispersion theo | CL% 90 se the follow 90 wave analysis f L3 data at ferred solutie ry based amp | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT II ACHASOV ving data for avera VOROBYEN VOROBYEN S of data using a k 91 and 183–209 (on based on χ^2 -anolitude analysis of E | 90 90 86B 84B 84 84 84 84 82F 81B 81 80B | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL CBAL SIND ND x forma d using | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ , \text{ etc.} \bullet \bullet \bullet \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \text{Isim with 5 poles.} \\ \text{SU(3) relations.} \\ \text{RSISKE 90, BEHRENI} \end{array}$ | π ⁰ - π π - 0 0 - π - π - 0 - π - π - 0 - π - π - π - 0 - π - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 |
| 2.35 \pm 0.65 3.19 \pm 0.09 $^+$ 0.22 3.19 \pm 0.09 $^+$ 0.38 3.2 \pm 0.1 \pm 0.4 2.5 \pm 0.1 \pm 0.5 2.85 \pm 0.25 \pm 0.5 2.85 \pm 0.25 \pm 0.5 2.70 \pm 0.05 \pm 0.20 2.52 \pm 0.13 \pm 0.38 2.7 \pm 0.2 \pm 0.6 2.9 $^+$ 0.6 3.2 \pm 0.6 3.2 \pm 0.6 3.2 \pm 0.6 3.6 \pm 0.3 \pm 0.5 2.3 \pm 0.8 $\Gamma(e^+e^-)$ WALUE (eV) Vector 11 • • We do not u 1.7 21 From a partial vector 22 From analysis o 22 From analysis o 33 Solution A (precated and MORI 07. 55 Solution B (wo included) | CL% 90 se the follow 90 wave analysi of L3 data at ferred solution ry based amp orse than sol | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV Ving data for avera VOROBYEV s of data using a k 91 and 183–209 C on based on χ^2 -an olitude analysis of E | 90 90 86B 84B 84 84 84 82F 82F 81B 80B 000kg es, fitt 7 88 4-matrit 7 88 8-matrit 9 80 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL CBAL SIND ND x forma d using | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ , \text{ etc. } \bullet \bullet \bullet \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \text{Isim with 5 poles.} \\ \text{SU(3) relations.} \end{array}$ | π ⁰ - π π - 0 0 - π - π - 0 - π - π - 0 - π - π - π - 0 - π - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 |
| 2.35 ± 0.65 3.19 ± 0.09 + 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.5 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.2 2.7 ± 0.6 3.6 ± 0.3 ± 0.5 2.3 ± 0.8 \[\begin{align*} | cL% 90 se the follow 90 wave analysis of L3 data at ferred solution ty based amp rse than sol | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV VING data using a k 91 and 183–209 (on based on χ^2 -anolitude analysis of Eution A; still acce | 90 90 86B 84B 84 84 84 82F 81B 81B 80B 00k (| RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL TASS MRK2 PLUT | $\begin{array}{l} e^+e^- \rightarrow e^+e^-\pi^0 \\ e^+e^- \rightarrow e^+e^-\pi^+ \\ e^+e^- \rightarrow \pi^0\pi^0 \\ , \text{ etc.} \bullet \bullet \bullet \\ e^+e^- \rightarrow \pi^0\pi^0 \\ \text{Isim with 5 poles.} \\ \text{SU(3) relations.} \\ \text{RSISKE 90, BEHRENI systematic uncertaintie} \\ \end{array}$ | π ⁰ - π π - 0 0 - π - π - 0 - π - π - 0 - π - π - π - 0 - π - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - π - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - π - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 |
| 2.35 ± 0.65 3.19 ± 0.09 + 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.7 3.3 ± 0.8 \[\begin{align*} \b | CL% 90 se the follow 90 wave analysi f L3 data at ferred soluti ry based amp rse than sol | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV Ving data for avera VOROBYEV s of data using a k 91 and 183–209 (on based on χ^2 -an olitude analysis of E ution A; still acce around 1220 MeV. Ith a 300 - 500 keV of IJYTH 85 | 90 90 86B 84B 84 84 82F 82F 81B 80B 00k ges, fits GeV and alysis). 30 YER pt able | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL TASS MRK2 PLUT TECN S, limits ND ND 90, MA when s; | $\begin{array}{lll} e^+e^- & & e^+e^-\pi^0 \\ e^+e^- & & e^+e^-\pi^+ \\ e^+e^- & & & e^+e^-\pi^+ \\ e^+e^- & & & & \pi^0\pi^0 \\ \end{array}$ | π ⁰ - π ⁻ - π |
| 2.35 ± 0.65 3.19 ± 0.09 + 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 3.3 ± 0.8 F(e+e-) WALUE (eV) Trom a partial-1 We do not u The manalysis of the control of the | cL% 90 se the follow 90 wave analysis f L3 data at ferred solution y based amp rise than solution scalar state: ed model wirded model wirded model pread of diff | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 32 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT II ACHASOV ving data for avera VOROBYEV s of data using a k 91 and 183–209 C on based on χ^2 -an olitude analysis of E ution A; still acce around 1220 MeV. ith a 300 – 500 keV of LYTH 85. erent solutions. Da | 90 90 86B 84B 84 84 84C 82F 81B 80B 00k ges, fits (88 GeV and alysis). SOYER ptable / wide | RVUE JADE TPC CELL PLUT DLCO MRK22 CBAL CBAL TASS MRK2 PLUT TECN ND 90, MA when s; scalar a MARK2 | $\begin{array}{lll} e^+e^- & e^+e^-\pi^0 \\ e^+e^- & e^+e^-\pi^+ \\ e^+e^- & e^+e^-\pi^0\pi^0 \\ , \ \text{etc.} & \bullet \bullet \\ e^+e^- & \pi^0\pi^0 \\ \text{Jism with 5 poles.} \\ \text{SU(3) relations.} \\ \text{RSISKE 90, BEHRENI } \\ \text{systematic uncertaintie} \\ \text{t 1100 MeV.} \\ \text{and CRYSTAL BALL} \\ \end{array}$ | π ⁰ - π ⁻ - π |
| 2.35 ± 0.65 3.19 ± 0.09 + 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 3.2 ± 0.6 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.7 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.7 3.3 ± 0.8 \(\begin{align*} ali | CL% 90 se the follow 90 wave analysis of L3 data at ferred solution ry based amp rse than solution scalar state sed model will rized model pread of diff Authors rep 6 ± 0.3 KeV | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 22 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV ving data for avera VOROBYEV s of data using a key 1 and 183–209 con based on χ^2 -an and 1810 and 183–209 con based on χ^2 -an contact of tyth 85. erent solutions. Dio ort strong correlat | 90 90 86B 84B 84 84 84 82F 81B 80B 000kges, fitts / 88 6(-matrit GeV and alysis). BOYER ptable / wide ata of f | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL TASS MRK2 PLUT TECN SND x forma d using 90, MA when s: scalar a a MARK2 th $\gamma\gamma$ w | $\begin{array}{lll} e^+e^- & e^+e^-\pi^0 \\ e^+e^- & e^+e^-\pi^+ \\ e^+e^- & e^-\pi^0\pi^0 \\ \end{array}$ | π^0 π^0 $\pi^ \pi^ $ |
| 2.35 ± 0.65 3.19 ± 0.09 ⁺ 0.22 3.2 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.4 2.5 ± 0.1 ± 0.5 2.85 ± 0.25 ± 0.5 2.70 ± 0.05 ± 0.20 2.52 ± 0.13 ± 0.38 2.7 ± 0.2 ± 0.6 2.9 ⁺ 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0.6 3.2 ± 0. | $\frac{CL\%}{90}$ se the follow 90 wave analysis of L3 data at ferred solution y based amprise than solutions the following that the scalar state seed model with the following that the following that the following seed of diff Authors rep 6 \pm 0.3 KeV ctions modified with the following seed of the following seed of the following seed that the following seed the following see | 29 MORGAN OEST 30 AIHARA BEHREND 31 BERGER COURAU 22 SMITH EDWARDS 33 EDWARDS BRANDELIK ROUSSARIE 34 BERGER DOCUMENT IN ACHASOV ving data for avera VOROBYEV s of data using a key 1 and 183–209 con based on χ^2 -an and 1810 and 183–209 con based on χ^2 -an contact of tyth 85. erent solutions. Dio ort strong correlat | 90 90 86B 84B 84 84 82F 82F 81B 80B 00k ges, fits GeV and alysis), 30 YER thiology wide | RVUE JADE TPC CELL PLUT DLCO MRK2 CBAL CBAL TASS MRK2 PLUT TECN ND y forman d using 90, MA when s scalar a MARK2 th $\gamma\gamma$ w instan | $\begin{array}{lll} e^+e^- & e^+e^-\pi^0 \\ e^+e^- & e^+e^-\pi^+ \\ e^+e^- & e^+e^-\pi^0\pi^0 \\ , \ \text{etc.} & \bullet \bullet \\ e^+e^- & \pi^0\pi^0 \\ \text{Jism with 5 poles.} \\ \text{SU(3) relations.} \\ \text{RSISKE 90, BEHRENI } \\ \text{systematic uncertaintie} \\ \text{t 1100 MeV.} \\ \text{and CRYSTAL BALL} \\ \end{array}$ | π^0 π^0 $\pi^ \pi^ $ |

33 If helicity = 2 assumption is not made. 34 Using mass, width and B($f_2(1270) \rightarrow 2\pi$) from PDG 78.

Meson Particle Listings $f_2(1270)$

| $f_2(1270)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ | $\Gamma(\eta\eta)/\Gamma_{	ext{total}}$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| $\Gamma(K\overline{K}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_3\Gamma_7/\Gamma$ | VALUE (units 10 ⁻³) 4.0±0.8 OUR FIT Error includes so |
| VALUE (keV) DO CUMENT ID TECN COMMENT 0.139±0.019 OUR FIT Error includes scale factor of 1.9. COMMENT | 2.9±0.5 OUR AVERAGE 2.7±0.7 |
| 0.091±0.007±0.027 35 ALBRECHT 90 G ARG $e^+e^- \rightarrow e^+e^- K^+ K^-$ • • • We do not use the following data for averages, fits, limits, etc. • • • | 2.8±0.7 |
| 0.104 \pm 0.007 \pm 0.072 36 ALBRECHT 90G ARG $e^+e^- \rightarrow e^+e^- K^+K^-$ | 5.2±1.7 |
| 35 Using an incoherent background. | $\Gamma(\eta\eta)/\Gamma(\pi\pi)$ VALUE CL% |
| 36 Using a coherent background. | 0.003±0.001 |
| $\Gamma(\eta\eta) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_5\Gamma_7/\Gamma$ VALUE (eV) DOCUMENT ID TECN COMMENT | • • • We do not use the following d <0.05 95 |
| 11.5 + 1.8 + 4.5 | < 0.016 95 |
| ³⁷ Including interference with the $f_2'(1525)$ (parameters fixed to the values from the 2008 edition of this review, PDG 08) and $f_0(Y)$. | <0.09 95 Γ (4π⁰)/Γ_{total} |
| Helicity-0/Helicity-2 RATIO IN $\gamma\gamma ightarrow f_2(1270) ightarrow \pi\pi$ | <u>VALUE</u> <u>EVTS</u> 0.0030±0.0010 OUR FIT |
| VALUE (units 10 ⁻²) DOCUMENT ID TECN COMMENT | 0.003 ±0.001 400 ± 50 |
| 3.7±0.3 $^{+15.9}_{-2.9}$ UEHARA 08A BELL 10.6 e^+e^{-1} | $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | <u>WALUE (units 10^{-5})</u> <u>DOC</u> • • • We do not use the following d |
| 13 38,39 PENNINGTON 08 RVUE Compilation 26 39,40 PENNINGTON 08 RVUE Compilation | $1.57 \pm 0.01 + 1.39 \atop -0.14$ UEH |
| 38 Solution A (preferred solution based on χ^2 -analysis). | |
| 39 Dispersion theory based amplitude analysis of BOYER 90, MARSISKE 90, BEHREND 92, and MORI 07 | Γ(ηππ)/Γ(ππ) <u>VALUE</u> <u>CL%</u> |
| 40 Solution B (worse than solution A; still acceptable when systematic uncertainties are included). | <0.010 95 |
| | $\Gamma(K^0K^-\pi^+ + \text{c.c.})/\Gamma(\pi\pi)$ |
| を(1270) BRANCHING RATIOS | VALUE CL% |
| $\Gamma(\pi\pi)/\Gamma_{	ext{total}}$ Γ_1/Γ | <0.004 95 |
| D.848 + 0.012 OUR FIT | $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ |
| 0.837±0.020 OUR AVERAGE | VALUE (units 10 ⁻¹⁰) CL% <6 90 |
| 0.849 \pm 0.025 CHABAUD 83 ASPK 17 π^-p polarized | 41 Coupled channel analysis of $\pi^+ 	au$ |
| 0.85 ± 0.05 | 42 Re-evaluated by CHABAUD 83. 43 Includes PAWLICKI 77 data. |
| $\Gamma(\pi^+\pi^-2\pi^0)/\Gamma(\pi\pi)$ Γ_2/Γ_1 | 44 Takes into account the $f_2(1270)$ - |
| Should be twice $\Gamma(2\pi^+ 2\pi^-)/\Gamma(\pi\pi)$ if decay is $\rho\rho$. (See ASCOLI 68b.) | f ₂ (1) |
| VALUEEVTSDOCUMENT IDTECNCOMMENT | -, |
| 0.084 +0.018 OUR FIT Error includes scale factor of 1.3. | UEHARA 10A PR D82 114031 ANISOVICH 09 IJMP A24 2481 PDG 08 PL B667 1 |
| 0.15 \pm0.06 600 EISENBERG 74 HBC 4.9 $\pi^+ p \rightarrow \Delta^{++} f_2$ • • • We do not use the following data for averages, fits, limits, etc. • • • | PENNINGTON 08 EPJ C56 1 UEHARA 08A PR D78 052004 |
| 0.07 EMMS 75D DBC 4 π^+ $n 	op pf_2$ | MORI 07 PR D75 051101R ABLIKIM 06V PL B642 441 |
| $\Gamma(K\overline{K})/\Gamma(\pi\pi)$ Γ_3/Γ_1 | SCHEGELSKY 06A EPJ A27 207 ABLIKIM 05 PL B607 243 BINON 05 PAN 68 960 |
| We average only experiments which either take into account $f_2(1270)$ - $a_2(1320)$ inter- | BINON 05 PAN 68 960 Translated from YAF (ABLIKIM 04E PL B603 138 |
| ference explicitly or demonstrate that a ₂ (1320) production is negligible. VALUEEVTSDOCUMENT IDTECNCOMMENT | BARGIOTTI 03 EPJ C26 371 TIKHOMIROV 03 PAN 66 828 |
| 0.054 ± 0.005 OUR FIT Error includes scale factor of 2.8. | Translated from YAF (ACHASOV 00K PL B492 8 BARBERIS 00E PL B479 59 |
| -0.004 0.041 <u>+</u> 0.005 OUR AVERAGE | BOGLIONE 99 EPJ C9 11 ALDE 98 EPJ A3 361 |
| 0.045 ± 0.01 41 BARGIOTTI 03 OBLX $\overline{p}p$ | Also PAN 62 405 Translated from YAF 1 ALDE 97 PL B397 350 |
| 0.037 $^{+0.008}_{-0.021}$ ETKIN 82B MPS 23 $\pi^- p \rightarrow n2K_S^0$ | ALDE 97 PL B397 350 BERTIN 97C PL B408 476 GRYGOREV 96 PAN 59 2105 |
| 0.045 \pm 0.009 CHABAUD 81 ASPK 17 $\pi^- p$ polarized | Translated from YAF 5 YABUKI 95 JPSJ 64 435 |
| 0.039 ± 0.008 LOVERRE 80 HBC 4 $\pi^- p \rightarrow K\overline{K}N$ • • • We do not use the following data for averages, fits, limits, etc. • • • | PROKOSHKIN 94 SPD 39 420 Translated from DANS BEHREND 92 ZPHY C56 381 |
| 0.052 ± 0.025 ABLIKIM 04E BES2 $J/\psi ightarrow \omega K^+ K^-$ | BLINOV 92 ZPHY C53 33 AGUILAR 91 ZPHY C50 405 |
| 0.036 \pm 0.005 42 COSTA 80 OMEG 1-2.2 $\pi^- p \to K^+ K^- n$ | AKER 91 PL B260 249 ADACHI 90D PL B234 185 |
| 0.027 \pm 0.009 A4 POLYCHRO 79 STRC 7 $\pi^- p \rightarrow n2K_S^0$ | ALBRECHT 90 G ZPHY C48 183 BOYER 90 PR D42 1350 |
| 0.025 ± 0.015 EMMS 75D DBC 4 π^+ $n 	o p f_2$ | BREAKSTONE 90 ZPHY C48 569 MARSISKE 90 PR D41 3324 MORGAN 90 ZPHY C48 623 |
| 0.031 ± 0.012 20 ADERHOLZ 69 HBC $8\pi^+\rho \to K^{\mp}K^-\pi^+\rho$ | OEST 90 ZPHY C48 623 AUGUSTIN 89 NP B320 1 |
| $\Gamma(2\pi^+2\pi^-)/\Gamma(\pi\pi)$ Γ_4/Γ_1 VALUEEVTS DOCUMENT ID TECN COMMENT | VOROBYEV 88 SJNP 48 273 Translated from YAF 4 |
| 0.033±0.005 OUR FIT Error includes scale factor of 1.2. | ALDE 87 PL B198 286 AUGUSTIN 87 ZPHY C36 369 ABACHI 86B PRL 57 1990 |
| 0.033\pm0.004 OUR AVERAGE Error includes scale factor of 1.1. 0.024 \pm 0.006 160 EMMS 75D DBC 4 π^+ $n \rightarrow p f_2$ | AIHARA 86B PRL 57 404 ALDE 86D NP B269 485 |
| · · · · · · · · · · · · · · · · | LANDRO 96 DI D172 445 |

EISENBERG 74 HBC 4.9 $\pi^+ p \rightarrow \Delta^{++} f_2$

74 HBC 3.9 $\pi^- p \to n f_2$ ANDERSON 73 DBC $6 \pi^+ n \to p f_2$ OH 70 HBC $1.26 \pi^- p \to \pi^+ \pi^- n$

 0.051 ± 0.025

 $\begin{array}{c} 0.043 \, {}^{+\, 0.007}_{-\, 0.011} \\ 0.037 \, {}^{\pm\, 0.007} \end{array}$

 0.047 ± 0.013

70

285

154

LOUIE

| | | | | 121 | 1210) |
|------------------------------------------|------------------------------------------------|------------------------------------------------|-------------------------|---------------------------------------------|--------------------------|
| $\Gamma(\eta\eta)/\Gamma_{\text{total}}$ | | | | | Г ₅ /Г |
| VALUE (units 10 | | DO CUMENT ID | | COMMENT | |
| 4.0 ± 0.8 OUR 2.9 ± 0.5 OUR | | es scale factor of 2 | 2.1. | | |
| 2.7±0.7 | AVENAGE | BINON | 05 GA M | 1S 33 π [−] p → | nnn |
| 2.8±0.7 | | ALDE | | 14 100 π ⁻ p — | |
| 5.2±1.7 | | BINON | | 12 38 $\pi^- p \rightarrow$ | |
| $\Gamma(\eta\eta)/\Gamma(\pi\pi)$ |) CL% | DO CHIMENT ID | TECA | COMMENT | Γ_5/Γ_1 |
| VALUE 0.003±0.001 | | <u>DOCUMENT ID</u> BARBERIS | 00E | $\frac{COMMENT}{450 pp \rightarrow}$ | Denno |
| | | ng data for averag | | | ציויוי די |
| < 0.05 | 95 | EDWARDS | 82F CBA | | $e^{+}e^{-}2\eta$ |
| < 0.016 | 95 | EMMS | 75D DBC | | pf ₂ |
| < 0.09 | 95 | EISENBERG | 74 HBC | | $\bar{\Delta}^{++} f_2$ |
| $\Gamma(4\pi^0)/\Gamma_{ m tota}$ | ıl | | | | Γ_6/Γ |
| VALUE | EVTS | DO CUMENT II | TEC | N COMMENT | |
| 0.0030 ± 0.0010 | | ALDE | 07 641 | 44 100 - | . 0 |
| 0.003 ±0.001 | 400 ± 50 | ALDE | 87 GA1 | M4 100 π ⁻ p - | |
| $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ | | | | | Γ_7/Γ |
| VALUE (units 10 ⁻¹ | | DOCUMENT ID | TECN C | | |
| | | ng data for averag | es, fits, limit | s, etc. • • • | |
| $1.57 \pm 0.01 + 1.01 - 0.01$ | 39 14 | JEHARA 08 | BELL 1 | $0.6 e^{+}e^{-}_{e^{+}e^{-}\pi^{0}\pi^{0}}$ | |
| $\Gamma(\eta\pi\pi)/\Gamma(\pi$ | | | | | Γ_8/Γ_1 |
| VALUE | <u>CL%_</u> | DO CUMENT ID | | | |
| <0.010 | 95 | EMMS | 75D DBC | $4 \pi^+ n \rightarrow$ | pf ₂ |
| $\Gamma(K^0K^-\pi^+$ | $+ c.c.)/\Gamma(\pi\pi)$ | | | | Γ_9/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | TECN | COMMENT | · |
| <0.004 | 95 | EMMS | 75D DBC | $4 \pi^+ n \rightarrow$ | pf ₂ |
| $\Gamma(e^+e^-)/\Gamma_t$ | otal | | | | Γ_{10}/Γ |
| VALUE (units 10 | | DO CUMENT ID | TECN | COMMENT | • |
| <6 | 90 | ACHASOV | 00k SND | | π0π0 |
| 41 Coupled ch | annel analysis of a | $_{r}^{+}\pi^{-}\pi^{0}$, $_{K}^{+}K^{-}$ | π^0 and $K^=$ | | |
| | d by CHABAUD | | , | 5 | |
| 43 Includes PA | WLICKI 77 data. | | | | |
| Takes into | account the $f_2(12)$ | 70)-f' ₂ (1525) inter | terence. | | |
| | f | (1270) REFER | ENCES | | |
| UEHARA 10 | A PR D82 114031 | S. Uehara et | al. | (BELL | E Collab.) |
| ANISOVICH 09 PDG 08 | IJMP A24 2481 PL B667 1 | V.V. Anisovic C. Amsler et | h, A.V. Sarants | ev | G Collab.) |
| PENNINGTON 08 | EPJ C56 1 | M.R. Penning | ton et al. | | |
| UEHARA 08 MORI 07 | PR D75 051101R | | | (BELL | E Collab.) E Collab.) |
| ABLIKIM 06 SCHEGELSKY 06 | V PL B642 441 | M. Ablikim e | t al. | ` (BE | S Collab.) |
| ABLIKIM 05 BINON 05 | PL B607 243 PAN 68 960 Translated from Y | V.A. Schegels M. Ablikim e F. Binon et a | : al. | (BE | S Collab.) |
| ABLIKIM 04 | E PL B603 138 | M. Ablikim e | t al. | (BE | S Collab.) |
| BARGIOTTI 03 TIKHOMIROV 03 | EPJ C26 371 PAN 66 828 | M. Bargiotti G.D. Tikhomi | et al. | (OBELI) | K Collab.) |
| ACHASOV 00 | | AF 66 860. M.N. Achasov D. Barberis e | et al. | (Novosibirsk SNI | D Collab.) |
| BARBERIS 00 BOGLIONE 99 | E PL B479 59 EPJ C9 11 | D. Barberis e M. Boglione | t al. M.R. Penningto | (WA 10 | 2 Collab.) |
| ALDE 98 | EPJ A3 361 | D. Alde et al | | (GAM | 4 Collab.) S Collab.) |
| AISU | Translated from Y PI B397 350 | D. Alde et al AF 62 446. | | , | S Collab.) |
| ALDE 97 | | | | | |

| UEHARA | 10 A | PR D82 114031 | S. Uehara <i>et al</i> . | (BELLE | Collab.) |
|-----------------|--------------|----------------------------------|----------------------------------------------|---------------------------------------------|----------------------|
| ANISOVICH | 09 | IJMP A24 2481 | V.V. Anisovich, A.V. Sarantsev | | |
| PDG | 08 | PL B667 1 | C. Amsler et al. | (PDG | Collab.) |
| PENNIN GT ON | | EPJ C56 1 | M.R. Pennington et al. | | |
| UEHARA | 08A | PR D78 052004 | S. Uehara <i>et al</i> . | (BELLE | Collab.) |
| MORI | 07 | PR D75 051101 | R T. Mori et al. | (BELLE | Collab.) |
| ABLIKIM | 06V | PL B642 441 | M. Ablikim et al. | `(BES | Collab.) |
| SCHEGELSKY | 06A | EPJ A27 207 | V.A. Schegelsky et al. | | |
| ABLIKIM | 05 | PL B607 243 | M. Ablikim et al. | (BES | Collab.) |
| BINON | 05 | PAN 68 960 | F. Binon et al. | * | |
| | | Translated from | | | |
| ABLIKIM | 04 E | PL B603 138 | M. Ablikim et al. | | Collab.) |
| BARGIOTTI | 03 | EPJ C26 371 | M. Bargiotti et al. | (OBĒLIX | Collab.) |
| TIKHOMIROV | 03 | PAN 66 828 | G.D. Tikhomirov et al. | | |
| A CHACON | 0016 | Translated from | | (Name of the Local Control | C-11-1-1 |
| ACHASOV | 00 K 00 E | PL B492 8 | | (Novosibirsk SND | |
| BARBERIS | 99 | PL B479 59 | D. Barberis et al. | (WA 102 | Collab.j |
| BOGLIONE | 98 | EPJ C9 11 | M. Boglione, M.R. Pennington | (CANA | C-U-L) |
| ALDE | 70 | EPJ A3 361 PAN 62 405 | D. Alde et al. D. Alde et al. | | Collab.) Collab.) |
| Also | | Translated from | | (GAMS | Collab.j |
| ALDE | 97 | PL B397 350 | D.M. Alde et al. | (GAMS | Collab.) |
| BERTIN | 97 C | PL B408 476 | A. Bertin et al. | (OBELIX | |
| GRYGOREV | 96 | PAN 59 2105 | V.K. Grigoriev, O.N. Baloshin, | | (ITEP) |
| GITTGOILE | ,,, | Translated from | YAF 59 2187. | J.I. Dalkov | (11 21) |
| YABUKI | 95 | JPSJ 64 435 | F. Yabuki et al. | (VENUS | Collab.) |
| PROKOSHKIN | 94 | SPD 39 420 | Y.D. Prokoshkin, A.A. Kondash | ov | (SERP) |
| | | Translated from | | | , |
| BEHREND | 92 | ZPHY C56 381 | | (CELLO | |
| BLINOV | 92 | ZPHY C53 33 | A.E. Blinov et al. | | (NOVO) |
| AGUILAR | 91 | ZPHY C50 405 | M. Aguilar-Benitez et al. | (LEBC-EHS | |
| AKER | 91 | PL B260 249 | E. Aker et al. | (Crystal Barrel | |
| ADACHI | 90 D | PL B234 185 | l. Adachi et al. | (T OPA Z | |
| ALBRECHT | 90 G | ZPHY C48 183 | H. Albrecht et al. | (ARGUS | |
| BOYER | 90 | PR D42 1350 | J. Boyer et al. | (Mark II | |
| BREAKSTONE | | ZPHY C48 569 | A.M. Breakstone et al. | (ISU, BGNA, G | |
| MARSISKE | 90 | PR D41 3324 | H. Marsiske et al. | (Crystal Ball | |
| MORGAN | 90 | ZPHY C48 623 | D. Morgan, M.R. Pennington | | DURH) |
| OEST | 90 | ZPHY C47 343 | T. Oest et al. | | Collab.) |
| AUGUSTIN | 89 | NP B320 1 | J.E. Augustin, G. Cosme | | Collab.) |
| VOROBYEV | 88 | SJNP 48 273 | P.V. Vorobiev et al. | | (NOVO) |
| ALDE | 87 | Translated from ' PL B198 286 | | NL, BRUX, SERP, | LADD) |
| | 87 | | | | |
| AUGUSTIN | | ZPHY C36 369 | J.E. Augustin et al. S. Abachi et al. (PU | (LALO, CLER, | |
| ABACHI | 86B | PRL 57 1990 | | JRĎ, ANL, IND, I | |
| AIHARA | 86B 86D | PRL 57 404 NP B269 485 | H. Aihara et al. D.M. Alde et al. (BEL) | $(TPC	ext{-}2\gamma)$ G, LAPP, SERP, $($ | COHAD.) |
| ALDE LANDRO | 86 86 | PL B172 445 | | | (UTRO) |
| LONGACRE | 86 | PL B172 445 PL B177 223 | M. Landro, K.J. Mork, H.A. O | (BNL, BRAN, G | |
| LYTH | 85 | | R.S. Longacre et al. | (DINL, DRAIN, C | JUNIT+) |
| | 84 B | JPG 11 459 | D.H. Lyth | (6511.0 | C-11-1-1 |
| BEHREND | | ZPHY C23 223 ZPHY C26 199 | H.J. Behrend et al. | (CELLO | |
| BERGER | 84 | | C. Berger et al. | (PLUTO | |
| COURAU SMITH | 84 84 C | PL 147B 227 PR D30 851 | A. Courau et al. J.R. Smith et al. | (SLAC, LBL, | , SLAC) |
| BINON | 83 83 | NC 78A 313 | F.G. Binon et al. | | |
| | 63 | | | (BELG, LAPP, 1 | |
| Also | | SJNP 38 561 Translated from | F.G. Binon et al. | (BELG, LAPP, | ockr+) |
| | | monstace mulli | IMI 30 234. | | |

$f_2(1270), f_1(1285)$

| CHABAUD DENNEY MENNESSIER APEL CASON EDWARDS ETKIN BRANDELIK CHABAUD GIDAL ROUSSARIE BERGER COSTA LOVERRE CORDEN MARTIN POLYPHRO PDG ANTIPOV PAWLICKI DEUTSCH APEL EMMS ESSENBERG EISENBERG EISENBERG ENGLER LOUIE ANDERSON TAKAHASHI BEAUPRE FLATTE ARMENISE OH STUNTEBECK ADERHOLZ ARMENISE ASCOLI BOESEBECK JOHNSON EISNER EISNER EISNER ERADO EISNER | 69 68 68 D 68 68 67 65 64 | NP B223 1 PR D28 2726 ZPHY C16 241 NP B201 197 PRL 48 1316 PL 1108 82 PR D25 1786 ZPHY C10 117 APP B12 575 PL 1078 153 PL 1078 153 PL 1058 304 PL 948 254 NP B155 402 ZPHY C6 187 NP B157 520 NP B158 520 PR D19 1317 PL 75B 1 NP B157 250 NP B158 520 PR D19 1317 PL 75B 1 NP B159 402 ZPHY C6 187 NP B159 520 PR D19 1317 PL 75B 1 NP B159 520 PR D19 1317 PL 75B 20 PR D19 1317 PL 75B 1 NP B10 45 PR D15 3196 NP B96 155 PR D1 52B 239 PR D10 2070 PL 48B 335 PRL 31 562 PR D6 1266 NP B28 77 PL 34B 551 LNC 4 199 PR D1 2494 PL 32B 391 NP B11 259 NC 54A 999 PRL 21 1712 NP B4 501 PR 176 1651 PR 164 1699 PRL 14 672 | V. Chabaud et al. D.L. Denney et al. D.L. Dennessier WD.V. Apel et al. D.L. Etkin et al. D.L. Etkin et al. D.R. Brandelik et al. D. Brandelik et al. D. Brandelik et al. D. Brandelik et al. D. Berger et al. D. Berger et al. D. Designen et al. D. Bricman et al. D. Bricman et al. D. Designen et al. D. Amderson et al. D. Amderson et al. D. Anderson et al. D. Designen et al. D |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| BONDAR | 63 | PL 5 153 | L. Bondar et al. (AACH, BIRM, BONN, DESY+) |

$f_1(1285)$

$$I^{G}(J^{PC}) = 0^{+}(1^{+})$$

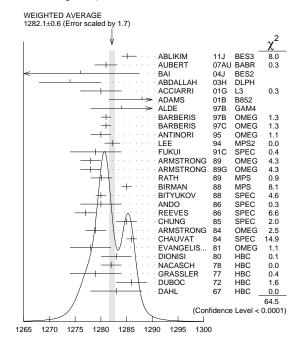
f1(1285) MASS

| VALUE (MeV) EVTS | DO CUMENT ID | TECN | COMMENT |
|------------------------------------------------|-----------------------------------------|------------------|----------------------------------------------------------------------------------------------------------|
| 1282.1± 0.6 OUR AVERAGE | | | 1.7. See the ideogram |
| below. | | | 9 |
| $1285.1 \pm \ 1.0 {}^{+}_{-} {}^{1.6}_{0.3}$ | ¹ ABLIKIM | 11J BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| $1281 \ \pm \ 2 \ \pm \ 1$ | AUBERT | 07AU BABR | 10.6 $e^+e^- \rightarrow f_1(1285) \pi^+\pi^- \gamma$ |
| $1276.1 \pm 8.1 \pm 8.0 203$ | BAI | 04J BES2 | $J/\psi \rightarrow \gamma \gamma \pi^+ \pi^-$ |
| 1274 ± 6 237 | ABDALLAH | 03H DLPH | |
| | | | $^{91.2}_{\ \ \kappa^0_S} {}^{e^+e^-}_{\kappa^{\mp}_{\ \pi^{\mp}} + \ X}$ |
| 1280 ± 4 | ACCIARRI | 01G L3 | |
| 1288 \pm 4 \pm 5 20k | ADAMS | 01B B852 | 18 GeV $\pi^- p \rightarrow K^+ K^- \pi^0 p$ |
| 1284 ± 6 1400 | ALDE | 97B GAM4 | $K^{+}K^{-}\pi^{0}n$ $100\pi^{-}p \rightarrow \eta\pi^{0}\pi^{0}n$ |
| 1281 ± 1 | BARBERIS | 97B OMEG | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| 1281 ± 1 | BARBERIS | | 450 $pp \rightarrow pp K_S^0 K^{\pm} \pi^{\mp}$ |
| 1280 ± 2 | ² antinori | | 300,450 pp → |
| 1200 ± 2 | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | , | $p p 2(\pi^{+} \pi^{-})$ |
| 1282.2± 1.5 | LEE | 94 MP S2 | $18 \pi^- p \rightarrow K^+ \overline{K}^0 2\pi^- p$ |
| 1279 ± 5 | FUKUI | 91c SPEC | 8.95 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 1278 ± 2 140 | ARMSTRONG | 89 OMEG | |
| 1278 ± 2 | ARMSTRONG | 89G OMEG | 85 $\pi^+ p \rightarrow 4\pi\pi p$, $p p \rightarrow$ |
| 1280.1± 2.1 60 | RATH | 89 MPS | $ \begin{array}{ccc} 4\pi p p \\ 21.4 \pi^{-} p \to & K_{S}^{0} K_{S}^{0} \pi^{0} n \end{array} $ |
| 1285 ± 1 4750 | 3 BIRMAN | 88 MPS | $8 \pi^{-} p \rightarrow K^{+} \frac{3}{K^{0}} \pi^{-} n$ |
| 1280 ± 1 504 | BITYUKOV | 88 SPEC | 32.5 $\pi^- p \rightarrow$ |
| 1200 ± 1 | 5 | 00 0.20 | $\kappa^+ \kappa^- \pi^0 n$ |
| 1280 ± 4 | ANDO | 86 SPEC | $8 \pi^- \rho \rightarrow \eta \pi^+ \pi^- \eta$ |
| 1277 ± 2 420 | REEVES | 86 SPEC | $6.6 p \overline{p} \rightarrow K K \pi X$ |
| 1285 ± 2 | CHUNG | 85 SPEC | $8 \pi^- p \rightarrow N K \overline{K} \pi$ |
| 1279 ± 2 604 | ARMSTRONG | 84 OMEG | 85 $\pi^+ p \rightarrow \underline{K} \overline{K} \pi \pi p$, $pp \rightarrow K \overline{K} \pi p p$ |
| 1286 ± 1 | CHAUVAT | 84 SPEC | ISR 31.5 pp |
| 1278 ± 4 | EVA NGELIS | 81 OMEG | 12 $\pi^- p \to \eta \pi^+ \pi^- \pi^- p$ |
| 1283 ± 3 103 | DIONISI | 80 HBC | $4 \pi^- p \rightarrow K \overline{K} \pi n$ |
| 1282 ± 2 320 | NA CA SCH | 78 HBC | $0.7, 0.76 \overline{p}p \rightarrow K\overline{K}3\pi$ |
| 1279 ± 5 210 | GRASSLER | 77 HBC | 16 π [∓] p |
| 1286 ± 3 180 | DUBOC | 72 HBC | $1.2 \overline{p} p \rightarrow 2K4\pi$ |
| 1283 ± 5 | DAHL | 67 HBC | 1.6-4.2 π ⁻ p |
| • • • We do not use the follow | ing data for avera | ges, fits, limit | s, etc. • • • |
| 1281.9± 0.5 | ⁴ SOSA | 99 SPEC | $pp \rightarrow p_{slow}$ |
| | | | $(K_S^0 K^+ \pi^-) p_{\text{fast}}$ |
| 1282.8± 0.6 | ⁴ SOSA | 99 SPEC | $pp \rightarrow p_{slow}$ |
| | | | $(\kappa_S^0 \kappa^- \pi^+) p_{\text{fast}}$ |
| 1270 ±10 | AMELIN | 95 VES | $37 \pi^- N \rightarrow$ |
| 1200 2 | A D AT 710 | M OMEC | $\pi^-\pi^+\pi^-\gamma N$ |
| 1280 ± 2 | ABATZIS | | $450 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| 1282 ± 4 | ARMSTRONG | | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| $1270 \pm 6 \pm 10$ | ARMSTRONG | 92C OMEG | 300 $pp \rightarrow pp \pi^+ \pi^- \gamma$ |
| | | | |

| 1281 ± 1 | | | ARMSTRONG | 89E | OMEG | $300 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
|---------------|--------|---|-----------|-----|------|-----------------------------------------------------------|
| 1279 ± 6 | ±10 16 | | BECKER | 87 | MRK3 | $e^+e^- \rightarrow \phi K \overline{K} \pi$ |
| 1286 ± 9 | | | GIDAL | 87 | MRK2 | e^+e^{\cdot} |
| | | | | | | $e^{+}e^{-}\eta\pi^{+}\pi^{-}$ |
| 1287 ± 5 | 35 3 | | BITYUKOV | 84B | SPEC | $32 \pi^- p \rightarrow K^+ K^- \pi^0 n$ |
| ~ 1279 | | 5 | TORNQVIST | 82B | RVUE | |
| 1275 ± 6 | 31 | | BROMBERG | 80 | SPEC | 100 π [−] $p \rightarrow K\overline{K}\pi X$ |
| 1288 ± 9 | 200 | | GURTU | 79 | HBC | 4.2 $K^-p \rightarrow n\eta 2\pi$ |
| ~ 1275.0 | 46 | 6 | STANTON | 79 | CNTR | $8.5 \pi^- p \rightarrow n2\gamma 2\pi$ |
| 1271 ± 10 | 34 | | CORDEN | 78 | OMEG | 12-15 $\pi^- p \rightarrow$ |
| | | | | | | $\kappa^+ \kappa^- \pi^n$ |
| 1295 ± 12 | 85 | | CORDEN | 78 | OMEG | $12\text{-}15 \ \pi^- p \rightarrow n5\pi$ |
| 1292 ± 10 | 150 | | DEFOIX | 72 | HBC | $0.7 \overline{\rho} p \rightarrow 7\pi$ |
| 1280 ± 3 | 500 | 7 | THUN | 72 | MMS | 13.4 π ⁻ p |
| 1303 ± 8 | | | BARDADIN | 71 | HBC | $8 \pi^+ \rho \rightarrow \rho 6\pi$ |
| 1283 ± 6 | | | BOESEBECK | 71 | HBC | $16.0 \pi p \rightarrow p5\pi$ |
| 1270 ± 10 | | | CAMPBELL | 69 | DBC | 2.7 π^+ d |
| 1285 ± 7 | | | LORSTAD | 69 | HBC | 0.7 \overline{p} p , 4,5-body |
| 1290 ± 7 | | | D'ANDLAU | 68 | HBC | 1.2 p p, 5−6 body |
| | | | | | | |

¹ The selected process is $J/\psi \rightarrow \omega a_0(980) \pi$.

⁷ Seen in the missing mass spectrum.



 $f_1(1285)$ mass (MeV)

f₁ (1285) WIDTH

Only experiments giving width error less than 20 MeV are kept for averaging.

ı

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------|--------|-----------------------|--------|-----------|----------------------------------------------------------------------------------------------------|
| 24.2± 1.1 OUR A | VERAGE | Error includes so | ale fa | ctor of 1 | .3. See the ideogram below. |
| $22.0 \pm 3.1 ^{+}_{-} \stackrel{2.0}{1.5}$ | | ⁸ ABLIKIM | 11J | BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| $35 \pm 6 \pm 4$ | | AUBERT | | | 10.6 $e^+ e^- \rightarrow f_1(1285) \pi^+ \pi^- \gamma$ |
| $40.0 \pm ~8.6 \pm ~9.3$ | 203 | BAI | 04 J | BES2 | $J/\psi \rightarrow \gamma \gamma \pi^+ \pi^-$ |
| 29 ±12 | 237 | ABDALLAH | 03н | DLPH | $^{91.2}_{\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ |
| $45 \pm 9 \pm 7$ | 20k | ADAMS | | B852 | 18 GeV $\pi^{-}p \rightarrow K^{+}K^{-}\pi^{0}n$ 100 $\pi^{-}p \rightarrow \eta\pi^{0}\pi^{0}n$ |
| 55 ±18 | 1400 | ALDE | 97B | GAM4 | $100 \ \pi^- p \rightarrow \eta \pi^0 \pi^0 n$ |
| 24 ± 3 | | BARBERIS | | | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| 20 ± 2 | | BARBERIS | 97c | OMEG | $450 pp \rightarrow pp K_S^0 K^{\pm} \pi^{\mp}$ |
| 36 ± 5 | | ⁹ ANTINORI | 95 | OMEG | 300,450 $pp \to p \to pp2(\pi^+\pi^-)$ |
| 29.0 ± 4.1 | | LEE | 94 | MPS2 | $18 \pi^- \rho \rightarrow K^+ \overline{K}{}^0 2\pi^- \rho$ |

² Supersedes ABATZIS 94, ARMSTRONG 89E.

³ From partial wave analysis of $K^+ \overline{K}{}^0 \pi^-$ system.

⁴ No systematic error given.

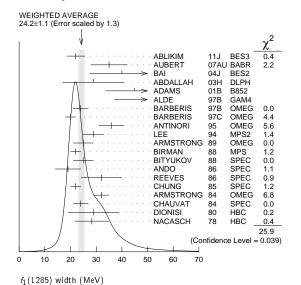
⁵ From a unitarized quark-model calculation.

 $^{^6\,\}mathrm{From}$ phase shift analysis of $\eta\,\pi^+\,\pi^-$ system.

| | 25 | ± 4 | | 140 | | ARMSTRONG | 89 | OMEG | 300 $pp \rightarrow K \overline{K} \pi pp$ |
|--------|------|----------------|----------|-----------|-----|-----------------------------------------|-------|------------|----------------------------------------------------------|
| | 22 | ± 2 | | 4750 | 10 | BIRMAN | 88 | MPS | $8 \pi^- p \rightarrow K^+ \overline{K}^0 \pi^- n$ |
| | 25 | ± 4 | | 504 | | BITYUKOV | 88 | SPEC | $32.5 \pi^- p \rightarrow K^+ K^- \pi^0 n$ |
| | 19 | ± 5 | | | | ANDO | 86 | SPEC | $8 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| | 32 | ± 8 | | 420 | | REEVES | 86 | SPEC | 6.6 $p\overline{p} \rightarrow K K \pi X$ |
| | 22 | ± 2 | | | | CHUNG | 85 | SPEC | $8 \pi^- p \rightarrow N K \overline{K} \pi$ |
| | 32 | ± 3 | | 604 | | ARMSTRONG | 84 | OMEG | 85 $\pi^+ p \rightarrow K \overline{K} \pi \pi p$, |
| | | | | | | | | | $pp \rightarrow K \overline{K} \pi pp$ |
| | 24 | \pm 3 | | | | CHAUVAT | 84 | SPEC | ISR 31.5 <i>pp</i> |
| | 29 | ± 10 | | 103 | | DIONISI | 80 | HBC | $4 \pi^- p \rightarrow K \overline{K} \pi n$ |
| | 28.3 | 8 ± 6.7 | 7 | 320 | | NACASCH | 78 | HBC | $0.7, 0.76 \overline{p}p \rightarrow K\overline{K}3\pi$ |
| • | • • | We do | not use | the follo | wir | ng data for avera | ages, | fits, limi | is, etc. • • • |
| | 100 | | , | | 11 | SOSA | 99 | SPEC | $$ $ (\kappa_0) \kappa_+ -$ |
| | 10.2 | 2± 1.2 | <u> </u> | | | 303A | 99 | SPEC | $pp \rightarrow p_{\text{Slow}} (K_S^0 K^+ \pi^-)$ |
| | 194 | ± 1.5 | | | 11 | SOSA | 99 | SPEC | $pp \rightarrow p_{\text{slow}} (K_S^0 K^- \pi^+)$ |
| | 17.7 | | , | | | 303/(| ,, | 3, 20 | Pfast Pslow (NS N N) |
| | 40 | ± 5 | | | | ABATZIS | 94 | OMEG | $450 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| | 31 | ± 5 | | | | ARMSTRONG | 89F | | $300 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| | 41 | ±12 | | | | ARMSTRONG | | | 85 $\pi^+ p \rightarrow 4\pi \pi p, pp \rightarrow$ |
| | | | | | | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | 0,0 | 020 | $4\pi DD$ |
| | 17.9 | ± 10.9 |) | 60 | | RATH | 89 | MPS | $21.4 \ \pi^- p \rightarrow \ K_S^0 \ K_S^0 \ \pi^0 \ n$ |
| | 14 | $^{+20}_{-14}$ | ± 10 | 16 | | BECKER | 87 | MDIZ | $e^+e^- \rightarrow \phi K \overline{K} \pi$ |
| | | | ±10 | 10 | | | | | , |
| | | ± 12 | | | | EVA NGELIS | 81 | | $12 \pi^- p \to \eta \pi^+ \pi^- \pi^- p$ |
| | 25 | ± 15 | | 200 | | GURTU | 79 | HBC | $4.2 \text{ K}^- p \rightarrow n\eta 2\pi$ |
| \sim | 10 | | | | 12 | STANTON | 79 | CNTR | $8.5 \pi^- p \rightarrow n 2\gamma 2\pi$ |
| | 24 | ± 18 | | 210 | | GRASSLER | 77 | HBC | 16 π [∓] p |
| | 28 | \pm 5 | | 150 | | DEFOIX | 72 | HBC | $0.7 \overline{p} p \rightarrow 7\pi$ |
| | 46 | ± 9 | | 180 | 13 | DUBOC | 72 | HBC | $1.2 \overline{p}p \rightarrow 2K4\pi$ |
| | 37 | \pm 5 | | 500 | 14 | THUN | 72 | MMS | 13.4 π ⁻ p |
| | 10 | ± 10 | | | | BOESEBECK | 71 | HBC | $16.0 \pi p \rightarrow p5\pi$ |
| | 30 | ± 15 | | | | CAMPBELL | 69 | DBC | $2.7 \pi^{+} d$ |
| | 60 | ± 15 | | | 13 | LORSTAD | 69 | HBC | 0.7 pp, 4,5-body |
| | 35 | ± 10 | | | 13 | DAHL | 67 | нвс | 1.6-4.2 π ⁻ p |
| | Ω | | | | | / | | | • |

⁸ The selected process is $J/\psi \rightarrow \omega a_0(980) \pi$.

¹³ Resolution is not unfolded.
14 Seen in the missing mass spectrum.



$f_1(1285)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|----------------------------------|-------------------------------|------------------------------------------|-----------------------------------|
| Γ_1 | 4π | $(33.1 + 2.1 \atop -1.8) \%$ | S=1.3 |
| Γ_2 | $\pi^0 \pi^0 \pi^+ \pi^-$ | $(22.0 {}^{+}_{-} {}^{1.4}_{1.2}) \%$ | S=1.3 |
| Γ_3 | $2\pi^+2\pi^-$ | $(11.0 {}^{+}_{-} {}^{0.7}_{0.6}) \%$ | S=1.3 |
| Γ_4 | $ ho^0\pi^+\pi^-$ | $(11.0 {}^{+}_{-} {}^{0.7}_{0.6}) \%$ | S=1.3 |
| Γ_5 | $4\pi^{0}$ $\rho^{0}\rho^{0}$ | seen | |
| Γ ₅ Γ ₆ | $4\pi^0$ | < 7 × 10 | ⁻⁴ CL=90% |
| Γ ₇ | $\eta \pi^+ \pi^-$ | $(35 \pm 15)\%$ | |
| Γ8 | $\eta\pi\pi$ | $(52.4 + 1.9 \atop - 2.2)$ % | S=1.2 |

| Γ9 | $a_0(980)\pi$ [ignoring $a_0(980) \rightarrow K\overline{K}$] | $(36 \pm 7)\%$ | |
|---------------|----------------------------------------------------------------|--------------------------------|--------|
| Γ_{10} | $\eta \pi \pi$ [excluding $a_0(980) \pi$] | $(16 \pm 7)\%$ | |
| Γ_{11} | $K\overline{K}\pi$ | (9.0 ± 0.4) % | S=1.1 |
| Γ_{12} | K K *(892) | not seen | |
| Γ_{13} | $\pi^{+} \pi^{-} \pi^{0}$ | $(3.0 \pm 0.9) \times 10^{-3}$ | |
| | $\rho^{\pm}\pi^{\mp}$ | $< 3.1 \times 10^{-3}$ | CL=95% |
| Γ_{15} | $\gamma \rho^0$ | $(5.5 \pm 1.3) \%$ | S=2.8 |
| Γ_{16} | $\phi\gamma$ | $(7.4\pm\ 2.6)\times10^{-4}$ | |
| Γ_{17} | $\gamma \gamma^*$ | | |
| Γ_{18} | $\gamma\gamma$ | | |

CONSTRAINED FIT INFORMATION

An overall fit to 7 branching ratios uses 16 measurements and one constraint to determine 5 parameters. The overall fit has a χ^2 = 24.7 for 12 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

 1.0 ± 0.4

$f_1(1285) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| VALUE (keV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------|------------------------------|------------------------|---------|------------|------------------------------------------------------------------------|
| <0.62 | 95 | GIDAL | 87 | MRK2 | $e^+e^- ightarrow e^+e^-\eta\pi^+\pi^-$ |
| $\Gamma(\eta\pi\pi)\times\Gamma(\gamma$ | $\gamma^*)/\Gamma_{ m tota}$ | l | | Га | $\Gamma_{17}/\Gamma = (\Gamma_9 + \Gamma_{10})\Gamma_{17}/\Gamma_{10}$ |
| VALUE (keV) | | | | TECN | COMMENT |
| 1.4 ±0.4 OUR A | VERAGE | Error includes sca | le fact | or of 1.4 | |
| $1.18 \pm 0.25 \pm 0.20$ | 26 ¹⁵ | ,16 AIHARA | 88B | TPC | $e^+e^- \rightarrow e^+e^-\eta\pi^+\pi^-$ |
| $2.30 \pm 0.61 \pm 0.42$ | | | | | $e^{+}e^{-} \rightarrow e^{+}e^{-}\eta\pi^{+}\pi^{-}$ |
| • • • We do not ι | ise the follo | owing data for ave | rages, | fits, limi | ts, etc. • • • |
| $1.8 \pm 0.3 \pm 0.3$ | 420 | ¹⁸ ACHARD | 02в | L3 | $^{183-209}_{e^{+}e^{-}\eta\pi^{+}\pi^{-}}$ |
| 15 Assuming a $ ho$ -p | ole form fa | ictor. | | | |
| 16 Published value | multiplied | by $n\pi\pi$ branching | g ratio | 0.49. | |
| 175 | وينوا المأسان والانتار | . 0 | bu tha | b. | anching ratio 0.49. |

f1(1285) BRANCHING RATIOS

| $\Gamma(K\overline{K}\pi)/\Gamma(4\pi)$ | | | | Γ_{11}/Γ_{1} |
|----------------------------------------------------------------------------------------|-----------------------------|---------|-----------------|------------------------------------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT | |
| 0.271 ± 0.016 OUR FIT | Error includes scale factor | of 1.3. | | |
| 0.271 ± 0.016 OUR AVE | RAGE Error includes scale | | | |
| 0.265 ± 0.014 | ¹⁹ BARBERIS 97 | OMEG | 450 <i>pp</i> → | $ppK_S^0K^{\pm}\pi^{\mp}$ |
| 0.28 ± 0.05 | ²⁰ ARMSTRONG 891 | OMEG | 300 <i>pp</i> → | $ppf_1(1285)$ |
| $0.37 \pm 0.03 \pm 0.05$ | ²¹ ARMSTRONG 89 | OMEG | 85 πp → | 4π X |
| 21 $_{4\pi}$ consistent with b $\Gamma(\pi^0\pi^0\pi^+\pi^-)/\Gamma_{\text{tot}}$ | al | S. | | $\Gamma_2/\Gamma = \frac{2}{3}\Gamma_1/\Gamma$ |
| VALUE | DO CUMENT ID | | | |
| 0.220 + 0.014 OUR FIT | Error includes scale factor | of 1.3. | | |
| $\Gamma(2\pi^+2\pi^-)/\Gamma_{\text{total}}$ | | | | $\Gamma_3/\Gamma=\tfrac{1}{3}\Gamma_1/\Gamma$ |
| VALUE | | | | |
| 0.110 + 0.007 OUR FIT | Error includes scale factor | of 1.3. | | |

$$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{\text{total}}$$
 $\Gamma_4/\Gamma = \frac{1}{3}\Gamma_1/\Gamma$

 $0.110 \begin{array}{l} +0.007 \\ -0.006 \end{array}$ OUR FIT Error includes scale factor of 1.3.

GRASSLER 77 HBC 16 GeV $\pi^{\pm} p$

⁹ Supersedes ABATZIS 94, ARMSTRONG 89E.

 $^{^{10}\,\}mathrm{From}$ partial wave analysis of $\mathit{K}^{+}\,\overline{\mathit{K}}{}^{0}\,\pi^{-}$ system.

¹¹ No systematic error given.

¹² From phase shift analysis of $\eta \pi^+ \pi^-$ system.

95

<5

BITYUKOV 91B SPEC 32 $\pi^- p \rightarrow \pi^+ \pi^- \gamma n$

 $f_1(1285)$

| $(\rho^0 \rho^0)/\Gamma_{\text{total}}$ | DOCUMENT ID COMMENT | Γ ₅ /Γ | $\Gamma(\gamma \rho^0)/\Gamma(2\pi^+)$ | | DOCUMENT ID | TECN COMME | $/\Gamma_3 = \Gamma_{15}/\frac{1}{3}\Gamma_{15}$ |
|-----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|--------------------------------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------------------|---------------------------------|------------------------------------------------------------------------------------------|
| • We do not use the following | data for averages, fits, limits, etc. • • • | | 0.50±0.13 OUR F | IT Error includes | scale factor of 2.5. | | |
| en | BARBERIS 00c 450 $pp \rightarrow p_f 4\pi p_g$ | S | 0.45 ± 0.18 | | | MRK3 J/ψ – | , , |
| $(4\pi^0)/\Gamma_{ m total}$ | | Γ ₆ /Γ | | $ ightarrow \gamma f_1(1285) ightarrow 1.55 	imes 10^{-4} 	ext{ given I}$ | $\gamma \gamma \rho^0$)=0.25 × 10 ⁻¹ | $^{-4}$ and B(J/ψ - | $\rightarrow \gamma f_1(1285)$ |
| NLUE (units 10 ⁻⁴) CL% | DOCUMENT ID TECN COMMENT | 16/1 | | • | Dy IVIIK 66. | | |
| C7 90 | ALDE 87 GAM4 100 $\pi^{-}p$ - | $\rightarrow 4\pi^0 n$ | $\Gamma(\eta\pi\pi)/\Gamma(\gamma ho^0)$ | DOCUMENT ID | TECN COM | Г8/Г ₁₅ = | · (Γ9+Γ ₁₀)/Γ |
| $(\pi^+\pi^-\pi^0)/\Gamma(\eta\pi^+\pi^-)$ | | Γ_{13}/Γ_{7} | | T Error includes s | | VILIVI | |
| | $rac{	extstyle DOCUMENT ID}{	extstyle DOROFEEV} rac{	extstyle TECN}{	extstyle VES} rac{	extstyle COMMENT}{\pi^- N ightarrow \pi^-}$ | - 6 (1005) N | $10.0\!\pm\!1.0\!\pm\!2.0$ | BARBERIS | 98c OMEG 450 | $pp \rightarrow p_f f_1(128)$ | 85) p _s |
| | DOROFEEV II VES $\pi^- N 	o \pi^-$ for corresponding to $f_0(980)$ in the $\pi^+ \pi^-$ | | | e multiplied by 1.5. | 92c OMEG 300 | $pp \rightarrow pp \pi^+ \pi^0$ | $^-\gamma$, pp $\eta\pi^+\pi^-$ |
| (ηππ)/Γ _{total} | $\Gamma_8/\Gamma=($ | Γ ₉ +Γ ₁₀)/Γ | Γ(γρ ⁰)/Γ(Κ Κ α <u>VALUE</u> | <u>CL%</u> | DO CUMENT ID | | |
| 524 + 0.019 OUR FIT Error inclu | | | >0.035 | 90 30 | | MRK3 J/ψ — | $\gamma \gamma \pi^+ \pi^-$ |
| $(4\pi)/\Gamma(\eta\pi\pi)$ | $\Gamma_1/\Gamma_8=\Gamma_1$ | /(Г9+Г ₁₀) | $\gamma K \overline{K} \pi$)=< 0. | | $\gamma\gamma\rho^0)=0.25\times 10^{-1}$ | $^{-4}$ and $B(J/\psi$ - | $\rightarrow \gamma f_1(1285)$ |
| <i>LUE</i> 63±0.06 OUR FIT Error include | | | $\Gamma(\phi\gamma)/\Gamma(K\overline{K}\pi$ |) | | | Γ ₁₆ /Γ |
| 41±0.14 OUR AVERAGE | POLTON 02 MOV2 1/1 | C (100F) | VALUE (units 10 ⁻²) | • | DOCUMENT ID | TECN CO | OMMENT |
| $37 \pm 0.11 \pm 0.11$ 54 ± 0.40 | BOLTON 92 MRK3 $J/\psi \rightarrow \gamma \tau$ GURTU 79 HBC 4.2 K^-p | 1(1285) | 0.82±0.21±0.2 | | BITYUKOV | 88 SPEC 32 | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| _ | data for averages, fits, limits, etc. • • • | | • • • We do not | use the following da | nta for averages, fits | , limits, etc. • • | • • " " |
| | 3 GRASSLER 77 HBC 16 $\pi^{\mp}p$ | | < 0.50 | 95 | BARBERIS | 98c OMEG 45 | $\begin{array}{c} 50 \ \rho \rho \rightarrow \\ \rho_f \ f_1(1285) \ \rho_S \end{array}$ |
| 3 Assuming $ ho\pi\pi$ and $a_0(980)\pi$ in | | : | < 0.93 | 95 | A MELIN | 95 VES 37 | $\pi^- N \rightarrow$ |
| (a ₀ (980)π [ignoring a ₀ (980) - LUE <u>CL%</u> EVTS 0.69±0.13 OUR FIT | $ ightarrow K\overline{K}])/\Gamma(\eta\pi\pi)$ | /(「g+「 ₁₀) | | # /:- | os) DEEEDEWS | -6 | $\pi^-\pi^+\pi^-\gamma N$ |
| | | | | f ₁ (12 | 85) REFERENCE | :5 | |
| 0.69 ^{+ 0.13} OUR AVERAGE | | | | PRL 107 182001 EPJ A47 68 | M. Ablikim <i>et al.</i> V. Dorofeev <i>et al.</i> | | (BES III Collab.) (SERP, MIPT) |
| 0.72 ± 0.15 | GURTU 79 HBC 4.2 K ⁻ p | | PDG 10 | JPG 37 075021 | K. Nakamura et al. | | (PDG Collab.) |
| $0.6 \begin{array}{c} +0.3 \\ -0.2 \end{array}$ | CORDEN 78 OMEG 12-15 $\pi^-\mu$ |) | AUBERT 07AU | JHEP 0703 018 PR D76 092005 | P. Achard et al. B. Aubert et al. | (| (L3 Collab.) (BABAR Collab.) |
| • We do not use the following | data for averages, fits, limits, etc. • • • | | ABDALLAH 03H | PL B594 47 PL B569 129 | J.Z. Bai et al. J. Abdallah et al. | (| (BES Collab.) DELPHI Collab.) |
| 0.69 95 318 | ACHARD 02B L3 183-209 e | + e ⁻ → | ACCIARRI 01G | PL B526 269 PL B501 1 | P. Achard et al. M. Acciarri et al. | | (L3 Collab.) (L3 Collab.) |
| 0.28 ± 0.07 1400 | ALDE 97B GAM4 100 $\pi^- p$ - | $\eta \pi^{-} \pi^{0} \pi^{0} \pi^{0} n$ | ADAMS 01B BARBERIS 00C | PL B516 264 PL B471 440 | G.S. Adams et al. D. Barberis et al. | ` (' | NL E852 Collab.) WA 102 Collab.) |
| 1.0 ±0.3 | GRASSLER 77 HBC 16 $\pi^{\mp} p$ | | SOSA 99 | PR D62 012003 PRL 83 913 PL B440 225 | J.J. Manak et al. M. Sosa et al. D. Barberis et al. | | NL E852 Collab.) WA 102 Collab.) |
| (Κ΄Κπ)/Γ(ηππ) LUE DO | $\Gamma_{11}/\Gamma_8 = \Gamma_{11}$ | /(Γ ₉ +Γ ₁₀) | ALDE 97B | PAN 60 386 Translated from YAF 60 PL B413 217 | D. Alde et al. | | (GAMS Collab.) WA 102 Collab.) |
| 171±0.013 OUR FIT Error inclu | | | BARBERIS 97C | PL B413 225 ZPHY C66 71 | D. Barberis et al. D.V. Amelin et al. | } | WA 102 Collab.) (VES Collab.) |
| 170±0.012 OUR AVERAGE 166±0.01 ±0.008 BA | ARBERIS 980 OMEG 450 $pp 	o p_f$ | f. (1.285) n | ANTINORI 95 | PL B353 589 PL B324 509 | F. Antinori et al. S. Abatzis et al. | | BARI, BIRM+) BARI, BIRM+) |
| | JRTU 79 HBC 4.2 K^-p | $\mu_{1}(1205) \mu_{S}$ | LEE 94 | PL B323 227 PL B307 394 | J.H. Lee et al. T.A. Armstrong et al | (BNL, IND, F | (YUN, MASD+) FERR, GENO+) |
| 5 ±0.2 24 CC | DRDEN 78 OMEG 12–15 π ⁻ p | | ARMSTRONG 92C | ZPHY C54 371 | T.A. Armstrong et al | . (ATHU, | BARI, BIRM+) Mark III Collab.) |
| 20 ±0.08 | FOIX 72 HBC $0.7 \overline{p} p \rightarrow 7 \pi$ MPBELL 69 DBC $2.7 \pi^+ d$ | | BITYUKOV 91B | PL B278 495 SJNP 54 318 Translated from YAF 54 | T. Bolton et al. S.I. Bityukov et al. | (| Mark III Collab.) (SERP) |
| | $\eta\pi\pi$ region is dominantly 1^{++} . See BA | RRERIS 98c | FUKUI 91C | Fransiated from YAF 54 PL B267 293 PR D41 1410 | S. Fukui et al. D.M. Coffman et al. | | KEK, KYOT+) Mark III Collab.) |
| and MANAK One for discussion | | | ARMSTRONG 89 | PL B221 216 | T.A. Armstrong et al | . (CERN, | Mark III Collab.) CDEF, BIRM+)JF BARI, BIRM+) |
| 'KK system characterized by the | $e\ I = 1$ threshold enhancement. (See unde | r a ₀ (980)). | ARMSTRONG 89G | PL B228 536 ZPHY C43 55 PR D40 693 | T.A. Armstrong, M. T.A. Armstrong et al | | BIRM. BARI+) |
| (<i>Κ'</i> ₹*(892))/Γ _{total} | | Γ_{12}/Γ | AIHARA 88B | PL B209 107 | M.G. Rath et al. H. Aihara et al. | . (| , BNL, CUNY+) TPC-2γ Collab.) U, IND, MASD)JF |
| LUE DOCUMENT ID | TECN COMMENT | | BITYUKOV 88 | PRL 61 1557 PL B203 327 Photon-Photon 88, 126 | A. Birman et al. S.I. Bityukov et al. P. Mir | , | U, IND, MASD)JF (SERP) Mark III Collab.) |
| seen NACASCH • • We do not use the following | 78 HBC 0.7,0.76 $\overline{p}p \rightarrow K\overline{K}3\pi$ data for averages, fits, limits, etc. • • • | | Conference | Photon-Photon 88, 126 PL B198 286 | R. Mir D.M. Alde et al. | , | K, SERP, LAPP) |
| n ²⁶ ACHARD | 07 L3 183-209 $e^+e^- \rightarrow e^+e^-$ | $\kappa^0_S \kappa^{\pm} \pi^{\mp}$ | BECKER 87 | PRL 59 186 PRL 59 2012 | J.J. Becker et al. G. Gidal et al. | (LBL | Mark III Collab.) _, SLAC, HARV) |
| 6 A clear signal of 19.8 \pm 4.4 even | | J | ANDO 86 REEVES 86 | PRL 57 1296 PR D34 1960 | A. Ando et al. D.F. Reeves et al. | (KEK, KÝOT, (FLC | NIRS, SAGA+)IJ DR, BNL, IND+)JF |
| $(\pi^+\pi^-\pi^0)/\Gamma_{ m total}$ | | Γ ₁₃ /Γ | ARMSTRONG 84 | PRL 55 779 PL 146B 273 PL 144B 133 | S.U. Chung et al. T.A. Armstrong et al S.I. Bityukov et al. | | L, FLOR, IND+)JF BARI, BIRM+)JF (SERP) |
| | DOCUMENT ID TECN COMMENT | | CHAUVAT 84 | PL 148B 382 | P. Chauvat et al. | (CERN, | CLER, UCLA+) |
| | DOROFEEV 11 VES $\pi^- N \rightarrow \pi^-$ | - · · · - | EVANGELIS 81 | NP B203 268 NP B178 197 | N.A. Tornqvist C. Evangelista et al. | (BARI, | (HELS) BONN, CERN+) |
| Yalue obtained selecting the reg trum. The sytematic error incl obtained from PDG 10 data. | ion corresponding to $f_0(980)$ in the $\pi^+\pi^-$ udes the uncertainty on the partial width | $f_1 ightarrow \eta \pi \pi$ | DIONISI 80 GURTU 79 STANTON 79 | PR D22 1513 NP B169 1 NP B151 181 PRL 42 346 | C.M. Bromberg et al C. Dionisi et al. A. Gurtu et al. N.R. Stanton et al. | (CERN, ZEE (OS U, | , FNAL, ILLC+) MADR, CDEF+) M, NIJM, OXF) CARL, MCGI+)JF |
| $(ho^{\pm}\pi^{\mp})/\Gamma_{ m total}$ | | Γ ₁₄ /Γ | NACASCH 78 | NP B144 253 NP B135 203 NP B121 189 | M.J. Corden <i>et al.</i> R. Nacasch <i>et al.</i> H. Grassler <i>et al.</i> | (PARIS, | RHEL, TELA+)JF MADR, CERN) BERL, BONN+) |
| LUE (%) | DOCUMENT ID TECN COMMENT | | DEFOIX 72 | NP B44 125 NP B46 429 | C. Defoix et al. J. Duboc et al. | (AACII3, | (CDEF, CERN) (PARIS, LIVP) |
| 0.31 95 | DOROFEEV 11 VES $\pi^- N \rightarrow \pi^-$ | $-f_1(1285) N$ | THUN 72 | PRL 28 1733 PR D4 2711 | R. Thun et al. M. Bardadin-Otwinow | ska et al | (STON, NEAS) (WARS) |
| $(\gamma ho^0)/\Gamma_{ m total}$ | | Γ ₁₅ /Γ | BOESEBECK 71 | PL 34B 659 PRL 22 1204 | K. Boesebeck (AA) J.H. Campbell et al. | | |
| | | | | | | | |
| • • | CUMENT ID TECN COMMENT | | | NP B14 63 NP B5 693 | B. Lorstad et al. C. d'Andlau et al. | (60.5- | (CDEF, CERN) JF CERN, IRAD+) IJ |

 $\eta(1295)$

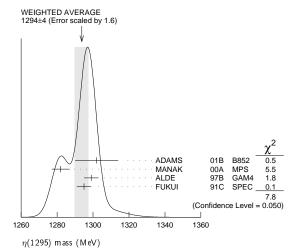
$$I^G(J^{PC}) = 0^+(0^{-+})$$

See also the mini-review under $\eta(1405)$

η (1295) MASS

| 1294±4 OUR AV | /ERAGE Erro | or includes scale | factor o | f 1.6. S | ee the ideogram below. |
|--------------------|-------------|-------------------|----------|----------|------------------------------------------------------------------------------|
| $1302 \pm 9 \pm 8$ | 20k | ADAMS | 01в | B852 | 18 GeV $\pi^- p \rightarrow$ |
| 1282±5 | 9082 | MANAK | 00A | MPS | $K^{+} K^{-} \pi^{0} n$ $18 \pi^{-} p \rightarrow \eta \pi^{+} \pi^{-} n$ |
| 1299 ± 4 | 2100 | ALDE | 97B | GA M4 | $100 \pi^- p \rightarrow \eta \pi^0 \pi^0 n$ |
| 1295 ± 4 | | FUKUI | 91c | SPEC | 8.95 $\pi^- p \rightarrow$ |

 1 AUGUSTIN 90 DM2 $J/\psi
ightarrow \gamma \eta \, \pi^+ \, \pi^ 1264\pm 8$ ~ 1275 79 CNTR 8.4 $\pi^- p \rightarrow n \eta 2\pi$



 $^{
m 1}\,{\rm PWA}$ analysis of AUGUSTIN 92 assigns 0 $^{-+}$ quantum numbers to this state rather than

η (1295) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|-------|--------------|-----|-------|---------------------------------------------------------------------------|
| 55 ± 5 OUR AV | ERAGE | | | | |
| $57 \pm 23 \pm 21$ | 20k | ADAMS | | | 18 GeV $\pi^- p \rightarrow$ |
| | | | | | $K^{+} K^{-} \pi^{0} n$ $18 \pi^{-} p \rightarrow \eta \pi^{+} \pi^{-} n$ |
| 66 ± 13 | 9082 | MA NA K | 00A | MPS | $18 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 53± 6 | | FUKUI | 91c | SPEC | 8.95 $\pi^- p \rightarrow$ |
| | | | | | $\eta \pi^+ \pi^- n$ |
| 107 1 | | | e | 12 24 | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| <40 | 2100 | ALDE | 97B | GAM4 | $100 \pi^- p \rightarrow \eta \pi^0 \pi^0 n$ |
|-----------|------|-----------------------|-----|------|----------------------------------------------|
| 44 ± 20 | | ² AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| ~ 70 | | STANTON | 79 | CNTR | $8.4 \pi^- p \rightarrow n\eta 2\pi$ |

 $^2\,\mathrm{PWA}$ analysis of AUGUSTIN 92 assigns 0^{-+} quantum numbers to this state rather than 1^{++} as before.

η (1295) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------|------------------------------|
| Γ_1 | $\eta \pi^+ \pi^-$ | seen |
| Γ_2 | $\eta \pi^+ \pi^ a_0(980) \pi$ | seen |
| Γ_3 | $\gamma \gamma$ | |
| Γ ₄ Γ ₅ | $\eta \pi^0 \pi^0$ | seen |
| | $\eta(\pi\pi)_{S	ext{-wave}}$ | seen |
| Γ ₆ | ση | |
| Γ ₇ | $KK\pi$ | |

$\eta(1295) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\eta\pi^+\pi^-)$ × | $\Gamma(\gamma\gamma)/\Gamma_{\rm total}$ | | | | | $\Gamma_1\Gamma_3/\Gamma$ |
|----------------------------|-------------------------------------------|-------------------|-------------|-----------|---------------------------|---------------------------|
| VALUE (keV) | CL% | DO CUMENT IE |) | TECN | COMMENT | |
| <0.066 | 95 | ACCIARRI | 01 G | L3 | 183-202 e+ e e+ e- n n | $\stackrel{-}{+}_{\pi^-}$ |
| • • • We do not | use the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| < 0.6 | 90 | AIHARA | 88 C | TPC | $e^+e^{e^+e^-\eta\pi}$ | + |
| < 0.3 | | ANTREASYA | N 87 | CBAL | $e^+e^- \rightarrow e^-$ | $+e^-n\pi\pi$ |

| $\Gamma(K\overline{K}\pi) \times \Gamma(\gamma)$ | $\gamma)/\Gamma_{total}$ | | | | | $\Gamma_7\Gamma_3/\Gamma$ |
|--------------------------------------------------|--------------------------|----------------------|-----------|-----------|--------------------------------------|--------------------------------------------------------------------------|
| VALUE (keV) | CL% | DO CUMENT I | ס | TECN | COMMENT | |
| • • • We do not us | e the followin | ng data for avera | ges, fits | , limits, | etc. • • • | |
| < 0.014 | 90 | ^{3,4} AHOHE | 05 | CLE2 | 10.6 e ⁺ e ⁻ K | $\stackrel{\rightarrow}{\stackrel{\rightarrow}{\sum}}_{K} \pm \pi^{\mp}$ |
| 311-1 (1205) | | h 1004 M-V/ 4 | FF 14-1 | , | Atomico | , |

 3 Using $\eta(1295)$ mass and width 1294 MeV and 55 MeV, respectively.

η (1295) BRANCHING RATIOS

| $\Gamma(a_0(980)\pi)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
|---------------------------------------------|----------------------------|---------|-----------|--------------------------------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • |
| not seen | BERTIN | 97 | OBLX | ${}^{0.0\overline{p}p \to}_{K^{\pm}(K^0)\pi^{\mp}\pi^{+}\pi^{-}}$ |
| seen | BIRMAN | 88 | | $ \begin{array}{c} 8 \pi^- p \rightarrow \\ K^+ \overline{K^0} \pi^- n \end{array} $ |
| large | ANDO | 86 | SPEC | $8 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| large | STANTON | 79 | CNTR | $8.4 \pi^- p \rightarrow n\eta 2\pi$ |

 $\Gamma(a_0(980)\pi)/\Gamma(\eta\pi^0\pi^0)$ Γ_2/Γ_4 TECN COMMENT DO CUMENT ID 97B GAM4 $100 \pi^{-} p \rightarrow \eta \pi^{0} \pi^{0} n$ ⁵ ALDE 0.65 ± 0.10

 $^{^5}$ Assuming that $a_0(980)$ decays only to $\eta\,\pi.$

| $\Gamma(\eta(\pi\pi)_{S-\text{wave}})/\Gamma(\eta)$ | $\eta \pi^0 \pi^0$ | DOCUMENT ID | | TECN | COMMENT | Γ_5/Γ_4 |
|-----------------------------------------------------|--------------------|--------------|-----|------|-----------------------------------------|----------------------|
| 0.35 ± 0.10 | | ALDE | 97в | | $\frac{100 \ \pi^- \rho \rightarrow}{}$ | $\eta \pi^0 \pi^0 n$ |
| $\Gamma(a_0(980)\pi)/\Gamma(\sigma\eta)$ | | | | | | Γ_2/Γ_6 |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.48 ± 0.22 | 9082 | MANAK | 00A | MPS | 18 $\pi^- \rho \rightarrow \pi$ | $\eta \pi^+ \pi^- n$ |

η(1295) REFERENCES

| AHOHE | 05 | PR D71 072001 | R. Ahohe et al. | (CLEO Collab.) |
|------------|------|---------------------|-------------------------|-----------------------------|
| ACCIARRI | 01 G | PL B501 1 | M. Acciarri et al. | (L3 Collab.) |
| ADAMS | 01B | PL B516 264 | G.S. Adams et al. | (BNL E852 Collab.) |
| MANAK | 00 A | PR D62 012003 | J.J. Manak et al. | (BNL E852 Collab.) |
| ALDE | 97 B | PAN 60 386 | D. Alde et al. | ` (GAMS Collab.) |
| | | Translated from YAF | 60 458. | , |
| BERTIN | 97 | PL B400 226 | A. Bertin et al. | (OBELIX Collab.) |
| AUGUSTIN | 92 | PR D46 1951 | J.E. Augustin, G. Cosme | (DM2 Collab.) |
| FUKUI | 91 C | PL B267 293 | S. Fukui et al. | (SUGI, NAGO, KEK, KYOT+) |
| AUGUS T IN | 90 | PR D42 10 | J.E. Augustin et al. | (DM2 Collab.) |
| AIHARA | 88 C | PR D38 1 | H. Aihara et al. | (TPC-2γ Collab.) |
| BIRMAN | 88 | PRL 61 1557 | A. Birman et al. | (BNL, FSU, IND, MASD) JP |
| ANTREASYAN | 87 | PR D36 2633 | D. Antreasyan et al. | (Crystal Ball Collab.) |
| ANDO | 86 | PRL 57 1296 | A. Ando et al. | (KEK, KYOT, NIRS, SAGA+)IJP |
| STANTON | 79 | PRL 42 346 | N.R. Stanton et al. | (OSU, CARL, MCGI+)JP |
| | | | | |

 $\pi(1300)$

$$I^{G}(J^{PC}) = 1^{-}(0^{-+})$$

$\pi(1300)$ MASS

| VALUE (MeV | ') | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|--------------|--------------|----------------------|-------|------------|------------------------------------------------------|
| 1300±1 | 00 OUR | ESTIMATE | | | | |
| • • • We | do not us | e the follow | wing data for aver | ages, | fits, limi | ts, etc. • • • |
| $1345\pm$ | $8\!\pm\!10$ | 18k | $^{ m 1}$ SCHEGELSKY | | | $\gamma \gamma \rightarrow \pi^{+} \pi^{-} \pi^{0}$ |
| $1200\pm$ | 40 | 90k | SALVINI | 04 | OBLX | $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| $1343\pm$ | 15 ± 24 | | CHUNG | 02 | | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |
| 1375 \pm | 40 | | ABELE | 01 | CBAR | $0.0 \overline{p} d \rightarrow \pi^- 4\pi^0 p$ |
| 1275 \pm | 15 | | BERTIN | 97D | | $0.05 \ \overline{p}p \rightarrow 2\pi^{+} 2\pi^{-}$ |
| ~ 1114 | | | ABELE | 96 | CBAR | $0.0 \overline{p}p \rightarrow 5\pi^0$ |
| $1190\pm$ | 30 | | ZIELINSKI | 84 | SPEC | 200 π^+ Z \rightarrow Z 3π |
| $1240\pm$ | 30 | | BELLINI | 82 | SPEC | 40 $\pi^- A \rightarrow A 3\pi$ |
| $1273\pm$ | 50 | | ² AARON | 81 | RVUE | |
| $1342\pm$ | 20 | | BONESINI | 81 | OMEG | $12 \pi^- p \rightarrow p 3\pi$ |
| ~ 1400 | | | DAUM | 81 B | SPEC | 63,94 $\pi^- p$ |
| 1 From a | analysis of | I 3 data at | t 183–209 GeV. | | | |

π (1300) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|----------------|-------------------------|-------|------------|-----------------------------------------------------|
| 200 to 600 OUR | ESTIMATE | | | | |
| ● ● We do not | use the follov | ving data for aver | ages, | fits, limi | ts, etc. • • • |
| $260\pm\ 20\pm30$ | 18k | ³ SCHEGELSKY | 06 | RVUE | $\gamma \gamma \rightarrow \pi^+ \pi^- \pi^0$ |
| 470 ± 120 | 90k | SALVINI | 04 | OBLX | $\overline{p}p \rightarrow 2\pi^{+} 2\pi^{-}$ |
| 449± 39±47 | | CHUNG | | | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |
| 268± 50 | | ABELE | 01 | CBAR | $0.0 \overline{p} d \rightarrow \pi^- 4\pi^0 p$ |
| 218 ± 100 | | BERTIN | | | $0.05 \overline{p}p \rightarrow 2\pi^{+} 2\pi^{-}$ |
| ~ 340 | | ABELE | 96 | CBAR | $0.0 \overline{n}n \rightarrow 5\pi^0$ |

⁴ Assuming three-body phase-space decay to K_S^0 $K^\pm \pi^\mp$

² Uses multichannel Aitchison-Bowler model (BOWLER 75). Uses data from DAUM 80 and DANKOWYCH 81.

 $\pi(1300)$, $a_2(1320)$

| 440± 80 | ZIELINSKI | 84 | SPEC | 200 π^+ Z \rightarrow Z 3π |
|---------------|--------------------|------|------|--------------------------------------|
| 360 ± 120 | BELLINI | 82 | SPEC | 40 $\pi^- A \rightarrow A 3\pi$ |
| 580 ± 100 | ⁴ AARON | 81 | RVUE | |
| 220± 70 | BONESINI | 81 | OMEG | $12 \pi^- p \rightarrow p 3\pi$ |
| ~ 600 | DAUM | 81 B | SPEC | 63,94 $\pi^- p$ |
| | | | | |

³ From analysis of L3 data at 183–209 GeV.

π (1300) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------------|------------------------------|
| Γ_1 | $\rho\pi$ | seen |
| Γ_2 | $\pi(\pi\pi)_{S	ext{-wave}}$ | seen |
| Γ ₃ | $\gamma \gamma$ | |

π (1300) Γ (i) Γ ($\gamma\gamma$)/ Γ (total)

| $\Gamma(\rho\pi) \times \Gamma(\gamma)$ | $(\gamma \gamma)/\Gamma_{\rm total}$ | | | | | $\Gamma_1\Gamma_3/\Gamma_3$ |
|-----------------------------------------|--------------------------------------|-------------------------|-------|-------------|-----------------------------------------------|----------------------------------------|
| VALUE (keV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| < 0.085 | 90 | ACCIARRI | 97T | L3 | $e^+e^- ightarrow e^+e^-$ | $_{\pi^{+}\pi^{-}\pi^{0}}$ |
| • • • We do n | ot use the fol | lowing data for ave | rages | , fits, lir | nits, etc. • • • | |
| < 0.8 | 95 | ⁵ SCHEGELSKY | 06 | RVUE | $\gamma \gamma \rightarrow \pi^+ \pi^- \pi^0$ | |
| < 0.54 | 90 | ALBRECHT | 97в | ARG | $e^+ e^- ightarrow e^+ e^-$ | $_{\pi}^{+}$ $_{\pi}^{-}$ $_{\pi}^{0}$ |
| 5 From analys | sis of L3 data | at 183-209 GeV. | | | | |

π (1300) BRANCHING RATIOS

| $\Gamma(\pi(\pi\pi)_{S-V})$ | _{vave})/Γ(ρ | π) | | | | Γ_2/Γ_1 |
|-----------------------------|---------------------------|------------|--------------|--------------|----------|------------------------------------------------------------------------------|
| VALUE | CL% E | <u>/TS</u> | DOCUMENT | ID | TECN | COMMENT |
| • • • We do | not use the | following | data for ave | erages, fits | , limits | , etc. • • • |
| $2.2\ \pm0.4$ | 9 | 90k | SALVINI | 04 | | $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| seen | | | CHUNG | 02 | B852 | 18.3 $\pi^- p \to \pi^+ 2\pi^- p$ 0.0 $\overline{p} d \to \pi^- 4\pi^0 p$ |
| < 0.15 | 90 | _ | ABELE | 01 | CBAR | $0.0 \overline{p} d \rightarrow \pi^- 4\pi^0 p$ |
| 2.12 | | 6 | AARON | 81 | RVUE | |
| | ichannel Ait KOWYCH 81 | | wler model | (BOWLE | R 75). | Uses data from DAUM 80 |

π (1300) REFERENCES

| S CHEGELS KY | 06 | EPJ A27 199 | V.A. Schegelsky et al. | |
|--------------|------|---------------|---------------------------|---------------------------|
| SALVINI | 04 | EPJ C35 21 | P. Salvini et al. | (OBELIX Collab.) |
| CHUNG | 02 | PR D65 072001 | S.U. Chung et al. | (BNL E852 Collab.) |
| ABELE | 01 | EPJ C19 667 | A. Abele et al. | (Crystal Barrel Collab.) |
| ACCIARRI | 97 T | PL B413 147 | M. Acciarri et al. | (L3 Collab.) |
| ALBRECHT | 97 B | ZPHY C74 469 | H. Albrecht et al. | (ARGUS Collab.) |
| BERTIN | 97 D | PL B414 220 | A. Bertin et al. | (ÒBELIX Collab.) |
| ABELE | 96 | PL B380 453 | A. Abele et al. | (Cryst'al Barrel Collab.) |
| ZIELINSKI | 84 | PR D30 1855 | M. Zielinski et al. | (RÓCH, MINN, FNAL) |
| BELLINI | 82 | PRL 48 1697 | G. Bellini et al. | (MILA, BGNA, JINR) |
| AARON | 81 | PR D24 1207 | R.A. Aaron, R.S. Longacre | (NEAS, BNL) |
| BONESINI | 81 | PL 103B 75 | M. Bonesini et al. | (MILA, LIVP, DARE+) |
| DANKOWY | 81 | PRL 46 580 | J.A. Dankowych et al. | (TNTO, BNL, CARL+) |
| DAUM | 81B | NP B182 269 | C. Daum et al. (AMST | , CERN, CRAC, MPIM+) |
| DAUM | 80 | PL 89B 281 | | CERN, CRAC, MPIM+) |
| BOWLER | 75 | NP B97 227 | M.G. Bowler et al. | (OXFTP. DARE) |



$$I^{G}(J^{PC}) = 1^{-}(2^{+})$$

a₂(1320) MASS

VALUE (MeV) DO CUMENT ID

3π MODE

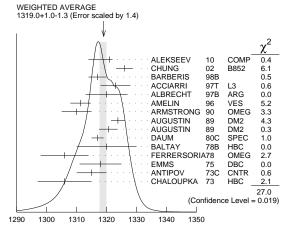
1319.0 $^+_{-}$ 1.0 OUR AVERAGE Error includes scale factor of 1.4. See the ideogram

| | — <u>т.э</u> | | | | | | · · |
|--------|--------------|------------|-------|-----------|-----|--------|---------------------------------------------------------------------------------------------------------------------------------------|
| below. | | | | | | | |
| 1321 | ± 1 | + 0 - 7 | 420k | ALEKSEEV | 10 | COMP | $^{190}\pi^{-}Pb \rightarrow \atop \pi^{-}\pi^{-}\pi^{+}Pb'$ |
| 1326 | ± 2 = | ±2 | | CHUNG | 02 | B 85 2 | 18.3 $\pi^{-} p \rightarrow \pi^{+} \pi^{-} \pi^{-} p$ |
| 1317 | ± 3 | | | BARBERIS | 98B | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 1323 | ± 4 = | ±3 | | ACCIARRI | 97т | L3 | $e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^0$ |
| 1320 | ± 7 | | | ALBRECHT | 97в | ARG | $e^{+} \stackrel{e^{-}}{\underset{e^{+}}{\longrightarrow}} \stackrel{\pi}{\underset{e^{-}}{\longrightarrow}} \pi^{+} \pi^{-} \pi^{0}$ |
| 1311.3 | ± 1.6 | ±3.0 | 72.4k | AMELIN | 96 | VES | $36 \begin{array}{c} \pi^- p \rightarrow \\ \pi^+ \pi^- \pi^0 \end{array}$ |
| 1310 | ± 5 | | | ARMSTRONG | 90 | OMEG 0 | $300.0pp \rightarrow 0.0p + 1000$ |

| 1323.8± 2.3 | 4022 | AUGUSTIN 89 | DM2 | \pm | $J/\psi \rightarrow \rho^{\pm} a_2^{\mp}$ |
|-------------------------------------------------------------------------|-------------------------|-----------------------------------------------------------------------------------------------|----------------------------------|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1320.6 ± 3.1 | 35 62 | AUGUSTIN 89 | DM2 | 0 | $J/\psi \rightarrow \rho^{\pm} a_2^{\mp}$ $J/\psi \rightarrow \rho^{0} a_2^{0}$ |
| 1317 ± 2 | 25 k | ¹ DAUM 80 | c SPEC | _ | 63,94 $\pi^- p \rightarrow 3\pi p$ |
| 1320 ± 10 | 1097 | ¹ BALTAY 78 | в НВС | +0 | $15 \pi^+ \rho \rightarrow \rho 4\pi$ |
| 1306 ± 8 | | FERRERSORIA 78 | OMEG | _ | $9 \pi^- p \rightarrow p 3\pi$ |
| 1318 ± 7 | 1.6k | ¹ EMMS 75 | DBC | 0 | $4 \pi^+ n \rightarrow p(3\pi)^0$ |
| 1315 ± 5 | | ¹ ANTIPOV 73 | C CNTR | _ | 25,40 $\pi^- p \rightarrow$ |
| | | | | | $p \eta \pi^-$ |
| 1306 ± 9 | 1580 | CHALOUPKA 7 | | - | 3.9 $\pi^{-}p$ |
| • • • We do not | use the foll | lowing data for averag | es, fits, lin | nits et | |
| e e e vic do not | 450 1110 1011 | ioning data for diving | ,, | , | |
| 1300 ± 2 ±4 | 18k | ² SCHEGELSKY 06 | | 0 | $\gamma \gamma \rightarrow \pi^+ \pi^- \pi^0$ |
| | | ² SCHEGELSKY 06 CONDO 93 | RVUE | | _ |
| $1300 ~\pm~ 2 ~\pm 4$ | | ² SCHEGELSKY 00 | RVUE SHF | 0 | $\gamma \gamma \rightarrow \pi^+ \pi^- \pi^0$ |
| $1300 \pm 2 \pm 4$ 1305 ± 14 | | ² SCHEGELSKY 06 CONDO 93 | RVUE SHF OMEG | 0 | $\begin{array}{ccc} \gamma\gamma \rightarrow & \pi^{+}\pi^{-}\pi^{0} \\ \gamma\rho \rightarrow & \eta\pi^{+}\pi^{+}\pi^{-} \end{array}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 18k | ² SCHEGELSKY 06 CONDO 93 ¹ EVANGELIS 83 | RVUE SHF OMEG BB HBC | 0 | $\begin{array}{ll} \gamma\gamma \rightarrow & \pi^{+}\pi^{-}\pi^{0} \\ \gamma\rho \rightarrow & \eta\pi^{+}\pi^{+}\pi^{-} \\ 12\pi^{-}\rho \rightarrow & 3\pi\rho \\ 15\pi^{+}\rho \rightarrow & \Delta3\pi \\ \pi^{-}\rho \; \text{near} \; a_{2} \; \text{thresh-} \end{array}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 18k 490 | ² SCHEGELSKY 00 CONDO 93 ¹ EVANGELIS 83 BALTAY 78 | RVUE SHF OMEG BB HBC MMS | 0 - 0 | $\begin{array}{ccc} \gamma\gamma \rightarrow & \pi^{+}\pi^{-}\pi^{0} \\ \gamma\rho \rightarrow & \eta\pi^{+}\pi^{+}\pi^{-} \\ 12\;\pi^{-}\rho \rightarrow & 3\pi\rho \\ 15\;\pi^{+}\rho \rightarrow & \Delta3\pi \end{array}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 18k 490 5k | ² SCHEGELSKY 00 CONDO 93 ¹ EVANGELIS 83 BALTAY 78 BINNIE 73 | RVUE SHF OMEG BB HBC MMS | 0 - 0 - | $\begin{array}{ccc} \gamma\gamma \rightarrow & \pi^{+}\pi^{-}\pi^{0} \\ \gamma\rho \rightarrow & \eta\pi^{+}\pi^{+}\pi^{-} \\ 12\pi^{-}\rho \rightarrow & 3\pi\rho \\ 15\pi^{+}\rho \rightarrow & \Delta3\pi \\ \pi^{-}\rho \text{ near } a_{2} \text{ threshold} \end{array}$ |
| 1300 ± 2 ±4 1305 ±14 1310 ± 2 1343 ±11 1309 ± 5 1299 ± 6 | 18k 490 5k 28k | 2 SCHEGELSKY 00 CONDO 93 1 EVANGELIS 83 BALTAY 74 BINNIE 73 BOWEN 75 | RVUE RVUE RHF OMEG RHHBC MMS MMS | 0 - 0 - | $\begin{array}{l} \gamma\gamma \rightarrow \ \pi^+ \pi^- \pi^0 \\ \gamma p \rightarrow \ \eta \pi^+ \pi^+ \pi^- \\ 12 \pi^- p \rightarrow \ 3\pi p \\ 15 \pi^+ p \rightarrow \ \Delta 3\pi \\ \pi^- p \ \text{near} \ a_2 \ \text{threshold} \\ 5 \pi^- p \end{array}$ |

¹ From a fit to $J^P=2^+$ $\rho\pi$ partial wave.

² From analysis of L3 data at 183–209 GeV.



 $a_2(1320)$ mass, 3π mode (MeV)

KK MODE

WALUE (MeV) EVTS DOCUMENT ID TECN CHG COMMENT

The data in this block is included in the average printed for a previous datablock.

| 1318. | Ι± | 0.7 | OUR AVERA | AGE | | | | |
|-------|-------|-----|-----------|------------------------|-----|------|---|-------------------|
| 1319 | \pm | 5 | 4700 | ^{3,4} CLELAND | 82B | SPEC | + | 50 π ⁺ |
| 1324 | \pm | 6 | 5 200 | ^{3,4} CLELAND | 82B | SPEC | _ | $50 \pi^-$ |
| 1320 | \pm | 2 | 4000 | CHABAUD | 80 | SPEC | _ | $17~\pi^-$ |
| 1312 | \pm | 4 | 11000 | CHABAUD | 78 | SPEC | _ | 9.8 π^- |
| 1316 | \pm | 2 | 4730 | CHABAUD | 78 | SPEC | _ | $18.8 \ \pi^{-}$ |

3,5 MARTIN $1318\ \pm\ 1$ 78D SPEC -MARGULIE 76 SPEC - $1320\ \pm\ 2$ 2724 1313 ± 4 730 FOLEY 72 CNTR - $20.3 \pi^- p \rightarrow K^- K_S^0 p$ ⁵ GRAYER 71 ASPK — 1319 ± 3 1500 $17.2 \pi^- p \rightarrow K^-$

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

| 1304 | | 870 | ⁶ SCHEGELSKY | 06A | RVUE | 0 | $\gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ |
|------|----------|------|-------------------------|-----|------|---|---------------------------------------------------|
| 1330 | ± 11 | 1000 | ^{3,4} CLELAND | 82B | SPEC | + | $30 \pi^+ p \rightarrow K_S^0 K^+ p$ |
| 1324 | | 350 | HYAMS | 78 | ASPK | + | 12.7 $\pi^+ p \rightarrow K^+ K_S^0 p$ |

 $^{^3}$ From a fit to $J^P=2^+$ partial wave.

1317.7 + 1.4 OUR AVERAGE

$n\pi$ MODE

<u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

| 1308 ±9 | BARBERIS | 00н | $450 pp \rightarrow p_f \eta \pi^0 p_S$ |
|--------------------------|---------------------|-----------|--------------------------------------------------------------------------------------------------------------------------------------|
| 1316 ±9 | BARBERIS | 00н | 450 <i>p p</i> → |
| | | | $\Delta_f^{++} \eta \pi^- p_S$ |
| 1317 ± 1 ± 2 | THOMPSON | 97 MPS | $ \begin{array}{ccc} 18 & \pi^{-} p \rightarrow \eta \pi^{-} p \\ 0.0 & \overline{p}p \rightarrow \pi^{0} \pi^{0} \eta \end{array} $ |
| 1315 ± 5 ± 2 | ⁷ AMSLER | 94D CBAR | $0.0 \overline{p} p \rightarrow \pi^0 \pi^0 \eta$ |
| 1325.1 ± 5.1 | A OYA GI | 93 BKEI | $\pi^- p \rightarrow \eta \pi^- p$ |
| $1317.7 \pm 1.4 \pm 2.0$ | BELADIDZE | 93 VES | $37\pi^- N \rightarrow \eta \pi^- N$ |
| 1323 +8 1000 | 8 KEY | 73 OSPK - | $6 \pi^- p \rightarrow p \pi^- p$ |

⁴ Uses multichannel Aitchison-Bowler model (BOWLER 75). Uses data from DAUM 80 and DANKOWYCH 81.

⁴ Number of events evaluated by us.

 $^{^5}$ Systematic error in mass scale subtracted. 6 From analysis of L3 data at 91 and 183–209 GeV.

| • • • We do no | t use the | following data for av | verage | es, fits, l | imits, | etc. • • • |
|------------------|-----------|-------------------------|--------|-------------|--------|-----------------------------------------------------------------|
| 1309 ±4 | | ANISOVICH | 09 | RVUE | | $\overline{\rho}p$, πN |
| 1324 ± 5 | | ARMSTRONG | 93 c | E760 | 0 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| 1336.2 ± 1.7 | 2561 | DELFOSSE | 81 | SPEC | + | $\pi^{\pm} p \rightarrow p \pi^{\pm} \eta$ |
| 1330.7 ± 2.4 | 1653 | DELFOSSE | 81 | SPEC | _ | $\pi^{\pm} p \rightarrow p \pi^{\pm} \eta$ |
| 1324 ± 8 | 6200 | ^{8,9} CONFORTO | 73 | OSPK | - | 6 $\pi^- p \rightarrow p \text{MM}^-$ |

- 7 The systematic error of 2 MeV corresponds to the spread of solutions.
- $^8\,\mathrm{Error}$ includes 5 MeV systematic mass-scale error.
- 9 Missing mass with enriched MMS $=\eta\pi^{-}$, $\eta=2\gamma$

The data in this block is included in the average printed for a previous datablock.

1322 ± 7 OUR AVERAGE

| $1318 \pm 8 \begin{array}{c} +3 \\ -5 \end{array}$ | IVANOV | 01 | B852 | $18 \pi^- \rho \rightarrow \eta' \pi^- \rho$ |
|----------------------------------------------------|-------------|----|------|----------------------------------------------|
| 1327.0 ± 10.7 | BELA DID ZE | 93 | VES | $37\pi^- N \rightarrow \eta' \pi^- N$ |

a₂(1320) WIDTH

| | | -2() | | | | |
|-----------------------------------------------------|-----------------------|------------------|-------------|-----------|-------------|-------------------------------------------------------------------------------------------------------------------------|
| 3π MODE VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | <u>CH G</u> | COMMENT |
| 105.0 + 1.6 OUR | AVERAGE | | | | | |
| $110 \pm 2 \begin{array}{c} + 2 \\ -15 \end{array}$ | 420k | ALEKSEEV | 10 | COMP | | 190 $\pi^- Pb \rightarrow 2.7$ |
| $108~\pm~3~\pm15$ | | CHUNG | 02 | B 85 2 | | $ \begin{array}{c} \pi^-\pi^-\pi^+Pb'\\ 18.3\ \pi^-p\rightarrow \end{array} $ |
| 120 ±10 | | BARBERIS | 98в | | | $ \begin{array}{c} \pi^{+} \pi^{-} \pi^{-} p \\ 450 pp \rightarrow \\ p_{f} \pi^{+} \pi^{-} \pi^{0} p_{s} \end{array} $ |
| $105 \pm 10 \pm 11$ | | ACCIARRI | 97T | L3 | | $e^+e^- \rightarrow e^+e^-\pi^+\pi^-\pi^0$ |
| $120\ \pm 10$ | | ALBRECHT | 97B | ARG | | $e^+e^- \xrightarrow{e^+e^-} _{e^+e^-\pi^+\pi^-\pi^0}$ |
| $103.0 \pm 6.0 \pm 3.3$ | 3 72.4k | AMELIN | 96 | VES | | $36 \begin{array}{c} \pi^{-} p \rightarrow \\ \pi^{+} \pi^{-} \pi^{0} n \end{array}$ |
| 120 ±10 | | ARMSTRONG | 90 | OMEG | 0 | $ 300.0p p \rightarrow p \pi^{+} \pi^{-} \pi^{0} $ $ p p \pi^{+} \pi^{-} \pi^{0} $ |
| 107.0 ± 9.7 | 4022 | AUGUSTIN | 89 | DM2 | \pm | $J/\psi \rightarrow \rho^{\pm} a_{2}^{\mp}$ |
| 118.5 ± 12.5 | 3562 | AUGUSTIN | 89 | DM2 | 0 | $J/\psi \rightarrow \rho^0 a_2^0$ |
| 97 ± 5 | 10 | EVANGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow 3\pi p$ |
| 96 ± 9 | 25k 10 | | 80 c | SPEC | _ | 63,94 $\pi^- p \rightarrow 3\pi p$ |
| 110 ±15 | 1097 10 | BALTAY | 78B | нвс | +0 | $15 \pi^+ p \rightarrow p4\pi$ |
| 112 ±18 | | EMMS | 75 | DBC | 0 | $4 \pi^{+} n \rightarrow p(3\pi)^{0}$ |
| 122 ±14 | 1.2k ^{10,11} | WAGNER | 75 | нвс | 0 | $7 \pi^+ p \rightarrow$ |
| 115 ±15 | 10 | ANTIPOV | 73 C | CNTR | - | $\Delta^{++}(3\pi)^0$ 25,40 $\pi^- p \to p \eta \pi^-$ |
| 99 ±15 | 1580 | CHALOUPKA | 73 | нвс | _ | 3.9 $\pi^- p$ |
| 105 ± 5 | 28k | BOWEN | 71 | MMS | _ | 5 π ⁻ p |
| 99 ± 5 | 24k | BOWEN | 71 | MMS | + | 5 π ⁺ p |
| 103 ± 5 | 17k | BOWEN | 71 | MMS | _ | 7 π ⁻ p |
| • • • We do not | use the follow | ing data for ave | rages, | fits, lim | its, etc | · · |
| 117 ± 6 ±20 | 18k 12 | SCHEGELSKY | 06 | RVUE | 0 | $\gamma \gamma \rightarrow \pi^{+} \pi^{-} \pi^{0}$ |
| 120 ±40 | 1011 | CONDO | 93 | SHF | • | $\gamma p \rightarrow \eta \pi^+ \pi^+ \pi^-$ |
| 115 ±14 | 490 | BALTAY | 78B | HBC | 0 | $15 \pi^+ p \rightarrow \Delta 3\pi$ |
| 72 ±16 | 5k | BINNIE | 71 | MMS | - | $\pi^- p$ near a_2 thresh- |
| 79 ±12 | 941 | ALSTON | 70 | нвс | + | 7.0 $\pi^+ p \rightarrow 3\pi p$ |
| 1.0 | D . | | | | | |

- 10 From a fit to $J^P=2^+$ $ho\pi$ partial wave.
- ¹¹ Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.
- $^{12}\mathrm{From}$ analysis of L3 data at 183–209 GeV.

$K\overline{K}$ AND $\eta\pi$ MODES

K**₹** MODE

VALUE (MeV) _ EVTS _ DOCUMENT ID _ TECN _ CHG _ COMMENT The data in this block is included in the average printed for a previous datablock.

109.8± 2.4 OUR AVERAGE

| 112 | ± 20 | 4700 13,14 | CLELAND | 82B | SPEC | + | $50 \pi^+ p \rightarrow K_S^0 K^+ p$ |
|-----|----------|-----------------------|----------|-----|------|---|----------------------------------------------|
| 120 | ±25 | ₅₂₀₀ 13,14 | CLELAND | 82B | SPEC | _ | $50 \pi^- p \rightarrow K_S^{0} K^- p$ |
| 106 | \pm 4 | 4000 | CHABAUD | 80 | SPEC | _ | $17 \pi^- A \rightarrow K_S^0 K^- A$ |
| 126 | ± 11 | 11000 | CHABAUD | 78 | SPEC | _ | 9.8 $\pi^- p \rightarrow K^- K_S^0 p$ |
| 101 | ± 8 | | CHABAUD | 78 | SPEC | _ | 18.8 $\pi^- p \rightarrow K^- K_S^0 p$ |
| 113 | \pm 4 | | MARTIN | 78D | SPEC | - | $10 \pi^{-} p \rightarrow K_{S}^{0} K^{-} p$ |
| 105 | ± 8 | 2724 ¹⁵ | MARGULIE | 76 | SPEC | - | $23 \pi^- p \rightarrow K^- K_S^0 p$ |
| 113 | ± 19 | 730 | FOLEY | 72 | CNTR | - | $20.3 \pi^- p \rightarrow K^- K_S^0 p$ |
| 123 | ± 13 | 1500 ¹⁵ | GRAYER | 71 | ASPK | _ | $17.2 \pi^- p \rightarrow K^- K_S^0 p$ |
| | | | | | | | |

| • • | • | We do | not | use | the | following | data | for | averages, | fits, | limits, etc | | • | • | |
|-----|---|-------|-----|-----|-----|-----------|------|-----|-----------|-------|-------------|--|---|---|--|
|-----|---|-------|-----|-----|-----|-----------|------|-----|-----------|-------|-------------|--|---|---|--|

| 120 | ± 15 | 870 | ¹⁶ SCHEGELSKY | 06A | RVUE | 0 | $\gamma \gamma \rightarrow K_S^0 K_S^0$ |
|-----|----------|------|--------------------------|-----|------|---|----------------------------------------------|
| 121 | ± 51 | 1000 | ^{13,14} CLELAND | 82B | SPEC | + | 30 $\pi^+ p \rightarrow K_S^0 K^+ p$ |
| 110 | ± 18 | 350 | HYAMS | 78 | ASPK | + | $12.7 \pi^+ \rho \rightarrow K^+ K_S^0 \rho$ |

- 13 From a fit to $J^P=2^+$ partial wave. 14 Number of events evaluated by us.
- 15 Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.
- 16 From analysis of L3 data at 91 and 183-209 GeV.

 VALUE (MeV)
 EVTS
 DOCUMENT ID
 TECN
 CHG
 COMMENT

 The data in this block is included in the average printed for a previous datablock.

111.1 ± 2.4 OUR AVERAGE

| 115 ± 20 | | | BARBERIS | 00н | | | $450 pp \rightarrow p_f \eta \pi^0 p_s$ |
|-------------------------|------------|------|-------------------|--------|-------------|----------|-----------------------------------------------------------------|
| 112 ±14 | | | BARBERIS | 00н | | | 450 <i>p p</i> → |
| | | | | | | | $\Delta_f^{++}\eta\pi^- ho_S^{}$ |
| $112 \pm 3 \pm 2$ | | 17 | AMSLER | 94D | CBAR | | $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \eta$ |
| $103~\pm~6~\pm3$ | | | BELADIDZE | 93 | VES | | $37\pi^- N \rightarrow \eta \pi^- N$ |
| 112.2 ± 5.7 | 2561 | | DELFOSSE | 81 | SPEC | + | $\pi^{\pm} \rho \rightarrow \rho \pi^{\pm} \eta$ |
| 116.6 ± 7.7 | 1653 | | DELFOSSE | 81 | SPEC | _ | $\pi^{\pm} \rho \rightarrow \rho \pi^{\pm} \eta$ |
| 108 ± 9 | 1000 | | KEY | 73 | OSP K | _ | $6 \pi^- p \rightarrow p \pi^- \eta$ |
| ullet $ullet$ We do not | use the fo | llov | ving data for ave | erages | , fits, lir | nits, el | ic. • • • |
| 110 ± 4 | | | ANISOVICH | 09 | RVUE | | $\overline{\rho} p$, πN |
| $127 \ \pm \ 2 \ \pm 2$ | | 18 | THOMPSON | 97 | MPS | | 18 $\pi^- p \rightarrow \eta \pi^- p$ |
| 118 ±10 | | | ARMSTRONG | 93c | E760 | 0 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| 104 ± 9 | 6200 | 19 | CONFORTO | 73 | OSP K | _ | $6 \pi^- p \rightarrow p MM^-$ |
| | | | | | | | |

- $\frac{17}{2}\,\text{The systematic error of 2 MeV corresponds to the spread of solutions.}$
- 18 Resolution is not unfolded. 19 Missing mass with enriched MMS $= \eta \pi^-$, $\eta = 2\gamma$.

$\eta'\pi$ MODE

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | |
|---------------------|--------------|----|------|----------------------------------------------|--|--|
| 119±25 OUR AVERAGE | | | | | | |
| $140 \pm 35 \pm 20$ | IVANOV | 01 | B852 | 18 $\pi^- \rho \rightarrow \eta' \pi^- \rho$ | | |
| 106 ± 32 | BELADIDZE | 93 | VES | $37\pi^- N \rightarrow \eta' \pi^- N$ | | |

a₂(1320) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-----------------------------------|----------------------------------|----------------------------------------------------------------|-----------------------------------|
| Γ ₁ Γ ₂ | $3\pi \rho(770) \pi$ | (70.1 ± 2.7) % | S=1.2 |
| Γ3 | $f_2(1270) \pi$ | | |
| Γ ₄ Γ ₅ | $ ho$ (1450) π $\eta\pi$ | (14.5 ±1.2) % | |
| Γ ₆ Γ ₇ | ωππ Κ Κ | (10.6 ±3.2) % (4.9 ±0.8) % | S=1.3 |
| Γ8 | η' (958) π | (5.3 ±0.9)×10 | _ |
| Γ ₉ Γ ₁₀ | $\pi^{\pm}\gamma$ $\gamma\gamma$ | $(2.68\pm0.31) \times 10^{-1}$ $(9.4\pm0.7) \times 10^{-1}$ | |
| Γ11 | e^+e^- | < 5 × 10 ⁻ | |

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 18 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 =$ $9.3 \ \text{for} \ 15 \ \text{degrees} \ \text{of} \ \text{freedom} \, .$

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to

$$\begin{array}{c|ccccc} x_5 & & 10 & & \\ x_6 & & -89 & -46 & & \\ x_7 & & & -1 & -2 & -24 \\ \hline & x_1 & x_5 & x_6 & & \end{array}$$

a2(1320) PARTIAL WIDTHS

| $\Gamma(\eta \pi)$ | | | | | Γε |
|-------------------------------------------------|----------------------------|--------------------------|------------------------|---------|-------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | CHG | COMMENT |
| • • • We do not | use the following | g data for averages, fit | s, limits, e | etc. • | • • |
| 18.5 ± 3.0 | 870 | 20 SCHEGELSKY 06A | RVUE | 0 | $\gamma \gamma \rightarrow K_S^0 K_S^0$ |
| ²⁰ From analysis o and SU(3) rela | of L3 data at 91 tions. | and 183–209 GeV, usi | ng Γ(a ₂ (1 | .320) - | $\rightarrow \gamma \gamma) = 0.91 \text{ keV}$ |

 $a_2(1320)$

| | $\Gamma(\eta\pi)/\Gamma(3\pi)$ Γ_5/Γ_1 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (MeV) EVTS DOCUMENT ID TECN CHG COMMENT | <u>VALUEEVTS</u> <u>DO CUMENT ID TECN CHG COMMENT</u> 0.207±0.018 OUR FIT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 0.213±0.020 OUR AVERAGE |
| 7.0 $^{+2.0}_{-1.5}$ 870 21 SCHEGELSKY 06A RVUE 0 $\gamma\gamma \to \kappa^0_S\kappa^0_S$ | 0.18 \pm 0.05 FORINO 76 HBC 11 $\pi^- p$ |
| 21 From analysis of L3 data at 91 and 183–209 GeV, using $\Gamma(a_2(1320) ightarrow \gamma \gamma) = 0.91$ keV | 0.22 ± 0.05 52 ANTIPOV 73 CNTR $-$ 40 $\pi^- \rho$ 0.211 ± 0.044 149 CHALOUPKA 73 HBC $-$ 3.9 $\pi^- \rho$ |
| and SU(3) relations. | 0.211 ± 0.044 149 CHALOUPKA 73 HBC $-$ 3.9 $\pi^- p$ 0.246 ± 0.042 167 ALSTON 71 HBC $+$ 7.0 $\pi^+ p$ |
| $\Gamma(\pi^{\pm}\gamma)$ | 0.25 \pm 0.09 15 BOECKMANN 70 HBC $+$ 5.0 π^+ p |
| VALUE (keV) EVTS DOCUMENT ID TECN CHG COMMENT | 0.23 \pm 0.08 22 ASCOLI 68 HBC $-$ 5 $\pi^- p$ |
| 287± 30 OUR AVERAGE | 0.12 ± 0.08 CHUNG 68 HBC $ 3.2 \pi^- p$ 0.22 ± 0.09 CONTE 67 HBC $ 11.0 \pi^- p$ |
| 284 \pm 25 \pm 25 7100 MOLCHANOV 01 SELX $600 \ \pi^- A \rightarrow \pi^+ \pi^- \pi^- A$ | 0.22 ± 0.09 CONTE 67 HBC $-$ 11.0 $\pi^- p$ |
| 295 \pm 60 CIHANGIR 82 SPEC $+$ 200 π^+ A | $\Gamma(\omega\pi\pi)/\Gamma(3\pi)$ Γ_6/Γ_1 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 461 ± 110 | VALUE EVTS DOCUMENT ID TECN CHG COMMENT |
| • | 0.15±0.05 OUR FIT |
| ²² Assuming one-pion exchange. | 0.28 ± 0.09 60 DIAZ 74 DBC 0 6 π^+ n |
| $\Gamma(\gamma\gamma)$ Γ_{10} | 0.18±0.08 29 KARSHON 74 HBC Avg. of above two |
| VALUE (keV) EVTS DOCUMENT ID TECN CHG COMMENT | 0.10 ± 0.05 279 CHALOUPKA 73 HBC $-$ 3.9 $\pi^- p$ |
| 1.00±0.06 OUR AVERAGE $0.98\pm0.05\pm0.09$ ACCIARRI 97T L3 e^+e^- → | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $e^{+}e^{-}\pi^{+}\pi^{-}\pi^{0}$ | 0.29 ± 0.08 |
| $0.96\pm0.03\pm0.13$ ALBRECHT 97B ARG $e^+e^{e^+e^{\pi}^+\pi^-\pi^0}$ | 0.10 ± 0.04 00 NAKSHON 14 HBC \pm 4.5 π \uparrow p 0.19 \pm 0.08 DEFOIX 73 HBC 0 0.7 \overline{p} p |
| $1.26 \pm 0.26 \pm 0.18$ 36 BARU 90 MD1 $e^{+}e^{-} \rightarrow + + + + + + + + + + + + + + + + + + $ | 29 KARSHON 74 suggest an additional $I=0$ state strongly coupled to $\omega\pi\pi$ which could |
| $e^+e^-\pi^+\pi^-\pi^0$ 1.00±0.07±0.15 415 BEHREND 90c CELL 0 $e^+e^-\to$ | explain discrepancies in branching ratios and masses. We use a central value and a systematic spread. |
| $e^{+}e^{-}\pi^{+}\pi^{-}\pi^{0}$ 1.03 \pm 0.13 \pm 0.21 BUTLER 90 MRK2 $e^{+}e^{-}	o$ | systematic spreau. |
| $e^{+}e^{-}\pi^{+}\pi^{-}\pi^{0}$ | WEIGHTED AVERAGE 0.15±0.05 (Error scaled by 1.3) |
| $1.01\pm 0.14\pm 0.22$ 85 OEST 90 JADE $e^+e^- 	o e^+e^- \pi^0 \eta$ 0.90 $\pm 0.27\pm 0.15$ 56 23 ALTHOFF 86 TASS 0 $e^+e^- 	o e^+e^- 3\pi$ | 0.15±0.05 (Error scaled by 1.3) |
| $0.90\pm0.27\pm0.13$ 56 - ALTHOFF 86 TASS 0 e e \rightarrow e e 3π $1.14\pm0.20\pm0.26$ 24 ANTREASYAN 86 CBAL 0 $e^+e^- \rightarrow e^+e^-\pi^0\eta$ | √ Values above of weighted average, error, |
| $1.06\pm0.18\pm0.19$ BERGER 84c PLUT 0 $e^+e^- \rightarrow e^+e^- 3\pi$ | /\ and scale factor are based upon the data in |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | this ideogram only. They are not necessarily the same as our 'best' values, |
| $0.81 \pm 0.19 ^{+~0.42}_{-~0.11}$ 35 23 BEHREND 83B CELL 0 $^{e^+e^-}_{-}$ $^{e^+e^-}_{-}$ 3 $^{\pi}$ | obtained from a least-squares constrained fit utilizing measurements of other (related) |
| $0.77\pm0.18\pm0.27$ 22 ²⁴ EDWARDS 82F CBAL 0 $e^+e^- ightarrow e^+e^-\pi^0\eta$ | quantities as additional information. |
| 23 From $ ho\pi$ decay mode. | |
| 24 From $\eta \pi^0$ decay mode. | |
| | |
| $\Gamma(e^+e^-)$ VALUE (eV) CL% DOCUMENT ID TECH COMMENT | |
| VALUE (eV) CL% DOCUMENT ID TECN COMMENT < 0.56 90 ACHASOV 00K SND $e^+e^- \rightarrow \pi^0\pi^0$ | χ^2 |
| ACTIASOV ON SIND C C A A | DIAZ 74 DDC 30 |
| - | DIAZ 74 DBC 2.0 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \to \pi^0\eta$ | HAZ 74 DBC 2.0 KARSHON 74 HBC 0.1 CHALOUPKA 73 HBC 1.0 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | → · · · · · · · · · · · · · KARSHON 74 HBC 0.1 → · · · · · · · · · · · · · CHALOUPKA 73 HBC 1.0 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \; \times \; \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma$ | -0.2 0 0.2 0.4 0.6 0.8 KARSHON 74 HBC 0.1 1.0 3.2 (Confidence Level = 0.199) |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} = \Gamma_1\Gamma_{10}/\Gamma_{tota$ | KARSHON 74 HBC 0.1 CHALOUPKA 73 HBC 1.0 3.2 (Confidence Level = 0.199) |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \; \times \; \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma$ | KARSHON 74 HBC 0.1 1.0 3.2 (Confidence Level = 0.199) -0.2 0 0.2 0.4 0.6 0.8 $\Gamma(\omega \pi \pi)/\Gamma(3\pi)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | $\Gamma(\kappa \overline{\kappa})/\Gamma(3\pi)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $ a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $ \Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} $ $ \nu_{ALUE (keV)} \qquad \nu_{EVTS} \qquad \nu_{DOCUMENT \; ID} \qquad \nu_{TECN} \qquad \nu_{COMMENT} $ • • We do not use the following data for averages, fits, limits, etc. • • • 0.665 \pm 0.02 \pm 0.02 \pm 18k $\nu_{COMMENT} \sim \nu_{COMMENT} \sim \nu_{CO$ | κ (Confidence Level = 0.199) -0.2 0 0.2 0.4 0.6 0.8 $\Gamma(\omega \pi \pi)/\Gamma(3\pi)$ $\frac{\Gamma(\kappa \overline{K})/\Gamma(3\pi)}{0.070\pm0.012 \text{ OUR}}$ $\frac{EVTS}{FIT}$ $\frac{DOCUMENT\ ID}{1.0}$ $\frac{TECN}{CHACOUPKA}$ $\frac{CHG}{COMMENT}$ $\frac{CHG}{COMMENT}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $ a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_1\Gamma_{10}/\Gamma_{VALUE (keV)}$ EVTS DOCUMENT ID TECN COMMENT Γ_1 • • We do not use the following data for averages, fits, limits, etc. • • • 0.055 $\pm 0.02 \pm 0.02$ 18k 25 SCHEGELSKY 06 RVUE $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$ 25 From analysis of L3 data at 183–209 GeV. $\Gamma(\eta\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ | $\Gamma(K\overline{K})/\Gamma(3\pi)$ -0.2 0 0.2 0.4 0.6 0.8 $\Gamma(\omega \pi \pi)/\Gamma(3\pi)$ Γ(K\overline{K})/Γ(3π) VALUE 0.070±0.012 OUR FIT 0.078±0.017 CHABAUD 78 RVUE |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $ a_2(1320) \; \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma_1$ $ F_1\Gamma_{10}/\Gamma_2$ $ F_2\Gamma_3 = \frac{EVTS}{EVTS} = \frac{DOCUMENT\;ID}{EVTS} = \frac{TECN}{EVTS} = \frac{COMMENT}{EVTS} = \frac{EVTS}{EVTS} $ | $\Gamma(K\overline{K})/\Gamma(3\pi)$ $\Gamma(K\overline{K})/\Gamma(3\pi)$ $\frac{VALUE}{0.070\pm0.012 \text{ OUR FIT}}$ $\frac{EVTS}{0.078\pm0.017}$ $\frac{DOCUMENT\ ID}{CHABAUD}$ $\frac{TECN}{78}$ $\frac{CHABAUD}{78}$ $\frac{CHABAUD}{78}$ $\frac{FVIS}{FVIS}$ FV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \to \pi^0\eta$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma_1$ $ F_1\Gamma_{10}/\Gamma_2$ $ F_2\Gamma_3 F_3 F_3 F_4 F_5 F_5 F_5 F_6 F_6 F_6 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7$ | $\Gamma(\kappa \overline{K})/\Gamma(3\pi)$ Γ(κ $\overline{K})/\Gamma(3\pi)$ $\Gamma(\kappa \overline{K})/\Gamma(3\pi)$ Γ(κ $\overline{K})/\Gamma(3\pi)$ Γ(κ $\overline{K})$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \to \pi^0\eta$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma_1$ $ F_1\Gamma_{10}/\Gamma_2$ $ F_2\Gamma_3 F_3 F_3 F_4 F_5 F_5 F_5 F_6 F_6 F_6 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \to \pi^0\eta$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma_1$ $ F_1\Gamma_{10}/\Gamma_2$ $ F_2\Gamma_3 F_2 F_3 F_3 F_4 F_5 F_5 F_5 F_6 F_6 F_6 F_6 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7 F_7$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_2\Gamma_1$ $\Gamma_1\Gamma_1$ $ \Gamma_1\Gamma_1$ $ \Gamma_2\Gamma_1$ $ \Gamma_1\Gamma_1$ $ \Gamma_2\Gamma_1$ $ \Gamma_1\Gamma_1$ $ \Gamma_2\Gamma_1$ $ \Gamma_1\Gamma_2$ $ \Gamma_2\Gamma_1$ $ \Gamma_2\Gamma_2$ $ \Gamma_2\Gamma_2$ $ \Gamma_2\Gamma_2$ $ \Gamma_2\Gamma_2$ $ \Gamma_2\Gamma_3$ $ \Gamma_3\Gamma_4$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tot$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $VALUE (keV) \qquad EVTS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ • • • We do not use the following data for averages, fits, limits, etc. • • • 0.65 \pm 0.02 \pm 0.02 18 k 25 SCHEGELSKY 06 RVUE $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$ 25 From analysis of L3 data at 183–209 GeV. $\Gamma(\eta\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0\eta$ $ a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total) $ $\Gamma_1\Gamma_{10}/\Gamma$ $ \Gamma_1\Gamma_1 \Gamma_1 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2 \Gamma_2$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | CHALOUPKA 73 HBC 1.0 3.2 (Confidence Level = 0.199) • 0.2 0 0.2 0.4 0.6 0.8 $ \Gamma(\kappa \overline{K})/\Gamma(3\pi) $ $ \Gamma(\kappa \overline{K})/\Gamma(3\pi) $ $ \Gamma(\kappa \overline{K})/\Gamma(3\pi) $ $ \frac{VALUE}{0.070\pm0.012} \frac{EVTS}{ODCUMENT ID} $ $ \frac{DOCUMENT ID}{10.003} \frac{TECN}{3} \frac{CHALOUPKA}{10.0056\pm0.014} \frac{CHALOUPKA}{50} \frac{CHALOUPKA}{3} \frac{CHALOUPKA}{10.0056\pm0.014} \frac{30}{3} \frac{BERTIN}{3} \frac{98B}{10.0056\pm0.014} \frac{98B}{10.0056\pm0.014} \frac{98B}{10.0056\pm0.014} \frac{31}{3} \frac{CHALOUPKA}{3} \frac{73}{1} \frac{HBC}{10.0056\pm0.014} \frac{31}{3} \frac{CHALOUPKA}{10.0056\pm0.014} \frac{31}{3} \frac{CHALOUPKA}{10.0056\pm0.014} \frac{73}{3} \frac{HBC}{10.0056\pm0.014} \frac{31}{3} \frac{1}{3} 1$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <25 90 VOROBYEV 88 ND $e^+e^- \rightarrow \pi^0 \eta$ $a_2(1320) \ \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$ $\Gamma(3\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{total} \qquad \qquad \Gamma_1\Gamma_{10}/\Gamma_{tota$ | CHALOUPKA 73 HBC 1.0 3.2 (Confidence Level = 0.199) •0.2 0 0.2 0.4 0.6 0.8 $\Gamma(\omega\pi\pi)/\Gamma(3\pi)$ $\frac{VALUE}{0.070\pm0.012} \frac{EVTS}{ODCUMENT ID} \frac{DOCUMENT ID}{TECN} \frac{TECN}{CHG} \frac{COMMENT}{COMMENT}$ ••• We do not use the following data for averages, fits, limits, etc. ••• 0.011±0.003 30 BERTIN 98B OBLX 0.0 $\overline{p}p \rightarrow K^{\pm}K_S \pi^{\mp}$ 0.056±0.014 50 31 CHALOUPKA 73 HBC - 3.9 π^-p 0.097±0.018 113 31 ALSTON 71 HBC + 7.0 π^+p 0.06 ±0.03 31 ABRAMOVI 70B HBC - 3.93 π^-p 0.054±0.022 31 CHUNG 68 HBC - 3.2 π^-p 30 Using 4π data from BERTIN 97D. 31 Included in CHABAUD 78 review. $\Gamma(K\overline{K})/\Gamma(\eta\pi)$ $VALUE$ $DOCUMENT ID$ $VALUE$ $DOCUMENT ID$ $VALUE$ $DOCUMENT ID$ $TECN$ |

| (<i>Κ'</i> Κ)/[Γ(3π |) + Γ(η: | π) + Γ(<i>l</i> | | | | | $\Gamma_7/(\Gamma_1+\Gamma_5+$ | Γ ₇) |
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| <i>\LUE</i> .054±0.009 OU | R FIT | <u>VTS</u> | DOCUMENT ID | | TECN | <u>CHG</u> | COMMENT | |
| 048±0.012 OU | R AVERA | GE | | | | | | |
| 05 ±0.02 | | | TOET | 73 | HBC | + | 5 π ⁺ p | |
| 09 ±0.04 | | | TOET | 73 | HBC | 0 | 5 π ⁺ p | |
| 03 ±0.02 | | 8 | DAMERI | 72 | HBC | _ | 11 $\pi^{-}p$ | |
| 06 ±0.03 | | 17 | BARNHAM | 71 | HBC | + | 3.7 π^{+} p | |
| • • We do not | use the f | ollowing d | lata for averages | s, fits, | limits, | etc. • | • • | |
| 020 ± 0.004 | | 33 | ESPIGAT | 72 | нвс | \pm | 0.0 p p | |
| ³ Not averaged | because o | of discrepa | ncy between m | asses | from K | \overline{K} and | $\rho\pi$ modes. | |
| | | · | - | | | | | |
| $(\eta'(958)\pi)/\Gamma$ | | | | | | | | в/Г |
| LUE | | <u>L%_</u> | DOCUMENT ID | | | | | |
| • VVe do not | use the f | ollowing d | lata for averages | s, fits, | , limits, | etc. • | • • | |
| 0.006 | 9 | 5 | ALDE | 92B | GAM2 | | 38,100 π ⁻ p | \rightarrow |
| | | | | | | | $\eta' \pi^0 n$ | |
| 0.02 | 9 | 7 | BARNHAM | 71 | HBC | + | 3.7 $\pi^{+} p$ | |
| 0.004 ± 0.004 | | | BOESEBECK | 68 | HBC | + | 8 π ⁺ ρ | |
| (m/(059) m) /I | (3-) | | | | | | Га | /r. |
| $(\eta'(958)\pi)/\Gamma$ | | . 0/ | DOCUMENT ID | | TECN | cuc | | /Γ ₁ |
| LUE | | <u>L%</u> | DO CUMENT ID | | | | COMMENT | |
| | | _ | lata for averages | | | etc. • | | |
| 0.011 | 9 | 0 | EISENSTEIN | 73 | HBC | - | 5 π ⁻ p | |
| 0.04 | | | ALSTON | 71 | HBC | + | 7.0 π^{+} p | |
| $0.04 \begin{array}{l} + 0.03 \\ - 0.04 \end{array}$ | | | BOECKMANN | 70 | нвс | 0 | 5.0 $\pi^{+} \rho$ | |
| - 0.04 | | | | | | | | |
| $(\eta'(958)\pi)/\Gamma$ | $(\eta\pi)$ | | | | | | Га | /Γ ₅ |
| LUE | | | DOCUMENT ID | | TECN | <u>CO</u> MI | | |
| 037±0.006 OU | R AVERA | GE | | | | | | |
| 032 ± 0.009 | | | ABELE | 97c | CBAR | $0.0 \overline{p}$ | $\bar{p} \rho \rightarrow \pi^0 \pi^0 \eta'$ | |
| $047 \pm 0.010 \pm 0.010$ | 004 | 34 | BELADIDZE | 93 | VES | $37\pi^{-}$ | $N \rightarrow a_2^- N$ | |
| $0.008 \pm 0.008 \pm 0.00$ | 005 | | BELADIDZE | 92 | VES | | $-C \rightarrow a\frac{2}{2}C$ | |
| | | | | | | | _ | |
| 0.236. | → π'π | $\eta) = 0.4$ | 41, B($\eta \rightarrow \gamma \gamma$ | 0 = 1 | J.389 an | а В(η | $g \rightarrow \pi^+\pi^-\pi^0$ |) = |
| $(\pi^{\pm}\gamma)/\Gamma_{ m total}$ | | | | | | | Г | 9/F |
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| • • We do not | - | | | | | | | |
| | use the f | ollowing d | lata for averages | | | | • • | |
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| | | 35 | EISENBERG | s, fits, | limits, | etc. • | | |
| ⁵ Pion-exchang | e model u | 35 | EISENBERG | s, fits, | limits, | etc. • | .25,7.5 γp | |
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| | e model u | 35 sed in this | EISENBERG | 72 | limits, | etc. • 4.3,5 | .25,7.5 γ <i>p</i> Γ <u>1</u> : | ۱/۲ |
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| BALTAY | 78 B | PR D17 62 | C. Baltay et al. | (COLU, BING) | |
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| CHABAUD | 78 | NP B145 349 | V. Chabaud et al. | (ČERN, MPIM) | |
| FERRERSORIA | 78 | PL 74B 287 | A. Ferrer Soria et al. | (ORSAY, CERN, CDEF+) | |
| HYAMS | 78 | NP B146 303 | B.D. Hyams et al. | (CERN, MPIM, ATEN) | |
| MARTIN | 78 D | PL 74B 417 | A.D. Martin et al. | (DURH, GEVA)JP | |
| MAY | 77 | PR D16 1983 | E.N. May et al. | (ROCH, CORN) | |
| FORINO | 76 | NC 35A 465 | A. Forino et al. | (BGNA, FIRZ, GENO, MILA+) | |
| MARGULIE | 76 | PR D14 667 | M. Margulies et al. | (BNL, CUNY) | |
| EMMS | 75 | PL 58B 117 | M.J. Emms et al. | (BIRM, DURH, RHEL)JP | |
| WAGNER | 75 | PL 58B 201 | F. Wagner, M. Tabak, D. | M. Chew (LBL) JP | |
| DIAZ | 74 | PRL 32 260 | J. Diaz et al. | (CASE, ČMU) | |
| KARSHON | 74 | PRL 32 852 | U. Karshon et al. | (REHO) | |
| ANTIPOV | 73 | NP B63 175 | Y.M. Antipov et al. | (CERN, SERP) JP | |
| ANTIPOV | 73 C | NP B63 153 | Y.M. Antipov et al. | (CERN, SERP)JP | |
| CHALOUPKA | 73 | PL 44B 211 | V. Chaloupka et al. | (CERN) | |
| CONFORTO | 73 | PL 45B 154 | G. Conforto et al. | (EFI, FNAL, TNTO+) | |
| DEFOIX | 73 | PL 43B 141 | C. Defoix et al. | (CDEF) | |
| EISENSTEIN | 73 | PR D7 278 | L. Eisenstein et al. | ` (ILL) | |
| KEY | 73 | PRL 30 503 | A.W. Kev et al. | (TNTO, EFI, FNAL, WÌSC) | |
| TOET | 73 | NP B63 248 | D.Z. Toet et al. | (NÌM, BONN, DURH, TORI) | |
| DAMERI | 72 | NC 9A 1 | M. Dameri et al. | (GENO, MILA, SACL) | |
| EISENBERG | 72 | PR D5 15 | Y. Eisenberg et al. | (REHO, SLAC, TELA) | |
| ES PIGAT | 72 | NP B36 93 | P. Espigat et al. | (CERN, CDEF) | |
| FOLEY | 72 | PR D6 747 | K.J. Foley et al. | `(BNL, CUNY) | |
| ALS T ON | 71 | PL 34B 156 | M. Alston-Garnjost et al. | (LRL) | |
| BARNHAM | 71 | PRL 26 1494 | K.W.I. Barnham et al | ίLBLΊ | |
| BINNIE | 71 | PL 36B 257 | D.M. Binnie et al. | (LOIC, SHMP) | |
| BOWEN | 71 | PRL 26 1663 | D.R. Bowen et al. | (NEAS, STON) | |
| GRAYER | 71 | PL 34B 333 | G. Grayer et al. | (CERN, MPIM) | |
| ABRAMOVI | 70 B | NP B23 466 | M. Abramovich et al. | (CERN) JP | |
| ALS T ON | 70 | PL 33B 607 | M. Alston-Garnjost et al. | `(LRL) | |
| BOECKMANN | 70 | NP B16 221 | K. Boeckmann et al. | (BONN, DURH, NIĴM+Ĵ | |
| AS COLI | 68 | PRL 20 1321 | G. Ascoli et al. | (ILL) JP | |
| BOESEBECK | 68 | NP B4 501 | K. Boesebeck et al. | (AACH, BERL, CÈRN) | |
| CHUNG | 68 | PR 165 1491 | S.U. Chung et al. | (LRL) | |
| CONTE | 67 | NC 51A 175 | F. Conte et al. | (GENO, HAMB, MILA, SACL) | |
| | | | | | |
| | | | | | |

 $f_0(1370)$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

See also the mini-reviews on scalar mesons under $f_0(500)$ (see the index for the page number) and on non- $q\overline{q}$ candidates in PDG 06, Journal of Physics, G 33 1 (2006).

f₀(1370) T-MATRIX POLE POSITION

Note that $\Gamma \approx 2 \text{ Im}(\sqrt{s_{pole}})$

```
DO CUMENT ID
                                                                                      TECN COMMENT
(1200-1500)-i(150-250) OUR ESTIMATE
• • • We do not use the following data for averages, fits, limits, etc. • • •
(1290 \pm 50) - i(170 + 20 \atop -40)
                                                     <sup>1</sup> ANISOVICH 09
                                                                                        RVUE 0.0 \overline{p} p, \pi N
                                                      <sup>2</sup> BARGIOTTI
(1373 \pm 15) - i(137 \pm 10)
                                                                                03
                                                                                        OBLX \overline{p}p
(1302 \pm 17) - i(166 \pm 18)
                                                      <sup>3</sup> BARBERIS
                                                                                00c
                                                                                                     450 pp \rightarrow p_f 4\pi p_S
(1312 \pm 25 \pm 10) - i(109 \pm
                                                        BARBERIS
                                                                                99D OMEG 450 pp \rightarrow K^+K^-,
22 \pm 15) 
 (1406 \pm 19) - i(80 \pm 6) 
 (1300 \pm 20) - i(120 \pm 20)
                                                                                        \pi^{+}\pi^{-}
RVUE \pi\pi \to \pi\pi. K\overline{K}. \sigma\sigma
                                                      4 KAMINSKI
                                                                                 99
                                                        ANISOVICH
                                                                                        RVUE Compilation
                                                                                 98B
(1290 \pm 15) - i(145 \pm 15)
                                                        BARBERIS
                                                                                97B OMEG 450 pp →
                                                                                97c OBLX 0.0 \overline{p}p \rightarrow \pi^+\pi^-\pi^0

96b CBAR 0.0 \overline{p}p \rightarrow \pi^0 K_L^0 K_L^0
(1548 \pm 40) - i(560 \pm 40)
                                                        BERTIN
(1380 \pm 40) - i(180 \pm 25)
                                                        ABELE
(1300 \pm 15) - i(115 \pm 8)
                                                        BUGG
                                                                                 96
                                                                                        RVUE
                                                      <sup>5</sup> AMSLER
                                                                                 95b CBAR \overline{
ho} 
ho 
ightarrow 3 \pi^0
(1330 + 50) - i(150 + 40)
                                                                                95b CBAR \bar{p}p \rightarrow 3\pi^{0}

95c CBAR \bar{p}p \rightarrow \pi^{0}\eta\eta

95D CBAR \bar{p}p \rightarrow 3\pi^{0}, \pi^{0}\eta\eta,

\pi^{0}\pi^{0}\eta

95 RVUE \pi\pi \rightarrow \pi\pi, KK
                                                      <sup>5</sup> AMSLER
(1360 \pm 35) - i(150 - 300)
                                                      ^{6}\,\mathrm{AMSLER}
(1390 \pm 30) - i(190 \pm 40)
                                                    <sup>7,8</sup> JANSSEN
1346 - i249
                                                    <sup>8,9</sup> TORNQVIST
                                                                                        RVUE \pi\pi \to \pi\pi, K\overline{K}, K\pi,
1214-i168
                                                                                95
                                                                                                         \eta \pi
                                                                                 94D CBAR \overline{p}p \rightarrow \pi^0\pi^0\eta
94 CBAR \overline{p}p \rightarrow 3\pi^0,\pi^0\eta\eta
1364 - i139 
 (1365 + 20 \atop -55) - i(134 \pm 35) 
 + 30
                                                        ANISOVICH
                                                                                        RVUE \overline{p}p \rightarrow 3\pi^{0}, \eta\eta\pi^{0}, \eta\eta\pi^{0}, \eta\eta\pi^{0}
                                                    <sup>10</sup> BUGG
(1340 \pm 40) - i(127 + \frac{30}{20})
                                                    ^{11} KAMINSKI
(1430 \pm 5) - i(73 \pm 13)
1420 - i220
                                                                                        RVUE \pi\pi \to \pi\pi, K\overline{K}
                                                    12 AU
                                                                                87
                                                                                        RVUE \pi\pi \rightarrow \pi\pi, K\overline{K}
```

- $^1\,\mathrm{Another}$ pole is found at (1510 \pm 130) $i~(800^{+}_{-150})$ MeV.
- ² Coupled channel analysis of $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, and $K^{\pm}K^0_S\pi^{\mp}$.
- $^3\,\mathrm{Average}$ between $\pi^+\,\pi^-\,2\pi^0$ and $2(\pi^+\,\pi^-)$
- ⁴T-matrix pole on sheet — —
- ⁵ Supersedes ANISOVICH 94.
- Supersetes Amosovicity $\overline{\sigma}_{PP} \to 3\pi^0, \pi^0\eta\eta$, and $\pi^0\pi^0\eta$ on sheet IV. Demonstrates explicitly that $f_0(500)$ and $f_0(1370)$ are two different poles.
- ⁷ Analysis of data from FALVARD 88.
- ⁸The pole is on Sheet III. Demonstrates explicitly that $f_0(500)$ and $f_0(1370)$ are two
- ⁹ Uses data from BEIER 72B, OCHS 73, HYAMS 73, GRAYER 74, ROSSELET 77, CASON 83, ASTON 88, and ARMSTRONG 91B. Coupled channel analysis with flavor symmetry and all light two-pseudoscalars systems.
- 10 Reanalysis of ANISOVICH 94 data.
- 11 T-matrix pole on sheet III.
- 12 Analysis of data from OCHS 73, GRAYER 74, BECKER 79, and CASON 83.

 $f_0(1370)$

f₀(1370) BREIT-WIGNER MASS OR K-MATRIX POLE PARAMETER

| | N.A | 0 | n | С |
|----------|-----|---|---|---|
| $\pi\pi$ | IVI | v | v | С |

| VALUE (MeV) | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------|--------|---------|-------------------|-------|--------------|----------------------------------------------------------------------|
| • • • We do not | use th | e follo | wing data for av | erage | es, fits, li | mits, etc. • • • |
| 1400 ± 40 | | 13 | AUBERT | 09L | BABR | $B^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$ |
| $1470 + 6 + 72 \\ -7 - 255$ | | 14 | UEHARA | A80 | BELL | $10.6~e^{+}e^{-}\rightarrowe^{+}e^{-}\pi^{0}\pi^{0}$ |
| 1259 ± 55 | 2.6k | | BONVICINI | 07 | | $D^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| $1309\pm~1\pm~15$ | | 15 | BUGG | 07A | RVUE | $0.0 \ p \overline{p} \rightarrow 3\pi^0$ |
| 1449 ± 13 | 4286 | 16 | GARMASH | 06 | BELL | $B^+ \rightarrow K^+ \pi^+ \pi^-$ |
| $1350 \pm \! 50$ | | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$ |
| $1265 \pm 30 {+\atop -} {20\atop 35}$ | | | ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| $1434 \pm 18 \pm 9$ | 848 | | AITALA | 01 A | E791 | $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| 1308 ± 10 | | | BARBERIS | 99B | OMEG | $450 pp \rightarrow p_S p_f \pi^+ \pi^-$ |
| 1315 ± 50 | | | BELLAZZINI | 99 | GAM4 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| 1315 ± 30 | | | ALDE | 98 | GAM4 | $100 \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| 1280 ± 55 | | | BERTIN | 98 | OBLX | $0.05-0.405 \ \overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 1186 | | 17,18 | TORNQVIST | 95 | RVUE | $\pi\pi \rightarrow \pi\pi$, K \overline{K} , K π , $\eta\pi$ |
| 1472 ± 12 | | | ${\sf ARMSTRONG}$ | 91 | OMEG | 300 $pp \rightarrow pp\pi\pi$, $ppK\overline{K}$ |
| 1275 ± 20 | | | BREAKSTONE | 90 | SFM | 62 $pp \rightarrow pp\pi^+\pi^-$ |
| 1420 ± 20 | | | AKESSON | 86 | SPEC | 63 $pp \rightarrow pp\pi^+\pi^-$ |
| 1256 | | | FROGGATT | 77 | RVUE | $\pi^+\pi^-$ channel |

$K\overline{K}$ MODE

| VALUE (MeV) | DO CUMENT ID | | TE CN | COMMENT |
|-------------------------------|------------------|--------|-------------|----------------------------------------------------------------|
| • • • We do not use the follo | wing data for av | erage: | s, fits, li | mits, etc. • • • |
| 1440± 6 | VLADIMIRSK | .06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 1391 ± 10 | TIKHOMIROV | 03 | SPEC | $40.0 \ \pi^{-} C \rightarrow K_{S}^{0} K_{S}^{0} K_{I}^{0} X$ |
| 1440 ± 50 | BOLONKIN | 88 | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 1463± 9 | ETKIN | 82B | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| 1425 ± 15 | | | | $6 \pi N \rightarrow K^+ K^- N$ |
| ~ 1300 | POLYCHRO | 79 | STRC | $7 \pi^- p \rightarrow n2K_S^0$ |

4π MODE $2(\pi\pi)_S + \rho\rho$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------------|-----------------------|----------|---------|----------------------------------------------------------|
| • • • We do not us | se the followin | ng data for averag | es, fits | limits, | etc. • • • |
| 1395 ± 40 | | ABELE | 01 | | $0.0 \overline{\rho} d \rightarrow \pi^- 4\pi^0 \rho$ |
| 1374 ± 38 | | AMSLER | 94 | CBAR | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}3\pi^{0}$ |
| 1345 ± 12 | | ADAMO | 93 | OBLX | $\overline{n}p \rightarrow 3\pi^{+}2\pi^{-}$ |
| 1386 ± 30 | | GASPERO | 93 | DBC | $0.0 \overline{p} n \rightarrow 2\pi^{+} 3\pi^{-}$ |
| ~ 1410 | 5751 | ¹⁹ BETTINI | 66 | DBC | $0.0 \ \overline{p} \ n \rightarrow 2\pi^{+} \ 3\pi^{-}$ |
| $^{19} ho ho$ dominant. | | | | | |

| ηη MODE | | | | |
|-----------------------------------|---------------------------------|------|-------------|--------------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| • • • We do not use | e the following data for avera | ges, | fits, limit | s, etc. • • • |
| $1262 ^{+51}_{-78} ^{+82}_{-103}$ | ²⁰ UEHARA | 1 0A | BELL | 10.6 $e^+e^- ightarrowe^+e^-\eta\eta$ |
| 1430 | AMSLER | 92 | CBAR | $0.0 \overline{p} p \rightarrow \pi^0 \eta \eta$ |
| 1220 ± 40 | ALDE | 86D | GAM4 | $100 \pi^- p \rightarrow n2\eta$ |
| ²⁰ Breit-Wigner ma | ss. May also be the $f_0(1500)$ | | | |

COUPLED CHANNEL MODE

| • • • We do n | ot use the following data for averages, fits, limits, etc. • • • |
|-------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1306 ± 20 | ²¹ anisovich 03 rvue |
| ²¹ K-matrix p | ole from combined analysis of $\pi^- p \rightarrow \pi^0 \pi^0 n$, $\pi^- p \rightarrow K \overline{K} n$, |
| $\pi^+\pi^- \rightarrow \tau$ | ole from combined analysis of $\pi^- p \to \pi^0 \pi^0 n$, $\pi^- p \to K \overline{K} n$, $\pi^+ \pi^-$, $\overline{p} p \to \pi^0 \pi^0 \pi^0$, $\pi^0 \eta$, $\pi^0 \eta$, $\pi^0 \eta$, $\pi^+ \pi^- \eta^0$, $K^+ K^- \eta^0$, $K^0_S K^0_S \eta^0$, |
| | at rest, $\overline{p}n \rightarrow \pi^-\pi^-\pi^+$, $K^0_S K^-\pi^0$, $K^0_S K^0_S \pi^-$ at rest. |

DOCUMENT ID

f₀(1370) BREIT-WIGNER WIDTH

| VALUE | IVICV | | | |
|--------|-------|-----|----------|--|
| 200 to | 500 | OHR | ESTIMATE | |

| DO CUMENT | ID |
|-----------|----|
| | |

| | MODE | |
|------------|-------|--|
| <i>n n</i> | MODE | |
| VALL. | (MeV) | |

| VALUE | MeV) | | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|-----------------|----------------|----------|---------|---------|------------------|-------|-------------|--------------------------------------------------------------------|
| • • • | We do | not | use the | e follo | wing data for av | erage | s, fits, li | mits, etc. • • • |
| $300\pm$ | 80 | | | 22 | AUBERT | 09L | BABR | $B^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{\mp}$ |
| 90 + | $^{2}_{1}^{+}$ | 50 22 | | 23 | UEHARA | 08A | BELL | $10.6~e^+e^-\toe^+e^-\pi^0\pi^0$ |
| $298\pm$ | 21 | | 2.6k | | BONVICINI | 07 | CLEO | $D^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| $126\pm$ | 25 | | 4286 | 24 | GARMASH | 06 | BELL | $B^+ \rightarrow K^+ \pi^+ \pi^-$ |
| $265\pm$ | 40 | | | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$ |
| 350 ± 1 | 00 + 1 | 05 60 | | | ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| $173\pm$ | $32\pm$ | 6 | 848 | | AITALA | 01A | E791 | $D_s^+ \rightarrow \pi^- \pi^+ \pi^+$ |
| $222\pm$ | 20 | | | | BARBERIS | 99B | OMEG | $450 pp \rightarrow p_S p_f \pi^+ \pi^-$ |
| $255 \pm$ | 60 | | | | BELLAZZINI | 99 | GAM4 | $450 pp \rightarrow pp \pi^0 \pi^0$ |
| $190\pm$ | 50 | | | | ALDE | 98 | GAM4 | $100 \ \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| $323\pm$ | 13 | | | | BERTIN | 98 | OBLX | $0.05-0.405 \ \overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 350 | | | | 25,26 | TORNQVIST | 95 | RVUE | $\pi\pi \rightarrow \pi\pi$, $K\overline{K}$, $K\pi$, $\eta\pi$ |
| $195 \pm$ | 33 | | | | ARMSTRONG | 91 | OMEG | 300 $pp \rightarrow pp\pi\pi$, $ppK\overline{K}$ |
| $285 \pm$ | 60 | | | | BREAKSTONE | 90 | SFM | 62 $pp \rightarrow pp \pi^+ \pi^-$ |
| 460± | 50 | | | | AKESSON | 86 | SPEC | 63 $pp \rightarrow pp\pi^+\pi^-$ |
| ~ 400 | | | | 27 | FROGGATT | 77 | RVUE | $\pi^+\pi^-$ channel |
| | | | | | | | | |

KK MODE

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------------------|------------------------------|--------------|--------------------------------------------------|
| • • • We do not use | the following data for avera | ges, fits, l | imits, etc. • • • |
| $121\pm\ 15$ | VLADIMIRSK06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 55 ± 26 | TIKHOMIROV 03 | SPEC | 40.0 π^- C $\rightarrow K_S^0 K_S^0 K_I^0 X$ |
| $250\pm$ 80 | BOLONKIN 88 | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ |
| $118 {}^{+ 138}_{- 16}$ | ETKIN 82 | B MPS | $23 \pi^- \rho \rightarrow n2K_S^0$ |
| $160\pm~30$ | | | $6 \pi N \rightarrow K^+ K^- N$ |
| ~ 150 | POLYCHRO 79 | STRC | $7 \pi^- p \rightarrow n2K_S^0$ |

4π MODE $2(\pi\pi)_S + \rho\rho$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------------------|-----------------------|-----------|---------|--------------------------------------------------------|
| • • • We do not | use the followin | g data for averag | es, fits, | limits, | etc. • • • |
| 275 ± 55 | | ABELE | | | $0.0 \overline{p} d \rightarrow \pi^- 4\pi^0 p$ |
| 375 ± 61 | | AMSLER | 94 | CBAR | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}3\pi^{0}$ |
| 398 ± 26 | | ADAMO | 93 | OBLX | $\overline{n}p \rightarrow 3\pi^{+}2\pi^{-}$ |
| 310 ± 50 | | GASPERO | 93 | DBC | $0.0 \overline{p} n \rightarrow 2\pi^{+} 3\pi^{-}$ |
| ~ 90 | 5751 | ²⁸ BETTINI | 66 | DBC | $0.0 \overline{p} n \rightarrow 2\pi^{+} 3\pi^{-}$ |
| $28 \rho \rho$ dominant. | | | | | |

| VALUE (MeV) | DO CUMENT II | DO CUMENT ID | | COMMENT |
|---------------------------------|-------------------------|--------------|------------|-------------------------------------------------|
| • • • We do not use th | e following data for av | erages, | fits, limi | ts, etc. • • • |
| $484 + 246 + 246 \\ -170 - 263$ | ²⁹ UEHARA | 10A | BELL | $10.6~e^+e^-\rightarrow~e^+e^-\eta\eta$ |
| 250 | AMSLER | 92 | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \eta \eta$ |
| 320± 40 | ALDE | 86D | GA M4 | $100 \pi^- p \rightarrow n2\eta$ |

COUPLED CHANNEL MODE

| VALUE (MeV) | DOCUMENT ID | <u>TECN</u> |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not use t | he following data for averages, fit | s, limits, etc. • • • |
| $147 \begin{array}{l} +30 \\ -50 \end{array}$ | 30 ANISOVICH 03 | RVUE |
| | m combined analysis of $\pi^- p$ $\overline{p}p \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, $\pi^0 \pi^0 \eta$, $\overline{p}n \rightarrow \pi^- \pi^- \pi^+$, $K_S^0 K^- \pi^0$, | $\begin{array}{c} \rightarrow \pi^0 \pi^0 n, \pi^- p \rightarrow K \overline{K} n \\ \pi^+ \pi^- \pi^0, K^+ K^- \pi^0, K^0_S K^0_S \pi^0 \\ K^0_S K^0_S \pi^- \text{at rest.} \end{array}$ |

f₀(1370) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\pi\pi$ | seen |
| Γ_2 | 4π | seen |
| Γ_3 | $4\pi^0$ | seen |
| Γ_4 | $2\pi^{+}2\pi^{-}$ | seen |
| Γ_5 | $\pi^{+} \pi^{-} 2 \pi^{0}$ | seen |
| Γ_6 | ho ho | dominant |
| Γ_7 | $2(\pi\pi)_{S-wave}$ | seen |
| Γ ₈ | $\pi(1300)\pi$ | seen |

 $^{^{13}\,\}mathrm{Breit\text{--}Wigner}$ mass. $^{14}\,\mathrm{Breit\text{--}Wigner}$ mass. May also be the $\mathit{f}_{0}(1500).$

¹⁵ Reanalysis of ABELE 96c data.

¹⁶ Also observed by GARMASH 07 in $B^0 \to K_S^0 \, \pi^+ \, \pi^-$ decays. Supersedes GARMASH 05. 17 Uses data from BEIER 72B, OCHS 73, HYAMS 73, GRAYER 74, ROSSELET 77, CASON 83, ASTON 88, and ARMSTRONG 91B. Coupled channel analysis with flavor symmetry and all light two-pseudoscalars systems. 18 Also observed by ASNER 00 in $\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$ decays

²² The systematic errors are not reported.
23 Breit-Wigner width. May also be the $f_0(1500)$.
24 Also observed by GARMASH 07 in $B^0 \to K_S^0 \pi^+ \pi^-$ decays. Supersedes GARMASH 05.
25 Uses data from BEIER 72B, OCHS 73, HYAMS 73, GRAYER 74, ROSSELET 77, CASON 83, ASTON 88, and ARMSTRONG 91B. Coupled channel analysis with flavor symmetry and all light two-pseudoscalars systems.
26 Also observed by ASNER 00 in $\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$ decays

²⁷ Width defined as distance between 45 and 135° phase shift.

Meson Particle Listings $f_0(1370)$

| $\Gamma(\rho\rho)/\Gamma(2(\pi\pi)_{S-wave})$ | Γ ₆ /Ι |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | DOCUMENT ID TECN COMMENT |
| | ng data for averages, fits, limits, etc. \bullet \bullet BARBERIS 00C 450 $pp \rightarrow p_f 4\pi p_S$ |
| 1.6 ±0.2 | AMSLER 94 CBAR $\overline{p}p \rightarrow \pi^{+}\pi^{-}3\pi^{0}$ |
| ~ 0.65 | GASPERO 93 DBC $0.0 \overline{p} n \rightarrow \text{hadrons}$ |
| $\Gamma(\pi(1300)\pi)/\Gamma(4\pi)$ | Γ ₈ /I |
| | DOCUMENT ID TECN COMMENT ng data for averages, fits, limits, etc. • • • |
| 0.17 ± 0.06 | ABELE 01B CBAR 0.0 $\overline{p} d \rightarrow 5\pi p$ |
| $\Gamma(a_1(1260)\pi)/\Gamma(4\pi)$ VALUE | Г9/I <u>document id</u> <u>tecn</u> <u>comment</u> |
| | ng data for averages, fits, limits, etc. $ullet$ $ullet$ $ullet$ $ullet$ ABELE 01B CBAR $0.0~\overline{p}d ightarrow 5\pi p$ |
| $\Gamma(\eta\eta)/\Gamma(4\pi)$ | $\Gamma_{10}/\Gamma_2 = \Gamma_{10}/(\Gamma_3 + \Gamma_4 + \Gamma_5)$ |
| | DOCUMENT ID TECN COMMENT ng data for averages, fits, limits, etc. • • • |
| $(28 \pm 11) \times 10^{-3}$ $(4.7 \pm 2.0) \times 10^{-3}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 37 From a combined K-matrix $\pi^0\pi^0\eta)$, GAMS $(\pip ightarrow\pi^0\eta)$ | analysis of Crystal Barrel (0. $p\overline{p} \to \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \pi^0 n$, $\eta \eta n$, $\eta \eta' n$), and BNL $(\pi p \to K\overline{K} n)$ data. |
| Γ(Κͳ)/Γ _{total} VALUE | Γ ₁₁ , DOCUMENT ID TECN |
| $ullet$ $ullet$ $ullet$ We do not use the following 0.35 ± 0.13 | ng data for averages, fits, limits, etc. • • • BUGG 96 RVUE |
| Γ(Κ Κ)/Γ(ππ) | Γ ₁₁ /I |
| | ng data for averages, fits, limits, etc. • • • |
| 0.91 ± 0.20 38 E | ABLIKIM 05 BES2 $J/\psi 	o \phi \pi^+ \pi^-, \phi K^+ K$ BARGIOTTI 03 OBLX $\overline{p}p$ ANISOVICH 02D SPEC Combined fit |
| | BARBERIS 99D OMEG 450 $pp \rightarrow K^+K^-, \pi^+\pi^-$ |
| | $_{	au}^{+}\pi^{-}\pi^{0}$, $_{K}^{+}K^{-}\pi^{0}$, and $_{K}^{\pm}K_{S}^{0}\pi^{\mp}$ |
| ³⁹ From a combined K-matrix | analysis of Crystal Barrel (0. $p\overline{p} 	o \pi^0\pi^0\pi^0$, $\pi^0\eta$ π^0n , $\eta\eta n$, $\eta\eta' n$), and BNL $(\pi p 	o K\overline{K}n)$ data. |
| | |
| | Γ ₁₂ , DOCUMENT ID TECN COMMENT |
| • • We do not use the following | |
| | ng data for averages, itts, illints, etc. • • • |
| < 0.03 | GASPERO 93 DBC $0.0 \overline{p} n \rightarrow \text{hadrons}$ |
| | - |
| <0.03 Γ(6π)/Γ_{total} <u>MALUE</u> | GASPERO 93 DBC $0.0 \ \overline{p} \ n \rightarrow \text{hadrons}$ |
| <0.03 Γ(6π)/Γ_{total} <u>MALUE</u> | GASPERO 93 DBC $0.0 \ \overline{p} \ n \rightarrow \text{hadrons}$ |
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| ETKIN 82B PR D25 1786 A. Etkin et al. (BNL, CUNY, TÜFTS, VAND) WICKLUND 80 PRL 45 1469 A.B. Wicklund et al. (MPIM, CERN, ZEEM, CRAC) BECKER 79 PN B151 46 H. Becker et al. (MPIM, CERN, ZEEM, CRAC) POLYCHRO 79 PR D19 1317 V.A. Polychronakos et al. (MDAM, ANL) ROSSELET 77 PR D15 574 L. Rosselet et al. (GEVA, SACL) GRAYER 74 NP B75 189 G. Grayer et al. (CERN, MPIM) HYAMS 73 NP B64 134 B.D. Hyams et al. (CERN, MPIM) BEIER 72B PRL 29 511 EW. Beier et al. (PENN) | | | | | | |
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$h_1(1380)$

$$I^G(J^{PC}) = ?^-(1^{+-})$$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the $K\overline{K}\pi$ system. Needs confirmation

h₁(1380) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|---------------------|--------------|-----|------|-----------------------------------------------------|--|
| 1386±19 OUR AVERAGE | | | | | |
| 1440 ± 60 | ABELE | 97н | CBAR | $\overline{p}p \rightarrow K_I^0 K_S^0 \pi^0 \pi^0$ | |
| 1380 ± 20 | ASTON | 88c | LASS | 11 K ⁻ p → | |
| | | | | $K_S^0 K^{\pm} \pi^{\mp} \Lambda$ | |

h₁ (1380) WIDTH

| VALUE (MeV) | DO CUMENT ID | DO CUMENT ID | | COMMENT |
|-------------------|----------------------------|--------------|------|-----------------------------------------------------|
| 91±30 OUR AVERAGE | Error includes scale facto | | | |
| 170 ± 80 | ABELE | 97н | CBAR | $\overline{p}p \rightarrow K_I^0 K_S^0 \pi^0 \pi^0$ |
| 80 ± 30 | ASTON | 88c | LASS | 11 $K^-p \rightarrow$ |
| | | | | $K_S^0 K^{\pm} \pi^{\mp} \Lambda$ |

h1(1380) DECAY MODES

| | Mode | | | |
|-----------------|--------------------------------------|-----------------------------|-------|-------------|
| Γ ₁ | $K\overline{K}^*(892) + \text{c.c.}$ | | | |
| | | h ₁ (1380) REFER | ENCES | |
| ABELE AST ON | 97H PL B415 1 88C PL B201 5 | | (-1) | ab.) US) |
| | | - | 0.6 | |

$\pi_1(1400)$

$$I^{G}(J^{PC}) = 1^{-}(1^{-+})$$

See also the mini-review under non- $q\overline{q}$ candidates in PDG 06, Journal of Physics, G **33** 1 (2006).

$\pi_1(1400)$ MASS

| VALUE | (MeV) | | EVTS | DO CUMENT ID | | TECN C | HG | COMMENT |
|-------|----------|----------------|---------|--------------------|---------|-------------|-----|------------------------------------------------------|
| 1354 | ±25 | OUR | AVERAGE | Error includes sc | ale fac | tor of 1.8. | See | the ideogram below. |
| 1257 | ± 20 | ± 25 | 23.5k | ADAMS | 07в | B852 | | $18 \pi^- p \rightarrow \eta \pi^0 n$ |
| 1384 | ± 20 | ± 35 | 90k | SALVINI | 04 | OBLX | | $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| 1360 | ± 25 | | | ABELE | 99 | CBAR | | $0.0 \ \overline{p}p \rightarrow \pi^0 \pi^0 \eta$ |
| 1400 | ±20 | ± 20 | | ABELE | 98B | CBAR | | $0.0 \overline{p} n \rightarrow \pi^- \pi^0 \eta$ |
| 1370 | ± 16 | $^{+50}_{-30}$ | | $^{ m 1}$ THOMPSON | 97 | MPS | | 18 $\pi^- \rho \rightarrow \eta \pi^- \rho$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

1406 \pm 20 3 ALDE 88B GAM4 0 $100~\pi^-p \to \eta \pi^0 n$ 1 Natural parity exchange, questioned by DZIERBA 03. $\frac{1}{2}$ Unnatural parity exchange.

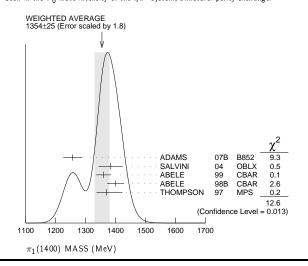
93 BKEI

 $\pi^- p \rightarrow \eta \pi^- p$

onnatural parity exchange. 3 Seen in the P_0 -wave intensity of the $\eta\pi^0$ system, unnatural parity exchange.

² AOYAGI

 1323.1 ± 4.6



$\pi_1(1400)$ WIDTH

| VALUE (N | leV) | EVTS | DO CUMENT ID | | TECN CHG | COMMENT |
|----------|------------------------------------------------------|---------------|-----------------------|--------|-------------------|------------------------------------------------------------|
| 330 ±3 | 35 OUR A | VERAGE | | | | |
| 354 ± | 64 ± 58 | 23.5k | ADAMS | 07в | B852 | $18 \pi^- p \rightarrow \eta \pi^0 n$ |
| 378 ±5 | 50 ± 50 | 90k | SALVINI | 04 | OBLX | $\overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| 220 ±9 | 90 | | ABELE | 99 | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \eta$ |
| 310 ±5 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | ABELE | 98в | CBAR | $0.0 \; \overline{p} n \rightarrow \; \pi^- \pi^0 \eta$ |
| 385 ±4 | $^{+0}_{-105}$ | | ⁴ THOMPSON | 97 | MPS | 18 $\pi^- p \rightarrow \eta \pi^- p$ |
| • • • V | Ve do not us | se the follow | ing data for avera | ges, f | its, limits, etc. | • • • |
| 143.2± | 12.5 | | ⁵ AOYAGI | 93 | BKEI | $\pi^- p \rightarrow \eta \pi^- p$ |
| 180 ±2 | 20 | | ⁶ ALDE | 88B | GA M4 0 | $100 \ \pi^- \rho \rightarrow \eta \pi^0 n$ |
| 4 Dece | dution is no | t unfolded | natural navitur aval | | guestioned by | DZIEDDA 02 |

 4 Resolution is not unfolded, natural parity exchange, questioned by DZIERBA 03.

⁵ Unnatural parity exchange.

 6 Seen in the P_0 -wave intensity of the $\eta\pi^0$ system, unnatural parity exchange.

π_1 (1400) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|-----------------------|-------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\eta\pi^0$ | seen |
| Γ_2 | $\dot{\eta}\pi^-$ | seen |
| Γ3 | $\eta'\pi$ | |

$\pi_1(1400)$ BRANCHING RATIOS

| $\Gamma(\eta\pi^0)/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|---------------------------------------|------------------------|-----------|-----------|--------|--------------------------------------------------------|
| VALUE | DO CUMENT | ID | TECN | CHG | COMMENT |
| • • • We do not use the fo | llowing data for avera | ges, fits | , limits, | etc. • | • • |
| not seen | PROKOSHI | KIN 95B | GAM4 | | 100 $\pi^- \rho \rightarrow$ |
| not seen | ⁷ BUGG | 94 | RVUE | | $\eta \pi^0 n$ $\overline{p}p \rightarrow \eta 2\pi^0$ |
| not seen | ⁸ APEL | 81 | NICE | 0 | 40 $\pi^- p \rightarrow$ |
| | | | | | $\eta \pi^{0} n$ |

⁷Using Crystal Barrel data.

 8 A general fit allowing S, D, and P waves (including $m{=}0$) is not done because of limited statistics.

| $\Gamma(\eta \pi^-)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
|-----------------------------------------------------|--------------------------|-------------|------------------|----------------------------|
| VALUE | DO CUMENT ID | TE | CN COMMEN | T |
| \bullet \bullet \bullet We do not use the fol | lowing data for averages | , fits, lin | nits, etc. • • • | • |
| possibly seen | BELADIDZE | 93 VE | ES $37\pi^- N$ | $\rightarrow \eta \pi^- N$ |

| $\Gamma(\eta'\pi)/\Gamma(\eta\pi^0)$ | | | | ļ | Г3/Г1 |
|--------------------------------------|----------------|---------------------------|-----------|----------------------------------------|-------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not us | e the followin | g data for averages, fits | , limits, | etc. • • • | |
| < 0.80 | 95 | BOUTEMEUR 90 | GA M4 | $100 \ \pi^- p \rightarrow 4 \gamma p$ | 1 |

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| ABELE | 99 | PL B446 349 | A. Abele et al. | (Crystal Barrel Collab.) |
| ABELE | 98 B | PL B423 175 | A. Abele et al. | (Crystal Barrel Collab.) |
| THOMPSON | 97 | PRL 79 1630 | D.R. Thompson et al. | (BNL E852 Collab.) |
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| | | Translated from YAF 58 | 662. | |
| BUGG | 94 | PR D50 4412 | D.V. Bugg et al. | (LOQM) |
| A OYA GI | 93 | PL B314 246 | H. Aoyagi et al. | (BKEI Collab.) |
| BELADIDZE | 93 | PL B313 276 | G.M. Beladidze et al. | (VES Collab.) |
| BOUTEMEUR | 90 | Hadron 89 Conf. p 119 | M. Boutemeur, M. Poulet | (SERP, BELG, LANL+) |
| ALDE | 88 B | PL B205 397 | D.M. Alde et al. (S | SERP, BELG, LANL, LAPP) IGJPC |
| APEL | 81 | NP B193 269 | W.D. Apel et al. | (SERP, CERN) |
| | | | | |

$$\eta(1405)$$

$$I^{G}(J^{PC}) = 0^{+}(0^{-}+)$$

THE $\eta(1405)$, $\eta(1475)$, $f_1(1420)$, AND $f_1(1510)$

Revised February 2012 by C. Amsler (Zürich) and A. Masoni (INFN Cagliari).

The first observation of the $\eta(1440)$ was made in $p\overline{p}$ annihilation at rest into $\eta(1440)\pi^+\pi^-$, $\eta(1440)\to K\overline{K}\pi$ [1]. This state was reported to decay through $a_0(980)\pi$ and $K^*(892)\overline{K}$ with roughly equal contributions. The $\eta(1440)$ was also observed in radiative $J/\psi(1S)$ decay into $K\overline{K}\pi$ [2–4] and $\gamma\rho$ [5]. There is evidence for the existence of two pseudoscalars in this mass region, the $\eta(1405)$ and $\eta(1475)$. The former decays mainly through $a_0(980)\pi$ (or direct $K\overline{K}\pi$) and the latter mainly to $K^*(892)\overline{K}$.

The simultaneous observation of two pseudoscalars is reported in three production mechanisms: π^-p [6,7]; radiative $J/\psi(1S)$ decay [8,9]; and $\overline{p}p$ annihilation at rest [10–13]. All of them give values for the masses, widths, and decay modes in reasonable agreement. However, Ref. [9] favors a state decaying into $K^*(892)\overline{K}$ at a lower mass than the state decaying into $a_0(980)\pi$. In $J/\psi(1S)$ radiative decay, the $\eta(1405)$ decays into $K\overline{K}\pi$ through $a_0(980)\pi$, and hence a signal is also expected in the $\eta\pi\pi$ mass spectrum. This was indeed observed by MARK III in $\eta\pi^+\pi^-$ [14], which reports a mass of 1400 MeV, in line with the existence of the $\eta(1405)$ decaying into $a_0(980)\pi$.

BES [15] reports an enhancement in $K^+K^-\pi^0$ around 1.44 GeV in $J/\psi(1S)$ decay, recoiling against an ω (but not a ϕ) without resolving the presence of two states nor performing a spin-parity analysis, due to low statistics. This state could also be the $f_1(1420)$ (see below). On the other hand, BES observes $\eta(1405) \to \eta \pi \pi$ in $J/\psi(1S)$ decay, recoiling against an ω [16].

The $\eta(1405)$ is also observed in $\overline{p}p$ annihilation at rest into $\eta \pi^+ \pi^- \pi^0 \pi^0$, where it decays into $\eta \pi \pi$ [17]. The intermediate $a_0(980)\pi$ accounts for roughly half of the $\eta \pi \pi$ signal, in agreement with MARK III [14] and DM2 [4].

However, the issue remains controversial as to whether two pseudoscalar mesons really exist. According to Ref. [18] the splitting of a single state could be due to nodes in the decay amplitudes which differ in $\eta\pi\pi$ and $K^*(892)\overline{K}$. Based on the isospin violating decay $J/\psi(1S) \to \gamma 3\pi$ observed by BES [19] the splitting could also be due to a triangular singularity mixing $\eta\pi\pi$ and $K^*(892)\overline{K}$ [20].

The $\eta(1295)$ has been observed by four π^-p experiments [7,21–23], and evidence is reported in $\overline{p}p$ annihilation [24–26].

In $J/\psi(1S)$ radiative decay, an $\eta(1295)$ signal is evident in the 0^{-+} $\eta\pi\pi$ wave of the DM2 data [9]. Also BaBar [27] reports evidence for a signal around 1295 MeV in B decays into $\eta\pi\pi K$. However, the existence of the $\eta(1295)$ is questioned in Refs. [18] and [28]. The authors claim a single pseudoscalar meson in the 1400 MeV region. This conclusion is based on properties of the wave functions in the 3P_0 model (and on an unpublished analysis of the annihilation $\bar{p}p \to 4\pi\eta$). The pseudoscalar signal around 1400 MeV is then attributed to the first radial excitation of the η .

Assuming establishment of the $\eta(1295)$, the $\eta(1475)$ could be the first radial excitation of the η' , with the $\eta(1295)$ being the first radial excitation of the η . Ideal mixing, suggested by the $\eta(1295)$ and $\pi(1300)$ mass degeneracy, would then imply that the second isoscalar in the nonet is mainly $s\bar{s}$, and hence couples to $K^*\bar{K}$, in agreement with properties of the $\eta(1475)$. Also, its width matches the expected width for the radially excited $s\bar{s}$ state [29,30]. A study of radial excitations of pseudoscalar mesons [31] favors the $s\bar{s}$ interpretation of the $\eta(1475)$. However, due to the strong kinematical suppression the data are not sufficient to exclude a sizeable $s\bar{s}$ admixture also in the $\eta(1405)$.

The $K\overline{K}\pi$ and $\eta\pi\pi$ channels were studied in $\gamma\gamma$ collisions by L3 [32]. The analysis led to a clear $\eta(1475)$ signal in $K\overline{K}\pi$, decaying into $K^*\overline{K}$, very well identified in the untagged data sample, where contamination from spin 1 resonances is not allowed. At the same time, L3 [32] did not observe the $\eta(1405)$, neither in $K\overline{K}\pi$ nor in $\eta\pi\pi$. The observation of the $\eta(1475)$, combined with the absence of an $\eta(1405)$ signal, strengthens the two-resonances hypothesis. Since gluonium production is presumably suppressed in $\gamma\gamma$ collisions, the L3 results [32] suggest that $\eta(1405)$ has a large gluonic content (see also Refs. [33] and [34]).

The L3 result is somewhat in disagreement with that of CLEO-II, which did not observe any pseudoscalar signal in $\gamma\gamma \to \eta(1475) \to K_S^0 K^{\pm}\pi^{\mp}$ [35]. However, more data are required. Moreover, after the CLEO-II result, L3 performed a further analysis with full statistics [36], confirming their previous evidence for the $\eta(1475)$. The CLEO upper limit [35] for $\Gamma_{\gamma\gamma}(\eta(1475))$, and the L3 results [36], are consistent with the world average for the $\eta(1475)$ width.

BaBar [27] also reports the $\eta(1475)$ in B decays into $K\bar{K}^*$ recoiling against a K, but upper limits only are given for the $\eta(1405)$. As mentioned above, in B decays into $\eta\pi\pi K$ the $\eta(1295) \to \eta\pi\pi$ is observed while only upper limits are given for the $\eta(1405)$. The $f_1(1420)$ (and the $f_1(1285)$) are not seen.

The gluonium interpretation for the $\eta(1405)$ is not favored by lattice gauge theories which predict the 0^{-+} state above 2 GeV [37,38] (see also the article on the "Quark model" in this issue of the Review). However, the $\eta(1405)$ is an excellent candidate for the 0^{-+} glueball in the fluxtube model [39]. In this model, the 0^{++} $f_0(1500)$ glueball is also naturally related to a 0^{-+} glueball with mass degeneracy broken in QCD. Also, Ref. 40 shows that the pseudoscalar glueball could lie at a lower

$\eta(1405)$

mass than predicted from lattice calculation. In this model the $\eta(1405)$ appears as the natural glueball candidate (see also Refs. [41] and [42]). A detailed review of the experimental situation is available in Ref. 43.

Let us now deal with 1⁺⁺ isoscalars. The $f_1(1420)$, decaying into $K^*\overline{K}$, was first reported in π^-p reactions at 4 GeV/c [44]. However, later analyses found that the 1400–1500 MeV region was far more complex [45–47]. A reanalysis of the MARK III data in radiative $J/\psi(1S)$ decay into $K\overline{K}\pi$ [8] shows the $f_1(1420)$ decaying into $K^*\overline{K}$. Also, a C=+1 state is observed in tagged $\gamma\gamma$ collisions (e.g., Ref. 48).

In $\pi^- p \to \eta \pi \pi n$ charge-exchange reactions at 8–9 GeV/c the $\eta \pi \pi$ mass spectrum is dominated by the $\eta(1440)$ and $\eta(1295)$ [21,49], and at 100 GeV/c Ref. 22 reports the $\eta(1295)$ and $\eta(1440)$ decaying into $\eta \pi^0 \pi^0$ with a weak $f_1(1285)$ signal, and no evidence for the $f_1(1420)$.

Axial (1⁺⁺) mesons are not observed in $\overline{p}p$ annihilation at rest in liquid hydrogen, which proceeds dominantly through S-wave annihilation. However, in gaseous hydrogen, P-wave annihilation is enhanced and, indeed, Ref. 11 reports $f_1(1420)$ decaying into $K^*\overline{K}$. The $f_1(1420)$, decaying into $K\overline{K}\pi$, is also seen in pp central production, together with the $f_1(1285)$. The latter decays via $a_0(980)\pi$, and the former only via $K^*\overline{K}$, while the $\eta(1440)$ is absent [50,51]. The $K_SK_S\pi^0$ decay mode of the $f_1(1420)$ establishes unambiguously C=+1. On the other hand, there is no evidence for any state decaying into $\eta\pi\pi$ around 1400 MeV, and hence the $\eta\pi\pi$ mode of the $f_1(1420)$ must be suppressed [52].

We now turn to the experimental evidence for the $f_1(1510)$. Two states, the $f_1(1420)$ and $f_1(1510)$, decaying into $K^*\overline{K}$, compete for the $s\overline{s}$ assignment in the 1^{++} nonet. The $f_1(1510)$ was seen in $K^-p\to \Lambda K\overline{K}\pi$ at 4 GeV/c [53], and at 11 GeV/c [54]. Evidence is also reported in π^-p at 8 GeV/c, based on the phase motion of the 1^{++} $K^*\overline{K}$ wave [47]. A somewhat broader 1^{++} signal is also observed in $J/\psi(1S)\to \gamma\eta\pi^+\pi^-$ [55] as well as a small signal in $J/\psi(1S)\to \gamma\eta'\pi^+\pi^-$, attributed to the $f_1(1510)$ [56].

The absence of $f_1(1420)$ in K^-p [54] argues against the $f_1(1420)$ being the $s\overline{s}$ member of the 1^{++} nonet. However, the $f_1(1420)$ was reported in K^-p but not in π^-p [57], while two experiments do not observe the $f_1(1510)$ in K^-p [57,58]. The latter is also not seen in central collisions [51], or $\gamma\gamma$ collisions [59], although, surprisingly for an $s\overline{s}$ state, a signal is reported in 4π decays [60]. These facts lead to the conclusion that $f_1(1510)$ is not well established [61].

Assigning the $f_1(1420)$ to the 1⁺⁺ nonet, one finds a nonet mixing angle of $\sim 50^{\circ}$ [61]. However, arguments favoring the $f_1(1420)$ being a hybrid $q\overline{q}g$ meson, or a four-quark state, were put forward in Refs. [62] and [63], respectively, while Ref. 64 argued for a molecular state formed by the π orbiting in a P-wave around an S-wave $K\overline{K}$ state.

Summarizing, there is convincing evidence for the $f_1(1420)$ decaying into $K^*\overline{K}$, and for two pseudoscalars (possibly one dynamically split into two) in the $\eta(1440)$ region, the $\eta(1405)$

and $\eta(1475)$, decaying into $a_0(980)\pi$ and $K^*\overline{K}$, respectively. The $f_1(1510)$ is not well established.

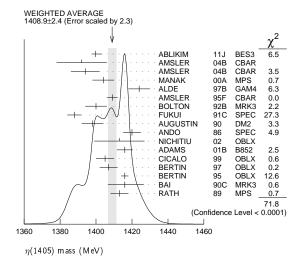
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η(1405) MASS

1408.9±2.4 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 2.3. See the ideogram below.

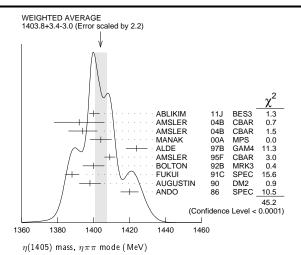


$\eta\pi\pi$ MODE

DOCUMENT ID TECN COMMENT The data in this block is included in the average printed for a previous datablock.

1403.8+ 3.4 OUR AVERAGE Error includes scale factor of 2.2. See the ideogram

| 1403.0 - 3.0 OUR AVERAGE | Error includes sca | ie factor of 2. | z. See the ideogram |
|-----------------------------------|-----------------------|-------------------|-------------------------------------------------------------|
| below. | | | |
| $1399.8 \pm 2.2 ^{+2.8}_{-0.1}$ | ¹ ABLIKIM | 11J BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| 1392 ± 14 900 \pm 375 | AMSLER | 04B CBAR | $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \eta$ |
| 1394 \pm 8 6.6 \pm 2.0k | AMSLER | 04B CBAR | $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0 \pi^0 \eta$ |
| 1404 ± 6 9082 | MANAK | 00A MPS | 18 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 1424 ± 6 2200 | ALDE | 97B GAM4 | $100 \pi^{-} p \rightarrow \eta \pi^{0} \pi^{0} n$ |
| 1409 ± 3 | AMSLER | 95F CBAR | $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0 \pi^0 \eta$ |
| 1400 ± 6 | ² BOLTON | 92B MRK3 | $J/\psi \rightarrow \gamma \eta \pi^{+} \pi^{-}$ |
| 1388 ± 4 | FUKUI | 91c SPEC | 8.95 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 1398 ± 6 261 | ³ AUGUSTIN | 90 DM2 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 1420 ± 5 | ANDO | 86 SPEC | $8 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| • • • We do not use the following | ing data for averag | ges, fits, limits | , etc. • • • |
| 1205 7 | DAI | 00 DEC | + - |



$K\overline{K}\pi$ MODE $(a_0(980)\pi$ or direct $K\overline{K}\pi)$

TECN <u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

The data in this block is included in the average printed for a previous datablock.

| | | | - | | |
|--------------------|---------------|-----------------------|--------|------------|--------------------------------------------------------------------------|
| 1413.9± 1.7 0 | OUR AVERAG | E Error includ | es sca | ile factor | of 1.1. |
| $1413 \ \pm 14$ | 3651 | ⁴ NICHITIU | 02 | OBLX | |
| 1416 \pm 4 \pm | 2 20k | ADAMS | | | 18 GeV $\pi^- p \rightarrow K^+ K^- \pi^0 n$ |
| 1405 ± 5 | | ⁵ CICALO | 99 | OBLX | $0 \overline{p} p \rightarrow K^{\pm} K_S^0 \pi^{\mp} \pi^+ \pi^-$ |
| 1407 ± 5 | | ⁵ BERTIN | 97 | OBLX | $0 \overline{p} p \rightarrow K^{\pm} (K^{0}) \pi^{\mp} \pi^{+} \pi^{-}$ |
| $1416~\pm~2$ | | ⁵ BERTIN | 95 | OBLX | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$ |
| 1416 \pm 8 $^+$ | 7 700 | ⁶ BAI | 90c | MRK3 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| $1413\ \pm\ 5$ | | ⁶ RATH | | | $21.4 \ \pi^- p \rightarrow n K_S^0 K_S^0 \pi^0$ |
| • • • We do r | ot use the fo | llowing data for | avera | ges, fits, | limits, etc. • • • |
| $1459\ \pm\ 5$ | | ⁷ AUGUSTIN | 92 | DM2 | $J/\psi \rightarrow \gamma K \overline{K} \pi$ |
| | | | | | |

$\pi\pi\gamma$ MODE

| " " / " OD = | | | | | |
|----------------------|----------------|-------------------------|---------|-----------|---------------------------------------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1390±12 | 235 ± 91 | AMSLER | 04в | CBAR | $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$ |
| • • • We do not | use the follow | ing data for averag | es, fit | s, limits | , etc. • • • |
| $1424 \pm 10 \pm 11$ | 547 | BAI | 04 J | BES2 | $J/\psi \rightarrow \gamma \gamma \pi^{+} \pi^{-}$ |
| 1401 ± 18 | | ^{8,9} AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \pi^+ \pi^- \gamma \gamma$ |
| 1432 ± 8 | | ⁹ COFFMAN | 90 | MRK3 | $J/\psi \rightarrow \pi^+ \pi^- 2\gamma$ |
| 4π MODE | | | | | |

| VALUE (MeV) | EVTS | DO CUMENT IE |) | TECN | COMMENT |
|-------------------|---------------|-----------------------|----------|------------|-----------------------------------------------------|
| • • • We do not u | se the follow | ving data for aver | ages, fi | ts, limits | , etc. • • • |
| 1420 ± 20 | | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 1489 ± 12 | 3270 | ¹⁰ BISELLO | 89B | DM2 | $J/\psi \rightarrow 4\pi\gamma$ |

$K\overline{K}\pi$ MODE (unresolved)

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|------------------|-------------------------|--------|-------------|-----------------------------------------------------------------|
| • • • We do | not use the fo | ollowing data for av | erages | , fits, lin | nits, etc. • • • |
| 1437.6 ± 3.2 | 249 ± 35^{1} | ^{1,12} ABLIKIM | 08E | BES2 | $J/\psi \rightarrow \omega K_S^0 K^+ \pi^- + \text{c.c.}$ |
| 1445.9 ± 5.7 | 62 \pm 18 1 | ^{1,12} ABLIKIM | 08E | BES2 | $J/\psi \rightarrow \omega K^{+} K^{-} \pi^{0}$ |
| 1442 ± 10 | 410 | ¹¹ BAI | 98c | BES | $J/\psi \rightarrow \gamma K^+ K^- \pi^0$ |
| 1445 ± 8 | 693 | ¹¹ AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| 1433 ± 8 | 296 | ¹¹ AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma K^+ K^- \pi^0$ |
| 1413 ± 8 | 500 | ¹¹ DUCH | 89 | ASTE | $\overline{p}p \rightarrow \pi^{+}\pi^{-}K^{\pm}\pi^{\mp}K^{0}$ |
| 1453 ± 7 | 170 | ¹¹ RATH | 89 | MPS | 21.4 $\pi^- p \rightarrow K_S^0 K_S^0 \pi^0 n$ |
| 1419 ± 1 | 8800 | ¹¹ BIRMAN | 88 | MPS | $8 \pi^- p \rightarrow K^+ \overline{K}^0 \pi^- n$ |
| 1424 ± 3 | 620 | ¹¹ REEVES | 86 | SPEC | 6.6 $p\overline{p} \rightarrow K\overline{K}\pi X$ |
| 1421 ± 2 | | ¹¹ CHUNG | 85 | SPEC | $8 \pi^- p \rightarrow K \overline{K} \pi n$ |
| $1440 \ \ \begin{array}{c} +20 \\ -15 \end{array}$ | 174 | ¹¹ EDWARDS | 82E | CBAL | $J/\psi \rightarrow \gamma K^+ K^- \pi^0$ |
| $1440 {}^{+\ 10}_{-\ 15}$ | | ¹¹ SCHARRE | 80 | MRK2 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| $1425 \ \pm \ 7$ | 800 ¹ | ^{1,13} BAILLON | 67 | HBC | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$ |

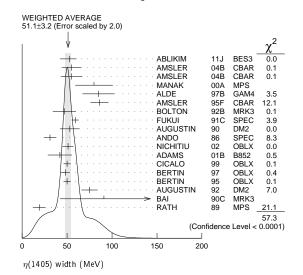
- ¹ The selected process is $J/\psi \rightarrow \omega a_0(980) \pi$.
- ² From fit to the $a_0(980) \pi 0^{-}$ + partial wave.
- ³Best fit with a single Breit Wigner.
- 4 Decaying dominantly directly to $K^+K^-\pi^0$. 5 Decaying into $(K\overline{K})_S\pi$, $(K\pi)_S\overline{K}$, and $a_0(980)\pi$. 6 From fit to the $a_0(980)\pi^0$ + partial wave. Cannot rule out a $a_0(980)\pi^1$ + + partial wave.
- $7\,\mbox{wave}.$ $7\,\mbox{Excluded}$ from averaging because averaging would be meaningless.
- ⁸Best fit with a single Breit Wigner.
- 9 This peak in the $\gamma \rho$ channel may not be related to the $\eta(1405)$. $^{
 m 10}\,{\rm Estimated}$ by us from various fits.
- 11 These experiments identify only one pseudoscalar in the 1400–1500 range. Data could

also refer to $\eta(1475)$.

 $\eta(1405)$

η(1405) WIDTH

51.1±3.2 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 2.0. See the ideogram below.

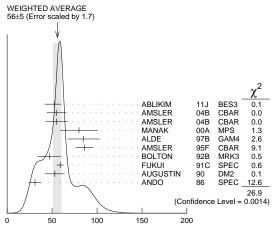


$\eta\pi\pi$ MODE

 VALUE (MeV)
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 The data in this block is included in the average printed
 for a previous datablock.

| 56 | ± 5 | OUR AVERAGE | Error includes scale | factor of 1.7. | See the ideogram below. |
|-----|----------|----------------|------------------------|----------------|---------------------------------------------------------------------|
| 52. | 8± 7.6 | + 0.1 - 7.6 | ¹⁴ ABLIKIM | 11」BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| 55 | ± 11 | 900 ± 375 | AMSLER | 04B CBAR | $0 \overline{\rho} \rho \rightarrow \pi^+ \pi^- \pi^+ \pi^- \eta$ |
| 55 | ± 12 | $6.6\pm2.0k$ | AMSLER | 04B CBAR | $0 \overline{\rho} \rho \rightarrow \pi^+ \pi^- \pi^0 \pi^0 \gamma$ |
| 80 | ± 21 | 9082 | MANAK | | 18 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 85 | ± 18 | 2200 | ALDE | 97B GAM4 | $100 \pi^- p \rightarrow \eta \pi^0 \pi^0 n$ |
| 86 | ± 10 | | AMSLER | 95 F CBAR | $0 \overline{p} \rho \rightarrow \pi^+ \pi^- \pi^0 \pi^0 \eta$ |
| 47 | ± 13 | | ¹⁵ BOLTON | 92B MRK | $3 J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 59 | ± 4 | | FUKUI | 91∈ SPEC | 8.95 $\pi^- p \to \eta \pi^+ \pi^- n$ |
| 53 | ± 11 | | ¹⁶ AUGUSTIN | 90 DM2 | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 31 | ± 7 | | ANDO | 86 SPEC | $8 \pi^- p \rightarrow n \pi^+ \pi^- n$ |



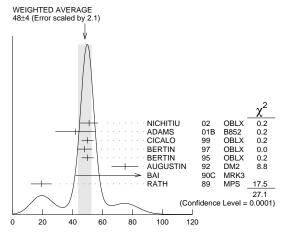
 η (1405) width $\eta\pi\pi$ mode (MeV)

$K\overline{K}\pi$ MODE $(a_0(980)\pi$ or direct $K\overline{K}\pi)$

VALUE (MeV) EVTS DOCUMENT ID TECN COMMENT

The data in this block is included in the average printed for a previous datablock

| 48± 4 OUR A | VERAGE | Error includes sca | le fac | tor of 2. | See the ideogram below. |
|----------------------------|--------|------------------------|--------|-----------|----------------------------------------------------------------------------------|
| 51± 6 | 3651 | ¹⁷ NICHITIU | 02 | OBLX | |
| $42\pm10\pm 9$ | 20k | A DA MS | 01B | B852 | 18 GeV $\pi^- p \rightarrow K^+ K^- \pi^0 n$ |
| 50± 4 | | CICALO | 99 | OBLX | $0 \overline{p} p \rightarrow K^{\pm} K_{5}^{0} \pi^{\mp} \pi^{+} \pi^{-}$ |
| 48± 5 | | 18 BERTIN | 97 | OBLX | $0.0 \overline{p}p \rightarrow K^{\pm}(K^{0}) \pi^{\mp} \pi^{+} \pi^{-}$ |
| 50± 4 | | ¹⁸ BERTIN | 95 | OBLX | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$ |
| 75 ± 9 | | AUGUSTIN | 92 | DM2 | $J/\psi \rightarrow \gamma K \overline{K} \pi$ |
| $91 + 67 + 15 \\ -31 - 38$ | | ¹⁹ BAI | | | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| $19\pm~7$ | | ¹⁹ RATH | 89 | MPS | $21.4 \ \pi^- p \rightarrow n K_S^0 K_S^0 \pi^0$ |



 $\eta(1405)$ width $K\,\overline{K}\,\pi$ mode ($a_0(980)\,\pi$ dominant)

$\pi\pi\gamma$ MODE

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|------------------|--------|-----------|---------------------------------------------------------------|
| 64 ±18 | 235 ± 91 | AMSLER | 04в | CBAR | $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^+ \pi^- \gamma$ |
| ● ● We do not | use the following | data for average | s, fit | s, limits | , etc. • • • |
| $101.0 \pm 8.8 \pm 8.8$ | 547 | BAI | 04 J | BES2 | $J/\psi \rightarrow \gamma \gamma \pi^{+} \pi^{-}$ |
| 174 ±44 | | AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \pi^+ \pi^- \gamma \gamma$ |
| 90 +26 | 2 | O COFEMAN | 90 | MRK3 | $1/\psi \rightarrow \pi^{+}\pi^{-}2\gamma$ |

4π MODE

ı

| VALUE (MeV) | EVTS | DO CUMENT II | ם כ | TECN | COMMENT |
|--------------------|----------------|-----------------------|-----------|------------|-----------------------------------------------------|
| • • • We do not us | se the followi | ng data for ave | rages, fi | ts, limits | , etc. • • • |
| 160 ± 30 | | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 144 ± 13 | 3270 | ²¹ BISELLO | 89B | DM2 | $J/\psi \rightarrow 4\pi\gamma$ |

$K\overline{K}\pi$ MODE (unresolved)

| | | , | | | |
|----------------|---------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| E (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| • We do | not use the | following data for av | erages | , fits, lin | nits, etc. • • • |
| 9± 9.0 | 249 ± 35 | 22,23 ABLIKIM | 08E | BES2 | $J/\psi \rightarrow \omega K_S^0 K^+ \pi^- + \text{c.c.}$ |
| 2 ± 18.5 | 62 ± 18 | | 08E | BES2 | $J/\psi \rightarrow \omega K^{+}K^{-}\pi^{0}$ |
| ± 14 | 296 | ²² AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma K^+ K^- \pi^0$ |
| ± 10 | 693 | ²² AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| ± 16 | 500 | ²² DUCH | 89 | ASTE | $\overline{p}p \rightarrow K \overline{K} \pi \pi \pi$ |
| ± 11 | 170 | ²² RATH | 89 | MPS | $21.4 \pi^- p \rightarrow K_S^0 K_S^0 \pi^0 n$ |
| ± 2 | 8800 | ²² BIRMAN | 88 | MPS | $8 \pi^- p \rightarrow K^+ \overline{K}^0 \pi^- n$ |
| ± 10 | 620 | ²² REEVES | 86 | SPEC | 6.6 $p\overline{p} \rightarrow KK\pi X$ |
| ± 10 | | ²² CHUNG | 85 | SPEC | $8 \pi^- p \rightarrow K \overline{K} \pi n$ |
| $^{+20}_{-30}$ | 174 | ²² EDWARDS | 82E | CBAL | $J/\psi \rightarrow \gamma K^+ K^- \pi^0$ |
| $^{+30}_{-20}$ | | ²² SCHARRE | 80 | MRK2 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| ± 10 | 800 | ^{22,24} BAILLON | 67 | нвс | $0.0 \ \overline{p} p \rightarrow K \ \overline{K} \pi \pi \pi$ |
| | • We do 9± 9.0 2±18.5 ±14 ±10 ±16 ±11 ± 2 ±10 +20 -30 +30 -20 | • We do not use the 9± 9.0 249 ± 35 2±18.5 62 ± 18 ±14 296 ±10 693 ±16 500 ±11 170 ± 2 8800 ±10 620 ±10 +20 -30 174 +30 -20 | ● We do not use the following data for av 9± 9.0 249±35 22,23 ABLIKIM 2±18.5 62±18 22,23 ABLIKIM ±14 296 22 AUGUSTIN ±10 693 22 AUGUSTIN ±16 500 22 DUCH ±11 170 22 RATH ± 2 8800 22 BIRMAN ±10 620 22 REEVES ±10 22 CHUNG +20 30 174 22 EDWARDS +30 22 SCHARRE | • We do not use the following data for averages 9 ± 9.0 249 ± 35 22.23 ABLIKIM 08E 2±18.5 62 ± 18 22.23 ABLIKIM 08E ± 14 296 22 AUGUSTIN 90 ± 10 693 22 AUGUSTIN 90 ± 11 170 22 RATH 89 ± 11 170 22 RATH 89 ± 2 8800 22 BIRMAN 88 ± 10 620 22 CHUNG 85 ± 10 174 22 EDWARDS 82E − 30 174 22 EDWARDS 82E − 30 174 22 SCHARRE 80 | ● We do not use the following data for averages, fits, ling 9± 9.0 249 ± 35 22,23 ABLIKIM 08E BES2 2±18.5 62 ± 18 22,23 ABLIKIM 08E BES2 ± 14 296 22 AUGUSTIN 90 DM2 ± 10 693 22 AUGUSTIN 90 DM2 ± 110 500 22 DUCH 89 ASTE ± 11 170 22 RATH 89 MPS ± 2 8800 22 REEVES 86 SPEC ± 10 620 22 CHUNG 85 SPEC ± 10 22 CHUNG 85 SPEC − 30 174 22 EDWARDS 82E CBAL + 30 CP STE CHUNG 85 MRK2 |

$\eta(1405)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|----------------------------------|-------------------------|------------------------------|------------------|
| $\overline{\Gamma_1}$ | $K\overline{K}\pi$ | seen | |
| Γ_2 | $\eta\pi\pi$ | seen | |
| Г3 | $a_0(980)\pi$ | seen | |
| Γ_4 | $\eta(\pi\pi)_{S-wave}$ | seen | |
| | $f_0(980)\eta$ | seen | |
| Γ ₆ | 4π | seen | |
| Γ_7 | ho ho | <58 % | 99.85% |
| Γ ₈ | $\gamma \gamma$ | | |
| Г ₈ Г ₉ | $ ho^0 \gamma$ | seen | |
| Γ ₁₀ | $\phi \gamma$ | | |
| Γ_{11} | K*(892) K | seen | |

 $^{^{14}}$ The selected process is $J/\psi\to \,\omega\,a_0(980)\,\pi.$ 15 From fit to the $a_0(980)\,\pi$ 0 $^-$ + partial wave.

 $^{^{16}\}mathrm{From}~\eta\pi^+\pi^-$ mass distribution - mainly $a_0(980)\pi$ - no spin-parity determination available. 17 Decaying dominantly directly to $K^+K^-\pi^0$.

¹⁸ Decaying into $(K^n)_S\pi$, $(K\pi)_SK$, and $a_0(980)\pi$. 19 From fit to the $a_0(980)\pi$ 0 $^{-+}$ partial wave , but $a_0(980)\pi$ 1 $^{++}$ cannot be excluded.

This peak in the $\gamma\rho$ channel may not be related to the $\eta(1405)$. 21 Estimated by us from various fits.

These experiments identify only one pseudoscalar in the 1400–1500 range. Data could also refer to $\eta(1475)$.

²⁹ Systematic uncertainty not evaluated. 24 From best fit to 0 $^{-}$ $^{+}$ partial wave , 50% $\it K^*(892)~K$, 50% $\it a_0(980)~\pi$.

Meson Particle Listings $\eta(1405), f_1(1420)$

| | $\eta(1405)$ | $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma$ | (total) | | |
|------------------------------------------------------------------------|-----------------------------------------------|----------------------------------------|---------------------|------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| $\Gamma(K\overline{K}\pi) \times \Gamma(\gamma\gamma)$ VALUE (keV) CL% | y)/F _{total} DOCUMENT ID | TECN | COMMEN | T | $\Gamma_1\Gamma_8/\Gamma$ |
| • • • We do not use | | | | | |
| <0.035 90 2 | ^{5,26} AHOHE | 05 CLE2 | 10.6 e ⁺ | $e^- \rightarrow e^+ e^- K$ | $_{S}^{0}$ K^{\pm} π^{\mp} |
| $\Gamma(\eta\pi\pi) \times \Gamma(\gamma\gamma)$ VALUE (keV) CL% |)/F _{total} | TECN | COMMENT | - | $\Gamma_2\Gamma_8/\Gamma$ |
| <0.095 95 | ACCIARRI | 01G L3 | 183-202 | $e^+ e^- \rightarrow e^+ e^-$ | $\eta_{\pi}^{+}\pi^{-}$ |
| $\Gamma(\rho^0\gamma) \times \Gamma(\gamma\gamma)$ VALUE (keV) | | MENT ID | TECN | COMMENT | Г9Г8/Г |
| • • We do not use | | | | | |
| $<$ 1.5 25 Using $\eta(1405)$ m 26 Assuming three-b | 95 ALTH | IOFF 84E) MeV and 51 | TASS MeV, respe | $e^+e^- \rightarrow e^+e^-$ | - _π + _π - _γ |
| | η(1405) B | RANCHING | RATIOS | | |
| $\Gamma(\eta\pi\pi)/\Gamma(K\overline{K}\pi)$ | | | | | Γ_2/Γ_1 |
| <i>VALUE</i> • • • We do not use | | UMENT ID | | | |
| 1.09±0.48 | the following data | | | $0 \overline{p} p \rightarrow \pi^+ \pi^-$ | + _π + _π - _n |
| < 0.5 | 90 EDW | VARDS 83 | в СВАL | $J/\psi \rightarrow \eta \pi \pi \gamma$ | , |
| <1.1 <1.5 | 90 SCH 95 FOS | ARRE 80 TER 68 | | $J/\psi \to \eta \pi \pi \gamma$ $0.0 \overline{\rho} \rho$ | |
| $\Gamma(ho^0\gamma)/\Gamma(\eta\pi\pi)$ | 0.0 | CUMENT ID | TECN | COMMENT | Γ9/Γ2 |
| D.111±0.064 | | MSLER | 04B CBAI | | |
| $\Gamma(a_0(980)\pi)/\Gamma(K$ | (\mathcal{R}_{π}) | | | | Γ_3/Γ_1 |
| | | MENT ID | TECN | COMMENT | . 3/ . 1 |
| • • • We do not use | - | _ | | | |
| ~ 0.15 | ²⁸ BERT 500 ²⁸ DUCH | | | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi^{-} K \overline{p} \rightarrow \pi^{+} \pi^{-} K^{-}$ | π + = μ0 |
| ∼ 0.8 ∼ 0.75 | 500 ²⁸ DUCH ²⁸ REEV | | | $5.6 p \rightarrow \pi + \pi + K = 5.6 p \overline{p} \rightarrow K K \pi$ | |
| Γ (a₀ (980) π)/ Γ(η NALUE | | MENT ID | TECN | COMMENT | Γ_3/Γ_2 |
| • • • We do not use | | | | | |
| 0.29 ± 0.10 | ABEL | | | $0 p \overline{p} \rightarrow \eta \pi^0 \pi^0$ | |
| 0.19±0.04 0.56±0.04±0.03 | 2200 ²⁹ ALDE ²⁹ AMSL | | | $100 \pi^- p \rightarrow \eta \pi^0$ $0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0$ | |
| | | LIK 331 | CDAR | 7 pp → n·n . | |
| Γ(a ₀ (980)π)/Γ(η NALUE | | MENT ID | TECN | COMMENT | Γ ₃ /Γ ₄ |
| • • • We do not use | the following data | | | | |
| 0.91±0.12 | | OVICH 01 | | $0.0 \ \overline{p}p \rightarrow \eta \pi^{+} \tau$ | |
| 0.15 ± 0.04 0.70 ± 0.12 ± 0.20 | 9082 ³⁰ MAN/ 31 BAI | | | $18 \pi^- p \to \eta \pi^+ $ $J/\psi \to \gamma \eta \pi^+ \pi^-$ | π n - |
| $\Gamma(ho^0\gamma)/\Gamma(K\overline{K}\pi)$ | | OCUMENT ID | TECN | COMMENT | Г9/Г1 |
| D.0152±0.0038 | 32 CC | | | $J/\psi \rightarrow \gamma \gamma \pi$ | + π- |
| $\Gamma(\eta(\pi\pi)_{S-wave})/$ | $\Gamma(\eta\pi\pi)$ | | | | Γ ₄ /Γ ₂ |
| | | CUMENT ID | | | |
| 0.81 \pm 0.04 | the following data 2200 Al | | | 4 100 π ⁻ ρ → | $\eta \pi^0 \pi^0 n$ |
| $\Gamma(f_0(980)\eta)/\Gamma(\eta\eta)$ | $\pi\pi$) | | | | Γ_5/Γ_2 |
| <i>VALUE</i> • • • We do not use | | OCUMENT ID | | | |
| • • • vve do not use 0.32±0.07 | _ | _ | | c. 0.9–1.2 $\overline{p}p \rightarrow$ | $\eta 3\pi^0$ |
| $\Gamma(ho ho)/\Gamma_{ m total}$ | | | | | Γ ₇ /Γ |
| | <u>CL%</u> | DOCUMENT ID | | <u>COMMENT</u> AR 0 p p | |
| <0.58 | 99.85 27,34 | 4 MSLER | | | |
| ^{∨ALUE} <0.58 Г(<i>K</i> *(892) <i>K</i>)/Г(| | AMSLER | 04B CB. | AK 0 <i>pp</i> | Γ ₁₁ /Γ ₂ |
| <0.58 Γ(K*(892)K)/Γ(VALUE • • • • We do not use | a ₀ (980) π) <u>DO CUMENT</u> | T ID <u>TE</u> | CN COMI | MENT | Γ ₁₁ /Γ ₃ |

| $\Gamma(\phi\gamma)/\Gamma(ho^0\gamma)$ | | | | | | Γ_{10}/Γ_{9} |
|--------------------------------------------------------------|---------------------------|----------------------------------------------------------|----------------------------------|-------------|------------------------------------|----------------------------------|
| VALUE | CL% | DO CUMENT IL |) | TECN | COMMENT | |
| • • • We do not use | the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| < 0.77 | 95 | ³⁵ BAI | ر04 | BES2 | $J/\psi \rightarrow \gamma \gamma$ | γ K ⁺ K ⁻ |
| 27 Using the data of | BAILLON 6 | $57 \text{ on } \overline{p}p \rightarrow K\overline{k}$ | π . | | | |
| ²⁸ Assuming that the | e a ₀ (980) de | cays only into <i>K</i> | K. | | | |
| ²⁹ Assuming that the | a ₀ (980) de | cays only into η | π. | | | |
| 30 Statistical error o | | | | | | |
| ³¹ Assuming that the | e a ₀ (980) de | cays only into η | π. | | | |
| 32 Using B($J/\psi \rightarrow$ | $\gamma \eta (1405)$ | $\rightarrow \gamma K \overline{K} \pi) = 4.$ | 2×10^{-1} | $^{-3}$ and | $B(J/\psi \rightarrow$ | $\gamma \eta (1405) \rightarrow$ |
| $\gamma \gamma \rho^{0}) = 6.4 \times 10^{-1}$ | ⁻⁵ and assun | ning that the γho^0 | signal | does no | t come from t | the $f_1(1420)$. |
| 33 Using preliminary | Crystal Barr | el data. | | | | 1, , |
| 34 Assuming that the | $=\eta(1405)$ de | cays are saturate | d by th | ε ππη, | $K\overline{K}\pi$ and ρ | ρ modes. |
| 35 Calculated by us $\eta(1405)\gamma ightarrow ho^0$ | from $B(J/\psi)$ | $\rightarrow \eta(1405) \gamma$ - | $\rightarrow \phi \gamma \gamma$ |) < 0.3 | 82 × 10 ⁻⁴ ai | nd B $(J/\psi ightharpoonup$ |
| | | | | | | |

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| | | | | |

 $f_1(1420)$

$$I^{G}(J^{PC}) = 0^{+}(1^{+})$$

See the minireview under $\eta(1405)$.

f₁(1420) MASS

| VALUE (N | _ | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------|----------|------|------------|------------------------|--------|-----------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1426.4 | 4 ± 0.9 | 9 OU | R AVERAGE | Error includes scal | le fac | tor of 1. | 1. |
| 1434 | ± 5 | ± ! | 5 133 | ¹ ACHARD | 07 | L3 | $^{183-209}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{_{K}}\overset{\rightarrow}{_{K}}\overset{\rightarrow}{_{K}}\overset{\rightarrow}{_{K}}\overset{\rightarrow}{_{K}}$ |
| 1426 | ± 6 | | 711 | ABDALLAH | 03н | DLPH | $^{91.2}_{K_{5}^{0}} \stackrel{e^{+}e^{-}}{\kappa^{\pm}}_{\pi^{\mp}} + X$ |
| 1420 | ± 14 | | 3651 | NICHITIU | 02 | OBLX | <u> </u> |
| 1428 | ± 4 | ± : | 2 20k | ADAMS | 01в | B852 | 18 GeV $\pi^- \rho \rightarrow \kappa^+ \kappa^- \pi^0 \rho$ |
| 1426 | ± 1 | | | BARBERIS | 97c | OMEG | |
| 1425 | ± 8 | | | BERTIN | 97 | OBLX | $0.0 \overline{p}p \rightarrow K^{\pm}(K^{0}) \pi^{\mp}\pi^{+}\pi^{-}$ |
| 1435 | + 9 | | | PROKOSHKIN | 97B | GA M4 | $100 \pi^{-} p \rightarrow \eta \pi^{0} \pi^{0} n$ |
| 1430 | ± 4 | | | ² ARMSTRONG | | | 85,300 $\pi^+ p$, $pp \rightarrow$ |
| 1462 | | | | ³ AUGUSTIN | 92 | DM2 | $\pi^+ p$, $pp(K\overline{K}\pi)$ $J/\psi \to \gamma K\overline{K}\pi$ |
| 1443 | + 7 | + | 3 1100 | BAI | 90c | MRK3 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| 1425 | ± 10 | | 17 | BEHREND | 89 | | $\gamma\gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| 1442 | ± 5 | +11 | 0 7 111 | BECKER | 87 | MRK3 | e^+e^- , ω K $\overline{K}\pi$ |
| 1423 | ± 4 | • | | GIDAL | 87в | MRK2 | $e^+e^- \rightarrow e^+e^- \kappa \overline{\kappa}_{\pi}$ |
| 1417 | ± 13 | | 13 | AIHARA | 86c | TPC | $e^+e^- \rightarrow K \overline{K} \pi$ |
| 1422 | \pm 3 | | | CHAUVAT | 84 | SPEC | ISR 31.5 pp |
| 1440 | ± 10 | | | ⁴ BROMBERG | 80 | SPEC | $100 \pi^- \rho \rightarrow K \overline{K} \pi X$ |
| 1426 | ± 6 | | 221 | DIONISI | 80 | нвс | $4 \pi^- p \rightarrow K \overline{K} \pi n$ |
| 1420 | ± 20 | | | DAHL | 67 | нвс | 1.6-4.2 π ⁻ p |

$f_1(1420)$

| • | • • V | Ve d | o not use | the following | data for averages | , fits, | limits, e | etc. • • • |
|---|--------|-------|-----------|---------------|-------------------|---------|-----------|------------------------------------------|
| | 1430.8 | В± | 0.9 | | ⁵ SOSA | 99 | SPEC | $pp \rightarrow p_{slow}$ |
| | | | | | 5 | | | $(K_S^0 K^+ \pi^-) p_{fast}$ |
| | 1433.4 | 1 ± | 0.8 | | ⁵ SOSA | 99 | SPEC | $pp \rightarrow p_{\text{Slow}}$ |
| | | | _ | | | | | $(K_S^0 K^- \pi^+) p_{\text{fast}}$ |
| | 1429 | \pm | 3 | 389 | ARMSTRONG | | | $300 pp \rightarrow K\overline{K}\pi pp$ |
| | 1425 | \pm | 2 | 1520 | ARMSTRONG | 84 | OMEG | 85 $\pi^+ p$, $pp \rightarrow$ |
| | | | | | | | | $(\pi^+, \rho)(K\overline{K}\pi)\rho$ |
| ~ | 1420 | | | | BITYUKOV | 84 | SPEC | 32 $K^-p \rightarrow$ |
| | | | | | | | | $\kappa^{+} \kappa^{-} \pi^{0} Y$ |
| | 1 | | | | | | | |

- $^{1}_{2}$ From a fit with a width fixed at 55 MeV. $^{2}_{2}$ This result supersedes ARMSTRONG 84, ARMSTRONG 89.
- 3 From fit to the $K^*(892) K 1 + +$ partial wave.
- 4 Mass error increased to account for $a_0(980)$ mass cut uncertainties.
- ⁵ No systematic error given.

f1 (1420) WIDTH

| | | | | | -\ / | | | |
|--------|-------|----------------|------------|-------------------|-------------------|---------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VA. | LUE (| | | EVTS | DOCUMENT ID | | TECN | COMMENT |
| | 54. | 9± 2. | 6 OUR | AVERAGE | | | | |
| | 51 | ±14 | | 711 | ABDALLAH | 03н | DLPH | $^{91.2}_{\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ |
| | 61 | ± 8 | | 3651 | NICHITIU | 02 | OBLX | • |
| | 38 | ± 9 | ±6 | 20k | ADAMS | 01в | B852 | 18 GeV $\pi^- p \rightarrow K^+ K^- \pi^0 p$ |
| | 58 | ± 4 | | | BARBERIS | 97c | OMEG | $450 \stackrel{\text{pp}}{pp} \stackrel{\text{d}}{\leftarrow} \pi^{\mp}$ $pp \stackrel{\text{d}}{\kappa} \stackrel{\text{d}}{\kappa} \stackrel{\text{d}}{\kappa} \pm \pi^{\mp}$ |
| | 45 | ± 10 | | | BERTIN | 97 | OBLX | $0.0 \overline{p}p \rightarrow K^{\pm}(K^{0}) \pi^{\mp}\pi^{+}\pi^{-}$ |
| | 90 | ± 25 | | | PROKOSHKIN | 97B | GA M4 | $100 \ \pi^- p \rightarrow \eta \pi^0 \pi^0 n$ |
| | 58 | ± 10 | | 6 | ARMSTRONG | 92E | OMEG | 85,300 $\pi^+ p$, $pp \rightarrow \pi^+ p$, $pp(K\overline{K}\pi)$ |
| : | 129 | ± 41 | | 7 | AUGUSTIN | 92 | DM2 | $J/\psi \rightarrow \gamma K \overline{K} \pi$ |
| | 68 | $^{+29}_{-18}$ | + 8 - 9 | 1100 | BAI | 90c | MRK3 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| | 42 | ±22 | | 17 | BEHREND | 89 | CELL | $\gamma \gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| | 40 | $^{+17}_{-13}$ | ± 5 | 111 | BECKER | 87 | MRK3 | $e^+e^- ightarrow \; \omega K \overline{K} \pi$ |
| | 35 | $^{+47}_{-20}$ | | 13 | AIHARA | 86c | TPC | $e^+e^{e^+e^-K\overline{K}\pi}$ |
| | 47 | ± 10 | | | CHAUVAT | 84 | SPEC | ISR 31.5 pp |
| | 62 | ± 14 | | | BROMBERG | 80 | SPEC | $100 \pi^- p \rightarrow K \overline{K} \pi X$ |
| | 40 | ± 15 | | 221 | DIONISI | 80 | нвс | $4 \pi^- \rho \rightarrow K \overline{K} \pi n$ |
| | 60 | ± 20 | | | DAHL | 67 | HBC | 1.6-4.2 π ⁻ p |
| • | • • ' | We do | not us | e the following o | lata for averages | , fits, | limits, e | etc. • • • |
| | 68. | 7± 2. | 9 | 8 | SOSA | 99 | SPEC | $pp \rightarrow p_{Slow}$ |
| | | | | | | | | $(K_S^0 K^+ \pi^-) p_{fast}$ |
| | 5 8.8 | 3± 3. | 3 | 8 | SOSA | 99 | SPEC | $pp \rightarrow p_{slow}$ |
| | | | | | | | | $(K_S^0 K^- \pi^+) p_{\text{fast}}$ |
| | 58 | ± 8 | | 389 | ARMSTRONG | 89 | OMEG | |
| | 62 | \pm 5 | | 1520 | ARMSTRONG | 84 | OMEG | 85 $\pi^+ p$, $pp \rightarrow$ |
| | | | | | | | | $(\pi^+, \rho)(K\overline{K}\pi)\rho$ |
| \sim | 50 | | | | BITYUKOV | 84 | SPEC | 32 K ⁻ p → |
| | , | | | | | | | $\kappa^+ \kappa^- \pi^0 Y$ |

- ⁶ This result supersedes ARMSTRONG 84, ARMSTRONG 89.
- ⁷ From fit to the $K^*(892) K 1 + +$ partial wave.
- ⁸ No systematic error given.

f₁(1420) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|--------------------------------------|------------------------------|
| Γ ₁ | $K\overline{K}_{\pi}$ | dominant |
| Γ_2 | $K\overline{K}^*(892) + \text{c.c.}$ | dominant |
| Γ_3 | $\eta\pi\pi$ | possibly seen |
| Γ_4 | $a_0(980)\pi$ | |
| Γ_5 | $\pi\pi ho$ | |
| Γ_6 | 4π | |
| Γ ₆ Γ ₇ | $\rho^0 \gamma$ | |
| Гв | $\phi \gamma$ | seen |

$f_1(1420) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

$\Gamma(K\overline{K}\pi) \times \Gamma(\gamma\gamma^*)/\Gamma_{\text{total}}$

| 1 | VALUE (keV) | CL% | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|---|-----------------------|----------|----------|-------|----------------|----------|-----------|-----------------------------------------------------------------------------------------------------------------------|
| | 1.9±0.4 OUR | AVER. | AGE | | | | | |
| | $3.2 \pm 0.6 \pm 0.7$ | | 133 | 9,10 | ACHARD | 07 | L3 | $^{183-209}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\kappa_{S}^{0}}\overset{\rightarrow}{\kappa^{\pm}_{\pi}}\mp$ |
| | $3.0 \pm 0.9 \pm 0.7$ | | | 11,12 | BEHREND | 89 | CELL | $e^+e^- \rightarrow e^+e^- \kappa_S^0 \kappa_\pi$ |
| | $2.3 + 1.0 \pm 0.8$ | | | | HILL | 89 | JADE | $\stackrel{e^+e^-}{{}_{e^+e^-}} \stackrel{\rightarrow}{{}_{\kappa^\pm}} \stackrel{\kappa^0}{{}_{\kappa^5}} \pi^{\mp}$ |
| | $1.3 \pm 0.5 \pm 0.3$ | | | | AIHARA | 88B | TPC | $e^+e^{e^+e^-} \xrightarrow{\kappa^{\pm}} \kappa^0_{5} \pi^{\mp}$ |
| | $1.6 \pm 0.7 \pm 0.3$ | | | | GIDAL | | | $e^+e^- \rightarrow e^+e^- K \overline{K} \pi$ |
| • | • • • We do no | t use ti | he follo | owing | data for avera | ges, fit | s, limits | , etc. • • • |

| <8.0 | 95 | JENNI | 83 | MRK2 | $e^{+}e^{-}$ - | $e^+e^-K\overline{K}\pi$ |
|------|----|-------|----|------|----------------|--------------------------|
|------|----|-------|----|------|----------------|--------------------------|

- $^9\,\text{From}$ a fit with a width fixed at 55 MeV. $^{10}\,\text{The}$ form factor parameter from the fit is 926 \pm 78 MeV.
- 11 Assume a ho-pole form factor.
- 12 A ϕ pole form factor gives considerably smaller widths.
- $^{13}\,\mathrm{Published}$ value divided by 2.

f1(1420) BRANCHING RATIOS

| $\Gamma(K\overline{K}^*(892) + \text{c.c.})/\Gamma(K\overline{K}\pi)$ | | | | | | | |
|-----------------------------------------------------------------------|------------------|---------|-----------|------------------------------|----------------------|--|--|
| VALUE | DOCUMENT ID | | TECN | COMMENT | | | |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • | | | |
| 0.76 ± 0.06 | BROMBERG | 80 | SPEC | 100 $\pi^- \rho \rightarrow$ | $K\overline{K}\pi X$ | | |
| 0.86 ± 0.12 | DIONISI | 80 | HBC | $4 \pi^- p \rightarrow K$ | $K\pi n$ | | |
| | | | | | | | |

| $\Gamma(\pi\pi\rho)/\Gamma(K\overline{K}\pi)$ | | | | | | Γ_5/Γ_1 |
|-----------------------------------------------|--------------|-------------------|----------|-----------|---------------------|---------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use | the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| < 0.3 | 95 | CORDEN | 78 | OMEG | $12-15 \pi^{-}p$ | |
| < 2.0 | | DAHL | 67 | HB C | $1.6-4.2 \pi^{-} p$ | |

| $\Gamma(\eta\pi\pi)/\Gamma(K\overline{K}\pi)$ | г) | | | | | Γ_3/Γ_1 |
|-----------------------------------------------|-----------------|------------------|-----------|-----------|-----------------------------|-------------------------------------|
| VALUE | CL% | DO CUMENT I | ס | TECN | COMMENT | |
| <0.1 | 95 | ARMSTRO | NG 91B | OMEG | 300 $pp \rightarrow$ | $pp\eta\pi^+\pi^-$ |
| | se the followin | g data for avera | ges, fits | , limits, | etc. • • • | |
| 1.35 ± 0.75 | | KOPKE | 89 | MRK3 | $J/\psi \rightarrow \omega$ | $\eta \pi \pi (K \overline{K} \pi)$ |
| < 0.6 | 90 | GIDAL | 87 | MRK2 | $e^+e^{e^+e^-\eta}$ | |
| | | | | | $e^+e^-\eta$ | $\pi^+\pi^-$ |

| $^{< 0.5}$ 1.5 ± 0.8 | 95 | | '8 OMEG '2 HBC | $12-15 \pi^{-} \rho$ $0.7 \overline{\rho} \rho$ | |
|--------------------------|----------------------|--------------|-------------------|-------------------------------------------------|----------------------|
| $\Gamma(a_0(980)\pi)/$ | $\Gamma(\eta\pi\pi)$ | | | | Γ4/Γ3 |
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| >0.1 | 90 | PROKOSHKIN 9 | 7в GAM4 | $100 \pi^- p \rightarrow$ | $\eta \pi^0 \pi^0 n$ |

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$ not seen in either mode 86 SPEC 8 π⁻ p not seen in either mode CORDEN 78 OMEG 12-15 π⁻ p 0.4 ± 0.2 DEFOIX 72 HBC $0.7 \overline{p}p \rightarrow 7\pi$

 $\Gamma(4\pi)/\Gamma(K\overline{K}^*(892) + c.c.)$ DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • DIONISI

 $\Gamma(K\overline{K}\pi)/[\Gamma(K\overline{K}^*(892)+c.c.)+\Gamma(a_0(980)\pi)]$ DO CUMENT ID TECN COMMENT \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 Γ_6/Γ_2

 14 DIONISI 80 HBC 4 $\pi^- p$ 14 Calculated using $\Gamma(K\overline{K})/\Gamma(\eta\pi)=0.24\pm0.07$ for $a_0(980)$ fractions.

 $\Gamma(a_0(980)\pi)/\Gamma(K\overline{K}^*(892) + c.c.)$ Γ_4/Γ_2 DOCUMENT ID TECN COMMENT VALUE BARBERIS 98c OMEG 450 pp -

• • • We do not use the following data for averages, fits, limits, etc. • • • ARMSTRONG 84 OMEG 85 $\pi^+ p$ 68

 $\Gamma(4\pi)/\Gamma(K\overline{K}\pi)$ Γ_6/Γ_1 CL% DOCUMENT ID TECN COMMENT < 0.62 ARMSTRONG 89G OMEG 85 $\pi p \rightarrow 4\pi X$ 95

 $\Gamma(
ho^0\gamma)/\Gamma_{
m total}$ Γ_7/Γ CL% DOCUMENT ID TECN COMMENT 15 ARMSTRONG 92c SPEC 300 $pp \rightarrow pp\pi^+\pi^-\gamma$ 95

 $^{15}\, {\rm Using}$ the data on the $\overline{\it K}\, {\it K}\, \pi$ mode from ARMSTRONG 89. $\Gamma(\rho^0 \gamma)/\Gamma(K\overline{K}\pi)$

 Γ_7/Γ_1 DOCUMENT ID TECN COMMENT <0.02 BARBERIS 98C OMEG 450 pp --

 $\Gamma(\phi\gamma)/\Gamma(K\overline{K}\pi)$ Γ_8/Γ_1 DOCUMENT ID TECN COMMENT $0.003 \pm 0.001 \pm 0.001$ BARBERIS 98c OMEG 450 $pp \rightarrow p_f f_1(1420) p_S$

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| HILL | 89 | ZPHY C42 355 | P. Hill et al. | `(JADE Collab.) JP |
| KOPKE | 89 | PRPL 174 67 | L. Kopke et al. | (CERN) |
| AIHARA | 88 B | PL B209 107 | H. Aihara et al. | (TPC-2γ Collab.) |
| BECKER | 87 | PRL 59 186 | J.J. Becker et al. | (Mark III Collab.) JP |
| GIDAL | 87 | PRL 59 2012 | G. Gidal et al. | (LBL, SLAC, HARV) |
| GIDAL | 87 B | PRL 59 2016 | G. Gidal et al. | (LBL, SLAC, HARV) |
| AIHARA | 86 C | PRL 57 2500 | H. Aihara et al. | (TPC-2γ Collab.) JP |
| ANDO | 86 | PRL 57 1296 | A. Ando et al. | (KEK, KYOT, NIRS, SAGA+) |
| ARMSTRONG | 84 | PL 146B 273 | T.A. Armstrong et al. | (ATHU, BARI, BIRM+) JP |
| BITYUKOV | 84 | SJNP 39 735 Translated from YAF 39 | S. Bityukov et al. | (SERP) |
| CHAUVAT | 84 | PL 148B 382 | P. Chauvat et al. | (CERN, CLER, UCLA+) |
| JENNI | 83 | PR D27 1031 | P. Jenni et al. | (SLAC, LBL) |
| BROMBERG | 80 | PR D22 1513 | C.M. Bromberg et al. | (CIT, FNAL, ILLC+) |
| DIONISI | 80 | NP B169 1 | C. Dionisi et al. | (CERN, MADR, CDEF+)IJP |
| CORDEN | 78 | NP B144 253 | M.J. Corden et al. | (BIRM, RHEL, TELA+) |
| DEFOIX | 72 | NP B44 125 | C. Defoix et al. | ` (CDEF, CERN) |
| DAHL | 67 | PR 163 1377 | O.I. Dahl et al. | (LRL) IJP |
| A Iso | | PRL 14 1074 | D.H. Miller et al. | (LRL, UCB) |

 $\omega(1420)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

$\omega(1420)$ MASS

DOCUMENT ID TECN COMMENT

| (1400-1450) OUK I | :SIIMAI | L . | | | | | |
|---------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|--|--|--|--|--|
| • • • We do not us | • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $1382\pm\ 23\pm\ 70$ | | AUBERT 07AU BABR 10.6 $e^+ e^- ightarrow \omega \pi^+ \pi^- \gamma$ | | | | | |
| $1350\pm\ 20\pm\ 20$ | | AUBERT,B 04N BABR 10.6 $e^+e^- ightarrow\pi^+\pi^-\pi^0\gamma$ | | | | | |
| $1400\!\pm\ 50\!\pm\!130$ | 1.2M | 1 ACHASOV 03D RVUE $0.44-2.00~e^{+}~e^{-} \rightarrow \pi^{+}~\pi^{-}~\pi^{0}$ | | | | | |
| 1450± 10 | | ² HENNER 02 RVUE 1.2–2.0 $e^+e^- \rightarrow \rho\pi$, $\omega\pi\pi$ | | | | | |
| $1373\pm\ 70$ | 177 | ³ AKHMETSHIN 00D CMD2 1.2-1.38 $e^+e^- \rightarrow$ | | | | | |
| $1370\pm\ 25$ | 5 0 9 5 | ANISOVICH 00H SPEC $0.0p\overline{p} 	o \omega\pi^0\pi^0\pi^0$ | | | | | |
| $1400 + 100 \\ -200$ | | 4 ACHA SOV 98H RVUE $e^+e^- ightarrow~\pi^+\pi^-\pi^0$ | | | | | |
| ~1400 | | 5 ACHASOV 98H RVUE $e^{+}e^{-} ightarrow\omega\pi^{+}\pi^{-}$ | | | | | |
| ~ 1460 | | 6 ACHA SOV 98H RVUE $e^{+}e^{-} ightarrow K^{+}K^{-}$ | | | | | |
| 1440± 70 | | ⁷ CLEGG 94 RVUE | | | | | |
| 1419± 31 | 315 | ⁸ ANTONELLI 92 DM2 $1.34-2.4e^+e^- ightarrow ho\pi$ | | | | | |

- ¹ From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.
- 2 Using results of CORDIER 81 and preliminary data of DOLINSKY 91 and AN-
- TONELLI 92. 3 Using the data of A KHMETSHIN 00D and ANTONELLI 92. The $ho\pi$ dominance for the energy dependence of the $\omega(1420)$ and $\omega(1650)$ width assumed
- ⁴Using data from BARKOV 87, DOLINSKY 91, and ANTONELLI 92.
- Using the data from ANTONELLI 92.
- ⁶Using the data from IVANOV 81 and BISELLO 88B.
- ⁷ From a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and
- ANTONELLI 92. 8 From a fit to two Breit-Wigner functions interfering between them and with the ω,ϕ tails with fixed (+,-,+) phases

ω (1420) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|------------|--------------------------|-------|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| (180-250) OUR I | ESTIMATI | . | | | |
| • • • We do not | use the fo | ollowing data for aw | erage | s, fits, li | mits, etc. • • • |
| $130 \pm 50 \pm 100$ | | AUBERT | | | 10.6 $e^+e^- ightarrow$ |
| $450 \pm70 \pm70$ | | AUBERT,B | 04N | BABR | 10.6 $e^+e^- \to \pi^+\pi^-\pi^0\gamma$ |
| $870^{+500}_{-300}\pm450$ | 1.2M | ⁹ ACHA SOV | 03D | RVUE | $\begin{array}{c} 0.44-2.00\ e^{+}e^{-}\rightarrow\\ \pi^{+}\pi^{-}\pi^{0} \\ 1.2-2.0\ e^{+}e^{-}\rightarrow\rho\pi,\omega\pi\pi \end{array}$ |
| 199± 15 | | ¹⁰ HENNER | 02 | RVUE | $1.2-2.0$ $e^+e^- \rightarrow \rho\pi, \omega\pi\pi$ |
| $188\pm~45$ | 177 | ¹¹ AKHMETSHIN | 100D | CMD2 | $1.2-1.38 e^+e^- \rightarrow \omega \pi^+\pi^-$ |
| $360 {}^{+ 1 00}_{- 60}$ | 5095 | ANISOVICH | 00н | SPEC | $0.0 \ p \overline{p} \rightarrow \omega \pi^0 \pi^0 \pi^0$ |
| 240 ± 70 | | ¹² CLEGG | 94 | RVUE | |
| 174 ± 59 | 315 | ¹³ ANT ONELLI | 92 | DM2 | $1.34-2.4e^{+}e^{-} \rightarrow \rho \pi$ |

- ⁹ From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92, achasov 01E, ACHASOV 02E, and ACHASOV 93D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E. 10 Using results of CORDIER 81 and preliminary data of DOLINSKY 91 and ANTONELLI 92. 11 Using the data of AKH METSHIN 00D and ANTONELLI 92. The $\rho\pi$ dominance for the

- energy dependence of the $\omega(1420)$ and $\omega(1650)$ width assumed. 12 From a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and
- antonelli 92. with fixed (+,-,+) phases

$\omega(1420)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|------------------|------------------------------|
| $\overline{\Gamma_1}$ | $ ho\pi$ | dominant |
| Γ_2 | $\omega \pi \pi$ | seen |
| Γ_3 | $b_1(1235)\pi$ | seen |
| Γ_4 | $e^+ e^-$ | seen |
| Γ ₅ | $\pi^0 \gamma$ | |

$\omega(1420) \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$

| $\Gamma(ho\pi)/\Gamma_{ m total}	imes\Gamma($ | | $\Gamma_1/\Gamma \times \Gamma_4/\Gamma$ | | | |
|------------------------------------------------|-----------------|------------------------------------------|-----------|---------|--------------------------------------------------------------|
| VALUE (units 10 ⁻⁶) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| • • • We do not use | the following d | lata for average | es, fits, | limits, | etc. • • • |
| $0.82 \ \pm 0.05 \ \pm 0.06$ | | AUBERT,B | 04N | BABR | $^{10.6}_{00000000000000000000000000000000000$ |
| $0.65\ \pm0.13\ \pm0.21$ | | ACHASOV | 03D | RVUE | $0.44-2.00_{\pi^{+}\pi^{-}\pi^{0}}^{e^{+}e^{-}} \rightarrow$ |
| 0.625 ± 0.160 | | CLEGG | 94 | RVUE | |
| 0.466 ± 0.178 | 18,19 | ANTONELLI | 92 | DM2 | $1.342.4e^+e^- ightarrow ho\pi$ |

 $\frac{14}{12}$ Calculated by us from the cross section at the peak.

- 15 From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.
- $^{16}\,\mathrm{From}$ a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and ANTONELLI 92. 17 From the partial and leptonic width given by the authors.
- 18 From a fit to two Breit-Wigner functions interfering between them and with the ω,ϕ tails with fixed (+,-,+) phases.
- 19 From the product of the leptonic width and partial branching ratio given by the authors.

$\Gamma(\omega\pi\pi)/\Gamma_{ m total}\, imes\,\Gamma(e^+\,e^-)/\Gamma_{ m total}$ $\Gamma_2/\Gamma \times \Gamma_4/\Gamma$

VALUE (units 10⁻⁸) DO CUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 19.7 ± 5.7 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow \omega \pi^+ \pi^- \gamma$ 20 AKHMETSHIN 00D CMD2 1.2-2.4 $e^+e^-
ightarrow \omega \pi^+\pi^ 1.9 \pm 1.9$

 20 Using the data of AKHMETSHIN 00D and ANTONELLI 92. The $ho\pi$ dominance for the energy dependence of the $\omega(1420)$ and $\omega(1650)$ width assumed.

$\Gamma(\pi^0 \gamma)/\Gamma_{\text{total}} \times \Gamma(e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_5/\Gamma \times \Gamma_4/\Gamma$

VALUE (units 10^{-8}) DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • 21 AKHMETSHIN 05 CMD2 0.60-1.38 $e^+\,e^-\,
ightarrow\,\pi^0\,\gamma$

ω (1420) BRANCHING RATIOS

| $\Gamma(\omega\pi\pi)/\Gamma_{ m total}$ | | | | Γ_2/Γ |
|------------------------------------------|----------------------------|----------------|---------------------------------------|----------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use th | e following data for avera | ges, fits, lir | nits, etc. • • • | |
| 0.301 ± 0.029 | 22 HENNER 0 | 2 RVUE | 1.2-2.0 e ⁺ e ⁻ | $\rightarrow \rho \pi, \omega \pi \pi$ |
| possibly seen | AKHMETSHIN 0 | 0p CMD2 | $e^+e^- \rightarrow \omega \pi^+$ | π_ |

$\Gamma(\omega\pi\pi)/\Gamma(b_1(1235)\pi)$ DO CUMENT ID TECN COMMENT

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$ ANISOVICH 00H SPEC 0.0 $p\overline{p} \rightarrow \; \omega \, \pi^0 \, \pi^0 \, \pi^0$ 0.60 ± 0.16 5095 _, ,,_

 Γ_2/Γ_3

| $\Gamma(ho\pi)/\Gamma_{ m total}$ | | | | Γ_1/Γ |
|------------------------------------|---------------------------------|------------|------------------|-------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT | |
| • • • We do not use | the following data for averages | , fits, li | mits, etc. • • • | |
| 0.600 0.000 | 22 HENNED 02 | DV/IIE | 1 2 2 0 -+ | |

| $\Gamma(e^+ e^-)/\Gamma_{\text{total}}$ | | | | Γ4/Γ |
|-----------------------------------------|--------------|------|---------|------|
| VALUE (units 10^{-7}) EVTS | DO CUMENT ID | TECN | COMMENT | |

• • • We do not use the following data for averages, fits, limits, etc. • • • 1.2M 23,24 ACHASOV 03D RVUE 0.44-2.00 $e^+e^- \to \pi^+\pi^-\pi^0$ \sim 6.6 02 RVUE 1.2-2.0 $e^+e^- \rightarrow \rho\pi$, $\omega\pi\pi$ ²² HENNER

- $^{22}_{-1}$ Assuming that the $\omega(1420)$ decays into $\rho\pi$ and $\omega\,\pi\,\pi$ only.
- 23 Calculated by us from the cross section at the peak. 24 Assuming that the $\omega(1420)$ decays into $\rho\pi$ only.

 $^{^{21}\,\}mathrm{Using}$ 1420 MeV and 220 MeV for the $\omega(1420)$ mass and width.

 $\omega(1420)$, $f_2(1430)$, $a_0(1450)$

ω (1420) REFERENCES

| AUBERT | 07 A U | PR D76 092005 | B. Aubert et al. | (BABAR Collab.) |
|------------|--------|-----------------------|---------------------------|------------------------------|
| AKHMETSHIN | 05 | PL B605 26 | R.R. Akhmetshin et al. | (Novosibirsk CM D-2 Collab.) |
| AUBERT,B | 04 N | PR D70 072004 | B. Aubert et al. | (BABAR Collab.) |
| A CHAS OV | 03 D | PR D68 052006 | M.N. Achasov et al. | (Novosibirsk SND Collab.) |
| ACHASOV | 02 E | PR D66 032001 | M.N. Achasov et al. | (Novosibirsk SND Collab.) |
| HENNER | 02 | EPJ C26 3 | V.K. Henner et al. | , |
| ACHASOV | 01E | PR D63 072002 | M.N. Achasov et al. | (Novosibirsk SND Collab.) |
| AKHMETSHIN | 00 D | PL B489 125 | R.R. Akhmetshin et al. | (Novosibirsk CMD-2 Collab.) |
| ANISOVICH | 00 H | PL B485 341 | A.V. Anisovich et al. | , |
| ACHASOV | 99E | PL B462 365 | M.N. Achasov et al. | (Novosibirsk SND Collab.) |
| ACHASOV | 98 H | PR D57 4334 | N.N. Achasov, A.A. Kozhev | nikov |
| CLEGG | 94 | ZPHY C62 455 | A.B. Clegg, A. Donnachie | (LANC, MCHS) |
| ANTONELLI | 92 | ZPHY C56 15 | A. Antonelli et al. | (DM2 Collab.) |
| DOLINS KY | 91 | PRPL 202 99 | S.I. Dolinsky et al. | ` (NOVO) |
| BISELLO | 88 B | ZPHY C39 13 | D. Bisello ét al. | (PADO, CLER, FRAS+) |
| BARKOV | 87 | JETPL 46 164 | L.M. Barkov et al. | (NOVO) |
| | | Translated from ZETFP | 46 132. | ` ' |
| CORDIER | 81 | PL 106B 155 | A. Cordier et al. | (ORSAY) |
| IVANOV | 81 | PL 107B 297 | P.M. Ivanov et al. | `(NOVO) |
| | | | | |

$f_2(1430)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

OMITTED FROM SUMMARY TABLE

This entry lists nearby peaks observed in the D wave of the $K\overline{K}$ and $\pi^+\pi^-$ systems. Needs confirmation.

£(1430) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | | |
|---------------------------------------------------------------------------------------------------------------------------------------|-------------------------|--------|------------|-------------------------------------------|--|--|
| ≈ 1430 OUR ESTIN | ATE | | | | | |
| ● ● We do not us | e the following data f | or ave | rages, fit | s, limits, etc. • • • | | |
| $1453\pm~4$ | ¹ VLADIMIRSK | 01 | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ | | |
| 1421 ± 5 | | | | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ | | |
| 1480 ± 50 | AKESSON | 86 | SPEC | $pp \rightarrow pp \pi^+ \pi^-$ | | |
| $1436 ^{+ 26}_{- 16}$ | DAUM | 84 | CNTR | 17-18 $\pi^- p \rightarrow K^+ K^- n$ | | |
| $1412\pm\ 3$ | DAUM | 84 | CNTR | 63 $\pi^- p \to K_S^0 K_S^0 n, K^+ K^- n$ | | |
| $1439 + 5 \\ -6$ | ² BEUSCH | 67 | OSPK | 5,7,12 $\pi^- p \to K_S^0 K_S^0 n$ | | |
| $ \begin{array}{ll} 1J^{PC} &= 0++\mathrm{or}2^{++},\\ 2\mathrm{Not}\mathrm{seen}\mathrm{by}\mathrm{WET}\mathrm{ZEL}76. \end{array} $ | | | | | | |

f2(1430) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|------------------------------------|---------------------------|-------|------------|---------------------------------------------------|--|
| • • • We do not | use the following data fo | r ave | rages, fit | s, limits, etc. • • • | |
| 13± 5 | ³ VLADIMIRSK. | 01 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ | |
| 30± 9 | | | | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ | |
| 150 ± 50 | AKESSON | 86 | SPEC | $pp \rightarrow pp \pi^+ \pi^-$ | |
| $81 + 56 \\ -29$ | DAUM | 84 | CNTR | 17-18 $\pi^- p \rightarrow K^+ K^- n$ | |
| $14\pm$ 6 | DAUM | 84 | CNTR | 63 $\pi^- p \rightarrow K_S^0 K_S^0 n, K^+ K^- n$ | |
| $43 + 17 \\ -18$ | ⁴ BEUSCH | 67 | OSPK | 5,7,12 $\pi^- p \to K_S^0 K_S^0 n$ | |
| $3 \ J^{PC} = 0 + + _{OT} 2 + + .$ | | | | | |

f2(1430) DECAY MODES

| 11 | лоче | | | | | | | |
|-----------|----------------------------------|------------------------------------|-------------------------|-----------------------------|--|--|--|--|
| | K rπ | | | | | | | |
| | f ₂ (1430) REFERENCES | | | | | | | |
| VLADIMIR | RSK 01 | PAN 64 1895 Translated from YAF | V.V. Vlad mirsky et al. | | | | | |
| AUGUS TII | N 87 | ZPHY C36 369 | J.E. Augustin et al. | (LALO, CLER, FRAS+) | | | | |
| AKESSON | 86 | NP B264 154 | T. Akesson et al. | (Axial Field Spec. Collab.) | | | | |
| DAUM | 84 | ZPHY C23 339 | C. Daum et al. | (AMSŤ, CERN, CRÁC, MPIM+)JP | | | | |
| WETZEL | 76 | NP B115 208 | W. Wetzel et al. | (ETH, CERN, LOIC) | | | | |
| BEUSCH | 67 | PL 25B 357 | W. Beusch et al. | (ETH, CERN) | | | | |

 $a_0(1450)$

$$I^{G}(J^{PC}) = 1^{-}(0^{+})$$

See minireview on scalar mesons under $f_0(500)$.

a₀(1450) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|-------------|---------------------|------|------|------------------------------------------------------------|
| 1474 ±19 | OUR AVERAGE | · | | | |
| $1480\ \pm 30$ | | ABELE | 98 | CBAR | $0.0 \overline{p} p \rightarrow K_L^0 K^{\pm} \pi^{\mp}$ |
| 1470 ± 25 | | ¹ AMSLER | 95 D | CBAR | $0.0 \overline{p} p \rightarrow \pi^0 \pi^0 \pi^0$, |
| | | | | | $\pi^{0}_{\eta\eta}$, $\pi^{0}\pi^{0}_{\eta}$ |

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\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
    1515\phantom{0}\pm30\phantom{0}
                                                             <sup>2</sup> ANISOVICH 09 RVUE 0.0 \overline{p}p, \pi N
   1316.8 { + \atop -} \begin{array}{l} 0.7 + 24.7 \\ 1.0 - \phantom{0} 4.6 \end{array}
                                                              <sup>3</sup> UEHARA
                                                                                             09A BELL \gamma\gamma \to \pi^0\eta
                                                              <sup>4</sup> BUGG
    1432\phantom{0}\pm13\phantom{0}\pm25\phantom{0}
                                                                                             08A RVUE \overline{p}p
                                                              ^{\rm 5} UMAN
                                                                                                     E835 5.2 \overline{p}p \rightarrow \eta \eta \pi^0
    1477\phantom{0}\pm10\phantom{0}
                                              80k
   1441 \begin{array}{c} +40 \\ -15 \end{array}
                                                             ^{2}\,\mathrm{BAKER}
                                                                                                     SPEC \overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}
                                           35280
    1303 ±16
                                                              <sup>6</sup> BARGIOTTI
                                                                                                      OBLX \overline{p}p
                                                                                             03
                                                              ^{7}\,\mathrm{AMSLER}
                                                                                                      CBAR 0.9 \, \overline{p} p \rightarrow \pi^0 \pi^0 \eta
    1296\phantom{0}\pm10\phantom{0}
                                                                                             02
                                                               <sup>7</sup> A NISOVICH
    1565 \pm 30
                                                                                             98B RVUE Compilation
                                                                                            98B RVGE Compilation

98B OBLX 0.0 \overline{p}p \rightarrow K^{\pm}K_S \pi^{\mp}

94D CBAR 0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \eta

82C MPS 23 \pi^- p \rightarrow n2K_S^0
                                                              <sup>8</sup> BERTIN
    1290 \pm 10
    1450\ \pm 40
                                                                 AMSLER
    1410 \pm 25
                                                                 ETKIN
                                                                 MARTIN
                                                                                                     SPEC 10 K^{\pm}p \rightarrow K_{S}^{0}\pi p
\sim 1300\,
                                                                                             78
                                                              9 CASON
    1255 \pm 5
                                                                                             76
```

- $^{
 m 1}$ Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D.
- $^{2}\,\mathrm{From}$ the pole position.
- ³ May be a different state.
- ⁴ Using data from AMSLER 94D, ABELE 98, and BAKER 03. Supersedes BUGG 94.
- ⁶ Coupled channel analysis of $\pi^+\pi^-\pi^0$, $K^+K^-\pi^0$, and $K^{\pm}K^0_{S}\pi^{\mp}$.
- ⁷T-matrix pole.
- ⁸ Not confirmed by BUGG 08A.
- ⁹Isospin 0 not excluded.

a₀(1450) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | | | | |
|-------------------------------------------------------------------------------|-------------|----------------------|-------------|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|--|--|
| 265 ±13 | OUR AVERAGE | | | | | | | | | |
| 265 ± 15 | | ABELE | 98 | CBAR | $0.0 \overline{p}p \rightarrow K_I^0 K^{\pm} \pi^{\mp}$ | | | | | |
| 265 ±30 | | ¹⁰ AMSLER | 95 D | CBAR | $\begin{array}{ccc} 0.0 \; \overline{\rho}\rho \to & \mathcal{K}^0_L \; \mathcal{K}^\pm \; \pi^\mp \\ 0.0 \; \overline{\rho}\rho \to & \pi^0 \; \pi^0 \; \pi^0, \\ \pi^0 \; \eta\eta, \; \pi^0 \; \pi^0 \; \eta \end{array}$ | | | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | | | | |

11 ANICOVICH OF BYILE OF

| | ± 36 | | ** A NISOVICH | 09 | RVUE | $0.0 pp, \pi N$ |
|------------|----------------------------------|-------|--------------------------|-----|------|------------------------------------------------------------|
| 65. | $0 + 2.1 + 99.1 \\ - 5.4 - 32.6$ | | ¹² UEHARA | 09A | BELL | $\gamma \gamma \rightarrow \pi^0 \eta$ |
| 196 | ± 10 ± 10 | | ¹³ BUGG | 08A | RVUE | $\overline{p}p$ |
| 267 | ± 11 | 80k | ¹⁴ UMAN | | | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 110 | ± 14 | 35280 | ¹¹ BAKER | 03 | SPEC | $\overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}$ |
| 92 | ± 16 | | ¹⁵ BARGIOTTI | 03 | OBLX | <u>₽</u> p |
| 81 | ± 21 | | ¹⁶ AMSLER | 02 | CBAR | $0.9 \overline{p}p \rightarrow \pi^0 \pi^0 \eta$ |
| 292 | ± 40 | | ¹⁶ A NISOVICH | 98B | RVUE | Compilation |
| 80 | ± 5 | | ¹⁷ BERTIN | 98B | OBLX | $0.0 \overline{p}p \rightarrow K^{\pm} K_S \pi^{\mp}$ |
| 270 | ± 40 | | AMSLER | 94D | CBAR | $0.0 \overline{p} p \rightarrow \pi^0 \pi^0 \eta$ |
| 230 | ± 30 | | ETKIN | 82c | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| ~ 250 | | | MARTIN | 78 | SPEC | $10 K^{\pm} p \rightarrow K_{S}^{0} \pi p$ |
| 79 | ± 10 | | ¹⁸ CASON | 76 | | 3 |
| | | | | | | |

- $^{
 m 10}$ Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D.
- $^{11}\,\mathrm{From}$ the pole position.
- 12 May be a different state.
- 13 Using data from AMSLER 94D, ABELE 98, and BAKER 03. Supersedes BUGG 94. 14 Statistical error only.
- 15 Coupled channel analysis of $\pi^+\pi^-\pi^0$, $\kappa^+\kappa^-\pi^0$, and $\kappa^\pm\kappa^0_S\pi^\mp$.
- ¹⁶ T-matrix pole.
- 17 Not confirmed by BUGG 08A.
- 18 Isospin 0 not excluded.

a₀(1450) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------|------------------------------|
| Γ_1 | $\pi\eta$ | seen |
| Γ_2 | π <u>η' (</u> 958) | seen |
| Γ_3 | $K\overline{K}$ | seen |
| Γ_4 | $\omega \pi \pi$ | seen |
| Γ_5 | $a_0(980) \pi \pi$ | seen |
| Γ ₆ | $\gamma \gamma$ | seen |

$a_0(1450) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\pi\eta) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ | | | | | $\Gamma_1\Gamma_6/\Gamma$ |
|---------------------------------------------------------------------|----------------------|----------|---------|-------------------------------|---------------------------|
| VALUE (eV) | DO CUMENT ID | 1 | TECN | COMMENT | |
| • • • We do not use the follow | ng data for averag | es, fits | limits, | etc. • • • | |
| $432 \pm 6 {}^{+ 1073}_{- 25 6}$ | ¹⁹ UEHARA | 09A | BELL | $\gamma\gamma \to ~\pi^0\eta$ | |
| $^{ m 19}$ May be a different state. | | | | | |

a₀(1450) BRANCHING RATIOS Γ_2/Γ_1 $\Gamma(\pi\eta'(958))/\Gamma(\pi\eta)$ DOCUMENT ID TECN COMMENT ²⁰ ABELE 0.35 ± 0.16 98 CBAR $0.0 \overline{p}p \rightarrow$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet 0.43 ± 0.19 ABELE 97c CBAR $0.0 \, \overline{p} p \rightarrow \pi^0 \pi^0 \eta'$ 20 Using $\pi^0\,\eta$ from AMSLER 94D. $\Gamma(K\overline{K})/\Gamma(\pi\eta)$ Γ_3/Γ_1 DOCUMENT ID TECN COMMENT $^{21}\,{}^{\mathrm{ABELE}}$ 0.88±0.23 CBAR 0.0 $\overline{p}p \rightarrow K_I^0 K^{\pm} \pi^{\mp}$ 98 $^{21}\,\mathrm{Using}~\pi^0\,\eta$ from AMSLER 94D. $\Gamma(\omega\pi\pi)/\Gamma(\pi\eta)$ Γ_4/Γ_1 EVTS DOCUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 35 28 0 22 BAKER 10.7 ± 2.3 03 SPEC $\overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}$ 22 Using results on $\overline{\rho}\rho\to a_0(1450)\,^0\,\pi^0$, $a_0(1450)\to \eta\pi^0$ from ABELE 96C and assuming the $\omega\rho$ mechanism for the $\omega\pi\pi$ state. $\Gamma(a_0(980)\pi\pi)/\Gamma_{\text{total}}$ Γ_5/Γ VALUE DOCUMENT ID TECN COMMENT 08A RVUE DD seen BUGG $\Gamma(a_0(980)\pi\pi)/\Gamma(\pi\eta)$ Γ_5/Γ_1 DOCUMENT ID TECN CHG COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ANISOVICH 01 RVUE 0 $\overline{p}p \rightarrow \eta 2\pi^{+} 2\pi^{-}$ < 4.3 $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_6/Γ

a₀(1450) REFERENCES

DOCUMENT ID $^{23}\,{}^{\rm UEHARA}$

| UEHARA (BUGG (UMAN (| 09 09A 08A 06 | IJMP A24 2481 PR D80 032001 PR D78 074023 PR D73 052009 PL B563 140 | V.V. Anisovich, A.V. Sara S. Uehara et al. D.V. Bugg I. Uman et al. C.A. Baker et al. | (BELLE Collab.) (LOQM) (FNAL E835) |
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| | 02 01 | EPJ C23 29 NP A690 567 | C. Amsler et al. A.V. Anisovich et al. | |
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| BUGG | 94 | PR D50 4412 | D.V. Bugg et al. | (LOQM) |
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| MARTIN : | 78 | NP B134 392 | A.D. Martin et al. | (DURH, GEVA) |
| | 76 | PRL 36 1485 | N.M. Cason et al. | (NDAM, ANL) |



VALUE

 23 May be a different state.

$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

TECN COMMENT

09A BELL $\gamma\gamma
ightarrow \pi^0\eta$

See our mini-review under the ho(1700).

ρ(1450) MASS

DOCUMENT ID

1465 ± 25 OUR ESTIMATE This is only an educated guess; the error given is larger than the error on the average of the published values.

$\eta \rho^0$ MODE

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------------------|-------|-----------|-----------------------------------------------|
| • • • We do not use the follow | wing data for aver | ages, | fits, lim | its, etc. • • • |
| 1497 ± 14 | ¹ AKHMETSHIN | | | |
| 1421 ± 15 | ² AKHMETSHIN | 00D | CMD2 | $e^+e^- \rightarrow \eta \pi^+\pi^-$ |
| 1470 ± 20 | ANTONELLI | 88 | DM2 | $e^+e^- \rightarrow \eta \pi^+\pi^-$ |
| 1446 ± 10 | FUKUI | 88 | SPEC | $8.95 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |

 1 Using the data of AKHMETSHIN 01B on $e^+\,e^-
ightarrow \, \eta\gamma$, AKHMETSHIN 00D and

ANTONELLI 88 on $e^+e^-\to \eta\pi^+\pi^-$. ² Using the data of ANTONELLI 88, DOLINSKY 91, and AKHMETSHIN 00D. The energy-independent width of the $\rho(1450)$ and $\rho(1700)$ mesons assumed.

| ωπ MODE VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------------|-------------------------|---------|-------------|----------------------------------------------|
| • • • We do not us | se the followin | g data for average | s, fits | , limits, e | etc. • • • |
| $1582 \pm 17 \pm 25$ | 2382 | ³ AKHMETSHIN | 1 03в | CMD2 | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| $1349 \pm 25 {}^{+}_{-} {}^{10}_{5}$ | 341 | ⁴ ALEXANDER | 01в | CLE2 | $B \rightarrow D^{(*)}\omega\pi^-$ |
| 1523 ± 10 | | 5 EDWARDS | 00A | CLE2 | $\tau^- \rightarrow \omega \pi^- \nu_{\tau}$ |
| 1463 ± 25 | | ⁶ CLEGG | 94 | RVUE | · |
| 1250 | | ⁷ ASTON | | | $20-70 \gamma p \rightarrow \omega \pi^0 p$ |
| 1290 ± 40 | | ⁷ BARBER | 80c | SPEC | $3-5 \gamma p \rightarrow \omega \pi^0 p$ |

 3 Using the data of AKHMETSHIN 03B and BISELLO 91B assuming the $\omega\pi^0$ and $\pi^+\pi^-$ mass dependence of the total width. $\rho(1700)$ mass and width fixed at 1700 MeV and and 340 MeV are selected as 1700 MeV and 17000 MeV and 17000 MeV and 240 MeV, respectively.

 4 Using Breit-Wigner parameterization of the $\rho(1450)$ and assuming the $\omega\pi^-$ mass dependence for the total width.

 5 Mass-independent width parameterization. ho(1700) mass and width fixed at 1700 MeV and 235 MeV respectively.

 6 Using data from BISELLO 91B, DOLINSKY 86 and ALBRECHT 87L. 7 Not separated from $b_1(1235)$, not pure $J^P=1^-$ effect.

4π MODE

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------|------------------------|-------|-----------|----------------------------------------------------------|
| • • • We do not use the fo | ollowing data for aver | ages, | fits, lim | its, etc. • • • |
| 1435 ± 40 | ABELE | 01B | CBAR | $0.0 \ \overline{p} n \rightarrow 2\pi^- 2\pi^0 \pi^+$ |
| 1350 ± 50 | | | | $e^+e^- \rightarrow 2(\pi^+\pi^-)$ |
| 1449± 4 | ⁸ ARMSTRONG | 89E | OMEG | $300 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| | | | | |

8 Not clear whether this observation has I = 1 or 0.

$\pi\pi$ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------|---------|------------------------|--------|-------------|------------------------------------------------------------|
| ullet $ullet$ We do not | use the | following data for ave | erages | , fits, lin | nits, etc. • • • |
| $1446 \pm 7 \pm 28$ | 5.4 M | 9,10 FUJIKAWA | 80 | BELL | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| 1328 ± 15 | | ¹¹ SCHAEL | 05 c | ALEP | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| 1406 ± 15 | 87k | 9,12 ANDERSON | 00A | CLE2 | $\tau^- \rightarrow \pi^- \pi^0 \nu_{\tau}$ |
| ~ 1368 | | ¹³ ABELE | 99c | CBAR | $0.0 \overline{p} d \rightarrow \pi^{+} \pi^{-} \pi^{-} p$ |
| 1348 ±33 | | BERTIN | 98 | OBLX | $0.05-0.405 \ \overline{n}p \rightarrow 2\pi^{+}\pi^{-}$ |
| 1411 ± 14 | | ¹⁴ ABELE | 97 | CBAR | $\overline{p}n \rightarrow \pi^- \pi^0 \pi^0$ |
| $1370 \begin{array}{c} +90 \\ -70 \end{array}$ | | ACHASOV | 97 | RVUE | $e^+e^- \rightarrow ~\pi^+\pi^-$ |
| 1359 ±40 | | ¹² BERTIN | 97c | OBLX | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 1282 ± 37 | | BERTIN | 97D | OBLX | $0.05 \overline{p}p \rightarrow 2\pi^{+}2\pi^{-}$ |
| 1424 ± 25 | | BISELLO | 89 | DM2 | $e^+ e^- \rightarrow \pi^+ \pi^-$ |
| 1265.5 ± 75.3 | | DUBNICKA | 89 | RVUE | $e^+ e^- \rightarrow \pi^+ \pi^-$ |
| 1292 ± 17 | | ¹⁵ KURDADZE | 83 | OLYA | $0.64-1.4~e^+e^- \rightarrow ~\pi^+\pi^-$ |
| | | | | | |

 $^{9}\,\mathrm{From}$ the GOUNARIS 68 parametrization of the pion form factor.

11 From the combined fit of the τ^- data from ANDERSON 00A and SCHAEL 05C and e^+e^- data from the compilation of BARKOV 85, AKHMET SHIN 04, and ALOISIO 05. $\rho(1700)$ mass and width fixed at 1713 MeV and 235 MeV, respectively. Supersedes BARATE 97M.

12 $\rho(1700)$ mass and width fixed at 1700 MeV and 235 MeV, respectively.

 $^{13}\rho(1700)^{'}$ mass and width fixed at 1780 MeV and 275 MeV respectively.

14 T-matrix pole

 $^{15}\, \hbox{Using for} \; \rho(1700)$ mass and width 1600 \pm 20 and 300 \pm 10 MeV respectively.

K₹ MODE

| VALUE (MeV) | EVTS | DOCUMENT I | ID | TECN | CHG | COMMENT | |
|------------------|--------------|---------------------|-----------|------------|--------|-----------------------------------|------------------|
| • • • We do no | t use the fo | ollowing data fo | r average | s, fits, l | imits, | etc. • • • | |
| 1422.8 ± 6.5 | 27k | ¹⁶ ABELE | 99D | CBAR | \pm | $0.0 \ \overline{p}p \rightarrow$ | K^+ $K^ \pi^0$ |
| 16 K-matrix pol | e. Isospin r | ot determined. | could be | ω(1420 | ٥. | | |

$K\overline{K}^*(892) + c.c. MODE$

| (032) . 0.0 022 | | | | | |
|--------------------------------|-------------------|-------|-------------|---------------------------|------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do not use the follow | ving data for ave | rages | , fits, lin | nits, etc. • • • | |
| $1505\pm19\pm7$ | AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow$ | $K\overline{K}^*(892)\gamma$ |

ρ(1450) WIDTH

DOCUMENT ID

400±60 OUR ESTIMATE This is only an educated guess; the error given is larger than the error on the average of the published values.

$\eta \rho^0$ MODE

| VALUE (MeV) | DO CUMENT ID | TECN COMMENT | |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|--|
| • • • We do not use the | following data for average | es, fits, limits, etc. • • • | |
| 226 ± 44 | ¹⁷ AKHMETSHIN 01B | B CMD2 $e^+e^- 	o \eta \gamma$ | |
| 211 ± 31 | ¹⁸ AKHMETSHIN 00D | D CMD2 $e^+e^- ightarrow \eta \pi^+\pi^-$ | |
| 230 ± 30 | ANTONELLI 88 | DM2 $e^+e^- \rightarrow \eta \pi^+\pi^-$ | |
| $60\!\pm\!15$ | FUKUI 88 | SPEC 8.95 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ | |
| 17 | and the second s | | |

 17 Using the data of AKHMETSHIN 01B on $e^+\,e^-\,
ightarrow\,\eta\gamma$, AKHMETSHIN 00D and ANTONELLI 88 on $e^+\,e^-
ightarrow \, \eta\,\pi^+\,\pi^-$

 $^{^{10}|{\}it F}_{\pi}({\it 0})|^2$ fixed to 1.

¹⁸ Using the data of ANTONELLI 88, DOLINSKY 91, and AKHMETSHIN 00D. The energyindependent width of the $\rho(1450)$ and $\rho(1700)$ mesons assumed

 $\rho(1450)$

| $\omega\pi$ MODE | | $ ho$ (1450) Γ (i) Γ (e^+ e^-)/ Γ (total) |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) EVTS DO • • • We do not use the following data | OCUMENT ID TECN COMMENT of for averages, fits, limits, etc. • • • | $\Gamma(\pi\pi) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_1\Gamma_9/\Gamma$ |
| 129± 42±10 2382 ¹⁹ Al | KHMETSHIN 03B CMD2 $e^+e ightarrow \pi^0\pi^0\gamma$ | VALUE (keV) DOCUMENT ID TECN COMMENT |
| 47± 86+46 -45 341 20 AI | EXANDER 01B CLE2 $B 	o D^{(*)} \omega \pi^-$ | • • We do not use the following data for averages, fits, limits, etc. |
| -43 | DWARDS 00A CLE2 $	au^- ightarrow \omega \pi^- u_	au$ | 0.12 32 DIEKMAN 88 RVUE $e^+e^- ightarrow\pi^+\pi^-$ |
| | EGG 94 RVUE | $0.027^{+0.015}_{-0.010}$ 33 KURDADZE 83 OLYA 0.64 – $1.4~e^+e^- ightarrow ~\pi^+~\pi^-$ |
| | STON 80c OMEG 20-70 $\gamma p ightarrow \omega \pi^0 p$ | |
| | ARBER 80c SPEC 3-5 $\gamma p \rightarrow \omega \pi^0 p$ | $\Gamma(\eta ho) \times \Gamma(e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_{10}\Gamma_{9}/\Gamma_{0}$ |
| mass dependence of the total width | BB and BISELLO 91B assuming the $\omega\pi^0$ and $\pi^+\pi^-$ | VALUE (eV) DOCUMENT ID TECN COMMENT |
| 240 MeV, respectively. | | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ³⁰ Using Breit-Wigner parameterizatio pendence for the total width. | n of the $ ho(1450)$ and assuming the $\omega\pi^-$ mass de- | 74 \pm 20 34 AKHMETSHIN 00D CMD2 $e^+e^- \rightarrow \eta \pi^+ \pi^-$ 91 \pm 19 ANTONELLI 88 DM2 $e^+e^- \rightarrow \eta \pi^+ \pi^-$ |
| ²¹ Mass-independent width parameteri | zation. $ ho(1700)$ mass and width fixed at 1700 MeV | , |
| and 235 MeV respectively. ²² Using data from BISELLO 91B, DO | | $\Gamma(\eta\gamma) \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{14}\Gamma_9/\Gamma_{	ext{total}}$ |
| Not separated from $b_1(1235)$, not p | wre $J^P = 1^-$ effect. | VALUE (eV) DO CUMENT ID TECN COMMENT |
| • | | • • • We do not use the following data for averages, fits, limits, etc. • • |
| Fπ MODE MLUE (MeV) DO | CUMENT ID TECN COMMENT | <16.4 35 AKHMETSHIN 05 CMD2 0.60-1.38 $e^+e^- \rightarrow \eta \gamma$ $2.2 \pm 0.5 \pm 0.3$ 36 AKHMETSHIN 01B CMD2 $e^+e^- \rightarrow \eta \gamma$ |
| We do not use the following data | for averages, fits, limits, etc. • • • | |
| 25 ± 1 00 AI | BELE 01B CBAR $0.0 \overline{p} n \rightarrow 2\pi^- 2\pi^0 \pi^+$ | $\Gamma(K\overline{K}^*(892) + \text{c.c.}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_{13}\Gamma_9/\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13}\Gamma_{13$ |
| π MODE | | VALUE (eV) <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| T π MODE ALUE(MeV) EVTS DOCUMEI | NT ID TECN COMMENT | • • We do not use the following data for averages, fits, limits, etc. |
| We do not use the following data | | 127 \pm 15 \pm 6 AUBERT 08s BABR 10.6 $e^+e^- ightarrow \kappa \overline{\kappa}^*$ (892) γ |
| 434±16±60 5.4M ^{24,25} FUJIKAN | | $\frac{32}{33}$ Using total width = 235 MeV. |
| 468±41 26 SCHAEL | | 33 Using for $ ho(1700)$ mass and width 1600 ± 20 and 300 ± 10 MeV respectively. 34 Using the data of ANTONELLI 88, DOLINSKY 91, and AKHMETSHIN 00D. The energy- |
| 455±41 87k ^{24,27} ANDERS | T | independent width of the $ ho(1450)$ and $ ho(1700)$ mesons assumed. |
| 374 ²⁸ ABELE 275 ± 10 BERTIN | 99C CBAR $0.0 \overline{p} d \to \pi^+ \pi^- \pi^- p$ 98 OBLX $0.05 - 0.405 \overline{n} p \to \pi^+ \pi^+ \pi^-$ | 35 From 2γ decay mode of η using 1465 MeV and 310 MeV for the $ ho(1450)$ mass and |
| 343±20 BERTIN | 97 CBAR $\overline{p}n \rightarrow \pi^-\pi^0\pi^0$ | width. Recalculated by us. 36 Using the data of AKHMETSHIN 01B on $e^+e^- ightarrow \eta\gamma$, AKHMETSHIN 00D and |
| 310±40 27 BERTIN | | ANTONELLI 88 on $e^+e^- 	o \eta \pi^+\pi^-$. Recalculated by us using width of 226 MeV. |
| 236±36 BERTIN | | |
| 269±31 BISELLO | | $\rho(1450) \Gamma(i)/\Gamma(total) \times \Gamma(e^+e^-)/\Gamma(total)$ |
| 391±70 DUB NIC 218±46 30 KURDAI | | |
| 24 From the GOUNARIS 68 parametriz | | $\Gamma(f_0(500)\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{15}/\Gamma \times \Gamma_9/\Gamma_{15}$ |
| $^{25} F_{\pi}(0) ^2$ fixed to 1. | ation of the pion form factor. | VALUE (units 10 ⁻⁹) CL% DOCUMENT ID TECN COMMENT |
| 26 From the combined fit of the $	au^-$ (| data from ANDERSON 00A and SCHAEL 05c and | <4.0 90 ACHASOV 11 SND $e^+e^- ightarrow \pi^0\pi^0\gamma$ |
| o(1700) mass and width fixed at 1 | BARKOV 85, AKHMETSHIN 04, and ALOISIO 05. 713 MeV and 235 MeV, respectively. Supersedes | $\Gamma(f_0(980)\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{16}/\Gamma \times \Gamma_9/\Gamma$ |
| BARATE 97м. | | VALUE (units 10 ⁻⁹) CL% DOCUMENT ID TECN COMMENT |
| $^{27} ho(1700)$ mass and width fixed at 17 $^{28} ho(1700)$ mass and width fixed at 17 | 00 MeV and 235 MeV, respectively | <2.6 90 ACHASOV 11 SND $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| $^{\rho(1700)}$ mass and width fixed at 17 Temperatrix pole. | 50 MeV and 275 MeV respectively. | E(C(4070) \/F |
| 30 Using for $ ho(1700)$ mass and width 1 | 600 ± 20 and 300 ± 10 MeV respectively. | $\Gamma(f_0(1370)\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{17}/\Gamma \times \Gamma_9/\Gamma_{\text{total}}$ |
| ⟨ K MODE | | VALUE (units 10^{-9}) CL% DOCUMENT ID TECN COMMENT 3.5 90 ACHASOV 11 SND $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| ALUE (MeV) EVTS DOCUME | | , |
| We do not use the following data | • • • • | $\Gamma(f_2(1270)\gamma)/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{18}/\Gamma \times \Gamma_{9}/\Gamma_{18}$ |
| 46.5 ± 10.5 27k ³¹ ABELE | 99D CBAR \pm 0.0 $\overline{ ho} ho ightarrow K^+K^-\pi^0$ | VALUE (units 10 ⁻⁹) CL% DOCUMENT ID TECN COMMENT |
| ³¹ K-matrix pole. Isospin not determin | ed, could be $\omega(1420)$. | <0.8 90 37 ACHASOV 11 SND $e^+e^- ightarrow \pi^0\pi^0\gamma$ |
| ⟨ K *(892) + c.c. MODE | | 37 Using Breit-Wigner parametrization of the $ ho(1450)$ with mass and width of 1465 MeV |
| ALUE (MeV) DO CUM | ENT ID TECN COMMENT | and 400 MeV, respectively. |
| We do not use the following data | | ho(1450) BRANCHING RATIOS |
| 8±25±4 AUBER | T 08s BABR 10.6 $e^+e^- \rightarrow K\overline{K}^*(892) \gamma$ | • • • |
| -(14E0) | DECAY MODES | $\Gamma(\pi\pi)/\Gamma(4\pi)$ Γ_1/Γ_2 VALUE DOCUMENT ID TECH COMMENT |
| ρ (1450) | DECAY MODES | VALUE DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • |
| Mode | Fraction (Γ_i/Γ) | 0.37 \pm 0.10 38,39 ABELE 01B CBAR 0.0 \overline{p} $n \rightarrow 5\pi$ |
| | <u> </u> | |
| $1 \pi\pi$ | seen | $\Gamma(\omega\pi)/\Gamma_{	ext{total}}$ |
| $\frac{1}{2}$ 4π | seen | VALUE DOCUMENT ID TECN |
| | | • • We do not use the following data for averages, fits, limits, etc. |
| $a_1 (1260)\pi$ | | \sim 0.21 CLEGG 94 RVUE |
| T | | $\Gamma(\pi\pi)/\Gamma(\omega\pi)$ Γ_1/Γ_3 |
| $h_1(1170)\pi$ | | |
| $h_1(1170)\pi$ $h_1(1300)\pi$ | | VALUE DOCUMENT ID TECN |
| $h_1(1170)\pi$ $\pi(1300)\pi$ $\rho \rho$ $\rho(\pi\pi)s$ -wave | | |
| $h_1(1170)\pi$ $\pi(1300)\pi$ $\rho\rho$ $\rho(\pi\pi)s$ -wave e^+e^- | Seen | VALUE DOCUMENT ID TECN |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(1300)\pi$ $h_3(170)\pi$ $h_4(170)\pi$ $h_5(170)\pi$ $h_7(1170)\pi$ $h_7(1170)\pi$ $h_7(1170)\pi$ $h_7(1170)\pi$ | possibly seen | VALUE DO CUMENT ID TECN • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 0.32 CLEGG 94 RVUE |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(1300)\pi$ $h_3(130)\pi$ $h_4(1300)\pi$ $h_5(1300)\pi$ $h_5(1300)\pi$ | possibly seen not seen | $\frac{VALUE}{}$ DOCUMENT ID TECN • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 0.32 CLEGG 94 RVUE $\Gamma(\omega\pi)/\Gamma(4\pi)$ |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(1300)\pi$ $h_3(130)\pi$ $h_4(1300)\pi$ $h_5(1300)\pi$ $h_5(1300)\pi$ $h_7(1300)\pi$ $h_7(1300)\pi$ $h_7(1300)\pi$ $h_7(1300)\pi$ | possibly seen not seen not seen | $\frac{VALUE}{\bullet \bullet \bullet \bullet} \text{ We do not use the following data for averages, fits, limits, etc.} \bullet |
| $h_1(1170)\pi$ π $\pi(1300)\pi$ π $\rho\rho$ π ρ | possibly seen not seen not seen possibly seen | $\frac{VALUE}{\bullet \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} \bullet \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.} \bullet |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(11300)\pi$ $h_3(1130)\pi$ $h_4(1170)\pi$ $h_$ | possibly seen not seen not seen possibly seen possibly seen | $\frac{VALUE}{VALUE} \qquad \frac{DOCUMENT\ ID}{VALUE} \qquad \frac{TECN}{VALUE}$ • • • We do not use the following data for averages, fits, limits, etc. • • • $\sim 0.32 \qquad \qquad CLEGG \qquad 94 \qquad RVUE$ $\frac{\Gamma(\omega\pi)/\Gamma(4\pi)}{VALUE} \qquad \frac{DOCUMENT\ ID}{VALUE} \qquad \frac{TECN}{VALUE}$ • • • We do not use the following data for averages, fits, limits, etc. • • • $< 0.14 \qquad \qquad CLEGG \qquad 88 \qquad RVUE$ |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(1300)\pi$ $h_3(1300)\pi$ $h_4(1170)\pi$ $h_5(1170)\pi$ $h_7(1170)\pi$ h_7 | possibly seen not seen not seen possibly seen possibly seen not seen | $\frac{VALUE}{\bullet \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} \bullet \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} \bullet \bullet \bullet \bullet \text{ CLEGG} 94 RVUE}$ $\frac{\Gamma(\omega \pi)/\Gamma(4\pi)}{VALUE} \qquad \qquad \frac{DOCUMENT\ ID}{DOCUMENT\ ID} \qquad \frac{TECN}{DOCUMENT\ ID}$ $\bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} \bullet \bullet \bullet \bullet$ |
| 5 $h_1(1170)\pi$ 6 $\pi(1300)\pi$ 7 $\rho\rho$ 8 $\rho(\pi\pi)_{S\text{-wave}}$ 9 e^+e^- 10 $\eta\rho$ 11 $a_2(1320)\pi$ 12 $K\overline{K}$ 13 $K\overline{K}^*(892) + \text{c.c.}$ | possibly seen not seen not seen possibly seen possibly seen | $\frac{VALUE}{\bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} = \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.}} = \bullet |
| $h_1(1170)\pi$ $h_1(1170)\pi$ $h_1(1170)\pi$ $h_2(1300)\pi$ $h_3(1300)\pi$ $h_4(1300)\pi$ $h_5(1300)\pi$ | possibly seen not seen not seen possibly seen possibly seen not seen not seen | $\frac{VALUE}{\bullet \bullet \bullet \bullet} \text{ We do not use the following data for averages, fits, limits, etc.} \bullet \bullet \bullet \bullet$ $\sim 0.32 \qquad \text{CLEGG} \qquad 94 \qquad \text{RVUE}$ $\frac{\Gamma(\omega \pi)/\Gamma(4\pi)}{VALUE} \qquad \frac{DOCUMENT\ ID}{A} \qquad \frac{TECN}{A}$ $\bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.} \bullet \bullet$ $< 0.14 \qquad \text{CLEGG} \qquad 88 \qquad \text{RVUE}$ $\Gamma(a_1(1260)\pi)/\Gamma(4\pi) \qquad \Gamma_4/\Gamma_2$ |

Meson Particle Listings $\rho(1450), \eta(1475)$

| $\Gamma(h_1(1170)\pi)/\Gamma(4\pi)$ | | | | | Γ_5/Γ_2 |
|-------------------------------------------------------------------------------------------------|------------------------------------------|-------------|--------------|--------------------------------------|----------------------------------|
| VALUE | DOCUMENT I | | | | |
| • • We do not use the following | ig data for avera ³⁸ ABELE | _ | | | _ |
| 0.08 ± 0.04 | 22 ABELE | 018 | CBAR | $0.0 \ \overline{p} \ n \rightarrow$ | 5π |
| $\Gamma(\pi(1300)\pi)/\Gamma(4\pi)$ | | | | | Γ_6/Γ_2 |
| VALUE | DO CUMENT I | 0 | TECN | COMMENT | • |
| ● We do not use the following | | ges, fits, | limits, | etc. • • • | |
| 0.37 ± 0.13 | ³⁸ ABELE | 01 B | CBAR | $0.0 \overline{p} n \rightarrow$ | 5π |
| $\Gamma(ho ho)/\Gamma(4\pi)$ | | | | | Γ_7/Γ_2 |
| VALUE | DO CUMENT I | | | | |
| ◆ ◆ We do not use the following | | _ | | | |
| 0.11 ± 0.05 | ³⁸ ABELE | 01B | CBAR | $0.0 \overline{p} n \rightarrow$ | 5π |
| $\Gamma(\rho(\pi\pi)_{S-wave})/\Gamma(4\pi)$ | | | | | Γ ₈ /Γ ₂ |
| VALUE | DO CUMENT I | 9 | TECN | COMMENT | |
| | | | | | |
| 0.17 ± 0.09 | ³⁸ ABELE | 01B | CBAR | $0.0 \ \overline{p} \ n \rightarrow$ | 5π |
| r/\/r | | | | | F /F |
| $\Gamma(\eta \rho)/\Gamma_{\text{total}}$ | DO CUMENT I | n | TECN | | Γ_{10}/Γ |
| VALUE ■ ■ We do not use the followir | | | | etc • • • | |
| < 0.04 | DONNACHI | _ | RVUE | cic. • • • | |
| | DOMINICIN | _ 0,5 | IL VOL | | |
| $\Gamma(\eta ho)/\Gamma(\omega\pi)$ | | | | | Γ_{10}/Γ_{3} |
| VALUE | DOCUMENT I | | | COMMENT | |
| • • We do not use the following | • | _ | | etc. • • • | |
| ~ 0.24 >2 | ⁴⁰ DONNACHI FUKUI | E 91 91 | RVUE SPEC | 0.05 | $\rightarrow \omega \pi^0 n$ |
| | FUNUI | 91 | SPEC | 0.95 π μ | $\rightarrow \omega \pi \Pi$ |
| $\Gamma(a_2(1320)\pi)/\Gamma_{	ext{total}}$ | | | | | Γ ₁₁ /Γ |
| VALUE | DO CUMENT I | | | | |
| | | | | | |
| not seen | AMELIN | 00 | VES | 37 π ⁻ p - | $\rightarrow \eta \pi^+ \pi^- n$ |
| $\Gamma(K\overline{K})/\Gamma(\omega\pi)$ | | | | | Γ_{12}/Γ_{3} |
| VALUE | DO CUMENT I | 5 | TECN | | , - |
| | ig data for avera | ges, fits, | limits, | etc. • • • | |
| < 0.08 | ⁴⁰ DONNACHI | E 91 | RVUE | | |
| Γ(<i>K</i> \(\overline{K}^*(892) + c.c.)/Γ _{total} | | | | | Γ ₁₃ /Γ |
| VALUE | DO CUMENT I | n | TECN | COMMENT | 113/1 |
| | | | | | |
| possibly seen | COAN | 04 | | | $-\pi^{-}K^{+}\nu_{-}$ |
| | 20/114 | V-1 | SELO | N | v _T |
| | | | | | |
| $^{38}\omega\pi$ not included. 39 Using ABELE 97. 40 Using data from BISELLO 91 | в, DOLINSKY 8 | 6 and A | LBREC | HT 87L. | |

| A CHAS OV | 11 | JETP 113 75 | M.N. Achasov et al. | (SND Collab.) |
|------------|------|----------------------|--------------------------------------|-----------------------------|
| | | Translated from ZETF | | ,_ î |
| AUBERT | 085 | PR D77 092002 | B. Aubert et al. | (BABAR Collab.) |
| FUJIKAWA | 80 | PR D78 072006 | M. Fujikawa et al. | (BELLE Collab.) |
| AKHMETSHIN | | PL B605 26 | R.R. Ákhmetshin <i>et al</i> . | (Novosibirsk CMD-2 Collab.) |
| A LOIS IO | 05 | PL B606 12 | A. Aloisio et al. | (KLOE Collab.) |
| SCHAEL | 05 C | PRPL 421 191 | S. Schael et al. | (ALEPH Collab.) |
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| AKHMETSHIN | | PL B562 173 | R.R. Akhmetshin et al. | (Novosibirsk CMD-2 Collab.) |
| ABELE | 01B | EPJ C21 261 | A. Abele <i>et al</i> . | (Crystal Barrel Collab.) |
| AKHMETSHIN | | PL B509 217 | R.R. Akhmetshin et al. | (Novosibirsk CMD-2 Collab.) |
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| ACHASOV | 97 | PR D55 2663 | N.N. Achasov et al. | (NOVM) |
| BARATE | 97 M | ZPHY C76 15 | R. Barate et al. | (ALEPH Collab.) |
| BERTIN | 97 C | PL B408 476 | A. Bertin et al. | (ÒBELIX Collab.) |
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| CLEGG | 94 | ZPHY C62 455 | A.B. Clegg, A. Donnachie | `(LANC, MCHS) |
| BISELLO | 91B | NPBPS B21 111 | D. Bisello | (DM2 Collab.) |
| DOLINS KY | 91 | PRPL 202 99 | S.I. Dolinsky et al. | ` (NOVO) |
| DONNACHIE | 91 | ZPHY C51 689 | A. Donnachie, A.B. Clegg | (MCHS, LANC) |
| FUKUI | 91 | PL B257 241 | | SUGI, NAGO, KEK, KYOT+) |
| ARMSTRONG | 89E | PL B228 536 | T.A. Armstrong, M. Benay | oun (ATHU, BARI, BIRM+) |
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| ANTONELLI | 88 | PL B212 133 | A. Antonelli et al. | (DM2 Collab.) |
| CLEGG | 88 | ZPHY C40 313 | A.B. Clegg, A. Donnachie | (MCHS, LANC) |
| DIEKMAN | 88 | PRPL 159 99 | B. Diekmann | (BONN) |
| FUKUI | 88 | PL B202 441 | S. Fukui et al. (| SUGI, NAGO, KEK, KYOT+1 |
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| ASTON | 80 C | PL 92B 211 | D. Aston (BONN, C | CERN, EPOL, GLAS, LANC+) |
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| GOUNARIS | 68 | PRL 21 244 | G.J. Gounaris, J.J. Sakurai | . , |
| | | | | |



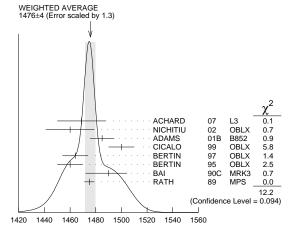
$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

See also the $\eta(1405)$.

η (1475) MASS

$K\overline{K}\pi$ MODE (K^* (892) K dominant)

| VALUE (MeV) E | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------|---------------|-------------------|--------|-------------|----------------------------------------------------------------------------------------------------------|
| 1476± 4 OUR AV | ERAGE E | Error includes sc | ale fa | ctor of 1 | .3. See the ideogram below. |
| $1469 \pm 14 \pm 13$ | 74 | ACHARD | 07 | L3 | $^{183-209}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\kappa_{S}}\overset{\rightarrow}{\kappa^{\pm}}_{\pi^{\mp}}$ |
| 1460 ± 19 3 | 3651 | NICHITIU | 02 | OBLX | 3 |
| $1485 \pm 8 \pm 5$ | 20k | ADA MS | 01в | B852 | 18 GeV $\pi^- p \to K^+ K^- \pi^0 n$ |
| 1500 ± 10 | | CICALO | 99 | OBLX | $0 \overline{p} p \rightarrow K^{\pm} K_{S}^{0} \pi^{\mp} \pi^{+} \pi^{-}$ |
| 1464 ± 10 | | BERTIN | 97 | OBLX | $0 \ \overline{p}p \rightarrow K^{\pm}(K^{0}) \pi^{\mp} \pi^{+} \pi^{-}$ |
| 1460 ± 10 | | BERTIN | 95 | OBLX | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$ |
| $1490 + 14 + 3 \\ -8 - 16$ | 100 | BAI | 90c | MRK3 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| 1475 ± 4 | | RATH | 89 | MPS | $21.4 \pi^- p \rightarrow n K_S^0 K_S^0 \pi^0$ |
| | use the follo | owing data for a | verag | es, fits, l | imits, etc. • • • |
| 1421 ± 14 | | AUGUSTIN | 92 | DM2 | $J/\psi \rightarrow \gamma K \overline{K} \pi$ |



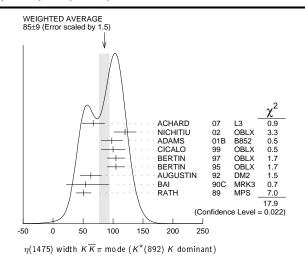
 $\eta(1475)$ mass, $K\overline{K}\pi$ mode ($K^*(892)$ K dominant) (MeV)

η (1475) WIDTH

$K\overline{K}\pi$ MODE (K^* (892) K dominant)

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|---------|-------------------|--------|-----------|----------------------------------------------------------------------------------------------------------|
| 85 ± 9 OUR | AVERAGE | Error includes so | ale fa | ctor of 1 | .5. See the ideogram below. |
| 67±18± 7 | 74 | ACHA RD | 07 | L3 | $^{183-209}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\kappa_{S}}\overset{\rightarrow}{\kappa^{\pm}}_{\pi^{\mp}}$ |
| 120 ± 19 | 3651 | NICHITIU | 02 | OBLX | ū |
| $98 \pm 18 \pm 3$ | 20 k | ADAMS | 01B | | 18 GeV $\pi^- p \to K^+ K^- \pi^0 n$ |
| 100 ± 20 | | CICALO | 99 | | $0 \overline{p} p \rightarrow K^{\pm} K_S^0 \pi^{\mp} \pi^+ \pi^-$ |
| 105 ± 15 | | BERTIN | 97 | OBLX | $0.0 \overline{p} p \rightarrow K^{\pm} (K^0) \pi^{\mp} \pi^+ \pi^-$ |
| 105 ± 15 | | BERTIN | 95 | OBLX | $0 \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$ |
| 63 ± 18 | | AUGUSTIN | 92 | DM2 | $J/\psi \rightarrow \gamma K \overline{K} \pi$ |
| $54 + 37 + 13 \\ -21 - 24$ | | BAI | 90c | MRK3 | $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ |
| $51\!\pm\!13$ | | RATH | 89 | MPS | $21.4 \; \pi^{-} p \to \; n K_{S}^{0} K_{S}^{0} \pi^{0}$ |
| | | | | | |

 $\eta(1475), f_0(1500)$



η (1475) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------------------------|------------------------------|
| Γ_1 | $K\overline{K}\pi$ | dominant |
| Γ ₂ | $K\overline{K}^*(892) + \text{c.c.}$ | seen |
| Γ_3 | $a_0(980)\pi$ | seen |
| Γ_4 | $\gamma\gamma$ | seen |

$\eta(1475) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(KK\pi) \times \Gamma(\gamma\gamma)$ |)/「 _{total} | | | | Γ ₁ Γ ₄ /Γ |
|---------------------------------------------|----------------------|---------------------|----------|-----------|----------------------------------------------------------------------------------------------------------|
| VALUE (keV) CL% | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT |
| $0.23 \pm 0.05 \pm 0.05$ | 74 | ¹ ACHARD | 07 | L3 | $^{183-209}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\kappa^{0}}\overset{\rightarrow}{\kappa^{\pm}}_{\pi^{\mp}}$ |
| • • • We do not use | the followi | ng data for averag | es, fits | , limits, | 9 |

05 CLE2 $10.6 e^{+} e^{-} \xrightarrow{0.6} K^{\pm} \pi^{\mp}$ < 0.089 ¹ Supersedes ACCIARRI 01G. Compatible with K^*K decay. Using B $(K^0_S \to \pi^+\pi^-)=$

³ Assuming three-body phase-space decay to K_S^0 $K^\pm\pi^\mp$.

η(1475) BRANCHING RATIOS

| $\Gamma(K\overline{K}^*(892) + \text{c.c.})/\Gamma(K\overline{K}\pi)$ | | | | | | |
|-----------------------------------------------------------------------|----------------------|-----------|---------|--------------------------------|--------------------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| • • • We do not use the follow | ving data for averag | es, fits, | limits, | etc. • • • | | |
| 0.50 ± 0.10 | ⁴ BAILLON | 67 | нвс | $0.0~\overline{p}p\rightarrow$ | $K\overline{K}\pi\pi\pi$ | |

| Γ(<i>K</i> K *(892)+ | c.c.)/[Г(<i>К'</i> К | *(892) + c.c.) · | + Г(а | o (980) | $\pi)]$ | $\Gamma_2/(\Gamma_2+\Gamma_3)$ |
|----------------------------------|-----------------------|------------------|-----------|---------|----------------------|----------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMEN | T |
| • • • We do not ι | ise the following | data for average | es, fits, | limits, | etc. • • | • |
| < 0.25 | 90 | EDWARDS | 82E | CBAL | $J/\psi \rightarrow$ | $\kappa^+ \kappa^- \pi^0 \gamma$ |

⁴ Data could also refer to $\eta(1405)$.

$\eta(1475)$ REFERENCES

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|----------|------|---------------|-------------------------|------------------------|
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| NICHITIU | 02 | PL B545 261 | F. Nichitiu et al. | (OBELIX Collab.) |
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| BAILLON | 67 | NC 50A 393 | P.H. Baillon et al. | (CERN. CDEF. IRAD) |

 $f_0(1500)$

$$I^G(J^{PC}) = 0^+(0^{++})$$

See also the mini-reviews on scalar mesons under $f_0(500)$ (see the index for the page number) and on non- $q\overline{q}$ candidates in PDG 06, Journal of Physics, G **33** 1 (2006).

f₀(1500) MASS

| the fol 8 k k 7 0 | ABLI 1 BEF ABLI 1 BEF ABLI 1 A | LIKIM RBERIS RBERIS REBERIS RTIN RTIN ELE SLER data for av SOVICH EMPT HARA SLER BERT AN ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS RBERIS RLAZZINI ENCH MINSKI | 06v 00a 00c 98 97c 96B 95c verage 09 08 08A 06 060 | OBLX OBLX CBAR CBAR CBAR E791 BELL CBAR BABR E835 SPELL RVUE CBAR OMEG OMEG OMEG GAM4 | 3. See the ideogram below. $e^+e^- \rightarrow J/\psi \rightarrow \gamma \pi^+ \pi^ 450~pp \rightarrow p_f \eta \eta p_S$ $450~pp \rightarrow p_f \eta \eta p_S$ $450~pp \rightarrow p_f \eta \eta p_S$ $450~pp \rightarrow p_f \eta \eta p_S$ $0.05-0.405~\overline{\eta}p \rightarrow \pi^+ \pi^+ \pi^+$ $0.0~\overline{p}p \rightarrow \pi^0 K_L^0 K_L^0$ $0.0~\overline{p}p \rightarrow \pi^0 K_L^0 K_L^0$ $0.0~\overline{p}p \rightarrow \eta \eta \pi^0$ mits, etc. •• $0.0~\overline{p}p, \pi N$ $p_S^+ \rightarrow \pi^- \pi^+ \pi^+$ $10.6~e^+e^- \rightarrow e^+e^- \pi^0 \pi^0$ $9~\overline{p}p \rightarrow K^+K^- \pi^0$ $9~\overline{p}p \rightarrow K^+K^- \pi^0$ $9~\overline{p}p \rightarrow K^+K^- \pi^0$ $9~\overline{p}p \rightarrow K^0 S_S^0 S_S^0$ $33~\pi^-p \rightarrow \eta \eta \pi^0$ $40~\pi^-p \rightarrow K_S^0 S_S^0$ $33~\pi^-p \rightarrow \eta \eta \pi^0$ $9~\overline{p}p \rightarrow K^+K^- \pi^0$ $9~\overline{p}p \rightarrow K^-K^- \pi^0$ $9~\overline{p}p \rightarrow p_T^0 \pi^0$ $9~\overline{p}p \rightarrow p_T^0 \pi^0$ $9~\overline{p}p \rightarrow p_T^0 \pi^0$ |
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| the fol 8 k k 7 0 | 1 BAR 2 BARAR BEF 1 BEF ABE 3 AMM 4 AMM (Ilow ning) 5 KLE 6 UEF AUE AUE 7 BIN 7 BAR 7 BAR 7 BAR 7 FRE 17 FRE 17 KALE | RBERIS RBERIS RBERIS RTIN RTIN ELE SLER Gata for av SOVICH EMPT HARA SLER BERT AN HOIMIRSK HOON RMASH SOVICH ERBERIS RBERIS | 00A 00C 00E 98 97C 96B 95B 95C 96B 008A 06 06O 06O 06O 05 05 03 01 99 99B 99D 99 | OBLX OBLX OBLX CBAR CBAR CBAR IS, fits, li RVUE E791 BELL CBAR BABR E335 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | 450 $pp \rightarrow p_f ηηρ_S$ 450 $pp \rightarrow p_f ηηρ_S$ 450 $pp \rightarrow p_f ηηρ_S$ 0.05–0.405 $\overline{n}p \rightarrow \pi^+\pi^-\pi^0$ 0.0 $\overline{p}p \rightarrow \pi^0 \kappa_L^0 \kappa_L^0$ 0.0 $\overline{p}p \rightarrow \pi^0 \kappa_L^0 \kappa_L^0$ 0.0 $\overline{p}p \rightarrow \eta \eta \pi^0$ mits, etc. • • 0.0 $\overline{p}p \rightarrow \eta \eta \pi^0$ |
| the fol 8 k k 7 0 | .2 BAR2 BAR2 BAR3 AM4 AM1 BLE4 AM5 KLE6 UEH8 UMVLA .7 BINN7 ABR7 BAR7 BAR7 FREI .1 FREI .1 ALE. | RBERIS RBERIS RTIN RTIN RTIN ELE SLER SLER SOVICH EMPT HARA SLER SERT AN HOIMIRSK ON R MASH ERERIS RBERIS RBERIS RBERIS RBERIS LAZZINI EMCH | 00c 00e 98 97c 96B 95c cerage 09 08 06 06 06 05 05 03 01 99 99 99 99 99 | OBLX CBAR CBAR CBAR s, fits, li RVUE E791 BELL CBAR BABR E335 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{c} 450 \ pp \rightarrow p_f 4\pi p_S \\ 450 \ pp \rightarrow p_f \eta\eta p_S \\ 0.05-0.405 \ \overline{n}p \rightarrow \pi^+\pi^+\pi^+\pi^-\\ 0.0.0 \ \overline{p}p \rightarrow \pi^+\pi^-\pi^0 \\ 0.0 \ \overline{p}p \rightarrow \pi^0 \ K_L^0 \ K_L^0 \\ 0.0 \ \overline{p}p \rightarrow 3\pi^0 \\ 0.0 \ \overline{p}p \rightarrow \eta\eta\pi^0 \\ \text{mits, etc.} \bullet \bullet \bullet \\ 0.0 \ \overline{p}p, \pi N \\ D_S^+ \rightarrow \pi^-\pi^+\pi^+ \\ 10.6 \ e^+e^- \rightarrow e^+e^-\pi^0\pi^0 \\ 8^+ \rightarrow K^+K^-\pi^0 \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \ \overline{p}p \rightarrow N^0_S \ K_S^0 \ n \\ 10.0 \$ |
| the fol 8 k k 7 0 | 1 BAR BEET BAR BEET BAR 1 BEET ABR 3 AMM 4 AMM 4 AMM 10 Wingg 1 ANI 1 AN | RBERIS RTIN RTIN ELE SLER SLER SLER G data for av SOVICH EMPT HARA SSUER SERT AN ADIMIRSK ON RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS LAZZINI EMCH | 00E 98 97C 96B 95B 95C cerage 09 08 08A 06 06 06 05 05 03 01 99 99 99 99 99 | OBLX CBAR CBAR CBAR s, fits, li RVUE E791 BELL CBAR BABR E335 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{lll} 450 \ pp \rightarrow & p_f \eta \eta p_s \\ 0.05 - 0.405 \ \overline{\eta}p \rightarrow & \pi^+ \pi^+ \pi^+ \\ 0.0 \ \overline{p}p \rightarrow & \pi^+ \pi^- \pi^0 \\ 0.0 \ \overline{p}p \rightarrow & \pi^+ \pi^- \pi^0 \\ 0.0 \ \overline{p}p \rightarrow & \pi^0 \ K_L^0 \\ 0.0 \ \overline{p}p \rightarrow & 3\pi^0 \\ 0.0 \ \overline{p}p \rightarrow & 3\pi^0 \\ \end{array}$ $\begin{array}{lll} 0.0 \ \overline{p}p \rightarrow & 3\pi^0 \\ 0.0 \ \overline{p}p \rightarrow & \eta \eta \pi^0 \\ \end{array}$ mits, etc. • • • $\begin{array}{lll} 0.0 \ \overline{p}p \rightarrow & \eta \eta \pi^0 \\ \text{mits, etc.} & \bullet \bullet \\ 0.0 \ \overline{p}p, \pi N \\ D_s^+ \rightarrow & \pi^- \pi^+ \pi^+ \\ 10.6 \ e^+ e^- \rightarrow & e^+ e^- \pi^0 \pi^0 \\ 0.9 \ \overline{p}p \rightarrow & K^+ K^- \pi^0 \\ B^+ \rightarrow & K^+ K^+ K^- \\ 5.2 \ \overline{p}p \rightarrow & \eta \eta \pi^0 \\ 40 \ \pi^- p \rightarrow & K_S^0 K_S^0 S \\ 33 \ \pi^- p \rightarrow & \eta \eta \pi \\ B^+ \rightarrow & K^+ K^+ K^- \\ \end{array}$ $\begin{array}{lll} 0.0 \ \overline{p}d \rightarrow & \pi^- 4\pi^0 p \\ 450 \ pp \rightarrow & p_S p_f \pi^+ \pi^- \\ 450 \ pp \rightarrow & p_S p_f \pi^+ \pi^- \\ 450 \ pp \rightarrow & p_F \eta^- \pi^0 \\ 300 \ pp \rightarrow & p_f (K^+ K^-) p_S \\ \end{array}$ |
| 8 k 7 i 0 : | BEFF ABE 3 AM 4 AM 4 AM 5 KLE 6 UEFF AUL 4 AU 7 BIN 7 ABE 7 BAF 11 BAF 7 BEL 7 FRE 12 KAL 7 AL 7 AL 7 AL 8 AB 8 AB 8 AB 8 AB 8 AB 9 AB 9 AB 10 AN 10 A | RTIN RTIN LLE SLER SLER data for av SOVICH EMPT HARA SLER BERT AN ADIMIRSK ION RMASH SOVICH LLE RBERIS RBERIS RBERIS RBERIS RLAZZINI ENCH MINSKI | 98 97C 96B 95B 95C verage 09 08 06 06 06 06 05 05 03 01 99 99B 99D 99 | OBLX CBAR CBAR CBAR s, fits, li RVUE E791 BELL CBAR BABR E335 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{lll} 0.05 - 0.405 & \overline{\eta} \rho \longrightarrow \pi^+ \pi^+ \pi^- \\ 0.0 & \overline{\rho} \rho \longrightarrow \pi^+ \pi^- \pi^0 \\ 0.0 & \overline{\rho} \rho \longrightarrow \pi^0 & K_0^0 & K_0^0 \\ 0.0 & \overline{\rho} \rho \longrightarrow 3\pi^0 & K_0^0 & K_0^0 \\ 0.0 & \overline{\rho} \rho \longrightarrow 3\pi^0 & K_0^0 & K$ |
| 8 k 7 i 0 : | 1 BEF ABE 3 AM 4 AM Illowing 1 ANI 5 KLE 6 UEF AM AUE 7 BIN 7 ABE 7 BAF 11 BAF 7 BEL 1 7 FRE 1 7 KALE | RTIN ELE SLER SLER SOVICH EMPT HARA SLER BERT AN HOIMIRSK SOVICH ELE REBERIS REERIS REERIS REERIS LLAZZINI ENCH | 97C 96B 95B 95C verage 09 08 08A 06 060 06 .06 05 05 03 01 99 99B 99D 99 | OBLX CBAR CBAR CBAR s, fits, li RVUE E791 BELL CBAR BABR E335 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{c} 0.0 \ \overline{\rho} p \to \pi^+ \pi^- \pi^0 \\ 0.0 \ \overline{\rho} p \to \pi^0 \ K_L^0 \ K_L^0 \\ 0.0 \ \overline{\rho} p \to 3\pi^0 \\ 0.0 \ \overline{\rho} p \to 3\pi^0 \\ 0.0 \ \overline{\rho} p \to \eta \eta \pi^0 \\ \text{mits, etc.} \bullet \bullet \\ 0.0 \ \overline{\rho} p \to \eta \eta \pi^0 \\ \text{mits, etc.} \bullet \bullet \bullet \\ 0.0 \ \overline{\rho} p, \ \pi N \\ D_s^+ \to \pi^- \pi^+ \pi^+ \\ 10.6 \ e^+ e^- \to e^+ e^- \pi^0 \pi^0 \\ 0.9 \ \overline{\rho} p \to K^+ K^- \pi^0 \\ B^+ \to K^+ K^+ K^- \\ 5.2 \ \overline{\rho} p \to \eta \eta \pi^0 \\ 40 \ \pi^- p \to K_S^0 \ K_S^0 n \\ 33 \ \pi^- p \to \eta \eta n \\ B^+ \to K^+ K^+ K^- \\ 0.0 \ \overline{\rho} d \to \pi^- 4\pi^0 p \\ 450 \ p p \to p_S p_f \ K^+ K^- \\ 450 \ p p \to p_S p_f \pi^+ \pi^- \\ 450 \ p p \to p_S \pi^- \pi^0 \\ 300 \ p p \to p_f (K^+ K^-) p_S \\ 300 \ p p \to p_f (K^+ K^-) p_S \end{array}$ |
| 8 k 7 i 0 : | ABE | ELE SLER SLER SLER SOVICH MPT HARA SLER BERT AN HOINIRSK SOVICH ELE REERIS REERIS REERIS REERIS LLAZZINI ENCH | 96B 95B 95C verage 09 08 08A 06 060 06 0.06 05 03 01 99 99B 99D 99 | CBAR CBAR CBAR RVUE E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{c} 0.0 \ \overline{p} \rho \to \pi^0 \ K_L^0 \ K_L^0 \\ 0.0 \ \overline{p} \rho \to 3\pi^0 \\ 0.0 \ \overline{p} \rho \to 3\pi^0 \\ 0.0 \ \overline{p} \rho \to \eta \eta \pi^0 \\ \text{mits, etc.} \bullet \bullet \bullet \\ 0.0 \ \overline{p} \rho, \pi N \\ D_s^+ \to \pi^- \pi^+ \pi^+ \\ 10.6 \ e^+ e^- \to e^+ e^- \pi^0 \pi^0 \\ 0.9 \ \overline{p} \rho \to K^+ K^- \pi^0 \\ B^+ \to K^+ K^+ K^- \\ 5.2 \ \overline{p} \rho \to \eta \eta \pi^0 \\ 40 \ \pi^- \rho \to K_S^0 \ K_S^0 n \\ 33 \ \pi^- \rho \to \eta \eta n \\ B^+ \to K^+ K^+ K^- \\ 0.0 \ \overline{p} \ d \to \pi^- 4\pi^0 \rho \\ 450 \ p \rho \to p_S p_f \ K^+ K^- \\ 450 \ p \rho \to p_S p_f \ \pi^+ \pi^- \\ 450 \ p \rho \to p_S p_T \pi^+ \pi^- \\ 450 \ p \rho \to p_P \pi^0 \pi^0 \\ 300 \ p \rho \to p_F \eta \pi^0 \\ 300 \ p \rho \to p_F \eta \pi^+ (K^+ K^-) p_S \\ \end{array}$ |
| 8 k 7 i 0 : | 3 AM 4 AM HIDOWING 1 ANI 1 ANI 5 KLE 6 UEF AM AUE 7 BINN VLA 7 BINN 7 ABE 10 ANI 7 ABE 11 BAF 7 BE 12 KA 7 ALC | SLER SLER data for av SOVICH EMPT HARA SLER SERT AN ADIMIRSK ON RMASH SOVICH ELE RBERIS RBERIS RBERIS LAZZINI EMCH | 95B 95C verage 09 08 08A 06 06O 06 0.06 05 03 01 99 99B 99D 99 | CBAR CBAR is, fits, li RVUE E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{l} 0.0 \ \overline{\rho} p \to 3\pi^0 \\ 0.0 \ \overline{\rho} p \to \eta \eta \pi^0 \\ \text{mits, etc.} \bullet \bullet \bullet \\ 0.0 \ \overline{\rho} p, \ \pi N \\ D_s^+ \to \pi^- \pi^+ \pi^+ \\ 10.6 \ e^+ e^- \to e^+ e^- \pi^0 \pi^0 \\ 8^+ \to K^+ K^- \pi^0 \\ 8^+ \to K^+ K^- K^- \\ 5.2 \ \overline{\rho} p \to \eta \eta \pi^0 \\ 40 \ \pi^- p \to K_S^0 K_S^0 n \\ 33 \ \pi^- p \to \eta \eta n \\ 8^+ \to K^+ K^- K^- \\ \end{array}$ $\begin{array}{l} 0.0 \ \overline{\rho} d \to \pi^- 4\pi^0 p \\ 450 \ pp \to p_S p_f K^+ K^- \\ 450 \ pp \to p_S p_f \pi^+ \pi^- \\ 450 \ pp \to p_T \eta \pi^0 \\ 300 \ pp \to p_T \eta \pi^0 \\ 300 \ pp \to p_T (K^+ K^-) p_S \end{array}$ |
| 8 k 7 i 0 : | 4 AM Howing 1 ANI 5 KLE 6 UEH AM AUE VLA 7 BIAN 7 ABB 7 BAR 7 BAR 11 BAR 7 BEL 7 FRE 12 KAA 7 ALC | SLER (data for av SOVICH EMPT HARA SLER SLER AN ADIMIRSK ON RMASH SOVICH ELE REERIS RBERIS RBERIS RLAZZINI EMICH | 95 c verage 09 08 08A 06 060 06 .06 05 03 01 99 99 99 99 99 | CBAR es, fits, li RVUE E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | $\begin{array}{lll} 0.0\overline{p} p \to \eta\eta\pi^0 \\ \text{mits, etc.} \bullet \bullet \bullet \\ 0.0\overline{p} p, \pi N \\ D_s^+ \to \pi^-\pi^+\pi^+ \\ 10.6 e^+e^- \to e^+e^-\pi^0\pi^0 \\ 0.9\overline{p} p \to K^+K^-\pi^0 \\ B^+ \to K^+K^-\pi^0 \\ B^+ \to K^0_5 K^0_5 K^0_5 n \\ 33 \pi^-p \to \eta\eta\pi^0 \\ 40 \pi^-p \to K^0_5 K^0_5 K^0_5 n \\ 33 \pi^-p \to \eta\eta\pi \\ B^+ \to K^+K^+K^- \\ \end{array}$ $\begin{array}{lll} 0.0\overline{p} d \to \pi^-4\pi^0 p \\ 450 pp \to p_5 p_f K^+K^- \\ 450 pp \to p_5 p_f \pi^+\pi^- \\ 450 pp \to p_5 p_f \pi^+\pi^- \\ 450 pp \to p_7 \pi^0 \pi^0 \\ 300 pp \to p_f (K^+K^-) p_5 \\ 300 pp \to p_f (K^+K^-) p_5 \\ \end{array}$ |
| 8 k 7 i 0 : | Illowing 1 ANI 1 ANI 5 KLE 6 UEH AM AUE AUE VLA 7 BIAN 1 BAR 7 BIAN 1 BAR 7 BER 1 BAR 7 BER 1 BAR 7 FER 1 ALE VLA 7 ALE VLA 7 ALE VLA 7 ALE VLA 7 ALE VLA 1 ANI 1 BAR 7 FER 1 ALE VLA 1 ALE VLA 1 ALE VLA 1 ANI 1 ANI 1 BAR 7 FER 1 ALE VLA 1 ALE VLA 1 ANI | data for av SOVICH EMPT HARA SLER BERT AN ADIMIRSK OON RMASH SOVICH ELE RBERIS RBERIS RBERIS LLAZZINI LLAZZINI | 09 08 08A 06 06O 06 .06 05 03 01 99 99B 99D 99 | es, fits, li RVUE E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG GAM4 | mits, etc. • • • • • • • • • • • • • • • • • • • |
| 8 k 7 i 0 : | 1 ANI 5 KLE 6 UEH AMAUE AUE 7 BINN 7 ABE 7 BAF 7 BEL 7 FRE 12 KAI 7 ALC | SOVICH EMPT HARA SLER BERT AN ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS LLAZZINI ENCH MINSKI | 09 08 08A 06 06c 06 05 05 03 01 99 99B 99D 99D 99 | RVUE E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{c} 0.0 \overline{\rho} p, \pi N \\ D_S^+ \to \pi^- \pi^+ \pi^+ \\ 10.6 e^+ e^- \to e^+ e^- \pi^0 \pi^0 \\ 0.9 \overline{\rho} p \to K^+ K^- \pi^0 \\ B^+ \to K^+ K^+ K^- \\ 5.2 \overline{\rho} p \to \eta \eta \pi^0 \\ 40 \pi^- p \to K_S^0 K_S^0 n \\ 33 \pi^- p \to \eta \eta n \\ B^+ \to K^+ K^+ K^- \\ \\ 0.0 \overline{\rho} d \to \pi^- 4 \pi^0 p \\ 450 p p \to p_S p_f K^+ K^- \\ 450 p p \to p_S p_f \pi^+ \pi^- \\ 450 p p \to p_F \eta \pi^0 \pi^0 \\ 300 p p \to p_F \eta \pi^0 \pi^0 \\ 300 p p \to p_F (K^+ K^-) p_S \end{array}$ |
| 'k 7 'k 7 | ⁵ KLE ⁶ UEH AM AUE 7,8 UM 7 BIN 9 GAF 10 ANI 7 ABE 7 BAF 7 BAF 7 BEL 7 FRE 12 KAI 7 ALC | EMPT HARA SLER BERT AN ADIMIRSK ION SOVICH ELE RBERIS RBERIS RBERIS LLAZZINI ENCH | 08A 06 060 06 05 05 03 01 99 99B 99D 99 99 | E791 BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{ll} D_{s}^{+} &\rightarrow \pi^{-}\pi^{+}\pi^{+} \\ 10.6 \ e^{+}e^{-} &\rightarrow e^{+}e^{-}\pi^{0}\pi^{0} \\ 0.9 \ \overline{\rho}p &\rightarrow K^{+}K^{-}\pi^{0} \\ B^{+} &\rightarrow K^{+}K^{+}K^{-} \\ 5.2 \ \overline{\rho}p &\rightarrow \eta\eta\pi^{0} \\ 40 \ \pi^{-}p &\rightarrow K_{S}^{0}K_{S}^{0}n \\ 33 \ \pi^{-}p &\rightarrow \eta\etan \\ B^{+} &\rightarrow K^{+}K^{+}K^{-} \\ \end{array}$ $\begin{array}{ll} 0.0 \ \overline{\rho}d &\rightarrow \pi^{-}4\pi^{0}p \\ 450 \ pp &\rightarrow p_{S}p_{f}K^{+}K^{-} \\ 450 \ pp &\rightarrow p_{S}p_{f}\pi^{+}\pi^{-} \\ 450 \ pp &\rightarrow p_{F}\eta^{\pi}n^{0} \\ 300 \ pp &\rightarrow p_{F}(K^{+}K^{-})p_{S} \\ \end{array}$ |
| 'k 7 'k 7 | 6 UEH AM AUE, 8 UM 7 BIN 9 GAF 10 ANI 7 ABE 7 BAF 7 BAF 7 BEL 7 FRE 12 KAI 7 ALC | HARA SLER SERT AN ADIMIRSK ON RMASH SOVICH ELE RBERIS RBERIS RBERIS LAZZINI ENCH | 08A 06 060 06 .06 05 03 01 99 99B 99D 99 | BELL CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{c} 10.6 \ e^{+}e^{-} \rightarrow \ e^{+}e^{-}\pi^{0}\pi^{0} \\ 0.9 \ \overline{p}\rho \rightarrow \ K^{+}K^{-}\pi^{0} \\ B^{+} \rightarrow \ K^{+}K^{+}K^{-} \\ 5.2 \ \overline{p}\rho \rightarrow \ \eta\eta\pi^{0} \\ 40 \ \pi^{-}\rho \rightarrow \ K_{S}^{0} \ K_{S}^{0} n \\ 33 \ \pi^{-}\rho \rightarrow \ \eta\etan \\ B^{+} \rightarrow \ K^{+}K^{+}K^{-} \\ \\ 0.0 \ \overline{\rho}d \rightarrow \ \pi^{-}4\pi^{0}\rho \\ 450 \ \rho\rho \rightarrow \ \rho_{S}\rho_{f} \ K^{+}K^{-} \\ 450 \ \rho\rho \rightarrow \ \rho_{S}\rho_{f} \ \pi^{+}\pi^{-} \\ 450 \ \rho\rho \rightarrow \ \rho_{F}\eta\pi^{0}\pi^{0} \\ 300 \ \rho\rho \rightarrow \ \rho_{F}\eta\pi^{0}\pi^{0} \\ 300 \ \rho\rho \rightarrow \ \rho_{F}(K^{+}K^{-})\rho_{S} \end{array}$ |
| k 7 | A M AUE ,8 U M V LA 7 BIN 9 GAF 10 A NI 7 ABE 7 BAF 7 BAF 7 BEL 7 FRE 12 KAI 7 ALC | SLER SERT AN ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS RLAZZINI INCH | 06 060 06 .06 05 03 01 99 99B 99D 99 | CBAR BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{c} 0.9 \overline{p} p \to K^+ K^- \pi^0 \\ B^+ \to K^+ K^+ K^- \\ 5.2 \overline{p} p \to \eta \eta \pi^0 \\ 40 \pi^- p \to K_S^0 K_S^0 n \\ 33 \pi^- p \to \eta \eta n \\ B^+ \to K^+ K^- \\ \\ \end{array}$ $\begin{array}{c} 0.0 \overline{p} d \to \pi^- 4 \pi^0 p \\ 450 p p \to p_S p_f K^+ K^- \\ 450 p p \to p_S p_f \pi^+ \pi^- \\ 450 p p \to p_S p_f \pi^+ \pi^- \\ 450 p p \to p_T \sigma^+ \pi^0 \\ 300 p p \to p_T \eta^- \pi^0 \\ 300 p p \to p_T f(K^+ K^-) p_S \end{array}$ |
| k 7 | AUE 7 BIN 9 GAF 7 ABE 7 BAF 10 ANI 7 BAF 11 BAF 7 BEL 7 FRE 12 KAI 7 ALC | BERT AN ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS LAZZINI ENCH MINSKI | 060 06 .06 05 03 01 99 99B 99D 99 | BABR E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{l} B^{+} \rightarrow \ \ K^{+} K^{+} K^{-} \\ 5.2 \overline{\rho} p \rightarrow \eta \eta \pi^{0} \\ 40 \pi^{-} p \rightarrow \ K_{0}^{0} K_{0}^{0} n \\ 33 \pi^{-} p \rightarrow \eta \eta n \\ B^{+} \rightarrow \ K^{+} K^{+} K^{-} \\ \\ 0.0 \overline{\rho} d \rightarrow \ \pi^{-} 4 \pi^{0} p \\ 450 p p \rightarrow \ p_{S} p_{f} K^{+} K^{-} \\ 450 p p \rightarrow \ p_{S} p_{f} \pi^{+} \pi^{-} \\ 450 p p \rightarrow \ p_{F} \pi^{0} \pi^{0} \\ 300 p p \rightarrow \ p_{f} (K^{+} K^{-}) p_{S} \\ \end{array}$ |
| k 7 | ,8 U M. VLA 7 BIN 9 GAF 10 A NI 7 ABE 7 BAF 11 BAF 7 BEL 7 FRE 12 KAI 7 ALC | AN ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS LLAZZINI ENCH MINSKI | 06 .06 .05 .05 .03 .01 .99 .99B .99D .99 | E835 SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{l} 5.2\overline{\rho}\rho \to \eta\eta\pi^0 \\ 40\pi^-\rho \to K_S^0K_S^0n \\ 33\pi^-\rho \to \eta\etan \\ B^+ \to K^+K^+K^- \\ \\ \\ 0.0\overline{\rho}d \to \pi^-4\pi^0\rho \\ 450\rho\rho \to \rho_S\rho_fK^+K^- \\ 450\rho\rho \to \rho_S\rho_f\pi^+\pi^- \\ 450\rho\rho \to \rho_S\rho_f\pi^+\pi^- \\ 450\rho\rho \to \rho_T\sigma^0\pi^0 \\ 300\rho\rho \to \rho_f(K^+K^-)\rho_S \end{array}$ |
| i0 | VLA 7 BIN 9 GAF 10 A NI 7 ABE 7 BAF 11 BAF 7 BEL 7 FRE 12 KAI 7 ALC | ADIMIRSK ION RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS RBERIS LLAZZINI ENCH MINSKI | .06 05 05 03 01 99 99B 99D 99 | SPEC GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{l} 40 \ \pi^- p \rightarrow \ K_S^0 \ K_S^0 \ n \\ 33 \ \pi^- p \rightarrow \eta \eta n \\ B^+ \rightarrow \ K^+ K^+ K^- \\ \\ \\ 0.0 \ \overline{p} d \rightarrow \ \pi^- 4 \pi^0 p \\ 450 \ p p \rightarrow \ p_S p_f \ K^+ K^- \\ 450 \ p p \rightarrow \ p_S p_f \ \pi^+ \pi^- \\ 450 \ p p \rightarrow \ K^+ K^-, \ \pi^+ \pi^- \\ 450 \ p p \rightarrow \ p_f p \pi^0 \pi^0 \\ 300 \ p p \rightarrow \ p_f (K^+ K^-) p_S \end{array}$ |
| : | ⁷ BIN ⁹ GAF ¹⁰ ANI ⁷ ABE ⁷ BAF ¹¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | ON RMASH SOVICH ELE RBERIS RBERIS RBERIS LAZZINI ENCH MINSKI | 05 05 03 01 99 99B 99D 99 | GAMS BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{l} 33 \ \pi^- p \to \eta \eta \eta \\ B^+ \to K^+ K^+ K^- \\ \\ 0.0 \ \overline{p}d \to \pi^- 4 \pi^0 p \\ 450 \ p p \to p_S p_f K^+ K^- \\ 450 \ p p \to p_S p_f \pi^+ \pi^- \\ 450 \ p p \to K^+ K^-, \pi^+ \pi^- \\ 450 \ p p \to p_p \pi^0 \pi^0 \\ 300 \ p p \to p_f (K^+ K^-) p_S \end{array}$ |
| : | 9 GAF 10 A NI 7 ABE 7 BAF 7 BAF 11 BAF 7 BEL 7 FRE 12 KAI 7 ALC | RMASH SOVICH ELE RBERIS RBERIS RBERIS RBERIS LAZZINI ENCH MINSKI | 05 03 01 99 99B 99D 99 | BELL RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{l} 33 \ \pi^- p \to \eta \eta \eta \\ B^+ \to K^+ K^+ K^- \\ \\ 0.0 \ \overline{p}d \to \pi^- 4 \pi^0 p \\ 450 \ p p \to p_S p_f K^+ K^- \\ 450 \ p p \to p_S p_f \pi^+ \pi^- \\ 450 \ p p \to K^+ K^-, \pi^+ \pi^- \\ 450 \ p p \to p_p \pi^0 \pi^0 \\ 300 \ p p \to p_f (K^+ K^-) p_S \end{array}$ |
| : | ¹⁰ A NI ⁷ ABE ⁷ BAF ⁷ BAF ¹¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | SOVICH ELE RBERIS RBERIS RBERIS LAZZINI ENCH MINSKI | 03 01 99 99B 99D 99 | RVUE CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| <u>:</u> | ⁷ ABE ⁷ BAF ⁷ BAF ¹ BEL ⁷ FRE ¹ KAI ⁷ ALC | ELE RBERIS RBERIS RBERIS LLAZZINI ENCH MINSKI | 01 99 99B 99D 99 | CBAR OMEG OMEG OMEG GAM4 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | ⁷ BAF ⁷ BAF ¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | RBERIS RBERIS RBERIS LLAZZINI ENCH MINSKI | 99 99B 99D 99 | OMEG OMEG OMEG GAM4 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | ⁷ BAF ¹¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | RBERIS RBERIS LLAZZINI ENCH MINSKI | 99B 99D 99 | OMEG OMEG GAM4 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | ⁷ BAF ¹¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | RBERIS RBERIS LLAZZINI ENCH MINSKI | 99D 99 99 | OMEG GAM4 | $\begin{array}{c} 450 \; pp \to \; p_{S}p_{f}\pi^{+}\pi^{-} \\ 450 \; pp \to \; K^{+}K^{-}, \; \pi^{+}\pi^{-} \\ 450 \; pp \to \; pp\pi^{0}\pi^{0} \\ 300 \; pp \to \; p_{f}(K^{+}K^{-})p_{S} \end{array}$ |
| | ¹¹ BAF ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | RBERIS LAZZINI ENCH MINSKI | 99 99 | OMEG GAM4 | 450 $pp \to K^+K^-, \pi^+\pi^-$ 450 $pp \to pp\pi^0\pi^0$ 300 $pp \to p_f(K^+K^-)p_s$ |
| | ⁷ BEL ⁷ FRE ¹² KAI ⁷ ALC | LAZZINI ENCH MINSKI | 99 99 | GAM4 | 450 $pp \to pp\pi^0\pi^0$ 300 $pp \to p_f(K^+K^-)p_s$ |
| : | ⁷ FRE ¹² KAI ⁷ ALE | ENCH MINSKI | | DV///E | $300 pp \rightarrow p_f(K^+K^-)p_s$ |
|] | ¹² KAI ⁷ ALE | MINSKI | 99 | DV///IE | |
| | 7 ALE | | | RVUE | $\pi\pi \rightarrow \pi\pi$, $K\overline{K}$, $\sigma\sigma$ |
| | | | 98 | GAM4 | $100 \ \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| | | SOVICH | 98B | RVUE | Compilation |
| | REY | /ES | 98 | SPEC | 800 $pp \rightarrow p_S p_f K_S^0 K_S^0$ |
| | 1 BAF | RBERIS | 97B | OMEG | |
| | | ABETTI | 97D | E687 | $D_s^{\pm} \rightarrow \pi^{\mp}\pi^{\pm}\pi^{\pm}$ |
| | ABE | ELE | 96 | CBAR | $0.0 \overline{\rho} \rho \rightarrow 5\pi^0$ |
| | ¹ ABE | | 96c | RVUE | Compilation |
| :0 | ^{7}AM | ELIN | 96B | VES | $37 \pi^- A \rightarrow \eta \eta \pi^- A$ |
| | BU | | 96 | RVUE | ••• |
| | ¹³ A M | SLER | 95D | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \eta \eta,$ |
| 1 | 14 A N | TINORI | 95 | OMEG | $\pi^{0} \pi^{0} \eta$ 300,450 $pp \rightarrow pp 2(\pi^{+} \pi^{-}$ |
| | | TINORI | 95 | OMEG | |
| | BU | | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| | 7 _{AB} | ATZIS | 94 | OMEG | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| | 7 AM | | 94E | CBAR | $0.0 \overline{p}p \rightarrow \pi^{0} \eta \eta'$ |
| 1,1 | 15 A NI | SOVICH | 94 | CBAR | $0.0 \overline{\rho} \rho \rightarrow 3\pi^0, \pi^0 \eta \eta$ |
| 1,1 | 16 BU (| GG | 94 | | $\overline{p}p \rightarrow 3\pi^0$, $\eta\eta\pi^0$, $\eta\pi^0\pi^0$ |
| | | | 92 | | $0.0 \overline{p}p \rightarrow \pi^0 \eta \eta$ |
| | 7 BEL | ADIDZE | | | 36 π^- Be $\rightarrow \pi^- \eta' \eta$ Be |
| | | | | | |
| | | | | | 300 π^- N $\rightarrow \pi^-$ N 2η |
| | | | 88D | | 11 $K^- p \rightarrow K_S^0 K_S^0 \Lambda$ |
| 0 | | | | | |
| | 17 AL C |)F | | | $100 \pi^- p \rightarrow 4\pi^- n$ $100 \pi^- p \rightarrow 2\eta n$ |
| | | | | | $38 \pi^- p \rightarrow \eta \eta' n$ |
| | | | | | $38 \pi^- p \rightarrow \eta \eta \eta$ $38 \pi^- p \rightarrow 2\eta \eta$ |
| | | I O IN | | | |
| | 7 GR | | 83 | DBC | $0.0 \overline{p} N \rightarrow 3\pi$ |
| | 1, | 1,16 BU 7 AM 7 BEL 7 ARI 7 ALI AS ⁻ 200 7 ALI 17 ALI 7 BIN | ⁷ ALDE ASTON OO ⁷ ALDE 17 ALDE ⁷ BINON ⁷ BINON | 1,16 BUGG 94 7 AMSLER 92 7 BELADIDZE 92C 7 ARMSTRONG 89E 7 ALDE 88 ASTON 88D 00 7 ALDE 87 17 ALDE 86D 7 BINON 84C 7 BINON 83 | 1,16 BUGG 94 RVUE 7 AMSLER 92 CBAR 7 BELADIDZE 92C VES 7 ARMSTRONG 89E OMEG 7 ALDE 88 GAM4 ASTON 88D LASS 00 7 ALDE 87 GAM4 17 ALDE 86D GAM4 17 BINON 84C GAM2 7 BINON 83 GAM2 |

^{0.6895. 2} Using $\eta(1475)$ mass of 1481 MeV and width of 48 MeV. The upper limit increases to 0.140 keV if the world average value, 87 MeV, of the width is used.

⁴ T-matrix pole, supersedes ANISOVICH 94 and AMSLER 92.

⁵ Reanalysis of AlTALA 01A data. This state could also be $f_0(1370)$.

 $^{^6\,\}mathrm{Breit ext{-}Wigner}$ mass. May also be the $\it f_0(1370)$.

⁷ Breit-Wigner mass.

⁸ Statistical error only.

o Statistical error only. 9 Breit-Wigner, solution 1, PWA ambiguous. 10 K-matrix pole from combined analysis of $\pi^-p \to \pi^0\pi^0n$, $\pi^-p \to K\overline{K}n$, $\pi^+\pi^- \to \pi^+\pi^-, \overline{p}p \to \pi^0\pi^0\pi^0, \pi^0\eta\eta, \pi^0\pi^0\eta, \pi^+\pi^-\pi^0, K^++\pi^-\eta^0, K^0_S K^0_S \pi^0, K^++K^0_S \pi^-$ at rest, $\overline{p}n \to \pi^-\pi^-\pi^+, K^0_S K^-\pi^0, K^0_S K^0_S \pi^-$ at rest. 11 Computed BARBERIS QUANTIFICATION OF THE PROPERTY
¹¹ Supersedes BARBERIS 99 and BARBERIS 99B.

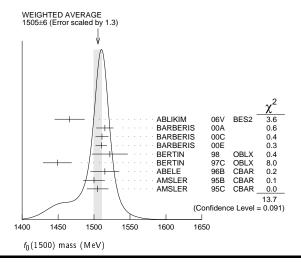
 $^{^{12}}$ T-matrix pole on sheet --+

- $^{13}\,\mathrm{T}\text{-matrix}$ pole. Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AM-The Hallix polynomial confidence analysis of Amelica 36, Amelia SLER 94D. $^{14} \text{ Supersedes ABATZIS 94, ARMSTRONG 89E. Breit-Wigner mass.}$ $^{15} \text{ From a simultaneous analysis of the annihilations } \overline{\rho} p \rightarrow 3\pi^0, \pi^0 \eta \eta.$

- 16 Reanalysis of ANISOVICH 94 data.

VALUE (MeV) EVTS

 $^{17}\mathrm{From}$ central value and spread of two solutions. Breit-Wigner mass.



f₀(1500) WIDTH

DOCUMENT ID TECN COMMENT

| 109± | 7 OUR | AVERAGE | • | | | |
|-------------|------------------|----------------------|----------------------|-----------|-------------|----------------------------------------------------------------------------------------|
| 108 + 1 | | | ABLIKIM | 06v | BES2 | $e^+e^-	oJ/\psi	o\gamma\pi^+\pi^-$ |
| 110± 2 | | 18 | BARBERIS | 00A | | 450 $pp \rightarrow p_f \eta \eta p_S$ |
| 102± 1 | 18 | 18,19 | BARBERIS | 00c | | $450 pp \rightarrow p_f 4\pi p_S$ |
| $110\pm$ 1 | 16 | 18 | BARBERIS | 00E | | $450 pp \rightarrow p_f \eta \eta p_S$ |
| 108± 3 | 33 | | BERTIN | 98 | OBLX | $0.05-0.405 \ \overline{n}\rho \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 114 ± 3 | 30 | 18 | BERTIN | 97c | OBLX | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 105 ± 1 | 15 | | ABELE | 96B | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 K_L^0 K_L^0$ |
| $120\pm$ 2 | 25 | | AMSLER | 95 B | | $0.0 \ \overline{p}p \rightarrow 3\pi^0$ |
| 120± 3 | | | AMSLER | 95 C | | $0.0 \ \overline{p}p \rightarrow \eta \eta \pi^0$ |
| • • • We | do not | use the follo | wing data for av | erage/ | s, fits, li | mits, etc. • • • |
| 114± 1 | | | ANISOVICH | 09 | RVUE | $0.0 \overline{\rho} \rho$, πN |
| 90 + | $^{2+50}_{1-22}$ | 22 | UEHARA | A80 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$ |
| $121\pm$ | 8 | | AMSLER | 06 | CBAR | 0.9 $\overline{p}p \rightarrow K^+K^-\pi^0$ |
| 257± 3 | 33 | 9.9k | AUBERT | 060 | | $B^+ \rightarrow K^+ K^+ K^-$ |
| 108 \pm | 9 | 80k ^{23,24} | | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 119± 1 | | | VLADIMIRSK | | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 90± 1 | | 23 | BINON | 05 | GAMS | 33 $\pi^- p \rightarrow \eta \eta n$ |
| 136 ± 2 | | 1400 25 | GARMASH | 05 | BELL | $B^+ \rightarrow K^+ K^+ K^-$ |
| 102± 1 | | 20 | ANISOVICH | 03 | RVUE | 0 |
| 140± 4 | | | ABELE | 01 | CBAR | $0.0 \ \overline{p} d \rightarrow \pi^- 4\pi^0 p$ |
| 104± 2 | | 23 | BARBERIS | 99 | OMEG | |
| 131± 1 | | | BARBERIS BARBERIS | 99B | OMEG | |
| | 18±16 | | BELLAZZINI | 99D 99 | GA M4 | 450 $pp \to K^+K^-, \pi^+\pi^-$ 450 $pp \to pp\pi^0\pi^0$ |
| 160± 5 | | 23 | FRENCH | 99 | GA IVI4 | $300 pp \rightarrow pf(K^+K^-)p_S$ |
| 100± 3 | | 28 | KAMINSKI | 99 | RVUE | $\pi\pi \to \pi\pi, K\overline{K}, \sigma\sigma$ |
| 280±10 | | 23 | ALDE | 98 | GAM4 | $100 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ |
| 130± 2 | | 18 | ANISOVICH | 98B | RVUE | Compilation |
| 120± 3 | | | BARBERIS | 97в | OMEG | $450 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| ~ 100 | | | FRABETTI | 97 D | E687 | $D_s^{\pm} \rightarrow \pi^{\mp}\pi^{\pm}\pi^{\pm}$ |
| ~ 169 | | | ABELE | 96 | CBAR | $0.0 \overline{p}p \rightarrow 5\pi^0$ |
| 100± 3 | 30 | 120 23 | AMELIN | 96B | VES | $37 \pi^- A \rightarrow \eta \eta \pi^- A$ |
| 132± 1 | | | BUGG | 96 | RVUE | |
| 154± 3 | 30 | 29 | AMSLER | 95 D | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \eta \eta,$ $\pi^0 \pi^0 \eta$ |
| 65 ± 1 | 10 | 30 | ANTINORI | 95 | OMEG | |
| 199± 3 | | 23 | ANTINORI | 95 | OMEG | |
| 56± 1 | 12 | 23 | ABATZIS | 94 | OMEG | 450 $pp \rightarrow pp 2(\pi^+\pi^-)$ |
| 100± 4 | 40 | 23 | AMSLER | 94 E | CBAR | $0.0 \overline{p}p \rightarrow \pi^0 \eta \eta'$ |
| 148 + 3 | 20 25 | | ANISOVICH | 94 | CBAR | $0.0 \; \overline{\rho} \rho \; \rightarrow \; 3 \pi^0 , \pi^0 \eta \eta$ |
| 150± 2 | | 18,32 | BUGG | 94 | RVUE | $\overline{p}p \rightarrow 3\pi^0$, $\eta\eta\pi^0$, $\eta\pi^0\pi^0$ |
| 245 ± 5 | | 23 | AMSLER | 92 | CBAR | $0.0 \ \overline{p}p \rightarrow \pi^0 \eta \eta$ |
| 153± 6 | 67±50 | 23 | BELADIDZE | 92c | VES | 36 π^- Be $\rightarrow \pi^- \eta' \eta$ Be |
| 78± 1 | 18 | 23 | ARMSTRONG | 89E | OMEG | |
| 170± 4 | 40 | | ALDE | 88 | GAM4 | 300 π^- N $\rightarrow \pi^-$ N 2η |
| $150\pm$ 2 | 20 | 600 23 | ALDE | 87 | GAM4 | $100 \ \pi^- \rho \rightarrow 4\pi^0 \ n$ |
| | | | | | | |

| 265 ± 65 | ³³ ALDE | 86D GAM4 | $100 \pi^- \rho \rightarrow 2\eta n$ |
|--------------|---------------------|----------|---------------------------------------|
| 260± 60 | ²³ BINON | 84c GAM2 | $38 \pi^- p \rightarrow \eta \eta' n$ |
| 210± 40 | ²³ BINON | 83 GAM2 | $38 \pi^- p \rightarrow 2\eta n$ |
| 101 ± 13 | ²³ GRAY | 83 DBC | $0.0 \overline{p} N \rightarrow 3\pi$ |

 $^{18}\,\text{T-matrix pole}.$

¹⁹ Average between $\pi^+\pi^-2\pi^0$ and $2(\pi^+\pi^-)$.

²⁰ T-matrix pole, supersedes ANISOVICH 94.

21 T-matrix pole, supersedes ANISOVICH 94 and AMSLER 92.

 22 Breit-Wigner width. May also be the $f_0(1370)$.

²³ Breit-Wigner width.

24 Statistical error only.

25 Breit-Wigner, solution 1, PWA ambiguous.

26 K-matrix pole from combined analysis of $\pi^-p \to \pi^0\pi^0$ n, $\pi^-p \to K\overline{K}n$, $\pi^+\pi^- \to \pi^+\pi^-$, $\overline{p}p \to \pi^0\pi^0$ π^0 , π^0 , π^0 , π^0 , $\pi^+\pi^-$, π^0 , K^0 ,

27 Supersedes BARBERIS 99 and BARBERIS 99B.

 28 T-matrix pole on sheet --+

T-matrix pole on sheet --+.

97-matrix pole. Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D.

30 Supersedes ABATZIS 94, ARMSTRONG 89E. Breit-Wigner mass.

31 From a simultaneous analysis of the annihilations $\bar{p}p \to 3\pi^0, \pi^0\eta\eta$.

32 Reanalysis of ANISOVICH 94 data.

33 From central value and spread of two solutions. Breit-Wigner mass.

fo(1500) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor |
|-----------------------|----------------------|------------------------------|--------------|
| $\overline{\Gamma_1}$ | $\pi\pi$ | (34.9±2.3) % | 1.2 |
| Γ_2 | $\pi^+\pi^-$ | seen | |
| Γ_3 | $2\pi^{0}$ | seen | |
| Γ_4 | 4π | $(49.5 \pm 3.3) \%$ | 1.2 |
| Γ_5 | $4\pi^{0}$ | seen | |
| Γ ₆ | $2\pi^{+}2\pi^{-}$ | seen | |
| Γ_7 | $2(\pi\pi)_{S-wave}$ | seen | |
| Γ8 | ho ho | seen | |
| Г9 | $\pi(1300)\pi$ | seen | |
| Γ_{10} | $a_1(1260)\pi$ | seen | |
| Γ_{11} | $\eta\eta$ | (5.1 ± 0.9) % | 1.4 |
| Γ_{12} | $\eta \eta'$ (958) | (1.9±0.8) % | 1.7 |
| Γ_{13} | KΚ | (8.6±1.0) % | 1.1 |
| Γ_{14} | $\gamma\gamma$ | not seen | |

CONSTRAINED FIT INFORMATION

An overall fit to 6 branching ratios uses 10 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2 =$ 11.4 for 6 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

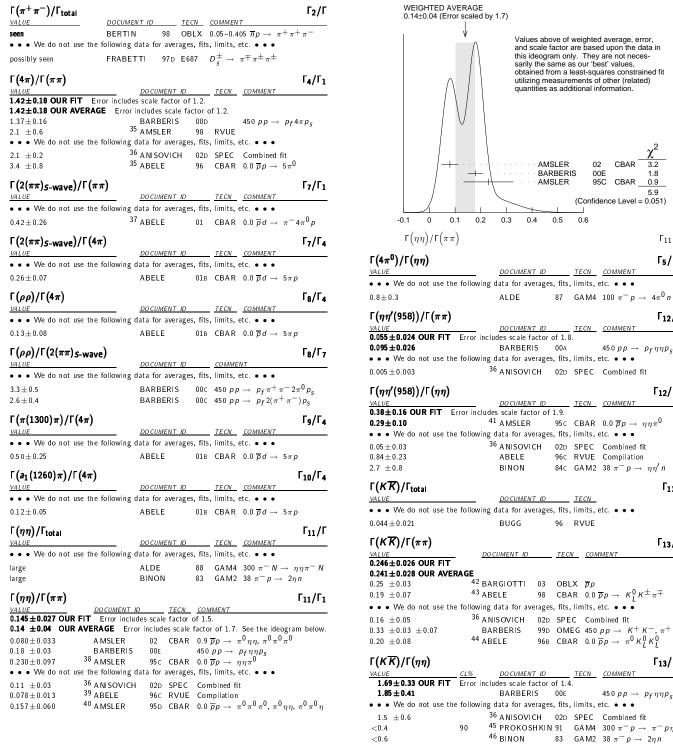
$f_0(1500) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\pi\pi) \times \Gamma(\gamma)$ | γ)/Γ _{total} | 1 | | | Γ ₁ Γ ₁₄ /Γ | |
|----------------------------------------|-----------------------|----------------------|---------|------------|----------------------------------------------------------------------------------|--|
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| ullet $ullet$ We do not | use the f | ollowing data for a | verage | s, fits, l | imits, etc. • • • | |
| 33 + 12 + 1809 | | ³⁴ UEHARA | 08A | BELL | 10.6 $e^+ e^- \rightarrow \ e^+ e^- \pi^0 \pi^0$ | |
| not seen | | ACCIARRI | 01н | L3 | $\gamma\gamma \rightarrow K_S^0 K_S^0$, $E_{\rm cm}^{\it ee} =$ 91, 183–209 GeV | |
| <460 | 95 | BARATE | 00E | ALEP | $\gamma \gamma \rightarrow \pi^+ \pi^-$ | |
| ³⁴ May also be t | he $f_0(137)$ | 0). Multiplied by u | is by 3 | to obta | ain the $\pi\pi$ value. | |

fo(1500) BRANCHING RATIOS

| $\Gamma(\pi\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|----------------------------------------|-----------------------------|-------------|---------------|-------------------|
| VALUE | DO CUMENT ID | TEC | <u>/</u> | |
| ullet $ullet$ We do not use the fol | lowing data for averages, t | fits, limit | s, etc. • • • | |
| 0.454 ± 0.104 | BUGG 9 | 6 RVU | ΙE | |

 $f_0(1500)$



03 OBLX *p̄*ρ 98 CBAR $0.0 \, \overline{p}p \rightarrow K_I^0 \, K^{\pm} \, \pi^{\mp}$ • • • We do not use the following data for averages, fits, limits, etc. • • $^{36}\,\text{ANISOVICH}$ 02D SPEC Combined fit 99D OMEG 450 $pp \rightarrow K^+K^-$ 96B CBAR $0.0 \overline{p}p \rightarrow \pi^0 K_L^0 K_L^0$ Γ_{13}/Γ_{11} TECN COMMENT $450 pp \rightarrow p_f \eta \eta p_g$ • • • We do not use the following data for averages, fits, limits, etc. • • 36 ANISOVICH 02D SPEC Combined fit 45 PROKOSHKIN 91 $\,$ GAM4 $\,$ 300 $\pi^-\,\rho \rightarrow \,$ $\pi^-\,\rho\,\eta\,\eta$ 83 GAM2 38 $\pi^- p \rightarrow 2 \eta n$ 35 Excluding ho
ho contribution to 4π ³⁶ From a combined K-matrix analysis of Crystal Barrel (0. $p\overline{p} \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, $\pi^0\,\pi^0\,\eta)$, GAMS $(\pi\,p\,\to\,\pi^0\,\pi^0\,n,\,\eta\eta\,n,\,\eta\eta'\,n)$, and BNL $(\pi\,p\,\to\,K\,\overline{K}\,n)$ data. $^{39}2\pi$ width determined to be 60 \pm 12 MeV. 40 Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D. ⁴¹ Using AMSLER 94E $(\eta \eta' \pi^0)$. ⁴² Coupled channel analysis of $\pi^+\pi^-\pi^0$, $\kappa^+\kappa^-\pi^0$, and $\kappa^\pm\kappa^0_s\pi^\mp$. 43 Using $\pi^0\pi^0$ from AMSLER 95B. 44 Using AMSLER 95B $(3\pi^0)$, AMSLER 94c $(2\pi^0\,\eta)$ and SU(3). 45 Combining results of GAM4 with those of WA76 on $K\overline{K}$ central production. 46 Using ETKIN 82B and COHEN 80.

00E

CBAR

 Γ_{11}/Γ_{1}

 Γ_5/Γ_{11}

 Γ_{12}/Γ_{1}

 Γ_{12}/Γ_{11}

 Γ_{13}/Γ

 Γ_{13}/Γ_{1}

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| AMSLER | 02 | EPJ C23 29 | | C. Amsler et al. | , |
| ANISOVICH | 02 D | PAN 65 1545 | | V.V. Anisovich et al. | |
| ABELE | 01 | Translated from Y EPJ C19 667 | YAF 65 | 1583. A. Abele <i>et al</i> . | (Crystal Barrel Collab.) |
| ABELE | 01B | EPJ C21 261 | | A. Abele et al. | (Crystal Barrel Collab.) |
| ACCIARRI | 01H | PL B501 173 | | M. Acciarri et al. | (L3 Collab.) |
| AITALA | 01A | PRL 86 765 | | E.M. Aitala et al. | (FNAL EŽ91 Collab.) |
| BARATE | 00 E | PL B472 189 | | R. Barate et al. | (ALEPH Collab.) |
| BARBERIS | 00 A | PL B471 429 | | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 C | PL B471 440 | | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 D | PL B474 423 | | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS BARBERIS | 00 E 99 | PL B479 59 PL B453 305 | | D. Barberis et al. D. Barberis et al. | (WA 102 Collab.) (Omega Expt.) |
| BARBERIS | 99B | PL B453 316 | | D. Barberis et al. | (Omega Expt.) |
| BARBERIS | 99 D | PL B462 462 | | D. Barberis et al. | (Omega Expt.) |
| BELLA ZZINI | 99 | PL B467 296 | | R. Bellazzini et al. | , , , |
| FRENCH | 99 | PL B460 213 | | B. French et al. | (WA76 Collab.) |
| KAMINSKI | 99 | EPJ C9 141 | | R. Kaminski, L. Lesnial | k, B. Loiseau (CRAC, PARIN) |
| ABELE | 98 | PR D57 3860 | | A. Abele et al. | (Crystal Barrel Collab.) |
| ALDE Also | 98 | EPJ A3 361 PAN 62 405 | | D. Alde et al. D. Alde et al. | (GAM4 Collab.) (GAMS Collab.) |
| Also | | Translated from Y | YAF 62 | | (GAMS COMBD.) |
| AMSLER | 98 | RMP 70 1293 | | C. Amsler | |
| ANISOVICH | 98 B | SPU 41 419 | | V.V. Anisovich et al. | |
| BERTIN | 98 | Translated from U | JFN 16 | 58 481. A. Bertin <i>et al.</i> | (OBELIX Collab.) |
| REYES | 98 | PR D57 55 PRL 81 4079 | | M.A. Reyes et al. | (OBELIX COIIAD.) |
| BARBERIS | 97 B | PL B413 217 | | D. Barberis et al. | (WA 102 Collab.) |
| BERTIN | | | | | |
| | 97 C | PL B408 476 | | A. Bertin et al. | (OBELIX Collab.) |
| FRABETTI | 97 D | PL B407 79 | | | (OBELIX Collab.) (FNAL E687 Collab.) |
| ABELE | 97 D 96 | PL B407 79 PL B380 453 | | A. Bertin <i>et al.</i> P.L. Frabetti <i>et al.</i> A. Abele <i>et al.</i> | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE | 97 D 96 96 B | PL B407 79 PL B380 453 PL B385 425 | | A. Bertin <i>et al.</i> P.L. Frabetti <i>et al.</i> A. Abele <i>et al.</i> A. Abele <i>et al.</i> | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE | 97 D 96 96 B 96 C | PL B380 453 PL B385 425 NP A609 562 | | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE | 97 D 96 96 B | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE AMELIN BUGG | 97 D 96 96 B 96 C 96 B | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from Y NP B471 59 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) |
| ABELE ABELE ABELE AMELIN BUGG AMS LER | 97 D 96 96 B 96 C 96 B 96 B | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from NP B471 59 PL B342 433 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. | (OBELIX Collab.) (FMAL E687 Collab.) (Cnystal Barrel Collab.) (Crystal Barrel Collab.) (Cstrystal Barrel Collab.) (SERP, TBIL) (tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE AMELIN BUGG AMS LER AMS LER | 97 D 96 96 B 96 C 96 B 95 B 95 C | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N NP B471 59 PL B342 433 PL B353 571 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER AMSLER | 97 D 96 96 B 96 C 96 B 95 B 95 C 95 D | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from NP B471 59 PL B342 433 PL B353 571 PL B355 425 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Cnystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER AMINORI | 97 D 96 96 B 96 C 96 B 95 B 95 C | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from NP B471 59 PL B342 433 PL B353 571 PL B355 425 PL B353 589 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. C. F. Antinori et al. D. Amsler et al. C. Amsler et al. D. Amsler et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU. BARI. BIRM+) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER AMSLER | 97D 96 96B 96C 96B 95 95 95D 95D | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from NP B471 59 PL B342 433 PL B353 571 PL B355 425 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antion et al. D.V. Bugg et al. D.V. Bugg et al. S. Abatzis et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU. BARI. BIRM+) |
| ABELE ABELE AMELIN BUGG AMS LER AMS LER AMS LER AMS LER ANTINORI BUGG ABATZIS AMS LER | 97D 96 96B 96C 96B 95 95 95 95 95 95 94 94 C | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N NP B471 59 PL B342 433 PL B353 571 PL B353 571 PL B353 378 PL B353 378 PL B353 378 PL B353 378 PL B353 378 PL B324 509 PL B327 425 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antion et al. D.V. Bugg et al. D.V. Bugg et al. S. Abatzis et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Chystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (sey, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal BARIC Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER AMSLER | 97D 96B 96C 96B 95C 95D 95C 95D 95 94 94C 94D | PL B407 79 PL B380 453 PL B385 425 NP A609 565 PAN 59 976 Translated from N NP B471 59 PL B353 571 PL B353 529 PL B353 589 PL B353 589 PL B353 378 PL B327 425 PL B327 425 PL B323 727 | YAF 59 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI, WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG BUGG AMSLER AMSLER AMSLER AMSLER AMSLER AMSLER | 97D 96B 96C 96B 95B 95C 95D 95 94 94C 94D 94E | PL B407 79 PL B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from NP B471 59 PL B342 433 PL B355 571 PL B355 378 PL B353 378 PL B353 378 PL B324 509 PL B327 425 PL B333 277 PL B333 277 PL B333 277 PL B333 277 PL B330 259 | YAF 59 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. C. Amsler et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (SERP, TBIL) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Chystal Barrel Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMINORI BUGG ABATZIS AMSLER AMSLER AMSLER AMSLER AMSLER AMSLER AMSLER AMSLER | 97D 96 96B 96C 96B 95 95D 95D 95 94 94C 94D 94E 94 | PL B807 79 PL B308 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N NP B471 59 PL B342 433 PL B353 569 PL B353 589 PL B353 378 PL B324 509 PL B324 509 PL B324 509 PL B325 376 PL B330 377 PL B340 259 PL B333 277 PL B340 259 PL B333 233 | YAF 59 | A. Bertin et al. P.L. Frabetti et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. E. Antinori et al. D.V. Bugg et al. S. Abalzis et al. C. Amsler et al. | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Cserp. TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER AMINORI BUGG AMSTER AMSLER | 97D 96 96B 96C 96B 95 95D 95D 95 94 94C 94D 94E 94 | PL B407 79 L B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from \ NP B471 59 PL B342 433 F1 B355 425 PL B353 378 PL B353 378 PL B353 378 PL B353 378 PL B324 509 PL B327 425 PL B327 425 PL B327 825 | YAF 59 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. D.V. Bugg et al. D.V. Bugg et al. D.V. Bugg et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (LOQM, PNPI) (Chystal Barrel Collab.) (Chystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Chystal Barrel Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER | 97D 96 96B 96C 96B 95 95D 95D 95 94 94C 94D 94E 94 | PL B807 79 PL B380 453 PL B385 425 PA N9 976 Translated from NP B471 59 PL B342 433 PL B353 571 PL B353 578 PL B353 378 PL B353 378 PL B353 378 PL B354 25 PL B353 377 PL B340 259 PL B327 425 PL B333 777 PL B340 259 PL B323 77 PL B340 259 PL B323 77 PL B340 259 PL B323 R7 PL B350 4412 PL B321 323 | YAF 59 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg, et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) (trystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER BELADIDZE | 97D 96 96B 96C 96B 95C 95D 95 94 94C 94D 94E 94 94 | PL B407 79 PL B380 453 PL B385 425 PA 89 976 Translated from \(\) PB 8471 59 PL B342 433 PL B353 571 PL B353 578 PL B353 378 PL B352 425 PL B353 378 PL B354 257 PL B352 7425 PL B353 277 PL B340 259 PL B327 425 PL B333 277 PL B340 259 PL B323 277 PL B347 SJNP 55 1535 | | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. E. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. G. M. Beladidze, S.I. Bi 2748. | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI), WAS HI (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) |
| ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER | 97D 96 96B 96C 96B 95C 95D 95 94 94C 94D 94E 94 94 | PL B407 79 L B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from \ NP B471 59 PL B342 433 FN B355 425 PL B353 378 PL B353 378 PL B353 378 PL B323 233 PL B323 233 PL B324 509 PL B327 425 PL B340 559 PL B | YAF 55 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. G. Amsler et al. G. M. Beladidze, S.I. Bi 2748. M. D. Prokoshkin | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) (trystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) |
| ABELE ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER BELADIDZE | 97D 96 96B 96C 96B 95C 95D 95 94 94C 94D 94E 94 94 | PL B407 79 PL B380 453 PL B385 425 PA 89 976 Translated from \(\) PB 8471 59 PL B342 433 PL B353 571 PL B353 578 PL B353 378 PL B352 425 PL B353 378 PL B354 257 PL B352 7425 PL B353 277 PL B340 259 PL B327 425 PL B333 277 PL B340 259 PL B323 277 PL B347 SJNP 55 1535 | YAF 55 | A. Bertin et al. A. Abele et al. D.V. Amelin et al. 1021. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. V.V. Anisovich et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. M. Beladidze, S.I. Bi 2748. V.D. Prokoshkin 316 900. T.A. Armstrong, M. Be | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (SERP, TBIL) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (GAM2, GAM4 Collab.) |
| ABELE ABELE ABELE ABELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER | 97D 96 96B 96C 96B 95 05 05 05 04 0 0 0 0 0 0 0 0 0 0 0 0 0 | PL B407 79 PL B380 453 PL B385 425 PA 89 976 Translated from \(\) PB 8471 59 PL B342 433 PL B353 571 PL B353 578 PL B353 378 PL B353 378 PL B353 378 PL B354 255 PL B353 378 PL B354 257 PL B357 425 PL B357 437 | YAF 55 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Devisovich et al. D.V. Poskoshkin 16 900. T.A. Armstrong, M. Be D.M. Alte et al. B. A. Beladidze, S. B. Bi D.M. Alte et al. | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI), WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (Coystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Sers) (GAM2, GAM4 Collab.) (SERP, BELG, LANL, LAPP+) |
| ABELE ABELE ABELE ABELE AMELIN BUGG AMS LER AMS LER AMS LER AMTINORI BUGG ABATZIS AMS LER AMS LER AMS LER AMS LER AMS LER AMS LER ANISOVICH BUGG AMS LER BELADIDZE PROKOSHKIN ARMSTRONG ALDE ASTON | 97D 96 96B 96C 96B 95 95 95 95 94 94C 94D 94 92 92 91 89E 88 88 88 | PL B407 79 L B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N P B471 59 PL B342 433 PL B355 425 PL B353 378 PL B353 378 PL B353 378 PL B354 509 PL B323 233 PL B324 243 PL B325 455 PL B337 425 FT A18184 509 PL B327 425 FT A18184 509 PL B328 327 FT A18184 509 PL B328 367 FT A18184 509 PL B328 367 FT A18184 509 PL B328 367 FT A18184 509 FT | YAF 55 | A. Bertin et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. S. Abatzis et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Anisovich et al. D.V. Bugg et al. C. Amsler et al. T.V. Anisovich et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. T. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. D | (OBELIX Collab.) (FMAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI), WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (Coystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Sers) (GAM2, GAM4 Collab.) (SERP, BELG, LANL, LAPP+) |
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| ABELE ABELE ABELE ABELE AMELIN BUGG AMS LER AMS LER AMS LER AMSTER AMSTE | 97D 96 96B 96C 96B 95C 95D 95 94D 94C 94D 94P 94P 92 92C 91 88B 88D 95 886D 95 886D | PL B807 79 L B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N P 8471 59 PL B342 433 PL B355 425 PL B353 371 PL B353 371 PL B353 379 PL B353 379 PL B353 379 PL B353 379 PL B353 377 PL B340 259 PL B327 425 Translated from E PL B228 563 PL B258 65 PL B260 1565 Translated from E PL B228 66 PL B201 160 PL B228 76 PL B228 66 PL B201 160 PL B228 76 PL B238 76 PL B23 | YAF 55 | A. Bertin et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abatzis et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. V.V. Anisovich et al. D.V. Bugg et al. C. Amsler et al. T. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et al. D.V. Bugg et al. D.V. Bugg et al. D.V. Bug et al. D.W. Alde et al. D.M. Alde et al. D.M. Alde et al. D.M. Alde et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (SERP BELG, LANL, LAPP+) (SERP, BELG, LANL, LAPP+) (SLAC, NAGO, CINC, INUS) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER ANISOVICH BUGG AMSLER BELADIDZE PROKOSHKIN ARMSTRONG ALDE ASTON ALDE BINON | 97 D 96 96 96 96 95 D 95 C 95 D 94 C 94 D 94 E 94 P 92 92 C 91 88 88 B 86 D 86 C 95 B 86 B 86 D 86 C 95 B 86 B 86 D 86 C 95 B 86 B 86 D 86 C 95 B 87 B 86 D 86 C 95 B 86 D 86 | PL B807 79 PL B380 453 PL B385 425 PA 809 562 PAN 99 976 Translated from \(\) PB 8471 59 PL B342 433 PL B353 579 PL B353 378 PL B353 378 PL B353 378 PL B354 255 PL B353 377 PL B340 259 PL B327 425 PL B353 277 PL B340 259 PL B323 277 PL B340 259 PL B321 377 PL B340 259 PL B321 377 PL B340 259 PL B321 377 PL B340 259 PL B321 147 SIMP 55 1535 PT Anslated from \(\) PL B201 160 NP B301 525 NP B301 525 NP B301 525 NP B301 526 NP B309 286 NP B269 485 NC 80A 363 | YAF 55 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg, et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.M. Alde et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL.) tsev, B.S. Zou (LOQM, PNPI) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (SERP, BARI, BIRM+) (SERP, BELG, LANL, LAPP+) (SLAC, NAGO, CINC, INUS) (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP, CERN+) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG BABATZIS AMSLER ANISOVICH BUGG AMSLER BELADIDZE PROKOSHKIN ARMSTRONG ALDE BINON BINON | 97D 96 96B 96C 96B 95C 95D 95 94D 94C 94D 94P 94P 92 92C 91 88B 88D 95 886D 95 886D | PL B807 79 L B380 453 PL B385 425 NP A609 562 PAN 59 976 Translated from N P 8471 59 PL B342 433 PL B355 425 PL B353 371 PL B353 371 PL B353 379 PL B353 379 PL B353 379 PL B353 379 PL B353 377 PL B340 259 PL B327 425 Translated from E PL B228 563 PL B258 65 PL B260 1565 Translated from E PL B228 66 PL B201 160 PL B228 76 PL B228 66 PL B201 160 PL B228 76 PL B238 76 PL B23 | YAF 55 | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. D.V. Bugg, A.V. Saran C. Amsler et al. D.V. Bugg et al. S. Abstzis et al. C. Amsler et al. V.V. Anisovich et al. D.V. Bugg et al. S. Abstzis et al. C. Amsler et al. T. Amsler et al. C. Amsler et al. D.V. Bugg et al. D.V. Bugg et al. C. Amsler et al. D.V. Bugg et | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (SERP, TBIL) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI), WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Loquin (Crystal Barrel Collab.) (SERP, BELG, LANL, LAPP+) (SEAC, NAGO, CINC, INUS) (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) |
| ABELE ABELE ABELE AMELIN BUGG AMS LER ANISOVICH BUGG AMS LER BELADIDZE PROKOSHKIN ARMSTRONG ALDE BINON BINON BINON BINON AISO | 97D 96 96B 96C 96B 95B 95D 95 94 94C 94D 94 94 92 92 92 91 88B 87 86D 87 86D 88B 88B 88B 88B 88B 88B 88B 88B 88B 88 | PL B807 79 PL B380 453 PL B385 425 PN A009 562 PAN 59 976 Translated from N PB4719 PL B342 433 PL B355 425 PL B353 378 PL B353 378 PL B353 378 PL B354 569 PL B323 233 PR D50 4412 PL B323 233 PR D50 4412 PL B321 377 PL B340 259 PL B321 263 PL B321 263 PL B321 377 PL B340 259 PL B321 765 PL B323 276 PL B321 765 PL B321 765 PL B321 765 PL B321 767 PL B340 759 PL B321 767 PL B340 759 PL B321 767 PL B340 759 PL B321 767 PL B328 56 PL B338 56 PL B338 767 P | YAF 55 DANS : | A. Bertin et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abstzis et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bug et al. D.N. Bug et al. D.N. Bug et al. D.N. Bug et al. D.N. Bug et al. D.M. Alde et al. F.G. Binon et al. F.G. Binon et al. F.G. Binon et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (SERP, TBIL) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI, WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (SERP, BELG, LANL, LAPP+) (SEAC, NAGO, CINC, INUS) (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) |
| ABELE ABELE ABELE AMELIN BUGG AMSLER AMSLER AMSLER ANTINORI BUGG ABATZIS AMSLER BELADIDZE PROKOSHKIN ARMSTRONG ALDE ASTON ALDE BINON B | 97D 96 96B 96B 95B 95C 95D 95 94 94C 94D 94P 94 92 92C 91 88B 88D 84C 83 | PL B807 79 PL B380 453 PL B385 425 PA N9 976 Translated from \(\) NP 8471 59 PL B342 433 PL B353 571 PL B353 578 PL B353 378 PL B353 378 PL B353 378 PL B354 25 PL B353 378 PL B354 059 PL B327 425 PL B353 378 PL B354 059 PL B327 425 PL B336 277 PL B340 259 PL B321 727 PL B340 259 PL B321 727 PL B340 259 PL B321 17 PL B324 059 PL B325 364 PL B201 160 NP B301 525 PL B301 525 NP 38 561 PL B328 366 NP B269 485 NC 80A 363 NC 76A 313 SNP 38 561 Translated from Translated from SNR 3651 | YAF 55 DANS : | A. Bertin et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg et al. S. Abstzis et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.V. Bug et al. D.N. Bug et al. D.N. Bug et al. D.N. Bug et al. D.N. Bug et al. D.M. Alde et al. F.G. Binon et al. F.G. Binon et al. F.G. Binon et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Chystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI) WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (LOQM) (CRYSTAL BARTEL COLLAB.) (ERAPL, SERP, BELG, LANL, LAPP+) (SLAC, NAGO, CINC, INUS) (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) (SYRA) |
| ABELE ABELE ABELE AMELIN BUGG AMS LER ANISOVICH BUGG AMS LER BELADIDZE PROKOSHKIN ARMSTRONG ALDE BINON BINON BINON BINON AISO | 97D 96 96B 96C 96B 95B 95D 95 94 94C 94D 94 94 92 92 92 91 88B 87 86D 87 86D 88B 88B 88B 88B 88B 88B 88B 88B 88B 88 | PL B807 79 PL B380 453 PL B385 425 PN A009 562 PAN 59 976 Translated from N PB4719 PL B342 433 PL B355 425 PL B353 378 PL B353 378 PL B353 378 PL B354 569 PL B323 233 PR D50 4412 PL B323 233 PR D50 4412 PL B321 377 PL B340 259 PL B321 263 PL B321 263 PL B321 377 PL B340 259 PL B321 765 PL B323 276 PL B321 765 PL B321 765 PL B321 765 PL B321 767 PL B340 759 PL B321 767 PL B340 759 PL B321 767 PL B340 759 PL B321 767 PL B328 56 PL B338 56 PL B338 767 P | YAF 55 DANS : | A. Bertin et al. A. Abele et al. A. Abele et al. A. Abele et al. A. Abele et al. D.V. Amelin et al. 1021. D.V. Bugg, A.V. Saran C. Amsler et al. C. Amsler et al. C. Amsler et al. F. Antinori et al. D.V. Bugg, et al. S. Abatzis et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. C. Amsler et al. D.V. Bugg et al. C. Amsler et al. D.M. Alde et al. F.G. Binon et al. F.G. Binon et al. | (OBELIX Collab.) (FNAL E687 Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (SERP, TBIL) (SERP, TBIL) (SERP, TBIL) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (Crystal Barrel Collab.) (ATHU, BARI, BIRM+) (LOQM, PNPI, WASH) (ATHU, BARI, BIRM+) (Crystal Barrel Collab.) (SERP, BELG, LANL, LAPP+) (SEAC, NAGO, CINC, INUS) (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP+) (BELG, LAPP, SERP+) |

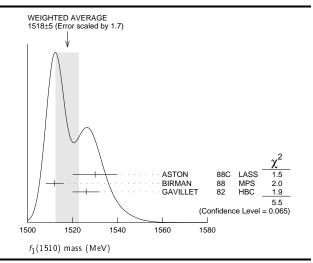
$f_1(1510)$

 $I^{G}(J^{PC}) = 0^{+}(1^{+})$

OMITTED FROM SUMMARY TABLE See the minireview under $\eta(1405)$.

f₁ (1510) MASS

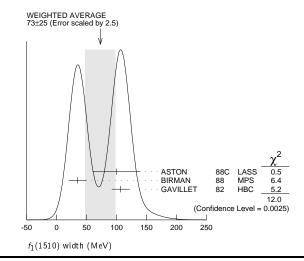
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|----------------|---------------------|-----------|-----------|-------------------------------------------------------|
| 1518± 5 OUR | AVERAGE | Error includes sc | ale facto | or of 1. | 7. See the ideogram below. |
| $1530{\pm}10$ | | ASTON | 88c | LASS | 11 $K^-p \rightarrow K_S^0 K^{\pm} \pi^{\mp} \Lambda$ |
| 1512± 4 | 600 | ¹ BIRMAN | | | $8 \pi^- p \rightarrow K^+ \overline{K}^0 \pi^- n$ |
| 1526 ± 6 | 271 | GAVILLET | 82 | HBC | 4.2 $K^-p \rightarrow \Lambda K K \pi$ |
| ullet $ullet$ We do not | use the follow | wing data for ave | rages, fi | ts, limit | s, etc. • • • |
| ~ 1525 | | ² BAUER | 93B | | $\gamma \gamma^* \rightarrow \pi^+ \pi^- \pi^0 \pi^0$ |
| 1 | | | | | |



f1 (1510) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT | D | TECN | COMMENT |
|----------------|---------------|---------------------|-------|------|--------------------------------------------------------|
| 73±25 OUR | AVERAGE Error | includes scale | | | See the ideogram below. |
| $100\!\pm\!40$ | | ASTON | 88c I | LASS | 11 $K^- p \rightarrow K_S^0 K^{\pm} \pi^{\mp} \Lambda$ |
| 35 ± 15 | 600 | ³ BIRMAN | 88 | MPS | $8 \pi^- p \rightarrow K^+ \overline{K}{}^0 \pi^- n$ |
| $107\!\pm\!15$ | 271 | GAVILLET | 82 | нвс | 4.2 $K^-p \rightarrow \Lambda K K \pi$ |

 3 From partial wave analysis of $K^+\overline{K}^0\pi^-$ state.



f1(1510) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $K\overline{K}^*(892) + \text{c.c.}$ | seen |
| Γ_2 | $\pi^+ \pi^- \eta'$ | seen |

f1(1510) BRANCHING RATIOS

| $\Gamma(\pi^+\pi^-\eta')/\Gamma_{ m total}$ | | | | | Γ_2/Γ |
|---------------------------------------------|------|--------------|-----|------|-----------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| seen | 230 | ABLIKIM | 110 | BES3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ |

f₁ (1510) REFERENCES

| ABLIKIM 11C PRL 106 BAUER 93B PR D48 3 AIHARA 88C PR D38 1 ASTON 88C PL B201 BIRMAN 88 PRL 61 1 GAVULET 92 7PLV C1 | 976 D.A. Bauer et al. H. Aihara et al. 573 D. Aston et al. 557 A. Birman et al. | ` (SLAC) (TPC-2γ Collab.) (SLAC, NAGO, CINC, INUS)JP (BNL, FSU, IND, MASD)JP |
|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| GAVILLET 82 ZPHY C1 | 5 119 P. Gavillet et al. | `(CERN, CDEF, PADO+) |

 $^{^1}$ From partial wave analysis of $\mathit{K}^+\overline{\mathit{K}^0}\,\pi^-$ state. 2 Not seen by AIHARA 88c in the $\mathit{K}^0_S\,\mathit{K}^\pm\pi^\mp$ final state.

 $f_2'(1525)$

(1525)

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

f'₂(1525) MASS

DOCUMENT ID

1525 ± 5 OUR ESTIMATE This is only an educated guess; the error given is larger than the error on the average of the published values.

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| VALUE (MeV) | <u>EVTS</u> | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|---------------|-----------------------|-------|------------|--------------------------------------------------|
| • • • We do n | ot use the fo | ollowing data for | avera | ges, fits, | limits, etc. • • • |
| 1521 ± 13 | | TIKHOMIROV | 03 | SPEC | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_L^0 X$ |
| $1547 {}^{+}_{-} {}^{10}_{2}$ | | ¹ LONGACRE | 86 | MPS | 22 $\pi^- p \rightarrow \kappa_S^0 \kappa_S^0 n$ |
| $1496 ^{+}_{-} \stackrel{9}{8}$ | | ² CHABAUD | 81 | A SP K | 6 $\pi^- p \rightarrow K^+ K^- n$ |
| 1497 + 8 | | CHABAUD | 81 | A SP K | 18.4 $\pi^- p \rightarrow K^+ K^- n$ |
| 1492 ± 29 | | GORLICH | | | 17 $\pi^- p$ polarized $\rightarrow K^+ K^- n$ |
| 1502 ± 25 | | ³ CORDEN | 79 | OMEG | 12-15 $\pi^- p \rightarrow \pi^+ \pi^- n$ |
| 1480 | 14 | CRENNELL | 66 | HBC | $6.0 \pi^{-} p \rightarrow K^{0} K^{0} p$ |

PRODUCED BY K± REAM

| PRODUCED BY A BEAM | | | | | | | | | | |
|--------------------|-----------------------|-------------------|--------|-----------|----------------------------------------------------------------------------------|--|--|--|--|--|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT | | | | | |
| 1523.4 ± 1.3 | OUR AVERAGE | Includes data fr | om th | ne datab | lock that follows this one. | | | | | |
| Error include | s scale factor of 1.1 | | | | | | | | | |
| 1526.8± 4.3 | 3 | ASTON | 88D | LASS | 11 $K^-p \rightarrow K_S^0 K_S^0 \Lambda$ | | | | | |
| 1504 ± 12 | | BOLONKIN | 86 | SPEC | 11 $K^-p \rightarrow K_S^0 K_S^0 \Lambda$ 40 $K^-p \rightarrow K_S^0 K_S^0 Y$ | | | | | |
| $1529\ \pm\ 3$ | | ${\tt ARMSTRONG}$ | 83B | OMEG | 18.5 $K^- p \rightarrow K^- K^+ \Lambda$ | | | | | |
| $1521\ \pm\ 6$ | 650 | AGUILAR | 81B | HBC | 4.2 $K^-p \rightarrow \Lambda K^+ K^-$ | | | | | |
| $1521 \ \pm \ 3$ | 572 | ALHARRAN | 81 | | 8.25 $K^- p \rightarrow \Lambda K \overline{K}$ | | | | | |
| $1522\ \pm\ 6$ | 123 | BARREIRO | 77 | HBC | $4.15 K^- \rho \rightarrow \Lambda K_S^0 K_S^0$ | | | | | |
| $1528 \ \pm \ 7$ | 166 | EVA NGELIS | 77 | OMEG | 10 $K^-p \rightarrow K^+K^-(\Lambda, \Sigma)$ | | | | | |
| $1527 \ \pm \ 3$ | 120 | BRANDENB | 76C | ASPK | 13 $K^-p \rightarrow K^+K^-(\Lambda, \Sigma)$ | | | | | |
| $1519\ \pm\ 7$ | 100 | AGUILAR | 72B | HBC | 3.9,4.6 $K^- p \rightarrow K \overline{K}(\Lambda, \Sigma)$ | | | | | |
| • • • We do | not use the follow | ing data for ave | rages, | fits, lim | its, etc. • • • | | | | | |
| 1514 ± 8 | 61 | BINON | 07 | GAMS | 32.5 $K^- p \rightarrow \eta \eta (\Lambda / \Sigma^0)$ | | | | | |
| 1513 ± 10 | 4 | BARKOV | 99 | SPEC | 40 $K^-p \rightarrow K_S^0 K_S^0 y$ | | | | | |
| | | | | | | | | | | |

PRODUCED IN e+e- ANNIHILATION

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|------------------|--------------|----------------------|-------------|----------------------|
| The data in this | block is inc | luded in the average | printed for | a provious datablock |

1520.7± 2.0 OUR AVERAGE

| TOZULT Z.O CON AVEN | AUL | | | |
|-----------------------------------------------------|-----------------------|----------|-------------------------------------------------------|--|
| 1521 ± 5 | ABLIKIM | 05 B | ES2 $J/\psi \rightarrow \phi K^+ K^-$ | |
| 1518 \pm 1 \pm 3 | ABE | 04 B | ELL 10.6 $e^+e^- \rightarrow e^+e^- \kappa^+\kappa^-$ | |
| | | | e ⊤ e − K ⊤ K − | |
| $1519 \pm 2 \begin{array}{c} +15 \\ -5 \end{array}$ | BAI | 03G B | ES $J/\psi \rightarrow \gamma K \overline{K}$ | |
| 1523 ± 6 331 | ⁵ ACCIARRI | 01H L3 | 3 91, 183-209 $e^+e^- \rightarrow$ | |
| | | | $e^{+}e^{-}\kappa_{S}^{0}\kappa_{S}^{0}$ | |
| $1535 \pm 5 \pm 4$ | ABREU | 96c D | | |
| 1516 \pm 5 $^{+}_{-15}^{9}$ | BAI | 96c B | ES $J/\psi \rightarrow \gamma K^+ K^-$ | |
| 1510 ± 5 -15 | DAI | JUC 15 | $LS J/\psi \rightarrow J/V \cdot V$ | |
| 1531.6 ± 10.0 | AUGUSTIN | 88 D | M2 $J/\psi \rightarrow \gamma K^+ K^-$ | |
| 1515 ± 5 | ⁶ FALVARD | 88 D | M2 $J/\psi \rightarrow \phi K^+ K^-$ | |
| $1525 \pm 10 \pm 10$ | BALTRUSAIT. | 87 M | IRK3 $J/\psi ightarrow \gamma K^+ K^-$ | |
| ullet $ullet$ We do not use the | following data for a | verages, | , fits, limits, etc. ● ● ● | |
| 1523 ± 5 870 | 7 SCHEGELSKY | 06A R | VUE $\gamma \gamma \rightarrow K_S^0 K_S^0$ | |
| 1406 0 | | | $M2 J/\psi \rightarrow \phi K^+ K^-$ | |
| 1496 ± 2 | - FALVARD | 88 D | INIZ $J/\psi \rightarrow \phi K K$ | |

PRODUCED IN pp ANNIHILATION

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|------------------------------|------------------------|---------------|--------------------------------------------------------------------|
| • • • We do not use the foll | lowing data for aver | ages, fits, l | mits, etc. • • • |
| 1530 ± 12 | 9 ANISOVICH 0 | 9 RVUE | 0.0 p ρ, πN |
| 1513± 4 | | | $0.9 \overline{p}p \rightarrow K^+ K^- \pi^0$ |
| 1508± 9 | ¹⁰ AMSLER 0 | 2 CBAR | $0.9 \overline{p}p \rightarrow \pi^0 \eta \eta, \pi^0 \pi^0 \pi^0$ |

| CENTRAL PRODUCTION | | | | | |
|--------------------|--------------|----|------|-----------------|-------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
| 1515 ± 15 | BARBERIS | 99 | OMEG | 450 <i>pp</i> → | $p_s p_f K^+ K^-$ |

PRODUCED IN ep COLLISIONS

| VALUE (MeV) | EVIS | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------|-------------|------------------------|----------|---------|--------------------------------|--|
| 1512±3+1.4 -0.5 | | 11 CHEKANOV | 08 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ | |
| • • • We do not use t | he followin | g data for average | s, fits, | limits, | etc. • • • | |
| 1537 + 9 | 84 | ¹² CHEKANOV | 04 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ | |

- $^1\,\text{From a partial-wave analysis of data using a K-matrix formalism with 5 poles.}$ CHABAUD 81 is a reanalysis of PAWLICKI 77 data.
- 3 From an amplitude analysis where the $f_2'(15\,\underline{25})$ width and elasticity are in complete disagreement with the values obtained from \overline{KK} channel, making the solution dubious.
- ⁴ Systematic errors not estimated.
- ⁵ Supersedes ACCIARRI 95J.
- ⁶ From an analysis ignoring interference with $f_0(1710)$.
- ⁷ From analysis of L3 data at 91 and 183–209 GeV. ⁸ From an analysis including interference with $f_0(1710)$.
- ⁹4-poles, 5-channel K matrix fit.
- ¹⁰ T-matrix pole.
- 11 In the SU(3) based model with a specific interference pattern of the $f_2(1270)$, $a_2^0(1320)$, and $f_2'(1525)$ mesons incoherently added to the $f_0(1710)$ and non-resonant background. 12 Systematic errors not estimated.

f'₂(1525) WIDTH

| VALUE (MeV) | DO CUMENT IL |) | COMMENT | |
|---------------------------|--------------|----|-------------|--|
| 73 ⁺ 6 OUR FIT | | | | |
| 76±10 | PDG | 90 | For fitting | |

PRODUCED BY PION BEAM

| VALUE (MeV) | <u>DOCUMENT ID</u> | | TECN | COMMENT |
|-------------------|----------------------------|-------|------------|------------------------------------------------|
| • • • We do not | use the following data for | avera | ges, fits, | limits, etc. • • • |
| $102\!\pm\!42$ | TIKHOMIROV | 03 | SPEC | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_L^0 X$ |
| $108 + 5 \\ - 2$ | ¹³ LONGACRE | 86 | MPS | $22 \pi^- \rho \rightarrow K_S^0 K_S^0 n$ |
| $69 + 22 \\ -16$ | ¹⁴ CHABAUD | 81 | A SP K | 6 $\pi^- p \rightarrow K^+ K^- n$ |
| $137 + 23 \\ -21$ | CHABAUD | 81 | ASPK | 18.4 $\pi^- p \rightarrow K^+ K^- n$ |
| 150^{+83}_{-50} | GORLICH | 80 | A SP K | 17 $\pi^- p$ polarized $\rightarrow K^+ K^- n$ |
| 165 ± 42 | ¹⁵ CORDEN | 79 | OMEG | 12-15 $\pi^- p \rightarrow \pi^+ \pi^- n$ |
| 92 + 39 | 16 POLYCHRO | 79 | STRC | $7 \pi^- p \rightarrow n K_S^0 K_S^0$ |

PRODUCED BY K± BEAM

| | UE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----|----------------|---------------|---------------------|-------------|---------------|--------------------------------------------------------------------|
| | 2± 2.6 OUR A | | | m the | $\overline{}$ | ck that follows this one. |
| 90 | ± 12 | | ASTON | 88D | LASS | 11 $K^- p \rightarrow K_c^0 K_c^0 \Lambda$ |
| 73 | ± 18 | | BOLONKIN | 86 | SPEC | 11 $K^- p \to K_S^0 K_S^0 \Lambda$ 40 $K^- p \to K_S^0 K_S^0 Y$ |
| 83 | ± 15 | | | | | 18.5 $K^-p \to K^-K^+\Lambda$ |
| 85 | ± 16 | 65 0 | AGUILAR | 81B | нвс | $4.2 K^- p \rightarrow \Lambda K^+ K^-$ |
| 80 | $^{+14}_{-11}$ | 572 | ALHARRAN | 81 | нвс | 8.25 $K^- p \rightarrow \Lambda K \overline{K}$ |
| 72 | ± 25 | 166 | EVA NGELIS | 77 | OMEG | 10 $K^- \rho \rightarrow K^+ K^- (\Lambda, \Sigma)$ |
| 69 | ± 22 | 100 | AGUILAR | 72B | HBC | 3.9,4.6 $K^- \rho \rightarrow K \overline{K} (\Lambda, \Sigma)$ |
| • • | • We do not | use the follo | wing data for ave | erages | , fits, lir | mits, etc. • • • |
| 92 | $^{+25}_{-16}$ | 61 | BINON | 07 | GAMS | 32.5 $K^-p \rightarrow \eta \eta (\Lambda/\Sigma^0)$ |
| 75 | ± 20 | 17 | ⁷ BARKOV | 99 | SPEC | 40 $K^- p \rightarrow K_S^0 K_S^0 y$ |
| 62 | $^{+19}_{-14}$ | 123 | BARREIRO | 77 | нвс | $4.15 \ K^- p \rightarrow \Lambda K_S^0 K_S^0$ |
| 61 | ± 8 | 120 | BRANDENB | 76 C | ASPK | 13 $K^-p \rightarrow K^+K^-(\Lambda, \Sigma)$ |
| | | | | | | |

| 79.9 | 9± 3.3 | 3 OUR | AVERAG | iE Error include: | s scale | factor o | of 1.1. |
|------|----------|----------------|-----------|--------------------------|---------|-----------|-----------------------------------------------------------------------------------------|
| 77 | ± 15 | | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi K^+ K^-$ |
| | ± 2 | | | ABE | 04 | BELL | $^{10.6}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\kappa^{+}}\overset{\rightarrow}{\kappa^{-}}$ |
| 75 | \pm 4 | $^{+15}_{-5}$ | | BAI | 03G | BES | $J/\psi \rightarrow \gamma K \overline{K}$ |
| 100 | ±15 | | 331 | ¹⁸ ACCIARRI | 01н | L3 | 91, 183-209 $e^+e^- \rightarrow e^+e^- \kappa_S^0 \kappa_S^0$ |
| 60 | ± 20 | ± 19 | | ABREU | 96c | DLPH | $Z^0 \rightarrow K^+ K^- + X$ |
| 60 | ± 23 | $^{+13}_{-20}$ | | BAI | 96c | BES | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 103 | ± 30 | | | AUGUSTIN | 88 | | |
| 62 | ± 10 | | | ¹⁹ FALVARD | 88 | DM2 | $J/\psi \rightarrow \phi K^+ K^-$ |
| 85 | ± 35 | | | BALTRUSAIT | 87 | MRK3 | $J/\psi \rightarrow \gamma K^+ K^-$ |
| • • | • We | do not | use the f | ollowing data for | averag | es, fits, | limits, etc. • • • |
| 104 | ± 10 | | | ²⁰ SCHEGELSKY | | | |
| 100 | + 3 | | | 21 FALVARD | 88 | DM2 | $L/\psi \rightarrow \phi K^+ K^-$ |

PRODUCED IN DO ANNIHILATION

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------|--------------------------|---------|-----------|------------------------------------------------------------------------------------|
| 79± 8 | ²² AMSLER | 02 | CBAR | $0.9 \; \overline{\rho} \rho \rightarrow \; \pi^0 \eta \eta, \; \pi^0 \pi^0 \pi^0$ |
| • • • We do not use the | following data for ave | erages, | fits, lim | its, etc. • • • |
| 128 ± 20 | ²³ A NISOVICH | 09 | RVUE | 0.0 p ρ, πN |
| 76 ± 6 | AMSLER | 06 | CBAR | $0.9 \overline{p}p \rightarrow K^+ K^- \pi^0$ |

CENTRAL PRODUCTION DOCUMENT ID TECN COMMENT BARBERIS 99 OMEG 450 $pp \rightarrow p_S p_f K^+ K^-$ PRODUCED IN ep COLLISIONS VALUE (MeV) TECN COMMENT 83± 9+5 ²⁴ CHEKANOV 08 ZEUS $ep \rightarrow \kappa_S^0 \kappa_S^0 X$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $50 + \frac{34}{22}$ ²⁵ CHEKANOV 04 ZEUS $ep \rightarrow K_S^0 K_S^0 X$

- $^{\rm 13}\,{\rm From}$ a partial-wave analysis of data using a K-matrix formalism with 5 poles.
- ¹⁴ CHABAUD 81 is a reanalysis of PAWLICKI 77 data.
- 15 From an amplitude analysis where the $f_2^\prime(15\,25)$ width and elasticity are in complete disagreement with the values obtained from $K\overline{K}$ channel, making the solution dubious.
- 16 From a fit to the D with $f_2(1270)$ - $f_2'(1525)$ interference. Mass fixed at 1516 MeV.
- $^{
 m 17}\,{
 m Systematic\,\,errors\,\,not\,\,estimated.}$
- ¹⁸ Supersedes ACCIARRI 95 J.
- ¹⁹ From an analysis ignoring interference with $f_0(1710)$.
- $^{20}_{-\cdot}$ From analysis of L3 data at 91 and 183–209 GeV.
- 21 From an analysis including interference with $f_0(1710)$.
- ²² T-matrix pole.
- ²³4-poles, 5-channel K matrix fit.
- 24 In the SU(3) based model with a specific interference pattern of the $f_2(1270)$, $a_2^0(1320)$, and $f_2'(1525)$ mesons incoherently added to the $f_0(1710)$ and non-resonant background.
- 25 Systematic errors not estimated.

$f_2'(1525)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------------------------------------------------------------------------|----------------------------------|
| $\overline{\Gamma_1}$ | $K\overline{K}$ | (88.7 ±2.2) % |
| Γ_2 | $\eta \eta$ | (10.4 ±2.2) % |
| Γ_3 | $\pi\pi$ | $(8.2 \pm 1.5) \times 10^{-3}$ |
| Γ_4 | $K\overline{K}^*(892) + \text{c.c.}$ | |
| Γ_5 | $\pi \pi$ $K \overline{K}^* (892) + \text{c.c.}$ $\pi K \overline{K}$ $\pi \pi \eta$ $\pi^+ \pi^+ \pi^- \pi^-$ | |
| Γ ₆ | $\pi\pi\eta$ | |
| Γ_7 | $\pi^{+}\pi^{+}\pi^{-}\pi^{-}$ | |
| Γ ₈ | $\gamma\gamma$ | $(1.11 \pm 0.14) \times 10^{-6}$ |

CONSTRAINED FIT INFORMATION

An overall fit to the total width, 2 partial widths, a combination of partial widths obtained from integrated cross sections, and ${\bf 3}$ branching ratios uses 16 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2=14.0$ for 12 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\sf total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (MeV) |
|----------------------------------------------------|----------------|---------------------------------------------|
| Γ_1 | KK | $65 \begin{array}{c} +5 \\ -4 \end{array}$ |
| Γ ₂ Γ ₃ Γ ₈ | $\eta \eta$ | 7.6 ±1.8 |
| Гз | $\pi\pi$ | 0.60 ± 0.12 |
| Γ ₈ | $\gamma\gamma$ | $(8.1 \pm 0.9) \times 10^{-5}$ |

f'2(1525) PARTIAL WIDTHS

| Г(<i>КҠ</i>) | | | | | | Γ ₁ |
|-----------------------|------|------------------------|----|------|--------------------------|-----------------------------|
| VALUE (MeV) | | DO CUMENT ID | | TECN | COMMENT | |
| 65 +5 OUR FIT | | | | | | |
| 63 ⁺⁶ 5 | | ²⁶ LONGACRE | 86 | MPS | 22 $\pi^- p \rightarrow$ | $\kappa_S^0 \kappa_S^0 n$ |
| $\Gamma(\eta\eta)$ | | | | | | Γ2 |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 5.0 ± 0.8 | 870 | ²⁷ SCHEGELSKY | 06A | RVUE | $\gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ |
|--------------------------------------------------|-----|--------------------------|-----|------|---------------------------------------------------|
| $\begin{array}{ccc} 24 & +3 \\ -1 & \end{array}$ | | ²⁶ LONGACRE | 86 | MPS | $22~\pi^-\rho \to~K^0_S~K^0_S~n$ |

| $\Gamma(\pi\pi)$ | | | | Гз |
|--------------------------------------------------------------------------|------------|-----------------------------------------------------|------------------------------|--------------------------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 0.60±0.12 OUR FIT | | | | |
| $1.4 \begin{array}{c} +1.0 \\ -0.5 \end{array}$ | | ²⁶ LONGACRE 86 | MPS | 22 $\pi^- p \rightarrow \kappa_S^0 \kappa_S^0 n$ |
| • • • We do not use th | ie followi | ng data for averages, fits | , limits, | etc. • • • |
| $0.2 \begin{array}{c} +1.0 \\ -0.2 \end{array}$ | 870 | ²⁷ SCHEGELSKY 06A | RVUE | $\gamma\gamma\to~K^0_SK^0_S$ |
| $\Gamma(\gamma\gamma)$ | | | | Гв |
| VALUE (keV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 0.081 ± 0.009 OUR FIT | | | | |
| • • • We do not use th | ie followi | ng data for averages, fits | , limits, | etc. • • • |
| $0.13\ \pm0.03$ | 870 | ²⁷ SCHEGELSKY 06A | RVUE | $\gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ |
| 26 From a partial-wave 27 From analysis of L3 and SU(3) relations. | data at 9 | of data using a K-matrix 1 and 183–209 GeV, usin | formalis g $\Gamma(f_2')$ | sm with 5 poles. $(1525) \rightarrow K\overline{K}) = 68 \text{ MeV}$ |

$f_2'(1525) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| Γ(<i>K</i> 7 | к) × г | $(\gamma \gamma)/\Gamma$ | total | | | | | $\Gamma_1\Gamma_8/\Gamma$ |
|----------------------------------------------------------------------------------------------------------------|--------------------|--------------------------|-----------|-----|------------------|--------|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | (keV) | | EVTS | | DOCUMENT ID | | TECN | COMMENT |
| 0.072 | ± 0.007 | OUR F | Т | | | | | |
| 0.072 | ± 0.007 | OUR A | VERAG | Е | | | | |
| 0.0564 | 1 ± 0.0048 | 3 ± 0.0116 | 5 | | ABE | 04 | BELL | $10.6 \ e^{+}e^{-} \rightarrow e^{-}e^{-}e^{-} \rightarrow e^{-}e^{-}e^{-} \rightarrow e^{-}e^{-}e^{-}e^{-}e^{-}e^{-}e^{-}e^{-}$ |
| 0.076 | ±0.006 | ±0.011 | 331 | 28 | ACCIARRI | 01н | L3 | $e^+e^- \times + K^-$ $e^+e^- \rightarrow e^+e^- K_S^0 K_S^0$ |
| 0.067 | ±0.008 | ±0.015 | | 29 | ALBRECHT | | ARG | $e^+ e^- \rightarrow e^+ e^- K^+ K^-$ |
| 0.11 | $^{+0.03}_{-0.02}$ | ±0.02 | | | BEHREND | 89c | CELL | $e^+e^- ightarrow \ e^+e^- K^0_S K^0_S$ |
| 0.10 | | +0.03 -0.02 | | | BERGER | 88 | PLUT | $e^+e^-\rightarrowe^+e^-\kappa^0_S\kappa^0_S$ |
| 0.12 | ±0.07 | ±0.04 | | | AIHARA | 86в | TPC | $e^+e^- ightarrowe^+e^-K^+K^-$ |
| 0.11 | ±0.02 | ±0.04 | | 29 | ALTHOFF | 83 | TASS | $e^+ e^- \rightarrow e^+ e^- K \overline{K}$ |
| • • • | We do n | ot use th | ne follow | win | g data for avera | ges, f | its, limit | s, etc. • • • |
| 0.0314 | 1 ± 0.0050 | ± 0.007 | 7 | 30 | ALBRECHT | 90g | ARG | $e^+e^-\rightarrow~e^+e^-K^+K^-$ |
| 28 Supersedes ACCIARRI 95J. From analysis of L3 data at 91 and 183–209 GeV, 29 Using an incoherent background. | | | | | | | | |

f'2(1525) BRANCHING RATIOS

| ' (*/*/) / | | | | 12/1 |
|---------------------|------------------------------|------|-------------|---------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use | the following data for avera | ges, | fits, limit | s, etc. • • • |
| seen | | | | $10.6~e^+e^-\rightarrow~e^+e^-\eta\eta$ |
| 0.10 ± 0.03 | ³¹ PROKOSHKIN | 91 | GA M4 | 300 $\pi^- p \rightarrow \pi^- p \eta \eta$ |
| | | | | |

 31 Combining results of GAM4 with those of WA76 on $K\overline{K}$ central production and results of CBAL, MRK3 and DM2 on $J/\psi
ightarrow \gamma \eta \eta$.

| $\Gamma(\eta\eta)/\Gamma(K\overline{K})$ | | | | | Γ_2/Γ_1 |
|------------------------------------------|-----------------|------------------------|------------|-----------|---------------------------------------------|
| VALUE | CL% EVTS | DOCUMENT II |) | TECN | COMMENT |
| 0.118±0.028 OUR F | IT | | | | |
| 0.115 ± 0.028 OUR A | VERAGE | | | | |
| $0.119 \pm 0.015 \pm 0.036$ | 61 | ³² BINON | 07 | GA MS | 32.5 $K^-p \rightarrow$ |
| | | | | | $\eta \eta (\Lambda / \Sigma^0)$ |
| 0.11 ± 0.04 | | ³³ PROKOSHK | IN 91 | GA M4 | $300 \pi^- p \rightarrow \pi^- p \eta \eta$ |
| • • • We do not use | the following | data for average | s, fits, l | imits, et | s. • • • |
| < 0.14 | 90 | BARBERIS | 00E | | 450 $pp \rightarrow p_f \eta \eta p_S$ |
| < 0.50 | | BARNES | 67 | нвс | 4.6,5.0 K ⁻ p |
| 32 Haing the compile | ation of the co | occ coctions for | el (1505 | :) produ | tion in V = n collisions |

³²Using the compilation of the cross sections for $f'_2(1525)$ production in K^-p collisions

from ASTON 88D. 33 Combining results of GAM4 with those of WA76 on $K\overline{K}$ central production and results of CBAL, MRK3 and DM2 on $J/\psi \to \gamma \eta \eta$.

| $\Gamma(\pi\pi)/\Gamma_{total}$ | | | | | Γ ₃ /Γ |
|-------------------------------------------------------|---------------|------------------------|-------|-----------|------------------------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
| 0.0082±0.0016 | OUR FIT | | | | |
| 0.0075 ± 0.0016 | OUR AVER | AGE | | | |
| 0.007 ± 0.002 | | COSTA | 80 | OMEG | $10 \pi^- p \rightarrow K^+ K^- n$ |
| $0.027 \begin{array}{l} +0.071 \\ -0.013 \end{array}$ | 3 | ³⁴ GORLICH | 80 | ASPK | 17,18 $\pi^- p$ |
| 0.0075 ± 0.0025 | 34,3 | ³⁵ MARTIN | 79 | RVUE | |
| ullet $ullet$ We do not u | se the follow | wing data for aver | ages, | fits, lim | ts, etc. • • • |
| < 0.06 | 95 | AGUILAR | 81 B | нвс | 4.2 $K^-p \rightarrow \Lambda K^+K^-$ |
| 0.19 ± 0.03 | | CORDEN | 79 | OMEG | $12-15 \pi^- p \rightarrow \pi^+ \pi^- n$ |
| < 0.045 | 95 | BARREIRO | 77 | нвс | 4.15 $K^-p \rightarrow \Lambda K_S^0 K_S^0$ |
| 0.012 ± 0.004 | 3 | ³⁴ PAWLICKI | | | $6 \pi N \rightarrow K^+ K^- N$ |
| < 0.063 | 90 | BRANDENB | 76 C | ASPK | 13 $K^-p \rightarrow K^+K^-(\Lambda, \Sigma)$ |
| < 0.0086 | 3 | ³⁴ BEUSCH | 75 B | OSPK | 8.9 $\pi^- p \rightarrow K^0 \overline{K}^0 n$ |
| 34 | | | | | |

- 34 Assuming that the $f_2'(1525)$ is produced by an one-pion exchange production mechanism.
- 35 MARTIN 79 uses the PAWLICKI 77 data with different input value of the $f_2'(1525)
 ightarrow$ \overline{K} branching ratio.

 $f_2'(1525), f_2(1565)$

| $\Gamma(\pi\pi)/\Gamma(K\overline{K})$ |) | DO CUMENT ID | | TECN | COMMENT | Γ_3/Γ_1 |
|--------------------------------------------|---------------------|-----------------------------------------|-----------|-----------|-----------------------------------|----------------------------------|
| 0.0092±0.0018 C 0.075 ±0.035 | OUR FIT | AUGUSTIN | 87 | | $J/\psi \rightarrow \gamma \pi^+$ | π- |
| [Γ(<i>Κ'</i> K *(892) | + c.c.) + Γ(π | $(\overline{K})]/\Gamma(K\overline{K})$ | | | (Γ ₄ | +Γ ₅)/Γ ₁ |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the followin | g data for average | es, fits, | limits, | etc. • • • | |
| < 0.35 | 95 | AGUILAR | 72B | нвс | 3.9,4.6 K ⁻ p | |
| < 0.4 | 67 | AMMAR | 67 | HBC | | |
| $\Gamma(\pi\pi\eta)/\Gamma(K\overline{I})$ | ₹) | | | | | Γ_6/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the followin | g data for average | es, fits, | , limits, | etc. • • • | |
| < 0.41 | 95 | AGUILAR | 72B | HBC | 3.9,4.6 K-p | |
| < 0.3 | 67 | AMMAR | 67 | HBC | | |
| $\Gamma(\pi^+\pi^+\pi^-\pi^-$ | -)/Γ(<i>Κ'</i> Κ') | | | | | Γ_7/Γ_1 |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| ● ● We do not | use the followin | g data for average | es, fits, | limits, | etc. • • • | |
| < 0.32 | 95 | AGUILAR | 72B | HBC | 3946K-n | |

f'₂(1525) REFERENCES

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| BINON | 07 | PAN 70 1713 Translated from YAF | F. Binon et al. | (GAMS Collab.) |
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| ABLIKIM | 05 | PL B607 243 | M. Ablikim et al. | (BES Collab.) |
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| AMSLER | 02 | EPJ C23 29 | C. Amsler et al. | |
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| BARBERIS | 00 E | PL B479 59 | D. Barberis et al. | (WA 102 Collab.) |
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| ABREU | 96 C | PL B379 309 | P. Abreu et al. | (DELPHI Collab.) |
| BAI | 96 C | PRL 77 3959 | J.Z. Baietal. | (BES Collab.) |
| ACCIARRI | 95 J | PL B363 118 | M. Acciarri et al. | (L3 Collab.) |
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| ALDDECUT | 00.0 | Translated from DAN | | (ADGUS C-U-L) |
| ALBRECHT | 90 G | ZPHY C48 183 | H. Albrecht et al. | (ARGUS Collab.) |
| PDG | 90 89 C | PL B239 1 | J.J. Hernandez et al. | (IFIC, BOST, CIT+) |
| BEHREND | 88 D | ZPHY C43 91 NP B301 525 | H.J. Behrend et al. | (CELLO Collab.) SLAC, NAGO, CINC, INUS) |
| AST ON AUGUSTIN | 88 88 | PRL 60 2238 | | |
| BERGER | 88 | ZPHY C37 329 | J.E. Augustin et al. C. Berger et al. | (DM2 Collab.) (PLUTO Collab.) |
| FALVARD | 88 | PR D38 2706 | A. Falvard et al. | (CLER, FRAS, LALO+) |
| AUGUSTIN | 87 | ZPHY C36 369 | J.E. Augustin et al. | (LALO, CLER, FRAS+) |
| BALTRUSAIT | | PR D35 2077 | R.M. Baltrusaitis et al. | (Mark III Collab.) |
| AIHARA | 86B | PRL 57 404 | H. Aihara et al. | (TPC-2γ Collab.) |
| BOLONKIN | 86 | SJNP 43 776 | B.V. Bolonkin et al. | (ITEP) JP |
| DOLONKIN | 00 | Translated from YAF | | (11 61) 31 |
| LONGACRE | 86 | PL B177 223 | R.S. Longacre et al. | (BNL, BRAN, CUNY+) |
| ALTHOFF | 83 | PL 121B 216 | M. Althoff et al. | (TASS O Collab.) |
| ARMSTRONG | 83 B | NP B224 193 | T.A. Armstrong et al. | (BARI, BIRM, CERN+) |
| A GUILA R | 81B | ZPHY C8 313 | M. Aguilar-Benitez et al. | (CERN, CDEF+) |
| ALHARRAN | 81 | NP B191 26 | S. Al-Harran et al. | (BIRM, CERN, GLAS+) |
| CHABAUD | 81 | APP B12 575 | V. Chabaud et al. | (CERN, CRAC, MPIM) |
| C OS TA | 80 | NP B175 402 | G. Costa de Beauregard et al | . (BARI, BONN+) |
| GORLICH | 80 | NP B174 16 | L. Gorlich et al. | (CRAC, MPIM, CERN+) |
| CORDEN | 79 | NP B157 250 | M.J. Corden et al. | (BIRM, RHEL, TELA+)JP |
| MARTIN | 79 | NP B158 520 | A.D. Martin, E.N. Ozmutlu | ` (DURH) |
| POLYCHRO | 79 | PR D19 1317 | V.A. Polychronakos et al. | (NDAM, ANL) |
| BARREIRO | 77 | NP B121 237 | F. Barreiro et al. | (CERN, AMST, NIJM+) |
| EVAN GELIS | 77 | NP B127 384 | C. Evangelista et al. | (BARI, BONN, CERN+) |
| PAWLICKI | 77 | PR D15 3196 | A.J. Pawlicki <i>et al.</i> | (ANL) IJP |
| BRANDENB | 76 C | NP B104 413 | G.W. Brandenburg et al. | (SLAC) |
| BEUSCH | 75 B | PL 60B 101 | W. Beusch et al. | (CERN, ETH) |
| A GUILAR | 72 B | PR D6 29 | M. Aguilar-Benitez et al. | (BNL) |
| AMMAR | 67 | PRL 19 1071 | R. Ammar et al. | (NWES, ANL) JP |
| BARNES | 67 | PRL 19 964 | V.E. Barnes et al. | (BNL, SYRA) IJPC |
| CRENNELL | 66 | PRL 16 1025 | D.J. Crennell et al. | (BNL) I |
| | | | | |

$f_2(1565)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

OMITTED FROM SUMMARY TABLE

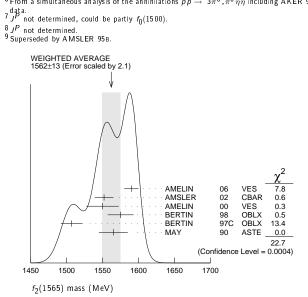
Seen mostly in antinucleon-nucleon annihilation. Needs confirmation $% \left(1\right) =\left(1\right) \left(1\right)$ in other channels

£(1565) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------|---------------------|-------|--------|--------------------------------------------------------------------|
| 1562±13 OUR AVERAG | E Error includes | scale | factor | of 2.1. See the ideogram below. |
| | ¹ AMELIN | | | 36 $\pi^- p \rightarrow \omega \omega n$ |
| 1552 ± 13 | ² AMSLER | 02 | CBAR | $0.9 \overline{p}p \rightarrow \pi^0 \eta \eta, \pi^0 \pi^0 \pi^0$ |
| $1550 \pm 10 \pm 20$ | AMELIN | | | $37 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 1575 ± 18 | BERTIN | | | $0.05-0.405 \ \overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 1507 ± 15 | ² BERTIN | | | $0.0 \ \overline{p}p \rightarrow \pi^+ \pi^- \pi^0$ |
| 1565 ± 20 | MAY | 90 | ASTE | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |

| • • • We do not use th | e following data for averages, t | iits, limits, etc. • • • |
|------------------------|----------------------------------|----------------------------------------------------------------------------|
| 1560 ± 15 | ³ ANISOVICH 09 RVI | JE $0.0 \overline{p}p$, πN |
| 1598±11± 9 | BAKER 99B SPE | $EC 0 \ \overline{\rho} p \rightarrow \omega \omega \pi^0$ |
| 1534 ± 20 | ⁴ ABELE 96c RVI | JE Compilation |
| ~ 1552 | ⁵ AMSLER 95D CB/ | AR $0.0 \overline{p}p \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, |
| | | $\pi^0 \pi^0 \eta$ |
| 1598 ± 72 | BALOSHIN 95 SPE | $EC 40 \; \pi^- C \xrightarrow{C} \; K_{S}^0 K_{S}^0 X$ |
| 1566 + 80 | 6 ANISOVICH 94 CB | AR $0.0 \overline{p}p \rightarrow 3\pi^0, \eta\eta\pi^0$ |
| • • • | 101110 00 00 | v = + + = |
| 1502± 9 | ADAMO 93 OBI | $\perp X \overline{n}p \rightarrow \pi^+\pi^+\pi^-$ |
| 1488 ± 10 | ⁷ ARMSTRONG 93c E76 | $0 \overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| 1508 ± 10 | ⁷ ARMSTRONG 93D E76 | $0 \overline{p}p \rightarrow 3\pi^0 \rightarrow 6\gamma$ |
| 1525 ± 10 | ⁷ ARMSTRONG 93D E76 | $0 \overline{p}p \rightarrow \eta \pi^0 \pi^0 \rightarrow 6\gamma$ |
| ~ 1504 | ⁸ WEIDENAUER 93 AST | TE $0.0 \overline{p} N \rightarrow 3\pi^- 2\pi^+$ |
| 1540 ± 15 | ⁷ ADAMO 92 OBI | |
| 1515 ± 10 | ⁹ AKER 91 CB | AR $0.0 \overline{p} p \rightarrow 3\pi^0$ |
| 1477± 5 | BRIDGES 86c DB | $C 0.0 \overline{p} N \rightarrow 3\pi^- 2\pi^+$ |

- 1 Supersedes the $\omega\omega$ state of BELADIDZE 92B earlier assigned to the $\mathit{f}_{2}(1640).$
- ²T-matrix pole. ³On sheet II in a two-pole solution.
- ⁴ T-matrix pole, large coupling to $\rho\rho$ and $\omega\omega$, could be $f_2(1640)$.
- ⁵ Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D.
- ⁶ From a simultaneous analysis of the annihilations $\overline{p} p \to 3\pi^0$, $\pi^0 \eta \eta$ including AKER 91



f2(1565) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|--------------------------|-------|------------|----------------------------------------------------------------------------|
| 134± 8 OUR AVERA | | | | |
| 140± 11 | ¹⁰ AMELIN | 06 | VES | 36 $\pi^- p \rightarrow \omega \omega n$ |
| 113± 23 | ¹¹ AMSLER | 02 | CBAR | $0.9 \overline{p}p \rightarrow \pi^0 \eta \eta, \pi^0 \pi^0 \pi^0$ |
| 130± 20±40 | AMELIN | 00 | VES | $37 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |
| 119± 24 | BERTIN | 98 | OBLX | $0.05-0.405 \ \overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 130± 20 | ¹¹ BERTIN | 97c | OBLX | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| 170± 40 | MAY | 90 | ASTE | $0.0 \overline{p}p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| • • • We do not use the | following data for a | verag | ges, fits, | limits, etc. • • • |
| 280± 40 | 12 ANISOVICH | 09 | RVUE | $0.0 \overline{p}p, \pi N$ |
| 180± 60 | ¹³ ABELE | 96c | RVUE | Compilation |
| ~ 142 | ¹⁴ AMSLER | 95 D | CBAR | $0.0 \overline{\rho} \rho \rightarrow \pi^0 \pi^0 \pi^0, \pi^0 \eta \eta,$ |
| | | | | $\pi^0 \pi^0 \eta$ |
| 263 ± 101 | BALOSHIN | 95 | SPEC | 40 π^- C $\rightarrow K_S^0 K_S^0 X$ |
| $166 + 80 \\ - 20$ | ¹⁵ ANISOVICH | 94 | CBAR | $0.0~\overline{p} p \rightarrow 3\pi^0$, $\eta\eta\pi^0$ |
| 130± 10 | ¹⁶ ADA MO | 93 | OBLX | $\overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ |
| 148± 27 | ¹⁷ ARMSTRONG | 93c | E760 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| 103± 15 | ¹⁷ ARMSTRONG | 93D | E760 | $\overline{p}p \rightarrow 3\pi^0 \rightarrow 6\gamma$ |
| 111 ± 10 | ¹⁷ ARMSTRONG | 93D | E760 | $\overline{\rho}\rho \rightarrow \eta \pi^0 \pi^0 \rightarrow 6\gamma$ |
| ~ 206 | ¹⁸ WEIDENAUER | 93 | ASTE | $0.0 \overline{p} N \rightarrow 3\pi^{-} 2\pi^{+}$ |
| 132± 37 | ¹⁷ ADA MO | 92 | | $\overline{n}p \rightarrow \pi^+ \pi^+ \pi^-$ |
| $120\pm~10$ | ¹⁹ AKER | 91 | CBAR | $0.0 \overline{p}p \rightarrow 3\pi^0$ |
| 116± 9 | BRIDGES | 86c | DBC | $0.0 \ \overline{p} \ N \rightarrow 3\pi^- 2\pi^+$ |
| 10 Supercedes the const | ate of BELADIDZE | 02p | earlier as | signed to the fo(1640) |

- 10 Supersedes the $\omega\omega$ state of BELADIDZE 92B earlier assigned to the $f_2(1640)$.
- 11 T-matrix pole.
- 13 T-matrix pole, large coupling to $\rho\rho$ and $\omega\omega$, could be $f_2(1640)$.
- 14 Coupled-channel analysis of AMSLER 95B, AMSLER 95C, and AMSLER 94D. 15 From a simultaneous analysis of the annihilations $\overline{\rho}p \to 3\pi^0$, π^0 $\eta\eta$ including AKER 91

| | .00 | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 6 Supersedes ADAMO 7 $_JP$ not determined, 6 | could be partly $f_0(1500)$. | |
| $^8J^P$ not determined. $^9{ m Superseded}$ by AMSL | LER 95B. | |
| | f ₂ (1565) DECAY MODES | |
| Mode | Fraction (Γ_j/Γ) | |
| $\pi\pi$ | seen | |
| $^{\pi^+\pi^-}_{\pi^0\pi^0}$ | seen | |
| $\rho^0 \stackrel{\pi}{\rho^0} \stackrel{\pi}{\rho^0}$ | seen seen | |
| $2\pi^{+}2\pi^{-}$ | seen | |
| $\eta\eta$ | seen | |
| $a_2(1320)\pi$ | 5000 | |
| $\frac{\omega}{K}\frac{\omega}{K}$ | seen | |
| $\gamma \gamma$ | | |
| | f2(1565) PARTIAL WIDTHS | |
| $\eta\eta)$ | 2() | Г ₆ |
| LUE (MeV) | EVTS DOCUMENT ID TECN CO | |
| | e following data for averages, fits, limits, etc. | |
| ± 0.3 | 870 20 SCHEGELSKY 06A RVUE γ^{\prime} | $\gamma \rightarrow K_S^0 K_S^0$ |
| ĸ₹) | | Г9 |
| | EVTS DOCUMENT ID TECN CO | |
| | e following data for averages, fits, limits, etc. | |
| ±1.0 | 870 20 SCHEGELSKY 06A RVUE γ | $\gamma \rightarrow K_S^0 K_S^0$ |
| $\gamma \gamma)$ | | Γ ₁₀ |
| | EVTS DOCUMENT ID TECN CO | |
| | e following data for averages, fits, limits, etc. 870 20 SCHEGELSKY 06A RVUE γ^c | |
| 0±0.14 | | |
| width of 160 MeV, Γ(| data at 91 and 183–209 GeV, using $f_2(1569,\pi\pi)=25$ MeV, and SU(3) relations. | o) mass or 1570 MeV, |
| | ∱(1565) BRANCHING RATIOS | |
| $(\pi\pi)/\Gamma_{\text{total}}$ | | Γ ₁ /Γ |
| . <i>UE</i> • We do not use the | <u>DOCUMENT ID</u> <u>TECN</u> <u>CC</u> e following data for averages, fits, limits, etc. | |
| n | | $\overline{p}p \rightarrow \omega \omega \pi^0$ |
| | | |
| _+\ /⊏ | | |
| $\pi^+\pi^-)/\Gamma_{\text{total}}$ | DOCUMENT ID TECN CO | -· |
| UE | <u>DOCUMENT ID</u> <u>TECN</u> <u>CC</u> e following data for averages, fits, limits, etc. | DMMENT |
| • • We do not use the | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. | $ \begin{array}{ccc} \hline OMMENT & \bullet & \bullet \\ \hline \bullet & \bullet & \bullet \\ 05-0.405 & \overline{n}p & \rightarrow \\ \pi^{+} & \pi^{+} & \pi^{-} \end{array} $ |
| . <u>UE</u> ■ We do not use the | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 戸 | OMMENT 05-0.405 $\overline{n}p \rightarrow \pi^+\pi^+\pi^ p \rightarrow \pi^+\pi^-\pi^0$ |
| • We do not use the seen | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 77, MAY 89 ASTE 77 | $ \begin{array}{ccc} \hline OMMENT \\ \bullet & \bullet & \bullet \\ 05-0.405 \overline{n}p \rightarrow \\ \pi^{+}\pi^{+}\pi^{-} \end{array} $ |
| WE one was the new seen new ANISOVICH 94B is fr | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 戸 | 05-0.405 $\overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ $p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| . • • We do not use the n seen ANISOVICH 94B is fr π ⁰ π ⁰)/Γ _{total} | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 戸, MAY 89 ASTE 戸, rom a reanalysis of MAY 90. | 05-0.405 $\overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ $p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| where $\frac{1}{2}$ | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE \overline{p}_i MAY 89 ASTE \overline{p}_i from a reanalysis of MAY 90. | 05-0.405 $\overline{n}p \rightarrow \pi^{+}\pi^{+}\pi^{-}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ $p \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| en t seen en 1 ANISOVICH 94B is fr $(\pi^0\pi^0)/\Gamma_{ m total}$ LUE | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 戸, MAY 89 ASTE 戸, rom a reanalysis of MAY 90. | OMMENT 05-0.405 $\overline{n}p \rightarrow \pi^+\pi^+\pi^ p \rightarrow \pi^+\pi^-\pi^0$ $p \rightarrow \pi^+\pi^-\pi^0$ |
| We do not use then seen ANISOVICH 94B is fr $\pi^0 \pi^0$)/ Γ_{total} | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE 77 MAY 89 ASTE 77 from a reanalysis of MAY 90. DOCUMENT ID TECN CO | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • We do not use the seen ANISOVICH 94B is from $\frac{0}{16}$ $\frac{\pi^0}{16}$ $\frac{1}{16}$ 1 | e following data for averages, fits, limits, etc. BERTIN 98 OBLX 0. 21 ANISOVICH 94B RVUE \overline{p}_i MAY 89 ASTE \overline{p}_i from a reanalysis of MAY 90. | OMMENT 05-0.405 $\overline{n}p \rightarrow \pi^+\pi^+\pi^ p \rightarrow \pi^+\pi^-\pi^0$ $p \rightarrow \pi^-\pi^0$ $p \rightarrow 3\pi^0$ |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 $^{22}J^{P}$ not determined, could be partly $f_{0}(1500)$.

DOCUMENT ID

DOCUMENT ID \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

BAKER

 Γ_6/Γ_3

Г8/Г

> 0.5

TECN COMMENT

TECN COMMENT

99B SPEC $0 \, \overline{p} \, p \rightarrow \omega \omega \pi^0$

 22 armstrong 93c E760 $\overline{p}p
ightarrow ~\pi^0 \, \eta \, \eta
ightarrow ~6 \gamma$

 $\Gamma(\eta\eta)/\Gamma(\pi^0\pi^0)$

 $0.024 \pm 0.005 \pm 0.012$

 $\Gamma(\omega\omega)/\Gamma_{\rm total}$

seen

f₂(1565) REFERENCES

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|------------|------|-------------------|--------------------------------|-----------------|-------------|
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| | | Translated from ` | | | |
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| | | Translated from ` | YAF 58 50. | | , , |
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| ARMSTRONG | 93 C | PL B307 394 | T.A. Armstrong et al. | (FNAL, FERR, C | ENO+) |
| ARMSTRONG | 93 D | PL B307 399 | T.A. Armstrong et al. | (FNAL, FERR, C | ENO+) |
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| MAY | 89 | PL B225 450 | B. Maý et al. | | Collab. JJP |
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| BRIDGES | 86 C | PRL 57 1534 | D.L. Bridges et al. | , , | (SYRA) |
| | | | | | |

$\rho(1570)$

$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

OMITTED FROM SUMMARY TABLE

May be an OZI-violating decay mode of ho(1700). See our minireview under the $\rho(1700)$.

$\rho(1570)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-------------|-----------------------|---------|-----------|---------------------------------------------|
| 1570 ± 36 ± 62 | 54 | 1 AUBERT | 08s | BABR | $10.6 e^+e^- \rightarrow \phi \pi^0 \gamma$ |
| • • • We do not use th | e following | g data for average | s, fits | , limits, | etc. • • • |
| 1480 ± 40 | | ² BITYUKOV | 87 | SPEC | 32.5 $\pi^- p \to \phi \pi^0 n$ |
| 1 From the fit with tw | o resonano | es. | | | |

ρ (1570) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|-----------------------|-----------|---------|---------------------------------------------|
| 144±75±43 | 54 | 3 AUBERT | 08s | BABR | $10.6 e^+e^- \rightarrow \phi \pi^0 \gamma$ |
| ● ● We do not | use the following | data for average | es, fits, | limits, | etc. • • • |
| $130\!\pm\!60$ | | ⁴ BITYUKOV | 87 | SPEC | 32.5 $\pi^- p \rightarrow \phi \pi^0 n$ |
| 3 From the fit | ith two reconone | 0.0 | | | |

³ From the fit with two resonances ⁴ Systematic errors not estimated.

ρ (1570) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|-----------------------|-------------|------------------------------|
| $\overline{\Gamma_1}$ | $e^+ e^-$ | |
| Γ_2 | $\phi\pi$ | not seen |
| Γ_3 | $\omega\pi$ | |

$\rho(1570) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\phi\pi) \times \Gamma(e^+$ | $e^-)/\Gamma_{\text{total}}$ | | | | Γ ₂ Γ | 1/Г |
|-------------------------------------|------------------------------|------------------------|---------|---------|--------------------------------------------|----------------------|
| VALUE (eV) | CL% EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 3.5 ± 0.9 ± 0.3 | 54 | 5 AUBERT | 08s | BABR | $10.6 e^+e^- \rightarrow \phi \pi$ | .0 _{\gamma} |
| ullet $ullet$ We do not | use the following | ng data for averages | s, fits | limits, | etc. • • • | |
| < 70 | 90 | ⁶ AULCHENKO | 87в | ND | $e^+e^- \rightarrow \kappa_S^0 \kappa_L^0$ | π^0 |
| ⁵ From the fit w | | | | | | |

$^{6}\,\text{Using mass}$ and width of BITYUKOV 87.

ρ(1570) BRANCHING RATIOS

| | | • | | | | |
|-------------------------------------|---------------|------------------------|---------|-----------|-------------------------------------|--------------------------|
| $\Gamma(\phi\pi)/\Gamma_{ m total}$ | | | | | | Γ_2/Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| not seen | | ABELE | 97н | CBAR | $\overline{p}p \rightarrow K_I^0 K$ | $^{0}_{5}\pi^{0}\pi^{0}$ |
| • • • We do not use | the following | data for average | s, fits | , limits, | etc. • • • | - |
| < 0.01 | | ⁷ DONNACHIE | 91 | RVUE | | |
| ⁷ Using data from | BISELLO 91B, | DOLINSKY 86, | and A | ALBREC | HT 87L. | |
| $\Gamma(\phi\pi)/\Gamma(\omega\pi)$ | | | | | | Γ_2/Γ_3 |
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT | |

BITYUKOV 87 SPEC 32.5 $\pi^- p \rightarrow \phi \pi^0 n$

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

95

² Systematic errors not estimated.

 $\rho(1570)$, $h_1(1595)$, $\pi_1(1600)$

ρ(1570) REFERENCES

| AUBERT | 085 | PR D77 092002 | B. Aubert et al. | (BABAR Collab.) |
|-----------|------|-----------------------|--------------------------|--------------------------|
| ABELE | 97 H | PL B415 280 | A. Abele et al. | (Crystàl Barrel Collab.) |
| BISELLO | 91 B | NPBPS B21 111 | D. Bisello | (DM2 Collab.) |
| DONNACHIE | 91 | ZPHY C51 689 | A. Donnachie, A.B. Clegg | (MCHS, LANC) |
| ALBRECHT | 87 L | PL B185 223 | H. Albrecht et al. | (ÀRGUS Collab.) |
| AULCHENKO | 87 B | JETPL 45 145 | V.M. Aulchenko et al. | ` (NOVO) |
| | | Translated from ZETFP | 45 118. | ` ' |
| BITYUKOV | 87 | PL B188 383 | S.I. Bityukov et al. | (SERP) |
| DOLINS KY | 86 | PL B174 453 | S.I. Dolinsky et al. | (Novo) |

$h_1(1595)$

$$I^G(J^{PC}) = 0^-(1^{+-})$$

OMITTED FROM SUMMARY TABLE

Seen in a partial-wave analysis of the $\omega\eta$ system produced in the reaction $\pi^-\,p\to\;\omega\eta\,n$ at 18 GeV/c.

h1(1595) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------|--------------|----|------|----------------------------------------|
| $1594 \pm 15 \substack{+10 \\ -60}$ | EUGENIO | 01 | SPEC | 18 $\pi^- p \rightarrow \omega \eta n$ |

h₁ (1595) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------------------------|--------------|--------|----------------------------------------|
| $384 \pm 60 ^{+}_{-100}^{70}$ | EUGENIO 0: | 1 SPEC | 18 $\pi^- p \rightarrow \omega \eta n$ |

h1(1595) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | | |
|-----------------------|---------------|------------------------------|--|--|
| $\overline{\Gamma_1}$ | $\omega \eta$ | seen | | |

h₁(1595) REFERENCES

EUGENIO 01 PL B497 190 P. Eugenio et al.



$$I^{G}(J^{PC}) = 1^{-}(1^{-+})$$

$\pi_1(1600)$ MASS

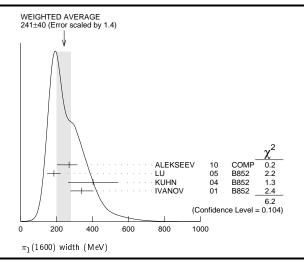
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|-------------|------------------------|---------|--------------|---------------------------------------------------|
| 1662 + 8 OUR | AVERAGE | | | | |
| $1660\pm10{}^{+}_{-64}^{0}$ | 420k | ALEKSEEV | 10 | СОМР | 190 $\pi^- Pb \rightarrow \pi^- \pi^- \pi^+ Pb'$ |
| $1664 \pm 8 \pm 10$ | 145 k | $^{ m 1}$ LU | 05 | | $18 \pi^- p \rightarrow \omega \pi^- \pi^0 p$ |
| $1709 \pm 24 \pm 41$ | 69k | ² KUHN | 04 | B 85 2 | 18 $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$ |
| $1597 \pm 10 {}^{+45}_{-10}$ | | ² IVA NOV | 01 | B 85 2 | 18 $\pi^- \rho \rightarrow \eta' \pi^- \rho$ |
| • • • We do no | t use the f | following data for | average | es, fits, li | mits, etc. • • • |
| $1593 \pm 8^{+29}_{-47}$ | | $^{2,3}\mathrm{ADAMS}$ | 98в | B 85 2 | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |

- $\frac{1}{2} \; \text{May be a different state: natural and unnatural parity exchanges.}$
- ² Natural parity exchange.

π_1 (1600) WIDTH

| VALUE (MeV) 241±40 OUR AV | | DOCUMENT ID Error includes sca | | <u>TECN</u> or of 1.4 | COMMENT See the ideogram below. |
|---------------------------|-----------|-----------------------------------|--------|--------------------------|---------------------------------------------------|
| $269 \pm 21 + 42 \\ -64$ | 420k | ALEKSEEV | 10 | COMP | 190 $\pi^- Pb \rightarrow \pi^- \pi^- \pi^+ Pb'$ |
| $185 \pm 25 \pm\ 28$ | 145k | ⁴ LU | 05 | B 85 2 | $18 \pi^- p \rightarrow \omega \pi^- \pi^0 p$ |
| $403 \pm 80 \pm 115$ | 69k | ⁵ KUHN | 04 | B 85 2 | 18 $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$ |
| $340 \pm 40 \pm 50$ | | ⁵ IVA NOV | 01 | B 85 2 | $18 \pi^- p \rightarrow \eta' \pi^- p$ |
| • • • We do no | t use the | following data for a | averag | es, fits, l | mits, etc. • • • |
| 168 + 20 + 150 | | 5,6 ADAMS | 98B | B 85.2 | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |

- $^{4}\ \text{May}$ be a different state: natural and unnatural parity exchanges.
- ⁵ Natural parity exchange.
- ⁶ Superseded by DZIERBA 06 excluding this state in a more refined PWA analysis, with 2.6 M events of $\pi^-p\to\pi^-\pi^-\pi^+p$ and 3 M events of $\pi^-p\to\pi^-\pi^0\pi^0p$ of E852 data



$\pi_1(1600)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-------------------|------------------------------|
| Γ ₁ | $\pi\pi\pi$ | not seen |
| Γ_2 | $ ho^0\pi^-$ | not seen |
| Γ_3 | $f_2(1270) \pi^-$ | not seen |
| Γ ₄ Γ ₅ | $b_1(1235)\pi$ | seen |
| Γ_5 | $\eta'(958)\pi^-$ | seen |
| Γ_6 | $f_1(1285)\pi$ | seen |

π_1 (1600) BRANCHING RATIOS

| $\Gamma(ho^0\pi^-)/\Gamma_{ m total}$ | | | | | Γ_2/Γ |
|----------------------------------------|----------------------|----|------|-----------------------------------------|-------------------|
| VALUE | DOCUMENT ID | 1 | TECN | COMMENT | |
| not seen | NOZAR | 09 | CLAS | $\gamma p \rightarrow 2\pi^{+}\pi^{-}n$ | |
| not seen | ⁷ DZIERBA | 06 | B852 | 18 π ⁻ p | |

 7 From the PWA analysis of 2.6 M $\pi^-p\to\pi^-\pi^-\pi^+p$ and 3 M events of $\pi^-p\to\pi^-\pi^0\,\pi^0\,p$ of E852 data. Supersedes ADAMS 98B.

| $\Gamma(f_2(1270)\pi^-)/\Gamma_{ m total}$ | | | | | Гз/Г |
|--------------------------------------------|----------------------|----|------|--------------|------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| not seen | ⁸ DZIERBA | 06 | B852 | 18 $\pi^- p$ | |

 8 From the PWA analysis of 2.6 M $\pi^-p\to\pi^-\pi^-\pi^+p$ and 3 M events of $\pi^-p\to\pi^-\pi^0\pi^0\,p$ of E852 data. Supersedes CHUNG 02.

| $\Gamma(b_1(1235)_1$ | r)/Γ _{total} | | | | Γ_4/Γ |
|-------------------------|-----------------------|--------------------|---------|-----------|------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| seen | 35280 | ⁹ BAKER | 03 | SPEC | $\overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}$ |
| • • • We do | not use the followin | g data for average | s, fits | , limits, | etc. • • • |
| seen | 145k | LU | 05 | B852 | 18 $\pi^- p \rightarrow \omega \pi^- \pi^0 p$ |
| $^{9}B((b_{1}\pi)_{D})$ | $-wave)/B((b_1\pi)_S$ | -wave)=0.3 ± 0.1 | | | |

| $\Gamma(\eta'(958)\pi^-)/\Gamma_{total}$ | | | | | Γ ₅ /Γ |
|------------------------------------------|--------------|------|------|----------------------------|-------------------|
| VALUE | DO CUMENT IE | TECN | | | |
| seen | IVANOV | 01 | B852 | $18 \pi^- p \rightarrow r$ | $\eta' \pi^- p$ |

| $\Gamma(f_1(1285)\pi)/\Gamma(\eta'(958)\pi^-)$ Γ_6/Γ_1 | | | | | | | |
|--------------------------------------------------------------------|------|--------------------|----|------|-----------------------------|----------------------------|--|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
| 3.80±0.78 | 69k | ¹⁰ KUHN | 04 | B852 | 18 $\pi^- \rho \rightarrow$ | $\eta \pi^+ \pi^- \pi^- p$ | |
| 10 Using $\eta'(958)\pi$ data from IVANOV 01. | | | | | | | |

π_1 (1600) REFERENCES

| ALEKSEEV NOZAR DZIERBA | 10 09 06 | PRL 104 241803 PRL 102 102002 PR D73 072001 | M.G. Alekseev <i>et al.</i> M. Nozar <i>et al.</i> A.R. Dzierba <i>et al.</i> | (COMPASS Collab.) (CLAS Collab.) (BNL E852 Collab.) |
|------------------------------|----------------|---------------------------------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------|
| LU | 05 | PRL 94 032002 | M. Lu et al. | (BNL E852 Collab.) |
| KUHN | 04 | PL B595 109 | J. Kuhn et al. | (BNL E852 Collab.) |
| BAKER | 03 | PL B563 140 | C.A. Baker et al. | , |
| CHUNG | 02 | PR D65 072001 | S.U. Chung et al. | (BNL E852 Collab.) |
| IVAN OV | 01 | PRL 86 3977 | E.I. Ivanov et al. | (BNL E852 Collab.) |
| ADAMS | 98 B | PRL 81 5760 | G.S. Adams et al. | (BNL E852 Collab.) |

³ Superseded by DZIERBA 06 excluding this state in a more refined PWA analysis, with 2.6 M events of $\pi^-p\to\pi^-\pi^-\pi^+p$ and 3 M events of $\pi^-p\to\pi^-\pi^0\pi^0p$ of E852 data

 $a_1(1640)$

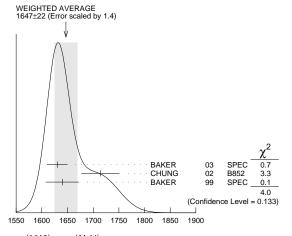
$$I^{G}(J^{PC}) = 1^{-}(1^{++})$$

OMITTED FROM SUMMARY TABLE

Seen in the amplitude analysis of the $3\pi^0$ system produced in $\overline{p}\,\rho\to 4\pi^0$. Possibly seen in the study of the hadronic structure in decay $\tau\to 3\pi\nu_{\tau}$ (ABREU 98G and ASNER 00). Needs confirmation.

a₁(1640) MASS

| VALUE (MeV) | EVTS | DOCUMENT | ID | TECN | COMMENT |
|---------------------|------------------|--------------------|-------------|------------|------------------------------------------------------------|
| 1647 ± 22 OUR | AVERAGE E | Error includes so | ale factor | of 1.4. | See the ideogram below. |
| 1630 ± 20 | 35280 | ¹ BAKER | 03 | SPEC | $\overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}$ |
| $1714 \pm 9 \pm 36$ | | CHUNG | | | 18.3 $\pi^- p \to \pi^+ \pi^- \pi^- p$ |
| $1640\pm 12\pm 30$ | | BAKER | 99 | SPEC | $1.94 \overline{p}p \rightarrow 4\pi^0$ |
| • • • We do no | ot use the follo | owing data for a | averages, f | fits, limi | ts, etc. • • • |
| 1670 ± 90 | | BELLINI | 85 | SPEC | 40 $\pi^- A \rightarrow \pi^- \pi^+ \pi^- A$ |



a₁(1640) mass (MeV)

$a_1(1640)$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT | ID | TECN | COMMENT | | | |
|------------------------------------------------------------|------------------|--------------------|------------|-----------|------------------------------------------------------------|--|--|--|
| 254± 27 OUR / | VERAGE E | ror includes so | ale factor | of 1.1. | | | | |
| 225 ± 30 | 35280 | ² BAKER | | | $\overline{p}p \rightarrow \omega \pi^{+} \pi^{-} \pi^{0}$ | | | |
| $308 \pm 37 \pm 62$ | | CHUNG | 02 | B852 | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ | | | |
| 300 ± 22 ± 40 | | BAKER | 99 | SPEC | $1.94 \overline{p}p \rightarrow 4\pi^0$ | | | |
| • • • We do no | t use the follow | wing data for a | verages, | fits, lim | ts, etc. • • • | | | |
| 300 ± 100 | | BELLINI | 85 | SPEC | 40 $\pi^- A \to \pi^- \pi^+ \pi^- A$ | | | |
| Using the $a_1(1260)$ mass and width results of BOWLER 88. | | | | | | | | |
| | | | | | | | | |

a₁(1640) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------|------------------------------|
| Γ_1 | $\pi\pi\pi$ | seen |
| Γ_2 | $f_2(1270) \pi$ | seen |
| Гз | $\sigma\pi$ | seen |
| Γ_4 | $\rho\pi_{S-wave}$ | seen |
| Γ_5 | $\rho\pi_{D-wave}$ | seen |
| Γ ₆ | $\omega \pi \pi$ | seen |
| Γ_7 | $f_1(1285)\pi$ | seen |
| Γ ₈ | $a_1(1260)\eta$ | not seen |

a₁(1640) BRANCHING RATIOS

| $\Gamma(f_2(1270)\pi)/\Gamma(\sigma\pi)$ | | | | | Γ_2/Γ_3 |
|--------------------------------------------------|--------------------|---------------|------------|------------------------------------|---------------------|
| VALUE | <u>DO CUME</u> | VT ID | TECN | COMMENT | |
| ullet $ullet$ We do not use the fol | lowing data for av | verages, fits | s, limits, | etc. • • • | |
| 0.24 ± 0.07 | BAKER | 99 | SPEC | 1.94 $\overline{p}p \rightarrow 4$ | π^0 |
| $\Gamma(\rho\pi_{D-wave})/\Gamma_{\text{total}}$ | | | | | Γ ₅ /Γ |
| VALUE | DO CUMENT ID | TEC | N COM | IMENT | |
| ullet $ullet$ We do not use the fol | lowing data for av | verages, fits | s, limits, | etc. • • • | |
| seen | CHUNG | | | $8 \pi^- p \rightarrow \pi^+ \pi$ | |
| seen | AMELIN | 95B VES | 36 τ | $\tau^- A \rightarrow \pi^+ \pi^-$ | $\pi^- A$ |

| $\Gamma(\omega\pi\pi)/\Gamma_{\text{total}}$ | EVTS | DO CUMENT | ID | TECN | сомм | Γ 6/Γ |
|----------------------------------------------|--------------|--------------------|----------|------------|-----------------------------|--------------------------------------------------------------------|
| • • • We do not use t | he following | g data for avera | ges, fit | s, limits, | etc. • | • • |
| seen | 35280 | ³ BAKER | 03 | SPEC | $\overline{p}p \rightarrow$ | $_{\omega\pi^+\pi^-\pi^0}$ |
| $\Gamma(f_1(1285)\pi)/\Gamma_{\text{tota}}$ | | CUMENT ID | TEC | N CON | 1MENT | Γ ₇ /Γ |
| • • • We do not use t | | | | | etc. • | • • |
| not seen seen | KU LE | | | | | $_{K^{+}\overline{K^{0}}\pi^{-}\pi^{-}p}^{\pi^{+}\pi^{-}\pi^{-}p}$ |
| $\Gamma(a_1(1260)\eta)/\Gamma_{\text{tota}}$ | | DOCUMENT ID | | ECN (| ОММЕЛТ | Γ ₈ /Γ |
| not seen 3 Assuming the $\omega \rho$ r | <u> </u> | KUHN | 04 E | | | $\rightarrow \eta \pi^+ \pi^- \pi^- \rho$ |

$a_1(1640)$ REFERENCES

| KUHN | 04 | PL B595 109 | J. Kuhn et al. | (BNL E852 Collab.) |
|---------|------|---------------------|--------------------|-------------------------|
| BAKER | 03 | PL B563 140 | C.A. Baker et al. | , |
| CHUNG | 02 | PR D65 072001 | S.U. Chung et al. | (BNL E852 Collab.) |
| ASNER | 00 | PR D61 012002 | D.M. Asner et al. | ` (CLEO Collab.) |
| BAKER | 99 | PL B449 114 | C.A. Baker et al. | |
| ABREU | 98 G | PL B426 411 | P. Abreu et al. | (DELPHI Collab.) |
| AMELIN | 95 B | PL B356 595 | D.V. Amelin et al. | ` (SERP, TBIL) |
| LEE | 94 | PL B323 227 | J.H. Lee et al. | (BNL, IND, KYÚN, MASD+) |
| BOWLER | 88 | PL B209 99 | M.G. Bowler | ` (OXF) |
| BELLINI | 85 | SJNP 41 781 | D. Bellini et al. | |
| | | Translated from YAE | 41 1223 | |

$f_2(1640)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

OMITTED FROM SUMMARY TABLE

f2(1640) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|--------------------------|--------------|--------|-----------------------------------------------------|
| 1639± 6 OUR AVERAGE | Error includes scale fac | ctor o | f 1.2. | |
| 1620 ± 16 | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 1647 ± 7 | ADAMO | 92 | OBLX | $\overline{n}p \rightarrow 3\pi^{+}2\pi^{-}$ |
| 1635 ± 7 | ALDE | 90 | GAM2 | 38 $\pi^- p \rightarrow \omega \omega n$ |
| • • • We do not use the fo | s, limits, | , etc. • • • | | |
| 1640 ± 5 | AMSLER | 06 | CBAR | $0.9 \overline{p}p \rightarrow K^+ K^- \pi^0$ |
| 1659± 6 | VLADIMIRSK | .06 | SPEC | $40 \pi^{-} p \rightarrow K_{S}^{0} K_{S}^{0} n$ |
| 1643 ± 7 | | | | 38 $\pi^- p \rightarrow \omega \omega n$ |
| $^{ m 1}$ Superseded by ALDE 90 | l, | | | |

f2(1640) WIDTH

| VALUE (MeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|-------------------|---------|------------|-----------------------------------------------------------|
| 99+60 OUR | AVERAGE Erro | or includes scale | facto | of 2.9. | |
| $140 + 60 \\ -20$ | | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 58 ± 20 | | ADAMO | | | $\overline{n} p \rightarrow 3\pi^+ 2\pi^-$ |
| ● ● We do not | use the followin | g data for averag | ges, fi | ts, limits | , etc. • • • |
| 44± 9 | | AMSLER | 06 | CBAR | $0.9 \overline{p} p \rightarrow K^+ K^- \pi^0$ |
| 152 ± 18 | | VLADIMIRSK. | .06 | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ |
| < 70 | 90 | ALDE | | | 38 $\pi^- p \rightarrow \omega \omega n$ |

f2(1640) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------|----------------------------------------|------------------------------|
| Γ ₁ Γ ₂ Γ ₃ | $\omega \omega$ 4π $K\overline{K}$ | seen seen seen |

f2(1640) BRANCHING RATIOS

| $\Gamma(K\overline{K})/\Gamma_{\text{total}}$ | | | | | Гз/Г |
|-----------------------------------------------|--------------|----|------|------------------|---------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | AMSLER | 06 | CBAR | 0.9 <u>p</u> p → | $K^+K^-\pi^0$ |

f2(1640) REFERENCES

| AMSLER VLADIMIRSK. | | PL B639 165 PAN 69 493 | C. Amsler et al. V.V. Vladimirsky et al. | (CBAR Collab.) (ITEP, Moscow) |
|-----------------------|-----|---------------------------|---------------------------------------------|----------------------------------|
| | | Translated from | YAF 69 515. | , |
| BUGG | 95 | PL B353 378 | D.V. Bugg et al. | (LOQM, PNPI, WASH)JP |
| ADAMO | 92 | PL B287 368 | A. Adamo et al. | (OBELIX Collab.) |
| ALDE | 90 | PL B241 600 | D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) |
| ALDE | 89B | PL B216 451 | D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) IGJPC |

 $^{^{1}\,\}mathrm{Using}$ the $a_{1}(1260)$ mass and width results of BOWLER 88.

 $\eta_2(1645), \omega(1650)$

| $\eta_2(1645)$ |
|----------------|
|----------------|

| $I^G(J^{PC})$ | = | $0^{+}(2^{-}$ | +) |
|---------------|---|---------------|----|
|---------------|---|---------------|----|

$\eta_{2}(1645)$ MASS

| VALUE (MeV) 1617± 5 OUR AVERAGE | DOCUMENT ID | | <u>TECN</u> | <u>CH G</u> | COMMENT |
|-------------------------------------------|-------------------|--------|-------------|-------------|------------------------------------------------------------------------------------------|
| 1613± 8 | BARBERIS | 00в | | | 450 $\rho \rho \rightarrow \rho_f \eta \pi^+ \pi^- \rho_s$ |
| 1617± 8 | BARBERIS | 00c | | | $450 pp \rightarrow p_f 4\pi p_S$ |
| 1620 ± 20 | BARBERIS | 97B | OMEG | | $450 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ $1.94 \overline{p}p \rightarrow \eta 3\pi^{0}$ |
| $1645\pm 14\pm 15$ | ADOMEIT | 96 | CBAR | 0 | $1.94 \overline{p}p \rightarrow \eta 3\pi^0$ |
| ● ● We do not use the | following data fo | or ave | rages, fits | , limit | s, etc. • • • |
| $1645 \pm 6 \pm 20$ | ANISOVICH | 00E | SPEC | | $0.9-1.94 \ \overline{p}p \rightarrow \eta 3\pi^0$ |

$\eta_{2}(1645)$ WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CH G | COMMENT |
|-------------------------|-------------------|-------|-----------|----------|---------------------------------------------------|
| 181±11 OUR AVERAGE | | | | | |
| 185 ± 17 | BARBERIS | 00в | | | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ |
| 177 ± 18 | BARBERIS | 00c | | | $450 pp \rightarrow p_f 4\pi p_S$ |
| 180 ± 25 | BARBERIS | 97B | OMEG | | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| $180^{+40}_{-21}\pm25$ | ADOMEIT | 96 | CBAR | 0 | 1.94 $\overline{p}p \rightarrow \eta 3\pi^0$ |
| • • • We do not use the | following data fo | r ave | ages, fit | s, limit | s, etc. • • • |
| 200 ± 25 | ANISOVICH | ΛΛc | SPEC | | $0.9 - 1.94 \overline{0}_{D} \rightarrow 23 - 0$ |

$\eta_2(1645)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------------|------------------------------|
| $\overline{\Gamma_1}$ | $a_2(1320)\pi$ | seen |
| Γ_2 | $K\overline{K}\pi$ | seen |
| Γ_3 | $K^*\overline{K}$ | seen |
| Γ_4 | $\eta \pi^+ \pi^-$ | seen |
| Γ_5 | $a_0(980)\pi$ | seen |
| Γ ₆ | $f_2(1270)\eta$ | not seen |

η₂ (1645) BRANCHING RATIOS

| | | | | Γ_2/Γ_1 |
|--------------|-----|------|-----------------|--------------------------------------------------------|
| DO CUMENT ID | | TECN | COMMENT | |
| 1 BARBERIS | 97c | OMEG | 450 <i>pp</i> → | $ppK\overline{K}\pi$ |
| | | | | DOCUMENT ID TECN COMMENT 1 BARBERIS 97C OMEG 450 pp → |

¹ Using $2(\pi^+\pi^-)$ data from BARBERIS 97B.

| $\Gamma(a_2(1320)\pi)/\Gamma(a_0(980)\pi)$ $\Gamma_{1,0}$ | | | | | Γ_1/Γ_5 |
|-----------------------------------------------------------|------------|-------------------------|-----|------|-----------------------------------------------|
| VALUE | , , | DOCUMENT ID | | TECN | COMMENT |
| 13.1±2.3 Ol | JR AVERAGE | | | | |
| 13.5 ± 4.6 | 3 | ² A NISOVICH | 11 | SPEC | 0.9−1.94 p p |
| 13.0 ± 2.7 | | BARBERIS | 00в | | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ |
| | | | | | |

²Reanalysis of ADOMEIT 96 and ANISOVICH 00E.

| $\Gamma(f_2(1270)\eta)/\Gamma_{\text{total}}$ | | | Г ₆ /Г |
|-----------------------------------------------|---------------------------|-------------------------|-------------------|
| VALUE | DO CUMENT ID | COMMENT | |
| • • We do not use the follow | ing data for averages, fi | its, limits, etc. • • • | |

$\eta_2(1645)$ REFERENCES

| ANISOVICH | 11 | EPJ C71 1511 | A.V. Anisovich et al. | (LOQM, RAL, PNPI) |
|-----------|------|--------------|-----------------------|--------------------------|
| ANISOVICH | 00 E | PL B477 19 | A.V. Anisovich et al. | |
| BARBERIS | 00 B | PL B471 435 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 C | PL B471 440 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 97 B | PL B413 217 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 97 C | PL B413 225 | D. Barberis et al. | (WA 102 Collab.) |
| ADOMEIT | 96 | ZPHY C71 227 | J. Adomeit et al. | (Crystal Barrel Collab.) |

 $\omega(1650)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

BARBERIS 00B 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$

$\omega(1650)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------|---------------|-------------------------|--------|-----------|------------------------------------------------------------------------------------------------------|
| 1670± 30 OUR | ESTIMAT | E | | | |
| • • • We do not a | use the follo | owing data for ave | rages, | fits, lim | its, etc. • • • |
| $1667\pm~13\pm~6$ | | AUBERT | 07AU | BABR | 10.6 $e^+e^- \rightarrow \omega \pi^+ \pi^- \gamma$ |
| 1645 ± 8 | 13 | AUBERT | 06D | BABR | 10.6 $e^+e^- \rightarrow \omega \eta \gamma$ |
| $1660 \pm 10 \pm 2$ | | AUBERT,B | | | 10.6 $e^+e^- \to \pi^+\pi^-\pi^0\gamma$ |
| $1770 \pm 50 \pm 60$ | 1.2M | $^{ m 1}$ ACHASOV | 03D | RVUE | $0.44-2.00_{\pi^{+}\pi^{-}\pi^{0}}e^{+}e^{-} \rightarrow$ |
| 1619± 5 | | ² HENNER | 02 | RVUE | $ \begin{array}{c} \pi^+\pi^-\pi^0\\ 1.2-2.0\ e^+e^-\rightarrow\rho\pi,\\ \omega\pi\pi \end{array} $ |
| 1700 ± 20 | | EUGENIO | 01 | SPEC | $18 \pi^- p \rightarrow \omega \eta n$ |
| 1705 ± 26 | 612 | ³ AKHMETSHIN | 00D | CMD2 | $e^+e^- \rightarrow \omega \pi^+\pi^-$ |
| $1820 + 190 \\ -150$ | | ⁴ ACHASOV | 98H | RVUE | $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ |

| $1840 + 100 \\ - 70$ | | ⁵ ACHASOV | 98н | RVUE | $e^+e^- ightarrow \; \omega\pi^+\pi^-$ |
|----------------------|-----|------------------------|-----|------|-----------------------------------------------------------|
| $1780 + 170 \\ -300$ | | ⁶ ACHASOV | 98н | RVUE | $e^+e^- ightarrow \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ |
| ~ 2100 | | ⁷ ACHASOV | 98н | RVUE | $e^+e^- \rightarrow \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ |
| 1606 ± 9 | | ⁸ CLEGG | 94 | RVUE | 3 |
| $1662\!\pm\ 13$ | 750 | ⁹ ANTONELLI | 92 | DM2 | 1.34-2.4 $e^+e^- ightarrow ho\pi$, |
| $1670\pm~20$ | | ATKINSON | 83в | OMEG | $20-70 \gamma p \rightarrow 3\pi X$ |
| 1657 ± 13 | | CORDIER | 81 | DM1 | $e^+e^- \rightarrow \omega 2\pi$ |
| 1679 ± 34 | 21 | ESP OSITO | 80 | FRAM | $e^+e^- 	o 3\pi$ |
| 1652 ± 17 | | COSME | 79 | OSPK | $e^+e^- ightarrow 3\pi$ |
| 1 | | | | | |

 1 From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.

Supersedes ACHASOV 992 and ACHASOV 922. 2 Using results of CORDIER 81 and preliminary data of DOLINSKY 91 and ANTONELLI 92. 3 Using the data of AKHMETSHIN 00D and ANTONELLI 92. The $\rho\pi$ dominance for the energy dependence of the ω (1420) and ω (150) width assumed.

⁴ Using data from BARKOV 87, DOLINSKY 91, and ANTONELLI 92.

Using the data from ANTONELLI 92.

6 Using the data from IVANOV 81 and BISELLO 88B.

7 Using the data from BISELLO 91c.
8 From a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and ANTONELLI 92. 9 From the combined fit of the $\rho\pi$ and $\omega\pi\pi$ final states.

ω (1650) WIDTH

| VALUE (| MeV) | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|-----------------|------------------------|------|-----|------------------|-------|-------------|--------------------------------------------------------------|
| | 35 OUR ES | | | DOCUMENT ID | | TECH | COMMENT |
| | | | llo | wing data for av | erage | s, fits, li | mits, etc. • • • |
| 222± | 25 ± 20 | | | AUBERT | 07AU | BABR | 10.6 $e^+e^- \rightarrow \omega \pi^+\pi^-\gamma$ |
| $114\pm$ | 14 | 13 | | AUBERT | 06D | BABR | 10.6 $e^+e^- \rightarrow \omega \eta \gamma$ |
| $230\pm$ | $30\pm~20$ | | | AUBERT,B | 04N | BABR | 10.6 $e^+e^- \to \pi^+\pi^-\pi^0\gamma$ |
| $490 + 2 \\ -1$ | $^{00}_{50}$ \pm 130 | 1.2M | 10 | ACHASOV | 03D | RVUE | $0.44-2.00_{\pi^{+}\pi^{-}\pi^{0}}^{e^{+}e^{-}} \rightarrow$ |
| 250± | 14 | | 11 | HENNER | 02 | RVUE | $1.2-2.0 e^{+}e^{-} \rightarrow \rho\pi, \omega\pi\pi$ |
| 250± | 50 | | | EUGENIO | 01 | SPEC | 18 $\pi^- p \rightarrow \omega \eta n$ |
| $370\pm$ | 25 | | | | 00D | CMD2 | $e^+e^- \rightarrow \omega \pi^+\pi^-$ |
| $113\pm$ | 20 | | 13 | CLEGG | 94 | RVUE | |
| $280\pm$ | 24 | 750 | 14 | ANTONELLI | 92 | DM2 | $1.34-2.4e^+e^- \rightarrow \rho\pi, \omega\pi\pi$ |
| $160\pm$ | 20 | | | ATKINSON | 83B | OMEG | $20-70 \gamma p \rightarrow 3\pi X$ |
| 136± | 46 | | | CORDIER | 81 | DM1 | $e^+ e^- \rightarrow \omega 2\pi$ |
| 99± · | 49 | 21 | | ESPOSITO | 80 | FRAM | $e^+ e^- \rightarrow 3\pi$ |
| $42\pm$ | 17 | | | COSME | 79 | OSPK | $e^+ e^- \rightarrow 3\pi$ |
| 10 | | | | | | | |

 10 From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E.

11 Using results of CORDIER 81 and preliminary data of DOLINSKY 91 and AN-

 12 DNBLLI 92. 12 Using the data of AKHMETSHIN 00D and ANTONELLI 92. The $\rho\pi$ dominance for the energy dependence of the $\omega(1420)$ and $\omega(1650)$ width assumed. 13 From a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and

 6.07 ± 0.61

$\omega(1650)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------|------------------------------|
| Γ ₁ | $\rho\pi$ | seen |
| Γ_2 | $\omega \pi \pi$ | seen |
| Γ_3 | $\omega \eta$ | seen |
| Γ ₄ | $e^+ e^-$ | seen |

$\omega(1650) \; \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$

| $\Gamma(\rho\pi)/\Gamma_{\rm total} \times$ | : Γ(e+e ⁻) | /Γ _{total} | | | $\Gamma_1/\Gamma \times \Gamma_4/\Gamma$ |
|---------------------------------------------------------|------------------------|----------------------|---------|-----------|-------------------------------------------------------------|
| VALUE (units 10^{-6}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| \bullet \bullet We do not | use the follow | ving data for av | erages, | fits, lim | nits, etc. • • • |
| $1.3\pm0.1\pm0.1$ | | AUBERT,B | 04 N | BABR | 10.6 $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma$ |
| $1.2 \begin{array}{c} +0.4 \\ -0.1 \end{array} \pm 0.8$ | 3 1.2M ^{15,1} | ⁶ ACHASOV | 03D | RVUE | $0.44-2.00 e^{+}_{\pi^{+}\pi^{-}\pi^{0}} e^{-} \rightarrow$ |
| 0.921 ± 0.230 | | ⁸ CLEGG | 94 | RVUE | |
| 0.479 ± 0.050 | 750 19,2 | OANTONELLI | 92 | DM2 | $1.34-2.4e^{+}e^{-} \rightarrow a\pi$ |

$\Gamma(\omega\pi\pi)/\Gamma_{\rm total} \times \Gamma(e^+e^-)/\Gamma_{\rm total}$ $\Gamma_2/\Gamma \times \Gamma_4/\Gamma$ TECN COMMENT VALUE (units 10^{-7}) EVTS DOCUMENT ID \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet AUBERT 07AU BABR 10.6 $e^+\,e^ightarrow~\omega\,\pi^+\,\pi$ 7.0 ± 0.5 4.1 ± 0.9 ± 1.3 1.2M 15,16 ACHASOV 03D RVUE 0.44-2.00 $e^+e^- \rightarrow e^+e^- = 0$ __21 AKHMETSHIN 00D CMD2 1.2-1.38 $e^+e^- ightarrow \omega \pi^+ \pi^-$ 17,18 CLEGG 3.18 ± 0.80 94 RVUE

750 19,20 ANTONELLI 92 DM2 1.34–2.4 $e^+e^-
ightarrow
ho\pi$, $\omega\pi\pi$

| $\Gamma(\omega\eta)/\Gamma_{\text{total}}$ × $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ Γ_3/Γ × Γ_4/Γ Γ_3/Γ × Γ_4/Γ Γ_3/Γ × Γ_4/Γ Γ_3/Γ × Γ_4/Γ Γ_3/Γ × We do not use the following data for averages, fits, limits, etc. • • • 0.57 ± 0.06 13 AUBERT 06D BABR 10.6 $e^+e^- \rightarrow \omega\eta\gamma$ < 6 90 22 AKHMETSHIN 03B CMD2 $e^+e^- \rightarrow \eta\pi^0\gamma$ 15 Calculated by us from the cross section at the peak. 16 From the combined fit of ANTONELLI 92, ACHASOV 01E, ACHASOV 02E, and | • • • We do not use the following data for averages, fits, limits, etc. • • • $ \sim 1700 \qquad \qquad 110 \qquad ^{1} \text{ CERRADA} \qquad 778 \text{HBC} \qquad 4.2 K^- p \rightarrow \Lambda 3\pi \\ 1695 \pm 20 \qquad \qquad \text{BARNES} \qquad 698 \text{HBC} \qquad 4.6 K^- p \rightarrow \omega 2\pi X \\ 1636 \pm 20 \qquad \qquad \text{ARMENISE} \qquad 688 \text{DBC} \qquad 5.1 \pi^+ n \rightarrow \rho 3\pi^0 \\ ^{1} \text{ Phase rotation seen for } J^P = 3^- \rho \pi \text{ wave.} \\ ^{2} \text{ From a fit to } I(J^P) = 0(3^-) \rho \pi \text{ partial wave.} $ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ACHASOV 03D data on the $\pi^+\pi^-\pi^0$ and ANTONELLI 92 on the $\omega\pi^+\pi^-$ final states. Supersedes ACHASOV 99E and ACHASOV 02E. | ω_3 (1670) WIDTH |
| 17 From a fit to two Breit-Wigner functions and using the data of DOLINSKY 91 and ANTONELLI 92. 18 From the partial and leptonic width given by the authors. 19 From the combined fit of the $\rho\pi$ and $\omega\pi\pi$ final states. 20 From the product of the leptonic width and partial branching ratio given by the authors. 21 Using the data of A KH METSHIN 00D and ANTONELLI 92. The $\rho\pi$ dominance for the energy dependence of the $\omega(1420)$ and $\omega(1650)$ width assumed. 22 $\omega(1650)$ mass and width fixed at 1700 MeV and 250 MeV, respectively. | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| ω (1650) BRANCHING RATIOS | 167±40 500 DIAZ 74 DBC $6 \pi^+ n \rightarrow p 3 \pi^0$ 122±39 200 DIAZ 74 DBC $6 \pi^+ n \rightarrow p \omega \pi^0 \pi^0$ |
| $\Gamma(\omega\pi\pi)/\Gamma_{	ext{total}}$ Γ_2/Γ | 155 \pm 40 200 ³ MATTHEWS 71D DBC 7.0 π^+ $n \rightarrow \rho 3\pi^0$ ••• We do not use the following data for averages, fits, limits, etc. ••• |
| VALUE EVTS DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 0.35 1.2M 23 ACHASOV 03D RVUE $0.4-2.00$ $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ 0.620 ± 0.014 24 HENNER 02 RVUE $1.2-2.0$ $e^+e^- \rightarrow \rho\pi$, $\omega\pi\pi$ $\Gamma(\rho\pi)/\Gamma_{total}$ FORMANDER $\rho\pi^+\pi^-\pi^0$ $\rho\pi^-\pi^-\pi^0$ VALUE EVTS DOCUMENT ID TECN COMMENT | 90 \pm 20 BARNES 698 HBC 4.6 $K^-p \rightarrow \omega 2\pi$ 100 \pm 40 KENYON 69 DBC 8 $\pi^+n \rightarrow p3\pi^0$ 112 \pm 60 ARMENISE 688 DBC 5.1 $\pi^+n \rightarrow p3\pi^0$ 3 Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the K^* (892) mass. 4 Phase rotation seen for $J^P=3^-\rho\pi$ wave. 5 From a fit to $I(J^P)=0(3^-)\rho\pi$ partial wave. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | ω_3 (1670) DECAY MODES |
| ~ 0.65 1.2M 23 ACHASOV 03D RVUE $0.44-2.00 e^{+}e^{-} \rightarrow \frac{1}{\pi^{+}\pi^{-}\pi^{-}}$ | Mode Fraction (Γ_i/Γ) |
| 0.380 ± 0.014 24 HENNER 02 RVUE 1.2-2.0 $e^+e^- ightarrow ho\pi$, $\omega\pi\pi$ | $\Gamma_1 \rho \pi$ seen |
| $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁷) EVTS DOCUMENT ID TECN COMMENT | Γ_2 $ωππ$ seen Γ_3 $b_1(1235)π$ possibly seen |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| $\sim 18 \qquad 1.2 \text{M} \frac{24,25}{\text{ACHASOV}} \qquad 03 \text{D} \text{RVUE} 0.44 - 2.00 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$ $32 \pm 1 \qquad 2^4 \text{HENNER} \qquad 02 \text{RVUE} 1.2 - 2.0 e^+ e^- \rightarrow \rho \pi, \omega \pi \pi$ $^{23} \text{From the combined fit of ANTONELLI} 92, \text{ACHASOV} 01 \text{E, ACHASOV} 02 \text{E, and ACHASOV} 030 \text{data on the } \pi^+ \pi^- \pi^0 \text{and ANTONELLI} 92 \text{on the } \omega \pi^+ \pi^- \text{final states.}$ Supersedes ACHASOV 99e and ACHASOV 02E. $^{24} \text{Assuming that the } \omega (1650) \text{decays into } \rho \pi \text{and } \omega \pi \pi \text{only.}$ $^{25} \text{Calculated by us from the cross section at the peak.}$ | $ω_3$ (1670) BRANCHING RATIOS $ \Gamma(ωππ)/\Gamma(ρπ) \qquad F_2/\Gamma_3 $ • • • We do not use the following data for averages, fits, limits, etc. • • • 0.71±0.27 100 DIAZ 74 DBC $6π^+n \rightarrow p5π^0$ $ \Gamma(b_1(1235)π)/\Gamma(ρπ) \qquad \Gamma_3/\Gamma_1 $ |
| ω (1650) REFERENCES | VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| AUBERT 07AU PR D76 092005 B. Aubert et al. (BABAR Collab.) AUBERT 06D PR D73 052003 B. Aubert et al. (BABAR Collab.) AUBERT.B 04N PR D70 072004 B. Aubert et al. (BABAR Collab.) | possibly seen DIAZ 74 DBC $6~\pi^+~n ightarrow~p5\pi^0$ $\Gamma(b_1(1235)\pi)/\Gamma(\omega\pi\pi)$ Γ_3/Γ_2 |
| ACHASOV 03D PR D68 052006 M.N. Achasov et al. (Novosibirsk SND Collab.) ACHAESOV 02E PR D66 032001 M.N. Achasov et al. (Novosibirsk CMD-2 Collab.) ACHASOV 02E PR D66 032001 M.N. Achasov et al. (Novosibirsk SND Collab.) | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| HENNER 02 EPJ C26 3 V.K. Henner et al. ACHASOV 01E PR D63 072002 M.N. Achasov et al. (Novosibirsk SND Collab.) | >0.75 68 BAUBILLIER 79 HBC 8.2 K ⁻ p backward |
| EUGENIO 01 PL B497 190 P. Eugenio et al. AKHMETSHIN ODD PL B489 125 R.R. Akhmetshin et al. (Novosibirsk CMD-2 Collab.) ACHASOV 99 E PL B462 365 M.N. Achasov et al. (Novosibirsk SND Collab.) | ω_3 (1670) REFERENCES |
| ACHASOV 98H PR D57 4334 N.N. Achasov, A.A. Kozhevnikov CLEGG 94 ZPPH C62 455 A.B. C.Geg, A. Donaschie (LANC, MCHS) ANTONELLI 92 ZPHY C56 15 A. Antonelli et al. (DM2 Collab.) BISELLO 91 ZPHY C59 27 D. Bisello et al. (DM2 Collab.) DOLINSKY 91 PRPL 202 99 S.I. Dolinsky et al. (DM2 Collab.) BISELLO 88B ZPHY C39 13 D. Bisello et al. (PADO, CLER, FRAS+) BARKOV 87 JETPL 46 164 L. Barkov et al. (NOVO) Translated from ZETP 46 132 M. Atkinson et al. (BONN, CERN, GLAS+) CORDIER 81 PL 1058 155 A. Cordier et al. (ORSAY) NANOV 81 PL 1078 297 P.M. Ivanov et al. (ROVO) ESPOSITO 80 LNC 28 195 B. Esposito et al. (FRAS, NAPL, PADO+) COSME 79 NP B152 215 G. Cosme et al. (FRAS, NAPL, PADO+) | AMELIN 96 ZPHY C70 71 D.V. Amelin et al. (SERP, TBIL) BAUBILLIER 79 P.R. 49 B 131 M. Baubillier et al. (BIRM, CERN, GLAS+) CORDEN 76B NP B138 235 M.J. Corden et al. (BIRM, RHEL, TELA+) CERRADA 77B NP B126 241 M. Cerrada et al. (AMST, CERN, MIM+) JP WAGNER 75 PL 58B 201 F. Wagner, M. Tabak, D.M. Chew (LBL) JP DIAZ 74 PRL 32 260 J. Diaz et al. (AMST, CERN, WILL) MATTHEWS 71D PR D3 2561 J.A.J. Matthews et al. (TNTO, WISC) BARNES 69B PRL 23 142 V.E. Barnes et al. (BNL, UCND, ORNL) KEWYON 69 PRL 23 146 I.R. Kenyon et al. (BNL, UCND, ORNL) ARMENISE 68B PL 26B 336 N. Armenise et al. (BARI, BGNA, FIRZ+) |

ω_3 (1670) MASS

 $\omega_3(1670)$

 $I^{G}(J^{PC}) = 0^{-}(3^{-})$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|---------|-----------------------|-----|------|-----------------------------------------------|
| 1667 ± 4 OUR | AVERAGE | | | | |
| $1665.3 \pm 5.2 \pm 4.5$ | 23400 | AMELIN | 96 | VES | 36 $\pi^- p \rightarrow 0$ |
| 1685 ±20 | 60 | BAUBILLIER | 79 | нвс | $\pi^+ \pi^- \pi^0 n$ 8.2 $K^- p$ backward |
| 1673 ± 12 | 430 | ^{1,2} BALTAY | 78E | HBC | 15 $\pi^+ p \rightarrow \Delta 3\pi$ |
| 1650 ± 12 | | CORDEN | 78B | | 8-12 $\pi^- p \rightarrow N3\pi$ |
| 1669 ± 11 | 600 | ² WAGNER | 75 | | $7 \pi^+ p \rightarrow \Delta^{++} 3\pi$ |
| 1678 ± 14 | 500 | DIAZ | 74 | | $6 \pi^+ n \rightarrow p 3 \pi^0$ |
| 1660 ± 13 | 200 | DIAZ | 74 | DBC | $6 \pi^+ n \rightarrow p \omega \pi^0 \pi^0$ |
| 1679 ± 17 | 200 | MATTHEWS | 71D | DBC | 7.0 $\pi^+ n \to \rho 3\pi^0$ |
| $1670\ \pm 20$ | | KENYON | 69 | DBC | $8 \pi^+ n \rightarrow p 3\pi^0$ |

$\pi_2(1670)$ MASS

 $\pi_2(1670)$

 $I^{G}(J^{PC}) = 1^{-}(2^{-+})$

| | (MeV) 2± 3. | O OUR A | <u>EVTS</u> VERAGE | | | TECN CHG | COMMENT e the ideogram below. |
|------|----------------|-------------|-----------------------|-----------------------|-----|----------|-------------------------------------------------------------------------------------------------------------|
| 1658 | ± 3 | + 24 - 8 | 420k | ALEKSEEV | 10 | COMP | $^{190}_{\pi^{-}\pi^{-}\pi^{+}Pb} _{Pb'}$ |
| 1749 | ±10 | ± 100 | 145 k | LU | 05 | B852 | 18 $\pi^- p \rightarrow$ |
| 1676 | ± 3 | ± 8 | | $^{ m 1}$ CHUNG | 02 | B852 | $\omega \pi^- \pi^0 p$ 18.3 $\pi^- p \rightarrow$ |
| 1685 | ± 10 | ± 30 | | ² BARBERIS | 01 | | $ \begin{array}{c} \pi^{+}\pi^{-}\pi^{-}p\\ 450\ pp\rightarrow\\p_{f}3\pi^{0}p_{s} \end{array} $ |
| 1687 | ± 9 | ± 15 | | AMELIN | 99 | VES | $ \begin{array}{c} \rho_f 3\pi^{\circ} \rho_S \\ 37 \pi^{-} A _{\omega \pi^{-} \pi^{0} A^{*}} \end{array} $ |
| 1669 | \pm 4 | | | BARBERIS | 98B | | $450 pp \rightarrow p_f \rho \pi p_S$ |

$\pi_2(1670)$

| 1670 | ± 4 | | BARBERIS | 98B | | | $450 pp \rightarrow p_f f_2(1270) \pi p_s$ | |
|-------|----------------------------------------------------------------------------|------|------------------------|------|------|---|---------------------------------------------------------------------------------------------------|--|
| 1730 | ±20 | | ³ AMELIN | 95 B | VES | | $36 \pi^- A \rightarrow$ | |
| 1690 | ±14 | | ⁴ BERDNIKOV | 94 | VES | | $ \begin{array}{c} \pi^+ \pi^- \pi^- A \\ 37 \pi^- A \rightarrow \\ K^+ K^- \pi^- A \end{array} $ | |
| 1710 | ±20 | 700 | ANTIPOV | 87 | SIGM | - | $50 \pi^- Cu \rightarrow \mu^+ \mu^- \pi^- Cu$ | |
| 1676 | ± 6 | | ⁴ EVANGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow 3\pi p$ | |
| 1657 | ± 14 | | ^{4,5} DAUM | 80D | SPEC | _ | 63-94 $\pi p \rightarrow 3\pi X$ | |
| 1662 | ± 10 | 2000 | ⁴ BALTAY | 77 | HBC | + | $15 \pi^+ p \rightarrow p 3\pi$ | |
| • • • | ■ We do not use the following data for averages, fits, limits, etc. ■ ● | | | | | | | |

| • • • | we do not use the follow | ing data for avera | ges, i | ns, mins, etc. | • • • |
|-------|--------------------------|----------------------|--------|----------------|------------------------------------------------------------------------------|
| 1742 | ±31 ±49 | ANTREASYAN | 90 | CBAL | $e^{+}e^{-}_{e^{+}e^{-}\pi^{0}\pi^{0}\pi^{0}}$ |
| 1624 | ±21 | ¹ BELLINI | 85 | SPEC | $40 \begin{array}{c} \pi^- A \rightarrow \\ \pi^- \pi^+ \pi^- A \end{array}$ |
| 1622 | ±35 | ⁶ BELLINI | 85 | SPEC | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 1693 | ± 28 | ⁷ BELLINI | 85 | SPEC | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 1710 | ±20 | ⁸ DAUM | 81B | SPEC - | 63,94 $\pi^{-}p$ |
| 1660 | ± 10 | ⁴ ASCOLI | 73 | HBC — | $5-25 \pi^- p \rightarrow p \pi_2$ |
| | | | | | |

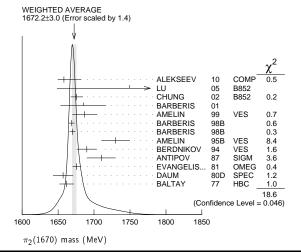
 $^{^1}$ From $f_2(1270) \pi$ decay.

² From a fit to the invariant mass distribution. From a fit to $J^{PC}=2^{-}+f_2(1270)\pi$, $f_0(1370)\pi$ waves.

⁴ From a fit to $J^P=2^-S$ -wave $f_2(1270)\,\pi$ partial wave.

 5 Clear phase rotation seen in $2^{-}\tilde{S}$, $2^{-}P$, $2^{-}D$ waves. We quote central value and spread of single-resonance fits to three channels.

From a two-resonance fit to four 2^-0^+ waves. This should not be averaged with all the single resonance fits.



$\pi_2(1670)$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------------------------------|---------------|-------------------------|--------|-------------|--------|------------------------------------------------------------------------------------|
| 260± 9 OUR A | VERAGE I | Error includes sca | le fac | tor of 1. | 2. | |
| $271 \pm 9^{+}_{-} \begin{array}{c} 22 \\ 24 \end{array}$ | 420k | ALEKSEEV | 10 | COMP | | $\begin{array}{c} 190 \ \pi^- Pb \rightarrow \\ \pi^- \pi^- \pi^+ Pb' \end{array}$ |
| 408± 60±250 | 145k | LU | 05 | B 85 2 | | 18 $\pi^- p \rightarrow \omega \pi^- \pi^0 p$ |
| $254\pm3\pm31$ | | ⁹ CHUNG | 02 | B 85 2 | | 18.3 $\pi^- p \rightarrow$ |
| | | • | | | | $\pi^{+}\pi^{-}\pi^{-}p$ |
| $265 \pm 30 \pm 40$ | 1 | ⁰ BARBERIS | 01 | | | $450 pp \rightarrow p_f 3\pi^0 p_S$ |
| 168± 43± 53 | | AMELIN | 99 | VES | | $37 \begin{array}{c} \pi^- A \rightarrow \\ \omega \pi^- \pi^0 A^* \end{array}$ |
| 268± 15 | | BARBERIS | 98B | | | $450 pp \rightarrow p_f \rho \pi p_s$ |
| 256± 15 | | BARBERIS | 98B | | | 450 pp → |
| | | | | | | $\rho_f f_2(1270) \pi \rho_S$ |
| 310± 20 | 1 | ¹ AMELIN | 95 B | VES | | 36 $\pi^- A \rightarrow$ |
| 190± 50 | 1 | ² BERDNIKOV | 94 | VES | | $\pi^+\pi^-\pi^-A$ 37 $\pi^-A \rightarrow$ |
| | | | | | | $K^{+}K^{-}\pi^{-}A$ |
| 170± 80 | 700 | ANTIPOV | 87 | SIGM | - | $50 \pi^- Cu \rightarrow \mu^+ \mu^- \pi^- Cu$ |
| 260± 20 | 1 | ² EVA NGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow 3\pi p$ |
| 219± 20 | | 3 DAUM | | SPEC | _ | $63-94 \pi p \rightarrow 3\pi X$ |
| 285 ± 60 | | ² BALTAY | 77 | нвс | + | $15 \pi^+ p \rightarrow p 3\pi$ |
| • • • We do not | use the follo | owing data for a | verage | es, fits, l | imits, | etc. • • • |
| 236± 49± 36 | | ANTREASYAN | 190 | CBAL | | $e^+e^- \rightarrow$ |
| 204 20 | | 9 BELLINI | 0.5 | CDEC | | $e^{+}e^{-}\pi^{0}\pi^{0}\pi^{0}$ |
| 304± 22 | | BELLINI | 85 | SPEC | | $\begin{array}{c} 40 \ \pi^- A \rightarrow \\ \pi^- \pi^+ \pi^- A \end{array}$ |
| 404 ± 108 | 1- | ⁴ BELLINI | 85 | SPEC | | $40 \begin{array}{c} \pi^- A \rightarrow \\ \pi^- \pi^+ \pi^- A \end{array}$ |
| 330± 90 | 1 | 5 BELLINI | 85 | SPEC | | 40 $\pi^- A \rightarrow$ |
| 312± 50 | 1 | ⁶ DAUM | 81 R | SPEC | _ | $\pi^-\pi^+\pi^-A$ 63.94 π^-p |
| 270± 60 | | ² ASCOLI | 73 | HBC | _ | $5-25 \pi^- p \rightarrow p\pi_2$ |
| 2101 00 | | //OCOLI | , , | IIDC | | 3 23 % p - p % 2 |

 9 From $f_2(1270) \pi$ decay.

10 From a fit to the invariant mass distribution. 11 From a fit to $JPC = 2^{-} + f_2(1270) \pi$, $f_0(1370) \pi$ waves.

From a fit to $J^P=2^{-\frac{1}{2}(1270)\pi}$ partial wave.

 13 Clear phase rotation seen in $^{2-}$ S, $^{2-}$ P, $^{2-}$ D waves. We quote central value and spread of single-resonance fits to three channels. 14 From $\rho\pi$ decay.

The form $\rho\pi$ decay. The form a flow of the following the form a flow-resonance fit to four 2^-0^+ waves. This should not be averaged with all the single resonance fits.

π_2 (1670) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-------------------------------|------------------------------|------------------|
| Γ_1 | 3π | (95.8±1.4) % | |
| _ | $\pi^{+} \pi^{-} \pi^{0}$ | | |
| Γ_3 | $\pi^0 \pi^0 \pi^0$ | | |
| Γ_4 | $f_2(1270)\pi$ | (56.3 ± 3.2) % | |
| Γ_5 | $ ho\pi$ | (31 ±4) % | |
| Γ_6 | $\sigma\pi$ | (10.9 ± 3.4) % | |
| Γ ₇ | $(\pi\pi)_{S-wave}$ | $(8.7 \pm 3.4) \%$ | |
| Γ ₈ | $K\overline{K}^*(892) + c.c.$ | $(4.2 \pm 1.4)\%$ | |
| Г9 | $\omega \rho$ | (2.7 ± 1.1) % | |
| | $\gamma\gamma$ | < 2.8 × 10 | 7 90% |
| Γ_{11} | $\eta\pi$ | | |
| | $\pi^{\pm} 2\pi^{+} 2\pi^{-}$ | | |
| | $ ho$ (1450) π | < 3.6 × 10 | |
| | $b_1(1235)\pi$ | < 1.9 × 10 | 97.7% |
| | $\eta 3\pi$ | | |
| | $f_1(1285)\pi$ | possibly seen | |
| Γ ₁₇ | $a_2(1320)\pi$ | not seen | |

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 6 measurements and one constraint to determine 4 parameters. The overall fit has a χ^2 = 1.9 for 3 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\mathsf{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$\begin{array}{c|ccccc} x_5 & -53 & & \\ x_7 & -29 & -59 & & \\ x_8 & -8 & -21 & -9 & \\ \hline & x_4 & x_5 & x_7 & & \end{array}$$

π_2 (1670) PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | | | | | | Γ ₁₀ |
|------------------------|---------|------------------------|-------|-----------|-----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (keV) | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
| <0.072 | 90 | ¹⁷ ACCIARRI | 97T | L3 | | $e^{+} e^{-} \xrightarrow{e^{+} e^{-} \pi^{+} \pi^{-} \pi^{0}}$ |
| • • • We do not use | the fol | lowing data for aver | ages, | fits, lim | | |
| < 0.19 | 90 | ¹⁷ ALBRECHT | 97в | ARG | | $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e$ |
| $1.41\ \pm0.23\pm0.28$ | | ANTREASYAN | 90 | CBAL | 0 | $e^{+}e^{-}_{e^{+}e^{-}\pi^{+}\pi^{-}\pi^{0}}$ $e^{+}e^{-}_{e^{+}e^{-}\pi^{0}\pi^{0}\pi^{0}}$ |
| $0.8 \pm 0.3 \pm 0.12$ | | ¹⁸ BEHREND | 90 c | CELL | 0 | $e^+e^- \xrightarrow{e^+e^-} \xrightarrow{\pi^+\pi^-} \pi^0$ |
| $1.3\pm0.3\pm0.2$ | | ¹⁹ BEHREND | 90 c | CELL | 0 | $e^+e^-e^- \rightarrow e^+e^-\pi^+\pi^-\pi^0$ |
| 17 | | | | | | $e^{+}e^{-}\pi^{+}\pi^{-}\pi^{0}$ |

 17 Decaying into $f_2(1270)\pi$ and $\rho\pi$.

 18 Constructive interference between $\mathit{f}_{2}(1270)\pi,\!\rho\pi$ and background.

¹⁹Incoherent Ansatz.

$\pi_2(1670) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\pi^+\pi^-\pi^0)\times\Gamma(\gamma$ | $\gamma)/\Gamma_t$ | otal | | $\Gamma_2\Gamma_{10}/\Gamma$ |
|----------------------------------------------|--------------------|------------------|------|---------------------------------------------------|
| VALUE (keV) | CL% | DOCUMENT ID | TECN | COMMENT |
| <0.1 | 95 | 20 SCHEGELSKY 06 | RVUE | $\gamma \gamma \rightarrow \pi^{+}\pi^{-}\pi^{0}$ |
| ²⁰ From analysis of L3 | data at | 183-209 GeV | | |

π_2 (1670) BRANCHING RATIOS

| $\Gamma(3\pi)/\Gamma_{\text{total}}$ | | $\Gamma_1/\Gamma = (\Gamma_4 + \Gamma_5)$ | $+\Gamma_7)/\Gamma$ |
|---------------------------------------------------|----------------|-------------------------------------------|---------------------|
| 0.958±0.014 OUR FIT | DOCUMENT ID | _ | |
| $\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ | | | Γ_3/Γ_2 |
| VALUE | DO CUMENT ID | COMMENT | |
| $0.29 \pm 0.03 \pm 0.05$ | 21 BARBERIS 01 | $450 pp \rightarrow p_f 3\pi^0 p_c$ | |

 $[\]frac{6}{2}$ From $\rho\pi$ decay.

| (With $f_2(1270) \rightarrow 1$ | $\Gamma_5/0.565$ $\Gamma_5/0.565$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | DOCUMENT ID TECN COMMENT |
| 0.97 ± 0.09 OUR AVERAGE $0.76 \pm 0.07 \pm 0.10$ 1.01 ± 0.05 | E Error includes scale factor of 1.9. CHUNG 02 B852 18.3 $\pi^- p \to \pi^+ \pi^- \pi^- p$ BARBERIS 98B 45.0 $pp \to p_f \pi^+ \pi^- \pi^0 p_S$ |
| | |
| Γ(σπ)/Γ(f ₂ (1270)π) VALUE | F6/I |
| 0.19±0.06 OUR AVERAGE 0.17±0.02±0.07 | E CHUNG 02 B852 $18.3 \ \pi^- p \to \pi^+ \pi^- \pi^- p$ |
| 0.24 ± 0.10 22,2 | ³ BAKER 99 SPEC 1.94 $\overline{p}p \rightarrow 4\pi^0$ |
| $\frac{1}{2}\Gamma(ho\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-})$ | $\frac{\frac{1}{2}\Gamma_{5}/(0.565\Gamma_{4}+\frac{1}{2}\Gamma_{5}+0.624\Gamma_{4})}{\frac{DOCUMENT\ ID}{1000000000000000000000000000000000000$ |
| 0.29±0.04 OUR FIT 0.29±0.05 | 24 DAUM 81B SPEC 63,94 $\pi^- p$ |
| | ollowing data for averages, fits, limits, etc. • • • |
| <0.3 | BARTSCH 68 HBC $+$ 8 $\pi^+ p ightarrow 3\pi p$ |
| (With $f_2(1270) \rightarrow f_2(1270)$ | |
| VALUE 0.604±0.035 OUR FIT | DOCUMENT ID TECN CHG COMMENT |
| 0.60 ±0.05 OUR AVERA 0.61 ±0.04 | IGE Error includes scale factor of 1.3. 24 DAUM 81B SPEC 63,94 $\pi^- p$ |
| 0.76 + 0.24 - 0.34 | ARMENISE 69 DBC + $5.1 \pi^+ d \rightarrow d 3\pi$ |
| -0.34 0.35 ±0.20 | BALTAY 68 HBC + 7-8.5 π^{+} p |
| | ollowing data for averages, fits, limits, etc. • • • |
| 0.5 9 | BARTSCH 68 HBC $+$ 8 $\pi^+ p \rightarrow 3\pi p$ |
| | $\begin{array}{ccc} (\pi^{\pm}\pi^{+}\pi^{-}) & 0.624\Gamma_{7}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{7}) \end{array}$ |
| (With $(\pi\pi)_{S	ext{-wave}}$ | → π · π ·) <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| 0.10±0.04 OUR FIT 0.10±0.05 | 24 DAUM 81B SPEC 63,94 $\pi^{-}p$ |
| | • |
| Γ(<i>Κ΄ Κ</i> *(892)+ c.c.)/Γ _{VALUE} | $(f_2(1270)\pi)$ F_8/I |
| 0.075 ± 0.025 OUR FIT 0.075 ± 0.025 | 15 ARMSTRONG 82B OMEG $-$ 16 $\pi^- p ightarrow K^+ K^- \pi^-$ |
| | |
| Γ (ωρ)/Γ_{total} VALUE | F9, |
| 0.027±0.004±0.010 | 26 A MELIN 99 VES $37 \frac{\pi}{\omega} \frac{A}{\pi} \xrightarrow{7} A^*$ |
| $\Gamma(\eta\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-})$ | $\Gamma_{11}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4)$ |
| VALUE | DOCUMENT ID TECN CHG COMMENT |
| <0.09 • • • We do not use the f | BALTAY 68 HBC + 7-8.5 π^+ p following data for averages, fits, limits, etc. • • • |
| | |
| < 0.10 | CRENNELL 70 HBC $-$ 6 $\pi^- p \rightarrow f_2 \pi^- N$ |
| | CRENNELL 70 HBC $-6\pi^-\rho \rightarrow f_2\pi^-N$ |
| Γ(π±2π+2π ⁻)/Γ(π± | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) = \frac{OCUMENT\ ID}{1000000000000000000000000000000000000$ |
| | CRENNELL 70 HBC $-6 \pi^{-} p \rightarrow f_{2} \pi^{-} N$ $\pi^{+} \pi^{-}$) $\Gamma_{12}/(0.565 \Gamma_{4} + \frac{1}{2} \Gamma_{5} + 0.624 \Gamma_{6} \Gamma_{6} \Gamma_{7} + 0.624 \Gamma_{7} $ |
| $\frac{\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})}{<0.10}$ | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) = \frac{OCUMENT\ ID}{1000000000000000000000000000000000000$ |
| $(\pi^{\pm} 2\pi^{+} 2\pi^{-})/\Gamma(\pi^{\pm} \sqrt{2\pi^{+}})$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}) \frac{\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})}{\Gamma_{CRENNELL}} \frac{DOCUMENT\ ID}{1000000000000000000000000000000000000$ |
| $\Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}R\right)$ <0.10 <0.1 $\Gamma\left(\rho(1450)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-$) $\Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4)$ $\Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_5)$ |
| $\Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}R\right)$ <0.10 <0.1 $\Gamma\left(\rho(1450)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})$ $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{5})$ $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{5})$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{5})$ |
| <0.10 <0.1 Γ (ρ(1450) π)/Γ _{total} <0.036 | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma_4) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + 0.624\Gamma_4) \qquad \qquad \Gamma_{13}/(0.565$ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{\text{total}}$ <0.0036 9 $\Gamma(b_{1}(1235)\pi)/\Gamma_{\text{total}}$ $VALUE$ | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\frac{\pi^+\pi^-}{\pi^-}) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{14}/(0.565\Gamma_4 + 0.624\Gamma) \qquad \qquad \Gamma_{14}/(0.565\Gamma_4 + 0.624\Gamma) \qquad \Gamma_{14}/(0.565\Gamma_4 + 0.624\Gamma) \qquad \qquad \Gamma_{14}/(0$ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{\text{total}}$ <0.0036 $\Gamma(b_{1}(1235)\pi)/\Gamma_{\text{total}}$ $VALUE$ ≤ 0.0036 | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\frac{\pi^{+}\pi^{-})}{CRENNELL} \frac{\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})}{CRENNELL} \frac{CHG}{70} \frac{COMMENT}{CRENNELL} \frac{CHG}{70} \frac{COMMENT}{CRENNELL} \frac{CHG}{70} \frac{COMMENT}{CRENNELL} \frac{CRENNELL}{CRENNELL} \frac{CRENNELL}{CRENNELL} \frac{COMMENT}{CRENNELL} \frac{CRENNELL}{CRENNELL} $ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{\text{total}}$ <0.0036 9 $\Gamma(b_{1}(1235)\pi)/\Gamma_{\text{total}}$ <0.0019 <0.0019 | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})$ CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ BALTAY 68 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ BALTAY 68 HBC $+7,8.5\pi^{+}p$ Γ_{13}/Γ_{17} AMELIN 99 VES $37\pi^{-}A \rightarrow 0 A^{*}$ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{\text{total}}$ <0.0036 $\Gamma(b_{1}(1235)\pi)/\Gamma_{\text{total}}$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{\text{total}}$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{\text{total}}$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{\text{total}}$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{\text{total}}$ | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{14}/(0.565\Gamma_4 + 0.524\Gamma_4 $ |
| $\Gamma(\pi^{\pm} 2\pi^{+} 2\pi^{-})/\Gamma(\pi^{\pm} 2\pi^{-} 2\pi^{-})/\Gamma(\pi^{\pm} 2\pi^{+} 2\pi^{-})/\Gamma(\pi^{\pm} 2\pi^{-} 2\pi^$ | CRENNELL 70 HBC $-6\pi^-p \rightarrow f_2\pi^-N$ $\pi^+\pi^-) \qquad \qquad \Gamma_{12}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{13}/(0.565\Gamma_4 + \frac{1}{2}\Gamma_5 + 0.624\Gamma) \qquad \qquad \Gamma_{14}/(0.565\Gamma_4 + 0.524\Gamma_4 $ |
| $\Gamma\left(\pi^{\pm} 2\pi^{+} 2\pi^{-}\right)/\Gamma\left(\pi^{\pm} 2\pi^{+} 2\pi^{+} 2\pi^{-}\right)}$ <0.01 $\Gamma\left(\rho\left(1450\right)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ <0.0019 $\Gamma\left(f_{1}\left(1285\right)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})$ CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ BALTAY 68 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ BALTAY 68 HBC $+7,8.5\pi^{+}p$ Γ_{13}/Γ_{17} AMELIN 99 VES $37\pi^{-}A \rightarrow 0 \rightarrow 0 \rightarrow 0$ $37\pi^{-}A \rightarrow 0 $ |
| $\Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}\right)$ <0.10 <0.1 $\Gamma\left(\rho(1450)\pi\right)/\Gamma_{\text{total}}$ <0.0036 9 $\Gamma\left(b_{1}(1235)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ <0.0019 9 $\Gamma\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ <0.0019 $F\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}}$ $VALUE$ $possibly seen 69$ $\Gamma\left(a_{2}(1320)\pi\right)/\Gamma_{\text{total}}$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{16}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5}/(0.56\Gamma_{5} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5}/(0.56\Gamma_{5} (0.56\Gamma_{5} + \frac{1}{2}\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5} + \frac{1}{2}\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma_{5}/(0.56\Gamma$ |
| $ \begin{array}{c c} \Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}\right) \\ \hline \Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}\right) \\ \hline < 0.10 \\ \hline < 0.1 \\ \hline \Gamma\left(\rho(1450)\pi\right)/\Gamma_{\text{total}} \\ \hline < 0.0036 \\ \hline \Gamma\left(b_{1}(1235)\pi\right)/\Gamma_{\text{total}} \\ \hline < 0.0019 \\ \hline = 0 \\ \hline \Gamma\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}} \\ \hline < 0.0019 \\ \hline = 0 \\ \hline \Gamma\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}} \\ \hline < 0.0019 \\ \hline = 0 \\ \hline = 0 \\ \hline \Gamma\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}} \\ \hline < 0.0019 \\ \hline = 0 \\ = 0 \\ \hline =$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{16}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{$ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{total}$ <0.0036 9 $\Gamma(b_{1}(1235)\pi)/\Gamma_{total}$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{total}$ $VALUE$ <0.0019 $\Gamma(f_{1}(1285)\pi)/\Gamma_{total}$ $VALUE$ $= \frac{EVT}{1000}$ $\Gamma(\sigma_{2}(1320)\pi)/\Gamma_{total}$ $VALUE$ $= \frac{EVT}{1000}$ $= \frac{EVT}{10000}$ $= \frac{EVT}{1000}$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + \frac$ |
| $\Gamma\left(\pi^{\pm}2\pi^{+}2\pi^{-}\right)/\Gamma\left(\pi^{\pm}\right)$ <0.10 <0.1 $\Gamma\left(\rho(1450)\pi\right)/\Gamma_{\text{total}}$ <0.0036 9 $\Gamma\left(b_{1}(1235)\pi\right)/\Gamma_{\text{total}}$ <0.0019 9 $\Gamma\left(f_{1}(1285)\pi\right)/\Gamma_{\text{total}}$ $= \frac{CVT}{\rho \text{ossibly seen}}$ $= \frac{CVT}{69}$ $\Gamma\left(a_{2}(1320)\pi\right)/\Gamma_{\text{total}}$ $= \frac{CVT}{\rho \text{ossibly seen}}$ $= \frac{CVT}{69}$ $= CVT$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4})$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4}$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4}$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4}$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4}$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{4}$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma_{5}$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + \frac$ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-})/\Gamma(\pi^{\pm})$ <0.10 <0.1 $\Gamma(\rho(1450)\pi)/\Gamma_{total}$ <0.0036 9 $\Gamma(b_{1}(1235)\pi)/\Gamma_{total}$ $VALUE$ <0.0019 9 $\Gamma(f_{1}(1285)\pi)/\Gamma_{total}$ $VALUE$ | CRENNELL 70 HBC $-6\pi^{-}p \rightarrow f_{2}\pi^{-}N$ $\pi^{+}\pi^{-}$) $\Gamma_{12}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{13}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{14}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{15}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{16}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{18}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{16}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{16}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + \frac{1}{2}\Gamma_{5} + 0.624\Gamma)$ $\Gamma_{17}/(0.565\Gamma_{4} + \frac{1}{2}\Gamma_{5} + $ |

| VALUE | <u>DOCUMENT I</u> | D | TECN | COMMENT |
|---------------------------------------------------|--------------------------------------|---------------|------|------------------------------------------------|
| $-0.72 \pm 0.07 \pm 0.14$ | CHUNG | 02 | B852 | 18.3 $\pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |
| 21 Using BARBERIS 98 | В. | | | |
| 22 Using preliminary CB | AR data. | | | |
| 23 With the $\sigma\pi$ in $L=2$ | and the fo(1270): | π in $L=$ | 0. | |
| | | | | |
| 24 From a turo reconance | | | | |
| 24 From a two-resonance 25 From a partial-wave | ent to four 2 0' analysis of K+K- | π^- sv | stem | |

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|------------|------|------------------------|---------------------------|-----------------------------|
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| LU | 05 | PRL 94 032002 | M. Lu et al. | (BNL E852 Collab.) |
| KUHN | 04 | PL B595 109 | J. Kuhn et al. | (BNL E852 Collab.) |
| CHUNG | 02 | PR D65 072001 | S.U. Chung et al. | (BNL E852 Collab.) |
| BARBERIS | 01 | PL B507 14 | D. Barberis et al. | , |
| AMELIN | 99 | PAN 62 445 | D.V. Amelin et al. | (VES Collab.) |
| | | Translated from YAF 62 | | ` / |
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| | 98 B | PL B422 399 | D. Barberis et al. | (WA 102 Collab.) |
| ACCIARRI | 97 T | PL B413 147 | M. Acciarri et al. | (L3 Collab.) |
| | 97 B | ZPHY C74 469 | H. Albrecht et al. | (ARGUS Collab.) |
| AMELIN | 95 B | PL B356 595 | D.V. Amelin et al. | (SERP, TBIL) |
| BERDNIKOV | 94 | PL B337 219 | E.B. Berdnikov et al. | (SERP, TBIL) |
| ANTREASYAN | 90 | ZPHY C48 561 | D. Antreasyan et al. | (Crystal`Ball Collab.) |
| BEHREND | 90 C | ZPHY C46 583 | H.J. Behrend et al. | (CELLO Collab.) |
| ANTIPOV | 87 | EPL 4 403 | Y.M. Antipov et al. | (SERP, JINR, INRM+) |
| BELLINI | 85 | SJNP 41 781 | D. Bellini et al. | |
| | | Translated from YAF 41 | | |
| | 82B | NP B202 1 | | ari (AACH3, BARI, BONN+) |
| | 81B | NP B182 269 | | AMST, CERN, CRAC, MPIM+) |
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| A Iso | | NP B186 594 | C. Evangelista | |
| | 80 D | PL 89B 285 | C. Daum et al. (i | AMST, CERN, CRAC, MPIM+)JP |
| | 77 | PRL 39 591 | C. Baltay, C.V. Cautis, M | |
| | 73 | PR D7 669 | | 'NTO, GENO, HAMB, MILA+) JP |
| | 70 | PRL 24 781 | D.J. Crennell et al. | (BNL) |
| | 69 | LNC 2 501 | N. Armenise et al. | (BARI, BGNA, FIRZ) |
| | 68 | PRL 20 887 | C. Baltay et al. | (COLU, ROCH, RUTG, YALE)I |
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 $\phi(1680)$

 $I^{G}(J^{PC}) = 0^{-}(1^{-})$

ϕ (1680) MASS

| e+e- PROD | UCTIO | N | | | |
|-----------------------|------------|-------------------------|-------|------------|------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1680 ± 20 OUR | ESTIMA" | TE | | | |
| • • • We do n | ot use the | following data fo | r ave | rages, fit | s, limits, etc. • • • |
| $1689 \pm \ 7 \pm 10$ | 4.8k | | | | 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ |
| $1709 \pm 20 \pm 43$ | | ² AUBERT | 08s | BABR | 10.6 $e^+e^- ightarrow$ hadrons |
| 1623 ± 20 | 948 | ³ AKHMETSHIN | 03 | CMD2 | $1.05-1.38 \ e^+ \ e^- \rightarrow \ K_L^0 \ K_S^0$ |
| ~ 1500 | | ⁴ ACHASOV | 98н | RVUE | $e^{+}e^{-} \rightarrow \pi^{+}\pi^{-}\pi^{0}, \omega\pi^{+}\pi^{-},$ |
| ~ 1900 | | | | | $e^{+}\stackrel{K^{+}}{e^{-}}\stackrel{K^{-}}{\rightarrow} \stackrel{K^{0}}{\kappa}_{S} \stackrel{K^{\pm}}{\pi^{\mp}}$ |
| 1700 ± 20 | | ⁶ CLEGG | 94 | RVUE | $e^+e^- \rightarrow K^+K^-, K^0_SK\pi$ |
| 1657 ± 27 | 367 | BISELLO | 91 c | DM2 | $e^+e^- \rightarrow \kappa_S^0 \kappa^{\pm} \pi^{\mp}$ |
| 1655 ± 17 | | ⁷ BISELLO | 88B | DM2 | $e^+e^- \rightarrow K^+K^-$ |
| 1680 ± 10 | | ⁸ BUON | 82 | DM1 | $e^+e^- ightarrow hadrons$ |
| 1677 ± 12 | | ⁹ MANE | 82 | DM1 | $e^+e^- \rightarrow K_S^0 K \pi$ |
| | | | | | |

1 From a fit with two incoherent Breit-Wigners.
2 From the simultaneous fit to the $K\overline{K}^*(892)+$ c.c. and $\phi\eta$ data from AUBERT 08s using the results of AUBERT 07AK.
3 From the combined fit of AKHMETSHIN 03 and MANE 81 also including ρ , ω , and ϕ . Neither isospin nor flavor structure known.
4 Using data from IVANOV 81, BARKOV 87, BISELLO 88B, DOLINSKY 91, and ANTONELLI 92.
5 Using the data from BISELLO 91c.
6 Using BISELLO 88B and MANE 82 data.
7 From global fit including ρ , ω , ϕ and ρ (1700) assume mass 1570 MeV and width 510 MeV for ρ radial excitation.
8 From global fit of ρ , ω , ϕ and their radial excitations to channels $\omega\pi^+\pi^-$, K^+K^- , K^0_S , K^0_L ,

PHOTOPRODUCTION

| VALUE (MeV) | | TECN | COMMENT |
|-------------------------------------|------------------------------------------------|-----------------|-----------------------------------------------|
| • • • We do not use | the following data for avera | ages, fits, lim | its, etc. • • • |
| 1753± 3 | ¹⁰ LINK | | 5 20–160 $\gamma p \rightarrow K^+ K^- p$ |
| 1726 ± 22 | ¹⁰ BUSENITZ | 89 TPS | $\gamma p \rightarrow K^+ K^- X$ |
| 1760 ± 20 | ¹⁰ ATKINSON | 85c OME | G 20-70 $\gamma p \rightarrow K\overline{K}X$ |
| 1690 ± 10 | ¹⁰ ASTON | 81F OME | G 25-70 $\gamma p \rightarrow K^+ K^- X$ |
| $^{10}	extsf{VVe}$ list here a stat | te decaying into $\mathit{K}^+\mathit{K}^-$ po | ossibly differe | nt from $\phi(1680)$. |

₽₽ ANNIHILATION

| F F | | | | | |
|-----------------------------------|------------------------------|----------|-----------|---------------------------------|----------------------------|
| VALUE (MeV) | DOCUMENT ID | ı | TECN | COMMENT | |
| • • • We do not use the | he following data for averag | es, fits | , limits, | etc. • • • | |
| 1700 ± 8 | ¹¹ AMSLER | 06 | CBAR | $0.9 \overline{p}p \rightarrow$ | κ^+ $\kappa^ \pi^0$ |
| 11 Could also be $\rho(170)$ | 00). | | | | |

 $\phi(1680), \rho_3(1690)$

φ(1680) WIDTH

e^+e^- PRODUCTION

DO CUMENT ID TECN COMMENT

150±50 OUR ESTIMATE This is only an educated guess; the error given is larger than the error on the average of the published values.

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| $211 \pm 14 \pm 19$ | | | | | 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ |
|--------------------------|-----|--------------------------|-------------|------|-----------------------------------------------------------------|
| $322\!\pm\!77\!\pm\!160$ | | ¹³ AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow \text{hadrons}$ |
| 139 ± 60 | 948 | ¹⁴ AKHMETSHIN | 03 | CMD2 | $1.05-1.38 \ e^{+} \ e^{-} \rightarrow \ K_{I}^{0} \ K_{S}^{0}$ |
| 300 ± 60 | | ¹⁵ CLEGG | 94 | RVUE | $e^+e^- \rightarrow K^+K^-, K_S^0K\pi$ |
| $146 \!\pm\! 55$ | | | 91 c | DM2 | $e^+e^- \rightarrow \kappa_S^0 \kappa^{\pm} \pi^{\mp}$ |
| 207 ± 45 | | ¹⁶ BISELLO | 88B | DM2 | $e^+e^- \rightarrow K^+K^-$ |
| 185 ± 22 | | | 82 | DM1 | $e^+e^- ightarrow$ hadrons |
| 102 ± 36 | | ¹⁸ MANE | 82 | DM1 | $e^+e^- \rightarrow K_c^0 K \pi$ |

 $^{^{12}\}mathrm{From}$ a fit with two incoherent Breit-Wigners.

PHOTOPRODUCTION

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------|-----------------------------------------------|----------------|-----------------------------------------------|
| • • • We do not use | the following data for avera | ges, fits, lim | ts, etc. • • • |
| 122 ± 63 | ¹⁹ LINK | | $20-160 \ \gamma p \rightarrow K^+ K^- p$ |
| 121 ± 47 | | 89 TPS | $\gamma p \rightarrow K^+ K^- X$ |
| 80 ± 40 | ¹⁹ ATKINSON | 85c OME | G 20–70 $\gamma p \rightarrow K\overline{K}X$ |
| 100 ± 40 | ¹⁹ ASTON | 81F OME | G 25-70 $\gamma p \rightarrow K^+K^-X$ |
| ¹⁹ We list here a state | e decaying into $\mathit{K}^+\mathit{K}^-$ po | ssibly differe | nt from $\phi(1680)$. |

ANNIHII ATION

| ppminimention | | | | | |
|-------------------------------------|----------------------|-----------|-----------|---------------------------------------|-----------------------------|
| VALUE (MeV) | DO CUMENT IL |) | TECN | COMMENT | |
| • • • We do not use the follow | wing data for averag | ges, fits | , limits, | etc. • • • | |
| 143 ± 24 | ²⁰ AMSLER | 06 | CBAR | $0.9 \overline{p} \rho \rightarrow$ | $\kappa^+ \kappa^- \pi^0$ |
| 20 Could also be $ ho(1700)$. | | | | | |

ϕ (1680) DECAY MODES

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-----------------------------------|-------------------------------|--------------------------------------|
| Γ_1 | $K\overline{K}^*(892) + c.c.$ | dominant |
| Γ_2^- | $K_S^0 K \pi$ | seen |
| Γ_3 | $K\overline{K}$ | seen |
| Γ_4 | $K_L^0 K_S^0$ | |
| Γ_5 | $e^+ e^-$ | seen |
| Γ_6 | $\omega \pi \pi$ | not seen |
| Γ_7 | $\phi\pi\pi$ | |
| Γ ₈ | $K^+ K^- \pi^+ \pi^-$ | seen |
| Γ ₉ Γ ₁₀ | $\phi \eta \ K^+ K^- \pi^0$ | |
| Γ_{10} | $K^+ K^- \pi^0$ | |

$\phi(1680) \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$

This combination of a branching ratio into channel (i) and branching ratio into e^+e^- is directly measured and obtained from the cross section at the peak. We list only data that have not been used to determine the branching ratio into (i) or e^+e^-

$\Gamma(K_L^0 K_S^0)/\Gamma_{ ext{total}} \times \Gamma(e^+ e^-)/\Gamma_{ ext{total}}$

| VALUE (units 10^{-6}) | EVTS | DO CUMENT ID | TECN | COMMENT |
|--------------------------|-----------|-----------------------------|-------------|----------------------------------------|
| • • • We do not | use the f | ollowing data for averages | , fits, lir | nits, etc. • • • |
| 0.131 ± 0.059 | 948 | ²¹ AKHMETSHIN 03 | CMD2 | 1.05-1.38 $e^+e^- \to K_L^{0}K_S^{0}$ |

 21 From the combined fit of AKHMETSHIN 03 and MANE 81 also including $\rho,\,\omega,$ and $\phi.$ Neither isospin nor flavor structure known. Recalculated by us.

$\Gamma(K\overline{K}^*(892) + \text{c.c.})/\Gamma_{\text{total}} \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_1/\Gamma \times \Gamma_5/\Gamma$

| VALUE (units 10 ⁻⁰) | EVTS | DO CUMENT | ID | TECN | COMMENT |
|---------------------------------|---------|-----------------------|---------|-----------|-------------------------------------------------------------------------|
| • • • We do not u | ise the | following data | for ave | ages, fit | s, limits, etc. • • • |
| $1.15 \pm 0.16 \pm 0.01$ | | ²² AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow K\overline{K}^*(892)\gamma +$ |
| 3.29±1.57 | 367 | ²³ BISELLO | 91 c | DM2 | $1.35-2.40~e^{+}e^{-} \rightarrow \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ |

 $^{^{22}}$ From the simultaneous fit to the $K\overline{K}^*(892)+{\rm c.c.}$ and $\phi\eta$ data from AUBERT 08s using the results of AUBERT 07AK.

| Γ(| $(\phi \pi \pi)$ | $)/\Gamma_{total}$ | ×Γ | (e+ e- | $)/\Gamma_{total}$ |
|----|------------------|--------------------|----|--------|--------------------|
|----|------------------|--------------------|----|--------|--------------------|

 $\Gamma_7/\Gamma \times \Gamma_5/\Gamma$

| ALUE | (units 10 ⁻⁷) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|------|---------------------------|------|--------------|------|---------|--|
| | | | | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •
$$1.86\pm0.14\pm0.21 \quad 4.8k \quad ^{24} \text{ SHEN} \qquad 09 \quad \text{BELL} \quad 10.6 \ e^+e^- \to K^+K^-\pi^+\pi^-\gamma^-$$
 24 Multiplied by 3/2 to take into account the $\phi\pi^0\pi^0$ mode. Using B($\phi\to K^+K^-$) =

$$\Gamma(\phi\eta)/\Gamma_{\rm total} \times \Gamma(e^+e^-)/\Gamma_{\rm total}$$
 $\Gamma_9/\Gamma \times \Gamma_5/\Gamma$

$$0.43\pm0.10\pm0.09$$
 25 AUBERT 08s BABR 10.6 $e^+e^- \rightarrow \phi\eta\gamma$

φ(1680) BRANCHING RATIOS

 • • • We do not use the following data for averages, fits, limits, etc. • • •
$$0.07\pm0.01$$
 BUON 82 DM1 e^+e^-

$$\Gamma(\phi\eta)/\Gamma(K\overline{K}^*(892) + c.c.)$$
 Γ9/Γ1 ΔΟΣ ΤΕΣΝ ΣΟΣΜΕΝΤ ΙΟ ΤΕΣΝ ΣΟΜΜΕΝΤ

$$pprox$$
 0.37 26 AUBERT 08s BABR 10.6 $e^+e^-
ightarrow$ hadrons

 ϕ (1680) REFERENCES

 $^{^{\}rm 26}\,{\rm From}$ the fit including data from AUBERT 07AK.

| | | • | - | |
|------------|--------|-------------------------|-------------------------------------------|------------------------|
| SHEN | 09 | PR D80 031101R | C.P. Shen et al. | (BELLE Collab.) |
| AUBERT | 085 | PR D77 092002 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 07 A K | PR D76 012008 | B. Aubert et al. | (BABAR Collab.) |
| AMSLER | 06 | PL B639 165 | C. Amsler et al. | (CBAR Collab.) |
| AKHMETSHIN | 03 | PL B551 27 | R.R. Akhmetshin et al. (Novo | sibirsk ČMD-2 Collab.) |
| A Iso | | PAN 65 1222 | E.V. Anashkin, V.M. Aulchenko, R | .R. Akhmetshin |
| | | Translated from YAF 65 | 1255. | |
| LINK | 02 K | | J.M. Link et al. (| FNAL FOCUS Collab.) |
| ACHAS OV | | | N.N. Achasov, A.A. Kozhevnikov | |
| CLEGG | 94 | ZPHY C62 455 | A.B. Clegg, A. Donnachie | (LANC, MCHS) |
| ANTONELLI | 92 | ZPHY C56 15 | A. Antonelli et al. | (DM2 Collab.) |
| BISELLO | 91 C | ZPHY C52 227 | D. Bisello et al. | (DM2 Collab.) |
| DOLINS KY | 91 | PRPL 202 99 | D. Bisello et al. S.I. Dolinsky et al. | ` (NOVO) |
| BUSENITZ | 89 | PR D40 1 | J.K. Busenitz et al. | (ILL, FNAL) |
| BISELLO | 88 B | ZPHY C39 13 | D. Bisello et al. (1 | PADO, CLÈR, FRAS+) |
| BARKOV | | | L.M. Barkov et al. | (NOVO) |
| | | Translated from ZETFP 4 | | * * |
| | | ZPHY C27 233 | | ONN, CERN, GLAS+) |
| BUON | 82 | PL 118B 221 | | (LALO, MONP) |
| | | PL 112B 178 | F. Mane et al. | (LALO) |
| ASTON | | PL 104B 231 | D. Aston (BONN, CERN, I | |
| | | PL 107B 297 | P.M. Ivanov et al. | (NOVO) |
| MANE | 81 | PL 99B 261 | F. Mane et al. | (ÒRSAY) |
| | | | | |

$\rho_3(1690)$

$$I^{G}(J^{PC}) = 1^{+}(3^{-})$$

$\rho_3(1690)$ MASS

DO CUMENT ID

1688.8 ± 2.1 OUR AVERAGE Includes data from the 5 datablocks that follow this one.

 $\Gamma_4/\Gamma \times \Gamma_5/\Gamma$

EVTS DO CUMENT ID TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock

1686 ± 4 OUR AVERAGE

| 1677 ± 14 | | EVA NGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow 2\pi p$ |
|---------------|------|----------------------|------|------|---|-----------------------------------------------------------------------|
| 1679 ± 11 | 476 | BALTAY | 78B | HBC | 0 | 15 $\pi^+ \rho \rightarrow$ |
| | | | | | | $\pi^+\pi^-n$ |
| 1678 ± 12 | 1 75 | ¹ ANTIPOV | 77 | CIBS | 0 | $25 \pi^- p \rightarrow p 3\pi$ |
| 1690 ± 7 | 600 | ¹ ENGLER | 74 | DBC | 0 | $\begin{array}{c} 6 \pi^+ n \rightarrow \\ \pi^+ \pi^- p \end{array}$ |
| | | _ | | | | $\pi^+\pi^-p$ |
| 1693± 8 | | ² GRAYER | 74 | ASPK | 0 | $17 \pi^- p \rightarrow$ |
| | | | | | | $\pi^+\pi^-$ n |
| 1678 ± 12 | | MATTHEWS | 71 C | DBC | 0 | $7 \pi^+ N$ |

 $^{^{13}}$ From the simultaneous fit to the $K\overline{K}^*(892)+{\rm c.c.}$ and $\phi\eta$ data from AUBERT 08s using the results of AUBERT 07AK.

 $^{^{14}}$ From the combined fit of AKHMETSHIN 03 and MANE 81 also including $\rho,\,\omega,$ and ϕ . Neither isospin nor flavor structure known.

¹⁵ Using BISELLO 88B and MANE 82 data.

¹⁶ From global fit including ho, ω , ϕ and ho(1700)

 $^{^{17}}$ From global fit of $\rho,\,\omega,\,\phi$ and their radial excitations to channels $\omega\pi^+\pi^-,\,K^+K^-,\,K^0_S\,K^1_L,\,K^0_S\,K^\pm\pi^\mp$. Assume mass 1570 MeV and width 510 MeV for ρ radial excitations, mass 1570 and width 500 MeV for ω radial excitations.

 $^{^{18}\,\}mathrm{Fit}$ to one channel only, neglecting interference with $\omega,\,\rho(1700)$

²³ Recalculated by us with the published value of B($K\overline{K}^*(892) + c.c.$) $\times \Gamma(e^+e^-)$.

 $^{^{25}}$ From the simultaneous fit to the $K\overline{K}^*(892)+$ c.c. and $\phi\eta$ data from AUBERT 08s using the results of AUBERT 07AK.

| • • • We do not us | e the following | data for averages | , fits, | limits, e | etc. • | • • |
|--------------------|-----------------|-------------------------|---------|-----------|--------|----------------------------------------|
| 1734 ± 10 | | ³ CORDEN | 79 | OMEG | | 12-15 $\pi^- p \rightarrow$ |
| $1692\!\pm\!12$ | 2, | ⁴ ESTABROOKS | 75 | RVUE | | $17 \frac{n2\pi}{\pi^- p} \rightarrow$ |
| 1737 ± 23 | | ARMENISE | 70 | DBC | 0 | $_{9}^{\pi^{+}\pi^{-}n}$ |
| 1650 ± 35 | 122 | BARTSCH | 70B | HBC | + | $8 \pi^+ p \rightarrow N2\pi$ |
| 1687 ± 21 | | STUNTEBECK | 70 | HDBC | 0 | $8 \pi^- p$, 5.4 $\pi^+ d$ |
| $1683{\pm}13$ | | ARMENISE | 68 | DBC | 0 | 5.1 $\pi^+ d$ |
| 1670 ± 30 | | GOLDBERG | 65 | HBC | 0 | 6 π^+ d, 8 π^- p |
| 1 мана поли поли | | (/ N , +, | | L 41 1/3 | k(000) | |

- Mass errors enlarged by us to Γ/\sqrt{N} ; see the note with the $K^*(892)$ mass.
- 2 Uses same data as HYAMS 75. 3 From a phase shift solution containing a $f_2'(1525)$ width two times larger than the $K\overline{K}$ result. 4 From phase-shift analysis. Error takes account of spread of different phase-shift solutions.

$K\overline{K}$ AND $K\overline{K}\pi$ MODES

DO CUMENT ID TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock.

1696 ± 4 OUR AVERAGE

| 1699± 5 | | ALPER | 80 | CNTR | 0 | $62 \pi^- p \rightarrow$ |
|---------------------------------------------|-------------------|---------------------|---------|-------------|--------|---------------------------------------------------------------------------|
| 1698 ± 12 | 6k ⁵ , | ⁶ MARTIN | 78D | SPEC | | $ \begin{array}{c} K^+ K^- n \\ 10 \pi p \to \\ K_S^0 K^- p \end{array} $ |
| 1692± 6 | | BLUM | 75 | ASPK | 0 | $18.4 \pi^- \rho \rightarrow$ |
| 1690±16 | | ADERHOLZ | | | | $ \begin{array}{c} nK^+K^-\\ 8\pi^+\rho\to K\overline{K}\pi \end{array} $ |
| ● ● We do not use the f | rollowing | data for averages | s, fits | , iimits, e | etc. • | • • |
| 1694± 8 | • | ⁷ COSTA | 80 | OMEG | | $10 \pi^- p \rightarrow \kappa^+ \kappa^- p$ |
| | | | | | | |

- 5 From a fit to ${\it J^{P}}=3^{-}$ partial wave.
- ⁶ Systematic error on mass scale subtracted.
- $^7\,\text{They cannot distinguish between } \rho_3(1690)$ and $\omega_3(1670).$

$(4\pi)^{\pm}$ MODE

VALUE (MeV) EVTS DOCUMENT ID TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock.

| 1686± 5 OUR AV | ERAGE Error | includes scale fact | or of | 1.1. | | |
|----------------|-------------|------------------------|-------|------|---|---------------------------------|
| 1694 ± 6 | | ⁸ EVANGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow p4$ |
| 1665 ± 15 | 177 | BALTAY | 78B | HBC | + | $15 \pi^+ p \rightarrow p4$ |
| 1670 ± 10 | | THOMPSON | 74 | HBC | + | 13 $\pi^{+}p$ |
| 1687 ± 20 | | | | | | 8,18.5 $\pi^- p$ |
| 1685 ± 14 | | ⁹ CASON | 73 | HBC | _ | 8,18.5 $\pi^- p$ |
| 1680 ± 40 | 144 | | | | | $8 \pi^+ p \rightarrow N4\pi$ |
| 1689 ± 20 | 102 | ⁹ BARTSCH | 70B | HBC | + | $8 \pi^+ p \rightarrow N 2\rho$ |

нвс

CASO $n \rho 2\pi$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

| 1718±10 1673± 9 | | | | | | $\begin{array}{ccc} 12 \ \pi^- p \rightarrow p \ 47 \\ 12 \ \pi^- p \rightarrow p \ 47 \end{array}$ |
|--------------------|----|----------|----|-----|---|-----------------------------------------------------------------------------------------------------|
| 1733 ± 9 | 66 | 9 KLIGER | | | | |
| 1630 ± 15 | | HOLMES | 72 | нвс | + | 10-12 K+p |
| 1720 ± 15 | | BAITAY | 68 | HBC | _ | 7 85 π ⁺ n |

 8 From $\rho^-\rho^0$ mode, not independent of the other two EVANGELISTA 81 entries. 9 From $\rho^\pm\rho^0$ mode. 10 From $a_2(1320)^-\pi^0$ mode, not independent of the other two EVANGELISTA 81 entries.

 11 From $a_2(1320)^0\,\pi^-$ mode, not independent of the other two EVANGELISTA 81 entries.

$\omega\pi$ MODE

 1705 ± 21

TECN CHG COMMENT

1681 ± 7 OUR AVERAGE

| 1670 ± 25 | ¹² ALDE | 95 | GAM2 | 38 $\pi^- p \rightarrow$ |
|--------------------|------------------------------------|--------|------------------|---------------------------------------|
| | | | | $\omega \pi^0 n$ |
| 1690 ± 15 | EVA NGELIS | 81 | OMEG - | $12 \pi^- p \rightarrow \omega \pi p$ |
| 1666 ± 14 | GESSAROLI | 77 | HBC | $11 \pi^- p \rightarrow \omega \pi p$ |
| 1686 ± 9 | THOMPSON | 74 | HBC + | 13 $\pi^{+} \rho$ |
| • • • We do not us | se the following data for averages | , fits | , limits, etc. • | • • |
| 1654 ± 24 | BARNHAM | 70 | HBC + | 10 $K^+ \rho \rightarrow$ |
| | | | | $\omega \pi X$ |

 $^{12}\,\mathrm{Supersedes}$ ALDE 92c.

$\eta\pi^+\pi^-$ MODE

(For difficulties with MMS experiments, see the $\it a_2(1320)$ mini-review in the 1973 edition.)

VALUE (MeV) DO CUMENT ID TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock.

1682±12 OUR AVERAGE

| $1685 \pm 10 \pm 20$ | AMELIN | 00 | VES | | $37 \pi^- p \rightarrow$ |
|----------------------|--------|----|------|---|----------------------------|
| | | | | | $\eta \pi^+ \pi^- n$ |
| 1680 ± 15 | FUKUI | 88 | SPEC | 0 | 8.95 $\pi^- p \rightarrow$ |
| | | | | | $\eta \pi^+ \pi^- n$ |

| • | • | • | We do | not | use the | following | data | for | averages, | fits, | limits, etc. | • | • | • |
|---|---|---|-------|-----|---------|-----------|------|-----|-----------|-------|--------------|---|---|---|
| | | | | | | | | | | | | | | |

| 1700 ± 47 | ¹³ ANDERSON | 69 | MMS | _ | |
|---------------|------------------------|----|-----|---|----------------------------------------|
| 1632 ± 15 | 13,14 FOCACCI | 66 | MMS | _ | |
| 1700 ± 15 | 13,14 FOCACCI | 66 | MMS | _ | |
| 1748 ± 15 | 13,14 FOCACCI | 66 | MMS | _ | $p MM$ $7-12 \pi^- p \rightarrow p MM$ |

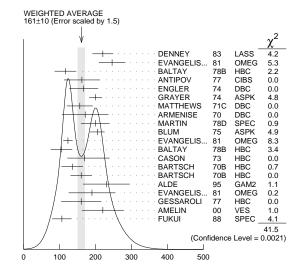
 $^{^{13}\,\}mathrm{Seen}$ in 2.5–3 GeV/c $\overline{\rho}\rho$. $2\pi^+\,2\pi^-$, with 0, 1, 2 $\pi^+\,\pi^-$ pairs in ρ band not seen by OREN 74 (2.3 GeV/c $\overline{\rho}p)$ with more statistics. (Jan. 1976)

$\rho_3(1690)$ WIDTH

2π , $K\overline{K}$, AND $K\overline{K}\pi$ MODES

DOCUMENT ID

161±10 OUR AVERAGE Includes data from the 5 datablocks that follow this one. Error includes scale factor of 1.5. See the ideogram below.



 $\rho_3(1690)$ width, 2π , $K\overline{K}$, and $K\overline{K}\pi$ modes (MeV)

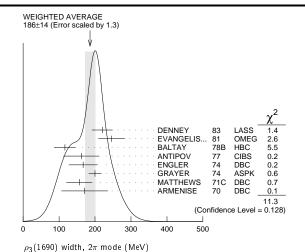
VALUE (MeV) EVTS DOCUMENT ID TECN CHG COMMENT
The data in this block is included in the average printed for a previous datablock.

| ******* | | | | | | |
|-------------------------|-----------|---------------------|---------|-------------|--------|--------------------------------------------------------------------------|
| 186±14 OUR AVERAGE | Error inc | cludes scale facto | or of : | 1.3. See | the id | eogram below. |
| 220 ± 29 | | DENNEY | 83 | LASS | | 10 π^{+} N |
| 246 ± 37 | | EVA NGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow 2\pi p$ |
| 116 ± 30 | 476 | BALTAY | 78B | HB C | 0 | 15 $\pi^+ \rho \rightarrow$ |
| | 11 | = | | | | $\pi^+\pi^-n$ |
| 162±50 | 175 | ANTIPOV | 77 | CIBS | 0 | $25 \pi^- p \rightarrow p 3\pi$ |
| 167 ± 40 | 600 | ENGLER | 74 | DBC | 0 | $6 \pi^+ n \rightarrow$ |
| 200 1 4 0 | 1. | ⁶ GRAYER | | | | $\pi^+\pi^-p$ |
| 200 ± 18 | - | GRAYER | 74 | ASPK | 0 | $17 \pi^{-} p \rightarrow$ |
| 156±36 | | MATTHEWS | 71 C | DBC | 0 | $\pi^+\pi^-$ n 7 π^+ N |
| 171±65 | | ARMENISE | 70 | DBC | 0 | $9\pi^+d$ |
| | following | | | | - | |
| • • • We do not use the | _ | | 5, 1115 | , 11111115, | eic. • | • • |
| 322 ± 35 | 1 | ⁷ CORDEN | 79 | OMEG | | 12-15 $\pi^- p \rightarrow$ |
| 240±30 | 16.1 | B ESTABROOKS | 75 | RVUE | | $n2\pi$ |
| 240±30 | , | ESTABROOKS | 0 10 | KVUE | | $ \begin{array}{c} 17 \pi^- p \rightarrow \\ \pi^+ \pi^- n \end{array} $ |
| 180 ± 30 | 122 | BARTSCH | 70B | нвс | + | $8 \pi^+ p \rightarrow N 2\pi$ |
| 267+72 | | STUNTEBECK | 70 | HDBC | 0 | $8 \pi^{-} p$, 5.4 $\pi^{+} d$ |
| $267 + 72 \\ -46$ | | SIUNIEBECE | (10 | првс | U | $o \pi \rho$, 5.4 π · a |
| 188 ± 49 | | ARMENISE | 68 | DBC | 0 | 5.1 $\pi^+ d$ |
| 180 ± 40 | | GOLDBERG | 65 | HB C | 0 | 6 π^+ d, 8 π^- p |

- ¹⁵ Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.
- 16 Uses same data as HYAMS 75 and BECKER 79.
- 17 From a phase shift solution containing a $f_2'(1525)$ width two times larger than the $K\overline{K}$
- $^{\rm result.}$ From phase-shift analysis. Error takes account of spread of different phase-shift solutions.

¹⁴ Not seen by BOWEN 72.

$\rho_3(1690)$



$K\overline{K}$ AND $K\overline{K}\pi$ MODES

<u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

| 204±18 OUR AVERAG | E | | | | |
|------------------------|------------|----------------------|---------|------------------|------------------------------------------------------------------------|
| 199±40 | | ¹⁹ MARTIN | 78D | SPEC | $\begin{array}{c} 10 \ \pi p \rightarrow \\ K_S^0 \ K^- p \end{array}$ |
| 205 ± 20 | | BLUM | 75 | ASPK 0 | $18.4 \pi^{-} p \rightarrow nK^{+}K^{-}$ |
| • • • We do not use th | e followin | g data for average | s, fits | , limits, etc. • | |
| 219± 4 | | ALPER | 80 | CNTR 0 | 62 $\pi^- p \rightarrow$ |
| 186 ± 11 | | ²⁰ COSTA | 80 | OMEG | $10 \pi^{+} \stackrel{K^{+}}{p} \stackrel{n}{\rightarrow}$ |
| 112±60 | | ADERHOLZ | 69 | HBC + | $8 \pi^{+} p \rightarrow K \overline{K} \pi$ |

 19 From a fit to $J^P = 3^-$ partial wave.

$(4\pi)^{\pm}$ MODE

The data in this block is included in the average printed for a previous datablock.

129±10 OUR AVERAGE

| 123±13 | | 21 | EVA NGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow p4\pi$ |
|---------------------------------|----------|-----|-------------------|---------|-----------|-------|---------------------------------|
| 105 ± 30 | 177 | | BALTAY | 78B | HBC | + | $15 \pi^+ p \rightarrow p 4\pi$ |
| $169 + 70 \\ -48$ | | | CASON | 73 | нвс | - | 8,18.5 $\pi^- \rho$ |
| 135 ± 30 | 144 | | BARTSCH | 70B | HBC | + | $8 \pi^+ p \rightarrow N4\pi$ |
| 160 ± 30 | 102 | | BARTSCH | 70B | HBC | + | $8 \pi^+ p \rightarrow N2\rho$ |
| ullet $ullet$ We do not use the | followin | g d | lata for averages | , fits, | limits, e | tc. • | • • |
| $230\!\pm\!28$ | | | EVANGELIS | | | | $12 \pi^- p \rightarrow p 4\pi$ |
| 184 ± 33 | | 23 | EVANGELIS | 81 | OMEG | _ | $12 \pi^- p \rightarrow p4\pi$ |
| 150 | 66 | 24 | KLIGER | 74 | HBC | _ | 4.5 $\pi^- \rho \rightarrow$ |
| | | | | | | | $p4\pi$ |
| 106 ± 25 | | | THOMPSON | 74 | HBC | + | 13 $\pi^{+} p$ |
| $125 + 83 \\ -35$ | | 24 | CASON | 73 | HBC | - | 8,18.5 $\pi^- p$ |
| 130 ± 30 | | | HOLMES | 72 | HBC | + | 10−12 K ⁺ p |
| 180 ± 30 | 90 | 24 | BARTSCH | 70B | HBC | + | $8 \pi^+ p \rightarrow Na_2\pi$ |
| 100 ± 35 | | | BALTAY | 68 | нвс | + | 7, 8.5 $\pi^+ p$ |
| | | | | | | | |

 21 From $\rho^-\,\rho^0$ mode, not independent of the other two EVANGELISTA 81 entries. 22 From $a_2(1320)^-\pi^0$ mode, not independent of the other two EVANGELISTA 81 entries. 23 From $a_2(1320)^0\,\pi^-$ mode, not independent of the other two EVANGELISTA 81 entries.

²⁴ From $\rho^{\stackrel{\frown}{\pm}}\rho^0$ mode.

$\omega\pi$ MODE

DOCUMENT ID TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock

190±40 OUR AVERAGE

| 230 ± 65 | ²⁵ ALDE | 95 | GAM2 | $38 \pi^- p \rightarrow \omega \pi^0 n$ |
|---------------------------------|-----------------------------|---------|------------------|--------------------------------------------------------|
| 190±65 | EVA NGELIS | 81 | OMEG - | $\omega \pi^0 n$ $12 \pi^- p \rightarrow \omega \pi p$ |
| 160±56 | GESSAROLI | 77 | нвс | $11 \pi^- p \rightarrow \omega \pi p$ |
| ullet $ullet$ We do not use the | following data for averages | s, fits | , limits, etc. • | • • • |
| $89\!\pm\!25$ | THOMPSON | 74 | HBC + | 13 $\pi^+ p$ |
| 130^{+73}_{-43} | BARNHAM | 70 | HBC + | $10 K + p \rightarrow$ |
| | | | | |

 25 Supersedes ALDE 92c.

$\eta\pi^+\pi^-$ MODE

(For difficulties with MMS experiments, see the $a_2(1320)$ mini-review in the 1973

<u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMEN</u>
The data in this block is included in the average printed for a previous datablock. TECN CHG COMMENT

| 126±40 OUR AVERAGE | Error includes scale fa | ctor o | of 1.8. | | |
|-----------------------------|--------------------------|---------|-------------|-------|---------------------------------------------------------------------------------------|
| $220 \pm 30 \pm 50$ | AMELIN | 00 | VES | | 37 $\pi^- \rho \rightarrow$ |
| 106 ± 27 | FUKUI | 88 | SPEC | 0 | $ \eta \pi^{+} \pi^{-} n $ $ 8.95 \pi^{-} p \rightarrow $ $ \eta \pi^{+} \pi^{-} n $ |
| • • • We do not use the fol | lowing data for average | s, fits | , limits, e | tc. • | • • |
| 1 95 | ²⁶ ANDERSON | 69 | MMS | - | $16~\pi^- p$ back- |
| < 21 | ^{26,27} FOCACCI | 66 | MMS | - | $7-12 \pi p \rightarrow pMM$ |
| < 30 | ^{26,27} FOCACCI | 66 | MMS | - | 7-12 π ⁻ p → |
| < 38 | ^{26,27} FOCACCI | 66 | MMS | - | 7-12 π ⁻ p → pMM |

 26 Seen in 2.5–3 GeV/c $\overline{p}p.$ $2\pi^+2\pi^-$, with 0, 1, 2 $\pi^+\pi^-$ pairs in ρ^0 band not seen by OREN 74 (2.3 GeV/c $\overline{p}p)$ with more statistics. (Jan. 1979) 27 Not seen by BOWEN 72.

$\rho_3(1690)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor |
|-----------------------|---------------------------------------|------------------------------|--------------|
| $\overline{\Gamma_1}$ | 4π | $(71.1 \pm 1.9)\%$ | |
| Γ_2 | $\pi^\pm\pi^+\pi^-\pi^0$ | $(67 \pm 22)\%$ | |
| Γ_3 | $\omega\pi$ | $(16 \pm 6)\%$ | |
| Γ_4 | $\pi\pi$ | $(23.6 \pm 1.3)\%$ | |
| Γ_5 | $K\overline{K}\pi$ | (3.8 ± 1.2) % | |
| Γ_6 | $K\overline{K}$ | $(1.58 \pm 0.26) \%$ | 1.2 |
| Γ_7 | $\eta\pi^+\pi^-$ | seen | |
| Γ ₈ | $\rho(770)\eta$ | seen | |
| Г9 | $\pi\pi ho$ | seen | |
| | Excluding $2 ho$ and $a_2(1320)\pi.$ | | |
| Γ_{10} | $a_2(1320)\pi$ | seen | |
| Γ_{11} | ho ho | seen | |
| Γ_{12} | $\phi\pi$ | | |
| Γ_{13} | $\eta\pi$ | | |
| Γ_{14} | $\pi^{\pm} 2\pi^{+} 2\pi^{-} \pi^{0}$ | | |

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 10 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2=$ 14.7 for 7 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\text{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one.

ρ_3 (1690) BRANCHING RATIOS

| $\Gamma(\pi\pi)/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | CHG | Γ ₄ /I |
|--------------------------------------------|--------------------------------|---------|-------------|--------|-------------------------------------------------|
| 0.236±0.013 OUR FIT 0.243±0.013 OUR AVE | RAGE | | | | |
| $0.259 {}^{+ 0.018}_{- 0.019}$ | BECKER | 79 | ASPK | 0 | $17 \pi^- p$ polar- |
| 0.23 ± 0.02 | | | OMEG | | $12-15 \pi^- p \rightarrow$ |
| 0.22 ± 0.04 | ²⁸ MATTHEWS | 71C | HDBC | 0 | $7 \pi^{+} n \rightarrow \pi^{-} p$ |
| ● ● We do not use the | ne following data for average: | s, fits | , limits, e | etc. • | • • |
| 0.245 ± 0.006 | ²⁹ ESTABROOKS | 5 75 | RVUE | | $17 \pi^- \rho \rightarrow \\ \pi^+ \pi^- \rho$ |

²⁸ One-pion-exchange model used in this estimation.

²⁹ From phase-shift analysis of HYAMS 75 data.

| $\Gamma(\pi\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ |) | | | | Γ_4/Γ_2 |
|---------------------------------------------------------|----------------------------|--------|-----------|--------|------------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.35 ± 0.11 | CASON | 73 | нвс | _ | 8,18.5 $\pi^- p$ |
| • • • We do not use the fo | ollowing data for averages | , fits | , limits, | etc. • | • • |
| < 0.2 | HOLMES | 72 | нвс | + | 10-12 K ⁺ p |
| -0.10 | DALLAM | | LIDG | | 16 - |

 $^{^{20}}$ They cannot distinguish between $ho_3(1690)$ and $\omega_3(1670)$.

Meson Particle Listings $\rho_3(1690)$

| ### DOCUMENT ID TECN CHG COMMENT 180 ±0.10 BALTAY 78B HBC 0 15 π ⁺ ρ → 167±0.011 OUR FIT Error includes scale factor of 1.1. ### BALTAY 78B HBC 0 15 π ⁺ ρ → 167±0.011 OUR FIT Error includes scale factor of 1.2. ### 118 ±0.040 OUR AVERAGE Error includes scale factor of 1.7. See the ideogram low. 91 ±0.037 GORLICH 80 ASPK 0 17,18 π ⁻ ρ pol 18 ±0.03 BARTSCH 70B HBC + 8 π ⁺ ρ → 18 ±0.03 BARTSCH 70B HBC + 8 π ⁺ ρ → 18 ±0.03 BARTSCH 70B HBC + 8 π ⁺ ρ → 18 ±0.03 BARTSCH 70B HBC + 8 π ⁺ ρ → 18 ±0.040 O.032 (Error scaled by 1.7) #### 15 ±0.05 OUR FIT Comment Comm |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $(K\overline{K})/\Gamma(\pi\pi)$ LUE DOCUMENT ID TECN CHG COMMENT 189-0.032 OUR AVERAGE LOW 191+0.040 BORLICH BORTSCH COMMENT COMME |
| DOCUMENT ID TECN CHG COMMENT 1087±0.011 OUR FIT Error includes scale factor of 1.2. 118 $^{+}$ 0.032 OUR AVERAGE Error includes scale factor of 1.7. See the ideogram low. 191 $^{+}$ 0.040 OUR AVERAGE Error includes scale factor of 1.7. See the ideogram low. 191 $^{+}$ 0.047 GORLICH 80 ASPK 0 17,18 π $^{-}$ ρ pol 18 $^{+}$ 0.03 BARTSCH 70B HBC + 8 π $^{+}$ ρ pol 18 $^{+}$ 0.03 BARTSCH 70B HBC + 8 π $^{+}$ ρ pol 18 $^{+}$ 0.08 CRENNELL 68B HBC 6.0 π $^{-}$ ρ WEIGHTED AVERAGE 0.118+0.040-0.032 (Error scaled by 1.7) Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our best values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information. GORLICH 80 ASPK 3.8 BARTSCH 70B HBC 1.6 See BHBC 0.4 5.9 (Confidence Level = 0.053 |
| 1067±0.011 OUR FIT |
| low. $.91_{1}^{+0.040} = 0.037$ GORLICH 80 ASPK 0 17,18 $\pi^{-}p$ pol 0.037 BARTSCH 708 HBC + 0.037 BALLAM 718 HBC - 0.037 BARTSCH 708 HBC + 0.037 BALLAM 718 HBC - 0.037 BALLAM 718 BAL |
| 1.91 + 0.040 |
| BARTSCH 70B HBC + $8\pi^+\rho$ ORENNELL 68B HBC 6.0 $\pi^-\rho$ WEIGHTED AVERAGE 0.118+0.040-0.032 (Error scaled by 1.7) Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information. GORLICH 80 ASPK 3.8 ASP |
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| $\Gamma(\kappa \overline{\kappa})/\Gamma(\pi \pi)$ LUE DOCUMENT ID TECN CHG COMMENT 1D 16±0.05 OUR FIT 10 10 Increased by us to correspond to $B(\rho_3(1690) \rightarrow \pi \pi) = 0.24$. 12 $\Gamma(\pi \pi \rho) + \Gamma(a_2(1320)\pi) + \Gamma(\rho \rho) / \Gamma(\pi^{\pm} \pi^{+} \pi^{-} \pi^{0})$ (Γ9+Γ10+Γ1 12 $\Gamma(\pi \pi \rho) + \Gamma(a_2(1320)\pi) + \Gamma(a_2(1320)\pi) + \Gamma(a_2(1320)\pi) / \Gamma(a_2(1320)\pi)$ (Γ9+Γ10+Γ1 12 $\Gamma(\pi \pi \rho) + \Gamma(a_2(1320)\pi) + \Gamma(a_2(1320)\pi) / \Gamma(a_$ |
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| $(K\overline{K}\pi)/\Gamma(\pi\pi)$ LUE DOCUMENT ID TECN CHG COMMENT 16 ± 0.05 OUR FIT 16 ± 0.05 OUR FIT 10 Increased by us to correspond to $B(\rho_3(1690) \rightarrow \pi\pi) = 0.24$. $(\pi\pi\rho) + \Gamma(a_2(1320)\pi) + \Gamma(\rho\rho)]/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ DOCUMENT ID TECN CHG COMMENT DOCUMENT ID TECN CHG COMMENT DOCUMENT ID TECN CHG COMMENT BALTAY 788 HBC + 15 π ⁺ ρ → BALTAM 718 HBC - 16 π ⁻ ρ BALTAM 718 HBC - 16 π ⁻ ρ BARTSCH 708 HBC + 8 π ⁺ ρ |
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| Oncreased by us to correspond to $B(\rho_3(1690) \to \pi\pi) = 0.24$. $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| LUE DO CUMENT ID TECN CHG COMMENT 04±0.09 OUR AVERAGE B6±0.21 BALTAY 788 HBC + 15 $\pi^+ p \rightarrow$ 18±0.15 BALLAM 718 HBC - 16 $\pi^- p$ ±0.15 BARTSCH 708 HBC + 8 $\pi^+ p$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 88 ± 0.15 BALLAM 71B HBC $ 16 \ \pi^- p$ ± 0.15 BARTSCH 70B HBC $+$ $8 \ \pi^+ p$ |
| ± 0.15 BARTSCH 70B HBC $+$ 8 π^+ p |
| nsistent with 1 CASO 68 HBC $-$ 11 $\pi^- p$ |
| |
| $(ho ho)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ |
| LUE <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> |
| • • We do not use the following data for averages, fits, limits, etc. • • • |
| BALTAY 788 HBC + 15 $\pi^+ p \rightarrow$ |
| 66 KLIGER 74 HBC – 4.5 π ⁻ p – p4π |
| 3 ± 0.09 31 THOMPSON 74 HBC + 13 $\pi^+ p$ |
| 7 \pm 0.15 BARTSCH 70B HBC $+$ 8 π^+ p |
| $^{1} ho ho$ and $^{2}($ 1320 $)$ π modes are indistinguishable. |
| $(\rho\rho)/[\Gamma(\pi\pi\rho)+\Gamma(a_2(1320)\pi)+\Gamma(\rho\rho)]$ $\Gamma_{11}/(\Gamma_9+\Gamma_{10}-\Gamma_{11})$ |
| LUE <u>DO CUMENT ID TECN CHG COMMENT</u> |
| • • We do not use the following data for averages, fits, limits, etc. • • • |
| 8 ± 0.16 CASO 68 HBC - 11 $\pi^- p$ |
| |
| $(a_2(1320)\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ |
| LUE <u>DO CUMENT ID</u> <u>TECN_CHG_COMMENT</u> |
| <u>DOCUMENT ID</u> <u>TECN CHG</u> <u>COMMENT</u> • • We do not use the following data for averages, fits, limits, etc. • • • |
| • • We do not use the following data for averages, fits, limits, etc. • • • $\frac{\text{COMMENT ID}}{66\pm0.08}$ BALTAY 78B HBC + $15 \pi^+ \rho \rightarrow$ |
| <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> • • We do not use the following data for averages, fits, limits, etc. • • • 66 ± 0.08 BALTAY 78B HBC + 15 π^+p → 32 THOMPSON 74 HBC + 13 π^+p |
| • • We do not use the following data for averages, fits, limits, etc. • • • $\frac{\text{COMMENT ID}}{66\pm0.08}$ BALTAY 78B HBC + $15 \pi^+ \rho \rightarrow$ |

| | | | | $\rho_3(1690)$ |
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| $\Gamma(\omega\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ | | | | Γ ₃ /Γ ₂ |
| VALUE CL% | DOCUMENT ID | TEC | | COMMENT |
| 0.33 ± 0.07 | Error includes scale f THOMPSON | 74 HB | | 13 π ⁺ p |
| 0.12 ± 0.07 | | 71B HB | C – | 16 π-ρ |
| 0.25 ± 0.10 0.25 ± 0.10 | | 68 HB 68 HB | | $7,8.5 \pi^+ p$ $7.0 \pi^- p$ |
| • • • We do not use the following | | | | • • |
| < 0.11 95 | BALTAY | 78B HB | C + | 15 $\pi^+ \rho \rightarrow \rho 4\pi$ |
| < 0.09 | KLIGER | 74 HB | C – | $4.5 \pi^- p \rightarrow p4\pi$ |
| $\Gamma(\phi\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ | DOCUMENT ID | TEC | N CHG | Γ_{12}/Γ_{2} |
| • • We do not use the following | ng data for averages, | , fits, limi | ts, etc. • | • • |
| <0.11 | BALTAY | 68 HB | C + | 7,8.5 π ⁺ ρ |
| $\Gamma(\pi^{\pm}2\pi^{+}2\pi^{-}\pi^{0})/\Gamma(\pi^{\pm}\pi^{+})$ VALUE | π π π η η) <u>DOCUMENT ID</u> | TEC | N CHG | Γ ₁₄ /Γ ₂ COMMENT |
| • • • We do not use the following | | | | |
| < 0.15 | BALTAY | 68 HB | C + | 7,8.5 $\pi^+ p$ |
| $\Gamma(\eta\pi)/\Gamma(\pi^{\pm}\pi^{+}\pi^{-}\pi^{0})$ | | | | Γ_{13}/Γ_{2} |
| VALUE | DO CUMENT ID | | | COMMENT |
| ◆ • We do not use the following | ng data for averages, THOMPSON | | | |
| | THOMPSON | 74 HB | C + | • |
| Γ(<i>Κ΄</i> Κ)/Γ _{total} | DOCUMENT IS | TF/ | N CUC | Γ ₆ /Γ |
| 0.0158±0.0026 OUR FIT Error | <u>DOCUMENT ID</u> includes scale facto | | N CHG | COMMENT |
| 0.0130±0.0024 OUR AVERAGE 0.013 ±0.003 | COSTA | 80 ON | IEG 0 | 10 $\pi^- p \rightarrow$ |
| 0.013 ±0.004 | 33 MARTIN | 78B SPI | C – | $K^+ K^- n$ 10 $\pi p \rightarrow$ |
| 22 1/2 | | | | $\kappa_S^0 \kappa^- p$ |
| $^{33}\text{From}\;(\Gamma_4\Gamma_6)^{1/2}=0.056\pm$ | 0.034 assuming B($ ho_1$ | 3(1690) - | $\rightarrow \pi\pi) =$ | 0.24. |
| $\Gamma(\omega\pi)/[\Gamma(\omega\pi)+\Gamma(\rho\rho)]$ | | | | $\Gamma_3/(\Gamma_3+\Gamma_{11})$ |
| <u>VALUE</u> ■ ■ We do not use the following | <u>DOCUMENT ID</u> | | | |
| 0.22±0.08 | - | 73 HB | | |
| | CASON | 13 110 | | |
| $\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ | CASON | 75 115 | | Γ ₇ /Γ |
| $\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ | DOCUMENT ID | TEC | N COM | MENT |
| | | | <u>N СОМ.</u> EC 8.95 | |
| VALUE | DOCUMENT ID | TEC | <u>N СОМ.</u> EC 8.95 | $\pi^- p \rightarrow$ |
| Seen $\Gamma(a_2(1320)\pi)/\Gamma(ho(770)\eta)$ VALUE | <u>DOCUMENT ID</u> FUKUI <u>DOCUMENT ID</u> | 7EC | <u>COM</u> EC 8.95 η | $ment \\ \pi^- \rho \to \\ \pi^+ \pi^- n$ Γ_{10}/Γ_8 MENT |
| Seen | DOCUMENT ID FUKUI DOCUMENT ID A MELIN | 88 SPI 7EC 00 VE: | <u>COM</u> EC 8.95 η | $\pi^- p \rightarrow \pi^+ \pi^- n$ Γ_{10}/Γ_8 |
| Seen | <u>DOCUMENT ID</u> FUKUI <u>DOCUMENT ID</u> | 88 SPI 7EC 00 VE: | <u>COM</u> EC 8.95 η | $ment \\ \pi^- \rho \to \\ \pi^+ \pi^- n$ Γ_{10}/Γ_8 MENT |
| Seen $ \Gamma\left(a_2(1320)\pi\right)/\Gamma\left(\rho(770)\eta\right) $ VALUE $ 5.5 \pm 2.0 $ $ \rho_{3} $ AMELIN 00 NP A668 83 | DOCUMENT ID FUKUI DOCUMENT ID A MELIN 3 (1690) REFERE D. Amelin et al | ### TEC 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 100 10 | <u>COM</u> EC 8.95 η | MENT $ \pi^{-} p \rightarrow \pi^{+} \pi^{-} n $ $ \Gamma_{10}/\Gamma_{8} $ MENT $ - p \rightarrow \eta \pi^{+} \pi^{-} n $ (VES Collab.) |
| Seen $\Gamma(a_2(1320)\pi)/\Gamma(\rho(770)\eta)$ VALUE 5.5 ± 2.0 AMELIN 00 NP A668 83 ALDE 95 ZPHY C66 379 ALDE 92C ZPHY C64 553 | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 1690) REFERE D. Amelin et al D.M. Alde et al D.M. Alde et al | 88 SPP 7EC 00 VE: | <u>COM</u> EC 8.95 η <u>COM</u> 5 37 π | MENT $ \begin{array}{c} \pi^- \rho \to \\ \pi^+ \pi^- n \end{array} $ $ \begin{array}{c} \Gamma_{10}/\Gamma_8 \\ \longrightarrow \\ \rho \to \eta \pi^+ \pi^- n \end{array} $ (VES Collab.) (GAMS Collab.) JP |
| Seen $\Gamma(a_2(1320)\pi)/\Gamma(\rho(770)\eta)$ VALUE 5.5 ± 2.0 P3 AMELIN 00 NP A 668 83 ALDE 95 ZPHY C66 379 ALDE 95 ZPHY C65 4553 FUKUI 88 PL B202 441 DENNEY 83 PR D28 2726 | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 3 (1690) REFERE D. Amelin et al D.M. Alde et al S. Fukui et al. D.L. Denney et | 7EC 888 SPI 00 VE: NCES | COM. EC 8.95 η N COM. S 37 π (BELG, SE SUGI, NAG | MENT $ \pi^{-} \rho \rightarrow \pi^{+} \pi^{-} n $ $ \Gamma_{10}/\Gamma_{8} $ MENT $ -\rho \rightarrow \eta \pi^{+} \pi^{-} n $ (VES Collab.) (GAMS Collab.) JP RP, KEK, LANL+) O, KEK, KYOT+) (IOWA, MICH) |
| (a ₂ (1320)π)/Γ (ρ(770)η) (AUUE 5.5 ± 2.0 P. | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 3 (1690) REFERE D. Amelin et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. | 7EC 88 SPI 7EC 00 VE: | N COM. EC 8.95 7 N COM. 5 37 π (BELG, SE SUGI, NAG | $\begin{array}{c} \frac{MENT}{\pi^-\rho \to \pi^+\pi^-n} \\ \hline \Gamma_{10}/\Gamma_8 \\ \frac{MENT}{-\rho \to \eta\pi^+\pi^-n} \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ RP, KEK, LANL+) \\ (IOWA, MICH) \\ BONN. CERN +) \\ \\ (IOWA, MICH) \\ BONN. CERN +) \\ \end{array}$ |
| (A) | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 3(1690) REFERE D. Amelin et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorlich et al. | 88 SPI 00 VE: NCES | COM. EC 8.95 η COM. S 37 π (BELG, SE SUGI, NAG (BAR MST, CERAC al. (CRAC | $\begin{array}{c} \frac{MENT}{\pi^-\rho \to \pi^+\pi^-n} \\ \hline \Gamma_{10}/\Gamma_8 \\ \frac{MENT}{-\rho \to \eta \pi^+\pi^-n} \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ (GAMS Collab.) JP \\ (REK, KYOT+) \\ (IOWA, MICH) \\ , BONN, CERN+) \\ , CRAC, MPIM +) \\ (BARI, BONN+) \\ . MPIM, CERN+) \\ (MPIM, CERN+) \\ . MPIM, CERN+) \\ . \end{array}$ |
| (a ₂ (1320)π)/Γ (ρ(770)η) (A ₂ (1320)π)/Γ (ρ(770)π)/Γ | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 3(1690) REFERE D. Amelin et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorlich et al. H. Becker et al. M.J. Corden et | 88 SPI 00 VE: NCES I. I | EC 8.95 7 COM. SOME GELG, SE SUGI, NAG WIST, CERN J. (CRACM MPIM, CERN $\begin{array}{c} \text{MENT} \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \\ \hline \Gamma_{10}/\Gamma_8 \\ \\ \text{MENT} \\ -\rho \rightarrow \eta \pi^+ \pi^- n \\ \\ \text{(VES Collab.)} \\ \text{(GAMS Collab.)} \\ \text{(GAMS Collab.)} \\ \text{JP} \\ \text{RP. KEK. LANL+} \\ \text{O. KEK. KYOT+} \\ \text{(IOWA, MICH)} \\ \text{IOWA, MICH)} \\ \text{J. CRAC. MPIM+} \\ \text{(BARI, BONN+} \\ \text{J. CRAC. MPIM+} \\ \text{(BARI, BONN+} \\ \text{J. MPIM. CERN+} \\ \text{N. ZEEM. CRAC.} \\ \\ \text{M. PIEL. I ELA+ JP} \\ \text{M. RHEL. I ELA+ JP} \\ \end{array}$ |
| (a ₂ (1320)π)/Γ(ρ(770)η) (A ₂ (1320)π)/Γ(ρ(770)π) (A ₂ (1320)π)/Γ(ρ(| DOCUMENT ID FUKUI DOCUMENT ID AMELIN 1640) REFERE D. Amelin et al D.M. Able et al D.M. Able et al C. Evangelista e B. Alper et al. G. Costa de Be- L. Gorlich et al M. Becker et al. M. J. Corden et C. Ballat et al | 7EC 00 VE: | EC 8.95 7 COM. SOME GELG, SE SUGI, NAG WIST, CERN J. (CRACM MPIM, CERN $\begin{array}{c} \text{MENT} \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \\ \hline \Gamma_{10}/\Gamma_8 \\ \\ \text{MENT} \\ -\rho \rightarrow \eta \pi^+ \pi^- n \\ \\ \text{(VES Collab.)} \\ \text{(GAMS Collab.) JP} \\ \text{RP, KEK, LANL+} \\ \text{0, KEK, KYOT+} \\ \text{(IOWA, MICH)} \\ \text{1, 6NN, CERN+} \\ \text{1, CRAC, MPIM+} \\ \text{(BARI, BONN+} \\ \text{1, MPIM, CERN+} \\ \text{N, ZEEM, CRAC} \\ \text{M, RHEL, IELA+ JP} \\ \text{M, RHEL, IELA+ JP} \\ \end{array}$ |
| (a ₂ (1320)π) / Γ (ρ(770)η) | DOCUMENT ID FUKUI DOCUMENT ID A MELIN 16690) REFERE D. Amelin et al D.M. Able et al S. Fukui et al, D.L. Denney et C. Evangelista e B. Alper et al, G. Costa de Be. L. Gorlich et al. H. Becker et al, M.J. Corden et C. Ballay et al, A.D. Martin et A.D. Martin et | 7EC 00 VE: NCES | EC 8.95 7 COM. SOME GELG, SE SUGI, NAG WIST, CERN J. (CRACM MPIM, CERN $\begin{array}{c} \frac{MENT}{\pi^-\rho \to \pi^+\pi^-n} \\ \hline \Gamma_{10}/\Gamma_8 \\ \frac{MENT}{-\rho \to \eta\pi^+\pi^-n} \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ RP, KEK, LANL+) \\ (IOWA, MICH) \\ BONN, CERN + I, CRAC, MPIM + I, CRAC, MPIM + I, CRAC, MPIM + I, MPIM, CERN + IN, ZEEM, CRAC) \\ A, RHEL, TELA+ JP \\ (COLU, BING) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ \end{array}$ |
| (a ₂ (1320)π)/Γ(ρ(770)η) (ALUE | DOCUMENT ID FUKUI DOCUMENT ID AMELIN (1690) REFERE D. Amelin et al D.M. Alde et al D.M. Alde et al S. Fukui et al. D. L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorlich et al. H. Becker et al. M.J. Corden et C. Ballay et al. A.D. Martin et A.D. Martin et Y.M. Antipov et R. Gessaroli et v. R. Gessaroli et v. R. Gessaroli et v. | NCES (A auregard et al. al. al. al. al. tal. | N COM. EC 8.95 η S COM. S 37 π (BELG, SE SUGI, NAG (BAR, SE SUGI, NAG (BAR, SE SUGI, NAG (BAR, SE SUGI, NAG (BAR, SE SUGI, NAG (BIR) (BIR) | $\begin{array}{c} MENT \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \\ \hline \\ MENT \\ \hline - \rho \rightarrow \eta \pi^+ \pi^- n \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ RP, KEK, LANL+) \\ O, KEK, KYOT+) \\ (IOWA, MICH) \\ (BONN, CERN+) \\ I, CRAC, MPIM+) \\ (BARI, BONN+) \\ T, MPIM, CERN+) \\ N, ZEEM, CRAC \\ M, RHEL, TELA+) JP \\ (COLU, BING) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ A, FIRZ, GENO+) \\ A, FIRZ, GENO+) \\ \end{array}$ |
| (a ₂ (1320)π) / Γ (ρ(770) η) | DOCUMENT ID FUKUI DOCUMENT ID AMELIN (1690) REFERE D. Amelin et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorifich et al. H. Becker et al. M.J. Corden c C. Ballay et al. A.D. Martin et Y.M. Antipov et R. Gessaroli et v. W. Blum et al. P.G. Estabrooks, | REC SPI TEC OO VE: NCES I. I | N COM. EC 8.95 N COM. S 37 π (BELG, SE SUGI, NAG (BAR MMST, CERN al. (CRAC MPIM, CERN (BIRI) (BGN) | $\begin{array}{c} \text{MENT} \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \hline \\ \Gamma_{10}/\Gamma_{8} \\ \text{MENT} \\ -\rho \rightarrow \eta \pi^+ \pi^- n \\ \\ \text{(VES Collab.)} \\ \text{(GAMS Collab.)} JP \\ \text{RP, KEK, LANL+} \\ \text{(IOWA, MICH)} \\ \text{(BOWA, MICH)} \\ \text{BONN, CERN+} \\ \text{I, CRAC, MPIM+} \\ \text{(ERR, BONN+)} \\ \text{MPIM, CERN+} \\ \text{N, ZEEM, CRAC} \\ \text{4, RHEL, TELA+JP} \\ \text{(COLU, BING)} \\ \text{(DURH, GEVA)} \\ \text{(DURH, GEVA)} \\ \text{(SERP, GEVA)} \\ \text{4, FIRZ, GENO+} \\ \text{(CERN, MPIM)JP} \\ \end{array}$ |
| (a2(1320)π)/Γ(ρ(770)η) | DOCUMENT ID FUKUI DOCUMENT ID AMELIN (1690) REFERE D. Amelin et al D.M. Alde et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorich et al. H. Becker et al. M.J. Corden et C. Baltay et al. A.D. Martin et Y.M. Antipov et R. Gessroll et v. W. Blum et al. P.G. Estabrooks, B.D. Hyams et A. Engler et al. | REC SPI TEC OO VE: NCES I. I | N COM. EC 8.95 N COM. S 37 π (BELG, SE SUGI, NAG (BAR MMST, CERN al. (CRAC MPIM, CERN (BIRI) (BGN) | $\begin{array}{c} MENT \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \\ \hline \\ MENT \\ - \rho \rightarrow \eta \pi^+ \pi^- n \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ (GAMS Collab.) JP \\ (REK, LANL+) \\ (KEK, KYOT+) \\ (IOWA, MICH) \\ , BONN, CERN+) \\ , CRAC, MPIM+) \\ (BARI, BONN+) \\ , MPIM, CERN+1 \\ N, ZEEM, CRAC) \\ M, (REL, TELA+) JP \\ (COLU, BING) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ (SERP, GEVA) \\ A, FIRZ, GENO+) \\ (CERN, MPIM) JP \\ (CERN, MPIM) \\ (CASE) \\ \end{array}$ |
| (a2(1320)π) / Γ (ρ(770)η) (ALUE | DOCUMENT ID FUKUI DOCUMENT ID AMELIN (1690) REFERE D. Amelin et al D.M. Alde et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorich et al. H. Becker et al. M.J. Corden et C. Ballay et al. A.D. Martin et Y.M. Antipov et R. Gessaroli et v. W. Blum et al. P.G. Estabrooks, B.D. Hyams et A. Estabrooks, B.D. Hyams et A. Estabrooks, B.D. Hyams et A. Engler et al. G. Grayer et al. G. K. Kliger et al. | REES I TEC OO VE: NCES I I I I I I I I I I I I I I I I I I I | N COM. EC 8.95 N COM. S 37 π (BELG, SE SUGI, NAG (BAR MMST, CERN al. (CRAC MPIM, CERN (BIRI) (BGN) | $\begin{array}{c} \text{MENT} \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \hline \\ \Gamma_{10}/\Gamma_{8} \\ \text{MENT} \\ \hline - \rho \rightarrow \eta \pi^+ \pi^- n \\ \\ \text{(VES Collab.)} \\ \text{(GAMS Collab.)} JP \\ \text{RP, KEK, LANL+} \\ \text{(IOWA, MICH)} \\ \text{(BOWA, MICH)} \\ \text{(BOWA, ERN+)} \\ \text{I. CRAC, MPIM+} \\ \text{(ERR, BONN+)} \\ \text{ MPIM, CERN+} \\ \text{I. MPIM, CERN+} \\ \text{(COLU, BING)} \\ \text{(DURH, GEVA)} \\ \text{(DURH, GEVA)} \\ \text{(DURH, GEVA)} \\ \text{(ERR, BONO+)} \\ \text{(CERN, MPIM)} \\ \text{(CERN, MPIM)} JP \\ \text{(CERN, MPIM)} JP \\ \text{(CERN, MPIM)} \\ \text{(CERN, MPIM)} \\ \text{(CERN, MPIM)} JP \\ \text{(CERN, MPIM)} \\ \text{(CERN, MPIM)} \\ \text{(CERN, MPIM)} JP \\ \text{(CERN, MPIM)} \\ $ |
| (a ₂ (1320)π)/Γ (ρ(770)η) (AUUE | DOCUMENT ID FUKUI DOCUMENT ID AMELIN 3 (1690) REFERE D. Amelin et al D.M. Alde et al D.M. Alde et al S. Fukui et al. D.L. Denney et C. Evangelista e B. Alper et al. G. Costa de Be. L. Gorifich et al. H. Becker et al. A.D. Martin et A.D. Martin et Y.M. Antipov et R. Gessroll et W. Blum et al. P.G. Estabrooks, B.D. Hyams et A. Engler et al. G. Grayer et al. AF 19 63.9. Y. Oren et al. | REC SPI TEC OO VE: NCES I. I | N COM. EC 8.95 N COM. S 37 π (BELG, SE SUGI, NAG (BAR MMST, CERN al. (CRAC MPIM, CERN (BIRI) (BGN) | $\begin{array}{c} MENT \\ \pi^- \rho \rightarrow \\ \pi^+ \pi^- n \\ \\ \hline \\ MENT \\ - \rho \rightarrow \eta \pi^+ \pi^- n \\ \\ \\ (VES Collab.) \\ (GAMS Collab.) JP \\ (GAMS Collab.) JP \\ (REK, LANL+) \\ (KEK, KYOT+) \\ (IOWA, MICH) \\ , BONN, CERN+) \\ , CRAC, MPIM+) \\ (BARI, BONN+) \\ , MPIM, CERN+1 \\ N, ZEEM, CRAC) \\ M, RHEL, TELA+ JP \\ (COLU, BING) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ (DURH, GEVA) \\ (CERN, MPIM) JP \\ (CERN, MPIM) \\ (CERN, MPIM) \\ (CERN, MPIM) \\ (CMU, CASE) \\ (CANL, OXF) \\ (ANL, OXF) \\ \end{array}$ |
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THE $\rho(1450)$ AND THE $\rho(1700)$

Updated May 2010 by S. Eidelman (Novosibirsk) and G. Venanzoni (Frascati).

In our 1988 edition, we replaced the $\rho(1600)$ entry with two new ones, the $\rho(1450)$ and the $\rho(1700)$, because there was emerging evidence that the 1600-MeV region actually contains two ρ -like resonances. Erkal [1] had pointed out this possibility with a theoretical analysis on the consistency of 2π and 4π electromagnetic form factors and the $\pi\pi$ scattering length. Donnachie [2], with a full analysis of data on the 2π and 4π final states in e^+e^- annihilation and photoproduction reactions, had also argued that in order to obtain a consistent picture, two resonances were necessary. The existence of $\rho(1450)$ was supported by the analysis of $\eta\rho^0$ mass spectra obtained in photoproduction and e^+e^- annihilation [3], as well as that of $e^+e^- \to \omega\pi$ [4].

The analysis of [2] was further extended by [5,6] to include new data on 4π -systems produced in e^+e^- annihilation, and in τ -decays (τ decays to 4π , and e^+e^- annihilation to 4π can be related by the Conserved Vector Current assumption). These systems were successfully analyzed using interfering contributions from two ρ -like states, and from the tail of the $\rho(770)$ decaying into two-body states. While specific conclusions on $\rho(1450) \to 4\pi$ were obtained, little could be said about the $\rho(1700)$.

Independent evidence for two 1⁻ states is provided by [7] in 4π electroproduction at $\langle Q^2 \rangle = 1$ (GeV/c)², and by [8] in a high-statistics sample of the $\eta\pi\pi$ system in π^-p charge exchange.

This scenario with two overlapping resonances is supported by other data. Bisello [9] measured the pion form factor in the interval 1.35–2.4 GeV, and observed a deep minimum around 1.6 GeV. The best fit was obtained with the hypothesis of ρ -like resonances at 1420 and 1770 MeV, with widths of about 250 MeV. Antonelli [10] found that the $e^+e^- \to \eta \pi^+ \pi^-$ cross section is better fitted with two fully interfering Breit-Wigners, with parameters in fair agreement with those of [2] and [9]. These results can be considered as a confirmation of the $\rho(1450)$.

Decisive evidence for the $\pi\pi$ decay mode of both $\rho(1450)$ and $\rho(1700)$ comes from $\overline{p}p$ annihilation at rest [11]. It has been shown that these resonances also possess a $K\overline{K}$ decay mode [12–14]. High-statistics studies of the decays $\tau \to \pi\pi\nu_{\tau}$ [15,16], and $\tau \to 4\pi\nu_{\tau}$ [17] also require the $\rho(1450)$, but are not sensitive to the $\rho(1700)$, because it is too close to the τ mass. A recent very-high-statistics study of the $\tau \to \pi\pi\nu_{\tau}$ decay performed at Belle [18] reports the first observation of both $\rho(1450)$ and $\rho(1700)$ in τ decays.

The structure of these ρ states is not yet completely clear. Barnes [19] and Close [20] claim that $\rho(1450)$ has a mass consistent with radial 2S, but its decays show characteristics of hybrids, and suggest that this state may be a 2S-hybrid mixture. Donnachie [21] argues that hybrid states could have a 4π decay mode dominated by the $a_1\pi$. Such behavior has been observed by [22] in $e^+e^- \to 4\pi$ in the energy range 1.05–1.38 GeV, and by [17] in $\tau \to 4\pi$ decays. Alexander [23] observes the $\rho(1450) \to \omega \pi$ decay mode in *B*-meson decays, however, does not find $\rho(1700) \to \omega \pi^0$. A similar conclusion is made by [24], who studied the process $e^+e^- \to \omega \pi^0$. Various decay modes of the $\rho(1450)$ and $\rho(1700)$ are observed in $\overline{p}n$ and $\overline{p}p$ annihilation [25,26], but no definite conclusions can be drawn. More data should be collected to clarify the nature of the ρ states, particularly in the energy range above 1.6 GeV.

We now list under a separate entry the $\rho(1570)$, the $\phi\pi$ state with $J^{PC}=1^{--}$ earlier observed by [27] (referred to as C(1480)) and recently confirmed by [28]. While [29] shows that it may be a threshold effect, [5] and [30] suggest two independent vector states with this decay mode. The C(1480) has not been seen in the $\overline{p}p$ [31] and e^+e^- [32,33] experiments. However, the sensitivity of the two latter is an order of magnitude lower than that of [28]. Note that [28] can not exclude that their observation is due to an OZI-suppressed decay mode of the $\rho(1700)$.

Several observations on the $\omega\pi$ system in the 1200-MeV region [34–40] may be interpreted in terms of either $J^P=1^ \rho(770) \to \omega\pi$ production [41], or $J^P=1^+$ $b_1(1235)$ production [39,40]. We argue that no special entry for a $\rho(1250)$ is needed. The LASS amplitude analysis [42] showing evidence for $\rho(1270)$ is preliminary and needs confirmation. For completeness, the relevant observations are listed under the $\rho(1450)$

Recently [43] reported a very broad 1^{--} resonance-like K^+K^- state in $J/\psi \to K^+K^-\pi^0$ decays. Its pole position corresponds to mass of 1576 MeV and width of 818 MeV. [44–46] suggest its exotic structure (molecular or multiquark), while [47] and [48] explain it by the interference between the $\rho(1450)$ and $\rho(1700)$. We quote [43] as X(1575) in the section "Further States."

Evidence for ρ -like mesons decaying into 6π states was first noted by [49] in the analysis of 6π mass spectra from e^+e^- annihilation [50,51] and diffractive photoproduction [52]. Clegg [49] argued that two states at about 2.1 and 1.8 GeV exist: while the former is a candidate for the $\rho(2150)$, the latter could be a manifestation of the $\rho(1700)$ distorted by threshold effects. BaBar reported observations of the new decay modes of the $\rho(2150)$ in the channels $\eta'(958)\pi^+\pi^-$ and $f_1(1285)\pi^+\pi^-$ [53]. The relativistic quark model [54] predicts the 2^3D_1 state with $J^{PC}=1^{--}$ at 2.15 GeV which can be identified with the $\rho(2150)$.

The E687 Collaboration at Fermilab reported an observation of a narrow-dip structure at 1.9 GeV in the $3\pi^+3\pi^-$ diffractive photoproduction [55]. A similar effect of the dip in the cross section of $e^+e^- \to 6\pi$ around 1.9 GeV has been earlier reported by DM2 [51], where 6π included both $3\pi^+3\pi^-$ and $2\pi^+2\pi^-2\pi^0$. Later the dip in the R value (the total cross section of $e^+e^- \to$ hadrons divided by the cross section of $e^+e^- \to \mu^+\mu^-$) was

[56], again around 1.9 GeV. This energy is close to the $N\overline{N}$ threshold, which hints at the possible relation between the dip and $N\overline{N}$, e.g., the frequently discussed narrow $N\overline{N}$ resonance or just a threshold effect. Such behaviour is also characteristic of exotic objects like vector $q\overline{q}$ hybrids. Note that [57] failed to find this state in the reaction $\overline{n}p \to 3\pi^+2\pi^-\pi^0$. A reanalysis of the E687 data by [58] shows that a dip may arise due to interference of a narrow object with a broad $\rho(1700)$ independently of the nature of the former. BaBar studied the processes $e^+e^- \to 3\pi^+3\pi^-$ and $e^+e^- \to 2\pi^+2\pi^-2\pi^0$ using the radiative return, and observed a structure around 1.9 GeV in both final states [59]. The data are not well described by a single Breit-Wigner state, and a good fit is achieved while taking into account the interference of such a structure with a Jacob-Slansky amplitude for continuum. The mass of this state obtained by BaBar is consistent with [56] and [55], but the width is substantially larger. Recently [28] observed a structure at 1.9 GeV in the radiative return to the $\phi\pi$ final state, with a much smaller width of 48 ± 17 MeV consistent with that of [56,58]. We list these observations under a separate particle $\rho(1900)$, which needs confirmation.

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$\rho(1700)$ MASS

$\eta \rho^0$ AND $\pi^+\pi^-$ MODES

1720±20 OUR ESTIMATE

DOCUMENT ID

$\eta \rho^0$ MODE

The data in this block is included in the average printed for a previous datablock

• • • We do not use the following data for averages, fits, limits, etc. • • •

1740 \pm 20 ANTONELLI 88 DM2 $e^+e^- \to \eta \pi^+\pi^-$ 1701 \pm 15 1 FUKUI 88 SPEC 8.95 $\pi^-p \to \eta \pi^+\pi^-$

1 Assuming $\rho^+ f_0(1370)$ decay mode interferes with $a_1(1260)^+ \pi$ background. From a two Breit-Wigner fit.

$\pi\pi$ MOD

<u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

The data in this block is included in the average printed for a previous datablock

| | We do not use th | e following | data for averages | , fits, | limits, e | etc. • • • |
|-------|-------------------|-------------|------------------------|---------|-----------|------------------------------------------------------------|
| 1728 | ± 17 ± 89 | 5.4M 2 | ^{,3} FUJIKAWA | 80 | BELL | $\tau^- \rightarrow \ \pi^- \pi^0 \nu_\tau$ |
| 1780 | + 37 - 29 | | ⁴ ABELE | 97 | CBAR | $\overline{p} n \rightarrow \pi^- \pi^0 \pi^0$ |
| 1719 | ± 15 | | ⁴ BERTIN | 97c | OBLX | $0.0 \; \overline{p} p \rightarrow \; \pi^+ \pi^- \pi^0$ |
| 1730 | ±30 | | CLEGG | 94 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 1768 | ± 21 | | BISELLO | 89 | DM2 | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 1745. | 7 ± 91.9 | | DUBNICKA | 89 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-$ |
| 1546 | ± 26 | | GESHKEN | 89 | RVUE | |
| 1650 | | | ⁵ ERKAL | 85 | RVUE | 20-70 $\gamma p \rightarrow \gamma \pi$ |
| 1550 | ± 70 | | ABE | 84B | HYBR | $20 \ \gamma p \rightarrow \ \pi^+ \pi^- p$ |
| 1590 | ± 20 | | ⁶ ASTON | 80 | OMEG | $20-70 \gamma \rho \rightarrow \rho 2\pi$ |
| 1600 | ± 10 | | ⁷ ATIYA | 79B | SPEC | 50 γ C \rightarrow C 2π |
| 1598 | + 24 - 22 | | BECKER | 79 | ASPK | $17~\pi^-p$ polarized |
| 1659 | ± 25 | | ⁵ LANG | 79 | RVUE | |
| 1575 | | | ⁵ MARTIN | 78C | RVUE | $17 \pi^{-} p \rightarrow \pi^{+} \pi^{-} n$ |
| 1610 | ± 30 | | ⁵ FROGGATT | 77 | RVUE | $17 \pi^- p \rightarrow \pi^+ \pi^- n$ |
| 1590 | ±20 | | ⁸ HYAMS | 73 | ASPK | $17~\pi^- \rho \rightarrow ~\pi^+ \pi^- n$ |

$\rho(1700)$

| $ F_{\pi}(0) ^2$ fixed to 1 |
|-----------------------------|
|-----------------------------|

³ From the GOUNARIS 68 parametrization of the pion form factor.

⁶ Simple relativistic Breit-Wigner fit with constant width.

⁷ An additional 40 MeV uncertainty in both the mass and width is present due to the choice of the background shape.

8 Included in BECKER 79 analysis.

$\pi\omega$ MODE

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|---------|---------|----------------------------------------|
| • • • We do not use the follow | wing data for average | s, fits | limits, | etc. • • • |
| 1550 to 1620 | ⁹ ACHASOV | 001 | SND | $e^+e^- ightarrow \ \pi^0\pi^0\gamma$ |
| 1580 to 1710 | ¹⁰ ACHASOV | 001 | SND | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ |
| 1710 ± 90 | ACHASOV | 97 | RVUE | $e^+ e^- ightarrow \omega \pi^0$ |

 9 Taking into account both $\rho(1450)$ and $\rho(1700)$ contributions. Using the data of ACHASOV 001 on $e^+e^-\to\omega\pi^0$ and of EDWARDS 00A on $\tau^-\to\omega\pi^-\nu_{\tau^+}$ $\rho(1450)$ mass and width fixed at 1400 MeV and 500 MeV respectively.

 10 Taking into account the $\rho(1700)$ contribution only. Using the data of ACHASOV 001 on $e^+e^-\to\omega\,\pi^0$ and of EDWARDS 00A on $\tau^-\to\omega\,\pi^-\nu_\tau$.

κκ mode

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT | |
|-------------------|---------|----------------------|---------|-------------|----------|------------------------|-------------------------|
| • • • We do not | use the | following data for a | verages | , fits, lir | nits, et | C. • • • | |
| 1740.8 ± 22.2 | 27k | ¹¹ ABELE | 99D | CBAR | | | $\kappa^+\kappa^-\pi^0$ |
| 1582 \pm 36 | 1600 | CLELAND | 82B | SPEC | \pm | $50 \pi p \rightarrow$ | $K_c^0 K^{\pm} p$ |

 11 K-matrix pole. Isospin not determined, could be $\omega(1650)$ or $\phi(1680)$.

$2(\pi^+\pi^-)$ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------|---------------|-------------------------|---------|-----------|--------------------------------------------|
| • • • We do not use | the following | g data for averages | , fits, | limits, e | etc. • • • |
| $1851 + 27 \\ - 24$ | | ACHASOV | 97 | RVUE | $e^+ e^- \rightarrow 2(\pi^+ \pi^-)$ |
| 1570 ± 20 | | ¹² CORDIER | 82 | DM1 | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 1520 ± 30 | | ¹³ ASTON | 81E | OMEG | 20-70 $\gamma p \rightarrow p 4\pi$ |
| 1654 ± 25 | | ¹⁴ DIBIANCA | 81 | DBC | $\pi^+ d \rightarrow pp 2(\pi^+ \pi^-)$ |
| 1666 ± 39 | | ¹² BACCI | 80 | FRAG | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 1780 | 34 | KILLIAN | 80 | SPEC | 11 $e^- p \rightarrow 2(\pi^+ \pi^-)$ |
| 1500 | | ¹⁵ ATIYA | 79B | SPEC | $50 \gamma C \rightarrow C4\pi^{\pm}$ |
| 1570 ± 60 | 65 | ¹⁶ ALEXANDER | 75 | HBC | $7.5 \gamma p \rightarrow p 4\pi$ |
| 1550 ± 60 | | ¹³ CONVERSI | 74 | OSPK | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 1550 ± 50 | 160 | SCHACHT | 74 | STRC | 5.5-9 $\gamma \rho \rightarrow \rho 4\pi$ |
| 1450 ± 100 | 340 | SCHACHT | 74 | STRC | 9–18 $\gamma p \rightarrow p 4\pi$ |
| 1430 ± 50 | 400 | BINGHAM | 72B | HBC | 9.3 $\gamma p \rightarrow p 4\pi$ |
| | | | | | |

 12 Simple relativistic Breit-Wigner fit with model dependent width.

16 Skew mass distribution compensated by Ross-Stodolsky factor.

$\pi^+\pi^-\pi^0\pi^0$ MODE

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT | |
|-----------------------------------|-----------------------|---------------|----------------|--|
| • • • We do not use the following | ng data for averages, | fits, limits, | etc. • • • | |
| 1660 ± 30 | ATKINSON 8 | 35B OMEG | $20-70 \sim p$ | |

$3(\pi^+\pi^-)$ AND $2(\pi^+\pi^-\pi^0)$ MODES

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
|--------------------|------------------------|-------|----------|-------------------------|--------------------------------------------|
| • • • We do not us | e the following data | for a | verages, | fits, limits, etc | . • • • |
| 1730 ± 34 | ¹⁷ FRABETTI | | | | |
| 1783 ± 15 | CLEGG | 90 | RVUE | $e^+ e^- \rightarrow 3$ | $(\pi^{+}\pi^{-})2(\pi^{+}\pi^{-}\pi^{0})$ |
| 17 From a fit with | wo resonances with | the J | АСОВ 7 | 2 continuum. | |

ho(1700) WIDTH

ηho^0 AND $\pi^+\pi^-$ MODES

VALUE (MeV)
250±100 OUR ESTIMATE

DO CUMENT ID

no⁰ MODE

| $\eta \rho^{\circ}$ MODE | | | |
|------------------------------------|-----------------------|---------|---------------------|
| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
| The data in this block is included | in the average printe | d for a | previous datablock. |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 150 ± 30 | | 88 | DM2 | $e^+ e^- ightarrow \eta \pi^+ \pi^-$ |
|--------------|----------------------|----|------|---------------------------------------------|
| 282±44 | ¹⁸ FU KUI | 88 | SPEC | 8.95 $\pi^- \rho \to \eta \pi^+ \pi^- \eta$ |

 $^{^{18}}$ Assuming $\rho^+\,f_0(1370)$ decay mode interferes with $a_1(1260)^+\,\pi$ background. From a two Breit-Wigner fit.

$\pi\pi$ MODE

VALUE (MeV) EVTS DOCUMENT ID TECN COMMENT
The data in this block is included in the average printed for a previous datablock.

• • • We do not use the following data for averages, fits, limits, etc. • •

| $164 \pm 21 \begin{array}{c} +89 \\ -26 \end{array}$ | 5.4 M ^{19,20} FUJIKAWA | 08 BELL | $\tau^- \to \ \pi^- \pi^0 \nu_\tau$ |
|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\begin{array}{cccc} 275 & \pm & 45 \\ 310 & \pm & 40 \\ 400 & \pm 100 \\ 224 & \pm & 22 \\ 242.5 \pm 163.0 \\ 620 & \pm & 60 \end{array}$ | 21 ABELE 21 BERTIN CLEGG BISELLO DUBNICKA GESHKEN | 97c OBLX 94 RVUE 89 DM2 89 RVUE 89 RVUE | $\begin{array}{l} \overline{p} n \rightarrow \pi^- \pi^0 \pi^0 \\ 0.0 \overline{p} p \rightarrow \pi^+ \pi^- \pi^0 \\ e^+ e^- \rightarrow \pi^+ \pi^- \\ e^+ e^- \rightarrow \pi^+ \pi^- \\ e^+ e^- \rightarrow \pi^+ \pi^- \end{array}$ |
| <315 $280 \begin{array}{c} + & 30 \\ - & 80 \end{array}$ | ²² ERKAL ABE | | 20-70 $\gamma p \rightarrow \gamma \pi$ 20 $\gamma p \rightarrow \pi^+ \pi^- p$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ²³ ASTON ²⁴ ATIYA | | $\begin{array}{ccc} 2070 \ \gamma p \ \rightarrow \ p \ 2\pi \\ 50 \ \gamma \text{C} \ \rightarrow \ \text{C} \ 2\pi \end{array}$ |
| $175 \begin{array}{c} + & 98 \\ - & 53 \end{array}$ | BECKER | 79 A SP K | 17 π^-p polarized |
| 232 ± 34 340 300 ± 100 180 ± 50 | ²² LANG ²² MARTIN ²² FROGGATT ²⁵ HYAMS | 77 RVUE | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

 $^{^{19}|}F_{\pi}(0)|^2$ fixed to 1.

κ₹ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------|---------------|---------------------|---------|----------------|-------------|-------------------------------------------------|
| • • • We do not | use the fol | lowing data for a | verages | , fits, lir | nits, e | tc. • • • |
| 187.2± 26.7 | 27k | ²⁶ ABELE | 99D | CBAR | \pm | $0.0 \overline{p} p \rightarrow K^+ K^- \pi^0$ |
| 265 ± 120 | 1600 | CLELAND | 82B | SPEC | \pm | $50 \pi p \rightarrow K_S^0 K^{\pm} p$ |
| ²⁶ K-matrix pole | e. Isospin no | ot determined, co | uld be | $\omega(1650)$ | or ϕ (| 1680). |

$2(\pi^+\pi^-)$ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|------------------|-------------------------|---------|-------------|--------------------------------------------|
| • • • We do not us | se the following | ng data for average | s, fits | , limits, e | etc. • • • |
| 510± 40 | | ²⁷ CORDIER | 82 | DM1 | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 400 ± 50 | | ²⁸ ASTON | 81E | OMEG | $20-70 \gamma p \rightarrow p 4\pi$ |
| 400 ± 146 | | ²⁹ DIBIANCA | 81 | DBC | $\pi^+ d \rightarrow pp2(\pi^+\pi^-)$ |
| 700 ± 160 | | ²⁷ BACCI | 80 | FRAG | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 100 | 34 | KILLIAN | 80 | SPEC | $11 e^- p \rightarrow 2(\pi^+ \pi^-)$ |
| 600 | | ³⁰ ATIYA | 79B | SPEC | $50 \gamma C \rightarrow C4\pi^{\pm}$ |
| 340 ± 160 | 65 | ³¹ ALEXANDER | 75 | HB C | $7.5 \gamma p \rightarrow p 4\pi$ |
| 360 ± 100 | | ²⁸ CONVERSI | 74 | OSPK | $e^{+}e^{-} \rightarrow 2(\pi^{+}\pi^{-})$ |
| 400 ± 120 | 160 | 32 SCHACHT | 74 | STRC | 5.5-9 $\gamma p \rightarrow p 4\pi$ |
| 850 ± 200 | 340 | ³² SCHACHT | 74 | STRC | $9-18 \gamma p \rightarrow p 4\pi$ |
| 650 ± 100 | 400 | BINGHAM | 72B | HBC | $9.3 \gamma p \rightarrow p4\pi$ |
| | | | | | |

²⁷ Simple relativistic Breit-Wigner fit with model-dependent width.

$\pi^+\pi^-\pi^0\pi^0$ MODE

| VALUE (MeV) | DOCUMENT ID | TECN COMMENT |
|-----------------------------------|----------------------------|--------------------|
| • • • We do not use the following | g data for averages, fits, | limits, etc. • • • |
| 300±50 | ATKINSON 85B | OMEG 20-70 γp |

$\omega\pi^0$ MODE

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|------------------------------------|--------------------------|----------|---------|---------------------------------------|--|
| ullet $ullet$ We do not use the fo | llowing data for average | s, fits, | limits, | etc. • • • | |
| 350 to 580 | ³³ ACHASOV | | | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ | |
| 490 to 1040 | ³⁴ ACHASOV | 001 | SND | $e^+e^- \rightarrow \pi^0\pi^0\gamma$ | |

 $^{^{33}}$ Taking into account both $\rho(1450)$ and $\rho(1700)$ contributions. Using the data of ACHASOV 001 on $e^+\,e^-\to\omega\pi^0$ and of EDWARDS 00A on $\tau^-\to\omega\pi^-\nu_\tau$. $\rho(1450)$ mass and width fixed at 1400 MeV and 500 MeV respectively.

$3(\pi^+\pi^-)$ AND $2(\pi^+\pi^-\pi^0)$ MODES

 VALUE (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 • • • We do not use the following data for averages, fits, limits, etc. • • •

⁴ T-matrix pole.

⁵ From phase shift analysis of HYAMS 73 data.

¹³ Simple relativistic Breit-Wigner fit with constant width.

¹⁴ One peak fit result.

¹⁵ Parameters roughly estimated, not from a fit.

From the GOUNARIS 68 parametrization of the pion form factor.

²¹ T-matrix pole

²² From phase shift analysis of HYAMS 73 data.

²³ Simple relativistic Breit-Wigner fit with constant width.

²⁴ An additional 40 MeV uncertainty in both the mass and width is present due to the choice of the background shape.

²⁵ Included in BECKER 79 analysis.

 $^{^{\}mbox{\footnotesize 28}}$ Simple relativistic Breit-Wigner fit with constant width.

²⁹ One peak fit result.

³⁰ Parameters roughly estimated, not from a fit.

³¹ Skew mass distribution compensated by Ross-Stodolsky factor.

 $^{^{32}}$ Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.

³⁴ Taking into account the ρ (1700) contribution only. Using the data of ACHASOV 00i on $e^+e^-\to\omega\pi^0$ and of EDWARDS 00A on $\tau^-\to\omega\pi^-\nu_\tau$.

³⁵ From a fit with two resonances with the JACOB 72 continuum.

 $^{41}\, {\rm The} \,\, \pi \, \pi$ system is in S-wave.

Meson Particle Listings $\rho(1700)$

| es, fits, limit: 5B OMEG 2 OMEG 2 OMEG FECA es, fits, limit: 01B CBA FECA Es, fits, limit: 01B CBA FECA CBA F | CHG COMMENT S, etc. • • • $20-70 \ \gamma p \rightarrow p4\pi$ $77/\Gamma$ N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ Fa/F N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ Fa/F N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ Fa/F N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ Fa/F N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ Fa/F N COMMENT S, etc. • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 55 OMEG 2 OMEG 2 OMEG FECA 2 OS, fits, limit: 01B CBA FECA 01B CBA TECA 01B CBA TECA 01B CBA TECA 01B CBA | $\begin{array}{c} 20-70 \ \gamma p \\ 20-70 \ \gamma p \rightarrow p 4\pi \end{array}$ $\begin{array}{c} \Gamma_7/\Gamma \\ \Gamma_7/\Gamma \\ \Gamma_8, \text{ etc.} \bullet \bullet \bullet \\ \Gamma_8 \ 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \Gamma_8/\Gamma \\ \Gamma_8/\Gamma \\ \Gamma_8, \text{ etc.} \bullet \bullet \bullet \\ \Gamma_8 \ 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \Gamma_8/\Gamma \\ \Gamma_8/\Gamma \\ \Gamma_8, \text{ etc.} \bullet \bullet \bullet \\ \Gamma_8 \ 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \Gamma_9/\Gamma \\ \Gamma_9/\Gamma \\ \Gamma_9, \Gamma_9/\Gamma \\ \Gamma_9, \Gamma_9/\Gamma \\ \Gamma_9, \Gamma_9/\Gamma \\ \Gamma_9, \Gamma_9/\Gamma \\ \Gamma_9/\Gamma \\ \Gamma_9, \Gamma_9/\Gamma \\ \Gamma_$ |
| PECA Ses, fits, limits OIB CBA FECA TECA OIB CBA TECA OIB CBA TECA OIB CBA OIB CBA OIB CBA | $\begin{array}{c c} & & & & & & & & \\ \hline N & & & & & & \\ S, \text{ etc.} & \bullet & \bullet & \bullet & \\ S, \text{ etc.} & \bullet & \bullet & \bullet & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ COMMENT & & & & \\ S, \text{ etc.} & \bullet & \bullet & \bullet & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & & \\ \hline N & & & & & \\ N & & & & & \\ \hline N & & & & \\ N & & & & & \\ \hline N & & & & & \\ \hline N & & & & & \\ \hline N & & & & \\ N & & & & & \\ \hline N & & & & & \\ N & & & & & \\ N & & & & &$ |
| es, fits, limit: 01B CBA TECA O1B CBA TECA TECA O1B CBA TECA TECA TECA O1B CBA TECA O1B CBA O1B CBA | $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \bullet \bullet \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet |
| es, fits, limit: 01B CBA TECA O1B CBA TECA TECA O1B CBA TECA TECA TECA O1B CBA TECA O1B CBA O1B CBA | $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \bullet \\ R & 0.0 \overline{\rho} n \to 5 \pi \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet \bullet \bullet \bullet \bullet \end{array}$ $\begin{array}{c} \frac{V}{S} & \underbrace{COMMENT}_{S, etc.} \bullet |
| TECA | IR $0.0 \ \overline{p} \ n \rightarrow 5\pi$ $\begin{array}{c} \hline R \ N \ \hline \\ N \ COMMENT \ \hline \\ S, etc. \bullet \bullet \bullet \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \hline R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ N \ COMMENT \ \hline \\ S, etc. \bullet \bullet \bullet \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ R \ 0.0 \ \overline{p} \ n \rightarrow 5\pi \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \ COMMENT \ S, etc. \bullet \\ \hline \\ N \ COMMENT \ S, etc. \bullet \ COMMENT \ S, etc. \ COMMENT $ |
| TECA on CBA TECA TECA TECA TECA TECA TECA TECA TE | $ \begin{array}{c c} & & & & & & \hline { \begin{tabular}{c} {\bf N} & \underline{\bf COMMENT} \\ {\bf S}, \ {\bf etc.} & \bullet & \bullet \\ {\bf R} & 0.0 \ \overline{p} \ n & \to 5 \pi \\ \hline & & & & & \hline {\bf \Gamma9/\Gamma} \\ {\bf S}, \ {\bf etc.} & \bullet & \bullet \\ {\bf R} & 0.0 \ \overline{p} \ n & \to 5 \pi \\ \hline & & & & & \hline {\bf \Gamma10/\Gamma} \\ {\bf S}, \ {\bf etc.} & \bullet & \bullet \\ & & & & & \\ {\bf S}, \ {\bf etc.} & \bullet & \bullet \\ \hline & & & & & \\ \hline & & & & & \\ \hline & & & &$ |
| es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA | $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \\ \text{RR} & 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \\ \text{RR} & 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \end{array}$ |
| es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA | $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \\ \text{RR} & 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \\ \text{RR} & 0.0 \ \overline{p}n \rightarrow 5\pi \end{array}$ $\begin{array}{c} \frac{N}{N} & \frac{COMMENT}{S}, \text{ etc.} \bullet \bullet \bullet \end{array}$ |
| es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA TECA es, fits, limit: 01B CBA | s, etc. $\bullet \bullet \bullet$ R $0.0 \ \overline{p}n \rightarrow 5\pi$ Fg/F s, etc. $\bullet \bullet \bullet$ R $0.0 \ \overline{p}n \rightarrow 5\pi$ $\Gamma = \frac{COMMENT}{5\pi}$ $\Gamma = \frac{V}{5\pi}$ $\Gamma = \frac{V}{5\pi}$ $\Gamma = \frac{V}{5\pi}$ $\Gamma = \frac{V}{5\pi}$ |
| OIB CBA TECA es, fits, limit OIB CBA TECA TECA OIB CBA | RR $0.0 \ \overline{p} n \rightarrow 5\pi$ $rac{\Gamma g / \Gamma}{N}$ s, etc. • • • RR $0.0 \ \overline{p} n \rightarrow 5\pi$ $rac{\Gamma g / \Gamma}{N}$ $rac{\Gamma g / \Gamma}{N}$ s, etc. • • • |
| TECA OIB CBA TECA TECA TECA OIB CBA | $ \frac{N}{N} = \frac{COMMENT}{N} $ s, etc. • • • $ \frac{N}{N} = \frac{0.0 \overline{p}n \rightarrow 5\pi}{10/\Gamma} $ s, etc. • • • |
| es, fits, limite 01B CBA TECA es, fits, limite 01B CBA | $\frac{N}{N}$ COMMENT $\frac{N}{N}$ etc. $\frac{N}{N}$ $\frac{N}{N}$ $\frac{N}{N}$ COMMENT $\frac{N}{N}$ etc. $\frac{N}{N}$ etc. $\frac{N}{N}$ |
| es, fits, limite 01B CBA TECA es, fits, limite 01B CBA | $\frac{N}{N}$ COMMENT $\frac{N}{N}$ etc. $\frac{N}{N}$ $\frac{N}{N}$ $\frac{N}{N}$ COMMENT $\frac{N}{N}$ etc. $\frac{N}{N}$ etc. $\frac{N}{N}$ |
| es, fits, limite 01B CBA TECA es, fits, limite 01B CBA | s, etc. $\bullet \bullet \bullet$ IR $0.0 \overline{p} n \to 5\pi$ Γ_{10} / Γ S, etc. $\bullet \bullet \bullet$ |
| <u>TECA</u> es, fits, limit: 01B CBA | Γ ₁₀ /Γ ν <u>comment</u> s, etc. • • • |
| es, fits, limit | <u>COMMENT</u> s, etc. • • • |
| es, fits, limit | <u>COMMENT</u> s, etc. • • • |
| es, fits, limit | <u>COMMENT</u> s, etc. • • • |
| 01B CBA | |
| | $R 0.0 \ \overline{p} n \rightarrow 5 \pi$ |
| | |
| TECN | |
| TECN | Γ ₁₁ / |
| se fite limit | <u>COMMENT</u> s, etc. • • • |
| | |
| | K 17 π ⁻ p polarized |
| | JE $17 \pi^- p \rightarrow \pi^+ \pi^- n$ JE $e^+ e^- \rightarrow 2\pi, 4\pi$ |
| 77 RVU | JE 17 $\pi^- p \to \pi^+ \pi^- n$ |
| | $5 \pi^+ p \rightarrow \Delta^{++} 2\pi$ |
| 73 ASP | K $17 \pi^{-} p \to \pi^{+} \pi^{-} n$ |
| e, Breit-Wig | ner. |
| , , | |
| | |
| | Γ ₁₁ /Γ |
| | |
| | EG 20-70 $\gamma p \rightarrow p 2\pi$ |
| 73 STR | C 6-18 $\gamma p \rightarrow p 4\pi$ |
| 72B HBC | 9.3 $\gamma p \rightarrow p 2\pi$ |
| | |
| | F /F |
| TECN | Γ ₁₂ /Γ <u>« COMMENT</u> |
| | s, etc. • • • |
| 01в СВА | $R = 0.0 \ \overline{p} n \rightarrow 5\pi$ |
| | |
| | |
| | Γ ₁₃ / |
| | V COMMENT |
| | s, etc. $ullet$ $ullet$ $ullet$ O $	au^- 	o 	extit{K}^- \pi^- 	extit{K}^+ u_{\pi}$ |
| UH CLE | \cup $I \rightarrow K \pi K^{\dagger} \nu_{T}$ |
| | Γ ₁₃ /Γ |
| | <u>COMMENT</u> s.etc. ● ● ● |
| | 1 $e^+e^- \rightarrow \overline{K}K\pi$ |
| | |
| g | _ |
| TECA | Г_{14/} v <u>соммент</u> |
| | s, etc. • • • |
| N 00D CME | 02 $e^+e^- \rightarrow \eta \pi^+\pi^-$ |
| 87B RVU | JE . |
| вев ОМЕ | EG 20-70 γp |
| | 77 RVL 73 HBC 73 ASP e, Breit-Wig Es, fits, limit 73 STR 72B HBC PES, fits, limit 01B CBA PECI Es, fits, limit 04 CLE Es, fits, limit 81B DM: 81B DM: 81B CBA PECI Es, fits, limit 81B RVL 81B RVL 81B RVL 81B RVL 81B RVL 81B RVL |

Meson Particle Listings

| $\Gamma(\eta \rho)/\Gamma(2$ | (π+ 1 | π ⁻)) | | | Γ_{14}/Γ_{1} |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | not i | use the following | DOCUMENT ID data for averages, fits | | |
| 0.123±0.0 | | ase the following | DELCOURT 82 | DM1 $e^+e^- 	o \pi$ | + π ⁻ ΜΜ |
| ~ 0.1 | | | ASTON 80 | OMEG 20-70 γp | |
| $(\pi^+\pi^-$ ne | eutral | ls)/Γ(2(π ⁺ π ⁻ |)) DOCUMENT ID | $(\Gamma_5 + \Gamma_6 + 0.71)$ | 4Γ ₁₄)/Γ |
| • • We do | not | use the following | data for averages, fits | | |
| 2.6 ± 0.4 | | | ⁵ BALLAM 74 | HBC 9.3 γ p | |
| | | ackground not su | btracted. | | |
| Γ (a₂(1320) ⁄ALUE | $ \pi\rangle$ | total | DO CUMENT ID | TECN COMMENT | Γ ₁₅ / |
| | not | use the following | data for averages, fits | | |
| ot seen | | | AMELIN 00 | VES 37 $\pi^- p \rightarrow 1$ | $\eta \pi^+ \pi^- \pi$ |
| $(K\overline{K})/\Gamma($ | 2(π ⁺ | | | | Γ ₁₆ /Γ |
| ALUE We do | not i | USE the following | DOCUMENT ID data for averages, fits | TECN CHG COMME | NT |
| 0.015 ± 0.0 | | _ | _ | | $\rightarrow \overline{K}K$ |
| <0.04 | (17 | 95 | | HBC 0 9.3 γ <i>p</i> | |
| | | | excitations to be dege | enerate in mass. | - /- |
| (KK)/I(| 'V K. | *(892) + c.c.) | DO CUMENT ID | TECN COMMENT | Γ ₁₆ /Γ ₁ |
| • • We do | not | use the following | data for averages, fits | s, limits, etc. • • • | |
| 0.052 ± 0.026 | | | BUON 82 | DM1 $e^+e^- \rightarrow ha$ | adrons |
| $\Gamma(\pi^0\omega)/\Gamma_{\rm t}$ | otal | EVEC | DO CHMENT ID | TECH COMMENT | Γ ₁₈ / |
| <i>∖ALUE</i> • • • We do | not | EVTS use the following | DOCUMENT ID data for averages, fits | | |
| not seen | | 2382 | | CMD2 $e^+e \rightarrow \pi^0 \eta$ | |
| een | | | ACHASOV 97 | RVUE $e^+e^- \rightarrow \omega$ | π^0 |
| EDWARDS ABELE ABELE ACHASOV BERTIN CLEGG CLEGG | 00 A 99 D 97 97 97 C 94 90 | NP A668 83 PR D61 072003 PL B468 178 PL B391 191 PR D55 2663 PL B408 476 ZPHY C62 455 ZPHY C45 677 | D. Amelin et al. K.W. Edwards et al. A. Abele et al. A. Abele et al. N.N. Achasov et al. A. Bertin et al. A.B. Clegg, A. Donn A.B. Clegg, A. Donn | (ĈLEO (Crystal Barrel (Crystal Barrel (OBELIX nachie (LANC, nachie (LANC, | Collab.) (NOVM) Collab.) MCHS) MCHS) |
| DUBNICKA GESHKEN ANTONELLI DIEKMAN | 89 89 88 88 | PL B220 321 JPG 15 1349 ZPHY C45 351 PL B212 133 PRPL 159 99 PL B202 441 ZPHY C34 257 | D. Bisello et al. S. Dubnicka et al. B.V. Geshkenbein A. Antonelli et al. B. Diekmann S. Fukui et al. A. Donnachie, A.B. | (DM2 (SUGI, NAGO, KEK, F | Collab.) , SLOV) (ITEP) Collab.) (BONN) (YOT+) |
| OONNACHIE ATKINSON | 86B | ZPHY C30 531 | M. Atkinson et al. | (BONN, CERN, | . LANC) |
| OONNACHIE JTKINSON JTKINSON JRKAL JBE | 86B 85B 85 84B | ZPHY C30 531 ZPHY C26 499 ZPHY C29 485 PRL 53 751 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. | (BONN, CERN, (BONN, CERN, on | GLAS+) GLAS+) GLAS+) (WISC) |
| OONNACHIE NTKINSON NTKINSON ERKAL NBE KURDADZE | 86B 85B 85 84B 83 | ZPHY C30 531 ZPHY C26 499 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. L.M. Kurdadze et al. FP 37 613. | (BONN, CERN, (BONN, CERN, ON | , LANC) GLAS+) GLAS+) (WISC) (NOVO) |
| DONNACHIE KTKINSON KTKINSON KRKAL BE KURDADZE KTKINSON BUON CLELAND | 86 B 85 B 85 84 B 83 . | ZPHY C30 531 ZPHY C26 499 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. L.M. Kurdadze et al. FP 37 613. M. Atkinson et al. J. Buon et al. W.E. Cleland et al. | (BONN, CERN, (BONN, CERN,). (BONN, CERN, | LANC) GLAS+) GLAS+) (WISC) (NOVO) GLAS+) MONP) LAUS+) |
| DONNACHIE LTKINSON LTKINSON LKKAL LBE LURDADZE LTKINSON LUCON LELAND CORDIER SELCOURT | 86 B 85 B 85 84 B 83 82 82 82 82 B 82 82 82 82 | ZPHY C30 531 ZPHY C26 499 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 NP B208 228 PL 109B 129 PL 113B 93 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. L.M. Kurd adze et al. FP 37 613. M. Atkinson et al. J. Buon et al. W.E. Cleland et al. A. Cordier et al. B. Delcourt et al. | (BONN, CERN, (BONN, CERN,). (BONN, CERN, (LALO, (DURH, GEVA, | , LANC) GLAS+) GLAS+) (WIS C) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) |
| DONNACHIE ITKINSON ITKINSON IRKAL IBE IURDADZE ITKINSON SUON ILELAND OORDIER DELCOURT | 86 B 85 B 85 84 B 83 - 82 82 82 82 82 82 82 82 81 E 81 B | ZPHY C30 531 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 NP B208 228 PL 109B 129 PL 113B 93 NP B189 15 Bonn Conf. 205 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. L.M. Kurd adze et al. FP 37 613. J. Buon et al. V.E. Cleland et al. A. Cordier et al. B. Deicourt et al. D. Aston (BC B. Deicourt | (BONN, CERN, (BONN, CERN, EDONN, CERN, (LALO, (DURH, GEVA, DNN, CERN, EPOL, GLAS, (| , LANC) GLAS+) GLAS+) (WISC) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) LANC+) ORSAY) (LALO) |
| DONNACHIE ITKINSON ITKINSON ITKAL BE KURDAD ZE KIKINSON BUON CORDIER DELCOURT AISO DIBIAN CA SSTON | 86 B 85 B 85 B 84 B 83 82 82 82 82 82 82 81 E 81 B | ZPHY C30 531 ZPHY C29 485 ZPHY C29 485 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 NP B208 228 PL 109B 129 PL 113B 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PR D23 595 PR D23 595 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M. G. Olsso K. Abe et al. L.M. Kurdadze et al. FP 37 613. M. Atkinson et al. J. Buon et al. A. Cordier et al. D. Aston B. Delcourt et al. D. Aston A. Cordier et al. D. Cordier et al. D. Aston B. Delcourt D. Aston C. B. Delcourt D. Aston | (BONN, CERN, (BONN, CERN, III) (BONN, CERN, (LALO, (DURH, GEVA, III) DNN, CERN, EPOL, GLAS, (CASI | LANC) GLAS+) GLAS+) (WIS C) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LANC+) ORSAY) (LALO) ELANC+) |
| DONNACHIE TYKINSON STKINSON STKINSON STKINSON STKINSON SUURT SUON LIELAND CORDIER DELCOURT AISO DIBLAN CA STON SACCI SIZOT | 86 B 85 B 85 B 85 B 84 B 83 B 82 B 82 B 82 B 81 B 81 B 80 80 80 | ZPHY C30 531 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 NP B208 228 PL 109B 129 PL 113B 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PR D23 595 PL 192B 215 PL 92B 215 PL 92B 215 PL 95B 139 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M. G. Olsso K. Abe et al. L.M. Kurd adze et al. FP 37 613. M. Atkinson et al. J. Buon et al. A. Cordier et al. B. Delcourt et al. D. Aston (BC B. Delcourt et al. Cordier et al. Cordie | (BONN, CERN, ON CERN, ON CERN, ON CERN, OLALO, ODRH, GEVA, ONN, CERN, EPOL, GLAS, (CAS) | LANC) GLAS+) GLAS+) (WISC) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LANC+) ORSAY) (LALO) (LALO) MONP) AND CHOCK (LALO) MONP) MONP) |
| DONNACHIE TYKINSON STRIMSON STRIMSON STRIMSON STRIMSON SUURDAD ZE SURDAD ZE | 86 B 85 B 85 B 84 B 83 - 82 82 82 82 81 E 81 B 81 80 80 80 80 79 B | ZPHY C30 531 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 1088 55 PL 1188 221 NP B208 228 PL 109B 129 PL 119B 33 NP B189 15 Bonn Conf. 205 PL 109B 129 PR D23 595 PL 92B 215 PL 95B 139 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsos K. Abe et al. L.M. Kurd adze et al. FP 37 613. J. Buon et al. J. Buon et al. J. Buon et al. A. Cordier et al. D. Aston B. Delcourt et al. D. Aston GBC B. Delcourt A. Cordier et al. F.A. di Blanca et al. C. Aston GBC C. Bacci et al. C. Bacci et al. C. Bacci et al. C. Bacci et al. | (BONN, CERN, ON CERN, ON CERN, ON CERN, OLALO, ODRH, GEVA, ONN, CERN, EPOL, GLAS, (CAS) | LANC) GLAS+) (WISC) (NOVO) GLAS+) MONP) (LALO) (LALO) (LALO) (LALO) (LANC+) -, FRAS) MONP) (CORN) -, FNAL) |
| DONNACHIE TYKINSON TYKINSON TYKINSON TYKINSON TYKINSON BUON BUON LORDIER SELCOURT AISO BILLOURT AISO BILLOURT AISO BILLOURT AISO BILLOURT BILLOURT AISO BILLOURT BILLOURT BILLOURT AISO BILLOURT | 86 B 85 B 85 B 84 B 83 - 82 82 82 82 82 81 E 81 B 81 B 80 80 80 79 B 79 79 78 C | ZPHY C30 531 ZPHY C29 485 ZPHY C29 485 ZPHY C29 485 ZPHS 37 733 Translated from ZET PL 1088 55 PL 1188 221 NP B208 228 PL 1198 129 PL 1138 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PR D23 595 PL 109B 215 PL 95B 139 Madison Conf. 546 PR D21 3005 PRL 43 1691 NP B161 46 PR D19 1956 ANP 114 1 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsso K. Abe et al. L.M. Kurd adze et al. FP 37 613. J. Buon et al. J. Buon et al. J. Buon et al. B. Delcourt et al. B. Delcourt et al. D. Aston B. Delcourt A. Cordier et al. C. Ad i Blanca et al. D. Aston C. Bacci et al. J.C. Bizot et al. T.J. Killian et al. M.S. Atiya et al. H. Becker et al. C.B. Lang, A. Mas-F A.D. Martin, M.R. P. A.D. Martin, M.R. P | (BONN, CERN, ON CERN, ON CERN, ON CERN, ON CERN, OLALO, ODRN, CERN, EPOL, GLAS, (ROMA (LALO, COLU, ILL (MPIM, CERN, ZEEM Perainds) | LANC) GLAS+) GLAS+) (WIS C) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LALO) E, CMU) LANC+) MONP) (CORN) - FRAS) MONP) (CORN) - FNAC) (GRAZ) (CERN) |
| DONNACHIE TYKINSON RTKINSON RTKINSON RTKINSON RTKINSON BUON LICTORIOR BUON LICTORIOR BUON BUON LICTORIOR BUON BUON BUON BUON BUON BUON BUON BUON | 86 B 85 B 85 B 84 B 83 82 82 82 82 81 E 81 B 80 80 80 80 80 79 B 79 79 77 C 77 B | ZPHY C30 531 ZPHY C29 485 ZPHY C29 485 ZPHY C29 485 ZPHS C37 531 JETPL 37 733 Translated from ZET PL 1088 55 PL 1188 221 NP B208 228 PL 1198 129 PL 1138 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PR D23 595 PL 109B 215 PL 95B 139 Madison Conf. 546 PR D21 3005 PRL 43 1691 NP B151 46 PR D19 956 ANP 114 1 PL 71B 345 NP B161 89 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsos K. Abe et al. L.M. Kurd adze et al. FP 37 613. J. Buon et al. J. Buon et al. J. Buon et al. B. Delcourt et al. D. Aston B. Delcourt et al. D. Aston Cordier et al. D. Aston C. Bacci et al. J.C. Bizot et al. J.C. Bizot et al. T.J. Killian et al. M.S. Atiya et al. H. Becker et al. C.B. Lang, A. Mas-F A.D. Martin, M.R. P B. Costa de Beaureg C.D. Froggatt, J.L. P | (BONN, CERN, ON CERN, ON CERN, CLALO, (LALO, OURH, GEVA, DNN, CERN, EPOL, GLAS, (CAS) (MPIM, CERN, EPOL, GLAS, (COLU, LLL (MPIM, CERN, ZEEM Parared a Pennington gard, B. Pire, T.N. Truong | LANC) GLAS+) GLAS+) (WIS C) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LANC+) ORSAY) (LANC+) (CRAC) |
| DONNACHIE TYKINSON TYKINSON TYKINSON TYKINSON BE TYKINSON BUON BUON DELCOURT AISO DELCOURT AISO DIBIANCA SSTON BACCI BIZOT GILLIAN TIPA BECKER ANG MARTIN LOSTAL ROGGATT LEXANDER ROGGATT LEXANDER BALLAM | 86B 85B 84B 83 82 82 82 82 81E 81B 81 80 80 80 80 80 79 77 77 77 77 77 77 | ZPHY C30 531 ZPHY C29 485 ZPHY C29 485 ZPHY C29 485 ZPHY C37 485 ZPH 37 733 Translated from ZET PL 1088 55 PL 1088 55 PL 1088 129 PL 113B 29 L 1098 129 PL 113B 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PL 09B 129 PL 09B 129 PL 09B 129 PL 09B 129 PL 95B 139 Madison Conf. 546 PR D21 3005 PRL 43 1691 NP B151 46 PR D19 956 ANP 114 1 PL 71B 345 NP B129 89 PL 57B 487 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olso K. Abe et al. L.M. Kurd adze et al. FP 37 613. M. Atkinson et al. J. Buon et al. B. Delcourt et al. B. Delcourt et al. D. Aston B. Delcourt A. Cordier et al. F.A. di Blanca et al. D. Aston C. Bacci et al. J.C. Bizot et al. T.J. Killian et al. M.S. Atiya et al. H. Becker et al. C.B. Lang, A. Massf A.D. Martin, M.R. P. B. Costa de Beaureg C.D. Froggatt, J.L. I. G. Alexander et al. J. Ballam et al. J. Ballam et al. | (BONN, CERN, ON CERN, ON CERN, ON CERN, ON CERN, (LALO, (DURH, GEVA, ONN, CERN, EPOL, GLAS, (ROMA (LALO, (MPIM, CERN, ZERM) COLU, ILL (MPIM, CERN, ZERM) CERN, ZERM Pranarda Pennington gard, B. Pire, T.N. Truong petersen (GLAS, (SLAC, LBL, CERN, LEBL) | LANC) GLAS+) (WISC) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LALO) (LALO) (LALO) (LANC+) (CARO) (CORN) - FNAL) - CRAC) (GRAZ) (GRAZ) (TELA) MONP) (TELA) MONP) (TELA) MONP) (TELA) MONP) (TELA) MPIM) |
| DONNACHIE ATKINSON TATKINSON TATKINSON TATKINSON TATKINSON TATKINSON TATKINSON TO THE TATKINSON THE | 86B 885 84B 885 84B 887 882 82B 82 82B 81E 81B 81 80 80 80 80 80 779 876 777 8 777 775 774 774 773 | ZPHY C30 531 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 1088 55 PL 1088 55 PL 1188 221 NP B208 228 PL 1138 93 NP B189 15 Bonn Conf. 205 PL 109B 129 PL 109B 129 PL 109B 129 PL 109B 129 PR D23 595 PL 19B 215 PL 95B 139 Madison Conf. 546 PR D21 3005 PRL 43 1691 NP B151 46 PR D19 956 ANP 114 1 PL 71B 345 NP B129 89 PL 57B 467 NP B76 375 NP B76 375 NP B81 205 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olsos K. Abe et al. L.M. Kurd adze et al. FP 37 613. J. Buon et al. J. Buon et al. J. Buon et al. D. Aston (BC B. Delcourt et al. D. Aston (BC B. Delcourt al. D. Aston (BC C. Bacci et al. J.C. Bizot et al. G.B. Lang, A. Mas-F A.D. Martin, M.R. P B. Costa de Beaureg C.D. Froggatt, J.L. I G. Alexander et al. J. Ballam et al. M. Conversi et al. P. Schacht et al. P. Schacht et al. | (BONN, CERN, ON CERN, ON CERN, ON CERN, ON CERN, (LALO, (DURH, GEVA, ONN, CERN, EPOL, GLAS, (ROMA (LALO, (MPIM, CERN, ZERM) COLU, ILL (MPIM, CERN, ZERM) CERN, ZERM Pranarda Pennington gard, B. Pire, T.N. Truong petersen (GLAS, (SLAC, LBL, CERN, LEBL) | LANC) GLAS+) (WISC) (NOVO) MONP) LAUS+) (LALO) LANC+) ORSAY) (LALO) LANC+) (LALO) LANC+) (CANC) (CORN) (CORN) (FNAL) (CORN) (FRAS) MONP) (TELA) MONP) (TELA) MPIM) (TELA) MPIM) (SLAC) |
| DONNACHIE TAKINSON TAKINSON TAKINSON TAKINSON TAKINSON TAKINSON THOM THOM THOM THOM THOM THOM THOM THOM | 86B 85B 88B 88B 88B 88B 88B 88B 88B 88B 88 | ZPHY C30 531 ZPHY C29 485 PRL 53 751 JETPL 37 733 Translated from ZET PL 108B 55 PL 118B 221 NP B208 228 PL 109B 129 PL 113B 93 NP B189 15 B0nn Conf. 205 PL 109B 129 PR D23 595 PL 92B 215 PL 92B 215 PL 92B 215 PR 133 Madison Conf. 546 PR D21 3005 PRL 191 191 NP B151 46 PR D19 956 ANP 114 1 NP B151 46 NP B129 89 L 71B 345 NP B129 89 L 57B 467 NP B76 375 PL 58B 493 NP B76 375 PL 58B 493 NP B76 375 PL 58B 493 NP B18 205 | M. Atkinson et al. M. Atkinson et al. C. Erkal, M.G. Olso K. Abe et al. L.M. Kurd adze et al. FP 37 613. M. Atkinson et al. J. Buon et al. W.E. Cleland et al. A. Cordier et al. B. Delcourt et al. D. Aston (BC B. Delcourt A. Cordier et al. F.A. di Bianca et al. F.A. di Bianca et al. J.C. Biaot et al. J.C. Biaot et al. J.J. Killian et al. M.S. Atiya et al. H. Becker et al. C.B. Lang, A. Mass-F A.D. Martin, M.R. B. Costa de Beaureg C.D. Froggatt, J.L. I. G. Alexander et al. J. Ballam et al. M. Conversi et al. M. Conversi et al. P. Schacht et al. | (BONN, CERN, (BONN, CERN, (LALO, (DURH, GEVA, DNN, CERN, EPOL, GLAS, (COLU, ILL (MPIM, CERN, ZEEM Pennington (GLAS, 1974), B. Pire, T.N. Truong Petersen (GLAS, (ROMA (LALO, CERN, EPOL, GLAS, (COLU, ILL (MPIM, CERN, ZEEM Pennington (GLAS, (ROMA (CERN, CERN, CROMA (CERN, CROMA (CERN, CERN, CERN, CROMA (CERN, CERN, CERN, CROMA (CERN, COLU, CERN, CER | LANC) GLAS+) (WISC) (NOVO) GLAS+) MONP) LAUS+) (LALO) (LALO) (LALO) (LALO) (LALO) (LALO) (LALO) (LALO) (LANC+) ORSAY) (LANC+) ORSAY) (LANC+) ORSAY) (LANC) (CERO) (CORN) - FNAL) - CRAC) (CERN) (EPOL) (TELA) - FNAC) (TELA) - FNAC) (MPIM) - FRAS) |

 $a_2(1700)$

 $I^{G}(J^{PC}) = 1^{-}(2^{+})$

OMITTED FROM SUMMARY TABLE

a₂(1700) MASS

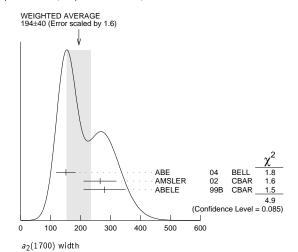
| NT ID TECN CHG COMMENT | | | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|--|
| udes scale factor of 1.9. | | | | |
| 04 BELL $10.6 e^+e^- \rightarrow e^+e^- \kappa^+ \kappa^-$ | | | | |
| 02 CBAR $0.9 \overline{p} p \rightarrow \pi^0 \eta \eta$ | | | | |
| 99B CBAR $1.94~\overline{p}p ightarrow ~\pi^0\eta\eta$ | | | | |
| for averages, fits, limits, etc. • • • | | | | |
| ICH 09 RVUE $0.0 \overline{p} p, \pi N$ | | | | |
| LSKY 06 RVUE 0 $\gamma\gamma \to \pi^+\pi^-\pi^0$ | | | | |
| 06 E835 5.2 $\overline{p}p \rightarrow \eta \eta \pi^0$ | | | | |
| 05 B852 $18 \pi^- p \rightarrow \omega \pi^- \pi^0 p$ | | | | |
| RI 01H L3 $\gamma\gamma \rightarrow K_S^0 K_S^0, E_{\rm cm}^{ee} = 91, 183-209 {\rm GeV}$ | | | | |
| 91, 183–209 GeV | | | | |
| REV 99 SPEC $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ | | | | |
| RI 97T L3 $\gamma\gamma ightarrow \pi^+\pi^-\pi^0$ | | | | |
| $1752\pm21\pm$ 4 ACCIARRI 97τ L3 $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$ 1 T-matrix pole. 2 From analysis of L3 data at $183-209$ GeV. 3 Statistical error only. 4 Spin 2 dominant, isospin not determined, could also be $l=1$. 5 Possibly two $J^P=2^+$ resonances with isospins 0 and 1. | | | | |
| F n / E | | | | |

a2(1700) WIDTH

| VALUE | | EVTS | DO CUMENT ID | | TECN CHG | COMMENT |
|-----------|-----------|-------------|-------------------------|--------|--------------------|-----------------------------------------------------------------------------------|
| 194± | 40 OUR AV | /ERAGE | Error includes scale | e fact | or of 1.6. See | the ideogram below. |
| $151\pm$ | 22 ± 24 | | ABE | 04 | BELL | $10.6 e^{+}e^{-} \rightarrow e^{+}e^{-} K^{+}K^{-}$ |
| $265\pm$ | 55 | | ⁶ AMSLER | 02 | CBAR | $0.9 \overline{p} p \rightarrow \pi^0 \eta \eta$ |
| $280\pm$ | 70 | | ABELE | 99B | CBAR | $1.94 \overline{p}p \rightarrow \pi^0 \eta \eta$ |
| • • • | We do not | use the fol | llowing data for ave | erages | s, fits, limits, e | tc. • • • |
| 270 + | 50 20 | | ANISOVICH | 09 | RVUE | $0.0 \ \overline{p}p, \ \pi N$ |
| $336\pm$ | 20 ± 20 | 18k | ⁷ SCHEGELSKY | 06 | RVUE 0 | $\gamma \gamma \rightarrow \pi^{+} \pi^{-} \pi^{0}$ |
| $417\pm$ | 19 | 80k | ⁸ UMAN | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| $279 \pm$ | 49 ± 66 | 145 k | LU | 05 | B852 | $18 \pi^- p \rightarrow \omega \pi^- \pi^0 p$ |
| $187\pm$ | 60 | 221 | ⁹ ACCIARRI | 01н | L3 | $\gamma \gamma \rightarrow K_S^0 K_S^0$, $E_{\text{cm}}^{ee} = 91$, 183–209 GeV |
| 150±1 | 10±34 | | ACCIARRI | 97т | L3 | $\gamma \gamma \rightarrow \pi^+ \pi^- \pi^0$ |

⁶ T-matrix pole.

⁹ Spin 2 dominant, isospin not determined, could also be l=1.



a₂(1700) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------------------|------------------------------|
| Γ_1 | $\eta\pi$ | seen |
| Γ_2 | $\gamma\gamma$ | |
| Гз | $ ho\pi$ | |
| Γ_4 | $f_2(1270)\pi$ | |
| Γ_5 | K K | seen |
| Γ_6 | $\omega \pi^- \pi^0$ | seen |
| Γ_7 | ωho | seen |

⁷ From analysis of L3 data at 183–209 GeV.

⁸ Statistical error only.

| a ₂ (1700) PARTIAL WIDTHS |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\eta\pi)$ |
| VALUE (MeV) EVTS DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 9.5 \pm 2.0 870 10 SCHEGELSKY 06A RVUE $\gamma\gamma \to K_S^0 K_S^0$ |
| $\Gamma(\gamma\gamma)$ Γ_2 |
| VALUE (keV) EVTS DOCUMENT ID TECN COMMENT |
| \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet |
| 0.30 ± 0.05 870 10 SCHEGELSKY 06A RVUE $\gamma \gamma ightarrow \kappa_S^0 \kappa_S^0$ |
| $\Gamma(K\overline{K})$ Γ_5 |
| <u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 5.0 \pm 3.0 870 ¹⁰ SCHEGELSKY 06A RVUE $\gamma\gamma \to \kappa^0_S \kappa^0_S$ |
| 10 From analysis of L3 data at 91 and 183–209 GeV, using $a_2(1700)$ mass of 1730 MeV and width of 340 MeV, and SU(3) relations. |
| $a_2(1700) \; \Gamma(i) \Gamma(\gamma \gamma) / \Gamma(total)$ |
| $\left[\Gamma(\rho\pi) + \Gamma(f_2(1270)\pi)\right] \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}} \qquad (\Gamma_3 + \Gamma_4)\Gamma_2/\Gamma$ |
| VALUE (keV)EVTSDOCUMENT_IDTECNCOMMENT_ |
| 0.29 \pm 0.04 \pm 0.02 ACCIARRI 97T L3 $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $0.37^{+0.12}_{-0.08}\pm0.10$ 18k 11 SCHEGELSKY 06 RVUE $\gamma\gamma\to\pi^+\pi^-\pi^0$ |
| $\Gamma(\overline{KK}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ VALUE (eV) DOCUMENT ID TECN COMMENT |
| |
| • • • We do not use the following data for averages, fits, limits, etc. • • |
| 20.6+ 4.2+ 4.6 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 20.6 \pm 4.2 \pm 4.6 12 ABE 49 \pm 11 \pm 13 13 ACCIARRI 01H L3 $\gamma\gamma \rightarrow \kappa_S^0 \kappa_S^0 \kappa_S^0$, $E_{\rm Cm}^{ee} = 91$, 183-209 GeV 12 Assuming spin 2. 13 Spin 2 dominant, isospin not determined, could also be $I=1$. $a_2(1700) \ \text{BRANCHING RATIOS}$ $\Gamma(\rho\pi)/\Gamma(f_2(1270)\pi) \qquad $ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 20.6 \pm 4.2 \pm 4.6 12 ABE 49 \pm 11 \pm 13 13 ACCIARRI 01H L3 $\gamma\gamma \rightarrow \kappa_0^5 \kappa_0^6 $ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |

$f_0(17\overline{10})$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

See our mini-review in the 2004 edition of this Review, Physics Letters $\mbox{\bf B592}\ 1\ (2004)$. See also the mini-review on scalar mesons under $f_0(500)$ (see the index for the page number).

f₀(1710) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------|------------|--------------------------|-------------|-----------|-------------------------------------------------------|
| 1720 ± 6 OU | IR AVERAGE | Error includes so | ale fa | ctor of 1 | I.6. See the ideogram below. |
| 1701 ± 5 + | 9 2 4k | $^{\mathrm{1}}$ CHEKANOV | 80 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ |
| $1765 {}^{+}_{-} {}^{4}_{3} \pm 1$ | 3 | ABLIKIM | 06v | BES2 | $e^+e^- \to ~J/\psi \to ~\gamma \pi^+ \pi^-$ |
| $1760 \pm 15 \begin{array}{c} +15 \\ -16 \end{array}$ | 5 0 | ² ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| 1738 ± 30 | | ABLIKIM | 04E | BES2 | $J/\psi \rightarrow \omega K^+ K^-$ |
| $1740 \pm 4 \begin{array}{c} +10 \\ -25 \end{array}$ | 0 5 | ³ BAI | 03 G | BES | $J/\psi \rightarrow \gamma K \overline{K}$ |
| $1740 + 30 \\ -25$ | | ³ BAI | 00A | BES | $J/\psi \rightarrow \gamma (\pi^+ \pi^- \pi^+ \pi^-)$ |
| 1698 ± 18 | | 4 BARBERIS | 00E | | $450 pp \rightarrow p_f \eta \eta p_g$ |

| 1710±12 | ±11 | | 5 | BARBERIS | 99D | OMEG | 450 $pp \rightarrow K^+K^-, \pi^+\pi^-$ |
|----------------------------|----------------|---------|--------|-----------------------|------------|-------------|-----------------------------------------------------------------|
| 1710 ± 25 | | | 6 | FRENCH | 99 | | $300 pp \rightarrow p_f(K^+K^-)p_S$ |
| 1707 ± 10 | | | 7 | AUGUSTIN | 88 | DM2 | $J/\psi \rightarrow \gamma K^+ K^-, K_S^0 K_S^0$ |
| 1698 ± 15 | | | | AUGUSTIN | 87 | DM2 | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 1720 ± 10 | ± 10 | | | BALTRUSAIT | | MRK3 | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 1742 ± 15 | | | | WILLIAMS | 84 | MPSF | $200 \pi^- N \rightarrow 2K_S^0 X$ |
| 1670±50 | | | | BLOOM | 83 | CBAL | $J/\psi \rightarrow \gamma 2\eta$ |
| | do not | use the | follow | ing data for ave | | | |
| 1750±13 | | | | AMSLER | 06 | CBAR | 1.64 $\overline{p}p \rightarrow K^+K^-\pi^0$ |
| 1730 ± 13 1747 ± 5 | | 80k | 9,10 | UMAN | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 1776 ± 15 | | OOK | | VLADIMIRSK | | SPEC | $40 \pi^- p \rightarrow K_S^0 K_S^0 n$ |
| $1790 + 40 \\ -30$ | | | 2 | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$ |
| | | | | | | | * * * * * * * * * * * * * * * * * * * * |
| 1670 ± 20 | | | | BINON | 05 | GAMS | 33 $\pi^- p \rightarrow \eta \eta n$ |
| 1726 ± 7 | | 74 | | CHEKANOV | 04 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ |
| 1732+15 | | | 11 | ANISOVICH | 03 | RVUE | |
| 1682 ± 16 | | | 2 1 2 | TIKHOMIROV | | SPEC | 40.0 $\pi^- C \to K_S^0 K_S^0 K_L^0 X$ |
| 1670 ± 26 | | 3651 | 12 14 | NICHITIU | 02 | OBLX | |
| 1770±12 | | | 13,14 | ANISOVICH | 99B | SPEC | $0.6-1.2 \ p\overline{p} \rightarrow \eta \eta \pi^0$ |
| 1730±15 | | | | BARBERIS | 99 | OMEG | $450 pp \rightarrow p_S p_f K^+ K^-$ |
| 1750 ± 20 | | | | BARBERIS ANISOVICH | 99B | OMEG | 450 $pp \rightarrow p_S p_f \pi^+ \pi^-$ |
| 1750 ± 30 | | | | BAI | 98в 98н | RVUE BES | Compilation 0 0 |
| 1720 ± 39 1775 ± 1.5 | - | 57 | 16 | BARKOV | 98H 98 | BES | $J/\psi \rightarrow \gamma \pi^0 \pi^0$ |
| | • | 5 / | | ABREU | | 5.5 | $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 1690 ± 11 | | | | | 96c | DLPH | $Z^0 \rightarrow K^+K^- + X$ |
| 1696± 5 | + 9 -34 | | 8 | BAI | 96c | BES | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 1781 ± 8 | $^{+10}_{-31}$ | | 3 | BAI | 96c | BES | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 1768 ± 14 | | | | BALOSHIN | 95 | SPEC | 40 $\pi^- C \rightarrow K_S^0 K_S^0 X$ |
| 1750 ± 15 | | | 18 | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 1620 ± 16 | | | 8 | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^{+} \pi^{-} \pi^{+} \pi^{-}$ |
| 1748 ± 10 | | | 7 | ARMSTRONG | 93c | E760 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| ~ 1750 | | | | BREAKSTONE | 93 | SFM | $pp \rightarrow pp\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ |
| 1744 ± 15 | | | 19 | ALDE | 92D | GAM2 | |
| 1713 ± 10 | | | 20 | ARMSTRONG | 89D | OMEG | |
| 1706 ± 10 | | | | ARMSTRONG | 89D | OMEG | |
| 1700 ± 15 | | | 8 | BOLONKIN | 88 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 1720 ± 60 | | | 3 | BOLONKIN | 88 | SPEC | $40 \pi^- p \rightarrow K_S^{0} K_S^{0} n$ |
| 1638 ± 10 | | | 21 | FALVARD | 88 | DM2 | $J/\psi \rightarrow \phi K^+ K^-, K_S^0 K_S^0$ |
| 1690± 4 | | | | FALVARD | 88 | DM2 | $J/\psi \rightarrow \phi K^+ K^-, K_S^0 K_S^0$ |
| 1755 ± 8 | | | | ALDE | 86c | GAM2 | $38 \pi^- p \rightarrow n2\eta$ |
| $1730 + 2 \\ -10$ | | | 24 | LONGACRE | 86 | RVUE | $22 \pi^- p \rightarrow n2K_S^0$ |
| 1650±50 | | | | BURKE | 82 | MRK2 | $J/\psi \rightarrow \gamma 2\rho$ |
| 1640 ± 50 | | | 25,26 | EDWARDS | 82D | CBAL | $J/\psi \rightarrow \gamma 2\eta$ |
| 1730 ± 10 | ± 20 | | 27 | ETKIN | 82c | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| 1 In the | SU(3) b | ased mo | odel w | ith a specific int | erfere | nce patt | ern of the $f_2(1270)$, $a_2^0(1320)$ |
| | | | | | | | |

In the SU(3) based model with a specific interference pattern of the $f_2(1270)$, $a_2^{
m U}(1320)$, and $f_2'(1525)$ mesons incoherently added to the $f_0(1710)$ and non-resonant background.

 2 This state may be different from $f_0(1710)$, see CLOSE 05.

 ${3 \atop 4} J^P = 0^+$ ${4 \atop T-matrix pole}$

⁵ Supersedes BARBERIS 99 and BARBERIS 99B.

Supersedes BARBERTS 99 and BARBERTS 99. 6 $JP = 0^+$, supersedes by ARMSTRONG 89D. 7 No JPC determination. 8 $JP = 2^+$. 9 Breit-Wigner mass.

9 Breit-Wigner mass. 10 Systematic errors not estimated. 11 K-matrix pole, assuming $J^P=0^+$, from combined analysis of $\pi^-p\to\pi^0\pi^0$ n, $\pi^-p\to K\overline{K}n$, $\pi^+\pi^-\to\pi^+\pi^-$, $\overline{p}p\to\pi^0\pi^0\pi^0$, $\pi^0\pi^0$, $\pi^0\eta\eta$, $\pi^0\pi^0\eta$, $\pi^+\pi^-\pi^0$, K^0_S ,

14 Not seen by AMSLER 02. 15 T-matrix pole, assuming $J^P=0+16$ No J^PC determination. 17 No J^PC determination, width not determined. 18 From a fit to the 0^+ partial wave. 19 ALDE 92D combines all the GAMS-2000 data. 20 $J^P=2^+$, superseded by FRENCH 99.

²¹ From an analysis ignoring interference with $f_2'(1525)$.

 22 From an analysis including interference with $\bar{t}_2'(1525)$.

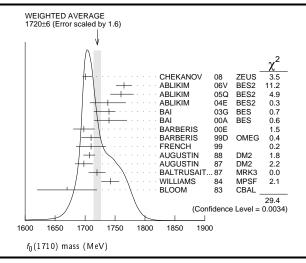
 $^{23}\,\mbox{Superseded}$ by ALDE 92D.

24 Uses MRK3 data. From a partial-wave analysis of data using a K-matrix formalism with 5 poles, but assuming spin 2. Fit with constrained inelasticity.
 25 P = 2+ preferred.

 26 From fit neglecting nearby $f_2^\prime(1525)$. Replaced by BLOOM 83.

²⁷ Superseded by LONGACRE 86.

$f_0(1710)$



fo(1710) WIDTH

| VALUE (MeV 135 ± 8 | | | DOCUMENT ID Error includes | scale | | COMMENT 1.1. |
|------------------------------------------------------|--------------|----------|-----------------------------|-----------|----------------|-------------------------------------------------------------------------------------------------------------|
| 100 ± 24 | + 7 41 | , 28 | CHEKANOV | 80 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ |
| 145 ± 8 | | | ABLIKIM | 06v | BES2 | $e^+ e^- \rightarrow J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 125 ± 25 | +10 -15 | 29 | ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow \gamma \pi^{+} \pi^{-} K^{+} K^{-}$ |
| 125 ± 20 | | | ABLIKIM | 04E | BES2 | $J/\psi \rightarrow \omega K^+ K^-$ |
| 166 + 5 | $^{+15}_{3}$ | 30 | BAI | 03G | BES | $J/\psi \rightarrow \gamma K \overline{K}$ |
| 120 + 50 | | 30 | BAI | 0 0 A | BES | $J/\psi \rightarrow \gamma(\pi^+\pi^-\pi^+\pi^-)$ |
| $120 - 40$ 120 ± 26 | | | BARBERIS | 00A | DLJ | $450 pp \rightarrow p_f \eta \eta p_S$ |
| 120 ± 20 | | 32 | BARBERIS | 99D | OMEG | 450 $pp \to p_f \eta \eta p_s$ 450 $pp \to K^+ K^-, \pi^+ \pi^-$ |
| 105 ± 34 | 1 | 33 | FRENCH | 99 | | $300 pp \rightarrow p_f(K^+K^-)p_s$ |
| 166.4 ± 33 | | | AUGUSTIN | 88 | DM2 | $J/\psi \rightarrow \gamma K^+ K^-, K_S^0 K_S^0$ |
| 136 ± 28 | | | AUGUSTIN | 87 | DM2 | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 130 ± 20 57 ± 38 | | | BALTRUSAIT WILLIAMS | .87 84 | MR K3 MP SF | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 57 ± 38 160 ± 80 | | | BLOOM | 83 | CBAL | $200 \pi^{-} N \rightarrow 2K_{S}^{0} X$ $J/\psi \rightarrow \gamma 2\eta$ |
| | | e follov | ving data for ave | | | |
| 140 + 40 |) | | AMSLER | 06 | CBAR | 1.64 $\overline{p}p \rightarrow K^+K^-\pi^0$ |
| 140 - 30 |) | 29 37 | UMAN | | | |
| 188 ± 13 250 ± 30 | | (23,31 | UMAN VLADIMIRSK | 06 | E835 SPEC | 5.2 $\overline{p} p \rightarrow \eta \eta \pi^0$ 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| | | 3.0 | | | | |
| 2 / 0 — 30 |) | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^+ \pi^-$ |
| 260 ± 50 | | | BINON | 05 | GAMS | 33 $\pi^- p \rightarrow \eta \eta n$ |
| ³⁰ – 14 | , ,, | | CHEKANOV | 04 | ZEUS | $ep \rightarrow K_S^0 K_S^0 X$ |
| 144 ± 30 | | | ANISOVICH | 03 | RVUE | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | 40,41 | ANISOVICH | 03 | RVUE | |
| 102 ± 26 | , | | TIKHOMIROV | 03 | SPEC | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_L^0 X$ |
| 267 ± 44 | | 30,42 | NICHITIU | 02 | OBLX | |
| 220 ± 40 | | 43,44 | ANISOVICH | 99B | SPEC | $0.6-1.2 \ p\overline{p} \rightarrow \eta \eta \pi^0$ |
| 100 ± 25 160 ± 30 | | 30 | BARBERIS BARBERIS | 99 99в | OMEG OMEG | $450 pp \rightarrow p_S p_f K^+ K^-$ $450 pp \rightarrow p_S p_f \pi^+ \pi^-$ |
| 250 ±140 | | 45 | ANISOVICH | 98B | RVUE | Compilation |
| 30 ± 7 | | | BARKOV | 98 | | $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 103 ± 18 | -11 | 35 | BAI | 96c | BES | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 85 ± 24 | +22 -19 | 30 | BAI | 96c | BES | $J/\psi \rightarrow \gamma K^+ K^-$ |
| 56 ± 19 | | | BALOSHIN | 95 | SPEC | 40 $\pi^- C \rightarrow K_S^0 K_S^0 X$ |
| 160 ± 40 |) | 47 | BUGG | 95 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 160 + 60 |) | 35 | BUGG | 95 | MR K3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$ |
| 264 ± 25 | | 34 | ARMSTRONG | 93c | E760 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| 200 to 30 | 00 | | BREAKSTONE | | SFM | $pp \rightarrow pp\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ |
| < 80 90% | | | ALDE | 92D | GAM2 | 38 $\pi^- p \rightarrow \eta \eta N^*$ |
| 181 ± 30 | | | ARMSTRONG | | OMEG | $300 pp \rightarrow pp K^+ K^-$ |
| 104 ± 30 | | | ARMSTRONG | | OMEG | $300 pp \rightarrow pp K_S^0 K_S^0$ |
| 30 ± 20 350 ±150 | | | BOLONKIN BOLONKIN | 88 88 | SPEC SPEC | $40 \pi^{-} p \rightarrow K_{S}^{0} K_{S}^{0} n$ |
| 350 ±150 | | | FALVARD | 88 | DM2 | $40 \pi^{-} p \rightarrow K_{S}^{0} K_{S}^{0} n$ $J/\psi \rightarrow \phi K^{+} K^{-}, K_{S}^{0} K_{S}^{0}$ |
| 148 ± 17 184 ± 6 | | | FALVARD | 88 | DM2 | $J/\psi \rightarrow \phi K^+ K^-, K_S^0 K_S^0$ $J/\psi \rightarrow \phi K^+ K^-, K_S^0 K_S^0$ |
| | | | | | | |
| 122 - 15 | | 52 | LONGACRE | 86 | RVUE | $22 \pi^- p \to n2K_S^0$ |
| 200 ±100 | ı | | BURKE | 82 | MRK2 | $J/\psi ightarrow \gamma 2 ho$ |

```
\begin{array}{ccc} 220 & +100 \\ -& 70 \end{array}
                                                         53,54 EDWARDS
                                                                                                         82D CBAL J/\psi 
ightarrow \gamma 2\eta
200 + 1569
                                                                55 ETKIN
                                                                                                          82B MPS 23 \pi^- p \to n2K_S^0
   ^{28} In the SU(3) based model with a specific interference pattern of the f_2(1270), a_2^0(1320),
        and f_2'(1525) mesons incoherently added to the f_0(1710) and non-resonant background.
   29 Breit-Wigner width.

30 J^P = 0^+.

31 T-matrix pole.
  33 J^P=0^+, supersedes by ARMSTRONG 89b. 34 No J^{PC} determination. 35 J^P=2^+.
   ^{
m 32}\,{\rm Supersedes} BARBERIS 99 and BARBERIS 99B.
   35 JP = 2^+
36 No JPC determination.
   37 Systematic errors not estimated.
   <sup>38</sup> This state may be different from f_0(1710), see CLOSE 05.
   <sup>39</sup> (Solution I)
   We will be a suming J^P=0^+, from combined analysis of \pi^-p\to\pi^0\pi^0 n, \pi^-p\to\kappa^0\pi^0 n, \pi^-p\to\kappa^0\pi^0 n, \pi^-p\to\pi^0\pi^0 n, \pi^+\pi^-\to\pi^+\pi^-, \pi^-p\to\pi^0\pi^0 n, \pi^0, \pi^0, \pi^0, \pi^0, \pi^0, \pi^0, \pi^0, \pi^+\pi^-\pi^0, \pi^0, 
   41 (Solution I)
   <sup>42</sup> Decaying to f_0(1370) \pi \pi.
   \begin{array}{l} 43 \ J^{P} = 0^{+} \\ 44 \ \text{Not seen by AMSLER 02.} \end{array}
   45 T-matrix pole, assuming J^P=0^+
46 No J^{PC} determination.
47 From a fit to the 0^+ partial wave.
   48 ALDE 92D combines all the GAMS-2000 data.
49 IP = 2+ (0+ \text{ excluded})
                 = 2^+, (0^+ \text{ excluded}).
   ^{50}\,\mathrm{From} an analysis ignoring interference with f_2'(1525)
   ^{51} From an analysis including interference with \bar{t}_2'(1525).
   ^{52} Uses MRK3 data. From a partial-wave analysis of data using a K-matrix formalism with 5 poles, but assuming spin 2. Fit with constrained inelasticity. ^{53}\,J^P=2^+ preferred.
   ^{54}\,\mathrm{From} fit neglecting nearby f_2'(1525). Replaced by BLOOM 83.
   ^{55} From an amplitude analysis of the \kappa_S^0 \kappa_S^0 system, superseded by LONGACRE 86.
                                                                   f<sub>0</sub>(1710) DECAY MODES
                                                                                                                  Fraction (\Gamma_i/\Gamma)
                 Mode
                 K\overline{K}
\Gamma_1
\Gamma_2
                \eta\eta
                                                                                                                   seen
\Gamma_3
                 \pi\pi
                                                                                                                   seen
 \Gamma_4
                \gamma \gamma
\Gamma_5
                \omega\omega
                                                                                                                   seen
                                                                 f_0(1710) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)
\Gamma(K\overline{K}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}
                                                                                                                                                                                      \Gamma_1\Gamma_4/\Gamma
                                                                                   DOCUMENT ID
                                                                                                                              TECN COMMENT
                                                         95
                                                                            <sup>56</sup> BEHREND 89C CELL \gamma\gamma \to \kappa_S^0 \kappa_S^0
 • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                  ALBRECHT 90G ARG \gamma\gamma \rightarrow K^+_-K^-_-
                                                         95
 <480
                                                                            <sup>56</sup> ALTHOFF
  <280
                                                                                                                      85B TASS \gamma\gamma \to K\overline{K}\pi
  <sup>56</sup> Assuming helicity 2.
\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}
                                                                                                                                                                                      \Gamma_3\Gamma_4/\Gamma
                                                                                   DOCUMENT ID
                                                                                                                                  TECN COMMENT
                                                                           57 BARATE
  <0.82
                                                                                                                      00E ALEP \gamma\gamma \to \pi^+\pi^-
  <sup>57</sup> Assuming spin 0.
                                                            fo(1710) BRANCHING RATIOS
\Gamma(K\overline{K})/\Gamma_{total}
                                                                                                                                                                                            \Gamma_1/\Gamma
                                                                                   DOCUMENT ID
                                                                                                                             TECN COMMENT
 • • • We do not use the following data for averages, fits, limits, etc. • •
                                                                                   ALBALADEJO 08 RVUE
0.36 \pm 0.12
0.38 + 0.09 \\ -0.19
                                                                     <sup>58,59</sup> LONGACRE 86 MPS 22 \pi^- p \rightarrow n2 \kappa_S^0
\Gamma(\eta\eta)/\Gamma_{\rm total}
                                                                                                                                                                                             \Gamma_2/\Gamma
                                                                                   DOCUMENT ID
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
0.22 \!\pm\! 0.12
                                                                                  ALBALADEJO 08 RVUE
0.18 + 0.03 \\ -0.13
                                                                     <sup>58,59</sup> LONGACRE 86 RVUE
                                                                                                                                                                                             \Gamma_3/\Gamma
\Gamma(\pi\pi)/\Gamma_{\text{total}}
```

DO CUMENT ID

^{58,59}LONGACRE 86

● ● ● We do not use the following data for averages, fits, limits, etc. ● ● AMSLER

not seen $0.039 + 0.002 \\ -0.024$ TECN COMMENT

RVUE

02 CBAR 0.9 $p \to \pi^0 \eta \eta, \pi^0 \pi^0 \pi^0$

I

| $\Gamma(\pi\pi)/\Gamma(K\overline{K})$ | | | | | | Γ_3/Γ_1 |
|-------------------------------------------------|-------------|----|-------------------|-------|-------------|--------------------------------------------------------------------|
| VALUE | CL% | | DOCUMENT ID | | TECN | COMMENT |
| $0.41 {}^{+ 0.11}_{- 0.17}$ | | | ABLIKIM | 06∨ | BES2 | $e^+ e^- \rightarrow J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| • • • We do not us | e the follo | ow | ing data for ave | rages | , fits, lin | nits, etc. • • • |
| 0.32 ± 0.14 | | | ALBALADEJO | 80 | RVUE | |
| < 0.11 | 95 | 60 | ABLIKIM | 04E | BES2 | $J/\psi \rightarrow \omega K^+ K^-$ |
| $5.8 \begin{array}{c} +9.1 \\ -5.5 \end{array}$ | | 61 | ANISOVICH | 02D | SPEC | Combined fit |
| $0.2\ \pm0.024\pm0.036$ | | | BARBERIS | 99D | OMEG | 450 $pp \rightarrow K^+K^-, \pi^+\pi^-$ |
| $0.39 \!\pm\! 0.14$ | | | ${\tt ARMSTRONG}$ | 91 | OMEG | 300 $pp \rightarrow pp\pi\pi, ppK\overline{K}$ |
| $\Gamma(\eta\eta)/\Gamma(K\overline{K})$ | | | | | | Γ_2/Γ_1 |

| $-1(\eta\eta)/1(K$ | K) | | | | 12/11 |
|-----------------------------|-----------------------|-------------------------|---------|---------|---------------------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
| 0.48 ± 0.15 | | BARBERIS | 00E | | 450 $pp \rightarrow p_f \eta \eta p_S$ |
| • • • We do | not use the following | data for averages | , fits, | limits, | etc. • • • |
| $0.46 {}^{+ 0.70}_{- 0.38}$ | 6 | $^{ m 1}$ A NISOVICH | 02D | SPEC | Combined fit |
| < 0.02 | 90 6 | ² PROKOSHKIN | 91 | GA 24 | $300 \pi^- p \rightarrow \pi^- p \eta \eta$ |

| $\Gamma(\omega\omega)/\Gamma_{total}$ | | | | | |
|---------------------------------------|------|-------------|-----|------|-------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| seen | 180 | ABLIKIM | 06н | BES | $J/\psi \rightarrow \gamma \omega \omega$ |

 $^{^{58}\,\}mathrm{From}$ a partial-wave analysis of data using a K-matrix formalism with 5 poles, but assuming spin 2.

59 Fit with constrained inelasticity.

60 Using data from ABLIKIM 04A.

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| ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | 02.0 | T 11 1 2 10 10 5 15 | | |
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$\eta(1760)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

OMITTED FROM SUMMARY TABLE

Seen by DM2 in the $\rho\rho$ system (BISELLO 89B). Structure in this region has been reported before in the same system (BAL-TRUSAITIS 86B) and in the $\omega\omega$ system (BALTRUSAITIS 85C, BISELLO 87).

$\eta(1760)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|-----------------|----------------------|--------|----------|-------------------------------------------|
| 1756± 9 OUR AVE | RAGE | | | | |
| $1744 \pm 10 \pm 15$ | 1045 | ¹ ABLIKIM | 06н | BES | $J/\psi \rightarrow \gamma \omega \omega$ |
| 1760 ± 11 | 320 | ² BISELLO | 89B | DM2 | $J/\psi ightarrow 4\pi\gamma$ |
| ¹ From a partial w | vave analysis i | ncluding $n(1760)$. | fo(17) | 10). fa(| 1640), and f ₂ (1910). |

η (1760) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------|----------------|-------------------------|-----------|------------------------|-------------------------------------------|
| 96±70 OUR AVERAG | E Error | includes scale fact | or of 5 | .1. | |
| $244 + 24 \pm 25$ | 1045 | ³ ABLIKIM | 06н | BES | $J/\psi \rightarrow \gamma \omega \omega$ |
| $60\!\pm\!16$ | 320 | ⁴ BISELLO | 89в | DM2 | $J/\psi ightarrow 4\pi\gamma$ |
| ³ From a partial wave | analysis i | ncluding $\eta(1760)$, | $f_0(17)$ | 10), f ₂ (1 | .640), and f ₂ (1910). |
| ⁴ Estimated by us fro | | | | | . 5, , |

$\eta(1760)$ REFERENCES

| ABLIKIM 0 | 6H PR | D73 112007 | M. Ablikim et al. | (BES Collab.) |
|---------------|--------|------------|--------------------------|---------------------|
| BISELLO 81 | 9B PR | D39 701 | G. Busetto et al. | (DM2 Collab.) |
| BISELLO 87 | 7 PL | B192 239 | D. Bisello et al. | (PADO, CLER, FRAS+) |
| BALTRUSAIT 8 | 6B PR | D33 1222 | R.M. Baltrusaitis et al. | (Mark III Collab.) |
| BALTRUSAIT 85 | 5C PRI | L 55 1723 | R.M. Baltrusaitis et al. | (CIT, UCSC+) |

$\pi(1800)$

 Γ_5/Γ

$$I^{G}(J^{PC}) = 1^{-}(0^{-+})$$

See also minireview under non- $q\overline{q}$ candidates in PDG 06, Journal of Physics, G 33 1 (2006).

$\pi(1800)$ MASS

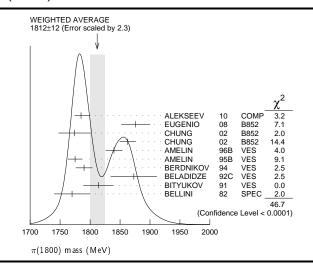
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|--------------------------------------------------------------|------------|------------------------|--------|-----------|--------|----------------------------------------------------------------------------------|
| 1812±12 OUR A | WERAGE | Error includes sc | ale fa | tor of 2 | 2.3. 5 | See the ideogram below. |
| $1785 \pm 9 + 12 \\ -6$ | 420k | ALEKSEEV | 10 | COMP | • | $^{190}_{\pi^{-}\pi^{-}\pi^{+}Pb} \xrightarrow{\pi^{+}Pb'}$ |
| $1876 \pm 18 \pm 16$ | 4 k | ¹ EUGENIO | 08 | B852 | _ | $18 \pi^- p \rightarrow \eta \eta \pi^- p$ |
| $1774 \pm 18 \pm 20$ | | ² CHUNG | 02 | B852 | | 18.3 $\pi^- p \rightarrow$ |
| 1062 0 10 | | ³ CHUNG | 0.0 | D 0F 0 | | $\pi^{+}\pi^{-}\pi^{-}p$ |
| 1863± 9±10 | | CHUNG | 02 | B852 | | $18.3 \pi^{-} p \rightarrow \pi^{+} \pi^{-} \pi^{-} p$ |
| $1840 \pm 10 \pm 10$ | 1200 | AMELIN | 96B | VES | _ | $37 \pi^- A \rightarrow \eta \eta \pi^- A$ |
| $1775 \pm 7 \pm 10$ | | ⁴ AMELIN | 95B | VES | _ | $36 \pi^- A \rightarrow \pi^+ \pi^- \pi^- A$ |
| 1790 ± 14 | | ⁵ BERDNIKOV | 94 | VES | - | $\begin{array}{ccc} 37 & \pi^- A \rightarrow \\ K^+ & K^- & \pi^- A \end{array}$ |
| $1873 \pm 33 \pm 20$ | | BELADIDZE | 92c | VES | _ | $36 \pi^- \text{Be} \rightarrow \pi^- \eta' \eta \text{Be}$ |
| $1814 \pm 10 \pm 23$ 4 | 26 ± 57 | BITYUKOV | 91 | VES | _ | $36 \pi^- C \rightarrow \pi^- \eta \eta C$ |
| 1770 ± 30 | 1100 | BELLINI | 82 | SPEC | _ | $40 \pi^- A \rightarrow 3\pi A$ |
| • • • We do not | use the fo | ollowing data for a | verag | es, fits, | limits | , etc. • • • |
| $1737 \pm 5 \pm 15$ | | AMELIN | 99 | VES | | $37~\pi^-A \rightarrow ~\omega\pi^-\pi^0A^*$ |
| $\frac{1}{2}$ From a single $\frac{1}{2}$ In the f_0 (980) | | | | | | |

⁶¹ From a combined K-matrix analysis of Crystal Barrel (0. $p\overline{p}\to\pi^0\pi^0\pi^0,\pi^0,\pi^0\eta\eta,\pi^0\pi^0\eta^0,\pi^0\pi^0,\pi^0\pi^0,\pi^0\eta\eta,\eta\eta^0,\eta^1\eta)$, and BNL $(\pi p\to K\overline{K}n)$ data. 62 Combining results of GAM4 with those of ARMSTRONG 89D.

²Estimated by us from various fits.

³ In the $f_0(500)\pi$ wave. 4 From a fit to $J^{PC}=0$ — + $f_0(980)\pi$, $f_0(1370)\pi$ waves. 5 From a fit to $J^{PC}=0$ — + $K_0^*(1430)$ K^- and $f_0(980)\pi^-$ waves.

 $\pi(1800)$



π (1800) WIDTH

I

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CH G | COMMENT |
|-------------------------------|----------------|-------------------------|-------|-------------|--------|----------------------------------------------------------------------------------|
| 208±12 OUR | AVERAGE | | | | | |
| $208 \pm 22 ^{+\ 21}_{-\ 37}$ | 420k | ALEKSEEV | 10 | СОМР | | $190 \begin{array}{c} \pi^- Pb \rightarrow \\ \pi^- \pi^- \pi^+ Pb' \end{array}$ |
| $221 \pm 26 \pm 38$ | 4 k | ⁶ EUGENIO | 08 | B 852 | _ | 18 $\pi^- p \rightarrow \eta \eta \pi^- p$ |
| $223 \pm 48 \pm 50$ | | ⁷ CHUNG | 02 | B 852 | | 18.3 $\pi^- p \rightarrow$ |
| | | _ | | | | $\pi^{+}\pi^{-}\pi^{-}p$ |
| $191\pm21\pm20$ | | ⁸ CHUNG | 02 | B 852 | | 18.3 $\pi^- p \rightarrow$ |
| | | | | | | $\pi^{+}\pi^{-}\pi^{-}p$ |
| $210 \pm 30 \pm 30$ | 1200 | AMELIN | 96B | VES | _ | $37 \pi^- A \rightarrow \eta \eta \pi^- A$ |
| $190 \pm 15 \pm 15$ | | ⁹ AMELIN | 95B | VES | _ | 36 $\pi^- A \rightarrow \pi^+ \pi^- \pi^- A$ |
| 210 ± 70 | | ¹⁰ BERDNIKOV | 94 | VES | _ | $37 \pi^- A \rightarrow$ |
| | | | | | | $K^+K^-\pi^-A$ |
| $225 \pm 35 \pm 20$ | | BELADIDZE | 92c | VES | _ | 36 π^- Be $\rightarrow \pi^- \eta' \eta$ Be |
| $205 \pm 18 \pm 32$ | 426 ± 57 | BITYUKOV | 91 | VES | _ | 36 $\pi^- C \rightarrow \pi^- \eta \eta C$ |
| 310 ± 50 | 1100 | BELLINI | 82 | SPEC | _ | 40 $\pi^- A \rightarrow 3\pi A$ |
| • • • We do | not use the fo | ollowing data for a | verag | es, fits, l | limits | , etc. • • • |
| $259 \pm 19 \pm 6$ | | AMELIN | 99 | VES | | 37 $\pi^- A \rightarrow \omega \pi^- \pi^0 A^*$ |
| ⁶ From a sin | orle-note fit | | | | | |
| 7 In the fol | | | | | | |

In the $f_0(980)\,\pi$ wave.

π (1800) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\pi^{+} \pi^{-} \pi^{-}$ | seen |
| Γ_2 | $f_0(500) \pi^-$ | seen |
| Γ_3 | $f_0(980) \pi^-$ | seen |
| Γ_4 | $f_0(1370)\pi^-$ | seen |
| Γ_5 | $f_0(1500) \pi^-$ | not seen |
| Γ_6 | $ ho\pi^-$ | not seen |
| Γ ₇ | $\eta\eta\pi^-$ | seen |
| Γ ₈ | a_0 (980) η | seen |
| Г9 | $a_2(1320)\eta$ | not seen |
| Γ_{10} | $f_2(1270) \pi$ | not seen |
| Γ_{11} | $f_0(1370) \pi^-$ | not seen |
| Γ_{12} | $f_0(1500) \pi^-$ | seen |
| | $\eta \eta'(958) \pi^-$ | seen |
| Γ_{14} | $K_0^*(1430) K^-$ | seen |
| Γ_{15} | $K^*(892)K^-$ | not seen |

π (1800) BRANCHING RATIOS

| $\Gamma(f_0(980)\pi^-)/\Gamma(i$ | $f_0(500)\pi^-)$ | | | Γ_3/Γ_2 |
|----------------------------------|--------------------------|----------------|-----------------------------------------|-----------------------|
| VALUE | DO CUMENT I | D TEC | N COMMENT | |
| $0.44 \pm 0.08 \pm 0.38$ | 11 CHUNG | 02 B85 | $2 18.3 \; \pi^- p \rightarrow \; \pi$ | $+\pi^{-}\pi^{-}\rho$ |
| $\Gamma(f_0(980)\pi^-)/\Gamma(6$ | $f_0(1370)\pi^-)$ | | | Γ_3/Γ_4 |
| VALUE | DO CUMENT ID | TECN C | HG COMMENT | |
| | the following data for a | verages, fits, | limits, etc. • • • | |
| 1.7 ± 1.3 | 12 AMELIN 95 | Бв VES - | $36 \pi^- A \rightarrow \pi^-$ | $+\pi^{-}\pi^{-}A$ |

| $\Gamma(f_0(1370)\pi^-)/\Gamma_{\text{tota}}$ | al <u>F4/F</u> <u>DOCUMENT ID TECN CHG COMMENT</u> |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| seen | BELLINI 82 SPEC $-40 \pi^- A \rightarrow 3\pi A$ |
| $\Gamma(f_0(1500)\pi^-)/\Gamma_{\text{tota}}$ | |
| <i>NALUE</i> not seen | DOCUMENT ID TECN COMMENT CHUNG 02 B852 $18.3 \pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ |
| $\Gamma(ho\pi^-)/\Gamma_{ m total}$ | Γ ₆ /Γ |
| VALUE | DOCUMENT ID TECN CHG COMMENT |
| not seen | BELLINI 82 SPEC $-$ 40 π^- A \rightarrow 3 π A |
| Γ(ρπ ⁻)/Γ(f ₀ (980)π ⁻ <u>VALUE</u> <u>CL%</u> | ·-) Γ ₆ /Γ ₃ <u>DOCUMENT ID TECN CHG COMMENT</u> |
| | e following data for averages, fits, limits, etc. • • • |
| <0.25 <0.14 90 | CHUNG 02 B852 $18.3 \pi^- p \rightarrow \pi^+ \pi^- \pi^- p$ AMELIN 95B VES $-36 \pi^- A \rightarrow \pi^+ \pi^- \pi^- A$ |
| $\Gamma(\eta\eta\pi^-)/\Gamma(\pi^+\pi^-\pi$ | |
| • • • We do not use the | S <u>DOCUMENT ID</u> <u>TECN CHG</u> <u>COMMENT</u> e following data for averages, fits, limits, etc. • • • |
| 0.5 ± 0.1 120 | 40 |
| $\Gamma(a_2(1320)\eta)/\Gamma_{\text{total}}$ | Г ₉ /Г |
| VALUE | DOCUMENT ID TECN COMMENT |
| not seen | EUGENIO 08 B852 18 $\pi^- \rho \rightarrow \eta \eta \pi^- \rho$ |
| $\Gamma(f_2(1270)\pi)/\Gamma_{\text{total}}$ | F ₁₀ /F |
| not seen | EUGENIO 08 B852 $18 \pi^- p \to \eta \eta \pi^- p$ |
| $\Gamma(f_0(1370)\pi^-)/\Gamma_{\text{tota}}$ | al DOCUMENT ID TECN COMMENT |
| not seen | EUGENIO 08 B852 $18 \pi^- p \rightarrow \eta \eta \pi^- p$ |
| $\Gamma(f_0(1500)\pi^-)/\Gamma(a_0$ | Γ_{12}/Γ_{8} |
| | |
| | DOCUMENT ID TECN CHG COMMENT |
| • • • We do not use the | e following data for averages, fits, limits, etc. • • • |
| • • • We do not use the 0.48 \pm 0.17 4k ¹ | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ | e following data for averages, fits, limits, etc. \bullet \bullet \bullet 2,13 EUGENIO 08 B852 $-$ 18 $\pi^- p \to \eta \eta \pi^- p$ |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta$ | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 $-$ 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^0\pi^0$ 2,14 AMELIN 96B VES $-$ 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ $^{13}/\Gamma_7$ |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta_{VALUE})$ | e following data for averages, fits, limits, etc. • • • • $2,13$ EUGENIO 08 B852 $-$ 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^0\pi^0$ 2,14 AMELIN 96B VES $-$ 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ $\eta\pi^-$ |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta)$ VALUE EV • • • We do not use the 0.29 ± 0.07 | e following data for averages, fits, limits, etc. • • • • • 2,13 EUGENIO 08 B852 - $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p \overline{p} \rightarrow \eta \eta \pi^0 \pi^0$ 2,14 AMELIN 96B VES - $37 \pi^- A \rightarrow \eta \eta \pi^- A$ 17 π^-) TES DOCUMENT ID TECN CHG COMMENT e following data for averages, fits, limits, etc. • • • 12 BELADIDZE 92C VES - $36 \pi^- \text{Be} \rightarrow \pi^- \eta' \eta \text{Be}$ |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+}$ 0.014 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta)$ $VALUE$ EV V • • We do not use the 0.29 ± 0.07 0.3 ± 0.1 426 ± 5 $\Gamma(K_{0}^{*}(1430)K^{-})/\Gamma_{tc}$ | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 - $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^0 \pi^0$ 2,14 AMELIN 96B VES - $37 \pi^- A \rightarrow \eta \eta \pi^- A$ F13/F1 T5 DOCUMENT ID TECN CHG COMMENT e following data for averages, fits, limits, etc. • • • 12 BELADIDZE 92c VES - $36 \pi^- \text{Be} \rightarrow \pi^- \eta' \eta \text{Be}$ 57 12 BITYUKOV 91 VES - $36 \pi^- \text{C} \rightarrow \pi^- \eta \eta \text{C}$ Otal |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+}$ 0.014 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\eta'(958)\pi^{$ | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 - $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p \overline{p} \rightarrow \eta \eta \pi^0 \pi^0$ 2,14 AMELIN 96B VES - $37 \pi^- A \rightarrow \eta \eta \pi^- A$ ($\eta \pi^-$) \overline{r}_{S} DOCUMENT ID e following data for averages, fits, limits, etc. • • • • 12 BELADIDZE 92c VES - $36 \pi^- Be \rightarrow \pi^- \eta' \eta Be$ 57 1^2 BITYUKOV 91 VES - $36 \pi^- C \rightarrow \pi^- \eta \eta C$ |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\chi)UE$ • • We do not use the 0.29 ± 0.07 0.3 ± 0.1 426 ± 5 $\Gamma(K_{0}^{*}(1430)K^{-})/\Gamma_{to}$ seen | e following data for averages, fits, limits, etc. |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 $^{+0.014}_{-0.011}$ 0.08 ± 0.03 1200 1 $\Gamma(\eta\eta'(958)\pi^{-})/\Gamma(\eta\chi) = 0.029\pm0.07$ 0.3 ± 0.1 426 ± 5 $\Gamma(K_0^*(1430)K^{-})/\Gamma_{tot}$ seen $\Gamma(K^*(892)K^{-})/\Gamma_{tot}$ | e following data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 2,13 EUGENIO 08 B852 — $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p \overline{p} \rightarrow \eta \eta \pi^0 \pi^0 \pi^0 2$,14 AMELIN 96B VES — $37 \pi^- A \rightarrow \eta \eta \pi^- A$ 713/ Γ_{1} Γ_{2} Γ_{3} |
| • • • We do not use the 0.48 ± 0.17 4k 1 0.030 + 0.014 1 0.08 ± 0.03 1200 1 \[\begin{align*} \Pi(\eta\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\frac{\eta}{\eta}\fr | e following data for averages, fits, limits, etc. 2,13 EUGENIO 08 B852 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^-q$ 2,14 AMELIN 96B VES 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ ($\eta\pi^-$) TES DOCUMENT ID TECN CHG COMMENT e following data for averages, fits, limits, etc. 12 BELADIDZE 92c VES 36 $\pi^-Be \rightarrow \pi^-\eta^\prime\eta Be$ 57 12 BITYUKOV 91 VES 36 $\pi^-C \rightarrow \pi^-\eta\eta C$ ODALI DOCUMENT ID TECN CHG COMMENT BERDNIKOV 94 VES 714/1 DOCUMENT ID TECN CHG COMMENT BERDNIKOV 94 VES 75 COMMENT 76 COMMENT 76 COMMENT 77 COMMENT 77 COMMENT 78 COMMENT 78 COMMENT 79 COMMENT 79 COMMENT 70 COMMENT 70 COMMENT 70 COMMENT 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 715/1 |
| • • • We do not use the 0.48 ± 0.17 | e following data for averages, fits, limits, etc. 2,13 EUGENIO 08 B852 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^-n$ 2,14 AMELIN 96B VES 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ ($\eta\pi^-$) 15 DOCUMENT ID 12 BELADIDZE 92C VES 12 BITYUKOV 91 VES 36 $\pi^-Be \rightarrow \pi^-\eta'\eta Be$ 12 BITYUKOV 91 VES 36 $\pi^-Be \rightarrow \pi^-\eta'\eta Be$ 18 BERDNIKOV 19 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 19 DOCUMENT ID 10 DOCUMENT ID 11 DOCUMENT ID 12 BERDNIKOV 14 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 19 DOCUMENT ID 10 DOCUMENT ID 11 DOCUMENT ID 12 BERDNIKOV 14 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 19 DOCUMENT ID 19 DOCUMENT ID 10 DOCUMENT ID 10 DOCUMENT ID 10 DOCUMENT ID 10 DOCUMENT ID 11 DOCUMENT ID 12 DOCUMENT ID 13 TECN 14 COMMENT 15 IN TECN 16 COMMENT 17 A A A K A K A A A K A A K A A A K A A A A A A A A A A A A A A A A A A A A |
| • • • We do not use the 0.48 ±0.17 | e following data for averages, fits, limits, etc. 2,13 EUGENIO 8 B852 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^-n$ 2,14 AMELIN 96B VES 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ 713/ Γ_{12} To DOCUMENT ID TECN CHG COMMENT 12 BLADIDZE 92c VES 36 π^- Be $\rightarrow \pi^-\eta'\eta$ Be 12 BITYUKOV 91 VES 36 π^- C $\rightarrow \pi^-\eta\eta$ C 12 BITYUKOV 91 VES 36 π^- C $\rightarrow \pi^-\eta\eta$ C 18 π^- C $\rightarrow \pi^-\eta\eta$ C 19 BERDNIKOV 19 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 19 DOCUMENT ID TECN CHG COMMENT BERDNIKOV 19 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 100 deays only to $\pi\pi$. te testimated. 10 testimated. 11 testimated. |
| • • • We do not use the 0.48 ±0.17 | e following data for averages, fits, limits, etc. 2,13 EUGENIO 8 B852 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 10 B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^-p$ 2,14 AMELIN 96B VES 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ 17 π^-) 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 19 π^- 19 DOCUMENT ID 10 EVES 12 BELADIDZE 12 BITYUKOV 91 VES 13 $\pi^-A \rightarrow \pi^-\eta^-\eta$ 14 π^- 15 DOCUMENT ID 16 SITYUKOV 17 ECN 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 19 $\pi^-h \rightarrow \eta\eta\pi^-p$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 BELADIDZE 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 19 $\pi^-h \rightarrow \eta\eta\pi^-p$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 $\pi^-h \rightarrow \eta\eta\pi^-A$ 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 $\pi^-h \rightarrow \eta\eta\pi^-A$ 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 $\pi^-h \rightarrow \eta\eta\pi^-A$ 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 $\pi^-h \rightarrow \eta\eta\pi^-A$ 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 11 $\pi^-h \rightarrow \eta\eta\pi^-A$ 12 $\pi^-h \rightarrow \eta\eta\pi^-A$ 13 $\pi^-h \rightarrow \eta\eta\pi^-A$ 14 $\pi^-h \rightarrow \eta\eta\pi^-A$ 15 $\pi^-h \rightarrow \eta\eta\pi^-A$ 16 $\pi^-h \rightarrow \eta\eta\pi^-A$ 17 $\pi^-h \rightarrow \eta\eta\pi^-A$ 18 $\pi^-h \rightarrow \eta\eta\pi^-A$ 19 $\pi^-h \rightarrow \eta\eta\pi^-A$ 10 $\pi^-h \rightarrow \eta\eta\pi^-A$ |
| • • • We do not use the 0.48 ±0.17 | e following data for averages, fits, limits, etc. 2,13 EUGENIO 8 B852 18 $\pi^-p \rightarrow \eta\eta\pi^-p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta\eta\pi^-n$ 2,14 AMELIN 96B VES 37 $\pi^-A \rightarrow \eta\eta\pi^-A$ 713/ Γ_{12} To DOCUMENT ID TECN CHG COMMENT 12 BLADIDZE 92c VES 36 π^- Be $\rightarrow \pi^-\eta'\eta$ Be 12 BITYUKOV 91 VES 36 π^- C $\rightarrow \pi^-\eta\eta$ C 12 BITYUKOV 91 VES 36 π^- C $\rightarrow \pi^-\eta\eta$ C 18 π^- C $\rightarrow \pi^-\eta\eta$ C 19 BERDNIKOV 19 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 19 DOCUMENT ID TECN CHG COMMENT BERDNIKOV 19 VES 37 $\pi^-A \rightarrow K^+K^-\pi^-A$ 100 deays only to $\pi\pi$. te testimated. 10 testimated. 11 testimated. |
| • • • We do not use the 0.48 ±0.17 | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 — $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^- q$ 2,14 AMELIN 96B VES — $37 \pi^- A \rightarrow \eta \eta \pi^- A$ [17 π^-] TS DOCUMENT ID TECN CHG COMMENT e following data for averages, fits, limits, etc. • • • 12 BELADIDZE 92c VES — $36 \pi^- \text{Be} \rightarrow \pi^- \eta' \eta \text{Be}$ 57 12BITYUKOV 91 VES — $36 \pi^- \text{CO} \rightarrow \pi^- \eta \eta \text{C}$ ODTAI TECN CHG COMMENT BERDNIKOV 94 VES — $37 \pi^- A \rightarrow K^+ K^- \pi^- A$ 131 $\frac{DOCUMENT ID}{DOCUMENT ID}$ TECN CHG COMMENT BERDNIKOV 94 VES — $37 \pi^- A \rightarrow K^+ K^- \pi^- A$ 130 decays only to $\pi \pi$. t estimated. t00) decays only to $\eta \eta$ and a_0 (980) decays only to $\eta \pi$. T(1800) REFERENCES 04 241803 M.G. Alekseev et al. (COMPASS Collab.) |
| • • • We do not use the 0.48 ± 0.17 | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 - $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^- q$ 2,14 AMELIN 96B VES - $37 \pi^- A \rightarrow \eta \eta \pi^- A$ 177 π^-) |
| • • • We do not use the 0.48 ± 0.17 | e following data for averages, fits, limits, etc. • • • 2,13 EUGENIO 08 B852 — $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^- p$ 2,14 AMELIN 96B VES — $37 \pi^- A \rightarrow \eta \eta \pi^- A$ 17 π^-) |
| • • • We do not use the 0.48 ± 0.17 | e following data for averages, fits, limits, etc. • • • 2,13 EUGENIO 08 B852 — $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^- q$ 0.74 0.6 0.6 0.6 0.6 0.74 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 0.7 |
| • • • We do not use the 0.48 ± 0.17 | e following data for averages, fits, limits, etc. • • • • 2,13 EUGENIO 08 B852 — $18 \pi^- p \rightarrow \eta \eta \pi^- p$ 12 ANISOVICH 01B SPEC 0 0.6–1.94 $p\overline{p} \rightarrow \eta \eta \pi^- q$ $0.00000000000000000000000000000000000$ |

In the $f_0(500)\,\pi$ wave. ⁹ From a fit to $J^{PC}=0$ — + $f_0(980)\,\pi$, $f_0(1370)\,\pi$ waves. ¹⁰ From a fit to $J^{PC}=0$ — + $K_0^*(1430)\,K^-$ and $f_0(980)\,\pi^-$ waves.

 $f_{5}(1810)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

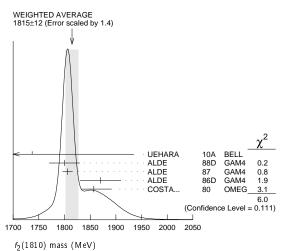
OMITTED FROM SUMMARY TABLE Needs confirmation.

£(1810) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|------------|-----------------------|---------|-------------|-------------------------------------------------|
| 1815 ± 12 OUR AVE | RAGE E | rror includes scale | factor | of 1.4. | See the ideogram below. |
| $1737 \pm 9^{+198}_{-65}$ | | ¹ UEHARA | 10A | BELL | $10.6~e^+e^-\rightarrow~e^+e^-\eta\eta$ |
| 1800 ± 30 | 40 | ALDE | 88D | GAM4 | $300 \pi^- p \rightarrow \pi^- p 4 \pi^0$ |
| 1806 ± 10 | 1600 | ALDE | 87 | GAM4 | $100 \ \pi^- \rho \rightarrow 4\pi^0 n$ |
| 1870 ± 40 | | ² ALDE | 86D | GAM4 | 100 $\pi^- p \rightarrow \eta \eta n$ |
| $1857 + 35 \\ -24$ | | ³ COSTA | 80 | OMEG | 10 $\pi^- p \rightarrow K^+ K^- n$ |
| • • • We do not use | the follow | wing data for avera | ages, 1 | fits, limit | is, etc. • • • |
| $1858 + \frac{18}{71}$ | | ⁴ LONGACRE | 86 | RVUE | Compilation |
| 1799 ± 15 | | ⁵ CASON | 82 | STRC | 8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| 4 | | | | | |

¹ Breit-Wigner mass.

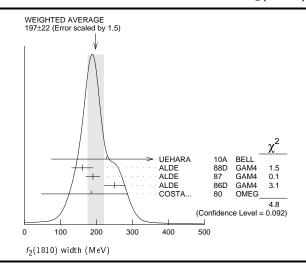
compilation of several other experiments. 5 From an amplitude analysis of the reaction $\pi^+\pi^-\to 2\pi^0$. The resonance in the $2\pi^0$ final state is not confirmed by PROKOSHKIN 97.



f2(1810) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|-----------------------|--------|------------|-------------------------------------------------|
| 197± 22 OUR A | VERAGE | Error includes scale | factor | of 1.5. | See the ideogram below. |
| $228 + 21 + 234 \\ - 20 - 153$ | | ⁶ UEHARA | | | $10.6~e^+~e^-~\rightarrow~e^+e^-~\eta\eta$ |
| 160 ± 30 | 40 | ALDE | | | $300 \pi^- p \rightarrow \pi^- p 4 \pi^0$ |
| $190\pm\ 20$ | 1600 | ALDE | 87 | GAM4 | $100 \pi^- \rho \rightarrow 4\pi^0 n$ |
| 250 ± 30 | | ⁷ ALDE | 86D | GAM4 | $100 \pi^- p \rightarrow \eta \eta n$ |
| $185 {}^{+ 1 02}_{- 1 39}$ | | ⁸ COSTA | 80 | OMEG | $10~\pi^-\rho \to~K^+~K^-~n$ |
| ● ● We do not | use the fol | llowing data for aver | ages, | fits, limi | ts, etc. • • • |
| $388 + 15 \\ - 21$ | | ⁹ LONGACRE | 86 | RVUE | Compilation |
| $280 + 42 \\ -35$ | | ¹⁰ CASON | 82 | STRC | 8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$ |

⁶ Breit-Wigner width.



f2(1810) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|----------------------------------------|------------------------------|
| <u></u> | $\pi\pi$ | |
| Γ ₂ Γ ₃ | $\eta \eta \atop 4\pi^0 \atop K^+ K^-$ | seen |
| Γ_4 | $K^+ K^-$ | |
| Γ_5 | $\gamma \gamma$ | seen |

$f_2(1810) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\eta\eta) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ | | | | $\Gamma_2\Gamma_5/\Gamma$ |
|---------------------------------------------------------------|--------------|-----|------|------------------------------------------|
| VALUE (eV) | DO CUMENT ID | | TECN | COMMENT |
| 5.2+0.9+37.3 5.2-0.8-4.5 | 11 UEHARA | 10A | BELL | $10.6 e^+e^- \rightarrow e^+e^-\eta\eta$ |

 $^{^{11}}$ Including interference with the $f_2^\prime(1525)$ (parameters fixed to the values from the 2008 edition of this review, PDG 08) and $f_2(1270)$. May also be the $f_0(1500)$.

f2(1810) BRANCHING RATIOS

| $\Gamma(\pi\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|----------------------------------------|---------------------------|-------|-----------|----------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the | e following data for aver | ages, | fits, lim | its, etc. • • • |
| not seen | AMSLER | 02 | CBAR | $\begin{array}{ccc} 0.9 \; \overline{p}p \to & \pi^0 \eta \eta, \; \pi^0 \pi^0 \pi^0 \\ 38 \; \pi^- p \to & \pi^0 \pi^0 n \end{array}$ |
| not seen | PROKOSHKIN | 97 | GAM2 | $38 \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| $0.21 {}^{+ 0.02}_{- 0.03}$ | ¹² LONGACRE | 86 | RVUE | Compilation |
| 0.44 ± 0.03 | ¹³ CASON | 82 | STRC | 8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$ |

 $^{^{\}rm 12}$ From a partial-wave analysis of data using a K-matrix formalism with 5 poles. Includes compilation of several other experiments.

compilation of several other experiments.

 $\Gamma(\eta\eta)/\Gamma_{\text{total}}$ Γ_2/Γ DOCUMENT ID • • • We do not use the following data for averages, fits, limits, etc. • • • $0.008 \,{}^{+\, 0.028}_{-\, 0.003}$ $^{14}\, {\sf LONGACRE}$ 86 RVUE Compilation

 $^{14}\,{\rm From}$ a partial-wave analysis of data using a K-matrix formalism with 5 poles. Includes compilation of several other experiments.

| $\Gamma(\pi\pi)/\Gamma(4\pi^0)$ | | | | Γ_1/Γ_3 |
|---------------------------------|--------------------------------|---------------|---------------------------|---------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT | |
| • • • We do not use the | following data for averages, f | fits, limits, | etc. • • • | |
| < 0.75 | ALDE 8 | 7 GAM4 | $100 \pi^- p \rightarrow$ | $4\pi^0 n$ |

| $\Gamma(4\pi^0)/\Gamma(\eta\eta)$ | | | Γ_3/Γ_2 |
|-----------------------------------|-------------------------------|------------|--------------------------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT |
| • • • We do not use the following | owing data for averages, fits | s, limits, | etc. • • • |
| 0.8 ± 0.3 | ALDE 87 | GAM4 | $100 \ \pi^- p \rightarrow 4\pi^0 n$ |

| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | | | | Γ4/Γ |
|----------------------------------------|---------------------------|--------------|-------------|------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the follow | wing data for averages, f | its, limits, | etc. • • • | |
| $0.003 {}^{+ 0.019}_{- 0.002}$ | ¹⁵ LONGACRE 8 | 6 RVUE | Compilation | |

80 OMEG 10 $\pi^- p \to K^+ K^- n$ seen COSTA... $^{15}\,\mathrm{From}$ a partial-wave analysis of data using a K-matrix formalism with 5 poles. Includes

² Seen in only one solution.

³ Error increased by spread of two solutions. Included in LONGACRE 86 global analysis.

 $^{^4\,\}mathrm{From}$ a partial-wave analysis of data using a K-matrix formalism with 5 poles. Includes

⁷ Seen in only one solution.

⁸ Error increased by spread of two solutions. Included in LONGACRE 86 global analysis. ⁹ From a partial-wave analysis of data using a K-matrix formalism with 5 poles. Includes compilation of several other experiments.

¹⁰ From an amplitude analysis of the reaction $\pi^+\pi^-$ final state is not confirmed by PROKOSHKIN 97. \rightarrow $2\pi^0$. The resonance in the $2\pi^0$

¹³ Included in LONGACRE 86 global analysis.

 $f_2(1810), X(1835), \phi_3(1850), \eta_2(1870)$

f₂(1810) REFERENCES

| UEHARA PDG | 10 A 08 | PR D82 114031 PL B667 1 FPJ C23 29 | C. Amsler et al. | (BELLE Collab.) (PDG Collab.) |
|----------------------------------------------|------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| AMS LER PROKOSHKIN | 02 97 | SPD 42 117 | C. Amsler et al. Y.D. Prokoshkin et al. | (SERP) |
| ALDE | 88 D | Translated from SJNP 47 810 Translated from | D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) |
| ALDE ALDE LONGACRE CAS ON COS TA | 87 86 D 86 82 80 | PL B198 286 NP B269 485 PL B177 223 PRL 48 1316 NP B175 402 | D.M. Alde <i>et al.</i> D.M. Alde <i>et al.</i> R.S. Longacre <i>et al.</i> N.M. Cason <i>et al.</i> G. Costa de Beauregard | (LANL, BRUX, SERP, LAPP) (BELG, LAPP, SERP, CERN+) (BNL, BRAN, CUNY+) (NDAM, ANL) et al. (BARI, BONN+) |

X(1835)

$$I^G(J^{PC}) = ??(?^{-+})$$

OMITTED FROM SUMMARY TABLE Could be a superposition of several states.

X(1835) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------------|-------------|------------------------|---------|---------|--------------------------------------------------|
| 1835.7 + 5.0 OUR AV | ERAGE | | | | |
| $1836.5 \pm 3.0 {}^{+}_{-} {}^{5.6}_{2.1}$ | 4265 | 1 ABLIKIM | 110 | BES3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ |
| $1833.7 \pm 6.1 \pm 2.7$ | 264 | ABLIKIM | 05R | BES2 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ |
| • • • We do not use | the followi | ng data for average | s, fits | limits, | etc. • • • |
| $1877.3 \pm 6.3 ^{+}_{-} \begin{array}{c} 3.4 \\ 7.4 \end{array}$ | | ² ABLIKIM | 111 | BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| $1837 \begin{array}{cccc} +10 & +9 \\ -12 & -7 \end{array}$ | 231 | 3,4 ALEXANDER | 10 | CLEO | $J/\psi \rightarrow \gamma p \overline{p}$ |
| 1831 ± 7 | | ^{4,5} ABLIKIM | 05R | BES2 | $J/\psi \rightarrow \gamma \rho \overline{\rho}$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | ⁴ BAI | 03F | BES2 | $J/\psi \rightarrow \gamma \rho \overline{\rho}$ |

 1 From a fit of the $\pi^+\pi^-\eta'$ mass distribution to a combination of γf_1 (1510), γX (1835), and two unconfirmed states γX (2120), and γX (2370), for $M(\rho \overline{\rho}) < 2.8$ GeV, and accounting for backgrounds from non- η' events and $J/\psi \to \pi^0 \, \pi^+ \, \pi^- \, \eta'$.

 2 The selected process is $J/\psi\to\omega\,a_0(980)\,\pi.$ This state may be due also to $\eta_2(1870)$ or to a combination of X(1835) and $\eta_2(1870).$

 3 From a fit of the $p\overline{p}$ mass distribution to a combination of $\gamma X(1835),\,\gamma R$ with M(R)=2100 MeV and $\Gamma(R)=160$ MeV, and $\gamma p\overline{p}$ phase space, for $M(p\overline{p})<2.85$ GeV. 4 Evidence for a threshold enhancement in the $p\overline{p}$ mass spectrum was also reported by

⁴ Evidence for a threshold enhancement in the $\rho \overline{\rho}$ mass spectrum was also reported by ABE 02K, AUBERT,B 05L, and WANG 05A in $B^+ \to \rho \overline{\rho} K^+$, WANG 05A in $B^0 \to \rho \overline{\rho} K^0$, ABE 02W in $\overline{B}{}^0 \to \rho \overline{\rho} D^0$, and WEI 08 in $B^+ \to \rho \overline{\rho} \pi^+$ decays. Not seen by ATHAR 06 in $\Upsilon(1S) \to \rho \overline{\rho} \gamma$.

⁵ From the fit including final state interaction effects in isospin 0 S-wave according to SIBIRTSEV 05A. Systematic errors not estimated.

X (1835) WIDTH

| VALU | E (MeV) | | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------|-----------------|----------------|----------|--------------|------------------------|-----------|-----------|------------------------------------------------|
| 99 | ±50 | OUR A | /ERAG | E Err | or includes scale fact | or of | 2.8. | |
| 190 | ± 9 | $^{+38}_{-36}$ | | 4265 | ⁶ ABLIKIM | 110 | BES3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ |
| 67.7 | ± 20.3 | ± 7.7 | | 264 | ABLIKIM | 05R | BES2 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ |
| • • • | • We d | lo not us | e the fo | ollowing | g data for averages, t | fits, lii | nits, etc | . • • • |
| 57 | ±12 | $^{+19}_{-4}$ | | | ⁷ ABLIKIM | 111 | BES3 | $J/\psi \rightarrow \omega (\eta \pi^+ \pi^-)$ |
| 0 | $^{+44}_{-\ 0}$ | | | 231 | 8,9 ALEXANDER | 10 | CLEO | $J/\psi \rightarrow \gamma p \overline{p}$ |
| < 15 | 3 | | 90 | | 9,10 ABLIKIM | 05 R | BES2 | $J/\psi \rightarrow \gamma p \overline{p}$ |
| < 30 | | | | | ⁹ BAI | 03F | BES2 | $J/\psi \rightarrow \gamma p \overline{p}$ |
| | | | | | | | | $\gamma f_{1}(1510), \gamma X(1835),$ |

⁶ From a fit of the $\pi^+\pi^-\eta'$ mass distribution to a combination of $\gamma f_1(1510), \gamma X(1835),$ and two unconfirmed states $\gamma X(2120),$ and $\gamma X(2370),$ for $M(p\overline{p}) < 2.8$ GeV, and accounting for backgrounds from non- η' events and $J/\psi \to \pi^0 \pi^+\pi^-\eta'$.

 7 The selected process is $J/\psi\to \omega\,a_0(980)\,\pi.$ This state may be due also to $\eta_2(1870)$ or to a combination of X(1835) and $\eta_2(1870).$

⁸ From a fit of the $p\overline{p}$ mass distribution to a combination of $\gamma X(1835)$, γR with M(R)=2100 MeV and $\Gamma(R)=160$ MeV, and $\gamma p\overline{p}$ phase space, for $M(p\overline{p})<2.85$ GeV.

⁹ Evidence for a threshold enhancement in the $p\overline{p}$ mass spectrum was also reported by ABE 02K, AUBERT,B 05L, and WANG 05A in $B^+ \to p\overline{p}\,K^+$, WANG 05A in $B^0 \to p\overline{p}\,K^0$, ABE 02W in $\overline{B}^0 \to p\overline{p}\,D^0$, and WEI 08 in $B^+ \to p\overline{p}\,\pi^+$ decays. Not seen by ATHAR 06 in $\Upsilon(1S) \to p\overline{p}\,\gamma$.

10 From the fit including final state interaction effects in isospin 0 S-wave according to SIBIRTSEV 05A. Systematic errors not estimated.

X(1835) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------|------------------------------|
| $\overline{\Gamma_1}$ | p p | seen |
| Γ_2 | $\pi^+\pi^-\eta'$ | seen |

X(1835) BRANCHING RATIOS

| | | | , | | | | |
|-------------------------------------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------|-----------------------------------------------|----------------------------------------------------------------|
| Γ(ρ φ)/Γ(<u>value</u> | $\pi^+\pi$ | -η') | <u>DO CUMENT II</u> |) | TECN | COMMENT | Γ ₁ /Γ ₂ |
| • • • We d | lo not | use the following | data for avera | ges, fits | , limits, | etc. • • • | |
| 0.333 | | | ABLIKIM | 05R | BES2 | $J/\psi \rightarrow \gamma \pi^{-}$ | + π ⁻ η' |
| | | X(| 1835) REFEI | RENCE | S | | |
| ABLIKIM ABLIKIM ALEXANDER WEI ATHAR ABLIKIM AUBERT,B SIBIRTSEV | 11 C 11 J 10 08 06 05 R 05 L 05 A | PRL 106 072002 PRL 107 182001 PR D82 092002 PL B659 80 PR D73 032001 PRL 95 262001 PR D72 051101R PR D71 054010 | M. Ablikim M. Ablikim J.P. Alexand JT. Wei ei S.B. Athar i M. Ablikim B. Aubert e A. Sibirtsey | et al. er et al. : al. et al. et al. t al. | nbauer | (BES III) (CLEO (BELLE (CLEO (BES | Collab.) Collab.) Collab.) Collab.) Collab.) Collab.) Collab.) |
| WAN G BAT | 05 A 03 F | PL B617 141 PRL 91 022001 | MZ. Wang J.Z. Bai et | et al. | | | Collab.) Collab.) |

$\phi_3(1850)$

$$I^{G}(J^{PC}) = 0^{-}(3^{-})$$

$\phi_3(1850)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|------|--------------|-----|------|-----------------------------------------------------------------------------------------------------------------------------------|
| 1854 ± 7 OUR AVER/ | AGE | | | | |
| 1855 ± 10 | | ASTON | 88E | LASS | 11 $K^- p \rightarrow K^- K^+ \Lambda$, $K^0_S K^{\pm} \pi^{\mp} \Lambda$ |
| $1870 + 30 \\ -20$ | 430 | ARMSTRONG | 82 | OMEG | 18.5 $K^- p \rightarrow K^- K^+ \Lambda$ |
| 1850 ± 10 | 123 | ALHARRAN | 81в | нвс | $8.25 \stackrel{\wedge}{K} \stackrel{\wedge}{p} \stackrel{\wedge}{\rightarrow} \stackrel{\wedge}{K} \stackrel{\wedge}{K} \Lambda$ |

ϕ_3 (1850) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------|-------------|--------------------|--------|------|----------------------------------------------------------------------------|
| 87 + 28 OUR AVERAG | E Error ind | cludes scale facto | r of 1 | 2. | |
| 64 ± 31 | | ASTON | 88E | LASS | 11 $K^- p \rightarrow K^- K^+ \Lambda$, $K_S^0 K^{\pm} \pi^{\mp} \Lambda$ |
| $160 + 90 \\ -50$ | 430 | ARMSTRONG | 82 | OMEG | 18.5 $K^- p \rightarrow K^- K^+ \Lambda$ |
| 80^{+40}_{-30} | 123 | ALHARRAN | 81в | нвс | 8.25 $K^-p \rightarrow K\overline{K}\Lambda$ |

ϕ_3 (1850) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------------|------------------------------|
| Γ ₁ | <u>K K</u> | seen |
| Γ ₂ | K K *(892) + c.c. | seen |

ϕ_3 (1850) BRANCHING RATIOS

| $\Gamma(K\overline{K}^*(892) + \text{c.c.})/\Gamma(K\overline{K})$ | | | | Γ_2/Γ_1 |
|--------------------------------------------------------------------|-------------|-----|------|-----------------------------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| $0.55 + 0.85 \\ -0.45$ | ASTON | 88E | LASS | 11 $K^- p \rightarrow K^- K^+ \Lambda$, $K^0 K^{\pm} \pi^{\mp} \Lambda$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

0.8 \pm 0.4 ALHARRAN 81B HBC 8.25 $K^-p \rightarrow K \overline{K} \pi \Lambda$

ϕ_3 (1850) REFERENCES

ASTON 88E PL B208 324 D. Aston et al. (SLAC, NAGO, CINC, INUS) IGJ PC
ARMSTRONG 82 PL 110B 77 T.A. Armstrong et al. (BARI, BIRM, CERN+) JP
ALHARRAN 81B PL 101B 357 S. Al-Harran et al. (BIRM, CERN, GLAS+)

 $\eta_2(1870)$

$$I^{G}(J^{PC}) = 0^{+}(2^{-+})$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

$\eta_{2}(1870) \text{ MASS}$

| VALUE (MeV) EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------|------------------|-------|------------|-------------------------------------------------------------------------------------|
| 1842± 8 OUR AVERAGE | | | | |
| 1835 ± 12 | BARBERIS | 00в | | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ |
| 1844 ± 13 | BARBERIS | 00c | | $450 pp \rightarrow p_f 4\pi p_S$ |
| 1840 ± 25 | BARBERIS | 97в | OMEG | $450 pp \rightarrow pp 2(\pi^+ \pi^-)$ $1.94 \overline{p}p \rightarrow \eta 3\pi^0$ |
| $1875 \pm 20 \pm 35$ | ADOMEIT | | | |
| $1881 \pm 32 \pm 40$ 26 | KARCH | 92 | CBAL | $e^{+} e^{-} \rightarrow e^{+} e^{-} \eta \pi^{0} \pi^{0}$ |
| • • • We do not use the fo | llowing data for | avera | ges, fits, | limits, etc. • • • |

| $\begin{array}{c} 1860 \pm & 5 \pm 15 \\ 1840 \pm 15 \end{array}$ | A NISOVICH BAI | 00E 99 | SPEC BES | 0.9–1.94 $\overline{\rho}\rho \rightarrow \eta 3\pi^0$ $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|--------------------------|-----------------------|-------------------------------------------------------------------------------------------------------------------------|
| | $\eta_2(187$ | '0) W | IDTH | |
| VALUE (MeV) EVTS | DO CUMENT ID | | TECN | COMMENT |
| 225 ±14 OUR AVERAGE | | | | |
| 235 ± 22 | BARBERIS | 00в | | $450 pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ |
| 228±23 | BARBERIS | 00c | OMEG | $450 pp \rightarrow p_f 4\pi p_s$ |
| 200±40 200±25±45 | BARBERIS ADOMEIT | 97в 96 | CBAR | $450 pp \rightarrow pp 2(\pi^+ \pi^-)$ $1.94 \overline{p}p \rightarrow \eta 3\pi^0$ |
| 200±23±43 221±92±44 26 | KARCH | 92 | CBAL | $e^+e^- \rightarrow e^+e^-\eta\pi^0\pi^0$ |
| • • • We do not use the | | | | |
| $250 \pm 25 + 50$ | ANISOVICH | 00E | SPEC | 0.9–1.94 $\overline{p}p \rightarrow \eta 3\pi^0$ |
| 170±40 | BAI | 99 | BES | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| Mode | | | Fracti | on (Γ_i/Γ) |
| $ \Gamma_{1} \eta \pi \pi \Gamma_{2} a_{2}(1320) \pi \Gamma_{3} f_{2}(1270) \eta \Gamma_{4} a_{0}(980) \pi \Gamma_{5} \gamma \gamma $ | | | seen | |
| | η ₂ (1870) BRA | NCH | ING RA | ATIOS |
| Γ (a ₂ (1320) π) / Γ (f ₂ (12 | 2 70)η) <u>DO CUMENT</u> | ID | TEC | Г ₂ /Г ₃ |
| 1.7 ±0.4 OUR AVERA | | | | |
| 1.60±0.40 | 1 ANISOVIC | | 1 SPE | |
| 20.4 ±6.6 4.1 ±2.3 | BARBERIS ADOMEIT | | 10в 16 СВ <i>А</i> | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ AR 1.94 $\overline{p}p \rightarrow \eta 3\pi^0$ |
| 1 Reanalysis of ADOME | | | | $1.94 pp \rightarrow \eta 3\pi^2$ |
| | | | 002. | F /F |
| E/ (1000) \ (E/ (0. | 801 <i>1</i> 71 | | ID | Γ ₂ /Γ ₄ |
| | | | | COMMENT |
| VALUE | <u>DOCUI</u> BARE | | 00в | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ |
| 32.6±12.6 | <u>DOCUI</u> BARE | | 00в | |
| $\frac{VALUE}{32.6 \pm 12.6}$ $\Gamma(a_0(980)\pi)/\Gamma(f_2(127))$ | <u>DOCUI</u> BARE 70)η) | | | 450 $pp \rightarrow p_f \eta \pi^+ \pi^- p_S$ Γ_4/Γ_3 TECN COMMENT |
| VALUE 32.6±12.6 Γ(a ₀ (980)π)/Γ(f ₂ (127 VALUE | <u>DOCUI</u> BARE 70)η) | BERIS MENT | ID. | Γ ₄ /Γ ₃ |
| VALUE 32.6±12.6 Γ(a ₀ (980)π)/Γ(f ₂ (127 VALUE | <u>DOCUI</u> BARE 70)η) 2 ANISO | BERIS MENT OVICH | ID 11 | Γ ₄ /Γ ₃ |
| $VALUE$ 32.6±12.6 $\Gamma(a_0(980)\pi)/\Gamma(f_2(127))$ $VALUE$ 0.48±0.45 $\Gamma(a_0(980)\pi)$ | <u>DOCUI</u> BARE 70)η) 2 ANISO | BERIS MENT OVICH | ID 11 | $\begin{array}{c c} & \Gamma_4/\Gamma_3 \\ \hline TECN & COMMENT \\ SPEC & 0.9-1.94 \ \rho \overline{\rho} \end{array}$ |
| $\Gamma(a_2(1320)\pi)/\Gamma(a_0(9)\pi)$ VALUE 32.6±12.6 $\Gamma(a_0(980)\pi)/\Gamma(f_2(127)\pi)$ VALUE 0.48±0.45 2 Reanalysis of ADOME $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ VALUE | <u>DOCUI</u> BARE 70)η) 2 ANISO | BERIS MENT : OVICH | ID 11 | Γ ₄ /Γ ₃ <u>TECN</u> <u>COMMENT</u> SPEC 0.9–1.94 ρ p |

η₂(1870) REFERENCES

| ANIS OVICH | 11 | EPJ C71 1511 | A.V. Anisovich et al. | (LOQM, RAL, PNPI) |
|------------|------|--------------|-----------------------|--------------------------|
| ANIS OVICH | 00 E | PL B477 19 | A.V. Anisovich et al. | |
| BARBERIS | 00 B | PL B471 435 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 C | PL B471 440 | D. Barberis et al. | (WA 102 Collab.) |
| BAI | 99 | PL B446 356 | J.Z. Bai et al. | (BES Collab.) |
| BARBERIS | 97 B | PL B413 217 | D. Barberis et al. | (WA` 102 Collab.) |
| ADOMEIT | 96 | ZPHY C71 227 | J. Adomeit et al. | (Crystal Barrel Collab.) |
| KARCH | 92 | 7PHY C54 33 | K Kamh et al | (Ćrystal Ball Collab |

 $\pi_2(1880)$

seen

$$I^{G}(J^{PC}) = 1^{-}(2^{-+})$$

92 CBAL $e^+\,e^ightarrow\,e^+\,e^-\,\eta\,\pi^0\,\pi^0$

$\pi(1880)$ MASS

| | VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|---|-----------------------|--------|--------------|-----|--------|------|--------------------------------------------------------------|
| | 1895 ± 16 OUR A | VERAGE | | | | | |
| 1 | $1929 \pm 24 \pm 18$ | 4k | EUGENIO | | | | 18 $\pi^- p \rightarrow \eta \eta \pi^- p$ |
| 1 | $1876 \pm 11 \pm 67$ | 145 k | LU | 05 | B 85 2 | _ | 18 $\pi^- p \to \omega \pi^- \pi^0 p$ |
| | $2003 \pm 88 \pm 148$ | 69k | KUHN | 04 | B 85 2 | _ | 18 $\pi^- p \to \eta \pi^+ \pi^- \pi^- p$ |
| | 1880 ± 20 | | ANISOVICH | 01B | SPEC | 0 | $0.6-1.94 \ \overline{p}p \rightarrow \eta \eta \pi^0 \pi^0$ |

π (1880) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CH G | COMMENT |
|-----------------------|--------|-------------|-----|--------|------|------------------------------------------------------------|
| 235 ± 34 OUR A | VERAGE | | | | | |
| $323\pm$ $87\pm$ 43 | 4k | EUGENIO | 80 | | | 18 $\pi^- p \rightarrow \eta \eta \pi^- p$ |
| $146\pm\ 17\pm\ 62$ | 145k | LU | 05 | B 85 2 | _ | 18 $\pi^- p \to \omega \pi^- \pi^0 p$ |
| $306\pm 132\pm 121$ | 69k | KUHN | 04 | | | 18 $\pi^- p \to \eta \pi^+ \pi^- \pi^- p$ |
| 255 ± 45 | | ANISOVICH | 01B | SPEC | 0 | 0.6-1.94 $\overline{p}p \rightarrow \eta \eta \pi^0 \pi^0$ |

π_2 (1880) DECAY MODES

| | Mode |
|----------------|----------------------------------------|
| Γ_1 | $\eta\eta\pi^-$ |
| Γ_2 | $a_0(980)\eta$ |
| Γ_3 | $a_2(1320)\eta$ |
| Γ_4 | $f_0(1500) \pi$ |
| Γ_5 | $f_1(1285)\pi$ |
| Γ ₆ | $f_1(1285)\pi$ $\omega \pi^- \pi^0$ |
| | |

| Γ(a ₂ (13 | $20)\eta)/\Gamma(f_1(1))$ | $285)\pi)$ | | | | Г3/Г5 |
|----------------------|---------------------------|--------------------|----------------|----------|-----------------------|---------------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | CHG | COMMENT | |
| • • • We | e do not use the | following data for | averages, fits | s, limit | s, etc. • • • | |
| 22 7 + 7 3 | 69k | KIIHN | 04 R852 | _ | 18 π [−] n → | $n\pi^{+}\pi^{-}\pi^{-}I$ |

 $\Gamma\big(f_0(1500)\pi\big)/\Gamma\big(a_0(980)\eta\big)$ Γ_4/Γ_2 DOCUMENT ID TECN CHG COMMENT ● ● We do not use the following data for averages, fits, limits, etc. ● ● ¹ ANISOVICH 01B SPEC 0

 $^{1}\,\mathrm{System}\,\mathrm{atic}$ errors not estimated.

$\pi_2(1880)$ REFERENCES

| UGENIO | 80 | PL B660 466 | P. Eugenio et al. | (BNL E852 Collab.) |
|----------|------|---------------|----------------------|--------------------|
| _U | 05 | PRL 94 032002 | M. Lu et al. | (BNL E852 Collab.) |
| KUHN | 04 | PL B595 109 | J. Kuhn et al. | (BNL E852 Collab.) |
| MISOMICH | 01 D | DI DEOU 222 | A.V. Anicovich at al | |

ρ (1900)

$$I^{G}(J^{PC}) = 1^{+}(1^{-})$$

OMITTED FROM SUMMARY TABLE See our mini-review under the $\rho(1700)$.

ρ (1900) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------|---------|-------------------------|--------|-----------|------------------------------------------------------|
| • • • We do not | use the | following data for | averag | es, fits, | limits, etc. • • • |
| $1909 \pm 17 \pm 25$ | 54 | ¹ AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow \phi \pi^0 \gamma$ |
| 1880 ± 30 | | AUBERT | 06D | BABR | 10.6 $e^+e^- \rightarrow 3\pi^+ 3\pi^- \gamma$ |
| 1860 ± 20 | | AUBERT | 06D | BABR | $10.6 \ e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)\gamma$ |
| 1910 ± 10 | | ^{2,3} FRABETTI | 04 | E687 | $\gamma p \rightarrow 3\pi^{+} 3\pi^{-} p$ |
| 1870 ± 10 | | ANTONELLI | 96 | SPEC | e+e− → hadrons |

 $^1_{\rm 2}$ From the fit with two resonances. $^2_{\rm 2}$ From a fit with two resonances with the JACOB 72 continuum. 3 Supersedes FRABETTI 01.

ρ (1900) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
|-------------------------------------|--------------|-------------------------|--------|-----------|------------------------------------------------------|--|--|--|
| • • • We do n | ot use the f | following data for | averag | es, fits, | limits, etc. • • • | | | |
| $48 \pm 17 \pm 2$ | 54 | ⁴ AUBERT | | | 10.6 $e^+e^- \rightarrow \phi \pi^0 \gamma$ | | | |
| 130 ± 30 | | AUBERT | 06D | BABR | 10.6 $e^+e^- \rightarrow 3\pi^+ 3\pi^- \gamma$ | | | |
| 160 ± 20 | | AUBERT | 06D | BABR | $10.6 \ e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)\gamma$ | | | |
| 37 ± 13 | | ^{5,6} FRABETTI | 04 | E687 | $\gamma p \rightarrow 3\pi^+ 3\pi^- p$ | | | |
| $10\pm$ 5 | | ANTONELLI | 96 | SPEC | $e^+e^-	o$ hadrons | | | |
| 4 From the fit with two resonances. | | | | | | | | |

⁵ From a fit with two resonances with the JACOB 72 continuum. ⁶ Supersedes FRABETTI 01.

ho(1900) Γ (i) Γ (e^+e^-)/ Γ^2 (total)

| $\Gamma(\phi\pi)/\Gamma_{\rm total} \times 1$ | $\Gamma_4/\Gamma \times \Gamma_6/\Gamma$ | | | | |
|-----------------------------------------------|------------------------------------------|---------------------|-----------|-----------|---------------------------------------------|
| VALUE (units 10 ⁻⁸) | EVTS | DO CUMENT II | ס | TECN | COMMENT |
| • • • We do not us | e the followin | g data for avera | ges, fits | , limits, | etc. • • • |
| $4.2 \pm 1.2 \pm 0.8$ | 54 | ⁷ AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow \phi \pi^0 \gamma$ |
| ⁷ From the fit with | n two resonan | ces. | | | |

ρ (1900) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------------------------------------------|------------------------------|
| Γ_1 | 6π | seen |
| Γ_2 | $3\pi^{+}3\pi^{-}$ | seen |
| Γ_3 | $3\pi^{+}3\pi^{-}\ 2\pi^{+}2\pi^{-}2\pi^{0}$ | |
| Γ_4 | $\phi\pi$ | |
| Γ_5 | hadrons | seen |
| Γ_6 | $e^+ e^-$ | seen |
| Γ_7 | \overline{N} N | not seen |

ho(1900), f_2 (1910)

ρ(1900) BRANCHING RATIOS

| $\Gamma(6\pi)/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|--------------------------------------|--------------|----|------|--------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| not seen | AGNELLO | 02 | OBLX | $\overline{n}\rho \rightarrow 3\pi^{+}2\pi^{-}\pi^{0}$ |
| seen | FRABETTI | 01 | E687 | $\gamma p \rightarrow 3\pi^{+}3\pi^{-}p$ |
| seen | ANTONELLI | 96 | SPEC | $e^+e^- ightarrow $ hadrons |

ho(1900) REFERENCES

| AUBERT | | PR D77 092002 | B. Aubert et al. | (BABAR Collab.) |
|-----------|------|---------------|----------------------|---------------------|
| AUBERT | 06 D | PR D73 052003 | B. Aubert et al. | (BABAR Collab.) |
| FRABETTI | 04 | PL B578 290 | P.L. Frabetti et al. | (FNÁL E687 Collab.) |
| AGNELLO | 02 | PL B527 39 | M. Agnello et al. | (OBELIX Collab.) |
| FRABETTI | 01 | PL B514 240 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| ANTONELLI | 96 | PL B365 427 | A. Antonelli et al. | (FENICE Collab.) |
| JACOB | 72 | PR D5 1847 | M. Jacob, R. Slansky | |

$f_2(1910)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

OMITTED FROM SUMMARY TABLE

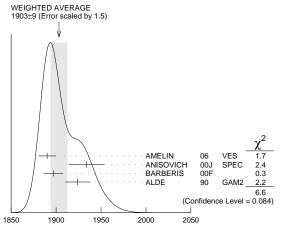
We list here three different peaks with close masses and widths seen in the mass distributions of $\omega\omega$, $\eta\eta'$, and K^+K^- final states. ALDE 91B argues that they are of different nature.

f2(1910) MASS

$f_2(1910) \omega \omega$ MODE

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|---------------------------|---------|----------|--------------------------------------------|
| 1903± 9 OUR AVERAGE | Error includes scale fact | or of 1 | 1.5. See | the ideogram below. |
| 1890 ± 10 | ¹ AMELIN | 06 | VES | 36 $\pi^- p \rightarrow \omega \omega n$ |
| 1934 ± 20 | ANISOVICH | 001 | SPEC | |
| 1897 ± 11 | BARBERIS | 00F | | 450 $pp \rightarrow p_f \omega \omega p_S$ |
| 1924 ± 14 | ALDE | 90 | GAM2 | 38 $\pi^- p \rightarrow \omega \omega n$ |

¹ Supersedes BELADIDZE 92B.



 $f_2(1910)~\omega\omega$ MODE MASS (MeV)

$f_2(1910) \eta \eta' \text{ MODE}$

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-----------------------|---------|-----------|-----------------------------------------|
| 1934±16 | ² BARBERIS | 00A | | 450 $pp \rightarrow p_f \eta \eta' p_S$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 1911 ± 10 | ALDE | 91B | GAM2 | 38 $\pi^- p \rightarrow \eta \eta' n$ |
| ² Also compatible with $J^{PC}=1$ | -+ | | | |

f2(1910) K+K- MODE

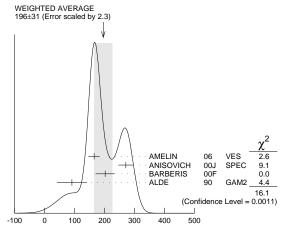
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------|-----------------------|----------|-----------|----------------------------------|---------------|
| • • • We do not use the follow | wing data for average | es, fits | , limits, | etc. • • • | |
| 1941 ± 18 | AMSLER | 06 | CBAR | 1.64 $\overline{p}p \rightarrow$ | $K^+K^-\pi^0$ |

f2(1910) WIDTH

$f_2(1910) \omega \omega$ MODE

| VALUE (MeV) | DOCUMENT ID TECN COMMENT | |
|--------------------|---------------------------------------------------------|---------------------|
| 196±31 OUR AVERAGE | Error includes scale factor of 2.3. See the ideogram be | low. |
| 165 ± 19 | 3 AMELIN 06 VES 36 $\pi^- p \rightarrow \omega$ | ω n |
| 271 ± 25 | ANISOVICH 00J SPEC | |
| 202 ± 32 | BARBERIS 00F 450 $pp \rightarrow p_f$ | $\omega \omega p_S$ |
| 91 ± 50 | ALDE 90 GAM2 38 $\pi^- p \rightarrow \omega$ | ωn |

³ Supersedes BELADIDZE 92B.



 $f_2(1910) \ \omega \omega \ \mathsf{MODE} \ \mathsf{WIDTH}(\mathsf{MeV})$

$f_2(1910) \eta \eta' \text{ MODE}$

| VALUE (MeV) | DO CUMENT ID | DOCUMENT ID | | COMMENT |
|-------------------------|-------------------------------|-------------|---------|-----------------------------------------|
| 141 ±41 | ⁴ BARBERIS | 00A | | 450 $pp \rightarrow p_f \eta \eta' p_S$ |
| • • • We do not use the | he following data for average | s, fits, | limits, | etc. • • • |
| 90 ± 35 | ALDE | 91B | GAM2 | 38 $\pi^- p \rightarrow \eta \eta' n$ |
| 4 Also compatible wit | $_{h} PC_{-1} - +$ | | | |

£ (1910) K+ K- MODE

 2.6 ± 0.6

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------|-----------------------|---------|-----------|----------------------------------|---------------------------|
| • • • We do not use the follo | wing data for average | s, fits | , limits, | etc. • • • | |
| 120±40 | AMSLER | 06 | CBAR | 1.64 $\overline{p}p \rightarrow$ | $\kappa^+ \kappa^- \pi^0$ |

f2(1910) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------|------------------------------|
| $\overline{\Gamma_1}$ | $\pi^0 \pi^0$ | _ |
| Γ_2 | K+ K- | seen |
| Γ ₃ | $K_S^0 K_S^0$ | |
| Γ_4 | $\eta\eta$ | seen |
| Γ ₅ Γ ₆ | $\omega\omega$ | seen |
| | $\eta\eta'$ | seen |
| Γ_7 | $\eta'\eta'$ | |
| Γ ₈ | ho ho | seen |
| Г9 | $a_2(1320)\pi$ | seen |
| Γ_{10} | $f_2(1270)\eta$ | seen |

f2(1910) BRANCHING RATIOS

| | 21 | , | | | | |
|------------------------------------------|--------------|--------------------|----------|-----------|------------------------------------|---------------------|
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | | | | | | Γ_2/Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| seen | | AMSLER | 06 | CBAR | $1.64 \ \overline{p}p \rightarrow$ | $K^{+}K^{-}\pi^{0}$ |
| $\Gamma(\pi^0\pi^0)/\Gamma(\eta\eta')$ | | | | | | Γ_1/Γ_6 |
| VALUE | | DO CUMENT ID | I | TECN | COMMENT | |
| • • • We do not use | the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| < 0.1 | | ALDE | 89 | GAM2 | $38\pi^-p \rightarrow$ | $\eta \eta' n$ |
| $\Gamma(K_S^0 K_S^0)/\Gamma(\eta \eta')$ | | | | | | Γ_3/Γ_6 |
| VALUE | CL% | DO CUMENT ID | 1 | TECN | COMMENT | |
| ● ● We do not use | the followin | ig data for averag | es, fits | , limits, | etc. • • • | |
| < 0.066 | 90 | BALOSHIN | 86 | SPEC | $40\pi p \rightarrow K$ | 0 K |
| $\Gamma(\eta\eta)/\Gamma(\eta\eta')$ | | | | | | Γ_4/Γ_6 |
| | CL% | DO CUMENT ID | ı | TECN | COMMENT | · |
| • • • We do not use | | | | | | |
| < 0.05 | 90 | ALDE | 91B | GA M2 | 38 $\pi^- \rho \rightarrow$ | $\eta \eta'$ n |
| $\Gamma(\omega\omega)/\Gamma(\eta\eta')$ | | | | | | Γ_5/Γ_6 |
| VALUE | | DO CUMENT ID | | COMME | NT | |
| ullet $ullet$ We do not use | the followin | ig data for averag | es, fits | , limits, | etc. • • • | |

BARBERIS 00F 450 $pp
ightarrow p_f \omega \omega p_S$

| $\Gamma(\eta'\eta')/\Gamma_{ m total}$ | | | | | Γ_7/Γ |
|---------------------------------------------|-------------------------|----------|-----------|------------------------------------------------|---------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| | ng data for averag | es, fits | , limits, | etc. • • • | |
| probably not seen | BARBERIS | 00A | | $450 pp \rightarrow p$ | $f \eta' \eta' p_s$ |
| possibly seen | BELADIDZE | 92D | VES | $37 \pi^- p \rightarrow r$ | $\eta' \eta' n$ |
| $\Gamma(ho ho)/\Gamma(\omega\omega)$ | | | | | Γ ₈ /Γ ₅ |
| VALUE | DO CUMENT ID | | COMME | NT | |
| | ng data for averag | es, fits | , limits, | etc. • • • | |
| 2.6 ± 0.4 | BARBERIS | 00F | 450 p | $\rho \rightarrow \rho_f \omega \omega \rho_S$ | |
| $\Gamma(f_2(1270)\eta)/\Gamma(a_2(1320)\pi$ | , | | | | Γ ₁₀ /Γ ₉ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.09±0.05 | ⁵ A NISOVICH | 11 | SPEC | 0.9–1.94 <i>p</i> p | |
| ⁵ Reanalysis of ADOMEIT 96 | and ANISOVICH 0 | 0E. | | | |

f2(1910) REFERENCES

| ANIS OVICH | 11 | EPJ C71 1511 A.V. Anisovich et al. | (LOQM, RAL, PNPI) |
|------------|------|------------------------------------|---------------------------|
| AMELIN | 06 | PAN 69 690 D.V. Amelin et al. | (VES Collab.) |
| | | Translated from YAF 69 715. | |
| AMS LER | 06 | PL B639 165 C. Amsler et al. | (CBAR Collab.) |
| ANISOVICH | 00 E | PL B477 19 A.V. Anisovich et al. | |
| ANISOVICH | 00 J | PL B491 47 A.V. Anisovich et al. | |
| BARBERIS | 00 A | PL B471 429 D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 F | PL B484 198 D. Barberis et al. | (WA 102 Collab.) |
| ADOMEIT | 96 | ZPHY C71 227 J. Adomeit et al. | (Cryst'al Barrel Collab.) |
| BELADIDZE | 92 B | ZPHY C54 367 G.M. Beladidze et al. | (VES Collab.) |
| BELADIDZE | 92 D | ZPHY C57 13 G.M. Beladidze et al. | (VES Collab.) |
| ALDE | 91B | SJNP 54 455 D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) |
| | | Translated from YAF 54 751. | |
| Also | | PL B276 375 D.M. Alde et al. | (BELG, SERP, KEK, LANL+) |
| ALDE | 90 | PL B241 600 D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) |
| ALDE | 89 | PL B216 447 D.M. Alde et al. | (SERP, BELG, LANL, LAPP) |
| Also | | SJNP 48 1035 D.M. Alde et al. | (BELG, SERP, LANL, LAPP) |
| | | Translated from YAF 48 1724. | |
| BALOSHIN | 86 | SJNP 43 959 O.N. Baloshin et al. | (ITEP) |
| | | Translated from YAF 43 1487. | , , |

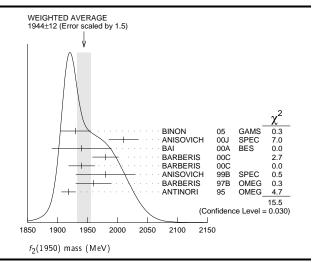
$f_2(1950)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

f2(1950) MASS

| VALUE (MeV) | | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------|-----------|------------------|--------|----------------------|---------------------------------------------------------------------------|
| 1944±12 OUR AVERAG | iΕ | Error includes | scale | factor c | of 1.5. See the ideogram below. |
| 1930 ± 25 | 1 | BINON | 05 | GAMS | 33 $\pi^- p \rightarrow \eta \eta n$ |
| 2010 ± 25 | | ANISOVICH | 001 | SPEC | |
| 1940±50 | | BAI | 00A | BES | $J/\psi \rightarrow \gamma (\pi^+ \pi^- \pi^+ \pi^-)$ |
| 1980 ± 22 | 2 | BARBERIS | 00c | | $450 pp \rightarrow pp4\pi$ |
| 1940 ± 22 | 3 | BARBERIS | 00c | | $450 pp \rightarrow pp2\pi2\pi^0$ |
| 1980±50 | | ANISOVICH | 99B | SPEC | 1.35-1.94 $p\overline{p} \rightarrow \eta \eta \pi^0$ |
| 1960 ± 30 | | BARBERIS | 97B | OMEG | 450 $pp \rightarrow pp2(\pi^{+}\pi^{-})$ |
| 1918 ± 12 | | ANTINORI | 95 | OMEG | $300,450 pp \rightarrow pp2(\pi^{+}\pi^{-})$ |
| • • • We do not use the fe | oll | owing data for a | averag | es, fits, | limits, etc. • • • |
| $2038 {}^{+ 1 3 + 12}_{- 11 - 73}$ | 4 | UEHARA | 09 | BELL | $10.6~e^{+}~e^{-}~\rightarrow~e^{+}~e^{-}~\pi^{0}~\pi^{0}$ |
| 1980± 2±14 | | ABE | 04 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-K^+K^-$ |
| 1867±46 | | AMSLER | 02 | CBAR | $0.9 \overline{\rho} \rho \rightarrow \pi^0 \eta \eta, \pi^0 \pi^0 \pi^0$ |
| ~ 1990 | | OAKDEN | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi\pi$ |
| 1950 ± 15 | 7 | ASTON | 91 | LASS | 11 $K^- p \rightarrow \Lambda K \overline{K} \pi \pi$ |
| $^{ m 1}$ First solution, PWA is a | an | biguous. | | | |
| ² Decaying into $\pi^+\pi^-$ 2: | $\pi^{(}$ |) | | | |
| ³ Decaying into $2(\pi^+\pi^-$ | | | | | |
| ⁴ Taking into account f_A | | 05 0). | | | |
| ⁵ T-matrix pole. | ι = | , | | | |
| | nli | tude analysis of | data | on $\overline{D}D$ - | $\rightarrow \pi\pi$. See however KLOET 96 |

who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly



f2(1950) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------|-------------------------|--------|-----------|-------------------------------------------------------|
| 472± 18 OUR AVE | RAGE | | | |
| 450± 50 | ⁸ BINON | 05 | GAMS | 33 $\pi^- p \rightarrow \eta \eta n$ |
| 495 ± 35 | ANISOVICH | 00J | SPEC | |
| $380 + 120 \\ -90$ | BAI | 00A | BES | $J/\psi \rightarrow \gamma (\pi^+\pi^-\pi^+\pi^-)$ |
| 520± 50 | ⁹ BARBERIS | 00c | | $450 pp \rightarrow pp4\pi$ |
| 485 ± 55 | ¹⁰ BARBERIS | 00c | | $450 pp \rightarrow pp4\pi$ |
| 500 ± 100 | ANISOVICH | 99B | SPEC | 1.35-1.94 $p\overline{p} \rightarrow \eta \eta \pi^0$ |
| 460± 40 | BARBERIS | 97B | OMEG | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| 390± 60 | ANTINORI | 95 | OMEG | $300,450 pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| | he following data for a | averag | es. fits. | limits, etc. • • • |

 $^{11}\,\mathrm{UEHARA}$ $441 \, {}^{+}_{-} \,\, {}^{}27 \, {}^{}192 \,\,$ BELL 10.6 $e^+\,e^-
ightarrow \,e^+\,e^-\,\pi^0\,\pi^0$ 04 BELL 10.6 $e^{+}e^{-} \rightarrow e^{+}e^{-} K^{+}K^{-}$ 02 CBAR 0.9 $\overline{p}p \rightarrow \pi^{0}\eta\eta$, $\pi^{0}\pi^{0}\pi^{0}$ 297± 12± 6 ABE 12 AMSLER 13 OAKDEN 385 ± 58 94 RVUE $0.36-1.55 \ \overline{p}p \rightarrow \pi\pi$ 91 LASS $11 \ K^-p \rightarrow \Lambda K \overline{K} \pi\pi$ ~ 100 ¹⁴ ASTON $250 \pm\ 50$

⁸ First solution, PWA is ambiguous.

9 Decaying into $\pi^+\pi^- 2\pi^0$.

10 Decaying into $2(\pi^+\pi^-)$. 11 Taking into account $f_4(2050)$.

 $^{12}\,\mathrm{T\text{-}matrix}$ pole.

13 From solution B of amplitude analysis of data on $\overline{p}p \to \pi\pi$. See however KLOET 96 who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly resonant. 14 Cannot determine spin to be 2.

f2(1950) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------|------------------------------|
| Γ_1 | $K^*(892)\overline{K}^*(892)$ | seen |
| Γ_2 | $\pi\pi$ | |
| Γ_3 | $\pi^{+}\pi^{-}$ | seen |
| Γ_4 | $\pi^0 \pi^0$ | seen |
| Γ ₅ Γ ₆ | 4π | seen |
| Γ ₆ | $\pi^{+} \pi^{-} \pi^{+} \pi^{-}$ | |
| Γ_7 | $a_2(1320)\pi$ | |
| Γ8 | $f_2(1270) \pi \pi$ | |
| Γ_9 | ηη | seen |
| Γ_{10} | $K\overline{K}$ | seen |
| Γ_{11} | $\gamma\gamma$ | seen |
| Γ_{12} | p p | seen |

$f_2(1950) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(KK) \times \Gamma(\gamma\gamma)$ | γ)/Γ _{total} | | | Γ | - ₁₀ Γ ₁₁ /Γ |
|------------------------------------------|--------------------------|----------|-------------|----------------------------------|------------------------------------|
| VALUE (eV) | DO CUMENT IL |) | TECN | COMMENT | |
| • • • We do not u | se the following data fo | or avera | ages, fits, | , limits, etc. ● ● ● | |
| $122 \pm 4 \pm 26$ | ¹⁵ ABE | 04 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-$ | - K+ K- |
| ¹⁵ Assuming spin | 2. | | | | |

resonant.
7 Cannot determine spin to be 2.

 $f_2(1950)$, $\rho_3(1990)$, $f_2(2010)$, $f_0(2020)$

| $\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ | DO CUMENT ID | TECN | COMMENT | $\Gamma_2\Gamma_{11}/\Gamma$ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|---------|-------------------------------------------|--------------------------------------------------|
| • • We do not use the following the fol | | | | |
| $162 \begin{array}{l} +69 + 1137 \\ -42 - 204 \end{array}$ | ⁶ UEHARA 0 | 9 BELL | 10.6 $e^+e^- ightarrowe^-$ | $e^{+}e^{-}\pi^{0}\pi^{0}$ |
| 16 Taking into account f_4 (20 | 05 0). | | | |
| Ą | (1950) BRANCH | ING RAT | ΓIOS | |
| Γ(<i>K</i> *(892) <i>K</i> *(892))/Γ _{to} | | | | Γ_1/Γ |
| value Seen | ASTON 9: | | 0 11 K - p - | $\rightarrow \Lambda K \overline{K} \pi \pi$ |
| Γ (a₂(1320)π)/ Γ _{total} | DOCUMENT ID | TECA | COMMENT | Γ ₇ /Γ |
| • • We do not use the following | | | | |
| not seen | = | 00в | $450 pp \rightarrow p_f$ | $\eta \pi^+ \pi^- p_s$ |
| not seen | | 00c | $450 pp \rightarrow p_f$ | $4\pi p_S$ |
| possibly seen | BARBERIS | 97B OME | EG 450 $pp \rightarrow pp$ | $2(\pi^{+}\pi^{-})$ |
| $\Gamma(\eta\eta)/\Gamma(4\pi)$ | | | | Γ_9/Γ_5 |
| VALUE CL% | | | | |
| • • We do not use the following to | ŭ | • | | |
| $< 5.0 \times 10^{-3}$ 90 | BARBERIS | 00E 4 | $450 pp \rightarrow p_f \eta \eta p$ | S |
| $\Gamma(\eta\eta)/\Gamma(\pi^+\pi^-)$ | DO CUMENT ID | T.C.(1 | COMMENT | Γ_9/Γ_3 |
| <u>VALUE</u> 0.14±0.05 | <u>DOCUMENT ID</u> AMSLER | | R 0.9 $\overline{p}p \rightarrow \pi^0 r$ | ηη, π ⁰ π ⁰ π ⁰ |
| $\Gamma(\overline{\rho}\overline{\rho})/\Gamma_{\text{total}}$ | | | | Γ12/Γ |

f₂(1950) REFERENCES

| ALEXANDER | 10 | PR D82 092002 | J.P. Alexander et al. | (CLEO Collab.) |
|-----------|------|------------------------|------------------------------|------------------------|
| UEHARA | 09 | PR D79 052009 | S. Uehara et al. | (BELLE Collab.) |
| BINON | 05 | PAN 68 960 | F. Binon et al. | , |
| | | Translated from YAF 68 | 998. | |
| ABE | 04 | EPJ C32 323 | K. Abe et al. | (BELLE Collab.) |
| AMSLER | 02 | EPJ C23 29 | C. Amsler et al. | ` ' |
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| BAI | 00 A | PL B472 207 | J.Z. Bai et al. | (BES Collab.) |
| BARBERIS | 00 B | PL B471 435 | D. Barberis et al. | (WA` 102 Collab.) |
| BARBERIS | 00 C | PL B471 440 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 E | PL B479 59 | D. Barberis et al. | (WA 102 Collab.) |
| ANISOVICH | 99B | PL B449 154 | A.V. Anisovich et al. | , |
| BARBERIS | 97 B | PL B413 217 | D. Barberis et al. | (WA 102 Collab.) |
| KLOET | 96 | PR D53 6120 | W.M. Kloet, F. Myhrer | `(RUTG, NORD) |
| ANTINORI | 95 | PL B353 589 | F. Antinori et al. | (ATHU, BARI, BIRM+) JP |
| OAKDEN | 94 | NP A574 731 | M.N. Oakden, M.R. Pennington | (DURH) |
| ASTON | 91 | NPBPS B21 5 | D. Aston et al. | (LASS Collab.) |
| | | | | |

 $\rho_3(1990)$

VALUE

 $I^{G}(J^{PC}) = 1^{+}(3^{-})$

OMITTED FROM SUMMARY TABLE

EVTS 111

$\rho_3(1990)$ MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|------------------------------|-------|---------|------------------------------------------------------------------------------------------------------------------------------------|
| ullet $ullet$ We do not use the | following data for averages, | fits, | limits, | etc. • • • |
| $1982\!\pm\!14$ | | | | $\begin{array}{c} 0.61.9 \ \rho \overline{\rho} \rightarrow \omega \pi^{0}, \\ \omega \eta \pi^{0}, \ \pi^{+} \pi^{-} \end{array}$ |
| ~ 2007 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| 1 From the combined a | nalysis of ANISOVICH 00J | , AN | ISOVIC | H 01D, ANISOVICH 01E, |

and ANISOVICH 02.

ho_3 (1990) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------------------------------------------------|------------------------------|-----------------|-------------------------------------------------------------------------------------|
| • • • We do not use the | following data for averages, | fits, limits, e | etc. • • • |
| $188\!\pm\!24$ | ² A NISOVICH | 02 SPEC | $0.6-1.9 p \overline{p} \rightarrow \omega \pi^0,$ $\omega \eta \pi^0, \pi^+ \pi^-$ |
| ~ 287 | HASAN | 94 RVUE | |
| ² From the combined a and ANISOVICH 02. | nnalysis of ANISOVICH 00J, | ANISOVICE | H 01D, ANISOVICH 01E, |

ρ_3 (1990) REFERENCES

| ANISOVICH | 02 | PL B542 8 | A.V. Anisovich et al. | |
|-----------|------|-------------|-----------------------|--------|
| ANISOVICH | 01 D | PL B508 6 | A.V. Anisovich et al. | |
| ANISOVICH | 01E | PL B513 281 | A.V. Anisovich et al. | |
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) |

 $f_2(2010)$

 $I^{G}(J^{PC}) = 0^{+}(2^{+})$

f2(2010) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------|------|-----------------------------------------------------------------------------------|--|--|--|
| 2011 + 62 | $^{ m 1}$ ETKIN | 88 | MPS | 22 $\pi^- p \rightarrow \phi \phi n$ | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| 2005 ± 12 | VLADIMIRSK | 06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ | | | |
| 1980± 20 | ² BOLONKIN | 88 | SPEC | $40 \pi^{-} p \to K_{S}^{0} K_{S}^{0} n$ $40 \pi^{-} p \to K_{S}^{0} K_{S}^{0} n$ | | | |
| $2050 + 90 \\ -50$ | | | | $22 \pi^- p \rightarrow 2\phi n$ | | | |
| $2120 + 20 \\ -120$ | LINDENBAU | Л 84 | RVUE | | | | |
| 2160 ± 50 | ETKIN | 82 | MPS | $22 \pi^- p \rightarrow 2\phi n$ | | | |
| ¹ Includes data of ETKIN 85. The percentage of the resonance going into $\phi\phi$ 2 + + S_2 , D_2 , and D_0 is 98 + $\frac{1}{2}$, 0 + $\frac{1}{0}$, and 2 + $\frac{2}{1}$, respectively. | | | | | | | |

 D_2 , and D_0 is 98 $\frac{1}{3}$, $0 \frac{1}{0}$, and $2 \frac{1}{2}$ 2 Statistically very weak, only 1.4 s.d.

f2 (2010) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | | |
|-------------------------------------------------------------------------------|-----------------------|----|------|------------------------------------------------------|--|--|
| 202 + 67 | 3 ETKIN | 88 | MPS | $22 \pi^- p \to \phi \phi n$ | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| 209± 32 | VLADIMIRSK | 06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ | | |
| 145 ± 50 | ⁴ BOLONKIN | 88 | SPEC | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | |
| $200 {}^{+ 1 60}_{- 5 0}$ | | | | $22 \pi^- p \rightarrow 2\phi n$ | | |
| $300 + 150 \\ -50$ | LINDENBAUM | 84 | RVUE | | | |
| 310± 70 | ETKIN | 82 | MPS | $22 \pi^- p \rightarrow 2\phi n$ | | |
| ³ Includes data of ETKIN 85. | | | | | | |

⁴ Statistically very weak, only 1.4 s.d.

f2(2010) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------|------------------------------|
| Γ ₁ Γ ₂ | $\phi \phi \over K \overline{K}$ | seen seen |

f2(2010) BRANCHING RATIOS

 $\Gamma(\overline{K})/\Gamma_{\text{total}}$

 Γ_2/Γ DO CUMENT ID

f2(2010) REFERENCES

| VLA DIMIRS K | 06 | | V.V. Vladimirsky et al. | (ITEP, Moscow) |
|--------------|----|-------------------|-------------------------|----------------|
| | | Translated from ' | YAF 69 515. | ` ' |
| BOLONKIN | 88 | NP B309 426 | B.V. Bolonkin et al. | (ITEP, SERP) |
| ETKIN | 88 | PL B201 568 | A. Etkin et al. | (BNL, CUNY) |
| ETKIN | 85 | PL 165B 217 | A. Etkin et al. | (BNL, CUNY) |
| LINDENBAUM | 84 | CNPP 13 285 | S.J. Lindenbaum | ` (CUNY) |
| ETKIN | 82 | PRL 49 1620 | A. Etkin et al. | (BNL, CUNY) |
| Also | | Brighton Conf. | 351 S.J. Lindenbaum | (BNL, CUNY) |

 $f_0(2020)$

 $I^{G}(J^{PC}) = 0^{+}(0^{+})$

OMITTED FROM SUMMARY TABLE

Needs confirmation.

f₀(2020) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|-----------------------|---------------------|-------|------------|-------------------------------------------------|
| 1992±16 | 1,2 | BARBERIS | 00c | | 450 $pp \rightarrow p_f 4\pi p_S$ |
| • • • We do not us | ethe followi | ng data for aver | ages, | fits, limi | ts, etc. • • • |
| 2037± 8 | 80k ³ | UMAN | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 2040 ± 38 | | ANISOVICH | | SPEC | |
| 2010 ± 60 | | ALDE | 98 | GAM4 | $100 \ \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| 2020 ± 35 | | BARBERIS | 97B | OMEG | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| ¹ Average between | $_{\pi^+\pi^-2\pi^0}$ | and $2(\pi^+\pi^-)$ | | | |

² T-matrix pole. ³ Statistical error only.

f₀ (2020) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|------|--------------|-----|------|-----------------------------------|
| 442± 60 | | 4,5 BARBERIS | 00c | | $450 pp \rightarrow p_f 4\pi p_S$ |

| • • • We do not use | the follow | ing data for aver | ages, | fits, limi | ts, etc. • • • |
|---------------------|------------|---------------------|-------|------------|--------------------------------------------------------|
| 296± 17 | 80k | ⁶ U MA N | 06 | E835 | $5.2 \overline{\rho} \rho \rightarrow \eta \eta \pi^0$ |
| 405 ± 40 | | | | SPEC | |
| 240 ± 100 | | | | | $100 \ \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| 410± 50 | | BARBERIS | 97в | OMEG | 450 $pp \rightarrow pp 2(\pi^{+}\pi^{-})$ |
| 4 | + - 0 (| 0 + 0 (+ -) | | | |

 4 Average between $\pi^+\pi^-\,2\pi^0$ and 2($\pi^+\,\pi^-$). 5 T-matrix pole. 6 Statistical error only.

f₀(2020) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\rho\pi\pi$ | seen |
| Γ_2 | $ \rho \pi \pi $ $ \pi^0 \pi^0 $ | seen |
| Γ_3 | ho ho | seen |
| Γ_4 | $\omega \omega$ | seen |
| Γ ₅ | $\eta \eta$ | seen |

fo(2020) BRANCHING RATIOS

| $\Gamma(\rho\rho)/\Gamma(\omega\omega)$ | | | | | Γ_3/Γ_4 |
|------------------------------------------|-----------------------|---------|-----------|--------------------------------------------|---------------------|
| VALUE | DO CUMENT ID | | COMME | NT | |
| • • • We do not use the follow | ving data for average | s, fits | , limits, | etc. • • • | |
| ~ 3 | BARBERIS | 00F | 450 pj | $p \rightarrow p_f \omega \omega p_g$ | |
| $\Gamma(\eta\eta)/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | COMMENT | Γ ₅ /Γ |
| seen | UMA N | 06 | E835 | $5.2 \overline{p} p \rightarrow \eta \eta$ | π0 |

f₀(2020) REFERENCES

| UMAN | 06 | PR D73 052009 | I. Uman et al. | (FNAL E835) |
|-----------|------|---------------------|-----------------------|------------------|
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| BARBERIS | 00 C | PL B471 440 | D. Barberis et al. | (WA 102 Collab.) |
| BARBERIS | 00 F | PL B484 198 | D. Barberis et al. | (WA 102 Collab.) |
| ALDE | 98 | EPJ A3 361 | D. Alde et al. | (GAM4 Collab.) |
| A Iso | | PAN 62 405 | D. Alde et al. | (GAMS Collab.) |
| | | Translated from YAF | 62 446. | , |
| BARBERIS | 97 B | PL B413 217 | D. Barberis et al. | (WA 102 Collab.) |

$a_4(2040)$

$$I^{G}(J^{PC}) = 1^{-}(4^{+})$$

a4(2040) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN CHG | COMMENT |
|-----------------------------------|------------|------------------------|--------|-------------------|----------------------------------------------------------------------------------------|
| 1996 + 10 OUR AVI | ERAGE | Error includes scale | e fact | or of 1.1. | |
| $1885\pm 13{}^{+50}_{-2}$ | 420k | ALEKSEEV | 10 | COMP | $190 \begin{array}{c} \pi^- Pb \rightarrow \\ \pi^- \pi^- \pi^+ Pb' \end{array}$ |
| $1985\pm 10\pm 13$ | 145k | LU | 05 | B852 | $18 \pi^- p \rightarrow$ |
| $1996 \pm 25 \pm 43$ | | CHUNG | 02 | B 85 2 | $\begin{array}{c} \omega \pi^- \pi^0 p \\ 18.3 \pi^- p \rightarrow 3\pi p \end{array}$ |
| $2005 + 25 \\ -45$ | | ¹ ANISOVICH | 01 F | SPEC | $2.0 \overline{p} p \rightarrow 3\pi^0, \pi^0 \eta,$ |
| $2000 \pm 40 + 60 \\ -20$ | | IVANOV | 01 | B 85 2 | 18 $\pi^- \rho \rightarrow \eta' \pi^- \rho$ |
| 1944 ± 8±50 | | ² AMELIN | 99 | VES | $37 \frac{\pi^- A}{\omega \pi^- \pi^0 A^*}$ |
| 2010 ± 20 | | ³ DONSKOV | 96 | GAM2 0 | $38 \pi^- p \rightarrow \eta \pi^0 n$ |
| 2040 ± 30 | | ⁴ CLELAND | 82B | $SPEC \ \pm$ | $50 \pi p \rightarrow K_S^0 K^{\pm} p$ |
| 2030 ± 50 | | ⁵ CORDEN | 78 C | OMEG 0 | $15 \pi^- p \rightarrow 3\pi n$ |
| ● ● We do not u | se the fol | lowing data for ave | rages | , fits, limits, e | tc. • • • |
| 2004 ± 6 | 80k | ⁶ UMAN | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| $1903{\pm}10$ | | ⁷ BALDI | 78 | SPEC — | $10 \pi^- p \rightarrow p K_S^0 K^-$ |

 $\frac{1}{2}$ From the combined analysis of ANISOVICH 99c, ANISOVICH 99E, and ANISOVICH 01F.

 2 May be a different state. 3 From a simultaneous fit to the ${\it G}_+$ and ${\it G}_0$ wave intensities.

 4 From an amplitude analysis. 5 $J^P=4^+$ is favored, though $J^P=2^+$ cannot be excluded.

6 Statistical error only.
7 From a fit to the Y_8^0 moment. Limited by phase space.

a4(2040) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN CH | G COMMENT |
|---------------------------|--------|---------------------------------|------------|---------------|-------------------------------------------------------------------------------------------------------------------------|
| 255 + 28 OUR A | VERAGE | Error includes scal | e fact | or of 1.3. Se | e the ideogram below. |
| $294 \pm 25 ^{+46}_{-19}$ | 420k | ALEKSEEV | 10 | COMP | $\begin{array}{c} 190 \ \pi^- Pb \rightarrow \\ \pi^- \pi^- \pi^+ Pb' \end{array}$ |
| $231 \pm 30 \pm 46$ | 145k | LU | 05 | B 85 2 | 18 $\pi^- \rho \rightarrow$ |
| 298± 81±85 180± 30 | | CHUNG ⁸ ANISOVICH | 02 01 F | B852 SPEC | $\omega \pi^{-} \pi^{0} p$ $18.3 \pi^{-} p \rightarrow 3\pi p$ $2.0 \overline{p} p \rightarrow 3\pi^{0}, \pi^{0} \eta,$ |

| $350\pm100^{+70}_{-50}$ | IVANOV | 01 | B852 | 18 $\pi^- \rho \rightarrow \eta' \pi^- \rho$ |
|-------------------------|------------------------------------------------|----------|------------------|----------------------------------------------------------------------------------------------------------------------------------|
| $324\pm26\pm75$ | ⁹ A MELIN | 99 | VES | $37 \begin{array}{c} \pi^- A 0 \\ \omega \pi^- \pi^0 A^* \end{array}$ |
| 370 ± 80 380 ± 150 | ¹⁰ DONSKOV ¹¹ CLELAND | | GAM2 0 SPEC ± | $38 \frac{\pi}{\pi} \stackrel{\pi}{p} \rightarrow \frac{\pi}{\eta} \pi^0 n$ $50 \pi p \rightarrow K_S^0 K^{\pm} p$ |
| 510±200 | ¹² CORDEN | 78 C | OMEG 0 | $15 \pi^- p \rightarrow 3\pi n$ |
| • • • We do not use | the following data for aver | rages, | fits, limits, e | tc. • • • |
| 401 ± 16 166 ± 43 | 80k ¹³ UMAN ¹⁴ BALDI | 06 78 | E835 SPEC — | $\begin{array}{ccc} 5.2 \overline{\rho} p \rightarrow & \eta \eta \pi^0 \\ 10 \pi^- p \rightarrow & p K_S^0 K^- \end{array}$ |

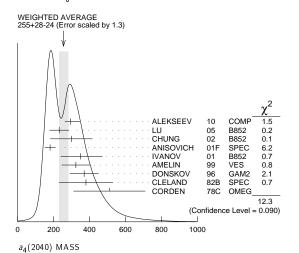
⁸ From the combined analysis of ANISOVICH 99c, ANISOVICH 99E, and ANISOVICH 01F.

⁹ May be a different state.

 10 From a simultaneous fit to the G_+ and G_0 wave intensities.

 $\frac{11}{12}$ From an amplitude analysis. $\frac{12}{J^P} = 4^+$ is favored, though $J^P = 2^+$ cannot be excluded.

 13 Statistical error only. 14 From a fit to the Y_8^0 moment. Limited by phase space.



a4 (2040) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | K K | seen |
| Γ_2 | $\pi^+\pi^-\pi^0$ | seen |
| Γ ₃ | $ ho\pi$ | seen |
| Γ_4 | $f_2(1270) \pi \ \omega \pi^- \pi^0$ | seen |
| Γ_5 | $\omega \pi^- \pi^0$ | seen |
| Γ ₆ Γ ₇ | $\frac{\omega}{\eta} \frac{ ho}{\pi^0}$ | seen |
| | | seen |
| Γ8 | $\eta'(958)\pi$ | seen |

a4 (2040) BRANCHING RATIOS

| $\Gamma(K\overline{K})/\Gamma_{\text{total}}$ | Γ ₁ /Γ |
|------------------------------------------------------|----------------------------------------------------------------|
| <u>VALUE</u> seen | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{ m total}$ | Γ ₂ /Γ |
| seen | CORDEN 780 OMEG 0 15 $\pi^- p \rightarrow 3\pi n$ |
| $\Gamma(\rho\pi)/\Gamma(f_2(1270)\pi)$ VALUE | Γ ₃ /Γ ₄ |
| 1.1±0.2±0.2 | CHUNG 02 B852 $18.3 \pi^- p \rightarrow 3\pi p$ |
| $\Gamma(\eta\pi^0)/\Gamma_{	ext{total}}$ | Γ ₇ /Γ |
| seen | DONSKOV 96 GAM2 $0 	ext{38 } \pi^- p \rightarrow \eta \pi^0 n$ |
| $\Gamma(\omega \rho)/\Gamma_{\text{total}}$ VALUE EV | Γ ₆ /Γ |
| seen 145 | $10 	 05 	 8852 	 18 \pi^- p 	o \omega \pi^- \pi^0 p$ |

 $a_4(2040), f_4(2050)$

a4(2040) REFERENCES

| ALEKSEEV UM AN | 10 06 | PRL 104 241803 PR D73 052009 | M.G. Alekseev et al. I. Uman et al. | (COMPASS Collab.) (FNAL E835) |
|-------------------|----------|---------------------------------|----------------------------------------|----------------------------------|
| LU | 05 | PRI 94 032002 | M Lu et al | (BNL E852 Collab.) |
| CHUNG | 02 | PR D65 072001 | S.U. Chung et al. | (BNL E852 Collab.) |
| ANISOVICH | 01 F | PL B517 261 | A V Anisovich et al | (BINE E032 CONAD.) |
| ANISOVICH | UIF | PL B517 261 | A.V. Allisovich et al. | |
| IVANOV | 01 | PRL 86 3977 | E.I. Ivanov et al. | (BNL E852 Collab.) |
| AMELIN | 99 | PAN 62 445 | D.V. Amelin et al. | ` (VES Collab.) |
| | | Translated from YAF | 62 487. | , , |
| ANISOVICH | 99 C | PL B452 173 | A.V. Anisovich et al. | |
| ANISOVICH | 99E | PL B452 187 | A.V. Anisovich et al. | |
| DONSKOV | 96 | PAN 59 982 | S.V. Donskov et al. | (GAMS Collab.) IGJPC |
| | | Translated from YAF | 59 1027. | , |
| CLELAND | 82 B | NP B208 228 | W.E. Cleland et al. | (DURH, GEVA, LAUS+) |
| BALDI | 78 | PL 74B 413 | R. Baldi et al. | (GEVA)JP |
| CORDEN | 78 C | NP B136 77 | M.J. Corden et al. | (BIRM, RHEL, TELA+)JP |

$f_4(2050)$

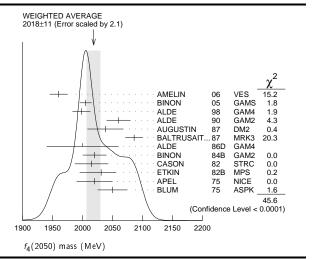
$$I^{G}(J^{PC}) = 0^{+}(4^{+})$$

f4(2050) MASS

| VALUE (MeV) 2018±11 OUR | <u>EVTS</u> AVEDAGE | DOCUMENT ID | calo f | | 2.1. See the ideogram below. |
|--------------------------------------------------------------------------------------------------|------------------------|-------------------|---------------|--------------------------------|-----------------------------------------------------------------------|
| 1960±15 | AVENAGE | AMELIN | 06 | VES | 36 $\pi^- p \rightarrow \omega \omega n$ |
| 2005±10 | 1 | BINON | 05 | | $33 \pi^- p \rightarrow \eta \eta \eta$ |
| 1998±15 | | ALDE | 98 | GA M4 | |
| 2060±20 | | ALDE | 90 | GA M2 | • |
| 2038±30 | | AUGUSTIN | 87 | DM2 | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 2086±15 | | BALTRUSAIT. | .87 | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^-$ |
| 2000 ± 60 | | ALDE | 86D | GAM4 | $100 \pi^- p \rightarrow n2\eta$ |
| 2020 ± 20 | | BINON | 84B | GAM2 | $38 \pi^- p \rightarrow n2\pi^0$ |
| 2015 ± 28 | 3 | CASON | 82 | STRC | $8 \pi^+ \rho \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| $2031 + 25 \\ -36$ | | ETKIN | 82B | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |
| 2020 ± 30 | 700 | APEL | 75 | NICE | $40 \pi^- p \rightarrow n2\pi^0$ |
| 2050 ± 25 | | BLUM | 75 | ASPK | $18.4 \pi^- p \rightarrow nK^+K^-$ |
| • • • We do not | use the follow | wing data for av | erages | s, fits, lir | mits, etc. • • • |
| 1966 ± 25 | | ANISOVICH | 09 | RVUE | 0.0 p ρ, πN |
| $1885 + 14 + 218 \\ -13 - 25$ | 5 | UEHARA | 09 | BELL | 10.6 $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0$ |
| 2018± 6 | | ANISOVICH | 001 | SPEC | $2.0 \overline{\rho} \rho \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ |
| ~ 2000 | (| MARTIN | 98 | RVUE | $\frac{\eta \eta, \eta \eta', \pi \pi}{N N \rightarrow \pi \pi}$ |
| ~ 2010 | | MARTIN | 97 | RVUE | $\overline{N}N \rightarrow \pi\pi$ |
| ~ 2040 | | OAKDEN | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi\pi$ |
| ~ 1990 | Ġ | | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi \pi$ |
| 1978± 5 | 10 |) ALPER | 80 | CNTR | $62 \pi^- p \rightarrow K^+ K^- n$ |
| 2040 ± 10 | 10 |) ROZANSKA | 80 | SPRK | 18 $\pi^- p \rightarrow p \overline{p} n$ |
| 1935 ± 13 | 10 | ORDEN | 79 | | $12\text{-}15 \ \pi^- \rho \rightarrow \ n2\pi$ |
| 1988± 7 | | EVA NGELIS | 79B | OMEG | $10 \pi^- \rho \rightarrow K^+ K^- n$ |
| 1922 ± 14 | 11 | ANTIPOV | 77 | CIBS | $25 \pi^- \rho \rightarrow \rho 3\pi$ |
| $rac{1}{2}$ From the first PWA solution. $rac{2}{1}$ From a partial-wave analysis of the data. | | | | | |
| | | of the reaction | $\pi^+\pi$ | - → 2 | π^0 |
| 4 K matrix pole | | | | | |
| ⁵ Taking into a | ccount the fo | (1950). Helicity- | -2 pro | duction | favored. |
| 6 Energy-dependent analysis. | | | | | |
| 7 Single energy analysis. | | | | | |
| | | ide analysis of d | ata o | $n \overline{p} p \rightarrow$ | $\pi\pi$. See however KLOET 96 |
| | only and fin | d waves only up | to <i>J</i> = | 3 to be | important but not significantly |
| resonant. 9 From solution | B of amplitu | ıda ənəlweie of d | ata o | n <u>n</u> n - · | $\pi\pi$. See however KLOET 96 |
| | | | | | ππ. See However KLOE 1 96 |

who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly

resonant. 10 $I(J^P)=0(4^+)$ from amplitude analysis assuming one-pion exchange. 11 Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.



f4 (2050) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------------------|---------------------|--------|------|--------------------------------------------------|
| | | | cale f | - | 1.9. See the ideogram below. |
| 290± 20 | | AMELIN | 06 | VES | 36 $\pi^- p \rightarrow \omega \omega n$ |
| 340± 80 | 1 | ^{.2} BINON | 05 | | 33 $\pi^- p \rightarrow \eta \eta \eta$ |
| 395 ± 40 | | ALDE | 98 | GAM4 | $100 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ |
| 170± 60 | | ALDE | 90 | GAM2 | 38 $\pi^- p \rightarrow \omega \omega n$ |
| 304 ± 60 | | AUGUSTIN | 87 | DM2 | $J/\psi \rightarrow \gamma \pi^{+} \pi^{-}$ |
| 210± 63 | | BALTRUSAIT. | 87 | MRK3 | $J/\psi \rightarrow \gamma \pi^{+} \pi^{-}$ |
| 400 ± 100 | | ALDE | 86D | GAM4 | $100 \pi^- p \rightarrow n2\eta$ |
| 240± 40 | 40k ¹ | .3 BINON | 84B | GAM2 | $38 \pi^- p \rightarrow n 2\pi^0$ |
| $190\pm~14$ | | DENNEY | 83 | LASS | 10 $\pi^{+} n/\pi^{+} p$ |
| $186 {}^{+ 103}_{- 58}$ | 1 | 4 CASON | 82 | STRC | 8 $\pi^+ ho ightarrow \Delta^{++} \pi^0 \pi^0$ |
| $305 {+} {36} \\ -119$ | | ETKIN | 82B | | $23 \pi^- p \rightarrow n2K_S^0$ |
| 180 ± 60 | 700 | APEL | 75 | NICE | $40 \pi^- p \rightarrow n2\pi^0$ |
| $225 {}^{+ 120}_{- 70}$ | | BLUM | 75 | ASPK | 18.4 $\pi^- p \rightarrow n K^+ K^-$ |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| 260± 40 | ¹⁵ A NISOVICH | 09 | RVUE | 0.0 p ρ, π N |
|---------------------------|--------------------------|-----|------|---------------------------------------------------------------------------------|
| $453 \pm 20 + 31 \\ -129$ | ¹⁶ UEHARA | 09 | BELL | $10.6~e^{+}~e^{-}~\rightarrow~e^{+}~e^{-}~\pi^{0}~\pi^{0}$ |
| 182± 7 | ANISOVICH | 00J | SPEC | $2.0 \overline{p}p \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ |
| ~ 170 | ¹⁷ MARTIN | 98 | RVUE | $\frac{\eta}{N} \eta, \eta \eta', \pi \pi$ $N \overline{N} \rightarrow \pi \pi$ |
| ~ 200 | | 97 | RVUE | $\overline{N} N \rightarrow \pi \pi$ |
| ~ 60 | ¹⁹ OAKDEN | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi \pi$ |
| ~ 80 | ²⁰ OAKDEN | 94 | RVUE | $0.36-1.55 \overline{p} p \rightarrow \pi \pi$ |
| 243± 16 | | 80 | CNTR | $62 \pi^- p \rightarrow K^+ K^- n$ |
| 140± 15 | ²¹ ROZANSKA | 80 | SPRK | 18 $\pi^- p \rightarrow p \overline{p} n$ |
| 263± 57 | ²¹ CORDEN | 79 | OMEG | $12\text{-}15 \ \pi^- p \rightarrow n2\pi$ |
| 100± 28 | EVA NGELIS | 79B | OMEG | $10 \pi^- p \rightarrow K^+ K^- n$ |
| 107± 56 | ²² ANTIPOV | 77 | CIBS | $25 \pi^- p \rightarrow p 3\pi$ |
| | | | | |

- 12 From the first PWA solution.
 13 From a partial-wave analysis of the data.
- 14 From an amplitude analysis of the reaction $\pi^+\pi^- \to 2\pi^0$.
- ¹⁵ K matrix pole.
- 16 Taking into account the $f_2(1950)$. Helicity-2 production favored.
- 17 Energy-dependent analysis.
- 18 Single energy analysis.
- ¹⁹ From solution A of amplitude analysis of data on $\overline{p}p \to \pi\pi$. See however KLOET 96 who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly
- resonant. 20 From solution B of amplitude analysis of data on $\overline{p}p \to \pi\pi$. See however KLOET 96 who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly
- 22 Width errors enlarged by us to $4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.

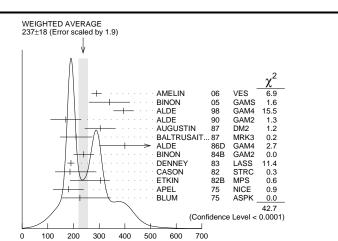
 $f_4(2050)$ WIDTH

 $\Gamma(\omega\omega)/\Gamma_{\rm total}$

 $\Gamma(\eta\eta)/\Gamma_{\text{total}}$

 2.1 ± 0.8

Meson Particle Listings $f_4(2050)$, $\pi_2(2100)$



f4(2050) DECAY MODES

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|----------------------------------|------------------------------|--------------------------------------|
| Γ ₁ | $\omega \omega$ | seen |
| Γ_2^- | $\pi\pi$ | (17.0 ± 1.5) % |
| Γ_3 | $K\overline{K}$ | $(6.8^{+3.4}_{-1.8}) \times 10^{-3}$ |
| Γ_4 | $\eta\eta$ | $(2.1\pm0.8)\times10^{-3}$ |
| Γ ₄ Γ ₅ | $^{\eta\eta}_{4\pi^0}$ | < 1.2 % |
| Γ_6 | $\gamma \gamma a_2(1320)\pi$ | |
| Γ_7 | $a_{2}(1320)\pi$ | seen |

$f_4(2050) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(K\overline{K}) \times \Gamma$ | $(\gamma\gamma)/$ | Γ_{total} | | | | | $\Gamma_3\Gamma_6/\Gamma$ |
|------------------------------------------------------------------------------|-------------------------|-------------------------|----------------------|----------|---------|---------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| VALUE (keV) | | CL% | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do | not use 1 | the followin | ig data for average | s, fits, | limits, | etc. • • • | |
| < 0.29 | | 95 | ALTHOFF | 85B | TASS | $\gamma \gamma \rightarrow K \overline{K} \pi$ | |
| $\Gamma(\pi\pi) \times \Gamma$ | $(\gamma\gamma)/\Gamma$ | total | | | | | $\Gamma_2\Gamma_6/\Gamma$ |
| VALUE (eV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do | not use 1 | the followin | ig data for average | s, fits, | limits, | etc. • • • | |
| $23.1 {}^{+ 3.6 + 70}_{- 3.3 - 15}$ | .5 .6 | | ²³ UEHARA | 09 | BELL | 10.6 e ⁺ e ⁻ - | .0 |
| <1100 | 95 | 13 ± 4 | | | | $ \begin{array}{c} 10.6 \ e^{+} e^{-} \\ e^{+} e^{-} \pi^{0} \pi^{0} \\ e^{+} e^{-} \xrightarrow{e^{+}} 0 \pi^{0} \end{array} $ | .0 |
| 23 Taking into account the $f_2(1950)$. Helicity-2 production favored. | | | | | | | |

f4 (2050) BRANCHING RATIOS

DOCUMENT ID

TECN COMMENT

86D GAM4 100 $\pi^- p \rightarrow n4\gamma$

| seen | | AMELIN | 06 | VES | $36 \pi^- p \rightarrow \omega \omega n$ |
|-------------------------------------------|------|------------------|----------|---------|----------------------------------------------------|
| | ng d | lata for average | s, fits, | limits, | etc. • • • |
| not seen | | BARBERIS | 00F | | 450 $pp \rightarrow p_f \omega \omega p_S$ |
| $\Gamma(\omega\omega)/\Gamma(\pi\pi)$ | | | | | Γ_1/Γ_2 |
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| 1.5 ± 0.3 | | ALDE | 90 | GAM2 | 38 $\pi^- p \rightarrow \omega \omega n$ |
| $\Gamma(\pi\pi)/\Gamma_{\text{total}}$ | | | | | Γ ₂ /Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| 0.170±0.015 OUR AVERAGE | | | | | |
| 0.18 ±0.03 | | BINON | 83c | GAM2 | $38 \pi^- p \rightarrow n4\gamma$ |
| 0.16 ±0.03 | | CASON | 82 | STRC | $8 \pi^+ \rho \rightarrow \Delta^{++} \pi^0 \pi^0$ |
| 0.17 ±0.02 | 24 | CORDEN | 79 | OMEG | $12\text{-}15 \ \pi^- p \rightarrow n2\pi$ |
| ²⁴ Assuming one pion exchange. | | | | | |
| $\Gamma(K\overline{K})/\Gamma(\pi\pi)$ | | | | | Γ ₃ /Γ ₂ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| 0.04 + 0.02 | | ETKIN | 82B | MPS | $23 \pi^- p \rightarrow n2K_S^0$ |

ALDE

| $\Gamma(4\pi^0)/\Gamma_{\text{total}}$ | DO CUMENT ID | | <u>TECN</u> | Γ ₅ /Γ |
|----------------------------------------------|--------------|----|-------------|---------------------------------------------|
| <0.012 | ALDE | 87 | GAM4 | 100 $\pi^- p \to 4\pi^0 n$ |
| $\Gamma(a_2(1320)\pi)/\Gamma_{\text{total}}$ | | | | Γ ₇ /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| seen | AMELIN | 00 | VES | $37 \pi^- p \rightarrow \eta \pi^+ \pi^- n$ |

f₄ (2050) REFERENCES

| ANIS OVICH | 09 | IJMP A24 2481 | V.V. Anisovich, A.V. S | |
|------------|------|-----------------------|--------------------------|---------------------------------------|
| UEHARA | 09 | PR D79 052009 | S. Uehara <i>et al</i> . | (BELLE Collab.) |
| AMELIN | 06 | PAN 69 690 | D.V. Amelin et al. | (VES Collab.) |
| | | Translated from YAF 6 | | · · · · · · · · · · · · · · · · · · · |
| BINON | 05 | PAN 68 960 | F. Binon et al. | |
| | | Translated from YAF 6 | | |
| AMELIN | 00 | NP A668 83 | D. Amelin <i>et al</i> . | (VES Collab.) |
| ANIS OVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| BARBERIS | 00 F | PL B484 198 | D. Barberis et al. | (WA 102 Collab.) |
| ALDE | 98 | EPJ A3 361 | D. Alde et al. | (GAM4 Collab.) |
| A Iso | | PAN 62 405 | D. Alde et al. | (GAMS Collab.) |
| | | Translated from YAF 6 | | |
| MARTIN | 98 | PR C57 3492 | B.R. Martin et al. | |
| MARTIN | 97 | PR C56 1114 | B.R. Martin, G.C. Oad | |
| KLOET | 96 | PR D53 6120 | W.M. Kloet, F. Myhrer | |
| OAKDEN | 94 | NP A574 731 | M.N. Oakden, M.R. Pe | nnington (DURH) |
| ALDE | 90 | PL B241 600 | D.M. Alde et al. | (SERP, BELG, LANL, LAPP+) |
| OEST | 90 | ZPHY C47 343 | T. Oest et al. | (JADE Collab.) |
| ALDE | 87 | PL B198 286 | D.M. Alde et al. | (LANL, BRUX, SERP, LAPP) |
| AUGUS T IN | 87 | ZPHY C36 369 | J.E. Augustin et al. | (LALO, CLER, FRAS+) |
| BALTRUSAIT | . 87 | PR D35 2077 | R.M. Baltrusaitis et al. | (Mark III Collab.) |
| ALDE | 86D | NP B269 485 | D.M. Alde et al. | (BELG, LAPP, SERP, CERN+) |
| ALTHOFF | 85 B | ZPHY C29 189 | M. Althoff et al. | (TASSO Collab.) |
| BINON | 84 B | LNC 39 41 | F.G. Binon et al. | (SERP, BELG, LAPP) |
| BINON | 83 C | SINP 38 723 | F.G. Binon et al. | (SERP, BRUX+) |
| | | Translated from YAF 3 | | (,) |
| DENNEY | 83 | PR D28 2726 | D.L. Denney et al. | (IOWA, MICH) |
| CASON | 82 | PRL 48 1316 | N.M. Cason et al. | (NDAM, ANL) |
| ETKIN | 82B | PR D25 1786 | A. Etkin et al. | (BNL, CUNY, TÜFTS, VAND) |
| ALPER | 80 | PL 94B 422 | B. Alper et al. | (AMST, CERN, CRAC, MPIM+) |
| ROZANSKA | 80 | NP B162 505 | M. Rozanska et al. | (MPIM, CERN) |
| CORDEN | 79 | NP B157 250 | M.J. Corden et al. | (BIRM, RHEL, TELA+)JP |
| EVANGELIS | 79B | NP B154 381 | C. Evangelista et al. | (BARI, BONN, CERN+) |
| ANTIPOV | 77 | NP B119 45 | Y.M. Antipov et al. | (SERP, GEVA) |
| APEL | 75 | PL 57B 398 | | (KARLK, KARLE, PISA, SERP+)JP |
| BLUM | 75 | PL 57B 403 | W. Blum et al. | (CERN, MPIM) JP |
| | | | | () |

$\pi_2(2100)$

 Γ_1/Γ

 Γ_4/Γ

$I^{G}(J^{PC}) = 1^{-}(2^{-+})$

OMITTED FROM SUMMARY TABLE Needs confirmation.

$\pi_2(2100)$ MASS

| VALUE (MeV) | DO CUMENT IE |) | TECN | COMMENT | | |
|---------------------------------------------------------------------------------|---------------------|-----|------|--------------------------------------------------------------------------------|--|--|
| 2090 ± 29 OUR AVERAGE | · | | | | | |
| 2090 ± 30 | ¹ AMELIN | 95B | VES | $\begin{array}{c} 36 \ \pi^- A \rightarrow \\ \pi^+ \pi^- \pi^- A \end{array}$ | | |
| 2100 ± 150 | ² DAUM | 81B | CNTR | $63,94 \pi^{-} \stackrel{\pi}{p} \stackrel{\pi}{\rightarrow} 3\pi X$ | | |
| ¹ From a fit to $J^{PC}=2^{-+}f_2(1270)\pi$, $(\pi\pi)_S\pi$ waves. | | | | | | |
| 2 From a two reconance fit to | | ı | | | | |

$\pi_2(2100)$ WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|---------------------------------|---------|------|------------------------------------------------------------------------|
| 625 ± 50 OUR AVERAGE | Error includes scale fa | ctor of | 1.2. | |
| 520 ± 100 | ³ AMELIN | 95 B | VES | 36 $\pi^- A \rightarrow \pi^+ \pi^- \pi^- A$ |
| 651± 50 | ⁴ DAUM | 81в | CNTR | $\pi^{+} \pi^{-} \pi^{-} A$ 63,94 $\pi^{-} \rho \rightarrow 3\pi X$ |
| 3 From a fit to $J^{PC} = 2^{-1}$ | $-+ f_2(1270) \pi, (\pi \pi)_s$ | π wave | s. | |

$\pi_2(2100)$ DECAY MODES

| | Mode | Fraction (Γ _i /Γ) |
|-----------------------|-----------------|------------------------------|
| $\overline{\Gamma_1}$ | 3π | seen |
| Γ_2 | $ ho\pi$ | seen |
| Γ_3 | $f_2(1270)\pi$ | seen |
| Γ_4 | $(\pi\pi)_s\pi$ | seen |
| | | |

π_2 (2100) BRANCHING RATIOS

| $\Gamma(\rho\pi)/\Gamma(3\pi)$ | DOCUMENT ID | | TECN | COMMENT | Γ_2/Γ_1 |
|-------------------------------------------------------------------|--------------------|-----|--------------|------------------------------------------|--------------------------------|
| 0.19±0.05 | ⁵ DAUM | 81в | | 63,94 π ⁻ ρ | |
| $\Gamma(f_2(1270)\pi)/\Gamma(3\pi)$ <u>VALUE</u> 0.36±0.09 | DOCUMENT ID 5 DAUM | 81B | TECN CNTR | <u>COMMENT</u> 63,94 π ⁻ p | Γ ₃ /Γ ₁ |
| $\frac{\Gamma((\pi\pi)_s\pi)/\Gamma(3\pi)}{^{VALUE}}$ 0.45 ± 0.07 | DOCUMENT ID 5 DAUM | 81B | <u>TECN</u> | <u>соммент</u> 63,94 т ⁻ р | Γ ₄ /Γ ₁ |

⁴ From a two-resonance fit to four 2⁻0⁺ waves.

 $\pi_2(2100)$, $f_0(2100)$, $f_2(2150)$

D-wave/S-wave RATIO FOR $\pi_2(2100) \rightarrow f_2(1270)\pi$

7ECN COMMENT 81B CNTR 63,94 π⁻ p DOCUMENT ID ⁵ DAUM 0.39 ± 0.23

 5 From a two-resonance fit to four $2^{-}0^{+}$ waves.

$\pi_2(2100)$ REFERENCES

AMELIN DAUM 95B PL B356 595 81B NP B182 269 D.V. Amelin et al. C. Daum et al. (SERP, TBIL) (AMST, CERN, CRAC, MPIM+)

 $f_0(2100)$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

f₀(2100) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
|----------------------------------------------------------------------------------|---------------|----------------------|--------|-----------|----------------------------------------------------------------|--|--|
| 2103± 8 OUR | AVERAGE | | | | | | |
| $2102{\pm}13$ | | $^{ m 1}$ A NISOVICH | 001 | SPEC | $2.0 \overline{p}p \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ | | |
| | | | | | $\eta \eta$, $\eta \eta'$, $\pi^+ \pi^-$ | | |
| 2090 ± 30 | | BAI | | | $J/\psi \rightarrow \gamma (\pi^+\pi^-\pi^+\pi^-)$ | | |
| 2105 ± 10 | | ANISOVICH | 99K | SPEC | $0.6-1.94 \overline{p}p \rightarrow \eta \eta, \eta \eta'$ | | |
| • • • We do not | use the follo | wing data for ave | rages, | fits, lim | ts, etc. • • • | | |
| $2105\pm~8$ | 80k | ² U MA N | 06 | E835 | $5.2 \overline{\rho} \rho \rightarrow \eta \eta \pi^0$ | | |
| ~ 2104 | | BUGG | 95 | | $J/\psi \rightarrow \gamma \pi^{+} \pi^{-} \pi^{+} \pi^{-}$ | | |
| ~ 2122 | | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ | | |
| $^{ m 1}$ Includes the data of ANISOVICH 00B indicating to exotic decay pattern. | | | | | | | |

f₀(2100) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------|-------------------------|---------|-----------|----------------------------------------------------------------|
| 209± 19 OUR | AVERAGE | | | | |
| 211 ± 29 | | ³ A NISOVICH | 001 | SPEC | $2.0 \overline{p}p \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ |
| | | | | | $\eta\eta$, $\eta\eta'$, $\pi^+\pi^-$ |
| 330 ± 100 | | BAI | | | $J/\psi \rightarrow \gamma (\pi^+\pi^-\pi^+\pi^-)$ |
| 200± 25 | | ANISOVICH | 99K | SPEC | $0.6-1.94 \overline{p}p \rightarrow \eta \eta, \eta \eta'$ |
| ● ● We do not | use the follo | wing data for ave | ages, | fits, lim | its, etc. • • • |
| 236± 14 | 80k | ⁴ U MA N | 06 | E835 | $5.2 \overline{p} p \rightarrow \eta \eta \pi^0$ |
| ~ 203 | | BUGG | 95 | | $J/\psi \rightarrow \gamma \pi^{+} \pi^{-} \pi^{+} \pi^{-}$ |
| ~ 273 | | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| 3 Includes the d | ata of A NIIC | OVICH OOD indica- | tine to | avetic | docay pattorn |

Includes the data of ANISOVICH 00B indicating to exotic decay pattern.

f₀(2100) REFERENCES

| UMAN | 06 | PR D73 052009 | I. Uman et al. | (FNAL E835) |
|-----------|------|---------------|-----------------------|--------------------|
| ANISOVICH | 00 B | NP A662 319 | A.V. Anisovich et al. | , |
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| BAI | 00 A | PL B472 207 | J.Z. Bai et al. | (BES Collab.) |
| ANISOVICH | 99K | PL B468 309 | A.V. Anisovich et al. | |
| BUGG | 95 | PL B353 378 | D.V. Bugg et al. | (LOQM, PNPI, WASH) |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) |



$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

OMITTED FROM SUMMARY TABLE This entry was previously called T_0 .

f2(2150) MASS

f2(2150) MASS, COMBINED MODES (MeV)

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|-------------------|--------------------|---------|-----------|-------------------------------------------------|
| 2157±12 OUR AVERA | GE Include | s data from the | 2 dat | ablocks 1 | hat follow this one. |
| • • • We do not use th | e following | data for average | s, fits | , limits, | etc. • • • |
| 2170 ± 6 | 80k | ¹ uma n | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| $^{ m 1}$ Statistical error only | | | | | |

$\eta\eta$ MODE

DOCUMENT ID The data in this block is included in the average printed for a previous datablock.

2157±12 OUR AVERAGE

| 2151 ± 16 | BARBERIS | 00E | | $450 pp \rightarrow p_f \eta \eta p_S$ |
|---------------------------------|--------------------|--------|-------------|----------------------------------------------------------|
| 2175 ± 20 | PROKOSHKIN | 95D | GA M4 | 300 $\pi^- N \rightarrow \pi^- N 2\eta$, |
| | | | | $450 pp \rightarrow pp2\eta$ |
| 2130 ± 35 | SINGOVSKI | 94 | GA M4 | $450 pp \rightarrow pp 2\eta$ |
| • • • We do not use the followi | ng data for avera | ges, 1 | fits, limit | s, etc. • • • |
| 2140 ± 30 | ² ABELE | 99B | CBAR | |
| 2104 ± 20 | 3 ARMSTRONG | 93c | E760 | $\overline{p}p \rightarrow \pi^0 nn \rightarrow 6\gamma$ |

 $^2\,{\rm Spin}$ not determined. $^3\,{\rm No}\,\,J^{P\,C}$ determination.

$\eta\pi\pi$ MODE

| VALUE (MeV) | DO CUMENT ID | TECN | CHG | COMMENT |
|------------------------------------|------------------------|---------|--------|------------|
| The data in this block is included | in the average printed | for a p | evious | datablock. |

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

⁴ ADOMEIT 96 CBAR 0 1.94 $\overline{p}p \rightarrow \eta 3\pi^0$

 4 ANISOVICH 00E recommends to withdraw ADOMEIT 96 that assumed a single $J^P=$ 2+ resonance.

$\overline{p}p \rightarrow \pi\pi$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------------------------------|--------|---------|------------------------------------------------|
| • • • We do not use t | he following data for averages | , fits | limits, | etc. • • • |
| ~ 2090 | ⁵ OA KDEN | 94 | RVUE | $0.361.55~\overline{p}\rho \rightarrow \pi\pi$ |
| ~ 2120 | ⁶ OA KDEN | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi\pi$ |
| ~ 2170 | ⁷ MARTIN | 80B | RVUE | |
| ~ 2150 | ⁷ MARTIN | 80c | RVUE | |
| ~ 2150 | ⁸ DULUDE | 78B | OSP K | $1-2 \overline{p} p \rightarrow \pi^0 \pi^0$ |

 $^{^5}$ OAKDEN 94 makes an amplitude analysis of LEAR data on $\overline{\rho}\rho\to\pi\pi$ using a method based on Barrelet zeros. This is solution A. The amplitude analysis of HASAN 94 includes earlier data as well, and assume that the data can be parametrized in terms of towers of nearly degenerate resonances on the leading Regge trajectory. See also KLOET 96 and MARTIN 97 who make related analyses.

⁶ From solution B of amplitude analysis of data on $\overline{p}p \to \pi\pi$.

71(JP) = 0(2+) from simultaneous analysis of $p\overline{p} \to \pi^+$ and $\pi^0\pi^0$. 81 G (JP) = 0+(2+) from partial-wave amplitude analysis.

S-CHANNEL $\overline{p}p$, $\overline{N}N$ or $\overline{K}K$

| VALUE (MeV) | DO CUMENT ID | TECN CF | IG COMMENT |
|---------------------|------------------------------|-------------------|--------------------------------------------------------------|
| • • • We do not use | the following data for avera | ges, fits, limits | , etc. • • • |
| 2139 + 8 | ⁹ EVA NGELIS 9 | 7 SPEC | $0.6\text{-}2.4 \ \overline{p}p \rightarrow \ K_S^0 \ K_S^0$ |
| ~ 2190 | | BB CNTR | $0.97-3 \overline{p}p \rightarrow \overline{N}N$ |
| 2155 ± 15 | ^{9,10} COUPLAND 7 | | $0.7-2.4 \overline{p}p \rightarrow \overline{p}p$ |
| 2193 ± 2 | 9,11 ALSPECTOR 7 | 3 CNTR | <u></u> pρ S channel |

 $^9\,\mbox{lsospins}$ 0 and 1 not separated.

10 From a fit to the total elastic cross section.

11 Referred to as *T* or *T* region by ALSPECTOR 73.

VT MODE

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------------|--------|-------------|----------------------------------------|
| • • • We do not use the followi | ng data for avera | ges, 1 | fits, limit | s, etc. • • • |
| 2200 ± 13 | VLADIMIRSK. | .06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 2150 ± 20 | ABLIKIM | 04E | BES2 | $J/\psi \rightarrow \omega K^+ K^-$ |
| 2130 ± 35 | BARBERIS | 99 | OMEG | $450 pp \rightarrow p_S p_f K^+ K^-$ |
| | | | | |

f2(2150) WIDTH

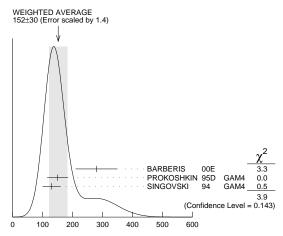
f₂(2150) WIDTH, COMBINED MODES (MeV)

EVTS DO CUMENT ID 152±30 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 1.4. See the ideogram below.

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

¹² UMAN $182\!\pm\!11$ 80k 06 E835 5.2 $\overline{p}p \rightarrow \eta \eta \pi^0$

 $^{12}\,\mathrm{Statistical}$ error only.



 $f_2(2150)$ WIDTH, COMBINED MODES (MeV)

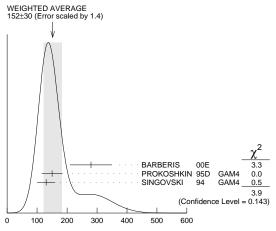
² Statistical error only.

⁴ Statistical error only.

| $\eta\eta$ MODE | | | |
|----------------------------------------|-------------------------|------------------|---------------------------------------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
| The data in this block is include | ed in the average p | orinted for a p | revious datablock. |
| 152±30 OUR AVERAGE Erro | or includes scale fa | ctor of 1.4. S | ee the ideogram below. |
| 280 ± 70 | BARBERIS | 00E | 450 $pp \rightarrow p_f \eta \eta p_S$ |
| 150 ± 35 | PROKOSHKIN | 95D GAM4 | 300 $\pi^- N \rightarrow \pi^- N 2\eta$, 450 $pp \rightarrow pp2\eta$ |
| 130 ± 30 | SINGOVSKI | 94 GA M4 | $450 pp \rightarrow pp2\eta$ |
| ullet $ullet$ We do not use the follow | ving data for avera | ges, fits, limit | s, etc. • • • |
| | ¹³ ABELE | | |
| 203±10 | ¹⁴ ARMSTRONG | 93c E760 | $\overline{p}p \rightarrow \pi^0 \eta \eta \rightarrow 6\gamma$ |
| ¹³ Spin not determined. | | | |







 $\mathit{f}_{2}(2150)$ WIDTH, $\eta\eta$ MODE (MeV)

$\eta\pi\pi$ MODE

<u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 15 ADOMEIT 96 CBAR 0 1.94 $\overline{p}p
ightarrow \eta 3\pi^0$ $250 \pm 25 \pm 45$

 $^{15}\,\mathrm{A\,NISOVICH}$ 00E recommends to withdraw ADOMEIT 96 that assumed a single J^P =2+ resonance.

$\overline{p}p \rightarrow \pi\pi$

| VALUE (MeV) | DO CUMENT ID | TECN COMMENT |
|-----------------------------------------------------------------------------------------------------|------------------------|---------------------------------------------------------------------------------------|
| 250 OUR ESTIMATE | | |
| • • • We do not use the fol | lowing data for averag | es, fits, limits, etc. • • • |
| ~ 70 | ¹⁶ OAKDEN | 94 RVUE $0.36-1.55 \overline{p}p \rightarrow \pi \pi$ |
| ~ 250 | ¹⁷ MARTIN | 80B RVUE |
| ~ 250 | ¹⁷ MARTIN | 80c RVUE |
| ~ 250 | ¹⁸ DULUDE | 78B OSPK 1-2 $\overline{p}p \rightarrow \pi^0\pi^0$ |
| ¹⁶ See however KLOET 96 important but not significant $I_{I}(J^{P}) = 0(2^{+})$ from sim | cantly resonant. | and find waves only up to $J=3$ to be $\sqrt{n} = \sqrt{\pi} - \pi^+$ and $\pi^0 = 0$ |
| 18IG(JP) = 0+(2+) from | | |

S-CHANNEL $\overline{p}p$, $\overline{N}N$ or $\overline{K}K$

| VALUE (MeV) | DO CUMENT ID | TECN | CHG | COMMENT |
|--------------------|--------------------------------------|--------------|----------|--------------------------------------------------------------------------------------------------------------------------|
| • • • We do not | use the following data for average | s, fits, lin | nits, et | C. • • • |
| $56 + 31 \\ -16$ | ¹⁹ EVANGELIS 97 | SPEC | | 0.6-2.4 $\overline{p}p \rightarrow K_S^0 K_S^0$ |
| 135 ± 75 98 ± 8 | 20,21 COUPLAND 77 21 ALSPECTOR 73 | | | $\begin{array}{ccc} 0.7-2.4 \ \overline{p}p \rightarrow \overline{p}p \\ \overline{p}p \ S \ \text{channel} \end{array}$ |
| 90± 0 | | CNIK | | pp 3 channel |

⁹lsospin 0 and 2 not separated.

κ**π** mode

| VALUE (MeV) | DOCUMENT ID | | TE CN | COMMENT |
|---------------------|------------------------------|------|-------------|----------------------------------------|
| • • • We do not use | the following data for avera | ges, | fits, limit | s, etc. • • • |
| 91 ± 62 | VLADIMIRSK | .06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 150 ± 30 | ABLIKIM | 04E | BES2 | $J/\psi \rightarrow \omega K^+ K^-$ |
| 270 ± 50 | BARBERIS | 99 | OMEG | 450 $pp \rightarrow p_S p_f K^+ K^-$ |

f2(2150) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------|------------------------------|
| Γ ₁ | $\pi\pi$ | |
| Γ_2 | $\eta\eta$ | seen |
| Γ_3 | $K\overline{K}$ | seen |
| Γ_4 | $f_2(1270)\eta$ | seen |
| Γ_5 | $a_2(1320)\pi$ | seen |
| Γ ₆ | p p | seen |

f2(2150) BRANCHING RATIOS

| $\Gamma(K\overline{K})/\Gamma(\eta\eta)$ | | | | Г3/Г2 |
|------------------------------------------|-----------------|-----------------------------|--------------|----------------------------------------------------------------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT |
| 1.28 ± 0.23 | | BARBERIS 00 |)E | $450 pp \rightarrow p_f \eta \eta p_S$ |
| ● ● We do not u | se the followin | g data for averages, fi | its, limits, | etc. • • • |
| < 0.1 | 95 | ²² PROKOSHKIN 95 | D GAM4 | 300 $\pi^- N \rightarrow \pi^- N 2\eta$, 450 $pp \rightarrow pp 2\eta$ |
| 22 | | | | 430 pp → pp2η |

22 Using data from ARMSTRONG 89D.

| $\Gamma(\pi\pi)/\Gamma(\eta\eta)$ | | | | | Γ_1/Γ_2 |
|-----------------------------------|-------------|----------------------------|-----------|-----------------------------|---------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use | the followi | ng data for averages, fits | , limits, | etc. • • • | |
| < 0.33 | 95 | 23 PROKOSHKIN 95D | GA M4 | 300 π^- N \rightarrow | $\pi^- N 2\eta$ |
| | | | | 450 pp — | ρρ2η ΄ |

 23 Derived from a $\pi^0\,\pi^0/\eta\eta$ limit.

| $\Gamma(f_2(1270)\eta)/\Gamma(a_2(1320)\eta)$ | $\pi)$ | | | | Γ_4/Γ_5 |
|-----------------------------------------------|-----------------------|----|------|----------------------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.79±0.11 | ²⁴ ADOMEIT | 96 | CBAR | 1.94 $\overline{p}p \rightarrow$ | $\eta 3\pi^0$ |
| 24 Hsing B(3a(1320) → 277) | - 0.145 | | | | |

| $\Gamma(p\overline{p})/\Gamma_{ m total}$ | | | | | Γ_6/Γ |
|-------------------------------------------|------|--------------|------|----------------------------------------------|-------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| seen | 73 | ALEXANDER 10 | CLEO | $\psi(2S) \rightarrow \gamma n \overline{n}$ | |

f2(2150) REFERENCES

| ALEXANDER | 10 | PR D82 092002 | J.P. Alexander et al. | (CLEO Collab.) | |
|--------------|------|---------------------------------------|------------------------------|-----------------------------------------|--|
| UMAN | 06 | PR D73 052009 | I. Uman et al. | (FNAL E835) | |
| VLA DIMIRS K | 06 | PAN 69 493 | V.V. Vladimirsky et al. | (ITEP, Moscow) | |
| | | Translated from YAF 69 | 515. | , , , | |
| ABLIKIM | 04 E | PL B603 138 | M. Ablikim et al. | (BES Collab.) | |
| ANISOVICH | 00 E | PL B477 19 | A.V. Anisovich et al. | , , , , , , , , , , , , , , , , , , , , | |
| BARBERIS | 00 E | PL B479 59 | D. Barberis et al. | (WA 102 Collab.) | |
| ABELE | 99B | EPJ C8 67 | A. Abele et al. | (Crystal Barrel Collab.) | |
| BARBERIS | 99 | PL B453 305 | D. Barberis et al. | (Omega Expt.) | |
| EVANGELIS | 97 | PR D56 3803 | C. Evangelista et al. | (LEAR Collab.) | |
| MARTIN | 97 | PR C56 1114 | B.R. Martin, G.C. Oades | (LOUC, AARH) | |
| ADOMEIT | 96 | ZPHY C71 227 | J. Adomeit et al. | (Crystal Barrel Collab.) | |
| KLOET | 96 | PR D53 6120 | W.M. Kloet, F. Myhrer | (RUTG, NORD) | |
| | | | | | |
| PROKOSHKIN | 95 D | SPD 40 495 Translated from DANS 3- | Y.D. Prokoshkin | (SERP) IGJ PC | |
| HACAN | 0.4 | | | (1,0011) | |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) | |
| OAKDEN | 94 | NP A574 731 | M.N. Oakden, M.R. Pennington | (DURH) | |
| SINGOVSKI | 94 | NC 107A 1911 | A.V. Singovsky | (SERP) | |
| ARMSTRONG | 93 C | PL B307 394 | T.A. Armstrong et al. | (FNAL, FERR, GÉNO+) | |
| ARMSTRONG | 89D | PL B227 186 | T.A. Armstrong, M. Benayoun | (ATHU, BARI, BIRM+) | |
| MARTIN | 80 B | NP B176 355 | B.R. Martin, D. Morgan | (LOUC, RHEL)JP | |
| MARTIN | 80 C | NP B169 216 | A.D. Martin, M.R. Pennington | (DURH) JP | |
| CUTTS | 78 B | PR D17 16 | D. Cutts et al. | (STON, WISC) | |
| DULUDE | 78 B | PL 79B 335 | R.S. Dulude et al. | (BROW, MIT, BARI) JP | |
| COUPLAND | 77 | PL 71B 460 | M. Coupland et al. | (LOQM, RHEL) | |
| ALSPECTOR | 73 | PRL 30 511 | J. Alspector et al. | (RUTG, UPNJ) | |
| ALSTECTOR | 13 | 1 KL 30 311 | a. mapocioi et al. | (1.010, 0110) | |

$\rho(2150)$

$$I^G(J^{PC}) = 1^+(1^{--})$$

OMITTED FROM SUMMARY TABLE

This entry was previously called $T_1(2190)$. See our mini-review under the $\rho(1700)$.

ρ (2150) MASS

e+e- PRODUCED

| VALUE (MeV) | DO CUMENT ID | TECN_COMMENT |
|----------------------|---------------------|--------------------------------------------------------------------------|
| 2149±17 OUR AV | ERAGE Includes | data from the datablock that follows this one. |
| $2150 \pm 40 \pm 50$ | AUBERT | 07AU BABR 10.6 $e^{+}e^{-} \rightarrow f_{1}(1285) \pi^{+}\pi^{-}\gamma$ |
| 2153 ± 37 | BIAGINI | 91 RVUE $e^+e^- ightarrow\pi^+\pi^-$, K^+K^- |
| 2110 ± 50 | ¹ CLEGG | 90 RVUE $e^+e^- \rightarrow 3(\pi^+\pi^-), 2(\pi^+\pi^-\pi^0)$ |
| | ise the following d | ata for averages, fits, limits, etc. ● ● |
| 1990 ± 80 | AUBERT | 07AU BABR 10.6 $e^+e^- ightarrow\eta^\prime\pi^+\pi^-\gamma$ |

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|----------------------|-----------|---------|----------------------------------------------|
| • • • We do not use the follow | ing data for averag | es, fits, | limits, | etc. • • • |
| ~ 2191 | HA SA N | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| ~ 2070 | ² oa kden | 94 | RVUE | $0.36-1.55 \overline{p}p \rightarrow \pi\pi$ |
| ~ 2170 | ³ MARTIN | 80B | RVUE | |
| ~ 2100 | ³ MARTIN | 80c | RVUE | |

²⁰ From a fit to the total elastic cross section. 21 Isospins 0 and 1 not separated.

 ρ (2150), ϕ (2170)

| s -channel \overline{N} | N |
|-----------------------------|---|
| VALUE (MeV) | |
| Mo do not i | |

| VALUE (MeV) | | | TECN | COMMENT |
|-----------------|--------------------------|-------|----------|---------------------------------------------------------------------------------------|
| • • • We do not | use the following data | for a | verages, | fits, limits, etc. • • • |
| 2110 ± 35 | | | | 0.6–1.9 $p\overline{p} \rightarrow \omega \pi^0$, $\omega \eta \pi^0$, $\pi^+\pi^-$ |
| ~ 2190 | ⁵ CUTTS | 78B | CNTR | $0.97-3 \overline{p} p \rightarrow \overline{N} N$ |
| 2155 ± 15 | | | | $0.7-2.4 \overline{p}p \rightarrow \overline{p}p$ |
| 2193 ± 2 | ^{5,7} ALSPECTOR | 73 | CNTR | <u>P</u> ρ S channel |
| 2190 ± 10 | ⁸ ABRAMS | 70 | CNTR | S channel p N |

$\pi^- p \rightarrow \omega \pi^0 n$

DOCUMENT ID TECN COMMENT

The data in this block is included in the average printed for a previous datablock.

2155 ± 21 OUR AVERAGE

| 2140 ± 30 | ALDE | | | 38 $\pi^- p \rightarrow \omega \pi^0 n$ |
|---------------|------|-----|------|-----------------------------------------------|
| 2170 ± 30 | ALDE | 92c | GAM4 | $100 \ \pi^- \rho \rightarrow \omega \pi^0 n$ |

 1 Includes ATKINSON 85. 2 See however KLOET 96 who fit $\pi^+\,\pi^-$ only and find waves only up to J= 3 to be important but not significantly resonant.

31(JP) = 1(1-) from simultaneous analysis of $p\overline{p}\to\pi^-\pi^+$ and $\pi^0\pi^0$. 4 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

Slsospins 0 and 1 not separated.

 6 From a fit to the total elastic cross section. 7 Referred to as T or T region by ALSPECTOR 73.

 8 Seen as bump in I=1 state. See also COOPER 68. PEASLEE 75 confirm $\overline{\rho}\,\rho$ results of ABRAMS 70, no narrow structure.

ρ (2150) WIDTH

e+e- PRODUCED

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|---------------------------------------|--------------------|----------------|------------------------------------------------------------|
| 359± 40 OUR AVER | RAGE Includes | data from the | datablock that follows this one. |
| 350 ± 40 ± 50 | AUBERT | 07AU BABI | R 10.6 $e^+e^- \rightarrow f_1(1285) \pi^+\pi^-\gamma$ |
| 389± 79 | BIAGINI | 91 RVUE | $e^+ e^- ightarrow \pi^+ \pi^-$, $K^+ K^-$ |
| 410 ± 100 | ⁹ CLEGG | 90 RVUE | $e^+ e^- \rightarrow 3(\pi^+ \pi^-), 2(\pi^+ \pi^- \pi^0)$ |
| ● ● We do not use | the following da | ata for averag | es, fits, limits, etc. • • • |
| 310 ± 140 | AUBERT | 07AU BABF | R 10.6 $e^+e^- \rightarrow \eta' \pi^+\pi^-\gamma$ |

$\overline{p}p \rightarrow \pi\pi$

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------|----------------------------|----------|---------|------------------------------------------------|
| • • • We do not use the | following data for average | s, fits, | limits, | etc. • • • |
| ~ 296 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| ~ 40 | ¹⁰ OAKDEN | 94 | RVUE | $0.36-1.55 \overline{p} p \rightarrow \pi \pi$ |
| ~ 250 | ¹¹ MARTIN | 80B | RVUE | |
| ~ 200 | 11 MARTIN | 80c | RVUE | |

S-CHANNEL **₹**N

| O CHANGE ! | | | | | |
|-----------------|---------------------------|-----|-----------|-------------------------------------|-------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the following data | for | averages, | fits, limits, etc. | • • • |
| 230±50 | | | | | $_{\omega}\pi^{0}$, $_{\omega}\eta\pi^{0}$, $_{\pi}^{+}\pi^{-}$ |
| 135 ± 75 | ^{13,14} COUPLAND | 77 | CNTR | $0.7-2.4 \overline{p}p \rightarrow$ | $\overline{p}p$ |
| 98± 8 | 14 ALSPECTOR | 73 | CNTR | <u>p</u> p S channel | |
| . 85 | 15 ARRAMS | 70 | CMTR | S channel N | |

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------------------------|--------------|------|-----------|
| The state of the state of the state of | | | 4 1 1 1 1 |

The data in this block is included in the average printed for a previous datablock

| | 320±70 | ALDE | 95 | GAM2 38 $\pi^- p \rightarrow \omega$ | $\pi^{0} n$ |
|---|-----------------------|------------------------|-----------------|--------------------------------------|--------------------|
| • | • • • We do not use t | the following data for | averages, fits, | limits, etc. • • • | |
| , | × 300 | ALDE | 920 | GΔM4 100 π [−] n → | ω_{π} 0 n |

 9 includes ATKINSON 85. 10 See however KLOET 96 who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly resonant. 11 ((J^P) = 1(1 $^-$) from simultaneous analysis of $p\overline{p}\to\pi^-\pi^+$ and $\pi^0\pi^0$.

11 $I(J^P)=1(1^-)$ from simultaneous analysis of $pp\to \pi^-\pi^+$ and $\pi^+\pi^-$.
12 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, 31 ANISOVICH 02.
13 From a fit to the total elastic cross section.
14 Isospins 0 and 1 not separated.
15 Seen as bump in I=1 state. See also COOPER 68. PEASLEE 75 confirm $\overline{p}p$ results of ABRAMS 70, no narrow structure.

ρ (2150) DECAY MODES

| | Mode | Fraction $(\Gamma_{\dot{I}}/\Gamma)$ |
|----------------------------------|----------------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | $e^{+} e^{-}$ | |
| Γ_2 | $\pi^+\pi^-$ | seen |
| Γ_3 | K^+K^- | seen |
| Γ ₄ Γ ₅ | $3(\pi^+\pi^-)$ | seen |
| Γ_5 | $2(\pi^{+}\pi^{-}\pi^{0})$ | seen |
| Γ_6 | $\eta'\pi^+\pi^-$ | seen |
| Γ ₇ | $f_1(1285)\pi^+\pi^-$ | seen |
| Γ8 | $\omega \pi^0$ | seen |
| Γ9 | $\omega \pi^0 \eta$ | seen |
| Γ_{10} | р <u> </u> | |

$\rho(2150) \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$

| $\Gamma(f_1(1285)\pi^+\pi^-)$ | $)/\Gamma_{\text{total}} \times \Gamma(e^{+}e^{-})$ | e ⁻)/Γ _{total} | | $\Gamma_7/\Gamma \times \Gamma_1/\Gamma$ | |
|-------------------------------|-----------------------------------------------------|-------------------------------------|--------------------------|------------------------------------------|--|
| VALUE (units 10^{-7}) | DO CUMENT ID | TECN | COMMENT | | |
| 3.1 ± 0.6 ± 0.5 | ¹⁶ AUBERT | 07AU BABR | 10.6 $e^+e^ \rightarrow$ | $f_1(1285) \pi^+ \pi^- \gamma$ | |

 $^{16}\,\mbox{Calculated}$ by us from the reported value of cross section at the peak.

 17 Calculated by us from the reported value of cross section at the peak.

$\rho(2150)$ REFERENCES

| AUBERT ANISOVICH ANISOVICH ANISOVICH ANISOVICH KLOET ALDE HASAN OAKDEN ALDE BIAGINI CLEGG ATKINSON MARTIN MARTIN CUTTS COUPLAND PEASLEE ALSPECTOR | 07AU 02 01D 01E 00J 96 95 94 92C 91 90 85 80B 80C 78B 77 | PL 8542 8 PL 8508 6 PL 8513 281 PL 8491 47 PL 663 79 PL 663 79 PL 8334 215 PL 8343 215 PL 8343 215 PL 8734 731 PSPHY C54 553 NC 104A 363 PS 174 731 PSPHY C29 333 PB 176 355 PP 8169 216 PR D17 16 PL 71B 460 PL 57B 189 PL 71B 1460 PL 57B 189 | M.E. Biagini et al. A.B. Clegg, A. Donnachie M. Atkinson et al. B.R. Martin, D. Morgan A.D. Martin, M.R. Pennington D. Cutts et al. M. Coupland et al. D.C. Peaslee et al. J. Alspector et al. | LEG, SERP, KEK, L'ANL+) (FRAS, PRAG) (LANC, MCHS) (BONN, CERN, GLAS+) (LOUC, RHEL) JP (STON, WISC) (LOQM, RHEL) (CANB, BARI, BROW+) (CMTG, UPNJ) |
|---------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| | | | | |
| COOPER | 68 | PRL 20 1059 | W.A. Cooper et al. | (ANL) |

 $\phi(2170)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

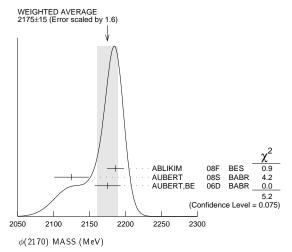
Observed by AUBERT, BE 06D in the initial-state radiation process $e^+\,e^- \to \ \phi\,f_0(980)\,\gamma.$

$\phi(2170)$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|-------------------|-----------------|--------|----------|----------------------------------------------------------------|
| 2175 ± 15 OUR | AVERAGE | Error includes | scale | factor | of 1.6. See the ideogram below. |
| $2186 \pm 10 \pm \ 6$ | 52 | ABLIKIM | 08F | BES | $J/\psi \rightarrow \eta \phi f_0(980)$ |
| $2125 \pm 22 \pm 10$ | 483 | AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow \phi \eta \gamma$ |
| $2175 \pm 10 \pm 15$ | 201 1 | AUBERT,BE | 06D | BABR | 10.6 $e^+e^- \rightarrow K^+K^-\pi\pi\gamma$ |
| • • • We do r | ot use the fo | llowing data fo | r aver | ages, fi | ts, limits, etc. • • • |
| $2079 \pm 13 + 79 \\ -28$ | 4.8k ² | SHEN | 09 | BELL | 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ |
| 2192 ± 14 | 116 ± 95 3 | AUBERT | | | 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ |
| 2169 ± 20 | 149 ± 36 3 | AUBERT | 07AK | BABR | $10.6 \ e^{+}e^{-} \rightarrow K^{+}K^{-}\pi^{0}\pi^{0}\gamma$ |

 $[\]frac{1}{2}$ From the $\phi f_0(980)$ component.

³ From the $K^+K^-f_0(980)$ component.



$\phi(2170)$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|---------|------------------------|-----|------|----------------------------------------------|
| 61±18 OUR | AVERAGE | | | | |
| $65 \pm 23 \pm 17$ | 52 | ABLIKIM | 08F | BES | $J/\psi \rightarrow \eta \phi f_0(980)$ |
| $61 \pm 50 \pm 13$ | 483 | AUBERT | 08s | BABR | 10.6 $e^+e^- \rightarrow \phi \eta \gamma$ |
| $58 \pm 16 \pm 20$ | 201 | ⁴ AUBERT,BE | 06D | BABR | 10.6 $e^+e^- \rightarrow K^+K^-\pi\pi\gamma$ |

² From a fit with two incoherent Breit-Wigners.

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $192 \pm 23 + 25 \\ -61$ 4.8k ⁵ SHEN 09 BELL 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ 71 ± 21 102 ± 27

$\phi(2170)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|----------------------------------------------------|------------------------------|
| Γ_1 | $e^+ e^-$ | seen |
| Γ_2 | $\phi\eta$ | |
| Γ_3 | $\phi\pi\pi$ | |
| Γ_4 | $\phi f_0(980)$ | seen |
| Γ_5 | $K^+ K^- \pi^+ \pi^-$ | |
| Γ_6 | $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^+ \pi^-$ | seen |
| Γ_7 | $\mathcal{K}^+ \mathcal{K}^- \pi^0 \pi^0$ | |
| Γ ₈ | $K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^0 \pi^0$ | seen |
| Г9 | $K^{*0}K^{\pm}\pi^{\mp}$ | not seen |
| Γ_{10} | $K^*(892)^0\overline{K}^*(892)^0$ | not seen |

$\phi(2170) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\phi\eta) \times \Gamma(e$ | $+e^-)/\Gamma_t$ | otal | | | $\Gamma_2\Gamma_1/\Gamma$ |
|------------------------------------------------------------------------------------------------------|------------------------|------------------------|----------------|----------------------------------------|------------------------------------|
| VALUE (eV) | E | VTS <u>DOCUM</u> | ENT ID | TECN COMME | NT |
| • • • We do no | t use the f | ollowing data for | averages, fits | , limits, etc. • • | • |
| $1.7\pm 0.7\pm 1.3$ | • | 483 AUBEF | RT 08s | BABR 10.6 e ⁺ | $e^- \rightarrow \phi \eta \gamma$ |
| $\Gamma(\phi f_0(980)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_4\Gamma_1/\Gamma_0(980)$ | | | | | |
| VALUE (eV) | EVTS | DOCUMENT ID | TECN | COMMENT | |
| $2.5 \pm 0.8 \pm 0.4$ | 201 | ⁷ AUBERT,BE | 06D BAB | R 10.6 e ⁺ e ⁻ - | $\rightarrow K^+K^-\pi\pi\gamma$ |
| 7 From the ϕ t | ₀ (980) cor | nponent. | | | |

$\phi(2170) \Gamma(i)\Gamma(e^+e^-)/\Gamma^2(total)$

| $\Gamma(\phi\pi\pi)/\Gamma_{\rm total} \times \Gamma(e^+$ | $e^-)/\Gamma_{ m total}$ | | | $\Gamma_3/\Gamma \times \Gamma_1/\Gamma$ |
|-----------------------------------------------------------|--------------------------|------------------|--------------------------|------------------------------------------|
| VALUE (units 10^{-7}) EVTS | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the fo | llowing data for ave | rages, fit | s, limits, etc. • | • • |
| $1.65 \pm 0.15 \pm 0.18$ 4.8k | ⁸ SHEN 09 | BELL | 10.6 $e^+e^ \rightarrow$ | $K^+K^-\pi^+\pi^-\gamma$ |
| 8 Multiplied by 3/2 to take (49.2 \pm 0.6)%. | ke into account the | $\phi\pi^0\pi^0$ | mode. Using B | $(\phi \to K^+ K^-) =$ |

φ(2170) BRANCHING RATIOS

| $\Gamma(K^+K^-f_0(980) \rightarrow K^+K^-\pi^+\pi^-)/\Gamma_{\text{total}}$ | | | | | |
|--------------------------------------------------------------------------------------|--------------|-----------|------------|----------------------------------------|---------------|
| VALUE | DO CUMENT ID | TECN | COMMEN | F | |
| seen | AUBERT | 07AK BABR | 10.6 e^+ | $e^- \rightarrow K^+ K^- \pi^+$ | $\pi^-\gamma$ |
| $\Gamma \big(K^+ K^- f_0 (980) \rightarrow$ | | | | | Гв/Г |
| VALUE | DO CUMENT ID | TECN | COMMEN | | |
| seen | AUBERT | 07AK BABR | 10.6 e+ | $e^- \rightarrow K^+ K^- \pi^0$ | $\pi^0\gamma$ |
| $\Gamma(K^{*0}K^{\pm}\pi^{\mp})/\Gamma_{\text{total}}$ | DO C | CUMENT ID | TECN | COMMENT | Γ9/Γ |
| not seen | | | | 10.6 GeV e ⁺ e ⁻ | |
| $\Gamma(K^*(892)^0\overline{K}^*(892)^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ | | | | | |
| VALUE | | ENT ID | TECN C | OMMENT | |
| not seen | ABLIK | IM 10c | BES2 J | $/\psi \rightarrow \eta K^+ \pi^- K^-$ | - π+ |

$\phi(2170)$ REFERENCES

| ABLIKIM | 10 C | PL B685 27 | M. Ablikim et al. | (BES II Collab.) |
|------------|------|----------------|-------------------|------------------|
| SHEN | 09 | PR D80 031101R | C.P. Shen et al. | (BELLE Collab.) |
| ABLIKIM | 08 F | PRL 100 102003 | M. Ablikim et al. | `(BES Collab.) |
| AUBERT | 085 | PR D77 092002 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 07AK | PR D76 012008 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT, BE | 06 D | PR D74 091103R | B. Aubert et al. | (BABAR Collab.) |

$f_0(2200)$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

OMITTED FROM SUMMARY TABLE Seen in K_0^S K_0^S (AUGUSTIN 88), K^+ K^- (ABLIKIM 05Q) and $\eta\eta$ (BINON 05) system. Not seen in $\varUpsilon(15)$ radiative decays (BARU 89).

f₀(2200) MASS

| VALUE (MeV) 2189±13 OUR AVERAGE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------------------|-----------------------|------|------|---------------------------------------------------|
| $2170\!\pm\!20\!+\!\frac{10}{-15}$ | ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| 2210±50 | ¹ BINON | 05 | GAMS | $33 \pi^- p \rightarrow \eta \eta n$ |
| 2197 ± 17 | ² AUGUSTIN | 88 | DM2 | $J/\psi \rightarrow \gamma K_S^0 K_S^0$ |
| | | | | |
| ~ 2122 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| ~ 2321 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| $^{1}\mathrm{First}$ solution, PWA is ambi $^{2}\mathrm{Cannot}$ determine spin to b | guous. e 0. | | | |

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|---------------------|---------|-------------|-----------------------------------------|
| 238±50 OUR AVERAGE | Error includes scal | e facto | or of 1.2. | |
| $220 \pm 60 + 40 \\ -45$ | ABLIKIM | 05 Q | BES2 | $\psi(2S) \rightarrow$ |
| 200 00 | ³ BINON | 0.5 | C 4 1 4 C | $\gamma \pi^{+} \pi^{-} K^{+} K^{-}$ |
| 380 ± 90 | | | | 33 $\pi^- p \rightarrow \eta \eta \eta$ |
| 201 ± 51 | 4 AUGUSTIN | 88 | DM2 | $J/\psi \rightarrow \gamma K_S^0 K_S^0$ |
| ullet $ullet$ We do not use the following | owing data for ave | rages, | fits, limit | ts, etc. • • • |
| ~ 273 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| ~ 223 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| 3 First solution DMA is am | higuous | | | |

f₀ (2200) WIDTH

³ First solution, PWA is ambiguous. ⁴ Cannot determine spin to be 0.

f₀(2200) REFERENCES

| ABLIKIM | 05 Q | PR D72 092002 | M. Ablikim et al. | (BES Collab.) |
|------------|------|--------------------|----------------------|-----------------------------------------|
| BINON | 05 | PAN 68 960 | | • • • • • • • • • • • • • • • • • • • • |
| | | Translated from YA | NF 68 998. | |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) |
| BARU | 89 | ZPHY C42 505 | S.E. Baru et al. | (NOVO) |
| AUGUS T IN | 88 | PRL 60 2238 | J.E. Augustin et al. | (DM2 Collab.) |
| | | | Ÿ | , , |

$f_J(2220)$

$$I^{G}(J^{PC}) = 0^{+}(2^{++} \text{ or } 4^{++})$$

OMITTED FROM SUMMARY TABLE

Needs confirmation. See our mini-review in the 2004 edition of this Review, PDG 04.

f_J(2220) MASS

| | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------------------|-------------------------|-----------------------------------|----------------|-----------------|-----------------------------------------------------------------------|
| 2231.1 ± 3.5 OUR | AVERAGE | | | | |
| $2235 \ \pm \ 4 \ \pm \ 6$ | 74 | BAI | 96B | BES | $e^+ e^- \rightarrow ~J/\psi \rightarrow ~\gamma \pi^+ \pi^-$ |
| 2230 $^{+}_{-}$ $^{6}_{7}$ ± 16 | 46 | BAI | 96B | BES | $e^+ e^- \rightarrow J/\psi \rightarrow$ |
| | | | | | $\gamma K^+ K^-$ |
| 2232 $^{+}_{-}$ $^{8}_{7}$ ± 15 | 23 | BAI | 96в | BES | $e^+ e^- \rightarrow J/\psi \rightarrow \gamma K_S^0 K_S^0$ |
| $2235 ~\pm~4~\pm~5$ | 32 | BAI | 96в | BES | $e^+ e^- \rightarrow J/\psi \rightarrow \gamma \rho \overline{\rho}$ |
| 2209 $^{+17}_{-15}$ ± 10 | | ASTON | 88F | LASS | 11 $K^-p \rightarrow K^+K^-\Lambda$ |
| $2230\ \pm 20$ | | BOLONKIN | 88 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| 2220 ± 10 | 41 | ¹ ALDE | | | 38-100 $\pi p \rightarrow n \eta \eta'$ |
| $2230 \pm 6 \pm 14$ | 93 | BALTRUSAIT. | 86D | MRK3 | $e^+e^- \rightarrow \gamma K^+K^-$ |
| $2232 ~\pm~ 7 ~\pm~ 7$ | 23 | BALTRUSAIT. | 86D | MRK3 | $e^+e^- \rightarrow \gamma K_S^0 K_S^0$ |
| ● ● We do not us | e the follo | wing data for av | erage | s, fits, lir | nits, etc. • • • |
| $2223.9 \pm \ 2.5$ | | ² VLADIMIRSK. | 08 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n + m \pi^0$ |
| 2246 ± 36 | | BAI | 98н | BES | $J/\psi \rightarrow \gamma \pi^0 \pi^0$ |
| $^{1}_{2}$ ALDE 86B uses $^{2}_{2}$ JPC $^{2}_{2}$ 2 $^{+}$ $^{+}$ | data from Systematio | both the GAMS uncertaities not | -2000 evali | and GA uated | MS-4000 detectors. |

| f _J (2220) WIDTH | | | | | | |
|------------------------------------|----------|--------------|-----|------|------------------------------------------------------------|--|
| VALUE (MeV) | CL% EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 23 + 8 OUR AV | ERAGE | | | | | |
| $^{19}_{-}{}^{+}_{11}^{13}{\pm}12$ | 74 | BAI | 96в | BES | $e^+e^- \rightarrow J/\psi \rightarrow \gamma \pi^+ \pi^-$ | |
| $20{}^{+}_{-}{}^{20}_{15}{\pm}17$ | 46 | BAI | 96в | BES | $e^+e^- \rightarrow J/\psi \rightarrow \gamma K^+K^-$ | |
| $20{}^{+}_{-}{}^{25}_{16}{\pm}14$ | 23 | BAI | 96в | BES | $e^+e^- \rightarrow J/\psi \rightarrow \gamma K_S^0 K_S^0$ | |

⁴ From the $\phi f_0(980)$ component.

⁵ From a fit with two incoherent Breit-Wigners.

 $^{^6\,\}mathrm{From}$ the $\mathrm{K}^+\,\mathrm{K}^-\,\mathrm{f}_0(980)$ component.

 $f_J(2220)$, $\eta(2225)$, $\rho_3(2250)$

| $15 ^{+}_{-}\ ^{12}_{9} \pm \ 9$ | 32 | BAI | 96в | BES | $e^+ e^- \rightarrow J/\psi \rightarrow \gamma p \overline{p}$ |
|------------------------------------|--------------------------------|--------------------------|---------|-----------|----------------------------------------------------------------|
| 60^{+107}_{-57} | | ASTON | 88F | LASS | 11 $K^- p \rightarrow K^+ K^- \Lambda$ |
| 80± 30 | | BOLONKIN | 88 | SPEC | 40 $\pi^- p \to K_S^0 K_S^0 n$ |
| $26^{+}_{-}\ ^{20}_{16}\!\pm\!17$ | 93 | BALTRUSAIT. | 86D | MRK3 | $e^+ e^- \rightarrow \gamma K^+ K^-$ |
| $18^{+}_{-}\ ^{23}_{15}\!\pm\! 10$ | 23 | BALTRUSAIT. | 86D | MRK3 | $e^+e^-\to~\gamma\kappa^0_S\kappa^0_S$ |
| • • • We do no | t use the following | data for averages | s, fits | limits, e | etc. • • • |
| 8.6 ± 2.5 | : | ³ VLADIMIRSK. | 08 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| <80 | 90 | ALDE | | GAM2 | $38 \pi^{-} p \rightarrow \eta' \eta n$ |
| $^{3}J^{PC}=2^{+}$ | ⁺ . Systematic unce | rtaities not evalu | ıated | | |

$f_J(2220)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|------------------------|------------------------------|
| Γ_1 | $\pi\pi$ | seen |
| Γ_2 | $\pi^+\pi^-$ | seen |
| Γ_3 | $K\overline{K}$ | seen |
| Γ_4 | $\rho \overline{\rho}$ | |
| Г ₅ Г ₆ | $\gamma\gamma$ | not seen |
| Γ_6 | $\eta \eta'$ (958) | seen |
| Γ_7 | $\phi \phi$ | not seen |
| Γ ₈ | $\eta\eta$ | not seen |

$f_J(2220) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| | | , , , , , , , , | • | • | |
|-----------------------------------------------|------------------------------|-----------------------|---------|-----------|-----------------------------------------------------------------------------------|
| $\Gamma(K\overline{K}) \times \Gamma(\gamma)$ | $\gamma)/\Gamma_{\rm total}$ | | | | $\Gamma_3\Gamma_5/\Gamma$ |
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| < 1.4 | 95 | ⁴ ACCIARRI | 01н | L3 | $\gamma \gamma \rightarrow K_S^0 K_S^0$, $E_{\text{cm}}^{ee} = 91$, 183–209 GeV |
| • • • We do not | use the followi | ng data for average | s, fits | , limits, | |
| < 5.6 | 95 | 4 GODANG | 97 | CLE2 | $\gamma \gamma \rightarrow K_S^0 K_S^0$ |
| < 86 | 95 | ⁴ ALBRECHT | 90g | ARG | $\gamma \gamma \rightarrow \kappa^+ \kappa^-$ |
| <1000 | 95 | ⁵ ALTHOFF | 85B | TASS | $\gamma \gamma$, $K\overline{K}\pi$ |
| $\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)$ |)/F _{total} | | | | Γ ₁ Γ ₅ /Γ |
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| < 2.5 | 95 | ALAM | 980 | CLE2 | $\gamma \gamma \rightarrow \pi^{+}\pi^{-}$ |

$f_J(2220) \Gamma(i)\Gamma(\rho \overline{\rho})/\Gamma^2(total)$

 4 Assuming $J^P=2^+$. 5 True for $J^P=0^+$ and $J^P=2^+$.

| $\Gamma(p\overline{p})/\Gamma_{\text{total}} \times \Gamma(p\overline{p})$ | (ππ)/Γ _{to} | tal | | | $\Gamma_4/\Gamma \times \Gamma_1/\Gamma$ |
|----------------------------------------------------------------------------|----------------------|---------------------|----------|-----------|------------------------------------------|
| VALUE (units 10 ⁻⁵) | CL% | DO CUMENT ID |) | TECN | COMMENT |
| <18 | 95 | ⁶ AMSLER | 01 | CBAR | 1.4-1.5 $p \overline{p} \to \pi^0 \pi^0$ |
| ● ● We do not use | the followi | ng data for averag | es, fits | , limits, | etc. • • • |
| <(11-42) | 99 | ⁷ HASAN | 96 | SPEC | $1.35-1.55 p \overline{p} \rightarrow$ |

| , | | | | $\pi^+\pi^-$ |
|----------------------------------------------------------------------------|------------------------------|--------------|------|------------------------------------------|
| $\Gamma(p\overline{p})/\Gamma_{\text{total}} \times \Gamma(p\overline{p})$ | $(\phi\phi)/\Gamma_{ m tot}$ | al | | $\Gamma_4/\Gamma \times \Gamma_7/\Gamma$ |
| VALUE (units 10^{-5}) | CL% | DO CUMENT ID | TECN | COMMENT |
| _ | | 0 | | |

| <0 | 95 | EVANGELIS | 98 | SPEC | 1.1-2.0 $pp \rightarrow \phi \phi$ | |
|-------------------------------------------------------------------------------------------------------------------|--------------------------------|---------------------|--------|--------|-------------------------------------------------------|----|
| $\Gamma(\overline{p})/\Gamma_{\text{total}} \times \Gamma$ | $(\eta\eta)/\Gamma_{\rm tota}$ | ıl | | | $\Gamma_4/\Gamma \times \Gamma_8$ | /г |
| VALUE (units 10^{-5}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <4 | 95 | ⁶ AMSLER | 01 | CBAR | $1.41.5 \ \rho \overline{\rho} \rightarrow \eta \eta$ | |
| 6 For $J^P=2^+$ in | the mass rai | nge 2222-2240 Me | eV and | the to | al width between 10 a | nd |
| 20 MeV. $^{7}{\rm For}~J^{P}=2^{+}$ and $J^{P}=4^{+}$ in the mass range 2220–2245 MeV and the total width of | | | | | | |
| 15 MeV. 8 For $^{JP}=^{2+}$, the | | | | | | |

f_J(2220) BRANCHING RATIOS

| A <i>LUE</i> (units 10 ⁻⁴) | CL% | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------|--------------|--------------------------|---------|-----------|------------------------------------------------------------|
| ullet • We do not | use the foll | owing data for avera | ages, f | its, limi | ts, etc. • • • |
| not seen | | ⁹ AUBERT | | | |
| not seen | | | | | $B^+ \rightarrow \overline{p} p K^+$ |
| <3.0 | 95 | ¹⁰ EVA NGELIS | 97 | SPEC | $1.96-2.40 \ \overline{p}p \rightarrow K_S^0 K_S^0$ |
| <1.1 | 99.7 | ¹¹ BARNES | 93 | SPEC | 1.3-1.57 $\overline{p}p \rightarrow \kappa_S^0 \kappa_S^0$ |
| <2.6 | 99.7 | ¹¹ BARDIN | 87 | CNTR | 1.3-1.5 $\overline{p}p \rightarrow K^+K^-$ |
| 3.6 | 99.7 | ¹¹ SCULLI | 87 | CNTR | $1.29-1.55 \overline{p}p \rightarrow K^+ K^-$ |

11 Assuming $\Gamma=30$ -35 MeV, $J^P=2^+$ and $B(f_J(2220)\to K\overline{K})=100\%$.

| $\Gamma(\pi\pi)/\Gamma(K\overline{K})$ | | | Γ_1/Γ_3 |
|-----------------------------------------------|--------------|---------|---------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 1.0 ± 0.5 | BAI 9 | 96B BES | $e^+e^- ightarrow \underline{J}/\psi ightarrow$ |
| | | | $\gamma2\pi$, K \overline{K} |
| $\Gamma(p\overline{p})/\Gamma(K\overline{K})$ | | | Γ_4/Γ_3 |
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 0.17±0.09 | BAI | 96в BES | $e^+e^- \rightarrow J/\psi \rightarrow$ |
| | | | $\gamma \rho \overline{\rho}$, K \overline{K} |

$f_J(2220)$ REFERENCES

| VLA DIMIRS K | 08 | PAN 71 2129 | V.V. Vladimirsky et al. | (ITEP) |
|--------------|-------|---------------------|-------------------------|----------------------------|
| | | Translated from YAF | 71 2166. | |
| AUBERT | 07 AV | | B. Aubert et al. | (BABAR Collab.) |
| WANG | 05 A | PL B617 141 | MZ. Wang et al. | (BELLE Collab.) |
| PDG | 04 | PL B592 1 | S. Eidelman et al. | (PDG Collab.) |
| ACCIARRI | 01H | PL B501 173 | M. Acciarri et al. | (L3 Collab.) |
| AMSLER | 01 | PL B520 175 | C. Amsler et al. | (Crystal Barrel Collab.) |
| ALAM | 98 C | PRL 81 3328 | M.S. Alam et al. | (CLEO Collab.) |
| BAI | 98 H | PRL 81 1179 | J.Z. Bai et al. | `(BES Collab.) |
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| GODANG | 97 | PRL 79 3829 | R. Godang et al. | (CLEO Collab.) |
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| HASAN | 96 | PL B388 376 | A. Hasan, D.V. Bugg | (BŘUN, LOQMÍ |
| BARNES | 93 | PL B309 469 | P.D. Barnes et al. | (PS 185 Collab.) |
| ALBRECHT | 90 G | ZPHY C48 183 | H. Albrecht et al. | (ÀRGUS Collab.) |
| ASTON | 88 F | PL B215 199 | D. Aston et al. | (SLAC, NAGO, CINC, INUS)JP |
| BOLONKIN | 88 | NP B309 426 | B.V. Bolonkin et al. | (ITEP, SERP) |
| ALDE | 87 C | SJNP 45 255 | D. Alde et al. | , |
| | | Translated from YAF | 45 405. | |
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| BALTRUSAIT | 86D | PRL 56 107 | R.M. Baltrusaitis | (CIT, UCSC, ILL, SLAC+) |
| ALTHORE | 85 B | 7PHY C29 189 | M Althoff et al | (TASSO Collab) |

- OTHER RELATED PAPERS -

DEL-AMO-SA... 100 PRL 105 172001 P. del Amo Sanchez et al. (BABAR Collab.)



$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

OMITTED FROM SUMMARY TABLE Seen in $J/\psi \to \gamma \phi \phi$. Possibly seen in $B \to \phi \phi K$ by LEES 11A.

η (2225) MASS

| VALUE (MeV) | EVTS | DO CUMENT II | פ | TECN | COMMENT |
|-----------------------------------------------------------|----------------|------------------|-----|------|-------------------------------------------------|
| 2226±16 OUR A | VERAGE | | | | |
| $\begin{array}{l} 2240 + 30 + 30 \\ -20 - 20 \end{array}$ | 196 ± 19 | ABLIKIM | 081 | BES | $J/\psi \to ~\gamma K^+ K^- K^0_S K^0_L$ |
| $2230 \pm 25 \pm 15$ | | BAI | 90в | MRK3 | $J/\psi \rightarrow \gamma K^+ K^- K^+ K^-$ |
| $2214 \pm 20 \pm 13$ | | BAI | 90в | MRK3 | $J/\psi \rightarrow \gamma K^+ K^- K_S^0 K_I^0$ |
| ● ● ● We do not | use the follow | ing data for ave | | | |
| ~ 2220 | | BISELLO | 86в | DM2 | $J/\psi \rightarrow \gamma K^+ K^- K^+ K^-$ |

η (2225) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------|-----------------|------------------|---------|-------------|---------------------------------------------|
| 185 + 70 OUR A | VERAGE | | | | |
| $190 \pm 30 ^{+60}_{-40}$ | 196 ± 19 | ABLIKIM | 081 | BES | $J/\psi \to ~\gamma K^+ K^- K^0_S K^0_L$ |
| $150 + {300 \atop -} \pm 60 \pm 60$ | | BAI | 90в | MRK3 | $J/\psi \rightarrow \gamma K^+ K^- K^+ K^-$ |
| ullet $ullet$ We do not | use the followi | ng data for aver | ages, 1 | fits, limit | s, etc. • • • |
| ~ 80 | | BISELLO | 86в | DM2 | $J/\psi \rightarrow \gamma K^+ K^- K^+ K^-$ |

$\eta(2225)$ REFERENCES

| LEES ABLIKIM | 11 A 08 I | PR D84 012001 PL B662 330 | J.P. Lees <i>et al.</i> M. Ablikim <i>et al.</i> | (BABAR Collab.) (BES Collab.) |
|-----------------|--------------|------------------------------|-----------------------------------------------------|----------------------------------|
| BAI | 90 B | PRL 65 1309 | Z. Bai et al. | (Mark III Collab.) |
| BISELLO | 86B | PL B179 294 | D. Bisello et al. | ` (DM2 Collab.) |

$\rho_3(2250)$

$$I^{G}(J^{PC}) = 1^{+}(3^{-})$$

OMITTED FROM SUMMARY TABLE

Contains results mostly from formation experiments. For further production experiments see the Further States entry. See also $\rho(2150)$, $f_2(2150)$, $f_4(2300)$, $\rho_5(2350)$.

ho_3 (2250) MASS

| $\overline{p} p \rightarrow \pi \pi \text{ or } KK$ VALUE (MeV) | | I | TECN CH | GCOMMENT |
|-----------------------------------------------------------------|-------------------------------|----------|----------------|----------------------------------------------|
| • • • We do not use | the following data for averag | es, fits | , limits, etc. | • • • |
| ~ 2232 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| ~ 2090 | ¹ oakden | 94 | RVUE | 0.36-1.55 $\overline{p}p \rightarrow$ |
| ~ 2250 | ² MARTIN | 80в | RVUE | $\pi\pi$ |
| ~ 2300 | ² MARTIN | 80c | RVUE | |
| ~ 2140 | ³ CARTER | 78B | CNTR 0 | $0.7-2.4 \overline{p}p \rightarrow$ |
| ~ 2150 | ⁴ CARTER | 77 | CNTR 0 | K^-K^+ 0.7-2.4 $\overline{p}p \rightarrow$ |

 $^{^1\,\}mathrm{See}$ however KLOET 96 who fit $\pi^+\,\pi^-$ only and find waves only up to $J\,=\,3$ to be important but not significantly resonant.

SCHANNEL WA

| VALUE (MeV) | DO CUMENT ID | | TECN CHG | COMMENT |
|------------------------------------------------------------|-------------------------------------------------|---------|----------------|----------------------------------------------------------------------|
| ullet $ullet$ $ullet$ We do not use the | following data for average | s, fits | , limits, etc. | • • • |
| 2260 ± 20 | ⁵ A NISOVICH | 02 | SPEC | $0.6-1.9 p\overline{p} \rightarrow \omega \pi^0, \omega \eta \pi^0,$ |
| ~ 2190 | ⁶ CUTTS | 78B | CNTR | $0.9\frac{\pi^+ \pi^-}{\overline{N} N} \rightarrow$ |
| 2155 ± 15 | ^{6,7} COUPLAND | 77 | CNTR 0 | $0.7-2.4 \overline{p}p \rightarrow \overline{p}p$ |
| $\begin{array}{ccc} 2193\pm & 2 \\ 2190\pm 10 \end{array}$ | ^{6,8} ALSPECTOR ⁹ ABRAMS | | CNTR CNTR | pp pp S channel S channel pN |

⁵ From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E,

$\pi^- p \rightarrow \eta \pi \pi$

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------|-----------------------------------------|------------|---------------------------------------------|
| • • • We do not ι | se the following data for averages, fit | s, limits, | etc. • • • |
| $2290 \pm 20 \pm 30$ | AMELIN 00 | VES | 37 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |

ho_3 (2250) WIDTH

$\overline{p}p \rightarrow \pi\pi \text{ or } K\overline{K}$

| VALUE (MeV) | DO CUMENT ID | | TECN CHG | COMMENT |
|-------------------------|----------------------------|---------|------------------|-------------------------------------------------|
| • • • We do not use the | following data for average | s, fits | , limits, etc. • | • • |
| ~ 220 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| ~ 60 | ¹⁰ OAKDEN | 94 | RVUE | 0.36–1.55 $\overline{p}p \rightarrow$ |
| ~ 250 | ¹¹ MARTIN | 80в | RVUE | $\pi\pi$ |
| ~ 200 | ¹¹ MARTIN | 80c | RVUE | |
| ~ 150 | ¹² CARTER | 78B | CNTR 0 | $0.7-2.4 \overline{p}p \rightarrow$ |
| ~ 200 | ¹³ CARTER | 77 | CNTR 0 | K^-K^+ 0.7-2.4 $\overline{p}p \rightarrow$ |

 $^{^{10}}$ See however KLOET 96 who fit $\pi^+\pi^-$ only and find waves only up to J=3 to be important but not significantly resonant.

S-CHANNEL NN

| VALUE (MeV) | | | TECN CHG | COMMENT |
|--------------------|-------------------------------------------------|---------|------------------|--------------------------------------------------------------------------------------------------------|
| • • • We do not us | e the following data for average: | s, fits | , limits, etc. • | • • |
| 160 ± 25 | ¹⁴ A NISOVICH | 02 | SPEC | $\begin{array}{c} 0.61.9~\rho\overline{\rho} \rightarrow \\ \omega\pi^0,~\omega\eta\pi^0, \end{array}$ |
| 135 ± 75 | 15,16 COUPLAND | 77 | CNTR 0 | $ \begin{array}{c} \pi^{+} \pi^{-} \\ 0.7-2.4 \overline{p}p \rightarrow \\ \overline{p}p \end{array} $ |
| 98± 8 ∼ 85 | ¹⁶ ALSPECTOR ¹⁷ ABRAMS | | CNTR CNTR | pp S channel S channel pN |

¹⁴ From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

15 From a fit to the total elastic cross section.

16 Isospins 0 and 1 not separated.

17 Seen as bump in l = 1 state. See also COOPER 68. PEASLEE 75 confirm $\overline{p}p$ results of ANISOVICH 02.

$\pi^- p \rightarrow \eta \pi \pi$

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT | |
|--------------------------------|------------------------|-----------------|--------------------------|-------------------------|
| • • • We do not use the follow | wing data for averages | s, fits, limits | , etc. • • • | |
| $230 \pm 50 \pm 80$ | AMELIN | 00 VES | 37 $\pi^- p \rightarrow$ | $\eta \pi^+ \pi^- n$ |

ρ_3 (2250) REFERENCES

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| CUTTS | 78 B | PR D17 16 | D. Cutts et al. | (STON, WISC) |
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| COOPER | 68 | PRL 20 1059 | W.A. Cooper et al. | (ANL) |
| | | | | |

$f_2(2300)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

f2(2300) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|--------------|-----|------|------------------------------------------|
| 2297 ± 28 | 1 ETKIN | 88 | MPS | $22 \pi^- p \rightarrow \phi \phi n$ |
| • • • We do not use the fo | | | | |
| 2270 ± 12 | VLADIMIRSK. | .06 | SPEC | 40 $\pi^- p \rightarrow K_S^0 K_S^0 n$ |
| $2327 \pm 9 \pm 6$ | ABE | 04 | BELL | 10.6 $e^+e^- \rightarrow e^+e^- K^+ K^-$ |
| 2231 ± 10 | воотн | 86 | OMEG | 85 π^- Be $ ightarrow$ 2ϕ Be |
| $2220 + 90 \\ -20$ | LINDENBAUM | 84 | RVUE | |
| 2320 ± 40 | ETKIN | 82 | MPS | $22 \pi^- p \rightarrow 2\phi n$ |

 $^{^{1}}$ Includes data of ETKIN 85. The percentage of the resonance going into $\phi\phi$ 2 $^{+}$ + S_{2} , $\it D_{\rm 2},$ and $\it D_{\rm 0}$ is 6 $^{+15}_{-}$, 25 $^{+18}_{-14}$, and 69 $^{+16}_{-27}$, respectively.

f2(2300) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|--------------------------|------|-------------|------------------------------------------|
| 149±41 | ² ETKIN | 88 | MPS | $22 \pi^- p \rightarrow \phi \phi n$ |
| • • • We do not use | e the following data for | aver | ages, fits, | limits, etc. • • • |
| $90\!\pm\!29$ | VLADIMIRSK | 06 | SPEC | 40 $\pi^- p \to K_S^0 K_S^0 n$ |
| $275 \pm 36 \pm 20$ | ABE | 04 | BELL | 10.6 $e^+e^- \rightarrow e^+e^- K^+ K^-$ |
| 133 ± 50 | | | | 85 π^- Be $\rightarrow 2\phi$ Be |
| 200 ± 50 | LINDENBAUN | A 84 | RVUE | |
| 220 ± 70 | ETKIN | 82 | MPS | $22 \pi^- p \rightarrow 2\phi n$ |
| ² Includes data of | ETKIN 85. | | | |

f₂(2300) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------|------------------------------|
| Γ ₁ | φφ Κ <i>K</i> | seen seen |
| Γ3 | $\gamma\gamma$ | seen |

$f_2(2300) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(K\overline{K}) \times \Gamma(\gamma)$ | $\gamma)/\Gamma_{total}$ | | | | $\Gamma_2\Gamma_3/\Gamma$ |
|-----------------------------------------------|---------------------------|---------|------------|--------------------------------------|---------------------------|
| VALUE (eV) | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the following data fo | r avera | ges, fits, | , limits, etc. 🔸 🔹 | • |
| $44 \pm 6 \pm 12$ | ³ ABE | 04 | BELL | 10.6 e ⁺ e ⁻ - | e+ e- K+ K- |
| ³ Assuming spin | 2. | | | | |

f2(2300) REFERENCES

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| ABE | 04 | Translated from EPJ C32 323 | YAF 69 515. K. Abe et al. | (BELLE Collab.) |
| ETKIN | 88 | PL B201 568 | A. Etkin et al. | (BNL, CUNY) |
| BOOTH | 86 | NP B273 677 | P.S.L. Booth et al. | (LIVP, GLAS, CERN) |
| ETKIN | 85 | PL 165B 217 | A. Etkin <i>et al</i> . | (BNL, CUNY) |
| LINDENBAUM | 84 | CNPP 13 285 | S.J. Lindenbaum | ` (CUNY) |
| ETKIN | 82 | PRL 49 1620 | A. Etkin et al. | (BNL, CUNY) |

$f_4(2300)$

$$I^{G}(J^{PC}) = 0^{+}(4^{++})$$

OMITTED FROM SUMMARY TABLE

This entry was previously called $U_0(2350)$. Contains results mostly from formation experiments. For further production experiments see the Further States entry. See also $\rho(2150),\ f_2(2150),\ \rho_3(2250),$ ρ_5 (2350).

Important but not significantly resonant. $2I(J^P)=1(3^-)$ from simultaneous analysis of $p\overline{p}\to\pi^-\pi^+$ and $\pi^0\pi^0$. 3I=0,1. $J^P=3^-$ from Barrelet-zero analysis.

 $^{^4}I(J^P)=1(3^-)$ from amplitude analysis.

and ANISOVICH 02. 6 Isospins 0 and 1 not separated.

From a fit to the total elastic cross section.

Referred to as T or T region by ALSPECTOR 73.

⁹ Seen as bump in I=1 state. See also COOPER 68. PEASLEE 75 confirm $\overline{p}p$ results of ABRAMS 70, no narrow structure.

important but not significantly resonant.
11 $I(J^P)=1(3^-)$ from simultaneous analysis of $p\overline{p}\to\pi^-\pi^+$ and $\pi^0\pi^0$.
12 I=0,1. $J^P=3^-$ from Barrelet-zero analysis.
13 $I(J^P)=1(3^-)$ from amplitude analysis.

of ABRAMS 70, no narrow structure.

 $f_4(2300), f_0(2330), f_2(2340)$

| f4 (| (2300) |) M | ASS |
|------|--------|-----|-----|
|------|--------|-----|-----|

| VALUE (MeV) | DO CUMENT ID | l . | TECN | COMMENT |
|-----------------------------------------------------------------------------------------|---------------------|-----------------------------|--------------|------------------------------------------------|
| ullet $ullet$ We do not use the follow | ing data for averag | es, fits | , limits, | etc. • • • |
| ~ 2314 | HASAN | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| ~ 2300 | ¹ MARTIN | 80B | RVUE | |
| ~ 2300 | ¹ MARTIN | 80c | RVUE | |
| ~ 2340 | ² CARTER | | | $0.7-2.4 \overline{p}p \rightarrow K^-K^+$ |
| ~ 2330 | DULUDE | 78B | OSPK | $1-2 \overline{p} p \rightarrow \pi^0 \pi^0$ |
| ~ 2310 | ³ CARTER | 77 | CNTR | $0.7-2.4 \ \overline{p} p \rightarrow \pi \pi$ |
| $1I(J^P)=0(4^+)$ from simult $2I(J^P)=0(4^+)$ from Barrele $3I(J^P)=0(4^+)$ from amplit | et-zero analysis. | $p\overline{p} \rightarrow$ | $\pi^-\pi^+$ | and $\pi^0 \pi^0$. |

S-CHANNEL $\overline{p}p$ or $\overline{N}N$

| VALUE (MeV) | DO CUMENT ID | | TECN COMMENT | |
|------------------------|-------------------------------|--------|--------------------------------------------------------|---|
| • • • We do not use th | e following data for averages | , fits | , limits, etc. • • • | |
| 2283 ± 17 | ⁴ A NISOVICH | | | |
| ~ 2380 | | | CNTR $0.97-3 \overline{p}p \rightarrow \overline{N}N$ | |
| 2345 ± 15 | | | CNTR $0.7-2.4 \overline{p}p \rightarrow \overline{p}p$ | |
| 2359± 2 | ^{5,7} ALSPECTOR | 73 | CNTR p p S channel | |
| 2375 ± 10 | ABRAMS | 70 | CNTR Schannel NN | |
| 4 | | | 0 | ^ |

- 4 From the combined analysis of ANISOVICH 99c and ANISOVICH 99F on $\overline{p}\,p \to ~\eta \pi^0 ~\pi^0$, $\pi^0 \pi^0$, $\eta \eta$, $\eta \eta'$, $\pi^+ \pi^-$. 5 Isospins 0 and 1 not separated.

- From a fit to the total elastic cross section.
 Referred to as U or U region by ALSPECTOR 73.

$\pi^- p \rightarrow \eta \pi \pi n$

| VALUE (MeV) | DO CUMENT ID | TECN COMMENT |
|-----------------------------|--------------------------------|-------------------------------------------------------|
| • • • We do not use the fol | lowing data for averages, fits | , limits, etc. • • • |
| $2330 \pm 20 \pm 40$ | AMELIN 00 | VES 37 $\pi^- \rho \rightarrow \eta \pi^+ \pi^- \eta$ |

| pp CENTRAL PRODUCTI | ON | | |
|------------------------|----------------------|-----------------------------------------------|---|
| VALUE (MeV) | DO CUMENT ID | COMMENT | |
| 2320 ± 60 OUR ESTIMATE | · | | - |
| | ing data for average | es, fits, limits, etc. • • • | |
| 2332 ± 15 | BARBERIS | 00F 450 $pp ightarrow p_f \omega \omega p_S$ | |

f4(2300) WIDTH

$\overline{p}p \rightarrow \pi\pi \text{ or } \overline{K}K$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------------------------------|--------------------------------------------------------------|----------------------------|--------------|-------------------------------------|----------|
| • • • We do not use the | following data for average | s, fits, | limits, | etc. • • • | |
| ~ 278 | HASAN | | | $\overline{p}p \rightarrow \pi\pi$ | |
| ~ 200 | | | RVUE | | |
| ~ 150 | ⁹ CARTER | 78B | CNTR | $0.7-2.4 \overline{p}p \rightarrow$ | K^-K^+ |
| ~ 210 | ¹⁰ CARTER | 77 | CNTR | 0.7-2.4 $\overline{p}p \rightarrow$ | $\pi\pi$ |
| ${8 I(J^P) = 0(4^+) \text{ from} \atop 9 I(J^P) = 0(4^+) \text{ from}}$ | simultaneous analysis of <i>p</i> Barrelet-zero analysis. | $\overline{p} \rightarrow$ | $\pi^-\pi^+$ | and $\pi^0\pi^0$. | |
| $10I(J^P) = 0(4^+)$ from | | | | | |

S-CHANNEL $\overline{p}p$ or $\overline{N}N$

| VALUE (MeV) | | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|--------------------|---------------------------|---------|-----------|--------------------------------------------------------------|
| • • • We do no | t use the followin | g data for average | s, fits | , limits, | etc. • • • |
| $310\pm\ 25$ | | 11 A NISOVICH | 001 | SPEC | |
| $135 {}^{+ 15 0}_{- 65}$ | 12 | ^{,13} COUPLAND | 77 | CNTR | $0.72.4~\overline{p}\rho \to ~\overline{p}\rho$ |
| $165 {}^{+}_{-} {}^{18}_{8}$ | | $^{13}\mathrm{ALSPECTOR}$ | 73 | CNTR | <u></u> ρρ S channel |
| ~ 190 | | ABRAMS | 70 | CNTR | S channel $\overline{N}N$ |
| 11 From the cor | mbined analysis of | ANISOVICH 99c | and A | NISOVI | CH 99F on $\overline{ ho} ho ightarrow \eta \pi^0 \pi^0$ |

- π^0 , π^0 , $\eta\eta$, $\eta\eta'$, $\pi^+\pi^-$. 12 From a fit to the total elastic cross section. 13 Isospins 0 and 1 not separated.

$\pi^- p \rightarrow \eta \pi \pi n$

| VALUE (MeV) | DOCUMENT ID | TECN COMMENT |
|-------------------------------|--------------------------------|-------------------------------------------------|
| • • • We do not use the follo | owing data for averages, fits, | limits, etc. • • |
| $235 \pm 50 \pm 40$ | AMELIN 00 | VES 37 $\pi^- p \rightarrow \eta \pi^+ \pi^- n$ |

| pp CENTRAL PRODUCTION | N | |
|-----------------------------------|-------------------------|--------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | COMMENT |
| 250±80 OUR ESTIMATE | | |
| • • • We do not use the following | data for averages, fits | , limits, etc. • • • |
| 260 ± 57 | BARBERIS 00F | 450 $pp \rightarrow p_f \omega \omega p_S$ |

f4(2300) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------|------------------------------|
| Γ_1 | $\rho\rho$ | seen |
| Γ_2 | $\omega \omega$ | seen |
| Γ_3 | $\eta\pi\pi$ | seen |
| Γ_4 | $\pi\pi$ | seen |
| Γ_5 | $K\overline{K}$ | seen |
| Γ ₆ | NN | seen |

f4(2300) BRANCHING RATIOS

| $\Gamma(ho ho)/\Gamma(\omega\omega)$ | | | Γ_1/Γ_2 |
|---------------------------------------|----------------------------|--------------------------------------------|---------------------|
| VALUE | DOCUMENT ID | COMMENT | |
| | ng data for averages, fits | , limits, etc. • • • | |
| 2.8 ± 0.5 | BARBERIS 00F | 450 $pp \rightarrow p_f \omega \omega p_S$ | |

f4 (2300) REFERENCES

| AMELIN ANISOVICH | 00 00 J | NP A668 83 PL B491 47 | D. Amelin et al. A.V. Anisovich et al. | (VES Collab.) |
|-----------------------|--------------|----------------------------|---------------------------------------------|---------------------|
| BARBERIS ANISOVICH | 00 F 99 C | PL B484 198 PL B452 173 | D. Barberis et al. A.V. Anisovich et al. | (WA 102 Collab.) |
| ANISOVICH | 99F | NP A651 253 | A.V. Anisovich et al. | |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) |
| MARTIN | 80 B | NP B176 355 | B.R. Martin, D. Morgan | (LOUC, RHEL) JP |
| MARTIN | 80 C | NP B169 216 | A.D. Martin, M.R. Pennington | (DURH) JP |
| CARTER | 78 B | NP B141 467 | A.A. Carter | (LOQM) |
| CUTTS | 78 B | PR D17 16 | D. Cutts et al. | (STON, WISC) |
| DULUDE | 78 B | PL 79B 335 | R.S. Dulude et al. | (BROW, MIT, BARI)JP |
| CARTER | 77 | PL 67B 117 | A.A. Carter et al. | ` (LOQM, RHEL)JP |
| COUPLAND | 77 | PL 71B 460 | M. Coupland et al. | (LOQM, RHEL) |
| ALS PECT OR | 73 | PRL 30 511 | J. Alspector et al. | (RUTG, UPNJ) |
| ABRAMS | 70 | PR D1 1917 | R.J. Abrams et al. | ` (BNL) |

 $f_0(2330)$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

OMITTED FROM SUMMARY TABLE

f₀(2330) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|-----------------------------------------------------------------|----------|-----------|--------------------------------------------------|
| • • • We do not use the folio | wing data for average | es, fits | , limits, | etc. • • • |
| 2314 ± 25 | $^{ m 1}$ BUGG | 04A | RVUE | |
| 2337±14 | ANISOVICH | 001 | SPEC | $2.0 \overline{p}p \rightarrow \pi\pi, \eta\eta$ |
| ~ 2321 | HA SA N | 94 | RVUE | $\overline{p}p \rightarrow \pi\pi$ |
| 1 Partial wave analysis of th | e data on $n\overline{n} \rightarrow \overline{\Lambda}\Lambda$ | from | RARNE | 5.00 |

f₀ (2330) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|--------------------------------------------------------------|----------|---------|--------------------------------------------------|
| • • • We do not use the | following data for average | s, fits, | limits, | etc. • • • |
| 144 ± 20 | ² BUGG | 04A | RVUE | |
| 217 ± 33 | ANISOVICH | 00J | SPEC | $2.0 \overline{p}p \rightarrow \pi\pi, \eta\eta$ |
| ~ 223 | HA SA N | 94 | RVUE | $\overline{p}p \rightarrow \pi \pi$ |
| ² Partial wave analysis | of the data on $p\overline{p} \to \overline{\Lambda}\Lambda$ | from E | BARNES | 5 00. |

fo(2330) REFERENCES

| BUGG | 04 A | EPJ C36 161 | D.V. Bugg | |
|-----------|------|---------------|-----------------------|--------|
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| BARNES | 00 | PR C62 055203 | P.D. Barnes et al. | |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | (LOQM) |

 $f_2(2340)$

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

f2(2340) MASS

| VALUE (MeV) | EVTS | DO CUMENT | ID | TECN | COMMENT |
|-------------------------------------|------------------|-------------------|------------|-----------|-------------------------------------------------|
| 2339±55 | | $^{ m 1}$ ETKIN | 88 | MPS | 22 $\pi^- p \rightarrow \phi \phi n$ |
| ● ● We do not u | se the following | g data for avera | iges, fits | , limits, | etc. • • • |
| 2350 ± 7 | 80k | ² UMAN | 06 | E835 | $5.2 \overline{p}p \rightarrow \eta \eta \pi^0$ |
| 2392 ± 10 | | воотн | 86 | OMEG | 85 π^- Be $ ightarrow~2\phi$ Be |
| 2360 ± 20 | | LINDENBA | UM 84 | RVUE | |
| 4 | | | | | |

 1 Includes data of ETKIN 85. The percentage of the resonance going into $\phi\phi$ 2 $^+$ + S_2 , $_D^2$, and $_D0$ is 37 \pm 19, 4 $_-^{+12}$, and 59 $_-^{+21}$, respectively. ² Statistical error only.

f2(2340) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|------|--------------|----|------|--------------------------------------|
| 319 + 81 | | 3 ETKIN | 88 | MPS | $22 \pi^- p \rightarrow \phi \phi n$ |

| • • • We do not u | se the followin | g data for avera | ges, fits | , limits, | etc. • • • |
|--------------------------|-----------------|--------------------|-----------|-----------|--------------------------------------------------|
| 218± 16 | 80k | ⁴ UMA N | 06 | E835 | $5.2 \overline{p} p \rightarrow \eta \eta \pi^0$ |
| 198± 50 | | воотн | 86 | OMEG | 85 $\pi^-\mathrm{Be} \to 2\phi\mathrm{Be}$ |
| $150 {}^{+ 150}_{- 50}$ | | LINDENBA | JM 84 | RVUE | |
| 2 | | | | | |

Includes data of ETKIN 85.
 Statistical error only.

f2(2340) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|---------------------------|------------------------------|
| Γ ₁ Γ ₂ | $\phi \phi \ \eta \eta$ | seen seen |

5 (2340) BRANCHING RATIOS

| $\Gamma(\eta\eta)/\Gamma_{ m total}$ | | | | | Γ2/Γ |
|--------------------------------------|--------------|----|------|----------------------------------------------|---------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | UMA N | 06 | E835 | $5.2 \ \overline{p} p \rightarrow \eta \eta$ | π^0 |

f₂(2340) REFERENCES

| UMAN | 06 | PR D73 052009 | I. Uman et al. | (FNAL E835) |
|------------|----|---------------|---------------------|--------------------|
| ETKIN | 88 | PL B201 568 | A. Etkin et al. | (BNL, CUNY) |
| BOOTH | 86 | NP B273 677 | P.S.L. Booth et al. | (LIVP, GLAS, CERN) |
| ETKIN | 85 | PL 165B 217 | A. Etkin et al. | ` (BNL, CUNY) |
| LINDENBAUM | 84 | CNPP 13 285 | S.J. Lindenbaum | ` (CUNY) |

$o_5(2350)$

$$I^G(J^{PC}) = 1^+(5^{--})$$

OMITTED FROM SUMMARY TABLE

This entry was previously called $U_1(2400)$. See also ho(2150), $f_2(2150), \, \rho_3(2250), \, f_4(2300).$

ho_5 (2350) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMN | 1ENT |
|-----------------------------------------|---------------------------------------------------------------------|----------|--------------|---------------|---------------------------------------------------------------------------------------|
| 2330 ± 35 | ALDE | 95 | GAM2 | 38 π | $- p \rightarrow \omega \pi^0 n$ |
| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
| ● ● We do not use t | he following data for average | s, fits | limits, | etc. • | • • |
| ~ 2303 ~ 2300 ~ 2250 | HASAN 1 MARTIN 1 MARTIN 2 MARTIN | | RVUE | | $\overline{p}p \rightarrow \pi\pi$ |
| ~ 25 00 | ² CARTER | 78B | CNTR | 0 | $0.7-2.4 \overline{p}p \rightarrow K^-K^+$ |
| ~ 2480 | ³ CARTER | 77 | CNTR | 0 | $0.7-2.4 \frac{R}{\overline{p}p} \rightarrow \pi \pi$ |
| S-CHANNEL N N VALUE (MeV) | DO CUMENT ID | | TECN | СНС | COMMENT |
| • • • We do not use t | he following data for average | s, fits | limits, | etc. • | •• |
| 2300±45 | ⁴ A NISOVICH | 02 | SPEC | | $0.6-1.9 \ p\overline{p} \rightarrow \omega \pi^0, \ \omega \eta \pi^0, \ \pi^+\pi^-$ |
| 2295 ± 30 | ANISOVICH | 00J | SPEC | | $\pi \cdot \pi$ |
| \sim 2380 | ⁵ CUTTS | 78B | CNTR | | $0.97-3 \overline{p}p \rightarrow \overline{N} N$ |
| 2345 ± 15 | ^{5,6} COUPLAND | 77 | CNTR | 0 | $0.7-2.4 \overline{p}p \rightarrow \overline{p}p$ |
| 2359± 2 | ^{5,7} ALSPECTOR | 73 | CNTR | | $\overline{p}p$ S channel |
| 2350 ± 10 | ⁸ ABRAMS | 70 | CNTR | | S channel $\overline{N}N$ |
| 2360 ± 25 | ⁹ он | 70B | HDBC | -0 | $\overline{p}(pn)$, $K^*K2\tau$ |
| $\pi^- p \rightarrow K^+ K^- n$ | | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
| • • • We do not use t | he following data for average | s, fits, | limits, | etc. • | • • |
| 2307 ± 6 | ALPER | 80 | CNTR | 0 | 62 $\pi^- p \rightarrow$ |
| | m simultaneous analysis of <i>p</i> from Barrelet-zero analysis. | | $\pi^-\pi^+$ | and $\pi^{'}$ | $0_{\pi}^{K^+K^-n}$ |

3/(JP) = 1(5-) from amplitude analysis. 4 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02. 5 Isospins 0 and 1 not separated.

6 From a fit to the total elastic cross section

 7 Referred to as U or U region by ALSPECTOR 73.

⁸ For $I = 1 \overline{N} N$.

For l=1 N N. 9 No evidence for this bump seen in the $\overline{p}p$ data of CHAPMAN 71B. Narrow state not confirmed by OH 73 with more data.

ho_5 (2350) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMN | 1ENT |
|------------------------------------------------------|---------------------------------|----------|---------|--------|-------------------------------------------------|
| 400±100 | ALDE | 95 | GAM2 | 38 π | $-\rho \rightarrow \omega \pi^0 n$ |
| $\overline{p}p \to \pi\pi \text{ or } \overline{K}K$ | | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
| • • • We do not use | the following data for average: | s, fits, | limits, | etc. • | • • |
| ~ 169 | HA SA N | 94 | RVUE | | $\overline{p}p \rightarrow \pi\pi$ |
| ~ 25 0 | ¹⁰ MARTIN | 80B | RVUE | | |
| ~ 300 | ¹⁰ MARTIN | 80c | RVUE | | |
| ~ 150 | ¹¹ CARTER | 78B | CNTR | 0 | $0.7-2.4 \overline{p}p \rightarrow$ |
| ~ 210 | ¹² CARTER | 77 | CNTR | 0 | K^-K^+ 0.7-2.4 $\overline{p}p \rightarrow$ |

S-CHANNEL $\overline{N}N$

| VALUE (MeV) | DO CUMENT ID | | TECN CHG | COMMENT |
|-------------------------------------|--------------------------------|---------|------------------|-------------------------------------------------------------------------------------------------------------------------------|
| ullet $ullet$ $ullet$ We do not use | the following data for average | s, fits | , limits, etc. • | • • |
| 260± 75 | ¹³ a nisovich | 02 | SPEC | $\begin{array}{c} 0.61.9 \ \rho \overline{\rho} \rightarrow \\ \omega \pi^0, \ \omega \eta \pi^0, \\ \pi^+ \pi^- \end{array}$ |
| $235 + 65 \\ - 40$ | ANISOVICH | 001 | SPEC | |
| $135{}^{+150}_{-65}$ | 14,15 COUPLAND | 77 | CNTR 0 | $\begin{array}{c} 0.72.4 \ \overline{p}p \longrightarrow \\ \overline{p}p \end{array}$ |
| 165 + 18 | ¹⁵ ALSPECTOR | 73 | CNTR | <u>p̄</u> ρ S channel |
| < 60 | ¹⁶ OH ABRAMS | | HDBC -0 CNTR | $\overline{p}(pn), K^*K2\pi$ |
| ~ 140 | ABKAWS | 0/0 | CIVIT | S channel p N |

$\pi^- p \rightarrow K^+ K^- n$

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------|------------------|---------|---------|--------|--------------------------|
| • • • We do not use the following | data for average | s, fits | limits, | etc. • | • • |
| 245 ± 20 | ALPER | 80 | CNTR | 0 | 62 $\pi^- p \rightarrow$ |
| | | | | | K^+K^-n |

 $^{10}l(J^P)=1(5^-)$ from simultaneous analysis of $p\overline{p}\to\pi^-\pi^+$ and $\pi^0\pi^0$. $^{11}l=0(1); J^P=5^-$ from Barrelet-zero analysis.

and ANISOVICH 02.

14 From a fit to the total elastic cross section.

15 Isospins 0 and 1 not separated.

- Toograms of and 1 not separated.
16 No evidence for this bump seen in the pp data of CHAPMAN 71B. Narrow state not confirmed by OH 73 with more data.

ρ₅ (2350) REFERENCES

| ANISOVICH ANISOVICH ANISOVICH ANISOVICH | 02 01D 01E 00J | PL B542 8 PL B508 6 PL B513 281 PL B491 47 | A.V. Anisovich et al. A.V. Anisovich et al. A.V. Anisovich et al. A.V. Anisovich et al. | |
|--------------------------------------------------|-------------------------|-----------------------------------------------------|--------------------------------------------------------------------------------------------------|-------------------|
| ALDE | 95 | ZPHY C66 379 | D.M. Alde et al. | (GAMS Collab.) JP |
| HASAN | 94 | PL B334 215 | A. Hasan, D.V. Bugg | ` (LOQM) |
| ALPER | 80 | PL 94B 422 | B. Alper et al. (AMST, CERN, | CRAC, MPIM+) |
| MARTIN | 80 B | NP B176 355 | B.R. Martin, D. Morgan | (LOUC, RHEL) JP |
| MARTIN | 80 C | NP B169 216 | A.D. Martin, M.R. Pennington | (DURH) JP |
| CARTER | 78 B | NP B141 467 | A.A. Carter | (LOQM) |
| CUTTS | 78 B | PR D17 16 | D. Cutts et al. | (STON, WISC) |
| CARTER | 77 | PL 67B 117 | A.A. Carter et al. | (LOQM, RHEL) JP |
| COUPLAND | 77 | PL 71B 460 | M. Coupland et al. | (LOQM, RHEL) |
| ALS PECT OR | 73 | PRL 30 511 | J. Alspector et al. | (RUTG, UPNJ) |
| OH | 73 | NP B51 57 | B.Y. Oh et al. | (MSU) |
| CHAPMAN | 71B | PR D4 1275 | J.W. Chapman et al. | (MICH) |
| ABRAMS | 70 | PR D1 1917 | R.J. Abrams et al. | (BNL) |
| OH | 70 B | PRL 24 1257 | B.Y. Oh et al. | (MSU) |
| ABRAMS | 67 C | PRL 18 1209 | R.J. Abrams et al. | (BNL) |

$a_6(2450)$

$$I^{G}(J^{PC}) = 1^{-}(6^{++})$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

a₆ (2450) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------|-------------|-----|------|-----|----------------------------------------|
| 2450±130 | 1 CLELAND | 82B | SPEC | ± | $50 \pi p \rightarrow K_S^0 K^{\pm} p$ |

 $^{1}\,\mathrm{From}$ an amplitude analysis.

a₆(2450) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------|-------------|-----|------|-----|----------------------------------------------|
| 400±250 | 2 CLELAND | 82в | SPEC | ± | $50 \pi \rho \rightarrow K_S^0 K^{\pm} \rho$ |

² From an amplitude analysis.

 $a_6(2450)$, $f_6(2510)$

a₆(2450) DECAY MODES

Mode ΚK

a₆(2450) REFERENCES

CLELAND 82B NP B208 228 W.E. Cleland et al.

(DURH, GEVA, LAUS+)



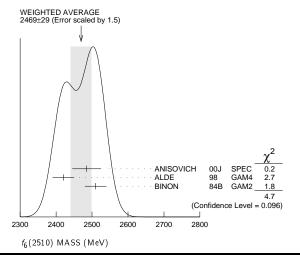
$$I^{G}(J^{PC}) = 0^{+}(6^{+})$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

€ (2510) MASS

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
|-----------------------|-----------------------------|-------------|-------------------------------------------|
| 2469 ± 29 OUR AVERAGE | Error includes scale factor | of 1.5. See | the ideogram below. |
| 2485 ± 40 | ¹ ANISOVICH 0 | | |
| 2420 ± 30 | ALDE 9 | 8 GAM4 | $100 \ \pi^- p \rightarrow \pi^0 \pi^0 n$ |
| 2510 ± 30 | BINON 8 | 4в GAM2 | $38 \pi^- p \rightarrow n 2\pi^0$ |

 $^1\,\rm From$ the combined analysis of ANISOVICH 99c, ANISOVICH 99F, ANISOVICH 99J, ANISOVICH 99K, and ANISOVICH 00B.



f₆ (2510) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | |
|------------------------------------------------------------------------------------------------------------------------------|-------------------------|-----|------|-----------------------------------------------|--|--|
| 283±40 OUR AVERAGE Erro | | | | | | |
| 410±90 | ² A NISOVICH | | | | | |
| 270 ± 60 | ALDE | 98 | GAM4 | $100 \pi^{-} p \rightarrow \pi^{0} \pi^{0} n$ | | |
| 240 ± 60 | BINON | 84B | GAM2 | $38 \pi^- p \rightarrow n 2\pi^0$ | | |
| ² From the combined analysis of ANISOVICH 99c, ANISOVICH 99F, ANISOVICH 99J, ANISOVICH 99к, and ANISOVICH 00в. | | | | | | |

f₆(2510) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------|------------------------------|
| Γ_1 | $\pi\pi$ | (6.0±1.0) % |

f₆(2510) BRANCHING RATIOS

| | | | | Γ_1/Γ |
|--------------------|-----|------|-----------------------------------|-------------------|
| DO CUMENT ID | | TECN | COMMENT | |
| ³ BINON | 83c | GAM2 | 38 $\pi^- p \rightarrow n4\gamma$ | |
| | | 2 | | |

 $^3\mbox{Assuming}$ one pion exchange and using data of BOLOTOV 74.

f₆(2510) REFERENCES

| ANISOVICH | 00 B | NP A662 319 | A.V. Anisovich et al. | |
|-----------|------|--------------------|-----------------------|-----------------------|
| ANISOVICH | 00 J | PL B491 47 | A.V. Anisovich et al. | |
| ANISOVICH | 99 C | PL B452 173 | A.V. Anisovich et al. | |
| ANISOVICH | 99 F | NP A651 253 | A.V. Anisovich et al. | |
| ANISOVICH | 99 J | PL B471 271 | A.V. Anisovich et al. | |
| ANISOVICH | 99K | PL B468 309 | A.V. Anisovich et al. | |
| ALDE | 98 | EPJ A3 361 | D. Alde et al. | (GAM4 Collab.) |
| Also | | PAN 62 405 | D. Alde et al. | (GAMS Collab.) |
| | | Translated from YA | F 62 446. | , , |
| BINON | 84 B | LNC 39 41 | F.G. Binon et al. | (SERP, BELG, LAPP) JP |
| BINON | 83 C | SJNP 38 723 | F.G. Binon et al. | (SERP, BRUX+) |
| | | Translated from YA | F 38 1199. | , , |
| BOLOTOV | 74 | PL 52B 489 | V.N. Bolotov et al. | (SERP) |
| | | | | |

Meson Particle Listings Further States

OTHER LIGHT MESONS

Further States

OMITTED FROM SUMMARY TABLE

This section contains states observed by a single group or states poorly established that thus need confirmation.

QUANTUM NUMBERS, MASSES, WIDTHS, AND BRANCHING

| X(360) | $I^{G}(J^{PC})$ | = ??(? | ??+) | | |
|-----------------------|-----------------------------------|----------|---------------------------|------|---------------------------------------|
| MASS (MeV) | WIDTH (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| $360 \pm 7 \pm 9$ | 64 ± 18 | 2.3k | ¹ ABRAAMYAN 09 | CNTR | $2.75 dC \rightarrow \gamma \gamma X$ |
| ¹ Not seen | in $pC \rightarrow \gamma \gamma$ | X at 5.5 | 5 GeV/c. | | |

| X(1070) | $I^{G}(J^{PC}) = ?$ | ?(0++) | | |
|-------------------------|---------------------|---------------------------|-----------------------------|------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | COMMENT | |
| 1072±1 | 3.5 ± 0.5 | ² VLADIMIRSK08 | $40 \pi^- \rho \rightarrow$ | $\kappa_S^0 \kappa_S^0 n + m\pi^0$ |
| ² Supersedes | GRIGOR'EV 05. | | | |

| X(1110 | $I^{G}(J^{PC}) = 0^{+}($ | even + +) | | | |
|------------|--------------------------|-------------|----|------|------------------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 1107±4 | 111 ± 8 ± 15 | DAFTARI 8 | 87 | DBC | $0. \ \overline{\rho} n \to \ \rho^- \pi^+ \pi^-$ |

| f ₀ (120 |)–1600) I ^G (J ^P (| $S(x) = 0^{+}(0^{+} + 1)$ | | |
|---------------------------|-------------------------------------------------|----------------------------|------------------------|--------------------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | TECN | COMMENT |
| 1323 ± 8 | 237 ± 20 | VLADIMIRSK06 | SPEC | $40 \pi^{-} p \rightarrow K_{S}^{0} K_{S}^{0} n$ |
| $1480 {}^{+ 100}_{- 150}$ | $1030 {}^{+}_{-} {}^{80}_{170}$ | ³ A NISOVICH 03 | SPEC | |
| $1530 + 90 \\ -250$ | 560 ± 40 | ⁴ A NISOVICH 03 | SPEC | |
| ³ K-matrix | pole from combin | ed analysis of $\pi^- p$ - | $\rightarrow \pi^0\pi$ | 0 n, π^{-} p \rightarrow $K\overline{K}$ n, |

3 K-matrix pole from combined analysis of $\pi^- p \rightarrow \pi^0 \pi^V n$, $\pi^- p \rightarrow KKn$, $\pi^+ \pi^- \rightarrow \pi^+ \pi^-$, $\overline{p} p \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, $\pi^0 \pi^0 \eta$, $\pi^+ \pi^- \pi^0$, $K^+ K^- \pi^0$, $K^0_S K^0_S \pi^0$, $K^+ K^0_S \pi^-$ at rest, $\overline{p} n \rightarrow \pi^- \pi^- \pi^+$, $K^0_S K^- \pi^0$, $K^0_S K^0_S \pi^-$ at rest.

4 K-matrix pole from combined analysis of $\pi^- p \rightarrow \pi^0 \pi^0 n$, $\pi^- p \rightarrow K\overline{K} n$, $\overline{p} p \rightarrow \pi^0 \pi^0 \pi^0$, $\pi^0 \eta \eta$, $\pi^0 \eta^0$ at rest.

| X(1420) | $I^G(J^{PC}) = 2^+(0$ | ++) | | | |
|------------------------|-----------------------|--------------|----|------|--------------------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $\overline{1420\pm20}$ | 160 ± 10 | FILIPPI | 00 | OBLX | $0 \ \overline{n}\rho \rightarrow \ \pi^+ \pi^+ \pi^-$ |

| X(1545) | $I^{G}(J^{PC}) = ?$? | (? + +) | | |
|-------------------------|-----------------------|----------------|--------------------------|------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | COMMENT | |
| 1545 ± 3 | 6.0 ± 2.5 | 5 VLADIMIRSK08 | $40 \pi^- p \rightarrow$ | $\kappa_S^0 \kappa_S^0 n + m\pi^0$ |
| ⁵ Supersedes | VLADIMIRSKII 00. | | | |

| X(1575) | $I^G(J^{PC}) = ??(1$ | 1) | | | |
|------------------------------|------------------------------|----------------------|-----|------|------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $1576 + 49 + 98 \\ -55 - 91$ | $818 + 22 + 64 \\ -23 - 133$ | ⁶ ABLIKIM | 06s | BES | $J/\psi \rightarrow K^+ K^- \pi^0$ |

 6 A broad peak observed at $K^+\,K^-$ invariant mass. Mass and width above are its pole position. The observed branching ratio is B(J/ $\psi\to~X\,\pi^0$) B(X $\to~K^+\,K^-$) = (8.5 $\pm~0.6^{+2.7}_{-3.6})\times 10^{-4}_{-}$.

| X(1650 | $I^{G}(J^{PC})$ | $) = 0^{-}(?^{?-}$ | -) | | |
|------------|-----------------|--------------------|---------------|-------|-----------------------------------------|
| MASS (MeV) | WIDTH (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 1652 ± 7 | < 50 | 100 | PROKOSHKIN 96 | GA M2 | 32,38 $\pi p \rightarrow \omega \eta n$ |

| X(1730) | $I^G(J^{PC}) = ??($ | ??+) | | | |
|--------------------------|-----------------------|------|--------------|------|--------------------------------------------------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| $1731.0 \pm 1.2 \pm 2.0$ | $3.2 \pm 0.8 \pm 1.3$ | 58 | VLADIMIRSK07 | SPEC | $\begin{array}{c} 40 \ \pi^- p \rightarrow \\ \kappa^0_S \kappa^0_S X \end{array}$ |

| X(1750) | $I^{G}(J^{PC}) = ??(1 -$ |) | | | | |
|--------------------------|--------------------------|-----------|-----|------|-------------|-----------|
| MASS (MeV) | WIDTH (MeV) | DO CUMENT | ID | TECN | COMMENT | |
| $1753.5 \pm 1.5 \pm 2.3$ | $122.2 \pm 6.2 \pm 8.0$ | LINK | 02K | FOCS | 20-160 γp → | K^+K^-D |

| | B(X(1750) → | ₹*(892) ⁰ κ ⁰ | $\rightarrow \kappa^{\pm}\pi^{\mp}\kappa^{0}_{S}$ | /B(<i>X</i> (| $(1750) \rightarrow K^+ K^-)$ |
|---------|-------------|---------------------------------------------|-------------------------------------------------------|----------------|--------------------------------|
| VALUE | | <u>CL%</u> | DO CUMENT ID | | TECN |
| < 0.065 | | 90 | LINK | 02K | FOCS |
| | B(X(1750) → | 7*(892)±κ ² | $\mp \rightarrow \kappa^{\pm}\pi^{\mp}\kappa^{0}_{S}$ |)/B(<i>)</i> | $K(1750) \rightarrow K^+ K^-)$ |
| | | | | | |
| VALUE | | CL% | DO CUMENT ID | | TECN |

| f ₂ (1750) | 1G(. | J ^{PC}) = | 0+(2+ | +) | | | | | |
|-----------------------|----------------------------|---------------------|------------------|------------|------------|--------|--------------------|---------------------------------------------------|---|
| MASS (MeV) | , | | | | ENT II | ס | TECN | COMMENT | |
| 1755 ± 10 | 67 ± 12 | ! | 870 | 8 SCHEG | ELS | (Y 06A | RVUE | $\gamma \gamma \rightarrow \kappa_S^0 \kappa_S^0$ | : |
| | Γ(<i>Κ</i> Κ) | | | | | | | | |
| VALUE (MeV) | | EVTS | DO 0 | CUMENT ID | | TECN | COMME | NT | _ |
| $17\!\pm\!5$ | | 870 | ⁹ SCF | HEGELSKY | 06A | RVUE | $\gamma\gamma\to$ | $\kappa_S^0 \kappa_S^0$ | |
| | $\Gamma(\gamma\gamma)$ | | | | | | | | |
| VALUE (keV) | | EVTS | | CUMENT ID | | | | | |
| $0.13 \!\pm\! 0.04$ | | 870 | 9 SCH | HEGELSKY | 06A | RVUE | $\gamma\gamma \to$ | $\kappa_S^0 \kappa_S^0$ | |
| | $\Gamma(\pi\pi)$ | | | | | | | | |
| VALUE (MeV) | | EVTS | DO 0 | CUMENT ID | | TECN | COMME | NT | _ |
| 1.3 ± 1.0 | | 870 | ⁹ SCH | HEGELSKY | 06A | RVUE | $\gamma\gamma\to$ | $\kappa_S^0 \kappa_S^0$ | |
| | $\Gamma(\eta\eta)$ | | | | | | | | |
| VALUE (MeV) | | EVTS | DO 0 | CUMENT ID | | TECN | COMME | NT | |
| 2.0 ± 0.5 | | 870 | ⁹ SCH | HEGELSKY | 06A | RVUE | $\gamma\gamma\to$ | $\kappa_S^0 \kappa_S^0$ | |
| 8 From analys | sis of L3 | data at | 91 and 1 | 83-209 GeV | <i>r</i> . | | | | |

| X(1775 | $I^{G}(J^{PC}) =$ | 1-(?-+) | | | |
|-------------|-------------------|-------------|----|------|---------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 1763 ± 20 | 192 ± 60 | CONDO | 91 | SHF | $\gamma p \to (p \pi^+)(\pi^+ \pi^- \pi^-)$ |
| 1787 ± 18 | 118 ± 60 | CONDO | 91 | SHF | $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$ |

From analysis of L3 data at 91 and 183-209 GeV and using SU(3) relations.

| X(1855) | $I^{G}(J^{PC}) = ??(???)$ | | | | |
|------------|---------------------------|--------------|-----|------|---------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 1856.6±5 | 20 ± 5 | BRIDGES | 86D | SPEC | $0. \ \overline{p} d \rightarrow \pi \pi N$ |

| X(1870) | $I^{G}(J^{PC}) = ??(2??)$ | | | | |
|------------|---------------------------|-------------|-----|------|-----------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 1870±40 | 250 ± 30 | ALDE | 86D | GAM4 | $100 \pi^- p \rightarrow 2\eta X$ |

a3(1875)

$$I^G(J^{PC}) = 1^-(3^{++})$$

 MASS (MeV)
 WIDTH (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 1874 ± 43 ± 96
 385 ± 121 ± 114
 CHUNG
 02
 B852
 18.3 $\pi^-p \rightarrow \pi^+\pi^-\pi^-p$

| a ₁ (1930 | $I^{G}(J^{PC}) =$ | 1-(1++) | | | | |
|-------------------------|-------------------|-------------|------|------|-----------------------------------|---------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | | TECN | COMMENT | |
| $1930 {}^{+ 30}_{- 70}$ | 155 ± 45 | ANISOVICH | 01 F | SPEC | $2.0 \ \overline{p}p \rightarrow$ | $3\pi^0$, $\pi^0\eta$, $\pi^0\eta'$ |

Further States

| X(1935) | $I^{G}(J^{PC}) = 1^{+}(1$ | 1-?) | | |
|------------|---------------------------|--------------|------|----------------------------------------------|
| MASS (MeV) | WIDTH (MeV) | DOCUMENT ID | TECN | COMMENT |
| 1935 ± 20 | 215 ± 30 | EVANGELIS 79 | OMEG | 10,16 $\pi^- p \rightarrow \overline{p} p n$ |
| | | | | |

 $^{14}\,\mbox{From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.}$

 $^{16}\mbox{From the combined analysis of ANISOVICH 99c, ANISOVICH 99e, and ANISOVICH 01f.}$

 18 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

 $^{21}\,\mathrm{From}$ analysis of L3 data at 183–209 GeV.

 ρ(2000)
 $I^G(J^{PC}) = 1^+(1^{--})$ DOCUMENT ID
 TECN
 COMMENT

 2000 ± 30
 260 ± 45
 23 BUGG
 04c
 RVUE
 Compilation

 ~ 1988
 ~ 244
 HASAN
 94
 RVUE
 $p_P \rightarrow \pi \pi$

 23 From the combined analysis of ANISOVICH 001. ANISOVICH 01D, ANISOVICH

 $^{23}\,\mbox{From}$ the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

 \mathbf{f} (2000)
 $I^G(J^{PC}) = 0^+(2^{++})$

 MASS (MeV)
 WIDTH (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 2001±10
 312 ± 32
 A NISOVICH
 00J
 SPEC

 ~ 1996
 ~ 134
 HASAN
 94
 RVUE
 $\overline{p}\rho \rightarrow \pi\pi$

 $\pi_1(2015)$ $I^G(J^{PC}) = 1^-(1^{-+})$

 MASS (MeV)
 WIDTH (MeV)
 EVTS DOCUMENT ID
 TECN COMMENT

 2014 ± 20 ± 16
 230 ± 32 ± 73
 145k
 LU
 05
 B852
 18 $\pi^-p \to \omega\pi^-\pi^0p$

 2001 ± 30 ± 92
 333 ± 52 ± 49
 69k
 KUHN
 04
 B852
 18 $\pi^-p \to \eta\pi^+\pi^-\pi^-p$

 $^{27}\,\text{From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.}$

Meson Particle Listings Further States

| MeV MIDTH (MeV 29 ANISOVICH 01F SPEC 1.96-2.41 $\overline{p}p$ 29 ANISOVICH 01F SPEC 1.96-2.41 $\overline{p}p$ 29 ANISOVICH 01F SPEC 1.96-2.41 $\overline{p}p$ 20m the combined analysis of ANISOVICH 09F, ANISOVICH 09F, and ANISOVICH 01F. MeV MIDTH (MeV 205 ± 10 ± 15 ANISOVICH 00E SPEC |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The combined analysis of ANISOVICH 99c, ANISOVICH 99e, and ANISOVICH 01F. The combined analysis of ANISOVICH 99c, ANISOVICH 99e, and ANISOVICH 01F. The combined analysis of ANISOVICH 99c, ANISOVICH 99e, and ANISOVICH 01F. The combined analysis of ANISOVICH 00E. The combined analysis of ANISOVICH 00E. The combined analysis of ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00E. The combined analysis of ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00E. The combined analysis of ANISOVICH 01 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00E. The combined analysis of ANISOVICH 02 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00E. The combined analysis of ANISOVICH 02 SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMEIT 96 and ANISOVICH 00D SPEC 0.9–1.94 $\rho \overline{\rho}$ analysis of ADOMENT $\rho \overline{\rho}$ and $\rho \rho$ |
| |
| $\frac{\text{MeV})}{\text{1:5}\pm 15} \frac{\text{WIDTH (MeV)}}{205\pm 10\pm 15} \frac{\text{DOCUMENT ID}}{\text{ANISOVICH}} \frac{\text{TECN}}{\text{SPEC}}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=0}/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{30 \text{ ANISOVICH}} 100 \text{ SPEC}}$ $\frac{\text{DOCUMENT ID}}{30 \text{ ANISOVICH}} 11 \text{SPEC} \frac{\text{COMMENT}}{0.9-1.94 \ \rho \overline{\rho}} 0.03$ $\frac{\text{ANISOVICH}}{31 \text{ ANISOVICH}} 11 \text{SPEC} \frac{\text{COMMENT}}{0.9-1.94 \ \rho \overline{\rho}} 0.09-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_0 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{31 \text{ ANISOVICH}} 11 \text{SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 11 \text{SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 11 \text{SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 11 \text{SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=2}}{32 \text{ ANISOVICH}} 100 \text{ SPEC} 0.9-1.94 \ \rho \overline{\rho}$ $\frac{\text{B}(\textbf{a}_2 \boldsymbol{\pi})/\text{B}(\textbf{a}_2 \boldsymbol{\pi})_{L=$ |
| $\frac{\text{MeV})}{\text{15} \pm 15} \frac{\text{WIDTH (MeV)}}{205 \pm 10 \pm 15} \frac{\text{DOCUMENT ID}}{\text{ANISOVICH}} \frac{\text{TECN}}{\text{ODE}}$ $\frac{\text{B}(\textbf{a}_2 \textbf{\pi})_{\textbf{L}=\textbf{0}}/\text{B}(\textbf{a}_2 \textbf{\pi})_{\textbf{L}=\textbf{2}}}{30 \text{ ANISOVICH}} \frac{\text{TECN}}{11} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}}$ $\frac{\text{DOCUMENT ID}}{31 \text{ ANISOVICH}} \frac{\text{TECN}}{11} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{TECN}}{\text{O.9-1.94 } \rho \overline{\rho}}$ $\frac{\text{DOCUMENT ID}}{31 \text{ ANISOVICH}} \frac{\text{TECN}}{11} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{TECN}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}}$ $\frac{\text{B}(\textbf{f}_2 \textbf{\eta})/\text{B}(\textbf{a}_2 \textbf{\pi})_{\textbf{L}=\textbf{2}}}{32 \text{ ANISOVICH}} \frac{\text{TECN}}{11} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{TECN}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}}$ $\frac{\text{B}(\textbf{f}_2 \textbf{\eta})/\text{B}(\textbf{a}_2 \textbf{\pi})_{\textbf{L}=\textbf{2}}}{32 \text{ ANISOVICH}} \frac{\text{TECN}}{11} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{TECN}}{\text{O.9-1.94 } \rho \overline{\rho}} \frac{\text{COMMENT}}{\text{O.9-1.94 } \rho \overline{\rho}}$ $\frac{\text{F}_3(\textbf{2050})}{\text{Comment MeV}} \frac{\text{IG}(J^{PC})}{\text{Comment MeV}} = 0 + (0 + + + + + + + + + + + + + + + + $ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\frac{DOCUMENT\ ID}{30\ ANISOVICH} \qquad \frac{TECN}{11\ SPEC} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ analysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{B(\textbf{a_0}\boldsymbol{\pi})/B(\textbf{a_2}\boldsymbol{\pi})}{31\ ANISOVICH} = 2$ $\frac{DOCUMENT\ ID}{31\ ANISOVICH} \qquad \frac{TECN}{31\ ANISOVICH} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ analysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{B(\textbf{f_2}\boldsymbol{\eta})/B(\textbf{a_2}\boldsymbol{\pi})}{32\ ANISOVICH} = 2$ $\frac{DOCUMENT\ ID}{32\ ANISOVICH} \qquad \frac{TECN}{32\ ANISOVICH} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ analysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{B(\textbf{f_2}\boldsymbol{\eta})/B(\textbf{a_2}\boldsymbol{\pi})}{32\ ANISOVICH} = 0.9-1.94\ \rho\overline{\rho}$ $\frac{F}{2} = \frac{DOCUMENT\ ID}{213\ \pm 34} \qquad \frac{TECN}{213\ \pm 34} \qquad \frac{COMMENT}{213\ \pm 34} \qquad \frac{DOCUMENT\ ID}{213\ ANISOVICH} \qquad \frac{TECN}{213\ \pm 34} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ \pm 34} \qquad \frac{DOCUMENT\ ID}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad \frac{COMMENT}{213\ ANISOVICH} \qquad \frac{TECN}{213\ ANISOVICH} \qquad TEC$ |
| 30 ANISOVICH 11 SPEC $0.9-1.94~p\overline{p}$ canalysis of ADOMEIT 96 and ANISOVICH 00E. $ \frac{B(a_0\pi)/B(a_2\pi)}{B(a_0\pi)/B(a_2\pi)} = 2 $ $ \frac{DOCUMENT~ID}{31~ANISOVICH~11} $ $ \frac{TECN}{SPEC} \frac{COMMENT}{0.9-1.94~p\overline{p}} $ canalysis of ADOMEIT 96 and ANISOVICH 00E. $ \frac{B(f_2\eta)/B(a_2\pi)}{32~ANISOVICH~11} \frac{TECN}{SPEC} \frac{COMMENT}{0.9-1.94~p\overline{p}} $ canalysis of ADOMEIT 96 and ANISOVICH 00E. $ \frac{B(f_2\eta)/B(a_2\pi)}{32~ANISOVICH~11} \frac{TECN}{SPEC} \frac{COMMENT}{0.9-1.94~p\overline{p}} $ canalysis of ADOMEIT 96 and ANISOVICH 00E. $ \frac{f_3(2050)}{16(J^{PC})} \frac{I^G(J^{PC})}{213~\pm~34} \frac{DOCUMENT~ID}{ANISOVICH~00J} \frac{TECN}{SPEC} \frac{COMMENT}{2.0~p\overline{p}\rightarrow~\eta\pi^0\pi^0} $ compared to $\frac{I^G(J^{PC})}{213~\pm~34} \frac{DOCUMENT~ID}{213~\pm~34} \frac{TECN}{213~\pm~34} \frac{COMMENT~TECN}{213~\pm~34} C$ |
| The property of ADOMEIT 96 and ANISOVICH 00E. $ \frac{B(a_0\pi)/B(a_2\pi)}{31} = 2 $ $ \frac{DOCUMENT\ ID}{31\ ANISOVICH} $ $ \frac{DOCUMENT\ ID}{31\ ANISOVICH} $ $ \frac{DOCUMENT\ ID}{31\ ANISOVICH} $ $ \frac{DOCUMENT\ ID}{32\ ANISOVICH} $ $ \frac{DOCUMENT\ ID}{33\ OAKDEN} $ $ DO$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\frac{DOCUMENT\ ID}{31\ ANISOVICH} \qquad \frac{TECN}{11\ SPEC} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ canalysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{B(f_2\eta)/B(a_2\pi)_L=2}{32\ ANISOVICH} \qquad \frac{DOCUMENT\ ID}{32\ ANISOVICH} \qquad \frac{TECN}{0.9-1.94\ \rho\overline{\rho}} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ canalysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{f_3(2050)}{16\ (D^PC)} \qquad \frac{I^G(J^{PC})=0^+(3^{++})}{16\ (D^PC)} \qquad \frac{DOCUMENT\ ID}{16\ (D^PC)} \qquad \frac{TECN}{0.9-1.94\ \rho\overline{\rho}} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ $\frac{f_3(2050)}{16\ (D^PC)} \qquad \frac{I^G(J^{PC})=0^+(0^{++})}{16\ (D^PC)} \qquad \frac{DOCUMENT\ ID}{0.00000000000000000000000000000000000$ |
| Fig. 2050) $I^G(J^{PC}) = 0 + (0 + +)$ MeV) $I^G(J^{PC}) = 0 + (0 + +)$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\frac{DOCUMENT\ ID}{32\ A\ NISOVICH} \qquad \frac{TECN}{11} \qquad \frac{COMMENT}{0.9-1.94\ \rho\overline{\rho}}$ analysis of ADOMEIT 96 and ANISOVICH 00E. $\frac{\mathbf{f_3(2050)}}{\mathbf{f_3(2050)}} \qquad \frac{I^G(J^{PC})}{U^{PC}} = 0^+(3^{++}) \qquad \frac{DOCUMENT\ ID}{U^{PC}} \qquad \frac{TECN}{U^{PC}} \qquad \frac{COMMENT}{U^{PC}} \qquad \frac$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Fig. (2050) $I^G(J^{PC}) = 0+(3++)$ $I^G(J^{PC}) = 0+(3++)$ $I^G(J^{PC}) = 0+(3++)$ $I^G(J^{PC}) = 0+(0++)$ $I^G(J^{PC}) = 0+$ |
| f ₃ (2050) $I^G(J^{PC}) = 0^+(3^{++})$ MeV) $MIDTH (MeV)$ $DOCUMENT ID$ $TECN$ $COMMENT$ f ₆ (2060) $I^G(J^{PC}) = 0^+(0^{++})$ MeV) $MIDTH (MeV)$ $DOCUMENT ID$ $TECN$ $COMMENT$ MEV $MIDTH (MEV)$ $MIDTH (M$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| f₀(2060) $I^G(J^{PC}) = 0+(0++)$ MeV) $WIDTH$ (MeV) $DOCUMENT$ ID $TECN$ $COMMENT$ 0 ~ 120 33 OAKDEN 94 RVUE 0.36–1.55 $\overline{p}p \rightarrow \pi\pi$ 0 ~ 50 33 OAKDEN 94 RVUE 0.36–1.55 $\overline{p}p \rightarrow \pi\pi$ e SEMENOV 99 and KLOET 96. π(2070) $I^G(J^{PC}) = 1^{-}(0^{-}+)$ MeV) $WIDTH$ (MeV) $DOCUMENT$ ID $TECN$ $COMMENT$ |
| $ \frac{\text{MeV})}{\text{O}} = \frac{\text{WIDTH (MeV)}}{\text{O}} = \frac{DO CUMENT ID}{33 \text{ OAKDEN}} = \frac{TECN}{94} = \frac{COMMENT}{\text{EVUE}} = 0.36-1.55 \overline{p}p \rightarrow \pi\pi$ $0 \sim 50 \qquad 33 \text{ OAKDEN} \qquad 94 \qquad \text{RVUE} \qquad 0.36-1.55 \overline{p}p \rightarrow \pi\pi$ $0 \approx \text{SEMENOV 99 and KLOET 96.} $ $\pi(2070) = \frac{1}{9} \frac{G(J^{PC})}{J^{PC}} = \frac{1}{9} \frac{1}{9} \frac{G(J^{PC})}{J^{PC}} = \frac{1}{9} \frac{1}{9} \frac{G(J^{PC})}{J^{PC}} = \frac{1}{9} G(J^{$ |
| 35 310^{+100} ANISOVICH 01F SPEC $2.0 \overline{p}p \rightarrow 3\pi^{0}, \pi^{0}\eta, \pi^{0}\eta'$ |
| $310 = 50$ ANISOVICII OIF SPEC 2.0 pp $\rightarrow 3\pi$, π η , π η |
| X(2075) $I^G(J^{PC}) = ??(???)$ |
| MeV) WIDTH (MeV) DOCUMENT ID TECN COMMENT |
| 12 ± 5 90 \pm 35 \pm 9 34 ABLIKIM 04J BES2 $J/\psi ightarrow 	extit{K}^- p \overline{\Lambda}$ |
| om a fit in the region $M_p \overline{\Lambda} - M_p - M_{\Lambda} < 150$ MeV. S-wave in the $p \overline{\Lambda}$ system preferred. |
| similar near-threshold enhancement in the $ ho\overline{\Lambda}$ system is observed in $B^+	o ho\overline{\Lambda}\overline{D}{}^0$ by IEN 11F. |
| |
| $X(2080)$ $I^G(J^{PC}) = ??(???)$ |
| MeV) WIDTH (MeV) DOCUMENT ID TECN COMMENT |
| 110 110 \pm 20 KREYMER 80 STRC 13 $\pi^- d \rightarrow p \overline{p} n(n_S)$ |
| |
| X(2080) $I^G(J^{PC}) = ?^2(3^{-2})$ MeV) WIDTH (MeV) DOCUMENT ID TECN COMMENT |
| $\frac{\text{WEV}}{10} = \frac{\text{WEV}}{190 \pm 15} \qquad \frac{\text{DOCOMENT 1D}}{\text{ROZANSKA}} = \frac{1200 \text{ COMMENT}}{100 \text{ COMMENT}}$ |
| TO 130 ± 10 KOZANSKA OO SIRK TO K p 7 ppii |
| $a_1(2095)$ $I^G(J^{PC}) = 1^-(1^{++})$ |
| MeV) WIDTH (MeV) EVTS DOCUMENT ID TECN COMMENT |
| $\pm 17 \pm 121$ 451 \pm 41 \pm 81 69k KUHN 04 B852 18 $\pi^- \rho \to \eta \pi^+ \pi^- \pi^- \rho$ |
| $B(a_1(2095) \rightarrow f_1(1285)\pi) / B(a_1(2095) \rightarrow a_1(1260))$ |
| |
| |

| X(2100) | $I^{G}(J^{PC}) =$ | · ??(0??) | | | | |
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| MASS (MeV) | WIDTH (MeV) | | DO CUMENT | ID | TECN | COMMENT |
| 2100±40 | 250 ± 40 | | ALDE | 86D | GA M4 | $100 \pi^- p \rightarrow 20$ |
| X(2110) | 1 ^G (J ^{PC}) = | = 1 ⁺ (3 ⁻ ? |) | | | |
| MASS (MeV) | | | | TE | CN COI | MMENT |
| 2110±10 | 330 ± 20 | EV | A NGELIS | 79 ON | ИEG 10, | $16 \pi^- \rho \to \overline{\rho} \rho n$ |
| f ₂ (2140) | 1 G (JPC) = | = 0 ⁺ (2 ⁺ | +) | | | |
| | WIDTH (MeV) | | DOCUMENT | | | COMMENT |
| 2141 ± 12 | 49 ± 28 | 389 | GREEN | 86 | MPSF | 400 pA → 4K |
| | $I^{G}(J^{PC}) =$ | | | | | |
| MASS (MeV) | | | | | | COMMENT |
| 2150±10 | 260 ± 10 | | ROZANSKA | 4 80 | SPRK | 18 $\pi^- p \rightarrow p \overline{p}$ |
| |) 1 ^G (J ^{PC}) | | | T. C. | | |
| MASS (MeV) 2175 ±40 | WIDTH (MeV) 310+90 -45 | A NISO\ | | | | $\rightarrow 3\pi^0, \pi^0\eta, \pi^0$ |
| | 17 | | | | | • |
| η(2190) MASS (MeV) | $I^G(J^{PC}) = \frac{WIDTH (MeV)}{}$ | | , | In | TECN | |
| 2190±50 | 850 ± 100 | | DO CUMENT BUGG | 1D 99 | BES | |
| | | | | | | |
| /01.05 | . C DC | | | | | |
| |) I ^G (J ^{PC}): | | | TECN | COMME | UT. |
| MASS (MeV) 2195 ± 30 36 From the co | $\frac{\text{WIDTH (MeV)}}{225 \pm 40} 3$ ombined analysis | <u>DOCUME</u> 6 ANISON of ANISO | VICH 02B | SPEC | 0.6-1.9 | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 |
| $\frac{MASS (MeV)}{2195 \pm 30}$ $\frac{36}{36}$ From the co | $\frac{WIDTH (MeV)}{225 \pm 40} = 3$ ombined analysis $I^{G}(J^{PC}) = \frac{WIDTH (MeV)}{1}$ | DOCUME 6 ANISO of ANISO 1 0 (1 - 1) DOCUME | VICH 02B VICH 00D, A | SPEC NISOVIC TECN | 0.6–1.9 CH 01c, a <u>COMME</u> | $ ho \overline{ ho} ightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 |
| $MASS (MeV)$ 2195 ± 30 36 From the co ω (2205) $MASS (MeV)$ 2205 ± 30 | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $IG(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ | DOCUME A NISON of A NISO 0 - (1 | VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC | 0.6-1.9 CH 01c, a COMMEN 0.6-1.9 | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co w(2205) MASS (MeV) 2205 ± 30 37 From the co | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $IG(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ | DOCUME 6 A NISON of A NISO 10 - (1 | VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC | 0.6-1.9 CH 01c, a COMMEN 0.6-1.9 | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 |
| $\frac{MASS (\text{MeV})}{2195 \pm 30}$ $\frac{36}{36} \text{From the co}$ $\frac{\omega(2205)}{MASS (\text{MeV})}$ $\frac{37}{37} \text{From the co}$ $\frac{\chi(2210)}{MASS (\text{MeV})}$ | $\frac{WIDTH (\text{MeV})}{225 \pm 40} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{350 \pm 90} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{WIDTH (\text{MeV})} = \frac{WIDTH (\text{MeV})}{WIDT$ | DOCUME 6 ANISO of ANISO of ANISO 0-(1 DOCUME 7 ANISO of ANISO of ANISO | VICH 02B VICH 00D, A | SPEC NISOVIO TECN SPEC NISOVIO | 0.6-1.9 CH 01c, a COMMEN 0.6-1.9 CH 01c, a | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 wt $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 |
| $\frac{MASS (\text{MeV})}{2195 \pm 30}$ $\frac{36}{36} \text{From the co}$ $\frac{\omega(2205)}{MASS (\text{MeV})}$ $\frac{37}{37} \text{From the co}$ $\frac{\chi(2210)}{MASS (\text{MeV})}$ | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^G (J^{PC}) = \frac{1}{3}$ | DOCUME DOCUME ANISO OF ANISO | POT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A | SPEC NISOVIO TECN SPEC NISOVIO | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 wt $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and ANISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 2210 + 79 2210 + 21 | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^{G}(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^{G}(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{203 + 437} = 3$ | DOCUME DOCUME O (1 DOCUME TANISO OF A NISO OF A NISO OF A NISO OF A NISO DOCUME EVAL | POT ID VICH 02B VICH 00D, A TO SENT ID VICH 02B VICH 00D, A WENT ID NGELIS 79 | SPEC NISOVIO TECN SPEC NISOVIO | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 \overline{p} $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 \overline{p} $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 2210 + 79 2210 + 21 | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{203 + 437} = 1$ $I^G(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{87} = 1$ | DOCUME 16 A NISON 16 A NISON 17 A NISON 17 A NISON 17 A NISON 18 DOCUME 19 EVAI 19 EVAI | POT ID VICH 02B VICH 00D, A TO SENT ID VICH 02B VICH 00D, A WENT ID NGELIS 79 | SPEC TECN SPEC NISOVIC TECN SPEC NISOVIC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMME | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \overline{p} |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 2210 + 79 - 21 X(2210) | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^{G}(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^{G}(J^{PC}) = \frac{WIDTH \text{ (MeV)}}{203 + \frac{437}{87}}$ $I^{G}(J^{PC}) = \frac{I^{G}(J^{PC})}{203 + \frac{1}{87}}$ | DOCUME 16 A NISON 16 A NISON 17 A NISON 17 A NISON 17 A NISON 18 DOCUME 19 EVAI 19 EVAI | ENT ID VICH 02B VICH 00D, A -) ENT ID VICH 02B VICH 00D, A | SPEC TECN SPEC NISOVIC TECN SPEC NISOVIC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMMEN COMME | $p\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} ightarrow \overline{p} |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co (2210) MASS (MeV) 2210 + 79 (2210) MASS (MeV) 2210 + 21 | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $\frac{IG(JPC)}{350 \pm 90} = 3$ ombined analysis $\frac{IG(JPC)}{350 \pm 90} = \frac{WIDTH \text{ (MeV)}}{203 \pm 437}$ $\frac{IG(JPC)}{130} = \frac{WIDTH \text{ (MeV)}}{130}$ | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | ENT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A WEENT ID NGELIS 79 DOCUMENT CASO | SPEC NISOVIC TECN SPEC NISOVIC TECN OB OME | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a I COMM TECN HBC | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co (2210) MASS (MeV) 2210 + 79 (2210 + 79 (2210) MASS (MeV) 2207 ± 22 h ₁ (2215) | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{203 + 437}$ $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{130}$ $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{130}$ | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | POCUMENT ID DOCUMENT ID DOCUMENT ID DOCUMENT ID CASO | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN | 0.6-1.9 CH 01c, a COMMEN 0.6-1.9 CH 01c, a I COMM H G 10 π TECN HB C | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 or 0 and A NI SOVI CH 0 or 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 - 21 X(2210) MASS (MeV) 2207 ± 22 h1(2215) MASS (MeV) 2215 ± 40 | $\frac{WIDTH \text{ (MeV)}}{225 \pm 40} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{350 \pm 90} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{203 + 437}$ $I^G (J^{PC}) = \frac{WIDTH \text{ (MeV)}}{130}$ $130 = \frac{WIDTH \text{ (MeV)}}{130} = \frac{WIDTH \text{ (MeV)}}{130} = \frac{WIDTH \text{ (MeV)}}{325 \pm 55} = 3$ | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | ENT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A VICH 0D, A VICH 0D, A VICH 0D, | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a I COMM H G 10 π TECN HB C COMMEN 0.6–1.9 | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 NT $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 $MENT$ $-p \rightarrow K^+ K^- p$ $\frac{COMMENT}{11.2 \pi^- p}$ NT $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 - 21 X(2210) MASS (MeV) 2207 ± 22 h1(2215) MASS (MeV) 2215 ± 40 | $\frac{WIDTH (\text{MeV})}{225 \pm 40} 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{350 \pm 90} 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{87} = \frac{WIDTH (\text{MeV})}{130} = \frac{WIDTH (\text{MeV})}{130} = \frac{WIDTH (\text{MeV})}{325 \pm 55} = \frac{WIDTH (\text{MeV})}{325 \pm 55} = \frac{WIDTH (\text{MeV})}{3000} = \frac{WIDTH (\text{MeV})}{325 \pm 55} = \frac{WIDTH (\text{MeV})}{3000} = \frac{WIDTH (\text{MeV})}{$ | 0 | ENT ID VICH 02B VICH 00D, A ONE ID VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a I COMM H G 10 π TECN HB C COMMEN 0.6–1.9 | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 or 0 and A NI SOVI CH 0 or 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co (2210) MASS (MeV) 2210 + 79 2210 + 79 2210 + 79 2210 + 22 (MASS (MeV) 2207 ± 22 (MASS (MeV) 2215 ± 40 38 From the co (2225) | $\frac{WIDTH(\text{MeV})}{225\pm40} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{350\pm90} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{203+437} = \frac{1}{87}$ $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{130}$ $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{325\pm55} = 3$ ombined analysis | 00000000000000000000000000000000000000 | ENT ID VICH 02B VICH 00D, A -) NOT ID VICH 02B VICH 00D, A VIMENT ID DOCUMENT CASO -) ENT ID VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC NISOVIC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a I COMM HBC COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and a NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ $\overline{p} \rightarrow \kappa^+ \kappa^- \rho$ and a NISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 - 21 X(2210) MASS (MeV) 2207 ± 22 h1(2215 ± 40 38 From the co ρ2(2225) MASS (MeV) | $\frac{WIDTH(\text{MeV})}{225\pm40} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{350\pm90} = 3$ ombined analysis $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{87}$ $203 + \frac{437}{87}$ $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{130}$ 130 $I^G(J^{PC}) = \frac{WIDTH(\text{MeV})}{325\pm55} = 3$ ombined analysis | 00000000000000000000000000000000000000 | POCUMENT ID DOCUMENT ID COMENT ID | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC NISOVIC | 0.6–1.9 COMMEN 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a TECN HB C COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 NT $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $MENT$ $COMMENT$ $11.2 \ \pi^- p$ NT $P\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 - 21 X(2210) MASS (MeV) 2207 ± 22 h1(2215 MASS (MeV) 2215 ± 40 38 From the co ρ2(2225 MASS (MeV) 2225 ± 35 | $\frac{WIDTH (\text{MeV})}{225 \pm 40} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{350 \pm 90} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{87} = \frac{WIDTH (\text{MeV})}{130} = \frac{WIDTH (\text{MeV})}{130} = \frac{WIDTH (\text{MeV})}{325 \pm 55} = 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{335 \pm 50} = \frac{WIDTH (\text{MeV})}{350} = \frac{WIDTH (\text{MeV})}{350} = \frac{WIDTH (\text{MeV})}{350} = WIDTH $ | DOCUME 1 | ENT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A MEENT ID NGELIS 79 DOCUMENT CASO ONT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC NISOVIC TECN SPEC NISOVIC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a J COMM HBC COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NI SOVI CH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ $\overline{p} \rightarrow \omega \pi^0$ $\overline{p} \rightarrow \omega \pi^0$ |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 - 21 X(2210) MASS (MeV) 2207 ± 22 h1(2215 MASS (MeV) 2215 ± 40 38 From the co ρ2(2225 MASS (MeV) 2225 ± 35 | $\frac{WIDTH(\text{MeV})}{225\pm40} = 3$ ombined analysis $\frac{I^G(J^PC)}{350\pm90} = \frac{WIDTH(\text{MeV})}{350\pm90} = 3$ ombined analysis $\frac{I^G(J^PC)}{203+\frac{4}{37}} = \frac{WIDTH(\text{MeV})}{130} = \frac{WIDTH(\text{MeV})}{130} = \frac{WIDTH(\text{MeV})}{325\pm55} = 3$ ombined analysis $\frac{I^G(J^PC)}{203+\frac{4}{37}} = \frac{WIDTH(\text{MeV})}{325\pm55} = \frac{WIDTH(\text{MeV})}{325\pm50} = \frac{WIDTH(\text{MeV})}{335\pm\frac{1}{50}} = WIDTH$ | DOCUME 1 | ENT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A MEENT ID NGELIS 79 DOCUMENT CASO ONT ID VICH 02B VICH 00D, A ONT ID VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC NISOVIC TECN 70 TECN SPEC NISOVIC TECN SPEC NISOVIC | 0.6–1.9 CH 01c, a COMMEN 0.6–1.9 CH 01c, a J COMM HBC COMMEN 0.6–1.9 CH 01c, a | $p\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 $\overline{p} \rightarrow \omega \eta, \ \omega \pi^0$ and A NISOVICH 0 |
| MASS (MeV) 2195 ± 30 36 From the co (2205) MASS (MeV) 2205 ± 30 37 From the co X(2210) MASS (MeV) 2210 + 79 X(2210) MASS (MeV) 2210 + 22 MASS (MeV) 2215 ± 40 38 From the co ρ ₂ (2225) MASS (MeV) 2225 ± 35 39 From the co | $\frac{WIDTH (\text{MeV})}{225 \pm 40} 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{350 \pm 90} 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{203 + 437}$ $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{130}$ 130 $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{325 \pm 55} 3$ ombined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{335 + 100}$ $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{3000}$ combined analysis $I^G (J^{PC}) = \frac{WIDTH (\text{MeV})}{3000}$ combined analysis | 00000000000000000000000000000000000000 | ENT ID VICH 02B VICH 00D, A VICH 02B VICH 00D, A | SPEC NISOVIC TECN SPEC NISOVIC | COMMEN (COMMEN (COMME | $\begin{array}{c} \rho\overline{\rho} \rightarrow \omega\eta, \ \omega\pi^0 \\ \text{and A NISOVICH 0} \\ \\ \hline NT \\ \rho\overline{\rho} \rightarrow \omega\eta, \ \omega\pi^0 \\ \\ \text{and A NISOVICH 0} \\ \\ \hline MENT \\ \hline -\rho \rightarrow K^+K^-\rho \\ \\ \hline \frac{COMMENT}{11.2 \ \pi^-\rho} \\ \\ \hline NT \\ \hline \rho\overline{\rho} \rightarrow \omega\eta, \ \omega\pi^0 \\ \\ \text{and A NISOVICH 0} \\ \\ \hline MMENT \\ \hline -1.9 \ \rho\overline{\rho} \rightarrow \omega\pi^0 \\ \\ \omega\eta\pi^0, \ \pi^+\pi^- \\ \\ D, \ \text{A NISOVICH 0} \\ \end{array}$ |

Further States

 41 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

 $^{42}\,\text{From}$ the combined analysis of ANISOVICH 99c, ANISOVICH 99f, ANISOVICH 99J, ANISOVICH 99K, and ANISOVICH 00B. See also ANISOVICH 12.

 43 From the combined analysis of ANISOVICH 00J, ANISOVICH 01D, ANISOVICH 01E, and ANISOVICH 02.

and ANISOVICH 01G.

 45 From the combined analysis of ANISOVICH 00D, ANISOVICH 01c, and ANISOVICH 02B.

 $^{
m 47}$ From the combined analysis of ANISOVICH 99c, ANISOVICH 99E, and ANISOVICH 01F.

 A2(2255)
 $I^G(J^{PC}) = 1^{-(2++)}$ $I^{DOCUMENT ID}$ I^{ECN} I^{ECN}

X(2260) $I^G(J^{PC}) = 0^+(4^{+?})$ MASS (MeV) WIDTH (MeV) DOCUMENT ID TECN COMMENT

X (2260) $I^{\circ}(J^{\circ}) = 0^{\circ}(4^{++})$ $I^{\circ}(J^{\circ}) = 0^{\circ}(4^{++})$ $I^{\circ}(J^{\circ}) = 0^{\circ}(4^{++})$ MASS (MeV)WIDTH (MeV)DOCUMENT IDTECNCOMMENT2260 ± 20 400 ± 100 EVANGELIS... 79OMEG $10,16 \pi^{-} p \rightarrow \overline{p} \rho n$

 50 From the combined analysis of A NISOVICH 00D, A NISOVICH 01c, and A NISOVICH 02B.

 $^{51}\,\mathrm{From}$ the combined analysis of ANISOVICH 99c, ANISOVICH 99e, ANISOVICH 01f, and ANISOVICH 01g.

 π_2 (2285)
 $I^G(J^{PC}) = 1^-(2^{-+})$ J^{PC} t

 54 From the combined analysis of A NISOVICH 00D, A NISOVICH 01C, and A NISOVICH 02B.

⁵⁵ Partial wave analysis of the data on $p\overline{p} \to \overline{\Lambda}\Lambda$ from BARNES 00.

 f₂(2295)
 $I^G(J^{PC}) = 0 + (2 + +)$

 MASS (MeV)
 WIDTH (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 2293±13
 216 ± 37
 56 ANISOVICH
 00J
 SPEC
 1.92-2.41 $p\overline{p}$

56 From the combined analysis of ANISOVICH 99c, ANISOVICH 99f, ANISOVICH 99J, ANISOVICH 99κ, and ANISOVICH 00B. See also ANISOVICH 12.

 f_3 (2300)
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 2334 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 234 ± 25
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$

 235 ± 26
 $I^G(J^{PC}) = 0^+(3^{++})$ $I^G(J^{PC}) = 0^+(3^{++})$ </td

 $^{57}\,\text{Partial}$ wave analysis of the data on $\rho\,\overline{p}\to~\overline{\Lambda}\Lambda$ from BARNES 00.

⁵⁸ From the combined analysis of $\overline{p}p \to \eta \eta \eta$ from ANISOVICH 00M and $\overline{p}p \to \eta \pi^0 \pi^0$ from ANISOVICH 00I

which contain $\rho^+ \rho^0 \pi^0$ and $2\rho^+ \pi^-$

 X(2360)
 $I^G(J^{PC}) = ?^2(4+?)$ DOCUMENT ID
 TECN
 COMMENT

 2360 ± 10
 430 ± 30
 ROZANSKA
 80
 SPRK
 $18 \pi^- p \rightarrow p \overline{p} n$

Meson Particle Listings Further States

| X(2632) X(2632) MASS (MEV) 2635.2±3.3 2631.6±2.1 60 From a mass of 61 From a ma | | ROZANSKA 80 SPRK $18 \pi^- p \rightarrow p\overline{p}$. $P^{(???)}$ $DOCUMENT ID$ $EVDOKIMOV 04$ |
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| MASS (MeV) 635.2±3.3 631.6±2.1 60 From a mass of 61 From a mass of B(| $\frac{\text{WIDTH (MeV)}}{<17}$ <17 difference to D_S^+ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| MASS (MeV) 2635.2±3.3 2631.6±2.1 60 From a mass of 61 From a mass of | $\frac{\text{WIDTH (MeV)}}{<17}$ <17 difference to D_S^+ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 2631.6±2.1 ⁶⁰ From a mass of ⁶¹ From a mass of B (| difference to D_S^+ | ⁶¹ EVDOKIMOV 04 SELX $X(2632) \rightarrow D^{0} K^{-1}$ |
| 60 From a mass of 61 From a mass of B (| difference to D_S^+ | ⁶¹ EVDOKIMOV 04 SELX $X(2632) \rightarrow D^{0} K^{-1}$ |
| В(| | |
| В(| | 「of 666.9 ± 3.3 MeV. |
| | | of 767.0 \pm 2.0 MeV. |
| ALUE | $(X(2632) \rightarrow D$ | ${}^{0}K^{+})/B(X(2632) \rightarrow D_{s}^{+}\eta)$ |
| 0.14±0.06 | | DOCUMENT ID TECN 62 EVDOKIMOV 04 SELX |
| | | |
| Possible interp | retation of this | decay pattern is discussed by YASUI 07. |
| X(2680) | $I^G(J^{PC}) = ?$ | ?(???) |
| MASS (MeV) WID | OTH (MeV) | DOCUMENT ID TECN COMMENT |
| 2676 ± 27 150 |) | CASO 70 HBC 11.2 $\pi^- p \to \rho^- \pi^+ \pi^-$ |
| X(2750) | IG(IPC) = 7 | ROZANSKA 80 SPRK $18 \pi^- p \rightarrow p \overline{p}$. |
| AASS (MeV) WID | $I^{G}(J^{PC}) = ?$ $OTH (MeV)$ 0 ± 75 | · · · · · · |
| MASS (MeV) WID 2747±32 195 f6(3100) | $\frac{OTH \text{ (MeV)}}{5 \pm 75}$ $I^G(J^{PC}) = 0$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| MASS (MeV) WID 1747±32 195 (3100) MASS (MeV) | $STH (MeV)$ $S \pm 75$ $I^G (J^{PC}) = 0$ $WIDTH (MeV)$ | $p^{2}(7^{-2})$ DOCUMENT ID DENNEY 83 LASS $10 \pi^{+} p \rightarrow K^{+} K^{-} \pi^{+}$ $0^{+}(6^{+})$ DOCUMENT ID TECN COMMENT |
| MASS (MeV) WID 1747±32 195 (3100) MASS (MeV) | $\frac{OTH \text{ (MeV)}}{5 \pm 75}$ $I^G(J^{PC}) = 0$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### ################################## | $\frac{1G(J^{PC})}{16 \pm 75} = 0$ $\frac{1G(J^{PC})}{16 \pm 75} = 0$ $\frac{WIDTH \text{ (MeV)}}{160 \pm 130}$ $1G(J^{PC}) = 0$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### ################################## | $IG(J^{PC}) = 0$ $IG(J^{PC}) = 0$ $WIDTH (MeV)$ 700 ± 130 $IG(J^{PC}) = 0$ $WIDTH (MeV)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### ################################## | $\frac{1G(J^{PC})}{16 \pm 75} = 0$ $\frac{1G(J^{PC})}{16 \pm 75} = 0$ $\frac{WIDTH \text{ (MeV)}}{160 \pm 130}$ $1G(J^{PC}) = 0$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### ### ### ### ### ### ### ### ### ## | $ \frac{1G(J^{PC})}{1G(J^{PC})} = 0 $ $ \frac{1G(J^{PC})}{130} = 0 $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### MASS (MeV) WILD 195 ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (3100) ### (310 | $ \frac{IG(J^{PC})}{IG(J^{PC})} = 0 $ $\frac{IG(J^{PC})}{IG(J^{PC})} = 0 $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ### ### ### ### ### ### ### ### ### ## | $ \frac{1G(J^{PC})}{1G(J^{PC})} = 0 $ $ \frac{1G(J^{PC})}{130} = 0 $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

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 K^{\pm}

STRANGE MESONS $(S = \pm 1, C = B = 0)$

$$K^+ = u\overline{s}$$
, $K^0 = d\overline{s}$, $\overline{K}^0 = \overline{d}s$, $K^- = \overline{u}s$, similarly for K^* 's



$$I(J^P) = \frac{1}{2}(0^-)$$

THE CHARGED KAON MASS

Revised 1994 by T.G. Trippe (LBNL).

The average of the six charged kaon mass measurements which we use in the Particle Listings is

$$m_{K^{\pm}} = 493.677 \pm 0.013 \text{ MeV (S} = 2.4),$$
 (1)

where the error has been increased by the scale factor S. The large scale factor indicates a serious disagreement between different input data. The average before scaling the error is

$$m_{K^{\pm}} = 493.677 \pm 0.005 \text{ MeV}$$
 ,
 $\chi^2 = 22.9 \text{ for 5 D.F., Prob.} = 0.04\%$, (2)

where the high χ^2 and correspondingly low χ^2 probability further quantify the disagreement.

The main disagreement is between the two most recent and precise results,

$$m_{K^{\pm}} = 493.696 \pm 0.007 \ \mbox{MeV} \ \ \ \ \mbox{DENISOV 91}$$

$$m_{K^{\pm}} = 493.636 \pm 0.011 \ \mbox{MeV (S} = 1.5) \ \mbox{GALL 88}$$

Average $=493.679 \pm 0.006 \text{ MeV}$

$$\chi^2 = 21.2 \text{ for } 1 \text{ D.F.}, \text{ Prob.} = 0.0004\%, (3)$$

both of which are measurements of x-ray energies from kaonic atoms. Comparing the average in Eq. (3) with the overall average in Eq. (2), it is clear that DENISOV 91 and GALL 88 dominate the overall average, and that their disagreement is responsible for most of the high χ^2 .

The GALL 88 measurement was made using four different kaonic atom transitions, K^- Pb (9 \to 8), K^- Pb (11 \to 10), K^- W (9 \to 8), and K^- W (11 \to 10). The m_{K^\pm} values they obtain from each of these transitions is shown in the Particle Listings and in Fig. 1. Their K^- Pb (9 \to 8) m_{K^\pm} is below and somewhat inconsistent with their other three transitions. The average of their four measurements is

$$m_{K^{\pm}} = 493.636 \pm 0.007$$
 ,
$$\gamma^2 = 7.0 \ \text{for 3 D.F., Prob.} = 7.2\% \ . \tag{4}$$

This is a low but acceptable χ^2 probability so, to be conservative, GALL 88 scaled up the error on their average by S=1.5 to obtain their published error ± 0.011 shown in Eq. (3) above and used in the Particle Listings average.

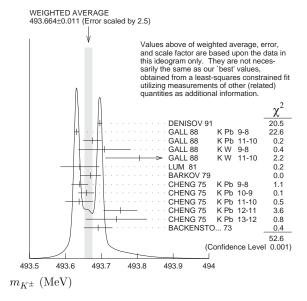


Figure 1: Ideogram of $m_{K^{\pm}}$ mass measurements. GALL 88 and CHENG 75 measurements are shown separately for each transition they measured.

The ideogram in Fig. 1 shows that the DENISOV 91 measurement and the GALL 88 K^- Pb (9 \rightarrow 8) measurement yield two well-separated peaks. One might suspect the GALL 88 K^- Pb (9 \rightarrow 8) measurement since it is responsible both for the internal inconsistency in the GALL 88 measurements and the disagreement with DENISOV 91.

To see if the disagreement could result from a systematic problem with the K^- Pb $(9 \to 8)$ transition, we have separated the CHENG 75 data, which also used K^- Pb, into its separate transitions. Figure 1 shows that the CHENG 75 and GALL 88 K^- Pb (9 \rightarrow 8) values are consistent, suggesting the possibility of a common effect such as contaminant nuclear γ rays near the K^- Pb (9 \rightarrow 8) transition energy, although the CHENG 75 errors are too large to make a strong conclusion. The average of all 13 measurements has a χ^2 of 52.6 as shown in Fig. 1 and the first line of Table 1, yielding an unacceptable χ^2 probability of 0.00005%. The second line of Table 1 excludes both the GALL 88 and CHENG 75 measurements of the K^- Pb (9 \rightarrow 8) transition and yields a χ^2 probability of 43%. The third [fourth] line of Table 1 excludes only the GALL 88 K^- Pb (9 \rightarrow 8) [DENISOV 91] measurement and yields a χ^2 probability of 20% [8.6%]. Table 1 shows that removing both measurements of the K^- Pb (9 \rightarrow 8) transition produces the most consistent set of data, but that excluding only the GALL 88 K^- Pb (9 \rightarrow 8) transition or DENISOV 91 also produces acceptable probabilities.

Table 1: $m_{K^{\pm}}$ averages for some combinations of Fig. 1 data.

| $m_{K^{\pm}} \; (\mathrm{MeV})$ | χ^2 | D.F. | Prob. (% | Measurements used | |
|---------------------------------|----------|------|-----------|---------------------------------------------|----|
| 493.664 ± 0.004 | 52.6 | 12 | 0.00005 a | all 13 measurements | |
| 493.690 ± 0.006 | 10.1 | 10 | | no $K^- \operatorname{Pb}(9 \rightarrow 8)$ | |
| 493.687 ± 0.006 | 14.6 | 11 | 20 | no GALL 88 K^- Pb(9 \rightarrow 8 | 8) |
| 493.642 ± 0.006 | 17.8 | 11 | 8.6 | no DENISOV 91 | |

Yu.M. Ivanov, representing DENISOV 91, has estimated corrections needed for the older experiments because of improved $^{192}\mathrm{Ir}$ and $^{198}\mathrm{Au}$ calibration $\gamma\text{-ray}$ energies. He estimates that CHENG 75 and BACKENSTOSS 73 m_{K^\pm} values could be raised by about 15 keV and 22 keV, respectively. With these estimated corrections, Table 1 becomes Table 2. The last line of Table 2 shows that if such corrections are assumed, then GALL 88 K^- Pb (9 \rightarrow 8) is inconsistent with the rest of the data even when DENISOV 91 is excluded. Yu.M. Ivanov warns that these are rough estimates. Accordingly, we do not use Table 2 to reject the GALL 88 K^- Pb (9 \rightarrow 8) transition, but we note that a future reanalysis of the CHENG 75 data could be useful because it might provide supporting evidence for such a rejection.

Table 2: $m_{K^{\pm}}$ averages for some combinations of Fig. 1 data after raising CHENG 75 and BACKENSTOSS 73 values by 0.015 and 0.022 MeV respectively.

| $m_{K^{\pm}} \; (\text{MeV})$ | χ^2 | D.F. | Prob. (% |) Measurements used |
|-------------------------------|----------|------|-----------|---------------------------------------------|
| 493.666 ± 0.004 | 53.9 | 12 | 0.00003 a | all 13 measurements |
| 493.693 ± 0.006 | 9.0 | 10 | 53 | no $K^- \operatorname{Pb}(9 \rightarrow 8)$ |
| 493.690 ± 0.006 | 11.5 | 11 | 40 ı | no GALL 88 K^- Pb(9 \rightarrow 8) |
| 493.645 ± 0.006 | 23.0 | 11 | 1.8 | no DENISOV 91 |

The GALL 88 measurement uses a Ge semiconductor spectrometer which has a resolution of about 1 keV, so they run the risk of some contaminant nuclear γ rays. Studies of γ rays following stopped π^- and Σ^- absorption in nuclei (unpublished) do not show any evidence for contaminants according to GALL 88 spokesperson, B.L. Roberts. The DENISOV 91 measurement uses a crystal diffraction spectrometer with a resolution of 6.3 eV for radiation at 22.1 keV to measure the 4f-3d transition in $K^{--12}C$. The high resolution and the light nucleus reduce the probability for overlap by contaminant γ rays, compared with the measurement of GALL 88. The DENISOV 91 measurement is supported by their high-precision measurement of the 4d-2p transition energy in $\pi^{--12}C$, which is good agreement with the calculated energy.

While we suspect that the GALL 88 K^- Pb (9 \rightarrow 8) measurements could be the problem, we are unable to find clear grounds for rejecting it. Therefore, we retain their measurement in the average and accept the large scale factor until further information can be obtained from new measurements and/or from reanalysis of GALL 88 and CHENG 75 data.

We thank B.L. Roberts (Boston Univ.) and Yu.M. Ivanov (Petersburg Nuclear Physics Inst.) for their extensive help in understanding this problem.

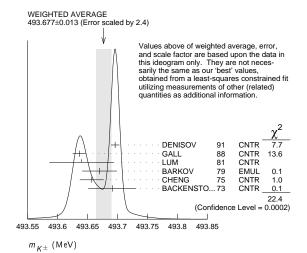
K± MASS

| VALUE (MeV) | DO CUMENT ID | | TECN CHG | COMMENT |
|-------------------------------|-----------------------|---------|------------------|----------------------------------|
| 493.677 ± 0.016 OUR FIT | Error includes scale | facto | of 2.8. | |
| 493.677 ± 0.013 OUR AVER | RAGE Error include | s scale | e factor of 2.4 | See the ideogram |
| below. | | | | · · |
| 493.696 ± 0.007 | ¹ DENISOV | 91 | CNTR - | Kaonic atoms |
| 493.636 ± 0.011 | ² GALL | 88 | CNTR - | Kaonic atoms |
| 493.640 ± 0.054 | LUM | 81 | CNTR - | Kaonic atoms |
| 493.670 ± 0.029 | BARKOV | 79 | EMUL \pm | $e^+ e^- ightarrow K^+ K^-$ |
| 493.657 ± 0.020 | ² CHENG | 75 | CNTR - | Kaonic atoms |
| 493.691 ± 0.040 | BACKENSTO | 73 | CNTR - | Kaonic atoms |
| • • • We do not use the fo | ollowing data for ave | erages, | fits, limits, et | C. • • • |
| 493.631 ± 0.007 | GALL | 88 | CNTR - | K ⁻ Pb (9→ 8) |
| 493.675 ± 0.026 | GALL | 88 | CNTR - | K^- Pb $(11 \rightarrow 10)$ |
| 493.709 ± 0.073 | GALL | 88 | CNTR - | K ⁻ W (9→ 8) |
| 493.806 ± 0.095 | GALL | 88 | CNTR - | K^-W (11 \rightarrow 10) |
| $493.640 \pm 0.022 \pm 0.008$ | ³ CHENG | 75 | CNTR - | K^- Pb (9 \rightarrow 8) |
| $493.658 \pm 0.019 \pm 0.012$ | ³ CHENG | 75 | CNTR - | K^- Pb $(10 \rightarrow 9)$ |
| $493.638 \pm 0.035 \pm 0.016$ | ³ CHENG | 75 | CNTR - | K^- Pb $(11 \rightarrow 10)$ |
| $493.753 \pm 0.042 \pm 0.021$ | ³ CHENG | 75 | CNTR - | K-Pb (12→ 11) |
| $493.742 \pm 0.081 \pm 0.027$ | ³ CHENG | 75 | CNTR - | K^- Pb $(13 \rightarrow 12)$ |

¹ Error increased from 0.0059 based on the error analysis in IVANOV 92.

 $^{2}\,\mbox{This value}$ is the authors' combination of all of the separate transitions listed for this paper.

 3 The CHENG 75 values for separate transitions were calculated from their Table 7 transition energies. The first error includes a 20% systematic error in the noncircular contaminant shift. The second error is due to a ± 5 eV uncertainty in the theoretical transition energies.



 $m_{K^+} - m_{K^-}$

Test of CPT.

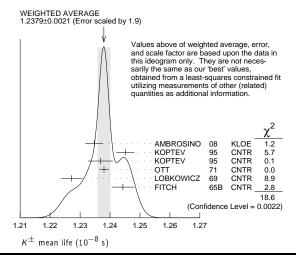
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG |
|-------------------------------|------------------|----------------------------------|----|------|-------|
| -0.032 ± 0.090 | 1.5 M | ⁴ FORD | 72 | ASPK | \pm |
| 4 FORD 72 uses m_{π^+} | m _π - | $_{-} = +28 \pm 70 \text{ keV}.$ | | | |

K[±] MEAN LIFE

| <i>VALUE</i> (10 ⁻⁸ s) | EVTS | DOCUMENT ID | | TECN CHG | COMMENT |
|-----------------------------------|----------------|------------------------|--------|------------------|---------------------------|
| 1.2380 ± 0.0021 C | UR FIT Err | or includes scale | factor | of 1.9. | |
| 1.2379 ± 0.0021 C | UR AVERAG | E Error includes | scale | factor of 1.9 | See the ideogram |
| below. | | | | | |
| 1.2347 ± 0.0030 | 15 M | ⁵ AMBROSINO | 80 | KLOE \pm | $\phi \rightarrow K^+K^-$ |
| 1.2451 ± 0.0030 | 250k | KOPTEV | 95 | CNTR | K at rest, U target |
| 1.2368 ± 0.0041 | 150k | KOPTEV | 95 | CNTR | K at rest, Cu target |
| 1.2380 ± 0.0016 | 3M | OTT | 71 | CNTR + | K at rest |
| 1.2272 ± 0.0036 | | LOBKOWICZ | 69 | CNTR + | K in flight |
| 1.2443 ± 0.0038 | | FITCH | 65 B | CNTR + | K at rest |
| • • • We do not | use the follow | ving data for aver | ages, | fits, limits, et | C. • • • |
| 1.2415 ± 0.0024 | 400k | ⁶ KOPTEV | 95 | CNTR | K at rest |
| 1.221 ± 0.011 | | FORD | 67 | CNTR ± | |
| $1.231\ \pm0.011$ | | BOYARSKI | 62 | CNTR + | |

K

into account. 6 KOPTEV 95 report this weighted average of their U-target and Cu-target results, where they have weighted by $1/\sigma$ rather than $1/\sigma^2$.



 $(\tau_{K^+} - \tau_{K^-}) / \tau_{average}$

This quantity is a measure of CPT invariance in weak interactions.

| VALUE (%) | DO CUMENT ID | TECN |
|------------------------|--------------------------|-------------|
| 0.10 ±0.09 OUR AVERAGE | Error includes scale fac | tor of 1.2. |
| -0.4 ± 0.4 | AMBROSINO 08 | KLOE |
| 0.090 ± 0.078 | LOBKOWICZ 69 | CNTR |
| 0.47 ± 0.30 | FORD 67 | CNTR |

RARE KAON DECAYS

Revised November 2011 by L. Littenberg (BNL) and G. Valencia (Iowa State University).

- A. Introduction: There are several useful reviews on rare kaon decays and related topics [1–15]. Activity in rare kaon decays can be divided roughly into four categories:
- 1. Searches for explicit violations of the Standard Model
- 2. Measurements of Standard Model parameters
- 3. Searches for ${\cal CP}$ violation
- 4. Studies of strong interactions at low energy.

The paradigm of Category 1 is the lepton flavor violating decay $K_L \to \mu e$. Category 2 includes processes such as $K^+ \to \pi^+ \nu \overline{\nu}$, which is sensitive to $|V_{td}|$. Much of the interest in Category 3 is focused on the decays $K_L \to \pi^0 \ell \overline{\ell}$, where $\ell \equiv e, \mu, \nu$. Category 4 includes reactions like $K^+ \to \pi^+ \ell^+ \ell^-$ which constitute a testing ground for the ideas of chiral perturbation theory. Category 4 also includes $K_L \to \pi^0 \gamma \gamma$ and $K_L \to \ell^+ \ell^- \gamma$. The former is important in understanding a CP-conserving contribution to $K_L \to \pi^0 \ell^+ \ell^-$, whereas the latter could shed light on long distance contributions to $K_L \to \mu^+ \mu^-$.

The interplay between Categories 2-4 can be illustrated in Fig. 1. The modes $K \to \pi \nu \overline{\nu}$ are the cleanest ones theoretically. They can provide accurate determinations of certain CKM parameters (shown in the figure). In combination with alternate determinations of these parameters, they also constrain new interactions. The modes $K_L \to \pi^0 e^+ e^-$, $K_L \to \pi^0 \mu^+ \mu^-$ and $K_L \to \mu^+ \mu^-$ are also sensitive to CKM parameters. However, they suffer from a series of hadronic uncertainties that can be addressed, at least in part, through a systematic study of the additional modes indicated in the figure.

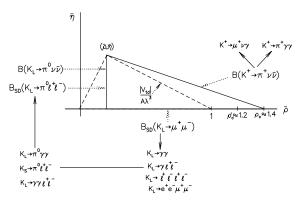


Figure 1: Role of rare kaon decays in determining the unitarity triangle. The solid arrows point to auxiliary modes needed to interpret the main results, or potential backgrounds to them.

B. Explicit violations of the Standard Model: Much activity has focussed on searches for lepton flavor violation (LFV). This is motivated by the fact that many extensions of the minimal Standard Model violate lepton flavor and by the potential to access very high energy scales. For example, the tree-level exchange of a LFV vector boson of mass M_X that couples to lefthanded fermions with electroweak strength and without mixing angles yields $B(K_L \to \mu e) = 4.7 \times 10^{-12} (148 \text{ TeV}/M_X)^4$ [4]. This simple dimensional analysis may be used to read from Table 1 that the reaction $K_L \to \mu e$ is already probing scales of over 100 TeV. Table 1 summarizes the present experimental situation vis a vis LFV. The decays $K_L \to \mu^{\pm} e^{\mp}$ and $K^+ \to \pi^+ e^{\mp} \mu^{\pm}$ (or $K_L \to \pi^0 e^{\mp} \mu^{\pm}$) provide complementary information on potential family number violating interactions, since the former is sensitive to parity-odd couplings and the latter is sensitive to parity-even couplings. Limits on certain lepton-number violating kaon decays also exist, some recent ones being those of Refs. [16–18]. Related searches in μ and au processes are discussed in our section "Tests of Conservation Laws."

Table 1: Searches for lepton flavor violation in K decay

| Mode | 90% CL upper limit | Exp't | Yr./Ref. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------|
| $\begin{array}{l} \overline{K^+ \to \pi^+ e^- \mu^+} \\ K^+ \to \pi^+ e^+ \mu^- \\ K_L \to \mu e \\ K_L \to \pi^0 e \mu \\ K_L \to \pi^0 \pi^0 e \mu \end{array}$ | $1.2 \times 10^{-11} \\ 5.2 \times 10^{-10} \\ 4.7 \times 10^{-12} \\ 7.6 \times 10^{-11} \\ 1.7 \times 10^{-10}$ | BNL-865 BNL-865 BNL-871 KTeV KTeV | 2005/Ref. 19 2000/Ref. 16 1998/Ref. 20 2008/Ref. 21 2008/Ref. 21 |

Physics beyond the SM is also pursued through the search for $K^+ \to \pi^+ X^0$, where X^0 is a new light particle. The searches cover both long-lived particles (e.g., hyperphoton, axion, familon, etc.), and short lived ones that decay to muon, electron or photon pairs. The 90% CL upper limit on $K^+ \to \pi^+ X^0$ is 7.3×10^{-11} [22]. Recent new bounds for a short lived

⁵ Result obtained by averaging the decay length and decay time analyses taking correlations

pseudoscalar X^0 decaying to muons or photons are $B(K_L \to \pi^0 \pi^0 \mu^+ \mu^-) < 1 \times 10^{-10}$ [23] and $B(K_L \to \pi^0 \pi^0 \gamma \gamma) < 2.4 \times 10^{-7}$ [24].

C. Measurements of Standard Model parameters:

In the SM, the decay $K^+ \to \pi^+ \nu \overline{\nu}$ is dominated by one-loop diagrams with top-quark intermediate states and long-distance contributions are known to be quite small [2,25]. This permits a precise calculation of this rate in terms of SM parameters. Studies of this process are thus motivated by the possibility of detecting non-SM physics when comparing with the results of global fits [28,29].

BNL-787 observed two candidate events [30,31] in the clean high π^+ momentum and one event [32] in the low-momentum region. The successor experiment BNL-949 observed one more in the high-momentum region [22] and three more in the low-momentum region [33] yielding a branching ratio of $(1.73^{+1.15}_{-1.05}) \times 10^{-10}$ [34]. A new experiment, NA62, with a sensitivity goal of $\sim 10^{-12}/\text{event}$ was proposed [35] at CERN in 2005. It has been approved and is scheduled to run with a partial detector in autumn 2012. In the future, this mode may provide grounds for precision tests of flavor dynamics [36]. The branching ratio can be written in a compact form that exhibits the different ingredients that go into the calculation [37],

$$B(K^{+} \to \pi^{+} \nu \overline{\nu}(\gamma)) = \kappa_{+} (1 + \Delta_{EM}) \left[\left(\frac{\operatorname{Im}(V_{ts}^{\star} V_{td})}{\lambda^{5}} X_{t} \right)^{2} + \left(\frac{\operatorname{Re}(V_{cs}^{\star} V_{cd})}{\lambda} (P_{c} + \delta P_{c,u}) + \frac{\operatorname{Re}(V_{ts}^{\star} V_{td})}{\lambda^{5}} X_{t} \right)^{2} \right]. \quad (1)$$

The parameters in Eq. (1) incorporate the a priori unknown hadronic matrix element in terms of the very well-measured K_{e3} rate [2] in κ_+ ; long distance QED corrections in $\Delta_{\rm EM}$ [27]; the Inami-Lim function for the short distance top-quark contribution [38] including NLO QCD corrections [39] and the two-loop electroweak correction [37], all in X_t ; and the charm-quark contributions due to short distance effects including NNLO QCD corrections [40] and NLO electroweak corrections via P_c [41], as well as certain long distance effects via $\delta P_{c,u}$ [26]. An interesting approximate way to cast this result in terms of the CKM parameters λ , V_{cb} , $\overline{\rho}$ and $\overline{\eta}$ (see our Section on "The Cabibbo-Kobayashi-Maskawa mixing matrix") [11] is:

$$B(K^+ \to \pi^+ \nu \overline{\nu}) \approx 1.6 \times 10^{-5} |V_{cb}|^4 [\sigma \overline{\eta}^2 + (\rho_c - \overline{\rho})^2],$$
 (2)

where $\rho_c \approx 1.45$ and $\sigma \equiv 1/(1-\frac{1}{2}\lambda^2)^2$. Thus, $\mathrm{B}(K^+ \to \pi^+ \nu \overline{\nu})$ determines an ellipse in the $\overline{\rho}$, $\overline{\eta}$ plane with center $(\rho_c,0)$ and semiaxes $\approx \frac{1}{|V_{cb}|^2} \sqrt{\frac{\mathrm{B}(K^+ \to \pi^+ \nu \overline{\nu})}{1.6 \times 10^{-5}}}$ and $\frac{1}{\sigma |V_{cb}|^2} \sqrt{\frac{\mathrm{B}(K^+ \to \pi^+ \nu \overline{\nu})}{1.6 \times 10^{-5}}}$. The latest numerical study leads to a predicted branching ratio $(7.81^{+0.80}_{-0.71} \pm 0.29) \times 10^{-11}$ [37], near the lower end of the measurement of BNL-787 and 949.

Modes with an extra pion, $K \to \pi\pi\nu\bar{\nu}$, could also be used in the extraction of CKM parameters as they are also dominated by short distance contributions [42]. However, they occur at much lower rates with branching rations of order 10^{-13} , and the current best bound from E391a is $B(K_L \to \pi^0\pi^0\nu\bar{\nu}) <$

 8.1×10^{-7} at 90% c.l. [43]. There is also an older bound of $B(K^+\to \pi^+\pi^0\nu\bar{\nu})<4.3\times 10^{-5}$ at 90% c.l. [44] from BNL E787.

The decay $K_L \to \mu^+ \mu^-$ also has a short distance contribution sensitive to the CKM parameter $\overline{\rho}$, given by [11]:

$$B_{SD}(K_L \to \mu^+ \mu^-) \approx 2.7 \times 10^{-4} |V_{cb}|^4 (\rho_c' - \overline{\rho})^2$$
 (3)

where ρ'_c depends on the charm quark mass and is approximately 1.2. This decay, however, is dominated by a long-distance contribution from a two-photon intermediate state. The absorptive (imaginary) part of the long-distance component is determined by the measured rate for $K_L \to \gamma \gamma$ to be $B_{abs}(K_L \to \mu^+ \mu^-) =$ $(6.64 \pm 0.07) \times 10^{-9}$; and it almost completely saturates the observed rate B($K_L \to \mu^+ \mu^-$) = $(6.84 \pm 0.11) \times 10^{-9}$ [45]. The difference between the observed rate and the absorptive component can be attributed to the (coherent) sum of the short-distance amplitude and the real part of the longdistance amplitude. The latter cannot be derived directly from experiment [46], but can be estimated with certain assumptions [47,48]. The decay $K_L \to e^+e^-$ is completely dominated by long distance physics and is easier to estimate. The result, $B(K_L \to e^+e^-) \sim 9 \times 10^{-12}$ [46,49], is in good agreement with the BNL-871 measurement, $(8.7^{+5.7}_{-4.1}) \times 10^{-12}$ [50].

D. Searches for direct CP violation: The mode $K_L \to \pi^0 \nu \overline{\nu}$ is dominantly CP-violating and free of hadronic uncertainties [2,51,52]. In the Standard Model, this mode is dominated by an intermediate top-quark state and does not suffer from the small uncertainty associated with the charm-quark intermediate state that affects the mode $K^+ \to \pi^+ \nu \overline{\nu}$. The branching ratio is given by Ref. 11:

$$B(K_L \to \pi^0 \nu \overline{\nu}) = \kappa_L \left(\frac{\text{Im}(V_{ts}^{\star} V_{td})}{\lambda^5} X_t \right)^2$$

$$\approx 7.6 \times 10^{-5} |V_{cb}|^4 \overline{\eta}^2 . \tag{4}$$

The hadronic matrix element can be related to that measured in $K_{\ell 3}$ decay and is parameterized in κ_L . The latest numerical evaluation leads to a predicted branching ratio $(2.43^{+0.40}_{-0.37}\pm0.06)\times10^{-11}$ [37]. The 90% CL bound on $K^+\to\pi^+\nu\overline{\nu}$ provides a nearly model-independent bound $B(K_L\to\pi^0\nu\overline{\nu})<1.46\times10^{-9}$ [53]. KEK-391a, which took data in 2004 and 2005, has published a 90% CL upper bound of $B(K_L\to\pi^0\nu\overline{\nu})\leq2.6\times10^{-8}$ [54] The KOTO experiment, whose initial goal is to reach the $10^{-11}/\text{event}$ level, is in the final stages of construction at J-PARC [55].

There has been much theoretical work on possible contributions to rare K decays beyond the SM. A comprehensive discussion of these can be found in Refs. [14] and [56].

The decay $K_L \to \pi^0 e^+ e^-$ also has sensitivity to the CKM parameter η through its CP-violating component. There are both direct and indirect CP-violating amplitudes which can interfere. The direct CP-violating amplitude is short distance dominated and has been calculated in detail within the SM [8]. The indirect CP-violating amplitude can be inferred from a

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measurement of $K_S \to \pi^0 e^+ e^-$. The complete CP-violating contribution to the rate can be written as [57,58]:

$$B_{\text{CPV}} \approx 10^{-12} \left[15.7 |a_S|^2 \pm 1.4 \left(\frac{|V_{cb}|^2 \overline{\eta}}{10^{-4}} \right) |a_S| + 0.12 \left(\frac{|V_{cb}|^2 \overline{\eta}}{10^{-4}} \right)^2 \right]$$
 (5)

where the three terms correspond to the indirect CP violation, the interference, and the direct CP violation respectively. The parameter a_S has been extracted by NA48 from a measurement of the decay $K_S \to \pi^0 e^+ e^-$ with the result $|a_S| = 1.06^{+0.26}_{-0.21} \pm 0.07$ [59], as well as from a measurement of the decay $K_S \to \pi^0 \mu^+ \mu^-$ with the result $|a_S| = 1.54^{+0.40}_{-0.32} \pm 0.06$ [60]. With current constraints on the CKM parameters, and assuming a positive sign for the interference term [58,61], this implies that $B_{\rm CPV}(K_L \to \pi^0 e^+ e^-) \approx (3.1 \pm 0.9) \times 10^{-11}$, and that the indirect CP violation is larger than the direct CP violation. The complete CP violating amplitude for the related mode $K_L \to \pi^0 \mu^+ \mu^-$ is predicted to be $B_{\rm CPV}(K_L \to \pi^0 \mu^+ \mu^-) \approx (1.4 \pm 0.5) \times 10^{-11}$ [62,15].

 $K_L \to \pi^0 \gamma \gamma$ also has a CP-conserving component dominated by a two-photon intermediate state. This component can be decomposed into an absorptive and a dispersive part. The absorptive part can be extracted from the measurement of the low $m_{\gamma\gamma}$ region of the $K_L \to \pi^0 \gamma \gamma$ spectrum. The rate and the shape of the distribution $d\Gamma/dm_{\gamma\gamma}$ in $K_L \to \pi^0 \gamma \gamma$ are well described in chiral perturbation theory in terms of three (a priori) unknown parameters [63,64].

Both KTeV and NA48 have studied the mode $K_L \to \pi^0 \gamma \gamma$, reporting similar results. KTeV finds $B(K_L \to \pi^0 \gamma \gamma) = (1.29 \pm 0.03_{\rm stat} \pm 0.05_{\rm sys}) \times 10^{-6}$ [65], while NA48 finds $B(K_L \to \pi^0 \gamma \gamma) = (1.36 \pm 0.03_{\rm stat} \pm 0.03_{\rm sys} \pm 0.03_{\rm norm}) \times 10^{-6}$ [66]. Both experiments are consistent with a negligible rate in the low $m_{\gamma\gamma}$ region, suggesting a very small CP-conserving component $B_{\rm CP}(K_L \to \pi^0 e^+ e^-) \sim \mathcal{O}(10^{-13})$ [58,64,66]. There remains some model dependence in the estimate of the dispersive part of the CP-conserving $K_L \to \pi^0 e^+ e^-$ [58].

The related process, $K_L \to \pi^0 \gamma e^+ e^-$, is potentially an additional background in some region of phase space [67]. This process has been observed with a branching ratio of $(1.62 \pm 0.14_{\rm stat} \pm 0.09_{\rm sys}) \times 10^{-8}$ [68].

The decay $K_L \to \gamma \gamma e^+ e^-$ constitutes the dominant background to $K_L \to \pi^0 e^+ e^-$. It was first observed by BNL-845 [69], and subsequently confirmed with a much larger sample by FNAL-799 [70]. It has been estimated that this background will enter at about the 10^{-10} level [71,72], comparable to or larger than the signal level. Because of this, the observation of $K_L \to \pi^0 e^+ e^-$ at the SM level will depend on background subtraction with good statistics. Possible alternative strategies are discussed in Ref. 58 and references cited therein.

The 90% CL upper bound for the process $K_L \to \pi^0 e^+ e^-$ is 2.8×10^{-10} [72]. For the closely related muonic process, the published upper bound is $B(K_L \to \pi^0 \mu^+ \mu^-) \leq 3.8 \times 10^{-10}$ [73], compared with the SM prediction of $(1.5 \pm 0.3) \times 10^{-11}$ [62]

(assuming positive interference between the direct- and indirect-CP violating components).

A study of $K_L \to \pi^0 \mu^+ \mu^-$ has indicated that it might be possible to extract the direct CP-violating contribution by a joint study of the Dalitz plot variables and the components of the μ^+ polarization [74]. The latter tends to be quite substantial so that large statistics may not be necessary.

Combined information from the two $K_L \to \pi^0 \ell^+ \ell^-$ modes complements the $K \to \pi \nu \overline{\nu}$ measurements in constraining physics beyond the SM [75].

E. Other long distance dominated modes:

The decays $K^+ \to \pi^+ \ell^+ \ell^-$ ($\ell = e$ or μ) have received considerable attention. The rate and spectrum have been measured for both the electron and muon modes [76,77,18]. Ref. 57 has proposed a parametrization inspired by chiral perturbation theory, which provides a successful description of data but indicates the presence of large corrections beyond leading order. More work is needed to fully understand the origin of these large corrections.

Much information has been recorded by KTeV and NA48 on the rates and spectrum for the Dalitz pair conversion modes $K_L \to \ell^+\ell^-\gamma$ [78,79], and $K_L \to \ell^+\ell^-\ell'^+\ell'^-$ for $\ell,\ell'=e$ or μ [17,80–82]. All these results are used to test hadronic models and could further our understanding of the long distance component in $K_L \to \mu^+\mu^-$.

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K+ DECAY MODES

| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | Mode | Frac | tion (Γ_i/Γ) | Scale factor/ Confidence level | |
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| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | Γ2 | | , | | | S=1.2 |
| Called K_{e3}^+ . | Γ3 | $\pi^{0} e^{+} \nu_{e}$ | ì | | | S=2.1 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | , | | , | | | |
| Called K_{μ}^{+3} . | Γ ₄ | | (| 3.353 ± 0.034 |) % | S=1.8 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | • | | ` | | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | ۲- | | (| 22 +04 | V 10-5 | |
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| Leptonic and semileptonic modes with photons | | | (| | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 11 | π ' π ' π | (| 5.59 ± 0.04 |) % | S=1.3 |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | | Leptonic and semile | ptonic mo | des with phot | ons | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | Γ ₁₂ | $\mu^+ \nu_\mu \gamma$ | [a,b] (| 6.2 ± 0.8 | $) \times 10^{-3}$ | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | T ₁₃ | $\mu^+ \dot{\nu_\mu} \gamma (SD^+)$ | [c,d] (| 1.33 ±0.22 | $) \times 10^{-5}$ | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 14 | | [c,d] < | 2.7 | $\times 10^{-5}$ | CL=90% |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | $\times 10^{-4}$ | CL=90% |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 16 | | | 9.4 ± 0.4 | $\times 10^{-6}$ | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | [a,b] (| | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 18 | $\pi^0 e^+ \nu_e \gamma (SD)$ | [c,d] < | 5.3 | $\times 10^{-5}$ | CL=90% |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | Γ_{19} | $\pi^0 \mu^+ u_\mu \gamma$ | [a,b] (| 1.25 ± 0.25 | $) \times 10^{-5}$ | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | Γ ₂₀ | $\pi^0 \pi^0 e^+ \nu_e \gamma$ | < | 5 | $\times 10^{-6}$ | CL=90% |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | 4 <u>4</u> | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | г | | • | | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\pi^{+}\pi^{0}\alpha(DE)$ | , | | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | | | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | [a,b] (| | | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | | , | [a,b] (| | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Γ ₂₅ | | [a] (| 1.10 ± 0.32 | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Γ ₂₆ | | [a] < | | _ | CL=90% |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | Γ ₂₇ | π^+ e^+ $e^ \gamma$ | (| 1.19 ± 0.13 | ×10 ⁻⁸ | |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | | Leptonic m | nodes with | <i>ℓ</i> ₹ pairs | | |
| | Гъ | · · | | | $\times 10^{-5}$ | CL=90% |
| | | | | | _ | CL=90% |
| $\begin{bmatrix} 31 & \mu^{+} \nu_{\mu} e^{+} e^{-} \\ 32 & e^{+} \nu_{e} \mu^{+} \mu^{-} \end{bmatrix}$ $\begin{pmatrix} 7.06 & \pm 0.31 \end{pmatrix} \times 10^{-8}$ | | | - | | | - 70 |
| $\Gamma_{32} = e^{+} \stackrel{\cdot}{\nu_e} \mu^{+} \mu^{-}$ (1.7 ±0.5)×10 ⁻⁸ | | | ĺ | 7.06 ± 0.31 | ×10-8 | |
| | | $e^{+} \nu_{0} u^{+} u^{-}$ | (| | | |
| | . 3∠ Γ ₃₃ | $\mu^{+} \nu_{\mu} \mu^{+} \mu^{-}$ | < | 4.1 | ×10 ⁻⁷ | CL=90% |

Lepton Family number (LF), Lepton number (L), $\Delta S = \Delta Q$ (SQ) violating modes, or $\Delta S = 1$ weak neutral current (S1) modes

| | • | | | | ` ' | |
|-----------------|---------------------------------------|------------|-------|------|---------------------------------|--------|
| Γ ₃₄ | $\pi^+\pi^+e^-\overline{ u}_e$ | SQ | < | 1.2 | $\times 10^{-8}$ | CL=90% |
| Γ ₃₅ | $\pi^+\pi^+\mu^-\overline{\nu}_{\mu}$ | SQ | < | 3.0 | $\times 10^{-6}$ | CL=95% |
| Γ ₃₆ | $\pi^{+} e^{+} e^{-}$ | S1 | (| 3.00 | ± 0.09) $\times 10^{-7}$ | |
| Γ ₃₇ | $\pi^{+} \mu^{+} \mu^{-}$ | S1 | (| 9.4 | ± 0.6) $\times 10^{-8}$ | S=2.6 |
| Γ ₃₈ | $\pi^+ \nu \overline{\nu}$ | S1 | (| 1.7 | ± 1.1) × 10 ⁻¹⁰ | |
| Γ_{39} | $\pi^+ \pi^0 \nu \overline{\nu}$ | <i>S</i> 1 | < | 4.3 | $\times 10^{-5}$ | CL=90% |
| Γ_{40} | $\mu^- u e^+ e^+$ | LF | < | 2.0 | $\times 10^{-8}$ | CL=90% |
| Γ_{41} | $\mu^+ \nu_e$ | LF | [f] < | 4 | $\times 10^{-3}$ | CL=90% |
| Γ_{42} | $\pi^{+}\mu^{+}e^{-}$ | LF | < | 1.3 | $\times 10^{-11}$ | CL=90% |
| Γ_{43} | $\pi^{+}\mu^{-}e^{+}$ | LF | < | 5.2 | $\times 10^{-10}$ | CL=90% |
| Γ_{44} | $\pi^{-}\mu^{+}e^{+}$ | L | < | 5.0 | $\times 10^{-10}$ | CL=90% |
| Γ ₄₅ | $\pi^- e^+ e^+$ | L | < | 6.4 | $\times 10^{-10}$ | CL=90% |
| Γ_{46} | $\pi^{-}\mu^{+}\mu^{+}$ | L | [f] | 1.1 | $\times 10^{-9}$ | CL=90% |
| Γ_{47} | $\mu^+ \overline{\nu}_e$ | L | [f] | 3.3 | $\times 10^{-3}$ | CL=90% |
| Γ ₄₈ | $\pi^0 e^+ \overline{\nu}_e$ | L | < | 3 | $\times 10^{-3}$ | CL=90% |
| Γ_{49} | $\pi^+ \gamma$ | | [g] < | 2.3 | $\times 10^{-9}$ | CL=90% |
| | | | | | | |

- [a] See the Particle Listings below for the energy limits used in this mea-
- $\mbox{\it [b]}$ Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.
- [c] Structure-dependent part.

- [d] See the "Note on $\pi^\pm \to \ \ell^\pm \nu \gamma$ and $K^\pm \to \ \ell^\pm \nu \gamma$ Form Factors" in the π^{\pm} Particle Listings for definitions and details.
- [e] Direct-emission branching fraction.
- [f] Derived from an analysis of neutrino-oscillation experiments.
- [g] Violates angular-momentum conservation.

CONSTRAINED FIT INFORMATION

An overall fit to the mean life, a decay rate, and 13 branching ratios uses 32 measurements and one constraint to determine 8 parameters. The overall fit has a $\chi^2=$ 51.8 for 25 degrees of

The following off-diagonal array elements are the correlation coefficients $\left<\delta
ho_i \delta
ho_j \right> / (\delta
ho_i \cdot \delta
ho_j)$, in percent, from the fit to parameters ho_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (10^8 s^{-1}) | Scale factor |
|-----------------|-----------------------------------|-------------------------------------------------|--------------|
| Γ ₂ | $\mu^+ \nu_{\mu}$ | 0.5133 ± 0.0013 | 1.5 |
| Γ_3 | $\pi^0e^+ u_e$ | $0.0410~\pm 0.0004$ | 2.1 |
| | Called K_{e3}^+ . | | |
| Γ_4 | $\pi^{0} \mu^{+} u_{\mu}$ | 0.02708 ± 0.00028 | 1.9 |
| | Called $K_{\mu 3}^+$. | | |
| Γ_5 | $\pi^0\pi^0e^+ u_e$ | $(1.77 {}^{+ 0.35}_{- 0.30}) \times 10^{-5}$ | |
| Г9 | $^{\pi^+\pi^0}_{\pi^+\pi^0\pi^0}$ | 0.1669 ± 0.0007 | 1.3 |
| Γ_{10} | $\pi^{+} \pi^{0} \pi^{0}$ | 0.01423 ± 0.00018 | 1.1 |
| Γ ₁₁ | $\pi^+ \pi^+ \pi^-$ | 0.04518 ± 0.00029 | 1.2 |

K± DECAY RATES

| $VALUE (10^6 \text{ s}^{-1})$ | | DO CUMENT I | D | TECN | CHG | |
|-------------------------------|------------------|-------------------|-----------|-----------|------------|---|
| 51.33±0.13 OUR | FIT Error inc | ludes scale facto | r of 1.5 | | | |
| • • • We do not ι | ıse the followin | ig data for avera | ges, fits | , limits, | etc. • • • | |
| 51.2 ±0.8 | | FORD | 67 | CNTR | ± | |
| $\Gamma(\pi^+\pi^+\pi^-)$ | | | | | | Γ |
| | EVTS | DO CUMENT I | D | TECN | CHG | |
| 4.518±0.029 OUR | FIT Error in | cludes scale fact | or of 1. | 2. | | |
| 4.511 ± 0.024 | | ⁷ FORD | 70 | ASPK | | |
| • • • We do not ι | ıse the followin | g data for avera | ges, fits | , limits, | etc. • • • | |
| 4.529 ± 0.032 | 3.2 M | ⁷ FORD | 70 | ASPK | | |
| 4.496 ± 0.030 | | 7 FORD | 67 | CNTR | _ | |

$(\Gamma(K^+) - \Gamma(K^-)) / \Gamma(K)$

$K^{\pm} \rightarrow \mu^{\pm} \nu_{\mu}$ RATE DIFFERENCE/AVERAGE Test of CPT conservation.

VALUE (%) DO CUMENT ID -0.54 ± 0.41

$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ RATE DIFFERENCE/AVERAGE

| Test of | CP conservation. | • | | | |
|------------------|-----------------------|--------------------|----------|-----------|------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | CHG |
| 0.08 ± 0.12 | | ⁸ FORD | 70 | ASPK | |
| • • • We do | not use the following | data for averag | es, fits | , limits, | etc. • • • |
| -0.02 ± 0.16 | | ⁹ SMITH | 73 | A SP K | ± |
| 0.10 ± 0.14 | 3.2 M | ⁸ FORD | 70 | ASPK | |
| -0.50 ± 0.90 | | FLETCHER | 67 | OSP K | |
| -0.04 ± 0.21 | | ⁸ FORD | 67 | CNTR | |

 8 First FORD 70 value is second FORD 70 combined with FORD 67. 9 SMITH 73 value of $K^\pm\to~\pi^\pm\pi^+\pi^-$ rate difference is derived from SMITH 73 value of $K^\pm\to~\pi^\pm2\pi^0$ rate difference.

6.16±0.22 5110 ESCHSTRUTH 68 OSPK + 5.89±0.21 1679 CESTER 66 OSPK + • • • We do not use the following data for averages, fits, limits, etc. • • • 5.92±0.65 15 WEISSENBE... 76 SPEC +

 15 Value calculated from WEISSENBERG 76 $(\pi^0\,e\,\nu),\,(\mu\nu),$ and $(\pi\,\pi^0)$ values to eliminate dependence on our 1974 $(\pi\,2\pi^0)$ and $(\pi\,\pi^+\,\pi^-)$ fractions.

| $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ RATE DIFFERENCE/AVERAGE | $\Gamma(\pi^0 e^+ \nu_e) / \left[\Gamma(\pi^0 \mu^+ \nu_\mu) + \Gamma(\pi^+ \pi^0) + \Gamma(\pi^+ \pi^0 \pi^0) \right] \qquad \Gamma_3 / (\Gamma_4 + \Gamma_9 + \Gamma_{10})$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Test of CP conservation. VALUE (%) EVTS DOCUMENT ID TECN CHG | <u>VALUEEVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> |
| 0.0 ±0.6 OUR AVERAGE | 0.1968±0.0016 OUR FIT Error includes scale factor of 2.4. 0.1962±0.0008±0.0035 71k SHER 03 B865 + |
| 0.08 ± 0.58 SMITH 73 ASPK \pm -1.1 ± 1.8 1802 HERZO 69 OSPK | |
| $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ RATE DIFFERENCE/AVERAGE | $\Gamma(\pi^0\mathrm{e}^+ u_\mathrm{e})/\Gamma(\pi^+\pi^0)$ Γ_3/Γ_9 |
| $\Lambda \rightarrow \pi^{-}\pi^{-}$ KAIE DIFFERENCE/AVERAGE Test of CPT conservation. | 0.2455 ± 0.0023 OUR FIT Error includes scale factor of 2.6. |
| VALUE (%) DO CUMENT ID TECN | 0.2470±0.0009±0.0004 87k BATLEY 07A NA48 ± |
| 0.8±1.2 HERZO 69 OSPK | \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet \bullet 0.221 \pm 0.012 786 16 LUCAS 73B HBC $^{-}$ Dalitz pairs only |
| $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$ RATE DIFFERENCE/AVERAGE | 16 LUCAS 73B gives N(K_{e3}) = 786 \pm 3.1%, N(2π) = 3564 \pm 3.1%. We use these values |
| Test of CP conservation. VALUE (%) EVTS DOCUMENT ID TECN CHG COMMENT | to obtain quoted result. |
| 0.9±3.3 OUR AVERAGE 0.8±5.8 2461 SMITH 76 WIRE ± E _π 55−90 MeV | $\Gamma(\pi^0 e^+ \nu_e) / \Gamma(\pi^+ \pi^+ \pi^-)$ Γ_3 / Γ_{11} |
| 0.8 ± 5.8 2461 SMITH 76 WIRE \pm E $_{\pi}$ 55-90 MeV 1.0 ± 4.0 4000 ABRAMS 73B ASPK \pm E $_{\pi}$ 51-100 MeV | VALUE EVTS DOCUMENT ID TECN CHG |
| π | 0.907±0.010 OUR FIT Error includes scale factor of 1.6. • • • We do not use the following data for averages, fits, limits, etc. • • • |
| K+ BRANCHING RATIOS | 0.867±0.027 2768 BARMIN 87 XEBC + |
| Leptonic and semileptonic modes ——— | 0.856±0.040 2827 BRAUN 75 HLBC + |
| $\Gamma(e^+\nu_e)/\Gamma(\mu^+\nu_\mu)$ Γ_1/Γ_2 | 0.850 ± 0.019 4385 17 HAIDT 71 HLBC $^{+}$ 0.846 ± 0.021 4385 17 EICHTEN 68 HLBC $^{+}$ |
| See the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_s^+ | 0.94 ±0.09 854 BELLOTTI 678 HLBC |
| Listings. | 0.90 ±0.06 230 BORREANI 64 HBC + |
| <u>VALUE (units 10⁻⁵) </u> | ¹⁷ HAIDT 71 is a reanalysis of EICHTEN 68. Not included in average because of large discrepancy in $\Gamma(\pi^0 \mu^+ \nu)/\Gamma(\pi^0 e^+ \nu)$ with more precise results. |
| 2.487±0.011±0.007 60k ¹⁰ LAZZERONI 11 NA62 + | |
| 2.4 93 \pm 0.025 \pm 0.019 13.8K 11 AMBROSINO 09E KLOE \pm | $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma_{\text{total}}$ Γ_4/Γ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 2.51 ±0.15 404 HEINTZE 76 SPEC + | VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN CHG COMMENT 3.353 ± 0.034 OUR FIT Error includes scale factor of 1.8. |
| 2.37 ±0.17 534 HEARD 75B SPEC + | 3.24 ±0.04 OUR AVERAGE |
| 2.42 ±0.42 112 CLARK 72 OSPK + | $3.233\pm0.029\pm0.026$ 18 AMBROSINO 08A KLOE \pm |
| 10 This ratio is defined to be fully inclusive, including internal-bremsstrahlung. | 3.33 ± 0.16 2345 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ¹¹ The ratio is defined to include internal-bremsstrahlung, ignoring direct-emission contributions. AMBROSINO 09E determined the ratio from the measurement of $\Gamma(K \to e\nu/\gamma)$, | 2.8 ± 0.4 19 TAYLOR 59 EMUL + |
| $E_{\gamma} <$ 10 MeV) $/$ $\Gamma(K ightarrow ~\mu u(\gamma))$. 89.8% of $K ightarrow ~e u(\gamma)$ events had $E_{\gamma} <$ 10 MeV. | 18 Depends on K^+ lifetime $	au$. AMBROSINO 08A uses PDG 06 value of $	au=(1.2385~\pm$ |
| $\Gamma(\mu^+ u_\mu)/\Gamma_{	ext{total}}$ Γ_2/Γ | $0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and K_{u3}^+ branching fraction mea- |
| See the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_c^+ | surements is 62.7% |
| Listings. | 19 Earlier experiments not averaged. |
| <u>VALUE (units 10⁻²)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> 63.55 ± 0.11 OUR FIT Error includes scale factor of 1.2. | $\Gamma(\pi^0 \mu^+ u_\mu) / \Gamma(\mu^+ u_\mu)$ Γ_4 / Γ_2 |
| 63.60±0.16 OUR AVERAGE | VALUE EVTS DOCUMENT ID TECN CHG 0.0528±0.0006 OUR FIT Error includes scale factor of 1.8. |
| 63.66±0.09±0.15 865k ¹² AMBROSINO 06A KLOE + 63.24±0.44 62k CHIANG 72 OSPK + 1.84 GeV/ <i>c K</i> + | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 12 Fully inclusive. Used tagged kaons from ϕ decays. | 0.054 \pm 0.009 240 ZELLER 69 ASPK $+$ |
| | 0.0480±0.0037 424 ²⁰ GARLAND 68 OSPK + 0.0486±0.0040 307 ²¹ AUERBACH 67 OSPK + |
| $\Gamma(\pi^0 e^+ \nu_e)/\Gamma_{\text{total}}$ Γ_3/Γ VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN CHG COMMENT | 0.0486 ± 0.0040 307 ²¹ AUERBACH 67 OSPK + 20 GARLAND 68 changed from 0.055 ± 0.004 in agreement with μ -spectrum calculation |
| 5.07 ±0.04 OUR FIT Error includes scale factor of 2.1. | GARLAND to changed from 0.000 \pm 0.004 in agreement with μ -spectrum calculation |
| 4.94 ±0.05 OUR AVERAGE | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). |
| 12 | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum |
| $4.965\pm0.038\pm0.037$ 13 AMBROSINO 08A KLOE \pm | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965±0.038±0.037 | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ |
| 4.965±0.038±0.037 | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ 4.7 ± 0.3 429 SHAKLEE 64 HLBC + ROE 61 HLBC + | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e) \frac{VALUE}{EVTS} \frac{DOCUMENT\ ID}{EVOS} \frac{TECN}{EVS} \frac{CHG}{EVS} \frac{COMMENT}{EVS} \frac{COMMENT}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | of GAILLARD 70 appendix B. L. G.Pondrom. (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ $\frac{VALUE}{0.6608 \pm 0.0030} \frac{EVTS}{0.0027} \frac{DOCUMENT\ ID}{0.6618 \pm 0.0027} \frac{TECN}{0.003} \frac{CHG}{0.003} \frac{COMMENT}{0.003} \frac$ |
| 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ 4.7 ± 0.3 429 SHAKLEE 64 HLBC + ROE 61 HLBC + | of GAILLARD 70 appendix B. L. G.Pondrom. (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ $\frac{MALUE}{0.6608\pm0.0030} \frac{EVTS}{0.6008\pm0.0030} \frac{DUR FIT}{0.6618\pm0.0027} \frac{DOCUMENT ID}{0.6618\pm0.0027} \frac{TECN}{0.671} \frac{CHG}{0.003} \frac{COMMENT}{0.008} \frac{COMMENT}{0.671} \frac{DOCUMENT ID}{0.6618\pm0.0027} \frac{TECN}{0.671} \frac{CHG}{0.003} \frac{COMMENT}{0.008} \frac{COMMENT}{0.671} \frac{DOCUMENT ID}{0.671} \frac{TECN}{0.671} \frac{CHG}{0.008} \frac{COMMENT}{0.008} \frac{DOCUMENT ID}{0.008} \frac{TECN}{0.671} \frac{CHG}{0.008} \frac{COMMENT}{0.008} \frac{DOCUMENT ID}{0.6618} \frac{TECN}{0.671} \frac{CHG}{0.008} \frac{DOCUMENT ID}{0.6618} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{CHG}{0.008} \frac{DOCUMENT ID}{0.6618} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{CHG}{0.008} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.671} \frac{TECN}{0.008} \frac{TECN}{0.671} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} \frac{TECN}{0.008} TEC$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | of GAILLARD 70 appendix B. L. G. Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ VALUE 0.6608 ± 0.0030 OUR FIT Error includes scale factor of 1.1. 0.6618 ± 0.0027 OUR AVERAGE 0.663 ± 0.003 ± 0.001 77k BATLEY 07A NA48 \pm 0.671 ± 0.007 ± 0.008 24k HORIE 01 SPEC 0.670 ± 0.014 22 HEINTZE 77 SPEC \pm 0.667 ± 0.017 5601 BOTTERILL 68B ASPK \pm |
| 4.965 \pm 0.038 \pm 0.037 13 AMBROSINO 08A KLOE \pm 4.86 \pm 0.10 3516 CHIANG 72 OSPK $+$ 1.84 GeV/ c K+ • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 \pm 0.3 429 SHAKLEE 64 HLBC $+$ 5.0 \pm 0.5 ROE 61 HLBC $+$ 13 Depends on K+ lifetime τ . AMBROSINO 08A uses PDG 00 value of τ = (1.2385 \pm 0.0024) \times 10 ⁻⁸ sec. The correlation between K_{e3}^+ and $K_{\mu3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE EVTS DOCUMENT ID TECN CHG | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ VALUE 0.6608 ±0.0030 OUR FIT Error includes scale factor of 1.1. 0.6618 ±0.0027 OUR AVERAGE 0.663 ±0.003 ±0.001 77k BATLEY 07A NA48 \pm 0.671 ±0.007 ±0.008 24k HORIE 01 SPEC 0.670 ±0.014 22 HEINTZE 77 SPEC ±0.007 ±0.017 5601 BOTTERILL 68B ASPK ±0.017 ±0.017 ±0.017 5601 BOTTERILL 68B ASPK ±0.017 \pm |
| 4.965 ± 0.038 ± 0.037 | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ VALUE 0.6608 ± 0.0030 OUR FIT Error includes scale factor of 1.1. 0.6618 ± 0.0027 OUR AVERAGE 0.663 ± 0.003 ± 0.001 77k BATLEY 07A NA48 \pm 0.671 ± 0.007 ± 0.008 24k HORIE 01 SPEC 0.670 ± 0.014 22 HEINTZE 77 SPEC \pm 0.667 ± 0.017 5601 BOTTERILL 68B ASPK \pm |
| 4.965 \pm 0.038 \pm 0.037 13 AMBROSINO 08A KLOE \pm 4.86 \pm 0.10 3516 CHIANG 72 OSPK $+$ 1.84 GeV/ c K+ • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 \pm 0.3 429 SHAKLEE 64 HLBC $+$ 5.0 \pm 0.5 ROE 61 HLBC $+$ 13 Depends on K+ lifetime τ . AMBROSINO 08A uses PDG 06 value of $\tau =$ (1.2385 \pm 0.0024) \times 10 ⁻⁸ sec. The correlation between K_{e3}^+ and $K_{\mu 3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE EVTS DOCUMENT ID TECN CHG 0.0798 \pm 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • • | of GAILLARD 70 appendix B. L. G.Pondrom. (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • We do not use the following data for averages, fits, limits, etc. • • • We do not use the following data for averages, fits, limits, etc. • • • We do not use the following data for averages, fits, limits, etc. • • • We do not use the following data for averages, fits, limits, etc. • • • O.058 ± 0.006 ± 0.006 350 ZELLER OSPAK + 1.84 GeV/c K ⁺ 1.85 GeV/c K ⁺ 1.86 GeV/c K ⁺ 1.87 GeV/c K ⁺ 1.8 | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ $\frac{VALUE}{VALUE} = \underbrace{EVTS}_{DOCUMENT\ ID} = \underbrace{TECN}_{TECN}_{CHG} = \underbrace{COMMENT}_{COMMENT}$ $0.6608\pm0.0030 \ OUR\ FIT = Error includes scale factor of 1.1.$ $0.6618\pm0.0027 \ OUR\ AVERAGE$ $0.663\pm0.0031 \ \pm0.001 \ 77k = BATLEY = 0.0000 \ ANA48 \ \pm 0.000000000000000000000000000000000$ |
| 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 AUSP SHAKLEE 64 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of τ = (1.2385 ± 0.0024) × 10 ⁻⁸ sec. The correlation between K_{e3}^+ and $K_{μ3}^+$ branching fraction measurements is 62.7%. $\Gamma(π^0 e^+ ν_e)/\Gamma(μ^+ ν_μ)$ VALUE EVTS DOCUMENT ID TECN 0.00798±0.0008 OUR FIT Error includes scale factor of 1.9. • • We do not use the following data for averages, fits, limits, etc. • • • 0.0069 ± 0.006 350 ZELLER 69 ASPK + 0.00775±0.0033 960 BOTTERILL 68 OSPK + | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + ROE 61 HBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of τ = (1.2385 ± 0.0024) × 10 ⁻⁸ sec. The correlation between K_{e3}^+ and $K_{μ3}^+$ branching fraction measurements is 62.7%. $\Gamma(π^0 e^+ ν_e)/\Gamma(μ^+ ν_μ)$ VALUE EVTS DOCUMENT ID TECN CHG 0.0798 ± 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775 ± 0.0033 960 BOTTERILL 68 OSPK + 0.0791 ± 0.0054 295 14 AUERBACH 67 OSPK + | of GAILLARD 70 appendix B. L. G.Pondrom. (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 13 AMBROSINO 08A KLOE ± 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{μ3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE EVTS DOCUMENT ID O0.0798 ± 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775 ± 0.0033 960 BOTTERILL 68C ASPK + 0.069 ± 0.006 561 GARLAND 68 OSPK + 0.0791 ± 0.0054 295 14 AUERBACH 67 OSPK + 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio Γ($\pi^0 \mu^+ \nu_\mu$)/ Γ($\mu^+ \nu_\mu$). The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ MALUE EVTS DOCUMENT ID TECN CHG COMMENT 0.6608 ± 0.0030 OUR FIT Error includes scale factor of 1.1. 0.6618 ± 0.0027 OUR AVERAGE 0.663 ± 0.003 ± 0.001 77k BATLEY 07A NA48 \pm 0.671 ± 0.007 ± 0.008 24k HORIE 01 SPEC 0.670 ± 0.014 22 HEINTZE 77 SPEC \pm 0.667 ± 0.017 5601 BOTTERILL 68B ASPK \pm • • We use the following data for averages but not for fits. • • • 0.6511 ± 0.0064 23 AMBROSINO 08A KLOE \pm • • We do not use the following data for averages, fits, limits, etc. • • 0.608 ± 0.014 1585 24 BRAUN 75 HLBC \pm 0.705 ± 0.063 554 25 LUCAS 73B HBC Dalitz pairs only 0.698 ± 0.025 3480 26 CHIANG 72 OSPK \pm 1.84 GeV/c \pm 0.596 ± 0.025 3480 26 CHIANG 72 OSPK \pm 1.84 GeV/c \pm 0.604 ± 0.022 1398 27 EICHTEN 68 HLBC 0.703 ± 0.056 1509 CALLAHAN 66B HLBC 22 HEINTZE 77 value from fit to ± 0.060 Assumes ± 0.000 4 Divide from fit to ± 0.000 Assumes ± 0.000 4 Divide from fit to ± 0.000 Assumes ± 0.000 4 Divide from fit to ± 0.000 Assumes ± 0.0000 4 Divide from fit to ± 0.0000 Assumes ± 0.00000 4 Divide from fit to ± 0.00000 Assumes ± 0.000000 4 Divide from fit to ± 0.0000000 Assumes $\pm 0.0000000000000000000000000000000000$ |
| 4.965 ± 0.038 ± 0.037 | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ VALUE 0.6608 \pm 0.0030 OUR FIT Error includes scale factor of 1.1. 0.6618 \pm 0.0027 OUR AVERAGE 0.663 \pm 0.003 \pm 0.001 77k BATLEY 07A NA48 \pm 0.671 \pm 0.003 \pm 0.001 77k BATLEY 07A NA48 \pm 0.671 \pm 0.007 \pm 0.008 \pm 4k HORIE 01 SPEC 0.670 \pm 0.014 22 HEINTZE 77 SPEC \pm 0.667 \pm 0.017 5601 BOTTERILL 68B ASPK \pm • • We use the following data for averages but not for fits. • • • 0.6511 \pm 0.0064 23 AMBROSINO 08A KLOE \pm • • We do not use the following data for averages, fits, limits, etc. • • 0.608 \pm 0.014 1585 24 BRAUN 75 HLBC \pm 0.705 \pm 0.063 554 25 LUCAS 73B HBC \pm Dalitz pairs only 0.698 \pm 0.025 3480 26 CHIANG 72 OSPK \pm 1.84 GeV/c K^+ 0.596 \pm 0.025 3480 26 CHIANG 72 OSPK \pm 1.84 GeV/c K^+ 0.596 \pm 0.025 37 HAIDT 71 HLBC \pm 0.703 \pm 0.056 1509 CALLAHAN 66B HLBC 22 HEINTZE 77 value from fit to λ_0 . Assumes μ -e universality. 23 Not used in the fit. This result enters the fit via correlation of K_{+2}^+ and K_{+2}^+ branching |
| 4.965 ± 0.038 ± 0.037 13 AMBROSINO 08A KLOE ± 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{μ3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE EVTS DOCUMENT ID O0.0798 ± 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775 ± 0.0033 960 BOTTERILL 68C ASPK + 0.069 ± 0.006 561 GARLAND 68 OSPK + 0.0791 ± 0.0054 295 14 AUERBACH 67 OSPK + 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio Γ($\pi^0 \mu^+ \nu_\mu$)/ Γ($\mu^+ \nu_\mu$). The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 ± 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 13 AMBROSINO 08A KLOE ± 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{\mu3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu) \qquad \qquad \Gamma_3/\Gamma_2$ $VALUE \qquad EVTS \qquad DOCUMENT ID \qquad TECN \qquad CHG \\ 0.00798 \pm 0.0008 \ OUR \ FIT \qquad Error includes scale factor of 1.9. • • We do not use the following data for averages, fits, limits, etc. • • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775 ± 0.0033 960 BOTTERILL 68C ASPK + 0.0791 ± 0.0054 295 14 AUERBACH 67 OSPK + 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio \Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\mu^+ \nu_\mu). The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 \Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu) and CESTER 66 \Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu) + \Gamma(\pi^+ \pi^0).$ | of GAILLARD 70 appendix B. L.G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 13 AMBROSINO 08A KLOE ± 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{μ3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE 10.00798± 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775±0.0033 960 BOTTERILL 68c ASPK + 0.0791±0.0054 295 14 AUERBACH 67 OSPK + 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\mu^+ \nu_\mu)$. The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 Γ (π ⁰ e + ν _e)/Γ (μ ⁺ ν _μ) and CESTER 66 Γ (π ⁰ e + ν _e)/[Γ (μ ⁺ ν _μ) + Γ (π ⁺ π ⁰)]. $\Gamma(\pi^0 e^+ \nu_e)/[\Gamma(\mu^+ \nu_\mu) + \Gamma(\pi^+ \pi^0)]$ | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 4.965 ± 0.038 ± 0.037 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{\mu3}^+$ branching fraction measurements is 62.7%. $\Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu)$ VALUE FUTS DOCUMENT ID TECN CHG 0.0799± 0.0008 OUR FIT Error includes scale factor of 1.9. • • • We do not use the following data for averages, fits, limits, etc. • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0775 ± 0.0033 960 BOTTERILL 68C ASPK + 0.0791± 0.0054 295 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio Γ(π ⁰ μ + ν _μ)/Γ(μ + ν _μ) Γ(μ + ν _μ). The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 Γ(π ⁰ e + ν _e)/Γ(μ + ν _μ) and CESTER 66 Γ(π ⁰ e + ν _e)/[Γ(μ + ν _μ) + Γ(π + π ⁰)] VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN CHG 73/(Γ2+Γ9) AUEUE (units 10 ⁻²) EVTS DOCUMENT ID TECN CHG TECN TECN CHG TECN CHC TECN TECN CHG TECN TECN CHG TECN TECN TECN T | of GAILLARD 70 appendix B. L. G.Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. |
| 4.965 ± 0.038 ± 0.037 13 AMBROSINO 08A KLOE ± 4.86 ± 0.10 3516 CHIANG 72 OSPK + 1.84 GeV/c K ⁺ • • • We do not use the following data for averages, fits, limits, etc. • • • • 4.7 ± 0.3 429 SHAKLEE 64 HLBC + 5.0 ± 0.5 ROE 61 HLBC + 13 Depends on K ⁺ lifetime τ. AMBROSINO 08A uses PDG 06 value of $\tau = (1.2385 \pm 0.0024) \times 10^{-8}$ sec. The correlation between K_{e3}^+ and $K_{\mu 3}^+$ branching fraction measurements is 62.7%. $ \Gamma(\pi^0 e^+ \nu_e)/\Gamma(\mu^+ \nu_\mu) \qquad \Gamma_3/\Gamma_2 $ $ \frac{VALUE}{VALUE} \qquad EVTS \qquad DOCUMENT ID \qquad TECN \ CHG $ 0.0798 ± 0.0008 OUR FIT Error includes scale factor of 1.9. • • We do not use the following data for averages, fits, limits, etc. • • • 0.069 ± 0.006 350 ZELLER 69 ASPK + 0.0791 ± 0.0054 295 14 AUERBACH 67 OSPK + 14 AUERBACH 67 changed from 0.0797 ± 0.0054. See comment with ratio Γ(π ⁰ μ + ν _μ)/ Γ(μ + ν _μ). The value 0.0785 ± 0.0025 given in AUERBACH 67 is an average of AUERBACH 67 Γ(π ⁰ e + ν _e)/Γ(μ + ν _μ) and CESTER 66 Γ(π ⁰ e + ν _e)/[Γ(μ + ν _μ) + Γ(π + π ⁰)]. Γ(π ⁰ e + ν _e)/[Γ(μ + ν _μ) + Γ(π + π ⁰)] Γ(π + π ⁰)/[Γ(μ + ν _μ) + Γ(π + π ⁰)] | of GAILLARD 70 appendix B. L.G. Pondrom, (private communication 73). 21 AUERBACH 67 changed from 0.0602 \pm 0.0046 by erratum which brings the μ -spectrum calculation into agreement with GAILLARD 70 appendix B. $\Gamma(\pi^0 \mu^+ \nu_\mu)/\Gamma(\pi^0 e^+ \nu_e)$ $\frac{VALUE}{VALUE} $ |

 31 Fully inclusive of final-state radiation. The branching ratio is evaluated using $^{K+}$ lifetime, τ = 12.385 ns.

 K^{\pm}

| $[\Gamma(\pi^0\mu^+\nu_\mu)+\Gamma(\pi^+\pi^0)]/\Gamma_{	ext{total}}$ (Γ4+Γ9)/Γ We combine these two modes for experiments measuring them in xenon bubble cham- | $\Gamma(\pi^+\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ NALUE EVIS DOCUMENT ID TECN CHG |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| ber because of difficulties of separating them there. | 3.694±0.029 OUR FIT Error includes scale factor of 1.2. |
| #ALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN CHG #4.02±0.08 OUR FIT Error includes scale factor of 1.2. | • • • We do not use the following data for averages, fits, limits, etc. • • |
| \bullet . We do not use the following data for averages, fits, limits, etc. \bullet . | 3.96 ±0.15 1045 CALLAHAN 66 FBC + |
| 5.4 ±0.9 886 SHAKLEE 64 HLBC + 3.4 ±1.1 ROE 61 HLBC + | $\Gamma(\pi^+\pi^0)/\Gamma(\mu^+ u_\mu)$ |
| | VALUEEVTS |
| $\Gamma(\pi^0\mu^+ u_\mu)/\Gamma(\pi^+\pi^0)$ Γ_4/Γ_9 ALUE EVTS DOCUMENT ID TECN CHG | 0.3325 ± 0.0032 OUR AVERAGE |
| .1637±0.0006±0.0003 77k BATLEY 07A NA48 ± | 0.3329±0.0047±0.0010 45k USHER 92 SPEC + pp at rest 0.3355±0.0057 32 WEISSENBE 76 SPEC + |
| $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_4/Γ_{11} | 0.3277±0.0065 4517 ³³ AUERBACH 67 OSPK + |
| ALUE EVTS DOCUMENT ID TECN CHG COMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • • 0.328 ±0.005 25k ³² WEISSENBE 74 STRC + |
| .599±0.007 OUR FIT Error includes scale factor of 1.6. • • We do not use the following data for averages, fits, limits, etc. • • • | 0.305 ±0.018 1600 ZELLER 69 ASPK + |
| .503±0.019 1505 ²⁸ HAIDT 71 HLBC + | 32 WEISSENBERG 76 revises WEISSENBERG 74. 33 AUERBACH 67 changed from 0.325 3 \pm 0.0065. See comment with ratio $\Gamma(\pi^0\mu^+\nu_\mu$ |
| 1.510 ± 0.017 1505 28 EICHTEN 68 HLBC + 1.63 ± 0.07 2845 29 BISI 65B BC + HBC+HLBC | $\Gamma(\mu^+ u_\mu)$. |
| 28 HAIDT 71 is a reanalysis of EICHTEN 68. Not included in average because of large | |
| discrepancy in $\Gamma(\pi^0 \mu^+ \nu)/\Gamma(\pi^0 e^+ \nu)$ with more precise results. | $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\text{total}}$ $\Gamma_{10}/\Gamma_{\text{total}}$ |
| ²⁹ Error enlarged for background problems. See GAILLARD 70. | <u>VALUE (units 10⁻²)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> 1.761±0.022 OUR FIT Error includes scale factor of 1.1. |
| $(\pi^0\pi^0e^+\nu_e)/\Gamma_{\text{total}}$ Γ_5/Γ | 1.775 ± 0.028 OUR AVERAGE Error includes scale factor of 1.2. |
| "ALUE (units 10 ^{−5}) | $1.763 \pm 0.013 \pm 0.022$ ALOISIO 04A KLOE \pm 1.84 ± 0.06 1307 CHIANG 72 OSPK $+$ 1.84 GeV/c K^+ |
| 54±0.89 10 BARMIN 88B HLBC + | • • • We do not use the following data for averages, fits, limits, etc. • • |
| $\Gamma(\pi^0 \pi^0 e^+ \nu_e) / \Gamma(\pi^0 e^+ \nu_e)$ Γ_5 / Γ_3 | 1.53 ± 0.11 198 34 PANDOULAS 70 EMUL + 1.8 ± 0.2 108 SHAKLEE 64 HLBC + |
| ALUE (units 10-4) EVTS DOCUMENT ID TECN CHG | 1.7 \pm 0.2 ROE 61 HLBC + |
| .3 ^{+0.9} _{-0.7} OUR FIT | 1.5 ±0.2 |
| .1 ^{+1.0} / _{0.7} OUR AVERAGE | ³⁴ Includes events of TAYLOR 59. ³⁵ Earlier experiments not averaged. |
| _ v. r | $\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^0)$ |
| .2+1.0 -0.9 25 BOLOTOV 86B CALO - | VALUE EVTS DOCUMENT ID TECN CHG COMMENT |
| .8 + 5.0 2 LJUNG 73 HLBC + | 0.0852±0.0011 OUR FIT Error includes scale factor of 1.1. |
| $\Gamma(\pi^+\pi^-e^+\nu_e)/\Gamma(\pi^+\pi^+\pi^-)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • 0.081 ±0.005 574 36 LUCAS 73B HBC — Dalitz pairs only |
| ALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN CHG | 36 LUCAS 73B gives N(π 2 π 0) = 574 ± 5.9%, N(2π) = 3564 ± 3.1%. We quo |
| .31±0.16 OUR AVERAGE .35±0.01±0.19 388k ³⁰ PISLAK 01 B865 | $0.5\mathrm{N}(\pi2\pi^0)/\mathrm{N}(2\pi)$ where 0.5 is because only Dalitz pair π^0 's were used. |
| 7.21 ± 0.32 30k ROSSELET 77 SPEC $+$ | $\Gamma(\pi^+\pi^0\pi^0)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_{10}/Γ_{10} |
| • • We do not use the following data for averages, fits, limits, etc. • • • | VALUEEVTSDOCUMENT_IDTECNCHG _COMMENT_ |
| 7.36±0.68 500 BOURQUIN 71 ASPK 7.0 ±0.9 106 SCHWEINB 71 HLBC + | 0.315 ± 0.004 OUR FIT |
| 5.83±0.63 269 ELY 69 HLBC + | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ³⁰ PISLAK 01 reports $\Gamma(\pi^+\pi^-e^+\nu_e)/\Gamma_{\text{total}} = (4.109 \pm 0.008 \pm 0.110) \times 10^{-5}$ using the | 0.393±0.099 17 YOUNG 65 EMUL + |
| PDG 00 value $\Gamma(\pi^+\pi^+\pi^-)/\Gamma_{total}=$ (5.59 \pm 0.05) \times 10 $^{-2}$. We divide by the PDG value and unfold its error from the systematic error. PISLAK 03 and PISLAK 10A give | $\Gamma(\pi^+\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma_{11}/\Gamma_{\text{total}}$ |
| additional details on the branching ratio measurement and give improved errors on the S-wave π - π scattering length: $a_0^0=0.235\pm0.013$ and $a_0^2=-0.0410\pm0.0027$. | VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN CHG COMMENT |
| · · · · · · · · · · · · · · · · · · · | 5.59±0.04 OUR FIT Error includes scale factor of 1.3. • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma_{\text{total}}$ | 5.56±0.20 2330 ³⁷ CHIANG 72 OSPK + 1.84 GeV/c K ⁺ |
| WALUE (units 10 ⁻⁵)EVTSDOCUMENT_IDTECNCHG | 5.34 ± 0.21 693 ³⁸ PANDOULAS 70 EMUL + |
| | 5.71±0.15 DEMARCO 65 HBC 6.0 ±0.4 44 YOUNG 65 EMUL + |
| 0.77 ± 0.54 1 CLINE 65 FBC + | 5.54±0.12 2332 CALLAHAN 64 HLBC + |
| | |
| $\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_7/Γ_{11} | 5.1 ±0.2 540 SHAKLEE 64 HLBC + 5.7 ±0.3 ROE 61 HLBC + |
| $\Gamma(\pi^+\pi^-\mu^+ u_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_7/Γ_{11} WALUE (units 10^{-4}) EVTS DOCUMENT ID TECN CHG | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+ u_\mu)/\Gamma_{ m total}$, $\Gamma(\pi^+ \pi^0)/\Gamma_{ m total}$ |
| $\Gamma(\pi^{+}\pi^{-}\mu^{+}\nu_{\mu})/\Gamma(\pi^{+}\pi^{+}\pi^{-})$ Γ_{7}/Γ_{11} (ALUE (units 10^{-4}) EVTS DOCUMENT ID TECN CHG 2.57 ± 1.55 7 BISI 67 DBC + | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+ u_\mu)/\Gamma_{ m total}$, $\Gamma(\pi^+ \pi^0)/\Gamma_{ m total}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. |
| | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ $\Gamma_{12}/\Gamma_{\rm total}$ VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN CHG COMMENT |
| | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN CHG COMMENT 6.2 \pm 0.8 OUR AVERAGE |
| $\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ ALUE (units 10 ⁻⁴) EVTS BISI 67 DBC + • • We do not use the following data for averages, fits, limits, etc. • • • 2.57 ±1.55 7 BISI 67 DBC + • • • We do not use the following data for averages, fits, limits, etc. • • • 2.5 1 GREINER 64 EMUL + $\Gamma(\pi^0\pi^0\pi^0e^+\nu_e)/\Gamma_{\text{total}}$ $\Gamma_{\text{ALUE (units 10^{-6})} CL\% EVTS DOCUMENT ID TECN CHG}$ 3.5 90 0 BOLOTOV 88 SPEC - • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 5.7 \pm 0.3 ROE 61 HLBC \pm 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ $VALUE (units 10^{-3})$ $EVTS$ 6.2 \pm 0.3 OUR AVERAGE 6.6 \pm 1.5 39,40 DEMIDOV 90 XEBC P(μ) < 231.5 MeV/ 6.0 \pm 0.9 BARMIN 88 HLBC + P(μ) < 231.5 MeV/ |
| | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm tot}$; $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0{\rm e}^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ VALUE (units 10 ⁻³) EVTS 6.2 \pm 0.3 OUR AVERAGE 6.6 \pm 1.5 39,40 DEMIDOV 90 XEBC P(μ) < 231.5 MeV/6.0 \pm 0.9 We do not use the following data for averages, fits, limits, etc. • • |
| | 5.7 ± 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm tot}$; $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ $\frac{VALUE (\rm units 10^{-3})}{6.2\pm 0.8 \; \rm OUR\; AVERAGE}$ 6.6 ± 1.5 6.2 $\pm 0.8 \; \rm OUR\; AVERAGE$ 6.6 $\pm 0.9 \; \rm BARMIN$ 88 HLBC $+ \; \rm P(\mu) < 231.5 \; MeV/$ • • We do not use the following data for averages, fits, limits, etc. • • • • 3.5 $\pm 0.8 \; \rm MeV/$ 3.2 $\pm 0.5 \; \rm 57 \; ^{42} \; \rm BARMIN \; 88 \; HLBC + \; E(\gamma) > 20 \; MeV$ 3.2 $\pm 0.5 \; \rm 57 \; ^{42} \; \rm BARMIN \; 88 \; HLBC + \; E(\gamma) > 20 \; MeV$ |
| $\Gamma(\pi^+\pi^-\mu^+\nu_\mu)/\Gamma(\pi^+\pi^+\pi^-)$ Γ_7/Γ_{11} Γ_7/Γ_{11 | 5.7 ± 0.3 ROE 61 HLBC + 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0{\rm e}^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ $\frac{\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}}{\frac{VALUE(\rm units10^{-3})}{\frac{EVTS}{6.2\pm 0.8\rm OURAVERAGE}}}$ 6.6 ± 1.5 39,40 DEMIDOV 90 XEBC $P(\mu) < 231.5\rm MeV/6.0\pm 0.9$ BARMIN 88 HLBC + $P(\mu) < 231.5\rm MeV/6.0\pm 0.9$ We do not use the following data for averages, fits, limits, etc. • • 3.5 ± 0.8 |
| | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$ $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^0\mu^+\nu_\mu)/\Gamma_{\rm total}$, and $\Gamma(\pi^0e^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ $\frac{NALUE (\text{units }10^{-3})}{6.2\pm 0.8\text{OUR}\text{AVERAGE}}$ 6.6 \pm 1.5 39,40 DEMIDOV 90 XEBC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 8. ARMIN 88 HLBC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 9. We do not use the following data for averages, fits, limits, etc. \bullet \bullet 0.3.5 \pm 0.8 40,41 DEMIDOV 90 XEBC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 3.2 \pm 0.5 57 42 BARMIN 88 HLBC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 3.2 \pm 0.5 57 42 BARMIN 88 HLBC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 5.4 \pm 0.3 4 AKIBA 85 SPEC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 5.4 \pm 0.3 4 AKIBA 85 SPEC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ 5.4 \pm 0.3 4 KIBA 85 SPEC $P(\mu) < 231.5\text{MeV}/6.0\pm 0.9$ |
| $\Gamma(\pi^{+}\pi^{-}\mu^{+}\nu_{\mu})/\Gamma(\pi^{+}\pi^{+}\pi^{-})$ $\frac{VALUE (units 10^{-4})}{2.57 \pm 1.55}$ $\frac{EVTS}{7}$ $\frac{BISI}{67}$ $\frac{67}{7}$ $\frac{DBC}{7}$ $\frac{VBC}{7}$ $\frac{VBC}{7}$ $\frac{EVTS}{7}$ $\frac{BISI}{67}$ $\frac{67}{7}$ $\frac{DBC}{7}$ $\frac{EVTS}{7}$ $\frac{DOCUMENT ID}{67}$ $\frac{EWUL}{7}$ $\frac{VBC}{7}$ | 5.7 \pm 0.3 ROE 61 HLBC \pm 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$, $\Gamma(\pi^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\nu)/\Gamma_{\rm total}$, |
| | 5.7 \pm 0.3 ROE 61 HLBC $+$ 37 Value is not independent of CHIANG 72 $\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$, $\Gamma(\pi^+\pi^0)/\Gamma_{\rm total}$, and $\Gamma(\pi^0{\rm e}^+\nu_e)/\Gamma_{\rm total}$. 38 Includes events of TAYLOR 59. Leptonic and semileptonic modes with photons $\Gamma(\mu^+\nu_\mu\gamma)/\Gamma_{\rm total}$ VALUE (units 10^{-3}) EVTS 6.2 \pm 0.8 OUR AVERAGE 6.6 \pm 1.5 39,40 DEMIDOV 90 XEBC P(μ) < 231.5 MeV/ 6.0 \pm 0.9 We do not use the following data for averages, fits, limits, etc. • • • • 3.5 \pm 0.8 40,41 DEMIDOV 90 XEBC E(γ) > 20 MeV 3.2 \pm 0.5 57 42 BARMIN 88 HLBC + $\Gamma(\gamma)$ > 20 MeV 3.2 \pm 0.5 57 42 BARMIN 88 HLBC + $\Gamma(\gamma)$ > 20 MeV 5.4 \pm 0.3 43 AKIBA 85 SPEC P(μ) < 231.5 MeV/ 9P(μ) cut given in DEMIDOV 90 paper, 235.1 MeV/ $\Gamma(\gamma)$ is a misprint according to author (private communication). |

 $\Theta_{\mu\gamma} > 20^{\circ}$

$\Gamma(\mu^+\nu_{\mu}\gamma(SD^+))/\Gamma_{total}$

 Γ_{13}/Γ

Structure-dependent part with $+\gamma$ helicity (SD $^+$ term). See the "Note on π^\pm \to $\ell^\pm
u \gamma$ and $\mathit{K}^\pm o \ \ell^\pm
u \gamma$ Form Factors" in the π^\pm section of the Particle Data Listings above.

<u>CL% EVTS</u> <u>DOCUMENT ID</u> 25 88 44 ADLER VALUE (units 10^{-5}) CL% EVTS $1.33 \pm 0.12 \pm 0.18$ 00в В787 • • • We do not use the following data for averages, fits, limits, etc. • • • 90 AKIBA 85 SPEC

 44 ADLER 00B obtains the branching ratio by extrapolating the measurement in the kinematic region E $_{\mu}$ > 137 MeV, E $_{\gamma}$ > 90 MeV to the full SD $^+$ phase-space. Also reports $|{\sf F}_V + {\sf F}_A| = 0.165 \pm 0.007 \pm 0.011$ and $-0.04 < {\sf F}_V - {\sf F}_A < 0.24$ at 90% CL.

$\Gamma(\mu^+\nu_{\mu}\gamma(SD+INT))/\Gamma_{total}$

Interference term between internal Bremsstrahlung and SD+ term. See the "Note on $\pi^\pm o \; \ell^\pm
u \gamma$ and $K^\pm o \; \ell^\pm
u \gamma$ Form Factors" in the π^\pm section of the Particle Data Listings above.

VALUE (units 10^{-5})

$\Gamma(\mu^+\nu_{\mu}\gamma(SD^-+SD^-|NT))/\Gamma_{total}$

 Γ_{15}/Γ

Sum of structure-dependent part with $-\gamma$ helicity (SD $^-$ term) and interference term between internal Bremsstrahlung and SD $^-$ term. See the "Note on $\pi^\pm \to \ell^\pm \nu \gamma$ and $\kappa^\pm \to \ell^\pm \nu \gamma$ Form Factors" in the π^\pm section of the Particle Data Listings above.

DO CUMENT ID TECN CL% 90 ⁴⁵ AKIBA 85 SPEC

45 Assumes $\mu\text{-}e$ universality and uses constraints from $extit{K}
ightarrow e \, \nu \, \gamma$

$\Gamma(e^+ \nu_e \gamma) / \Gamma(\mu^+ \nu_\mu)$

VALUE (units 10^{-2}) EVTS

 Γ_{16}/Γ_{2}

VALUE (units 10^{-5}) EVTSDOCUMENT ID TECN CHG COMMENT 1.483 \pm 0.066 \pm 0.013 1.4K 46 AMBROSINO 09E KLOE \pm E_{∞} in 10-250 MeV, $p_e > 200 \text{ MeV/c}$

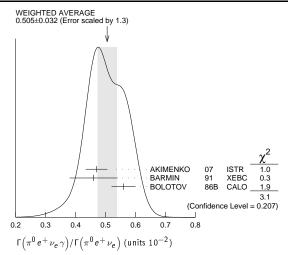
⁴⁶ AMBROSINO 09E measured the differential width $dR_{\infty}/dE_{\infty} = (1/\Gamma(K \rightarrow \mu\nu))$ $(d\Gamma(K \to e \nu \gamma)/dE_{\gamma})$. Result obtained by integrating the differential width over E_{γ} from 10 to 250 MeV.

TECN CHG COMMENT

$\Gamma(\pi^0 e^+ \nu_e \gamma) / \Gamma(\pi^0 e^+ \nu_e)$ Γ_{17}/Γ_{3} DO CUMENT ID

| VALUE (units 10 2) | EVIS | | DOCUMENT ID | | IECN | CHG | COMMENT |
|----------------------------------------------------|-------------|----|----------------|-------|-----------|------|--------------------------------------------------------|
| 0.505 ±0.032 OUR | VERAGE | | Error includes | scale | factor of | 1.3. | See the ideogram below. |
| $0.47\ \pm0.02\ \pm0.03$ | 4476 ' | 47 | AKIMENKO | 07 | ISTR | _ | $E_{\gamma} > 10 \; {\rm MeV}, \; 0.6 <$ |
| | | | | | | | $\cos(\theta_{e\gamma}) < 0.9$ |
| 0.46 ± 0.08 | 82 ' | 48 | BARMIN | 91 | XEBC | | $E_{\gamma} > 10$ MeV, $0.6 <$ |
| | | | | | | | $\cos(\theta_{e\gamma}) < 0.9$ |
| 0.56 ± 0.04 | 192 ' | 49 | BOLOTOV | 86B | CALO | _ | $E_{\gamma} > 10 \text{MeV}$ |
| • • • We do not us | e the follo | wi | | | | | |
| $1.81 \pm 0.03 \pm 0.07$ | 4476 | 47 | AKIMENKO | 07 | ISTR | _ | $E_{\gamma}{>}10$ MeV, $\theta_{e\gamma}>{10}^{\circ}$ |
| $0.63 \pm 0.02 \pm 0.03$ | 4476 ' | 47 | AKIMENKO | 07 | ISTR | _ | $E_{\gamma} > 30$ MeV, $\theta_{e\gamma} > 20^{\circ}$ |
| 1.51 ±0.25 | 82 ' | 48 | BARMIN | 91 | | | $E_{\gamma} > 10 \text{ MeV, } \cos(\theta_{e\gamma})$ |
| | - | | | | | | < 0.98 |
| 0.48 ± 0.20 | 16 | 50 | LJUNG | 73 | HLBC | + | $E_{\gamma} > 30 \text{ MeV}$ |
| $0.22 \begin{array}{c} +0.15 \\ -0.10 \end{array}$ | ! | 50 | LJUNG | 73 | HLBC | + | $E_{\gamma} > 30 \text{ MeV}$ |
| 0.76 ±0.28 | 13 | 51 | ROMANO | 71 | HLBC | | $E_{\gamma}^{\prime} > 10 \text{ MeV}$ |
| 0.53 ±0.22 | | | ROMANO | 71 | | | |
| | | | | | | | $E_{\gamma} >$ 30 MeV |
| 1.2 ± 0.8 | | | BELLOTTI | 67 | HLBC | | $E_{\gamma} > 30 \text{ MeV}$ |
| | | | | | | | |

 $^{^{47}}$ AKIMENKO 07 provides values for three kinematic regions. For averaging, we use value with $E_{\gamma}>10$ MeV and $0.6<\cos(\theta_{\rm e\gamma})<0.9$.



 $\Gamma(\pi^0 e^+ \nu_e \gamma(SD))/\Gamma_{total}$ Γ_{18}/Γ Structure-dependent part. VALUE (units 10^{-5}) BOLOTOV 86B CALO

 $\Gamma(\pi^0 \mu^+ \nu_\mu \gamma)/\Gamma_{\rm total}$ Γ_{19}/Γ VALUE (units 10⁻⁵) CL% DOCUMENT ID TECN CHG COMMENT 1.25 ± 0.25 OUR AVERAGE ⁵² ADLER 10 B787 $30 < E_{\gamma} < 60 \text{ MeV}$ $1.10 \pm 0.32 \pm 0.05$ 153 53 TCHIKILEV 07 ISTR - 30 < $E_{\gamma}^{'}$ < 60 MeV $1.46 \pm 0.22 \pm 0.32$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $2.4 \pm 0.5 \pm 0.6$ SHIMIZU 06 K470 + $E_{\gamma} > 30$ MeV;

< 6.1 90 0 LJUNG 73 HLBC + $E(\gamma) > 30 \text{ MeV}$ 52 Value obtained from B($K^+\to\pi^0\,\mu^+\,\nu_\mu\gamma)=(2.51\pm0.74\pm0.12)\times10^{-5}$ obtained in the kinematic region $E_\gamma>20$ MeV, and then theoretical $K_{\mu3\gamma}$ spectrum has been used. Also B($K^+\to\pi^0\,\mu^+\nu_\mu\gamma)=(1.58\pm0.46\pm0.08)\times10^{-5}$, for $E_\gamma>30$ MeV

and $\theta_{\mu\gamma} > 20^{\circ}$, was determined. Obtained from measuring B($K_{\mu3\gamma}$) /B($K_{\mu3}$) and using PDG 02 value B($K_{\mu3}$) = 3.27%. B($K_{\mu3\gamma}$) = (8.82 \pm 0.94 \pm 0.86) \times 10⁻⁵ is obtained for 5 MeV < E_{γ} < 30 MeV.

$\Gamma(\pi^0\pi^0e^+\nu_e\gamma)/\Gamma_{\text{total}}$

VALUE (units 10-6) CL% EVTS DOCUMENT ID TECN CHG COMMENT 92 XEBC + E_{γ} > 10 MeV BARMIN

Hadronic modes with photons -

$\Gamma(\pi^+\pi^0\gamma(|NT))/\Gamma_{total}$

The $K^+ \to \pi^+ \pi^0 \gamma$ differential decay rate can be described in terms of T_{π^+} , the charged pion kinetic energy, and W^2 = (${\rm P}_K \, \cdot \, {\rm P}_\gamma$) (${\rm P}_{\pi^+} \, \cdot \, {\rm P}_\gamma$) / ($m_K \, m_{\pi^+}$)²; then we can write $d^2\Gamma(K^+ \to \pi^+ \pi^0 \gamma) / (dT_{\pi^+} dW^2) = d^2\Gamma(K^+ \to \pi^+ \pi^0 \gamma)_{IB}$ X_{M}^{2}) W⁴]. The IB differential and total branching ratios are expressed in terms of the non-radiative experimental width $\Gamma(K^+ \to \pi^+ \pi^0)$ by Low's theorem. Using PDG 10 B(K $^+$ \rightarrow $\pi^+\pi^0)$ = 0.2066 \pm 0.0008, one obtains respectively B(K $^+$ \rightarrow $\pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 55} \, < \, {\rm T}_{\pi^+} \; < \, {\rm 90 \; MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \; {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \, {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \, {\rm and} \; {\rm B}({\rm \textit{K}}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm 000} \, {\rm MeV}) = \, 2.55 \, \times \, 10^{-4} \, {\rm and} \; {\rm B}({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \, \gamma)_{IB} \; ({\rm N}^+ \rightarrow \; \pi^+ \, \pi^0 \,$ < T_{_+} < 80 MeV)= 1.80×10^{-4} . Fitting respectively the piece proportional to W² and the piece proportional to W^4 , the interference contribution (INT), proportional to X_E , and the direct contribution (DE) proportional to $\mathsf{X}_E^2 + \mathsf{X}_M^2$ are extracted.

VALUE (units 10^{-6}) DOCUMENT ID TECN CHG COMMENT EVTS 600k 54 BATLEY 10A NA48 \pm T $_{\pi^+}$ 0-80 MeV

 $\Gamma(\pi^+\pi^0\gamma(DE))/\Gamma_{total}$ Γ_{22}/Γ

Direct emission (DE) part of $\Gamma(\pi^+\pi^0\gamma)/\Gamma_{\rm total}$, assuming that interference (INT) component is zero.

VALUE (units 10^{-6}) DO CUMENT ID TECN CHG COMMENT ⁵⁵ BATLEY 10A NA48 \pm T $_{\pi^+}$ 0-80 MeV $5.99 \pm 0.27 \pm 0.25$ 600k

⁴⁸BARMIN 91 quotes branching ratio $\Gamma(K \to e \pi^0 \nu \gamma)/\Gamma_{\rm all}$. The measured normalization is $[\Gamma(K \to e \pi^0 \nu) + \Gamma(K \to \pi^+ \pi^+ \pi^-)]$. For comparison with other experiments we used $\Gamma(K \rightarrow e \pi^0 \nu)/\Gamma_{\rm all} = 0.0482$ to calculate the values quoted here.

 $^{^{49}\}cos(heta_{e\gamma})$ between 0.6 and 0.9.

 $^{^{50}}$ First LJUNG 73 value is for $\cos(\theta_{e\gamma})$ <0.9, second value is for $\cos(\theta_{e\gamma})$ between 0.6 and 0.9 for comparison with ROMANO 71.

 $^{^{51}}$ Both ROMANO 71 values are for $\cos(\theta_{e\gamma})$ between 0.6 and 0.9. Second value is for comparison with second LJUNG 73 value. We use lowest E_{γ} cut for Summary Table value. See ROMANO 71 for \boldsymbol{E}_{γ} dependence.

 $^{^{54}}$ The cut on the photon energy implies W $^2>0.2.$ BATLEY 10A obtains the INT and DE fractional branchings with respect to IB from a simultaneous kinematical fit of INT and DE and then we use the PDG 10 value for B(K $^+\to~\pi^+\pi^0$) = 20.66 \pm 0.08 to determine the IB. The INT and DE correlation coefficients - 0.83. Assuming a constant electric amplitude, ${\rm X}_E$, this INT value implies ${\rm X}_E=-$ 24 \pm 6 GeV $^{-4}$.

 K^{\pm}

| | ot use the i | followin | g data for average | es, mis | , limits, | etc. • | • • |
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| $3.8 \pm 0.8 \pm 0.$ | 7 | 10k | ALIEV | 06 | K470 | + | ${\rm T}_{\pi^+}$ 55–90 MeV |
| 3.7 ±3.9 ±1. | | 930 | UVAROV | 06 | ISTR | _ | $T_{\pi^-}^{''}$ 55–90 MeV |
| 3.2 ±1.3 ±1. | | 4k | ALIEV | 03 | K470 | + | T _{π+} 55-90 MeV |
| 6.1 ±2.5 ±1. | | 4k | ALIEV ⁵⁶ ADLER | 03 | K470 | + | T _{π+} full range |
| $4.7 \pm 0.8 \pm 0.$ | | 20k | | 00c | B787 | + | T_{π^+} 55–90 MeV |
| $-20.5 \pm 4.0 - 2.$ | 3 | | BOLOTOV | 87 | WIRE | - | ${ m T}_{\pi^-}$ 55–90 MeV |
| $15.6 \pm 3.5 \pm 5.$ | | | ABRA MS | 72 | ASPK | ± | T_{π^\pm} 55–90 MeV |
| DE fractional and DE and determine the electric and -24 ± 6 Ge | al branching then we use IB. The magnetic as | gs with use the INT an amplitud XM = | respect to IB fro PDG 10 value for IDE correlation des, \mathbf{X}_E and \mathbf{X}_M $-254 \pm 9~\mathrm{GeV}^{-1}$ | m asi B(K coeffi , thes | multaneo + → π- cients − e INTano | ous kin + π ⁰) 0.93. d DE ν | otains the INT and ematical fit of INT $= 20.66 \pm 0.08$ to Assuming constant values imply ${\sf X}_E =$ |
| ⁵⁶ ADLER 00c lung (IB) co | me asures t | heINT | component to be | (-0.4 | 1 ± 1.6)% | of th | e inner bremsstrah- |
| $\Gamma(\pi^+\pi^0\pi^0\gamma)$ | • | $^{0}\pi^{0})$ | | | | | Γ_{23}/Γ_{10} |
| VALUE (units 10 ⁻⁴ |) | | DO CUMENT ID | | TECN | CHG | COMMENT |
| $4.3 + 3.2 \\ -1.7$ | | | BOLOTOV | 85 | SPEC | - | $\mathit{E}(\gamma) > 10~\mathrm{MeV}$ |
| $\Gamma(\pi^+\pi^+\pi^-\gamma$ | /)/F _{total} | | | | | | Γ ₂₄ /Γ |
| VALUE (units 10 ⁻⁴ 1.04±0.31 OUR | | VTS | DO CUMENT ID | | TECN | <u>CHG</u> | COMMENT |
| 1.10 ± 0.48 | · AVENAG | 7 | BARMIN | 89 | XEBC | | $\textit{E}(\gamma) >$ 5 MeV |
| 1.0 ±0.4 | | | STAMER | 65 | EMUL | + | $E(\gamma) > 11 \text{ MeV}$ |
| $\Gamma(\pi^+\gamma\gamma)/\Gamma_{\rm to}$ | otal | | | | | | Γ ₂₅ /Γ |
| VALUE (units 10 ⁻⁷ | ') <u>CL% EV</u> | | DOCUMENT ID | <u>T</u> | ECN C | 4 <u>6 CO</u> | MMENT |
| 11±3±1 | | | | | 787 | | |
| | | | g data for average | | | | • • |
| < 0.083 < 10 | 90 90 | 0 | ARTAMONOV (| | 949 + 787 | | , > 213 MeV/c r 117–127 MeV |
| < 84 | 90 | 0 | | | NTR + | | r 117–127 MeV r 117–127 MeV |
| -420 ± 520 | | 0 | | | PEC + | | r < 92 MeV |
| < 350 | 90 | 0 | L JUNG 7 | 73 H | LBC + | 6- | 102, 114-127 MeV |
| $< 500 \\ -100 \pm 600$ | 90 | 0 | | 71 C | SPK + | Tπ | r < 117 MeV |
| 57 | | | | | SPK + | | r 60–90 MeV |
| $1.5\pm0.7)\times$ | 10^{-7} for 1 | .00 MeV | from their mode $^{\prime}/c<$ P $_{\pi^+}<$ 180 I | l-indep MeV/a | endent I | oranch hiral P | ing fraction (6.0 \pm erturbation Theory. |
| 1.5 ± 0.7) × 58 ARTA MONO 1.6 and no | 10 ^{—7} for 1 OV 05 limi unitarity c itio is predi | .00 MeV t assum orrectio icted to | from their mode $^{\prime}/c<$ P $_{\pi^+}<$ 180 less ChPT with $\hat{c}=$ ns they obtain $<$ | l-indep MeV/a 1.8 w 2.3 | endent laws using Countries of the unitate of the countries of the countri | oranch hiral Po rity co at 90' | ing fraction (6.0 \pm |
| $1.5 \pm 0.7) \times$ 58 ARTA MONG 1.6 and no branching ra without unit | 10 ^{—7} for 1 OV 05 limi unitarity c itio is predi arity correc | .00 MeV t assum orrectio icted to | from their mode $^{\prime}/c<$ P $_{\pi^+}<$ 180 less ChPT with $\hat{c}=$ ns they obtain $<$ | l-indep MeV/a 1.8 w 2.3 | endent laws using Countries of the unitate of the countries of the countri | oranch hiral Po rity co at 90' | ing fraction (6.0 \pm erturbation Theory. rrections. With $\hat{c}=\%$ CL. This partial the cases with and |
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| $1.5 \pm 0.7) 	imes$ 58 ARTA MON(1.6 and no branching rawithout unit $\Gamma(\pi^+ 3\gamma)/\Gamma_{to}$ Values giv | 10 ^{—7} for 1 OV 05 limitunitarity cutio is prediarity correct arity correct tal ren here as | .00 MeV t assum orrectio icted to ction. | from their mode $'/c < P_{\pi^+} < 180$ l es ChPT with $\hat{c}=$ ns they obtain $<$ be 6.10×10^{-9} | l-inder MeV/ <i>c</i> 1.8 w : 2.3 and 0. | pendent I cusing C ith unita \times 10 ⁻⁸ 49 \times 10 ⁻³ | oranch hiral Po rity co at 90' -9 for | ing fraction (6.0 \pm erturbation Theory. rrections. With $\hat{c}=\%$ CL. This partial the cases with and |
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```
\Gamma(\mu^+\nu_\mu\,e^+\,e^-)/\Gamma_{\rm total}
                                                                                            \Gamma_{31}/\Gamma
VALUE (units 10^{-8}) EVTS
                                      DOCUMENT ID
                                                           TECN CHG COMMENT
                                      7.06 ± 0.16 ± 0.26 2.7k
• • • We do not use the following data for averages, fits, limits, etc. • • •
                          14
                                      DIAMANT-... 76 SPEC + m_{e^+e^-} > 140 \; \mathrm{MeV}
\Gamma(e^+ \nu_e \mu^+ \mu^-)/\Gamma_{\rm total}
                                                                                            \Gamma_{32}/\Gamma
VALUE (units 10<sup>-8</sup>) CL%
                                         DO CUMENT ID
                                                               TECN
                                         MA
                                                          06 B865
   1.72 \pm 0.45
• • • We do not use the following data for averages, fits, limits, etc. • • •
                            90
                                         ADLER
                                                          98 B787
\Gamma(\mu^+ 
u_\mu \mu^+ \mu^-)/\Gamma_{
m total}
                                                                                            \Gamma_{33}/\Gamma
VALUE (units 10^{-7}) CL\%
                                         DOCUMENT ID
                                                              TECN CHG
                                                          89 B787 +
<4.1
                            90
                                         ATIYA
      Lepton Family number (LF), Lepton number (L), \Delta S = \Delta Q (SQ)
        violating modes, or \Delta S = 1 weak neutral current (S1) modes
\Gamma(\pi^+\pi^+e^-\overline{\nu}_e)/\Gamma_{\rm total}
                                                                                            \Gamma_{34}/\Gamma
      Test of \Delta S = \Delta Q rule.
VALUE (units 10^{-7}) CL% EVTS
                                         DOCUMENT ID TECN CHG
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
< 9.0
                    95
                              0
                                         SCHWEINB... 71 HLBC +
< 6.9
                     95
                                         FIY
                                                          69 HLBC
< 20.
                    95
                                         BIRGE
                                                          65 FBC
\Gamma(\pi^+\pi^+e^-\overline{\nu}_e)/\Gamma(\pi^+\pi^-e^+\nu_e)
                                                                                          \Gamma_{34}/\Gamma_6
      Test of \Delta S = \Delta Q rule.
VALUE (units 10^{-4}) CL\% EVTS
                                         DOCUMENT ID TECN
                                     61 BLOCH
                   90
                             3
                                                         76 SPEC
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. 
 \bullet \bullet
<130.
           95 0
                                    BOURQUIN 71 ASPK
 ^{61} BLOCH 76 quotes 3.6 \times 10<sup>-4</sup> at CL = 95%, we convert.
\Gamma(\pi^+\pi^+\mu^-\overline{\nu}_{\mu})/\Gamma_{\text{total}}
Test of \Delta S = \Delta Q rule.
                                                                                            \Gamma_{35}/\Gamma
\underline{\textit{VALUE}\ (units\ 10^{-6})} \underline{\textit{CL\%}} \underline{\textit{EVTS}}
                                                         65 FBC +
                                         DO CUMENT ID
< 3.0
                                         BIRGE
electromagnetic interactions.
 VALUE (units 10^{-7})
                                        DOCUMENT ID
                                                               TECN CHG
3.00±0.09 OUR AVERAGE
                                    <sup>62</sup> BATLEY
3.11 \pm 0.04 \pm 0.12
                         7253
                                                         09
                                                             NA48 ±
                                    63 APPEL
64 ALLIEGRO
2.94 \pm 0.05 \pm 0.14
                         10300
                                                         99 SPEC
2.75 \pm 0.23 \pm 0.13
                          500
                                                         92 SPEC
                                    65 BLOCH
2.7 \pm 0.5
                                                         75 SPEC +
                            41
 ^{62} Value extrapolated from a measurement in the region z = (m_{ee}/m_K)^2~> 0.08. BATLEY 09 also evaluated the shape of the form factor using four different theoretical models.
 ^{63}APPEL 99 establishes vector nature of this decay and determines form factor f(Z)
    f_0(1+\delta Z), Z=M_{ee}^2/m_K^2, \delta=2.14\pm0.13\pm0.15.
 ^{64} ALLIEGRO 92 assumes a vector interaction with a form factor given by \lambda=0.105 \pm
 0.035\pm0.015 and a correlation coefficient of -0.82. 65 BLOCH 75 assumes a vector interaction.
\Gamma(\pi^+\mu^+\mu^-)/\Gamma_{\text{total}}
      Test for \Delta S=1 weak neutral current. Allowed by higher-order electroweak interac-
      tions.
   9.4 ±0.6 OUR AVERAGE Error includes scale factor of 2.6. See the ideogram
below.
                                         <sup>66</sup> BATLEY
    9.62 \pm 0.21 \pm 0.13
                               3120
                                                              11A NA48 ±
                                         67 PARK
    9.8\ \pm 1.0\ \pm 0.5
                                110
                                                              02 HYCP \pm
                                         68 MA
    9.22 \pm 0.60 \pm 0.49
                                 402
                                                              00 B865
                                         69 ADLER
   5.0 \pm 0.4 \pm 0.9
                                 207
                                                              97c B787
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
   9.7\ \pm 1.2\ \pm 0.4
                                  65
                                            PARK
                                                              02 HYCP +
  10.0 \ \pm 1.9 \ \pm 0.7
                                  35
                                            PARK
                                                              02 HYCP
                                            ATIYA
                                                              89 B787
 ^{66} BATLEY 11A also studies the form factor \it f(z) dependence of the decay, described via single photon exchange: i) assuming a linear form factor, \it f(z) = f_0~(1+~\delta~z), \it z = 10.00
    (M_{\mu\mu}/m_K)^2, finding f_0=0.470\pm0.040 and \delta=3.11\pm0.57 and ii) assuming a linear
    form factor including \pi-\pi rescattering , W_{\pi\,\pi} , as in DAMBROSIO 98A, finding f({\bf z})=
    G_F m_K^2 (a_+ + b_+ z) + W_{\pi\pi}(z), a_+ = -0.575 \pm 0.039, b_+ = -0.813 \pm 0.145.
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⁶⁷ PARK 02 "±" result comes from combining $K^+ \to \pi^+ \mu^+ \mu^-$ and $K^- \to \pi^- \mu^+ \mu^-$,

68 MA 00 establishes vector nature of this decay and determines form factor $f(z) = f_0$ (1

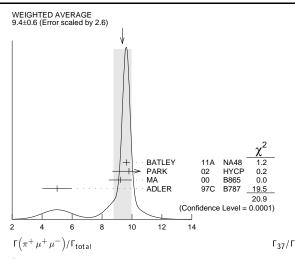
 69 ADLER 97c gives systematic error 0.7×10^{-8} and theoretical uncertainty 0.6×10^{-8} ,

assuming CP is conserved.

 $+ \delta z$), $z = (M_{\mu\mu}/m_K)^2$, $\delta = 2.45 {+ 1.30 \atop - 0.95}$.

which we combine in quadrature to obtain our second error.

I



 $\Gamma(\pi^+ \nu \overline{\nu})/\Gamma_{\text{total}}$ Test for $\Delta S=1$ weak neutral current. Allowed by higher-order electroweak interactions. Branching ratio values are extrapolated from the momentum or energy regions. shown in the comments assuming Standard Model phase space except for those labeled "Scalar" or "Tensor" to indicate the assumed non-Standard-Model interaction.

| VALU | <i>JE</i> (units 10 ⁻⁹) | CL% EV7 | S | | DOCUMENT ID | | TECN | CHG | COMMENT |
|------|------------------------------------------------------|------------|-------|----|------------------|---------|-----------|-------|---------------------------------------------------------|
| | $0.173 {}^{+ 0.115}_{- 0.105}$ | | 7 | 70 | ARTAMONOV | 80 | B949 | + | $^{140 < P_{\pi}}_{211 < P_{\pi}} < ^{199} {\rm MeV},$ |
| • • | • We do not ι | ise the fo | llowi | ng | data for average | es, fit | ts, limit | s, et | C. • • • |
| | $0.789 {}^{+ 0.926}_{- 0.510}$ | | 3 | 71 | ARTAMONOV | 08 | B949 | + | $140{<}{\rm P}_{\pi}<\!\!199~{\rm MeV}$ |
| < | 2.2 | 90 | 1 | 72 | ADLER | 04 | B787 | + | $211 < P_{\pi} < 229 \; { m MeV}$ |
| < | 2.7 | 90 | | | ADLER | 04 | B787 | + | Scalar |
| < | 1.8 | 90 | | | ADLER | 04 | B787 | + | Tensor |
| | $0.147 {}^{+ 0.1 30}_{- 0.0 89}$ | | 3 | 73 | ANISIMOVSK | .04 | B949 | + | $^{211<\!P_{\pi}}<\!^{229}{\rm MeV}$ |
| | $0.157 {}^{+ 0.175}_{- 0.082}$ | | 2 | | ADLER | 02 | B787 | + | $P_\pi >$ 211 MeV/ c |
| < | 4.2 | 90 | 1 | | ADLER | 02c | B787 | + | $140 < P_{\pi} < 195 \; { m MeV}$ |
| < | 4.7 | 90 | | | ADLER | 02c | B787 | + | Scalar |
| < | 2.5 | 90 | | 74 | ADLER | 02c | B787 | + | Tensor |
| | $0.15 \begin{array}{l} + 0.34 \\ - 0.12 \end{array}$ | | 1 | | ADLER | 00 | B787 | | In ADLER 02 |
| | $0.42 \ ^{+\ 0.97}_{-\ 0.35}$ | | 1 | | ADLER | 97 | B787 | | |
| < | 2.4 | 90 | | | ADLER | 96 | B787 | | |
| < | 7.5 | 90 | | | ATIYA | 93 | B787 | + | $T(\pi)$ 115–127 MeV |
| < | 5.2 | 90 | | 75 | ATIYA | 93 | B787 | + | |
| < 1 | 17 | 90 | 0 | | ATIYA | 93B | B787 | + | $T(\pi)$ 60–100 MeV |
| < 3 | 34 | 90 | | | ATIYA | 90 | B787 | + | |
| <14 | 10 | 90 | | | A SA NO | 81 B | CNTR | + | $T(\pi)$ 116–127 MeV |

 70 Value obtained combining ANISIMOVSKY 04, ADLER 04, and the present ARTA-

71 MONOV 08 results. 71 Observed 3 events with an estimated background of 0.93 \pm 0.17 \pm 0.32 Signal-to-

background ratio for each of these 3 events is 0.20, 0.42, and 0.47. $^{72} \mbox{Value obtained combining the previous result ADLER 02c with 1 event and the present result with 0 events to obtain an expected background 1.22 <math display="inline">\pm$ 0.24 events and 1 event 73 Observed. Value obtained combining the previous E787 result ADLER 02 with 2 events and the

present E949 with 1 event. The additional event has a signal-to-background ratio 0.9. Superseded by ARTAMONOV 08.

75 Combining ATIYA 93 and ATIYA 93B results. Superseded by ADLER 96.

 $\frac{\Gamma(\pi^+\pi^0\,\nu\overline{\nu})/\Gamma_{total}}{\text{Test for }\Delta S=1 \text{ weak neutral current. Allowed by higher-order electroweak interaction}}$ CL% VALUE (units 10^{-5}) DO CUMENT ID <4.3 90 76 ADLER 01 SPEC

 76 Search region defined by 90 MeV/c<P $_{\pi^+}$ <188 MeV/c and 135 MeV<E $_{\pi^0}$ <180 MeV.

 $\Gamma \left(\mu^- \nu \, e^+ \, e^+ \right) / \Gamma \left(\pi^+ \, \pi^- \, e^+ \, \nu_e \right)$ Test of lepton family number conservation. Γ_{40}/Γ_{6} TECN CHG

 VALUE (units 10⁻³)
 CL%
 EVTS
 DOCUMENT ID
 TECN
 CH

 <0.5</td>
 90
 0
 77
 DIAMANT-...
 76
 SPEC
 +

 $^{77}\, {\rm DIAMANT\text{-}BERGER}$ 76 quotes this result times our 1975 $\pi^+\,\pi^-\,e\nu$ BR ratio.

 $\Gamma(\mu^+\nu_e)/\Gamma_{total}$ Forbidden by lepton family number conservation.
 CL%
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 90
 0
 78 LYONS
 81
 HLBC
 200 GeV
 K⁺ narrow
 VALUE • • • We do not use the following data for averages, fits, limits, etc. • • • < 0.012 90 78 COOPER 82 HLBC Wideband ν beam

 78 COOPER 82 and LYONS 81 limits on ν_ϱ observation are here interpreted as limits on lepton family number violation in the absence of mixing.

 $\Gamma(\pi^+\mu^+e^-)/\Gamma_{\rm total}$ Γ_{42}/Γ Test of lepton family number conservation.

VALUE (units 10^{-10}) DO CUMENT ID TECN CHG 05 RVUE + \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 90 SHER 05 B865 + < 0.39 APPEL B865 90 00 90 LEE 90 SPEC + < 2.1

79 This result combines SHER 05 1998 data, APPEL 00 1996 data, and data from BERGMAN 97 and PISLAK 97 theses, all from BNL-E865, with LEE 90 BNL-E777

 $\Gamma(\pi^+\mu^-e^+)/\Gamma_{\rm total}$ Γ_{43}/Γ Test of lepton family number conservation.

<u>VALUE (units 10⁻¹⁰) CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN CHG</u> **< 5.2** 90 0 APPEL 00B B865 + • • • We do not use the following data for averages, fits, limits, etc. • • •

<70 90 0 ⁸⁰ DIAMANT-... 76 SPEC + 80 Measurement actually applies to the sum of the $\pi^+\mu^-e^+$ and $\pi^-\mu^+e^+$ modes.

 $\Gamma(\pi^-\mu^+e^+)/\Gamma_{\rm total}$ Γ_{44}/Γ

Test of total lepton number conservation. VALUE (units 10⁻¹⁰) CL% EVTS DOCUMENT ID TECN CHG

90 0 APPEL 00B B865 + \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet <70 90 0 81 DIAMANT-... 76 SPEC +

 81 Measurement actually applies to the sum of the $\pi^+\,\mu^-\,e^+$ and $\pi^-\,\mu^+\,e^+$ modes.

 $\Gamma(\pi^- e^+ e^+)/\Gamma_{\text{total}}$ Γ_{45}/Γ

Test of total lepton number conservation. <u>VALUE</u> <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN CHG</u> **<6.4 × 10⁻¹⁰** 90 0 APPEL 008 B865 + • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.2 \times 10 $^{-9}$ 90 0 DIAMANT-... 76 SPEC +

 $< 1.5 \times 10^{-5}$ CHANG $\Gamma(\pi^-\mu^+\mu^+)/\Gamma_{\text{total}}$ Γ_{46}/Γ

68 HBC

Forbidden by total lepton number conservation. VALUE <u>CL%</u> <u>DO CUMENT ID</u> TECN CHG 90 BATLEY 11A NA48 \pm

<1.1 × 10⁻⁹ \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $< 3.0 \times 10^{-9}$ 90 APPEL 00B B865 + 82 LITTENBERG 92 HBC $< 1.5 \times 10^{-4}$ 90

 $^{82}\mbox{LITTENBERG}$ 92 is from retroactive data analysis of CHANG 68 bubble chamber data.

 $\Gamma(\mu^+\overline{
u}_e)/\Gamma_{
m total}$ Γ_{47}/Γ Forbidden by total lepton number conservation.

 83 COOPER 82 limit on $\overline{\nu}_e$ observation is here interpreted as a limit on lepton number violation in the absence of mixing.

 Γ_{48}/Γ

 $\Gamma(\pi^0 e^+ \overline{\nu}_e)/\Gamma_{total}$ Forbidden by total lepton number conservation.
 CL%
 DOCUMENT ID
 TECN
 COMMENT

 90
 84 COOPER
 82
 HLBC
 Wideband ν beam
 < 0.003

 84 COOPER 82 limit on $\overline{\nu}_e$ observation is here interpreted as a limit on lepton number violation in the absence of mixing.

 $\Gamma(\pi^+\gamma)/\Gamma_{\text{total}}$

Violates angular momentum conservation and gauge invariance. Current interest in this decay is as a search for non-commutative space-time effects as discussed in AR-TAMONOV 05 and for exotic physics such as a vacuum expectation value of a new vector field, non-local Superstring effects, or departures from Lorentz invariance, as discussed in ADLER 02B.

<u>VALUE (units 10⁻⁹)</u> <u>CL%</u> TECN CHG DO CUMENT ID ARTA MONOV 05 B949 + 90 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet< 360 90 ADLER 02в В787 + <1400 ASANO 82 CNTR ⁸⁵ KLEMS <4000 90 71 OSPK + 85 Test of model of Selleri, Nuovo Cimento **60A** 291 (1969).

K^+ LONGITUDINAL POLARIZATION OF EMITTED μ^+

| <u>VALUE</u> | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
|--------------------|------------|---------------------------|---------|------------|--------|------------------|
| <-0.990 | 90 | ⁸⁶ AOKI | 94 | SPEC | + | |
| | the follow | wing data for averag | ges, fi | ts, limits | , etc. | • • • |
| <-0.990 | 90 | IMAZATO | | SPEC | + | Repl. by AOKI 94 |
| -0.970 ± 0.047 | | ⁸⁷ YA MA NA KA | 86 | SPEC | + | |
| -1.0 ± 0.1 | | ⁸⁷ CUTTS | 69 | SPRK | + | |
| -0.96 ± 0.12 | | 87 COOMBES | 5.7 | CNTR | _ | |

DALITZ PLOT PARAMETERS FOR $K \rightarrow 3\pi$ DECAYS

Revised 1999 by T.G. Trippe (LBNL).

The Dalitz plot distribution for $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\mp}$, $K^{\pm} \to$ $\pi^0\pi^0\pi^\pm$, and $K_L^0\to\pi^+\pi^-\pi^0$ can be parameterized by a series expansion such as that introduced by Weinberg [1]. We use the form

$$\left| M \right|^2 \propto 1 + g \frac{(s_3 - s_0)}{m_{\pi^+}^2} + h \left[\frac{s_3 - s_0}{m_{\pi^+}^2} \right]^2$$

$$+ j \frac{(s_2 - s_1)}{m_{\pi^+}^2} + k \left[\frac{s_2 - s_1}{m_{\pi^+}^2} \right]^2$$

$$+ f \frac{(s_2 - s_1)}{m_{\pi^+}^2} \frac{(s_3 - s_0)}{m_{\pi^+}^2} + \cdots , \qquad (1)$$

where $m_{\pi^{+}}^{2}$ has been introduced to make the coefficients g, h, j, and k dimensionless, and

$$s_i = (P_K - P_i)^2 = (m_K - m_i)^2 - 2m_K T_i , i = 1, 2, 3,$$

 $s_0 = \frac{1}{3} \sum_i s_i = \frac{1}{3} (m_K^2 + m_1^2 + m_2^2 + m_3^2) .$

Here the P_i are four-vectors, m_i and T_i are the mass and kinetic energy of the i^{th} pion, and the index 3 is used for the odd pion.

The coefficient g is a measure of the slope in the variable s_3 (or T_3) of the Dalitz plot, while h and k measure the quadratic dependence on s_3 and $(s_2 - s_1)$, respectively. The coefficient j is related to the asymmetry of the plot and must be zero if CPinvariance holds. Note also that if CP is good, q, h, and k must be the same for $K^+ \to \pi^+ \pi^+ \pi^-$ as for $K^- \to \pi^- \pi^- \pi^+$.

Since different experiments use different forms for M, in order to compare the experiments we have converted to g, h, j, and k whatever coefficients have been measured. Where such conversions have been done, the measured coefficient a_u , a_t , a_u , or a_v is given in the comment at the right. For definitions of these coefficients, details of this conversion, and discussion of the data, see the April 1982 version of this note [2].

References

- 1. S. Weinberg, Phys. Rev. Lett. 4, 87 (1960).
- Particle Data Group, Phys. Lett. 111B, 69 (1982).

ENERGY DEPENDENCE OF K^{\pm} DALITZ PLOT

|matrix element|^2 = 1 + gu + hu^2 + kv^2
where
$$u=(s_3-s_0)$$
 / m_π^2 and $v=(s_2-s_1)$ / m_π^2

LINEAR COEFFICIENT g FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

Some experiments use Dalitz variables x and y. In the comments we give $a_y=$ coefficient of y term. See note above on "Dalitz Plot Parameters for $K\to 3\pi$ Decays." For discussion of the conversion of a_v to g, see the earlier version of the same note in the Review published in Physics Letters 111B 70 (1982).

EVTS DO CUMENT ID TECN CHG COMMENT 88 BATLEY -0.21134 ± 0.00017 07в NA48 ± 471 M

| • • • W | e do not use th | ne follov | ving d | ata for averages | , fits, | limits, | etc. • | • • |
|---------|-----------------|-----------|--------|------------------|---------|---------|--------|----------------------------|
| -0.2221 | ±0.0065 | 225 k | | DEVAUX | 77 | SPEC | + | $a_V = .2814 \pm .0082$ |
| -0.199 | ± 0.008 | 81 k | 89 | LUCAS | 73 | нвс | - | $a_V = 0.252 \pm 0.011$ |
| -0.2157 | ±0.0028 | 750k | | FORD | 72 | ASPK | + | $a_V = .2734 \pm .0035$ |
| -0.2186 | ±0.0028 | 750k | | | 72 | ASPK | - | $a_V = .2770 \pm .0035$ |
| -0.200 | ± 0.009 | 39819 | | HOFFMASTER | 72 | HLBC | + | • |
| -0.196 | ±0.012 | 17898 | 91 | GRAUMAN | 70 | HLBC | + | $a_V = 0.228 \pm 0.030$ |
| -0.193 | ±0.010 | 50919 | | MAST | 69 | HBC | - | $a_V = 0.244 \pm 0.013$ |
| -0.218 | ±0.016 | 9994 | 92 | BUTLER | 68 | нвс | + | $a_V = 0.277 \pm 0.020$ |
| -0.190 | ±0.023 | 5778 | 92,93 | MOSCOSO | 68 | нвс | - | $a_V = 0.242 \pm 0.029$ |
| -0.22 | ±0.024 | 5428 | 92,93 | ZINCHENKO | 67 | нвс | + | $a_{V} = 0.28 \pm 0.03$ |
| -0.220 | ± 0.035 | 1347 | 94 | FERRO-LUZZI | 61 | нвс | _ | $a_{\nu} = 0.28 \pm 0.045$ |

 $^{^{\}mbox{88}}\mbox{Final state}$ strong interaction and radiative corrections not included in the fit

QUADRATIC COFFFICIENT h FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

| 40.1010110 | | | | | | |
|--------------------------|------------------|-------------------|------------|---------|--------|---|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT IL |) | TECN | CHG | |
| 1.848 ± 0.040 | 471 M | 95 BATLEY | 07в | NA 48 | ± | |
| | se the following | g data for averag | ges, fits, | limits, | etc. • | • |
| -0.06 ± 1.43 | 225 k | DEVAUX | 77 | SPEC | + | |
| 1.87 ± 0.62 | 75 0k | FORD | 72 | ASPK | + | |
| 1.25 ± 0.62 | 75 0k | FORD | 72 | ASPK | _ | |
| -0.9 ± 1.4 | 39819 | HOFFMAST | ER 72 | HLBC | + | |
| -0.1 + 1.2 | 50919 | MAST | 69 | HBC | _ | |

 $^{^{95}}$ Final state strong interaction and radiative corrections not included in the fit.

QUADRATIC COEFFICIENT k FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | CHG |
|---------------------------------------|---------------|----------------------|----------|-----------|------------|
| -4.63 ± 0.14 | 471 M | ⁹⁶ BATLEY | 07в | NA 48 | \pm |
| ● ● We do not use | the following | ng data for averag | es, fits | , limits, | etc. • • • |
| -20.5 ± 3.9 | 225 k | DEVAUX | 77 | SPEC | + |
| -7.5 ± 1.9 | 750k | FORD | 72 | ASPK | + |
| $-$ 8.3 \pm 1.9 | 750k | FORD | 72 | ASPK | _ |
| -10.5 ± 4.5 | 39819 | HOFFMASTE | R 72 | HLBC | + |
| -14 ± 12 | 50919 | MAST | 69 | HBC | _ |

⁹⁶ Final state strong interaction and radiative corrections not included in the fit.

$(\mathbf{g}_{+} - \mathbf{g}_{-}) \; / \; (\mathbf{g}_{+} + \mathbf{g}_{-}) \; \mathrm{FOR} \; \mathbf{K}^{\pm} \rightarrow \; \pi^{\pm} \pi^{+} \pi^{-}$

This is a *CP* violating asymmetry between linear coefficients g_+ for ${\it K}^+
ightarrow \, \pi^+ \, \pi^+ \, \pi^$ decay and g_- for $K^- \rightarrow \pi^- \pi^+ \pi^-$ decay.

| VALUE (units 10 ⁻⁴) | EVTS | DOCUMENT IE |) | TECN | |
|-----------------------------------------|-----------|----------------------|-----------|--------------|-------|
| $-1.5\pm1.5\pm1.6$ | 3.1G | ⁹⁷ BATLEY | 07E | NA48 | |
| ullet $ullet$ $ullet$ We do not use the | following | data for averages, | fits, lin | nits, etc. 🛭 | • • • |
| $1.7 \pm 2.1 \pm 2.0$ | 1.7G | ⁹⁸ BATLEY | 06 | NA48 | |
| -70.0 ± 53 | 3.2M | FORD | 70 | ASPK | |

⁹⁷ BATLEY 07E includes data from BATLEY 06. Uses quadratic parametrization and value $g_+ + g_- = 2g$ from BATLEY 07B. This measurement neglects any possible charge asymmetries in higher order slope parameters \hbar or k.

LINEAR COEFFICIENT g FOR $K^\pm ightarrow \ \pi^\pm \pi^0 \pi^0$

Unless otherwise stated, all experiments include terms quadratic in (s_3-s_0) / $m_{\pi^\pm}^2$. See note above on "Dalitz Plot Parameters for $K\to 3\pi$ Decays."

See BATUSOV 98 for a discussion of the discrepancy between their result and others, especially BOLOTOV 86. At this time we have no way to resolve the discrepancy so

| we depend on the i | iarge scale | tactor as a warnir | ıg. | | | |
|--------------------------------|----------------------|--------------------------|-----------|-----------|--------|---------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
| 0.626 ±0.007 OUR AV | ERAGE | | | | | |
| $0.6259 \pm 0.0043 \pm 0.0093$ | 493k | AKOPDZHAN | 105в | TNF | \pm | |
| $0.627 \pm 0.004 \pm 0.010$ | 252k ^{99,1} | ¹⁰⁰ A JINENKO | 03в | ISTR | _ | |
| • • • We do not use the | following | data for averages | , fits, l | imits, et | c. • • | • |
| $0.736 \pm 0.014 \pm 0.012$ | 33k | BATUSOV | 98 | SPEC | + | |
| 0.582 ± 0.021 | 43k | BOLOTOV | 86 | CALO | _ | |
| 0.670 ± 0.054 | 3263 | BRAUN | 76B | HLBC | + | |
| 0.630 ± 0.038 | 5635 | SHEAFF | 75 | HLBC | + | |
| 0.510 ± 0.060 | 27k | SMITH | 75 | WIRE | + | |
| 0.67 ± 0.06 | 1365 | AUBERT | 72 | HLBC | + | |
| 0.544 ± 0.048 | 4048 | DAVISON | 60 | HIBC | 1 | Also emulsion |

 $^{99}\,\mathrm{Measured}$ using in-flight decays of the 25 GeV negative secondary beam.

They form new world averages $g_-=(0.617\pm0.018)$ and $g_+=(0.684\pm0.033)$ which give $\Delta g_{\tau'} = 0.051 \pm 0.028$.

 $^{^{86}}$ AOKI 94 measures $\xi P_{\mu}=-$ 0.9996 \pm 0.0030 \pm 0.0048. The above limit is obtained by summing the statistical and systematic errors in quadrature, normalizing to the physically significant region $(|\xi P_{\mu}|<1)$ and assuming that $\xi{=}1$, its maximum value ⁸⁷ Assumes $\xi=1$.

⁸⁹ Quadratic dependence is required by κ_I^0 experiments.

⁹⁰ HOFFMASTER 72 includes GRAUMAN 70 data.
91 Emulsion data added — all events included by HOFFMASTER 72.
92 Experiments with large errors not included in average.

⁹³ Also includes DBC events.

⁹⁴ No radiative corrections included.

⁹⁸ This measurement neglects any possible charge asymmetries in higher order slope pa-

| QUADRATIC COEF | FICIENT h | FOR K [±] → | π± π0 | π^0 | | |
|-----------------------------------------------|----------------------|-------------------------|-----------|------------|-------|---------------|
| VALUE | <u>EVTS</u> | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.052 ±0.008 OUR | AVERAGE | | | | | |
| $0.0551 \pm 0.0044 \pm 0.00$ | 086 493k | AKOPDZHAN | √05в | TNF | \pm | |
| $0.046 \pm 0.004 \pm 0.03$ | L2 252k ¹ | ¹⁰¹ AJINENKO | 03в | ISTR | _ | |
| \bullet \bullet \bullet We do not use t | he following d | ata for averages, | fits, lin | nits, etc. | • • | • |
| $0.128 \pm 0.015 \pm 0.03$ | 24 33k | BATUSOV | 98 | SPEC | + | |
| 0.037 ± 0.024 | 43k | BOLOTOV | 86 | CALO | _ | |
| 0.152 ± 0.082 | 3263 | BRAUN | 76B | HLBC | + | |
| 0.041 ± 0.030 | 5635 | SHEAFF | 75 | HLBC | + | |
| 0.009 ± 0.040 | 27k | SMITH | 75 | WIRE | + | |
| -0.01 ± 0.08 | 1365 | AUBERT | 72 | HLBC | + | |
| 0.026 ± 0.050 | 4048 | DAVISON | 69 | HLBC | + | Also emulsion |

QUADRATIC COEFFICIENT k FOR $K^\pm \to ~\pi^\pm \pi^0 \pi^0$

| VALUE | EVTS | | DOCUMENT I | D | TECN | CHG |
|-------------------------------------------------|-----------|-------|---------------|-------------|------------|-------|
| 0.0054±0.0035 OUR AVE | RAGE | Error | includes scal | e factor | of 2.5. | |
| $0.0082 \pm 0.0011 \pm 0.0014$ | 493k | | AKOPDZHA | | | \pm |
| $0.001 \pm 0.001 \pm 0.002$ | 252k | 102 | AJINENKO | 03B | ISTR | _ |
| \bullet \bullet \bullet We do not use the | following | data | for averages, | , fits, lin | nits, etc. | • • • |
| $0.0197 \pm 0.0045 \pm 0.0029$ | 33k | | BATUSOV | 98 | SPEC | + |

 $^{101}\,\mathrm{Measured}$ using in-flight decays of the 25 GeV negative secondary beam.

 $102\,\mathrm{Measured}$ using in-flight decays of the 25 GeV negative secondary beam.

$(\mathbf{g}_{+}-\mathbf{g}_{-})\;/\;(\mathbf{g}_{+}+\mathbf{g}_{-})\;\mathrm{FOR}\;K^{\pm}\rightarrow\;\pi^{\pm}\pi^{0}\,\pi^{0}$

A nonzero value for this quantity indicates CP violation.

| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | |
|---------------------------------|------------|--------------------------|----------|--------------|--------|
| 1.8 ± 1.8 OUR AVE | | | | | |
| $1.8 \pm 1.7 \pm 0.6$ | | ¹⁰³ BATLEY | | | |
| $2 \pm 18 \pm 5$ | 619k | ¹⁰⁴ AKOPDZHAI | N05 | TNF | |
| • • • We do not use | the follow | ing data for averag | es, fits | , limits, et | c. • • |
| $1.8 \pm 2.2 \pm 1.3$ | 47M | 105 BATLEY | 06A | NA48 | |

 $^{103}\,\mathrm{BATLEY}$ 07E includes data from BATLEY 06A. Uses quadratic parametrization and PDG 06 value $g=0.626\pm0.007$ to obtain $g_+-g_-=(2.2\pm2.1\pm0.7)\times10^{-4}$. Neglects any possible charge asymmetries in higher order slope parameters h or k.

104 Asymmetry obtained assuming that $g_+ + g_- = 2 \times 0.652$ (PDG 02) and that asymmetries in h and k are zero.

105 Linear and quadratic slopes from PDG 04 are used. Any possible charge asymmetries in higher order slope parameters h or k are neglected.

ALTERNATIVE PARAMETRIZATIONS OF $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ DALITZ PLOT

The following functional form for the matrix element suggested by $\pi\pi$ rescattering in $K^+\to \pi^+\,\pi^+\pi^-^{n}\to \pi^+\pi^0\,\pi^0$ is used for this fit (CABIBBO 04A, CABIBBO 05): Matrix element $= M_0 + M_1$ where $M_0 = 1 + (1/2)g_0 \ u + (1/2) \ h' \ u^2 + (1/2)k_0 \ v^2$ with $u = (s_3 - s_0)/(m_{\pi^+})^2$, $v=(s_2-s_1)/(m_{\pi^+})^2$ and where M_1 takes into account the non-analytic piece due to pi pi rescattering amplitudes a_0 and a_2 ; The parameters g_0 and h' are related to the parameters g and h of the matrix element squared given in the previous section by the approximations $g_0 \sim g^{PDG}$ and $h' \sim h^{PDG} - (\mathrm{g}/2)^2$ and $k_0 \sim k^{PDG}$.

In addition, we also consider the effective field theory framework of COLANGELO 06A and BISSEGGER 09 to extract \mathbf{g}_{BB} and \mathbf{h}_{BB}' .

LINEAR COEFFICIENT g_0 FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$

| VALUE | EVTS | EVTS DOCUMENT I | | TECN | CHG |
|--------------------------------|----------|--------------------|------------|----------|-------|
| $0.6525 \pm 0.0009 \pm 0.0033$ | 60M | 106 BATLEY | 09A | NA48 | ± |
| • • • We do not use the fo | ollowing | data for averages, | fits, limi | ts, etc. | • • • |
| 0.645 ±0.004 ±0.000 | 2314 | 107 DATIEV | 060 | NA 49 | _ |

 106 This fit is obtained with the CABIBBO 05 matrix element in the $2\pi^0$ invariant mass squared range $0.074094 < m_{2\pi^0}^2 < 0.104244 \text{ GeV}^2$. Electromagnetic corrections and CHPT constraints for $\pi\pi$ phase shifts (a_0 and a_2) have been used. Also measured (a_0-a_2) $m_{\pi^+}=0.2646\pm0.0021\pm0.0023$, where k_0 was kept fixed in the fit at -0.0099.

107 Superseded by BATLEY 09A. This fit is obtained with the CABIBBO 05 matrix element in the $2\pi^0$ invariant mass squared range 0.074 GeV 2 $< m_{2\pi^0}^2 < 0.097$ GeV 2 , assuming k=0 (no term proportional to $(s_2-s_1)^2$) and excluding the kinematic region around the cusp $(m_{2\pi^0}^2=(2m_{\pi^+})^2\pm 0.00525~{\rm GeV}^2).$ Also π - π phase shifts a_0 and a_2 are measured: $(a_0-a_2)m_{\pi^+}=0.268\pm 0.010\pm 0.004\pm 0.013 ({\rm external})$ and a_2 $m_{\pi^+}=-0.041\pm 0.022\pm 0.014$.

QUADRATIC COEFFICIENT h' FOR $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

| WOULDIANIS COFFIE | | " 10KK → | <i>^ ^</i> | ^ | |
|---------------------------------|--------|-----------------------|------------|-----------|-------|
| VALUE | EVTS | EVTS DOCUMENT ID | | | CHG |
| $-0.0433 \pm 0.0008 \pm 0.0026$ | 60M | ¹⁰⁸ BATLEY | 09A | NA48 | \pm |
| • • • We do not use the fol | lowing | data for averages, | fits, lim | its, etc. | • • • |
| $-0.047 \pm 0.012 \pm 0.011$ | 23M | ¹⁰⁹ BATLEY | 06в | NA48 | ± |

 108 This fit is obtained with the CABIBBO 05 matrix element in the $2\pi^0$ invariant mass squared range $0.074094 < m_{2\pi^0}^2 < 0.104244$ GeV 2 . Electromagnetic corrections and CHPT constraints for $\pi\pi$ phase shifts (a_0 and a_2) have been used. Also measured (a_0-a_2) $m_{\pi^+}=0.2646\pm0.0021\pm0.0023$, where k_0 was kept fixed in the fit at -0.0099.

109 Superseded by BATLEY 09A. This fit is obtained with the CABIBBO 05 matrix element in the $2\pi^0$ invariant mass squared range 0.074 GeV 2 $< m_{2\pi^0}^2 < 0.097$ GeV 2 , assuming k=0 (no term proportional to $(s_2-s_1)^2$) and excluding the kinematic region around the cusp $(m_{2\pi^0}^2=(2m_{\pi^+})^2\pm 0.000525~{\rm GeV^2})$. Also π - π phase shifts a_0 and a_2 are measured: $(a_0^n-a_2)m_{\pi^+}^-=0.268\pm0.010\pm0.004\pm0.013$ (external) and a_2 $m_{\pi^+}=-0.041\pm0.022\pm0.014$.

QUADRATIC COEFFICIENT \emph{k}_0 FOR $\emph{K}^\pm \to ~\pi^\pm \pi^0 \pi^0$

 VALUE
 EVTS
 DOCUMENT ID
 TECN
 CHG

 0.0095 ± 0.00017 ± 0.00048
 60M
 110 BATLEY
 09a
 NA48
 ±

 $^{110}\,\mathrm{Assumed}~a_2~m_{\pi^+}=-0.0044$ in the fit.

 111 This fit is obtained using parametrizations of COLANGELO 06A and BISSEGGER 09 in the $2\pi^0$ invariant mass squared range $0.074094 < m_{2\pi^0}^2 < 0.104244$ GeV². Electromagnetic corrections and CHPT constraints for $\pi\pi$ phase shifts (a_0 and a_2) have been used. Also measured ($a_0 - a_2$) $m_{\pi^+} = 0.2633 \pm 0.0024 \pm 0.0024$, where k_0 was kept fixed in the fit at 0.0085

 $^{112}\mathrm{This}$ fit is obtained using parametrizations of COLANGELO 06A and BISSEGGER 09 in the $2\pi^0$ invariant mass squared range $0.074094 < m_{2\pi^0}^2 < 0.104244 \text{ GeV}^2$. Electromagnetic corrections and CHPT constraints for $\pi\pi$ phase shifts $(a_0$ and $a_2)$ have been used. Also measured (a_0-a_2) $m_{\pi^+}=0.2633\pm0.0024\pm0.0024$, where k_0 was kept fixed in the first 0.0026fixed in the fit at 0.0085.

$K_{\ell 3}^{\pm}$ AND $K_{\ell 3}^{0}$ FORM FACTORS

Updated March 2012 by T.G. Trippe (LBNL) and C.-J. Lin

Assuming that only the vector current contributes to $K \rightarrow$ $\pi\ell\nu$ decays, we write the matrix element as

$$M \propto f_{+}(t) \left[(P_K + P_{\pi})_{\mu} \overline{\ell} \gamma_{\mu} (1 + \gamma_5) \nu \right]$$

+ $f_{-}(t) \left[m_{\ell} \overline{\ell} (1 + \gamma_5) \nu \right] ,$ (1)

where P_K and P_{π} are the four-momenta of the K and π mesons, m_{ℓ} is the lepton mass, and f_{+} and f_{-} are dimensionless form factors which can depend only on $t = (P_K - P_\pi)^2$, the square of the four-momentum transfer to the leptons. If timereversal invariance holds, f_+ and f_- are relatively real. $K_{\mu3}$ experiments, discussed immediately below, measure f_{+} and f_{-} , while K_{e3} experiments, discussed further below, are sensitive only to f_+ because the small electron mass makes the f_- term

 $K_{\mu 3}$ Experiments. Analyses of $K_{\mu 3}$ data frequently assume a linear dependence of f_+ and f_- on t, *i.e.*,

$$f_{\pm}(t) = f_{\pm}(0) \left[1 + \lambda_{\pm}(t/m_{\pi^{+}}^{2}) \right] .$$
 (2)

Most $K_{\mu 3}$ data are adequately described by Eq. (2) for f_+ and a constant f_{-} (i.e., $\lambda_{-}=0$).

There are two equivalent parametrizations commonly used in these analyses:

(1) $\lambda_+, \xi(0)$ parametrization. Older analyses of $K_{\mu 3}$ data often introduce the ratio of the two form factors

$$\xi(t) = f_{-}(t)/f_{+}(t) . \tag{3}$$

 K^{\pm}

The $K_{\mu 3}$ decay distribution is then described by the two parameters λ_{+} and $\xi(0)$ (assuming time reversal invariance and $\lambda_{-}=0$).

(2) λ_+ , λ_0 parametrization. More recent $K_{\mu 3}$ analyses have parametrized in terms of the form factors f_+ and f_0 , which are associated with vector and scalar exchange, respectively, to the lepton pair. f_0 is related to f_+ and f_- by

$$f_0(t) = f_+(t) + \left[t/(m_K^2 - m_\pi^2) \right] f_-(t)$$
 (4)

Here $f_0(0)$ must equal $f_+(0)$ unless $f_-(t)$ diverges at t=0. The earlier assumption that f_+ is linear in t and f_- is constant leads to f_0 linear in t:

$$f_0(t) = f_0(0) \left[1 + \lambda_0 (t/m_{\pi^+}^2) \right]$$
 (5)

With the assumption that $f_0(0) = f_+(0)$, the two parametrizations, $(\lambda_+, \xi(0))$ and (λ_+, λ_0) are equivalent as long as correlation information is retained. (λ_+, λ_0) correlations tend to be less strong than $(\lambda_+, \xi(0))$ correlations.

Since the 2006 edition of the Review [4], we no longer quote results in the $(\lambda_+, \xi(0))$ parametrization. We have removed many older low statistics results from the Listings. See the 2004 version of this note [5] for these older results, and the 1982 version [6] for additional discussion of the $K_{\mu 3}^0$ parameters, correlations, and conversion between parametrizations.

Quadratic Parametrization. More recent high-statistics experiments have included a quadratic term in the expansion of $f_{+}(t)$,

$$f_{+}(t) = f_{+}(0) \left[1 + \lambda'_{+}(t/m_{\pi^{+}}^{2}) + \frac{\lambda''_{+}}{2}(t/m_{\pi^{+}}^{2})^{2} \right]$$
 (6)

If there is a non-vanishing quadratic term, then λ_+ of Eq. (2) represents the average slope, which is then different from λ'_+ . Our convention is to include the factor $\frac{1}{2}$ in the quadratic term, and to use m_{π^+} even for K^+_{e3} and $K^+_{\mu3}$ decays. We have converted other's parametrizations to match our conventions, as noted in the beginning of the " $K^\pm_{\ell3}$ and $K^0_{\ell3}$ Form Factors" sections of the Listings.

Pole Parametrization: The pole model describes the t-dependence of $f_+(t)$ and $f_0(t)$ in terms of the exchange of the lightest vector and scalar K^* mesons with masses M_v and M_s , respectively:

$$f_{+}(t) = f_{+}(0) \left[\frac{M_{v}^{2}}{M_{v}^{2} - t} \right] , \quad f_{0}(t) = f_{0}(0) \left[\frac{M_{s}^{2}}{M_{s}^{2} - t} \right] .$$
 (7)

Dispersive Parametrization [7,8]. This approach uses dispersive techniques and the known low-energy K- π phases to parametrize the vector and scalar form factors:

$$f_{+}(t) = f_{+}(0) \exp\left[\frac{t}{m_{\pi}^{2}}(\Lambda_{+} + H(t))\right];$$
 (8)

$$f_0(t) = f_+(0) \exp\left[\frac{t}{(m_K^2 - m_\pi^2)} (\ln[C] - G(t))\right],$$
 (9)

where Λ_+ is the slope of the vector form factor, and $\ln[C] = \ln[f_0(m_K^2 - m_\pi^2)]$ is the logarithm of the scalar form factor at

the Callan-Treiman point. The functions H(t) and G(t) are dispersive integrals.

 K_{e3} Experiments: Analysis of K_{e3} data is simpler than that of $K_{\mu3}$ because the second term of the matrix element assuming a pure vector current [Eq. (1) above] can be neglected. Here f_+ can be assumed to be linear in t, in which case the linear coefficient λ_+ of Eq. (2) is determined, or quadratic, in which case the linear coefficient λ_+' and quadratic coefficient λ_+'' of Eq. (6) are determined.

If we remove the assumption of a pure vector current, then the matrix element for the decay, in addition to the terms in Eq. (1), would contain

$$+2m_K f_S \overline{\ell}(1+\gamma_5)\nu$$

$$+(2f_T/m_K)(P_K)_{\lambda}(P_{\pi})_{\mu} \overline{\ell} \sigma_{\lambda\mu}(1+\gamma_5)\nu , \qquad (10)$$

where f_S is the scalar form factor, and f_T is the tensor form factor. In the case of the K_{e3} decays where the f_- term can be neglected, experiments have yielded limits on $|f_S/f_+|$ and $|f_T/f_+|$.

Fits for $K_{\ell 3}$ Form Factors. For K_{e3} data, we determine best values for the three parametrizations: linear (λ_+) , quadratic $(\lambda'_+, \lambda''_+)$ and pole (M_v) . For $K_{\mu 3}$ data, we determine best values for the three parametrizations: linear (λ_+, λ_0) , quadratic $(\lambda'_+, \lambda''_+, \lambda_0)$ and pole (M_v, M_s) . We then assume $\mu - e$ universality so that we can combine K_{e3} and $K_{\mu 3}$ data, and again determine best values for the three parametrizations: linear (λ_+, λ_0) , quadratic $(\lambda'_+, \lambda''_+, \lambda_0)$, and pole (M_v, M_s) . When there is more than one parameter, fits are done including input correlations. Simple averages suffice in the two K_{e3} cases where there is only one parameter: linear (λ_+) and pole (M_v) .

Both KTeV and KLOE see an improvement in the quality of their fits relative to linear fits when a quadratic term is introduced, as well as when the pole parametrization is used. The quadratic parametrization has the disadvantage that the quadratic parameter λ'_+ is highly correlated with the linear parameter λ'_+ , in the neighborhood of 95%, and that neither parameter is very well determined. The pole fit has the same number of parameters as the linear fit, but yields slightly better fit probabilities, so that it would be advisable for all experiments to include the pole parametrization as one of their choices [9].

The "Kaon Particle Listings" show the results with and without assuming μ -e universality. The "Meson Summary Tables" show all of the results assuming μ -e universality, but most results not assuming μ -e universality are given only in the Listings.

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KA FORM FACTORS

In the form factor comments, the following symbols are used.

 f_{+} and f_{-} are form factors for the vector matrix element.

 $f_{\mathcal{S}}$ and $f_{\mathcal{T}}$ refer to the scalar and tensor term.

$$f_0 = f_+ + f_- t/(m_{K^+}^2 - m_{\pi^0}^2).$$

t= momentum transfer to the π .

 λ_+ and λ_0 are the linear expansion coefficients of f_+ and f_0

$$f_{+}(t) = f_{+}(0) (1 + \lambda_{+} t / m_{\pi^{+}}^{2})$$

For quadratic expansion

$$f_{+}(t) = f_{+}(0) \left(1 + \lambda'_{+} t / m_{\pi^{+}}^{2} + \frac{\lambda''_{+}}{2} t^{2} / m_{\pi^{+}}^{4}\right)$$

as used by KTeV. If there is a non-vanishing quadratic term, then λ_+ represents an average slope, which is then different from λ'_{+} .

NA48 and ISTRA quadratic expansion coefficients are converted with

$$\lambda''_{+} \stackrel{PDG}{=} 2 \left(\frac{m_{\pi^{+}}}{m_{\pi^{0}}} \right)^{4} \lambda'_{+} \stackrel{ISTRA}{=}$$

ISTRA linear expansion coefficients are converted with $\lambda_{+}^{~PDG}=(\frac{m_{\pi^{+}}}{m_{\pi^{0}}})^{2}~\lambda_{+}^{~ISTRA}$ and $\lambda_{0}^{~PDG}=(\frac{m_{\pi^{+}}}{m_{\pi^{0}}})^{2}~\lambda_{0}^{~ISTRA}$

$$f_{+}(t) = f_{+}(0) \left(\frac{M_{V}^{2}}{M_{V}^{2} - t} \right)$$

$$f_{0}(t) = f_{0}(0) \left(\frac{M_{S}^{5}}{M_{S}^{5} - t} \right)$$

where M_V and M_S are the vector and scalar pole masses

The following abbreviations are used:

 $\mathsf{DP} \,=\, \mathsf{Dalitz} \,\, \mathsf{plot} \,\, \mathsf{analysis}.$

 $PI = \pi$ spectrum analysis.

 $MU = \mu$ spectrum analysis.

 $\mathsf{POL} = \mu$ polarization analysis. BR = $K_{\mu 3}^{\pm}/K_{e3}^{\pm}$ branching ratio analysis.

E = positron or electron spectrum analysis.

 ${\sf RC} = {\sf radiative} \ {\sf corrections}.$

 λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K_{e3}^\pm DECAY)

These results are for a linear expansion only. See the next section for fits including a quadratic term. For radiative correction of the K_{e3}^\pm Dalitz plot, see GINSBERG 67, BECHERRAWY 70, CIRIGLIANO 02, CIRIGLIANO 04, and ANDRE 07. Results labeled OUR FIT are discussed in the review " K_{e3}^\pm and K_{e3}^0 Form Factors" above. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters ${\bf B592}$ 1 (2004).

| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------|-----------|-------------------------------|---------|-----------|-------|-----------|
| 2.97 ±0.05 OUR FIT | T Assu | ming μ - e universality | | | | |
| 2.98 ±0.05 OUR AV | ERAGE | | | | | |
| $3.044 \pm 0.083 \pm 0.074$ | 1.1M | AKOPDZANOV | 09 | TNF | \pm | |
| $2.966 \pm 0.050 \pm 0.034$ | 919k | ¹¹³ YUSHCHENKO | 04B | ISTR | _ | DP |
| $2.78 \pm 0.26 \pm 0.30$ | 41k | SHIMIZU | 00 | SPEC | + | DP |
| $2.84 \pm 0.27 \pm 0.20$ | 32k | ¹¹⁴ AKIMENKO | 91 | SPEC | | PI, no RC |
| 2.9 ±0.4 | 62k | ¹¹⁵ BOLOTOV | 88 | SPEC | | PI, no RC |
| • • • We do not use | the follo | wing data for averages, fi | ts, lii | nits, etc | | • |
| 3.06 ±0.09 ±0.06 | 550k | 113,116 A JINENKO | 03c | ISTR | _ | DP |
| 2.93 + 0.15 + 0.2 | 130k | ¹¹⁶ A JINENKO | 02 | SPEC | | DP |

- $^{113}\operatorname{Rescaled}$ to agree with our conventions as noted above.
- 114 AKIMENKO $^{\circ}$ 1 state that radiative corrections would raise λ_{+} by 0.0013.
- $^{115}\,\mathrm{BOLOTOV}$ 88 state radiative corrections of GINSBERG 67 would raise λ_+ by 0.002.
- $^{116}\,\mathrm{Superseded}$ by YUSHCHENKO 04B.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K_{\mu 3}^\pm$ DECAY)

Results labeled OUR FIT are discussed in the review " $K_{\ell 3}^{\pm}$ and $K_{\ell 3}^{0}$ Form Factors" above. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters **B592** 1 (2004).

| 0 | | | | | | |
|-------------------------------------|----------------------|---------------------------|---------|-----------|-------|---------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
| 2.97±0.05 OUR FIT | Assuming μ - e | universality | | | | |
| 2.96±0.17 OUR FIT | | | | | | |
| $2.96 \pm 0.14 \pm 0.10$ | 540k | ^{l17} YUSHCHENK | O 04 | ISTR | _ | DP |
| ullet $ullet$ $ullet$ We do not use | the following da | ta for averages, fit | ts, lim | its, etc. | • • • | |
| 3.21 ± 0.45 | 112k | ^{l 18} a JINENKO | 03 | ISTR | _ | DP |
| 117 Rescaled to agree | with our conven | tions as noted abo | ove | | | |

λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K_{\mu3}^\pm$ DECAY)

Results labeled OUR FIT are discussed in the review " $K_{\ell,3}^{+}$ " and $K_{\ell,3}^{0}$ Form Factors" above. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters **B592** 1 (2004).

| VALUE (units 10^{-2}) | $d\lambda_0/d\lambda_+$ | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT | | | |
|---------------------------------------------------------------------------------|-------------------------|--------|------------------------|------|------|------|---------|--|--|--|
| 1.95 \pm 0.12 OUR FIT Assuming μ - e universality | | | | | | | | | | |
| 1.96 \pm 0.13 OUR FIT Not assuming μ - e universality | | | | | | | | | | |
| $+1.96\pm0.12\pm0.06$ | -0.348 | 540k | 119 YUSHCHENK | O 04 | ISTR | _ | DP | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | | | | |
| $+2.09\pm0.45$ | -0.46 | 112k | | 03 | ISTR | _ | DP | | | |
| $+1.9 \pm 0.64$ | | 24k | ¹²¹ HORIE | | SPEC | + | BR | | | |
| $+1.9 \pm 1.0$ | +0.03 | 55k | ¹²² HEINTZE | 77 | SPEC | + | BR | | | |
| 119 Rescaled to agree with our conventions as noted above. | | | | | | | | | | |
| 120 Superseded by Y | USHCHENI | CO 04. | | | | | | | | |

¹²¹ HORIE 01 assumes μ -e universality in $K_{\ell 3}^+$ decay and uses SHIMIZU 00 value λ =0.0278 \pm 0.0040 from K_{e3}^{\pm} decay.

 $^{122}\,\mathrm{HEINTZE}$ 77 uses $\lambda_{+}=$ 0.029 \pm 0.003. $d\lambda_{0}/d\lambda_{+}$ estimated by us.

λ'_{+} (LINEAR K_{e3}^{\pm} FORM FACTOR FROM QUADRATIC FIT)

| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | TECN | CHG | COMMENT | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------------------------------|---------|-----|---------|--|--|--|--|
| $2.485 \pm 0.163 \pm 0.034$ | 919k 12 | ^{3,124} YUSHCHENKO0 | 4B ISTR | _ | DP | | | | |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | | | | | | | | | |
| 3.07 ± 0.21 | 550k 12 | ^{3,125} AJINENKO 0 | 3c ISTR | _ | DP | | | | |
| 123 Rescaled to agree with our conventions as noted above. 124 YUSHCHENKO 04B λ'_+ and λ''_+ are strongly correlated with coefficient $\rho(\lambda'_+,\lambda''_+)$ | | | | | | | | | |

125 Superseded by YUSHCHENKO 04B.

λ''_{+} (QUADRATIC K_{e3}^{\pm} FORM FACTOR)

 ALUE (units 10⁻²)
 EVTS
 DOCUMENT ID
 TECN
 CMG
 COM

 0.192±0.062±0.071
 919k
 126,127
 YUSHCHENKO04B
 ISTR
 DP
 • • • We do not use the following data for averages, fits, limits, etc. • • • -0.5 ± 0.7 ± 1.5 550k 126,128 AJINENKO 03c ISTR - DP 126 Rescaled to agree with our conventions as noted above. 127 YUSHCHENKO 04B λ'_+ and λ''_+ are strongly correlated with coefficient $\rho(\lambda'_+,{\lambda''}_+)$. ^ or

128 Superseded by YUSHCHENKO 04B.

 $|f_{\rm S}/f_{+}|$ FOR $K_{\rm e3}^{\pm}$ DECAY
Ratio of scalar to f_{+} couplings

| $VALUE$ (units 10^{-2}) | CL% | EVTS | DO CUMENT ID | TECN | CHG | COMMENT |
|------------------------------------------------------|---------|---------|----------------------------|----------------|-------|------------------------------------------|
| $-0.3 \begin{array}{c} +0.8 \\ -0.7 \end{array}$ OUR | AVER. | AGE | | | | |
| $-0.37^{+0.66}_{-0.56}\pm0.43$ | L | 919k | YUSHCHENKO0 | 4в ISTR | - | λ'_+ , λ''_+ , f_S fit |
| $0.2 \pm 2.6 \pm 1.4$ | | 41k | SHIMIZU 0 | 0 SPEC | + | λ_+ , f_S , f_T fit |
| • • • We do not u | ise the | followi | ng data for averages, fi | its, limits, e | tc. • | • • |
| $0.2 \ ^{+ 2.0}_{- 2.2} \ \pm 0.3$ | | 550k | 129 A JINENKO 0 | 3c ISTR | - | λ_+ , f_S , f_T fit |
| $-1.9 \begin{array}{l} +2.5 \\ -1.6 \end{array}$ | | 130k | ¹²⁹ A JINENKO 0 | 2 SPEC | | λ_+ , f_S fit |
| $7.0 \pm 1.6 \pm 1.6$ | | 32k | | 1 SPEC | | λ_+ , f_S , f_T , ϕ fit |
| 0 ± 10 | | 2827 | ¹³⁰ BRAUN 7 | 5 HLBC | + | , , , |
| < 13 | 90 | 4017 | | 2 OSPK | + | |
| $14 + \frac{3}{4}$ | | 2707 | ¹³⁰ STEINER 7 | 1 HLBC | + | λ_+ , f_S , f_T , ϕ fit |
| < 23 | 90 | | BOTTERILL 6 | 8c ASPK | | |
| < 18 | 90 | | BELLOTTI 6 | 7B HLBC | | |
| < 30 | 95 | | KALMUS 6 | 7 HLBC | + | |
| 400 | | | | | | |

 $^{129}\,\mathrm{Superseded}$ by YUSHCHENKO 04B.

130 Statistical errors only.

 $|f_T/f_+|$ FOR K_{e3}^{\pm} DECAY Ratio of tensor to f_+ couplings.

| V | ALUE (units 10^{-2}) | CL% EVTS | DO CUMENT ID | TECN | CHG | COMMENT |
|---|-------------------------|----------|--------------|---------|-----|------------------------------------------|
| - | - 1.2± 2.3 OUR / | VERAGE | | | | |
| - | $-1.2 \pm 2.1 \pm 1.1$ | 919k | YUSHCHENKO0 | 4B ISTR | _ | $\lambda'_{+}, \lambda''_{+}, f_{T}$ fit |
| | $1 \pm 14 \pm 9$ | 41k | SHIMIZU 0 | 0 SPEC | + | λ_{\perp} , f_S , f_T fit |

 $^{^{118}\,\}mathrm{Superseded}$ by YUSHCHENKO 04.

- ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
- $2.1^{\,+}_{\,-}\,\,{}^{6.4}_{7.5}\,\pm\,\,2.6$ 550k 131 AJINENKO 03c ISTR - λ_+ , f_S , f_T fit $-4.5 + 6.0 \\ -5.7$ 130k 131 AJINENKO 02 SPEC λ_{\perp} , f_{T} fit $53 \begin{array}{c} + & 9 \\ -10 \end{array} \pm 10$ 91 32k AKIMENKO SPEC λ_+ , f_S , f_T , ϕ fit 2827 132 BRAUN 7 ± 37 75 HLBC + < 75 90 4017 CHIANG 72 OSPK + $\begin{array}{ccc} 24 & +16 \\ -14 \end{array}$ 2707 132 STEINER HLBC + λ_+ , f_S , f_T , ϕ fit < 58 90 BELLOTTI 67B HLBC < 110 95 KALMUS HLBC
- 131 Superseded by YUSHCHENKO 04B.
- $^{132}\,\mathrm{Statistical}$ errors only

$f_{\rm S}/f_{+}$ FOR $K_{\mu 3}^{\pm}$ DECAY Ratio of scalar to f_{+} couplings.

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT | |
|---------------------------------------|------------|-------------------------|----------|---------|--------|---------|--|
| 0.17±0.14±0.54 | 540k | 133 YUSHCHENK | 004 | ISTR | _ | DP | |
| ● ● We do not use | the follow | ing data for average | s, fits, | limits, | etc. • | • • | |
| $0.4 \pm 0.5 \pm 0.5$ | 112k | ¹³⁴ AJINENKO | 03 | ISTR | _ | DP | |

 133 The second error is the theoretical error from the uncertainty in the chiral perturbation theory prediction for λ_0 , ± 0.0053 , combined in quadrature with the systematic error

 $\pm 0.0009.$ $134\,\text{The second error}$ is the theoretical error from the uncertainty in the chiral perturbation theory prediction for λ_0 . Superseded by YUSHCHENKO 04.

f_T/f_+ FOR $K_{\mu 3}^\pm$ DECAY Ratio of tensor to f_+ couplings.

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT | |
|---------------------------------|-------------|-------------------------|----------|-----------|--------|---------|--|
| -0.07± 0.71±0.20 | 540k | YUSHCHENK | O 04 | ISTR | _ | DP | |
| | he followin | g data for average | es, fits | , limits, | etc. • | • • | |
| $-2.1 \pm 2.8 \pm 1.4$ | 112k | ¹³⁵ ajinenko | 03 | ISTR | _ | DP | |
| 2 +12 | 15.85 | RRAIIN | 75 | HIRC | | | |

 $135\,\mathrm{The}$ second error is the theoretical error from the uncertainty in the chiral perturbation theory prediction for λ_0 . Superseded by YUSHCHENKO 04.

K₄ FORM FACTORS

Based on the parametrizations of AMOROS 99, the $K^\pm_{\ell 4}$ form factors can

$$F_{s} = f_{s} + f'_{s} q^{2} + f''_{s} q^{4} + f'_{e} S_{e} / 4m_{\pi}^{2}$$

$$F_{p} = f_{p} + f'_{p} q^{2}$$

$$G_{p} = g_{p} + g'_{p} q^{2}$$

$$H_{p} = h_{p} + h'_{p} q^{2}$$

 $\begin{array}{c} H_p = h_p + h_p^{\prime} \ {\bf q}^2 \\ \text{where } {\bf q}^2 = ({\bf S}_\pi \ / \ 4m_\pi^2) - {\bf 1}, \ {\bf S}_\pi \ \text{is the invariant mass squared of the dipion, and } {\bf S}_e \ \text{is the invariant mass squared of the dilepton.} \end{array}$

f_s FOR $K^{\pm} \rightarrow \pi^+ \pi^- e^{\pm} \nu$ DECAY

| VALUE | EVTS | DO CUMENT ID | | TECN | CHG |
|--------------------|------|--------------|----|------|-----|
| 5.75 ± 0.02 ± 0.08 | 400k | 136 PISLAK | 03 | B865 | + |

 136 Radiative corrections included. Using Roy equations and not including isospin breakreal PISLAK 03 obtains the following $\pi\pi$ scattering lengths $a_0^0=0.228\pm0.012\pm0.004^{+0.012} ({\rm theor.})$ and $a_0^2=-0.0365\pm0.0023\pm0.0008^{+0.0031} ({\rm theor.})$.

f_s'/f_s FOR $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ DECAY

| VALUE (units 10 ⁻²) | EVTS | DOCUMENT | ID | TECN | CHO | ŝ | |
|---------------------------------|---------------|-------------------|-------------|---------|------|-----|--|
| 15.2±0.7±0.5 | 1.13M | 137 BATLEY | 10c | NA48 | ± | | |
| | se the follow | ing data for aver | ages, fits, | limits, | etc. | • • | |
| 17 2+0 9+0 6 | 670k | 138 BATLEY | 084 | NA48 | + | | |

 137 Radiative corrections included. Using Roy equations and including isospin breaking, BATLEY 10C obtains the following scattering lengths $a_0^0=0.2220\pm0.0128\pm0.0050\pm$ 0.0037 (theor.), $a_0^2 = -0.0432 \pm 0.0086 \pm 0.0034 \pm 0.0028$ (theor.). The correlation with $f_S^{\prime\prime}/f_S=-0.954$ and with $f_E^\prime/f_S=0.080$. Supersedes BATLEY 08A.

138 Radiative corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

f_s''/f_s FOR $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ DECAY

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT | ID | TECN | CHG | _ | |
|---------------------------------|---------------|-----------------------|-------------|---------|-------|-----|---|
| $-7.3\pm0.7\pm0.6$ | 1.13M | ¹³⁹ BATLEY | 10 c | NA48 | \pm | | |
| | se the follow | ing data for aver | ages, fits, | limits, | etc. | • • | • |
| $-9.0\pm0.9\pm0.7$ | 670k | 140 BATLEY | 08A | NA48 | + | | |

 139 Radiative corrections included. Using Roy equations and including isospin breaking, BATLEY 10C obtains the following scattering lengths $a_0^0=0.2220\pm0.0128\pm0.0050\pm0.00128$ 0.0037 (theor.), $a_0^2 = -0.0432 \pm 0.0086 \pm 0.0034 \pm 0.0028$ (theor.). The correlation with $f_S^\prime/f_S^{}=-$ 0.954 and with $f_E^\prime/f_S^{}=$ 0.019. Supersedes BATLEY 08A.

 140 Radiative corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

f_a'/f_s FOR $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ DECAY

| VALUE (units | 10-2) | EVTS | DO CUMENT IE | | TECN | CHG | |
|-------------------|---------------|----------|-----------------------|-----------|---------|--------|-----|
| 6.8±0.6± | 0.7 | 1.13M | 141 BATLEY | 10c | NA 48 | ± | |
| • • • We | do not use th | e follow | ing data for averag | es, fits, | limits, | etc. • | • • |
| $8.1 \pm 0.8 \pm$ | 0.9 | 670k | ¹⁴² BATLEY | 08A | NA 48 | \pm | |

 141 Radiative corrections included. Using Roy equations and including isospin breaking, BATLEY 10c obtains the following scattering lengths $a_0^0=$ 0.2220 \pm 0.0128 \pm 0.0050 \pm 0.0037 (theor.), $a_0^2 = -0.0432 \pm 0.0086 \pm 0.0034 \pm 0.0028$ (theor.). The correlation with $f_S^\prime/f_S^{}=0.080$ and with $f_S^{\prime\prime}/f_S^{}=0.019$. Supersedes BATLEY 08A.

 $^{142}\mathrm{Radiative}$ corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

f_D/f_S FOR $K^{\pm} \rightarrow \pi^+ \pi^- e^{\pm} \nu$ DECAY

| • | | | | | | |
|---------------------------------------|------------|--------------------|-------------|---------|--------|-----|
| VALUE (units 10 ⁻²) | EVTS | DO CUMENT I | D | TECN | CHG | |
| $-4.8 \pm 0.3 \pm 0.4$ | 1.13M | 143 BATLEY | 10 c | NA 48 | ± | |
| ● ● We do not use | the follow | ing data for avera | ges, fits, | limits, | etc. • | • • |
| | | 144 | | | | |

 143 Radiative corrections included. Using Roy equations and including isospin breaking, BATLEY 10c obtains the following scattering lengths $a_0^0=0.2220\pm0.0128\pm0.0050\pm0.0000$ 0.0037 (theor.), $a_0^2 = -0.0432 \pm 0.0086 \pm 0.0034 \pm 0.0028$ (theor.). Supersedes BAT-

LEY 08A. 144 Radiative corrections included. Using Roy equations and not including isospin breaking. BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

g_0/f_s FOR $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ DECAY

| VALUE (units 10^{-2}) | EVTS | DO CUMENT I | D | TECN | CHG | |
|--------------------------|------------|-----------------------|------------|---------|----------|-----|
| 86.8±1.0±1.0 | 1.13M | 145 BATLEY | 10c | NA 48 | ± | |
| | the follow | ing data for avera | ges, fits, | limits, | etc. • • | • • |
| $87.3 \pm 1.3 \pm 1.2$ | 670k | ¹⁴⁶ BATLEY | 08A | NA 48 | \pm | |
| 80 9+0 9+1 2 | 400k | 147 PISLAK | 0.3 | B 865 | + | |

 $^{145}\,\mathrm{Radiative}$ corrections included. Using Roy equations and including isospin breaking, BATLEY 10c obtains the following scattering lengths $a_0^0=$ 0.2220 \pm 0.0128 \pm 0.0050 \pm 0.0037 (theor.), $a_0^2=-0.0432\pm0.0086\pm0.0034\pm0.0028$ (theor.). Supersedes BAT-LEY 08A. The correlation with $g_D^{\prime}/f_S=-$ 0.914. Supersedes BATLEY 08A.

 146 Radiative corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

147 Radiative corrections included. Using Roy equations PISLAK 03 obtains the following scattering lengths $a_0^0=0.203\pm0.033\pm0.004, a_0^2=-0.055\pm0.023\pm0.003.$

g_n'/f_s FOR $K^{\pm} \rightarrow \pi^+\pi^-e^{\pm}\nu$ DECAY

| $VALUE$ (units 10^{-2}) | EVTS | DO CUMENT | D | TECN | CHG | |
|----------------------------|---------------|-----------------------|------------|---------|------------|--|
| 8.9±1.7±1.3 | 1.13M | 148 BATLEY | 10€ | NA 48 | ± | |
| • • • We do not use | the following | ng data for avera | ges, fits, | limits, | etc. • • • | |
| $8.1 \pm 2.2 \pm 1.5$ | | ¹⁴⁹ BATLEY | 08A | NA 48 | ± | |
| 120+19+07 | 400k | 150 PISLAK | 0.3 | B 865 | + | |

 $^{148}\mathrm{Radiative}$ corrections included. Using Roy equations and including isospin breaking, BATLEY 10c obtains the following scattering lengths $a_0^0=0.2220\pm0.0128\pm0.0050\pm$ 0.0037 (theor.), $a_0^2=-0.0432\pm0.0086\pm0.0034\pm0.0028$ (theor.). The correlation with $g_p/f_{\rm S}=-0.914$. Supersedes BATLEY 08A.

 149 Radiative corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2 = -0.0471 \pm 0.011 \pm 0.004.$

150 Radiative corrections included. Using Roy equations PISLAK 03 obtains the following scattering lengths $a_0^0=0.203\pm0.033\pm0.004, a_0^2=-0.055\pm0.023\pm0.003.$

h_D/f_S FOR $K^{\pm} \rightarrow \pi^+ \pi^- e^{\pm} \nu$ DECAY

| VALUE (units 10^{-2}) | EVTS | DO CUMENT IE |) | TECN | CHG |
|--------------------------|------------|-----------------------|------------|---------|------------|
| $-39.8 \pm 1.5 \pm 0.8$ | 1.13M | ¹⁵¹ BATLEY | 10⊂ | NA 48 | ± |
| • • • We do not use | the follow | ing data for averag | ges, fits, | limits, | etc. • • • |
| $-41.1\pm1.9\pm0.8$ | | 152 BATLEY | 08A | NA 48 | ± |
| $-51.3 \pm 3.3 \pm 3.5$ | 400k | ¹⁵³ PISLAK | 03 | B865 | 土 |

 151 Radiative corrections included. Using Roy equations and including isospin breaking, BATLEY 10c obtains the following scattering lengths $a_0^0=0.2220\pm0.0128\pm0.0050\pm0.0037$ (theor.), $a_0^2=-0.0432\pm0.0086\pm0.0034\pm0.0028$ (theor.). Supersedes BATLEY 08A.

LEY 08A. 152 Radiative corrections included. Using Roy equations and not including isospin breaking, BATLEY 08A obtains the following $\pi\pi$ scattering length $a_0^0=0.233\pm0.016\pm0.007$ $a_0^2=-0.0471\pm0.011\pm0.004$.

153 Radiative corrections included. Using Roy equations PISLAK 03 obtains the following scattering lengths $a_0^0=0.203\pm0.033\pm0.004, a_0^2=-0.055\pm0.023\pm0.003.$

DECAY FORM FACTOR FOR $\mathit{K}^{\pm} \rightarrow \ \pi^{0} \, \pi^{0} \, e^{\pm} \nu$

Given in BOLOTOV 86B, BARMIN 88B, and SHIMIZU 04.

$K^{\pm} \rightarrow \ell^{\pm} \nu \gamma$ FORM FACTORS

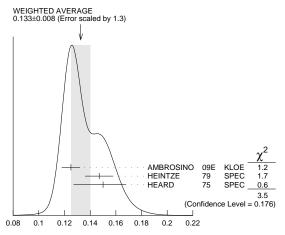
For definitions of the axial-vector F_A and vector F_V form factor, see the "Note on $\pi^\pm\to~\ell^\pm\nu\gamma$ and $K^\pm\to~\ell^\pm\nu\gamma$ Form Factors" in the π^\pm section. In the kaon literature, often different definitions $a_K=F_A/m_K$ and $v_K=F_V/m_K$ are used.

$F_A + F_V$, SUM OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \to e \nu_e \gamma$

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|------|--------------------------|-----|------|-----------------------------|
| 0.133±0.008 OUR AVE | | | | | See the ideogram below. |
| $0.125 \pm 0.007 \pm 0.001$ | 1.4K | ¹⁵⁴ AMBROSINO | 09E | KLOE | E_{γ} in 10-250 MeV, |
| | | | | | $p_{e} > 200 \text{ MeV/c}$ |
| 0.147 ± 0.011 | 51 | ¹⁵⁵ HEINTZE | 79 | SPEC | |
| $0.150 {}^{+ 0.018}_{- 0.023}$ | 56 | ¹⁵⁶ HEARD | 75 | SPEC | |
| | | | | | |

 154 Vector form factor fitted with a linear function, V(x) = F_V (1 + $\lambda(1-{\rm x}))$, x = $2E_\gamma/m_K$. The fitted value of $\lambda=0.38\pm0.20\pm0.02$ with a correlation of -0.93 between (F_V+F_A) and λ .

 155 HEINTZE 79 quotes absolute value of $|F_A+F_V|\sin\theta_C$. We use $\sin\theta_C=V_{US}=0.2205.$ 156 HEARD 75 quotes absolute value of $|F_A+F_V|\sin\theta_C$. We use $\sin\theta_C=V_{US}=0.2205.$



 $\mathit{F_A} + \mathit{F_V},$ SUM OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $\mathit{K} \rightarrow \mathit{e}\, \nu_\mathit{e}\, \gamma$

$F_A + F_V$, SUM OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \to \mu \nu_\mu \gamma$

| VALUE | CL% EVTS | DOCUMENT ID | | TECN | CHG | | | |
|-------------------------------------------------------------------------------------------------|--------------------|----------------------|-----|------|-----|--|--|--|
| $0.165 \pm 0.007 \pm 0.01$ | 1 2588 | ¹⁵⁷ ADLER | 00в | B787 | + | | | |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | | | | | | | | |
| -1.2 to 1.1 | 90 | DEMIDOV | 90 | XEBC | | | | |
| < 0.23 | 90 | ¹⁵⁷ AKIBA | 85 | SPEC | | | | |
| 157 Quotes absolute val | ue. Sign not deter | mined. | | | | | | |

F_A-F_V , DIFFERENCE OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K\to e u_e \gamma$

| VALUE | EVTS | DO CUMENT ID | | TECN |
|----------------------------------|------------------|-----------------------------|-------|------|
| <0.49 | 90 | 158 HEINTZE | 79 | SPEC |
| ¹⁵⁸ HEINTZE 79 quotes | F _A - | $ F_V < \sqrt{11} F_A +$ | F_V | |

$F_A = F_V$, DIFFERENCE OF AXIAL-VECTOR AND VECTOR FORM FACTOR FOR $K \to \mu \nu_\mu \gamma$

| VALUE | CL% EVT | <u>DO CUMENT</u> | ID | TECN | CHG | |
|---------------------|------------------|---------------------|-------------|---------|----------|---|
| -0.24 to 0.04 | 90 2588 | 8 ADLER | 00в | B787 | + | |
| ullet $ullet$ We do | not use the foll | owing data for aver | ages, fits, | limits, | etc. • • | • |
| -2.2 to 0.6 | 90 | DEMIDOV | 90 | XEBC | | |
| $-2.5 to\ 0.3$ | 90 | AKIBA | 85 | SPEC | | |
| | | | | | | |

K± CHARGE RADIUS

| VALUE (fm) | DO CUMENT ID | | COMMENT |
|---------------------------------|---------------------|----------|--------------------------------|
| 0.560±0.031 OUR AVERAGE | , | | |
| 0.580 ± 0.040 | AMENDOLIA | 86B | $Ke \rightarrow Ke$ |
| 0.530 ± 0.050 | DALLY | 80 | $Ke \rightarrow Ke$ |
| • • • We do not use the followi | ng data for average | s, fits, | , limits, etc. • • • |
| 0.620 ± 0.037 | BLATNIK | 79 | $VMD + dispersion \ relations$ |

CP VIOLATION TESTS IN K+ AND K- DECAYS

$$\begin{array}{c} \Delta(K^{\pm}_{\pi e\,e}) = \frac{\Gamma(K^{+}_{\pi e\,e}) - \Gamma(K^{-}_{\pi e\,e})}{\Gamma(K^{+}_{\pi e\,e}) + \Gamma(K^{-}_{\pi e\,e})} \\ \frac{\text{VALUE (units } 10^{-2})}{-2.2 \pm 1.5 \pm 0.6} & \frac{\text{DOCUMENT } \text{ID}}{159} & \frac{\text{TECN}}{\text{BATLEY}} & 09 & \text{NA48} \\ \end{array}$$

 $^{159}\,\text{This}$ implies an upper limit of 2.1×10^{-2} at 90% CL.

$$\Delta(K_{\pi\mu\mu}^{\pm}) = \frac{\Gamma(K_{\pi\mu\mu}^{+}) - \Gamma(K_{\pi\mu\mu}^{-})}{\Gamma(K_{\pi\mu\mu}^{+}) + \Gamma(K_{\pi\mu\mu}^{-})}$$
VALUE

DOCUMEN

| VALUE | | DO CUMENT | ID | TECN | |
|-------------------|-------------|-----------------------|-----|------|--|
| 0.010 ± 0.023 | OUR AVERAGE | | | | |
| 0.011 ± 0.023 | 1 | ¹⁶⁰ BATLEY | 11A | NA48 | |
| -0.02 ± 0.11 | ±0.04 | PARK | 02 | HYCP | |
| 160 | | | | 10-2 | |

 160 This corresponds to the asymmetry upper limit of $<~2.9 \times 10^{-2}$ at 90% CL.

$$\Delta(K_{\pi\pi\gamma}^{\pm}) = \frac{\Gamma(K_{\pi\pi\gamma}^{+}) - \Gamma(K_{\pi\pi\gamma}^{-})}{\Gamma(K_{\pi\pi\gamma}^{+}) + \Gamma(K_{\pi\pi\gamma}^{-})}$$

FORWARD-BACKWARD ASYMMETRY IN K± DECAYS

$$\begin{array}{lll} \mathbf{A}_{FB}(\mathbf{K}_{\pi\mu\mu}^{\pm}) = \frac{\Gamma(\cos(\theta_{K\mu})>0) - \Gamma(\cos(\theta_{K\mu})<0)}{\Gamma(\cos(\theta_{K\mu})>0) + \Gamma(\cos(\theta_{K\mu})<0)} & \\ \frac{VALUE}{\sqrt{2.3}\times10^{-2}} & \frac{CL\%}{90} & \frac{DOCUMENT\ ID}{162\ BATLEY} & 11A & NA48 \\ \end{array}$$

T VIOLATION TESTS IN K+ AND K- DECAYS

P_T in $K^+ ightarrow ~\pi^0 \, \mu^+ \, u_\mu$

T-violating muon polarization. Sensitive to new sources of *CP* violation beyond the Standard Model.

| VALUE (units 10 ⁻³) | EVTS | DO CUME | NT ID | TECN | CHG | | |
|---------------------------------|--------------|--------------------|-----------------|---------|--------|---|---|
| $-1.7\pm2.3\pm1.1$ | | ¹⁶³ ABE | 04F | K246 | + | | |
| • • • We do not use | the followin | g data for a | averages, fits, | limits, | etc. • | • | • |
| $-4.2 \pm 4.9 \pm 0.9$ | 3.9M | ABE | 99s | K246 | + | | |

 163 Includes three sets of data: 96-97 (ABE 99s), 98, and 99-00 totaling about three times the ABE 99s data sample. Corresponds to P $_T~<~5.0\times10^{-3}$ at 90% CL.

P_T in $K^+ o \mu^+ u_\mu \gamma$

 $T\text{-}violating\ muon\ polarization.}$ Sensitive to new sources of $\mathit{CP}\ violation\ beyond\ the\ Standard\ Model.}$

164 Muons stopped and polarization measured from decay to positrons.

Im(ξ) in $K^+ \to \pi^0 \mu^+ \nu_\mu$ DECAY (from transverse μ pol.)

| rest of 1 reversal | invariance. | | | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-------------------|-------|-----------|-------|---------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
| -0.006 ±0.008 OUR | | | | | | |
| $-0.0053 \pm 0.0071 \pm 0.003$ | 36 16 | ⁵ ABE | 04F | K 246 | + | |
| -0.016 ± 0.025 | 20 M | CAMPBELL | 81 | CNTR | + | Pol. |
| • • • We do not use the | e following d | ata for averages, | fits, | limits, e | tc. • | • • |
| $-0.013 \pm 0.016 \pm 0.003$ | 3.9M | ABE | 99s | CNTR | + | p_T ${\it K}^+$ at rest |
| 165 Includes three sets of data: 96-97 (ABE 99s), 98, and 99-00 totaling about three times the ABE 99s data sample. Corresponds to $\mathrm{Im}(\xi)<0.016$ at 90% CL. | | | | | | |

K[±] REFERENCES

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|--------------|------|--------------------------|------------------------|--------------|----------|
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| ADLER 1 | .0 | PR D81 092001 | S. Adler et al. | (BNL E787 | Collab.) |
| BATLEY 1 | .0Α | EPJ C68 75 | J.R. Batley et al. | (CERN NA48/2 | Collab.) |
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| | | Translated from VAF 71 ' | | | ٠ / |

Meson Particle Listings \mathcal{K}^{\pm}

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|-----------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------|---------------------------------|------------------|-----------------------------------------------------|---------------------------------------------------------------------|-------------------------------------------------------------|
| BATLEY 09 BATLEY 09A | PL B677 246 EPJ C64 589 | J.R. Batley et al. (CERN N) | 448/2 Collab.) 448/2 Collab.) | BARMIN BOLOTOV | 88 B 88 | SJNP 48 1032 Translated from YAF 48 : | V.V. Barmin <i>et al.</i> 1719. V.N. Bolotov <i>et al.</i> | (ITEP) (ASCI) |
| BISSEGGER 09 AMBROSINO 08 AMBROSINO 08A | NP B806 178 JHEP 0801 073 JHEP 0802 098 | M. Bissegger et al. F. Ambrosino et al. F. Ambrosino et al. (| KLOE Collab.) KLOE Collab.) | GALL | 88 | Translated from ZETFP 4 PRL 60 186 | 7 8. K.P. Gall et al. | (BOST, MIT, WILL, CIT+) |
| AMBROSINO 08E ARTAMONOV 08 | PL B666 305 PRL 101 191802 | F. Ambrosino et al. | KLOE Collab.) E949 Collab.) | BARMIN BOLOTOV | 87 87 | SJNP 45 62 Translated from YAF 45 SJNP 45 1023 | V.V. Barmin <i>et al.</i> 97. V.N. Bolotov <i>et al.</i> | (ITEP) (INRM) |
| Also BATLEY 08 | PR D79 092004 PL B659 493 | A.V. Artamonov et al. (BNL | E949 Collab.) A48/2 Collab.) | AMENDOLIA | | Translated from YAF 45 | | (CERN NA7 Collab.) |
| BATLEY 08A AKIMENKO 07 | EPJ C54 411 PAN 70 702 | J.R. Batley et al. (CERN NA S.A. Akimenko et al. (IST | A48/2 Collab.) FRA+ Collab.) | BOLOTOV | 86 | SJNP 44 73 Translated from YAF 44 | V.N. Bolotov et al. 117. | (INRM) |
| ANDRE 07 BATLEY 07A | Translated from YAF 70 ANP 322 2518 EPJ C50 329 | 734. T. Andre J.R. Batley <i>et al.</i> (CERN N) | (EFI) A48/2 Collab.) | BOLOTOV YAMANAKA | 86B 86 | SJNP 44 68 Translated from YAF 44 : PR D34 85 | V.N. Bolotov <i>et al.</i> 108. T. Yamanaka <i>et al.</i> | (INRM) (KEK, TOKY) |
| Also BATLEY 07B | EPJ C50 329 EPJ C52 1021 (errat) PL B649 349 | J.R. Batley et al. (CERN N) | 446/2 Collab.) 448/2 Collab.) 448/2 Collab.) | Also AKIBA | 85 | PRL 52 329 PR D32 2911 | R.S. Hayano et al. Y. Akiba et al. | (TOKY, KEK) (TOKY, KEK) |
| BATLEY 07E TCHIKILEV 07 | EPJ C52 875 PAN 70 29 | J.R. Batley et al. (CERN Na | A48/2 Collab.) FRA+ Collab.) | BOLOTOV | 85 | JETPL 42 481 Translated from ZETFP 4 | V.N. Bolotov et al. 2 390. | (INRM) |
| ALIEV 06 AMBROSINO 06A | EPJ C46 61 PL B632 76 | M.A. Aliev et al. (KÈK F. Ambrosino et al. (| E470 Collab.) KLOE Collab.) | AS ANO COOPER | 82 82 | PL 113B 195 PL 112B 97 | Y. Asano et al. A.M. Cooper et al. | (KEK, TOKY, INUS, OSAK) (RL) |
| BATLEY 06 BATLEY 06A | PL B634 474 PL B638 22 | J.R. Batley et al. (CERN N) | 448/2 Collab.) 448/2 Collab.) | PDG AS AN O CAMPBELL | 82B 81B 81 | PL 111B 70 PL 107B 159 PRL 47 1032 | M. Roos et al. Y. Asano et al. M.K. Campbell et al. | (HELS, CIT, CERN) (KEK, TÖKY, INUS, OSAK) (YALE, BNL) |
| Also BATLEY 06B COLANGELO 06A | PL B640 297 (erratum) PL B633 173 PL B638 187 | J.R. Batley et al. (CERN N) | A48/2 Collab.) A48/2 Collab.) | Also LUM | 81 | PR D27 1056 PR D23 2522 | S.R. Blatt et al. G.K. Lum et al. | (YALE, BNL) (LBL, NBS+) |
| MA 06 PDG 06 | PR D73 037101 JPG 33 1 | G. Colangelo et al. H. Ma et al. WM. Yao et al. (BNL | E865 Collab.) (PDG Collab.) | LYONS DALLY | 81 80 | ZPHY C10 215 PRL 45 232 | L. Lyons, C. Albajar, G. M. E.B. Dally et al. | |
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| AKOPDZHAN05B | Translated from YAF 68 JETPL 82 675 Translated from ZETFP | G.A. Akopdzhanov et al. | (IHEP) | DEVAUX HEINT ZE ROSSELET | 77 77 77 | NP B126 11 PL 70B 482 PR D15 574 | B. Devaux et al. J. Heintze et al. L. Rosselet et al. | (SACL, GEVA) (HEIDP, CERN) (GEVA, SACL) |
| ARTAMONOV 05 CABIBBO 05 | PL B623 192 JHEP 0503 021 | A.V. Artamonov et al. (BNL | E949 Collab.) OMAI, FRAS) | BLOCH BRAUN | 76 76B | PL 60B 393 LNC 17 521 | P. Bloch et al. H.M. Braun et al. | (GEVA, SACE) (GEVA, SACL) (AACH3, BARI, BELG+) |
| SHER 05 ABE 04F | PR D72 012005 PRL 93 131601 | A. Sher et al. (BNL | E865 Collab.) E246 Collab.) | DIAMANT HEINT ZE | 76 76 | PL 62B 485 PL 60B 302 | A.M. Diamant-Berger et al. J. Heintze et al. | |
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| AJINENKO 03B AJINENKO 03C ALIEV 03 | PL B567 159 PL B574 14 | I.V. Ajinenko <i>et al.</i> | (IHEP, INRM) (IHEP, INRM) E470 Collab.) | A Iso A Iso | | PRL 28 523 PRL 28 1287 | D. Ljung D. Cline, D. Ljung | (WISC) (WISC) |
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| ADLER 00B ADLER 00C APPEL 00 | PRL 85 2256 PRL 85 4856 PRL 85 2450 | S. Adler et al. (BNL | E787 Collab.) E787 Collab.) L 865 Collab.) | SCHWEINB STEINER | 71 71 | PL 36B 246 PL 36B 521 | W. Schweinberger (A H.J. Steiner (AACH, BA | ACH, BELG, CERN, NIJM+) ARI, CERN, EPOL, ORSAY+) |
| Also Also | Thesis, Yale Univ. Thesis, Univ. Zurich | D.R. Bergman S. Pislak | L 665 CONAU.) | BARDIN BECHERRAWY | | PL 32B 121 PR D1 1452 | D.Y. Bardin, S.N. Bilenky, T. Becherrawy | (ROCH) |
| APPEL 00B MA 00 | PRL 85 2877 PRL 84 2580 | R. Appel et al. (BN | L 865 Collab.) L 865 Collab.) | FORD GAILLARD | 70 70 | PRL 25 1370 CERN 70-14 | W.T. Ford et al. J.M. Gaillard, L.M. Choune | (PRIN) t (CERN, ORSAY) |
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 K^{\pm} , K^{0}

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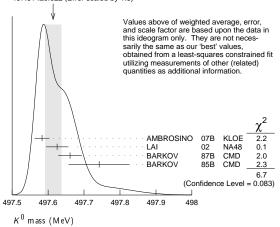


$$I(J^P) = \frac{1}{2}(0^-)$$

κ⁰ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-------------|--------------------|---------|-----------|--------------------------------------------------------------------------------------------|
| 497.614 ± 0.024 OUR FI | | | | | |
| 497.614 ± 0.022 OUR AV | /ERAGE E | irror includes sca | le fac | tor of 1. | 5. See the ideogram |
| $497.583\pm0.005\pm0.020$ | 35 k | AMBROSINO | 07в | KLOE | $e^+e^- \rightarrow \kappa_I^0 \kappa_S^0$ |
| $497.625\pm0.001\pm0.031$ | 655 k | LAI | 02 | NA 48 | K_I^0 beam |
| 497.661 ± 0.033 | 3713 | BARKOV | 87в | CMD | $e^{+}e^{-} \rightarrow K_{L}^{0}K_{S}^{0}$ $e^{+}e^{-} \rightarrow K_{L}^{0}K_{S}^{0}$ |
| 497.742 ± 0.085 | 780 | BARKOV | 85B | CMD | $e^+ e^- \rightarrow \kappa_L^{0} \kappa_S^{0}$ |
| • • • We do not use th | e following | data for averages | s, fits | , limits, | etc. • • • |
| 497.44 ± 0.50 | | FITCH | 67 | OSPK | |
| 498.9 ±0.5 | 4500 | BALTAY | 66 | HBC | K^0 from $\overline{p}p$ |
| 497.44 ± 0.33 | 2223 | KIM | 65B | | K^0 from $\overline{p}p$ |
| 498.1 ±0.4 | | CHRISTENS | 64 | OSPK | |





$m_{K^0} - m_{K^{\pm}}$

 VALUE (MeV)
 EVTS
 DOCUMENT ID
 TECN
 CHG
 COMMENT

 3.937±0.028 OUR FIT
 Error includes scale factor of 1.8.
 CHG
 COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • •

K⁰ MEAN SQUARE CHARGE RADIUS

| VALUE (fm ²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|------------------|----------|-----------|-----------------------------------------------------------------------------------------------------------------------|
| -0.077±0.010 OUR A | VERAGE | · | | | |
| $-0.077\pm0.007\pm0.011$ | 5037 | ABOUZAID | 06 | KTEV | $\mathcal{K}_{L}^{0} \rightarrow \pi^{+}\pi^{-}e^{+}e^{-}$ $\mathcal{K}_{L}^{0} \rightarrow \pi^{+}\pi^{-}e^{+}e^{-}$ |
| -0.090 ± 0.021 | | LAI | 03c | NA48 | $K_I^{0} \rightarrow \pi^{+}\pi^{-}e^{+}e^{-}$ |
| -0.054 ± 0.026 | | MOLZON | 78 | | K_S^2 regen. by electrons |
| • • • We do not use t | he following | data for average | es, fits | , limits, | etc. • • • |
| -0.087 ± 0.046 | | BLATNIK | 79 | | VMD + dispersion rela- tions |
| -0.050 ± 0.130 | | FOETH | 69B | | K_S regen. by electrons |

T-VIOLATION PARAMETER IN KO-KO MIXING

The asymmetry $A_T = \frac{\Gamma(\overline{K}^0 \to K^0) - \Gamma(K^0 \to \overline{K}^0)}{\Gamma(\overline{K}^0 \to K^0) + \Gamma(K^0 \to \overline{K}^0)}$ must vanish if

ASYMMETRY AT IN KO-KO MIXING

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN |
|---------------------------------|------|----------------|------|
| 6.6±1.3±1.0 | 640k | 1 ANGELOPO 98E | CPLR |

 1 ANGELOPOULOS 98E measures the asymmetry $A_{T} = [\Gamma(\overline{K}_{1=0}^0 \to e^+ \pi^- \nu_{t=\tau}) - \Gamma(K_{0=0}^0 \to e^- \pi^+ \overline{\nu}_{t=\tau})]/[\Gamma(\overline{K}_{1=0}^0 \to e^+ \pi^- \nu_{t=\tau}) + \Gamma(K_{t=0}^0 \to e^- \pi^+ \overline{\nu}_{t=\tau})]$ as a function of the neutral-kaon eigentime τ . The initial strangeness of the neutral kaon is tagged by the charge of the accompanying charged kaon in the reactions $p\overline{p} \to K^- \pi^+ K^0$ and $p\overline{p} \to K^+ \pi^- \overline{K}^0$. The strangeness at the time of the decay is tagged by the lepton charge. The reported result is the average value of A_T over the interval $1\tau_S < \tau < 20\tau_S$. From this value of A_T ANGELOPOULOS 018, assuming CPT invariance in the $e\pi\nu$ decay amplitude, determine the T-violating as $\Delta S = \Delta S$ conserving parameter (for its definition, see Review below) $4\text{Re}(\epsilon) = (6.2 \pm 1.4 \pm 1.0) \times 10^{-3}$.

CPT INVARIANCE TESTS IN NEUTRAL KAON DECAY

Updated April 2012 by M. Antonelli (LNF-INFN, Frascati) and G. D'Ambrosio (INFN Sezione di Napoli).

CPT theorem is based on three assumptions: quantum field theory, locality, and Lorentz invariance, and thus it is a fundamental probe of our basic understanding of particle physics. Strangeness oscillation in $K^0-\overline{K}^0$ system, described by the equation

$$i\frac{d}{dt} \left[\frac{K^0}{\overline{K}^0} \right] = \left[M - i \Gamma/2 \right] \left[\frac{K^0}{\overline{K}^0} \right] \ ,$$

where M and Γ are hermitian matrices (see PDG review [1], references [2,3], and KLOE paper [4] for notations and previous literature), allows a very accurate test of CPT symmetry; indeed since CPT requires $M_{11}=M_{22}$ and $\Gamma_{11}=\Gamma_{22}$, the mass and width eigenstates, $K_{S,L}$, have a CPT-violating piece, δ , in addition to the usual CPT-conserving parameter ϵ :

$$K_{S,L} = \frac{1}{\sqrt{2\left(1 + \left|\epsilon_{S,L}\right|^{2}\right)}} \left[\left(1 + \epsilon_{S,L}\right) K^{0} + \left(1 - \epsilon_{S,L}\right) \overline{K}^{0} \right]$$

$$\epsilon_{S,L} = \frac{-i\Im(M_{12}) - \frac{1}{2}\Im(\Gamma_{12}) \mp \frac{1}{2} \left[M_{11} - M_{22} - \frac{i}{2} (\Gamma_{11} - \Gamma_{22}) \right]}{m_L - m_S + i(\Gamma_S - \Gamma_L)/2}$$

$$\equiv \epsilon \pm \delta. \tag{1}$$

Using the phase convention $\Im(\Gamma_{12})=0$, we determine the phase of ϵ to be $\varphi_{SW}\equiv\arctan\frac{2(m_L-m_S)}{\Gamma_S-\Gamma_L}$. Imposing unitarity to an arbitrary combination of K^0 and \overline{K}^0 wave functions, we obtain the Bell-Steinberger relation [5] connecting CP and

K^0

CPT violation in the mass matrix to CP and CPT violation in the decay; in fact, neglecting $\mathcal{O}(\epsilon)$ corrections to the coefficient of the CPT-violating parameter, δ , we can write [4]

$$\left[\frac{\Gamma_S + \Gamma_L}{\Gamma_S - \Gamma_L} + i \tan \phi_{\text{SW}}\right] \left[\frac{\Re(\epsilon)}{1 + |\epsilon|^2} - i\Im(\delta)\right] = \frac{1}{\Gamma_S - \Gamma_L} \sum_f A_L(f) A_S^*(f), \tag{2}$$

where $A_{L,S}(f) \equiv A(K_{L,S} \to f)$. We stress that this relation is phase-convention-independent. The advantage of the neutral kaon system is that only a few decay modes give significant contributions to the r.h.s. in Eq. (2); in fact, defining for the hadronic modes

$$\alpha_i \equiv \frac{1}{\Gamma_S} \langle \mathcal{A}_L(i) \mathcal{A}_S^*(i) \rangle = \eta_i \ \mathcal{B}(K_S \to i),$$

$$i = \pi^0 \pi^0, \pi^+ \pi^-(\gamma), 3\pi^0, \pi^0 \pi^+ \pi^-(\gamma),$$
 (3)

the recent data from CPLEAR, KLOE, KTeV, and NA48 have led to the following determinations (the analysis described in Ref. 4 has been updated by using the recent measurements of K_L branching ratios from KTeV [6,7], NA48 [8,9], and the results described in the CP violation in K_L decays minireview)

$$\begin{split} \alpha_{\pi^+\pi^-} &= \left((1.112 \pm 0.010) + i (1.061 \pm 0.010) \right) \times 10^{-3} \;, \\ \alpha_{\pi^0\pi^0} &= \left((0.493 \pm 0.005) + i (0.471 \pm 0.005) \right) \times 10^{-3} \;, \\ \alpha_{\pi^+\pi^-\pi^0} &= \left((0 \pm 2) + i (0 \pm 2) \right) \times 10^{-6}, \\ |\alpha_{\pi^0\pi^0\pi^0}| &< 7 \times 10^{-6} \quad \text{at } 95\% \; \text{CL} \;. \end{split} \tag{4}$$

The semileptonic contribution to the right-handed side of Eq. (2) requires the determination of several observables: we define [2,3]

$$\mathcal{A}(K^{0} \to \pi^{-}l^{+}\nu) = \mathcal{A}_{0}(1-y) ,$$

$$\mathcal{A}(K^{0} \to \pi^{+}l^{-}\nu) = \mathcal{A}_{0}^{*}(1+y^{*})(x_{+}-x_{-})^{*} ,$$

$$\mathcal{A}(\overline{K}^{0} \to \pi^{+}l^{-}\nu) = \mathcal{A}_{0}^{*}(1+y^{*}) ,$$

$$\mathcal{A}(\overline{K}^{0} \to \pi^{-}l^{+}\nu) = \mathcal{A}_{0}(1-y)(x_{+}+x_{-}) ,$$
(5)

where x_+ (x_-) describes the violation of the $\Delta S = \Delta Q$ rule in CPT-conserving (violating) decay amplitudes, and y parametrizes CPT violation for $\Delta S = \Delta Q$ transitions. Taking advantage of their tagged $K^0(\overline{K}^0)$ beams, CPLEAR has measured $\Im(x_+)$, $\Re(x_-)$, $\Im(\delta)$, and $\Re(\delta)$ [11]. These determinations have been improved in Ref. 4 by including the information $A_S - A_L = 4[\Re(\delta) + \Re(x_-)]$, where $A_{L,S}$ are the K_L and K_S semileptonic charge asymmetries, respectively, from the PDG [12] and KLOE [13]. Here we are also including the T-violating asymmetry measurement from CPLEAR [14].

Table 1: Values, errors, and correlation coefficients for $\Re(\delta)$, $\Im(\delta)$, $\Re(x_-)$, $\Im(x_+)$, and $A_S + A_L$ obtained from a combined fit, including KLOE [4] and CPLEAR [14].

| | value | Correlations coefficients |
|---------------|-----------------------------------|---------------------------------|
| $\Re(\delta)$ | $(3.0 \pm 2.3) \times 10^{-4}$ | 1 |
| $\Im(\delta)$ | $(-0.66 \pm 0.65) \times 10^{-2}$ | -0.21 1 |
| $\Re(x)$ | $(-0.30 \pm 0.21) \times 10^{-2}$ | -0.21 -0.60 1 |
| $\Im(x_+)$ | $(0.02 \pm 0.22) \times 10^{-2}$ | $-0.38 \ -0.14 \ 0.47 \ 1$ |
| $A_S + A_L$ | $(-0.40 \pm 0.83) \times 10^{-2}$ | -0.10 -0.63 0.99 0.43 1 |

The value $A_S + A_L$ in Table 1 can be directly included in the semileptonic contributions to the Bell Steinberger relations in Eq. (2)

$$\sum_{\pi\ell\nu} \langle \mathcal{A}_L(\pi\ell\nu) \mathcal{A}_S^*(\pi\ell\nu) \rangle$$

$$= 2\Gamma(K_L \to \pi\ell\nu) (\Re(\epsilon) - \Re(y) - i(\Im(x_+) + \Im(\delta)))$$

$$= 2\Gamma(K_L \to \pi\ell\nu) ((A_S + A_L)/4 - i(\Im(x_+) + \Im(\delta))) . (6)$$

Defining

$$\alpha_{\pi\ell\nu} \equiv \frac{1}{\Gamma_S} \sum_{\pi\ell\nu} \langle \mathcal{A}_L(\pi\ell\nu) \mathcal{A}_S^*(\pi\ell\nu) \rangle + 2i \frac{\tau_{K_S}}{\tau_{K_L}} \mathcal{B}(K_L \to \pi\ell\nu) \Im(\delta) ,$$
(7)

we find:

$$\alpha_{\pi\ell\nu} = ((-0.2 \pm 0.5) + i(0.1 \pm 0.5)) \times 10^{-5}$$
.

Inserting the values of the α parameters into Eq. (2), we find

$$\Re(\epsilon) = (161.1 \pm 0.5) \times 10^{-5},$$

 $\Im(\delta) = (-0.7 \pm 1.4) \times 10^{-5}.$ (8)

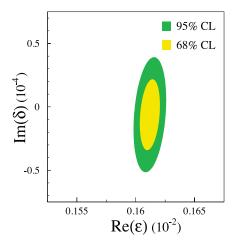
The complete information on Eq. (8) is given in Table 2.

Table 2: Summary of results: values, errors, and correlation coefficients for $\Re(\epsilon)$, $\Im(\delta)$, $\Re(\delta)$, and $\Re(x_-)$.

| | value | Correlations coefficients |
|-----------------|----------------------------------|---------------------------|
| $\Re(\epsilon)$ | $(161.1 \pm 0.5) \times 10^{-5}$ | +1 |
| $\Im(\delta)$ | $(-0.7\pm1.4)\times10^{-5}$ | +0.09 1 |
| $\Re(\delta)$ | $(2.4 \pm 2.3) \times 10^{-4}$ | +0.08 -0.12 1 |
| $\Re(x)$ | $(-4.1 \pm 1.7) \times 10^{-3}$ | + 0.14 0.22 -0.43 1 |

Now the agreement with CPT conservation, $\Im(\delta) = \Re(\delta) = \Re(x_-) = 0$, is at 18% C.L.

The allowed region in the $\Re(\epsilon) - \Im(\delta)$ plane at 68% CL and 95% C.L. is shown in the top panel of Fig. 1.



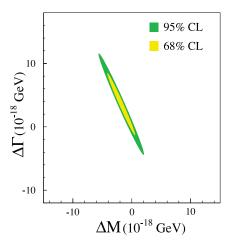


Figure 1: Top: allowed region at 68% and 95% C.L. in the $\Re(\epsilon)$, $\Im(\delta)$ plane. Bottom: allowed region at 68% and 95% C.L. in the $\Delta M, \Delta \Gamma$ plane.

The process giving the largest contribution to the size of the allowed region is $K_L \to \pi^+\pi^-$, through the uncertainty on ϕ_{+-} .

The limits on $\Im(\delta)$ and $\Re(\delta)$ can be used to constrain the $K^0-\overline{K}^0$ mass and width difference

$$\delta = \frac{i(m_{K^0} - m_{\overline{K}^0}) + \frac{1}{2}(\Gamma_{K^0} - \Gamma_{\overline{K}^0})}{\Gamma_S - \Gamma_L} \cos \phi_{SW} e^{i\phi_{SW}} [1 + \mathcal{O}(\epsilon)].$$

The allowed region in the $\Delta M=(m_{K^0}-m_{\overline{K}^0}), \Delta \Gamma=(\Gamma_{K^0}-\Gamma_{\overline{K}^0})$ plane is shown in the bottom panel of Fig. 1. As a result, we improve on the previous limits (see for instance, P. Bloch in Ref. 12) and in the limit $\Gamma_{K^0}-\Gamma_{\overline{K}^0}=0$ we obtain

$$-4.0\times 10^{-19}~{\rm GeV} < m_{K^0} - m_{\overline{K}^0} < 4.0\times 10^{-19}~{\rm GeV}~~{\rm at}~95~\%~{\rm C.L}\,.$$

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- 15. We thank M. Palutan for the collaboration in this analysis.

CP-VIOLATION PARAMETERS

Re(ϵ)DOCUMENT IDTECN1.596 \pm 0.0132 AMBROSINO 06HKLOE• • • We do not use the following data for averages, fits, limits, etc. 1.664 \pm 0.0103 LAI05ANA48

 2 AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K_L^0 \to \pi^+\pi^-)$ in AMBROSINO 06F, B($K_S^0 \to \pi^0\pi^0\pi^0)$ in AMBROSINO 05B, the K_S^0 -semileptonic charge asymmetry in AMBROSINO 06E, and K^0 -semileptonic results in ANGELOPOULOS 98F.

 3 LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of η_{000} and combining other data from PDG 04 and APOSTOLAKIS 99B.

CPT-VIOLATION PARAMETERS

In K^0 – \overline{K}^0 mixing, if *CP*-violating interactions include a T conserving part then

$$\begin{split} |\mathcal{K}_{\mathcal{S}}\rangle &= [|\mathcal{K}_{1}\rangle + (\epsilon+\delta)|\mathcal{K}_{2}\rangle]/\sqrt{1+|\epsilon+\delta|^{2}} \\ |\mathcal{K}_{L}\rangle &= [|\mathcal{K}_{2}\rangle + (\epsilon-\delta)|\mathcal{K}_{1}\rangle]/\sqrt{1+|\epsilon-\delta|^{2}} \\ \text{there} \\ |\mathcal{K}_{1}\rangle &= [|\mathcal{K}^{0}\rangle + |\overline{\mathcal{K}^{0}}\rangle]/\sqrt{2} \end{split}$$

 $\begin{aligned} |\kappa_1\rangle &= [|\kappa^0\rangle + |\overline{\kappa}^0\rangle]/\sqrt{2} \\ |\kappa_2\rangle &= [|\kappa^0\rangle - |\overline{\kappa}^0\rangle]/\sqrt{2} \end{aligned}$

 $|\overline{K}^0\rangle = CP|K^0\rangle.$

The parameter δ specifies the *CPT*-violating part.

 K^{0}, K^{0}_{s}

Estimates of δ are given below assuming the validity of the $\Delta S = \Delta Q$ rule. See also THOMSON 95 for a test of *CPT*-symmetry conservation in K^0 decays using the Bell-Steinberger relation.

REAL PART OF δ

A nonzero value violates CPT invariance.

| VALUE | (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | _ |
|-------|---------------------------|-------------|------------------------|---------|-----------|----------------------------|---|
| 2.5 | 1 ± 2.25 | | ⁴ ABOUZAID | 11 | KTEV | | 1 |
| • • • | We do not use th | e following | data for averages | , fits, | limits, e | etc. • • • | |
| 2.3 | ± 2.7 | | ⁵ AMBROSINO | 06н | KLOE | | |
| 2.4 | ± 2.8 | | ⁶ APOSTOLA | 99B | RVUE | | |
| 2.9 | \pm 2.6 \pm 0.6 | | ⁷ ANGELOPO | | CPLR | | |
| 180 | ±200 | 6481 | ⁸ DEMIDOV | 95 | | K _{ℓ3} reanalysis | |
| 4 Δ | BOUZAID 11 uses | Rell_Steinh | perger relations | | | | 1 |

TABOUZAID II uses Bell-Steinberger relations. S AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: $B(K_0^0 \to \pi^+\pi^-) \text{ in AMBROSINO 06F, } B(K_0^0 \to \pi^0\pi^0\pi^0) \text{ in AMBROSINO 05B, the}$ κ_S^0 -semileptonic charge asymmetry in AMBROSINO 06E, and κ_S^0 -semileptonic results

in ANGELOPOULOS 98F. 6 APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results. 7 ANGELOPOULOS 98F use $\Delta S = \Delta Q$. If $\Delta S = \Delta Q$ is not assumed, they find ${\rm Re}\delta = (3.0 \pm 1.00)$ $3.3 \pm 0.6) \times 10^{-4}$

⁸DEMIDOV 95 reanalyzes data from HART 73 and NIEBERGALL 74.

IMAGINARY PART OF δ

nonzero value violates CPT invariance

| A HOHZEIO Value VIOIA | ites CF I | III vai iaiice. | | |
|---------------------------------|-----------|-----------------------------|------------|----------------------------|
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | TECN | COMMENT |
| - 1.5 ± 1.6 | | ⁹ ABOUZAID 11 | KTEV | |
| | ollowing | data for averages, fits, li | mits, etc. | • • • |
| 0.4± 2.1 | | ¹⁰ AMBROSINO 06F | | |
| − 0.2± 2.0 | | ¹¹ LAI 05/ | | |
| 2.4± 5.0 | | ¹² APOSTOLA 99E | | |
| $-$ 90 \pm 290 \pm 100 | 1.3M | 13 ANGELOPO 98F | CPLR | |
| 2100 ±3700 | 6481 | ¹⁴ DEMIDOV 95 | | K _{ℓ3} reanalysis |
| | | | | ~~ |

 9 ABOUZAID 11 uses Bell-Steinberger relations. 10 AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($K_0^0 \rightarrow \pi^+\pi^-$) in AMBROSINO 06F, B($K_S^0 \rightarrow \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the κ_{S}^{0} -semileptonic charge asymmetry in AMBROSINO 06E, and κ^{0} -semileptonic results

in ANGELOPOULOS 98F. 11 LAI 05A values are obtained through unitarity (Bell-Steinberger relations), improving determination of η_{000} and combining other data from PDG 04 and APOSTOLAKIS 99B. 12 APOSTOLAKIS 99B assumes only unitarity and combines CPLEAR and other results. 13 if $\Delta S = \Delta Q$ is not assumed, ANGELOPOULOS 98F finds $\ln \delta = (-15 \pm 23 \pm 3) \times 10^{-3}$. 14 DEMINO) 05 reaching the table 12 and NIERBECOLL 73 and NIERBECOLL 73. 14 DEMIDOV 95 reanalyzes data from HART 73 and NIEBERGALL 74.

Re(y)A non-zero value would violate *CPT* invariance in $\Delta S = \Delta Q$ amplitude. Re(y) is the

following combination of
$$K_{e3}$$
 decay amplitudes:
$$\text{Re}(\mathbf{y}) = \text{Re}\Big(\begin{array}{ll} \frac{A(\overline{K^0} \to e^-\pi^+\overline{\nu}_e)^* - A(K^0 \to e^+\pi^-\nu_e)}{A(\overline{K^0} \to e^-\pi^+\overline{\nu}_e)^* + A(K^0 \to e^+\pi^-\nu_e)} \end{array} \Big)$$

15 AMBROSINO 06E KLOE VALUE (units 10⁻³) 0.4 ± 2.5 13k

 15 They use the PDG 04 for the K_L^0 semileptonic charge asymmetry and PDG 04 (*CP* review, *CPT* NOT ASSUMED) for ${\rm Re}(\epsilon).$

16 Constrained by Bell-Steinberger (or unitarity) relation.

Re(x_)A non-zero value would violate *CPT* invariance in decay amplitudes with $\Delta S \neq \Delta Q$. A non-zero variety would violate CY invariance in decay amplitudes with $\Delta S \neq \Delta Q$. \times , used here to define $Re(x_-)$, and x_+ used below in the $\Delta S = \Delta Q$ section are the following combinations of K_{e3} decay amplitudes: $x_{\pm} = \frac{1}{2} \left(\frac{A(\overline{K^0} \to \pi^- e^+ \nu_e)}{A(K^0 \to \pi^- e^+ \nu_e)} \pm \frac{A(K^0 \to \pi^+ e^- \overline{\nu}_e)^*}{A(\overline{K^0} \to \pi^+ e^- \overline{\nu}_e)^*} \right).$

$$\mathsf{x}_{\pm} = \frac{1}{2} \left(\frac{A(\overline{K}^0 \to \pi^- e^+ \nu_e)}{A(K^0 \to \pi^- e^+ \nu_e)} \pm \frac{A(K^0 \to \pi^+ e^- \overline{\nu}_e)^*}{A(\overline{K}^0 \to \pi^+ e^- \overline{\nu}_e)^*} \right).$$

VALUE (units 10⁻³) EVTS DO CUMENT ID 17 AMBROSINO 06H KLOE -2.9 ± 2.0 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet18 AMBROSINO 06E KLOE -0.8 ± 2.5 13k 19 APOSTOLA... 99B CPLR Strangeness tagged -0.5 ± 3.0 650k ANGELOPO... 98F CPLR Strangeness tagged

 17 AMBROSINO 06H uses Bell-Steinberger relations with the following measurements: B($\kappa_L^0 \to \pi^+\pi^-$) in AMBROSINO 06F, B($\kappa_S^0 \to \pi^0\pi^0\pi^0$) in AMBROSINO 05B, the K_S^0 -semileptonic charge asymmetry in AMBROSINO 06E, and K^0 -semileptonic results

K \S -semineprome charge asymmetry and Re(δ) from CPLEAR, 18 Uses PDG 04 for the K_L^0 semileptonic charge asymmetry and Re(δ) from CPLEAR,

ANGELOPOULOS 98F.

19 Constrained by Bell-Steinberger (or unitarity) relation.

$|m_{K^0} - m_{\overline{K^0}}| / m_{average}$

A test of CPT invariance. "Our Evaluation" is described in the "Tests of Conservation Laws" section. It assumes $\ensuremath{\textit{CPT}}$ invariance in the decay and neglects some contributions from decay channels other than $\pi\pi$.

| VALUE | CL% | DO CUMENT ID | | TECN | | |
|------------------------------|-----------|-------------------|---------|--------------|---|--|
| $< 6 \times 10^{-19}$ | 90 | PDG | 12 | | | |
| • • • We do not use the | following | lata for averages | , fits, | limits, etc. | • | |
| $(-3 \pm 4) \times 10^{-18}$ | 20 | ANGELOPO | 99B | RVUE | | |

 $20\,\mathrm{ANGELOPOULOS}$ 99B assumes only unitarity and combines CPLEAR and other results.

$(\Gamma_{K^0} - \Gamma_{\overline{K^0}})/m_{\text{average}}$

A test of CPT invariance

DO CUMENT ID 21 ANGELOPO... 99B RVUE $(7.8\pm8.4)\times10^{-18}$

 21 ANGELOPOULOS 99B assumes only unitarity and combines CPLEAR with other results. Correlated with $(m_{K^0} - m_{\overline{K^0}}) / m_{\text{average}}$ with a correlation coefficient of -0.95.

TESTS OF $\Delta S = \Delta Q$ RULE

Re(x₊)A non-zero value would violate the $\Delta S = \Delta Q$ rule in *CPT* conserving transitions. x_+ is defined above in the $Re(x_{-})$ section.

| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | | TECN |
|--------------------------|------|-------------------------|-----|-------|
| -0.9± 3.0 OUR AVE | RAGE | | | |
| -2 ± 10 | | ²² BATLEY | 07D | NA 48 |
| -0.5 ± 3.6 | 13k | ²³ AMBROSINO | 06E | KLOE |
| -1.8 ± 6.1 | | 24 ANGELOPO | 98D | CPLR |

 22 Result obtained from the measurement $\Gamma(\,{\cal K}^0_S \to \,\pi\,e\,\nu)\,\,/\,\,\Gamma(\,{\cal K}^0_L \to \,\pi\,e\,\nu) = 0.993 \pm 0.34$, neglecting possible *CPT* non-invariance and using PDG 06 values of B($K_L^0
ightarrow \pi e
u$) = 0.4053 ± 0.0015 , $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$ s and $\tau_S = (0.8958 \pm 0.0005) \times 10^{-10}$ s. $^{23}\,\mathrm{Re}(\mathrm{x}_+)$ can be shown to be equal to the following combination of rates:

$$Re(x_{+}) = \frac{1}{2} \frac{\Gamma(K_{S}^{0} \to \pi e \nu) - \Gamma(K_{L}^{0} \to \pi e \nu)}{\Gamma(K_{S}^{0} \to \pi e \nu) + \Gamma(K_{L}^{0} \to \pi e \nu)}$$

 $\begin{array}{l} {\rm Re}({\bf x}_+) \ {\rm Can \ De \ Shown \ Io \ De \ Equal \ O \ To \ Formula} \\ {\rm Re}({\bf x}_+) = \frac{1}{2} \ \frac{\Gamma(K_S^0 \to \pi e \nu) - \Gamma(K_L^0 \to \pi e \nu)}{\Gamma(K_S^0 \to \pi e \nu) + \Gamma(K_L^0 \to \pi e \nu)} \\ {\rm which \ is \ valid \ up \ to \ first \ order \ in \ terms \ violating \ \it CPT \ and/or \ the \ \Delta S = \Delta Q \ rule.} \\ \end{array}$ ²⁴ Obtained neglecting *CPT* violating amplitudes.

K⁰ REFERENCES

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|----------------------|--------------|----------------------------|---------------------------------------------------------------|--------------------------------------|
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| ABOUZAID | 06 | PRL 96 101801 | | (KTeV Collab.) |
| AMBROS INO | 06E | PL B636 173 | F. Ambrosino et al. | (KLOE Collab.) |
| AM BR OS IN O | 06F | PL B638 140 | F. Ambrosino et al. | (KLOE Collab.) |
| AMBROS INO | 06H | JHEP 0612 011 | | (KLOE Collab.) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| AMBROSINO | 05 B 05 A | PL B619 61 | F. Ambrosino et al. | (KLOE Collab.) |
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| | | Translated from | | () |
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| | | Translated from | | * * * |
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| | | | | |



$$I(J^P) = \frac{1}{2}(0^-)$$

KS MEAN LIFE

For earlier measurements, beginning with BOLDT 58B, see our 1986 edition, Physics Letters **170B** 130 (1986).

OUR FIT is described in the note on "CP violation in K_L decays" in the K_L^0 Particle Listings. The result labeled "OUR FIT Assuming CPT" ["OUR FIT Not assuming CPT''] includes all measurements except those with the comment "Not assuming CPT'' ["Assuming CPT'']. Measurements with neither comment do not assume CPT and enter both fits.

| $0.89562 \pm 0.00029 \pm 0.0004$ | 3 20 M | ⁴ AMBROSINO 11 KLOE Not assuming <i>CPT</i> |
|----------------------------------|----------|-----------------------------------------------------------|
| $0.89598 \pm 0.00048 \pm 0.0005$ | 1 16M | LAI 02c NA48 |
| 0.8971 ± 0.0021 | | BERTANZA 97 NA31 |
| 0.8941 ±0.0014 ±0.0009 | | SCHWINGEN95 E773 Assuming CPT |
| 0.8929 ±0.0016 | | GIBBONS 93 E731 Assuming CPT |
| • • • We do not use the f | ollowing | data for averages, fits, limits, etc. • • • |
| 0.8965 ± 0.0007 | | ⁵ ALAVI-HARATI03 KTEV Assuming <i>CPT</i> |
| 0.8958 ±0.0013 | | ⁶ ALAVI-HARATI 03 KTEV Not assuming <i>CPT</i> |
| 0.8920 ± 0.0044 | 214k | GROSSMAN 87 SPEC |
| 0.905 ± 0.007 | | ⁷ ARONSON 82B SPEC |
| 0.881 ± 0.009 | 26k | ARONSON 76 SPEC |
| $0.8926 \pm 0.0032 \pm 0.0002$ | | ⁸ CARITHERS 75 SPEC |
| 0.8937 ±0.0048 | 6M | GEWENIGER 74B ASPK |
| 0.8958 ±0.0045 | 50k | ⁹ SKJEGGEST 72 HBC |
| 0.856 ±0.008 | 19994 | ¹⁰ DONALD 68B HBC |
| 0.872 ±0.009 | 20000 | ^{9,10} HILL 68 DBC |

- 1 The two ABOUZAID 11 values use the same full KTeV dataset from 1996, 1997, and 1999. The first enters the "assuming CPT" fit and the second enters the "not assuming $_{\rm CPT'}$ fit.
- ²ABOUZAID 11 fit has Δm , τ_5 , ϕ_ϵ , $\mathrm{Re}(\epsilon'/\epsilon)$, and $\mathrm{Im}(\epsilon'/\epsilon)$ as free parameters. See $\mathrm{Im}(\epsilon'/\epsilon)$ in the " K_L^0 CP violation" section for correlation information.
- ³ABOUZAID 11 fit has Δm and τ_S free but constrains ϕ_ϵ to the Superweak value, i.e. assumes *CPT*. This τ_S value is correlated with their $\Delta m = m_{K_L^0} m_{K_S^0}$ measurement
- in the K_L^0 listings. The correlation coefficient $ho(au_{\rm S}$, $\Delta m)=-0.670$.
- 4 Fit to the proper time distribution. 5 This ALAVI-HARATI 03 fit has Δm and τ_S free but constrains ϕ_{+-} to the Superweak value, i.e. assumes CPT. This τ_S value is correlated with their $\Delta m = m_{K_L^0} m$
- $m_{K_L^0}$ measurement in the K_L^0 listings. The correlation coefficient $ho(au_s,\Delta m)=-0.396$. Superseded by ABOUZAID 11.
- 6 This ALAVI-HARATI 03 fit has $\Delta m, \ \phi_{+-}$, and τ_{K_S} free. See ϕ_{+-} in the " κ_L CP violation" section for correlation information. Superseded by ABOUZAID 11.
- $^7\,\text{ARONSON}$ 82 find that $\,\mathcal{K}_S^0\,$ mean life may depend on the kaon energy.
- 8 CARITHERS 75 measures the Δm dependence of the total decay rate (inverse mean life) to be $\Gamma(K_S^0) = [(1.122 \pm 0.004) + 0.16(\Delta m - 0.5348)/\Delta m] 10^{10}/s$, or, in terms of mean life, CARTHERS 75 measures $\tau_S = (0.8913 \pm 0.0032) - 0.238 [\Delta m - 0.5348]$ mean life, CARTHERS 15 ineasures $\tau_5 = (0.0913 \pm 0.0002) - 0.250$ [$\Delta m = (10^{-10} \text{ s})$. We have adjusted the measurement to use our best values of ($\Delta m = 0.5293 \pm 0.0009$) ($10^{10} \ h \ s^{-1}$). Our first error is their experiment's error and our second error is the systematic error from using our best values.

 9 HILL 68 has been changed by the authors from the published value (0.865 \pm 0.009) because of a correction in the shift due to η_+ . SKJEGGESTAD 72 and HILL 68 give detailed discussions of systematics encountered in this type of experiment.
- $^{10}\,\mathrm{Pre}\text{-}1971$ experiments are excluded from the average because of disagreement with later more precise experiments.

KO DECAY MODES

| | | Scale factor/ |
|------|------------------------------|------------------|
| Mode | Fraction (Γ_i/Γ) | Confidence level |
| | | |

| | | Hadronic modes |
|------------|-------------------|------------------------------------------------------------------|
| Γ_1 | $\pi^{0}\pi^{0}$ | (30.69±0.05) % |
| Γ_2 | $\pi^+\pi^-$ | (69.20±0.05) % |
| Γ_3 | $\pi^+\pi^-\pi^0$ | $(3.5 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10^{-7}$ |

Modes with photons or $\ell \overline{\ell}$ pairs

| 14 | $\pi^+\pi^-\gamma$ | [a,b] | $(1.79 \pm 0.05) \times 10^{-3}$ | |
|----------------|----------------------------|-------|----------------------------------|---------|
| Γ_5 | $\pi^{+}\pi^{-}e^{+}e^{-}$ | | $(4.79\pm0.15)\times10^{-5}$ | |
| Γ ₆ | $\pi^0 \gamma \gamma$ | [a] | $(4.9 \pm 1.8) \times 10^{-8}$ | |
| Γ_7 | $\gamma \gamma$ | | $(2.63\pm0.17)\times10^{-6}$ | S = 3.0 |

Semilentonic modes

CP violating (CP) and $\Delta S = 1$ weak neutral current (S1) modes

| Γ_{10} | $3\pi^0$ | CP | < 1.2 | $\times 10^{-7}$ | CL=90% |
|---------------|---------------------------|------------|------------------------------------------------------|--------------------|--------|
| Γ_{11} | $\mu^+\mu^-$ | <i>S</i> 1 | < 3.2 | $\times 10^{-7}$ | CL=90% |
| Γ_{12} | $e^+ e^-$ | <i>S</i> 1 | < 9 | $\times 10^{-9}$ | CL=90% |
| Γ_{13} | $\pi^0e^+e^-$ | <i>S</i> 1 | [a] $(3.0 \begin{array}{c} +1.5 \\ -1.2 \end{array}$ | $) \times 10^{-9}$ | |
| Гти | $\pi^{0} \mu^{+} \mu^{-}$ | S1 | (2.9 + 1.5) | 1×10^{-9} | |

- [a] See the Particle Listings below for the energy limits used in this mea-
- [b] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.
- [c] The value is for the sum of the charge states or particle/antiparticle
- [d] Not a measurement. Calculated as $0.666 \cdot B(\pi^{\pm} e^{\mp} \nu_e)$.

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 5 measurements and one constraint to determine 4 parameters. The overall fit has a χ^2 = 0.1 for 2 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

r/_± _= .. \

K DECAY RATES

| $\pi^-e^-\nu_e$ | | | | | | 18 |
|-----------------|--------------|--------------------------|-------|------------|--------------------------------------------------|------|
| VALUE (106 s-1) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do no | ot use the 1 | following data for | avera | ges, fits, | limits, etc. • • • | |
| 8.1 ±1.6 | 75 | ¹¹ AKHMETSHIN | 99 | CMD2 | Tagged K^0_S using $\phi 	o$ | KIKS |
| 7.50 ± 0.08 | | ¹² PDG | 98 | | 95 5 5 | LJ |
| seen | | BURGUN | 72 | HBC | $K^+ p \rightarrow K^0 p \pi^+$ | |
| 9.3 ± 2.5 | | AUBERT | 65 | HLBC | $\Delta S\!=\!\Delta Q,~\mbox{\it CP}$ cons. not | as- |
| | | | | | sumed | |

- 11 AKHMETSHIN 99 is from a measured branching ratio B(K $^0_S
 ightarrow ~\pi e
 u_e$) = (7.2 \pm 1.4) imes 10^{-4} and $\tau_{\rm K_c^0} = (0.8934 \pm 0.0008) \times 10^{-10}$ s. Not independent of measured branching
- 12 PDG 98 from K_L^0 measurements, assuming that $\Delta S = \Delta Q$ in K^0 decay so that $\Gamma(K_S^0 \to 0)$ $\pi^{\pm} e^{\mp} \nu_e) = \Gamma(\overset{L}{\kappa}_L^0 \rightarrow \pi^{\pm} e^{\mp} \nu_e).$

 $\Gamma \big(\pi^{\pm}\,\mu^{\mp}\,\nu_{\mu}\big)$ Го

VALUE (106 s-1) DOCUMENT ID \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ¹³ PDG 5.25 ± 0.07

 13 PDG 98 from K_L^0 measurements, assuming that $\Delta S = \Delta Q$ in K^0 decay so that $\Gamma(K_S^0 \to S)$ $\pi^{\pm}\,\mu^{\mp}\,\nu_{\mu}) = \,\Gamma(\bar{K}^{\,0}_L\,\rightarrow\,\,\pi^{\pm}\,\mu^{\mp}\,\nu_{\mu})\,.$

KS BRANCHING RATIOS

- Hadronic modes -

| $\Gamma(\pi^0\pi^0)/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|----------------------------------------|-----------------|-------------------|----------|----------------------|-------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | |
| 0.3069 ± 0.0005 OU | RFIT | | | | |
| • • • We do not u | se the followin | g data for averag | es, fits | , limits, etc. • • • | |
| 0.335 ± 0.014 | 1066 | BROWN | 63 | HLBC | |
| 0.288 ± 0.021 | 198 | CHRETIEN | 63 | HLBC | |
| 0.30 ± 0.035 | | BROWN | 61 | HLBC | |
| | | | | | |

 $\Gamma(\pi^+\pi^-)/\Gamma_{total}$ Γ_2/Γ DOCUMENT ID TECN COMMENT

• • • We do not use the following data for averages, fits, limits, etc. • •

| 0.670 ± 0.010 | 3447 | DOYLE 69 | HBC π | $p \rightarrow \Lambda K^0$ |
|---------------------------------------------------------------------|---------------------|-----------------------------------------------------|--------------------------------------------|------------------------------------------------------------------------------------------|
| $\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ | | DOCUMENT ID | TECN | Γ ₂ /Γ ₁ |
| 2.255 ±0.005 OUR F 2.2549±0.0054 • • • We do not use t | T T | 14 AMBROSINO | 06c KLOE | • • • |
| $2.2555 \pm 0.0012 \pm 0.005$ $2.236 \pm 0.003 \pm 0.015$ | 4 | 15 AMBROSINO 15 ALOISIO | | |
| $\begin{array}{ccc} 2.11 & \pm0.09 \\ 2.169 & \pm0.094 \end{array}$ | 1315 16k | EVERHART COWELL | 76 WIRE74 OSP K | $\pi^- \rho \rightarrow \Lambda K^0$ |
| 2.16 ± 0.08 2.22 ± 0.10 | 4799 3068 | HILL 16 ALITTI | 72 HBC | $ \begin{array}{ccc} K^+ d \to K^0 p p \\ K^+ p \to \pi^+ p K^0 \end{array} $ |
| 2.22 ± 0.08 2.10 ± 0.11 | 6380 701 | MORSE ¹⁷ NAGY ¹⁸ BALTAY | | $K^+ n \rightarrow K^0 p$ $K^+ n \rightarrow K^0 p$ $K p \rightarrow K^0$ neutrals |
| 2.22 ± 0.095 2.282 ± 0.043 2.12 ± 0.17 | 6150 7944 267 | 19 MOFFETT 17 BOZOKI | | $K^+ n \rightarrow K^0 p$ |
| 2.285 ± 0.055 2.10 ± 0.06 | 3016 3700 | ¹⁹ GOBBI MORFIN | 69 OSPK | $K^+ n \rightarrow K^0 p$ $K^+ n \rightarrow K^0 p$ |

- 14 This result combines AMBROSINO 06c KLOE 2001-02 data with ALOISIO 02B KLOE 2000 data. $\it K_0^{\rm P} \rightarrow \pi^+\pi^-$ fully inclusive.
- 15 Includes radiative decays $\pi^+\,\pi^-\,\gamma$
- The directly measured quantity is $K_S^0 \rightarrow \pi^+\pi^-/\text{all } K^0 = 0.345 \pm 0.005$.
- 17 NAGY 72 is a final result which includes BOZOKI 69. The directly measured quantity is $K_S^0 \to \ \pi^+\pi^-/\text{all}\ \overline{K}{}^0 = 0.345 \pm 0.005.$
- $^{19}\,\mathrm{MOFFETT}$ 70 is a final result which includes GOBBI 69.

K_{s}^{0}

| F(-+0)/F | W. J. S. W. Aller S. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{	ext{total}}$ Γ_3/Γ VALUE (units 10^{-7}) EVTS DOCUMENT ID TECN COMMENT | • • We do not use the following data for averages, fits, limits, etc. • • • $2.58 \pm 0.36 \pm 0.22$ 149 LAI 00 NA48 |
| | 2.58 ±0.36 ±0.22 149 LAI 00 NA48 2.2 ±1.1 16 ³⁴ BARR 95B NA31 |
| 3.5 ± 1.1 0.9 OUR AVERAGE | 2.4 ±0.9 35 ³⁵ BARR 95B NA31 < 13 90 BALATS 89 SPEC |
| 4.7 + 2.2 + 1.7 -1.7 - 1.5 20 BATLEY 05 NA48 | <pre>< 13 90 BALATS 89 SPEC 2.4 ±1.2 19 BURKHARDT 87 NA31</pre> |
| 2.5 + 1.3 + 0.5 $-1.0 - 0.6$ 500k 21 ADLER 97B CPLR | <133 90 BARMIN 86B XEBC |
| $4.8^{+2.2}_{-1.6}\pm 1.1$ 22 ZOU 96 E621 | ³² AMBROSINO 08c reports $(2.26 \pm 0.12 \pm 0.06) \times 10^{-6}$ from a measurement of $[\Gamma(K_S^0 - 0.00) \times 10^{-6}]$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $\gamma \gamma / \Gamma_{\text{total}} \times [B(\kappa_S^0 \to \pi^0 \pi^0)] \text{ assuming } B(\kappa_S^0 \to \pi^0 \pi^0) = (30.69 \pm 0.05) \times 10^{-2}$ |
| 4.1 + 2.5 + 0.5 | ³³ LAI 03 reports $[\Gamma(K_0^0 \to \gamma \gamma)/\Gamma_{\text{total}}]/[B(K_0^0 \to \pi^0 \pi^0)] = (8.84 \pm 0.18 \pm 0.10) \times 10^{-6}$ |
| 3.9 +5.4 + 0.9 | which we multiply by our best value B($K_0^0 \to \pi^0 \pi^0$) = (30.69 \pm 0.05) \times 10 ⁻² . Our first error is their experiment's error and our second error is the systematic error from |
| | using our best value. 34 BARR 95B result is calculated using B($K_L 	o \gamma \gamma$) = (5.86 \pm 0.17) $	imes$ 10 ⁻⁴ . |
| ²⁰ BATLEY 05 is obtained by measuring the interference parameters in K_S , $K_L \rightarrow \pi^+\pi^-\pi^0$: Re(λ) = 0.038 + 0.008 + 0.006 and Im(λ) = -0.013 + 0.005 + 0.004: | 35 BARR 95B quotes this as the combined BARR 95B $+$ BURKHARDT 87 result afte |
| $\pi^+\pi^-\pi^0$: Re(λ) = 0.038 ± 0.008 ± 0.006 and Im(λ) = -0.013 ± 0.005 ± 0.004; the correlation coeff. between Re(λ) and Im(λ) is 0.66 (statistical only). | rescaling BURKHARDT 87 to use same branching ratios and lifetimes as BARR 95B. |
| 21 ADLER 97B find the <i>CP</i> -conserving parameters $\text{Re}(\lambda)=(28\pm7\pm3)\times10^{-3}$, $\text{Im}(\lambda)=(-10\pm8\pm2)\times10^{-3}$. They estimate $\text{B}(\mathcal{K}_0^0\to\pi^+\pi^-\pi^0)$ from $\text{Re}(\lambda)$ and the | Semileptonic modes ——— |
| κ_0^0 decay parameters. See also ANGELOPOULOS 98c. | $\Gamma(\pi^{\pm} e^{\mp} \nu_{e})/\Gamma_{\text{total}}$ Γ_{8}/Γ_{0} |
| ²² ZOU 96 is from the the measured quantities $ ho_{+-0} =0.039^{+0.009}_{-0.006}\pm0.005$ and $\phi_{ ho}$ | VALUE (units 10 ⁻⁴) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| $=(-9\pm18)^{\circ}$. | 7.04 ±0.08 OUR FIT |
| ²³ ADLER 96E is from the measured quantities Re(λ) = 0.036 ± 0.010 $^{+}_{-}$ 0.003 and Im(λ) | 7.04 \pm 0.08 OUR AVERAGE 7.046 \pm 0.18 \pm 0.16 3^6 BATLEY 07D NA48 $\mathcal{K}^0(\overline{\mathcal{K}^0})(t) \rightarrow \pi e \nu$ |
| consistent with zero. Note that the quantity λ is the same as ρ_{+-0} used in other footnotes. | 6.91 $\pm 0.34 \pm 0.15$ 624 ³⁷ ALOISIO 02 KLOE Tagged κ_S^0 using $\phi \to \kappa_L^0 \kappa_S^0$ |
| 24 THOMSON 94 calculates this branching ratio from their measurements $ ho_{+-0} =$ | • • • We use the following data for averages but not for fits. • • • |
| $0.035 + 0.019 \pm 0.004$ and $\phi_{\rho} = (-59 \pm 48)^{\circ}$ where $ \rho_{+-0} e^{i\phi_{\rho}} = A(K_S^0 \to \pi^+ \pi^- \pi^0, -1)$ | 7.05 ±0.09 13k ³⁸ AMBROSINO 06E KLOE Not fitted |
| $I = 2)/A(K_L^0 \to \pi^+\pi^-\pi^0).$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| — Modes with photons or $\ell \overline{\ell}$ pairs — | 7.2 ± 1.4 75 AKHMETSHIN 99 CMD2 Tagged K_S^0 using $\phi \to K_L^0 K_S^0$ |
| $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-)$ Γ_4/Γ_2 | 36 Reconstructed from K^0 (\overline{K}^0)(t) $\to -\pi e \nu$ distributions using PDG values of B($K_L^0 = \pi e \nu$) = 0.4053 \pm 0.0015, $\tau_L = (5.114 \pm 0.021) \times 10^{-8}$ s and $\tau_S = (0.8958 \pm 0.0005) \times 10^{-8}$ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | 10^{-10} s. |
| 2.59±0.08 OUR AVERAGE | 37 Uses the PDG 00 value for B($K_S^0 \rightarrow \pi^+\pi^-$). |
| 2.56 \pm 0.09 1286 RAMBERG 93 E731 p $_{\gamma}$ >50 MeV/ c | 38 Obtained by imposing Σ_i B($K_S^0 \to i$) = 1, where <i>i</i> runs over all the four branching ratios |
| 2.68 ± 0.15 25 TAUREG 76 SPEC $\mathrm{p}_{\gamma}^{\prime} > 50~\mathrm{MeV}/c$ | $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi^0\pi^0$, and π^μ . Input value of B($\kappa^0_S \to \pi^+\pi^-$) / B($\kappa^0_S \to \pi^0\pi^0$) |
| • • We do not use the following data for averages, fits, limits, etc. • • | from AMBROSINO 06c is used. To derive $\Gamma(K_S^0 \to \pi^+ + \mu \nu) / \Gamma(K_S^0 \to \pi^+ e \nu)$, lepton universality is assumed, radiative corrections from ANDRE 07 are used, and phase space |
| 7.10 \pm 0.22 3723 RAMBERG 93 E731 p $_{\gamma}$ >20 MeV/c 3.0 \pm 0.6 29 ²⁶ BOBISUT 74 HLBC p $_{\sim}$ >40 MeV/c | integrals are taken from KTeV, ALEXOPOULOS 04A. This branching fraction enters our |
| 3.0 \pm 0.6 29 26 BOBISUT 74 HLBC $\rm p_{\gamma}^{\prime} >$ 40 MeV/c 2.8 \pm 0.6 27 BURGUN 73 HBC $\rm p_{\gamma}^{\prime} >$ 50 MeV/c | fit via their $\Gamma(\pi^\pme^\mp u_e)/\Gamma(\pi^+\pi^-)$ branching ratio measurement. |
| 25 TAUREG 76 find direct emission contribution <0.06, CL = 90%. | $\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})/\Gamma_{\text{total}}$ |
| 26 BOBISUT 74 not included in average because $ ho_{\gamma}$ cut differs. Estimates direct emission | The PDG 06 value below has not been measured but is computed to be 0.666 times the |
| contribution to be 0.5 or less, CL $=$ 95%. 27 BURGUN 73 estimates that direct emission contribution is 0.3 \pm 0.6. | $K_S 	o \pi^\pm e^\mp u_e$ branching fraction. It is included in the fit that constrains the four branching ratios $\pi^+\pi^-$, $\pi^0\pi^0$, $\pi e u$, and $\pi \mu u$ to sum to 1. This treatment, used by |
| | <code>AMBROSINO</code> 06E, is preferable to our previous practice of constraining the $\pi^+\pi^-$ |
| $\Gamma(\pi^+\pi^-e^+e^-)/\Gamma_{\text{total}}$ Γ_5/Γ | and $\pi^0 \pi^0$ modes to sum to 1. The 0.666 factor is obtained from AMBROSINO 06E |
| <u>VALUE (units 10⁻⁵)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 4.79±0.15 OUR AVERAGE | and assumes lepton universality, radiative corrections from ANDRE 07, and phase space integrals from KTeV, ALEXOPOULOS 04A. |
| 4.79±0.13 OUR AVERAGE 4.83±0.11±0.14 23k ²⁸ BATLEY 11 NA48 2002 data | VALUE (units 10 ⁻⁴) DO CUMENT ID COMMENT |
| 4.69±0.30 676 ²⁹ LAI 03C NA48 1998+1999 data | 4.69 ±0.06 OUR FIT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $4.71\pm0.23\pm0.22$ 620 29,30 LAI 03c NA48 1999 data | 4.691 \pm 0.001 \pm 0.056 39 PDG 06 calculated from $\pi^{\pm} e^{\mp} u_e$ |
| 4.71±0.23±0.22 620 ^{29,30} LAI 03C NA48 1999 data 4.5 ±0.7 ±0.4 56 LAI 00B NA48 1998 data | ³⁹ The PDG 06 value is computed to be $B_{PDG06}(\pi\mu\nu) = 0.666 \ B_{FIT}(\pi e \nu)$. The first |
| ²⁸ BATLEY 11 reports $\left[\Gamma(K_S^0 \rightarrow \pi^+\pi^-e^+e^-)/\Gamma_{\mathrm{total}}\right]/\left[\mathrm{B}(K_L^0 \rightarrow \pi^+\pi^-\pi^0)\right]/\left[\mathrm{B}(K_L^0 \rightarrow \pi^+\pi^-\pi^0)\right]$ | error specifies the arbitrarily small error, 0.001×10^{-4} , on $B_{PDG06}(\pi\mu\nu)$ for fixed $B_{FIT}(\pi e \nu)$. The second error is that due to the uncertainty in $B_{FIT}(\pi e \nu)$. |
| $[B(\pi^0 \rightarrow e^+e^-\gamma)] = (3.28 \pm 0.06 \pm 0.04) \times 10^{-2}$ which we multiply by our best | |
| $\begin{array}{ll} [B(\pi^0\to\ e^+e^-\gamma)] = (3.28\pm0.06\pm0.04)\times 10^{-2} \ \text{which we multiply by our best} \\ values\ B(\kappa^0_L\to\ \pi^+\pi^-\pi^0) = (12.54\pm0.05)\times 10^{-2}, \ B(\pi^0\to\ e^+e^-\gamma) = (1.174\pm0.05)\times 10^{-2}. \end{array}$ | $\Gamma(\pi^{\pm} e^{\mp} \nu_e)/\Gamma(\pi^{+} \pi^{-})$ Γ_8/Γ_2 |
| $0.035) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best values. Also a limit on the absolute value of the | <u>VALUE (units 10⁻⁴) </u> |
| interference between bremsstrahlung and E1 transition is given $z < 4 \times 10^{-7}$ at 90% | 10.19±0.11±0.07 13k AMBROSINO 06E KLOE |
| C.L. 29 Uses normalization BR($K_L \to \pi^+ \pi^- \pi^0$)*BR($\pi^0 \to e^+ e^-$) = (1.505 ± 0.047)×10 ⁻³ | ————————————————————————————————————— |
| From our 2000 Edition. 30 Second error is 0.16(syst) ± 0.15 (norm) combined in quadrature. | |
| Second error is $0.16({\sf syst}) \pm 0.15({\sf norm})$ combined in quadrature. | $\Gamma(3\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ |
| $\Gamma(\pi^0\gamma\gamma)/\Gamma_{\text{total}}$ Γ_6/Γ | Violates <i>CP</i> conservation. VALUE (units 10^{-7}) <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> |
| VALUE (units 10 ⁻⁸) CL% EVTS DOCUMENT ID TECN COMMENT | < 1.2 90 37.8M AMBROSINO 05B KLOE |
| 4.9 ± 1.6 ± 0.9 17 31 LAI 04 NA48 $m_{\gamma\gamma}^2/m_K^2 > 0.2$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | < 7.4 90 4.9 M 40 LAI 05A NA48 |
| <33 90 LAI 03B NA48 $m_{\gamma\gamma}^2/m_{K}^2 > 0.2$ | <140 90 7M ACHASOV 99D SND <190 90 17300 ⁴¹ ANGELOPO 98B CPLR |
| $^{ m 31}{ m Spectrum}$ also measured and found consistent with the one generated by a constant | <370 90 BARMIN 83 HLBC |
| matrix element. | 40 LAI 05A value is obtained from their bound on $ \eta_{000} $ (not assuming <i>CPT</i>) and B(K_L^0 $ ightarrow$ |
| $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_7/Γ | $3\pi^0)=0.211\pm0.003$, and PDG 04 values for K_L^0 and K_S^0 lifetimes. If <i>CPT</i> is assumed |
| VALUE (units 10 ⁻⁶) CL% EVTS DOCUMENT ID TECN COMMENT | then B(K $_S^0 ightarrow ~3\pi^0)_{CPT}~<~2.3	imes 10^{-7}$ at 90% CL |
| 2.63 ±0.17 OUR AVERAGE Error includes scale factor of 3.0. 2.26 ±0.12 ±0.06 711 32 AMBROSINO 08c KLOE $\phi \rightarrow K_S^0 K_I^0$ | 41 ANGELOPOULOS 98B is from $Im(\eta_{000}) = -0.05 \pm 0.12 \pm 0.05$, assuming $Re(\eta_{000})$ |
| 2.26 $\pm 0.12 \pm 0.06$ 711 ³² AMBROSINO 08C KLOE $\phi \rightarrow K_S^0 K_L^0$ 2.713 $\pm 0.063 \pm 0.005$ 7.5k ³³ LAI 03 NA48 | = Re(ϵ) = 1.635 $	imes$ 10 $^{-3}$ and using the value B($K_L^0 ightarrow \pi^0 \pi^0 \pi^0$) = 0.2112 \pm 0.0027. |
| 2.113±0.003±0.000 1.5K LAI U3 NA48 | |

 $\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Γ_1 Test for $\Delta S=1$ weak neutral current. Allowed by first-order weak interaction comb Γ_{11}/Γ with electromagnetic interaction.

VALUE (units 10^{-5}) DO CUMENT ID CL% < 0.032 90 GJESDAL ASPK 73 • • • We do not use the following data for averages, fits, limits, etc. • • • **HYAMS**

 $\frac{\Gamma(e^+\,e^-)/\Gamma_{total}}{\text{Test for }\Delta S=1\text{ weak neutral current. Allowed by first-order weak interaction combined}}$ with electromagnetic interaction.

| VALUE (units 10^{-7}) | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|----------------------|--------|------------|-------------------------------------------------------------|
| < 0.09 | 90 | 42 AMBROSINO | 09A | KLOE | $e^+e^- \rightarrow \phi \rightarrow \kappa_S^0 \kappa_L^0$ |
| | e the follow | ing data for average | s, fit | s, limits, | etc. • • • |
| < 1.4 | 90 | ANGELOPO | 97 | CPLR | |
| < 28 | 90 | BLICK | 94 | CNTR | Hyperon facility |
| <100 | 90 | BARMIN | 86 | XEBC | |

 42 AMBROSINO 09A reports < 0.09 \times 10 $^{-7}$ from a measurement of [$\Gamma(\kappa_S^0
ightarrow e^+ e^-)/$ Γ_{total}] / [B($\kappa_S^0 \to \pi^+\pi^-$)] assuming B($\kappa_S^0 \to \pi^+\pi^-$) = (69.20 \pm 0.05) \times 10⁻².

 $\Gamma(\pi^0 e^+ e^-)/\Gamma_{\text{total}}$ Test for $\Delta S=1$ weak neutral current. Allowed by first-order weak interaction combined with electromagnetic interaction.

| VALUE (units 10 ⁻⁹) | CL% | <u>EVTS</u> | DO CUMENT ID | 1 | TECN | COMMENT |
|---------------------------------|--------------|-------------|----------------------|-----------|-----------|----------------------------------------|
| $3.0^{+1.5}_{-1.2}\pm$ | 0.2 | 7 | ⁴³ BATLEY | 03 | NA48 | $\mathrm{m}_{ee}>\!0.165~\mathrm{GeV}$ |
| • • • We do not | use the foll | owing | lata for averages, | fits, lim | its, etc. | • • • |
| < 140 | 90 | | LAI | 01 | NA48 | |
| < 1100 | 90 | 0 | BARR | 93B | NA 31 | |
| <45 000 | 90 | | GIBBONS | 88 | E731 | |

43 BATLEY 03 extrapolate also to the full kinematical region using a constant form factor and a vector matrix element. The resulting branching ratio is $(5.8 + 2.9) \times 10^{-9}$

 $\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{total}$ Γ_{14}/Γ Test for $\Delta S=1$ weak neutral current. Allowed by first-order weak interaction combined

| VALUE (units 10 ⁻⁹) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|---------------------------------|------|--------------|------|---------|-----------------|
| 2.9+1.5±0.2 | 6 | 44 BATLEY | 04A | NA48 | NA48/1 K o beam |

 44 Background estimate is $0.22^{+0.18}_{-0.11}$ events. Branching ratio assumes a vector matrix element and unit form factor

K FORM FACTORS

For discussion, see note on $\mathit{K}_{\ell 3}$ form factors in the K^{\pm} section of the Particle Listings above. Because the semileptonic branching fraction is smaller in K_0^0 than K_0^0 by the ratio of the mean lives, the K_0^0 semileptonic form factor has so far been measured only in the K_{e3} mode using the linear expansion $f_+(t)=f_+(0)$ $(1+\lambda_+\,t\,/m_{\pi^+}^2)$, which gives the vector form factor $f_+(t)$ relative to its value at t=0.

λ_{+} (LINEAR ENERGY DEPENDENCE OF f_{+} IN K_{e3}^{0} DECAY)

| VALUE (upite 10-2) EVTS DOCUMENT ID TECN | 3 39+0 41 | 151 | A MBROSINO | 06- | 1 LCW | |
|------------------------------------------|--------------------|------|-------------|-----|-------|--|
| | VALUE (units 10-2) | FVTS | DOCUMENT ID | | TECN | |

CP VIOLATION IN $K_S \rightarrow 3\pi$

Written 1996 by T. Nakada (Paul Scherrer Institute) and L. Wolfenstein (Carnegie-Mellon University).

The possible final states for the decay $K^0 \to \pi^+\pi^-\pi^0$ have isospin I = 0, 1, 2, and 3. The I = 0 and I = 2 states have CP = +1 and K_S can decay into them without violating CPsymmetry, but they are expected to be strongly suppressed by centrifugal barrier effects. The I=1 and I=3 states, which have no centrifugal barrier, have CP = -1 so that the K_S decay to these requires ${\cal CP}$ violation.

In order to see CP violation in $K_S \to \pi^+\pi^-\pi^0$, it is necessary to observe the interference between K_S and K_L decay, which determines the amplitude ratio

$$\eta_{+-0} = \frac{A(K_S \to \pi^+ \pi^- \pi^0)}{A(K_L \to \pi^+ \pi^- \pi^0)} \ . \tag{1}$$

If η_{+-0} is obtained from an integration over the whole Dalitz plot, there is no contribution from the I=0 and I=2 final states and a nonzero value of η_{+-0} is entirely due to CP

Only I = 1 and I = 3 states, which are CP = -1, are allowed for $K^0 \to \pi^0 \pi^0 \pi^0$ decays and the decay of K_S into $3\pi^0$ is an unambiguous sign of CP violation. Similarly to η_{+-0} , η_{000} is defined as

$$\eta_{000} = \frac{A(K_S \to \pi^0 \pi^0 \pi^0)}{A(K_L \to \pi^0 \pi^0 \pi^0)} \ . \tag{2}$$

If one assumes that CPT invariance holds and that there are no transitions to I=3 (or to nonsymmetric I=1 states), it can be shown that

$$\eta_{+-0} = \eta_{000}$$

$$= \epsilon + i \frac{\operatorname{Im} a_1}{\operatorname{Re} a_1} .$$
(3)

With the Wu-Yang phase convention, a_1 is the weak decay amplitude for K^0 into I=1 final states; ϵ is determined from CP violation in $K_L \to 2\pi$ decays. The real parts of η_{+-0} and η_{000} are equal to Re(ϵ). Since currently-known upper limits on $|\eta_{+-0}|$ and $|\eta_{000}|$ are much larger than $|\epsilon|$, they can be interpreted as upper limits on $\text{Im}(\eta_{+-0})$ and $\text{Im}(\eta_{000})$ and so as limits on the CP-violating phase of the decay amplitude a_1 .

CP-VIOLATION PARAMETERS IN KO DECAY

$$\begin{array}{lll} \textbf{\textit{AS}} = \left[\ \Gamma(\textbf{\textit{K}}_{S}^{0} \rightarrow \boldsymbol{\pi}^{-} \, \mathbf{e}^{+} \, \boldsymbol{\nu}_{e}) - \Gamma(\textbf{\textit{K}}_{S}^{0} \rightarrow \boldsymbol{\pi}^{+} \, \mathbf{e}^{-} \, \boldsymbol{\mathcal{\nu}}_{e}) \ \right] \ / \ \text{SUM} \\ \text{Such asymmetry violates } \textit{CP}. \ \text{If } \textit{CPT} \text{ is assumed then } \textit{A}_{S} = 2 \ \text{Re}(\epsilon). \\ \frac{\textit{VALUE} \left(\text{units } 10^{-3} \right)}{1.5 \pm 9.6 \pm 2.9} & \frac{\textit{EVTS}}{13 \text{k}} & \frac{\textit{DOCUMENT ID}}{\text{AMBROSINO}} & \frac{\textit{TECN}}{\text{KLOE}} \\ \end{array}$$

PARAMETERS FOR $K_S^0 \rightarrow 3\pi$ DECAY -

 $\begin{array}{l} \text{Im}(\eta_{+-0})^2 = \Gamma(K_5^0 \to \pi^+\pi^-\pi^0, \textit{CP-violating}) \; / \; \Gamma(K_L^0 \to \pi^+\pi^-\pi^0) \\ \textit{CPT} \; \text{assumed valid (i.e. } \; \text{Re}(\eta_{+-0}) \simeq \; 0). \end{array}$

CL% EVTS • • • We do not use the following data for averages, fits, limits, etc. • • • ⁴⁵ BARMIN 601 < 0.23 90 85 HLBC < 0.12 90 384 METCALF 72 ASPK

 45 BARMIN 85 find Re $(\eta_{+-0})=(0.05\pm0.17)$ and Im($\eta_{+-0})=(0.15\pm0.33).$ Includes events of BALDO-CEOLIN 75.

 $\operatorname{Im}(\eta_{+-0}) = \operatorname{Im}(\mathsf{A}(K^0_S \to \ \pi^+\pi^-\pi^0, \ \mathit{CP}\text{-violating}) \ / \ \mathsf{A}(K^0_L \to \ \pi^+\pi^-\pi^0))$ DOCUMENT ID

 $-0.002\pm0.009 + 0.002$ 500k ⁴⁶ ADLER

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

 $-0.002 \pm 0.018 \pm 0.003 \quad 137 k$ ⁴⁷ ADLER 96D CPLR Sup. by ADLER 97B ⁴⁸ ZOU $-\,0.015\pm0.017\pm0.025\,272\,k$ 94 SPEC

 $^{46}\, {\rm ADLER}$ 97B also find ${\rm Re}(\eta_{+-0}) = -0.002 \pm 0.007 ^{+0.004}_{-0.001}.$ See also ANGELOPOU-

 47 LOS 98C. The ADLER 96D fit also yields ${\rm Re}(\eta_{+-0})=0.006\pm0.013\pm0.001$ with a correlation + 0.66 between real and imaginary parts. Their results correspond to $|\eta_{+-0}| <$ 0.037

with 90% CL. 48 ZOU 94 use theoretical constraint $\text{Re}(\eta_{+-0}) = \text{Re}(\epsilon) = 0.0016$. Without this constraint they find ${\rm Im}(\eta_{+-0}) = 0.019 \pm 0.061$ and ${\rm Re}(\eta_{+-0}) = 0.019 \pm 0.027$

 ${
m Im}(\eta_{000})^2 = \Gamma(K_S^0 o 3\pi^0) / \Gamma(K_L^0 o 3\pi^0)$ CPT assumed valid (i.e. ${
m Re}(\eta_{000}) \simeq 0$). This limit determines branching ratio

 $\Gamma \left(3\pi^0\right)/\Gamma_{total}$ above.

VALUE CL% EVTS DO CUMENT ID TECN COMMENT ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet⁴⁹ BARMIN 90 83 HLBC ⁵⁰ GJESDAL 90 74B SPEC Indirect meas.

 49 BARMIN 83 find Re($\eta_{000})=(-0.08\pm0.18)$ and Im($\eta_{000})=(-0.05\pm0.27).$ Assuming CPT invariance they obtain the limit quoted above.

 50 GJESDAL 74B uses $K2\pi$, $K_{\mu3}$, and K_{e3} decay results, unitarity, and *CPT*. Calculates $|(\eta_{0.00})|=0.26\pm0.20$. We convert to upper limit.

 K_S^0 , K_L^0

$\operatorname{Im}(\eta_{000}) = \operatorname{Im}(A(K_S^0 \to \ \pi^0 \, \pi^0 \, \pi^0) / A(K_L^0 \to \ \pi^0 \, \pi^0 \, \pi^0))$ $\kappa^0_S \to \pi^0 \pi^0 \pi^0$ violates *CP* conservation, in contrast to $\kappa^0_S \to \pi^+ \pi^- \pi^0$ which has a *CP*-conserving part. DOCUMENT ID TECN COMMENT VALUE EVTS)×10⁻² OUR AVERAGE (-0.1 ± 1.6) 51 LAI $\,$ 05A assumes Re(η_{000})=Re(ϵ)=1.66 \times 10 $^{-3}$. The equivalent limit is 1.14~ 05A assumes Re(η_{000})=Re(ϵ)=1.66 \times 10 $^{-3}$. The equivalent limit is $|\eta_{000}|_{CPT}<0.025$ at 90% CL Without assuming CPT invariance, they obtain Re(η_{000})= $-0.002\pm0.011\pm0.015$ and $\mathrm{Im}(\eta_{000})=-0.003\pm0.013\pm0.017$ with a statistical correlation coefficient of 0.77 and an overall correlation coefficient of 0.57 between imaginary and real part. The equivalent limit is $|\eta_{000}|<0.045$ at 90% CL 52 ANGELOPOULOS 98B assumes $\mathrm{Re}(\eta_{000})=\mathrm{Re}(\epsilon)=1.635\times10^{-3}$. Without assuming CPT invariance, they obtain $\mathrm{Re}(\eta_{000})=0.18\pm0.14\pm0.06$ and $\mathrm{Im}(\eta_{000})=0.15\pm0.20\pm0.03$. $\begin{array}{c|c} |\eta_{000}| = |A(K_S^0 \rightarrow 3\pi^0)/A(K_L^0 \rightarrow 3\pi^0)| \\ \text{A non-zero value violates CP invariance.} \\ \underline{VALUE} & \underline{CL\%} & \underline{EVTS} & \underline{DOCUMENT ID} \\ \hline \textbf{<0.018} & 90 & 37.8M & AMBROSINO \\ \end{array}$ AMBROSINO 05B KLOE \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet < 0.045 90 4.9 M LAI 05A NA48

- DECAY-PLANE ASYMMETRY IN $\pi^+\pi^-e^+e^-$ DECAYS -

This is the CP-violating asymmetry

$$A = \frac{N_{\sin\phi\cos\phi > 0.0} - N_{\sin\phi\cos\phi < 0.0}}{N_{\sin\phi\cos\phi > 0.0} + N_{\sin\phi\cos\phi < 0.0}}$$

where ϕ is the angle between the e^+e^- and $\pi^+\pi^-$ planes in the $K^0_{\mathcal{S}}$

CP asymmetry A in $K_S^0 \rightarrow \pi^+\pi^-e^+e^-$

| VALUE (%) | DO CUMENT IE | DOCUMENT ID | | COMMENT | |
|-------------------------------------------|------------------------|-------------|---------|----------------|---|
| -0.4±0.8 OUR AVERAGE | | | | | |
| -0.4 ± 0.8 | ⁵³ BATLEY | 11 | NA48 | 2002 data | |
| -1.1 ± 4.1 | LAI | 03c | NA48 | 1998+1999 data | |
| | owing data for averag | ges, fits, | limits, | etc. • • • | |
| $0.5 \pm 4.0 \pm 1.6$ | LAI | 03c | NA48 | 1999 data | |
| ⁵³ The result is used to set t | he limit $A < 1.5\%$ a | t 90% C | L. | | I |

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| BIRGE 60 | Rochester Conf. 601 | R.W. Birge et al. | (LRL, WISC) |
| MULLER 60 | PRL 4 418 | F. Muller et al. | `(LRL, BNL) |



$$I(J^P) = \frac{1}{2}(0^-)$$

$m_{K_L^0} - m_{K_S^0}$

For earlier measurements, beginning with GOOD 61 and FITCH 61, see our 1986 edition, Physics Letters $\bf 170B$ 132 (1986).

OUR FIT is described in the note on "CP violation in K_L decays" in the K_L^0 Particle Listings. The result labeled "OUR FIT Assuming CPT" ["OUR FIT Not assuming CPT"] includes all measurements except those with the comment "Not assuming CPT" ["Assuming CPT"]. Measurements with neither comment do not assume CPT and enter both fits.

| $VALUE (10^{10} h s^{-1})$ | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|--------------------------------|--------------|------------------------------------------|
| 0.5293 ±0.0009 OUR FIT | Error includes scale factor | of 1.3. A | ssuming CPT |
| 0.5289 ±0.0010 OUR FIT | Not assuming CPT | | |
| 0.52797 ± 0.00195 | ^{1,2} ABOUZAID 11 | KTEV | Not assuming CPT |
| 0.52699 ± 0.00123 | ^{1,3} ABOUZAID 11 | KTEV | Assuming CPT |
| $0.5240 \pm 0.0044 \pm 0.0033$ | APOSTOLA 99c | CPLR | K^0 - \overline{K}^0 to $\pi^+\pi^-$ |
| $0.5297 \pm 0.0030 \pm 0.0022$ | 4 SCHWINGEN 95 | E773 | 20-160 GeV K beams |
| 0.5286 ±0.0028 | ⁵ GIBBONS 93 | E731 | Assuming CPT |
| $0.5257 \pm 0.0049 \pm 0.0021$ | | E731 | Not assuming CPT |
| $0.5340 \pm 0.00255 \pm 0.0015$ | | SPEC | Gap method |
| $0.5334 \pm 0.0040 \pm 0.0015$ | ^{6,7} GJESDAL 74 | SPEC | Assuming CPT |
| • • • We do not use the fol | lowing data for averages, fits | s, limits, e | etc. • • • |
| 0.5261 ±0.0015 | 8 ALAVI-HARATI 03 | KTEV | Assuming CPT |
| 0.5288 ±0.0043 | ⁹ ALAVI-HARATI 03 | | Not assuming CPT |
| $0.5343 \pm 0.0063 \pm 0.0025$ | ¹⁰ ANGELOPO 01 | CPLR | |
| $0.5295 \pm 0.0020 \pm 0.0003$ | 11 ANGELOPO 98D | CPLR | Assuming CPT |
| 0.5307 ±0.0013 | ¹² ADLER 96c | RVUE | |
| $0.5274 \pm 0.0029 \pm 0.0005$ | ¹¹ ADLER 95 | CPLR | Sup. by A NGELOP OU- LOS 98D |
| 0.482 ±0.014 | ¹³ ARONSON 82B | SPEC | E=30-110 GeV |
| 0.534 ±0.007 | ¹⁴ CARNEGIE 71 | ASPK | Gap method |
| 0.542 ±0.006 | ¹⁴ ARONSON 70 | ASPK | Gap method |
| 0.542 ±0.006 | CULLEN 70 | CNTR | |

| 1 | The two ABOUZAID 11 values use the same data. | The first enters the "assuming CPT" |
|---|--------------------------------------------------|-------------------------------------|
| | fit and the second enters the "not assuming CPT" | |

- ²ABOUZAID 11 fit has Δm , $au_{\mathcal{S}}$, ϕ_{ϵ} , $\mathrm{Re}(\epsilon'/\epsilon)$, and $\mathrm{Im}(\epsilon'/\epsilon)$ as free parameters. See $\operatorname{Im}(\epsilon'/\epsilon)$ in the " K_L^0 CP violation" section for correlation information.
- 3 ABOUZAID 11 fit has Δm and $\tau_{\rm S}$ free but constrains ϕ_{ϵ} to the Superweak value, i.e. assumes *CPT*. See " K_S^0 Mean Life" section for correlation information.
- 4 Fits Δm and ϕ_{+-} simultaneously. GIBBONS 93c systematic error is from B. Winstein via private communication. 20–160 GeV K beams.
- 5 GIBBONS 93 value assume $\phi_{+-}=\phi_{00}=\phi_{\rm SW}=(43.7\pm0.2)^\circ$, i.e. assumes *CPT*. 20-160 GeV K beams.
- 6 ZD-100 GeV / Dearns.

 These two experiments have a common systematic error due to the uncertainty in the momentum scale, as pointed out in WAHL 89.
- 7 GJESDAL 74 uses charge asymmetry in $K_{\ell 3}^0$ decays.
- 8 ALAVI-HARATI 03 fit Δm and $au_{K^0_S}$ simultaneously. ϕ_{+-} is constrained to the Superweak value, i.e. CPT is assumed. See " K_S^0 Mean Life" section for correlation information. Superseded by ABOUZAID 11. 9 ALAVI-HARATI 03 fit Δm , ϕ_{+-} , and τ_{K_S} simultaneously. See ϕ_{+-} in the " K_L CP
- violation" section for correlation information. Superseded by ABOUZAID 11.
- 10 ANGEL OPOULOS 01 uses strong interactions strangeness tagging at two different times. 11 Uses \overline{K}^0_{e3} and K^0_{e3} strangeness tagging at production and decay. Assumes CPT conservation on $\Delta S = -\Delta Q$ transitions.
- vation on $\Delta S = \Delta Q$ transitions. 12 ADLER 96c is the result of a fit which includes nearly the same data as entered into the "OUR FIT" value above. 13 ARONSON 82 find that Δm may depend on the kaon energy. 14 ARONSON 70 and CARNEGIE 71 use K_0^0 mean life = $(0.862 \pm 0.006) \times 10^{-10}$ s. We
- have not attempted to adjust these values for the subsequent change in the K^0_S mean

K, MEAN LIFE

| VALUE (10 ⁻⁸ s) | EVTS | DO CU | MENT ID | | TECN | COMMENT |
|------------------------------------------------------|--------------------------|-----------------------------------|----------------------|-----------------------|------------------------|--------------------------------------------------------|
| 5.116±0.021 OUR FIT | Error | includes sca | le factor | of 1.1 | | - |
| 5.099±0.021 OUR AVE | RAGE | | | | | |
| $5.072 \pm 0.011 \pm 0.035$ | 13M | ¹ AMB | ROSINO | 06 | KLOE | $\sum_{i} B_{i} = 1$ |
| $5.092 \pm 0.017 \pm 0.025$ | 15 M | AMB | ROSINO | 05 C | KLOE | |
| 5.154 ± 0.044 | 0.4 M | VOSE | BURGH | 72 | CNTR | |
| • • • We do not use th | e follov | ving data fo | r average | s, fits | limits, | etc. • • • |
| 5.15 ± 0.14 | | DEVI | IN | 67 | CNTR | |
| ¹ AMBROSINO 06 us | es $\phi \rightarrow$ | K _I K _S wit | h K _I tag | ged b | $y K_S \rightarrow$ | $\pi^+\pi^-$. The four major |
| This KLOE K _L lifet among the four mea | ime is sured <i>l</i> | obtained by Kr BR's and | imposin; Ithis Ki | g \sum_i lifetin | $B_i = 1$ ne is | γ) is taken from PDG 04 The correlation matrix |
| | κ_{e3} | $\kappa_{\mu 3}$ | $3\pi^0$ | π^+ | $_{\rm r}$ $ _{\pi}$ 0 | $\tau_{K_{I}}$ |
| κ_{e3} | 1 | - 0.25 | -0.56 | _ | 0.07 | 0.25 |
| $\kappa_{\mu 3} \atop 3\pi^0$ | | 1 | -0.43 | - | 0.20 | 0.33 |
| $3\pi^{0}$ | | | 1 | _ | 0.39 | -0.21 |
| $_{\pi}^{+}$ $_{\pi}^{-}$ $_{\pi}^{0}$ | | | | | 1 | -0.39 |
| $\tau_{K_{l}}$ | | | | | | 1 |

These correlations are taken into account in our fit. The average of this KLOE mean life measurement and the independent KLOE measurement in AMBROSINO 05c is (5.084 \pm $0.023) \times 10^{-8} \text{ s.}$

KI DECAY MODES

| | Mode | Fra | ction (Γ_i/Γ) | Confidence level |
|------------|----------------------------------------------------------------------------------------------|-------------------|-----------------------------|------------------|
| | | Semileptonic mode | s | |
| Γ_1 | $\pi^{\pm}e^{\mp} u_{e}$ Called $K_{e3}^{0}.$ | [a] (| 40.55 ±0.11) % | S=1.7 |
| Га | Called K_{e3}° . | [a] (' | 27.04 ±0.07)% | S=1.1 |
| ' 2 | $\pi^\pm \mu^\mp u_\mu^{}$ Called $K^0_{\mu 3}$. | [6] (| 27.04 20.07) 70 | 3=1.1 |
| | $(\pi \mu atom) \nu$ $\pi^0 \pi^{\pm} e^{\mp} \nu$ $\pi^{\pm} e^{\mp} \nu e^{+} e^{-}$ | (| 1.05 ± 0.11) $	imes 1$ | 10-7 |
| Γ_4 | $\pi^0 \pi^{\pm} e^{\mp} \nu$ | [a] (| $5.20 \pm 0.11) \times 1$ | LO ⁻⁵ |
| Γ_5 | $\pi^\pme^\mp ue^+e^-$ | [a] (| $1.26 \pm 0.04) \times 1$ | 10-5 |

Hadronic modes, including Charge conjugation×Parity Violating (CPV) modes

| Γ_6 | $3\pi^{0}$ | | $(19.52 \pm 0.12)\%$ | S=1.6 |
|------------|-------------------|---------|----------------------------------|-------|
| Γ_7 | $\pi^+\pi^-\pi^0$ | | $(12.54 \pm 0.05)\%$ | |
| Γ8 | $\pi^+\pi^-$ | CPV [b] | $(1.967\pm0.010)\times10^{-3}$ | S=1.5 |
| Γα | $\pi^{0}\pi^{0}$ | CPV | $(8.64 \pm 0.06) \times 10^{-4}$ | S=1.8 |

Semileptonic modes with photons

Hadronic modes with photons or $\ell \overline{\ell}$ pairs

| Γ_{12} | $\pi^0 \pi^0 \gamma$ | | < 2.43 | $\times 10^{-7}$ | CL=90% |
|---------------|------------------------------|-------|-----------------|--------------------------------|---------|
| Γ_{13} | $\pi^+\pi^-\gamma$ | [c,d] | $(4.15 \pm 0.$ | 15) \times 10 ⁻⁵ | S = 2.8 |
| Γ_{14} | $\pi^+\pi^-\gamma(DE)$ | | $(2.84 \pm 0.$ | $11) \times 10^{-5}$ | S=2.0 |
| Γ_{15} | $\pi^0 2\gamma$ | [c] | $(1.273 \pm 0.$ | $033) \times 10^{-6}$ | |
| Γ16 | $\pi^{0} \gamma_{e} + e^{-}$ | | (162 ± 0) | 17.1×10^{-8} | |

Other modes with photons or $\ell \overline{\ell}$ pairs

| Γ_{17} | 2γ | $(5.47 \pm 0.04) \times 10^{-4}$ | S=1.1 |
|---------------|--------------------------|----------------------------------------|--------|
| Γ_{18} | 3γ | $< 7.4 \times 10^{-8}$ | CL=90% |
| Γ_{19} | $e^+e^-\gamma$ | $(9.4 \pm 0.4) \times 10^{-6}$ | S=2.0 |
| | $\mu^+ \mu^- \gamma$ | $(3.59 \pm 0.11) \times 10^{-7}$ | S=1.3 |
| Γ_{21} | $e^+e^-\gamma\gamma$ | [c] $(5.95 \pm 0.33) \times 10^{-7}$ | |
| Γ_{22} | $\mu^+\mu^-\gamma\gamma$ | [c] $(1.0 + 0.8 - 0.6) \times 10^{-8}$ | |

Charge conjugation \times Parity (CP) or Lepton Family number (LF) violating modes, or $\Delta S = 1$ weak neutral current (S1) modes

| Γ ₂₃ | $\mu^+ \mu^-$ | 51 | | | | | $\times 10^{-9}$ | |
|-----------------|------------------------------------|------------|-----|---|------|------------|---------------------|---------------|
| Γ_{24} | $e^+ e^-$ | <i>S</i> 1 | | (| 9 | + 6 - 4 | $) \times 10^{-12}$ | |
| Γ ₂₅ | $\pi^{+}\pi^{-}e^{+}e^{-}$ | <i>S</i> 1 | [c] | (| 3.11 | ± 0.19 | $\times 10^{-7}$ | |
| Γ_{26} | $\pi^0 \pi^0 e^+ e^-$ | S1 | | < | 6.6 | | $\times 10^{-9}$ | $CL\!=\!90\%$ |
| Γ_{27} | $\pi^0 \pi^0 \mu^+ \mu^-$ | <i>S</i> 1 | | < | 9.2 | | $\times 10^{-11}$ | CL=90% |
| Γ ₂₈ | $\mu^{+}\mu^{-}e^{+}e^{-}$ | <i>S</i> 1 | | (| 2.69 | ±0.27 | $\times 10^{-9}$ | |
| Γ_{29} | $e^{+} e^{-} e^{+} e^{-}$ | <i>S</i> 1 | | | | | $\times 10^{-8}$ | |
| Γ ₃₀ | $\pi^0\mu^+\mu^-$ | CP,S1 | [e] | < | 3.8 | | $\times 10^{-10}$ | CL=90% |
| Γ_{31} | $\pi^{0}e^{+}e^{-}$ | CP,S1 | [e] | < | 2.8 | | $\times 10^{-10}$ | CL=90% |
| Γ_{32} | $\pi^0 \nu \overline{\nu}$ | CP,S1 | [f] | < | 2.6 | | $\times 10^{-8}$ | CL=90% |
| Γ_{33} | $\pi^0 \pi^0 \nu \overline{\nu}$ | <i>S</i> 1 | | < | 8.1 | | $\times 10^{-7}$ | CL=90% |
| Γ ₃₄ | $e^{\pm}\mu^{\mp}$ | LF | [a] | < | 4.7 | | $\times 10^{-12}$ | CL=90% |
| Γ ₃₅ | $e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp}$ | LF | [a] | < | 4.12 | | $\times 10^{-11}$ | CL=90% |
| Γ ₃₆ | $\pi^0 \mu^\pm e^\mp$ | LF | [a] | < | 7.6 | | $\times 10^{-11}$ | CL=90% |
| Γ_{37} | $\pi^0 \pi^0 \mu^{\pm} e^{\mp}$ | LF | | < | 1.7 | | $\times 10^{-10}$ | $CL\!=\!90\%$ |
| | | | | | | | | |

- [a] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [b] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K_L^0 \rightarrow \pi^+ \pi^- \gamma(DE)$.
- [c] See the Particle Listings below for the energy limits used in this mea-
- [d] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.
- [e] Allowed by higher-order electroweak interactions.
- [f] Violates $\ensuremath{\mathit{CP}}$ in leading order. Test of direct $\ensuremath{\mathit{CP}}$ violation since the indirect CP-violating and CP-conserving contributions are expected to be suppressed.

CONSTRAINED FIT INFORMATION

An overall fit to the mean life and 15 branching ratios uses 27 measurements and one constraint to determine 11 parameters. The overall fit has a $\chi^2=$ 37.4 for 17 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (10^8 s^{-1}) | Scale factor |
|----------------|--------------------------------------------------------|------------------------------|--------------|
| Γ ₁ | $\pi^{\pm}e^{\mp} u_{e}$ Called K_{e3}^{0} . | [a] 0.07927 ± 0.00034 | 1.1 |
| Γ_2 | Called K_{e3}^0 . $\pi^{\pm} \mu^{\mp} \nu_{\mu}$ | [a] 0.05286 ± 0.00025 | 1.1 |
| _ | $\pi^\pm \mu^\mp u_\mu$ Called $K^0_{\mu 3}$. | - | |

| Γ ₆ | $3\pi^0$ | 0.03815 ± 0.00030 | 1.5 |
|-----------------|-------------------------|-------------------------------------------|-----|
| Γ_7 | $\pi^+\pi^-\pi^0$ | 0.02451 ± 0.00015 | |
| Γ ₈ | $\pi^+\pi^-$ | [b] (3.844 ± 0.023) $\times 10^{-4}$ | 1.2 |
| Г9 | $\pi^{0}\pi^{0}$ | $(1.690 \pm 0.013) \times 10^{-4}$ | 1.4 |
| Γ_{13} | $\pi^+\pi^-\gamma$ | $[c,d](8.11 \pm 0.29) \times 10^{-6}$ | 2.7 |
| Γ_{14} | $\pi^+\pi^-\gamma$ (DE) | $(5.55 \pm 0.21) \times 10^{-6}$ | 2.0 |
| Γ_{17} | 2γ | $(1.069 \pm 0.010) \times 10^{-4}$ | 1.2 |
| Γ ₁₉ | $e^+ e^- \gamma$ | $(1.84 \pm 0.08) \times 10^{-6}$ | 1.9 |

K⁰ DECAY RATES

| $\Gamma(\pi^+\pi^-\pi^0)$ | | | | | | Γ ₇ |
|----------------------------------------------------|-----------------|---------------------|----------|-----------|------------|----------------|
| VALUE (106 s-1) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 2.451 ± 0.015 OUR | FIT | | | | | |
| • • • We do not us | se the followin | ng data for average | es, fits | , limits, | etc. • • • | |
| $2.32 \begin{array}{l} +0.13 \\ -0.15 \end{array}$ | 192 | BALDO | 75 | HLBC | Assumes CP | |
| 2.35 ± 0.20 | 180 | ¹ JAMES | 72 | HBC | Assumes CP | |
| 2.71 ± 0.28 | 99 | CHO | 71 | DBC | Assumes CP | |
| 2.5 ± 0.3 | 98 | ¹ JAMES | 71 | HBC | Assumes CP | |
| 2.12 ± 0.33 | 50 | MEISNER | 71 | HBC | Assumes CP | |
| 2.20 ± 0.35 | 53 | WEBBER | 70 | HBC | Assumes CP | |
| $2.62 \begin{array}{l} +0.28 \\ -0.27 \end{array}$ | 136 | BEHR | 66 | HLBC | Assumes CP | |
| 3.26 ± 0.77 | 18 | ANDERSON | 65 | HBC | | |
| 1.4 ±0.4 | 14 | FRANZINI | 65 | HBC | | |
| | | | | | | |

¹ JAMES 72 is a final measurement and includes JAMES 71.

| $\Gamma(\pi^{\pm} e^{\mp} \nu_e)$ | | | | | | Γ_1 |
|-----------------------------------|-----------------|--------------------|-----------|-----------|------------|------------|
| VALUE (106 s-1) | EVTS | DO CUMENT IL |) | TECN | COMMENT | |
| 7.927±0.034 OUR I | FIT Error ind | cludes scale facto | or of 1. | 1. | · | |
| | se the followin | g data for avera | ges, fits | , limits, | etc. • • • | |
| 7.81 ±0.56 | 620 | CHAN | 71 | нвс | | |
| ⊥ 0.85 | | | | | | |

| $\Gamma(\pi^{\pm} e^{\mp} \nu_e) + \Gamma(\pi^{\pm}$ | $^{\perp}\mu^{\mp}\nu_{\mu}$ | | | | $(\Gamma_1 + \Gamma_2)$ |
|------------------------------------------------------|------------------------------|--------|----|------|--------------------------------------|
| $7.52 \begin{array}{c} +0.85 \\ -0.72 \end{array}$ | | AUBERT | 65 | HLBC | $\Delta S = \Delta Q$, CP assumed |
| 7.81 ± 0.56 | 620 | CHAN | 71 | HBC | |
| | | | | | |

DOCUMENT ID

| 13.21±0.05 OUR FIT | | | | | | | | |
|-------------------------------------------------------------------------------|-----|---------------------|----|-----|---------------------------------------|--|--|--|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | | |
| 12.4 ±0.7 | | | | | $K^+ \rho \rightarrow K^0 \rho \pi^+$ | | | |
| 8.47 ± 1.69 | | | | | $K^- p \rightarrow n \overline{K}^0$ | | | |
| 13.1 ± 1.3 | | ¹ WEBBER | | | $K^- p \rightarrow n \overline{K}^0$ | | | |
| 11.6 ± 0.9 | 0,0 | ^{1,2} сно | | | $K^+ n \rightarrow K^0 p$ | | | |
| 10.3 ± 0.8 | 335 | ² HILL | 67 | DBC | $K^+ n \rightarrow K^0 p$ | | | |

¹ FRANZINI

K) BRANCHING RATIOS

Semileptonic modes

65 HBC

TECN COMMENT

 Γ_1/Γ

| $\Gamma(\pi^{\pm}e^{\mp} u_{e})/\Gamma_{ m total}$ | | | |
|----------------------------------------------------|-------|-------------------------------------|--|
| VALUE | EVTS | DOCUMENT ID TECN | |
| 0.4055 ± 0.0011 OUR FIT | Error | includes scale factor of 1.7. | |
| 0.4047±0.0028 OUR AVE | RAGE | Error includes scale factor of 3.1. | |
| $0.4007 \pm 0.0005 \pm 0.0015$ | 13M | ¹ AMBROSINO 06 KLOE | |
| 0.4067 ± 0.0011 | | ² ALEXOPOU 04 KTEV | |

 $^{^1}$ There are correlations between these five KLOE measurements: B($extit{K}_L
ightarrow \pi \, e \,
u$), B($extit{K}_L
ightarrow$ $\pi\mu\nu$), B($K_L\to 3\pi^0$), B($K_L\to \pi^+\pi^-\pi^0$), and τ_{K_L} measured in AMBROSINO 06. See the footnote for the τ_{K_L} measurement for the correlation matrix.

² ALEXOPOULOS 04 constrains $\sum_i B_i = 0.9993$ for the six major K_L branching fractions. The correlations among these branching fractions are taken into account in our fit. The correlation matrix is

| ation matrix | K_{e3} | $\kappa_{\mu 3}$ | $3\pi^0$ | $_{\pi^+\pi^-\pi^0}$ | $_{\pi^{+}\pi^{-}}$ | $_{\pi}^{0}_{\pi}^{0}$ |
|-------------------------|----------|------------------|----------|----------------------|---------------------|------------------------|
| κ_{e3} | 1 | | | | | |
| $K_{\mu 3}$ | 0.15 | 1 | | | | |
| $3\pi^0$ | -0.77 | -0.62 | 1 | | | |
| $\pi^{+}\pi^{-}\pi^{0}$ | | 0.08 | -0.54 | 1 | | |
| $\pi^+\pi^-$ | | 0.22 | -0.48 | 0.49 | 1 | |
| $\pi^0\pi^0$ | -0.72 | -0.54 | 0.89 | -0.46 | -0.39 | 1 |

 $\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})/\Gamma_{\text{total}}$ Γ_2/Γ

 VALUE
 EVTS
 DOCUMENT ID

 0.2704 ± 0.0007 OUR FIT
 Error includes scale factor of 1.1.
 0.2700 ± 0.0008 OUR AVERAGE

 $0.2698 \pm 0.0005 \pm 0.0015$ 13M ¹ AMBROSINO 06 KLOE ² ALEXOPOU... 04 KTEV 0.2701 ± 0.0009

| $\left[\Gamma\left(\pi^{\pm}e^{\mp}\nu_{e}\right)+\Gamma\left(\pi^{\pm}\mu\right)\right]$ | $(\Gamma_1 + \Gamma_2)/\Gamma$ | |
|-------------------------------------------------------------------------------------------|--------------------------------|--|
| VALUE | DO CUMENT ID | |
| | | |

0.6760 ± 0.0012 OUR FIT Error includes scale factor of 1.6.

 $\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})/\Gamma(\pi^{\pm}e^{\mp}\nu_{e})$ Γ_2/Γ_1
 VALUE
 EVTS
 DOCUMENT ID

 0.6669±0.0027 OUR FIT
 Error includes scale factor of 1.2.
 TECN COMMENT

 0.666 ± 0.004 OUR AVERAGE Error includes scale factor of 1.6. • • • We use the following data for averages but not for fits. • • •

 0.6740 ± 0.0059 13M ¹ A MBROSINO 06 KLOE Not in fit ² ALEXOPOU... 04 KTEV Not in fit $0.6640 \pm 0.0014 \pm 0.0022$ 394K

• • • We do not use the following data for averages, fits, limits, etc. • • • $0.702\ \pm0.011$ 33k CHO 80 HBC 0.662 ± 0.037 10k WILLIAMS 74 ASPK 0.741 ± 0.044 6700 BRANDENB... 73 нвс

 0.662 ± 0.030 1309 **EVANS** 73 HLBC 0.68 ± 0.08 3548 **BASILE** 70 OSP K 0.71 ± 0.05 770 BUDAGOV 68 HLBC

 $^{\rm 1}\,{\rm A\,MBROSINO}$ 06 enters the fit via their separate measurements of these two modes. $^2\,\mbox{ALEXOPOULOS}$ 04 enters the fit via their separate measurements of these two modes.

$\Gamma((\pi \mu \text{ atom}) \nu) / \Gamma(\pi^{\pm} \mu^{\mp} \nu_{\mu})$ Γ_3/Γ_2 VALUE (units 10^{-7}) EVTS DO CUMENT ID ¹ ARONSON 86 SPEC 3.90 ± 0.39 155 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

COOMBES 76 WIRE 18 $^1\,\text{ARONSON}$ 86 quote theoretical value of (4.31 \pm 0.08) $\times\,10^{-7}$.

 $\Gamma(\pi^0 \pi^{\pm} e^{\mp} \nu) / \Gamma_{\text{total}}$ Γ_4/Γ DOCUMENT ID

<u>VALUE (units 10⁻⁵)</u> <u>CL%</u> **5.20±0.11 OUR AVERAGE** $5.21 \pm 0.07 \pm 0.09$ 5402 BATLEY 04 NA48 $5.16 \pm 0.20 \pm 0.22$ 729 MAKOFF 93 E731 • • • We do not use the following data for averages, fits, limits, etc. • • • 6.2 ± 2.0 16 CARROLL 80c SPEC 90

¹ DONALDSON 74 SPEC 1 DONALDSON 74 uses $K_{L}^{0} \rightarrow \ \pi^{+} \, \pi^{-} \, \pi^{0} / ($ all $K_{L}^{0})$ decays = 0.126.

 $\Gamma(\pi^{\pm} e^{\mp} \nu e^{+} e^{-})/\Gamma(\pi^{+} \pi^{-} \pi^{0})$ Γ_5/Γ_7

 $\frac{\text{VALUE (units 10}^{-5})}{\textbf{10.02\pm0.17\pm0.29}} \quad \frac{\text{EVTS}}{19\text{k}} \quad \frac{\text{DOCUMENT ID}}{\text{ABOUZAID}} \quad \frac{\text{TECN}}{0.7\text{C}} \quad \frac{\text{COMMENT}}{\text{KTEV}} \quad \text{M}_{ee} > 5 \text{ MeV, E}_{ee}^* > 30 \text{ MeV}$

 $^{1}\mathrm{E}_{ee}^{*}$ is the energy of the $e^{+}e^{-}$ pair in the kaon rest frame. ABOUZAID 07c reports $\begin{bmatrix} \Gamma(\kappa_L^0 \rightarrow \pi^\pm e^\mp \nu e^+ e^-) / \Gamma(\kappa_L^0 \rightarrow \pi^+ \pi^- \pi^0) \end{bmatrix} / \begin{bmatrix} B(\pi^0 \rightarrow e^+ e^- \gamma) \end{bmatrix} = (8.54 \pm 1.5)$ $0.07\pm0.13)\times10^{-3}$ which we multiply by our best value B($\pi^0\to e^+e^-\gamma$) = (1.174 \pm $0.035)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

- Hadronic modes, -including Charge conjugation×Parity Violating (CPV) modes

 $\Gamma(3\pi^0)/\Gamma_{total}$

 VALUE
 EVTS
 DOCUMENT ID

 0.1952±0.0012 OUR FIT
 Error includes scale factor of 1.6.

0.1969±0.0026 OUR AVERAGE Error includes scale factor of 2.0.

 \bullet \bullet We use the following data for averages but not for fits. \bullet \bullet $0.1997 \pm 0.0003 \pm 0.0019$ 13M $\frac{1}{2}$ AMBROSINO 06 KLOE Not fitted

¹ ALEXOPOU... 04 KTEV Not fitted 0.1945 ± 0.0018

 1 We exclude these B($K_L \to 3\pi^0$) measurements from our fit because the authors have constrained K_L branching fractions to sum to one. It enters our fit via the other measurements from the experiment and their correlations, along with our constraint that the fitted branching fractions sum to one.

 $\Gamma(3\pi^0)/\Gamma(\pi^{\pm}\,e^{\mp}\,\nu_e)$ Γ_6/Γ_1 TECN COMMENT

 VALUE
 EVTS
 DO CUMENT ID

 0.481 ±0.004
 OUR FIT
 Error includes scale factor of 1.8.
 • • • We use the following data for averages but not for fits. • • •

¹ ALEXOPOU... 04 KTEV Not in fit 0.4782 ± 0.0014 ± 0.0053 209K

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $0.545 \pm 0.004 \pm 0.009$ 38k KREUTZ 95 NA31

 $^{
m 1}$ This measurement enters the fit via their separate measurements of these two modes.

 $\Gamma(3\pi^0)/\big[\Gamma(\pi^\pm\,e^\mp\,\nu_e)+\Gamma(\pi^\pm\,\mu^\mp\,\nu_\mu)+\Gamma(\pi^+\,\pi^-\,\pi^0)\big]$ $\Gamma_6/(\Gamma_1+\Gamma_2+\Gamma_7)$ WALUE EVTS DOCUMENT ID TE

0.2436±0.0018 OUR FIT Error includes scale factor of 1.6. COMMENT

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 0.251 ± 0.014 BUDAGOV 68 HLBC ORSAY measur. 444 68 0.277 ± 0.021 BUDAGOV HLBC Ecole polytec.meas

 $\begin{array}{ccc} 0.31 & +0.07 \\ -0.06 \end{array}$ 29 KULYUKINA 68 CC 0.24 ± 0.08 ANIKINA 64

 $^{9.85 \,{}^{+\, 1.15}}_{-\, 1.05}$ $\frac{1}{2}$ Assumes $\Delta S = \Delta Q$ rule.

² CHO 70 includes events of HILL 67.

 $^{^1}$ There are correlations between these five KLOE measurements: B(${\it K_L} \rightarrow \pi \, e \, \nu)$, B(${\it K_L} \rightarrow \pi \, e \, \nu)$ $\pi\mu\nu$), B(${\it K_L} \to 3\pi^0$), B(${\it K_L} \to \pi^+\pi^-\pi^0$), and ${\it \tau_{\it K_L}}$ measured in AMBROSINO 06. See the footnote for the τ_{K_L} measurement for the correlation matrix.

² For correlations with other ALEXOPOULOS 04 measurements, see the footnote with their $\mathsf{B}(\mathit{K}_{L} \to \pi e \nu)$ measurement.

 Γ_8/Γ_7

 Γ_9/Γ

 Γ_9/Γ_8

 Γ_9/Γ_6

 Γ_{10}/Γ_{1}

```
\Gamma(\pi^{\pm} e^{\mp} \nu_e) / \Gamma(2 \text{ tracks})
\Gamma(3\pi^0)/\Gamma(\pi^+\pi^-\pi^0)
                                                                                                         \Gamma_6/\Gamma_7
                                                                                                                                                                                                   \Gamma_1/(\Gamma_1+\Gamma_2+0.03508\Gamma_6+\Gamma_7+\Gamma_8)
                                                                                                                                        \Gamma(2 \text{ tracks}) = \Gamma(\pi^{\pm} e^{\mp} \nu_{e}) + \Gamma(\pi^{\pm} \mu^{\mp} \nu_{\mu}) + 0.03508 \ \Gamma(3\pi^{0}) + \Gamma(\pi^{+} \pi^{-} \pi^{0})
<u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u>

1.557±0.012 OUR FIT Error includes scale factor of 1.3.
                                                                         TECN COMMENT
                                                                                                                                         + \Gamma(\pi^+\pi^-) where 0.03508 is the fraction of 3\pi^0 events with one Dalitz decay (\pi^0 
ightarrow
• • • We use the following data for averages but not for fits. • • •
                                          <sup>1</sup> AMBROSINO 06 KLOE Not in fit
                              13M
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                 <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TH</u>
0.5006±0.0009 OUR FIT Error includes scale factor of 1.3
1.611 \pm 0.014 \pm 0.034
                                 28k
                                               KREUTZ
                                                                  95 NA 31
                                                                                                                                 0.4978 \pm 0.0035
                                                                                                                                                                6.8M
1.65\ \pm0.07
                                               BARMIN
                                                                  72B HLBC Error statistical only
                                                                                                                                  \Gamma(\pi^{+}\pi^{-})/\left[\Gamma(\pi^{\pm}e^{\mp}\nu_{e}) + \Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu}) + \Gamma(\pi^{+}\pi^{-}\pi^{0})\right] 
Violates CP conservation.

WALUE (units 10<sup>-3</sup>)

EVTS

DOCUMENT ID

TECH
                                               BUDAGOV
                                                                  68 HLBC
                                                                                                                                                                                                                        \Gamma_8/(\Gamma_1+\Gamma_2+\Gamma_7)
                                               ALEKSANYAN 64B FBC
                                188
  ^{
m 1}\,{\sf A\,MBROSINO} 06 enters the fit via their separate measurements of these two modes.
                                                                                                                                                                                                          TECN COMMENT
\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}
                                                                                                          \Gamma_7/\Gamma
                                                                                                                                 2.454 ± 0.011 OUR FIT Error includes scale factor of 1.3.
<u>VALUE</u> <u>0.1254±0.0005 OUR FIT</u> <u>EVTS</u>
                                                                                                                                 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                           TE CN
                                                   DOCUMENT ID
                                                                                                                                                               4200
                                                                                                                                                                           ^{1} MESSNER 73 ASPK \eta_{+-} = 2.23 \pm 0.05
0.1255 \pm 0.0006 OUR AVERAGE
                                                                                                                                    ^1 From same data as \Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0) MESSNER 73, but with different normal-
0.1263 \pm 0.0004 \pm 0.0011
                                                 <sup>1</sup> AMBROSINO 06
                                                                             KLOE
                                                 <sup>2</sup> ALEXOPOU... 04 KTEV
0.1252 \pm 0.0007
   ^1 There are correlations between these five KLOE measurements: B( K_L 
ightarrow \pi \, e \, \nu ), B( K_L 
ightarrow
                                                                                                                                 \Gamma(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)
     \pi\,\mu\,
u), B( K_L \to 3\pi^0 ), B( K_L \to \pi^+\,\pi^-\,\pi^0 ), and \tau\,K_I measured in AMBROSINO 06.
                                                                                                                                  Violates CP conservation.

VALUE (units 10<sup>-2</sup>) EVTS
                                                                                                                                                                                <u>DO CUMENT</u> ID
     See the footnote for the 	au_{\mathcal{K}_L} measurement for the correlation matrix.
                                                                                                                                                                                                          TECN COMMENT
                                                                                                                                                                 EVTS
                                                                                                                                 1.568±0.010 OUR FIT Error includes scale factor of 1.3.
   ^2\,\text{For correlations} with other ALEXOPOULOS 04 measurements, see the footnote with
                                                                                                                                 \bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
     their \mathrm{B}(\mathit{K}_L \to \pi \, e \, \nu) measurement.
                                                                                                                                                                4200
                                                                                                                                                                                MESSNER 73 ASPK \eta_{\perp} = 2.23
\Gamma(\pi^+\pi^-\pi^0)/\Gamma(\pi^\pm\,e^\mp\,\nu_e)
                                                                                                         \Gamma_7/\Gamma_1

    WALUE
    EVTS
    DOCUMENT ID

    0.3092±0.0016 OUR FIT
    Error includes scale factor of 1.1.

                                                                                                                                 \Gamma(\pi^0\pi^0)/\Gamma_{\rm total}
                                                                                                                                  Violates CP conservation.
VALUE (units 10^{-3})
\bullet \bullet \bullet We use the following data for averages but not for fits. 
 \bullet \bullet
                                                                                                                                                                                DO CUMENT ID
                                                <sup>1</sup> ALEXOPOU... 04 KTEV Not in fit
0.3078 \pm 0.0005 \pm 0.0017
                                   799K
                                                                                                                                  0.864 ± 0.006 OUR FIT Error includes scale factor of 1.8.
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                             1 ALEXOPOU... 04 KTEV
                                                                                                                                 0.865 \pm 0.012
                                                   KREUTZ
0.336 \pm 0.003 \pm 0.007
                                     28k
                                                                       95 NA 31
                                                                                                                                    <sup>1</sup> For correlations with other ALEXOPOULOS 04 measurements, see the footnote with
   <sup>1</sup> This measurement enters the fit via their separate measurements for the two modes.
                                                                                                                                      their B(K_L 
ightarrow \pi e \nu) measurement.
 \Gamma \big( \pi^+ \pi^- \pi^0 \big) / \big[ \Gamma \big( \pi^\pm e^\mp \nu_e \big) + \Gamma \big( \pi^\pm \mu^\mp \nu_\mu \big) + \Gamma \big( \pi^+ \pi^- \pi^0 \big) \big] \ \Gamma_7 / (\Gamma_1 + \Gamma_2 + \Gamma_7) 
                                                                                                                                 \Gamma(\pi^0\pi^0)/\Gamma(\pi^+\pi^-)
<u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

0.1565 ± 0.0006 OUR FIT Error includes scale factor of 1.1.
                                                                                                                                        Violates CP conservation.
                                                                                                                                                                                DOCUMENT ID
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                 0.4395 ± 0.0023 OUR FIT Error includes scale factor of 2.0.
0.163 \pm 0.003
                               6499
                                                                                                                                  0.4390 \pm 0.0012
                                                                                                                                                                                ETAFIT
0.1605 \pm 0.0038
                                               ALEXANDER 73B
                               1590
                                                                                                                                 \Gamma(\pi^0\pi^0)/\Gamma(3\pi^0)
0.146 \pm 0.004
                                3200
                                               BRANDENB... 73
                                                                                                                                 Violates CP conservation.

VALUE (units 10<sup>-2</sup>)

EV
0.159 \pm 0.010
                                 558
                                               EVANS
                                                                  73
                                                                         HLBC
                                               KULYUKINA
                                                                                                                                                                     EVTS
                                                                                                                                                                                     DOCUMENT ID
                                                                                                                                                                                                                TECN COMMENT
0.167 \pm 0.016
                               1402
                                                                  68
                                                                         CC
                                                                                                                                 0.443 ±0.004 OUR FIT Error includes scale factor of 2.1.
                                               HOPKINS
                                                                         нвс
0.161 \pm 0.005
                                                                  67
                                 126
                                               HAWKINS
                                                                         нвс
                                                                                                                                 • • • We use the following data for averages but not for fits. • • •
0.162 \pm 0.015
                                                                  66
0.159\ \pm0.015
                                 326
                                               ASTBURY
                                                                  65B CC
                                                                                                                                                                                  <sup>1</sup> ALEXOPOU... 04 KTEV Not in fit
                                                                                                                                 0.4446 ± 0.0016 ± 0.0019 100K
                                               GUIDONI
0.178 \pm 0.017
                                                                   65
                                                                         HBC
                                                                                                                                 \bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
0.144\ \pm0.004
                                               HOPKINS
                                                                  65 HBC
                                                                                   See HOPKINS 67
                               1729
                                                                                                                                 0.37\phantom{0}\pm0.08\phantom{0}
                                                                                                                                                                                     BARMIN
                                                                                                                                                                                                         70 HLBC \eta_{00}{=}2.02\pm0.23
                                                                                                                                                                         29
\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}
Violates CP conservation.
VALUE (units 10^{-3})
                                                                                                                                                                                                                HLBC \eta_{00} = 1.9 \pm 0.5
                                                                                                          \Gamma_8/\Gamma
                                                                                                                                 0.32 \pm 0.15
                                                                                                                                                                         30
                                                                                                                                                                                     BUDAGOV
                                                                                                                                                                                                         70
                                                                                                                                 0.46\phantom{0}\pm0.11\phantom{0}
                                                                                                                                                                         57
                                                                                                                                                                                     BANNER
                                                                                                                                                                                                         69 OSPK \eta_{00} = 2.2 \pm 0.3
                                               DO CUMENT ID
                                                                                                                                    ^{
m 1} This measurement enters the fit via their separate measurements for the two modes.
1.967±0.010 OUR FIT Error includes scale factor of 1.5.
1.975 \pm 0.012
                                            <sup>1</sup> ALEXOPOU... 04 KTEV

    Semileptonic modes with photons -

   ^{
m 1} For correlations with other ALEXOPOULOS 04 measurements, see the footnote with
     their B(K_L \to \pi e \nu) measurement.
                                                                                                                                 \Gamma(\pi^{\pm} e^{\mp} \nu_e \gamma) / \Gamma(\pi^{\pm} e^{\mp} \nu_e)
                                                                                                                                                                            DOCUMENT ID
                                                                                                                                                                                                       TECN COMMENT
\Gamma(\pi^+\pi^-)/\Gamma(\pi^{\pm}e^{\mp}\nu_e)
                                                                                                         \Gamma_8/\Gamma_1
                                                                                                                                 0.935 ± 0.015 OUR AVERAGE
                                                                                                                                                                        Error includes scale factor of 1.9. See the ideogram below.
TECN COMMENT
                                                                                                                                 0.924 \pm 0.023 \pm 0.016
                                                                                                                                                                          ^{1} AMBROSINO 08F KLOE E_{\gamma}^{*}>30 MeV, \theta_{e\,\gamma}^{*}>20^{\circ}
                                                                                                                                                                          <sup>2</sup> ALEXOPOU... 05
                                                                                                                                                                                                       KTEV E_{\gamma}^{*}>30 MeV, \theta_{e\gamma}^{*}>20°
4.840±0.020 OUR AVERAGE
                                                                                                                                 0.916 \pm 0.017
4.826 \pm 0.022 \pm 0.016
                               47k
                                           1 LAI
                                                                  07 NA48
                                                                                                                                 0.964 \pm 0.008 ^{+0.011}_{-0.009} 19K
                                                                                                                                                                                                05
                                                                                                                                                                                                       NA48 E_{\gamma}^* > 30 MeV, \theta_{e\gamma}^* > 20^{\circ}
\bullet \bullet \bullet We use the following data for averages but not for fits. 
 \bullet \bullet
                                          <sup>2</sup> ALEXOPOU... 04 KTEV Not in fit
                                                                                                                                                                            ALAVI-HARATI01J KTEV E_{\gamma}^* \geq 30 MeV, \theta_{e\,\gamma}^* \geq 20^\circ
4.856 \pm 0.017 \pm 0.023
                              84 k
                                                                                                                                 0.908 \pm 0.008 + 0.013 \atop -0.012 15 k
  ^1 The LAI 07 central value of 4.835 \times 10^{-3} has been reduced by 0.19% to 4.826 \times 10^{-3}
                                                                                                                                 0.934 \pm 0.036 ^{+0.055}_{-0.039} 1384
                                                                                                                                                                            LEBER
                                                                                                                                                                                                96 NA31 E_{\gamma}^* \geq 30 \text{ MeV}, \theta_{\rho\gamma}^* \geq 20^{\circ}
     to subtract the contribution from the direct emission mode K_I^{\hat{0}} \to \pi^+\pi^-\gamma({\sf DE}).
   <sup>2</sup>This measurement enters the fit via their separate measurements for the two modes.
                                                                                                                                    <sup>1</sup> Direct emission contribution measured \langle X \rangle = -2.3 \pm 1.3 \pm 1.4.
                                                                                                                                    <sup>2</sup> Also measured cut E_{\gamma}^* > 10 MeV, \theta_{e\gamma}^* > 0° 14221 evts: \Gamma(\pi^{\pm} e^{\mp} \nu_e \gamma) / \Gamma(\pi^{\pm} e^{\mp} \nu_e)
\left[\Gamma(\pi^{+}\pi^{-}) + \Gamma(\pi^{+}\pi^{-}\gamma(\mathsf{DE}))\right]/\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})
                                                                                              (\Gamma_8 + \Gamma_{14})/\Gamma_2
                                                                                                                                      = (4.942 \pm 0.062)\%
<sup>1</sup> AMBROSINO 06F KLOE
7.275 ±0.042±0.054 45 k
  ^1 Fully inclusive. Taking B(K_L^0 	o \pi \mu 
u) from KLOE, AMBROSINO 06, B(K_L^0 	o
     \pi^+\pi^- + \pi^+\pi^-\gamma({\sf DE})) = (1.963 \pm 0.012 \pm 0.017) 	imes 10^{-3} is obtained.
 \Gamma(\pi^{+}\pi^{-}) / \left[ \Gamma(\pi^{\pm}e^{\mp}\nu_{e}) + \Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu}) \right]  Violates CP conservation.
                                                                                               \Gamma_8/(\Gamma_1+\Gamma_2)
VALUE (units 10<sup>-3</sup>) EVTS DOCUMENT ID

2.909±0.013 OUR FIT Error includes scale factor of 1.3.
                                                                         TECN COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                               COUPAL
                                                                  85 SPEC \eta_{+-} = 2.28 \pm 0.06
3.13 \pm 0.14
                               1687
                               2703
                                              DEVOE
                                                                  77
                                                                         SPEC \eta_{+-}^{\cdot}=2.25 ± 0.05
3.04 \pm 0.14
```

 1 DEBOUARD 67 OSPK η_{+-}^{\cdot} = 2.00 \pm 0.09

67 OSPK η_{+-}^{\cdot} =1.94 ± 0.08

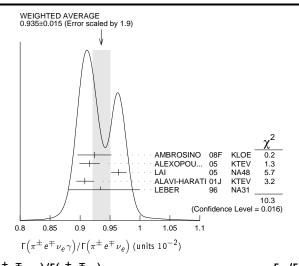
 2.51 ± 0.23

309

525

 $^{
m 1}$ FITCH

 1 Old experiments excluded from fit. See subsection on η_{+-} in section on "PARAMETERS FOR $\kappa_I^0 \to 2\pi$ DECAY" below for average η_{+-} of these experiments and for note on



| $I(\pi^+\mu^+\nu_\mu\gamma)/I(\pi^-$ | $^+\mu^+ u_\mu)$ | | | | I 11/I | |
|--------------------------------------|------------------|-----------------------|----|------|------------------------------------|--|
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.09±0.08 OUR AVER | AGE | | | | | |
| $2.09\!\pm\!0.09$ | | ¹ ALEXOPOU | 05 | KTEV | $E_{\gamma}^* > 30 \text{ MeV}$ | |
| $2.08 \pm 0.17 ^{+0.16}_{-0.21}$ | 25 2 | BENDER | 98 | NA48 | $E_{\gamma}^* \geq 30 \text{ MeV}$ | |

 1 Also measured cut E_{γ}^* >10 MeV, 1385 evts: $\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu}\gamma)~/~\Gamma(\pi^{\pm}\mu^{\mp}\nu_{\mu})=(0.530~\pm 0.00)$ $0.014 \pm 0.012)\%$

— Hadronic modes with photons or $\ell \overline{\ell}$ pairs —

| $\Gamma(\pi^0\pi^0\gamma)/\Gamma$ | total | | | | Γ ₁₂ /Γ |
|-----------------------------------|-------------|----------------------|-------|-------------|--------------------------------------------------------------------------|
| VALUE (units 10 | 6) CL% | DOCUMENT ID | | TECN | COMMENT |
| < 0.243 | 90 | ABOUZAID | 08в | KTEV | $K_L^0 \rightarrow \pi^0 \pi_D^0 \gamma, \pi_D^0 \rightarrow e e \gamma$ |
| • • • We do | not use the | following data for a | verag | es, fits, l | limits, etc. • • • |
| < 5.6 | 90 | BARR | 94 | NA 31 | |
| <230 | 90 | ROBERTS | 94 | E799 | |

 $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$ For earlier limits see our 1992 edition Physical Review **D45** S1 (1992). Γ_{13}/Γ_{7}

| VALUE (units 10^{-4}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|------------|------------------------|----------|-----------|---------------------------------|
| • • • We do not use | the follow | ving data for averag | es, fits | , limits, | etc. • • • |
| 1.23 ± 0.13 | 516 | ^{1,2} CARROLL | 80B | SPEC | $E_{\gamma}^* > 20 \text{ MeV}$ |
| $2.33 \!\pm\! 0.23$ | | ^{1,3} CARROLL | 80B | SPEC | , |
| 3.56 ± 0.26 | 1062 | ^{1,4} CARROLL | 80B | SPEC | $E_{\sim}^* > 20 \text{ MeV}$ |

- $^1\, {\rm CARROLL}$ 80B quotes ${\rm B}(\pi^+\,\pi^-\,\gamma)$ using normalization ${\rm B}(\pi^+\,\pi^-\,\pi^0) =$ 0.1239. We divide by this value to obtain their measured $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-\pi^0)$
- ²Internal Bremsstrahlung component only.
- 3 Direct γ emission component only.
- ⁴ Both IB and DE components.

| $\Gamma(\pi^+\pi^-\gamma)/\Gamma(\pi^+\pi^-)$ | | | Γ ₁₃ /Γ |
|-----------------------------------------------|------------------------------|---------|-----------------------------------|
| VALUE (units 10 ⁻²) EVTS | DO CUMENT ID | TECN | COMMENT |
| 2.11±0.08 OUR FIT Error inclu | ides scale factor of 2.9 | | |
| 2.11±0.08 OUR AVERAGE Err | or includes scale factor | of 2.9. | |
| $2.08 \pm 0.02 \pm 0.02$ 8669 | ¹ ALAVI-HARATI 01 | 3 KTEV | $E_{\infty}^{*} > 20 \text{ MeV}$ |
| $2.30 \pm 0.07 \hspace{1.5cm} 3136$ | RAMBERG 93 | E731 | $E_{\gamma}^{*} > 20 \text{ MeV}$ |

 $^{
m 1}$ ALAVI-HARATI 01B includes both Direct Emission (DE) and Inner Bremsstrahlung (IB) processes.

 $\Gamma(\pi^+\pi^-\gamma(DE))/\Gamma(\pi^+\pi^-\gamma)$ These values assume that $\Gamma(K_L^0 \to \pi^+\pi^-\gamma) = \Gamma(K_L^0 \to \pi^+\pi^-\gamma(DE)) + \Gamma(K_L^0 \to \pi^+\pi^-\gamma(DE))$

 $\pi^+\pi^-\gamma({\rm IB})$), the sum of widths for the direct emission (DE) and inner bremsstrahlung (IE) processes, with no IB-DE interference. DE assumes a form factor as described in RAMBERG 93

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.684 ± 0.009 OUR FIT | | | | | |
| 0.684 ± 0.009 OUR AVE | RAGE | | | | |
| 0.689 ± 0.021 | 111k | ABOUZAID | 06A | KTEV | $E_{\gamma}^* > 20 \text{ MeV}$ |
| 0.683 ± 0.011 | 8669 | ALAVI-HARAT | 01в | KTEV | $E_{\gamma}^{*} > 20 \text{ MeV}$ |
| 0.685 ± 0.041 | 3136 | RAMBERG | 93 | E731 | $E_{\gamma}^{*} > 20 \text{ MeV}$ |
| | $\begin{array}{c} \hline \textbf{0.684} \! \pm \! \textbf{0.009} \ \textbf{OUR} \ \textbf{FIT} \\ \textbf{0.684} \! \pm \! \textbf{0.009} \ \textbf{OUR} \ \textbf{AVE} \\ 0.689 \! \pm \! \textbf{0.021} \\ 0.683 \! \pm \! \textbf{0.011} \end{array}$ | 0.684±0.009 OUR FIT 0.684±0.009 OUR AVERAGE 0.689±0.021 111k 0.683±0.011 8669 | 0.684±0.009 OUR FIT 0.684±0.009 OUR AVERAGE 0.689±0.021 111k ABOUZAID 0.683±0.011 8669 ALAVI-HARAT | 0.684±0.009 OUR FIT 0.684±0.009 OUR AVERAGE 0.689±0.021 111k ABOUZAID 06A 0.683±0.011 8669 ALAVI-HARATI01B | 0.684±0.009 OUR FIT 0.684±0.009 OUR AVERAGE 0.689±0.021 111k ABOUZAID 06A KTEV 0.683±0.011 8669 ALAVI-HARATI 01B KTEV |

| $\Gamma(\pi^0 2\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₁₅ /Γ |
|--------------------------------------------|------------------------|-------------------------------|-------------------------------------------|-----------------|---------------------|-----------------------------------------------------|
| VALUE (units 10 ⁻⁶) | CL % | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1.273±0.033 OUR | AVERAG | iΕ | | | | |
| $1.28 \pm 0.06 \pm 0.0$ | 1 | 1.4k | ¹ ABOUZAID | 80 | KTEV | |
| $1.27 \pm 0.04 \pm 0.0$ | 1 | 2.5k | ² LAI | 02в | NA48 | |
| • • • We do not use | the follo | wing dat | a for averages, fits, | limits | , etc. • | • • |
| $1.68 \pm 0.07 \pm 0.0$ | 8 | 884 | 3 ALAVI-HARA | Г199в | KTEV | |
| $1.7 \pm 0.2 \pm 0.2$ | | 63 | ⁴ BARR | 92 | NA 31 | |
| $1.86 \pm 0.60 \pm 0.6$ | 0 | 60 | PAPA DIMIT R | 91 | E731 | $m_{\gamma\gamma} > 280 \text{ MeV}$ |
| < 5.1 | 90 | | PAPADIMITR | 91 | E731 | $m_{\gamma\gamma} < 264 \text{ MeV}$ |
| 2.1 ± 0.6 | | 14 | ⁵ BARR | 90 c | NA 31 | $m_{\gamma\gamma}^{\prime\prime} > 280 \text{ MeV}$ |
| ¹ ABOUZAID 08 re | eports (1.: | 29 ± 0.0 | $3 \pm 0.05) \times 10^{-6}$ | from a | measur | rement of $[\Gamma(K_I^0 \rightarrow$ |
| | | | | | | $.69 \pm 0.04) \times 10^{-4}$, |
| which we rescale | to our bes | st value l | $3(K_L^0 \to \pi^0 \pi^0) =$ | (8.64 | ± 0.06 | $)	imes10^{-4}$. Our first |
| error is their expe | eriment's | error and | our second error i | sthes | systema | tic error from using |
| 21 Al O2B roports | rr/ 1/20 . | -0 201) | /r 1/rp/w ⁰ | 0 | 0_0,1_ | : (1.467 ± 0.032 ± |
| 0.000 10-3 | lı (v ^r → | n 2.7) | / totall / [D(NL | → 7i | ")] — | (1.407 ± 0.032 ± |
| | | | | | | $)=(8.64\pm0.06)\times$ |
| | | | | | | or is the systematic |
| error from using | our best | value. | They also find tha | t B(π' | $^{0}2\gamma$, m | $\gamma\gamma$ <110 MeV) < |
| $0.6 \times 10^{-8} (90\%$ | | | | | | |
| ³ ALAVI-HARATI 9 | 99B finds t | hat Γ(π ⁽ | $^{0}2\gamma$, $m_{\gamma\gamma}$ <240 M | leV)) / | $\Gamma(\pi^{0})$ | γ) = (17.3 \pm 1.3 \pm |
| 1.5)%. Supersede | d by ABO | DUZAID | 08. | | | |
| ⁴ BARR 92 find th | at Γ(π ⁰ 2- | γ , $m_{\gamma\gamma}$ | $<$ 240 MeV)/ $\Gamma(\pi^0$ | 2γ) < 0 | 0.09 (90 |)% CL). |
| ⁵ BARR 90c supers | | | | | , | * |
| 300 bupon | | | | | | |

 $\Gamma(\pi^0 \gamma e^+ e^-)/\Gamma_{
m total}$ Γ_{16}/Γ VALUE (units 10⁻⁸) <u>CL%</u> EVTS DOCUMENT ID ¹ ABOUZAID 07D KTEV $1.62 \pm 0.14 \pm 0.09$ 125

• • • We do not use the following data for averages, fits, limits, etc. • • • $2.34 \pm 0.35 \pm 0.13$ ALAVI-HARATI 01E KTEV 44 MURAKAMI 99 SPEC 0

 $^{1}\,\mathrm{ABOUZAID}$ 07D includes 1997 (ALAVI-HARATI 01E) and 1999 data. It measures the ratio of B($K_L^0 \to \pi^0 \gamma e^+ e^-$) / B($K_L^0 \to \pi^0 \pi_D^0$), where π_D^0 is the Dalitz decaying π^0 , and uses PDG 06 values B($K_L^0 \to \pi^0 \pi^0$) = (8.69 ± 0.04) × 10⁻⁴, and B($\pi_D^0 \to \pi^0 \pi^0$) $e^+\,e^-\,\gamma)=(1.198\pm0.032) imes10^{-2}.$ Supersedes ALAVI-HARATI 01E result.

- Other modes with photons or $\ell \overline{\ell}$ pairs -

| $\Gamma(2\gamma)/\Gamma_{\text{total}}$ | | | | | Γ ₁₇ /Γ |
|-----------------------------------------|----------------|------------------------|----------|-----------|--------------------------------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 5.47±0.04 OUR FIT | Error inclu | ides scale factor o | f 1.1. | | |
| • • • We do not use | e the followin | ng data for averag | es, fits | , limits, | etc. • • • |
| 4.54±0.84 | | ¹ BANNER | 72B | OSPK | |
| 4.5 ±1.0 | 23 | ENSTROM | 71 | OSP K | K ⁰ ₁ 1.5−9 GeV/c |
| 5.0 ±1.0 | | ² REPELLIN | 71 | OSPK | _ |
| 5.5 ±1.1 | 90 | KUNZ | 68 | OSPK | Norm.to 3 π (C+N) |
| | | $= 1.05 \pm 0.14$. In | genera | , Γ (2γ)/ | $\Gamma_{total} = [(4.32 \pm 0.55) \times$ |
| 10^{-4}] [(η_{00}/η_{+} | $_{-})^{2}].$ | | | | |
| ² Assumes regener | ation amplitu | ide in copper at 2 | 2 GeV | s 22 mb | . To evaluate for a given |

| regenerat | on amplitude and error, multiply by (regeneration amplitude/22mb |) ² . |
|-----------------------------------|------------------------------------------------------------------|------------------------|
| $\Gamma(2\gamma)/\Gamma(3\gamma)$ | r ⁰) | Γ_{17}/Γ_6 |

| . (=1)/. () | | | | | | . 11/ |
|---------------------------------|----------------|-------------------|----------|-----------|--------------|-------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID |) | TECN | COMMENT | |
| 2.802±0.017 OUR F | IT. | | | | | |
| 2.802±0.018 OUR A | VERAGE | | | | | |
| $2.79 \pm 0.02 \pm 0.02$ | 27k | ADINOLFI | 03 | KLOE | | |
| $2.81 \pm 0.01 \pm 0.02$ | | LAI | 03 | NA48 | | |
| • • • We do not us | e the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| 2.13 ± 0.43 | 28 | BARMIN | 71 | HLBC | | |
| 2.24 ± 0.28 | 115 | BANNER | 69 | OSP K | | |
| 25 +07 | 16 | ARNOLD | 68B | HLBC | Vacuum decav | |

$\Gamma(2\gamma)/\Gamma(\pi^0\pi^0)$ Γ_{17}/Γ_{9} <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> **0.633±0.006 OUR FIT** Error includes scale factor of 1.4

| $0.632 \pm 0.004 \pm 0.008$ | 110k | BURKHARDT 87 | NA 31 |
|-------------------------------------|------|--------------|-------------|
| $\Gamma(3\gamma)/\Gamma_{ m total}$ | | | |
| VALUE | CL% | DO CUMENT ID | <u>TECN</u> |

 Γ_{18}/Γ <7.4 × 10⁻⁸ $^{
m 1}$ TUNG 90 11 K391 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 90 ² BARR 95 C NA 31

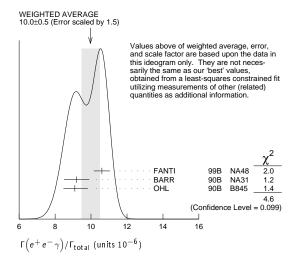
 $^{^{1}}$ TUNG 11 reports the result assuming parity violating interaction and using 2005 data (Run-II and III). Assuming parity conserving or phase space interaction, the 90% upper limits obtained are 7.5 $\times10^{-8}$ and 8.6 $\times10^{-8}$, respectively.

 $^{^2\,\}mbox{Assumes}$ a phase-space decay distribution.

93B B791

| $\Gamma(e^+e^-\gamma)/\Gamma_{ m total}$ | | | | | Γ ₁₉ /Γ |
|------------------------------------------|---------------|--------------------|-----------|------------|--------------------|
| VALUE (units 10 ⁻⁶) | EVTS | DO CUMENT | ID | TECN | |
| 9.4±0.4 OUR FIT | Error include | es scale factor | of 2.0. | | |
| 10.0±0.5 OUR AVER | AGE Error | includes scale | factor of | 1.5. See t | he ideogram below. |
| $10.6 \pm 0.2 \pm 0.4$ | 6864 | ¹ FANTI | 99B | NA48 | |
| $9.2 \pm 0.5 \pm 0.5$ | 1053 | BARR | 90в | NA 31 | |
| $9.1 \pm 0.4 + 0.6 \\ -0.5$ | 919 | OHL | 90в | B845 | |

 1 For FANTI 99B, the ± 0.4 systematic error includes for uncertainties in the calculation, primarily uncertainties in the π^0 \rightarrow $\,e^+\,e^-\,\gamma$ and $\,\kappa^0_L$ \rightarrow $\,\pi^0\,\pi^0$ branching ratios, evaluations, $e^+\,e^-\,\gamma$ uated using our 1999 Web edition values.



| $\Gamma(e^+e^-\gamma)/\Gamma(3\pi^0$ | ') | | | Γ19/Γ6 |
|--------------------------------------|-------------|-----------------------|----------|--------|
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | TECN | |
| 4.82±0.21 OUR FIT | Error inclu | des scale factor of 2 | .0. | |
| 46210041012 | 0.214 | 1 ABOUZAID (| 17p KTEV | |

 $^1\,\mathrm{ABOUZAID}$ 07B reports $[\Gamma\left(\kappa^0_L\ \rightarrow\ e^+\,e^-\,\gamma\right)/\Gamma\left(\kappa^0_L\ \rightarrow\ 3\pi^0\right)]\ /\ [3\Gamma\left(\pi^0\ \rightarrow\ 2\gamma\right)/\Gamma\left(\kappa^0_L\ \rightarrow\ 3\pi^0\right)]$ $\Gamma_{\text{total}} \times \Gamma(\pi^0 \to e^+e^-\gamma)/\Gamma_{\text{total}}] = (1.3302 \pm 0.0046 \pm 0.0103) \times 10^{-3} \text{ which we multiply by our best value } 3\Gamma(\pi^0 \to 2\gamma)/\Gamma_{\text{total}} \times \Gamma(\pi^0 \to e^+e^-\gamma)/\Gamma_{\text{total}} = 0.0348 \pm 0.0010. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value.}$

| $\Gamma(\mu^+\mu^-\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂₀ /Γ |
|----------------------------------------------|----------|-------------------|--------|---------|--------------------|
| VALUE (units 10 ⁻⁷) | EVTS | DOCUMENT ID |) | TECN | |
| 3.59±0.11 OUR AVE | RAGE Err | or includes scale | factor | of 1.3. | |
| $3.62 \pm 0.04 \pm 0.08$ | 9100 | ALAVI-HARA | TI01G | KTEV | |
| $3.4 \pm 0.6 \pm 0.4$ | 45 | FA NTI | 97 | NA48 | |
| $3.23 \pm 0.23 \pm 0.19$ | 197 | SPENCER | 95 | E799 | |

| $\Gamma(e^+e^-\gamma\gamma)/\Gamma_{\rm total}$ | | | | | | Γ ₂₁ /Γ |
|---------------------------------------------------------|------|--------------|-------|-------|-------------------------------------|--------------------|
| VALUE (units 10 ⁻⁷) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 5.95±0.33 OUR AVER | AGE | | | | | |
| $5.84 \pm 0.15 \pm 0.32$ | 1543 | ALAVI-HARA | TI01F | KTEV | $E_{\gamma}^* > 5 \text{ MeV}$ | |
| 8.0 $\pm 1.5 \begin{array}{c} +1.4 \\ -1.2 \end{array}$ | 40 | SETZU | 98 | NA 31 | $E_{\gamma}^{*} > 5 \text{ MeV}$ | |
| $6.5\ \pm 1.2\ \pm 0.6$ | 58 | NAKAYA | 94 | E799 | $E_{\gamma}^* > 5 \text{ MeV}$ | |
| $6.6\ \pm3.2$ | | MORSE | 92 | B845 | $E_{\gamma}^{'}>$ 5 MeV | |
| $\Gamma(\mu^+\mu^-\gamma\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₂₂ /Γ |
| VALUE (units 10 ⁻⁹) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $10.4^{+7.5}_{-5.9}\pm0.7$ | 4 | ALAVI-HARA | TI00E | KTEV | $m_{\gamma\gamma} \geq 1~{ m MeV}/$ | c^2 |

- Charge conjugation imes Parity (CP) or Lepton Family number (LF) -— violating modes, or $\Delta S = 1$ weak neutral current (S1) modes

| VALUE (units 10 ⁻⁶) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|--------------|----------------------|----------|------------|---------------|
| 3.48 ±0.05 OUR | AVERAGE | | | | |
| 3.474 ± 0.057 | 6210 | AMBROSE | 00 | B 871 | |
| 3.87 ± 0.30 | 179 | ¹ AKAGI | 95 | SPEC | |
| 3.38 ± 0.17 | 707 | HEINSON | 95 | B 791 | |
| • • • We do not us | e the follow | ing data for avera | ges, fit | s, limits, | etc. • • • |
| 3.9 ±0.3 ±0.1 | 178 | ² AKAGI | | | In AKAGI 95 |
| $3.45 \pm 0.18 \pm 0.13$ | 368 | ³ HEINSON | 91 | SPEC | In HEINSON 95 |
| 4.1 ±0.5 | 54 | INAGAKI | 89 | | In AKAGI 91B |
| $2.8 \pm 0.3 \pm 0.2$ | 87 | MATHIAZHA | 89в | SPEC | In HEINSON 91 |

| ¹ AKAGI | 95 | gives | this | number | multiplied | by | the | PDG | 1992 | average | for | Γ(<i>K</i> _L ⁰ | \rightarrow |
|---------------------|------|-------|------|--------|------------|----|-----|------|------|---------|-----|---------------------------------------|---------------|
| $\pi^{+}\pi^{-}$ | | | | | | | | | | | | | |
| ² A KAGI | 91 F | give | this | number | multiplied | by | the | 1990 | PDG | average | for | $\Gamma(K^0)$ | \rightarrow |

 $\pi^+\pi^-)/\Gamma(total)$.

HEINSON 91 give $\Gamma(K_L^0 o \mu \mu)/\Gamma_{ ext{total}}$. We divide out the $\Gamma(K_L^0 o \pi^+ \pi^-)/\Gamma_{ ext{total}}$ PDG average which they used.

Test for $\Delta S=1$ weak neutral current. Allowed by higher-order electroweak interaction. VALUE (units 10^{-10}) CL% EVTS DOCUMENT ID TECN 0.087 + 0.057A MBROSE 98 B871 4

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 90 <1.6 1 A KA GI 95 SPEC $^{1}\,\mathrm{A}\,\mathrm{RISA}\,\mathrm{KA}$ 90

 1 ARISAKA 93B includes all events with <6 MeV radiated energy.

 $\Gamma(\pi^+\pi^-e^+e^-)/\Gamma_{total} \\ \text{Test for } \Delta \mathcal{S}=1 \text{ weak neutral current. Allowed by higher-order electroweak interaction.}$ Γ_{25}/Γ

| VALUE (units 10 ⁻⁷) | CL% EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|--------------------|---------------------|-----------|----------|------------|
| 3.11 ± 0.19 OUR | AVERAGE | · | | | |
| $3.08 \pm 0.09 \pm 0.18$ | 1125 | 1 LAI | 03c | NA48 | |
| $3.2 \pm 0.6 \pm 0.4$ | 37 | ADAMS | 98 | KTEV | |
| $4.4 \pm 1.3 \pm 0.5$ | 13 | TAKEUCHI | 98 | SPEC | |
| • • • We do not us | se the following d | ata for averages, f | its, limi | ts, etc. | • • • |
| < A 6 | 0.0 | NOMEDA | 0.7 | CDEC | m > 4 MoV/ |

NOMURA 97 SPEC $m_{e\,e} > 4~{
m MeV}$ 1 LAI 03c second error is 0.15(syst) \pm 0.10(norm) combined in quadrature. The normalization uses BR(K $_L$ \to $\pi^+\pi^-\pi^0$) * BR(π^0 \to e^+e^-) = (1.505 \pm 0.047) \times 10 $^{-3}$ from our 2000 Edition.

 Γ_{26}/Γ

90 ALAVI-HARATI 02c E799 < 6.6

 $\Gamma(\pi^0\pi^0\pi^0\mu^+\mu^-)/\Gamma_{total}$ Test for $\Delta S=1$ weak neutral current. Allowed by higher-order electroweak interaction.

DO CUMENT ID TECN CL% ABOUZAID 11A E799 90

 1 ABOUZAID 11A also reports B(K $_I^0$ ightarrow $\pi^0\pi^0$ X 0 ightarrow $\pi^0\pi^0$ μ^+ μ^-) < 1.0 imes 10 $^{-10}$ at 90% C.L., where the x^0 is a possible new neutral boson that was reported by PARK 05 with a mass of 214.3 \pm 0.5 MeV/c².

 $\Gamma(\mu^+\mu^-e^+e^-)/\Gamma_{\rm total}$ Γ_{28}/Γ Test for $\Delta S=1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10⁻⁹) EVTS DOCUMENT ID TECN COMMENT 2.69 ± 0.27 OUR AVERAGE ¹ ALAVI-HARATI 03B KTEV $2.69 \pm 0.24 \pm 0.12$ 131 $2.9 \begin{array}{c} +6.7 \\ -2.4 \end{array}$ 1 • • • We do not use the following data for averages, fits, limits, etc. • • • ALAVI-HARATI 01H KTEV Sup. by ALAVI-HARATI 03B

BALATS 83 SPEC

 1 ALAVI-HARATI 03B also measures the linear slope $lpha = -1.59 \pm 0.37$.

 $\begin{array}{c} \Gamma(e^+e^-e^+e^-)/\Gamma_{total} & \Gamma_{29}/\Gamma \\ \text{Test for } \Delta S=1 \text{ weak neutral current. Allowed by higher-order electroweak interaction.} \end{array}$

DOCUMENT ID TECN COMMENT 3.56±0.21 OUR AVERAGE 1 LAI $3.30 \pm 0.24 \pm 0.25$ 200 05B NA48 ALAVI-HARATI 01D KTEV $3.72 \pm 0.18 \pm 0.23$ 441 $3.96 \pm 0.78 \pm 0.32$ 27 GU VAGINS $3.07 \pm 1.25 \pm 0.26$ • • • We do not use the following data for averages, fits, limits, etc. • • •

² AKAGI 6 ± 2 ± 1 18 95 SPEC $m_{e\,e} >$ 470 MeV ² AKAGI $7 \pm 3 \pm 2$ 95 SPEC $m_{e\,e} > 470 \; \mathrm{MeV}$ 3 BARR $10.4 \pm 3.7 \pm 1.1$ 8 95 NA 31 93 CNTR Sup. by AKAGI 95 $6 \pm 2 \pm 1$ 18 AKAGI BARR 91 NA31 Sup. by BARR 95 4 +3 2

 1 LAI 05B uses 1998 and 1999 data. Data are normalized to the observed events of $K_I^0
ightarrow$ $\pi^+\pi^-\pi^0$ (π^0 into Dalitz pair) and PDG 04 values are used for B($K_L^0 \to \pi^+\pi^-\pi^0$) and B($\pi^0 \to e^+ e^- \gamma$). The systematic error includes a normalization error of ± 0.10 . 2 Values are for the total branching fraction, acceptance-corrected for the $\it m_{
m ee}$ cuts shown. 3 Distribution of angles between two e^+e^- pair planes favors $extit{CP}{=}-1$ for $extit{K}^0_L$

 $\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{\rm total}$ Violates CP in leading order. Test for $\Delta S=1$ weak neutral current. Allowed by higher-order electroweak interaction.

VALUE (units 10⁻⁹) CL% EVTS DO CUMENT ID ALAVI-HARATIOOD KTEV 90 • • • We do not use the following data for averages, fits, limits, etc. • • • 90 0 HARRIS 93 E799

 K_I^0

| $\Gamma(\pi^0 e^+ e^-)/\Gamma_{\text{total}}$ Γ_{31}/Γ |
|--------------------------------------------------------------------------------------------------|
| Violates CP in leading order. Direct and indirect CP-violating contributions are ex- |
| pected to be comparable and to dominate the CP-conserving part. LAI 02B result |
| suggests that <i>CP</i> -violation effects dominate. Test for $\Delta S=1$ weak neutral current. |
| Allowed by higher-order electroweak interaction. |

| VALUE (units 10 ⁻¹⁰) | CL% EVTS | DOCUMENT ID | TECN | COMMENT |
|---------------------------------------|---------------|----------------------------|-----------------|--------------------|
| < 2.8 | 90 | ¹ ALAVI-HARATI | 04A KTEV | combined result |
| ● ● We do not use | the following | g data for averages, fits, | , limits, etc. | • • • |
| < 3.5 | 90 | ALAVI-HARATI | 04A KTEV | |
| $0.0047 {}^{+ 0.0022}_{- 0.0018}$ | | ² LAI | 02в NA48 | CP-conserving part |
| < 5.1 | 90 2 | ALAVI-HARATI | 01 KTEV | |
| 0.01 to 0.02 | | ALAVI-HARATI | 99B KTEV | CP-conserving part |
| < 43 | 90 0 | HARRIS | 93B E799 | |
| < 75 | 90 0 | BARKER | 90 E731 | |
| < 55 | 90 0 | OHL | 90 B845 | |
| < 400 | 90 | BARR | 88 NA31 | |
| <3200 | 90 | JASTRZEM | 88 SPEC | |

¹ Combined result of ALAVI-HARATI 04A 1999-2000 data set and ALAVI-HARATI 01 1997 data set.

 $\Gamma(\pi^0 \nu \overline{
u})/\Gamma_{total}$ Γ_{32}/Γ Violates CP in leading order. Test of direct CP violation since the indirect CP-violating and CP-conserving contributions are expected to be suppressed. Test of $\Delta S=1$ weak

| VALU | /E (units 10 ⁻⁷) | CL% | DO CUMENT | ID | TECN | | |
|------|---------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| < | 0.26 | 90 | ¹ AHN | 10 | K391 | | |
| • • | We do not | use the following | data for aver | ages, fits, | limits, etc. | • • • | |
| < | 0.67 | 90 | ² AHN | 08 | K391 | | |
| < | 2.1 | 90 | ³ AHN | 06 | K391 | | |
| < | 5.9 | 90 | ALAVI-HAF | RATI00 | KTEV | | |
| < | 16 | 90 | ADAMS | 99 | KTEV | | |
| < 5 | 80 | 90 | WEAVER | 94 | E799 | | |
| <22 | :00 | 90 | GRAHAM | 92 | CNTR | | |
| | < < < < < < < < < < < < < < < < < < < | 0.26 • • • We do not 0.67 2.1 | 0.26 90 • • • We do not use the following < 0.67 90 < 2.1 90 < 5.9 90 < 16 90 < 580 90 | ✓ 0.26 90 1 AHN • • • We do not use the following data for aver < | ✓ 0.26 90 1 AHN 10 • • • We do not use the following data for averages, fits, < | 0.26 90 1 AHN 10 K391 • • • We do not use the following data for averages, fits, limits, etc. < 0.67 | 0.26 90 1 AHN 10 K391 • • • We do not use the following data for averages, fits, limits, etc. • • • < 0.67 |

¹ Obtained combining Run-2 (AHN 08) and Run-3 data.

³ Value obtained analyzing 10% of data of RUN 1 (performed in 2004).

| $\Gamma(\pi^0\pi^0 u\overline{ u})/\Gamma_{ m total}$ | | | | | Γ_{33}/Γ |
|-------------------------------------------------------|-----------|--------------------|---------|----------------------|----------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | |
| <8.1 × 10 ⁻⁷ | 90 | ¹ OGATA | 11 | K391 | |
| • • • We do not use the | following | data for average | s, fits | , limits, etc. • • • | |
| $<4.7 \times 10^{-5}$ | 90 | ² NIX | 07 | K391 | |

ı

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{\text{total}}$ Test of lepton family number conservation.

| $VALUE$ (units 10^{-11}) | CL% | EVTS | DO CUMENT ID | | TECN |
|---------------------------------|--------|-------------|----------------------|---------|--------------------|
| <0.47 | 90 | | AMBROSE | 98B | B871 |
| ● ● We do not | use th | e following | data for averages | , fits, | limits, etc. • • • |
| < 9.4 | 90 | 0 | AKAGI | 95 | SPEC |
| < 3.9 | 90 | 0 | ARISAKA | 93 | B791 |
| < 3.3 | 90 | 0 | ¹ ARISAKA | 93 | B791 |
| | | | | | |

 $^{
m 1}$ This is the combined result of ARISAKA 93 and MATHIAZHAGAN 89.

| $\Gamma(e^{\pm}e^{\pm}\mu^{\mp}\mu^{\mp})/\Gamma_{\text{total}}$ | Γ ₃₅ / Γ |
|------------------------------------------------------------------|---------------------|
| Test of lepton family number conservation. | |

| 1 | VALUE | $(units 10^{-11})$ | CL% E | VTS | DO CUMENT ID | | TECN | COMMENT |
|---|-------|--------------------|---------|-----------|-------------------|-----------|-------------|----------------|
| | < 4 | 1.12 | 90 | 0 | ALAVI-HARA | Г103в | KTEV | |
| • | • • • | We do not | use the | following | data for average | es, fits, | , limits, e | etc. • • • |
| | < 12 | 2.3 | 90 | 0 | 1 ALAVI-HARA | ГІ01н | KTEV | Sup. by ALAVI- |
| | <610 |) | 90 | 0 | ¹ GU | 96 | E799 | HARATI 03B |

¹ Assuming uniform phase space distribution.

| $\Gamma(\pi^0\pi^0\mu^{\pm}e^{\mp})/\Gamma_{to}$ Test of lepton fa | otal amily numb | er conservation. | | | Γ ₃₇ /Γ |
|--------------------------------------------------------------------|--------------------|------------------|-----|------|--------------------|
| VALUE (units 10 ⁻¹⁰) | CL% | DO CUMENT ID | | TECN | |
| <1.7 | 90 | ABOUZAID | 08c | KTEV | |

$V_{ud}, V_{us}, \text{THE CABIBBO ANGLE},$ AND CKM UNITARITY

Updated March 2012 by E. Blucher (Univ. of Chicago) and W.J. Marciano (BNL)

The Cabibbo-Kobayashi-Maskawa (CKM) [1,2] three-generation quark mixing matrix written in terms of the Wolfenstein parameters (λ, A, ρ, η) [3] nicely illustrates the orthonormality constraint of unitarity and central role played by λ .

$$V_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$= \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4) \ . \ (1)$$

That cornerstone is a carryover from the two-generation Cabibbo angle, $\lambda = \sin(\theta_{\text{Cabibbo}}) = V_{us}$. Its value is a critical ingredient in determinations of the other parameters and in tests of CKM unitarity.

Unfortunately, the precise value of λ has been somewhat controversial in the past, with kaon decays suggesting [4] $\lambda \simeq 0.220$, while hyperon decays [5] and indirect determinations via nuclear β -decays imply a somewhat larger $\lambda \simeq 0.225-0.230$. That discrepancy is often discussed in terms of a deviation from the unitarity requirement

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1. (2)$$

For many years, using a value of V_{us} derived from $K \to \pi e \nu$ (K_{e3}) decays, that sum was consistently 2–2.5 sigma below unity, a potential signal [6] for new physics effects. Below, we discuss the current status of V_{ud} , V_{us} , and their associated unitarity test in Eq. (2). (Since $|V_{ub}|^2 \simeq 1 \times 10^{-5}$ is negligibly small, it is ignored in this discussion.)

V_{ud}

The value of V_{ud} has been obtained from superallowed nuclear, neutron, and pion decays. Currently, the most precise determination of V_{ud} comes from superallowed nuclear beta-decays [6] $(0^+ \to 0^+$ transitions). Measuring their half-lives, t, and Q values which give the decay rate factor, f, leads to a precise determination of V_{ud} via the master formula [7–9]

$$|V_{ud}|^2 = \frac{2984.48(5)\sec}{ft(1+RC)}$$
 (3)

where RC denotes the entire effect of electroweak radiative corrections, nuclear structure, and isospin violating nuclear effects. RC is nucleus-dependent, ranging from about +3.0% to +3.6% for the best measured superallowed decays. The most recent analysis of Hardy and Towner [10, 11] gives a weighted average (with errors combined in quadrature) of

$$V_{ud} = 0.97425(22)$$
 (superallowed), (4)

data set. 2 LAI 02B uses the absence of a signal in $K_L^0 \to \pi^0 \gamma \gamma$ with $m(\gamma \gamma) < m(\pi^0)$ and their a_V value to predict this value.

² Value obtained using data from February to April 2005.

 $^{^1}$ Using 2005 Run-I data. OGATA 11 also sets a limit on the $K_L^0 \to \pi^0\pi^0 X \to \text{invisible}$ particles process: the limit on the branching fraction varied from 7.0×10^{-7} to 4.0×10^{-5} for the mass of X ranging from 50 to 200 MeV/c².

 $^{^2}$ Observed 1 event with expected background of 0.43 \pm 0.35 events. NIX 07 also measured B(K $_0^1 \rightarrow \pi^0 \pi^0 P) < 1.2 \times 10^{-6}$ at 90% CL, where P is the pseudoscalar particle and $m_P < 100$ MeV.

which, assuming unitarity, corresponds to $\lambda = 0.2255(10)$. The new average value of V_{ud} is shifted upward compared to our 2007 value of 0.97418(27) primarily because of improvements in the experimental ft values and nuclear isospin breaking corrections employed. We note, however, that the possibility of additional nuclear coulombic corrections has been raised recently [12].

Combined measurements of the neutron lifetime, τ_n , and the ratio of axial-vector/vector couplings, $g_A \equiv G_A/G_V$, via neutron decay asymmetries can also be used to determine V_{ud} :

$$|V_{ud}|^2 = \frac{4908.7(1.9) \text{ sec}}{\tau_n (1+3q_A^2)},$$
 (5)

where the error stems from uncertainties in the electroweak radiative corrections [8] due to hadronic loop effects. Those effects have been recently updated and their error was reduced by about a factor of 2 [9], leading to a ± 0.0002 theoretical uncertainty in V_{ud} (common to all V_{ud} extractions). Using the world averages from this Review

$$\tau_n^{\text{ave}} = 880.1(1.1) \text{ sec}$$

$$g_A^{\text{ave}} = 1.2701(25) \tag{6}$$

leads to

$$V_{ud} = 0.9773(6)_{\tau_n}(16)_{q_A}(2)_{RC}$$
 (7)

with the error dominated by g_A uncertainties (which have been expanded due to experimental inconsistencies). The new shorter neutron lifetime average (since the last review) now leads to a value of V_{ud} that is inconsistent with the superallowed nuclear beta decay result in Eq. (4). That disagreement suggests that a shift of g_A to about 1.275 (consistent with more modern day measurements [14]) is likely. Future neutron studies are expected to resolve these inconsistencies and significantly reduce the uncertainties in g_A and τ_n , potentially making them the best way to determine V_{ud} .

The recently completed PIBETA experiment at PSI measured the very small $(\mathcal{O}(10^{-8}))$ branching ratio for $\pi^+ \to \pi^0 e^+ \nu_e$ with about $\pm 1/2\%$ precision. Their result gives [15]

$$V_{ud} = 0.9749(26) \left[\frac{BR(\pi^+ \to e^+ \nu_e(\gamma))}{1.2352 \times 10^{-4}} \right]^{\frac{1}{2}}$$
 (8)

which is normalized using the very precisely determined theoretical prediction for $BR(\pi^+ \to e^+\nu_e(\gamma)) = 1.2352(5) \times 10^{-4}$ [7], rather than the experimental branching ratio from this *Review* of $1.230(4)\times10^{-4}$ which would lower the value to $V_{ud}=0.9728(30)$. Theoretical uncertainties in that determination are very small; however, much higher statistics would be required to make this approach competitive with others.

V_{us}

 $|V_{us}|$ may be determined from kaon decays, hyperon decays, and tau decays. Previous determinations have most often used $K\ell 3$ decays:

$$\Gamma_{K\ell3} = \frac{G_F^2 M_K^5}{192\pi^3} S_{EW} (1 + \delta_K^{\ell} + \delta_{SU2}) C^2 |V_{us}|^2 f_+^2(0) I_K^{\ell}.$$
 (9)

Here, ℓ refers to either e or μ , G_F is the Fermi constant, M_K is the kaon mass, S_{EW} is the short-distance radiative correction, δ_K^{ℓ} is the mode-dependent long-distance radiative correction, $f_{+}(0)$ is the calculated form factor at zero momentum transfer for the $\ell\nu$ system, and I_K^{ℓ} is the phase-space integral, which depends on measured semileptonic form factors. For charged kaon decays, δ_{SU2} is the deviation from one of the ratio of $f_{+}(0)$ for the charged to neutral kaon decay; it is zero for the neutral kaon. C^2 is 1 (1/2) for neutral (charged) kaon decays. Most determinations of $|V_{us}|$ have been based only on $K \to \pi e \nu$ decays; $K \to \pi \mu \nu$ decays have not been used because of large uncertainties in I_K^{μ} . The experimental measurements are the semileptonic decay widths (based on the semileptonic branching fractions and lifetime) and form factors (allowing calculation of the phase space integrals). Theory is needed for S_{EW} , δ_K^{ℓ} , δ_{SU2} , and $f_+(0)$.

Many new measurements during the last few years have resulted in a significant shift in V_{us} . Most importantly, recent measurements of the $K \to \pi e \nu$ branching fractions are significantly different than earlier PDG averages, probably as a result of inadequate treatment of radiation in older experiments. This effect was first observed by BNL E865 [16] in the charged kaon system and then by KTeV [17,18] in the neutral kaon system; subsequent measurements were made by KLOE [19-22], NA48 [23-25], and ISTRA+ [26]. Current averages (e.g., by the PDG [27] or Flavianet [28]) of the semileptonic branching fractions are based only on recent, highstatistics experiments where the treatment of radiation is clear. In addition to measurements of branching fractions, new measurements of lifetimes [29] and form factors [30–34], resulted in improved precision for all of the experimental inputs to V_{us} . Precise measurements of form factors for $K_{\mu3}$ decay now make it possible to use both semileptonic decay modes to extract V_{us} .

Following the analysis of the Flavianet group [28], one finds the values of $|V_{us}|f_+(0)$ in Table 1. The average of these measurements gives

$$f_{+}(0)|V_{us}| = 0.21664(48). (10)$$

Figure 1 shows a comparison of these results with the PDG evaluation from 2002 [35], as well as $f_+(0)(1-|V_{ud}|^2-|V_{ub}|^2)^{1/2}$, the expectation for $f_+(0)|V_{us}|$ assuming unitarity, based on $|V_{ud}|=0.9742\pm0.0003,\ |V_{ub}|=(3.6\pm0.7)\times10^{-3}$, and the lattice calculation of $f_+(0)=0.9644\pm0.0049$ [36](Lattice calculations of $f_+(0)$ have improved significantly in recent years, and therefore replace the classic calculation of Leutwyler and Roos [37].) Combining the result in Eq. (10) with the above value of $f_+(0)$ gives

$$|V_{us}| = \lambda = 0.2246 \pm 0.0012. \tag{11}$$

Table 1: $|V_{us}|f_+(0)$ from $K_{\ell 3}$.

| Decay Mode | $ V_{us} f_+(0)$ |
|----------------|---------------------|
| $K^{\pm}e3$ | 0.2173 ± 0.0008 |
| $K^{\pm}\mu 3$ | 0.2176 ± 0.0011 |
| K_Le3 | 0.2163 ± 0.0006 |
| $K_L\mu 3$ | 0.2168 ± 0.0007 |
| K_Se3 | 0.2154 ± 0.0013 |
| Average | 0.2166 ± 0.0005 |

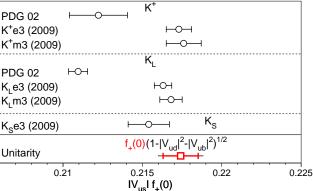


Figure 1: Comparison of determinations of $|V_{us}|f_+(0)$ from this review (labeled 2009), from the PDG 2002, and with the prediction from unitarity using $|V_{ud}|$ and the lattice calculation of $f_+(0)$ [36]. For $f_+(0)(1-|V_{ud}|^2-|V_{ub}|^2)^{1/2}$, the inner error bars are from the quoted uncertainty in $f_+(0)$; the total uncertainties include the $|V_{ud}|$ and $|V_{ub}|$ errors.

A value of V_{us} can also be obtained from a comparison of the radiative inclusive decay rates for $K \to \mu\nu(\gamma)$ and $\pi \to \mu\nu(\gamma)$ combined with a lattice gauge theory calculation of f_K/f_π via [42]

$$\frac{|V_{us}|f_K}{|V_{ud}|f_\pi} = 0.2387(4) \left[\frac{\Gamma(K \to \mu\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))} \right]^{\frac{1}{2}}$$
(12)

with the small error coming from electroweak radiative corrections. Employing

$$\frac{\Gamma(K \to \mu\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))} = 1.3337(46),\tag{13}$$

which averages in the KLOE result [43], $B(K \to \mu\nu(\gamma)) = 63.66(9)(15)\%$ and [44]

$$f_K/f_{\pi} = 1.189(7)$$
 (14)

along with the value of V_{ud} in Eq. (4) leads to

$$|V_{us}| = 0.2259(5)(13). (15)$$

It should be mentioned that hyperon decay fits suggest [5]

$$|V_{us}| = 0.2250(27)$$
 Hyperon Decays (16)

modulo SU(3) breaking effects that could shift that value up or down. We note that a recent representative effort [45] that incorporates SU(3) breaking found $V_{us} = 0.226(5)$. Similarly, inclusive strangeness changing tau decays give [46]

$$|V_{us}| = 0.2208(34)$$
 Tau Decays (17)

where the central value depends on the strange quark mass. However, a recent BaBar study [47] of $\tau \to K\nu/\tau \to \pi\nu$ using the lattice value of f_K/f_π from Eq. (14) finds $V_{us}=0.2255(24)$, in good agreement with other determinations.

Employing the value of V_{ud} in Eq. (4) and $V_{us} = 0.2252(9)$, the average of the $K\ell 3$ (Eq. (11)) and $K\mu 2$ (Eq. (15) determinations of V_{us} , leads to the unitarity consistency check

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(4)(4).$$
(18)

where the first error is the uncertainty from $|V_{ud}|^2$ and the second error is the uncertainty from $|V_{us}|^2$.

CKM Unitarity Constraints

The current good experimental agreement with unitarity, $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9999(6)$, provides strong confirmation of Standard Model radiative corrections (which range between 3-4% depending on the nucleus used) at better than the 50 sigma level [48]. In addition, it implies constraints on "New Physics" effects at both the tree and quantum loop levels. Those effects could be in the form of contributions to nuclear beta decays, K decays and/or muon decays, with the last of these providing normalization via the muon lifetime [49], which is used to obtain the Fermi constant, $G_{\mu} = 1.166371(6) \times 10^{-5} \mathrm{GeV}^{-2}$.

In the following sections, we illustrate the implications of CKM unitarity for (1) exotic muon decays [50](beyond ordinary muon decay $\mu^+ \to e^+ \nu_e \bar{\nu}_\mu$) and (2) new heavy quark mixing V_{uD} [51]. Other examples in the literature [52,53] include Z_χ boson quantum loop effects, supersymmetry, leptoquarks, compositeness etc.

Exotic Muon Decays

If additional lepton flavor violating decays such as $\mu^+ \to e^+ \bar{\nu}_e \nu_\mu$ (wrong neutrinos) occur, they would cause confusion in searches for neutrino oscillations at, for example, muon storage rings/neutrino factories or other neutrino sources from muon decays. Calling the rate for all such decays Γ (exotic μ decays), they should be subtracted before the extraction of G_μ and normalization of the CKM matrix. Since that is not done and unitarity works, one has (at one-sided 95% CL)

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 - BR(\text{exotic } \mu \text{ decays}) \ge 0.9989$$
(19)

or

$$BR(\text{exotic } \mu \text{ decays}) < 0.001$$
. (20)

This bound is a factor of 10 better than the direct experimental bound on $\mu^+ \to e^+ \bar{\nu}_e \nu_\mu$.

New Heavy Quark Mixing

Heavy D quarks naturally occur in fourth quark generation models and some heavy quark "new physics" scenarios such as E_6 grand unification. Their mixing with ordinary quarks gives rise to V_{ud} which is constrained by unitarity (one sided 95% CL)

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 - |V_{uD}|^2 > 0.9989$$

$$|V_{uD}| < 0.03.$$
(21)

A similar constraint applies to heavy neutrino mixing and the couplings $V_{\mu N}$ and $V_{e N}$.

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ENERGY DEPENDENCE OF K_i^0 DALITZ PLOT

For discussion, see note on Dalitz plot parameters in the \mathcal{K}^\pm section of the Particle Listings above. For definitions of a_V , a_t , a_t , a_u , and a_y , see the earlier version of the same note in the 1982 edition of this *Review* published in Physics Letters 111B 70 (1982).

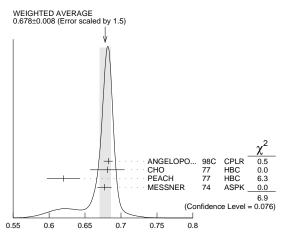
 $|{\rm matrix\ element}|^2=1+gu+hu^2+jv+kv^2+fuv$ where $u=(s_3-s_0)$ / m_π^2 and $v=(s_2-s_1)$ / m_π^2

LINEAR COEFFICIENT g FOR $K_{I}^{0} \rightarrow \pi^{+}\pi^{-}\pi^{0}$

| | | 5 | • | | |
|--------------------------------|----------|-------------------------|---------|-----------|-----------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.678 ±0.008 OUR AV | ERAGE | Error includes scal | e fact | or of 1.5 | See the ideogram |
| below. | | | | | |
| $0.6823 \pm 0.0044 \pm 0.0044$ | 500k | ANGELOPO | 98 c | CPLR | |
| 0.681 ± 0.024 | 6499 | СНО | 77 | HBC | |
| 0.620 ± 0.023 | 4709 | PEACH | 77 | HBC | |
| 0.677 ± 0.010 | 509k | MESSNER | 74 | ASPK | $a_V = -0.917 \pm 0.013$ |
| • • • We do not use the | followin | g data for averages, | , fits, | limits, e | tc. • • • |
| 0.69 ± 0.07 | 192 | ¹ BALDO | 75 | HLBC | |
| $0.590~\pm0.022$ | 56k | ¹ BUCHANAN | 75 | SPEC | $a_{II} = -0.277 \pm 0.010$ |
| 0.619 ± 0.027 | 20k | 1,2 BISI | 74 | ASPK | $a_t = -0.282 \pm 0.011$ |
| 0.612 ± 0.032 | | ¹ ALEXANDER | | HBC | |
| 0.73 ± 0.04 | 3200 | ¹ BRANDENB | 73 | HBC | |
| 0.608 ± 0.043 | 1486 | ¹ KRENZ | 72 | HLBC | $a_t = -0.277 \pm 0.018$ |
| 0.650 ± 0.012 | 29k | ¹ ALBROW | 70 | ASPK | $a_V = -0.858 \pm 0.015$ |
| $0.593~\pm0.022$ | 36k | ^{1,3} BUCHANAN | 70 | SPEC | $a_{II} = -0.278 \pm 0.010$ |
| 0.664 ± 0.056 | 4400 | $^{ m 1}$ SMITH | 70 | OSP K | $a_t = -0.306 \pm 0.024$ |
| $0.400\ \pm 0.045$ | 2446 | ¹ BASILE | | OSP K | $a_t = -0.188 \pm 0.020$ |
| 0.649 ± 0.044 | 1350 | ¹ HOPKINS | 67 | нвс | $a_t = -0.294 \pm 0.018$ |
| 0.428 ± 0.055 | 1198 | ¹ NEFKENS | 67 | OSP K | $a_{U} = -0.204 \pm 0.025$ |
| 1 | | | | | |

 $^{^1}$ Quadratic dependence required by some experiments. (See sections on "QUADRATIC COEFFICIENT h" and "QUADRATIC COEFFICIENT k" below.) Correlations prevent us from averaging results of fits not including $g,\ h,$ and k terms.

³BUCHANAN 70 result revised by BUCHANAN 75 to include radiative correlations and to use more reliable K_L^0 momentum spectrum of second experiment (had same beam).



Linear coeff. g for $K_L^0 \to \pi^+\pi^-\pi^0$ matrix element squared

QUADRATIC COEFFICIENT h FOR $K_L^0 \rightarrow \pi^+\pi^-\pi^0$

| | | - | | |
|------------------------------------------|---------------|-------------------|---------|------------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | <u>TECN</u> |
| 0.076 ± 0.006 OUR AV | ERAGE | | | |
| $0.061 \pm 0.004 \pm 0.015$ | 500k | A NGEL OP O | 98c | CPLR |
| 0.095 ± 0.032 | 6499 | CHO | 77 | HBC |
| 0.048 ± 0.036 | 4709 | PEACH | 77 | HBC |
| 0.079 ± 0.007 | 509k | MESSNER | 74 | ASPK |
| ● ● We do not use th | e following o | data for averages | , fits, | , limits, etc. • • • |
| -0.011 ± 0.018 | 29k 1 | ALBROW | 70 | ASPK |
| 0.043 ± 0.052 | 4400 1 | SMITH | 70 | OSPK |
| | | COEFFICIENT | g F | OR $K_L^0 \rightarrow \pi^+\pi^-\pi^0$ MATRIX |
| ELEMENT 2" abo | ove. | | | |

 $^{^1}$ Quadratic coefficients h and k required by some experiments. (See section on "QUADRATIC COEFFICIENT k" below.) Correlations prevent us from averaging results of fits not including $g,\ h,$ and k terms.

QUADRATIC COEFFICIENT k FOR $K_L^0 \to \pi^+\pi^-\pi^0$

| VALUE | EVTS | DO CUMENT ID | | TECN |
|--------------------------------|-------|--------------|------|------|
| 0.0099±0.0015 OUR AVE | RAGE | | | |
| $0.0104 \pm 0.0017 \pm 0.0024$ | 5 00k | ANGELOPO | 98 c | CPLR |
| 0.024 ± 0.010 | 6499 | СНО | 77 | HBC |
| -0.008 ± 0.012 | 4709 | PEACH | 77 | HBC |
| 0.0097 ± 0.0018 | 5.09k | MESSNER | 74 | ASPK |

LINEAR COEFFICIENT j FOR $K_L^0 \to \, \pi^+\pi^-\pi^0$ (CP-VIOLATING TERM)

QUADRATIC COEFFICIENT f FOR $K_L^0 o \pi^+ \pi^- \pi^0$ (CP-VIOLATING TERM)

Listed in *CP*-violation section below.

QUADRATIC COEFFICIENT h FOR $K_L^0 \to \pi^0\pi^0\pi^0$ No average is computed because not all measurements included the effect of final state

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | |
|---------------------------------|-------|-------------------------|-----|-------|--|
| $+0.59\pm0.20\pm1.16$ | 6.8M | ¹ ABOUZAID | 08A | KTEV | |
| $-6.1 \pm 0.9 \pm 0.5$ | 14.7M | ² LAI | 01B | NA 48 | |
| $-3.3 \pm 1.1 \pm 0.7$ | 5 M | ^{2,3} SOMALWAR | 92 | E731 | |

 1 Result obtained using CI3pI model of CABIBBO 05 to include $\pi\pi$ rescattering effects. The systematic error includes an external error of 1.06×10^{-3} from the parametrization input of (a_0-a_2) $m_{\pi^+}=0.268\pm0.017$ from BATLEY 06B.

 2 LAI 01B and SOMALWAR 92 results do not include $\pi\pi$ final state rescattering effects. 3 SOMALWAR 92 chose m_{π^+} as normalization to make it compatible with the Particle Data Group $K_L^0\to~\pi^+\pi^-\pi^0$ definitions.

K⁰_L FORM FACTORS

For discussion, see note on form factors in the K^{\pm} section of the Particle

In the form factor comments, the following symbols are used.

 f_{\perp} and f_{\perp} are form factors for the vector matrix element.

 f_S and f_T refer to the scalar and tensor term.

$$f_0(t) = f_+(t) + f_-(t) t/(m_{K^0}^2 - m_{\pi^+}^2).$$

t= momentum transfer to the $\pi.$

 λ_+ and λ_0 are the linear expansion coefficients of f_+ and f_0

$$f_{+}(t) = f_{+}(0) \left(1 + \lambda_{+} t / m_{\pi^{+}}^{2}\right)$$

For quadratic expansion

$$f_{+}(t) = f_{+}(0) \left(1 + \lambda'_{+} t / m_{\pi^{+}}^{2} + \frac{\lambda''_{+}}{2} t^{2} / m_{\pi^{+}}^{4}\right)$$

as used by KTeV. If there is a non-vanishing quadratic term, then λ_{\pm}

represents an average slope, which is then different from λ'_{+} .

NA48 (
$$K_{e3}$$
) and ISTRA quadratic expansion coefficients are converted with $\lambda'_{+}{}^{PDG} = \lambda_{+}{}^{NA48}$ and $\lambda''_{+}{}^{PDG} = 2 \, \lambda'_{+}{}^{NA48}$ $\lambda''_{+}{}^{PDG} = (\frac{m_{\,\pi^{+}}}{m_{\,0}})^{2} \, \lambda_{+}{}^{ISTRA}$ and $\lambda''_{+}{}^{PDG} = 2 \, (\frac{m_{\,\pi^{+}}}{m_{\,\pi^{0}}})^{4} \, \lambda'_{+}{}^{ISTRA}$

ISTRA linear expansion coefficients are converted with $\lambda_{+}^{PDG}=(\frac{m_{\pi^{+}}}{m_{\pi^{0}}})^{2}~\lambda_{+}^{~ISTRA}$ and $\lambda_{0}^{~PDG}=(\frac{m_{\pi^{+}}}{m_{\pi^{0}}})^{2}~\lambda_{0}^{~ISTRA}$

The pole parametrization is

$$f_{+}(t) = f_{+}(0) \left(\frac{M_{V}^{2}}{M_{V}^{2} - t} \right)$$

$$f_{0}(t) = f_{0}(0) \left(\frac{M_{S}^{2}}{M_{S}^{2} - t} \right)$$

where M_{V} and M_{S} are the vector and scalar pole masses.

The dispersive parametrization is

$$\begin{split} f_+(t) &= f_+(0) \, \exp[\,\frac{t}{m_\pi^2} \, (A_+ \, + \, H(t)) \,\,]; \\ f_0(t) &= f_+(0) \, \exp[\,\frac{t}{m_K^2 - m_\pi^2} \, (\ln[\,C] \, - \, G(\,t)) \,\,], \end{split}$$

where Λ_+ is the slope parameter and $\ln[{\it C}\,] = \ln[\,{\it f}_0\,(m_K^2\,-\,m_\pi^2\,)\,]$

is the logarithm of the scalar form factor at the Callan-Treiman point

H(t) and G(t) are dispersive integrals

The following abbreviations are used:

DP = Dalitz plot analysis.

 $PI = \pi$ spectrum analysis.

 $MU = \mu$ spectrum analysis.

 $\mathsf{POL} = \mu$ polarization analysis.

BR = $K_{\mu 3}^0/K_{e3}^0$ branching ratio analysis.

 $\mathsf{E} \, = \mathsf{positron} \, \, \mathsf{or} \, \, \mathsf{electron} \, \, \mathsf{spectrum} \, \, \mathsf{analysis}.$ RC = radiative corrections.

 λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN K^0_{03} DECAY)

For radiative correction of K^0_{03} DP, see GINSBERG 67, BECHERRAWY 70, CIRIGLIANO 02, CIRIGLIANO 04, and ANDRE 07. Results labeled OUR FIT are discussed in the review " $K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" in the K^\pm Listings. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters B592 1 (2004)

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | TECN | COMMENT |
|---------------------------------|---------------|------------------------|---------|--------------------|
| 2.82 ±0.04 OUR FIT | Error include | s scale factor of 1.1. | Assumin | g μ-e universality |
| 2.85 ±0.04 OUR AVE | RAGE | | | |
| $2.86 \pm 0.05 \pm 0.04$ | 2 M | AMBROSINO 06D | KLOE | |
| $2.832 \pm 0.037 \pm 0.043$ | 1.9M | ALEXOPOU 04A | KTEV | PI, no $\mu=e$ |
| $2.88 \ \pm 0.04 \ \pm 0.11$ | 5.6M | ¹ LAI 04c | NA48 | DP |

² BISI 74 value comes from quadratic fit with quad. term consistent with zero. *g* error is thus larger than if linear fit were used.

| ● ● We do not use | the following da | ita for averages, | fits, lir | nits, etc | |
|---------------------------------------|------------------|-------------------|-----------|-----------|----|
| $2.84 \pm 0.07 \pm 0.13$ | 5.6 M | ² LAI | 04c | NA48 | DP |
| $2.45 \pm 0.12 \pm 0.22$ | 366k | APOSTOLA | . 00 | CPLR | DP |
| 3.06 ± 0.34 | 74 k | BIRULEV | 81 | SPEC | DP |
| 3.12 ± 0.25 | 500k | GJESDAL | 76 | SPEC | DP |
| 2.70 ± 0.28 | 25 k | BLUMENTHA | AL 75 | SPEC | DP |
| | | | | | |

 $\frac{1}{2}$ Results from linear fit and assuming only vector and axial couplings.

λ_+ (LINEAR ENERGY DEPENDENCE OF f_+ IN $K_{\mu3}^0$ DECAY)

Results labeled OUR FIT are discussed in the review " $\kappa_{\ell 3}^{\pm}$ and $\kappa_{\ell 3}^{0}$ Form Factors" in the ${\it K}^{\pm}$ Listings. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters B592 1 (2004).

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|-------------|-------------------|----------|-----------|--------------------------|
| 2.82 ±0.04 OUR FIT | Error incl | udes scale factor | of 1.1 | Assum | ning μ-e universality |
| 2.71 ±0.10 OUR FIT | Error incl | udes scale factor | of 1.4 | . Not as | ssuming μ-e universality |
| $2.67 \pm 0.06 \pm 0.08$ | 2.3M | ¹ LAI | 07A | NA48 | DP |
| $2.745 \pm 0.088 \pm 0.063$ | 1.5 M | ALEXOP OU | 04A | KTEV | DP, no $\mu=e$ |
| 2.813 ± 0.051 | 3.4 M | ALEXOP OU | 04A | KTEV | PI, DP, $\mu = e$ |
| 3.0 ±0.3 | 1.6 M | DONALDSON | 74B | SPEC | DP |
| ● ● We do not use th | e following | data for average | s, fits, | limits, e | etc. • • • |
| 4.27 ± 0.44 | 150k | BIRULEV | 81 | SPEC | DP |

 $^{^1}$ LAI 07A gives a correlation - 0.40 between their λ_0 and λ_+ measurements.

 λ_0 (LINEAR ENERGY DEPENDENCE OF f_0 IN $K_{\mu3}^0$ DECAY) Wherever possible, we have converted the above values of $\xi(0)$ into values of λ_0 using the associated λ_+^μ and $d\xi(0)/d\lambda_+$. Results labeled OUR FIT are discussed in the review " $K_{\ell 3}^\pm$ and " $K_{\ell 3}^0$ Form Factors" in the K^\pm Listings. For earlier, lower statistics results, see the 2004 edition of this review, Physics Letters **B592** 1 (2004).

| $VALUE$ (units 10^{-2}) | $d\lambda_0/d\lambda_+$ | EVTS | DO CUMENT ID | TECN | COMMENT |
|----------------------------|-------------------------|------------|-------------------------|----------------|-----------------------|
| 1.38 ±0.18 OU | R FIT Erro | r includes | scale factor of 2.2. | Assuming μ | <i>e</i> universality |
| 1.42 ±0.23 OU | R FIT Erro | r includes | scale factor of 2.8. | Not assumin | ng μ-e universal- |
| ity | | | | | |
| $1.17 \pm 0.07 \pm 0$ | .10 | 2.3 M | 1 LAI | | |
| 1.657 ± 0.125 | -0.44 | 1.5 M | ² ALEXOPOU | | |
| 1.635 ± 0.121 | -0.85 | 3.4 M | | | |
| $+1.9 \pm 0.4$ | -0.47 | 1.6 M | ⁴ DONALDSON | 74B SPEC | DP |
| | ise the follow | ing data | for averages, fits, lir | nits, etc. 🔸 🔸 | • |
| 2 41 1 0 67 | unknouen | 15 01 | 5 DIDILIEV | 01 CDEC | DD |

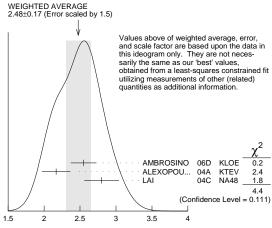
 $^{^1}$ LAI 07A gives a correlation -0.40 between their λ_0 and λ_+ measurements.

λ'_{+} (LINEAR K_{e3}^{0} FORM FACTOR FROM QUADRATIC FIT)

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------|--------------------------|---------|---------|---------------------------------|
| 2.40 ±0.12 OUR FIT | Error | includes scale factor of | of 1.2. | Assum | ing μ-e universality |
| 2.49 ±0.13 OUR FIT | Error | includes scale factor of | of 1.1. | Not as | suming μ - e universality |
| 2.48 ±0.17 OUR AVE | RAGE | Error includes scale | factor | of 1.5. | See the ideogram below |
| $2.55 \pm 0.15 \pm 0.10$ | 2M | | | | |
| $2.167 \pm 0.137 \pm 0.143$ | 1.9M | | 04A | KTEV | PI, no $\mu=e$ |
| $2.80 \pm 0.19 \pm 0.15$ | 5.6M | ³ LAI | 04c | NA48 | DP |

 $^{^1}$ We use AMBROSINO 06D result in the fit not assuming $\mu - e$ universality. This result enters the fit assuming $\mu-e$ universality via AMBROSINO 07c measurement of λ'_+ in $\kappa_{\mu3}$ decays. AMBROSINO 06D gives a correlation -0.95 between their λ'_+ and λ''_+ . 2 ALEXOPOULOS 04A gives a correlation -0.97 between their λ'_+ and λ''_+

 $^{^3}$ For LAI 04C we calculate a correlation - 0.88 between their λ'_{+} and λ''_{+} .

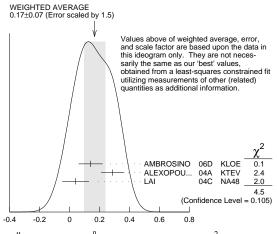


 λ'_{+} (LINEAR κ_{e3}^{0} FORM FACTOR FROM QUADRATIC FIT) (units 10^{-2})

λ''_{+} (QUADRATIC K_{e3}^{0} FORM FACTOR)

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------|------------------------|---------|---------|-------------------------|
| 0.20 ±0.05 OUR FIT | Error | includes scale factor | of 1.2. | Assum | ing μ-e universality |
| 0.16 ±0.05 OUR FIT | Error | includes scale factor | of 1.1. | Not as | suming μ-e universality |
| 0.17 ±0.07 OUR AVE | RAGE | Error includes scale | factor | of 1.5. | See the ideogram below. |
| $0.14 \pm 0.07 \pm 0.04$ | 2 M | ¹ AMBROSINO | | | |
| $0.287 \pm 0.057 \pm 0.053$ | 1.9 M | | 04A | KTEV | PI, no $\mu=e$ |
| $0.04 \pm 0.08 \pm 0.04$ | 5.6M | 3,4 LAI | 04c | NA 48 | DP |

1 We use AMBROSINO 06D result in the fit not assuming $\mu-e$ universality. This result enters the fit assuming $\mu-e$ universality via AMBROSINO 07c measurement of $\lambda''_{\ +}$ in Chiefs the Hi assuming $\mu-e$ universality via AMBROSINO 07c measurement of λ''_+ in $K_{\mu3}$ decays. AMBROSINO 06b gives a correlation -0.95 between their λ'_+ and λ''_+ . ALEXOPOLIL OS 04a gives a correlation -0.95 between their λ'_+ and λ''_+ .



 λ''_{+} (QUADRATIC κ_{e3}^{0} FORM FACTOR) (units 10^{-2})

λ'_{+} (LINEAR $K^{0}_{\mu3}$ FORM FACTOR FROM QUADRATIC FIT)

| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID TECN COMMENT |
|-----------------------------|------------|--------------------------------------------------------------|
| 2.40 ±0.12 OUR FIT | Error incl | ludes scale factor of 1.2. Assuming μ - e universality |
| 1.89 ±0.24 OUR FIT | | ming $\mu	ext{-}e$ universality |
| $2.23 \pm 0.98 \pm 0.37$ | | 1 AMBROSINO 07c KLOE no $\mu=e$ |
| $2.56 \pm 0.15 \pm 0.09$ | | AMBROSINO 07c KLOE $\mu=e$ |
| $2.05 \pm 0.22 \pm 0.24$ | | ¹ LAI 07A NA48 DP |
| $1.703 \pm 0.319 \pm 0.177$ | 1.5 M | 1 ALEXOPOU 04A KTEV DP, no $\mu=e$ |
| 2.064 ± 0.175 | 3.4 M | 1 ALEXOPOU 04A KTEV PI, DP, $\mu=e$ |
| | | |

¹ See section λ_0 below for correlations.

λ''_{+} (QUADRATIC $K_{\mu 3}^{0}$ FORM FACTOR)

0.63

-0.73

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|----------|------------------------|--------|---------|------------------------------------|
| 0.20 ±0.05 OUR FIT | Error | includes scale factor | of 1.2 | Assun | ning μ-e universality |
| 0.37 ±0.12 OUR FIT | Error | includes scale factor | of 1.3 | . Not a | ssuming $\mu	ext{-}e$ universality |
| $0.48 \pm 0.49 \pm 0.16$ | | ¹ AMBROSINO | | | |
| $0.15 \pm 0.07 \pm 0.04$ | 3.8M | ¹ AMBROSINO | | | |
| $0.26 \pm 0.09 \pm 0.10$ | 2.3 M | ¹ LAI | | | |
| $0.443 \pm 0.131 \pm 0.072$ | 1.5 M | ¹ ALEXOP OU | | | |
| 0.320 ± 0.069 | 3.4 M | ¹ ALEXOP OU | 04A | KTEV | PI, DP, $\mu=e$ |
| 1 See section λ_0 below | w for co | orrelations. | | | |

$\lambda_a(I)NFAR f_a K^0$. FORM FACTOR FROM QUADRATIC FIT)

| λ ₀ (LINEAR t ₀ K _μ s | 3 FORM | FACTOR FROM | /I QUA | DKA | IIC FII) |
|--------------------------------------------------------|--------------------|------------------------------|----------|-----------|----------------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.16 ±0.09 OUR FIT | Error ii | ncludes scale factor | of 1.2. | Assum | ing μ-e universality |
| 1.07 ±0.14 OUR FIT | Error i | ncludes scale factor | of 1.3. | Not as | ssuming μ – e universality |
| $0.91 \pm 0.59 \pm 0.26$ | 1.8M | ¹ AMBROSINO | | | |
| $1.54 \pm 0.18 \pm 0.13$ | 3.8 M | ² AMBROSINO | | | |
| $0.95 \pm 0.11 \pm 0.08$ | | | | | |
| $1.281 \pm 0.136 \pm 0.122$ | 1.5 M | ⁴ ALEXOPOU | 04A | KTEV | DP, no $\mu = e$ |
| 1.372 ± 0.131 | 3.4 M | ⁵ ALEXOPOU | 04A | KTEV | PI, DP, $\mu=e$ |
| ¹ AMBROSINO 07c, | not assur | ning μ – e universalit | y, gives | a corre | elation matrix |
| | λ'_{\perp} | λ'''_{\pm} | | | |
| λ''_{+} - λ_{0} | - 0.97 | 1 | | | |
| λ_0 | 0.81 | -0.91 | | | |
| ² AMBROSINO 07c, | assuming | μ -e universality, g | ves a co | orrelatio | on matrix |
| | λ'_{+} | λ''_{+} | | | |
| λ''_{+} - λ_{0} | - 0.95 | 1 | | | |
| λ_0 | 0.29 | -0.38 | | | |
| ³ LAI 07A gives a cor | relation n | natrix | | | |
| | λ'_+ | λ''_{\pm} | | | |
| | 0.06 | | | | |

 $^{^2\,\}mathrm{Results}$ from linear fit with $\left|f_S/f_+\right|$ and $\left|f_T/f_+\right|$ free.

 $^{^2\,\}mathrm{ALEXOP}\,\mathrm{OULOS}$ 04A gives a correlation - 0.38 between their λ_0 and λ_+ measurements.

 $^{^3}$ ALEXOPOULOS 04A gives a correlation - 0.36 between their λ_0 and λ_+ measurements.

 $^{^4}$ DONALDSON 74B $d\lambda_0/d\lambda_+$ obtained from figure 18.

 $^{^5}$ BIRULEV 81 gives $d\lambda_0/d\lambda_+=-1.5$, giving an unreasonably narrow error ellipse which dominates all other results. We use $d\lambda_0/d\lambda_+=0$.

²ALEXOPOULOS 04A gives a correlation -0.97 between their λ'_+ and λ''_+ .

 $^{^3}$ Values doubled to agree with PDG conventions described above. 4 LAI 04c gives a correlation -0.88 between their λ'_+ and $\lambda''_+.$

 4 ALEXOPOULOS 04A, not assuming $\mu\text{-}e$ universality, gives a correlation matrix λ'_+ 1 λ'''_+ -0.961 0.65 -0.75⁵ ALEXOPOULOS 04A, assuming μ -e universality, gives a correlation matrix $\lambda'_+ \lambda''_+ \lambda''_+ \lambda_0$ λ'_+

1 -0.971 0.34 -0.44

M_V^e (POLE MASS FOR K_{e3}^0 DECAY)

| VALUE (MeV) | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------|--------------|-------|-----------------------|-------|----------|-------------------------------|
| 878 ± 6 | OUR FIT | Error | includes scale factor | of 1. | 1. Assur | ming μ - e universality |
| 875 ± 5 | OUR AV | ERAGE | | | | |
| 870 ± 6 | ± 7 | 2M | AMBROSINO | 06D | KLOE | |
| 881.03± 5.1 | 2 ± 4.94 | 1.9M | ALEXOP OU | 04A | KTEV | PI, no $\mu=e$ |
| 859 ± 18 | | 5.6M | LAI | 04c | NA48 | |

M_V^{μ} (POLE MASS FOR $K_{\mu 3}^0$ DECAY)

| VALUE | E (MeV) | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------|--------------|---------------|----------------|-----------------------|---------|----------|-----------------------------------|
| 878 | ± 6 | OUR FI | T Error | includes scale facto | or of 1 | .1. Assu | ming μ - e universality |
| 900 | ±21 | OUR FI | T Error | includes scale facto | or of 1 | .7. Not | assuming μ - e universality |
| | | | | 1 LAI | | | |
| 889.1 | 9 ± 12.8 | 31 ± 9.92 | 1.5 M | ¹ ALEXOPOU | | | |
| 882.3 | 2± 6.5 | 4 | 3.4 M | ¹ ALEXOPOU | . 04A | KTEV | PI, DP, $\mu=e$ |

 $^{^1}$ See section M_S^μ below for correlations.

M_S^{μ} (POLE MASS FOR $K_{\mu 3}^0$ DECAY)

| - | | | | | - | | | | | | |
|--------|---------------|---------------|-----|-------|-----------------|---------|-------|---------|-----|------|--------------------------------|
| VALUE | (MeV) | | E١ | /TS | DO | CUMENT | T ID | | TE | CN_ | COMMENT |
| 1252 | ±90 | OUR FI | T | Error | include | s scale | facto | or of 2 | .6. | Assı | iming μ - e universality |
| 1222 | ±80 | OUR FI | Т | Error | include | s scale | facto | or of 2 | .3. | Not | assuming μ - e univers |
| ity | | | | | | | | | | | ٠, |
| 1400 | ± 46 | ± 53 | 2.3 | 3M | 1 LA | | | 07A | NΑ | 48 | DP |
| 1167.1 | 4 ± 28.30 | 0 ± 31.04 | 1.5 | δM | ² AL | EXOP | DU | 04A | ΚT | EV | PI, no $\mu=e$ |
| 1173.8 | 0 ± 39.47 | 7 | 3.4 | 4 M | ³ AL | EXOP | DU | 04A | ΚT | EV | PI, DP, $\mu=e$ |
| | | | | | | | | | | | |

 $^{^1}$ LAI 07A gives a correlation - 0.47 between their M_S^μ and M_V^μ measurements, not assuming $\mu\text{-}e$ universality.

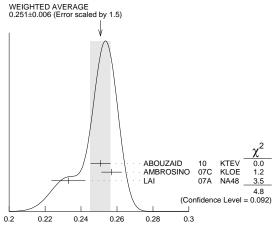
Λ_+ (DISPERSIVE VECTOR FORM FACTOR FOR $K_{\mu 3}^0$ DECAY)

See the review on " $K^\pm_{\ell 3}$ and $K^0_{\ell 3}$ Form Factors" for details of the dispersive parametrization.

| VALUE (units 10^{-1}) | EVTS | DO CUMENT ID | TECN | COMMENT |
|--------------------------------|-------|------------------------|----------------|------------------|
| 0.251 ±0.006 OUR AVE | RAGE | Error includes scale t | factor of 1.5. | See the ideogram |
| below. | | | | |
| $0.2509 \pm 0.0035 \pm 0.0043$ | 3.4 M | ¹ ABOUZAID | | |
| $0.257 \pm 0.004 \pm 0.004$ | 3.8 M | ² AMBROSINO | 07c KLOE | $\mu = e$ |
| $0.233 \pm 0.005 \pm 0.008$ | 2.3 M | ³ LAI | 07A NA48 | DP |

 $^{^1}$ Obtained from a sample of 1.9 M K_{e3} and 1.5 M $K_{\mu3}$. The correlation between \varLambda_+ and ln(C) is -0.269.

 $^{^3}$ LAI 07A gives a correlation -0.44 between their Λ_+ and $\ln(C)$ measurements.



 Λ_+ (DISPERSIVE VECTOR FORM FACTOR FOR κ^0_{u3} DECAY) (units

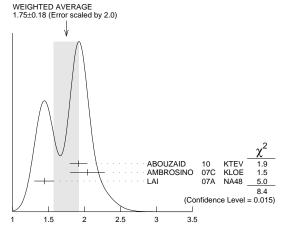
ln(C) (DISPERSIVE SCALAR FORM FACTOR FOR $K_{\mu3}^0$ DECAY)

See the review on " $K_{\ell 3}^{\pm}$ and $K_{\ell 3}^{0}$ Form Factors" for details of the dispersive

| VALUE (units 10^{-1}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|-------|------------------------|--------|---------|-------------------------|--|
| 1.75 ±0.18 OUR AVE | RAGE | Error includes scale | factor | of 2.0. | See the ideogram below. | |
| $1.915 \pm 0.078 \pm 0.094$ | 3.4 M | ¹ ABOUZAID | | | | |
| $2.04 \pm 0.19 \pm 0.15$ | 3.8M | ² AMBROSINO | | | | |
| $1.438 \pm 0.080 \pm 0.112$ | 2.3 M | ³ LAI | 07A | NA 48 | DP | |

 $^{^1}$ Obtained from a sample of 1.9 M K_{e3} and 1.5 M $K_{\mu3}$. The correlation between \varLambda_+ and ln(C) is -0.269.

 $^{^3}$ LAI 07A gives a correlation -0.44 between their Λ_+ and $\ln(\mathcal{C})$ measurements.



 $\ln(\mathcal{C})$ (DISPERSIVE SCALAR FORM FACTOR FOR $\mathcal{K}_{\mu3}^0$ DECAY) (units

$a_1(t_0, Q^2)$ FORM FACTOR PARAMETER

See HILL 06 for a definition of this parameter.

| VALUE | EVTS | DO CUMENT ID | | TECN | | |
|-----------------------------------------|-----------|------------------------|--------|----------------------|------------------------|--------------|
| $1.023 \pm 0.028 \pm 0.029$ | 2 M | $^{ m 1}$ ABOUZAID | 06c | KTEV | | |
| $^{1}Q^{2}= 2 \text{ GeV}^{2}, t_{0} =$ | 0.49 (m 🗸 | $-m_{-})^2$. Correlat | ion be | tween a ₁ | and a ₂ : ρ | 12 = -0.064. |

$a_2(t_0, Q^2)$ FORM FACTOR PARAMETER

See HILL 06 for a definition of this parameter.

| VALUE | EVTS | DO CUMENT ID | | TECN | | |
|--------------------------|----------|----------------------------|--------|----------|---------------|---------|
| $0.75 \pm 1.58 \pm 1.47$ | 2 M | $^{ m 1}$ abouzaid | 06c | KTEV | | |
| 1 Q2- 2 GeV2 to - | 0.49 (m | -m) ² Correlat | ion be | tween a. | and act are - | - 0 064 |

$|f_S/f_+|$ FOR K_{e3}^0 DECAY Ratio of scalar to f_+ couplings.

ı

| VALUE (units 10 | ²) CL% | EVTS | DO CUMENT | ID | TECN | COMMENT |
|--------------------------|--------------------|-------------|---------------------|-------------|---------|---------------------|
| $1.5 + 0.7 \pm 1$ | .2 | 5.6M | 1 LAI | 04 C | NA 48 | |
| • • • We do | not use th | ne followii | ng data for aver | ages, fits, | limits, | etc. • • • |
| < 9.5 | 95 | 18k | HILL | 78 | STRC | |
| <7. | 68 | 48k | BIRULEV | 76 | SPEC | See also BIRULEV 81 |
| <4. | 68 | 25k | BLUMENT | HAL75 | SPEC | |
| ¹ Results fro | m linear 1 | it with f | s/f_+ and $ f_7 $ | $-/f_+$ fre | e. | |

$|f_T/f_+|$ FOR K_{e3}^0 DECAY

Ratio of tensor to f_{\perp} couplings.

| ALUE (units 10 | ⁻²) CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------|---------------------|-------------|--------------------|----------|-----------|---------------------|
| $5^{+3}_{-4}\pm3$ | | 5.6 M | 1 LAI | 04c | NA 48 | |
| • • We do | not use th | ne followii | ng data for averag | es, fits | , limits, | etc. • • • |
| <40. | 95 | 18k | HILL | 78 | STRC | |
| <34. | 68 | 48k | BIRULEV | 76 | SPEC | See also BIRULEV 81 |
| <23. | 68 | 25k | BLUMENTH | ΛΙ 75 | SPEC | |

$|f_T/f_+|$ FOR $K_{\mu 3}^0$ DECAY

Ratio of tensor to f_+ couplings.

| VALUE (units 10 ⁻²) | DO CUMENT ID | TECN |
|---------------------------------|--------------|------|
| 12.±12. | BIRULEV 81 | SPEC |

 $^{^2}$ ALEXOPOULOS 04A gives a correlation - 0.46 between their M_S^μ and M_V^μ and measurements, not assuming $\mu\text{-}e$ universality.

 $^{^3}$ ALEXOPOULOS 04A gives a correlation - 0.40 between their M_S^μ and M_V^μ and measurements, assuming $\mu\text{-}e$ universality.

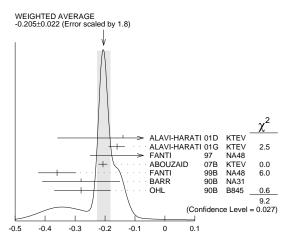
 $^{^2}$ AMBROSINO 07c results include 2M K_{e3} events from AMBROSINO 06D. The correlative from AMBROSINO 06D and 2 tion between Λ_+ and $\ln(\it{C})$ is -0.26.

and in(C) is -0.209. 2 AMBROSINO 07c results include 2M K_{e3} events from AMBROSINO 06D. We convert (A_+, A_0) to (A_+, A_0) to (A_+, A_0) to (A_+, A_0) and in (A_+, A_0) to (A_+, A_0) to (A_+, A_0) to theory parametrization of the form factor. The correlation between A_+ and $\ln(C)$ is -0.26.

 $lpha_{K^*}$ DECAY FORM FACTOR FOR $K_L o \ell^+\ell^-\gamma$, $K_L^0 o \ell^+\ell^-\ell'^+\ell'^-$ Average of all $lpha_{K^*}$ measurements (from each of three datablocks following this one) assuming lepton universality.

DO CUMENT ID

one. Error includes scale factor of 1.8. See the ideogram below.



 α_{K^*} DECAY FORM FACTOR FOR $K_L \to \ell^+ \ell^- \gamma$, $K_L^0 \to \ell^+ \ell^- \ell'^+ \ell'^-$

 $lpha_{K^*}$ DECAY FORM FACTOR FOR $K_L o e^+ \, e^- \gamma$ α_{K^*} is the constant in the model of BERGSTROM 83 which measures the relative strength of the vector-vector transition $K_L \to K^* \gamma$ with $K^* \to \rho$, ω , $\phi \to \gamma^*$ and the pseudoscalar-pseudoscalar transition $\mathit{K}_L \rightarrow \pi$, η , $\eta' \rightarrow \gamma \gamma^*$.

<u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u>
The data in this block is included in the average printed for a previous datablock.

| -0.217±0.034 OUR AV | ERAGE | Error includes sca | ile fact | tor of 2.4 |
|------------------------------|-------|--------------------|----------|------------|
| $-0.207 \pm 0.012 \pm 0.009$ | 83k | $^{ m 1}$ abouzaid | 07в | KTEV |
| $-0.36 \pm 0.06 \pm 0.02$ | 6864 | FA NT I | 99B | NA48 |
| -0.28 ± 0.13 | | BARR | 90B | NA 31 |
| . 0.000 | | | | |

 $-0.280\,{}^{+\,\,0.099}_{-\,\,0.090}$ OHL 90B B845

 $^1\,\mathrm{ABOUZAID}$ 07B measures $\mathit{C}\cdot\alpha_{\ensuremath{\mbox{\it K}}^*}=-0.517\pm0.030\pm0.022.$ We assume $\mathit{C}=2.5$, as in all other measurements.

 $lpha_{K^*}$ DECAY FORM FACTOR FOR $\kappa_L o \mu^+ \mu^- \gamma$ α_{K^*} is the constant in the model of BERGSTROM 83 described in the previous section.

DO CUMENT ID <u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>IECN</u>
The data in this block is included in the average printed for a previous datablock.

-0.158 ± 0.027 OUR AVERAGE

| $-0.160 + 0.026 \\ -0.028$ | 9100 | ALAVI-HARAT | 01G | KTEV |
|-----------------------------------------------------|------|-------------|-----|------|
| $-0.04 \begin{array}{c} +0.24 \\ -0.21 \end{array}$ | | FA NT I | 97 | NA48 |

$lpha_{ u *}^{ m eff}$ DECAY FORM FACTOR FOR $K_L ightarrow e^+ e^- e^+ e^-$

 $lpha_{_{_{m{U}*}}}^{
m eff}$ is the parameter describing the relative strength of an intermediate pseu- K^* doscalar decay amplitude and a vector meson decay amplitude in the model of BERGSTROM 83. It takes into account both the radiative effects and the form factor. Since there are two e^+e^- pairs here compared with one in $e^+e^-\gamma$ decays, a factorized expression is used for the $e^+e^-e^+e^-$ decay form factor.

<u>VALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u>
The data in this block is included in the average printed for a previous datablock.

$-0.14 \pm 0.16 \pm 0.15$ ALAVI-HARATIO1D KTEV

$lpha_{DIP}$ DECAY FORM FACTOR FOR $\emph{K}^0_1 \rightarrow \emph{\ell}^+ \emph{\ell}^- \gamma$, $\emph{K}^0_1 \rightarrow \emph{\ell}^+ \emph{\ell}^- \emph{\ell}'^+ \emph{\ell}'^-$ Average of all $lpha_{DIP}$ measurements (from each of three datablocks following this one)

assuming lepton universality.

DO CUMENT ID

DOCUMENT ID -1.69±0.08 OUR AVERAGE Includes data from the 3 datablocks that follow this one. Error includes scale factor of 1.7.

$lpha_{DIP}$ DECAY FORM FACTOR FOR $K_L^0 ightarrow e^+ \, e^- \gamma$

 α_{DIP} parameter in $K_I^0 \rightarrow \gamma^* \gamma^*$ form factor by DAMBROSIO 98, motivated by vector meson dominance and a proper short distance behavior. DO CUMENT ID EVTS

The data in this block is included in the average printed for a previous datablock.

-1.729 ± 0.043 ± 0.028 83k ABOUZAID

 $lpha_{DIP}$ DECAY FORM FACTOR FOR $K_L^0 o \mu^+\mu^-\gamma$ $lpha_{DIP}$ is a constant in the model of DAMBROSIO 98 described in the previous section. VALUE EVTS DOCUMENT ID TECN
The data in this block is included in the average printed for a previous datablock.

 -1.54 ± 0.10 ALAVI-HARATI01G KTEV

$lpha_{DIP}$ DECAY FORM FACTOR FOR $K_L^0 ightarrow e^+ \, e^- \, \mu^+ \, \mu^-$

 $lpha_{DIP}$ is a constant in the model of DAMBROSIO 98 described in the previous section. DOCUMENT ID

The data in this block is included in the average printed for a previous datablock.

ALAVI-HARATI 03B KTEV 131

a₁/a₂ FORM FACTOR FOR M1 DIRECT EMISSION AMPLITUDE

| Form factor $=	ilde{g}_M$ | $r_1\left[1+\frac{1}{(M)}\right]$ | $\frac{a_1/a_2}{\rho - M_K^2} + 2M_K E^2$ | as | describe | d in ALAVI-HARATI 00в. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------------------------|----------|-------------------------|-------------------------------|
| VALUE (GeV ²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| -0.737±0.014 OUR AV | ERAGE | | | | |
| $-0.744\pm0.027\pm0.032$ | 5241 | ¹ ABOUZAID | | | |
| $-0.738\pm0.007\pm0.018$ | 111k | ² ABOUZAID | 06A | KTEV | $\pi^+\pi^+\gamma$ |
| $-0.81 {}^{+\ 0.07}_{-\ 0.13} \pm 0.02$ | | ³ LAI | | | $\pi^+\pi^-e^+e^-$ |
| $-0.737\pm0.026\pm0.022$ | | ⁴ ALAVI-HARAT ⁵ ALAVI-HARAT | 101в | | $\pi^+\pi^-\gamma$ |
| $-0.720\pm0.028\pm0.009$ | 1766 | ⁵ ALAVI-HARAT | 100в | KTEV | $\pi^{+} \pi^{-} e^{+} e^{-}$ |
| ¹ ABOUZAID 06 also | measured | $ \tilde{g}_{M1} = 1.11 \pm$ | 0.14. | | |
| ² ABOUZAID 06A also | measured | $ \widetilde{g}_{M1} = 1.198$: | ± 0.0 | 35 ± 0.0 | 186. |
| ³ LAI 03c also measur | ed \widetilde{g}_{M1} = | $= 0.99^{+0.28}_{-0.27} \pm 0.0$ | 07. | | |
| ⁴ ALAVI-HARATI 01B fit gives $\chi^2/\text{DOF} = 38.8/27$. Linear and quadratic fits give $\chi^2/\text{DOF} = 43.2/27$ and 37.6/26 respectively. | | | | | |
| ⁵ ALAVI-HARATI 00B | also meas | ured $ \widetilde{g}_{M1} =1.3$ | 5 + 0.00 | $\frac{20}{17} \pm 0.0$ | 04. |

\overline{f}_S DECAY FORM FACTOR FOR $K_i^0 \rightarrow \pi^{\pm}\pi^0 e^{\mp}\nu_e$

| 5 | <u> </u> | |
|-----------------------------|-----------------------------|---------|
| VALUE | DO CUMENT ID | TECN |
| 0.049±0.011 OUR AVERAGE | Error includes scale factor | of 1.7. |
| $0.052 \pm 0.006 \pm 0.002$ | BATLEY 04 | NA48 |
| $0.010 \pm 0.016 \pm 0.017$ | MAKOFF 93 | E731 |

\overline{f}_P DECAY FORM FACTOR FOR $K_I^0 \rightarrow \pi^{\pm}\pi^0 e^{\mp}\nu_e$

| VALUE | DO CUMENT ID |) | TECN |
|------------------------------|--------------|----|------|
| -0.052±0.012 OUR AVERAGE | | | |
| $-0.051\pm0.011\pm0.005$ | BATLEY | 04 | NA48 |
| $-0.079 \pm 0.049 \pm 0.022$ | MAKOFF | 93 | E731 |

λ_{q} DECAY FORM FACTOR FOR $K_{L}^{0} ightarrow \pi^{\pm}\pi^{0}\,e^{\mp}\nu_{e}$

| VALUE | DO CUMENT IL |) | TECN |
|-----------------------------|--------------|----|------|
| 0.085 ± 0.020 OUR AVE | RAGE | | |
| $0.087 \pm 0.019 \pm 0.006$ | BATLEY | 04 | NA48 |
| $0.014 \pm 0.087 \pm 0.070$ | MAKOFF | 93 | E731 |

\overline{h} DECAY FORM FACTOR FOR $K_{I}^{0} \rightarrow \pi^{\pm}\pi^{0} e^{\mp}\nu_{e}$

| VALUE | DO CUMENT IL |) | TECN |
|----------------------------|--------------|----|------|
| -0.30 ± 0.13 OUR AVERAGE | | | |
| $-0.32 \pm 0.12 \pm 0.07$ | BATLEY | 04 | NA48 |
| $-0.07 \pm 0.31 \pm 0.31$ | MAKOFF | 93 | E731 |

L_3 CHIRAL PERT. THEO. PARAM. FOR $K_I^0 \to \pi^{\pm}\pi^0 e^{\mp}\nu_e$

| _ | <u>-</u> | |
|---------------------------------|----------------------------|-----------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TECN |
| -3.96±0.28 OUR AVERAGE | Error includes scale facto | r of 1.6. |
| -4.1 ± 0.2 | BATLEY 04 | NA48 |
| -34 + 04 | 1 MAKOFF 93 | F 731 |

 $^{^{}m 1}$ MAKOFF 93 sign has been changed to negative to agree with the sign convention used in BATLEY 04

av, VECTOR MESON EXCHANGE CONTRIBUTION

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-------------|-------------------------|--------|------|------------------------------------------------------------------------------------------------------------------------------------|
| -0.43 ± 0.06 OUR AV | ERAGE E | | | | |
| $-0.31\pm0.05\pm0.07$ | 1.4k | ¹ ABOUZAID | 08 | KTEV | |
| $-0.46\pm0.03\pm0.04$ | | LAI | 02в | NA48 | $K_I^0 \rightarrow \pi^0 2\gamma$ |
| $-0.67\pm0.21\pm0.12$ | | ALAVI-HARA | T 01E | KTEV | $egin{array}{ll} \mathcal{K}^0_L & ightarrow & \pi^0 2\gamma \ \mathcal{K}^0_L & ightarrow & \pi^0 e^+ e^- \gamma \end{array}$ |
| • • • We do not use t | he followin | | | | |
| $-0.72\pm0.05\pm0.06$ | | ² ALAVI-HARA | ТІ 99в | KTEV | $K_L^0 \rightarrow \pi^0 2\gamma$ |
| 100 27 27 4 | | 1006 1007 | | | - |

Using KTeV dataset collected in 1996, 1997, and 1999

CP VIOLATION IN K_L DECAYS

Updated April 2012 by L. Wolfenstein (Carnegie-Mellon University), C.-J. Lin (LBNL), and T.G. Trippe (LBNL).

The symmetries C (particle-antiparticle interchange) and P (space inversion) hold for strong and electromagnetic interactions. After the discovery of large C and P violation in the weak interactions, it appeared that the product CP was a good symmetry. In 1964 CP violation was observed in K^0 decays at a level given by the parameter $\epsilon \approx 2.3 \times 10^{-3}$.

A unified treatment of CP violation in K, D, B, and B_s mesons is given in "CP Violation in Meson Decays" by

² Superseded by ABOUZAID 08.

K_{I}^{0}

D. Kirkby and Y. Nir in this *Review*. A more detailed review including a thorough discussion of the experimental techniques used to determine CP violation parameters is given in a book by K. Kleinknecht [1]. Here we give a concise summary of the formalism needed to define the parameters of CP violation in K_L decays, and a description of our fits for the best values of these parameters.

1. Formalism for CP violation in Kaon decay:

CP violation has been observed in the semi-leptonic decays $K_L^0\to\pi^\mp\ell^\pm\nu$, and in the nonleptonic decay $K_L^0\to2\pi$. The experimental numbers that have been measured are

$$A_{L} = \frac{\Gamma(K_{L}^{0} \to \pi^{-}\ell^{+}\nu) - \Gamma(K_{L}^{0} \to \pi^{+}\ell^{-}\nu)}{\Gamma(K_{L}^{0} \to \pi^{-}\ell^{+}\nu) + \Gamma(K_{L}^{0} \to \pi^{+}\ell^{-}\nu)}$$
(1a)

$$\eta_{+-} = A(K_L^0 \to \pi^+ \pi^-) / A(K_S^0 \to \pi^+ \pi^-)$$

$$= |\eta_{+-}| e^{i\phi_{+-}}$$
(1b)

$$\eta_{00} = A(K_L^0 \to \pi^0 \pi^0) / A(K_S^0 \to \pi^0 \pi^0)$$

$$= |\eta_{00}| e^{i\phi_{00}} .$$
(1c)

CP violation can occur either in the $K^0 - \overline{K}^0$ mixing or in the decay amplitudes. Assuming CPT invariance, the mass eigenstates of the $K^0 - \overline{K}^0$ system can be written

$$|K_S\rangle = p|K^0\rangle + q|\overline{K}^0\rangle$$
, $|K_L\rangle = p|K^0\rangle - q|\overline{K}^0\rangle$. (2)

If CP invariance held, we would have q=p so that K_S would be CP-even and K_L CP-odd. (We define $|\overline{K}^0\rangle$ as CP $|K^0\rangle$). CP violation in $K^0 - \overline{K}^0$ mixing is then given by the parameter $\widetilde{\epsilon}$ where

$$\frac{p}{q} = \frac{(1+\widetilde{\epsilon})}{(1-\widetilde{\epsilon})} \,. \tag{3}$$

CP violation can also occur in the decay amplitudes

$$A(K^0 \to \pi \pi(I)) = A_I e^{i\delta_I} , \quad A(\overline{K}^0 \to \pi \pi(I)) = A_I^* e^{i\delta_I} ,$$
 (4)

where I is the isospin of $\pi\pi$, δ_I is the final-state phase shift, and A_I would be real if CP invariance held. The CP-violating observables are usually expressed in terms of ϵ and ϵ' defined by

$$\eta_{+-} = \epsilon + \epsilon', \quad \eta_{00} = \epsilon - 2\epsilon'.$$
(5a)

One can then show [2]

$$\epsilon = \widetilde{\epsilon} + i \text{ (Im } A_0/\text{Re } A_0),$$
(5b)

$$\sqrt{2}\epsilon' = ie^{i(\delta_2 - \delta_0)} (\operatorname{Re} A_2 / \operatorname{Re} A_0) \ (\operatorname{Im} A_2 / \operatorname{Re} A_2 - \operatorname{Im} A_0 / \operatorname{Re} A_0) ,$$
(5c)

$$A_L = 2 \operatorname{Re} \epsilon / (1 + |\epsilon|^2) \approx 2 \operatorname{Re} \epsilon .$$
 (5d)

In Eqs. (5a), small corrections [3] of order $\epsilon' \times \text{Re } (A_2/A_0)$ are neglected, and Eq. (5d) assumes the $\Delta S = \Delta Q$ rule.

The quantities Im A_0 , Im A_2 , and Im $\tilde{\epsilon}$ depend on the choice of phase convention, since one can change the phases of K^0 and \overline{K}^0 by a transformation of the strange quark state $|s\rangle \rightarrow |s\rangle e^{i\alpha}$; of course, observables are unchanged. It is possible by a choice of phase convention to set Im A_0 or Im A_2 or Im $\tilde{\epsilon}$ to zero, but none of these is zero with the usual phase conventions in the Standard Model. The choice Im $A_0 = 0$ is called the

Wu-Yang phase convention [4], in which case $\epsilon = \tilde{\epsilon}$. The value of ϵ' is independent of phase convention, and a nonzero value demonstrates CP violation in the decay amplitudes, referred to as direct CP violation. The possibility that direct CP violation is essentially zero, and that CP violation occurs only in the mixing matrix, was referred to as the superweak theory [5].

By applying CPT invariance and unitarity the phase of ϵ is given approximately by

$$\phi_{\epsilon} \approx \tan^{-1} \frac{2(m_{K_L} - m_{K_S})}{\Gamma_{K_S} - \Gamma_{K_L}} \approx 43.52 \pm 0.05^{\circ} ,$$
 (6a)

while Eq. (5c) gives the phase of ϵ' to be

$$\phi_{\epsilon'} = \delta_2 - \delta_0 + \frac{\pi}{2} \approx 42.3 \pm 1.5^{\circ} ,$$
 (6b)

where the numerical value is based on an analysis of π - π scattering using chiral perturbation theory [6]. The approximation in Eq. (6a) depends on the assumption that direct CP violation is very small in all K^0 decays. This is expected to be good to a few tenths of a degree, as indicated by the small value of ϵ' and of η_{+-0} and η_{000} , the CP-violation parameters in the decays $K_S \to \pi^+\pi^-\pi^0$ [7], and $K_S \to \pi^0\pi^0\pi^0$ [8]. The relation in Eq. (6a) is exact in the superweak theory, so this is sometimes called the superweak-phase $\phi_{\rm SW}$. An important point for the analysis is that $\cos(\phi_{\epsilon'}-\phi_{\epsilon})\simeq 1$. The consequence is that only two real quantities need be measured, the magnitude of ϵ and the value of (ϵ'/ϵ) , including its sign. The measured quantity $|\eta_{00}/\eta_{+-}|^2$ is very close to unity so that we can write

$$|\eta_{00}/\eta_{+-}|^2 \approx 1 - 6\text{Re}\left(\epsilon'/\epsilon\right) \approx 1 - 6\epsilon'/\epsilon$$
, (7a)

$$\operatorname{Re}(\epsilon'/\epsilon) \approx \frac{1}{3}(1 - |\eta_{00}/\eta_{+-}|)$$
 (7b)

From the experimental measurements in this edition of the *Review*, and the fits discussed in the next section, one finds

$$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$$
, (8a)

$$\phi_{\epsilon} = (43.5 \pm 0.5)^{\circ} ,$$
 (8b)

$$\operatorname{Re}(\epsilon'/\epsilon) \approx \epsilon'/\epsilon = (1.66 \pm 0.23) \times 10^{-3}$$
, (8c)

$$\phi_{+-} = (43.4 \pm 0.5)^{\circ} , \qquad (8d)$$

$$\phi_{00} - \phi_{+-} = (0.34 \pm 0.32)^{\circ}$$
, (8e)

$$A_L = (3.32 \pm 0.06) \times 10^{-3}$$
 (8f)

Direct CP violation, as indicated by ϵ'/ϵ , is expected in the Standard Model. However, the numerical value cannot be reliably predicted because of theoretical uncertainties [9]. The value of A_L agrees with Eq. (5d). The values of ϕ_{+-} and $\phi_{00} - \phi_{+-}$ are used to set limits on CPT violation [see "Tests of Conservation Laws"].

2. Fits for K_L^0 CP-violation parameters:

In recent years, K_L^0 CP-violation experiments have improved our knowledge of CP-violation parameters, and their consistency with the expectations of CPT invariance and unitarity. To determine the best values of the CP-violation parameters in $K_L^0 \to \pi^+\pi^-$ and $\pi^0\pi^0$ decay, we make two types of fits, one for the phases ϕ_{+-} and ϕ_{00} jointly with Δm and τ_S , and the other for the amplitudes $|\eta_{+-}|$ and $|\eta_{00}|$ jointly with the $K_L^0 \to \pi\pi$ branching fractions.

Fits to ϕ_{+-} , ϕ_{00} , $\Delta\phi$, Δm , and τ_S data: These are joint fits to the data on ϕ_{+-} , ϕ_{00} , the phase difference $\Delta\phi = \phi_{00} - \phi_{+-}$, the $K_L^0 - K_S^0$ mass difference Δm , and the K_S^0 mean life τ_S , including the effects of correlations.

Measurements of ϕ_{+-} and ϕ_{00} are highly correlated with Δm and τ_S . Some measurements of τ_S are correlated with Δm . The correlations are given in the footnotes of the ϕ_{+-} and ϕ_{00} sections of the K_L^0 Listings, and the τ_S section of the K_S^0 Listings.

In most cases, the correlations are quoted as 100%, i.e., with the value and error of ϕ_{+-} or ϕ_{00} given at a fixed value of Δm and τ_S , with additional terms specifying the dependence of the value on Δm and τ_S . These cases lead to diagonal bands in Figs. 1 and 2. The KTeV experiment [10] quotes its results as values of Δm , τ_S , ϕ_ϵ , Re(ϵ'/ϵ), and Im(ϵ'/ϵ) with correlations, leading to the ellipses labeled "b." The correlations for the KTeV measurements are given in the Im(ϵ'/ϵ) section of the K_L^0 Listings. For small $|\epsilon'/\epsilon|$, $\phi_{+-} \approx \phi_\epsilon + \text{Im}(\epsilon'/\epsilon)$.

Table 1: References, Document ID's, and sources corresponding to the letter labels in the figures. The data are given in the ϕ_{+-} and Δm sections of the K_L Listings, and the τ_S section of the K_S Listings.

| Label | Source | PDG Document ID | Ref. |
|-------|-------------------|-------------------|---------|
| a | this Review | OUR FIT | |
| b | ${\rm FNAL~KTeV}$ | ABOUZAID 11 | [10] |
| c | CERN CPLEAR | APOSTOLAKIS 99C | [11] |
| d | FNAL E773 | SCHWINGENHEUER 95 | [12] |
| e | FNAL E731 | GIBBONS 93,93C | [13,14] |
| f | CERN | GEWENIGER 74B,74C | [15,16] |
| g | CERN NA31 | CAROSI 90 | [17] |
| h | CERN NA48 | LAI 02C | [18] |
| i | CERN NA31 | BERTANZA 97 | [19] |
| j | this $Review$ | SUPERWEAK 12 | |

The data on τ_S , Δm , and ϕ_{+-} shown in Figs. 1 and 2 are combined with data on ϕ_{00} and $\phi_{00}-\phi_{+-}$ in two fits, one without assuming CPT, and the other with this assumption. The results without assuming CPT are shown as ellipses labeled "a." These ellipses are seen to be in good agreement with the superweak phase

$$\phi_{\text{SW}} = \tan^{-1} \left(\frac{2\Delta m}{\Delta \Gamma} \right) = \tan^{-1} \left(\frac{2\Delta m \tau_S \tau_L}{\hbar (\tau_L - \tau_S)} \right) .$$
 (9)

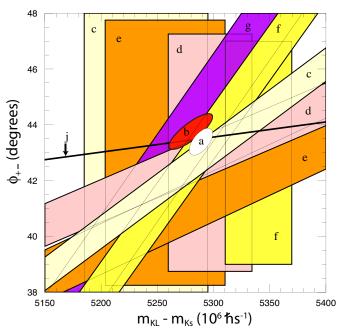


Figure 1: ϕ_{+-} vs Δm for experiments which do not assume CPT invariance. Δm measurements appear as vertical bands spanning $\Delta m \pm 1\sigma$, cut near the top and bottom to aid the eye. Most ϕ_{+-} measurements appear as diagonal bands spanning $\phi_{+-} \pm \sigma_{\phi}$. Data are labeled by letters: "b"–FNAL KTeV, "c"–CERN CPLEAR, "d"–FNAL E773, "e"–FNAL E731, "f"–CERN, "g"–CERN NA31, and are cited in Table 1. The narrow band "j" shows $\phi_{\rm SW}$. The ellipse "a" shows the $\chi^2=1$ contour of the fit result.

In Figs. 1 and 2, $\phi_{\rm SW}$ is shown as narrow bands labeled "j."

Table 2 column 2, "Fit w/o CPT," gives the resulting fitted parameters, while Table 3 gives the correlation matrix for this fit. The white ellipses labeled "a" in Fig. 1 and Fig. 2 are the $\chi^2=1$ contours for this fit.

For experiments which have dependencies on unseen fit parameters, that is, parameters other than those shown on the x or y axis of the figure, their band positions are evaluated using the fit results and their band widths include the fitted uncertainty in the unseen parameters. This is also true for the $\phi_{\rm SW}$ bands.

If CPT invariance and unitarity are assumed, then by Eq. (6a), the phase of ϵ is constrained to be approximately equal to

$$\phi_{\rm SW} = (43.5165 \pm 0.0002)^{\circ} + 54.1 (\Delta m - 0.5290)^{\circ} + 32.0 (\tau_{s} - 0.8958) \tag{10}$$

where we have linearized the Δm and τ_S dependence of Eq. (9). The error ± 0.0002 is due to the uncertainty in τ_L . Here Δm has units $10^{10}\,\hbar\,\mathrm{s^{-1}}$ and τ_S has units 10^{-10} s.

If in addition we use the observation that $Re(\epsilon'/\epsilon) \ll 1$ and $cos(\phi_{\epsilon'} - \phi_{\epsilon}) \simeq 1$, as well as the numerical value of $\phi_{\epsilon'}$ given in

 K_{I}^{0}

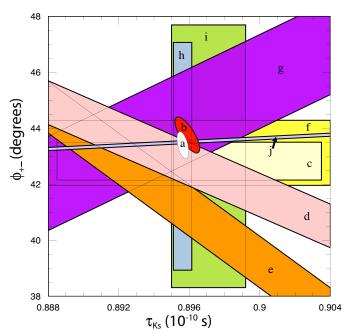


Figure 2: ϕ_{+-} vs τ_S . τ_S measurements appear as vertical bands spanning $\tau_S \pm 1\sigma$, some of which are cut near the top and bottom to aid the eye. Most ϕ_{+-} measurements appear as diagonal or horizontal bands spanning $\phi_{+-} \pm \sigma_{\phi}$. Data are labeled by letters: "b"–FNAL KTeV, "c"–CERN CPLEAR, "d"–FNAL E773, "e"–FNAL E731, "f"–CERN, "g"–CERN NA31, "h"–CERN NA48, "i"–CERN NA31, and are cited in Table 1. The narrow band "j" shows $\phi_{\rm SW}$. The ellipse "a" shows the fit result's $\chi^2=1$ contour.

Table 2: Fit results for ϕ_{+-} , Δm , τ_S , ϕ_{00} , $\Delta \phi = \phi_{00} - \phi_{+-}$, and ϕ_ϵ without and with the CPT assumption.

| Quantity(units) | Fit w/o CPT | Fit w/ CPT |
|------------------------------------------------|--------------------------------|-------------------------------------|
| $\overline{\phi_{+-}}(^{\circ})$ | $43.4 \pm 0.5 \text{ (S=1.2)}$ | $43.51 \pm 0.05 \text{ (S=1.2)}$ |
| $\Delta m (10^{10} \hbar \text{ s}^{-1})$ | 0.5289 ± 0.0010 | $0.5293 \pm 0.0009 \text{ (S=1.3)}$ |
| $\tau_{\scriptscriptstyle S}(10^{-10}{\rm s})$ | 0.89564 ± 0.00033 | $0.8954 \pm 0.0004 \; (S{=}1.1)$ |
| $\phi_{00}(^{\circ})$ | $43.7 \pm 0.6 \; (S{=}1.2)$ | $43.52 \pm 0.05 \text{ (S=1.3)}$ |
| $\Delta\phi(^{\circ})$ | 0.34 ± 0.32 | $0.006 \pm 0.014 \; (S{=}1.7)$ |
| $\phi_{\epsilon}(^{\circ})$ | $43.5 \pm 0.5 \text{ (S=1.3)}$ | $43.52 \pm 0.05 \text{ (S=1.2)}$ |
| χ^2 | 16.4 | 20.0 |
| # Deg. Free. | 14 | 16 |

Eq. (6b), then Eqs. (5a), which are sketched in Fig. 3, lead to the constraint

$$\phi_{00} - \phi_{+-} \approx -3 \operatorname{Im} \left(\frac{\epsilon'}{\epsilon} \right)$$

$$\approx -3 \operatorname{Re} \left(\frac{\epsilon'}{\epsilon} \right) \tan(\phi_{\epsilon'} - \phi_{\epsilon})$$

$$\approx 0.006^{\circ} \pm 0.008^{\circ} , \qquad (11)$$

In the fit assuming CPT, we constrain $\phi_{\epsilon} = \phi_{\rm SW}$ using the linear expression in Eq. (10), and constrain $\phi_{00} - \phi_{+-}$ using Eq. (11). These constraints are inserted into the Listings with the Document ID of SUPERWEAK 12. Some additional data for which the authors assumed CPT are added to this fit or substitute for other less precise data for which the authors did not make this assumption. See the Listings for details.

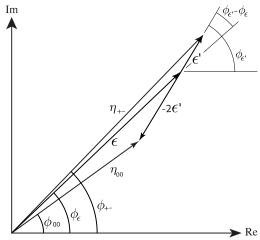


Figure 3: Sketch of Eqs. (5a). Not to scale.

The results of this fit are shown in Table 2, column 3, "Fit w/CPT," and the correlation matrix is shown in Table 4. The Δm precision is improved by the CPT assumption.

Table 3: Correlation matrix for the results of the fit without the CPT assumption

| | ϕ_{+-} | Δm | $	au_S$ | ϕ_{00} | $\Delta \phi$ | ϕ_{ϵ} |
|------------------------|-------------|------------|---------|-------------|---------------|-------------------|
| $\overline{\phi_{+-}}$ | 1.000 | 0.596 | -0.488 | 0.827 | -0.040 | 0.976 |
| Δm | 0.596 | 1.000 | -0.572 | 0.487 | -0.035 | 0.580 |
| $	au_S$ | -0.488 | -0.572 | 1.000 | -0.423 | -0.014 | -0.484 |
| ϕ_{00} | 0.827 | 0.487 | -0.423 | 1.000 | 0.529 | 0.929 |
| $\Delta \phi$ | -0.040 | -0.035 | -0.014 | 0.529 | 1.000 | 0.178 |
| ϕ_{ϵ} | 0.976 | 0.580 | -0.484 | 0.929 | 0.178 | 1.000 |

Table 4: Correlation matrix for the results of the fit with the CPT assumption

| | ϕ_{+-} | Δm | $	au_S$ | ϕ_{00} | $\Delta \phi$ | ϕ_{ϵ} |
|------------------------|-------------|------------|---------|-------------|---------------|-------------------|
| $\overline{\phi_{+-}}$ | 1.000 | 0.972 | -0.311 | 0.957 | -0.105 | 0.995 |
| Δm | 0.972 | 1.000 | -0.509 | 0.958 | -0.007 | 0.977 |
| $	au_S$ | -0.311 | -0.509 | 1.000 | -0.306 | 0.004 | -0.312 |
| ϕ_{00} | 0.957 | 0.958 | -0.306 | 1.000 | 0.189 | 0.981 |
| $\Delta \phi$ | -0.105 | -0.007 | 0.004 | 0.189 | 1.000 | -0.006 |
| ϕ_{ϵ} | 0.995 | 0.977 | -0.312 | 0.981 | -0.006 | 1.000 |

Fits for ϵ'/ϵ , $|\eta_{+-}|$, $|\eta_{00}|$, and B $(K_L \to \pi\pi)$

We list measurements of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ . Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from measurements of the K_L^0 and K_S^0 lifetimes $(\tau_L, \, \tau_S)$, and branching ratios (B) to $\pi\pi$, using the relations

$$|\eta_{+-}| = \left[\frac{B(K_L^0 \to \pi^+ \pi^-)}{\tau_L} \frac{\tau_S}{B(K_S^0 \to \pi^+ \pi^-)} \right]^{1/2} , \quad (12a)$$

$$|\eta_{00}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^0 \pi^0)}{\tau_L} \frac{\tau_S}{\mathrm{B}(K_S^0 \to \pi^0 \pi^0)} \right]^{1/2} .$$
 (12b)

For historical reasons, the branching ratio fits and the CP-violation fits are done separately, but we want to include the influence of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ measurements on ${\rm B}(K_L^0\to\pi^+\pi^-)$ and ${\rm B}(K_L^0\to\pi^0\pi^0)$ and vice versa. We approximate a global fit to all of these measurements by first performing two independent fits: 1) BRFIT, a fit to the K_L^0 branching ratios, rates, and mean life, and 2) ETAFIT, a fit to the $|\eta_{+-}|, |\eta_{00}|, |\eta_{+-}/\eta_{00}|$, and ϵ'/ϵ measurements. The results from fit 1, along with the K_S^0 values from this edition, are used to compute values of $|\eta_{+-}|$ and $|\eta_{00}|$, which are included as measurements in the $|\eta_{00}|$ and $|\eta_{+-}|$ sections with a document ID of BRFIT 12. Thus, the fit values of $|\eta_{+-}|$ and $|\eta_{00}|$ given in this edition include both the direct measurements and the results from the branching ratio fit.

The process is reversed in order to include the direct $|\eta|$ measurements in the branching ratio fit. The results from fit 2 above (before including BRFIT 12 values) are used along with the K_L^0 and K_S^0 mean lives and the $K_S^0 \to \pi\pi$ branching fractions to compute the K_L^0 branching ratio $\Gamma(K_L^0 \to \pi^0 \pi^0)/\Gamma(K_L^0 \to \pi^+ \pi^-)$. This branching ratio value is included as a measurement in the branching ratio section with a document ID of ETAFIT 12. Thus, the K_L^0 branching ratio fit values in this edition include the results of the direct measurement of $|\eta_{00}/\eta_{+-}|$ and ϵ'/ϵ . Most individual measurements of $|\eta_{+-}|$ and $|\eta_{00}|$ enter our fits directly via the corresponding measurements of $\Gamma(K_L^0 \to \pi^+\pi^-)/\Gamma(\text{total})$ and $\Gamma(K_L^0 \to \pi^0 \pi^0)/\Gamma(\text{total})$, and those that do not have too large errors to have any influence on the fitted values of these branching ratios. A more detailed discussion of these fits is given in the 1990 edition of this Review [20].

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CP-VIOLATION PARAMETERS IN K1 DECAYS

CHARGE ASYMMETRY IN KO DECAYS -

Such asymmetry violates CP . It is related to $\mathrm{Re}(\epsilon)$.

$A_L=$ weighted average of $A_L(\mu)$ and $A_L(e)$

In previous editions and in the literature the symbol used for this asymmetry was δ_L or δ . We use A_L for consistency with B^0 asymmetry notation and with recent $K_S^{\vec{0}}$

| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------|---------|----------------------|-------|----------|--------------------------|
| 0.332±0.006 OUR | AVERAGE | Includes data from t | the 2 | databloc | ks that follow this one. |
| 0.333 ± 0.050 | 33M | WILLIAMS | 73 | ASPK | $K_{\mu 3} + K_{\rho 3}$ |

 $\begin{array}{lll} A_L(\mu) = & [\Gamma(\pi^-\mu^+\nu_\mu) - \Gamma(\pi^+\mu^-\overline{\nu}_\mu)]/\text{SUM} \\ & \text{Only the combined value below is put into the Meson Summary Table.} \\ & \underline{\text{VALUE (\%)}} & \underline{\text{EVTS}} & \underline{\text{DOCUMENT ID}} & \underline{\text{TECN}} \\ & \text{The data in this block is included in the average printed for a previous datablock.} \end{array}$

0.304 ± 0.025 OUR AVERAGE

| 0.313 ± 0.029 | 15 M | GEWENIGER | 74 | ASPK | | |
|-------------------|-------------------|-----------------------|---------|----------------|-------|---|
| 0.278 ± 0.051 | 7.7 M | PICCIONI | 72 | ASPK | | |
| • • • We do not | use the following | data for average | s, fits | , limits, etc. | • • • | , |
| 0.60 ± 0.14 | 4.1 M | MCCARTHY | 73 | CNTR | | |
| 0.57 ± 0.17 | 1 M | ¹ PACIOTTI | 69 | OSP K | | |
| 0.403 ± 0.134 | 1 M | 1 DORFAN | 67 | OSPK | | |

 $^{^1}$ PACIOTTI 69 is a reanalysis of DORFAN 67 and is corrected for $\mu^+\,\mu^-$ range difference in MCCARTHY 72.

 $\begin{array}{lll} \textbf{\textit{A}}_{\textit{L}}(\textbf{\textit{e}}) = [\Gamma(\pi^-\textbf{\textit{e}}^+\nu_{\textbf{\textit{e}}}) - \Gamma(\pi^+\textbf{\textit{e}}^-\overline{\nu_{\textbf{\textit{e}}}})]/\text{SUM} \\ & \text{Only the combined value below is put into the Meson Summary Table.} \\ & \underline{\textit{VALUE}\,(\%)} & \underline{\textit{EVTS}} & \underline{\textit{DOCUMENT ID}} & \underline{\textit{TECN}} \\ & \text{The data in this block is included in the average printed for a previous datablock.} \end{array}$

0.334 ±0.007 OUR AVERAGE

| 0.3322 | $\pm 0.0058 \pm 0.0047$ | 298 IVI | ALAVI-HAKAI | 102 | | |
|--------|-------------------------|-----------|----------------------|----------|------------|-------|
| 0.341 | ±0.018 | 34 M | GEWENIGER | 74 | ASPK | |
| 0.318 | ±0.038 | 40M | FITCH | 73 | ASPK | |
| 0.346 | ±0.033 | 10M | MARX | 70 | CNTR | |
| • • • | We do not use the | following | data for averages, | fits, li | mits, etc. | • • • |
| 0.36 | ±0.18 | 600k | ASHFORD | 72 | ASPK | |
| 0.246 | ±0.059 | 10M | ¹ SAAL | | CNTR | |
| 0.224 | ± 0.036 | 10M | ¹ BENNETT | 67 | CNTR | |

¹ SAAL 69 is a reanalysis of BENNETT 67.

- PARAMETERS FOR $K_I^0 ightarrow 2\pi$ DECAY -

$$\begin{array}{l} \eta_{+-} = \mathsf{A}(\mathsf{K}_L^0 \to \pi^+\pi^-) \; / \; \mathsf{A}(\mathsf{K}_S^0 \to \pi^+\pi^-) \\ \eta_{00} = \mathsf{A}(\mathsf{K}_L^0 \to \pi^0\pi^0) \; / \; \mathsf{A}(\mathsf{K}_S^0 \to \pi^0\pi^0) \end{array}$$

The fitted values of $|\eta_{+-}|$ and $|\eta_{00}|$ given below are the results of a fit to $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and $\mathrm{Re}(\epsilon'/\epsilon)$. Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from the fitted values of the ${\cal K}^0_I$ ightarrow $\pi\pi$ and $K_S^0 \to \pi\pi$ branching ratios and the K_I^0 and K_S^0 lifetimes. This information is included as data in the $|\eta_{\perp}-|$ and $|\eta_{00}|$ sections with a Document ID "BRFIT." See the note "CP violation in K_L decays" above

$\left|\eta_{00}\right| = \left|\mathsf{A}(\mathcal{K}_L^0 \to\ 2\pi^0)\ /\ \mathsf{A}(\mathcal{K}_S^0 \to\ 2\pi^0)\right|$

| 1 | | | | |
|---------------------------------|------------------------|-------|-----------|-------------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT |
| 2.220±0.011 OUR FIT | Error includes scale | facto | of 1.8. | |
| 2.243±0.014 | BRFIT | 12 | | |
| • • • We do not use th | e following data for a | verag | es, fits, | limits, etc. • • • |
| $2.47 \pm 0.31 \pm 0.24$ | ANGELOPO | 98 | CPLR | |
| 2.49 ± 0.40 | ¹ ADLER | 96B | CPLR | Sup. by ANGELOPOULOS 98 |
| 2.33 ± 0.18 | CHRISTENS | | | |
| 2.71 ± 0.37 | ² WOLFF | 71 | OSPK | Cu reg., 4γ's |
| 2.95 ± 0.63 | ² CHOLLET | 70 | OSPK | Cu reg., 4γ 's |
| | | | | |

¹ Error is statistical only.

2CHOLLET 70 gives $|\eta_{00}|=(1.23\pm0.24)\times$ (regeneration amplitude, 2 GeV/c Cu)/10000mb. WOLFF 71 gives $|\eta_{00}|=(1.13\pm0.12)\times$ (regeneration amplitude, 2 GeV/c Cu)/10000mb. We compute both $|\eta_{00}|$ values for (regeneration amplitude, 2 GeV/c Cu) = 24 ± 2mb. This regeneration amplitude results from averaging over FAISSNER 69, extrapolated using optical-model calculations of Bohm et al., Physics Letters 276 604 (160) and to the fAIATS 71 (160). Letters 27B 594 (1968) and the data of BALATS 71. (From H. Faissner, private com-

$|\eta_{+-}| = |A(K_L^0 \to \pi^+\pi^-) / A(K_S^0 \to \pi^+\pi^-)|$

| 111 1 1 1 | | | · · · · | |
|----------------------------------------|-------------|------------------------|------------------|------------------------------------|
| <u>VALUE</u> (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 2.232±0.011 OUR FIT | Error in | cludes scale factor | of 1.8. | |
| 2.226 ± 0.007 | | BRFIT | 12 | |
| • • • We do not use the | ne followin | g data for average | s, fits, limits, | , etc. • • • |
| 2.223 ± 0.012 | | ¹ LAI | 07 NA48 | |
| 2.219 ± 0.013 | | ² AMBROSINO | | |
| 2.228 ± 0.010 | | ³ ALEXOPOU | 04 KTEV | <i>'</i> |
| $2.286 \pm 0.023 \pm 0.026$ | 70M | ⁴ APOSTOLA | | K^0 - \overline{K}^0 asymmetry |
| $2.310 \pm 0.043 \pm 0.031$ | | ⁵ ADLER | | K^0 - \overline{K}^0 asymmetry |
| $2.32 \pm 0.14 \pm 0.03$ | 10^{5} | ADLER | 92B CPLR | K^0 - \overline{K}^0 asymmetry |
| 2.30 ±0.035 | | GEWENIGER | 74B ASPK | |

 1 Value obtained from the NA48 measurements of $\Gamma(K_L^0\to\pi^+\pi^-)/\Gamma(K_L^0\to\pi e\nu_e)$ and $\tau_{K_S^0}$ and KLOE measurements of $B(K_S^0\to\pi^+\pi^-)$ and $\tau_{K_L^0}$. $\Gamma(K_L^0\to\pi^+\pi^-)$ is defined to include the inner bremsstrahlung component $\Gamma(K_L^0\to\pi^+\pi^-\gamma({\rm IB}))$ but

exclude the direct emission component B($K_S^0 \to \pi^+\pi^-(DE)$). Their $|\eta_{+-}|$ value is not directly used in our fit, but enters the fit via their branching ratio and lifetime

² AMBROSINO 06F uses KLOE branching ratios and τ_L together with τ_S from PDG 04. Their $|\eta_{+-}|$ value is not directly used in our fit, but enters the fit via their branching ratio and lifetime measurements.

ALEXOPOULOS 04 $|\eta_{+-}|$ uses their $\kappa_L^0 o \pi\pi$ branching fractions, $au_S = (0.8963 \pm 0.000)$ 0.0005) $\times\,10^{-10}\,\mathrm{s}$ from the average of KTeV and NA48 τ_S measurements, and assumes is not directly used in our fit, but enters our fit via their branching ratio measurements.

⁴ APOSTOLAKIS 99c report (2.264 \pm 0.023 \pm 0.026 + 9.1[au_s - 0.8934]) imes 10⁻³. We evaluate for our 2006 best value au_s = (0.8958 \pm 0.0005) imes 10⁻¹⁰ s. $^{5}\,\text{ADLER 95B report}\;(2.312\pm0.043\pm0.030\,-1[\Delta\mathit{m}-0.5274]+9.1[\tau_{\mathit{S}}-0.8926])\times10^{-3}.$ We evaluate for our 1996 best values $\Delta m = (0.5304 \pm 0.0014) \times 10^{-10} \, hs^{-1}$ and τ_S $= (0.8927 \pm 0.0009) \times 10^{-10} \, \mathrm{s}$. Superseded by APOSTOLAKIS 99c.

$|\epsilon| = (2|\eta_{+-}| + |\eta_{00}|)/3$

This expression is a very good approximation, good to about one part in 10^{-4} because of the small measured value of $\phi_{00}-\phi_{+-}$ and small theoretical ambiguities.

DOCUMENT ID TECN

DOCUMENT ID

2.228±0.011 OUR FIT Error includes scale factor of 1.8.

EVTS

$|\eta_{00}/\eta_{+-}|$

| 0.9950±0.0007 OUR FIT | Error includes | scale factor | of 1.6. | | |
|------------------------------------|-----------------|---------------------|---------------|----------|---|
| 0.9930 ± 0.0020 OUR AVER | RAGE | | | | |
| 0.9931 ± 0.0020 | 1 | ^{1,2} BARR | | NA 31 | |
| $0.9904 \pm 0.0084 \pm 0.0036$ | | ³ woods | 88 | E731 | |
| ullet $ullet$ We do not use the fo | ollowing data f | or averages, 1 | fits, limits, | etc. • • | • |
| $0.9939 \pm 0.0013 \pm 0.0015$ | 1M | ¹ BARR | | NA 31 | |
| $0.9899 \pm 0.0020 \pm 0.0025$ | | 1 BURKHAI | RDT 88 | NΔ 31 | |

 $^{
m 1}$ This is the square root of the ratio R given by BURKHARDT 88 and BARR 93D.

²This is the combined results from BARR 93D and BURKHARDT 88, taking into account a common systematic uncertainty of 0.0014.

 3 We calculate $\left|\eta_{00}/\eta_{+-}\right|=1-3(\epsilon'/\epsilon)$ from WOODS 88 (ϵ'/ϵ) value.

$Re(\epsilon'/\epsilon) = (1-|\eta_{00}/\eta_{+-}|)/3$

I

We have neglected terms of order $\omega \cdot \mathrm{Re}(\epsilon'/\epsilon)$, where $\omega = \mathrm{Re}(\mathrm{A}_2)/\mathrm{Re}(\mathrm{A}_0) \simeq \ 1/22$. If

| included, this correction wo | ould lower ${\sf Re}(\epsilon'/\epsilon)$ l | y ab | out 0.04 | \times 10 ⁻³ . See SOZZI 04. |
|---------------------------------------------------|---------------------------------------------|---------|-----------|-------------------------------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT |
| 1.66 ±0.23 OUR FIT Error | includes scale facto | r of 1 | .6. | |
| 1.68 ±0.20 OUR AVERAGE | Error includes scale | e fact | or of 1.4 | See the ideogram |
| below. | | | | |
| 1.92 ±0.21 | ¹ ABOUZAID | 11 | KTEV | Assuming CPT |
| 1.47 ± 0.22 | BATLEY | 02 | NA48 | |
| $0.74 \pm 0.52 \pm 0.29$ | GIBBONS | 93B | E731 | |
| ● ● We use the following data | for averages but no | t for | fits. • • | • |
| 2.3 ±0.65 | ^{2,3} BARR | 93D | NA 31 | |
| • • • We do not use the followi | ng data for averages | , fits, | limits, e | tc. • • • |
| 2.110 ± 0.343 | ^{1,4} ABOUZAID | 11 | KTEV | Not assuming CPT |
| 2.07 ±0.28 | ALAVI-HARAT | 103 | KTEV | In ABOUZAID 11 |
| 1.53 ±0.26 | LAI | 01c | NA48 | Incl. in BATLEY 02 |
| $2.80 \pm 0.30 \pm 0.28$ | ALAVI-HARAT | 199D | KTEV | In ALAVI-HARATI 03 |
| $1.85 \pm 0.45 \pm 0.58$ | FA NTI | 99c | NA48 | In LAI 01c |
| 2.0 ±0.7 | ⁵ BARR | 93D | NA 31 | |
| -0.4 ± 1.4 ± 0.6 | PATTERSON | 90 | E731 | in GIBBONS 93B |
| 3.3 ±1.1 | ⁵ BURKHARDT | 88 | NA 31 | |
| $3.2 \pm 2.8 \pm 1.2$ | ² woods | 88 | E731 | |
| ¹ The two ABOUZAID 11 val | | ata. | The fits | are performed with and |

without CPT invariance requirement.

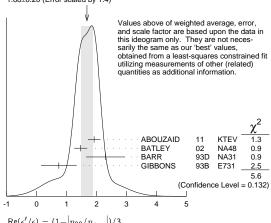
These values are derived from $|\eta_{00}/\eta_{+-}|$ measurements. They enter the average in this section but enter the fit via the $|\eta_{00}/\eta_{+-}|$ only.

 3 This is the combined results from BARR 93D and BURKHARDT 88, taking into account their common systematic uncertainty.

 4 We use ABOUZAID 11 Re($\epsilon'/\epsilon)$ value with *CPT* assumption in our fits for $|\eta_{+-}|$, $|\eta_{00}|$,

 5 These values are derived from $\left|\eta_{00}/\eta_{+-}\right|$ measurements.

WEIGHTED AVERAGE 1.68±0.20 (Error scaled by 1.4)



 $\operatorname{Re}(\epsilon'/\epsilon) = (1-|\eta_{00}/\eta_{+-}|)/3$

 ϕ_{+-} , PHASE of η_{+-} The dependence of the phase on Δm and τ_S is given for each experiment in the comments below, where Δm is the $K_L^0-K_S^0$ mass difference in units $10^{10}~h\mathrm{s}^{-1}$ and τ_S is the K_S mean life in units 10^{-10} s. We also give the regeneration phase ϕ_f

OUR FIT is described in the note on "CP violation in K_L decays" in the K_0^0 Particle Listings. Most experiments in this section are included in both the "Not Assuming CPT" and "Assuming CPT" fits. In the latter fit, they have little direct influence on $_$ because their errors are large compared to that assuming CPT , but they influence Δm and au_S through their dependencies on these parameters, which are given in the

| EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------------------|----------------------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Error includes | s scale factor of 1. | 2. Ass | suming | CP T |
| 43.4 ±0.5 OUR FIT Error includes scale factor of 1.2. Not assuming <i>CPT</i> | | | | |
| 70M | | | | |
| | | .95 | E773 | CH _{1.1} regenerator |
| ; | | | | B₄ C regenerator |
| | | | | Vacuum regen. |
| | ⁶ GEWENIGER | 74B | ASPK | Vacuum regen. |
| | | | | |
| | | | | Not assuming CPT |
| _ | | 103 | KTEV | Not assuming CPT |
| | | 96c | | |
| | ¹¹ ADLER | | CPLR | ∠0 ∠ 0 . |
| | | 95B | CPLR | K^0 - \overline{K}^0 asymmetry |
| 100k | ¹² ADLER | | CPLR | $K^0 - \overline{K}^0$ asymmetry |
| 100k 3 | | | | |
| | Error include: Error include: 70M he following da | Error includes scale factor of 1. Error includes scale factor of 1. 70M | Error includes scale factor of 1.2. Ass Error includes scale factor of 1.2. No 70M | Error includes scale factor of 1.2. Assuming Error includes scale factor of 1.2. Not assum 70M |

 1 APOSTOLAKIS 99c measures $\phi_{+-}=(43.19\pm0.53\pm0.28)\,+\,300\,\, [\Delta m-0.5301]\,\, (^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5\,293\pm0.0009)\,\, (10^{10}\,\,\hbar\,\,\mathrm{s}^{-1}).$ Our first error is their experiment's error and our second error is the systematic error from using our best values.

 2 SCHWINGENHEUER 95 measures $\phi_{+-}=(43.53\pm0.76)~+173~[\Delta m-0.5282]-275~[\tau_S-0.8926]~(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)~(10^{10}~h~s^{-1}),~(\tau_S=0.8954\pm0.0004)~(10^{-10}~s).$ Our first error is their experiment's error and our second error is the systematic error from using our best values

values. 3 These experiments measure ϕ_{+-} – ϕ_f and calculate the regeneration phase from the power law momentum dependence of the regeneration amplitude using analyticity and dispersion relations. SCHWINGENHEUER 95 [GIBBONS 93] includes a systematic error of 0.35° [0.5°] for uncertainties in their modeling of the regeneration amplitude.

 4 GIBBONS 93 measures $\phi_{+-}=(42.21\pm0.9)+189~[\Delta m-0.5257]-460~[\tau_S-0.8922]$ (°). We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)~(10^{10}~h_{\rm S}^{-1}),~(\tau_S=0.8954\pm0.0004)~(10^{-10}~{\rm s}).$ Our first error is their experiment's error and our second error is the systematic error from using our best values. This is actually reported in SCHWINGENHEUER 95, footnote 8. GIBBONS 93 reports $\phi_{+-}~(42.2\pm1.4)^{\rm o}.$ They measure $\phi_{+}^{}-\phi_{f}^{}$ and calculate the regeneration phase ϕ_{f} from the power law momentum dependence of the regeneration amplitude using analyticity. An error of $0.6^{\rm o}$ is included for possible uncertainties in the regeneration phase.

 5 CAROSI 90 measures $\phi_{+-}=(46.9\pm1.4\pm0.7)~+579~[\Delta m-~0.5351]+303~[\tau_S-~0.8922]~(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=~0.5293\pm0.0009)~(10^{10}~\hbar~s^{-1}),~(\tau_S=0.8954\pm0.0004)~(10^{-10}~s).$ Our first error is their experiment's error and our second error is the systematic error from using our best values.

 6 GEWENIGER 74B measures $\phi_{+-}=(49.4\pm1.0)~+565~[\Delta m-0.540]~(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)~(10^{10}~\hbar~s^{-1}).$ Our first error is their experiment's error and our second error is the systematic error from using our best values.

⁷ Not independent of other phase parameters reported in ABOUZAID 11.

 8 ALAVI-HARATI 03 ϕ_{+-} is correlated with their $\Delta m=m_{K_L^0}-m_{K_S^0}$ and au_{K_S} mea-

surements in the K_L^0 and K_S^0 sections respectively. The correlation coefficients are $\rho(\phi_+,\Delta m)=+0.955$, $\rho(\phi_+-,\tau_S)=-0.871$, and $\rho(\tau_S,\Delta m)=-0.840$. CPT is not assumed. Uses scintillator Pb regenerator. Superseded by ABOUZAID 11.

 9 ADLER 96c measures $\phi_{+-}=(43.82\pm0.41)~+339~[\Delta m-0.5307]-252~[\tau_S-0.8922]~(^\circ). We have adjusted the measurement to use our best values of <math display="inline">(\Delta m=0.5293\pm0.0009)~(10^{10}~h~s^{-1}),~(\tau_S=0.8954\pm0.0004)~(10^{-10}~s).$ Our first error is their experiment's error and our second error is the systematic error from using our best values.

10 ADLER 96c is the result of a fit which includes nearly the same data as entered into the "OUR FIT" value in the 1996 edition of this Review (Physical Review **D54** 1 (1996)). $^{11} \text{ADLER 95B measures} \ \phi_{+-} = (42.7 \pm 0.9 \pm 0.6) \ + \ 316 \ [\Delta m - 0.5274] \ + \ 30 \ [\tau_S - 0.5274] \ + \ 30 \ [$

¹¹ ADLER 95B measures $\phi_{+-}=(42.7\pm0.9\pm0.6)+316$ [$\Delta m-0.5274$] +30 [$\tau_S-0.8926$] (°). We have adjusted the measurement to use our best values of ($\Delta m=0.5293\pm0.0009$) (10^{10} \hbar s $^{-1}$), ($\tau_S=0.8954\pm0.0004$) (10^{-10} s). Our first error is their experiment's error and our second error is the systematic error from using our best values.

10 values. 12 values. 12 ADLER 92B quote separately two systematic errors: ± 0.4 from their experiment and ± 1.0 degrees due to the uncertainty in the value of Δm .

13 KARLSSON 90 systematic error does not include regeneration phase uncertainty.

 14 CARITHERS 75 measures $\phi_{+-}=(45.5\pm2.8)+224$ [$\Delta m-0.5348$] $(^{\circ}).$ We have adjusted the measurement to use our best values of ($\Delta m=0.5293\pm0.0009)$ ($10^{10}~\hbar$ s $^{-1}$). Our first error is their experiment's error and our second error is the systematic error from using our best values. $\phi_f=-40.9\pm2.6^{\circ}.$

ϕ_{00} , PHASE OF η_{00}

See comment in ϕ_{+-} header above for treatment of Δm and τ_{S} dependence, as well as for the inclusion of data in both the "Assuming CPT" and "Not Assuming CPT"

OUR FIT is described in the note on "CP violation in K_L decays" in the K_L^0 Particle Listings.

DO CUMENT ID TECN COMMENT 43.52±0.05 OUR FIT Error includes scale factor of 1.3. Assuming CPT **43.7** \pm **0.6 OUR FIT** Error includes scale factor of 1.2. Not assuming *CPT* ¹ CAROSI $44.5 \pm 2.3 \pm 0.5$ 90 NA31 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ² ABOUZAID 11 KTEV Not assuming CPT 44.06 ± 0.68 ³ ANGELOPO... 98 CPLR $41.7 \pm 5.9 \pm 0.2$ ⁴ ADLER 96B CPLR Sup. by ANGELOPOULOS 98 $50.8 \pm 7.1 \pm 1.7$ 47.4 ±1.4 ±0.9 ⁵ KARLSSON 90 E731

 1 CAROSI 90 measures $\phi_{00}=(47.1\pm2.1\pm1.0)~+579~[\Delta m-0.5351]+252~[\tau_S-0.8922]~(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)~(10^{10}~\hbar~s^{-1}),~(\tau_S=0.8954\pm0.0004)~(10^{-10}~s).$ Our first error is their experiment's error and our second error is the systematic error from using our best values

 3 ANGELOPOULOS 98 measures $\phi_{00}=(42.0\pm5.6\pm1.9)~+~240~[\Delta m-~0.5307]~(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)~(10^{10}~\hbar~s^{-1}).$ Our first error is their experiment's error and our second error is the systematic error from using our best values. The $\tau_{\rm S}$ dependence is negligible.

 4 ADLER 96B identified initial neutral kaon individually as being a K^0 or a \overline{K}^0 . The systematic uncertainty is $\pm 1.5^\circ$ combined in quadrature with $\pm 0.8^\circ$ due to Δm .

⁵ KARLSSON 90 systematic error does not include regeneration phase uncertainty.

$\phi_\epsilon=(2\phi_{+-}+\phi_{00})/3$

This expression is a very good approximation, good to about 10^{-3} degrees because of the small measured values of $\phi_{00}-\phi_{+-}$ and Re ϵ'/ϵ , and small theoretical ambiguities.

 VALUE (°)
 DOCUMENT ID
 TECN
 COMMENT

 43.52
 ± 0.55
 OUR FIT
 Error includes scale factor of 1.2. Assuming CPT

 43.5164 ± 0.0002 ± 0.0518
 ± 0.0518
 1 SUPERWEAK 12
 Assuming CPT

 43.86
 ± 0.63
 2 ABOUZAID
 11 KTEV
 Not assuming CPT

 1 SUPERWEAK 12 is a fake measurement used to impose the CPT or Superweak constraint $\phi_{+-}=\phi_{\rm SW}=\tan^{-1}[2\,\frac{\Delta_n}{\hbar}\,\left(\frac{\tau_S\tau_L}{(\tau_-\tau_S)}].$ This "measurement" is linearized using values near the RPP 2004 edition values of $\Delta m,\,\tau_S$ and τ_L , and then adjusted to our current values as described in the following "measurement". SUPERWEAK 12 measures $\phi_\epsilon=(43.5\,0258\pm0.00021)\,+\,54.1\,[\Delta m-0.5289]\,+\,32.0\,[\tau_S-0.89564]\,(^\circ).$ We have adjusted the measurement to use our best values of $(\Delta m=0.5293\pm0.0009)\,(10^{10}\,\hbar\,{\rm s}^{-1}),\,(\tau_S=0.8954\pm0.0004)\,(10^{-10}\,{\rm s}).$ Our first error is their experiment's error and our second error is the systematic error from using our best values.

 2 ABOUZAID 11 uses the full KTeV dataset collected in 1996, 1997, and 1999. See ${\rm Im}(\epsilon'/\epsilon)$ section for correlation information.

$\operatorname{Im}(\epsilon'/\epsilon) = -(\phi_{00} - \phi_{+-})/3$

For small $|\epsilon'/\epsilon|$, ${\rm Im}(\epsilon'/\epsilon)$ is related to the phases of η_{00} and η_{+-} by the above expression.

 VALUE (°)
 DOCUMENT ID
 TECN
 COMMENT

 − 0.002 ±0.005
 OUR FIT
 Error includes scale factor of 1.7. Assuming CPT

 − 0.11 ±0.11
 OUR FIT
 Not assuming CPT

 − 0.0985±0.1157
 1 ABOUZAID
 11 KTEV
 Not assuming CPT

 1 ABOUZAID 11 uses the full KTeV dataset collected in 1996, 1997, and 1999. The fit has $\Delta m, \tau_{5}, \phi_{c}, \, \text{Re}(\epsilon'/\epsilon), \, \text{and} \, \, \text{Im}(\epsilon'/\epsilon)$ as free parameters. The reported value of $\text{Im}(\epsilon'/\epsilon)$ = $(-17.20 \pm 20.20) \times 10^{-4}$ rad. The correlation coefficients are $\rho(\phi_{\epsilon}, \, \Delta m) = 0.828, \, \rho(\phi_{\epsilon}, \, \tau_{5}) = -0.765, \, \rho(\Delta m, \, \tau_{5}) = -0.858, \, \rho(\text{Im}(\epsilon'/\epsilon), \, \phi_{\epsilon}) = -0.041, \, \rho(\text{Im}(\epsilon'/\epsilon), \, \Delta m) = 0.026, \, \rho(\text{Im}(\epsilon'/\epsilon), \, \tau_{5}) = -0.010.$

DECAY-PLANE ASYMMETRY IN $\pi^+\pi^-e^+e^-$ DECAYS

This is the CP-violating asymmetry

$$A = \frac{N_{\sin\phi\cos\phi > 0.0} - N_{\sin\phi\cos\phi < 0.0}}{N_{\sin\phi\cos\phi > 0.0} + N_{\sin\phi\cos\phi < 0.0}}$$

where ϕ is the angle between the $e^+\,e^-$ and $\pi^+\,\pi^-$ planes in the K^0_L rest frame.

CP ASYMMETRY A in $K_I^0 \rightarrow \pi^+\pi^-e^+e^-$

| VALUE (%) | DO CUMENT ID | | TECN |
|------------------------|--------------|-------|------|
| 13.7±1.5 OUR AVERAGE | | | |
| $13.6 \pm 1.4 \pm 1.5$ | ABOUZAID | 06 | KTEV |
| $14.2 \pm 3.0 \pm 1.9$ | LAI | 03c | NA48 |
| $13.6 \pm 2.5 \pm 1.2$ | ALAVI-HARA | Г100в | KTEV |

— PARAMETERS FOR e+ e- e+ e- DECAYS -

These are the *CP*-violating parameters in the ϕ distribution, where ϕ is the angle between the planes of the two $e^+\,e^-$ pairs in the kaon rest frame:

$$d\Gamma/d\phi \propto 1 + \beta_{CP} \cos(2\phi) + \gamma_{CP} \sin(2\phi)$$

β_{CP} from $K_L^0 \rightarrow e^+e^-e^+e^-$

| VALUE | EVTS | DO CUMEN | T ID | TECN | COMMENT |
|---------------------------------|-------------|----------------|----------------------|----------|----------------------------------|
| -0.19±0.07 OUR AVI | RAGE | | | | |
| $-0.13\pm0.10\pm0.03$ | 200 | 1 LAI | 05B | NA 48 | |
| $-0.23\pm0.09\pm0.02$ | 441 | ALAVI-H | ARATI01D | KTEV | $M_{ee} > 8 \text{MeV} / c^2$ |
| 1 LAI 05 B obtains eta_C | $c_P = -0.$ | 13 ± 0.10 (sta | it) if γ_{CP} | = 0 is a | ssu med. |

γ_{CP} from $K_L^0 \rightarrow e^+e^-e^+e^-$

| VALUE | EVTS | DO CUMENT | ID | TECN | COMMENT | |
|-----------------------|------|-------------------|------------|---------|----------------------------|--|
| 0.01 ± 0.11 OUR AVE | RAGE | Error includes so | ale factor | of 1.6. | | |
| $+0.13\pm0.10\pm0.03$ | 200 | LAI | 05B | NA48 | | |
| -0.09 + 0.09 + 0.02 | 441 | ALAVI-HA | RATI01D | KTEV | $M_{} > 8 \text{ MeV}/c^2$ | |

- CHARGE ASYMMETRY IN $\pi^+\pi^-\pi^0$ DECAYS :

These are CP-violating charge-asymmetry parameters, defined at beginning of section "LINEAR COEFFICIENT g FOR $K_L^0 \to \pi^+\pi^-\pi^0$ above. See also note on Dalitz plot parameters in K^\pm section and note on "CP violation in K_L decays" above.

LINEAR COEFFICIENT j FOR $K_L^0 ightarrow \pi^+\pi^-\pi^0$

| VALUE | EVTS | DOCUMENT ID | | TECN |
|--------------------------------|------|-------------|-----|------|
| 0.0012±0.0008 OUR AVE | RAGE | | | |
| $0.0010 \pm 0.0024 \pm 0.0030$ | 500k | A NGEL OP O | 98c | CPLR |
| -0.001 ± 0.011 | 6499 | СНО | 77 | |
| 0.001 ± 0.003 | 4709 | PEACH | 77 | |
| 0.0013 ± 0.0009 | 3M | SCRIBANO | 70 | |
| 0.0 ± 0.017 | 4400 | SMITH | 70 | OSPK |
| 0.001 ± 0.004 | 238k | BLANPIED | 68 | |

QUADRATIC COEFFICIENT f FOR $K_L^0 ightarrow \pi^+\pi^-\pi^0$

DOCUMENT ID <u>VALUE</u> <u>EVTS</u> **0.0045±0.0024±0.0059** 500k ANGELOPO... 98c CPLR

- PARAMETERS for $K_I^0 ightarrow \, \pi^+ \, \pi^- \gamma$ DECAY -

$|\eta_{+-\gamma}| = |A(K_L^0 \to \pi^+\pi^-\gamma, CP \text{ violating})/A(K_S^0 \to \pi^+\pi^-\gamma)|$ DOCUMENT ID TECN 2.35 ±0.07 OUR AVERAGE

 $2.359 \pm 0.062 \pm 0.040$ MATTHEWS 95 E773 $2.15\ \pm0.26\ \pm0.20$ RAMBERG 93B E731

 $\phi_{+-\gamma}=$ phase of $\eta_{+-\gamma}$

VALUE (°) EV 43.8± 3.5± 1.9 $72 \pm 23 \pm 17$

DO CUMENT ID MATTHEWS 95 E773

 $\big|\epsilon_{+-\gamma}^{'}\big|/\epsilon \text{ for } K_L^0 \to \ \pi^+\pi^-\gamma$

DOCUMENT ID 1 RAMBERG 93B E731

 $^1\,{\rm RA\,MBERG}$ 93B limit on $|\epsilon_{+-\gamma}'|/\epsilon$ assumes than any difference between η_{+-} and $\eta_{+-\gamma}$ is due to direct *CP* violation.

$|{\bf g}_{E1}|$ for $K_L^0\to~\pi^+\pi^-\gamma$

This parameter is the amplitude of the direct emission of a *CP* violating E1 electric dipole photon.

VALUE CL% EVTS DO CUMENT ID TECN COMMENT ABOUZAID 06A KTEV $E_{\gamma}^{*} > 20~{
m MeV}$ < 0.21

T VIOLATION TESTS IN K1 DECAYS

${\sf Im}(\xi)$ in $K^0_{\mu3}$ DECAY (from transverse μ pol.)

| Test of T rev | rersal invariance | S | | | | |
|-----------------------|-------------------|------------------------|---------|---------|-------------------|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| -0.007 ± 0.026 OU | R AVERAGE | | | | | |
| 0.009 ± 0.030 | 12M | MORSE | 80 | CNTR | Polarization | |
| 0.35 ± 0.30 | 207k | ¹ CLARK | | SPEC | POL, $t=0$ | |
| -0.085 ± 0.064 | 2.2M | ² SANDWEISS | 73 | CNTR | POL, $t=0$ | |
| -0.02 ± 0.08 | | LONGO | 69 | CNTR | POL, $t=3.3$ | |
| -0.2 ± 0.6 | | ABRA MS | 68B | OSP K | Polarization | |
| • • • We do not ι | ıse the following | g data for average | s, fits | limits, | etc. • • • | |
| 0.012 ± 0.026 | | SCHMIDT | 79 | CNTR | Repl. by MORSE 80 | |

¹ CLARK 77 value has additional $\xi(0)$ dependence $+0.21 \mathrm{Re} [\xi(0)]$.

CPT-INVARIANCE TESTS IN K? DECAYS

PHASE DIFFERENCE ϕ_{00} - ϕ_{+-}

Test of CPT.

OUR FIT is described in the note on "CP violation in K_L decays" in the K_L^0 Particle

| VALUE (°) | DO CUMENT ID | TECN | COMMENT |
|----------------------------|-----------------------------------|---------|---------------------|
| 0.006 ± 0.014 OUR FIT | Error includes scale factor of 1 | .7. Ass | uming CPT |
| 0.34 ± 0.32 OUR FIT | Not assuming CPT | | |
| 0.006 ± 0.008 | ¹ SUPERWEAK 12 | | Assuming CPT |
| -0.30 ± 0.88 | ² SCHWINGEN 95 | | Combined E731, E773 |
| • • • We do not use the f | ollowing data for averages, fits, | limits, | etc. • • • |
| 0.30 ± 0.35 | ³ ABOUZAID 11 | KTEV | Not assuming CPT |
| $0.39 \pm 0.22 \pm 0.45$ | 4 ALAVI-HARATI 03 | KTEV | |
| $0.62 \pm 0.71 \pm 0.75$ | _ SCHWINGEN 95 | E773 | |
| -1.6 ± 1.2 | ⁵ GIBBONS 93 | E731 | |
| $0.2 \pm 2.6 \pm 1.2$ | ⁶ CAROSI 90 | NA 31 | |
| -0.3 ± 2.4 ± 1.2 | KARLSSON 90 | E731 | |

 $^{^1}$ SUPERWEAK 12 is a fake experiment to constrain $\phi_{00}-\phi_{+-}$ to a small value as described in the note "CP violation in K_L decays."

PHASE DIFFERENCE ϕ_{+-} - ϕ_{SW}

Test of *CPT*. The Superweak phase $\phi_{
m SW} \equiv an^{-1} \left(2\Delta m/\Delta\Gamma
ight)$ where $\Delta m = m_{K_0^0}$ $m_{K_S^0}$ and $\Delta\Gamma = \hbar(au_L - au_S)/(au_L au_S).$

VALUE (°)
 VALUE (°)
 DOCUMENT ID
 TECN

 0.61±0.62±1.01
 1 ALAVI-HARATIO3
 KTEV

 1 ALAVI-HARATI 03 fit is the same as their ϕ_{+-} , τ_{K_S} , Δm fit, except that the parameter $\phi_{+-} - \phi_{\mathrm{SW}}$ is used in place of ϕ .

$Re(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}) - \frac{A_L}{2}$ Test of *CPT*

VALUE (units 10^{-6}) $\frac{_{DOCUMENT\ ID}}{^{1}}\frac{_{DOCUMENT\ ID}}{^{1}}\frac{_{TECN}}{^{1}}\frac{_{COMMENT}}{^{1}}\frac{_{COMMENT}}{^{1}}$ -3 ± 35 $^1\,\mathrm{ALAVI}\text{-HARATI}$ 02 uses PDG 00 values of η_{+-} and $\eta_{00}.$

$\Delta S = \Delta Q \text{ IN } K^0 \text{ DECAYS}$

The relative amount of $\Delta S \neq \Delta Q$ component present is measured by the parameter x, defined as

$$x = A(\overline{K}^0 \to \pi^- \ell^+ \nu) / A(K^0 \to \pi^- \ell^+ \nu)$$
.

We list $Re\{x\}$ and $Im\{x\}$ for K_{e3} and $K_{\mu3}$ combined.

$x = A(\overline{K}^0 \rightarrow \pi^- \ell^+ \nu)/A(K^0 \rightarrow \pi^- \ell^+ \nu) = A(\Delta S = -\Delta Q)/A(\Delta S = \Delta Q)$

REAL PART OF x

| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------|--------------------|-------------|-----------------------|---------|------------|-------------------------------------------|
| -0.0018 | B±0.0041±0.0045 | | ANGELOPO | 98D | CPLR | K_{e3} from K^0 |
| • • • V | Ve do not use the | following d | ata for averages, fi | ts, lin | nits, etc. | |
| 0.10 | $^{+0.18}_{-0.19}$ | 79 | SMITH | 75B | WIRE | $\pi^- \rho \rightarrow \kappa^0 \Lambda$ |
| 0.04 | ±0.03 | 4724 | NIEBERGALL | 74 | ASPK | $K^+ p \rightarrow K^0 p \pi^+$ |
| -0.008 | ±0.044 | 1757 | FACKLER | 73 | OSP K | K_{e3} from K_{e3}^0 |
| -0.03 | ± 0.07 | 1367 | HART | 73 | OSP K | K_{e3} from $K^{0}\Lambda$ |
| -0.070 | ± 0.036 | 1079 | MALLARY | 73 | OSP K | K_{e3} from $K^0\Lambda X$ |
| 0.03 | ± 0.06 | 410 | ¹ BURGUN | 72 | HBC | $K^+ \rho \rightarrow K^0 \rho \pi^+$ |
| 0.04 | $^{+0.10}_{-0.13}$ | 100 | ² GRAHA M | 72 | OSP K | $K_{\mu 3}$ from $K^0 \Lambda$ |
| -0.05 | ± 0.09 | 442 | ² GRAHAM | 72 | OSP K | $\pi^- p \rightarrow K^0 \Lambda$ |
| 0.26 | $+0.10 \\ -0.14$ | 126 | MANN | 72 | нвс | $K^- \rho \rightarrow n \overline{K}^0$ |
| -0.13 | ±0.11 | 342 | ² MANTSCH | 72 | OSP K | K_{e3} from $K^0\Lambda$ |
| 0.04 | $^{+0.07}_{-0.08}$ | 222 | ¹ BURGUN | 71 | нвс | $K^+\rho\to~K^0\rho\pi^+$ |
| 0.25 | +0.07 -0.09 | 252 | WEBBER | 71 | нвс | $K^- p \rightarrow n \overline{K}^0$ |
| 0.12 | ± 0.09 | 215 | ³ сно | 70 | DBC | $K^+d \rightarrow K^0pp$ |
| -0.020 | ±0.025 | | ⁴ BENNETT | 69 | CNTR | Charge asym+ Cu regen. |
| 0.09 | $^{+0.14}_{-0.16}$ | 686 | LITTENBERG | 69 | OSPK | $K^+ n \rightarrow K^0 p$ |
| 0.03 | ± 0.03 | | ⁴ BENNETT | 68 | CNTR | |
| 0.09 | $^{+0.07}_{-0.09}$ | 121 | JA MES | 68 | нвс | $\overline{p}p$ |
| 0.17 | $^{+0.16}_{-0.35}$ | 116 | FELDMAN | 67в | OSP K | $\pi^- p \rightarrow \kappa^0 \Lambda$ |
| 0.17 | ±0.10 | 3 3 5 | ³ HILL | 67 | DBC | $K^+ d \rightarrow K^0 pp$ |
| 0.035 | $^{+0.11}_{-0.13}$ | 196 | AUBERT | 65 | HLBC | K^+ charge exch. |
| 0.06 | $^{+0.18}_{-0.44}$ | 152 | ⁵ BALDO | 65 | HLBC | K^+ charge exch. |
| -0.08 | $^{+0.16}_{-0.28}$ | 109 | ⁶ FRANZINI | 65 | нвс | $\overline{\rho} p$ |

 $^6\,\mathrm{FRA\,NZI\,NI}$ 65 gives x and θ for $\mathrm{Re}(x)$ and $\mathrm{Im}(x)$. See SCHMIDT 67.

IMAGINARY PART OF x

ı

Assumes $m_{\kappa_L^0}-m_{\kappa_S^0}$ positive. See Listings above. CVTC

| VALUE | EVIS | DOCUMENTID | | IECN | COMMENT |
|--------------------------------------------------------|---------|-------------------------|--------|----------|---------------------------------------|
| $0.0012 \pm 0.0019 \pm 0.0009$ | 640k | A NGEL OP O | 01в | CPLR | K_{e3} from K^0 |
| • • • We do not use the fo | llowing | data for averages, fits | , limi | ts, etc. | • • • |
| $0.0012\!\pm\!0.0019$ | 640k | ¹ A NGELOP O | 98E | CPLR | K_{e3} from K^0 |
| $-0.10 {}^{+\ 0.16}_{-\ 0.19}$ | 79 | SMITH | | | |
| -0.06 ± 0.05 | 4724 | NIEBERGALL | 74 | ASPK | $K^+ \rho \rightarrow K^0 \rho \pi^+$ |
| -0.017 ± 0.060 | 1757 | FACKLER | 73 | OSPK | K_{e3} from K^0 |
| 0.09 ±0.07 | 1367 | HART | 73 | OSPK | K_{e3} from $K^0\Lambda$ |
| $0.107 \begin{array}{l} +0.092 \\ -0.074 \end{array}$ | 1079 | MALLARY | 73 | OSPK | K_{e3} from $K^0\Lambda X$ |
| $\begin{array}{ccc} 0.07 & +0.06 \\ -0.07 \end{array}$ | 410 | ² BURGUN | 72 | нвс | $K^+ \rho \to K^0 \rho \pi^+$ |

 $^{^2}$ SANDWEISS 73 value corrected from value quoted in their paper due to new value of Re(\$\xi\$). See footnote 4 of SCHMIDT 79.

²This SCHWINGENHEUER 95 values is the combined result of SCHWINGENHEUER 95 and GIBBONS 93, accounting for correlated systematic errors.

 $^{^{3}\,\}mathrm{Not}$ independent of other phase parameters reported in ABOUZAID 11.

 $^{^4}$ ALAVI-HARATI 03 fit Re($\epsilon'/\epsilon)$, Im($\epsilon'/\epsilon)$, Δm , τ_S , and ϕ_{+-} simultaneously, not assuming CPT. Phase difference is obtained from $\phi_{00}-\phi_{+-}\approx -3{\rm Im}(\epsilon'/\epsilon)$ for small $|\epsilon'/\epsilon|$. Superseded by ABOUZAID 11.

⁵ GIBBONS 93 give detailed dependence of systematic error on lifetime (see the section on the K_S^0 mean life) and mass difference (see the section on $m_{K_L^0}-m_{K_S^0}$.

 $^{^6}$ CAROSI 90 is excluded from the fit because it it is not independent of ϕ_{+-} and ϕ_{00}

 $[\]frac{1}{2}$ BURGUN 72 is a final result which includes BURGUN 71. $\frac{2}{3}$ First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72. $\frac{3}{3}$ CHO 70 is analysis of unambiguous events in new data and HILL 67.

⁴BENNETT 69 is a reanalysis of BENNETT 68.

⁵ BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x).

| 0.12 | $^{+0.17}_{-0.16}$ | 100 | ³ GRAHAM | 72 | OSPK | $K_{\mu 3}$ from $K^0 \Lambda$ |
|--------|--------------------|-----|-----------------------|-----|------|--------------------------------------|
| 0.05 | ±0.13 | 442 | ³ GRAHAM | 72 | OSPK | $\pi^- p \rightarrow K^0 \Lambda$ |
| 0.21 | $^{+0.15}_{-0.12}$ | 126 | MANN | 72 | нвс | $K^- p \rightarrow n \overline{K}^0$ |
| -0.04 | ±0.16 | 342 | ³ MANTSCH | 72 | OSPK | K_{e3} from $K^0 \Lambda$ |
| 0.12 | $^{+0.08}_{-0.09}$ | 222 | ² BURGUN | 71 | нвс | $K^+ \rho \to K^0 \rho \pi^+$ |
| 0.0 | ± 0.08 | 252 | WEBBER | 71 | HBC | $K^- p \rightarrow n \overline{K}^0$ |
| -0.08 | ±0.07 | 215 | ⁴ CHO | 70 | DBC | $K^+ d \rightarrow K^0 p p$ |
| -0.11 | $^{+0.10}_{-0.11}$ | 686 | LITTENBERG | 69 | OSPK | $K^+ n \rightarrow K^0 p$ |
| + 0.22 | $^{+0.37}_{-0.29}$ | 121 | JAMES | 68 | нвс | $\overline{p}p$ |
| 0.0 | ±0.25 | 116 | FELDMAN | 67B | | $\pi^- p \rightarrow K^0 \Lambda$ |
| -0.20 | ±0.10 | 335 | ⁴ HILL | 67 | DBC | $K^+ d \rightarrow K^0 p p$ |
| -0.21 | $^{+0.11}_{-0.15}$ | 196 | AUBERT | 65 | HLBC | K^+ charge exch. |
| -0.44 | $^{+0.32}_{-0.19}$ | 152 | ⁵ BALDO | 65 | HLBC | K^+ charge exch. |
| + 0.24 | $^{+0.40}_{-0.30}$ | 109 | ⁶ FRANZINI | 65 | нвс | $\overline{p}p$ |
| | | | | | | |

- 1 Superseded by ANGELOPOULOS 01B. 2 BURGUN 72 is a final result which includes BURGUN 71. 3 First GRAHAM 72 value is second GRAHAM 72 value combined with MANTSCH 72. 4 Footnote 10 of HILL 67 should read + 0.58, not 0.58 (private communication) CHO 70 is analysis of unambiguous events in new data and HILL 67. 5 BALDO-CEOLIN 65 gives x and θ converted by us to Re(x) and Im(x). 6 FRANZINI 65 gives x and θ for Re(x) and Im(x). See SCHMIDT 67.

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| ADAMS 98 | 8 | PRL 80 4123 | J. Adams et al. D. Ambrose et al. | (FNAL KTeV Collab.) |
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| ARISAKA 98 | 8 | PL B432 230 | A. Angelopoulos et al. K. Arisaka et al. | (FNAL E799 Collab.) |
| BENDER 98 DAMBROSIO 98 | | PL B418 411 PL B423 385 | M. Bender et al. G. D'Ambrosio, G. Isidor | (ČERN NA48 Collab.) |
| SETZU 98 | 8 | PL B420 205 | M.G. Setzu et al. | |
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| NOMURA 97 | 7 | PL B408 445 | T. Nomura et al. | (KYOT, KEK, HIRO) |
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| ADLER 95 AKAGI 95 | 5 | PL B363 243 PR D51 2061 | R. Adler et al. T. Akagi et al. | (CPLEAR Collab.) (TOHOK, TOKY, KYOT, KEK) |
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| NAKAYA 94 | 4 | PRL 73 2169 PR D50 1874 | T. Nakaya et al. D. Roberts et al. | (OSAK, UCLA, EFI, COLU+) (UCLA, EFI, COLU+) |
| ROBERTS 94 WEAVER 94 | | PR D50 1874 PRL 72 3758 | M. Weaver et al. | (UCLA, EFI, COLU+) (UCLA, EFI, COLU, ELMT+) |
| AKAGI 93 | 3 | PR D47 R2644 | T. Akagi et al. | (TÔHOK, TOKY, KYOT, KEK) |
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| HARRIS 93 MAKOFF 93 | | PRL 71 3918 PRL 70 1591 | D.A. Harris et al. G. Makoff et al. | (EFI, UCLA, COLO+) (FNAL E731 Collab.) |
| A Iso | | PRL 75 2069 (erratum) | G. Makoff et al. | |
| RAMBERG 93 RAMBERG 93 | 3B | PRL 70 2525 PRL 70 2529 | E. Ramberg et al. E.J. Ramberg et al. | (FNAL E731 Collab.) (FNAL E731 Collab.) |
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| BARR 92 GRAHAM 92 | | PL B284 440 PL B295 169 | G.D. Barr et al. G.E. Graham et al. | (CERN, EDIN, MANZ, LALO+) (FNAL E731 Collab.) |
| MORSE 92 | | PR D45 36 PR D45 S1 | W.M. Morse et al. | (BNL, YALE, VASS) (KEK, LBL, BOST+) |
| PDG 92 SOMALWAR 92 | | PR D45 S1 PRL 68 2580 | K. Hikasa et al. S.V. Somalwar et al. | (KEK, LBL, BOST+) (FNAL E731 Collab.) |
| AKA GI 91 | 1B | PRL 67 2618 | T. Akagi et al. | (TOHOK, TOKY, KYOT, KEK) |
| BARR 91 HEINSON 91 | 1 | PL B259 389 PR D44 R1 | G.D. Barr et al. A.P. Heinson et al. | (CERN, EDIN, MANZ, LALO+) (UCI, UCLA, LANL+) |
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| Also PDG 86 | | PRL 48 1078 PL 170B 132 | S.H. Aronson et al. | (BNL, CHIC, STAN+) |
| COUPAL 85 | 5 | PRL 55 566 | M. Aguilar-Benitez et al. D.P. Coupal et al. | (CERN, CIT+) (CHIC, SACL) |
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K_L^0 , $K_0^*(800)$

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| GJESDAL BALDO | 76 75 | NP B109 118 NC 25A 688 | G. Gjesdal et al. M. Baldo-Ceolin et al. | (CÉRN, HEIDH) |
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| SMITH BISI | 75 B 74 | Thesis UCSD unpub. | J.G. Smith | (UCSD) |
| DONALDSON | 74 | PL 50B 504 Thesis SLAC-0184 | V. Bisi, M.I. Ferrero G. Donaldson | (TORI) (SLAC) |
| Also DONALDS ON | 74 B | PR D14 2839 PR D9 2960 | G. Donaldson et al. G. Donaldson et al. | (SLAC) (SLAC, UCSC) |
| A Iso | | PRL 31 337 | G. Donaldson et al. | (SLAC, UCSC) (CERN, HEIDH) |
| GEWENIGER Also | 74 | PL 48B 483 Thesis CERN Int. 74-4 | C. Geweniger <i>et al.</i> V. Luth | (CERN, HEIDH) (CERN) |
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| Also | | PR D9 2939 PR D6 1834 | R. Piccioni et al. | (SLAC, UCSC, COLO) (RUTG, MASA) (RUTG, MASA) |
| V OS BUR GH Also | 72 | PRL 26 866 | K.G. Vosburgh et al. K.G. Vosburgh et al. | (RUTG, MASA) |
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| KLEINKNECHT | 92 | CNPP 20 281 | K. Kleinknecht | (MANZ) |
| | | CP Violation in Decays of | | |
| KLEINKNECHT | | ZPHY C46 S57 | K. Kleinknecht | (MANZ) |
| PEACH | 90 | JPG 16 131 | K.J. Peach | (EDIN) |
| BRYMAN | 89 | IJMP A4 79 | D.A. Bryman | (TRIU) |
| "Rare Kaoi | | | | |
| KLEINKNECHT | 76 | ARNS 26 1 | K. Kleinknecht | (DORT) |
| GINSBERG | 73 | PR D8 3887 | E.S. Ginsberg, J. Smith | (MIT, STON) |
| GINSBERG | 70 | PR D1 229 | E.S. Ginsberg | (HAIF) |
| HEUSSE | 70 | LNC 3 449 | P. Heusse et al. | (ORSAY) |
| CRONIN | 68 C | Vienna Conf. 281 | J.W. Cronin | `(PRIN) |
| RUBBIA | 67 | PL 24B 531 | C. Rubbia, J. Steinberger | (CERN, COLUÍ) |
| A Iso | | PL 23 167 | C. Rubbia, J. Steinberger | (CERN, COLU) |
| A Iso | | PL 20 207 | C. Alff-Steinberger et al. | ` (CERN) |
| Also | | PL 21 595 | C. Alff-Steinberger et al. | (CERN) |
| AUERBACH | 66 | PR 149 1052 | L.B. Auerbach et al. | (PENN) |
| Also | | PRL 14 192 | L.B. Auerbach et al. | (PENN) |
| FIRESTONE | 66B | PRL 17 116 | A. Firestone et al. | (YALE, BNL) |
| BEHR | 65 | Argonne Conf. 59 | I Behr et al | (EPOL, MILA, PADO) |
| MESTVIRISH | 65 | JINR P 2449 | A.N. Mestvirishvili et al. | (JINR) |
| TRILLING | 65 B | UCRL 16473 | G.N. Trilling | `(LRL) |
| | | 65 Argonne Conference, p | | () |
| JOVA NOV | 63 | | J.V. Jovanovich et al. | (BNL, UMD) |
| | | | | |



$$I(J^P) = \frac{1}{2}(0^+)$$

OMITTED FROM SUMMARY TABLE

Needs confirmation. See the mini-review on scalar mesons under $f_0(500)$ (see the index for the page number).

$K_0^*(800)$ MASS

| VALU | E (MeV | | EVTS | DO CUMENT ID | T | ECN C | COMMENT |
|-------|----------------|--------------------|------------|-------------------------|-----------|--------------|----------------------------------------------------|
| 682 | ±29 | OUR A | /ERAGE | Error includes scal | e factor | of 2.4. | See the ideogram below |
| 826 | ± 49 | $^{+49}_{-34}$ | 1338 | ¹ ABLIKIM | 11B B | ES2 | $J/\psi \rightarrow K_S^0 K_S^0 \pi^+ \pi^-$ |
| 849 | ±77 | $^{+18}_{-14}$ | 1421 | ^{2,3} ABLIKIM | 10E B | ES2 . | $J/\psi \rightarrow K^{\pm} K_S^0 \pi^{\mp} \pi^0$ |
| 841 | ± 30 | $^{+\ 81}_{-\ 73}$ | 25 k | ^{4,5} ABLIKIM | 06c B | ES2 | $J/\psi \to \overline{K}^*(892)^0 K^+ \pi^-$ |
| 658 | ± 13 | | | ⁶ DESCOTES-G | 06 R | VUE 1 | $\tau K \rightarrow \pi K$ |
| 797 | ± 19 | ± 43 | 15k | ^{7,8} AITALA | 02 E | 791 <i>I</i> | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| • • | • We | do not us | e the foll | owing data for avera | ges, fits | , limits | , etc. • • • |
| 663 | ± 8 | ± 34 | | ⁹ BUGG | 10 R | VUE S | S-matrix pole |
| 706.0 | 0 ± 1.8 | 3 ± 22.8 | 141k | ¹⁰ BONVICINI | 08A C | LEO <i>I</i> | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| 856 | ± 17 | ± 13 | 54k | ¹¹ LINK | 07B F | ocs I | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| 750 | $^{+30}_{-55}$ | | | ¹² BUGG | 06 R | VUE | |
| 855 | ± 15 | | 0.6k | ¹³ CAWLFIELD | 06A C | LEO <i>I</i> | $D^0 \rightarrow K^+ K^- \pi^0$ |
| 694 | ± 53 | | | ^{3,14} ZHOU | 06 R | VUE / | $Kp \rightarrow K^-\pi^+ n$ |
| 753 | ± 52 | | | ¹⁵ PELAEZ | 04A R | VUE / | $K\pi \rightarrow K\pi$ |
| 594 | ±79 | | | ¹⁴ ZHENG | 04 R | VUE / | $K^- p \rightarrow K^- \pi^+ n$ |
| 722 | ±60 | | | ¹⁶ BUGG | 03 R | VUE 1 | $1 K^- p \rightarrow K^- \pi^+ n$ |
| 905 | $^{+65}_{-30}$ | | | ¹⁷ ISHIDA | 97B R | VUE 1 | $1 K^- p \rightarrow K^- \pi^+ n$ |

 $^{^1}$ The Breit-Wigner parameters from a fit with seven intermediate resonances. The S-matrix pole position is $(764\pm63^{+71}_{-54})-i~(306\pm149^{+143}_{-85})$ MeV.

The second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of t

from ABLIKIM 06c well describes the left slope of the $\kappa_S^0\pi^-$ invariant mass spectrum in $au^-
ightarrow au^0_S \pi^-
u_ au$ decay studied by EPIFA NOV 07.

⁶ S-matrix pole. Using Roy-Steiner equations (ROY 71) as well as unitarity, analyticity and crossing symmetry constraints.

- 7 Not seen by KOPP 01 using 7070 events of ${\it D}^{\,0} \rightarrow {\it K}^-\,\pi^+\,\pi^0.$ LINK 02E and LINK 051 show clear evidence for a constant non-resonant scalar amplitude rather than $K_0^*(800)$ in their high statistics analysis of D^+ ightarrow $\kappa^-\pi^+\mu^+\nu_{\mu^+}$
- 8 AUBERT 07T does not find evidence for the charged $K_0^*(800)$ using 11k events of $D^0 \to$
- 9 S-Matrix pole. Supersedes BUGG 06. Combined analysis of ASTON 88, ABLIKIM 06c, AITALA 06, and LINK 09 using an s-dependent width with couplings to $K\pi$ and $K\eta'$, and the Adler zero near thresholds.

 10 T-matrix pole.

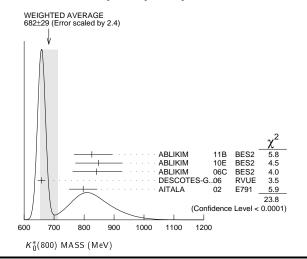
- 12 A Breit-Wigner mass and width. 12 S-matrix pole. Reanalysis of ASTON 88, AITALA 02, and ABLIKIM 06c using for the κ an s-dependent width with an Adler zero near threshold.
- 13 Breit-Wigner parameters. A significant S-wave can be also modeled as a non-resonant contribution.

 14 Using ASTON 88.
- 17 Using ASION 88.

 15 T-matrix pole. Reanalysis of data from LINGLIN 73, ESTABROOKS 78, and ASTON 88 in the unitarized ChPT model.

 16 T-matrix pole. Reanalysis of ASTON 88 data.

 17 Reanalysis of ASTON 88 using interfering Breit-Wigner amplitudes.



K*(800) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|--------------------------------------------------------|-------------------|-------------------------|-----------------|------------------------------------------------------|
| | /ERAGE | Error includes sca | le factor of 1 | 1. |
| 449 $\pm 156 \begin{array}{c} +144 \\ -81 \end{array}$ | 1338 | ¹⁸ ABLIKIM | 11B BES2 | $J/\psi \rightarrow K_S^0 K_S^0 \pi^+ \pi^-$ |
| $512 \pm 80 + 92 \\ - 44$ | 1421 19 | , ²⁰ ABLIKIM | 10E BES2 | $J/\psi \rightarrow K^{\pm} K_S^0 \pi^{\mp} \pi^0$ |
| 618 \pm 90 $^{+}_{-144}$ | 25k ¹⁹ | ,21 ABLIKIM | 06c BES2 | $J/\psi \rightarrow \overline{K}^*(892)^0 K^+ \pi^-$ |
| 557 ± 24 | | 22 DESCOTES-G. | 06 RVUE | $\pi K \rightarrow \pi K$ |
| 410 \pm 43 \pm 87 | 15k ²³ | ^{,24} AITALA | 02 E791 | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| ● ● We do not use | the follow | ving data for averag | ges, fits, limi | ts, etc. • • • |
| $658 \pm 10 \pm 44$ | | ²⁵ BUGG | 10 RVUE | S-matrix pole |
| 638.8± 4.4± 40.4 | 141k | ²⁶ BONVICINI | 08A CLEO | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| $464 \pm 28 \pm 22$ | 54k | ²⁷ LINK | 07B FOCS | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| 684 ±120 | | ²⁸ BUGG | 06 RVUE | |
| 251 ± 48 | 0.6k | ²⁹ CAWLFIELD | 06A CLEO | $D^0 \rightarrow K^+ K^- \pi^0$ |
| 606 ± 59 | 19 | ^{,30} ZHOU | 06 RVUE | $Kp \rightarrow K^-\pi^+ n$ |
| 470 ± 66 | | ³¹ PELAEZ | 04A RVUE | $K\pi \rightarrow K\pi$ |
| 724 ±332 | | ³⁰ ZHENG | 04 RVUE | $K^- p \rightarrow K^- \pi^+ n$ |
| 772 ± 100 | | ³² BUGG | 03 RVUE | 11 $K^-p \rightarrow K^-\pi^+n$ |
| $545 \begin{array}{c} +235 \\ -110 \end{array}$ | | ³³ ISHIDA | 97B RVUE | 11 $K^- p \rightarrow K^- \pi^+ n$ |

- $^{18}\,\mathrm{The}$ Breit-Wigner parameters from a fit with seven intermediate resonances. The Smatrix pole position is $(764 \pm 63^{+71}_{-54}) - i (306 \pm 149^{+143}_{-85})$ MeV.
- $^{\rm 20}\,{\rm From}$ a fit including ten additional resonances and energy-independent Breit-Wigner
- 21 A fit in the $K_0^*(800) + K^*(892) + K^*(1410)$ model with mass and width of the $K_0^*(800)$ from ABLIKIM 06c well describes the left slope of the $K_S^0\pi^-$ invariant mass spectrum in $\tau^- \to K_S^0 \pi^- \nu_\tau$ decay studied by EPIFANOV 07.
- $^{22}\,\text{S-matrix pole.}$ Using Roy-Steiner equations (ROY 71) as well as unitarity, analyticity and crossing symmetry constraints.
- 23 Not seen by KOPP 01 using 7070 events of $D^0 \to K^-\pi^+\pi^0$. LINK 02E and LINK 051 show clear evidence for a constant non-resonant scalar amplitude rather than $K_0^*(800)$ in their high statistics analysis of ${\it D}^+ \rightarrow ~{\it K}^- \pi^+ \mu^+ \, \nu_\mu.$
- $^{24}\,\text{AUBERT}$ 07T does not find evidence for the charged $K_0^*(800)$ using 11k events of $D^0\to$
- $K^-K^+\pi^0.$ 25 S-Matrix pole. Supersedes BUGG 06. Combined analysis of ASTON 88, ABLIKIM 06c, AITALA 06, and LINK 09 using an s-dependent width with couplings to $K\pi$ and $K\eta'$, and the Adler zero near thresholds.

- ²⁶ T-matrix pole.
- ²⁷ A Breit-Wigner mass and width.
- 28 S-matrix pole. Reanalysis of ASTON 88, AITALA 02, and ABLIKIM 06c using for the κ
- non-resonant contribution.
 30 Using ASTON 88.
- 31 T-matrix pole. Reanalysis of data from LINGLIN 73, ESTABROOKS 78, and ASTON 88
- in the unitarized ChPT model.

 32 T-matrix pole. Reanalysis of ASTON 88 data.
- 33 Reanalysis of ASTON 88 using interfering Breit-Wigner amplitudes.

K*(800) REFERENCES

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|--------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CAWLFIELD 06A | PR D74 031108R | C. Cawlfield et al. | (CLEO Collab.) |
| DESCOTES-G06 GUO 06 ZHOU 06 | EPJ C48 553 NP A773 78 NP A775 212 | S. Descotes-Genon, B. Mo F.K. Guo et al. Z.Y. Zhou, H.Q. Zheng | uss a llam |
| LINK 051 PELAEZ 04A ZHENG 04 BUGG 03 | PL B621 72 MPL A19 2879 NP A733 235 PL B572 1 | J.M. Link et al. J.R. Pelaez H.Q. Zheng et al. D.V. Bugg | (FNAL FOCUS Collab.) |
| AITALA 02 LINK 02E | PRL 89 121801 PL B535 43 | E.M. Aitala et al. J.M. Link et al. | (FNAL E791 Collab.) (FNAL FOCUS Collab.) |
| KOPP 01 ISHIDA 97B | PR D63 092001 PTP 98 621 | S. Kopp et al. S. Ishida et al. | (CLEO Collab.) |
| ASTON 88 ESTABROOKS 78 LINGLIN 73 ROY 71 | NP B296 493 NP B133 490 NP B55 408 PL 36B 353 | D. Aston <i>et al.</i> P.G. Estabrooks <i>et al.</i> D. Linglin S.M. Roy | (SLAC, NAGO, CINC, INUS) (MCGI, CARL, DURH+) (CERN) |

K*(892)

$$I(J^P) = \frac{1}{2}(1^-)$$

K*(892) MASS

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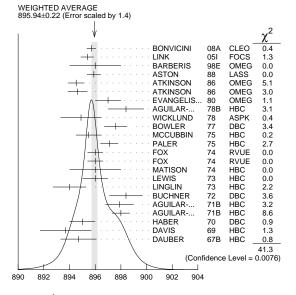
| CHA | RGED ONL | Y, HAD | ΚU | PRODUCE | ט | | | |
|--------|------------------|----------------|-----|-----------------|-------|-----------|---------|-------------------------------------------------------------------------------|
| VALUE | | EVTS | | DOCUMENT ID | | TECN | CHG | COMMENT |
| 891.66 | ±0.26 OUR | AVERAG | Ε | | | | | |
| 892.6 | ±0.5 | 5840 | | BAUBILLIER | 84B | HBC | - | 8.25 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 888 | ± 3 | | | NAPIER | 84 | SPEC | + | $200 \pi^{-} p \rightarrow 2K_{S}^{0} X$ |
| 891 | ± 1 | | | NAPIER | 84 | SPEC | _ | $200 \pi^- p \rightarrow 2K_S^0 X$ |
| 891.7 | ±2.1 | 3700 | | BARTH | 83 | нвс | + | 70 $K^+ p \rightarrow K^0 \pi^+ X$ |
| 891 | ± 1 | 4100 | | TOAFF | 81 | HBC | _ | 6.5 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 892.8 | ± 1.6 | | | AJINENKO | 80 | HBC | + | 32 $K^+ p \rightarrow K^0 \pi^+ X$ |
| 890.7 | ±0.9 | 1800 | | AGUILAR | 78B | HBC | \pm | $0.76 \overline{p} p \rightarrow K^{\mp} K_S^0 \pi^{\pm}$ |
| 886.6 | ±2.4 | 1225 | | BALAND | 78 | HBC | \pm | $12 \overline{p}p \rightarrow (K\pi)^{\pm} X$ |
| 891.7 | ±0.6 | 6706 | | COOPER | 78 | HBC | \pm | $0.76 \overline{p} p \rightarrow (K \pi)^{\pm} X$ |
| 891.9 | ±0.7 | 9000 | 1 | PALER | 75 | нвс | - | 14.3 $K^- p \rightarrow (K \pi)^-$ |
| 892.2 | ±1.5 | 4404 | | AGUILAR | 71B | нвс | - | $\begin{array}{c} X \\ 3.9,4.6 \ K^- p \rightarrow \\ (K\pi)^- p \end{array}$ |
| 891 | ± 2 | 1000 | | CRENNELL | 69D | DBC | _ | $3.9 K^- N \rightarrow K^0 \pi^- X$ |
| 890 | ± 3.0 | 720 | | BARLOW | 67 | нвс | \pm | $1.2 \overline{p} p \rightarrow (K^0 \pi)^{\pm} K^{\mp}$ |
| 889 | ± 3.0 | 600 | | BARLOW | 67 | нвс | \pm | $1.2 \overline{p}p \rightarrow (K^0 \pi)^{\pm} K \pi$ |
| 891 | ± 2.3 | 620 | 2 | DEBAERE | 67B | нвс | + | 3.5 $K^+ p \rightarrow K^0 \pi^+ p$ |
| 891.0 | ± 1.2 | 1700 | 3 | WOJCICKI | 64 | HBC | _ | 1.7 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| • • • | We do not u | se the fol | low | ing data for av | erage | es, fits, | limits, | etc. • • • |
| 893.5 | ± 1.1 | 27k | 4 | ABELE | 99D | CBAR | \pm | $0.0 \overline{p} p \rightarrow K^+ K^- \pi^0$ |
| 890.4 | $\pm0.2\ \pm0.5$ | $80 \pm 0.8 k$ | 5 | BIRD | 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 890.0 | ±2.3 | 800 | 2,3 | CLELAND | 82 | SPEC | + | 30 $K^+ p \rightarrow K^0_S \pi^+ p$ |
| 896.0 | ± 1.1 | 3200 | 2,3 | CLELAND | 82 | SPEC | + | 50 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| 893 | ± 1 | 3600 | 2,3 | CLELAND | 82 | SPEC | _ | 50 $K^+ p \rightarrow K_S^0 \pi^- p$ |
| 896.0 | ± 1.9 | 380 | | DELFOSSE | 81 | SPEC | + | $50 K^{\pm} p \rightarrow K^{\pm} \pi^{0} p$ |
| 886.0 | ± 2.3 | 187 | | DELFOSSE | 81 | SPEC | _ | 50 $K^{\pm} p \rightarrow K^{\pm} \pi^{0} p$ |
| 894.2 | ±2.0 | 765 | | CLARK | 73 | нвс | _ | 3.13 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 894.3 | ± 1.5 | 1150 | | CLARK | 73 | нвс | - | 3.3 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 892.0 | ±2.6 | 341 | 2 | SCHWEING | .68 | HBC | _ | 5.5 $K^-p \rightarrow \overline{K}^0\pi^-p$ |

CHARGED ONLY, PRODUCED IN T LEPTON DECAYS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN COMMENT |
|-------------------------|-----------|-------------------------|---------|---------------------------------------------------------------------------------------|
| 895.47±0.20±0.74 | 5 3k | 6 EPIFANOV | 07 | $\overline{\text{BELL}} \overline{\tau^- \rightarrow \ \text{K}_S^0 \pi^- \nu_\tau}$ |
| • • • We do not use the | ne follow | ing data for average | s, fits | , limits, etc. • • • |
| 892.0 ± 0.5 | | ⁷ BOITO | | RVUE $\tau^- \rightarrow K_S^0 \pi^- \nu_{\tau}$ |
| 892.0 ± 0.9 | | ^{8,9} BOITO | | RVUE $\tau^- \rightarrow K_S^{0} \pi^- \nu_{\tau}$ |
| 895.3 ± 0.2 | | 8,10 JA MIN | 80 | RVUE $\tau^- \rightarrow K_S^0 \pi^- \nu_{\tau}$ |
| 896.4 ±0.9 | 11970 | ¹¹ BONVICINI | 02 | CLEO $\tau^- \rightarrow K^- \pi^0 \nu_{\tau}$ |
| 895 ± 2 | | ¹² BARATE | 99R | ALEP $\tau^- \rightarrow K^- \pi^0 \nu_{\tau}$ |

$K^*(892)$

| NEUTRAL ONLY | ′ | | | | |
|--------------------------------------|-------------|-------------------------|-------|------------|---------------------------------------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 895.94 ± 0.22 OUR / | AVERAGE | | | | .4. See the ideogram below. |
| 895.7 $\pm 0.2 \pm 0.3$ | 141k | ¹³ BONVICINI | 08A | | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| $895.41 \pm 0.32 ^{+ 0.35}_{- 0.43}$ | 18k | ¹⁴ LINK | 05 ı | | ${\rm D}^+ \rightarrow {\rm K}^-\pi^+\mu^+\nu_\mu$ |
| 896 ±2 | | BARBERIS | 98E | OMEG | 450 $pp \rightarrow p_f p_S K^* \overline{K}^*$ |
| 895.9 ± 0.5 ± 0.2 | | ASTON | 88 | LASS | 11 $K^-p \rightarrow K^-\pi^+n$ |
| 894.52 ± 0.63 | 25 k | ¹ ATKINSON | 86 | OMEG | 20-70 γp |
| 894.63 ± 0.76 | 20k | ¹ ATKINSON | 86 | OMEG | 20-70 γp |
| 897 ±1 | 28k | EVA NGELIS | 80 | | 10 $\pi^- \rho \rightarrow K^+ \pi^- (\Lambda, \Sigma)$ |
| 898.4 ±1.4 | 1180 | AGUILAR | 78B | HBC | $0.76 \overline{p}p \rightarrow K^{\mp} K_S^0 \pi^{\pm}$ |
| 894.9 ±1.6 | | WICKLUND | 78 | ASPK | 3,4,6 $K^{\pm} N \rightarrow (K \pi)^{0} N$ |
| 897.6 ± 0.9 | | BOWLER | 77 | DBC | $5.4 K^+ d \rightarrow K^+ \pi^- pp$ |
| 895.5 ±1.0 | 3600 | MCCUBBIN | 75 | HBC | 3.6 $K^-p \rightarrow K^-\pi^+n$ |
| 897.1 ± 0.7 | 22k | ¹ PALER | 75 | HBC | 14.3 $K^- p \to (K \pi)^0 X$ |
| 896.0 ±0.6 | 10k | FOX | 74 | RVUE | $2 K^- p \rightarrow K^- \pi^+ n$ |
| 896.0 ±0.6 | | FOX | 74 | RVUE | $2 K^+ n \rightarrow K^+ \pi^- p$ |
| 896 ±2 | | ¹⁵ MATISON | 74 | HBC | 12 $K^+ p \rightarrow K^+ \pi^- \Delta$ |
| 896 ±1 | 3186 | LEWIS | 73 | HBC | $2.1-2.7 \ K^+ p \rightarrow K \pi \pi p$ |
| 894.0 ±1.3 | | ¹⁵ LINGLIN | 73 | HBC | $2-13 K^+ p \rightarrow$ |
| | | • | | | $K^{+}\pi^{-}\pi^{+}\rho$ |
| 898.4 ±1.3 | 1700 | ² BUCHNER | 72 | DBC | $4.6 K^+ n \rightarrow K^+ \pi^- p$ |
| 897.9 ±1.1 | 2934 | ² AGUILAR | 71B | | 3.9,4.6 $K^-p \to K^-\pi^+ n$ |
| 898.0 ± 0.7 | 5 3 6 2 | ² AGUILAR | 71 B | HBC | 3.9,4.6 $K^- p \rightarrow$ |
| | | 2 | | | $K^{-}\pi^{+}\pi^{-}p$ |
| 895 ±1 | 4300 | ³ HABER | 70 | DBC | $3 K^- N \rightarrow K^- \pi^+ X$ |
| 893.7 ±2.0 | 10k | DAVIS | 69 | нвс | 12 $K^+ p \to K^+ \pi^- \pi^+ p$ |
| 894.7 ±1.4 | 1040 | ² DAUBER | 67B | | $2.0 \ K^- p \rightarrow K^- \pi^+ \pi^- p$ |
| | e the follo | owing data for aver | ages, | fits, limi | ts, etc. • • • |
| 894.9 ± 0.5 ± 0.7 | 14.4k | ¹⁶ MITCHELL | 09A | CLEO | $D_s^+ \rightarrow K^+ K^- \pi^+$ |
| 896.2 ±0.3 | 20k | ⁸ AUBERT | 07AK | BABR | 10.6 $e^+e^{K^{*0}} \xrightarrow{K^{\pm}}_{\pi^{\mp}} \gamma$ |
| 900.7 ±1.1 | 5 900 | BARTH | 83 | НВС | 70 K ⁺ p \rightarrow K ⁺ π^- X |



$K^*(892)^0$ mass (MeV)

- $^{
 m 1}$ Inclusive reaction. Complicated background and phase-space effects.
- ² Mass errors enlarged by us to Γ/\sqrt{N} . See note.
- ³ Number of events in peak reevaluated by us.
- ⁴ K-matrix pole.
- ⁵ From a partial wave amplitude analysis.
- ⁶ From a fit in the $K_0^*(800) + K^*(892) + K^*(1410)$ model.
- 7 From the pole position of the $K\,\pi$ vector form factor using EPIFANOV 07 and constraints from K_{I3} decays in ANTONELLI 10.
- ⁸ Systematic uncertainties not estimated.
- $^9\,{\sf From}$ the pole position of the $K\,\pi$ vector form factor in the complex s-plane and using
- EPIFANOV 07 data. $^{10}\,\text{Reanalysis}$ of EPIFANOV 07 using resonance chiral theory.
- 11 Calculated by us from the shift by 4.7 \pm 0.9 MeV (statistical uncertainty only) reported in BONVICINI 02 with respect to the world average value from PDG 00.
- 12 With mass and width of the $K^*(1410)$ fixed at 1412 MeV and 227 MeV, respectively.
- 13 From the isobar model with a complex pole for the κ .
- $^{14}\,\mathrm{Fit}$ to $\,\mathit{K}\,\pi$ mass spectrum includes a non-resonant scalar component.
- $^{15}\, {\sf From\ pole\ extrapolation}$.
- 16 This value comes from a fit with χ^2 of 178/117.

$K^*(892)$ MASSES AND MASS DIFFERENCES

Unrealistically small errors have been reported by some experiments. We use simple "realistic" tests for the minimum errors on the determination of a mass and width from a sample of N events:

$$\delta_{\min}(m) = \frac{\Gamma}{\sqrt{N}}, \quad \delta_{\min}(\Gamma) = 4\frac{\Gamma}{\sqrt{N}}.$$
 (1)

We consistently increase unrealistic errors before averaging. For a detailed discussion, see the 1971 edition of this Note.

| $m_{K^*(892)^0} - m_{K^*(892)^{\pm}}$ | | | | | | | | | |
|---------------------------------------|-------------|----------------------|-----|------|---------|---------------------------------------------------------|--|--|--|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT | | | |
| 6.7±1.2 OUR | AVERAGE | | | , | | | | | |
| 7.7 ± 1.7 | 2980 | AGUILAR | 78B | нвс | ± 0 | $0.76 \overline{p}p \rightarrow K^{\mp}K_S^0 \pi^{\pm}$ | | | |
| 5.7 ± 1.7 | 7338 | AGUILAR | 71B | нвс | -0 | 3.9,4.6 K ⁻ p | | | |
| 6.3 ± 4.1 | 283 | ¹⁷ BARASH | 67B | нвс | | 0.0 p p | | | |
| ¹⁷ Number of | events in p | eak reevaluated by | us. | | | | | | |

K*(892) RANGE PARAMETER

All from partial wave amplitude analyses

| VALUE (GeV - 1) EVTS | DO CUMENT ID | TECN | CHG | COMMENT |
|-------------------------------------|--------------------------|--------------|---------|-----------------------------------------------------|
| $3.96 \pm 0.54 + 1.31 \\ -0.90$ 18k | ¹⁸ LINK 051 | FOCS | 0 | $D^+ \to \ \mathrm{K}^- \pi^+ \mu^+ \nu_\mu$ |
| 3.4 ± 0.7 | ASTON 88 | LASS | 0 | 11 $K^-p \rightarrow K^-\pi^+n$ |
| • • • We do not use the f | ollowing data for averag | es, fits, li | mits, e | tc. • • • |
| $12.1 \pm 3.2 \pm 3.0$ | BIRD 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 18 Fit to $K\pi$ mass spectru | ım includes a non-reson | ant scalar | comp | onent. |

K*(892) WIDTH

CHARGED ONLY, HADROPRODUCED

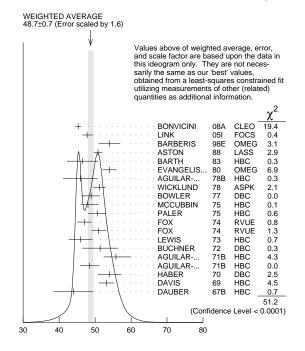
| VALUE (MeV) | EVTS | | DOCUMENT ID | | TECN | CHG | COMMENT |
|--------------------|----------------|---------|------------------|-------|-----------|---------|-----------------------------------------------------------|
| 50.8±0.9 OU | RFIT | | | | | | |
| 50.8±0.9 OU | R AVERA | GE | | | | | |
| 49 ±2 | 5840 | | BAUBILLIER | 84B | HBC | - | 8.25 $K^- p \rightarrow \overline{K}^0 \pi^- p$ |
| 56 ± 4 | | | NAPIER | 84 | SPEC | - | $200 \pi^{-} p \rightarrow 2K_{S}^{0} X$ |
| 51 ± 2 | 4100 | | TOAFF | 81 | HBC | _ | $6.5 \ K^- p \rightarrow \overline{K}{}^0 \pi^- p$ |
| 50.5 ± 5.6 | | | AJINENKO | 80 | HBC | + | 32 $K^+ p \to K^0 \pi^+ X$ |
| 45.8 ± 3.6 | 1800 | | A GUILA R | 78B | HBC | \pm | $0.76 \overline{p} p \rightarrow K^{\mp} K_S^0 \pi^{\pm}$ |
| 52.0 ± 2.5 | 6706 | | COOPER | 78 | HBC | \pm | $0.76 \overline{p} p \rightarrow (K \pi)^{\pm} X$ |
| 52.1 ± 2.2 | 9000 | 20 | PALER | 75 | HBC | - | 14.3 $K^- p \to (K \pi)^-$ |
| 46.3±6.7 | 765 | 19 | CLARK | 73 | нвс | _ | $3.13 K^- p \rightarrow \overline{K}^0 \pi^- p$ |
| 48.2±5.7 | 1150 | 19,21 | CLARK | 73 | нвс | _ | $3.3 K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 54.3 ± 3.3 | 4404 | 19 | AGUILAR | 71B | нвс | _ | 3.9,4.6 $K^-p \rightarrow$ |
| | | | | | | | (Kπ) - p |
| 46 ± 5 | 1700 | 19,21 | MOTCICKI | 64 | HBC | _ | 1.7 $K^- p \rightarrow \overline{K}^0 \pi^- p$ |
| • • • We do | not use t | he foll | owing data for a | verag | es, fits, | limits, | etc. • • • |
| 54.8 ± 1.7 | 27k | 22 | ABELE | 99D | CBAR | \pm | $0.0 \overline{p} p \rightarrow K^+ K^- \pi^0$ |
| $45.2 \pm 1 \pm 2$ | 79.7 ± 0.3 | 8k 23 | BIRD | 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 42.8 ± 7.1 | 3700 | | BARTH | 83 | HBC | + | 70 $K^+ p \rightarrow K^0 \pi^+ X$ |
| 64.0 ± 9.2 | 800 | | CLELAND | 82 | SPEC | + | 30 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| $62.0 \!\pm\! 4.4$ | 3200 | | CLELAND | 82 | SPEC | + | 50 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| 55 ± 4 | 3600 | 19,21 | CLELAND | 82 | SPEC | _ | 50 $K^+ p \rightarrow K_S^{0} \pi^- p$ |
| 62.6 ± 3.8 | 380 | | DELFOSSE | 81 | SPEC | + | $50 K^{\pm} p \rightarrow K^{\pm} \pi^{0} p$ |
| 505+39 | 187 | | DELEOSSE | 81 | SPEC | _ | $50 K^{\pm} p \rightarrow K^{\pm} \pi^{0} p$ |

CHARGED ONLY, PRODUCED IN au LEPTON DECAYS DO CUMENT ID

| 46.2±0.6±1.2 | 53k 27 EPIFANOV | 07 BELL $\tau^- \rightarrow K_S^0 \pi^- \nu$ | $^-\nu_{	au}$ |
|---------------------------------------|-------------------------------|------------------------------------------------|---------------|
| ● ● We do not use | the following data for averag | ges, fits, limits, etc. • • • | |
| 46.5 ± 1.1 | ²⁵ BOITO | 10 RVUE $\tau^- \rightarrow K_S^0 \pi^- \nu$ | $-\nu_{\tau}$ |
| 46.2 ± 0.4 | ^{26,27} BOITO | 09 RVUE $\tau^- \rightarrow K_S^0 \pi^- \nu$ | $-\nu_{\tau}$ |
| 47.5 ± 0.4 | 26,28 JA MIN | 08 RVUE $\tau^- \rightarrow K_S^{0} \pi^- \nu$ | $-\nu_{\tau}$ |
| EE0 | 29 DADATE | 000 ALED K -0 | |

ı

| NEUTRAL ONLY | | | |
|-------------------------------------------------------|----------------------------|-----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) EVTS | DOCUMENT ID | | G COMMENT |
| | rror includes scale fac | | |
| 48.7 ±0.7 OUR AVERA | | ale factor of 1 | .6. See the ideogram below. |
| 45.3 ± 0.5 ± 0.6 141k | ³⁰ BONVICINI 08 | A CLEO | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| $47.79 \pm 0.86 ^{+1.32}_{-1.06}$ 18k | ³¹ LINK 05 | FOCS 0 | $D^+ \rightarrow K^- \pi^+ \mu^+ \nu_{\mu}$ |
| 54 ±3 | BARBERIS 98 | E OMEG | 450 $pp \rightarrow p_f p_S K^* \overline{K}^*$ |
| $50.8 \pm 0.8 \pm 0.9$ | ASTON 88 | LASS 0 | 11 $K^-p \rightarrow K^-\pi^+n$ |
| 46.5 ±4.3 5900 | BARTH 83 | HBC 0 | 70 $K^+ p \rightarrow K^+ \pi^- X$ |
| 54 ±2 28k | EVANGELIS80 | OMEG 0 | $10 \pi^- p \rightarrow K^+ \pi^- (\Lambda, \Sigma)$ |
| 45.9 ±4.8 1180 | AGUILAR 78 | в НВС 0 | $0.76 \overline{p}p \rightarrow K^{\mp} K_S^0 \pi^{\pm}$ |
| 51.2 ±1.7 | WICKLUND 78 | ASPK 0 | 3,4,6 $K^{\pm} N \rightarrow (K \pi)^{0} N$ |
| 48.9 ±2.5 | BOWLER 77 | DBC 0 | 5.4 $K^+ d \rightarrow K^+ \pi^- p p$ |
| $\begin{array}{ccc} 48 & +3 \\ & -2 \end{array}$ 3600 | MCCUBBIN 75 | HBC 0 | 3.6 $K^- p \rightarrow K^- \pi^+ n$ |
| 50.6 ± 2.5 22k | ²⁰ PALER 75 | HBC 0 | 14.3 $K^- p \to (K \pi)^0 X$ |
| 47 ±2 10k | FOX 74 | RVUE 0 | $2 K^- p \rightarrow K^- \pi^+ n$ |
| 51 ±2 | FOX 74 | RVUE 0 | $2 K^+ n \rightarrow K^+ \pi^- p$ |
| 46.0 ±3.3 3186 | ¹⁹ LEWIS 73 | HBC 0 | $2.1-2.7 K+p \rightarrow K\pi\pi p$ |
| 51.4 ±5.0 1700 | ¹⁹ BUCHNER 72 | DBC 0 | 4.6 $K^{+} n \rightarrow K^{+} \pi^{-} p$ |
| $55.8 \begin{array}{l} +4.2 \\ -3.4 \end{array}$ 2934 | ¹⁹ AGUILAR 71 | в НВС 0 | 3.9,4.6 $K^-p \rightarrow K^-\pi^+ n$ |
| 48.5 ±2.7 5362 | AGUILAR 71 | в НВС 0 | 3.9,4.6 $K^- p \rightarrow K^- \pi^+ \pi^- p$ |
| 54.0 ±3.3 4300 ¹ | 9,21 HABER 70 | DBC 0 | $3 K^- N \rightarrow K^- \pi^+ X$ |
| 53.2 ±2.1 10k | 19 DAVIS 69 | | $12 K^+ p \rightarrow K^+ \pi^- \pi^+ p$ |
| 44 ±5.5 1040 | ¹⁹ DAUBER 67 | | $2.0 \ K^-p \rightarrow K^-\pi^+\pi^-p$ |
| • • • We do not use the | | | |
| | - | - | |
| 45.7 ±1.1 ±0.5 14.4k | | A CLEO | $D_s^+ \rightarrow K^+ K^- \pi^+$ |
| 50.6 ±0.9 20k | ²⁶ AUBERT 07 | ak BABR | $^{10.6}_{\kappa^{*0}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}}^{+$ |



NEUTRAL ONLY (MeV)

- $^{19}\,\text{Width}$ errors enlarged by us to 4 $\times\,\Gamma/\sqrt{\textit{N}}$; see note.
- $^{\rm 20}\,\text{lnclusive}$ reaction. Complicated background and phase-space effects.
- 21 Number of events in peak reevaluated by us.
- 22 K-matrix pole.
- 23 From a partial wave amplitude analysis.
- 24 From a fit in the $K_0^*(800)\,+\,K^*(892)\,+\,K^*(1410)$ model.
- 25 From the pole position of the $\it K\,\pi$ vector form factor using EPIFANOV 07 and constraints from K_{I3} decays in ANTONELLI 10.
- 26 Systematic uncertainties not estimated.
- 27 From the pole position of the $K\pi$ vector form factor in the complex s-plane and using EPIFANOV 07 data.
- 28 Reanalysis of EPIFANOV 07 using resonance chiral theory.
- 29 With mass and width of the $K^*(1410)$ fixed at 1412 MeV and 227 MeV, respectively.
- 30 From the isobar model with a complex pole for the κ .
- 31 Fit to $K\pi$ mass spectrum includes a non-resonant scalar component. 32 This value comes from a fit with χ^2 of 178/117.

K*(892) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|--------------------------------------------------------------|------------------------------|----------------------|
| $\overline{\Gamma_1}$ | Κπ | ~ 100 | % |
| Γ_2 | $(K\pi)^{\pm}$ | (99.901 ± 0.009) | % |
| Γ ₃ | $(\kappa_{\pi})^{0}$ $\kappa^{0}\gamma$ $\kappa^{\pm}\gamma$ | (99.761 ± 0.021) | |
| Γ_4 | $K^0_{\cdot}\gamma$ | (2.39 ± 0.21) | |
| Γ_5 | $K^{\pm}\gamma$ | (9.9 ± 0.9) | |
| Γ ₆ | $K\pi\pi$ | < 7 | $\times 10^{-4}$ 95% |

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 13 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 = 7.8$ for 11 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta
ho_i \delta
ho_j
angle / (\delta
ho_i \cdot \delta
ho_j)$, in percent, from the fit to parameters ho_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$x_5$$
 $\begin{bmatrix} -100 \\ 19 \\ x_2 \end{bmatrix}$

| | Mode | Rate (MeV) |
|----------------|-----------------|-------------------|
| Γ_2 | $(K\pi)^{\pm}$ | 50.7 ±0.9 |
| Γ ₅ | $K^{\pm}\gamma$ | 0.050 ± 0.005 |

CONSTRAINED FIT INFORMATION

An overall fit to the total width and a partial width uses 21 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2=$ 51.2 for 19 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta
ho_i \delta
ho_j \right>/(\delta
ho_i \cdot \delta
ho_j)$, in percent, from the fit to parameters ho_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\sf total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (MeV) | Scale factor |
|----------------|-----------------|---------------|--------------|
| Γ ₃ | $(K\pi)^{0}$ | 48.6 ± 0.8 | 1.7 |
| Γ. | $\kappa^0 \sim$ | 0.117 + 0.010 | |

K*(892) PARTIAL WIDTHS

| $\Gamma(K^0\gamma)$ | | | | | | | | Γ_4 |
|-------------------------|------|----------|--------|------|------|-------|--------------------------------------|----------------|
| VALUE (keV) | EVTS | DO CUMI | ENT ID | | TECN | CHG | COMMENT | |
| 117 ±10 OUR F | ΊΤ | | | | | | | |
| 116.5 ± 9.9 | 584 | CARLS | MITH | 86 | SPEC | 0 | $K_L^0 A \rightarrow K_S^0 \pi^0$ | A |
| $\Gamma(K^{\pm}\gamma)$ | | | | | | | | Γ ₅ |
| VALUE (keV) | DO C | UMENT ID | | TECN | CHG | COMM | IENT | |
| 50± 5 OUR FIT | | | | | | | | |
| 50± 5 OUR AVER | AGE | | | | | | | |
| 48±11 | BER | G | 83 | SPEC | _ | | $(-A \rightarrow \overline{K}\pi A)$ | |
| 51± 5 | CHA | NDLEE | 83 | SPEC | + | 200 F | $(^{+}A \rightarrow K\pi A)$ | |

K*(892) BRANCHING RATIOS

| $\Gamma(K^0\gamma)/\Gamma_{\rm t}$ | otal | | | | | | Γ4/Γ |
|------------------------------------|------------------------------|--------------|------------|--------------|---------|-------------------------------|-------------------|
| VALUE (units 10 | | CUMENT ID | TEC | N CHG | COM | MENT | |
| • • • We do | not use the fo | llowing data | for averag | es, fits, li | mits, e | etc. • • • | |
| $1.5\ \pm0.7$ | C | ARITHERS | 75B CN | TR 0 | 8-16 | 5 K ⁰ A | |
| $\Gamma(K^{\pm}\gamma)/\Gamma_{1}$ | otal | | | | | | Γ ₅ /Γ |
| VALUE (units 10 |) ⁻³) <u>CL%</u> | DO CUMEN | T ID | TECN | CHG | COMMENT | |
| 0.99 ± 0.09 | OUR FIT | | | | | | |
| • • • We do | not use the fo | llowing data | for averag | es, fits, li | mits, e | etc. • • • | |
| <1.6 | 95 | BEMPOR | AD 73 | CNTR | + | 10-16 K+A | |

 $K^*(892), K_1(1270)$

| $\Gamma(K\pi\pi)/\Gamma($ | $(K\pi)^{\pm}$ | | | | | Γ_6/Γ_2 |
|----------------------------------|----------------|--------------------|----|------|-----|-------------------------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | CHG | COMMENT |
| $< 7 \times 10^{-4}$ | 95 | JONGEJANS | 78 | HBC | | 4 K ⁻ p \rightarrow p \overline{K}^0 2 π |
| ● ● We do no | t use the fo | llowing data for a | | | | |
| $<20 \times 10^{-4}$ | | WOJCICKI | 64 | нвс | - | $1.7 \ K^- p \rightarrow \ \overline{K}{}^0 \pi^- p$ |

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| | | | y | (ERE) |

 $K_1(1270)$

$$I(J^P) = \frac{1}{2}(1^+)$$

81C CNTR - 63 $K^-p \rightarrow K^-2\pi p$

K1(1270) MASS

 VALUE (MeV)
 DOCUMENT ID

 1272±7 OUR AVERAGE
 Includes data from the 2 datablocks that follow this one.

PRODUCED BY K^- , BACKWARD SCATTERING, HYPERON EXCHANGE

TECN CHG COMMENT The data in this block is included in the average printed for a previous datablock.

1275 ± 10 GAVILLET 78 HBC + 4.2 $K^-p \rightarrow \Xi^-(K\pi\pi)^+$

PRODUCED BY K BEAMS

1270±10

TECN CHG COMMENT

The data in this block is included in the average printed for a previous datablock.

| • • • We do not use | the following dat | a for | averages, | fits, | limits, etc. • • • |
|---------------------|------------------------|-------|-----------|-------|----------------------------------------------------|
| ~ 1276 | ² TORNQVIST | 82B | RVUE | | |
| ~ 1300 | VERGEEST | 79 | HBC | _ | 4.2 $K^- p \rightarrow (\overline{K} \pi \pi)^- p$ |
| 1289 ± 25 | ³ CARNEGIE | 77 | ASPK | \pm | 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ |
| a. 1300 | RRANDENR | 76 | ASDK | + | $13 K \pm p \rightarrow (K\pi\pi) \pm p$ |

 ~ 1270 76 HBC -10,14,16 $K^- p \to (\overline{K} \pi \pi)^- p$ OTTER 72 HBC 12 $K^{+}p$ 1260 1234 ± 12 FIRESTONE 72B DBC + 12 K + d

 $^{\mathrm{1}}$ DAUM

| PRODUCED B | Y BEAM | | | | | NS G COMMENT |
|--------------------------------------------------|------------|----------------------|-------|-----------|-------|----------------------------------------------|
| 1248.1 ± 3.3 ± 1.4 | l | GULER | 11 | BELL | | $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ |
| ullet $ullet$ $ullet$ We do not | use the fo | llowing data for | avera | ges, fits | , lim | its, etc. • • • |
| 1279 ± 10 | 25 k | ⁴ ABLIKIM | 06c | BES2 | | $J/\psi \to \overline{K}^*(892)^0 K^+ \pi^-$ |
| 1294 ± 10 | 310 | RODEBACK | 81 | HBC | | $4 \pi^- p \rightarrow \Lambda K 2\pi$ |
| 1300 | 40 | CRENNELL | 72 | HBC | 0 | 4.5 $\pi^- \rho \rightarrow \Lambda K 2\pi$ |
| $1242 \begin{array}{c} + & 9 \\ -10 \end{array}$ | | ⁵ ASTIER | 69 | нвс | 0 | <u>p</u> p |
| 1300 | 45 | CRENNELL | 67 | HBC | 0 | $6 \pi^- p \rightarrow \Lambda K 2\pi$ |

⁴ Systematic errors not estimated.

PRODUCED IN τ LEPTON DECAYS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------|------|--------------|-----|------|-------|-------------------------------------------------|
| 1254 ± 33 ± 34 | 7k | ASNER | 00в | CLEO | \pm | $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_{\tau}$ |

K1 (1270) WIDTH

 VALUE (MeV)
 DOCUMENT ID

 90±20 OUR ESTIMATE
 This is only an educated guess; the error given is larger than the error on the average of the published values.

 87± 7 OUR AVERAGE
 Includes data from the 2 datablocks that follow this one.

PRODUCED BY K-, BACKWARD SCATTERING, HYPERON EXCHANGE

<u>VALUE (MeV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

75 ± 15 GAVILLET 78 HBC + 4.2 $K^- p \rightarrow \Xi^- K \pi \pi$ 700

PRODUCED BY K BEAMS

TECN CHG COMMENT <u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>JECN</u> <u>CHG</u> <u>COMMENT</u>

The data in this block is included in the average printed for a previous datablock.

⁶ DAUM 81c CNTR -63 $K^-p \rightarrow K^-2\pi p$ • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 150 VERGEEST 79 HBC -4.2 $K^- p \rightarrow (\overline{K} \pi \pi)^- p$ 13 $K^{\pm} \rho \rightarrow (K \pi \pi)^{\pm} \rho$ 150 ± 71 7 CARNEGIE 77 ASPK \pm

13 $K^{\pm} p \rightarrow (K \pi \pi)^{\pm} p$ ~ 200 BRANDENB... 76 ASPK \pm 120 DAVIS 72 HBC + 12 $K^{+}p$ $1\,88\pm21$ FIRESTONE 72B DBC 12 K + d

PRODUCED BY REAMS OTHER THAN K MESONS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHC | COMMENT |
|-------------------------------------------------|-------------|----------------------|------|-----------|--------|------------------------------------------------------|
| 119.5 ± 5.2 ± 6.7 | | GULER | 11 | BELL | | $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ |
| ● ● We do not | use the fo | ollowing data for | aver | ages, fit | s, lim | nits, etc. • • • |
| 131 ±21 | 25 k | ⁸ ABLIKIM | 060 | BES2 | | $J/\psi \rightarrow \overline{K}^*(892)^0 K^+ \pi^-$ |
| 66 ±15 | 310 | RODEBACK | 81 | HBC | | $4 \pi^- p \rightarrow \Lambda K 2\pi$ |
| 60 | 40 | CRENNELL | 72 | HBC | 0 | 4.5 $\pi^- p \rightarrow \Lambda K 2\pi$ |
| $127 \begin{array}{c} + & 7 \\ -25 \end{array}$ | | ASTIER | 69 | нвс | 0 | $\overline{p}p$ |
| 60 | 45 | CRENNELL | 67 | нвс | 0 | $6 \pi^- p \rightarrow \Lambda K 2\pi$ |
| ⁸ Systematic er | rors not es | stimated. | | | | |

PRODUCED IN T LEPTON DECAYS

| VALUE (MeV) | EVTS | DOCUMENT I | D | TECN | CHG | COMMENT |
|------------------------|------|------------|-----|------|-----|---------------------------------------------------|
| $260^{+90}_{-70}\pm80$ | 7k | ASNER | 00в | CLEO | ± | $\tau^- \xrightarrow{K^- \pi^+ \pi^- \nu_{\tau}}$ |

K1(1270) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------------------------|---------------|-----------------------------------------------------------------------|
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ | $K f_0(1370)$ | (42 ±6) % (28 ±4) % (16 ±5) % (11.0±2.0) % (3.0±2.0) % |
| Γ ₆ | γK^0 | seen |

K1(1270) PARTIAL WIDTHS

| $\Gamma(K\rho)$ | | | | | | Γ ₁ |
|--------------------------|-----------------------|--------|---------|-----------|---------------------------|--------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT | |
| • • • We do not use the | following data | for av | erages, | fits, lin | nits, etc. • • | • |
| 57±5 | MAZZUCATO | 79 | HBC | + | 4.2 $K^-p \rightarrow$ | $\Xi^-(K\pi\pi)^+$ |
| 75 ± 6 | MAZZUCATO CARNEGIE | 77B | ASPK | \pm | 13 $K^{\pm}p \rightarrow$ | $(K\pi\pi)^{\pm}p$ |
| $\Gamma(K_0^*(1430)\pi)$ | | | | | | Γ ₂ |

DO CUMENT ID TECN CHG COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • •

CARNEGIE 77B ASPK \pm 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$

 $^{^1}$ Well described in the chiral unitary approach of GENG 07 with two poles at 1195 and 1284 MeV and widths of 246 and 146 MeV, respectively.

 $^{^2\}mathrm{From}$ a unitarized quark-model calculation.

³ From a model-dependent fit with Gaussian background to BRANDENBURG 76 data.

⁵ This was called the *C* meson.

 $^{^6}$ Well described in the chiral unitary approach of GENG 07 with two poles at 1195 and 1284 MeV and widths of 246 and 146 MeV, respectively.

From a model-dependent fit with Gaussian background to BRANDENBURG 76 data.

| $\Gamma(K^*(892)\pi)$ | | Гз |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|-------------------|
| VALUE (MeV) | DOCUMENT ID TECN CHG COMMENT | |
| | use the following data for averages, fits, limits, etc. • • • | ٧. |
| 14±11 2± 2 | MAZZUCATO 79 HBC $+$ 4.2 $K^-p \rightarrow \Xi^-(K\pi\pi)$ CARNEGIE 77B ASPK \pm 13 $K^\pm p \rightarrow (K\pi\pi)^\pm p$ |)' |
| 2 ± 2 | CARNEGIC TIB ASER \pm 13 K $p \rightarrow (K\pi\pi)$ p | |
| $\Gamma(K\omega)$ | | Γ4 |
| VALUE (MeV) | DOCUMENT ID TECN CHG COMMENT | |
| • • • We do not | use the following data for averages, fits, limits, etc. • • • | |
| 4 ± 4 | MAZZUCATO 79 HBC $+$ 4.2 $K^-p \rightarrow \Xi^-(K\pi\pi)$ CARNEGIE 77B ASPK \pm 13 $K^\pm p \rightarrow (K\pi\pi)^\pm p$ |)+ |
| 24±3 | CARNEGIE 77B ASPK \pm 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ | |
| Γ(<i>K f</i> ₀ (1370)) | | Г |
| VALUE (MeV) | DOCUMENT ID TECN CHG COMMENT | . 3 |
| | use the following data for averages, fits, limits, etc. • • • | |
| 22±5 | CARNEGIE 77B ASPK \pm 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ | |
| _ | CARNEGIC TIB ASI R \pm 13 R $p \rightarrow (RRR)$ p | |
| Γ(γ <i>Κ</i> ⁰) | | Γ6 |
| VALUE (keV) | DOCUMENT ID TECN COMMENT | |
| 73.2±6.1±28.3 | ALAVI-HARATI02B KTEV $K + A \rightarrow K^* +$ | Α |
| | K1 (1270) BRANCHING RATIOS | |
| $\Gamma(K\rho)/\Gamma_{\text{total}}$ | _, , | 1/Г |
| VALUE | DOCUMENT ID TECN COMMENT | -1' |
| 0.42 ±0.06 | ⁹ DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ | |
| • • • We do not | use the following data for averages, fits, limits, etc. • • • | |
| 0.584 ± 0.043 | 10 GULER 11 BELL $B^+ 	o J/\psi {\it K}^+ \pi^+ \pi^-$ | |
| dominant | RODEBACK 81 HBC 4 $\pi^- p ightarrow \Lambda K 2\pi$ | |
| $\Gamma(K_0^*(1430)\pi)$ | /r | - ₂ /Γ |
| VALUE | | 2/' |
| 0.28 ±0.04 | 9 DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ | |
| | use the following data for averages, fits, limits, etc. • • • | |
| 0.0201 ± 0.0064 | ¹⁰ GULER 11 BELL $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ | |
| = (44+4) | <u>.</u> | |
| Γ(<i>K</i> *(892) <i>π</i>)/I | | 3/Г |
| VALUE | | |
| 0.16 ±0.05 | 9 DAUM 81c CNTR 63 $K^{-}p \rightarrow K^{-}2\pi p$ | |
| | use the following data for averages, fits, limits, etc. • • • | |
| 0.171 ± 0.023 | ¹⁰ GULER 11 BELL $B^+ 	o J/\psi K^+ \pi^+ \pi^-$ | |
| $\Gamma(K\omega)/\Gamma_{\text{total}}$ | j | 4/[|
| VALUE TOTAL | DOCUMENT ID TECN COMMENT | |
| 0.11 ±0.02 | ⁹ DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ | |
| • • • We do not | use the following data for averages, fits, limits, etc. • • • | |
| 0.225 ± 0.052 | 10 GULER 11 BELL $B^+ 	o J/\psi K^+ \pi^+ \pi^-$ | |
| $\Gamma(K\omega)/\Gamma(K\rho)$ | г | ,/Γ ₁ |
| | <u>CL% DOCUMENT ID TECN COMMENT</u> | 17 ' 1 |
| | use the following data for averages, fits, limits, etc. • • • | |
| < 0.30 | 95 RODEBACK 81 HBC 4 $\pi^- p \rightarrow \Lambda K 2\pi$ | |
| | · | |
| Γ(<i>K f</i> ₀ (1370))/ | Γ _{total} Ι | -5/Γ |
| VALUE | DOCUMENT ID TECN COMMENT | |
| 0.03 ± 0.02 | 9 DAUM 81c CNTR 63 $K^- p ightarrow K^- 2\pi p$ | |
| D-wave/S-wave | RATIO FOR $K_1(1270) \rightarrow K^*(892)\pi$ | |
| VALUE | DOCUMENT ID TECN COMMENT | |
| 1.0±0.7 | ⁹ DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ | |
| ⁹ Average from | low and high t data. | |
| 10 Assuming that | decays are saturated by the $K \rho$, $K_0^*(1430) \pi$, $K^*(892) \pi$, $K \omega$ | |
| | | - \ |
| modes and ne | eglecting interference between them. The values $B(\omega 	o \pi^+\pi^-)$ |) = |
| modes and ne | 6 and $B(K_0^*(1430) ightarrow \ \mathit{K}\pi) = (93\pm10)\%$ are used. Systematic |) = : un- |

$K_1(1270)$ REFERENCES

| GULER | 11 | PR D83 032005 | H. Guler et al. | (BELLE Collab.) |
|--------------|------|---------------|------------------------|-------------------------------|
| GENG | 07 | PR D75 014017 | L.S. Geng et al. | |
| ABLIKIM | 06 C | PL B633 681 | M. Ablikim et al. | (BES Collab.) |
| ALAVI-HARATI | 02B | PRL 89 072001 | A. Alavi-Harati et al. | (FNAL ŘTeV Collab.) |
| ASNER | 00 B | PR D62 072006 | D.M. Asner et al. | ` (CLEO Collab.) |
| TORNQVIST | 82 B | NP B203 268 | N.A. Torngvist | ` (HELS) |
| DAUM | 81 C | NP B187 1 | C. Daum et al. | (AMST, CERN, CRAC, MPIM+) |
| RODEBACK | 81 | ZPHY C9 9 | S. Rodeback et al. | (CERN, CDEF, MADR+) |
| MAZZUCATO | 79 | NP B156 532 | M. Mazzucato et al. | `(CERN, ZEEM, NIJM+) |
| VERGEEST | 79 | NP B158 265 | J.S.M. Vergeest et al. | (NIJM, AMST, CERN+) |
| GAVILLET | 78 | PL 76B 517 | P. Gavillet et al. | (AMST, CERN, NIJM+)JP |
| CARNEGIE | 77 | NP B127 509 | R.K. Carnegie et al. | ` (SLAC) |
| CARNEGIE | 77 B | PL 68B 287 | R.K. Carnegie et al. | (SLAC) |
| BRANDENB | 76 | PRL 36 703 | G.W. Brandenburg et a | ! (SLAC) JP |
| OTTER | 76 | NP B106 77 | G. Otter et al. | (AACH3, BERL, CERN, LOIC+) JP |
| CRENNELL | 72 | PR D6 1220 | D.J. Crennell et al. | (BNL) |
| DAVIS | 72 | PR D5 2688 | P.J. Davis et al. | (LBL) |
| FIRESTONE | 72 B | PR D5 505 | A. Firestone et al. | (LBL) |
| ASTIER | 69 | NP B10 65 | A. Astier et al. | (CDEF, CERN, IPNP, LIVP) IJP |
| CRENNELL | 67 | PRI 19 44 | D.J. Crennell et al. | (BNI)I |

$K_1(1400)$

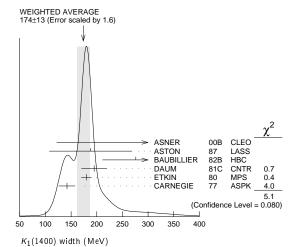
$I(J^P) = \frac{1}{2}(1^+)$

K1(1400) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|----------------------|------------|------------------------|-------|------------|--------|-----------------------------------------------------|
| 1403± 7 OUR | AVERAG | E | | | | |
| $1463 \pm 64 \pm 68$ | 7k | ASNER | 00в | CLEO | \pm | $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_{\tau}$ |
| $1373{\pm}14{\pm}18$ | | ¹ ASTON | 87 | LASS | 0 | 11 $K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| 1392 ± 18 | | BAUBILLIER | 82B | HBC | 0 | 8.25 $K^-p \rightarrow$ |
| | | | | | | $\kappa_S^0 \pi^+ \pi^- n$ |
| 1410 ± 25 | | DAUM | 81c | CNTR | _ | 63 $K^-p \rightarrow K^-2\pi p$ |
| 1415 ± 15 | | ETKIN | 80 | MPS | 0 | $6 K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| 1404 ± 10 | | ² CARNEGIE | 77 | ASPK | \pm | $13 K^{\pm} p \rightarrow (K \pi \pi)^{\pm} p$ |
| • • • We do not | use the fo | ollowing data for | avera | ges, fits, | limits | , etc. • • • |
| 1418± 8 | 25 k | ³ ABLIKIM | 06c | BES2 | | $J/\psi \rightarrow$ |
| | | | | | | $\overline{K}^*(892)^0 K^+ \pi^-$ |
| ~ 1350 | | ⁴ TORNQVIST | 82B | RVUE | | · / |
| ~ 1400 | | VERGEEST | 79 | HBC | _ | 4.2 $K^- p \rightarrow (\overline{K} \pi \pi)^- p$ |
| ~ 1400 | | BRA NDENB | 76 | ASPK | \pm | 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ |
| 1420 | | DAVIS | 72 | HBC | + | 12 K ⁺ p |
| 1368 ± 18 | | FIRESTONE | 72B | DBC | + | 12 K ⁺ d |
| 1 | | | | | | |

K1 (1400) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT | |
|---------------------------------------------------------------------|--------------|------------------|-------|------------|----------|--------------------------------------------------------|--|
| | | Error include: | scal | e factor | of 1.6. | See the ideogram below. | |
| $300 + 370 \pm 14$ | 0 7k | ASNER | 00в | CLEO | | $\tau^- \rightarrow ~{\rm K}^-\pi^+\pi^-\nu_\tau$ | |
| 188± 54± 6 | 0 5 | ASTON | 87 | LASS | 0 | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^+ \pi^- n$ | |
| 276 ± 65 | | BAUBILLIER | 82в | HBC | 0 | 8.25 K ⁻ p → | |
| | | | | | | $\kappa_S^0 \pi^+ \pi^- n$ | |
| 195 ± 25 | | DAUM | 81c | CNTR | | | |
| 180 ± 10 | | ETKIN | 80 | | | $6 K^- p \rightarrow \overline{K}{}^0 \pi^+ \pi^- n$ | |
| 142± 16 | (| CARNEGIE | 77 | ASPK | \pm | $13 K^{\pm} p \rightarrow (K \pi \pi)^{\pm} p$ | |
| ● ● We do no | t use the fo | llowing data for | avera | ges, fits, | , limits | , etc. • • • | |
| 152± 16 | 25 k | ABLIKIM | 06c | BES2 | | $J/\psi \rightarrow$ | |
| | | | | | | $\overline{K}^*(892)^0 K^+ \pi^-$ | |
| ~ 200 | | VERGEEST | 79 | HBC | _ | 4.2 $K^- p \rightarrow (\overline{K} \pi \pi)^- p$ | |
| ~ 160 | | BRA NDE NB | 76 | ASPK | \pm | 13 $K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$ | |
| 80 | | DAVIS | 72 | HBC | + | 12 K ⁺ p | |
| 241 ± 30 | | FIRESTONE | 72B | DBC | + | 12 K + d | |
| ⁵ From partial-wave analysis of $K^0 \pi^+ \pi^-$ system | | | | | | | |



K1(1400) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|------------------|------------------------------|
| $\overline{\Gamma_1}$ | $K^*(892)\pi$ | (94 ±6)% |
| Γ_2 | $K \rho$ | (3.0±3.0) % |
| Γ_3 | $K f_0(1370)$ | (2.0 ± 2.0) % |
| Γ_4 | $K \omega$ | (1.0±1.0) % |
| Γ ₄ Γ ₅ | $K_0^*(1430)\pi$ | not seen |
| Γ_6 | γK^0 | seen |

 $^{^1}$ From partial-wave analysis of $K^0\pi^+\pi^-$ system. 2 From a model-dependent fit with Gaussian background to BRA NDENBURG 76 data. 3 Systematic errors not estimated. 4 From a unitarized quark-model calculation.

 $^{^5}$ From partial-wave analysis of $K^0\,\pi^+\,\pi^-$ system. 6 From a model-dependent fit with Gaussian background to BRA NDENBURG 76 data. 7 Systematic errors not estimated.

 $K_1(1400)$, $K^*(1410)$, $K_0^*(1430)$

| K ₁ (1400) PARTIAL WIDTHS | | | | | | |
|--------------------------------------|-------------|--------|-------------|------------|------------------------------------------------|----------------|
| Γ(K*(892)π) VALUE (MeV) | DOCUMENT ID | | <u>TECN</u> | <u>CHG</u> | COMMENT | Γ1 |
| 117±10 | CARNEGIE | 77 | ASPK | ± | 13 $K^{\pm} p \rightarrow (K \pi \pi)^{\pm} p$ | г. |
| Γ(Κρ) VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT | Г2 |
| 2±1 | CARNEGIE | 77 | ASPK | ± | $13 \ K^{\pm} p \to (K \pi \pi)^{\pm} p$ | |
| Γ(Κω) VALUE (MeV) | DOCUMENT ID | | TECN | <u>CHG</u> | COMMENT | Γ4 |
| 23±12 | CARNEGIE | 77 | ASPK | ± | $13 K^{\pm} p \rightarrow (K \pi \pi)^{\pm} p$ | |
| $\Gamma(\gamma K^0)$ | | S.1145 | | _ | 5.5W 50.4M5N7 | Γ ₆ |
| VALUE (keV) 280.8±23.2±40.4 | | AVI-F | IARATIO | | TEV $K + A \rightarrow K^* +$ | A |

K1 (1400) BRANCHING RATIOS

| al | | | | Γ_1/Γ |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| |) | TECN | COMMENT | |
| ⁸ DAUM | 81c | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ | |
| | | | | Γ_2/Γ |
| | | | | |
| ⁸ DAUM | 81 C | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ | |
| tal | | | | Γ_3/Γ |
| DOCUMENT IL |) | TECN | COMMENT | |
| ⁸ DAUM | 81 C | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ | |
| | | | | Γ4/Γ |
| DOCUMENT II |) | TECN | COMMENT | |
| ⁸ DAUM | 81 C | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ | |
| ntal | | | | Г ₅ /Г |
| |) | TECN | COMMENT | -, |
| | | | | |
| | 8 DOCUMENT III 8 DAUM B DAUM | B DOCUMENT ID 8 DAUM 81C 9 DOCUMENT ID 8 DAUM 81C 10 DOCUMENT ID 8 DAUM 81C | ## DOCUMENT ID ### TECN C NTR ## DOCUMENT ID ### TECN ## DOCUMENT I | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

D-wave/S-wave RATIO FOR $K_1(1400) \rightarrow K^*(892)\pi$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------|-------------|-----|------|-----------------------------------|
| 0.04±0.01 | 8 DAUM | 81c | CNTR | $63 K^- p \rightarrow K^- 2\pi p$ |
| 8. | | | | |

 8 Average from low and high t data.

K₁(1400) REFERENCES

| ABLIKIM | 06 C | PL B633 681 | M. Ablikim et al. | (BES Collab.) |
|---------------|------|---------------|------------------------|---------------------------|
| ALAVI-HARAT I | 02B | PRL 89 072001 | A. Alavi-Harati et al. | (FNAL ŘTeV Collab.) |
| ASNER | 00 B | PR D62 072006 | D.M. Asner et al. | (CLEO Collab.) |
| ASTON | 87 | NP B292 693 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |
| BAUBILLIER | 82B | NP B202 21 | M. Baubillier et al. | (BIRM, CERN, GLAS+) |
| TORNQVIST | 82 B | NP B203 268 | N.A. Torngvist | (HELS) |
| DAUM | 81 C | NP B187 1 | C. Daum et al. | (AMST, CERN, CRAC, MPIM+) |
| ETKIN | 80 | PR D22 42 | A. Etkin et al. | (BNL, CUNY) JP |
| VERGEEST | 79 | NP B158 265 | J.S.M. Vergeest et al. | (NIJM, AMST, CERN+) |
| CARNEGIE | 77 | NP B127 509 | R.K. Carnegie et al. | (SLAC) |
| BRANDENB | 76 | PRL 36 703 | G.W. Brandenburg et a | al. (SLAC) JP |
| DAVIS | 72 | PR D5 2688 | P.J. Davis et al. | `(LBL) |
| FIRESTONE | 72 B | PR D5 505 | A. Firestone et al. | (LBL) |

 $K^*(1410)$

$$I(J^P) = \frac{1}{2}(1^-)$$

K*(1410) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------------------|------------------------|---------|------------|-----------|-----------------------------------------------------|
| 1414±15 OUR AVE | RAGE Error includ | les sca | ale factor | of 1.3 | 3. |
| $1380\pm 21\pm 19$ | ASTON | | | | 11 $K^- p \rightarrow K^- \pi^+ n$ |
| $1420 \pm 7 \pm 10$ | ASTON | 87 | LASS | 0 | 11 $K^-p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| • • • We do not use | the following data | for a | verages, | fits, lir | mits, etc. • • • |
| $1276 + \frac{72}{-77}$ | $^{1,2}\mathrm{BOITO}$ | 09 | RVUE | | $\tau^- \to \ \mathrm{K}_S^0 \pi^- \nu_\tau$ |
| 1367 ± 54 | BIRD | 89 | LASS | _ | 11 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| 1474 ± 25 | BAUBILLIER | 82B | HBC | 0 | 8.25 $K^-p \rightarrow \overline{K}^0 2\pi n$ |
| 1500 ± 30 | ETKIN | 80 | MPS | 0 | 6 K $^-$ p $\rightarrow \overline{K}^0\pi^+\pi^-$ n |

 1 From the pole position of the $K\pi$ vector form factor in the complex s-plane and using EPIFA NOV $\,$ 07 data. $\,$ 2 Systematic uncertainties not estimated.

K*(1410) WIDTH

| VALUE (MeV) | DOCUMENT II | ס | TECN | CHG | COMMENT | |
|---------------------|-----------------|----------|-----------|--------|-----------------------------------------------------|--|
| 232± 21 OUR AVE | RAGE Error incl | udes sca | le factor | of 1.1 | | |
| $176 \pm 52 \pm 22$ | ASTON | | | | 11 $K^-p \rightarrow K^-\pi^+ n$ | |
| 240 ± 18 ± 12 | ASTON | 87 | LASS | 0 | $11 K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ | |

• • • We do not use the following data for averages, fits, limits, etc. • •

| 198 + 61 - 87 | ^{3,4} BOITO | 09 | RVUE | | $\tau^- \to \ \mathrm{K}_S^{0} \pi^- \nu_\tau$ |
|------------------|----------------------|-----|------|---|-----------------------------------------------------|
| 114 ± 101 | BIRD | 89 | LASS | | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 275 ± 65 | BAUBILLIER | 82B | HBC | | 8.25 $K^-p \rightarrow \overline{K}^0 2\pi n$ |
| 500 ± 100 | ETKIN | 80 | MPS | 0 | $6 K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |

 3 From the pole position of the $\it K\pi$ vector form factor in the complex s-plane and using EPIFANOV 07 data. 4 Systematic uncertainties not estimated.

K*(1410) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence leve |
|-----------------------|--------------|------------------------------|-----------------|
| $\overline{\Gamma_1}$ | K*(892)π | > 40 % | 95% |
| Γ_2 | $K\pi$ | (6.6±1.3) % | |
| Γ_3 | $K \rho$ | < 7 % | 95% |
| Γ_4 | γK^0 | seen | |

K*(1410) PARTIAL WIDTHS

| $\Gamma(\gamma K^0)$ | | | | | Γ4 |
|----------------------|-----|------------------|------|-----------------------------|----|
| VALUE (keV) | CL% | DOCUMENT ID | TECN | COMMENT | |
| <52.9 | 90 | ALAVI-HARATI 02B | KTEV | $K + A \rightarrow K^* + A$ | 4 |

K*(1410) BRANCHING RATIOS

| $\Gamma(K\rho)/\Gamma(K^*)$ | 392) π |) | | | | | Γ_3/Γ_1 |
|-------------------------------|------------|--------------|------|--------------|------|-------------------------|-------------------------|
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | CHG | COMMENT | |
| < 0.17 | 95 | ASTON | 84 | LASS | 0 | 11 $K^-p \rightarrow$ | $\overline{K}^0 2\pi n$ |
| $\Gamma(K\pi)/\Gamma(K^*)$ | 892)π |) | | | | | Γ_2/Γ_1 |
| VALUE | CL% | DO CUMENT ID | | TECN | CHG | COMMENT | |
| < 0.16 | 95 | ASTON | 84 | LASS | 0 | 11 $K^- p \rightarrow$ | $\overline{K}^0 2\pi n$ |
| $\Gamma(K\pi)/\Gamma_{total}$ | | | | | | | Γ_2/Γ |
| VALUE | - | DOCUMENT ID | TEC | N <u>CHG</u> | COM | MENT | |
| 0.066±0.010±0. | 800 | ASTON 88 | LA S | S 0 | 11 F | $K^- p \rightarrow K^-$ | $\pi^+ n$ |

K*(1410) REFERENCES

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|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|
| ETKIN 80 PR D22 42 A. Etkin et al. (BNL, | CUNY) JP |

 $K_0^*(1430)$

$$I(J^P) = \frac{1}{2}(0^+)$$

See our minireview in the 1994 edition and in this edition under the

K*(1430) MASS

| | EV.T.C | | 000000000000000000000000000000000000000 | | T | | COMMENT |
|------------------------------|--------|-----|-----------------------------------------|------|-----------|---------|---------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) 1425 ±50 OUR E | | | DO CUMENT ID | | TECN | CHG | COMMENT |
| | | | | | . 414 11- | | |
| • • • We do not use | the to | | _ | - | | nits, e | |
| $1427 \pm 4 \pm 13$ | | | BUGG | 10 | RVUE | | S-matrix pole |
| $1466.6 \pm 0.7 \pm 3.4$ | 141k | | BONVICINI | 08A | | | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| ~ 1412 | | 3 | LINK | 07 | FOCS | 0 | $D^+ \rightarrow K^- K^+ \pi^+$ |
| $1461.0 \pm \ 4.0 \pm \ 2.1$ | 54k | | LINK | 07в | FOCS | | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| 1406 ± 29 | | | BUGG | 06 | RVUE | | |
| 1435 ± 6 | | 6 | ZHOU | 06 | RVUE | | $K p \rightarrow K^- \pi^+ n$ |
| $1455 \pm 20 \pm 15$ | | | ABLIKIM | 05 Q | BES2 | | $\psi(2S) \rightarrow$ |
| | | | | | | | $\gamma \pi^+ \pi^- K^+ K^-$ |
| 1456 ± 8 | | | ZHENG | 04 | RVUE | | $K^- p \rightarrow K^- \pi^+ n$ |
| ~ 1419 | | | BUGG | 03 | RVUE | | 11 $K^-p \rightarrow K^-\pi^+ n$ |
| ~ 1440 | | | LI | 03 | RVUE | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| 1459 ± 9 | 15k | | AITALA | 02 | E791 | | $D^+ \rightarrow K^-\pi^+\pi^+$ |
| ~ 1440 | | 11 | JA MI N | 00 | RVUE | | $Kp \rightarrow Kp$ |
| 1436 ± 8 | | 12 | BARBERIS | 98E | OMEG | | 450 $pp \rightarrow$ |
| | | | | | | | $p_f p_S K^+ K^- \pi^+ \pi^-$ |
| 1415 ± 25 | | 8 | ANISOVICH | 97c | RVUE | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| ~ 1450 | | 13 | TORNQVIST | 96 | RVUE | | $\pi\pi \rightarrow \pi\pi$, $K\overline{K}$, $K\pi$ |
| 1412 ± 6 | | 14 | ASTON | 88 | LASS | 0 | 11 $K^-p \rightarrow K^-\pi^+n$ |
| ~ 1430 | | | BAUBILLIER | 84B | нвс | _ | 8.25 $K^-p \rightarrow \overline{K}^0\pi^-p$ |
| ~ 1425 | 15 | ,16 | ESTABROOKS | 78 | ASPK | | 13 $K^{\pm}p \rightarrow$ |
| | | | | | | | $K^{\pm}\pi^{\pm}(n,\Delta)$ |
| ~ 1450.0 | | | MARTIN | 78 | SPEC | | $ \begin{array}{c} \kappa^{\pm}\pi^{\pm}(n,\Delta) \\ 10 \ \kappa^{\pm}\rho \to \kappa^{0}_{S}\pi\rho \end{array} $ |
| | | | | | | | . 3 . |

- ¹ S-Matrix pole. Supersedes BUGG 06. Combined analysis of ASTON 88, ABLIKIM 06c, AITALA 06, and LINK 09 using an s-dependent width with couplings to $K\pi$ and $K\eta'$, and the Adler zero near thresholds. 2 From the isobar model with a complex pole for the κ .
- ³ From a non-parametric analysis.
- ⁴ A Breit-Wigner mass and width.
- A Differentiation in mass and worth. S-matrix pole. Reanalysis of ASTON 88, AITALA 02, and ABLIKIM 06c including the κ with an s-dependent width and an Adler zero near threshold.
- ⁶ S-matrix pole. Using ASTON 88 and assuming $K_0^*(800)$, $K_0^*(1950)$.
- ⁷Using ASTON 88 and assuming $K_0^*(800)$.
- 8 T-matrix pole. Reanalysis of ASTON 88 data.
- ⁹Breit-Wigner fit. Using ASTON 88.
- 10 Assuming a low-mass scalar $K\pi$ resonance, $\kappa(800)$. 11 T-matrix pole. Using data from ESTABROOKS 78 and ASTON 88.
- $^{12}J^{P}$ not determined, could be $K_{2}^{*}(1430)$.
- ¹³T-matrix pole.
- $^{14}\,\mathrm{Uses}$ a model for the background, without this background they get a mass 1340 MeV,
- where the phase shift passes 90° . 15 Mass defined by pole position.
- $^{16}\,\mathrm{From}$ elastic $K\pi$ partial-wave analysis.

K*(1430) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|------------------------------------------------------|------------|----------------------------------------------------------------------------------------------------|------------------------------|-------------------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 270 ±80 OUR E | STIMAT | Έ | | | | |
| • • • We do not u | se the fol | lowing data for a | verag | es, fits, | limits, | etc. • • • |
| $270 \pm 10 \pm 40$ | | ⁷ BUGG | 10 | RVUE | | S-matrix pole |
| $174.2 \pm 1.9 \pm 3.2$ | | ⁸ BONVICINI | 08A | CLEO | | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| ~ 500 | | ⁹ LINK | 07 | FOCS | 0 | $D^+ \rightarrow K^- K^+ \pi^+$ |
| $177.0 \pm 8.0 \pm 3.4$ | | ⁰ LINK | 07в | FOCS | | $D^+ \rightarrow K^- \pi^+ \pi^+$ |
| 350 ±40 | 2 | ¹ BUGG | 06 | RVUE | | |
| 288 ± 22 | 2 | ² zhou | 06 | RVUE | | $Kp \rightarrow K^-\pi^+ n$ |
| 270 $\pm 45 \begin{array}{c} +30 \\ -35 \end{array}$ | | ABLIKIM | 05 Q | BES2 | | $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| 217 ±31 ~ 316 ~ 350 175 ±17 | 2 | ³ ZHENG ⁴ BUGG _{5 LI} ⁶ AITALA | 04 03 03 02 | RVUE RVUE RVUE E791 | | $K^{-}p \rightarrow K^{-}\pi^{+}n$ $11 K^{-}p \rightarrow K^{-}\pi^{+}n$ $11 K^{-}p \rightarrow K^{-}\pi^{+}n$ $D^{+} \rightarrow K^{-}\pi^{+}\pi^{+}$ |
| ~ 300 | | ⁷ JAMIN | 00 | RVUE | | $Kp \rightarrow Kp$ |
| 196 ±45 | | ⁸ BARBERIS | 98E | OMEG | | 450 pp → |
| 330 ±50 ~ 320 294 ±23 ~ 200 200 to 300 | 2 | ⁴ ANISOVICH ⁹ TORNQVIST ASTON BAUBILLIER ⁰ ESTABROOKS | 97c 96 88 84B 78 | RVUE RVUE LASS HBC ASPK | 0 — | $\begin{array}{c} p_{f}p_{S}K^{+}K^{-}\pi^{+}\pi^{-} \\ 11K^{-}p \to K^{-}\pi^{+}n \\ \pi\pi^{-}\to\pi\pi^{-}K^{\overline{K}}K\pi \\ 11K^{-}p \to K^{-}\pi^{+}n \\ 8.25K^{-}p \to \overline{K^{0}}\pi^{-}p \\ 13K^{\pm}p \to K^{\pm}\pi^{\pm}(n,\Delta) \end{array}$ |

- $^{17}\,\mathrm{S\text{-}Matrix}$ pole. Supersedes BUGG 06. Combined analysis of ASTON 88, ABLIKIM 06c, AITALA 06, and LINK 09 using an s-dependent width with couplings to $K\pi$ and $K\eta'$, and the Adler zero near thresholds.
- The From the isobar model with a complex pole for the κ .
- ¹⁹ From a non-parametric analysis.
- ²⁰ A Breit-Wigner mass and width.
- 21 S-matrix pole. Reanalysis of ASTON 88, AITALA 02, and ABLIKIM 06c including the κ with an s-dependent width and an Adler zero near threshold.
- 22 S-matrix pole. Using ASTON 88 and assuming $K_0^*(800)$, $K_0^*(1950)$.
- 23 Using ASTON 88 and assuming $K_0^*(800)$.
- ²⁴ T-matrix pole. Reanalysis of ASTON 88 data.
- ²⁵ Breit-Wigner fit. Using ASTON 88.
- 26 Assuming a low-mass scalar $K\pi$ resonance, $\kappa(800)$.
- 27 T-matrix pole. Using data from ESTABROOKS 78 and ASTON 88. $28 \ J^P$ not determined, could be $K_2^*(1430)$.
- $^{29}\,\text{T-matrix pole}.$
- 30 From elastic $K\pi$ partial-wave analysis.

K*(1430) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|------|------------------------------|
| $\overline{\Gamma_1}$ | Κπ | (93±10) % |

K*(1430) BRANCHING RATIOS

| $\Gamma(K\pi)/\Gamma_{total}$ | | | | | Γ | 1/Г |
|-------------------------------|-------------|----|------|-----|--------------------------------------------|-----|
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT | |
| $0.93 \pm 0.04 \pm 0.09$ | ASTON | 88 | LASS | 0 | $11 \ K^- \rho \rightarrow \ K^- \pi^+ n$ | |

K*(1430) REFERENCES

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|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|
| BUGG 06 | | Ub | | | |
| ZHOU | | 06 | | | |
| ZHENG | ZHOU | 06 | NP A775 212 | | , , , |
| BUGG 03 | ABLIKIM | 05 Q | PR D72 092002 | M. Ablikim et al. | (BES Collab.) |
| LI 03 PR D67 034025 L. Li, B. Zou, G. Li AITALA 02 PRL P8 1921801 E.M. Altala et ai. (FNAL E791 Collab.) JAMIN 00 NP B587 331 M. Jamin et al. (FNAL E791 Collab.) BANBERU PL B436 204 D. Barberis et al. (Omega Expt.) ANISOVICH 97C PL B413 137 A.V. Anisovich, A.V. Sarantsev TORNQVIST 96 PRL 76 1575 N.A. Tornqvist, M. Roos ASTON 88 NP B296 493 D. Aston et al. (SLAC, NAGO, CINC, INUS) BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| AITALA 02 PRL 89 121801 E.M. Aitala et al. (FNAL E791 Collab.) | | | | | |
| JAMIN 00 NP B587 331 M. Jamin et al. BARBERIS 96E PL B435 204 D. Barberis et al. ANISOVICH 97C PL B413 137 A.V. Anisovich, A.V. Sarantsev TORNQVIST 96 PRL 76 1575 N.A. Tornqvist, M. Roos ASTON 88 NP B296 493 D. Aston et al. (SLAC, NAGO, CINC, INUS) BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOK 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
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| ANISOVICH 97C PL B413 137 A.V. ANISOVICH, A.V. Sarantsev TORNQVIST 96 PRL 7.6 1575 N.A. Tornqvist, M. Roos ASTON 88 NP B296 493 D. Aston et al. (SLAC, NAGO, CINC, INUS) BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| TORNQVIST 96 PRL 76 1575 N.A. Tornqvist, M. Roos M. Roos (HELS) ASTON 88 NP 8296 493 D. Aston et al. (SLAC, NAGO, CINC, INUS) BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| ASTON 88 NP B296 493 D. Aston et al. (SLAC, NAGO, CINC, 'NUS) BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| BAUBILLIER 84B ZPHY C26 37 M. Baubillier et al. (BIRM, CERN, GLAS+) ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) | | | | | |
| | | | | | |
| MARTIN 78 NP B134 392 A.D. Martin et al. (DURH, GEVA) | | | | | |
| | MARIIN | 78 | NP B134 392 | A.D. Martin et al. | (DURH, GEVA) |

$K_2^*(1430)$

$$I(J^P) = \frac{1}{2}(2^+)$$

We consider that phase-shift analyses provide more reliable determinations of the mass and width.

K*(1430) MASS

CHARGED ONLY, WITH FINAL STATE $K\pi$

| 0.0.0000 | , | | | | | |
|--------------------|-----------|----------------------|--------|----------|------|---------------------------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| 1425.6± 1.5 OUR | AVERAGE | Error includes s | cale f | actor of | 1.1. | |
| 1420 ± 4 | 1587 | BAUBILLIER | 84B | HBC | _ | 8.25 K ⁻ p → |
| | | | | | | $\overline{K}^0 \pi^- \rho$ |
| $1436 \ \pm \ 5.5$ | 400 1,2 | ² CLELAND | 82 | SPEC | + | 30 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| $1430 \ \pm \ 3.2$ | 15 00 1,2 | ² CLELAND | 82 | SPEC | + | 50 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| $1430 \ \pm \ 3.2$ | 1200 1,2 | ² CLELAND | 82 | SPEC | _ | $50 K^+ p \rightarrow K_S^0 \pi^+ p$ $50 K^+ p \rightarrow K_S^0 \pi^- p$ |
| $1423 \ \pm \ 5$ | 935 | TOAFF | 81 | нвс | - | 6.5 $K^-p \rightarrow$ |
| | | _ | | | | $\overline{K}^0\pi^-p$ |
| 1428.0 ± 4.6 | 3 | ³ MARTIN | 78 | SPEC | + | 10 $K^{\pm} p \rightarrow K_S^0 \pi p$ |
| $1423.8 \pm\ 4.6$ | 1 | ³ MARTIN | 78 | SPEC | - | 10 $K^{\pm} p \rightarrow K_{S}^{0} \pi p$ |
| 1420.0 ± 3.1 | 1400 | AGUILAR | 71B | HBC | _ | 3.9,4.6 K ⁻ p |
| 1425 ± 8.0 | 225 1,2 | ² BARNHAM | 71 C | HBC | + | $K^+ p \rightarrow K^0 \pi^+ p$ |
| 1416 ± 10 | 220 | CRENNELL | 69D | DBC | - | $3.9 \frac{K - N}{K_0} \xrightarrow{\pi - N}$ |
| 1414 ±13.0 | 60 | ¹ LIND | 69 | нвс | + | $9 K^+ p \rightarrow K^0 \pi^+ p$ |
| 1427 ±12 | 63 | 1 SCHWEING | 68 | нвс | _ | 5.5 $K^- p \rightarrow \overline{K} \pi N$ |
| 1423 ± 11.0 | 39 | ¹ BASSANO | 67 | нвс | _ | 4.6-5.0 $K^-p \rightarrow$ |
| | | | | | | $\overline{K}^0 \pi^- \rho$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $24809\,\pm\,$ ⁴ BIRD 89 LASS - 11 $K^- p \to \overline{K}^0 \pi^- p$ $1423.4\pm2\pm3$

DO CUMENT ID TECN COMMENT

71 DBC 9 $K^+ n \rightarrow K^+ \pi^- \rho$

69 HBC 12 $K^+p \to K^+\pi^-X$

NEUTRAL ONLY

 1416 ± 6

 1421.1 ± 2.6

| 1432.4 ± 1.3 OUI | R AVERAGI | i | | | |
|-----------------------------------|--------------|-------------------------|-------|-------------|----------------------------------------------------------------------------------------------------|
| $1431.2 \pm 1.8 \pm 0$ | .7 | ⁵ ASTON | 88 | LASS | $11 K^-p \rightarrow K^-\pi^+n$ |
| $1434 ~\pm~4 ~\pm~6$ | | ⁵ ASTON | 87 | | $11 K^- \rho \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| $1433 ~\pm~ 6 ~\pm 10$ | | ⁵ ASTON | 84 B | LASS | $11 K^- p \rightarrow \overline{K}^0 2\pi n$ |
| 1471 ± 12 | | ⁵ BAUBILLIER | 82B | нвс | $8.25 K^- p \rightarrow NK_S^0 \pi \pi$ |
| 1428 ± 3 | | | | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| 1434 ± 2 | | | | | $13 K^{\pm}p \rightarrow pK\pi$ |
| 1440 ± 10 | | ⁵ BOWLER | 77 | DBC | $5.5 K^+ d \rightarrow K \pi p p$ |
| ● ● We do not | use the foll | owing data for ave | rages | , fits, lin | nits, etc. • • • |
| $1428.5 \pm \ 3.9$ | 1786± 127 | ⁶ AUBERT | 07AF | BABR | $\begin{array}{c} 10.6 \ e^{+} e^{-} \rightarrow \\ K^{*0} \ K^{\pm} \pi^{\mp} \gamma \end{array}$ |
| 1420 ± 7 | 300 | HENDRICK | 76 | DBC | 8.25 $K^+ N \rightarrow K^+ \pi N$ |
| 1421.6 ± 4.2 | 800 | MCCUBBIN | 75 | HBC | 3.6 $K^- p \rightarrow K^- \pi^+ n$ |
| 1420.1 ± 4.3 | | ⁷ LINGLIN | 73 | нвс | 2-13 $K^+ p \rightarrow K^+ \pi^- X$ |
| 1419.1 ± 3.7 | 1800 | AGUILAR | 71 B | HBC | 3.9,4.6 K ⁻ p |

- CORDS DAVIS $\frac{1}{2}$ Errors enlarged by us to $\Gamma/\sqrt{\textit{N}};$ see the note with the $\textit{K}^*(892)$ mass.
- Number of events in peak re-evaluated by us.

600

2200

- ³ Systematic error added by us.
- ⁴ From a partial wave amplitude analysis.
- $^{5}\,\mbox{From phase shift or partial-wave analysis.}$
- ⁶ Systematic errors not estimated.
- ⁷ From pole extrapolation, using world K^+p data summary tape.

$K_2^*(1430)$

K*(1430) WIDTH

CHARGED ONLY, WITH FINAL STATE $K\pi$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|------------------------------|-------------|------------------------|--------|-----------|----------|----------------------------------------------------------------------------------------------------------------------------|
| 98.5 ± 2.7 OUR | FIT Erro | r includes scale fac | tor of | 1.1. | | |
| 98.5 ± 2.9 OUR | AVERAGE | Error includes so | ale fa | ctor of : | | |
| 109 ± 22 | 400 | ^{8,9} CLELAND | 82 | SPEC | + | 30 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| 124 ± 12.8 | 1500 | ^{8,9} CLELAND | 82 | SPEC | + | 50 $K^+ p \rightarrow K_S^0 \pi^+ p$ |
| 113 ± 12.8 | 1200 | ^{8,9} CLELAND | 82 | SPEC | - | 30 $K^+ p \rightarrow K_S^0 \pi^+ p$ 50 $K^+ p \rightarrow K_S^0 \pi^+ p$ 50 $K^+ p \rightarrow K_S^0 \pi^- p$ |
| 85 ±16 | 935 | TOAFF | 81 | нвс | _ | $6.5 K^- p \rightarrow$ |
| | | | | | | $\overline{K}^0\pi^-p$ |
| 96.5 ± 3.8 | | MARTIN | 78 | SPEC | + | $10 K^{\pm} p \rightarrow K_S^0 \pi p$ |
| 97.7± 4.0 | | MARTIN | 78 | SPEC | - | $ \frac{\overline{K}^{0}\pi^{-}p}{10 \ K^{\pm}p \rightarrow K_{S}^{0}\pi p} $ $ 10 \ K^{\pm}p \rightarrow K_{S}^{0}\pi p $ |
| $94.7 {}^{+ 15.1}_{- 1 2.5}$ | 1400 | AGUILAR | | | | 3.9,4.6 K-p |
| • • • We do not | use the fol | lowing data for ave | rages. | fits, lin | nits, et | C. • • • |

| 98 \pm 4 \pm 4 25k 10 BIRD 89 LASS $-$ 11 $K^-p \rightarrow \overline{K}^0$ | $98 \pm 4 \pm 4$ | \pm 4 \pm 4 \pm 25k 10 BIRD | 89 LASS | - 11 | $K^-p \rightarrow$ | $K^{\sigma}\pi^{-}p$ |
|--------------------------------------------------------------------------------------|------------------|----------------------------------------|---------|------|--------------------|----------------------|
|--------------------------------------------------------------------------------------|------------------|----------------------------------------|---------|------|--------------------|----------------------|

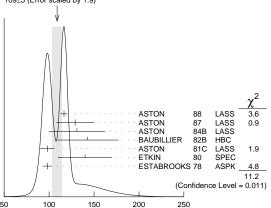
NEUTRAL ONLY_

| VALU | E (MeV |) EVTS | DO CUMENT ID | | TECN | COMMENT |
|------|----------|-------------|--------------------------|-----|------|--------------------------------------------------------|
| 109 | ± 5 | OUR AVERA | | | | .9. See the ideogram below. |
| 116. | 5 ± 3. | 6 ± 1.7 | | | | 11 $K^- \rho \rightarrow K^- \pi^+ n$ |
| 129 | ± 15 | ± 15 | ¹¹ ASTON | 87 | LASS | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| 131 | ± 24 | ± 20 | ¹¹ ASTON | 84B | LASS | 11 $K^- \rho \rightarrow \overline{K}^0 2\pi n$ |
| 143 | ± 34 | | ¹¹ BAUBILLIER | 82B | HBC | 8.25 $K^- p \to N K_S^0 \pi \pi$ |
| 98 | ± 8 | | | | | 11 $K^- p \rightarrow K^- \pi^+ n$ |
| 140 | ± 30 | | | | | $6 K^- \rho \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| 98 | \pm 5 | | ¹¹ ESTABROOKS | 78 | ASPK | 13 $K^{\pm}p \rightarrow pK\pi$ |

We do not use the following data for averages, fits, limits, etc.

| | | | Owille data for aver | | | |
|--------|----------------|--------------|-----------------------|------|------|----------------------------------------------------------------------------|
| 113.7∃ | ± 9.2 | 1786± 127 | ¹² AUBERT | 07ak | BABR | $^{10.6}_{K^{*0}} {}^{e^+e^-}_{K^{\pm}} {}^{\mp}_{\pi^{\mp}} {}_{\gamma}$ |
| 125 ± | | 300 | ⁸ HENDRICK | 76 | DBC | 8.25 $K^+ N \rightarrow K^+ \pi N$ |
| 116 ± | ±18 | 800 | | | | 3.6 $K^-p \rightarrow K^-\pi^+ n$ |
| 61 ± | ±14 | | ¹³ LINGLIN | 73 | HBC | 2-13 $K^+ p \to K^+ \pi^- X$ |
| 116.6 | ⊦10.3 -15.5 | 1800 | AGUILAR | 71 B | нвс | 3.9,4.6 K ⁻ p |
| 144 ∃ | ±24.0 | 600 | ⁸ CORDS | 71 | DBC | 9 K+ n \rightarrow K+ π^- p |
| 101 ± | ±10 | 2200 | DAVIS | 69 | нвс | 12 $K^+p \rightarrow K^+\pi^-\pi^+p$ |

WEIGHTED AVERAGE 109±5 (Error scaled by 1.9)



 $K_2^*(1430)^0$ width (MeV)

- 8 Errors enlarged by us to $^4\Gamma/\sqrt{N}$; see the note with the $K^*(892)$ mass.
- 9 Number of events in peak re-evaluated by us.
- ¹⁰ From a partial wave amplitude analysis.
- 11 From phase shift or partial-wave analysis.
- 12 Systematic errors not estimated.
- ¹³ From pole extrapolation, using world K^+p data summary tape.

K*(1430) DECAY MODES

| | Mode | $\begin{array}{ccc} & & & Scale \ factor/ \\ & & Fraction \ (\Gamma_{\dot{I}}/\Gamma) & & Confidence \ level \end{array}$ |
|-----------------------|------------------|---------------------------------------------------------------------------------------------------------------------------|
| $\overline{\Gamma_1}$ | Κπ | (49.9±1.2) % |
| Γ_2 | $K^*(892)\pi$ | (24.7 ± 1.5) % |
| Γ_3 | $K^*(892)\pi\pi$ | (13.4 ± 2.2) % |
| Γ_4 | $K \rho$ | (8.7 ± 0.8) % S=1.2 |
| Γ_5 | $K \omega$ | (2.9 ± 0.8) % |
| Γ_6 | $K^+ \gamma$ | $(2.4 \pm 0.5) \times 10^{-3}$ S=1.1 |
| Γ ₇ | $K\eta$ | $(1.5^{+3.4}_{-1.0}) \times 10^{-3}$ S=1.3 |
| Γ8 | $K \omega \pi$ | $< 7.2 \times 10^{-4} $ CL=95% |
| Γ ₉ | $K^0\gamma$ | $<$ 9 \times 10 ⁻⁴ CL=90% |

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, and 10 branching ratios uses 31 measurements and one constraint to determine 8 parameters. The overall fit has a $\chi^2=$ 20.2 for 24 degrees of

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta p_i \delta p_j \right
angle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| | Mode | Rate (MeV) | Scale factor |
|----------------|------------------|------------------------------|--------------|
| Γ ₁ | Κπ | 49.1 ±1.8 | |
| Γ_2^- | $K^*(892)\pi$ | 24.3 ±1.6 | |
| Γ_3 | $K^*(892)\pi\pi$ | 13.2 ± 2.2 | |
| Γ_4 | $K\rho$ | 8.5 ±0.8 | 1.2 |
| Γ_5 | $K\omega$ | 2.9 ±0.8 | |
| Γ_6 | $K^+ \gamma$ | 0.24 ± 0.05 | 1.1 |
| Γ ₇ | $K\eta$ | $0.15 {}^{+ 0.33}_{- 0.10}$ | 1.3 |

K*(1430) PARTIAL WIDTHS

| $\Gamma(K^+\gamma)$ | | | | | | Γ |
|---------------------|----------------------|--------|---------|-----|----------------------------------|---|
| VALUE (keV) | DO CUMENT ID | | TE CN | CHG | COMMENT | |
| 241 ±50 OUR FIT | Error includes scale | factor | of 1.1. | | | |
| 240±45 | CIHANGIR | 82 | SPEC | + | 200 $K+Z \rightarrow ZK+\pi^0$, | |
| | | | | | $ZK_c^0\pi^+$ | |

| $\Gamma(K^{u}\gamma)$ | | | | | | Г9 |
|--------------------------------|--------------|---------------------|---------------|---------|------------------------------|-----|
| VALUE (keV) | CL% | DOCUMENT ID | TECN | CHG | COMMENT | |
| < 5.4 | 90 | | | | $K + A \rightarrow K^*$ | + A |
| ● ● We do no | t use the fo | llowing data for av | erages, fits, | limits, | etc. • • • | |
| <84 | 90 | CARLSMITH | 87 SPEC | 0 | , | |
| | | | | | $\kappa_S^0 \pi^0 \tilde{A}$ | |

K*(1430) BRANCHING RATIOS

 Γ_1/Γ

 $\Gamma(K\pi)/\Gamma_{\text{total}}$

 $0.16\ \pm0.05$

 $0.14\ \pm0.10$

 $0.14\ \pm0.07$

| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------------------------|--------------------------|-------------|-------|-------|----------------------------------------------|
| 0.499±0.012 OUR FIT | | | | | |
| 0.488 ± 0.014 OUR AV | | | | | |
| $0.485 \pm 0.006 \pm 0.020$ | ¹⁴ ASTON | 88 | LA SS | 0 | $11 K^- p \rightarrow K^- \pi^+ n$ |
| $0.49\ \pm0.02$ | ¹⁴ ESTABROOKS | 78 | ASPK | \pm | 13 $K^{\pm} p \rightarrow p K \pi$ |
| $\Gamma(K^*(892)\pi)/\Gamma(K^*$ | π) | | | | Γ_2/Γ_1 |
| VALUE | DOCUMENT ID | | TE CN | CHG | COMMENT |
| 0.496±0.034 OUR FIT | | | | | |
| 0.47 ±0.04 OUR AVI | ERAGE | | | | 2 |
| 0.44 ± 0.09 | ASTON | 84B | LASS | 0 | 11 $K^- p \rightarrow \overline{K}^0 2\pi n$ |
| 0.62 ± 0.19 | LAUSCHER | 75 | HBC | 0 | 10,16 $K^-p \to K^-\pi^+n$ |
| 0.54 ± 0.16 | DEHM | 74 | DB C | 0 | 4.6 K ⁺ N |
| 0.47 ± 0.08 | AGUILAR | 71B | HBC | | 3.9,4.6 K ⁻ p |
| 0.47 ± 0.10 | BASSANO | 67 | HBC | -0 | 4.6,5.0 K ⁻ p |
| 0.45 ± 0.13 | BADIER | 65 C | HBC | _ | 3 K-p |
| $\Gamma(K\omega)/\Gamma(K\pi)$ | | | | | Γ_5/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.059±0.017 OUR FIT | | | | | |

| 0.45 ±0.13 | BADIER | 65 C | HRC | _ | зк р | |
|--------------------------------|--------------|------|------|-----|--------------------------|---------------------|
| $\Gamma(K\omega)/\Gamma(K\pi)$ | | | | | | Γ_5/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT | |
| 0.059±0.017 OUR FIT | · | | | | | |
| 0.070±0.035 OUR AVER | AGE | | | | | |
| 0.05 ± 0.04 | AGUILAR | 71B | HBC | | 3.9,4.6 K ⁻ p | |
| 0.13 ±0.07 | BASSOMPIE | 69 | HBC | 0 | 5 K ⁺ p | |

| 0.13 ±0.07 | BASSOMPIE | 69 | нвс | 0 | 5 K ⁺ p | |
|-------------------------------------------------------|--------------|--------|----------|-------|-------------------------------------------|---------------------|
| $\Gamma(K\rho)/\Gamma(K\pi)$ | | | | | | Γ_4/Γ_1 |
| VALUE 0.174±0.017 OUR FIT | DO CUMENT ID | colo f | TECN_ | CHG | COMMENT | |
| 0.150 + 0.029 OUR AVER | | Cale I | actor or | 1. 2. | | |
| $0.18\ \pm0.05$ | ASTON | 84B | LASS | 0 | 11 $K^-p \rightarrow \overline{K}^0 2\pi$ | n |
| $\begin{array}{cc} 0.02 & +0.10 \\ -0.02 \end{array}$ | DEHM | 74 | DBC | 0 | 4.6 K ⁺ N | |
| | | | | | | |

71B HBC

67 HBC

65c HBC

3.9,4.6 K-p

 $4.6,5.0~K^-p$

AGUILAR-...

BASSANO

BADIER

Meson Particle Listings $K_2^*(1430)$, K(1460)

| $\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ Γ_4/Γ_2 | ETKIN 80 PR D22 42 A. Etkin et al. (BNL, CUNY) JP ESTABROOKS 78 NP B133 490 P.G. Estabrooks et al. (MCGI, CARL, DURH+) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | Also PR D17 658 P.G. Estabrooks et al. (M.CGI, CAPL, DURH+) JONGEJANS 78 NP B139 383 B. Jongejans et al. (ZEEM, CERN, NIJM+) MARTIN 78 NP B134 392 A.D. Martin et al. (DURH, GEVA) BOWLER 77 NP B126 31 M.G. Bowler et al. (DURH, GEVA) GOLDBERG 76 NP B112 189 K. Hendrickx et al. (MOSS, SACL, PARIS+) LAUSCHER 75 NP B86 189 P. Lauscher et al. (ABCU Collab.) JP MCCUBBIN 75 NP B86 18 NA. McCubbin, L. Lyons DEHM 74 NP B75 47 G. Dehm et al. (MPIM, BRUX, MONS, CERN) |
| WEIGHTED AVERAGE 0.354±0.033 (Error scaled by 1.4) | LINGLIN 73 NP B55 408 D. Linglin (CERN) AGUILAR 71B PR D4 2583 M. Aguilar-Benitez, R.L. Eisner, J.B. Kinson (BNL) BARNHAM 71C NP B28 171 K.W.J. Barnham et al. (BIRM, GLAS) CORDS 71 PR D4 1974 D. Conts et al. (PURD, UCD, 1UPU) |
| Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information. | CORDS 71 PR D4 1974 D. Cords et al. (PURD, UCD, UPPU) BASSOMPIE 69 NP B13 189 G. Bassompierre et al. (CERN, BRUX) JP BISHOP 69 NP B9 403 J.M. Bishop et al. (WISC) CRENNELL 69D PRL 22 487 D.J. Crennell et al. (BNL) DAVIS 69 PRL 23 1071 P.J. Davis et al. (LRL) LIND 69 NP B14 1 V.G. Lind et al. (LRL) JP SCHWEING 69 PR 166 1317 F. Schweingruber et al. (ANL, NWES) Also Thesis F.L. Schweingruber (MWES, NWES) BASSANO 67 PRL 19 968 D. Bassano et al. (BNL, SYRA) FIELD 67 PRL 19 612 J. Badier et al. (EPOL, SACL, AMST) |
| ASTON 87 LASS $\frac{\chi^2}{2.6}$ | $I(J^P) = \frac{1}{2}(0^-)$ OMITTED FROM SUMMARY TABLE |
| BAUBILLIER 82B HBC 0.1 | Observed in $K\pi\pi$ partial-wave analysis. K(1460) MASS |
| (Confidence Level = 0.126) 0.1 0.2 0.3 0.4 0.5 0.6 0.7 | VALUE (MeV) |
| $\Gamma(\kappa \rho)/\Gamma(\kappa^*(892)\pi)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 1460 DAUM 81c CNTR $-$ 63 $K^-p \to K^-2\pi p$ |
| $\Gamma(K\omega)/\Gamma(K^*(892)\pi)$ Γ_5/Γ_2 | \sim 1400 1 BRANDENB 76B ASPK \pm 13 $K^\pm p \rightarrow K^+ 2\pi p$ 1 Coupled mainly to $K f_0(1370)$. Decay into $K^*(892)\pi$ seen. |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> 0.118±0.034 OUR FIT 0.10 ±0.04 FIELD 67 HBC − 3.8 K⁻p | |
| $\Gamma(K\eta)/\Gamma(K^*(892)\pi)$ Γ_7/Γ_2 | VALUE (MeV) DOCUMENT ID TECN CHG COMMENT |
| value DOCUMENT ID TECN CHG COMMENT 0.006 ± 0.014 OUR FIT Error includes scale factor of 1.2. 0.07 ± 0.04 FIELD 67 HBC - 3.8 K ⁻ p | • • • We do not use the following data for averages, fits, limits, etc. • • • $\sim 260 \qquad \qquad \text{DAUM} \qquad 81 \text{C NTR} \qquad - \qquad 63 K^- p \rightarrow \qquad K^- 2\pi p \\ \sim 250 \qquad \qquad ^2 \text{ BRANDENB 76B ASPK} \qquad \pm \qquad 13 K^\pm p \rightarrow \qquad K^+ 2\pi p \\ ^2 \text{ Coupled mainly to } K f_0(1370). \text{ Decay into } K^*(892) \pi \text{ seen.}$ |
| $\Gamma(K\eta)/\Gamma(K\pi)$ VALUE CL% DOCUMENT ID TECN CHG COMMENT TOTAL | K(1460) DECAY MODES |
| 0.0030 + 0.0070 OUR FIT | Mode Fraction (Γ_i/Γ) |
| 0 ±0.0056 15 ASTON 88B LASS − 11 $K^-p \rightarrow K^-\eta p$ • • • We do not use the following data for averages, fits, limits, etc. • • • • <0.04 95 AGUILAR 71B HBC 3.9,4.6 K^-p <0.065 16 BASSOMPIE 69 HBC 5.0 K^+p | Γ_1 $K^*(892)\pi$ seen Γ_2 $K ho$ seen Γ_3 $K_0^*(1430)\pi$ seen |
| <0.02 BISHOP 69 HBC 3.5 $K^+ p$ $\Gamma(K^*(892)\pi\pi)/\Gamma_{\text{total}}$ | K(1460) PARTIAL WIDTHS |
| $\Gamma(K^*(892)\pi\pi)/\Gamma_{\text{total}}$ $\Gamma_3/\Gamma_{\text{2AUE}}$ DOCUMENT ID TECN CHG COMMENT 0.134 \pm 0.022 OUR FIT | $\Gamma(K^*(892)\pi)$ Γ_1 VALUE (MeV) DOCUMENT ID TECN COMMENT |
| 0.12 \pm 0.04 17 GOLDBERG 76 HBC $-$ 3 $K^- \rho \rightarrow \rho \overline{K}{}^0 \pi \pi \pi$ $\Gamma(K^*(892)\pi\pi)/\Gamma(K\pi)$ Γ_3/Γ_1 | • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 109 DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> <u>COMMENT</u> 0.27±0.05 OUR FIT | $\Gamma(K ho)$ VALUE (MeV) DOCUMENT ID TECN COMMENT |
| 0.21 \pm 0.08 16,17 JONGEJANS 78 HBC $-$ 4 $K^- ho ightarrow ho \overline{K}^0 \pi \pi \pi$ $\Gamma(K\omega\pi)/\Gamma_{total}$ | • • • We do not use the following data for averages, fits, limits, etc. • • • ~ 34 DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ |
| VALUE (units 10^{-3})CL%EVTSDOCUMENT IDTECNCOMMENT<0.72 | $\Gamma(K_0^*(1430)\pi)$ |
| 14 From phase shift analysis. 15 ASTON 88B quote $<$ 0.092 at CL=95%. We convert this to a central value and 1 sigma | <u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> • • • We do not use the following data for averages, fits, limits, etc. • • • |
| error in order to be able to use it in our constrained fit. 16 Restated by us. 17 Assuming $\pi\pi$ system has isospin 1, which is supported by the data. | \sim 117 DAUM 81c CNTR 63 $K^- p \rightarrow K^- 2\pi p$ |
| K*3(1430) REFERENCES | K(1460) REFERENCES DAUM 81C NP B187 1 C. Daum et al. (AMST, CERN, CRAC, MPIM+) |
| AUBERT 07AK PR D76 012008 A. Alavi-Harati et al. (BABAR Collab.) | BRANDENB 76B PRL 36 1239 G.W. Brandenburg et al. (SLAC) JP |

 $K_2(1580)$, K(1630), $K_1(1650)$, $K^*(1680)$

 $K_2(1580)$

 $I(J^P) = \frac{1}{2}(2^-)$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the ${\it K}^-\pi^+\pi^-$ system. Needs confirmation.

K2(1580) MASS

| VALUE (MeV) | DOCUMENT ID | | CHG | COMMENT |
|-------------------------|----------------|--------|---------|---------------------------|
| • • • We do not use the | following data | for av | erages, | fits, limits, etc. • • • |
| ~ 1580 | OTTER | 79 | _ | 10,14,16 K ⁻ p |

K2(1580) WIDTH

| VALUE (MeV) | DOCUMENT ID | | CHG | COMMENT |
|-------------------------|----------------|---------|---------|--------------------------|
| • • • We do not use the | following data | for ave | erages, | fits, limits, etc. • • • |
| ~ 110 | OTTER | 79 | _ | 10,14,16 K-p |

K2(1580) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|----------------|-----------------------------------|------------------------------|
| Γ ₁ | $K^*(892)\pi$ $K^*_2(1430)\pi$ | seen possibly seen |

K2(1580) BRANCHING RATIOS

| $\Gamma(K^*(892)\pi)/\Gamma_{\text{tota}}$ | I | | | | Γ_1/Γ | |
|--------------------------------------------|------------------|---------|----------|-----------|------------------------------------------|--|
| VALUE | DOCUMENT IL |) | TECN | CHG | COMMENT | |
| seen | OTTER | 79 | нвс | _ | 10,14,16 K ⁻ p | |
| ● ● We do not use t | he following dat | a for a | verages, | fits, lir | nits, etc. • • • | |
| possibly seen | GULER | 11 | BELL | | $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ | |

| $\Gamma(K_2^*(1430)\pi)/\Gamma_{\text{tota}}$ | il | | | | | Γ2/Γ |
|-----------------------------------------------|-------------|----|------|-----|--------------|------|
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT | |
| possibly seen | OTTER | 79 | HBC | _ | 10,14,16 K-p | |

K₂(1580) REFERENCES

| GULER | 11 | PR D83 032005 | н | Guler et al | | (BELLE | Collab.) | |
|-------|----|---------------|----|--------------|---------|--------|----------|----|
| OTTER | 79 | NP B147 1 | G. | Otter et al. | (ААСНЗ, | | | JΡ |



$$I(J^P) = \frac{1}{2}(??)$$

OMITTED FROM SUMMARY TABLE

Seen as a narrow peak, compatible with the experimental resolution, in the invariant mass of the $K_S^0\pi^+\pi^-$ system produced in π^-p interactions at high momentum transfers.

K(1630) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------|------|--------------|------|----------------------------------------------------------------------------------------------------------------------------------------|
| 1629±7 | ~ 75 | KARNAUKHOV98 | ВС | $ \begin{array}{c} \hline 16.0 \ \pi^{-} p \to \\ (K_{S}^{0} \pi^{+} \pi^{-}) \\ \chi^{+} \pi^{-} \chi^{0} \end{array} $ |

K(1630) WIDTH

| | | ` ' | | |
|-----------------------|------|---------------------------|------|-----------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 16 ⁺¹⁹ -16 | ∼ 75 | ¹ KARNAUKHOV98 | ВС | 16.0 $\pi^- p \to (K_S^0 \pi^+ \pi^-)$ $X^+ \pi^- X^0$ |

 $^{1}\,\text{Compatible}$ with an experimental resolution of 14 $\pm\,1\,$ MeV.

K(1630) DECAY MODES

| | Mode |
|----------------|---------------------|
| Γ ₁ | $K^0_S \pi^+ \pi^-$ |

K(1630) REFERENCES

KARNAUKHOV 98 PAN 61 203 V.M. Karnaukhov, C. Coca, V.I. Moroz Translated from YAF 61 252.

 $K_1(1650)$

$$I(J^P) = \frac{1}{2}(1^+)$$

OMITTED FROM SUMMARY TABLE

This entry contains various peaks in strange meson systems ($K^+\phi$, $K\pi\pi$) reported in partial-wave analysis in the 1600–1900 mass region

K1(1650) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------------------------|------------------|--------|------------|----------|-----------------------------------|
| 1650±50 | | | | | 13 $K^+ p \rightarrow \phi K^+ p$ |
| • • • We do not use the | following data t | for av | erages, fi | its, lim | its, etc. • • • |
| ~ 1840 | ARMSTRONG | 83 | OMEG | _ | $18.5 \ K^-p \rightarrow 3Kp$ |
| ~ 1800 | DAUM | 81c | CNTR | _ | 63 $K^-p \rightarrow K^-2\pi p$ |

K1 (1650) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------------------|----------------|--------|-----------|----------|-----------------------------------|
| 150±50 | FRAME | 86 | OMEG | + | 13 $K^+ p \rightarrow \phi K^+ p$ |
| • • • We do not use the | following data | for av | erages, f | its, lim | nits, etc. • • • |
| ~ 250 | DAUM | 81c | CNTR | _ | 63 K $^-p \rightarrow K^-2\pi p$ |

K1(1650) DECAY MODES

| | Mode |
|----------------------------------|-------------------|
| Γ ₁ Γ ₂ | $K\pi\pi \ K\phi$ |

K₁(1650) REFERENCES

| FRAME | 86 | NP | B276 | 667 | D. Frame et al. | | | (GLAS) |
|-----------|------|----|------|-----|-----------------------|--------|--------------|----------|
| ARMSTRONG | 83 | NP | B221 | 1 | T.A. Armstrong et al. | | (BARI, BIRM, | CERN+) |
| DAUM | 81 C | NP | B187 | 1 | C. Daum et al. | (AMST, | ČERN, CRAC, | MPIM + 1 |



$$I(J^P) = \frac{1}{2}(1^-)$$

K*(1680) MASS

| VALUE (MeV) | DOCUMENT ID | TECN | CHG | COMMENT |
|------------------------|----------------------|--------------|-----------|-----------------------------------------------------|
| 1717±27 OUR AVER | AGE Error include | es scale fac | tor of | 1.4. |
| $1677{\pm}10{\pm}32$ | | | | 11 $K^- p \rightarrow K^- \pi^+ n$ |
| $1735 \pm 10 \pm 20$ | ASTON 8 | 7 LASS | 0 | 11 $K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| • • • We do not use th | e following data for | r averages, | fits, lir | mits, etc. • • • |
| 1678 ± 64 | BIRD 8 | 9 LASS | | |
| 1800 ± 70 | ETKIN 8 | 0 MPS | 0 | $6 K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| ~ 1650 | ESTABROOKS 7 | 8 ASPK | 0 | 13 $K^{\pm}p \rightarrow K^{\pm}\pi^{\pm}n$ |

K*(1680) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------------------------------------|-----------------|--------|-----------|----------|-----------------------------------------------------|
| 322±110 OUR AVERAG | E Error include | s scal | e factor | of 4.2 | |
| | | | | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| $423 \pm 18 \pm 30$ | ASTON | 87 | LASS | 0 | 11 $K^-p \rightarrow \overline{K}^0\pi^+\pi^-n$ |
| ● ● We do not use the | following data | for av | erages, f | its, lim | nits, etc. • • • |
| 454 ± 270 | BIRD | | | | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 170 ± 30 | ETKIN | | | | $6 K^- p \rightarrow \overline{K}^0 \pi^+ \pi^- n$ |
| 250 to 300 | ESTABROOKS | 78 | ASPK | 0 | 13 $K^{\pm} \rho \rightarrow K^{\pm} \pi^{\pm} n$ |

K*(1680) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------|------------------------------|
| Γ ₁ | Κπ | (38.7±2.5) % |
| Γ ₂ | $K \rho$ | $(31.4^{+5.0}_{-2.1})$ % |
| Γ ₃ | $K^*(892)\pi$ | $(29.9^{+2.2}_{-5.0})$ % |

 Γ_2/Γ_1

 Γ_3/Γ_1

 Γ_4/Γ_1

 Γ_5/Γ

 Γ_6/Γ

Meson Particle Listings $K^*(1680), K_2(1770)$

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 4 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 =$ 2.9 for 2 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\widehat{\Gamma_i}/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$\begin{array}{c|cccc}
x_2 & -36 \\
x_3 & -39 & -72 \\
\hline
& x_1 & x_2
\end{array}$$

K*(1680) BRANCHING RATIOS

| $\Gamma(K\pi)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | сна | Γ_1/Γ |
|------------------------------------------------|-------------|----|------|------------|-------------------------------------------------|
| 0.387±0.026 OUR FIT 0.388±0.014±0.022 | ASTON | 88 | | | $11 \ K^- \rho \rightarrow \ K^- \pi^+ n$ |
| Γ(Kπ)/Γ(K*(892)π | DOCUMENT ID | | TECN | CHG | Γ_1/Γ_3 |
| 1.30 ^{+0.23} _{-0.14} OUR FIT | - | | | | |
| 2.8 ±1.1 | ASTON | 84 | LASS | 0 | 11 $K^- \rho \rightarrow \overline{K}^0 2\pi n$ |
| $\Gamma(K\rho)/\Gamma(K\pi)$ VALUE | DOCUMENT ID | | TECN | <u>CHG</u> | Γ ₂ /Γ ₁ |
| 0.81 ^{+ 0.14} OUR FIT 1.2 ±0.4 | ASTON | 84 | LASS | 0 | $11 \ K^- p \to \ \overline{K}^{0} 2\pi n$ |
| $\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ | DOCUMENT ID | | TECN | <u>CHG</u> | Γ ₂ /Γ ₃ |
| 1.05 + 0.27 OUR FIT | | | | | |
| $0.97 \pm 0.09 + 0.30 \\ -0.10$ | ASTON | 87 | LASS | 0 | 11 $K^-p \rightarrow \overline{K}^0\pi^+\pi^-n$ |

K*(1680) REFERENCES

| BIRD | 89 | SLAC-332 | P.F. Bird | (SLAC) |
|------------|----|-------------|------------------------|--------------------------|
| ASTON | 88 | NP B296 493 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |
| ASTON | 87 | NP B292 693 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |
| ASTON | 84 | PL 149B 258 | D. Aston et al. | (SLAC, CARL, OTTA) JP |
| ETKIN | 80 | PR D22 42 | A. Etkin et al. | ` (BNL, CUNY)JP |
| ESTABROOKS | 78 | NP B133 490 | P.G. Estabrooks et al. | (MCGI, CARL, DURH+)JP |



$$I(J^P) = \frac{1}{2}(2^-)$$

See our mini-review in the 2004 edition of this Review, PDG 04.

K2(1770) MASS

| VALUE (Me | V) EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|-------------|-------------------|------------------------|-------|-----------|---------|-------------------------------------------------------------------|
| 1773± | 8 | $^{ m 1}$ ASTON | 93 | LASS | | $11K^-p \rightarrow K^-\omega p$ |
| • • • We | do not use the fo | llowing data for aver | ages, | fits, lim | its, et | C. • • • |
| 1743± | 15 | TIKHOMIROV | 03 | SPEC | | $^{40.0}_{\ \ \kappa_{S}^{0}} \kappa_{S}^{0} \kappa_{I}^{0} X$ |
| $1810\pm$ | 20 | FRAME | 86 | OMEG | + | 13 $K^+ p \rightarrow \phi K^+ p$ |
| ~ 1730 | | ARMSTRONG | 83 | OMEG | _ | $18.5 K^-p \rightarrow 3Kp$ |
| ~ 1780 | | ² DAUM | 81 C | CNTR | _ | $63~\textrm{K}^- p \rightarrow ~\textrm{K}^- 2\pi p$ |
| $1710\pm$ | 15 60 | CHUNG | 74 | HBC | _ | 7.3 $K^-p \rightarrow K^-\omega p$ |
| $1767\pm$ | 6 | BLIEDEN | 72 | MMS | _ | 11-16 K p |
| $1730\pm$ | 20 306 | ³ FIRESTONE | 72B | DBC | + | $12 K^+ d$ |
| $1765\pm$ | 40 | ⁴ COLLEY | 71 | HBC | + | $10 K^+ p \rightarrow K 2\pi N$ |
| 1740 | | DENEGRI | 71 | DBC | _ | 12.6 $K^-d \rightarrow \overline{K} 2\pi d$ |
| $1745\pm$ | 20 | AGUILAR | 70C | HBC | _ | 4.6 K ⁻ p |
| $1780\pm$ | 15 | BARTSCH | 70C | HBC | _ | $10.1~K^{-}p$ |
| $1760\pm$ | 15 | LUDLAM | 70 | HBC | _ | 12.6 K ⁻ p |
| 1 | | | | | | |

- 1 From a partial wave analysis of the $K^{-}\omega$ system.
- ² From a partial wave analysis of the $K=2\pi$ system.
- $^3\,\mbox{Produced}$ in conjunction with excited deuteron.
- ⁴ Systematic errors added correspond to spread of different fits.

K2(1770) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|-------------|------|--------------|----|------|------|----------------------------------|
| 186±14 | | 5 ASTON | 93 | LASS | | $11K^-p \rightarrow K^-\omega p$ |

| • | • | • | We do | not | use the | following | data | for | averages, | fits, | limits, etc. | • | • | • |
|---|---|---|-------|-----|---------|-----------|------|-----|-----------|-------|--------------|---|---|---|
|---|---|---|-------|-----|---------|-----------|------|-----|-----------|-------|--------------|---|---|---|

| 147±70 | | TIKHOMIROV | 03 | SPEC | | $\kappa_S^0 \kappa_S^0 \kappa_L^0 X$ |
|------------------|-----|------------------------|------|------|---|---------------------------------------------|
| 140 ± 40 | | FRAME | 86 | OMEG | + | 13 $K^+ p \rightarrow \phi K^+ p$ |
| ~ 220 | | ARMSTRONG | 83 | OMEG | - | $18.5 K^-p \rightarrow 3Kp$ |
| ~ 210 | | ⁶ DAUM | 81 C | CNTR | _ | 63 $K^- p \rightarrow K^- 2\pi p$ |
| 110 ± 50 | 60 | CHUNG | 74 | HBC | _ | 7.3 $K^-p \rightarrow K^-\omega p$ |
| 100 ± 26 | | BLIEDEN | 72 | MMS | - | 11-16 K ⁻ p |
| 210 ± 30 | 306 | ⁷ FIRESTONE | 72B | DBC | + | 12 K ⁺ d |
| 90 ± 70 | | ⁸ COLLEY | 71 | HBC | + | $10 K^+ p \rightarrow K 2\pi N$ |
| 130 | | DENEGRI | 71 | DBC | _ | 12.6 $K^-d \rightarrow \overline{K} 2\pi d$ |
| 100 ± 50 | | AGUILAR | 70 C | HBC | - | 4.6 K - p |
| $138\!\pm\!40$ | | BARTSCH | 70 C | HBC | - | 10.1 K ⁻ p |
| $50 + 40 \\ -20$ | | LUDLAM | 70 | нвс | - | 12.6 K ⁻ p |

 $^{^5\,\}mathrm{From}$ a partial wave analysis of the $\mathit{K}^{-}\,\omega$ system.

K2(1770) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|------------------|------------------------------|
| $\overline{\Gamma_1}$ | Κππ | _ |
| Γ_2 | $K_2^*(1430)\pi$ | dominant |
| Γ_3 | $K^*(892)\pi$ | seen |
| Γ_4 | $K f_2(1270)$ | seen |
| Γ_5 | $K f_0(980)$ | |
| Γ ₆ | $K\phi$ | seen |
| Γ_7 | $K \omega$ | seen |

K2(1770) BRANCHING RATIOS

$\Gamma(K_2^*(1430)\pi)/\Gamma(K\pi\pi)$ $(K_2^*(1430) \to K\pi)$

| VALUE | DO CUMENT ID | | TE CN | CHG | COMMENT |
|------------------------------|------------------------|--------|----------|-----------|----------------------------------|
| • • • We do not us | se the following data | for av | verages, | fits, lin | nits, etc. • • • |
| ~ 0.03 | DAUM | | CNTR | | 63 K $^-p \rightarrow K^-2\pi p$ |
| ~ 1.0 | ⁹ FIRESTONE | 72B | DBC | + | 12 K ⁺ d |
| <1.0 | COLLEY | 71 | HBC | | 10 K ⁺ p |
| 0.2 ± 0.2 | AGUILAR | 70c | HBC | _ | 4.6 K ⁻ p |
| <1.0 | BARTSCH | 70c | HBC | - | 10.1 K ⁻ p |
| 1.0 | BARBARO | 69 | HBC | + | 12.0 K ⁺ p |
| ⁹ Produced in con | junction with excited | deut | eron. | | |

 $\Gamma(K^*(892)\pi)/\Gamma(K\pi\pi)$ DO CUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

81c CNTR 63 $K^-p \rightarrow K^-2\pi p$ ~ 0.23 DAUM

 $\frac{\Gamma(\textit{K}\,\textit{f}_{2}(1270))/\Gamma(\textit{K}\,\pi\,\pi)}{(\textit{f}_{2}(1270)\,\rightarrow\,\pi\,\pi)}$ NALUE DO DO CUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ~ 0.74 DAUM 81c CNTR 63 $K^-p \rightarrow K^-2\pi p$

| $\Gamma(K f_0(980))/\Gamma_{\text{total}}$ | | | |
|--------------------------------------------|---------------------------|------------|------------|
| VALUE | DOCUMENT ID | TECN | COMMENT |
| • • We do not use the following | ng data for averages, fit | s. limits. | etc. • • • |

TIKHOMIROV 03 SPEC $40.0 \, \pi^{-}_{K} \stackrel{C}{\varsigma} \stackrel{\rightarrow}{\kappa_{L}^{0}} \stackrel{C}{\kappa} \stackrel{O}{\kappa} possibly seen

 $\Gamma(K\phi)/\Gamma_{\text{total}}$

| VALUE | DOCUMENTID | TECN CHO | COMMENT |
|-------------------------------------|--------------|-----------|-----------------------------------------|
| seen | ARMSTRONG 83 | OMEG - | $18.5 \ K^- p \rightarrow \ K^- \phi N$ |
| $\Gamma(K\omega)/\Gamma_{ m total}$ | | | Γ ₇ /Γ |
| VALUE | DO CUMENT ID | TECN CHG | COMMENT |
| seen | OTTER 81 | HBC \pm | 8.25,10,16 K [±] p |
| seen | CHUNG 74 | HBC — | 7.3 $K^- p \rightarrow K^- \omega p$ |

⁶ From a partial wave analysis of the $K = 2\pi$ system.

⁷Produced in conjunction with excited deuteron.

⁸ Systematic errors added correspond to spread of different fits.

 $K_2(1770), K_3^*(1780)$

K₂(1770) REFERENCES

| PDG | 04 | PL B592 1 | S. Eidelman <i>et al</i> . | (PDG Collab.) |
|------------|------|-------------------------------|---------------------------------------|------------------|
| TIKHOMIROV | 03 | PAN 66 828 Translated from | G.D. Tikhomirov et al. | |
| | | | | |
| ASTON | 93 | PL B308 186 | D. Aston et al. (SLAC, NA | AGO, CINC, INUS) |
| FRAME | 86 | NP B276 667 | D. Frame et al. | (GLAS) |
| ARMSTRONG | 83 | NP B221 1 | T.A. Armstrong et al. (BAR | I, BIRM, CÉRN+) |
| DAUM | 81 C | NP B187 1 | C. Daum et al. (AMST, ČERN | I, CRAC, MPIM+) |
| OTTER | 81 | NP B181 1 | G. Otter (AACH3, BERL, LO | IC, VIEN, BIRM+) |
| CHUNG | 74 | PL 51B 413 | S.U. Chung et al. | (BNL) |
| BLIEDEN | 72 | PL 39B 668 | H.R. Blieden et al. | (STON, NEAS) |
| FIRESTONE | 72 B | PR D5 505 | A. Firestone et al. | (LBL) |
| COLLEY | 71 | NP B26 71 | D.C. Colley et al. | (BIRM, GLAS) |
| DENEGRI | 71 | NP B28 13 | D. Denegri et al. | (JHU) JP |
| AGUILAR | 70 C | PRL 25 54 | M. Aguilar-Benitez et al. | (BNL) |
| BARTS CH | 70 C | PL 33B 186 | J. Bartsch et al. (AACI | H, BERL, CERN+) |
| LUDLAM | 70 | PR D2 1234 | T. Ludlam, J. Sandweiss, A.J. Släught | er (YALE) |
| BARBARO | 69 | PRL 22 1207 | A. Barbaro-Galtieri et al. | `(LRL) |

$K_3^*(1780)$

$$I(J^P) = \frac{1}{2}(3^-)$$

K*(1780) MASS

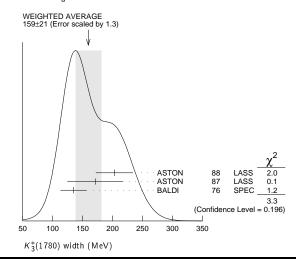
| VALUE (MeV) E | VTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|----------------------|------------|-------------------|-------|-------------|---------|------------------------------------------------------------------------------------------|
| 1776± 7 OUR AVER | | or includes scale | facto | or of 1.1 | | |
| $1781\pm~8\pm~4$ | 1 | ASTON | 88 | LASS | 0 | 11 $K^-p \rightarrow$ |
| 4740 1 44 1 45 | 1 | | | | | $K^-\pi^+$ n |
| $1740 \pm 14 \pm 15$ | | ASTON | 87 | LASS | 0 | $\begin{array}{c} 11 \ K^- p \rightarrow \\ \overline{K}^0 \pi^+ \pi^- n \end{array}$ |
| 1779 ± 11 | 2 | P BALDI | 76 | SPEC | + | $10 K^+ p \rightarrow K^0 \pi^+ p$ |
| 1776 ± 26 | 3 | BRANDENB | 76D | | 0 | 13 $K^{\pm} p \rightarrow$ |
| | | | | | | $\kappa^{\pm}\pi^{\mp}N$ |
| • • • We do not use | the follow | ing data for ave | rages | , fits, lim | its, et | C. • • • |
| 1720±10±15 6 | 111 4 | BIRD | 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |
| 1749 ± 10 | | ASTON | 88B | LASS | _ | 11 $K^-p \rightarrow K^-\eta p$ |
| 1780 ± 9 | 300 | BAUBILLIER | 84B | HBC | _ | 8.25 K ⁻ p → |
| | | | | | | $\overline{K}^0 \pi^- \rho$ |
| 1790 ± 15 | | BAUBILLIER | 82B | нвс | 0 | $8.25 K^- p \rightarrow$ |
| | | | | | | $K_S^0 2\pi N$ |
| 1784 ± 9 2 | 060 | CLELAND | 82 | SPEC | \pm | 50 K ⁺ p \rightarrow K ⁰ _S π^{\pm} p |
| 1786 ± 15 | 5 | ASTON | 81 D | LASS | 0 | 11 $K^-p \rightarrow$ |
| | | | | | | $K^-\pi^+n$ |
| 1762± 9 | 190 | TOAFF | 81 | нвс | _ | $\begin{array}{c} 6.5 & K^{-} p \rightarrow \\ \overline{K}^{0} & \pi^{-} p \end{array}$ |
| 1850±50 | | ETKIN | 80 | MPS | 0 | $6 K^- p \rightarrow$ |
| 1030 ± 30 | | LIKIN | 00 | IVIF 3 | U | $\frac{0}{K} \frac{\rho}{\pi} + \frac{\pi}{\pi}$ |
| 1812 ± 28 | | BEUSCH | 78 | OMEG | | $10 \stackrel{K}{K}^{-}\stackrel{n}{p} \stackrel{n}{\rightarrow}$ |
| | | | | | | $\overline{K}^0\pi^+\pi^-n$ |
| 1786± 8 | | CHUNG | 78 | MPS | 0 | $6 K^- p \rightarrow K^- \pi^+ n$ |

- $^1\,{\rm From}$ energy-independent partial-wave analysis. $^2\,{\rm From}$ a fit to $\,Y_6^2\,$ moment. $\,J^P\,\equiv\,3^-\,$ found.
- 3 Confirmed by phase shift analysis of ESTABROOKS 78, yields $J^P \equiv 3^-$.
- 4 From a partial wave amplitude analysis. 5 From a fit to the Y_6^0 moment.

K*(1780) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------------|-------------|------------------------|-------------|-----------|---------|------------------------------------------------------------------------------------------------|
| 159±21 OUR A | VERAGE | Error includes sca | le fac | or of 1. | 3. See | the ideogram below. |
| $203\!\pm\!30\!\pm\!8$ | | ⁶ ASTON | 88 | LASS | 0 | 11 $K^- \rho \rightarrow$ |
| $171 \pm 42 \pm 20$ | | ⁶ ASTON | 87 | LASS | 0 | $ \begin{array}{c} K^-\pi^+ n \\ 11 K^- p \to \\ \overline{K}^0 \pi^+ \pi^- n \end{array} $ |
| 135 ± 22 | | ⁷ BALDI | 76 | SPEC | + | 10 $K^+ p \rightarrow K^0 \pi^+ p$ |
| • • • We do not | use the fol | lowing data for ave | rages, | fits, lim | its, et | S. • • • |
| $187\pm31\pm20$ | 6111 | ⁸ BIRD | 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}{}^0 \pi^- \rho$ |
| $193 + 51 \\ -37$ | | ASTON | 88B | LASS | _ | $11~K^-p\to~K^-\eta p$ |
| 99±30 | 300 | BAUBILLIER | 84B | нвс | - | $\begin{array}{c} 8.25 K^- p \rightarrow \\ \overline{K}^0 \pi^- p \end{array}$ |
| ~ 130 | | BAUBILLIER | 82в | НВС | 0 | $8.25 \begin{array}{c} K - p \\ K - p \rightarrow \\ K_S^0 2\pi N \end{array}$ |
| 191 ± 24 | 2060 | CLELAND | 82 | SPEC | \pm | $50 K^{+} p \rightarrow K_{S}^{0} \pi^{\pm} p$ |
| 225 ± 60 | | ⁹ ASTON | 81 D | LASS | 0 | 11 K [−] p → |
| ~ 80 | 190 | TOAFF | 81 | нвс | - | $ \begin{array}{c} K^-\pi^+ n \\ 6.5 & K^-\rho \to \\ \overline{K}^0 & \pi^-\rho \end{array} $ |
| $240{\pm}50$ | | ETKIN | 80 | MPS | 0 | $ \begin{array}{ccc} K & p & \rightarrow \\ K^0 & \pi^+ & \pi^- \end{array} $ |
| 181 ± 44 | | ¹⁰ BEUSCH | 78 | OMEG | | $10 \frac{K^{\circ} \pi^{+} \pi}{K^{0} \pi^{+} \pi^{-} n}$ |
| 96 ± 31 | | CHUNG | 78 | MPS | 0 | $6 \stackrel{K^-}{K^-} \stackrel{\pi^+}{p} \rightarrow \stackrel{\pi^+}{K^-} \pi^+ n$ |
| 270 ± 70 | | ¹¹ BRANDENB | 76 D | ASPK | 0 | 13 $K^{\pm} p \rightarrow K^{\pm} \pi^{\mp} N$ |

- ⁶ From energy-independent partial-wave analysis. ⁷ From a fit to Y_6^2 moment. $J^P=3^-$ found.
- 8 From a partial wave amplitude analysis. 9 From a fit to Y_6^0 moment.
- $^{10}_{-}$ Errors enlarged by us to $4\Gamma/\sqrt{\textit{N}};$ see the note with the $\textit{K}^*(892)$ mass.
- 11 ESTABROOKS 78 find that BRANDENBURG 76D data are consistent with 175 MeV width. Not averaged.



K*(1780) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|----------------|------------------|------------------------------|------------------|
| Γ ₁ | Κρ | (31 ± 9)% | |
| Γ_2 | $K^*(892)\pi$ | (20 ± 5) % | |
| Γ_3 | $K\pi$ | (18.8± 1.0) % | |
| Γ_4 | $K\eta$ | (30 ±13) % | |
| Γ ₅ | $K_2^*(1430)\pi$ | < 16 % | 95 % |

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 4 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2=$ 0.0 for 1 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j
angle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one

K₃(1780) BRANCHING RATIOS

| $\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ | | | | | | Γ_1/Γ_2 |
|--------------------------------------|-------------------|--------|--------------|-----------|---------------------------|-----------------------------|
| VALUE | DOCUMENT ID | | <u>TE CN</u> | CHG | COMMENT | |
| 1.52±0.23 OUR FIT 1.52±0.21±0.10 | ASTON | 87 | LASS | 0 | 11 $K^- \rho \rightarrow$ | $\overline{K}^0\pi^+\pi^-n$ |
| $\Gamma(K^*(892)\pi)/\Gamma(K\pi)$ |) | | | | | Γ_2/Γ_3 |
| VALUE | DO CUMENT ID | | TE CN | CHG | COMMENT | |
| 1.09±0.26 OUR FIT | | | | | | |
| 1.09±0.26 | ASTON | 84B | LA SS | 0 | 11 $K^-p \rightarrow$ | $\overline{K}^0 2\pi n$ |
| $\Gamma(K\pi)/\Gamma_{\text{total}}$ | | | | | | Γ_3/Γ |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT | |
| 0.188±0.010 OUR FIT | · | | | | | |
| 0.188±0.010 OUR AVER | RAGE | | | | | |
| $0.187 \pm 0.008 \pm 0.008$ | ASTON | 88 | LASS | 0 | 11 $K^-p \rightarrow$ | |
| 0.19 ± 0.02 | ESTABROOKS | 78 | ASPK | 0 | 13 $K^{\pm}p \rightarrow$ | $K \pi N$ |
| $\Gamma(K\eta)/\Gamma(K\pi)$ | | | | | | Γ_4/Γ_3 |
| VALUE | DOCUMENT ID | | TE CN | CHG | COMMENT | |
| 1.6 ±0.7 OUR FIT | | | | | | |
| • • • We do not use the | e following data | for av | /erages, | fits, lir | nits, etc. 🔸 🔸 | • |
| 0.41 ± 0.050 | ² BIRD | 89 | LA SS | _ | 11 $K^-p \rightarrow$ | $\overline{K}^0\pi^-\rho$ |
| 0.50 ± 0.18 | ASTON | 88B | LASS | - | 11 $K^-p \rightarrow$ | $\kappa^- \eta p$ |

 $^{^{12}\,\}mathrm{This}$ result supersedes ASTON 88B.

| $\Gamma(K_2^*(1430)\pi)/\Gamma(K^*(892)\pi)$ | | | | | | |
|----------------------------------------------|-----|--------------|----|-------|-----|-----------------------------|
| VALUE | CL% | DO CUMENT ID | | TE CN | CHG | COMMENT |
| <0.78 | 95 | ASTON | 87 | LASS | 0 | 11 $K^- \rho \rightarrow$ |
| | | | | | | $\overline{K}^0\pi^+\pi^-n$ |

K₃(1780) REFERENCES

| BIRD ASTON ASTON | 89 88 88 B | SLAC-332 NP B296 493 PL B201 169 | P.F. Bird D. Aston et al. D. Aston et al. | (SLAC) (SLAC, NAGO, CINC, INUS) (SLAC, NAGO, CINC, INUS)JP |
|------------------------|------------------|----------------------------------------|-------------------------------------------|------------------------------------------------------------------|
| ASTON | 87 | NP B292 693 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |
| ASTON | 84 B | NP B247 261 | D. Aston et al. | (SLAC, CARL, OTTA) |
| BAUBILLIER | 84 B | ZPHY C26 37 | M. Baubillier et al. | (BIRM, CERN, GLAS+) |
| BAUBILLIER | 82 B | NP B202 21 | M. Baubillier et al. | (BIRM, CERN, GLAS+) |
| CLELAND | 82 | NP B208 189 | W.E. Cleland et al. | (DURH, GEVA, LAUS+) |
| ASTON | 81 D | PL 99B 502 | D. Aston et al. | (SLAC, CARL, OTTA) JP |
| TOAFF | 81 | PR D23 1500 | S. Toaff et al. | ` (ANL, KANS) |
| ETKIN | 80 | PR D22 42 | A. Etkin et al. | (BNL, CUNY) JP |
| BEUSCH | 78 | PL 74B 282 | W. Beusch et al. | (CERN, ÀACH3, ETH)JP |
| CHUNG | 78 | PRL 40 355 | S.U. Chung et al. | (BNL, BRAN, CUNY+)JP |
| ESTABROOKS | 78 | NP B133 490 | P.G. Estabrooks et al. | (MCGI, CARL, DURH+)JP |
| Also | | PR D17 658 | P.G. Estabrooks et al. | (MCGI, CARL, DURH+) |
| BALDI | 76 | PL 63B 344 | R. Baldi et al. | (GEVA) JP |
| BRANDENB | 76 D | PL 60B 478 | G.W. Brandenburg et al. | (SLAC) JP |



$$I(J^P) = \frac{1}{2}(2^-)$$

See our mini-review in the 2004 edition of this Review (PDG 04)

K2(1820) MASS

| VALUE (MeV) | DO CUMENT I | 'D | TECN | COMMENT |
|-----------------------------------------------------------------------|---------------------|------------|---------|---------------------------------------|
| 1816±13 | 1 ASTON | 93 | LASS | $11K^-\rho \rightarrow K^-\omega\rho$ |
| | ving data for avera | ges, fits, | limits, | etc. • • • |
| \sim 1840 | ² DAUM | 81 C | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ |
| 1 From a partial wave analysi 2 From a partial wave analysi | | | | |

K2(1820) WIDTH

| VALUE (MeV) | DO CUMENT II | | TECN | COMMENT |
|--------------------------------|---------------------|-------------|---------|----------------------------------|
| 276±35 | 3 ASTON | 93 | LASS | $11K^-p \rightarrow K^-\omega p$ |
| • • • We do not use the follow | ing data for averag | ges, fits, | limits, | etc. • • • |
| ~ 230 | ⁴ DAUM | 81 C | CNTR | 63 $K^-p \rightarrow K^-2\pi p$ |

 $^{^3}$ From a partial wave analysis of the $K^-\omega$ system. 4 From a partial wave analysis of the $K^-\,2\pi$ system.

K2(1820) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|----------------|------------------|------------------------------|
| Γ ₁ | Κππ | |
| Γ_2^- | $K_2^*(1430)\pi$ | seen |
| Γ_3 | $K^{*}(892)\pi$ | seen |
| Γ_4 | $K f_2(1270)$ | seen |
| Γ_5 | $K \omega$ | seen |

K2(1820) BRANCHING RATIOS

| $\Gamma(K_2^*(1430)\pi)/\Gamma(K\pi\pi)$ | | | | | Γ_2/Γ_1 |
|------------------------------------------|--------------------|-------------|---------|----------------------|-----------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do not use the following | g data for average | es, fits, | limits, | etc. • • • | |
| ~ 0.77 | DAUM | 81∈ | CNTR | $63K^-p \rightarrow$ | $\overline{K} 2\pi p$ |
| $\Gamma(K^*(892)\pi)/\Gamma(K\pi\pi)$ | DOCUMENT ID | | TECN | COMMENT | Γ_3/Γ_1 |
| • • • We do not use the following | | | | | |
| ~ 0.05 | DAUM | 81∈ | CNTR | $63K^-p \rightarrow$ | $\overline{K} 2\pi p$ |
| $\Gamma(K f_2(1270))/\Gamma(K\pi\pi)$ | | | | | Γ_4/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use the following | g data for average | es, fits, | limits, | etc. • • • | |
| ~ 0.18 | DAUM | 81 C | CNTR | $63K^-p \rightarrow$ | $\overline{K} 2\pi p$ |
| К2 | (1820) REFER | ENCI | S | | |

| PDG | 04 | PL B592 1 | S. Eidelman et al. | (PDG Collab. |
|-------|------|-------------|--------------------|---------------------------|
| ASTON | 93 | PL B308 186 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |
| DAUM | 81 C | NP B187 1 | C. Daum et al. | (AMST, CERN, CRAC, MPIM+) |



$$I(J^P) = \frac{1}{2}(0^-)$$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of $K^-\phi$ system. Needs confirmation.

K(1830) MASS

| VALUE (MeV) | DOCUMENT ID | TECN CHG | COMMENT |
|-------------------------|------------------------|-------------------|------------------------------|
| • • • We do not use the | following data for ave | erages, fits, lim | its, etc. • • • |
| ~ 1830 | ARMSTRONG 83 | OMEG - | $18.5 K^- p \rightarrow 3Kp$ |

K(1830) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN CHG | COMMENT |
|-------------------------|-----------------------|-------------------|---------------------------------|
| • • • We do not use the | following data for av | erages, fits, lin | nits, etc. • • • |
| ~ 250 | ARMSTRONG 83 | OMEG - | $18.5 \ K^- p \rightarrow 3K p$ |

K(1830) DECAY MODES

Mode $K\phi$

K(1830) REFERENCES

ARMSTRONG 83 NP B221 1 T.A. Armstrong et al. (BARI, BIRM, CERN+) JP

 $K_0^*(1950)$

$$I(J^P) = \frac{1}{2}(0^+)$$

OMITTED FROM SUMMARY TABLE

Seen in partial-wave analysis of the ${\it K}^-\pi^+$ system. Needs confir-

K*(1950) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|---------------------------|-------------------------|--------|----------|-----------|---------------------------------|
| $1945 \pm 10 \pm 20$ | $^{ m 1}$ ASTON | 88 | LASS | 0 | 11 $K^-p \rightarrow K^-\pi^+n$ |
| ullet $ullet$ We do not | use the following data | for av | verages, | fits, lir | nits, etc. • • • |
| 1917 ± 12 | ² ZHOU | | | | $Kp \rightarrow K^-\pi^+n$ |
| 1820 ± 40 | ³ A NISOVICH | 97c | RVUE | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| $^{ m 1}$ We take the c | entral value of the two | solut | ions and | the la | rger error given. |

K*(1950) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------------------------------------------------------------|-------------------------|--------|----------|-----------|---------------------------------------|
| 201 ± 34 ± 79 | ⁴ ASTON | 88 | LASS | 0 | 11 $K^- \rho \rightarrow K^- \pi^+ n$ |
| • • • We do not use | the following data | for av | verages, | fits, lin | nits, etc. • • • |
| 145 ± 38 | ⁵ ZHOU | 06 | RVUE | | $K p \rightarrow K^- \pi^+ n$ |
| 250 ± 100 | ⁶ A NISOVICH | 97c | RVUE | | 11 $K^-p \rightarrow K^-\pi^+n$ |
| ⁴ We take the central value of the two solutions and the larger error given. | | | | | |

 $^{^5}$ S-matrix pole. Using ASTON 88 and assuming $K_0^*(800)$, $K_0^*(1430)$.

K*(1950) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------|------------------------------|
| Г ₁ | Κπ | (52±14) % |

K*(1950) BRANCHING RATIOS

| $\Gamma(K\pi)/\Gamma_{\text{total}}$ | | | | | | Γ_1/Γ_1 |
|-----------------------------------------------------------------|-----------------------------------------|-------------------|---------------------------|------------------|----------------------------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT | |
| $0.52 \pm 0.08 \pm 0.12$ | ⁷ ASTON | 88 | LA SS | 0 | 11 $K^-p \rightarrow K^-\pi^+$ | n |
| ● ● We do not use | the following data | a for a | verages, | fits, lir | nits, etc. • • • | |
| ~ 0.60 | ⁸ ZHOU | 06 | RVUE | | $K\rho \rightarrow K^-\pi^+ n$ | |
| ⁷ We take the cent ⁸ S-matrix pole. Us | ral value of the tw sing ASTON 88 an | o solu ıd assı | ions and iming K_0^* | the la (800), | rger error given. , $K_0^*(1430)$. | |

K*(1950) REFERENCES

| ZHOU | 06 | NP A775 212 | Z.Y. Zhou, H.Q. Zheng | |
|-----------|------|-------------|--------------------------------|-----------------------|
| ANISOVICH | 97 C | PL B413 137 | A.V. Anisovich, A.V. Sarantsev | |
| ASTON | 88 | NP B296 493 | D. Aston et al. (SLA | NC, NAGO, CINC, INUS) |

 $^{^2}$ S-matrix pole. Using ASTON 88 and assuming $K_0^*(800)$, $K_0^*(1430)$.

 $^{^3\,\}text{T-matrix}$ pole. Reanalysis of ASTON 88 data.

⁶T-matrix pole. Reanalysis of ASTON 88 data.

 $K_2^*(1980), K_4^*(2045)$

 $K_2^*(\overline{1980})$

 $I(J^P) = \frac{1}{2}(2^+)$

OMITTED FROM SUMMARY TABLE Needs confirmation.

| $K_2^*(1980)$ | MASS |
|---------------|------|
|---------------|------|

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|---------------------------------|----------------|-----------------|-------|------------|--------|----------------------------------------------------------|
| 1973± 8±25 | | ASTON | 87 | LASS | 0 | 11 $K^-p \rightarrow \overline{K}^0\pi^+\pi^-n$ |
| ● ● We do n | ot use the fol | lowing data for | avera | ages, fits | , limi | ts, etc. • • • |
| 2020 ± 20 | | TIKHOMIROV | | | | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_I^0 X$ |
| 1978 ± 40 | 241 ± 47 | BIRD | 89 | LASS | - | 11 $K^- p \rightarrow \overline{K}^0 \pi^- \overline{p}$ |

K*(1980) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|--------------|----------------|------------------|------|------------|-------|-----------------------------------------------------------|
| 373±33±60 | | ASTON | 87 | LASS | 0 | $11 \ K^- p \rightarrow \ \overline{K}{}^0 \pi^+ \pi^- n$ |
| • • • We do | not use the fo | llowing data for | aver | ages, fits | , lim | its, etc. • • • |
| 180 ± 70 | | TIKHOMIROV | | | | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_I^0 X$ |
| 398 ± 47 | 241 ± 47 | BIRD | 89 | LASS | _ | 11 $K^- \rho \rightarrow \overline{K}^0 \pi^- \rho$ |

K*(1980) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $K^*(892)\pi$ | possibly seen |
| Γ_2 | $K\rho$ | possibly seen |
| Γ ₃ | K f ₂ (1270) | possibly seen |

K*(1980) BRANCHING RATIOS

| $\Gamma(K^*(892)\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|---------------------------------------------|----------------|-------------|------------|-----------------------------------------------------------|
| VALUE | DO CUMENT I | 'D | TECN | COMMENT |
| possibly seen | GULER | 11 | BELL | $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ |
| $\Gamma(K\rho)/\Gamma_{\text{total}}$ | | | | Γ ₂ /Γ |
| VALUE | DO CUMENT I | 'D | TECN | COMMENT |
| possibly seen | GULER | 11 | BELL | $B^+ \rightarrow J/\psi K^+ \pi^+ \pi^-$ |
| $\Gamma(K\rho)/\Gamma(K^*(892)\pi)$ | DOCUMENT ID | <u>TECN</u> | <u>CHG</u> | Γ_2/Γ_1 |
| 1.49±0.24±0.09 | ASTON 87 | LASS | 0 | $11 \ K^- p \rightarrow \ \overline{K}^0 \pi^+ \pi^- n$ |
| $\Gamma(Kf_2(1270))/\Gamma_{\text{total}}$ | 0.0 0.04547 40 | | | Г ₃ /Г |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| possibly seen | TIKHOMIRO | / 03 5 | SPEC | 40.0 $\pi^- C \rightarrow K_S^0 K_S^0 K_L^0 X$ |

K₂*(1980) REFERENCES

| GULER | 11 | PR D83 032005 | H. Guler et al. | (BELLE Collab.) |
|------------|----|-----------------------|------------------------|--------------------------|
| TIKHOMIROV | 03 | PAN 66 828 | G.D. Tikhomirov et al. | |
| | | Translated from YAF 6 | 6 860. | |
| BIRD | 89 | SLAC-332 | P.F. Bird | (SLAC) |
| ASTON | 87 | NP B292 693 | D. Aston et al. | (SLAC, NAGO, CINC, INUS) |



$$I(J^P) = \frac{1}{2}(4^+)$$

K*(2045) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CH G | COMMENT |
|--------------------------|------------|------------------------|--------|-------------|----------|------------------------------------------------------------------------------|
| 2045 ± 9 OUR A | VERAGE | Error includes sca | le fac | tor of 1. | 1. | |
| $2062\!\pm\ 14\!\pm\!13$ | | $^{ m 1}$ ASTON | 86 | LASS | 0 | 11 K ⁻ p → |
| $2039\!\pm\ 10$ | 400 | ^{2,3} CLELAND | 82 | SPEC | ± | $50 \stackrel{K^-\pi^+ n}{K^+ p \rightarrow} \stackrel{K^0\pi^{\pm} p}{K^0}$ |
| $2070 + 100 \\ - 40$ | | ⁴ ASTON | 81 C | LASS | 0 | 11 $K^- \rho \rightarrow$ |
| • • • We do not u | use the fo | llowing data for ave | rages, | , fits, lin | nits, et | K ⁻ π ⁺ n |
| 2079 ± 7 | 431 | TORRES | 86 | MPSF | | $400 pA \rightarrow 4KX$ |
| 2088 ± 20 | 650 | BAUBILLIER | 82 | нвс | _ | $8.25 \ K^-p \rightarrow$ |
| | | | | | | $\kappa_S^0 \pi^- \rho$ |
| 2115 ± 46 | 488 | CARMONY | 77 | нвс | 0 | $9 K^+ d \rightarrow K^+ \pi's \lambda$ |

K*(2045) WIDTH

| VALUE (MeV) 198± 30 OUR A | EVTS | DOCUMENT ID | | TECN | <u>CHG</u> | COMMENT |
|-----------------------------|---------------|---------------------|--------|-------------|------------|---------------------------------------------------------------------------|
| 221 ± 48 ± 27 | WERAGE | ⁵ ASTON | | | | 11 K [−] p → |
| 189± 35 | 400 | 6,7 CLELAND | 82 | SPEC | ± | $50 \stackrel{K^-\pi^+n}{K^+p} \rightarrow \stackrel{K^0\pi^{\pm}p}{K^S}$ |
| • • • We do no | t use the fol | lowing data for ave | rages, | , fits, lim | its, et | c. • • • |
| 61 ± 58 | 431 | TORRES | 86 | MPSF | | $400 pA \rightarrow 4KX$ |
| $170 {}^{+ 1 0 0}_{- 5 0}$ | 650 | BAUBILLIER | 82 | НВС | - | 8.25 $K^- p \to K_S^0 \pi^- p$ |
| $240{}^{+500}_{-100}$ | | ⁸ ASTON | 81 C | LASS | | 11 K [−] p → |
| 300±200 | | CARMONY | 77 | нвс | 0 | 9 $K^+ d \rightarrow K^+ \pi$'s X |
| 5 Erom a fit to | all moment | c | | | | |

$K_4^*(2045)$ DECAY MODES

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-----------------------|---------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | Κπ | (9.9±1.2) % |
| Γ_2 | $K^*(892)\pi\pi$ | (9 ±5)% |
| Γ_3 | $K^*(892)\pi\pi\pi$ | (7 ±5)% |
| Γ_4 | $\rho K \pi$ | (5.7±3.2) % |
| Γ_5 | $\omega K \pi$ | (5.0±3.0) % |
| Γ_6 | $\phi K \pi$ | (2.8 ± 1.4) % |
| Γ ₇ | $\phi K^*(892)$ | (1.4 ± 0.7) % |

K₄(2045) BRANCHING RATIOS

| $\Gamma(K\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------------|---------------------|----|-------|-------|-----------------------------------------|
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT |
| 0.099±0.012 | ASTON | 88 | LA SS | 0 | 11 $K^-p \rightarrow K^-\pi^+n$ |
| $\Gamma(K^*(892)\pi\pi)/\Gamma($ | (Kπ) | | | | Γ_2/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.89±0.53 | BAUBILLIER | 82 | нвс | | $8.25 \ K^- p \rightarrow p K_S^0 3\pi$ |
| $\Gamma(K^*(892)\pi\pi\pi)/$ | Γ(Κπ) | | | | Γ_3/Γ_1 |
| VALUE | DO CUMENT ID | | | | |
| 0.75 ± 0.49 | BAUBILLIER | 82 | нвс | _ | 8.25 $K^- p \rightarrow p K_S^0 3\pi$ |
| $\Gamma(\rho K\pi)/\Gamma(K\pi)$ | | | | | Γ_4/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.58±0.32 | BAUBILLIER | 82 | HBC | - | 8.25 $K^- p \to p K_S^0 3\pi$ |
| $\Gamma(\omega K\pi)/\Gamma(K\pi)$ | | | | | Γ_5/Γ_1 |
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT |
| 0.50±0.30 | BAUBILLIER | 82 | HBC | _ | 8.25 $K^- p \rightarrow p K_S^0 3\pi$ |
| $\Gamma(\phi K \pi)/\Gamma_{\text{total}}$ | | | | | Γ ₆ /Γ |
| VALUE | DO CUMENT ID | | TECN | COMI | MENT |
| 0.028±0.014 | 9 TORRES | 86 | MPSF | 400 p | PA → 4KX |
| Γ(φ K* (892))/Γ _{tot} | ai | | | | Γ ₇ /Γ |
| VALUE | DOCUMENT ID | | TECN | COM | MENT |
| 0.014 ± 0.007 | ⁹ TORRES | 86 | MPSF | 400 p | PA → 4KX |

K₄*(2045) REFERENCES

 $^{9}\,\mbox{Error}$ determination is model dependent.

| ASTON ASTON TORRES BAUBILLIER CLELAND ASTON | 88 86 86 82 82 81 C | PL 118B 447 NP B208 189 PL 106B 235 | D. Aston et al. D. Aston et al. S. Torres et al. M. Baubillier et al. W.E. Cleland et al. D. Aston et al. | (SLAC, NAGO, CINC, INUS) (SLAC, NAGO, CINC, INUS) (VPI, ARIZ, FNAL, FSU+) (BIRM, CERN, GLAS+) (DURH, GEVA, LAUS+) (SLAC, CARL, OTTA) JP |
|------------------------------------------------------------|------------------------------------|-------------------------------------------|-----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
| CARMONY | 77 | PR D16 1251 | D.D. Carmony et al. | (PURD, UCD, IUPU) |

¹ From a fit to all moments.
2 From a fit to 8 moments.
3 Number of events evaluated by us.
4 From energy-independent partial-wave analysis.

From a fit to all moments. From a fit to 8 moments.

Number of events evaluated by us.

⁸ From energy-independent partial-wave analysis.

 $K_2(2250)$, $K_3(2320)$, $K_5^*(2380)$, $K_4(2500)$

$K_2(2250)$

$$I(J^P) = \frac{1}{2}(2^-)$$

OMITTED FROM SUMMARY TABLE

This entry contains various peaks in strange meson systems reported in the 2150–2260 MeV region, as well as enhancements seen in the antihyperon-nucleon system, either in the mass spectra or in the J^P

K2(2250) MASS

| VALUE (MeV) 2247±17 OUR A | <u>EVTS</u> | DO CUMENT ID | TECN | <u>CH G</u> | COMMENT |
|---------------------------|---------------|-------------------------------------------------------|---------------|-------------|---------------------------------------------------------------------------------------------------------|
| 2247 ±17 OUR A | | 1 ARMSTRONG 83 | c OMEG | _ | 18 $K^- p \rightarrow \Lambda \overline{p} X$ |
| 2235 ± 50 | | ¹ BAUBILLIER 81 ¹ CLELAND 81 | HBC | - | $8 K^- p \rightarrow \Lambda \overline{p} X$ |
| 2260 ± 20 | | ¹ CLELAND 81 | SPEC | \pm | 50 $K^+ p \rightarrow \Lambda \overline{p} X$ |
| • • • We do not | use the follo | wing data for averag | es, fits, lim | nits, et | C. • • • |
| 2280 ± 20 | | TIKHOMIROV 03 | | | $\kappa_{S}^{0.0}$ κ_{S}^{-} κ_{I}^{0} κ_{I}^{0} κ_{I}^{0} κ_{I}^{0} |
| 2147 ± 4 | 37 | CHLIAPNIK 79 | HBC | + | 32 $K^+ \rho \rightarrow \overline{\Lambda} \rho X$ |
| 2240 ± 20 | 20 | LISSAUER 70 | HBC | | 9 K+p |
| $^{1}J^{P}=2^{-}$ fro | m moments a | malvsis. | | | |

K₂(2250) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------------|---------------|-------------------------|--------|-------------|---------|------------------------------------------------------------------------------|
| 180±30 OUR | AVERAGE | Error includes scal | | | | |
| 150 ± 30 | | | | | | 18 $K^-p \rightarrow \Lambda \overline{p}X$ |
| 210 ± 30 | | ² CLELAND | 81 | SPEC | \pm | 50 $K^+ p \rightarrow \Lambda \overline{p} X$ |
| • • • We do not | use the follo | owing data for ave | rages, | , fits, lim | its, et | C. • • • |
| 180 ± 60 | | TIKHOMIROV | 03 | SPEC | | κ_{S}^{0} κ_{S}^{0} κ_{S}^{0} κ_{I}^{0} \times |
| ~ 200 | | ² BAUBILLIER | 81 | нвс | _ | $8 K^{-} \rho \rightarrow \Lambda \overline{\rho} X$ |
| ~ 40 | 37 | CHLIAPNIK | 79 | нвс | + | 32 $K^+ p \rightarrow \overline{\Lambda} p X$ |
| 80 ± 20 | 20 | LISSAUER | 70 | нвс | | 9 K ⁺ p |
| $^{2}J^{P}=2^{-}$ from | m moments | analysis. | | | | |

K2(2250) DECAY MODES

| | Mode |
|----------------|---------------------|
| Γ ₁ | Κππ |
| Γ_2 | $K f_2(1270)$ |
| Γ_3 | $K^*(892) f_0(980)$ |
| Гл | p Λ |

K₂(2250) REFERENCES

| TIKHOMIROV | 03 | PAN 66 828 Translated from | G.D. Tikhomirov et al. | |
|-------------|------|-------------------------------|-------------------------|-----------------------|
| ARMSTRONG | 83 C | NP B227 365 | T.A. Armstrong et al. | (BARI, BIRM, CERN+) |
| BAUBILLIER | 81 | NP B183 1 | M. Baubillier et al. | (BIRM, CERN, GLAS+)JP |
| CLELAND | 81 | NP B184 1 | W.E. Cleland et al. | (PITT, GEVA, LAUS+)JP |
| CHLIA PN IK | 79 | NP B158 253 | P.V. Chliapnikov et al. | (CERN, BELG, MONS) |
| LISSAUER | 70 | NP B18 491 | D. Lissauer et al. | ` (LBL) |



$$I(J^P) = \frac{1}{2}(3^+)$$

OMITTED FROM SUMMARY TABLE Seen in the $J^P=3^+$ wave of the antihyperon-nucleon system. Needs confirmation.

K₃(2320) MASS

| VALUE (MeV) | DOCUMENT ID | TECN | CHG | COMMENT |
|------------------|------------------|---------|-------|-----------------------------------------------|
| 2324 ± 24 OUR AV | | | | |
| 2330 ± 40 | | | | 18 $K^- p \rightarrow \Lambda \overline{p} X$ |
| 2320 ± 30 | 1 CLELAND 8 | 81 SPEC | \pm | 50 $K^+ p \rightarrow \Lambda \overline{p} X$ |
| 1 IP - 3+ from | moments analysis | | | |

K₃(2320) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT | |
|-------------------|------------------------|-------|----------|----------|-----------------------------------------------|--|
| 150±30 | ² ARMSTRONG | 83c | OMEG | _ | 18 $K^- p \rightarrow \Lambda \overline{p} X$ | |
| • • • We do not u | ise the following data | for a | verages, | fits, li | mits, etc. • • • | |
| ~ 250 | ² CLELAND | 81 | SPEC | \pm | 50 $K^+ p \rightarrow \Lambda \overline{p} X$ | |
| $^2J^P=3^+$ from | moments analysis. | | | | | |

K₃(2320) DECAY MODES

| | Mode | |
|-----------------------|------|--|
| $\overline{\Gamma_1}$ | p Λ | |

K₃(2320) REFERENCES

| ARMSTRONG 83C NP B227 365 | T.A. Armstrong et al. | (BARI, BIRM, CERN+ |
|---------------------------|-----------------------|--------------------|
| CLELAND 81 NP B184 1 | W.E. Cleland et al. | (PITT, GEVA, LAUS+ |



$$I(J^P) = \frac{1}{2}(5^-)$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

K*(2380) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG | COMMENT |
|-----------------------|-------------|----|-------|-----|-------------------------------------------|
| 2382±14±19 | 1 ASTON | 86 | LA SS | 0 | $11 \ K^- \rho \rightarrow \ K^- \pi^+ n$ |
| 1 From a fit to all t | he moments | | | | |

K*(2380) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------------------|--------------------|----|------|-----|------------------------------------|
| 178±37±32 | ² ASTON | 86 | LASS | 0 | $11 K^- p \rightarrow K^- \pi^+ n$ |
| ² From a fit to a | ll the moments. | | | | |

K*(2380) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | | |
|------------|------|------------------------------|--|--|
| Γ_1 | Κπ | (6.1±1.2) % | | |

K*(2380) BRANCHING RATIOS

| $\Gamma(K\pi)/\Gamma_{\text{total}}$ | | | | | Γ ₁ /Γ |
|--------------------------------------|--------------|----|------|-----|----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.061 ± 0.012 | ASTON | 88 | LASS | 0 | $11 \ K^- p \rightarrow \ K^- \pi^+ n$ |

K*(2380) REFERENCES

| | ٥, | , | |
|--------------------------------------|----|---|------------------------------------------------------|
| ASTON 88 NP B296 ASTON 86 PL B180 | | | (SLAC, NAGO, CINC, INUS) (SLAC, NAGO, CINC, INUS) |



$$I(J^P) = \frac{1}{2}(4^-)$$

OMITTED FROM SUMMARY TABLE Needs confirmation.

K4(2500) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|---------------------|------------------|----|------|-----|---------------------------------------------|
| 2490 ± 20 | 1 CLELAND | 81 | SPEC | ± | $50 K^+ p \rightarrow \Lambda \overline{p}$ |
| $1 P_{-A}^{-}$ from | momente analysis | | | | |

K4 (2500) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------------|------------------------|-------|----------|-----------|---------------------------------------------------|
| • • • We do not | use the following data | for a | verages, | fits, lir | nits, etc. • • • |
| ~ 250 | ² CLELAND | 81 | SPEC | \pm | 50 $K^+ \rho \rightarrow \Lambda \overline{\rho}$ |
| $^{2}J^{P}=4^{-}$ from | n moments analysis. | | | | |

K4(2500) DECAY MODES

| | Mode | | | | |
|----------------|-------|-----------|---------------------|-------|-------------|
| Γ ₁ | p∏ | | | | |
| | | | K₄(2500) REFERENCES | | |
| CLELAI | ND 81 | NP B184 1 | W.F. Cleland et al | (PITT | GEVA LAUS+) |

Meson Particle Listings K(3100)

K(3100)

¹ Supersedes ALEEV 90.

 $I^{G}(J^{PC}) = ?^{?}(?^{??})$

OMITTED FROM SUMMARY TABLE

Narrow peak observed in several $(\Lambda \overline{p} + pions)$ and $(\overline{\Lambda} p + pions)$ states in Σ^- Be reactions by BOURQUIN 86 and in $n\,p$ and $n\,\mathrm{A}$ reactions by ALEEV 93. Not seen by BOEHNLEIN 91. If due to strong decays, this state has exotic quantum numbers (B=0, Q=+1,S=-1 for $\Lambda \, \overline{p} \, \pi^+ \, \pi^+$ and $I \geq 3/2$ for $\Lambda \, \overline{p} \, \pi^-$). Needs confirmation.

| | K(3100) M | ASS | | |
|-------------------------------------|------------------------|----------|-----------|------------------------------------------------------------|
| VALUE (MeV) ≈ 3100 OUR ESTIMATE | |) | - | |
| 3-BODY DECAYS | DO CUMENT IE |) | TECN | COMMENT |
| 3054±11 OUR AVERAGE | _ | | | |
| 3060 ± 7 ± 20 | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^{+}$ |
| 3056 ± 7 ± 20 | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} p \pi^-$ |
| 3055 ± 8 ± 20 | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^-$ |
| $3045 \pm 8 \pm 20$ | $^{ m 1}$ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} p \pi^+$ |
| 4-BODY DECAYS | | | | |
| VALUE (MeV) | DO CUMENT ID |) | TECN | COMMENT |
| 3059±11 OUR AVERAGE | | | | |
| $3067 \pm 6 \pm 20$ | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^+ \pi^+$ |
| 3060 ± 8 ± 20 | $^{ m 1}$ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^{+} \pi^{-}$ |
| $3055 \pm 7 \pm 20$ | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} \rho \pi^- \pi^-$ |
| 3052± 8±20 | ¹ ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} \rho \pi^- \pi^+$ |
| ullet $ullet$ We do not use the fol | lowing data for averag | es, fits | , limits, | etc. • • • |
| 3105 ± 30 | BOURQUIN | 86 | SPEC | $K(3100) \rightarrow \Lambda \overline{p} \pi^+ \pi^+$ |
| 3115 ± 30 | BOURQUIN | 86 | | |
| 5-BODY DECAYS | | | | |
| VALUE (MeV) | DO CUMENT ID |) | TECN | COMMENT |
| ullet $ullet$ We do not use the fol | lowing data for averag | es, fits | , limits, | etc. • • • |
| 3095 ± 30 | BOURQUIN | 86 | SPEC | $K(3100) \rightarrow$ |
| | • | | | $\Lambda \overline{D} \pi^+ \pi^+ \pi^-$ |

K(3100) WIDTH

| 3-BODY DECAYS VALUE (MeV) | <u>DO CUMENT</u> | 'D | TECN | COMMENT |
|-------------------------------|----------------------|-----------|-----------|-------------------------------------------------------|
| • • • We do not use the follo | owing data for avera | ges, fits | , limits, | etc. • • • |
| 42±16 | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^{+}$ |
| 36 ± 15 | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} \rho \pi^-$ |
| 50 ± 18 | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^{-}$ |
| 30 ± 15 | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} \rho \pi^{+}$ |

4-BODY DECAYS

| VALUE (MeV) | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
|--------------------|-----------------|--------------------|---------|-----------|------------------------------------------------------------|
| • • • We do not us | se the followin | g data for average | s, fits | , limits, | etc. • • • |
| 22± 8 | | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^+ \pi^+$ |
| 28 ± 12 | | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \Lambda \overline{p} \pi^{+} \pi^{-}$ |
| 32 ± 15 | | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} p \pi^- \pi^-$ |
| $30\!\pm\!15$ | | ² ALEEV | 93 | BIS2 | $K(3100) \rightarrow \overline{\Lambda} p \pi^- \pi^+$ |
| < 30 | 90 | BOURQUIN | 86 | SPEC | $K(3100) \rightarrow \Lambda \overline{p} \pi^+ \pi^+$ |
| <80 | 90 | BOURQUIN | 86 | SPEC | $K(3100) \rightarrow \Lambda \overline{p} \pi^{+} \pi^{-}$ |
| | | | | | |

5-BODY DECAYS

| VALUE (MeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------------|---------------------|------------------|---------|-----------|---------------------------------------------|
| • • • We do no | t use the following | data for average | s, fits | , limits, | etc. • • • |
| < 30 | 90 | BOURQUIN | 86 | SPEC | $K(3100) \rightarrow$ |
| | | | | | $\Lambda \overline{\rho} \pi^+ \pi^+ \pi^-$ |

² Supersedes ALEEV 90.

K(3100) DECAY MODES

| NΛ | \sim | А | ۵ |
|----|--------|---|---|

| Γ_1 | $K(3100)^0 \rightarrow$ | $\Lambda \overline{p} \pi^+$ |
|------------|-------------------------|------------------------------|
| _ | 1/(0100) | 4 — |

$$\Gamma_3$$
 $K(3100)^- \rightarrow \Lambda \overline{p} \pi^+ \pi^-$

$$\Gamma_5 = K(3100)^0 \rightarrow \Lambda \overline{p} \pi^+ \pi^+ \pi^-$$

$\Gamma(\Sigma(1385)^{+}\overline{D})/\Gamma(\Lambda\overline{D}\pi^{+})$

| $\Gamma(\Sigma(1385)^+\overline{p})/\Gamma(\Lambda\overline{p}\pi^+)$ | | | | | | |
|-----------------------------------------------------------------------|------------|--------------|----|------|-------------------------------|--|
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| < 0.04 | 90 | ALEEV | 93 | BIS2 | $K(3100)^{0} \rightarrow$ | |
| | | | | | $\Sigma(1385) + \overline{p}$ | |

K(3100) REFERENCES

| ALEEV | 93 | PAN 56 1358 | | (BIS-2 Collab.) |
|-----------|----|--------------------------------------|--------------------------------|---------------------|
| BOEHNLEIN | 91 | Translated from YAF NPBPS B21 174 | 56 100. A. Boehnlein et al. | (FLOR, BNL, IND+) |
| ALEEV | 90 | ZPHY C47 533 | A.N. Aleev et al. | (BIS-2 Collab.) |
| BOURQUIN | 86 | PL B172 113 | M.H. Bourquin et al. | (GEVA, RAL, HEIDP+) |

CHARMED MESONS $(C = \pm 1)$

 $D^+ = c \overline{d}, D^0 = c \overline{u}, \overline{D}{}^0 = \overline{c} u, D^- = \overline{c} d,$ similarly for D^* 's



$$I(J^P) = \frac{1}{2}(0^-)$$

D± MASS

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|----------|------------------------|-------|------------|--------------------------------------|
| 1869.62± 0.15 OUR FIT | Error i | ncludes scale factor | of 1 | .1. | |
| 1869.5 ± 0.4 OUR AVE | RAGE | | | | |
| $1869.53 \pm 0.49 \pm 0.20$ 110 | ± 15 | ANASHIN | 10A | KEDR | $e^{+}e^{-}$ at $\psi(3770)$ |
| $1870.0 \pm 0.5 \pm 1.0$ | 317 | BARLAG | 90 c | ACCM | π^- Cu 230 GeV |
| 1869.4 ± 0.6 | | ¹ TRILLING | 81 | RVUE | e^+e^- 3.77 GeV |
| • • • We do not use the f | ollowing | data for averages, | fits, | limits, et | .c. • • • |
| 1875 ± 10 | 9 | ADA MOVICH | 87 | EMUL | Photoproduction |
| 1860 ±16 | 6 | ADA MOVICH | 84 | EMUL | Photoproduction |
| 1863 ± 4 | | DERRICK | 84 | HRS | e ⁺ e ⁻ 29 GeV |
| 1868.4 ± 0.5 | | ¹ SCHINDLER | 81 | | $e^{+}e^{-}$ 3.77 GeV |
| 1874 ± 5 | | GOLDHABER | 77 | MRK1 | D^0 , D^+ recoil spectra |
| 1868.3 ± 0.9 | | ¹ PERUZZI | 77 | LGW | $e^{+}e^{-}$ 3.77 GeV |
| 1874 ± 11 | | PICCOLO | 77 | | e^+e^- 4.03, 4.41 GeV |
| 1876 ± 15 | 50 | PERUZZI | 76 | MRK1 | $K^{\mp}\pi^{\pm}\pi^{\pm}$ |

 $^{^1}$ PERUZZI 77 and SCHINDLER 81 errors do not include the 0.13% uncertainty in the absolute SPEAR energy calibration. TRILLING 81 uses the high precision $J/\psi(1\mathrm{S})$ and $\psi(2\mathrm{S})$ measurements of ZHOLENTZ 80 to determine this uncertainty and combines the PERUZZI 77 and SCHINDLER 81 results to obtain the value quoted.

D[±] MEAN L∣FE

Measurements with an error $>100\times10^{-15}\mbox{ s have been omitted from the}$

| VALUE (10 ⁻¹⁵ s) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------------------------------------------------|------------|---------------------|---------|------------|-----------------------------------------------------|--|
| 1040 ± 7 OUR A | VERAGE | | | | | |
| $1039.4 \pm \ 4.3 \pm \ 7.0$ | 110k | LINK | 02F | FOCS | γ nucleus, $pprox$ 180 GeV | |
| $1033.6 \pm 22.1 + 9.9 \\ -12.7$ | 3777 | BONVICINI | 99 | CLEO | $e^+ e^- \approx \Upsilon(4S)$ | |
| 1048 ± 15 ± 11 | 9k | FRABETTI | 94D | E687 | $D^+ \rightarrow K^-\pi^+\pi^+$ | |
| ● ● We do not use | the follow | ring data for avera | iges, f | its, limit | s, etc. • • • | |
| 1075 ± 40 ± 18 | 2455 | FRABETTI | 91 | E687 | γ Be, $D^+ ightarrow \ \ K^- \pi^+ \pi^+$ | |
| $1030 \pm 80 \pm 60$ | 200 | ALVAREZ | 90 | NA14 | γ , D $^+$ \rightarrow K $^ \pi^+$ π^+ | |
| $1050 \begin{array}{c} +77 \\ -72 \end{array}$ | 317 | ² BARLAG | 90c | ACCM | $\pi^-\mathrm{Cu}$ 230 GeV | |
| $1050 \pm 80 \pm 70$ | 363 | ALBRECHT | 881 | ARG | e^+e^- 10 GeV | |
| $1090 \pm 30 \pm 25$ | 2992 | RAAB | 88 | E691 | Photoproduction | |
| ² BARLAG 90c estimates the systematic error to be negligible. | | | | | | |

D+ DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as K_S^0 modes, not as \overline{K}^0 modes. Nearly always it is a K_S^0 that is measured, and interference between Cabibbo-allowed and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\Gamma(K_S^0) = \Gamma(\overline{K^0})$.

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-----------------|---------------------------------------------------------|------------------------------|-----------------------------------|
| | Inclusive m | nodes | |
| Γ_1 | $D^+ ightarrow e^+$ semileptonic | (16.07 ± 0.30) % | |
| Γ_2 | $D^+ ightarrow \ \mu^+$ anything | $(17.6 \pm 3.2)\%$ | |
| Γ_3^- | $D^+ \rightarrow K^-$ anything | (25.7 ±1.4)% | |
| Γ_4 | $D^+ ightarrow \overline{K}{}^0$ anything $+ K^0$ any- | (61 ±5)% | |
| | thing | | |
| Γ_5 | $D^+ ightarrow K^+$ a nything | $(5.9 \pm 0.8)\%$ | |
| Γ_6 | $D^+ \rightarrow K^*(892)^-$ anything | (6 ±5)% | |
| Γ ₇ | $D^+ \rightarrow \overline{K}^*(892)^0$ anything | (23 ±5)% | |
| Γ ₈ | $D^+ \rightarrow K^*(892)^0$ anything | < 6.6 % | CL=90% |
| Γ9 | $D^+ 	o \eta$ anything | $(6.3 \pm 0.7)\%$ | |
| Γ ₁₀ | $D^+ \rightarrow \eta'$ anything | $(1.04 \pm 0.18)\%$ | |
| Γ11 | $D^+ ightarrow \stackrel{f}{\phi}$ anything | (1.03±0.12) % | |

| Leptonic and semileptonic modes | | | | | |
|---------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------|---------|--|--|
| Γ_{12} | $D^+ ightarrow \ e^+ u_e$ | < 8.8 × 10 ⁻⁶ | CL=90% | | |
| | $D^+ 	o \mu^+ u_{\mu}$ | $(3.82\pm0.33)\times10^{-4}$ | | | |
| Γ_{14} | $D^+ ightarrow \ 	au^+ u_	au$ | $< 1.2 \times 10^{-3}$ | CL=90% | | |
| | $D^+ \rightarrow \overline{K}^0 e^+ \nu_e$ | $(8.83 \pm 0.22)\%$ | | | |
| Γ_{16} | $D^+ ightarrow \ \overline{K}{}^0 \mu^+ u_{\mu}$ | (9.2 \pm 0.6) % | | | |
| Γ_{17} | $D^+ \rightarrow K^- \pi^+ e^+ \nu_e$ | $(4.00\pm0.10)\%$ | | | |
| Γ ₁₈ | $D^+ ightarrow \overline{K}^*(892)^0 e^+ u_e$, $\overline{K}^*(892)^0 ightarrow K^- \pi^+$ | $(3.68 \pm 0.10)\%$ | | | |
| _ | | 2 | | | |
| Γ ₁₉ | $D^+ \rightarrow (K^-\pi^+)_{S-wave} e^+ \nu_e$ | $(2.32\pm0.10)\times10^{-3}$ | | | |
| Γ ₂₀ | $D^+ \to \overline{K}^* (1410)^0 e^+ \nu_e$, | $< 6 \times 10^{-3}$ | CL=90% | | |
| г | $\overline{K}^*(1410)^0 \to K^-\pi^+$ | < 5 ×10 ⁻⁴ | CI 000/ | | |
| Γ ₂₁ | $D^+ ightarrow \overline{K}_2^*(1430)^0e^+ u_e$, $\overline{K}_2^*(1430)^0 ightarrow K^-\pi^+$ | < 5 × 10 · | CL=90% | | |
| F | $K_{\frac{1}{2}}(1430)^{\circ} \rightarrow K \pi^{+}$ $D^{+} \rightarrow$ | 3 | G1 000 | | |
| Γ ₂₂ | $K^-\pi^+e^+ u_e$ nonresonant | $< 7 \times 10^{-3}$ | CL=90% | | |
| Γ23 | $D^+ ightarrow K^- \pi^+ \mu^+ u_{\mu}$ | (3.8 ±0.4) % | | | |
| Γ ₂₄ | $D^+ \to \frac{\kappa}{K^*} (892)^0 \mu^+ \nu_{\mu}$ | (3.5 2 ± 0.10) % | | | |
| 1 24 | $K^*(892)^0 \to K^- \pi^+$ | (3.32 ± 0.10) /0 | | | |
| Γ ₂₅ | $D^+ \rightarrow$ | $(2.0 \pm 0.5) \times 10^{-3}$ | | | |
| ' 25 | $K^-\pi^+\mu^+ u_\mu$ nonresonant | (2.0 ± 0.3) × 10 | | | |
| Γ ₂₆ | $D^+ \rightarrow K^- \pi^+ \pi^0 \mu^+ \nu_\mu$ | $< 1.6 \times 10^{-3}$ | CL=90% | | |
| | $D^+ \rightarrow \pi^0 e^+ \nu_e$ | $(4.05\pm0.18)\times10^{-3}$ | 02-7070 | | |
| 21 | $D^+ \rightarrow \eta e^+ \nu_e$ | $(1.14\pm0.10)\times10^{-3}$ | | | |
| | $D^+ \rightarrow \rho^0 e^+ \nu_e$ | $(2.2 \pm 0.4) \times 10^{-3}$ | | | |
| | $D^+ \rightarrow \rho^0 \mu^+ \nu_\mu$ | $(2.4 \pm 0.4) \times 10^{-3}$ | | | |
| | $D^+ ightarrow \omega e^+ u_e$ | $(1.6 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \times 10^{-3}$ | | | |
| 91 | · · | | | | |
| | $\begin{array}{ll} D^+ \to & \eta'(958) e^+ \nu_e \\ D^+ \to & \phi e^+ \nu_e \end{array}$ | $(2.2 \pm 0.5) \times 10^{-4}$ $< 9 \times 10^{-5}$ | CI 000/ | | |
| Γ ₃₃ | $\nu \rightarrow \varphi e \cdot \nu_e$ | $< 9 \times 10^{-5}$ | CL=90% | | |

Fractions of some of the following modes with resonances have already appeared above as submodes of particular charged-particle modes.

$$\begin{array}{llll} \Gamma_{34} & D^{+} \to & \overline{K}^{*}(892)^{0} \, e^{+} \nu_{e} & (5.52 \pm 0.15) \, \% \\ \Gamma_{35} & D^{+} \to & \overline{K}^{*}(892)^{0} \, \mu^{+} \nu_{\mu} & (5.28 \pm 0.15) \, \% \\ \Gamma_{36} & D^{+} \to & \overline{K}^{*}_{0}(1430)^{0} \, \mu^{+} \nu_{\mu} & < 2.4 & \times 10^{-4} \\ \Gamma_{37} & D^{+} \to & \overline{K}^{*}(1680)^{0} \, \mu^{+} \nu_{\mu} & < 1.5 & \times 10^{-3} \end{array}$$

Hadronic modes with a \overline{K} or $\overline{K}K\overline{K}$

| nauronic modes with a A or A A A | | | | | | |
|----------------------------------|-----------------------------------------------------------|---------------------|-------|--|--|--|
| Γ_{38} | $D^+ \rightarrow K_S^0 \pi^+$ | (1.47 ± 0.07) % | S=2.0 | | | |
| Γ_{39} | $D^+ 	o 	extit{K}_L^{0} \pi^+$ | (1.46 ± 0.05) % | | | | |
| Γ_{40} | $D^+ \rightarrow K^- 2\pi^+$ | [a] (9.13±0.19) % | | | | |
| Γ_{41} | $D^+ ightarrow (K^-\pi^+)_{S-{ m wave}} \pi^+$ | $(7.32 \pm 0.19)\%$ | | | | |
| Γ_{42} | $D^+ ightarrow \ \overline{K}_0^*(800)^0\pi^+$, | | | | | |
| | $\overline{K}_0^*(800) \rightarrow K^- \pi^+$ | | | | | |
| Γ_{43} | $D^+ 	o \overline{K}_0^* (1430)^0 \pi^+$, | [b] (1.21±0.06) % | | | | |
| | $\overline{K}_{0}^{*}(1430)^{0} \rightarrow K^{-}\pi^{+}$ | | | | | |
| Γ_{44} | $D^+ \to \overline{K}^* (892)^0 \pi^+$ | (1.01 ± 0.11) % | | | | |
| | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | | | | | |
| Γ_{45} | $D^+ \to \overline{K}^* (1410)^0 \pi^+$, | not seen | | | | |

$$\Gamma_{47} \qquad \begin{array}{c} D^{+} \rightarrow \overline{K}^{*}(1680)^{0} \pi^{+}, \\ \overline{K}^{*}(1680)^{0} \rightarrow K^{-} \pi^{+} \end{array} \qquad [b] \quad (2.1 \pm 1.1) \times 10^{-} \times 10$$

$$\overline{K}^*(892)^0 \rightarrow K^-\pi^+$$
 $D^+ \rightarrow \overline{K}^*(892)^0 \rho^0\pi^+$, (2.2 ±0.4) × 10⁻³
 $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$

D^{\pm}

| _ | | | |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|---------|
| Γ ₆₁ | $D^+ \rightarrow K^- \rho^0 2\pi^+$ | $(1.68\pm0.27)\times10^{-3}$ | |
| Γ ₆₂ | $D^+ 	o$ | (3.9 ± 2.9) $\times 10^{-4}$ | |
| _ | $D^+ ightarrow K^- 3\pi^+\pi^-$ nonresonant $D^+ ightarrow K^+ 2K_S^0$ | (3 | |
| Γ ₆₃ | $D^+ \rightarrow K^+ Z K_S$ $D^+ \rightarrow K^+ K^- K_S^0 \pi^+$ | $(4.5 \pm 2.0) \times 10^{-3}$ | |
| Г ₆₄ | $D^+ \rightarrow K^+ K^- K_S^- \pi^+$ | $(2.4 \pm 0.6) \times 10^{-4}$ | |
| _ | Pionic m | | |
| Г ₆₅ | $D^+ \to \pi^+ \pi^0$ $D^+ \to 2\pi^+ \pi^-$ | $(1.19\pm0.06)\times10^{-3}$ | |
| Γ ₆₆ Γ ₆₇ | $D^{+} \rightarrow 2\pi^{+}\pi$ $D^{+} \rightarrow \rho^{0}\pi^{+}$ | $(3.18\pm0.18) \times 10^{-3}$ $(8.1 \pm 1.5) \times 10^{-4}$ | |
| Γ ₆₈ | $D^+ \rightarrow \pi^+ (\pi^+ \pi^-)_{S-\text{wave}}$ | $(1.78\pm0.16)\times10^{-3}$ | |
| Γ ₆₉ | $D^+ ightarrow \sigma \pi^+$, $\sigma ightarrow \pi^+ \pi^-$ | $(1.34\pm0.12)\times10^{-3}$ | |
| Γ ₇₀ | $D^+ ightarrow f_0(980) \pi^+$, | $(1.52\pm0.33)\times10^{-4}$ | |
| _ | $f_0(980) \to \pi^+ \pi^-$ | _ | |
| Γ ₇₁ | $D^+ \to f_0(1370) \pi^+$, | $(8 \pm 4) \times 10^{-5}$ | |
| Γ ₇₂ | $f_0(1370) 	o \pi^+ \pi^- \ D^+ 	o f_2(1270) \pi^+$, | $(4.9 \pm 0.9) \times 10^{-4}$ | |
| ' 72 | $f_2(1270) \rightarrow \pi^+ \pi^-$ | (4.7 ±0.7) × 10 | |
| Γ ₇₃ | $D^+ \to \rho (1450)^0 \pi^+$, | $<$ 8 $\times 10^{-5}$ | CL=95% |
| | $\rho(1450)^0 \to \pi^+\pi^-$ | | |
| Γ ₇₄ | $D^+ \rightarrow f_0(1500) \pi^+$, | $(1.1 \pm 0.4) \times 10^{-4}$ | |
| г | $f_0(1500) ightarrow \pi^+ \pi^- \ D^+ ightarrow f_0(1710) \pi^+ ,$ | < 5 ×10 ⁻⁵ | CL OFN/ |
| Γ ₇₅ | $f_0(1710) \rightarrow \pi^+ \pi^-$ | < 5 ×10 ⁻⁵ | CL=95% |
| Γ ₇₆ | $D^+ \to f_0(1790)\pi^+$, | $< 6 \times 10^{-5}$ | CL=95% |
| 70 | $f_0(1790) \to \pi^+ \pi^-$ | | |
| Γ ₇₇ | $D^+ ightarrow (\pi^+\pi^+)_{S-{\sf wave}} \pi^-$ | $< 1.2 \times 10^{-4}$ | CL=95% |
| Γ ₇₈ | $D^+ \rightarrow 2\pi^+\pi^-$ nonresonant | $< 1.1 \times 10^{-4}$ | CL=95% |
| Г ₇₉ | $\begin{array}{ccc} D^+ \rightarrow & \pi^+ 2\pi^0 \\ D^+ \rightarrow & 2\pi^+ \pi^- \pi^0 \end{array}$ | $(4.6 \pm 0.4) \times 10^{-3}$ | |
| Г ₈₀ Г ₈₁ | $D^+ ightarrow 2\pi^+\pi^-\pi^0$ $D^+ ightarrow \eta\pi^+$, $\eta ightarrow \pi^+\pi^-\pi^0$ | $(1.13\pm0.08)\%$ $(8.0\pm0.5)\times10^{-4}$ | |
| Γ ₈₂ | $D^+ \rightarrow \omega \pi^+, \omega \rightarrow \pi^+ \pi^- \pi^0$ | < 3 ×10 ⁻⁴ | CL=90% |
| Γ ₈₃ | $D^+ \rightarrow 3\pi^+ 2\pi^-$ | $(1.61\pm0.16)\times10^{-3}$ | |
| Γ ₈₄ | Fractions of some of the following mo appeared above as submodes of particular $D^+ \to \eta \pi^+$ | llar charged-particle modes. $(3.53\pm0.21)\times10^{-3}$ | ad y |
| Г ₈₅ Г ₈₆ | $\begin{array}{ccc} D^+ \to & \eta \pi^+ \pi^0 \\ D^+ \to & \omega \pi^+ \end{array}$ | $(1.38\pm0.35) \times 10^{-3}$ $< 3.4 \times 10^{-4}$ | CL=90% |
| Γ ₈₇ | $D^+ \rightarrow \omega \pi$ $D^+ \rightarrow \eta'(958)\pi^+$ | $(4.67\pm0.29)\times10^{-3}$ | CL_90/0 |
| Γ ₈₈ | $D^+ \to \eta'(958)\pi^+\pi^0$ | $(1.6 \pm 0.5) \times 10^{-3}$ | |
| | Hadronic modes w | ith a K K nair | |
| Γ ₈₉ | $D^+ \rightarrow K^+ K_S^0$ | $(2.83\pm0.16)\times10^{-3}$ | S=2.2 |
| Γ ₉₀ | $D^+ \rightarrow K^+ K^- \pi^+$ | [a] $(9.54\pm0.26)\times10^{-3}$ | S=1.1 |
| Γ ₉₁ | $D^+ ightarrow \; \phi \pi^+$, $\phi ightarrow \; K^+ K^-$ | $(2.65^{+0.08}_{-0.09}) \times 10^{-3}$ | |
| | $D^+ \rightarrow K^+ \overline{K}^* (892)^0$, | | |
| 「92 _ | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | $(2.45 + 0.09 \atop -0.14) \times 10^{-3}$ | |
| Г ₉₃ | $D^+ 	o K^+ \overline{K}_0^* (1430)^0$, $\overline{K}_0^* (1430)^0 	o K^- \pi^+$ | $(1.79\pm0.34)\times10^{-3}$ | |
| Γ ₉₄ | $D^+ ightarrow K^+ \overline{K}_2^* (1430)^0$, $\overline{K}_2^* ightarrow K^- \pi^+$ | $(1.6 \begin{array}{c} +1.2 \\ -0.8 \end{array}) \times 10^{-4}$ | |
| Γ ₉₅ | $K_2 \rightarrow K^- \pi^+$ $D^+ \rightarrow K^+ \overline{K}_0^* (800), \ \overline{K}_0^* \rightarrow K^- \pi^+$ | $(6.7 \ ^{+3.4}_{-2.1}) \times 10^{-4}$ | |
| Γ ₉₆ | $D^{+} ightarrow a_{0}(1450)^{0} \pi^{+}, \ a_{0}^{0} ightarrow K^{+} K^{-}$ | $(4.4 \begin{array}{c} +7.0 \\ -1.8 \end{array}) \times 10^{-4}$ | |
| Γ ₉₇ | $D^+ \rightarrow \phi(1680) \pi^+, \phi \rightarrow$ | $(\begin{array}{cc} 4.9 & ^{+}4.0 \\ -1.9 \end{array}) \times 10^{-5}$ | |
| Γ ₉₈ | $D^{+} \xrightarrow{K^{+}} K^{-}$ | not seen | |
| Г99 | $D^+ \rightarrow K^+ K_c^0 \pi^+ \pi^-$ | $(1.75 \pm 0.18) \times 10^{-3}$ | |
| Γ ₁₀₀ | $K^+K^-\pi^+$ nonresonant $D^+ 	o K^+K^0_S\pi^+\pi^ D^+ 	o K^0_SK^-2\pi^+$ $D^+ 	o K^+K^0_S\pi^+\pi^-$ | $(2.40\pm0.18)\times10^{-3}$ | |
| Γ ₁₀₁ | $D^+ \rightarrow K^+ K^- 2\pi^+ \pi^-$ | (2.2 ± 1.2) $\times 10^{-4}$ | |
| | A few poorly measured branching fract | ions: | |
| Γ ₁₀₂ | | (2.3 ± 1.0) % | |
| Γ ₁₀₃ | | < 1.5 % | CL=90% |
| Γ ₁₀₄ | | $(1.5 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \%$ | |
| г | $D^+ = \kappa * (992) + \kappa^0$ | (16 107) 0/ | |

 $(1.6 \pm 0.7)\%$

 $\Gamma_{105} D^+ \rightarrow K^*(892)^+ K_S^0$

```
Doubly Cabibbo-suppressed modes
 \Gamma_{106} \ D^+ \rightarrow \ K^+ \pi^0
                                                                                                           (1.83\pm0.26)\times10^{-4}
                                                                                                                                                                            S = 1.4
 \Gamma_{107}^{100} D^+ \rightarrow K^+ \eta
                                                                                                             (\ 1.08\!\pm\!0.17)\times10^{-4}
 \Gamma_{108} D^+ \to K^+ \eta'(958)
                                                                                                             (1.76\pm0.22)\times10^{-4}

\begin{array}{lll}
\Gamma_{108} & D^{+} \rightarrow & K^{+} \eta'(958) \\
\Gamma_{109} & D^{+} \rightarrow & K^{+} \pi^{+} \pi^{-} \\
\Gamma_{110} & D^{+} \rightarrow & K^{+} \rho^{0} \\
\Gamma_{111} & D^{+} \rightarrow & K^{*} (892)^{0} \pi^{+}, \\
& & K^{*} (892)^{0} \rightarrow & K^{+} \pi^{-} \\
\Gamma_{112} & D^{+} \rightarrow & K^{+} f_{0}(980), \\
& & f_{0}(980), \\
\end{array}

                                                                                                             (5.27\pm0.23)\times10^{-4}
                                                                                                             ( 2.0~\pm 0.5 ) \times 10^{-4}
                                                                                                             (2.5 \pm 0.4) \times 10^{-4}
                                                                                                              ( 4.7~\pm 2.8 ) \times\,10^{\,-5}
                    f_0(980) \rightarrow \pi^+\pi^-

D^+ \rightarrow K_2^*(1430)^0\pi^+,
                                                                                                             (4.2 \pm 2.9) \times 10^{-5}
                            K_2^*(1430)^0 \rightarrow K^+\pi^-
                     D^+ \stackrel{2}{\rightarrow} K^+ \pi^+ \pi^- nonreso-
 \Gamma_{114}
\Gamma_{115} D^+ \rightarrow 2K^+K^-
                                                                                                              ( 8.7~\pm 2.0 ) \times\,10^{\,-5}
```

$\Delta C=1$ weak neutral current (C1) modes, or Lepton Family number (LF) or Lepton number (L) violating modes

| | | ٠, | • | | ,, - | |
|------------------|-----------------------------------------------------------|-------------|--------------|-------|---------------------------------------------------------------|--------|
| Γ_{116} | $D^+ ightarrow \ \pi^+ e^+ e^-$ | (| 71 | < 1. | 1×10^{-6} | CL=90% |
| Γ_{117} | $D^+ ightarrow \pi^+ \phi$, $\phi ightarrow$ | | [<i>e</i>] | (1. | $7 \begin{array}{c} +1.4 \\ -0.9 \end{array}) \times 10^{-6}$ | |
| Γ ₁₁₈ | $D^+ \stackrel{e^+ e^-}{ ightarrow} \pi^+ \mu^+ \mu^-$ | (| | < 3. | 9 × 10 ⁻⁶ | CL=90% |
| Γ ₁₁₉ | $D^+ \rightarrow \pi^+ \phi$, $\phi \rightarrow$ | | [<i>e</i>] | (1.3 | 8 ± 0.8) $\times 10^{-6}$ | |
| | $\mu^+ \mu^-$ | | | | | |
| Γ_{120} | $D^+ \rightarrow \rho^+ \mu^+ \mu^-$ | (| 7.1 | < 5. | 6×10^{-4} | CL=90% |
| Γ_{121} | | | [f] | < 1. | 0×10^{-6} | CL=90% |
| Γ_{122} | $D^+ \rightarrow K^+ \mu^+ \mu^-$ | | [f] | < 4. | 3×10^{-6} | CL=90% |
| Γ_{123} | $D^+ \rightarrow \pi^+ e^+ \mu^-$ | L | F | < 2. | 9×10^{-6} | CL=90% |
| Γ_{124} | | L | F | < 3. | 6×10^{-6} | CL=90% |
| Γ_{125} | | L | F | < 1.3 | 2×10^{-6} | CL=90% |
| Γ_{126} | $D^+ ightarrow K^+ e^- \mu^+$ | L | F | < 2.5 | 8×10^{-6} | CL=90% |
| Γ_{127} | $D^+ ightarrow \pi^- 2e^+$ | L | | < 1. | 1×10^{-6} | CL=90% |
| Γ_{128} | $D^+ \rightarrow \pi^- 2\mu^+$ | L | | < 2. | | CL=90% |
| Γ_{129} | $D^+ ightarrow \pi^- e^+ \mu^+$ | L | | < 2. | 0×10^{-6} | CL=90% |
| Γ_{130} | $D^+ \rightarrow \rho^- 2\mu^+$ | L | | < 5. | 6×10^{-4} | CL=90% |
| Γ_{131} | | L | | < 9 | $\times 10^{-7}$ | CL=90% |
| Γ_{132} | $D^+ \rightarrow K^- 2 \mu^+$ | L | | < 1. | | CL=90% |
| Γ_{133} | | L | | < 1. | 9×10^{-6} | CL=90% |
| Γ_{134} | $D^+ \rightarrow K^*(892)^- 2\mu$ | ι^+ L | | < 8.5 | $\times 10^{-4}$ | CL=90% |

- Γ_{135} Unaccounted decay modes (51.2 \pm 1.0) %
 - [a] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the relevant papers.
 - [b] These subfractions of the $K^-2\pi^+$ mode are uncertain: see the Particle Listings
 - [c] Submodes of the $D^+ \to K^- 2\pi^+ \pi^0$ and $K_S^0 2\pi^+\pi^-$ modes were studied by ANJOS 92C and COFFMAN 92B, but with at most 142 events for the first mode and 229 for the second not enough for precise results. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.
 - [d] The unseen decay modes of the resonances are included.
 - [e] This is not a test for the $\Delta \it C\!=\!1$ weak neutral current, but leads to the $\pi^+\,\ell^+\,\ell^-$ final state.
 - [f] This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks must change flavor in this decay.

 Γ_3/Γ

 Γ_{4}/Γ

 Γ_5/Γ

 Γ_6/Γ

 Γ_8/Γ

Γ9/Γ

 Γ_{10}/Γ

CONSTRAINED FIT INFORMATION

An overall fit to 22 branching ratios uses 31 measurements and one constraint to determine 15 parameters. The overall fit has a $\chi^2=$ 32.1 for 17 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

| X29 | 0 | | | | | | | | | |
|-------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|------------------------|------------------------|------------------------|------------------------|-------------|
| x ₃₄ | 0 | 3 | | | | | | | | |
| x ₃₅ | 22 | 0 | 0 | | | | | | | |
| x ₃₈ | 6 | 0 | 0 | 1 | | | | | | |
| <i>x</i> ₄₀ | 15 | 0 | 0 | 3 | 44 | | | | | |
| <i>x</i> ₅₀ | 5 | 0 | 0 | 1 | 14 | 31 | | | | |
| x ₅₄ | 6 | 0 | 0 | 1 | 18 | 40 | 56 | | | |
| <i>X</i> 55 | 7 | 0 | 0 | 2 | 22 | 50 | 50 | 0 | | |
| <i>X</i> 56 | 3 | 0 | 0 | 1 | 10 | 24 | 7 | 10 | 12 | |
| x ₈₃ | 3 | 0 | 0 | 1 | 10 | 22 | 7 | 9 | 11 | 76 |
| <i>x</i> 89 | 6 | 0 | 0 | 1 | 75 | 38 | 12 | 15 | 19 | 9 |
| <i>x</i> 90 | 10 | 0 | 0 | 2 | 29 | 66 | 24 | 38 | 36 | 16 |
| <i>X</i> 106 | 2 | 0 | 0 | 0 | 6 | 13 | 4 | 5 | 6 | 3 |
| X ₁₃₅ | -75 | -4 | -15 | -32 | -32 | -58 | -54 | -48 | -42 | -20 |
| | <i>x</i> ₁₆ | <i>x</i> ₂₉ | <i>x</i> ₃₄ | <i>x</i> ₃₅ | x ₃₈ | <i>x</i> ₄₀ | <i>x</i> ₅₀ | <i>x</i> ₅₄ | <i>x</i> ₅₅ | <i>X</i> 56 |
| X89 | 8 | | | | | | | | | |
| <i>X</i> 90 | 14 | 25 | | | | | | | | |
| <i>x</i> ₁₀₆ | 3 | 5 | 9 | | | | | | | |
| X ₁₃₅ | -18 | -27 | -43 | -8 | | | | | | |
| | x ₈₃ | X89 | <i>X</i> 90 | <i>X</i> 106 | | | | | | |

D+ BRANCHING RATIOS

Some now-obsolete measurements have been omitted from these Listings.

— *c*-quark decays –

$\Gamma(c \rightarrow e^+ \text{ anything}) / \Gamma(c \rightarrow \text{ anything})$

For the Summary Table, we only use the average of e^+ and μ^+ measurements from $\rightarrow c\overline{c}$ decays; see the second data block below.

| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
|-------------------------|------|--------------|----------|----------------------------------|--|
| $0.103\pm0.009 + 0.009$ | 378 | 3 ABBIENDI | 99k OPAL | $Z^0 \rightarrow c \overline{c}$ | |

 $^3\,\text{ABBIENDI}$ 99K uses the excess of right-sign over wrong-sign leptons opposite reconstructed $D^*(2010)^+ \rightarrow D^0 \pi^+$ decays in $Z^0 \rightarrow c \overline{c}$.

$\Gamma(c \to \mu^+ \text{ anything})/\Gamma(c \to \text{ anything})$

For the Summary Table, we only use the average of e^+ and μ^+ measurements from $Z^0 \to c \overline{c}$ decays; see the next data block.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|-------|-----------------------|-------------|------|---------------------------------------------|
| 0.082±0.005 OUR AV | ERAGE | | | | |
| $0.073 \pm 0.008 \pm 0.002$ | 73 | KAYIS-TOPA K | C.05 | CHRS | $ u_{\mu}$ emulsion |
| $0.095 \pm 0.007 ^{+0.014}_{-0.013}$ | 2829 | ASTIER | 00D | NOMD | $ u_{\mu}$ Fe $ ightarrow \mu^- \mu^+ X$ |
| $0.090 \pm 0.007 ^{+\ 0.007}_{-\ 0.006}$ | 476 | ⁴ ABBIENDI | 99K | OPAL | $Z^0 \to c \overline{c}$ |
| $0.086 \pm 0.017 ^{+0.008}_{-0.007}$ | 69 | ⁵ ALBRECHT | 92F | ARG | e^+e^-pprox 10 GeV |
| $0.078 \pm 0.009 \pm 0.012$ | | ONG | 88 | MRK2 | e^+e^- 29 GeV |
| $0.078 \pm 0.015 \pm 0.02$ | | BARTEL | 87 | JADE | e^+e^- 34.6 GeV |
| $0.082 \pm 0.012 ^{+\ 0.02}_{-\ 0.01}$ | | ALTHOFF | 84 G | TASS | e^+e^- 34.5 GeV |

• • • We do not use the following data for averages, fits, limits, etc. • • • $0.093 \pm 0.009 \pm 0.009$ 88 KAYIS-TOPAK.02 CHRS See KAYIS-TOPAKSU 05 BARTEL 85 J JADE See BARTEL 87

⁴ ABBIENDI 99κ uses the excess of right-sign over wrong-sign leptons opposite reconstructed $D^*(2010)^+ \to D^0\pi^+$ decays in $Z^0 \to c\overline{c}$.

5 ALBRECHT 92F uses the excess of right-sign over wrong-sign leptons in a sample of events tagged by fully reconstructed $D^*(2010)^+ \rightarrow D^0 \pi^+$ decays.

$\Gamma(c \rightarrow \ell^+ \text{ anything})/\Gamma(c \rightarrow \text{ anything})$

This is an average (not a sum) of e^+ and μ^+ measurements.

| VALUE EVTS | DO CUMENT ID | TECN | COMMENT |
|-----------------------------------------------------------------|-----------------------|----------|----------------------------------|
| 0.096 ±0.004 OUR AVERAGE | | | |
| $0.0958 \pm 0.0042 \pm 0.0028 \ 1828$ | ⁶ ABREU | 00o DLPH | $Z^0 \rightarrow c \overline{c}$ |
| $0.095 \pm 0.006 \stackrel{+}{-} \stackrel{0.007}{-} 0.006$ 854 | ⁷ ABBIENDI | 99к OPAL | $Z^0 \rightarrow c\overline{c}$ |

 6 ABREU 000 uses leptons opposite fully reconstructed $D^*(2010)^+$, D^+ , or D^0 mesons. 7 ABBIENDI 99κ uses the excess of right-sign over wrong-sign leptons opposite reconstructed $D^*(2010)^+ \rightarrow D^0\pi^+$ decays in $Z^0 \rightarrow c\overline{c}$.

$\Gamma(c \rightarrow D^*(2010)^+ \text{ anything})/\Gamma(c \rightarrow \text{ anything})$

| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
|-----------------------|------|--------------|------|----------------------------------|
| 0.255 ± 0.015 ± 0.008 | 2371 | 8 ABREU 00 | | $Z^0 \rightarrow c \overline{c}$ |

 8 ABREU 000 uses slow pions opposite fully reconstructed $D^*(2010)^+$, D^+ , or D^0 mesons as a signal of $D^*(2010)$ production.

---- Inclusive modes -

$\Gamma(e^+ \text{ semileptonic})/\Gamma_{\text{total}}$ The sum of our \overline{K}^0 e+ ν_e , \overline{K}^* (892) 0 e+ ν_e , π^0 e+ ν_e , η e+ ν_e , ρ^0 e+ ν_e , and ω e+ ν_e branching fractions is 15.3 \pm 0.4%. DOCUMENT ID TECN COMMENT 16.07±0.30 OUR AVERAGE

⁹ ASNER $16.13 \pm 0.10 \pm 0.29 \qquad 26.2 \pm 0.2 k$ 10 CLEO $e^{+}e^{-}$ at 3774 MeV $15.2 \pm 0.9 \pm 0.8$ $521\,\pm\,32$ ABLIKIM 07G BES2 $e^{+}e^{-} \approx \psi(3770)$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $16.13 \pm 0.20 \pm 0.33 \qquad 8798 \pm 105 \quad {}^{10} \; \text{ADAM}$ 06A CLEO See ASNER 10

158 BALTRUSAIT...85B MRK3 e^+e^- 3.77 GeV $17.0 \pm 1.9 \pm 0.7$ 9 Using the ${\it D^+}$ and ${\it D^0}$ lifetimes, ASNER 10 finds that the ratio of the ${\it D^+}$ and ${\it D^0}$

smileptonic widths is $0.985\pm0.015\pm0.024$. ¹⁰ Using the D^+ and D^0 lifetimes, ADAM 06A finds that the ratio of the D^+ and D^0 inclusive e^+ widths is 0.985 \pm 0.028 \pm 0.015, consistent with the isospin-invariance prediction of 1.

F(utanything)/F

| $I(\mu \cdot anything)$ | / ' total | | | | 12/1 |
|-------------------------|-----------|--------------|-----|------|-----------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 17.6±2.7±1.8 | 100 ± 12 | 11 ABLIKIM | 08L | BES2 | $e^+e^- \approx \psi(3772)$ |

 11 ABLIKIM 08L finds the ratio of $D^+\to \mu^+ X$ and $D^0\to \mu^+ X$ branching fractions to be 2.59 \pm 0.70 \pm 0.25, in accord with the ratio of D^+ and D^0 lifetimes, 2.54 \pm 0.02.

$\Gamma(K^- \text{ anything})/\Gamma_{\text{total}}$

| VALUE (%) | EVTS | DOCUMENT ID | TECN | COMMENT |
|------------------------|------------|-------------|----------|-----------------------------|
| 25.7±1.4 OUR AVERA | GE | | | |
| $24.7 \pm 1.3 \pm 1.2$ | 631 ± 33 | ABLIKIM | 07G BES2 | $e^+e^- \approx \psi(3770)$ |
| $27.8 + 3.6 \\ -3.1$ | | BARLAG | 92c ACCM | π^- Cu 230 GeV |
| $27.1 \pm 2.3 \pm 2.4$ | | COFFMAN | 91 MRK3 | $e^{+}e^{-}$ 3.77 GeV |

$[\Gamma(\overline{K}^0 \text{ anything}) + \Gamma(K^0 \text{ anything})]/\Gamma_{\text{total}}$

| [. (=, | () | -6/]/ · LOLAI | | | / - |
|------------------------|------------|---------------|----------|---------------------|-------|
| VALUE (%) | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 61 ±5 OUR AV | ERAGE | | | | |
| $60.5 \pm 5.5 \pm 3.3$ | 244 ± 22 | ABLIKIM | 06∪ BES2 | $e^{+}e^{-}$ at 377 | 3 MeV |
| $61.2 \pm 6.5 \pm 4.3$ | | C OFF MA N | 91 MRK3 | $e^{+}e^{-}$ 3.77 (| ieV |

$\Gamma(K^+ \text{ anything})/\Gamma_{\text{total}}$

| VALUE (%) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------------|------------|-------------|----------|---------------------------------|
| 5.9±0.8 OUR AVERA | GE | | | |
| $6.1 \pm 0.9 \pm 0.4$ | 189 ± 27 | ABLIKIM | 07G BES2 | $e^{+}e^{-} \approx \psi(3770)$ |
| $5.5\pm1.3\pm0.9$ | | COFFMAN | 91 MRK3 | e^+e^- 3.77 GeV |

$\Gamma(K^*(892)^- \text{ anything})/\Gamma_{\text{total}}$ VA

| ` ' ' | 0// 1014 | | | | ٠, |
|------------------------------------------|-----------------------------------|--------------|----------|--------------------|-----|
| ALUE (%) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 7±5.2±0.7 | 7.2 ± 6.5 | ABLIKIM | 06U BES2 | e^+e^- at 3773 M | leV |
| (K *(892) ⁰ anyth | $_{\rm ling})/\Gamma_{\rm total}$ | | | Г | 7/Γ |

$\Gamma(\overline{K}^*(892)^0 \text{ anything})/\Gamma_{\text{total}}$

| VALUE (%) | EVTS | DOCUMENT ID TECN | COMMENT |
|--------------|----------|------------------|--------------------------------------|
| 23.2±4.5±3.0 | 189 ± 36 | ABLIKIM 05P BES | $e^+ e^- \approx 3773 \; \text{MeV}$ |

$\Gamma(K^*(892)^0 \text{ anything})/\Gamma_{\text{total}}$

| VALUE (%) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------|-----|-------------|-----|------|------------------------|
| <6.6 | 90 | ABLIKIM | 05P | BES | e^+e^-pprox 3773 MeV |

$\Gamma(\eta \text{ anything})/\Gamma_{\text{total}}$

This ratio includes η particles from η' decays. VALUE (%) TECN COMMENT EVTS DOCUMENT ID $6.3 \pm 0.5 \pm 0.5$ 1972 ± 142 HUANG 06B CLEO e^+e^- at $\psi(3770)$

$\Gamma(\eta' \text{ anything})/\Gamma_{\text{total}}$ $1.04 \pm 0.16 \pm 0.09$

| EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------|-------------|----------|--------------------------|
| 82 ± 13 | HUANG | 06B CLEO | e^+e^- at $\psi(3770)$ |
| otal | | | Γ ₁₁ /Γ |

$\Gamma(\phi \text{ anything})/\Gamma_{\text{total}}$ VALUE (%) $1.03 \pm 0.10 \pm 0.07$ 248 ± 21

| 5 | DOCUMENT ID | | TECN | COMMENT |
|---|-------------|-----|------|--------------------------|
| 1 | HUANG | 06в | CLEO | e^+e^- at $\psi(3770)$ |

Leptonic and semileptonic modes =

| $\Gamma(e^+ \nu_e)/\Gamma_{ m total}$ | | | | Γ ₁₂ /Γ |
|---------------------------------------|--------------|----------------------|---------------|------------------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT |
| $< 8.8 \times 10^{-6}$ | 90 | EISENSTEIN | 08 CLEO | $e^{+}e^{-}$ at $\psi(3770)$ |
| \bullet \bullet We do not use | the followin | g data for averages, | fits, limits, | etc. • • • |
| $< 2.4 \times 10^{-5}$ | 90 | ARTUSO | 05A CLEO | See FISENSTEIN 08 |

 D^{\pm}

```
\Gamma(\overline{K}^*(892)^0 e^+ \nu_e) / \Gamma(K^- 2\pi^+)
\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}
                                                                                                                                     Unseen decay modes of the \overline{K}^*(892)^0 are included. See the end of the D^+ Listings
       See the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_s^+
                                                                                                                                     for measurements of D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell form-factor ratios.
VALUE (units 10^{-4})
                                               DOCUMENT ID
                                                                      TECN COMMENT
                                 EVTS
                                                                                                                                                            EVTS
                                                                                                                                                                           DO CUMENT ID
                                                                                                                                                                                                     TECN COMMENT
                                           <sup>12</sup> EISENSTEIN 08 CLEO e^+e^- at \psi(3770)
 3.82± 0.32±0.09 150 \pm 12
                                                                                                                              \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                                                                           BRANDENB... 02 CLEO e^+e^-\approx \Upsilon(4S)
                                                                                                                              0.74 \pm 0.04 \pm 0.05
                                           <sup>13</sup> ABLIKIM
                                                                                                                                                                           ADAMOVICH 91 OMEG \pi^- 340 GeV
                                                                                                                              0.62 \pm 0.15 \pm 0.09
                                                                                                                                                               35
                                                                                                                                                                           ALBRECHT 91 ARG e^+e^-pprox 10.4 GeV
 4.40 \pm \phantom{0}0.66 ^{\,+\,0.09}_{\,-\,0.12}
                                                                                                                              0.55 \pm 0.08 \pm 0.10
                                                                                                                                                              880
                                            <sup>14</sup> ARTUSO
                              47\,\pm\,7
                                                                   05A CLEO See EISENSTEIN 08
                                                                                                                              0.49 \pm 0.04 \pm 0.05
                                                                                                                                                                           ANJOS
                                                                                                                                                                                              89B E691 Photoproduction
                                            <sup>15</sup> BONVICINI
 3.5 ~\pm~ 1.4 ~\pm 0.6
                                    7
                                                                 04A CLEO Incl. in ARTUSO 05A
                                                                                                                              \Gamma(\overline{K}^*(892)^0 e^+ \nu_e, \overline{K}^*(892)^0 \to K^- \pi^+) / \Gamma(K^- \pi^+ e^+ \nu_e)
                                            ^{16}\,\mathrm{BAI}
                                                                   98B BES e^+e^- \to D^{*+}D^-
                                                                                                                              VALUE (%)
                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                   TECN COMMENT
  ^{12}EISENSTEIN 08, using the ^{D+} lifetime and assuming |V_{cd}|=\left|V_{US}\right|, gets f_{D^{+}}=
                                                                                                                              94.11 ± 0.74 ± 0.75
                                                                                                                                                                           DEL-AMO-SA...111 BABR e^+e^-pprox 10.6 GeV
    (205.8 \pm 8.5 \pm 2.5) MeV from this measurement.
  ^{13}ABLIKIM 05D finds a background-subtracted 2.67 \pm 1.74 D^+ 
ightarrow ~\mu^+ ~
u_{\mu} events, and
                                                                                                                              \Gamma((K^-\pi^+)_{S-wave} e^+\nu_e)/\Gamma(K^-\pi^+e^+\nu_e)
    from this obtains f_{D^+} = 371^{+129}_{-119} \pm 25 \,\, \mathrm{MeV}.
                                                                                                                                                                           DO CUMENT ID
                                                                                                                                                                                                    TECN COMMENT
  ^{14} ARTUSO 05A obtains f_{D^+}=222.6\pm16.7^{+2.8}_{-3.4} MeV from this measurement.
                                                                                                                              5.79 \pm 0.16 \pm 0.15
                                                                                                                                                                           DEL-AMO-SA...11: BABR e^+e^-pprox 10.6 GeV
 ^{15}\,\mathrm{BONVICINI} 04A finds eight events with an estimated background of one, and from the
                                                                                                                              \Gamma(\overline{K}^*(1410)^0\,e^+
u_e , \overline{K}^*(1410)^0	o K^-\pi^+)/\Gamma_{	ext{total}}
                                                                                                                                                                                                                                    \Gamma_{20}/\Gamma
 branching fraction obtains f_{D^+}=202\pm41\pm17 MeV. 
 ^{16} BAI 98B obtains f_{D^+}=(300^{+180}_{-150}^{+80}) MeV from this measurement.
                                                                                                                                                                                                 TECN COMMENT
                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                           DEL-AMO-SA...111 BABR e^+e^-\approx 10.6 \text{ GeV}
\Gamma(\tau^+\nu_{\tau})/\Gamma_{\rm total}
                                                                                                      \Gamma_{14}/\Gamma
                                                                                                                              \Gamma(\overline{K}_2^*(1430)^0\,e^+\,
u_e , \overline{K}_2^*(1430)^0	o\,K^-\,\pi^+)/\Gamma_{total}
<u>VALUE</u>
                               CL%
                                             DOCUMENT ID
                                                                       TECN COMMENT
                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                  TECN COMMENT
 <1.2 \times 10^{-3}
                                             EISENSTEIN 08 CLEO e^+\,e^- at \psi(3770)
                               90
                                                                                                                                                                           DEL-AMO-SA...111 BABR e^+e^-pprox 10.6 GeV
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
 < 2.1 \times 10^{-3}
                                                                                                                              \Gamma(K^-\pi^+e^+\nu_e \text{ nonresonant})/\Gamma_{\text{total}}
                               90
                                             RUBIN
                                                                 06A CLEO See EISENSTEIN 08
                                                                                                                                                                                                                                    \Gamma_{22}/\Gamma
                                                                                                                                                                                                     TECN COMMENT
\Gamma(\overline{K}^0\,e^+\,
u_e)/\Gamma_{
m total}
                                                                                                      \Gamma_{15}/\Gamma
                                                                                                                                                                           ANJOS
                                                                                                                                                                                              89B E691 Photoproduction
                                                    DOCUMENT ID
VALUE (%)
                                  EVTS
                                                                           TECN COMMENT
8.83±0.22 OUR AVERAGE
                                                                                                                              \lceil \left( K^- \pi^+ \mu^+ \nu_\mu \right) / \lceil \left( \overline{K}{}^0 \mu^+ \nu_\mu \right)
                                                                                                                                                                                                                                 \Gamma_{23}/\Gamma_{16}
                                                ^{17}\,\mathrm{BESSON}
8.83 \pm 0.10 \pm 0.20
                                  8467
                                                                       09 CLEO e^+e^- at \psi(3770)
                                                                                                                                                                              DOCUMENT ID
                                                                                                                                                                                                 TECN COMMENT
                                               <sup>18</sup> ABLIKIM
8.95 \pm 1.59 \pm 0.67
                                  34 \pm 6
                                                                       05A BES e^+\,e^- at \psi(3770)
                                                                                                                              0.417±0.030±0.023 555 ± 39
                                                                                                                                                                                             04E FOCS \gamma nucleus, \overline{E}_{\gamma} \approx 180~{\rm GeV}
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                               <sup>19</sup> DOBBS
                                                                                                                              \Gamma(\overline{K}^*(892)^0 \mu^+ \nu_\mu)/\Gamma_{\text{total}}
8.5\,3\pm0.13\pm0.23
                                                                       08 CLEO See BESSON 09
                                                                                                                                                                                                                                    \Gamma_{35}/\Gamma
                                 545 \pm 24 HUANG
                                                                       05B CLEO See DOBBS 08
                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                     TECN COMMENT
 ^{17} See the form-factor parameters near the end of this D^+ Listing. ^{18} The ABLIKIM 05A result together with the D^0 \to ~K^-\,e^+\nu_e branching fraction of
                                                                                                                              5.28±0.15 OUR FIT
                                                                                                                              5.27 \pm 0.07 \pm 0.14
                                                                                                                                                                           BRIERE
                                                                                                                                                                                               10 CLEO e^+e^- at \psi(3770)
    ABLIKIM 04c and Particle Data Group lifetimes gives \Gamma(D^0 \to K^- e^+ \nu_e) / \Gamma(D^+ \to K^- e^+ \nu_e)
                                                                                                                              \Gamma\big(\overline{K}^*(892)^0\,\mu^+\,\nu_\mu\big)/\Gamma\big(\overline{K}^0\,\mu^+\,\nu_\mu\big)
                                                                                                                                                                                                                                 \Gamma_{35}/\Gamma_{16}
    \overline{\it K}^0\,e^+
u_e) = 1.08\pm 0.22\pm 0.07; isospin invariance predicts the ratio is 1.0.
 ^{19} DOBBS 08 establishes |\frac{V_{Cd}}{V_{CS}}\cdot\frac{f_+^\pi(0)}{f_+^K(0)}|= 0.188 \pm 0.008 \pm 0.002 from the D^+ and D^0
                                                                                                                                     Unseen decay modes of the \overline{K}^*(892)^0 are included. See the end of the D^+ Listings
                                                                                                                                     for measurements of D^+ 	o \overline{K^*}(892)^0 \ell^+ \nu_\ell form-factor ratios.
    decays to \overline{K}e^+\nu_e and \pi e^+\nu_e. It also finds \Gamma(D^0\to K^-e^+\nu_e)/\Gamma(D^+\to \overline{K}^0e^+\nu_e)=1.06\pm0.02\pm0.03; isospin invariance predicts the ratio is 1.0.
                                                                                                                              0.58 ±0.04 OUR FIT
                                                                                                                                                                              DOCUMENT ID TECN COMMENT
                                                                                                                              0.594 \pm 0.043 \pm 0.033 555 ± 39
                                                                                                                                                                              LINK
                                                                                                                                                                                             04E FOCS \gamma nucleus, \overline{E}_{\gamma} \! \approx \! 180 \; \mathrm{GeV}
\Gamma(\overline{K}^0\mu^+\nu_\mu)/\Gamma_{
m total}
                                               DOCUMENT ID
                                                                       TECN COMMENT
                                                                                                                              \Gamma(\overline{K}^*(892)^0\mu^+\nu_\mu)/\Gamma(K^-2\pi^+)
0.092±0.006 OUR FIT
                                                                                                                                     Unseen decay modes of the \overline{K}^*(892)^0 are included. See the end of the D^+ Listings
0.103±0.023±0.008 29 ± 6
                                                                   07 BES2 e^+e^- at 3773 MeV
                                               ABLIKIM
                                                                                                                                     for measurements of D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell form-factor ratios.
\Gamma(\overline{K}^0\mu^+\nu_\mu)/\Gamma(K^-2\pi^+)
                                                                                                   \Gamma_{16}/\Gamma_{40}
                                                                                                                                                             EVTS
                                                                                                                                                                           DO CUMENT ID
                                                                                                                                                                                                     TECN COMMENT
1.00 ±0.07 OUR FIT
                                               DOCUMENT ID TECN COMMENT
                                                                                                                              0.578±0.021 OUR FIT Error includes scale factor of 1.1.
                                                                                                                              0.57 ±0.06 OUR AVERAGE Error includes scale factor of 1.2.
1.019 \pm 0.076 \pm 0.065 555 ± 39
                                               LINK
                                                             04E FOCS \gamma nucleus, \overline{E}_{\gamma} \approx 180 \; \mathrm{GeV}
                                                                                                                                                                           BRANDENB... 02 CLEO e^+e^-_-pprox~\varUpsilon(4S)
                                                                                                                              0.72 \pm 0.10 \pm 0.05
                                                                                                                                                                                              93E E687 \gamma Be \overline{E}_{\gamma} \approx 200 GeV
                                                                                                                              0.56\ \pm0.04\ \pm0.06
                                                                                                                                                              875
                                                                                                                                                                           FRABETTI
\Gamma(K^-\pi^+e^+\nu_e)/\Gamma_{\text{total}}
                                                                                                                              0.46 \pm 0.07 \pm 0.08
                                                                                                                                                             224
                                                                                                                                                                           KODA MA
                                                                                                                                                                                              92c E653 \pi^- emulsion 600 GeV
VALUE (units 10<sup>-2</sup>) EVTS
                                               DOCUMENT ID TECN COMMENT
                                                                                                                              \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                                                                      <sup>21</sup> LINK
                                                                                                                                                          12k
                                                                                                                                                                                              02J FOCS \gamma nucleus, pprox 180 GeV
                                                                                                                               ^{21} This LINK 02J result includes the effects of an interference of a small S-wave K^-\,\pi^+ amplitude with the dominant \overline{K}^{*0} amplitude. (The interference effect is reported in
3.5\,0\pm0.75\pm0.27
                             29 + 6
                                               ABLIKIM
                                                                  060 BES2 e+e- at 3773 MeV
3.5 \begin{array}{c} +1.2 \\ -0.7 \end{array} \pm 0.4
                                                                   91 MRK3 e^+e^-\approx 3.77~\text{GeV}
                                                                                                                                  LINK 02E.) This result is redundant with results of LINK 04E elsewhere in these Listings.
\Gamma(K^-\pi^+e^+\nu_e)/\Gamma(K^-2\pi^+)
                                                                                                   \Gamma_{17}/\Gamma_{40}
                                                                                                                              \Gamma(K^-\pi^+\mu^+\nu_\mu \text{ nonresonant})/\Gamma(K^-\pi^+\mu^+\nu_\mu)
                                                  DOCUMENT ID
                                                                         TECN COMMENT
                                                                                                                                                                             DOCUMENT ID
                                                                                                                                                                                                     TECN COMMENT
                                                                                                                                                           EVTS
0.4380±0.0036±0.0042 70k±363
                                                 DEL-AMO-SA..111 BABR e^+e^-pprox 10.6 \text{ GeV}
                                                                                                                              0.0530 \pm 0.0074 + 0.0099
                                                                                                                                                                                                 05: FOCS \gamma nucleus, \overline{E}_{\gamma} \approx 180
                                                                                                                                                                             LINK
\Gamma(\overline{K}^*(892)^0\,e^+\,\nu_e)/\Gamma_{
m total}
                                                                                                                                                                                                                     GeV
       Unseen decay modes of \overline{K}^*(892)^0 are included. See the end of the D^+ Listings for
                                                                                                                              \Gamma(K^-\pi^+\pi^0\mu^+\nu_\mu)/\Gamma(K^-\pi^+\mu^+\nu_\mu)
                                                                                                                                                                                                                                 \Gamma_{26}/\Gamma_{23}
       measurements of D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell form-factor ratios.
                                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                     TECN COMMENT
                                                                                                                                                                           FRABETTI 93E E687 \gamma Be \overline{E}_{\gamma} \approx 200 \text{ GeV}
VALUE (units 10^{-2})
                                                     DOCUMENT ID TECN COMMENT
                               EVTS
5.52+0.15 OUR FIT
                                                                                                                              \Gamma(\overline{K}_0^*(1430)^0 \mu^+ \nu_\mu) / \Gamma(K^- \pi^+ \mu^+ \nu_\mu)
                                                                                                                                                                                                                                 \Gamma_{36}/\Gamma_{23}
5.52 \pm 0.07 \pm 0.13
                                                     BRIERE 10 CLEO e^+e^- at \psi(3770)
                                 \approx 5 \, \text{k}
                                                                                                                                     Unseen decay modes of the \overline{K}_0^*(1430)^0 are included.
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                                     EVTS
                                                                                                                                                                       DO CUMENT ID
                                                                                                                                                                                                 TECN COMMENT
                                28 \pm 7
                                                    ABLIKIM 060 BES2 e^+e^- at 3773 MeV
5.06 \pm 1.21 \pm 0.40
                                                                                                                                                                                           05: FOCS \gamma nucleus, \overline{E}_{\gamma}
                                                                                                                                                                        LINK
                                422 \pm 21 20 HUANG 05B CLEO e^+e^- at \psi(3770)
5.56 \pm 0.27 \pm 0.23
 ^{20}\,\text{HUANG} 05B finds \Gamma(D^0\to K^{*-}\,e^+\nu_e) / \Gamma(D^+\to \overline{K}^{*0}\,e^+\nu_e)=0.98\pm0.08\pm0.04; isospin invariance predicts the ratio is 1.0.
                                                                                                                              \Gamma(\overline{K}^*(1680)^0 \mu^+ \nu_\mu) / \Gamma(K^- \pi^+ \mu^+ \nu_\mu)
                                                                                                                                                                                                                                 \Gamma_{37}/\Gamma_{23}
                                                                                                                                   Unseen decay modes of the \overline{K}^*(1680)^0 are included.
                                                                                                                                                     EVTS
                                                                                                                              VALUE
                                                                                                                                                                       DO CUMENT ID
                                                                                                                                                                                                TECN COMMENT
                                                                                                                                                                                           051 FOCS \gamma nucleus, \overline{E}_{\gamma}~\approx~180
                                                                                                                               < 0.04
                                                                                                                                                            90
                                                                                                                                                                       LINK
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GeV

| | | | | | _ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| $\Gamma(\pi^0 e^+ \nu_e) / \Gamma_{\text{total}}$ | EVEC | DOCUM | ENT ID TEC | N COMMENT | Γ ₂₇ /Γ |
| 0.405 ±0.016±0.009 | 838 | 22 BESSO | | | ψ(3770) |
| • We do not use the | e following | _ | | | |
| 0.373±0.022±0.013 0.44 ±0.06 ±0.03 | 63 ± 9 | 23 DOBBS HUANG | | | |
| ²² See the form-factor | parameters i | near the end of | this D^+ Lis | ting. | |
| ²³ DOBBS 08 establish | ies $\left \frac{V_{cd}}{V_{cs}} \cdot \frac{f}{f} \right $ | $\frac{f_{+}^{\pi}(0)}{f_{-}^{K}(0)} = 0.188$ | \pm 0.008 \pm | 0.002 from the | ${\it D}^{+}$ and ${\it D}^{0}$ |
| decays to $\overline{K}e^+\nu_e$ a 2.03 \pm 0.14 \pm 0.08; | nd $\pi e^+ \nu_e$. | It finds $\Gamma(D^0 - 1)$ | $\rightarrow \pi^- e^+ \nu$ the ratio is | e) / Γ(D ⁺ → 2.0. | $\pi^0 e^+ \nu_e) =$ |
| $(\eta e^+ u_e) / \Gamma_{ m total}$ | · | | | | Γ ₂₈ /Γ |
| ALUE (units 10 ⁻⁴) | EVTS | DOCUMENT : | | CN COMMENT | |
| 1.4±0.9±0.4 • • We do not use th | e following | YELTON data for averag | | | $\psi(3770)$ |
| 3.3±2.0±0.6 | 46 ± 8 | MITCHELL | 09в CL | EO See YELT | ΓΟΝ 11 |
| $(ho^0 e^+ u_e) / \Gamma_{\text{total}}$ | EVTS | DOCUME | NT ID | TECN COMMI | Γ ₂₉ /Γ |
| .0022±0.0004 OUR FI | T | | | | <u>.</u> |
| 1. 0021 ± 0.0004 ± 0.000 1 2 ⁴ HUANG 05B finds 1 | | HUANG (1, 1 ± 4 = 1 | | CLEO e+e- | |
| isospin invariance pr | | | (D , p | c ve) = 1.2 | -0.3 - 0.1, |
| $\Gamma(\rho^0 e^+ \nu_e)/\Gamma(\overline{K}^*(8))$ | 92) $^{0}e^{+}\nu_{e}$ |) | | | Γ_{29}/Γ_{34} |
| ALUE 0.039±0.007 OUR FIT | EVTS | DOCUMENT ID | TECI | <u>COMMENT</u> | |
| $0.045 \pm 0.014 \pm 0.009$ | | AITALA | 97 E79 | | • |
| ²⁵ AITALA 97 explicitly | subtracts D | $^+ \rightarrow \eta' e^+ \nu_e$ | and other b | ackgrounds to g | get this result. |
| $(ho^0 \mu^+ u_\mu) / \Gamma(\overline{K}^*)$ | $(92)^0 \mu^+ \nu_\mu$ | | | | Γ_{30}/Γ_{35} |
| <u> </u> | <u>EVTS</u> RAGE Erro | <u>DOCUMENT</u> or includes scal | | <u>CN COMMENT</u> .1. | <u> </u> |
| | 320 ± 44 | LINK | | CS γ A, \overline{E}_{γ} | |
| $.051 \pm 0.015 \pm 0.009$ $.079 \pm 0.019 \pm 0.013$ | 54 39 | ²⁶ AITALA ²⁷ FRABETT | 97 E7 1 97 E6 | _ | us, 500 GeV ,≈ 220 GeV |
| ²⁶ AITALA 97 explicit | | | | , | |
| result. | iy subtracts | $D \cdot \rightarrow \eta \mu$ | $ u_{\mu}$ and on | iei background | s to get tills |
| 27 103411. | | | · | | |
| ²⁷ Because the reconst | ruction effici | ency for photo $\underset{\rightarrow}{\text{ency for photo}}$ | ns is low, th | is FRABETTI | 97 result also |
| ²¹ Because the reconst includes any $D^+ \rightarrow$ | ruction effici $\eta' \mu^+ u_\mu$ - | ency for photo $\gamma \rho^0 \mu^+ \nu_\mu$ (| ns is low, th events in the | is FRABETTI numerator. | |
| ²¹ Because the reconst includes any $D^+ \rightarrow$ | ruction effici $\eta' \mu^+ u_{\mu}$ - | $\rightarrow \gamma \rho^0 \mu^+ \nu_{\mu} \epsilon$ | events in the | is FRABETTI numerator. N COMMENT | 97 result also Γ ₃₁ /Γ |
| ²⁷ Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma_{\text{total}}$ | η' μ ⁺ ν _μ - | $\rightarrow \gamma \rho^0 \mu^+ \nu_{\mu} \epsilon$ | events in the | numerator. | Г ₃₁ /Г |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{\Gamma(\omega e^+ \nu_e)}{\Gamma(0.0006 \pm 0.0006)}$ | $\frac{\eta' \mu^{+} \nu_{\mu} - \frac{EVTS}{1}}{7.6 + \frac{3.3}{2.7}}$ | $\gamma ho^0 \mu^+ u_{\mu} $ | events in the | numerator. N <u>COMMENT</u> | Γ₃₁/Γ ψ(3770) |
| ²⁷ Because the reconst includes any $D^+ \rightarrow \frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} \frac{1}{2} \frac{1}$ | $\frac{\eta' \mu^{+} \nu_{\mu} - \frac{EVTS}{1}}{7.6 + \frac{3.3}{2.7}}$ | → γρ ⁰ μ ⁺ ν _μ α <u>DOCUM</u> HUANG | events in the ENT ID TEC G 05B CLE | numerator. N COMMENT O e^+e^- at | Г ₃₁ /Г |
| ²⁷ Because the reconst includes any $D^+ \rightarrow \frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} \frac{1}{2} \frac{1}$ | $\frac{\eta' \mu^{+} \nu_{\mu} - \frac{EVTS}{1}}{7.6 + \frac{3.3}{2.7}}$ | $\gamma ho^0 \mu^+ u_{\mu} $ | events in the | numerator. N COMMENT O e^+e^- at N COMMENT | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} = 0.0016 \pm 0.0003$ $\frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} = 0.0003 \pm 0.0003$ $\frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} = 0.0003$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1.00}$ 1. $7.6^{+3.3}_{-2.7}$ Obtaine following of | → γρ ⁰ μ+ν _μ α <u>DOCUMENT ID</u> YELTON data for averag | ENT ID TEC G 05B CLE TECH 11 CLE es, fits, limit | numerator. $ \frac{N}{N} = \frac{COMMENT}{e^+e^- \text{ at }} $ $ \frac{N}{N} = \frac{COMMENT}{e^+e^- \text{ at }} $ $ \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} $ $ \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} $ $ \frac{N}{N} = \frac{N}$ | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{(\omega e^+ \nu_e)}{\Gamma(\text{total})}$ $\frac{(\omega e^+ \nu_e)}{\Gamma(tot$ | $\eta'\mu^+\nu_{\mu}$ - EVTS 1. $7.6^{+3.3}_{-2.7}$ Otal CL% | → γρ ⁰ μ ⁺ ν _μ α <u>DOCUM.</u> HUANG <u>DOCUMENT ID</u> YELTON | ENT ID TEC G 05B CLE TECI 11 CLE | numerator. N COMMENT O e^+e^- at O e^+e^- at e^+e^- at e^+e^- at e^+e^- at e^+e^- at e^+e^- at e^+ | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{(\omega e^+ \nu_e)}{\Gamma \text{total}}$ $\frac{(\omega e^+ \nu_e)}{\Gamma \text{total}}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ 1 7.6+3.3 Obtained following of the followin | → γρ ⁰ μ+ν _μ α <u>DOCUMENT ID</u> YELTON data for averag MITCHELL | ENT ID TEC G 05B CLE TECH 11 CLE es, fits, limit | numerator. $ \frac{N}{N} = \frac{COMMENT}{e^+e^- \text{ at }} $ $ \frac{N}{N} = \frac{COMMENT}{e^+e^- \text{ at }} $ $ \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} $ $ \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} = \frac{N}{N} $ $ \frac{N}{N} = \frac{N}$ | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ |
| 27 Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma_{\text{total}}$ $\frac{(\omega e^+ \nu_e)}{(0.0016 + 0.0007} \pm 0.0001$ $\frac{(\eta'(958) e^+ \nu_e)}{(0.0016 + 0.53 \pm 0.07)}$ $\frac{(\Delta LUE \text{ (units } 10^{-4})}{(0.0016 + 0.53 \pm 0.07)}$ $\frac{(\omega e^+ \nu_e)}{(0.0016 + 0.0007)}/\Gamma_{\text{total}}$ Unseen decay moral $\frac{(\omega e^+ \nu_e)}{(0.0016 + 0.0007)}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1.5}$ 1. $7.6^{+3.3}_{-2.7}$ Ottal $CL\%$ The following of the ϕ $CL\%$ | DOCUMENT ID DOCUMENT ID YELTON data for averag MITCHELL are included. DOCUMENT ID | ENT ID TEC G 05B CLE TECH 11 CLE es, fits, limit 09B CLE | numerator. N COMMENT O e^+e^- at N COMMENT O e^+e^- at e^- at e^+e^- at e^- a | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ |
| 2f Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma_{\text{total}}$ $\frac{ALUE}{ALUE} = 0.0006 \pm 0.0003$ $\frac{(\eta'(958) e^+ \nu_e)/\Gamma_{\text{total}}}{2.16 \pm 0.53 \pm 0.07}$ • • We do not use the case of the case | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ EVTS $7.6 + \frac{3.3}{2.7}$ Otal CL% The following of the ϕ $\frac{CL\%}{90}$ | DOCUMENT ID DOCUMENT ID YELTON data for averag MITCHELL are included. DOCUMENT ID YELTON | ENT ID TECE | numerator. N COMMENT O e^+e^- at N COMMENT O e^+e^- at $e^ e^ $ | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ |
| 2f Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma_{\rm total}$ $\frac{ALUE}{0.0016 + 0.0007} \pm 0.0001$ $\frac{(\eta'(958) e^+ \nu_e)}{(1.0006 + 0.0001}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ EVTS $7.6 + \frac{3.3}{2.7}$ Otal CL% The following of the ϕ $\frac{CL\%}{90}$ | DOCUMENT ID DOCUMENT ID YELTON data for averag MITCHELL are included. DOCUMENT ID YELTON | ### PROPRIES OF THE PROPRIES O | numerator. N COMMENT O e^+e^- at N COMMENT O e^+e^- at $e^ e^ $ | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ |
| 2f Because the reconst includes any $D^+ \rightarrow \frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}} = \frac{1}{2} \frac{1}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ EVTS $1 - \frac{6 + 3.3}{7.6 + 2.7}$ Otal CL% The following of the ϕ CL% 90 des of the ϕ CL% 90 90 90 | DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM | ### PROPRIES OF THE PROPRIES O | numerator. N COMMENT O e^+e^- at e^- | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ Φ(3770) DN 11 B773 MeV |
| 2f Because the reconst includes any $D^+ \rightarrow \frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{1}{2} \frac{(\omega e^+ \nu_e)}{\Gamma_{\text{total}}}$ $\frac{1}{2} \frac{1}{2} \frac{1}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1 - 2.7}$ So tal $CL\%$ The following of the ϕ $CL\%$ The following o | DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM BAI | ENT ID TECC 11 CLE es, fits, limit 09B CLE 11 CLE es, fits, limit 09B CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 CLE 11 | numerator. N COMMENT O e^+e^- at v^- COMMENT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ Φ(3770) DN 11 B773 MeV |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{(\omega e^+ \nu_e)}{\Gamma \text{total}}$ $\frac{(\omega e^+ \nu_e)}{\Gamma \text{total}}$ $\frac{(\lambda LUE)}{\Gamma tota$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1 - 2.7}$ So tal $CL\%$ The following of the ϕ $CL\%$ The following o | DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM | ENT ID TECC 11 CLE es, fits, limit O9B CLE 11 CLE es, fits, limit O9B CLE 06P BES 91 MRI | numerator. N COMMENT O e^+e^- at v^- COMMENT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • O See YELT O e^+e^- at v^- S, etc. • • • | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ ψ(3770) DN 11 3773 MeV 3.77 GeV |
| 27 Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma_{\rm total}$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0001$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0001$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007 + 0.0007} \pm 0.0007$ $\frac{(\lambda LUE)}{(0.0016 + 0.0007 + 0.0007} \pm 0.0007$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1 - 2.7}$ So tal $CL\%$ The following of the ϕ $CL\%$ The following o | DOCUMENT ID YELTON data for averag MITCHELL are included. DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM BAI modes with a | ENT ID TECE 11 CLE es, fits, limit O9B CLE 15 CLE Es, fits, limit O9B CLE 16 CLE Es, fits, limit O9B CLE O6P BES O91 MRI | numerator. N COMMENT O e^+e^- at e^- | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ Φ(3770) DN 11 3773 MeV 3.77 GeV |
| 27 Because the reconst includes any $D^+ \rightarrow (\omega e^+ \nu_e)/\Gamma$ total (ΔLUE) | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ EVTS 1 7.6 + 3.3 7.6 + 2.7 Otal CL% 1 of following of 90 90 90 90 Hadronic | DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM BAI modes with a DOCUMENT ID YELTON modes with a | PENT ID TECE TECE 11 CLE es, fits, limit OPB CLE 12 CLE es, fits, limit OPB CLE 13 CLE es, fits, limit OPB CLE OFF OFF OFF OFF OFF OFF OFF OFF OFF OF | numerator. N COMMENT O e^+e^- at e^- at e^+e^- at e^+e^- at e^- at e | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ Φ(3770) DN 11 3773 MeV 3.77 GeV |
| 27 Because the reconst includes any $D^+ \rightarrow \frac{(\omega e^+ \nu_e)}{\Gamma(\cos e^+ \nu_e)}/\Gamma_{\text{total}}$ $\frac{(\Delta LUE)}{L.0016 + 0.0007} \pm 0.0001$ $\frac{(\pi/(958) e^+ \nu_e)}{\Gamma(\cos e^+ \nu_e)}/\Gamma_{\text{total}}$ $\frac{(\Delta LUE)}{\Gamma(\cos e^+ \nu_e)}/\Gamma_{\text{total}}$ | $\eta' \mu^+ \nu_{\mu} - \frac{EVTS}{1}$ EVTS 1 7.6 + 3.3 7.6 + 2.7 Otal CL% 1 of following of 90 90 90 90 Hadronic | DOCUMENT ID YELTON data for averag MITCHELL ABLIKIM BAI modes with a DOCUMENT ID YELTON modes with a | PENT ID TECK 11 CLE es, fits, limit OPB CLE 12 CLE es, fits, limit OPB CLE OFP BES OPP MRIA K OF K MENT ID OPB CREST ID OPB CRES | numerator. N COMMENT O e^+e^- at e^- at e^+e^- at e^+e^- at e^- at e | Γ ₃₁ /Γ ψ(3770) Γ ₃₂ /Γ ψ(3770) DN 11 Γ ₃₃ /Γ Φ(3770) 3.77 GeV |
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| $\Gamma(K_L^0\pi^+)/\Gamma_{ m total}$ | | | | | Г ₃₉ /Г |
|--------------------------------------------------------|------------------|----------------------------------|-----------------|----------------------------------|------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID |) TE | CN COMME | ENT |
| $1.460 \pm 0.040 \pm 0.035$ | 2023 ± 54 | ³⁰ HE | 08 CL | EO e^+e^- | at $\psi(3770)$ |
| ³⁰ The difference of CI (DOBBS 07 and HE | | | | hing fraction | s over the sum |
| $\Gamma(K^-2\pi^+)/\Gamma_{\text{total}}$ | | | | | Γ_{40}/Γ |
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID |) TEC | N COMMEI | VT |
| 9.13±0.19 OUR FIT | | | | | |
| $9.14 \pm 0.10 \pm 0.17$ | | ³¹ DOBBS | | | |
| • • • We do not use th | ne following da | | | , etc. • • • | |
| $9.5 \pm 0.2 \pm 0.3$ | $15.1k \pm 130$ | ³¹ HE | | EO See DO | |
| $9.3 \pm 0.6 \pm 0.8$ | 1502 | ³² BALEST | 94 CLE | EO e ⁺ e [−] | $\approx \Upsilon(4S)$ |
| $6.4 \begin{array}{c} +1.5 \\ -1.4 \end{array}$ | | ³³ BARLAG | 92c AC | CM π^- Cu | 230 GeV |
| $9.1 \pm 1.3 \pm 0.4$ | 1164 | ADLER | | K3 e ⁺ e ⁻ | |
| 9.1 ±1.9 | 239 | ³⁴ SCHINDLER | 81 MR | K2 e ⁺ e ⁻ | 3.771 GeV |
| 31 DOBBS 07 and HE supersedes HE 05. | 05 use single- | and double-tagge | d events i | n an overall | fit. DOBBS 07 |
| ³² BALEST 94 measur | es the ratio o | $f D^+ \rightarrow K^- \pi^+$ | π^+ and | $D^0 \rightarrow \kappa^-$ | π^+ branching |
| fractions to be 2.35 | | | | | |
| $K^-\pi^+$ fraction (A) | KERIB 93). | | | | |
| 33 BARLAG 92c comp | utes the branc | hing fraction by t | opologica | ı normalizat | ion. |
| 34 SCHINDLER 81 (M be 0.38 ± 0.05 nb. \ | IARK-2) meas | ures $\sigma(e^+e^- \rightarrow$ | $\psi(3770)$ |))) × branch | ing fraction to |
| De 0.38 ± 0.05 ND. 1 | ive use the ivii | AKK-3 (ADLEK 8 | oc) value | $\sigma = 4.2$ | ± 0.6 ± 0.3 ND. |
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DALITZ PLOT ANALYSIS FORMALISM

Revised March 2012 by D. Asner (Pacific Northwest National Laboratory) and C. Hanhart (Forschungszentrum Jülich).

Introduction: Weak nonleptonic decays of D and B mesons are expected to proceed dominantly through resonant two-body decays [1]; see Ref. 2 for a review of resonance phenomenology. The amplitudes are typically calculated with the Dalitz-plot analysis technique [3], which uses the minimum number of independent observable quantities. For three-body decays of a spin-0 particle to all pseudo-scalar final states, such as D or $B \to abc$, the decay rate [4] is

$$\Gamma = \frac{1}{(2\pi)^3 32\sqrt{s^3}} |\mathcal{M}|^2 dm_{ab}^2 dm_{bc}^2,$$
 (1)

where m_{ij} is the invariant mass of particles i and j. Here the prefactor contains all kinematic factors, while $|\mathcal{M}|^2$ contains the dynamics. The scatter plot in m_{ab}^2 versus m_{bc}^2 is the Dalitz plot. If $|\mathcal{M}|^2$ is constant, the kinematically allowed region of the plot will be populated uniformly with events. Any variation in the population over the Dalitz plot is due to dynamic rather than kinematic effects. It is straightforward to extend the formalism beyond three-body final states.

Formalism: The amplitude for the process $R \to rc, r \to ab$ where R is a D or B meson, r is an intermediate resonance, and a, b, c are pseudo-scalars, is given by

$$\mathcal{M}_r(J, L, l, m_{ab}, m_{bc}) = \sum_{\lambda} \langle ab | r_{\lambda} \rangle T_r(m_{ab}) \langle cr_{\lambda} | R_J \rangle \quad (2)$$

$$= Z(J, L, l, \vec{p}, \vec{q}) B_L^R(|\vec{p}|) B_L^r(|\vec{q}|) T_r(m_{ab}).$$

The sum is over the helicity states λ of r; J is the total angular momentum of R (for D and B decays, J=0); L is the orbital angular momentum between r and c; l is the orbital angular momentum between a and b; (the spin of r); \vec{p} and \vec{q} are the momenta of c and of a in the r rest frame; Z describes the angular distribution of the final-state particles; B_L^R and B_L^r are

D^{\pm}

the barrier factors for the production of rc and of ab; and T_r is the dynamical function describing the resonance r. T_r is a phenomenological object, with the resonances modeled often by a Breit-Wigner form, although some more recent analyses use a K-matrix formalism [5–7] with the P-vector approximation [8] to describe the $\pi\pi$ S-wave.

The nonresonant (NR) contribution to $D \to abc$ is parametrized as constant (S-wave), with no variation in magnitude or phase across the Dalitz plot. The available phase space is much greater for B decays than for D decays, and the nonresonant contribution to $B \to abc$ requires a more sophisticated parametrization. Experimentally, several parametrizations have been used [9,10]. Differences in the parametrizations of the NR contributions, and in Z, B_L , and T_r , as well as in the set of resonances r, complicate the comparison of results from different experiments.

Angular distribution Z: The tensor or Zemach formalism [11,12] and the helicity formalism [13,12] yield identical descriptions of the angular distributions for the decay process $R \to rc, r \to ab$ when a, b and c all have spin 0. The angular distributions for L=0,1, and 2 are given in Table 1. For a derivation of the expressions, see, e.g., Ref. 12. For final-state particles with non-zero spin (e.g., radiative decays), the helicity formalism is required.

Table 1: Angular distributions for L=0,1,2 for the decay process $R\to rc, r\to ab$ when a,b and c all have spin 0. Here θ is the angle between particles a and c in the rest frame of resonance $r,\sqrt{1+\zeta^2}=E_r/m_{ab}$ is a relativistic correction, where $E_r=(m_R^2+m_{ab}^2-m_c^2)/2m_R$ is the energy of resonance r in the rest frame of R.

| $\overline{J \to L + l}$ | Angular distribution |
|--------------------------|----------------------------------------------------------------|
| $0 \rightarrow 0 + 0$ | uniform |
| $0\!\to\!1\!+\!1$ | $(1+\zeta^2)\cos^2\theta$ |
| $0 \rightarrow 2+2$ | $\left(\zeta^2 + \frac{3}{2}\right)^2 (\cos^2 \theta - 1/3)^2$ |

Barrier Factor B_L : The maximum angular momentum L in a strong decay is limited by the linear momentum q—the relative momentum of the decay particles in the center of mass frame of the decaying resonance. Decay particles moving slowly with an impact parameter (meson radius) d of order 1 fm have difficulty generating sufficient angular momentum to conserve the spin of the resonance. The Blatt-Weisskopf [14,15] functions B_L , given in Table 2, weight the reaction amplitudes to account for this spin-dependent effect. These functions are normalized to give $B_L = 1$ for $z = (|q|d)^2 = 1$. Another common formulation, B'_L , also in Table 2, is normalized to give $B'_L = 1$ for $z = z_0 = (|q_0|d)^2$ where q_0 is the value of q when $m_{ab} = m_r$. An important difference between the B_L and the B'_L is that the former include explictly the centrifugal barrier,

while it is to be moved to the dynamical functions in the case of B'_L .

Table 2: Blatt-Weisskopf barrier factors weight the reaction amplitudes to account for spin-dependent effects (c.f. Sec. VIII.5 of Ref. 14). Two formulations with different normalization conditions (described in text) are shown. B_L is commonly used in Dalitz plot analyses; B_L' is commonly used with the helicity formalism.

| L | $B_L(q)$ | $B_L'(q,q_0)$ |
|---|-------------------------------------|--------------------------------------------|
| 0 | 1 | 1 |
| 1 | $\sqrt{\frac{2z}{1+z}}$ | $\sqrt{\frac{1+z_0}{1+z}}$ |
| 2 | $\sqrt{\frac{13z^2}{(z-3)^2 + 9z}}$ | $\sqrt{\frac{(z_0-3)^2+9z_0}{(z-3)^2+9z}}$ |
| | where $z = (q d)^2$ | and $z_0 = (q_0 d)^2$ |

Dynamical Function T_r : The dynamical function T_r is derived from the S-matrix formalism [5]. In general, the amplitude that a final state f couples to an initial state i is $S_{fi} = \langle f|S|i\rangle$, where the scattering operator S is unitary: $SS^{\dagger} = S^{\dagger}S = I$. The Lorentz-invariant transition operator \hat{T} is defined by separating the probability that f = i, yielding

$$S = I + 2iT = I + 2i\{\rho\}^{1/2} \hat{T}\{\rho\}^{1/2}, \qquad (3)$$

where I is the identity operator and ρ is the diagonal phasespace matrix. If channel i denotes the two-body state ab, then

$$\rho_{ii} = \rho_i = \frac{2q_i}{m_{ab}} \; \theta \left[m_{ab} - (m_a + m_b) \right] \,, \tag{4}$$

where m_{ab} is the invariant mass of the system;

$$q_i = \frac{1}{2m_{ab}} \sqrt{(m_{ab}^2 - (m_a + m_b)^2)(m_{ab}^2 - (m_a - m_b)^2)}$$
 (5)

is the momentum of a in the r rest frame, and $\theta[...]$ is the step function. In the single-channel case, unitarity allows one to express S through a single parameter, $S=e^{2i\delta}$, and

$$\hat{T} = \frac{1}{\rho} e^{i\delta} \sin \delta. \tag{6}$$

There are three common formulations of the dynamical function. The Breit-Wigner form—the first term in a Taylor expansion about a T-matrix pole—is the simplest. The K-matrix formalism [5] is more general (allowing more than one T-matrix pole and coupled channels while preserving unitarity). The Flatté distribution [16] is used to parametrize resonances near threshold, located at $s = (m_a + m_b)^2$, and is equivalent to a one-pole, two-channel K-matrix.

${\it Breit-Wigner\ Formulation:}$

The common formulation of a Breit-Wigner resonance decaying to spin-0 particles a and b is

$$T_r(m_{ab}) \propto \frac{1}{m_r^2 - m_{ab}^2 - im_r \Gamma_{ab}(m_{ab})}.$$
 (7)

A standard formulation for the "mass-dependent" width Γ_{ab} reads

$$\Gamma_{ab}(m_{ab}) = \sum_{i} \Gamma_i^r \left(\frac{q_i}{q_r}\right)^{2L_i + 1} \left(\frac{m_r}{m_{ab}}\right) B_{L_i}'(q_i, q_0)^2, \quad (8)$$

where q_i , L_i , Γ_i^r and $B'_{L_i}(q_i,q_0)$ are the momentum and angular momentum of the decay products, the partial width and Blatt-Weisskopf barrier factor (see Table 2) for the decay of resonance r into channel i, respectively. A Breit-Wigner parametrization best describes isolated, non-overlapping resonances far from the threshold of additional decay channels. For the $\rho(770)$ and $\rho(1450)$ a more complex parametrization suggested by Gounaris-Sakarai [17] is often used [18-22]. Unitarity is violated when the dynamical function is parametrized as the sum of two or more overlapping Breit-Wigners — see the discussion below Eq. (13). The proximity of a threshold to a resonance distorts the line shape from a simple Breit-Wigner. Here the Flatté formula provides a better description and is discussed below.

K-matrix Formulation

The T matrix can be written as

$$\hat{T} = (I - i\hat{K}\rho)^{-1}\hat{K},\tag{9}$$

where \hat{K} is the Lorentz-invariant K-matrix describing the scattering process and ρ is the phase-space factor defined below Eq. (3). Resonances appear as poles in the K-matrix:

$$\hat{K}_{ij} = \sum_{\alpha} \frac{\sqrt{m_{\alpha} \Gamma_{\alpha i}(m) m_{\alpha} \Gamma_{\alpha j}(m)}}{(m_{\alpha}^2 - m^2) \sqrt{\rho_i \rho_j}}.$$
 (10)

The K-matrix is real by construction, and so the associated T-matrix respects unitarity. However, in the given form it has the wrong analytic structure. To improve it, some authors use the analytic continuation for the momentum q_i , defined in Eq. (5), to below-threshold values, where for $m_a \neq m_b$ the phase space factor needs to be modified to avoid false singularities (see, e.g., Ref. 7, Sec. 2.1). For further improvements see below.

For a single pole in a single channel, $K = \rho \hat{K}$ is

$$K = \frac{m_0 \Gamma(m)}{m_0^2 - m^2} \tag{11}$$

and

$$T = K(1 - iK)^{-1} = \frac{m_0 \Gamma(m)}{m_0^2 - m^2 - i m_0 \Gamma(m)},$$
 (12)

which is the relativistic Breit-Wigner formula. For two poles in a single channel, K is

$$K = \frac{m_{\alpha}\Gamma_{\alpha}(m)}{m_{\alpha}^2 - m^2} + \frac{m_{\beta}\Gamma_{\beta}(m)}{m_{\beta}^2 - m^2}.$$
 (13)

If m_{α} and m_{β} are far apart relative to the widths, the T matrix is approximately the sum of two Breit-Wigners, $T(K_{\alpha} + K_{\beta}) \approx T(K_{\alpha}) + T(K_{\beta})$, each of the form of Eq. (12). This approximation is not valid for two nearby resonances, for it violates unitarity. For example, for $m = m_{\alpha}$ the full, unitary K-matrix expression gives Im(T) = 1, while the imaginary part of $T(K_{\alpha}) + T(K_{\beta})$ is $1 + (m_{\beta}\Gamma_{\beta})^2/[(m_{\beta}^2 - m_{\alpha}^2)^2 + (m_{\beta}\Gamma_{\beta})^2]$.

This formulation, which applies to S-channel production in two-body scattering, $ab \rightarrow cd$, can be generalized to describe the production of resonances in processes such as the decay of charm mesons. The key assumption here is that the two-body system described by the K-matrix does not interact with the rest of the final state [8]. The validity of this assumption varies with the production process and is appropriate for reactions such as $\pi^- p \to \pi^0 \pi^0 n$ in the several-GeV regime, and for semileptonic decays such as $D \to K\pi\ell\nu$. The assumption may be of limited validity for production processes such as $p\overline{p} \to \pi\pi\pi$, $D \to \pi\pi\pi$, $D \to K\pi\pi$ and $J/\psi \to \omega\pi\pi$. In the last two cases, additional three–body rescatterings were found to be relevant. In the J/ψ decays, they appeared where the two-body amplitudes were very small [23]; in the D decays, they were shown to lead to a significant difference between the $K\pi$ scattering phase and the phase extracted from the production process [24]. If threebody interactions are neglected, the two-body Lorentz-invariant amplitude, \hat{F} , is given by

$$\hat{F}_i = (I - i\hat{K}\rho)_{ij}^{-1}\hat{P}_j = (\hat{T}\hat{K}^{-1})_{ij}\hat{P}_j, \qquad (14)$$

where P is the production vector that parametrizes the resonance production in the open channels.

For the $\pi\pi$ S-wave, a common formulation of the K-matrix [7,20,21,25] is

$$K_{ij}(s) = \left[\sum_{\alpha} \left(\frac{g_i^{(\alpha)} g_j^{(\alpha)}}{m_{\alpha}^2 - s} \right) + f_{ij}^{sc} \frac{1 + s_0^{sc}}{s + s_0^{sc}} \right] \left[\frac{(s - s_A)}{(s + s_{A0})} \right]. \tag{15}$$

The factor $g_i^{(\alpha)}$ is the real coupling constant of the K-matrix pole m_α to meson channel i; the parameters f_{ij}^{sc} and s_0^{sc} describe a smooth part of the K-matrix elements; the second factor in square brackets, with $s_A \sim (0.1-0.5)m_\pi^2$ contains the Adler zero and at the same time suppresses a false kinematical singularity; e.g., in Ref. 25, $s_{A0}=0.15~{\rm GeV^2}$ and $s_A=0.5m_\pi^2$ were used. The number 1 has units ${\rm GeV^2}$.

The production vector, with i = 1 denoting $\pi\pi$, is

$$P_{j}(s) = \left[\sum_{\alpha} \left(\frac{\beta_{\alpha} g_{j}^{(\alpha)}}{m_{\alpha}^{2} - s} \right) + f_{1j}^{pr} \frac{1 + s_{0}^{pr}}{s + s_{0}^{pr}} \right], \tag{16}$$

where the free parameters of the Dalitz-plot fit are the complex production couplings β_{α} and the production-vector background parameters f_{1j}^{pr} and s_{0}^{pr} . All other parameters are fixed by scattering experiments. Ref. 6 describes the $\pi\pi$ scattering data with a 4-pole, 2-channel $(\pi\pi, K\bar{K})$ model, while Ref. 7 describes the scattering data with a 5-pole, 5-channel $(\pi\pi, K\bar{K}, \eta\eta, \eta'\eta')$ and $(\pi\pi, K\bar{K}, \eta\eta, \eta')$

D^{\pm}

CLEO [26] and the latter by FOCUS [21] and BABAR [20]. In both cases, only the $\pi\pi$ channel was analyzed. A more complete coupled-channel analysis would simultaneously fit all final states accessible by rescattering.

Flatté Formalism

The Flatté formulation is used when a second channel opens close to a resonance. This situation occurs in the $\pi\pi$ S-wave where the $f_0(980)$ is near the $K\overline{K}$ threshold, and in the $\pi\eta$ channel where the $a_0(980)$ also lies near the $K\overline{K}$ threshold. The T-matrix is parameterized as

$$\hat{T}(m_{ab})_{ij} = \frac{g_i g_j}{m_r^2 - m_{ab}^2 - i(\rho_1 g_1^2 + \rho_2 g_2^2)},$$
(17)

where $\rho_1 g_1^2 + \rho_2 g_2^2 = m_0 \Gamma_r$, when the phase spaces are evaluated at the resonance mass. For the $a_0(980)$ resonance, the relevant coupling constants are $g_1 = g_{\pi\eta}$ and $g_2 = g_{KK}$, and the phase space terms are $\rho_1 = \rho_{\pi\eta}$ and $\rho_2 = \rho_{KK}$, with ρ_i defined in Eq. (4). For the $f_0(980)$ the relevant coupling constants are $g_1 = g_{\pi\pi}$ and $g_2 = g_{KK}$, and the phase space terms are $\rho_1 = \rho_{\pi\pi}$ and $\rho_2 = \rho_{KK}$. The charged and neutral K channels are usually assumed to have the same coupling constant but different phase space factors, due to $m_{K^+} \neq m_{K^0}$; the result is

$$\rho_{KK} = \frac{1}{2} \left(\sqrt{1 - \left(\frac{2m_{K^{\pm}}}{m_{KK}}\right)^2} + \sqrt{1 - \left(\frac{2m_{K^0}}{m_{KK}}\right)^2} \right) . \tag{18}$$

The effect of using this expression compared to using the averaged kaon masses is confined in the region very near threshold and is significant only in between the two kaon thresholds. If the coupling of a resonance to the channel opening nearby is strong, the Flatté parametrization shows a scaling invariance and does not allow for an extraction of the parameters individually, but only of ratios [27].

Further improvements:

The K-matrix described above usually allows one to get a proper fit of physical amplitudes and it is easy to deal with. However, it also has an important deficit: it violates constraints from analyticity — e.g., ρ_{ii} has a pole at s=0, and for unequal masses develops an unphysical cut. An analytic continuation of the amplitudes into the complex plane is not controlled, and typically the parameters of broad resonances come out wrong (see, e.g., the minireview on scalar mesons). A method to improve the analytic properties was suggested in Refs. [25,28–30]. It basically amounts to replacing the phase-space factor $i\rho_i$ in Eqs. 9 and 14 with an analytic function that produces the identical imaginary part. In the simplest case of a channel with equal masses the expressions are

$$-\frac{\rho_i}{\pi}\log\left|\frac{1+\rho_i}{1-\rho_i}\right|,\ -\frac{2\rho_i}{\pi}\arctan\left(\frac{1}{\rho_i}\right),\ -\frac{\rho_i}{\pi}\log\left|\frac{1+\rho_i}{1-\rho_i}\right|+i\rho_i$$

for $m^2 < 0$, $0 < m^2 < (m_a + m_b)^2$, and $(m_a + m_b)^2 < m^2$, respectively. Here $\rho_i = \sqrt{|1 - (m_a + m_b)^2/m^2|}$ for all values of m^2 , extending the expression of Eq. (4) into the regime

below threshold. The more complicated expression for the case of different masses can be found, e.g., in Ref. 29.

Branching Ratios from Dalitz Plot Fits: A fit to the Dalitz plot distribution using either a Breit-Wigner or a K-matrix formalism factorizes into a resonant contribution to the amplitude \mathcal{M}_j and a complex coefficient, $a_j e^{i\delta_j}$, where a_j and δ_j are real. The definition of a rate of a single process, given a set of amplitudes a_j and phases δ_j , is the square of the relevant matrix element (see Eq. (1)). The "fit fraction" is usually defined as the integral over the Dalitz plot $(m_{ab} \text{ vs. } m_{bc})$ of a single amplitude squared divided by the integral over the Dalitz plot of the square of the coherent sum of all amplitudes, or

fit fraction_j =
$$\frac{\int \left| a_j e^{i\delta_j} \mathcal{M}_j \right|^2 dm_{ab}^2 dm_{bc}^2}{\int \left| \sum_k a_k e^{i\delta_k} \mathcal{M}_k \right|^2 dm_{ab}^2 dm_{bc}^2},$$
 (19)

where \mathcal{M}_j is defined in Eq. (2) and described in Ref. 31. In general, the sum of the fit fractions for all components will not be unity due to interference.

When the K-matrix of Eq. (9) is used to describe a wave (e.g., the $\pi\pi$ S-wave), then \mathcal{M}_j refers to the entire wave. In this case, it may not be straightforward to separate \mathcal{M}_j into a sum of individual resonances unless these are narrow and well separated.

Reconstruction Efficiency and Resolution: The efficiency for reconstructing an event as a function of position on the Dalitz plot is in general non-uniform. Typically, a Monte Carlo sample generated with a uniform distribution in phase space is used to determine the efficiency. The variation in efficiency across the Dalitz plot varies with experiment and decay mode. Most recent analyses utilize a full GEANT [32] detector simulation.

Finite detector resolution can usually be safely neglected, as most resonances are comparatively broad. Notable exceptions where detector resolution effects must be modeled are $\phi \to K^+K^-$, $\omega \to \pi^+\pi^-$, and $a_0 \to \eta\pi^0$. One approach is to convolve the resolution function in the Dalitz-plot variables m_{ab}^2 and m_{bc}^2 with the function that parametrizes the resonant amplitudes. In high-statistics data samples, resolution effects near the phase-space boundary typically contribute to a poor goodness of fit. The momenta of the final-state particles can be recalculated with a D or B mass constraint, which forces the kinematic boundaries of the Dalitz plot to be strictly respected. If the three-body mass is not constrained, then the efficiency (and the parametrization of background) may also depend on the reconstructed mass.

Backgrounds: The contribution of background to D and B samples varies by experiment and final state. The background naturally falls into six categories: (1) Purely combinatoric background containing no resonances. (2) Combinatoric background containing intermediate resonances, such as a real K^* or ρ , plus additional random particles. (3) Final states containing identical particles as in $D^0 \to K_S^0 \pi^0$ background to $D^0 \to \pi^+ \pi^- \pi^0$

and $B \to D\pi$ background to $B \to K\pi\pi$. (4) Mistagged decays such as a real $\overline{D}{}^0$ or $\overline{B}{}^0$ incorrectly identified as a D^0 or B^0 . (5) Particle misidentification of the decay products, such as $D^+ \to \pi^-\pi^+\pi^+$ or $D^+_s \to K^-K^+\pi^+$ reconstructed as $D^+ \to K^-\pi^+\pi^+$. (6) Background from decays of charged pions or kaons in flight.

The contribution from combinatoric background with intermediate resonances is distinct from the resonances in the signal because the former do not interfere with the latter since they are not from true resonances. The usual identification tag of the initial particle as a D^0 or a \overline{D}^0 is the charge of the distinctive slow pion in the decay sequence $D^{*+} \to D^0 \pi_s^+$ or $D^{*-} \to \overline{D}^0 \pi_s^-$. Another possibility is the identification or "tagging" of one of the D mesons from $\psi(3770) \to D^0 \overline{D}^0$, as is done for B mesons from $\Upsilon(4S)$. The mistagged background is subtle and may be mistakenly enumerated in the signal fraction determined by a D^0 mass fit. Mistagged decays contain true \overline{D}^0 's or \overline{B}^0 's and so the resonances in the mistagged sample exhibit interference on the Dalitz plot.

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REVIEW OF D-MESON DALITZ PLOT ANALYSES

Revised April 2010 by D. Asner (Pacific Northwest National Laboratory)

The formalism of Dalitz-plot analysis is reviewed in the preceding note. Recent studies of multi-body decays of charm mesons probe a variety of physics, including γ/ϕ_3 , $D^0-\overline{D}^0$ mixing, searches for CP violation, doubly Cabibbo-suppressed decays, and properties of S-wave $\pi\pi$, $K\pi$, and $K\overline{K}$ resonances. In the following, we discuss: (1) $D^0 \to K_S^0\pi^+\pi^-$; (2) doubly Cabibbo-suppressed decays; and (3) CP violation. The properties of the light meson resonances determined in D-meson Dalitz-plot analyses are reported in the light unflavored meson section of this Review.

 $D^0 \to K_S^0 \pi^+ \pi^-$: Several experiments have analyzed $D^0 \to K_S^0 \pi^+ \pi^-$ decay. A CLEO analysis [1] included ten resonances: $K_S^0 \rho^0$, $K_S^0 \omega$, $K_S^0 f_0(980)$, $K_S^0 f_2(1270)$, $K_S^0 f_0(1370)$, $K^*(892)^- \pi^+$, $K_0^*(1430)^- \pi^+$, $K_2^*(1430)^- \pi^+$, $K^*(1680)^- \pi^+$, and the doubly Cabibbo-suppressed (DCS) mode $K^*(892)^+ \pi^-$. The CLEO model does not provide a good description of higher-statistics BABAR and Belle data samples. An improved description is obtained in three ways: First, by adding more Breit-Wigner resonances. Second, following the methodology of FOCUS [2], by applying a K-matrix model [3–5] to the $\pi\pi$ S-wave [6,7]. Third, by adding a parameterization to the $K\pi$ S-wave motivated by the LASS experiment [8].

A BABAR analysis [7,9,10] added to the CLEO model the $K^*(1410)^-\pi^+$, $K_S^0\rho^0(1450)$, the DCS modes $K_0^*(1430)^+\pi^-$ and $K_2^*(1430)^+\pi^-$, and two Breit-Wigner $\pi\pi$ S-wave contributions. A Belle analysis [11–13] included all the components of BABAR and added two more DCS modes, $K^*(1410)^+\pi^-$ and

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 $K^*(1680)^+\pi^-$. Recently, BABAR has modeled the $\pi\pi$ S-wave using a K-matrix model for the $\pi\pi$ and $K\pi$ S-waves [14].

The primary motivation for the analysis of the decay $D^0 \to K_S^0 \pi^+ \pi^-$ is to study $D^0 - \overline{D}{}^0$ oscillations and the CKM angles. The quasi-two-body intermediate states include both CP-even and CP-odd eigenstates as well as doubly Cabibbo-suppressed channels. Time-dependent analyses of the Dalitz plot from CLEO [15] and Belle [6] simultaneously determined the strong transition amplitudes and phases, the mixing parameters x and y without phase or sign ambiguity, and the CP-violating parameter |q/p| and $\operatorname{Arg}(q/p)$. See the note on " $D^0 - \overline{D}^0$ Mixing" for a discussion.

The CKM angle γ/ϕ_3 [16] and the quark-mixing parameter $\cos 2\beta/\phi_1$ [17] can be determined using the decays $B^- \to D^{(*)}K^{(*)-}$ and $\overline B{}^0 \to Dh^0$, respectively, followed by the decay $D \to K_S^0\pi^+\pi^-$. The Belle and BABAR experiments measured γ/ϕ_3 (Belle [11–13] and BABAR [7,9,10,14,18] and $\cos 2\beta/\phi_1$ (Belle [19], BABAR [20]). In these analyses, a large systematic uncertainty in the relative phase between the D^0 and $\overline D{}^0$ amplitudes point by point across the Dalitz plot remains to be fully understood.

The quantum entangled production of $D^0\overline{D}^0$ pairs from $\psi(3770)$ enables a model-independent determination of the D^0/\overline{D}^0 relative phase. Studying CP-tagged Dalitz plots [21,22] provides sensivity to the cosine of the relative phase, while studying double-tagged Dalitz plots [22] probes both the cosine and sine of the D^0/\overline{D}^0 phase difference. CLEO analyzed [23] the $D^0 \to K_S^0\pi^+\pi^-$ and $D^0 \to K_L^0\pi^+\pi^-$ samples using the CP-even tag modes K^+K^- , $\pi^+\pi^-$, $K_L^0\pi^0$ (vs. $K_S^0\pi^+\pi^-$ only), the CP-odd tag modes $K_S^0\pi^0$, $K_S^0\eta$, and the double-tag modes $(K_S^0\pi^+\pi^-)^2$ and $(K_S^0\pi^+\pi^-)(K_L^0\pi^+\pi^-)$. These measurements can reduce the model uncertainty on γ/ϕ_3 to about 3°.

Doubly Cabibbo-Suppressed Decays: There are two classes of multibody doubly Cabibbo-suppressed (DCS) decays of D mesons. The first consists of those in which the DCS and corresponding Cabbibo-favored (CF) decays populate distinct Dalitz plots; the pairs $D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^-\pi^+\pi^0$, or $D^+ \to K^+\pi^+\pi^-$ and $D^+ \to K^-\pi^+\pi^+$, are examples. Our average of three measurements of $\Gamma(D^0 \to K^+\pi^-\pi^0)/\Gamma(D^0 \to K^-\pi^+\pi^0)$ is $(2.20 \pm 0.10) \times 10^{-3}$. Our average of four measurements of $\Gamma(D^+ \to K^+\pi^-\pi^+)/\Gamma(D^+ \to K^-\pi^+\pi^+)$ is $(5.77 \pm 0.22) \times 10^{-3}$; see the Particle Listings.

The second class consists of decays in which the DCS and CF modes populate the same Dalitz plot; for example, $D^0 \to K^{*-}\pi^+$ and $D^0 \to K^{*+}\pi^-$ both contribute to $D^0 \to K^0_S\pi^+\pi^-$. In this class, the potential for interference of DCS and CF amplitudes increases the sensitivity to the DCS amplitude and allows direct measurement of the relative strong phases between amplitudes. CLEO [1] and Belle [6] have measured the relative phase between $D^0 \to K^*(892)^+\pi^-$ and $D^0 \to K^*(892)^-\pi^+$ to be $(189 \pm 10 \pm 3^{+15}_{-5})^\circ$ and $(171.9 \pm 1.3)^\circ$ (statistical error only). These results are close to the 180° expected from Cabibbo factors and a small strong phase.

In addition, Belle [6] has results for both the relative phase (statistical errors only) and ratio R (central values only) of the DCS fit fraction relative to the CF fit fractions for $K^*(892)^+\pi^-, K_0^*(1430)^+\pi^-, K_2^*(1430)^+\pi^-, K^*(1410)^+\pi^-, \text{ and }$ $K^*(1680)^+\pi^-$. The systematic uncertainties on R must be evaluated. The values for R in units of $\tan^4 \theta_c$ are 2.94 ± 0.12 , 22.0 ± 1.6 , 34 ± 4 , 87 ± 13 , and 500 ± 500 . For $K^{+}\pi^{-}$, the corresponding value for R_D is $(1.28 \pm 0.02) \times \tan^4 \theta_c$. Similarly, BABAR [7] has reported central values for R for $K^*(892)^+\pi^-$, $K_0^*(1430)^+\pi^-$, and $K_2^*(1430)^+\pi^-$. The values for R in units of $\tan^4 \theta_c$ are 3.45 ± 0.31, 7.7 ± 3.0, and 1.7 ± 1.7, respectively. Recently, BABAR [14] has used a K-matrix formalism to describe the $\pi\pi$ S-wave in $K_S^0\pi^+\pi^-$. The reported values for R in units of $\tan^4 \theta_c$ are 2.78 ± 0.11, 0.5 ± 0.2, and 1.4 ± 0.5, respectively. The large differences in R among these final states could point to an interesting role for hadronic effects.

There are other ways, not involving DCS decays, in which D^0 and $\overline{D}{}^0$ singly Cabibbo-suppressed decays can populate the same Dalitz plot. Examples are D^0 and $\overline{D}{}^0$ decays to $K_S^0K^+\pi^-$, or to $K_S^0K^-\pi^+$. These final states can be used to study $D^0-\overline{D}{}^0$ mixing and the CKM angle γ/ϕ_3 .

CP Violation: In the limit of CP conservation, charge conjugate decays will have the same Dalitz-plot distribution. The $D^{*\pm}$ tag enables the discrimination between D^0 and $\overline{D}{}^0$. The integrated CP violation across the Dalitz plot is determined in two ways. The first uses

$$\mathcal{A}_{CP} = \int \left(\frac{|\mathcal{M}|^2 - |\overline{\mathcal{M}}|^2}{|\mathcal{M}|^2 + |\overline{\mathcal{M}}|^2} \right) dm_{ab}^2 dm_{bc}^2 / \int dm_{ab}^2 dm_{bc}^2 , \quad (1)$$

where \mathcal{M} and $\overline{\mathcal{M}}$ have the same normalization and represent the D^0 and \overline{D}^0 Dalitz-plot amplitudes for the three-body decay $D \to abc$, and m_{ab} (m_{bc}) is the invariant mass of ab (bc). The second uses the asymmetry in the efficiency-corrected D^0 and \overline{D}^0 yields,

$$\mathcal{A}_{CP} = \frac{N_{D^0} - N_{\overline{D}^0}}{N_{D^0} + N_{\overline{D}^0}}.$$
 (2)

These expressions are less sensitive to CP violation than are the individual resonant submodes [24–26]. Our Particle Listings give limits on CP violation for 12 D^+ , 52 D^0 , and 13 D_S^+ decay modes. No evidence of CP violation has been observed in D-meson decays.

The possibility of interference between CP-conserving and CP-violating amplitudes provides a more sensitive probe of CP violation. The constraints on the square of the CP-violating amplitudes obtained in the resonant submodes of $D^0 \to K_S^0 \pi^+ \pi^-$ range from 3.5×10^{-4} to 28.4×10^{-4} at 95% confidence level [24]. A similar analysis has been performed by CLEO [25] searching for CP violation in $D^+ \to K^+ K^- \pi^+$. The constraints on the square of the CP-violating amplitudes in the resonant submodes range from 4×10^{-4} to 51×10^{-4} at 95%. BABAR finds no evidence for CP-violating amplitudes in the resonant submodes of $D^0 \to K^+ K^- \pi^0$ and $D^0 \to \pi^+ \pi^- \pi^0$ [26].

E791 See AITALA 06

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 $\Gamma \big((K^-\pi^+)_{S-\text{wave}} \pi^+ \big) / \Gamma \big(K^-2\pi^+ \big)$ This is the "fit fraction" from the Dalitz-plot analysis. The $K^-\pi^+$ S-wave includes a broad scalar κ $(\overline{K}_0^*(800))$, the $\overline{K}_0^*(1430)^0$, and non-resonant background.

| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
|--------------------------------|-------------------------|-----------|---------|--------------------------|--|--|
| 0.801 ±0.012 OUR AVERAG | | | | | | |
| $0.8024 \pm 0.0138 \pm 0.0043$ | ³⁵ LINK | 09 | FOCS | MIPWA fit, 53k evts | | |
| 0.838 ± 0.038 | ³⁶ BONVICINI | 08A | CLEO | QMIPWA fit, 141k evts | | |
| $0.786 \pm 0.014 \pm 0.018$ | AITALA | 06 | E791 | Dalitz fit, 15.1k events | | |
| | ing data for averag | es, fits, | limits, | etc. • • • | | |
| $0.8323 \pm 0.0150 \pm 0.0008$ | ³⁷ LINK | 07в | FOCS | See LINK 09 | | |

 35 This LINK 09 model-independent partial-wave analysis of the $K^-\pi^+$ *S*-wave slices the

 $K^-\pi^+$ mass range into 39 bins. 36 The BONVICINI 08A QMIPWA (quasi-model-independent partial-wave analysis) of the $K^-\pi^+$ S-wave amplitude slices the $K^-\pi^+$ mass range into 26 bins but keeps the Breit-Wigner $\overline{K}_0^*(1430)^0$.

37 This LINK 07B fit uses a K matrix. The $K^-\pi^+$ S-wave fit fraction given above breaks down into $(207.3\pm25.5\pm12.4)\%$ isospin-1/2 and $(40.5\pm9.6\pm3.2)\%$ isospin-3/2 with large interference between the two. The isospin-1/2 component includes the κ (or $\overline{K}_0^*(800)^0$) and $\overline{K}_0^*(1430)^0$.

| $\Gamma(\overline{K}_0^*(800)^0\pi^+, \overline{K}_0^*(800) \to K^-\pi^+)/\Gamma(K^-2\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. | | | | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|------------|------------|--|--|--|
| VALUE | DO CUMENT ID | TECN | COMMENT | | | |
| • • • We do not use the follow | wing data for averages, fits | s, limits, | etc. • • • | | | |

| 0.111 ±0.012 OUR AVER | RAGE Error includ | es sca | le factor | of 3.7. |
|--------------------------------|----------------------|--------|-------------|--------------------------|
| $0.1236 \pm 0.0034 \pm 0.0034$ | LINK | 09 | FOCS | MIPWA fit, 53k evts |
| 0.0988 ± 0.0046 | BONVICINI | 08A | CLEO | QMIPWA fit, 141k evts |
| $0.119 \pm 0.002 \pm 0.020$ | AITALA | 06 | E791 | Dalitz fit, 15.1k events |
| • • • We do not use the fo | ollowing data for av | erages | , fits, lir | nits, etc. • • • |
| $0.1361 \pm 0.0041 \pm 0.0030$ | ³⁸ LINK | 07в | FOCS | See LINK 09 |
| $0.123 \pm 0.010 \pm 0.009$ | AITALA | 02 | E791 | See AITALA 06 |
| $0.137 \pm 0.006 \pm 0.009$ | FRABETTI | 94 G | E687 | Dalitz fit, 8800 evts |
| $0.170 \pm 0.009 \pm 0.034$ | ANJOS | 93 | E691 | γBe 90-260 GeV |
| $0.14 \pm 0.04 \pm 0.04$ | ALVAREZ | 91B | NA14 | Photoproduction |
| $0.13 \pm 0.01 \pm 0.07$ | ADLER | 87 | MRK3 | $e^{+}e^{-}$ 3.77 GeV |

³⁸ The statistical error on this LINK 07B value is corrected in LINK 09.

 $\Gamma(\overline{K}^*(1410)^0\pi^+$, $\overline{K}^{*0} \rightarrow K^-\pi^+)/\Gamma(K^-2\pi^+)$

 $0.478 \pm 0.121 \pm 0.053$

 $\Gamma_{45} / \Gamma_{40}$

| . ((=.==) , | ,,, (| | , | . 40/ |
|---------------------------------|-------------------------|--------|-------------|-----------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT |
| not seen | LINK | 09 | FOCS | MIPWA fit, 53k evts |
| not seen | BONVICINI | 08A | CLEO | QMIPWA fit, 141k evts |
| • • • We do not use th | e following data for av | erage: | s, fits, li | mits, etc. • • • |
| $4.8 \pm 2.1 \pm 1.7$ | LINK | 07в | FOCS | See LINK 09 |

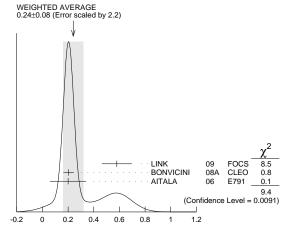
 $\Gamma(\overline{K}_0^*(1430)^0\pi^+, \overline{K}_0^*(1430)^0 \to K^-\pi^+)/\Gamma(K^-2\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis.

 Γ_{43}/Γ_{40}

This is the "fit fraction" from the Dalitz-plot analysis. DO CUMENT ID TECN COMMENT 0.1330 ± 0.0062 BONVICINI 08A CLEO QMIPWA fit, 141k evts \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$ $0.125 \pm 0.014 \pm 0.005$ AITALA 02 E791 See AITALA 06 $0.284 \ \pm 0.022 \ \pm 0.059$ FRABETTI 946 E687 Dalitz fit, 8800 evts $0.248\ \pm0.019\ \pm0.017$ ANJOS 93 E691

 $\Gamma(\overline{K}_2^*(1430)^0\pi^+, \overline{K}_2^*(1430)^0 \to K^-\pi^+)/\Gamma(K^-2\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. Γ_{46}/Γ_{40}

VALUE (units 10⁻²) DO CUMENT ID TECN COMMENT 0.24 ±0.08 OUR AVERAGE Error includes scale factor of 2.2. See the ideogram below. $0.58 \ \pm 0.10 \ \pm 0.06$ LINK 09 FOCS MIPWA fit, 53k evts BONVICIN CLEO QMIPWA fit, 141k evts $0.2\pm0.1\pm0.1$ AITALA E791 • • • We do not use the following data for averages, fits, limits, etc. • • 07B FOCS See LINK 09 $0.39 \pm 0.09 \pm 0.05$ LINK 02 E791 $\pm 0.1 \pm 0.2$ AITALA See AITALA 06



 $\Gamma \Big(\overline{K}_2^* (1430)^0 \, \pi^+ \, , \, \overline{K}_2^* (1430)^0 \to \, K^- \, \pi^+ \Big) / \Gamma \Big(K^- \, 2 \pi^+ \Big)$ (units 10^{-2})

 $\Gamma(\overline{K}^*(1680)^0\pi^+,\overline{K}^*(1680)^0\to K^-\pi^+)/\Gamma(K^-2\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis.

DO CUMENT ID TECN COMMENT 0.23 ±0.12 OUR AVERAGE $1.75 \pm 0.62 \pm 0.54$ MIPWA fit, 53k evts LINK 09 FOCS 0.196 ± 0.118 BONVICINI 08A CLEO QMIPWA fit, 141k evts $1.2 \pm 0.6 \pm 1.2$ AITALA 06 E791 Dalitz fit, 15.1k events \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $1.90 \pm 0.63 \pm 0.43$ LINK 07B FOCS See LINK 09 $2.5 \pm 0.7 \pm 0.3$ AITALA E791 See AITALA 06 ± 0.6 ± 0.7 FRABETTI E687 Dalitz fit, 8800 evts $3.0 \pm 0.4 \pm 1.3$ ANJOS 93 E691 γ Be 90-260 GeV

 D^{\pm}

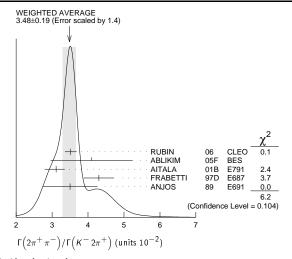
 $0.09 \ \pm 0.01 \ \pm 0.01$

ANJOS

90D E691 Photoproduction

| $\Gamma(K^-(2\pi^+)_{I=2})/\Gamma(K^-2\pi^+)$ VALUE | DOCUMENT ID | TECN | COMMENT | Γ_{48}/Γ_{40} | Γ(K *(892) ⁰ ρ ⁰ π | + <i>K</i> *(892) ⁰ | $\rightarrow K^-\pi^+)/\Gamma$ | |) COMMENT | Γ_{58}/Γ_{56} |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|------------------------------------------------|-----------------------------------------------|---------------------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------|-----------------------------------------------------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| 0.155 ± 0.028 | BONVICINI | 08A CLEO | | fit, 141k evts | 0.40±0.03±0.06 | | LINK | 03D FOCS | γ A, $\overline{E}_{\gamma} \approx$ | 180 GeV |
| $\Gamma(K^-2\pi^+ \text{ nonresonant})/\Gamma(K^-$ This is the "fit fraction" from | | analysis. Late | r analyses fi | Γ_{49}/Γ_{40} nd little need | $\Gamma(\overline{K}^*(892)^0 ho^0\pi)$ | + , K *(892) ⁰ | | (K ⁻ 2π ⁺) | COMMENT | Γ ₅₈ /Γ ₄₀ |
| for this decay mode. VALUE | DO CUMENT ID | TECN | COMMENT | | ● ● We do not u | | | | | |
| • • We do not use the following d | | | | | $0.016 \pm 0.007 \pm 0.00$ | 14 | FRABETTI | 97c E687 | γ Be, $\overline{E}_{\gamma} \approx$ | 200 GeV |
| $0.130 \pm 0.058 \pm 0.044$ $0.998 \pm 0.037 \pm 0.072$ $0.838 \pm 0.088 \pm 0.275$ | AITALA FRABETTI ANJOS | | See AITAL Dalitz fit, 3 γ Be 90–26 | 3800 evts | Γ(Γ *(892) ⁰ 2π+ <u>ναιυε</u> | | DO CUMENT ID | TECN | COMMENT | Γ ₆₀ /Γ ₄₀ |
| $0.79 \pm 0.07 \pm 0.15$ $\Gamma(K_S^0 \pi^+ \pi^0)/\Gamma_{\text{total}}$ | ADLER | 87 MRK3 | e ⁺ e ⁻ 3.7 | 7 GeV Г₅₀/Г | • • • We do not u $0.032 \pm 0.010 \pm 0.00$ | | data for average FRABETTI | | etc. $ullet$ $ullet$ $ullet$ $ullet$ \overline{E}_{γ} $pprox$ | 200 GeV |
| VALUE (units 10 ⁻²) EVTS | <u>DO CUMENT</u> | TID TE | CN COMM | · · · | $\Gamma(K^- ho^0 2\pi^+)/\Gamma$ | $(K^{-}3\pi^{+}\pi^{-}$ |) | | | Γ_{61}/Γ_{56} |
| .99±0.27 OUR FIT .99±0.09±0.25 . • • We do not use the following d | 39 DOBBS | | | at $\psi(3770)$ | $\frac{VALUE}{0.30 \pm 0.04 \pm 0.01}$ | | <u>DOCUMENT ID</u> LINK | 03D FOCS | γ A, $\overline{E}_{\gamma} \approx$ | 180 GeV |
| 7.2 \pm 0.2 \pm 0.4 5090 \pm 100 5.1 \pm 1.3 \pm 0.8 15 9 | 39 HE ADLER | 05 CL | EO See D RK3 e ⁺ e ⁻ | | Γ(Κ ⁻ ρ ⁰ 2π ⁺)/Γ | $(K^-2\pi^+)$ | DO CUMENT ID | TECN | <u>COMMENT</u> | Γ ₆₁ /Γ ₄₀ |
| ³⁹ DOBBS 07 and HE 05 use single- supersedes HE 05. | | | | | • • • We do not u $0.034 \pm 0.009 \pm 0.00$ | - | data for average | | etc. \bullet \bullet \bullet γ Be, $\overline{E}_{\gamma} \approx$ | 200 GeV |
| $\Gamma(K_S^0 ho^+)/\Gamma(K_S^0 \pi^+ \pi^0)$ This is the "fit fraction" from | | | | Γ_{51}/Γ_{50} | Γ (Κ* (892) ⁰ a ₁ (1 | | | (1000)+ | , | Γ ₅₉ /Γ ₄₀ |
| /ALUE 0.68±0.08±0.12 | ADLER | | e^+e^- 3.7 | 7 GeV | Unseen decay <u>VALUE</u> 0.099±0.008±0.01 | | K*(892) ⁰ and a ₁ <u>DOCUMENT ID</u> LINK | TECN | ncluded. $\frac{COMMENT}{\gamma \text{ A, } \overline{E}_{\gamma}} \approx$ | 180 GeV |
| $(\overline{K}^*(892)^0\pi^+,\overline{K}^*(892)^0\rightarrow F$ This is the "fit fraction" from | the Dalitz-plot a | ınalysis. | COMMENT | Γ_{52}/Γ_{50} | $\Gamma(K^-3\pi^+\pi^-)$ no | , . | ` , | ı | | Γ ₆₂ /Γ ₅₆ |
| <i>∨ALUE</i> 0.19±0.06±0.06 | ADLER | | $\frac{COMMENT}{e^+ e^- 3.7}$ | 7 GeV | <u>VALUE</u> 0.07 ±0.05±0.0 | <u>CL%_</u>)1 | <u>DO CUMENT ID</u> LINK | 03D FOCS | $\gamma A, \overline{E}_{\gamma} \approx$ | 180 GeV |
| $\Gamma(K_5^0\pi^+\pi^0 \text{ nonresonant})/\Gamma(K_5^0\pi^+\pi^0 \text{ nonresonant})$ | | ınalysis. | | Γ_{53}/Γ_{50} | • • • We do not u <0.026 | | | es, fits, limits, | . , | |
| VALUE | DO CUMENT ID | TECN | $\frac{COMMENT}{e^+e^-3.7}$ | 7 GeV | Γ(K+2K ⁰ _S)/Γ(F | $(-2\pi^{+})$ | | | , | Γ ₆₃ /Γ ₄₀ |
| $\Gamma(K^-2\pi^+\pi^0)/\Gamma_{total}$ See our 2008 Review (Physics I of this mode. There is nothing 91 \pm 12 events above backgro could not determine submode 1 WALUE (units 10^{-2}) EVTS | new since 1992, und, and COFFI | and the two p MAN 92B, wit uch accuracy. | papers, AN. th 142 ± 20 | JOS 92c, with such events, | 0.049±0.022 OUR 0.035±0.010±0.00 0.085±0.018 $\Gamma(K^+K^-K^0_5\pi^+$ | 39 ± 9 70 ± 12 $T)/\Gamma(K_S^0 2\pi^+)$ | ALBRECH $^{-}$ AMMAR π^{-}) | F 941 ARG 91 CLEC | $e^+e^-\approx 1$ $e^+e^-\approx 1$ | |
| 5.99±0.18 OUR FIT 5.98±0.08±0.16 | ⁴⁰ DOBBS | 07 CLE | EO e+e- | | VALUE (units 10 ⁻³) 7.7±1.5±0.9 | 35 ± 7 | | 01c FOCS γ | nucleus, \overline{E}_{γ} | ≈ 180 GeV |
| • • • We do not use the following d $6.0 \pm 0.2 \pm 0.2$ 4840 ± 100 | ⁴⁰ HE | | EO See DO | OBBS 07 | | | — Pionic mod | es —— | | |
| 5.8 ±1.2 ±1.2 142 | COFFMAN | | K3 e ⁺ e ⁻ | | $\Gamma(\pi^+\pi^0)/\Gamma(K^-)$ VALUE (units 10^{-2}) | • | DO CUMENT | ID TECN | COMMENT | Γ_{65}/Γ_{40} |
| $6.3 \begin{array}{c} +1.4 \\ -1.3 \end{array} \pm 1.2$ 175 40 DOBBS 07 and HE 05 use single-supersedes HE 05. | | AIT86E MR ged events in | | | 1.31 \pm 0.06 OUR AV 1.29 \pm 0.04 \pm 0.05 1.33 \pm 0.11 \pm 0.09 | /ERAGE 2649 ± 76 1229 ± 99 | DOCUMENT MENDEZ AUBERT,B | 10 CLEC | $\begin{array}{c} \underline{\text{COMMENT}} \\ \text{O} & e^+ e^- \text{ at :} \\ \text{R} & e^+ e^- \approx \end{array}$ | |
| $\Gamma(K_5^0 2\pi^+\pi^-)/\Gamma_{	ext{total}}$ See our 2008 Review (Physics I | Letters B667 1 (| 2008)) for me | easurements | Γ ₅₅ /Γ of submodes | 1.44±0.19±0.10 • • • We do not u | 171 ± 22 | ARMS | 04 CLEC es, fits, limits, | e^+e^-pprox etc. • • • | 10 GeV |
| of this mode. There is nothing 229 ± 17 events above background not determine submode to | ound, and COFF | MAN 92B, wi | th 209 \pm 20 | | $1.33 \pm 0.07 \pm 0.06$ $\Gamma(2\pi^{+}\pi^{-})/\Gamma(K)$ | 914 ± 46 | RUBIN | 06 CLEC | See MEND | EZ 10 Γ ₆₆ /Γ ₄₀ |
| VALUE (units 10^{-2}) EVTS | Tractions With M DOCUMENT I | , | | т | VALUE (units 10 ⁻²) | EVTS | DOCUMENT I | D TECN | COMMENT | '00/'40 |
| 3.12 ±0.11 OUR FIT 3.122±0.046±0.096 | ⁴¹ DOBBS | 07 CLEO | e+e-a | = t ab(3770) | 3.48±0.19 OUR A | /ERAGE Erro | rincludes scale fa | ctor of 1.4. S | ee the ideogra | |
| • • • We do not use the following d | ata for averages | | | (• •) | $3.52 \pm 0.11 \pm 0.12$ $4.1 \pm 1.1 \pm 0.3$ | 3303 ± 95 85 ± 22 | RUBIN ABLIKIM | 05 CLEO 05F BES | e^+e^- at ψ $e^+e^- \approx v$ | |
| 3.2 ± 0.1 ± 0.2 3210 \pm 85 | | | See DOE | | $3.11 \pm 0.18 {}^{+\; 0.16}_{-\; 0.26}$ | 1172 | AITALA | 01B E791 | π^- nucleus | , 500 GeV |
| $\begin{array}{ccc} 2.1 & +1.0 \\ -0.9 & & \\ \end{array}$ | 42 BARLAG | | $M \pi^- Cu 2$ | | $4.3 \pm 0.3 \pm 0.3$ | 236 | FRABETTI | 97D E687 | γ Be ≈ 20 | |
| 41 DOBBS 07 and HE 05 use single- supersedes HE 05. | - | ged events in | | t. DOBBS 07 | $3.5 \pm 0.7 \pm 0.3$ | 83 | ANJOS | 89 E691 | Photoprodu | CUOII |
| 42 BARLAG 92C computes the bran $\Gamma(K^-3\pi^+\pi^-)/\Gamma(K^-2\pi^+)$ | coming traction D) | , robological I | normanzatio | _{г.} Г ₅₆ /Г ₄₀ | | | | | | |
| VALUE EVTS | DO CUMENT ID | | COMMENT | . 50/ . 40 | | | | | | |
| 0.061 ± 0.005 OUR FIT Error includ | | | | | | | | | | |
| 0.062±0.008 OUR AVERAGE Erro 0.058±0.002±0.006 2923 0.077±0.008±0.010 239 • • • We do not use the following d | | 03D FOCS 97C E687 | γ Be, \overline{E}_{γ}' | | | | | | | |

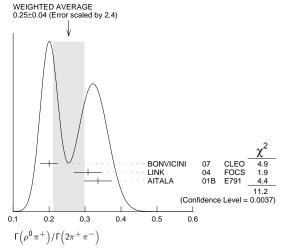
 D^{\pm}



 $\Gamma(\rho^0\pi^+)/\Gamma(2\pi^+\pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis.

 Γ_{67}/Γ_{66}

| | | | m the Dantz p | 0 | a., 50.0. | | | | | |
|--------|----------------|--------------|----------------|-------|-----------|---------------------------------|--|--|--|--|
| VALUE | | | DO CUMENT ID | | TECN | COMMENT | | | | |
| 0.25 | ±0.04 | OUR AVERAGE | Error includes | scale | factor of | 2.4. See the ideogram | | | | |
| below. | | | | | | _ | | | | |
| 0.200 | ±0.023 | ± 0.009 | BONVICINI | 07 | CLEO | Dalitz fit, \approx 2240 evts | | | | |
| 0.3082 | 2 ± 0.0314 | ± 0.0230 | LINK | 04 | FOCS | Dalitz fit, 1527 \pm 51 evts | | | | |
| 0.336 | ± 0.032 | ± 0.022 | AITALA | 01в | E791 | Dalitz fit, 1172 evts | | | | |



 VALUE
 DOCUMENT ID
 TECN
 COMMENT

 0.5600 ± 0.0324 ± 0.0214
 43 LINK
 04 FOCS
 Dalitz fit, 1527 ± 51 evts

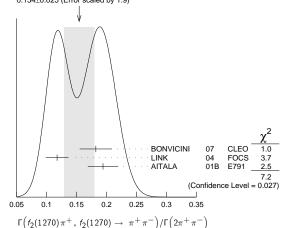
 43 LINK 04 borrows a K-matrix parametrization from ANISOVICH 03 of the full π - π S-wave isoscalar scattering amplitude to describe the $\pi^+\pi^-$ S-wave component of the $\pi^+\pi^+\pi^-$ state. The fit fraction given above is a sum over five f_0 mesons, the $f_0(980)$, $f_0(1300)$, $f_0(1200-1600)$, $f_0(1500)$, and $f_0(1750)$. See LINK 04 for details and discussion.

 $\Gamma(\sigma\pi^+,\sigma\to\pi^+\pi^-)/\Gamma(2\pi^+\pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis.

| This is the intindensi | the Daniel piot | | | |
|-----------------------------|---------------------|-----|------|---------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.422±0.027 OUR AVERAGE | | | | |
| $0.418 \pm 0.014 \pm 0.025$ | BONVICINI | 07 | CLEO | Dalitz fit, \approx 2240 evts |
| $0.463 \pm 0.090 \pm 0.021$ | AITALA | 01в | E791 | Dalitz fit, 1172 evts |
| | | | | |

 $\Gamma \left(f_0(980) \pi^+ , f_0(980) \to \pi^+ \pi^- \right) / \Gamma \left(2\pi^+ \pi^- \right)$ This is the "fit fraction" from the Dalitz-plot analysis.

 $\Gamma\left(f_0(1370)\,\pi^+\,,f_0(1370)\to\pi^+\,\pi^-\right)/\Gamma(2\pi^+\,\pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis. $\Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^+\,\pi^- \Gamma_{71}/\Gamma_{60}(1370)\,\pi^- \Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71}/\Gamma_{71$



| $\Gamma(ho(1450)^0\pi^+$, $ ho(1450)^0\pi^+$ | 1450)⁰ → fraction" fr | · π ⁺ π ⁻)/Γ(2π ⁺ :om the Dalitz-plot | π^-) | sis. | Γ ₇₃ /Γ ₆₆ | |
|------------------------------------------------|--------------------------------------------|----------------------------------------------------------------------------|-----------|-----------|----------------------------------|--|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.024 | 95 | BONVICINI | 07 | CLEO | Dalitz fit, \approx 2240 evts | |
| ● ● We do not use | the followi | ng data for average | s, fits | , limits, | etc. • • • | |
| $0.007 \pm 0.007 \pm 0.00$ | 3 | AITALA | 01в | E791 | Dalitz fit, 1172 evts | |

 VALUE (units 10^{-2})
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 12.4 ± 0.5 ± 0.6
 5701 ± 205
 RUBIN
 06
 CLEO
 e^+e^- at $\psi(3770)$

ARTUSO

08 CLEO See MENDEZ 10

 1033 ± 42

34.3 + 1.4 + 1.7

 D^{\pm}

| $\Gamma(\eta\pi^+)/\Gamma(K^-2\pi^+)$ Unseen decay modes of the η are included. | $\Gamma(K^+K^-\pi^+)/\Gamma(K^-2\pi^+)$ Γ_{90}/Γ_{40} |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | VALUE EVTS DOCUMENT ID TECN COMMENT 0.1045 ± 0.0022 OUR FIT Error includes scale factor of 1.3. |
| 3.87 \pm 0.09 \pm 0.19 2940 \pm 68 MENDEZ 10 CLEO e^+e^- at 3774 MeV | 0.1058±0.0029 OUR AVERAGE Error includes scale factor of 1.4. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 0.117 \pm 0.013 \pm 0.007 181 \pm 20 ABLIKIM 05F BES $e^+e^- \approx \psi(3770)$ |
| $3.81 \pm 0.26 \pm 0.21$ 377 ± 26 RUBIN 06 CLEO See ARTUSO 08 | $0.107 \pm 0.001 \pm 0.002$ 43k AUBERT 05s BABR $e^+e^- \approx \Upsilon(4S)$ |
| $\Gamma(\omega\pi^+)/\Gamma_{ m total}$ | 0.093 \pm 0.010 $^{+0.008}_{-0.006}$ JUN 00 SELX Σ^- nucleus, 600 GeV |
| Unseen decay modes of the ω are included. | $0.0976 \pm 0.0042 \pm 0.0046$ FRABETTI 95B E687 γ Be, $\overline{\mathcal{E}}_{\gamma} \approx 200$ GeV |
| VALUE CL% DOCUMENT ID TECN COMMENT | $\Gamma(\phi\pi^+,\phi\to K^+K^-)/\Gamma(K^+K^-\pi^+)$ Γ_{91}/Γ_{90} |
| <3.4 × 10⁻⁴ 90 RUBIN 06 CLEO e^+e^- at $\psi(3770)$ | This is the "fit fraction" from the Dalitz-plot analysis. |
| $\Gamma(3\pi^+2\pi^-)/\Gamma(K^-2\pi^+)$ Γ_{83}/Γ_{40} | VALUE (%) DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | 27.8±0.4 ^{+0.2} _{-0.5} RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| 1.77±0.17 OUR FIT | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 1.73\pm0.20\pm0.17 732 \pm 77 RUBIN 06 CLEO e^+e^- at $\psi(3770)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | $29.2 \pm 3.1 \pm 3.0$ FRABETTI 95B E687 Dalitz fit, 915 evts |
| 2.3 \pm 0.4 \pm 0.2 58 FRABETTI 97C E687 γ Be, $\overline{E}_{\gamma} \approx$ 200 GeV | $\Gamma(K^{+}\overline{K}^{*}(892)^{0}, \overline{K}^{*}(892)^{0} \to K^{-}\pi^{+})/\Gamma(K^{+}K^{-}\pi^{+})$ Γ_{92}/Γ_{90} |
| [(2-+2)/[(K-2-+a-) | This is the "fit fraction" from the Dalitz-plot analysis. VALUE (%) DOCUMENT ID TECN COMMENT |
| $\Gamma(3\pi^{+}2\pi^{-})/\Gamma(K^{-}3\pi^{+}\pi^{-})$ VALUE EVTS DOCUMENT ID TECN COMMENT | 25.7±0.5 ^{+0.4} RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| 0.289±0.019 OUR FIT | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.290 \pm 0.017 \pm 0.011 835 LINK 03D FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV | $30.1\pm2.0\pm2.5$ FRABETTI 95B E687 Dalitz fit, 915 evts |
| $\Gamma(\eta \pi^+ \pi^0)/\Gamma_{\text{total}}$ Γ_{85}/Γ | |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(K^+\overline{K}_0^*(1430)^0, \overline{K}_0^*(1430)^0 \to K^-\pi^+)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. |
| 13.8±3.1±1.6 149 ± 34 ARTUSO 08 CLEO e^+e^- at $\psi(3770)$ | I his is the "fit fraction" from the Dalitz-plot analysis. <u>VALUE (%) DOCUMENT ID TECN COMMENT</u> |
| | 18.8±1.2 ^{+3.3} RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| $\Gamma(\eta'(958)\pi^+)/\Gamma_{\text{total}}$ Unseen decay modes of the $\eta'(958)$ are included. | • • • We do not use the following data for averages, fits, limits, etc. • • |
| VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT | $37.0\pm3.5\pm1.8$ FRABETTI 95B E687 Dalitz fit, 915 evts |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| $44.2\pm2.5\pm2.9$ 352 ± 20 ARTUSO 08 CLEO See MENDEZ 10 | $\Gamma(K^+\overline{K}_2^*(1430)^0, \overline{K}_2^* \to K^-\pi^+)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. |
| $\Gamma(\eta'(958)\pi^+)/\Gamma(K^-2\pi^+)$ Γ_{87}/Γ_{40} | VALUE (%) DO CUMENT ID TECN COMMENT |
| Unseen decay modes of the $\eta'(958)$ are included. | 1.7±0.4 ^{+1.2} RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | = (4) [4 4(22) [4 2 |
| 5.12±0.17±0.25 1037 ± 35 MENDEZ 10 CLEO e^+e^- at 3774 MeV | $\Gamma(K^+\overline{K}_0^*(800), \overline{K}_0^* \to K^-\pi^+)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. |
| $\Gamma(\eta'(958)\pi^+\pi^0)/\Gamma_{\text{total}}$ Γ_{88}/Γ | VALUE (%) DO CUMENT ID TECN COMMENT |
| Unseen decay modes of the $\eta'(958)$ are included. | 7.0±0.8+3.5 RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | -2.0 |
| 15.7±4.3±2.5 33 ± 9 ARTUSO 08 CLEO e^+e^- at $\psi(3770)$ | $\Gamma(a_0(1450)^0\pi^+, a_0^0 \to K^+K^-)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis. |
| ——— Hadronic modes with a $K\overline{K}$ pair ——— | VALUE (%) DOCUMENT ID TECN COMMENT |
| $\Gamma(K^+K^0_S)/\Gamma_{total}$ Γ_{89}/Γ | 4.6±0.6 ^{+7.2} _{1.8} RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | 1.0 |
| • • • We do not use the following data for averages, fits, limits, etc. • • | $\Gamma(\phi(1680)\pi^+, \phi \to K^+K^-)/\Gamma(K^+K^-\pi^+)$ Γ_{97}/Γ_{90} |
| $3.14\pm0.09\pm0.08$ 1971 ± 51 BONVICINI 08 CLEO See MENDEZ 10 | This is the "fit fraction" from the Dalitz-plot analysis. VALUE (%) DOCUMENT ID TECN COMMENT |
| $\Gamma(K^+K_5^0)/\Gamma(K_5^0\pi^+)$ Γ_{89}/Γ_{38} | 0.51±0.11 +0.37 RUBIN 08 CLEO Dalitz fit, 19,458±163 evts |
| VALUE EVTS DOCUMENT ID TECN COMMENT | 1,12 |
| 0.193 ±0.007 OUR FIT Error includes scale factor of 3.2. | $\Gamma(K^*(892)^+ K_S^0) / \Gamma(K_S^0 \pi^+)$ $\Gamma_{105} / \Gamma_{38}$ |
| 0.1901 ± 0.0024 OUR AVERAGE $0.1899 \pm 0.0011 \pm 0.0022$ $101k \pm 561$ WON 09 BELL e^+e^- at $\Upsilon(4S)$ | Unseen decay modes of the $K^*(892)^+$ are included. |
| $0.1892 \pm 0.0155 \pm 0.0073$ 278 ± 21 ARMS 04 CLEO $e^+e^- \approx 10 \text{ GeV}$ | VALUEEVTSDOCUMENT IDTECNCOMMENT $1.1 \pm 0.3 \pm 0.4$ 67FRABETTI95E687 γ Be $\overline{E}_{\gamma} \approx 200$ GeV |
| $0.1996 \pm 0.0119 \pm 0.0096$ 949 LINK 02B FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV | ' 1 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(\phi\pi^+\pi^0)/\Gamma_{	ext{total}}$ Unseen decay modes of the ϕ are included. |
| 0.222 ± 0.037 ± 0.013 63 ± 10 ABLIKIM 05F BES $e^+e^-\approx \psi(3770)$ 0.222 ± 0.041 ± 0.019 70 BISHAI 97 CLEO See ARMS 04 | VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| 0.25 ± 0.04 ± 0.02 129 FRABETTI 95 E687 γ Be $\overline{E}_{\gamma} \approx 200$ GeV | 0.023\pm0.010 46 BARLAG 92c ACCM π^- Cu 230 GeV |
| 0.271 ± 0.065 ± 0.039 69 ANJOS 90c E691 γ Be | ⁴⁶ BARLAG 92c computes the branching fraction using topological normalization. |
| 0.317 \pm 0.086 \pm 0.048 31 BALTRUSAIT85E MRK3 e^+e^- 3.77 GeV 0.25 \pm 0.15 6 SCHINDLER 81 MRK2 e^+e^- 3.771 GeV | $\Gamma(\phi ho^+)/\Gamma(K^-2\pi^+)$ Γ_{103}/Γ_{40} |
| | Unseen decay modes of the ϕ are included. |
| $\Gamma(K^+ K_S^0)/\Gamma(K^- 2\pi^+) \qquad \qquad \Gamma_{89}/\Gamma_{40}$ | VALUE CL% DOCUMENT ID TECN COMMENT <0.16 90 DAOUDI 92 CLEO $e^+e^- \approx 10.5 \text{ GeV}$ |
| VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT 3.11 \pm 0.16 OUR FIT Error includes scale factor of 3.3. | |
| 3.35 \pm 0.06 \pm 0.07 5161 \pm 86 MENDEZ 10 CLEO e^+e^- at 3774 MeV | $\Gamma(K^+K^-\pi^+\pi^0\text{non-}\phi)/\Gamma_{	ext{total}}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE DOCUMENT ID TECN COMMENT |
| $3.02\pm0.18\pm0.15$ 949 ⁴⁴ LINK 02B FOCS γ nucleus, $\overline{\it E}_{\gamma} pprox$ 180 GeV | 0.015 ⁺ 0.007 47 BARLAG 92c ACCM π ⁻ Cu 230 GeV |
| 44 This LINK 02B result is redundant with a result in the previous datablock. | ⁴⁷ BARLAG 92c computes the branching fraction using topological normalization. |
| $\Gamma(K^+K^-\pi^+)/\Gamma_{\text{total}}$ Γ_{90}/Γ | $\Gamma(K^+K^-\pi^+\pi^0\operatorname{non-}\phi)/\Gamma(K^-2\pi^+)$ Γ_{104}/Γ_{40} |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | VALUE CL% DOCUMENT ID TECN COMMENT |
| 0.954±0.026 OUR FIT Error includes scale factor of 1.1. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.935 \pm 0.017 \pm 0.024 | < 0.25 90 ANJOS 89E E691 Photoproduction |
| • • • Vive do not use the following data for averages, fits, limits, etc. • • • $0.97 \pm 0.04 \pm 0.04$ 1250 ± 40 45 HE 05 CLEO See DOBBS 07 | $\Gamma(K^{+}K_{S}^{0}\pi^{+}\pi^{-})/\Gamma(K_{S}^{0}2\pi^{+}\pi^{-})$ Γ_{99}/Γ_{55} |
| 45 DOBBS 07 and HE 05 use single- and double-tagged events in an overall fit. DOBBS 07 | VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT |
| supersedes HE 05. | 5.62\pm0.39\pm0.40 469 \pm 32 LINK 01c FOCS γ nucleus, $\overline{E}_{\gamma} \approx $ 180 GeV |
| | |

| $(K_S^0 K^- 2\pi^+)/\Gamma(K_S^0 2\pi^+\pi^-)$ Γ_{100}/Γ_{55} | $\Gamma(2K^+K^-)/\Gamma(K^-2\pi^+)$ VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4LUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT. 68 \pm 0.41 \pm 0.32 670 \pm 35 LINK 01c FOCS γ nucleus, $\overline{E}_{\gamma} \approx 180$ GeV | $VALUE$ (units 10^{-4}) $EVTS$ $DOCUMENT ID$ $TECN$ $COMMENT$ 9.49±2.17±0.22 65 49 LINK 02 FOCS $γ$ nucleus, ≈ 180 GeV |
| , , , , | 49 LINK 021 finds little evidence for ϕK^+ or $f_0(980) K^+$ submodes. |
| $(K^+ K^- 2\pi^+ \pi^-)/\Gamma(K^- 3\pi^+ \pi^-)$ Γ_{101}/Γ_{56} | Ÿ |
| ALUE EVTS DOCUMENT ID TECN COMMENT | Rare or forbidden modes |
| .040 \pm 0.009 \pm 0.019 38 LINK 03D FOCS γ A, $\overline{E}_{\gamma} \approx$ 180 GeV | $\Gamma(\pi^+ e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_{116}/\Gamma_{\text{total}}$ |
| ——— Doubly Cabibbo-suppressed modes ——— | A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electrowea interactions. |
| $(K^+\pi^0)/\Gamma_{\text{total}}$ Γ_{106}/Γ | VALUE <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN COMMENT</u> |
| 4LUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | <1.1 × 10⁻⁶ 90 -3.9± LEES 11G BABR $e^+e^- \approx \Upsilon(4S)$ |
| .83±0.26 OUR FIT Error includes scale factor of 1.4. | 2.3 • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 52±0.47±0.26 189 ± 37 AUBERT,B 06F BABR $e^+e^- \approx \Upsilon(4S)$ | $<$ 5.9 \times 10 $^{-6}$ 90 50 RUBIN 10 CLEO e^+e^- at $\psi(3770)$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • 28±0.36±0.17 148±23 DYTMAN 06 CLEO See MENDEZ 10 | $<7.4 \times 10^{-6}$ 90 HE 05A CLEO See RUBIN 10 |
| | $<$ 5.2 \times 10 ⁻⁵ 90 AITALA 99G E791 π^- N 500 GeV $<$ 1.1 \times 10 ⁻⁴ 90 FRABETTI 97B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV |
| $(K^+\pi^0)/\Gamma(K^-2\pi^+)$ Γ_{106}/Γ_{40} | $<6.6 \times 10^{-5}$ 90 AITALA 96 E791 π^- N 500 GeV |
| ALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $<$ 2.5 $	imes$ 10 $^{-3}$ 90 WEIR 90B MRK2 e^+e^- 29 GeV |
| .01±0.29 OUR FIT | $< 2.6 \times 10^{-3}$ 90 39 HAAS 88 CLEO e^+e^- 10 GeV |
| | ⁵⁰ This RUBIN 10 limit is for the e^+e^- mass in the continuum away from the $\phi(1020)$ See the next data block. |
| $(K^+\eta)/\Gamma(\eta\pi^+)$ Γ_{107}/Γ_{84} | |
| ALUE (%) EVTS DOCUMENT ID TECN COMMENT .06 \pm 0.43 \pm 0.14 166 \pm 23 WON 11 BELL $e^+e^-\approx \Upsilon(45)$ | $\Gamma(\pi^+\phi,\phi\to e^+e^-)/\Gamma_{\text{total}}$ |
| | This is <i>not</i> a test for the $\Delta C=1$ weak neutral current, but leads to the $\pi^+e^+e^-$ final state. |
| $(K^+\eta)/\Gamma(K^-2\pi^+)$ Γ_{107}/Γ_{40} | <u>VALUEEVTS DOCUMENT ID TECN COMMENT</u> |
| Unseen decay modes of the η are included. 4LUE (units 10^{-2}) CL% DOCUMENT ID TECN COMMENT | $(1.7^{+1.4}_{-0.9}\pm 0.1) \times 10^{-6}$ 4 ⁵¹ RUBIN 10 CLEO e^+e^- at $\psi(3770)$ |
| • • We do not use the following data for averages, fits, limits, etc. • • | • • • We do not use the following data for averages, fits, limits, etc. • • |
| < 0.15 90 MENDEZ 10 CLEO e^+e^- at 3774 MeV | $(2.7^{+3.6}_{-1.8}\pm 0.2) \times 10^{-6}$ 2 HE 05A CLEO See RUBIN 10 |
| | 51 This RUBIN 10 result is consistent with the known $D^+	o\phi\pi^+$ and $\phi	o e^+e^-$ |
| $(K^+\eta'(958))/\Gamma(\eta'(958)\pi^+)$ Γ_{108}/Γ_{87} | fractions. |
| ALUE (%) EVTS DOCUMENT ID TECN COMMENT 77 \pm 0.39 \pm 0.10 180 \pm 19 WON 11 BELL $e^+e^-\approx \Upsilon(4S)$ | $\Gamma(\pi^+\mu^+\mu^-)/\Gamma_{	ext{total}}$ |
| | A test for the $\Delta C = 1$ weak neutral current. Allowed by higher-order electrowea |
| $(K^+ \eta'(958))/\Gamma(K^- 2\pi^+)$ Γ_{108}/Γ_{40} | interactions. |
| Unseen decay modes of the $\eta'(958)$ are included. | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| ALUE (units 10 ⁻²) CL% DO CUMENT ID TECN COMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • |
| • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • | $<$ 6.5 \times 10 ⁻⁶ 90 -0.2 \pm LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ |
| <0.20 90 MENDEZ 10 CLEO e ⁺ e ⁻ at 3774 MeV | 2.9 consists $\sim 8.8 \times 10^{-6}$ g0 LINK 03F FOCS γ nucleus, $\overline{E}_{\gamma} \approx$ 180 GeV |
| $(K^{+}\pi^{+}\pi^{-})/\Gamma(K^{-}2\pi^{+})$ Γ_{109}/Γ_{40} | $<1.5 \times 10^{-5}$ 90 AITALA 99G E791 π^- N 500 GeV |
| ALUE (units 10 ⁻³) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $<$ 8.9 \times 10 $^{-5}$ 90 FRABETTI 97B E687 γ Be, $\overline{E}_{\gamma} \approx$ 220 GeV |
| .77±0.22 OUR AVERAGE | $<$ 1.8 $	imes$ 10 $^{-5}$ 90 AITALA 96 E791 π^- N 500 GeV |
| 69 ± 0.18 ± 0.14 2638 ± 84 KO 09 BELL e^+e^- at $\Upsilon(4S)$ 5 ± 0.8 ± 0.4 189 ± 24 LINK 04F FOCS γ A, $\overline{E}_{\gamma} \approx$ 180 GeV | $< 2.2 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV $< 5.9 \times 10^{-3}$ 90 WEIR 90B MRK2 e^+e^- 29 GeV |
| $7 \pm 1.7 \pm 0.8$ 59 ± 13 AITALA 97C E791 π^- A, 500 GeV | $<5.9 \times 10^{-3}$ 90 WEIR 90B MRK2 e^+e^- 29 GeV $<2.9 \times 10^{-3}$ 90 36 HAAS 88 CLEO e^+e^- 10 GeV |
| .2 $\pm 2.3~\pm 1.7$ 21 FRABETTI 95E E687 γ Be, $\overline{E}_{\gamma} =$ 220 GeV | 52 This ABA ZOV 08D limit is for the $\mu^+\mu^-$ mass in the continuum away from the $\phi(1020)$ |
| (V+ -0) /F(V+ -+) | See the next data block. |
| $(K^+\rho^0)/\Gamma(K^+\pi^+\pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis. | $\Gamma(\pi^+\phi, \phi \to \mu^+\mu^-)/\Gamma_{\text{total}}$ |
| ALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | This is not a test for the $\Delta C=1$ weak neutral current, but leads to the $\pi^+\mu^+\mu^-$ |
| .39 ±0.09 OUR AVERAGE .3943±0.0787±0.0815 LINK 04F FOCS Dalitz fit, 189 evts | final state. VALUE DOCUMENT ID TECN COMMENT |
| $0.3943\pm0.0077\pm0.0013$ ETNN $0.4F$ FOCS Dalitz III, 169 eVis | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> (1.8±0.5±0.6) × 10 ^{−6} 53 ABAZOV 08D D0 pp, E _{Cm} = 1.96 TeV |
| | 53 This ABAZOV 08D value is consistent with the known $D^+ 	o \phi \pi^+$ and $\phi 	o \mu^+ \mu^-$ |
| $(K^+ f_0(980), f_0(980) \rightarrow \pi^+ \pi^-)/\Gamma(K^+ \pi^+ \pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis. | fractions. |
| ALUE DOCUMENT ID TECN COMMENT | $\Gamma(ho^+\mu^+\mu^-)/\Gamma_{	ext{total}}$ |
| .0892±0.0333±0.0412 LINK 04F FOCS Dalitz fit, 189 evts | $\lceil (\rho^+ \mu^+ \mu^-) / \Gamma_{\text{total}} \rceil$ A test for the $\Delta C = 1$ weak neutral current. Allowed by higher-order electrowea |
| $(K^*(892)^0\pi^+, K^*(892)^0 \to K^+\pi^-)/\Gamma(K^+\pi^+\pi^-)$ $\Gamma_{111}/\Gamma_{109}$ | interactions. |
| This is the "fit fraction" from the Dalitz-plot analysis. | <u>VALUE</u> <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN COMMENT</u> <5.6 × 10⁻⁴ 90 0 KODAMA 95 E653 π [−] emulsion 600 GeV |
| ALUE DOCUMENT ID TECN COMMENT 47 ±0.08 OUR AVERAGE | |
| 5220±0.0684±0.0638 LINK 04F FOCS Dalitz fit, 189 evts | $\Gamma(K^+e^+e^-)/\Gamma_{\text{total}}$ |
| $35 \pm 0.14 \pm 0.01$ AlTALA 97c E791 Dalitz fit, 59 evts | Both quarks would have to change flavor for this decay to occur. VALUECL%EVTSDOCUMENT IDTECNCOMMENT |
| $(K_2^*(1430)^0\pi^+, K_2^*(1430)^0 \to K^+\pi^-)/\Gamma(K^+\pi^+\pi^-)$ $\Gamma_{113}/\Gamma_{109}$ | <1.0 × 10⁻⁶ 90 -3.7 ± LEES 11G BABR $e^+e^- \approx \Upsilon(4S)$ |
| | 4.4 • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(K_2^*(1430)^0 \pi^+, K_2^*(1430)^0 \to K^+\pi^-)/\Gamma(K^+\pi^+\pi^-)$ This is the "fit fraction" from the Dalitz-plot analysis. | consists the following data for averages, fits, fillings, etc. $< 3.0 \times 10^{-6}$ 90 RUBIN 10 CLEO e^+e^- at $\psi(3770)$ |
| This is the "fit fraction" from the Dalitz-plot analysis. <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | \sim 10 CLEO 8 8 at $\psi(3770)$ |
| This is the "fit fraction" from the Dalitz-plot analysis. | $<$ 6.2 \times 10 ⁻⁶ 90 HE 05A CLEO See RUBIN 10 |
| This is the "fit fraction" from the Dalitz-plot analysis. ALUE DOCUMENT ID TECN COMMENT .0803±0.0372±0.0391 LINK 04F FOCS Dalitz fit, 189 evts | $<6.2 \times 10^{-6}$ 90 HE 05A CLEO See RUBIN 10 $<2.0 \times 10^{-4}$ 90 AITALA 99G E791 π^- N 500 GeV |
| This is the "fit fraction" from the Dalitz-plot analysis. <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | |

 $^{\mbox{\sc 48}}\mbox{\sc LINK}$ 04F, with three times as many events, finds no need for a nonresonant amplitude.

 D^{\pm}

| $\Gamma(K^+\mu^+\mu^-)/Both quark$ | T_{total} s would have to ch | ange flavor for this | Γ_{122}/Γ decay to occur. | | $\Gamma(ho^-2\mu^+)/\Gamma_t$ A test of I | otal epton-number c | onservation. | | Γ ₁₃₀ /Γ |
|--------------------------------------------------|------------------------------------------------|---------------------------------|----------------------------------------------------------------------------------------------|----------------|-----------------------------------------------|------------------------------------|------------------------------------------------------------|----------------------------|---------------------------------------------------------------------------------|
| <4.3 × 10 ⁻⁶ | <u>CL% EVTS</u> 90 −1.3± | DOCUMENT ID LEES | 11G BABR $e^+e^- \approx \Upsilon(4S)$ | - _I | <5.6 × 10 ⁻⁴ | <u>CL%</u> <u>EVTS</u> 90 0 | <u>DO CUMENT ID</u> KODA MA | 95 E653 | $\frac{COMMENT}{\pi^-}$ emulsion 600 GeV |
| | = | = | ts, limits, etc. • • • | | Γ(K-2e+)/Γ | | | | Γ ₁₃₁ /Γ |
| $< 9.2 \times 10^{-6}$ | 90 | LINK | 03F FOCS γ nucleus, $\overline{E}_{\gamma} \approx 180$ | | VALUE | epton-number c <u>CL%</u> | | IENT ID | TECN COMMENT |
| $<4.4 \times 10^{-5}$ $<9.7 \times 10^{-5}$ | 90 90 | AITALA FRABETTI | 99G E791 π^- N 500 GeV 97B E687 γ Be, $\overline{E}_{\gamma} \approx$ 220 | | <0.9 × 10 ⁻⁶ | | -2.8 ± LEES 2.4 | | BABR $e^+e^-pprox \ \varUpsilon(4S)$ |
| $< 3.2 \times 10^{-4}$ | 90 | KODAMA | $^{-}$ GeV 95 E653 π^{-} emulsion 600 | | • • • We do no $<3.5 \times 10^{-6}$ | t use the follow 90 | ing data for average: RUBIN | | etc. • • • CLEO e^+e^- at |
| $< 9.2 \times 10^{-3}$ | 90 | WEIR | 90в MRK2 <i>e</i> ⁺ <i>e</i> ⁻ 29 GeV | | $< 3.5 \times 10$ $< 4.5 \times 10^{-6}$ | 90 | HE | 05 A | $\psi(3770)$ |
| $\Gamma(\pi^+e^+\mu^-)/\Gamma$ | total pton-family-numbe | r conservation | Γ ₁₂₃ /Γ | - | $<1.2 \times 10^{-4}$ | 90 | FRABI | | _ |
| VALUE | CL% EVTS | DO CUMENT ID | TECN COMMENT | | $< 9.1 \times 10^{-3}$ | 90 | WEIR | 90в | |
| $< 2.9 \times 10^{-6}$ | 90 −2.9± 4.2 | LEES 11 | G BABR $e^+e^-pprox \varUpsilon(4S)$ | | $\Gamma(K^-2\mu^+)/\Gamma$ | | | | Γ ₁₃₂ /Γ |
| | = | = | ts, limits, etc. • • • — | | A test of I <u>VALUE</u> | epton-number c <i>CL%EVTS</i> | onservation. DOCUMENT ID | TECN | COMMENT |
| $<1.1 \times 10^{-4}$ $<3.3 \times 10^{-3}$ | 90 90 | | B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV B MRK2 e^+e^- 29 GeV | | <10 × 10 ⁻⁶ | 90 7.2 ± | LEES | | $e^+e^- \approx \Upsilon(45)$ |
| | | WEIR 90 | B MRNZ e e 29 GeV | | • • • We do no | 5.6 t use the follow | ing data for average | s, fits, limits, | etc. • • • |
| $\Gamma(\pi^+e^-\mu^+)/\Gamma$ | 「 <mark>tota</mark> l pton-family-numbe | v conservation | Γ ₁₂₄ /Γ | • | $<1.3\times10^{-5}$ | 90 | LINK | 03F FOCS | γ nucleus, $\overline{E}_{\gamma} \! pprox 180$ |
| VALUE VALUE | _ <u>CL% _ EVTS</u> | DO CUMENT ID | TECN COMMENT | | $< 1.2 \times 10^{-4}$ | 90 | FRABETTI | 97B E687 | γ Be, $\overline{E}_{\gamma} \approx $ 220 GeV |
| $< 3.6 \times 10^{-6}$ | 90 3.6 ± 4.5 | LEES 11 | G BABR $e^+e^-pprox \varUpsilon(4S)$ | | $< 3.2 \times 10^{-4}$ | 90 0 | KODAMA | 95 E653 | π^- emulsion 600 GeV |
| • • • We do not | | data for averages, fi | ts, limits, etc. • • • | | $< 4.3 \times 10^{-3}$ | 90 | WEIR | 90в MRK2 | e ⁺ e [−] 29 GeV |
| $<1.3 \times 10^{-4}$ | 90 | | B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV | | $\Gamma(K^-e^+\mu^+)$ | /Γ _{total} | | | Γ ₁₃₃ /Γ |
| $< 3.3 \times 10^{-3}$ | 90 | WEIR 90 | B MRK2 <i>e</i> ⁺ <i>e</i> ⁻ 29 GeV | | | epton-number c CL% EVTS | onservation. DOCUMENT ID | TECN | COMMENT |
| $\Gamma(K^+e^+\mu^-)/$ | F_{total} pton-family-numbe | r concernation | Γ ₁₂₅ /Γ | - | $<1.9\times10^{-6}$ | 90 -11.6 | | | $e^+e^- \approx \Upsilon(4S)$ |
| VALUE VALUE | _ <u>CL% _EVTS</u> | DO CUMENT ID | TECN COMMENT | _ | • • • We do no | 5.1 t use the follow | ing data for average | s, fits, limits, | etc. • • • |
| $<1.2 \times 10^{-6}$ | 90 −4.3± 1.9 | LEES 11 | G BABR $e^+e^-pprox \varUpsilon(4S)$ | | $< 1.3 \times 10^{-4}$ | 90 | FRABETTI | 97B E687 | γ Be, $\overline{\it E}_{\gamma} pprox $ 220 GeV |
| • • • We do not | | data for averages, fi | ts, limits, etc. • • • | | $<4.0 \times 10^{-3}$ | 90 | WEIR | 90в MRK2 | e ⁺ e ⁻ 29 GeV |
| $<1.3 \times 10^{-4}$ | 90 | | B E687 γ Be, $\overline{\it E}_{\gamma} \approx$ 220 GeV | | Γ(<i>K</i> *(892) [—] 2 | $\mu^+)/\Gamma_{total}$ | | | Γ ₁₃₄ /Γ |
| $< 3.4 \times 10^{-3}$ | 90 | WEIR 90 | B MRK2 <i>e</i> ⁺ <i>e</i> ⁻ 29 GeV | | | epton-number c | onservation . DO CUMENT ID | TECN | COMMENT |
| | pton-family-numbe | | Γ ₁₂₆ /Γ | - | <8.5 × 10 ⁻⁴ | <u>CL% EVTS</u> 90 0 | KODA MA | 95 E653 | π^- emulsion 600 GeV |
| <2.8 × 10 ⁻⁶ | 90 3.2 ± | DOCUMENT ID LEES 11 | $rac{TECN}{G}$ $rac{COMMENT}{G}$ BABR $e^+e^-\approx \Upsilon(4S)$ | - | D | ± <i>CP</i> -VIOLA | TING DECAY-RA | TE ASYM | METRIES |
| • • • We do not | 4.0 use the following | data for averages, fi | ts, limits, etc. • • • | | | | etween ${\it D}^+$ and ${\it D}^-$ | partial widths | for these modes |
| $< 1.2 \times 10^{-4}$ | 90 | FRABETTI 97 | B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV | | divided | by the sum of t | he widths. | | |
| $< 3.4 \times 10^{-3}$ | 90 | WEIR 90 | B MRK2 e ⁺ e ⁻ 29 GeV | | $A_{CP}(\mu^{\pm} u)$ in | $D^+ \rightarrow \mu^+ \nu$ | ν_{μ} , $D^- \rightarrow \mu^- \overline{\nu}_{\mu}$ | | |
| $\Gamma(\pi^-2e^+)/\Gamma_{to}$ | otai | | Γ ₁₂₇ /Γ | • | VALUE (%) | | DO CUMENT ID | <u>TECN</u> | COMMENT |
| | pton-number conse CL% EVTS | ervation. DOCUMENT ID | TECN COMMENT | | +8±8 | | EISENSTEIN | 08 CLEO | $e^{+}e^{-}$ at $\psi(3770)$ |
| <1.1 × 10 ⁻⁶ | 90 | RUBIN 10 | | 1 | $A_{CP}(K_S^0\pi^\pm)$ | in $D^{\pm} \rightarrow K_{3}^{0}$ | ⁰ π [±] | | |
| | use the following $\\$ | data for averages, fi | ts, limits, etc. • • • | _ | VALUE (%) - 0.54 ± 0.14 OL | EVTS IR AVERAGE | DO CUMENT ID | TECN C | OMMENT |
| $<1.9 \times 10^{-6}$ | 90 4.7 ± 4.7 | LEES 11 | G BABR $e^+e^-pprox~ \varUpsilon(4S)$ | | $-0.44 \pm 0.13 \pm 0$ | | DEL-AMO-SA1 | 1н BABR <i>e</i> | $+e^- \approx \Upsilon(4S)$ |
| $< 3.6 \times 10^{-6}$ | 90 | | A CLEO See RUBIN 10 | | $-0.71 \pm 0.19 \pm 0$ | | | | $+e^- \approx r(4S)$ |
| $<9.6 \times 10^{-5}$ $<1.1 \times 10^{-4}$ | 90 90 | | G E791 π^- N 500 GeV B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV | | $-1.3 \pm 0.7 \pm 0$ $-1.6 \pm 1.5 \pm 0$ | .3 30k .9 10.6k ⁵ | | | $^+e^-$ at 3774 MeV $_{\prime}$ nucleus, $\overline{E}_{\gamma}\approx$ 180 GeV |
| $<4.8 \times 10^{-3}$ | 90 | | B MRK2 e^+e^- 29 GeV | | | | ing data for average | | / |
| $\Gamma(\pi^- 2\mu^+)/\Gamma_{to}$ | | | Γ ₁₂₈ /Γ | - | $-0.6 \ \pm 1.0 \ \pm 0$ | | | | ee MENDEZ 10 |
| | xai pton-number conse | ervation. | ' 128/ ' | | | | - | $\rightarrow K^-\pi^+\tau$ | r^+), the ratio of numbers |
| VALUE 10-6 | CL% EVTS | DO CUMENT ID | TECN COMMENT | | | | larly for the D^- . | | |
| $<2.0 \times 10^{-6}$ | 90 -3.1 ± 1.3 | | G BABR $e^+e^-pprox \Upsilon(4S)$ | | • | | $K^-2\pi^+$, $D^- \rightarrow$ | | |
| | | | ts, limits, etc. • • • | | <u>VALUE (%)</u> −0.1±0.4±0.9 | | DOCUMENT ID | 10 CLEO | comment |
| <4.8 × 10 ⁻⁶ | 90 | LINK 03 | F FOCS γ nucleus, $\overline{E}_{\gamma} \! pprox 180$ GeV | | | 231k t use the follow | MENDEZ ing data for average: | | e^+e^- at 3774 MeV etc. \bullet \bullet |
| $<1.7 \times 10^{-5}$ $<8.7 \times 10^{-5}$ | 90 | | G E791 $\pi^ N$ 500 GeV | | $-0.5\pm0.4\pm0.9$ | | DOBBS | | See MENDEZ 10 |
| $< 8.7 \times 10^{-3}$ $< 2.2 \times 10^{-4}$ | 90 90 0 | FRABETTI 97 KODAMA 95 | B E687 γ Be, $\overline{E}_{\gamma} \approx 220$ GeV E653 π^- emulsion 600 GeV | | $A_{CD}(K^{\mp}\pi^{\pm}\pi$ | ±π ⁰) in D+ | $\rightarrow K^-\pi^+\pi^+\pi^0$ | . D ⁻ → K | $(+_{\pi}^{-}_{\pi}^{-}_{\pi}^{-}_{\pi}^{0})$ |
| $<6.8 \times 10^{-3}$ | 90 | | B MRK2 e^+e^- 29 GeV | | VALUE (%) | | DO CUMENT ID | TECN | COMMENT |
| $\Gamma(\pi^- e^+ \mu^+)/\Gamma$ | | | Γ ₁₂₉ /Γ | - | +1.0±0.9±0.9 | _ | DOBBS | | $e^{+}e^{-}$ at $\psi(3770)$ |
| A test of le | pton-number conse <u>CL% EVTS</u> | ervation. <u>DOCUMENT ID</u> | TECN COMMENT | | _ | D) in $D^+ \rightarrow$ | $K_{5}^{0}\pi^{+}\pi^{0}$, D^{-} | | |
| <2.0 × 10 ⁻⁶ | 90 -5.1 ± | | G BABR $e^+e^- \approx r(4S)$ | - I | VALUE (%) +0.3±0.9±0.3 | | DOBBS | | $\frac{COMMENT}{e^+e^-}$ at $\psi(3770)$ |
| • • • We do not | 4.7 use the following | data for averages, fi | ts, limits, etc. • • • | | | : | | | , , |
| $< 5.0 \times 10^{-5}$ | 90 | AITALA 99 | G E791 π ⁻ N <u>5</u> 00 GeV | | | $^+\pi^-$) in D^+ | $\rightarrow K_S^0 \pi^+ \pi^+ \pi^-$ | | |
| $<1.1 \times 10^{-4}$ | 90 | | B E687 γ Be, $\overline{E}_{\gamma} \approx 220 \text{ GeV}$ | | <u>VALUE (%)</u> +0.1±1.1±0.6 | | DOCUMENT ID | | e^+e^- at $\psi(3770)$ |
| $< 3.7 \times 10^{-3}$ | 90 | WEIR 90 | B MRK2 <i>e</i> ⁺ <i>e</i> ⁻ 29 GeV | | , | | 20003 | J. CLLO | - υ ω φιστιο) |

 $+8\pm6^{+4}_{-2}$

RUBIN

08 CLEO Fit-fraction asymmetry

| <u>VALUE (%)</u> +2.9±2.9±0.3 | $^{\pm} \rightarrow \pi^{\pm}\pi^{0}$ | DO CUMENT ID | TECN | COMMENT | $A_{CP}(K^{\pm}K_2^*(1430)^0)$ i | | | |
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| | 2.6k | | | e^+e^- at 3774 MeV | VALUE (%) +43±19 ⁺ .5 | <u>DOCUMENT IE</u> RUBIN | | Fit-fraction asymmetry |
| $\Lambda_{CP}(\pi^{\pm}\eta)$ in D^{\pm} | $\rightarrow \pi^{\pm}\eta$ | | | | | | | |
| 1.0 ±1.5 OUR AV | <u>EVTS</u> /FRAGE Err | DOCUMENT ID | ctor of 1.4 | COMMENT | $A_{CP}(K^{\pm}K_{0}^{*}(800))$ in | $D^+ \rightarrow K^+ K_0^* (800)$ | | ⁻ К ₀ (800) |
| $1.74 \pm 1.13 \pm 0.19$ | | WON 1 | 1 BELL | $e^+e^-\approx \gamma(4S)$ | $-12\pm11^{+14}_{-6}$ | RUBIN | | Fit-fraction asymmetry |
| 2.0 ±2.3 ±0.3 | 2.9k | | .0 CLEO | e ⁺ e [−] at 3774 MeV | - | D+ (*****)0 | | |
| λ _{CP} (π [±] η' (958)) i ^{ALUE (%)} | in $D^{\pm} \rightarrow \pi$ | r±η'(958) DOCUMENT ID | TECN | COMMENT | <i>Α_{CP}</i> (a ₀ (1450) ⁰ π [±]) in | $D^+ \rightarrow a_0(1450)^{\circ}\pi$ | | COMMENT |
| 0.5 ±1.2 OUR AV | 'ERAGE Err | | | $e^+ e^- \approx \Upsilon(45)$ | $-19\pm12^{+8}_{-11}$ | RUBIN | 08 CLEO | Fit-fraction asymmetry |
| 4.0 ±3.4 ±0.3 | 1.0k | MENDEZ 1 | | e ⁺ e ⁻ at 3774 MeV | $A_{CP}(\phi(1680)\pi^\pm)$ in L | | | |
| CP (K5 K±) in D | $0^{\pm} \rightarrow K_S^0 h$ | (± DOCUMENT ID | TECN CO | MMENT | <u>∨ALUE (%)</u> -9±22±14 | <u>DOCUMENT ID</u> RUBIN | | Fit-fraction asymmetry |
| 0.1 ±0.6 OUR AV | | | | | $A_{CP}(\pi^+\pi^-\pi^\pm)$ in D^\pm | $^{\pm} \rightarrow \pi^{+}\pi^{-}\pi^{\pm}$ | | |
| $0.16 \pm 0.58 \pm 0.25$ $0.2 \pm 1.5 \pm 0.9$ | 5.2k | | | $e^- \approx \Upsilon(4S)$ e^- at 3774 MeV | VALUE (%) DO | CUMENT ID TECH | COMMENT | |
| 7.1 ±6.1 ±1.2 | | - | | nucleus, $\overline{E}_{\gamma} pprox 180 \; { m GeV}$ | | | | <i>CP</i> < +0.052 (90% CL |
| • • We do not use | | | | | ⁶³ AITALA 97B measure numbers of events obs | $N(D^+ 	o \pi^+ \pi^- \pi^+)$ served, and similarly for t | | $K^-\pi^+\pi^+$), the ratio |
| 6.9 ±6.0 ±1.5 ⁵⁵ LINK 02B measur | | | | nucleus, $\overline{E}_{\gamma}pprox$ 180 GeV $$ the ratio of numbers of | $A_{CP}(K^0_SK^\pm\pi^+\pi^-)$ is | - | | |
| events observed, a | and similarly fo | or the D^- . | J | | VALUE (%) | EVTS DOCUME | NT ID TE | CN COMMENT |
| | | | → K ⁻ π ⁺ π | $^{+}$), the ratio of numbers | -4.2±6.4±2.2 | 523 ± 32 LINK | 05E FC | OCS γ A, $\overline{E}_{\gamma} \! pprox$ 180 Ge |
| of events observed $CP(K^+K^-\pi^\pm)$ i | | | | | $A_{CP}(K^{\pm}\pi^{0})$ in D^{\pm} – | | T 10 TE | COMMENT. |
| | | | rvin the D∃ | $\rightarrow K^+K^-\pi^{\pm}$ Dalitz | <u>VALUE (%)</u> −3.5±10.7±0.9 34 | EVTS DOCUMEN 43 ± 37 MENDEZ | | EO e ⁺ e ⁻ at 3774 Me |
| | k decays and | | | s. No evidence for <i>CP</i> | | | | |
| LUE (%) | EVTS | DO CUMENT ID | TECN | COMMENT | D+-D- T- | VIOLATING DECAY | RATE ASYI | MMETRIES |
| 0.3 ±0.6 OUR AV | 'ERAGE | DUDIN | 00 (15) | + = 2774.14.14 | $A_{Tviol}(K_S^0K^{\pm}\pi^+\pi^-)$ | in $D^{\pm} \rightarrow K_s^0 K^{\pm} \pi$ | + _π - | |
| $0.03 \pm 0.84 \pm 0.29$ $0.1 \pm 1.5 \pm 0.8$ | | RUBIN DOBBS | | 0 e ⁺ e ⁻ , 3774 MeV 0 e ⁺ e ⁻ at ψ(3770) | | $	imes ec{p}_{\pi^-}$) is a <i>T</i> -odd corre | | $^+$, π^+ , and π^- mome |
| 1.4 ±1.0 ±0.8 | 43k±321 | ⁵⁷ AUBERT | | $R e^+e^- \approx \Upsilon(4S)$ | | $\equiv \vec{p}_{K^-} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\pi})$ | | |
| $0.6 \pm 1.1 \pm 0.5$ | 14k | ⁵⁸ LINK | 00B FOC | | | $\Sigma_T > 0$) - $\Gamma(C_T < 0)$] | | |
| 1.4 ± 2.9 | | ⁵⁸ AITALA | 97B E791 | | | ng phases, test for T vic | | |
| 3.1 ±6.8 | | ⁵⁸ FRABETTI | 94ı E687 | + 0.034 (90% CL) - 0.14 < <i>A_{CP}</i> < | widths). With \overline{A}_T | $\equiv [\Gamma(-\overline{C}_{T_{\bullet}} > 0) - \Gamma(-\overline{C}_{T_{\bullet}})]$ | $-\overline{c}_T <$ 0)] $/$ [| $\Gamma(-\overline{c}_T > 0) + \Gamma(-\overline{c}_T)$ |
| E7 | | | | + 0.081 (90% CL) | 0)], the asymmetry a strong phases. | $A_{Tviol} \equiv \frac{1}{2}(A_T - \overline{A}_T)$ | r) tests for I v | riolation even with nonze |
| | | | | $(K^+ K^- \pi^+)$, the ratio of | VALUE (units 10^{-3}) | EVTS DOCUME | NT ID TE | CN COMMENT |
| the numbers of ev 58 FRABETTI 941. A | ents observed ITALA 98c. a | , and similarly for t nd LINK 00B measu | he D^- . Ire $N(D^+ \rightarrow$ | $K^-K^+\pi^+)/N(D^+ \rightarrow$ | | .2±0.4k LEES | | ABR $e^+e^- \approx \Upsilon(4S)$ |
| | | ers of events observ | | | • • • We do not use the $23 \pm 62 \pm 22$ 5 | following data for averag 23 ± 32 LINK | | etc. $ullet$ $ullet$ $ullet$ γ A, $\overline{E}_{\gamma} \!pprox$ 180 Ge |
| CP (K ± K*0) in L | | | | | | | | . , |
| | EVTS ERAGE | DOCUMENT ID | | COMMENT | | $(\overline{K}^0/\pi^0/\eta/\overline{K}^{*0})\ell^+$ | ν _ℓ FORM F | ACTORS |
| 0.1 ± 1.3 OUR AV | | RUBIN | 08 CLEO | Fit-fraction asymmetry | $f_+(0) V_{cs} $ in $D^+ \rightarrow$ | $\overline{K}^0 \ell^+ \nu_e$ | | |
| 0.1 ± 1.3 OUR AV 0.4 ± 2.0 ± 0.6 | 11k±122 | ⁵⁹ AUBERT | | e ' e ≈ 1 (45) | | | | |
| 0.1± 1.3 OUR AV 0.4± 2.0±0.6 0.9± 1.7±0.7 | 11k±122 | ⁵⁹ AUBERT ⁶⁰ AITALA | 05s BABR | e · e ≈ 7 (45) -0.092 <a<sub>CP < +0.072 (90% CL)</a<sub> | 0.707±0.010±0.009 | DOCUMENT ID BESSON | | $\frac{\textit{COMMENT}}{K^0e^+ u_e}$ 3-parameter |
| 0.1± 1.3 OUR AV 0.4± 2.0±0.6 0.9± 1.7±0.7 1.0± 5.0 12 ±13 | | ⁵⁹ AUBERT ⁶⁰ AITALA ⁶⁰ FRABETTI | 05s BABR 97B E791 94I E687 | $\begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \end{array}$ | $0.707 \pm 0.010 \pm 0.009$ $r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow$ | BESSON $K^0\ell^+ u_\ell$ | 09 CLEO | |
| 0.1± 1.3 OUR AV 0.4± 2.0±0.6 0.9± 1.7±0.7 1.0± 5.0 12 ±13 | asures N(D^+ | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E^-)$ | 05s BABR 97B E791 94I E687 $\mathcal{O}_s^+ \rightarrow \mathcal{K}^+ \mathcal{I}$ | -0.092 <a<sub>CP < +0.072 (90% CL) -0.33 <a<sub>CP <</a<sub></a<sub> | $0.707 \pm 0.010 \pm 0.009$ $r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \text{VALUE}$ | $\frac{DOCUMENT\ ID}{BESSON}$ | 09 CLEO | $\overline{K}^0 e^+ \nu_e$ 3-parameter |
| 0.1± 1.3 OUR AV 0.4± 2.0±0.6 0.9± 1.7±0.7 1.0± 5.0 12 ±13 PAUBERT 05s meanumbers of events numbers of events | asures <i>N</i> (<i>D</i> ⁺ s observed, an and AITALA | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow \kappa^+ \overline{\kappa}^{*0})/N(E$ d similarly for the E 97 B measure $N(E)$ | 05s BABR 97B E791 94I E687 D ⁺ _s → K ⁺ _I D ⁻ _s D ⁺ → K | $\begin{array}{c} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ < -\pi^{+}), \text{ the ratio of the} \\ +\overline{K}^{*}(892)^{0}/N(D^{+} \rightarrow \\ \end{array}$ | $\begin{array}{c} \frac{MLUE}{0.707 \pm 0.010 \pm 0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-1.66 \pm 0.44 \pm 0.10} \end{array}$ | BESSON TO E+ VE DOCUMENT ID BESSON | 09 CLEO | $\overline{K}^0e^+ u_e$ 3-parameter |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 19 AUBERT 05s meanumbers of events 10 FRABETT1 941 13 16 10 FRABETT1 941 13 16 10 FRABETT1, 1941 13 10 10 FRABETT1, 1941 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 $^{$ | asures <i>N(D</i> ⁺ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E$ d similarly for the E | 05s BABR 97B E791 94I E687 D ⁺ _s → K ⁺ _I D ⁻ _s D ⁺ → K | $\begin{array}{c} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ < -\pi^{+}), \text{ the ratio of the} \\ +\overline{K}^{*}(892)^{0}/N(D^{+} \rightarrow \\ \end{array}$ | $\begin{array}{l} \frac{\text{MALUE}}{0.707 \pm 0.010 \pm 0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{-1.66 \pm 0.44 \pm 0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{\text{MALUE}} \end{array}$ | $\frac{DOCUMENT\ ID}{\text{BESSON}}$ $\overline{K}^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{\text{BESSON}}$ $\overline{K}^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{DOCUMENT\ ID}$ | 09 CLEO 1ECN 1ECN | $\overline{K}^0e^+\nu_e$ 3-parameter ${COMMENT\over \overline{K}^0e^+\nu_e}$ 3-parameter ${COMMENT\over COMMENT}$ |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 9 AUBERT 05s meanumbers of events (0.64FRABETT) 941 (3.64FRABETT) 10 (3.64FRABETT) 10 (3.64FRABETT) 11 | asures <i>N(D</i> ⁺ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E$ d similarly for the E 97B measure $N(E)$ ers of events observed. | 05s BABR 97B E791 94I E687 $D_s^+ \rightarrow K^+ I$ $D_s^- \rightarrow K$ $D_s^+ \rightarrow K$ ved, and sim | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ \hline (-\pi^+), \text{ the ratio of the} \\ \hline +\overline{K}^*(892)^0)/N(D^+ \rightarrow \\ \text{larly for the } D^ \end{array} $ | $\begin{array}{l} \frac{\text{MALUE}}{0.707 \pm 0.010 \pm 0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{-1.66 \pm 0.44 \pm 0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{-14 \pm 11 \pm 1} \end{array}$ | ESSON DOCUMENT ID BESSON ROPTOR DOCUMENT ID BESSON DOCUMENT ID BESSON | 09 CLEO 1ECN 1ECN | $\overline{K}^0e^+\nu_e$ 3-parameter ${COMMENT\over \overline{K}^0e^+\nu_e}$ 3-parameter ${COMMENT\over COMMENT}$ |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 19 AUBERT 05s meanumbers of events of ERABETTI 941 \pm $K^-\pi^+\pi^+$), the Park 1.1 UE (%) 0.42 \pm 0.28 OUR AV | asures $N(D^+)$ s observed, an and AITALA ratio of numb $ \rightarrow \phi \pi^{\pm} $ $ EVTS / ERAGE $ | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(C$ d similarly for the L 97B measure $N(L)$ ers of events observed $\underline{DOCUMENT\ ID}$ | 05s BABR 97B E791 94I E687 05 → K+ I 0 − . 0 + → K ved, and sim | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \\ \text{larly for the } D^ \\ \\ \underline{COMMENT} \\ \end{array} $ | $\begin{array}{l} \frac{MLUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-1.66\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-14\pm11\pm1} \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \end{array}$ | ESSON DOCUMENT ID BESSON ROPTOR DOCUMENT ID BESSON DOCUMENT ID BESSON | 09 CLEO TECN 09 CLEO TECN 09 CLEO | $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 13 AUBERT 05s meanumbers of events of EXECUTE 1941 of K $-\pi$ $+\pi$ $+$), the of K $-\pi$ $+\pi$ $+$ 0.5 $+\pi$ $+\pi$ $+\pi$ $+\pi$ $+\pi$ $+\pi$ $+\pi$ $+\pi$ | assures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E$ d similarly for the E 97B measure $N(E)$ ers of events observed $\underline{DOCUMENT\ ID}$ STARIC | 05s BABR 97B E791 94I E687 95 → K+ I D- D+ → K ved, and sim TECN 12 BELL | $\begin{array}{c} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \\ \text{larly for the } D^ \\ \\ \hline \\ & \\ \underline{COMMENT} \\ \\ & \\ \hline \\ & \\ & \\ \hline \\ & \\ & \\ & \\ & \\$ | $\begin{array}{l} \frac{\text{MALUE}}{0.707 \pm 0.010 \pm 0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{-1.66 \pm 0.44 \pm 0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{\text{MALUE}}{-14 \pm 11 \pm 1} \end{array}$ | $\frac{DOCUMENT\ ID}{BESSON}$ $\overline{K}^{0}\ell^{+}\nu_{\ell}$ $\frac{DOCUMENT\ ID}{BESSON}$ $\overline{K}^{0}\ell^{+}\nu_{\ell}$ $\frac{DOCUMENT\ ID}{BESSON}$ $\pi^{0}\ell^{+}\nu_{\ell}$ | 09 CLEO 7ECN 09 CLEO 1ECN 1TECN TECN | $\overline{K}^0e^+ u_e$ 3-parameter t ${comment} \over \overline{K}^0e^+ u_e$ 3-parameter t |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 13 AUBERT 05s meanumbers of events of events of ERABETTI 941 \pm $K^-\pi^+\pi^+$), the example (%) 0.42 \pm 0.28 OUR AV 0.51 \pm 0.28 \pm 0.05 1.8 \pm 1.6 \pm 0.2 - 0.4 | asures $N(D^+)$ s observed, an and AITALA ratio of numb $ \rightarrow \phi \pi^{\pm} $ $ EVTS / ERAGE $ | 59 AUBERT 60 AITALA 60 FRABETTI → K+ K*0)/N(E d similarly for the L 97B measure N(L ers of events observed DOCUMENT ID STARIC RUBIN 61 AUBERT | 05s BABR 97B E791 94I E687 $D_s^+ \rightarrow K^+ I$ $D_s^- \rightarrow K$ $D_s^+ \rightarrow $ | $-0.092 < A_{CP} < +0.072 (90\% \text{ CL})$ $-0.33 < A_{CP} < +0.094 (90\% \text{ CL})$ $(-\pi^+), \text{ the ratio of the}$ $+\overline{K}^*(892)^0)/N(D^+ \rightarrow \text{larly for the } D^$ $\underline{COMMENT}$ Mainly at $\Upsilon(4S)$ Fit-fraction asymmetry $e^+e^- \approx \Upsilon(4S)$ | $\begin{array}{l} \frac{NALUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{-1.66\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{-14\pm11\pm1} \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \\ \frac{NALUE}{NALUE} \end{array}$ | $\frac{DOCUMENT \ ID}{BESSON}$ $\overline{K}^0 \ell^+ \nu_{\ell}$ $\frac{DOCUMENT \ ID}{BESSON}$ $\overline{K}^0 \ell^+ \nu_{\ell}$ $\frac{DOCUMENT \ ID}{BESSON}$ $\pi^0 \ell^+ \nu_{\ell}$ $\frac{DOCUMENT \ ID}{BESSON}$ | 09 CLEO 7ECN 09 CLEO 1ECN 1TECN TECN | $\overline{K}^0e^+\nu_e$ 3-parameter 1 $\frac{COMMENT}{\overline{K}^0e^+\nu_e}$ 3-parameter 1 $\frac{COMMENT}{\overline{K}^0e^+\nu_e}$ 3-parameter 1 |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 9 AUBERT 05s mer numbers of events 0 FRABETTI 941 ϵ κ | asures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow \kappa^+ \overline{\kappa}^{*0})/N(E$ d similarly for the E 97B measure $N(E)$ ers of events observed E DOCUMENT ID STARIC RUBIN | 05s BABR 97B E791 94I E687 $D_s^+ \rightarrow K^+ I$ $D_s^- \rightarrow K$ $D_s^+ \rightarrow $ | $-0.092 < A_{CP} < +0.072 (90\% \text{ CL})$ $-0.33 < A_{CP} < +0.094 (90\% \text{ CL})$ $(-\pi^+), \text{ the ratio of the}$ $+\overline{K}^*(892)^0)/N(D^+ \rightarrow \text{larly for the } D^$ $\underline{COMMENT}$ Mainly at $\Upsilon(4S)$ Fit-fraction asymmetry $e^+e^-\approx \Upsilon(4S)$ $-0.087 < A_{CP} <$ | $\begin{array}{l} \frac{MLUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.166\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.14\pm11\pm1} \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.146\pm0.007\pm0.002} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.140\pm0.007\pm0.002} \end{array}$ | $\frac{DOCUMENT\ ID}{BESSON}$ $\overline{K}^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{BESSON}$ $\overline{K}^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{BESSON}$ $\pi^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{BESSON}$ $\pi^0\ell^+\nu_\ell$ $\frac{DOCUMENT\ ID}{DOCUMENT\ ID}$ | 09 CLEO 7ECN 09 CLEO 7ECN 09 CLEO 7ECN 09 CLEO | $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter f |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 9 AUBERT 05s meanumbers of events 0 FRABETTI 941 ϵ $\kappa^-\pi^+\pi^+$), the ϵ CP $(\phi\pi^\pm)$ in D^\pm LUE (%) 0.42 \pm 0.28 OUR AV 0.51 \pm 0.28 0.05 1.8 \pm 1.6 \pm 0.4 0.2 \pm 1.5 \pm 0.6 2.8 \pm 3.6 | asures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI → K+ K*0)/N(E d similarly for the L 97B measure N(L ers of events observed DOCUMENT ID STARIC RUBIN 61 AUBERT | 05s BABR 97b E791 94l E687 $D_s^+ \rightarrow K^+ K^ D_s^+ \rightarrow K^+ K^ D_s^+ \rightarrow K^ D_s^$ | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \text{larly for the } D^ \\ \\ \hline \\ \frac{COMMENT}{} \\ \text{Mainly at } \mathcal{T}(4S) \\ \text{Fit-fraction asymmetry} \\ e^+e^- \approx \mathcal{T}(4S) \\ -0.087 < A_{CP} < \\ +0.031 (90\% \text{ CL}) \\ -0.075 < A_{CP} < \\ \end{array} $ | $\begin{array}{l} NALUE \\ 0.707 \pm 0.010 \pm 0.009 \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ NALUE \\ -1.66 \pm 0.44 \pm 0.10 \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ NALUE \\ -14 \pm 11 \pm 1 \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \\ NALUE \\ 0.146 \pm 0.007 \pm 0.002 \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ NALUE \\ -1.37 \pm 0.88 \pm 0.24 \end{array}$ | FOUNDAMENT ID BESSON | 09 CLEO 7ECN 09 CLEO 7ECN 09 CLEO 7ECN 09 CLEO | $\overline{K}^0e^+\nu_e$ 3-parameter $\frac{COMMENT}{\overline{K}^0e^+\nu_e}$ 3-parameter $\frac{COMMENT}{\overline{K}^0e^+\nu_e}$ 3-parameter $\frac{COMMENT}{\pi^0e^+\nu_e}$ 3-parameter f |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 9 AUBERT 05s meanumbers of events (10 FRABETTI 941 10 K $^{-}$ π^{+} π^{+}), the (10 CP (ϕ π^{\pm}) in D^{\pm} LUE (10) 0.42 \pm 1.28 OUR AV 0.51 \pm 0.28 \pm 0.05 1.8 \pm 1.6 \pm 0.2 \pm 0.2 \pm 1.5 \pm 0.6 2.8 \pm 3.6 6.6 \pm 8.6 | asures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI → K+K*0)/N(E d similarly for the L 97B measure N(L ers of events observ DOCUMENT ID STARIC RUBIN 61 AUBERT 62 AITALA 62 FRABETTI | 05s BABR 97B E791 94I E687 05 → K+ I D- D+ → K ved, and sim 12 BELL 08 CLEO 05s BABR 97B E791 94I E687 | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \text{larly for the } D^ \\ \\ \hline \\ \frac{COMMENT}{A} \\ \text{Mainly at } \mathcal{T}(4S) \\ -0.087 < A_{CP} < \\ +0.031 (90\% \text{ CL}) \\ -0.075 < A_{CP} < \\ +0.21 (90\% \text{ CL}) \\ \end{array} $ | $\begin{array}{l} \frac{MLUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.166\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.14\pm11\pm1} \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.146\pm0.007\pm0.002} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.140\pm0.007\pm0.002} \end{array}$ | FOUNDAMENT ID BESSON | 09 CLEO 1ECN 1ECN 1ECN 09 CLEO 1ECN | $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter f |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 9 AUBERT 05s meanumbers of events 0.6 FRABETTI 941 \approx $K^-\pi^+\pi^+$), the $E^ E^ $ | asures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E$ d similarly for the I 97B measure $N(I$ ers of events observed. $\underline{DOCUMENT\ ID}$ STARIC RUBIN 61 AUBERT 62 AITALA 62 FRABETTI $\rightarrow \phi \pi^+)/N(D_s^+$ d similarly for the I | 05s BABR 97B E791 94i E687 $D_{S}^{+} \rightarrow K^{+}I$ $D_{C}^{-} \rightarrow K^{+}I$ 12 BELL 08 CLEO 05s BABR 97B E791 94i E687 $D_{C}^{+} \rightarrow K^{+}K$ $D_{C}^{-} \rightarrow K^{+}K$ | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \\ \text{larly for the } D^ \\ \\ \hline \\ Mainly at \ T(4S) \\ \hline Fit-fraction asymmetry \\ e^+e^- \approx T(4S) \\ -0.087 < A_{CP} < \\ +0.031 (90\% \text{ CL}) \\ -0.075 < A_{CP} < \\ +0.21 (90\% \text{ CL}) \\ \hline -\pi^+), \text{ the ratio of the} \\ \end{array} $ | $\begin{array}{l} \frac{MLUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-1.66\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-14\pm11\pm1} \\ f_+(0) V_{cd} \text{ in } D^+ \rightarrow \\ \frac{MLUE}{0.146\pm0.007\pm0.002} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{MLUE}{-1.37\pm0.88\pm0.24} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \end{array}$ | $\frac{DOCUMENT \ ID}{BESSON}$ $\overline{K}^{0}\ell^{+}\nu_{\ell}$ $DOCUMENT \ ID}$ $BESSON$ $\overline{K}^{0}\ell^{+}\nu_{\ell}$ $DOCUMENT \ ID}$ $BESSON$ $\pi^{0}\ell^{+}\nu_{\ell}$ $DOCUMENT \ ID}$ $BESSON$ $\pi^{0}\ell^{+}\nu_{\ell}$ $DOCUMENT \ ID}$ $BESSON$ $\pi^{0}\ell^{+}\nu_{\ell}$ $DOCUMENT \ ID}$ $BESSON$ | 09 CLEO 1 TECN $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ 3-parameter 1 $\underline{COMMENT}$ $\pi^0e^+\nu_e$ 3-parameter 1 |
| 0.1 \pm 1.3 OUR AV 0.4 \pm 2.0 \pm 0.6 0.9 \pm 1.7 \pm 0.7 1.0 \pm 5.0 12 \pm 13 \pm 3 AUBERT 05s mean numbers of events 10 FRABETTI 941 \pm 67 \pm 10 \pm | asures $N(D^+)$ s observed, an and AITALA ratio of numb | 59 AUBERT 60 AITALA 60 FRABETTI $\rightarrow K^+ \overline{K}^{*0})/N(E$ d similarly for the I 97B measure $N(I$ ers of events observed. $\underline{DOCUMENT\ ID}$ STARIC RUBIN 61 AUBERT 62 AITALA 62 FRABETTI $\rightarrow \phi \pi^+)/N(D_s^+$ d similarly for the I | 05s BABR 97B E791 94l E687 $D_{-}^{+} \rightarrow K^{+} I$ $D_{-}^{-} \rightarrow K^{+} I$ 12 BELL 08 CLEO 05s BABR 97B E791 94l E687 $- \rightarrow K^{+} K$ $- \rightarrow K^{+} K$ $- \rightarrow K^{+} K$ | $ \begin{array}{l} -0.092 < A_{CP} < \\ +0.072 (90\% \text{ CL}) \\ -0.33 < A_{CP} < \\ +0.094 (90\% \text{ CL}) \\ (-\pi^+), \text{ the ratio of the} \\ +\overline{K}^*(892)^0)/N(D^+ \rightarrow \\ \text{larly for the } D^ \\ \\ \hline \\ Mainly at \ T(4S) \\ \hline Fit-fraction asymmetry \\ e^+e^- \approx T(4S) \\ -0.087 < A_{CP} < \\ +0.031 (90\% \text{ CL}) \\ -0.075 < A_{CP} < \\ +0.21 (90\% \text{ CL}) \\ \hline -\pi^+), \text{ the ratio of the} \\ N(D^+ \rightarrow K^-\pi^+\pi^+), \end{array} $ | $\begin{array}{l} \frac{NALUE}{0.707\pm0.010\pm0.009} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.166\pm0.44\pm0.10} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ r_1 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ r_3 \equiv a_1/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ r_2 \equiv a_2/a_0 \text{ in } D^+ \rightarrow \\ \frac{NALUE}{0.146\pm0.007\pm0.002} \\ \end{array}$ | POCUMENT ID BESSON | 09 CLEO 1 TECN 09 CLEO 09 CLEO 09 CLEO 09 CLEO 09 CLEO 09 TECN 09 CLEO | $\overline{K}^0e^+\nu_e$ 3-parameter $\overline{K}^0e^+\nu_e$ |

 $r_1 \equiv a_1/a_0 \text{ in } D^+ \to \eta e^+ \nu_e \ \frac{VALUE}{-1.83 \pm 2.23 \pm 0.28}$

TECN COMMENT

11 CLEO z expansion

DOCUMENT ID

$r_{\rm V} \equiv V(0)/A_1(0) \ {\rm in} \ D^+ \to \ \overline{K}^*(892)^0 \ell^+ \nu_{\ell}$

See also BRIERE 10 for $\overline{\mathsf{K}}^*\ell^+\nu_\ell$ helicity-basis form-factor measurements.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|--------|---------------------------|-----|-------|-----------------------------------------|
| 1.51 ±0.07 OUR A | VERAGE | | | | See the ideogram below. |
| $1.463 \pm 0.017 \pm 0.031$ | | ⁶⁴ DEL-AMO-SA. | | | |
| $1.504\pm0.057\pm0.039$ | 15 k | ⁶⁵ LINK | 02L | FOCS | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| $1.45 \pm 0.23 \pm 0.07$ | 763 | ADAMOVICH | 99 | BEAT | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| $1.90 \pm 0.11 \pm 0.09$ | 3000 | ⁶⁶ AITALA | | | $\overline{K}^*(892)^0 e^+ \nu_e$ |
| $1.84 \ \pm 0.11 \ \pm 0.09$ | 3034 | AITALA | 98F | E791 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| $1.74 \ \pm 0.27 \ \pm 0.28$ | 874 | FRABETTI | 93E | E687 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| $2.00 \ ^{+ 0.34}_{- 0.32} \ \pm 0.16$ | 305 | KODAMA | 92 | E653 | \overline{K}^* (892) $^0\mu^+ u_\mu$ |
| | | | | 44 44 | |

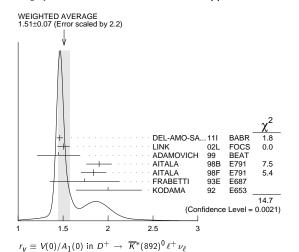
 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 $2.0 \pm 0.6 \pm 0.3$ 183 ANJOS 90E E691 $\overline{K}^*(892)^0 e^+ \nu_e$

 $^{64}\,{\rm DEL}$ A MO-SANCHEZ 111 finds the pole mass $m_A=($ 2.63 \pm 0.10 \pm 0.13) GeV (m_V is

65 LIMK OZU includes the effects of interference with an S-wave background. This much improves the goodness of fit, but does not much shift the values of the form factors.

66 This is slightly different from the AITALA 98B value: see ref. [5] in AITALA 98F.



 $r_2 \equiv A_2(0)/A_1(0)$ in $D^+ \to \overline{K}^*(892)^0 \ell^+ \nu_\ell$ See also BRIERE 10 for $\overline{K}^* \ell^+ \nu_\ell$ helicity-basis form-factor measurements.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------------------|-------------|---------------------------|--------------|---------|------------------------------------------------------|---|
| 0.807±0.025 OUR AVE | RAGE | | | | | _ |
| $0.801 \pm 0.020 \pm 0.020$ | | ⁶⁷ DEL-AMO-SA. | 11) | BABR | | |
| $0.875 \pm 0.049 \pm 0.064$ | 15 k | ⁶⁸ LINK | 02L | | \overline{K}^* (892) $^0 \mu^+ \nu_{\mu}$ | |
| $1.00 \ \pm 0.15 \ \pm 0.03$ | 763 | ADAMOVICH | 99 | BEAT | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ | |
| $0.71 \ \pm 0.08 \ \pm 0.09$ | 3000 | AITALA | 98B | E791 | $\overline{K}^*(892)^0 e^+ \nu_e$ | |
| $0.75 \pm 0.08 \pm 0.09$ | 3034 | AITALA | 98F | E791 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ | |
| $0.78 \ \pm 0.18 \ \pm 0.10$ | 874 | FRABETTI | 93E | E687 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ | |
| $0.82 \ ^{+ 0.22}_{- 0.23} \ \pm 0.11$ | 305 | KODAMA | 92 | E653 | \overline{K}^* (892) $^0 \mu^+ \nu_{\mu}$ | |
| • • • We do not use the | ne followir | ng data for averages | , fits, | limits, | etc. • • • | |
| $0.0 \pm 0.5 \pm 0.2$ | 183 | ANJOS | 90E | E691 | \overline{K}^* (892) 0 e^+ ν_e | |
| ⁶⁷ DEL-A MO-SA NCHI | EZ 11ı fin | ds the pole mass <i>m</i> | 4 = (| 2.63 ± | $0.10 \pm 0.13) \; { m GeV} \; (m_{V} \; { m is} \;$ | ı |

fixed at 2 GeV). 68 LINK 02L includes the effects of interference with an S-wave background. This much improves the goodness of fit, but does not much shift the values of the form factors.

$r_3 \equiv A_3(0)/A_1(0) \ { m in} \ D^+ ightarrow \ \overline{K}{}^*(892)^0 \, \ell^+ \, u_\ell$

See also BRIERE 10 for $\overline{K}^*\ell^+\nu_\ell$ helicity-basis form-factor measurements.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|------|--------------|-----|------|-----------------------------------------|
| 0.04±0.33±0.29 | 3034 | AITALA | 98F | E791 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |

Γ_L/Γ_T in $D^+ \rightarrow \overline{K}^*(892)^0 \ell^+ \nu_\ell$

See also BRIERE 10 for $\overleftarrow{K}^*\ell^+\nu_\ell$ helicity-basis form-factor measurements.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|-------------|--------------|-----|------|---------------------------------------------------------------------------------------|
| 1.13±0.08 OUR AVER | AGE | | | | |
| $1.09 \pm 0.10 \pm 0.02$ | 763 | ADAMOVICH | 99 | BEAT | \overline{K}^* (892) $^0 \mu^+ \nu_{\mu}$ |
| $1.20 \pm 0.13 \pm 0.13$ | 874 | FRABETTI | 93E | E687 | $\frac{\overline{K}^*(892)^0 \mu^+ \nu_{\mu}}{\overline{K}^*(892)^0 \mu^+ \nu_{\mu}}$ |
| $1.18 \pm 0.18 \pm 0.08$ | 305 | KODAMA | 92 | E653 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| • • • We do not use t | he followin | | | | |
| $1.8 \ ^{+ 0.6}_{- 0.4} \ \pm 0.3$ | 183 | ANJOS | 90E | E691 | \overline{K}^* (892) $^0e^+ u_e$ |

Γ_+/Γ_- in $D^+ \rightarrow \overline{K}^*(892)^0 \ell^+ \nu_\ell$

12 PRL 108 071801

STARIC

See also BRIERE 10 for $\overline{K}^*\ell^+\nu_\ell$ helicity-basis form-factor measurements.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------------|-------------------|---------|-----------|----------------------------------------------|
| 0.22±0.06 OUR AVERA | GE Error | | | | |
| $0.28\pm0.05\pm0.02$ | 763 | ADAMOVICH | 99 | BEAT | \overline{K}^* (892) $^0 \mu^+ \nu_{\mu}$ |
| $0.16\pm0.05\pm0.02$ | 305 | KODA MA | 92 | E653 | $\overline{K}^*(892)^0 \mu^+ \nu_{\mu}$ |
| • • • We do not use the | efollowing | data for averages | s, fits | , limits, | etc. • • • |
| $0.15 {}^{+ 0.07}_{- 0.05} \pm 0.03$ | 183 | ANJOS | 90E | E691 | $\overline{\mathit{K}}^*$ (892) $^0e^+\nu_e$ |

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$$I(J^P) = \frac{1}{2}(0^-)$$

DO MASS

The fit includes D^\pm , D^0 , D_s^\pm , $D^{*\pm}$, D^{*0} , $D_s^{*\pm}$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{s1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (N | /leV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------|-----------------------|-------------------|------------------------|--------|----------|-------------------------------------------------|
| 1864.86 | ± 0.13 OUR | FIT | | | | |
| 1864.91 | ± 0.17 OUR | AVERAGE | | | | |
| 1865.30 | \pm 0.33 \pm 0.2 | 398 ± 13 | ANASHIN | 10A | | $e^{+}e^{-}$ at $\psi(3770)$ |
| 1864.84 | $7 \pm 0.150 \pm 0.0$ | 95 319 \pm 18 | CAWLFIELD | 07 | CLEO | $D^0 \rightarrow K_S^0 \phi$ |
| 1864.6 | \pm 0.3 \pm 1.0 | 641 | BARLAG | 90c | ACCM | π^- Cu 230 GeV |
| • • • V | Ve do not use ti | he following data | for averages, fits, | limits | , etc. • | • • |
| 1852 | ± 7 | 16 | ADAMOVICH | 87 | EMUL | Photoproduction |
| 1856 | ± 36 | 22 | ADAMOVICH | 84B | EMUL | Photoproduction |
| 1861 | ± 4 | | DERRICK | 84 | HRS | e^+e^- 29 GeV |
| 1847 | ± 7 | 1 | FIORINO | 81 | EMUL | $\gamma N \rightarrow \overline{D}^0 +$ |
| 1863.8 | ± 0.5 | | ¹ SCHINDLER | 81 | MRK2 | e^+e^- 3.77 GeV |
| 1864.7 | ± 0.6 | | ¹ TRILLING | 81 | RVUE | e^+e^- 3.77 GeV |
| 1863.0 | ± 2.5 | 238 | ASTON | 80E | OMEG | $\gamma p \rightarrow \overline{D}^0$ |
| 1860 | ± 2 | 143 | ² AVERY | 80 | SPEC | $\gamma N \rightarrow D^{*+}$ |
| 1869 | ± 4 | 35 | ² AVERY | 80 | SPEC | $\gamma N \rightarrow D^{*+}$ |
| 1854 | ± 6 | 94 | ² ATIYA | 79 | SPEC | $\gamma N \rightarrow D^0 \overline{D}{}^0$ |
| 1850 | ± 15 | 64 | BALTAY | 78C | нвс | $\nu N \rightarrow K^0 \pi \pi$ |
| 1863 | ± 3 | | GOLDHABER | 77 | MRK1 | D^0 , D^+ recoil |
| | | | 1 | | | spectra |
| 1863.3 | ± 0.9 | | ¹ PERUZZI | 77 | LGW | e ⁺ e ⁻ 3.77 GeV |
| 1868 | ± 11 | | PICCOLO | 77 | MRK1 | e ⁺ e ⁻ 4.03, 4.41 GeV |
| 1865 | ± 15 | 234 | GOLDHABER | 76 | MRK1 | $K\pi$ and $K3\pi$ |

 $^{D^{\perp}}$ Coro does not include possible systematic mass scale shift, estimated to be less than 5 MeV.

$m_{D^{\pm}} - m_{D^0}$

The fit includes D^{\pm} , D^0 , D_s^{\pm} , D_s^{\pm} , D_s^{\pm} , D_s^{\pm} , $D_1(2420)^0$, $D_2^{*}(2460)^0$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|---------------------------------|------|----------|-----------------------|
| 4.76±0.10 OUR FIT | Error includes scale factor of | 1.1. | | |
| 4.74±0.28 OUR AVE | RAGE | | | |
| 4.7 ± 0.3 | ¹ SCHINDLER | 81 | MRK2 | $e^{+}e^{-}$ 3.77 GeV |
| 5.0 ±0.8 | ¹ PERUZZI | 77 | LGW | e^+e^- 3.77 GeV |
| ¹ See the footnote o | n TRILLING 81 in the D^{0} an | d D± | sections | on the mass. |

DO MEAN LIFE

Measurements with an error $> 10 \times 10^{-15} \, \text{s}$ have been omitted from the average.

| VALUE (10 ⁻¹⁵ s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------|------------|----------------------|----------|------------|----------------------------------------|
| 410.1 ± 1.5 OUR AV | ERAGE | | | | |
| 409.6 \pm 1.1 \pm 1.5 | 210k | LINK | 02F | | γ nucleus, $pprox 180~{ m GeV}$ |
| $407.9 \pm 6.0 \pm 4.3$ | 10k | KUSH NIR | 01 | SELX | $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ |
| 413 \pm 3 \pm 4 | 35 k | AITALA | 99E | E791 | $K^-\pi^+$ |
| $408.5 \pm 4.1 ^{+}_{-} \begin{array}{l} 3.5 \\ 3.4 \end{array}$ | 25 k | BONVICINI | 99 | CLE2 | $e^+ e^- \approx \ \varUpsilon(4S)$ |
| 413 \pm 4 \pm 3 | 16k | FRABETTI | 94 D | E687 | $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ |
| ● ● We do not use | the follow | ing data for average | es, fits | s, limits, | etc. • • • |
| 424 ± 11 \pm 7 | 5118 | FRABETTI | 91 | E687 | $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ |
| 417 ± 18 ± 15 | 890 | ALVAREZ | 90 | NA14 | $K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$ |
| $ \begin{array}{rr} + 23 \\ - 21 \end{array} $ | 641 | ¹ BARLAG | 90c | ACCM | $\pi^-\mathrm{Cu}$ 230 GeV |
| 480 ±40 ±30 | 776 | ALBRECHT | 881 | ARG | e^+e^- 10 GeV |
| 422 \pm 8 \pm 10 | 4212 | RAAB | 88 | E691 | Photoproduction |
| 420 ±50 | 90 | BARLAG | 87B | ACCM | K^- and π^- 200 GeV |
| ¹ BARLAG 90c esti | mate syste | matic error to be n | egligil | ole. | |

$D^0-\overline{D}{}^0$ MIXING

Revised March 2012 by D. Asner (Pacific Northwest National Laboratory)

The detailed formalism for $D^0-\overline{D}{}^0$ mixing is presented in the note on "CP Violation in Meson Decays" in this Review. For completeness, we present an overview here. The time evolution of the $D^0-\overline{D}{}^0$ system is described by the Schrödinger equation

$$i\frac{\partial}{\partial t} \left(\frac{D^{0}(t)}{\overline{D}^{0}(t)} \right) = \left(\mathbf{M} - \frac{i}{2} \Gamma \right) \left(\frac{D^{0}(t)}{\overline{D}^{0}(t)} \right), \tag{1}$$

where the **M** and Γ matrices are Hermitian, and CPT invariance requires that $M_{11}=M_{22}\equiv M$ and $\Gamma_{11}=\Gamma_{22}\equiv \Gamma$. The off-diagonal elements of these matrices describe the dispersive and absorptive parts of the mixing.

Because CP violation is expected to be quite small here, it is convenient to label the mass eigenstates by the CP quantum number in the limit of CP conservation. Thus, we write

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle,$$
 (2)

where

$$\left(\frac{q}{p}\right)^2 = \frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}.$$
 (3)

The normalization condition is $|p|^2 + |q|^2 = 1$. Our phase convention is $CP|D^0\rangle = +|\overline{D}^0\rangle$, and the sign is chosen so that D_1 has CP even, or nearly so.

 $^{^1}$ PERUZZI 77 and SCHINDLER 81 errors do not include the 0.13% uncertainty in the absolute SPEAR energy calibration. TRILLING 81 uses the high precision $J/\psi(1.5)$ and $\psi(2.5)$ measurements of ZHOLENTZ 80 to determine this uncertainty and combines the PERUZZI 77 and SCHINDLER 81 results to obtain the value quoted. TRILLING 81 enters the fit in the D^\pm mass, and PERUZZI 77 and SCHINDLER 81 enter in the $m_{D^\pm}-m_{D^0}$, below.

 D^0

The corresponding eigenvalues are

$$\omega_{1,2} \equiv m_{1,2} - \frac{i}{2}\Gamma_{1,2} = \left(M - \frac{i}{2}\Gamma\right) \pm \frac{q}{p}\left(M_{12} - \frac{i}{2}\Gamma_{12}\right),$$
 (4)

where $m_{1,2}$ and $\Gamma_{1,2}$ are the masses and widths of the $D_{1,2}$. We define dimensionless mixing parameters x and y by

$$x \equiv (m_1 - m_2)/\Gamma = \Delta m/\Gamma \tag{5}$$

and

$$y \equiv (\Gamma_1 - \Gamma_2)/2\Gamma = \Delta\Gamma/2\Gamma, \tag{6}$$

where $\Gamma \equiv (\Gamma_1 + \Gamma_2)/2$. If CP is conserved, then M_{12} and Γ_{12} are real, $\Delta m = 2M_{12}$, $\Delta \Gamma = 2\Gamma_{12}$, and $p = q = 1/\sqrt{2}$. The signs of Δm and $\Delta \Gamma$ are to be determined experimentally.

The parameters x and y are measured in several ways. The most precise values are obtained using the time dependence of D decays. Since $D^0 - \overline{D}{}^0$ mixing is a small effect, the identifying tag of the initial particle as a D^0 or a \overline{D}^0 must be extremely accurate. The usual tag is the charge of the distinctive slow pion in the decay sequence $D^{*+} \to D^0 \pi^+$ or $D^{*-} \to \overline{D}{}^0 \pi^-$. In current experiments, the probability of mistagging is about 0.1%. The large data samples produced at the B-factories allow the production flavor to also be determined by fully reconstructing charm on the "other side" of the event—significantly reducing the mistag rate [1]. Another tag of comparable accuracy is identification of one of the D's produced from $\psi(3770) \to D^0 \overline{D}{}^0$ decays. Although time-dependent analyses are not possible at symmetric charm-threshold facilities (the D^0 and \overline{D}^0 do not travel far enough), the quantum-coherent $C = -1 \ \psi(3770) \rightarrow D^0 \overline{D}{}^0$ state provides time-integrated sensitivity [2,3].

Time-Dependent Analyses: We extend the formalism of this Review's note on "CP Violation in Meson Decays." In addition to the "right-sign" instantaneous decay amplitudes $\overline{A}_f \equiv \langle f|H|\overline{D}^0\rangle$ and $A_{\overline{f}} \equiv \langle \overline{f}|H|D^0\rangle$ for CP conjugate final states $f=K^+\pi^-,\ldots$ and $\overline{f}=K^-\pi^+,\ldots$, we include "wrongsign" amplitudes $\overline{A}_{\overline{f}} \equiv \langle \overline{f}|H|\overline{D}^0\rangle$ and $A_f \equiv \langle f|H|D^0\rangle$.

It is conventional to normalize the wrong-sign decay distributions to the integrated rate of right-sign decays and to express time in units of the precisely measured neutral D-meson mean lifetime, $\tau_{D^0} = 1/\Gamma = 2/(\Gamma_1 + \Gamma_2)$. Starting from a pure $|D^0\rangle$ or $|\overline{D}^0\rangle$ state at t=0, the time-dependent rates of decay to wrong-sign final states relative to the integrated right-sign decay rates are, to leading order:

$$r(t) \equiv \frac{\left| \langle f|H|D^{0}(t)\rangle \right|^{2}}{\left| \overline{A}_{f} \right|^{2}} = \left| \frac{q}{p} \right|^{2} \left| g_{+}(t) \lambda_{f}^{-1} + g_{-}(t) \right|^{2}, \quad (7)$$

and

$$\overline{r}(t) \equiv \frac{\left| \langle \overline{f} | H | \overline{D}^{0}(t) \rangle \right|^{2}}{\left| A_{\overline{f}} \right|^{2}} = \left| \frac{p}{q} \right|^{2} \left| g_{+}(t) \lambda_{\overline{f}} + g_{-}(t) \right|^{2}. \tag{8}$$

where

$$\lambda_f \equiv q \overline{A}_f / p A_f \,, \quad \lambda_{\bar{f}} \equiv q \overline{A}_{\bar{f}} / p A_{\bar{f}} \,,$$
 (9)

and

$$g_{\pm}(t) = \frac{1}{2} \left(e^{-iz_1 t} \pm e^{-iz_2 t} \right), \quad z_{1,2} = \frac{\omega_{1,2}}{\Gamma}.$$
 (10)

Note that a change in the convention for the relative phase of D^0 and $\overline{D}{}^0$ would cancel between q/p and \overline{A}_f/A_f and leave λ_f unchanged. We expand r(t) and $\overline{r}(t)$ to second order in x and y for modes in which the ratio of decay amplitudes, $R_D = |A_f/\overline{A}_f|^2$, is very small.

Semileptonic decays: Consider the final state $f=K^+\ell^-\bar{\nu}_\ell$, where $A_f=\overline{A}_{\overline{f}}=0$ in the Standard Model. The final state f is only accessible through mixing and r(t) is

$$r(t) = |g_{-}(t)|^{2} \left| \frac{q}{p} \right|^{2} \approx \frac{e^{-t}}{4} (x^{2} + y^{2}) t^{2} \left| \frac{q}{p} \right|^{2}$$
 (11)

For $\overline{r}(t)$ q/p is replaced by p/q. In the Standard Model, CP violation in charm mixing is small and $|q/p|\approx 1$. In the limit of CP conservation, $r(t)=\overline{r}(t)$, and the time-integrated mixing rate relative to the time-integrated right-sign decay rate for semileptonic decays is

$$R_M = \int_0^\infty r(t)dt = \left| \frac{q}{p} \right|^2 \frac{x^2 + y^2}{2 + x^2 - y^2} = \frac{1}{2} (x^2 + y^2).$$
 (12)

Table 1: Results for R_M in D^0 semileptonic decays.

| Year | Exper. | Final state(s) | $R_M \ (\times 10^{-3})$ | 90% C.L. |
|-------|--------------------------------|-----------------------------------|--------------------------------------|-----------------------------|
| 2008 | Belle [4] | $K^{(*)+}e^{-}\overline{\nu}_{e}$ | $0.13\pm0.22\pm0.20$ | $< 0.61 \times 10^{-3}$ |
| 2007 | BaBar [1] | $K^{(*)+}e^{-}\overline{\nu}_{e}$ | $0.04^{+0.70}_{-0.60}$ | $(-1.3, 1.2)\times 10^{-3}$ |
| 2005* | Belle [5] | $K^{(*)+}e^{-}\overline{\nu}_{e}$ | $0.02 \pm 0.47 \pm 0.14$ | $< 1.0 \times 10^{-3}$ |
| 2005 | CLEO [6] | $K^{(*)+}e^{-}\overline{\nu}_{e}$ | $1.6 \pm 2.9 \pm 2.9$ | $< 7.8 \times 10^{-3}$ |
| 2004* | BaBar [7] | $K^{(*)+}e^{-}\overline{\nu}_{e}$ | $2.3 \!\pm\! 1.2 \!\pm\! 0.4$ | $< 4.2 \times 10^{-3}$ |
| 2002* | $\mathrm{FOCUS}\left[8\right]$ | $K^+\mu^-\overline{\nu}_\mu$ | $-0.76^{+0.99}_{-0.93}$ | $<1.01\times10^{-3}$ |
| 1996 | E791 [9] | $K^+\ell^-\overline{\nu}_\ell$ | $(1.1^{+3.0}_{-2.7}) \times 10^{-3}$ | $<5.0\times10^{-3}$ |
| | HFAG [10] | | 0.13 ± 0.27 | |

*These measurements are excluded from the HFAG average. The FOCUS result is unpublished, the BaBar result has been superseded by Ref. 1, and the Belle result has been superseded by Ref. 4.

Table 1 summarizes results for R_M from semileptonic decays; the world average from the Heavy Flavor Averaging Group (HFAG) [10] is $R_M = (1.30 \pm 2.69) \times 10^{-4}$.

Wrong-sign decays to hadronic non-CP eigenstates: Consider the final state $f = K^+\pi^-$, where A_f is doubly Cabibbo-suppressed. The ratio of decay amplitudes is

$$\frac{A_f}{\overline{A}_f} = -\sqrt{R_D} e^{-i\delta_f}, \quad \left| \frac{A_f}{\overline{A}_f} \right| \sim O(\tan^2 \theta_c), \quad (13)$$

where R_D is the doubly Cabibbo-suppressed (DCS) decay rate relative to the Cabibbo-favored (CF) rate, δ_f is the strong phase difference between DCS and CF processes, and θ_c is the Cabibbo angle. The minus sign originates from the sign of V_{us} relative to V_{cd} .

 $D^{(}$

We characterize the violation of CP with the real-valued parameters A_M , A_D , and ϕ . We adopt the parametrization (see Refs. 11 and 12)

$$\left|\frac{q}{p}\right|^2 = \sqrt{\frac{1+A_M}{1-A_M}},\tag{14}$$

$$\lambda_f^{-1} \equiv \frac{pA_f}{q\overline{A}_f} = -\sqrt{R_D} \left(\frac{(1+A_D)(1-A_M)}{(1-A_D)(1+A_M)} \right)^{1/4} e^{-i(\delta_f + \phi)}, \tag{15}$$

$$\lambda_{\overline{f}} \equiv \frac{q\overline{A_{\overline{f}}}}{pA_{\overline{f}}} = -\sqrt{R_D} \left(\frac{(1 - A_D)(1 + A_M)}{(1 + A_D)(1 - A_M)} \right)^{1/4} e^{-i(\delta_f - \phi)}, \tag{16}$$

and A_D is a measure of direct CP violation, while A_M is a measure of CP violation in mixing. From these relations, we obtain

$$\sqrt{\frac{1+A_D}{1-A_D}} = \frac{|A_f/\overline{A}_f|}{|\overline{A}_f/A_f|} , \qquad (17)$$

The angle ϕ measures CP violation in interference between mixing and decay. While A_M is independent of the decay process, A_D and ϕ , in general, depend on f.

In general, $\lambda_{\overline{f}}$ and λ_f^{-1} are independent complex numbers. More detail on CP violation in meson decays can be found in Ref. 13. To leading order, for A_D and $A_M \ll 1$,

$$r(t) = e^{-t} \left[R_D(1 + A_D) + \sqrt{R_D(1 + A_M)(1 + A_D)} y_-' t + \frac{1}{2} (1 + A_M) R_M t^2 \right]$$
(18)

and

$$\overline{r}(t) = e^{-t} \left[R_D (1 - A_D) + \sqrt{R_D (1 - A_M)(1 - A_D)} y'_+ t + \frac{1}{2} (1 - A_M) R_M t^2 \right]$$
(19)

Here

$$y'_{\pm} \equiv y' \cos \phi \pm x' \sin \phi$$

= $y \cos(\delta_{K\pi} \mp \phi) - x \sin(\delta_{K\pi} \mp \phi)$, (20)

where

$$x' \equiv x \cos \delta_{K\pi} + y \sin \delta_{K\pi},$$

$$y' \equiv y \cos \delta_{K\pi} - x \sin \delta_{K\pi} \,, \tag{21}$$

and $R_M = (x^2 + y^2)/2 = (x'^2 + y'^2)/2$ is the mixing rate relative to the time-integrated Cabibbo-favored rate.

The three terms in Eq. (18) and Eq. (19) probe the three fundamental types of CP violation. In the limit of CP conservation, A_M , A_D , and ϕ are all zero. Then

$$r(t) = \overline{r}(t) = e^{-t} \left(R_D + \sqrt{R_D} y' t + \frac{1}{2} R_M t^2 \right),$$
 (22)

and the time-integrated wrong-sign rate relative to the integrated right-sign rate is

$$R = \int_0^\infty r(t) \, dt = R_D + \sqrt{R_D} \, y' + R_M \,. \tag{23}$$

The ratio R is the most readily accessible experimental quantity. In Table 2 are reported the measurements of R, R_D and A_D in $D^0 \to K^+\pi^-$, and their HFAG average [20] from a general fit; all allow for both mixing and CP violation. Typically, the fit parameters are R_D , x'^2 , and y'. Table 3 summarizes the results for x'^2 and y'. Allowing for CP violation, the separate contributions to R can be extracted by fitting the $D^0 \to K^+\pi^-$ and $\overline{D}^0 \to K^-\pi^+$ decay rates.

Table 2: Results for R, R_D , and A_D in $D^0 \rightarrow K^+\pi^-$.

| Year | Exper. | $R(\times 10^{-3})$ | $R_D(\times 10^{-3})$ | $A_D(\%)$ |
|-------|-------------------|---------------------------------|---------------------------------|-------------------------|
| 2007 | CDF [14] | 4.15 ± 0.10 | 3.04 ± 0.55 | _ |
| 2007 | BaBar [15] | $3.53 \pm 0.08 \pm 0.04$ | $3.03\pm0.16\pm0.10$ | $-2.1 \pm 5.2 \pm 1.5$ |
| 2006 | Belle [16] | $3.77\!\pm\!0.08\!\pm\!0.05$ | $3.64 \!\pm\! 0.17$ | $2.3 \!\pm\! 4.7$ |
| | ${\rm FOCUS}[17]$ | 0.01 | $5.17^{+1.47}_{-1.58} \pm 0.76$ | $13^{+33}_{-25} \pm 10$ |
| 2000* | CLEO[18] | $3.32^{+0.63}_{-0.65} \pm 0.40$ | $4.8 \pm 1.2 \pm 0.4$ | $-1^{+16}_{-17}\pm1$ |
| 1998 | E791[19] | $6.8^{+3.4}_{-3.3} \pm 0.7$ | _ | _ |
| | Average | 3.80 ± 0.05 | 3.31 ± 0.08 [20] | -1.7 ± 2.4 [20] |

^{*}These measurements are excluded from the HFAG average due to poor precision.

Table 3: Results on the time-dependence of r(t) in $D^0 \to K^+\pi^-$ and $\overline{D}{}^0 \to K^-\pi^+$ decays. The CDF result assumes no CP violation. The FOCUS, CLEO, and Belle results restrict x'^2 to the physical region. The confidence intervals from FOCUS, CLEO, and BaBar are obtained from the fit, whereas Belle uses a Feldman-Cousins method, and CDF uses a Bayesian method.

| Year Exper. | y' (%) | $x'^{2} (\times 10^{-3})$ |
|-----------------|----------------------------------|-------------------------------|
| 2007 CDF [14] | 0.85 ± 0.76 | -0.12 ± 0.35 |
| 2007 BaBar [15] | $0.97 \!\pm\! 0.44 \!\pm\! 0.31$ | $-0.22 \pm 0.30 \pm 0.21$ |
| 2006 Belle [16] | -2.8 < y' < 2.1 | < 0.72~(95%~C.L.) |
| 2005 FOCUS [17] | -11.2 < y' < 6.7 | < 8.0 (95% C.L.) |
| 2000 CLEO [18] | -5.8 < y' < 1.0 | $< 0.81 (95\% \mathrm{C.L.})$ |

Extraction of the mixing parameters x and y from the results in Table 3 requires knowledge of the relative strong phase $\delta_{K\pi}$. An interference effect that provides useful sensitivity to $\delta_{K\pi}$ arises in the decay chain $\psi(3770){\to}D^0\overline{D}^0{\to}(f_{CP})(K^+\pi^-)$, where f_{CP} denotes a CP-even or -odd eigenstate from D^0 decay, such as K^+K^- or $K^0_S\pi^0$, respectively [23]. Here, the amplitude relation

$$\sqrt{2} A(D_{\pm} \to K^{-} \pi^{+}) = A(D^{0} \to K^{-} \pi^{+}) \pm A(\overline{D}^{0} \to K^{-} \pi^{+}).$$
(24)

where D_{\pm} denotes a CP-even or -odd eigenstate, implies that

$$\cos \delta_{K\pi} = \frac{|A(D_+ \to K^- \pi^+)|^2 - |A(D_- \to K^- \pi^+)|^2}{2\sqrt{R_D} |A(D^0 \to K^- \pi^+)|^2}.$$
 (25)

This neglects CP violation and uses $\sqrt{R_D} \ll 1$.

For multibody final states, Eqs. (13)–(23) apply separately to each point in phase-space. Although x and y do not vary across the space, knowledge of the resonant substructure is

D^{0}

needed to extrapolate the strong phase difference δ from point to point to determine x and y.

A time-dependent analysis of the process $D^0 \to K^+\pi^-\pi^0$ from BaBar [21,22] determines the *relative* strong phase variation across the Dalitz plot and reports $x'' = (2.61^{+0.57}_{-0.68} \pm 0.39)\%$, and $y'' = (-0.06^{+0.55}_{-0.64} \pm 0.34)\%$, where x'' and y'' are defined as

$$x'' \equiv x \cos \delta_{K\pi\pi^0} + y \sin \delta_{K\pi\pi^0},$$

$$y'' \equiv y \cos \delta_{K\pi\pi^0} - x \sin \delta_{K\pi\pi^0},$$
(26)

in parallel to x', y', and $\delta_{K\pi}$ of Eq. (21). Here $\delta_{K\pi\pi^0}$ is the remaining strong phase difference between the DCS $D^0 \to K^+\rho^-$ and the CF $\overline{D}{}^0 \to K^+\rho^-$ amplitudes and does not vary across the Dalitz plot. Both strong phases, $\delta_{K\pi}$ and $\delta_{K\pi\pi^0}$, can be determined from time-integrated CP asymmetries in correlated $D^0\overline{D}{}^0$ produced at the $\psi(3770)$ [23,24].

Both the sign and magnitude of x and y without phase or sign ambiguity may be measured using the time-dependent resonant substructure of multibody D^0 decays [25,26]. In $D^0 \to K_S^0 \pi^+ \pi^-$, the DCS and CF decay amplitudes populate the same Dalitz plot, which allows direct measurement of the relative strong phases. CLEO [27], Belle [26], and BaBar [28] have measured the relative phase between $D^0 \to K^*(892)^-\pi^+$ and $D^0 \to K^*(892)^+\pi^-$ to be $(189 \pm 10 \pm 3^{+15}_{-5})^\circ$, $(171.9 \pm 1.3 \text{ (stat. only)})^\circ$, and $(177.6 \pm 1.1 \text{ (stat. only)})^\circ$, respectively. These results are close to the 180° expected from Cabibbo factors and a small strong phase. Table 4 summarizes the results of a time-dependent Dalitz-plot analyses.

Table 4: Results from time-dependent Dalitz-plot analysis of $D^0 \to K_S^0 \pi^+ \pi^-$ (CLEO and Belle) and $D^0 \to K_S^0 \pi^+ \pi^-, K_S^0 K^+ K^-$ (BaBar). The errors are statistical, experimental systematic, and decay-model systematic, respectively.

| | No CP Violation | | | | | | | |
|------|-----------------|----------------------------------------------------------|-----------------------------------------------------|--|--|--|--|--|
| Year | Exper. | $x \times 10^{-3}$ | $y \times 10^{-3}$ | | | | | |
| 2010 | BaBar [28] | $1.6 \pm 2.3 \pm 1.2 \pm 0.8$ | $5.7 \pm 2.0 \pm 1.3 \pm 0.7$ | | | | | |
| 2007 | Belle [26] | $8.0 \pm 2.9^{+0.9}_{-0.7}{}^{+1.0}_{-1.4}$ | $3.3 \pm 2.4^{+0.8}_{-1.2}{}^{+0.6}_{-0.8}$ | | | | | |
| 2005 | CLEO [25] | $19^{+32}_{-33} \pm 4 \pm 4$ | $-14 \pm 24 \pm 8 \pm 4$ | | | | | |
| | HFAG [20] | 4.2 ± 2.1 | 4.6 ± 1.9 | | | | | |
| - | | With CP Violation | 1 | | | | | |
| Year | Exper. | q/p | ϕ | | | | | |
| 2007 | Belle [26] | $0.86^{+0.30}_{-0.29}^{+0.06}_{-0.03}^{+0.06}_{\pm0.08}$ | $(-14^{+16}_{-18}{}^{+5}_{-3}{}^{+2}_{-4})^{\circ}$ | | | | | |

In addition, Belle [26] has results for both the relative phase (statistical errors only) and ratio R (central values only) of the DCS fit fraction relative to the CF fit fractions for $K^*(892)^+\pi^-$, $K_0^*(1430)^+\pi^-$, $K_2^*(1430)^+\pi^-$, $K^*(1410)^+\pi^-$, and $K^*(1680)^+\pi^-$. The systematic uncertainties on R must be evaluated. The values for R in units of $\tan^4\theta_c$ are 2.94 ± 0.12 , 22.0 ± 1.6 , 34 ± 4 , 87 ± 13 , and 500 ± 500 , respectively. For $K^+\pi^-$, the corresponding value for R_D is $(1.28 \pm 0.02) \times \tan^4\theta_c$.

Similarly, BaBar [28–30] has reported central values for R for $K^*(892)^+\pi^-$, $K_0^*(1430)^+\pi^-$, and $K_2^*(1430)^+\pi^-$. The large differences in R among these final states could point to an interesting role for hadronic effects.

Decays to CP Eigenstates: When the final state f is a CP eigenstate, there is no distinction between f and \overline{f} , and $A_f = A_{\overline{f}}$ and $\overline{A}_{\overline{f}} = \overline{A}_f$. We denote final states with CP eigenvalues ± 1 by f_{\pm} and write λ_{\pm} for $\lambda_{f_{\pm}}$.

The quantity y may be measured by comparing the rate for D^0 decays to non-CP eigenstates such as $K^-\pi^+$ with decays to CP eigenstates such as K^+K^- [12]. If decays to K^+K^- have a shorter effective lifetime than those to $K^-\pi^+$, y is positive.

In the limit of slow mixing $(x, y \ll 1)$ and the absence of direct CP violation $(A_D = 0)$, but allowing for small indirect CP violation $(|A_M|, |\phi| \ll 1)$, we can write

$$\lambda_{\pm} = \left| \frac{q}{p} \right| e^{\pm i\phi} \ . \tag{27}$$

In this scenario, to a good approximation, the decay rates for states that are initially D^0 and $\overline{D}{}^0$ to a CP eigenstate have exponential time dependence:

$$r_{\pm}(t) \propto \exp\left(-t/\tau_{\pm}\right) ,$$
 (28)

$$\overline{r}_{\pm}(t) \propto \exp\left(-t/\overline{\tau}_{\pm}\right) ,$$
 (29)

where τ is measured in units of $1/\Gamma$.

The effective lifetimes are given by

$$1/\tau_{\pm} = 1 \pm \left| \frac{q}{p} \right| (y \cos \phi - x \sin \phi) , \qquad (30)$$

$$1/\overline{\tau}_{\pm} = 1 \pm \left| \frac{p}{q} \right| (y \cos \phi + x \sin \phi) . \tag{31}$$

The effective decay rate to a CP eigenstate combining both D^0 and $\overline{D}{}^0$ decays is

$$r_{\pm}(t) + \overline{r}_{\pm}(t) \propto e^{-(1 \pm y_{CP})t}$$
 (32)

Here

$$y_{CP} = \frac{1}{2} \left(\left| \frac{q}{p} \right| + \left| \frac{p}{q} \right| \right) y \cos \phi - \frac{1}{2} \left(\left| \frac{q}{p} \right| - \left| \frac{p}{q} \right| \right) x \sin \phi \quad (33)$$

$$\approx y \cos \phi - A_M x \sin \phi$$
 (34)

If CP is conserved, $y_{CP} = y$.

All measurements of y_{CP} and A_{Γ} are relative to the $D^0 \to K^-\pi^+$ decay rate. Table 5 summarizes the current status of measurements. Belle [35], BaBar [32,34], and LHCb [31] have reported y_{CP} and the decay-rate asymmetry for CP even final states

$$A_{\Gamma} = \frac{\overline{\tau}_{+} - \tau_{+}}{\overline{\tau}_{+} + \tau_{+}} = \frac{(1/\tau_{+}) - (1/\overline{\tau}_{+})}{(1/\tau_{+}) + (1/\overline{\tau}_{+})}$$
(35)

$$=\frac{1}{2}\left(\left|\frac{q}{p}\right|-\left|\frac{p}{q}\right|\right)y\cos\phi-\frac{1}{2}\left(\left|\frac{q}{p}\right|+\left|\frac{p}{q}\right|\right)x\sin\phi \ \ (36)$$

$$\approx A_M y \cos \phi - x \sin \phi$$
 (37)

Table 5: Results for y_{CP} from $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$.

| Year | Exper. | final state(s) | $y_{CP}(\%)$ | $A_{\Gamma}(\times 10^{-3})$ |
|------|------------------|-----------------------------|------------------------------|------------------------------|
| 2011 | LHCb [31] | $K^{+}K^{-},\pi^{+}\pi^{-}$ | $0.55 \pm 0.63 \pm 0.41$ | $-0.59\pm0.59\pm0.21$ |
| 2009 | BaBar [32] | K^+K^- | $1.16\!\pm\!0.22\!\pm\!0.18$ | _ |
| 2009 | Belle [33] | $K_S^0K^+K^-$ | $0.11\!\pm\!0.61\!\pm\!0.52$ | _ |
| 2008 | $BaBar^* \ [34]$ | $K^+K^-\!,\!\pi^+\pi^-$ | $1.03\!\pm\!0.33\!\pm\!0.19$ | $2.6 \pm 3.6 \pm 0.8$ |
| 2007 | Belle [35] | $K^+K^-,\pi^+\pi^-$ | $1.31\!\pm\!0.32\!\pm\!0.25$ | $0.1 \pm 3.0 \pm 1.5$ |
| | | , | $-1.2\pm2.5\pm1.4$ | _ |
| | | | $-0.5\pm1.0^{+0.7}_{-0.8}$ | _ |
| 2000 | FOCUS~[38] | K^+K^- | $3.42\!\pm\!1.39\!\pm\!0.74$ | _ |
| 1999 | E791 [39] | K^+K^- | $0.8 \pm 2.9 \pm 1.0$ | _ |
| | HFAG [20] | | 1.06 ± 0.21 | 0.03 ± 0.23 |

^{*}This measurement is included in the result reported by Ref. 32.

Belle [33] has also reported y_{CP} for the final state $K_S^0K^+K^-$ which is dominated by the CP odd final state $K_S^0\phi$. If CP is conserved, $A_{\Gamma}=0$.

Substantial work on the time-integrated CP asymmetries in decays to CP eigenstates are consistent [40]. Recently, LHCb has reported 3.5σ evidence for the difference in time-integrated CP asymmetry, $\Delta A_{CP} = A_K - A_\pi$, between $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$, yielding $\Delta A_{CP} = [-0.82 \pm 0.21(stat.) \pm 0.11(sys.)]\%$ [41]. Subsequently, CDF has reported $\Delta A_{CP} = [-0.62 \pm 0.21(stat.) \pm 0.10(sys.)]\%$ [42].

Coherent $D^0\overline{D}^0$ Analyses: Measurements of R_D , $\cos \delta_{K\pi}$, $\sin \delta_{K\pi}$, x, and y can be determined simultaneously from a combined fit to the time-integrated single-tag (ST) and double-tag (DT) yields in correlated $D^0\overline{D}^0$ produced at the $\psi(3770)$ [23,24].

Due to quantum correlations in the C=-1 and C=+1 $D^0\overline{D}{}^0$ pairs produced in the reactions $e^+e^-\to D^0\overline{D}{}^0(\pi^0)$ and $e^+e^-\to D^0\overline{D}{}^0\gamma(\pi^0)$, respectively, the time-integrated $D^0\overline{D}{}^0$ decay rates are sensitive to interference between amplitudes for indistinguishable final states. The size of this interference is governed by the relevant amplitude ratios and can include contributions from $D^0-\overline{D}{}^0$ mixing.

The following categories of final states are considered:

f or \bar{f} : Hadronic states accessed from either D^0 or \overline{D}^0 decay but that are not CP eigenstates. An example is $K^-\pi^+$, which results from Cabibbo-favored D^0 transitions or DCS \overline{D}^0 transitions.

 ℓ^+ or ℓ^- : Semileptonic or purely leptonic final states, which, in the absence of mixing, tag unambiguously the flavor of the parent D^0 .

 f_+ or f_- : CP-even and CP-odd eigenstates, respectively.

The decay rates for $D^0\overline{D}^0$ pairs to all possible combinations of the above categories of final states are calculated in Ref. 2, for both C=-1 and C=+1, reproducing the work of Ref. 3. Such $D^0\overline{D}^0$ combinations, where both D final states are specified, are double tags. In addition, the rates for single tags, where either the D^0 or \overline{D}^0 is identified and the other neutral D decays generically are given in Ref. 2.

CLEO-c has reported results using 818 pb⁻¹ of $e^+e^- \rightarrow \psi(3770)$ data [43–45], where the quantum-coherent $D^0\overline{D}^0$ pairs are in the C=-1 state. The values of $y,\ R_M,\ \cos\delta_{K\pi}$, and $\sin\delta_{K\pi}$ are determined from a combined fit to the ST (hadronic only) and DT yields. The hadronic final states included are $K^-\pi^+(f),\ K^+\pi^-(\bar{f}),\ K^-K^+(f_+),\ \pi^+\pi^-(f_+),\ K^0_S\pi^0\pi^0$ $(f_+),\ K^0_L\pi^0(f_+),\ K^0_L\pi^0(f_+),\ K^0_L\pi^0(f_+),\ K^0_S\pi^0(f_-),\ K^0_S\pi^0(f_-),\ K^0_S\pi^0(f_-),\ And\ K^0_L\pi^0\pi^0(f_-),\ and\ K^0_S\pi^+\pi^-$ (mixure of $f,\bar{f},\ f_+$, and f_-). The two flavored final states, $K^-\pi^+$ and $K^+\pi^-$, can be reached via CF or DCS transitions.

Semileptonic DT yields are also included, where one D is fully reconstructed in one of the hadronic modes listed above, and the other D is partially reconstructed in either $D \to Ke\nu$ or $D \to K\mu\nu$. When the lepton is accompanied by a flavor tag $(D \to K^-\pi^+ \text{ or } K^+\pi^-)$, both the "right-sign" and "wrongsign" DT samples are used, where the electron and kaon charges are the same and opposite, respectively.

The main results of the CLEO-c analysis are the determination of $\cos \delta_{K\pi} = 0.98^{+0.27}_{-0.20} \pm 0.08$, $\sin \delta_{K\pi} = -0.04 \pm 0.49 \pm 0.08$, and World Averages for the mixing parameters from an "extended" fit that combines the CLEO-c data with previous mixing and branching-ratio measurements [45]. These fits allow $\cos \delta_{K\pi}$, $\sin \delta_{K\pi}$ and x^2 to be unphysical. Constraining $\cos \delta_{K\pi}$ and $\sin \delta_{K\pi}$ to [-1,+1]—that is interpreting $\delta_{K\pi}$ as an angle—yields $\delta_{K\pi} = (15^{+11}_{-17} \pm 7)^{\circ}$. Note that measurements of y (Table 4 and Table 5) and y' (Table 3) contribute to the determination of $\delta_{K\pi}$.

Summary of Experimental Results: Several recent results indicate that charm mixing is at the upper end of the range of Standard Model estimates.

For $D^0 \to K^+\pi^-$, BaBar [15] and CDF [14] find evidence for oscillations with 3.9σ ($\Delta \text{Log}\mathcal{L}$) and 3.8σ (Bayesian), respectively. The most precise measurement for mixing parameters is from Belle [16], which excludes $x'^2 = y' = 0$ at 2.1σ .

For y_{CP} in $D^0 \to K^+K^-$ and $\pi^+\pi^-$, Belle [35] and BaBar [32] find 3.2 σ and 4.1 σ effects. The most sensitive measurement of x and y is in $D^0 \to K_S^0\pi^+\pi^-$, $K_S^0K^+K^-$ from BaBar [28] and the no mixing solution is only excluded at 1.9 σ . The current situation would benefit from better knowledge of the strong phase difference $\delta_{K\pi}$ than provided by the current CLEO-c result [45]. This would allow one to unfold x and y from the $D^0 \to K^+\pi^-$ measurements of x'^2 and y', and directly compare them to the $D^0 \to K_S^0\pi^+\pi^-$ results.

The experimental data consistently indicate that the D^0 and $\overline{D}{}^0$ do mix. The mixing is presumably dominated by long-range processes. Under the assumption that the observed mixing is due entirely to short-range processes, significant constraints on a variety of new physics models are obtained [46]. A serious limitation to the interpretation of charm oscillations in terms of New Physics is the theoretical uncertainty of the Standard Model prediction. However, recent evidence opens the window to searches for CP violation in mixing, which would provide unequivocal evidence of New Physics. The evidence for time

D^0

integrated CP-violation, $\Delta A_{CP} \neq 0$, observed by LHCb is intriguing. This result is marginally consistent with Standard Model expectation [47–49].

HFAG Averaging of Charm Mixing Results:

The Heavy Flavor Averaging Group (HFAG) has made a global fit to all mixing measurements to obtain values of $x,\ y,\ \delta_{K\pi},\ \delta_{K\pi\pi^0},\ R_D,\ A_D\equiv (R_D^+-R_D^-)/(R_D^++R_D^-),\ |q/p|,$ Arg $(q/p)\equiv\phi,$ and the time-integrated CP asymmetries A_K and $A_\pi.$ Correlations among observables are taken into account by using the error matrices from the experiments. The measurements of $D^0\to K^{(*)}+\ell^-\overline{\nu},\ K^+K^-,\ \pi^+\pi^-,\ K^+\pi^-,\ K^+\pi^-\pi^0,\ K^+\pi^-\pi^+\pi^-,\ K_S^0\pi^+\pi^-,\ {\rm and}\ K_S^0K^+K^-$ decays, as well as CLEO-c results for double-tagged branching fractions measured at the $\psi(3770)$ are used.

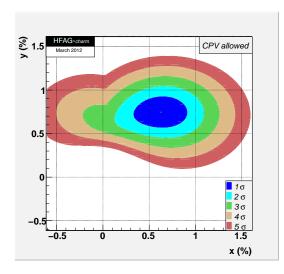


Figure 1: Two-dimensional 1σ - 5σ contours for (x,y) from measurements of $D^0 \rightarrow K^{(*)+}\ell\nu$, h^+h^- , $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, $K^0_S\pi^+\pi^-$, and $K^0_SK^+K^-$ decays, and double-tagged branching fractions measured at the $\psi(3770)$ resonance (from HFAG [20]).

Table 6: HFAG Charm Mixing Average allowing for CP violation [20].

| Parameter | HFAG average | 95% C.L. interval |
|------------------------------|------------------------|-------------------|
| x(%) | $0.63^{+0.19}_{-0.20}$ | [0.24, 0.99] |
| y(%) | 0.75 ± 0.12 | [0.51, 0.98] |
| $R_D(\%)$ | 0.331 ± 0.008 | [0.315, 0.347] |
| $\delta_{K\pi}(^{\circ})$ | $22.1^{+9.7}_{-11.1}$ | [-2.6, 40.6] |
| $\delta_{K\pi\pi^0}(^\circ)$ | 19 ± 22 | [-26, 62] |
| $A_D(\%)$ | -1.7 ± 2.4 | [-6.4, 3.0] |
| q/p | $0.88^{+0.18}_{-0.16}$ | [0.59, 1.26] |
| $\phi(^{\circ})$ | $-10.1^{+9.5}_{-8.9}$ | [-27.4, 8.7] |
| A_K | -0.31 ± 0.24 | [-0.78, 0.15] |
| A_{π} | 0.36 ± 0.25 | [-0.13, 0.86] |

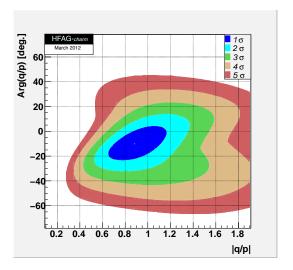


Figure 2: Two-dimensional 1σ -5 σ contours for $(|q/p|, \operatorname{Arg}(q/p))$ from measurements of $D^0 \to K^{(*)}+\ell\nu$, h^+h^- , $K^+\pi^-$, $K^+\pi^-\pi^0$, $K^+\pi^-\pi^+\pi^-$, $K^0_S\pi^+\pi^-$, and $K^0_SK^+K^-$ decays, and double-tagged branching fractions measured at the $\psi(3770)$ resonance (from HFAG [20]) .

For the global fit, confidence contours in the two dimensions (x,y) and $(|q/p|,\phi)$ are obtained by letting, for any point in the two-dimensional plane, all other fit parameters take their preferred values. Figures 1 and 2 show the resulting 1-to-5 σ contours. The fits exclude the no-mixing point (x=y=0) at 10.2σ , whether or not CP violation is allowed. The parameters x and y differ from zero by 2.7σ and 6.0σ , respectively. One-dimensional likelihood functions for parameters are obtained by allowing, for any value of the parameter, all other fit parameters to take their preferred values. The resulting likelihood functions give central values, 68.3% C.L. intervals, and 95% C.L. intervals as listed in Table 6.

From the results of the HFAG averaging, the following can be concluded: (1) Since CP violation is small and y_{CP} is positive, the CP-even state is shorter-lived, as in the $K^0\overline{K}^0$ system; (2) However, since x appears to be positive, the CP-even state is heavier, unlike in the $K^0\overline{K}^0$ system; (3) The strong phase difference $\delta_{K\pi}$ is consistent with the SU(3) expectation of zero but large values are not excluded; (4) There is no evidence yet for CP-violation in $D^0\overline{D}^0$ mixing. Observing CP-violation in mixing at the current level of sensitivity would indicate new physics.

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$\left|m_{D_1^0}-m_{D_2^0}\right|=x\ \Gamma$

The D_1^0 and D_2^0 are the mass eigenstates of the D^0 meson, as described in the note on " D^0 - \overline{D}^0 Mixing,' above. The experiments usually present $x \equiv \Delta m/\Gamma$. Then $\Delta m = x \Gamma = x \hbar/\tau$.

"OUR EVALUATION" comes from averages provided by the Heavy Flavor Averaging Group, see the note on " \mathcal{D}^0 - $\overline{\mathcal{D}}^0$ Mixing."

VALUE (10¹⁰ ħ s⁻¹) CL% DOCUMENT ID TECN COMMENT

1.44 $\substack{+0.48 \\ -0.50}$ OUR EVALUATION

1.0 ±0.8 OUR AVERAGE Error includes scale factor of 1.5.

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | 0 0 | | | |
|--------------------------------|----|------------------------|------|------|--------------------------|
| 6.4 $^{+1.4}_{-1.7}$ ± 1.0 | | ³ AUBERT | 09A1 | BABR | e^+e^- at 10.58 GeV |
| $-2 {}^{+7}_{-6}$ | | ⁴ LOWREY | 09 | CLEO | e^+e^- at $\psi(3770)$ |
| < 7 | 95 | ⁵ ZHANG | 06 | BELL | e^+e^- |
| -11 to $+22$ | | ² A SNER | 05 | CLEO | e^+e^-pprox 10 GeV |
| < 11 | 90 | BITENC | 05 | BELL | |
| < 30 | 90 | CAWLFIELD | 05 | CLEO | |
| < 7 | 95 | ⁵ LI | 05 A | BELL | See ZHANG 06 |
| < 22 | 95 | ⁶ LINK | 05н | FOCS | γ nucleus |
| < 23 | 95 | AUBERT | 04 Q | BABR | |
| < 11 | 95 | ⁵ AUBERT | 03z | BABR | $e^{+}e^{-}$, 10.6 GeV |
| < 7 | 95 | ⁷ godang | 00 | CLE2 | e^+e^- |
| < 32 | 90 | ^{8,9} AITALA | 98 | E791 | π^- nucleus, 500 GeV |
| < 24 | 90 | ¹⁰ AITALA | 96c | E791 | π^- nucleus, 500 GeV |
| < 21 | 90 | ^{9,11} A NJOS | 88c | E691 | Photoproduction |
| | | | | | |

 1 DEL-AMO-SANCHEZ 10D uses 540,800 \pm 800 K_S^0 π^+ π^- and 79,900 \pm 300 K_S^0 K^+ K^- events in a time-dependent amplitude analysis of the D^0 and \overline{D}^0 Dalitz plots. No evidence was found for $\it CP$ violation, and the values here assume no such violation.

 2 The ASNER 05 and ZHANG 07B values are from the time-dependent Dalitz-plot analysis of $D^0 \rightarrow \ K^0_0 \pi^+ \pi^-$. Decay-time information and interference on the Dalitz plot are used to distinguish doubly Cabibbo-suppressed decays from mixing and to measure the relative phase between $D^0 \rightarrow \ K^{*+} \pi^-$ and $\overline{D}^0 \rightarrow \ K^{*+} \pi^-$. This value allows CP violation and is sensitive to the sign of Δm .

 3 The AUBERT 09AN values are inferred from the branching ratio $\Gamma(D^0\to K^+\pi^-\pi^0$ via $\overline{D}^0)/\Gamma(D^0\to K^-\pi^+\pi^0)$ given near the end of this Listings. Mixing is distinguished from DCS decays using decay-time information. Interference between mixing and DCS is allowed. The phase between $D^0\to K^+\pi^-\pi^0$ and $\overline{D}^0\to K^+\pi^-\pi^0$ is assumed to be small. The width difference here is $y^{\prime\prime}$, which is not the same as y_{CP} in the note on $D^0-\overline{D}^0$ mixing.

 4 LOWREY 09 uses quantum correlations in $e^+e^-\to D^0\overline{D}^0$ at the $\psi(3770)$. See below for coherence factors and average relative strong phases for both $D^0\to K^-\pi^+\pi^0$ and $D^0\to K^-\pi^-2\pi^+$. A fit that includes external measurements of charm mixing parameters gets $\Delta m=(2.34\pm0.61)\times10^{10}~\hbar\,\mathrm{s}^{-1}$.

⁵ The AUBERT 03z, LI 05A, and ZHANG 06 limits are inferred from the $D^0-\overline{D}^0$ mixing ratio $\Gamma(K^+\pi^-)$ (via \overline{D}^0))/ $\Gamma(K^-\pi^+)$ given near the end of this D^0 Listings. Decaytime information is used to distinguish DCS decays from $D^0-\overline{D}^0$ mixing. The limit allows interference between the DCS and mixing ratios, and also allows CP violation. AUBERT 03z assumes the strong phase between $D^0\to K^+\pi^-$ and $\overline{D}^0\to K^+\pi^-$ amplitudes is small; if an arbitrary phase is allowed, the limit degrades by 20%. The LI 05A and ZHANG 06 limits are valid for an arbitrary strong phase. 6 This LINK 05H limit is inferred from the $D^0-\overline{D}^0$ mixing ratio $\Gamma(K^+\pi^-)$ (via \overline{D}^0) with \overline{D}^0 mixing ratio $\Gamma(K^+\pi^-)$ (via \overline{D}^0) with \overline{D}^0 0.

⁶This LINK 05H limit is inferred from the $D^0-\overline{D}^0$ mixing ratio $\Gamma(K^+\pi^-)$ (via $\overline{D}^0))/\Gamma(K^-\pi^+)$ given near the end of this D^0 Listings. Decay-time information is used to distinguish DCS decays from $D^0-\overline{D}^0$ mixing. The limit allows interference between the DCS and mixing ratios, and also allows CP violation. The strong phase between $D^0\to K^+\pi^-$ and $\overline{D}^0\to K^+\pi^-$ is assumed to be small. If an arbitrary relative strong phase is allowed, the limit degrades by 25%.

⁸ AITALA 98 allows interference between the doubly Cabibbo-suppressed and mixing amplitudes, and also allows *CP* violation in this term, but assumes that $A_D = A_R = 0$. See the note on " $D^0 - \overline{D}^0$ Mixing," above.

⁹ This limit is inferred from R_M for $f=K^+\pi^-$ and $f=K^+\pi^-\pi^+\pi^-$. See the note on " $D^0-\overline{D}^0$ Mixing," above. Decay-time information is used to distinguish doubly Cabibbosuppressed decays from $D^0-\overline{D}^0$ mixing.

This limit is inferred from R_M for $f=K^+\ell^-\overline{\nu}_\ell$. See the note on " $D^0-\overline{D}^0$ Mixing,"

 D^0

$(\Gamma_{D_1^0} - \Gamma_{D_2^0})/\Gamma = 2y$

The D_1^0 and D_2^0 are the mass eigenstates of the D^0 meson, as described in the note on " $D^0 - \overline{D}^0$ Mixing," above.

Due to the strong phase difference between ${\it D}^{\,0} \,
ightarrow \, {\it K}^{\,+} \, \pi^{\,-}$ and ${\it \overline{D}}^{\,0} \,
ightarrow$ $K^+\pi^-$, we exclude from the average those measurements of y' that are inferred from the D^0 - \overline{D}^0 mixing ratio $\Gamma(K^+\pi^-)$ via $\overline{D}^0)$ / $\Gamma(K^+\pi^-)$ given near the end of this D^0 Listings.

Some early results have been omitted. See our 2006 Review (Journal of Physics, G 33 1 (2006)).

"OUR EVALUATION" comes from averages provided by the Heavy Flavor Averaging Group, see the note on " D^0 - \overline{D}^0 Mixing."

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
|------------------------------------------------------------------------|----------------------------|--------------------------------------------|--------------|------------|--------------------------------------------|--|--|--|
| | 1.60 + 0.25 OUR EVALUATION | | | | | | | |
| | AVERAGE | Error includes scale fa | ctor o | f 1.3. Se | ee the ideogram | | | |
| below. | | 1 | | | | | | |
| $0.55 \pm 0.63 \pm 0.4$ | | 1 AAIJ | | | pp at 7 TeV | | | |
| $1.14 \pm 0.40 \pm 0.3$ | | | | | e ⁺ e ⁻ , 10.6 GeV | | | |
| 2.32 ± 0.44 ± 0.3 | - | 3 AUBERT | | | $e^+e^-\approx \Upsilon(4S)$ | | | |
| 0.22 ± 1.22 ±1.0 | | ⁴ ZUPANC ⁵ STARIC | 09 | BELL | \ / | | | |
| 2.62 ± 0.64 ± 0.5 | | | 07 | BELL | () | | | |
| $0.74 \pm 0.50 {+0.2 \atop -0.3}$ | 534k | ⁶ ZHANG | 07в | BELL | $e^+e^-\approx \Upsilon(45)$ | | | |
| $-1.0 \pm 2.0 \begin{array}{l} +1.4 \\ -1.6 \end{array}$ | 18k | ⁷ ABE | 021 | BELL | $e^+e^- \approx \Upsilon(4S)$ | | | |
| $-2.4 \pm 5.0 \pm 2.8$ | 3393 | ⁸ CSOR NA | 02 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ | | | |
| 6.84 ± 2.78 ±1.4 | 3 10k | ⁷ LINK | 00 | FOCS | γ nucleus | | | |
| $+1.6 \pm 5.8 \pm 2.1$ | | ⁷ AITALA | 99E | E791 | $K^-\pi^+$, K^+K^- | | | |
| • • • We do not us | se the followin | g data for averages, fi | its, lin | nits, etc. | • • • | | | |
| $-0.12^{+}_{-}{}^{1.10}_{1.28}\!\pm\!0.6$ | 8 | ⁹ AUBERT | 09AN | BABR | e^+e^- at 10.58 GeV | | | |
| $1.4 \begin{array}{c} + & 4.8 \\ - & 5.4 \end{array}$ | | ¹⁰ LOWREY | 09 | CLEO | e^+e^- at $\psi(3770)$ | | | |
| 1.70 ± 1.52 | $12.7\pm0.3\text{k}$ | ¹¹ AALTONEN | 08E | CDF | $p\overline{p}$, $\sqrt{s}=1.96~{ m TeV}$ | | | |
| $2.06 \pm 0.66 \pm 0.3$ | В | 12 AUBERT | 0 8 U | BABR | See AUBERT 09AI | | | |
| $1.94 \pm 0.88 \pm 0.6$ | $2\ 4030 \pm 90$ | ¹¹ AUBERT | 07w | BABR | e^+e^-pprox 10.6 GeV | | | |
| -0.7 ± 4.9 | $4k \pm 88$ | 11,13 ZHANG | 06 | BELL | e+e- | | | |
| $-3.0 ^{+}_{-} \overset{5.0}{4.8} \overset{+}{-} \overset{1.6}{0.8}$ | | ⁶ ASNER | 05 | CLEO | e^+e^-pprox 10 GeV | | | |
| -0.3 ± 5.7 | | 11,13 _{LI} | 05 A | BELL | See ZHANG 06 | | | |
| $-5.2 \begin{array}{l} +18.4 \\ -16.8 \end{array}$ | | ^{11,13} LINK | 05 н | FOCS | γ nucleus | | | |
| $1.6 \pm 0.8 ^{+1.0}_{-0.8}$ | 450k | ¹⁴ AUBERT | 03P | BABR | See AUBERT 080 | | | |
| $1.6 \begin{array}{l} + & 6.2 \\ - & 12.8 \end{array}$ | | ^{11,13} AUBERT | 03z | BABR | e^+e^- , $10.6~{ m GeV}$ | | | |
| $-5.0 \ \ ^{+}_{-} \ \ ^{2.8}_{3.2} \ \pm 0.6$ | | ¹¹ GODANG | 00 | CLE2 | e^+e^- | | | |

 1 Compared the lifetimes of D^0 decay to the *CP* eigenstate K^+K^- with D^0 decay to

 $^{+}K^-$. The values here assume no CP violation. 2 DEL-AMO-SANCHEZ 10D uses 540,800 \pm 800 $K_{S}^{0}\pi^{+}\pi^{-}$ and 79,900 \pm 300 $K_{S}^{0}K^{+}K^{-}$ events in a time-dependent amplitude analyses of the D^0 and $\overline{D}{}^0$ Dalitz plots. No

evidence was found for CP violation, and the values here assume no such violation. ³ This combines the $y_{CP}=(\tau_{K\pi}/\tau_{KK})-1$ using untagged $K^-\pi^+$ and K^-K^+ events of AUBERT 09AI with the disjoint y_{CP} using tagged $K^-\pi^+$, K^-K^+ , and $\pi^-\pi^+$ events of AUBERT 08U. ⁴ ZUPANC 09 uses a method based on measuring the mean decay time of $D^0 \to D^0$

 $K_S^0 K^+ K^-$ events for different $K^+ K^-$ mass intervals.

 5 STARIC 07 compares the lifetimes of ${\it D}^{\,0}$ decay to the ${\it CP}$ eigenstates ${\it K}^+{\it K}^-$ and $\pi^+\pi^-$ with D^0 decay to $K^-\pi^+$

⁶ The ASNER 05 and ZHANG 07B values are from the time-dependent Dalitz-plot analysis of $D^0 \to K^0_S \pi^+ \pi^-$. Decay-time information and interference on the Dalitz plot are used to distinguish doubly Cabibbo-suppressed decays from mixing and to measure the relative phase between $D^0 \to K^{*+}\pi^-$ and $\overline{D}^0 \to K^{*+}\pi^-$. This limit allows CP

violation. 7 LINK 00, AITALA 99E, and ABE 02I measure the lifetime difference between $D^0 \to K^-K^+$ (CP even) decays and $D^0 \to K^-\pi^+$ (CP mixed) decays, or $y_{CP} = \frac{[\Gamma(CP+)-\Gamma(CP-)]/[\Gamma(CP+)+\Gamma(CP-)]}{[\Gamma(CP+)+\Gamma(CP-)]}$. We list $2y_{CP} = \Delta\Gamma/\Gamma$

CSORNA 02 measures the lifetime difference between $D^0 \to K^-K^+$ and $\pi^-\pi^+$ (CP-even) decays and $D^0 \to K^-\pi^+$ (CP-mixed) decays, or $y_{CP} = \frac{[\Gamma(CP+)-\Gamma(CP-)]/[\Gamma(CP+)+\Gamma(CP-)]}{[\Gamma(CP+)+\Gamma(CP-)]}$. We list $2y_{CP} = \Delta\Gamma/\Gamma$.

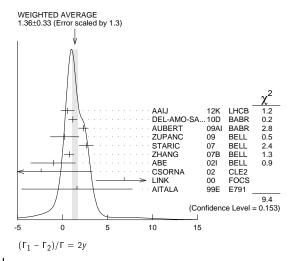
⁹ The AUBERT 09AN values are inferred from the branching ratio $\Gamma(D^0 \to K^+\pi^-\pi^0)$ via $\overline{D^0})/\Gamma(D^0\to K^-\pi^+\pi^0)$ given near the end of this Listings. Mixing is distinguished from DCS decays using decay-time information. Interference between mixing and DCS is allowed. The phase between $D^0\to K^+\pi^-\pi^0$ and $\overline{D}^0\to K^+\pi^-\pi^0$ is assumed to be small. The width difference here is y'', which is not the same as y_{CP} in the note on $D^0 - \overline{D}{}^0$ mixing.

 10 LOWREY 09 uses quantum correlations in $e^+e^- \to D^0 \overline{D}{}^0$ at the $\psi(3770)$. See below for coherence factors and average relative strong phases for both $D^0 \to K^-\pi^+\pi^0$ and $D^0 o K^-\pi^-2\pi^+$. A fit that includes external measurements of charm mixing parameters gets $2y = (1.62 \pm 0.32) \times 10^{-2}$

 11 The GODANG 00, AUBERT 03z, LINK 05H, LI 05A, ZHANG 06, AUBERT 07w, and AALTONEN 08E limits are inferred from the $D^0\!-\!\overline{D}^0$ mixing ratio $\Gamma(K^+\pi^-)$ (via $\overline{D}^0))/\Gamma(K^-\pi^+)$ given near the end of this D^0 Listings. Decay-time information is used to distinguish DCS decays from $D^0 - \overline{D}{}^0$ mixing. The limits allow interference between the DCS and mixing ratios, and all except AUBERT 07w and AALTONEN 08E also allow CP violation. The phase between $D^0 \to K^+ \pi^-$ and $\overline{D}{}^0 \to K^+ \pi^-$ is assumed to be small. This is a measurement of y^\prime and is not the same as the $y_{C\!P}$ of our note above on " $D^0 - \overline{D}{}^0$ Mixing."

 12 This value combines the results of AUBERT 08U and AUBERT 03P. 13 The ranges of AUBERT 032, LINK 05H, LI 05A, and ZHANG 06 measurements are for

195% confidence level. 14 AUBERT 03P measures Y $\equiv 2 \ \tau^0 \ / \ (\tau^+ + \tau^-) - 1$, where τ^0 is the $D^0 \to K^- \pi^+$ (and $\overline{D}{}^0 \to K^+\pi^-$) lifetime, and τ^+ and τ^- are the D^0 and $\overline{D}{}^0$ lifetimes to *CP*-even states (here K^-K^+ and $\pi^-\pi^+$). In the limit of *CP* conservation, $Y=y\equiv\Delta\Gamma/2\Gamma$ (we list $2y = \Delta\Gamma/\Gamma$). AUBERT 03P also uses $\tau^+ - \tau^-$ to get $\Delta Y = -0.008 \pm 0.006 \pm 0.002$.



The mass eigenstates D_1^0 and D_2^0 are related to the ${\it C}=\pm 1$ states by $|D_{1,2}>=$ p $|D^0\rangle + q |\overline{D}^0\rangle$. See the note on " $D^0-\overline{D}^0$ Mixing" above.

"OUR EVALUATION" comes from averages provided by the Heavy Flavor Averaging Group. This would include as-yet-unpublished results, see the note on " \mathcal{D}^0 - $\overline{\mathcal{D}}^0$

DO CUMENT ID TECN COMMENT **0.88** $^{+0.16}_{-0.15}$ **OUR EVALUATION** HFAG fit; see the note on " $D^0 - \overline{D}{}^0$ Mixing." $^{
m 1}$ ZHANG 07B BELL $e^+e^- \approx \Upsilon(4S)$

 1 The phase of p/q is $(-14^{+16}_{-18}\pm 5)^\circ$. The ZHANG 07B value is from the time-dependent Dalitz-plot analysis of $D^0\to \kappa^0_S\pi^+\pi^-$. Decay-time information and interference on the Dalitz plot are used to distinguish doubly Cabibbo-suppressed decays from mixing and to measure the relative phase between $D^0 \to K^{*+}\pi^-$ and $\overline{D}^0 \to K^{*+}\pi^-$. This

 ${\sf A}_{\Gamma}$ is the decay-rate asymmetry for *CP*-even final states ${\sf A}_{\Gamma}=(\overline{\tau}_+-\tau_+)/(\overline{\tau}_++\tau_+)$. See the note on " $D^0 - \overline{D}{}^0$ Mixing" above.

| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------|------------------------|----------|---------|---------------------------------------------------|
| 0.26 ± 2.31 OUR EVALUATION | ON | | | |
| 0.3 ±2.5 OUR AVERAGE | | | | |
| $-5.9 \pm 5.9 \pm 2.1$ | AAIJ | 12K | LHCB | pp at 7 TeV |
| $+2.6 \pm 3.6 \pm 0.8$ | AUBERT | 08u | BABR | $e^+e^-pprox \Upsilon(4S)$ |
| $+0.1 \pm 3.0 \pm 2.5$ | STARIC | 07 | BELL | $e^+e^- \approx \Upsilon(4S)$ |
| • • • We do not use the follow | ving data for averages | s, fits, | limits, | etc. • • • |
| $+8$ ± 6 ± 2 | AUBERT | 03P | BABR | $e^+e^- \approx \Upsilon(4S)$ |
| $\cos \delta$ | | | | |
| δ is the $D^0 ightarrow ~K^+ \pi^-$ i | elative strong phase. | | | |
| VALUE | | TEC | CON | IMENT |
| $1.03^{+0.31}_{-0.17} \pm 0.06$ | ASNER 08 | CLE | 0 e+ | $e^- \rightarrow D^0 \overline{D}{}^0$, 3.77 GeV |

¹ ASNER 08 uses quantum correlations in $e^+e^- \rightarrow D^0 \overline{D}{}^0$ at the $\psi(3770)$, where decay rates of CP-tagged $K\pi$ final states depend on $\cos\delta$ because of interfering amplitudes. The above measurement implies $|\delta| < 75^\circ$ with a confidence level of 95%. A fit that includes external measurements of charm mixing parameters finds $\cos\delta = 1.10 \pm 0.35 \pm 0.35 \pm 0.35$ 0.07. See also the note on " $D^0 - \overline{D}^0$ Mixing" p. 783 in our 2008 Review (PDG 08).

 $^{^{11}}$ ANJOS 88c assumes that y=0. See the note on " D^0 - $\overline{D}{}^0$ Mixing," above. Without this assumption, the limit degrades by about a factor of two.

$D^0 ightarrow \ K^-\pi^+\pi^0$ coherence factor $R_{K\pi\pi^0}$

See the note on ' D^0 - \overline{D}^0 Mixing' for the definition. $R_{K\pi\pi^0}$ can have any value between 0 and 1. A value near 1 indicates the decay is dominated by a few intermediate states

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|------------------------|---------------------|----|------|-----------------------|---------------------------------------|
| $0.78 + 0.11 \\ -0.25$ | ¹ LOWREY | 09 | CLEO | $e^+ e^- \rightarrow$ | $D^0\overline{D}{}^0$ at $\psi(3770)$ |

 $^{1}\,\mathrm{LOWREY}$ 09 uses quantum correlations in $e^{+}\,e^{-}\,\rightarrow\,\,D^{\,0}\,\overline{D}{}^{0}$ at the $\psi(\,3770\,)$, where the decay rates of *CP*-tagged $K^-\pi^+\pi^0$ final states depend on $R_{K\pi\pi^0}$ and $\delta^{K\pi\pi^0}$. A fit that includes external measurements of charm mixing parameters gets $R_{K\pi\pi^0}=0.84\pm0.07$

$D^0 ightarrow \ K^-\pi^+\pi^0$ AVERAGE RELATIVE STRONG PHASE $\delta^{K\pi\pi^0}$

| VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
|---------------|--------------|----|------|-----------------------------------------------------|------|
| 239+32 -28 | 1 LOWREY | 09 | CLEO | $e^+e^- \rightarrow D^0\overline{D}^0$ at $\psi(3)$ | 770) |

 $^1\,{\rm LOWREY}$ 09 uses quantum correlations in $e^+\,e^-\,\to\,\,D^{\,0}\,\overline{D}{}^{\,0}$ at the $\psi(\,3770\,)$, where the decay rates of CP-tagged $K^-\pi^+\pi^0$ final states depend on $R_{K\pi\pi^0}$ and $\delta^{K\pi\pi^0}$.

A fit that includes external measurements of charm mixing parameters gets $\delta^{K}\pi\pi^0=(227^{+14}_{-17})^\circ.$

$D^0 \rightarrow K^-\pi^-2\pi^+$ COHERENCE FACTOR $R_{K3\pi}$

See the note on ' D^0 - \overline{D}^0 Mixing' for the definition. $R_{K3\pi}$ can have any value between 0 and 1. A value near 1 indicates the decay is dominated by a few intermediate states with limited interference.

| VALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT | |
|-------------|---------------------|----|------|---------------------|---------------------------------------|
| 0.36 + 0.24 | ¹ LOWREY | 09 | CLEO | $e^+e^ \rightarrow$ | $D^0\overline{D}{}^0$ at $\psi(3770)$ |

 1 LOWREY 09 uses quantum correlations in $e^+\,e^-\,
ightarrow\,\,D^{\,0}\,\overline{D}{}^0$ at the $\psi($ 3770), where the decay rates of CP-tagged $K^-\pi^-2\pi^+$ final states depend on $R_{K3\pi}$ and $\delta^{K3\pi}$. A fit that includes external measurements of charm mixing parameters gets $R_{K3\pi}=$

$D^0 \rightarrow K^-\pi^- 2\pi^+$ AVERAGE RELATIVE STRONG PHASE $\delta^{K3\pi}$

| <i>D</i> → <i>N N</i> 2 <i>N</i> | AVEIVAGE IVEEA I | VE SINO | MO I HASE | , |
|----------------------------------|---------------------|---------|--------------------------|---------------------------------------|
| VALUE (°) | DO CUMENT ID | TECN | COMMENT | |
| 118 + 62 -53 | ¹ LOWREY | 09 CLE | $e^+e^- \rightarrow e^-$ | $D^0\overline{D}{}^0$ at $\psi(3770)$ |

 1 LOWREY 09 uses quantum correlations in $e^{+}\,e^{-}$ \rightarrow $D^{\,0}\,\overline{D}{}^{\,0}$ at the $\psi(3770)$, where the decay rates of CP-tagged $K^-\pi^-2\pi^+$ final states depend on $R_{K\,3\pi}$ and $\delta^{K\,3\pi}$ A fit that includes external measurements of charm mixing parameters gets $\delta^{K\,3\pi}=(114^{+\,26}_{-\,23})^\circ.$

D⁰ DECAY MODES

Most decay modes (other than the semileptonic modes) that involve a neutral K meson are now given as $K_{\mathcal{S}}^0$ modes, not as \overline{K}^0 modes. Nearly always and doubly Cabibbo-suppressed modes can invalidate the assumption that $2\Gamma(K_0^S)=\Gamma(\overline{K}^0).$ it is a K_S^0 that is measured, and interference between Cabibbo-allowed

| | Mode | | | Fraction (| Γ _i . | /Γ) | | | ale factor/ lence level |
|-----------------|---------------------|----------------------------------------|-----|------------|------------------|------|-----|-----------|----------------------------|
| | | Topological | mo | odes | | | | | |
| Γ ₁ | $D^0 \rightarrow$ | 0-prongs | [a] | (15 | ± | 6 |) % | | |
| Γ_2 | | 2-prongs | • • | (70 | ± | 6 |) % | | |
| Γ3 | $D^0 \rightarrow$ | 4-prongs | [b] | (14.5 | \pm | 0.5 |) % | | |
| Γ_4 | $D^0 \rightarrow$ | 6-prongs | [c] | (6.4 | \pm | 1.3 |) × | 10^{-4} | |
| | | Inclusive r | mod | es | | | | | |
| Γ_5 | $D^0 \rightarrow$ | e ⁺ anything | | (6.49 | ± | 0.11 |) % | | |
| Γ ₆ | $D^0 \rightarrow$ | μ^+ anything | | (6.7 | \pm | 0.6 |) % | | |
| Γ ₇ | $D^0 \rightarrow$ | K [−] anything | | (54.7 | \pm | 2.8 |) % | | S=1.3 |
| Γ8 | $D^0 \rightarrow$ | \overline{K}^0 anything $+ K^0$ any- | | (47 | \pm | 4 |) % | | |
| | thir | | | | | | | | |
| Г9 | | K ⁺ anything | | (3.4 | | | | | |
| Γ_{10} | $D^0 \rightarrow$ | <u>K</u> *(892) anything | | (15 | \pm | 9 |) % | | |
| Γ_{11} | $D_0^0 \rightarrow$ | $\overline{K}^*(892)^0$ anything | | (9 | \pm | 4 |) % | | |
| Γ_{12} | $D^0 \rightarrow$ | K*(892)+ anything | | < 3.6 | | | % | | CL=90% |
| Γ_{13} | | K*(892) ⁰ anything | | (2.8 | \pm | 1.3 |) % | | |
| Γ_{14} | | η anything | | (9.5 | | | | | |
| Γ_{15} | | η' anything | | (2.48 | \pm | 0.27 |) % | | |
| Γ_{16} | $D^0 \rightarrow$ | ϕ anything | | (1.05 | ± | 0.11 |) % | | |
| | | Semileptoni | c m | odes | | | | | |
| | | $K^-\ell^+ u_\ell$ | | | | | | | |
| Γ ₁₈ | $D^0 \rightarrow$ | $K^-e^+ u_e$ | | (3.55 | \pm | 0.04 |) % | | S=1.2 |
| Γ ₁₉ | $D^0 \rightarrow$ | $K^-\mu^+ u_\mu$ | | (3.30 | \pm | 0.13 |) % | | |
| Γ_{20} | $D^0 \rightarrow$ | $K^*(892)^-e^+\nu_e$ | | (2.16 | ± | 0.16 |) % | | |
| Γ ₂₁ | $D^0 \rightarrow$ | $K^*(892)^- \mu^+ \nu_{\mu}$ | | (1.90 | | | - | | |
| Γ ₂₂ | | $K^-\pi^0 e^+ \nu_e$ | | (1.6 | | | - | | |
| | | | | | | | | | |

| | | | | | | | | D |
|------------------------------------|---------------------------------------------------------------------------------------------------------|--------------|----------------|-------|--------------|---|--------------------|---------------|
| Γ ₂₃ | $D^0 ightarrow \overline{K}{}^0 \pi^- e^+ u_e$ | | (2.7 | + | 0.9 0.7 |) | % | |
| Γ ₂₄ | $D^0 ightarrow K^-\pi^+\pi^-e^+ u_e$ | | (2.8 | | | | × 10 ⁻⁴ | |
| Γ ₂₅ | $D^0 \to K_1(1270)^- e^+ u_e$ | | (7.6 | | |) | ×10 ⁻⁴ | |
| Γ ₂₆ | $D^0 \rightarrow K^-\pi^+\pi^-\mu^+ u_\mu$ | | < 1.2 | | | | $\times 10^{-3}$ | CL=90% |
| Γ ₂₇ | $D^0 \to (\overline{K}^*(892)\pi)^- \mu^+ \nu_{\mu}$ | | < 1.4 | | | | $\times 10^{-3}$ | CL=90% |
| Γ ₂₈ | $D^0 \rightarrow \pi^- e^+ \nu_e$ | | (2.89 | \pm | 0.08 |) | $\times 10^{-3}$ | S=1.1 |
| Γ ₂₉ | $D^0 \rightarrow \pi^- \mu^+ \nu_\mu$ | | | | | | $\times 10^{-3}$ | |
| Γ ₃₀ | $D^0 ightarrow ho^- e^+ u_e^-$ | | (1.9 | ± | 0.4 |) | ×10 ⁻³ | |
| F | $D^0 ightarrow K^- \pi^+$ | wit | | | 0.05 | , | 0/ | 6 10 |
| Г ₃₁ Г ₃₂ | $D^0 \rightarrow K \pi^0$ $D^0 \rightarrow K_S^0 \pi^0$ | | (3.88 | | | | | S=1.2 |
| Γ ₃₃ | $D^0 \rightarrow K_0^0 \pi^0$ | | (10.0 | | | | × 10 ⁻³ | |
| Γ ₃₄ | $D^0 \rightarrow \kappa_S^{\dagger} \pi^+ \pi^-$ | [e] | | | | | | S=1.1 |
| Г ₃₅ | $D^0 ightarrow \stackrel{\circ}{\mathcal{K}_S^0} ho^0$ | | (6.3 | + | 0.7 |) | $\times10^{-3}$ | |
| Γ ₃₆ | $D^0 ightarrow ~ {\cal K}^0_S \omega$, $\omega ightarrow ~ \pi^+ \pi^-$ | | | | | | ×10 ⁻⁴ | |
| Γ ₃₇ | $D^0 \rightarrow K_S^0(\pi^+\pi^-)_{S-\text{wave}}$ | | (3.4 | ± | 0.8 |) | ×10 ⁻³ | |
| Γ ₃₈ | $D^0 \rightarrow K_S^0 f_0(980)$, | | (121 | | | | $\times 10^{-3}$ | |
| . 30 | $f_0(980) \to \pi^+\pi^-$ | | (1.11 | _ | 0.24 | , | | |
| Γ ₃₉ | $D^0 \to K_S^0 f_0(1370)$, | | (2.8 | + | 0.9 | ١ | $\times 10^{-3}$ | |
| . 39 | $f_0(1370) \to \pi^+ \pi^-$ | | (2.0 | - | 1.3 | , | | |
| Γ ₄₀ | $D^0 \to K_S^0 f_2(1270)$, | | (9 | + | 10 |) | ×10 ⁻⁵ | |
| 40 | $f_2(1270) \rightarrow \pi^+\pi^-$ | | , - | _ | ь | , | | |
| Γ ₄₁ | $D^0 \to K^*(892)^- \pi^+$, | | (1.66 | + | 0.15 |) | % | |
| . 41 | $K^*(892)^- \rightarrow K_S^0 \pi^-$ | | (| _ | 0.17 | , | | |
| Γ_{42} | $D^0 	o \ K_0^*(1430)^- \pi^+$, | | (2.69 | + | 0.40 |) | $\times10^{-3}$ | |
| | $K_0^*(1430)^- \to K_S^0 \pi^-$ | | , | _ | 0.33 | • | | |
| Γ ₄₃ | $D^0 	o K_2^*(1430)^- \pi^+$, | | (3.4 | + | 1.9 |) | ×10 ⁻⁴ | |
| -13 | $K_2^*(1430)^- \to K_S^0 \pi^-$ | | | _ | 1.0 | ĺ | | |
| Γ_{44} | $D^0 \to K^*(1680)^- \pi^+$, | | (4 | \pm | 4 |) | $\times 10^{-4}$ | |
| | $K^*(1680)^- \to K_S^0 \pi^-$ | | | | | | | |
| Γ_{45} | $D^0 \to K^*(892)^+ \pi^-,$ | [<i>f</i>] | (1.13 | + | 0.60 0.34 |) | $\times10^{-4}$ | |
| _ | $K^*(892)^+ \rightarrow K_S^0 \pi^+$ | | | | | | 5 | |
| Γ ₄₆ | $D^0 \to K_0^*(1430)^+ \pi^-$, | [†] | < 1.4 | | | | × 10 ⁻³ | CL=95% |
| Γ ₄₇ | $K_0^*(1430)^+ 	o K_S^0 \pi^+ \ D^0 	o K_2^*(1430)^+ \pi^- ,$ | [<i>f</i>] | < 3.4 | | | | v 10−5 | CL=95% |
| . 47 | $K_2^*(1430)^+ \rightarrow K_5^0 \pi^+$ | [1] | | | | | A 10 | CL = 30 70 |
| Γ ₄₈ | $D^0 \rightarrow K_S^0 \pi^+ \pi^-$ nonresonant | | (2.5 | + | 6.0 1.6 | ١ | ×10 ⁻⁴ | |
| Γ ₄₉ | $D^0 \rightarrow K^- \pi^+ \pi^0$ | [a] | | | |) | | S=1.7 |
| Γ ₅₀ | $D^0 \rightarrow K^- \rho^+$ | [<i>e</i>] | (13.9 (10.8 | | |) | | 3_1.7 |
| Γ ₅₁ | $D^0 \to K^- \rho (1700)^+$ | | (7.9 | | | | ×10 ⁻³ | |
| | $ ho(1700)^+ \rightarrow \pi^+ \pi^0$ | | | | | | | |
| Γ_{52} | $D^0 	o K^*(892)^- \pi^+$, | | (2.22 | + | 0.40 |) | % | |
| _ | $K^*(892)^- \to K^-\pi^0$ | | | | | | | |
| Γ ₅₃ | $D^0 \to \overline{K}^*(892)^0 \pi^0$, $\overline{K}^*(892)^0 \to K^- \pi^+$ | | (1.88 | ± | 0.23 |) | % | |
| Γ ₅₄ | $D^0 \to K_0^*(1430)^- \pi^+$, | | (4.6 | ± | 2.1 |) | ×10 ⁻³ | |
| 34 | $K_0^*(1430)^- \to K^-\pi^0$ | | , | | | , | | |
| Γ ₅₅ | $D^0 	o \ \overline{K}_0^* (1430)^0 \pi^0$, | | (5.7 | + | 5.0 |) | $\times 10^{-3}$ | |
| . 55 | $\overline{K}_0^*(1430)^0 \to K^-\pi^+$ | | (0 | _ | 1.5 | , | | |
| Γ ₅₆ | $D^0 \stackrel{\leftarrow}{\to} K^*(1680)^- \pi^+, \ K^*(1680)^- \stackrel{\rightarrow}{\to} K^- \pi^0$ | | (1.8 | \pm | 0.7 |) | $\times 10^{-3}$ | |
| | $K^*(1680)^- \rightarrow K^-\pi^0$ | | | | | | | |
| Γ_{57} | $D^0 ightarrow \ K^- \pi^+ \pi^0$ nonresonant | | (1.11 | + | 0.50 |) | % | |
| Γ_{58} | $D^0 \rightarrow K_S^0 2\pi^0$ | | (9.1 | \pm | 1.1 |) | $\times 10^{-3}$ | S=2.2 |
| Γ_{59} | $D^0 ightarrow K_S^0 (2\pi^0)$ - S-wave | | (2.6 | | | | $\times 10^{-3}$ | |
| Γ ₆₀ | $D^0 \to \overline{K}^*(892)^0 \pi^0, \ \overline{K}^*(892)^0 \to K^0_S \pi^0$ | | (7.8 | ± | 0.7 |) | $\times 10^{-3}$ | |
| Γ | $D^0 \rightarrow \overline{K}^*(1430)^0 \pi^0, \overline{K}^{*0} \rightarrow$ | | (A | J. | 23 | ١ | × 10-5 | |
| Γ ₆₁ | $\mathcal{L} \rightarrow \mathcal{K}_{c}^{0} \pi^{0}$ | | (4 | ± | ۷3 | J | ×10 ⁻⁵ | |
| Γ ₆₂ | $K_S^0 \pi^0$ $D^0 \to \overline{K}^* (1680)^0 \pi^0, \overline{K}^{*0} \to$ | | (1.0 | ± | 0.4 |) | $\times 10^{-3}$ | |
| | $K_S^0 \pi^0$ $D^0 ightarrow K_S^0 f_2(1270), f_2 ightarrow$ | | | | | | | |
| Γ ₆₃ | $D^0 \to K_S^0 f_2(1270), f_2 \to$ | | (2.3 | ± | 1.1 |) | $\times 10^{-4}$ | |
| Γ ₆₄ | $D^0 \stackrel{2\pi^0}{\rightarrow} 2K_S^0$, one $K_S^0 \rightarrow 2\pi^0$ | | (32 | + | 1.1 | ١ | ×10 ⁻⁴ | |
| Γ ₆₅ | $D^0 \rightarrow K_S^0 2\pi^0$ nonresonant | | (3.2 | 1 | 1.1 | , | A 10 | |
| Γ ₆₆ | $D^0 \rightarrow K^- 2\pi^+ \pi^-$ | [e] | (8.07 | + | 0.21 | ١ | % | S=1.3 |
| ' 66 | 2 / N 2N N | [c] | (0.07 | - | 0.19 |) | /0 | <i>3</i> =1,3 |

D^0

| Г ₆₇ | $D^0 ightarrow \ K^- \pi^+ ho^0 { m total}$ | (6.74 ± 0.33) % | Hadronic modes with three K's |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Γ ₆₈ | $D^0 \rightarrow K^- \pi^+ \rho^0$ 3-body | $(5.1 \pm 2.3) \times 10^{-3}$ | $\Gamma_{117} \ D^0 \rightarrow \ K_S^0 \ K^+ K^- \ (4.45 \pm 0.34) \times 10^{-3}$ |
| Γ ₆₉ | $D^0 \to \overline{K}^*(892)^0 \rho^0$ | (1.05 ± 0.23) % | $\Gamma_{118} \qquad D^0 ightarrow \; K_S^0 a_0 (980)^0 \; , \; a_0^0 ightarrow \qquad (\; 3.0 \; \pm \; 0.4 \; \;) 	imes 10^{-3}$ |
| | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | | |
| Γ_{70} | $D^0 ightarrow~K^-a_1(1260)^+$, | $(3.6 \pm 0.6)\%$ | Γ_{119} $D^0 \stackrel{K^+ K^-}{\to} K^- a_0(980)^+, a_0^+ \to (6.0 \pm 1.8) \times 10^{-4}$ |
| _ | $a_1(1260)^+ \rightarrow 2\pi^+\pi^-$ | | $K^+K^0_{S}$ |
| Γ ₇₁ | $D^0 \to \overline{K}^*(892)^0 \pi^+ \pi^- \text{total},$ | (1.6 ± 0.4) % | $\Gamma_{120} D^0 \to K^+ a_0(980)^-, a_0^- \to < 1.1 \times 10^{-4} CL = 95\%$ |
| _ | $\overline{K}^*(892)^{0} \rightarrow K^-\pi^+$ | (0 0 1 0 0) 10=3 | $K^-K^0_S$ Γ_{121} $D^0 	o K^0_S f_0(980), f_0 	o < 9$ $	imes 10^{-5}$ CL=95% |
| Γ ₇₂ | $D^0 \to \overline{K}^*(892)^0 \pi^+ \pi^- 3$ | $(9.9 \pm 2.3) \times 10^{-3}$ | |
| | $rac{	extsf{b ody,}}{K^*(892)^0} ightarrow K^-\pi^+$ | | $\Gamma_{122} D^0 \stackrel{K^+ K^-}{\to K_S^0} \phi, \phi \to K^+ K^- $ (2.04 ± 0.16) × 10 ⁻³ |
| Γ ₇₃ | $D^0 \to K_1(1270)^- \pi^+$, | [g] $(2.9 \pm 0.3) \times 10^{-3}$ | $\Gamma_{122} \qquad D^0 \to K_S^0 \phi, \phi \to K^+ K^- \qquad (2.04 \pm 0.16) \times 10^{-3}$ |
| . 13 | $K_1(1270)^- \to K^- \pi^+ \pi^-$ | 101 (2.1 = 1.1) | $\Gamma_{123} 	 D^0 	o 	imes 	ilde{K}_0^{\tilde{0}} f_0(1370), f_0 	o 	 (1.7 \pm 1.1) 	imes 10^{-4}$ |
| Γ_{74} | $D^0 \stackrel{\frown}{\rightarrow} K^- 2\pi^+ \pi^-$ nonreso- | (1.88 ± 0.26) % | $K^+ K^- \atop \Gamma_{124} D^0 \to 3K_S^0$ (9.1 ± 1.3)×10 ⁻⁴ |
| _ | $D^0 \stackrel{nant}{	o} \overset{\mathcal{K}^0_S}{\mathcal{K}^0_S} \pi^+ \pi^- \pi^0$ | | $\Gamma_{124} D \rightarrow 5K_5$ (9.1 ± 1.3)×10 $\Gamma_{125} D^0 \rightarrow K^+ 2K^- \pi^+$ (2.21 ± 0.31)×10 ⁻⁴ |
| Γ ₇₅ | $D^0 \rightarrow K_S^0 \pi^+ \pi^- \pi^0$ | [h] (5.2 ± 0.6)% | $\Gamma_{126} D^0 \rightarrow K^+ K^- \overline{K}^* (892)^0, \qquad (2.21 \pm 0.31) \times 10^{-5}$ |
| Γ ₇₆ | $D^0 ightarrow K_S^0 \eta$, $\eta ightarrow \pi^+ \pi^- \pi^0$ $D^0 ightarrow K_S^0 \omega$, $\omega ightarrow \pi^+ \pi^- \pi^0$ | $(1.02 \pm 0.09) \times 10^{-3}$ | $\overline{K}^*(892)^0 \to K^-\pi^+$ |
| Γ ₇₇ | $D^0 \rightarrow K_S^* \omega, \omega \rightarrow \pi^+ \pi^- \pi^0$ $D^0 \rightarrow K^- \pi^+ 2\pi^0$ | $(9.9 \pm 0.5) \times 10^{-3}$ | Γ_{127} $D^0 \rightarrow K^- \pi^+ \phi$, $\phi \rightarrow$ $(4.0 \pm 1.7) \times 10^{-5}$ |
| Γ ₇₈ | $D^0 \rightarrow K \pi^+ 2\pi^0$ $D^0 \rightarrow K^- 2\pi^+ \pi^- \pi^0$ | (| K+ K- |
| Γ ₇₉ Γ ₈₀ | $D^0 \rightarrow \overline{K} \stackrel{2\pi^+\pi^-\pi^0}{\overline{K}^*(892)^0} \pi^+\pi^-\pi^0$, | $\begin{pmatrix} 4.2 & \pm & 0.4 & \end{pmatrix} \%$ $\begin{pmatrix} 1.3 & \pm & 0.6 & \end{pmatrix} \%$ | |
| ' 80 | $\overline{K}^*(892)^0 \rightarrow K^-\pi^+$ | (1.5 ± 0.0) /6 | $rac{\phi ightarrow K^+ K^-}{K^*(892)^0 ightarrow K^- \pi^+}$ |
| Γ ₈₁ | $D^0 \rightarrow K^-\pi^+\omega$. $\omega \rightarrow$ | (2.7 ± 0.5) % | Γ_{129} $D^0 \rightarrow K^+ 2K^- \pi^+$ nonreso- $(3.3 \pm 1.5) \times 10^{-5}$ |
| | $D^{0} \stackrel{\pi^{+}\pi^{-}\pi^{0}}{\to} K^{*}(892)^{0}\omega$, | · · · · · · · · · · · · · · · · · · · | |
| Γ ₈₂ | $D^{\circ} \rightarrow K^*(892)^{\circ} \omega$, | $(6.5 \pm 3.0) \times 10^{-3}$ | $\Gamma_{130} \ D^0 \stackrel{\text{nant}}{	o} 2K_S^0 K^{\pm} \pi^{\mp} \qquad \qquad (6.0 \pm 1.3) \times 10^{-4}$ |
| | $\overline{K}^*(892)^0 \to K^-\pi^+,$ | | Pionic modes |
| Γ ₈₃ | $D^0 \to \overset{\omega}{\overset{\to}{\overset{\to}{K_S^0}}} \overset{\pi^+}{\eta^{\pi^0}} \pi^{-1} \pi^{0}$ | $(5.5 \pm 1.1) \times 10^{-3}$ | $\Gamma_{131} D^0 \rightarrow \pi^+ \pi^- \qquad (1.401 \pm 0.027) \times 10^{-3} S=1.1$ |
| Γ ₈₄ | $D^0 \to K_S^0 a_0(980)$, | $(6.5 \pm 2.0) \times 10^{-3}$ | $\Gamma_{132} D^0 \rightarrow 2\pi^0$ (8.0 + 0.5)×10 ⁻⁴ |
| ٠. | $a_0(980) \to \eta \pi^0$ | | $\Gamma_{133} D^0 \to \pi^+ \pi^- \pi^0$ (1.43 ± 0.06)% S=1.9 |
| Γ ₈₅ | $D^0 \xrightarrow{\overline{K}^*} \overline{K}^*(892)^{\stackrel{\circ}{0}} \eta$, $\overline{K}^*(892)^0 K_S^0 \pi^0$ | $(1.6 \pm 0.5) \times 10^{-3}$ | $\Gamma_{134} D^0 \to \rho^+ \pi^- \qquad (9.8 \pm 0.4) \times 10^{-3}$ |
| | $\overline{K}^*(892)^0 \stackrel{\checkmark}{\rightarrow} K_S^0 \pi^0$ | | $\Gamma_{135} D^0 \to \rho^0 \pi^0$ (3.72 ± 0.22) × 10 ⁻³ |
| Γ ₈₆ | $D^0 \to K_S^0 2\pi^+ 2\pi^-$ | $(2.68 \pm 0.30) \times 10^{-3}$ | $\Gamma^{136}_{137} D^0 \to \rho^- \pi^+ \qquad (4.96 \pm 0.24) \times 10^{-3} \ \Gamma^{137}_{137} D^0 \to \rho (1450)^+ \pi^-, \qquad (1.6 \pm 2.0) \times 10^{-5}$ |
| Γ ₈₇ | $D^0 ightarrow \mathcal{K}^0_{\mathcal{S}} ho^0 \pi^+ \pi^-$, | $(1.1 \pm 0.7) \times 10^{-3}$ | Γ_{137} $D^0 	o ho (1450)^+ \pi^-$, $(1.6 \pm 2.0) 	imes 10^{-5}$ $ ho (1450)^+ 	o \pi^+ \pi^0$ |
| | no <i>K</i> *(892) [—] | | $\Gamma_{138} D^0 \xrightarrow{\rho(1450)^0} \pi^0, \qquad (4.3 \pm 1.9) \times 10^{-5}$ |
| Γ ₈₈ | $D^0 \to K^*(892)^- 2\pi^+ \pi^-$, | $(5 \pm 8) \times 10^{-4}$ | $\rho(1450)^0 \to \pi^+\pi^-$ |
| | $K^*(892)^- \to K^0_S \pi^-$, no | | $\Gamma_{139} D^0 \rightarrow \rho(1450)^- \pi^+, \qquad (2.6 \pm 0.4) \times 10^{-4}$ |
| Γ ₈₉ | $D^0 \stackrel{\rho^0}{\to} K^*(892)^- \rho^0 \pi^+$, | $(1.6 \pm 0.6) \times 10^{-3}$ | $\rho(1450)^- \to \pi^- \pi^0$ |
| 1 89 | $K^*(892)^- \rightarrow K_S^0 \pi^-$ | (1.0 ± 0.0) × 10 | Γ_{140} $D^0 \rho(1700)^+ \pi^-, \qquad (5.9 \pm 1.4) \times 10^{-4} \\ \rho(1700)^+ \pi^+ \pi^0$ |
| Γ ₉₀ | $D^0 \rightarrow K_S^0 2\pi^+ 2\pi^- \text{ nonreso-}$ | $< 1.2 \times 10^{-3} \text{ CL} = 90\%$ | $\Gamma_{141} \qquad D^0 \rightarrow \rho(1700)^0 \pi^0$, $(7.2 \pm 1.7) \times 10^{-4}$ |
| | | | $\rho(1700)^{0} \to \pi^{+}\pi^{-}$ |
| Γ ₉₁ | $D^0 \to \frac{\text{na nt}}{K^0} \pi^+ \pi^- 2\pi^0 (\pi^0)$ | | $\Gamma_{14.2} D^0 \to \rho(1700)^- \pi^+$, $(4.6 \pm 1.1) \times 10^{-4}$ |
| Γ_{92} | $D^0 \rightarrow K^- 3\pi^+ 2\pi^-$ | $(2.2 \pm 0.6) \times 10^{-4}$ | $\rho(1700)^- \rightarrow \pi^- \pi^0$ |
| | Fractions of many of the following n | nodes with resonances have already | Γ_{143} $D^0 \rightarrow f_0(980) \pi^0$, $f_0(980) \rightarrow$ (3.6 ± 0.8)×10 ⁻⁵ |
| | appeared above as submodes of partic | | $\Gamma_{144} \qquad D^0 \stackrel{\pi^+ \pi^-}{\to} f_0(500) \pi^0$, $f_0(500) \to (1.18 \pm 0.21) \times 10^{-4}$ |
| | for which there are only upper limits a | nd $\overline{K}^*(892) ho$ submodes only appear | $\pi^{+}\pi^{-}$ |
| - | below.) | | $\Gamma_{145} \qquad D_0^{0} \xrightarrow{\pi^+ \pi^-} (\pi^+ \pi^-)_{S \text{-wave } \pi^0}$ |
| Γ ₉₃ | $D^0 \rightarrow K_S^0 \eta$ | $(4.78 \pm 0.30) \times 10^{-3}$ | $\Gamma_{146} D^{\circ} \rightarrow \Gamma_0(1370)\pi^{\circ}, \qquad (5.3 \pm 2.0) \times 10^{-3}$ |
| Γ ₉₄ | $D^0 \rightarrow K_S^0 \omega$ | $(1.11 \pm 0.06)\%$ | $f_0(1370) \to \pi^+ \pi^-$ |
| Γ ₉₅ | $D^0 \to K_S^0 \eta'(958)$ | $(9.4 \pm 0.5) \times 10^{-3}$ | $\Gamma_{147} D^0 \to f_0(1500) \pi^0, \qquad (5.6 \pm 1.5) \times 10^{-5}$ |
| Г ₉₆ | $D^0 \rightarrow K^- a_1 (1260)^+ D^0 \rightarrow K^- a_2 (1320)^+$ | $(7.8 \pm 1.1)\%$ < 2 $\times 10^{-3}$ CL=90% | $f_0(1500) \rightarrow \pi^+ \pi^- \ \Gamma_{148} D^0 \rightarrow f_0(1710) \pi^0, \qquad (4.4 \pm 1.5) \times 10^{-5}$ |
| Г ₉₇ Г ₉₈ | $D^0 \rightarrow \overline{K}^*(892)^0 \pi^+ \pi^- \text{total}$ | < 2 × 10 ° CL=90% (2.4 ± 0.5) % | $f_0(1710) \rightarrow \pi^+\pi^-$ |
| г 98 Г99 | $D^0 \to \overline{K}^*(892)^0 \pi^+ \pi^- 3$ | (2.4 ± 0.5) % (1.48 ± 0.34) % | $\Gamma_{149} D^0 \to f_2(1270) \pi^0$, (1.89 ± 0.20) × 10 ⁻⁴ |
| ,, | body | , , , , , | $f_2(1270) \to \pi^+ \pi^-$ |
| Γ_{100} | $D^0 \rightarrow \overline{K}^*(892)^0 \rho^0$ | $(1.57 \pm 0.34)\%$ | Γ_{150} $D^0 \rightarrow \pi^+\pi^-\pi^0$ nonresonant $(1.20 \pm 0.35) \times 10^{-4}$ |
| Γ_{101} | $D_0^0 \rightarrow \overline{K}^*(892)_0^0 \rho_0^0$ transverse | $(1.7 \pm 0.6)\%$ | $\Gamma_{151} D^0 \to 3\pi^0$ < 3.5 $\times 10^{-4} \text{ CL} = 90\%$ |
| Γ ₁₀₂ | | (3.0 ± 0.6)% | $\Gamma_{152} D^0 \rightarrow 2\pi^+ 2\pi^- $ (7.42 ± 0.21) × 10 ⁻³ S=1.1 |
| Γ ₁₀₃ | $D^0 \rightarrow \overline{K}^*(892)^0 \rho^0 S$ -wave | $< 3 \times 10^{-3} \text{ CL} = 90\%$ | Γ_{153} $D^0 \to a_1(1260)^+\pi^-$, $a_1^+ \to (4.45 \pm 0.31) \times 10^{-3}$ |
| Γ ₁₀₄ | $D^0 	o \overline{K}^*(892)^0 \rho^0 P$ -wave | $< 3 \times 10^{-3} \text{ CL} = 90\%$ | $\Gamma_{154} \hspace{1cm} D^0 {	o} \hspace{1cm} a_1(1260)^+\pi^- , \hspace{1cm} (3.21 \pm 0.25) 	imes 10^{-3}$ |
| Γ ₁₀₅ | | (2.1 ± 0.6) % | $a_1^+ \rightarrow \rho^0 \pi^+$ S-wave |
| Γ ₁₀₆ | $D^0 \to K^- \pi^+ f_0(980)$ | | $\Gamma_{155} \qquad D^0 \stackrel{1}{	o} a_1(1260)^+\pi^-$, $(1.9 \pm 0.5) \times 10^{-4}$ |
| Γ_{107} | $D^0 \to \overline{K}^*(892)^0 f_0(980)$ | | $a_1^+ \rightarrow \rho^0 \pi^+$ D-wave |
| Γ ₁₀₈ | | [g] (1.6 \pm 0.8) % | $\Gamma_{156} \qquad D^0 \stackrel{1}{\to} a_1(1260)^+ \pi^-, \qquad (6.2 \pm 0.7) \times 10^{-4}$ |
| Γ ₁₀₉ | $D^0 \to K_1(1400)^- \pi^+$ | < 1.2 % CL=90% | $a_1^+ ightarrow \sigma \pi^+$ |
| | $D^0 \to K^*(1410)^- \pi^+ D^0 \to K^*(892)^0 \pi^+ \pi^- \pi^0$ | (1.9 ± 0.9) % | $\Gamma_{157} \qquad D^0 ightarrow ^2 ho^0$ total $(1.82 \pm 0.13) 	imes 10^{-3}$ |
| Γ ₁₁₁ Γ ₁₁₂ | A | (1.9 ± 0.9) 70 | $\Gamma_{158} \qquad D^0 ightarrow $ |
| Γ ₁₁₃ | $D^0 \rightarrow K^-\pi^+\omega$ | (3.0 ± 0.6) % | Γ_{159} $D^0 \stackrel{	ext{ties}}{	o} 2 ho^0$, perpendicular $($ 4.7 \pm 0.6 $) 	imes 10^{-4}$ |
| Γ114 | $D^0 \rightarrow \overline{K}^*(892)^0 \omega$ | (1.1 ± 0.5) % | helicities (4.7 ± 0.0) × 10 |
| | $D^0 \to K^- \pi^+ \eta'(958)$ | $(7.5 \pm 1.9) \times 10^{-3}$ | Γ_{160} $D^0 	o 2 ho^0$, longitudinal $($ 1.25 \pm 0.10 $) 	imes 10^{-3}$ |
| Γ ₁₁₆ | $D^0 \to \overline{K}^*(892)^0 \eta'(958)$ | $< 1.1 \times 10^{-3} \text{ CL} = 90\%$ | helicities |
| | | | |

| | | | | | | | | | D |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|-----------------|------------------------|----------------------------------------------------------------------------------------------------------------------------------------|----------|------------------------|------------------------------------------|------------------|
| | $D^0 	o Resonant$ | (140 + 012) 10=3 | | | Doubly Cabibbo | sunnre | ssed (DC) mode | s or | |
| Γ ₁₆₁ | $(\pi^+ \pi^-) \pi^+ \pi^-$ | $(1.48 \pm 0.12) \times 10^{-3}$ | | | $\Delta C = 2$ forbidde | | | | |
| | 3-body total | | | F21.0 | $D^0 ightarrow K^+ \ell^- \overline{ u}_\ell$ via $\overline{D}{}^0$ | | < 2.2 | | CL=90% |
| Γ ₁₆₂ | $D^0 \rightarrow \sigma \pi^+ \pi^-$ | $(6.1 \pm 0.9) \times 10^{-4}$ | | Γ _{21.1} | $D^0 \rightarrow$ | | < 6 | | CL=90% |
| Γ ₁₆₃ | $D^0 \to f_0(980) \pi^+ \pi^-$, | $(1.8 \pm 0.5) \times 10^{-4}$ | | 211 | K^+ or $K^*(892)^+ e^- \overline{\nu}_e$ vi | a | | | |
| | $f_0 \rightarrow \pi^+\pi^-$ | | | _ | \overline{D}^0 | | | 4 | |
| Γ_{164} | $D^0 	o f_2(1270) \pi^+ \pi^-$, | $(3.6 \pm 0.6) \times 10^{-4}$ | | [₂₁₂ | $D^0 \to K^+ \pi^-$ | DC | | .07) × 10 ⁻⁴ | S=2.8 |
| _ | $f_2 \rightarrow \pi^+\pi^-$ | 2 | | 213 | $D^0 \rightarrow K^+ \pi^- \text{ via } \overline{D}^0 S$ $D^0 \rightarrow K^+ \pi^- \text{ via } \overline{D}^0$ | | | $.08) \times 10^{-4}$ | CI 050/ |
| | $D^0 \rightarrow \pi^+\pi^-2\pi^0$ | $(10.0 \pm 0.9) \times 10^{-3}$ | | ¹ 214 | $D^0 \rightarrow K^+\pi^- \text{ via } D^0$ $D^0 \rightarrow K_S^0\pi^+\pi^- \text{ in } D^0 \rightarrow$ | | < 1.6 < 1.8 | | CL=95% CL=95% |
| 166 | $egin{array}{ccc} D^0 & ightarrow & \eta \pi^0 \ D^0 & ightarrow & \omega \pi^0 \end{array}$ | [i] $(6.8 \pm 0.7) \times 10^{-4}$ | G1 000/ | ' 215 | $\frac{\overline{D}}{\overline{D}}$ | | < 1.0 | × 10 · | CL=93 % |
| Γ ₁₆₇ | $D^0 \rightarrow \omega \pi^0$ $D^0 \rightarrow 2\pi^+ 2\pi^- \pi^0$ | [i] < 2.6 | CL=90% | r | $D^0 \to K^*(892)^+ \pi^-$, | | ± 0 | 60 | |
| | $D^0 \rightarrow \eta \pi^+ \pi^-$ | $[i]$ (1.09 \pm 0.16) \times 10 ⁻³ | | 1 21 6 | $K^*(892)^+ \rightarrow K^0_S \pi^+$ | DC | (1.13 ± 0) | $^{60}_{34}$) \times 10 ⁻⁴ | |
| Γ ₁₆₉ Γ ₁₇₀ | $D^0 \rightarrow \eta \pi^+ \pi^-$ $D^0 \rightarrow \omega \pi^+ \pi^-$ | [i] $(1.09 \pm 0.16) \times 10^{-3}$ | | г | $D^0 \to K_0^*(1430)^+ \pi^-,$ | D.C | - 14 | 10=5 | |
| | $D^0 \rightarrow 3\pi^+ 3\pi^-$ | $(4.2 \pm 1.2) \times 10^{-4}$ | | ' 217 | $K_0^*(1430)^+ \rightarrow K_S^0 \pi^+$ | DC | < 1.4 | ×10 ⁻⁵ | |
| | $D^0 \to \eta'(958) \pi^0$ | $(8.9 \pm 1.4) \times 10^{-4}$ | | г | $D^0 \to K_2^*(1430)^+ \pi^-,$ | D.C | . 2.4 | 10-5 | |
| Γ ₁₇₃ | $D^0 \to \eta'(958) \pi^+ \pi^-$ | $(4.5 \pm 1.7) \times 10^{-4}$ | | 1 21 8 | | DC | < 3.4 | ×10 ⁻⁵ | |
| Γ_{174} | $D^0 \rightarrow 2\eta$ | $(1.67 \pm 0.20) \times 10^{-3}$ | | r | $K_2^*(1430)^+ \to K_5^0 \pi^+$ $D^0 \to K^+ \pi^- \pi^0$ | | (0 0 4 1 0 | | |
| Γ_{175} | $D^0 \rightarrow \eta \eta'(958)$ | $(1.05 \pm 0.26) \times 10^{-3}$ | | l 219 | $D^0 \rightarrow K^+\pi^-\pi^0$ via $\overline{D}{}^0$ | DC | | $17) \times 10^{-4}$ | |
| | Hadronic modes v | with a KK nair | | | | | | .5) × 10 ⁻⁴ | |
| Γ | $D^0 \rightarrow K^+ K^-$ | (3.96 ± 0.08) $\times 10^{-3}$ | S=1.4 | | $D^0 \rightarrow K^+ \pi^+ 2\pi^-$ | DC | (2.61 + 0 | $^{21}_{19}$) × 10 ⁻⁴ | |
| 1/6 [177 | $D^0 \rightarrow 2K_S^0$ | $(3.96 \pm 0.06) \times 10$ $(1.7 \pm 0.4) \times 10^{-4}$ | S=1.4 S=2.5 | Γ ₂₂₂ | $D_0^0 \rightarrow K^+ \pi^+ 2\pi^- \text{via } \overline{D}{}^0$ | | < 4 | $\times 10^{-4}$ | CL=90% |
| · 1// | $D^0 \rightarrow K_S^0 K^- \pi^+$ | $(3.3 \pm 0.5) \times 10^{-3}$ | S=1.1 | Γ ₂₂₃ | $D^0 \rightarrow K^+ \pi^- \text{ or } \overline{}$ | | | | |
| Γ ₁₇₉ | $D^0 \rightarrow K_{\stackrel{\circ}{K}}^{\stackrel{\circ}{K}}(892)^0 K_{\stackrel{\circ}{S}}^0$, | | 3_1.1 CL=90% | г | $D^0 \stackrel{K^+\pi^+2\pi^-}{\rightarrow}$ via $\overline{D}{}^0$ $\stackrel{D^0}{\rightarrow}$ μ^- anything via | | - A | . 10-4 | CL=90% |
| . 1/9 | $\overline{K}^*(892)^0 \to K^-\pi^+$ | , J | -2-50/0 | 1 224 | $\frac{D^2 \rightarrow \mu}{D^0}$ anything via | | < 4 | × 10 T | CL=90% |
| Γ100 | $D^0 \to K_S^0 K^+ \pi^-$ | $(2.6 \pm 0.5) \times 10^{-3}$ | | | 2 | | . (51) | | |
| Γ ₁₈₁ | $D^0 \to K^*(892)^0 K_S^0$, | | CL=90% | | $\Delta C = 1$ weak no | | | | |
| . 101 | $K^*(892)^0 \to K^+\pi^-$ | 2.0 | 02=30,0 | | Lepton Family nu | | | | |
| Γ100 | $D^0 \to K^+ K^- \pi^0$ | $(3.28 \pm 0.14) \times 10^{-3}$ | | г | Lepton (L) or Baryo $D^0 \rightarrow \gamma \gamma$ | | _ | | CL=90% |
| Γ ₁₈₃ | $D^0 \to K^*(892)^+ K^-$, | $(1.46 \pm 0.07) \times 10^{-3}$ | | Γ 225 | $D^0 \rightarrow \gamma \gamma \gamma \ D^0 \rightarrow e^+ e^-$ | C1 C1 | < 2.6 < 7.9 | | CL=90% CL=90% |
| 103 | $K^*(892)^+ \rightarrow K^+\pi^0$ | _ , , , , | | Γ ₂₂₆ | $D^0 \rightarrow \mu^+ \mu^-$ | C1 | < 1.4 | _ | CL=90% |
| Γ ₁₈₄ | $D^0 \to K^*(892)^- K^+$, | $(5.2 \pm 0.4) \times 10^{-4}$ | | Γ227 | $D^0 \rightarrow \pi^0 e^+ e^-$ | C1 | < 4.5 | | CL=90% |
| | $K^*(892)^- \rightarrow K^-\pi^0$ | | | F220 | $D^0 \rightarrow \pi^0 \mu^+ \mu^-$ | C1 | < 1.8 | | CL=90% |
| Γ_{185} | $D^0 \rightarrow (K^+ \pi^0)_{S-wave} K^-$ | $(2.34 \pm 0.17) \times 10^{-3}$ | | Γ230 | $D^0 \rightarrow \eta e^+ e^-$ | C1 | < 1.1 | | CL=90% |
| Γ_{186} | $D^0 \rightarrow (K^-\pi^0)_{S-wave} K^+$ | $(1.3 \pm 0.4) \times 10^{-4}$ | | Γ231 | $D^0 \rightarrow \eta \mu^+ \mu^-$ | C1 | < 5.3 | | CL=90% |
| Γ_{187} | $D^0 \to f_0(980) \pi^0, f_0 \to$ | $(3.4 \pm 0.6) \times 10^{-4}$ | | Γ232 | $D^0 \rightarrow \pi^+\pi^-e^+e^-$ | C1 | < 3.73 | $\times 10^{-4}$ | CL=90% |
| г | $D^0 \stackrel{K^+ K^-}{ ightarrow} \phi \pi^0, \; \phi ightarrow \; K^+ K^-$ | (| | Γ ₂₃₃ | $D^0 \rightarrow \rho^0 e^+ e^-$ | C1 | < 1.0 | $\times 10^{-4}$ | CL=90% |
| 「 ₁₈₈ | $D^0 \rightarrow \phi \pi^0$, $\phi \rightarrow K^+ K$ $D^0 \rightarrow K^+ K^- \pi^0$ nonresonant | $(6.4 \pm 0.4) \times 10^{-4}$ | | Γ ₂₃₄ | $D_{0}^{0} \rightarrow \pi^{+}\pi^{-}\mu^{+}\mu^{-}$ | C1 | < 3.0 | | CL=90% |
| Г ₁₈₉ | $D^0 \rightarrow K^+K^-\pi^0$ monresonant $D^0 \rightarrow 2K_S^0\pi^0$ | < 5.9 × 10 ⁻⁴ | | Γ ₂₃₅ | $D_0^0 \to \rho^0 \mu^+ \mu^-$ | C1 | < 2.2 | | CL=90% |
| Γ ₁₉₀ | $D^0 \to K^+ K^- \pi^+ \pi^-$ | $[j]$ (2.43 \pm 0.12) \times 10 ⁻³ | | Γ ₂₃₆ | $D^0 \rightarrow \omega e^+ e^-$ | C1 | < 1.8 | | CL=90% |
| Γ ₁₉₁ Γ ₁₉₂ | $D^0 \rightarrow \phi \pi^+ \pi^- 3$ -body, $\phi \rightarrow \phi \pi^+ \pi^- 3$ | $(2.4 \pm 2.4) \times 10^{-5}$ | | I 237 | $D^0 \rightarrow \omega \mu^+ \mu^-$ | C1 | < 8.3 | | CL=90% |
| 192 | K+ K- | (2.4 ± 2.4) × 10 | | I 238 | $D^{0} \rightarrow K^{-}K^{+}e^{+}e^{-}$ $D^{0} \rightarrow \phi e^{+}e^{-}$ | C1 | < 3.15 | | CL=90% CL=90% |
| Γ_{193} | $D^0 \stackrel{K^+ K^-}{ ightarrow} \phi ho^0$, $\phi ightarrow K^+ K^-$ | $(7.0 \pm 0.6) \times 10^{-4}$ | | I 239 | $D^0 \rightarrow K^- K^+ \mu^+ \mu^-$ | C1 C1 | < 5.2 < 3.3 | | CL=90% CL=90% |
| Γ_{194} | $D^0_{\perp} ightarrow K^+ K^- ho^0$ 3-body | $(5 \pm 7) \times 10^{-5}$ | | Г240 | $D^0 \rightarrow \phi \mu^+ \mu^-$ | C1 | < 3.1 | | CL=90% |
| Γ_{195} | $D^0 ightarrow f_0(980) \pi^+ \pi^-$, $f_0 ightarrow$ | $(3.6 \pm 0.9) \times 10^{-4}$ | | Γ _{24.2} | $D^0 \rightarrow \overline{K}^0 e^+ e^-$ | Cı | [/] < 1.1 | _ | CL=90% |
| Е | $D^0 \stackrel{K^+}{\to} \stackrel{K^-}{K^*} (892)^0 K^{\mp} \pi^{\pm} 3$ | [1] (0 = 1 0 6) 10=4 | | Γ243 | $D^0 \rightarrow \overline{K}{}^0 \mu^+ \mu^-$ | | [/] < 2.6 | | CL=90% |
| Γ ₁₉₆ | | [k] $(2.7 \pm 0.6) \times 10^{-4}$ | | Γ ₂₄₄ | $D^0 \rightarrow K^-\pi^+e^+e^-$ | C1 | < 3.85 | $\times 10^{-4}$ | CL=90% |
| | body, $K^{*0} \rightarrow K^{\pm}\pi^{\mp}$ | | | Γ ₂₄₅ | $D^0 \to \overline{K}^*(892)^0 e^+ e^-$ | | [1] < 4.7 | $\times 10^{-5}$ | CL=90% |
| Γ ₁₉₇ | $D^{0} \rightarrow K^{*}(892)^{0} K^{*}(892)^{0}$, | $(7 \pm 5) \times 10^{-5}$ | | Γ ₂₄₆ | $D^0 \rightarrow K^- \pi^+ \mu^+ \mu^-$ | C1 | < 3.59 | | CL=90% |
| 171 | $K^{*0} \rightarrow K^{\pm} \pi^{\mp}$ | | | Γ_{247} | $D^0 \to \overline{K}^*(892)^0 \mu^+ \mu^-$ | | [1] < 2.4 | | CL=90% |
| Γ ₁₉₈ | $D^0 \to K_1(1270)^{\pm} K^{\mp}$, | $(8.0 \pm 1.8) \times 10^{-4}$ | | Γ ₂₄₈ | $D^0 \to \pi^+ \pi^- \pi^0 \mu^+ \mu^-$ | C1 | < 8.1 | | CL=90% |
| _ | $K_1(1270)^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ | , | | Γ ₂₄₉ | $D^0 \rightarrow \mu^{\pm} e^{\mp}$ | LF | [<i>m</i>] < 2.6 | _ | CL=90% |
| Γ ₁₉₉ | $D^0 \to K_1(1400)^{\pm} K^{\mp},$ | $(5.3 \pm 1.2) \times 10^{-4}$ | | l 25 0 | $D^0 \rightarrow \pi^0 e^{\pm} \mu^{\mp}$ | LF | [<i>m</i>] < 8.6 | | CL=90% |
| г | $K_1(1400)^{\pm} \rightarrow K^{\pm}\pi^{+}\pi^{-}$ | (1 22 0 22) 12=3 | | l 251 | $\begin{array}{ccc} D^0 \rightarrow & \eta \ e^{\pm} \ \mu^{\mp} \\ D^0 \rightarrow & \pi^+ \ \pi^- \ e^{\pm} \ \mu^{\mp} \end{array}$ | LF | [m] < 1.0 | | CL=90% |
| 1 200 F | $D^0 \to 2K_S^0 \pi^+ \pi^-$ | $(1.23 \pm 0.23) \times 10^{-3}$ | CL 000/ | ¹ 25 2 г | $D^0 \rightarrow \pi^+\pi^-e^{\pm}\mu^{\mp}$ $D^0 \rightarrow \rho^0 e^{\pm}\mu^{\mp}$ | LF LE | [m] < 1.5 | | CL=90% CL=90% |
| l 201 | $D^{0} \rightarrow K_{S}^{0} K^{-} 2\pi^{+} \pi^{-}$ $D^{0} \rightarrow K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | | CL=90% | Г 25 3 Гол - | $D^0 \rightarrow \rho^* e^{\pm} \mu^{\mp}$ | LF LF | [m] < 4.9 [m] < 1.2 | | CL=90% CL=90% |
| 1 202 | $\nu \rightarrow \kappa \cdot \kappa \pi \cdot \pi \pi^{\circ}$ | $(3.1 \pm 2.0) \times 10^{-3}$ | | · 254 | $D^0 \rightarrow K^- K^+ e^{\pm} \mu^{\mp}$ | LF | [m] < 1.2 [m] < 1.8 | _ | CL=90% |
| | Other $K\overline{K}X$ modes. They include all | decay modes of the domand or | | Γ25.6 | $D^0 \rightarrow \phi e^{\pm} \mu^{\mp}$ | LF | [m] < 3.4 | | CL=90% |
| Γ | $D^0 ightarrow \phi \pi^0$ | 2.2.2, modes of the φ , η , and ω . | | Γ _{25.7} | $D^0 ightarrow \overline{K}{}^0 e^{\pm} \mu^{\mp}$ | LF | [m] < 1.0 | | CL=90% |
| 1 203 Fana | $D^0 \rightarrow \phi \pi$ $D^0 \rightarrow \phi \eta$ | $(1.4 \pm 0.5) \times 10^{-4}$ | | Γ _{25.8} | $D^0 \rightarrow K^- \pi^+ e^{\pm} \mu^{\mp}$ | LF | [m] < 5.53 | $\times10^{-4}$ | CL=90% |
| · 204 | $D^0 \rightarrow \phi \eta$ $D^0 \rightarrow \phi \omega$ | | CL=90% | Γ _{25.9} | $D^0 \to \overline{K}^*(892)^0 e^{\pm} \mu^{\mp}$ | LF | [m] < 8.3 | $\times10^{-5}$ | CL=90% |
| . 200 | | | /9 | Γ ₂₆₀ | $D_0^0 \to 2\pi^- 2e^+ + \text{c.c.}$ | L | < 1.12 | | CL=90% |
| г | Radiative | | CI 222 | Γ ₂₆₁ | $D^0 \to 2\pi^- 2\mu^+ + \text{c.c.}$ | L | < 2.9 | | CL=90% |
| I 206 Г | $\begin{array}{ccc} D^0 \to & \rho^0 \gamma \\ D^0 \to & \omega \gamma \end{array}$ | | CL=90% | [₂₆₂ | $D^0 \to K^- \pi^- 2e^+ + \text{c.c.}$ | L | < 2.06 | | CL=90% |
| ! 207 Гат- | $D^0 \rightarrow \omega \gamma$ $D^0 \rightarrow \phi \gamma$ | $< 2.4 \times 10^{-4}$ (2.70 ± 0.35) $\times 10^{-5}$ | CL=90% | I 263 | $D^0 \to K^- \pi^- 2\mu^+ + \text{c.c.}$ | L | < 3.9 | | CL=90% |
| 1 208 Fann | $D^0 \rightarrow \overline{K}^*(892)^0 \gamma$ | $(2.70 \pm 0.33) \times 10^{-3}$ $(3.27 \pm 0.34) \times 10^{-4}$ | | I 264 | $D^0 \to 2K^- 2e^+ + \text{c.c.}$ | L | < 1.52 | | CL=90% |
| 209 | D / N (032) 1 | (3.21 ± 0.34) X 10 · | | I 265 Г | $D^0 \rightarrow 2K^- 2\mu^+ + \text{c.c.}$ $D^0 \rightarrow \pi^- \pi^- e^+ \mu^+ +$ | L L | < 9.4 < 7.9 | | CL=90% CL=90% |
| | | | | | | L | < 1.9 | × 10 ° | CL=90% |
| | | | | Γ ₂₆₇ | $D^0 \stackrel{{ m c.c.}}{	o} K^- \pi^- e^+ \mu^+ +$ | L | < 2.18 | $\times 10^{-4}$ | CL=90% |
| | | | | 201 | c.c. | | | | |
| | | | | | | | | | |

D^0

| Γ ₂₆₈ | $D^0 \rightarrow$ | $2K^-e^+\mu^+ + \text{c.c.}$ | L | < 5.7 | $\times 10^{-5}$ | CL=90% |
|------------------|-------------------|------------------------------|-----|-----------|------------------|--------|
| | $D^0 \rightarrow$ | | | [n] < 1.0 | $\times 10^{-5}$ | CL=90% |
| | $D^0 \rightarrow$ | | L.B | [o] < 1.1 | $\times 10^{-5}$ | CL=90% |

 Γ_{271} Unaccounted decay modes

$$(38.2 \pm 1.3)\%$$
 S=1.

- [a] This value is obtained by subtracting the branching fractions for 2-, 4- and 6-prongs from unity.
- [b] This is the sum of our $K^-2\pi^+\pi^-$, $K^-2\pi^+\pi^-\pi^0$, $K^-K^-\pi^+\pi^-\pi^0$, $K^-K^-\pi^+\pi^-\pi^0$, $K^-K^-\pi^+\pi^-\pi^0$, branching fractions.
- [c] This is the sum of our $K^-3\pi^+2\pi^-$ and $3\pi^+3\pi^-$ branching fractions.
- [d] The branching fractions for the $K^-e^+\nu_e$, $K^*(892)^-e^+\nu_e$, $\pi^-e^+\nu_e$, and $\rho^-e^+\nu_e$ modes add up to 6.19 \pm 0.17 %.
- [e] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the relevant papers.
- [f] This is a doubly Cabibbo-suppressed mode.
- [g] The two experiments measuring this fraction are in serious disagreement. See the Particle Listings .
- [h] Submodes of the $D^0 \to K_S^0 \pi^+ \pi^- \pi^0$ mode with a K^* and/or ρ were studied by COFFMAN 92B, but with only 140 events. With nothing new for 18 years, we refer to our 2008 edition, Physics Letters **B667** 1 (2008), for those results.
- [i] This branching fraction includes all the decay modes of the resonance in the final state.
- [j] The experiments on the division of this charge mode amongst its submodes disagree, and the submode branching fractions here add up to considerably more than the charged-mode fraction.
- [k] However, these upper limits are in serious disagreement with values obtained in another experiment.
- [/] This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks must change flavor in this decay.
- $[\emph{m}]$ The value is for the sum of the charge states or particle/antiparticle states indicated.
- [n] This limit is for either D^0 or $\overline{D}{}^0$ to pe^- .
- [o] This limit is for either D^0 or $\overline{D}{}^0$ to $\overline{p}\,e^+$.

CONSTRAINED FIT INFORMATION

An overall fit to 52 branching ratios uses 104 measurements and one constraint to determine 31 parameters. The overall fit has a $\chi^2=99.0$ for 74 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one

| | ۱ ^ | | | | | | | | | |
|-------------------------|-----------------------|-----------------|-------------------------|-----------------|-----------------|-----|-------------------------|-------------------------|--------------|-------------------------|
| <i>X</i> ₁₈ | 2 | | | | | | | | | |
| <i>x</i> ₁₉ | 20 | 9 | | | | | | | | |
| <i>x</i> ₂₀ | 0 | 1 | 0 | _ | | | | | | |
| x ₂₈ | 0 | 0 | 0 | 0 | | | | | | |
| x ₂₉ | 3 | 2 | 17 | 0 | 0 | | | | | |
| ^X 31 | 4 | 49 | 19 | 2 | 0 | 3 | | | | |
| x ₃₂ | 1 | 17 | 7 | 2 | 0 | 1 | 36 | | | |
| X34 | 1 | 7 | 3 | 15 | 0 | 0 | 14 | 16 | | |
| <i>x</i> ₄₉ | 0 | -2 | -1 | 0 | 0 | 0 | -4 | -1 | 0 | |
| ×66 | 1 | 11 | 4 | 0 | 0 | 1 | 22 | 8 | 3 | 55 |
| <i>x</i> ₇₅ | 0 | 3 | 1 | 6 | 0 | 0 | 5 | 6 | 39 | 0 |
| x ₇₉ | 0 | 4 | 2 | 0 | 0 | 0 | 8 | 3 | 1 | 8 |
| <i>x</i> 93 | 1 | 9 | 3 | 0 | 0 | 1 | 19 | 7 | 3 | -1 |
| x ₉₄ | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 5 | 0 |
| <i>X</i> 95 | 1 | 10 | 4 | 3 | 0 | 1 | 21 | 10 | 21 | -1 |
| <i>x</i> ₁₃₁ | 2 | 31 | 12 | 1 | 0 | 2 | 63 | 22 | 9 | -2 |
| <i>x</i> ₁₃₂ | 1 | 9 | 4 | 0 | 0 | 1 | 19 | 7 | 3 | -1 |
| <i>x</i> ₁₃₃ | 0 | -1 | 0 | 0 | 0 | 0 | -1 | 0 | 0 | 82 |
| <i>x</i> ₁₅₂ | 1 | 13 | 5 | 1 | 0 | 1 | 27 | 10 | 4 | 29 |
| <i>X</i> 166 | 0 | 5 | 2 | 0 | 0 | 0 | 11 | 4 | 2 | 0 |
| <i>x</i> ₁₇₂ | 0 | 4 | 1 | 0 | 0 | 0 | 7 | 3 | 1 | 0 |
| <i>x</i> ₁₇₄ | 0 | 5 | 2 | 0 | 0 | 0 | 10 | 4 | 1 | 0 |
| <i>X</i> 175 | 0 | 2 | 1 | 0 | 0 | 0 | 5 | 2 | 1 | 0 |
| <i>X</i> 176 | 2 | 30 | 11 | 1 | 0 | 2 | 61 | 22 | 8 | -2 |
| <i>x</i> ₁₇₇ | 0 | 2 | 1 | 1 | 0 | 0 | 5 | 3 | 8 | 0 |
| <i>x</i> ₁₇₈ | 0 | 3 | 1 | 5 | 0 | 0 | 6 | 6 | 36 | 0 |
| <i>X</i> ₁₈₀ | 0 | 2 | 1 | 4 | 0 | 0 | 5 | 5 | 26 | 0 |
| X ₂₀₈ | 0 | 4 | 2 | 0 | 0 | 0 | 9 | 3 | 1 | 0 |
| x ₂₁₂ | 1 | 12 | 5 | 1 | 0 | 1 | 24 | 9 | 4 | -1 |
| x ₂₇₁ | -48 | -13 | -22 | -17 | -1 | -6 | -22 | -14 | -40 | -51 |
| | <i>x</i> ₆ | <i>X</i> 18 | <i>X</i> ₁ 9 | x ₂₀ | X ₂₈ | X29 | <i>X</i> 31 | <i>X</i> 32 | X34 | X49 |
| | Ī | | | | | | | | | |
| x ₇₅ | 1 | | | | | | | | | |
| <i>x</i> ₇₉ | 16 | 0 | | | | | | | | |
| <i>x</i> ₉₃ | 4 | 1 | 2 | | | | | | | |
| X94 | 0 | 12 | 0 | 0 | | | | | | |
| X95 | 5 | 8 | 2 | 4 | 1 | | | | | |
| X ₁₃₁ | 14 | 3 | 5 | 12 | 0 | 13 | | | | |
| X ₁₃₂ | 4 | 1 | 2 | 4 | 0 | 4 | 12 | | | |
| <i>X</i> 133 | 45 | 0 | 6 | 0 | 0 | 0 | -1 | 0 | | |
| <i>X</i> 152 | 58 | 1 | 10 | 5 | 0 | 6 | 17 | 5 | 24 | |
| <i>X</i> 166 | 2 | 1 | 1 | 2 | 0 | 2 | 7 | 2 | 0 | 3 |
| <i>X</i> 172 | 2 | 0 | 1 | 1 | 0 | 2 | 5 | 1 | 0 | 2 |
| X ₁₇₄ | 2 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 3 |
| <i>X</i> 175 | 1 | 0 | 0 | 1 | 0 | 1 | 3 | 1 | 0 | 1 |
| <i>X</i> 176 | 13 | 3 | 5 | 11 | 0 | 13 | 38 | 12 | -1 | 16 |
| <i>x</i> ₁₇₇ | 1 | 3 | 0 | 1 | 0 | 2 | 3 | 1 | 0 | 1 |
| <i>X</i> 178 | 1 | 14 | 1 | 1 | 2 | 8 | 4 | 1 | 0 | 2 |
| X ₁₈₀ | 1 | 10 | 0 | 1 | 1 | 6 | 3 | 1 | 0 | 1 |
| x ₂₀₈ | 2 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 2 |
| <i>x</i> ₂₁₂ | 5 | 1 | 2 | 5 | 0 | 5 | 15 | 5 | 0 | 7 |
| <i>X</i> 271 | -46 | -54 | -37 | -6 | -11 | -15 | -14 | -5 | -44 | -30 |
| | x ₆₆ | X ₇₅ | X79 | <i>X</i> 93 | X94 | X95 | <i>x</i> ₁₃₁ | <i>x</i> ₁₃₂ | <i>X</i> 133 | <i>x</i> ₁₅₂ |
| | | | | | | | | | | |

| x ₁₇₂ | 1 | | | | | | | | | |
|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|------------------|
| ×174 | 1 | 1 | | | | | | | | |
| <i>X</i> 175 | 1 | 0 | 0 | | | | | | | |
| <i>X</i> 176 | 7 | 5 | 6 | 3 | | | | | | |
| <i>x</i> ₁₇₇ | 1 | 0 | 1 | 0 | 3 | | | | | |
| <i>x</i> ₁₇₈ | 1 | 0 | 1 | 0 | 4 | 3 | | | | |
| <i>x</i> ₁₈₀ | 1 | 0 | 1 | 0 | 3 | 2 | 9 | | | |
| x ₂₀₈ | 1 | 1 | 1 | 0 | 8 | 0 | 1 | 0 | | |
| x ₂₁₂ | 3 | 2 | 3 | 1 | 15 | 1 | 2 | 1 | 2 | |
| x ₂₇₁ | -3 | -3 | -4 | -3 | -14 | -4 | -18 | -14 | -2 | <u>-5</u> |
| | <i>x</i> ₁₆₆ | <i>x</i> ₁₇₂ | <i>x</i> ₁₇₄ | <i>x</i> ₁₇₅ | <i>x</i> ₁₇₆ | <i>x</i> ₁₇₇ | <i>X</i> ₁₇₈ | <i>x</i> ₁₈₀ | <i>x</i> ₂₀₈ | x ₂₁₂ |

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 3 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2 =$ 0.0 for 0 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\mathrm{total}}$. The fit constrains the x_i whose labels appear in this array to sum to

DO BRANCHING RATIOS

Some older now obsolete results have been omitted from these Listings.

Topological modes -

 $\Gamma \text{(0-prongs)/} \Gamma_{\text{total}}$ This value is obtained by subtracting the branching fractions for 2-, 4-, and 6-prongs from unity.

DO CUMENT ID

0.15±0.06 OUR FIT

| $\Gamma(4-prongs)/\Gamma_{total}$ | Г ₃ /Г |
|-------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| | $K^{-}2\pi^{+}\pi^{-}$, $K^{-}2\pi^{+}\pi^{-}\pi^{0}$, $\overline{K}^{0}2\pi^{+}2\pi^{-}$, $K^{+}2K^{-}\pi^{+}$, |
| $2\pi + 2\pi - 2\pi + 2\pi - \pi^0$ | $K^{+}K^{-}\pi^{+}\pi^{-}$ and $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ branching fractions |

DO CUMENT ID

| 0.145 ± 0.005 O 0.145 ± 0.005 | UR FIT | PDG | 12 | | |
|----------------------------------|-------------|-------------|------|---------|---------------------|
| Γ(4-prongs)/ | Γ(2-prongs) | | | | Γ_3/Γ_2 |
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| $0.207 \pm 0.016 \Omega$ | UR FIT | | | | |

| 0.207±0.016±0.004 | 226 | ONENGUT | 05 | CHRS | ν_{μ} emulsion, $\overline{\it E}_{\nu}\approx$ 27 GeV |
|--------------------------------|-----|---------|----|------|--------------------------------------------------------------|
| Γ(6-prongs)/Γ _{total} | | | | | Γ ₄ /Γ |

| · (- P·0-// · LULAI | | - |
|-------------------------------|--------------------------------------|----------------------|
| This is the sum of our | $K^-3\pi^+2\pi^-$ and $3\pi^+3\pi^-$ | branching fractions. |
| VALUE (units 10^{-4}) EVTS | DOCUMENT ID T | ECN_COMMENT |

| VALUE (units 10 ⁻⁴) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|-------------|-------------------|--------|-----------|-------------------------------------------------------|
| 6.4± 1.3 OUR FIT | • | · | | | |
| 6.4± 1.3 | | PDG | 12 | | |
| | e the follo | wing data for ave | rages, | fits, lim | ts, etc. • • • |
| $12 \begin{array}{cc} +13 \\ -9 \end{array} \pm 2$ | 3 | ONENGUT | 05 | CHRS | $ u_{\mu}$ emulsion, $\overline{E}_{ u} pprox$ 27 GeV |

Inclusive modes

$\Gamma(e^+ \text{ anything})/\Gamma_{\text{total}}$ The branching fractions for the $K^-e^+\nu_e$, $K^*(892)^-e^+\nu_e$, $\pi^-e^+\nu_e$, and $\rho^-e^+\nu_e$ modes add up to 6.20 \pm 0.17 %.

| VALUE (% |) | EVTS | DO CUMENT ID | TECN | COMMENT |
|----------------|---------------|-------------|--------------------|----------|--------------------------------|
| 6.49±0.1 | 1 OUR AVER | AGE | | | |
| 6.46 ± 0.0 | 09 ± 0.11 | 6584 ± 96 | ¹ ASNER | 10 CLEO | e^+e^- at 3774 MeV |
| 6.3 ± 0.7 | 7 ± 0.4 | 290 ± 32 | ABLIKIM | 07G BES2 | $e^{+}e^{-}\approx \psi(3770)$ |
| 6.46 ± 0.1 | 7 ± 0.13 | 2246 ± 57 | A DA M | 06A CLEO | See ASNER 10 |
| 6.9 ± 0.3 | 3 ± 0.5 | 1670 | ALBRECHT | 96c ARG | e^+e^-pprox 10 GeV |
| 6.64 ± 0.1 | 18 ± 0.29 | 4609 | KUBOTA | 96B CLE2 | $e^+e^-pprox \Upsilon(4S)$ |

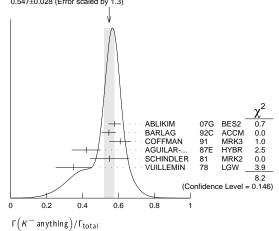
1 Using the D^+ and D^0 lifetimes, ASNER 10 finds that the ratio of the D^+ and D^0 semileptonic widths is 0.985 \pm 0.015 \pm 0.024.

| $\Gamma(\mu^+ \text{ anything})$ | /Γ _{total} | | | | Γ ₆ /Γ |
|----------------------------------|---------------------|----------------------|------|------|---------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 6.7 ± 0.6 OUR FIT | • | | | | - |
| 6.4 ± 0.8 OUR AV | ERAGE | | | | |
| $6.8 \pm 1.5 \pm 0.8$ | 79 ± 10 | ¹ ABLIKIM | 08L | BES2 | $e^{+}e^{-} \approx \psi(3772)$ |
| $6.5 \pm 1.2 \pm 0.3$ | 36 | KAYIS-TOPA I | <.Ω5 | CHRS | $ u_{\mu}$ emulsion |
| $6.0\pm 0.7\!\pm\! 1.2$ | 310 | ALBRECHT | 96c | ARG | e^+e^-pprox 10 GeV |
| 1 | | | | | |

 1 ABLIKIM 08L finds the ratio of $D^+
ightarrow \ \mu^+ {\it X}$ and $D^0
ightarrow \ \mu^+ {\it X}$ branching fractions to be 2.59 \pm 0.70 \pm 0.25, in accord with the ratio of D^+ and D^0 lifetimes, 2.54 \pm 0.02.

| $\Gamma(K^- \text{ anything})/\Gamma_t$ | otal | | | Γ ₇ /Γ | | |
|---------------------------------------------------------------------------------------|---------------|----------------------|----------|---------------------------------|--|--|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | | |
| 0.547±0.028 OUR AV | ERAGE Erro | or includes scale fa | | See the ideogram below. | | |
| $0.578 \pm 0.016 \pm 0.032$ | 2098 ± 59 | ABLIKIM | 07G BES2 | $e^{+}e^{-} \approx \psi(3770)$ | | |
| $0.546 {}^{+ 0.039}_{- 0.038}$ | | ¹ BARLAG | 92c ACCM | π^- Cu 230 GeV | | |
| $0.609 \pm 0.032 \pm 0.052$ | | COFFMAN | 91 MRK3 | e^+e^- 3.77 GeV | | |
| 0.42 ± 0.08 | | AGUILAR | 87E HYBR | πp, pp 360, 400 GeV | | |
| 0.55 ± 0.11 | 121 | SCHINDLER | 81 MRK2 | e^+e^- 3.771 GeV | | |
| 0.35 ± 0.10 | 19 | VUILLEMIN | 78 LGW | $e^{+}e^{-}$ 3.772 GeV | | |
| $^{ m 1}$ BARLAG 92c computes the branching fraction using topological normalization. | | | | | | |

WEIGHTED AVERAGE 0.547±0.028 (Error scaled by 1.3)



| $[\Gamma(\overline{K}^0)]$ anything) + | $\Gamma(K^0$ anythin | g)]/F _{total} | | | Γ8/Γ |
|----------------------------------------|----------------------|------------------------|----------|---------------------|-------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 0.47 ±0.04 OUR AV | ERAGE | | | | |
| $0.476 \pm 0.048 \pm 0.030$ | 250 ± 25 | ABLIKIM | 06∪ BES2 | $e^{+}e^{-}$ at 377 | 3 MeV |
| $0.455 \pm 0.050 \pm 0.032$ | | COFFMAN | 91 MRK3 | $e^{+}e^{-}$ 3.77 G | eV |
| | | | | | |

| $\Gamma(K^+ \text{ anything})/\Gamma_t$ | otal | | | Г9/Г |
|-----------------------------------------|------------|---------------------|----------|-----------------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
| 0.034 ± 0.004 OUR AV | ERAGE | | | |
| $0.035 \pm 0.007 \pm 0.003$ | 119 ± 23 | ABLIKIM | 07G BES2 | $e^+e^- \approx \psi(3770)$ |
| $0.034 {}^{+ 0.007}_{- 0.005}$ | | ¹ BARLAG | 92c ACCM | π^- Cu 230 GeV |
| $0.028\!\pm\!0.009\!\pm\!0.004$ | | COFFMAN | 91 MRK3 | $e^{+}e^{-}$ 3.77 GeV |
| $0.03 \ ^{+ 0.05}_{- 0.02}$ | | AGUILAR | 87E HYBR | πρ, ρρ 360, 400 GeV |
| 0.08 ± 0.03 | 25 | SCHINDLER | 81 MRK2 | $e^{+}e^{-}$ 3.771 GeV |

 $^{
m 1}$ BARLAG 92c computes the branching fraction using topological normalization.

| Γ(K*(892) - anythi | $ng)/\Gamma_{total}$ | | | Γ_{10}/Γ |
|----------------------------------------|------------------------|--------------|----------|------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| $0.153 \pm 0.083 \pm 0.019$ | 28 ± 15 | ABLIKIM | 06∪ BES2 | e^+e^- at 3773 MeV |
| $\Gamma(\overline{K}^*(892)^0$ anythin | ng)/Γ _{total} | | | Г ₁₁ /Г |
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
| $0.087 \pm 0.040 \pm 0.012$ | 96 ± 44 | ABLIKIM | 05P BES | e^+e^-pprox 3773 MeV |
| Γ(K*(892) ⁺ anythi | ng)/Γ _{total} | | | Γ ₁₂ /Γ |

| , , , , | 0// total | | | | | | • |
|-------------|-----------|--------------|-------------|------|-----------------------------------------|------|----|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | | |
| <0.036 | 90 | ABLIKIM | 06 U | BES2 | e ⁺ e ⁻ at 3773 N | /leV | |
| E///*/000\0 | L!\ /E | | | | | _ | ٠. |

| Γ(<i>K</i> *(892) ⁰ anythir | $_{\rm lg})/\Gamma_{ m total}$ | | | | Γ_{13}/Γ |
|-----------------------------------------|--------------------------------|-------------|----------|---------|----------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 0.028+0.012+0.004 | 31 + 12 | ARIIKIM | 05 P RES | e+e- ~ | 3773 MeV |

| $\Gamma(\eta \text{ anything})/\Gamma_{	ext{total}}$ | Γ ₁₄ /Γ |
|-----------------------------------------------------------|--------------------|
| This ratio includes η particles from η' decays. | |

| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|--------------|--------------|------|------|------------------------------|
| 9.5 ± 0.4 ± 0.8 | 4463 ± 197 | HUANG | 06 E | CLEO | $e^{+}e^{-}$ at $\psi(3770)$ |
| $\Gamma(\eta' \text{ anything})/\Gamma_{to}$ | otal | | | | Γ ₁₅ /Γ |
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 2.48±0.17±0.21 | 299 ± 21 | HUANG | 06в | CLEO | e^+e^- at $\psi(3770)$ |
| | | | | | |

| $\Gamma(\phi \text{ anything})/\Gamma_{	ext{tot}}$ | al | | | | Γ_{16}/Γ |
|----------------------------------------------------|----------|--------------|---------|---------------------------|----------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | TECN_ | COMMENT | |
| 1.05 ± 0.08 ± 0.07 • • • We do not use | 368 ± 24 | HUANG | | e^+e^- at $\psi(3)$ | 3770) |
| $1.71^{+0.76}_{-0.71} \pm 0.17$ | 0.000 | | | $e^+e^- \rightarrow D$ | <u>-</u> * -* -* |
| 1.71 ± 0.17 | 9 | BAI | OUC BES | $e \cdot e \rightarrow D$ | ט י ט י ט |

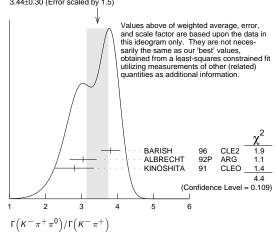
 D^0

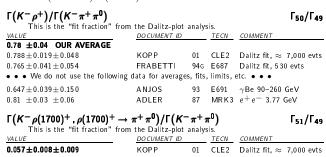
| Semileptonic modes ——— | $\Gamma(K^*(892)^- e^+ \nu_e)/\Gamma_{\text{total}}$ Γ_{20}/Γ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(K^-e^+ u_e)/\Gamma_{	ext{total}}$ Γ_{18}/Γ | Both decay modes of the $K^*(892)^-$ are included. |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | <u>VALUE (units 10⁻²)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.16±0.16 OUR FIT |
| 3.55±0.04 OUR FIT Error includes scale factor of 1.2. | 2.16±0.15±0.08 219 ± 16 1 COAN 05 CLEO $e^{+}e^{-}$ at $\psi(3770)$ |
| 3.50 \pm 0.05 OUR AVERAGE 3.50 \pm 0.03 \pm 0.04 | 1 COAN 05 uses both $\kappa^{-}\pi^{0}$ and $\kappa^{0}_{S}\pi^{-}$ events. |
| $3.45 \pm 0.10 \pm 0.19$ 1318 ± 38 2 WIDHALM 06 BELL $e^+e^- \approx \Upsilon(4S)$ | 5 |
| $3.82 \pm 0.40 \pm 0.27$ 104 \pm 11 ABLIKIM 04c BES e^+e^- , 3.773 GeV | $\Gamma(K^*(892)^- e^+ \nu_e) / \Gamma(K_S^0 \pi^+ \pi^-)$ $\Gamma_{20} / \Gamma_{34}$ |
| 3.4 ± 0.5 ± 0.4 55 ADLER 89 MRK3 e^+e^- 3.77 GeV | Unseen decay modes of the $K^*(892)^-$ are included. |
| • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE EVTS DOCUMENT ID TECN COMMENT 0.77±0.07 OUR FIT |
| 3.56±0.03±0.09 | 0.76±0.12±0.06 152 ¹ BEAN 93c CLE2 $e^+e^- \approx \Upsilon(4S)$ |
| $3.44\pm0.10\pm0.10$ 1311 \pm 37 COAN 05 CLEO See DOBBS 08 $^{-1}$ See the form-factor parameters near the end of this D^0 Listing. | 1 BEAN 93c uses $\mathit{K^{*-}}\mu^+\nu_\mu$ as well as $\mathit{K^{*-}}e^+\nu_e$ events and makes a small phase-space |
| cm(a) | adjustment to the number of the μ^+ events to use them as e^+ events. |
| ² The $\pi^-e^+\nu_e$ and $K^-e^+\nu_e$ results of WIDHALM 06 give $ \frac{V_{Cd}}{V_{Cs}}\cdot\frac{f_+^+(0)}{f_+^K(0)} ^2=0.042\pm$ | $\Gamma(K^*(892)^-\mu^+\nu_\mu)/\Gamma(K_S^0\pi^+\pi^-)$ Γ_{21}/Γ_{34} |
| 0.003 ± 0.003 . | · · · · · · · · · · · · · · · · · · · |
| ³ DOBBS 08 establishes $\left \frac{V_{cd}}{V_{cs}} \cdot \frac{f_+^*(0)}{f^K(0)} \right = 0.188 \pm 0.008 \pm 0.002$ from the D^+ and D^0 | Unseen decay modes of the K*(892)— are included. <u>VALUEEVTSDOCUMENT IDTECNCOMMENT</u> |
| decays to $\overline{K}e^+ u_e$ and $\pi e^+ u_e$. | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | 1 LINK 05B finds that in $D^0	o \overline{K}{}^0\pi^-\mu^+ u_\mu$ the $\overline{K}{}^0\pi^-$ system is 6% in S-wave. |
| $\Gamma(K^-e^+\nu_e)/\Gamma(K^-\pi^+)$ Γ_{18}/Γ_{31} | · |
| VALUEEVTSDOCUMENT_IDTECNCOMMENT | $\Gamma(K^-\pi^+\pi^-e^+\nu_e)/\Gamma_{\text{total}}$ Γ_{24}/Γ_{24} |
| 0.930±0.011 OUR AVERAGE | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| $0.927 \pm 0.007 \pm 0.012$ $76 \text{k} \pm 323$ | 2.8 $^{+1.4}_{-1.1}\pm$ 0.3 8 ARTUSO 07A CLEO e^+e^- at $\Upsilon(3770)$ |
| $0.978 \pm 0.027 \pm 0.044$ 2510 $\frac{2}{3}$ BEAN 93C CLE2 $e^+e^- \approx \Upsilon(4S)$ | |
| $0.90\pm0.06\pm0.06$ 584 3 CRAWFORD 91B CLEO $e^+e^-pprox 10.5$ GeV $0.91\pm0.07\pm0.11$ 250 4 ANJOS 89F E691 Photoproduction | $\Gamma(K_1(1270)^-e^+\nu_e)/\Gamma_{\text{total}}$ Γ_{25}/Γ |
| $0.91~\pm0.07~\pm0.11$ 250 ⁴ ANJOS 89F E691 Photoproduction $^{-1}$ The event samples in this AUBERT 07BG result include radiative photons. The D^{0} $ ightarrow$ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| $K^-e^+\nu_e$ form factor at $q^2=0$ is $f_+(0)=0.727\pm0.007\pm0.005\pm0.007$. | 7.6 $^{+4.1}_{-3.0}$ \pm 0.9 8 ¹ ARTUSO 07A CLEO e^+e^- at $\Upsilon(3770)$ |
| ² BEAN 93c uses $K^-\mu^+\nu_\mu$ as well as $K^-e^+\nu_e$ events and makes a small phase-space | $^{-}$ This ARTUSO 07A result is corrected for all decay modes of the $K_1(1270)^-$. |
| adjustment to the number of the μ^+ events to use them as e^+ events. A pole mass of | |
| $2.00 \pm 0.12 \pm 0.18 \mathrm{GeV}/c^2$ is obtained from the q^2 dependence of the decay rate. | $\Gamma(K^-\pi^+\pi^-\mu^+\nu_\mu)/\Gamma(K^-\mu^+\nu_\mu)$ |
| 3 CRAWFORD 91B uses ${\it K}^-e^+ u_e$ and ${\it K}^-\mu^+ u_\mu$ candidates to measure a pole mass of | <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> |
| $2.1 {+ 0.4 + 0.3 \atop - 0.2 - 0.2}$ GeV $/c^2$ from the q^2 dependence of the decay rate. | <0.037 90 KODAMA 93B E653 π^- emulsion 600 GeV |
| 4 ANJOS 89F measures a pole mass of 2.1 $^+_{-0.2}$ $^+$ $^+$ $^+$ $^+$ $^+$ $^+$ $^+$ $^+$ | $\Gamma((\overline{K}^*(892)\pi)^-\mu^+\nu_\mu)/\Gamma(K^-\mu^+\nu_\mu)$ Γ_{27}/Γ_{19} |
| of the decay rate. | |
| $\Gamma(K^-\mu^+ u_\mu)/\Gamma_{\text{total}}$ Γ_{19}/Γ | <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN COMMENT</u> <0.043 90 ¹ KODAMA 93B E653 π [−] emulsion 600 GeV |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | 1 KODAMA 93B searched in $K^-\pi^+\pi^-\mu^+ u_\mu$, but the limit includes other $(\overline{K}^*(892)\pi)^-$ |
| 3.30±0.13 OUR FIT | charge states. |
| 3.45 \pm 0.10 \pm 0.21 1249 \pm 43 WIDHALM 06 BELL $e^+e^-\approx \Upsilon(4S)$ | $\Gamma(\pi^- e^+ u_e) / \Gamma_{\text{total}}$ $\Gamma_{28} / \Gamma_{28} / \Gamma_{2$ |
| $\Gamma(K^-\mu^+\nu_\mu)/\Gamma(K^-\pi^+)$ Γ_{19}/Γ_{31} | VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT |
| VALUE EVTS DOCUMENT ID TECN COMMENT | 0.289±0.008 OUR FIT Error includes scale factor of 1.1. |
| 0.853±0.033 OUR FIT 0.84 ±0.04 OUR AVERAGE | 0.287±0.008 OUR AVERAGE |
| $0.852 \pm 0.034 \pm 0.028$ 1897 ¹ FRABETTI 95G E687 γ Be \overline{E}_{γ} = 220 GeV | $0.288 \pm 0.008 \pm 0.003$ 1374 $\frac{1}{2}$ BESSON 09 CLEO e^+e^- at $\psi(3770)$ $0.279 \pm 0.027 \pm 0.016$ 126 \pm 12 $\frac{2}{2}$ WIDHALM 06 BELL $e^+e^- \approx \Upsilon(4S)$ |
| $0.82 \pm 0.13 \pm 0.13$ 338 ² FRABETTI 931 E687 γ Be $\overline{E}_{\gamma}^{\gamma}$ 221 GeV | • • • We do not use the following data for averages, fits, limits, etc. • • |
| 0.79 \pm 0.08 \pm 0.09 231 ³ CRAWFORD 91B CLEO $e^+e^-\approx$ 10.5 GeV | 0.299±0.011±0.009 3 DOBBS 08 CLEO See BESSON 09 |
| 1 FRABETTI 95G extracts the ratio of form factors $f_{-}(0)/f_{+}(0)=-1.3^{+3.6}_{-3.4}\pm0.6$, and | $0.262 \pm 0.025 \pm 0.008$ 117 ± 11 COAN 05 CLEO See DOBBS 08 |
| measures a pole mass of $1.87 ^{+0.11}_{-0.08} ^{+0.07}_{-0.08}$ GeV/ c^2 from the q^2 dependence of the decay | $^{ m 1}$ See the form-factor parameters near the end of this ${\it D}^{ m 0}$ Listing. |
| | 2 The $\pi^-e^+ u_e$ and $K^-e^+ u_e$ results of WIDHALM 06 give $ rac{V_{c.d.}}{V_{c.s.}}\cdotrac{f_+^\pi(0)}{f_+^R(0)} ^2=0.042\pm0.042$ |
| 2 FRABETTI 93I measures a pole mass of $2.1^{+0.7}_{-0.3}^{+0.7}_{-0.3}$ GeV/ c^2 from the q^2 dependence of the decay rate | 0.003 ± 0.003 . |
| of the decay rate. 3 CRAWFORD 91B measures a pole mass of 2.00 \pm 0.12 \pm 0.18 GeV/ c^2 from the q^2 | |
| dependence of the decay rate. | 3 DOBBS 08 establishes $ rac{V_{Cd}}{V_{cs}}\cdotrac{f_+^h(0)}{f_+^K(0)} =0.188\pm0.008\pm0.002$ from the D^+ and D^0 |
| $\Gamma(K^-\mu^+ u_\mu)/\Gamma(\mu^+	ext{ anything})$ Γ_{19}/Γ_6 | decays to $\overline{K}e^+ u_e$ and $\pie^+ u_e$. |
| VALUE EVTS DOCUMENT ID TECN COMMENT | |
| 0.50 ±0.05 OUR FIT | $\Gamma(\pi^-e^+ u_e)/\Gamma(K^-e^+ u_e)$ VALUE EVTS DOCUMENT ID TECH COMMENT |
| 0.472±0.051±0.040 232 KODAMA 94 E653 π ⁻ emulsion 600 GeV | VALUE EVTS DOCUMENT ID TECN COMMENT 0.0814±0.0025 OUR FIT Error includes scale factor of 1.1. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 0.085 ±0.007 OUR AVERAGE |
| $0.32 \pm 0.05 \pm 0.05$ 124 KODAMA 91 EMUL p A 800 GeV | $0.082 \pm 0.006 \pm 0.005$ |
| $\Gamma(K^-\pi^0 e^+ u_e)/\Gamma_{ m total}$ $\Gamma_{ m 22}/\Gamma$ | 0.101 $\pm 0.020 \pm 0.003$ 91 2 FRABETTI 96B E687 γ Be, $\overline{E}_{\gamma} \approx 200$ GeV 0.103 $\pm 0.039 \pm 0.013$ 87 3 BUTLER 95 CLE2 < 0.156 (90% CL) |
| VALUE <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | 1 HUANG 05 uses both e and μ events, and makes a small correction to the μ |
| $0.016 + 0.013 \pm 0.002$ 4 ¹ BAI 91 MRK3 $e^+e^- \approx 3.77 \; \text{GeV}$ | |
| 1 BAI 91 finds that a fraction $^{0.79}_{-0.17}^{+0.15}_{-0.03}^{+0.09}$ of combined 0 and 0 decays to | events to make them effectively e events. This result gives $ rac{V_{Cd}}{V_{Cs}}\cdotrac{f_+^*(0)}{f^K(0)} ^2=$ |
| $\overline{K}\pi e^+ \nu_e$ (24 events) are \overline{K}^* (892) $e^+ \nu_e$. BAI 91 uses 56 $K^- e^+ \nu_e$ events to measure | 0.038 + 0.006 + 0.005 - 0.007 - 0.003 |
| a pole mass of $1.8 \pm 0.3 \pm 0.2$ GeV/ c^2 from the q^2 dependence of the decay rate. | 2 FRABETTI 96B uses both e and μ events, and makes a small correction to the μ events to |
| | |
| $\Gamma(\overline{K}^0\pi^-e^+\nu_e)/\Gamma_{\text{total}}$ Γ_{23}/Γ | make them effectively e events. This result gives $ rac{V_{Cd}}{V_{Cs}}\cdotrac{f_+^{\pi}(0)}{f_+^{K}(0)} ^2=0.050\pm0.011\pm0.002.$ |
| | 3 BUTLER 95 has 87 \pm 33 $\pi^ e^+$ $ u_e$ events. The result gives $ rac{V_c d}{V_{cS}}\cdotrac{f_+^{\pi}(0)}{f_+^{K}(0)} ^2=0.052\pm0.052$ |
| VALUE (units 10 ⁻²) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | V_{e} events. The result gives $ V_{e} ^{-1} = 0.002 \pm 0.002$ |
| VALUE (units 10 ⁻²) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.7 + 0.9 OUR AVERAGE | |
| 2.7 +0.9 OUR AVERAGE | 0.020 ± 0.007 . |
| 2.7 ± 0.9 OUR AVERAGE 2.61±1.04±0.28 9±3 ABLIKIM 060 BES2 e ⁺ e ⁻ at 3773 MeV | |
| 2.7 +0.9 OUR AVERAGE | 0.020 ± 0.007 . |

| $(\pi^-\mu^+ u_\mu)/\Gamma(K^-\mu^+ u_\mu)$ Γ_{29}/Γ_{19} | $\Gamma(K_S^0\pi^+\pi^-)/\Gamma_{	ext{total}}$ VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 072 \pm 0.007 OUR FIT 074 \pm 0.008 \pm 0.007 288 \pm 29 1 LINK 05 FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV | • • • We do not use the following data for averages, fits, limits, etc. • • |
| ¹ LINK 05 finds the form-factor ratio $ f_0^{\pi}(0)/f_0^{K}(0) $ to be 0.85 \pm 0.04 \pm 0.01. | $2.52\pm0.20\pm0.25$ 284 ± 22 1 ALBRECHT 9 4F ARG e $^{+}$ e $^{-}$ $pprox$ $^{-}$ $^{-}$ (4.5) |
| LINK US finds the form-factor ratio $ r_0^{**}(0)/r_0^{**}(0) $ to be 0.85 \pm 0.04 \pm 0.04 \pm 0.01. | 3.2 \pm 0.3 \pm 0.5 ADLER 87 MRK3 e^+e^- 3.77 GeV |
| $(ho^- e^+ u_e)/\Gamma_{ m total}$ $\Gamma_{ m 30}/\Gamma$ | 2.6 \pm 0.8 32 \pm 8 2 SCHINDLER 81 MRK2 e^+e^- 3.771 GeV 4.0 \pm 1.2 28 3 PERUZZI 77 LGW e^+e^- 3.77 GeV |
| LUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | 1 See the footnote on the ALBRECHT 94F measurement of $\Gamma(K^{-}\pi^{+})/\Gamma_{\text{total}}$ for th |
| 194 ± 0.039 ± 0.013 31 ± 6 COAN 05 CLEO e^+e^- at $\psi(3770)$ | method used |
| ───── Hadronic modes with a single K ──── | ² SCHINDLER 81 (MARK-2) measures $\sigma(e^+e^- \rightarrow \psi(3770)) \times$ branching fraction t be 0.30 ± 0.08 nb. We use the MARK-3 (ADLER 88c) value of $\sigma = 5.8 \pm 0.5 \pm 0.6$ nt |
| (V==+\/F | 3 PERUZZI 77 (MARK-1) measures $\sigma(e^+e^- 	o \psi(3770)) 	imes$ branching fraction to b |
| $(K^-\pi^+)/\Gamma_{	ext{total}}$ $\Gamma_{31}/\Gamma_{	ext{LUE (units }10^{-2})}$ EVTS DOCUMENT ID TECN COMMENT | 0.46 \pm 0.12 nb. We use the MARK-3 (ADLER 88c) value of $\sigma=$ 5.8 \pm 0.5 \pm 0.6 nb. |
| 88 ±0.05 OUR FIT Error includes scale factor of 1.2. | $\Gamma(K_S^0\pi^+\pi^-)/\Gamma(K^-\pi^+)$ Γ_{34}/Γ_{32} |
| 91 ±0.05 OUR AVERAGE Error includes scale factor of 1.1. | VALUE EVTS DOCUMENT ID TECN COMMENT 0.73±0.05 OUR FIT Error includes scale factor of 1.1. |
| $007 \pm 0.037 \pm 0.072$ 33.8 \pm 0.3k AUBERT 08L BABR e^+e^- at $\varUpsilon(4S)$ 891 \pm 0.035 \pm 0.069 1 DOBBS 07 CLEO e^+e^- at $\psi(3770)$ | $\textbf{0.81\pm0.05\pm0.08}$ 856 \pm 35 FRABETTI 94J E687 γ Be \overline{E}_{γ} =220 GeV |
| 82 ± 0.07 ± 0.12 ARTUSO 98 CLE2 CLEO average | • • We do not use the following data for averages, fits, limits, etc. |
| 90 \pm 0.09 \pm 0.12 5392 ³ BARATE 97c ALEP From Z decays | 0.85 ± 0.40 35 AVERY 80 SPEC $\gamma N ightarrow D^{*+}$ |
| 41 ± 0.12 ± 0.28 1173 \pm 37 3 ALBRECHT 94F ARG $e^+e^- \approx \varUpsilon(4S)$ 62 ± 0.34 ± 0.44 91J ALEP From Z decays | 1.4 ± 0.5 116 PICCOLO 77 MRK1 e^+e^- 4.03, 4.41 GeV |
| ● • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(K_S^0 \rho^0)/\Gamma(K_S^0 \pi^+ \pi^-) \qquad \qquad \Gamma_{35}/\Gamma_3$ |
| 91 ± 0.08 ± 0.09 10.3k ± 100 ¹ HE 05 CLEO See DOBBS 07 | This is the "fit fraction" from the Dalitz-plot analysis. |
| 81 ± 0.15 ± 0.16 1165 ${}^4_{\sigma}$ ARTUSO 98 CLE2 e^+e^- at $\Upsilon(4S)$ | VALUE DO CUMENT ID TECN COMMENT |
| 69 ±0.11 ±0.16 | $0.224_{-0.023}^{+0.017}$ OUR AVERAGE Error includes scale factor of 1.7. |
| $5 \pm 0.6 \pm 0.4$ 6 ALBRECHT 94 ARG $e^+e^- \approx \varUpsilon(4S)$ 95 $\pm 0.08 \pm 0.17$ 4208 3,7 AKERIB 93 CLE2 See ARTUSO 98 | 0.210 ± 0.016 1 AUBERT 08AL BABR Dalitz fit, \approx 487 k evts |
| $5 \pm 0.8 \pm 0.5$ 56 3 ABACHI 88 HRS e^+e^- 29 GeV | $0.264 \pm 0.009 ^{+0.010}_{-0.026}$ MURAMATSU 02 CLE2 Dalitz fit, 5299 evts |
| 2 ± 0.4 ± 0.4 930 ADLER 88C MRK3 $e^{+}e^{-}$ 3.77 GeV | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 1 ± 0.6 263 ± 17 8 SCHINDLER 81 MRK2 $e^{+}e^{-}$ 3.771 GeV 3 ± 1.0 130 9 PERUZZI 77 LGW $e^{+}e^{-}$ 3.77 GeV | |
| | $0.267 \pm 0.011 + 0.009 \atop -0.028$ ASNER 04A CLEO See MURAMATSU 02 |
| ¹ DOBBS 07 and HE 05 use single- and double-tagged events in an overall fit. DOBBS 07 supersedes HE 05. | 0.350±0.028±0.067 FRABETTI 94G E687 Dalitz fit, 597 evts 0.227±0.032±0.009 ALBRECHT 93D ARG Dalitz fit, 440 evts |
| ² This combines the CLEO results of ARTUSO 98, COAN 98, and AKERIB 93. | 0.215±0.051±0.037 ANJOS 93 E691 γBe 90-260 GeV |
| ³ ABACHI 88, DECAMP 91J, AKERIB 93, ALBRECHT 94F, and BARATE 97c use $D^*(2010)^+ \rightarrow D^0\pi^+$ decays. The π^+ is both slow and of low p_T with respect | 0.20 \pm 0.06 \pm 0.03 FRABETTI 92B E687 γ Be, $\overline{E}_{\gamma} =$ 221 GeV |
| to the event thrust axis or nearest jet ($\approx D^{*+}$ direction). The excess number of such | 0.12 $\pm 0.01 \pm 0.07$ ADLER 87 MRK3 e^+e^- 3.77 GeV |
| π^+ 's over background gives the number of $D^*(2010)^+ \rightarrow D^0\pi^+$ events, and the | $^{ m 1}$ The error on this AUBERT 08AL value includes both statistical and systematic unce |
| fraction with $D^0 \to K^-\pi^+$ gives the $D^0 \to K^-\pi^+$ branching fraction. | taities; the latter dominates. |
| ⁴ ARTUSO 98, following ALBRECHT 94, uses D^0 mesons from $\overline{B}^0 \rightarrow$ | $\Gamma(K_S^0\omega,\omega\to\pi^+\pi^-)/\Gamma(K_S^0\pi^+\pi^-)$ Γ_{36}/Γ_3 |
| $D^*(2010)^+ X \ell^- \overline{\nu}_\ell$ decays. Our average uses the CLEO average of this value with the values of COAN 98 and AKERIB 93. | This is the "fit fraction" from the Dalitz-plot analysis. VALUE DOCUMENT ID TECN COMMENT |
| 5 the values of COAN 98 and AKERIB 93. 5 COAN 98 assumes that $\Gamma(B \to \overline{D} X \ell^+ \nu)/\Gamma(B \to X \ell^+ \nu) = 1.0 - 3 V_{ub}/V_{cb} ^2 - 1.0 = 1.0 = 10$ | 0.0073±0.0020 OUR AVERAGE |
| 0.010 ± 0.005 , the last term accounting for $\overline{B}\to D_s^+ KX\ell^-\overline{\nu}$. COAN 98 is included | $0.009~\pm 0.010$ 1 AUBERT 08AL BABR Dalitz fit, $pprox$ 487 k evts |
| in the CLEO average in ARTUSO 98. 6 ALBRECHT 94 uses D^0 mesons from $\overline{B}{}^0 \to D^{*+} \ell^- \overline{\nu}_\ell$ decays. This is a different set | $0.0072\pm0.0018 {+0.0010 \atop -0.0009}$ MURAMATSU 02 CLE2 Dalitz fit, 5299 evts |
| of events then used by ALDRECHT 045 | -0.0009 Moration of Care and the care and th |
| of events than used by ALBRECHT 94F. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 7 This AKERIB 93 value includes radiative corrections; without them, the value is $0.0391\pm$ | \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet |
| 7 This AKERIB 93 value includes radiative corrections; without them, the value is 0.0391 \pm 0.0008 \pm 0.0017. AKERIB 93 is included in the CLEO average in ARTUSO 98. | • • • We do not use the following data for averages, fits, limits, etc. • • • $0.0081 \pm 0.0019 ^{+0.0018}_{-0.0010} \qquad \text{ASNER} \qquad \text{04A CLEO} \text{See MURAMATSU 02}$ |
| 7 This AKERIB 93 value includes radiative corrections; without them, the value is 0.0391 \pm 0.0008 \pm 0.0017. AKERIB 93 is included in the CLEO average in ARTUSO 98. 8 SCHINDLER 81 (MARK-2) measures $\sigma(e^+e^- \rightarrow \psi(3770)) \times$ branching fraction to be 0.24 \pm 0.02 nb. We use the MARK-3 (ADLER 88c) value of $\sigma=5.8\pm0.5\pm0.6$ nb. | ullet $ullet$ $$ |
| ⁷ This AKERIB 93 value includes radiative corrections; without them, the value is 0.0391 ± 0.0008 ± 0.0017. AKERIB 93 is included in the CLEO average in ARTUSO 98. SCHINDLER 81 (MARK-2) measures $\sigma(e^+e^- \rightarrow \psi(3770))$ × branching fraction to be 0.24 ± 0.02 nb. We use the MARK-3 (ADLER 88c) value of σ = 5.8 ± 0.5 ± 0.6 nb. PERUZZI 77 (MARK-1) measures $\sigma(e^+e^- \rightarrow \psi(3770))$ × branching fraction to be | $ \begin{array}{llllllllllllllllllllllllllllllllllll$ |
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| ⁷ This AKERIB 93 value includes radiative corrections; without them, the value is 0.0391 ± 0.0008 ± 0.0017. AKERIB 93 is included in the CLEO average in ARTUSO 98. ⁸ SCHINDLER 81 (MARK-2) measures $\sigma(e^+e^- \to \psi(3770)) \times$ branching fraction to be 0.24 ± 0.02 nb. We use the MARK-3 (ADLER 88c) value of σ = 5.8 ± 0.5 ± 0.6 nb. ⁹ PERUZZI 77 (MARK-1) measures $\sigma(e^+e^- \to \psi(3770)) \times$ branching fraction to be 0.25 ± 0.05 nb. We use the MARK-3 (ADLER 88c) value of σ = 5.8 ± 0.5 ± 0.6 nb. (K $^0_8\pi^0$)/Γtotal | • • • We do not use the following data for averages, fits, limits, etc. • • • • $0.0081 \pm 0.0019 + 0.0018 \\ -0.0010 \\ 1 \\ \text{The error on this AUBERT 08AL value includes both statistical and systematic uncertaities; the latter dominates.}$ $\Gamma(K_S^0(\pi^+\pi^-)_{S-\text{wave}})/\Gamma(K_S^0\pi^+\pi^-) \\ \text{This is the "fit fraction" from the Dalitz-plot analysis. The } \frac{1}{\pi^-} 1$ |
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| $\Gamma\left(K_S^0 f_2(1270), f_2(1270) \rightarrow This is the "fit fraction" f$ | from the Dalitz-plot | analys | is. | Γ ₄₀ /Γ ₃₄ |
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| NALUE 0.0035 OUD AVEDACE | DO CUMENT ID | | TECN | COMMENT |
| 0.0032 ± 0.0035 OUR AVERAGE | | | | B. W. W |
| 0.006 ±0.007 | 1 AUBERT | | BABR | • |
| $0.0027 \pm 0.0015 + 0.0037 \\ -0.0017$ | MURAMATSU | | CLE2 | Dalitz fit, 5299 evts |
| | _ | | | |
| $0.0036 \pm 0.0022 + 0.0032 \\ -0.0019$ | ASNER | 04A | CLEO | See MURAMATSU 02 |
| 0.037 ±0.014 ±0.017 0.050 ±0.021 ±0.008 | FRABETTI ALBRECHT | 94G 93D | E687 ARG | Dalitz fit, 597 evts Dalitz fit, 440 evts |
| ¹ The error on this AUBERT taities; the latter dominates. | 08AL value include: | | | |
| $\Gamma(K^*(892)^-\pi^+, K^*(892)^-$ | $\rightarrow K_S^0 \pi^-)/\Gamma(R$ | < ⁰ ₅ π ⁺ | $\pi^-)$ | Γ ₄₁ /Γ ₃₄ |
| This is the "fit fraction" f | rom the Dalitz-plot <u>DOCUMENT ID</u> | | TECN | COMMENT |
| 0.588 + 0.034 OUR AVERAGE | Error includes scale | e facto | r of 2.0. | |
| 0.557±0.028 | ¹ AUBERT | | BABR | |
| $0.657 \pm 0.013 \pm 0.018$ | MURAMATSU | | CLE2 | Dalitz fit, 5299 evts |
| • • • We do not use the follow | ing data for average | es, fits, | limits, | |
| $0.663 \pm 0.013 + 0.024 \\ -0.043$ | ASNER | | CLEO | See MURAMATSU 02 |
| $0.625 \pm 0.036 \pm 0.043$ $0.625 \pm 0.036 \pm 0.026$ | FRABETTI | | E687 | Dalitz fit, 597 evts |
| $0.718 \pm 0.042 \pm 0.030$ | ALBRECHT | 93D | ARG | Dalitz fit, 440 evts |
| 0.480±0.097 0.56 ±0.04 ±0.05 | A NJOS ADLER | 93 87 | E691 | γ Be 90–260 GeV e^+e^- 3.77 GeV |
| The error on this AUBERT | | | | |
| taities; the latter dominates. | | 5 500 | Seatisti | car and systematic ander |
| $\Gamma(K_0^*(1430)^-\pi^+,K_0^*(1430)^-\pi^+)$ This is the "fit fraction" for Γ | $()^- 	o K_S^0 \pi^-)/\Gamma$ from the Dalitz-plot DOCUMENT ID | (K _S 1 | π+ π ⁻) sis. TECN | Γ ₄₂ /Γ ₃₄ |
| 0.095 + 0.014 OUR AVERAGE | <u>DO COMENT ID</u> | | TECN | COMMENT |
| 0.102±0.015 | ¹ AUBERT | 08AL | BABR | Dalitz fit, \approx 487 k evts |
| $0.073 \pm 0.007 ^{+0.031}_{-0.011}$ | MURAMATSU | J 02 | CLE2 | Dalitz fit, 5299 evts |
| • • We do not use the follow | ing data for average | es, fits, | limits, | etc. • • • |
| $0.072 \pm 0.007 + 0.014 \\ -0.013$ | ASNER | 04A | CLEO | See MURAMATSU 02 |
| $0.109 \pm 0.027 \pm 0.029$ | FRABETTI | 94 G | E687 | Dalitz fit, 597 evts |
| $0.129 \pm 0.034 \pm 0.021$ | ALBRECHT | | ARG | Dalitz fit, 440 evts |
| ¹ The error on this AUBERT taities; the latter dominates. | | s both | statisti | cal and systematic uncer- |
| $\Gamma(K_2^*(1430)^-\pi^+$, $K_2^*(1430)^+$ | $(J)^- ightarrow K_S^0 \pi^-)/\Gamma$ from the Dalitz-plot | (K 5 1 | π+ π-) | Γ ₄₃ /Γ ₃₄ |
| MALUE 0.0120 + 0.0070 OUR AVERAGE | <u>DO CUMENT ID</u> | | TECN | COMMENT |
| 0.0120 ± 0.0070 OUR AVERAGE | 1 AUBERT | 00 | DADD | D-13- 64 - 407 1 - 44 |
| 0.022 ± 0.016 | AUBERI | | BABK | Dalitz fit, \approx 487 k evts |
| | | | CLES | Dalitz fit F 200 outs |
| $0.011\ \pm0.002\ ^{+\ 0.007}_{-\ 0.003}$ | MURAMATSU | J 02 | CLE2 | Dalitz fit, 5299 evts |
| $0.011 \pm 0.002 \stackrel{+}{-} 0.007 \atop -0.003$ • • • We do not use the follow | MURAMATSU | J 02 es, fits, | limits, | etc • • • |
| 0.011 $\pm 0.002 ^{+0.007}_{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ | MURAMATSU ing data for average ASNER | J 02 es, fits, 04A | limits, | etc. • • • See MURAMATSU 02 |
| $0.011 \pm 0.002 \stackrel{+0.007}{-0.003}$ • • • We do not use the follow $0.011 \pm 0.002 \stackrel{+0.005}{-0.003}$ ¹ The error on this AUBERT talties; the latter dominates. | MURAMATSU ing data for average ASNER OBAL value includes | J 02 es, fits, 04A s both | , limits, CLEO statisti | etc. • • • See MURAMATSU 02 cal and systematic uncer- |
| 0.011 $\pm 0.002 ^{+0.007}_{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ The error on this AUBERT taities; the latter dominates. T $(K^*(1680)^-\pi^+, K^*(1680)^-\pi^+)$ This is the "fit fraction" for the second of the secon | MURAMATSU ASNER 08AL value include: 0) $\rightarrow K_0^0 \pi^-$)/From the Dalitz-plot | J 02 es, fits, 04A s both | CLEO statistic $\pi^+\pi^-$ sis. | See MURAMATSU 02 cal and systematic uncer- |
| 0.011 $\pm 0.002 \stackrel{+}{}_{-}0.007$ • • • We do not use the follow 0.011 $\pm 0.002 \stackrel{+}{}_{-}0.003$ 1 The error on this AUBERT taities; the latter dominates. T($K^*(1680)^-\pi^+$, $K^*(1680)^+\pi^+$) This is the "fit fraction" for the contract of the second of | MURAMATSU ASNER 08AL value include: 0) $\rightarrow K_0^0 \pi^-)/\Gamma$ from the Dalitz-plot | J 02 es, fits, 04A s both | CLEO statistic $\pi^+\pi^-$ sis. | etc. • • • See MURAMATSU 02 cal and systematic uncer- |
| 0.011 $\pm 0.002 \stackrel{+0.007}{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 \stackrel{+0.005}{-0.003}$ The error on this AUBERT taities; the latter dominates. (K*(1680) $^-\pi^+$, K*(1680) This is the "fit fraction" for the tailor of tail | MURAMATSU ASNER 08AL value include: 0) $\rightarrow K_0^0 \pi^-$)/From the Dalitz-plot | J 02 es, fits, 04A s both (KS1 analys | CLEO statistic π+π- sis. TECN | See MURAMATSU 02 cal and systematic uncer- |
| 0.011 $\pm 0.002 ^+_{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 ^+_{-0.003}$ 1 The error on this AUBERT taities; the latter dominates. F ($K^*(1680)^-\pi^+_{-}, K^*(1680)^-\pi^+_{-}$) This is the "fit fraction" for the table 0.016 ± 0.013 OUR AVERAGE 0.007 ± 0.019 0.022 $\pm 0.004 ^+_{-0.015}$ | MURAMATSU ASNER 08AL value include: 1) → K ⁰ π −)/Γ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURAMATSU | J 02 es, fits, 04A s both (K61 analys) 08AL J 02 | CLEO statistic $\pi^+\pi^-$ sis. TECN BABR CLE2 | etc. • • • • See MURAMATSU 02 cal and systematic uncer- Γ_{44}/Γ_{34} $\underline{COMMENT}$ Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts |
| 0.011 $\pm 0.002 ^{+0.007}_{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ 1 The error on this AUBERT taities; the latter dominates. $\Gamma (K^*(1680)^-\pi^+, K^*(1680)^-\pi^+) = K^*(1680)^-\pi^+ = K^*(1$ | MURAMATSU ASNER 08AL value include: 1) → K ⁰ π −)/Γ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURAMATSU | J 02 es, fits, 04A s both (K61 analys) 08AL J 02 | CLEO statistic $\pi^+\pi^-$ sis. TECN BABR CLE2 | etc. • • • • See MURAMATSU 02 cal and systematic uncer- Γ_{44}/Γ_{34} $\underline{COMMENT}$ Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts |
| 0.011 $\pm 0.002 ^{+0.007}_{-0.003}$ • • • We do not use the follow 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ The error on this AUBERT taities; the latter dominates. $\Gamma \left(K^* (1680)^- \pi^+, K^* (1680)^- \pi^+, K^* (1680)^- \pi^+ \right)$ This is the "fit fraction" for the property of the propert | MURAMATSU ASNER 08AL value include: 1) → K ⁰ π −)/Γ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURAMATSU | J 02 es, fits, 04A s both (K0; analys 08AL J 02 es, fits, | cleo statistic $\pi^+\pi^-$); is. TECN BABR CLE2 | etc. • • • • See MURAMATSU 02 cal and systematic uncer- Γ_{44}/Γ_{34} $\underline{COMMENT}$ Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts |
| 0.011 $\pm 0.002 ^{+0.007}_{-0.003}$ 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ 0.011 $\pm 0.002 ^{+0.005}_{-0.003}$ 1 The error on this AUBERT taities; the latter dominates. (K*(1680) $^{-}\pi^{+}$, K*(1680 This is the "fit fraction" for the standard of the "fit fraction" for the standard of the standard | MURAMATSU ASNER 08AL value include: 1) → K 3 π -)/Γ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURAMATSU ing data for average ASNER 08AL value include: | J 02 es, fits, 04A s both (K%1 analys 08AL J 02 es, fits, 04A | timits, CLEO statistic TECN BABR CLE2 limits, CLEO | setc. • • • • See MURAMATSU 02 cal and systematic uncertainty Γ_{44}/Γ_{34} $\underline{COMMENT}$ Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts etc. • • • See MURAMATSU 02 |
| 0.011 ±0.002 +0.007 ••• We do not use the follow 0.011 ±0.002 +0.005 1 The error on this AUBERT taities; the latter dominates. (K*(1680) - π+ . K*(1680 This is the "fit fraction" of the state | MURAMATSU ASNER 08AL value includes 1 | J 02 es, fits, 04A s both (K01 analys 08AL J 02 es, fits, 04A s both | statistic m+ m- sis. TECN BABR CLE2 limits, CLEO statistic | See MURAMATSU 02 cal and systematic uncer- |
| 0.011 ±0.002 ±0.007 0.003 ±0.002 ±0.003 0.011 ±0.002 ±0.005 1 The error on this AUBERT taities; the latter dominates. Γ (Κ*(1680) - π+ , Κ*(1680) - π+ is the "fit fraction" for the state of the s | MURA MATSU ASNER 08AL value include: 0) $\rightarrow K_S^0 \pi^-)/\Gamma$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU ing data for average ASNER 08AL value include: $\rightarrow K_S^0 \pi^+)/\Gamma(\mu$ from the Dalitz-plot | J 02 es, fits, 04A s both (K ⁰ ₅ 2 analys 08AL J 02 es, fits, 04A s both | CLEO statistic π+π-) sis. TECN BABR CLE2 limits, CLEO statistic π-) lysis. T | setc. • • • • See MURAMATSU 02 cal and systematic uncerval of the systemat |
| 0.011 ±0.002 +0.007 -0.003 ••• We do not use the follow 0.011 ±0.002 +0.005 -0.003 ¹ The error on this AUBERT taities; the latter dominates. Γ (Κ*(1680) - π + . Κ*(1680) - π | MURAMATSU ASNER 08AL value includes 1 | J 02 es, fits, 04A s both (K ⁰ ₅ 2 analys 08AL J 02 es, fits, 04A s both | CLEO statistic π+π-) sis. TECN BABR CLE2 limits, CLEO statistic π-) lysis. T | setc. • • • • See MURAMATSU 02 cal and systematic uncer- Γ_{44}/Γ_{34} $\underline{COMMENT}$ Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts etc. • • • See MURAMATSU 02 cal and systematic uncer- Γ_{45}/Γ_{34} This is a doubly Cabibbo |
| 0.011 ±0.002 +0.007 ••• We do not use the follow 0.011 ±0.002 +0.003 1 The error on this AUBERT taities; the latter dominates. Γ (Κ*(1680) - π+ , K*(1680 This is the "fit fraction" of the "fit | MURA MATSU ASNER 08AL value include: 0) $\rightarrow K_{5}^{0}\pi^{-}$)/ Γ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU ASNER 08AL value include: $\rightarrow K_{5}^{0}\pi^{+}$)/ Γ (Γ from the Dalitz-plot DOCUMENT ID | J 02 04A s both (K6 analys 08AL J 02 es, fits, 04A S both 08AL S both (S | limits, CLEO statistic $\pi^+\pi^-$, $\pi^+\pi^-$) BABR CLE2 limits, CLEO statistic π^-) π^-) π^-) π^-) π^-) π^- | See MURAMATSU 02 cal and systematic uncertainty of the systematic |
| 0.011 $\pm 0.002 + 0.007$ • • • We do not use the follow 0.011 $\pm 0.002 + 0.003$ 1 The error on this AUBERT taities; the latter dominates. F ($K^*(1680)^-\pi^+$, $K^*(1680)^$ | MURA MATSU ASNER 08AL value include: $0.0^{-} \rightarrow K_{5}^{0} \pi^{-})/\Gamma$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU ASNER 08AL value include: $0.0^{-} \rightarrow K_{5}^{0} \pi^{+})/\Gamma(\mu$ from the Dalitz-plot DOCUMENT ID | J 02 es, fits, 04A s both (K0, 08AL J 02 es, fits, 04A s both (08AL C(0, 08AL C(0, 0 | limits, CLEO statistic statistic sis. $TECN$ BABR CLE2 limits, CLEO statistic $TECN$ statistic $TECN$ statistic $TECN$ statistic $TECN$ BABR BABR | setc. • • • See MURAMATSU 02 cal and systematic uncer- T44/ Γ 34 COMMENT Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts etc. • • • See MURAMATSU 02 cal and systematic uncer- T45/ Γ 34 This is a doubly Cabibbo- COMMENT Dalitz fit, \approx 487 k evts |
| 0.011 ± 0.002 ± 0.007 • • • We do not use the follow 0.011 ± 0.002 ± 0.003 ¹ The error on this AUBERT taities; the latter dominates. Γ (Κ*(1680) ¬ π + , Κ*(1680) This is the "fit fraction" fraction" fraction" fraction" fraction on this state of the fraction on the follow of | MURA MATSU ASNER 08AL value include: $0.0^- \rightarrow K_5^0 \pi^-)/\Gamma$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU MORAL value include: $0.0^+ \rightarrow K_5^0 \pi^+)/\Gamma(\mu$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU | J 02 es, fits, 04A s both (K0, 08AL J 02 es, fits, 04A s both (0, 08AL J 02 es, fits, 04A s both 08AL J 02 | limits, CLEO statistic statistic sists. TECN BABR CLE2 limits, CLEO statistic π^-) τ | setc. • • • See MURAMATSU 02 cal and systematic uncer- F44/ Γ_{34} COMMENT Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts etc. • • • See MURAMATSU 02 cal and systematic uncer- cal and systematic uncer- F45/ Γ_{34} This is a doubly Cabibbo- COMMENT Dalitz fit, \approx 487 k evts Dalitz fit, 5299 evts |
| 0.011 ±0.002 +0.007 ••• We do not use the follow 0.011 ±0.002 +0.003 1 The error on this AUBERT taities; the latter dominates. Γ (Κ*(1680) - π+ , K*(1680 This is the "fit fraction" of the "fit | MURA MATSU ASNER 08AL value include: $0.0^- \rightarrow K_5^0 \pi^-)/\Gamma$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU MORAL value include: $0.0^+ \rightarrow K_5^0 \pi^+)/\Gamma(\mu$ from the Dalitz-plot DOCUMENT ID 1 AUBERT MURA MATSU | J 02 es, fits, 04A s both 08AL J 02 es, fits, 04A 08AL J 02 J 02 es, fits, 08AL | limits, CLEO statistic $\pi^+\pi^-$ BABR CLE2 limits, CLEO statistic π^- Dyspis. The statistic π^- BABR CLEO statistic π^- BABR CLEO limits, CLEO limits, CLEO limits, π^- BABR CLEO limits, π^- BABR CLEO limits, | See MURAMATSU 02 cal and systematic uncer- rate of the first part of the first par |

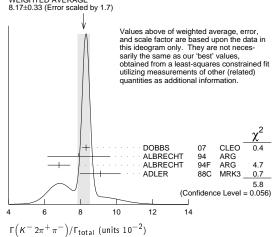
| suppressed mod VALUE | CL%_ | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------------------------------------------------------------------|---------------------------|---------------------------------------------------|-------------------------------------|--------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|----------------------------|
| <5 × 10 ⁻⁴ | 95 | | | | Dalitz fit, \approx 487 k | evts |
| $\Gamma(K_2^*(1430)^+\pi^-, This is the "fit suppressed mod$ | e. | | | | | |
| <1.2 × 10 ⁻³ | <u>CL%</u> 95 | AUBERT | 08A1 | BABR | COMMENT Dalitz fit, ≈ 487 F | evts |
| $\Gamma(K_5^0\pi^+\pi^- \text{ nonre})$ This is the "fit ALBRECHT 93t for a nonresonal" | fraction"fr (quoted in | om the Dalitz-plo many of the earli | ot anal ersubn | ysis. Ne nodes of | ther FRABETTI 9 $\kappa_S^0\pi^+\pi^-)$ sees ev | 8/Γ34 14G no vidence |
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| $0.009 \pm 0.004 + 0.020 \\ -0.004$ | | MURAMATS | U 02 | CLE2 | Dalitz fit, 5299 ev | √ts |
| • • • We do not use | the followin | ng data for averag | es, fits | , limits, | etc. • • • | |
| $0.007 \pm 0.007 + 0.021 \\ -0.006$ | | ASNER | 04A | CLEO | See MURAMATS | U 02 |
| $0.263 \pm 0.024 \pm 0.041$ | | ANJOS | 93 | E691 | , | |
| 0.26 ±0.08 ±0.05 0.33 ±0.05 ±0.10 | | FRABETTI ADLER | 92B 87 | | γ Be, $\overline{E}_{\gamma} = 221$ Ce ⁺ e ⁻ 3.77 GeV | ieV |
| | | ADLLIN | 01 | IVIIVIV | | |
| $\Gamma(K^-\pi^+\pi^0)/\Gamma_{\rm tota}$ | | | | | | Γ49/ |
| VALUE (units 10 ⁻²) 13.9 ±0.5 OUR FIT | | <u>DOCUME</u> ludes scale factor | of 1.7. | TEC | COMMENT | |
| 14.57±0.12±0.38 | | ¹ DOBBS | | | EO e^+e^- at ψ (3 | 770) |
| • • • We do not use | | | es, fits | | | |
| 14.9 ±0.3 ±0.5 13.3 ±1.2 ±1.3 | 19k ±15 93 | | | | EO See DOBBS (K3 e ⁺ e ⁻ 3.77 G | |
| 11.7 ±4.3 | 3 | | LER | 81 MR | $K2 e^+e^-$ 3.771 | |
| ¹ DOBBS 07 and HI | | gle- and double-t | agged e | vents in | an overall fit. DOE | BS 0 |
| supersedes HE 05. 2 SCHINDLER 81 (be 0.68 \pm 0.23 nb. | MARK-2) r | measures $\sigma(e^+e^-)$ e MARK-3 (ADLI | - → . ER 88c | $\psi(3770))$) value o | $	imes$ branching fractif $\sigma=$ 5.8 \pm 0.5 \pm | tion t 0.6 nl |
| $\Gamma(K^-\pi^+\pi^0)/\Gamma(K^-\pi^+\pi^0)$ | $-\pi^{+}$) | | | | Γ4 | 9/Γ3 |
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 3.58±0.14 OUR FIT 3.44±0.30 OUR AVEI | | | | of 1.5. S | ee the ideogram be | low. |
| $3.81 \pm 0.07 \pm 0.26$ | 10k | BARISH | 96 | | $e^+e^- \approx \Upsilon(4S)$ | |
| $3.04 \pm 0.16 \pm 0.34$ $2.8 \pm 0.14 \pm 0.52$ | 931 1050 | ¹ ALBRECHT KINOSHITA | 92P 91 | ARG | $e^+e^-\approx 10 \text{ GeV}$ $e^+e^-\sim 10.7 \text{ GeV}$ | |
| 2.8 ±0.14±0.52 ¹ This value is calcu | | | | | | ٠V |
| WEIGHTED | | numbers in Table | 1017 | LDIVLCI | 11 721. | |
| 3.44±0.30 (E | | by 1.5) | | | | |
| | | and scale this ideog sarily the obtained | factor gram or same from a | are base aly. They as our 'be least-squ | d average, error, ed upon the data in vare not neces- est' values, uares constrained fil f other (related) | t |

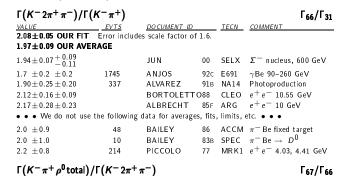




| $\Gamma(K^*(892)^-\pi^+,K^*(892)^+$ This is the "fit fraction | " from the Dalitz-plo | analvs | is. | Γ ₅₂ /Γ ₄₉ |
|----------------------------------------------------------------------------------|-----------------------------------------------------------|-------------------|-----------------------------------------------|----------------------------------------------------|
| ALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT |
| 0.160 ^{+ 0.025} OUR AVERAGI | E | | | |
| $0.161 \pm 0.007 ^{+0.027}_{-0.011}$ | KOPP | 01 | CLE2 | Dalitz fit, ≈ 7,000 evts |
| 0.011 | FRABETTI | 94 G | E687 | Dalitz fit, 530 evts |
| ullet • We do not use the foll | owing data for averag | es, fits | , limits, | etc. • • • |
| $.084 \pm 0.011 \pm 0.012$ | ANJOS | 93 | E691 | γ Be 90-260 GeV |
| $.12 \pm 0.02 \pm 0.03$ | ADLER | 87 | MR K3 | 3 e ⁺ e [−] 3.77 GeV |
| $(\overline{K}^*(892)^0\pi^0, \overline{K}^*(892))$ This is the "fit fraction | " from the Dalitz-plo | analys | sis. | Γ ₅₃ /Γ ₄₉ |
| 4 <i>LUE</i> .135±0.016 OUR AVERAGI | <u>DO CUMENT ID</u> | | TECN | COMMENT |
| $.127 \pm 0.009 \pm 0.016$ | KOPP | 01 | CLE2 | Dalitz fit, \approx 7,000 evts |
| .165 ± 0.031 ± 0.015 | FRABETTI | | E687 | Dalitz fit, 530 evts |
| • We do not use the foll | - | | | |
| .142±0.018±0.024 .13 ±0.02 ±0.03 | A NJOS ADLER | 93 87 | E691 MRK3 | γ Be 90-260 GeV 3 e^+e^- 3.77 GeV |
| /1/*/******* ± 1/*/** | | -/ | _ O | |
| $(K_0^*(1430)^-\pi^+, K_0^*(14$ This is the "fit fraction | $3UJ^- \rightarrow K^-\pi^0)/I$ " from the Dalitz plan | (K ⁻ : | π π ⁻ / ₂) | Γ ₅₄ /Γ ₄₉ |
| ALUE | DOCUMENT ID | | TECN | COMMENT |
| $.033 \pm 0.006 \pm 0.014$ | KOPP | 01 | CLE2 | Dalitz fit, \approx 7,000 evts |
| $(\overline{K}_0^*(1430)^0\pi^0, \overline{K}_0^*(143)^0\pi^0)$ | $(0)^0 \rightarrow K^-\pi^+)/\Gamma$ | (K-π | + \pi^0) | Γ ₅₅ /Γ ₄₉ |
| This is the "fit fraction | " from the Dalitz-plo | analys | sis. | 50, 45 |
| ALUE | DO CUMENT ID | | TECN | COMMENT |
| $.041 \pm 0.006 ^{+ 0.032}_{- 0.009}$ | KOPP | 01 | CLE2 | Dalitz fit, \approx 7,000 evts |
| ·///*/1/00\= + 1/*/ | 00)= | -/v- | _+ 0 | - /- |
| $(K^*(1680)^-\pi^+$, $K^*(16$ This is the "fit fraction" | SUJ $\rightarrow K^-\pi^{\circ})/I$ " from the Dalitz-plo | (K ⁻ | π'π") sis. | Γ ₅₆ /Γ ₄₉ |
| ALUE | | | TECN | COMMENT |
| $.013 \pm 0.003 \pm 0.004$ | KOPP | 01 | CLE2 | Dalitz fit, \approx 7,000 evts |
| $(K^-\pi^+\pi^0)$ nonresonant | ·)/[(K=#+#0) | | | Γ ₅₇ /Γ ₄₉ |
| This is the "fit fraction | | analys | sis. | 157/149 |
| .080 + 0.040 OUR AVERAGI .075 ± 0.009 + 0.056 - 0.011 | KOPP | 01 | CLE2 | Dalitz fit, ≈ 7,000 evts |
| $.101 \pm 0.033 \pm 0.040$ • • We do not use the foll | FRABETTI owing data for averag | | E687 , limits, | Dalitz fit, 530 evts etc. • • • |
| .036±0.004±0.018 | ANJOS | 93 | E691 | γBe 90-260 GeV |
| $.09 \pm 0.02 \pm 0.04$ | ADLER | 87 | MR K3 | e ⁺ e ⁻ 3.77 GeV |
| .51 ±0.22 2: | 1 SUMMERS | 84 | E691 | Photoproduction |
| $(K_S^0 2\pi^0)/\Gamma_{	ext{total}}$ | TS DOCUMENT | ID | TECI | Γ ₅₈ /Γ |
| 9.1 ±1.1 OUR AVERAGE | _ | | of 2.2. | |
| | 159 LOWREY | 11 | CLE | |
| $8.34 \pm 0.45 \pm 0.42$ | ASNER | 80 | CLE | O $e^+e^- ightarrow D^0\overline{D}{}^0,$ 3.77 GeV |
| $(K_S^0(2\pi^0)$ -S-wave $)/\Gamma(R_S^0(2\pi^0)$ | κ ⁰ 2π ⁰ \ | | | Γ ₅₉ /Γ ₅₈ |
| (Λξ (2π°)- 3-wave)/ Γ (r ALUE (%) | DOCUMENT ID | TF | CN C | |
| 8.9±6.3±3.1 | | | | Palitz analysis, 1259 evts |
| | | | | |
| $(\overline{K}^*(892)^0\pi^0, \overline{K}^*(892))$ | | | -cu | Γ ₆₀ /Γ ₃₂ |
| %LUE (%) 5.6± 5.3±2.5 | DOCUMENT ID | | | OMMENT Dalitz analysis, 1259 evts |
| • We do not use the foll | | | | • |
| $5 \begin{array}{c} +13 \\ -10 \end{array} \pm 7$ | | Э3в СІ | | Palitz plot fit, 122 evts |
| -10 [⊥] ′ | TROCARIO | , 30 CI | L | rantz piot int, 122 evis |
| $(\overline{K}^*(1430)^0\pi^0, \overline{K}^{*0} \rightarrow$ | $K_{s}^{0}\pi^{0})/\Gamma(K_{s}^{0}2\pi^{0})$ |) | | Γ ₆₁ /Γ ₅₈ |
| ALUE (%) | | | CN C | OMMENT |
| .49±0.45±2.51 | DOCUMENT ID LOWREY | 1 CI | | alitz analysis, 1259 evts |
| ·(1680\0~0 12*0 . | K0 =0\/F(K0 2=0 | η. | | Γ ₆₂ /Γ ₅₈ |
| $(\overline{K}^*(1680)^0\pi^0, \overline{K}^{*0} \rightarrow$ | | | CN C | , |
| 1.2±2.7±2.5 | DOCUMENT ID LOWREY | | | OMMENT Dalitz analysis, 1259 evts |
| | | | J L | |
| $(K_S^0 f_2(1270), f_2 \rightarrow 2\pi^0$ | | | | Γ ₆₃ /Γ ₅₈ |
| ALUE (%) | DOCUMENT ID | | | OMMENT |
| .48±0.91±0.78 | LOWREY | ıı CI | FO [| alitz analysis, 1259 evts |
| $(2K_S^0$, one $K_S^0 ightarrow 2\pi^0)$ | $/\Gamma(K_S^0 2\pi^0)$ | | | Γ ₆₄ /Γ ₅₈ |
| ALUE (%) | DOCUMENT ID | TE | CN C | |
| | | | | |
| 3.46±0.92±0.66 | LOWREY | | | alitz analysis, 1259 evts |

| Γ(K _S ⁰ 2π ⁰ nonres | onant $)/\Gamma(K_S^0$ | π ⁰) DO CUMENT ID | | TECN | COMMENT | Γ ₆₅ /Γ ₃₂ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| • • • We do not us | e the following | | | | | |
| $0.37 \pm 0.08 \pm 0.04$ | | PROCARIO | 93B | CLE2 | Dalitz plot fit | t, 122 evts |
| $\Gamma(K^-2\pi^+\pi^-)/\Gamma$ | - total | | | | | Г ₆₆ /Г |
| $VALUE$ (units 10^{-2}) | EVTS | DO CUMENT | ID | TECN | COMMENT | |
| 8.07 + 0.21 OUR F | IT Error includ | des scale factor o | of 1.3. | | | |
| 8.17±0.33 OUR A | VERAGE Erro | r includes scale 1 | factor | of 1.7. | See the ideogr | am below. |
| $8.30 \pm 0.07 \pm 0.20$ | | ¹ DOBBS | 0 | 7 CLEC | e^+e^- at u | b(3770) |
| $7.9 \pm 1.5 \pm 0.9$ | | ² ALBRECHT | - 9, | 1 ARG | $e^+ e^- \approx 1$ | r(45) |
| $6.80 \pm 0.27 \pm 0.57$ | 1430 ± 52 | | | | $e^+ e^- \approx \gamma$ | |
| $9.1 \pm 0.8 \pm 0.8$ | 992 | ADLER | 8 | BC MRK | 3 e ⁺ e ⁻ 3.77 | 7 GeV |
| • • • We do not us | e the following | data for average | s, fits | limits, | etc. • • • | |
| $8.3 \pm 0.2 \pm 0.3$ | 15k ±130 | ¹ HE | 0! | CLEC | See DOBB: | S 07 |
| 11.7 ±2.5 | 185 | 4 SCHINDLEI | R 8: | L MRK | 2 e ⁺ e ⁻ 3.77 | 71 GeV |
| 6.2 ±1.9 | 44 | ⁵ PERUZZI | 7 | 7 LGW | $e^{+}e^{-}$ 3.77 | 7 GeV |
| ¹ DOBBS 07 and supersedes HE 0 ² ALBRECHT 94 of events than u ³ See the footnot method used. ⁴ SCHINDLER 81 be 0.68 ± 0.11 n ⁵ PERUZZI 77 (N 0.36 ± 0.10 nb. | 5. uses D ⁰ mesons sed by ALBREC e on the ALBR (MARK-2) me b. We use the I | from $\overline{B}^0 \to D$ CHT 94F. ECHT 94F meansures $\sigma(e^+e^-)$ MARK-3 (ADLEI res $\sigma(e^+e^-) \to D$ | $0.8 + \ell^{-1}$ usurem $\rightarrow 0.0$ R 880 | $\overline{\nu}_{\ell}$ deca ent of Γ $\psi(3770)$ $\psi(3770)$ $\psi(3770)$ $\psi(3770)$ | ays. This is a configuration $\Gamma(K^-\pi^+)/\Gamma_{\rm to}$ $\Gamma(K^-\pi^+)/\Gamma_{\rm to}$ | different set $_{ m otal}$ for the fraction to $_{ m 5}$ \pm 0.6 nb. ction to be |
| WEIGHTE | D AVERAGE | | | | | |





This includes $K^-a_1(1260)^+$, $\overline{K}^*(892)^0$, ρ^0 , etc. The next entry gives the specifically 3-body fraction. We rely on the MARK III and E691 full amplitude analyses of the $K^-\pi^+\pi^+\pi^-$ channel for values of the resonant substructure.

 VALUE
 DOCUMENT ID
 TECN
 COMMENT

 0.835 ± 0.035 OUR AVERAGE
 ANJOS
 92c
 E691
 $1745 \ K^-2\pi^+\pi^-$ evts

 $0.855 \pm 0.032 \pm 0.030$ COFF MAN
 92b
 MRK3
 $1281 \pm 45 \ K^-2\pi^+\pi^-$ evts

 • • We do not use the following data for averages, fits, limits, etc. • • •
 0.98 $\pm 0.12 \pm 0.10$ ALVAREZ
 91b
 NA14
 Photoproduction

 D^0

| Unseen decay modes of the $K_1(1270)^-$ are included. The MARK3 and E691 experiments disagree considerably here. VALUE OL194±0.056±0.088 COFFMAN 92B MRK3 1281 ± 45 $K^-2\pi^+\pi^-$ evit <0.013 90 ANJOS 92C E691 1745 $K^-2\pi^+\pi^-$ evit <0.013 90 ANJOS 92C E691 1745 $K^-2\pi^+\pi^-$ evit <0.013 Fig. (a) Fig. (b) Fig. (b) Fig. (c) Fig. (c |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.194 \pm 0.056 \pm 0.088 COFFMAN 92B MRK3 1281 \pm 45 $K^-2\pi^+\pi^-$ evt • • We do not use the following data for averages, fits, limits, etc. • • • <0.013 90 ANJOS 92c E691 1745 $K^-2\pi^+\pi^-$ evts $\Gamma(K_1(1400)^-\pi^+)/\Gamma_{total}$ VALUE CL% DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <0.013 90 A NJOS 92c E691 1745 $K^-2\pi^+\pi^-$ evts $\Gamma(K_1(1400)^-\pi^+)/\Gamma_{total} \qquad |
| $\Gamma(K_1(1400)^-\pi^+)/\Gamma_{	ext{total}}$ $\Gamma_{109}/\Gamma_{	ext{VALUE}}$ $\Gamma_{109}/\Gamma_{	ext{LUE}}$ $\Gamma_{109}/\Gamma_{	ex$ |
| VALUE <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| |
| |
| $\Gamma(K^*(1410)^-\pi^+)/\Gamma_{	ext{total}}$ |
| <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <0.012 90 COFFMAN 928 MRK3 1281 \pm 45 $K^-2\pi^+\pi^-$ evt |
| $\Gamma(\overline{K}^*(892)^0\pi^+\pi^-$ total)/ $\Gamma(K^-2\pi^+\pi^-)$ This includes $\overline{K}^*(892)^0 ho^0$, etc. The next entry gives the specifically 3-body fraction |
| Unseen decay modes of the $\overline{K}^*(892)^0$ are included. VALUE DOCUMENT ID TECH COMMENT |
| 0.30\pm0.06\pm0.03 ANJOS 92c E691 1745 $K^-2\pi^+\pi^-$ evts |
| $\Gamma(\overline{K}^*(892)^0\pi^+\pi^-3\text{-body})/\Gamma(K^-2\pi^+\pi^-)$ |
| Unseen decay modes of the $\overline{K}^*(892)^0$ are included. VALUE DOCUMENT ID TECN COMMENT OUTDOOR STATES OF THE PROPERTY OF TH |
| 0.18 ±0.04 OUR AVERAGE 0.165±0.03 ±0.045 ANJOS 92c E691 1745 K ⁻ 2π ⁺ π ⁻ evts |
| $0.105\pm0.03\pm0.045$ ANJOS 92C E691 1745 K $2\pi^+\pi^-$ eVIS $0.210\pm0.027\pm0.06$ COFFMAN 92B MRK3 1281 \pm 45 $K^-2\pi^+\pi^-$ eVIS |
| $\Gamma(K^-2\pi^+\pi^-$ nonresonant)/ $\Gamma(K^-2\pi^+\pi^-)$ Γ_{74}/Γ_6 |
| VALUE DOCUMENT ID TECN COMMENT 0.233±0.032 OUR AVERAGE |
| 0.233 ± 0.032 OOR AVERAGE $0.23\pm0.02\pm0.03$ ANJOS 92 C E691 1745 $K^-2\pi^+\pi^-$ evts |
| 0.242 \pm 0.025 \pm 0.06 COFFMAN 92B MRK3 1281 \pm 45 K $^-$ 2 π^+ π^- evt |
| $\Gamma(K_0^0\pi^+\pi^-\pi^0)/\Gamma_{	ext{total}}$ $\Gamma_{75}/\Gamma_{	ext{VALUE} (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT$ |
| 5.2±0.6 OUR FIT |
| 5.2±1.1±1.2 140 COFFMAN 92B MRK3 e ⁺ e ⁻ 3.77 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 5 |
| -1.7 |
| ¹ BARLAG 92c computes the branching fraction using topological normalization. |
| $\Gamma(K_S^0\pi^+\pi^-\pi^0)/\Gamma(K_S^0\pi^+\pi^-)$ |
| Branching fractions for submodes of this mode with narrow resonances (the η , ω , η' are fairly well determined (see below). COFFMAN 92B gives fractions of K^* and submodes, but with only 140 ± 28 events above background could not determine ther |
| with much accuracy. We omit those measurements here; they are in our 2008 Review |
| (Physics Letters B667 1 (2008)). VALUE EVTS DOCUMENT ID TECN COMMENT |
| 1.84±0.20 OUR FIT 1.86±0.23 OUR AVERAGE |
| $1.80\pm0.20\pm0.21$ 190 ¹ ALBRECHT 92P ARG e^+e^-pprox 10 GeV |
| $\pm 0.8 \pm 0.8 \pm 0.8$ 46 ANJOS 92C E691 γ Be 90–260 GeV $\pm 0.26 \pm 0.30$ 158 KINOSHITA 91 CLEO $e^+e^- \sim 10.7$ GeV |
| $^{ m 1}$ This value is calculated from numbers in Table 1 of ALBRECHT 92P. |
| $\Gamma(K_5^0\eta)/\Gamma_{total}$ Γ_{93}/Γ_{100} |
| Unseen decay modes of the η are included. VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 4.42±0.15±0.28 ASNER 08 CLEO See MENDEZ 10 |
| $\Gamma(K_0^0\eta)/[\Gamma(K^-\pi^+)+\Gamma(K^+\pi^-)]$ F93/ $(\Gamma_{31}+\Gamma_{212})$ Unseen decay modes of the η are included. |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT 12.3±0.8 OUR FIT OUT FIT TECN COMMENT |
| 12.3\pm0.3\pm0.7 2864 \pm 65 MENDEZ 10 CLEO e^+e^- at 3774 MeV |
| $\Gamma(K_S^0\eta)/\Gamma(K_S^0\pi^0)$ |
| VALUE EVTS DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $0.32 \pm 0.04 \pm 0.03$ 225 ± 30 PROCARIO 93B CLE2 $n \rightarrow \sim \sim$ |
| $0.32\pm0.04\pm0.03$ 225 ± 30 PROCARIO 93B CLE2 $\eta \rightarrow \gamma\gamma$ |
| $\Gamma(K_S^0\eta)/\Gamma(K_S^0\pi^+\pi^-)$ Unseen decay modes of the η are included. |
| $\Gamma(K_S^0\eta)/\Gamma(K_S^0\pi^+\pi^-)$ |
| |

| $\Gamma(K_0^0\omega)/\Gamma_{ m total}$ | $\Gamma(K_S^0\eta\pi^0)/\Gamma(K_S^0\pi^0)$ Γ_{83}/Γ_3 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>NALUE (%)</u> <u>DO CUMENT ID</u> <u>TECN COMMENT</u> 1.11±0.06 OUR FIT | 0.46 \pm 0.07 \pm 0.06 155 ± 22 1 RUBIN |
| 1.12 \pm 0.04 \pm 0.05 ASNER 08 CLEO $e^+e^- ightarrow \mathcal{D}^0\overline{\mathcal{D}}^0$, 3.77 GeV $ \lceil (K_S^0\omega)/\Gamma(K^-\pi^+) \qquad | $\Gamma(K_S^0 a_0(980), a_0(980) \to \eta \pi^0) / \Gamma(K_S^0 \eta \pi^0)$ Γ_{84} / Γ_{8} |
| Unseen decay modes of the ω are included. ALUE DOCUMENT ID TECN COMMENT | This is the "fit fraction" from the Dalitz-plot analysis, with interference. <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.50\pm0.18\pm0.10$ ALBRECHT 89D ARG e^+e^- 10 GeV | 1.19 \pm 0.09 \pm 0.26 |
| $\Gamma(K_S^0\omega)/\Gamma(K_S^0\pi^+\pi^-)$ | $0.246\pm0.092\pm0.091$ for other, undetermined modes. $\Gamma(\overline{K}^*(892)^0\eta,$ |
| ALUE EVTS DOCUMENT ID TECN COMMENT 0.394±0.033 OUR FIT Error includes scale factor of 1.1. 0.33 ±0.09 OUR AVERAGE Error includes scale factor of 1.1. | $\overline{K}^*(892)^0 	o K_5^0 \pi^0)/\Gamma(K_5^0 \eta \pi^0)$ Γ_{85}/Γ_8 This is the "fit fraction" from the Dalitz-plot analysis, with interference. NALUE DOCUMENT ID TECN COMMENT |
| 1.29 ± 0.08 ± 0.05 16 1 ALBRECHT 92 p ARG $e^{+}e^{-}\approx 10$ GeV 1.54 ± 0.14 ± 0.16 40 KINOSHITA 91 CLEO $e^{+}e^{-}\sim 10.7$ GeV $e^{+}e^{-}\approx 10.7$ This value is calculated from numbers in Table 1 of ALBRECHT 92 p . | 0.293±0.062±0.035 1 RUBIN 04 CLEO Dalitz fit, 155 evts ¹ See the note on RUBIN 04 in the preceding data block. |
| $\Gamma(K_S^0\omega)/\Gamma(K_S^0\pi^+\pi^-\pi^0)$ Unseen decay modes of the ω are included. | $\Gamma(K^-\pi^+\omega)/\Gamma(K^-\pi^+)$ Γ_{113}/Γ_3 Unseen decay modes of the ω are included. <u>VALUE EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| <u>VALUE</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.214±0.026 OUR FIT 0.220±0.048±0.0116 COFFMAN 92B MRK3 1281±45 K ⁻ 2π ⁺ π ⁻ evts | 0.78\pm0.12\pm0.10 99 1 ALBRECHT 92P ARG e^+e^-pprox 10 GeV 1 This value is calculated from numbers in Table 1 of ALBRECHT 92P. |
| $\Gamma(K_S^0\eta'(958))/[\Gamma(K^-\pi^+)+\Gamma(K^+\pi^-)]$ $\Gamma_{95}/(\Gamma_{31}+\Gamma_{212})$ Unseen decay modes of the $\eta'(958)$ are included. | $\Gamma(\overline{K}^*(892)^0\omega)/\Gamma(K^-\pi^+)$ Unseen decay modes of the $\overline{K}^*(892)^0$ and ω are included. |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT 24.1±1.3 OUR FIT | VALUEEVTSDOCUMENT IDTECNCOMMENT $\bf 0.28 \pm 0.11 \pm 0.04$ 17 1 ALBRECHT92PARG $e^+e^-\approx 10$ GeV 1 This value is calculated from numbers in Table 1 of ALBRECHT92P. |
| $(K_S^0 \eta'(958))/\Gamma(K_S^0 \pi^+ \pi^-)$ Γ_{95}/Γ_{34} | $\Gamma(K^-\pi^+\eta'(958))/\Gamma(K^-2\pi^+\pi^-)$ Unseen decay modes of the $\eta'(958)$ are included. |
| Unseen decay modes of the η' (95.8) are included. VALUE EVTS DOCUMENT ID TECN COMMENT D.332 \pm 0.025 OUR FIT | VALUEEVTSDOCUMENT IDTECNCOMMENT0.093 \pm 0.014 \pm 0.019286PROCARIO938CLE2 $\eta' \to \eta \pi^+ \pi^-, \rho^0 \gamma$ |
| 1.32 \pm 0.04 OUR AVERAGE 1.31 \pm 0.02 \pm 0.04 594 PROCARIO 93B CLE2 $\eta' \rightarrow \eta \pi^+ \pi^-$, $\rho^0 \gamma$ 1.37 \pm 0.13 \pm 0.06 18 1 ALBRECHT 92P ARG $e^+ e^- \approx 10$ GeV 1 This value is calculated from numbers in Table 1 of ALBRECHT 92P. | $\Gamma(\overline{K}^*(892)^0\eta'(958))/\Gamma(K^-\pi^+\eta'(958))$ Γ ₁₁₆ /Γ ₁₁ Unseen decay modes of the $\overline{K}^*(892)^0$ are included. VALUE CL% DOCUMENT ID TECN <0.15 90 PROCARIO 93B CLE2 |
| $\Gamma(K^-\pi^+2\pi^0)/\Gamma_{	ext{total}}$ Γ78/Γ VALUE LEVIS DOCUMENT ID TECN COMMENT | $\Gamma(K_S^0 2\pi^+ 2\pi^-)/\Gamma(K_S^0 \pi^+ \pi^-)$ Γ_{86}/Γ_{3} |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 1 BARLAG 92c ACCM π^- Cu 230 GeV .149 \pm 0.037 \pm 0.030 24 2 ADLER 88c MRK3 e^+e^- 3.77 GeV .209 \pm 0.074 \pm 0.012 9 1 AGUILAR 87F HYBR $\pi p, pp$ 360, 400 GeV .14GUILAR-BENITEZ 87F and BARLAG 92c compute the branching fraction using topological normalization. They do not distinguish the presence of a third π^0 , and thus are | • • • We do not use the following data for averages, fits, limits, etc. • • • $0.07 \pm 0.02 \pm 0.01 \qquad 11 \qquad ^{1} \text{ ALBRECHT} \qquad 92\text{P ARG} \qquad e^{+} e^{-} \approx 10 \text{ GeV} \\ 0.149 \pm 0.026 \qquad 56 \qquad \text{AMMAR} \qquad 91 \qquad \text{CLEO} \qquad e^{+} e^{-} \approx 10.5 \text{ GeV} \\ 0.18 \pm 0.07 \pm 0.04 \qquad 6 \qquad \text{ANJOS} \qquad 90\text{D E691} \qquad \text{Photoproduction} \\ 1 = 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 +$ |
| logical normalization. They do not distinguish the presence of a third π^{ν} , and thus are not included in the average. ² ADLER 88C uses an absolute normalization method finding this decay channel opposite a detected $\overline{D}^0 \to K^+\pi^-$ in pure $D\overline{D}$ events. | 1 This value is calculated from numbers in Table 1 of ALBRECHT 92P. $\Gamma(K_S^0\rho^0\pi^+\pi^-,\text{no}K^*(892)^-)/\Gamma(K_S^02\pi^+2\pi^-) \qquad \qquad \Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/\Gamma_{87}/$ |
| $\Gamma(K^-2\pi^+\pi^-\pi^0)/\Gamma(K^-\pi^+)$ Γ_{79}/Γ_{31} | 0.40±0.24±0.07 LINK 04D FOCS γ A, $\overline{E}_{\gamma} \approx$ 180 GeV |
| ALUE EVTS DOCUMENT ID TECN COMMENT .09±0.10 OUR FIT | $\Gamma(K^*(892)^-2\pi^+\pi^-, K^*(892)^- 	o K_0^5\pi^-, \operatorname{no}\rho^0)/\Gamma(K_0^52\pi^+2\pi^-)$ Γ_{88}/Γ_{88} |
| 1 This value is calculated from numbers in Table 1 of ALBRECHT 92P. | VALUE DOCUMENT ID TECN COMMENT 0.17 \pm 0.28 \pm 0.02 LINK 04D FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV |
| $\Gamma(K^-2\pi^+\pi^-\pi^0)/\Gamma(K^-2\pi^+\pi^-)$ Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} Γ_{79}/Γ_{66} | $ \begin{array}{c c} \Gamma\left(K^*(892)^-\rho^0\pi^+ \text{ , } K^*(892)^- \to K_0^0\pi^-\right)/\Gamma\left(K_0^02\pi^+2\pi^-\right) & \Gamma_{89}/\Gamma_8 \\ \hline NALUE & DOCUMENT ID & TECN & COMMENT \\ \textbf{0.60\pm0.21\pm0.09} & LINK & 04D & FOCS & γ A, \overline{E}_{γ} $\approx 180 \text{ GeV} \\ \end{array} $ |
| 0.56±0.07 OUR AVERAGE | · |
| $0.55\pm0.07^{+0.12}_{-0.09}$ 167 KINOSHITA 91 CLEO $e^+e^-\sim 10.7~{ m GeV}$ $0.57\pm0.06\pm0.05$ 180 ANJOS 90D E691 Photoproduction | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\overline{K}^*(892)^0\pi^+\pi^-\pi^0)/\Gamma(K^-2\pi^+\pi^-\pi^0)$ Γ_{111}/Γ_{79} Unseen decay modes of the $\overline{K}^*(892)^0$ are included. | $\Gamma(K^-3\pi^+2\pi^-)/\Gamma(K^-2\pi^+\pi^-)$ |
| ALUE DO CUMENT ID TECN COMMENT | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $-1.45\pm0.15\pm0.15$ ANJOS 90D E691 Photoproduction $\Gamma(K^*(892)^0\eta)/\Gamma(K^-\pi^+)$ Γ_{112}/Γ_{31} | Hadronic modes with three K 's ——— |
| Unseen decay modes of the $\overline{K}^*(892)^{m{0}}$ and η are included. | $\Gamma(K_S^0K^+K^-)/\Gamma(K_S^0\pi^+\pi^-)$ Γ_{117}/Γ_3 |
| | VALUE |
| | 0.150.1.0.001.1.0.005 141.1.1.4 AUDEDTB 05 04.00 ± |
| VALUE EVTS DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • 0.58 \pm 0.19 $^{+}$ 0.24 46 KINOSHITA 91 CLEO $e^{+}e^{-}\sim$ 10.7 GeV | 0.158±0.001±0.005 14k±116 AUBERT,B 05J BABR $e^+e^-\approx \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • 0.20 ±0.05 ±0.04 47 FRABETTI 92B E687 γ Be, \overline{E}_{γ} = 221 GeV |

0.13 \pm 0.02 \pm 0.03 214 PROCARIO 93B CLE2 $\overline{\it K}^{*0}\,\eta \to \,{\it K}^-\,\pi^+\,/\gamma\gamma$

 D^0

| | DOCUMENT ID TECN COMMENT AUBERT,B 05J BABR Dalitz fit, 12540 ± 112 evts |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| .664±0.016±0.070 -(K-a ₀ (980)+ a ⁺ → J | |
| This is the "fit fraction $ALUE$ | K ⁺ K ^c ₅)/Γ(K ^c ₅ K ⁺ K ⁻) n" from the Dalitz-plot analysis, with interference. <u>DOCUMENT ID TECN</u> <u>COMMENT</u> |
| 0.134±0.011±0.037 | AUBERT,B 05J BABR Dalitz fit, 12540 ± 112 evts |
| $(K^+a_0(980)^-, a_0^- \rightarrow K$ This is a doubly Cabible | $(K^- K_S^0) / \Gamma (K_S^0 K^+ K^-)$ $\Gamma_{120} / \Gamma_{117}$ |
| <u>ALUE</u> <u>CL%</u> <0.025 95 | |
| $(K_S^0 f_0(980), f_0 \to K^+)$ | κ ⁻)/Γ(κ ⁰ ₅ κ ⁺ κ ⁻) Γ ₁₂₁ /Γ ₁₁₇ |
| ALUE <u>CL%</u> <0.021 95 | · · · · · · · · · · · · · · · · · · · |
| -(K0 4 4 → K+ K-)/I | evts |
| This is the "fit fraction $ALUE$ | $\Gamma(K_S^0K^+K^-)$ Γ |
| .459±0.007±0.007 | AUBERT,B 05J BABR Dalitz fit, 12540 ± 112 evts |
| $(K_5^0 f_0(1370), f_0 \rightarrow K^+$ This is the "fit fraction | $^+K^-)/\Gamma(K_0^0K^+K^-)$ $\Gamma_{123}/\Gamma_{117}$ n" from the Dalitz-plot analysis, with interference. |
| ALUE | DOCUMENT ID TECN COMMENT |
| .038±0.007±0.023 AUBERT,B 05J calls the | 1 AUBERT,B 05J BABR Dalitz fit, 12540 ± 112 evts e mode K_S^0 $f_0(1400)$, but insofar as it is seen here at all, it is |
| certainly the same as f_0 | 1370). |
| $(3K_S^0)/\Gamma(K_S^0\pi^+\pi^-)$ | Γ ₁₂₄ /Γ ₃₄ |
| .2 ±0.4 OUR AVERAGE | EVTS DOCUMENT ID TECN COMMENT |
| | \pm 26 LINK 05A FOCS $\gamma {\rm Be}, \overline{E}_{\gamma} \approx$ 180 GeV 61 ASNER 96B CLE2 $e^+ e^- \approx \varUpsilon (4S)$ |
| $.78 \pm 0.38 \pm 0.48$ $.0 \pm 2.4 \pm 1.2$ 10 | 61 ASNER 96B CLE2 $e^+e^-\approx \Upsilon(4S)$ 0 \pm 3 FRABETTI 94J E687 γ Be, \overline{E}_{γ} = 220 GeV |
| .2 ±1.0 .4 ±1.4 ±1.0 | 22 AMMAR 91 CLEO $e^+e^-\approx 10.5~{\rm GeV}$ 5 ALBRECHT 90c ARG $e^+e^-\approx 10~{\rm GeV}$ |
| $(K^{+}2K^{-}\pi^{+})/\Gamma(K^{-}2\pi^{+})$ | |
| ALUE | <u>EVTS DOCUMENT ID TECN COMMENT</u> |
| 0.0027 ±0.0004 OUR AVE 0.00257±0.00034±0.00024 | ERAGE Error includes scale factor of 1.1. 143 LINK 03G FOCS γ A, $\overline{E}_{\gamma} \approx$ 180 GeV |
| 0054 ±0.0016 ±0.0008 | 18 AITALA 01D E791 π ⁻ A, 500 GeV |
| .0028 ±0.0007 ±0.0001 | |
| $(\varphi \land (\delta \forall 2)^*, \phi \rightarrow K^{+})$ | $K^-, \overline{K}^*(892)^0 \to K^-\pi^+)/\Gamma(K^+2K^-\pi^+) \Gamma_{128}/\Gamma_{125}$ |
| ALUE .48±0.06±0.01 | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | |
| | $-)/\Gamma(K^+2K^-\pi^+)$ $\Gamma_{10}-/\Gamma_{10}$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ | DOCUMENT ID TECN COMMENT |
| $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(18\pm 0.06\pm 0.04)$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $K(K^-\pi^+\phi, \phi \to K^+K^-)$ ALUE 1.18±0.06±0.04 | $\frac{\text{DOCUMENT iD}}{\text{LINK}} \qquad \frac{\text{TECN}}{\text{03G}} \qquad \frac{\text{COMMENT}}{\text{FOCS}} \qquad \frac{180 \text{ GeV}}{\gamma \text{ A, } \overline{E}_{\gamma} \approx 180 \text{ GeV}}$ $(892)^{0} \rightarrow K^{-}\pi^{+})/\Gamma(K^{+}2K^{-}\pi^{+}) \qquad \Gamma_{126}/\Gamma_{125}$ |
| $\frac{1}{K}(K^-\pi^+\phi,\phi\to K^+K^-)$ $\frac{1}{K}$ $\frac{1}{1}$ $\frac{1}$ $\frac{1}{1}$ $\frac{1}$ $\frac{1}{1}$ $\frac{1}$ $\frac{1}{1}$ $\frac{1}$ $\frac{1}{1}$ $\frac{1}$ $\frac{1}$ 1 | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi, \phi \to K^+K^-)$ (1.18±0.06±0.04 $(K^+K^-\overline{K}^*(892)^0, \overline{K}^*)$ (ALUE 1.20±0.07±0.02 | $\frac{DOCUMENT \ ID}{LINK} \qquad 03G FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{F(892)^0}{DOCUMENT \ ID} \qquad \frac{TECN}{TECN} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G FOCS \qquad \gamma \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ |
| $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(1.18\pm0.06\pm0.04$ $(K^+K^-\overline{K}^*(892)^0, \overline{K}^*)$ $(1.20\pm0.07\pm0.02$ $(K^+2K^-\pi^+)$ nonresona | $\frac{DOCUMENT \ ID}{LINK} \qquad 03G FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{1}{2}(892)^{0} \rightarrow K^{-}\pi^{+})/\Gamma(K^{+}2K^{-}\pi^{+}) \qquad \Gamma_{126}/\Gamma_{125}$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G FOCS \qquad \gamma \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{1}{2}(892)^{0} \rightarrow K^{-}\pi^{+})/\Gamma(K^{+}2K^{-}\pi^{+}) \qquad \Gamma_{126}/\Gamma_{125}$ $\frac{1}{2}(892)^{0} \rightarrow K^{-}\pi^{+})/\Gamma(K^{+}2K^{-}\pi^{+}) \qquad \Gamma_{129}/\Gamma_{125}$ |
| $-(K^-\pi^+\phi,\phi\to K^+K^-)$ $0.18\pm0.06\pm0.04$ $-(K^+K^-\overline{K}^*(892)^0,\overline{K}^*)$ $0.20\pm0.07\pm0.02$ $-(K^+2K^-\pi^+)$ nonresona $0.15\pm0.06\pm0.02$ | $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ $\frac{F(892)^0 \rightarrow K^-\pi^+)/\Gamma(K^+2K^-\pi^+)}{LINK} \qquad \frac{F(892)^0 \rightarrow K^-\pi^+)/\Gamma(K^+2K^-\pi^+)}{LINK} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ $\frac{DOCUMENT \ ID}{LINK} \qquad \frac{TECN}{03G} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ |
| $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(K^+K^-\overline{K}^*(892)^0, \overline{K}^*)$ $(K^+K^-\overline{K}^*(892)^0, \overline{K}^*)$ $(L00\pm 0.07\pm 0.02$ $(K^+2K^-\pi^+ \text{ nonresona})$ $(L00\pm 0.06\pm 0.02$ $(L00\pm 0.06\pm 0.02)$ $(L00\pm 0.06\pm 0.02)$ | $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ $\frac{F(892)^0 \rightarrow K^-\pi^+)/\Gamma(K^+2K^-\pi^+)}{LINK} \qquad \frac{TECN}{03G} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ \text{GeV}$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ (K^+UE) $(20\pm0.07\pm0.02)$ $(K^+2K^-\pi^+$ nonresona (KUE) $(2K_S^0K^\pm\pi^\mp)/\Gamma(K_S^0\pi^+)$ $(2K_S^0K^\pm\pi^\mp)/\Gamma(K_S^0\pi^+)$ (KUE) (units 10^{-2}) (K^+UE) | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(K^-\pi^+\phi, \phi \to K^+K^-)$ $(K^+K^-K^*(892)^0, K^*)$ $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(2K^0_SK^\pm\pi^\mp)/\Gamma(K^0_S\pi^+)$ $(2K^0_SK^\pm\pi^+)/\Gamma(K^0_S\pi^+)$ | $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{F(892)^0 \rightarrow K^-\pi^+)/\Gamma(K^+2K^-\pi^+)}{LINK} \qquad \frac{TECN}{03G} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{DOCUMENT \ ID}{LINK} \qquad 03G \qquad FOCS \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ $\frac{T129}{\gamma} \Gamma_{125}$ $\frac{DOCUMENT \ ID}{\gamma} \qquad \frac{TECN}{\gamma} \qquad \frac{COMMENT}{\gamma} \ A, \ \overline{E}_{\gamma} \approx 180 \ GeV$ |
| $(K^-\pi^+\phi,\phi\to K^+K^ (1.18\pm0.06\pm0.04$ $(K^+K^-K^*(892)^0,K^*)$ $(4.10E$ $(2.20\pm0.07\pm0.02$ $(K^+2K^-\pi^+\text{nonresona}$ $(4.10E$ $($ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)/\Gamma(K_S^0\pi^+)$ $(2K_S^0K^\pm\pi^\mp)/\Gamma(K_S^0\pi^+)$ $(2K_S^0K^\pm\pi^\mp)/\Gamma(K_S^0\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K_S^0\pi^+)$ $(K^+\pi^-)/\Gamma(K^-\pi^+)$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)$ $(K^0_S\pi^-)$ $(K^+2K^-\pi^+)$ $(K^0_S\pi^-)$ $(K^+2K^-\pi^+)$ $(K^0_S\pi^-)$ $(K^+2K^-\pi^+)$ $(K^0_S\pi^-)$ $(K^0_S\pi$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^ (ALUE)$ $(18\pm0.06\pm0.04)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+)$ nonresonal ALUE $(15\pm0.06\pm0.02)$ $(2K_S^0K^\pm\pi^\mp)/\Gamma(K_S^0\pi^+)$ $(12\pm0.38\pm0.20)$ $(2K_S^0K^\pm\pi^\mp)/\Gamma(K^-\pi^+)$ $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ (12 ± 0.05) | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^+)$ $(K^+\pi^-)/\Gamma(K^-\pi^+)$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+)$ nonresona $(K^+2K^-\pi^+)$ $(K^0\pi^+)$ $(K^0\pi^+$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ (ALUE .18±0.06±0.04 $(K^+K^-K^*(892)^0,K^*)$ (ALUE .20±0.07±0.02 $(K^+2K^-\pi^+ \text{ nonresona}$ (ALUE .15±0.06±0.02 $(2K_0^0K^\pm\pi^\mp)/\Gamma(K_0^0\pi^+)$ (ALUE (units 10^{-2}) .12±0.38±0.20 $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ (ALUE (units 10^{-2}) .12±0.38±0.20 $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$.59±0.06 OUR AVERAGI .59±0.05 OUR FIT .59±0.06 OUR AVERAGI .59±0.05 AUR .040 .59±0.0 | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K - \pi^{+} \phi, \phi \rightarrow K^{+} K^{-} K^{-} K^{-} (892)^{0}, K^{+} K^{-} K^{-} K^{-} (892)^{0}, K^{+} K^{-} | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^-\pi^+\phi,\phi\to K^+K^-)$ $(K^+K^-K^*(892)^0,K^*)$ $(K^+2K^-\pi^+(892)^0,K^*)$ $(K^+2K^-\pi^+)$ $(K^+2K^-\pi^+)/\Gamma(K^0_S\pi^-)$ $(K^0_SK^\pm\pi^\mp)/\Gamma(K^0_S\pi^-)$ $(\pi^+\pi^-)/\Gamma(K^-\pi^+)$ $(\pi^+\pi^-)/\Gamma(K^-\pi^-)$ $(\pi^-\pi^-)/\Gamma(K^-\pi^-)$ $(\pi^-\pi^-)/\Gamma$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

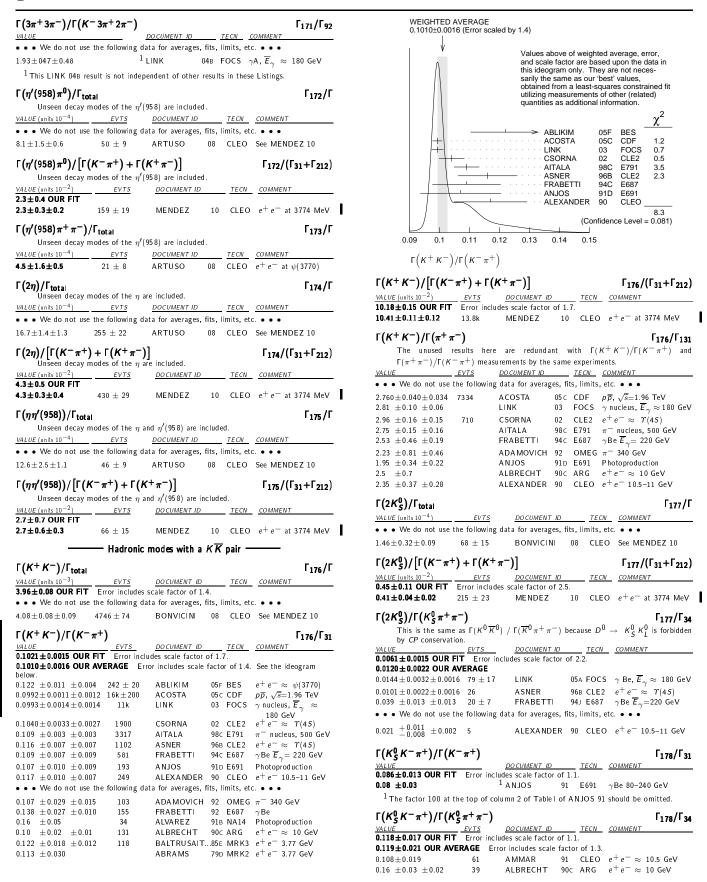
| $\Gamma(\pi^+\pi^-)/[\Gamma(K^-\pi^+)+\Gamma(K^-\pi^+)]$ | + π-)] | Γ ₁₃₁ /(Γ ₃₁ +Γ ₂₁₂) |
|--------------------------------------------------------------------------------------------------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻²) EVTS | | ECN COMMENT |
| 3.60±0.05 OUR FIT 3.70±0.06±0.09 6210±93 | MENDEZ 10 C | LEO e^+e^- at 3774 MeV |
| $\Gamma(2\pi^0)/\Gamma(K^-\pi^+)$ NALUE (units 10^{-2}) EVTS | DOCUMENT ID | Γ ₁₃₂ /Γ ₃₁ |
| • • • We do not use the following | DOCUMENT ID data for averages, fits, limit | |
| $2.05 \pm 0.13 \pm 0.16$ 499 ± 32 $2.2 \pm 0.4 \pm 0.4$ 40 | | CLEO See MENDEZ 10 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\Gamma(2\pi^0)/[\Gamma(K^-\pi^+)+\Gamma(K^+\pi^+)]$ | • • | $\Gamma_{132}/(\Gamma_{31}+\Gamma_{212})$ |
| WALUE (units 10 ⁻²) EVTS 2.06±0.12 OUR FIT | | ECN COMMENT |
| 2.06±0.07±0.10 1567±54 $\Gamma(\pi^{+}\pi^{-}\pi^{0})/\Gamma(K^{-}\pi^{+})$ | MENDEZ 10 C | LEO e ⁺ e ⁻ at 3774 MeV Γ _{1.33} /Γ ₃₁ |
| VALUE (units 10^{-2}) EVTS | DOCUMENT ID TECH s scale factor of 2.1. | |
| 34.4±0.5±1.2 11k±164 | | O $e^{+}e^{-}$ at $\psi(3770)$ |
| $\Gamma(\pi^{+}\pi^{-}\pi^{0})/\Gamma(K^{-}\pi^{+}\pi^{0})$ | DO CUMENT ID | Γ ₁₃₃ /Γ ₄₉ |
| | des scale factor of 2.2. | COMMENT. |
| 10.41±0.23 OUR AVERAGE Erro 10.12±0.04±0.18 123k±490 | |). ELL $e^+e^-pprox~\varUpsilon(45)$ |
| $10.12 \pm 0.04 \pm 0.16$ $123 \text{K} \pm 490$ $10.59 \pm 0.06 \pm 0.13$ $60 \text{K} \pm 343$ | AUBERT,B 06x B | |
| $\Gamma(\rho^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ This is the "fit fraction" of | from the Dalitz plot analys | Γ ₁₃₄ /Γ ₁₃₃ |
| GASPERO 08 and BHATTA | CHARYA 10A for isospin de | ecompositions of the $D^0 ightarrow$ |
| $\pi^+\pi^0\pi^-$ Dalitz plot, both t the conclusion that the final | | |
| VALUE (units 10^{-2}) | | I COMMENT |
| 68.1±0.6 OUR AVERAGE 67.8±0.0±0.6 | AUBERT 07BJ BAB | · |
| $76.3\pm1.9\pm2.5$ $\Gamma(\rho^0\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ | CRONIN-HEN05 CLE | |
| This is the "fit fraction" from $VALUE$ (units 10^{-2}) | | |
| 25.9±1.1 OUR AVERAGE | DOCUMENT ID TECH | COMMENT |
| $26.2 \pm 0.5 \pm 1.1$ $24.4 \pm 2.0 \pm 2.1$ | AUBERT 07BJ BAB CRONIN-HEN05 CLE | The state of the s |
| $\Gamma(ho^-\pi^+)/\Gamma(\pi^+\pi^-\pi^0)$ This is the "fit fraction" from | n the Dalitz-plot analysis, wi | $\Gamma_{136}/\Gamma_{133}$ th interference. |
| VALUE (units 10 ⁻²) 34.6±0.8 OUR AVERAGE | DO CUMENT ID TECH | COMMENT |
| $34.6 \pm 0.8 \pm 0.3$ $34.5 \pm 2.4 \pm 1.3$ | AUBERT 07BJ BAB CRONIN-HEN05 CLE | R Dalitz fit, 45k events O e^+e^-pprox 10 GeV |
| $\Gamma(ho(1450)^+\pi^-$, $ ho(1450)^+$ $ ightarrow$ | $\pi^+\pi^0$)/ $\Gamma(\pi^+\pi^-\pi^0)$ | Γ ₁₃₇ /Γ ₁₃₃ |
| VALUE (units 10 ⁻²) 0.11±0.07±0.12 | DOCUMENT ID TECH AUBERT 07BJ BAB | |
| $\Gamma(ho(1450)^0\pi^0$, $ ho(1450)^0	o\pi$ | $^{+}\pi^{-})/\Gamma(\pi^{+}\pi^{-}\pi^{0})$ | Γ ₁₃₈ /Γ ₁₃₃ |
| VALUE (units 10^{-2}) | DOCUMENT ID TECH | |
| 0.30±0.11±0.07 $\Gamma(\rho(1450)^-\pi^+, \rho(1450)^- \rightarrow$ | | R Dalitz fit, 45k events |
| VALUE (units 10^{-2}) | DOCUMENT ID TECH | |
| 1.79±0.22±0.12 | | R Dalitz fit, 45k events |
| $\Gamma(\rho(1700)^+\pi^-, \rho(1700)^+ \rightarrow \frac{VALUE \text{ (units }10^{-2})}{}$ | $\pi^+\pi^0$)/ $\Gamma(\pi^+\pi^-\pi^0)$ | Γ ₁₄₀ /Γ ₁₃₃ ν <i>COMMENT</i> |
| $4.1 \pm 0.7 \pm 0.7$ | AUBERT 07BJ BAB | |
| $\Gamma(\rho(1700)^0 \pi^0, \rho(1700)^0 \to \pi^0)$ VALUE (units 10 ⁻²) | $^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ | Γ ₁₄₁ /Γ ₁₃₃ |
| 5.0±0.6±1.0 | AUBERT 07BJ BAB | R Dalitz fit, 45k events |
| $\Gamma(\rho(1700)^-\pi^+, \rho(1700)^- \rightarrow MALUE (units 10^{-2})$ | | $\Gamma_{142}/\Gamma_{133}$ |
| 3.2±0.4±0.6 | DOCUMENT ID TECH AUBERT 07BJ BAB | R Dalitz fit, 45k events |
| $\Gamma(f_0(980)\pi^0, f_0(980) \to \pi^+\pi^-$ | , , , | Γ ₁₄₃ /Γ ₁₃₃ |
| VALUE (units 10 ⁻²) CL% 0.25 ±0.04±0.04 | AUBERT 07BJ BAB | COMMENT R Dalitz fit, 45k events |
| • • • We do not use the following | data for averages, fits, limit | s, etc. • • • |
| <0.026 95 | | O e^+e^-pprox 10 GeV |
| 1 The CRONIN-HENNESSY 05 fi only the $f_0(980) \pi^0$ mode. See | also the next entries for limi | ts obtained in the same way |
| for the $f_0(500)\pi^0$ mode and fo | r an S -wave $\pi^+\pi^-$ paramet | rized using a K-matrix. Our |
| $ ho\pi$ branching ratios, given abov | ve, use the fit with the K-ma | ittix 3 wave. |

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| The $f_0(500)$ is the σ . | $\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ | $\Gamma_{144}/\Gamma_{133}$ | | tion from the coherent ar | • | |
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| VALUE (units 10 ⁻²) CL% | DOCUMENT ID TECN COMM | | VALUE (units 10 ⁻²) | DO CUMENT I | | COMMENT |
| 0.82±0.10±0.10 • • We do not use the followin | AUBERT 07BJ BABR Dalitz g data for averages, fits, limits, etc. • | • | 1.1±0.3±0.3 | LINK | | 4-body fit, ≈ 5.7 k evts |
| < 0.21 95 | 1 CRONIN-HEN05 CLEO $e^{+}e^{-}$ | | $\Gamma(2\rho^0$, perpendicular | helicities)/ $\Gamma(2\pi^+2\pi^-)$ | -) | Γ ₁₅₉ /Γ ₁₅ |
| • | NNESSY 05 in the proceeding data bloc | | This is the fit fractive (units 10 ⁻²) | tion from the coherent an DOCUMENT I | | COMMENT |
| $\Gamma((\pi^+\pi^-)_{S-wave}\pi^0)/\Gamma(\pi^+$ | | $\Gamma_{145}/\Gamma_{133}$ | 6.4 ± 0.6 ± 0.5 | LINK | | 4-body fit, ≈ 5.7k evts |
| VALUE CL% | DOCUMENT ID TECN COMM | | E/2 of Longitudinal h | elicities)/ $\Gamma(2\pi^+ 2\pi^-)$ | 1 | Γ/Γ |
| • • • We do not use the followin <0.019 95 | g data for averages, fits, limits, etc. • 1 CRONIN-HEN05 CLEO $e^{+}e^{-}$ | • • | This is the fit fractivature (units 10 ⁻²) | tion from the coherent an | nplitude analysis | Γ ₁₆₀ /Γ ₁₅ |
| · . | NNESSY 05 two data blocks up. | | 16.8±1.0±0.8 | LINK | | 4-body fit, \approx 5.7k evts |
| $\Gamma(f_0(1370)\pi^0, f_0(1370) \to \pi$ | $(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ | $\Gamma_{146}/\Gamma_{133}$ | | $\pi^+\pi^-$ 3-body total)/ | | Γ_{161}/Γ_{15} |
| VALUE (units 10 ⁻²) 0.37±0.11±0.09 | AUBERT 07BJ BABR Dalitz | | VALUE (units 10 ⁻²) | DO CUMENT I | | COMMENT |
| | | III, 45K events | 20.0±1.2±1.0 | LINK | 07A FOCS | 4-body fit, ≈ 5.7 k evts |
| $\Gamma\left(f_0(1500)\pi^0, f_0(1500) ightarrow\pi$ | $(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ | $\Gamma_{147}/\Gamma_{133}$ | $\Gamma(\sigma\pi^+\pi^-)/\Gamma(2\pi^+2)$ | o_{π}^{-} | | Γ ₁₆₂ /Γ ₁₅ |
| VALUE (units 10 ⁻²) | DOCUMENT ID TECN COMM | | This is the fit frac | tion from the coherent ar | mplitude analysis | . 102/ - 15 |
| 0.39±0.08±0.07 | AUBERT 07BJ BABR Dalitz | fit, 45k events | VALUE (units 10^{-2}) | DO CUMENT I | | COMMENT |
| $\Gamma(f_0(1710)\pi^0, f_0(1710) \to \pi$ | $(\pi^+\pi^-)/\Gamma(\pi^+\pi^-\pi^0)$ | $\Gamma_{148}/\Gamma_{133}$ | $8.2 \pm 0.9 \pm 0.7$ | LINK | 07A FOCS | 4-body fit, ≈ 5.7 k evts |
| VALUE (units 10 ⁻²) | DOCUMENT ID TECN COMM | | $\Gamma(f_0(980)\pi^+\pi^-$, f_0 - | $\rightarrow \pi^+\pi^-)/\Gamma(2\pi^+2\pi$ | -) | $\Gamma_{163}/\Gamma_{153}$ |
| $0.31 \pm 0.07 \pm 0.08$ | AUBERT 07BJ BABR Dalitz | fit, 45k events | This is the fit frac | tion from the coherent ar | mplitude analysis | • |
| $\Gamma(f_2(1270)\pi^0, f_2(1270) \to \pi$ | $(\pi^{+}\pi^{-})/\Gamma(\pi^{+}\pi^{-}\pi^{0})$ | $\Gamma_{149}/\Gamma_{133}$ | $VALUE (units 10^{-2})$ 2.4 ± 0.5 ± 0.4 | <u>DOCUMENT I</u> LINK | | COMMENT 4-body fit, ≈ 5.7 k evts |
| VALUE (units 10^{-2}) | DOCUMENT ID TECN COMM | · · | | | | • |
| 1.32±0.08±0.10 | AUBERT 07BJ BABR Dalitz | fit, 45k events | $\Gamma(f_2(1270)\pi^+\pi^-,f_2)$ | $ ho 	o \pi^+\pi^-)/\Gamma(2\pi^+2\pi^+)$ tion from the coherent an | π [—]) | Γ ₁₆₄ /Γ ₁₅ |
| $\Gamma(\pi^+\pi^-\pi^0 { m nonresonant})/\Gamma($ | $(\pi^{+}\pi^{-}\pi^{0})$ | $\Gamma_{150}/\Gamma_{133}$ | VALUE (units 10 ⁻²) | DOCUMENT I | | COMMENT |
| VALUE (units 10 ⁻²) | DOCUMENT ID TECN COMM | • | 4.9±0.6±0.5 | LINK | | 4-body fit, ≈ 5.7k evts |
| 0.84±0.21±0.12 | AUBERT 07BJ BABR Dalitz | | $\Gamma(\pi^+\pi^-2\pi^0)/\Gamma(K^-$ | +\ | | Γ /Γ. |
| $\Gamma(3\pi^0)/\Gamma_{ m total}$ | | Γ /Γ | ` , ` | N') EVTS DOCUMI | ENT ID TEC | Г ₁₆₅ /Г ₃ :N СОММЕНТ |
| r (3π°)/ rotal VALUECL%_ | DOCUMENT ID TECN COMM | Γ ₁₅₁ /Γ | | 2724 ± 166 RUBIN | | EO e^+e^- at $\psi(3770)$ |
| <3.5 × 10 ⁻⁴ 90 | RUBIN 06 CLEO e^+e^- | | | | 00 021 | |
| | | | $\Gamma(\eta\pi^0)/\Gamma_{ m total}$ | dan akaba — ana kalindad | | Γ ₁₆₆ /Ι |
| $\Gamma(2\pi^+2\pi^-)/\Gamma(K^-\pi^+)$ | | Γ_{152}/Γ_{31} | VALUE (units 10 ⁻⁴) | des of the η are included. EVTS DOCUMENT | T ID TECN | COMMENT |
| VALUE (units 10 ⁻²) EVTS | DOCUMENT ID TECN CO | | | | | |
| | | OMMENT | | | | |
| 19.1±0.5 OUR FIT Error includ | les scale factor of 1.1. | + e - at ψ(3770) | • • • We do not use the | e following data for avera 56 ± 24 ARTUSO | ges, fits, limits, | |
| 19.1±0.5 OUR FIT Error includ 19.1±0.4±0.6 7331 ± 13 | les scale factor of 1.1. 30 RUBIN 06 CLEO e^{\pm} | + e - at ψ(3770) | • • • We do not use the $6.4\pm1.0\pm0.4$ 15 | e following data for avera | ges, fits, limits, | etc. • • • D See MENDEZ 10 |
| 19.1 \pm 0.5 OUR FIT Error includ 19.1 \pm 0.4 \pm 0.6 7331 \pm 13 $\Gamma(2\pi^{+}2\pi^{-})/\Gamma(K^{-}2\pi^{+}\pi^{-})$ | les scale factor of 1.1. 30 RUBIN 06 CLEO e | $+_{e}$ at $\psi(3770)$ Γ_{152}/Γ_{66} | • • • We do not use the $6.4\pm1.0\pm0.4$ 15 $\Gamma(\eta\pi^0)/\Gamma(K^-\pi^+)$ | e following data for avera | ges, fits, limits, o | etc. • • • D See MENDEZ 10 |
| 19.1±0.5 OUR FIT Error includ 19.1±0.4±0.6 7331 ± 13 | les scale factor of 1.1. 30 RUBIN 06 CLEO e - DOCUMENT ID TECN COM | $+_{e}$ at $\psi(3770)$ Γ_{152}/Γ_{66} | • • • We do not use the $6.4\pm1.0\pm0.4$ 15 $\Gamma(\eta\pi^0)/\Gamma(K^-\pi^+)$ Unseen decay mod | e following data for avera 56 ± 24 ARTUSO | ges, fits, limits, 08 CLEC | etc. • • • D See MENDEZ 10 |
| 19.1 \pm 0.5 OUR FIT Error includ 19.1 \pm 0.4 \pm 0.6 7331 \pm 13 $\Gamma(2\pi^{+}2\pi^{-})/\Gamma(K^{-}2\pi^{+}\pi^{-})$ VALUE (units 10 $^{-2}$) EVTS 9.19 \pm 0.23 OUR FIT Error includ 9.20 \pm 0.26 OUR AVERAGE | les scale factor of 1.1. 30 RUBIN 06 CLEO e ⁻¹ DOCUMENT ID TECN COM ludes scale factor of 1.1. | $+e^-$ at $\psi(3770)$ Γ_{152}/Γ_{66} MMENT | • • • We do not use the $6.4\pm1.0\pm0.4$ 15 $\Gamma(\eta\pi^0)/\Gamma(K^-\pi^+)$ Unseen decay mod WALUE (units 10^{-2}) | e following data for avera 56 ± 24 ARTUSO | ges, fits, limits, on the other of the other | etc. • • • D See MENDEZ 10 Γ ₁₆₆ /Γ ₃ |
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| $\Gamma(\overline{K}^*(892)^0 K_S^0, \overline{K}^*(892)^0 \to K^- \pi^+) / \Gamma(K_S^0 \pi^+ \pi^-)$ | | Γ ₁₇₉ /Γ ₃₄ | $\Gamma(2K_S^0\pi^0)/\Gamma_{\text{total}}$ | | DOCUMENT ID | | TECN | COMMENT | Γ ₁₉₀ /Γ |
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| VALUE CL% DOCUMENT | IT ID TECN COMMEN | | <0.00059 | | ASNER | 96B | | $e^+e^-\approx$ | T(45) |
| <0.019 90 AMMAR • • • We do not use the following data for ave | | ≈ 10.5 GeV | $\Gamma(\phi\pi^0)/\Gamma(K^+K^-)$ | .) | | | | | Γ ₂₀₃ /Γ ₁₇₆ |
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| $\Gammaig(K_{oldsymbol{S}}^{0}K^{+}\pi^{-}ig)/\Gammaig(K^{-}\pi^{+}ig)$ VALUE DOCUMENT | IT ID TECN COMMEN | Γ ₁₈₀ /Γ ₃₁ | $0.194 \pm 0.006 \pm 0.009$ | 1254 | TA JI MA | 04 | RELL | e+e− at | 7(45) |
| 0.066±0.013 OUR FIT | | | $\Gamma(\phi\eta)/\Gamma(K^+K^-)$ | | | | | | $\Gamma_{204}/\Gamma_{170}$ |
| 0.05 \pm 0.025 1 ANJOS 1 The factor 100 at the top of column 2 of Ta | 91 E691 γ Be 80- | | VALUE (units 10 ⁻²) 3.59±1.14±0.18 | | TA JI MA | 04 | TECN BELL | $\frac{COMMENT}{e^+e^-}$ at | Υ(4 C) |
| · | able for Allasos of should b | | | 31 | TAJIMA | 04 | BLLL | e e ai | |
| $\Gammaig(K_S^0K^+\pi^-ig)/\Gammaig(K_S^0\pi^+\pi^-ig)$ VALUE EVTS DOCUMENT | IT ID TECN COMMEN | Γ ₁₈₀ /Γ ₃₄ | Γ(φω)/Γ _{total} | CL% | DO CUMENT ID | | TECN | COMMENT | Γ ₂₀₅ / Ι |
| 0.091±0.017 OUR FIT | | | <0.0021 | 90 | ALBRECHT | 941 | ARG | $e^+e^-\approx 1$ | .0 GeV |
| 0.098±0.020 55 AMMAR | 91 CLEO e ⁺ e ⁻ s | ≈ 10.5 GeV | r/v+ v+) | /F/ <i>V</i> = 1_+ . | \ | | | | F /F |
| $\Gamma(K^*(892)^0 K_5^0,$ | | | $\Gamma(K^+ K^- \pi^+ \pi^-)$ VALUE (units 10^{-2}) | FVTS | T) DOCUMENT | ID | TECN | COMMEN | Γ ₁₉₁ /Γ ₆₀ |
| $K^*(892)^0 \rightarrow K^+\pi^-)/\Gamma(K_S^0\pi^+\pi^-)$ VALUE CL% DOCUMENT | IT ID TECN COMMEN | Γ ₁₈₁ /Γ ₃₄ | 3.00±0.13 OUR AVE | RAGE | | | | _ | |
| <0.010 90 AMMAR | | | $2.95 \pm 0.11 \pm 0.08$ $3.13 \pm 0.37 \pm 0.36$ | 2669 ± 101 | 1 LINK | | G FOCS | | , ≈ 180 GeV eus, 500 GeV |
| $\Gamma(K^+K^-\pi^0)/\Gamma(K^-\pi^+\pi^0)$ | | Γ /Γ | $3.13 \pm 0.37 \pm 0.36$ $3.5 \pm 0.4 \pm 0.2$ | 136 ± 15 244 ± 26 | AITALA FRABETTI | | BD E791 C E687 | _ | $_{_{_{V}}} \approx 200 \text{ GeV}$ |
| ` ' ' ' | UMENTID TECN COM. | Γ₁₈₂/Γ₄₉ ΜΕΝΤ | ● ● We do not use | the following | data for average | es, fits, | limits, ϵ | | 1 |
| | ERT,B 06x BABR e ⁺ e | _ | $4.4 \ \pm 1.8 \ \pm 0.5$ | 19 ± 8 | ABLIKIM | | F BES | | $\approx \psi(3770)$ |
| • • • We do not use the following data for average and the following data for a verage and the following data for the following data for a verage and the following data for a verage data f | | | $4.1 \pm 0.7 \pm 0.5$ 3.14 ± 1.0 | 114 ± 20 89 ± 29 | ALBRECH ⁻ | | li ARG . CLEO | | : 10 GeV ≈ 10.5 GeV |
| 0.95 ± 0.26 151 A S NE | IER 96B CLE2 <i>e</i> + <i>e</i> | $e^- \approx r(45)$ | $\begin{array}{c} 3.14 \pm 1.0 \\ 2.8 & +0.8 \\ -0.7 \end{array}$ | 09 ± 29 | A MMAR A N J O S | | . E691 | | 240 GeV |
| $\Gamma(K^*(892)^+K^-)$ | | | | | | | | | |
| $\hat{K}^*(892)^+ \to K^+\pi^0)/\Gamma(K^+K^-\pi^0)$ | | $\Gamma_{183}/\Gamma_{182}$ | ¹ LINK 05G uses a that gives the res | | |) ± 48 | events n | or the amp | iitude anaiysi |
| This is the "fit fraction" from the Dalitz- | | | $\Gamma(\phi\pi^+\pi^-$ 3-b ody, | φ→ K+K- | -)/[(K+K- | π+π- | -) | | Γ192/Γ19 |
| <u>VALUE (units 10⁻²)</u> <u>DO CUMENT</u> 44.4±0.8±0.6 AUBERT | | | This is the frac | tion from a co | herent amplitud | | vsis. | | 192/19 |
| • • • We do not use the following data for average and the following data for a very data. | | | <u>VALUE</u> | | MENT ID | TECN | | - | /- + - |
| 46.1 ± 3.1 LAWLFIE | ELD 06A CLEO Dalitz fi | t, 627 \pm 30 evts | 0.01 ± 0.01 | LINK | . 056 | FUCS | evts | ± 48 K ⁺ I s. | \ π · π |
| $^{ m 1}$ The error on this CAWLFIELD 06A result is | s statistical only. | | $\Gamma(\phi ho^0, \phi ightarrow K^+ K^-$ | (-)/Γ(<i>K</i> + κ | $(-\pi^+\pi^-)$ | | | | Γ193/Γ191 |
| Γ(K* (892) ⁻ K ⁺ , | | | This is the frac | tion from a co | herent amplitud | | | | 175, 17. |
| $K^*(892)^- \to K^-\pi^0)/\Gamma(K^+K^-\pi^0)$ | | $\Gamma_{184}/\Gamma_{182}$ | <u>VALUE</u> 0.29±0.02±0.01 | _ <u>DOCU</u> LINK | IMENT ID | FOCS | | <u>ENT</u> ± 48 К ⁺ I | (-π+π- |
| This is the "fit fraction" from the Dalitz- | | ce. | 0.29±0.02±0.01 | LIMA | . 036 | FUCS | evts | | Λ π · π |
| <u>VALUE (units 10⁻²)</u> <u>DOCUMENT</u> 15.9±0.7±0.6 AUBERT | | | $\Gamma(K^+K^-\rho^0$ 3-boo | v)/Γ(K+ K | $-\pi^{+}\pi^{-}$) | | | | Γ ₁₉₄ /Γ ₁₉₃ |
| • • • We do not use the following data for average and the following data for a verage and the verage and the following data for a verage and the | | | This is the frac | tión from a co | herent amplitud | | | | 134, 13 |
| _ | ELD 06A CLEO Dalitz fi | | <u>VALUE</u> 0.02±0.02±0.02 | | MENT ID 05.6 | FOCS | 1 279 - | <u>ENT</u> ± 48 К ⁺ I | (-π+π- |
| $^{ m 1}$ The error on this CAWLFIELD 06A result is | s statistical only. | | 0.0210.0210.02 | LINIX | . 000 | . 005 | evts | | |
| $\Gamma((K^+\pi^0)_{S-wave}K^-)/\Gamma(K^+K^-\pi^0)$ | | $\Gamma_{185}/\Gamma_{182}$ | $\Gamma(f_0(980)\pi^+\pi^-)$ | $f_0 \rightarrow K^+ K^-$ | -)/Γ(K+K- | π+π- | .) | | Γ195/Γ19: |
| This is the "fit fraction" from the Dalitz- | • | ce. | This is the frac | | herent amplitud IMENT ID | e analy <i>TECN</i> | rsis. COMMI | ENT | |
| <u>VALUE (units 10⁻²)</u> <u>DOCUMENT</u> 71.1±3.7±1.9 | TECN COMMEN O7T BABR Dalitz fi | | 0.15 ± 0.03 ± 0.02 | _ <u>boco</u> LINK | | | | ± 48 K+ I | (-π+π- |
| ¹ The only major difference between fits I an | | | | | | | evts | | |
| mode, where the fit-1 fraction is (16.3 \pm 3.4 | | , | Γ(K* <u>(</u> 892) ⁰ K [∓] π | | | | | $^{+}\pi^{-})$ | $\Gamma_{196}/\Gamma_{191}$ |
| $\Gamma((K^-\pi^0)_{S-wave}K^+)/\Gamma(K^+K^-\pi^0)$ | | $\Gamma_{186}/\Gamma_{182}$ | This is the frac VALUE | | herent amplitud IMENT ID | | rsis. <u>COMMI</u> | ENT | |
| This is the "fit fraction" from the Dalitz- | | | 0.11±0.02±0.01 | LINK | . 05 G | | 1279 : | ± 48 K+ I | (-π+π- |
| VALUE (units 10 ⁻²) DOCUMENT 3.9±0.9±1.0 AUBERT | | | | | | | evts | | |
| | | | Γ(<i>K</i> *(892) ⁰ <i>K</i> *(89 | | · K ±π [∓])/Γ(. herent amplitud | | | -) | $\Gamma_{197}/\Gamma_{191}$ |
| $\Gamma(f_0(980)\pi^0, f_0 \rightarrow K^+K^-)/\Gamma(K^+K^-\pi^0)$ This is the "fit fraction" from the Dalitz- | $\pi^{u})$ | Γ ₁₈₇ /Γ ₁₈₂ | VALUE VALUE | | | | rsis. <u>COMMI</u> | ENT | |
| VALUE (units 10^{-2}) DOCUMENT | | | $0.03 \pm 0.02 \pm 0.01$ | LINK | 05 G | FOCS | | ± 48 K+ F | √-π+π- |
| | | | | | | | evts | | |
| 10.5±1.1±1.2 1 AUBERT | 0 | e fit fraction is a | | tion from a co | herent amplitud | é analy | | • | Γ ₁₉₈ /Γ ₁₉₁ |
| $\begin{array}{c} \textbf{10.5\pm1.1\pm1.2} & 1 \text{ AUBERT} \\ \text{1 When AUBERT 07T replace the $f_0(980)$ π^0} \\ \text{negligibly different } (11.0\pm1.5\pm1.2)\%. \end{array}$ | * mode with 20(980) π°, the | | <u>VA L UE</u> | DOCU | | | | | γ ⁻ π ⁺ π ⁻ |
| ¹ When AUBERT 07T replace the $f_0(980)\pi^0$ negligibly different $(11.0\pm1.5\pm1.2)\%$. $\Gamma(\phi\pi^0,\phi\to K^+K^-)/\Gamma(K^+K^-\pi^0)$ | Q | Γ ₁₈₈ /Γ ₁₈₂ | 0.33±0.06±0.04 | <u>DOCU</u> 1 LINK | | FOCS | | | |
| 1 When AUBERT 07T replace the $f_0(980)\pi^0$ negligibly different $(11.0\pm1.5\pm1.2)\%.$ $\Gamma\left(\phi\boldsymbol{\pi^0},\phi\to\boldsymbol{K^+K^-}\right)\!/\Gamma\left(\boldsymbol{K^+K^-\pi^0}\right)$ This is the "fit fraction" from the Dalitz- | :–plot analysis with interferen | Γ₁₈₈/Γ₁₈₂ | 0.33±0.06±0.04 | 1 LINK | 05 G | | evts | S. | 30)0 ± 30 |
| $ \begin{array}{ll} \mbox{1 When AUBERT 07T replace the } f_0(980) \pi^0 \\ \mbox{negligibly different } (11.0 \pm 1.5 \pm 1.2)\%. \\ \mbox{1 } $ | r-plot analysis with interferender of the transfer of the tran | Г ₁₈₈ /Г ₁₈₂ ce. | 0.33±0.06±0.04 ¹ This LINK 05G | 1 LINK | 05 G | | evts | S. | 30) ⁰ π [±] , and |
| $ \begin{array}{lll} \mbox{1 When AUBERT 07T replace the } f_0 (980) \pi^0 \\ \mbox{negligibly different } (11.0 \pm 1.5 \pm 1.2) \%. \\ \mbox{\Gamma } (\phi \pi^0, \phi \rightarrow K^+ K^-) / \Gamma (K^+ K^- \pi^0) \\ \mbox{This is the "fift fraction"} & \mbox{from the Dalitz-} \\ \mbox{VALUE (units 10^{-2})$} & \mbox{\underline{DOCUMENT}} \\ \mbox{19.4 $\pm 0.6 \pm 0.5$} & \mbox{4} \mbox{WB do not use the following data for ave} \end{array} $ | r-plot analysis with interferen- IT ID TECN COMMEN 07T BABR Dalitz firerages, fits, limits, etc. • • | Γ₁₈₈/Γ₁₈₂ ce. t II, 11k evts | $0.33 \pm 0.06 \pm 0.04$ This LINK 05G $K^*(892)^0 \pi^\pm$. | 1 LINK value includes | κ_1 05 G κ_1 (1270) $^\pm$ - | $\rightarrow \rho^0$ | evts K [±] , – | s. → K ₀ *(14 | |
| $ \begin{array}{lll} \mbox{1 When AUBERT 07T replace the } f_0 (980) \pi^0 \\ \mbox{negligibly different } (11.0 \pm 1.5 \pm 1.2) \%. \\ \mbox{\Gamma } (\phi \pi^0, \phi \rightarrow K^+ K^-) / \Gamma \big(K^+ K^- \pi^0 \big) \\ \mbox{This is the "fit fraction"} & \mbox{from the Dalitz-} \\ \mbox{VALUE (units 10^{-2})$} & \mbox{DOCUMENT} \\ \mbox{19.4 \pm 0.6 \pm 0.5} & \mbox{AUBERT} \\ \mbox{\bullet \bullet We do not use the following data for ave} \\ \mbox{14.9 \pm 1.6} & \mbox{1 CAWLFIE} \\ \end{array} $ | r-plot analysis with interferen- IT ID TECN COMMEN 07T BABR Dalitz firerages, fits, limits, etc. • • ELD 06A CLEO Dalitz fir | Γ₁₈₈/Γ₁₈₂ ce. t II, 11k evts | 1 This LINK 056 κ*(892) ⁰ π [±] . Γ(Κ ₁ (1400) [±] Κ [∓] . | $1 \frac{1}{\text{LINK}}$ value includes $K_1(1400)^{\pm}$ | κ_1 05 G κ_1 (1270) $^\pm$ - | → ρ ⁰ | evts K [±] , – | s. → K ₀ *(14 | |
| $ \begin{array}{ll} \text{1 When AUBERT 07T replace the } f_0\left(980\right)\pi^0 \\ \text{negligibly different } (11.0\pm1.5\pm1.2)\%. \\ \hline \Gamma\left(\phi\pi^0,\phi\to K^+K^-\right)/\Gamma\left(K^+K^-\pi^0\right) \\ \text{This is the "fit fraction" from the Dalitz-} \\ \underline{VALUE \left(\text{units }10^{-2}\right)} \\ \hline 19.4\pm0.6\pm0.5 \\ \hline \bullet \bullet \text{ We do not use the following data for average} \end{array} $ | r-plot analysis with interferen- IT ID TECN COMMEN 07T BABR Dalitz firerages, fits, limits, etc. • • ELD 06A CLEO Dalitz fir | Γ₁₈₈/Γ₁₈₂ ce. t II, 11k evts | 0.33 \pm 0.06 \pm 0.04 ¹ This LINK 056 $K^*(892)^0 \pi^{\pm}$. This is the fraction of the state o | 1 LINK value includes K ₁ (1400) [±] tion from a co | $6.6 	ext{ } 	 | → ρ ⁰ •)/Γ(/ e analy • • • • • • • • • • • • • • • • • • • | evts K [±] , – K+ K – rsis. <u>COMM</u> | κ_0^* κ_0^* κ_0^* κ_0^* | Γ199/Γ19 |
| 1 When AUBERT 07T replace the $f_0\left(980\right)\pi^0$ negligibly different $(11.0\pm1.5\pm1.2)\%$. $\Gamma\left(\phi\pi^0,\phi\to K^+K^-\right)/\Gamma\left(K^+K^-\pi^0\right)$ This is the "fit fraction" from the Dalitz-MALUE (units 10^{-2}) DOCUMENT 19.4 $\pm 0.6 \pm 0.5$ AUBERT • • • We do not use the following data for ave 14.9 ± 1.6 1 CAWLFIE 1 The error on this CAWLFIELD 06A result is $\Gamma\left(K^+K^-\pi^0\text{nonresonant}\right)/\Gamma\left(K^+K^-\pi^0\right)$ | r-plot analysis with interference of the property of the prope | $\Gamma_{188}/\Gamma_{182}$ ce. $\frac{77}{1}$ t II, 11k evts • t, 627 ± 30 evts $\Gamma_{189}/\Gamma_{182}$ | 0.33±0.06±0.04 ¹ This LINK 056 K*(892) ⁰ π±. Γ(K ₁ (1400)± K∓. This is the frac | $\frac{1}{\text{LINK}}$ value includes $K_1(1400)^{\pm}$ tion from a co | $6.6 	ext{ } 	 | → ρ ⁰ •)/Γ(/ e analy • • • • • • • • • • • • • • • • • • • | evts K [±] , – K+ K – rsis. <u>COMM</u> | s. $ \pi^{+}\pi^{-}) $ ENT $ \pm 48 K^{+} I $ | Γ199/Γ19 |
| 1 When AUBERT 07T replace the $f_0(980)\pi^0$ negligibly different $(11.0\pm1.5\pm1.2)\%$. $\Gamma(\phi\pi^0,\phi\to K^+K^-)/\Gamma(K^+K^-\pi^0)$ This is the "fit fraction" from the Dalitz-VALUE (units $10^{-2})$ AUBERT •• We do not use the following data for average 14.9 ±1.6 1 CAWLFIE 1 The error on this CAWLFIELD 06A result is $\Gamma(K^+K^-\pi^0$ nonresonant)/ $\Gamma(K^+K^-\pi^0$ This is the "fit fraction" from the Dalitz- | T-plot analysis with interference of the property of the prope | Γ ₁₈₈ /Γ ₁₈₂ ce. //Γ t II, 11k evts • t, 627 ± 30 evts Γ ₁₈₉ /Γ ₁₈₂ ce. | 0.33 \pm 0.06 \pm 0.04 ¹ This LINK 056 $K^*(892)^0 \pi^{\pm}$. F($K_1(1400)^{\pm} K^{\mp}$. This is the frac <u>NALUE</u> 0.22 \pm 0.03 \pm 0.04 | 1 LINK value includes K1(1400) tion from a co <u>DOCU</u> LINK | $6.6 	ext{ } 	 | → ρ ⁰ •)/Γ(/ e analy • • • • • • • • • • • • • • • • • • • | evts K [±] , - K+ K- rsis. COMMI 1279 : | s. $ \pi^{+}\pi^{-}) $ ENT $ \pm 48 K^{+} I $ | Γ ₁₉₉ /Γ ₁₉ (-π+π- |
| ¹ When AUBERT 07T replace the $f_0(980)\pi^0$ negligibly different $(11.0 \pm 1.5 \pm 1.2)\%$. Γ $(\phi \pi^0, \phi \rightarrow K^+K^-)/\Gamma(K^+K^-\pi^0)$ This is the "fit fraction" from the Dalitz-VALUE (units 10^{-2}) 19.4±0.6±0.5 • • We do not use the following data for ave 14.9±1.6 ¹ The error on this CAWLFIELD 06A result is Γ $(K^+K^-\pi^0$ nonresonant) /Γ $(K^+K^-\pi^0$ This is the "fit fraction" from the Dalitz-VALUE | T-plot analysis with interference of the property of the prope | Γ ₁₈₈ /Γ ₁₈₂ ce. IT II, 11k evts t, 627 ± 30 evts Γ ₁₈₉ /Γ ₁₈₂ ce. | 0.33±0.06±0.04 ¹ This LINK 056 $K^*(892)^0 \pi^{\pm}$ $\Gamma(K_1(1400)^{\pm} K^{\mp})$ This is the frac MALUE 0.22±0.03±0.04 $\Gamma(2K_5^0 \pi^+ \pi^-)/\Gamma(6K_5^0 | value includes $K_1(1400)^{\pm}$ tion from a co $\frac{DOCU}{LINK}$ | $05 G$ $5 K_1(1270)^{\pm}$ $\rightarrow K^{\pm}\pi^{+}\pi^{-}$ herent amplitud $MENT ID$ $05 G$ | $ ho^0$ $ ho^0$ $ ho^0$ e analy $ ho^0$ FOCS | evts K+ K- rsis. <u>COMMI</u> 1279 : evts | s. $ \begin{array}{ccc} \kappa_0^*(14) \\ \pi^+\pi^-) \\ \hline \kappa_0^{ENT} \\ \pm 48 & \kappa^+ I \end{array} $ | Γ ₁₉₉ /Γ ₁₉ (-π+π- Γ ₂₀₀ /Γ ₃ |
| ¹ When AUBERT 07T replace the $f_0(980)$ π ⁰ negligibly different $(11.0 \pm 1.5 \pm 1.2)$ %. Γ ($\phi \pi^0$, $\phi \rightarrow K^+K^-$)/Γ ($K^+K^-\pi^0$) This is the "fit fraction" from the Dalitz-WALUE (units 10^{-2}) 19.4±0.6±0.5 • • We do not use the following data for ave 14.9±1.6 1 The error on this CAWLFIELD 06A result is 1. The error on this CAWLFIELD 06A result is Γ ($K^+K^-\pi^0$ nonresonant)/Γ ($K^+K^-\pi^0$ This is the "fit fraction" from the Dalitz-WALUE • • • We do not use the following data for ave | T-plot analysis with interference of the property of the prope | Γ ₁₈₈ /Γ ₁₈₂ ce. UT t II, 11k evts • t, 627 ± 30 evts Γ ₁₈₉ /Γ ₁₈₂ ce. UT | 0.33 \pm 0.06 \pm 0.04 ¹ This LINK 056 $K^*(892)^0 \pi^{\pm}$. F($K_1(1400)^{\pm} K^{\mp}$. This is the frac <u>NALUE</u> 0.22 \pm 0.03 \pm 0.04 | value includes $K_1(1400)^{\pm}$ tion from a co $\frac{DOCU}{LINK}$ $K_0^0 \pi^+ \pi^ \frac{EVTS}{}$ | $6.6 	ext{ } 	 | $ ho^0$ $ ho^0$ $ ho^0$ e analy $ ho^0$ FOCS | evts K [±] , - K+ K- rsis. COMMI 1279 : | s. $ \pi^{+}\pi^{-}) $ ENT $ \pm 48 K^{+} I $ | Γ_{199}/Γ_{19} $\overline{\langle{\pi^+\pi^-}}$ Γ_{200}/Γ_{3} |
| ¹ When AUBERT 07T replace the $f_0(980)$ π ⁰ negligibly different $(11.0 \pm 1.5 \pm 1.2)$ %. Γ ($\phi \pi^0$, $\phi \rightarrow K^+K^-$)/Γ ($K^+K^-\pi^0$) This is the "fit fraction" from the Dalitz-VALUE (units 10^{-2}) 19.4±0.6±0.5 • • We do not use the following data for ave 14.9±1.6 1 The error on this CAWLFIELD 06A result is 1 The error on this CAWLFIELD 06A result is Γ ($K^+K^-\pi^0$ nonresonant)/Γ ($K^+K^-\pi^0$ This is the "fit fraction" from the Dalitz-VALUE • • • We do not use the following data for ave | t-plot analysis with interference of the property of the prope | ce. IT t II, 11k evts t, 627 \pm 30 evts IT IT t, 627 \pm 30 evts IT t, 627 \pm 30 evts | 0.33 \pm 0.06 \pm 0.04 1 This LINK 056 $K^*(892)^0 \pi^{\pm}$. $\Gamma(K_1(1400)^{\pm} K^{\mp})$ This is the frac VALUE 0.22 \pm 0.03 \pm 0.04 $\Gamma(2K_5^0 \pi^+ \pi^-)/\Gamma(4K_5^0 L^{2})$ | value includes $K_1(1400)^{\pm}$ tion from a co $\frac{DOCU}{LINK}$ $K_0^0 \pi^+ \pi^ \frac{EVTS}{}$ | $05G 5 K_1(1270)^{\pm} - K^{\pm}\pi^{+}\pi^{-}$ herent amplitud MENT ID $05G$ | $\rho^0 \rightarrow \rho^0$ e analy TECN FOCS | evts K+ K- rsis. COMMI 1279 : evts | s. $ \pi^{+}\pi^{-}) $ ENT $ \pm 48 K^{+} I $ COMMEN | Γ_{199}/Γ_{19} Γ_{199}/Γ_{19} Γ_{200}/Γ_{3} $\Gamma_{7} \approx 180 \text{ GeV}$ |

 D^0

| $\Gamma(K_S^0K^-2\pi^+\pi^-)$ | $^{-})/\Gamma(K_{S}^{0} 2\pi$ | ⁺ 2π ⁻) | | | Γ ₂₀₁ /Γ ₈₆ |
|-------------------------------|-------------------------------|--------------------------------|--------|----------|---------------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| < 0.054 | 90 | LINK | 04D | FOCS | γ A, $\overline{E}_{\gamma} pprox$ 180 GeV |
| $\Gamma(K^+K^-\pi^+\pi^-$ | $\pi^0)/\Gamma_{ m total}$ | | | | Γ ₂₀₂ /Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| 0.0031 ± 0.0020 | | ¹ BARLAG | 92c | ACCM | π^- Cu 230 GeV |
| 1 BARLAG 92c c | omnutes the h | ranching fraction i | sing t | onologic | al normalization |

| ¹ BARLAG 92c cor | nputes the bra | nching fraction ι | ısing | topologica | I normalization. |
|----------------------------------------------------------------|----------------|-------------------|-------|------------|---------------------------------------|
| | | Radiative mo | des : | | |
| $\Gamma(ho^0\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂₀₆ /Γ |
| VALUE | CL% | DOCUMENT ID | | TECN | |
| $<2.4 \times 10^{-4}$ | 90 | ASNER | 98 | CLE2 | |
| $\Gamma(\omega\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂₀₇ /Γ |
| VALUE | <u>CL%</u> | DOCUMENT ID | | TECN | |
| $< 2.4 \times 10^{-4}$ | 90 | ASNER | 98 | CLE2 | |
| $\Gamma(\phi\gamma)/\Gamma(K^+K^-)$ |) | | | | Γ ₂₀₈ /Γ ₁₇₆ |
| WALUE (units 10 ⁻³) 6.8 ±0.9 OUR FIT | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 6.31 + 1.70 + 0.30 - 1.48 - 0.36 | 28 | TA JI MA | 04 | BELL | e^+e^- at $\varUpsilon(4S)$ |
| $\Gamma(\phi\gamma)/\Gamma(K^-\pi^+)$ VALUE (units 10^{-4}) | EVTS | <u>DO CUMENT</u> | ID | TECN | Γ ₂₀₈ /Γ ₃₁ |
| 7.0 ±0.9 OUR FIT 7.15±0.78±0.69 | 243 ± 25 | AUBERT | | 08az BAB | R $e^+e^- \approx 10.6 \text{ GeV}$ |
| $\Gamma(\overline{K}^*(892)^0\gamma)/\Gamma($ | $(K^-\pi^+)$ | | | | Γ_{209}/Γ_{31} |
| VALUE (units 10 ⁻³) | EVTS | <u>DO CUMENT</u> | ID | TECN | COMMENT |
| $8.43 \pm 0.51 \pm 0.70$ | 2286 ± 113 | AUBERT | | 08AZ BAB | R $e^+e^- \approx 10.6 \text{ GeV}$ |

Doubly Cabibbo-suppressed / Mixing modes

$\Gamma(K^+\ell^-\overline{\nu}_\ell \text{ via } \overline{D}^0)/\Gamma(K^-\ell^+\nu_\ell)$

This is a limit on R_M without the complications of possible doubly Cabibbo-suppressed decays that occur when using hadronic modes. For the limits on $|m_1-m_2|$ and $(\Gamma_1-\Gamma_2)/\Gamma$ that come from the best mixing limit, see near the beginning of these D^0 Listings.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|---------------------|---------|---------|-------------------------------------------|
| $< 6.1 \times 10^{-4}$ | 90 | 1 BITENC | 08 | BELL | e ⁺ e ⁻ , 10.58 GeV |
| • • • We do not use the | following | data for averages | , fits, | limits, | etc. • • • |
| $< 50 \times 10^{-4}$ | 90 | ² AITALA | 96c | E791 | π^- nucleus, 500 GeV |

96C E791 π^- nucleus, 500 GeV 1 The BITENC 08 right-sign sample includes about 15% of ${\it D}^0
ightarrow \, {\it K}^- \, \pi^0 \, \ell^+ \,
u_\ell$ and other

$\Gamma \left(K^+ \text{ or } K^*(892)^+ \, e^- \overline{\nu}_e \text{ via } \overline{D}{}^0 \right) / \left[\Gamma \left(K^- \, e^+ \, \nu_e \right) + \Gamma \left(K^*(892)^- \, e^+ \, \nu_e \right) \right]$ $\Gamma_{211}/(\Gamma_{18}+\Gamma_{20})$

This is a limit on R_M without the complications of possible doubly Cabibbo-suppressed decays that occur when using hadronic modes. The experiments use ${\it D^{*+}}
ightarrow {\it D^{\,0}}\,\pi^+$ (and charge conjugate) decays to identify the charm at production and the charge of the e to identify the charm at decay. These limits do not allow CP violation. For the limits on $|m_1 - m_2|$ and $(\Gamma_1 - \Gamma_2)/\Gamma$ that come from the best mixing limit, see near the beginning of these D^0 Listings.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|-------------------|---------|---------|------------------------------|
| < 0.001 | 90 | BITENC | 05 | BELL | e^+e^-pprox 10.6 GeV |
| • • • We do not use the | following | data for averages | , fits, | limits, | etc. • • • |
| -0.0013 < R < +0.0012 | 90 | AUBERT | 07AB | BABR | $e^+e^-pprox~10.58~{ m GeV}$ |
| < 0.0078 | 90 | CAWLFIELD | 05 | CLEO | e^+e^-pprox 10.6 GeV |
| < 0.0042 | 90 | AUBERT,B | 04Q | BABR | See AUBERT 07AB |

 $\Gamma(K^+\pi^-)/\Gamma(K^-\pi^+)$ This is R, the time-integrated wrong-sign rate compared to the right-sign rate. See the note on " D^0 - \overline{D}^0 Mixing," near the start of the D^0 Listings.

The experiments here use the charge of the pion in $D^*(2010)^\pm \to (D^0 \text{ or } \overline{D}{}^0) \ \pi^\pm$ decay to tell whether a D^0 or a $\overline{D}{}^0$ was born. The $D^0 \to K^+\pi^-$ decay can occur directly by doubly Cabibbo-suppressed (DCS) decay, or indirectly by $D^0 \to \overline{D}{}^0$ mixing followed by $\overline{D}{}^0 \to K^+\pi^-$ decay. Some of the experiments can use the decaytime information to disentangle the two mechanisms. Here, we list the experimental branching ratio, which if there is no mixing is the DCS ratio. See the next data block for values of the DCS ratio R_D , and the following data block for limits on the mixing ratio R_M . See the section on CP-violating asymmetries near the end of this D^0 Listing for values of A_D , and the note on " D^0 - \overline{D}^0 Mixing" for limits on x' and y'.

Some early limits have been omitted from this Listing; see our 1998 edition (The European Physical Journal C3 1 (1998)) and our 2006 edition (Journal of Physics, G

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------------------------|------------------|------------------------|----------|------------|---------------------------------------------|
| 3.79±0.18 OUR FIT | Error includes | scale factor of 3.3 | 3. | | |
| 3.79±0.18 OUR AVE | RAGE Error in | cludes scale facto | r of 3 | .3. See 1 | he ideogram below. |
| 4.15 ± 0.10 | $12.7 \pm 0.3 k$ | $^{ m 1}$ aaltonen | 08E | CDF | $p\overline{p}$, $\sqrt{s}=1.96~{\rm TeV}$ |
| $3.53 \pm 0.08 \pm 0.04$ | 4030 ± 90 | | | | e^+e^-pprox 10.6 GeV |
| $3.77 \pm 0.08 \pm 0.05$ | 4024 ± 88 | ¹ ZHANG | 06 | BELL | e^+e^- |
| ullet $ullet$ We do not use | the following da | ata for averages, fi | its, lir | nits, etc. | • • • |
| $4.05 \pm 0.21 \pm 0.11$ | $2.0\pm0.1k$ | ³ ABULENCIA | 06x | CDF | See AALTONEN 08E |
| $3.81 \pm 0.17 ^{+0.08}_{-0.16}$ | 845 ± 40 | 2 LI | 05 A | BELL | See ZHANG 06 |
| $4.29^{+0.63}_{-0.61}\pm0.27$ | 234 | ⁴ LINK | 05 н | FOCS | γ nucleus |
| $3.57 \pm 0.22 \pm 0.27$ | | ⁵ AUBERT | 03z | BABR | See AUBERT 07w |
| $4.04 \pm 0.85 \pm 0.25$ | 149 | ⁶ LINK | 01 | FOCS | γ nucleus |
| $3.32^{+0.63}_{-0.65}\pm0.40$ | 45 | $^{\mathrm{1}}$ GODANG | 00 | CLE2 | e^+e^- |
| $\begin{array}{ccc} 6.8 & +3.4 & \pm 0.7 \\ & -3.3 & \pm 0.7 \end{array}$ | 34 | ² AITALA | 98 | E791 | π^- nucl., 500 GeV |
| | | | | | |

WEIGHTED AVERAGE 3.79±0.18 (Error scaled by 3.3) Values above of weighted average, error and scale factor are based upon the data in this ideogram only. They are not necessarily the same as our 'best' values,

obtained from a least-squares constrained fit utilizing measurements of other (related) quantities as additional information. AALTONEN 08F AUBERT 07W BABR ZHANG BELL (Confidence Level < 0.0001)

4.5

5

 $\Gamma(K^+\pi^-)/\Gamma(K^-\pi^+)$ (units 10^{-3})

$\Gamma(K^+\pi^-\text{via DCS})/\Gamma(K^-\pi^+)$

3.5

 Γ_{213}/Γ_{31}

This is R_D , the doubly Cabibbo-suppressed ratio when mixing is allowed

| VALUE (units 10^{-3}) CL | % EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------------------------------------|----------------------|----------------------|-----------------|---------------------------------------|
| 3.37± 0.21 OUR AVI | ERAGE Error ind | cludes scale factor | of 1.8. See | the ideogram below. |
| 3.04 ± 0.55 | $12.7\pm0.3\text{k}$ | | | $p\overline{p}$, $\sqrt{s}=1.96$ TeV |
| $3.03 \pm 0.16 \pm 0.10$ | | | | $e^+e^-pprox 10.6~{ m GeV}$ |
| 3.64 ± 0.17 | 4024 ± 88 | ² ZHANG | 06 BELL | e^+e^- |
| $5.17^{+}_{-}{}^{1.47}_{1.58}\!\pm\!0.76$ | 234 | ³ LINK | 05н FOCS | γ nucleus |
| $4.8 \pm 1.2 \pm 0.4$ | 45 | ⁴ GODANG | 00 CLE2 | e^+e^- |
| ● ● We do not use | the following data | a for averages, fits | s, limits, etc. | • • • |
| 2.87± 0.37 | 845 ± 40 | LI | 05A BELL | See ZHANG 06 |
| $2.3 < R_D < 5.2$ 95 | | ⁵ AUBERT | 03z BABR | See ZHANG 06 See AUBERT 07w |
| $9.0 \ ^{+12.0}_{-10.9} \ \pm 4.4$ | 34 | ⁶ AITALA | 98 E791 | π^- nucl., 500 GeV |

 $^{^1}$ This AUBERT 07W result is the same whether or not $\it CP$ violation is allowed 2 This ZHANG 06 assumes no $\it CP$ violation.

 $^{^2}$ AITALA 96c uses $D^{*+} \rightarrow D^0 \pi^+$ (and charge conjugate) decays to identify the charm at production and ${\it D}^{\,0}
ightarrow \, {\it K}^{\,-} \, \ell^+ \, \nu_\ell$ (and charge conjugate) decays to identify the charm

 $^{^1}$ GODANG 00, ZHANG 06, and AALTONEN 08e allow $\it CP$ violation. 2 AlTALA 98, LI 05A, and AUBERT 07W assume no $\it CP$ violation.

³This ABULENCIA 06x result assumes no mixing.

⁴ This LINK 05H result assumes no mixing but allows CP violation. If neither mixing nor CP violation is allowed, $R = (4.29 \pm 0.63 \pm 0.28) \times 10^{-3}$

 $^{^5}$ This AUBERT 03z result allows $\it CP$ violation. If $\it CP$ violation is not allowed, $\it R=0.00359\pm0.00020\pm0.00027.$

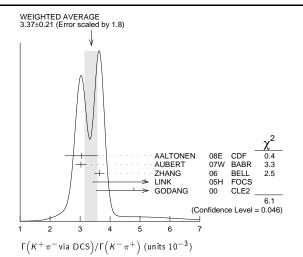
⁶ This LINK 01 result assumes no mixing or *CP* violation.

This LHANG 0b assumes no CP violation. 3 This LINK 05H result allows CP violation. Allowing mixing but not CP violation, $R_D=(3.81^{+1.67}_{-1.63}\pm0.92)\times10^{-3}$.

This GODANG 00 result allows *CP* violation.

⁵ This AUBERT 032 result allows *CP* violation. If only mixing is allowed, the 95% confidence level interval is (2.4 < R_D < 4.9) imes 10 $^{-3}$

⁶This AITALA 98 result assumes no *CP* violation



$\Gamma(K^+\pi^-\text{via }\overline{D}^0)/\Gamma(K^-\pi^+)$

This is R_M in the note on " D^0 - \overline{D}^0 Mixing" near the start of the D^0 Listings. The experiments here (1) use the charge of the pion in $D^*(2010)^{\pm} \rightarrow (D^0 \text{ or } \overline{D}^0)$ π^{\pm} decay to tell whether a D^0 or a \overline{D}^0 was born; and (2) use the decay-time distribution to distribution to distribution to distribution. to disentangle doubly Cabibbo-suppressed decay and mixing. For the limits on $\left|m_1
ight|$ m_2 and $(\Gamma_1 - \Gamma_2)/\Gamma$ that come from the best mixing limit, see near the beginning of these D^0 Listings.

| VALUE | CL% EVTS | DO CUMENT ID | TE | CNCOMMENT | |
|---------------|-------------------|-----------------------|---------------|----------------------------------|--|
| < 0.00040 | 95 | ¹ ZHA NG | 06 BE | LL e^+e^- | |
| • • • We do n | ot use the follow | ving data for average | es, fits, lim | its, etc. • • • | |
| < 0.00046 | 95 | ² LI | 05A BE | LL See ZHANG 06 | |
| < 0.0063 | 95 | ³ LINK | 05н FO | CS γ nucleus | |
| < 0.0013 | 95 | ⁴ AUBERT | 03z BA | BR $e^{+}e^{-}$, 10.6 GeV | |
| < 0.00041 | 95 | ⁵ GODANG | 00 CL | E2 e ⁺ e ⁻ | |
| < 0.0092 | 95 | ⁶ BARATE | 98w AL | EP e^+e^- at Z^0 | |
| < 0.005 | 90 1 + 4 | ⁷ ANJOS | 88c E6 | 91 Photoproduction | |

 $^{^{}m 1}$ This ZHANG 06 result allows $\it CP$ violation, but the result does not change if $\it CP$ violation is not allowed.

Violation is not allowed. 3 LINK 05H obtains the same result whether or not CP violation is allowed. 4 This AUBERT 03z result allows CP violation and assumes that the strong phase between $D^0 \to K^+\pi^-$ and $\overline{D}{}^0 \to K^+\pi^-$ is small, and limits only $D^0 \to \overline{D}{}^0$ transitions via off-shell intermediate states. The limit on transitions via on-shell intermediate states is

0.0016. 5 This GODANG 00 result allows CP violation and assumes that the strong phase between $D^{0} \rightarrow K^{+}\pi^{-}$ and $\overline{D}^{0} \rightarrow K^{+}\pi^{-}$ is small, and limits only $D^{0} \rightarrow \overline{D}^{0}$ transitions via off-shell intermediate states. The limit on transitions via on-shell intermediate states is

 6 This BARATE 98w result assumes no interference between the DCS and mixing amplitudes (y' = 0 in the note on "D^0- \overline{D}^0 Mixing" near the start of the D^0 Listings). When interference is allowed, the limit degrades to 0.036 (95%CL)

 7 This A NJOS 88c result assumes no interference between the DCS and mixing amplitudes (y'=0 in the note on " \mathcal{D}^0 - $\overline{\mathcal{D}}^0$ Mixing" near the start of the \mathcal{D}^0 Listings). When interference is allowed, the limit degrades to 0.019.

 $\Gamma \big(K_5^0 \pi^+ \pi^- \text{ in } D^0 \to \overline{D}{}^0 \big) / \Gamma \big(K_5^0 \pi^+ \pi^- \big) \\ \text{This is } R_M \text{ in the note on "$D^0 $-$\overline{D}{}^0$ Mixing" near the start of the D^0 Listings. The }$ experiments here (1) use the charge of the pion in $D^*(2010)^\pm \to (D^0 \text{ or } \overline{D^0}) \ \pi^\pm$ decay to tell whether a D^0 or a $\overline{D^0}$ was born; and (2) use the decay-time distribution to disentangle doubly Cabibbo-suppressed decay and mixing. For the limits on $|m_1-m_2|$ and $(\Gamma_1-\Gamma_2)/\Gamma$ that come from the best mixing limit, see near the beginning of these D^0 Listings.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------|-----|--------------|----|------|--------------------------------|
| < 0.0063 | 95 | 1 ASNER | 05 | CLEO | $e^+e^-\approx 10 \text{ GeV}$ |

 $^{
m 1}$ This ASNER 05 limit allows $\it CP$ violation. If $\it CP$ violation is not allowed, the limit is 0.0042 at 95% CL

$\Gamma(K^+\pi^-\pi^0)/\Gamma(K^-\pi^+\pi^0)$

The experiments here use the charge of the pion in $D^*(2010)^\pm o (D^0$ or $\overline{D}{}^0)$ π^\pm decay to tell whether a D^0 or a \overline{D}^0 was born. The $D^0 \to K^+\pi^-\pi^0$ decay can occur directly by doubly Cabibbo-suppressed (DCS) decay, or indirectly by $D^0 \to \overline{D}^0$ mixing followed by $\overline{D}{}^0 \rightarrow K^+\pi^-\pi^0$ decay.

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | COMMENT |
|---------------------------------------------------------|--------------|-----------------------|----------|--------------------------------------|
| 2.20±0.10 OUR AV | ERAGE | · | | |
| $2.14 \pm 0.08 \pm 0.08$ | 763 ± 51 | ¹ AUBERT,B | 06N BABR | $e^+ e^- \approx \Upsilon(4S)$ |
| $2.29 \pm 0.15 {}^{+\; 0.13}_{-\; 0.09}$ | 1978 ± 104 | TIAN | 05 BELL | $e^+ e^- \approx ~ \varUpsilon(45)$ |
| $4.3 \begin{array}{c} +1.1 \\ -1.0 \end{array} \pm 0.7$ | 38 | BRANDENB | 01 CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

¹ This AUBERT,B 06N result assumes no mixing.

$\Gamma(K^+\pi^-\pi^0 \text{ via } \overline{D}{}^0)/\Gamma(K^-\pi^+\pi^0)$

 Γ_{220}/Γ_{49}

This is R_M in the note on " $D^0 - \overline{D}{}^0$ Mixing" near the start of the D^0 Listings. The experiments here (1) use the charge of the pion in $D^*(2010)^\pm \to (D^0 \text{ or } \overline{D}^0)$ π^\pm decay to tell whether a D^0 or a \overline{D}^0 was born; and (2) use the decay-time distribution to disentangle doubly Cabibbo-suppressed decay and mixing. For the limits on $\left|m_1
ight.$ m_2 and $(\Gamma_1 - \Gamma_2)/\Gamma$ that come from the best mixing limit, see near the beginning of these D^0 Listings.

TECN COMMENT $5.25 + 0.25 \pm 0.12$ AUBERT 09AN BABR e^+e^- at 10.58 GeV

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

¹ AUBERT,B 06N BABR $e^+e^- \approx \Upsilon(4S)$ 95

 $^{
m 1}$ This AUBERT,B 06N limit assumes no $\it CP$ violation. The measured value corresponding to the limit is $(2.3^{+1.8}_{-1.4}\pm0.4) imes10^{-4}$ If *CP* violation is allowed, this becomes $(1.0^{+2.2}_{-0.7}\pm0.3)\times10^{-4}$

 $\Gamma(K^{+}\pi^{+}2\pi^{-})/\Gamma(K^{-}2\pi^{+}\pi^{-})$

The experiments here use the charge of the pion in $D^*(2010)^{\pm} \to (D^0 \text{ or } \overline{D}^0) \pi^{\pm}$ decay to tell whether a D^0 or a \overline{D}^0 was born. The $D^0 \to K^+\pi^-\pi^+\pi^-$ decay can occur directly by doubly Cabibbo-suppressed (DCS) decay, or indirectly by $D^0 \to \overline{D}^0$ mixing followed by $\overline{D}^0 \to K^+\pi^-\pi^+\pi^-$ decay. Some of the experiments can use the decay-time information to disentangle the two mechanisms. Here, we list the experimental branching ratio which if there is no mixing is the DCS action in the part experimental branching ratio, which if there is no mixing is the DCS ratio; in the next data block we give the limits on the mixing ratio.

Some early limits have been omitted from this Listing; see our 1998 edition (EPJ C3

VALUE (units 10^{-3}) CL% EVTS DOCUMENT ID TECN COMMENT 3.24 + 0.25 OUR AVERAGE $3.20 \pm 0.18 + 0.18 \\ -0.13$ 1 TIAN 1721 ± 75 05 BELL $e^+e^- \approx \Upsilon(4S)$

 $\begin{array}{ccc} 4.4 & +1.3 \\ -1.2 & \pm 0.4 \end{array}$ ¹ DYTMAN 01 CLE2 $e^+e^-\approx \Upsilon(4S)$ $2.5 \ ^{+3.6}_{-3.4} \ \pm 0.3$ ² AITALA 98 E791 π^- nucl., 500 GeV

• • • We do not use the following data for averages, fits, limits, etc. • • •

91 CLEO $e^+e^-\approx 10.5$ <18 90 ¹ AMMAR ³ ANJOS 90 5 ± 12 88c E691 Photoproduction

 $^{
m 1}\,{\rm AMMAR}$ 91 cannot and DYTMAN 01 and TIAN 05 do not distinguish between doubly Cabibbo-suppressed decay and $D^0-\overline{D}^0$ mixing.

² This AITALA 98 result assumes no $D^{0}-\overline{D}^{0}$ mixing (R_{M} in the note on " $D^{0}-\overline{D}^{0}$ Mixing"). It becomes $-0.0020^{+0.0117}_{-0.0106} \pm 0.0035$ when mixing is allowed and decay-time information is used to distinguish doubly Cabibbo-suppressed decays from mixing.

 3 A NJOS 88c uses decay-time information to distinguish doubly Cabibbo-suppressed (DCS) decays from D^0 - $\overline{D^0}$ mixing. However, the result assumes no interference between the DCS and mixing amplitudes (y'=0 in the note on " D^0 - $\overline{D^0}$ Mixing" near the start of the $D^{\,0}$ Listings). When interference is allowed, the limit degrades to 0.033.

$\Gamma(K^+\pi^+2\pi^-\text{via }\overline{D}^0)/\Gamma(K^-2\pi^+\pi^-)$ Γ_{222}/Γ_{66}

This is a $D^0 - \overline{D}{}^0$ mixing limit. The experiments here (1) use the charge of the pion in $D^*(2010)^\pm o (D^0 \ {
m or} \ \overline{D}{}^0) \ \pi^\pm$ decay to tell whether a D^0 or a $\overline{D}{}^{ar{0}}$ was born; and (2) use the decay-time distribution to disentangle doubly Cabibbo-suppressed decay and mixing. For the limits on $\left|m_{D_1^0}-m_{D_2^0}\right|$ and $\left(\Gamma_{D_1^0}-\Gamma_{D_2^0}\right)/\Gamma_{D^0}$ that come from

the best mixing limit, see near the beginning of these D^0 Listings

DOCUMENT ID TECN COMMENT $^{
m 1}$ ANJOS <0.005 88c E691 Photoproduction

 $1\,\mathrm{A\,NJOS}$ 88C uses decay-time information to distinguish doubly Cabibbo-suppressed (DCS) decays from $D^0 - \overline{D^0}$ mixing. However, the result assumes no interference between the DCS and mixing amplitudes (y'=0 in the note on " $D^0-\overline{D}^0$ Mixing" near the start of the $D^{\,0}$ Listings). When interference is allowed, the limit degrades to 0.007.

 $\Gamma(K^+\pi^- \text{ or } K^+\pi^+ 2\pi^- \text{ via } \overline{D}^0)/\Gamma(K^-\pi^+ \text{ or } K^- 2\pi^+\pi^-)$ This is a $D^0-\overline{D}{}^0$ mixing limit. For the limits on $|m_{D_1^0}-m_{D_2^0}|$ and $(\Gamma_{D_1^0}-\Gamma_{D_2^0})/\Gamma_{D^0}$

that come from the best mixing limit, see near the beginning of these \hat{D}^0 Listings.

CL% DO CUMENT ID TECN COMMENT

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

¹ AITALA < 0.0085 90 98 E791 π^{-} nucleus 500 GeV < 0.0037 2 ANJOS 90 88c E691 Photoproduction

¹ AITALA 98 uses decay-time information to distinguish doubly Cabibbo-suppressed decays from D^0 - \overline{D}^0 mixing. The fit allows interference between the two amplitudes, and also allows CP violation in this term. The central value obtained is $0.0039 + 0.0036 \pm 0.0016$. When interference is disallowed, the result becomes $0.0021 \pm 0.0009 \pm 0.0002$. 2 This combines results of ANJOS 88c on $K^+\pi^-$ and $K^+\pi^-\pi^+\pi^-$ (via \overline{D}^0) reported in the data block above (see footnotes there). It assumes no interference.

 $^{^2}$ This LI 05A result allows *CP* violation. The limit becomes < 0.00042 (95% CL) if *CP* violation is not allowed.

 D^0

| | ⁰ mixing limit. | See the somewl | | | $\Gamma(ho^0e^+e^-)/\Gamma_{total}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. |
|--------------------------------------------------------------|---------------------------------|----------------------------------|--------------------------|--------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>∨ALUE</u> <0.0056 | <u>CL%</u> 90 | DOCUMENT ID | | C π^- W 225 GeV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| • • We do not use | | | | | <1.0 \times 10 ⁻⁴ 90 2 ¹ FREYBERGER 96 CLE2 $e^+e^-\approx \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <0.012 <0.044 | 90 90 | BENVENUTI BODEK | | R μ C, 200 GeV C π^- , ρ Fe $ ightarrow$ D^0 | $<$ 1.24 $	imes$ 10 $^{-4}$ 90 1 AITALA 01C E791 π^- nucleus, 500 GeV |
| _ | Rare | or forbidden | modes — | | $^{ m 1}$ This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes |
| $\Gamma(\gamma\gamma)/\Gamma(2\pi^0)$ | | | | $\Gamma_{225}/\Gamma_{132}$ | to $<1.8	imes10^{-4}$ using a photon pole amplitude model. |
| at the tree level | l. | | | idden in the Standard Model | $\Gamma(\pi^+\pi^-\mu^+\mu^-)/\Gamma_{	ext{total}}$ |
| <0.033 | <u>CL%</u> 90 | COAN | 03 CLE | $\begin{array}{ccc} & & & & & & \\ COMMENT & & & \\ 2 & & e^+ e^- \approx & & \\ & & & \\ \end{array}$ | <u>VALUE</u> <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN COMMENT</u> <3.0 × 10⁻⁵ 90 2 AITALA 01c E791 π [−] nucleus, 500 GeV |
| | | | Allowed by | Γ_{226}/Γ first-order weak interaction | $\Gamma(ho^0\mu^+\mu^-)/\Gamma_{	ext{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak |
| | electromagneti <u>% EVTS</u> | CINTERACTION. <u>DOCUMENT ID</u> | TECI | ICOMMENT | interactions. <u>VALUECL%_EVTS</u> DOCUMENT_IDTECNCOMMENT |
| <7.9 × 10^{−8} 90 • • We do not use | | PETRIC data for averages | | L $e^+e^-pprox \varUpsilon(4S)$ s, etc. $ullet$ $ullet$ | <2.2 × 10 ⁻⁵ 90 0 AITALA 01c E791 π ⁻ nucleus, 500 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $<1.2 \times 10^{-6}$ 90 | | AUBERT,B | | R $e^+e^-pprox \varUpsilon(4S)$ | $<$ 4.9 $	imes$ 10 $^{-4}$ 90 1 1 FREYBERGER 96 CLE2 $e^{+}e^{-} \approx \varUpsilon(4S)$ |
| $< 8.19 \times 10^{-6}$ 90 $< 6.2 \times 10^{-6}$ 90 | | PRIPSTEIN AITALA | 00 E789 | | $<2.3 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV $<8.1 \times 10^{-4}$ 90 5 HAAS 88 CLEO e^+e^- 10 GeV |
| <1.3 × 10 ⁻⁵ 90 | | FREYBERGER | 96 CLE | $e^+e^-pprox \Upsilon(4S)$ | 28.1 × 10 · 90 5 HAAS 88 CLEO e · e · 10 GeV This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes |
| $<1.3 \times 10^{-4}$ 90 $<1.7 \times 10^{-4}$ 90 | | ADLER | | (3 e ⁺ e ⁻ 3.77 GeV | to $< 4.5 \times 10^{-4}$ using a photon pole amplitude model. |
| $<1.7 \times 10^{-4}$ 90 $<2.2 \times 10^{-4}$ 90 | | ALBRECHT HAAS | 88G ARG 88 CLE | $e^{+}e^{-}$ 10 GeV O $e^{+}e^{-}$ 10 GeV | $\Gamma(\omegae^+e^-)/\Gamma_{ m total}$ |
| $(\mu^+\mu^-)/\Gamma_{\rm total}$ | | | | Γ ₂₂₇ /Γ | interactions. |
| A test for the 2 combined with | | | Allowed by | first-order weak interaction | <u>VALUE</u> <u>CL''</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> <1.8 × 10 − 4 90 1 1 FREYBERGER 96 CLE2 $e^{+}e^{-}\approx \Upsilon(4S)$ |
| | <u> EVTS</u> | DO CUMENT ID | TECI | | $^{ m 1}$ This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes |
| <1.4 × 10 ⁻⁷ 90 • • We do not use | | PETRIC data for averages | 10 BEL s, fits, limit | · , | to $<$ 2.7 $	imes$ 10^{-4} using a photon pole amplitude model. |
| $< 2.1 \times 10^{-7}$ 90 | _ | AALTONEN | 10x CDF | | $\Gamma(\omega \mu^+ \mu^-)/\Gamma_{	ext{total}}$ Γ_{237}/Γ |
| $< 2.0 \times 10^{-6}$ 90 | | ABT | | B pA, 920 GeV | A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. |
| <1.3 × 10 ⁻⁶ 90 <2.5 × 10 ⁻⁶ 90 | | AUBERT,B ACOSTA | 04Y BAE | R $e^+e^-pprox \varUpsilon(4S)$ See AALTONEN 10x | VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| $<1.56 \times 10^{-5}$ 90 | | PRIPSTEIN | 00 E789 | | <8.3 x 10 ⁻⁴ 90 0 1 FREYBERGER 96 CLE2 $e^{+}e^{-}\approx \Upsilon(4S)$ |
| <5.2 × 10 ⁻⁶ 90 <4.1 × 10 ⁻⁶ 90 | | ADAMOVICU | 99G E79 | | 1 This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes to $< 6.5 \times 10^{-4}$ using a photon pole amplitude model. |
| $<4.1 \times 10^{-6}$ 90 $<4.2 \times 10^{-6}$ 90 | | ADAMOVICH ALEXOPOU | | · · | |
| $< 3.4 \times 10^{-5}$ 90 | | FREYBERGER | | · , | $\Gamma(K^-K^+e^+e^-)/\Gamma_{	ext{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak |
| $<7.6 \times 10^{-6}$ 90 $<4.4 \times 10^{-5}$ 90 | | ADA MOVICH KODA MA | 95 BEA 95 E653 | | interactions. |
| $<3.1 \times 10^{-5}$ 90 | | MISHRA | 94 E789 | | <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> <3.15 × 10⁻⁴ 90 9 AITALA 01c E791 π [−] nucleus, 500 GeV |
| <7.0 × 10 ⁻⁵ 90 | | ALBRECHT | 88G ARG | | |
| $<1.1 \times 10^{-5}$ 90 $<3.4 \times 10^{-4}$ 90 | | LOUIS AUBERT | 86 SPE 85 EMO | | $\Gamma(\phi e^+e^-)/\Gamma_{	ext{total}}$ |
| | | | | the PDG." For an alternate | interactions. |
| approach, giving a | a limit of $9 	imes 1$ | 0−6 at 90% con | ifidence lev | el, see the paper. | <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> <5.2 × 10⁻⁵ 90 2 1 FREYBERGER 96 CLE2 $e^+e^- \approx r(4s)$ |
| $(\pi^0 e^+ e^-)/\Gamma_{\text{tota}}$ | I | | | Γ ₂₂₈ /Γ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| A test for the interactions. | $\Delta C = 1$ weak | neutral current. | Allowed | by higher-order electroweak | $<$ 5.9 $	imes$ 10^{-5} 90 0 AITALA 01C E791 π^- nucleus, 500 GeV |
| <u>ALUE</u> <u>CL</u> <4.5 × 10⁻⁵ 90 | | DOCUMENT ID | | $\frac{OMMENT}{2} e^{+}e^{-} \approx \Upsilon(4S)$ | 1 This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes to $<$ 7.6 \times 10 $^{-5}$ using a photon pole amplitude model. |
| $(\pi^0 \mu^+ \mu^-)/\Gamma_{\rm tota}$ | | | | Γ ₂₂₉ /Γ | $\Gamma(K^-K^+\mu^+\mu^-)/\Gamma_{	ext{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak |
| actions. | ∆C=1 weak nei % <i>EVTS</i> | itral current. All DOCUMENT ID | owed by hig | gher-order electroweak inter- | interactions. <u>VALUECL%EVTS</u> |
| <1.8 × 10 ⁻⁴ 90 | 2 | KODAMA | 95 E653 | π^- emulsion 600 GeV | <3.3 × 10^{-5} 90 0 AITALA 01c E791 π^- nucleus, 500 GeV |
| • • We do not use $<5.4 \times 10^{-4}$ 90 | _ | = | | s, etc. $ullet$ $ullet$ $ullet$ $e^+ e^- pprox \varUpsilon(4S)$ | $\Gammaig(\phi\mu^+\mu^-ig)/\Gamma_{	ext{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak |
| $(\eta e^+ e^-)/\Gamma_{\text{total}}$ | | | | Γ ₂₃₀ /Γ | interactions. <u>VALUECL%_EVTS</u> <u>DOCUMENT IDTECN</u> <u>COMMENT</u> |
| | | neutral current. | | by higher-order electroweak I COMMENT | <3.1 × 10 ⁻⁵ 90 0 AITALA 01C E791 π ⁻ nucleus, 500 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <1.1 × 10 ⁻⁴ 90 | | | | $\frac{1}{2} \frac{COMMENT}{e^+ e^-} \approx \Upsilon(4S)$ | <4.1 \times 10 ⁻⁴ 90 0 ¹ FREYBERGER 96 CLE2 $e^+e^-\approx \tau$ (45) ¹ This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes |
| | $\Delta {\it C}=1$ weak | neutral current. | . Allowed | Γ_{231}/Γ by higher-order electroweak | to $<$ $2.4 	imes 10^{-4}$ using a photon pole amplitude model. |
| | <u> EVTS</u> | DO CUMENT ID | | I COMMENT | $\Gamma(\overline{K}^0e^+e^-)/\Gamma_{	ext{total}}$ Not a useful test for $\Delta C=1$ weak neutral current because both quarks must change |
| <5.3 × 10 ⁻⁴ 90 | 0 | FREYBERGER | 96 CLE | $e^+e^-\approx \Upsilon(4S)$ | flavor. <u>VALUECL% _EVTS </u> |
| $(\pi^+\pi^-e^+e^-)/\Gamma$ A test for the | | neutral current. | . Allowed | Γ_{232}/Γ by higher-order electroweak | <1.1 \times 10 ⁻⁴ 90 0 FREYBERGER 96 CLE2 $e^+e^-\approx \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| interactions. | | | | - | $<$ 1.7 \times 10 $^{-3}$ 90 ADLER 89c MRK3 e^+e^- 3.77 GeV |
| | % EVTS | DO CUMENT ID | TEC | I COMMENT | CI.7 × 10 30 ABEEN OSC WINNS C C 3.77 GCV |

| $\Gamma(\overline{K^0}\mu^+\mu^-)/\Gamma_{	ext{total}}$ Not a useful test for $\Delta C=1$ weak neutral current because both quarks must change | $\Gamma(\rho^0 e^\pm \mu^\mp)/\Gamma_{	ext{total}}$ A test of lepton family number conservation. The value is for the sum of the two |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| flavor. VALUE CL% EVTS DOCUMENTID TECN COMMENT | charge states. |
| VALUE CL% EVTS DOCUMENT ID TECN COMMENT $<2.6 \times 10^{-4}$ 90 2 KODAMA 95 E653 π^- emulsion 600 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE CL% EVTS DOCUMENT ID TECN COMMENT $<$ 4.9 × 10 ⁻⁵ 90 0 1 FREYBERGER 96 CLE2 $e^+e^-\approx T(4S)$ |
| < 6.7 \times 10 ⁻⁴ 90 1 FREYBERGER 96 CLE2 $e^+e^-\approx r(45)$ | ullet $ullet$ $$ |
| $\Gamma(K^-\pi^+e^+e^-)/\Gamma_{total}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. | 1 This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes to $< 5.0 \times 10^{-5}$ using a photon pole amplitude model. |
| VALUECL%EVTSDOCUMENT IDTECNCOMMENT<3.85 \times 10 ⁻⁴ 906AITALA01cE791 π^- nucleus, 500 GeV | $\Gamma(\omega e^{\pm}\mu^{\mp})/\Gamma_{total}$ Γ_{254}/Γ A test of lepton family number conservation. The value is for the sum of the two charge states. |
| $\Gamma(\overline{K}^*(892)^0 e^+ e^-)/\Gamma_{\text{total}}$ Γ_{245}/Γ | VALUE CL% EVTS DOCUMENT ID TECN COMMENT $<1.2 \times 10^{-4}$ 90 0 1 FREYBERGER 96 CLE2 $e^+e^- \approx \Upsilon(4S)$ |
| Not a useful test for $\Delta C=1$ weak neutral current because both quarks must change flavor. <u>VALUE</u> <u>CL%</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | ¹ This FREYBERGER 96 limit is obtained using a phase-space model. The same limit is obtained using a photon pole amplitude model. |
| <4.7 \times 10⁻⁵ 90 2 AITALA 01c E791 π^- nucleus, 500 GeV • • • We do not use the following data for averages, fits, limits, etc. • • • <1.4 \times 10 ⁻⁴ 90 1 1 FREYBERGER 96 CLE2 $e^+e^-\approx \Upsilon(45)$ | $\Gamma(K^-K^+e^\pm\mu^\mp)/\Gamma_{total}$ A test of lepton family-number conservation. The value is for the sum of the two |
| 1 This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes | charge states. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| to $< 2.0 	imes 10^{-4}$ using a photon pole amplitude model. | <1.8 × 10 ⁻⁴ 90 5 AlTALA 01c E791 π ⁻ nucleus, 500 GeV |
| $\Gamma(K^-\pi^+\mu^+\mu^-)/\Gamma_{total}$ | $\Gamma(\phi e^{\pm}\mu^{\mp})/\Gamma_{total}$ Γ_{256}/Γ A test of lepton family number conservation. The value is for the sum of the two charge states. |
| VALUE CL% EVTS DOCUMENT ID TECN COMMENT 250 × 10 ⁻⁴ 00 12 ALTALA 01c E701 - purpose F00 CoV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| $<3.59 \times 10^{-4}$ 90 12 AITALA 01c E791 π^- nucleus, 500 GeV $\Gamma(\overline{K}^*(892)^0\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{247}/Γ | <3.4 \times 10⁻⁵ 90 0 ¹ FREYBERGER 96 CLE2 $e^+e^-\approx \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| Not a useful test for $\Delta C=1$ weak neutral current because both quarks must change | $<4.7 \times 10^{-5}$ 90 0 AITALA 01c E791 π^- nucleus, 500 GeV |
| flavor. CL% EVTS DOCUMENT ID TECN COMMENT $< 2.4 \times 10^{-5}$ 90 3 AITALA 01C E791 π^- nucleus, 500 GeV | $^1\text{This}$ FREYBERGER 96 limit is obtained using a phase-space model. The limit changes to $<3.3	imes10^{-5}$ using a photon pole amplitude model. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(\overline{K^0}e^{\pm}\mu^{\mp})/\Gamma_{\text{total}}$ A test of lepton family number conservation. The value is for the sum of the two |
| $<1.18 \times 10^{-3}$ 90 1 ¹ FREYBERGER 96 CLE2 $e^+e^-\approx \varUpsilon(4S)$ ¹ This FREYBERGER 96 limit is obtained using a phase-space model. The limit changes | charge states. <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> |
| to $< 1.0 \times 10^{-3}$ using a photon pole amplitude model. | <1.0 x 10 ⁻⁴ 90 0 FREYBERGER 96 CLE2 $e^+e^-\approx \Upsilon(4S)$ |
| $\Gamma(\pi^+\pi^-\pi^0\mu^+\mu^-)/\Gamma_{	ext{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. | $\Gamma(K^-\pi^+e^\pm\mu^\mp)/\Gamma_{ m total}$ |
| VALUECL%EVTSDOCUMENT IDTECNCOMMENT $<8.1 \times 10^{-4}$ 901KODAMA95E653 π^- emulsion 600 GeV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT <5.53 × 10 ⁻⁴ 90 15 AITALA 01c E791 π = nucleus, 500 GeV |
| $\Gamma(\mu^{\pm}e^{\mp})/\Gamma_{	ext{total}}$ Γ_{249}/Γ | $\Gamma(\overline{K}^*(892)^0 e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ Γ_{259}/Γ |
| A test of lepton family number conservation. VALUE CL% EVTS DOCUMENT ID TECN COMMENT | A test of lepton family number conservation. The value is for the sum of the two |
| < 2.6 \times 10 ⁻⁷ 90 PETRIC 10 BELL $e^+e^- \approx r(4S)$ | charge states. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | <8.3 × 10 ⁻⁵ 90 9 AITALA 01c E791 π [−] nucleus, 500 GeV |
| $<$ 8.1 \times 10 ⁻⁷ 90 0 AUBERT,B 04Y BABR $e^+e^-pprox \varUpsilon(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $< 1.72 \times 10^{-5}$ 90 PRIPSTEIN 00 E789 p nucleus, 800 GeV $< 8.1 \times 10^{-6}$ 90 AITALA 99G E791 π^- N 500 GeV | $<$ 1.0 $	imes$ 10 $^{-4}$ 90 0 1 FREYBERGER 96 CLE2 $e^+e^-pprox \varUpsilon(4S)$ |
| $< 1.9 \times 10^{-5}$ 90 2 1 FREYBERGER 96 CLE2 $e^+e^- \approx \Upsilon(4S)$ | $^{ m 1}$ This FREYBERGER 96 limit is obtained using a phase-space model. The same limit is |
| $<$ 1.0 $	imes$ 10 $^{-4}$ 90 4 ALBRECHT 88G ARG e^+e^- 10 GeV | obtained using a photon pole amplitude model. |
| $< 2.7 \times 10^{-4}$ 90 9 HAAS 88 CLEO $e^{+}e^{-}$ 10 GeV | $\Gamma(2\pi^-2e^+ + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{260}/Γ |
| $< 1.2 \times 10^{-4}$ 90 BECKER 87c MRK3 e ⁺ e ⁻ 3.77 GeV $< 9 \times 10^{-4}$ 90 PALKA 87 SILI 200 GeV πp | A test of lepton-number conservation. The value is for the sum of the two charge |
| $<21 \times 10^{-4}$ 90 0 2 RILES 87 MRK2 e^+e^- 29 GeV | states. <u>VALUE CL%_EVTS</u> <u>DOCUMENT ID TECN_COMMENT</u> |
| $^{ m 1}$ This is the corrected result given in the erratum to FREYBERGER 96. | <1.12 × 10⁻⁴ 90 1 AITALA 01c E791 π^- nucleus, 500 GeV |
| 2 RILES 87 assumes B($D \to K \pi$) = 3.0% and has production model dependency. $\Gamma(\pi^0 e^{\pm} \mu^{\mp})/\Gamma_{\rm total}$ | $\Gamma(2\pi^-2\mu^++c.c.)/\Gamma_{total}$ A test of lepton-number conservation. The value is for the sum of the two charge |
| A test of lepton family number conservation. The value is for the sum of the two charge states. | states. <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> |
| VALUECL%EVTSDOCUMENT IDTECNCOMMENT | <2.9 \times 10⁻⁵ 90 1 AITALA 01C E791 π^- nucleus, 500 GeV |
| <8.6 x 10⁻⁵ 90 2 FREYBERGER 96 CLE2 $e^+e^- \approx \Upsilon(4S)$ | $\Gamma(K^-\pi^-2e^+ + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{262}/Γ |
| $\Gamma(\eta e^{\pm} \mu^{\mp})/\Gamma_{\text{total}}$ A test of lepton family number conservation. The value is for the sum of the two charge states. | A test of lepton-number conservation. The value is for the sum of the two charge states. VALUE CL% _EVTS DOCUMENT ID TECN COMMENT |
| VALUE CL% EVTS DOCUMENT ID TECN COMMENT | $< 2.06 \times 10^{-4}$ 90 2 AITALA 01c E791 π^- nucleus, 500 GeV |
| <1.0 × 10⁻⁴ 90 0 FREYBERGER 96 CLE2 e^+e^- ≈ $\Upsilon(4S)$ | $\Gamma(K^-\pi^-2\mu^+ + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{263}/Γ |
| $\Gamma(\pi^+\pi^-e^\pm\mu^\mp)/\Gamma_{total}$ | A test of lepton-number conservation. The value is for the sum of the two charge states. WALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| charge states. <u>VALUECL%_EVTSDOCUMENT IDTECNCOMMENT</u> | <3.9 × 10⁻⁴ 90 14 AITALA 01c E791 π^- nucleus, 500 GeV |
| <1.5 × 10 ⁻⁵ 90 1 AlTALA 01c E791 π ⁻ nucleus, 500 GeV | $\Gamma(2K^-2e^++c.c.)/\Gamma_{total} \qquad \qquad \Gamma_{264}/\Gamma$ A test of lepton-number conservation. The value is for the sum of the two charge |
| | states. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| | $<1.52 \times 10^{-4}$ 90 2 AITALA 01c E791 π^- nucleus, 500 GeV |
| | · , |

| $\Gamma(2K^{-}2\mu^{+} +$ | c.c.)/F _{total} | | | Γ ₂₆₅ /Γ | $A_{CP}(\pi^0\pi^0)$ in | D^0 , $\overline{D}{}^0 \rightarrow \pi^0 \pi^0$ | | |
|----------------------------------------------------------------------|-----------------------------------------------|--------------------------------------------------------|----------------------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------------|-------------------------------------------------------------|------------------------------------|
| A test of I states. | lepton-number o | onservation. The | value is for th | he sum of the two charge | VALUE (%) | | OCUMENT ID | TECN |
| VALUE VALUE | CL% EVTS | DO CUMENT ID | TECN | COMMENT | $+0.1 \pm 4.8$ | 810 E | BONVICINI 01 | CLE2 |
| <9.4 × 10 ⁻⁵ | 90 1 | AITALA | 01c E791 | π^- nucleus, 500 GeV | $A_{CP}(\pi^+\pi^-\pi^0)$ |) in D^0 , $\overline{D}{}^0 	o \pi$ | $+\pi^{-}\pi^{0}$ | |
| $\Gamma(\pi^-\pi^-e^+\mu^-$ A test of | + + c.c.)/Γ _{tot} lepton-number c | al conservation. The | value is for th | Γ_{266}/Γ ne sum of the two charge | VALUE (%) 0.3 ±0.4 OUF + 0.43 ± 1.30 | EVTS R AVERAGE 123k±490 | DOCUMENT ID ARINSTEIN (| 08 BELI |
| states. /ALUE | CL% EVTS | DO CUMENT ID | TECN | COMMENT | $+0.43\pm1.50$ $+0.31\pm0.41\pm0.1$ | | | 08AO BAB |
| <7.9 × 10 ⁻⁵ | 90 4 | AITALA | | π^- nucleus, 500 GeV | $+1 \begin{array}{cc} +9 \\ -7 \end{array} \pm 5$ | | CRONIN-HEN | |
| ·(K= == e+ u | + + c.c.)/Γ _{tot} | 1 | | Γ ₂₆₇ /Γ | A /-(770)+- | +0\ | :00+ | - 750 . |
| ` A test of l | | | value is for th | he sum of the two charge | ACP (ρ(110) ' π VALUE (%) | $\tau^- \rightarrow \pi^+ \pi^- \pi^0$) | • | , D° → : <u>CN _ COM</u> |
| states. VALUE | CL% EVTS | DO CUMENT ID | TECN | COMMENT | +1.2±0.8±0.3 | AUBI | | ABR Tabl |
| <2.18 × 10 ⁻⁴ | 90 7 | AITALA | | π^- nucleus, 500 GeV | A (-(770)0 -(| $^{0} \rightarrow \pi^{+}\pi^{-}\pi^{0}$) is | | |
| (2K- +++ | L c c) /F | | | F /F | ACP (ρ(110)° π` | | | πυ CN COM |
| (2 K⁻e⁺ μ ⁺ . A test of l | | onservation. The | value is for th | Γ₂₆₈/Γ ne sum of the two charge | -3.1±2.7±1.2 | AUBI | | ABR Tabl |
| states. | • | | | · · | | | | |
| VALUE | CL% EVTS | DO CUMENT ID | | COMMENT | | $\tau^+ \rightarrow \pi^+ \pi^- \pi^0$ | | |
| <5.7 × 10 ⁻⁵ | 90 0 | AITALA | 01c E791 | π^- nucleus, 500 GeV | <u>VALUE (%)</u> −1.0±1.6±0. 7 | | | ABR Tabl |
| $(pe^-)/\Gamma_{total}$ | 1 | | | Γ ₂₆₉ /Γ | | | | |
| | | on-number conserv | | | $A_{CP}(\rho(1450)^{+})$ | $\pi^- \rightarrow \pi^+ \pi^- \pi^0$ |) in $D^0 ightarrow ho (14)$ | \$50)+ π ⁻ |
| <1.0 × 10 ⁻⁵ | <u>CL%</u> 90 | DOCUMENT ID 1 RUBIN | | COMMENT | $ ho$ (1450) $^- \pi^+$ | | | |
| | | | | $e^{+}e^{-}$ at $\psi(3770)$ | VALUE (%) | | | CN COM |
| ¹ This RUBIN | 09 limit is for ei | ther $D^0 	o pe^-$ | or $D^0 \rightarrow pe^-$ | decay. | 0±50±50 | AUBI | ERT 08A0BA | ABR Tabl |
| Γ(p e ⁺)/Γ _{total} | Ī | | | Γ ₂₇₀ /Γ | $A_{CB}(o(1450)^{0})$ | $\pi^0 \rightarrow \pi^+\pi^-\pi^0)$ | in D^0 , $\overline{D}{}^0 \rightarrow C$ | o(1450) ⁰ |
| A test of b | aryon- and lepto | on-number conserv | ation. | | VALUE (%) | | | CN COM |
| ALUE | <u>CL%</u> | DO CUMENT ID | | COMMENT | $-17 \pm 33 \pm 17$ | AUBI | ERT 08A0BA | ABR Tabl |
| <1.1 × 10 ⁻⁵ | 90 | 1 RUBIN | | $e^{+}e^{-}$ at $\psi(3770)$ | A (-(14E0)= | $\pi^+ \rightarrow \pi^+ \pi^- \pi^0$ | \:- D0/14 | 150\— _+ |
| * This RUBIN | 09 limit is for ei | ther $D^0 	o \overline{p}e^+$ | or $D^0 \rightarrow \overline{p}e^{-\overline{p}}$ | ⊤ decay. | $\rho(1450)^{+}\pi^{-}$ | $\pi^{\cdot} \rightarrow \pi^{\cdot} \pi^{-} \pi^{-}$ | $\rho = \rho$ | ιου) π |
| | 0 CD VIOLAT | ING DECAY-R | ATE ACVIA | METRICE | ρ(1430) · π VALUE (%) | DOCU | MENT ID TE | CN COM |
| | | | | | +6±8±3 | AUBI | | ABR Tabl |
| This is | the difference be | tween D^0 and \overline{D}^0 he widths. The D | partial widths | for these modes | • | | | |
| divided | by the sum of t | he widths. The $D^*:D^{*+}\to D$ | ond D° and D^{*-} | distinguished by | | $\pi^- \rightarrow \pi^+ \pi^- \pi^0$ |) in $D^{\scriptscriptstyle \mathrm{U}} ightarrow ho(17)$ | 700)+ π ⁻ |
| | | | η· aliu D | → D π . | $\rho(1700)^{-}\pi^{+}$ | | | |
| $A_{CP}(K^+K^-)$ | in D^0 , $\overline{D}{}^0 \rightarrow$ | K+ K- | | | VALUE (%) | | | CN COM |
| VALUE (%) | EVTS | DO CUMENT ID | TECN | COMMENT | -5±13±5 | AUBI | | ABR Tab |
| -0.21±0.17 OU | | 1 | | | $A_{CP}(\rho(1700)^{0})$ | $\pi^0 \rightarrow \pi^+\pi^-\pi^0)$ | in D^0 , $\overline{D}{}^0 \rightarrow \ell$ | o(1700) ⁰ |
| $-0.24 \pm 0.22 \pm 0.$ | | ¹ AALTONEN ² AUBERT | 12B CDF | $p\overline{p},\sqrt{s}{=}1.96{ m TeV}$ $e^+e^-pprox10.6{ m GeV}$ | VALUE (%) | | | CN COM |
| $0.00 \pm 0.34 \pm 0.$ $-0.43 \pm 0.30 \pm 0.$ | | 3 STARIC | | $e^+e^- \approx 10.6 \text{ GeV}$ $e^+e^- \approx \Upsilon(4S)$ | $+13 \pm 8 \pm 3$ | AUBI | ERT 08A0 BA | ABR Tab |
| $+2.0 \pm 1.2 \pm 0.$ | | 4 ACOSTA | 05c CDF | $p\overline{p}$, $\sqrt{s}=1.96$ TeV | A / (1700)- | n | \:- D0 (1- | 700\- 4 |
| 0.0 ±2.2 ±0. | | ⁴ CSORNA | | $e^+e^-\approx \Upsilon(45)$ | | $\pi^+ \rightarrow \pi^+ \pi^- \pi^0$ |) in $D^{\sigma} ightarrow ho(17)$ | /00) = π · |
| -0.1 ±2.2 ±1. | | ⁴ LINK | 00B FOCS | , | $ ho (1700)^+ \pi^-$ | | | |
| -1.0 ±4.9 ±1. | .2 609 | ⁴ AITALA | 98c E791 | $-0.093 < A_{CP} < 0.073 (0.00) < 0.01$ | VALUE (%) +8±10±5 | <u>DOCU</u> AUBI | | ABR Tabl |
| 1 | | 1.00 | | + 0.073 (90% CL) | - | | | |
| - See also "D" metries | CP-violating as | symmetry differenc | es" at the end | of the <i>CP-</i> violating asym- | $A_{CP}(f_0(980)\pi^0$ | $0 \rightarrow \pi^+\pi^-\pi^0$) in | $D^0, \overline{D}{}^0 \rightarrow f_0($ | $(980)\pi^{0}$ |
| 2 AUBERT 08 | M uses corrected | numbers of events | s directly, not r | ratios with $K^{\mp}\pi^{\pm}$ events. | VALUE (%) | | | CN COM |
| STARIC US I | uses $D^{\circ} \rightarrow K$ | $^-\pi^+$ and $\overline{D}{}^0$ $ ightarrow$ | $K^+\pi^-$ decay | ys to correct for detector- | 0 ± 25 ± 25 | AUBI | | ABR Tabl |
| induced asym | | CCODNA 33 | 1 1000= | or of | A / (/ 4 0 7 5) | $\pi^0 \rightarrow \pi^+\pi^-\pi^0$ | : DO TO . | (1270) |
| | LINK UUB. | CSURNA U2. a | na ACOSTA | 05c measure $N(D^0 \rightarrow$ | Acp(In(13/0)π | $\tau \to \pi \cdot \pi \cdot \pi'$ | m ν , ν → h | 1(13/U) <i>1</i> |
| | | | | ts observed, and similarly | VALUE (%) | | MENT ID TE | |

- $A_{CP}(K^0_S\,K^0_S)$ in $D^0,\,\overline{D}{}^0
 ightarrow\,K^0_S\,K^0_S$
- -23±19 65

$\Delta_{CD}(\pi^+\pi^-)$ in $D^0 \overline{D}^0$ -

| $A_{CP}(\pi'\pi)$ in D | $^{\circ}$, $D^{\circ} \rightarrow$ | π ' π | | | |
|-----------------------------|--------------------------------------|---------------------|------|------|----------------------------------------|
| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.22 ± 0.21 OUR A | /ERAGE | · | | | |
| $+0.22\pm0.24\pm0.11$ | 215 k | $^{ m 1}$ aaltonen | 12B | CDF | $p\overline{p}$, \sqrt{s} =1.96 TeV |
| $-0.24\pm0.52\pm0.22$ | 63.7k | ² AUBERT | 08м | BABR | e^+e^-pprox 10.6 GeV |
| $+\ 0.43 \pm 0.52 \pm 0.12$ | 51k | ³ STARIC | 80 | BELL | $e^+ e^- \approx \Upsilon(4S)$ |
| $+1.0 \pm 1.3 \pm 0.6$ | | ⁴ ACOSTA | 05 € | CDF | $p\overline{p}$, \sqrt{s} =1.96 TeV |
| $+1.9 \pm 3.2 \pm 0.8$ | 1136 | ⁴ CSORNA | 02 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |
| $+4.8 \pm 3.9 \pm 2.5$ | 1177 | ⁴ LINK | 00в | FOCS | |
| $-4.9 \pm 7.8 \pm 3.0$ | 343 | ⁴ AITALA | 98c | E791 | $-0.186 < A_{CP} <$ |
| | | | | | 1 0 000 (00% CL) |

- ¹ See also " D^0 CP-violating asymmetry differences" at the end of the CP-violating asymmetries.

 ² AUBERT 08M uses corrected numbers of events directly, not ratios with $K^{\mp}\pi^{\pm}$ events.

 ³ STARIC 08 uses $D^0 \to K^-\pi^+$ and $\overline{D}^0 \to K^+\pi^-$ decays to correct for detector-induced asymmetries.
- ⁴ AITALA 98c, LINK 00B, CSORNA 02, and ACOSTA 05c measure $N(D^0 \to \pi^+\pi^-)/N(D^0 \to K^-\pi^+)$, the ratio of numbers of events observed, and similarly for the \overline{D}^0 .

| +0.1±4.8 | 810 BONVICINI 01 CLE2 e^+e^-pprox 10.6 GeV |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $A_{CP}(\pi^+\pi^-\pi^0)$ in I | D^0 , $\overline{D}{}^0 \rightarrow \pi^+\pi^-\pi^0$ |
| VALUE (%) | EVTS DOCUMENT ID TECN COMMENT |
| 0.3 ±0.4 OUR AVI +0.43±1.30 | ERAGE 123k \pm 490 ARINSTEIN 08 BELL $e^+e^-pprox \varUpsilon(4S)$ |
| $+0.43\pm0.41\pm0.17$ | 80 \pm .3k AUBERT 08A0 BABR $e^+e^-\approx 10.6$ GeV |
| $+1 \begin{array}{ccc} +9 & \pm 5 \\ -7 & \end{array}$ | CRONIN-HEN05 CLEO $e^+e^-pprox 10$ GeV |
| · | |
| A _{CP} (ρ(770)+ π ⁻ – MLUE (%) | $\pi^+\pi^-\pi^0$) in $D^0 \to \rho^+\pi^-$, $\overline{D^0} \to \rho^-\pi^+$ DOCUMENT ID TECN COMMENT |
| +1.2±0.8±0.3 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| $A_{CP}(\rho(770)^0\pi^0 \rightarrow$ | $\pi^+\pi^-\pi^0$) in D^0 , $\overline D{}^0 	o ho^0\pi^0$ |
| VALUE (%) -3.1±2.7±1.2 | DOCUMENT ID TECN COMMENT AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| | |
| | $ ightarrow$ $\pi^+\pi^-\pi^0$) in $D^0	o ho^-\pi^+$, $\overline{D}{}^0	o ho^+\pi^-$ |
| VALUE (%) | DOCUMENT ID TECN COMMENT AUBERT 08A0 BABR Table 1, —Col.5/2×Col.2 |
| -1.0±1.6±0.7 | |
| $A_{CP}(ho(1450)^+\pi^- \cdot ho(1450)^-\pi^+$ | \rightarrow $\pi^+\pi^-\pi^0)$ in $D^0 \rightarrow \rho(1450)^+\pi^-$, $\overline{D}{}^0 \rightarrow$ |
| ρ(1430) π· VALUE(%) | DOCUMENT ID TECN COMMENT |
| 0±50±50 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| A (a(1450\0 -0 | |
| Α _{CP} (ρ(1450)°π° — _{VALUE} (%) | $	au$ $\pi^+\pi^-\pi^0$) in D^0 , $\overline{D}{}^0$ $	au$ $ ho$ (1450) 0 π^0 |
| -17±33±17 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| | · · |
| $A_{CP}(ho(1450)^-\pi^+ \cdot ho(1450)^+\pi^-$ | \rightarrow $\pi^+\pi^-\pi^0$) in $D^0\rightarrow$ $\rho(1450)^-\pi^+$, $\overline{D}{}^0\rightarrow$ |
| VALUE (%) | DO CUMENT ID TECN COMMENT |
| +6±8±3 | AUBERT 08A0 BABR Table 1, —Col.5/2×Col.2 |
| $A_{CP}(ho(1700)^+\pi^- + ho(1700)^-\pi^+$ | \rightarrow $\pi^+\pi^-\pi^0)$ in D^0 \rightarrow $ ho(1700)^+\pi^-$, $\overline{D}{}^0$ \rightarrow |
| VALUE (%) | DOCUMENT ID TECN COMMENT |
| -5±13±5 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| $A_{CP}(ho(1700)^0\pi^0$ — | $ ightarrow$ $\pi^+\pi^-\pi^0$) in D^0 , $\overline{D}{}^0$ $ ightarrow$ $ ho(1700)^0\pi^0$ |
| VALUE (%) | DO CUMENT ID TECN COMMENT |
| +13±8±3 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| $A_{CP}(ho(1700)^-\pi^+ + ho(1700)^+\pi^-$ | \rightarrow $\pi^+\pi^-\pi^0)$ in D^0 \rightarrow $ ho(1700)^-\pi^+$, $\overline{D}{}^0$ \rightarrow |
| VALUE (%) | DOCUMENT ID TECN COMMENT |
| +8±10±5 | AUBERT 08A0 BABR Table 1, —Col.5/2×Col.2 |
| $A_{CP}(f_0(980)\pi^0 \rightarrow$ | $\pi^+\pi^-\pi^0$) in D^0 , $\overline{D}{}^0 	o f_0(980)\pi^0$ |
| VALUE (%) | DO CUMENT ID TECN COMMENT |
| 0 ± 25 ± 25 | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| A (f (1270)_0 . | $\pi^+\pi^-\pi^0$) in D^0 , $\overline{D}{}^0 	o f_0(1370)\pi^0$ |
| $M \subset P(M(12101) M \longrightarrow$ | , Ut , |
| MCP(10(1370)% — | DO CUMENT IDTECN COMMENT |
| VALUE (%) | DO CUMENT IDTECN COMMENT |
| \(\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\tiny{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\tint{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\ti}\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\text{\ti}\text{\text{\text{\text{\text{\text{\texi}\ti}\titt{\text{\tex{\texi}\text{\text{\text{\text{\text{\text{\text{\text{\tet | AUBERT 08A0 BABR Table 1, -Col.5/2×Col.2 |
| $+25\pm13\pm13$ $+2(f_0(1500)\pi^0 \rightarrow$ | $\frac{DOCUMENT \ ID}{AUBERT} \qquad \frac{TECN}{08A0 \ BABR} \qquad \frac{COMMENT}{Table \ 1, -Col.5/2 \times Col.2}$ $\rightarrow \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ |
| $ \begin{array}{l} \text{VALUE (%)} \\ +25 \pm 13 \pm 13 \\ \text{A_{CP}(f_0(1500)} \pi^0 \rightarrow \\ \text{VALUE (%)} \end{array} $ | $\frac{DOCUMENT \ ID}{AUBERT} \qquad \frac{TECN}{08A0 \ BABR} \qquad \frac{COMMENT}{Table \ 1, -Col.5/2 \times Col.2}$ $\rightarrow \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT \ ID}{TECN} \qquad \frac{TECN}{TECN} \qquad \frac{COMMENT}{TECN}$ |
| $^{VALUE}(\%)$ +25±13±13 $A_{CP}(f_0(1500)\pi^0 \rightarrow ^{VALUE}(\%)$ 0±13±13 | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{08A0\ BABR} \qquad \frac{COMMENT}{Table\ 1,\ -Col.5/2\times Col.2}$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08A0\ BABR \qquad Table\ 1,\ -Col.5/2\times Col.2$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1710)\pi^{0}$ |
| $\begin{array}{c} \text{(ALUE (\%))} \\ +25\pm13\pm13 \\ A_{CP}(f_0(1500)\pi^0 \rightarrow (ALUE (\%)) \\ 0\pm13\pm13 \\ A_{CP}(f_0(1710)\pi^0 \rightarrow (ALUE (\%)) \\ \end{array}$ | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08A0\ BABR \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1710)\pi^{0}$ |
| $\begin{array}{l} \text{MALUE (\%)} \\ +25\pm13\pm13 \\ A_{CP}(f_0(1500)\pi^0 \to \text{MALUE (\%)}) \\ 0\pm13\pm13 \\ A_{CP}(f_0(1710)\pi^0 \to \text{MALUE (\%)}) \end{array}$ | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{08A0\ BABR} \qquad \frac{COMMENT}{Table\ 1,\ -Col.5/2\times Col.2}$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08A0\ BABR \qquad Table\ 1,\ -Col.5/2\times Col.2$ $+ \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1710)\pi^{0}$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{WALUE (%)})$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{WALUE (%)})$ | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08A0\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1710)\pi^{0}$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08A0\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{2}(1270)\pi^{0}$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{WALUE (%)})$ $-4 \pm 4 \pm 4$ | $\frac{DOCUMENT ID}{AUBERT} \qquad \frac{TECN}{BABB} \qquad \frac{COMMENT}{Table 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1500)\pi^{0}$ $\frac{DOCUMENT ID}{AUBERT} \qquad 08A0 \text{ BABR} \qquad \frac{COMMENT}{Table 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{0}(1710)\pi^{0}$ $\frac{DOCUMENT ID}{AUBERT} \qquad 08A0 \text{ BABR} \qquad \frac{COMMENT}{Table 1, -Col.5/2 \times Col.2}$ $\star \pi^{+}\pi^{-}\pi^{0}) \text{ in } D^{0}, \overline{D}^{0} \rightarrow f_{2}(1270)\pi^{0}$ $\frac{DOCUMENT ID}{DOCUMENT ID} \qquad \frac{TECN}{Table 1, -Col.5/2 \times Col.2}$ $AUBERT \qquad 08A0 \text{ BABR} \qquad \frac{COMMENT}{Table 1, -Col.5/2 \times Col.2}$ |
| WALUE (%) +25 ±13±13 $A_{CP}(f_0(1500)\pi^0 \rightarrow (1500)\pi^0 \rightarrow (1500)\pi^$ | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_0(1500)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_0(1710)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_2(1270)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow \sigma(400)\pi^0$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{VALUE} (\%) \\ 0 ± 13 ± 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{VALUE} (\%) \\ 0 ± 17 ± 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{VALUE} (\%) \\ -4 ± 4 ± 4$ | $\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_0(1500)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_0(1710)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\star \pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow f_2(1270)\pi^0$ $\frac{DOCUMENT\ ID}{AUBERT} \qquad 08AO\ BABR} \qquad \frac{COMMENT}{Table\ 1, -Col.5/2 \times Col.2}$ $\pi^+\pi^-\pi^0) \text{ in } D^0, \overline{D}^0 \rightarrow \sigma(400)\pi^0$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{WALUE (%)})$ $-4 \pm 4 \pm 4$ $A_{CP}(\sigma(400)\pi^0 \rightarrow \text{WALUE (%)})$ $+6 \pm 6 \pm 6$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| WALUE (%) + 25 ± 13 ± 13 $A_{CP}(f_0(1500)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 13 \pm 13$ $A_{CP}(f_0(1710)\pi^0 \rightarrow \text{WALUE (%)})$ $0 \pm 17 \pm 17$ $A_{CP}(f_2(1270)\pi^0 \rightarrow \text{WALUE (%)})$ $-4 \pm 4 \pm 4$ $A_{CP}(\sigma(400)\pi^0 \rightarrow \text{WALUE (%)})$ $+6 \pm 6 \pm 6$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

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 11 ± 0.11 k

-1.00±1.67±0.25

| K*(892) – K+ | | CUMENT ID | TEA | N 60 | MMENT |
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| ALUE (%) - 0.9 ± 1.2 ± 0.4 | | JBERT 08/ | | | ble 1, -Col.5/2×Col.2 |
| A _{CP} (K*(1410) ⁺ K (*(1410) ⁻ K ⁺ | | | | | |
| 4 LUE (%) | | CUMENT ID | | | |
| ·21±23±8 | | | | | ble 1, -Col.5/2×Col.2 |
| $(K^-\pi^0)_SK^+$ | | | | | $(+\pi^0)_S K^-$, $\overline{D}{}^0 	o$ |
| ALUE (%) 7±15±3 | | JBERT 08/ | | | ble 1, —Col.5/2×Col.2 |
| $_{CP}(\phi(1020)\pi^{0}-$ | | | | | |
| ALUE (%) | | CUMENT ID | TEC | N CO | MMENT |
| 1.1±2.1±0.5 | | | | | ble 1, -Col.5/2×Col.2 |
| $CP(f_0(980)\pi^0 \rightarrow$ | $K^+K^-\pi^0$ |) in D^0 , $\overline{D}{}^0$ – | → f ₀ | (980) π | -0 |
| ALUE (%) ·3±19±1 | | JBERT 08/ | | | ble 1, -Col.5/2×Col.2 |
| A _{CP} (a ₀ (980) ⁰ π ⁰ - | | r ⁰) in <i>D</i> ⁰ , <i>D</i> ⁰ | | | |
| 5±16±2 | 1 AL | JBERT 08/ | 10 BAI | BR Ta | ble 1, -Col.5/2×Col.2 |
| ¹ This AUBERT 08 | | | | | aces the $f_0(980)$ in the fit |
| $I_{CP}(f_2'(1525)\pi^0$ - | | • | | | • |
| 4 <i>LUE</i> (%) ±50±150 | | CUMENT ID | | | MMENT ble 1, —Col.5/2×Col.2 |
| | | | | | , |
| CP (K*(892) - K+ (*(892) + K- | - → K+K | $^-\pi^{ m v}$) in $D^{ m v}$ $-$ | → K* | (892) | -K+, D" → |
| ALUE (%) | | CUMENT ID | | | |
| 5±4±1 | AL | JBERT 08/ | AO BAI | 3R Ta | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ |
| _{СР} (K*(1410) [—] К (*(1410) ⁺ К [—] | | - | | - | |
| 4 <i>LUE</i> (%) · 17±28±7 | | CUMENT ID JBERT 08/ | TEC | N CO | MMENT |
| $K_{CP}((K^-\pi^0)_{S-w})$ | $_{ave}K^{+}\rightarrow$ | | | | ble 1, $-$ Col.5/2×Col.2 $(-\pi^0)_S K^+$, $\overline{D}{}^0 \to$ |
| K ⁺ π ⁰) _S K ⁻ 4LUE (%) -7±40±8 | <u>DO</u> AU | K⁺ K⁻ π⁰) in | D ⁰ - | → (K | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ |
| $egin{array}{l} (K^+\pi^0)_S K^- \ & 	ag{ALUE} (\%) \ & 	ag{7} \pm 40 \pm 8 \ & 	ag{CP} (K^0_S \pi^0) 	ext{in} D^0 \end{array}$ | $ \frac{DO}{AU} $ $ \overrightarrow{D} \longrightarrow K $ | $K^+K^-\pi^0$) in OCUMENT ID UBERT 08/05 π^0 | D⁰ - <u>тес</u> ло ВАІ | → (<i>K</i> <u>N</u> <u>CO</u> BR Ta | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D}{}^0 \rightarrow MMENT$ ble 1, $-\text{Col.}5/2\times\text{Col.}2$ |
| $K^+\pi^0)_S K^-$ ALUE (%) $-7\pm40\pm8$ $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27 ± 0.21 OUR AV | DO AL P. DO → K EVTS ERAGE | K+ K-π ⁰) in OCUMENT ID OBERT 08/ OS π ⁰ DOCUMENT ID | D⁰ - _ <u>TEC</u> AO BAI | → (<i>K</i> <u>N CO</u> BR Ta | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D}{}^0 \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ |
| $K^{+}\pi^{0})_{S}K^{-}$ $ALUE(\%)$ $7\pm40\pm8$ $ACP(K_{S}^{0}\pi^{0})$ in D^{0} $ALUE(\%)$ 0.27 ± 0.21 OUR AV $0.28\pm0.19\pm0.10$ | $ \begin{array}{c} \underline{DO} \\ AU \end{array} $ $ \begin{array}{c} \overline{D} \\ \overline{D} \\ \underline{EVTS} \end{array} $ | $K^+K^-\pi^0$) in OCUMENT ID UBERT 08/05 π^0 | D⁰ - τες Αο ΒΑΙ | → (<i>K</i> <u>N CO</u> BR Ta <u>TECN</u> BELL | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D}{}^0 \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ COMMENT $e^+e^-\approx r(45)$ |
| $(K^+\pi^0)_S K^-$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6$ | $ \begin{array}{c} \underline{DO} \\ A \downarrow \\ C, \overline{D^0} \rightarrow K \end{array} $ $ \begin{array}{c} \underline{EVTS} \\ 2 & \text{CRAGE} \\ 326k \\ 9099 \end{array} $ | K+K- π^0) in COUMENT ID UBBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages | 11 01 s, fits, | → (K N CO BR Ta TECN BELL CLE2 limits, | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • |
| $(K^+\pi^0)_S K^-$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6)}$ $(ALUE)^{(6$ | DO ALL EVTS FEAGE 326k 9099 the following | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages BARTELT | D ⁰ - | → (K <u>N</u> <u>CO</u> BR Ta <u>TECN</u> BELL CLE2 | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $\frac{COMMENT}{e^+e^-\approx r(4S)}$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. • • • |
| $K^+\pi^0$) _S K^- ALUE (%) $1.7\pm40\pm8$ $1.C_P(K_0^5\pi^0)$ in D^0 ALUE (%) $1.0.27\pm0.21$ OUR AV $0.28\pm0.19\pm0.10$ 0.1 ± 1.3 • • We do not use 1.8 ± 3.0 1.8 ± 3.0 1.8 ± 3.0 | $ \begin{array}{c} DO \\ \overline{AU}, \overline{D^0} \rightarrow \overline{K^0} \\ \underline{EVTS} \\ \overline{VERAGE} \\ 326k \\ 9099 \\ \text{the following} \end{array} $ | K+K-π ⁰) in COUMENT ID UBERT 08/ 05 π ⁰ DOCUMENT ID KO BONVICINI data for averages BARTELT | 11 01 s, fits, | N CO BR Ta TECN BELL CLE2 limits, CLE2 | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • |
| $(K^+\pi^0)_S K^-$ (ALUE (%)) (ALUE (%)) | DO ALL EVTS FEAGE 326k 9099 the following | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages BARTELT | 11 01 s, fits, | → (K N CO BR Ta TECN BELL CLE2 limits, | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • |
| $K^+\pi^0$) _S K^- ALUE (%) $1.7\pm40\pm8$ $1.C_P(K_S^0\pi^0)$ in D^0 ALUE (%) $1.0.27\pm0.21$ OUR AV $0.28\pm0.19\pm0.10$ 0.1 ±1.3 • We do not use 1.8 ±3.0 1.8 ±3.0 1.8 ±0.10 in D^0 ALUE (%) 1.8 ±0.51±0.16 | $ \begin{array}{c} DO \\ \hline AU \end{array} $ $ \begin{array}{c} \overline{D^0} \rightarrow K^0 \\ \underline{EVTS} \\ \hline YERAGE $ $ \begin{array}{c} 326k \\ 9099 \\ \text{the following} \end{array} $ $ \begin{array}{c} \overline{D^0} \rightarrow K^0 \\ \underline{EVTS} \\ 46k \end{array} $ | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages BARTELT 1 DOCUMENT ID KO | 11 01 s, fits, 95 | → (K N CO BR Ta TECN BELL CLE2 limits, CLE2 TECN | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $\frac{COMMENT}{e^+e^-\approx r(4S)}$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 |
| $K^+\pi^0$) _S $K^ ^{ALUE}$ (%) $^{17}\pm 40\pm 8$ 18 18 19 19 19 in D^0 18 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 19 | $ \begin{array}{c} DO \\ \hline AU \end{array} $ $ \begin{array}{c} \overline{D^0} \rightarrow K^0 \\ \underline{EVTS} \\ \hline YERAGE $ $ \begin{array}{c} 326k \\ 9099 \\ \text{the following} \end{array} $ $ \begin{array}{c} \overline{D^0} \rightarrow K^0 \\ \underline{EVTS} \\ 46k \end{array} $ | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages BARTELT 1 DOCUMENT ID KO | 11 01 s, fits, 95 | → (K N CO BR Ta TECN BELL CLE2 Iimits, CLE2 TECN | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $\frac{COMMENT}{e^+e^-\approx r(4S)}$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 |
| $(K^+\pi^0)_S K^ (ALUE (\%)$ $(-7\pm40\pm8)$ $(ACP (K_S^0\pi^0) \text{ in } D^0$ $(ALUE (\%)$ $(-0.27\pm0.21 \text{ OUR AV})$ $(-0.28\pm0.19\pm0.10$ (-0.11 ± 1.3) | $ \begin{array}{c} DO \\ \hline AU \end{array} $ $ \begin{array}{c} \overline{D}^{0} \rightarrow K_{S}^{0} \\ \hline \overline{ERAGE} \\ 326k \\ 9099 \\ \text{the following} \end{array} $ $ \begin{array}{c} \overline{D}^{0} \rightarrow K_{S}^{0} \\ \underline{EVTS} \\ 46k \\ \end{array} $ $ \begin{array}{c} \underline{EVTS} \\ 40k \\ \end{array} $ $ \begin{array}{c} \underline{EVTS} \\ 27k \\ \end{array} $ | K+K-π ⁰) in COUMENT ID DEERT 08/ Sπ ⁰ DOCUMENT ID KO BONVICINI data for average: BARTELT η DOCUMENT ID KO DOCUMENT ID KO DOCUMENT ID KO | 11 01 s, fits, 95 | → (K N CO BR Ta TECN BELL CLE2 Iimits, CLE2 TECN BELL | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+$, $\overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ COMMENT $e^+e^-\approx \Upsilon(4S)$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. ••• See BONVICINI 01 $COMMENT$ $e^+e^-\approx \Upsilon(4S)$ |
| $K^+\pi^0)_S K^ ALUE (\%)$ $-7 \pm 40 \pm 8$ $A_{CP}(K_S^0\pi^0)$ in D^0 $ALUE (\%)$ -0.27 ± 0.21 OUR AV $0.28 \pm 0.19 \pm 0.10$ -0.1 ± 1.3 \bullet We do not use -0.1 ± 0.1 $-0.1 $ | $ \begin{array}{c} DO \\ AL \end{array} $ $ \begin{array}{c} \overline{D} \\ \overline{C} \\ C$ | K+K-π ⁰) in COUMENT ID DEERT 08/ 05 π ⁰ DOCUMENT ID KO BONVICINI data for average: BARTELT η DOCUMENT ID KO COUMENT ID KO | D ⁰ - TEC 11 01 01 s, fits, 95 | When the second | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+$, $\overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ COMMENT $e^+e^-\approx \Upsilon(4S)$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $COMMENT$ $e^+e^-\approx \Upsilon(4S)$ |
| $K^+\pi^0)_S K^-$ ALUE (%) $7.\pm 40\pm 8$ $C_P(K_S^0\pi^0)$ in D^0 ALUE (%) 0.27 ± 0.21 OUR AV $0.28\pm 0.19\pm 0.10$ 0.1 ± 1.3 • • We do not use 1.8 ± 3.0 $C_P(K_S^0\eta)$ in D^0 , $C_P(K_S^0\eta)$ in D^0 , $C_P(K_S^0\eta)$ in D^0 | $ \begin{array}{ccc} & DO \\ AU, \overline{D^0} \rightarrow & K' \\ & \underline{EVTS} \\ \hline 'ERAGE & 326k \\ 9099 & 1000 & 1000 \\ \hline D^0 \rightarrow & K' \\ & \underline{EVTS} \\ 46k & 1000 & 1000 \\ \hline D^0 \rightarrow & K' \\ & \underline{EVTS} \\ 27k & 1000 & 1000 \\ \hline D^0 \rightarrow & K' \\ & \underline{D^0} \rightarrow | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for average: BARTELT T DOCUMENT ID KO DOCUMENT ID KO DOCUMENT ID KO TECN | D0 - TECOMO BAI | WELL TECN BELL CLE2 Ilimits, CLE2 TECN BELL TECN BELL | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+$, $\overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ COMMENT $e^+e^- \approx r(4S)$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ |
| $K^+\pi^0)_S K^-$ ALUE (%) $-7\pm40\pm8$ $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27 ± 0.21 OUR AV $0.28\pm0.19\pm0.10$ -0.1 ±1.3 \bullet We do not use -1.8 ±3.0 $A_{CP}(K_S^0\eta)$ in D^0 , A_{LUE} (%) $-0.54\pm0.51\pm0.16$ $A_{CP}(K_S^0\eta')$ in D^0 $-0.98\pm0.67\pm0.14$ | DO AL $ \begin{array}{c} DO \\ \hline C \\ C \\ \hline C \\ C \\ \hline C \\ C \\ C \\ \hline C \\ | K+K-π ⁰) in COUMENT ID DEERT 08/ 05 π ⁰ DOCUMENT ID KO BONVICINI data for averages BARTELT η DOCUMENT ID KO 5 η DOCUMENT ID KO Φ DOCUMENT ID KO Φ TECN 95 CLE2 | 11 01 s, fits, 95 11 11 | WELL TECN BELL CLE2 Iimits, CLE2 TECN BELL TECN BELL | ble 1, $-\text{Col.}5/2\times\text{Col.}2$ $(-\pi^0)_S K^+$, $\overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2\times\text{Col.}2$ COMMENT $e^+e^-\approx \Upsilon(4S)$ $e^+e^-\approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $COMMENT$ $e^+e^-\approx \Upsilon(4S)$ |
| $K^+\pi^0$) _S K^- ALUE (%) $-7\pm40\pm8$ $C_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27 ± 0.21 OUR AV $0.28\pm0.19\pm0.10$ 0.1 ±1.3 • • We do not use -1.8 ± 3.0 $C_{CP}(K_S^0\eta)$ in D^0 ALUE (%) $-0.54\pm0.51\pm0.16$ $C_{CP}(K_S^0\eta')$ in D^0 ALUE (%) $-0.98\pm0.67\pm0.14$ -0.98 ± 0.14 | $\begin{array}{c} DO \\ AU \\ D \\ \hline D \\ O \\ \hline O \\ O \\$ | K+K-π ⁰) in COUMENT ID DEERT 08/ DOCUMENT ID KO BONVICINI data for averages BARTELT | D ⁰ - TEC Λο BAN 11 01 01 s, fits, 95 11 11 | N COBR Ta TECN BELL CLE2 TECN BELL TECN BELL TECN BELL ZECN BELL | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+$, $\overline{D^0} \rightarrow$ MMENT ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ COMMENT $e^+e^- \approx r(4S)$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ |
| $(K^+\pi^0)_S K^ (ALUE (\%))$ $(7\pm40\pm8)$ $(ACP(K_S^0\pi^0)$ in D^0 $(ALUE (\%))$ $(0.27\pm0.21$ OUR AV $(0.28\pm0.19\pm0.10)$ (0.1 ± 1.3) $(0.28\pm0.19\pm0.10)$ (0.1 ± 1.3) $(0.28\pm0.19\pm0.10)$ (0.28 ± 0.10) $(0.28\pm$ | $\begin{array}{c} DO \\ AU \\ O, \overline{D^0} \rightarrow K_s^0 \\ \hline {}_{EVTS}^{VERAGE} \\ 326k \\ 9099 \\ \text{the following} \\ \hline D^0 \rightarrow K_s^0 \\ \hline {}_{46k}^0 \\ \hline {}_{EVTS}^0 \rightarrow K_s^0 \\ \hline {}_{27k}^0 \rightarrow K_s^0 \\ \hline {}_{DO\ CUMENT}^0 \\ \hline {}_{BARTELT}^0 \rightarrow K^-\pi^- \\ \hline {}_{EVTS}^{EVTS} \\ \hline {}_{RAGE}^0 \end{array}$ | K+K- π^0) in COUMENT ID UBERT 08/ 05 π^0 DOCUMENT ID KO BONVICINI data for averages BARTELT T DOCUMENT ID KO O TECN 95 CLE2 TECN TE | 11 01 11 11 | → (K N COBR Ta TECN BELL CLE2 Imits, CLE2 TECN BELL TECN BELL TECN TECN TECN TECN TECN | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ |
| $K^+\pi^0$) _S K^- ALUE (%) -7±40±8 $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27±0.21 OUR AV -0.28±0.19±0.10 -0.1 ±1.3 • • We do not use -1.8 ±3.0 $A_{CP}(K_S^0\pi)$ in D^0 , ALUE (%) -0.54±0.51±0.16 $A_{CP}(K_S^0\pi')$ in D^0 ALUE (%) -0.98±0.67±0.14 $A_{CP}(K_S^0\phi)$ in D^0 , ALUE (%) -2.8±9.4 $A_{CP}(K^0\pi^+)$ in D^0 ALUE (%) -0.1±0.7 OUR AVEF -0.5±0.4±0.9 | $\begin{array}{c} DO \\ AU \\ D \\ \hline D \\ O \\ \hline O \\ O \\$ | K+K-π ⁰) in COUMENT ID DEERT 08/ DOCUMENT ID KO BONVICINI data for averages BARTELT | D ⁰ - TEC Λο BAN 11 01 01 s, fits, 95 11 11 | → (K N COBR Ta TECN BELL CLE2 TECN BELL TECN BELL TECN TECN CLE2 TECN CLE2 | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ |
| $K^+\pi^0$) _S K^- ALUE (%) -7±40±8 $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27±0.21 OUR AV -0.28±0.19±0.10 -0.1 ±1.3 • • We do not use -1.8 ±3.0 $A_{CP}(K_S^0\eta)$ in D^0 , ALUE (%) -0.54±0.51±0.16 $A_{CP}(K_S^0\eta')$ in D^0 -0.54±0.51±0.14 $A_{CP}(K_S^0\eta')$ in D^0 -0.98±0.67±0.14 $A_{CP}(K_S^0\eta')$ in D^0 -2.28±9.4 $A_{CP}(K^0\pi^\pm)$ in D^0 -0.1±0.7 OUR AVEF -0.5±0.4±0.9 -0.4±0.5±0.9 $A_{CP}(K^\pm\pi^\mp)$ in D^0 | $\begin{array}{c} DO \\ AU \\ P \\ $ | $K+K-\pi^0$) in COUMENT ID DEBERT 08/ DOS π^0 DOCUMENT ID HOUSE BARTELT η DOCUMENT ID KO $0.5 \eta'$ DOCUMENT ID KO $0.5 \eta'$ DOCUMENT ID $0.5 \eta'$ DOCUMENT ID $0.5 \eta'$ 0 | D ⁰ - TEC OO BAI 11 01 01 11 01 11 11 11 11 11 11 07 π 10 07 π + | → (K N COBR Ta TECN BELL CLE2 TECN BELL TECN BELL TECN TECN CLE2 TECN CLE2 | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ |
| $(K^+\pi^0)_S K^ (ALUE (\%)$ $(7^+\pm 40\pm 8)$ $(ALUE (\%)$ $(7^+\pm 40\pm 8)$ $(ALUE (\%)$ $(7^+\pm 40\pm 8)$ $(7^+\pm 40\pm 1)$ $(7^+\pm 40\pm$ | $\begin{array}{c} DO \\ AU \\ \hline O, \overline{D^0} \rightarrow K \\ \hline EVTS \\ \hline (ERAGE \\ 9099 \\ \text{the following} \\ \hline D^0 \rightarrow K^0 \\ \hline 27k \\ \hline D^0 \rightarrow K^0 \\ \hline 27k \\ \hline D^0 \rightarrow K^0 \\ \hline BARTELT \\ \hline O \rightarrow K^-\pi \\ \hline EVTS \\ \hline 150k \\ \hline O \rightarrow K^+\pi \\ \hline EVTS \\ \hline EVTS \\ \hline EVTS \\ \hline \end{tabular}$ | K+K- π^0) in COUMENT ID DEERT 08/ DOCUMENT ID KO BONVICINI data for averages BARTELT POCUMENT ID KO OF 10 OF 10 OF 10 MENDEZ DOBBS DOCUMENT ID MENDEZ DOBBS | 11 01 11 11 11 11 11 11 11 11 11 11 11 1 | N CO BR Ta TECN BELL CLE2 Ilimits, CLE2 TECN BELL TECN DELL TECN CLEO CLEO | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx r(4S)}$ |
| $K^+\pi^0$) _S K^- ALUE (%) -7.±40±8 $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) -0.27±0.21 OUR AV -0.28±0.19±0.10 -0.1 ±1.3 • • We do not use -1.8 ±3.0 $A_{CP}(K_S^0\pi)$ in D^0 , ALUE (%) -0.54±0.51±0.16 $A_{CP}(K_S^0\pi)$ in D^0 , ALUE (%) -0.98±0.67±0.14 $A_{CP}(K_S^0\phi)$ in D^0 , ALUE (%) -2.8±9.4 $A_{CP}(K_S^0\pi)$ in D^0 , ALUE (%) -0.1±0.7 OUR AVER -0.5±0.4±0.9 -0.4±0.5±0.9 $A_{CP}(K_S^0\pi)$ in D^0 ALUE (%) -0.4±0.5±0.9 -0.4±0.5±0.9 -0.4±0.5±0.9 -0.2±3.2 OUR AV -2.1±5.2±1.5 | $ \begin{array}{c} DO \\ AU \end{array} $ $ \begin{array}{c} \overline{D}O \rightarrow K \\ \underline{FVTS}\\ \overline{FRAGE} \\ 326k \\ 9099 \\ \text{the following} \end{array} $ $ \begin{array}{c} \overline{D}O \rightarrow K \\ \underline{FVTS} \\ 46k \\ \overline{D}O \rightarrow K \\ \underline{FVTS} \\ 27k \\ \overline{D}O \rightarrow K \\ \underline{FVTS} \\ DO \cup MENT \\ BARTELT $ $ \begin{array}{c} DO \rightarrow K \\ \underline{FVTS} \\ DO \cup MENT \\ BARTELT $ $ \begin{array}{c} O \rightarrow K \\ \underline{FVTS} \\ \hline FRAGE \\ 150k \\ \hline O \rightarrow K \\ \underline{FVTS} \\ \hline FRAGE \\ 150k \\ \hline O \rightarrow K \\ \underline{FVTS} \\ \hline O \rightarrow K $ | $K+K-\pi^0$) in COUMENT ID DEBERT 08/ $S\pi^0$ DOCUMENT ID KO BONVICINI data for averages BARTELT η DOCUMENT ID KO S^0 S | 11 01 11 11 11 11 11 11 11 11 11 11 11 1 | N CO BR Ta TECN BELL CLE2 Ilimits, CLE2 TECN BELL TECN DELL TECN CLEO CLEO | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx \Upsilon(4S)}$ |
| $K^+\pi^0$) _S K^- ALUE (%) -7±40±8 ACP($K_S^0\pi^0$) in D^0 ALUE (%) -0.27±0.21 OUR AV -0.28±0.19±0.10 -0.1 ±1.3 • • We do not use -1.8 ±3.0 ACP($K_S^0\pi$) in D^0 , ALUE (%) -0.54±0.51±0.16 ACP($K_S^0\pi$) in D^0 ALUE (%) -0.98±0.67±0.14 ACP($K_S^0\pi$) in D^0 , ALUE (%) -2.8±9.4 ACP($K_S^0\pi$) in D^0 , ALUE (%) -0.1±0.7 OUR AVEF -0.5±0.4±0.9 -0.4±0.5±0.9 ACP($K^\pm\pi^\mp$) in D^0 ALUE (%) -2.2± 3.2 OUR AV -2.1± 5.2±1.5 -2.3± 4.7 -18 ±14 ±4 | $\begin{array}{c} DO \\ AU \\ D \\ $ | K+K-π ⁰) in COUMENT ID DEERT 08/ DO DO CUMENT ID KO BONVICINI data for averages BARTELT | D ⁰ - TEC NO BAIL 11 01 s, fits, 95 11 11 | N COBR Ta TECN BELL CLE2 TECN BELL TECN BELL TECN CLE0 CLE0 CLE0 TECN BABR BABR BABR BABR BABR BABR BABR BAB | ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col.}5/2 \times \text{Col.}2$ $\frac{COMMENT}{e^+e^- \approx T(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx T(4S)}$ |
| $K^+\pi^0$) _S K^- ALUE (%) -7.±40±8 ACP($K_S^0\pi^0$) in D^0 ALUE (%) -0.27±0.21 OUR AV -0.28±0.19±0.10 -0.1 ±1.3 • • We do not use -1.8 ±3.0 ACP($K_S^0\pi$) in D^0 , ALUE (%) -0.54±0.51±0.16 ACP($K_S^0\pi$) in D^0 , ALUE (%) -0.98±0.67±0.14 ACP($K_S^0\pi$) in D^0 , ALUE (%) -2.8±9.4 ACP($K_S^0\pi$) in D^0 , ALUE (%) -2.25±0.4±0.9 -0.4±0.5±0.9 ACP($K_S^0\pi^0$) in D^0 , ALUE (%) -1.50.7 OUR AVEF -0.5±0.4±0.9 -0.4±0.5±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1.50.4±0.9 -1. | $\begin{array}{c} DO \\ AU \\ P \\ $ | K+ K-π ⁰) in COUMENT ID DEERT 08/ DO DO CUMENT ID KO BONVICINI data for averages BARTELT | 11 01 s, fits, 95 11 11 | N COBR Ta TECN BELL CLE2 TECN BELL TECN BELL TECN CLE0 CLE0 CLE0 CLE0 BABR BBBLL FOCS BABR | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \rightarrow MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx T(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx T(4S)}$ |
| $K^+\pi^0$) $_SK^-$ ALUE (%) $^{-7\pm40\pm8}$ $A_{CP}(K_S^0\pi^0)$ in D^0 ALUE (%) $^{-0.27\pm0.21}$ OUR AV $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.28\pm0.19\pm0.10}$ $^{-0.40}$ $^{-0.54\pm0.51\pm0.16}$ $^{-0.54\pm0.51\pm0.16}$ $^{-0.54\pm0.51\pm0.16}$ $^{-0.54\pm0.51\pm0.16}$ $^{-0.88\pm0.67\pm0.14}$ $^{-0.98\pm0.67\pm0.14}$ $^{-0.98\pm0.67\pm0.14}$ $^{-0.84\pm0.67\pm0.14}$ $^{-0.84\pm0.67\pm0.14}$ $^{-0.84\pm0.67\pm0.14}$ $^{-0.84\pm0.67\pm0.14}$ $^{-0.84\pm0.7}$ $^{-0.1\pm0.7}$ OUR AVER $^{-0.5\pm0.4\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ $^{-0.4\pm0.5\pm0.9}$ | $\begin{array}{c} DO \\ AU \\ O, \overline{D^0} \rightarrow K \\ \underline{EVTS} \\ \hline \begin{array}{c} VTS \\ \hline EAGE \\ 326k \\ 9099 \\ \text{the following} \\ \end{array}$ $\begin{array}{c} DO \rightarrow K \\ S \\ \hline \begin{array}{c} O \rightarrow K \\ S \\ \hline \begin{array}{c} EVTS \\ 46k \\ \end{array} \\ \begin{array}{c} EVTS \\ \hline \begin{array}{c} 27k \\ \end{array} \\ \hline \begin{array}{c} DO \rightarrow K \\ S \\ \hline \begin{array}{c} EVTS \\ \hline \end{array} \\ \hline \begin{array}{c} DO \rightarrow K \\ S \\ \hline \begin{array}{c} EVTS \\ \hline \end{array} \\ \hline \begin{array}{c} DO \rightarrow K \\ \hline \begin{array}{c} EVTS \\ \hline \end{array} \\ \hline \begin{array}{c} DO \rightarrow K \\ \hline \end{array} \\ \begin{array}{c} DO \rightarrow K \\ \hline \begin{array}{c} EVTS \\ \hline \end{array} \\ \hline \begin{array}{c} EVTS \\ \hline \end{array} \\ \end{array} \\ \begin{array}{c} EVTS \\ \hline \end{array} \\ \end{array} \\ \begin{array}{c} EVTS \\ \hline \end{array} $ | K+K-π ⁰) in COUMENT ID DEBERT 08/ DOCUMENT ID KO BONVICINI data for averages BARTELT | D ⁰ - TEC NO BAIL 11 01 15, fits, 95 11 11 11 | → (K N COBR Ta TECN BELL CLE2 CLE2 CLE2 TECN BELL TECN BELL TECN BELL TECN BELL CLE0 CLE0 CLE0 BABR BELL FOCS BABR CLE2 | ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $(-\pi^0)_S K^+, \overline{D^0} \to MMENT$ ble 1, $-\text{Col}.5/2 \times \text{Col}.2$ $\frac{COMMENT}{e^+e^- \approx r(4S)}$ $e^+e^- \approx 10.6 \text{ GeV}$ etc. • • • See BONVICINI 01 $\frac{COMMENT}{e^+e^- \approx r(4S)}$ |

- ¹ This ZHANG 06 result allows mixing.
- 2 This LINK 05H result assumes no mixing. If mixing is allowed, it becomes $0.13^{+0.33}_{-0.25}$ \pm
- 3 This AUBERT 03z limit assumes no mixing. If mixing is allowed, the 95% confidence-level interval is $(-2.8 < A_D < 4.9)\times 10^{-3}$.
- ⁴ This GODANG 00 result assumes no $D^0-\overline{D}{}^0$ mixing; it becomes $-0.01^{+0.16}_{-0.17}\pm0.01$ when mixing is allowed. 5 This LI 05A result allows mixing.

$A_{CP}(K^{\mp}\pi^{\pm}\pi^{0})$ in $D^{0} \rightarrow K^{-}\pi^{+}\pi^{0}$, $\overline{D}{}^{0} \rightarrow K^{+}\pi^{-}\pi^{0}$

| VALUE (%) | DO CUMENT ID | | I E CN | COMMENT |
|---------------------|--------------|----|--------|------------------------------|
| 0.2±0.9 OUR AVERAGE | | | | |
| $+0.2\pm0.4\pm0.8$ | DOBBS | | | $e^{+}e^{-}$ at $\psi(3770)$ |
| -3.1 ± 8.6 | 1 KOPP | 01 | CLE2 | $e^+e^-pprox~10.6~{ m GeV}$ |

 1 KOPP 01 fits separately the ${\it D}^{\,0}$ and $\overline{\it D}^{\,0}$ Dalitz plots and then calculates the integrated difference of normalized densities divided by the integrated sum.

$A_{CP}(K^{\pm}\pi^{\mp}\pi^{0})$ in $D^{0} \rightarrow K^{+}\pi^{-}\pi^{0}$, $\overline{D}{}^{0} \rightarrow K^{-}\pi^{+}\pi^{0}$

| VALUE (%) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------|--------------|-------------|----|------|---------------------------------|
| 0 ± 5 OUF | AVERAGE | | | | |
| -0.6 ± 5.3 | 1978 ± 104 | TIAN | 05 | BELL | $e^+e^-pprox \ \varUpsilon(4S)$ |
| $+9 + \frac{25}{22}$ | 38 | BRANDENB | 01 | CLE2 | $e^+e^-pprox \Upsilon(45)$ |

$A_{CP}(K_S^0\pi^+\pi^-)$ in $D^0, \overline{D}{}^0 \to K_S^0\pi^+\pi^-$

| VALUE (%) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------|------|-------------|-----|------|----------------------|
| $-0.9\pm2.1^{+1.6}_{-5.7}$ | 4854 | 1 ASNER | 04A | CLEO | e^+e^-pprox 10 GeV |

¹ This is the overall result of ASNER 04A; *CP*-violating limits are also given below for each of the 10 resonant submodes found in an amplitude analysis of the D^0 and $\overline{D}{}^0$ $K_S^0 \, \pi^+ \, \pi^-$ Dalitz plots. These limits range from < 3.5 \times 10 $^{-4}$ to 28.4 \times 10 $^{-4}$ at 95%

 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline{D}{}^0$ ightarrow $\kappa_S^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K^*(892)^{\pm}\pi^{\mp} \rightarrow K_S^0\pi^+\pi^-) \text{ in } D^0 \rightarrow K^{*+}\pi^-, \overline{D}{}^0 \rightarrow K^{*-}\pi^+$

 VALUE (units 10⁻⁴)
 CL%
 DOCUMENT ID
 TECN
 COMMENT

 <7.8</td>
 95
 1 ASNER
 04A
 CLEO
 Dalitz fit, 4
 04A CLEO Dalitz fit, 4854 $D^0 + \overline{D}^0$ evts

 $^1\,\text{This}$ ASNER 04A limit comes from an amplitude analysis of the $\mathit{D}^{\,0}$ and $\overline{\mathit{D}}^{\,0}$ \rightarrow $K_s^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K^0_S ho^0 o K^0_S \pi^+ \pi^-) \text{ in } D^0 o \overline{K}^0 ho^0, \overline{D}{}^0 o K^0 ho^0$

VALUE (units 10⁻⁴) CL% DO CUMENT ID TECN COMMENT 1 ASNER 04A CLEO Dalitz fit, 4854 $D^{0} + \overline{D}{}^{0}$ evts

 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline{D}{}^0$ ightarrow $K_S^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K^0_S\omega \to K^0_S\pi^+\pi^-) \text{ in } D^0 \to \overline{K}{}^0\omega, \overline{D}{}^0 \to K^0\omega$

VALUE (units 10⁻⁴) CL% DO CUMENT ID TECN COMMENT 95 $1 \overline{\mathsf{ASNER}}$ 04A CLEO Dalitz fit, 4854 $D^0 + \overline{D}{}^0$ evts

 1 This ASNER 04A limit comes from an amplitude analysis of the ${\it D}^{\,0}$ and ${\overline {\it D}}^{\,0}$ ightarrow $K_c^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K^0_S\,f_0(980)\to\ K^0_S\,\pi^+\,\pi^-)\ \text{in}\ D^0\to\ \overline{K}^0\,f_0(980),\ \overline{D}{}^0\to\ K^0\,f_0(980)$

 1 ASNER 04A CLEO Dalitz fit, 4854 $D^{0} + \overline{D}{}^{0}$ evts 95

 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline{D}{}^0$ ightarrow $K_S^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K_S^0 f_2(1270) \rightarrow K_S^0 \pi^+ \pi^-) \text{ in } D^0 \rightarrow \overline{K}^0 f_2(1270), \overline{D}{}^0 \rightarrow K^0 f_2(1270)$

VALUE (units 10⁻⁴) CL% DOCUMENT ID TECN COMMENT ¹ ASNER 95 04A CLEO Dalitz fit, 4854 $D^0 + \overline{D}{}^0$ evts <13.5

 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline{D}{}^0$ ightarrow $K_s^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K_S^0 f_0(1370) \to K_S^0 \pi^+ \pi^-) \text{ in } D^0 \to \overline{K}^0 f_0(1370), \overline{D}^0 \to K^0 f_0(1370)$

VALUE (units 10⁻⁴) CL% DOCUMENT ID TECN COMMENT 1 ASNER 04A CLEO Dalitz fit, 4854 $D^{0}+\overline{D}{}^{0}$ evts 95

 $^1\,\text{This}$ ASNER 04A limit comes from an amplitude analysis of the ${\it D}^{\,0}$ and ${\overline {\it D}}^{\,0}$ \to $K_S^0 \pi^+ \pi^-$ Dalitz plots.

$A_{CP}(K_0^*(1430)^\mp\pi^\pm\to K_S^0\pi^+\pi^-) \text{ in } D^0\to K_0^*(1430)^-\pi^+, \overline{D}{}^0\to$ $K_0^*(1430)^+\pi^-$

- VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT ASNER 04A CLEO Dalitz fit, 4854 $D^0 + \overline{D}^0$ evts
- 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline{D}{}^0$ ightarrow $K_S^0 \pi^+ \pi^-$ Dalitz plots.

 D^0

$A_{CP}(K_2^*(1430)^\mp\pi^\pm\to K_5^0\pi^+\pi^-)$ in $D^0\to K_2^*(1430)^-\pi^+$, $\overline{D}{}^0\to K_2^*(1430)^+\pi^-$

 1 This ASNER 04A limit comes from an amplitude analysis of the D^0 and $\overline D{}^0\to K^0_S\pi^+\pi^-$ Dalitz plots.

$A_{CP}(K^*(1680)^{\mp}\pi^{\pm} \rightarrow K_5^0\pi^{+}\pi^{-}) \text{ in } D^0 \rightarrow K^*(1680)^{-}\pi^{+}, \overline{D}{}^0 \rightarrow K^*(1680)^{+}\pi^{-}$

 1 This ASNER 04A limit comes from an amplitude analysis of the $\it D^0$ and $\it \overline{D}{}^0 \to \it K^0_S \, n^+ \, n^-$ Dalitz plots.

D⁰ CP-VIOLATING ASYMMETRY DIFFERENCES

$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$

CP violation in these modes can come from the decay amplitudes (direct) and/or from mixing or interference of mixing and decay (indirect). The difference ΔA_{CP} is primarily sensitive to the direct component, and only retains a second-order dependence on the indirect component for measurements where the mean decay time of the K^+K^- and $\pi^+\pi^-$ samples are not identical. The results below are averaged assuming the indirect component can be neglected.

| VALUE (%) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|---------|---------------------|-----|------|-----------------|
| -0.65 ± 0.18 OUR | AVERAGE | | | | |
| $-0.82\pm0.21\pm0.11$ | | AAIJ | 12G | LHCB | Time-integrated |
| $-0.46 \pm 0.31 \pm 0.12$ | ! | AALTONEN | 12B | CDF | Time-integrated |
| $+0.24\pm0.62\pm0.26$ | ı | ¹ AUBERT | 08м | BABR | Time-integrated |
| $-0.86\pm0.60\pm0.07$ | 120k | STARIC | 80 | BELL | Time-integrated |

 1 Calculated from the AUBERT 08M values of $A_{CP}({\it K}^+\,{\it K}^-)$ and $A_{CP}(\pi^+\pi^-).$ The systematic error here combines the systematic errors in quadrature, and therefore somewhat over-estimates it.

$D^0-\overline{D}{}^0$ T-VIOLATING DECAY-RATE ASYMMETRIES

 D^0 and \overline{D}^0 are distinguished by the charge of the parent $D^*\colon D^{*+}\to D^0\pi^+$ and $D^{*-}\to \overline{D}^0\pi^-$. Assuming *CPT* is good, *T* violation implies *CP* violation

$A_{Tviol}(K^+K^-\pi^+\pi^-)$ in D^0 , $\overline{D}{}^0 \to K^+K^-\pi^+\pi^-$

 $\begin{array}{lll} \mathsf{C}_T \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) \text{ is a T-odd correlation of the K^+, π^+, and π^- momenta (evaluated in the D^0 rest frame) for the D^0. $\overline{\mathsf{C}}_T \equiv \vec{p}_{K^-} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\pi^+})$ is the corresponding quantity for the \overline{D}^0.} \end{array}$

 $\mathbf{A}_T \equiv \left[\Gamma(\mathbf{C}_T > 0) - \Gamma(\mathbf{C}_T < 0) \right] \ / \left[\Gamma(\mathbf{C}_T > 0) + \Gamma(\mathbf{C}_T < 0) \right]$

would, in the absence of strong phases, test for T violation in D^0 decays (the Γ 's are partial widths). With

 $\overline{A}_T \equiv \left[\Gamma(-\overline{C}_T > 0) - \Gamma(-\overline{C}_T < 0)\right] / \left[\Gamma(-\overline{C}_T > 0) + \Gamma(-\overline{C}_T < 0)\right],$

the asymmetry ${\bf A}_{Tviol}\equiv\frac{1}{2}({\bf A}_T-\overline{\bf A}_T)$ tests for T violation even with nonzero strong phases.

D⁰ CPT-VIOLATING DECAY-RATE ASYMMETRIES

$A_{CPT}(K^{\mp}\pi^{\pm})$ in $D^0 \to K^-\pi^+$, $\overline{D}{}^0 \to K^+\pi^-$

 $A_{CPT}(t)$ is defined in terms of the time-dependent decay probabilities $P(D^0 \to K^-\pi^+)$ and $\overline{P}(\overline{D}^0 \to K^+\pi^-)$ by $A_{CPT}(t) = (\overline{P}-P)/(\overline{P}+P)$. For small mixing parameters $x \equiv \Delta m/\Gamma$ and $y \equiv \Delta \Gamma/2\Gamma$ (as is the case), and times t, $A_{CPT}(t)$ reduces to [$y Re \ \xi - x Im \ \xi$] Γt , where ξ is the CPT-violating parameter.

The following is actually y $Re \xi$ - x $Im \xi$.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------|-----|------|-------------------------------------------------------------|
| $0.0083 \pm 0.0065 \pm 0.0041$ | LINK | 03B | FOCS | γ nucleus, $\overline{\it E}_{\gamma} pprox$ 180 GeV |

$D^0 \rightarrow K^*(892)^- \ell^+ \nu_{\ell}$ FORM FACTORS

$D^0 \rightarrow K^-/\pi^-\ell^+\nu_\ell$ FORM FACTORS

 $f_{+}(0) \text{ in } D^{0} \rightarrow K^{-}\ell^{+}\nu_{\ell}$ DO CUMENT ID TECN COMMENT 0.727±0.007±0.009 AUBERT 07BG BABR $K^-e^+\nu_e$ 2-parameter fit $f_+(0)|V_{cs}|$ in $D^0 \rightarrow K^-\ell^+\nu_\ell$ DO CUMENT ID TECN COMMENT 0.726±0.008±0.004 09 CLEO $K^-e^+\nu_e$ 3-parameter fit BESSON $r_1 \equiv a_1/a_0 \text{ in } D^0 \rightarrow K^-\ell^+\nu_\ell$ DO CUMENT ID <u>VALUE</u> TECN COMMENT $-2.65 \pm 0.34 \pm 0.08$ BESSON 09 CLEO $K^-e^+\nu_e$ 3-parameter fit $r_2 \equiv a_1/a_0 \text{ in } D^0 \rightarrow K^-\ell^+\nu_\ell$ DO CUMENT ID TECN COMMENT VALUE $13 \pm 9 \pm 1$ BESSON 09 CLEO $K^-e^+\nu_{\rho}$ 3-parameter fit $f_{+}(0)|V_{cd}| \text{ in } D^{0} \rightarrow \pi^{-}\ell^{+}\nu_{\ell}$ DO CUMENT ID TECN COMMENT $0.152 \pm 0.005 \pm 0.001$ 09 CLEO $\pi^-\,e^+\,\nu_e$ 3-parameter fit BESSON $r_1 \equiv a_1/a_0 \text{ in } D^0 \rightarrow \pi^- \ell^+ \nu_\ell$ DOCUMENT ID TECN COMMENT <u>VALUE</u> $-2.80 \pm 0.49 \pm 0.04$ 09 CLEO $\pi^-\,e^+\,\nu_e$ 3-parameter fit BESSON $r_2 \equiv a_1/a_0 \text{ in } D^0 \rightarrow \pi^- \ell^+ \nu_\ell$

D⁰ REFERENCES

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BESSON

VALUE 6±3±0 TECN COMMENT

09 CLEO $\pi^-\,e^+\,\nu_e$ 3-parameter fit

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| ANJUS DADIAC | 90 C | PR D42 2414 ZPHY C46 563 | S. Dorlog et al. | (FNAL E691 Collab.) | | | | | |
| ADLER | 89 | PRL 62 1821 | J. Adler et al. | (Mark III Collab.) | | | | | |
| ADLER | 89 C | PR D40 906 | J. Adler et al. | (Mark III Collab.) | | | | | |
| ALVAREZ ANJOS BARLAG ADLER ADLER ALBRECHT ANJOS ABACHI ADLER | 89D | ZPHY C43 181 | H. Albrecht et al. | (FNAL E691 COIIab.) (ACCMOR COIIab.) (Mark III COIIab.) (Mark III COIIab.) (ARGUS COIIab.) (FNAL E691 COIIab.) (HRS COIIab.) | | | | | |
| ANJOS | 89F | PRL 62 1587 | J.C. Anjos et al. | (FNAL E691 Collab.) | | | | | |
| ABACHI | 88 | PL B205 411 | S. Abachi et al. | (HRS Collab.) | | | | | |
| ADLER | 88 C | PK D37 2023 | J. Adler et al. | (Mark III Collab.) | | | | | |
| ALBRECHT | 88 G | PL B209 380 | H Albrecht et al. | (ARGUS Collab.) | | | | | |
| ALBRECHT | 881 | PL B210 267 | H. Albrecht et al. | (ARGUS Collab.) | | | | | |
| ANJOS | 88 C | PRL 60 1239 | J.C. Anjos et al. | (FNÅL E691 Collab.) | | | | | |
| BORTOLETTO | 88 | PR D37 1719 | D. Bortoletto et al. | (CLEO Collab.) | | | | | |
| Also | 88 | PR D39 14/1 (erratum) | D. Bortoletto et al. | (CLEO Collab.) | | | | | |
| HAAS RAAB | 88 | PKL 60 1614 DD D27 2201 | P. Haas et al. | (CLEO CONAD.) | | | | | |
| ADAMOVICH | 87 | EPL 4 887 | M.I. Adamovich et al. | (Photon Emulsion Collab.) | | | | | |
| ADLER | 87 | PL B196 107 | J. Adler et al. | (Mark III Collab.) | | | | | |
| ADLER AGUILAR Also AGUILAR | 87 E | ZPHY C36 551 | M. Aguilar-Benitez et al | . (LEBC-EHS Collab.) | | | | | |
| Also | 07 F | ZPHY C40 321 | M. Aguilar-Benitez et al | . (LEBC-EHS Collab.) | | | | | |
| AGUILAR | 011 | ZPHY C38 520 (erratum | M. Aguilar-Benitez et al | (Mark III Collab.) (Mark III Collab.) (Mark III Collab.) (FNAL E691 Collab.) (HRS Collab.) (Mark III Collab.) (Mark III Collab.) (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) (FNAL E691 Collab.) (CLEO Collab.) (CLEO Collab.) (PNAL E691 Collab.) (Photon Emulsion Collab.) (Mark III Collab.) (LEBC-EHS Collab.) (LEBC-EHS Collab.) (LEBC-EHS Collab.) | | | | | |
| Also BARLAG BECKER Also PALKA RILES | 87 B | ZPHY C38 520 (erratum ZPHY C37 17 | S. Barlag et al. | (ACCMOR Collab.) | | | | | |
| BECKER | 87 C | PL B193 147 | J.J. Becker et al. | `(Mark III Collab.) | | | | | |
| Also | | PL B198 590 (erratum) | J.J. Becker et al. | (Mark III Collab.) | | | | | |
| PALKA RILES | 87 87 | PL B189 238 | H. Palka et al. | (ACCMOR Collab.) | | | | | |
| RAILES BAILEY | 86 | PR D35 2914 ZPHY C30 51 | R. Riles et al. | (ACCMOR Collab.) | | | | | |
| BAILEY BEBEK | 86 | PRL 56 1893 | C. Bebek et al. | (CLEO Collab.) | | | | | |
| | | PRL 56 1027 | W.C. Louis et al. | (PRÌN, CHIC, ISU) | | | | | |
| ALBRECHT ALBRECHT | 85 B | PL 158B 525 | H. Albrecht et al. | (ARGUS Collab.) | | | | | |
| | 85 F | PL 150B 235 PL 155B 461 | H. Albrecht et al. | (ARGUS COllab.) | | | | | |
| AUBERT BALTRUSAIT | | PRL 55 150 | R.M. Raltrusaitic at al. | (Mark III Collab.) | | | | | |
| BENVENUTI | | PL 158B 531 | A.C. Benvenuti et al. | (BCDMS Collab.) | | | | | |
| ADAMOVICH | 84B | PL 140B 123 | M.I. Adamovich et al. | (CERN WA58 Collab.) | | | | | |
| | 84 | PRL 53 1971 | M. Derrick et al. | (HRS Collab.) | | | | | |
| SUMMERS BAILEY | 84 83 B | PRL 52 410 PL 132B 237 | D.J. Summers et al. | (UCSB, CARL, COLO+) | | | | | |
| BODEK | 82 | PL 132B 237 PL 113B 82 | A Bodek et al | (ROCH CIT CHIC ENAL+) | | | | | |
| | 81 | LNC 30 166 | A. Fiorino et al. | (Photon-Emul/Omega-Photon) | | | | | |
| SCHINDLER | 81 | PR D24 78 | R.H. Schindler et al. | (Mark II Collab.) | | | | | |
| TRILLING | 81 | PRPL 75 57 | G.H. Trilling | (LBL, UCB) J | | | | | |
| AS T ON AV ER Y | 80 E 80 | PL 94B 113 PRL 44 1309 | D. Aston et al. | (BONN, CERN, EPOL, GLAS+) | | | | | |
| ZHOLENTZ | 80 | PL 96B 214 | A A Zholents et al | (NOVO) | | | | | |
| Also | - | SJNP 34 814 | A.A. Zholents et al. | (NOVO) | | | | | |
| | | Translated from YAF 34 | 1471 | LEBC-EHS COIlab.) (LEBC-EHS COIlab.) (LEBC-EHS COIlab.) (ACCMOR COIlab.) (Mark III COIlab.) (CLEO COIlab.) (PRIN, CHIC, ISU) (ARGUS COIlab.) (ARGUS COIlab.) (ARGUS COIlab.) (EMC COIlab.) (Mark III COIlab.) (CERN WASS COIlab.) (CERN WASS COIlab.) (COIL COIL COIL COIL COIL COIL COIL COIL | | | | | |
| ABRAMS ATIYA | 79D 79 | PRL 43 481 | G.S. Abrams et al. | | | | | | |
| BALTAY | 78 C | PRL 43 414 PRL 41 73 | M.S. Atiya et al. C. Baltav et al. | (COLU, ILL, FNAL) (COLU, BNL) | | | | | |
| ATIYA BALTAY VUILLEMIN | 78 | PRL 41 1149 | V. Vuillemin et al. | (LGW Collab.) | | | | | |
| GOLDHABER | 77 | PL 69B 503 | G. Goldhaber et al. | (Mark I Collab.) | | | | | |
| PERUZZI | 77 | PL 69B 503 PRL 39 1301 PL 70B 260 | I. Peruzzi et al. | (LGW Collab.) | | | | | |
| PICCOLO GOLDHABER | 77 76 | PL 70B 260 PRL 37 255 | 1471. M.S. Atiya et al. M.S. Atiya et al. C. Baltay et al. V. Vuillemin et al. G. Goldhaber et al. I. Peruzzi et al. M. Piccolo et al. G. Goldhaber et al. | (Mark I Collab.) (Mark I Collab.) | | | | | |
| SOLDIIADEK | | | S. SSIGNODEL EL DI. | (mark i collab.) | | | | | |
| | OTHER RELATED PAPERS | | | | | | | | |

RICHMAN 95 RMP 67 893 J.D. Richman, P.R. Burchat (UCSB, STAN)
ROSNER 95 CNPP 21 369 J. Rosner (CHIC)



 $I(J^P) = \frac{1}{2}(1^-)$ I, J, P need confirmation.

J consistent with 1, value 0 ruled out (NGUYEN 77).

D*(2007)0 MASS

The fit includes D^\pm , D^0 , D_S^\pm , $D^{*\pm}$, D^{*0} , $D_S^{*\pm}$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{S1}(2536)^\pm$ mass and mass difference measurements.

<u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> **2006.98 ± 0.15 OUR FIT**

$m_{D^*(2007)^0} - m_{D^0}$

The fit includes D^\pm , D^0 , D^\pm_S , $D^{*\pm}$, $D^{*\pm}$, D^{*0} , $D^{*\pm}_S$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{s1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------|--------------|------------------------|----------|-----------|------------------------------------|
| 142.12±0.07 OUR FI | Т | | | | |
| 142.12±0.07 OUR AV | /ERAGE | | | | |
| $142.2 \ \pm 0.3 \ \pm 0.2$ | 145 | ALBRECHT | 95 F | ARG | $e^+e^- ightarrow hadrons$ |
| $142.12 \pm 0.05 \pm 0.05$ | 1176 | BORTOLETT | О92в | CLE2 | $e^+e^- ightarrow hadrons$ |
| ● ● We do not use | the followin | g data for average | s, fits, | limits, e | etc. • • • |
| 142.2 ± 2.0 | | SADROZINSK | 180 | CBAL | $D^{*0} \rightarrow D^{0} \pi^{0}$ |
| 142.7 +1.7 | | ² GOLDHABER | 77 | MRK1 | e+e- |

 $D^*(2007)^0$, $D^*(2010)^{\pm}$

 2 From simultaneous fit to $D^*(2010)^+$, $D^*(2007)^0$, D^+ , and D^0 .

D*(2007)0 WIDTH

| VALUE (MeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|------------|--------------------------|-----|------|-----------------------------------|
| <2.1 | 90 | 3 ABACHI | 88B | HRS | $D^{*0} \rightarrow D^{+}\pi^{-}$ |
| 3 Assuming $m_{D*0} =$ | : 2007.2 ± | 2.1 MeV/c ² . | | | |

D*(2007)0 DECAY MODES

 $\overline{\it D}{}^*(2007)^0$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|----------------|------------------------------|
| Γ ₁ | $D^{0}\pi^{0}$ | (61.9±2.9) % |
| Γ ₂ | $D^{0}\gamma$ | (38.1±2.9) % |

CONSTRAINED FIT INFORMATION

An overall fit to a branching ratio uses 3 measurements and one constraint to determine 2 parameters. The overall fit has a $\chi^2=$ 0.5 for 2 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta x_i\delta x_j\right>/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i\equiv$ $\Gamma_i/\Gamma_{\mathrm{total}}$. The fit constrains the x_i whose labels appear in this array to sum to

$$x_2 \qquad \boxed{-100}$$

D*(2007) BRANCHING RATIOS

| $\Gamma(D^0\pi^0)/\Gamma(D^0\gamma)$ | | | | | Γ_1/Γ_2 |
|------------------------------------------|----------------------|--------------------------|-------------|---------|-----------------------------------------------------|
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| 1.74±0.02±0.13 | | AUBERT,BE | 05 G | BABR | 10.6 $e^+e^- \rightarrow \text{hadrons}$ |
| $\Gamma(D^0\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₁ /Γ |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.619±0.029 OUR FIT | | | | | |
| • • • We do not use t | he followi | ng data for averages | , fits, | limits, | etc. • • • |
| $0.635 \pm 0.003 \pm 0.017$ | 69k | ⁴ AUBERT,BE | 05 G | BABR | 10.6 $e^+e^- \rightarrow$ hadrons |
| $0.596 \pm 0.035 \pm 0.028$ | 85 8 | ⁵ ALBRECHT | 95 F | ARG | $e^+e^- \rightarrow hadrons$ |
| $0.636 \pm 0.023 \pm 0.033$ | 1097 | ⁵ BUTLER | 92 | CLE2 | $e^+e^- ightarrow $ hadrons |
| $\Gamma(D^0\gamma)/\Gamma_{	ext{total}}$ | EVTS | DO CUMENT ID | | TECN | Γ ₂ /Γ |
| 0.381 ± 0.029 OUR FIT | | DOCUMENT ID | | TECN | COMMENT |
| 0.381 ± 0.029 OUR AV | | | | | |
| $0.404 \pm 0.035 \pm 0.028$ | 45 6 | ⁵ ALBRECHT | 95 F | ARG | $e^+e^- ightarrow hadrons$ |
| $0.364 \pm 0.023 \pm 0.033$ | 621 | ⁵ BUTLER | 92 | CLE2 | $e^+e^- \rightarrow hadrons$ |
| $0.37 \pm 0.08 \pm 0.08$ | | ADLER | 88D | MRK3 | e^+e^- |
| • • • We do not use t | he followi | ng data for averages | , fits, | limits, | etc. • • • |
| $0.365 \pm 0.003 \pm 0.017$ | 68k | ⁴ AUBERT,BE | 05 G | BABR | 10.6 $e^+e^- \rightarrow$ hadrons |
| 0.47 ±0.23 | | LOW | 87 | HRS | 29 GeV e ⁺ e ⁻ |
| 0.53 ±0.13 | | BARTEL | 85 G | JADE | e^+e^- , hadrons |
| 0.47 ±0.12 | | COLES | 82 | MRK2 | e^+e^- |
| 0.45 ±0.15 | | GOLDHABER | 77 | MRK1 | e^+e^- |
| $D^{*0} ightarrow D^0 \pi^0$ and | $D^{*0} \rightarrow$ | $D^0\gamma$ decays sum t | o 100 | % | he branching fractions of ot independent, they have |

D*(2007)0 REFERENCES

been constrained by the authors to sum to 100%.

| AUBERT, BE | 05 G | PR D72 091101 | B. Aubert et al. | (BABAR Collab.) |
|-------------|------|-------------------|---------------------------|-------------------------|
| ALBRECHT | 95 F | ZPHY C66 63 | H. Albrecht et al. | (ARGUS Collab.) |
| BORTOLETTO | 92B | PRL 69 2046 | D. Bortoletto et al. | `(CLEO Collab.) |
| BUTLER | 92 | PRL 69 2041 | F. Butler et al. | (CLEO Collab.) |
| ABACHI | 88 B | PL B212 533 | S. Abachi et al. | (ANL, IND, MICH, PURD+) |
| ADLER | 88 D | PL B208 152 | J. Adler et al. | (Mark III Collab.) |
| LOW | 87 | PL B183 232 | E.H. Low et al. | ` (HRS Collab.) |
| BARTEL | 85 G | PL 161B 197 | W. Bartel et al. | (ĴADE Collab.) |
| COLES | 82 | PR D26 2190 | M.W. Coles et al. | `(LBL, SLAC) |
| SADROZINSKI | 80 | Madison Conf. 681 | H.F.W. Sadrozinski et al. | (PRIN, CIT+) |
| GOLDHABER | 77 | PL 69B 503 | G. Goldhaber et al. | (Mark I Collab.) |
| NGUYEN | 77 | PRL 39 262 | H.K. Nguyen et al. | `(LBL, SLAC)J |

 $D^*(2010)^{\pm}$

 $I(J^P) = \frac{1}{2}(1^-)$ I, J, P need confirmation.

D*(2010) * MASS

The fit includes D^{\pm} , D^{0} , D_{S}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{S}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

DO CUMENT ID TECN CHG COMMENT 2010.28 ± 0.13 OUR FIT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 1 GOLDHABER 77 MRK1 \pm $e^{+}\,e^{-}$ 2 PERUZZI 77 LGW \pm $e^{+}\,e^{-}$ 2008.6 ± 1.0 1 From simultaneous fit to $D^*(2010)^+,\ D^*(2007)^0,\ D^+,\ {\rm and}\ D^0;$ not independent of FELDMAN 77B mass difference below. 2 PERUZZI 77 mass not independent of FELDMAN 77B mass difference below and PERUZZI 77 D^0 mass value.

 $m_{D^*(2010)^+} - m_{D^+}$ The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(25\,36)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|----------------------------|-------|------------------------------|------|-----------------------------|
| 140.66 ± 0.10 OUR FIT | Error | includes scale factor of 1.1 | | |
| $140.64 \pm 0.08 \pm 0.06$ | 620 | BORTOLETT O92B | CLE2 | $e^+e^- ightarrow hadrons$ |

$m_{D^*(2010)^+} - m_{D^0}$

The fit includes D^{\pm} , D^{0} , D_{S}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{S}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (M | | | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------|----------------------|---------------|--------------|------------------------|--------|-----------|-----------------------------------------------------------------------------------------------------|
| | | | | cludes scale factor | of 1 | 1. | |
| | _ | OUR A | VERAGE | ANASTASSOV | 00 | CLE2 | $D^{*\pm} \rightarrow D^0 \pi^{\pm} \rightarrow$ |
| 145.41 | 2 ± 0.002 | 2 ± 0.012 | | ANASTASSOV | 02 | CLE2 | $(K\pi) \pi^{\pm} \rightarrow D^{\circ} \pi^{\pm} \rightarrow$ |
| 145.54 | ± 0.08 | | 611 | ³ ADINOLFI | 99 | BEAT | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| 145.45 | ±0.02 | | | ³ BREITWEG | 99 | ZEUS | $D^{*\pm} \rightarrow D^0 \pi^{\pm} \rightarrow$ |
| | | | | 2 | | | $(K\pi)\pi^{\pm}$ |
| 145.42 | ± 0.05 | | | ³ BREITWEG | 99 | ZEUS | $D^{*\pm} \xrightarrow{D^0} D^0 \pi^{\pm} \rightarrow (K^-3\pi)\pi^{\pm}$ |
| 145.5 | ± 0.15 | | 103 | ⁴ ADLOFF | 97в | H1 | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| | ± 0.08 | | 152 | ⁴ BREITWEG | 97 | ZEUS | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| | | | | | | | $D^{*\pm} \rightarrow D^{0} \rightarrow K^{-3\pi}$ |
| 145.42 | ± 0.11 | | 199 | ⁴ BREITWEG | 97 | ZEUS | $D^{*\pm} \rightarrow D^{0} \pi^{\pm}$, |
| 145.4 | ±0.2 | | 48 | ⁴ DERRICK | 95 | ZEUS | $D^*\stackrel{D}{=} \stackrel{D}{\to} \stackrel{K}{\to} \stackrel{\pi}{\to} \stackrel{\pi}{\to}$ |
| 145.4 | | +0.03 | 40 | BARLAG | | ACCM | π^- 230 GeV |
| 145.5 | ± 0.00 | ±0.05 | 115 | ⁴ ALEXANDER | | OPAL | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| | ± 0.06 | | 110 | ⁴ DECAMP | 91. | ALEP | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| | ± 0.05 | ± 0.10 | | ABACHI | 88B | HRS | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| | ± 0.07 | | | ALBRECHT | 85 F | ARG | $D^{*\pm} \rightarrow D^0 \pi^+$ |
| 145.5 | ±0.3 | | 28 | BAILEY | 83 | SPEC | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$ |
| 145.5 | ±0.3 | | 60 | FITCH | 81 | SPEC | π^- A |
| 145.3 | ±0.5 | | 30 | FELDMAN | 77B | MRK1 | $D^{*+} \rightarrow D^0 \pi^+$ |
| • • • W | e do not | use the | following da | ta for averages, fit | s, lim | its, etc. | • • • |
| 145.44 | ±0.09 | | 122 | ⁴ BREITWEG | 97B | ZEUS | $D^{*\pm} \rightarrow D^0 \pi^{\pm}$, |
| 145.8 | 115 | | 16 | AHLEN | 83 | HRS | $D^{0} \xrightarrow{\rightarrow} D^{0} \pi^{\pm},$ $D^{++} \xrightarrow{\rightarrow} D^{0} \pi^{+}$ |
| 145.8 | $\pm 1.5 \\ \pm 1.8$ | | 10 | BAILEY | 83 | SPEC | $D^{*\pm} \rightarrow D^{0}\pi^{\pm}$ |
| 145.1 | ±1.6 ±0.5 | | 14 | BAILEY | 83 | SPEC | $D^{+\pm} \rightarrow D^{0}\pi^{\pm}$ |
| 145.5 | ± 0.5 | | 14 | YELTON | 82 | MRK2 | 29 e ⁺ e [−] → |
| | _ 0.5 | | 1.7 | | | | $\kappa^-\pi^+$ |
| ~ 145.5 | | | | AVERY | 80 | SPEC | γ A |
| 145.2 | ± 0.6 | | 2 | BLIETSCHAU | 79 | BEBC | νp |
| 3 Statis | stical err | ors only. | | | | | |

$m_{D^*(2010)^+} - m_{D^*(2007)^0}$

TECN COMMENT DOCUMENT ID VALUE (MeV) ullet ullet We do not use the following data for averages, fits, limits, $\overline{\text{etc.}}$ ullet ullet 5 PERUZZI 77 LGW $e^{+}e^{-}$ 5 Not independent of FELDMAN 77B mass difference above, PERUZZI 77 $\mathit{D}^{\,0}$ mass, and

GOLDHABER 77 $D*(2007)^0$ mass.

D*(2010) + WIDTH

| VALUE (keV) | CL% | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------|--------|------------|-----------------------|----------|---------------------------------------------------------------|
| 96±4±22 | | | ANASTASSOV | 02 CLE2 | $ \frac{D^{*\pm} \to D^0 \pi^{\pm}}{(K\pi) \pi^{\pm}} \to 0 $ |
| • • • We do not | use th | e followir | ng data for averages, | | |
| <131 | 90 | 110 | BARLAG | 92B ACCN | π^- 230 GeV |

$D^*(2010)^{\pm}$ DECAY MODES

 $D^*(2010)^-$ modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------|------------------------------|
| $\overline{\Gamma_1}$ | $D^0\pi^+$ | (67.7±0.5) % |
| Γ ₁ | $D^+\pi^0$ | (30.7±0.5) % |
| Γ3 | $D^+ \gamma$ | (1.6±0.4) % |

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 6 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 =$ $0.3 \ \text{for 4 degrees of freedom.}$

The following off-diagonal array elements are the correlation coefficients $\left<\delta x_i\delta x_j\right>/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i\equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$\begin{array}{c|cccc} x_2 & -62 & \\ x_3 & -43 & -44 & \\ \hline & x_1 & x_2 & \end{array}$$

D*(2010)+ BRANCHING RATIOS

| $\Gamma(D^0\pi^+)/\Gamma_{ m total}$ | | | | | Γ1/Γ |
|--------------------------------------|----------------------------|---------|-----------|----------------------|---------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.677 ±0.005 OUR FIT | | | | | |
| 0.677 ±0.006 OUR AVER | AGE | | | | |
| $0.6759 \pm 0.0029 \pm 0.0064$ | 6,7,8 BARTELT | 98 | CLE2 | e^+e^- | |
| $0.688 \pm 0.024 \pm 0.013$ | ALBRECHT | 95 F | ARG | e^+e^- | hadrons |
| $0.681 \pm 0.010 \pm 0.013$ | ⁶ BUTLER | 92 | CLE2 | $e^+e^- \rightarrow$ | hadrons |
| ullet $ullet$ We do not use the fo | ollowing data for averages | s, fits | , limits, | etc. • • • | |
| $0.57 \pm 0.04 \pm 0.04$ | ADLER | 88D | MRK3 | e^+e^- | |
| 0.44 ± 0.10 | COLES | 82 | MRK2 | e^+e^- | |
| 0.6 ± 0.15 | ⁸ GOLDHABER | 77 | MRK1 | e^+e^- | |

| I | $\Gamma(D^+\pi^0)/\Gamma$ | total | | | | | | Γ_2/Γ |
|---|---------------------------|-------------|------------|---------------------|------|------|----------------------|-------------------|
| | ALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| | 0.307 ±0.005 | | | ,7,8 BARTELT | 00 | CLES | -+ | |
| | _ | _ | | ata for averages, f | | | | |
| • | • • vve do i | ioi use ine | ionowing u | ata ioi averages, i | | | | |
| (| 0.312 ± 0.011 | ± 0.008 | 1404 | ALBRECHT | 95 F | ARG | $e^+e^- \rightarrow$ | hadrons |
| (| $.308 \pm 0.004$ | ±0.008 | 410 | ⁶ BUTLER | 92 | CLE2 | $e^+e^- \rightarrow$ | hadrons |
| (| .26 ± 0.02 | ± 0.02 | | ADLER | 88D | MRK3 | e^+e^- | |
| (| 0.34 ± 0.07 | | | COLES | 82 | MRK2 | e^+e^- | |

| $\Gamma(D^+\gamma)/\Gamma_{ m total}$ | | | | | Гз/Г |
|---------------------------------------|------|------------------------|----|------|----------|
| VALUE CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.016 ±0.004 OUR FIT | | | | | |
| 0.016 ±0.005 OUR AVERA | GE | | | | |
| $0.0168 \pm 0.0042 \pm 0.0029$ | | ^{6,7} BARTELT | 98 | CLE2 | e^+e^- |
| $0.011 \ \pm 0.014 \ \pm 0.016$ | 12 | ⁶ BUTLER | 92 | CLE2 | e+e− → |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| < 0.052 | 90 | ALBRECHT | 95 F | ARG | e^+e^- |
|--------------------------|-----------|---------------|-----------|------|----------|
| 0.17 ±0.05 0.22 ±0.12 | ±0.05 | ADLER 9 COLES | 88D 82 | MRK3 | |

 $^{\rm 6}\,{\rm The}$ branching ratios are not independent, they have been constrained by the authors to

D*(2010) * REFERENCES

| ANASTASSOV | 02 | PR D65 032003 | A. Anastassov et al. | (CLEO (| Collab.) |
|------------|------|---------------|----------------------|---------------------|----------|
| ADINOLFI | 99 | NP B547 3 | M. Adinolfi et al. | (Beatrice (| Collab.) |
| BREITWEG | 99 | EPJ C6 67 | J. Breitweg et al. | `(ZEUS (| Collab.) |
| BARTELT | 98 | PRL 80 3919 | J. Bartelt et al. | (CLEO (| Collab.) |
| ADLOFF | 97 B | ZPHY C72 593 | C. Adloff et al. | ` (H1 C | Collab.) |
| BREITWEG | 97 | PL B401 192 | J. Breitweg et al. | (ZEUS (| Collab.) |
| BREITWEG | 97 B | PL B407 402 | J. Breitweg et al. | (ZEUS (| Collab.) |
| ALBRECHT | 95 F | ZPHY C66 63 | H. Albrecht et al. | (ARGUS (| Collab.) |
| DERRICK | 95 | PL B349 225 | M. Derrick et al. | `(ZEUS (| Collab.) |
| BARLAG | 92 B | PL B278 480 | S. Barlag et al. | (ACCMOR O | Collab.) |
| BORTOLETTO | 92 B | PRL 69 2046 | D. Bortoletto et al. | ` (CLEO (| Collab.) |
| BUTLER | 92 | PRL 69 2041 | F. Butler et al. | (CLEO (| Collab.) |
| ALEXANDER | 91B | PL B262 341 | G. Alexander et al. | (OPAL (| Collab.) |
| DECAMP | 91 J | PL B266 218 | D. Decamp et al. | (ALEPH (| Collab.) |
| ABACHI | 88 B | PL B212 533 | S. Abachi et al. | (ANL, IND, MICH, PL | JRD+) |
| ADLER | 88 D | PL B208 152 | J. Adler et al. | ` (Mark III (| Collab.) |

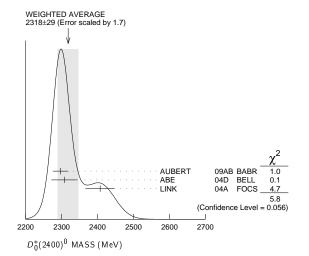
$D_0^*(\overline{2400})^0$

$$I(J^P) = \frac{1}{2}(0^+)$$

 $\overline{J^P} = 0^+$ assignment favored (ABE 04D).

$D_0^*(2400)^0$ MASS

| VALUE (MeV) | EVTS | DO CUMENT | ID TECN | COMMENT |
|----------------------|------------|----------------|--------------------|-----------------------------------|
| 2318 ± 29 OUR AVE | RAGE Error | includes scale | factor of 1.7. See | the ideogram below. |
| $2297 \pm 8 \pm 20$ | 3.4k | AUBERT | 09AB BABR | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $2308 \pm 17 \pm 32$ | | ABE | 04D BELL | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $2407\pm21\pm35$ | 9.8k | LINK | 04A FOCS | γ A |



D*(2400)0 WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|---------------------|------|-------------|-----------|-----------------------------------|
| 267±40 OUR AVER | RAGE | | | |
| $273 \pm 12 \pm 48$ | 3.4k | AUBERT | 09AB BABR | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $276 \pm 21 \pm 63$ | | ABE | 04D BELL | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $240 \pm 55 \pm 59$ | 9.8k | LINK | 04A FOCS | γ A |

$D_0^*(2400)^0$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | | |
|----------------|------------|------------------------------|--|--|
| Γ ₁ | $D^+\pi^-$ | seen | | |

$D_0^*(2400)^0$ REFERENCES

| AUBERT | 09AB PR D79 112004 | B. Aubert et al. | (BABAR Collab.) |
|--------|--------------------|------------------|-----------------|
| ABE | 04D PR D69 112002 | K. Abe et al. | (BELLE Collab.) |
| LINK | 04A PL B586 11 | J.M. Link et al. | (FOCUS Collab.) |

$D_0^*(2400)^{\pm}$

$$I(J^P) = \frac{1}{2}(0^+)$$

OMITTED FROM SUMMARY TABLE

J, P need confirmation.

| D_0^* (| 2400)± | MASS |
|-----------|--------|------|
|-----------|--------|------|

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------|-------|-------------|-----|------|------------|
| $2403 \pm 14 \pm 35$ | 18.8k | LINK | 04A | FOCS | γ A |

$D_0^*(2400)^{\pm}$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|-------|--------------|-----|------|------------|
| 283±24±34 | 18.8k | LINK | 04A | FOCS | γ A |

sum to 100%. 7 Systematic error includes theoretical error on the prediction of the ratio of hadronic modes. 8 Assuming that isospin is conserved in the decay. 9 Not independent of $\Gamma(D^0\pi^+)/\Gamma_{\text{total}}$ and $\Gamma(D^+\pi^0)/\Gamma_{\text{total}}$ measurement.

 $D_0^*(2400)^\pm$, $D_1(2420)^0$

$D_0^*(2400)^{\pm}$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------|------------------------------|
| Γ ₁ | $D^0\pi^+$ | seen |

D₀*(2400)* REFERENCES

LINK 04A PL B586 11 J.M. Link et al. (FOCUS Collab.)



 $I(J^P) = \frac{1}{2}(1^+)$ I needs confirmation.

D1 (2420)0 MASS

The fit includes D^\pm , D^0 , D^\pm_S , $D^{*\pm}$, $D^{*\pm}$, D^{*0} , $D^{*\pm}_S$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{S1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|-------------------|-----------------------|-------------|-----------|-------------------------------------------------|
| 2421.3±0.6 OUR | FIT Error inclu | ides scale factor (| of 1.2. | | |
| 2420.9±0.8 OUR | AVERAGE Err | or includes scale | factor | of 1.2. | |
| $2420.1 \pm 0.1 \pm 0.8$ | 103k | DEL-AMO-SA | | | $e^+e^- \rightarrow D^{*+}\pi^- X$ |
| $2426 \pm 3 \pm 1$ | 151 | ABE | 05 A | BELL | $B^- \to D^0 \pi^+ \pi^- \pi^-$ |
| $2421.4\pm1.5\pm0.9$ | | ¹ ABE | 04D | BELL | $B^- \rightarrow D^{*+}\pi^-\pi^-$ |
| $2421 \begin{array}{c} +1 \\ -2 \end{array} \pm 2$ | 286 | AVERY | 94 C | CLE2 | $e^+e^-\to~D^{*+}\pi^-\mathrm{X}$ |
| $2422\ \pm 2\ \pm 2$ | 51 | FRABETTI | 94B | E687 | $\gamma \text{Be} \rightarrow D^{*+} \pi^- X$ |
| $2428 \pm 3 \pm 2$ | 279 | AVERY | 90 | CLEO | $e^+ e^- \rightarrow D^{*+} \pi^- X$ |
| 2414 ± 2 ± 5 | 171 | ALBRECHT | 89н | ARG | $e^+ e^- \rightarrow D^{*+} \pi^- X$ |
| $2428 \pm 8 \pm 5$ | 171 | ANJOS | 89c | TPS | $\gamma N \rightarrow D^{*+}\pi^{-}X$ |
| • • • We do not | use the following | g data for average | s, fits | , limits, | etc. • • • |
| $2420.5 \pm 2.1 \pm 0.9$ | 3110 ± 340 | ² CHEKANOV | 09 | ZEUS | $e^{\pm} \rho \rightarrow D^{*+} \pi^{-} X$ |
| $2421.7 \pm 0.7 \pm 0.6$ | 7.5k | ABULENCIA | 06A | CDF | 1900 $p\overline{p} \rightarrow D^{*+}\pi^{-}X$ |
| 2425 ±3 | 235 | ³ ABREU | 98м | DLPH | e^+e^- |
| 4 | | | | | |

 $^{^{1}\,\}mathrm{Fit}$ includes the contribution from $D_{\,1}^{\,*}(2430)^{\,0}.$

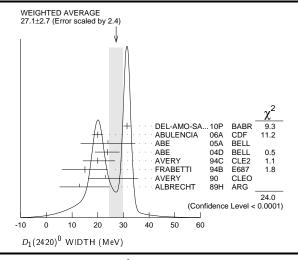
$m_{D_1^0} - m_{D^{*+}}$

The fit includes D^\pm , D^0 , D^\pm_s , $D^{*\pm}$, $D^{*\pm}$, D^{*0} , $D^{*\pm}_s$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{s1}(2536)^\pm$ mass and mass difference measurements.

| VALUE | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------------|--------------------|------|------|----------------------------------------------------|
| 411.0±0.6 OUR I | IT Error includ | es scale factor of | 1.2. | | |
| 411.5 ± 0.8 OUR / | AVERAGE | | | | |
| $410.2 \pm 2.1 \pm 0.9$ | 3110 ± 340 | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{*+} \pi^{-} X$ |
| $411.7 \pm 0.7 \pm 0.4$ | 7.5k | ABULENCIA | 06A | CDF | 1900 $p \overline{p} \rightarrow D^{*+} \pi^{-} X$ |

D₁ (2420) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------|--------------------|---------------------|----------|----------|-------------------------------------------------------------|
| 27.1 ± 2.7 OUR A | WERAGE Error | includes scale fa | ctor o | f 2.4. S | ee the ideogram below. |
| $31.4 \pm\ 0.5 \pm\ 1.3$ | 103k | DEL-AMO-SA | 10P | BABR | $e^+ e^- \rightarrow D^{*+} \pi^- X$ |
| $20.0 \pm \ 1.7 \pm \ 1.3$ | 7.5 k | ABULENCIA | | | 1900 $p \overline{p} \rightarrow D^{*+} \pi^{-} \lambda$ |
| $24~\pm~7~\pm~8$ | 151 | ABE | | | $B^- \rightarrow D^0 \pi^+ \pi^- \pi^-$ |
| $23.7\!\pm\ 2.7\!\pm\ 4.0$ | | ⁴ ABE | 04D | BELL | $B^- \rightarrow D^{*+}\pi^-\pi^-$ |
| $20 \ \ ^{+}_{-} \ \ ^{6}_{5} \ \ \pm \ 3$ | 286 | AVERY | 94c | CLE2 | $e^+e^-\to~D^{*+}\pi^-\mathrm{X}$ |
| $15 \pm 8 \pm 4$ | 51 | FRABETTI | 94B | E687 | $\gamma \mathrm{Be} \rightarrow D^{*+} \pi^- \mathrm{X}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 279 | AVERY | 90 | CLEO | $e^+e^- \rightarrow ~D^{*+}\pi^-\mathrm{X}$ |
| $13 \ \pm \ 6 \ \begin{array}{c} +10 \\ -5 \end{array}$ | 171 | ALBRECHT | 89н | ARG | $e^+e^-\to~D^{*+}\pi^-\mathrm{X}$ |
| ullet $ullet$ We do not | use the following | data for average | s, fits, | limits, | etc. • • • |
| $53.2 \pm 7.2 ^{+}_{-}3.3 $ | 3110 ± 340 | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{*+} \pi^- X$ |
| 58 ± 14 ± 10 | 171 | ANJOS | 89c | TPS | $\gamma N \rightarrow D^{*+}\pi^{-}X$ |
| ⁴ Fit includes th | e contribution fro | m $D_1^*(2430)^0$. | | | |



$D_1(2420)^0$ DECAY MODES

 $\overline{D}_1(2420)^0$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------------|------------------------------|
| Γ_1 | $D_{-}^{*}(2010)^{+}\pi^{-}$ | seen |
| Γ_2 | $D^{0}\pi^{+}\pi^{-}$ | seen |
| Γ_3 | $D^{0} \rho^{0}$ | |
| Γ ₄ | $D^0 f_0(500)$ | |
| Γ ₅ | $D_0^*(2400)^+\pi^-$ | |
| Γ ₆ | $D^+\pi^-$ | not seen |
| Γ_7 | $D^{*0} \pi^+ \pi^-$ | not seen |

D1(2420) BRANCHING RATIOS

| $\Gamma(D^*(2010)^+\pi^-)/\Gamma$ | total | | | | Γ_1/Γ |
|------------------------------------|-------|--------------|-----|---------------------|---------------------------------------|
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| seen | | ACKERSTAFF | 97w | OPAL | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| seen | | AVERY | 90 | CLEO | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| seen | | ALBRECHT | 89н | ARG | $e^+e^- \rightarrow D^*\pi^-X$ |
| seen | | ANJOS | 89c | TPS | $\gamma N \rightarrow D^{*+}\pi^{-}X$ |
| $\Gamma(D^+\pi^-)/\Gamma(D^*(20))$ | | | | Γ_6/Γ_1 | |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <0.24 | 90 | AVERY | 90 | CLEO | $e^+e^- \rightarrow D^+\pi^-X$ |

$D_1(2420)^0$ POLARIZATION AMPLITUDE A D_1

A polarization amplitude A_{D_1} is a parameter that depends on the initial polarization of the D_1 and is sensitive to a possible S-wave contribution to its decay. For D_1 decays the helicity angle, θ_h , distribution varies like $1+A_{D_1}{\cos^2\theta_h}$, where θ_h is the angle in the D^* rest frame between the two pions emitted by the $D_1 \rightarrow D^*\pi$ and the $D^* \rightarrow D\pi$.

Unpolarized D_1 decaying purely via D-wave is predicted to give A $_{D_1}=3$.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|---------------------|-------------|------|-------------------------------------------|--|
| 5.72±0.25 OUR AVERAGE | | | | | | |
| 5.72 ± 0.25 | 103k | DEL-AMO-SA | 10P | BABR | $e^+e^- \rightarrow D^{*+}\pi^-X$ | |
| $5.9 \begin{array}{c} +3.0 \\ -1.7 \end{array} \begin{array}{c} +2.4 \\ -1.0 \end{array}$ | | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{*+} \pi^{-} X$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $3.8 \pm 0.6 \pm 0.8$ | | ⁵ AUBERT | 09Y | BABR | $B^+ \rightarrow D_1^0 \ell^+ \nu_{\ell}$ | |
| $2.74 {}^{+ 1.40}_{- 0.93}$ | | ⁶ AVERY | 94 C | CLE2 | $e^+e^- \rightarrow D^{*+}\pi^- X$ | |
| ⁵ Assuming $\Gamma(\Upsilon(4S) \to B^+B^-) / \Gamma(\Upsilon(4S) \to B^0\overline{B}{}^0) = 1.065 \pm 0.026$ and equal partial widths and helicity angle distributions for charged and neutral D_1 mesons. | | | | | | |

D₁(2420)0 REFERENCES

 6 Systematic uncertainties not estimated.

| DEL-AMO-SA | 10 P | PR D82 111101 | P. del Amo Sanchez et al. | (BABAR | Collab.) |
|------------|------|----------------|---------------------------|------------|-------------|
| AUBERT | 09Y | PRL 103 051803 | B. Aubert et al. | (BABAR | Collab.) |
| CHEKANOV | 09 | EPJ C60 25 | S. Chekanov et al. | (ZEUS | Collab.) |
| ABULENCIA | 06A | PR D73 051104 | A. Abulencia et al. | `(CDF | Collab.) |
| ABE | 05 A | PRL 94 221805 | K. Abe et al. | (BÈLLE | Collab.) |
| ABE | 04 D | PR D69 112002 | K. Abe et al. | (BELLE | Collab.) |
| ABREU | 98 M | PL B426 231 | P. Abreu et al. | (ĎELPHI | Collab.) |
| ACKERSTAFF | 97 W | ZPHY C76 425 | K. Ackerstaff et al. | `(OPAL | Collab.) |
| AVERY | 94 C | PL B331 236 | P. Avery et al. | (CLEO | Collab.) |
| FRABETTI | 94 B | PRL 72 324 | P.L. Frabetti et al. | (FNAL E687 | Collab.) |
| AVERY | 90 | PR D41 774 | P. Avery, D. Besson | (CLEO | Collab.) |
| ALBRECHT | 89H | PL B232 398 | H. Albrecht et al. | (ARGUS | Collab.) JP |
| ANJOS | 89 C | PRL 62 1717 | J.C. Anjos et al. | (FNAL E691 | Collab.) |
| | | | | | |

 $^{^2}$ Calculated using the mass difference $m(D_1^0)-m(D^{*+})_{PDG}$ reported below and $m(D^{*+})_{PDG}=2010.27\pm0.17$ MeV. The 0.17 MeV uncertainty of the PDG mass value should be added to the experimental uncertainty of 0.9 MeV. 3 No systematic error given.

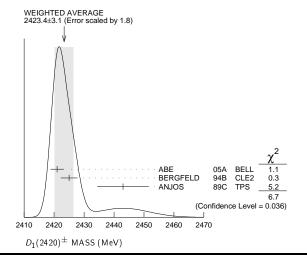
 $D_1(2420)^{\pm}$

 $I(J^P) = \frac{1}{2}(?^?)$ I needs confirmation.

OMITTED FROM SUMMARY TABLE Seen in $D^*(2007)^0\pi^+$. $J^P=0^+$ ruled out.

$D_1(2420)^{\pm}$ MASS

| VALUE | (MeV) | | EVTS | | DO CUME | NT ID | l | TECN | COMME | NT |
|--------|---------|---------|---------|-------|----------|-------|--------|---------|------------------------|------------------------------|
| 2423.4 | ±3.1 | OUR | AVERAGE | Error | includes | scale | factor | of 1.8. | See the i | deogram below. |
| 2421 | ± 2 | ± 1 | 124 | | ABE | | | | | $D^{+}\pi^{+}\pi^{-}\pi^{-}$ |
| 2425 | ± 2 | ± 2 | 146 | | BERGF | ELD | 94B | CLE2 | e^+e^- | $\rightarrow D^{*0} \pi^+ X$ |
| 2443 | ± 7 | ± 5 | 190 | | ANJOS | | 89c | TPS | $\gamma N \rightarrow$ | $D^{0}\pi^{+}X^{0}$ |



$m_{D_1^*(2420)^{\pm}} - m_{D_1^*(2420)^0}$

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
|--------------------|--------------|------|--------------------|
| $4^{+2}_{-3}\pm 3$ | BERGFELD 94B | CLE2 | $e^+e^-	o$ hadrons |

$D_1(2420)^{\pm}$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------|------|--------------|------|------|----------------------------------------------------|
| 25± 6 OUR AVERAGE | | | | | |
| $21\pm5\pm8$ | 124 | ABE | 05 A | BELL | $\overline{B}^0 \rightarrow D^+ \pi^+ \pi^- \pi^-$ |
| 26 + 8 ± 4 | 146 | BERGFELD | 94B | CLE2 | $e^+ e^- \to \ D^{*0} \pi^+ {\rm X}$ |
| $41 \pm 19 \pm 8$ | 190 | ANJOS | 89c | TPS | $\gamma N \rightarrow D^0 \pi^+ X^0$ |
| | | | | | |

$D_1(2420)^{\pm}$ DECAY MODES

 $D_1^*(2420)^-$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $D^*(2007)^0 \pi^+$ | seen |
| Γ_2 | $D^{+} \pi^{+} \pi^{-}$ | seen |
| Γ_3 | $D^+ ho^0$ | |
| Γ_4 | $D + f_0(500)$ | |
| Γ_5 | $D^+ f_0(500) D_0^*(2400)^0 \pi^+$ | |
| Γ_6 | $D^{0}\pi^+$ | not seen |
| Γ_7 | $D^{*+} \pi^{+} \pi^{-}$ | not seen |

$D_1(2420)^{\pm}$ BRANCHING RATIOS

| $\Gamma(D^*(2007)^0\pi^+)/\Gamma_{to}$ | tal | | | | | Γ1/Γ | | |
|-----------------------------------------------------------------|-----------|------------------|----------|---------|----------------------------|-------------|--|--|
| VALUE | | DO CUMENT ID | | TECN | COMMENT | | | |
| seen | | ANJOS | 89c | TPS | $\gamma N \rightarrow D^0$ | $\pi^+ X^0$ | | |
| $\Gamma(D^0\pi^+)/\Gamma(D^*(2007)^0\pi^+)$ Γ_6/Γ_1 | | | | | | | | |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | | | |
| • • • We do not use the | following | data for average | s, fits, | limits, | etc. • • • | | | |
| < 0.18 | 90 | BERGFELD | 94B | CLE2 | $e^+e^- \to$ | hadrons | | |

$D_1(2420)^{\pm}$ POLARIZATION AMPLITUDE A_{D1}

A polarization amplitude A_{D_1} is a parameter that depends on the initial polarization of the D_1 and is sensitive to a possible S-wave contribution to its decay. For D_1 decays the helicity angle, θ_h , distribution varies like

 $1+{\rm A}_{D_1}{\rm cos}^2\theta_h$, where θ_h is the angle in the D^* rest frame between the two pions emitted by the $D_1\to D^*\pi$ and the $D^*\to D\pi$.

Unpolarized D_1 decaying purely via D-wave is predicted to give $A_{D_1} = 3$.

Assuming $\Gamma(\Upsilon(4S) \to B^+B^-)$ / $\Gamma(\Upsilon(4S) \to B^0B^0) = 1.065 \pm 0.026$ and equa partial widths and helicity angle distributions for charged and neutral D_1 mesons.

D₁ (2420) ± REFERENCES

| AUBERT | 09Y | PRL 103 051803 | B. Aubert et al. | (BABAR Collab.) |
|----------|------|----------------|--------------------|---------------------|
| ABE | 05 A | PRL 94 221805 | K. Abe et al. | (BELLE Collab.) |
| BERGFELD | 94 B | PL B340 194 | T. Bergfeld et al. | `(CLEO Collab.) |
| ANJOS | 89 C | PRL 62 1717 | J.C. Anios et al. | (FNAL E691 Collab.) |

 $D_1(2430)^0$

$$I(J^P) = \frac{1}{2}(1^+)$$

 $\begin{array}{c} {\sf OMITTED} \;\; {\sf FROM} \;\; {\sf SUMMARY} \;\; {\sf TABLE} \\ {\it J} = 1^+ \;\; {\sf assignment} \;\; {\sf favored} \;\; ({\sf ABE} \;\; {\sf 04D}). \end{array}$

D1 (2430)0 MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | | | | |
|--------------------------------------------|---------------------|---------|-----------|----------------------------------------------------|--|--|--|--|
| 2427 ± 26 ± 25 | ABE | 04D | BELL | $B^- \rightarrow D^{*+}\pi^-\pi^-$ | | | | |
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • | | | | |
| 2477 ± 28 | ¹ AUBERT | 06L | BABR | $\overline{B}{}^0 \rightarrow D^{*+} \omega \pi^-$ | | | | |
| $^{ m 1}$ Systematic errors not estimated. | | | | | | | | |

D₁ (2430) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | | | |
|-----------------------------------------------|---------------------|-----|------|--------------------------------------------------|--|--|--|--|
| 384 + 107 ± 74 | ABE | 04D | BELL | $B^- \rightarrow D^{*+}\pi^-\pi^-$ | | | | |
| | | | | | | | | |
| 266± 97 | ² AUBERT | 06L | BABR | $\overline{B}^0 \rightarrow D^{*+} \omega \pi^-$ | | | | |
| ² Systematic errors not estimated. | | | | | | | | |

$D_1(2430)^0$ DECAY MODES

| N | Лode | Fraction (Γ_i/Γ) | | | |
|----------------|--------------------|------------------------------|--|--|--|
| Γ ₁ | $O^*(2010)^+\pi^-$ | seen | | | |

D₁(2430)⁰ REFERENCES

 AUBERT
 06L
 PR D74 012001
 B. Aubert et al.
 (BABAR Collab.)

 ABE
 04D
 PR D69 112002
 K. Abe et al.
 (BELLE Collab.)

 $D_2^*(2460)^0$

 2461 ± 6

$$I(J^P) = \frac{1}{2}(2^+)$$

98м DLPH *e*+*e*-

95 BEBC 53,40 $\nu(\overline{\nu}) \rightarrow pX, dX$

 $J^P=2^+$ assignment strongly favored(ALBRECHT 89B, ALBRECHT 89H), natural parity confirmed by the helicity analysis(DEL-AMO-SANCHEZ 10P),

D*(2460)0 MASS

The fit includes $D^\pm, D^0, D_S^\pm, D^{*\pm}, D^{*\pm}, D^{*0}, D_S^{*\pm}, D_1(2420)^0, D_2^*(2460)^0$, and $D_{S1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|------------------|-----------------------|----------|---------|---------------------------------------------------|
| 2462.6 ± 0.7 OUR | FIT Error inc | ludes scale factor o | of 1.3. | | |
| 2461.8 ± 0.8 OUR | AVERAGE Er | ror includes scale t | factor o | of 1.2. | |
| $2462.2 \pm 0.1 \pm 0.8$ | 243k | DEL-A MO-SA | 10P | BABR | $e^+e^- \rightarrow D^+\pi^-X$ |
| $2460.4 \pm 1.2 \pm 2.2$ | 3.4k | AUBERT | 09AB | BABR | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $2461.6 \pm 2.1 \pm 3.3$ | | ¹ ABE | 04D | BELL | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $2464.5 \pm 1.1 \pm 1.9$ | 5.8k | ¹ LINK | 04A | FOCS | γ A |
| $2465 \pm 3 \pm 3$ | 486 | AVERY | 94c | CLE2 | $e^+e^- \rightarrow D^+\pi^-X$ |
| $2453 \pm 3 \pm 2$ | 128 | FRABETTI | 94B | E687 | $\gamma \text{Be} \rightarrow D^+ \pi^- X$ |
| $2461 \pm 3 \pm 1$ | 440 | AVERY | 90 | CLEO | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| $2455 \pm 3 \pm 5$ | 337 | ALBRECHT | 89B | ARG | $e^+e^- \rightarrow D^+\pi^-X$ |
| 2459 ±3 ±2 | 153 | ANJOS | 89c | TPS | $\gamma N \rightarrow D^{+} \pi^{-} X$ |
| • • • We do not u | ıse the followir | ng data for average | s, fits, | limits, | etc. • • • |
| $2469.1 \pm 3.7 + 1.2 \\ -1.3$ | 1560 ± 230 | ² CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{(*)} + \pi^{-} X$ |
| $2463.3 \pm 0.6 \pm 0.8$ | 20k | ABULENCIA | 064 | CDF | $1900 \ p\overline{p} \rightarrow D^{+}\pi^{-} X$ |

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$D_2^*(2460)^0$

$m_{D_2^{*0}} - m_{D^+}$

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|--------------|---------------------|------|------|--------------------------------------------|
| 593.0±0.7 OUR FIT | Error includ | les scale factor of | 1.3. | | |
| $593.9 \pm 0.6 \pm 0.5$ | 20k | ABULENCIA | 06A | CDF | 1900 $p\overline{p} \rightarrow D^+\pi^-X$ |

$m_{D_2^{*0}} - m_{D^{*+}}$

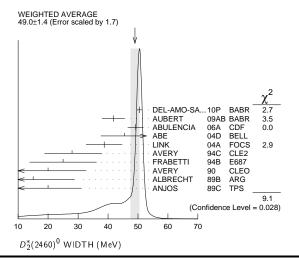
The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|-----------------|--------------------|------|------|---------------------------------------------|
| 452.3±0.7 OUR F | T Error include | es scale factor of | 1.3. | | |
| $458.8 \pm 3.7 + \frac{1.2}{-1.3}$ | 1560 ± 230 | CHEKANOV | 09 | ZEUS | $e^{\pm} \rho \rightarrow D^{(*)+} \pi^- X$ |

D*(2460)0 WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------------------------------------------------|-----------|----------------------|---------------|-----------------------------------------------|
| 49.0± 1.4 OUR AVE | RAGE Erro | r includes scale fac | tor of 1.7. S | ee the ideogram below. |
| $50.5 \pm\ 0.6 \pm\ 0.7$ | 243k | DEL-AMO-SA | | $e^+e^- \rightarrow D^+\pi^-X$ |
| $41.8 \pm \ 2.5 \pm \ 2.9$ | 3.4k | AUBERT | 09AB BABR | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $49.2 \pm\ 2.3 \pm\ 1.3$ | 20k | ABULENCIA | 06A CDF | 1900 $p \overline{p} \rightarrow D^+ \pi^- X$ |
| $45.6 \pm 4.4 \pm 6.7$ | | ⁴ ABE | 04D BELL | $B^- \rightarrow D^+ \pi^- \pi^-$ |
| $38.7 \pm 5.3 \pm 2.9$ | 5.8k | ⁴ LINK | 04A FOCS | γ A |
| 28 $^{+}_{-}$ $^{8}_{7}$ \pm 6 | 486 | AVERY | 94c CLE2 | $e^+e^-\to~D^+\pi^-\mathrm{X}$ |
| 25 ± 10 ± 5 | 128 | FRABETTI | 94B E687 | $\gamma\mathrm{Be}\toD^+\pi^-\mathrm{X}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 440 | AVERY | 90 CLEO | $e^+e^- ightarrow {\it D^{*+}}\pi^-{\rm X}$ |
| $15 \begin{array}{ccc} +13 & +5 \\ -10 & -10 \end{array}$ | 337 | ALBRECHT | 89в ARG | $e^+e^-\to~D^+\pi^-\mathrm{X}$ |
| 20 ± 10 \pm 5 | 153 | ANJOS | 89c TPS | $\gamma N \rightarrow D^+ \pi^- X$ |

⁴ Fit includes the contribution from $D_0^*(2400)^0$.



$D_2^*(2460)^0$ DECAY MODES

 $\overline{D}_{2}^{*}(2460)^{0}$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------|
| Γ ₁ Γ ₂ Γ ₃ Γ ₄ | $D^{+}\pi^{-}$ $D^{*}(2010)^{+}\pi^{-}$ $D^{0}\pi^{+}\pi^{-}$ $D^{*0}\pi^{+}\pi^{-}$ | seen seen not seen not seen |

D₂(2460)⁰ BRANCHING RATIOS

| $\Gamma(D^+\pi^-)/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|----------|---------|---------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| seen | 3.4k | AUBERT | | BABR | |
| seen | 337 | ALBRECHT | | ARG | |
| seen | | ANJOS | 89c | TPS | $\gamma N \rightarrow D^{+} \pi^{-} X$ |
| $\Gamma(D^*(2010)^+\pi^-)$ | /Γ _{total} | | | | Γ_2/Γ |
| VALUE | | DOCUMENT ID | | | |
| seen | | ACKERSTAFF | 97w | OPAL | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| seen | | AVERY | 90 | CLEO | $e^+e^- ightarrow D^{*+}\pi^- X$ |
| seen | | ALBRECHT | 89н | ARG | $e^+e^- \rightarrow D^*\pi^-X$ |
| $\Gamma(D^+\pi^-)/\Gamma(D^*($ | $2010)^{+}\pi^{-})$ | | | | Γ_1/Γ_2 |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.56±0.16 OUR AVE | RAGE | | | | |
| $1.47 \pm 0.03 \pm 0.16$ | 379k | DEL-AMO-SA. | 10P | BABR | $e^+e^- \rightarrow D(*)+\pi^- X$ |
| $2.8 \pm 0.8 \substack{+0.5 \\ -0.6}$ | 560 ± 230 | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{(*)} + \pi^{-} X$ |
| $2.2 \pm 0.7 \pm 0.6$ | | AVERY | 94 c | CLE2 | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| 2.3 ± 0.8 | | AVERY | 90 | CLEO | e^+e^- |
| $3.0 \pm 1.1 \pm 1.5$ | | ALBRECHT | 89н | ARG | $e^+e^- \rightarrow D^*\pi^-X$ |
| • • • We do not use | the following | data for average | s, fits, | limits, | etc. • • • |
| $1.9\ \pm0.5$ | , and the second | ABE | 04D | BELL | $B^- \rightarrow D^{(*)} + \pi^- \pi^-$ |

| $\Gamma(D^+\pi^-)/\bigl[\Gamma(D^+\pi$ | -) + Γ(<i>D</i> | *(2010)+ π^{-})] | | $\Gamma_1/(\Gamma_1+\Gamma_2)$ |
|----------------------------------------|------------------|-----------------------|------|--------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

⁵ AUBERT 09Y BABR $B^+ o D_2^{*0} \ell^+ \nu_\ell$ 8414

 5 Assuming $\Gamma(\Upsilon(4S) \to B^{+}B^{-}) / \Gamma(\Upsilon(4S) \to B^{0}\overline{B}{}^{0}) = 1.065 \pm 0.026$ and equal partial widths for charged and neutral \mathcal{D}_2^* mesons.

$D_2^*(2460)^0$ POLARIZATION AMPLITUDE A_D,

A polarization amplitude A $_{D_2}$ is a parameter that depends on the initial polarization of the D_2 . For D_2 decays the helicity angle, θ_H , distribution varies like $1+{\rm A}_{D_2}\cos(\theta_H)$, where θ_H is the angle in the D^* rest frame between the two pions emitted by the $D_2 \to D^*\pi$ and $D^* \to D\pi$.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | _ |
|---------------------------|----------------|-------------------|---------|----------------------|----------------------|----------------|---|
| • • • We do not use th | e following (| data for averages | , fits, | , limits, ϵ | etc. • • • | | |
| consistent with -1 | 243k | DEL-AMO-SA | 10P | BABR | $e^+e^- \to$ | $D^+\pi^-X$ | |
| $-0.74{}^{+0.49}_{-0.38}$ | 6 | 6 AVERY | 94c | CLE2 | $e^+e^- \rightarrow$ | $D^{*+}\pi^-X$ | |
| 6 Systematic uncertain | ities not esti | imated | | | | | |

D*(2460)0 REFERENCES

| DEL-AMO-SA | 10 D | PR D82 111101 | P. del Amo Sanchez et al. | (BABAR Collab.) |
|------------|------|----------------|---------------------------|---------------------|
| | | | | |
| AUBERT | | PR D79 112004 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 09Y | PRL 103 051803 | B. Aubert et al. | (BABAR Collab.) |
| CHEKANOV | 09 | EPJ C60 25 | S. Chekanov et al. | `(ZEUS Collab.) |
| ABULENCIA | 06A | PR D73 051104 | A. Abulencia et al. | (CDF Collab.) |
| ABE | 04 D | PR D69 112002 | K. Abe et al. | (BÈLLE Collab.) |
| LINK | 04 A | PL B586 11 | J.M. Link et al. | (FOCUS Collab.) |
| ABREU | 98 M | PL B426 231 | P. Abreu et al. | (ĎELPHI Collab.) |
| ACKERSTAFF | 97 W | ZPHY C76 425 | K. Ackerstaff et al. | (OPAL Collab.) |
| AS RATYA N | 95 | ZPHY C68 43 | A.E. Asratyan et al. | (BIRM, BELG, CERN+) |
| AVERY | 94 C | PL B331 236 | P. Avery et al. | (CLEO Collab.) |
| FRABETTI | 94 B | PRL 72 324 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| AVERY | 90 | PR D41 774 | P. Avery, D. Besson | ` (CLEO Collab.) |
| ALBRECHT | 89B | PL B221 422 | H. Albrecht et al. | (ARGUS Collab.) JP |
| ALBRECHT | 89H | PL B232 398 | H. Albrecht et al. | (ARGUS Collab.) JP |
| ANJOS | 89 C | PRL 62 1717 | J.C. Anjos et al. | (FNAL E691 Collab.) |

¹ Fit includes the contribution from $D_0^*(2400)^0$.

 $^{^2\, {\}mbox{\it Calculated}}$ using the mass difference ${\it m}(D_2^{*0})\, -\, {\it m}(D^{*+})_{PDG}$ reported below and $\mathit{m(D^{*+})}_{PDG} =$ 2010.27 \pm 0.17 MeV. The 0.17 MeV uncertainty of the PDG mass value should be added to the experimental uncertainty of $\frac{+1.2}{-1.3}$ MeV.

 $^{^{3}}$ No systematic error given.

 $D_2^*(\overline{2460})^{\pm}$

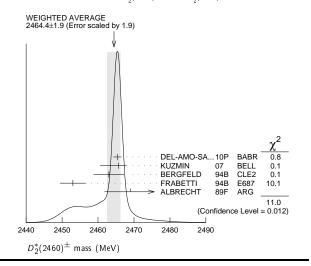
$$I(J^P) = \frac{1}{2}(2^+)$$

 $J^P = 2^+$ assignment strongly favored(ALBRECHT 89B).

$D_2^*(2460)^{\pm}$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------|--------------|-------------------------|----------|---------|------------------------------------------------------|---|
| 2464.4±1.9 OUR AVE | RAGE Er | ror includes scale | factor | of 1.9. | See the ideogram below. | |
| $2465.4 \pm 0.2 \pm 1.1$ | 111 k | ¹ DEL-AMO-SA | 10P | BABR | $e^+ e^- \rightarrow D^0 \pi^+ X$ | ı |
| $2465.7 \pm 1.8 + 1.4 \\ -4.8$ | 2909 | KUZMIN | 07 | BELL | $e^+e^-	o$ hadrons | |
| 2463 ± 3 ± 3 | 310 | | | | $e^+ e^- \rightarrow D^0 \pi^+ X$ | |
| $2453 \pm 3 \pm 2$ | 185 | FRABETTI | | | $\gamma \text{Be} \rightarrow D^0 \pi^+ \text{X}$ | |
| $2469 \pm 4 \pm 6$ | | ALBRECHT | 89F | ARG | $e^+ e^- \rightarrow D^0 \pi^+ X$ | |
| • • • We do not use | the followin | g data for average | s, fits, | limits, | etc. • • • | |
| $2467.6 \pm 1.5 \pm 0.8$ | 3.5 k | ² LINK | 04A | FOCS | γ A | |

 $^{^1}$ At a fixed width of 50.5 MeV. 2 Fit includes the contribution from $D_0^*(2400)^\pm$. Not independent of the corresponding mass difference measurement, $(m_{D_2^*(2460)^{\pm}}) - (m_{D_2^*(2460)^0})$.



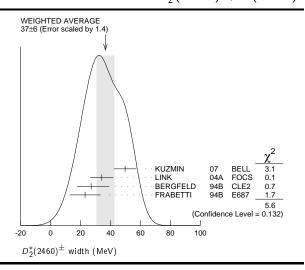
$m_{D_2^*(2460)^{\pm}} - m_{D_2^*(2460)^0}$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------------|-----|------|--------------------------------|
| 2.4±1.7 OUR AVERAGE | | | | |
| $3.1 \pm 1.9 \pm 0.9$ | LINK | 04A | FOCS | γ A |
| $-2 \pm 4 \pm 4$ | BERGFELD | 94B | CLE2 | $e^+e^- ightarrow hadrons$ |
| 0 ±4 | FRABETTI | 94B | E687 | |
| 14 ±5 ±8 | ALBRECHT | 89F | ARG | $e^+e^- \rightarrow D^0\pi^+X$ |

D*(2460) *WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN COMMENT |
|----------------------------------------------------|-----------------|-------------------|--------|-------------------------------------------------|
| 37 ± 6 OUR AVERA | GE Error | includes scale fa | ctor c | of 1.4. See the ideogram below. |
| $49.7 \pm 3.8 \pm 6.4$ | 2909 | KUZMIN | 07 | BELL $e^+e^- \rightarrow \text{hadrons}$ |
| $34.1 \pm 6.5 \pm 4.2$ | 3.5k | ³ LINK | 04A | FOCS γ A |
| $27 \begin{array}{cc} +11 \\ -8 \end{array} \pm 5$ | 310 | BERGFELD | 94B | CLE2 $e^+ e^- \rightarrow D^0 \pi^+ X$ |
| $23 \pm 9 \pm 5$ | 185 | FRABETTI | 94B | E687 $\gamma \text{Be} \rightarrow D^0 \pi^+ X$ |

³ Fit includes the contribution from $D_0^*(2400)^{\pm}$.



$D_2^*(2460)^{\pm}$ DECAY MODES

 $D_2^*(2460)^-$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------|------------------------------|
| Γ_1 Γ_2 | $D^0 \pi^+ \ D^{*0} \pi^+$ | seen |
| Γ_2 | $D^{*0} \pi^{+}$ | seen |
| Γ_3 | $D^+\pi^+\pi^-$ | not seen |
| Γ_4 | $D^{*+}\pi^{+}\pi^{-}$ | not seen |

D*(2460)* BRANCHING RATIOS

| $\Gamma(D^0\pi^+)/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|----------------------------------------|--------------|-----|------|----------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | ALBRECHT | 89F | ARG | e^+e^- | $D^0\pi^+X$ |
| $\Gamma(D^0\pi^+)/\Gamma(D^{*0}\pi^+)$ | | | | | Γ_1/Γ_2 |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 1.9+1.1+0.3 | BERGEELD | 94B | CLE2 | e+e | hadrons |

| $1.9 \pm 1.1 \pm 0.3$ | | BERGFELD | 94B | CLE2 | e ⁺ e [−] → hadrons |
|-----------------------------------|------------------|-----------------------------------|-----|------|-----------------------------------------|
| $\Gamma(D^0\pi^+)/[\Gamma(D^0\pi$ | +) + Γ(<i>D</i> |)* ⁰ π ⁺)] | | | $\Gamma_1/(\Gamma_1+\Gamma_2)$ |
| VALUE | EVT C | DOCUMENT ID | | TECN | COMMENT |

• • • We do not use the following data for averages, fits, limits, etc. • • • 3361 ⁴ AUBERT

09Y BABR $\overline{B}^0 \rightarrow D_2^{*+} \ell^- \nu_{\ell}$ 4 Assuming $\Gamma(\Upsilon(4S) \to B^+B^-) \ / \ \Gamma(\Upsilon(4S) \to B^0\overline{B}{}^0) = 1.065 \pm 0.026$ and equal partial widths for charged and neutral D_2^{*} mesons.

$D_2^*(2460)^{\pm}$ REFERENCES

| AUBERT | 09Y | PR D82 111101 PRL 103 051803 | P. del Amo Sanchez et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
|----------|------|---------------------------------|-----------------------------------------------|------------------------------------|
| KUZMIN | 04 A | PR D76 012006 | A. Kuzmin <i>et al.</i> | (BELLE Collab.) |
| LINK | | PL B586 11 | J.M. Link <i>et al.</i> | (FOCUS Collab.) |
| BERGFELD | | PL B340 194 | T. Bergfeld <i>et al.</i> | (CLEO Collab.) |
| FRABETTI | 94 B | PRL 72 324 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| ALBRECHT | | PL B221 422 | H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECHT | 89F | PL B231 208 | H. Albrecht et al. | (ARGUS Collab.) |

$D(2550)^{0}$

$$I(J^P) = \frac{1}{2}(0^-)$$

OMITTED FROM SUMMARY TABLE $J^P = 0^-$ assignment based on the $=0^-$ assignment based on the helicity analysis (DEL-AMO-SANCHEZ 10P).

| $D(2550)^{0}$ | MASS |
|---------------|------|
|---------------|------|

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|--------------------|------|---------------|------|------------------------------------|
| 2539.4 ± 4.5 ± 6.8 | 34k | DEL-AMO-SA10P | BABR | $e^+e^- \rightarrow D^{*+}\pi^- X$ |

D(2550)0 WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------|------|---------------|------|------------------------------------|
| 130±12±13 | 34k | DEL-AMO-SA10P | BABR | $e^+e^- \rightarrow D^{*+}\pi^- X$ |

 $D(2550)^0$, D(2600), $D^*(2640)^{\pm}$, D(2750)

D(2550)0 DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------|------------------------------|
| $\overline{\Gamma_1}$ | $D^{*+}\pi^{-}$ | seen |

D(2550)0 REFERENCES

DEL-AMO-SA... 10P PR D82 111101

P. del Amo Sanchez et al.

(BABAR Collab.)



$$I(J^P) = \frac{1}{2}(??)$$

OMITTED FROM SUMMARY TABLE J^P consistent with natural parity (D

consistent with natural parity (DEL-AMO-SANCHEZ 10P).

D(2600) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | CHG | COMMENT |
|--------------------------|----------|----------------------------|-----------|-----|-----------------------------------|
| 2612 ±6 OUR A | VERAGE | Error includes scale fac | tor of 1. | 9. | |
| $2608.7 \pm 2.4 \pm 2.5$ | 26k | DEL-AMO-SA10P | BABR | 0 | $e^+ e^- \rightarrow D^+ \pi^- X$ |
| $2621.3 \pm 3.7 \pm 4.2$ | 13k | ¹ DEL-AMO-SA10P | BABR | + | $e^+ e^- \rightarrow D^0 \pi^+ X$ |
| 1 At a fixed width | of 93 Me | V | | | |

D(2600) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------|------|---------------|------|-----------------------------------|
| 93±6±13 | 26k | DEL-AMO-SA10P | BABR | $e^+ e^- \rightarrow D^+ \pi^- X$ |

D(2600) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|---------------------------------|------------------------------|
| Γ_1 | $D\pi$ | seen |
| Γ_2 | $D^{+}\pi^{-} \ D^{0}\pi^{\pm}$ | seen |
| Γ_3 | $D^0\pi^\pm$ | seen |
| Γ_4 | $D^*\pi$ | seen |
| Γ_5 | $D^{*+}\pi^{-}$ | seen |

D(2600) BRANCHING RATIOS

| $\Gamma(D^+\pi^-)/\Gamma(D^{*+}\pi^-)$ | ·-) | | | Γ_2/Γ_5 | |
|----------------------------------------|------|---------------|------|-----------------------------------|--|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| $0.32 \pm 0.02 \pm 0.09$ | 76 k | DEL-AMO-SA10P | BABR | $e^+e^- \rightarrow P(*)+\pi^- X$ | |

D(2600) REFERENCES

DEL-AMO-SA... 10P PR D82 111101 P. del Amo Sanchez et al. (BABAR Collab.)



$$I(J^P) = \frac{1}{2}(?^?)$$

OMITTED FROM SUMMARY TABLE

Seen in Z decays by ABREU 98M. Not seen by ABBIENDI 01N and CHEKANOV 09. Needs confirmation.

D*(2640) + MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|---------|-------------|-----|------|---------------------------------------|
| 2637±2±6 | 66 ± 14 | ABREU | 98м | DLPH | $e^+e^- \rightarrow P^*+\pi^+\pi^- X$ |

D*(2640) * WIDTH

| VALUE (MeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------|-----|-------------|-----|------|--------------------------------------------------------------------------|
| <15 | 95 | ABREU | 98м | DLPH | $ \begin{array}{c} e^+e^- \rightarrow \\ D^{*+}\pi^+\pi^-X \end{array} $ |

D*(2640)+ DECAY MODES

 $D^*(2640)^-$ modes are charge conjugates of modes below.

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-----------------------|-------------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | $D^*(2010)^+\pi^+\pi^-$ | seen |

D*(2640) + REFERENCES

| 09 | EPJ C60 | 25 | S. Chekanov et . | al. | (ZEUS | Collab |
|------|---------|-------------|------------------|----------------------------------|------------------------------------|------------------------------------------|
| 01N | EPJ C20 | 445 | G. Abbiendi et a | al. | OPAL | Collab |
| 98 M | PL B426 | 231 | P. Abreu et al. | ([| DÈLPHI | Collab |
| | 01N | 01N EPJ C20 | 01N EPJ C20 445 | 01N EPJ C20 445 G. Abbiendi et a | O1N EPJ C20 445 G. Abbiendi et al. | 01N EPJ C20 445 G. Abbiendi et al. (OPAL |

D(2750)

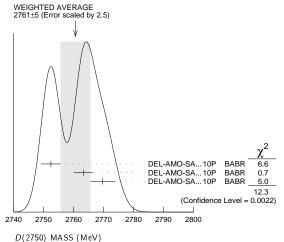
$$I(J^P) = \frac{1}{2}(?^?)$$

OMITTED FROM SUMMARY TABLE

D(2750) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | CHG | COMMENT |
|--------------------------|---------|------------------------------|-----------|---------|---------------------------------|
| 2761 ±5 OUR | AVERAGE | Error includes scale fa | ctor of 2 | 2.5. Se | e the ideogram below. |
| $2752.4 \pm 1.7 \pm 2.7$ | 23.5k | ¹ DEL-AMO-SA10P | BABR | 0 | $e^+e^- \rightarrow$ |
| | | 4 | | | $e^+e^- \rightarrow D^+\pi^- X$ |
| $2763.3 \pm 2.3 \pm 2.3$ | | ¹ DEL-AMO-SA10P | | | |
| $2769.7 \pm 3.8 \pm 1.5$ | 5.7k | ^{1,2} DEL-AMO-SA10P | BABR | + | $e^+e^- \rightarrow D^0\pi^+X$ |
| 1 | | | | | |

 1 The states observed in the $D^*\pi$ and $D\pi$ final states are not necessarily the same. ² At a fixed width of 60.9 MeV.



D(2750) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|------------------------|------------|----------------------------|----------|-----------------------------------|
| 63 ±6 OUR AVER | GE | · | | |
| 71 ± 6 ± 11 | 23.5k | | | $e^+e^- \rightarrow D^{*+}\pi^-X$ |
| $60.9 \pm 5.1 \pm 3.6$ | 11.3k | ³ DEL-AMO-SA10P | BABR | $e^+e^- \rightarrow D^+\pi^-X$ |
| 3 The states absence | tin the Di | * - and D - final states s | ro not n | acassarily the same |

D(2750) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $D\pi$ | seen |
| Γ_2 | $D^{+}\pi^{-} \ D^{0}\pi^{\pm}$ | seen |
| Γ_3 | | seen |
| Γ_4 | $D^*\pi \atop D^{*+}\pi^-$ | seen |
| Γ_5 | $D^{*+}\pi^-$ | seen |

D(2750) BRANCHING RATIOS

$$\frac{\Gamma(D^{+}\pi^{-})/\Gamma(D^{*+}\pi^{-})}{\text{0.42\pm0.05\pm0.11}} \underbrace{\frac{EVTS}{34.8k}} \underbrace{\frac{DOCUMENT\ ID}{4} \underbrace{\frac{TECN}{BABR}}_{DEL-AMO-SA...10P} \underbrace{\frac{COMMENT}{BABR}}_{D(*)+\pi^{-}} \underbrace{\frac{\Gamma_{2}/\Gamma_{5}}{BABR}}_{D(*)+\pi^{-}}$$

 4 The states observed in the $D^*\pi$ and $D\pi$ final states are not necessarily the same.

D(2750) POLARIZATION AMPLITUDE AD

A polarization amplitude ${\rm A}_D$ is a parameter that depends on the initial polarization of the D(2750). For D(2750) decays the helicity angle, θ_H , distribution varies like $1+{\rm A}_D\cos(\theta_H)$, where θ_H is the angle in the D^* rest frame between the two pions emitted by the $D(2750)
ightarrow D^*\pi$ and $D^* \to D\pi.$

| VALUE | EVIS | DOCUMENT | ID | IECN | COMMENT | | |
|-------------------------|--------------------|-------------|--------------|-----------|---------------------|-----------------|--------|
| • • • We do not use the | e following d | ata for ave | rages, fits, | limits, e | tc. • • • | | |
| -0.33 ± 0.28 | 23.5k ⁵ | DEL-AMO | -SA10P | BABR | $e^+e^ \rightarrow$ | $D^{*+}\pi^{-}$ | X |
| 5 Systematic uncertain | | | states ob | served in | the $D^*\pi$ | and $D\pi$ | fin al |

D(2750) REFERENCES

DEL-AMO-SA... 10P PR D82 111101 (BABAR Collab.) P. del Amo Sanchez et al

 $D_s^+ = c\overline{s}$, $D_s^- = \overline{c}s$, similarly for D_s^* 's



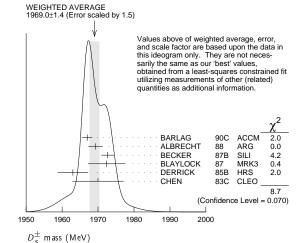
$$I(J^P) = 0(0^-)$$

The angular distributions of the decays of the ϕ and $\overline{K}^*(892)^0$ in the $\phi\pi^+$ and $K^+\overline{K}^*(892)^0$ modes strongly indicate that the spin is zero. The parity given is that expected of a $c\,\overline{s}$ ground state.

D_s^{\pm} MASS

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements. Measurements of the D_S^\pm mass with an error greater than 10 MeV are omitted from the fit and average. A number of early measurements have been omitted

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|--------------------|--------------------------------|----------|-----------|--------------------------------------------|
| 1968.49 ± 0.32 OUR FIT | F Error i | ncludes scale fact | or of 1 | .3. | |
| 1969.0 ± 1.4 OUR AV | ERAGE | Error includes sca | ile fac | tor of 1. | 5. See the ideogram |
| below. | | | | | |
| $1967.0 \pm 1.0 \pm 1.0$ | 54 | BARLAG | 90c | ACCM | π^- Cu 230 GeV |
| $1969.3 \pm 1.4 \pm 1.4$ | | ALBRECHT | 88 | ARG | e ⁺ e ⁻ 9.4–10.6 GeV |
| 1972.7 \pm 1.5 \pm 1.0 | 21 | BECKER | 87B | SILI | 200 GeV π,K,p |
| $1972.4 \pm 3.7 \pm 3.7$ | 27 | BLAYLOCK | 87 | MRK3 | e^+e^- 4.14 GeV |
| $1963 \pm \ 3 \pm \ 3$ | 30 | DERRICK | 85B | HRS | e^+e^- 29 GeV |
| 1970 \pm 5 \pm 5 | 104 | CHEN | 83c | CLEO | $e^{+}e^{-}$ 10.5 GeV |
| • • • We do not use the | e following | data for average | s, fits, | limits, e | etc. • • • |
| 1968.3 \pm 0.7 \pm 0.7 | 290 | ¹ ANJOS | 88 | E691 | Photoproduction |
| 1980 ±15 | 6 | USHIDA | 86 | EMUL | u wideband |
| 1973.6 \pm 2.6 \pm 3.0 | 163 | ALBRECHT | 85 D | ARG | e^+e^- 10 GeV |
| 1948 ± 28 ± 10 | 65 | AIHARA | 84D | TPC | e^+e^- 29 GeV |
| 1975 \pm 9 \pm 10 | 49 | ALTHOFF | 84 | TASS | $e^{+}e^{-}$ 14–25 GeV |
| 1975 ± 4 | 3 | BAILEY | 84 | ACCM | hadron $^+$ Be $ ightarrow \phi \pi^+$ X |
| $^{ m 1}$ ANJOS 88 enters the | e fit via <i>m</i> | $D_s^{\pm} - m_{D^{\pm}}$ (see | below | r). | |



$m_{D_s^{\pm}} - m_{D^{\pm}}$

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-----------|---------------------|---------|---------|---------------------------------------------------------|
| 98.87±0.29 OUR FIT | Error inc | ludes scale factor | of 1.4. | | |
| 98.85 ± 0.25 OUR AVE | RAGE E | rror includes scale | factor | of 1.1. | |
| $99.41 \pm 0.38 \pm 0.21$ | | ACOSTA | 03D | CDF2 | $\overline{\rho} \rho$, $\sqrt{s} = 1.96 \text{ TeV}$ |
| 98.4 ± 0.1 ± 0.3 | 48k | AUBERT | 02G | BABR | $e^+e^-pprox \Upsilon(4S)$ |
| 99.5 $\pm 0.6 \pm 0.3$ | | BROWN | 94 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ |
| 98.5 ±1.5 | 555 | CHEN | 89 | CLEO | e^+e^- 10.5 GeV |
| 99.0 ±0.8 | 290 | ANJOS | 88 | E691 | Photoproduction |
| | | | | | |

D MEAN LIFE

Measurements with an error greater than $100\times 10^{-15}\,\text{s}$ or with fewer than 100 events have been omitted from the Listings.

| | EVTS | | | | COMMENT |
|------------------------------------------------|------------------|------------------------|------------|------------|----------------------------------------------------------|
| 500 ± 7 OUR AVER | AGE Erro | r includes scale fa | ctor of | 1.3. Se | e the ideogram below. |
| $507.4 \pm 5.5 \pm 5.1$ | 13.6k | LINK | 05J | FOCS | $\phi\pi^+$ and $\overline{\mathit{K}}^{*0}\mathit{K}^+$ |
| $472.5 \pm 17.2 \pm 6.6$ | 760 | IORI | 01 | SELX | 600 GeV Σ^- , π^- , p |
| 518 ± 14 \pm 7 | 1662 | AITALA | 99 | E791 | π^- nucleus, 500 GeV |
| $486.3 \pm 15.0 ^{+}_{-} \stackrel{4.9}{5.1}$ | 2167 | ² BONVICINI | 99 | CLE2 | $e^+ e^- \approx ~ \Upsilon(45)$ |
| 475 ± 20 ± 7 | 900 | FRABETTI | | | γ Be, $\phi\pi^+$ |
| $500 \pm 60 \pm 30$ | 104 | FRABETTI | 90 | E687 | γ Be, $\phi\pi^+$ |
| 470 ± 40 ± 20 | 228 | RAAB | 88 | E691 | Photoproduction |
| ² BONVICINI 99 obta | ins 1.19 \pm (| 0.04 for the ratio | of D_s^+ | to D^0 I | ifet im es. |

WEIGHTED AVERAGE 500±7 (Error scaled by 1.3) LINK IORI AITALA 01 99 BONVICINI FRABETTI FRABETTI RAAB 90 E687 (Confidence Level = 0.154) 600 650

D+ DECAY MODES

 D_s^{\pm} mean life (10⁻¹⁵ s)

Unless otherwise noted, the branching fractions for modes with a resonance in the final state include all the decay modes of the resonance. D_s^- modes

| | Mode | Fraction (Γ_i/Γ) | Scale factor / Confidence leve |
|------------|---------------------------------------------------|----------------------------------------------|-----------------------------------|
| | Inclusive | modes | |
| Γ_1 | e^+ semileptonic | [a] (6.5 ± 0.4) % | |
| Γ2 | π^+ anything | $(119.3 \pm 1.4) \%$ | ,) |
| 3 | π^- anything | $(43.2 \pm 0.9)\%$ | |
| 4 | π^0 anything | (123 ±7) % | ,) |
| 5 | K^- anything | $(18.7 \pm 0.5)\%$ | |
| 6 | K^+ anything | $(28.9 \pm 0.7)\%$ | ,) |
| 7 | K_S^0 anything | $(19.0 \pm 1.1)\%$ | |
| 8 | η anything | [b] (29.9 ± 2.8) % | , |
| 9 | ω anything | $(6.1 \pm 1.4)\%$ | Ď |
| 10 | η' anything | [c] (11.7 ±1.8) % | Ď |
| - 11 | $f_0(980)$ anything, $f_0 \rightarrow \pi^+\pi^-$ | < 1.3 % | CL=90% |
| 12 | ϕ anything | $(15.7 \pm 1.0)\%$ | |
| 13 | K ⁺ K [−] anything | $(15.8 \pm 0.7)\%$ | |
| 14 | $K_S^0 K^+$ anything | (5.8 ± 0.5) % | |
| - 15 | $K_S^{\emptyset} K^-$ anything | $(1.9 \pm 0.4)\%$ | , |
| 16 | $2K_{S}^{0}$ anything | $(1.70 \pm 0.32)\%$ | |
| 17 | 2K ⁺ anything | < 2.6 × | 10 ⁻³ CL=90% |
| 18 | 2K anything | | 10 ⁻⁴ CL=90% |
| 10 | Leptonic and sem | | |
| 19 | $e^+ u_e$ | | 10 ⁻⁴ CL=90% |
| 19 20 | ě | (5.90 ± 0.33) × | _ |
| | | , | |
| | $	au^+ u_	au$ $	au^+ u_	au^-$ | (5.43±0.31) % |) |
| 22 23 | $\phi e^+ \nu_e$ | [d] / 2.40 0.14) 9/ | |
| 23 | $\eta e^{+} \nu_{e} + \eta'(958) e^{+} \nu_{e}$ | [d] (2.49 ± 0.14) % [d] (3.66 ± 0.37) % | |
| | | | |
| 25 | $\eta'(958) e^+ \nu_e$ | | |
| 26 | $\omega e^+ \nu_e$ | | 10 ⁻³ CL=90% |
| 27 | $K^0 e^+ \nu_e$ | (3.7 ±1.0)× | _ |
| 「28 「29 | $K^*(892)^0 e^+ \nu_e$ | [d] (1.8 ±0.7)× | _ |
| _29 | f (000) -+ f + - | [U] (1.0 ± 0.7) × | |

 $(-2.00\pm0.32)\times10^{-3}$

 $f_0(980) e^+ \nu_e$, $f_0 \rightarrow \pi^+ \pi^-$

 Γ_{93}

 $K^+ \omega \pi^+ \pi^-$

```
Hadronic modes with a K\overline{K} pair
           K^+K_S^0
\Gamma_{31}
                                                                                         1.48 ± 0.08) %
           K^+K^-\pi^+
                                                                                   (5.49 \pm 0.27)\%
\Gamma_{32}
                                                                            [f]
                \phi\pi^+
\Gamma_{33}
                                                                                         4.5 \pm 0.4 ) %
                                                                         [d,g]
                \phi\pi^+, \phi\to K^+K^-
K^+\overline{K}^*(892)^0, \overline{K}^{*0}\to
                                                                                   (2.28 \pm 0.12)\%
\Gamma_{34}
                                                                           [g]
\Gamma_{35}
                                                                                     (2.63\pm0.13)\%
                f_0(980)\pi^+, f_0 \rightarrow K^+K^-
\Gamma_{36}
                                                                                    (1.16\pm0.32)\%
                f_0(380) \pi^+, f_0 \to K^+ K^-

f_0(1370) \pi^+, f_0 \to K^+ K^-

f_0(1710) \pi^+, f_0 \to K^+ K^-

K^+ \overline{K}_0^* (1430)^0, \overline{K}_0^* \to
                                                                                    (\phantom{-}7\phantom{\pm}\pm5\phantom{-})\times10^{-4\phantom{0}}
Γ<sub>37</sub>
\Gamma_{38}
                                                                                    (6.7 \pm 2.9) \times 10^{-4}
                                                                                     ( 1.9~\pm0.4 ) \times\,10^{-3}
\Gamma_{39}
            K^0 \overline{K^0}_{\pi^+}^{K^- \pi^+}
\Gamma_{40}
                K^*(892)^+ \overline{K}^0
                                                                           [d] ( 5.4 ±1.2)%
\Gamma_{41}
            K^{+}K^{-}\pi^{+}\pi^{0}
\Gamma_{42}
                                                                                    ( 5.6\ \pm0.5 ) %
                                                                           [d] (8.4 + 1.9 - 2.3)
\Gamma_{43}
                \phi \rho^+
\Gamma_{44}
            K_S^0 K^- 2\pi^+
                                                                                    (1.64 \pm 0.12)\%
                K^*(892) + \overline{K}^*(892)^0
                                                                                   ( 7.2 ±2.6 ) %
\Gamma_{45}
\Gamma_{46}
            K^{+}K_{S}^{0}\pi^{+}\pi^{-}
                                                                                        9.6 \pm 1.3 \times 10^{-3}
                                                                                    ( 8.8~\pm1.6~)\times10^{-3}
            K^{+}K^{-}2\pi^{+}\pi^{-}
\Gamma_{47}
                \phi 2\pi^+\pi^-
                                                                           [d] (1.21 \pm 0.16) \%
Γ<sub>48</sub>
                K^+K^-\rho^0\pi^+ non-\phi \phi\rho^0\pi^+ , \phi\to K^+K^-
                                                                                                            \times 10^{-4}
                                                                                   < 2.6
\Gamma_{49}
                                                                                                                                CI - 90\%
                                                                                    ( 6.6~\pm1.3~)\times10^{-3}
\Gamma_{50}
                    \phi a_1(1260)^+ , \phi 
ightarrow
                                                                                    (\phantom{-}7.5\phantom{0}\pm1.3\phantom{0})\times10^{-3\phantom{0}}
\Gamma_{51}
                           K^+\,K^- , a_1^+ 
ightarrow 
ho^0\,\pi^+
                K^+K^-2\pi^+\pi^- nonresonant
                                                                                    (\phantom{-}9\phantom{\pm}\pm7\phantom{-})\times10^{-4\phantom{0}}
\Gamma_{52}
           2K_{S}^{0}2\pi^{+}\pi^{-}
\Gamma_{53}
                                                                                    (8.3 \pm 3.5) \times 10^{-4}
                                             Hadronic modes without K's
           \pi^+\pi^0
                                                                                                             \times\,10^{-4}
\Gamma_{54}
                                                                                  < 3.4
                                                                                                                                CL=90%
           2\pi^{+}\pi^{-}
\Gamma_{55}
                                                                                    (1.10\pm0.06)\%
                \rho^{0} \pi^{+}
                                                                                     (2.0 \pm 1.2) \times 10^{-4}
\Gamma_{56}
               \pi^{+}(\pi^{+}\pi^{-})_{S-\text{wave}}
f_{0}(980)\pi^{+}, f_{0} \rightarrow \pi^{+}\pi^{-}
f_{0}(1370)\pi^{+}, f_{0} \rightarrow \pi^{+}\pi^{-}
                                                                           [h] (9.2 \pm 0.6) \times 10^{-3}
\Gamma_{57}
\Gamma_{58}
\Gamma_{59}
                     f_0(1500)\pi^+, f_0 \to \pi^+\pi^-
\Gamma_{60}
                f_2(1270) \pi^+, f_2 \rightarrow \pi^+ \pi^-
\rho(1450)^0 \pi^+, \rho^0 \rightarrow \pi^+ \pi^-
                                                                                     (1.11\pm0.20)\times10^{-3}
Γ<sub>61</sub>
                                                                                    (3.0 \pm 2.0) \times 10^{-4}
\Gamma_{62}
           \pi^+\,\dot{2}\pi^0
                                                                                     ( 6.5~\pm1.3~)\times10^{-3}
           2\pi^+\pi^-\pi^0
Γ<sub>64</sub>
              \eta \pi^+
\Gamma_{65}
                                                                           [d] ( 1.83 ± 0.15) %
                                                                                   (2.5 \pm 0.7) \times 10^{-3}
               \omega \pi^+
Γ<sub>66</sub>
                                                                                    ( 8.0~\pm 0.9~)\times 10^{-3}
           3\pi^{+} 2\pi^{-}
Γ<sub>67</sub>
           2\pi^{+}\pi^{-}2\pi^{0}
\Gamma_{68}
\Gamma_{69}
                                                                           [d] ( 8.9 \pm 0.8)%
                \eta \rho^+
                \eta \pi^+ \pi^0 3-b ody
\Gamma_{70}
                                                                           [d] < 5
                                                                                                                                CL=90%
                \stackrel{\cdot}{\omega}\pi^+\pi^0
\Gamma_{71}
                                                                           [d] ( 2.8 \pm 0.7) %
           3\pi^{+}\,2\pi^{-}\,\pi^{0}
                                                                                        4.9 \pm 3.2 \%
\Gamma_{72}
                \omega 2\pi^+\pi^-
                                                                           [d]
                                                                                   (1.6 \pm 0.5)\%
Γ<sub>73</sub>
                \eta'(958)\pi^{+}
\Gamma_{74}
                                                                         [c,d] ( 3.94 ± 0.33) %
           3\pi^{+}2\pi^{-}2\pi^{0}
\Gamma_{75}
\Gamma_{76}
                \omega \eta \pi^+
                                                                           [d] < 2.13
                                                                                                                                CL=90%
\Gamma_{77}
                \eta'(958) \rho^+
                                                                         [c,d] ( 12.5 ±2.2 ) %
                \eta'(958)\pi^+\pi^0 3-body
\Gamma_{78}
                                                                                                                                CL=90%
                                                                           [d] < 1.8
                                             Modes with one or three K's
           K^+\pi^0
\Gamma_{79}
                                                                                    ( 6.2~\pm 2.1 ) \times\,10^{-4}
\Gamma_{80}
           K_S^0 \pi^+
                                                                                    (1.21\pm0.08)\times10^{-3}
                                                                           [d] (1.75\pm0.35)\times10^{-3}
           K^+ \eta
\Gamma_{81}
                                                                                                           \times 10^{-3}
\Gamma_{82}
           K^+\omega
                                                                           [d] < 2.4
                                                                                   (1.8 \pm 0.6) \times 10^{-3}
           K^+ \eta'(958)
Γ<sub>83</sub>
           K^+ \stackrel{\cdot}{\pi^+} \stackrel{\cdot}{\pi^-} K^+ \stackrel{\cdot}{\rho^0}
                                                                                         6.9~\pm0.5 )\times10^{-3}
\Gamma_{84}
                                                                                         2.7 \pm 0.5 ) \times 10^{-3}
Γ<sub>85</sub>
                K^+ 
ho (1450)^0 , 
ho^0 
ightarrow \ \pi^+ \, \pi^-
\Gamma_{86}
                                                                                    (7.3 \pm 2.6) \times 10^{-4}
                K^*(892)^0 \pi^+, K^{*0} \to K^+ \pi^- K^*(1410)^0 \pi^+, K^{*0} \to K^+ \pi^- K^*(1410)^0 \pi^+
                                                                                    (-1.50\pm0.26)\times10^{-3}
Γ<sub>87</sub>
\Gamma_{88}
                                                                                    (1.30\pm0.31)\times10^{-3}
                K^*(1430)^0 \pi^+ , K^{*0} \rightarrow
Γ89
                K^+\pi^-
K^+\pi^+\pi^- nonresonant
                                                                                     (1.1 \pm 0.4) \times 10^{-3}
\Gamma_{90}
           K^0 \pi^+ \pi^0
\Gamma_{91}
                                                                                    (1.00\pm0.18)\%
           K_S^0 2\pi^+ \pi^-
                                                                                    (-2.9\ \pm 1.1\ )\times 10^{-3}
\Gamma_{92}
           K^{+}\omega\pi^{0}
```

 $\times\,10^{-3}$

 $\times\,10^{-3}$

CL=90%

CL=90%

[d] < 8.2

[d] < 5.4

```
\times\,10^{-3}
         K^+\omega\eta
\Gamma_{95}
                                                                                                          CL=90%
                                                               [d] < 7.9
        2K^{+}K^{-}
                                                                         2.20 \pm 0.23) \times 10^{-4}
\Gamma_{96}
             \phi\, {\it K}^+ , \phi 
ightarrow \, {\it K}^+\, {\it K}^-
                                                                      (9.0 \pm 2.1) \times 10^{-5}
Γ97
                                 Doubly Cabibbo-suppressed modes
         2K^+\pi^-
                                                                      (-1.28\pm0.14)\times10^{-4}
\Gamma_{98}
             K^+\,K^*(892)^0 , K^{*0} 
ightarrow
                                                                      (6.0 \pm 3.5) \times 10^{-5}
Γ99
                  K^+\pi
```

Baryon-antibaryon mode

 $\Gamma_{100} \ p\, \overline{n}$ $(1.3 \pm 0.4) \times 10^{-3}$

$\Delta C = 1$ weak neutral current (C1) modes, Lepton family number (LF), or Lepton number (L) violating modes

| Γ_{101} | π^+ e^+ e^- | | [i] | 1.3 | $\times 10^{-5}$ | CL=90% |
|------------------|----------------------------------------|----|-------|----------------------------------------------|--------------------|--------|
| Γ ₁₀₂ | $\pi^+\phi$, $\phi ightarrow e^+e^-$ | | [j] (| $\begin{array}{cc} & +8 \\ & -4 \end{array}$ | $) \times 10^{-6}$ | |
| Γ_{103} | $\pi^+\mu^+\mu^-$ | | [i] < | 2.6 | $\times 10^{-5}$ | CL=90% |
| Γ_{104} | $K^{+}e^{+}e^{-}$ | C1 | < | 3.7 | $\times 10^{-6}$ | CL=90% |
| | $K^+ \mu^+ \mu^-$ | C1 | < | 2.1 | $\times 10^{-5}$ | CL=90% |
| Γ_{106} | $K^*(892)^+ \mu^+ \mu^-$ | C1 | < | 1.4 | $\times 10^{-3}$ | CL=90% |
| Γ_{107} | π^+ e^+ μ^- | LF | < | 1.2 | $\times 10^{-5}$ | CL=90% |
| | $\pi^+e^-\mu^+$ | LF | < | 2.0 | $\times 10^{-5}$ | CL=90% |
| Γ ₁₀₉ | $K^+e^+\mu^-$ | LF | < | 1.4 | $\times 10^{-5}$ | CL=90% |
| Γ_{110} | K^+ $e^-\mu^+$ | LF | < | 9.7 | $\times 10^{-6}$ | CL=90% |
| Γ_{111} | π^- 2 e^+ | L | < | 4.1 | $\times 10^{-6}$ | CL=90% |
| Γ_{112} | $\pi^{-}2\mu^{+}$ | L | < | 1.4 | $\times 10^{-5}$ | CL=90% |
| Γ_{113} | $\pi^-e^+\mu^+$ | L | < | 8.4 | $\times 10^{-6}$ | CL=90% |
| Γ_{114} | $K^{-}2e^{+}$ | L | < | 5.2 | $\times 10^{-6}$ | CL=90% |
| Γ_{115} | $K^-2\mu^+$ | L | < | 1.3 | $\times 10^{-5}$ | CL=90% |
| Γ_{116} | $K^-e^+\mu^+$ | L | < | 6.1 | $\times 10^{-6}$ | CL=90% |
| | $K^*(892)^- 2\mu^+$ | L | < | 1.4 | $\times 10^{-3}$ | CL=90% |
| | | | | | | |

- $\it [a]$ This is the purely $\it e^+$ semileptonic branching fraction: the $\it e^+$ fraction from au^+ decays has been subtracted off. The sum of our (non-au) e^+ exclusive fractions — an $e^+\nu_e$ with an $\eta, \eta', \phi, K^0, K^{*0}$, or $f_0(980)$ is $7.0 \pm 0.4 \%$
- [b] This fraction includes η from η' decays.
- [c] Two times (to include μ decays) the $\eta' e^+ \nu_e$ branching fraction, plus the $\eta' \pi^+$, $\eta' \rho^+$, and $\eta' K^+$ fractions, is (18.6 \pm 2.3)%, which considerably exceeds the inclusive η' fraction of $(11.7\pm1.8)\%$. Our best guess is that the $\eta' \rho^+$ fraction, (12.5 \pm 2.2)%, is too large.
- [d] This branching fraction includes all the decay modes of the final-state resonance.
- [e] A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+ . Neither Cabibbo-favored nor Cabibbo-suppressed decays can contribute, and $\omega - \phi$ mixing is an unlikely explanation for any fraction above about 2×10^{-4} .
- [f] The branching fraction for this mode may differ from the sum of the submodes that contribute to it, due to interference effects. See the
- [g] We decouple the $D_c^+ \rightarrow \phi \pi^+$ branching fraction obtained from mass projections (and used to get some of the other branching fractions) from the $D_s^+ \to \phi \pi^+$, $\phi \to K^+ K^-$ branching fraction obtained from the Dalitz-plot analysis of $D_s^+ \to K^+ K^- \pi^+$. That is, the ratio of these two branching fractions is not exactly the $\phi \to K^+K^-$ branching fraction
- $[\hbar]$ This is the average of a model-independent and a \emph{K} -matrix parametrization of the $\pi^+\pi^-$ S-wave and is a sum over several f_0 mesons.
- [i] This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks must change flavor in this decay.
- [j] This is not a test for the $\Delta C=1$ weak neutral current, but leads to the $\pi^+ \ell^+ \ell^-$ final state.

CONSTRAINED FIT INFORMATION

An overall fit to 16 branching ratios uses 17 measurements and one constraint to determine 12 parameters. The overall fit has a $\chi^2=2.4$ for 6 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle/(\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.

| X ₂₅ | 16 | | | | | | | | | |
|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|----------|----------|------------------------|-----------------|-----------------|
| <i>x</i> ₂₆ | 12 | 2 | | | | | | | | |
| <i>x</i> ₃₁ | 0 | 0 | 0 | | | | | | | |
| <i>x</i> ₃₂ | 0 | 0 | 0 | 76 | | | | | | |
| x_{42} | 0 | 0 | 0 | 42 | 48 | | | | | |
| x ₄₄ | 0 | 0 | 0 | 51 | 59 | 32 | | | | |
| <i>x</i> ₅₅ | 0 | 0 | 0 | 59 | 74 | 37 | 45 | | | |
| X ₆₅ | 0 | 0 | 0 | 67 | 51 | 29 | 35 | 40 | | |
| x ₆₆ | 0 | 0 | 0 | 11 | 8 | 5 | 6 | 6 | 16 | |
| ×84 | 0 | 0 | 0 | 37 | 45 | 22 | 28 | 33 | 25 | 4 |
| | <i>x</i> ₂₃ | <i>x</i> ₂₅ | <i>x</i> ₂₆ | <i>x</i> ₃₁ | x ₃₂ | x_{42} | x_{44} | <i>x</i> ₅₅ | x ₆₅ | x ₆₆ |

D_S^+ BRANCHING FRACTIONS

Written April 2010 by J.L. Rosner (University of Chicago) and C.G. Wohl (LBNL).

More than a dozen papers on the D_s^+ , most of them from the CLEO experiment, have been published since the 2008 Review. We now know enough to attempt an overview of the branching fractions. Figure 1 shows a partial breakdown of the fractions. The rest of this note is about how the figure was constructed. The values shown make heavy use of CLEO measurements of inclusive branching fractions [1] For other data and references cited in the following, see the Listings.

Modes with leptons: The bottom $(20.0 \pm 0.9)\%$ of Fig. 1 shows the fractions for the exclusive modes that include leptons. Measured $e^+\nu_e$ fractions have been doubled to get the semileptonic $\ell^+\nu$ fractions. The sum of the exclusive $e^+\nu_e$ fractions is $(6.9 \pm 0.4)\%$, consistent with an inclusive semileptonic $e^+\nu_e$ measurement of $(6.5 \pm 0.4)\%$. There seems to be little missing here.

Inclusive hadronic $K\overline{K}$ fractions: The Cabibbo-favored $c \to s$ decay in D_s^+ decay produces a final state with both an s and an \overline{s} ; and thus decay modes with a $K\overline{K}$ pair or with an η , ω , η' , or ϕ predominate (see, for example, in Fig. 1 the fractions with leptons). We consider the $K\overline{K}$ modes first. A complete picture of the exclusive $K\overline{K}$ charge modes is not yet possible, because branching fractions for more than half of those modes have yet to be measured. However, CLEO has measured the inclusive K^+ , K^- , K^0_S , K^+K^- , $K^+K^0_S$, $K^-K^0_S$, and $2K^0_S$ fractions (which include modes with leptons) [1]. And each of these inclusive fractions f with a K^0_S is equal to the corresponding fraction with a K^0_L : $f(K^+K^0_L) = f(K^+K^0_S)$, $f(2K^0_L) = f(2K^0_S)$, etc. Therefore, of all inclusive fractions pairing a K^+ , K^0_S , or K^0_L with a K^- , K^0_S , or K^0_L , we know all but $f(K^0_SK^0_L)$.

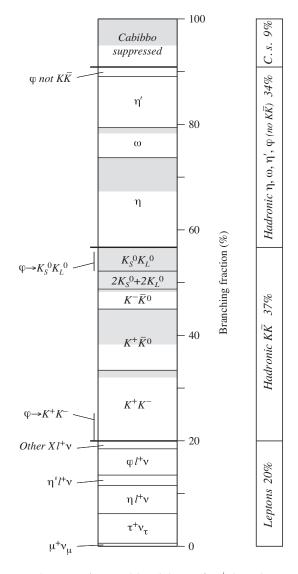


Figure : A partial breakdown of D_s^+ branching fractions. Shading indicates parts of bins allotted to as-yet unmeasured exclusive modes. The inclusive hadronic ϕ fraction is spread over three bins. See the text for further explanations.

We can get that fraction. The total K_S^0 fraction is

$$\begin{split} f(K_S^0) &= f(K^+ K_S^0) + f(K^- K_S^0) + 2 f(2K_S^0) + f(K_S^0 K_L^0) \\ &+ f(\text{single } K_S^0) \ , \end{split}$$

where $f(\operatorname{single} K_S^0)$ is the sum of the branching fractions for modes such as $K_S^0\pi^+2\pi^0$ with a K_S^0 and no second K. The $K_S^0\pi^+2\pi^0$ mode is in fact the only unmeasured single- K_S^0 mode (throughout, we shall assume that fractions for modes with a K or $K\overline{K}$ and more than three pions are negligible), and we shall take its fraction to be the same as for the $K_S^02\pi^+\pi^-$ mode, $(0.29\pm0.11)\%$. Any reasonable deviation from this value would be too small to matter much in the following. Adding the several small single- K_S^0 branching fractions, including those from semileptonic modes, we get $f(\operatorname{single} K_S^0) = (1.67\pm0.26)\%$.

 D_s^{\pm}

Using this, we have:

$$\begin{split} f(K_S^0 K_L^0) &= f(K_S^0) - f(K^+ K_S^0) - f(K^- K_S^0) - 2f(2K_S^0) \\ &- f(\text{single } K_S^0) \\ &= (19.0 \pm 1.1) - (5.8 \pm 0.5) - (1.9 \pm 0.4) \\ &- 2 \times (1.70 \pm 0.32) - (1.67 \pm 0.26) \\ &= (6.2 \pm 1.4)\% \; . \end{split}$$

Here and below we treat the errors as uncorrelated, although often they are not. However, our main aim is to get numbers for Fig. 1; errors will be secondary.

There is a check on our result: The ϕ inclusive branching fraction is $(15.7 \pm 1.0)\%$, of which 34%, or $(5.34 \pm 0.34)\%$ of D_s^+ decays, produces a $K_S^0 K_L^0$. Our $f(K_S^0 K_L^0) = (6.2 \pm 1.4)\%$ has to be at least this large—and it is.

We now make a table. The first column gives the various particle pairings; here we use $f(K^+\overline{K}^0)=2\,f(K^+K^0_S)$, and likewise for $f(K^-K^0)$. The second column gives the inclusive branching fractions; the third column gives the fractions for K^+K^- and $K^0_SK^0_L$ from $\phi\ell^+\nu$ decay; the last column subtracts these off to get the purely hadronic $K\overline{K}$ inclusive fractions.

$$\begin{array}{cccccccc} K^+K^- & 15.8 \; (0.7)\% & 2.44 \; (0.14)\% & 13.4 \; (0.7)\% \\ K^+\overline{K}^0 & 11.6 \; (1.0) & 11.6 \; (1.0) \\ K^-K^0 & 3.8 \; (0.8) & 3.8 \; (0.8) \\ K^0_SK^0_S + K^0_LK^0_L & 3.4 \; (0.64) & 3.4 \; (0.64) \\ K^0_SK^0_L & 6.2 \; (1.4) & 1.69 \; (0.10) & 4.5 \; (1.4) \; . \end{array}$$

The values in the last column are shown in Fig. 1. Their sum is $(36.7 \pm 2.1)\%$.

We can add more information to the figure by summing up measured branching fractions for exclusive modes within each bin:

 K^+K^- modes—The sum of measured $K^+K^-\pi^+$, $K^+K^-\pi^+\pi^0$, and $K^+K^-2\pi^+\pi^-$ branching fractions is $(12.0\pm0.6)\%$. That leaves $(1.4\pm0.9)\%$ for the $K^+K^-\pi^+2\pi^0$ mode, which is the only other K^+K^- mode with three or fewer pions. In Fig. 1, this unmeasured part of the K^+K^- bin is shaded.

 $K^+\overline{K}^0$ modes—Twice the sum of measured $K^+K^0_S$ and $K^+K^0_S\pi^+\pi^-$ branching fractions is $(4.9\pm0.3)\%$. This leaves $(6.7\pm1.0)\%$ for the unmeasured $K^+\overline{K}^0$ modes (there are four such modes with three or fewer pions). This is shaded in the figure.

 K^-K^0 modes—Twice the $K^-K^0_S 2\pi^+$ fraction is (3.28 \pm 0.24)%, which leaves about (0.5 \pm 0.8)% for $K^-K^0 2\pi^+\pi^0$, the only other K^-K^0 mode with three or fewer pions.

 $K^0\overline{K}^0$ modes—The only measurement of $K^0\overline{K}^0$ decays is of the $2K_S^02\pi^+\pi^-$ fraction, $(0.084\pm0.035)\%$; so nearly everything is shaded here. However, most of the $K_S^0K_L^0$ fraction is accounted for by ϕ decays (see below).

Inclusive hadronic η , ω , η' , and ϕ fractions: These are easier. We start with the inclusive branching fractions, and then, to avoid double counting, subtract: (1) fractions for modes

with leptons; (2) η mesons that are included in the inclusive η' fraction; and (3) K^+K^- and $K_S^0K_L^0$ from ϕ decays:

$$\begin{split} f(\eta \text{ hadronic}) &= f(\eta \text{ inclusive}) - 0.65 \, f(\eta' \text{ inclusive}) \\ &- f(\eta \ell^+ \nu) = (17.0 \pm 3.1)\% \\ f(\omega \text{ hadronic}) &= f(\omega \text{ inclusive}) - 0.03 \, f(\eta' \text{ inclusive}) \\ &= (5.7 \pm 1.4)\% \\ f(\eta' \text{ hadronic}) &= f(\eta' \text{ inclusive}) - f(\eta' \ell^+ \nu) \\ &= (9.7 \pm 1.9)\% \\ f(\phi \text{ hadronic}, \not \rightarrow K\overline{K}) &= 0.17 \, [f(\phi \text{ inclusive}) \\ &- f(\phi \ell^+ \nu)] &= (1.8 \pm 0.2)\% \; . \end{split}$$

The factors 0.65, 0.03, and 0.17 are the $\eta' \to \eta$, $\eta' \to \omega$, and $\phi \not\to K\overline{K}$ branching fractions. Figure 1 shows the results; the sum is $(34.2 \pm 3.9)\%$, which is about equal to the hadronic $K\overline{K}$ total.

Note that the bin marked ϕ near the top of Fig. 1 includes neither the $\phi \ell^+ \nu$ decays nor the 83% of other ϕ decays that produce a $K\overline{K}$ pair. Compared to the size of that ϕ bin, there is twice as much ϕ in the $K^0_S K^0_L$ bin, and nearly three times as much in the K^+K^- bin. These contributions are indicated in those bins.

Again, we can show how much of each bin is accounted for by measured exclusive branching fractions:

 η modes—The sum of $\eta \pi^+$, $\eta \rho^+$, and ηK^+ branching fractions is $(10.6 \pm 0.8)\%$, which leaves a good part of the inclusive hadronic η fraction, $(17.0 \pm 3.1)\%$, to be accounted for. This is shaded in the figure.

 ω modes—The sum of $\omega \pi^+$, $\omega \pi^+ \pi^0$, and $\omega 2\pi^+ \pi^-$ fractions is $(4.6 \pm 0.9)\%$, which is nearly as large as the inclusive hadronic ω fraction, $(5.7 \pm 1.4)\%$.

 η' modes—The sum of $\eta'\pi^+$, $\eta'\rho^+$, and $\eta'K^+$ fractions is $(16.5 \pm 2.2)\%$, which is much larger than the inclusive hadronic η' fraction, $(9.7 \pm 1.9)\%$. If an exclusive measurement is at fault, it almost has to be the $\eta'\rho^+$ fraction, which is $(12.5 \pm 2.2)\%$. It has been suggested that some of this signal might instead be misidentified kinematic reflections of other modes [2].

Cabibbo-suppressed modes: Remaining is $(9.1 \pm 4.5)\%$ for hadronic Cabibbo-suppressed modes having no η , ω , η' , or ϕ . The contributions are:

 $K^0 + pions$ —Above, we found that $f(\text{single } K_S^0) = (1.67 \pm 0.26)\%$; subtracting leptonic contributions leaves $(1.20 \pm 0.24)\%$. The hadronic single- K^0 fraction is twice this, $(2.40 \pm 0.48)\%$.

 $K^+ + pions$ —The $K^+\pi^0$ and $K^+\pi^+\pi^-$ fractions sum to $(0.77 \pm 0.05)\%$. Much of the $K^+n\pi$ modes, where $n \geq 3$, is already in the η , ω , and η' bins, and the rest is not measured. The total K^+ fraction wanted here is probably in the 1-to-2% range.

Multi-pions—The $2\pi^+\pi^-$, $\pi^+2\pi^0$, and $3\pi^+2\pi^-$ fractions total $(2.6\pm0.2)\%$. Modes not measured might double this.

 D_s^\pm

The sum of the three contributions is certainly not inconsistent with the Cabibbo-suppressed total of $(9.1 \pm 4.5)\%$. The sum of actually measured fractions is $(4.2 \pm 0.2)\%$.

A model: With CLEO about to publish inclusive branching fractions [1], Gronau and Rosner predicted those fractions using a "statistical isospin" model [2]. Consider, say, the $D_s^+ \to K\overline{K}\pi$ charge modes: the $K^+K^-\pi^+$ branching fraction is measured, the $K^+\overline{K}^0\pi^0$ and $K^0\overline{K}^0\pi^+$ fractions are not. The statistical isospin model assumes that all the independent isospin amplitudes for $D_s^+ \to K\overline{K}\pi$ decay are equal in magnitude and incoherent in phase—in which case, the ratio of the three fractions here is 3:3:2. (Actually, use was also made of the fact that $D_s^+ \to K\overline{K}\pi$ decay is dominated by $\phi\pi^+$, $K^+\overline{K}^{*0}$, and $K^{*+}\overline{K}^0$ submodes; but the estimated charge-mode ratios were not far from 3:3:2.) A different, quark-antiquark pair-production model was used to estimate systematic uncertainties.

In this way, unmeasured exclusive fractions were calculated from measured exclusive fractions (the latter were taken from the 2008 Review, and so did not benefit from recent results). In the hadronic sector, the measured total of 59.4% of D_s^+ decays led to an estimated total of 24.2% for unmeasured modes. Weighted counts of π^+ , K_S^0 , etc., were then made to get the inclusive fractions.

Of interest here is that the sum of all the exclusive fractions—a way-stop in getting the inclusive values—was a nearly correct 103%. In the absence of complete measurements, the model is a way to, in effect, average over ignorance. It probably works better summed over a number of charge-mode sets than in detail. It is known to sometimes give incorrect results when there are sufficient measurements to test it.

References

- 1. S. Dobbs et al., Phys. Rev. **D79**, 112008 (2009).
- M. Gronau and J.L. Rosner, Phys. Rev. D79, 074022 (2009).

D+ BRANCHING RATIOS

A number of older, now obsolete results have been omitted. They may be found in earlier editions.

----- Inclusive modes -----

 VALUE (units 10^{-2})
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 6.52±0.39±0.15 536 ± 29 3 ASNER
 10 CLEO
 e^+e^- at 3774 MeV

 3 Using the D_S^+ and D^0 lifetimes, ASNER 10 finds that the ratio of the D_S^+ and D^0 semileptonic widths is 0.828 \pm 0.051 \pm 0.025.

< 0.06

 $\Gamma(\pi^+ \text{anything})/\Gamma_{\text{total}}$ Events with two π^+ 's count twice, etc. But π^+ 's from $K^0_S \to \pi^+\pi^-$ are not included.

 VALUE (units 10^{-2})
 DOCUMENT ID
 TECN
 COMMENT

 119.3±1.2±0.7
 DOBBS
 09
 CLEO
 e^+e^- at 4170 MeV

VALUE (units 10^{-2})DO CUMENT IDTECNCOMMENT43.2 \pm 0.9 \pm 0.3DOBBS09CLEO e^+e^- at 4170 MeV

| | | | | | D_s |
|-----------------------------------------------------------------------|------------------------------|-------------------------------------|---------|--------------|-----------------------------------------------------------|
| $\Gamma(\pi^0 \text{ anything})/\Gamma_0$ Events with two | $total$ o π^0 's count t | wice, etc. But π | .0's fr | om K^0_S - | Γ_4/Γ $\rightarrow 2\pi^0$ are not included. |
| VALUE (units 10^{-2}) | | DO CUMENT ID | | | |
| $123.4 \pm 3.8 \pm 5.3$ | | DOBBS | 09 | CLEO | e^+e^- at 4170 MeV |
| Γ(K ⁻ anything)/Γ VALUE (units 10 ⁻²) | | DO CUMENT ID | | TECN | Γ ₅ /Γ |
| 18.7±0.5±0.2 | | DOBBS | 09 | | e ⁺ e ⁻ at 4170 MeV |
| Γ(K ⁺ anything)/Γ | total | | | | Γ ₆ /Γ |
| VALUE (units 10^{-2}) | | DO CUMENT ID | | | COMMENT |
| 28.9±0.6±0.3 | | DOBBS | 09 | CLEO | e ⁺ e ⁻ at 4170 MeV |
| $\Gamma(K_S^0 \text{ anything})/\Gamma$ | total | | | | Γ ₇ /Γ |
| VALUE (units 10 ⁻²) | | DO CUMENT ID | | | COMMENT |
| 19.0±1.0±0.4 | | DOBBS | 09 | CLEO | e ⁺ e ⁻ at 4170 MeV |
| $\Gamma(\eta \text{ a nything})/\Gamma_{to}$ This ratio inclu | | s from η' decays. | | | Г ₈ /Г |
| | EVTS | | | | COMMENT |
| 29.9±2.2±1.7 • • • We do not use | the following | DOBBS data for average | | | O e ⁺ e [−] at 4170 MeV etc. • • • |
| $23.5 \pm 3.1 \pm 2.0$ | 674 ± 91 | HUANG | | 6B CLEC | |
| $\Gamma(\omega \text{ anything})/\Gamma_{to}$ | otal | | | | Г9/Г |
| VALUE (units 10^{-2}) | | DO CUMENT ID | | | COMMENT |
| 6.1±1.4±0.3 | | DOBBS | 09 | CLEO | e ⁺ e ⁻ at 4170 MeV |
| $\Gamma(\eta' \text{ anything})/\Gamma_{to}$ WALUE (units 10^{-2}) | | DO CUMENT | ID | TECN | Γ ₁₀ /Γ |
| 11.7±1.7±0.7 | | DOBBS | 0 | 9 CLEC | e^+e^- at 4170 MeV |
| • • • We do not use | _ | - | | | |
| $8.7 \pm 1.9 \pm 0.8$ | 68 ± 15 | HUANG | 0 | 6B CLEC | See DOBBS 09 |
| Γ(f ₀ (980) anything | | τ [—])/Γ _{total} | | | Γ ₁₁ /Γ |
| VALUE (units 10 ⁻²) | | DOCUMENT ID | | | COMMENT |
| <1.3 | 90 | DOBBS | 09 | CLEO | |
| $\Gamma(\phi \text{ anything})/\Gamma_{to}$ | | | | | Γ ₁₂ /Γ |
| VALUE (units 10 ⁻²) 15.7±0.8±0.6 | EVTS | DOCUMENT DODDC | | | COMMENT |
| • • • We do not use | the following | DOBBS data for average | | | O e ⁺ e ⁻ at 4170 MeV etc. • • • |
| $16.1\!\pm\!1.2\!\pm\!1.1$ | 398 ± 27 | HUANG | | 6B CLEC | |
| Γ(K+K-anything | ζ)/Γ _{total} | | | | Γ ₁₃ /Γ |
| VALUE (units 10 ⁻²) 15.8±0.6±0.3 | | DOBBS | 09 | | e^+e^- at 4170 MeV |
| | \ | DOBBS | 09 | CLEO | |
| $\Gamma(K_S^0K^+ \text{ a nything})$ | 3)/I total | | | | Γ ₁₄ /Γ |
| VALUE (units 10 ⁻²) 5.8±0.5±0.1 | | DOCUMENT ID DOBBS | 09 | | e^+e^- at 4170 MeV |
| $\Gamma(K_S^0 K^- \text{ a nything})$ | ;)/Γ _{total} | 5 6556 | | 0.20 | Г ₁₅ /Г |
| VALUE (units 10^{-2}) | | DO CUMENT ID | | TECN | COMMENT |
| $1.9 \pm 0.4 \pm 0.1$ | | DOBBS | 09 | CLEO | e^+e^- at 4170 MeV |
| $\Gamma(2K_5^0 \text{ anything})/$ | Γ _{total} | 00 000 450 7 40 | | TE 011 | Г ₁₆ /Г |
| VALUE (units 10 ⁻²) 1.7±0.3±0.1 | | DOBBS | 09 | | e+e- at 4170 MeV |
| $\Gamma(2K^+ \text{ anything})/$ | Ttotal | | ., | | Γ ₁₇ /Γ |
| | | | | | |
| VALUE (units 10 ⁻²) | | DO CUMENT ID | | TECN | COMMENT |
| <0.26 | | DOBBS | 09 | TECN CLEO | |
| • | <u>CL%</u> 90 | | 09 | | |
| <0.26 | 90 7 7 | | 09 | CLEO | e ⁺ e ⁻ at 4170 MeV |

DOBBS

Leptonic and semileptonic modes -

09 CLEO e^+e^- at 4170 MeV

 D^{ϵ}

DECAY CONSTANTS OF CHARGED PSEUDO-SCALAR MESONS

Revised February 2012 by J. Rosner (Univ. Chicago) and S. Stone (Syracuse Univ.)

Introduction: Charged mesons formed from a quark and an antiquark can decay to a charged lepton pair when these objects annihilate via a virtual W boson [1]. Fig. 1 illustrates this process for the purely leptonic decay of a D^+ meson.

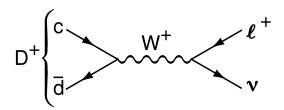


Figure 1: The annihilation process for pure D^+ leptonic decays in the Standard Model.

Similar quark-antiquark annihilations via a virtual W^+ to the $\ell^+\nu$ final states occur for the π^+ , K^+ , D_s^+ , and B^+ mesons. (Charge-conjugate particles and decays are implied.) Let P be any of these pseudoscalar mesons. To lowest order, the decay width is

$$\Gamma(P \to \ell \nu) = \frac{G_F^2}{8\pi} f_P^2 \ m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2} \right)^2 |V_{q_1 q_2}|^2 \ . \tag{1}$$

Here M_P is the P mass, m_ℓ is the ℓ mass, $V_{q_1q_2}$ is the Cabibbo-Kobayashi-Maskawa (CKM) matrix element between the constituent quarks $q_1\bar{q}_2$ in P, and G_F is the Fermi coupling constant. The parameter f_P is the decay constant, and is related to the wave-function overlap of the quark and antiquark.

The decay P^{\pm} starts with a spin-0 meson, and ends up with a left-handed neutrino or right-handed antineutrino. By angular momentum conservation, the ℓ^{\pm} must then also be left-handed or right-handed, respectively. In the $m_{\ell} = 0$ limit, the decay is forbidden, and can only occur as a result of the finite ℓ mass. This helicity suppression is the origin of the m_{ℓ}^2 dependence of the decay width.

There is a complication in measuring purely leptonic decay rates. The process $P \to \ell \nu \gamma$ is not simply a radiative correction, although radiative corrections contribute. The P can make a transition to a virtual P^* , emitting a real photon, and the P^* decays into $\ell \nu$, avoiding helicity suppression. The importance of this amplitude depends on the decaying particle and the detection technique. The $\ell \nu \gamma$ rate for a heavy particle such as B decaying into a light particle such as a muon can be larger than the width without photon emission [2]. On the other hand, for decays into a τ^\pm , the helicity suppression is mostly broken and these effects appear to be small.

Measurements of purely leptonic decay branching fractions and lifetimes allow an experimental determination of the product $|V_{q_1q_2}|f_P$. If the CKM element is well known from other

measurements, then f_P can be well measured. If, on the other hand, the CKM element is not well measured, having theoretical input on f_P can allow a determination of the CKM element. The importance of measuring $\Gamma(P \to \ell \nu)$ depends on the particle being considered. For example, the measurement of $\Gamma(B^- \to \tau^- \overline{\nu})$ provides an indirect determination of $|V_{ub}|$ provided that f_B is provided by theory. In addition, f_B is crucial for using measurements of $B^0 - \overline{B}^0$ mixing to extract information on the fundamental CKM parameters. Knowledge of f_{B_s} is also needed, but it cannot be directly measured as the B_s is neutral, so the violation of the SU(3) relation $f_{B_s} = f_B$ must be estimated theoretically. This difficulty does not occur for D mesons as both the D^+ and D_s^+ are charged, allowing the direct measurement of SU(3) breaking and a direct comparison with theory.

For B^- and D_s^+ decays, the existence of a charged Higgs boson (or any other charged object beyond the Standard Model) would modify the decay rates; however, this would not necessarily be true for the D^+ [3,4]. More generally, the ratio of $\tau\nu$ to $\mu\nu$ decays can serve as one probe of lepton universality [3,5].

As $|V_{ud}|$ has been quite accurately measured in superallowed β decays [6], with a value of 0.97425(22) [7], measurements of $\Gamma(\pi^+ \to \mu^+ \nu)$ yield a value for f_π . Similarly, $|V_{us}|$ has been well measured in semileptonic kaon decays, so a value for f_K from $\Gamma(K^- \to \mu^- \bar{\nu})$ can be compared to theoretical calculations. Lattice gauge theory calculations, however, have been claimed to be very accurate in determining f_K , and these have been used to predict $|V_{us}|$ [8].

 D^+ and D_s^+ decay constants: We review current measurements, starting with the charm system. The CLEO collaboration has performed the only measurement of the branching fraction for $D^+ \to \mu^+ \nu$ [9]. CLEO uses e^+e^- collisions at the $\psi(3770)$ resonant energy where D^-D^+ pairs are copiously produced. They fully reconstruct one of the D's, find a candidate muon track of opposite sign to the tag, and then use kinematical constraints to infer the existence of a missing neutrino and hence the $\mu\nu$ decay of the other D. They find $\mathcal{B}(D^+ \to \mu^+ \nu) = (3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$. We use the well-measured D^+ lifetime of 1.040(7) ps, and assuming $|V_{cd}|$ equals $|V_{us}| = 0.2246(12)$ [7] minus higher order correction terms [10], we find $|V_{cd}| = 0.2245(12)$. The CLEO branching fraction result then translates into a value of

$$f_{D^+} = (206.7 \pm 8.5 \pm 2.5) \text{ MeV}$$
.

This result includes a 1% correction (lowering) of the rate due to the presence of the radiative $\mu^+\nu\gamma$ final state based on the estimate by Dobrescu and Kronfeld [11].

Before we compare this result with theoretical predictions, we discuss the D_s^+ . Measurements of $f_{D_s^+}$ have been made by several groups and are listed in Table 1 [12–16]. We exclude older values obtained by normalizing to D_s^+ decay modes that are not well defined. Many measurements, for example, used

the $\phi\pi^+$ mode. This decay is a subset of the $D_s^+ \to K^+K^-\pi^+$ channel which has interferences from other modes populating the K^+K^- mass region near the ϕ , the most prominent of which is the $f_0(980)$. Thus the extraction of effective $\phi\pi^+$ rate is sensitive to the mass resolution of the experiment and the cuts used to define the ϕ mass region [17,18]. The CLEO, BaBar, and Belle $\mu^+\nu$ results rely on fully reconstructing all the final-state particles except for the neutrino and using a missing-mass technique to infer the existence of the neutrino. CLEO uses $e^+e^- \to D_sD_s^*$ collisions at 4170 MeV, while Babar and Belle use $e^+e^- \to DKn\pi D_s^*$ collisions at energies near the $\Upsilon(4S)$.

Table 1: Experimental results for $\mathcal{B}(D_s^+ \to \mu^+ \nu)$, $\mathcal{B}(D_s^+ \to \tau^+ \nu)$, and $f_{D_s^+}$. Numbers for $f_{D_s^+}$ have been extracted using updated values for masses and $|V_{cs}|$ (see text). Radiative corrections and systematic uncertainties for errors on the D_s^+ lifetime and mass have been included. Common systematic errors in the CLEO results have been taken into account.

| Experiment | Mode | $\mathcal{B}(\%)$ | $f_{D_s^+} \; (\mathrm{MeV})$ |
|---------------|-----------------------------------------------|-----------------------------|-------------------------------|
| CLEO-c [12] | $\mu^+ \nu$ | $0.565 \pm 0.045 \pm 0.017$ | $257.6 \pm 10.3 \pm 4.3$ |
| BaBar [16] | $\mu^+ \nu$ | $0.602 \pm 0.038 \pm 0.034$ | $265.9 \pm 8.4 \pm 7.7$ |
| Belle [13] | $\mu^+ \nu$ | $0.638 \pm 0.076 \pm 0.057$ | $274 \pm 16 \pm 12$ |
| Average | $\mu^+ \nu$ | 0.589 ± 0.033 | 263.0 ± 7.3 |
| CLEO-c [12] | $\tau^+ \nu \ (\pi^+ \overline{\nu})$ | $6.42 \pm 0.81 \pm 0.18$ | $278.0 \pm 17.5 \pm 4.4$ |
| CLEO-c [14] | $\tau^+ \nu \ (\rho^+ \overline{\nu})$ | $5.52 \pm 0.57 \pm 0.21$ | $257.8 \pm 13.3 \pm 5.2$ |
| CLEO-c $[15]$ | $\tau^+ \nu \ (e^+ \nu \overline{\nu})$ | $5.30 \pm 0.47 \pm 0.22$ | $252.6 \pm 11.1 \pm 5.2$ |
| BaBar [16] | $\tau^+ \nu \ (e^+/\mu^+ \nu \overline{\nu})$ | $5.00 \pm 0.35 \pm 0.49$ | $245.4 \pm 8.6 \pm 12.2$ |
| Average | $\tau^+ \nu$ | 5.43 ± 0.31 | 255.7 ± 7.2 |

When selecting the $\tau^+ \to \pi^+ \bar{\nu}$ and $\tau^+ \to \rho^+ \bar{\nu}$ decay modes, CLEO uses both calculation of the missing-mass and the fact that there should be no extra energy in the event beyond that deposited by the measured tagged D_s^- and the τ^+ decay products. The $\tau^+ \to e^+ \nu \bar{\nu}$ mode, however, uses only no extra energy. BaBar measures $\Gamma(D_s^+ \to \tau^+ \nu)/\Gamma(D_s^+ \to \overline{K}^0 K^+)$ using the $\tau^+ \to e^+ \nu \bar{\nu}$ mode.

We extract the decay constant from the measured branching ratios using the D_s^+ mass of 1.96847(33) GeV, the τ^+ mass of 1.77682(16) GeV, and a lifetime of 0.500(7) ps. We use the first-order correction $|V_{cs}| = |V_{ud}| - |V_{cb}|^2/2$ [10]; taking $|V_{ud}| = 0.97425(22)$ [6], and $|V_{cb}| = 0.04$ from an average of exclusive and inclusive semileptonic B decay results as discussed in Ref. [19], we find $|V_{cs}| = 0.97345(22)$. CLEO has included the radiative correction of 1% in the $\mu^+\nu$ rate listed in the Table [11] (the $\tau^+\nu$ rates need not be corrected). Other theoretical calculations show that the $\mu^+\nu\gamma$ rate is a factor of 40–100 below the $\mu^+\nu$ rate for charm [20]. As this is a small effect we do not attempt to correct the other measurements.

The average decay constant cannot simply be obtained by averaging the values in Table 1 since there are correlated errors between the $\mu^+\nu$ and $\tau^+\nu$ values. Table 2 gives the average values of f_{D_s} where the experiments have included the correlations.

Table 2: Experimental results for $f_{D_s^+}$ taking into account the common systematic errors in the $\mu^+\nu$ and $\tau^+\nu$ measurements.

| Experiment | $f_{D_s^+} 	ext{ (MeV)}$ |
|-------------------------|---------------------------|
| CLEO-c | $259.0 \pm 6.2 \pm 3.0$ |
| BaBar | $258.8 \pm 6.4 \pm 7.5$ |
| Belle | $273.8 \pm 16.3 \pm 12.2$ |
| Average of $\mu^+\nu$ + | $\tau^+ \nu$ 260.0 ± 5.4 |

Our experimental average is

$$f_{D_{-}^{\pm}} = (260.0 \pm 5.4) \text{ MeV}.$$

Furthermore, the ratio of branching fractions is found to be

$$R \equiv \frac{\mathcal{B}(D_s^+ \to \tau^+ \nu)}{\mathcal{B}(D_s^+ \to \mu^+ \nu)} = 9.2 \pm 0.7,$$

where a value of 9.76 is predicted in the Standard Model. Assuming lepton universality then we can derive improved values for the leptonic decay branching fractions of

$${\cal B}(D_s^+\to \mu^+\nu) = (5.75\pm 0.24)\times 10^{-3}, \quad {\rm and} \quad$$

$$\mathcal{B}(D_s^+ \to \tau^+ \nu) = (5.61 \pm 0.24) \times 10^{-2}$$
.

The experimentally determined ratio of decay constants is $f_{D^{\pm}}/f_{D^{+}}=1.26\pm0.06.$

Table 3 compares the experimental $f_{D_s^+}$ with theoretical calculations [21–27]. While most theories give values lower than the $f_{D_s^+}$ measurement, the errors are sufficiently large, in most cases, to declare success.

Upper limits on f_{D^+} and f_{D_s} of 230 and 270 MeV, respectively, have been determined using two-point correlation functions by Khodjamirian [28]. Both the D^+ and D_s^+ values are safely below this limit.

Akeroyd and Chen [29] pointed out that leptonic decay widths are modified in two-Higgs-doublet models (2HDM). Specifically, for the D^+ and D_s^+ , Eq. (1) is modified by a factor r_q multiplying the right-hand side [30]:

$$r_q = \left[1 + \left(\frac{1}{m_c + m_q}\right) \left(\frac{M_{D_q}}{M_{H^+}}\right)^2 \left(m_c - \frac{m_q \tan^2 \beta}{1 + \epsilon_0 \tan \beta}\right)\right]^2,$$

Table 3: Theoretical predictions of $f_{D_s^+}$, f_{D^+} , and $f_{D_s^+}/f_{D^+}$. Quenched lattice calculations are omitted, while PQL indicates a partially-quenched lattice calculation. (Only selected results having errors are included.)

| Model | $f_{D_s^+}({ m MeV})$ | $f_{D^+}({ m MeV})$ | $f_{D_s^+}/f_{D^+}$ |
|---------------------------|--------------------------|-------------------------|-----------------------------|
| Experiment (our averages) | 260.0 ± 5.4 | 206.7 ± 8.9 | 1.26 ± 0.06 |
| Lattice (HPQCD) [21] | 248.0 ± 2.5 | 213 ± 4 | 1.164 ± 0.018 |
| Lattice (FNAL+MILC) [22] | 260.1 ± 10.8 | 218.9 ± 11.3 | 1.188 ± 0.025 |
| PQL [23] | 244 ± 8 | 197 ± 9 | 1.24 ± 0.03 |
| QCD sum rules [24] | 205 ± 22 | 177 ± 21 | $1.16 \pm 0.01 \pm 0.03$ |
| QCD sum rules [25] | $245.3 \pm 15.7 \pm 4.5$ | $206.2 \pm 7.3 \pm 5.1$ | $1.193 \pm 0.025 \pm 0.007$ |
| Field correlators [26] | 260 ± 10 | 210 ± 10 | 1.24 ± 0.03 |
| Light front [27] | 268.3 ± 19.1 | 206 (fixed) | 1.30 ± 0.04 |

where m_{H^+} is the charged Higgs mass, M_{D_q} is the mass of the D meson (containing the light quark q), m_c is the charm quark mass, m_q is the light-quark mass, and $\tan \beta$ is the ratio of the vacuum expectation values of the two Higgs doublets. In models where the fermion mass arises from coupling to more than one vacuum expectation value ϵ_0 can be non-zero, perhaps as large as 0.01. For the D^+ , $m_d \ll m_c$, and the change due to the H^+ is very small. For the D_s^+ , however, the effect can be substantial.

A major concern is the need for the Standard Model (SM) value of $f_{D_s^+}$. We can take that from a theoretical model. Our most aggressive choice is that of the unquenched lattice calculation [21], because it claims the smallest error. Since the charged Higgs would lower the rate compared to the SM, in principle, experiment gives a lower limit on the charged Higgs mass. However, the value for the predicted decay constant using this model is 2.0 standard deviations below the measurement. If this small discrepancy is to be taken seriously, either (a) the model of Ref. [21] is not representative; (b) no value of m_{H^+} in the two-Higgs doublet model will satisfy the constraint at 99% confidence level; or (c) there is new physics, different from the 2HDM, that interferes constructively with the SM amplitude such as in the R-parity-violating model of Akeroyd and Recksiegel [31].

To sum up, the situation is not clear. To set limits on new physics we need an independent calculation of f_{Ds} with comparable accuracy, and more precise measurements would also be useful.

The B^+ decay constant: The Belle and BaBar collaborations have found evidence for $B^- \to \tau^- \overline{\nu}$ decay in $e^+ e^- \to B^- B^+$ collisions at the $\Upsilon(4S)$ energy. The analysis relies on reconstructing a hadronic or semi-leptonic B decay tag, finding a τ candidate in the remaining track and or photon candidates, and examining the extra energy in the event which should be close to zero for a real τ^- decay to $e^- \nu \bar{\nu}$ or $\mu^- \nu \bar{\nu}$ opposite a B^+ tag. The results are listed in Table 4.

Table 4: Experimental results for $\mathcal{B}(B^- \to \tau^- \overline{\nu})$. We have computed an average for the two Belle measurements assuming that the systematic errors are fully correlated.

| Experiment | Tag | \mathcal{B} (units of 10^{-4}) |
|------------|--------------|-------------------------------------|
| Belle [32] | Hadronic | $1.79^{+0.56+0.46}_{-0.49-0.51}$ |
| Belle [33] | Semileptonic | $1.54^{+0.38+0.29}_{-0.37-0.31}$ |
| Belle | Our average | 1.62 ± 0.40 |
| BaBar [34] | Hadronic | $1.80^{+0.57}_{-0.54} \pm 0.26$ |
| BaBar [35] | Semileptonic | $1.7\pm0.8\pm0.2$ |
| BaBar | Average [34] | 1.76 ± 0.49 |
| | Our average | 1.68 ± 0.31 |

There are large backgrounds under the signals in all cases. The systematic errors are also quite large, on the order of 20%. Thus, the significance of the signals is not that large. Belle quotes 3.5σ and 3.6σ for their hadronic and semileptonic tags, while BaBar quotes 3.3σ and 2.3σ for these tags. We note that the four central values are remarkably close to the average considering the large errors on all the measurements. More accuracy would be useful to investigate the effects of new physics.

We extract a SM value using Eq. (1). Here theory provides a value of $f_B = (194 \pm 9)$ MeV [36]. We also need a value for $|V_{ub}|$. Here significant differences arise between using inclusive charmless semileptonic decays and the exclusive decay $B \rightarrow \pi \ell^+ \nu$ [37]. The inclusive decays give rise to a value of $|V_{ub}| = (4.27 \pm 0.38) \times 10^{-3}$ while the exclusive measurements yield $|V_{ub}| = (3.38 \pm 0.36) \times 10^{-3}$, where the errors are dominantly theoretical [38]. Their average, enlarging the error in the standard manner because the results differ, is $|V_{ub}| = (3.80 \pm 0.44) \times 10^{-3}$. Using these values and the PDG values for the B^+ mass and lifetime, we arrive at the SM prediction for the $\tau^-\bar{\nu}$ branching fraction of $(0.96 \pm 0.24) \times 10^{-4}$. This value is about

a factor of two smaller than the measurements. There is a 6.6% probability that the data and the SM prediction are consistent. This difference is more clearly seen by examining the correlation between the CKM angle β and $\mathcal{B}(B^- \to \tau^- \bar{\nu})$. The CKM fitter group provides a fit to a large number of measurements involving heavy quark transitions [39]. The point in Fig. 2 shows the directly measured values, while the predictions from their fit without the direct measurements are also shown. There is about a factor of two discrepancy between the measured value of $\mathcal{B}(B^- \to \tau^- \overline{\nu})$ and the fit prediction.

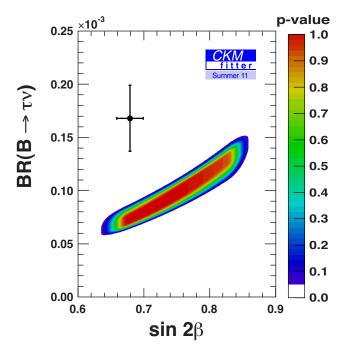


Figure 2: Measured and predicted values of $\mathcal{B}(B^- \to \tau^- \overline{\nu})$ versus $\sin 2\beta$ from the CKM fitter group [39]. The point with error bars shows the measured values, while the predictions are in shaded contours, with the shading related to the confidence level.

 π^+ and K^+ decay constants: The sum of branching fractions for $\pi^- \to \mu^- \bar{\nu}$ and $\pi^- \to \mu^- \bar{\nu} \gamma$ is 99.98770(4)%. The two modes are difficult to separate experimentally, so we use this sum, with Eq. (1) modified to include photon emission and radiative corrections [40]. The branching fraction together with the lifetime 26.033(5) ns gives

$$f_{\pi^-} = (130.41 \pm 0.03 \pm 0.20) \text{ MeV}$$
.

The first error is due to the error on $|V_{ud}|$, 0.97425(22) [6]; the second is due to the higher-order corrections, and is much larger.

Similarly, the sum of branching fractions for $K^- \to \mu^- \bar{\nu}$ and $K^- \to \mu^- \bar{\nu} \gamma$ is 63.55(11)%, and the lifetime is 12.3840(193) ns [41]. Measurements of semileptonic kaon decays provide a

value for the product $f_+(0)|V_{us}|$, where $f_+(0)$ is the form-factor at zero four-momentum transfer between the initial state kaon and the final state pion. We use a value for $f_+(0)|V_{us}|$ of 0.21664(48) [41]. The $f_+(0)$ must be determined theoretically. We follow Blucher and Marciano [7] in using the lattice calculation $f_+(0) = 0.9644 \pm 0.0049$ [42], since it appears to be more precise than the classic Leutwyler-Roos calculation $f_+(0) = 0.961 \pm 0.008$ [43]. [Other recent averages are 0.956 ± 0.008 [49] and 0.9588 ± 0.0044 [44].] Using the value from Ref. [42], the result is $|V_{us}| = 0.2246 \pm 0.0012$, consistent with the hyperon decay value of 0.2250 ± 0.0027 [45]. We derive

$$f_{K^-} = (156.1 \pm 0.2 \pm 0.8 \pm 0.2) \text{ MeV}$$
.

The first error is due to the error on Γ ; the second is due to the CKM factor $|V_{us}|$, and the third is due to the higher-order corrections. The largest source of error in these corrections depends on the QCD part, which is based on one calculation in the large N_c framework. We have doubled the quoted error here; this would probably be unnecessary if other calculations were to come to similar conclusions. A large part of the additional uncertainty vanishes in the ratio of the K^- and π^- decay constants, which is

$$f_{K^-}/f_{\pi^-} = 1.197 \pm 0.002 \pm 0.006 \pm 0.001$$
.

The first error is due to the measured decay rates; the second is due to the uncertainties on the CKM factors; the third is due to the uncertainties in the radiative correction ratio.

These measurements have been used in conjunction with calculations of f_K/f_π in order to find a value for $|V_{us}|/|V_{ud}|$. Three recent lattice predictions of f_K/f_π are 1.189 ± 0.007 [46], $1.192 \pm 0.007 \pm 0.006$ [47], and $1.197 \pm 0.002^{+0.003}_{-0.007}$ [48], yielding an average by the FLAG group of 1.195 ± 0.005 [49]. (A new average 1.1872 ± 0.0041 is quoted with statistical errors only [50]). Together with the precisely measured $|V_{ud}|$, this gives an independent measure of $|V_{us}|$ [8,41].

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| Γ_{19}/Γ $\Gamma(K^+K^-e^+\nu_e)/\Gamma(K^+K^-\pi^+)$ Γ_{22}/Γ_{32} ID TECN COMMENT DOCUMENT ID TECN COMMENT | | | CLW DOCUMENT TO THE | $(e^+ \nu_e)/\Gamma_{\text{total}}$ |
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| | 10 | | ne following data for averages, fits, limits, | • • We do not use th |
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| Γ_{20}/Γ $\Gamma(\phi e^+ \nu_e)/\Gamma_{\text{total}}$ Γ_{23}/Γ_{23} | $\Gamma(\phie^+ u_e)/\Gamma_{ m total}$ | | | $(\mu^+ u_\mu)/\Gamma_{ m total}$ |
| See the end of the D_c^+ Listings for measurements of $D_c^+ 	o \phi e^+ \nu_{ ho}$ form factors | See the end of the D_s^+ Listings for measurements of | | 'Decay Constants of Charged Pseudoscalar | See the note on " NLUE (units 10 ⁻³) |
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| 2.61 \pm 0.03 \pm 0.17 (25 \pm 0.5)k AUBERT 08AN BABR e^+e^- at $T(45)$ | · · · · · · · · · · · · · · · · · · · | | , | 94±0.66±0.31 |
| 2.29±0.37±0.11 45 YELTON 09 CLEO See ECKLUND 09 | | Z decays | 553 ⁷ HEISTER 021 ALEF | 8 ±1.1 ±1.8 |
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| ged Pseudoscalar Mesons" above. 0.49 ± 0.10 $^{+0.10}_{-0.14}$ 54 ALEXANDER 90B CLEO Uses $\phi e^+ \nu_e^-$ and $\phi \mu^+ \nu_e^-$ | $0.49~\pm0.10~^{+0.10}_{-0.14}$ 54 ALEXANDER 90B CL | Mesons" above. | Decay Constants of Charged Pseudoscalar | |
| | $\Gamma(\eta e^+ u_e)/\Gamma_{ m total}$ | | ne following data for averages, fits, limits, | NLUE ■ • We do not use th |
| $_{07	extsf{V}}$ BABR $_{e}^{+}e^{-}pprox ~\gamma(4S)$ Unseen decay modes of the η are included. | Unseen decay modes of the η are included. | | | $143 \pm 0.018 \pm 0.006$ |
| | 2.67±0.29 OUR FIT Error includes scale factor of 1.1. | $e^+e^-pprox \Upsilon(4S)$ | 182 ¹⁰ CHADHA 98 CLE2 | $23 \pm 0.06 \pm 0.04$ $173 \pm 0.023 \pm 0.035$ $245 \pm 0.052 \pm 0.074$ |
| May using $\Gamma(D^{+}, A^{-+})/\Gamma(total)$ | [(na+ u) /[(da+ u) | | | |
| Unseen decay modes of the η and the ϕ are included. | Unseen decay modes of the η and the ϕ are included | | - <i>s</i> | $(4.71 \pm 0.46)\%$ |
| 0.09 from a lattice-gauge-theory calculation μ and $D_S^+ \rightarrow \mu^+ \nu_\mu$ events. The present 1.07±0.12 OUR FIT 1.24±0.125 440 120 BRANDENB 95 CLE2 $e^+e^- \approx r(4S)$ | 1.07±0.12 OUR FIT Error includes scale factor of 1.1. 1.24±0.12±0.15 440 ²⁰ BRANDENB 95 (| | umbers of $D^+ \rightarrow \mu^+ \nu_\mu$ and $D_s^+ \rightarrow \mu$ | to get the relative n |
| 20 BRANDENBURG 95 uses both e^+ and μ^+ events and makes a phase-space adjustme to use the μ^+ events as e^+ events. | | n this measurement, using | : (323 \pm 44 \pm 36) MeV. s $f_{D_c}=(280\pm19\pm28\pm34)$ MeV from | Tesuit leads to T_{D_s} = 10 CHADHA 98 obtain |
| | , | | total) = 0.036 ± 0.009 . | |
| \pm 42) MeV from this measurement, using $\Gamma(\eta'(958) e^+ \nu_e)/\Gamma_{\text{total}}$ Unseen decay modes of the $\eta'(958)$ are included. | | n this measurement, using | is $f_{D_S} = (344 \pm 37 \pm 52 \pm 42)$ MeV from | ¹ ACOSTA 94 obtains |
| VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT | | | total) = 0.037 ± 0.009 . | $\Gamma(D_S^+ \rightarrow \phi \pi^+)/\Gamma($ |
| Γ ₂₊ /Γ 0.99±0.23 OUR FIT | 0.99±0.23 OUR FIT | Γα1 /Γ | | $(au^+ u_	au)/\Gamma_{ m total}$ |
| | 0.91±0.33±0.05 7.5 YELTON 09 | | Decay Constants of Charged Pseudoscalar | See the note on " |
| $\Gamma(\eta'(958)e^+\nu_e)/\Gamma(\phi e^+\nu_e)$ | $\Gamma(\eta'(958) e^+ \nu_e)/\Gamma(\phi e^+ \nu_e)$ | COMMENT | | LUE (units 10 ⁻²) |
| Unseen decay modes of the resonances are included. | Unseen decay modes of the resonances are included. | e- <u>v</u> v u- v v | | 43±0.31 OUR AVER 00±0.35±0.49 748 |
| R 09 CLEO $	au^+ 	o \pi^+ \overline{ u}$ VALUE EVTS DOCUMENT ID TECN COMMENT 0.40 \pm 0.09 OUR FIT | | $\tau^+ \rightarrow \pi^+ \overline{\nu}$ | | $42 \pm 0.81 \pm 0.18$ 126 |
| 09A CLEO $\tau^+ \rightarrow \rho^+ \overline{\nu}_{\tau}^-$ 0.43 \pm 0.11 \pm 0.07 29 21 BRANDENB 95 CLE2 $e^+ e^- \approx T(4S)$ | | | | 52±0.57±0.21 155 |
| 09 CLEO $	au^+	o e^+ u^e\overline{ u}^	au$ 21 BRANDENBURG 95 uses both e^+ and μ^+ events and makes a phase-space adjustme | 21 BRANDENBURG 95 uses both e^+ and μ^+ events and | | | $30 \pm 0.47 \pm 0.22$ 181 |
| ages, fits, limits, etc. $ullet$ $ullet$ $ullet$ to use the μ^+ events as e^+ events. | to use the μ^+ events as e^+ events. | | ne following data for averages, fits, limits, | |
| | $[\Gamma(ne^+\nu_e) + \Gamma(n'(958)e^+\nu_e)]/\Gamma(\phi e^+\nu_e)$ | | | $17 \pm 0.71 \pm 0.34$ 0 $\pm 1.3 \pm 0.4$ |
| 08 CLEO See ONYISI 09 07A CLEO See ALEXANDER 09 $ [\Gamma(\eta e^+ \nu_e) + \Gamma(\eta'(958) e^+ \nu_e)]/\Gamma(\phi e^+ \nu_e) $ $ \Gamma_{24}/\Gamma_{23} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{24}/\Gamma_{23} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{24}/\Gamma_{24} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{24}/\Gamma_{24} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{24}/\Gamma_{25} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{24}/\Gamma_{25} = (\Gamma_{25} + \Gamma_{26})/\Gamma_{25}/\Gamma_{25}/\Gamma_{26}/\Gamma_{25}/\Gamma_{26}/\Gamma_{25}/\Gamma_{26}/\Gamma_{25}/\Gamma_{26}/\Gamma_{25}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/$ | | See ALEXANDER 09 | | $79 \pm 0.77 \pm 1.84$ |
| 07A CLEO See ALEXANDER 09 | Unseen decay modes of the resonances are included. | | | 1 7 1 0.11 1 1.04 |
| 07A CLEO See ALEXANDER 09 | Unseen decay modes of the resonances are included. <u>VALUE</u> <u>DOCUMENT ID</u> | Z decays $D_S^{*+} ightarrow \ \gamma D_S^+$ from Z 's | 881 ¹⁵ HEISTER 021 ALEP 22 ¹⁶ ABBIENDI 01L OPAL | |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's 97F L3 $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's | Unseen decay modes of the resonances are included. VALUE DOCUMENT ID • • • We do not use the following data for averages, fits, | Z decays $D_S^{*+} ightarrow \ \gamma D_S^+$ from Z 's | 881 ¹⁵ HEISTER 021 ALEP 22 ¹⁶ ABBIENDI 01L OPAL | $0 \pm 2.1 \pm 2.0$ |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{++} \rightarrow \gamma D_s^{+}$ from Z's 97F L3 $D_s^{++} \rightarrow \gamma D_s^{+}$ from Z's 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 1.67 ± 0.17 ± 0.17 | Unseen decay modes of the resonances are included. WALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67 \pm 0.17 \pm 0.17$ BRANDENB 95 | Z decays $D_S^{*+} ightarrow \gamma D_S^+$ from Z 's $D_S^{*+} ightarrow \gamma D_S^+$ from Z 's | 881 15 HEISTER 021 ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 | $0 \pm 2.1 \pm 2.0$ $4 \pm 2.8 \pm 2.4$ |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{++} 	o \gamma D_s^+$ from Z's 97F L3 $D_s^{++} 	o \gamma D_s^+$ from Z's + v_T events together to get $f_{D_s} = (258.6 \pm 10^{-10})$ $\begin{bmatrix} \Gamma(\eta e^+ \nu_e) + \Gamma(\eta'(958) e^+ \nu_e) \end{bmatrix} / \Gamma(\phi e^+ \nu_e) & \Gamma_{24}/\Gamma_{23} = (\Gamma_{25} + \Gamma_{26}) / \Gamma_{24}/\Gamma_{23} = (\Gamma_{25} + \Gamma_{26}) / \Gamma_{24}/\Gamma_{23} = (\Gamma_{25} + \Gamma_{26}) / \Gamma_{24}/\Gamma_{25}/\Gamma_{25}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{2$ | Unseen decay modes of the resonances are included. MALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67 \pm 0.17 \pm 0.17$ 22 BRANDENB 95 22 This BRANDENBURG 95 data is redundant with data | Z decays $D_s^{*+} \rightarrow \gamma D_s^+$ from Z 's $D_s^{*+} \rightarrow \gamma D_s^+$ from Z 's her to get $f_{D_s} = (258.6 \pm$ | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 . EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget | 0 ± 2.1 ± 2.0 4 ± 2.8 ± 2.4 12 DEL-A MO-SA NCHE 6.4 \pm 7.5) MeV. |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's 97F L3 $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's + ν_{τ} events together to get $f_{D_s} = (258.6 \pm 1.67 \pm 0.17 \pm 0.17)$ 0 use different τ decay modes and are indevented by the contraction of the cont | Unseen decay modes of the resonances are included. MALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67\pm0.17\pm0.17$ 22 BRANDENB 95 22 This BRANDENBURG 95 data is redundant with data $\Gamma(\omega e^+ \nu_e)/\Gamma_{\text{total}}$ | Z decays $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's her to get $f_{D_s} = (258.6 \pm$ lecay modes and are inde- | 881 15 HEISTER 021 ALEP . 22 16 ABBIENDI 01L OPAL . 16 17 ACCIARRI 97F L3 . EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget | $0 \pm 2.1 \pm 2.0$ $4 \pm 2.8 \pm 2.4$ 1^{2} DEL-A MO-SA NCHE 6.4 ± 7.5) MeV. 1^{3} ALEXA NDER 09, N |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{++} 	oup 	oup 	oup 	oup 	oup 	oup 	oup 	oup$ | Unseen decay modes of the resonances are included. MALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67\pm0.17\pm0.17$ 22 BRANDENB 95 22 This BRANDENBURG 95 data is redundant with data $\Gamma(\omega e^+ \nu_e)/\Gamma_{\text{total}}$ A test for $u\overline{u}$ or $d\overline{d}$ content in the D_c^+ . Neither | Z decays $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's her to get $f_{D_s} = (258.6 \pm 1)$ decay modes and are inde- $3 \pm 3.4)$ MeV. | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 . EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget IAIK 09A, and ONYISI 09 use different τ c papers combined give $f_{D_S}=(259.7\pm7.8)$ | $0 \pm 2.1 \pm 2.0$ $4 \pm 2.8 \pm 2.4$ 1^2 DEL-A MO-SA NCHE 6.4 ± 7.5) MeV. 1^3 ALEXANDER 09, N pendent. The three |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's 97F L3 $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's + ν_T events together to get $f_{D_s} = (258.6 \pm 1)$ 0 use different τ decay modes and are indecay equation in the ECKLUND 08 uses $\tau^+ \rightarrow e^+ \nu_e \overline{\nu}_\tau$ ents. | Unseen decay modes of the resonances are included. MALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67\pm0.17\pm0.17$ 2^2 BRANDENB 95 2^2 This BRANDENBURG 95 data is redundant with data $\Gamma(\omega e^+\nu_e)/\Gamma_{\rm total}$ A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+ . Neither suppressed decays can contribute, and $\omega-\phi$ mixing | Z decays $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's her to get $f_{D_s} = (258.6 \pm$ decay modes and are inde-3 \pm 3.4) MeV. 08 uses $\tau^+ \rightarrow e^+ \nu_e \overline{\nu}_{\tau}$ | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 . EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget IAIK 09A, and ONYISI 09 use different τ c papers combined give $f_{D_S}=(259.7\pm7.3)$ PEDLAR 07A are independent: ECKLUND A uses $\tau^+\to\pi^+\overline{\nu}_\tau$ events. | 0 ±2.1 ±2.0 4 ±2.8 ±2.4 12 DEL-A MO-SA NCHE 6.4 ± 7.5) MeV. 13 ALEXANDER 09, N pendent. The three 14 ECKLUND 08 and F events, PEDLAR 07 |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{*+} \to \gamma D_s^{+}$ from Z's 97F L3 $D_s^{*+} \to \gamma D_s^{+}$ from Z's + ν_T events together to get $f_{D_S} = (258.6 \pm 1)$ 0 use different τ decay modes and are indesigned by the control of the control of the resonance are included. 1 Unseen decay modes of the resonances are included. 2 Unseen decay modes of the resonances are included. 1 EVALUE 1 DOUMENT ID TECN COMMENT 2 BRANDENB 95 CLE2 $e^+e^- \approx T(4S)$ 22 This BRANDENBURG 95 data is redundant with data in previous blocks. 1 C($\omega e^+ \nu_e$)/ Γ_{total} 2 A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+ . Neither Cabibbo-favored nor Cabibbo suppressed decays can contribute, and $\omega = \phi$ mixing is an unlikely explanation of | Unseen decay modes of the resonances are included. <u>MALUE DOCUMENT ID DOCUMENT ID DOCUMENT ID</u> | Z decays $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's $D_s^{*+} \rightarrow \gamma D_s^+$ from Z's her to get $f_{D_s} = (258.6 \pm$ decay modes and are inde-3 \pm 3.4) MeV. 08 uses $\tau^+ \rightarrow e^+ \nu_e \overline{\nu}_{\tau}$ | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 . EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget IAIK 09A, and ONYISI 09 use different τ c papers combined give $f_{D_S}=(259.7\pm7.3)$ PEDLAR 07A are independent: ECKLUND A uses $\tau^+\to\pi^+\overline{\nu}_\tau$ events. | 0 ±2.1 ±2.0 4 ±2.8 ±2.4 ² DEL-AMO-SANCHE 6.4 ± 7.5) MeV. 3 ALEXANDER 09, N pendent. The three ⁴ ECKLUND 08 and F events, PEDLAR 07 |
| 07A CLEO See ALEXANDER 09 021 ALEP Z decays 01L OPAL $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's 97F L3 $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's + ν_{τ} events together to get $f_{D_s} = (258.6 \pm 1)$ 0 use different τ decay modes and are indecays (259.7 $\pm 7.8 \pm 3.4$) MeV. dent: ECKLUND 08 uses $\tau^+ \rightarrow e^+ \nu_e \overline{\nu}_{\tau}$ ents. Ind $\mu^+ \nu_{\mu}$ branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 1 ($\mu^+ \nu_{\mu}$) branching fractions to get $f_{D_s} = (258.6 \pm 1)$ 2 (2020) 90 MARTIN 11 CLEO $\mu^+ \nu_{\mu}$) Tech 2 (200.00 From Equivariance) Technology (258.6 \tau) (258.6 \ | Unseen decay modes of the resonances are included. NALUE DOCUMENT ID • • • We do not use the following data for averages, fits, $1.67\pm0.17\pm0.17$ 22 BRANDENB 95 22 This BRANDENBURG 95 data is redundant with data $\Gamma(\omega e^+\nu_e)/\Gamma_{total}$ A test for $u\overline{u}$ or $d\overline{d}$ content in the D_s^+ . Neither suppressed decays can contribute, and $\omega-\phi$ mixing any fraction above about 2×10^{-4} . NALUE (%) DOCUMENT ID | Z decays $D_s^{*+} 	o \gamma D_s^+$ from Z 's $D_s^{*+} 	o \gamma D_s^+$ from Z 's her to get $f_{D_s} = (258.6 \pm$ lecay modes and are indead $3 \pm 3.4)$ MeV. 08 uses $\tau^+ 	o e^+ \nu_e \overline{\nu}_{\tau}$ ing fractions to get $f_{D_s} =$ | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 16 EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget IAIK 09A, and ONYISI 09 use different τ copapers combined give $f_{D_S}=(259.7\pm7.3)$ PEDLAR 07A are independent: ECKLUND A uses $\tau^+\to\pi^+\overline{\nu}_\tau$ events. ines its $D_S^+\to\tau^+\nu_\tau$ and $\mu^+\nu_\mu$ branch eV. | 0 ±2.1 ±2.0 4 ±2.8 ±2.4 ² DEL-AMO-SANCHE 6.4 ± 7.5) MeV. ³ ALEXANDER 09, N pendent. The three ⁴ ECKLUND 08 and F events, PEDLAR 07 ⁵ HEISTER 021 comb (285 ± 19 ± 40) M |
| 07A CLEO See ALEXANDER 09 02I ALEP Z decays 01L OPAL $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's 97F L3 $D_s^{*+} \rightarrow \gamma D_s^{+}$ from Z's + ν_{τ} events together to get $f_{D_s} = (258.6 \pm 1)$ Use different τ decay modes and are indecays τ events together to get τ and τ events together to get τ events together to τ events together to get τ events together to get τ events together | Unseen decay modes of the resonances are included. NALUE OCCUMENT ID •• • We do not use the following data for averages, fits, $1.67\pm0.17\pm0.17$ 22 BRANDENB 95 22 This BRANDENBURG 95 data is redundant with data $\Gamma(\omega e^+\nu_e)/\Gamma_{\text{total}}$ A test for $u\overline{u}$ or $d\overline{d}$ content in the D_S^+ . Neither suppressed decays can contribute, and $\omega - \phi$ mixing any fraction above about 2×10^{-4} . NALUE (%) CL% DOCUMENT ID C0.20 90 MARTIN 11 | Z decays $D_s^{*+} 	o \gamma D_s^+$ from Z 's $D_s^{*+} 	o \gamma D_s^+$ from Z 's her to get $f_{D_s} = (258.6 \pm$ lecay modes and are indead $3 \pm 3.4)$ MeV. 08 uses $\tau^+ 	o e^+ \nu_e \overline{\nu}_{\tau}$ ing fractions to get $f_{D_s} = \pm 44 \pm 41)$ MeV. | 881 15 HEISTER 02: ALEP 22 16 ABBIENDI 01L OPAL 16 17 ACCIARRI 97F L3 16 EZ 10J uses $\mu^+\nu_\mu$ and $\tau^+\nu_\tau$ events toget IAIK 09A, and ONYISI 09 use different τ copapers combined give $f_{D_S}=(259.7\pm7.3)^{16}$ PEDLAR 07A are independent: ECKLUND A uses $\tau^+\to\pi^+\overline{\nu}_\tau$ events. ines its $D_S^+\to\tau^+\nu_\tau$ and $\mu^+\nu_\mu$ branch eV. value gives a decay constant f_{D_S} of (286 | 0 ±2.1 ±2.0 4 ±2.8 ±2.4 ² DEL-A MO-SA NCHE 6.4 ± 7.5) MeV. ³ ALEXA NDER 09, N pendent. The three ⁴ ECKLUND 08 and F events, PEDLAR 07 ⁵ HEISTER 021 comb (285 ± 19 ± 40) M ⁶ This ABBIENDI 01L |
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 D_s^\pm

| $\Gamma(f_0(980) e^+ \nu_e, f_0 \rightarrow \pi^+ \pi^-)/\Gamma_{\text{total}}$ VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN CO | Γ ₃₀ /Γ | $\Gamma(f_0(1370)\pi^+, f_0 \to K^+K^-)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysi | |
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| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | |
| ——— Hadronic modes with a $K\overline{K}$ pair. —— $\Gamma(K^+K^0_S)/\Gamma_{total}$ | Г ₃₁ /Г | $\Gamma(f_0(1710)\pi^+, f_0 \to K^+K^-)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysi NALUE (%) DOCUMENT ID TEC | |
| 1.48±0.08 OUR FIT 1.49±0.07±0.05 23 ALEXANDER 08 CLEO e+ e | | | BR Dalitz fit, 96k±369 evts EO Dalitz fit, 12k evts |
| 23 ALEXANDER 08 uses single- and double-tagged events in an overal matrix for the branching fractions is used in the fit. | | 3.4±2.3±3.5 FRABETTI 95B E68 | 701 Palitz fit, 701 evts |
| 5.49±0.27 OUR FIT | Г32/Г _{МЕПТ} | $\Gamma(K^+\overline{K}_0^*(1430)^0, \overline{K}_0^* \to K^-\pi^+)/\Gamma(K^+K^-\pi^+)$ This is the "fit fraction" from the Dalitz-plot analysis $\frac{DOCUMENT\ ID}{ALDE\ (\%)}$ 2.4 ±0.7 OUR AVERAGE Error includes scale factor of 1. | CN COMMENT |
| 5.50±0.23±0.16 24 ALEXANDER 08 USES single- and double-tagged events in an overal matrix for the branching fractions is used in the fit. | | 2.4±0.3±1.0 DEL-AMO-SA11G BA | BR Dalitz fit, 96k±369 evts EO Dalitz fit, 12k evts |
| $\Gamma(\phi\pi^+)/\Gamma_{	ext{total}}$ The results here are model-independent. For earlier, model-depen | Γ ₃₃ /Γ | 9.3±3.2±3.2 FRABETTI 95B E68 | |
| PDG 06 edition. We decouple the $D_s^+ 	o \phi \pi^+$ branching frammass projections (and used to get some of the other branching $D_s^+ 	o \phi \pi^+$, $\phi \to K^+ K^-$ branching fraction obtained from the | ction obtained from fractions) from the | $\Gamma(K^*(892)^+\overline{K^0})/\Gamma(\phi\pi^+)$ Unseen decay modes of the resonances are included. NALUE DOCUMENT ID | Γ ₄₁ /Γ ₃₃ |
| of $D_s^+ 	o K^+ K^- \pi^+$. That is, the ratio of these two branch | | | CLEO e+e- 10 GeV |
| exactly the $\phi \rightarrow K^+K^-$ branching fraction 0.491. WALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COI 4.5 ±0.4 OUR AVERAGE | MMENT | | Γ ₄₂ /Γ TECN COMMENT |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $e^- \approx \Upsilon(4S)$ $e^- \text{ at } \Upsilon(4S)$ | 5.6 ±0.5 OUR FIT 5.65±0.29±0.40 29 ALEXANDER 08 29 ALEXANDER 08 uses single- and double-tagged events matrix for the branching fractions is used in the fit. | CLEO e^+e^- at 4.17 GeV in an overall fit. The correlation |
| 3.9 +5.1 +1.8 | | $\Gamma(\phi ho^+)/\Gamma(\phi\pi^+)$ VALUEEVTS DOCUMENT ID | Γ ₄₃ /Γ ₃₃ |
| ²⁵ This AUBERT 06N measurement uses $\overline{B}^0 \to D_S^{(*)-}D^{(*)+}$ and B decays, including some from other papers. However, the resultable AUBERT 05v. | is independent of | 1.86±0.26 ^{+0.29} 253 AVERY 92 | CLE2 $e^+e^- \simeq 10.5 \text{ GeV}$ |
| 26 AUBERT 05v uses the ratio of $B^0 \to D^{*-}D_s^{*+}$ events seen in two both of which the $D^{*-} \to \overline{D}{}^0\pi^-$ decay is fully reconstructed: (1) $D_s^+ \to \phi\pi^+$ decay is fully reconstructed. (2) The number of event the missing mass spectrum against the $D^{*-}\gamma$ is measured. 27 ARTUSO 96 uses partially reconstructed $\overline{B}{}^0 \to D^{*+}D_s^{*-}$ decay | The $D_S^{*+}	o D_S^+ \gamma$, s in the D_S^+ peak in | 1.64±0.12 OUR FIT 1.64±0.10±0.07 30 ALEXANDER 08 30 ALEXANDER 08 uses single- and double-tagged events | TECN COMMENT CLEO e^+e^- at 4.17 GeV in an overall fit. The correlation |
| ARTOSO 96 uses partially reconstructed $B^0 \to D^0 + D_S^0$ decided independent value for $\Gamma(D_S^- \to \phi\pi^-)/\Gamma(D^0 \to K^-\pi^+)$ of 0.92 28 BAI 95 c uses $e^+e^- \to D_S^+D_S^-$ events in which one or both of the | \pm 0.20 \pm 0.11. | matrix for the branching fractions is used in the fit. $\Gamma(K^*(892)^+\overline{K}^*(892)^0)/\Gamma(\phi\pi^+)$ Unseen decay modes of the resonances are included. | Γ ₄₅ /Γ ₃₃ |
| obtain the first model-independent measurement of the $D_s^+ 	o \phi \pi^+$ without assumptions about $\sigma(D_s^\pm)$. However, with only two "doubly statistical error is very large. | | VALUE DOCUMENT ID 1.6±0.4±0.4 ALBRECHT 92B | |
| $\Gamma(\phi\pi^+, \phi \to K^+K^-)/\Gamma(K^+K^-\pi^+)$ | Γ ₃₄ /Γ ₃₂ | $\frac{\Gamma(K^+ \kappa_S^0 \pi^+ \pi^-)/\Gamma(K_S^0 K^- 2\pi^+)}{\frac{VALUE}{0.586 \pm 0.052 \pm 0.043}} \underbrace{\frac{EVTS}{476}}_{LINK} \underbrace{\frac{DOCUMENT ID}{LINK}}_{O1C} \underbrace{\frac{TE}{FO}}_{FO}$ | Γ_{46}/Γ_{44} CN COMMENT Γ_{γ} nucleus, $\overline{E}_{\gamma} \approx 180 \text{ GeV}$ |
| This is the "fit fraction" from the Dalitz-plot analysis. We decoup branching fraction obtained from mass projections (and used to g branching fractions) from the $D_s^+ 	o \phi \pi^+$, $\phi 	o K^+ K^-$ branchi | et some of the other ng fraction obtained | $\Gamma(K^+K^-2\pi^+\pi^-)/\Gamma(K^+K^-\pi^+)$ | Γ ₄₇ /Γ ₃₂ ΤΕCN COMMENT |
| from the Dalitz-plot analysis of $D_S^+ 	o K^+ K^- \pi^+$. That is, the branching fractions is not exactly the $\phi 	o K^+ K^-$ branching fractions is not exactly the $\phi 	o K^+ K^-$ branching fractions is not exactly the $\phi 	o K^+ K^-$ branching fractions of the property o | action 0.491. | 0.160±0.027 OUR AVERAGE | FOCS γ A, $\overline{\underline{E}}_{\gamma} \approx 180 \; \text{GeV}$ |
| 41.6±0.8 OUR AVERAGE 41.4±0.8±0.5 DEL-AMO-SA116 BABR Dalitz f 42.2±1.6±0.3 MITCHELL 09A CLEO Dalitz f • • • We do not use the following data for averages, fits, limits, etc. • | it, 12k evts | $\Gamma(\phi 2\pi^+\pi^-)/\Gamma(\phi\pi^+)$ VALUE EVIS DOCUMENT ID TECH | Γ ₄₈ /Γ ₃₃ |
| 39.6 \pm 3.3 \pm 4.7 FRABETTI 95B E687 Dalitz f $\Gamma(K^+\overline{K}^*(892)^0,\overline{K}^{*0}\to K^-\pi^+)/\Gamma(K^+K^-\pi^+)$ | | 0.269±0.027 OUR AVERAGE 0.249±0.024±0.021 136 LINK 03D FOC 0.28 ±0.06 ±0.01 40 FRABETTI 97c E687 | γ Be, $\overline{E}_{\gamma}^{\prime} \approx 200$ GeV |
| This is the "fit fraction" from the Dalitz-plot analysis. VALUE (%) DOCUMENT ID TECN COMME. 47.8±0.6 OUR AVERAGE | • | 0.58 ±0.21 ±0.10 21 FRABETTI 92 E687 0.42 ±0.13 ±0.07 19 ANJOS 88 E691 1.11 ±0.37 ±0.28 62 ALBRECHT 85D ARG | Photoproduction |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | it, 12k evts | | Γ_{49}/Γ_{47} TECN COMMENT FOCS $\sim A \overline{E} \sim 180 \text{ GeV}$ |
| 47.8 \pm 4.6 \pm 4.0 FRABETTI 958 E687 Dalitz f $\Gamma\left(f_0(980)\pi^+, f_0 \to K^+K^-\right)/\Gamma\left(K^+K^-\pi^+\right)$ | it, 701 evts Γ₃₆/Γ₃₂ | $\Gamma(\phi ho^0 \pi^+, \phi ightarrow K^+ K^-)/\Gamma(K^+ K^- 2\pi^+ \pi^-)$ | FOCS γ A, $E_{\gamma} \approx 180$ GeV Γ_{50}/Γ_{47} |
| This is the "fit fraction" from the Dalitz-plot analysis. VALUE (%) DOCUMENT ID TECN | | 0.75±0.06±0.04 LINK 03D | FOCS γ A, $\overline{E}_{\gamma} \approx 180 \text{ GeV}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | it, 12k evts | | $+K^-\pi^+$) Γ_{51}/Γ_{32} $\frac{COMMENT}{\gamma \text{ A, } \overline{E}_{\gamma} \approx 180 \text{ GeV}}$ |
| $11.0\pm3.5\pm2.6$ FRABETTI 95B E687 Dalitz f | | 0.131 ± 0.017 ± 0.011 LINK 03D | IOCO γA, Lγ ≈ 100 dev |

| 10.10.0C 10.0C 1.00.C 1 | $\Gamma(f_2(1270)\pi^+, f_2 \to \pi^+\pi^-)/\Gamma(2\pi^+\pi^-)$ This is the "fit fraction" from the Dailtz-plot analysis. VALUE DOCUMENT ID TECN COMMENT |
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| 10 \pm 0.06 \pm 0.05 LINK 03D FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV | 0.101 ±0.018 OUR AVERAGE |
| $(2K_S^0 2\pi^+\pi^-)/\Gamma(K_S^0 K^- 2\pi^+)$ Γ_{53}/Γ_{44} | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| LUEEVTSDOCUMENT IDTECNCOMMENT $151 \pm 0.015 \pm 0.015$ 37 ± 10 LINK04D FOCS γ A, $\overline{E}_{\gamma} \approx 180$ GeV | • • • We do not use the following data for averages, fits, limits, etc. • • |
| Pionic modes —— | 0.197 $\pm 0.033 \pm 0.006$ AITALA 01A E791 Dalitz fit, 848 evts 0.123 $\pm 0.056 \pm 0.018$ FRABETTI 97D E687 γ Be ≈ 200 GeV |
| | $\Gamma(\rho(1450)^0\pi^+, \rho^0 \to \pi^+\pi^-)/\Gamma(2\pi^+\pi^-)$ Γ_{62}/Γ_{5} |
| $(\pi^{+}\pi^{0})/\Gamma(K^{+}K_{5}^{0})$ Γ_{54}/Γ_{31} | This is the "fit fraction" from the Dalitz-plot analysis. |
| LUE (units 10^{-2}) CL% DOCUMENT ID TECN COMMENT 2.3 90 MENDEZ 10 CLEO e^+e^- at 4170 MeV | <u>VALUE</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.027 ±0.018 OUR AVERAGE |
| We do not use the following data for averages, fits, limits, etc. | $0.023~\pm 0.008~\pm 0.017$ AUBERT 090 BABR Dalitz fit, ≈ 10.5 k evts |
| 4.1 90 ADAMS 07A CLEO See MENDEZ 10 | 0.0656±0.0343±0.0440 LINK 04 FOCS Dalitz fit, 1475 ± 50 evts • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(2\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{55}/Γ | 0.044 \pm 0.021 \pm 0.002 AITALA 01A E791 Dalitz fit, 848 evts |
| LUE (units 10 ⁻²) <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $\Gamma(\pi^+ 2\pi^0)/\Gamma_{\text{total}}$ Γ_{63}/Γ_{63} |
| .0±0.06 OUR FIT .1±0.07±0.04 31 ALEXA NDER 08 CLEO e^+e^- at 4.17 GeV | VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT |
| ALEXANDER 08 uses single- and double-tagged events in an overall fit. The correlation | 0.65 \pm 0.13 \pm 0.03 72 \pm 16 NAIK 09A CLEO e^+e^- at 4170 MeV |
| matrix for the branching fractions is used in the fit. | $\Gamma(2\pi^+\pi^-\pi^0)/\Gamma(\phi\pi^+)$ Γ_{64}/Γ_3 |
| $(2\pi^{+}\pi^{-})/\Gamma(K^{+}K^{-}\pi^{+})$ Γ_{55}/Γ_{32} | VALUE CL% DOCUMENT ID TECN COMMENT |
| LUE EVTS DOCUMENT ID TECN COMMENT | • • We do not use the following data for averages, fits, limits, etc. • • • |
| 200±0.008 OUR FIT 1.99±0.004±0.009 ≈ 10.5k AUBERT 090 BABR e ⁺ e ⁻ ≈ 10.6 GeV | <3.3 90 ANJOS 89E E691 Photoproduction |
| We do not use the following data for averages, fits, limits, etc. | $\Gamma(\eta \pi^+)/\Gamma_{\text{total}}$ |
| $265\pm0.041\pm0.031$ 98 FRABETTI 97D E687 γ Be $pprox$ 200 GeV | Unseen decay modes of the η are included. VALUE (units 10^{-2}) DOCUMENT ID TECN COMMENT |
| $(ho^0 \pi^+)/\Gamma(2\pi^+ \pi^-)$ Γ_{56}/Γ_{55} | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| LUECL%DOCUMENT IDTECNCOMMENT | 1.58±0.11±0.18 |
| 0.018±0.005±0.010 AUBERT 090 BABR Dalitz fit, ≈ 10.5k evts • • We do not use the following data for averages, fits, limits, etc. • • • | ³⁵ ALEXANDER 08 uses single- and double-tagged events in an overall fit. |
| not seen LINK 04 FOCS Dalitz fit, 1475 ±50 evts | $\Gamma(\eta \pi^+)/\Gamma(K^+ K_0^0)$ Γ_{65}/Γ_3 |
| 0.058±0.023±0.037 AITALA 01A E791 Dalitz fit, 848 evts | Unseen decay modes of the η are included. <u>VALUE EVTS DOCUMENT ID TECN</u> <u>COMMENT</u> |
| 0.073 90 FRABETTI 97D E687 γ Be $pprox$ 200 GeV | 1.23 ±0.08 OUR FIT |
| $(\pi^{+}(\pi^{+}\pi^{-})_{S-\text{wave}})/\Gamma(2\pi^{+}\pi^{-})$ | 1.236±0.043±0.063 2587±89 MENDEZ 10 CLEO e ⁺ e ⁻ at 4170 MeV |
| This is the "fit fraction" from the Dalitz-plot analysis. See also KLEMPT 08, which uses $568 D_c^+ \rightarrow 3\pi$ decays (over 280 background events) from FNAL E791 to study | $\Gamma(\eta\pi^+)/\Gamma(\phi\pi^+)$ |
| various parametrizations of the decay amplitudes. The emphasis there is more on | Unseen decay modes of the resonances are included. <u>VALUEEVTSDOCUMENT IDTECNCOMMENT</u> |
| S-wave $\pi\pi$ decay products — 20 different solutions are given — than on D_S^+ fit fractions. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| LUE DOCUMENT ID TECN COMMENT | $0.48\pm0.03\pm0.04$ 920 JESSOP 98 CLE2 $e^+e^-pprox \varUpsilon(4S)$ |
| | 0.54 ± 0.09 ± 0.06 1.65 ALEXANDER 92 CLE2 See JESSOP 98 |
| | 0.54±0.09±0.06 165 ALEXANDER 92 CLE2 See JESSOP 98 |
| 833 ±0.020 OUR AVERAGE 330 ±0.009 ±0.019 32 AUBERT 090 BABR Dalitz fit, ≈ 10.5k evts 3704±0.0560±0.0438 33 LINK 04 FOCS Dalitz fit, 1475 ± 50 evts | $\Gamma(\omega\pi^+)/\Gamma_{ m total}$ $\Gamma_{ m 66}/\Gamma_{ m 1}$ |
| $330\pm0.009\pm0.019$ 32 AUBERT 090 BABR Dalitz fit, ≈ 10.5 k evts $3704\pm0.0560\pm0.0438$ 33 LINK 04 FOCS Dalitz fit, 1475 ± 50 evts 2 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 $\pi^+\pi^-$ | $\Gamma(\omega\pi^+)/\Gamma_{	ext{total}}$ Unseen decay modes of the ω are included. WALUE (units $10^{-2})$ EVTS DOCUMENT ID TECN COMMENT |
| $330\pm0.009\pm0.019$ 32 AUBERT 090 BABR Dalitz fit, ≈ 10.5 k evts $3704\pm0.0560\pm0.0438$ 33 LINK 04 FOCS Dalitz fit, 1475 ± 50 evts 2 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 $\pi^+\pi^-$ invariant-mass bins. 3 LINK 04 borrows a K-matrix parametrization from ANISOVICH 03 of the full $\pi^-\pi$ S- | $\Gamma(\omega\pi^+)/\Gamma_{	ext{total}}$ Unseen decay modes of the ω are included. $\frac{VALUE\ (units\ 10^{-2})}{0.25\pm0.07\ 	ext{OUR}\ 	ext{FIT}}$ $\frac{DOCUMENT\ ID}{DOCUMENT\ ID}$ $\frac{TECN}{DOCUMENT}$ $\frac{COMMENT}{DOCUMENT}$ |
| 330 \pm 0.009 \pm 0.019 32 AUBERT 090 BABR Dalitz fit, \approx 10.5k evts 3704 \pm 0.0560 \pm 0.0438 33 LINK 04 FOCS Dalitz fit, 1475 \pm 50 evts 2 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 $\pi^+\pi^-$ invariant-mass bins. 3 LINK 04 borrows a K-matrix parametrization from ANISOVICH 03 of the full $\pi^-\pi$ S-wave isoscalar scattering amplitude to describe the $\pi^+\pi^-$ S-wave component of the | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 330 \pm 0.009 \pm 0.019 32 AUBERT 090 BABR Dalitz fit, \approx 10.5k evts 3704 \pm 0.0560 \pm 0.0438 32 LINK 04 FOCS Dalitz fit, 1475 \pm 50 evts 2 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 $\pi^+\pi^-$ invariant-mass bins. 3 LINK 04 borrows a K-matrix parametrization from ANISOVICH 03 of the full π - π S-wave isoscalar scattering amplitude to describe the $\pi^+\pi^-$ S-wave component of the $\pi^+\pi^-$ state. The fit fraction given above is a sum over five f_0 mesons, the f_0 (980), f_0 (1300), f_0 (1200–1600), f_0 (1500), and f_0 (1750). See LINK 04 for details and discus- | $\Gamma(\omega\pi^+)/\Gamma_{\text{total}} \qquad \qquad \qquad \Gamma_{66}/\Gamma_{66} \qquad \Gamma_{66}/\Gamma_{66} \qquad \qquad \Gamma_{66}/\Gamma_{66} \qquad$ |
| $330\pm0.009\pm0.019$ $32\pm0.009\pm0.019$ $33\pm0.009\pm0.009$ BABR Dalitz fit, ≈ 10.5 k evts $3704\pm0.0560\pm0.0438$ 33 ± 0.009 ENCLODED Dalitz fit, 1475 ± 50 evts 2 ± 0.009 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 ± 0.009 matriant-mass bins. 3 ± 0.009 ENCLODED Dalitz fit, 1475 ± 50 evts 2 ± 0.009 ENCLODED Dalitz fit, 1475 ± 50 evts 2 ± 0.009 AUBERT 090 gives the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 ± 0.009 for the full $\pi^-\pi$ S-wave isoscalar scattering amplitude to describe the $\pi^+\pi^-$ S-wave component of the $\pi^+\pi^+\pi^-$ state. The fit fraction given above is a sum over five f_0 mesons, the f_0 (980), f_0 (1300), f_0 (1200–1600), f_0 (1500), and f_0 (1750). See LINK 04 for details and discussion. | $\Gamma(\omega\pi^+)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{66}/\Gamma_{$ |
| $330\pm0.009\pm0.019$ $32\pm0.009\pm0.019$ $33\pm0.009\pm0.009$ BABR Dalitz fit, ≈ 10.5 k evts $3704\pm0.0560\pm0.0438$ 33 ± 0.009 EVEX. Dalitz fit, 1475 ± 50 evts 2 ± 0.009 Gauss the amplitude and phase of the $\pi^+\pi^-$ S-wave in 29 ± 0.009 minvariant-mass bins. BLINK 04 borrows a K-matrix parametrization from ANISOVICH 03 of the full $\pi^-\pi$ S-wave isoscalar scattering amplitude to describe the $\pi^+\pi^-$ S-wave component of the $\pi^+\pi^-$ state. The fit fraction given above is a sum over five f_0 mesons, the $f_0(980)$, $f_0(1300)$, $f_0(1200-1600)$, $f_0(1500)$, and $f_0(1750)$. See LINK 04 for details and discussion. $(f_0(980)\pi^+, f_0 \to \pi^+\pi^-)/\Gamma(2\pi^+\pi^-)$ | $\Gamma(\omega\pi^+)/\Gamma_{\text{total}} \qquad \qquad \qquad \Gamma_{66}/\Gamma_{\text{total}} \qquad \qquad \Gamma$ |
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LUE DOCUMENT ID TECN COMMENT 0+ We do not use the following data for averages, fits, limits, etc. •• 165 ±0.043 ±0.047 AITALA 01A E791 Dalitz fit, 848 evts FRABETTI 97D E687 γ Be ≈ 200 GeV 166 (1370) π^+ , $f_0 \to \pi^+\pi^-$)/ Γ ($2\pi^+\pi^-$) This is the "fit fraction" from the Dalitz-plot analysis. See above for the full $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. LUE DOCUMENT ID TECN COMMENT 160 (1500) π^+ , $f_0 \to \pi^+\pi^-$)/ Γ ($2\pi^+\pi^-$) This is the "fit fraction" from the Dalitz-plot analysis. See above for the full $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. LUE DOCUMENT ID TECN COMMENT 160 (1500) π^+ , $f_0 \to \pi^+\pi^-$)/ Γ ($2\pi^+\pi^-$) This is the "fit fraction" from the Dalitz-plot analysis. See above for the full $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 160 (1500) π^+ , $f_0 \to \pi^+\pi^-$)/ Γ ($2\pi^+\pi^-$) This is the "fit fraction" from the Dalitz-plot analysis. 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See above for the full $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 160 (1500) π^+ , $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 161 (1500) π^+ , $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 162 (1500) π^+ , $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 163 (1500) π^+ , $\pi^+(\pi^+\pi^-)S_{-wave}$ fit fraction. 164 | $\Gamma(\omega\pi^+)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{66}/\Gamma_{66}/\Gamma_{60}$ Unseen decay modes of the ω are included. $\frac{VALUE \text{ (units }10^{-2})}{0.25\pm0.07 \text{ OUR FIT}} \qquad EVTS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $0.21\pm0.09\pm0.01 \qquad 6\pm2.4 \qquad \text{GE} \qquad 09A \qquad \text{CLEO} \qquad e^+e^- \text{ at }4170 \text{ MeV}$ $\Gamma(\omega\pi^+)/\Gamma(\eta\pi^+) \qquad \qquad \Gamma_{66}/\Gamma_{6}$ Unseen decay modes of the resonances are included. $\frac{VALUE}{0.14\pm0.04 \text{ OUR FIT}} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $0.16\pm0.04\pm0.03 \qquad \text{BALEST} \qquad 97 \qquad \text{CLE2} \qquad e^+e^- \approx \Upsilon(4S)$ $\Gamma(3\pi^+2\pi^-)/\Gamma(K^+K^-\pi^+) \qquad \qquad \Gamma_{67}/\Gamma_{3}$ $\frac{VALUE}{0.146\pm0.014 \text{ OUR AVERAGE}} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $0.146\pm0.014 \text{ OUR AVERAGE}} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $0.158\pm0.012\pm0.031 \qquad 37 \qquad \text{FRABETTI} \qquad 97C \qquad \text{E687} \qquad \gamma \text{Be}, \overline{E_{\gamma}} \approx 180 \text{ GeV}$ $0.158\pm0.042\pm0.031 \qquad 37 \qquad \text{FRABETTI} \qquad 97C \qquad \text{E687} \qquad \gamma \text{Be}, \overline{E_{\gamma}} \approx 200 \text{ GeV}$ $\Gamma(\eta\rho^+)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{\text{G9}}/\Gamma_{\text{3}}$ Unseen decay modes of the η are included. $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{EVTS}{NAIK} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT}$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{VTS}{NAIK} \qquad 09A \qquad \text{CLEO} \qquad \gamma \rightarrow 2\gamma$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{VTS}{NAIK} \qquad 09A \qquad \text{CLEO} \qquad \gamma \rightarrow 2\gamma$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{VTS}{NAIK} \qquad 09A \qquad \text{CLEO} \qquad \gamma \rightarrow 2\gamma$ $\frac{VALUE \text{ (units }10^{-2})}{Unseen decay \text{ modes}} \qquad \frac{VTS}{NAIK} \qquad 09A \qquad \text{CLEO} \qquad \gamma \rightarrow 2\gamma$ $\frac{VALUE \text{ (units }10$ |

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| $\Gamma(\omega \pi^+ \pi^0)/\Gamma_{\text{total}}$ Unseen decay modes of the | | Γ ₇₁ /Γ | $\Gamma(K^+\omega)/\Gamma_{\text{total}}$ Unseen decay modes of t | | Γ ₈₂ /Ι |
|-----------------------------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------------------|
| $VALUE (units 10^{-2})$ EVTS 2.78±0.65±0.25 34±7.9 | DO CUMENT ID TECN GE 09A CLEO | $\frac{COMMENT}{e^+ e^- \text{ at 4170 MeV}}$ | <u>VALUE (units 10−2)</u> <u>CL%</u> <0.24 90 | DO CUMENT ID TE | $\frac{CON}{ECN} = \frac{COMMENT}{e^+e^-}$ at 4170 MeV |
| $\Gamma(3\pi^+2\pi^-\pi^0)/\Gamma_{\text{total}}$ | | Γ ₇₂ /Γ | $\Gamma(K^+\eta'(958))/\Gamma(K^+K_S^0)$ | | Γ ₈₃ /Γ ₃₁ |
| VALUE | DOCUMENT ID TECN | COMMENT | Unseen decay modes of t | | - 637 - 31 |
| 0.049 + 0.033 - 0.030 | BARLAG 92c ACCN | 1 π^- 230 GeV | VALUE (units 10 ⁻²) EV 11.8±3.6±0.7 56 ± | 775 <u>DOCUMENT ID</u> 17 MENDEZ 10 | $\frac{TECN}{CLEO} = \frac{COMMENT}{e^+e^- \text{ at } 4170 \text{ MeV}}$ |
| $\Gamma(\omega 2\pi^+\pi^-)/\Gamma_{ m total}$ | | Γ ₇₃ /Γ | | | |
| Unseen decay modes of the | | | $\Gamma(K^+\eta'(958))/\Gamma(\eta'(958)\eta)$ VALUE (units 10 ⁻²) EVTS | • | Γ83/Γ74 CON COMMENT |
| $VALUE \text{ (units } 10^{-2}\text{)} \qquad EVTS$ 1.58±0.45±0.09 29±8.2 | DO CUMENT ID TECN GE 09A CLEO | e ⁺ e ⁻ at 4170 MeV | • • We do not use the follow | | |
| $\Gamma(\eta'(958)\pi^+)/\Gamma_{\text{total}}$ | | Γ ₇₄ /Γ | $4.2\pm1.3\pm0.3$ 28 ± 9 | ADAMS 07A CL | EO See MENDEZ 10 |
| Unseen decay modes of the | $\eta'(958)$ are included. | . 147. | $\Gamma(K^+\pi^+\pi^-)/\Gamma_{\text{total}}$ | | Г ₈₄ / |
| /ALUE (units 10 ⁻²) | | COMMENT | VALUE (units 10 ⁻²) 0.69±0.05 OUR FIT | DOCUMENT ID TE | COMMENT COMMENT |
| • • • We do not use the following $3.77 \pm 0.25 \pm 0.30$ | g data för averages, fits, filmits, ³⁷ ALEXANDER 08 CLEO | | $0.69 \pm 0.05 \pm 0.03$ | ³⁸ ALEXANDER 08 CL | |
| ³⁷ ALEXANDER 08 uses single- | | | ³⁸ ALEXANDER 08 uses single matrix for the branching fra | e- and double-tagged events in actions is used in the fit. | an overall fit. The correlatio |
| $\Gamma(\eta'(958)\pi^+)/\Gamma(K^+K_S^0)$ | | Γ_{74}/Γ_{31} | $\Gamma(K^+\pi^+\pi^-)/\Gamma(K^+K^-\pi$ | +) | Г ₈₄ /Г _{3:} |
| Unseen decay modes of the | | | <u>VALUE</u> | DO CUMENT ID | TECN COMMENT |
| <u>EVTS</u> 2.654±0.088±0.139 1436 ± 47 | | CN COMMENT EO e ⁺ e ⁻ at 4170 MeV | 0.127±0.007±0.014 567 ± | 31 LINK 04F I | FOCS γ A, $\overline{E}_{\gamma} pprox$ 180 GeV |
| $\Gamma(\eta'(958)\pi^+)/\Gamma(\phi\pi^+)$ | | - Г ₇₄ /Г ₃₃ | $\Gamma(K^+ ho^0)/\Gamma(K^+ \pi^+ \pi^-)$ | | Г85/Г8 |
| Unseen decay modes of the | | , 55 | | from the Dalitz-plot analysis. DOCUMENT ID TE | COMMENT |
| /ALUE | DOCUMENT ID TECN g data for averages, fits, limits, | <u>COMMENT</u> etc. • • • | 0.3883 ± 0.0531 ± 0.0261 | | DCS Dalitz fit, 567 evts |
| 1.03±0.06±0.07 537 | JESSOP 98 CLE2 | $e^+ e^- \approx \Upsilon(4S)$ | $\Gamma(K^+ ho(1450)^0$, $ ho^0	o\pi^+$: | $\pi^-)/\Gamma(K^+\pi^+\pi^-)$ | Γ ₈₆ /Γ ₈₄ |
| $1.20 \pm 0.15 \pm 0.11$ 281 $2.5 \pm 1.0 \stackrel{+1.5}{-0.4}$ 22 | ALEXANDER 92 CLE2 ALVAREZ 91 NA14 | See JESSOP 98 Photoproduction | This is the "fit fraction" VALUE | from the Dalitz-plot analysis. | ECN COMMENT |
| $0.5 \pm 0.5 \pm 0.3$ 215 | ALBRECHT 90D ARG | $e^+e^- \approx 10.4 \text{ GeV}$ | $0.1062 \pm 0.0351 \pm 0.0104$ | LINK 04F FC | DCS Dalitz fit, 567 evts |
| | | _ | $\Gamma(K^*(892)^0\pi^+$, $K^{*0}	o K$ | $(+\pi^{-})/\Gamma(K^{+}\pi^{+}\pi^{-})$ | Γ ₈₇ /Γ ₈ |
| $(\omega\eta\pi^+)/\Gamma_{	ext{total}}$ Unseen decay modes of the | | Γ ₇₆ /Γ | This is the "fit fraction" <u>VALUE</u> | from the Dalitz-plot analysis. <u>DOCUMENT ID</u> <u>TE</u> | COMMENT |
| <u>CL%</u> <u>CL%</u> 90 | DO CUMENT ID TECN GE 09A CLEO | | $0.2164 \pm 0.0321 \pm 0.0114$ | LINK 04F FC | DCS Dalitz fit, 567 evts |
| $(\eta'(958) ho^+)/\Gamma(\phi\pi^+)$ | | Γ ₇₇ /Γ ₃₃ | $\Gamma(K^*(1410)^0\pi^+, K^{*0} \rightarrow K^*)$ This is the "fit fraction" | from the Dalitz-plot analysis. | Γ ₈₈ /Γ ₈ |
| Unseen decay modes of the | DOCUMENT ID TECN | COMMENT | $0.1882 \pm 0.0403 \pm 0.0122$ | | CCN <u>COMMENT</u> DCS Dalitz fit, 567 evts |
| 1.78±0.28±0.30 137 • • • We do not use the following | JESSOP 98 CLE2 data for averages, fits, limits, | $e^+e^-\approx \Upsilon(4S)$ etc. • • • | $\Gamma(K^*(1430)^0\pi^+$, $K^{*0}	o I$ | $(K^+\pi^-)/\Gamma(K^+\pi^+\pi^-)$ | Га9/Га |
| $.44 \pm 0.62 + 0.44 \\ -0.46 $ 68 | , | See JESSOP 98 | This is the "fit fraction" <u>WALUE</u> | from the Dalitz-plot analysis. | ECNCOMMENT |
| | | | $0.0765 \pm 0.0500 \pm 0.0170$ | | DCS Dalitz fit, 567 evts |
| $(\eta'(958)\pi^+\pi^0$ 3-b ody)/ $\Gamma(\phi)$ Unseen decay modes of the | | Γ ₇₈ /Γ ₃₃ | $\Gamma(K^+\pi^+\pi^-\text{ nonresonant})$ | $/\Gamma(K^+\pi^+\pi^-)$ | Γ ₉₀ /Γ ₈ |
| ALUE CL% | DO CUMENT ID TECN | $\frac{COMMENT}{e^+ e^- \approx \Upsilon(4S)}$ | This is the "fit fraction" <u>VALUE</u> | from the Dalitz-plot analysis. <u>DOCUMENT ID</u> <u>TE</u> | COMMENT |
| <0.4 90 • • We do not use the followin _ℓ | | \ / | $0.1588 \pm 0.0492 \pm 0.0153$ | LINK 04F FC | DCS Dalitz fit, 567 evts |
| < 0.85 90 | DAOUDI 92 CLE2 | See JESSOP 98 | $\Gamma(K^0\pi^+\pi^0)/\Gamma_{ m total}$ | | Г91/І |
| M od | es with one or three K 's - | | VALUE (units 10 ⁻²) EVT. 1.00±0.18±0.04 44 ± 8 | | TECN COMMENT |
| $\Gamma(K^+\pi^0)/\Gamma(K^+K^0_S)$ | | Γ ₇₉ /Γ ₃₁ | | | CLEO e ⁺ e ⁻ at 4170 MeV |
| (ALUE (units 10^{-2}) EVTS | DOCUMENT ID TECN | COMMENT | $\Gamma(K_S^0 2\pi^+\pi^-)/\Gamma(K_S^0 K^- 2\pi^+\pi^-)$ | 2π ⁺) DOCUMENT ID | Γ92/Γ ₄ . TECN COMMENT |
| 1.2\pm1.4\pm0.2 202 \pm 70 • • We do not use the following | | e^+e^- at 4170 MeV etc. • • • | 0.18±0.04±0.05 179±3 | | FOCS γ A, $\overline{E}_{\gamma} \approx 180 \text{ GeV}$ |
| 5.5 ± 1.3 ± 0.7 141 ± 34 | | See MENDEZ 10 | $\Gamma(K^+\omega\pi^0)/\Gamma_{ m total}$ | | Г93/1 |
| $\Gamma(K_S^0\pi^+)/\Gamma(K^+K_S^0)$ | | Γ ₈₀ /Γ ₃₁ | Unseen decay modes of t VALUE (units 10 ⁻²) CL% | | ECN COMMENT |
| (ALUE (units 10^{-2}) EVTS | DOCUMENT ID TECN | COMMENT | <0.82 90 | · · · · · · · · · · · · · · · · · · · | .EO e ⁺ e ⁻ at 4170 MeV |
| 8.12±0.28 OUR AVERAGE 8.5 ±0.7 ±0.2 393 ± 33 | MENDEZ 10 CLEO | e ⁺ e ⁻ at 4170 MeV | $\Gamma(K^+\omega\pi^+\pi^-)/\Gamma_{ m total}$ | | Г94/ |
| 8.03±0.24±0.19 17.6k±481 | WON 09 BELL | e^+e^- at $\Upsilon(4S)$ | Unseen decay modes of t | | • |
| 0.4 ± 2.4 ± 1.4 113 ± 26 • We do not use the following | | γ A, $E_{\gamma} \approx$ 180 GeV etc. • • | <u>VALUE (units 10^{−2}) CL%</u> <0.54 90 | DO CUMENT ID TE | $\frac{CN}{ECN} = \frac{COMMENT}{e^+e^-}$ at 4170 MeV |
| 8.2 ±0.9 ±0.2 206 ± 22 | · | See MENDEZ 10 | $\Gamma(K^+\omega\eta)/\Gamma_{\text{total}}$ | | Γ ₉₅ / Ι |
| $(K^+\eta)/\Gamma(K^+K_S^0)$ | | Γ_{81}/Γ_{31} | Unseen decay modes of t | | · |
| Unseen decay modes of the $\angle ALUE$ (units 10^{-2}) EVTS | η are included. DOCUMENTID TEC | N COMMENT | VALUE (units 10 ⁻²) CL% <0.79 90 | | $\frac{CON}{ECN} = \frac{COMMENT}{e^+e^-}$ at 4170 MeV |
| 1.8±2.2±0.6 222 ± 41 | | e+ e- at 4170 MeV | $\Gamma(2K^+K^-)/\Gamma(K^+K^-\pi^+$ | | Г96/Г3 |
| $\Gamma(K^+\eta)/\Gamma(\eta\pi^+)$ | | Γ ₈₁ /Γ ₆₅ | <u>VALUE (units 10⁻³)</u> <u>EVT.</u> | • | TECN <u>COMMENT</u> |
| (ALUE (units 10 ⁻²) EVTS | DOCUMENT ID TECN | COMMENT | 4.0 ±0.3 ±0.2 748 ± 60 | DEL-AMO-SA11G | BABR $e^+e^-\approx \Upsilon(4S)$ |
| | data for averages, fits, limits, | -4 | ● ● We do not use the follow | ving data for averages, fits, lin | nits, etc. • • • |

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| $\Gamma(\phi K^+, \phi \to K^+ K^-)/\Gamma(2K^+ K^-)$ ALUE DOCUMENT ID TECH COMMENT | $\Gamma(\pi^+e^-\mu^+)/\Gamma_{	ext{total}}$ A test of lepton-family-number conservation. |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 41±0.08±0.03 DEL-AMO-SA116 BABR $e^+e^-\approx \Upsilon(4S)$ | VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| ——— Doubly Cabibbo-suppressed modes ——— | <20 × 10⁻⁶ 90 9.3 \pm 7.8 LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ |
| $\Gamma(2K^+\pi^-)/\Gamma(K^+K^-\pi^+)$ | $\Gamma(K^+e^+\mu^-)/\Gamma_{total}$ |
| (27. $^{\prime\prime}$)/- (1. $^{\prime\prime}$) | A test of lepton-family-number conservation. <u>VALUECL%EVTSDOCUMENT_IDTECNCOMMENT</u> |
| .33±0.23 OUR AVERAGE | <14 × 10⁻⁶ 90 9.1 ± 6.6 LEES 11G BABR $e^+e^- \approx r(4S)$ |
| $350 \pm 0.3 \pm 0.2$ 350 ± 52 DEL-AMO-SA11G BABR $e^+e^- \approx \Upsilon(45)$.29 $\pm 0.28 \pm 0.12$ 281 ± 34 KO 09 BELL e^+e^- at $\Upsilon(45)$ | $\Gamma(K^+e^-\mu^+)/\Gamma_{\text{total}}$ $\Gamma_{110}/\Gamma_{\text{total}}$ |
| .2 $\pm 1.7 \pm 1.1$ 27 ± 9 LINK 05K FOCS <0.78%, CL = 90% | A test of lepton-family-number conservation. <u>VALUE CL% EVTS DOCUMENT ID TECN COMMENT</u> |
| $(K^+ K^* (892)^0, K^{*0} \to K^+ \pi^-) / \Gamma(2K^+ \pi^-)$ | <9.7 × 10⁻⁶ 90 3.4 ± 7.3 LEES 11G BABR $e^+e^- \approx r(4S)$ |
| ALUE DOCUMENT ID TECN COMMENT | $\Gamma(\pi^- 2e^+)/\Gamma_{\text{total}}$ $\Gamma_{111}/\Gamma_{\text{total}}$ |
| .47±0.22±0.15 DEL-AMO-SA11G BABR $e^+e^-\approx \Upsilon(4S)$ | A test of lepton-number conservation. |
| Baryon-antibaryon mode | VALUE CL% EVTS DOCUMENT ID TECN COMMENT $< 4.1 \times 10^{-6}$ 90 -5.7 \pm LEES 11G BABR $e^+e^- \approx \Upsilon(4S)$ |
| $(p\overline{n})/\Gamma_{\text{total}}$ Γ_{100}/Γ | 14 • • • We do not use the following data for averages, fits, limits, etc. • • • |
| This is the only baryonic mode allowed kinematically. ALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT | $< 1.8 	imes 10^{-5}$ 90 RUBIN 10 CLEO e^+e^- at 4170 MeV |
| .30 \pm 0.36 \pm 0.12 13.0 \pm 3.6 ATHAR 08 CLEO e^+e^- , $E_{\rm cm} \approx$ 4170 MeV | $<$ 69 $	imes 10^{-5}$ 90 AITALA 99G E791 π^- N 500 GeV |
| | $\Gamma(\pi^- 2\mu^+)/\Gamma_{\text{total}}$ $\Gamma_{112}/\Gamma_{\text{total}}$ |
| Rare or forbidden modes | A test of lepton-number conservation. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| $(\pi^+e^+e^-)/\Gamma_{\text{total}}$ This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks | <14 $	imes$ 10 ⁻⁶ 90 0.6 \pm LEES 11G BABR $e^+e^-pprox \varUpsilon(4S)$ |
| must change flavor in this decay. | 5.8 • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ALUE CL% EVTS DOCUMENT ID TECN COMMENT $<$ 13 \times 10 ⁻⁶ 90 8 \pm LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ | $<$ $2.9 	imes 10^{-5}$ 90 LINK 03F FOCS γ nucleus, $\overline{E}_{\gamma} pprox$ 180 |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $<$ 8.2 $	imes$ 10 $^{-5}$ 90 AITALA 99G E791 π^- N 500 GeV |
| • • We do not use the following data for averages, fits, filmits, etc. • • • • < 2.2×10^{-5} 90 39 RUBIN 10 CLEO e^+e^- at 4170 MeV | $< 4.3 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV |
| $<\!27 	imes 10^{-5}$ 90 AITALA 99G E791 π^- N 500 GeV | $\Gamma(\pi^- e^+ \mu^+)/\Gamma_{\text{total}}$ $\Gamma_{113}/\Gamma_{113}$ |
| 39 This RUBIN 10 limit is for the e^+e^- mass in the continuum away from the $\phi(1020)$. See the next data block. | A test of lepton-number conservation. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\pi^+\phi,\phi\to e^+e^-)/\Gamma_{	ext{total}}$ This is not a test for the $\Delta C=1$ weak neutral current, but leads to the $\pi^+e^+e^-$ | 7.9 • • • We do not use the following data for averages, fits, limits, etc. • • • |
| final state. | $<$ 7.3 \times 10 $^{-4}$ 90 AlTALA 99G E791 π^- N 500 GeV |
| ALUE EVTS DOCUMENT ID TECN COMMENT $6^{+8}_{-8}\pm1)\times10^{-6}$ 3 RUBIN 10 CLEO e^+e^- at 4170 MeV | $\Gamma(K^-2e^+)/\Gamma_{\text{total}}$ $\Gamma_{114}/\Gamma_{114}$ |
| 6-4 = 1) X 10 S CLEO e · e at 4170 MeV - | A test of lepton-number conservation. |
| $(\pi^+\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{103}/Γ | VALUE CL% EVTS DOCUMENT ID TECN COMMENT $< 5.2 \times 10^{-6}$ 90 2.3 \pm LEES 116 BABR $e^+e^- \approx \Upsilon(4S)$ |
| This mode is not a useful test for a $\Delta C=1$ weak neutral current because both quarks must change flavor in this decay. | 8.6 • • • We do not use the following data for averages, fits, limits, etc. • • |
| ALUE CL% EVTS DOCUMENT ID TECN COMMENT | $< 1.7 \times 10^{-5}$ 90 RUBIN 10 CLEO e^+e^- at 4170 MeV |
| < ${f 2.6 	imes 10^{-5}}$ 90 LINK 03F FOCS γ nucleus, $\overline{F}_{\gamma} pprox$ 180 | $<$ 63 \times 10 ⁻⁵ 90 AITALA 99G E791 π^- N 500 GeV |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(K^-2\mu^+)/\Gamma_{\text{total}}$ $\Gamma_{115}/\Gamma_{\text{total}}$ |
| $<$ 43 \times 10 $^{-6}$ 90 20 \pm LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ | A test of lepton-number conservation. |
| $< 1.4 \times 10^{-4}$ 90 AITALA 99G E791 $\pi^ N$ 500 GeV $< 4.3 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT $<$ 1.3 × 10 ⁻⁵ 90 -2.3 ± LEES 11G BABR $e^+e^- \approx \Upsilon(4S)$ |
| | 5.7 <1.3 × 10 ⁻⁵ 90 LINK 03F FOCS γ nucleus, $\overline{E}_{\gamma} \approx 180$ |
| $(K^+e^+e^-)/\Gamma_{\text{total}}$ A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak inter- | GeV |
| actions. ALUECL%_EVTS DOCUMENT ID TECN_COMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • • $<1.8 \times 10^{-4}$ 90 AITALA 99G E791 π^- N 500 GeV |
| $\frac{\sqrt{1000}}{\sqrt{1000}}$ $\frac{\sqrt{1000}}{\sqrt{1000}}$ $\frac{\sqrt{1000}}{\sqrt{1000}}$ $\frac{\sqrt{1000}}{\sqrt{1000}}$ $\frac{\sqrt{1000}}{\sqrt{1000}}$ $\frac{\sqrt{1000}}{\sqrt{1000}}$ | $< 1.0 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV |
| | $\Gamma(K^-e^+\mu^+)/\Gamma_{\text{total}}$ $\Gamma_{116}/\Gamma_{\text{total}}$ |
| $< 5.2 \times 10^{-5}$ 90 RUBIN 10 CLEO e^+e^- at 4170 MeV | A test of lepton-number conservation. |
| $< 1.6 \times 10^{-3}$ 90 AITALA 99G E791 π^- N 500 GeV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT <6.1 × 10⁻⁶ 90 $-14\pm$ LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ |
| $(K^+\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{105}/Γ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| A test for the ΔC =1 weak neutral current. Allowed by higher-order electroweak interactions. | $<$ 6.8 \times 10 ⁻⁴ 90 AITALA 99G E791 π^- N 500 GeV |
| ALUE <u>CL% EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | |
| <21 \times 10 ⁻⁶ 90 4.8 \pm LEES 11G BABR $e^+e^-\approx \Upsilon(4S)$ | $\Gamma(K^*(892)^-2\mu^+)/\Gamma_{total}$ $\Gamma_{117}/\Gamma_{total}$ A test of lepton-number conservation. |
| • • We do not use the following data for averages, fits, limits, etc. • • • $< 3.6 \times 10^{-5}$ 90 LINK 03F FOCS γ nucleus, $\overline{E}_{\gamma} \approx 180$ GeV | VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| $<$ 3.6 \times 10 $^{-9}$ 90 LINK 03F FOCS γ nucleus, E_{γ} \approx 180 GeV $<$ 1.4 \times 10 $^{-4}$ 90 AITALA 99G E791 π^- N 500 GeV | <1.4 × 10 ⁻³ 90 0 KODAMA 95 E653 π ⁻ emulsion 600 GeV |
| $<5.9	imes10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV | $D_s^+ - D_s^-$ CP-violating decay-rate asymmetries |
| | |
| $\Gamma(K^*(892)^+\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{106}/Γ | This is the difference of the $D_{\mathcal{S}}^+$ and $D_{\mathcal{S}}^-$ partial widths divided by the sum of the widths. |
| A test for the $\Delta C = 1$ weak neutral current. Allowed by higher-order electroweak inter- | |
| A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. ALUE CLM EVTS DOCUMENT ID TECN COMMENT | A (v±v):= p± v v± p= == |
| A test for the $\Delta \tilde{\mathcal{C}}{=}1$ weak neutral current. Allowed by higher-order electroweak interactions. | $A_{CP}(\mu^{\pm} u)$ in $D_s^+	o \mu^+ u$, $D_s^-	o \mu^-\overline{ u}_\mu$ |
| A test for the $\Delta C=1$ weak neutral current. Allowed by higher-order electroweak interactions. ALUE CLM EVTS DOCUMENT ID TECN COMMENT | $A_{CP}(\mu^{\pm}\nu)$ in $D_s^+ \rightarrow \mu^+ \nu$, $D_s^- \rightarrow \mu^- \overline{\nu}_{\mu}$ $A_{LUE}(\%)$ $+4.8 \pm 6.1$ $A_{LEXANDER}$ 09 CLEO $e^+ e^-$ at 4170 MeV |

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|-------------------------------------------------------------------------------------------------|---------------------------------------|--------------|---------------------------------------------|
| $A_{CP}(K^{\pm}K^0_S) \text{ in } D^{\pm}_S \rightarrow K^{\pm}$ | K ⁰ ₅ | | |
| /ALUE (%) EVTS 0.3 ±0.4 OUR AVERAGE | DOCUMENT ID | TECN | COMMENT |
| +0.12±0.36±0.22 | KO 10 | BELL | $e^+ e^- \approx \gamma(4S)$ |
| +4.7 ±1.8 ±0.9 4.0k | MENDEZ 10 | | e ⁺ e ⁻ at 4170 MeV |
| • • We do not use the following | data for averages, fits | | |
| -4.9 ±2.1 ±0.9 | ALEXANDER 08 | CLEO | See MENDEZ 10 |
| $_{CP}(\mathit{K}^{+}\mathit{K}^{-}\pi^{\pm}) \; in \; \mathit{D}_{s}^{\pm} \; ightarrow \; .$ | K+ K− π± | | |
| ALUE (%) | DO CUMENT ID | TECN | COMMENT |
| -0.3±1.1±0.8 | ALEXANDER 08 | | e^+e^- at 4.17 GeV |
| (v+v+-0):- n± | | | |
| $L_{CP}(K^+K^-\pi^\pm\pi^0)$ in $D_s^\pm-L_{ALUE~(\%)}$ | | TECN | COMMENT |
| -5.9±4.2±1.2 | | | $\frac{COMMENT}{e^+e^-}$ at 4.17 GeV |
| | | 0220 | 0 0 00 1127 007 |
| $_{CP}(K_S^0K^\mp 2\pi^\pm) \text{ in } D_s^+ \rightarrow$ | | | |
| ALUE (%) | DO CUMENT ID | | |
| 0.7±3.6±1.1 | | CLEO | e ⁺ e ⁻ at 4.17 GeV |
| $\Lambda_{CP}(\pi^+\pi^-\pi^\pm)$ in $D_s^\pm	o\pi$ | $+\pi^{-}\pi^{\pm}$ | | |
| ALUE (%) | DOCUMENT ID | TECN | COMMENT |
| -2.0±4.6±0.7 | ALEXANDER 08 | CLEO | e^+e^- at 4.17 GeV |
| $A_{CP}(\pi^{\pm}\eta)$ in $D_s^{\pm} ightarrow~\pi^{\pm}\eta$ | | | |
| ALUE (%) EVTS | DOCUMENT ID | <u>TE</u> CN | COMMENT |
| -4.6±2.9±0.3 2.5k | MENDEZ 10 | | e ⁺ e ⁻ at 4170 MeV |
| ullet We do not use the following | | | |
| 8.2±5.2±0.8 | ALEXANDER 08 | CLEO | See MENDEZ 10 |
| $\Lambda_{CP}(\pi^{\pm}\eta')$ in $D_s^{\pm} ightarrow \pi^{\pm}\eta'$ | | | |
| ALUE (%) EVTS | DOCUMENT ID | TECN | COMMENT |
| 6.1±3.0±0.3 1.4k | MENDEZ 10 | | e ⁺ e ⁻ at 4170 MeV |
| • We do not use the following | | | |
| $-5.5 \pm 3.7 \pm 1.2$ | ALEXANDER 08 | CLEO | See MENDEZ 10 |
| $\Lambda_{CP}(K^\pm\pi^0)$ in $D_s^\pm	o K^\pm\pi$ | ^L 0 | | |
| ALUE (%) EVTS | DO CUMENT ID | | |
| -26.6 \pm 23.8 \pm 0.9 202 \pm 70 | | | |
| We do not use the following | | | |
| · 2 ±29 | | 7A CLE | O See MENDEZ 10 |
| $\Lambda_{CP}(K_S^0\pi^\pm)$ in $D_s^\pm	o K_S^0\pi$ | r± | | |
| ALUE (%) EVTS | DO CUMENT ID | TECI | COMMENT |
| 6.6 ± 3.3 OUR AVERAGE 1 - 5.45 ± 2.50 ± 0.33 | | | L $e^+e^-pprox \varUpsilon(4S)$ |
| -16.3 ± 7.3 ± 0.3 393 ± 33 | MENDEZ 1 | | O e^+e^- at 4170 MeV |
| \bullet We do not use the following | data for averages, fits | | |
| 27 ±11 | ADAMS 0 | 7A CLE | O See MENDEZ 10 |
| $_{CP}(\mathit{K}^{\pm}\pi^{+}\pi^{-})$ in $\mathit{D}_{s}^{\pm} ightarrow$ | $\kappa^{\pm} \pi^{+} \pi^{-}$ | | |
| NLUE (%) | DO CUMENT ID | TECN | COMMENT |
| 11.2±7.0±0.9 | ALEXANDER 08 | CLEO | e^+e^- at 4.17 GeV |
| $_{CP}(\mathit{K}^{\pm}\eta)$ in $\mathit{D}_{s}^{\pm} ightarrow\ \mathit{K}^{\pm}\eta$ | | | |
| $CP(K \eta) = D_S \rightarrow K \eta$ $EVTS$ | DOCUMENT ID | TECI | N COMMENT |
| 9.3±15.2±0.9 222 ± 41 | | | O e ⁺ e ⁻ at 4170 MeV |
| • We do not use the following | | | |
| 20 ±18 | ADAMS 0 | 7a CLE | O See MENDEZ 10 |
| $_{CP}(\mathit{K}^{\pm}\eta'(958))$ in $D_{s}^{\pm} ightarrow$ | K±n/(958) | | |
| $CP(N-\eta (930)) \parallel D_S^- \rightarrow UUE(\%)$ | | TEC | NCOMMENT |
| 6.0±18.9±0.9 56 ± 17 | MENDEZ 1 | | O e ⁺ e ⁻ at 4170 MeV |
| We do not use the following | | | |
| 17 ±37 | | | O See MENDEZ 10 |
| | | | |
| $D_s^+ - D_s^-$ T-VIOLA | TING DECAY-RAT | E ASY | MMETRIES |
| $A_{Tviol}(K_S^0K^\pm\pi^+\pi^-)$ in D_S^\pm | → K0 K± -+ | | |
| $C_{T} \equiv \vec{p}_{K^{+}} \cdot (\vec{p}_{\pi^{+}} \times \vec{p}_{\pi^{-}})$ | → rsr-n·n is a T-odd correlation | of the K | $+$ $_{\pi}$ + and $_{\pi}$ - moment |
| | | | |
| for the D_s^+ . $\overline{C}_T \equiv \vec{p}_{K^-}$ | $(p_{\pi^-} \wedge p_{\pi^+})$ is the | ie corres | . F/C - 201 |
| $D_s^ A_T \equiv [\Gamma(C_T > 0)]$ | $-$ 1 (C $_T$ $<$ 0)] $/$ [F(C | T > 0 | $+$ 1 (C $_T$ $<$ 0)] would, i |
| the abconce of strong phases | toot for Taxiolation | in DT 4 | ocave Itho Fie are partia |

the absence of strong phases, test for T violation in D_s^+ decays (the Γ 's are partial widths). With $\overline{A}_T \equiv [\Gamma(-\overline{C}_T > 0) - \Gamma(-\overline{C}_T < 0)] / [\Gamma(-\overline{C}_T > 0) + \Gamma(-\overline{C}_T < 0)]$, the asymmetry $A_{Tviol} \equiv \frac{1}{2}(A_T - \overline{A}_T)$ tests for T violation even with nonzero strong phases.

| VALUE (units 10 ⁻³) | EVTS | DOCUMENT I | D TECN | COMMENT |
|-------------------------------------------|-------------------|---------------|--------------------------|-------------------------------------------------------|
| -13.6± 7.7± 3.4 | 29.8 ± 0.3k | LEES | 11E BABR | $e^+e^-\approx \Upsilon(4S)$ |
| ● ● We do not use the | ne following data | for averages, | $fits, \ limits, \ etc.$ | • • • |
| $-36\pm67\pm23$ | 508 ± 34 | LINK | 05E FOCS | γ A, $\overline{\it E}_{\gamma} pprox$ 180 GeV |

$D_s^+ ightarrow \, \phi \ell^+ \, u_\ell$ FORM FACTORS

$r_2 \equiv A_2(0)/A_1(0)$ in $D_s^+ \rightarrow \phi \ell^+ \nu_\ell$

| VALUE | <u>EVTS</u> | DOCUMENT ID | TECN | COMMENT |
|--------------------------------------------------------------------|-------------|----------------------|--------------|-----------------------------------------|
| 0.84 ±0.11 OUR AVE | ERAGE Erro | r includes scale fa | ctor of 2.4. | |
| $0.816 \pm 0.036 \pm 0.030$ | $25\pm0.5k$ | ⁴⁰ AUBERT | 08AN BABR | $\phi e^+ \nu_e$ |
| $0.713 \pm 0.202 \pm 0.284$ | 793 | LINK | 04c FOCS | $\phi \mu^+ \nu_{\mu}$ |
| $1.57 \ \pm 0.25 \ \pm 0.19$ | 271 | AITALA | 99D E791 | $\phi e^+ \nu_e$, $\phi \mu^+ \nu_\mu$ |
| $1.4 \pm 0.5 \pm 0.3$ | 308 | AVERY | 94B CLE2 | $\phi e^+ \nu_e$ |
| $1.1\pm0.8\pm0.1$ | 90 | FRABETTI | 94F E687 | $\phi \mu^+ \nu_{\mu}$ |
| $\begin{array}{ccc} 2.1 & ^{+\;0.6}_{-\;0.5} & \pm0.2 \end{array}$ | 19 | KODAMA | 93 E653 | $\phi \mu^+ \nu_{\mu}$ |

 $^{^{40}}$ To compare with previous measurements, this AUBERT 08AN value is from a fit that fixes the pole masses at $m_A=2.5~{\rm GeV/c^2}$ and $m_{V}=2.1~{\rm GeV/c^2}.$ A simultaneous fit to r_2 , r_{V} , r_{0} (a significant s-wave contribution) and m_A , gives $r_2=0.763\pm0.071\pm0.065.$

$r_{\rm V} \equiv V(0)/A_1(0) \text{ in } D_{\rm S}^+ \rightarrow \phi \ell^+ \nu_{\ell}$

| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
|----------------------------------|-------------|----------------------|-----------|-----------------------------------------|
| 1.80 ±0.08 OUR AV | ERAGE | | | |
| $1.807 \pm 0.046 \pm 0.065$ | $25\pm0.5k$ | ⁴¹ AUBERT | 08AN BABR | $\phi e^+ \nu_e$ |
| $1.549 \pm 0.250 \pm 0.148$ | 793 | LINK | 04c FOCS | $\phi \mu^+ \nu_{\mu}$ |
| $2.27 \ \pm 0.35 \ \pm 0.22$ | 271 | AITALA | 99D E791 | $\phi e^+ \nu_e$, $\phi \mu^+ \nu_\mu$ |
| $0.9 \pm 0.6 \pm 0.3$ | 308 | AVERY | 94B CLE2 | $\phi e^+ \nu_e$ |
| $1.8 \pm 0.9 \pm 0.2$ | 90 | FRABETTI | 94F E687 | $\phi \mu^+ \nu_{\mu}$ |
| $2.3 {}^{+}1.1_{-}0.9 \pm 0.4$ | 19 | KODAMA | 93 E653 | $\phi \mu^+ \nu_{\mu}$ |

 $^{^{41}}$ To compare with previous measurements, this AUBERT 08AN value is from a fit that fixes the pole masses at $m_A=2.5~{\rm GeV/c^2}$ and $m_V=2.1~{\rm GeV/c^2}$. A simultaneous fit to r_2 , $r_{\rm V}$, r_0 (a significant s-wave contribution) and m_A , gives $r_{\rm V}=1.849\pm0.060\pm0.095$.

Γ_L/Γ_T in $D_s^+ \rightarrow \phi \ell^+ \nu_\ell$

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|------------------------|-----|------|------------------------|
| 0.72±0.18 OUR AVE | RAGE | | | | |
| $1.0 \pm 0.3 \pm 0.2$ | 308 | AVERY | 94B | CLE2 | $\phi e^+ \nu_e$ |
| $1.0 \pm 0.5 \pm 0.1$ | 90 | ⁴² FRABETTI | 94F | E687 | $\phi \mu^+ \nu_{\mu}$ |
| $0.54 \pm 0.21 \pm 0.10$ | 19 | ⁴² KODAMA | 93 | E653 | $\phi \mu^+ \nu_{\mu}$ |

 $^{^{42}\,\}mathrm{FRABETTI}$ 94F and KODAMA 93 evaluate $\mathrm{\Gamma}_L/\mathrm{\Gamma}_T$ for a lepton mass of zero.

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 $D_s^{*\pm}$

$$I(J^P) = 0(??)$$

 P^{P} is natural, width and decay modes consistent with 1^{-} .

D** MASS

The fit includes D^\pm , D^0 , D^\pm_s , $D^{*\pm}$, $D^{*\pm}$, D^{*0} , $D^{*\pm}_s$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{s1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|--------------------------|-------------------------------------|------|------------------------------------------|
| 2112.3±0.5 OUR FIT | Error includes scale factor of 1.1. | | |
| $2106.6 \pm 2.1 \pm 2.7$ | ¹ BLAYLOCK 87 | MRK3 | $e^+ e^- \rightarrow D_s^{\pm} \gamma X$ |

¹ Assuming D_s^{\pm} mass = 1968.7 \pm 0.9 MeV.

$m_{D_s^{*\pm}} - m_{D_s^{\pm}}$

The fit includes $D^\pm, D^0, D_S^\pm, D^{*\pm}, D^{*\pm}, D^{*0}, D_S^{*\pm}, D_1(2420)^0, D_2^*(2460)^0$, and $D_{S1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
|----------------------------------------------------|-----------|--------------------|---------|-----------|------------------------------------------|--|--|
| 143.8 ± 0.4 OUR FIT | | | | | | | |
| 143.9 ± 0.4 OUR AVE | RAGE | | | | | | |
| $143.76 \pm 0.39 \pm 0.40$ | | GRONBERG | 95 | CLE2 | e^+e^- | | |
| $144.22 \pm 0.47 \pm 0.37$ | | BROWN | | | | | |
| $142.5 \ \pm \ 0.8 \ \pm 1.5$ | | | | | $e^+ e^- \rightarrow D_s^{\pm} \gamma X$ | | |
| 139.5 \pm 8.3 \pm 9.7 | 60 | AIHARA | 84D | TPC | $e^+ e^- ightarrow $ hadrons | | |
| • • • We do not use the | following | g data for average | s, fits | , limits, | etc. • • • | | |
| 143.0 ± 18.0 | 8 | | | | FNAL 15-ft, ν - ² H | | |
| 110 ± 46 | | BRA NDELIK | 79 | DASP | $e^+ e^- \rightarrow D_s^{\pm} \gamma X$ | | |
| ² Result includes data of ALBRECHT 84B. | | | | | | | |

D*± WIDTH

| VALUE (MeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------|-------------|------------------|---------|-----------|--------------------------------------------------|
| < 1.9 | 90 | GRONBERG | 95 | CLE2 | e+ e- |
| < 4.5 | 90 | ALBRECHT | 88 | ARG | $E_{\text{cm}}^{\textit{ee}} = 10.2 \text{ GeV}$ |
| • • • We do not use th | e following | data for average | s, fits | , limits, | etc. • • • |
| < 4.9 | 90 | BROWN | 94 | CLE2 | e^+e^- |
| <22 | 90 | BLAYLOCK | 87 | MRK3 | $e^+ e^- \rightarrow D_c^{\pm} \gamma X$ |

D*+ DECAY MODES

 D_s^{*-} modes are charge conjugates of the modes below.

| Mode | Fraction (Γ_i/Γ) |
|------------------------------------------------------------|------------------------------|
| $\begin{array}{c} D_s^+ \gamma \\ D_s^+ \pi^0 \end{array}$ | (94.2±0.7) % (5.8±0.7) % |

CONSTRAINED FIT INFORMATION

An overall fit to a branching ratio uses 2 measurements and one constraint to determine 2 parameters. The overall fit has a $\chi^2=$ 0.0 for 1 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle/(\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.

$$x_2 \quad \boxed{-100}{x_1}$$

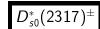
D*+ BRANCHING RATIOS

| $\Gamma(D_s^+ \gamma)/\Gamma_{\text{total}}$ | | | | | | Γ_1/Γ |
|----------------------------------------------|-----------|-------------------------------------|-------------|-----------|------------------------------------------------|---------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.942±0.007 OUR FIT | | | | | | |
| | he follow | ing data for average | s, fits | , limits, | etc. • • • | |
| $0.942 \pm 0.004 \pm 0.006$ | 16k | ³ AUBERT,BE | 05 G | BABR | 10.6 $e^+e^- \rightarrow$ hadrons | |
| see n | | ASRATYAN | 91 | HLBC | $\overline{\nu}_{\mu}$ Ne | |
| seen | | ALBRECHT | 88 | ARG | $e^+e^- \rightarrow D_s^{\pm}$ | γX |
| seen | | AIHARA | 84D | | 3 | |
| seen | | ALBRECHT | 84B | | | |
| seen | | BRANDELIK | 79 | | | |
| $\Gamma(D_s^+\pi^0)/\Gamma_{ m total}$ | | | | | | Γ2/Γ |
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| ● ● We do not use to | he follow | ing data for average | s, fits | , limits, | etc. • • • | |
| $0.059 \pm 0.004 \pm 0.006$ | 560 | ³ AUBERT,BE | 05 G | BABR | $^{10.6~e^+~e^-}_{\text{hadrons}} \rightarrow$ | |
| $\Gamma(D_s^+\pi^0)/\Gamma(D_s^+\gamma)$ | | | | | | Γ_2/Γ_1 |
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| 0.062±0.008 OUR FIT | | | | | | |
| 0.062±0.008 OUR AVE | RAGE | | | | | |
| $0.062 \pm 0.005 \pm 0.006$ | | AUBERT,BE | 05 G | BABR | 10.6 $e^+e^- \rightarrow$ hadrons | |
| $0.062^{+0.020}_{-0.018} \pm 0.022$ | | GRONBERG | 95 | CLE2 | e^+e^- | |
| ³ Derived from the ra | tio Γ(D | $(\pi^0) / \Gamma(D_s^+ \gamma)$ as | sumir | ng that t | he branching fra | tions of |

D*± REFERENCES

 $D_s^{*+} \rightarrow D_s^+ \pi^0$ and $D_s^{*+} \rightarrow D_s^+ \gamma$ decays sum to 100%.

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|-----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
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$$I(J^P) = O(0^+)$$

 $J, P \text{ need confirmation}.$

AUBERT 06P does not observe neutral and doubly charged partners of the $D_{\rm 50}^{*}(2317)^{+}$.

$D_{s0}^*(2317)^{\pm}$ MASS

The fit includes $D^\pm, D^0, D_S^\pm, D^{*\pm}, D^{*\pm}, D^{*0}, D_S^{*\pm}, D_1(2420)^0, D_2^*(2460)^0$, and $D_{S1}(25\,36)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT | |
|--------------------------|------------|------------------------|----------------|--------------------------|---------------------|
| 2317.8 ± 0.6 OUR FI | T Error in | cludes scale factor of | of 1.1. | | |
| 2318.0 ± 1.0 OUR A | VERAGE E | Error includes scale | factor of 1.4. | | |
| $2319.6 \pm 0.2 \pm 1.4$ | 3180 | AUBERT | 06P BABR | 10.6 $e^+e^ \rightarrow$ | $D_{c}^{+}\pi^{0}X$ |
| $2317.3 \pm 0.4 \pm 0.8$ | 1022 | ¹ AUBERT | 04E BABR | $10.6 e^{+}e^{-}$ | , |

 $D_{s0}^*(2317)^\pm$, $D_{s1}(2460)^\pm$

| ullet $ullet$ $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | | | | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|-----------------------|----------|--------------------------------------------------|--|--|--|
| 2317.2 ± 1.3 | 88 | ² AUBERT,B | 04s BABR | $B \to D_{s0}^{(*)}(2317)^{+}\overline{D}^{(*)}$ | | | |
| $2317.2 \pm 0.5 \pm 0.9$ | 761 | ³ MIKAMI | 04 BELL | 10.6 e+e- | | | |
| $2316.8 \pm 0.4 \pm 3.0$ | 1267 ± 53 | | 03G BABR | | | | |
| 2317.6 ± 1.3 | 273 ± 33 | ^{3,5} AUBERT | | | | | |
| $2319.8 \pm 2.1 \pm 2.0$ | 24 | ³ KROKOVNY | 03в BELL | $10.6 \ e^{+} e^{-}$ | | | |
| 2319.8 \pm 2.1 \pm 2.0 24 ³ KROKOVNY 03B BELL 10.6 e^+e^- ¹ Supersedes AUBERT 03G. ² Systematic errors not evaluated. ³ Not independent of the corresponding $m_{D_{S0}^*(2317)} - m_{D_S}$. ⁴ From $D_S^+ \rightarrow K^+K^-\pi^+$ decay. ⁵ From $D_S^+ \rightarrow K^+K^-\pi^+\pi^0$ decay. | | | | | | | |
| m m . | | | | | | | |

$m_{D_{s0}^*(2317)^{\pm}} - m_{D_s^{\pm}}$

The fit includes D^\pm , D^0 , D^\pm_s , $D^{*\pm}$, $D^{*\pm}$, $D^{*\pm}$, $D^{*\pm}$, $D_5^{(2420)}$, D_2^* (2460) 0 , and D_{s1} (2536) $^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------------------|------------------------------|----------|---------|------------------------------------|
| 349.3±0.6 OUR F | IT Error incl | udes scale factor of | 1.1. | | |
| 349.2±0.7 OUR A | VERAGE | | | | |
| $348.7 \pm 0.5 \pm 0.7$ | 761 | MIKAMI | 04 | BELL | 10.6 e ⁺ e ⁻ |
| $350.0 \pm 1.2 \pm 1.0$ | 135 | | 03 | CLE2 | 10.6 e^+e^- |
| $351.3 \pm 2.1 \pm 1.9$ | 24 | ⁶ KROKOVNY | 03в | BELL | 10.6 e ⁺ e ⁻ |
| • • • We do not ι | use the followin | ng data for average | s, fits, | limits, | etc. • • • |
| $349.6 \pm 0.4 \pm 3.0$ | | | | | |
| 350.2 ± 1.3 | 273 | ^{9,10} AUBERT | 03G | BABR | 10.6 e^+e^- |
| ⁶ Recalculated by | y us using <i>m</i> D | _s = 1968.5 ± 0.6 | MeV. | | |
| ⁷ From $D_s^+ \rightarrow$ | $K^+ K^- \pi^+$ de | cay. | | | |
| ⁸ Recalculated by | y us using <i>m</i> D | ₊ = 1967.20 ± 0.0 |)3 Me | V. | |
| ⁹ From $D_s^+ \rightarrow$ | | | | | |
| | | | MeV. | System | atic errors not estimated. |

$D_{s0}^*(2317)^{\pm} \text{ WIDTH}$

| VALUE (MeV) | CL% | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT |
|-----------------|--------|-------------|------------------|---------|------------|----------------------------------------|
| < 3.8 | 95 3 | 3180 | AUBERT | 06P | BABR | 10.6 $e^+e^- \rightarrow D_S^+\pi^0 X$ |
| • • • We do not | use th | e following | data for average | es, fit | s, limits, | etc. • • • |
| < 4.6 | 90 | 761 | MIKAMI | 04 | BELL | 10.6 e ⁺ e ⁻ |
| <10 | | | AUBERT | 03G | BABR | 10.6 e ⁺ e ⁻ |
| < 7 | 90 | 135 | BESSON | 03 | CLE2 | 10.6 e ⁺ e ⁻ |
| | | | | | | |

$D_{s0}^{*}(2317)^{\pm}$ DECAY MODES

 $D_{s0}^{*}(2317)^{-}$ modes are charge conjugates of modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $D_s^+\pi^0$ | seen |
| Γ_2 | $D_s^+ \gamma$ | |
| Γ_3 | $D_s^*(2112)^+ \gamma$ | |
| Γ_4 | $D_s^+ \gamma \gamma$ | |
| Γ_5 | $D_s^*(2112)^+ \pi^0$ | |
| Γ_6 | $D_{s}^{+}\pi^{+}\pi^{-}$ $D_{s}^{+}\pi^{0}\pi^{0}$ | |
| Γ_7 | $D_{s}^{+}\pi^{0}\pi^{0}$ | not seen |

$D_{s0}^*(2317)^{\pm}$ BRANCHING RATIOS

| $\Gamma(D_s^+\pi^0)/\Gamma_{\rm tot}$ | al | | | | | Γ_1/Γ |
|---------------------------------------|------------------------|--------------------|----------|-----------|------------------------------------|---------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| seen | 1540 ± 62 | AUBERT | 03 G I | BABR | 10.6 e^+e^- | |
| $\Gamma(D_s^+ \gamma)/\Gamma(D_s^+$ | π^{0}) | | | | | Γ_2/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| < 0.05 | 90 | MIKAMI | 04 | BELL | 10.6 e^+e^- | |
| • • • We do not | use the following | ng data for averag | es, fits | , limits, | etc. • • • | |
| < 0.14 | 95 | AUBERT | 06P | BABR | 10.6 e ⁺ e ⁻ | |
| < 0.052 | 90 | BESSON | 03 | CLE2 | 10.6 $e^{+}e^{-}$ | |
| Γ(D*(2112)+γ | $)/\Gamma(D_s^+\pi^0)$ | | | | | Γ_3/Γ_1 |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| < 0.059 | 90 | BESSON | 03 | CLE2 | 10.6 $e^+ e^-$ | |
| ullet $ullet$ We do not | use the following | ng data for averag | es, fits | , limits, | etc. • • • | |
| < 0.16 | 95 | AUBERT | 06P | BABR | 10.6 e ⁺ e ⁻ | |
| < 0.18 | 90 | MIKAMI | 04 | BELL | 10.6 $e^+ e^-$ | |

| $\Gamma(D_s^+ \gamma \gamma)$ |)/r(<i>t</i> | $O_s^+ \pi^0$) | | | | | Γ_4/Γ_1 |
|-------------------------------------------------------------------------|--------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------|-----------|------------------------------------|----------------------------------------------------------|
| VALUE | • | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| <0.18 | | 95 | AUBERT | 06P | BABR | 10.6 e^+e^- | |
| • • • We o | do not | use the followin | ig data for averag | es, fits | limits, | etc. • • • | |
| not seen | | | AUBERT | 03 G | BABR | 10.6 $e^+ e^-$ | |
| Γ(D*(211 | .2)+1 | $(r^0)/\Gamma(D_s^+\pi^0)$ | | | | | Γ ₅ /Γ ₁ |
| VALUE | | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT | |
| <0.11 | | 90 | BESSON | 03 | CLE2 | 10.6 e^+e^- | |
| $\Gamma(D_s^+\pi^+$ | $\pi^-)/$ | $\Gamma(D_s^+\pi^0)$ | | | | | Γ_6/Γ_1 |
| VALUE | | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT | |
| <0.004 | | 90 | MIKAMI | 04 | BELL | 10.6 $e^{+}e^{-}$ | |
| • • • We d | do not | use the followin | ig data for averag | es, fits, | , limits, | | |
| < 0.005 | | 95 | AUBERT | 06P | | 10.6 e ⁺ e ⁻ | |
| < 0.019 | | 90 | BESSON | 03 | CLE2 | 10.6 e ⁺ e ⁻ | |
| $\Gamma(D_s^+\pi^0\tau)$ | τ ⁰)/Γ | $(D_s^+ \pi^0)$ | | | | | Γ_7/Γ_1 |
| VALUE | | CL% | DOCUMENT ID | | TECN | COMMENT | |
| < 0.25 | | 95 | AUBERT | 06P | BABR | 10.6 $e^+ e^-$ | |
| | | D* _{s0} | (2317) [±] REFE | REN | CES | | |
| AUBERT AUBERT AUBERT,B MIKAMI AUBERT BESS ON KROKOVNY | 06 P 04 E 04 S 04 03 G 03 03 B | PR D74 032007 PR D69 031101R PRL 93 181801 PRL 92 012002 PRL 90 242001 PR D68 032002 PRL 91 262002 | B. Aubert et B. Aubert et B. Aubert et Y. Mikami et B. Aubert et D. Besson et P. Krokovny | al. al. al. al. al. | | | Collab.) Collab.) Collab.) Collab.) Collab.) |

$D_{s1}(2460)^{\pm}$

 $I(J^P) = 0(1^+)$

$D_{s1}(2460)^{\pm}$ MASS

The fit includes D^\pm , D^0 , D_s^\pm , $D^{*\pm}$, D^{*0} , $D_s^{*\pm}$, $D_1(2420)^0$, $D_2^*(2460)^0$, and $D_{s1}(2536)^\pm$ mass and mass difference measurements.

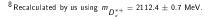
| | EVTS | DOCUMENT ID | | TECN | COMMENT | |
|--------------------------------------------------------------------------------------------|-----------|--------------------------|---------------------|-------------------------------------|---------------------------------------------------|--|
| 2459.6±0.6 OUR FIT Error includes scale factor of 1.1. | | | | | | |
| | AVERA | GE Error includes | | | | |
| $2460.1 \pm 0.2 \pm 0.8$ | | ¹ AUBERT | | BABR | 10.6 e ⁺ e ⁻ | |
| $2458.0\pm1.0\pm1.0$ | 195 | AUBERT | | | 10.6 e ⁺ e ⁻ | |
| • • • We do not | use the | following data for a | | | | |
| $2459.5\pm1.2\pm3.7$ | 920 | AUBERT | 06P | BABR | 10.6 $e^+e^- \rightarrow D_S^+ \gamma X$ | |
| $2458.6 \pm 1.0 \pm 2.5$ | 560 | AUBERT | | | 10.6 $e^+e^- \to D_S^+\pi^0 \gamma X$ | |
| $2460.2 \pm 0.2 \pm 0.8$ | 123 | AUBERT | | | 10.6 $e^+e^- \to D_S^+\pi^+\pi^-X$ | |
| 2458.9 ± 1.5 | 112 | ² AUBERT,B | 04s | BABR | $B \rightarrow D_{s1}(2460) + \overline{D}(*)$ | |
| 2461.1 ± 1.6 | 139 | ³ AUBERT,B | 04s | BABR | $B \to D_{S1}(2460) + \overline{D}(*)$ | |
| $2456.5\pm 1.3\pm 1.3$ | 126 | 4,5 MIKAMI | 04 | BELL | 10.6 e ⁺ e ⁻ | |
| $2459.5\pm1.3\pm2.0$ | 152 | 6,7 MIKAMI | 04 | BELL | 10.6 e ⁺ e ⁻ | |
| $2459.9\pm0.9\pm1.6$ | 60 | 6,7 MIKAMI | | BELL | | |
| $2459.2\pm1.6\pm2.0$ | 57 | KROKOVNY | 03в | BELL | 10.6 e ⁺ e ⁻ | |
| $^{ m 1}$ The average o | f the val | ues obtained from t | he D | $^+_{\rm S} \gamma$, $D_{\rm S}^+$ | $\pi^0 \gamma$, $D_S^+ \pi^+ \pi^-$ final state. | |
| | | evaluated. From the | | | | |
| ³ Systematic err | ors not | evaluated. From the | deca | y to D+ | γ. | |
| ⁴ Not independe | nt of th | e corresponding <i>m</i> | D _{s1} (24 | 60)± - | m _{D*±} . | |
| 5 Using $m_{D_c^{*+}} = 2112.4 \pm 0.7 \; { m MeV}.$ | | | | | | |
| ⁶ Not independent of the corresponding $m_{D_{s1}(2460)^{\pm}} - m_{D_s^{\pm}}$ | | | | | | |
| ⁷ Using $m_{D_s^+} = 1968.5 \pm 0.6$ MeV. | | | | | | |

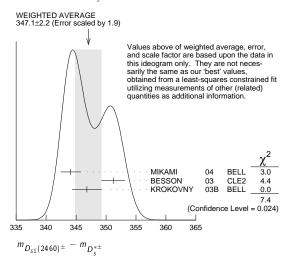
$m_{D_{s1}(2460)^\pm}-m_{D_s^{*\pm}}$

The fit includes $D^\pm, D^0, D_S^\pm, D^{*\pm}, D^{*\pm}, D^{*0}, D_S^{*\pm}, D_1(2420)^0, D_2^*(2460)^0$, and $D_{S1}(2536)^\pm$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|-----------|-----------------------|---------|---------|------------------------------------|
| 347.2±0.7 OUR FIT | | | | | |
| 347.1 ± 2.2 OUR AVER | AGE Error | includes scale fa | ctor of | 1.9. Se | e the ideogram below. |
| $344.1 \pm 1.3 \pm 1.1$ | 126 | MIKA MI | 04 | BELL | 10.6 e ⁺ e ⁻ |
| $351.2 \pm 1.7 \pm 1.0$ | 41 | BESSON | 03 | CLE2 | 10.6 e^+e^- |
| $346.8\!\pm\!1.6\!\pm\!1.9$ | 57 | ⁸ KROKOVNY | 03в | BELL | 10.6 e ⁺ e ⁻ |

Meson Particle Listings $D_{s1}(2460)^{\pm}$





$m_{D_{s1}(2460)^{\pm}} - m_{D_s^{\pm}}$

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}({\it 2536})^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | | DO CUMENT I | | TECN | COMMENT |
|--------------------------------------------------|-----------------------|------|--------------|---------|------|----------------|
| 491.1±0.7 OUR FIT | | udes | scale factor | of 1.1. | | |
| 491.3±1.4 OUR AVE | RAGE | | | | | |
| $491.0\pm1.3\pm1.9$ | 152 | 9 | MIKAMI | 04 | BELL | 10.6 e^+e^- |
| $491.4\pm0.9\pm1.5$ | 60 | 10 | MIKAMI | 04 | BELL | 10.6 $e^+ e^-$ |
| ⁹ From the decay to | $D_s^{\pm} \gamma$. | | | | | |
| 9 From the decay to 10 From the decay to | $D_s^{\pm} \pi^+ \pi$ | | | | | |

$D_{s1}(2460)^{\pm}$ WIDTH

| VALUE (MeV) | CL% | EVTS | DO CUMENT I | D | TECN | COMMENT |
|-------------|---------|-----------|-----------------|--------|-------------|---------------------------------------------------|
| < 3.5 | 95 | 123 | AUBERT | 06P | BABR | 10.6 $e^+e^- \rightarrow D_c^+\pi^+\pi^-X$ |
| • • • We do | not use | the follo | wing data for a | verage | es, fits, l | imits, etc. • • • |
| < 6.3 | 95 | 560 | AUBERT | 06P | BABR | $10.6 \ e^+ e^- \rightarrow D_s^+ \pi^0 \gamma X$ |
| <10 | | 195 | AUBERT | 04 E | BABR | 10.6 e ⁺ e ⁻ |
| < 5.5 | 90 | 126 | MIKAMI | 04 | BELL | $10.6 \ e^{+} e^{-}$ |
| < 7 | 90 | 41 | BESSON | 03 | CLE2 | 10.6 e ⁺ e ⁻ |

$D_{s1}(2460)^+$ DECAY MODES

 $D_{s1}(2460)^-$ modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_j/Γ) | Scale factor/ Confidence level |
|-----------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|
| $\overline{\Gamma_1}$ | $D_s^{*+} \pi^0$ | (48 ±11) % | |
| Γ_2 | $D_s^+ \gamma$ | (18 ± 4) % | |
| Γ_3 | $D_{s}^{+}\pi^{+}\pi^{-}$ | (4.3 ± 1.3) % | S=1.1 |
| Γ_4 | $D_s^{*+} \gamma$ | < 8 % | CL=90% |
| | $D_{s0}^*(2317)^+ \gamma$ | $(3.7^{+}_{-}$ $\overset{5.0}{\overset{2.4}{}})$ % | |
| Γ_6 | $D_s^+ \pi^0 \ D_s^+ \pi^0 \pi^0$ | | |
| Γ_7 | $D_{s}^{+}\pi^{0}\pi^{0}$ | | |
| Γ8 | $D_s^{\frac{5}{4}} \gamma \gamma$ | | |

CONSTRAINED FIT INFORMATION

An overall fit to 7 branching ratios uses 8 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2=$ 3.4 for 4 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

< 0.33

$D_{s1}(2460)^{\pm}$ BRANCHING RATIOS

| | D_{s1} (2460 |) - BRANCHING | KATIU | 3 | |
|------------------------------------------------------------------------|--------------------------------|------------------------------------------------|------------------------|--------------------------------------|----------------------------------|
| $\Gamma(D_s^{*+}\pi^0)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
| , , | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 0.48±0.11 OUR FIT | 11 | AUDEDT 06 | DADD | D 0.4440 | - |
| 0.56±0.13±0.09 • • • We do not use th | e following | AUBERT 06N | ts. limits. | etc. \bullet \bullet |) D(*) |
| seen | 41 | BESSON 03 | | 10.6 e ⁺ e ⁻ | |
| $^{11}	exttt{Evaluated}$ in AUBER | T 06N incl | | from AU | BERT,B 04s. | |
| $\Gamma(D_s^+ \gamma)/\Gamma_{\text{total}}$ | | | | | Γ_2/Γ |
| VALUE | DO CUI | MENT ID TECN | і сомм | ENT | 12/1 |
| 0.18±0.04 OUR FIT | | | | | ` |
| 0.16±0.04±0.03 | | | | $D_{s1}(2460) = \overline{D}(*$ | , |
| ¹² Evaluated in AUBER | | uding measurements | Trom AU | BERT,B 045. | |
| $\Gamma(D_s^+\gamma)/\Gamma(D_s^{*+}\pi^0)$ | | | | | Γ_2/Γ_1 |
| 0.38 ±0.05 OUR FIT | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 0.44 ±0.09 OUR AVE | | | | | |
| $0.55 \pm 0.13 \pm 0.08$ $0.38 \pm 0.11 \pm 0.04$ | 152 38 | MIKAMI 04 KROKOVNY 03i | | | |
| | | | | | |
| $0.274 \pm 0.045 \pm 0.020$ | 251 ¹ | 3 AUBERT,B 04s | BABR | <i>B</i> → | (.) |
| < 0.49 90 | | BESSON 03 | CLE2 | $D_{s1}(2460)^{+}$ 10.6 $e^{+}e^{-}$ | D(*) |
| 13 Used by AUBERT 00 | | | | | |
| | | casarement of b(L | 5 " 1 " | 3 D(D _S 1). | |
| $\Gamma(D_s^+\pi^+\pi^-)/\Gamma(D_s^*$ | | | | | Γ_3/Γ_1 |
| 0.090±0.020 OUR FI | T Error in | <u>DOCUMEN</u> Icludes scale factor o | <i>T ID</i> f 1.2. | TECNCOMME | NT |
| $0.14 \pm 0.04 \pm 0.02$ | | 60 MIKAMI | 04 | | + e ⁻ |
| • • • We do not use th | | | | | |
| <0.08 | 90 | BESSON | 03 | CLE2 10.6 e | + e ⁻ |
| $\Gamma(D_s^{*+}\gamma)/\Gamma(D_s^{*+}\pi^0$ |) | | | | Γ_4/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | | |
| <0.16 • • • We do not use th | 90 e following | BESSON 03 data for averages, fi | | | |
| <0.31 | 90 | MIKAMI 04 | | | |
| E/D* (0217)+ \/E/ | /n*+ 0\ | | | | F /F |
| $\Gamma(D_{s0}^*(2317)^+\gamma)/\Gamma($ | (D_{s}^{*}, π^{s}) | DOCUMENT ID | TECN | COMMENT | Γ_5/Γ_1 |
| <0.22 | 95 | | | 10.6 e ⁺ e ⁻ | |
| • • • We do not use th | e following | data for averages, fi | ts, limits, | etc. • • • | |
| < 0.58 | 90 | BESSON 03 | CLE2 | 10.6 $e^{+}e^{-}$ | |
| $\Gamma(D_s^{*+}\pi^0)/[\Gamma(D_s^{*+})]$ | π^0) + $\Gamma(I$ | $D_{s0}^*(2317)^+ \gamma)$ | | Γ1/(| $\Gamma_1 + \Gamma_5$) |
| VALUE | | DO CUMENT ID | TECN | | |
| 0.93±0.09 OUR FIT 0.97±0.09±0.05 | | AUBERT 06 | p RARR | 10.6 e+e- | |
| | / | | DADIO | | |
| $\Gamma(D_s^+\gamma)/[\Gamma(D_s^{*+}\pi^0)]$ | $) + \Gamma(D_s^*)$ | $_{0}(2317)^{+}\gamma)$ | TECN | | $\Gamma_1 + \Gamma_5$) |
| 0.35 ±0.04 OUR FIT | | DOCUMENT ID | <u>IECN</u> | COMMENT | |
| $0.337 \pm 0.036 \pm 0.038$ | | AUBERT 06 | P BABR | 10.6 e^+e^- | |
| $\Gamma(D_s^+\pi^+\pi^-)/[\Gamma(D_s^+\pi^-)]$ | $^{*+}\pi^{0}) +$ | Γ(D*。(2317)+γ) | 1 | Гз/(| Γ ₁ +Γ ₅) |
| VALUE | | DO CUMENT ID | <u>TECN</u> | | |
| 0.083±0.017 OUR FIT 0.077±0.013±0.008 | Error incl | udes scale factor of 1 AUBERT 06 | 2. p R∆RR | 10.6 e+e- | |
| | 0> | | | | |
| $\frac{\Gamma(D_s^{*+}\gamma)/[\Gamma(D_s^{*+}\pi)]}{< 0.24}$ | ν) + Γ(<i>D</i> | $_{s0}^{*}(2317)^{+}\gamma)$ | | Γ4/(Ι | $\Gamma_1 + \Gamma_5$) |
| <0.24 | 95 | AUBERT 06 | P BABR | 10.6 e ⁺ e ⁻ | |
| | | | | | \ |
| $\frac{\Gamma(D_{s0}^*(2317)^+\gamma)/[\Gamma]}{\frac{VALUE}{<0.25}}$ | (D_s^*, π^*) | $+ 1 (D_{s0}^* (2317)^{-1})$ | γ)] _{TECN} | I 5/(I | 1+15) |
| <0.25 | 95 | AUBERT 06 | P BABR | 10.6 e ⁺ e ⁻ | |
| | | | | | |
| $I(D_s^1\pi^2)/[I(D_s^1\pi^2)]$ | ~)+1(D | (2311) ' γ)] | TECN | I 6/ (I | Γ1+Γ5) |
| $\frac{\Gamma(D_s^+\pi^0)/\left[\Gamma(D_s^{*+}\pi^0)\right]}{<0.042}$ | 95 | AUBERT 06 | P BABR | 10.6 e ⁺ e ⁻ | |
| | | | | | F. 1 F N |
| $\frac{\Gamma(D_s^+\pi^0\pi^0)/\left[\Gamma(D_s^*\right]}{<0.68}$ | π- j+l | $(\nu_{s0}(2317), \lambda)]$ | TECN | Γ ₇ /(I | 1+15) |
| <0.68 | 95 | AUBERT 06 | P BABR | 10.6 e ⁺ e ⁻ | |
| | | | | | |
| | .0)/- |)* (2217\+ <u>-</u> .\] | | F_ // | г. д г. Х |
| VALUE | r ⁰) + Γ(<i>E</i> | P* _{s0} (2317)+γ)] <u>DOCUMENT ID</u> | TECN | Γ ₈ /(I | Γ ₁ +Γ ₅) |

06P BABR 10.6 e^+e^-

AUBERT

 $D_{s1}(2460)^{\pm}$, $D_{s1}(2536)^{\pm}$

$D_{\rm s1}(2460)^{\pm}$ REFERENCES

| AUBERT | 06 N | PR D74 031103R | B. Aubert et al. | (BABAR Collab.) |
|----------|------|----------------|--------------------|-----------------|
| AUBERT | 06P | PR D74 032007 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 04 E | PR D69 031101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT,B | 04S | PRL 93 181801 | B. Aubert et al. | (BABAR Collab.) |
| MIKAMI | 04 | PRL 92 012002 | Y. Mikami et al. | (BELLE Collab.) |
| BESSON | 03 | PR D68 032002 | D. Besson et al. | (CLEO Collab.) |
| KROKOVNY | 03B | PRL 91 262002 | P. Krokovny et al. | (BELLE Collab.) |

$D_{s1}(2536)^{\pm}$

$$I(J^P) = 0(1^+)$$

J, P need confirmation.

Seen in $D^*(2010)^+ K^0$, $D^*(2007)^0 K^+$, and $D_s^+ \pi^+ \pi^-$. Not seen in $D^+ K^0$ or $D^0 K^+$. $J^P = 1^+$ assignment strongly favored.

$D_{s1}(2536)^{\pm}$ MASS

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|---------------------------------------|---------------|-------------------------|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2535.12 ± 0.13 OUR F | iT. | | | |
| 2535.18 ± 0.24 OUR A | VERAGE | | | |
| $2535.7\ \pm0.6\ \pm0.5$ | 46 ± 9 | $^{ m 1}$ ABAZOV | 09G D0 | $B_s^0 \to D_{s1}^- \mu^+ \nu_{\mu} X$ |
| $2534.78\pm0.31\pm0.40$ | 182 | AUBERT | 08B BABR | $B \rightarrow \overline{D}^{(*)} D^* K$ |
| $2534.6 \pm 0.3 \pm 0.7$ | 193 | AUBERT | 06P BABR | 10.6 $e^+e^- \rightarrow$ |
| | | | | $D_{S}^{+}\pi^{+}\pi^{-}X$ |
| 2535.3 ±0.7 | 92 | ² HEISTER | 02B ALEP | $e^+e^{\stackrel{3}{-}} \rightarrow D^{*+}K^0X$ |
| | | | | $D^{*0} K^{+} X$ |
| 2534.2 ± 1.2 | 9 | ASRATYAN | 94 BEBC | $\nu N \rightarrow$ |
| | | | | $\stackrel{\nu}{\stackrel{N}{\stackrel{\rightarrow}{D^*}}} \stackrel{K^0}{\stackrel{\times}{\stackrel{N}}} \stackrel{X,D^{*0}}{\stackrel{K^{\pm}}{\stackrel{\times}{\stackrel{\times}}}} \stackrel{K}{\stackrel{\times}{\stackrel{\times}}} \stackrel{X}{\stackrel{\times}{\stackrel{\times}}}$ |
| 2535 $\pm 0.6 \pm 1$ | 75 | FRABETTI | 94B E687 | $\gamma \text{Be} \rightarrow D^{*+} K^{0} X$, |
| | | | | $e^{+}e^{-} \xrightarrow{D^{*0}} K^{+} X$ |
| $2535.3 \pm 0.2 \pm 0.5$ | 134 | ALEXA NDER | 93 CLE2 | |
| $2534.8 \pm 0.6 \pm 0.6$ | 44 | ALEXA NDER | | $e^+ e^- \rightarrow D^{*+} K^0 X$ |
| $2535.2 \pm 0.5 \pm 1.5$ | 28 | ALBRECHT | 92R ARG | $10.4 \ e^+ \ e^- \rightarrow$ |
| 05066 10-10- | | A1 (ED) (| | $e^{+}e^{-} \rightarrow D^{*+}K^{0}X$ |
| $2536.6 \pm 0.7 \pm 0.4$ | | AVERY | 90 CLEO | |
| $2535.9 \pm 0.6 \pm 2.0$ | | ALBRECHT | 89E ARG | $D_{s1}^* \to D^*(2010) K^0$ |
| ● ● We do not use | the following | g data for average | s, fits, limits, | etc. • • • |
| 2534.1 ± 0.6 | 116 | ³ AUSHEV | 11 BELL | $B \rightarrow D_{s1}(2536)^+ D^{(*)}$ |
| 2535.08 ± 0.01 ± 0.15 | 8038 | ⁴ LEES | 11B BABR | $10.6 e^{+\frac{31}{e^{-}}} \rightarrow$ |
| 2000.00 ± 0.01 ± 0.10 | 0030 | 2223 | IID DADI | $D^{*+} \kappa_S^0 X$ |
| $2535.57 + 0.44 \pm 0.10$ | 236 + 30 | ⁵ CHEKANOV | 09 ZEUS | $e^{\pm} p \rightarrow D^{*+} K^0_S X$, |
| -0.41 | | | 2200 | $D^{*0}K^+X$ |
| 2535 ± 28 | | ⁶ A SRATYA N | 88 HLBC | $\nu N \rightarrow D_s \gamma \gamma X$ |

 $^{^{1}}$ Using the $D^{*}(2010)^{\pm}$ mass of 2010.0 \pm 0.4 MeV from PDG 06.

$m_{D_{s1}(2536)^{\pm}} - m_{D_{s}^{*}(2111)}$

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|--------------------|-------------------------------------|------|--------------------|
| 422.8± 0.5 OUR FIT | Error includes scale factor of 1.1. | | |
| 424 ±28 | A SRATYA N 88 | HLBC | $D_s^{*\pm}\gamma$ |

$m_{D_{s1}(2536)^{\pm}} - m_{D^*(2010)^{\pm}}$

The fit includes D^{\pm} , D^{0} , D_{s}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{s}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------|----------|-------------------|-----|------|---------------------------------------------|---|
| 524.84 ± 0.04 OUR | FIT | | | | | |
| 524.84±0.04 OUR | AVERAGE | | | | | |
| $524.83 \pm 0.01 \pm 0.04$ | 8038 | ⁷ LEES | 11B | BABR | $10.6 \ e^+ e^- \rightarrow D^{*+} K_S^0 X$ | ı |
| $525.30 + 0.44 \pm 0.10$ | 236 ± 30 | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{*+} K_S^0 X$, | |
| 525.3 ±0.6 ±0.1 | 41 | HEISTER | 02в | ALEP | $e^{+}e^{-} \xrightarrow{D^{*0}} K^{+} X$ | |

⁷ Assuming S-wave decay of the $D_{s1}(2536)$ to D^{*+} K_S^0 , using a Breit-Wigner line shape corresponding to $L\!=\!0$

$m_{D_{s1}(2536)^{\pm}} - m_{D^*(2007)^0}$

The fit includes D^{\pm} , D^{0} , D_{c}^{\pm} , $D^{*\pm}$, D^{*0} , $D_{c}^{*\pm}$, $D_{1}(2420)^{0}$, $D_{2}^{*}(2460)^{0}$, and $D_{s1}(2536)^{\pm}$ mass and mass difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|---------|--------------|-----|------|---------------------------------|
| 528.14 ± 0.08 OUR I | FIT | | | | |
| 528.1 ±1.5 OUR | AVERAGE | | | | |
| 528.7 $\pm 1.9 \pm 0.5$ | 51 | HEISTER | | | $e^+e^- \rightarrow D^{*0}K^+X$ |
| 527.3 ± 2.2 | 29 | ACKERSTAFF | 97W | OPAL | $e^+e^- \rightarrow D^{*0}K^+X$ |

D_{s1} (2536) ± WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|---------|---------|-------------------------|-------|-----------|-----------------------------------------------|
| 0.92±0.03±0.0 | 14 | 8038 | 8 LEES | 11B | BABR | $10.6 \ e^+ e^- \rightarrow D^{*+} K_S^0 X$ |
| • • • We do no | t use t | he folk | owing data for aver | ages, | fits, lim | its, etc. • • • |
| $\boldsymbol{0.75 \pm 0.23}$ | | 116 | ⁹ AUSHEV | 11 | BELL | $B \rightarrow D_{s1}(2536) + D^{(*)}$ |
| < 2.5 | 95 | 193 | AUBERT | | | 10.6 $e^+e^- \rightarrow$ |
| | | | | | | $D_{S}^{+}\pi^{+}\pi^{-}X$ |
| < 3.2 | 90 | 75 | FRABETTI | | | $\gamma \text{Be} \rightarrow D^{*+} K^0 X$, |
| | | | | | | $e^+e^- \rightarrow D^{*0}K^+X$ |
| < 2.3 | 90 | | ALEXANDER | 93 | | |
| < 3.9 | 90 | | ALBRECHT | 92R | | 10.4 $e^+e^- \to D^{*0} K^+ X$ |
| < 5.44 | 90 | | AVERY | 90 | CLEO | $e^+ e^- \rightarrow D^{*+} K^0 X$ |
| < 4.6 | 90 | | ALBRECHT | 89E | ARG | $D_{c1}^* \rightarrow D^*(2010) K^0$ |
| 8 Assuming S- | | | f the $D_{s1}(2536)$ to | > D*+ | | ing a Breit-Wigner line shape |

corresponding to L=0.

$D_{s1}(2536)$ + DECAY MODES

 $D_{\rm S1}(2536)^{-}$ modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------------|------------------------------|
| Γ_1 | $D^*(2010)^+ K^0$ | seen |
| Γ_2 | $(D^*(2010)^+ K^0)_{S-wave}$ | |
| Γ_3 | $(D^*(2010)^+ K^0)_{D-wave}$ | |
| Γ_4 | $D^+\pi^-K^+$ | |
| Γ_5 | $D^*(2007)^0 K^+$ | seen |
| Γ_6 | $D^+ K^0$ | not seen |
| Γ_7 | $D^0 K^+$ | not seen |
| Γ ₈ | $D_s^{*+}\gamma$ | possibly seen |
| Γ_9 | $D_s^+\pi^+\pi^-$ | seen |

D_{s1}(2536)+ BRANCHING RATIOS

| Γ(D*(2007) ⁰ K+ | Γ_5/Γ_1 | | | | |
|---------------------------------------------------------|---------------------|--------------------------|-----|------|--------------------------------------------------------------------------------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1.18±0.16 OUR AV | /ERAGE | | | | |
| $0.88 \pm 0.24 \pm 0.08$ | 116 | AUSHEV | 11 | BELL | $B \to D_{s1}(2536) + D^{(*)}$ |
| $2.3 \ \pm 0.6 \ \pm 0.3$ | 236 ± 30 | CHEKANOV | 09 | ZEUS | $e^{\pm} p \rightarrow D^{*+} K_{S}^{0} X$ |
| 1.32±0.47±0.23 | | ¹⁰ HEISTER | | | $e^{+} \stackrel{D^{*0}}{e^{-}} \stackrel{K^{+}}{\longrightarrow} \stackrel{X}{D^{*+}} \stackrel{K^{0}}{K^{0}} X,$ |
| $1.9 \begin{array}{c} +1.1 \\ -0.9 \end{array} \pm 0.4$ | 35 | ¹⁰ ACKERSTAFF | 97w | OPAL | |
| 1.1 ±0.3 | | | 93 | CLEO | $e^{+}e^{-} \rightarrow 0$ $e^{+}e^{-} \rightarrow 0$ $0 * 0 K + X, D * + K^{0}X$ |
| $1.4 \pm 0.3 \pm 0.2$ | | ¹¹ ALBRECHT | 92R | ARG | $^{10.4}_{D^{*0}} ^{e^{+}}_{K^{+}} ^{-}_{X,D^{*+}} ^{+}_{K^{0}} X$ |

 $^{^{10}\,\}mathrm{Ratio}$ of the production rates measured in Z^0 decays.

 $^{^{11}\,\}mathrm{Evaluated}$ by us from published inclusive cross-sections.

| $\Gamma((D^*(2010)^+ K^0)_{S-wave})/\Gamma(D^*(2010)^+ K^0)$ | | | | | | | |
|----------------------------------------------------------------------------------|---------|-------------|----|------|--------------------------------|--|--|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
| $0.72 \pm 0.05 \pm 0.01$ | 5 4 8 5 | BALAGURA | 80 | BELL | 10.6 $e^+e^- \to D^{*+} K^0 X$ | | |
| $\Gamma(D^{+}\pi^{-}K^{+})/\Gamma(D^{*}(2010)^{+}K^{0})$ Γ_{4}/Γ_{1} | | | | | | | |

| $\Gamma(D^+\pi^-K^+)/\Gamma$ | (<i>D</i> *(201 | 10)+ <i>K</i> ⁰) | | | Γ_4/Γ_1 |
|------------------------------|------------------|------------------------------|----|------|--------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| $3.27 \pm 0.18 \pm 0.37$ | 1264 | BALAGURA | 80 | BELL | 10.6 $e^+e^- ightarrow~D^+\pi^-K^+X$ |

| $\Gamma(D^+K^{\circ})/\Gamma(A^+K^{\circ})$ | D*(2010)+ Kº) | | | | Γ ₆ /Γ |
|---------------------------------------------|---------------|--------------|-----|------|-----------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| < 0.40 | 90 | ALEXANDER | 93 | CLEO | $e^+e^- \rightarrow D^{*+} K^0 X$ |
| < 0.43 | 90 | ALBRECHT | 89E | ARG | $D_{s1}^* \to D^*(2010) K^0$ |

² Calculated using $m(D^*(2010)^\pm)=2010.0\pm0.5$ MeV, $m(D^*(2007)^0)=2006.7\pm0.5$ MeV, and the mass difference below. ³ Systematic uncertainties not evaluated.

⁴ Calculated using the mass difference $m(D_{s1}^+)-m(D^{*+})_{PDG}$ below and $m(D^{*+})_{PDG}$ = 2010.25 \pm 0.14 MeV. Assuming *S*-wave decay of the D_{s1} (2536) to D^{*+} K_S^0 , using a Breit-Wigner line shape corresponding to L=0.

 $^{^5}$ Calculated using the mass difference $\it m(D^{\,+}_{\,s1})$ - $\it m(D^{\,*+})_{PDG}$ reported below and $\it m(D^{*+})_{PDG} = 2010.27 \pm 0.17$ MeV. 6 Not seen in $\it D^*K$.

⁹ Systematic uncertainties not evaluated.

| $\Gamma(D^0 K^+)/\Gamma(D^*(20$ | 07) ⁰ K ⁺) | | | | Γ ₇ /Γ ₅ |
|---------------------------------------------|-----------------------------------|--------------|-------|--------|-------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <0.12 | 90 | ALEXANDER | 93 | CLEO | $e^+e^- ightarrow ~D^{st 0}K^+X$ |
| $\Gamma(D_s^{*+}\gamma)/\Gamma_{ m total}$ | | | | | Γ ₈ /Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| possibly seen | | ASRATYAN | 88 | HLBC | $\nu N 	o D_{S} \gamma \gamma X$ |
| $\Gamma(D_s^{*+}\gamma)/\Gamma(D^*(200))$ |)7) ⁰ K+) | | | | Г8/Г5 |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <0.42 | 90 | ALEXANDER | 93 | CLEO | $e^+e^- ightarrow~D^{st 0}K^+X$ |
| $\Gamma(D_s^+\pi^+\pi^-)/\Gamma_{ m total}$ | | | | | ٦/و٦ |
| VALUE | <u>DO C</u> | UMENT ID | TE CN | COM: | MENT |
| seen | AUE | BERT 06P | BAB | R 10.6 | $e^+ e^- \rightarrow D_S^+ \pi^+ \pi^- X$ |

$D_{s1}(2536)^{\pm}$ REFERENCES

| AUSHEV LEES ABAZOV CHEKANOV AUBERT PDG HEISTER ACKERSTAFF ASRATYAN FRABETTI ALEXANDER AUBRECHT AVERY ALBRECHT | 11 11B 09G 09 08B 08 06P 06 02B 97W 94 94B 93 92R 90 | PR D83 051102 PR D83 072003 PRL 102 051801 EPJ C60 25 PR D77 011102R PR D77 032001 PR D78 33 1 PL B526 34 ZPHY C61 563 PRL 72 324 PL B303 377 PL B297 425 PR D41 774 PL B201 162 | T. Aushev et al. J.P. Lees et al. J.P. Lees et al. S. Chekanov et al. S. Chekanov et al. B. Aubert et al. V. Balagura et al. B. Aubert et al. WM. Yao et al. A. Heister et al. A. E. Asratyan et al. P.L. Frabetti et al. J. Alexander et al. H. Albrecht et al. P. Avery, D. Besson H. Albrecht et al. | (BELLE Collab.) (BABAR Collab.) (DO Collab.) (ZEUS Collab.) (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) (PDG Collab.) (ALEPH Collab.) (OPAL Collab.) (BIRM. BELG. CERN+) (FNAL E687 Collab.) (CLEO Collab.) (ALGUS Collab.) (CLEO Collab.) (ALGUS Collab.) |
|---------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALBRECHT ASRATYAN | 89E 88 | PL B230 162 ZPHY C40 483 | H. Albrecht et al. A.E. Asratyan et al. | (ARGUS Collab.) (ITEP, SERP) |
| | | | | |

 $D_{s2}^*(2573)$

$$I(J^P) = 0(??)$$

 ${\it J}^{\it P}$ is natural, width and decay modes consistent with 2^+ .

D*2(2573) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|------------------|----------------------|---------|------------|-------------------------------------------------------|
| 2571.9±0.8 OUR | AVERAGE | | | | |
| $2569.4\pm1.6\pm0.5$ | 82 ± 17 | AAIJ | 11 A | LHCB | $B_S \rightarrow D_{s2}^*(2573) \mu \overline{\nu} X$ |
| $2572.2 \pm 0.3 \pm 1.0$ | | AUBERT,BE | | | $e^+e^- \rightarrow D K X$ |
| $2574.5\pm3.3\pm1.6$ | | ALBRECHT | 96 | ARG | $e^+ e^- \rightarrow D^0 K^+ X$ |
| $2573.2^{+1.7}_{-1.6}\pm0.9$ | 217 | KUBOTA | 94 | CLE2 | $e^+e^-{\sim}$ 10.5 GeV |
| • • • We do not ι | ise the followin | g data for average | es, fit | s, limits, | etc. • • • |
| 2570.0 ± 4.3 | 25 | | | | 600 $\Sigma^- A \rightarrow D^0 K^+ X$ |
| 2568.6 ± 3.2 | 64 | ² HEISTER | 02в | ALEP | $e^+ e^- \rightarrow D^0 K^+ X$ |
| 1 Not independer | nt of the mass | difference helow | | | |

 2 Calculated using $m_{D^0} = 1864.5 \pm 0.5 \ {\rm MeV}$ and the mass difference below.

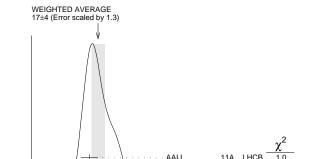
$m_{D_{s2}^*(2573)} - m_{D^0}$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------|------------|------------------------|--------|-----------|----------------------------------------|
| 704 ±3 ±1 | 64 | HEISTER | 02в | ALEP | $e^+e^- \rightarrow D^0 K^+ X$ |
| • • • We do not | use the f | ollowing data for | averag | es, fits, | limits, etc. • • • |
| 705.4 ± 4.3 | 25 | ³ EVDOKIMOV | 04 | SELX | 600 $\Sigma^- A \rightarrow D^0 K^+ X$ |
| 3 Systematic or | rors not s | etimated | | | |

D*2(2573) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------|---------------|---------------------|---------|----------|-------------------------------------------------------|
| 17 ±4 OUR AVE | RAGE Erro | r includes scale fa | ctor o | f 1.3. S | ee the ideogram below. |
| $12.1 \pm 4.5 \pm 1.6$ | 82 ± 17 | AAIJ | 11A | LHCB | $B_S \rightarrow D_{S2}^*(2573) \mu \overline{\nu} X$ |
| $27.1 \pm 0.6 \pm 5.6$ | | | | | $e^+e^- \rightarrow D K X$ |
| $10.4 \pm 8.3 \pm 3.0$ | | ALBRECHT | 96 | ARG | $e^+ e^- \rightarrow D^0 K^+ X$ |
| $16 \begin{array}{cc} +5 \\ -4 \end{array} \pm 3$ | 217 | KUBOTA | 94 | CLE2 | $e^+e^-{\sim}$ 10.5 GeV |
| • • • We do not use | the following | ordata for averaσ | es fits | limits | etc • • • |

14 $^{+9}$ 25 4 EVDOKIMOV 04 SELX 600 $\Sigma^-A \rightarrow D^0K^+X$



ALBRECHT KUBOTA

80

60

4.9 (Confidence Level = 0.182)

D*_{\$2}(2573) WIDTH (MeV)

⁴ Systematic errors not estimated.

$D_{s2}^{*}(2573)^{+}$ DECAY MODES

 $D_{52}^*(2573)^-$ modes are charge conjugates of the modes below.

| | Mode | Fraction $(\Gamma_{\dot{I}}/\Gamma)$ |
|-----------------------|-------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | $D^0 K^+$ | seen |
| Γ_2 | $D^*(2007)^0 K^+$ | not seen |

D*2(2573)+ BRANCHING RATIOS

| $\Gamma(D^0K^+)/\Gamma_{\text{total}}$ | | | | | | Г ₁ /Г |
|-------------------------------------------|------|--------------|----|------|-------|-------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| seen | 217 | KUBOTA | 94 | CLE2 | \pm | $e^+e^-{\sim}~10.5~{\rm GeV}$ |
| $\Gamma(D^*(2007)^0 K^+)/\Gamma(D^0 K^+)$ | | | | | | Γ_2/Γ_1 |
| VALUE | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
| <0.33 | 90 | KUBOTA | 94 | CLE2 | + | $e^+e^-{\sim}~10.5~{\rm GeV}$ |

D_{s2}(2573) REFERENCES

| AAIJ | 11A | PL B698 14 | R. Aaij et al. | (LHCb Collab.) |
|-----------|-----|---------------|-----------------------|-----------------|
| AUBERT,BE | 06E | PRL 97 222001 | B. Aubert et al. | (BABAR Collab.) |
| EVDOKIMOV | 04 | PRL 93 242001 | A.V. Evdokimov et al. | (SELEX Collab.) |
| HEISTER | 02B | PL B526 34 | A. Heister et al. | (ALEPH Collab.) |
| ALBRECHT | 96 | ZPHY C69 405 | H. Albrecht et al. | (ARGUS Collab.) |
| KUBOTA | 94 | PRL 72 1972 | Y. Kubota et al. | `(CLEO Collab.) |

 $D_{s1}^*(2700)^{\pm}$

$$I(J^P) = 0(1^-)$$

OMITTED FROM SUMMARY TABLE

$D_{s1}^*(2700)^+$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|-------------------|------------------------|----------|-----------|---------------------------------------|
| 2709 + 9 OUR AVE | RAGE | | | | |
| $2710 \pm 2 + 12 \\ -7$ | 10.4k | ¹ AUBERT | 09AR | BABR | $e^+e^- ightarrow D^{(*)} K X$ |
| $2708 \pm 9 {}^{+11}_{-10}$ | 182 | BRODZICKA | 80 | BELL | $B^+ \to D^0 \overline{D}{}^0 K^+$ |
| • • • We do not ι | ise the following | g data for average | s, fits, | limits, e | etc. • • • |
| $2688 \pm 4 \pm 3$ | | ² AUBERT,BE | 06E | BABR | 10.6 $e^+e^- \rightarrow DKX$ |

 $^1\,\rm From$ simultaneous fits to the two D K mass spectra and to the total D* K mass spectrum. $^2\,\rm Superseded$ by AUBERT 09AR.

$D_{s1}^*(2700)^+$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | TE | CN | COMMENT |
|-------------------------------------------------------------------------------------|-----------------|---------------------|--------------|---------|--------------------------------------------|
| 125 ±30 OUR AVE | RAGE | | | | |
| $149 \pm 7^{+39}_{-52}$ | 10.4k | ³ AUBERT | 09AR BA | ABR | $e^+e^- 	o D^{(*)}KX$ |
| $108\!\pm\!23\!+\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ | 182 | BRODZICKA | 08 BE | ELL | $B^+ \rightarrow D^0 \overline{D}{}^0 K^+$ |
| • • • We do not us | se the followin | g data for average | s, fits, lim | nits, e | tc. • • • |
| 112 + 7 + 36 | | 4 ALIBERT RE | 06c B/ | A R R | 10 6 a+ a DKY |

 $12\pm~7\pm36$ 4 AUBERT,BE 06E BABR 10.6 $e^+\,e^-\to D\,KX$ 3 From simultaneous fits to the two $D\,K$ mass spectra and to the total $D^*\,K$ mass spec

⁴ Superseded by AUBERT 09AR.

 $D_{s1}^*(2700)^\pm$, $D_{sJ}^*(2860)^\pm$, $D_{sJ}(3040)^\pm$

$D_{s1}^{*}(2700)^{\pm}$ DECAY MODES

| | Mode | | | |
|----------------|----------------------------|--|--|--|
| Γ_1 | DK | | | |
| Γ_2^- | $D^0 K^+$ | | | |
| Γ_3 | D^0K^+ $D^+K^0_S$ | | | |
| Γ_4 | D* K | | | |
| Γ ₅ | $D^{*0}K^+$ $D^{*+}K^0$ | | | |
| Γ ₆ | $D^{*+} K_S^0$ | | | |

D* (2700) BRANCHING RATIOS

| $\Gamma(D^*K)/\Gamma(DK)$ | | | | | Γ_4/Γ |
|-------------------------------|--------------|---------------------|-------------|----------------------|-------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 0.91±0.13±0.12 | 10.4k | 5 AUBERT | 09AR BABR | $e^+e^- \rightarrow$ | D(*) KX |
| ⁵ From the average | of the corre | esponding ratios wi | th D(*)0 K+ | and $D^{(*)+}$ | κ ⁰ . |

| $\Gamma(D^{*0}K^+)/\Gamma(D^0$ | K+) | | | | Γ_5/Γ |
|--------------------------------|---------------------|----------------------------------|-------------------|--------------|-------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use | the followin | g data for average | es, fits, limits, | etc. • • • | |
| $0.88 \pm 0.14 \pm 0.14$ | 7716 | ⁶ AUBERT | 09AR BABR | $e^+e^- \to$ | $D^{(*)}KX$ |
| 6 From the $D^{*0}K^{-1}$ | \vdash and D^0K | $^+$, where $D^{*0} ightarrow$ | $D^{0}\pi^{0}$. | | |

| $\Gamma(D^{*+}K_S^0)/\Gamma(D^+)$ | K_S^0 | | | | Γ ₆ /Γ ₃ |
|-----------------------------------|--------------------------------------|-------------------------------------|------------------|--------------|--------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use | the following | ng data for averages | s, fits, limits, | etc. • • • | |
| $1.14 \pm 0.39 \pm 0.23$ | 2700 | ⁷ AUBERT | 09AR BABR | $e^+e^- \to$ | $D^{(*)}KX$ |
| 7 From the D^{*+} K | $_{S}^{0}$ and $_{D}^{+}$ $_{F}^{0}$ | $(^0_S$, where $D^{*+} ightarrow$ | $D^{+}\pi^{0}$. | | |

$D_{s1}^*(2700)^{\pm}$ REFERENCES

| AUBERT | 09AR | PR D80 092003 | B. Aubert et al. | (BABAR Collb.) |
|-----------|------|----------------|-----------------------------|-----------------|
| BRODZICKA | 80 | PRL 100 092001 | J. Brodzicka <i>et al</i> . | (BELLE Collab.) |
| AUBERT,BE | 06E | PRL 97 222001 | B. Aubert et al. | (BABAR Collab.) |

$$D_{sJ}^*(2860)^{\pm}$$

$$I(J^P) = 0(??)$$

OMITTED FROM SUMMARY TABLE

Observed by AUBERT, BE 06E and AUBERT 09AR in inclusive production of DK and D^*K in e^+e^- annihilation. J^P is natural.

$D_{sJ}^*(2860)^+$ MASS

| VALUE (MeV) | EVIS | DO CUMENT ID | | IECN | COMMENT | |
|------------------------|-------------|-------------------|---------|-----------|-----------------------------------|--|
| 2862 ±2 +5 | 3122 | 1 AUBERT | 09AR | BABR | $e^+ e^- \rightarrow D^{(*)} K X$ | |
| • • • We do not use th | e following | data for averages | , fits, | limits, e | etc. • • • | |
| 2056 6 1 1 5 1 5 0 | | 2 AUDEDT DE | 065 | DADD | -+ -= D K Y | |

 $^{^{1}\,\}mathrm{From}$ simultaneous fits to the two $^{D}\,\mathrm{K}$ mass spectra and to the total $^{D}\,\mathrm{K}$ mass spec-

trum. 2 Superseded by AUBERT 09AR.

$D_{s,J}^*(2860)^+$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|---------------------|---------------|----------------------|---------|---------|--------------------------------|--|
| 48±3± 6 | 3122 | 3 AUBERT | 09AR | BABR | $e^+e^- \rightarrow D^{(*)}KX$ | |
| • • • We do not use | the following | g data for averages, | , fits, | limits, | etc. • • • | |
| 47 7 10 | | 4 AUDEDT DE | 065 | DADD | a+ a= D K V | |

 $^{^3\,\}mathrm{From}$ simultaneous fits to the two D K mass spectra and to the total D* K mass spec-

trum. 4 Superseded by AUBERT 09AR.

$D_{s,I}^*(2860)^{\pm}$ DECAY MODES

| | Mode | |
|-----------------------|--------------------------------|--|
| $\overline{\Gamma_1}$ | DK | |
| Γ_2 | $D^0 K^+$ | |
| Гз | $D^0 K^+ D^0 K^+ D^+ K^0 S$ | |
| Γ_4 | 1 D* K | |
| Γ_5 | $D^{*0}K^+$ 5 $D^{*+}K^0_S$ | |
| Γ_6 | $D^{*+}K_S^0$ | |

$D_{s,I}^*(2860)^{\pm}$ BRANCHING RATIOS

| $\Gamma(D^*K)/\Gamma(DK)$ | | | | | Γ_4/Γ_1 |
|-------------------------------|-------------|---------------------|-------------------|------------------------|---------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| $1.10 \pm 0.15 \pm 0.19$ | 3122 | ⁵ AUBERT | 09AR BABR | $e^+e^- \rightarrow L$ | o(*) K X |
| ⁵ From the average | of the corr | esponding ratios w | ith $D^{(*)0}K^+$ | and $D^{(*)+}K$ | 0 |

| Γ | ['] (D* ⁰ K+)/Γ(D ⁰ K | (+) | | | | Γ_5/Γ_2 |
|---|------------------------------------------------------|--------------|----------------------------------|-------------------|--------------|---------------------|
| V | ALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| • | • • We do not use t | he followin | g data for average | es, fits, limits, | etc. • • • | |
| 1 | $.04 \pm 0.17 \pm 0.20$ | 2241 | ⁶ AUBERT | 09AR BABR | $e^+e^- \to$ | $D^{(*)}KX$ |
| | $^6\mathrm{From\ the}\ D^{*0}K^+$ | and D^0K^- | $^+$, where $D^{*0} ightarrow$ | $D^{0}\pi^{0}$. | | |

$D_{s,I}^*(2860)^{\pm}$ REFERENCES

| AUBERT | 09AR PR D80 092003 | B. Aubert <i>et al.</i> | (BABAR Collb.) |
|-----------|--------------------|-------------------------|-----------------|
| AUBERT,BE | 06E PRL 97 222001 | B. Aubert et al. | (BABAR Collab.) |



$$I(J^P) \ = \ 0(?^?)$$

OMITTED FROM SUMMARY TABLE

Observed by AUBERT 09AR in inclusive production of D^*K in $e^+\,e^-$ annihilation.

$D_{sJ}(3040)^{+}$ MASS

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT | |
|---------------|-------------|-----------|---------|--------|
| 3044 + 8 + 30 | AURERT | 09ΔR BΔBR | e+e | D* K X |

$D_{sJ}(3040)^{+}$ WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------|--------------|-----------|----------------------------|
| 239±35+46 | AUBERT | 09AR BABR | $e^+e^- \rightarrow D^*KX$ |

$D_{sJ}(3040)^{\pm}$ DECAY MODES

| | Mod | e | | | | | | | |
|---------------------------------------------------------------------------------|------|----------------------------------------------|------|------------|---|--------------|-------|----------|---------|
| Γ ₁ Γ ₂ | D* I | K)* ⁰ K ⁻)*+ K | + | | | | | | |
| $\frac{\Gamma_3 \qquad D^{*+} K_S^0}{\mathbf{D_{sJ}(3040)^{\pm} REFERENCES}}$ | | | | | | | | | |
| AUBE | RT | 09AR | PR I | D80 092003 | 3 | B. Aubert et | al. | (BABAR C | Collb.) |
| OTHER RELATED PAPERS | | | | | | | | | |
| SUN | | 09 | PR I | D80 07403 | 7 | ZF. Sun, X | . Lin | | |

BOTTOM MESONS $(B = \pm 1)$

 $B^+ = u \overline{b}$, $B^0 = d \overline{b}$, $\overline{B}{}^0 = \overline{d} b$, $B^- = \overline{u} b$, similarly for B^* 's

B-particle organization

Many measurements of B decays involve admixtures of B hadrons. Previously we arbitrarily included such admixtures in the B^\pm section, but because of their importance we have created two new sections: " B^\pm/B^0 Admixture" for T(4S) results and " $B^\pm/B^0/B_S^0$ /B-baryon Admixture" for results at higher energies. Most inclusive decay branching fractions and χ_D at high energy are found in the Admixture sections. $B^0-\overline{B}^0$ mixing data are found in the B^0 section, while $B^0_S-\overline{B}^0_S$ mixing data and $B-\overline{B}$ mixing data for a B^0/B_S^0 admixture are found in the B^0_S section. CP-violation data are found in the B^\pm_S , B^0 , and B^\pm B^0 Admixture sections. b-baryons are found near the end of the Baryon section. Recently, we also created a new section: " $V_{C,D}$ and $V_{U,D}$ CKM Matrix Elements."

The organization of the ${\cal B}$ sections is now as follows, where bullets indicate particle sections and brackets indicate reviews.

```
[Production and Decay of b-flavored Hadrons]
[A Short Note on HFAG Activities]
\bullet B^{\pm}
    mass, mean life
    branching fractions
    polarization in B^{\pm} decay
    CP violation
\bullet B^0
    mass, mean life
    branching fractions
    [Polarization in B decay]
    polarization in B^0 decay
    [B-\overline{B}] Mixing]
    B^0 - \overline{B}{}^0 mixing
    CP violation
\bullet B^{\pm} B^{0} Admixture
    branching fractions, CP violation
    CP violation
• B^{\pm}/B^{0}/B_{s}^{0}/b-baryon Admixture
    mean life
    production fractions
    branching fractions
    \chi_b at high energy
   production fractions in hadronic Z decay
ullet V_{C\, b} and V_{U\, b} CKM Matrix Elements
    [Determination of V_{C\, D} and V_{U\, D}]
• B*
    mass
\bullet\,B_1(5721)^0
• B*<sub>1</sub>(5732)
   mass, width
\bullet\,B_2(5747)^0
    mass
• B 0
    mass, mean life
   branching fractions
    polarization in B_s^0 decay
    B_c^0 - \overline{B}_s^0 mixing
• B *
   mass
\bullet\,B_{sJ}^*(5850)
    mass, width
```

mass, mean life

branching fractions

At the end of Baryon Listings:
• Λ_b mass, mean life branching fractions
• Σ_b , Σ_b^* mass
• Ξ_b^0 , Ξ_b^- mean life
• Ω_b^- mass, mean life branching fractions
• b-baryon Admixture mean life branching fractions

PRODUCTION AND DECAY OF b-FLAVORED HADRONS

Updated March 2012 by M. Kreps (U. of Warwick, Coventry, UK), J.G. Smith (U. of Colorado, Boulder, USA), and Y. Kwon (Yonsei U., Seoul, Korea).

The b quark belongs to the third generation of quarks and is the weak–doublet partner of the t quark. The existence of the third–generation quark doublet was proposed in 1973 by Kobayashi and Maskawa [1] in their model of the quark mixing matrix ("CKM" matrix), and confirmed four years later by the first observation of a $b\bar{b}$ meson [2]. In the KM model, CP violation is explained within the Standard Model (SM) by an irreducible phase of the 3×3 unitary matrix. The regular pattern of the three lepton and quark families is one of the most intriguing puzzles in particle physics. The existence of families gives rise to many of the free parameters in the SM, including the fermion masses, and the elements of the CKM matrix.

Since the b quark is the lighter element of the third–generation quark doublet, the decays of b-flavored hadrons occur via generation-changing processes through this matrix. Because of this, and the fact that the CKM matrix is close to a 3×3 unit matrix, many interesting features such as loop and box diagrams, flavor oscillations, as well as large CP asymmetries, can be observed in the weak decays of b-flavored hadrons.

The CKM matrix is parameterized by three real parameters and one complex phase. This complex phase can become a source of CP violation in B meson decays. A crucial milestone was the first observation of CP violation in the B meson system in 2001, by the BaBar [3] and Belle [4] collaborations. They measured a large value for the parameter $\sin 2\beta$ (= $\sin 2\phi_1$) [5], almost four decades after the discovery of a small CP asymmetry in neutral kaons. A more detailed discussion of the CKM matrix and CP violation can be found elsewhere in this Review [6,7].

The structure of this mini-review is organized as follows. After a brief description of theory and terminology, we discuss b-quark production and current results on spectroscopy

b-flavored hadrons

and lifetimes of b-flavored hadrons. We then discuss some basic properties of B-meson decays, followed by summaries of hadronic, rare, and electroweak penguin decays of B-mesons. There are separate mini-reviews for $B\overline{B}$ mixing [8] and the extraction of the CKM matrix elements V_{cb} and V_{ub} from B-meson decays [9] in this Review.

Theory and terminology: The ground states of b-flavored hadrons decay via weak interactions. In most hadrons, the b-quark is accompanied by light-partner quarks (d, u, or s), and the decay modes are well described by the decay of the b quark (spectator model) [10]. The dominant decay mode of a b quark is $b \to cW^{*-}$ (referred to as a "tree" or "spectator" decay), where the virtual W materializes either into a pair of leptons $\ell\bar{\nu}$ ("semileptonic decay"), or into a pair of quarks which then hadronizes. The decays in which the spectator quark combines with one of the quarks from W^* to form one of the final state hadrons are suppressed by a factor $\sim (1/3)^2$, because the colors of the two quarks from different sources must match ("color–suppression").

Many aspects of B decays can be understood through the Heavy Quark Effective Theory (HQET) [11]. This has been particularly successful for semileptonic decays. For further discussion of HQET, see for instance Ref. 12. For hadronic decays, one typically uses effective Hamiltonian calculations that rely on a perturbative expansion with Wilson coefficients. In addition, some form of the factorization hypothesis is commonly used. where, in analogy with semileptonic decays, two-body hadronic decays of B mesons are expressed as the product of two independent hadronic currents, one describing the formation of a charm meson (in case of the dominant $b \to cW^{*-}$ decays), and the other the hadronization of the remaining $\overline{u}d$ (or $\overline{c}s$) system from the virtual W^- . Qualitatively, for a B decay with a large energy release, the $\overline{u}d$ pair (produced as a color singlet) travels fast enough to leave the interaction region without influencing the charm meson. This is known to work well for the dominant spectator decays [13]. There are several common implementations of these ideas for hadronic B decays, the most common of which are QCD factorization (QCDF) [14], perturbative QCD (pQCD) [15], and soft collinear effective theory (SCET) [16].

The transition $b \to u$ is suppressed by $|V_{ub}/V_{cb}|^2 \sim (0.1)^2$ relative to $b \to c$ transitions. The transition $b \to s$ is a flavor-changing neutral-current (FCNC) process, and although not allowed in the SM as a tree-process, can occur via more complex loop diagrams (denoted "penguin" decays). The rates for such processes are comparable or larger than CKM-suppressed $b \to u$ processes. Penguin processes involving $b \to d$ transitions are also possible, and have been observed [17,18]. Other decay processes discussed in this Review include W-exchange (a W is exchanged between initial-state quarks), penguin annihilation (the gluon from a penguin loop attaches to the spectator quark, similar to an exchange diagram), and pure-annihilation (the initial quarks annihilate to a virtual W, which then decays).

Production and spectroscopy: The bound states of a \overline{b} antiquark and a u, d, s, or c quark are referred to as the B_u (B^+), B_d (B^0), B_s , and B_c mesons, respectively. The B_c is the heaviest of the ground–state b-flavored mesons, and the most difficult to produce: it was observed for the first time in the semileptonic mode by CDF in 1998 [19], but its mass was accurately determined only in 2006, from the fully reconstructed mode $B_c^+ \to J/\psi \pi^+$ [20].

The first excited meson is called the B^* meson, while B^{**} is the generic name for the four orbitally excited (L=1) B-meson states that correspond to the P-wave mesons in the charm system, D^{**} . Excited states of the B_s meson are similarly named B_s^* and B_s^{**} . Of the possible bound $\bar{b}b$ states, the Υ series (S-wave) and the χ_b (P-wave) are well studied. The pseudoscalar ground state η_b also has been observed by BaBar [21](and confirmed by CLEO [22]), indirectly through the decay $\Upsilon(3S) \to \gamma \eta_b$. See Ref. 23 for classification and naming of these and other states.

Experimental studies of b decays have been performed in e^+e^- collisions at the $\Upsilon(4S)$ (ARGUS, CLEO, Belle, BaBar) and $\Upsilon(5S)$ (CLEO, Belle) resonances, as well as at higher energies, at the Z resonance (SLC, LEP) and in $p\bar{p}$ collisions (Tevatron). The $e^+e^- \to b\bar{b}$ production cross-section at the Z, $\Upsilon(4S)$, and $\Upsilon(5S)$ resonances are about 6.6 nb, 1.1 nb, and 0.3 nb respectively. High-energy hadron collisions produce b-flavored hadrons of all species with much larger cross-sections: $\sigma(p\bar{p}\to bX,|\eta|<1)\sim 30~\mu b$ at the Tevatron ($\sqrt{s}=1.96~{\rm TeV}$), and even higher at the energies of the LHC pp collider (up to a factor of ten at $\sqrt{s}=14~{\rm TeV}$).

BaBar and Belle have accumulated respectively 560 fb⁻¹ and 1020 fb⁻¹ of data, of which 433 fb⁻¹ and 710 fb⁻¹ respectively are at the $\Upsilon(4S)$ resonance; CDF and D0 have currently accumulated about 10 fb⁻¹ each. At the LHC, CMS and AT-LAS have collected 5 fb⁻¹ of data and LHCb has collected about 1 fb $^{-1}$. These numbers indicate that the majority of b-quarks have been produced in hadron collisions, but the large backgrounds cause the hadron collider experiments to have lower selection efficiency. Only the few decay modes for which triggering and reconstruction are easiest have been studied so far in hadron collisions. These have included final states with leptons, and exclusive modes with all charged particles in the final state. In contrast, detectors operating at e^+e^- colliders ("B-Factories") have a high efficiency for most decays, and have provided large samples of a rich variety of decays of B^0 and B^+ mesons.

In hadron collisions, most production happens as $b\overline{b}$ pairs, either via s-channel production or gluon–splitting, with a smaller fraction of single b-quarks produced by flavor excitation. The total b-production cross section is an interesting test of our understanding of QCD processes. For many years, experimental measurements have been several times higher than predictions. With improved measurements [24], more accurate input parameters, and more advanced calculations [25], the discrepancy between theory and data is now much reduced, although the

presence of inconsistencies among existing measurements makes further studies desirable.

Each quark of a $b\overline{b}$ pair produced in hadron collisions hadronizes separately and incoherently from the other, but it is still possible, although difficult, to obtain a statistical indication of the charge of a produced b/\overline{b} quark ("flavor tag" or "charge tag") from the accompanying particles produced in the hadronization process, or from the decay products of the other quark. The momentum spectrum of produced b-quarks typically peaks near the b-quark mass, and extends to much higher momenta, dropping by about a decade for every ten GeV. This implies typical decay lengths of the order of a millimeter; the resolution for the decay vertex must be more precise that this to resolve the fast oscillations of B_s mesons.

In e^+e^- colliders, since the B mesons are very slow in the $\Upsilon(4S)$ rest frame, asymmetric beam energies are used to boost the decay products to improve the precision of time-dependent measurements that are crucial for the study of CP violation. At KEKB, the boost is $\beta\gamma=0.43$, and the typical B-meson decay length is dilated from $\approx 20~\mu m$ to $\approx 200~\mu m$. PEP-II uses a slightly larger boost, $\beta\gamma=0.55$. The two B mesons produced in $\Upsilon(4S)$ decay are in a coherent quantum state, which makes it easier than in hadron collisions to infer the charge state of one B meson from observation of the other; however, the coherence also requires determination of the decay time of both mesons, rather than just one, in order to perform time-dependent CP-violation measurements.

For the measurement of branching fractions, the initial composition of the data sample must be known. The $\Upsilon(4S)$ resonance decays predominantly to $B^0\overline{B}^0$ and B^+B^- ; the current experimental upper limit for non- $B\overline{B}$ decays of the $\Upsilon(4S)$ is less than 4% at the 95% confidence level (CL) [26]. The only known modes of this category are decays to lower Υ states and a pion pair, observed with branching fractions of order 10^{-4} [27]. The ratio f_+/f_0 of the fractions of charged to neutral B productions from $\Upsilon(4S)$ decays has been measured by CLEO, BaBar, and Belle in various ways. They typically use pairs of isospin-related decays of B^+ and B^0 , such that it can be assumed that $\Gamma(B^+ \to x^+) = \Gamma(B^0 \to x^0)$. In this way, the ratio of the number of events observed in these modes is proportional to $(f_+\tau_+)/(f_0\tau_0)$ [28–31]. BaBar has also performed an independent measurement of f_0 with a different method that does not require isospin symmetry or the value of the lifetime ratio, based on the number of events with one or two reconstructed $B^0 \to D^{*-}\ell^+\nu$ decays [32]. The combined result, from the current average of τ_+/τ_0 , is $f_+/f_0 = 1.055 \pm$ 0.025 [33]. Though the current 2.2σ discrepancy with equal production of B^+B^- and $B^0\overline{B}^0$ pairs is somewhat larger than previous averages, we still assume $f_{+}/f_{0}=1$ in this mini-review except where explicitly stated otherwise. This assumption is also supported by the near equality of the B^+ and B^0 masses: our fit of CLEO, ARGUS, and CDF measurements yields $m(B^0) =$ $5279.50 \pm 0.33 \text{ MeV}/c^2$, $m(B^+) = 5279.13 \pm 0.31 \text{ MeV}/c^2$, and $m(B^0)-m(B^+)=0.37\pm0.24~{\rm MeV}/c^2$. The latest measurement

from the LHCb agrees well with those and further improves precision [34].

CLEO and Belle have also collected some data at the $\Upsilon(5S)$ resonance [35,36]. Belle has accumulated more than 100 fb^{-1} at this resonance. This resonance does not provide the simple final states of the $\Upsilon(4S)$: there are seven possible final states with a pair of non-strange B mesons and three with a pair of strange B mesons $(B_s^*\overline{B}_s^*, B_s^*\overline{B}_s, \text{ and } B_s\overline{B}_s)$. The fraction of events with a pair of B_s mesons over the total number of events with a pair of b-flavored hadrons has been measured to be $f_s[\Upsilon(5S)] = 0.199 \pm 0.030$, of which 90% is $B_s^* \bar{B}_s^*$ events. A few branching fractions of the B_s have been measured in this way; if the precision of f_s were improved, they would become the most accurate. Belle has observed a few new B_s modes that are difficult to reconstruct in hadron colliders and the most precise mass measurement of the B_s^* meson has been obtained [36,37]. However, the small boost of B_s mesons produced in this way prevents resolution of their fast oscillations for time-dependent measurements; these are only accessible in hadron collisions or at the Z peak.

In high-energy collisions, the produced b or \bar{b} quarks can hadronize with different probabilities into the full spectrum of b-hadrons, either in their ground or excited states. Table 1 shows the measured fractions f_d , f_u , f_s , and $f_{\rm baryon}$ of B^0 , B^+ , B_s^0 , and b baryons, respectively, in an unbiased sample of weakly decaying b hadrons produced at the Z resonance or in $p\bar{p}$ collisions [33]. The results were obtained from a fit where the sum of the fractions were constrained to equal 1.0, neglecting production of B_c mesons. The observed yields of B_c mesons at the Tevatron [19] yields $f_c = 0.2\%$, in agreement with expectations [38], and well below the current experimental uncertainties in the other fractions.

Table 1: Fractions of weakly-decaying b-hadron species in $Z \to b\overline{b}$ decay, in $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV and combination of fractions in $Z \to b\overline{b}$ decay at Tevatron, $p\overline{p}$ and pp collisions at LHC.

| b hadron | Fraction at Z $[\%]$ | Fraction at $\overline{p}p[\%]$ | Combined $[\%]$ |
|------------|----------------------|---------------------------------|-----------------|
| B^+, B^0 | 40.3 ± 0.9 | 33.9 ± 3.9 | 40.1 ± 0.8 |
| B_s | 10.3 ± 0.9 | 11.1 ± 1.4 | 10.5 ± 0.6 |
| b baryons | 9.0 ± 1.5 | 21.2 ± 6.9 | 9.3 ± 1.6 |

The combined values assume identical hadronization in $p\overline{p}$ collisions and in Z decay. These could in principle differ, because of the different momentum distributions of the b-quark in these processes; the sample used in the $p\overline{p}$ measurements has momenta close to the b mass, rather than $m_Z/2$. A test of the agreement between production fractions may be given by comparison of values of the average time-integrated mixing probability parameter $\bar{\chi} = f_d \chi_d + f_s \chi_s$ [8]. This is an important input in the determination of the world-averages of production fractions. The current measurements of $\bar{\chi}$ from LEP and the

b-flavored hadrons

Tevatron differ by 1.8 σ [33]. This slight discrepancy increases the uncertainty in the combined fractions in Table 1. It should be noted that the combination is not well defined as both the CDF and LHCb experiments observe a significant dependence of the Λ_b production fraction on transverse momentum. With the availability of large samples of b-flavored mesons and baryons at $p\overline{p}$ colliders, the limited knowledge of these fractions has become an important limiting factor in the determination of their branching fractions.

Excited B-meson states have been observed by CLEO, LEP, CUSB, D0, and CDF. The current world average of the B^* -B mass difference is $45.78 \pm 0.35 \text{ MeV}/c^2$. Evidence for B^{**} (L=1) production has been initially obtained at LEP [39], as a broad resonance in the mass of an inclusively reconstructed bottom hadron candidate combined with a charged pion from the primary vertex. Detailed results from exclusive modes have been obtained at the Tevatron, allowing separation of the narrow states B_1 and B_2^* and also a measurement of the B_2^* width [40].

Also the narrow B_s^{**} states, first sighted by OPAL as a single broad enhancement in the B^+K mass spectrum [41], have now been clearly observed and separately measured at the Tevatron [42]: $M(B_{s1}) = 5829.4 \pm 0.7 \text{ MeV}/c^2 \text{ (CDF)}$ and $M(B_{s2}^*) = 5839.7 \pm 0.7 \text{ MeV}/c^2 \text{ (CDF)}$, $M(B_{s2}^*) = 5839.6 \pm 1.1 \pm 0.7 \text{ MeV}/c^2 \text{ (D0)}$.

Baryon states containing a b quark are labeled according to the same scheme used for non-b baryons, with the addition of a b subscript [23]. For many years, the only well-established bbaryon was the Λ_b^0 (quark composition udb), with only indirect evidence for Ξ_b (dsb) production from LEP [43]. This situation has changed dramatically in the past few years due to the large samples being accumulated at the Tevatron and LHCb. Clear signals of four strongly-decaying baryon states, Σ_h^+ , Σ_h^{*+} $(uub), \Sigma_b^-, \Sigma_b^{*-}$ (ddb) have been obtained by CDF in $\Lambda_b^0 \pi^{\pm}$ final states [44]. The strange bottom baryon Ξ_b^{\pm} was observed in the exclusive mode $\Xi_b^{\pm} \to J/\psi \Xi^{\pm}$ by D0 [45], and CDF [46]. More recently CDF has also observed the Ξ_b in the $\Xi_c \pi$ final state [47]. The relative production of Ξ_b and Λ_b baryons has been found to be consistent with the B_s to B_d production ratio [45]. Observation of the doubly-strange bottom baryon Ω_b^- has been published by both D0 [48] and CDF [49]. However the masses measured by the two experiments show a large discrepancy. The resolution appears to be provided by LHCb; they recently presented a preliminary measurement of the Ω_b^- mass consistent with the CDF measurement [50]. Apart from the discrepancy on Ω_b^- mass, the masses of all these new baryons have been measured to a precision of a few MeV/c^2 , and found to be in agreement with predictions from HQET.

Lifetimes: Precise lifetimes are key in extracting the weak parameters that are important for understanding the role of the CKM matrix in CP violation, such as the determination of V_{cb} and $B_s\overline{B}_s$ mixing parameters. In the naive spectator model, the heavy quark can decay only via the external spectator

mechanism, and thus, the lifetimes of all mesons and baryons containing b quarks would be equal. Non–spectator effects, such as the interference between contributing amplitudes, modify this simple picture and give rise to a lifetime hierarchy for b-flavored hadrons similar to the one in the charm sector. However, since the lifetime differences are expected to scale as $1/m_Q^2$, where m_Q is the mass of the heavy quark, the variations in the b system are expected to be only 10% or less [51]. We expect:

$$\tau(B^+) > \tau(B^0) \approx \tau(B_s) > \tau(\Lambda_b^0) \gg \tau(B_c^+)$$
. (1)

For the B_c^+ , both quarks decay weakly, so the lifetime is much shorter.

Measurements of the lifetimes of the different b-flavored hadrons thus provide a means to determine the importance of non-spectator mechanisms in the b sector. Over the past decade, the precision of silicon vertex detectors and the increasing availability of fully–reconstructed samples has resulted in much-reduced statistical and systematic uncertainties (\sim 1%). The averaging of precision results from different experiments is a complex task that requires careful treatment of correlated systematic uncertainties; the world averages given in Table 2 have been determined by the Heavy Flavor Averaging Group (HFAG) [33].

Table 2: Summary of inclusive and exclusive world-average b-hadron lifetime measurements. For the two B_s averages, see text below.

| $\begin{array}{llll} \text{Particle} & \text{Lifetime [ps]} \\ \hline B^+ & 1.641 \pm 0.008 \\ B^0 & 1.519 \pm 0.007 \\ B_s & \text{(flavor-specific)} & 1.463 \pm 0.032 \\ B_s & (1/\Gamma_s) & 1.495 \pm 0.015 \\ B_c^+ & 0.453 \pm 0.041 \\ \Lambda_b^0 & 1.425 \pm 0.032 \\ \Xi_b^- & 1.56^{+0.27}_{-0.25} \\ \Omega_b^- & 1.13^{+0.53}_{-0.40} \\ \hline \Xi_b & \text{mixture} & 1.49^{+0.19}_{-0.18} \\ b\text{-baryon mixture} & 1.382 \pm 0.029 \\ b\text{-hadron mixture} & 1.568 \pm 0.009 \\ \hline \end{array}$ | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| $\begin{array}{lll} B^0 & 1.519 \pm 0.007 \\ B_s \text{ (flavor-specific)} & 1.463 \pm 0.032 \\ B_s \text{ (}1/\Gamma_s) & 1.495 \pm 0.015 \\ B_c^+ & 0.453 \pm 0.041 \\ \Lambda_b^0 & 1.425 \pm 0.032 \\ \Xi_b^- & 1.56^{+0.27}_{-0.25} \\ \Omega_b^- & 1.13^{+0.33}_{-0.40} \\ \Xi_b \text{ mixture} & 1.49^{+0.19}_{-0.18} \\ b\text{-baryon mixture} & 1.382 \pm 0.029 \\ \end{array}$ | Particle | Lifetime [ps] |
| $\begin{array}{ll} \Omega_b^- & 1.13^{+0.53}_{-0.40} \\ \Xi_b \text{ mixture} & 1.49^{+0.19}_{-0.18} \\ b\text{-baryon mixture} & 1.382 \pm 0.029 \end{array}$ | $\begin{array}{l} B^0 \\ B_s \text{ (flavor-specific)} \\ B_s (1/\Gamma_s) \\ B_c^+ \\ \Lambda_b^0 \end{array}$ | $\begin{aligned} 1.519 &\pm 0.007 \\ 1.463 &\pm 0.032 \\ 1.495 &\pm 0.015 \\ 0.453 &\pm 0.041 \\ 1.425 &\pm 0.032 \end{aligned}$ |
| b-nadron mixture 1.308 ± 0.009 | $\frac{\Omega_b^-}{\Xi_b \text{ mixture}}$ b-baryon mixture | $ \begin{array}{c} 1.13^{+0.53}_{-0.40} \\ 1.49^{+0.19}_{-0.18} \\ 1.382 \pm 0.029 \end{array} $ |
| | o-nadron mixture | 1.008 ± 0.009 |

The short B_c^+ lifetime is in good agreement with predictions [52]. For precision comparisons with theory, lifetime ratios are more sensitive. Experimentally we find:

$$\begin{split} \frac{\tau_{B^+}}{\tau_{B^0}} &= 1.079 \pm 0.007 \,,\; \frac{\tau_{B_s}}{\tau_{B^0}} = 0.984 \pm 0.011 \,,\\ \frac{\tau_{\Lambda_b}}{\tau_{B^0}} &= 0.938 \pm 0.022 \,, \end{split}$$

while theory makes the following predictions [51,53]

$$\frac{\tau_{B^+}}{\tau_{B^0}} = 1.06 \pm 0.02 \; , \; \; \frac{\tau_{B_s}}{\tau_{B^0}} = 1.00 \pm 0.01 \; , \; \; \frac{\tau_{\Lambda_b}}{\tau_{B^0}} = 0.88 \pm 0.05.$$

The ratio of B^+ to B^0 lifetimes has a precision of better than 1%, and is significantly different from 1.0, in agreement with predictions [51]. The ratio of B_s to B^0 lifetimes is expected to be very close to 1.0; while there used to be mild tension between experiment and theory, the discrepancy is disappearing with newer measurements with large samples of fully reconstructed B_s decays [54]. The Λ_b lifetime has a history of discrepancies. Predictions were higher than data before the introduction of higher-order effects lowered them. The precision of the measurements has recently been improved by more than a factor of two by two CDF measurements [57,58]. The measurements are in marginal agreement with each other and previous measurements; the new world average is somewhat larger than the theoretical predictions. The most significant discrepancy comes from the CDF measurement in $\Lambda_b \to J/\psi \Lambda$ channel which differs by 3.3σ from the average of all other measurements. With more data available at both D0 and CDF and large samples available at LHCb, new results will hopefully resolve this discrepancy in the near future.

Neutral B mesons are two-component systems similar to neutral kaons, with a light (L) and a heavy (H) mass eigenstate, and independent decay widths Γ_L and Γ_H . The SM predicts a non-zero width difference $\Delta\Gamma = \Gamma_L - \Gamma_H > 0$ for both B_s and B_d . For B_d , $\Delta \Gamma_d/\Gamma_d$ is expected to be $\sim 0.2\%$. Analysis of BaBar and DELPHI data on CP-specific modes of the B^0 yield a combined result: $\Delta \Gamma_d / \Gamma_d = 0.015 \pm 0.018$ [33]. The issue is much more interesting for the B_s , since the SM expectation for $\Delta\Gamma_s/\Gamma_s$ is of order 10%. This potentially nonnegligible difference requires care when defining the B_s lifetime. As indicated in Table 2, two different lifetimes are defined for the B_s meson: one is defined as $1/\Gamma_s$, where Γ_s is the average width of the two mass eigenstates $(\Gamma_L + \Gamma_H)/2$; the other is obtained from "flavor-specific" (e.g., semileptonic) decays and depends both on Γ_s and $\Delta\Gamma_s$. Experimentally, the quantity $\Delta\Gamma_s$ can be accessed by measuring lifetimes in decays into CPeigenstates, which in the standard model are expected to be close approximations to the mass eigenstates. This has been done with the $J/\psi\phi$ mode, where the two CP eigenstates are distinguished by angular distributions, and in $B_s \to K^+K^$ or $B_s \to J/\psi f_0(980)$ which are CP-eigenstates. The current experimental information is dominated by measurements on the $J/\psi\phi$ mode performed by CDF, D0 and LHCb experiments. By appropriately combining all published measurements of $J/\psi\phi$ lifetimes and flavor-specific lifetimes, the HFAG group obtains a world-average $\Delta\Gamma_s/\Gamma_s=0.092^{+0.051}_{-0.054}$ [33], which is compatible with zero; the latest theoretical predictions yield $\Delta\Gamma_s/\Gamma_s = 0.133 \pm 0.032$ [59], in agreement with measurements within the large uncertainties on both. From the theoretical point of view, the best quantity to use is $\Delta\Gamma_s/\Delta M_s$, which is much less affected by hadronic uncertainties [59]. Exploiting the very accurate measurement of ΔM_s now available [60], this can be turned into a SM prediction with an uncertainty of only 20%: $\Delta\Gamma_s/\Gamma_s = 0.137 \pm 0.027$. This is likely to be of importance in future comparisons, as the experimental precision improves with the growth of Tevatron samples. Further improvements are coming from lifetime measurements in the CP-eigenstates

such as $B_s \to K^+K^-$ [61] and $B_s \to J/\psi f_0(980)$ [62], and alternative (model–dependent) determinations via the $B_s \to D_s^{(*)+}D_s^{(*)-}$ branching fraction [63].

The width difference $\Delta\Gamma_s$ is connected to the B_s mixing phase ϕ_s by $\Delta\Gamma_s = \Gamma_{12}\cos\phi_s$, where Γ_{12} is the off-diagonal term of the decay matrix [6,8,59]. The early measurements by CDF [64] and D0 [65] have produced CL contours in the $(\phi_s, \Delta\Gamma)$ plane, and both observe a mild deviation, in the same direction, from the expectation of the Standard model of the phase ϕ_s near $\Delta\Gamma$ = 0. The possibility of a large value of ϕ_s has attracted significant interest, as it would be very clean evidence for the existence of new sources of CP violation beyond the standard model. However the latest measurements from CDF [66], D0 [67] and LHCb [68], which provide significant improvements over initial measurements, show good agreement with the standard model. The LHCb experiment also used the decay $B_s \to J/\psi f_0(980)$ to measure ϕ_s [69]. While this measurement is not as precise as the one from $B_s \to J/\psi \phi$, it does not require analysis of angular distributions, which simplifies the analysis. It should be noted that all above measurements have a two-fold ambiguity in their results. We can resolve this ambiguity using the interferance between the decays to $J/\psi\phi$ and $J/\psi K^+K^-$, where K^+K^- is in relative S-wave state. This has been used by LHCb experiment to determine the sign of the $\Delta\Gamma_s$ to be positive [70].

B meson decay properties: Semileptonic B decays $B \rightarrow$ $X_c\ell\nu$ and $B\to X_u\ell\nu$ provide an excellent way to measure the magnitude of the CKM elements $|V_{cb}|$ and $|V_{ub}|$ respectively, because the strong interaction effects are much simplified due to the two leptons in the final state. Both exclusive and inclusive decays can be used, and the nature of uncertainties are quite complementary. For exclusive decay analysis, knowledge of the form factors for the exclusive hadronic system $X_{c(u)}$ is required. For inclusive analysis, it is usually necessary to restrict the available phase-space of the decay products to suppress backgrounds; subsequently uncertainties are introduced in the extrapolation to the full phase-space. Moreover, restriction to a small corner of the phase-space may result in breakdown of the operator-product expansion scheme, thus making theoretical calculations unreliable. A more detailed discussion of Bsemileptonic decays and the extraction of $|V_{cb}|$ and $|V_{ub}|$ is given elsewhere in this Review [9].

On the other hand, hadronic decays of B are complicated because of strong interaction effects caused by the surrounding cloud of light quarks and gluons. While this complicates the extraction of CKM matrix elements, it also provides a great opportunity to study perturbative and non-perturbative QCD, hadronization, and Final State Interaction (FSI) effects. Purepenguin decays were first established by the observation of $B \to K^*\gamma$ [71]. Some observed decay modes such as $B^0 \to D_s^-K^+$, may be interpreted as evidence of a W-exchange process [72]. The evidence for the decay $B^+ \to \tau^+\nu$ from Belle [73] and BaBar [74] is the first sign of a pure annihilation decay. There

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is growing evidence that penguin annihilation processes may be important in decays with two vector mesons in the final state [75].

Hadronic decays: Most of the hadronic B decays involve $b \to c$ transition at the quark level, resulting in a charmed hadron or charmonium in the final state. Other types of hadronic decays are very rare and will be discussed separately in the next section. The experimental results on hadronic Bdecays have steadily improved over the past few years, and the measurements have reached sufficient precision to challenge our understanding of the dynamics of these decays. With the good neutral particle detection and hadron identification capabilities of B-factory detectors, a substantial fraction of hadronic Bdecay events can be fully reconstructed. Because of the kinematic constraint of $\Upsilon(4S)$, the energy sum of the final-state particles of a B meson decay is always equal to one half of the total energy in the center of mass frame. As a result, the two variables, ΔE (energy difference) and M_B (B candidate mass with a beam-energy constraint) are very effective for suppressing combinatorial background both from $\Upsilon(4S)$ and $e^+e^- \to q\bar{q}$ continuum events. In particular, the energy-constraint in M_B improves the signal resolution by almost an order of magnitude.

The kinematically clean environment of B meson decays provides an excellent opportunity to search for new states. For instance, quark-level $b \to c\bar{c}s$ decays have been used to search for new charmonium and charm-strange mesons and study their properties in detail. In 2003, BaBar discovered a new narrow charm-strange state $D_{sJ}^*(2317)$ [76], and CLEO observed a similar state $D_{sJ}(2460)$ [77]. The properties of these new states were studied in the B meson decays, $B \to DD_{sJ}^*(2317)$ and $B \to DD_{sJ}(2460)$ by Belle [78]. Further studies of $D_{sJ}^{(*)}$ meson production in B decays have been made by Belle [79] and BaBar [80]. Now these charm-strange meson states are identified as $D_{s0}^*(2317)$ and $D_{s1}(2460)$, respectively.

More recently, Belle observed a new D_{sJ} meson produced in $B^+ \to \bar{D}^0 D_{sJ} \to \bar{D}^0 D^0 K^+$ [81]. Combined with a subsequent measurement by BaBar [82], the mass and width of this state are determined to be 2709^{+9}_{-6} MeV/ c^2 and 125 ± 30 MeV, respectively. An analysis of the helicity angle distribution determines its spin-parity to be 1^- .

A variety of exotic particles have been discovered in B decays. Belle found the X(3872) state [83], which is confirmed by CDF [84] and BaBar [85]. Analyzing their full $\Upsilon(4S)$ data sample, Belle finds a new upper limit on the width of X(3872) to be $\Gamma_{X(3872)} < 1.2$ MeV [86], improving on the existing limit by nearly a factor of 2. Radiative decays of X(3872) can play a crucial role in understanding the nature of the particle. For example, in the molecular model the decay of X(3872) to $\psi'\gamma$ is expected to be highly suppressed in comparison to the decay to $J/\psi\gamma$ [87]. BaBar has seen the evidence for the decay to $J/\psi\gamma$ [88]. The ratio $R \equiv \mathcal{B}(X(3872) \to \psi'\gamma)/\mathcal{B}(X(3872) \to J/\psi\gamma)$ is measured to be 3.4 ± 1.4 by BaBar [89], while Belle obtains R < 2.1 at 90% CL [90].

Belle has observed a near-threshold enhancement in the $J/\psi\omega$ invariant mass for $B\to J/\psi\omega K$ decays [91]. BaBar has studied $B\to J/\psi\pi^+\pi^-K$, finding an excess of $J/\psi\pi^+\pi^-$ events with a mass just above 4.2 GeV/ c^2 ; this is consistent with the Y(4260) that was observed by BaBar in ISR (Initial State Radiation) events [93]. A Belle study of $B\to \psi'K\pi^\pm$ [94] finds a state called $X(4430)^\pm$ that decays to $\psi'\pi^\pm$. Since it is charged, it could not be a charmonium state. This state was searched for by BaBar with similar sensitivity but was not found [95]. In a Dalitz plot analysis of $\overline{B}^0\to \chi_{c1}K^-\pi^+$, Belle has observed two resonance-like structures in the $\chi_{c1}\pi^+$ mass distribution [96], labelled as $X(4050)^\pm$ and $X(4250)^\pm$ in this Review, while no evidence is found by BaBar in a search with similar sensitivity [97].

The hadronic decays $\overline{B}^0 \to D^{(*)0}h^0$, where h^0 stands for light neutral mesons such as $\pi^0, \eta^{(')}, \rho^0, \omega$, proceed through color-suppressed diagrams, hence they provide useful tests on the factorization models. Both Belle and BaBar have made comprehensive measurements of such color-suppressed hadronic decays of \overline{B}^0 [98].

Information on B_s and Λ_b decays is limited, though improving with recent studies of large samples at the Tevatron and LHC experiments. Recent additions are decays of $B_s \to J/\psi f_0(980)$ [62,99], $B_s \to J/\psi f_2'(1525)$ [100], and $\Lambda_b \to \Lambda_c \pi^+ \pi^- \pi^-$ [101]. For the later, not only the total rate is measured, but also structure involving decays through excited Λ_c and Σ_c baryons.

There have been hundreds of publications on hadronic B decays to open-charm and charmonium final states mostly from the B-factory experiments. These results are nicely summarized in a recent report by HFAG [33].

Rare B decays: All B-meson decays that do not occur through the $b \to c$ transition are usually called rare B decays. These include both semileptonic and hadronic $b \to u$ decays that are suppressed at leading order by the small CKM matrix element V_{ub} , as well as higher-order $b \to s(d)$ processes such as electroweak and gluonic penguin decays.

Charmless B meson decays into two-body hadronic final states such as $B \to \pi\pi$ and $K\pi$ are experimentally clean, and provide good opportunities to probe new physics and search for indirect and direct CP violations. Since the final state particles in these decays tend to have larger momenta than average Bdecay products, the event environment is cleaner than for $b \rightarrow c$ decays. Branching fractions are typically around 10^{-5} . Over the past decade, many such modes have been observed by BaBar, Belle, and CLEO. More recently, comparable samples of the modes with all charged final particles have been reconstructed in $p\bar{p}$ collisions by CDF by triggering on the impact parameter of the charged tracks. This has also allowed observation of charmless decays of the B_s , in final states such as $\phi\phi$ [102], K^+K^- [103], and $K^-\pi^+$ [104], and of charmless decays of the Λ_b^0 baryon [104]. Charmless B_s modes are related to corresponding B^0 modes by U-spin symmetry, and are determined

by similar amplitudes. Combining the observables from B_s and B^0 modes is a further way of eliminating hadronic uncertainties and extracting relevant CKM information [105].

Because of relatively high-momenta for final state particles, the dominant source of background in e^+e^- collisions is $q\bar{q}$ continuum events; sophisticated background suppression techniques exploiting event shape variables are essential for these analyses. In hadron collisions, the dominant background comes from QCD or partially reconstructed heavy flavors, and is similarly suppressed by a combination of kinematic and isolation requirements. The results are in general consistent among the experiments.

BaBar [106] and Belle [107] have observed the decays $B^+ \to \overline{K}^0 K^+$ and $B^0 \to K^0 \overline{K}^0$. The world-average branching fractions are $\mathcal{B}(B^0 \to K^0 \overline{K}^0) = (0.96^{+0.20}_{-0.18}) \times 10^{-6}$ and $\mathcal{B}(B^+ \to \overline{K}^0 K^+) = (1.36 \pm 0.27) \times 10^{-6}$. These are the first observations of hadronic $b \to d$ transitions, with significance $> 5\sigma$ for all four measurements. CP asymmetries have even been measured for these modes, though with large errors.

Most rare decay modes including $B^0 \to K^+\pi^-$ have contributions from both $b \to u$ tree and $b \to sg$ penguin processes. If the size of the two contributions are comparable, the interference between them may result in direct CP violation, seen experimentally as a charge asymmetry in the decay rate measurement. BaBar [108], Belle [109], and CDF [103] have measured the direct CP violating asymmetry in $B^0 \to K^+\pi^-$ decays. The BaBar and Belle measurements constitute observation of direct CP violation with a significance of more than 5σ . The world average for this quantity is now rather precise, -0.098 ± 0.013 . There are sum rules [110] that relate the decay rates and decay-rate asymmetries between the four $K\pi$ charge states. The experimental measurements of the other three modes are not yet precise enough to test these sum rules.

There is now evidence for direct CP violation in three other decays: $B^+ \to \rho^0 K^+$ [111], $B^+ \to \eta K^+$ [112], and $B^0 \to \eta K^{*0}$ [113]. The significance is typically 3–4 σ , though the significance for the $B^+ \to \eta K^+$ decay is now nearly 5σ with the recent Belle measurement [112]. In at least the first two cases, a large direct CP violation might be expected since the penguin amplitude is suppressed so the tree and penguin amplitudes may have comparable magnitudes.

The decay $B^0 \to \pi^+\pi^-$ can be used to extract the CKM angle α . This is complicated by the presence of significant contributions from penguin diagrams. An isospin analysis [114] can be used to untangle the penguin complications. The decay $B^0 \to \pi^0\pi^0$, which is now measured by both BaBar and Belle, is crucial in this analysis. Unfortunately the amount of penguin pollution in the $B \to \pi\pi$ system is rather large. In the past few years, measurements in the $B^0 \to \rho\rho$ system have produced more precise values of α , since penguin amplitudes are generally smaller for decays with vector mesons. An important ingredient in the analysis is the $B^0 \to \rho^0 \rho^0$ branching fraction. The average of measurements from BaBar and Belle BaBar [115] yields a branching fraction of $(0.73\pm0.28)\times10^{-6}$. This is only 3% of the

 $\rho^+\rho^-$ branching fraction, much smaller than the corresponding ratio in the $\pi\pi$ system.

The decay $B \to a_1 \pi$ has been seen by BaBar. An analysis of the time evolution of this decay [116] together with measurements of other related decays has been used to measure the CKM angle α [117] in agreement with the more precise measurements from the $\rho\rho$ system.

Since $B\to\rho\rho$ has two vector mesons in the final state, the CP eigenvalue of the final state depends on the longitudinal polarization fraction f_L for the decay. Therefore, a measurement of f_L is needed to extract the CKM angle α . Both BaBar and Belle have measured f_L for the decays $\rho^+\rho^-$ and $\rho^+\rho^0$ and in both cases the measurements show $f_L>0.9$, making a complete angular analysis unnecessary.

By analyzing the angular distributions of the B decays to two vector mesons, we can learn a lot about both weakand strong-interaction dynamics in B decays. Decays that are penguin-dominated surprisingly have values of f_L near 0.5. The list of such decays has now grown to include $B \to \phi K^*$, $B \to \rho K^*$, and $B \to \omega K^*$. The reasons for this "polarization puzzle" are not fully understood. A detailed description of the angular analysis of B decays to two vector mesons can be found in a separate mini-review [118] in this Review.

There has been substantial progress in measurements of many other rare-B decays. The decay $B \to \eta' K$ stood out as the largest rare-B decay for many years. The reasons for the large rate are now largely understood [14,119]. However, there are now measurements of several 3-body or quasi-3-body modes with similarly large branching fractions. States seen so far include $K\pi\pi$ (three charge states) [120], KKK (four charge states) [121], and $K^*\pi\pi$ (two charged states) [122]. Many of these analyses now include Dalitz plot treatments with many intermediate resonances. There has also been an observation of the decay $B^+ \to K^+K^-\pi^+$ by BaBar [123], noteworthy because an even number of kaons is typically indicative of suppressed $b \to d$ transitions as discussed above.

Belle [73] and BaBar [74] have found evidence for $B^+ \to \tau^+\nu$; the average branching fraction, with a significance of nearly 5σ is $(165\pm34)\times10^{-6}$. This is somewhat larger than, though consistent with, the value expected in the SM. This is the first observation of a pure annihilation decay. A substantial region of parameter space of charged Higgs mass vs. $\tan\beta$ is excluded by the measurements of this mode.

Electroweak penguin decays: More than a decade has passed since the CLEO experiment first observed an exclusive radiative $b \to s \gamma$ transition, $B \to K^*(892) \gamma$ [71], thus providing the first evidence for the one-loop FCNC electromagnetic penguin decay. Using much larger data samples, both Belle and BaBar have updated this analysis [124] with an average branching raction $\mathcal{B}(B^0 \to K^{*0} \gamma) = (43.3 \pm 1.5) \times 10^{-6}$, and have added several new decay modes such as $B \to K_1 \gamma$, $K_2^*(1430) \gamma$, etc. [125]. With a sample of 24 fb⁻¹ at $\Upsilon(5S)$, Belle observed the radiative penguin decay of $B_s \to \phi \gamma$ with a branching fraction $(57^{+22}_{-19}) \times 10^{-6}$ [126].

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Compared to $b \to s\gamma$, the $b \to d\gamma$ transitions such as $B \to \rho\gamma$, are suppressed by the small CKM element V_{td} . Both Belle and BaBar have observed these decays [17,18]. The world average $\mathcal{B}(B \to (\rho,\omega)\gamma) = (1.28 \pm 0.21) \times 10^{-6}$. This can be used to calculate $|V_{td}/V_{ts}|$ [127]; the measured values are $0.233^{+0.033}_{-0.032}$ from BaBar [18] and $0.195^{+0.025}_{-0.024}$ from Belle [17].

The observed radiative penguin branching fractions can constrain a large class of SM extensions [128]. However, due to the uncertainties in the hadronization, only the inclusive $b \to s \gamma$ rate can be reliably compared with theoretical calculations. This rate can be measured from the endpoint of the inclusive photon spectrum in B decay. By combining the measurements of $B \to X_s \gamma$ from CLEO, BaBar, and Belle experiments [129,130], HFAG obtains the new average: $\mathcal{B}(B \to X_s \gamma) = (3.55 \pm 0.24 \pm 0.09) \times 10^{-4}$ [33] for $E_{\gamma} \geq 1.6$ GeV. Consistent results have been reported by ALEPH for inclusive b-hadrons produced at the Z. The measured branching fraction can be compared to theoretical calculations. Recent calculations of $\mathcal{B}(b \to s \gamma)$ at NNLO level predict the values of $(3.15 \pm 0.23) \times 10^{-4}$ [131] and $(2.98 \pm 0.26) \times 10^{-4}$ [132], where the latter is calculated requiring $E_{\gamma} > 1.6$ GeV.

The CP asymmetry in $b \to s\gamma$ is extensively studied theoretically both in the SM and beyond [133]. According to the SM, the CP asymmetry in $b \to s\gamma$ is smaller than 1%, but some non-SM models allow significantly larger CP asymmetry ($\sim 10\%$) without altering the inclusive branching fraction. The current world average is $A_{CP} = -0.012 \pm 0.028$, again dominated by BaBar and Belle [134]. In addition to the CP asymmetry, BaBar also measured the isospin asymmetry $\Delta_{0-} = 0.06 \pm 0.17$ in $b \to s\gamma$ by measuring the companion B with full reconstruction in the hadronic decay modes [135].

In addition, all three experiments have measured the inclusive photon energy spectrum for $b \to s \gamma$, and by analyzing the shape of the spectrum they obtain the first and second moments for photon energies. Belle has measured these moments covering the widest range in the photon energy (1.7 < E_{γ} < 2.8 GeV) [130]. These results can be used to extract non-perturbative HQET parameters that are needed for precise determination of the CKM matrix element V_{ub} .

Additional information on FCNC processes can be obtained from $B \to X_s \ell^+ \ell^-$ decays, which are mediated by electroweak penguin and W-box diagrams. Their branching fractions have been measured by Belle [136], BaBar [137], and CDF [138]. Average branching fractions over all charged and neutral modes have been determined from BaBar and Belle data for $B \to K\ell^+\ell^-$: $(0.45\pm0.04)\times10^{-6}$ and for $B\to K^*(892)\ell^+\ell^-$: $(1.08\pm0.11)\times10^{-6}$, consistent with the SM expectation. B-factory experiments also measured the branching fractions for inclusive $B\to X_s\ell^+\ell^-$ decays [139], with an average of $(3.66^{+0.76}_{-0.77})\times10^{-6}$ [140]. Recently corresponding decays of B_s and Λ_b were observed [138,141]. Branching fraction for the decay $B_s\to\phi\mu^+\mu^-$ is measured to be $(1.47\pm0.24\pm0.46)\times10^{-6}$ and for the decay $\Lambda_b\to\Lambda\mu^+\mu^-$ to be $(1.73\pm0.42\pm0.55)\times10^{-6}$. Excitment was generated by measurements of forward-backward

asymmetry in $B \to K^*(892)\ell^+\ell^-$ decays, which exhibited mild tension with the standard model in earlier measurements. The most recent measurements by CDF [142] and LHCb [143] agree with standard model, suggesting that the earlier discrepancy was mainly due to statistical fluctuations.

Finally the decays $B_{(s)}^0 \to e^+e^-$ and $\mu^+\mu^-$ are interesting since they only proceed at second order in weak interactions in the SM, but may have large contributions from supersymmetric loops, proportional to $(\tan \beta)^6$. Experiments at Tevatron, Bfactories and now also LHC have obtained results that exclude a portion of the region allowed by SUSY models. The most stringent limits in these modes are obtained by LHCb. The limits in the $\mu^{+}\mu^{-}$ mode are: $< 1.4 \times 10^{-8}$ and $< 3.2 \times 10^{-9}$ at 95% confidence level, respectively, for B_s and B^0 [144]. For the B_s mode, the result is about factor of five above SM predictions [145]. It should be noted, that the most recent search by CDF observes an excess above expected background [146]. While the branching fraction for decay $B_s \to \mu^+ \mu^-$ of $(1.8^{+1.1}_{-0.9}) \times 10^{-8}$ is extracted, CDF concludes that most plausible explanation for the excess is a statistical fluctuation. The limits for the $e^+e^$ modes are: $< 2.8 \times 10^{-7}$ and $< 8.3 \times 10^{-8}$, respectively, for B_s and B^0 [147]. There are also limits for lepton flavor-violating channels $B_{(s)}^0 \to e^+\mu^-$, which are around 10^{-7} [147].

Summary and Outlook: The study of B mesons continues to be one of the most productive fields in particle physics. With the two asymmetric B-factory experiments Belle and BaBar, we now have a combined data sample of well over 1 ab⁻¹. CP violation has been firmly established in many decays of B mesons. Evidence for direct CP violation has been observed. Many rare decays resulting from hadronic $b \to u$ transitions and $b \to s(d)$ penguin decays have been observed, and the emerging pattern is still full of surprises. Despite the remarkable successes of the B-factory experiments, many fundamental questions in the flavor sector remain unanswered.

At Fermilab, CDF and D0 each has accumulated about 10 fb^{-1} , which is the equivalent of about 10^{12} *b*-hadrons produced. In spite of the low trigger efficiency of hadronic experiments, a selection of modes have been reconstructed in large quantities, giving a start to a program of studies on B_s and *b*-flavored baryons, in which a first major step has been the determination of the B_s oscillation frequency.

As Tevatron and B-factories stop their taking data, the new experiments at the LHC have become very active. The LHC accelerator performed very well in 2011. The general purpose experiments ATLAS and CMS collected about 5 fb⁻¹ while LHCb collected about 1 fb⁻¹. LHCb, which is almost fully dedicated to studies of b- and c-hadrons, has a very large data sample. Of particular note is the sensitivity of the LHC experiments for the decay $B_s \to \mu^+\mu^-$ which is expected to approach the standard model level in 2012.

In addition, two projects for next generation high-luminosty B-factories at KEK and Frascati are approved. Their aim to increase samples to $\sim 50~{\rm ab^{-1}}$ will make it possible to explore the

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indirect evidence of new physics beyond the SM in the heavy-flavor particles $(b, c, \text{ and } \tau)$, in a way that is complementary to the LHC.

These experiments promise a rich spectrum of rare and precise measurements that have the potential to fundamentally affect our understanding of the SM and CP-violating phenomena.

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- 5. Currently two different notations (ϕ_1, ϕ_2, ϕ_3) and (α, β, γ) are used in the literature for CKM unitarity angles. In this mini-review, we use the latter notation following the other mini-reviews in this *Review*. The two notations are related by $\phi_1 = \beta$, $\phi_2 = \alpha$ and $\phi_3 = \gamma$.
- See the "CP Violation in Meson Decays" by D. Kirkby and Y. Nir in this Review.
- See the "CKM Quark Mixing Matrix," by A. Cecucci,
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A NOTE ON HFAG ACTIVITIES

The Heavy Flavor Averaging Group (HFAG) has been formed, continuing the activities of the LEP Heavy Flavor Steering group, to provide the averages for measurements dedicated to the b-flavor related quantities. The HFAG consists of representatives and contacts from the experimental groups: BaBar, Belle, CDF, CLEO, DØ, LEP, SLD, and LHCb.

In the averaging the input parameters used in the various analyses are adjusted (rescaled) to common values, and all known correlations are taken into account. The HFAG has seven sub-groups providing averages for b-hadron lifetimes and B-oscillation parameters, CP-violation measurements, semileptonic parameters, rare branching fractions, b-hadron decays to charm, charm mixing and decays, and τ decays. The averages provided by the HFAG are listed as "OUR EVALUATION" with a corresponding note.

The most up-to-date and complete listing of averages and more detailed information on the averaging procedures are available at:

http://www.slac.stanford.edu/xorg/hfag .



$$I(J^P) = \frac{1}{2}(0^-)$$

Quantum numbers not measured. Values shown are quark-model

See also the B^{\pm}/B^0 ADMIXTURE and $B^{\pm}/B^0/B_s^0/b$ -baryon AD-MIXTURE sections.

B± MASS

The fit uses $m_{B^+},\,(m_{B^0}-m_{B^+}),$ and m_{B^0} to determine $m_{B^+},\,m_{B^0},$ and the mass difference.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|-------------|-----------------------|---------|---------|------------------------------------|
| 5279.25 ± 0.17 OUR FI | Т | | | | |
| 5 279.25 ± 0.26 OUR A | /ERAGE | | | | |
| $5279.38 \pm 0.11 \pm 0.33$ | | 1 AAIJ | 12E | LHCB | pp at 7 TeV |
| $5279.10 \pm 0.41 \pm 0.36$ | | ² ACOSTA | 06 | CDF | <i>p</i> p at 1.96 TeV |
| $5279.1 \pm 0.4 \pm 0.4$ | 526 | ³ CSORNA | 00 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $5279.1 \pm 1.7 \pm 1.4$ | 147 | ABE | 96B | CDF | ρ p at 1.8 TeV |
| • • • We do not use t | he followir | ng data for averages | , fits, | limits, | etc. • • • |
| $5278.8\ \pm0.54\pm2.0$ | 362 | ALAM | 94 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $5278.3 \pm 0.4 \pm 2.0$ | | BORTOLETTO | 92 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $5280.5 \pm 1.0 \pm 2.0$ | | ⁴ ALBRECHT | 90J | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $5275.8 \pm 1.3 \pm 3.0$ | 32 | ALBRECHT | 87c | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| $5278.2 \pm 1.8 \pm 3.0$ | 12 | 5 ALBRECHT | 87D | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| $5278.6\ \pm0.8\ \pm2.0$ | | BEBEK | 87 | CLEO | $e^+ e^- \rightarrow r(4S)$ |

- 1 Uses $B^{+} \rightarrow J/\psi K^{+}$ fully reconstructed decays.
- ²Uses exclusively reconstructed final states containing a $J/\psi \rightarrow \mu^+\mu^-$ decays.
- 3 CSORNA 00 uses fully reconstructed 526 $B^+ o J/\psi^{(\prime)}$ K^+ events and invariant masses without beam constraint. 4 ALBRECHT 90J assumes 10580 for $\Upsilon(4S)$ mass. Supersedes ALBRECHT 87c and
- Found using fully reconstructed decays with $J/\psi(1S)$. ALBRECHT 87D assume $m_{\Upsilon(4S)}$ = 10577 MeV

B± MEAN LIFE

See $B^{\pm}/B^0/B_{\rm c}^0/b$ -baryon ADMIXTURE section for data on B-hadron mean life averaged over species of bottom particles

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors

| VALUE (10 ⁻¹² s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------|------------|-------------------------|-------------|-----------|-----------------------------------|
| 1.641±0.008 OUR EV | ALUATIO | | | | |
| $1.639\!\pm\!0.009\!\pm\!0.009$ | | ¹ AALTONEN | 11 | CDF | $p\overline{p}$ at 1.96 TeV |
| $1.663 \pm 0.023 \pm 0.015$ | | ² AALTONEN | 11B | CDF | p p at 1.96 TeV |
| $1.635 \pm 0.011 \pm 0.011$ | | ³ ABE | 05B | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.624 \pm 0.014 \pm 0.018$ | | ⁴ ABDALLAH | 04E | DLPH | $e^+e^- \rightarrow Z$ |
| $1.636 \pm 0.058 \pm 0.025$ | | ⁵ ACOSTA | 02c | CDF | $\rho \overline{\rho}$ at 1.8 TeV |
| $1.673 \pm 0.032 \pm 0.023$ | | ⁶ AUBERT | 01F | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.648 \pm 0.049 \pm 0.035$ | | ⁷ BARATE | 00R | ALEP | $e^+e^- \rightarrow Z$ |
| $1.643 \pm 0.037 \pm 0.025$ | | ⁸ abbiendi | 99J | OPAL | $e^+e^- \rightarrow Z$ |
| $1.637 \pm 0.058 ^{+\ 0.045}_{-\ 0.043}$ | | ⁷ ABE | 98Q | CDF | $p\overline{p}$ at 1.8 TeV |
| $1.66 \pm 0.06 \pm 0.03$ | | ⁸ A C CIARRI | 98s | L3 | $e^+e^- \rightarrow Z$ |
| $1.66 \pm 0.06 \pm 0.05$ | | ⁸ ABE | ر97 | SLD | $e^+e^- \rightarrow Z$ |
| $1.58 \ ^{+ 0.21}_{- 0.18} \ ^{+ 0.04}_{- 0.03}$ | 94 | ⁵ BUSKULIC | 96J | ALEP | $e^+e^- ightarrow ~Z$ |
| $1.61 \pm 0.16 \pm 0.12$ | | ^{7,9} ABREU | 95 Q | DLPH | $e^+e^- \rightarrow Z$ |
| $1.72 \pm 0.08 \pm 0.06$ | | ¹⁰ ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| $1.52 \ \pm 0.14 \ \pm 0.09$ | | ⁷ AKERS | 95T | OPAL | $e^+ e^- \rightarrow Z$ |
| • • • We do not use | the follow | ing data for averag | es, fits | , limits, | etc. • • • |
| $1.695 \pm 0.026 \pm 0.015$ | | ⁶ ABE | 02н | BELL | Repl. by ABE 05B |
| $1.68 \pm 0.07 \pm 0.02$ | | ⁵ ABE | 98B | CDF | Repl. by ACOSTA 02c |
| $1.56 \pm 0.13 \pm 0.06$ | | ⁷ ABE | 96c | CDF | Repl. by ABE 98Q |
| $1.58 \pm 0.09 \pm 0.03$ | | ¹¹ BUSKULIC | 96J | ALEP | $e^+e^- \rightarrow Z$ |
| $1.58 \pm 0.09 \pm 0.04$ | | ⁷ BUSKULIC | 96J | ALEP | Repl. by BARATE 00R |
| 1.70 ± 0.09 | | ¹² ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| $1.61 \pm 0.16 \pm 0.05$ | 148 | ⁵ ABE | 94D | CDF | Repl. by ABE 98B |
| $1.30 \ ^{+ 0.33}_{- 0.29} \ \pm 0.16$ | 92 | ⁷ ABREU | 93D | DLPH | Sup. by ABREU 95Q |
| $1.56 \pm 0.19 \pm 0.13$ | 134 | ¹⁰ ABREU | 93G | DLPH | Sup. by ADAM 95 |
| $1.51 \begin{array}{l} +0.30 \\ -0.28 \end{array} \begin{array}{l} +0.12 \\ -0.14 \end{array}$ | 59 | ⁷ ACTON | 93 c | OPAL | Sup. by AKERS 95T |
| $1.47 \ \substack{+0.22 \\ -0.19} \ \substack{+0.15 \\ -0.14}$ | 77 | ⁷ BUSKULIC | 93D | ALEP | Sup. by BUSKULIC 96J |

- ¹ Measured mean life using fully reconstructed decays $(J/\psi K^{(*)})$.
- 2 Measured using $B^- \to \ D^0 \, \pi^-$ with $D^0 \to \ \ K^- \, \pi^+$ events that were selected using a silicon vertex trigger.
- ³ Measurement performed using a combined fit of *CP*-violation, mixing and lifetimes
- 4 Measurement performed using an inclusive reconstruction and \emph{B} flavor identification
- Measured mean life using fully reconstructed decays.
- 6 Events are selected in which one B meson is fully reconstructed while the second B meson is reconstructed inclusively.
- Oata analyzed using D / D* ℓX event vertices.
- B Data analyzed using charge of secondary vertex. 9 ABREU 95Q assumes B($B^0 \to D^{**-}\ell^+\nu_\ell$) = 3.2 \pm 1.7%.
- $^{
 m 10}\,{
 m Data}$ analyzed using vertex-charge technique to tag ${\it B}$ charge.
- ¹¹ Combined result of $D/D^*\ell X$ analysis and fully reconstructed B analysis.
- 12 Combined ABREU 95Q and ADAM 95 result.

B+ DECAY MODES

B - modes are charge conjugates of the modes below. Modes which do not identify the charge state of the B are listed in the B^\pm/B^0 ADMIXTURE

The branching fractions listed below assume 50% $B^{0}\,\overline{B}^{0}$ and 50% $B^{+}\,B^{-}$ production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, D_S, D*, and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state

For inclusive branching fractions, e.g., $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater

```
[K^{+}\pi^{-}]_{(D\pi)}\pi^{+}
                                                                                                                                                                  Γ<sub>58</sub>
                                                                                                                                                                            [K^-\pi^+]_{(D\gamma)}\pi^+
                                                                                                                                                                  \Gamma_{59}
                                                                                                                          Scale factor/
                                                                                 Fraction (\Gamma_i/\Gamma)
                                                                                                                     Confidence level
                                                                                                                                                                            [K^{+}\pi^{-}]_{(D\gamma)}\pi^{+}
                                                                                                                                                                  \Gamma_{60}
                                                                                                                                                                            [K^-\pi^+]_{(D\pi)}K^+
                                                                                                                                                                  \Gamma_{61}
                                        Semileptonic and leptonic modes
                                                                                                                                                                            [K^{+}\pi^{-}]_{(D\pi)}K^{+}
           \ell^+\,
u_\ell anything
                                                                                                                                                                  \Gamma_{62}
                                                                            [a] ( 10.99 ±0.28 ) %
               e^+\,\nu_e\,X_c
                                                                                    (10.8 \pm 0.4)\%
                                                                                                                                                                            [K^-\pi^+]_{(D\gamma)}K^+
\Gamma_2
                                                                                                                                                                  \Gamma_{63}
                D\,\ell^+\,
u_\ell anything
\Gamma_3
                                                                                        9.8 \pm 0.7 ) %
                                                                                                                                                                            [K^{+}\pi^{-}]_{(D\gamma)}K^{+}
                                                                                                                                                                 \Gamma_{64}
               \overline{D}{}^0\ell^+\nu_\ell
\Gamma_4
                                                                            [a]
                                                                                   (2.26 \pm 0.11)\%
                                                                                                                                                                             [\pi^{+}\pi^{-}\pi^{0}]_{D}K^{-}
                                                                                                                                                                 \Gamma_{65}
                                                                                                                                                                                                                                                      (4.6 \pm 0.9) \times 10^{-6}
               \overline{D}^0 \tau^+ \nu_{\tau}
\Gamma_5
                                                                                     (7.7 \pm 2.5) \times 10^{-3}
                                                                                                                                                                             \overline{D}^0 K^*(892)^+
                                                                                                                                                                                                                                                      (5.3 \pm 0.4) \times 10^{-4}
                                                                                                                                                                 \Gamma_{66}
               \overline{D}^*(2007)^0 \ell^+ \nu_{\ell}
\Gamma_6
                                                                                   ( 5.70 \pm 0.19 ) %
                                                                                                                                                                                  D_{CP(-1)}K^*(892)^+
                                                                                                                                                                  \Gamma_{67}
                                                                                                                                                                                                                                             [b] (2.7 \pm 0.8) \times 10^{-4}
                \overline{D}^*(2007)^0 \tau^+ \nu_{\tau}
\Gamma_7
                                                                                    (2.04 \pm 0.30)\%
                                                                                                                                                                             \frac{D_{CP(+1)}}{\overline{D}^0 \, K^+ \, \overline{K}^0} K^*(892)^+
                                                                                                                                                                  \Gamma_{68}
                                                                                                                                                                                                                                             [b] (5.8 \pm 1.1) \times 10^{-4}
                D^-\pi^+\ell^+\nu_\ell
                                                                                     ( 4.2 \pm 0.5 ) \times 10^{-3}
Γ8
                    \overline{D}_0^*(2420)^0\ell^+\nu_\ell \times
                                                                                     (\phantom{-}2.5\phantom{0}\pm0.5\phantom{0})\times10^{-3}
                                                                                                                                                                  \Gamma_{69}
                                                                                                                                                                                                                                                          5.5 \pm 1.6 \times 10^{-4}
                                                                                                                                                                             \overline{D}^0 K^+ \overline{K}^* (892)^0
                                                                                                                                                                                                                                                       (7.5 \pm 1.7) \times 10^{-4}
                                                                                                                                                                  Γ<sub>70</sub>
                           B(\overline{D}_0^{*0} \rightarrow D^-\pi^+)
                                                                                                                                                                             \frac{1}{D^0}\pi^+\pi^+\pi^-
                                                                                                                                                                                                                                                          5.7 \pm 2.2 ) \times 10^{-3}
                                                                                                                                                                 \Gamma_{71}
                                                                                                                                                                                                                                                                                                       S = 3.6
                    \overline{D}_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}\times
                                                                                    (1.53 \pm 0.16) \times 10^{-3}
\Gamma_{10}
                                                                                                                                                                                 \frac{\overline{D}{}^0\pi^+\pi^+\pi^- \text{ nonresonant}}{\overline{D}{}^0\pi^+\rho^0}
                                                                                                                                                                  \Gamma_{72}
                                                                                                                                                                                                                                                                                   \times 10^{-3}
                           B(\overline{D}_2^{*0} \rightarrow D^-\pi^+)
                                                                                                                                                                                                                                                       ( 4.2~\pm 3.0~)\times 10^{-3}
                                                                                                                                                                  \Gamma_{73}
                D^{(*)} \, \mathsf{n} \, \pi \, \ell^{+} \, \overline{\nu_{\ell}} \, (\mathsf{n} \geq 1)
\Gamma_{11}
                                                                                     ( 1.87\ \pm0.26 ) %
                                                                                                                                                                                     \overline{D}{}^0 \, \dot{a_1} (1260)^+
                                                                                                                                                                                                                                                       (4 \pm 4) \times 10^{-3}
                                                                                                                                                                  \Gamma_{74}
                    D^{*-}\pi^+\ell^+\nu_\ell
                                                                                    (\phantom{-}6.1\phantom{0}\pm0.6\phantom{0})\times10^{-3}
\Gamma_{12}
                                                                                                                                                                             \overline{D}{}^0\omega\pi^+
                                                                                                                                                                  \Gamma_{75}
                                                                                                                                                                                                                                                       (4.1 \pm 0.9) \times 10^{-3}
           D_s^{*-}\,K^+\,\ell^+\,\nu_\ell
                                                                                    (6.1 \pm 1.2) \times 10^{-4}
\Gamma_{13}
                                                                                                                                                                                                                                                      ( 1.35 \pm 0.22 ) \times 10^{-3}
                                                                                                                                                                                  D^*(2010)^-\pi^+\pi^+
                                                                                                                                                                  Γ<sub>76</sub>
                    \overline{D}_1(2420)^0 \ell^+ \nu_{\ell} \times \mathsf{B}(\overline{D}_1^0 \to
                                                                                    (3.03 \pm 0.20) \times 10^{-3}
                                                                                                                                                                                      \overline{D}_1(2420)^0 \pi^+ \times B(\overline{D}_1^0 \rightarrow
\Gamma_{14}
                                                                                                                                                                                                                                                      (\phantom{-}5.3\phantom{0}\pm2.3\phantom{0})\times10^{-4\phantom{0}}
                                                                                                                                                                 \Gamma_{77}
                           D^{*-}\pi^{+})
                                                                                                                                                                                            D^*(2010)^-\pi^+)
                     \overline{D}'_1(2430)^0 \acute{\ell}^+ \nu_\ell \times \mathsf{B}(\overline{D}'^0_1) \rightarrow
\Gamma_{15}
                                                                                    (2.7 \pm 0.6) \times 10^{-3}
                                                                                                                                                                             D^-\,\pi^+\,\pi^+
                                                                                                                                                                                                                                                     ( 1.07 \pm 0.05 ) \times 10^{-3}
                                                                                                                                                                  Γ<sub>78</sub>
                                                                                                                                                                             D^+ K^0
                           D^{*-}\pi^{+})
                                                                                                                                                                                                                                                                                \times 10^{-6} CL=90%
                                                                                                                                                                  \Gamma_{79}
                                                                                                                                                                                                                                                    < 2.9
                    \overline{D}_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}\times
                                                                                    ( 1.01 \pm 0.24 ) \times 10^{-3}
                                                                                                                                                                            D^{+} K^{*0}
                                                                                                                                                                                                                                                                                   \times 10^{-6} CL=90%
\Gamma_{16}
                                                                                                                                                                 \Gamma_{80}
                                                                                                                                                                                                                                                    < 3.0
                                                                                                                                     S = 2.0
                                                                                                                                                                            \overline{D}^*(2007)^0 \pi^+
                                                                                                                                                                                                                                                      ( 5.18 \pm 0.26 ) \times 10^{-3}
                          B(\overline{D}_2^{*0} \rightarrow D^{*-}\pi^+)
                                                                                                                                                                  \Gamma_{81}
                \pi^0\,\ell^+\,\nu_\ell
                                                                                                                                                                  \Gamma_{82}
                                                                                                                                                                                 \overline{D}_{CP(+1)}^{*0} \pi^{+}
                                                                                                                                                                                                                                             [d] (2.9 \pm 0.7) \times 10^{-3}
\Gamma_{17}
                                                                                     (7.78 \pm 0.28) \times 10^{-5}
                   \pi^0 e^+ \nu_e
                                                                                                                                                                                  D_{CP(-1)}^{*0}\pi^{+}
\Gamma_{18}
                                                                                                                                                                  \Gamma_{83}
                                                                                                                                                                                                                                             [d] (2.6 \pm 1.0) \times 10^{-3}
                \eta \ell^+ \nu_{\ell}
                                                                                     (\phantom{-}3.9\phantom{0}\pm0.8\phantom{0})\times10^{-5}
\Gamma_{19}
                                                                                                                                     S = 1.3
                                                                                                                                                                             \overline{D}^*(2007)^{0}\omega\pi^+
                                                                                                                                                                  Γ<sub>84</sub>
                                                                                                                                                                                                                                                      (4.5 \pm 1.2) \times 10^{-3}
                                                                                        2.3 \pm 0.8 \times 10^{-5}
                \eta' \ell^+ \nu_{\ell}
                                                                                                                                                                             \overline{D}^*(2007)^0 \rho^+
\Gamma_{20}
                                                                                                                                                                  \Gamma_{85}
                                                                                                                                                                                                                                                      (9.8 \pm 1.7) \times 10^{-3}
\Gamma_{21}
               \omega \ell^+ \nu_\ell
                                                                                   (1.15 \pm 0.17) \times 10^{-4}
                                                                                                                                                                             \overline{D}^*(2007)^0 K^+
                                                                                                                                                                                                                                                      ( 4.20 \pm 0.34 ) \times 10^{-4}
               \omega\,\mu^+\,\nu_\mu
                                                                                                                                                                                 \overline{D}_{CP(+1)}^{*0}K^+
                                                                                                                                                                                                                                             [d] (2.8 \pm 0.4) \times 10^{-4}
                                                                                                                                                                  Γ<sub>87</sub>

ho^0 \ell^+ \dot{\nu_\ell}
\Gamma_{23}
                                                                            [a] (1.07 \pm 0.13) \times 10^{-4}
                                                                                                                                                                 \Gamma_{88}
                                                                                                                                                                                 \overline{D}_{CP(-1)}^{*0}K^+
                                                                                                                                                                                                                                             [d] (2.31 \pm 0.33) \times 10^{-4}
                p\overline{p}e^+\nu_e
                                                                                                                \times 10^{-3} CL=90%
\Gamma_{24}
                                                                                 < 5.2
                                                                                                                 \times\,10^{-7} CL=90%
                                                                                                                                                                 \Gamma_{89}
                                                                                                                                                                             \overline{D}^*(2007)^{0}K^*(892)^{+}
                                                                                                                                                                                                                                                     (8.1 \pm 1.4) \times 10^{-4}
\Gamma_{25}
                e^+ \nu_e
                                                                                  < 9.8
                                                                                                                                                                             \overline{D}^*(2007)^0 K^+ \overline{K}^0
               \mu^+ \nu_\mu
                                                                                                                                                                                                                                                                                   \times 10^{-3} CL=90%
\Gamma_{26}
                                                                                                                 \times 10^{-6} CL=90%
                                                                                                                                                                                                                                                    < 1.06
                                                                                  < 1.0
                                                                                                                                                                  \Gamma_{90}
                                                                                                                                                                             \overline{D}^*(2007)^0 K^+ K^*(892)^0
                \tau^+\,\nu_\tau
                                                                                                                                                                  \Gamma_{91}
                                                                                                                                                                                                                                                     (1.5 \pm 0.4) \times 10^{-3}
                                                                                   ( 1.65 \pm 0.34 ) \times 10^{-4}
\Gamma_{27}
                                                                                                                                                                            \overline{D}^*(2007)^0\pi^+\pi^+\pi^-
                                                                                                                                                                                                                                                     (1.03 \pm 0.12)\%
                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                                  \Gamma_{92}
\Gamma_{28}
                \ell^+ \nu_\ell \gamma
                                                                                  < 1.56
                                                                                                                                                                                 \stackrel{\smile}{D}*(2007)^0 a_1(1260)^+
                  e^+ \nu_e \gamma
                                                                                  < 1.7
                                                                                                                \times 10^{-5} CL=90%
                                                                                                                                                                  \Gamma_{93}
                                                                                                                                                                                                                                                     (1.9 \pm 0.5)\%
\Gamma_{29}
                                                                                                                                                                             \overline{D}^*(2007)^0\pi^-\pi^+\pi^+\pi^0
                                                                                                                \times 10^{-5} CL=90%
                                                                                                                                                                  \Gamma_{94}
                                                                                                                                                                                                                                                     (1.8 \pm 0.4)\%
                   \mu^+ \nu_\mu \gamma
                                                                                         2.4
\Gamma_{30}
                                                                                                                                                                             \frac{1}{D}*0 3\pi^{+}2\pi^{-}
                                                                                                                                                                                                                                                     (5.7 \pm 1.2) \times 10^{-3}
                                                         Inclusive modes
                                                                                                                                                                            D^*(2010)^+\pi^0
                                                                                                                                                                                                                                                                                   \times 10^{-6}
                                                                                                                                                                                                                                                    < 3.6
                                                                                                                                                                  \Gamma_{96}
           D^0X
Γ<sub>31</sub>
                                                                                         8.6 \pm 0.7 ) %
                                                                                                                                                                            D^*(2010)^+ K^0
                                                                                                                                                                  \Gamma_{97}
                                                                                                                                                                                                                                                    < 9.0
                                                                                                                                                                                                                                                                                   \times\,10^{-6} CL=90%
           \overline{D}^0 X
\Gamma_{32}
                                                                                     (79 ±4 )%
                                                                                                                                                                            D^*(2010)^-\pi^+\pi^+\pi^0
                                                                                                                                                                                                                                                     (1.5 \pm 0.7)\%
\Gamma_{33}
          D^+ X
                                                                                     (2.5 \pm 0.5)\%
                                                                                                                                                                  Γ99
                                                                                                                                                                            D^*(2010)^-\pi^+\pi^+\pi^+\pi^-
                                                                                                                                                                                                                                                      ( 2.6
                                                                                                                                                                                                                                                                   \pm 0.4 ) \times 10^{-3}
                                                                                                                                                                 \Gamma_{100} = \frac{D}{D}^{**0} \pi^{+}
           D^-X
\Gamma_{34}
                                                                                         9.9 \pm 1.2 ) %
                                                                                                                                                                                                                                              [e] ( 5.9 \pm 1.3 ) \times 10^{-3}
          D_s^+ X
                                                                                                                                                                  \Gamma_{101}^{-3.3} \ \overline{D}_1^* (2420)^0 \, \pi^+
\Gamma_{35}
                                                                                     (7.9 \begin{array}{c} +1.4 \\ -1.3 \end{array})\%
                                                                                                                                                                                                                                                       (\phantom{-}1.5\phantom{0}\pm0.6\phantom{0})\times10^{-3}
                                                                                                                                                                                                                                                                                                       S = 1.3
                                                                                                                                                                  \Gamma_{102} \ \overline{D}_1(2420)^0 \pi^+ \times \ \mathsf{B}(\overline{D}_1^0 \to
                                                                                     (\quad 1.10 \  \, ^{+\; 0.40}_{-\; 0.32} \ ) \ \%
                                                                                                                                                                                                                                                       (2.5 \quad \begin{array}{c} +1.7 \\ -1.4 \end{array}) \times 10^{-4}
\Gamma_{36}
           D_s^- X
                                                                                                                                                                                                                                                                                                       S = 4.0
                                                                                                                                                                                   \overline{D}^0 \pi^+ \pi^-
\Gamma_{37}
           \Lambda_c^+ X
                                                                                                                                                                                 \overline{D}_1(2420)^0 \pi^+ \times \mathsf{B}(\overline{D}_1^0 \to
                                                                                                                                                                                                                                                       (2.3 \pm 1.0) \times 10^{-4}
                                                                                                                                                                                        \overline{D}{}^0\pi^+\pi^- (nonresonant))
          \overline{\Lambda}_{c}^{-}X
                                                                                     (2.8 + 1.1 \\ -0.9) %
\Gamma_{38}
                                                                                                                                                                  \Gamma_{104} \ \overline{D}_{2}^{*}(2462)^{0} \pi^{+}
                                                                                                                                                                                                                                                       (3.5 \pm 0.4) \times 10^{-4}
          \overline{c}X
\Gamma_{39}
                                                                                     (97
                                                                                                ±4 )%
                                                                                                                                                                                 \times B(\overline{D}_2^*(2462)^0 \rightarrow D^-\pi^+)
          c X
                                                                                     (23.4 \begin{array}{c} +2.2 \\ -1.8 \end{array}) \%
\Gamma_{40}
                                                                                                                                                                  \Gamma_{105} \ \overline{D}_2^*(2462)^{\overline{0}} \, \pi^+ \times B(\overline{D}_2^{*0} \, \rightarrow \,
                                                                                                                                                                                                                                                       (\phantom{-}2.3\phantom{0}\pm1.1\phantom{0})\times10^{-4\phantom{0}}
\Gamma_{41}
          \overline{c} c X
                                                                                     (120
                                                                                                ±6 )%
                                                                                                                                                                                    D^0 \pi^- \pi^+
                                                                                                                                                                                 \overline{D}_2^*(2462)^{0}\pi^+ \times B(\overline{D}_2^{*0} \rightarrow
                                                                                                                                                                                                                                                                                   \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                                     < 1.7
                                                                                                                                                                  \Gamma_{106}
                                                     D, D^*, or D_s modes
                                                                                                                                                                                        \overline{D}{}^0\pi^-\pi^+ (nonresonant))
          \overline{D}^0 \pi^+
                                                                                    (4.81 \pm 0.15) \times 10^{-3}
\Gamma_{42}
                                                                                                                                                                  \Gamma_{107} \ \overline{D}_2^*(2462)^0 \pi^+ \times \dot{B}(\overline{D}_2^{*0} \rightarrow
                                                                                                                                                                                                                                                       (2.2 \pm 1.1) \times 10^{-4}
                                                                            [b] (2.5 \pm 0.4) \times 10^{-3}
               D_{CP(+1)} \pi^{+}
\Gamma_{43}
                                                                                                                                                                                    D^*(2010)^-\pi^+)
\Gamma_{44}
                D_{CP(-1)} \pi^{+}
                                                                            [b] (2.0 \pm 0.4) \times 10^{-3}
                                                                                                                                                                  \Gamma_{108} \ \overline{D}_0^* (2400)^0 \pi^+
                                                                                                                                                                                                                                                       (6.4 \pm 1.4) \times 10^{-4}
           \frac{\overline{D}{}^0 \rho^+}{\overline{D}{}^0 K^+}
\Gamma_{45}
                                                                                     ( 1.34 \pm 0.18)%
                                                                                                                                                                  \Gamma_{109} \  \  \, \overset{\overset{\smile}{\nearrow}}{\overline{D}_{1}} (2421)^{0} \, \xrightarrow{\pi^{+}} \  \, D^{-} \, \pi^{+})
\Gamma_{46}
                                                                                     ( \quad 3.65 \ \pm 0.33 \ ) \times 10^{-4}
                                                                                                                                                                                                                                                       (6.8 \pm 1.5) \times 10^{-4}
               D_{CP(+1)} K^+
                                                                            [b] ( 2.18 \pm 0.26) \times 10^{-4}
\Gamma_{47}
                                                                                                                                                                                  \times B(\overline{D}_{1}(2421)^{0} \rightarrow D^{*-}\pi^{+})
                                                                            [b] (1.97 \pm 0.24) \times 10^{-4}
\Gamma_{48}
                D_{CP(-1)}K^{+}
                                                                                                                                                                  \Gamma_{110} \ \overline{D}_2^* (2462)^{0} \pi^+
                                                                                                                                                                                                                                                       (1.8 \pm 0.5) \times 10^{-4}
           [K^{-}\pi^{+}]_{D}K^{+} 
 [K^{+}\pi^{-}]_{D}K^{+} 
 [K^{-}\pi^{+}\pi^{0}]_{D}K^{+} 
                                                                                                        \times 10^{-7} CL=90%
\Gamma_{49}
                                                                            [c] < 2.8
                                                                                                                                                                 \begin{array}{ccc} & \stackrel{\cdot}{\times} & B(\stackrel{\prime}{\overline{D}}_{2}^{*}(2462)^{0} \rightarrow & D^{*-}\pi^{+}) \\ \Gamma_{111} & \overline{D}_{1}^{*}(2427)^{0}\pi^{+} \end{array}
                                                                                                                \times 10^{-5} CL=90%
\Gamma_{50}
                                                                            [c] < 1.8
                                                                                                                                                                                                                                                       (5.0 \pm 1.2) \times 10^{-4}
\Gamma_{51}
                                                                                                                                                                  [K^{+}\pi^{-}\pi^{0}]_{D}^{-}K^{+}
            [K^-\pi^+]_D K^*(892)^+
                                                                                                                                                                                                                                                                                   \times 10^{-6} CL=90%
\Gamma_{53}
                                                                            [c]
\Gamma_{54}
           [K^{+}\pi^{-}]_{D}K^{*}(892)^{+}
                                                                                                                                                                                    \overline{D}^{*0}\pi^+\pi^-
                                                                            [c]
           \begin{bmatrix} K & \pi & D & K \\ [K - \pi^+]_D & \pi^+ \\ [K + \pi^-]_D & \pi^+ \\ [K - \pi^+]_{(D \pi)} & \pi^+ \end{bmatrix} 
                                                                                                                                                                  \Gamma_{113} \ \overline{D}_1^* (2420)^0 \rho^+
                                                                                   (6.3 \pm 1.1) \times 10^{-7}
                                                                                                                                                                                                                                                                                   \times 10^{-3} CL=90%
                                                                                                                                                                                                                                                    < 1.4
                                                                                    (2.0 \pm 0.4) \times 10^{-4}
                                                                                                                                                                  \Gamma_{114} \ \overline{D}_{2}^{*}(2460)^{0} \pi^{+}
                                                                                                                                                                                                                                                                                   \times 10^{-3} CL=90%
\Gamma_{56}
                                                                                                                                                                                                                                                    < 1.3
```

 B^{\pm}

```
\begin{array}{ccc} \Gamma_{163} & D_s^{*+} \, \rho^0 \\ \Gamma_{164} & D_s^+ \, \omega \end{array}
\Gamma_{115} \ \overline{D}_2^* \underline{(2460)^0} \, \pi^+ \times \mathsf{B}(\overline{D}_2^{*0} \to
                                                                                                               \times\,10^{-5}\quad\text{CL}\!=\!90\%
                                                                                 < 2.2
                                                                                                                                                                                                                                                                             \times 10^{-4} CL=90%
                                                                                                                                                                                                                                               < 4
                 \overline{D}^{*0}\pi^+\pi^-)
                                                                                                                                                                                                                                                                              ×10<sup>-4</sup> CL=90%
                                                                                                                                                                                                                                               <
                                                                                                                                                                                                                                                    4
                                                                                                                                                              \Gamma_{165} D_s^{*+} \omega
\Gamma_{116} \ \overline{D}_2^*(2460)^0 \, \rho^+
                                                                                                              \times 10^{-3} CL=90%
                                                                                                                                                                                                                                                                              \times 10^{-4} CL=90%
                                                                                 < 4.7
                                                                                                                                                                                                                                               < 6
\Gamma_{117} \overline{D}^{\circ} D^{+}_{\circ}
                                                                                                                                                              \Gamma_{166} \quad D_s^+ a_1(1260)^0
                                                                                   ( 10.0 \pm 1.7 ) \times 10^{-3}
                                                                                                                                                                                                                                                                              \times 10^{-3} CL=90%
                                                                                                                                                                                                                                               < 1.8
                                                                                                                                                               \Gamma_{167} D_s^{*+} a_1 (1260)^0
                                                                                                                                                                                                                                                                              \times 10^{-3} CL=90%
\Gamma_{118} \ D_{s0}(2317)^{+} \overline{D}{}^{0} \times
                                                                                   \begin{pmatrix} 7.3 & +2.2 \\ -1.7 & \end{pmatrix} \times 10^{-4}
                                                                                                                                                                                                                                               < 1.3
                                                                                                                                                              \Gamma_{168} D_s^+\phi
                                                                                                                                                                                                                                                                              \times 10^{-6} CL=90%
                 B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)
                                                                                                                                                                                                                                              < 1.9

\Gamma_{169} \quad D_{5}^{s} + \phi \\
\Gamma_{170} \quad D_{5}^{s} + \overline{K}^{0} \\
\Gamma_{171} \quad D_{5}^{s} + \overline{K}^{0} \\
\Gamma_{172} \quad D_{5}^{s} + \overline{K}^{s} (892)^{0}

\Gamma_{119} D_{s0}(2317)^{+} \overline{D}^{0} \times
                                                                                                               \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                              < 1.2
                                                                                                                                                                                                                                                                             \times\,10^{-5} CL=90%
\mathsf{B}(D_{s0}(2317)^+ \to D_s^{*+}\gamma)

\Gamma_{120} \ D_{s0}(2317)^+ \overline{D}^*(2007)^0 \times
                                                                                                                                                                                                                                              < 8
                                                                                                                                                                                                                                                                             \times 10^{-4} CL=90%
                                                                                                                                                                                                                                              < 9
                                                                                                                                                                                                                                                                             \times 10^{-4} CL=90%
                                                                                   (9
                                                                                               \pm 7 ) × 10<sup>-4</sup>
                  B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)
                                                                                                                                                                                                                                                                             \times\,10^{\textstyle -4}\quad \text{CL}\!=\!90\%
                                                                                                                                                                                                                                              < 4
                                                                                                                                                              \Gamma_{173} D_s^{*+} \overline{K}^* (892)^0
                                                                                                                                                                                                                                              < 3.5
                                                                                                                                                                                                                                                                             \times\,10^{-4} CL=90%
\Gamma_{121} \quad D_{sJ}(2457)^+\, \overline{D}{}^0
                                                                                   (\quad 3.1 \quad {}^{+\ 1.0}_{-\ 0.9} \quad )\times 10^{-3}
                                                                                                                                                              \Gamma_{174} D_s^- \pi^+ K^+
                                                                                                                                                                                                                                              (1.80 \pm 0.22) \times 10^{-4}
                                                                                   (\phantom{-}4.6\phantom{0}^{\phantom{0}+1.3}_{\phantom{0}-1.1}\phantom{0})\times10^{-4}
\Gamma_{122} D_{s,I}(2457)^{+} \overline{D}{}^{0} \times
                                                                                                                                                              \Gamma_{175} D_s^{*-} \pi^+ K^+
                                                                                                                                                                                                                                               (1.45 \pm 0.24) \times 10^{-4}
                  B(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)
                                                                                                                                                              \Gamma_{176} \ D_s^{-} \pi^+ K^*(892)^+
                                                                                                                                                                                                                                                                             \times 10^{-3} CL=90%
                                                                                                                                                                                                                                              < 5
\Gamma_{123} D_{sJ}(2457)^+ \overline{D}^0 \times
                                                                                                               \times 10^{-4} CL=90%
                                                                                                                                                              \Gamma_{177} \quad D_s^{*-} \pi^+ K^*(892)^+
\Gamma_{178} \quad D_s^{-} K^+ K^+
\Gamma_{179} \quad D_s^{*-} K^+ K^+
                                                                                 < 2.2
                                                                                                                                                                                                                                                                             \times\,10^{-3}\text{ CL}\!=\!90\%
                                                                                                                                                                                                                                               < 7
                 \mathsf{B}(D_{sJ}(2457)^+ 	o
                                                                                                                                                                                                                                                (1.1 \pm 0.4) \times 10^{-5}
                  D_s^+ \pi^+ \pi^-)
                                                                                                                                                                                                                                                                             \times 10^{-5} CL=90%
\Gamma_{124} D_{sJ}(2457)^{+} \overline{D}^{0} \times
                                                                                                               \times\,10^{-4} CL=90%
                                                                                 < 2.7
                  B(D_{sJ}(2457)^+ \to D_s^+ \pi^0)
                                                                                                                                                                                                                  Charmonium modes
                                                                                                                                                              \Gamma_{180} \eta_c\,K^+
                                                                                                                                                                                                                                                 (9.6 \pm 1.2) \times 10^{-4}
\Gamma_{125} D_{sJ}(2457)^+ \overline{D}{}^0 \times
                                                                                                               \times 10^{-4} CL=90%
                                                                                 < 9.8
                                                                                                                                                              \Gamma_{181} \eta_c \, K^+ , \eta_c 
ightarrow \, K^0_S \, K^\mp \, \pi^\pm
                                                                                                                                                                                                                                                 (\phantom{-}2.7\phantom{0}\pm0.6\phantom{0})\times10^{-5}
                 B(D_{sJ}(2457)^+ \to D_s^{*+} \gamma)
                                                                                                                                                              \Gamma_{182} \eta_c K^*(892)^+
\Gamma_{126} \ D_{sJ}(2457)^{+} \overline{D}^{*}(2007)^{0}
                                                                                                                                                                                                                                                 (1.1 \quad ^{+\ 0.5}_{-\ 0.4} \quad ) \times 10^{-3}
                                                                                   (1.20 \pm 0.30)\%
                                                                                                                                                              \Gamma_{183} \ \eta_c(2S)\,K^+
\Gamma_{127} \ D_{sJ}(2457)^+ \overline{D}{}^*(2007)^0 \times
                                                                                                                                                                                                                                                 ( 3.4~\pm 1.8~)\times 10^{-4}
                                                                                   (1.4 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \times 10^{-3}
                                                                                                                                                                                                                                                 (\quad 3.4 \quad {}^{+\, 2.3}_{-\, 1.6} \quad )\times 10^{-6}
                  B(D_{sJ}(2457)^+ \rightarrow D_s^+ \gamma)
                                                                                                                                                              \Gamma_{184} \qquad \eta_c(2S)\,K^+ , \eta_c(2S) 
ightarrow
                                                                                                                                                                                    K_s^0 K^{\mp} \pi^{\pm}
\Gamma_{128} \ \overline{D}{}^0 D_{s1}(2536)^+ \times
                                                                                    (\phantom{-}4.0\phantom{0}\pm1.0\phantom{0})\times10^{-4\phantom{0}}
                  B(D_{s1}(2536)^{+} \rightarrow
                                                                                                                                                              \Gamma_{185} J/\psi(1S)K^+
                                                                                                                                                                                                                                                 (1.016 \pm 0.033) \times 10^{-3}
                  D^*(2007)^0 K^+ +
                                                                                                                                                              \Gamma_{186} J/\psi(1S) K^+ \pi^+ \pi^-
                                                                                                                                                                                                                                                (8.1 \pm 1.3) \times 10^{-4}
                  D^*(2010)^+ K^0
                                                                                                                                                              \Gamma_{187} h_c(1P)K^+ \times B(h_c(1P) \rightarrow
                                                                                                                                                                                                                                                                             \times 10^{-6} CL=90%
                                                                                                                                                                                                                                               < 3.4
                                                                                                                                                                                J/\dot{\psi}\pi^+\pi^-)
               \overline{D}{}^{0}D_{s1}(2536)^{+} \times
                                                                                   (2.2 \pm 0.7) \times 10^{-4}
\Gamma_{129}
                      B(D_{s1}(2536)^{+} \rightarrow
                                                                                                                                                               \Gamma_{188} X (3872) K^{+}
                                                                                                                                                                                                                                                                             \times 10^{-4} CL=90%
                                                                                                                                                                                                                                               < 3.2
D^*(2007)^0 K^+)

\Gamma_{130} \overline{D}^*(2007)^0 D_{s1}(2536)^+ \times
                                                                                                                                                              \Gamma_{189} X(3872)K^+ \times B(X \rightarrow
                                                                                                                                                                                                                                                 (\phantom{-}8.6\phantom{0}\pm0.8\phantom{0})\times10^{-6\phantom{0}}
                                                                                                                                                              J/\psi \pi^+ \pi^-)

\Gamma_{190} X (3872) K^+ \times B(X \rightarrow J/\psi \gamma)
                                                                                   (\phantom{-}5.5\phantom{0}\pm1.6\phantom{0})\times10^{-4\phantom{0}}
                  B(D_{s1}(2536)^{+} \rightarrow
                                                                                                                                                                                                                                                (2.1 \pm 0.4) \times 10^{-6} S=1.1
                  D^*(2007)^0 K^+
                                                                                                                                                                                                                                                                              \times\,10^{-6} CL=90%
                                                                                                                                                               \Gamma_{191} X(3872) K^*(892)^+ \times B(X \rightarrow
                                                                                                                                                                                                                                               < 4.8
\Gamma_{131} \ \overline{D}{}^0 D_{s1}(2536)^+ \times
                                                                                   (2.3 \pm 1.1) \times 10^{-4}
                  B(D_{s1}(2536)^+ \rightarrow D^{*+} K^0)
                                                                                                                                                              \Gamma_{192} X(3872) \overset{\frown}{K}^{+} \times B(X \rightarrow \psi(2S) \gamma)
                                                                                                                                                                                                                                                (4 \pm 4) \times 10^{-6} S=2.5
                                                                                                                                                              \Gamma_{193} X(3872) K^*(892)^+ \times B(X \to X)
\Gamma_{132} \ \overline{D}{}^{0} D_{sJ}(2700)^{+} \times B(D_{sJ}(2700)^{+} \to D^{0} K^{+})
                                                                                                                                                                                                                                                                             \times\,10^{-5}\text{ CL}\!=\!90\%
                                                                                                                                                                                                                                               < 2.8
                                                                                   (1.13 \begin{array}{c} +0.26 \\ -0.40 \end{array}) \times 10^{-3}
                                                                                                                                                              \psi(2S)\gamma)
\Gamma_{194} \quad X(3872)K^{+} \times B(X \rightarrow D^{0}\overline{D}^{0})
\Gamma_{133} \overline{D}^{*0} \overline{D}_{s1}^{-(2536)^{+}} \times \\ \underline{D}_{s1}^{B} (2536)^{+} \rightarrow D^{*+} K^{0})
                                                                                                                                                                                                                                                                             \times\,10^{-5} CL=90%
                                                                                                                                                                                                                                               < 6.0
                                                                                   (3.9 \pm 2.6) \times 10^{-4}
                                                                                                                                                              \Gamma_{195} X(3872)K^{+} \times B(X \rightarrow D^{+}D^{-})
                                                                                                                                                                                                                                                                             \times\,10^{-5}\text{ CL}\!=\!90\%
                                                                                                                                                                                                                                                < 4.0
                                                                                                                                                              \Gamma_{196} \quad X (3872) K^+ \times B(X \rightarrow D^0 \overline{D^0} \pi^0)
                                                                                                                                                                                                                                                 (1.0 \pm 0.4) \times 10^{-4}
\Gamma_{134} \ \overline{D}^{*0} D_{sJ}(2573)^{+} \times
                                                                                                              \times 10^{-4} CL=90%
B(D_{sJ}(2573)^+ \to D^0 K^+)

\Gamma_{135} \overline{D}^*(2007)^0 D_{sJ}(2573)^+ \times
                                                                                                                                                              \begin{array}{ccc} \Gamma_{197} & X(3872) \overset{\cdots}{K^{+}} \times & B(X \to \overline{D}^{*0} D^{0}) \\ \Gamma_{198} & X(3872) \, K^{+} \end{array}
                                                                                                                                                                                                                                                 (8.5 \pm 2.6) \times 10^{-5} S=1.4
                                                                                                               \times 10^{-4} CL=90%
                                                                                 < 5
                                                                                                                                                                                                                                                                             \times\,10^{-6} CL=90%
                  B(D_{sJ}(2573)^+ \rightarrow D^0 K^+)
                                                                                                                                                                                                                                               < 7.7
                                                                                                                                                                              \times B(X(3872) \rightarrow J/\psi(1S)\eta)
\Gamma_{136} \overline{D}^0 D_s^{*+}
                                                                                   (7.6 \pm 1.6) \times 10^{-3}
                                                                                                                                                               \Gamma_{199} X(3872)^{+} K^{0} \times B(X(3872)^{+} \rightarrow
                                                                                                                                                                                                                                                                              \times\,10^{-6} CL=90%
                                                                                                                                                                                                                                        [f] < 6.1
\Gamma_{137} \ \overline{D}^*(2007)^0 D_s^+
                                                                                   (8.2 \pm 1.7) \times 10^{-3}
                                                                                                                                                              J/\psi(1S)\pi^{+}\pi^{0})

\Gamma_{200} X(4430)^{+}K^{0} \times B(X^{+} \rightarrow
\Gamma_{138} \ \overline{D}^*(2007)^0 D_5^{*+}
                                                                                   (1.71 \pm 0.24)\%
                                                                                                                                                                                                                                                                              \times\,10^{-5} CL=95%
\Gamma_{139} D_s^{(*)} + \overline{D}_{**0}
                                                                                                                                                                                                                                               < 1.5
                                                                                  (2.7 \pm 1.2)\%
                                                                                                                                                                                J/\psi \pi^+)
          \overline{D}_{*}^{s}(2007)^{0}D_{*}^{*}(2010)^{+}
                                                                                                                                                               \Gamma_{201} X(4430)^{+} K^{0} \times B(X^{+} \rightarrow
                                                                                  (8.1 \pm 1.7) \times 10^{-4}
\Gamma_{140}
                                                                                                                                                                                                                                               < 4.7
                                                                                                                                                                                                                                                                             \times\,10^{-5} CL=95%
\Gamma_{141} \ \overline{D}{}^{0} D^{*}(2010)^{+} +
                                                                                 < 1.30
                                                                                                                              CL=90%
                                                                                                                                                                               \psi(2S)\pi^{+})
\overline{D}^*(2007)^0 D^+
\Gamma_{142} \ \overline{\underline{D}}^0 D^*(2010)^+
                                                                                                                                                               \Gamma_{202} \ X(4260)^{0} \ K^{+} \times B(X^{0} \rightarrow
                                                                                                                                                                                                                                                                              \times\,10^{-5} CL=95%
                                                                                                                                                                                                                                               < 2.9
                                                                                                                                                                                J/\psi \pi^+ \pi^-)
                                                                                  (3.9 \pm 0.5) \times 10^{-4}
\Gamma_{143} \overline{D}{}^{0} \overline{D}^{+}
                                                                                                                                                               \Gamma_{203} \ X (3915)^{0} \ K^{+} \times \ B(X^{0} \rightarrow
                                                                                  (3.8 \pm 0.4) \times 10^{-4}
                                                                                                                                                                                                                                                                             \times\,10^{-5}\quad\text{CL}\!=\!90\%
                                                                                                                                                                                                                                               < 1.4
\Gamma_{144} \ \overline{D}{}^{0} \, \overline{D}{}^{+} \, K^{0}
                                                                                  ( 1.55 \pm 0.21 ) \times 10^{-3}
 \Gamma_{145} D^{+} \overline{D}^{*} (2007)^{0}
                                                                                                                                                              \Gamma_{204} \ Z(3930)^{0} K^{+} \times B(Z^{0} \rightarrow J/\psi \gamma)
                                                                                  (6.3 \pm 1.7) \times 10^{-4}
                                                                                                                                                                                                                                               < 2.5
                                                                                                                                                                                                                                                                             \times 10^{-6} CL=90%
\Gamma_{146} \ \overline{D}^* (2007)^0 \ D^+ K^0
                                                                                   (2.1 \pm 0.5) \times 10^{-3}
                                                                                                                                                              \Gamma_{205} J/\psi(1S) K^*(892)^+
                                                                                                                                                                                                                                                ( 1.43~\pm 0.08 ) \times\,10^{-3}
\Gamma_{147} \ \overline{D}{}^{0} \overline{D}{}^{*} (2010)^{+} K^{0}
                                                                                   (\phantom{-}3.8\phantom{0}\pm0.4\phantom{0})\times10^{-3}
                                                                                                                                                                                                                                                (\phantom{-}1.8\phantom{0}\pm0.5\phantom{0})\times10^{-3}
                                                                                                                                                               \Gamma_{206} J/\psi(1S) K(1270)^+
\Gamma_{148} \ \overline{D}^*(2007)^0 \ D^*(2010)^+ \ K^0
                                                                                                                                                              \Gamma_{207} J/\psi(1S) K(1400)^+
                                                                                  (9.2 \pm 1.2) \times 10^{-3}
                                                                                                                                                                                                                                                                             \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                               < 5
\Gamma_{149} \overline{D}^0 D^{\overline{0}} K^+
                                                                                  (1.45 \pm 0.33) \times 10^{-3}
                                                                                                                                                                                                                                               ( 1.08 \pm 0.33 ) \times 10^{-4}
                                                                                                                                                              \Gamma_{208} J/\psi(1S)\eta \dot{K}^+
\Gamma_{150} \ \overline{D}^* (2007)^0 D^0 K^+
                                                                                  ( 2.26~\pm0.23 ) \times\,10^{-3}
                                                                                                                                                               \Gamma_{209} J/\psi(1S) \eta' K^{+}
                                                                                                                                                                                                                                                                             \times\,10^{-5} CL=90%
                                                                                                                                                                                                                                               < 8.8
\Gamma_{151} \quad \overline{D}{}^{0} D^{*} (2007)^{0} K^{+}
                                                                                  (6.3 \pm 0.5) \times 10^{-3}
                                                                                                                                                              \Gamma_{210} J/\psi(1S)\phi K^{+}
                                                                                                                                                                                                                                                ( 5.2 \pm 1.7 ) \times 10^{-5}
                                                                                                                                                                                                                                                                                                S=1.2
\Gamma_{152}^{--} \overline{D}^*(2007)^0 D^*(2007)^0 K^+
                                                                                  ( 1.12 \pm 0.13 ) %
                                                                                                                                                                                                                                                 (3.20 \begin{array}{c} +0.60 \\ -0.32 \end{array}) \times 10^{-4}
                                                                                                                                                              \Gamma_{211} J/\psi(1S)\omega K^+
( 2.2 \pm 0.7 ) \times 10^{-4}
                                                                                                                                                               \Gamma_{212} X(3872)K^+ \times B(X \rightarrow
                                                                                                                                                                                                                                                 (6.0 \pm 2.2) \times 10^{-6}
                                                                                  (6.3 \pm 1.1) \times 10^{-4}
\Gamma_{155} D^*(2010)^- D^+ K^+
                                                                                                                                                                                    J/\psi\omega)
                                                                                  (6.0 \pm 1.3) \times 10^{-4}
\Gamma_{156} D^*(2010) - D^*(2010) + K^+
                                                                                  ( 1.32 \pm 0.18) \times 10^{-3}
                                                                                                                                                              \Gamma_{213} X(3915)K^+ \times B(X \rightarrow
                                                                                                                                                                                                                                                 ( 3.0 \begin{array}{c} +0.9 \\ -0.7 \end{array} ) \times 10^{-5}
\Gamma_{157} (\overline{D} + \overline{D}^*)(D + D^*)K
                                                                                  (4.05 \pm 0.30)\%
                                                                                                                                                                                    J/\psi\omega)
\Gamma_{158} \quad D_s^+ \pi^0
\Gamma_{159} \quad D_s^{*+} \pi^0
                                                                                                                                                              \Gamma_{214} J/\psi(1S)\pi^+
                                                                                  ( 1.6~\pm 0.5~)\times 10^{-5}
                                                                                                                                                                                                                                                (4.9 \pm 0.4) \times 10^{-5}
                                                                                                                                                                                                                                                                                                S = 1.2
                                                                                                                                                                                                                                                ( 5.0 \pm 0.8 ) \times 10 ^{-5}
                                                                                                             \times\,10^{-4} CL=90%
                                                                                                                                                              \Gamma_{215} J/\psi(1S)\rho^+
                                                                                < 2.6
\Gamma_{160} \quad D_{s}^{+} \eta \\ \Gamma_{161} \quad D_{s}^{*+} \eta \\ \Gamma_{162} \quad D_{s}^{+} \rho^{0}
                                                                                                                                                              \Gamma_{216} J/\psi(1S)\pi^+\pi^0 nonresonant
                                                                                                                                                                                                                                              < 7.3
                                                                                                                                                                                                                                                                             \times\,10^{-6} CL=90%
                                                                                                              \times 10^{-4} CL=90%
                                                                                 < 4
                                                                                                                                                                                                                                                                             \times 10^{-3} CL=90%
                                                                                                                                                              \Gamma_{217} J/\psi(1S) a_{1}(1260)^{+}
                                                                                                                                                                                                                                               < 1.2
                                                                                                              \times\,10^{-4} CL=90%
                                                                                < 6
                                                                                                                                                                                                                                                 ( 1.18 \pm 0.31 ) \times 10^{-5}
                                                                                                                                                              \Gamma_{218} J/\psi(1S) p \overline{\Lambda}
                                                                                                              \times\,10^{-4} CL=90%
                                                                                 < 3.0
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\times\,10^{-5} CL=90%
                                                                                                                                                               K^+ \rho^0
\Gamma_{219} J/\psi(1S) \overline{\Sigma}^0 p
                                                                                                                                                                                                                            (3.7 \pm 0.5) \times 10^{-6}
                                                                          < 1.1
                                                                                                                                                \Gamma_{275}
\Gamma_{220} J/\psi(1S)D^{+}
                                                                          < 1.2
                                                                                                     \times\,10^{-4} CL=90%
                                                                                                                                                              K_0^*(1430)^0\pi^+
                                                                                                                                                                                                                            (4.5 \begin{array}{c} +0.9 \\ -0.7 \end{array}) \times 10^{-5}
                                                                                                                                                \Gamma_{276}
                                                                                                                                                                                                                                                                        S = 1.5
\Gamma_{221} J/\psi(1S) \overline{D}{}^0 \pi^+
                                                                                                     \times\,10^{-5} CL=90%
                                                                          < 2.5
                                                                                                                                                               K_2^*(1430)^0\pi^+
                                                                                                                                                \Gamma_{277}
                                                                                                                                                                                                                                        ^{+\,2.2}_{-\,1.5} ) \times 10^{-6}
\Gamma_{222} \psi(2S) \pi^+
                                                                                2.44\ \pm0.30\ )\times10^{-5}
                                                                                                                                                                                                                            ( 5.6
\Gamma_{223} \psi(2S)K^+
                                                                                6.39 \pm 0.33) \times 10^{-4}
                                                                                                                                                               K^*(1410)^0\pi^+
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                \Gamma_{278}
                                                                                                                                                                                                                          < 4.5
\Gamma_{224} \psi(2S) K^*(892)^+
                                                                                6.7 \pm 1.4 ) \times 10^{-4}
                                                                                                                                                                                                                                                      \times 10^{-5}
                                                                                                                                                               K^*(1680)^0\pi^+
                                                                                                                       S = 1.3
                                                                                                                                                 \Gamma_{279}
                                                                                                                                                                                                                          < 1.2
                                                                                                                                                                                                                                                                   CL=90%
\Gamma_{225} \psi(2S) K^{+} \pi^{+} \pi^{-}
                                                                           (4.3 \pm 0.5) \times 10^{-4}
                                                                                                                                                \Gamma_{280} \quad K^+ \pi^{\dot{0}} \pi^0
                                                                                                                                                                                                                            ( 1.62~\pm 0.19 ) \times\,10^{-5}
\Gamma_{226} \psi(3770) K^{+}
                                                                           (4.9 \pm 1.3) \times 10^{-4}
                                                                                                                                                               f_0(980) K^+ \times B(f_0 \rightarrow \pi^0 \pi^0)
                                                                                                                                                                                                                                2.8 \pm 0.8 ) \times 10^{-6}
                                                                                                                                                 \Gamma_{281}
                                                                                                                                                                                                                           (
\Gamma_{227} \psi(3770)K^+ \times B(\psi \rightarrow D^0\overline{D}^0)
                                                                           (1.6 \pm 0.4) \times 10^{-4}
                                                                                                                                                \Gamma_{282} \quad K^{-}\pi^{+}\pi^{+}
                                                                                                                                                                                                                                                     \times 10^{-7} CL=90%
                                                                                                                                                                                                                          < 9.5
                                                                                                                                                              K^-\pi^+\pi^+ nonresonant
\Gamma_{228} \ \psi(3770) K^{+} \times B(\psi \rightarrow D^{+}D^{-})
                                                                          (9.4 \pm 3.5) \times 10^{-5}
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                                                                                          < 5.6
                                                                                                                                                Γ<sub>283</sub>
                                                                                                     \times\,10^{-7}
                                                                                                                                                          K_1(1270)^0\pi^+
\Gamma_{229} \quad \chi_{c0} \, \pi^+ \times B(\chi_{c0} \xrightarrow{\cdot} \pi^+ \pi^-)
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                          < 1
                                                                                                                  CL=90%
                                                                                                                                                 \Gamma_{284}
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                 4.0
                                                                                                                                                          K_1(1400)^0 \pi^+ 

K^0 \pi^+ \pi^0
                                                                           (\quad 1.34 \ ^{+\ 0.19}_{-\ 0.16}\ )\times 10^{-4}
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
\Gamma_{230} \chi_{c0}(1P) K^{+}
                                                                                                                                                 \Gamma_{285}
                                                                                                                                                                                                                          < 3.9
                                                                                                                                                                                                                                                      ×10<sup>-5</sup> CL=90%
                                                                                                                                                \Gamma_{286}
                                                                                                                                                                                                                          < 6.6
                                                                         < 2.1
\Gamma_{231} \quad \chi_{c0} \, K^*(892)^+
                                                                                                     \times\,10^{-4} CL=90%
                                                                                                                                                              K^0 \rho^+
                                                                                                                                                                                                                                        \pm 1.5 ) \times 10^{-6}
                                                                                                                                                 \Gamma_{287}
                                                                                                                                                                                                                                 8.0
\Gamma_{232} \quad \chi_{c2} \, \pi^+ \times \mathsf{B}(\chi_{c2} \rightarrow \pi^+ \pi^-)
                                                                                                     ×10<sup>-7</sup> CL=90%
                                                                                                                                                                                                                           (
                                                                          < 1
                                                                                                                                                 \Gamma_{288} \quad \dot{K}^*(892)^+ \pi^+ \pi^-
                                                                                                                                                                                                                            (7.5 \pm 1.0) \times 10^{-5}
\Gamma_{233} \chi_{c2}K^+
                                                                           ( 1.1~\pm0.4~)\times10^{-5}
                                                                                                                                                              K^*(892)^+ \rho^0
                                                                                                                                                                                                                                        \pm 1.1 ) \times 10^{-6}
                                                                                                                                                \Gamma_{289}
                                                                                                                                                                                                                            ( 4.6
\Gamma_{234} \quad \chi_{c2} \, K^*(892)^+
                                                                          < 1.2
                                                                                                   \times 10^{-4}
                                                                                                                  CL=90%
                                                                                                                                                               K^*(892) + f_0(980)
                                                                                                                                                 \Gamma_{290}
                                                                                                                                                                                                                                 4.2
                                                                                                                                                                                                                                        \pm 0.7 ) \times 10^{-6}
\Gamma_{235} \quad \chi_{c1}(1P) \pi^{+}
                                                                           (\phantom{-}2.2\phantom{0}\pm0.5\phantom{0})\times10^{-5}
                                                                                                                                                \Gamma_{291} \ a_1^+ K^0
                                                                                                                                                                                                                            (3.5 \pm 0.7) \times 10^{-5}
\Gamma_{236} \quad \chi_{c1}(1P) K^{+}
                                                                                4.79\ \pm0.23\ )\times10^{-4}
                                                                                                                                                 \Gamma_{292} b_1^+ K^0 \times B(b_1^+ \rightarrow \omega \pi^+)
                                                                                                                                                                                                                            (9.6 \pm 1.9) \times 10^{-6}
\Gamma_{237} \chi_{c1}(1P) K^*(892)^+
                                                                               3.0 \pm 0.6 \times 10^{-4}
                                                                                                                       S = 1.1
                                                                           (
                                                                                                                                                 \Gamma_{293} K^*(892)^0 \rho^+
\Gamma_{238} h_c(1P)K^+
                                                                                                     \times\,10^{-5}
                                                                                                                                                                                                                           (9.2 \pm 1.5) \times 10^{-6}
                                                                          < 3.8
                                                                                                                                                 \Gamma_{294} K_1(1400)^{+} \rho^{0}
                                                                                                                                                                                                                                                      \times 10^{-4} CL=90%
                                                                                                                                                                                                                          < 7.8
                                                   K or K* modes
                                                                                                                                                                                                                                                      \times 10^{-3} CL=90%
                                                                                                                                                \Gamma_{295} K_2^*(1430)^+ \rho^0
                                                                                                                                                                                                                          < 1.5
\Gamma_{239}~K^0\pi^+
                                                                                2.31 \pm 0.10 \times 10^{-5}
                                                                                                                                                \Gamma_{296} b_1^{0} K^+ \times B(b_1^0 \rightarrow \omega \pi^0)
                                                                                                                                                                                                                           ( 9.1 \pm 2.0 ) \times 10^{-6}
\Gamma_{240} \ K^+ \, \pi^0
                                                                               1.29 \pm\,0.06 ) \times\,10^{-5}
                                                                                                                                                \Gamma_{297} b_1^+ K^{*0} \times B(b_1^+ \to \omega \pi^+)
                                                                                                                                                                                                                                                      \times\,10^{-6}\text{ CL}\!=\!90\%
                                                                                                                                                                                                                          < 5.9
\Gamma_{241} \ \eta' \, K^+
                                                                            ( 7.06~\pm0.25 ) \times\,10^{-5}
                                                                                                                                                \Gamma_{298} \quad b_1^{0} K^{*+} \times B(b_1^{0} \rightarrow \omega \pi^{0})
                                                                                                                                                                                                                                                      \times 10^{-6} CL=90%
                                                                                                                                                                                                                          < 6.7
\Gamma_{242} \quad \eta' \, K^*(892)^+
                                                                            (4.8 \quad \begin{array}{cc} +1.8 \\ -1.6 \end{array}) \times 10^{-6}
                                                                                                                                                 \Gamma_{299} \vec{K}^+ \overline{K}^0
                                                                                                                                                                                                                           (1.36 \pm 0.27) \times 10^{-6}
                                                                                                                                                 \Gamma_{300}^{-} \ \overline{K}{}^0 \, K^+ \, \pi^0
\Gamma_{243} \quad \eta' \, K_0^* (1430)^+
                                                                            (\phantom{-}5.2\phantom{0}\pm2.1\phantom{0})\times10^{-6}
                                                                                                                                                                                                                                                      \times\,10^{-5}\text{ CL}\!=\!90\%
                                                                                                                                                                                                                          < 2.4
                                                                                                                                                 \Gamma_{301}^{300} K^+ K_S^0 K_S^0
                                                                                                                                                                                                                           ( 1.15~\pm0.13 ) \times\,10^{-5}
\Gamma_{244} \quad \eta' \, K_2^* (1430)^+
                                                                           (2.8 \pm 0.5) \times 10^{-5}
                                                                                                                                                \Gamma_{302} \ \ K_S^0 \ K_S^0 \pi^+
                                                                                                                                                                                                                                                      \times\,10^{-7} CL=90%
\Gamma_{245} \eta K^{+}
                                                                            (\phantom{-}2.4\phantom{0}\pm0.4\phantom{0})\times10^{-6}
                                                                                                                                                                                                                          < 5.1
                                                                                                                       S = 1.7
\Gamma_{246} \eta K^*(892)^+
                                                                                                                                                 \Gamma_{303} K^{+}K^{-}\pi^{+}
                                                                           ( 1.93 \pm 0.16 ) \times 10^{-5}
                                                                                                                                                                                                                                5.0 \pm 0.7 \times 10^{-6}
                                                                                                                                                                                                                           (
                                                                                                                                                              K^+\,K^-\,\pi^+ nonresonant
\Gamma_{247} \eta K_0^* (1430)^+
                                                                           ( 1.8~\pm0.4~)\times10^{-5}
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                \Gamma_{304}
                                                                                                                                                                                                                          < 7.5
                                                                                                                                                                                                                                                      ×10<sup>-6</sup> CL=90%
                                                                                                                                                              K^{+}\overline{K}^{*}(892)^{0}
                                                                           (\phantom{-}9.1\phantom{0}\pm3.0\phantom{0})\times10^{-6}
                                                                                                                                                                                                                          < 1.1
\Gamma_{248} \eta K_2^* (1430)^+
                                                                                                                                                \Gamma_{305}
                                                                                                                                                              K^{+} \overline{K}_{0}^{*}(1430)^{0}
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
                                                                                                                                                 \Gamma_{306}
                                                                                                                                                                                                                                2.2
                                                                                                                                                                                                                          <
\Gamma_{249} \eta(1295) K^+ \times B(\eta(1295) \rightarrow
                                                                           (2.9 \begin{array}{c} +0.8 \\ -0.7 \end{array}) \times 10^{-6}
                                                                                                                                                          K^{+}K^{+}\pi^{-}
                                                                                                                                                                                                                                                      \times 10^{-7} CL=90%
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                1.6
                                                                                                                                                 \Gamma_{307}
                \eta \pi \pi
                                                                                                                                                               K^+K^+\pi^- nonresonant
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                 \Gamma_{308}
                                                                                                                                                                                                                               8.79
\Gamma_{250} \eta(1405)K^+ \times B(\eta(1405) \rightarrow
                                                                                                     \times 10^{-6} CL=90%
                                                                         < 1.3
                                                                                                                                                          K^+ f_J(2220)
                                                                                                                                                          K^{*+}\pi^{+}K^{-}
                                                                                                                                                 \Gamma_{310}
                                                                                                                                                                                                                               1.18
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                     \times\,10^{-6}\text{ CL}{=}90\%
\Gamma_{251} \eta(1405)K^+ \times B(\eta(1405) \rightarrow
                                                                          < 1.2
                                                                                                                                                               K^*(892)^+ K^*(892)^0
                                                                                                                                                                                                                           (1.2 \pm 0.5) \times 10^{-6}
                                                                                                                                                 \Gamma_{311}
                K^*K
                                                                                                                                                          K^{*+}\dot{K}^{+}\pi^{-}
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
                                                                                                                                                \Gamma_{312}
                                                                                                                                                                                                                          < 6.1
\Gamma_{25\,2} \eta(1475)\,K^+ 	imes \mathsf{B}(\eta(1475) 	o
                                                                           (\quad 1.38 \ ^{+\ 0.21}_{-\ 0.18}\ )\times 10^{-5}
                                                                                                                                                          K^{+}K^{-}K^{+}
                                                                                                                                                                                                                                3.37 \pm 0.22) \times 10^{-5}
                                                                                                                                                 \Gamma_{313}
                K*K)
                                                                                                                                                                                                                                 8.3 \pm 0.7 ) \times 10^{-6}
                                                                                                                                                 \Gamma_{314}
\Gamma_{253} f_1(1285)K^+
                                                                                                     \times 10^{-6} CL=90%
                                                                          < 2.0
                                                                                                                                                               f_0(980) K^+ \times B(f_0(980) \rightarrow
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
                                                                                                                                                \Gamma_{315}
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                2.9
\Gamma_{254} f_1(1420)K^+ \times B(f_1(1420) \rightarrow
                                                                             2.9
                                                                                                     \times\,10^{-6} CL=90%
                                                                                                                                                                     K^+K^-
                \eta \pi \pi
                                                                                                                                                               a_2(1320) \, \dot{K} + \times \, \mathsf{B}(a_2(1320) \to
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
                                                                                                                                                                                                                              1.1
                                                                                                                                                Γ<sub>316</sub>
                                                                                                                                                                                                                          <
\Gamma_{255} f_1(1420)K^+ \times B(f_1(1420) \rightarrow
                                                                                                     \times 10^{-6} CL=90%
                                                                          < 4.1
                                                                                                                                                                     K^+K^-
                K^*K
                                                                                                                                                               f_2'(1525)K^+ \times B(f_2'(1525) \rightarrow
                                                                                                                                                                                                                                                      \times 10^{-6} CL=90%
                                                                                                                                                 \Gamma_{317}
\Gamma_{256} \ \phi(1680) \ K^+ \times \ \mathsf{B}(\phi(1680) \to
                                                                                                     \times\,10^{-6} CL=90%
                                                                         < 3.4
                                                                                                                                                                    K^+K^-
               K* K)
                                                                                                                                                               X_0(1550) \, \acute{K}^+ \times
                                                                                                                                                 Γ<sub>318</sub>
                                                                                                                                                                                                                            (\phantom{-}4.3\phantom{0}\pm0.7\phantom{0})\times10^{-6\phantom{0}}
\Gamma_{257}~\omega\,K^+
                                                                           (\phantom{-}6.7\phantom{0}\pm0.8\phantom{0})\times10^{-6\phantom{0}}
                                                                                                                       S=1.8
                                                                                                                                                                    B(X_0(1550) \to K^+ K^-)
\Gamma_{258} \ \omega K^*(892)^+
                                                                                                     \times\,10^{-6} CL=90%
                                                                          < 7.4
                                                                                                                                                               \phi(1680) \dot{K}^+ \times \dot{B}(\phi(1680) \rightarrow
                                                                                                                                                \Gamma_{319}
                                                                                                                                                                                                                           < 8
                                                                                                                                                                                                                                                      \times 10^{-7} CL=90%
                                                                           ( 2.8~\pm0.4~)\times10^{-5}
\Gamma_{259} \omega (K\pi)_0^*
                                                                                                                                                                     K^+K^-
                                                                           (\phantom{-}2.4\phantom{0}\pm0.5\phantom{0})\times10^{-5}
\Gamma_{260} \ \omega K_0^* (1430)^+
                                                                                                                                                \Gamma_{320}
                                                                                                                                                               f_0(1710) \, K^+ \times \, \mathsf{B}(f_0(1710) \to
                                                                                                                                                                                                                            (1.7 \pm 1.0) \times 10^{-6}
                                                                           ( 2.1 \pm 0.4 ) \times 10^{-5}
\Gamma_{261} \ \omega K_2^*(1430)^+
                                                                                                                                                                     K^{+}K^{-}
\Gamma_{262} \ a_0(980)^+ K^0 \times B(a_0(980)^+ \rightarrow
                                                                                                    \times\,10^{-6} CL=90%
                                                                          < 3.9
                                                                                                                                                \Gamma_{321}
                                                                                                                                                                                                                            (\quad 2.8 \quad {}^{+\; 0.9}_{-\; 1.6} \quad )\times 10^{-5}
                                                                                                                                                               K^+K^-K^+ nonresonant
                                                                                                                                                                                                                                                                        S = 3.3
                \eta \pi^+)
                                                                                                                                                \Gamma_{322} K^*(892)^+K^+K^-
         a_0(980)^{0} K^{+} \times B(a_0(980)^{0} \rightarrow
                                                                                                                                                                                                                            (3.6 \pm 0.5) \times 10^{-5}
                                                                                                     \times 10^{-6} CL=90%
\Gamma_{263}
                                                                          < 2.5
               \eta \pi^{0})
                                                                                                                                                                                                                                                   ) \times 10^{-6}
                                                                                                                                                              K^*(892)^+ \phi
                                                                                                                                                                                                                            (10.0
                                                                                                                                                                                                                                        \pm 2.0
                                                                                                                                                \Gamma_{323}
                                                                                                                                                                                                                            (8.3 \pm 1.6) \times 10^{-6}
\Gamma_{264} \quad K^*(892)^0 \pi^+
                                                                                                                                                \Gamma_{324} \phi (K\pi)_0^{*+}
                                                                            (1.01 \pm 0.09) \times 10^{-5}
                                                                                                                                                                                                                            (\phantom{-}6.1\phantom{0}\pm1.9\phantom{0})\times10^{-6\phantom{0}}
\Gamma_{265}^{-1} K^*(892)^+ \pi^0
                                                                            (8.2 \pm 1.9) \times 10^{-6}
                                                                                                                                                \Gamma_{325} \phi K_1 (1270)^+
\Gamma_{266} \quad K^{+} \pi^{-} \pi^{+}
                                                                                                                                                \Gamma_{326} \phi K_1 (1400)^+
                                                                                                                                                                                                                                                      \times\,10^{-6} CL=90%
                                                                            ( 5.10~\pm0.29 ) \times\,10^{-5}
                                                                                                                                                                                                                          < 3.2
                                                                                                                                                \Gamma_{327} \phi K^* (1410)^+
                                                                                                                                                                                                                                                      \times 10^{-6} CL=90%
                                                                           (\quad 1.63 \ ^{+\ 0.21}_{-\ 0.15}\ )\times 10^{-5}
                                                                                                                                                                                                                          < 4.3
              K^+\pi^-\pi^+ nonresonant
\Gamma_{267}
                                                                                                                                                \Gamma_{328} \phi K_0^* (1430)^+
                                                                                                                                                                                                                                       \pm 1.6 ) \times 10^{-6}
                                                                                                                                                                                                                           ( 7.0
                                                                           ( 6 \pm 9 ) \times 10^{-6}
\Gamma_{268}
              \omega(782) K^{+}
                                                                                                                                                \Gamma_{329} \phi K_2^* (1430)^+
                                                                                                                                                                                                                            (8.4 \pm 2.1) \times 10^{-6}
                                                                           \begin{pmatrix} 9.4 & +1.0 \\ -1.2 & ) \times 10^{-6}
              K^+ f_0(980) \times B(f_0(980) \rightarrow
                                                                                                                                                \Gamma_{330} \phi K_2^* (1770)^+
\Gamma_{269}
                                                                                                                                                                                                                          < 1.50
                                                                                                                                                                                                                                                      \times\,10^{-5} CL=90%
                    \pi^{+}\pi^{-}
                                                                                                                                                \Gamma_{331} \phi K_2^{*}(1820)^{+}
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                1.63
                                                                                                                                                                                                                                                      \times\,10^{-5} CL=90%
              f_2(1270)^0 K^+
                                                                           (1.07 \pm 0.27) \times 10^{-6}
                                                                                                                                                \Gamma_{332} \quad a_1^+ \stackrel{?}{K}^{*0} \\ \Gamma_{333} \quad K^+ \phi \phi
\Gamma_{270}
                                                                                                                                                                                                                                                      \times 10^{-6} CL=90%
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                                3.6
              \bar{f_0}(1370)^0 K^+ \times
                                                                                                     \times\,10^{-5} CL=90%
\Gamma_{271}
                                                                          < 1.07
                                                                                                                                                                                                                           (5.0 \pm 1.2) \times 10^{-6} S=2.3
                    B(f_0(1370)^0 \rightarrow \pi^+\pi^-)
                                                                                                                                                \Gamma_{334} \ \eta' \eta' K^+
                                                                                                                                                                                                                                                      \times 10^{-5} CL=90%
                                                                                                                                                                                                                          < 2.5
              \rho^{0}(1450)K^{+} \times B(\rho^{0}(1450) \rightarrow
\Gamma_{272}
                                                                                                     \times 10^{-5} CL=90%
                                                                          < 1.17
                                                                                                                                                \Gamma_{335} \omega \phi K^+
                                                                                                                                                                                                                                                      \times 10^{-6} CL=90%
                                                                                                                                                                                                                          <
                                                                                                                                                                                                                               1.9
                                                                                                                                                                                                                                                      \times 10^{-7} CL=90%
                                                                                                                                                             X(1812)K^+ \times B(X \rightarrow \omega \phi)
                                                                                                                                                                                                                          < 3.2
                                                                                                                                                Γ336
              f_0(1500) \, \dot{K}^+ \times \, \mathsf{B}(f_0(1500) \to
                                                                           (\phantom{-}7\phantom{\pm}\pm5\phantom{-})\times10^{-7}
\Gamma_{273}
                                                                                                                                                \Gamma_{337} K^*(892)^+ \gamma
                                                                                                                                                                                                                            ( 4.21~\pm0.18 ) \times\,10^{-5}
                   \pi^{+}\pi^{-}
                                                                                                                                                 \Gamma_{338} K_1(1270)^+ \gamma
                                                                                                                                                                                                                                4.3 \pm 1.3 ) \times 10^{-5}
                                                                                                     \times\,10^{-6}\text{ CL}{=}90\%
              f_2'(1525)K^+ \times B(f_2'(1525) \rightarrow
                                                                          < 3.4
\Gamma_{274}
                                                                                                                                                \Gamma_{339} \eta K^+ \gamma
                                                                                                                                                                                                                            (7.9 \pm 0.9) \times 10^{-6}
                    \pi^{+}\pi^{-})
                                                                                                                                                \Gamma_{340} \eta' K^+ \gamma
                                                                                                                                                                                                                            (2.9 \quad ^{+1.0}_{-0.9} \quad ) \times 10^{-6}
```

 B^{\pm}

 $p\overline{\Lambda}(1520)$

 Γ_{397}

```
(2.7 \pm 0.4) \times 10^{-6}
\Gamma_{341} \phi K^+ \gamma
                                                                                                                                                             \Gamma_{398} p \overline{p} K^+ nonresonant
                                                                                                                                                                                                                                             < 8.9
                                                                                                                                                                                                                                                                          \times 10^{-5} CL=90%
                                                                                                                                 S=1.2
\Gamma_{342} K^+\pi^-\pi^+\gamma
                                                                                  (2.76 \pm 0.22) \times 10^{-5}
                                                                                                                                S=1.2
                                                                                                                                                             \Gamma_{399} p \overline{p} K^*(892)^+
                                                                                                                                                                                                                                             \begin{pmatrix} 3.6 & +0.8 \\ -0.7 \end{pmatrix} \times 10^{-6}
\Gamma_{343} = K^*(892)^0 \pi^+ \gamma
                                                                                 (2.0 \begin{array}{c} +0.7 \\ -0.6 \end{array}) \times 10^{-5}
                                                                                                                                                             \Gamma_{400} f_J(2220) K^{*+} \times B(f_J(2220) \rightarrow
                                                                                                                                                                                                                                                                          \times\,10^{-7} CL=90%
                                                                                                                                                                                                                                             < 7.7
                                                                                                                                                            \Gamma_{401} \quad p \overline{\Lambda} \stackrel{-3}{\overline{\rho}}
               K^+ \rho^0 \gamma
                                                                                                             \times\,10^{-5} CL=90%
                                                                               < 2.0
Γ<sub>344</sub>
               K^+\pi^-\pi^+\gamma nonresonant
                                                                                                              \times 10^{-6} CL=90%
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                               < 9.2
                                                                                                                                                                                                                                             < 3.2
\Gamma_{345}
\Gamma_{346} \quad K^0 \pi^+ \pi^0 \gamma
                                                                               (\phantom{-}4.6\phantom{0}\pm0.5\phantom{0})\times10^{-5}
                                                                                                                                                                                                                                              \begin{pmatrix} 2.4 & +0.5 \\ -0.4 & 0.5 \end{pmatrix} \times 10^{-6}
                                                                                                                                                             \Gamma_{402} p \overline{\Lambda} \gamma
\Gamma_{347} K_1(1400)^{+}\gamma
                                                                                                            \times 10^{-5} CL=90%
                                                                               < 1.5
                                                                                                                                                             \Gamma_{403} \ p\, \overline{\varLambda} \pi^0
\Gamma_{348} K_2^*(1430)^+ \gamma
                                                                                (1.4 \pm 0.4) \times 10^{-5}
                                                                                                                                                             \Gamma_{404} \quad p \, \overline{\Sigma} (1385)^0
\Gamma_{349} K^{\bar{*}}(1680)^+ \gamma
                                                                                                            \times 10^{-3} CL=90%
                                                                                < 1.9
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                                                                                                                                                                                             < 4.7
\Gamma_{350} K_3^*(1780)^+ \gamma
                                                                               < 3.9
                                                                                                             \times 10^{-5} CL=90%
                                                                                                                                                             \Gamma_{405} \Delta^{+} \overline{\Lambda}
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                                                                                                                                                                                             < 8.2
                                                                                                             \times\,10^{-3} CL=90%
                                                                                                                                                             \Gamma_{406} p\overline{\Sigma}\gamma
\Gamma_{351} K_4^*(2045)^+ \gamma
                                                                                < 9.9
                                                                                                                                                                                                                                                                           \times 10^{-6} CL=90%
                                                                                                                                                                                                                                             < 4.6
                                                                                                                                                             \Gamma_{407} p \overline{\Lambda} \pi^{+} \pi
                                                                                                                                                                                                                                             (5.9 \pm 1.1) \times 10^{-6}
                                          Light unflavored meson modes
                                                                                                                                                             \Gamma_{408} p \overline{\Lambda} \rho^0
                                                                                                                                                                                                                                             ( 4.8 \pm 0.9 ) \times 10^{-6}
                                                                                  ( 9.8 \pm 2.5 ) \times 10^{-7}
\Gamma_{352} \rho^+ \gamma
                                                                                                                                                                          p \, \overline{\Lambda} \, f_2(1270)
                                                                                                                                                                                                                                             (2.0 \pm 0.8) \times 10^{-6}
                                                                                                                                                             \Gamma_{409}
\Gamma_{35\,3} \pi^+\,\pi^0
                                                                                  (5.7 \pm 0.5) \times 10^{-6}
                                                                                                                                 S = 1.4
                                                                                                                                                             \Gamma_{410} \ \Lambda \overline{\Lambda} \pi^+
                                                                                                                                                                                                                                             < 9.4
                                                                                                                                                                                                                                                                         \times 10^{-7} CL=90%
\Gamma_{35\,4} \quad \pi^+\,\pi^+\,\pi^-
                                                                                  ( 1.52 \pm 0.14 ) \times 10^{-5}
                                                                                                                                                             \Gamma_{411} \ \Lambda \overline{\Lambda} K^+
                                                                                                                                                                                                                                             ( 3.4 \pm 0.6 ) \times 10^{-6}
            \rho^{0}\pi^{+}
                                                                                  (8.3 \pm 1.2) \times 10^{-6}
\Gamma_{355}
                                                                                                                                                             \Gamma_{412} \Lambda \overline{\Lambda} K^{*+}
                                                                                                                                                                                                                                             \begin{pmatrix} 2.2 & +1.2 \\ -0.9 \end{pmatrix} \times 10^{-6}
               \pi^+ f_0(980) \times B(f_0(980) \rightarrow
                                                                               < 1.5
                                                                                                            \times 10^{-6} CL=90%
\Gamma_{356}
                                                                                                                                                             \Gamma_{413} \ \overline{\Delta}{}^0 p
                                                                                                                                                                                                                                                                           \times 10^{-6} CL=90%
                                                                                                                                                                                                                                            < 1.38
                                                                                                                                                             \Gamma_{414} \Delta^{++} \overline{p}
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                                                                                                                                                                                             < 1.4
                                                                                  (1.6 \begin{array}{c} +0.7 \\ -0.4 \end{array}) \times 10^{-6}
               \pi^+ f_2(1270)
\Gamma_{357}
                                                                                                                                                             \Gamma_{415} D^+ p \overline{p}
                                                                                                                                                                                                                                                                           \times\,10^{-5} CL=90%
                                                                                                                                                                                                                                             < 1.5
               \rho(1450)<sup>0</sup> \pi<sup>+</sup> \times B(\rho<sup>0</sup> \rightarrow
                                                                                  (1.4 \begin{array}{cc} +0.6 \\ -0.9 \end{array}) \times 10^{-6}
                                                                                                                                                             \Gamma_{416} D^*(2010)^+ p \overline{p}
                                                                                                                                                                                                                                                                          \times\,10^{-5} CL=90%
\Gamma_{35.8}
                                                                                                                                                                                                                                            < 1.5
                                                                                                                                                             \Gamma_{417} p \overline{\Lambda}{}^{0} \overline{D}{}^{0}
                                                                                                                                                                                                                                             ( 1.43~\pm0.32 ) \times\,10^{-5}
                     \pi^{+}\pi^{-}
                                                                                                                                                             \Gamma_{418} p \overline{\Lambda}{}^0 \overline{D}{}^* (2007)^0
                f_0(1370) \pi^+ \times B(f_0(1370) \rightarrow
                                                                                                            \times 10^{-6} CL=90%
                                                                                                                                                                                                                                                                         \times 10^{-5} CL=90%
\Gamma_{359}
                                                                               < 4.0
                                                                                                                                                                                                                                            < 5
                                                                                                                                                                                                                                            ( 2.8 \pm 0.8 ) \times 10^{-4}
                    \pi^{+}\pi^{-}
                                                                                                                                                             \Gamma_{419} \overline{\Lambda}_c^- p \pi^+
               f_0(500) \pi^{+} \times B(f_0(500) \rightarrow
                                                                                                            \times 10^{-6} CL=90%
                                                                               < 4.1
                                                                                                                                                             \Gamma_{420}
                                                                                                                                                                            \overline{\Lambda}_c^- \Delta (1232)^{++}
                                                                                                                                                                                                                                                                         \times\,10^{-5} CL=90%
                                                                                                                                                                                                                                            < 1.9
                                                                                                                                                                          \frac{c}{\overline{\Lambda}_{c}^{-}} \frac{\Delta_{X}(1600)^{++}}{\Delta_{X}(2420)^{++}}
\frac{(\overline{\Lambda}_{c}^{-} p)_{s} \pi^{+}}{\overline{\Lambda}_{c}^{-} (2520)^{0}}
                    \pi^{+}\pi^{-}
                                                                                                                                                                                                                                             (5.9 \pm 1.9) \times 10^{-5}
                                                                                                                                                             \Gamma_{421}
               \pi^+\,\pi^-\,\pi^+ nonresonant
                                                                                (5.3 \begin{array}{c} +1.5 \\ -1.1 \end{array}) \times 10^{-6}
                                                                                                                                                                                                                                             ( 4.7 \pm 1.6 ) \times 10^{-5}
\Gamma_{361}
                                                                                                                                                            \Gamma_{422}
\Gamma_{362}\ \pi^+\pi^0\pi^0
                                                                                                           \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                      [h] ( 3.9 \pm 1.3 ) \times 10^{-5}
                                                                               < 8.9
                                                                                                                                                             \Gamma_{423}
               \rho^+\pi^0
                                                                                ( 1.09 \pm 0.14 ) \times 10^{-5}
                                                                                                                                                                            \frac{\overline{\Sigma}_{c}(2520)^{0}}{\Sigma_{c}(2800)^{0}} p
                                                                                                                                                             \Gamma_{424}
                                                                                                                                                                                                                                           < 3
                                                                                                                                                                                                                                                                         \times 10^{-6} CL=90%
\Gamma_{363}
\Gamma_{364} \quad \pi^{\dot{+}} \, \pi^- \, \pi^+ \, \pi^0
                                                                                < 4.0 \times 10^{-3} CL=90%
                                                                                                                                                                                                                                             (3.3 \pm 1.3) \times 10^{-5}
                                                                                                                                                             \Gamma_{425}
            \rho^+ \rho^0
                                                                                ( 2.40~\pm0.19 ) \times\,10^{-5}
                                                                                                                                                             \Gamma_{426} \overline{\Lambda}_c^- p \pi^+ \pi^0
\Gamma_{365}
                                                                                                                                                                                                                                             (1.8 \pm 0.6) \times 10^{-3}
                                                                                                            \times 10^{-6} CL=90%
               \rho^+ f_0(980) \times B(f_0(980) \rightarrow
                                                                               < 2.0
                                                                                                                                                             \Gamma_{427} \ \overline{\Lambda}_c^- \, p \, \pi^+ \, \pi^+ \, \pi^-
Γ<sub>366</sub>
                                                                                                                                                                                                                                            (2.2 \pm 0.7) \times 10^{-3}
                                                                                                                                                             \Gamma_{428} \ \overline{\Lambda}_c^{-} p \pi^{+} \pi^{+} \pi^{-} \pi^{0}
                                                                                                                                                                                                                                            < 1.34
                                                                                                                                                                                                                                                                          %
                                                                                                                                                                                                                                                                                       CL=90%
               a_1(1260)^{+'}\pi^0
                                                                                                                                                             \begin{array}{lll} \Gamma_{428} & \Lambda_{c} & \rho \pi^{+} \pi^{+} \pi^{-} \pi^{0} \\ \Gamma_{429} & \Lambda_{c}^{+} & \Lambda_{c}^{-} & K^{+} \\ \Gamma_{430} & \overline{\Sigma}_{c} (2455)^{0} \rho \pi^{0} \\ \Gamma_{431} & \overline{\Sigma}_{c} (2455)^{0} \rho \pi^{0} \\ \Gamma_{432} & \overline{\Sigma}_{c} (2455)^{0} \rho \pi^{-} \pi^{+} \\ \Gamma_{433} & \overline{\Sigma}_{c} (2455)^{-} \rho \pi^{+} \pi^{+} \\ \Gamma_{434} & \overline{\Lambda}_{c} (2593)^{-} / \overline{\Lambda}_{c} (2625)^{-} \rho \pi^{+} \\ \Gamma_{435} & \overline{\Xi}_{c}^{0} & \Lambda_{c}^{+} \times B (\overline{\Xi}_{c}^{0} \to \overline{\Xi}^{+} \pi^{-}) \\ \Gamma_{436} & \overline{\Xi}_{c}^{0} & \Lambda_{c}^{+} \times B (\overline{\Xi}_{c}^{0} \to \Lambda K^{+} \pi^{-}) \end{array} 
                                                                                 ( 2.6~\pm0.7~)\times10^{-5}
                                                                                                                                                                                                                                             (8.7 \pm 3.5) \times 10^{-4}
              a_1(1260)^0\pi^+
                                                                                  ( 2.0~\pm 0.6~)\times 10^{-5}
\Gamma_{368}
                                                                                                                                                                                                                                             (3.7 \pm 1.3) \times 10^{-5}
                                                                                  (6.9 \pm 0.5) \times 10^{-6}
\Gamma_{369} \omega \pi^{\bar{+}}
                                                                                                                                                                                                                                             (4.4 \pm 1.8) \times 10^{-4}
\Gamma_{370}~\omega\,\rho^+
                                                                                  ( 1.59\ \pm0.21 ) \times\,10^{-5}
                                                                                                                                                                                                                                              (4.4 \pm 1.7) \times 10^{-4}
\Gamma_{371} \eta \pi^+
                                                                                  ( 4.02~\pm0.27 ) \times\,10^{-6}
                                                                                                                                                                                                                                             (2.8 \pm 1.2) \times 10^{-4}
                                                                                  (7.0 \pm 2.9) \times 10^{-6}
\Gamma_{372}~\eta\rho^{+}
                                                                                                                                 S = 2.8
                                                                                                                                                                                                                                                                          \times 10^{-4} CL=90%
                                                                                                                                                                                                                                             < 1.9
\Gamma_{373} \ \dot{\eta'} \pi^+
                                                                                  (2.7 \pm 0.9) \times 10^{-6}
                                                                                                                                S-19
                                                                                                                                                                                                                                             (\phantom{-}3.0\phantom{0}\pm1.1\phantom{0})\times10^{-5\phantom{0}}
                                                                                  (9.7 \pm 2.2) \times 10^{-6}
\Gamma_{374} \eta' \rho^+
                                                                                                                                                                                                                                              (2.6 \pm 1.1) \times 10^{-5}
                                                                                                           \times 10^{-7} CL=90%
\Gamma_{375}~\phi\pi^{+}
                                                                                < 2.4
                                                                                                             \times 10^{-6} CL=90%
\Gamma_{376}~\phi\rho^{+}
                                                                               < 3.0
                                                                                                                                                                Lepton Family number (LF) or Lepton number (L) or Baryon number (B)
\Gamma_{377} \quad a_0(980)^0 \pi^+ \times B(a_0(980)^0 \rightarrow
                                                                                                             ×10<sup>-6</sup> CL=90%
                                                                               < 5.8
                                                                                                                                                                     violating modes, or/and \Delta B = 1 weak neutral current (B1) modes
                \eta \pi^{0})
                                                                                                                                                                                                                                                                         \times 10^{-8} CL=90%
                                                                                                                                                             \Gamma_{437} \quad \pi^+ \, \ell^+ \, \ell^-
                                                                                                                                                                                                                          B1
                                                                                                                                                                                                                                           < 4.9
\Gamma_{378} \ a_0(980)^+ \pi^0 \times B(a_0^+ \to \eta \pi^+)
                                                                                                             \times 10^{-6} CL=90%
                                                                               < 1.4
                                                                                                                                                             \Gamma_{438} = \pi^+ e^+ e^-
                                                                                                                                                                                                                                                                           \times\,10^{-8} CL=90%
                                                                                                                                                                                                                           В1
                                                                                                                                                                                                                                             < 8.0
\Gamma_{379} \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}
                                                                               < 8.6
                                                                                                             \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                                                           \times 10^{-8} CL=90%
                                                                                                                                                                         \pi^{+} \, \mu^{+} \, \mu^{-}
                                                                                                                                                             \Gamma_{439}
                                                                                                                                                                                                                          B1
                                                                                                                                                                                                                                             <
                                                                                                                                                                                                                                                  6.9

ho^0 a_1(1260)^+
                                                                                                              \times 10^{-4} CL=90%
                                                                               < 6.2
\Gamma_{380}
                                                                                                                                                             \Gamma_{440} \pi^+ \nu \overline{\nu}
                                                                                                                                                                                                                                                                           \times\,10^{-4} CL=90%
                                                                                                                                                                                                                                             < 1.0
                                                                                                              ×10<sup>-4</sup> CL=90%
               \rho^0 a_2(1320)^+
\Gamma_{381}
                                                                                < 7.2
                                                                                                                                                             \Gamma_{441} K^+ \ell^+ \ell^-
                                                                                                                                                                                                                                      [a] (5.1 \pm 0.5) \times 10^{-7}
                                                                                                                                                                                                                           В1
\Gamma_{382} b_1^0 \pi^+ \times B(b_1^0 \rightarrow \omega \pi^0)
                                                                               (6.7 \pm 2.0) \times 10^{-6}
                                                                                                                                                                        K^+\,e^+\,e^-
                                                                                                                                                                                                                                              ( 5.5 \pm 0.7 ) \times 10^{-7}
                                                                                                                                                             \Gamma_{442}
                                                                                                                                                                                                                          B1
\Gamma_{383} b_1^+ \pi^0 \times B(b_1^+ \to \omega \pi^+)
                                                                                                            \times 10^{-6} CL=90%
                                                                               < 3.3
                                                                                                                                                                           K^+ \mu^+ \mu^-
                                                                                                                                                                                                                                              (4.8 \pm 0.4) \times 10^{-7}
                                                                                                                                                             \Gamma_{443}
                                                                                                                                                                                                                           В1
\Gamma_{384} \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0}
                                                                                                            \times 10^{-3} CL=90%
                                                                               < 6.3
                                                                                                                                                             \Gamma_{444} K^+ \overline{\nu} \nu
                                                                                                                                                                                                                                                                          \times\,10^{-5} CL=90%
                                                                                                                                                                                                                           R1
                                                                                                                                                                                                                                            < 1.3
          b_1^+ \rho^0 \times \mathsf{B}(b_1^+ \to \omega \pi^+)
                                                                                                            \times 10^{-6} CL=90%
                                                                                                                                                                                                                                                                           \times 10^{-4} CL=90%
\Gamma_{385}
                                                                               < 5.2
                                                                                                                                                             \Gamma_{445} \ \rho^+ \, \nu \, \overline{\nu}
                                                                                                                                                                                                                          R1
                                                                                                                                                                                                                                            < 1.5
\Gamma_{386} a_1(1260)^+ a_1(1260)^0

\Gamma_{387} b_1^0 \rho^+ \times B(b_1^0 \to \omega \pi^0)
                                                                                                                                                             \Gamma_{446} K^*(892)^+ \ell^+ \ell^-
                                                                                                                                                                                                                                      [a] ( 1.29 \pm0.21 ) \times 10<sup>-6</sup>
                                                                               < 1.3
                                                                                                                         CL=90%
\Gamma_{386}
                                                                                                              %
                                                                                                             \times 10^{-6} CL=90%
                                                                                < 3.3
                                                                                                                                                                                                                                             (1.55 \begin{array}{c} +0.40 \\ -0.31 \end{array}) \times 10^{-6}
                                                                                                                                                             \Gamma_{447} K^*(892)^+e^+e^-
                                                                                                                                                                                                                           В1
                                                                                                                                                             \Gamma_{448} = K^*(892)^+ \mu^+ \mu^-
                                                                                                                                                                                                                                             ( 1.07 \pm 0.22 ) \times 10^{-6}
                                                                                                                                                                                                                           R1
                                            Charged particle (h^{\pm}) modes
                                                                                                                                                             \Gamma_{449} K^*(892)^+ \nu \overline{\nu}
                                                                                                                                                                                                                           В1
                                                                                                                                                                                                                                             < 8
                                                                                                                                                                                                                                                                          \times 10^{-5} CL=90%
             h^{\pm} = K^{\pm} \text{ or } \pi^{\pm}
                                                                                                                                                             \Gamma_{450} \pi^{+} e^{+} \mu^{-}
                                                                                                                                                                                                                                                                           \times\,10^{-3} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                             < 6.4
\Gamma_{388} \quad h^+ \, \pi^0
                                                                                  (1.6 \quad ^{+\ 0.7}_{-\ 0.6} \quad ) \times 10^{-5}
                                                                                                                                                             \Gamma_{451} \pi^{+} e^{-} \mu^{+}
                                                                                                                                                                                                                                                                           \times 10^{-3} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                             <
                                                                                                                                                                                                                                                    6.4
                                                                                                                                                             \Gamma_{452} \pi^{+} e^{\pm} \mu^{\mp}
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                                   1.7
                                                                                  (\quad 1.38 \ ^{+\ 0.27}_{-\ 0.24}\ )\times 10^{-5}
\Gamma_{389} \omega h^+
                                                                                                                                                             \Gamma_{453} K<sup>+</sup> e<sup>+'</sup> \mu^{-}
                                                                                                                                                                                                                                                                           \times\,10^{-8} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                                    9.1
                                                                                                                                                                                                                                            <
\Gamma_{390} h^+ X^0 (Familon)
                                                                                                            \times 10^{-5} CL=90%
                                                                                                                                                                                                                                                                           \times 10^{-7} CL=90%
                                                                               < 4.9
                                                                                                                                                             \Gamma_{454} K<sup>+</sup> e<sup>-</sup> \mu^{+}
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                             <
                                                                                                                                                                                                                                                   1.3
                                                                                                                                                             \Gamma_{455} \quad K^+ e^{\pm} \mu^{\mp}
                                                                                                                                                                                                                                                                           \times 10^{-8} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                             <
                                                                                                                                                                                                                                                  9.1
                                                         Baryon modes
                                                                                                                                                             \Gamma_{456} K^+ \mu^{\pm} \tau^{\mp}
                                                                                                                                                                                                                                                                           \times\,10^{-5} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                             <
                                                                                                                                                                                                                                                   7.7
                                                                 ( 1.62 \pm 0.20 ) \times 10^{-6}
\Gamma_{391} p \overline{p} \pi^+
                                                                                                                                                                                                                                                                           \times 10^{-6} CL=90%
                                                                                                                                                             \Gamma_{457} K^*(892)^+ e^+ \mu^-
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                            <
                                                                                                                                                                                                                                                  1.3
               p\overline{p}\pi^+ nonresonant
                                                                                                            \times 10^{-5} CL=90%
                                                                               < 5.3
\Gamma_{392}
                                                                                                                                                             \Gamma_{458} K^*(892)^+ e^- \mu^+
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                                                           \times\,10^{-7} CL=90%
                                                                                                                                                                                                                                             < 9.9
\Gamma_{393} p \overline{p} \pi^+ \pi^+ \pi^-
                                                                                                                                                             \Gamma_{459} K^*(892)^+ e^{\pm} \mu^{\mp}
                                                                                                                                                                                                                                                                           \times 10^{-6} CL=90%
                                                                                                                                                                                                                          LF
                                                                                                                                                                                                                                            < 1.4
\Gamma_{394} p \overline{p} K^+
                                                                                ( 5.9 \pm 0.5 ) \times 10^{-6} S=1.5
                                                                                                                                                                                                                                                                           ×10<sup>-6</sup> CL=90%
                                                                                                                                                             \Gamma_{460} \pi^{-} e^{+} e^{+}
                                                                                                                                                                                                                          L
                                                                                                                                                                                                                                            < 1.6
                                                                                                           \times 10^{-8} CL=90%
               \Theta(1710)^{++}\overline{p}\times
\Gamma_{395}
                                                                         [g] < 9.1
                                                                                                                                                                                                                                                                           \times 10^{-8} CL=90%
                                                                                                                                                             \Gamma_{461} \ \pi^- \, \mu^+ \, \mu^+
                                                                                                                                                                                                                          L
                                                                                                                                                                                                                                             < 4.4
                     B(\Theta(1710)^{++} \rightarrow pK^{+})
                                                                                                                                                             \Gamma_{462} \pi^- e^+ \mu^+
                                                                                                                                                                                                                                                                           \times 10^{-6} CL=90%
                                                                                                                                                                                                                                             < 1.3
                                                                                                                                                                                                                          L
                                                                                                            \times 10^{-7} CL=90%
               f_I(2220) K^+ \times B(f_I(2220) \rightarrow
\Gamma_{396}
                                                                        [g] < 4.1
                                                                                                                                                             \Gamma_{463} \rho^{-} e^{+} e^{+}
                                                                                                                                                                                                                                                                           ×10<sup>-6</sup> CL=90%
                                                                                                                                                                                                                          L
                                                                                                                                                                                                                                             < 2.6
```

 $\Gamma_{464} \ \rho^- \mu^+ \, \mu^+$

 $\times\,10^{-6}$ CL=90%

< 1.5

×10⁻⁶ CL=90%

| Γ_{466} | $ \rho^- e^+ \mu^+ \\ K^- e^+ e^+ $ | L L | < | 3.3 1.0 | $\times 10^{-6}$ | CL=90% CL=90% |
|----------------|-------------------------------------|--------|---|------------|------------------|------------------|
| | $K^{-}\mu^{+}\mu^{+}$ | L | - | 4.1 | | CL=90% |
| | $K^- e^+ \mu^+$ | L | - | 2.0 | | CL=90% |
| | $K^*(892)^- e^+ e^+$ | L | < | 2.8 | | CL=90% |
| | $K^*(892)^- \mu^+ \mu^+$ | L | < | 8.3 | | CL=90% |
| | $K^*(892)^- e^+ \mu^+$ | L | < | 4.4 | | CL=90% |
| | $D^{-} e^{+} e^{+}$ | L | < | 2.6 | | CL=90% |
| | $D^{-}e^{+}\mu^{+}$ | L | < | 1.8 | | CL=90% |
| | $D^{-}\mu^{+}\mu^{+}$ | L | < | 1.1 | | CL=90% |
| Γ_{475} | $\Lambda^0_{\mu}^+$ | L,B | < | 6 | | CL=90% |
| Γ_{476} | $\Lambda^0 e^+$ | L,B | < | 3.2 | $\times 10^{-8}$ | CL=90% |
| | $\overline{\Lambda}^0_{\mu}^+$ | L,B | < | 6 | | CL=90% |
| Γ_{478} | $\overline{\Lambda}{}^0 e^+$ | L,B | < | 8 | $\times 10^{-8}$ | CL=90% |

- [a] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [b] An $CP(\pm 1)$ indicates the CP=+1 and CP=-1 eigenstates of the $D^0-\overline{D}{}^0$ system.
- [c] D denotes D^0 or \overline{D}^0 .
- [d] D_{CP+}^{*0} decays into $D^0\pi^0$ with the D^0 reconstructed in $C\!P$ -even eigenstates K^+K^- and $\pi^+\pi^-$.
- [e] \overline{D}^{**} represents an excited state with mass 2.2 < M < 2.8 GeV/c².
- [f] $X(3872)^+$ is a hypothetical charged partner of the X(3872).
- $[g] \Theta(1710)^{++}$ is a possible narrow pentaquark state and G(2220) is a possible glueball resonance.
- [h] $(\overline{\Lambda}_c^- p)_s$ denotes a low-mass enhancement near 3.35 GeV/c².

CONSTRAINED FIT INFORMATION

An overall fit to 18 branching ratios uses 48 measurements and one constraint to determine 12 parameters. The overall fit has a $\chi^2 = 38.8$ for 37 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

| | ı | | | | | | | | | |
|------------------------|-----------------------|-----------------------|------------------------|------------------------|-------------------------|-------------------|-------------------------|------------------|-------------------------|------------------|
| <i>x</i> ₇ | 14 | | | | | | | | | |
| x_{42} | 0 | 0 | | | | | | | | |
| <i>x</i> ₇₁ | 0 | 0 | 8 | | | | | | | |
| x ₁₀₂ | 0 | 0 | 1 | 13 | | | | | | |
| X ₁₈₅ | 0 | 0 | 0 | 0 | 0 | | | | | |
| x ₂₀₅ | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| X214 | 0 | 0 | 0 | 0 | 0 | 36 | 0 | | | |
| x ₂₂₃ | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 5 | | |
| X ₄₄₃ | 0 | 0 | 0 | 0 | 0 | 27 | 0 | 10 | 4 | |
| X ₄₄₈ | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 |
| | <i>x</i> ₆ | <i>x</i> ₇ | <i>x</i> ₄₂ | <i>x</i> ₇₁ | <i>x</i> ₁₀₂ | X _{1 85} | <i>x</i> ₂₀₅ | ^X 214 | <i>x</i> ₂₂₃ | X ₄₄₃ |

B+ BRANCHING RATIOS

 $\Gamma(\ell^+ \nu_\ell a \, nything)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below.

The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

| VALUE (units 10^{-2}) | DO CUMENT ID | TECN | COMMENT |
|-------------------------------|-----------------------|----------------|--------------------------------------|
| 10.99±0.28 OUR EVALUATION | ON | | |
| 10.76±0.32 OUR AVERAGE | Error includes scale | factor of 1.1 | |
| $11.17 \pm 0.25 \pm 0.28$ | | | $e^+e^- ightarrow \gamma(4S)$ |
| $10.28 \pm 0.26 \pm 0.39$ | ² AUBERT,B | 06Y BAB | $R e^+ e^- \rightarrow \Upsilon(4S)$ |
| $10.25 \pm 0.57 \pm 0.65$ | ³ ARTUSO | 97 CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the follo | wing data for average | s, fits, limit | s, etc. • • • |
| $11.15 \pm 0.26 \pm 0.41$ | ⁴ OKABE | 05 BELI | L Repl. by URQUIJO 07 |
| 10.1 +1.8 +1.5 | ATHANAS | 94 CLE | Sup by ARTHSO 97 |

- 1 URQUIJO 07 report a measurement of (10.34 \pm 023 \pm 0.25)% for the partial branching fraction of $B^+\to~e^+\nu_e\,X_{\rm C}$ decay with electron energy above 0.6 GeV. We converted the result to $B^{\,+}\,\rightarrow\,\,e^{\,+}\,\overline{\nu_e\,X}$ branching fraction.
- 2 The measurements are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame. The best precision on the ratio is achieved for a momentum threshold of 1.0 GeV: B($B^+
 ightarrow$ $\label{eq:epsilon} {\rm e}^+\,\nu_e\,X)\;/\;{\rm B}(B^0\to\;{\rm e}^+\,\nu_e\,X)\,=\,1.074\,\pm\,0.041\,\pm\,0.026.$
- 3 ARTUSO 97 uses partial reconstruction of $B\to D^*\ell\nu_\ell$ and branching ratio from BARISH 96B (0.1049 \pm 0.0017 \pm 0.0043). and inclusive semileptonic
- ⁴ The measurements are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame, and their ratio of B(B⁺ $\to e^+ \nu_e X)/B(B^0 \to e^+ \nu_e X) = 1.08 \pm 0.05 \pm 0.02$.

| $\Gamma(e^+ \nu_e X_c) / \Gamma_{ m total}$ | | | | | Γ2, | /Г |
|---------------------------------------------|----------------------|----|------|----------------------|----------------|----|
| VALUE (units 10 ⁻²) | DO CUMENT ID | | TECN | COMMENT | | |
| $10.79 \pm 0.25 \pm 0.27$ | ¹ urquijo | 07 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |

 1 Measure the independent B^{+} and B^{0} partial branching fractions with electron threshold energies of 0.4 GeV

 $\Gamma(\overline{D}^0\ell^+\nu_\ell)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

| $\ell=e$ or μ , not sum ove | r e and μ modes. | | | | | |
|-----------------------------------------------------------------------------|------------------------|----------|-----------|-----------------------------------|--|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| 0.0226 ± 0.0011 OUR EVALUA | TION | | | | | |
| 0.0229 ± 0.0008 OUR AVERAG | E | | | | | |
| $0.0229 \pm 0.0008 \pm 0.0009$ | ¹ AUBERT | 10 | BABR | $e^+e^- ightarrow \gamma(4S)$ | | |
| $0.0234 \pm 0.0003 \pm 0.0013$ | AUBERT | 09A | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | | |
| $0.0221 \pm 0.0013 \pm 0.0019$ | ² BARTELT | 99 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ | | |
| $0.016 \pm 0.006 \pm 0.003$ | ³ FULTON | 91 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ | | |
| | wing data for average | es, fits | , limits, | etc. • • • | | |
| $0.0233 \pm 0.0009 \pm 0.0009$ | ¹ AUBERT | 08Q | BABR | Repl. by AUBERT 09A | | |
| $0.0194 \pm 0.0015 \pm 0.0034$ | ⁴ ATHANAS | 97 | CLE2 | Repl. by BARTELT 99 | | |
| $^{ m 1}$ Uses a fully reconstructed B meson as a tag on the recoil side. | | | | | | |
| ² Assumes equal production | | | | | | |
| 3 FILLTON 91 assumes equal | | | | at the $\Upsilon(AS)$ | | |

FULTON 91 assumes equal production of $B^{0}\overline{B}{}^{0}$ and $B^{+}B^{-}$ at the $\Upsilon(4S)$.

 $^{^4}$ ATHANAS 97 uses missing energy and missing momentum to reconstruct neutrino.

| $\Gamma(\overline{D}{}^0\ell^+ u_\ell)/\Gamma(\ell^+ u_\ell$ anythin | ıg) | | | | Γ_4/Γ_1 |
|----------------------------------------------------------------------|--------------|----|------|----------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.255 ±0.009 ± 0.009 | 1 AUBERT | 10 | BABR | e^+e^- | Y(45) |

¹ Uses a fully reconstructed B meson on the recoil side.

| $\Gamma(D^{\circ}	au^{+} u_{	au})/\Gamma_{total}$ | | | | | Γ5/Γ |
|---------------------------------------------------|----------------------|----------|-----------|----------------------|-----------|
| VALUE (units 10 ⁻²) | DO CUMENT ID | ı | TECN | COMMENT | |
| $0.77 \pm 0.22 \pm 0.12$ | ¹ BOZEK | 10 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| | wing data for averag | es, fits | , limits, | etc. • • • | |
| $0.67 \pm 0.37 \pm 0.13$ | ² AUBERT | 08N | BABR | Repl. by A | UBERT 09s |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

²Uses a fully reconstructed B meson as a tag on the recoil side.

| $\Gamma(\overline{D}{}^0	au^+ u_	au)/\Gamma(\overline{D}{}^0\ell^+ u_\ell)$ | | | | | Γ_5/Γ_4 |
|-----------------------------------------------------------------------------|--------------|-----|------|----------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.314±0.170±0.049 | 1 AUBERT | 09s | BABR | $e^+e^- \rightarrow$ | Y(45) |

¹Uses a fully reconstructed B meson as a tag on the recoil side.

| $\Gamma(\overline{D}{}^0\ell^+ u_\ell)/\Gamma(D\ell^+ u_\ell$ a nything) | | | | | | |
|--------------------------------------------------------------------------|--------------|-----------|----------|-------|---|--|
| VALUE | DO CUMENT ID | TECN | COMMENT | | _ | |
| 0.227±0.014±0.016 | 1 AUBERT | 07AN BABR | e^+e^- | r(45) | | |

 $^{
m 1}$ Uses a fully reconstructed B meson on the recoil side.

 $\Gamma(\overline{D}^*(2007)^0\ell^+\nu_\ell)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group $(HFAG) \ and \ are \ described \ at \ http://www.slac.stanford.edu/xorg/hfag/. \ The \ average of the average of the control

aging/rescaling procedure takes into account correlations between the measurements. $\ell=e$ or μ , not sum over e and μ modes.

<u>VALUE</u> <u>EVTS</u> **0.0570±0.0019 OUR EVALUATION** 0.0559 ± 0.0026 OUR FIT Error includes scale factor of 1.5.

0.0558±0.0026 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram $0.0540 \pm 0.0002 \pm 0.0021$ 09A BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT $^{\mathrm{1}}$ AUBERT 08AT BABR $e^+e^- \rightarrow \Upsilon(4S)$ $0.0556 \pm 0.0008 \pm 0.0041$ $^{2}\,\mathrm{ADAM}$ 03 CLE2 $e^+e^- \rightarrow r(4S)$ $0.0650 \pm 0.0020 \pm 0.0043$ 92c ARG $e^+e^- \rightarrow \Upsilon(4S)$ ³ ALBRECHT $0.066 \pm 0.016 \pm 0.015$ • • • We do not use the following data for averages, fits, limits, etc. • • •

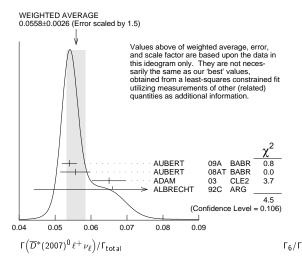
 $0.0583 \pm 0.0015 \pm 0.0030$ ⁴ AUBERT 08Q BABR Repl. by AUBERT 09A ⁵ BRIERE $0.0650 \pm 0.0020 \pm 0.0043$ 02 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ $0.0513 \pm 0.0054 \pm 0.0064$ 302 ⁶ BARISH CLE2 Repl. by ADAM 03 ⁷ SANGHERA 93 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ $0.041 \pm 0.008 \begin{array}{c} + 0.008 \\ - 0.009 \end{array}$ ⁸ FULT ON 91 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ $^{9}\,\mathrm{ANTREASYAN\,90B}$ CBAL $e^{+}\,e^{-}
ightarrow ~ \varUpsilon(4S)$ $0.070\ \pm0.018\ \pm0.014$

- 1 Measured using the dependence of $B^- o D^{*0} \, e^- \overline{
 u}_e$ decay differential rate and the form factor description by CAPRINI 98.
- ² Simultaneous measurements of both $B^0 \to D^*(2010)^- \ell \nu$ and $B^+ \to \overline{D}(2007)^0 \ell \nu$.
- 3 ALBRECHT 92c reports $0.058 \pm 0.014 \pm 0.013$. We rescale using the method described in STONE 94 but with the updated PDG 94 B($D^0 \rightarrow K^- \pi^+$). Assumes equal production of $B^0\overline{B}^0$ and B^+B^- at the $\Upsilon(4S)$
- ⁴ Uses a fully reconstructed B meson as a tag on the recoil side.
- 5 The results are based on the same analysis and data sample reported in ADAM 03. 6 BARISH 95 use B($D^0\to K^-\pi^+)=(3.91\pm0.08\pm0.17)\%$ and B($D^{*0}\to D^0\pi^0)=(63.6\pm2.3\pm3.3)\%$.
- ⁷Combining $\overline{D}^{*0}\ell^+\nu_\ell$ and $\overline{D}^{*-}\ell^+\nu_\ell$ SANGHERA 93 test $V\!-\!A$ structure and fit the decay angular distributions to obtain $A_{FB}=3/4*(\Gamma^--\Gamma^+)/\Gamma=0.14\pm0.06\pm0.03$.

Assuming a value of V_{CD} , they measure V, A_1 , and A_2 , the three form factors for the $D^*\ell\nu_\ell$ decay, where results are slightly dependent on model assumptions.

⁸ Assumes equal production of $B^0 \overline{B^0}$ and $B^+ B^-$ at the $\Upsilon(4S)$. Uncorrected for D and D^* branching ratio assumptions.

 9 ANTREASYAN 90B is average over B and $\overline{D}*(2010)$ charge states.



| $\Gamma(D^*(2007)^0 \tau^+ \nu_{\tau})/\Gamma_{\text{tota}}$ | l | | | | Γ_7/Γ |
|--------------------------------------------------------------|---------------------------------------------|------------------|-----------|--------------|-------------------|
| VALUE (units 10 ⁻²) | DO CUMENT IL |) | TECN | COMMENT | |
| 2.04±0.30 OUR FIT | | | | | |
| $2.12^{+0.28}_{-0.27}\pm0.29$ | $^{ m 1}$ BOZEK | 10 | BELL | $e^+e^- \to$ | $\Upsilon(4S)$ |
| • • • We do not use the follow | wing data for averag | ges, fits | , limits, | etc. • • • | |
| $2.25 \pm 0.48 \pm 0.28$ | ² AUBERT | 08N | BABR | Repl. by A | UBERT 09s |
| ¹ Assumes equal production | of \mathcal{B}^+ and \mathcal{B}^0 at t | he $\Upsilon(4)$ | S). | | |
| ² Uses a fully reconstructed | | | | | |

| $\Gamma(\overline{D}^*(2007)^0 \tau^+ \nu_{	au})/\Gamma(\overline{D}^*(2007)^0 \ell^+ \nu_{\ell})$ | | | | | Γ_7/Γ_6 |
|----------------------------------------------------------------------------------------------------|---------------------|-----|------|----------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.36 ±0.05 OUR FIT | | | | | |
| $0.346 \pm 0.073 \pm 0.034$ | ¹ AUBERT | 09s | BABR | $e^+e^- \rightarrow$ | Y(45) |

 $^{
m 1}$ Uses a fully reconstructed $\it B$ meson as a tag on the recoil side.

| $\Gamma(\overline{D}^*(2007)^0\ell^+\nu_\ell)/\Gamma(D\ell$ | $^+ u_\ell$ anything) | | | Γ_6/Γ_3 |
|-------------------------------------------------------------|-----------------------|-----------|--------------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| $0.582\pm0.018\pm0.030$ | ¹ AUBERT | 07AN BABR | $e^+e^- \to$ | $\Upsilon(4S)$ |

 $^{\mathrm{1}}$ Uses a fully reconstructed B meson on the recoil side.

| $\Gamma(D^{(*)} n \pi \ell^+ u_\ell (n \geq 1)) /$ | $\Gamma(D\ell^+ u_\ell$ anything | 3) | | Γ_{11}/Γ_3 |
|--------------------------------------------------------|----------------------------------|-----------|----------------------|------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| 0.191±0.013±0.019 | 1 AUBERT | 07AN BABR | $e^+e^- \rightarrow$ | T(45) |

 $^{
m 1}$ Uses a fully reconstructed B meson on the recoil side.

| $\Gamma(D \pi' \ell' \nu_{\ell})/\Gamma_{\text{total}}$ | | | | | 18/1 |
|---------------------------------------------------------|--------------------------|----------|------------|-----------------------------------|-------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT | |
| 4.2±0.5 OUR AVERAGE | | | | | |
| $4.2 \pm 0.6 \pm 0.3$ | ¹ AUBERT | | | $e^+e^- \rightarrow \gamma(4S)$ | |
| $4.2 \pm 0.6 \pm 0.2$ | ^{1,2} LIVENTSEV | 08 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| • • • We do not use the fo | ollowing data for avera | iges, fi | its, limit | s, etc. • • • | |
| $5.5 \pm 0.9 \pm 0.3$ | 3 LIVENTSEV | 05 | BELL | Repl. by LIVENTS | EV 08 |

 $^{
m 1}$ Uses a fully reconstructed ${\it B}$ meson as a tag on the recoil side.

 $^2\,\text{LIVENTSEV}$ 08 reports (4.0 \pm 0.4 \pm 0.6) \times 10 $^{-3}$ from a measurement of [Г(B+ \rightarrow $D^-\pi^+\ell^+\nu_\ell)/\Gamma_{\rm total}]\,/\,[{\rm B}(B^+\to\,\overline{D}{}^0\ell^+\nu_\ell)] \ {\rm assuming} \ {\rm B}(B^+\to\,\overline{D}{}^0\ell^+\nu_\ell)=(2.15\pm0.00)$ $0.22) \times 10^{-2}$, which we rescale to our best value B($B^+ \to \overline{D}{}^0 \ell^+ \nu_{\ell}$) = $(2.26 \pm 0.11) \times$ 10^{-2} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

3 LIVENTSEV 05 reports $[\Gamma(B^+ \to D^-\pi^+ \ell^+ \nu_\ell)/\Gamma_{\text{total}}]$ / $[B(B^0 \to D^- \ell^+ \nu_\ell)]$ = 0.25 \pm 0.03 \pm 0.03 which we multiply by our best value B($B^0 \rightarrow D^- \ell^+ \nu_\ell$) = $(2.18 \pm 0.12) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\overline{D}_0^*(2420)^0\ell^+\nu_\ell \times B(\overline{D}_0^{*0})^{-1})$ | $\rightarrow D^-\pi^+))/\Gamma_1$ | otal | | | Г9 | /г |
|-------------------------------------------------------------------------------------|-----------------------------------|--------|------|--------------|----------------|----|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TE | E CN | COMMENT | | |
| 2.5 ± 0.5 OUR AVERAGE | | | | | | |
| $2.6 \pm 0.5 \pm 0.4$ | ¹ AUBERT | 08BL B | ABR | e^+e^- | $\Upsilon(4S)$ | |
| $2.4 \pm 0.4 \pm 0.6$ | $^{ m 1}$ LIVENTSEV | 08 BI | ELL | $e^+e^- \to$ | Y(45) | |

 $^{^{}m 1}$ Uses a fully reconstructed $\it B$ meson as a tag on the recoil side.

| $\Gamma(\overline{D}_2^*(2460)^0 \ell^+ \nu_\ell \times B($ | $\sqrt{D}^{*0} \rightarrow D^{-}\pi^{+}))/\Gamma_{*}$ | | | Γ ₁₀ /Γ |
|----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|----------------------------------------------|--------------------------|------------------------|
| VALUE (units 10 ⁻³) | DOCUMENT ID | .OLAI TECN | COMMENT | . 10/. |
| 1.53±0.16 OUR AVERAGE | | | | |
| $1.42 \pm 0.15 \pm 0.15$ | ¹ AUBERT | 09Y BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $1.5 \pm 0.2 \pm 0.2$ | ² AUBERT | 08BL BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.2 \pm 0.3 \pm 0.4$ | ² LIVENTSEV | 08 BELL | $e^+e^- \rightarrow$ | r(45) |
| ¹ Uses a simultaneous fit AUBERT 09Y reports E (2.29 ± 0.23 ± 0.21)×10 ² Uses a fully reconstruct | $3(B^+ \to \overline{D}_2^*(2460)^0 \ell^+$ | $\nu_{\ell}) \cdot B(\overline{D}_{2}^{*}(2$ | $(2460)^0 \rightarrow I$ | $O^{(*)} - \pi^{+}) =$ |
| $\Gamma(D^{*-}\pi^+\ell^+ u_\ell)/\Gamma_{ m total}$ | - | | | Γ ₁₂ /Γ |

| · (= £// · total | | | | | . 121 . |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|-----------------------------------------|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT | |
| 6.1 ± 0.6 OUR AVERAGE | | | | | |
| $5.9 \pm 0.5 \pm 0.4$ | ¹ AUBERT | 08Q | BABR | $e^+e^- \rightarrow$ | Y(45) |
| $6.7 \pm 1.1 \pm 0.3$ | 1,2 LIVENTSEV | 08 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not use the fol | | | | | |
| $5.9\!\pm\!1.4\!\pm\!0.1$ | ^{3,4} LIVENTSEV | 05 | BELL | Repl. by L | IVENTSEV 08 |
| 1 Uses a fully reconstructed 2 LIVENTSEV 08 reports $D^* - \pi^+ \ell^+ \nu_\ell / \Gamma_{\rm total} \\ (2.15 \pm 0.22) \times 10^{-2}, \\ (2.26 \pm 0.11) \times 10^{-2}. \\ \text{C} \\ \text{the systematic error from} \\ ^3$ Excludes D^{*+} contributing the LIVENTSEV of the systematic error from the systemat | $(6.4 \pm 0.8 \pm 0.9) \times$ $/ [B(B^+ \rightarrow \overline{D}^0 \ell^+]$ which we rescale to Our first error is their using our best value on to $D\pi$ modes. | 10^{-3} (ν_ℓ) our becomes | from a assumin est valu ment's | measureme g B(B^+ \rightarrow ue B(B^+ \rightarrow error and ou | $ \frac{\overline{D}^0 \ell^+ \nu_{\ell}}{\overline{D}^0 \ell^+ \nu_{\ell}} = $ |
| $\Gamma_{	ext{total}}] / [B(B^0 ightarrow D^*]$ our best value $B(B^0 ightarrow$ their experiment's error a | $(2010)^{-}\ell^{+}\nu_{\ell})] = 0$ $D^{*}(2010)^{-}\ell^{+}\nu_{\ell}) = 0$ | 0.12 ± = (4.95 | 0.02 ± ± 0.11 | 0.02 which 1×10^{-2} | we multiply by Our first error is |

| $\Gamma(D_s^{*-}K^+\ell^+ u_\ell)/\Gamma_{ m total}$ | | | | Γ ₁₃ /Γ |
|------------------------------------------------------|----------------------------|------|--------------|--------------------|
| VALUE (units 10 ⁻⁴) | DOCUMENT ID | TECN | COMMENT | |
| $6.13^{+1.04}_{-1.03} \pm 0.67$ | ¹ DEL-AMO-SA11L | BABR | $e^+e^- \to$ | Y(45) |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(\overline{D}_1(2420)^0 \ell^+ \nu_{\ell} \times B(\overline{D}_1^0 -$ | → D*-π+))/Γ _{to} | otal | | | Γ_{14}/Γ |
|-------------------------------------------------------------------------------|---------------------------|------|------|----------------------|----------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT | |
| 3.03±0.20 OUR AVERAGE | | | | | |
| $2.97 \pm 0.17 \pm 0.17$ | ¹ AUBERT | 09Y | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.9 \pm 0.3 \pm 0.3$ | ² AUBERT | 08BL | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $4.2 \pm 0.7 \pm 0.7$ | ² LIVENTSEV | 80 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| $3.73 \pm 0.85 \pm 0.57$ | ³ ANASTASSOV | 98 | CLE2 | $e^+e^- \rightarrow$ | Y(45) |

 $^{
m 1}$ Uses a simultaneous measurement of all $\it B$ semileptonic decays without full reconstruction

of events. 2 Uses a fully reconstructed B meson as a tag on the recoil side. 3 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

 $\Gamma(\overline{D}_1'(2430)^0 \ell^+ \nu_\ell \times \mathsf{B}(\overline{D}_1'^0 o D^{*-} \pi^+))/\Gamma_{\mathsf{total}}$ Γ_{15}/Γ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT ¹ AUBERT 08BL BABR $e^+e^-
ightarrow$ $2.7 \pm 0.4 \pm 0.5$ • • • We do not use the following data for averages, fits, limits, etc. • • • 1 LIVENTSEV 08 BELL $e^+e^-
ightarrow ~ \varUpsilon$ (45) 90

1 Uses a fully reconstructed B meson as a tag on the recoil side.

| $(\overline{D}_{2}^{*}(2460)^{0}\ell^{+}\nu_{\ell}$ | \times B(\overline{D}_{2}^{*0} | $\rightarrow D^{*-}\pi^{+}))/\Gamma$ | total | | | Γ_{16}/Γ |
|-----------------------------------------------------|-------------------------------------|--------------------------------------|----------|---------|----------------------|----------------------|
| ALUE (units 10^{-3}) | CL% | DOCUMENT ID | | TECN | COMMENT | |
| 1.01 ± 0.24 OUR A | VERAGE | Error includes scale | facto | of 2.0. | | |
| $0.87 \pm 0.11 \pm 0.07$ | | ¹ AUBERT | 09Y | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $1.5 \pm 0.2 \pm 0.2$ | | ² AUBERT | 08BL | BABR | $e^+e^- \rightarrow$ | Y(45) |
| $1.8 \pm 0.6 \pm 0.3$ | | ² LIVENTSEV | 08 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • We do not use | the followi | ng data for average | s, fits, | limits, | etc. • • • | |
| <1.6 | 90 | ³ ANASTASSO\ | / 98 | CLE2 | $e^+e^- \rightarrow$ | Y(45) |
| 1 Uses a simultaneo | | B semileptonic deca | | | | |

 $\rightarrow \overline{D}_{2}^{*}(2460)^{0} \ell^{+} \nu_{\ell}) \cdot B(\overline{D}_{2}^{*}(2460)^{0})$ $(2.29\pm0.23\pm0.21)\times10^{-3}$ and the authors have provided us the individual measurement. ² Uses a fully reconstructed B meson as a tag on the recoil side. ³ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(\pi^0\ell^+\nu_\ell)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

| 0 0/ | | | |
|-----------------------------------|------------------------|------------------|-----------------------------------|
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN | COMMENT |
| 0.778±0.028 OUR EVALUAT | TON | | |
| 0.72 ±0.04 OUR AVERAGE | | | |
| $0.705 \pm 0.025 \pm 0.035$ | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.82 \pm 0.09 \pm 0.05$ | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.77 \pm 0.14 \pm 0.08$ | ² HOKUUE | 07 BELL | $e^+e^- \rightarrow \gamma(4S)$ |
| • • • We do not use the following | owing data for average | s, fits, limits, | etc. • • • |
| $0.74 \ \pm 0.05 \ \pm 0.10$ | ³ AUBERT,B | 050 BABR | Repl. by DEL-AMO- |

ı

 $^{^2}$ The signal events are tagged by a second B meson reconstructed in the semileptonic mode $B \to D^{(*)} \ell \nu_{\ell}$.

 B^+ and B^0 decays combined assuming isospin symmetry. Systematic errors include both experimental and form-factor uncertainties.

| $\Gamma(\pi^0 e^+ \nu_e)/\Gamma_{\rm tot}$ | al | | | | Г ₁₈ /Г |
|--------------------------------------------|-----------------|---------------------------|-------------|----------------------|--------------------|
| VALUE (units 10^{-4}) | CL% | DOCUMENT ID | TECN | COMMENT | |
| • • • We do not us | se the followin | g data for averages, fi | ts, limits, | etc. • • • | |
| $0.9 \pm 0.2 \pm 0.2$ | | ¹ ALEXANDER 96 | T CLE2 | $e^+e^- \to$ | Y(45) |
| <22 | 90 | ANTREASYAN 90 | в CBAL | $e^+e^- \rightarrow$ | Y(45) |

 1 Derived based in the reported B^0 result by assuming isospin symmetry: $\Gamma(B^0
ightarrow$ $\pi^- \ell^+ \nu$)= $2\Gamma(B^+ \to \pi^0 \ell^+ \nu)$.

| $\Gamma(\eta \ell^+ u_\ell) / \Gamma_{\text{total}}$ | Г19/Г |
|-------------------------------------------------------|-------|
| ' ('/'C PEJ/' total | 119/1 |

| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|------------|---------------------|----------|-----------|-----------------------------------|
| 0.39 ± 0.08 OUR AVE | RAGE E | rror includes scale | | | |
| $0.36 \pm 0.05 \pm 0.04$ | | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.64 \pm 0.20 \pm 0.03$ | | ² AUBERT | 08AV | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ullet $ullet$ $ullet$ We do not use th | e followin | g data for averages | s, fits, | limits, e | etc. • • • |
| $0.31 \pm 0.06 \pm 0.08$ | | ³ AUBERT | 09Q | BABR | Repl. by DEL-AMO- SANCHEZ 11F |
| <1.01 | 90 | ⁴ ADAM | 07 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.84 \pm 0.31 \pm 0.18$ | | ⁵ ATHAR | 03 | CLE2 | Repl. by ADAM 07 |
| 4 | | | | | |

¹ Uses the neutrino reconstruction technique. Assumes B($Y(4S) \rightarrow B^+B^-$) = (51.6 \pm 0.6)% and B($Y(4S) \rightarrow B^0 \overline{B}^0$) = (48.4 ± 0.6)%. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(\eta'\ell^+\nu_\ell)/\Gamma_{\mathrm{total}}$ Γ_{20}/Γ

| VALUE (units 10 ⁻⁴) | DOCUMENT ID | | TECN | COMMENT | |
|---------------------------------|--------------------------|------|------|---------------------|----------------|
| 0.23±0.08 OUR AVERAGE | | | | | |
| $0.24\pm0.08\pm0.03$ | ¹ DEL-AMO-SA. | 11F | BABR | $e^+e^- ightarrow$ | Y(45) |
| $0.04 \pm 0.22 + 0.05 \\ -0.02$ | ² AUBERT | 08AV | BABR | $e^+e^- \to$ | $\Upsilon(4S)$ |
| $2.66 \pm 0.80 \pm 0.56$ | ³ ADAM | 07 | CLE2 | $e^+e^- \to$ | $\Upsilon(4S)$ |

 $^{^{1}}$ Uses the neutrino reconstruction technique. Assumes B(Y(4S) ightarrow B $^{+}$ B $^{-}$) = (51.6 \pm

$\Gamma(\omega \ell^+ \nu_\ell)/\Gamma_{\text{total}}$ Γ_{21}/Γ

 $\ell = e$ or μ , not sum over e and μ modes.

| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------------------|-------------|------------------------|----------|---------|------------------------------------------|--|
| 1.15 ± 0.17 OUR AV | ERAGE | · | | | | |
| $1.14 \pm 0.16 \pm 0.08$ | | | | | $e^+ e^- \rightarrow \Upsilon(4S)$ | |
| $1.3 \pm 0.4 \pm 0.4$ | | ² SCHWA NDA | 04 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | |
| ● ● We do not use t | he followin | g data for average | s, fits, | limits, | etc. • • • | |
| <2.1 | 90 | ³ BEAN | 93в | CLE2 | $e^+ e^- \rightarrow \ \varUpsilon(4S)$ | |

1 Uses B($\Upsilon(4S) \to B^+ B^-$) = (51.6 ± 0.6)% and B($\Upsilon(4S) \to B^0 \overline{B}{}^0$) = (48.4 ± 0.6)%.

³ BEAN 93B limit set using ISGW Model. Using isospin and the quark model to combine $\Gamma(
ho^0\,\ell^+
u_\ell)$ and $\Gamma(
ho^-\,\ell^+
u_\ell)$ with this result, they obtain a limit $<\!(1.6$ –2.7) imes 10^{-4} at 90% CL for $B^+ \to \omega \ell^+ \nu_\ell$. The range corresponds to the ISGW, WSB, and KS models. An upper limit on $|V_{ub}/V_{cb}| < 0.8-0.13$ at 90% CL is derived as well.

$\Gamma(\omega \mu^+ \nu_\mu)/\Gamma_{\text{total}}$ Γ_{22}/Γ

| VALUE | DO CUMENT ID | I E CIV |
|-------------------------------------------|----------------------------|----------------------|
| ullet $ullet$ We do not use the following | ng data for averages, fits | , limits, etc. • • • |
| seen | ¹ ALBRECHT 91c | ARG |

 $^{^{1}}$ In ALBRECHT 91c, one event is fully reconstructed providing evidence for the b
ightarrow u

$\Gamma(ho^0\ell^+ u_\ell)/\Gamma_{ m total}$ Γ_{23}/Γ ntsum overeand umodes

| $\epsilon = \epsilon$ or μ , not so | iiii ovci c | and μ modes. | | | |
|-----------------------------------------|-------------|------------------------|---------|---------|---------------------------------------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT |
| 1.07±0.13 OUR AVE | RAGE | | | | |
| $0.94 \pm 0.08 \pm 0.14$ | | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.33 \pm 0.23 \pm 0.18$ | | ² HOKUUE | 07 | BELL | $e^+e^- \rightarrow \gamma(4S)$ |
| $1.34 \pm 0.15 {}^{+ 0.28}_{- 0.32}$ | | ³ BEHRENS | 00 | CLE2 | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| ullet $ullet$ $ullet$ We do not use th | e following | g data for averages | , fits, | limits, | etc. • • • |
| $1.16 \pm 0.11 \pm 0.30$ | | ¹ AUBERT,B | 050 | BABR | Repl. by DEL-AMO- SANCHEZ 11c |
| $1.40 \pm 0.21 {}^{+ 0.32}_{- 0.33}$ | | ³ BEHRENS | 00 | CLE2 | $e^+e^- ightarrow ~ \varUpsilon(45)$ |
| $1.2\ \pm0.2\ ^{+0.3}_{-0.4}$ | | ³ ALEXANDER | 96T | CLE2 | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| <21 | 90 | 4 REAN | 03b | CLE2 | $e^+e^- \rightarrow \gamma(45)$ |

 $^1B^+$ and B^0 decays combined assuming isospin symmetry. Systematic errors include both

experimental and form-factor uncertainties. 2 The signal events are tagged by a second $^{\it B}$ meson reconstructed in the semileptonic mode $B o D^{(*)} \ell
u_\ell$

 3 Derived based in the reported B^0 result by assuming isospin symmetry: $\Gamma(B^0
ightarrow$ $\rho^-(\ell^+\nu)=2\Gamma(B^+\to\rho^0(\ell^+\nu)\approx 2\Gamma(B^+\to\omega\ell^+\nu)$. 4 BEAN 93B limit set using ISGW Model. Using isospin and the quark model to combine

 $\Gamma(\omega^0\ell^+\nu_\ell)$ and $\Gamma(\rho^-\ell^+\nu_\ell)$ with this result, they obtain a limit <(1.6–2.7) \times 10⁻⁴ at 90% CL for $B^+\to \rho^0\ell^+\nu_\ell$. The range corresponds to the ISGW, WSB, and KS models. An upper limit on $\left|V_{ub}/V_{cb}\right| < 0.8$ –0.13 at 90% CL is derived as well.

$\Gamma(p \overline{p} e^+ \nu_e) / \Gamma_{\text{total}}$ Γ_{24}/Γ

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
|------------------------|-----|-------------------|-----|------|--------------------------------|--|
| $< 5.2 \times 10^{-3}$ | 90 | ¹ ADAM | 03в | CLE2 | $e^+e^- ightarrow \gamma(4S)$ | |

 $^{
m 1}$ Based on phase-space model; if $V\!-\!A$ model is used, the 90% CL upper limit becomes

$\Gamma(e^+\nu_e)/\Gamma_{\rm total}$ Γ_{25}/Γ

| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------|-------------|-------------------|---------|-----------|----------------------|----------------|
| < 0.98 | 90 1 | SATOYA MA | 07 | BELL | $e^+e^ \rightarrow$ | Y(45) |
| ● ● We do not use the | following o | data for averages | , fits, | limits, e | tc. • • • | |
| < 8 | | | 10E | BABR | e^+e^- | Y(45) |
| < 1.9 | 90 1 | AUBERT | 09∨ | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| < 5.2 | 90 1 | | | | $e^+e^- \rightarrow$ | |
| <15 | 90 | ARTUSO | 95 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(\mu^+\nu_\mu)/\Gamma_{\rm total}$ Γ_{26}/Γ

| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-----------|-----------------------|---------|-----------|-----------------------------------|
| < 1.0 | 90 | 1 AUBERT | 09∨ | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| ● ● We do not use the | following | data for averages | , fits, | limits, e | etc. • • • |
| <11 | 90 | ¹ AUBERT | 10E | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 5.6 | 90 | ¹ AUBERT | 08AD | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 1.7 | 90 | ¹ SATOYAMA | 07 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 6.6 | 90 | AUBERT | 040 | BABR | Repl. by AUBERT 09V |
| <21 | 90 | ARTUSO | 95 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

I

$\Gamma(\tau^+\nu_{\tau})/\Gamma_{\rm total}$

See the note on "Decay Constants of Charged Pseudoscalar Mesons" in the D_c^+ Listings.

| NLUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | | |
|--------------------------------------------------|---------|--------------|-----|------|----------------------|----------------|--|
| 1.65 ± 0.34 OUR | AVERAGE | | | | | | |
| $1.7 \ \pm 0.8 \ \pm 0.2$ | 1,2 | AUBERT | 10E | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |
| $1.54 {}^{+ 0.38}_{- 0.37} {}^{+ 0.29}_{- 0.31}$ | 1,3 | HARA | 10 | BELL | $e^+e^- \to$ | $\Upsilon(4S)$ | |
| $1.8 {}^{+ 0.9}_{- 0.8} \pm 0.45$ | 1,4 | AUBERT | 08D | BABR | $e^+e^- \to$ | $\Upsilon(4S)$ | |
| 1.79 + 0.56 + 0.46 | 1,4 | IKADO | 06 | BELL | $e^+e^- \rightarrow$ | Y(45) | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | $0.9 \ \pm 0.6 \ \pm 0.1$ | | 1,2 AUBERT | 07A L | BABR | Repl. by AUBERT 10E |
|-----|---------------------------|----|-----------------------|-------|------|-----------------------------------|
| < | 2.6 | 90 | ¹ AUBERT | 06K | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < | 4.2 | 90 | ¹ AUBERT,B | 05B | BABR | Repl. by AUBERT 06K |
| < | 8.3 | 90 | ⁵ BARATE | 01E | ALEP | $e^+e^- \rightarrow Z$ |
| < | 8.4 | 90 | ¹ BROWDER | 01 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < | 5.7 | 90 | ⁶ ACCIARRI | 97F | L3 | $e^+e^- \rightarrow Z$ |
| <10 | 04 | 90 | ⁷ ALBRECHT | 95 D | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| < 2 | 22 | 90 | ARTUSO | 95 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < : | 18 | 90 | ⁸ BUSKULIC | 95 | ALEP | $e^+e^- \rightarrow Z$ |

 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

Requires one reconstructed semileptonic B decay $B^- \to D^0 \ell^- \overline{\nu}_\ell X$ in the recoil. Requires one reconstructed semileptonic B decay $B^- \to D^{(*)0} \ell^- \overline{\nu}_\ell X$ in the recoil.

 4 The analysis is based on a sample of events with one fully reconstructed tag B in a hadronic decay mode $B^-\to D^{(*)0}\,X^-.$

nationic decay mode $B\to D^+ \Lambda^- \Lambda^-$.

5 The energy-flow and b-tagging algorithms were used.

6 ACCIARRI 97F uses missing-energy technique and $f(b\to B^-)=(38.2\pm 2.5)\%$.

7 ALBRECHT 95D uses full reconstruction of one B decay as tag.

8 BUSKULIC 95 uses same missing-energy technique as in $\overline{b}\to \tau^+\nu_{\tau} X$, but analysis is restricted to endpoint region of missing-energy distribution.

$\Gamma(\ell^+ \nu_\ell \gamma) / \Gamma_{\text{total}}$

VALUE DOCUMENT ID TECN COMMENT $<15.6 \times 10^{-6}$ 1 AUBERT 90 09AT BABR $e^+e^- \rightarrow \Upsilon(4S)$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(e^+ \nu_e \gamma) / \Gamma_{\text{total}}$ Γ_{29}/Γ VALUE CL% DOCUMENT ID TECN COMMENT $< 17 \times \overline{10^{-6}}$ 1 AUBERT 09AT BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • 2 BROWDER 97 CLE2 $e^+e^- ightarrow \gamma(4S)$ 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

³ Uses the neutrino reconstruction technique. Assumes B($\Upsilon(4S) \rightarrow B^+B^-$) = (51.6 ± 0.6)% and B($\Upsilon(4S) \to B^0 \overline{B}{}^0$) = $(48.4 \pm 0.6)\%$.

 $^{^4}$ The B 0 and B + results are combined assuming the isospin, B lifetimes, and relative charged/neutral B production at the $\varUpsilon(4S)$.

⁵ ATHAR 03 reports systematic errors 0.16 ± 0.09, which are experimental systematic and systematic due to model dependence. We combine these in quadrature.

^{0.6)%} and $B(Y(4S) \to B^0\overline{B^0}) = (48.4 \pm 0.6)\%$. 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 3 The B^0 and B^+ results are combined assuming the isospin, B lifetimes, and relative charged/neutral B production at the $\Upsilon(4S)$. Corresponds to 90% CL interval $(1.20-4.46) \times 10^{-4}$

²Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

²BROWDER 97 uses the hermiticity of the CLEOII detector to reconstruct the neutrino energy and momentum.

 $0.966 \pm 0.039 \pm 0.012$

| VALUE CL% | Γ ₃₀ /Γ DOCUMENT ID TECN COMMENT | $\Gamma(D_s^- X)/[\Gamma(D_s^+ X) + \Gamma(D_s^- X)]$ | $\left[\Gamma_{s}^{-X} ight]$ $\left[\Gamma_{36} / (\Gamma_{35} + \Gamma_{36}) \right]$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <24 × 10⁻⁶ 90 | 1 AUBERT 09AT BABR $e^{+}e^{-} ightarrow \gamma$ (4.5) | <0.126 90 | AUBERT,BE 04B BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| • • • We do not use the following $<52 \times 10^{-6}$ 90 | g data for averages, fits, limits, etc. \bullet \bullet \bullet ² BROWDER 97 CLE2 $e^+e^- 	o 	ag{4.5}$ | $\Gamma(\Lambda_c^+ X)/\Gamma_{\text{total}}$ | Г ₃₇ / |
| $^{ m 1}$ Assumes equal production of $^{ m 1}$ | B^+ and B^0 at the $\varUpsilon(4S)$. | VALUE | DOCUMENT ID TECN COMMENT |
| ² BROWDER 97 uses the hermi energy and momentum. | iticity of the CLEOII detector to reconstruct the neutrino | $0.021 \pm 0.005 \stackrel{+}{-} \stackrel{0.008}{-} \stackrel{0.004}{0.004}$ | 1 AUBERT 07N BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\Gamma(D^0X)/\Gamma_{\text{total}}$ | Γ ₃₁ /Γ | $0.029 \pm 0.008 + 0.011 \pm 0.007$ | ing data for averages, fits, limits, etc. • • • 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N |
| VALUE | DOCUMENT ID TECN COMMENT 1 AUBERT 07N BABR $e^+e^- 	oup \Upsilon(45)$ | | etely reconstructing one B and searching for a reconstructe |
| 0.086±0.006±0.004 • • • We do not use the following | g data for averages, fits, limits, etc. \bullet \bullet | | of the event. The last error includes systematic and charr |
| $0.098 \pm 0.009 \pm 0.006$ | AUBERT,BE 04B BABR Repl. by AUBERT 07N | $\Gamma(\overline{\Lambda}_c^- X)/\Gamma_{\text{total}}$ | Г ₃₈ / |
| charmed particle in the rest of | ely reconstructing one ${\cal B}$ and searching for a reconstructed ${\sf f}$ the event. The last error includes systematic and charm | VALUE | DOCUMENT ID TECN COMMENT |
| branching ratio uncertainties. | - /- | $0.028 \pm 0.005 {}^{+ 0.010}_{- 0.007}$ | 1 AUBERT 07N BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| Γ(D ⁰ X)/Γ _{total} | Γ ₃₂ /Γ DOCUMENT ID TECN COMMENT | | ing data for averages, fits, limits, etc. • • • |
| $0.786 \pm 0.016 + 0.034 \\ -0.033$ | 1 AUBERT 07N BABR $e^{+}e^{-} ightarrow~ arGamma(4S)$ | $0.035 \pm 0.008 ^{+0.013}_{-0.009}$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N |
| | g data for averages, fits, limits, etc. • • • | ¹ Events are selected by comple charmed particle in the rest | etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charr |
| $0.793 \pm 0.025 {}^{+ 0.045}_{- 0.044}$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N | branching ratio uncertainties | |
| | ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm | $\Gamma(\Lambda_c^+ X)/[\Gamma(\Lambda_c^+ X) + \Gamma(\overline{\Lambda}_c^-)]$ | · • |
| branching ratio uncertainties. | 2.2 The last of S | 0.427±0.071±0.001 | AUBERT 07N BABR $e^+e^- ightarrow angle \gamma(4S)$ |
| $\Gamma(D^0X)/[\Gamma(D^0X)+\Gamma(\overline{D^0}X)]$ | /1 | | ing data for averages, fits, limits, etc. • • • |
| VALUE 0.098±0.007±0.001 | AUBERT 07N BABR $e^+e^- ightarrow \varUpsilon(4S)$ | 0.452±0.090±0.003 | AUBERT,BE 04B BABR Repl. by AUBERT 07N |
| | g data for averages, fits, limits, etc. • • • | 「(でX)/「 _{total} | Γ ₃₉ / |
| 0.110±0.010±0.003 | AUBERT,BE 04B BABR Repl. by AUBERT 07N | $0.968 \pm 0.019 + 0.041 \\ -0.039$ | 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 = |
| Γ(D ⁺ X)/Γ _{total} | Γ ₃₃ /Γ DOCUMENT ID TECN COMMENT | | ing data for averages, fits, limits, etc. • • • |
| 0.025 ± 0.005 ± 0.002 | 1 AUBERT 07N $\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ | $0.983 \pm 0.030 {}^{+ 0.054}_{- 0.051}$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N |
| $ullet$ $ullet$ $ullet$ We do not use the following $0.038 {\pm} 0.009 {\pm} 0.005$ | g data for averages, fits, limits, etc. • • • 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N | | etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charr |
| ¹ Events are selected by complet | ely reconstructing one B and searching for a reconstructed | branching ratio uncertainties | |
| charmed particle in the rest of branching ratio uncertainties. | f the event. The last error includes systematic and charm | $\Gamma(cX)/\Gamma_{\text{total}}$ | Γ ₄₀ / |
| $\Gamma(D^-X)/\Gamma_{\text{total}}$ | Γ ₃₄ /Γ | VALUE + 0.018 | DOCUMENT ID TECN COMMENT |
| VALUE | DOCUMENT ID TECN COMMENT | $0.234 \pm 0.012 ^{+0.018}_{-0.014}$ | 1 AUBERT 07N BABR $e^{+}e^{-} ightarrow~ arGamma(4S)$ |
| | 1 AUDEDT 070 DADD -+ -= 7/4C) | • • We do not use the follow | ing data for averages fits limits etc. |
| | 1 AUBERT 07N BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$ g data for averages, fits, limits, etc. • • • | | ing data for averages, fits, limits, etc. • • • 1 AUBERT.BE 04B BABR Repl. by AUBERT 07N |
| • • • We do not use the following $0.098 \pm 0.012 \pm 0.014$ | g data for averages, fits, limits, etc. • • • • 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N | $0.330 \pm 0.022 {}^{+ 0.055}_{- 0.037}$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N |
| $0.098\pm0.012\pm0.014$ Events are selected by complet | g data for averages, fits, limits, etc. • • • | $\begin{array}{l} 0.330\pm0.022 {}^{+0.055}_{-0.037} \\ \\ ^{1}\text{ Events are selected by complecharmed particle in the rest branching ratio uncertainties} \end{array}$ | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one ${\it B}$ and searching for a reconstructe of the event. The last error includes systematic and charr . |
| • • • We do not use the following 0.098±0.012±0.014 ¹ Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X) + Γ(D-X)] | g data for averages, fits, limits, etc. • • • • AUBERT,BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm \[\text{T33} / (\Gamma_{33} + \Gamma_{34}) \] | $0.330\pm0.022 {}^{+0.055}_{-0.037}$ Events are selected by complecharmed particle in the rest | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one <i>B</i> and searching for a reconstructe of the event. The last error includes systematic and charr |
| • • • We do not use the following 0.098±0.012±0.014 ¹ Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X) + Γ(D-VALUE | g data for averages, fits, limits, etc. $ullet$ $ullet$ $ullet$ AUBERT,BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties Γ(τα)/Γ _{total} | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one ${\it B}$ and searching for a reconstructe of the event. The last error includes systematic and charr. |
| • • • We do not use the following 0.098±0.012±0.014 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X) + Γ(D-X)] VALUE 0.204±0.035±0.001 • • • We do not use the following | g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm -X)] DOCUMENT ID AUBERT 07N BABR $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ | 0.330 ± 0.022 + 0.055 1 Events are selected by complication charmed particle in the rest branching ratio uncertainties \[\forall (\tau c \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07M etely reconstructing one $\mathcal B$ and searching for a reconstructe of the event. The last error includes systematic and charm. ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${}$ ${$ |
| • • • We do not use the following $0.098\pm0.012\pm0.014$ ¹ Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^+X)/[\Gamma(D^+X) + \Gamma(D^-X)]$ VALUE 0.204±0.035±0.001 • • We do not use the following 0.278±0.052±0.009 | g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm FX) DOCUMENT ID AUBERT 07N BABR COMMENT AUBERT 07N BABR ef $e^+e^- \rightarrow \Upsilon(4S)$ g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,BE 04B BABR Repl. by AUBERT 07N | 0.330 ± 0.022 + 0.055 1 Events are selected by complication charmed particle in the rest branching ratio uncertainties \[\forall (\tau c \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charry $\frac{DOCUMENT\ ID}{1}$ TECN COMMENT $\frac{TA1}{1}$ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ ing data for averages, fits, limits, etc. • • |
| • • • We do not use the following 0.098±0.012±0.014 ¹ Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X)+Γ(D-X)] • • • We do not use the following 0.278±0.052±0.009 Γ(D,X)/Γtotal MALUE | g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm Fa) DOCUMENT ID AUBERT 07N BABR COMMENT AUBERT 07N BABR efe $- \rightarrow \Upsilon(4S)$ g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,BE 04B BABR Repl. by AUBERT 07N DOCUMENT ID TECN COMMENT | $0.330\pm0.022^{+0.055}_{-0.037}$ 1 Events are selected by comple charmed particle in the rest branching ratio uncertainties $\Gamma(Tcx)/\Gamma_{total}$ $VALUE$ 1.202 \pm 0.023 $^{+0.053}_{-0.049}$ • • We do not use the follow 1.313 \pm 0.037 $^{+0.088}_{-0.075}$ 1 Events are selected by comple | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes $\frac{DOCUMENT\ ID}{1}$ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ ing data for averages, fits, limits, etc. • • • $\frac{1}{1}$ AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes systematic and cha |
| • • • We do not use the following $0.098\pm0.012\pm0.014$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^+X)/[\Gamma(D^+X) + \Gamma(D^-X)] = 0.0000000000000000000000000000000000$ | g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 0.330±0.022+0.055 1 Events are selected by complication charmed particle in the rest branching ratio uncertainties \[\begin{align*} \begin | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror $\frac{DOCUMENT\ ID}{1}$ TECN COMMENT $\frac{T}{1}$ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ ing data for averages, fits, limits, etc. • • • $\frac{1}{1}$ AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes systematic and charror includes systematic and charror includes a systematic and charror includes and charror includes and charror includes a systematic and charror includes a systematic and charror includes a systematic and charror includes and charror includes a systematic and char |
| • • • We do not use the following 0.098±0.012±0.014 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X) + Γ(D-XALUE) • • • We do not use the following 0.278±0.052±0.009 Γ(D+X)/Γtotal XALUE 0.079±0.006±0.013 • • • We do not use the following 0.009±0.006±0.013 | g data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N ely reconstructing one B and searching for a reconstructed f the event. The last error includes systematic and charm 2 X) 1 DOCUMENT ID 1 DOCUMENT ID 2 DOCUMENT ID 3 AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ 2 BABR Repl. by AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ 3 AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ 4 AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ 5 Gata for averages, fits, limits, etc. $\bullet \bullet \bullet$ 6 GOMMENT ID 1 AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ 6 data for averages, fits, limits, etc. $\bullet \bullet \bullet$ | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties \[\begin{align*} align | 1 AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes $\frac{DOCUMENT\ ID}{1}$ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ ing data for averages, fits, limits, etc. • • • $\frac{1}{1}$ AUBERT,BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes systematic and cha |
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| • • • We do not use the following $0.098\pm0.012\pm0.014$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^+X)/[\Gamma(D^+X) + \Gamma(D^-X) + \Gamma(D$ | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330 \pm 0.022 $^{+0.055}_{-0.037}$ 1 Events are selected by complication charmed particle in the rest branching ratio uncertainties $\Gamma(Tc X)/\Gamma_{\text{total}}$ **Nature** 1.202 \pm 0.023 $^{+0.053}_{-0.049}$ • • We do not use the follow 1.313 \pm 0.037 $^{+0.088}_{-0.075}$ 1 Events are selected by complication the rest branching ratio uncertainties $\Gamma(D^0\pi^+)/\Gamma_{\text{total}}$ **MALUE** **MALUE** **MALUE** **Long to the follow of the | 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charr $\frac{DOCUMENT\ ID}{1} \frac{TECN}{1} \frac{COMMENT}{1} \frac{TECN}{1} \frac{TECN}{1} \frac{COMMENT}{1} \frac{TECN}{1} \frac{TECN}{1} \frac{COMMENT}{1} \frac{TECN}{1} TECN$ |
| • • We do not use the following $0.098\pm0.012\pm0.014$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^+X)/[\Gamma(D^+X)+\Gamma(D^-X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)+\Gamma(D^-X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)+\Gamma(D^-X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ $\Gamma(D^+X)/[\Gamma(D^+X)]$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^-X)/[\Gamma(D^-X)]$ | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330 \pm 0.022 $^{+0.055}_{-0.037}$ 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties $\Gamma(Tc X)/\Gamma_{\text{total}}$ **Note: The particle of the rest branching ratio uncertainties 1.202 \pm 0.023 $^{+0.053}_{-0.049}$ • • • We do not use the follow 1.313 \pm 0.037 $^{+0.088}_{-0.075}$ 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties $\Gamma(\overline{D^0}\pi^+)/\Gamma_{\text{total}}$ **MALUE** (units 10 $^{-3}$) 4.81 \pm 0.15 OUR FIT 4.84 \pm 0.15 OUR AVERAGE 4.90 \pm 0.07 \pm 0.22 5.3 \pm 0.6 \pm 0.3 4.49 \pm 0.21 \pm 0.23 4.97 \pm 0.12 \pm 0.29 5.0 \pm 0.7 \pm 0.6 54 | 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes includes systematic and charror includes system |
| We do not use the following $0.098\pm0.012\pm0.014$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D+X)/[\Gamma(D+X)+\Gamma(D-X)]$ $\Gamma(D+X)/[\Gamma(D+X)+\Gamma(D-X)]$ $0.204\pm0.035\pm0.001$ $0.278\pm0.052\pm0.009$ $\Gamma(D_s^+X)/\Gamma_{total}$ $0.079\pm0.006\pm0.013$ $0.079\pm0.006\pm0.013$ $0.0143\pm0.016\pm0.034$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D_s^-X)/\Gamma_{total}$ | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties \[\begin{align*} \begin{align*} \begin{align*} \begin{align*} \cdot | at AUBERT, BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes a systematic and charror includes |
| • • • We do not use the following $0.098\pm0.012\pm0.014$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D^+X)/[\Gamma(D^+X) + \Gamma(D^-X)]$ $\Gamma(D^+X)/[\Gamma(D^+X) + \Gamma(D^-X)]$ $0.204\pm0.035\pm0.001$ • • We do not use the following $0.278\pm0.052\pm0.009$ $\Gamma(D_s^+X)/\Gamma_{total}$ $0.079\pm0.006\pm0.013$ • • We do not use the following $0.143\pm0.016\pm0.016$ $0.0143\pm0.016\pm0.0034$ 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. $\Gamma(D_s^-X)/\Gamma_{total}$ $VALUE$ $0.011\pm0.003\pm0.001$ • • We do not use the following 0.140 ± 0.002 | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties \[\begin{align*} \begin{align*} \begin{align*} \begin{align*} \cdot | at AUBERT, BE 04B BABR Repl. by AUBERT 07M etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error includes systematic and characteristic of the event. The last error include |
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| • • • We do not use the following 0.098±0.012±0.014 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X)+Γ(D-X)] • • • We do not use the following 0.204±0.035±0.001 • • • We do not use the following 0.278±0.052±0.009 Γ(D+X)/Γtotal WALUE 0.0079±0.006±0.013 • • • We do not use the following 0.143±0.016±0.051 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D-X)/Γtotal WALUE 0.011±0.004±0.002 • • • We do not use the following 0.012±0.003±0.001 0.012±0.003±0.001 0.011±0.003±0.001 0.001±0.003±0.001 0.002±0.002 1 Events are selected by complet | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties \[\begin{align*} \begin{align*} \begin{align*} \begin{align*} \cdot | 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes systematic and charror includes and charror includes systematic and charror includes systematic and charror includes systematic and charror includes includes included inc |
| • • • We do not use the following 0.098±0.012±0.014 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D+X)/[Γ(D+X)+Γ(D-X)] • • • We do not use the following 0.278±0.035±0.009 Γ(D, X)/Γtotal 0.013 • • • We do not use the following 0.143±0.016+0.013 1 Events are selected by complet charmed particle in the rest of branching ratio uncertainties. Γ(D, X)/Γtotal 0.011+0.003+0.001 • • • We do not use the following 0.143±0.016+0.013 1 Events are selected by complet charmed particle in the rest of 0.011+0.003-0.001 • • • We do not use the following 0.140±0.002-0.001 • • • We do not use the following 0.140±0.002-0.001 | g data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 0.330±0.022+0.055 1 Events are selected by complicharmed particle in the rest branching ratio uncertainties \[\begin{align*} align | 1 AUBERT, BE 04B BABR Repl. by AUBERT 07N etely reconstructing one B and searching for a reconstructe of the event. The last error includes systematic and charror includes systematic and charror includes and charror includes systematic and charror includes systematic and charror includes and charror includes systematic and charror includes |

AUBERT,BE 04B BABR Repl. by AUBERT 07N

ı

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$. 2 ABULENCIA 06J reports $[\Gamma(B^+\to \overline{D}{}^0\pi^+)/\Gamma_{\rm total}] \ / \ [B(B^0\to D^-\pi^+)] = 1.97 \pm 0.10 \pm 0.21$ which we multiply by our best value B($B^0\to D^-\pi^+) = (2.68 \pm 0.13) \times 10^{-1}$ 10^{-3} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

 3 Uses a missing-mass method. Does not depend on D branching fractions or B^+/B^0 production rates.

AHMED 02B reports an additional uncertainty on the branching ratios to account for 4.5% uncertainty on relative production of B^0 and B^+ , which is not included here. ⁵ Assumes equal production of B^+ and B^0 at the T(4S) and uses the Mark III branching

6 BEBEK 87 value has been updated in BERKELMAN 91 to use same assumptions as

7 AUBERT, B 04P reports $[\Gamma(B^+ \to \overline{D}{}^0\pi^+)/\Gamma_{\text{total}}] \times [B(D^0 \to K^-\pi^+)] = (1.846 \pm 1.00)$ 0.032 ± 0.097) $\times 10^{-4}$ which we divide by our best value B($D^0 \rightarrow K^- \pi^+$) = (3.88 \pm $0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁸ ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(4S)$ and use the CLEOII absolute $\mathsf{B}(D^0\to K^-\pi^+)$ and the PDG 1992 $\mathsf{B}(D^0\to K^-\pi^+\pi^0)/\mathsf{B}(D^0\to K^-\pi^+)$ and $B(D^0\to K^-2\pi^+\pi^-)/B(D^0\to K^-\pi^+)$. 9 ALBRECHT 88k assumes $B^0\overline{B}^0:B^+B^-$ ratio is 45:55. Superseded by ALBRECHT 90J.

 $\Gamma(\overline{\mathcal{D}}{}^{0}\rho^{+})/\Gamma_{\mathrm{total}}$ Γ_{45}/Γ EVTS DOCUMENT ID TECN COMMENT

| 0.0134±0.0018 OUR AVE | RAGE | | | | | |
|--------------------------------|----------|-----------------------|-----------|-----------|----------|----------------|
| $0.0135 \pm 0.0012 \pm 0.0015$ | 212 | ¹ ALAM | | | e^+e^- | |
| $0.013 \pm 0.004 \pm 0.004$ | 19 | ² ALBRECHT | 90J | ARG | e^+e^- | $\Upsilon(4S)$ |
| • • • We do not use the fe | ollowing | data for averages, f | fits, lim | its, etc. | • • • | |
| | | _ | | | | |

 3 ALBRECHT 88K ARG $e^+e^-
ightarrow \varUpsilon(4S)$ 1 ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(4S)$ and use the CLEOII absolute B(D^0 \rightarrow K^- π^+) and the PDG 1992 B(D^0 \rightarrow K^- $\pi^+\pi^0$)/B(D^0 \rightarrow K^- π^+) and B($D^0 \to K^- 2\pi^+ \pi^-$)/B($D^0 \to K^- \pi^+$).

² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses the Mark III branching

fractions for the D.

3 ALBRECHT 88 κ assumes $B^0\overline{B}^0$: B^+B^- ratio is 45:55

10

 $\Gamma(\overline{D}{}^0K^+)/\Gamma(\overline{D}{}^0\pi^+)$

 $0.021 \pm 0.008 \pm 0.009$

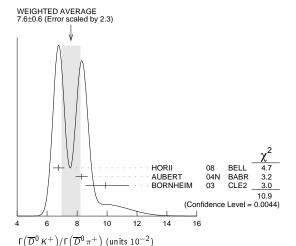
 Γ_{46}/Γ_{42}

43

TECN COMMENT

| 7.6 ±0.6 OUR AVERAGE | Error includes scal | e factor of 2 | .3. See the ideogram below. |
|---------------------------------------------------------------|---------------------|-----------------|----------------------------------------|
| $6.77 \pm 0.23 \pm 0.30$ | HORII | 08 BELI | $e^+e^- ightarrow \gamma(4S)$ |
| $8.31 \pm 0.35 \pm 0.20$ | AUBERT | 04N BAB | R $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| $9.9 \begin{array}{c} +1.4 & +0.7 \\ -1.2 & -0.6 \end{array}$ | BORNHEIM | 03 CLE | $e^+e^- ightarrow \gamma(45)$ |
| • • • We do not use the foll | owing data for ave | rages, fits, li | mits, etc. • • • |
| 9.4 ±0.9 ±0.7 | ABE | 03D BELI | Repl. by SWAIN 03 |
| $7.7 \pm 0.5 \pm 0.6$ | SWAIN | 03 BELI | Repl. by HORII 08 |
| $7.9 \pm 0.9 \pm 0.6$ | ABE | 01ı BELI | Repl. by ABE 03D |
| $5.5 \pm 1.4 \pm 0.5$ | ATHANAS | 98 CLE2 | Repl. by BORNHEIM 03 |

DOCUMENT ID



| $\Gamma(D_{CP(+1)}K^+)/\Gamma(D_{CF})$ | $_{(+1)}\pi^{+})$ | | | Γ ₄₇ | 7/F |
|----------------------------------------|-------------------------|-----------|---------|---------------------------------|-----|
| VALUE | <u>DOCUMENT ID</u> | | TECN | COMMENT | |
| 0.086±0.009 OUR AVERAG | iE | | | | |
| $0.086 \pm 0.008 \pm 0.007$ | $^{1,2}ABE$ | 06 | BELL | $e^+e^- \rightarrow \gamma(4S)$ | i |
| $0.088 \pm 0.016 \pm 0.005$ | ³ AUBERT | 04N | BABR | $e^+e^- \rightarrow \gamma(4S)$ | i |
| • • • We do not use the fo | llowing data for averag | es, fits, | limits, | etc. • • • | |
| $0.125 \pm 0.036 \pm 0.010$ | ³ ABE | 03D | BELL | Repl. by SWAIN (| 03 |
| $0.093 \pm 0.018 \pm 0.008$ | 3 SWAIN | 0.3 | BELL | Rent by ABF 06 | |

 1 Reports a double ratio of B($B^+ o D_{CP(+1)}K^+$)/B($B^+ o D_{CP(+1)}\pi^+$) and $B(B^+ \to \overline{D}^0 K^+)/B(B^+ \to \overline{D}^0 \pi^+)$, 1.13 \pm 0.16 \pm 0.08. We multiply by our best value of B(B⁺ $\rightarrow \overline{D}^0 K^+$)/B(B⁺ $\rightarrow \overline{D}^0 \pi^+$) = 0.083 \pm 0.006. Our first error is their experiment's error and the second error is systematic error from using our best value. ²ABE 06 reports $[\Gamma(B^+ \rightarrow D_{CP(+1)} K^+)/\Gamma(B^+ \rightarrow D_{CP(+1)} \pi^+)] / [\Gamma(B^+ \rightarrow D_{CP(+1)} \pi^+)]$ $\overline{D}{}^0\,K^+)/\Gamma(B^+ \to \overline{D}{}^0\,\pi^+)] = 1.13\,\pm\,0.06\,\pm\,0.08$ which we multiply by our best value $\Gamma(B^+ \to \overline{D}^0 K^+)/\Gamma(B^+ \to \overline{D}^0 \pi^+) = 0.076 \pm 0.006$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 3 CP=+1 eigenstate of $D^0\overline{D^0}$ system is reconstructed via K^+K^- and $\pi^+\pi^-$.

| $\Gamma(D_{CP(+1)}K^+)/\Gamma(\overline{D}^0K^-)$ | +) | | | | Γ_{47}/Γ_{46} |
|---------------------------------------------------|-----------------------------------------|------------|---------|------------------------|---------------------------|
| VALUE | DOCUMENT ID | | ECN | COMMENT | |
| 0.60 ±0.05 OUR AVERAGE | | | | | |
| $0.65 \pm 0.12 \pm 0.06$ | ¹ AALTONEN | 10A C | DF | p p at 1.96 | TeV |
| $0.590 \pm 0.045 \pm 0.025$ | ² DEL-A MO-S/ | A10G E | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| ullet $ullet$ We do not use the following | wing data for avera | ges, fits, | limits, | etc. • • • | |
| $0.53 \ \pm 0.05 \ \pm 0.025$ | AUBERT | 08AA E | BABR | Repl. by D SANCH | |
| $0.45 \pm 0.06 \pm 0.02$ | AUBERT | 06J E | BABR | | UBERT 08AA |
| 1 Reports $R_{CP+} = 2$ (B(| $B^- \rightarrow D_{CP(+1)}$ |) K-) + | B(B+ | \rightarrow D_{CI} | P(+1) K+)) / |
| $(B(B^- \rightarrow D^0 K^-) + B$ vided by 2. | $(B^+ \rightarrow \overline{D}^0 K^+))$ | = 1.30 | ± 0.24 | \pm 0.12 th | at we have di- |
| 1 | | | | | |

 $^2\,\mathrm{Reports}\,R_{CP+}=1.18\pm0.09\pm0.05$ that we have divided by 2. $\Gamma(D_{CP(-1)}K^+)/\Gamma(D_{CP(-1)}\pi^+)$ Γ_{48}/Γ_{44} 1 ABE 0.097±0.016±0.007 06 BELL $e^+e^- \rightarrow$

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet03D BELL Repl. by SWAIN 03 $0.119\!\pm\!0.028\!\pm\!0.006$ ² ABE 03 BELL Repl. by ABE 06 $0.108 \pm 0.019 \pm 0.007$ ² SWAIN

 $^{1}\,\mathrm{Reports}$ a double ratio of $\mathrm{B}(B^{+}\to~D_{CP(-1)}\,\mathrm{K}^{+})/\mathrm{B}(B^{+}\to~D_{CP(-1)}\,\pi^{+})$ and $B(B^+\to \overline{D}{}^0K^+)/B(B^+\to \overline{D}{}^0\pi^+), 1.17\pm 0.14\pm 0.14. \text{ We multiply by our best value of } B(B^+\to \overline{D}{}^0K^+)/B(B^+\to \overline{D}{}^0\pi^+)=0.083\pm 0.006. \text{ Our first error is their}$ experiment's error and the second error is systematic error from using our best value. 2 CP = -1 eigenstate of $D^0 \overline{D}^0$ system is reconstructed via $K^0_S \pi^0$, $K^0_S \omega$, $K^0_S \phi$, $K^0_$ and $K_S^0 \eta'$.

 $\Gamma(D_{CP(-1)}\,K^+)/\Gamma(\overline{D}{}^0\,K^+)$ Γ_{48}/Γ_{46} DOCUMENT ID TECN COMMENT 0.54 ±0.04±0.02 1 DEL-AMO-SA...10G BABR $e^{+}e^{-} \rightarrow$ • • • We do not use the following data for averages, fits, limits, etc. • • • 08AA BABR Repl. by DEL-AMO-SANCHEZ 10G 06J BABR Repl. by AUBERT 08AA $0.515 \pm 0.05 \pm 0.025$ AUBERT AUBERT 1 Reports $R_{CP+}=1.07\pm0.08\pm0.04$ that we have divided by 2.

 $\Gamma([K^-\pi^+]_DK^+)/\Gamma_{\rm total}$ Γ_{49}/Γ DOCUMENT ID TECN COMMENT <2.8 × 10⁻⁷ HORII 08 BELL $e^+e^- \rightarrow$ • • We do not use the following data for averages, fits, limits, etc. $< 6.3 \times 10^{-7}$ 05 BELL $e^+e^- \rightarrow \Upsilon(4S)$ SAIGO

 $\Gamma([K^-\pi^+]_DK^+)/\Gamma([K^+\pi^-]_DK^+)$ Γ_{49}/Γ_{50} DOCUMENT ID TECN COMMENT 15.6±3.3 OUR AVERAGE

¹ AALTONEN $22.0 \pm 8.6 \pm 2.6$ 11AJ CDF $p\overline{p}$ at 1.96 TeV $16.3 \,{}^{+\, 4.4 \,+\, 0.7}_{-\, 4.1 \,-\, 1.3}$ HORII 11 BELL $e^+e^- \rightarrow \Upsilon(4S)$ $11\ \pm 6\ \pm 2$ DEL-AMO-SA...10H BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • •

 $7.8 + 6.2 + 2.0 \\ -5.7 - 2.8$ HORII 08 BELL Repl. by HORII 11

² AUBERT 05 G BABR Repl. by DEL-AMO-<29 SANCHEZ 10H $e^+e^- \rightarrow \Upsilon(4S)$ 3 SAIGO BELL <44 ⁴ AUBERT,B <26 04L BABR Repl. by AUBERT 05 G

 1 AALT ONEN 11AJ also measures the ratio separately for B^+ $(\mathsf{R}^+(K))$ and $B^ (\mathsf{R}^-(K))$ and obtains: $R^+(K) = (42.6 \pm 13.7 \pm 2.8) \times 10^{-3}$, $R^-(K) = (3.8 \pm 10.3 \pm 2.7) \times 10^{-3}$. ² AUBERT 05G extract a constraint on the magnitude of the ratio of amplitudes $|A(B^+ \rightarrow A)|$ ${\it D^{\,0}\,K^+)}$ / ${\it A(B^+\to~\overline{D}^{\,0}\,K^+)}|~<$ 0.23 at 90% CL (Bayesian). Similar measurements from $B^+ \to D^{*0} K^+$ are also reported.

 3 SAIGO 05 extract a constraint on the magnitude of the ratio of amplitudes $|{\sf A}(B^+
ightarrow$ $D^{0}\,K^{+})$ / A(B $^{+}$ \rightarrow $\overline{D}^{0}\,K^{+})|$ < 0.27 at 90% CL.

⁴ AUBERT,B 04L extract a constraint on the magnitude of the ratio of amplitudes $|A(B^+ \rightarrow D^0 K^+)/A(B^+ \rightarrow \overline{D}^0 K^+)| < 0.22$ at 90% CL.

 B^{\pm}

| • | , | $\pi^-\pi^0]_DK^+$ | | | Γ_{51}/Γ_{52} |
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| .UE (units 10 ⁻³) 2 1 | <u>CL%</u> | DOCUMENT ID 1 LEES | 11D BABR | <u>COMMENT</u> e+e− → | T(45) |
| • We do not use | | | | | 7 (43) |
| 39 | 95 | ² AUBERT | 07BN BABR | Repl. by L | EES 11D |
| Extracts a constra | | | tio of amplitu | udes $ A(B^+) $ | $\rightarrow D^0 K^+)/$ |
| $A(B^+ \rightarrow \overline{D}^0 K^+)$ Extracts a constra | | | tio of amplitu | idos IA (P+ | , n0 k+) |
| $A(B^+ \rightarrow \overline{D}^0 K^+$ | | | tio or amplit | ades A(D) | → <i>D</i> (K ·)/ |
| [K ⁻ π ⁺] _D K*(8 | 92)+)/F(I | K+1- K*(8 | 02)+) | | Γ ₅₃ /Γ ₅₄ |
| .UE .UE | | DO CUMENT ID | | COMMENT | 153/154 |
| 66±0.031±0.010 | | AUBERT | 09AJ BABR | | $\Upsilon(4S)$ |
| • We do not use $46 \pm 0.031 \pm 0.008$ | the following | ; data for average: AUBERT,B | | | UBERT 09AJ |
| | | AUDER 1,D | USV BABIN | Kepi. by A | |
| $[K^-\pi^+]_D\pi^+)/$ | T _{total} | 00.004545 | TE 611 | | Г ₅₅ / Г |
| UE (units 10 ⁻⁷) +1.02 + 0.37 | | DO CUMENT ID | TECN | | m(+c) |
| 9+1.02+0.37 -0.98-0.48 • We do not use | the following | HORII | 08 BELL | e ⁺ e [−] → | 1 (45) |
| | the following | - | | | 10.011.00 |
| $^{+1.9}_{-1.7}$ ± 0.5 | | SAIGO | 05 BELL | Repl. by F | IORII 08 |
| $[K^-\pi^+]_D\pi^+)/$ | $\Gamma([K^+\pi^-]$ | $D\pi^+$ | | | Γ_{55}/Γ_{56} |
| UE (units 10 ⁻³) | DO CUMENT | T ID TECN | COMMENT | | |
| 1±0.32 OUR AVE $\pm 0.7 \pm 0.4$ | ¹ AALTONE | EN 11AJ CDF | p p at 1.96 | TeV | |
| $8 + 0.38 + 0.12 \\ -0.36 - 0.18$ | HORII | 11 BELL | $e^+e^- \rightarrow$ | Y(45) | |
| $\pm0.6\ \pm0.4$ | | O-SA10H BABR | | | |
| We do not use | _ | - | | | |
| $0 + 0.55 + 0.15 \\ -0.53 - 0.22$ | HORII | 08 BELL | Repl. by H | ORII 11 | |
| $^{+1.0}_{-0.9}$ ±0.2 | SAIGO | 05 BELL | Repl. by H | ORII 08 | |
| AALTONEN 11AJ | also measure | s the ratio separa | tely for B+ (| $R^+(\pi))$ and | $B^{-}(R^{-}(\pi))$ |
| and obtains: $R^+(\cdot)$ | π) = (2.4 ± | $1.0 \pm 0.4) \times 10^{-5}$ | $Y, R^-(K) = 0$ | $(3.1 \pm 1.1 \pm$ | $(0.4) \times 10^{-3}$ |
| $[K^-\pi^+]_{(D\pi)}\pi^+$ | +)/Γ(Γ <i>K</i> +2 | $\pi^{-1}(n-1)\pi^{+1}$ | | | F /F |
| $('' '' I(D\pi)''$ | <i>)</i> / · (L·· · | · 1(D\pi) · / | | | Γ_{57}/Γ_{58} |
| <i>UE</i> (units 10 ⁻³) | | DO CUMENT ID | <u>TECN</u> | COMMENT | |
| .UE (units 10 ⁻³) ± 0.9±0.8 | <u> </u> | DEL-AMO-SA. | | | 7(4S) |
| $\frac{UE \text{ (units } 10^{-3})}{\pm 0.9 \pm 0.8}$ [$K^-\pi^+$] $_{(D\gamma)}\pi^+$ | <u> </u> | DEL-AMO-SA. | | | |
| $UE \text{ (units } 10^{-3})$ $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D\gamma)}\pi^+$ $UE \text{ (units } 10^{-3})$ | <u> </u> | $\frac{\text{DOCUMENT ID}}{\text{DEL-AMO-SA.}}$ $\tau^{-}]_{(D\gamma)} \pi^{+})$ $\frac{\text{DOCUMENT ID}}{\text{DOCUMENT ID}}$ | 10н BABR | $e^+ e^- \rightarrow$ COMMENT | τ _(4S) Γ ₅₉ /Γ ₆₀ |
| $\begin{array}{l} UE \text{ (units } 10^{-3}) \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ UE \text{ (units } 10^{-3}) \\ \pm 1.4 \pm 2.2 \end{array}$ | +)/Γ([<i>K</i> +1 | $ \frac{DOCUMENT\ ID}{DEL-A\ MO-SA} $ $ \tau^{-1} _{(D\gamma)}\pi^{+}) $ $ \frac{DOCUMENT\ ID}{DEL-A\ MO-SA} $ | 10н BABR | $e^+ e^- \rightarrow$ COMMENT | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ |
| $ \frac{UE \text{ (units } 10^{-3})}{\pm 0.9 \pm 0.8} $ $ [K^{-}\pi^{+}]_{(D\gamma)}\pi^{+} $ $ \frac{UE \text{ (units } 10^{-3})}{\pm 1.4 \pm 2.2} $ $ [K^{-}\pi^{+}]_{(D\pi)}K^{-} $ | +)/Γ([<i>K</i> +1 | $ \frac{DOCUMENT\ ID}{DEL-A\ MO-SA} $ $ \tau^{-1} _{(D\gamma)}\pi^{+}) $ $ \frac{DOCUMENT\ ID}{DEL-A\ MO-SA} $ | 10н BABR | $e^+ e^- \rightarrow$ COMMENT | τ _(4S) Γ ₅₉ /Γ ₆₀ |
| $\begin{array}{l} \text{$\pm 0.9 \pm 0.8$} \\ \text{$(K^-\pi^+)_{(D\gamma)}\pi^+$} \\ \text{$\pm 0.9 \pm 0.8$} \\ \text{$(K^-\pi^+)_{(D\gamma)}\pi^+$} \\ \text{$\pm 1.4 \pm 2.2$} \\ \text{$(K^-\pi^+)_{(D\pi)}K^-$} \\ $\pm 0.00000000000000000000000000000000000$ | +)/Γ([<i>K</i> +1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-}]_{(D\gamma)} \pi^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \tau^{-}]_{(D\pi)} K^{+}) $ DOCUMENT ID | 10H BABR | $e^+e^- \rightarrow$ $\frac{COMMENT}{e^+e^- \rightarrow}$ $\frac{COMMENT}{e^+e^- \rightarrow}$ | $r(4S)$ Γ_{59}/Γ_{60} $r(4S)$ Γ_{61}/Γ_{62} |
| $\begin{array}{l} UE \text{ (units } 10^{-3}\text{)} \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ UE \text{ (units } 10^{-3}\text{)} \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ UE \text{ (units } 10^{-3}\text{)} \\ \pm 0.9 \pm 0.4 \end{array}$ | +)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-}]_{(D\gamma)} \pi^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-}]_{(D\pi)} K^{+}) $ DOCUMENT ID DEL-AMO-SA. | 10H BABR | $e^+e^- \rightarrow$ $\frac{COMMENT}{e^+e^- \rightarrow}$ $\frac{COMMENT}{e^+e^- \rightarrow}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ |
| UE (units 10^{-3}) $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D\gamma)}\pi^+$ $\pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D\pi)}K^ \pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D\pi)}K^ \pm 0.9 \pm 0.4$ $[K^-\pi^+]_{(D\gamma)}K^-$ | +)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-}]_{(D\gamma)} \pi^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-}]_{(D\pi)} K^{+}) $ DOCUMENT ID DEL-AMO-SA. | 10H BABR | $e^+e^- \rightarrow$ $\frac{COMMENT}{e^+e^- \rightarrow}$ $\frac{COMMENT}{e^+e^- \rightarrow}$ | $r(4S)$ Γ_{59}/Γ_{60} $r(4S)$ Γ_{61}/Γ_{62} |
| UE (units 10^{-3}) $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D\gamma)}\pi^+$ UE (units 10^{-3}) $\pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D\pi)}K^ UE$ (units 10^{-3}) $\pm 0.9 \pm 0.4$ $[K^-\pi^+]_{(D\gamma)}K^ UE$ (units 10^{-3}) | +)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-1} _{(D\gamma)}\pi^{+} $ DOCUMENT ID DEL-AMO-SA. $ \tau^{-1} _{(D\pi)}K^{+} $ DOCUMENT ID DEL-AMO-SA. $ \tau^{-1} _{(D\gamma)}K^{+} $ DOCUMENT ID DOCUMENT ID | .10H BABR .10H BABR .10H BABR .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{-}} \end{array}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} |
| $\begin{array}{l} \pm 0.9 \pm 0.8 \\ [K-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 1.4 \pm 2.2 \\ [K-\pi^+]_{(D\pi)} K \\ \pm 0.9 \pm 0.4 \\ [K-\pi^+]_{(D\pi)} K \\ \pm 0.9 \pm 0.4 \\ [K-\pi^+]_{(D\gamma)} K \\ \pm 0.9 \pm 0.8 \\ \pm 0.9 \pm 0.8 \\ \end{array}$ | +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 | $\frac{DOCUMENT ID}{DEL-AMO-SA.}$ $\tau^{-} _{(D\gamma)}\pi^{+})$ $\frac{DOCUMENT ID}{DEL-AMO-SA.}$ $\pi^{-} _{(D\pi)}K^{+})$ $\frac{DOCUMENT ID}{DEL-AMO-SA.}$ $\pi^{-} _{(D\gamma)}K^{+})$ | .10H BABR .10H BABR .10H BABR .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^{-}} \end{array}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} |
| $\begin{array}{l} \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \end{array}$ | +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. | .10H BABR .10H BABR .10H BABR .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \end{array}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} |
| $\begin{array}{l} \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^+ \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \\ UE (units 10^{-6}) \end{array}$ | +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-1} _{(D\gamma)}\pi^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-1} _{(D\pi)}K^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-1} _{(D\gamma)}K^{+}) $ DOCUMENT ID DEL-AMO-SA. | 10H BABR10H BABR10H BABR10H BABR10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ \end{array}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} $r_{(4S)}$ |
| $\begin{array}{l} \text{$\pm 0.9 \pm 0.8$} \\ \text{$\pm 0.9 \pm 0.8$} \\ \text{$[K^-\pi^+]_{(D\gamma)}\pi^+$} \\ \text{$\pm 1.4 \pm 2.2$} \\ \text{$[K^-\pi^+]_{(D\pi)}K^-$} \\ \text{$\pm 0.9 \pm 0.4$} \\ \text{$[K^-\pi^+]_{(D\gamma)}K^-$} \\ \text{$\pm 0.9 \pm 0.4$} \\ \text{$[K^-\pi^+]_{(D\gamma)}K^-$} \\ \text{$\pm 1.4 \pm 0.8$} \\ \text{$[\pi^+\pi^-\pi^0]_{D}K^-$} \\ \text{$\pm 0.8 \pm 0.4$} \end{array}$ | +)/Γ([K+1 +)/Γ([K+1 +)/Γ([K+1 -)/Γ([K+1 -)/Γ([K+1 -)/Γ([K+1 -)/Γ([K+1 | DOCUMENT ID DEL-AMO-SA. $ \tau^{-1} _{(D\gamma)}\pi^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-1} _{(D\pi)}K^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \pi^{-1} _{(D\gamma)}K^{+}) $ DOCUMENT ID DEL-AMO-SA. $ \frac{DOCUMENT ID}{DEL-AMO-SA} $ 1 AUBERT | 10H BABR10H BABR10H BABR10H BABR10H BABR10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \hline \end{array}$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} $r_{(4S)}$ |
| $\begin{array}{l} \text{UE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \text{UE (units 10^{-3})} \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \text{UE (units 10^{-3})} \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \\ \text{UE (units 10^{-6})} \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ We do not use} \\ \pm 1.0 \pm 0.7 \end{array}$ | +)/\(\(\left(\left[K+1]\)\)\(\(\left(\left[K+1]\)\)\(\left(\left[K+1]\)\)\(\(\left(\left[K+1]\)\)\(\reft(\left[K+1]\)\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ | DOCUMENT ID DEL-AMO-SA. | .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ COMM$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} $r_{(4S)}$ |
| $\begin{array}{l} \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \end{array}$ | +)/\(\(\left(\left[K+1]\)\)\(\(\left(\left[K+1]\)\)\(\left(\left[K+1]\)\)\(\(\left(\left[K+1]\)\)\(\reft(\left[K+1]\)\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ | DOCUMENT ID DEL-AMO-SA. | .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ COMM$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} $r_{(4S)}$ r_{65}/r_{65} |
| $\begin{array}{l} \text{$UE$ (units 10^{-3})$} \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D\gamma)} \pi^+ \\ \text{UE (units 10^{-3})$} \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^+ \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ \bullet We do not use} \\ \pm 1.0 \pm 0.7 \end{array}$ | +)/\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1) | DOCUMENT ID DEL-AMO-SA. | .10H BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ COMM$ | $r(4S)$ r_{59}/r_{60} $r_{(4S)}$ r_{61}/r_{62} $r_{(4S)}$ r_{63}/r_{64} $r_{(4S)}$ r_{65}/r_{65} |
| $\begin{array}{l} \text{LE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ \text{[$K^-\pi^+$]_{(D^\gamma)}$} \pi^+ \\ \text{LE (units 10^{-3})} \\ \pm 1.4 \pm 2.2 \\ \text{[$K^-\pi^+$]_{(D\pi)}$} K^- \\ \pm 0.9 \pm 0.4 \\ \text{[$K^-\pi^+$]_{(D\gamma)}$} K^- \\ \text{LE (units 10^{-3})} \\ \pm 1.4 \pm 0.8 \\ \text{[$\pi^+\pi^-\pi^0$]_D$} K^- \\ \text{LE (units 10^{-6})} \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ We do not use} \\ \pm 1.0 \pm 0.7 \\ \text{Assumes equal pro} \\ \hline{D^0} K^*(892)^+)/\text{IUE (units 10^{-4})} \\ \text{LE (units 10^{-4})} \\ L$ | +)/\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1) | DOCUMENT ID DEL-AMO-SA. | 10H BABR | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ EDJ. \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | τ(4 <i>S</i>) Γ ₅₉ /Γ ₆₀ τ(4 <i>S</i>) Γ ₆₁ /Γ ₆₂ τ(4 <i>S</i>) Γ ₆₃ /Γ ₆₄ τ(4 <i>S</i>) Γ ₆₅ /Γ |
| UE (units 10^{-3}) $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D\gamma)}\pi^+$ UE (units 10^{-3}) $\pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D\pi)}K^-$ UE (units 10^{-3}) $\pm 0.9 \pm 0.4$ $[K^-\pi^+]_{(D\gamma)}K^-$ UE (units 10^{-3}) $\pm 1.4 \pm 0.8$ $[\pi^+\pi^-\pi^0]_DK^-$ UE (units 10^{-6}) $\pm 0.8 \pm 0.4$ • We do not use $\pm 1.0 \pm 0.7$ Assumes equal pro $[D^0K^*(892)^+]_{(DE)}K^-$ UE (units 10^{-4}) $[D^0K^*(892)^+]_{(DE)}K^-$ UE (units 10^{-4}) | +)/\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1))\(\Gamma(K+1) | DOCUMENT ID DEL-AMO-SA. T (D \(\gamma\) \(\pi \) DEL-AMO-SA. T (D \(\pi \) \(\pi \) DEL-AMO-SA. T (D \(\pi \) \(\pi \) DOCUMENT ID DEL-AMO-SA. T (D \(\gamma \) \(\pi \) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 4 data for averages 1 AUBERT, B 1 AUBERT, B 2 and B \(\pi \) at the | 10H BABR 10H | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ COMMENT \\ e^+e^- \rightarrow \\ \hline \\ Repl. \ by \ A \\ \hline \\ \underline{COMMENT} \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | T(4S) Γ ₅₉ /Γ ₆₀ T(4S) Γ ₆₁ /Γ ₆₂ T(4S) Γ ₆₃ /Γ ₆₄ T(4S) Γ ₆₅ /Γ T(4S) UBERT 07BJ |
| UE (units 10^{-3}) $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D^\gamma)}\pi^+$ UE (units 10^{-3}) $\pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D^\pi)}K^+$ UE (units 10^{-3}) $\pm 0.9 \pm 0.4$ $[K^-\pi^+]_{(D^\gamma)}K^-$ UE (units 10^{-3}) $\pm 1.4 \pm 0.8$ $[\pi^+\pi^-\pi^0]_DK^-$ UE (units 10^{-6}) $\pm 0.8 \pm 0.4$ • We do not use $\pm 1.0 \pm 0.7$ Assumes equal pro $[D^0K^+(892)^+]/[UE (units 10^{-4}) \pm 0.4 OUR AVE [9\pm 0.30 \pm 0.34] \pm 1.6 \pm 1.7$ | +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) the following oduction of \(B\) \(\Gamma(\beta\) \(\Gamma(\bet | DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(K^+ \) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(K^+ \) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 MAHAPATRA | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \end{array}$ | 7(45) F59/F60 7(45) F61/F62 7(45) F63/F64 7(45) F65/F 7(45) UBERT 078J |
| UE (units 10 ⁻³) ±0.9±0.8 $K - \pi^+]_{(D\gamma)} \pi^+$ UE (units 10 ⁻³) ±1.4±2.2 $K - \pi^+]_{(D\pi)} K^-$ UE (units 10 ⁻³) ±0.9±0.4 $K - \pi^+]_{(D\gamma)} K^-$ UE (units 10 ⁻³) ±1.4±0.8 $\pi^+ \pi^- \pi^0]_D K^-$ UE (units 10 ⁻⁶) ±0.8±0.4 • We do not use ±1.0±0.7 Assumes equal pro VE (units 10 ⁻⁶) ±0.8±0.4 • We do not use ±1.0±0.7 Assumes equal pro VE (units 10 ⁻⁴) ±0.4 OUR AVE ±0.30±0.34 ±1.6 ±1.7 • We do not use | +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) the following oduction of \(B\) \(\Gamma(\beta\) \(\Gamma(\bet | DOCUMENT ID DEL-AMO-SA. T (D\(\pi\))\(\pi\) + \) DOCUMENT ID DEL-AMO-SA. T (D\(\pi\))\(K^+\) DOCUMENT ID DEL-AMO-SA. T (D\(\pi\))\(K^+\) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID AUBERT (data for average: 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 MAHAPATRA (data for average: 1 AUBERT 1 AUBERT 1 MAHAPATRA | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \hline \end{array}$ | τ(4s) Γ ₅₉ /Γ ₆₀ τ(4s) Γ ₆₁ /Γ ₆₂ τ(4s) Γ ₆₃ /Γ ₆₄ τ(4s) Γ ₆₅ /Γ τ(4s) UBERT 07BJ Γ ₆₆ /Γ |
| $\begin{array}{l} \text{LUE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ [K^-\pi^+]_{(D^\gamma)} \pi^+ \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ \pm 1.4 \pm 2.2 \\ [K^-\pi^+]_{(D\pi)} K^- \\ \pm 0.9 \pm 0.4 \\ [K^-\pi^+]_{(D\gamma)} K^- \\ \pm 1.4 \pm 0.8 \\ [\pi^+\pi^-\pi^0]_D K^- \\ \pm 0.8 \pm 0.4 \\ \bullet \text{We do not use} \\ \pm 1.0 \pm 0.7 \\ \text{Assumes equal pro} \\ \hline{D^0} K^*(892)^+)/1 \\ \pm 0.4 \text{Our AVE} \\ 9 \pm 0.30 \pm 0.34 \\ \pm 1.6 \pm 1.7 \\ \bullet \text{We do not use} \\ \pm 1.7 \text{We do not use} \\ \pm 0.7 \pm 0.5 \\ \end{array}$ | +)/\(\Gamma(\beta\)/\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\Gamma(\beta\))\(\ | DOCUMENT ID DEL-AMO-SA. T (D\(\pi\))\(\pi\) + \\ DOCUMENT ID DEL-AMO-SA. T (D\(\pi\))\(K^+\)\(DOCUMENT ID\) DEL-AMO-SA. T (D\(\pi\))\(K^+\)\(DOCUMENT ID\) DEL-AMO-SA. DEL-AMO-SA. DOCUMENT ID AUBERT (data for average: 1 AUBERT 1 AUBERT 1 AUBERT 1 MAHAPATRA (data for average: 1 AUBERT 1 MAHAPATRA (data for average: 1 AUBERT | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \hline \end{array}$ | 7(45) F59/F60 7(45) F61/F62 7(45) F63/F64 7(45) F65/F 7(45) UBERT 078J |
| $\begin{array}{l} \text{LUE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ \text{[$K^-\pi^+$]_{(D\gamma)}\pi^+$} \\ \pm 1.4 \pm 2.2 \\ \text{[$K^-\pi^+$]_{(D\pi)}K^-$} \\ \pm 0.9 \pm 0.4 \\ \text{[$K^-\pi^+$]_{(D\gamma)}K^-$} \\ \pm 1.4 \pm 0.8 \\ \text{[$K^-\pi^+$]_{(D\gamma)}K^-$} \\ \pm 1.4 \pm 0.8 \\ \text{[$\pi^+\pi^-\pi^0$]_{D}K^-$} \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ Ve do not use } \\ \pm 1.0 \pm 0.7 \\ \text{Assumes equal pro} \\ \hline{D^0K^*(892)^+}/\text{I} \\ \pm 0.4 \text{ OUR AVE} \\ 9 \pm 0.30 \pm 0.34 \\ \pm 1.6 \pm 1.7 \\ \bullet \text{ We do not use } \\ \pm 0.7 \pm 0.5 \\ \text{Assumes equal pro} \end{array}$ | +)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\) the following oduction of \(B\) RAGE the following oduction of \(B\) | DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(\pi \) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(\pi \) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(K^+ \)) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(K^+ \)) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 MAHAPATRA data for averages 1 AUBERT 1 AUB | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \hline \end{array}$ | 7(45) F59/F60 7(45) F61/F62 7(45) F63/F64 7(45) F65/F 7(45) F66/F 7(45) F66/F |
| $\begin{array}{l} \text{LUE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ \text{[$K^-\pi^+$]}_{(D\gamma)}\pi^+\\ \pm 1.4 \pm 2.2 \\ \text{[$K^-\pi^+$]}_{(D\pi)}K^-\\ \pm 0.9 \pm 0.4 \\ \text{[$K^-\pi^+$]}_{(D\pi)}K^-\\ \pm 1.4 \pm 0.8 \\ \text{[$K^-\pi^+$]}_{(D\gamma)}K^-\\ \pm 1.4 \pm 0.8 \\ \text{[$\pi^+\pi^-\pi^0$]}_{D}K^-\\ \pm 0.8 \pm 0.4 \\ \pm 0.8 \pm 0.4 \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ We do not use} \\ \pm 1.0 \pm 0.7 \\ \text{Assumes equal pro} \\ \hline{D^0}K^*(892)^+)/\text{I}_{UE (units 10^{-4})} \\ \pm 0.4 \text{ OUR AVE} \\ 9 \pm 0.3 \text{ OUR AVE} \\ 9 \pm 0.3 \text{ OUR AVE} \\ 9 \pm 0.5 \text{ Assumes equal pro} \\ \pm 0.7 \pm 0.5 \\ \text{Assumes equal pro} \\ D_{CP(-1)}K^*(892)^+ $ | +)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\) the following oduction of \(B\) RAGE the following oduction of \(B\) | DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(\pi \) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(\pi \) \(\pi \) DEL-AMO-SA. T (D \(\pi \)) \(K^+ \)) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \)) \(K^+ \)) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT IS 3 data for averages 1 AUBERT IS 4 AUBERT 1 MAHAPATRA data for averages 1 AUBERT 1 AUBE | 10H BABR 10H | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \hline \\ \\ \underline{COMMENT} \\ \\ \\ \\ \underline{COMMENT} \\ \\ \\ \\ \underline{COMMENT} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | τ(4s) Γ ₅₉ /Γ ₆₀ τ(4s) Γ ₆₁ /Γ ₆₂ τ(4s) Γ ₆₃ /Γ ₆₄ τ(4s) Γ ₆₅ /Γ τ(4s) UBERT 07BJ Γ ₆₆ /Γ |
| $\begin{array}{l} \text{LUE (units 10^{-3})} \\ \pm 0.9 \pm 0.8 \\ \text{[$K^-\pi^+$]_{(D\gamma)}\pi^+$} \\ \pm 1.4 \pm 2.2 \\ \text{[$K^-\pi^+$]_{(D\pi)}K^-$} \\ \pm 0.9 \pm 0.4 \\ \text{[$K^-\pi^+$]_{(D\gamma)}K^-$} \\ \pm 1.4 \pm 0.8 \\ \text{[$K^-\pi^+$]_{(D\gamma)}K^-$} \\ \pm 1.4 \pm 0.8 \\ \text{[$\pi^+\pi^-\pi^0$]_{D}K^-$} \\ \pm 0.8 \pm 0.4 \\ \bullet \text{ We do not use } \\ \pm 1.0 \pm 0.7 \\ \bullet \text{Assumes equal pro} \\ \hline{D^0K^*(892)^+}/\text{I} \\ \pm 0.4 \text{ OUR AVE} \\ 9 \pm 0.30 \pm 0.34 \\ \pm 1.6 \pm 1.7 \\ \bullet \text{ We do not use } \\ \pm 0.7 \pm 0.5 \\ \text{Assumes equal pro} \\ \hline{D^0K^*(892)^+}/\text{I} \\ \pm 0.8 \pm 0.30 \\ \pm 0.4 \text{ OUR AVE} \\ \text{Substantial } \\ Substa$ | +)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\)/\(\Gamma(\beta)\) the following oduction of \(B\) RAGE the following oduction of \(B\) | DOCUMENT ID DEL-AMO-SA. T (D\(\pi\)) \(\pi\) + \(\p) DOCUMENT ID DEL-AMO-SA. T (D\(\pi\)) \(K^+\) DOCUMENT ID DEL-AMO-SA. T (D\(\pi\)) \(K^+\) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 MAHAPATRA 1 data for averages 1 AUBERT 1 AUBER | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ e^+ e^- \rightarrow \\ \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ \\ \underline{COMMENT} \\ \\ \end{array}$ | 7(45) F59/F60 7(45) F61/F62 7(45) F63/F64 7(45) F65/F 7(45) F66/F 7(45) F66/F |
| UE (units 10^{-3}) $\pm 0.9 \pm 0.8$ $[K^-\pi^+]_{(D\gamma)}\pi^+$ UE (units 10^{-3}) $\pm 1.4 \pm 2.2$ $[K^-\pi^+]_{(D\pi)}K^-$ UE (units 10^{-3}) $\pm 0.9 \pm 0.4$ $[K^-\pi^+]_{(D\gamma)}K^-$ UE (units 10^{-3}) $\pm 1.4 \pm 0.8$ $[\pi^+\pi^-\pi^0]_DK^-$ UE (units 10^{-6}) $\pm 0.8 \pm 0.4$ • We do not use $\pm 1.0 \pm 0.7$ Assumes equal properties 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} 10^{-6} $10^$ | +)/ $\Gamma([K+1]$ +)/ $\Gamma([K+1]$ +)/ $\Gamma([K+1]$ +)/ $\Gamma([K+1]$ the following eduction of E Total RAGE the following eduction of E | DOCUMENT ID DEL-AMO-SA. T (D \(\gamma\) \(\pi \) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \) \(\pi \) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \) \(\pi \) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 1 AUBERT 2 AUBERT 1 MAHAPATRA 2 data for averages 1 AUBERT 2 H AND BERT 3 H AUBERT 4 H AUBERT 4 H AUBERT 5 H AUBERT 5 H AUBERT 6 H AUBERT 7 H AUBERT 8 H AUBERT 8 H AUBERT 9 H AUBERT 9 H AUBERT 1 AUBERT 2 AUBERT 3 AUBERT 3 AUBERT 4 AUBERT 5 AUBERT 6 AUBERT 6 AUBERT 7 AUBERT 7 AUBERT 8 AUBER | 10H BABR 10H | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{etc.} \bullet \\ \hline$ | T(4S) Γ59/Γ60 T(4S) Γ61/Γ62 T(4S) Γ63/Γ64 T(4S) Γ65/Γ T(4S) UBERT 07BJ Γ66/Γ T(4S) UBERT 06Z |
| VE (units 10 ⁻³) \pm 0.9 \pm 0.8 $K - \pi^+$] (D_T) π^+ VE (units 10 ⁻³) \pm 1.4 \pm 2.2 $K - \pi^+$] (D_T) K^- VE (units 10 ⁻³) \pm 0.9 \pm 0.4 $K - \pi^+$] (D_T) K^- VE (units 10 ⁻³) \pm 1.4 \pm 0.8 $\pi^+ \pi^- \pi^0$] D_T K^- VE (units 10 ⁻⁶) \pm 1.0 \pm 0.7 Assumes equal pro D^0 K^* (892) \pm) /1 \pm 0.4 OUR AVE \pm 0.5 Assumes equal pro D^0 D^0 D | +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) +)/\(\Gamma(\beta\) the following oduction of \(B\) RAGE the following oduction of \(B\) the following the following the following oduction of \(B\) | DOCUMENT ID DEL-AMO-SA. T (D \(\gamma\) \(\pi \) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \) \(\pi \) DOCUMENT ID DEL-AMO-SA. T (D \(\pi \) \(\pi \) DOCUMENT ID DEL-AMO-SA. DOCUMENT ID 1 AUBERT 3 AUBERT 4 AUBERT 5 AUBERT 6 AUBERT 6 AUBERT 7 AUBERT 8 AUBERT 8 AUBERT 8 AUBERT 9 AUBERT 1 AUBERT 2 AUBERT 3 AUBERT 4 AUBERT 5 AUBERT 6 AUBERT 6 AUBERT 7 AUBERT 8 AUBERT 8 AUBERT 8 AUBERT 9 AUBERT | 10H BABR 10H | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \text{etc.} \bullet \bullet \\ \hline \\ \text{Repl. by A} \\ \hline \\ \underline{COMMENT} \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ \end{array}$ | T(45) T59/F60 T(45) T61/F62 T(45) T63/F64 T(45) T65/F T(45) UBERT 07BJ T66/F T(45) UBERT 062 T67/F66 T(45) UBERT 09AJ |

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\Gamma(D_{CP(+1)} K^*(892)^+)/\Gamma(\overline{D}{}^0 K^*(892)^+)
                                                                                                \Gamma_{68}/\Gamma_{66}
                                           DOCUMENT ID
                                                                    TECN COMMENT
.085 \pm 0.175 \pm 0.045
                                         ^{\mathrm{1}} AUBERT
                                                             09AJ BABR e^+e^- \rightarrow
 \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet\,\,\bullet
                                        <sup>2</sup> AUBERT,B 05U BABR Repl. by AUBERT 09AJ
.98 + 0.20 + 0.055
 ^1 The authors report R_{CP+}\!= 2.17 \pm 0.35 \pm 0.09 which is, assuming \it CP conservation, twice the value of the quoted above branching ratio,
 ^2 The authors report R_{CP+} = 1.96 \pm 0.40 \pm 0.11 which is, assuming \it CP conservation,
   twice the value of the quoted above branching ratio.
(\overline{D}^0 K^+ \overline{K}^0) / \Gamma_{\text{total}}
                                                                                                  \Gamma_{69}/\Gamma
ALUE (units 10<sup>-4</sup>)
                                           DOCUMENT ID
                                                                 TECN COMMENT
                                         ^{1} DRUTSKOY 02 BELL e^{+}e^{-} 
ightarrow \gamma (4S)
5.5 ±1.4 ± 0.8
 ^1\,\mathrm{Assumes} equal production of \mathit{B}^{\,+} and \mathit{B}^{\,0} at the \,\varUpsilon(4\mathit{S}\,).
(\overline{D}^{0}K^{+}\overline{K}^{*}(892)^{0})/\Gamma_{total}
                                                                                                  \Gamma_{70}/\Gamma
                                           DOCUMENT ID
ALUE (units 10<sup>-4</sup>)
                                                                 TECN COMMENT
                                         ^{1} DRUTSKOY 02 BELL e^{+}\,e^{-} 
ightarrow \, \varUpsilon(4\,{\it S})
7.5 ±1.3±1.1
 <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
(\overline{D}{}^0\pi^+\pi^+\pi^-)/\Gamma_{\rm total}
                                                                                                  \Gamma_{71}/\Gamma
                                           DOCUMENT ID
                                                                    TECN COMMENT
.0057±0.0022 OUR FIT Error includes scale factor of 3.6.
.0115 \pm 0.0029 \pm 0.0021
                                        <sup>1</sup> BORTOLETTO92 CLEO e^+e^- \rightarrow r(4S)
 ^1BORTOLETTO 92 assumes equal production of B^+ and B^0 at the arphi(4S) and uses
   Mark III branching fractions for the D.
\Gamma(\overline{D}{}^0\pi^+\pi^+\pi^-)/\Gamma(\overline{D}{}^0\pi^+)
                                                                                                \Gamma_{71}/\Gamma_{42}
                                           DO CUMENT ID
                                                                 TECN COMMENT
L.2 ±0.4 OUR FIT Error includes scale factor of 3.8.
                                                             11E LHCB pp at 7 TeV
.27 \pm 0.06 \pm 0.11
                                           AAIJ
(\overline{D}{}^0\pi^+\pi^+\pi^- nonresonant)/\Gamma_{
m total}
                                                                                                  \Gamma_{72}/\Gamma
                                           DOCUMENT ID
                                                                   TECN COMMENT
                                         1 \overline{\mathsf{BORTOLETTO92}} CLEO e^+e^- \to r(4S)
.0051 \pm 0.0034 \pm 0.0023
 ^1BORTOLETTO 92 assumes equal production of B^+ and B^0 at the \varUpsilon(4S) and uses
   Mark III branching fractions for the D.
 (\overline{D}{}^0\pi^+\rho^0)/\Gamma_{\rm total}
                                                                                                  \Gamma_{73}/\Gamma
ALUE
                                           DO CUMENT ID
                                                                  TECN COMMENT
.0042 ± 0.0023 ± 0.0020
                                         ^{1} BORTOLETTO92 CLEO e^{+}e^{-} 
ightarrow \varUpsilon (4S)
 ^1BORTOLETTO 92 assumes equal production of B^+ and B^0 at the \Upsilon(4S) and uses
   Mark III branching fractions for the D.
(\overline{D}^0 a_1(1260)^+)/\Gamma_{\text{total}}
                                                                                                  \Gamma_{74}/\Gamma
ALUE
                                           DOCUMENT ID TECN COMMENT
0.0045 \pm 0.0019 \pm 0.0031
                                        1 \overline{\mathsf{BORTOLETTO92}} CLEO e^+e^- \to \varUpsilon(4S)
 ^1BORTOLETTO 92 assumes equal production of B^+ and B^0 at the \varUpsilon(4S) and uses
   Mark III branching fractions for the D.
(\overline{\mathcal{D}}{}^0\omega\pi^+)/\Gamma_{
m total}
                                                                                                  \Gamma_{75}/\Gamma
ALUE
                                           DOCUMENT ID
                                                                  TECN COMMENT
                                        1 \overline{\sf ALEXA\,NDER} 01B CLE2 e^+e^- 
ightarrow \varUpsilon(4S)
.0041 \pm 0.0007 \pm 0.0006
 ^1 Assumes equal production of B^+ and B^0 at the \Upsilon(4S). The signal is consistent with
   all observed \omega\pi^+ having proceeded through the \rho'^+ resonance at mass 1349 \pm 25 ^{+\,10}_{-\,5}
   MeV and width 547 \pm 86^{+46}_{-45} MeV.
T(D^*(2010)^-\pi^+\pi^+)/\Gamma_{\text{total}}
                                                                                                  \Gamma_{76}/\Gamma
ALUE (units 10<sup>-3</sup>)
                                                                          TECN COMMENT
                                                 DO CUMENT ID
 1.35 ± 0.22 OUR AVERAGE
 1.25\pm0.08\pm0.22
                                               <sup>1</sup> ABE
                                                                    04D BELL e^+e^- \rightarrow \Upsilon(4S)
 1.9 + 0.7 + 0.3
                                     14
                                               <sup>2</sup> ALAM
                                                                     94 CLE2 e^+e^- \rightarrow \Upsilon(4S)
                                                                          ARG e^+e^- \rightarrow \Upsilon(4S)
                                               <sup>3</sup> ALBRECHT
 2.6 \pm 1.4 \pm 0.7
                                     11
                                                                    90J
 ^{4} BEBEK
                                      3
                                                                    87 CLEO e^+e^- \rightarrow \Upsilon(4S)
 \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
                                              <sup>5</sup> BORTOLETTO92 CLEO e^+e^- \rightarrow \Upsilon(4S)
                                               ^{6} ALBRECHT 87c ARG e^{+}\,e^{-} 
ightarrow \, \varUpsilon(4\,{\it S})
 <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
 ^2 ALAM 94 assume equal production of B^+ and B^0 at the \varUpsilon(45) and use the CLEOII
   {\rm B}(D^*(2010)^+ \to D^0\pi^+) and absolute {\rm B}(D^0 \to K^-\pi^+) and the PDG 1992 {\rm B}(D^0 \to K^-\pi^+)
   K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+) and B(D^0\to K^-2\pi^+\pi^-)/B(D^0\to K^-\pi^+).
 <sup>3</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S) and uses the Mark III branching
   fractions for the D.
 4 BEBEK 87 value has been updated in BERKELMAN 91 to use same assumptions as
   noted for BORTOLETTO 92.
 <sup>5</sup> BORTOLETTO 92 assumes equal production of B^+ and B^0 at the \Upsilon(4S) and uses
   MarkIII branching fractions for the D and D^*(2010). The authors also find the product
   branching fraction into D^{**}\pi followed by D^{**}\to D^*(2010)\pi to be 0.0014^{+0.0008}_{-0.0006}\pm
   0.0003 where D^{**} represents all orbitally excited D mesons.
 ^6ALBRECHT 87c use PDG 86 branching ratios for D and D^*(2010) and assume
   B(\Upsilon(4S) \rightarrow B^+B^-) = 55\% and B(\Upsilon(4S) \rightarrow B^0\overline{B}^0) = 45\%. Superseded by AL-
```

| $\Gamma(\overline{D}_1(2420)^0\pi^+\times B(\overline{D}_1^0\to D^*(2010)^-\pi^+))/\Gamma(\overline{D}^0\pi^+\pi^+\pi^-)$ | | | | | | |
|---------------------------------------------------------------------------------------------------------------------------|-------------------------|-----|------|-------------|--|---|
| VALUE (units 10^{-2}) | DO CUMENT ID | | TECN | COMMENT | | |
| 9.3±1.6±0.9 | $^{ m 1}$ AAIJ | 11E | LHCB | pp at 7 TeV | | I |
| ¹ Uses B($D^*(2010)^+ \rightarrow D^0$ | $\pi^+) = (67.7 + -0.5$ |)%. | | | | I |
| 1 Uses B(D*(2010) 1 → D* | $\pi^+) = (67.7 + -0.5$ |)%. | | | | • |

| $\Gamma(D^-\pi^+\pi^+)/\Gamma_{\text{tot}}$ | al | | | | | Γ ₇₈ /Γ |
|------------------------------------------------------|-----------------|------------------------|----------|-----------|----------------------|--------------------|
| VALUE (units 10 ⁻³) | CL% EVTS | DOCUMENT ID |) | TECN | COMMENT | |
| 1.07±0.05 OUR AV | /ERAGE | | | | | |
| $1.08 \pm 0.03 \pm 0.05$ | | ¹ AUBERT | | | $e^+e^- \rightarrow$ | |
| $1.02 \pm 0.04 \pm 0.15$ | | ¹ ABE | 04D | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| ● ● We do not use | the following d | data for averages, f | its, lim | its, etc. | • • • | |
| <1.4 | 90 | | | | $e^+e^- \to$ | |
| <7 | 90 | ³ BORT OLET | TO 92 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 1 | ⁴ BEBEK | 87 | CLEO | $e^+e^- \to$ | $\Upsilon(4S)$ |

- ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.
- 2 ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(4S)$ and use the MarkIII B(D^+ \to $K^-2\pi^+).$
- 3 BORTOLETTO 92 assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses Mark III branching fractions for the D. The product branching fraction into $D_0^*(2340)\,\pi$ followed by $D_0^*(2340)\,\rightarrow\,D\pi$ is <0.005 at 90%CL and into $D_2^*(2460)$ followed by $D_2^*(2460)\,\rightarrow\,D\pi$ is <0.004 at 90%CL.
- 4 BEBEK 87 assume the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}{}^0.$ B($D^-\to K^+\pi^-\pi^-)=(9.1\pm1.3\pm0.4)\%$ is assumed.

| $\Gamma(D^+K^{\circ})/\Gamma_{\text{total}}$ | | | | Γ ₇₉ /Γ |
|----------------------------------------------|-----------|----------------------------|------------|------------------------------------|
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT |
| <2.9 | 90 | ¹ DEL-AMO-SA10k | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the | following | data for averages, fit | s, limits, | etc. • • • |
| < 5.0 | 90 | ¹ AUBERT,B 05E | BABR | Repl. by DEL-AMO- SANCHEZ 10K |

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(D^+K^{*0})/\Gamma_{\text{total}}$ | | | | | Γ ₈₀ /Γ |
|-------------------------------------------|-----------|-----------------------------------------|------|-----------------------|--------------------|
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | |
| <3.0 | 90 | ¹ DEL-AMO-SA10k | BABR | $e^+ e^- \rightarrow$ | Y(45) |
| 1 Assumes equal proc | fuction o | of B^+ and B^0 at the $\Upsilon(A)$ | 5) | | |

| $\Gamma(\overline{D}^*(2007)^0\pi^+)/\Gamma_{ m total}$ | | | | Γ ₈₁ /Γ |
|---------------------------------------------------------|---------|-----------------------------|------------|-----------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 5.18±0.26 OUR AVERAGE | | | | |
| $5.52 \pm 0.17 \pm 0.42$ | | ¹ AUBERT 07 | | |
| 5.5 ±0.4 ±0.2 | | 2,3 AUBERT,BE 06, | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $4.34 \pm 0.47 \pm 0.18$ | | ⁴ BRANDENB 98 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5.2 ±0.7 ±0.7 | 71 | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $7.2 \pm 1.8 \pm 1.6$ | | ⁶ BORTOLETTO92 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $4.0 \pm 1.4 \pm 1.2$ | 9 | ⁶ ALBRECHT 90J | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the fo | llowing | data for averages, fits, li | mits, etc. | • • • |

⁷BEBEK

87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and B^0 at the arphi(4S).

 2.7 ± 4.4

- 2 AUBERT,BE 061 reports $[\Gamma(B^+\to \overline{D}^*(2007)^0\pi^+)/\Gamma_{\text{total}}]$ / $[B(B^+\to \overline{D}^0\pi^+)]$ = 1.14 \pm 0.07 \pm 0.04 which we multiply by our best value $B(B^+\to \overline{D}^0\pi^+)$ = (4.81 \pm 0.15) \times 10 $^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- 3 Uses a missing-mass method. Does not depend on $\it D$ branching fractions or $\it B^+/\it B^0$ production rates.
- 4 BRANDENBURG 98 assume equal production of B^+ and B^0 at $\Upsilon(4S)$ and use the D^* reconstruction technique. The first error is their experiment's error and the second error is the systematic error from the PDG 96 value of $B(D^*\to D\pi)$.
- 5 ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(4S)$ and use the CLEOII $B(D^*(2007)^0 \rightarrow D^0\pi^0)$ and absolute $B(D^0 \rightarrow K^-\pi^+)$ and the PDG 1992 $B(D^0 \rightarrow K^-\pi^+\pi^0)/B(D^0 \rightarrow K^-\pi^+)$ and $B(D^0 \rightarrow K^-\pi^+\pi^-)/B(D^0 \rightarrow K^-\pi^+)$.
- 6 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses Mark III branching fractions for the D and $D^*(2010)$.
- 7 This is a derived branching ratio, using the inclusive pion spectrum and other two-body B decays. BEBEK 87 assume the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}{}^0$.

| $\Gamma(\overline{D}^*(2007)^0\omega\pi^+)/\Gamma_{ m total}$ | | | | | Г ₈₄ /Г |
|---------------------------------------------------------------|---------------------|-----|------|-------------|--------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.0045 \pm 0.0010 \pm 0.0007$ | $^{ m 1}$ ALEXANDER | 01в | CLE2 | $e^+e^-\to$ | Y(45) |

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$. The signal is consistent with all observed $\omega\,\pi^+$ having proceeded through the ρ'^+ resonance at mass 1349 \pm 25 $^{+10}_{-5}$ MeV and width 547 \pm 86 $^{+46}_{-45}$ MeV.

| $\Gamma(\overline{D}^*(2007)^0 \rho^+)/\Gamma_{\text{total}}$ | | | | | | Г85 / Г |
|---------------------------------------------------------------|-----------|-----------------------|-----------|------------|----------------------|----------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.0098±0.0017 OUR AVER | AGE | | | | | |
| $0.0098 \pm 0.0006 \pm 0.0017$ | | $^{ m 1}$ CSORNA | | | | |
| $0.010 \pm 0.006 \pm 0.004$ | 7 | ² ALBRECHT | 90J | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not use the fo | llowing d | ata for averages, f | fits, lin | nits, etc. | • • • | |
| 0.0169 ± 0.0021 ± 0.0029 | 96 | 3 41 4 44 | 0.4 | CLES | a+a- | 2(15) |

- 1 Assumes equal production of B^0 and B^+ at the $\varUpsilon(4S)$ resonance. The second error combines the systematic and theoretical uncertainties in quadrature. CSORNA 03 includes data used in ALAM 94. A full angular fit to three complex helicity amplitudes is performed.
- 2. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses MarkIII branching fractions for the D and $D^*(2010)$.
- and actions for the D and D (2010). SALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(4S)$ and use the CLEOII $B(D^*(2007)^0 \to D^0\pi^0)$ and absolute $B(D^0 \to K^-\pi^+)$ and the PDG 1992 $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$ and $B(D^0 \to K^-2\pi^+\pi^-)/B(D^0 \to K^-\pi^+)$. The nonresonant $\pi^+\pi^0$ contribution under the ρ^+ is negligible.

| | | _ | • | |
|----------------------------------------------------------------------------------------------------------------------------------|----------------------|----------|----------|------------------------------------------|
| $\Gamma(\overline{D}^*(2007)^0 K^+)/\Gamma_{ m total}$ | | | | Γ ₈₆ /Γ |
| VALUE (units 10 ⁻⁴) | DO CUMENT IL |) | TECN | COMMENT |
| 4.20±0.34 OUR AVERAGE | | | | |
| $4.21^{+0.30}_{-0.26}\pm0.21$ | ¹ AUBERT | 05 N | BABR | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| $4.0 \pm 1.1 \pm 0.2$ | ² ABE | 011 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ¹ AUBERT 05N reports [Γ(B | | | | |
| $= 0.0813 \pm 0.0040 ^{+0.0}_{-0.0}$ | | | | |
| $\overline{D}^*(2007)^0 \pi^+) = (5.18 \pm 3)$ and our second error is the ² ABE 011 reports $[\Gamma(B^+ \to 3)]$ | systematic error fro | om usin | g our be | st value. |
| $0.078\pm0.019\pm0.009$ whi | ch we multiply by o | our best | value B | $(B^+ \to \overline{D}^*(2007)^0 \pi^+)$ |
| $= (5.18 \pm 0.26) \times 10^{-3}$. On is the systematic error from | | | iment's | error and our second error |

| $\Gamma(\overline{\mathcal{D}}_{CP(+1)}^{*0}K^+)/\Gamma_{total}$ | | | Γ ₈₇ /Ι |
|------------------------------------------------------------------|------------------|-----------|-----------------------------------|
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN | COMMENT |
| $2.75 \pm 0.29 + 0.23 \\ -0.22$ | $^{ m 1}$ AUBERT | 08BF BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |

 1 AUBERT 08BF reports [\Gamma(B^+ \to \overline{D}^{*0}_{CP(+1)} \, \text{K}^+)/\Gamma_{\text{total}}] \, / \, [\text{B}(B^+ \to \overline{D}^*(2007)^0 \, \text{K}^+)] = 0.655 \pm 0.065 \pm 0.020 which we multiply by our best value B (B^+ $\to \overline{D}^*(2007)^0 \, \text{K}^+)$ = (4.20 \pm 0.34) \times 10⁻⁴. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $(^{D}CP(+1)^{K+})/(^{D}CP(+1)^{K+})$ |) ^{71 ·}) | | | | 1 87/1 | 82 |
|---------------------------------------|---------------------|------|------|----------------------|----------------|----|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| 0.095 ± 0.017 OUR AVERAGE | | | | | | |
| $0.11 \pm 0.02 \pm 0.02$ | ¹ ABE | 06 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |
| $0.086 \pm 0.021 \pm 0.007$ | ² AUBERT | 05 N | BABR | $e^+e^- \rightarrow$ | $\Upsilon(45)$ | |

√+\/r(¬*0

1 Reports a double ratio of B($B^+ \to D_{CP(+1)}^{*0} \, K^+)/B(B^+ \to D_{CP(+1)}^{*0} \, \pi^+)$ and B($B^+ \to \overline{D}^{*0} \, K^+)/B(B^+ \to \overline{D}^{*0} \, \pi^+)$, $1.41 \pm 0.25 \pm 0.06$. We multiply by our best value of B($B^+ \to \overline{D}^{*0} \, K^+)/B(B^+ \to \overline{D}^{*0} \, \pi^+) = 0.080 \pm 0.011$. Our first error is their experiment's error and the second error is systematic error from using our best value.

 2 Value. 2 Uses $D^{*0} \to D^0 \pi^0$ with D^0 reconstructed in the CP-even eigenstates ${\it K}^+ \, {\it K}^-$ and $\pi^+ \pi^-$

 1 AUBERT 08BF reports [\Gamma(B^+ \rightarrow \overline{D}_{CP(-1)}^{*0} \, \text{K}^+)/\Gamma_{\text{total}}] \, / \, [\text{B}(B^+ \rightarrow \overline{D}^*(2007)^0 \, \text{K}^+)] \\ = 0.55 \pm 0.06 \pm 0.02 which we multiply by our best value B(B^+ $\rightarrow \overline{D}^*(2007)^0 \, \text{K}^+) \\ = (4.20 \pm 0.34) \times 10^{-4}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

 1 Reports a double ratio of B(B^+ $\rightarrow (D^*_{CP(-1)})^0 \, K^+)/B(B^+ \rightarrow (D^*_{CP(-1)})^0 \, \pi^+)$ and B(B^+ $\rightarrow \overline{D}^{*0} \, K^+)/B(B^+ \rightarrow \overline{D}^{*0} \, \pi^+)$, 1.15 \pm 0.31 \pm 0.12. We multiply by our best value of B(B^+ $\rightarrow \overline{D}^{*0} \, K^+)/B(B^+ \rightarrow \overline{D}^{*0} \, \pi^+) = 0.080 \pm 0.011$. Our first error is their experiment's error and the second error is systematic error from using our best value.

 $\Gamma(\overline{D}^*(2007)^0 K^*(892)^+)/\Gamma_{\text{total}}$ Γ_{89}/Γ

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------------------|--------------|------|------------------------------------------------------------------------|
| 8.1 ±1.4 OUR AVERAGE | | | |
| $8.3 \pm 1.1 \pm 1.0$ $7.2 \pm 2.2 \pm 2.6$ | | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ |

Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and an unpolarized final state.

| $\Gamma(D^*(2007)^{\circ}K^+I$ | (°)/F _{total} | | | | Γ 9 0/ |
|--------------------------------|------------------------|-------------------------|--------|----------------------|----------------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TECN | COMMENT | |
| <10.6 | 90 | ¹ DRUTSKOY 0 | 2 BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 B^{\pm}

| $\Gamma(\overline{D}^*(2007)^0 K^+ K^*(892)^0)/\Gamma_{\text{total}}$ | Γ ₉₁ /Γ | $\Gamma(\overline{D}^{**0}\pi^+)/\Gamma_{\text{total}}$ | s an excited state with mas | - 2 2 - 14 - 2 2 2 | Γ ₁₀ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| (ALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT 1 DRUTSKOY 02 BELL $e^+e^- \rightarrow \gamma$ | (4.6) | VALUE (units 10 ⁻³) | s an excited state with mas DOCUMENT | | JeV/C~. COMMENT |
| 1.3.25.1.2.39 • DROTSKOT 02 BELL $e^+e^- \rightarrow r$ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | (43) | 5.9±1.3±0.2 | | E 06J BABR | |
| * * | - /- | ¹ AUBERT,BE 06J | reports $[\Gamma(B^+	o \overline D^{**0}\pi^+)]$ | ⁻)/Γ _{total}] / [B(<i>B</i> - | $+ \rightarrow \overline{D}^0 \pi^+)] = 1.3$ |
| $\Gamma(\overline{D}^*(2007)^0\pi^+\pi^+\pi^-)/\Gamma_{\text{total}}$ | Γ ₉₂ /Γ | 0.13 ± 0.23 which | we multiply by our best va | alue B($B^+	o \overline{D}^0$ | $\pi^+) = (4.81 \pm 0.1$ |
| VALUE (units 10^{-2}) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 1.03 \pm 0.12 OUR AVERAGE | <u> </u> | error from using o | rror is their experiment's e ur best value. | | • |
| $1.055\pm0.047\pm0.129$ $\frac{1}{2}$ MAJUMDER 04 BELL $e^+e^- ightarrow$ | | ² Uses a missing-m | ass method. Does not dep | end on <i>D</i> branchi | ng fractions or B^+ |
| 0.94 \pm 0.20 \pm 0.17 48 ^{2,3} ALAM 94 CLE2 $e^+e^- \rightarrow$ | · \(\gamma(45) | production rates. | | | |
| 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. 2 ALAM 94 assume equal production of B^{+} and B^{0} at the $\Upsilon(4S)$ and use the | he CLEOU | $\Gamma(\overline{D}_1^*(2420)^0\pi^+)/$ | | | Γ ₁₀ |
| $B(D^*(2007)^0 \rightarrow D^0\pi^0)$ and absolute $B(D^0 \rightarrow K^-\pi^+)$ and the PDG 199 | $2 B(D^0 \rightarrow$ | 0.0015 ± 0.0006 OUR | AVERAGE Error includes | | I <u>COMMENT</u> i. |
| $K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ and $B(D^0\to K^-2\pi^+\pi^-)/B(D^0\to K^-\pi^+\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-\pi^-)/B(D^0\to K^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^$ | π^+). | $0.0011 \pm 0.0005 \pm 0.00$ | 02 8 ¹ ALAM | 94 CLE | $e^+e^- \rightarrow \gamma(4)$ |
| ³ The three pion mass is required to be between 1.0 and 1.6 GeV consistent meson. (If this channel is dominated by a_1^+ , the branching ratio for $\overline{\mathcal{D}}^{*0}$ a | with an a_1 | $0.0025 \pm 0.0007 \pm 0.000$ | | CHT 94D ARG | , |
| that for $\overline{D}^{*0}\pi^+\pi^+\pi^-$.) | 1 is twice | | equal production of B^+ a $D^0\pi^+$) and absolute B(D | | |
| $\Gamma(\overline{D}^*(2007)^0 a_1(1260)^+)/\Gamma_{\text{total}}$ | F /F | $K^{-}\pi^{+}\pi^{0})/B(D^{0}$ | $^{0} ightarrow$ $K^{-}\pi^{+}$) and assuming | $B(D_1(2420)^{\dot{0}} \rightarrow 0$ | $D^*(2010)^+\pi^-)=0$ |
| VALUE | Γ ₉₃ /Γ | | assume equal production of | | |
| 0.0188 \pm 0.0040 \pm 0.0034 1.2 ALAM 94 CLE2 $e^+e^- \rightarrow r$ | (45) | CLEO II B(D*(20 67%. | $10)^+ \rightarrow D^0 \pi^+$) assumi | ng B(D ₁ (2420) ^o | $\rightarrow D^*(2010)^+ \pi^-$ |
| 1 ALAM 94 value is twice their $\Gamma(\overline{D}^*(2007)^0\pi^+\pi^+\pi^-)/\Gamma_{\rm total}$ value base observation that the three pions are dominantly in the $a_1(1260)$ mass range | ed on their | Γ(Π . (2420)0 - + × | $B(\overline{D}_1^0 \to \overline{D}{}^0\pi^+\pi^-))$ | /F | Гаа |
| observation that the three pions are dominantly in the $a_1 (1260)$ mass range GeV. | 1.0 to 1.6 | VALUE (units 10 ⁻⁴) | $D(D_1 \rightarrow D \times X))$ | | Γ ₁₀ COMMENT |
| 2 ALAM 94 assume equal production of B^+ and B^0 at the \varUpsilon (4 S) and use the | | - | | | COMMENT |
| ${\sf B}(D^*(2007)^0 \to D^0\pi^0)$ and absolute ${\sf B}(D^0 \to K^-\pi^+)$ and the PDG 199 $K^-\pi^+\pi^0)/{\sf B}(D^0 \to K^-\pi^+)$ and ${\sf B}(D^0 \to K^-2\pi^+\pi^-)/{\sf B}(D^0 \to K^-\pi^+)$ | $2 B(D^0 \rightarrow \pi^+)$ | | Error includes scale facto | r 01 4.0. | |
| | | $1.85 \pm 0.29 {}^{+ 0.35}_{- 0.55}$ | ¹ ABE | 05A BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(\overline{D}^*(2007)^0\pi^-\pi^+\pi^+\pi^0)/\Gamma_{	ext{total}}$ VALUE DOCUMENT ID TECN COMMENT | Г94/Г | ¹ Assumes equal pro | oduction of ${\it B}^{+}$ and ${\it B}^{0}$ at | the $\Upsilon(4S)$. | |
| 0.0180 \pm 0.0024 \pm 0.0027 | (45) | $\Gamma(\overline{D}_{1}(2420)^{0}\pi^{+}\times$ | $B(\overline{D}_1^0 \to \overline{D}{}^0\pi^+\pi^-))$ | $\Gamma(\overline{D}{}^0\pi^+\pi^+\pi^-$ | -) Γ ₁₀₂ / |
| 1 Assumes equal production of B^+ and B^0 at the $arphi(4S)$. The signal is cons | istent with | VALUE (units 10 ⁻²) | - | • | COMMENT |
| all observed $\omega\pi^+$ having proceeded through the $ ho'^+$ resonance at mass 1349 | $9 \pm 25 + 10 \\ - 5$ | 4.4 + 3.3 OUR FIT | Error includes scale factor | of 4.0. | |
| MeV and width 547 \pm 86 $^{+46}_{-45}$ MeV. | | -2.6 10.3±1.5±0.9 | AAIJ | 11E LHCB | nn at 7 TeV |
| $\Gamma(\overline{D}^{*0}3\pi^{+}2\pi^{-})/\Gamma_{	ext{total}}$ | Г ₉₅ /Г | | | | |
| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | . 337 . | $I(D_1(2420)^{\circ}\pi^{+}\times$ | $B(\overline{D}_1^0 \to \overline{D}{}^0\pi^+\pi^-)$ (no | onresonant)))/I | $(D^{\circ}\pi^{+}\pi^{+}\pi^{-})$ $\Gamma_{103}/$ |
| 5.67 \pm 0.91 \pm 0.85 1 majumder 04 bell $^{e^+e^-} ightarrow r$ | (45) | VALUE (units 10 ⁻²) | DO CUMENT | ID TECN | '1U3/ COMMENT |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | 4.0±0.7±0.5 | 1 AAIJ | 11E LHCB | |
| $\Gamma(D^*(2010)^+\pi^0)/\Gamma_{\text{total}}$ | Γ ₉₆ /Γ | ¹ Excludes decays w | there $\overline{D}_1(2420)^0 \rightarrow D*(2420)^0$ | $2010) - \pi^{+}$ | |
| VALUECL%DOCUMENT IDTECNCOMMENT | | Γ <i>(Τ</i>)*/2462\0 ₋ + ν | $B(\overline{D}_2^*(2462)^0 \to D^-$ | _+\\ /F | Г |
| <3.6 \times 10 ⁻⁶ 1 IWABUCHI 08 BELL $e^+e^- \rightarrow \tau$ | (45) | VALUE (units 10 ⁻⁴) | DOCUMENT | , | Γ ₁₀ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $<1.7 \times 10^{-4}$ 90 ² BRANDENB 98 CLE2 $e^+e^- \rightarrow \gamma$ | Y (6 C) | 3.5 ± 0.4 OUR AVERA | | ID TECN | COMMENT |
| <1.7 \times 10 ⁻⁴ 90 ² BRA NDENB 98 CLE2 $e^+e^- \rightarrow r$ ¹ Assumes equal production of B^+ and B^0 at the $r(45)$. | (45) | $3.5 \pm 0.2 \pm 0.4$ | 1 AUBERT | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ² BRANDENBURG 98 assume equal production of B^+ and B^0 at $\Upsilon(4S)$ a | nd use the | 3.4±0.3±0.72 | $^{1}{	t ABE}$ oduction of B^{+} and B^{0} at | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| D* partial reconstruction technique. The first error is their experiment's err | | | | | |
| second error is the systematic error from the PDG 96 value of B($D^* ightarrow D\pi$ | ·). | ` - | $B(\overline{D}_2^{*0}\to \overline{D}{}^0\pi^-\pi^+)),$ | • | -) Γ ₁₀₅ / |
| $\Gamma(D^*(2010)^+ K^0)/\Gamma_{\text{total}}$ | Г97/Г | VALUE (units 10 ⁻²) 4.0±1.0±0.4 | <u>DOCUMENT</u> AAIJ | 11E LHCB | COMMENT D.D. at. 7 ToV |
| VALUE CL% DOCUMENT ID TECN COMMENT $<$ 9.0 \times 10 ⁻⁶ 90 1 AUBERT,B 05E BABR $e^+e^- \rightarrow \Upsilon$ | (4.6) | | | | |
| 7.0 X 10 - 90 -AUDEN I,D USE DADK e'e → 1 | (43) | $\Gamma(\overline{D}_{2}^{*}(2462)^{U}\pi^{+}\times$ | $R(D^{*0} \rightarrow D^{0}\pi^{-}\pi^{+})$ | anrecanant)))// | |
| | | | $D(D_2 \rightarrow D \times | onresonant)))/i | $\Gamma(\overline{D}{}^0\pi^+\pi^+\pi^-)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^+e^- \rightarrow \gamma$ | `(4 <i>S</i>) | VALUE | · • | ,. | Γ ₁₀₆ / |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | (45) | VALUE <3.0 × 10 ^{−2} | | ,. | Γ ₁₀₆ / |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 ¹ GRITSAN 01 CLE2 $e^+e^- \to \tau$ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | <3.0 × 10 ⁻² | CL% DO CUMENT | ID TECN 11E LHCB | Γ ₁₀₆ / |
| • • • We do not use the following data for averages, fits, limits, etc. • • • <9.5 \times 10 ⁻⁵ 90 1 GRITSAN 01 CLE2 $e^+e^- \rightarrow \tau$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma \left(D^*(2010)^-\pi^+\pi^+\pi^0\right)/\Gamma_{total}$ | Г ₉₈ /Г | $<3.0 \times 10^{-2}$ ¹ Excludes decays w | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(216262)$ | 11ε LHCB 010) - π ⁺ . | F ₁₀₆ / COMMENT pp at 7 TeV |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow r$ 1 Assumes equal production of B^{+} and B^{0} at the $r(4S)$. $ \Gamma(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0})/\Gamma_{\text{total}} $ $VALUE$ | Г ₉₈ /Г | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $\Gamma(\overline{D_2^*}(2462)^0 \pi^+ \times$ | <u>CL%</u> <u>DO CUMENT</u> 90 ¹ AA J | 11E LHCB 110) - π+. r+))/Γ(\(\overline{D}^0 π + π) | $\Gamma_{106}/\Gamma_{106}/\Gamma_{106}/\Gamma_{106}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{107}/\Gamma_{1$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow r$ Assumes equal production of B^{+} and B^{0} at the $r(4S)$. | Γ ₉₈ /Γ · γ(4S) | -3.0×10^{-2} ¹ Excludes decays w $\Gamma(\overline{D}_{2}^{*}(2462)^{0}\pi^{+} \times \frac{MLUE \text{ (units } 10^{-2})}{}$ | $\frac{\frac{\text{CL\%}}{90}}{90} \frac{\frac{DOCUMENT}{1 \text{ AAIJ}}}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{DOCUMENT}$ | 11ε LHCB 11ο τ LHCB 11ο) - π+. (τ+))/Γ(D ⁰ π+ π | Γ_{106}/C_{OMMENT} pp at 7 TeV $\Gamma^{+}\pi^{-}$ COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. $ \Gamma(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0})/\Gamma_{\text{total}} $ And $E^{*}(4S)$ | Γ ₉₈ /Γ - τ(45) | $ < 3.0 \times 10^{-2} $ 1 Excludes decays with the following form of the followin | $\frac{\frac{\text{CL\%}}{90}}{90} \frac{\frac{DOCUMENT}{1 \text{ AAIJ}}}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{\frac{DOCUMENT}{1 \text{ AAIJ}}}{1 \text{ AAIJ}}$ | 11ε LHCB 11ε LHCB 110) - π ⁺ . r+))/Γ(D ⁰ π ⁺ π 11ε LHCB | Γ_{106}/C_{OMMENT} pp at 7 TeV $\Gamma^{+}\pi^{-}$ COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow r$ 1 Assumes equal production of B^{+} and B^{0} at the $r(45)$. | Γ98/Γ • Υ(45) rement of | | $\frac{\text{CL\%}}{90} \qquad \frac{DOCUMENT}{1 \text{ AAIJ}}$ there $\overline{D}_{2}^{*}(2462)^{0} \rightarrow D^{*}(210)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^{0} \pi^{+}) = (67.7 + -1)^{-1}$ | 11E LHCB 110 TECN 11F LHCB 110) - \(\pi^+ \) / \(\bar{D}^0 \pi^+ \pi \) 11F LHCB 11F LHCB 0.5)%. | Γ106/ P p at 7 TeV Γ107/ COMMENT P p at 7 TeV Γ107/ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow r$ Assumes equal production of B^{+} and B^{0} at the $T(4S)$. $ T(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0})/\Gamma_{\text{total}} $ $ \frac{EVTS}{0.0152\pm0.0071\pm0.0001} $ | F98/F • Y (45) • Y (45) rement of †)] assum- best value | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $\Gamma(\overline{D_2^*}(2462)^0\pi^+ \times \frac{VALUE \text{ (units } 10^{-2})}{3.9 \pm 1.2 \pm 0.4}$ ¹ Uses B(D^* (2010) $\Gamma(\overline{D_0^*}(2400)^0\pi^+ \times \frac{1}{2}$ | $\frac{\frac{CL\%}{90}}{1} \frac{\frac{DOCUMENT}{AA J}}{1}$ where $\overline{D}_{2}^{*}(2462)^{0} \rightarrow D^{*}(2010)^{-1}$ $\frac{\frac{DOCUMENT}{1}}{1} \frac{1}{AA J}$ $+ \rightarrow D^{0}\pi^{+}) = (67.7 + -1)$ $\times B(\overline{D}_{2}^{*}(2400)^{0} \rightarrow D^{-1})$ | 11E LHCB 11O 7 TECN 11F LHCB 11O 7 TECN 11F LHCB 0.5)%. | Γ106/ P p at 7 TeV Γ107/ COMMENT P p at 7 TeV Γ107/ COMMENT P p at 7 TeV Γ10 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow r$ Assumes equal production of B^{+} and B^{0} at the $T(4S)$. $ T\left(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}\right)/\Gamma_{\text{total}} $ $ \frac{EVTS}{1} \frac{DOCUMENT\ ID}{1} \frac{TECN}{1} \frac{COMMENT}{1} COMMEN$ | Γ98/Γ · Υ(45) · Υ(45) · Υ(45) rement of †)] assum- best value xperiment's | | $\frac{\text{CL\%}}{90} 1 \frac{\text{DOCUMENT}}{\text{AAIJ}}$ there $\overline{D}_{2}^{*}(2462)^{0} \rightarrow D^{*}(2100)^{-1}$ $\frac{\text{DOCUMENT}}{1} \frac{\text{DOCUMENT}}{\text{AAIJ}}$ $+ \rightarrow D^{0} \pi^{+}) = (67.7 + -1)$ $\times B(\overline{D}_{0}^{*}(2400)^{0} \rightarrow D^{-1})$ $\frac{\text{DOCUMENT}}{\text{DOCUMENT}}$ | 11E LHCB 11O 7 TECN 11F LHCB 11O 7 TECN 11F LHCB 0.5)%. | Γ106/ P p at 7 TeV Γ107/ COMMENT P p at 7 TeV Γ107/ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. $ \Gamma(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0})/\Gamma_{\text{total}} $ PLOTE SOLUTION 100 ARG $e^{+}e^{-} \rightarrow \Upsilon$ 1. ALBRECHT 90. ARG $e^{+}e^{-} \rightarrow \Upsilon$ 1. ALBRECHT 90. ARG $e^{+}e^{-} \rightarrow \Upsilon$ 2. ALBRECHT 90. ARG $e^{+}e^{-} \rightarrow \Upsilon$ 2. ALBRECHT 90. Technology 1. ALBRECHT 90. Tech | rement of the periment's consumes | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $\Gamma(\overline{D_2^*}(2462)^0 \pi^+ \times \frac{VALUE \text{ (units } 10^{-2})}{3.9 \pm 1.2 \pm 0.4}$ ¹ Uses B(D^* (2010) $\Gamma(\overline{D_0^*}(2400)^0 \pi^+ \times \frac{VALUE}{2}$ | $\frac{\text{CL\%}}{90} 1 \frac{\text{DOCUMENT}}{\text{AAIJ}}$ there $\overline{D}_{2}^{*}(2462)^{0} \rightarrow D^{*}(2100)^{-1}$ $\frac{\text{DOCUMENT}}{1} \frac{\text{DOCUMENT}}{\text{AAIJ}}$ $+ \rightarrow D^{0} \pi^{+}) = (67.7 + -1)$ $\times B(\overline{D}_{0}^{*}(2400)^{0} \rightarrow D^{-1})$ $\frac{\text{DOCUMENT}}{\text{DOCUMENT}}$ | 11E LHCB 110) - \(\pi^+\), \(\pi\) \(\frac{D^0 \pi^+ \pi}{LHCB}\) 11E LHCB 0.5)%. \(\pi^+\)) \(\frac{TECN}{total}\) 09AB BABR | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \qquad \Gamma_{107}/\\ \hline \\ \hline COMMENT \\ PP \text{ at 7 TeV} \\ \hline \\ \hline \\ \hline \\ COMMENT \\ \hline \\ e^+e^- \rightarrow r(4S) \\ \hline \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. $\Gamma\left(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}\right)/\Gamma_{\text{total}} = \frac{EVTS}{1} = \frac{DOCUMENT\ ID}{1} = \frac{TECN}{1} = COMMENT\ BOCOMENT\ $ | rgs/r r(45) rement of hijl assumbest value periment's assumes ractions for | | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - 6.6)$ $\frac{DOCUMENT}{1 \text{ ABE}}$ | 11E LHCB 110) - \(\pi^+\) / \(\begin{array}{c} \overline{\D^0 \pi^+ \pi} \\ \overline{\D^0 \pi^+ \pi^+ \pi^+ \D^0 \pi^+ \pi} \\ \D^0 \pi^+ \pi^+ \pi^+ \D^0 \pi^+ \pi^+ \D^0 \\ \overline{\D^0 \pi^+ \pi^+ \D^0 \pi^+ \D^0 \\ \overline{\D^0 \pi^+ \pi^+ \D^0 \D^0 \D^0 \D^0 \\ \overline{\D^0 \pi^+ \D^0 \D^0 \D^0 \D^0 \D^0 \D^0 \D^0 \D^0 | Γ106/ Pp at 7 TeV Γ107/ COMMENT Pp at 7 TeV Γ107/ COMMENT Γ10 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. $ \Gamma\left(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}\right)/\Gamma_{\text{total}} $ A department of the production of B^{+} and B^{0} at the $\Upsilon(4S)$. $ \Gamma\left(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}\right)/\Gamma_{\text{total}} $ A department of the production of B^{+} and B^{0} at the $T(4S)$. $ \Gamma\left(D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}\right)/\Gamma_{\text{total}} $ A department of $B^{*}(2010)^{+}\pi^{0}$ and $B^{*}(2010)^{+$ | rement of the state of the stat | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $ \Gamma(\overline{D_2^*(2462)^0}\pi^+ \times 0.00000000000000000000000000000000000$ | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - 6.6)$ $\frac{DOCUMENT}{1 \text{ ABE}}$ and and B^0 at | 11E LHCB $010)^{-}\pi^{+}$. $r^{+}))/\Gamma(\overline{D^{0}}\pi^{+}\pi^{+})$ 11E LHCB $0.5)\%$. $\pi^{+}))/\Gamma_{total}$ 109AB BABR $04D$ BELL the $\Upsilon(45)$. | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \qquad \Gamma_{107}/\\ \hline \\ \hline COMMENT \\ PP \text{ at 7 TeV} \\ \hline \\ \hline \\ \hline \\ COMMENT \\ \hline \\ e^+e^- \rightarrow r(4S) \\ \hline \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. The following data for averages, fits, limits, etc. • • • $\frac{1}{2}$ ALBRECHT 90.0071 $\pm 0.0071 \pm 0.0001$ 26 $\frac{1}{2}$ ALBRECHT 90.1 ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 24 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 24 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 24 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 24 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 25 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 26 $\frac{1}{2}$ ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.0043 \pm 0.013 \pm 0.026$ 37 $\frac{1}{2}$ ALBRECHT 90.0 First error is their experimental error and our second error is the systematic error from using our best value equal production of B^{+} and B^{0} at the T (45) and uses Mark III branching for the D . 2 ALBRECHT 87c use PDG 86 branching ratios for D and $D^{*}(2010)$ an | rement of the state of the stat | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $ \Gamma(\overline{D_2^*(2462)^0}\pi^+ \times 0.00000000000000000000000000000000000$ | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - 6.6)$ $\frac{DOCUMENT}{1 \text{ ABE}}$ | 11E LHCB $010)^{-}\pi^{+}$. $r^{+}))/\Gamma(\overline{D^{0}}\pi^{+}\pi^{+})$ 11E LHCB $0.5)\%$. $\pi^{+}))/\Gamma_{total}$ 109AB BABR $04D$ BELL the $\Upsilon(45)$. | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \qquad \Gamma_{107}/\\ \hline \\ \hline COMMENT \\ PP \text{ at 7 TeV} \\ \hline \\ \hline \\ \hline \\ COMMENT \\ \hline \\ e^+e^- \rightarrow r(4S) \\ \hline \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. F($D^{*}(2010)^{-}\pi^{+}\pi^{+}\pi^{0}$)/ Γ_{total} MALUE EYTS DOCUMENT ID TECN COMMENT $0.0152\pm0.0071\pm0.0001$ 26 1 ALBRECHT 90J ARG $e^{+}e^{-} \rightarrow 0.043\pm0.013\pm0.026$ 24 2 ALBRECHT 87c ARG $e^{+}e^{-} \rightarrow 0.043\pm0.013\pm0.026$ 25 2 ALBRECHT 80J reports $0.018\pm0.007\pm0.005$ from a measure in $B(B^{+}(2010)^{+} \rightarrow D^{0}\pi^{+}) = 0.57\pm0.06$, which we rescale to our $B(D^{*}(2010)^{+} \rightarrow D^{0}\pi^{+}) = (67.7\pm0.5)\times10^{-2}$. Our first error is their exertor and our second error is the systematic error from using our best value equal production of B^{+} and B^{0} at the $\Upsilon(4S)$ and uses Mark III branching fit the D . D^{0} And $D^{*}(2010)^{+} \rightarrow D^{0}\pi^{+}$ and D^{0} at the $T(4S)$ and uses Mark III branching fit the D . D^{0} Alberthalp D^{0} | rement of the state of the stat | $<3.0 \times 10^{-2}$ ¹ Excludes decays w $ \Gamma(\overline{D_2^*(2462)^0}\pi^+ \times 0.00000000000000000000000000000000000$ | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - 66)$ $\frac{B(\overline{D}_0^*(2400)^0 \rightarrow D^{-1})}{1 \text{ ABE}}$ $\frac{DOCUMENT}{1 \text{ ABE}}$ where $\frac{1}{1}$ AUBERT $\frac{1}{1}$ ABE oduction of B^+ and B^0 at $\frac{1}{1}$ BE $\frac{1}{1}$ ABE $\frac{1}{1}$ | 11E LHCB 110) - \(\pi^+\) \\ \(\begin{array}{c} \D^0 \pi^+ \pi \\ \D^0 \end{array} \rightarrow \\ \tau \\ \D \\ \D^0 \rightarrow \\ \D \\ \D^0 \rightarrow \\ \D \\ \D^0 \rightarrow \\ \D^0 \rightarrow \\ \D^0 \\ | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \qquad \Gamma_{107}/\\ \hline \\ \hline COMMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ \hline \\ \hline COMMENT} \\ \hline \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ \hline \\ \Gamma_{10} \\ \hline \\ COMMENT \\ \hline \\ \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | rement of the state of the sta | | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + 6 \text{ B}(\overline{D}_0^*(2400)^0 \rightarrow D^{-1})$ $\frac{DOCUMENT}{1 \text{ ABE}}$ and B^0 at $B = B^0$ | 11E LHCB 11E LHCB 110) - π + π 11F LHCB 110 TECN 11E LHCB 0.5)%. π+))/Γtotal 1D TECN 09AB BABR 04D BELL the Γ(45). π+))/Γtotal 1D TECN 09AB BABR 04D BELL the Γ(45). | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \\ \hline \Gamma_{107}/\\ \hline COMMENT \\ \hline PP \text{ at 7 TeV} \\ \hline \\ \hline \\ COMMENT \\ \hline PP \text{ at 7 TeV} \\ \hline \\ \hline \\ COMMENT \\ \hline \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ \hline \\ \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^+e^- \rightarrow \tau$ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(D^*(2010)^-\pi^+\pi^+\pi^0)/\Gamma_{\text{total}}$ $\frac{EVTS}{0.0152 \pm 0.0071 \pm 0.0001}$ 26 1 ALBRECHT 90. ARG $e^+e^- \rightarrow 0.004$ • • We do not use the following data for averages, fits, limits, etc. • • • $0.043 \pm 0.013 \pm 0.026$ 24 2 ALBRECHT 87c ARG $e^+e^- \rightarrow 0.004$ 1 ALBRECHT 90. reports $0.018 \pm 0.007 \pm 0.005$ from a measur $[\Gamma(B^+ \rightarrow D^*(2010)^-\pi^+\pi^+\pi^0)/\Gamma_{\text{total}}] \times [B(D^*(2010)^+ \rightarrow D^0\pi^+) = 0.57 \pm 0.06$, which we rescale to our $B(D^*(2010)^+ \rightarrow D^0\pi^+) = (67.7 \pm 0.5) \times 10^{-2}$. Our first error is their exeror and our second error is the systematic error from using our best value equal production of B^+ and B^0 at the $T(4S)$ and uses Mark III branching fit the D . 2 ALBRECHT 87c use PDG 86 branching ratios for D and $D^*(2010)$ at $B(T(4S) \rightarrow B^0B^0) = 45\%$. Supersecond supersonable in $B(T(4S) \rightarrow B^0B^0) = 45\%$. Supersecond is B | rement of the state of the sta | $<3.0 \times 10^{-2}$ The Excludes decays with the following states and the exclusion of t | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - \frac{DOCUMENT}{1 \text{ ABE}}$ $\frac{1}{1 \text{ ABE}}$ adduction of B^+ and B^0 at B^0 | 11E LHCB $010)^{-}\pi^{+}$. $r^{+}))/\Gamma(\overline{D^{0}}\pi^{+}\pi^{+})$ 11E LHCB $0.5)\%$. $\pi^{+}))/\Gamma total$ 10 $09AB$ BABR $04D$ BELL the $T(4S)$. $\pi^{+}))/\Gamma total$ 10 $\pi^{-}ECN$ 11D $\pi^{-}ECN$ 11 | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \qquad \Gamma_{107}/\\ \hline \\ \hline COMMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ \hline \\ \hline COMMENT} \\ \hline \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ \hline \\ \Gamma_{10} \\ \hline \\ COMMENT \\ \hline \\ \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | rement of the present of the presen | $<3.0 \times 10^{-2}$ The Excludes decays with the following states and the exclusion of t | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + 6 \text{ B}(\overline{D}_0^*(2400)^0 \rightarrow D^{-1})$ $\frac{DOCUMENT}{1 \text{ ABE}}$ and B^0 at $B = B^0$ | 11E LHCB $010)^{-}\pi^{+}$. $r^{+}))/\Gamma(\overline{D^{0}}\pi^{+}\pi^{+})$ 11E LHCB $0.5)\%$. $\pi^{+}))/\Gamma total$ 10 $09AB$ BABR $04D$ BELL the $T(4S)$. $\pi^{+}))/\Gamma total$ 10 $\pi^{-}ECN$ 11D $\pi^{-}ECN$ 11 | $\begin{array}{c} \Gamma_{106}/\\ \hline \Gamma_{00MMENT} \\ \hline PP \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) \\ \hline \Gamma_{107}/\\ \hline COMMENT \\ \hline PP \text{ at 7 TeV} \\ \hline \\ \hline \\ COMMENT \\ \hline \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ e^+e^- \rightarrow r(4S) \\ \hline \\ \Gamma_{10} \\ \hline \\ COMMENT \\ \hline \\ \end{array}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 9.5×10^{-5} 90 1 GRITSAN 01 CLE2 $e^+e^- \rightarrow \tau$ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $ T(D^*(2010)^-\pi^+\pi^+\pi^0)/\Gamma_{\text{total}} $ | rement of the present of the presen | $<3.0 \times 10^{-2}$ The Excludes decays with the following states and the exclusion of t | $\frac{cL\%}{90} \frac{DOCUMENT}{1 \text{ AAIJ}}$ where $\overline{D}_2^*(2462)^0 \rightarrow D^*(2010)^{-1}$ $\frac{DOCUMENT}{1 \text{ AAIJ}}$ $+ \rightarrow D^0 \pi^+) = (67.7 + - \frac{DOCUMENT}{1 \text{ ABE}}$ $\frac{1}{1 \text{ ABE}}$ adduction of B^+ and B^0 at B^0 | 11E LHCB $010)^{-}\pi^{+}$. $r^{+}))/\Gamma(\overline{D^{0}}\pi^{+}\pi^{+})$ 11E LHCB $0.5)\%$. $\pi^{+}))/\Gamma total$ 10 $09AB$ BABR 040 BELL the $T(4S)$. $\pi^{+}))/\Gamma total$ 10 $04D$ BELL the $T(4S)$. $\pi^{+})/\Gamma total$ 11 π^{+} 12 π^{-} 13 π^{-} 14 π^{-} 15 π^{-} 16 π^{-} 17 π^{-} 17 π^{-} 18 π^{-} 19 π^{-} 19 π^{-} 10 π^{-} 10 π^{-} 11 π^{-} 12 π^{-} 13 π^{-} 14 π^{-} 15 π^{-} 16 π^{-} | $\begin{array}{c} & \Gamma_{106}/\\ \hline \Gamma_{pp} \text{ at 7 TeV} \\ \hline \\ r^+\pi^-) & \Gamma_{107}/\\ \hline \\ \hline COMMENT} \\ \hline pp \text{ at 7 TeV} \\ \hline \\ \hline COMMENT} \\ \hline e^+e^- \rightarrow & \Upsilon(4S) \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ \hline COMMENT} \\ \hline \\ \hline COMMENT} \\ \hline \\ \hline COMMENT} \\ \hline \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ \hline COMMENT} \\ \hline \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \end{array}$ |

| $\Gamma(\overline{D}'_1(2427)^0\pi^+$ | $\times B(\overline{D}'_1(2$ | | | | | Г ₁₁₁ /Г |
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| VALUE (units 10 ⁻⁴) 5.0±0.4±1.1 | | DOCUMENT II | | | e^+e^- | |
| | production of | B^+ and B^0 at t | | | C - C - | 7 (43) |
| $\Gamma(\overline{D}_1(2420)^0\pi^+$ | | | | | | Г ₁₁₂ /Г |
| | CL% | | | TECN | COMMENT | |
| <0.06 | 90 | ¹ ABE | 05 A | | e ⁺ e [−] → | |
| $^{ m 1}$ Assumes equal | production of | $^{+}B^{+}$ and B^{0} at t | he $\Upsilon(4)$ | S). | | |
| $\Gamma(\overline{D}_1^*(2420)^0 \rho^+)$ | | | | | | Γ ₁₁₃ /Γ |
| VALUE | // · total | DO CUMENT IL |) | TECN | COMMENT | - 113/ - |
| <0.0014 | 90 | ¹ ALAM | 94 | CLE2 | $e^+e^ \rightarrow$ | · \(\gamma(45) |
| ¹ ALAM 94 assur B(D*(2010)+ | me equal prod $\to D^0\pi^+$) a | duction of B^+ an assuming B(D_1 (24 | d <i>B</i> ⁰ a ·20) ⁰ – | t the Υ $D^*(2)$ | (4 <i>S</i>) and u (010) ⁺ π ⁻) | se the CLEOII $= 67\%$. |
| $\Gamma(\overline{D}_{2}^{*}(2460)^{0}\pi^{+}$ | , . | | | | | Г ₁₁₄ /Г |
| <u>VALUE</u> <0.0013 | <u>CL%</u> 90 | DOCUMENT II. 1 ALAM | | | e^+e^- | |
| • • • We do not u | | | | | | 7 (43) |
| <0.0028 <0.0023 | 90 90 | ² ALAM ³ ALBRECHT | 94 94 d | CLE2 ARG | e+ e e+ e | |
| - ALAM 94 assur | me equal prod | duction of B+ an | d <i>B</i> ⁰ a | t the γ | (4 <i>5</i>) and u | se the MarkIII |
| $B(D^+ \rightarrow K^-)^2$ ALAM 94 assur $B(D^+ \rightarrow K^-)^2$ $D^*(2010)^+ \pi^-$ 3 ALBRECHT 94 | $2\pi^+)$ and B(me equal proof $2\pi^+)$, the C $0 = 20\%$. HD assume eq | duction of B^+ an $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEOII $B(D^*(201)^0)$ ual production of $D^0 \pi^+$) and $B(D_2^*)$ | $^{+}\pi^{-})$ d 0 a 10 $^{+}$ $^{-}$ | = 30%. t the γ $\rightarrow D^0 \pi$ and B^0 a | $\Gamma(4S)$ and $\Gamma(+S)$ and $\Gamma(+S)$ and $\Gamma(+S)$ | se the MarkIII $D_2^*(2460)^0 \rightarrow$ S) and use the |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $D^{*}(2010)^{+}\pi^{-}$ 3 ALBRECHT 94 CLEO II $B(D^{*}(T^{*})^{2})^{2}$ | $2\pi^+$) and B(me equal proof $2\pi^+$), the C) = 20%. BD assume eq 2010) $+ \rightarrow L$ $\times B(\overline{D_2^{*0}} - + L)$ | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $D^0\pi^+$ and $D^0\pi^+$ | $+\pi^{-}$) d B^{0} a ± 0) + - B^{+} a $\pm (2460)$ | $= 30\%$. It the Υ $\rightarrow D^0 \pi$ and $B^0 = 0$ $\rightarrow D^0 \pi$ | $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ $\Gamma(4S)$ | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the $-$) = 30%. |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $D^{*}(2010)^{+}\pi^{-}$ 3 ALBRECHT 94 CLEO II $B(D^{*}(T^{*})^{2})^{2}$ | $2\pi^+$) and B(me equal proof $2\pi^+$), the C) = 20%. BD assume eq 2010) $+ \rightarrow L$ $\times B(\overline{D_2^{*0}} - + L)$ | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $D^0\pi^+$ and $D^0\pi^+$ | $+\pi^{-}$) d B^{0} a ± 0) + - B^{+} a $\pm (2460)$ | $= 30\%$. It the Υ $\rightarrow D^0 \pi$ and $B^0 = 0$ $\rightarrow D^0 \pi$ | $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ $\Gamma(4S)$ | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the $-$) = 30%. |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $D^{*}(2010)^{+}\pi^{-}$ ALBRECHT 94 CLEO II $B(D^{*}(\Gamma (D^{*}_{2}(2460)^{0}\pi^{+})^{4})^{4}$ $D^{*}(D^{*}(D^{*}(Units 10^{-4}))^{4})^{4}$ | $2\pi^+$) and B(me equal proof $2\pi^+$), the C) = 20%. ID assume eq 2010) $^+$ $^ ^ \times$ B($\overline{D_2^{*0}}$ $^ ^ 90$ | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II $B(D^*(201)^0 \pi^+)$ and $B(D_2^*)$ $D^{*0}\pi^+\pi^-)$ $DCUMENT II$ 1 ABE | $(B^{0} = A^{-1})$ $(B^{0} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{-1} = A^{-1})$ $(B^{-1$ | = 30%. It the Υ and $D^0 \pi$ and $D^0 \pi$ below $D^0 \pi$ below $D^0 \pi$ below $D^0 \pi$ | $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ $\Gamma(4S)$ | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the $-$) = 30%. |
| $\begin{array}{c} B(D^+\to K^-\\ ^2ALAM \ 94 \ assun\\ B(D^+\to K^-\\ D^*(2010)^+\pi^-\\ ^3ALBRECHT \ 94 \\ CLEOII \ B(D^*(\\ \mathbf{\Gamma}(\overline{\pmb{D_2^*}}(2460)^0\pi^+\\ \mathbf{VALUE}\ (units\ 10^{-4})\\ \mathbf{<0.22} \\ ^1Assumes\ equal \end{array}$ | $2\pi^{+}$) and B(me equal proof $2\pi^{+}$), the C) = 20%. BD assume eq 2010) $+ \rightarrow L$ \times B($\overline{D_{2}^{*0}}$) $\rightarrow L$ 0 production of | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $D^0\pi^+$ and $D^0\pi^+$ | $(B^{0} = A^{-1})$ $(B^{0} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{+1} = A^{-1})$ $(B^{-1} = A^{-1})$ $(B^{-1$ | = 30%. It the Υ and $D^0 \pi$ and $D^0 \pi$ below $D^0 \pi$ below $D^0 \pi$ below $D^0 \pi$ | $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ and $\Gamma(4S)$ $\Gamma(4S)$ | see the Mark III $D_2^*(2460)^0 \rightarrow 0$ (5) and use the T_1 T_2 T_3 T_4 T_4 T_5 T_4 T_5 |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $D^{*}(2010)^{+}\pi^{-}$ 3 ALBRECHT 94 CLEO II $B(D^{*}(\Gamma)^{-})^{2}$ (2460) $0\pi^{+}$ $VALUE$ (units $10^{-4})$ $<$ 0.22 1 Assumes equal $\Gamma(\overline{D}_{2}^{*}(2460)^{0}\rho^{+}$ | $2\pi^{+}$) and B(me equal proof $2\pi^{+}$), the C) = 20%. BD assume eq 2010) $+ \rightarrow L$ \times B($\overline{D_{2}^{*0}}$) $\rightarrow L$ 0 production of | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an LEO II $B(D^*(201$ ual production of $D^0\pi^+$) and $B(D_2^*)$ $D^{*0}\pi^+\pi^-)$ $D_{COMMENT\ II}$ D_{BE} E_B^+ and B^0 at t | $+\pi^-)$ d B^0 a $10)+ B^+$ a $10)+$ Γ (2460) Γ Total 05A | = 30%. the Υ the Υ and B^0 and $B^0 \to D$. Δ BELL S). | $r(4S)$ and u r^+) and B(at the $r(4S)$ r^* (2010) $+\pi$ | se the MarkIII $D_2^*(2460)^0 \rightarrow 0$ (5) and use the 0 0 0 0 0 0 0 0 0 0 |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $D^{*}(2010)^{+}\pi^{-}$ 3 ALBRECHT 94 CLEO II $B(D^{*}(\Gamma)^{-})^{2}$ (2460) $0\pi^{+}$ $VALUE$ (units $10^{-4})$ $<$ 0.22 1 Assumes equal $\Gamma(\overline{D}_{2}^{*}(2460)^{0}\rho^{+}$ | $2\pi^{+}$) and B(me equal proof $2\pi^{+}$), the C) = 20%. BD assume eq 2010) $+ \rightarrow L$ \times B($\overline{D_{2}^{*0}}$) $\rightarrow L$ 0 production of | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II $B(D^*(201)^0$ ual production of $D^0\pi^+$) and $B(D_2^*$ $\longrightarrow D^{*0}\pi^+\pi^-$) D_0 D | $+\pi^-)$ d B^0 a $10)+ B^+$ a $10)+$ Γ (2460) Γ Total 05A | = 30%. the Υ the Υ and B^0 and $B^0 \to D$. Δ BELL S). | (45) and u (45) and B (45) at the $T(43)$ at the $T(43)$ at $T(43)$ at $T(43)$ and $T(43)$ at the $T(43)$ at $T(43)$ and $T(43)$ at the $T(43)$ at th | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the $T_1 = 30\%$. T_{115}/Γ T_{116}/Γ |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}(\Gamma, V)^{2})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}(\Gamma, V)^{2})^{2}$ Assumes equal $\Gamma(D^{*}(2460)^{0}\rho^{+})^{2}$ VALUE $(0.0047)^{2}$ $(0.0047)^{2}$ | $2\pi^{+}$) and B(me equal proof $2\pi^{+}$), the C) = 20%. D assume eq 2010) ⁺ \rightarrow L \times B($\overline{D_{2}^{*0}}$) 0 production of 0 0 0 0 0 0 0 | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an CLEO II B($D^*(201)^0$ ual production of $D^0\pi^+$) and B(D_2^* $D^{*0}\pi^+\pi^-$) D_0 | $+\pi^{-}$) d B^{0} a ± 10) + ± 10 B + a ± 10 | = 30%. It the Υ \rightarrow $D^0 \pi$ and $B^0 \approx 0 \rightarrow D$ \rightarrow D \rightarrow | (45) and u $+$ and B(at the $\Upsilon(43)$ *(2010) $+$ π $\frac{COMMENT}{e^+e^-}$ e^+e^- e^+e^- | se the MarkIII $D_2^*(2460)^0 \rightarrow 0$ (2460) so the set of the set o |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $2\pi^+$) and B(me equal proof $2\pi^+$), the C $2\pi^+$), the C $2\pi^+$), the C $2\pi^+$), the C $2\pi^+$) $2\pi^+$ 0 $2\pi^0$ 0 2π | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an ILEO II $B(D^*(201)^0$ ual production of $D^0\pi^+$) and $B(D_2^*)$ $D^{*0}\pi^+\pi^-$) $D^{*0}\pi^+\pi^-$ 0 $D^{*0}\pi^-$ 0 D^{*0 | $+\pi^{-}$) d B^{0} a $(0)^{+}$ - B^{+} a (2460) // (2460) // (2460) // (2460) // (2460) // (2460) // (2460) // (2460) // (2460) // (2460) // (2460) | $= 30\%.$ t the Υ $\to D^0 \pi$ and $B^0 \approx 0 \to D$ $= \frac{TECN}{CLE2}$ $CLE2$ t the Υ $= 30\%.$ | (45) and u e^+) and $B(e^+)$ and $B(e^+)$ e^+ $e^ e^+$ $e^ e^+$ $e^ e^+$ $e^ e^+$ $e^ e^ $ | se the MarkIII $D_2^*(2460)^0 \rightarrow$ $S) \text{ and use the } \rightarrow$ $S) = 30\%.$ Γ_{115}/Γ T_{116}/Γ T_{116}/Γ T_{14}/Γ $T_{$ |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}(\nabla D_{2}^{*}(2460)^{0}\pi^{+})^{2}$ $(0.22)^{1}$ Assumes equal $(\nabla D_{2}^{*}(2460)^{0}\rho^{+})^{2}$ $(0.0047)^{2}$ $(0.045)^{2}$ $(0.045)^{3}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ $(0.045)^{4}$ | $2\pi^+$) and B(me equal proof $2\pi^+$), the C $2\pi^+$) $2\pi^0$ $2\pi^0$ $2\pi^0$ production of CL% $2\pi^+$) and B(me equal proof $2\pi^+$) and B(me equal proof $2\pi^+$), the C | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an ILEO II $B(D^*(201)^0$ ual production of $D^0\pi^+$) and $B(D_2^*)$ $D^{*0}\pi^+\pi^-)$ $D_{CUMENT\ II}$ $D_{CUMENT\ III}$ $D_{CUMET\ IIII}$ $D_{CUMET\ IIII}$ $D_{CUMET\ IIII}$ $D_{CUMET\ IIII}$ $D_{CUMET\ IIII}$ $D_{CUMET\ IIII}$ D_{CUME | $+\pi^{-}$) d B^{0} a $10)+ B^{+}$ a $10)$ // Ftotal 0 05A the $\Upsilon(4)$ 0 94 94 d B^{0} a 0 0 0 0 0 0 0 0 | $= 30\%.$ t the Υ $\to D^0 \pi$ and $B^0 \approx 0$ $\to D$ $\frac{TECN}{BELL}$ S). $\frac{TECN}{CLE2}$ $CLE2$ $CLE2$ t the Υ $= 30\%.$ t the Υ | (45) and u (45) and B(at the $T(43)$ * $(2010)^+\pi$ $\frac{COMMENT}{e^+e^-}$ • e^+e^- | se the MarkIII $D_2^*(2460)^0 \rightarrow 50$ and use the $T=0$ and $T=0$ and $T=0$ and $T=0$ and $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ a |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}($ $\Gamma(D_{2}^{*}(2460)^{0}\pi^{+})^{4}$ $(0.22)^{2}$ 1 Assures equal $\Gamma(D_{2}^{*}(2460)^{0}\rho^{+})^{4}$ $(0.005)^{2}$ 1 ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assur $B(D^{+} \rightarrow K^{-})^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ $(0.2010)^{2}$ | $2\pi^+$) and B(me equal prod $2\pi^+$), the C) = 20%. But assume equal production of $2\pi^+$ 0 production of $2\pi^+$ 1 and B(me equal prod $2\pi^+$ 1, the C) = 20%. | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an ILEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $D^0\pi^+$) and $D^0\pi^+$ $D^{*0}\pi^+\pi^-$) $D^{*0}\pi^+\pi^ D^{*0}\pi^+\pi^ $ | $+\pi^{-}$) d B^{0} a $10)+ B^{+}$ a $10)$ // Ftotal 0 05A the $\Upsilon(4)$ 0 94 94 d B^{0} a 0 0 0 0 0 0 0 0 | $= 30\%.$ t the Υ $\to D^0 \pi$ and $B^0 \approx 0$ $\to D$ $\frac{TECN}{BELL}$ S). $\frac{TECN}{CLE2}$ $CLE2$ $CLE2$ t the Υ $= 30\%.$ t the Υ | (45) and u (45) and B(at the $T(43)$ * $(2010)^+\pi$ $\frac{COMMENT}{e^+e^-}$ • e^+e^- | se the MarkIII $D_2^*(2460)^0 \rightarrow 50$ and use the $T=0$ and $T=0$ and $T=0$ and $T=0$ and $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ and $T=0$ are $T=0$ a |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}(D^{*})^{2})^{2}$ (2460) 0 π^{+} VALUE (units $10^{-4})^{2}$ <0.22 1 Assumes equal $\Gamma(D^{*})^{2}$ (2460) 0 ρ^{+} VALUE $(D^{*})^{2}$ <0.0047 <0.005 1 ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ (2010) $^{+}$ π^{-} $\Gamma(D^{*})^{0}$ D^{+}_{s})/ Γ_{tota} VALUE | $2\pi^+$) and B(me equal proof $2\pi^+$), the C $2\pi^+$) $2\pi^0$ $2\pi^0$ $2\pi^0$ production of CL% $2\pi^+$) and B(me equal proof $2\pi^+$) and B(me equal proof $2\pi^+$), the C $2\pi^+$), the C $2\pi^+$), the C $2\pi^+$), the C | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an LEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $B(D_2^*)$ $D^{*0}\pi^+\pi^-)$ $D^{*0}\pi^+\pi^-)$ $D^{*0}M^+\pi^-)$ $D^$ | $+\pi^{-})$ d B^{0} a 0 a 0 b $+\pi^{-}$ | $= 30\%.$ t the Υ $D^{0}\pi$ and B^{0} $0 \rightarrow D$ $= \frac{TECN}{BELL}$ $EXAMPLE CLE2 CLE2 CLE2 CLE4 TECN | (45) and u (45) and B(at the $T(43)$ * $(2010)^+\pi$ $\frac{COMMENT}{e^+e^-}$ • e^+e^- | se the Mark III $D_2^*(2460)^0 \rightarrow 0$ 5) and use the $T_1 = 0$ T_1 |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*}(D^{*})^{2})^{2}$ C460) 0 π^{+} VALUE (units $10^{-4})^{2}$ <0.22 1 Assumes equal $\Gamma(\overline{D_{2}^{*}}(2460)^{0} \rho^{+})^{2}$ VALUE <0.005 1 ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ (2010) $^{+}$ π^{-} $\Gamma(\overline{D^{0}} D_{5}^{+})/\Gamma_{\text{tota}}$ $\frac{VALUE}{VALUE}$ $\frac{VALUE}{UE}$ 0.0100 $\frac{1}{2}$ 0.0110 $\frac{VALUE}{UE}$ 0.0117 OU | $2\pi^{+}$) and B(me equal proof $2\pi^{+}$), the C $2\pi^{+}$) $2\pi^{+}$ | $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an ILEO II $B(D^*(201)^0 \rightarrow D^*)$ ual production of $D^0 \pi^+$) and $D^0 \pi^+$ and $D^0 \pi^+ \rightarrow D^*$ $D^{**}(D^0 \pi^+ \rightarrow D^*)$ $D^{**}(D^0 \pi^+ \rightarrow D^*)$ $D^{**}(D^0 \pi^+ \rightarrow D^*)$ $D^0 \pi^+ \rightarrow D^*$ $D^0 \pi^+ \rightarrow D^0$ | + \(\pi^-\)) \[\begin{array}{c} \text{B}^0 \text{ a} \\ \text{B}^0 \text{ a} \\ \text{B}^0 \text{ a} \\ \text{B}^1 \text{ a} \\ \text{(2460)} \end{array} \[\begin{array}{c} \text{Totala} \\ \text{B}^0 \text{ a} \\ \text{B}^0 \\ \text{B}^0 \text{ a} \\ \text{B}^0 \te | $= 30\%.$ t the Υ $D^0 \pi$ | (45) and u e^+) and $B(45)$ and $B(45)$ e^+ $e^ e^ e^+$ $e^ e^ e^+$ $e^ e^ e^+$ $e^ e^ e^+$ $e^ e^ $ | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the T_1 : T_{115}/Γ T_{116}/Γ T_{145} T_{145} se the MarkIII se the MarkIII $T_2^*(2460)^0 \rightarrow T_{117}/\Gamma$ |
| $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ ALBRECHT 94 CLEO II $B(D^{*})^{2}$ (2460) 0 π^{+} VALUE (units $10^{-4})^{2}$ <0.22 1 Assumes equal $\Gamma(\overline{D}_{2}^{*}(2460)^{0} \rho^{+}$ VALUE <0.0047 <0.005 1 ALAM 94 assum $B(D^{+} \rightarrow K^{-})^{2}$ D_{3}^{*} D_{3} | $2\pi^+$) and B(me equal proof $2\pi^+$), the C($2\pi^+$) and B(| $D_2^*(2460)^0 \rightarrow D$ duction of B^+ an LEO II $B(D^*(201)^0)$ ual production of $D^0\pi^+$) and $B(D_2^*)$ $D^{*0}\pi^+\pi^-)$ $D^{*0}\pi^+\pi^-)$ $D^{*0}M^+\pi^-)$ $D^$ | + \(\pi^-\)) \[\begin{array}{c} \text{B}^0 \text{ a} \\ \text{B}^0 \text{ a} \\ \text{B}^0 \text{ a} \\ \text{B}^1 \text{ a} \\ \text{(2460)} \end{array} \[\begin{array}{c} \text{Totala} \\ \text{B}^0 \text{ a} \\ \text{B}^0 \\ \text{B}^0 \text{ a} \\ \text{B}^0 \te | $= 30\%.$ t the Υ $D^0 \pi$ | (45) and u (45) and u (45) and u (45) u (45) u (45) u (45) u u (45) and u (45) and u (45) and u (45) and u | se the MarkIII $D_2^*(2460)^0 \rightarrow 5$) and use the T) = 30%. T_{115}/Γ T_{116}/Γ T_{116}/Γ T_{116}/Γ T_{116}/Γ se the MarkIII se the MarkIII $T_2^*(2460)^0 \rightarrow T_{117}/\Gamma$ T_{117}/Γ |

| $\Gamma(\overline{D}^0 D_s^+)/\Gamma_{\text{total}}$ | | | | | | Γ ₁₁₇ / |
|------------------------------------------------------|--------------|------------------------|--------------|----------|-----------------------|--------------------|
| VALUE | EVTS | DOCUMENT ID | | TE CN | COMMENT | |
| 0.0100±0.0017 OUR | AVERAGE | | | | | |
| $0.0095 \pm 0.0020 \pm 0.00$ | 800 | ¹ AUBERT | | | $e^+ e^- \rightarrow$ | |
| $0.0098 \pm 0.0026 \pm 0.00$ | 009 | ² GIBAUT | 96 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.014 \ \pm 0.008 \ \pm 0.0$ | 01 | ³ ALBRECHT | 92G | ARG | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.013\ \pm0.006\ \pm0.0$ | 01 5 | ⁴ BORTOLETT | O90 | CLEO | $e^+e^- ightarrow$ | $\Upsilon(4S)$ |
| ¹ AUBERT 06N rep | orts (0.92 ± | 0.14 ± 0.18) × | $_{10}^{-2}$ | from a r | measuremen | t of [Γ(B+ - |

 $\overline{D}{}^0D_S^+)/\Gamma_{\mbox{total}}] \times [\mbox{B}(D_S^+ \to \ \phi \pi^+)] \mbox{ assuming B}(D_S^+ \to \ \phi \pi^+) = 0.0462 \pm 0.0062,$ which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. 2 GIBAUT 96 reports 0.0126 \pm 0.0022 \pm 0.0025 from a measurement of [\Gamma ($\!B^+ \to$

 $\overline{D}{}^0D_s^+)/\Gamma_{
m total}] \times [{\rm B}(D_s^+ o \phi \pi^+)]$ assuming ${\rm B}(D_s^+ o \phi \pi^+) = 0.035$, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best

 3 ALBRECHT 92G reports 0.024 \pm 0.012 \pm 0.004 from a measurement of [$\Gamma(B^+
ightarrow$ $\overline{D}{}^0D_S^+)/\Gamma_{\text{total}} \times [B(D_S^+ \to \phi \pi^+)]$ assuming $B(D_S^+ \to \phi \pi^+) = 0.027$, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^0 branching ratios, e.g., $B(D^0 \to K^-\pi^+) = 3.71 \pm 0.25\%$.

 4 BORTOLETTO 90 reports 0.029 \pm 0.013 from a measurement of $[\Gamma(B^+ o \overline{D}{}^0D_S^+)/$ $\Gamma_{ ext{total}}] imes [B(D_S^+ o \phi \pi^+)]$ assuming $B(D_S^+ o \phi \pi^+) = 0.02$, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(D_{s0}(2317)^+ \overline{D}{}^0 \times B(D_{s0})$ | (2217)+ D+= | 011/1 | - | | Г | /г |
|-----------------------------------------------------------|-------------------------|-------|------|--------------|--------------------|------------|
| $VALUE$ (units 10^{-3}) | | • | | COMMENT | Г ₁₁₈ , | <i>'</i> ' |
| 0.73+0.22 OUR AVERAGE | | | | | | |
| $0.80^{+0.35}_{-0.21}\pm0.07$ | 1,2 AUBERT,B | 04s | BABR | $e^+e^- \to$ | T(45) | |
| $0.65 + 0.26 \pm 0.06$ | ^{1,3} KROKOVNY | 03в | BELL | $e^+e^-\to$ | Y(45) | |
| | | | | | | |

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^1 Assumes equal production of B^+ and B^0 at the arGamma(4S).
^2 AUBERT,B 04s reports (1.0\,\pm\,0.3^{+\,0.4}_{-\,0.2})\times10^{-3} from a measurement of [Γ(B+ \rightarrow
  D_{s0}(2317)^{+} \, \overline{D}{}^{0} \times \, \mathsf{B}(D_{s0}(2317)^{+} \to \, D_{s}^{+} \, \pi^{0})) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(D_{s}^{+} \to \, \phi \, \pi^{+})] \, \, \mathsf{assuming}
  B(D_c^+ \to \phi \pi^+) = 0.036 \pm 0.009, which we rescale to our best value B(D_c^+ \to \phi \pi^+)
  = (4.5\pm0.4)\times10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value.
^3 KROKOVNY 03B reports (0.81^+_{-0.27}^+0.30^+_{-0.27}^+0.24)\times 10^{-3} from a measurement of [Γ(B+ \rightarrow
  D_{s0}(2317)^{+} \, \overline{D}{}^{0} \times \, \mathsf{B}(D_{s0}(2317)^{+} \to \, D_{s}^{+} \, \pi^{0})) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(D_{s}^{+} \to \, \phi \, \pi^{+})] \; \mathsf{assuming}
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 $B(D_c^+ \to \phi \pi^+) = 0.036 \pm 0.009$, which we rescale to our best value $B(D_c^+ \to \phi \pi^+)$ = (4.5 \pm 0.4) \times 10 $^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(D_{s0}(2317)^+ \overline{D}{}^0 \times B(D_{s0}(2317)^+ \rightarrow D_s^{*+} \gamma)) / \Gamma_{\text{total}}$ Γ_{119}/Γ $\underline{\mathit{VALUE}}$ (units 10^{-3}) DOCUMENT ID TECN COMMENT 1 KROKOVNY 03B BELL $e^{+}e^{-}
ightarrow \gamma (4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$

 $\Gamma(D_{s0}(2317)^+ \overline{D}^*(2007)^0 \times B(D_{s0}(2317)^+ \to D_s^+ \pi^0)) / \Gamma_{\text{total}}$ Γ_{120}/Γ DOCUMENT ID TECN COMMENT $0.9 \pm 0.6 ^{+0.4}_{-0.3}$ 1 AUBERT,B 04s BABR $e^{+}e^{-}
ightarrow \varUpsilon (4\,S)$

 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

| $\Gamma(D_{sJ}(2457)^+\overline{D}{}^0)/\Gamma_{ m total}$ | | | | | Γ_{121}/Γ |
|------------------------------------------------------------|-------------------------|-----|------|----------------------|-----------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | COMMENT | |
| $3.1^{+1.0}_{-0.9}$ OUR AVERAGE | | | | | |
| $4.3 \pm 1.6 \pm 1.3$ | $^{ m 1}$ AUBERT | 06N | BABR | $e^+e^- \to$ | $\Upsilon(4S)$ |
| $4.6^{+1.8}_{-1.6} \pm 1.0$ | ^{2,3} AUBERT,B | 04s | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.1 + \frac{1}{2} \cdot \frac{1}{2} + 0.5$ | 2,4 KROKOVNY | 03B | BELL | e+e | $\Upsilon(AS)$ |

1 Uses a missing-mass method in the events that one of the ${\it B}$ mesons is fully reconstructed. ²Assumes equal production of B^+ and B^0 at the $\Upsilon(45)$.

 3 AUBERT,B 04s reports $[\Gamma(B^+ o D_{sJ}(2457)^+ \overline{D}{}^0)/\Gamma_{ ext{total}}] imes [B(D_{s1}(2460)^+ o D_{sJ}(2457)^+ \overline{D}{}^0)/\Gamma_{ ext{total}}]$ $D_s^{*+}\pi^0)] = (2.2^{+0.8}_{-0.7}\pm 0.3)\times 10^{-3}$ which we divide by our best value B($D_{s1}(2460)^+ \rightarrow 0.00$ $D_c^{*+}\pi^0)=(48\pm11)\times 10^{-2}.$ Our first error is their experiment's error and our second 4 KROKOVNY 03B reports $[\Gamma(B^+ \to D_{sJ}(2457)^+ \overline{D}^0)/\Gamma_{\text{total}}] \times [B(D_{s1}(2460)^+ \to D_{sJ}(2457)^+ \overline{D}^0)/\Gamma_{\text{total}}]$

 $D_s^{*+}\pi^0)] = (1.0 + 0.5 \pm 0.1) \times 10^{-3}$ which we divide by our best value B($D_{s1}(2460)^+ \rightarrow 0.4 \pm 0.1$) $D_s^{*+}\pi^0)=(48\pm11)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D_{sJ}(2457)^+ \overline{D}{}^0 \times \mathsf{B}(D_{sJ}(2457)^+ \to D_s^+ \gamma)) / \Gamma_{\mathsf{total}}$ Γ_{122}/Γ DOCUMENT ID TECN COMMENT

$0.46^{+0.13}_{-0.11}$ OUR AVERAGE

 $0.48 + 0.19 \pm 0.04$ 1,2 AUBERT,B 04s BABR $e^+e^-
ightarrow \gamma(4S)$ 1,3 KROKOVNY 03B BELL $e^+e^-
ightarrow ~ \varUpsilon$ (4*S*) $0.45 + 0.15 \pm 0.04$

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 AUBERT,B_04s reports (0.6 \pm 0.2 $^+_-$ 0.2) \times 10 $^{-3}$ from a measurement of [Γ(B^+ \rightarrow $D_{sJ}(\text{2457})^+ \, \overline{D}{}^0 \times \, \text{B}(D_{sJ}(\text{2457})^+ \, \rightarrow \, D_s^+ \gamma)) / \Gamma_{\text{total}}] \times [\text{B}(D_s^+ \rightarrow \, \phi \pi^+)] \, \, \text{assuming}$ $B(D_s^+ \to \phi \pi^+) = 0.036 \pm 0.009$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+)$ = $(4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 3 KROKOVNY 03B reports $(0.56 + 0.16 \pm 0.17) \times 10^{-3}$ from a measurement of [$\Gamma(B^+ \to 0.16 \pm 0.17) \times 10^{-3}$] from the measurement of 3 KROKOVNY 03B reports 3 KROK

 $D_{sJ}(2457)^+ \overline{D}{}^0 \times \mathsf{B}(D_{sJ}(2457)^+ \to D_s^+ \gamma)) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(D_s^+ \to \phi \pi^+)] \text{ assuming }$ $B(D_c^+ \to \phi \pi^+) = 0.036 \pm 0.009$, which we rescale to our best value $B(D_c^+ \to \phi \pi^+)$ = $(4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(D_{sJ}(2457)^+ \overline{D}{}^0 \times B(D_{sJ}(2457)^+ \to D_s^+ \pi^0)) / \Gamma_{\text{total}}$ Γ_{124}/Γ DOCUMENT ID TECN COMMENT <0.27 1 KROKOVNY 03B BELL $e^+e^-
ightarrow \varUpsilon (4\,{\it S})$ 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(D_{sJ}(2457)^+\,\overline{D}{}^0\times \mathsf{B}(D_{sJ}(2457)^+\to\,D_s^{*+}\,\gamma))/\Gamma_{\mathsf{total}}$ Γ_{125}/Γ VALUE (units 10-3) DO CUMENT ID TECN COMMENT 1 KROKOVNY 03B BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ < 0.98

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 B^{\pm}

| $\Gamma(D_{sJ}(2457) + \overline{D}^*(2007)^0$ | • | | | | Γ_{126}/Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-------------------|-------------------------------|-------------------------------------------------------------------------------------------------------------|---------------------------------------------|
| /ALUE (units 10 ⁻³) 12.0±3.0 OUR AVERAGE | DO CUMENT ID | | TECN | COMMENT | |
| 1.2±2.6±2.0 | ¹ AUBERT | 06N | BABR | $e^+ e^- \rightarrow$ | Y(45) |
| 6 +8 ±4 | ^{2,3} AUBERT,B | 04s | BABR | $e^+e^-\to$ | $\Upsilon(4S)$ |
| 1 Uses a missing-mass metho 2 AUBERT,B 04s report $[\mathrm{B}(D_{s1}(2460)^{+}\rightarrow D_{s}^{*+})$ | ts $[\Gamma(B^+ \rightarrow \pi^0)] = (7.6 \pm 1.7^+)$ | D_{sJ} | $^{(2457)^+}_{	imes 10^{-3}}$ | $\overline{D}^*(2007)^0$ which we |)/Γ _{total}] × divide by our |
| best value $B(D_{s1}(2460)^+$ experiment's error and our ³ Assumes equal production | $\rightarrow D_s$, π^2) = (48 second error is the system of B^+ and B^0 at the | temate γ | ic error (S) | from using o | ur best value. |
| (D _{sJ} (2457)+ \(\overline{D}\)*(2007) ⁰ | × B(<i>D_{sJ}</i> (2457)+ | | | | Γ ₁₂₇ /Γ |
| $.4 \pm 0.4 + 0.6$ | 1 AUBERT,B | | | | 20(4.6) |
| === | | | | e · e → | 1 (45) |
| ¹ Assumes equal production | | , | • | | |
| $(\overline{D}^0 D_{s1}(2536)^+ \times B(D_s)^+ \times B(D_s)$ | | | | | Γ ₁₂₉ /Γ |
| 2.16 ± 0.52 ± 0.45 | ¹ AUBERT | | | $e^+e^- \to$ | $\Upsilon(4S)$ |
| • • We do not use the follo | owing data for average AUBERT | | | | UBERT 08B |
| $^{<2}$ 90 1 Assumes equal production | | | | кері. Бу А | OBENI NOR |
| | | | | D*/0010\ | + 1/0)\ / |
| $(\overline{D}^0 D_{s1}(2536)^+ \times B(D_s)^+$ | $_1(2536)^{\top} \rightarrow D^*(2$ | UU7) | 'K ⁺ + | ע⁻(2010) | + Κ ^υ))/ Γ ₁₂₈ /Γ |
| total ALUE (units 10 ^{—4}) | DOCUMENT ID | | TECN | COMMENT | 128/1 |
| .97±0.85±0.56 | 1,2 AUSHEV | 11 | BELL | $e^+e^- \rightarrow$ | Υ(4S) |
| 1 Uses $\Gamma(D^*(2007)^0 \rightarrow$ | $D^0\pi^0$) / $\Gamma(D^*(200$ | 7)0 - | \rightarrow D^0 | γ) = 1.74 | \pm 0.13 and |
| $\Gamma(D_{s1}(2536)^+ \rightarrow D^*(2002)^+$ Assumes equal production | $(07)^0 K^+) / \Gamma(D_{s1}(25))$ | 36)+ . ~(4) | $\rightarrow D^*(1)$ | 2010) ⁺ K ⁰) | $= 1.36 \pm 0.2$ |
| | | | | • | |
| $(\overline{D}^*(2007)^0 D_{s1}(2536)^+$ | \times B($D_{s1}(2536)^+$ - | → D' | (2007) | º <i>K</i> +))/Γ ₁ | |
| ALUE (units 10 ⁻⁴) CL% | DOCUMENT ID | | TECN | COMMENT | Γ ₁₃₀ /Γ |
| 5.46±1.17±1.04 | 1 AUBERT | | | $e^+e^- \rightarrow$ | Υ(45) |
| • We do not use the follo | wing data for average | s, fits | , limits, | etc. • • • | |
| <7 90 | AUBERT | | | Repl. by A | UBERT 08B |
| Assumes equal production | | , | | | |
| $(\overline{D}^0 D_{s1}(2536)^+ \times B(D_s)^+$ | $_{1}(2536)^{+} \rightarrow D^{*+}$ | K ⁰)) | $/\Gamma_{total}$ | | Γ ₁₃₁ /Γ |
| ALUE (units 10 ⁻⁴) | DOCUMENT ID | | | | |
| $.30 \pm 0.98 \pm 0.43$ ¹ Assumes equal production | 1 AUBERT | | | $e^+ e^- \rightarrow$ | T(45) |
| • • | | , | | | |
| $(\overline{D}{}^0 D_{sJ}(2700)^+ \times B(D_s)$ | | (+))/ | | | Γ ₁₃₂ /Γ |
| ALUE (units 10 ⁻⁴) | DO CUMENT ID | | | COMMENT | |
| $1.3\pm2.2^{+1.4}_{-2.8}$ | ¹ BRODZICKA | 80 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| $^{ m 1}$ Assumes equal production | of \mathcal{B}^+ and \mathcal{B}^0 at the | r(4 | S). | | |
| $(\overline{D}^{*0}D_{s1}(2536)^{+} \times B(D_{s1}(2536)^{+})$ | $P_{s1}(2536)^+ \rightarrow D^{*+}$ | K ⁰) |)/ $\Gamma_{ m tota}$ | l) | Г ₁₃₃ /Г |
| ALUE (units 10 ⁻⁴) | DOCUMENT ID 1 AUBERT | | TECN | COMMENT | • |
| .92±2.46±0.83 | | | | $e^+e^- \to$ | $\Upsilon(4S)$ |
| ¹ Assumes equal production | | | ′ | | |
| $(\overline{D}^{*0}D_{sJ}(2573)^+ \times B(D)$ | | | | | Γ ₁₃₄ /Γ |
| ALUE (units 10 ⁻⁴) <u>CL%</u> | | | | | |
| <2 90 | AUBERT | 03x | BABR | $e^+ e^- \rightarrow$ | Y(45) |
| $(\overline{D}^*(2007)^0 D_{sJ}(2573)^+$ | \times B(D_{sJ} (2573)+ | → D | ⁰ K+)) | $/\Gamma_{total}$ | Г ₁₃₅ /Г |
| ALUE (units 10 ⁻⁴) <u>CL%</u> | | | TECN | COMMENT | |
| | AUBERT | | | $e^+e^- \to$ | |
| <5 90 | | | | | _ |
| | | | | | Γ ₁₃₆ /Γ |
| $(\overline{\mathcal{D}}^0 \mathcal{D}_s^{*+})/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | COMMENT | Γ ₁₃₆ /Γ |
| $(\overline{D}^0 D_s^{*+})/\Gamma_{\text{total}}$ ALUE .0076 \pm 0.0016 OUR AVERAGE | GE | | | | |
| 90 (D ⁰ O _s *+)/\(\Gamma_{\text{total}}\) (ALUE 1.0076±0.0016 OUR AVERAGO 1.0079±0.0017±0.0007 1.0068±0.0025±0.0006 | | | BABR | $\begin{array}{c} \underline{\text{COMMENT}} \\ e^+ \ e^- \rightarrow \\ e^+ \ e^- \rightarrow \end{array}$ | Υ(4S) |

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^1 AUBERT 06N reports (0.77\pm0.15\pm0.13)\times10^{-2} from a measurement of [\Gamma(B^+\to \overline{\mathcal{D}}^0D_s^{*+})/\Gamma_{total}]\times[B(D_s^+\to\phi\pi^+)] assuming B(D_s^+\to\phi\pi^+)=0.0462\pm0.0062, which we rescale to our best value B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value 2 GIBAUT 96 reports 0.0087\pm0.0027\pm0.0017 from a measurement of [\Gamma(B^+\to \overline{\mathcal{D}}^0D_s^{*+})/\Gamma_{total}]\times[B(D_s^+\to\phi\pi^+)] assuming B(D_s^+\to\phi\pi^+)=0.035, which we rescale to our best value B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best
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 $_{s}^{3}$ Value. $_{s}^{3}$ ALBRECHT 92G reports 0.016 \pm 0.012 \pm 0.003 from a measurement of $[\Gamma(B^{+}\rightarrow\overline{D}^{0}D_{s}^{*+})/\Gamma_{total}]\times[B(D_{s}^{+}\rightarrow\phi\pi^{+})]$ assuming $B(D_{s}^{+}\rightarrow\phi\pi^{+})=0.027$, which we rescale to our best value $B(D_{s}^{+}\rightarrow\phi\pi^{+})=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^{0} branching ratios, e.g., $B(D^{0}\rightarrow K^{-}\pi^{+})=3.71\pm0.25\%$.

 1 AUBERT 06N reports $(0.76\pm0.15\pm0.13)\times10^{-2}$ from a measurement of $[\Gamma(B^+\to \overline{\mathcal{D}}^*(2007)^0D_s^+)/\Gamma_{\rm total}]\times[B(D_s^+\to\phi\pi^+)]$ assuming $B(D_s^+\to\phi\pi^+)=0.0462\pm0.0062$, which we rescale to our best value $B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 2 GIBAUT 96 reports 0.0140 \pm 0.0043 \pm 0.0035 from a measurement of $[\Gamma(B^+\to \overline{\cal D}^*(2007)^0D_s^+)/\Gamma_{\rm total}] \times [B(D_s^+\to \phi\pi^+)]$ assuming $B(D_s^+\to \phi\pi^+)=0.035$, which we rescale to our best value $B(D_s^+\to \phi\pi^+)=(4.5\pm0.4)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

our best value. 3 ALBRECHT 92G reports $0.013\pm0.009\pm0.002$ from a measurement of $[\Gamma(B^+\to \overline{D}^*(2007)^0D_s^+)/\Gamma_{\text{total}}] \times [B(D_s^+\to\phi\pi^+)]$ assuming $B(D_s^+\to\phi\pi^+)=0.027$, which we rescale to our best value $B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^0 and $D^*(2007)^0$ branching ratios, e.g., $B(D^0\to K^-\pi^+)=3.71\pm0.25$ % and $B(D^*(2007)^0\to D^0\pi^0)=55\pm6$ %.

 $\Gamma(\overline{D}^*(2007)^0 D_s^{*+})/\Gamma_{total}$ DOCUMENT ID TECN COMMENT

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|-----|------|-----------------------------------|
| 0.0171 ± 0.0024 OUR AVERAGE | | | | |
| $0.0167 \pm 0.0019 \pm 0.0015$ | ¹ AUBERT | 06N | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| $0.024 \pm 0.009 \pm 0.002$ | ² GIBAUT | 96 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.019 \pm 0.010 \pm 0.002$ | ³ ALBRECHT | 92G | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |

 1 AUBERT 06N reports $(1.62\pm0.22\pm0.18)\times10^{-2}$ from a measurement of [\Gamma ($B^+\to \overline{D}^*(2007)^0\,D_s^{*+})/\Gamma_{total}]\times [B(D_s^+\to\phi\pi^+)]$ assuming $B(D_s^+\to\phi\pi^+)=0.0462\pm0.0062$, which we rescale to our best value $B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

² GIBAUT 96 reports 0.0310 \pm 0.0088 \pm 0.0065 from a measurement of $[\Gamma(B^+ \to \overline{D}^*(2007)^0 D_s^{*+})/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi\pi^+)]$ assuming $B(D_s^+ \to \phi\pi^+) = 0.035$, which we rescale to our best value $B(D_s^+ \to \phi\pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

3 our best value. $\begin{array}{l} \text{3 ALBRECHT 92G reports 0.031} \pm 0.016 \pm 0.005 \text{ from a measurement of } \left[\Gamma\left(B^+ \to \overline{D}^*(2007)^0 \, D_s^{*+}\right)/\Gamma_{\text{total}}\right] \times \left[B(D_s^+ \to \phi\pi^+)\right] \text{ assuming } B(D_s^+ \to \phi\pi^+) = 0.027, \\ \text{which we rescale to our best value } B(D_s^+ \to \phi\pi^+) = (4.5 \pm 0.4) \times 10^{-2}. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 <math>D^0$ and $D^*(2007)^0$ branching ratios, e.g., $B(D^0 \to K^-\pi^+) = 3.71 \pm 0.25\%$ and $B(D^*(2007)^0 \to D^0\pi^0) = 55 \pm 6\%. \end{array}$

 1 AHMED 00B reports their experiment's uncertainties (±0.78 ± 0.48 ± 0.68)%, where the first error is statistical, the second is systematic, and the third is the uncertainty in the $D_S \to \phi \pi$ branching fraction. We combine the first two in quadrature.

Γ(Φ*(2007)⁰ Φ*(2010)⁺)/Γ_{total} Γ₁₄₀/Γ

<u>MAUUE (units 10⁻⁴) CL% DOCUMENT ID TECN COMMENT</u>

1 AND TECN COMMENT

1 AND TECN COMMENT

1 AND TECN COMMENT

1 AND TECN COMMENT

8.1±1.2±1.2
1 AUBERT,B 06A BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • <110 90 BARATE 98Q ALEP $e^+e^- \rightarrow Z$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\frac{\left[\left\lceil (\overline{D}^0 D^*(2010)^+ \right) + \left\lceil (\overline{D}^*(2007)^0 D^+ \right) \right] / \Gamma_{total}}{VALUE \left(units 10^{-4} \right)} \frac{CL\%}{90} \frac{DOCUMENT \ ID}{BARATE} \frac{TECN}{98Q} \frac{COMMENT}{e^+e^- \rightarrow Z}$

Meson Particle Listings

| | | | | | | | | | B^{\pm} |
|-------------------------------------------------------------------------------------|---------------------------------------------------------------------|--------------------------------------------|---|--------------------------------------------------------------------------------------------------------|---------------------------------------------|---------------------------------------------|------------------------------|-------------------------------------------|----------------------------------------------------|
| $\Gamma(\overline{D}^0 D^*(2010)^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) | DOCUMENT ID TECN | Γ ₁₄₂ / | Γ | Γ(D *(2007) ⁰ D*(200 | 7) ⁰ K+)/ | 'T _{total} | , T | ECN COMMENT | Γ ₁₅₂ /Γ |
| 3.9 ±0.5 OUR AVERAGE | | | _ | 11.23±0.36±1.26 | | | | ABR $e^+e^- \rightarrow$ | Υ(4S) |
| $3.6 \pm 0.5 \pm 0.4$ $4.57 \pm 0.71 \pm 0.56$ | ¹ AUBERT,B 06A BABR ¹ MAJUMDER 05 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | | • • • We do not use the | | | | | |
| 1 Assumes equal production of E | | e· e → 7(43) | | $5.3 \begin{array}{c} +1.1 \\ -1.0 \end{array} \pm 1.2$ | | ¹ AUBERT | 03x B | ABR Repl. by D | |
| $\Gamma(\overline{D}^0 D^+)/\Gamma_{\text{total}}$ | and B at the 7 (10). | Γ/ | г | ¹ Assumes equal produ | iction of B | + and B ⁰ at ti | he $\Upsilon(4S)$. | SANCE | IEZ 11B |
| VALUE (units 10 ⁻⁴) CL% | DO CUMENT ID TECN | Γ ₁₄₃ / | 1 | $\Gamma(D^-D^+K^+)/\Gamma_{\text{total}}$ | - | | , , | | Г ₁₅₃ /Г |
| 3.8 ±0.4 OUR AVERAGE | | | _ | VALUE (units 10 ⁻³) | CL% | DO CUMENT IE |) TE | ECN COMMENT | 153/1 |
| $3.85 \pm 0.31 \pm 0.38$ $3.8 \pm 0.6 \pm 0.5$ | ¹ ADACHI 08 BELL ¹ AUBERT,B 06A BABR | . ' ' | | 0.22 ± 0.05 ± 0.05 | | | | ABR $e^+e^- \rightarrow$ | Υ(4S) |
| • • • We do not use the following | · | . , | | • • • We do not use the | | _ | • | | |
| $4.83 \pm 0.78 \pm 0.58$ | ¹ MAJUMDER 05 BELL | Repl. by ADACHI 08 | | <0.90 <0.4 | | ¹ CHISTOV ¹ AUBERT | | ELL $e^+e^- ightarrow$ ABR Repl. by D | |
| $<$ 67 90 1 Assumes equal production of E | BARATE 98Q ALEP 8^+ and 8^0 at the $\Upsilon(45)$ | $e^+ e^- \rightarrow Z$ | | ¹ Assumes equal produ | iction of B | + and B ⁰ at th | | | IEZ 11B |
| $\Gamma(\overline{D}^0 D^+ K^0)/\Gamma_{\text{total}}$ | | Γ ₁₄₄ / | г | Γ(D- D*(2010)+ K+ | | | (/. | | Γ ₁₅₄ /Γ |
| VALUE (units 10 ⁻³) CL% | DOCUMENT ID TECN | COMMENT | • | VALUE (units 10 ⁻³) | , | DO CUMENT IE |) TE | ECN COMMENT | 154/ |
| 1.55 ± 0.17 ± 0.13 | ¹ DEL-AMO-SA11B BABR | | _ | 0.63±0.09±0.06 | | | | ABR $e^+e^- \rightarrow$ | Υ(4S) |
| • • • We do not use the following | · . | | | • • • We do not use the | | | • | | |
| <2.8 90 | ¹ AUBERT 03x BABR | Repl. by DEL-AMO- SANCHEZ 11B | | < 0.7 | 90 | ¹ AUBERT | 03x B/ | ABR Repl. by D SANCH | DEL-AMO- IEZ 11B |
| $^{ m 1}$ Assumes equal production of $^{ m E}$ | $^{+}$ and 0 at the $arphi(45)$. | | | ¹ Assumes equal produ | iction of B | $^+$ and B^{0} at th | he $\varUpsilon(4S)$. | | |
| $\Gamma(D^+\overline{D}^*(2007)^0)/\Gamma_{\text{total}}$ | | Γ ₁₄₅ / | Γ | Γ(D*(2010)-D+K+ |)/F _{total} | | | | Γ ₁₅₅ /Γ |
| VALUE (units 10^{-4}) | DOCUMENT ID TECN | | _ | VALUE (units 10 ⁻³) | | DO CUMENT ID | | COMMENT | |
| 6.3±1.4±1.0 | , | $e^+e^- \rightarrow \Upsilon(4S)$ | | 0.60±0.10±0.08 | | | | ABR $e^+e^- \rightarrow$ | Y(45) |
| ¹ Assumes equal production of E | B^+ and B^0 at the $\Upsilon(4S)$. | | | • • • We do not use the $1.5 \pm 0.3 \pm 0.2$ | | 1 AUBERT | | ABR Repl. by D | DEL-AMO- |
| $\Gamma(\overline{D}^*(2007)^0D^+K^0)/\Gamma_{\text{total}}$ | | Γ ₁₄₆ / | Γ | | | | | | IEZ 11B |
| VALUE (units 10 ⁻³) CL% | 1 DEL-AMO-SA11B BABR | . ——— | | ¹ Assumes equal produ | | | ne T (45). | | |
| 2.06±0.38±0.30 • • • We do not use the following | | | | Γ(D*(2010) - D*(201 | , | • | | | Γ ₁₅₆ /Γ |
| < 6.1 90 | ¹ AUBERT 03x BABR | Repl. by DEL-AMO- | | VALUE (units 10 ⁻³) 1.32±0.13±0.12 | | DELAMOS | | ABR $e^+e^- \rightarrow$ | Υ(4 C) |
| $^{ m 1}$ Assumes equal production of $\it E$ | B^+ and B^0 at the $\Upsilon(4S)$. | SANCHEZ 11B | | • • • We do not use the | | | | | 7 (43) |
| $\Gamma(\overline{D}^0\overline{D}^*(2010)^+K^0)/\Gamma_{\text{total}}$ | , | Γ ₁₄₇ / | г | <1.8 | 90 | ¹ AUBERT | 03x B | ABR Repl. by E | |
| VALUE (units 10 ⁻³) | DOCUMENT ID TECN | ' 147/ COMMENT | | ¹ Assumes equal produ | iction of B | $^+$ and B^{0} at th | he $\Upsilon(4S)$. | SANCE | IEZ 11B |
| $3.81 \pm 0.31 \pm 0.23$ | 1 DEL-AMO-SA11B BABR | $e^+e^- \rightarrow r(4S)$ | _ | $\Gamma((\overline{D}+\overline{D}^*)(D+D^*)$ |) K) / [| | | | Γ ₁₅₇ /Γ |
| • • • We do not use the following | data for averages, fits, limits, | etc. • • • | | VALUE (units 10 ⁻²) | / · · / / · tota | DO CUMENT ID |) TE | CN COMMENT | . 1977. |
| $5.2 \begin{array}{c} +1.0 \\ -0.9 \end{array} \pm 0.7$ | ¹ AUBERT 03x BABR | Repl. by DEL-AMO- SANCHEZ 11B | | 4.05 ± 0.11 ± 0.28 | | | | ABR $e^+e^- \rightarrow$ | Υ(4S) |
| $^{ m 1}$ Assumes equal production of $^{ m E}$ | $^{+}$ and 0 at the $arphi(4S)$. | | | • • • We do not use the $3.5 \pm 0.3 \pm 0.5$ | - | data for averag 1 AUBERT | | nits, etc. • • • ABR Repl. by D | NEL AMO |
| $\Gamma(\overline{D}^*(2007)^0 D^*(2010)^+ K^0)$ | /F _{total} | Γ ₁₄₈ / | Г | | | | | | IEZ 11B |
| VALUE (units 10^{-3}) | DOCUMENT ID TECN | COMMENT | _ | ¹ Assumes equal produ | iction of B | ⁺ and B ^U at th | he $\Upsilon(4S)$. | | |
| 9.17±0.83±0.90 | ¹ DEL-AMO-SA11B BABR | | ı | $\Gamma(D_s^+\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₁₅₈ /Γ |
| • • • We do not use the following | , | | | VALUE (units 10 ⁻⁵) | CL% | DO CUMENT ID | <u>TE</u> | COMMENT | |
| 7.8 $^{+2.3}_{-2.1}$ ± 1.4 | ¹ AUBERT 03x BABR | SANCHEZ 11B | | $1.6^{+0.6}_{-0.5}\pm0.1$ | | ¹ AUBERT | 07м В | ABR $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $^{ m 1}$ Assumes equal production of $\it E$ | $^{+}$ and 0 at the \varUpsilon (45). | | | • • • We do not use the | | | | | |
| $\Gamma(\overline{D}{}^0 D^0 K^+)/\Gamma_{\text{total}}$ | | Γ ₁₄₉ / | Γ | <16 | | | | _E2 e ⁺ e ⁻ → | |
| | DOCUMENT ID TECN C | COMMENT | _ | 1 AUBERT 07M report $(7.0 + 2.4 + 0.6) \times 1$ | orts [I(B | $D_S \pi$ | ')/I _{total}] | \times [B($D_s^+ \rightarrow RD_s^+$ | $\phi \pi^+)] =$ |
| 1.45 ± 0.33 OUR AVERAGE Erro 1.31 ± 0.07 ± 0.12 | rincludes scale factor of 2.6. DEL-AMO-SA 11 B BABR ϵ | $e^+e^- \rightarrow r(4S)$ | I | $(7.0 - 2.1 - 0.8) \times 1$ $(4.5 + 0.4) \times 10^{-2}$ | . Our first | error is their | experimen | t's error and our | $\rightarrow \varphi \pi \cdot) =$ r second error |
| . 0.00 | BRODZICKA 08 BELL 6 | , , | - | $(4.5 \pm 0.4) \times 10^{-2}$ is the systematic erro | or from usir | ng our best valu | je. | - / | 1 0 |
| • • • We do not use the following | | etc. • • • | | ² ALEXANDER 93B re $\Gamma_{\text{total}}] \times [B(D_s^+ \rightarrow$ | eports < 2 . | 0 × 10 ⁻⁴ from | a measure . ⊥_+\ | ement of $[\Gamma(B^{+})]$ | $\rightarrow D_S^+ \pi^0)/$ |
| $1.17 \pm 0.21 \pm 0.15$ 1 $1.9 \pm 0.3 \pm 0.3$ 1 | | Repl. by BRODZICKA 08 Repl. by DEL-AMO- | | our best value B($D_s^+ \rightarrow D_s^+$ | $\phi \pi$ ·)] as $\rightarrow \phi \pi^+$ | $(D_{s}) = 4.5 \times 10^{-2}$ | $\rightarrow \phi \pi^{+}$) | = 0.037, WINCH | we rescale to |
| ¹ Assumes equal production of E | | SANCHEZ 11B | | 5 | | | | (Γ ₁ , | 58+[160]/F |
| $\Gamma(\overline{D}^*(2007)^0 D^0 K^+)/\Gamma_{\text{total}}$ | 30 0.10 7 (40). | Γ ₁₅₀ / | Г | $\frac{\left[\Gamma\left(D_s^+ \pi^0\right) + \Gamma\left(D_s^{*+}\right)\right]}{< 5 \times 10^{-4}}$ | /]/'10 | . <u>DO CUMENT ID</u> 1 | <u>TE</u> | COMMENT | 20 137// ' |
| VALUE (units 10 ⁻³) CL% | DOCUMENT ID TECN | | • | | | | | | |
| 2.26±0.16±0.17 | ¹ DEL-AMO-SA11B BABR | $e^+e^- \rightarrow \gamma(4S)$ | _ | 1 ALBRECHT 93E rep | | | | | |
| • • • We do not use the following <3.8 | 1 | Repl. by DEL-AMO- | | $\Gamma(B^+	o D_S^{*+}\pi^0)\Big]$ which we rescale to G | | | | | π^{+}) = 0.027, |
| $^{ m 1}$ Assumes equal production of $\it E$ | | SANCHEZ 11B | | | | . 5 | • | | c /c |
| | , and в at the 1 (43). | | - | $\Gamma(D_s^{*+}\pi^0)/\Gamma_{\text{total}}$ | CI% | DOCUMENT IF |) + | CN COMMENT | Γ ₁₅₉ /Γ |
| $\Gamma(\overline{D}^0 D^*(2007)^0 K^+)/\Gamma_{\text{total}}$ | DO CUMENT 12 | Γ ₁₅₁ / | I | <2.6 × 10 ⁻⁴ | 90 | 1 ALEXANDER | R 93B CL | $\frac{COMMENT}{e^+e^-}$ | Υ(4S) |
| VALUE (units 10 ⁻³) 6.32±0.19±0.45 | DOCUMENT ID TECN 1 DEL-AMO-SA11B BABR | | | ¹ ALEXANDER 93B re | | | | | |
| • • • We do not use the following | | | • | $\Gamma_{total}] \times [B(D_s^+ \to$ | $\phi\pi^+)]$ as | ssuming $B(D_s^+)$ | $\rightarrow \phi \pi^+$ | | |
| $4.7 \pm 0.7 \pm 0.7$ | ¹ AUBERT 03x BABR | Repl. by DEL-AMO- SANCHEZ 11B | | our best value $B(D_s^+)$ | $\rightarrow \phi \pi^{+}$ | $) = 4.5 \times 10^{-2}$ | 2 | | |
| $^{ m 1}$ Assumes equal production of $^{ m 4}$ | $^{8+}$ and 8 at the $^{\gamma}(4S)$. | JANCHEZ IIB | | | | | | | |

 $\Gamma(D_s^+ a_1(1260)^0)/\Gamma_{\text{total}}$

90

| B^\pm | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| $\Gamma(D_s^+\eta)/\Gamma_{	ext{total}}$ Γ_{160}/Γ | $\Gamma(D_s^{*+}a_1(1260)^0)/\Gamma_{total}$ $\Gamma_{167}/\Gamma_{value}$ $\Gamma_{cl\%}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{split} &\Gamma_{\text{total}}] \times [B(D_S^+ \to \phi \pi^+)] \text{ assuming } B(D_S^+ \to \phi \pi^+) = 0.027, \text{ which we rescale to} \\ &\text{our best value } B(D_S^+ \to \phi \pi^+) = 4.5 \times 10^{-2}. \\ &^3 \text{ALEXANDER 93B reports} < 4.2 \times 10^{-4} \text{ from a measurement of } [\Gamma(B^+ \to D_S^{*+} \phi)/\Gamma_{\text{total}}] \times [B(D_S^+ \to \phi \pi^+)] \text{ assuming } B(D_S^+ \to \phi \pi^+) = 0.037, \text{ which we rescale to} \\ &\text{our best value } B(D_S^+ \to \phi \pi^+) = 4.5 \times 10^{-2}. \end{split}$ |
| $\left[\left[\left(D_s^{*+} \rho^0 \right) + \Gamma \left(D_s^{*+} \overline{K}^* (892)^0 \right) \right] / \Gamma_{\text{total}} \right] \qquad (\Gamma_{163} + \Gamma_{173}) / \Gamma$ | $\Gamma(D_s^+\overline{K}^0)/\Gamma_{	ext{total}}$ $\Gamma_{170}/\Gamma_{	ext{VALUE}}$ $\Gamma_{170}/\Gamma_{	ext{DOCUMENT ID}}$ $\Gamma_{170}/\Gamma_{	ext{TECN}}$ $\Gamma_{170}/\Gamma_{	ext{DOCUMENT ID}}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | <8 × 10 ⁻⁴ 90 1 ALEXANDER 93B CLE2 $e^+e^- \rightarrow \tau(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • <1.5 × 10 ⁻³ 90 2 ALBRECHT 93E ARG $e^+e^- \rightarrow \tau(4S)$ ¹ ALEXANDER 93B reports < 10.3 × 10 ⁻⁴ from a measurement of $[\Gamma(B^+ \rightarrow D_S^+ \overline{K}^0)/\Gamma_{\text{total}}] \times [B(D_S^+ \rightarrow \phi \pi^+)]$ assuming $B(D_S^+ \rightarrow \phi \pi^+) = 0.037$, which we rescale to our best value $B(D_S^+ \rightarrow \phi \pi^+) = 4.5 \times 10^{-2}$. ² ALBRECHT 93E reports < 2.5 × 10 ⁻³ from a measurement of $[\Gamma(B^+ \rightarrow D_S^+ \overline{K}^0)/\Gamma_{\text{total}}] \times [B(D_S^+ \rightarrow \phi \pi^+)]$ assuming $B(D_S^+ \rightarrow \phi \pi^+) = 0.027$, which we rescale to |
| $<$ 2.0 $	imes$ 10 $^{-3}$ 90 2 ALBRECHT 93E ARG $e^+e^- ightarrow~ \varUpsilon(4S)$ | our best value B($D_s^+ 	o \phi \pi^+$) = 4.5 $	imes 10^{-2}$. |
| $ \begin{array}{c} ^{1}\text{ALEXANDER 93B reports} < 4.8 \times 10^{-4} \text{ from a measurement of } \left[\Gamma\left(B^{+} \rightarrow D_{s}^{+} \omega\right)/\Gamma_{\text{total}}\right] \times \left[B(D_{s}^{+} \rightarrow \phi\pi^{+})\right] \text{ assuming } B(D_{s}^{+} \rightarrow \phi\pi^{+}) = 0.037, \text{ which we rescale to our best value } B(D_{s}^{+} \rightarrow \phi\pi^{+}) = 4.5 \times 10^{-2}. \\ ^{2}\text{ALBRECHT 93E reports} < 3.4 \times 10^{-3} \text{ from a measurement of } \left[\Gamma\left(B^{+} \rightarrow D_{s}^{+} \omega\right)/\Gamma_{\text{total}}\right] \times \left[B(D_{s}^{+} \rightarrow \phi\pi^{+})\right] \text{ assuming } B(D_{s}^{+} \rightarrow \phi\pi^{+}) = 0.027, \text{ which we rescale to our best value } B(D_{s}^{+} \rightarrow \phi\pi^{+}) = 4.5 \times 10^{-2}. \\ \hline \Gamma\left(D_{s}^{*+}\omega\right)/\Gamma_{\text{total}} & \Gamma_{165}/\Gamma_{s}^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+}\omega^{*+$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 1 ALEXANDER 93B reports $<$ 6.8 $	imes$ 10 $^{-4}$ from a measurement of [$\Gamma(B^+ 	o D_S^{*+} \omega)/$ | $\Gamma(D_s^+\overline{K}^*(892)^0)/\Gamma_{total}$ Γ_{172}/Γ |
| $\begin{split} &\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ assuming } B(D_s^+ \to \phi \pi^+) = 0.037, \text{ which we rescale to} \\ &\text{our best value } B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}. \\ &^2ALBRECHT 93E reports < 1.9 \times 10^{-3} \text{ from a measurement of } [\Gamma(B^+ \to D_s^{*+} \omega)/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ assuming } B(D_s^+ \to \phi \pi^+) = 0.027, \text{ which we rescale to} \\ &\text{our best value } B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}. \end{split}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

90 1 ALEXANDER 93B reports < 4.3 \times 10 $^{-4}$ from a measurement of [$\Gamma(B^+$ ightarrow $C_s^{*+}\overline{K}^*(892)^0)/\Gamma_{total}]\times [B(D_s^+\to\phi\pi^+)] \text{ assuming } B(D_s^+\to\phi\pi^+)=0.037,$ which we rescale to our best value $B(D_s^+\to\phi\pi^+)=4.5\times10^{-2}.$

 Γ_{173}/Γ

 $\Gamma(D_s^{*+}\overline{K}^*(892)^0)/\Gamma_{total}$

 Γ_{166}/Γ

 $\frac{DOCUMENT\ ID}{1}$ ALBRECHT 93E ARG $e^+e^ightarrow \Upsilon(4S)$

 $^1 \, \text{ALBRECHT}$ 93E reports $<~3.0 \, \times \, 10^{-3}$ from a measurement of [$\Gamma(B^+ \, \rightarrow \,$

which we rescale to our best value B($D_s^+ \rightarrow \phi \pi^+$) = 4.5 \times 10⁻².

 $D_{s}^{+}a_{1}(1260)^{0})/\Gamma_{\text{total}}] \times [B(D_{s}^{+} \rightarrow \phi\pi^{+})] \text{ assuming } B(D_{s}^{+} \rightarrow \phi\pi^{+}) = 0.027,$

02 BABR Repl. by AUBERT 05J

94 CLE2 Repl. by JESSOP 97

92G ALEP $e^+e^-
ightarrow Z$

87D ARG $e^+e^- \rightarrow \Upsilon(4S)$

| | B ⁺ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(D_s^-\pi^+K^+)/\Gamma_{total}$ Γ_{174}/Γ | $\Gamma(B^+ \to \eta_c K^+)/\Gamma_{ m total} \times \Gamma(\eta_c(1S) \to \gamma \gamma)/\Gamma_{ m total}$ |
| <u>VALUE (units 10⁻⁴) </u> | $\Gamma_{180}/\Gamma 	imes \Gamma_{29}^{\eta_c(15)}/\Gamma^{\eta_c(15)}$ VALUE (units 10 ⁻⁶) DOCUMENT ID TECH COMMENT |
| $1.71 + 0.08 \pm 0.25$ 1 WIECHCZYN09 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | 0.22 $^{+0.09}_{-0.07}$ $^{+0.04}_{-0.07}$ 1 WICHT 08 BELL $e^{+}e^{-} \rightarrow \gamma(45)$ |
| $2.02\pm0.13\pm0.38$ 1 AUBERT 08G BABR $e^+e^- 	o 	au(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • | ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $<$ 7 90 2 ALBRECHT 93E ARG $e^+e^- ightarrow arphi(45)$ | $\Gamma(\eta_c K^+, \eta_c \to K_S^0 K^\mp \pi^\pm)/\Gamma_{\text{total}}$ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | VALUE (units 10 ⁻⁶) DOCUMENT ID TECN COMMENT |
| ² ALBRECHT 93E reports $< 1.1 \times 10^{-3}$ from a measurement of $[\Gamma(B^+ \to D_S^- \pi^+ K^+)/$ | 26.7±1.4 $^{+5.7}_{-5.5}$ |
| $\Gamma_{	ext{total}}] 	imes [B(D_s^+ 	o \phi \pi^+)]$ assuming $B(D_s^+ 	o \phi \pi^+) = 0.027$, which we rescale to our best value $B(D_s^+ 	o \phi \pi^+) = 4.5 	imes 10^{-2}$. | 1 Assumes equal production of B^{0} and B^{+} from Upsilon(4S) decays. |
| · · | ² VINOKUROVA 11 reports $(26.7 \pm 1.4 + \frac{2.9}{-2.6} \pm 4.9) \times 10^{-6}$, where the first uncertaint |
| $\Gamma\left(D_{s}^{+}\pi^{+}K^{+} ight)/\Gamma_{	ext{total}}$ Γ_{175}/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT | is statistical, the second is due to systematics, and the third comes from interference on $\eta_C(1S) \to \mathcal{K}_S^0 K^\pm \pi^\mp$ with nonresonant $\mathcal{K}_S^0 K^\pm \pi^\mp$. We combined both systematics |
| 1.45 ± 0.24 OUR AVERAGE | uncertainties to single values. |
| $1.31^{+0.13}_{-0.12}\pm0.28$ 1 WIECHCZYN09 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ | $\Gamma(\eta_c K^*(892)^+)/\Gamma_{\text{total}}$ $\Gamma_{182}/\Gamma_{182}$ |
| $1.67 \pm 0.16 \pm 0.35$ | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| <10 90 2 ALBRECHT 93E ARG $e^+e^- ightarrow 	au(4.5)$ | 1.1 $^{+0.5}_{-0.4}$ ± 0.1 1,2 AUBERT 07AV BABR $e^+e^- 	o 	au(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ¹ AUBERT 07AV reports $[\Gamma(B^+ \to \eta_c K^*(892)^+)/\Gamma_{\text{total}}] \times [B(\eta_c(1S) \to p\overline{p})] =$ |
| ² ALBRECHT 93E reports $<$ 1.6 \times 10 ⁻³ from a measurement of [$\Gamma(B^+ \to D_S^{*-}\pi^+ K^+)/$ | $(1.57 + 0.56 + 0.45) \times 10^{-6}$ which we divide by our best value $B(\eta_C(1S)) \rightarrow p\overline{p}$ = $(1.41 + 0.17) \times 10^{-3}$. Our first error is their experiment's error and our second error. |
| $\Gamma_{	ext{total}}] 	imes [B(D_s^+ 	o \phi \pi^+)]$ assuming $B(D_s^+ 	o \phi \pi^+) = 0.027$, which we rescale to our best value $B(D_s^+ 	o \phi \pi^+) = 4.5 \times 10^{-2}$. | $(1.41\pm0.17)\times10^{-3}$. Our first error is their experiment's error and our second error in the systematic error from using our best value. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| | $\Gamma(\eta_c(2S)K^+)/\Gamma_{\text{total}}$ |
| $\Gamma(D_s^-\pi^+K^*(892)^+)/\Gamma_{	ext{total}}$ $\Gamma_{176}/\Gamma_{	ext{VALUE}}$ CL^* DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT |
| value <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> <5 × 10⁻³ 90 1 ALBRECHT 93E ARG $e^{+}e^{-}$ → $\Upsilon(4S)$ | 3.4 \pm 1.8 \pm 0.3 1 AUBERT 06E BABR $e^+e^- \rightarrow r$ (4 S) |
| which we rescale to our best value B($D_s^+ \to \phi \pi^+$) = 4.5 \times 10 ⁻² . $ \Gamma (D_s^{*-} \pi^+ K^*(892)^+) / \Gamma_{total} $ $\Gamma_{177} / \Gamma_{total}$ | $\Gamma_{238}/\Gamma 	imes \Gamma_{4}^{h_c(1P)}/\Gamma_{4}^{h_c(1P)}$ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT |
| VALUE CL% DOCUMENT ID TECN COMMENT | <0.48 90 1 AUBERT 08AB BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| | 1 Uses the production ratio of $(B^{+}B^{-})/(B^{0}\overline{B}{}^{0})=1.026\pm0.032$ at $~\Upsilon(45)$. |
| 1 ALBRECHT 93E reports $<1.1\times10^{-2}$ from a measurement of $[\Gamma(B^+\to D_s^{+}-\pi^+K^*(892)^+)/\Gamma_{\rm total}]\times[B(D_s^+\to\phi\pi^+)]$ assuming $B(D_s^+\to\phi\pi^+)=0.027,$ | $\Gamma(B^+ \to \eta_c(2S) K^+) / \Gamma_{ m total} 	imes \Gamma(\eta_c(2S) \to \gamma \gamma) / \Gamma_{ m total}$ |
| which we rescale to our best value B($D_s^+ \rightarrow \phi \pi^+$) = 4.5 × 10 ⁻² . | $\Gamma_{183}/\Gamma 	imes \Gamma_{14}^{\eta_c(2S)}/\Gamma^{\eta_c(2S)}$ |
| v v | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(D_s^-K^+K^+)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{178}}/\Gamma$ VALUE (units $10^{-4})$ DOCUMENT ID TECN COMMENT | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| 0.11 \pm 0.04 \pm 0.02 | 4 |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | $\Gamma(\eta_c(2S)K^+,\eta_c(2S) 	o K_S^*K^+\pi^\pm)/\Gamma_{\text{total}}$ $\Gamma_{184}/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) DOCUMENT ID TECN COMMENT |
| $\Gamma(D_s^{*-}K^+K^+)/\Gamma_{\text{total}}$ Γ_{179}/Γ | 3.4 $^{+2.2}_{-1.5}^{+0.5}$ 1,2 VINOKUROVA 11 BELL $e^{+}e^{-} \rightarrow r(4S)$ |
| VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | ¹ Assumes equal production of B^0 and B^+ from Upsilon(4S) decays. |
| <0.15 90 1 AUBERT 08G BABR $e^+e^- ightarrow \varUpsilon(4S)$ | $^2\mathrm{The}$ first uncertainty includes both statistical and interference effects while the second is |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | due to systematics. |
| $\Gamma(\eta_c K^+)/\Gamma_{\text{total}}$ Γ_{180}/Γ | $\Gamma(J/\psi(1S)K^+)/\Gamma_{\text{total}}$ $\Gamma_{185}/\Gamma_{185}$ |
| VALUE (units 10 ⁻³) 0.96±0.12 OUR AVERAGE DOCUMENT ID TECN COMMENT 0.96±0.12 OUR AVERAGE | <u>VALUE (units 10⁻⁴) EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 10.16± 0.33 OUR FIT |
| 0.87 ± 0.15 $1,2$ AUBERT 06E BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ | 10.22± 0.35 OUR AVERAGE |
| $1.28 + 0.26 + 0.16 \atop -0.20 - 0.15$ 3 AUBERT,B 05L BABR $e^+e^- 	o 	au(4S)$ | 8.1 \pm 1.3 \pm 0.7 $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $1.25\pm0.14 ^{+~0.39}_{-~0.40}$ 4 FANG 03 BELL $e^+e^- ightarrow$ $\Upsilon(4S)$ | 10.1 \pm 1.0 \pm 0.3 3 AUBERT,B 05L BABR $e^+e^- ightarrow \Upsilon(4S)$ |
| $0.69^{+0.26}_{-0.21}\pm0.22$ 5 EDWARDS 01 CLE2 $e^{+}e^{-} ightarrow \varUpsilon(45)$ | 10.1 \pm 0.2 \pm 0.7 |
| • • We do not use the following data for averages, fits, limits, etc. • • • | 9.3 \pm 3.1 \pm 0.1 4 BORTOLETTO92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.03\pm0.12^{+0.09}_{-0.08}$ 2,6 AUBERT,B 04B BABR $e^+e^- ightarrow$ \varUpsilon (45) | 8.1 \pm 3.5 \pm 0.1 6 ⁵ ALBRECHT 90J ARG $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| | 2 AUDEDT 02 DAED Deed by AUDEDT 05 |

 $^{
m 1}$ Perform measurements of absolute branching fractions using a missing mass technique.

2 The ratio of B(B $^\pm$ \rightarrow $K^\pm\eta_c$) B(η_c \rightarrow $K\overline{K}\pi$) = (7.4 \pm 0.5 \pm 0.7) × 10-5 reported in AUBERT,B 04B and B(B $^\pm$ \rightarrow $K^\pm\eta_c$) = (8.7 \pm 1.5) × 10⁻³ reported in AUBERT 06E contribute to the determination of B(η_c \rightarrow $K\overline{K}\pi$), which is used by

3 AUBERT,B 05L reports $[\Gamma(B^+ \to \eta_C K^+)/\Gamma_{\text{total}}] \times [B(\eta_C(1S) \to p\overline{p})] = (1.8^{+0.3}_{-0.2} \pm 1.8^{+0.3}_{-0.2} \pm 1.8^{+0.3}_{-0.2})$

 $0.2)\times 10^{-6}$ which we divide by our best value $B(\eta_C(1S)\to \rho\overline{\rho})=(1.41\pm0.17)\times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from

disting our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 5 EDWARDS 01 assumes equal production of B^0 and B^+ at the $\Upsilon(4S)$. The correlated uncertainties (28.3)% from $\mathrm{B}(J/\psi(1S) \to \gamma\eta_C)$ in those modes have been accounted

⁶ AUBERT,B 04B reports $[\Gamma(B^+ \to \eta_c K^+)/\Gamma_{\text{total}}] \times [B(\eta_c(1S) \to K\overline{K}\pi)] = (0.074 \pm 0.074)$

0.005 \pm 0.007) \times 10 $^{-3}$ which we divide by our best value B($\eta_{c}(1S) \rightarrow K\overline{K}\pi$) =

 $(7.2\pm0.6) imes10^{-2}$. Our first error is their experiment's error and our second error is

others for normalization.

using our best value.

the systematic error from using our best value.

87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ 86 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ ⁸ ALAM $^{1}\operatorname{Perform}$ measurements of absolute branching fractions using a missing mass technique. ²Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

² AUBERT

BUSKULIC

⁶ ALBRECHT

² ALAM

⁷ BEBEK

3

3

3

10.1 + 0.3 + 0.5

11.0 + 1.5 + 0.9

22 ± 10 ± 2

 ± 2

7 ± 4

 10 ± 7

± 5

3 AUBERT,B 05L reports $\left[\overline{\Gamma} \left(B^+ \to J/\psi(1S) K^+ \right) / \Gamma_{\mathsf{total}} \right] \times \left[B(J/\psi(1S) \to \rho \overline{\rho}) \right] =$ (2.2 \pm 0.1) \times 10⁻⁶ which we divide by our best value B($J/\psi(1S) \to p\overline{p}$) = (2.17 \pm 0.07) \times 10⁻³. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 4 BORTOLETTO 92 reports (8 \pm 2 \pm 2) imes 10 $^{-4}$ from a measurement of [$\Gamma(B^+ o$ ${\it J/\psi(1S)~K^+)/\Gamma_{\mbox{total}}] \times [B({\it J/\psi(1S)} \,\rightarrow\,\, e^+\,e^-)] \mbox{ assuming } B({\it J/\psi(1S)} \,\rightarrow\,\, e^+\,e^-) =$ 0.069 \pm 0.009, which we rescale to our best value B(J/ ψ (1S) \rightarrow e^+e^-) = (5.94 \pm 0.06) \times 10 $^{-2}$. Our first error is their experiment's error and our second error is the

 B^{\pm}

systematic error from using our best value. Assumes equal production of ${\it B}^+$ and ${\it B}^{\,0}$ at

 5 ALBRECHT 90J reports (7 \pm 3 \pm 1) imes 10 $^{-4}$ from a measurement of [$\Gamma(B^{+}$ ightarrow $\textit{J/}\psi(1\textit{S})\;\textit{K}^{+}\,)/\Gamma_{\mbox{total}}]\;\times\; [\mbox{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\; e^{+}\,e^{-})]\;\; \mbox{assuming}\;\; \mbox{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\; e^{+}\,e^{-})$ = 0.069 \pm 0.009, which we rescale to our best value B($J/\psi(1S) \rightarrow e^+e^-$) = $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

⁶ ALBRECHT 87D assume $B^+B^-/B^0\overline{B}^0$ ratio is 55 /45. Superseded by ALBRECHT 90J. $^{7}\,\mathrm{BEBEK}$ 87 value has been updated in BERKELMAN 91 to use same assumptions as

noted for BORTOLETTO 92. 8 ALAM 86 assumes B^{\pm}/B^0 ratio is 60/40.

$\Gamma(\eta_c K^+)/\Gamma(J/\psi(1S)K^+)$ $\Gamma_{180}/\Gamma_{185}$ DOCUMENT ID TECN COMMENT $1.33 \pm 0.10 \pm 0.43$ ¹ AUBERT,B 04B BABR $e^+e^- \rightarrow$

¹ Uses BABAR measurement of B($B^+ \rightarrow J/\psi K^+$) = (10.1 \pm 0.3 \pm 0.5) \times 10⁻⁴.

$\Gamma\big(B^+ \to J/\psi(1S)\,K^+\big)/\Gamma_{\rm total} \,\times\, \Gamma\big(J/\psi(1S) \to \gamma\gamma\big)/\Gamma_{\rm total}$ $\Gamma_{185}/\Gamma \times \Gamma_{191}^{J/\psi(1S)}/\Gamma_{J/\psi(1S)}$

| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----|--------------|----|------|---------------------------------|
| <0.16 | 90 | 1 WICHT | 08 | BELL | $e^+e^- \rightarrow \gamma(4S)$ |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(J/\psi(1S)\,K^+\,\pi^+\,\pi^-)/\Gamma_{ m total}$

DOCUMENT ID CL% EVTS TECN COMMENT 0.81 ±0.13 OUR AVERAGE Error includes scale factor of 2.5. See the ideogram $^{\mathrm{1}}$ GULER $0.716 \pm 0.010 \pm 0.060$ 11 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 05R BABR $e^+e^- \rightarrow r(4S)$ $^{\mathrm{1}}$ AUBERT $1.16 \pm 0.07 \pm 0.09$

 Γ_{186}/Γ

 $0.69 \ \pm 0.18 \ \pm 0.12$ ² ACOSTA 02F CDF *p* p 1.8 TeV 3 BORTOLETTO92 CLEO $e^+e^-
ightarrow ag{7(45)}$ $1.39 \pm 0.82 \pm 0.01$ 4 ALBRECHT 87D ARG $e^+e^- \rightarrow \Upsilon(4S)$ $1.39 \pm 0.91 \pm 0.01$ 6 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

 5 ALBRECHT 9 OJ ARG $^{}$ e $^{+}$ e $^{-}$ \rightarrow $^{}$ r(4 $^{}$ S)

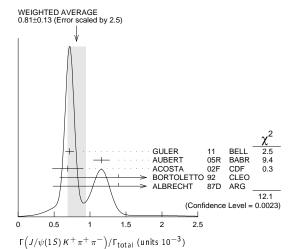
¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

² ACOSTA 02F uses as reference of B(B \rightarrow J/ $\psi(1S)$ K $^{+}$) = (10.1 \pm 0.6) \times 10⁻⁴. The second error includes the systematic error and the uncertainties of the branching ratio. 3 BORTOLETTO 92 reports $(1.2\pm0.6\pm0.4)\times10^{-3}$ from a measurement of [\Gamma(B^+ \rightarrow

 ${\it J/\psi(1S)~K^+\,\pi^+\,\pi^-)/\Gamma_{\rm total}]~\times~[{\rm B}({\it J/\psi(1S)}~\rightarrow~e^+\,e^-)]~{\rm assuming}~{\rm B}({\it J/\psi(1S)}~\rightarrow~e^+\,e^-)$ $e^+e^-)=0.069\pm0.009$, which we rescale to our best value B $(J/\psi(1S)\to e^+e^-)=$ $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

⁴ALBRECHT 87D reports $(1.2\pm0.8) imes10^{-3}$ from a measurement of $[\Gamma(B^+\to$ $J/\psi(1S)~K^+\pi^+\pi^-)/\Gamma_{\mathsf{total}}]~\times~[\mathsf{B}(J/\psi(1S)~\to~e^+\,e^-)]$ assuming $\mathsf{B}(J/\psi(1S)~\to~e^+\,e^-)$ $e^+\,e^-)=$ 0.069 \pm 0.009, which we rescale to our best value B $(J/\psi(1S)
ightarrow\,e^+\,e^-)=$ $(5.94\pm0.06) imes 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. They actually report 0.0011 \pm 0.0007 assuming $B^+B^-/B^0\overline{B}^0$ ratio is 55/45. We rescale to 50/50. Analysis explicitly removes $B^+ \rightarrow \psi(2S) K^+$

 5 ALBRECHT $^{'}$ 90J reports $<~1.6~ imes~10^{-3}$ from a measurement of $[\Gamma(B^{+}~ o$ $J/\psi(1S)~K^+~\pi^+~\pi^-)/\Gamma_{ ext{total}}]~\times~[\mathrm{B}(J/\psi(1S)~\to~e^+~e^-)]$ assuming $\mathrm{B}(J/\psi(1S)~\to~e^+~e^-)$ $e^+e^-)=0.069$, which we rescale to our best value B $(J/\psi(1S)\to e^+e^-)=$ 5.94×10^{-2} . Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.



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\Gamma(h_c(1P)K^+ \times B(h_c(1P) \rightarrow J/\psi \pi^+ \pi^-))/\Gamma_{\text{total}}
                                                                                                       \Gamma_{187}/\Gamma
                                             DOCUMENT ID TECN COMMENT
                              CL%
 < 3.4 \times 10^{-6}
                                           <sup>1</sup> AUBERT
                               90
                                                                  05R BABR e^+e^- \rightarrow \Upsilon(4S)
   <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
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 $\Gamma(X(3872)K^+)/\Gamma_{\text{total}}$ Γ_{188}/Γ DO CUMENT ID TECN COMMENT <3.2 × 10⁻⁴ ¹ AUBERT 90 06E BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^{
m 1}$ Perform measurements of absolute branching fractions using a missing mass technique.

$\Gamma(B^+ \to X(3872)\,K^+)/\Gamma_{ m total} \, imes \, \Gammaig(X(3872) \to \gamma\gammaig)/\Gamma_{ m total}$ $\Gamma_{188}/\Gamma \times \Gamma_7^{X(3872)}/\Gamma_7^{X(3872)}$

TECN COMMENT VALUE (units 10-6) DO CUMENT ID CL% $^{
m 1}$ WICHT < 0.24 90 08 BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^0 at the $\varUpsilon(4S)$.

$\Gamma(X(3872)K^+ \times B(X \rightarrow J/\psi \pi^+ \pi^-))/\Gamma_{\text{total}}$ Γ_{189}/Γ <u>VALUE (units 10^{−6})</u> **8.6 ±0.8 OUR AVERAGE** DOCUMENT ID TECN COMMENT

| $8.63 \pm 0.82 \pm 0.52$ | ¹ сноі | 11 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
|-------------------------------------------|---------------------|----------|-------------|-----------------------------------|
| 8.4 ±1.5 ±0.7 | ¹ AUBERT | 08Y | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ullet $ullet$ We do not use the following | data for averages | s, fits, | , limits, e | etc. • • • |
| 10.1 ±2.5 ±1.0 | ¹ AUBERT | 06 | BABR | Repl. by AUBERT 08Y |

 12.8 ± 4.1 1 AUBERT 05R BABR Repl. by AUBERT 06 ² CHOI $12.8 \pm 2.8 \pm 0.7$ 03 BELL Repl. by CHOI 11

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

² CHOl 03 reports $\left[\Gamma\left(B^{+}\to X(3872)\,K^{+}\times B(X\to J/\psi\pi^{+}\pi^{-})\right)/\Gamma_{\mathsf{total}}\right]/\left[B(B^{+}\to J/\psi\pi^{+}\pi^{-})\right]$ $\psi(2S)~K^+)]=0.0200\pm0.0038\pm0.0023$ which we multiply by our best value B(B^+ ightarrow $\psi(2S)(K^+)=(6.39\pm0.33)\times10^{-4}$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(X(3872)K^+ \times B(X \to J/\psi\gamma))/\Gamma_{\text{total}}$ Γ_{190}/Γ

TECN COMMENT $1.78^{\,+\,0.48}_{\,-\,0.44}\pm0.12$ 1 BHARDWAJ 11 BELL $e^{+}e^{-}
ightarrow \gamma (4S)$ ² AUBERT 09B BABR $e^+e^- \rightarrow \Upsilon(4S)$ $2.8 \pm 0.8 \pm 0.1$

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 $3.3 \ \pm 1.0 \ \pm 0.3$ 1 AUBERT,BE 06 M BABR Repl. by AUBERT 09 B

 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

 $^{2}\,\text{Uses B}(\,\varUpsilon(^{4}S)\,\rightarrow\,B^{+}\,B^{-}) = (51.6\pm0.6)\%\,\,\text{and B}(\,\varUpsilon(^{4}S)\,\rightarrow\,B^{\,0}\,\overline{B}{}^{\,0}) = (48.4\pm0.6)\%.$

$\Gamma(X(3872)K^*(892)^+ \times B(X \rightarrow J/\psi\gamma))/\Gamma_{\text{total}}$

DOCUMENT ID TECN COMMENT ¹ AUBERT 90 09B BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^{1}\, \mathsf{Uses}\; \mathsf{B}(\, \varUpsilon(4S) \to \, B^{\,+}\, B^{\,-}) = (51.6 \pm 0.6)\% \; \mathsf{and} \; \mathsf{B}(\, \varUpsilon(4S) \to \, B^{\,0}\, \overline{B}{}^{\,0}) = (48.4 \pm 0.6)\%.$

$\Gamma(X(3872)K^+ \times B(X \to \psi(2S)\gamma))/\Gamma_{\text{total}}$

 WLUE (units 10⁻⁶)
 DOCUMENT ID
 TECN

 4
 ±4
 OUR AVERAGE
 Error includes scale factor of 2.5.
 TECN COMMENT $0.83^{\,+\,1.98}_{\,-\,1.83}\,{\pm}\,0.44$ 1,2 BHARDWAJ 11 BELL $e^+e^-
ightarrow \ \varUpsilon(4S)$ 3 AUBERT 09B BABR $e^+e^- \rightarrow \Upsilon(4S)$ $9.5 \pm 2.7 \pm 0.6$

 1 BHARDWAJ 11 measurement is equivalent to a limit of $< 3.45 \times 10^{-6}$ at 90% CL.

 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

³ Uses B($\Upsilon(4S) \to B^+B^-$) = (51.6 ± 0.6)% and B($\Upsilon(4S) \to B^0\overline{B}^0$) = (48.4 ± 0.6)%.

$\Gamma(X(3872)K^*(892)^+ \times B(X \rightarrow \psi(2S)\gamma))/\Gamma_{\text{total}}$ Γ_{193}/Γ TECN COMMENT CL% DO CUMENT ID $1 \overline{\text{AUBERT}}$ 09B BABR $e^+e^- \rightarrow \Upsilon(4S)$ 90

 $^{1}\,\text{Uses B}(\,\varUpsilon(4S)\to\,B^{+}\,B^{-})=(51.6\pm0.6)\%\text{ and B}(\,\varUpsilon(4S)\to\,B^{\,0}\,\overline{B}{}^{\,0})=(48.4\pm0.6)\%.$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(X(3872)K^+ \times B(X \rightarrow D^+D^-))/\Gamma_{\text{total}}$ Γ_{195}/Γ TECN COMMENT CL% 1 CHISTOV 04 BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(X(3872)K^+ \times B(X \rightarrow D^0 \overline{D}{}^0 \pi^0))/\Gamma_{\text{total}}$ Γ_{196}/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID $^{1}\, { m GOKHROO}$ 06 BELL $e^{+}\,e^{-} ightarrow \, \varUpsilon(4\, S)$ $1.02 \pm 0.31 + 0.21 \\ -0.29$

 ● We do not use the following data for averages, fits, limits, etc. ² CHISTOV 04 BELL Repl. by GOKHROO 06 90

- 1 Measure the near-threshold enhancements in the $({\it D}^{\,0}\,\overline{\it D}^{\,0}\,\pi^0)$ system at a mass 3875.2 \pm $0.7^{+0.3}_{-1.6} \pm 0.8 \text{ MeV/c}^2$
- 2 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

| | $\overline{D}^{*0}D^{0}))/\Gamma_{\text{total}}$ | | Γ ₁₉₇ /Γ | $\Gamma(J/\psi(1S) K^*(892))$ | $(J/\psi)^{+}$ | . , , | | | | Γ_{205}/Γ_{18} |
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| VALUE (units 10 ⁻⁴) 0.85 ± 0.26 OUR AVERAGE | DOCUMENT ID | of 1 A | | 1.39±0.09 OUR AVE | RAGE | DO CUMENT ID | | TECN | COMMENT | |
| 0.77±0.16±0.10 | | BELL $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | $1.37 \pm 0.05 \pm 0.08$ | | AUBERT | 05 J | BABR | $e^+e^- \to$ | Y(45) |
| $.67 \pm 0.36 \pm 0.47$ | | B BABR $e^+e^- \rightarrow$ | | $1.45 \pm 0.20 \pm 0.17$ | | ¹ JESSOP | | | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| ¹ Assumes equal production | n of B^+ and B^0 at the $\Upsilon(A)$ | 45). | , | $1.92 \pm 0.60 \pm 0.17$ | | ABE | - | | p p | |
| · · · | , | * | F /F | • • • We do not use | _ | _ | | | | |
| $(X(3872)K^+\times B(X(3$ | • | | Γ ₁₉₈ /Γ | $1.37 \pm 0.10 \pm 0.08$ | | ² AUBERT | | | Repl. by A | |
| ALUE CL% | | TECN COMMENT | | ¹ JESSOP 97 assum is actually measur | nes equal prod | uction of B^+ a | ind B ^U | at the 7 | ^(4 <i>S</i>). The | measureme |
| <7.7 × 10 ⁻⁶ 90 | | Y BABR $e^+e^- \rightarrow$ | T(45) | ² Assumes equal pro | ed as an avera eduction of B | + and B ⁰ at th | ie $\Upsilon(4S)$ | and neut 1). | i ai states. | |
| ¹ Assumes equal production | , | <i>'</i> | | | | | | <i>'</i> | | _ |
| $(X(3872) + K^0 \times B(X(3$ | $(872)^+ \to J/\psi(1S)\pi^+ \pi^+$ | $\pi^0))/\Gamma_{ m total}$ | Γ ₁₉₉ /Γ | $\Gamma(J/\psi(1S) K(1270)$ |))+)/Γ _{total} | | | | | Γ206 |
| ALUE (units 10^{-6}) CL% | | TECN COMMENT | | VALUE (units 10 ⁻³) | | DOCUMENT ID | | | COMMENT | |
| 6.1 90 | | BELL $e^+e^- \rightarrow$ | | $1.80 \pm 0.34 \pm 0.39$ | | ¹ ABE | 01L | BELL | $e^+e^- \rightarrow$ | Y(45) |
| • We do not use the foll | | | . () | $^{ m 1}$ Uses the PDG val | ue of B(B^+ – | $\rightarrow J/\psi(1S) K^{+}$ | ·) = (1. | 00 ± 0.3 | $10) \times 10^{-3}$ | |
| <22 90 | 3 AUBERT 056 | B BABR $e^+e^- \rightarrow$ | Y(45) | $\Gamma(J/\psi(1S)K(1400))$ | 1)+1/[(/// | (15) K(1270 | ۱+۱ | | | Γ ₂₀₇ /Γ ₂ |
| ¹ Assumes $\pi^+\pi^0$ originates | s from ρ^+ | | ī | VALUE | ,)) (3 / φ <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | 1207/12 |
| ² Assumes equal production | of B^{+} and B^{0} at the $\Upsilon (A)$ | 45). | Ī | <0.30 | 90 | ABE | | | $e^+e^- \rightarrow$ | Y(45) |
| ³ Assumes equal production | n of B^+ and B^0 at the $\varUpsilon(\cdot)$ | 45). The isovector-X | (hypothesis is | | | ADL | OIL | DELL | C · C → | 7 (45) |
| excluded with a likelihood | I test at $1	imes 10^{-4}$ level. | | | $\Gamma(J/\psi(1S)\eta K^+)/$ | Γ _{total} | | | | | Γ208 |
| $(X(4430)^+ K^0 \times B(X^+))$ | $\rightarrow 1/2/\pi^{+}))/\Gamma_{}$ | | Γ ₂₀₀ /Γ | VALUE (units 10^{-5}) | | DOCUMENT ID | | TECN | COMMENT | |
| • • • | , | TECN COMMENT | | 10.8±2.3±2.4 | | 1 AUBERT | | | $e^+e^- \rightarrow$ | Y(45) |
| LUE (units 10 ⁻⁵) CL% | | TECN COMMENT | | ¹ Assumes equal pro | | | | | , | . () |
| 1.5 95 | | AA BABR $e^+e^- \rightarrow$ | r(45) | | | unu Dalli | / (43 | 1. | | |
| ¹ Assumes equal production | , | 45). | | $\Gamma(J/\psi(1S)\eta'K^+)$ | $/\Gamma_{\text{total}}$ | | | | | Γ209 |
| $(X(4430)^+ K^0 \times B(X^+))$ | $\rightarrow \psi(2S)\pi^{+}))/\Gamma_{total}$ | | Γ ₂₀₁ /Γ | VALUE (units 10^{-5}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| ALUE (units 10^{-5}) CL% | | TECN COMMENT | • | <8.8 | 90 | 1 XIE | 07 | BELL | $e^+e^- \rightarrow$ | Υ(45) |
| (4.7 95 | | AA BABR $e^+e^- \rightarrow$ | | ¹ Assumes equal pro | duction of B | + and B ⁰ at th | ie 17(4.5 | .). | | |
| 1 Assumes equal production | | | . (45) | | | | , - | , | | - |
| | , | , | | $\Gamma(J/\psi(1S)\phi K^+)/$ | ['] total | | | | | Γ ₂₁₀ |
| $(X(4260)^0 K^+ \times B(X^0 + X^0))$ | $ ightarrow$ $J/\psi\pi^+\pi^-))/\Gamma_{ m total}$ | Í | Γ ₂₀₂ /Γ | VALUE | -5 | DOCUMENT ID | | | COMMENT | |
| LUE (units 10^{-6}) CL% | 6 DOCUMENT ID | TECN COMMENT | | , , | _ | RAGE Errorin | | | | |
| 29 95 | 1 AUBERT 06 | BABR $e^+e^- \rightarrow$ | Υ(4S) | $(4.4 \pm 1.4 \pm 0.5) \times 10^{-1}$ | | ¹ AUBERT | | | $e^+e^- \rightarrow$ | |
| | n of B^+ and B^0 at the $\Upsilon(A)$ | | ` ' | $(8.8 + 3.5 \pm 1.3) \times 10^{-3}$ | -5 | ² ANASTASSO | V 00 | CLE2 | e^+e^- | $\Upsilon(4S)$ |
| | , | ,. | | ¹ Assumes equal pro | duction of B | + and RO at th | ο Υ(1S | :) | | |
| $(X(3915)^0 K^+ \times B(X^0 + X^0))$ | $ ightarrow J/\psi\gamma))/\Gamma_{ m total}$ | | Γ ₂₀₃ /Γ | ² ANASTASSOV 00 | | | | | Assumes | equal prod |
| ALUE (units 10^{-6}) CL% | 6 DOCUMENT ID | TEGN | | | | to on a backgro | | | | |
| | | TECN COMMENT | | | | S), a uniform D | alitz plo | t distrib | ution, isotr | onic $J/\psi(1$ |
| | | | | tion of B^{0} and B^{0} | $^+$ at the $	au(4.5)$ | | | | | opic $J/\psi(1$ |
| <14 90 | 1 AUBERT,BE 06M | M BABR $e^+e^- \rightarrow$ | | tion of B^0 and B^2 and ϕ decays, and | $^+$ at the Υ (45) B($B^+ 	o J_J$ | | | | | _ |
| <14 90 Assumes equal production | 1 AUBERT,BE 0 Of $^{B+}$ and 0 at the $^{\gamma}(^{-1})$ | M BABR $e^+e^- \rightarrow$ | Υ(4S) | tion of B^{0} and B^{0} | $^+$ at the Υ (45) B($B^+ 	o J_J$ | | | | | _ |
| <14 90 Assumes equal production | 1 AUBERT,BE 0 Of $^{B+}$ and 0 at the $^{\gamma}(^{-1})$ | M BABR $e^+e^- \rightarrow$ | | tion of B^0 and B^2 and ϕ decays, and | $^+$ at the Υ (45) B($B^+ 	o J_J$ | | : В(<i>В</i> ⁰ | $\rightarrow J/\psi$ | | _ |
| (14 90 1 Assumes equal production $(Z(3930)^{0} K^{+} \times B(Z^{0} -$ | 1 AUBERT,BE 06h of B^+ and B^0 at the Υ (· → $J/\psi \gamma$))/ Γ_{total} 6 DOCUMENT ID | BABR $e^+e^- \rightarrow$ 45). | Γ ₂₀₄ /Γ | tion of B^0 and B^0 and ϕ decays, and $\Gamma(J/\psi(1S)\omegaK^+)/U$ | $^+$ at the $\Upsilon(45)$ B($B^+ 	o J_f$ | $\psi(1S) \phi K^+) = 0$ | B(B ⁰ | $\rightarrow J/\psi$ $\frac{TECN}{}$ | (1S) φ K ⁰). <u>COMMENT</u> | Г211 |
| <14 90 ¹ Assumes equal production $(Z(3930)^0 K^+ \times B(Z^0 - L)^0 K^- \times B(Z^0 - L)^0 K^0 K^- \times B(Z^0 - L)^0 K^0 K^- \times B(Z^0 - L)^0 K^- \times B(Z^0 - L)^0 K^0 K^0 K^0$ | 1 AUBERT,BE 06n of B^+ and B^0 at the Υ (\rightarrow $J/\psi \gamma$))/ Γ_{total} 6 DOCUMENT ID | BABR $e^+e^- \rightarrow$ 45). | Γ ₂₀₄ /Γ | tion of B^0 and B^- and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_J$ $\frac{VALUE \text{ (units }10^{-4}\text{)}}{3.2\pm0.1_{-0.3}^{+0.6}}$ | $^+$ at the $\Upsilon(4.5)$ B($B^+ 	o J_f$)/ $\Gamma_{	ext{total}}$ | $\psi(1S) \phi K^+) =$ $\psi(1S) \phi K^+$ | B(B ⁰ | $\rightarrow J/\psi$ $\frac{TECN}{BABR}$ | $\frac{COMMENT}{e^+e^-} \rightarrow$ | Γ ₂₁₁ , |
| <14 90 ¹ Assumes equal production ($Z(3930)^0 K^+ \times B(Z^0 - CL^0)$ (2.5 90 | 1 AUBERT,BE 061 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 AUBERT,BE 061 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ | Γ ₂₀₄ /Γ | tion of B^0 and B^- and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_J \frac{VALUE\ (units\ 10^{-4})}{3.2\pm0.1\pm0.5}$ • • • We do not use | $^+$ at the $\Upsilon(4.5^+)$ B($B^+ 	o J_f$) // // // the following | $\psi(1S) \phi K^+) = \frac{DOCUMENT \ ID}{1}$ DEL-AMO-S ϕ data for averag | A10B es, fits, | $\rightarrow J/\psi$ TECN BABR limits, ϵ | $(1S) \phi K^0$. $COMMENT$ $e^+e^- \rightarrow etc. \bullet \bullet \bullet$ | Γ ₂₁₁ |
| <14 90 1 Assumes equal production $(Z(3930)^0 K^+ \times B(Z^0 - LL)^0 CL)^0$ <2.5 90 1 Assumes equal production | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ | Γ ₂₀₄ /Γ - τ(45) | tion of B^0 and B^- and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_J$ $\frac{VALUE \text{ (units }10^{-4}\text{)}}{3.2\pm0.1_{-0.3}^{+0.6}}$ | $^+$ at the $\Upsilon(4.5^+)$ B($B^+ 	o J_f$) // // // the following | $\psi(1S) \phi K^+) =$ $\psi(1S) \phi K^+$ | A10B es, fits, | $\rightarrow J/\psi$ TECN BABR limits, ϵ | $\frac{COMMENT}{e^+e^-} \rightarrow$ | Γ ₂₁₁ , (45) |
| $<$ 14 90 1 Assumes equal production $(Z(3930)^{0} K^{+} \times B(Z^{0} - L)) \times L | $\begin{array}{c} 1 \\ \hline \text{AUBERT,BE} & 060 \\ \text{n of } B^+ \text{ and } B^0 \text{ at the } \Upsilon(A) \\ \hline \rightarrow J/\psi\gamma))/\Gamma_{\text{total}} \\ \hline \frac{DOCUMENT ID}{1} \\ \hline \text{AUBERT,BE} & 060 \\ \text{n of } B^+ \text{ and } B^0 \text{ at the } \Upsilon(A) \\ \hline \\ \vdots \\ \hline \end{array}$ | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). | Γ ₂₀₄ /Γ Γ ₂₀₅ /Γ | tion of B^0 and B^- and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_J \frac{VALUE\ (units\ 10^{-4})}{3.2\pm0.1\pm0.5}$ ••• We do not use | $^+$ at the $\Upsilon(4.5^+)$ B($B^+ 	o J_J$)/ $\Gamma_{	ext{total}}$ | $\psi(1S) \phi K^+) =$ $\frac{DOCUMENT\ ID}{1} \text{ DEL-AMO-S} MO = 1$ data for average 1 AUBERT | - B(<i>B</i> ⁰ | $\rightarrow J/\psi$ TECN BABR limits, ϵ BABR | $(1S) \phi K^0$). COMMENT $e^+e^- \rightarrow$ etc. • • • | Γ ₂₁₁ , (45) |
| 1 Assumes equal production $(Z(3930)^0 K^+ \times B(Z^0 - 2L)) \times (Z \times B) \times (Z \times $ | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). | Γ ₂₀₄ /Γ Γ ₂₀₅ /Γ | tion of B^0 and B^1 and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J}$ $\frac{VALUE\ (units\ 10^{-4})}{3.2\pm0.1^{+0.5}}$ • • We do not use $3.5\pm0.2\pm0.4$ 1 Assumes equal pro- | $^+$ at the $\Upsilon(4S^+)$ at the $\Upsilon(4S^+)$ $\to J_J$ $^+$ $\Gamma_{	ext{total}}$ the following oduction of B^- | $\psi(1S) \phi K^+) =$ $\frac{DOCUMENT \ ID}{1} DEL-AMO-SON data for average 1 AUBERT + and B^0 at the$ | - B(<i>B</i> ⁰ | $\rightarrow J/\psi$ TECN BABR limits, ϵ BABR | $(1S) \phi K^0$). COMMENT $e^+e^- \rightarrow$ etc. • • • | Γ ₂₁₁ , Γ(45) EL-AMO- EZ 10B |
| 1 Assumes equal production $(Z(3930)^0 K^+ \times B(Z^0 - ALUE (units 10^{-6})) Ct\%$ 22.5 90 1 Assumes equal production $(J/\psi(15) K^*(892)^+)/\Gamma$ For polarization informs section. | 1 AUBERT,BE 060 of B^+ and B^0 at the $\Upsilon(A^0)$ of B^+ and B^0 at the $T(A^0)$ of B^0 of B^0 at the $T(A^0)$ of B^0 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). e end of the "B ⁰ Brain | Γ ₂₀₄ /Γ Γ ₂₀₅ /Γ nching Ratios" | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J/\psi(1S)}$ 3.2±0.1±0.5 • • • We do not use 3.5±0.2±0.4 1 Assumes equal pro $\Gamma(X(3872)K^+\times E)$ | $^+$ at the $\Upsilon(4S^+)$ at the $\Upsilon(4S^+)$ $\to J_J$ $^+$ $\Gamma_{	ext{total}}$ the following oduction of B^- | $\frac{DOCUMENT\ ID}{1}$ DEL-AMO-S/data for average 1 AUBERT + and B^0 at the ω) // Γ total | A10B es, fits, 08W se $\Upsilon(45)$ | $\rightarrow J/\psi$ TECN BABR limits, ϵ BABR | $(1S) \phi K^0$). COMMENT $e^+e^- \rightarrow$ etc. • • • | Γ ₂₁₁ , Γ(45) EL-AMO- EZ 10B |
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| 14 90 1 Assumes equal production ($Z(3930)^0 K^+ \times B(Z^0 - ALUE (units 10^{-6}) Ct^{1/2}$ 22.5 90 1 Assumes equal production ($J/\psi(15) K^*(892)^+)/\Gamma$ For polarization informs section. ALUE (units 10^{-3}) ALUE (units 10^{-3}) ALUE (units 10^{-3}) A3 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI | 1 AUBERT, BE 060 of B^+ and B^0 at the Υ (\rightarrow $J/\psi \gamma$))/ Γ total DOCUMENT ID 1 AUBERT, BE 060 of B^+ and B^0 at the Υ (\rightarrow total ation see the Listings at the | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). e end of the "B ⁰ Brain | Γ ₂₀₄ /Γ Γ ₂₀₅ /Γ nching Ratios" | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J/\psi(1S)}$ 3.2±0.1±0.5 • • • We do not use 3.5±0.2±0.4 1 Assumes equal pro $\Gamma(X(3872)K^+\times E)$ | + at the $\Upsilon(45^{\circ} \text{B}(B^+ \to J))$ // Total the following oduction of B^- | $\frac{DOCUMENT\ ID}{1}$ DEL-AMO-S/data for average 1 AUBERT + and B^0 at the ω) // Γ total | A10B es, fits, 08W se \(\gamma(45) | J/ψ TECN BABR limits, ϵ BABR (). | $\begin{array}{c} (1S) \phi K^0). \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \\ \underline{COMMENT} \end{array}$ | Γ ₂₁₁ , (45) EL-AMO- EZ 10B Γ ₂₁₂ , |
| 14 90 1 Assumes equal production ($Z(3930)^0 K^+ \times B(Z^0 - ALUE (units 10^{-6}) CL% 22.5 90 1 Assumes equal production (J/\psi(15) K^*(892)^+)/\Gamma For polarization informs section. ALUE (units 10^{-3}) ALUE (units 10^{-3}) A3 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI$ | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ of $T(A$ | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). He end of the "B ⁰ Brain TECN COMMENT | Γ ₂₀₄ /Γ Γ ₂₀₅ /Γ nching Ratios" | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{I}$ $\frac{VALUE\ (units\ 10^{-4})}{3.2\pm0.1\pm0.5}$ ••• We do not use $3.5\pm0.2\pm0.4$ $\frac{1}{4}$ Assumes equal profix $(X(3872)K^+\times E)$ $\frac{VALUE\ (units\ 10^{-6})}{4}$ | + at the $\Upsilon(45^{\circ} \text{B}(B^+ \to J))$ $\Gamma(45^{\circ} \text{B}(B^+ \to J))$ $\Gamma(45^{\circ} \text{B}(B^+ \to J))$ the following oduction of B^+ $\Gamma(45^{\circ} \text{B}(X \to J))$ | $\frac{DOCUMENT ID}{1}$ 1 DEL-AMO-S/data for average 1 AUBERT + and B^0 at the whole $\frac{DOCUMENT ID}{1}$ 2 DEL-AMO-S/d | A10B es, fits, 08w ae Υ(45 | J/ψ TECN BABR BABR TECN BABR | $\begin{array}{c} (1S) \phi K^0). \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \\ \underline{COMMENT} \end{array}$ | Γ ₂₁₁ (45) EL-AMO- EZ 10B Γ ₂₁₂ |
| 14 90 1 Assumes equal production ($Z(3930)^0 K^+ \times B(Z^0 - 4LUE (units 10^{-6}) CL\%$ 22.5 90 1 Assumes equal production ($J/\psi(1.5) K^*(892)^+$)/ Γ For polarization informs section. ALUE (units 10^{-3}) EL 43 ± 0.08 OUR FIT 43 ± 0.08 OUR AVERAGION COURS AVERAGION | 1 AUBERT, BE 060 1 of B^+ and B^0 at the $T(A^0)$ 3 DOCUMENT ID 1 AUBERT, BE 060 1 of B^+ and B^0 at the $T(A^0)$ 1 total 2 ation see the Listings at the $T(A^0)$ 4 DOCUMENT ID 2 DOCUMENT ID 3 DOCUMENT ID 4 DOCUMENT ID 5 DOCUMENT ID 6 1,2 AUBERT 0 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). Hend of the "B ⁰ Brain TECN COMMENT TECN COMMENT | $\frac{\Gamma_{204}/\Gamma}{\Gamma_{204}/\Gamma}$ $\frac{\Gamma_{205}/\Gamma}{\Gamma_{nching Ratios"}}$ $\rightarrow \Upsilon(4S)$ | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J}$ 3.2±0.1±0.6 3.2±0.1±0.3 • • • We do not use 3.5±0.2±0.4 1 Assumes equal pro $\Gamma(X(3B72)K^+\times E)$ 3.4±0 E (units 10-6) 4 Assumes equal pro | $^+$ at the $\Upsilon(45^\circ)$ B($B^+ \to J_f$) Total the following duction of B^- adduction of B^- adduction of B^- | $\frac{DOCUMENT\ D}{1}$ DEL-AMO-SI data for average 1 AUBERT + and B^0 at the above 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT AMO B 0 at the above 1 AMO-SI + and B^0 | A10B es, fits, 08w ae Υ(45 | J/ψ TECN BABR BABR TECN BABR | $\begin{array}{c} (1S) \phi K^0). \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \\ \underline{COMMENT} \end{array}$ | Γ ₂₁₁ Γ(45) EL-AMO- EZ 10B Γ ₂₁₂ Γ(45) |
| (214) 90 1 Assumes equal production $(Z(3930)^{0} K^{+} \times B(Z^{0} - 4LUE (units 10^{-6}) CL\% 22.5 90 ^{1} Assumes equal production (J/\psi(1S) K^{*}(892)^{+})/\Gamma For polarization inform: section. ALUE (units 10^{-3}) L^{1} 43 \pm 0.08 OUR FIT 43 \pm 0.08 OUR AVERAGI 74 \pm 0.36 \pm 0.06 | 1 AUBERT, BE 060 of B^+ and B^0 at the $\Upsilon(A^0)$ $\frac{1}{2}$ AUBERT, BE 060 of B^+ and B^0 at the $\Upsilon(A^0)$ $\frac{1}{2}$ AUBERT, BE 060 of B^+ and B^0 at the $\Upsilon(A^0)$ $\frac{1}{2}$ $\frac{1}{2}$ AUBERT $\frac{1}{2}$ $\frac{1}{2}$ AUBERT 0 $\frac{1}{2}$ AUBERT 0 $\frac{1}{2}$ AUBERT 0 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). e end of the "B ⁰ Brai TECN COMMEN 77AV BABR e^+e^- 15J BABR e^+e^- | $ \begin{array}{c c} $ | tion of B^0 and B^1 and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)$, where ΔLUE (units 10^{-4}) 3.2 ± 0.1 + 0.6 3.5 ± 0.2 ± 0.4 Assumes equal profit $\Gamma(X(3872)K^+ \times E)$ 1 Assumes ΔLUE (units ΔLUE) 6 ± 2 ± 1 | $^+$ at the $\Upsilon(45^\circ)$ B($B^+ \to J_f$) Total the following duction of B^- adduction of B^- adduction of B^- | $\frac{DOCUMENT\ D}{1}$ DEL-AMO-SI data for average 1 AUBERT + and B^0 at the above 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT AMO B 0 at the above 1 AMO-SI + and B^0 | A10B es, fits, 08w ae Υ(45 | J/ψ TECN BABR BABR TECN BABR | $\begin{array}{c} (1S) \phi K^0). \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \\ \underline{COMMENT} \end{array}$ | Γ ₂₁₁ Γ(45) EL-AMO- EZ 10B Γ ₂₁₂ Γ(45) |
| (14 90 1 Assumes equal production ($Z(3930)^0$ $K^+ \times B(Z^0 - (2.5 90)^1$ Assumes equal production ($J/\psi(1S)$ $K^*(892)^+)/\Gamma$ For polarization informs section. ($J/\psi(1S)$ $K^*(892)^+)/\Gamma$ 43 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI 74 +0.36 ±0.06 +0.31 ±0.06 454 ±0.047 ±0.097 ±0.14 | 1 AUBERT, BE 060 of B^+ and B^0 at the $\Upsilon(A^0)$ \to $J/\psi \gamma) / \Gamma$ total $\Delta = 0$ Δ | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). e end of the " B^0 Brain TECN COMMENT TOTAL STATE OF THE ST | $ \begin{array}{c c} $ | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J}$ 3.2±0.1±0.6 3.2±0.1±0.3 • • • We do not use 3.5±0.2±0.4 1 Assumes equal pro $\Gamma(X(3B72)K^+\times E)$ 3.4±0 E (units 10-6) 4 Assumes equal pro | $^+$ at the $\Upsilon(45^\circ)$ B($B^+ \to J_f$) Total the following duction of B^- adduction of B^- adduction of B^- | $\frac{DOCUMENT\ ID}{1}$ DEL-AMO-S/data for average 1 AUBERT + and B^0 at the $\frac{DOCUMENT\ ID}{1}$ DEL-AMO-S/+ and B^0 at the $\frac{DOCUMENT\ ID}{1}$ DEL-AMO-S/+ and B^0 at the ω))/ Γ total | A10B es, fits, 08w ae Υ(45 | | $\begin{array}{c} (1S) \phi K^0). \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \\ \underline{COMMENT} \end{array}$ | Γ ₂₁₁ Γ(45) EL-AMO- EZ 10B Γ ₂₁₂ Γ(45) |
| 114 90 1 Assumes equal production ($Z(3930)^0$ K+ × B(Z^0 - 1 Assumes equal production ($Z(55)^0$ 90 1 Assumes equal production ($J/\psi(15)$ K*(892)+)/ Γ For polarization informs section. 14.0.06 OUR FIT 43 ±0.08 OUR FIT 43 ±0.09 45 ±0.06 44 ±0.047±0.097 28 ±0.07 ±0.14 41 ±0.23 ±0.24 | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ E 1,2 AUBERT 0 2 AUBERT 0 3 JESSOP 9 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT TECN COM | $ \begin{array}{c c} & \Upsilon(4S) \\ \hline & \Gamma_{204}/\Gamma \\ \hline & \Upsilon(4S) \\ \hline & \Gamma_{205}/\Gamma \\ \text{nching Ratios"} \\ \hline & \\ & & \\ \hline & $ | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J}$ 3.2±0.1±0.5 • • • We do not use 3.5±0.2±0.4 1 Assumes equal profit of the state | the following the following $A = \frac{1}{2} \left(\frac{1}{2} + \frac{1}{2} \frac{1}{2} \right)$ the following duction of B^{-1} and duction of B^{-1} and duction of B^{-1} and $B = \frac{1}{2} \left(\frac{1}{2} | $\frac{DOCUMENT ID}{1}$ DEL-AMO-SI data for average $\frac{1}{1}$ AUBERT $\frac{DOCUMENT ID}{1}$ | B(B^0 A10B es, fits, 08W Te $\Upsilon(4S)$ A10B ee $\Upsilon(4S)$ | TECN BABR limits, e BABR). TECN BABR). | $(1S) \phi K^{0}).$ $\frac{comment}{e^{+}e^{-}} \rightarrow \text{etc.} \bullet \bullet \bullet$ Repl. by D SANCH $\frac{comment}{e^{+}e^{-}} \rightarrow \bullet$ | Γ ₂₁₁ Γ(45) EL-AMO- EZ 10B Γ ₂₁₂ Γ(45) |
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| 214 90 1 Assumes equal production ($Z(3930)^0$ K+ × B(Z^0 - ALUE (units 10^{-6}) CL% 22.5 90 1 Assumes equal production ($J/\psi(1S)$ K*(892)+)/ Γ For polarization informs section. ALUE (units 10^{-3}) EV 43 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI 74 +0.36 ±0.06 454±0.047±0.097 28 ±0.07 ±0.14 41 ±0.23 ±0.24 58 ±0.47 ±0.27 51 ±1.08 ±0.02 86 ±1.30 ±0.02 | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A^0)$ $DOCUMENT ID$ 1 DOCUMENT ID 1 DOCUMENT ID 2 AUBERT 0 2 AUBERT 0 2 AUBERT 0 2 AUBERT 0 3 AUBE 0 3 AUBE 0 4 BORTOLETTO9 0 5 ALBRECHT 9 | M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT M BABR $e^+e^- \rightarrow$ 45). TECN COMMENT TECN COM | $T(4S)$ Γ_{204}/Γ $T(4S)$ Γ_{205}/Γ Γ_{305}/Γ Γ_{305}/Γ Γ_{305}/Γ Γ_{4S}/Γ | tion of B^0 and B and ϕ decays, and $\Gamma(J/\psi(1S)\omega K^+)_{J}$ $WALUE (units 10^{-4})$ $WALUE (units 10^{-4})$ $WALUE (units 10^{-4})$ $WALUE (units 10^{-4})$ $WALUE (units 10^{-6})$ $WALUE (units 10^{-6})$ $WALUE (units 10^{-6})$ $WALUE (units 10^{-5})$ | + at the $\Upsilon(45^{\circ} \text{B}(B^+ \to J))$ | $\frac{DOCUMENT ID}{1}$ 1 DEL-AMO-S/d data for average $\frac{1}{1}$ AUBERT $\frac{1}{1}$ AUBERT $\frac{1}{1}$ DEL-AMO-S/d \frac | E B(B^0 A10B es, fits, 08W de $T(4S)$ A10B er $T(4S)$ A10B er $T(4S)$ ER $T(4S)$ ER $T(4S)$ | | $\begin{array}{c} (1S) \phi K^0). \\ \hline comment \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH} \\ \hline \\ \hline comment \\ e^+e^- \rightarrow \\ \hline \\ T(4S) \\ \text{etc.} \bullet \bullet \bullet \\ \hline \end{array}$ | Γ211 Γ(4S) EL-AMO- EZ 10B Γ212 Γ(4S) |
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| 114 90 1 Assumes equal production (Z(3930) 0 0 $^{+}$ × 0 0 1 Assumes equal production (Z(3930) 0 0 $^{+}$ × 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A)$ of B^+ and B^0 at the $T(A)$ of A^+ and B^0 at the A^+ of A^+ and A^0 of B^+ and A^0 at the A^+ of A^+ and A^0 at the A^+ of A^+ o | M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT M BABR $e^+e^- \rightarrow 4S$ M BABR Repl. by M CLE2 Sup. by M CLE3 Sup. by M CLE4 Sup. by M CLE5 Sup. by M CLE6 Sup. by M CLE6 Sup. by M CLE7 Sup. by M CLE9 S | From the following properties of the first firs | tion of B^0 and B^1 and ϕ decays, and $F(J/\psi(1S)\omega K^+)/V_{MLUE}$ (units 10^{-4}) 3.2±0.1±0.6 3.5±0.2±0.4 1 Assumes equal profile I_{ASS} (units I_{ASS}) 2 0.0±0.7±0.5 3.0±0.7±0.5 1 Assumes equal profile I_{ASS} (units I_{ASS}) 2 0.049 ±0.004 OUR 0.052 ±0.004 OUR 0.0537 ±0.0045 ±0.00 0.0507 ±0.0197 ±0.00 0.0507 ±0.0197 ±0.00 0.0507 ±0.024 | + at the $\Upsilon(45)$ B($B^+ \rightarrow J$) Total | DOCUMENT ID DOCUMENT ID DEL-AMO-S data for average AUBERT and B ⁰ at the and B ⁰ at the bocument id DEL-AMO-S and B ⁰ at the bocument id TECI -SA10B BAE data for average 08w BAE and B ⁰ at the DOCUMENT ID Error includes 1 ABE ABULENCIA AUBERT ABE BISHAI | A10B A | | $(1S) \phi K^{0}).$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by D} \\ \text{SANCH}$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \text{EL-AMO-SA}$ $\frac{COMMENT}{1.2.} \\ e^{+}e^{-} \rightarrow \\ \frac{COMMENT}{p\overline{p}} \text{ at 1.9} \\ e^{+}e^{-} \rightarrow \\ \frac{p\overline{p}}{p} \text{ 1.8 Te} \\ e^{+}e^{-} \rightarrow \\ \text{e}^{+}e^{-} \rightarrow \\ \text{e}^{+}e^{-} \rightarrow \\ \text{opp 1.8 Te} \\ \text{e}^{+}e^{-} \rightarrow \\ \text{opp 1.8 Te} \\ \text{e}^{+}e^{-} \rightarrow \\ \text{opp 1.8 Te} \\ \text{opp 2.8 Te} \\ \text{opp 3.8 Te} \\ \text{opp 4.8 Te} \\ \text{opp 3.8 Te} \\ \text{opp 4.8 Te} \\ \text{opp 3.8 Te} \\ \text{opp 3.8 Te} \\ \text{opp 4.8 Te} \\ \text{opp 3.8 Te} \\ \text{opp 4.8 Te} \\ \text{opp 6.8 Te} \\ opp 6.8 T$ | Γ211 Γ(45) EL-AMO-EZ 10B Γ212 Γ(45) Γ213 NNCHEZ 1 Γ214 Γ(45) Γ214/Γ1 6 TeV Γ(45) V |
| 14 90 1 Assumes equal production (Z(3930) ⁰ K+× B(Z ⁰ - 1 Assumes equal production (Z(3930) ⁰ K+× B(Z ⁰ - 1 Assumes equal production (J/ ψ (15) K*(892)+)/ Γ For polarization inform: section. ALUE (units 10 ⁻³) 43 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI 74 +0.36 ±0.06 454±0.047±0.097 28 ±0.07 ±0.14 41 ±0.23 ±0.24 58 ±0.07 ±0.14 41 ±0.23 ±0.27 51 ±1.08 ±0.02 8 • 1.09 ±0.11 78 ±0.51 ±0.23 1 AUBERT 0TAV reports [Γ = $(3.78 + 0.72 + 0.28) \times 10.64 + 0.23) \times 10.64 + 0.23$ 2 Assumes equal production 3 ABE 96H assumes that B 4 BORTOLETTO 92 report J/ ψ (15) K*(892)+)/ Γ 10 e^+e^-) = 0.069 ± 0.009 E^+ 0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 at the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^+ 0 of the systematic error from B0 at the E^- 0 of the systematic error from B0 at the E^- 0 of the systematic error from B0 at the E^- 0 of the systematic error from the systematic | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A)$ and B^0 of the $T(A)$ and B^0 at the $T(A)$ and $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ and $T(A)$ and $T(A)$ at the $T(A)$ and $T(A)$ an | M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT TECN COM | F204/ Γ F204/ Γ T205/ Γ Inching Ratios" VT | tion of B^0 and B and ϕ decays, and $F(J/\psi(1S)\omega K^+)$, where $F(J/\psi(1S)\omega K^+)$ is -10.5 and | + at the $\Upsilon(45)$ B($B^+ \rightarrow J$) Total | DOCUMENT ID DOCUMENT ID DEL-AMO-S data for average 1 AUBERT and B ⁰ at the DOCUMENT ID DEL-AMO-S and B ⁰ at the DOCUMENT ID TECI SA10B BAE data for average 08W BAE and B ⁰ at the DOCUMENT ID Error includes 1 ABE AUBERT ABE BISHAI data for average BISHAI data for average AUBERT ABE BISHAI data for average BISHAI data for average BISHAI data for average BISHAI data for average | A10B A | | $(1S) \phi K^{0}).$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \text{ttc.} \bullet \bullet \bullet \bullet$ Repl. by D SANCH $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \bullet$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Γ_{211} $T(45)$ EL-AMO-EZ 10B Γ_{212} $T(45)$ Γ_{213} ANCHEZ 1 Γ_{214} $T(45)$ Γ_{214}/Γ_{11} 6 TeV $T(45)$ V $T(45)$ |
| 14 90 1 Assumes equal production (Z(3930) ⁰ K+× B(Z ⁰ - 1 Assumes equal production (Z(3930) ⁰ K+× B(Z ⁰ - 22.5 90 1 Assumes equal production (J/ ψ (1.5) K*(892)+)/ Γ For polarization inform: section. ALUE (units 10^{-3}) 43 ±0.08 OUR FIT 43 ±0.08 OUR AVERAGI 74 +0.36 ±0.06 454±0.047±0.097 28 ±0.07 ±0.14 41 ±0.23 ±0.24 58 ±0.47 ±0.27 51 ±1.08 ±0.02 86 ±1.30 ±0.02 86 ±1.30 ±0.02 86 ±0.09 ±0.11 78 ±0.51 ±0.23 1 AUBERT 07AV reports [Γ = (3.78 ±0.64 ±0.23) × 1 (2.17 ±0.07) × 10 ⁻³ . Othe systematic error from 2 Assumes equal production 3 ABE 96H assumes that B 4 BORTOLETTO 92 report J/ ψ (1.5) K*(892)+)/ Γ to e^+e^-) = 0.069 ± 0.009, (5.94 ± 0.06) × 10 ⁻² . (is the systematic error from B^0 at the Υ (4.5). 5 ALBRECHT 90J reports J/ ψ (1.5) K*(892)+)/ Γ to e^+e^-) = 0.069 ± 0.009, (5.94 ± 0.06) × 10 ⁻² . (is the systematic error from B^0 at the Υ (4.5). 5 ALBRECHT 90J reports J/ ψ (1.5) K*(892)+)/ Γ to e^+e^-) = 0.069 ± 0.009, (5.94 ± 0.06) × 10 ⁻² . (1.5) | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A)$ of B^+ and B^0 at the $T(A)$ of A^+ and B^0 at the A^+ of A^+ and A^0 of B^+ and A^0 at the A^+ of A^+ and A^0 at the A^+ of A^+ o | M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT TECN COM | F204/ Γ T205/ | tion of B^0 and B^1 and ϕ decays, and $F(J/\psi(1S)\omega K^+)/V_{MLUE}$ (units 10^{-4}) 3.2±0.1±0.6 3.5±0.2±0.4 1 Assumes equal profile I_{ASS} (units I_{ASS}) 2 0.0±0.7±0.5 3.0±0.7±0.5 1 Assumes equal profile I_{ASS} (units I_{ASS}) 2 0.049 ±0.004 OUR 0.052 ±0.004 OUR 0.0537 ±0.0045 ±0.00 0.0507 ±0.0197 ±0.00 0.0507 ±0.0197 ±0.00 0.0507 ±0.024 | + at the $\Upsilon(45)$ B($B^+ \rightarrow J$) Total | DOCUMENT ID DOCUMENT ID DEL-AMO-S data for average AUBERT and B ⁰ at the and B ⁰ at the bocument id DEL-AMO-S and B ⁰ at the bocument id TECI -SA10B BAE data for average 08w BAE and B ⁰ at the DOCUMENT ID Error includes 1 ABE ABULENCIA AUBERT ABE BISHAI | A10B A10B A10B A10B A10B A10B A10B A10B A10B COA COA A10B COA COA A10B COA COA COA COA COA COA COA CO | $\rightarrow J/\psi$ BABR BABR BABR ()). TECN BABR BABR (). TECN BABR (). TECN COF BABR COF BABR COF BABR CDF CDF BABR CDF BABR CDF CDF BABR CDF CDF BABR CDF CDF CDF CDF CDF CDF CDF CD | $(1S) \phi K^{0}).$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \text{ttc.} \bullet \bullet \bullet \bullet$ $\text{Repl. by } D$ $SANCH$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \bullet$ $\text{ttc.} \bullet \bullet \bullet$ $EL-A MO-SA$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \bullet$ $\frac{COMMENT}{e^{+}$ | Γ211 (45) EL-AMO-EZ 10B Γ212 (45) Γ213 NCHEZ 1 Γ214 Γ(45) Γ214/Γ1 6 TeV |
| (14 90 1 Assumes equal production (Z(3930)) K+ × B(Z ⁰ - (Z(3930)) (Z(3930)) (Z(3930) Z(3930) (Z(3930)) (Z(3930) (Z(3930)) (Z(3930) (Z(3930)) (Z | 1 AUBERT, BE 060 of B^+ and B^0 at the $T(A)$ and B^0 of the $T(A)$ by $T(A)$ | M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT M BABR $e^+e^- \rightarrow 4S$). TECN COMMENT TECN COM | F204/ Γ T205/ | tion of B^0 and B^1 and ϕ decays, and Φ and ϕ decays, and Φ ($J/\psi(1S)\omega K^+)$, where $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K^+$ are $J/\psi(1S)\omega K^+$ and $J/\psi(1S)\omega K$ | + at the $\Upsilon(45)$ B($B^+ \rightarrow J$) // Total the following duction of B^- oduction of B^- | DOCUMENT ID DOCUMENT ID DOCUMENT ID DOCUMENT ID AUBERT AND BO AT the DOCUMENT ID DOCUMENT ID TECH SALL BO BABE AND BABE AND BO AT the DOCUMENT ID ETFOR INCLUDES ABUENCIA A | A10B A10B A10B A10B A10B A10B A10B A10B A10B COA COA A10B COA COA A10B COA COA COA COA COA COA COA CO | $\rightarrow J/\psi$ BABR BABR BABR ()). TECN BABR BABR (). TECN BABR (). TECN COF BABR COF BABR COF BABR CDF CDF BABR CDF BABR CDF CDF BABR CDF CDF BABR CDF CDF CDF CDF CDF CDF CDF CD | $(1S) \phi K^{0}).$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \text{ttc.} \bullet \bullet \bullet \bullet$ $\text{Repl. by } D$ $SANCH$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \bullet$ $\text{ttc.} \bullet \bullet \bullet$ $EL-A MO-SA$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow \bullet$ $\frac{COMMENT}{e^{+}$ | Γ ₂ (45) EL-AM EZ 10B Γ ₂ (45) Γ ₂ (45) Γ ₂ (45) Γ ₂ (45) Γ ₂ (46) Γ ₂ (46) Γ ₂ (47) (47) (48) |

 B^{\pm}

| $\Gamma(J/\psi(1S)\rho^+)/\Gamma_{to}$ | | | | | Γ ₂₁₅ /Γ | $\Gamma(\psi(2S)K^*(892)^+)/\Gamma_{\text{total}}$ Γ_{224}/Γ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻⁵) 5.0±0.7±0.3 | <u>CL%</u> | DOCUMENT ID AUBERT | | R $e^+e^- \rightarrow$ | Υ(4 S) | VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT 6.7 ±1.4 OUR AVERAGE Error includes scale factor of 1.3. |
| • • • We do not use t | | | | | 7 (43) | $5.92\pm0.85\pm0.89$ 1 AUBERT 05J BABR $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| <77 | 90 | BISHAI | 96 CLE: | $e^+e^- \rightarrow$ | Y(45) | 9.2 \pm 1.9 \pm 1.2 1 RICHICHI 01 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| ¹ Assumes equal pro- | duction of B | $^+$ and B^{0} at the | e Υ(4S). | | | • • • We do not use the following data for averages, fits, limits, etc. • • • <30 90 1 ALAM 94 CLE2 Repl. by RICHICHI 01 |
| $\Gamma(J/\psi(1S)\pi^+\pi^0$ no | onresonant | 1/[| | | Γ ₂₁₆ /Γ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| VALUE (units 10^{-5}) | CL% | DOCUMENT ID | TECN | COMMENT | . 210/ . | <49 90 1 ALBRECHT 90J ARG $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| <0.73 | | 1 AUBERT | | $R e^+e^- \rightarrow$ | Y(45) | 1 Assumes equal production of B^+ and B^{0} at the $ {\it \Upsilon}(45)$. |
| ¹ Assumes equal pro- | duction of B | $^+$ and ${\it B}^{0}$ at the | e γ(45). | | | $\Gamma(\psi(2S)K^*(892)^+)/\Gamma(\psi(2S)K^+)$ $\Gamma_{224}/\Gamma_{223}$ |
| $\Gamma(J/\psi(1S) a_1(1260)$ |)+)/[_{total} | | | | Γ ₂₁₇ /Γ | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| VALUE | | DO CUMENT ID | TECN | COMMENT | | 0.96±0.15±0.09 AUBERT 05J BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $<1.2 \times 10^{-3}$ | 90 | BISHAI | 96 CLE: | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | $\Gamma(\psi(2S)K^+\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{225}/Γ |
| $\Gamma(J/\psi(1S) \rho \overline{\Lambda})/\Gamma_{tc}$ | ntai | | | | Γ ₂₁₈ /Γ | VALUE (units 10 ⁻⁴)EVTSDOCUMENT_IDTECNCOMMENT_ |
| VALUE (units 10 ⁻⁶) 11.8±3.1 OUR AVE | | DOCUMENT ID | TECN | COMMENT | | 4.3 ± 0.5 OUR AVERAGE $4.31\pm 0.20\pm 0.50$ 1 GULER 11 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | | | | | 19 ± 11 ± 4 3 ALBRECHT 90J ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| $11.7 \pm 2.8 {}^{+\ 1.8}_{-\ 2.3}$ | | ¹ XIE | 05 BELI | . e ⁺ e [−] → | Y(45) | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\begin{array}{ccc} 12 & +9 \\ -6 & \end{array}$ | | ¹ AUBERT | 03K BAB | R $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | $\Gamma(\psi(3770) K^+)/\Gamma_{\text{total}}$ $\Gamma_{226}/\Gamma_{\text{total}}$ |
| • • • We do not use t | the following | data for average | | | | $(\psi(S(TO)) \land T) \land TOTAL$ VALUE (units 10^{-3}) DOCUMENT ID TECH COMMENT |
| <41 | 90 | ZANG | | $e^+e^- \rightarrow$ | T(45) | 0.49±0.13 OUR AVERAGE |
| ¹ Assumes equal pro- | duction of B | $^+$ and B^0 at the | e Υ(45). | | | $3.5 \pm 2.5 \pm 0.3$ AUBERT 06E BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(J/\psi(1S)\overline{\Sigma}^0 \rho)/\Gamma$ | total | | | | Γ ₂₁₉ /Γ | $0.48\pm0.11\pm0.07$ |
| VALUE | <u>CL%</u> | DO CUMENT ID | | COMMENT | | ¹ Perform measurements of absolute branching fractions using a missing mass technique. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| <1.1 × 10 ⁻⁵ Assumes equal pro- | | 1 XIE $^+$ and 0 at the | | . e ⁺ e [−] → | Υ(45) | $\Gamma(\psi(3770) K^+ \times B(\psi \to D^0 \overline{D}^0)) / \Gamma_{\text{total}}$ Γ_{227} / Γ |
| $\Gamma(J/\psi(1S)D^+)/\Gamma_{\rm t}$ | | | () | | Γ ₂₂₀ /Γ | VALUE (units 10 ⁻⁴) DO CUMENT ID TECN COMMENT |
| (3/ψ(13)D·)/ t VALUE (units 10 ⁻⁵) | otal CL% | DO CUMENT ID | TECA | COMMENT | 1 220/1 | 1.6 \pm0.4 OUR AVERAGE Error includes scale factor of 1.1. 1.41 \pm 0.30 \pm 0.22 AUBERT 08B BABR $e^+e^- \rightarrow \gamma(4S)$ |
| <12 | | 1 AUBERT | | R $e^+e^- \rightarrow$ | Υ(4.5) | 1.41 \pm 0.30 \pm 0.22 |
| ¹ Assumes equal pro- | | | | | 1 (43) | |
| $\Gamma(J/\psi(1S)\overline{D}{}^0\pi^+)$ | | | () | | F /F | 3.4 \pm 0.8 \pm 0.5 1 CHISTOV 04 BELL Repl. by BRODZICKA 08 |
| $VALUE$ (units 10^{-5}) | | DO CUMENT ID | TECA | COMMENT | Γ ₂₂₁ /Γ | 1 Assumes equal production of B^+ and B^{0} at the \varUpsilon (45). |
| <2.5 | <u>CL%</u> | ¹ ZHA NG | | $e^+e^- \rightarrow$ | Υ(4.5) | $\Gamma(\psi(3770) K^+ \times B(\psi \to D^+ D^-)) / \Gamma_{\text{total}}$ Γ_{228} / Γ |
| • • • We do not use t | the following | data for average | | | (/ | VALUE (units 10 ⁻⁴) <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| < 5.2 | | ¹ AUBERT | | $R e^+ e^- \rightarrow$ | Y(45) | 0.94 \pm 0.35 OUR AVERAGE $0.84\pm0.32\pm0.21$ 1 AUBERT 08B BABR $e^+e^- ightarrow 	au(4.5)$ |
| ¹ Assumes equal pro- | duction of B | $^+$ and B^0 at the | e Υ(45). | | | $1.4 \pm 0.8 \pm 0.2$ AUBERT 008 BABR $e^+e^- \rightarrow r(45)$ |
| $\Gamma(\psi(2S)\pi^+)/\Gamma_{\text{total}}$ | | | | | Γ ₂₂₂ /Γ | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| VALUE (units 10 ⁻⁵) | | DO CUMENT ID | TECN | | | $\Gamma(\chi_{c0} \pi^+ \times B(\chi_{c0} \to \pi^+ \pi^-))/\Gamma_{total}$ Γ_{229}/Γ |
| 2.44±0.22±0.20 | | ¹ BHARDWAJ | | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| ¹ Assumes equal pro | duction of B | $^+$ and B^0 at the | e Υ(45). | | | <0.1 90 1 AUBERT 09L BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(\psi(2S)\pi^+)/\Gamma(\psi($ | 2S) K+) | | | | $\Gamma_{222}/\Gamma_{223}$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| VALUE (units 10^{-2}) | | DO CUMENT ID | TECN | COMMENT | | <0.3 90 ¹ AUBERT,B 05G BABR Repl. by AUBERT 09L |
| $3.99 \pm 0.36 \pm 0.17$ | | BHARDWAJ | 08 BEL | _ e ⁺ e [−] → | Y(45) | 1 Assumes equal production of B^+ and B^{0} at the $\varUpsilon(4S)$. |
| $\Gamma(\psi(2S)K^+)/\Gamma_{\text{tota}}$ | Í | | | | Γ ₂₂₃ /Γ | $\Gamma(\chi_{c0}(1P)K^+)/\Gamma_{total}$ Γ_{230}/Γ |
| VALUE (units 10 ⁻⁴) | EVTS | DOCUMENT ID | TECN | COMMENT | | VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT |
| 6.39 ± 0.33 OUR FIT 6.5 ± 0.4 OUR AV | | | | | | $1.34^{+0.19}_{-0.16}$ OUR AVERAGE |
| 6.65 ± 0.17 ± 0.55 | | GULER | 11 BELI | . e+e− → | Y(45) | 1.8 \pm 0.8 \pm 0.1 |
| $4.9 \ \pm \ 1.6 \ \pm 0.4$ | - | AUBERT | 06E BAB | $R e^+e^- \rightarrow$ | Υ(45) | 1.23 $^{+0.27}_{-0.25}$ ± 0.06 2,3 AUBERT 08AI BABR $e^{+}e^{-} \rightarrow r$ (45) |
| $6.17 \pm 0.32 \pm 0.44$ | | AUBERT RICHICHI | 05J BAB 01 CLE: | R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ | | $1.84 \pm 0.32 \pm 0.31$ 2.4 AUBERT 060 BABR $e^+e^- ightarrow \Upsilon(4S)$ |
| 79 1 07 100 | | | 90J ARG | | | 5.2 \pm 2.4 \pm 0.4 5 AUBERT,BE 06M BABR $e^+e^- ightarrow \Upsilon(4S)$ |
| 7.8 ± 0.7 ±0.9 18 ± 8 ±4 | | ALBRECHT | | | . / | $1.12\pm0.12^{+0.30}_{-0.20}$ 2 GARMASH 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| | 5 the following | data for average | | s, etc. • • • | | |
| $18 \pm 8 \pm 4$ • • • We do not use to 6.9 ± 0.6 | 5 he following | data for average ABE | es, fits, limit 03B BELI | Repl. by | | • • We do not use the following data for averages, fits, limits, etc. |
| 18 \pm 8 \pm 4 • • • We do not use to 6.9 \pm 0.6 6.4 \pm 0.5 \pm 0.8 | 5 he following | data for average ABE AUBERT | es, fits, limit 03B BELI 02 BAB | Repl. by (| AUBERT 05J | <5 90 2,6 WICHT 08 BELL $e^+e^- ightarrow \varUpsilon$ (4 s) |
| 18 \pm 8 \pm 4 • • • We do not use to 6.9 \pm 0.6 6.4 \pm 0.5 \pm 0.8 6.1 \pm 2.3 \pm 0.9 | 5 the following 7 | data for average ABE AUBERT ALAM BORTOLETTO | es, fits, limit 03B BELI 02 BAB 94 CLE: O 92 CLE | Repl. by 0 R Repl. by 1 Repl. by 1 D $e^+e^- \rightarrow$ | AUBERT 05 J RICHICHI 01 $\Upsilon(4S)$ | <5 90 2,6 WICHT 08 BELL $e^+e^- \rightarrow \Upsilon(4S)$ <1.8 90 7 AUBERT 06E BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 18 ± 8 ± 4 • • • We do not use to the second of the secon | 5 the following 7 3 | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT | es, fits, limit 03B BELI 02 BAB 94 CLE: O 92 CLE 87D ARG | Repl. by 0 R Repl. by 1 Repl. by 1 D $e^+e^- \rightarrow$ | AUBERT 05 J RICHICHI 01 $\Upsilon(4S)$ | <5 90 2,6 WICHT 08 BELL $e^+e^- ightarrow \varUpsilon$ (4 s) |
| 18 ± 8 ± 4 • • • • We do not use 1 6.9 ± 0.6 6.4 ± 0.5 ± 0.8 6.1 ± 2.3 ± 0.9 <5 at 90% CL 22 ±17 ¹ Assumes equal pro- | 5 The following 7 3 duction of B | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT + and B ⁰ at the | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e $\Upsilon(4S)$. | Repl. by 6 Repl. by 6 Repl. by 8 Repl. by 8 $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^+e^- \rightarrow e^-e^- ^- \rightarrow e^-e^- ^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^$ | AUBERT 05J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ± 4 • • • We do not use to the second of the secon | 5 the following 7 3 duction of <i>B</i> ents of absol | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT + and B ⁰ at the ute branching fr | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e $\Upsilon(4S)$. actions using | Repl. by GR Repl. by I Repl. by I $e^+e^- \rightarrow e^+e^- \rightarrow G$ a missing m | AUBERT 05J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ±4 • • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ±0.8 6.1 ± 2.3 ±0.9 <5 at 90% CL 22 ±17 ¹ Assumes equal pro- ² Perform measurem ³ ALBRECHT 87D as | 5 the following 7 3 duction of B ents of absol | data for average ABE AUBERT ALAM BORTOLETTO BALBRECHT $+$ and B^0 at the ute branching fr $-/B^0\overline{B^0}$ ratio is | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e $\Upsilon(4S)$. actions using | Repl. by GR Repl. by I Repl. by I $e^+e^- \rightarrow e^+e^- \rightarrow G$ a missing m | AUBERT 05J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. BRECHT 90J. | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ±4 • • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ±0.8 6.1 ± 2.3 ±0.9 <5 at 90% CL 22 ±17 ¹ Assumes equal pro- ² Perform measurem ³ ALBRECHT 87D as: Γ(ψ(25) K+)/Γ(J/) | 5 the following 7 3 duction of B ents of absol | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT and B^0 at the ute branching fr $-/B^0\overline{B}^0$ ratio is | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e \(\gamma(45) \). actions using 555/45. Sup | Repl. by 0 Repl. by 0 Repl. by 1 Repl. by 1 $e^+e^- \rightarrow e^+e^- \rightarrow e^+e^-$ Repl. by 1 Repl. by 0 Repl. by 1 Repl. by 0 Repl. | AUBERT 05J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ± 4 • • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ± 0.8 6.1 ± 2.3 ± 0.9 <5 at 90% CL 22 ± 17 ¹ Assumes equal pro- ² Perform measurem ³ ALBRECHT 87D as Γ(ψ(2S) K+)/Γ(J/ VALUE 0.629±0.035 OUR FIT | the following 7 3 duction of B ents of absolessume B+B (\psi(15) K+ | data for average ABE AUBERT ALAM BORTOLETTO BALBRECHT $+$ and B^0 at the ute branching fr $-/B^0\overline{B^0}$ ratio is | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e $\Upsilon(4S)$. actions using | Repl. by 0 Repl. by 1 Repl. by 1 Repl. by 1 $e^+e^- \rightarrow e^+e^- \rightarrow e^+e^-$ Repl. by 1 Repl. | AUBERT 05J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. BRECHT 90J. | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ±4 • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ±0.8 6.1 ± 2.3 ±0.9 <5 at 90% CL 22 ±17 1 Assumes equal proc2 Perform measurem 3 ALBRECHT 87D as F (ψ(2S) K+)/F (J/WALUE 0.629±0.035 OUR FIT 0.60 ±0.07 OUR AV | the following 7 3 duction of B ents of absolessume B+B (\psi(15) K+ | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT + and B ⁰ at the ute branching fr -/B ⁰ B ⁰ ratio is DOCUMENT ID | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e \(T(4S) \). actions using 555/45. Sup | Repl. by 0 R Repl. by 0 R Repl. by 1 Repl. by 2 Repl. by 4 Repl. | AUBERT 05 J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. BRECHT 90 J. | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ± 4 • • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ±0.8 6.1 ± 2.3 ±0.9 <5 at 90% CL 22 ±17 ¹ Assumes equal prod ² Perform measurem ³ ALBRECHT 87D as Γ(ψ(25) K ⁺)/Γ(J/WALUE MALUE 0.6629±0.035 OUR FIT 0.60 ±0.07 OUR AV 0.63 ±0.05 ±0.08 | the following 7 3 duction of B ents of absolessume B+B (\psi(15) K+ | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT and B^0 at the ute branching fr $-/B^0\overline{B}^0$ ratio is | es, fits, limit 03B BELI 02 BAB 94 CLE: 0 92 CLE: 87D ARG e \(\gamma(45) \). actions using 555/45. Sup | Repl. by 0 R Repl. by 1 Repl. by 0 Repl. by 1 Repl. by | AUBERT 05 J RICHICHI 01 $r(4s)$ $r(4s)$ ass technique. BRECHT 90 J. $r(223/\Gamma_{185})$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 18 ± 8 ± 4 • • • We do not use to 6.9 ± 0.6 6.4 ± 0.5 ± 0.8 6.1 ± 2.3 ± 0.9 <5 at 90% CL 22 ± 17 1 Assumes equal pro- 2 Perform measurem | the following 7 3 duction of B ents of absol ssume B+B* (\psi(15) K+ ERAGE | data for average ABE AUBERT ALAM BORTOLETTO ALBRECHT + and B ⁰ at the ute branching fr -/B ⁰ B ⁰ ratio is) DOCUMENT ID ABAZOV ABE | 94 CLE: 95 Q 2 CLE: 87D ARG e T (45). actions using s 55 / 45. Sup 097 D0 980 CDF es, fits, limit | Repl. by 0 R Repl. by 1 R Repl | AUBERT 05 J RICHICHI 01 $\Upsilon(4S)$ $\Upsilon(4S)$ ass technique. BRECHT 90 J. $\Gamma_{223}/\Gamma_{185}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

| See key on page 457 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 LEES 111 reports $[\Gamma(B^+ \to \chi_c 0(1P)K^+)/\Gamma_{total}] \times [B(\chi_c 0(1P) \to \pi\pi)] = (1.53 \pm 0.66 \pm 0.27) \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \pi\pi) = (8.5 \pm 0.4) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 2 Assumes equal production of B^+ and B^0 at the $T(4S)$. 3 AUBERT 08AI reports $(0.70 \pm 0.10^+0.12) \times 10^{-6}$ for $B(B^+ \to \chi_c 0 K^+) \times B(\chi_c 0 \to \pi^+\pi^-)$. We compute $B(B^+ \to \chi_c 0 K^+)$ using the PDG value $B(\chi_c 0 \to \pi\pi) = (8.5 \pm 0.4) \times 10^{-3}$ and $2/3$ for the $\pi^+\pi^-$ fraction. Our first error is their experiment's error and the second error is systematic error from using our best value. 4 Measured in the $B^+ \to K^+K^-K^+$ decay. 5 AUBERT, BE 06M reports $[\Gamma(B^+ \to \chi_c 0(1P) K^+)/\Gamma_{total}] \times [B(\chi_c 0(1P) \to \gamma J/\psi(1S))] = (6.1 \pm 2.6 \pm 1.1) \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma J/\psi(1S))] = (1.17 \pm 0.08) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. The significance of the observed signal is 2.4 σ. 6 WICHT 08 reports $[\Gamma(B^+ \to \chi_c 0(1P) K^+)/\Gamma_{total}] \times [B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by our best value $B(\chi_c 0(1P) \to \gamma\gamma)] < 0.11 \times 10^{-6}$ which we divide by $B(\chi_c 0(1P) \to \gamma\gamma) = 0.11 \times 10^{-6}$ which we divide by $B(\chi_c 0(1P) \to \gamma\gamma) = 0.11 $ |
| for. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(\chi_{C2}\pi^+\times B(\chi_{C2}\to\pi^+\pi^-))/\Gamma_{total}$ Γ_{232}/Γ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| <0.1 90 1 AUBERT 09L BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(\chi_{c2}K^+)/\Gamma_{	ext{total}}$ Γ_{233}/Γ VALUE (units 10^{-5}) CL% DOCUMENT ID TECN COMMENT |

| <0.1 | 90 | 1 AUBERT | 09L | BABR | $e^+e^- \rightarrow$ | Υ(4S) |
|------------------------------------------|-----------|---------------------------|-----|-------------|----------------------|---------------------|
| ¹ Assumes equal pro | duction o | of B^+ and B^0 at the | r(4 | S). | | |
| $\Gamma(\chi_{c2}K^+)/\Gamma_{ m total}$ | | | | | | Γ ₂₃₃ /Γ |
| VALUE (units 10^{-5}) | CL% | DOCUMENT ID | | <u>TECN</u> | COMMENT | |
| $1.11^{+0.36}_{-0.34}\pm0.09$ | | ¹ BHARDWAJ | 11 | BELL | $e^+e^-\to$ | Y(45) |

| 0.04 | | | | | |
|-------------------------|----------------|---------------------|-----------|------------|-----------------------------------|
| ullet $ullet$ We do not | use the follow | ing data for avera | ges, fits | s, limits, | etc. • • • |
| < 1.8 | 90 | ² AUBERT | 09в | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| <20 | 90 | ³ AUBERT | 06E | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| < 2.9 | 90 | ¹ soni | 06 | BELL | Repl. by BHARDWAJ 11 |
| < 3.0 | 90 | ¹ AUBERT | 05 K | BABR | Repl. by AUBERT 06E |
| | | | | | |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

³ Perform measurements of absolute branching fractions using a missing mass technique.

$\Gamma(B^+ \to \chi_{c2} K^+)/\Gamma_{\text{total}} \times \Gamma(\chi_{c2}(1P) \to \gamma \gamma)/\Gamma_{\text{total}}$ $\Gamma_{233}/\Gamma \times \Gamma_{62}^{\chi_{c2}(1P)}/\Gamma_{c2}^{\chi_{c2}(1P)}$

| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----|--------------|----|------|----------------------------------|
| <0.09 | 90 | 1 WICHT | 80 | BELL | $e^+ e^- \rightarrow \gamma(4S)$ |

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(\chi_{c2}K^*(892)^+)/\Gamma_t$ | otal | | | | | Γ ₂₃₄ /Γ |
|-----------------------------------------------------------|------------|--------------------------------------|---------------|-----------|--------------|------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <12 × 10 ⁻⁵ | 90 | $^{ m 1}$ AUBERT | 09в | BABR | $e^+e^- \to$ | Y(45) |
| ● ● We do not use th | e followin | g data for average | es, fits | , limits, | etc. • • • | |
| $< 12.7 \times 10^{-5}$ | 90 | ² SONI | | | | |
| $< 1.2 \times 10^{-5}$ | 90 | ² AUBERT | 05 K | BABR | Repl. by A | UBERT 09B |
| ¹ Uses $\chi_{c1,2} \rightarrow J/\psi \gamma$ | . Assume | $s B(\Upsilon(4S) \rightarrow B^{-}$ | + <i>B</i> −) | = (51.6 | ±0.6)% and | $B(\Upsilon(4S) \rightarrow$ |

 $B^0 \overline{B}{}^0) = (48.4 \pm 0.6)\%.$ ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(\chi_{c1}(1P)\pi^+)/\Gamma_{ m total}$ | | | | | Γ ₂₃₅ /Γ |
|------------------------------------------------|--------------|----|------|----------------------|---------------------|
| VALUE (units 10 ⁻⁵) | DO CUMENT ID | | TECN | COMMENT | |
| 2.2±0.4±0.3 | 1 KUMAR | 06 | BELL | $e^+e^- \rightarrow$ | Υ(4S) |

 $^{^1}$ Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

| $\Gamma(\chi_{c1}(1P)K^+)/\Gamma_{\text{total}}$ | | | | | Γ ₂₃₆ /Γ |
|--------------------------------------------------|-----------------------|------|-----------|-----------------------------------|---------------------|
| VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 4.79± 0.23 OUR AVERAGE | | | | | |
| $4.94 \pm 0.11 \pm 0.33$ | ¹ BHARDWAJ | 11 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $4.5 \pm 0.1 \pm 0.3$ | ² AUBERT | 09в | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $8.1 \pm 1.4 \pm 0.7$ | ³ AUBERT | 06E | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $15.5 \pm 5.4 \pm 2.0$ | ⁴ A C OSTA | 02F | CDF | <i>p</i> p 1.8 TeV | |
| • • We do not use the follow | wing data for aver | ages | fits limi | ts etc • • • | |

| $5.1 \pm 0.4 \pm 0.2$ | | | 06м | BABR | Repl. by AUBERT 09B |
|--------------------------|---|-----------------------|-----|------|------------------------------------|
| $4.49 \pm 0.19 \pm 0.53$ | | ¹ SONI | 06 | BELL | Repl. by BHARDWAJ 11 |
| $5.79 \pm 0.26 \pm 0.65$ | | | 05J | BABR | Repl. by AUBERT, ВЕ 06м |
| $6.0 \pm 0.9 \pm 0.3$ | | ⁶ AUBERT | 02 | BABR | Repl. by AUBERT 051 |
| $9.7 \pm 4.0 \pm 0.9$ | 6 | ¹ ALAM | 94 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| 19 ± 13 ± 6 | | ⁷ ALBRECHT | 92E | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |

 1 Assumes equal production of ${\it B}^+$ and ${\it B}^{\,0}$ at the ${\it \Upsilon}({\it 4S})$.

 2 Uses $\chi_{c1,2} \rightarrow ~J/\psi \, \gamma.~$ Assumes B($\varUpsilon(4S) \rightarrow ~B^+ \, B^-) = (51.6 \pm 0.6)\%$ and B($\varUpsilon(4S) \rightarrow ~$ $B^{0}\overline{B}^{0}) = (48.4 \pm 0.6)\%.$

 $^3\,\mathrm{Perform}$ measurements of absolute branching fractions using a missing mass technique. 4 ACOSTA 02F uses as reference of B($B \to J/\psi(15)\,K^+)=(10.1\pm0.6)\times 10^{-4}$. The second error includes the systematic error and the uncertainties of the branching ratio.

 6 AUBERT 02 reports (7.5 \pm 0.9 \pm 0.8) imes 10 $^{-4}$ from a measurement of [$\Gamma(B^+
ightarrow$ $\chi_{c1}(1P)\,K^+)/\Gamma_{total}]\times [B(\chi_{c1}(1P)\to\gamma J/\psi(1S))]$ assuming $B(\chi_{c1}(1P)\to\gamma J/\psi(1S))=0.273\pm0.016,$ which we rescale to our best value $B(\chi_{c1}(1P)\to\gamma J/\psi(1S))=(34.4\pm1.5)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

⁷ALBRECHT 92E assumes no $\chi_{\mathcal{C}2}(1P)$ production and B($\varUpsilon(4S) \to B^+B^-) = 50\%$.

$\Gamma\big(\chi_{c1}(1P)\,K^+\big)/\Gamma\big(J/\psi(1S)\,K^+\big)$ $\Gamma_{236}/\Gamma_{185}$ TECN COMMENT DO CUMENT ID $1 \; \overline{\text{AUBERT}} \qquad \text{02} \quad \text{BABR} \quad e^+ \, e^- \, \rightarrow \, \, \varUpsilon(\text{4S})$ $0.60 \pm 0.07 \pm 0.03$

 1 AUBERT 02 reports 0.75 \pm 0.08 \pm 0.05 from a measurement of [F (B $^+$ \rightarrow $\chi_{C1}(1P)$ K $^+$)/ $\Gamma(B^+ \to J/\psi(1S) \, K^+)] \times [\mathsf{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \text{ assuming } \, \mathsf{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \text{ assuming } \, \mathsf{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S)) = 0.273 \pm 0.016, \text{ which we rescale to our best value } \, \mathsf{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))]$ $\gamma J/\psi(15)$) = $(34.4\pm1.5)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(\chi_{c1}(1P)\pi^+)/\Gamma(\chi_{c1}(1P)K^+)$ $\Gamma_{235}/\Gamma_{236}$ DOCUMENT ID TECN COMMENT ¹ KUMAR $0.043 \pm 0.008 \pm 0.003$ 06 BELL $e^+e^- \rightarrow$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

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$\Gamma(\chi_{c1}(1P)K^*(892)^+)/\Gamma_{total}$ Γ_{237}/Γ DOCUMENT ID TECN COMMENT

| 3.0 ±0.6 OUR AVERAGE Error includes scale factor of 1.1. 2.6 ±0.5 ±0.4 4.05±0.59±0.95 2 SONI • • • We do not use the following data for averages, fits, limits, etc. • • • 2.94±0.95±0.98 2 AUBERT 90 2 ALAM 94 CLE2 $e^+e^- \rightarrow r(4S)$ | MEDE (BIRKS 10) | CL70 | DOCUMENT | | TECH | COMMENT |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|----------|---------------------|------------|---------|-----------------------------------|
| $4.05\pm0.59\pm0.95$ 2 SONI 06 BELL $e^+e^- \rightarrow r(4.5)$ • • We do not use the following data for averages, fits, limits, etc. • • • $2.94\pm0.95\pm0.98$ 2 AUBERT 05J BABR Repl. by AUBERT 09 | 3.0 ±0.6 OUR AVE | RAGE | Error includes sc | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $2.94 \pm 0.95 \pm 0.98 \qquad \qquad \begin{array}{c} 2 \text{ AUBERT} \qquad \text{05J} \text{BABR} \text{Repl. by AUBERT} \text{09} \end{array}$ | $2.6 \pm 0.5 \pm 0.4$ | | ¹ AUBERT | 09в | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 2.94±0.95±0.98 | $4.05 \pm 0.59 \pm 0.95$ | | ² soni | 06 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | • • • We do not use the | e follow | ing data for averag | ges, fits, | limits, | etc. • • • |
| $<$ 21 90 2 ALAM 94 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ | $2.94 \pm 0.95 \pm 0.98$ | | | 05 J | BABR | Repl. by AUBERT 098 |
| | <21 | 90 | ² ALAM | 94 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |

1 Uses $\chi_{c1,2} \rightarrow ~J/\psi \, \gamma.~$ Assumes B($\Upsilon(4S) \rightarrow ~B^+ \, B^-) = (51.6 \pm 0.6)\%$ and B($\Upsilon(4S) \rightarrow ~$ $B^0 \overline{B}^0$) = (48.4 ± 0.6)%.

² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(\chi_{c1}(1P)K^*(892)^+)/\Gamma(\chi_{c1}(1P)K^+)$ $\Gamma_{237}/\Gamma_{236}$ TECN COMMENT $0.51 \pm 0.17 \pm 0.16$ 05J BABR $e^+e^- ightarrow$ AUBERT

 $\Gamma(h_c(1P)K^+)/\Gamma_{total}$ Γ_{238}/Γ VALUE (units 10-5) DOCUMENT ID TECN COMMENT 90 ¹ FANG 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and $B^{\,0}$ at the $\varUpsilon(4S)$ and ${\rm B}(h_C \to ~\eta_C \,\gamma) = 50\%.$

| $\Gamma(K^0\pi^+)/\Gamma_{ m total}$ | | | | | Γ ₂₃₉ /Γ |
|-------------------------------------------------|--------------------------|-----|------|---------------------|---------------------|
| VALUE (units 10 ⁻⁶) CL% | DO CUMENT ID | | TECN | COMMENT | |
| 23.1± 1.0 OUR AVERAGE | E . | | | | |
| $22.8 ^{+}_{-}\; {\stackrel{0.8}{0.7}} \pm 1.3$ | ¹ LIN | 07 | BELL | $e^+e^- \to$ | $\Upsilon(4S)$ |
| $23.9 \pm 1.1 \pm 1.0$ | $^{ m 1}$ AUBERT,BE | 06c | BABR | $e^+e^ \rightarrow$ | Y(45) |
| $18.8 + 3.7 + 2.1 \\ -3.3 - 1.8$ | $^{\mathrm{1}}$ bornheim | 03 | CLE2 | $e^+e^-\to$ | $\Upsilon(4S)$ |

Uses $\chi_{c1,2} \to J/\psi \gamma$. Assumes B($\varUpsilon(4S) \to B^+ B^-) = (51.6 \pm 0.6)\%$ and B($\varUpsilon(4S) \to B^+ B^-) = (51.6 \pm 0.6)\%$ $B^0 \overline{B}{}^0) = (48.4 \pm 0.6)\%.$

 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

 B^{\pm}

| • • • We do not use the following data for averages, fits, limits, etc. • • • 26.0± 1.3±1.0 | Γ(η' Κ* ₀ (1430)+)/Γ _{total} | Γ ₂₄₃ / DOCUMENT ID TECN COMMENT |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $22.3\pm~1.7\pm1.1$ AUBERT 04M BABR Repl. by AUBERT,BE 05E | 5.2±1.9±1.0 | 1 DEL-AMO-SA10A BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 22.0± 1.9±1.1 | $^{ m 1}$ Assumes equal production of | f B^+ and B^0 at the $\varUpsilon(4S)$. |
| $19.4 + \frac{3.1}{3.0} \pm 1.6$ | [/_/ K*(1420)+) /F | Γ |
| $13.7 + \begin{array}{ccc} 5.7 + 1.9 \\ -4.8 - 1.8 \end{array}$ 1 ABE 01H BELL Repl. by CASEY 02 | $\Gamma(\eta' K_2^*(1430)^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) | √244 ■ DOCUMENT ID TECN COMMENT |
| $18.2 + \begin{array}{ccc} 3.3 \\ -3.0 \end{array} \pm 2.0$ 1 AUBERT 01E BABR Repl. by AUBERT 04M | 28.0 +4.6 ±2.6 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $18.2 + 4.6 \pm 1.6$ 1 CRONIN-HEN00 CLE2 Repl. by BORNHEIM 03 | | , , |
| 23 $^{+11}_{-10}$ ± 3.6 GODANG 98 CLE2 Repl. by CRONIN- | ¹ Assumes equal production of | $f B^+$ and B^0 at the $T(4S)$. |
| -10 HENNESSY 00 < 48 90 ASNER 96 CLE2 Repl. by GODANG 98 | $\Gamma(\eta K^+)/\Gamma_{\text{total}}$ | Г ₂₄₅ / |
| <190 90 ALBRECHT 91B ARG $e^+e^- ightarrow~ \varUpsilon(4S)$ | VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT |
| <100 90 2 AVERY 89B CLEO $e^+e^- ightarrow \varUpsilon(4S)$ <680 90 AVERY 87 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | 2.4 ±0.4 OUR AVERAGE 2.12±0.23±0.11 | Error includes scale factor of 1.7. ¹ HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| <680 90 AVERY 87 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | $2.94 + 0.39 \pm 0.21$ | 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 2 AVERY 89B reports $< 9 	imes 10^{-5}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. We rescale | | ¹ RICHICHI 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| to 50%. | 2.2 +2.8 -2.2 | ing data for averages, fits, limits, etc. \bullet \bullet |
| $\Gamma(K^+\pi^0)/\Gamma_{\text{total}}$ Γ_{240}/Γ | | 1.0 |
| <u>ALUE (units 10^{−6}) CL% DOCUMENT ID TECN COMMENT</u> 12.9±0.6 OUR AVERAGE | -0.42 | 1,2 WICHT 08 BELL Repl. by HOI 12 1 AUBERT 07AE BABR Repl. by AUBERT 09AV |
| 13.6 \pm 0.6 \pm 0.7 1 AUBERT 07BC BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $3.7 \pm 0.4 \pm 0.1$ $1.9 \pm 0.3 \stackrel{+}{-} 0.2$ | ¹ AUBERT 07AE BABR Repl. by AUBERT 09AV ¹ CHANG 07B BELL Repl. by HOI 12 |
| $12.4\pm0.5\pm0.6$ 1 LIN 0 7A BELL $e^+e^- 	o 	ag{4S}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ¹ AUBERT,B 05 K BABR Repl. by AUBERT 07AE |
| $12.9^{+2.4}_{-2.2}^{+1.2}$ 1 BORNHEIM 03 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | 2.1 ±0.6 ±0.2 | ¹ CHANG 05A BELL Repl. by CHANG 07B |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $3.4 \pm 0.8 \pm 0.2$ < 14 90 | ¹ AUBERT 04H BABR Repl. by AUBERT,B 05 BEHRENS 98 CLE2 Repl. by RICHICHI 00 |
| 12.0±0.7±0.6 | $<$ 14 90 1 Assumes equal production of | |
| | ² WICHT 08 reports $[\Gamma(B^+ -$ | r B r and B r at the $T(45)$. r r r r r r r r r r |
| $12.8 + 1.2 \pm 1.0$ | 10^{-6} which we divide by ou | Ir best value B($\eta ightarrow 2\gamma$) = (39.31 \pm 0.20) $	imes$ 10 $^{-2}$. O |
| $13.0^{+2.5}_{-2.4}\pm 1.3$ | first error is their experimen using our best value. | t's error and our second error is the systematic error fro |
| $16.3 + \frac{3.5 + 1.6}{-3.3 - 1.8}$ 1 ABE 01H BELL Repl. by CASEY 02 | • | r |
| 10.8 + 2.1 = 1.0 | $\Gamma(\eta K^*(892)^+)/\Gamma_{\text{total}}$ | Γ ₂₄₆ / |
| -1.9 11.6 + 3.0 + 1.4 11.6 - 2.7 - 1.3 1 CRONIN-HEN00 CLE2 Repl. by BORNHEIM 03 | VALUE (units 10 ⁻⁶) CL% 19.3±1.6 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| 11.0 - 2.7 - 1.3 CROMINI-TEN50 CEE2 Repl. by BORRINE NO. 3 C16 90 GODANG 98 CLE2 Repl. by CRONIN- | $19.3 + 2.0 \pm 1.5$ | 1 WANG 07B BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| HENNESSY 00 <14 90 ASNER 96 CLE2 Repl. by GODANG 98 | $18.9 \pm 1.8 \pm 1.3$ | ¹ AUBERT,B 06H BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| <14 90 ASNER 90 CLE2 Repl. by GODANG 90 | | |
| | $26.4 + \frac{9.6}{8.2} \pm 3.3$ | 1 RICHICHI 00 CLE2 $e^{+}e^{-} ightarrow \gamma(45)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | $26.4 + 9.6 \pm 3.3$ • • • We do not use the follow | 1 RICHICHI 00 CLE2 $e^{+}e^{-} ightarrow~ \varUpsilon(4S)$ ing data for averages, fits, limits, etc. • • • |
| | V.2 | ing data for averages, fits, limits, etc. • • • 1 AUBERT,B 04D BABR Repl. by |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE 0.54 \pm 0.03 \pm 0.04 $\Gamma(K^0\pi^+)$ LIN $\Gamma(K^0\pi^+)$ $\Gamma(K^0$ | • • We do not use the follow | ing data for averages, fits, limits, etc. • • • |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ | ing data for averages, fits, limits, etc. • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ <30 90 1 Assumes equal production of | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ < 30 90 | ing data for averages, fits, limits, etc. • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 |
| TAssumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE DOCUMENT ID TECN COMMENT 10054 ± 0.03 ± 0.04 LIN 07A BELL $e^+e^- \rightarrow \Upsilon(4S)$ ABE 01H BELL Repl. by LIN 07A $\Gamma(\gamma'K^+)/\Gamma_{total}$ FOUMENT ID TECN COMMENT F241/ Γ COMMENT | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{total}$ | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE 0.54 \pm 0.03 \pm 0.04 LIN 07A BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 0.98 \pm 0.39 ABE 01H BELL Repl. by LIN 07A $\Gamma(\eta'K^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) 70.6 \pm 2.5 OUR AVERAGE | • • • We do not use the follow 25.6±4.0±2.4 <30 90 1 Assumes equal production of \(\begin{align*} al | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR C^- COMMENT 10 1 AUBERT,B 06H BABR $C^ C^ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE 0.54 \pm 0.03 \pm 0.04 1 LIN 0.70 A BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 0.39 -1.10 -0.26 ABE 0.1H BELL Repl. by LIN 0.70 $\Gamma(\eta'K^+)/\Gamma_{total}$ VALUE (units 10^{-6}) 70.6 \pm 2.5 OUR AVERAGE 1 AUBERT 0 9AV BABR 0 AT $(4S)$ 1 AUBERT 0 9AV BABR 0 BABR 0 AT $(4S)$ 0 AUGUS (2000) 0 AUGUS (2000) 1 AUBERT 0 9AV BABR 0 AT $(4S)$ 0 AUBERT 0 9AV BABR 0 AUGUS (2000) 0 AUGUS (2000) 0 AUGUS (2000) 1 AUBERT 0 9AV BABR 0 AUGUS (2000) 0 AUGUS (2000) 0 AUGUS (2000) 1 AUBERT 0 9AV BABR 0 AUGUS (2000) 0 AUGUS (2000) 0 AUGUS (2000) 1 AUBERT 0 9AV BABR 0 AUGUS (2000) 0 AUGUS | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6}\text{)}}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H Repl. by RICHICHI 00 f B^+ and B^0 at the $T(4S)$. $^{DOCUMENT\ ID}$ $TECN$ $COMMENT$ 1 AUBERT,B 06H BABR $e^+e^- \to T(4S)$ f B^+ and B^0 at the $T(4S)$. |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE DOCUMENT ID 1 TECN COMMENT 0.54 \pm 0.03 \pm 0.04 LIN 0.70 A BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 0.98 \pm 0.39 -1.10 -0.26 ABE 0.11 BELL Repl. by LIN 07A $\Gamma(\eta'K^+)/\Gamma_{total}$ VALUE (units \pm 10 | • • • We do not use the follow 25.6±4.0±2.4 <30 90 1 Assumes equal production of \(\begin{align*} al | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $VALUE$ $D.54\pm 0.03\pm 0.04$ $0.54\pm 0.98 + 0.39 \\ -1.10 - 0.26$ $0.54\pm 0.98 + 0.39$ 0.54 ± 0.39 $0.54\pm 0.98 + 0.39$ $0.56\pm 0.98 + 0.39$ $0.56\pm 0.98 + 0.39$ $0.56\pm 0.98 + 0.39$ $0.56\pm 0.98 + 0.39$ $0.58\pm 0.98 + 0.39$ $0.59\pm 0.98 + 0.39$ 0.59 | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{12.2\pm2.7\pm1.4}$ | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ From Equation 10 feet B^0 at the |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{MLUE(\text{units }10^{-6})}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{MLUE(\text{units }10^{-6})}{MLUE(\text{units }10^{-6})}$ | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ From Equation 10 feet B^0 at the |
| TAssumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ VALUE 0.54 \pm 0.03 \pm 0.04 ••• We do not use the following data for averages, fits, limits, etc. •• 2.38 \pm 0.98 \pm 0.99 -1.10 \pm 0.26 ABE 01H BELL Repl. by LIN 07A $T(\eta'K^+)/\Gamma_{total}$ VALUE (units 10^{-6}) 70.6 \pm 2.5 OUR AVERAGE 71.5 \pm 1.3 \pm 3.2 1 AUBERT 09AV BABR 0+0 BELL 0+0 0+0 0+0 0+0 0+0 0+0 0+0 | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{MALUE (units 10^{-6})}{18.2\pm2.6\pm2.6} 1 Assumes equal production of \Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}} \frac{MALUE (units 10^{-6})}{142.7\pm1.4} 1 Assumes equal production of$ | ing data for averages, fits, limits, etc. • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. |
| TAssumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ WALUE 0.54 \pm 0.03 \pm 0.04 ••• We do not use the following data for averages, fits, limits, etc. •• 2.38 \pm 0.98 \pm 0.99 -1.10 \pm 0.26 ABE 01H BELL Repl. by LIN 07A $T(\eta'K^+)/\Gamma_{\text{total}}$ WALUE (units 10^{-6}) 70.6 \pm 2.5 OUR AVERAGE 71.5 \pm 1.3 \pm 3.2 1 AUBERT 09AV BABR 01H BELL Repl. by LIN 07A F241/ Γ WICHT 08 BELL $e^+e^- \rightarrow T(4S)$ F241/ Γ F24 | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{12.2\pm2.7\pm1.4}$ | ing data for averages, fits, limits, etc. • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ $VALUE$ 0.54 \pm 0.03 \pm 0.04 LIN 0.70 A BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 0.39 -1.10 -0.26 ABE 01H BELL Repl. by LIN 07A $\Gamma(\gamma'K^+)/\Gamma_{total}$ 1 AUBERT 1 AUBERT 1 SCHUEMANN 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 1.3 \pm 3.2 1 SCHUEMANN 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.54 \pm 1.3 \pm 3.2 1 RICHICHI 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 1 RICHICHI 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 01 SCHUERT 02 We do not use the following data for averages, fits, limits, etc. 03 EVALUE (units 10^{-6}) 1 SCHUEMANN 06 1 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 05 COMMENT 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 07 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 07 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 08 EVALUE $e^+e^- \rightarrow \Upsilon(4S)$ 09 EVALUE e^+ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-6})}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-6})}{12.2\pm2.7\pm1.4}$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295))$ $\frac{VALUE (units 10^{-6})}{12.25\pm1.4}$ | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B+ and B 0 at the $T(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to T(4S)$ f B+ and B 0 at the $T(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to T(4S)$ f B+ and B 0 at the $T(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to T(4S)$ f B+ and B 0 at the $T(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to T(4S)$ f B+ and B 0 at the $T(4S)$. |
| Tassumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ NALUE 0.54 \pm 0.03 \pm 0.04 1.1N 0.7A BELL $e^+e^- \rightarrow T(4S)$ 1.1N 0.7A BELL $e^+e^- \rightarrow T(4S)$ 0.5A \pm 0.98 \pm 0.39 1.10 - 0.26 ABE 0.1H BELL Repl. by LIN 0.7A Tech ech | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{18.2 \pm 2.6 \pm 2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{10.2 \pm 2.7 \pm 1.4}$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta$ | ing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 04D BABR Repl. by BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. 1 AUBERT,B 06H BABR $e^+e^- \to \Upsilon(4S)$ 1 AUBERT 08K BABR $e^+e^- \to \Upsilon(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ $VALUE$ $0.54\pm 0.03\pm 0.04$ $0.54\pm 0.03\pm 0.39$ $-0.40 \text{ We do not use the following data for averages, fits, limits, etc.} \bullet \bullet$ $2.38^{+0.98}_{-1.10} - 0.26$ -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 -0.26 $-$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{WLUE}{(\text{units }10^{-6})}$ 18.2 $\pm 2.6 \pm 2.6$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{WLUE}{(\text{units }10^{-6})}$ 9.1 $\pm 2.7 \pm 1.4$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295)) \frac{WLUE}{(\text{units }10^{-6})}$ 2.9 $\frac{4}{-0.7} \pm 0.2$ 1 Assumes equal production of | ing data for averages, fits, limits, etc. • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $T(4S)$. $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| TAssumes equal production of B^+ and B^0 at the $T(4S)$. T($K^+\pi^0$)/ $\Gamma(K^0\pi^+)$ DISA $\pm 0.03\pm 0.04$ EIN 07A BELL $e^+e^- \rightarrow T(4S)$ DISA $\pm 0.98\pm 0.39$ ABE 01H BELL Repl. by LIN 07A TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT ID TECN COMMENT TOURS OF TOURS OF THE COMMENT TOURS OF TOURS OF TOURS OF TOURS TOURS OF TOURS OF THE COMMENT TOURS OF TOURS OF TOURS TOURS O | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 18.2 $\pm2.6\pm2.6$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 9.1 $\pm2.7\pm1.4$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295)) K^+ \times B(\eta(1295)) K^+ \times B(\eta(1405) K^+ \times B(\eta$ | ing data for averages, fits, limits, etc. • • • • 1 AUBERT, B 04D BABR Repl. by AUBERT, B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. $ \begin{array}{cccccccccccccccccccccccccccccccccc$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)$ $VALUE$ $0.54\pm0.03\pm0.04$ $0.54\pm0.03\pm0.04$ $0.54\pm0.98+0.39$ $-1.10-0.26$ $0.54\pm0.98+0.39$ $0.54\pm0.98+$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{WLUE \text{ (units }10^{-6})}{18.2\pm2.6\pm2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{WLUE \text{ (units }10^{-6})}{12.27\pm1.4}$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta(1495) K^+ \times B(\eta(1405) K^+ \times B(\eta$ | ing data for averages, fits, limits, etc. • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^+)/\Gamma(K^0\pi^+)$ $T(K^0$ | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-6})}{18.2 \pm 2.6 \pm 2.6}$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-6})}{10.2 \pm 2.7 \pm 1.4}$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta(1405) $ | ing data for averages, fits, limits, etc. • • • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $\Upsilon(4S)$. DOCUMENT ID TECN COMMENT TECN TECN COMMENT TECN |
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| Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^+)$ $T(K^0\pi^$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 18.2 $\pm2.6\pm2.6$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 9.1 $\pm2.7\pm1.4$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta(1405) K^+ \times B(\eta(1$ | ing data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • |
| TAssumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^+)/\Gamma(K^0\pi^+)$ $T(K^$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 18.2 $\pm2.6\pm2.6$ 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ MALUE (units 10^{-6}) 9.1 $\pm2.7\pm1.4$ 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295)) K^+ \times B(\eta(1295)) K^+ \times B(\eta(1405) K^+ \times B(\eta$ | ing data for averages, fits, limits, etc. • • • • • • 1 AUBERT, B 04D BABR Repl. by AUBERT, B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 f B^+ and B^0 at the $T(4S)$. DOCUMENT ID TECN COMMENT AUBERT, B 06H BABR $e^+e^- \rightarrow T(4S)$ $T_0 = T_0 = T$ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the follow $25.6\pm4.0\pm2.4$ < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ $\frac{MALUE (units 10^{-6})}{18.2\pm2.6\pm2.6} 1 Assumes equal production of \Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}} \frac{MALUE (units 10^{-6})}{19.1\pm2.7\pm1.4} 1 Assumes equal production of \Gamma(\eta(1295) K^+ \times B(\eta(1295)) \frac{MALUE (units 10^{-6})}{19.7\pm0.7} 2.9 \frac{+0.8}{-0.7}\pm0.2 1 Assumes equal production of \Gamma(\eta(1405) K^+ \times B(\eta(1405)) \frac{MALUE (units 10^{-6})}{19.7\pm0.7} < 1.3 90 1 Assumes equal production of \Gamma(\eta(1405) K^+ \times B(\eta(1405)) \frac{CL\%}{1.3} < 1.4 Sames equal production of \Gamma(\eta(1405) K^+ \times B(\eta(1405)) \frac{CL\%}{1.3\pm0.000} < 1.2 90 90$ | ing data for averages, fits, limits, etc. • • • • • • 1 AUBERT, B 04D BABR Repl. by AUBERT, B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. DOCUMENT ID TECN COMMENT AUBERT, B 06H BABR $e^+e^- \rightarrow T(4S)$ of B^+ and B^0 at the $T(4S)$. DOCUMENT ID TECN COMMENT T_0 |
| Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^+)$ $T(K^0$ | • • • We do not use the follow 25.6 \pm 4.0 \pm 2.4 <30 | ing data for averages, fits, limits, etc. • • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. $\begin{array}{ccccccccccccccccccccccccccccccccccc$ |
| Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^+)$ $T(K^0\pi^0)/\Gamma(K^0\pi^0)$ $T(K^0$ | • • • We do not use the follow 25.6 \pm 4.0 \pm 2.4 <30 | ing data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • |
| TAssumes equal production of B^+ and B^0 at the $T(4S)$. T($K^+\pi^0$)/ $\Gamma(K^0\pi^+)$ DOCUMENT ID TECN COMMENT TOCA | • • • We do not use the follow 25.6 \pm 4.0 \pm 2.4 < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ **MALUE (units 10^-6) 18.2 \pm 2.6 \pm 2.6 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ **MALUE (units 10^-6) 9.1 \pm 2.7 \pm 1.4 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295))$ **MALUE (units 10^-6) 2.9 \pm 0.7 \pm 0.2 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **ALUE (units 10^-6) <1.3 90 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **MALUE (units 10^-6) <1.2 90 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **ALUE (units 10^-6) <1.2 90 1 Assumes equal production of $\Gamma(\eta(1475) K^+ \times B(\eta(1475))$ **ALUE (units 10^-6) **C1.8 1 Assumes equal production of $\Gamma(\eta(1475) K^+ \times B(\eta(1475))$ **MALUE (units 10^-6) | ing data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • |
| 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $T(K^+\pi^0)/\Gamma(K^0\pi^+)$ $DOCUMENT ID$ $TECN$ $COMMENT$ $TOCH 2.5 OUR AVERAGE$ $T(1.5 \pm 1.3 \pm 3.2)$ $1 AUBERT$ 1 | • • • We do not use the follow $25.6 \pm 4.0 \pm 2.4$ <30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ **MLUE (units 10^{-6}) 18.2 \pm 2.6 \pm 2.6 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ **MLUE (units 10^{-6}) 9.1 \pm 2.7 \pm 1.4 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta(1295) K^+ \times B(\eta(1405) K^+ \times B($ | ing data for averages, fits, limits, etc. • • • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. DOCUMENT ID TECN COMMENT TECN COMMENT TECN COMMENT TECN TEC |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\frac{\Gamma(K^+\pi^0)/\Gamma(K^0\pi^+)}{\Gamma(K^0\pi^+)}$ 1 In 07A BELL $e^+e^- \to \Upsilon(4S)$ • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | • • • We do not use the follow 25.6 \pm 4.0 \pm 2.4 < 30 90 1 Assumes equal production of $\Gamma(\eta K_0^*(1430)^+)/\Gamma_{\text{total}}$ **MALUE (units 10^-6) 18.2 \pm 2.6 \pm 2.6 1 Assumes equal production of $\Gamma(\eta K_2^*(1430)^+)/\Gamma_{\text{total}}$ **MALUE (units 10^-6) 9.1 \pm 2.7 \pm 1.4 1 Assumes equal production of $\Gamma(\eta(1295) K^+ \times B(\eta(1295))$ **MALUE (units 10^-6) 2.9 \pm 0.7 \pm 0.2 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **ALUE (units 10^-6) <1.3 90 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **MALUE (units 10^-6) <1.2 90 1 Assumes equal production of $\Gamma(\eta(1405) K^+ \times B(\eta(1405))$ **ALUE (units 10^-6) <1.2 90 1 Assumes equal production of $\Gamma(\eta(1475) K^+ \times B(\eta(1475))$ **ALUE (units 10^-6) **C1.8 1 Assumes equal production of $\Gamma(\eta(1475) K^+ \times B(\eta(1475))$ **MALUE (units 10^-6) | ing data for averages, fits, limits, etc. • • • • • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. DOCUMENT ID TECN COMMENT TECN COMMENT TECN COMMENT TECN TEC |

| $\Gamma(f_1(1285)K^+)/\Gamma_{\text{total}}$ | Γ ₂₅₃ /Γ | $\Gamma(K^*(892)^0\pi^+)/\Gamma_{	ext{total}}$ | Γ ₂₆₄ / |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10^{-6}) CL% | DOCUMENT ID TECN COMMENT | <u>VALUE (units 10⁻⁶) </u> | DO CUMENT ID TECN COMMENT |
| <2.0 90 | ¹ AUBERT 08x BABR $e^+e^- \rightarrow \Upsilon(4S)$ | 10.1 ±0.9 OUR AVERA | |
| ¹ Assumes equal production of | of B^+ and B^0 at the $\varUpsilon(4S)$. | $10.8 \pm 0.6 \stackrel{+1.2}{-1.4}$ | |
| $\Gamma(f_1(1420)K^+ \times B(f_1(1420)K^+))$ | $(0) \rightarrow \eta \pi \pi) / \Gamma_{\text{total}}$ Γ_{254} / Γ | $9.67 \pm 0.64 {}^{+0.81}_{-0.89}$ | 1 GARMASH 06 BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT | ● ● We do not use the fol | llowing data for averages, fits, limits, etc. • • • |
| <2.9 90 | 1 AUBERT 08x BABR $e^{+}e^{-} ightarrow~ \varUpsilon(4S)$ | 13.5 $\pm 1.2 \begin{array}{c} +0.8 \\ -0.9 \end{array}$ | $^{ m 1}$ AUBERT,B $^{ m 05}$ N BABR Repl. by AUBERT 08AI |
| $^{ m 1}$ Assumes equal production $_{ m 0}$ | of B^+ and B^0 at the $arphi(4S)$. | $9.8 \pm 0.9 ^{+1.1}_{-1.2}$ | ¹ GARMASH 05 BELL Repl. by GARMASH 06 |
| $\Gamma(f_1(1420)K^+ \times B(f_1(1420)K^+))$ | $0) \rightarrow K^*K) / \Gamma_{\text{total}}$ Γ_{255} / Γ | $\begin{array}{c} -1.2 \\ 15.5 \pm 1.8 \ \pm 1.5 \\ -4.0 \end{array}$ | 1,2 AUBERT,B 04P BABR Repl. by AUBERT,B 05N |
| <u>VALUE (units 10⁻⁶)</u> <u>CL%</u> | DOCUMENT ID TECN COMMENT | | |
| <4.1 90 | 1 AUBERT 08X BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | $19.4 \begin{array}{c} +4.2 \\ -3.9 \end{array} \begin{array}{c} +4.1 \\ -7.1 \end{array}$ | ³ GARMASH 02 BELL Repl. by GARMASH 05 |
| $^{ m 1}$ Assumes equal production $^{ m c}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. | <119 90 < 16 90 | 4 ABE 00c SLD $e^+e^- \rightarrow Z$ 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(\phi(1680) K^+ \times B(\phi(1680) K^+))$ | $() \rightarrow K^*K))/\Gamma_{\text{total}}$ Γ_{256}/Γ | <390 90 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| VALUE (units 10^{-6}) CL% | DOCUMENT ID TECN COMMENT | < 41 90 | ASNER 96 CLE2 Repl. by JESSOP 00 |
| < 3.4 90 | 1 AUBERT 08X BABR $e^+e^- \rightarrow \Upsilon(4S)$ | <480 90 <170 90 | 5 ABREU 95N DLPH Sup. by ADAM 96D ALBRECHT 91B ARG $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| ¹ Assumes equal production of | of B^+ and B^0 at the $\varUpsilon(4S)$. | <150 90 | ⁶ AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(45)$ |
| Γ(ν +) /Γ | Γ/Γ | <260 90 | AVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(\omega K^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) CL% | Γ ₂₅₇ /Γ DOCUMENT ID TECN COMMENT | | n of B^+ and B^0 at the $arphi(4S)$. |
| | DOCUMENT ID TECN COMMENT Fror includes scale factor of 1.8. | $K* \rightarrow K^+\pi^-$, (25.1 \pm | It a branching ratio for $B^+	o$ "higher $K*$ resonances" π^+ |
| $6.3 \pm 0.5 \pm 0.3$ | 1 AUBERT 07AE BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | 3 Uses a reference decay | mode $B^+ 	o \overline{D}{}^0\pi^+$ and $\overline{D}{}^0	o K^+\pi^-$ with $B(B^+-1)$ |
| $8.1 \pm 0.6 \pm 0.6$ | 1 JEN 06 BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | $\overline{D}^0 \pi^+$)·B($\overline{D}^0 \rightarrow K^+ \pi$ | $^{-}) = (20.3 \pm 2.0) \times 10^{-5}$ |
| $3.2 + 2.4 \pm 0.8$ | ¹ JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | | \rightarrow $b\overline{b})=(21.7\pm0.1)\%$ and the B fractions $f_{B^0}=f_{B^+}=$ |
| | ving data for averages, fits, limits, etc. • • • | $(39.7 + 1.8 \atop -2.2)\%$ and $f_{B_s} = ($ | $10.5 + 1.8 \\ -2.2$)%. |
| $6.1 \pm 0.6 \pm 0.4$ $4.8 \pm 0.8 \pm 0.4$ | ¹ AUBERT,B 06E BABR AUBERT 07AE ¹ AUBERT 04H BABR Repl. by AUBERT,B 06E | 5 Assumes a B ^U , B [—] prod | uction fraction of 0.39 and a B_s production fraction of 0.12. 1.3 $	imes$ 10 ⁻⁴ assuming the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}{}^0$. W |
| $6.5 + 1.3 \pm 0.6$ | ¹ WANG 04A BELL Repl. by JEN 06 | rescale to 50%. | 1.3×10^{-3} assuming the $I(45)$ decays 43% to $B^{\circ}B^{\circ}$. We |
| | , | $\Gamma(K^*(892)^+\pi^0)/\Gamma_{	ext{total}}$ | Γ ₂₆₅ / |
| $9.2 + \frac{2.6}{2.3} \pm 1.0$ | | VALUE (units 10 ⁻⁶) CL | • |
| <4 90 | 1 AUBERT 01G BABR $e^+e^- \rightarrow \Upsilon(4S)$ | 8.2±1.5±1.1 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $1.5 + 7 \pm 2$ | ¹ BERGFELD 98 CLE2 Repl. by JESSOP 00 | | llowing data for averages, fits, limits, etc. • • • |
| $^{ m 1}$ Assumes equal production $^{ m c}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. | $6.9 \pm 2.0 \pm 1.3$ | AUBERT 05x BABR Repl. by LEES 11 |
| $\Gamma(\omega K^*(892)^+)/\Gamma_{\text{total}}$ | Γ ₂₅₈ /Γ | <31 90 <99 90 | · / |
| VALUE (units 10^{-6}) CL% | DOCUMENT ID TECN COMMENT | | n of B^+ and B^0 at the $\Upsilon(4S)$. |
| < 7.4 90 | 1 AUBERT 09H BABR $e^+e^- ightarrow~\varUpsilon$ (4 S) | | |
| | ving data for averages, fits, limits, etc. • • • | $\Gamma(K^+\pi^-\pi^+)/\Gamma_{\text{total}}$ | Г266/ |
| < 3.4 90 < 7.4 90 | ¹ AUBERT,В 06T BABR Repl. by AUBERT 09H ¹ AUBERT 050 BABR Repl. by AUBERT,В 06T | <u>VALUE</u> (units 10 ^{−6}) 51.0±2.9 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| <87 90 | ¹ BERGFELD 98 CLE2 | $54.4 \pm 1.1 \pm 4.6$ | 1 AUBERT 08AI BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| $^{ m 1}$ Assumes equal production $^{ m c}$ | of B^+ and B^0 at the $arphi(4S)$. | $48.8 \pm 1.1 \pm 3.6$ | 1 GARMASH 06 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| $\Gamma(\omega(K\pi)_0^{*+})/\Gamma_{\text{total}}$ | Γ ₂₅₉ /Γ | 64.1±2.4±4.0 | llowing data for averages, fits, limits, etc. • • • 1 AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| | ب ودی به دوره و در | 46.6±2.1±4.3 | ¹ GARMASH 05 BELL Repl. by GARMASH 06 |
| using LASS shape. | 76 composed of 11 ₀ (1450) and nonresonant that are described | 53.6±3.1±5.1 | ¹ GARMASH 04 BELL Repl. by GARMASH 05 ² AUBERT 03M BABR Repl. by AUBERT,B 05N |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | $59.1 \pm 3.8 \pm 3.2$ $55.6 \pm 5.8 \pm 7.7$ | ² AUBERT 03M BABR Repl. by AUBERT,B 05N 3 GARMASH 02 BELL Repl. by GARMASH 04 |
| 27.5 ± 3.0 ± 2.6 | 1 AUBERT 09H BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | | n of B^+ and B^0 at the $\varUpsilon(45)$. |
| ¹ Assumes equal production of | of B^+ and B^0 at the $\varUpsilon(4S)$. | 2 Assumes equal production | n of B^0 and B^+ at the $\Upsilon(4S)$ charm and charmonium contri |
| $\Gamma(\omega K_0^*(1430)^+)/\Gamma_{\text{total}}$ | Γ ₂₆₀ /Γ | butions are subtracted, o 3 Uses a reference decay | therwise no assumptions about intermediate resonances. mode $B^+ 	o \overline D^0 \pi^+$ and $\overline D^0 	o K^+ \pi^-$ with B(B^+ - |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | $\overline{D}{}^0\pi^+)\cdot B(\overline{D}{}^0\to K^+\pi$ | $^{-}$) = (20.3 ± 2.0) × 10 ⁻⁵ . |
| | 1 AUBERT 09H BABR $e^{+}e^{-} ightarrow~ \varUpsilon$ (4 S) | $\Gamma(K^+\pi^-\pi^+$ nonresonan | t)/Γ _{total} Γ ₂₆₇ /Ι |
| 24.0±2.6±4.4 | | VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT |
| 24.0±2.6±4.4 ¹ Assumes equal production of | of B^+ and B^0 at the $\varUpsilon(4S)$. | | |
| $^{ m 1}$ Assumes equal production $_{ m 0}$ | ` ' | | |
| 1 Assumes equal production of $\Gamma(\omegaK_2^*(1430)^+)/\Gamma_{	ext{total}}$ | of B^+ and B^0 at the \varUpsilon (45). $ \Gamma_{f 261}/\Gamma $ | 16.3+2.1 OUR AVERAG | |
| 1 Assumes equal production of $\Gamma(\omega K_{2}^{*}(1430)^{+})/\Gamma_{	ext{total}}$ | Γ ₂₆₁ /Γ | 16.3 ^{+2.1} OUR AVERAG 9.3±1.0 ⁺ 6.9 1.7 | |
| 1 Assumes equal production of $\Gamma(\omega K_{2}^{*}(1430)^{+})/\Gamma_{	ext{total}}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3+2.1 OUR AVERAG | |
| 1 Assumes equal production of $\Gamma(\omega K_{2}^{*}(1430)^{+})/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) 21.5 \pm 3.6 \pm 2.4 1 Assumes equal production of | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+}$ 2.1 OUR AVERAG 9.3 \pm 1.0 $^{+}$ 6.9 16.9 \pm 1.3 $^{+}$ 1.7 | 1,2 AUBERT 08AI BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| 1 Assumes equal production of $\Gamma(\omega K_2^*(1430)^+)/\Gamma_{\rm total}$ 21.5 ± 3.6 ± 2.4 1 Assumes equal production of $\Gamma(a_0(980)^0 K^+ \times B(a_0(980)^0 K^+))$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+2.1}_{-1.5}$ OUR AVERAG 9.3 \pm 1.0 $^{+6.9}_{-1.7}$ 16.9 \pm 1.3 $^{+1.7}_{-1.6}$ • • • We do not use the following the second of the s | 1,2 AUBERT 08AI BABR $e^+e^- ightarrow r(4S)$ 1 GARMASH 06 BELL $e^+e^- ightarrow r(4S)$ |
| 1 Assumes equal production of $\Gamma(\omega K_{2}^{*}(1430)^{+})/\Gamma_{\text{total}}$ $^{\text{VALUE}}$ (units $^{10^{-6}}$) 2 1.5 ± 3.6 ± 2.4 1 Assumes equal production of $\Gamma(a_{0}(980)^{0}K^{+} \times B(a_{0}(980)^{0}K^{+})$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+2.1}_{-1.5}$ OUR AVERAG 9.3 \pm 1.0 $^{+6.9}_{-1.7}$ 16.9 \pm 1.3 $^{+1.7}_{-1.6}$ • • • We do not use the fol 2.9 \pm 0.6 $^{+0.8}_{-0.5}$ | 1.2 AUBERT 08AI BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 GARMASH 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| 1 Assumes equal production of $\Gamma\left(\omega K_{2}^{*}(1430)^{+}\right)/\Gamma_{\text{total}}$ $\frac{VALUE}{VALUE}$ (units 10^{-6}) 21.5 ± 3.6 ± 2.4 1 Assumes equal production of $\Gamma\left(a_{0}\left(980\right)^{0}K^{+}\times\text{B}\left(a_{0}\left(980\right)^{0}K^{+}\right)\right)$ $\frac{CL\%}{<2.5}$ 90 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+}$ 2.1 OUR AVERAG 9.3 \pm 1.0 $^{+}$ 6.9 16.9 \pm 1.3 $^{+}$ 1.7 16.9 \pm 1.3 $^{+}$ 1.6 • • • We do not use the fol 2.9 \pm 0.6 $^{+}$ 0.8 17.3 \pm 1.7 $^{+}$ 17.2 17.3 \pm 1.7 $^{-}$ 8.0 | 1.2 AUBERT 08AI BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 GARMASH 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 GOUNING data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 05N BABR Repl. by AUBERT 08AI 1 GARMASH 05 BELL Repl. by GARMASH 06 |
| 1 Assumes equal production of $\Gamma(\omega K_2^*(1430)^+)/\Gamma_{\text{total}}$ $^{\text{VALUE}}$ (units 10^{-6}) 2 1.5 ± 3.6 ± 2.4 1 Assumes equal production of $\Gamma(a_0(980)^0 K^+ \times B(a_0(980)^0 K^+ \times B(a_0(980)^$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+2.1}_{-1.5}$ OUR AVERAG 9.3 \pm 1.0 $^{+6.9}_{-1.7}$ 16.9 \pm 1.3 $^{+1.7}_{-1.6}$ • • • We do not use the fol 2.9 \pm 0.6 $^{+0.8}_{-0.5}$ | 1.2 AUBERT 08AI BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 GARMASH 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| 1 Assumes equal production of $\Gamma(\omega K_2^*(1430)^+)/\Gamma_{\rm total}$ $^{21.5\pm3.6\pm2.4}$ 1 Assumes equal production of $\Gamma(a_0(980)^0 K^+ \times B(a_0(980)^0 K^- \times B(a_0(98$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+}$ 2.1 OUR AVERAG 9.3 \pm 1.0 $^{+}$ 6.9 16.9 \pm 1.3 $^{+}$ 1.7 16.9 \pm 1.3 $^{+}$ 1.7 • • We do not use the fol 2.9 \pm 0.6 $^{+}$ 0.8 17.3 \pm 1.7 $^{+}$ 17.2 < 17 < 330 90 < 28 90 | 1.2 AUBERT 08AI BABR $e^+e^- \rightarrow \mathcal{T}(4S)$ 1 GARMASH 06 BELL $e^+e^- \rightarrow \mathcal{T}(4S)$ 1 OSNI BABR Repl. by AUBERT 08AI 1 AUBERT,B 05N BABR Repl. by AUBERT 08AI 1 GARMASH 05 BELL Repl. by GARMASH 06 1 AUBERT,B 04P BABR Repl. by AUBERT,B 05N 3 ADAM 96D DLPH $e^+e^- \rightarrow \mathcal{Z}$ BERGFELD 96B CLE2 $e^+e^- \rightarrow \mathcal{T}(4S)$ |
| $\Gamma(\omega K_2^*(1430)^+)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) 21.5 ± 3.6 ± 2.4 ¹ Assumes equal production of $\Gamma(a_0(980)^0 K^+ \times B(a_0(980)^0 K^+))$ VALUE (units 10 ⁻⁶) 2.5 90 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 16.3 $^{+2.1}_{-1.5}$ OUR AVERAG 9.3 \pm 1.0 $^{+}_{-1.7}$ 6.9 \pm 1.7 16.9 \pm 1.3 $^{+}_{-1.7}$ 1.6 • • • We do not use the fol 2.9 \pm 0.6 $^{+}_{-0.5}$ 0.5 17.3 \pm 1.7 $^{+17.2}_{-8.0}$ 90 < 17 90 < 330 90 | 1.2 AUBERT 08AI BABR $e^+e^- \rightarrow r(4S)$ 1 GARMASH 06 BELL $e^+e^- \rightarrow r(4S)$ 1 GOVING data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • |

Assumes equal production of B^+ and B^0 at the T(4S). 2 Calculate the total nonresonant contribution by combining the S-wave composed of $K_0^*(1430)$ and nonresonant that are described using LASS shape. 3 Assumes a B^0 , B^- production fraction of 0.39 and a B_S production fraction of 0.12. 4 AVERY 89B reports $< 1.7 \times 10^{-4}$ assuming the T(4S) decays 43% to T(4S)0 we rescale to 50%.

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

| $\Gamma(\omega(782)K^+)/\Gamma_{\text{total}}$ Γ_{268}/Γ | $\Gamma(K^+ ho^0)/\Gamma_{ m total}$ | | | | | Γ ₂₇₅ / |
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| VALUE (units 10 ⁻⁶) DO CUMENT ID TECN COMMENT | <u>VALUE (units 10^{−6})</u> 3.7 ±0.5 O U | CL% | DOCUMENT ID | TECN | COMMENT | |
| $5.9^{+8.8}_{-9.0}^{+0.5}_{-0.4}$ 08AI BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | 3.56±0.45+0 | | ¹ AUBERT | 08AI BAB | R $e^+e^- \rightarrow \gamma$ | ^(45) |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $3.89 \pm 0.47 + 0.47 + 0.47 = 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + 0.47 + $ | | ¹ GARMASH | | $e^+e^- \rightarrow \gamma$ | ` ' |
| ² AUBERT 08AI reports $[\Gamma(B^+ \to \omega(782) K^+)/\Gamma_{total}] \times [B(\omega(782) \to \pi^+ \pi^-)] = (0.09 \pm 0.13^{+0.036}_{-0.045}) \times 10^{-6}$ which we divide by our best value $B(\omega(782) \to \pi^+ \pi^-)$ | • • • We do not i | | | | | (43) |
| $= (1.53 + 0.11 - 0.045) \times 10^{-2}.$ Our first error is their experiment's error and our second error | $5.07 \pm 0.75 + 0.75 + 0.00$ | | ¹ AUBERT,B | | R Repl. by AUI | BERT 08AL |
| is the systematic error from using our best value. | $4.78 \pm 0.75 + 1$ | | ¹ GARMASH | 05 BELI | | |
| $\Gamma(K^+ f_0(980) \times B(f_0(980) \to \pi^+ \pi^-)) / \Gamma_{\text{total}}$ Γ_{269} / Γ | < 6.2 | 90 | ² AUBERT,B | | R Repl. by AUI | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | < 12 | 90 | ³ GARMASH ⁴ ABE | 02 BELI | $e^+e^- \rightarrow \gamma$ | ^(4 <i>S</i>) |
| 9.4 $^{+1.0}_{-1.2}$ our average | < 86 < 17 | 90 90 | 1 JESSOP | 00c SLD 00 CLE | $e^+e^- \rightarrow Z$ 2 $e^+e^- \rightarrow I$ | |
| 10.3 \pm 0.5 $^{+2.0}_{-1.4}$ 1 AUBERT 08AI BABR $\mathrm{e^{+}e^{-}} ightarrow \varUpsilon(4S)$ | <120 < 19 | 90 90 | ⁵ ADAM ASNER | 96D DLP 96 CLE | | |
| $8.78\pm0.82^{+0.85}_{-1.76}$ 1 GARMASH 1 06 BELL $^{+}$ $^{-}$ \rightarrow 1 1 1 1 1 GARMASH 1 2 | <190 | 90 | ⁵ ABREU | | H Sup. by ADA | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | <180 < 80 | 90 90 | ALBRECHT ⁶ AVERY | 91B ARG | $e^+e^- ightarrow \gamma \ e^+e^- ightarrow \gamma$ | |
| $9.47\pm0.97^{+0.62}_{-0.88}$ 1 AUBERT,B 05 N BABR Repl. by AUBERT 08 AI | <260 | 90 | AVERY | | $0 e^+e^- \rightarrow 1$ | |
| $7.55\pm1.24^{+1.63}_{-1.18}$ 1 GARMASH 05 BELL Repl. by GARMASH 06 | | | B^+ and B^0 at the | | 6 | |
| 9.2 $\pm 1.2 {}^{+2.1}_{-2.6}$ 2 AUBERT,B 04P BABR Repl. by AUBERT,B 05N | AUBERT 04P r | eports a centra | al value of $(3.9 \pm B^+ \rightarrow \overline{D}{}^0\pi^0$ | $1.2^{+1.3}_{-3.5}) \times 1.2^{+1.3}_{-3.5}$ | 10 ^{—6} for this bra | inching ratio |
| 9.6 + 2.5 + 3.7 9.6 - 2.3 - 1.7 3 GARMASH 02 BELL Repl. by GARMASH 05 | $\overline{D}{}^0\pi^+)\cdot B(\overline{D}{}^0$ | \rightarrow $K^+\pi^-)$ = | $e B \rightarrow D \pi$ = $(20.3 \pm 2.0) \times$ | 10 ⁻⁵ . | → K·π WII | .пв(в - |
| -2.3 - 1.7 <80 90 4 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(45)$ | | | $(b \overline{b}) = (21.7 \pm 0)$ | 0.1)% and | the <i>B</i> fractions | $f_{B^0} = f_{B^+}$ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | (39.7 + 1.8)% | | | 20 16 | 0.10 | |
| ² AUBERT,B 04P also reports B($B^+ \to$ "higher f^0 resonances" π^+ , $f(980)^0 \to \pi^+\pi^-$) = $(3.2 \pm 1.2 \pm 0.9) \times 10^{-6}$. | 6 AVERY 898 rei | ction tractions | $f_{B^0} = f_{B^-} = 0$ -5 assuming the | .39 and ${}^{7}B_{S}$ | = 0.12. _{vs 43% to R} 0 R 0 |) We resca |
| 3 Uses a reference decay mode $B^+ \to \overline{D}{}^0\pi^+$ and $\overline{D}{}^0 \to K^+\pi^-$ with $B(B^+ \to D^0\pi^+)$ | to 50%. | poits (1 × 10 | ussumme the | 7 (45) deca | y3 4370 to D D | . vvc resea |
| $\overline{D}^0\pi^+)	imes B(\overline{D}^0	o K^+\pi^-)=(20.3\pm2.0)	imes 10^{-5}$. Only charged pions from the $f_0(980)$ are used. | $\Gamma(K_0^*(1430)^0\pi^+$ | ·)/Γ _{total} | | | | Γ ₂₇₆ / |
| 4 AVERY 89B reports $< 7 \times 10^{-5}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. We rescale | VALUE (units 10 ⁻⁶) | | DO CUMENT IE |) TEC | COMMENT | |
| to 50%. | 45 +9 OUR AV | ERAGE Erro | or includes scale f | actor of 1.5. | | |
| $\Gamma(f_2(1270)^0 K^+)/\Gamma_{\text{total}}$ Γ_{270}/Γ | $32.0\pm1.2^{+10.8}_{-6.0}$ | | $^{ m 1}$ AUBERT | 08AI BA | BR $e^+e^- \rightarrow$ | Y(45) |
| <u>VALUE (units 10⁻⁶) CL% DOCUMENT ID TECN COMMENT</u> 1.07±0.27 OUR AVERAGE | $51.6 \pm 1.7 + \begin{array}{c} 7.0 \\ -7.5 \end{array}$ | | ¹ GARMASH | 06 BEI | LL $e^+e^- \rightarrow$ | T(45) |
| $0.88 ^{+}_{-} 0.38 + 0.01 \atop -0.33 - 0.03$ | • • • We do not | | - | ges, fits, limi | ts, etc. • • • | |
| $1.33\pm0.30^{+}0.23$ $1.33\pm0.30^{+}0.23$ $1.33\pm0.30^{+}0.23$ $1.33\pm0.30^{+}0.23$ | 44.4±2.2± 5.3 | | ^{1,2} AUBERT,B | | BR Repl. by Al | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $45.0 \pm 2.9 + 15.0 \\ -10.7$ | | ¹ GARMASH | | LL Repl. by G | ARMASH 0 |
| <16 90 ³ AUBERT,B 05N BABR Repl. by AUBERT 08AI < 2.3 90 ⁴ GARMASH 05 BELL Repl. by GARMASH 06 | ¹ Assumes equal ² See erratum: <i>A</i> | | \mathcal{B}^+ and \mathcal{B}^0 at ti SA. | he $\Upsilon(4S)$. | | |
| 1 Assumes equal production of B^+ and B^0 at the $arGamma(4S)$. | $\Gamma(K_2^*(1430)^0\pi^+$ | ·) / Γ | | | | Γ277/ |
| ² AUBERT 08AI reports $(0.50 \pm 0.15 ^{+0.15}_{-0.11}) \times 10^{-6}$ for B(B ⁺ \rightarrow f ₂ (1270) K ⁺) \times B(f ₂ \rightarrow | VALUE (units 10 ⁻⁶) | | DOCUMENT IE |) TEC | N COMMENT | . 2117 |
| $\pi^+\pi^-$). We compute B($B^+\to f_2(1270)K^+$) using the PDG value B($f_2(1270)\to\pi\pi$)=(84.8 ${}^{+}2.4 \atop 1.2 \atop$ | $5.6^{+2.2}_{-1.5}\pm0.1$ | | 1,2 AUBERT | 08AI BA | BR $e^+e^- \rightarrow$ | T(45) |
| | | | ng data for averag | ges, fits, limi | ts, etc. • • • | |
| experiment's error and the second error is systematic error from using our best value. | • • vve do not i | | | | | JBERT 08A |
| experiment's error and the second error is systematic error from using our best value. 3 AUBERT,B 05N reports 8.9 \times 10 $^{-6}$ at 90% CL for B($B^+ \rightarrow f_2(1270)K^+)$ \times | < 23 | 90 | 3 AUBERT,B | 05N BA | BR Repl by Al | 00(-0) |
| experiment's error and the second error is systematic error from using our best value. 3 AUBERT,B 05N reports 8.9×10^{-6} at 90% CL for B($B^+ \rightarrow f_2(1270) K^+) \times B(f_2(1270) \rightarrow \pi^+\pi^-)$. We rescaled it using the PDG value B($f_2(1270) \rightarrow \pi\pi$) | | | ⁴ GARMASH | 05 BEI | LL $e^+e^- \rightarrow$ | |
| experiment's error and the second error is systematic error from using our best value. 3 AUBERT,B 05N reports 8.9×10^{-6} at 90% CL for B($B^+ \to f_2(1270) \ K^+) \times B(f_2(1270) \to \pi^+\pi^-)$. We rescaled it using the PDG value B($f_2(1270) \to \pi\pi$) = 84.7% and 2/3 for the $\pi^+\pi^-$ fraction. 4 GARMASH 05 reports 1.3 \times 10 ⁻⁶ at 90% CL for B($B^+ \to f_2(1270) \ K^+) \times B(f_2(1270) \ K^+)$ | < 23 < 6.9 <680 ¹ Assumes equal | 90 90 90 production of | 4 GARMASH ALBRECHT B^+ and B^0 at the second secon | 05 BEI 91 B AR he $\Upsilon(4S)$. | LL $e^+e^- \rightarrow G e^+e^- \rightarrow G$ | Y(45) |
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| experiment's error and the second error is systematic error from using our best value. ${}^{3}\text{AUBERT,B} \text{ 05n reports } 8.9 \times 10^{-6} \text{ at } 90\% \text{ CL for B}(B^{+} \rightarrow f_{2}(1270) K^{+}) \times \\ \text{B}(f_{2}(1270) \rightarrow \pi^{+}\pi^{-}). \text{ We rescaled it using the PDG value B}(f_{2}(1270) \rightarrow \pi\pi) \\ = 84.7\% \text{ and } 2/3 \text{ for the } \pi^{+}\pi^{-} \text{ fraction.}$ ${}^{4}\text{ GARMASH 05 reports } 1.3 \times 10^{-6} \text{ at } 90\% \text{ CL for B}(B^{+} \rightarrow f_{2}(1270) K^{+}) \times \\ \text{B}(f_{2}(1270) \rightarrow \pi^{+}\pi^{-}). \text{ We rescaled it using the PDG value B}(f_{2}(1270) \rightarrow \pi\pi) \\ = 84.7\% \text{ and } 2/3 \text{ for the } \pi^{+}\pi^{-} \text{ fraction.}$ $\Gamma(f_{0}(1370)^{0}K^{+} \times \text{B}(f_{0}(1370)^{0} \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad \Gamma_{\text{ECN}} \qquad COMMENT \\ \text{VALUE} \qquad CL\% \qquad DOCUMENT ID \qquad TECN \\ \text{1 ASSumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \Upsilon(4S).$ $\Gamma(\rho^{0}(1450)K^{+} \times \text{B}(\rho^{0}(1450) \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad \Gamma_{\text{272}}/\Gamma_{\text{VALUE}} \qquad CL\% \qquad DOCUMENT ID \qquad TECN \\ \text{21.7} \times 10^{-6} \qquad 90 \qquad 1 \text{ AUBERT,B} \qquad 05\text{ N} \qquad BABR \qquad e^{+}e^{-} \rightarrow \Upsilon(4S)$ $\Gamma(f_{0}(1500)K^{+} \times \text{B}(f_{0}(1500) \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad \Gamma_{\text{272}}/\Gamma_{\text{VALUE}} \qquad COMMENT \qquad e^{+}e^{-} \rightarrow \Upsilon(4S)$ $\Gamma(f_{0}(1500)K^{+} \times \text{B}(f_{0}(1500) \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad \Gamma_{\text{273}}/\Gamma_{\text{VALUE}} \qquad COMMENT \qquad e^{+}e^{-} \rightarrow \Upsilon(4S)$ $\Gamma(f_{0}(1500)K^{+} \times \text{B}(f_{0}(1500) \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad \Gamma_{\text{273}}/\Gamma_{\text{VALUE}} \qquad COMMENT \qquad COMME$ | < 23 < 6.9 <680 1 Assumes equal 2 AUBERT 08AI B($K_2^*(1430)^0$ value B($K_2^*(14)^0$ Our first error using our best 3 AUBERT, B 05 B($K_2^*(1430)^0$ $K\pi) = 49.9\%$ 4 GARMASH 05 B($K_2^*(1430)^0$ $K\pi) = 49.9\%$ F($K^*(1410)^0\pi^4$ MLUE (units 10^{-6}) <45 1 GARMASH 05 | 90 90 90 90 production of reports $(1.85 \rightarrow K^+\pi^-)$. $(30)^0 \rightarrow K\pi$ is their experivalue. 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| experiment's error and the second error is systematic error from using our best value. $^{3}\text{AUBERT,B} \text{ 05n reports } 8.9 \times 10^{-6} \text{ at } 90\% \text{ CL for B}(B^{+} \rightarrow f_{2}(1270) K^{+}) \times \\ B(f_{2}(1270) \rightarrow \pi^{+}\pi^{-}). \text{ We rescaled it using the PDG value B}(f_{2}(1270) \rightarrow \pi\pi) \\ = 84.7\% \text{ and } 2/3 \text{ for the } \pi^{+}\pi^{-} \text{ fraction.}$ $^{4}\text{ GARMASH 05 reports } 1.3 \times 10^{-6} \text{ at } 90\% \text{ CL for B}(B^{+} \rightarrow f_{2}(1270) K^{+}) \times \\ B(f_{2}(1270) \rightarrow \pi^{+}\pi^{-}). \text{ We rescaled it using the PDG value B}(f_{2}(1270) \rightarrow \pi\pi) \\ = 84.7\% \text{ and } 2/3 \text{ for the } \pi^{+}\pi^{-} \text{ fraction.}$ $\mathbf{\Gamma}(f_{0}(1370)^{0} K^{+} \times \mathbf{B}(f_{0}(1370)^{0} \rightarrow \pi^{+}\pi^{-}))/\Gamma_{\text{total}} \qquad $ | < 23 < 6.9 <680 1 Assumes equal 2 AUBERT 08AI B($K_2^*(1430)^0$ value B($K_2^*(14)^0$ Our first error using our best 3 AUBERT, B 05 B($K_2^*(1430)^0$ $K\pi) = 49.9\%$ 4 GARMASH 05 B($K_2^*(1430)^0$ $K\pi) = 49.9\%$ F($K^*(1410)^0$ π^4 MLUE (units 10^{-6}) <45 1 GARMASH 05 B($K_1^*(1410)^0$ $K\pi) = 6.6\%$ a | 90 90 90 90 production of reports $(1.85 \rightarrow K^+\pi^-)$. $(30)^0 \rightarrow K\pi$ is their experivalue. N reports $7.7 \rightarrow K^+\pi^-$). and $2/3$ for the reports $2.3 \rightarrow K^+\pi^-$). and $2/3$ for the creports $2.0 \rightarrow K^+\pi^-$). If reports $2.0 \rightarrow K^+\pi^-$). In $2/3$ for the $2/3$ | 4 GARMASH ALBRECHT B^+ and B^0 at $11\pm0.41\pm0.61$) \times We compute B($1=(49.9\pm1.2)\times$ ment's error and \times 10^{-6} at 90% We rescaled it \times 10^{-6} at | 05 BEI $_{91B}$ AR he $_{7}$ (45). $_{10^{-6}}$ for B $_{8^{+}}$ — $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ $_{8^{+}}$ | LL $e^+e^- \rightarrow G$ | $\Upsilon(45)$ $(330)^0 \pi^+)$ ing the PD π^- fractio ic error fro $(30)^0 \pi^+)$ $(310)^0 \pi^+)$ $(310)^0 \pi^+)$ $(310)^0 \pi^+)$ $(310)^0 \pi^+)$ $(310)^0 \pi^+)$ $(310)^0 \pi^+)$ |
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<15

90 $^{-2}$ AUBERT,B 05N BABR $e^+e^ightarrow \varUpsilon(4S)$

 $\Gamma(K^*(892)^+ f_0(980))/\Gamma_{\text{total}}$

 Γ_{290}/Γ

| $B(K^*(1680)^0$ | ν± -) | 8 × 10 ^{— o} at 90 | , | $B(B^+$ | → K*() | 680) $^{0}\pi^{+}) \times$ |
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| | | . We rescaled in the $K^+\pi^-$ fraction | | ie PDG | value B(| (*(1680) ⁰ → |
| $\kappa \pi = 38.7\%$ and $(K^+ \pi^0 \pi^0)/\Gamma_{\text{tot}}$ | | пекія тасы | on. | | | Γ ₂₈₀ /Γ |
| N <i>LUE</i> (units 10 ⁻⁶) | | DO CUMENT | ID | TECN | COMMENT | |
| .2±1.2±1.5 | | ¹ LEES | | | $e^+e^- \to$ | $\Upsilon(4S)$ |
| ¹ Assumes equal p | | | the $\Upsilon(4S$ |). | | |
| $(f_0(980) K^+ \times B_{LUE \text{ (units } 10^{-6})}$ | $(f_0 \to \pi^0)$ | π ⁰))/Γ _{total} <u>DOCUMENT</u> | ID | TECN | COMMENT | Γ ₂₈₁ /Γ |
| 8±0.6±0.5 | | $^{ m 1}$ LEES | 11) | BABR | $e^+e^- \rightarrow$ | T(45) |
| Assumes equal p | | f B ⁺ and B ⁰ at | the $\Upsilon(4S)$ |). | | |
| (Κ ⁻ π ⁺ π ⁺)/Γ _{to} LUE (units 10 ⁻⁶) | | DO CUMENT ID |) ТІ | ECN (| OMMENT | Γ ₂₈₂ /Γ |
| 0.95 | 90 | 1 AUBERT | | | + e ⁻ → 1 | r(45) |
| • • We do not use | e the follow | ing data for aver | ages, fits, | limits, | etc. • • • | |
| 4.5 | 90 | 1 GARMASH | | | $^+e^- \rightarrow ^-$ | |
| (1.8 (7.0 | 90 90 | ² AUBERT ³ GARMASH | | | Repl. by AU $e^+e^- \rightarrow 1$ | BERT 08BE |
| .7.0 ¹ Assumes equal p | | | | | c → . | (43) |
| ² Assumes equal p | roduction of | ום - and B + at | the $\Upsilon(4S)$ | ,. ; charm | n and charm | onium contri- |
| butions are subtr | acted, othe | rwise no assumpt | ions about | t intern | nediate reso | nances. |
| ³ Uses a reference | | | |)υ → | $K^+\pi^-$ w | ith B($B^+ \rightarrow$ |
| $\overline{D}{}^0\pi^+)\cdotB(\overline{D}{}^0-$ | | , , | × 10 °. | | | |
| $(K^-\pi^+\pi^+$ nonr | esonant)/ | Γ_{total} | | | | Γ ₂₈₃ /Γ |
| <i>LUE</i> (units 10 ⁻⁶) | CL% | DO CUMENT | ID | TECN | COMMENT | |
| 56 | 90 | BERGFELD | 96в | CLE2 | $e^+e^- \to$ | Y(45) |
| $(K_1(1270)^0\pi^+)$ | /Ftotal | | | | | Γ ₂₈₄ /Γ |
| LUE | CL% | <u>DO CUMENT</u> | ID | TECN | COMMENT | - 2047 - |
| (4.0 × 10 ⁻⁵ | 90 | 1 AUBERT | | | $e^+e^- \rightarrow$ | Υ(4S) |
| ¹ Assumes equal p | roduction o | $f B^+$ and B^0 at | the $\Upsilon(4S)$ | ١. | | , , |
| | | . 5 4.14 5 41 | (| ,. | | |
| $(K_1(1400)^0\pi^+)$ | | | | | | Г ₂₈₅ /Г |
| NLUE | <u>CL%</u> | DOCUMENT | | | | 20(4.0) |
| (3.9 × 10^{−5} • • We do not use | 90 e the follow | ¹ AUBERT ing data for aver | | | e+ e− → | r(45) |
| \sim 6 vve do not use (2.6×10^{-3}) | e the follow 90 | ALBRECH | _ | | $e^+e^- \rightarrow$ | Y(45) |
| ∠.v × 1v ~ | 90 | | | ARG | e · e → | 1 (43) |
| 1 Accumes | roduct! | t D+ 221 DII . | | J - | | |
| ¹ Assumes equal p | | f B ⁺ and B [∪] at | the T(45 | | | |
| 1 Assumes equal p $(\kappa^0\pi^+\pi^0)/\Gamma_{ m tot}$ | al | | , | | | Γ ₂₈₆ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ | al <u>CL%</u> | <u>DO CUMENT</u> | <i>ID</i> . | | | |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (66×10^{-6}) | CL% 90 | DOCUMENT 1 ECKHART | <i>ID</i> 02 | CLE2 | $\frac{\textit{COMMENT}}{e^+ e^- \rightarrow}$ | |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ | CL% 90 | DOCUMENT 1 ECKHART | <i>ID</i> 02 | CLE2 | | |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (66×10^{-6}) 1 Assumes equal p | CL% 90 | DOCUMENT 1 ECKHART | <i>ID</i> 02 | CLE2 | | Υ(45) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ | CL% 90 | DOCUMENT 1 ECKHART | $\frac{ID}{02}$ the $\Upsilon(4S)$ | CLE2). | $e^+ e^- \rightarrow$ | |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ | CL% 90 roduction o | $rac{DOCUMENT}{1}$ ECKHART f B^+ and B^0 at $rac{DOCUMENT}{1}$ | $\frac{ID}{02}$ the $\Upsilon(4S)$ | CLE2). <u>TECN</u> | $e^+e^- \rightarrow$ | τ(4 <i>S</i>) Γ ₂₈₇ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ (LUE) (units 10^{-6}) (LUE) (units 10^{-6}) | CL% 90 roduction of | $rac{DOCUMENT}{1}$ ECKHART f B^+ and B^0 at $rac{DOCUMENT}{1}$ | $\frac{ID}{02}$ the $\Upsilon(4S)$ $\frac{ID}{07Z}$ | CLE2). <u>TECN</u> BABR | $e^+e^- \rightarrow$ $\frac{\text{COMMENT}}{e^+e^- \rightarrow}$ | τ(4 <i>S</i>) Γ ₂₈₇ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (LUE) $(.66 \times 10^{-6}$ 1 Assumes equal p $(K^0\rho^+)/\Gamma_{\text{total}}$ 1 Assumes equal p | 90 roduction o | $\frac{\textit{DOCUMENT}}{1} \text{ ECKHART}$ f \textit{B}^+ and \textit{B}^0 at $\frac{\textit{DOCUMENT}}{\text{AUBERT}}$ ing data for aver | the $r(4S)$ 02 ID 07 07 ages, fits, | CLE2). <u>TECN</u> BABR limits, | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \underline{} \\ \underline{} \\ \underline{} \\ e^{+}e^{-} \rightarrow \\ \underline{} \\ \underline$ | τ(4S) Γ ₂₈₇ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(LUE \text{ (units } 10^{-6})$ $(LUE \text{ (units } 10^{-6})$ $(LUE \text{ (units } 10^{-6})$ | CL% 90 roduction of | $rac{DOCUMENT}{1}$ ECKHART f B^+ and B^0 at $rac{DOCUMENT}{1}$ | the $r(4S)$ 02 ID 07 07 ages, fits, | CLE2). <u>TECN</u> BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \underline{} \\ \underline{} \\ \underline{} \\ e^{+}e^{-} \rightarrow \\ \underline{} \\ \underline$ | τ(4 <i>S</i>) Γ ₂₈₇ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ | go ct% 90 roduction of ct% ct% 90 | $\frac{\textit{DOCUMENT}}{1} \text{ ECKHART}$ f \textit{B}^+ and \textit{B}^0 at $\frac{\textit{DOCUMENT}}{\text{AUBERT}}$ ing data for aver | the $r(4S)$ 02 ID 07 07 ages, fits, | CLE2). <u>TECN</u> BABR limits, | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \underline{} \\ \underline{} \\ \underline{} \\ e^{+}e^{-} \rightarrow \\ \underline{} \\ \underline$ | τ(4S) Γ ₂₈₇ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ | or oduction of the following of the foll | $\frac{\textit{DOCUMENT}}{1} \text{ ECKHART}$ f \textit{B}^+ and \textit{B}^0 at $\frac{\textit{DOCUMENT}}{\text{AUBERT}}$ ing data for aver | 02 the T(45 1D 07z ages, fits, 96 | CLE2). <u>TECN</u> BABR limits, CLE2 | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \phantom{aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa$ | r(45) $r(45)$ $r(45)$ $r(45)$ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ (LUE) (units 10^{-6}) $8.0^{+}_{-1.3}^{+1.3}^{+0.6}$ • • We do not use (48) $(K^*(892)^+\pi^+\pi^+\pi^+\pi^-)$ (LUE) (units 10^{-6}) $(K^*(892)^+\pi^+\pi^+\pi^-)$ | cL% 90 roduction of CL% e the follow 90)/\(\triangle \text{total} \) | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{4}$ AUBERT ing data for aver ASNER $\frac{DOCUMENT}{1}$ AUBERT,B | 1D 02 the γ(45) 1D 07z ages, fits, 96 | CLE2). TECN BABR limits, CLE2 TECN BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | τ(45) Γ ₂₈₇ /Γ τ(45) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ (LUE) (units 10^{-6}) $8.0^{+}_{-1.3}^{+1.3}^{+0.6}$ • • We do not use (48) $(K^*(892)^+\pi^+\pi^+\pi^+\pi^-)$ (LUE) (units 10^{-6}) $(K^*(892)^+\pi^+\pi^+\pi^-)$ | cL% 90 roduction of CL% e the follow 90)/\(\triangle \text{total} \) | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{1} \text{ AUBERT}$ as ASNER $\frac{DOCUMENT}{1} \text{ AUBERT,B}$ ing data for aver data for aver | 02 the \(\tau(45) \) 07z ages, fits, 96 | CLE2). TECN BABR limits, CLE2 TECN BABR limits, directions | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | τ(45) Γ ₂₈₇ /Γ τ(45) τ(45) τ(45) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (LUE) $(.66 \times 10^{-6})$ 1 Assumes equal p $(K^0\rho^+)/\Gamma_{\text{total}}$ 1 Assumes equal p (LUE) (units 10^{-6}) 1 8.0 $+$ 1.3 \pm 0.6 • We do not use 1 48 $(K^*(892)^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | cL% 90 roduction of CL% e the follow 90)/\(\triangle \text{total} \) | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{4}$ AUBERT ing data for aver ASNER $\frac{DOCUMENT}{1}$ AUBERT,B | 02 the \(\tau(45) \) 07z ages, fits, 96 | CLE2). TECN BABR limits, CLE2 TECN BABR limits, directions | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | τ(45) Γ ₂₈₇ /Γ τ(45) τ(45) Γ ₂₈₈ /Γ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (LUE) $(.66 \times 10^{-6})$ 1 Assumes equal p $(K^0\rho^+)/\Gamma_{\text{total}}$ 1 Assumes equal p (LUE) (units 10^{-6}) 1 8.0 $+$ 1.3 \pm 0.6 • We do not use 1 48 $(K^*(892)^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | ct% 90 roduction o ct% 90)/Ftotal ct% e the follow 90 | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{1} \text{ AUBERT}$ ing data for aver 4 SNER $\frac{DOCUMENT}{1} \text{ AUBERT,B}$ ing data for aver 4 LBRECH^- | 02 the γ(45 1D 07z ages, fits, 96 1D 08s, fits, 7 91E | TECN BABR limits, CLE2 TECN BABR limits, ARG | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \hline \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ \hline \\ e^{+}e^{-} \rightarrow \\ \\ \hline \end{array}$ | τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) |
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| $(K^0\pi^+\pi^0)/\Gamma_{\rm tot}$ (LUE) (LUE) 1 Assumes equal p $(K^0\rho^+)/\Gamma_{\rm total}$ (LUE) (units 10^{-6}) 8.0 $^{+1.4}_{-1.3} \pm 0.6$ • We do not use $(K^*(892)^+\pi^+\pi^+\pi^+\pi^-)$ (LUE) (units 10^{-6}) 75.3 $\pm 6.0 \pm 8.1$ • We do not use (LUE) (units (LUE)) 1 Assumes equal p $(K^*(892)^+\rho^0)/(K^*(892)^+\rho^0)$ | cL% 90 roduction of cl% e the follow 90)/Ftotal cL% e the follow 90 roduction of colored co | DOCUMENT 1 ECKHART f B+ and B ⁰ at DOCUMENT AUBERT ing data for aver ASNER 1 AUBERT,B ing data for aver ALBRECHT f B+ and B ⁰ at | the $\Upsilon(4S)$ 02 the $\Upsilon(4S)$ 07 07 ages, fits, 96 ages, fits, 7 10 11 12 13 14 15 16 17 18 18 18 18 18 18 18 18 18 | TECN BABR limits, CLE2 TECN BABR limits, ARG | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \hline \\ comment \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \hline \\ comment \\ e^{+}e^{-} \rightarrow \\ \\ \hline \\ e^{+}e^{-} \rightarrow \\ \\ e^{+}e^{-} \rightarrow \\ \\ \end{array}$ | τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (LUE) (66×10^{-6}) $(K^0\rho^+)/\Gamma_{\text{total}}$ (LUE) (units $10^{-6})$ (LUE) (units $10^{-6})$ $(K^*(892)^+\rho^0)$ (LUE) (units $10^{-6})$ | cL% 90 roduction of cl% e the follow 90)/Ftotal cL% e the follow 90 roduction of colored co | DOCUMENT 1 ECKHART 1 B + and B at DOCUMENT AUBERT ing data for aver ASNER DOCUMENT 1 AUBERT,B ing data for aver ALBRECH 1 B + and B at DOCUMENT ID | 02 the \(\tau(4S) \) 07 07 07z ages, fits, 96 10 10 10 10 11 11 12 13 14 15 16 17 17 18 18 18 18 18 18 18 18 | CLE2). TECN BABR limits, CLE2 TECN BABR limits, GARG). | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \end{array}$ | T(4S) Γ287/Γ T(4S) T(4S) Γ288/Γ T(4S) Γ(4S) Γ(4S) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ (LUE) (units 10^{-6}) $8.0^{+1}.3^{+0.6}$ • • We do not use (48) $(K^*(892)^+\pi^+\pi^+\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | cL% 90 roduction of cL% e the follow 90)/Ftotal CL% e the follow 90 roduction of cL% | DOCUMENT 1 ECKHART 1 ECKHART 1 B+ and B ⁰ at DOCUMENT AUBERT 1 AUBERT 1 AUBERT,B ing data for aver ALBRECH 1 B+ and B ⁰ at DOCUMENT ID 1 DEL-AMO-SA | the $\Upsilon(4S)$ 02 the $\Upsilon(4S)$ 07 07 ages, fits, 96 06 ages, fits, 7 10 TEC TEC BA | CLE2 TECN BABR BABR BABR BABR BBABR | $\begin{array}{c} e^{+}e^{-}\rightarrow\\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}}\rightarrow\\ \\ e^{+}e^{-}\rightarrow\\ \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}}\rightarrow\\ \\ e^{+}e^{-}\rightarrow\\ \\ e^{+}e^{-}\rightarrow\\ \\ \end{array}$ | T(4S) Γ287/Γ T(4S) T(4S) Γ288/Γ T(4S) Γ(4S) Γ(4S) |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(K^0\rho^+)/\Gamma_{\text{total}}$ $(LUE (units 10^{-6})$ $8.0^{+1}_{-1.3} \pm 0.6$ \bullet • We do not use (48) $(K^*(892)^+\pi^+\pi^+\pi^-)$ $(K^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^0\pi^$ | cL% 90 roduction of cL% e the follow 90)/Ftotal CL% e the follow 90 roduction of cL% ct% e the follow | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{1} \text{ AUBERT}$ ing data for aver ASNER $\frac{DOCUMENT}{1} \text{ AUBERT,B}$ ing data for aver $\text{ALBRECH}^- \text{ f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT ID}{1} \text{ DEL-A MO-SA}$ ing data for aver | the $\Upsilon(4S)$ 02 the $\Upsilon(4S)$ 07 07z ages, fits, 96 1D 1D 1D 1D 1D 1D 1D 1D 1D 1 | CLE2 BABR limits, CLE2 TECN BABR Rimits, ARG). | $\begin{array}{c} e^{+}e^{-}\rightarrow\\ \\ \hline comment\\ e^{+}e^{-}\rightarrow\\ e^{+}e^{-}\rightarrow\\ \hline c^{+}e^{-}\rightarrow\\ e^{+}e^{-}\rightarrow\\ e^{+}e^{-}\rightarrow\\ \end{array}$ | r(4S) $r(4S)$ $r(4S)$ $r(4S)$ $r(4S)$ $r(4S)$ $r(4S)$ $r(4S)$ $r(4S)$ |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(K^0\pi^+)/\Gamma_{\text{total}}$ $(LUE (\text{units }10^{-6})$ $8.0^{+1}.3^{\pm}0.6$ • We do not use (48) $(K^*(892)^+\pi^+\pi^+\pi^-)$ $(K^0\pi^0)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm}(100)^{\pm$ | cL% 90 roduction of cL% e the follow 90)/Ftotal CL% e the follow 90 roduction of cL% | DOCUMENT 1 ECKHART 1 B + and B 0 at DOCUMENT AUBERT 1 AUBERT, 1 AUBERT, Ing data for aver ALBRECH 1 B + and B 0 at DOCUMENT ID 1 DEL-A MO-SA ing data for aver 1 AUBERT,B | 1D 02 the Υ(4S 1D 07Z ages, fits, 96 1D 60 ages, fits, Γ 91E the Υ(4S | CLE2 BABR limits, , CLE2 TECN BABR limits, , ARG). | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMEN}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-$ | τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) -AMO-11D |
| $(K^0\pi^+\pi^0)/\Gamma_{\rm tot}$ $(K^0\pi^+\pi^0)/\Gamma_{\rm tot}$ $(K^0\rho^+)/\Gamma_{\rm tot}$ $($ | cL% 90 roduction of cL% e the follow 90)/Ftotal CL% e the follow 90 roduction of cL% ct% e the follow | $\frac{DOCUMENT}{1} \text{ ECKHART}$ $\text{f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT}{1} \text{ AUBERT}$ ing data for aver ASNER $\frac{DOCUMENT}{1} \text{ AUBERT,B}$ ing data for aver $\text{ALBRECH}^- \text{ f } B^+ \text{ and } B^0 \text{ at}$ $\frac{DOCUMENT ID}{1} \text{ DEL-A MO-SA}$ ing data for aver | 1D 02 the Υ(4S 1D 07Z ages, fits, 96 1D 60 ages, fits, Γ 91E the Υ(4S | CLE2 BABR limits, , CLE2 TECN BABR limits, , ARG). | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \frac{COMMENT}{e^{+$ | τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) τ(45) -AMO-11D |
| $(K^0\pi^+\pi^0)/\Gamma_{\text{tot}}$ (LUE) $(.666 \times 10^{-6}$ 1 Assumes equal p $(K^0\rho^+)/\Gamma_{\text{total}}$ 1 Assumes equal p 1 1 1 1 1 1 1 1 1 1 | cL% 90 roduction of cL% e the follow 90)/Ftotal CL% e the follow 90 roduction of cL% ct% e the follow | DOCUMENT 1 ECKHART 1 B + and B 0 at DOCUMENT AUBERT 1 AUBERT, 1 AUBERT, Ing data for aver ALBRECH 1 B + and B 0 at DOCUMENT ID 1 DEL-A MO-SA ing data for aver 1 AUBERT,B | 1D 02 the Υ(4S 1D 07Z ages, fits, 96 1D 60 ages, fits, Γ 91E the Υ(4S | CLE2 TECN BABR Ilimits, CLE2 TECN BABR Ilimits, ARG). DA CC BR e ⁻¹ Ilimits, BR Re BR Re BR Re | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^+e^- \rightarrow \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMEN}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \frac{COMMENT}{e^+e^-$ | T(45) Γ287/Γ T(45) T(45) Γ288/Γ T(45) Γ(45) Γ289/Γ (45) -AMO- 11D ERT,B 066 (45) |

| ALUE (units 10 ⁻⁶) | 1 DEL-A | MO-SA11D BABR $e^+e^- ightarrow \varUpsilon(4S)$ | |
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| | | ing data for averages, fits, limits, etc. • • • | |
| .2±1.2±0.5 | | RT,B 06G BABR Repl. by DEL-AMO-SANCHEZ 1 | 1 D |
| 1 Assumes equal (| production of | f B^+ and B^0 at the $arphi(4S)$. | |
| | | | |
| $\Gamma(a_1^+ K^0)/\Gamma_{\text{total}}$ | | Г291 | /Γ |
| ALUE (units 10 ⁻⁶) | | $\frac{DOCUMENT\ ID}{1.2} \frac{TECN}{AUBERT} 08F BABR e^+e^- \rightarrow \Upsilon(4S)$ | |
| 4.9±5.0±4.4 | | () | |
| Assumes equal p | production of | f B^+ and B^0 at the $\Upsilon(4S)$. | |
| ² Assumes a_1^{\pm} de | cays only to | 3π and $B(a_1^{\pm} \rightarrow \pi^{\pm}\pi^{\mp}\pi^{\pm}) = 0.5$. | |
| $\Gamma(b_1^+ K^0 \times B(b_1^+))$ | → ωπ+1` |)/F _{total} F ₂₉₂ | /г |
| ALUE (units 10 ⁻⁶) | | | ′ |
| 0.6±1.7±0.9 | | $rac{DOCUMENT\ ID}{1} rac{TECN}{AUBERT} rac{COMMENT}{e^+e^- ightarrow arphi(4S)}$ | |
| | production of | f B^+ and B^0 at the $\varUpsilon(4S)$. | |
| | | | |
| $\Gamma(K^*(892)^0 \rho^+)$ | /Γ _{total} | Γ293 | /г |
| ALUE (units 10 ⁻⁶) | | DOCUMENT ID TECN COMMENT | |
| 9.2±1.5 OUR AVE 9.6±1.7±1.5 | KAGE | 1 AUBERT,B 06G BABR $e^+e^- ightarrow \varUpsilon(4S)$ | |
| 3.9±1.7±1.2 | | 1 ZHANG 05D BELL $e^+e^- \rightarrow \Upsilon(45)$ | |
| | production of | f B^+ and B^0 at the $\Upsilon(4S)$. | |
| | | , , | |
| $(K_1(1400)^+ \rho^0)$ | | Γ ₂₉₄ | /۲ |
| <u> </u> | <u>CL%</u> 90 | ALBRECHT 91B ARG $e^+e^- 	o 	au(45)$ | |
| ***** | | ALDRECHT SIR AKO $e \cdot e \rightarrow I(45)$ | |
| $\Gamma(K_2^*(1430)^+ \rho^0)$ |)/F _{total} | Г ₂₉₅ | /г |
| ALUE <1.5 × 10 ⁻³ | CL% | DOCUMENT ID TECN COMMENT | |
| $< 1.5 \times 10^{-3}$ | 90 | ALBRECHT 91B ARG $e^+e^- ightarrow \varUpsilon(4S)$ | |
| $\Gamma(b_1^0 K^+ \times B(b_1^0$ | $\rightarrow \omega \pi^0$)) | /F _{total} F ₂₉₆ | /г |
| /ALUE (units 10 ⁻⁶) | | DO CUMENT ID TECN COMMENT | ′ |
| | | | |
| $9.1 \pm 1.7 \pm 1.0$ | | * AUBERT U/BLBABR e e → /(45) | |
| 3.1±1.7±1.0 1 Assumes equal (| aroduction of | () | |
| ¹ Assumes equal | | f B^+ and B^0 at the $\Upsilon(4S)$. | |
| ¹ Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^-))$ | $_{\rm L}^{+} \rightarrow \omega \pi^{+})$ | f B^+ and B^0 at the $\varUpsilon(4S)$. | /г |
| ¹ Assumes equal $(b_1^+ K^{*0} \times B(b_1^-))$ | ⁺ → ωπ ⁺) | f B^+ and B^0 at the $\Upsilon(4S)$.)/ $\Gamma_{	ext{total}}$ | /г |
| Assumes equal properties $(b_1^+ K^{*0} \times B(b_1^-))$ $(ALUE)$ (5.9×10^{-6}) | $\frac{\stackrel{+}{}_{1} \rightarrow \omega \pi^{+}}{\stackrel{CL\%}{90}}$ | f B^+ and B^0 at the $\Upsilon(4S)$. 1)/ $\Gamma_{	ext{total}}$ DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 OPAF BABR 2 COMMENT 1 AUBERT | /г |
| Assumes equal $(b_1^+ K^{*0} \times B(b_1^- $ | $\frac{1}{1} \rightarrow \omega \pi^+$) $\frac{CL\%}{90}$ production of | if B^+ and B^0 at the $\Upsilon(4S)$. 1)/ Γ_{total} DOCUMENT ID 1 AUBERT 1 AUBER | /Г |
| Assumes equal $(b_1^+ K^{*0} \times B(b_1^- $ | $\frac{1}{1} \rightarrow \omega \pi^+$) $\frac{CL\%}{90}$ production of | if B^+ and B^0 at the $\Upsilon(4S)$. 1)/ Γ_{total} DOCUMENT ID 1 AUBERT 1 AUBER | _ |
| ¹ Assumes equal $ \Gamma(b_1^+ K^{*0} \times B(b_1^- K^{*0}) \times B(b_1^- K^{*0}) \times B(b_1^- K^{*0}) $ ** Assumes equal $ \Gamma(b_1^0 K^{*+} \times B(b_1^- K^{*0}) \times B(b_1^- K^{*0}) $ ** ALUE | $rac{1}{1} ightarrow \omega \pi^+ ight) rac{CL\%}{90}$ production of $2 ightarrow \omega \pi^0 ight) angle$ | f B^+ and B^0 at the $\Upsilon(4S)$. 1)/ Γ_{total} DOCUMENT ID 1 AUBERT 2 AUBERT 3 AUBERT 4 AUBERT 4 AUBERT 5 AUBERT 6 AUBERT | _ |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $\frac{\frac{1}{1} \rightarrow \omega \pi^{+}}{90}$ production of $\frac{1}{2} \rightarrow \omega \pi^{0}$ $\frac{cL\%}{90}$ | f B^+ and B^0 at the $\Upsilon(4S)$. 1)/ Γ_{total} DOCUMENT ID 1 AUBERT 1 OPAF BABR 1 OPAF BAB | _ |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $\frac{\frac{1}{1} \rightarrow \omega \pi^{+}}{90}$ production of $\frac{1}{2} \rightarrow \omega \pi^{0}$ $\frac{cL\%}{90}$ | f B^+ and B^0 at the $\Upsilon(4S)$. 1)/ Γ_{total} DOCUMENT ID 1 AUBERT 2 AUBERT 3 AUBERT 4 AUBERT 4 AUBERT 5 AUBERT 6 AUBERT | _ |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $\frac{1}{1} \rightarrow \omega \pi^+$) $\frac{CL\%}{90}$ production of $\frac{1}{2} \rightarrow \omega \pi^0$) $\frac{CL\%}{90}$ production of | if B^+ and B^0 at the $\Upsilon(4S)$. \begin{align*} align | /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $\frac{1}{1} \rightarrow \omega \pi^{+}$ 90 production of $\frac{1}{1} \rightarrow \omega \pi^{0}$ $\frac{1}{1} \rightarrow \omega \pi^{0}$ 90 production of | if B^+ and B^0 at the $T(4S)$. | /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^-) K^$ | $t \rightarrow \omega \pi^+$) $0 \rightarrow \omega \pi^0$) production of $0 \rightarrow \omega \pi^0$) $0 \rightarrow \omega \pi^0$) production of $0 \rightarrow \omega \pi^0$ | if B^+ and B^0 at the $T(4S)$. Image | /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $t \rightarrow \omega \pi^+$) $0 \rightarrow \omega \pi^0$) production of $0 \rightarrow \omega \pi^0$) $0 \rightarrow \omega \pi^0$) production of $0 \rightarrow \omega \pi^0$ | if B^+ and B^0 at the $T(4S)$. | /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- KLUE) \times 5.9 \times 10^{-6}$ 1 Assumes equal $\Gamma(b_1^0 K^{*+} \times B(b_1^- KLUE) \times 5.7 \times 10^{-6}$ 1 Assumes equal $\Gamma(K^+ \overline{K}^0)/\Gamma_{\text{total}}$ $\frac{(K^+ \overline{K}^0)}{1.36 \pm 0.27 \text{ out}}$ $\frac{(K^+ LUE)}{1.22 \pm 0.32 \pm 0.1}$ $\frac{(K^+ LUE)}{1.22 \pm 0.32 \pm 0.1}$ | $\stackrel{+}{l} \rightarrow \omega \pi^+$) $\stackrel{CL\%}{90}$ production of $\stackrel{CL\%}{l} \rightarrow \omega \pi^0$) $\stackrel{CL\%}{90}$ production of $\stackrel{CL\%}{l} \rightarrow \omega \pi^0$ | if B^+ and B^0 at the $\Upsilon(4S)$.)/\Gamma_{DOCUMENT ID} \text{TECN} \text{COMMENT} \text{7297} \\ 1 AUBERT \text{09AF BABR} \text{e}^+e^- \rightarrow \text{7(4S)} \\ /\Gamma_{total} \text{DOCUMENT ID} \text{TECN} \text{COMMENT} \text{TECN} \\ \frac{DOCUMENT ID}{1} \text{AUBERT} \text{09AF BABR} \text{e}^+e^- \rightarrow \text{7(4S)} \\ \frac{DOCUMENT ID}{6} \text{TECN} \text{COMMENT} \text{TECN} \\ \frac{DOCUMENT ID}{299} \text{TECN} \text{COMMENT} \\ \frac{DOCUMENT ID}{1} \text{TECN} \text{COMMENT} \\ \frac{1}{1} \text{LIN} \text{07 BELL} \text{e}^+e^- \rightarrow \text{7(4S)} \\ \frac{1}{1} \text{07 BELL} \text{e}^+e^- \rightarrow \text{7(4S)} \\ \frac{1}{1} \text{LIN} \text{07 BELL} \\ \frac{1}{1} \t | /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $\frac{t}{0} \rightarrow \omega \pi^{+}$ 90 production of $\frac{c + w}{90}$ 90 production of $\frac{c + w}{90}$ production of $\frac{c + w}{8}$ R AVERAGE 36 9 | f B^+ and B^0 at the $\Upsilon(4S)$. 1) / Γ_{total} Γ_{297} 1 AUBERT 09AF BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 F Φ^+ and Φ^0 at the Φ^0 at the Φ^0 Φ^0 at the Φ^0 at | /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- KLUE}) \times (5.9 \times 10^{-6})$ 1 Assumes equal $\Gamma(b_1^0 K^{*+} \times B(b_1^- K^{*-1} \times B(b_1^- K^{*-$ | $t \to \omega \pi^+$) 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $\Upsilon(4S)$. // Γ_{total} | /r /r |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $t \rightarrow \omega \pi^+$) $c t \%$ 90 production of $t \rightarrow \omega \pi^0$) $c t \%$ 90 production of $t \rightarrow \omega \pi^0$ 81 $c t \%$ 82 83 69 99 see the follow | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /г /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- KLUE) \times 5.9 \times 10^{-6}]$ 1 Assumes equal $(b_1^0 K^{*+} \times B(b_1^0 K^{*+} \times B(b_1$ | $t \rightarrow \omega \pi^+$) $0 \rightarrow 0$ production of $0 \rightarrow 0$ $0 \rightarrow 0$ production of $0 \rightarrow 0$ $0 \rightarrow $ | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /г /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b$ | $t \rightarrow \omega \pi^+$) $0 \leftarrow 0$ production of $t \rightarrow 0$ $0 \leftarrow 0$ $0 \leftarrow 0$ production of $t \rightarrow 0$ $0 \leftarrow 0$ | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /г /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- KLUE}) \times (5.9 \times 10^{-6})$ 1 Assumes equal $\Gamma(b_1^0 K^{*+} \times B(b_1^- K^{*-1} \times B(b_1^- K^{*-$ | $t \rightarrow \omega \pi^+$) $c t \%$ $g 0$ production of $t \rightarrow \omega \pi^0$) $g \rightarrow \omega \pi^0$) $g \rightarrow \omega \pi^0$ | f B^+ and B^0 at the $\Upsilon(4S)$. \begin{align*} align* | /г /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b$ | $t \rightarrow \omega \pi^+$) $c t \%$ 90 production of $t \rightarrow \omega \pi^0$) $c t \%$ 90 production of $t \rightarrow \omega \pi^0$ 80 $t \rightarrow \omega \pi^0$ 90 90 90 90 90 90 90 | f B^+ and B^0 at the $T(4S)$.)/\Gamma_{total} \begin{align*} alig | /г /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- KLUE}) \times (5.9 \times 10^{-6})$ 1 Assumes equal $\Gamma(b_1^0 K^{*+} \times B(b_1^- KLUE}) \times (6.7 \times 10^{-6})$ 1 Assumes equal $\Gamma(K^+ \overline{K}^0) / \Gamma_{\text{total}} \times (6.7 \times 10^{-6})$ 1 Assumes equal $\Gamma(K^+ \overline{K}^0) / \Gamma_{\text{total}} \times (6.7 \times 10^{-6})$ 1.36±0.27 Out 1.22+0.32+0.1 1.61±0.44±0.0 ••• We do not us 1.0±0.4±0.1 1.5±0.5±0.1 < 2.5 < 3.3 < 3.3 < 3.3 < 3.3 < 3.0 < 2.0 < 5.0 < 2.4 | $t \rightarrow \omega \pi^+$) $0 \rightarrow \omega \pi^0$ 90 production of $t \rightarrow \omega \pi^0$) $0 \rightarrow \omega \pi^0$ 90 production of $t \rightarrow \omega \pi^0$ 90 90 90 90 90 90 90 | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /г /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b_$ | $t \rightarrow \omega \pi^+$) $0 \rightarrow \omega \pi^0$ 90 production of $t \rightarrow \omega \pi^0$) $0 \rightarrow \omega \pi^0$ 90 production of $t \rightarrow \omega \pi^0$ 90 90 90 90 90 90 90 | f B^+ and B^0 at the $T(4S)$. Item | /г /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- KLUE) \times S.9 \times 10^{-6})$ 1 Assumes equal $(b_1^- K^* \times B(b_1^- K^* K^* \times B(b_1^- K^$ | $t \rightarrow \omega \pi^+$) $c \in \mathbb{N}$ 90 production of $t \rightarrow \omega \pi^0$) $c \in \mathbb{N}$ 90 production of $t \rightarrow \omega \pi^0$) 8 AVERAGE 36 99 90 90 90 90 90 90 90 90 | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /г /г |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- K^{*0} \times B(b$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Problem of the color of t | /г /г |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- KLUE) \times (5.9 \times 10^{-6})$ 1 Assumes equal $(b_1^- K^+ \times B(b_1^- K^- K^- K^- K^- K^- K^- K^- K^- K^- K$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Problem of the proble | /r /r |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- K^- K^- K^- K^- K^- K^- K^- K^- K^- K$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$.)/ Γ_{total} | /r /r |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- KLUE}) \times (5.9 \times 10^{-6}) \times (6.1 \times 10^{-$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Teach of the content | /r /r |
| 1 Assumes equal | $t 	o \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Problem of the component of t | /r /r |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B b_1^-)$ ΔLUE $< 5.9 \times 10^{-6}$ 1 Assumes equal $\Gamma(b_1^0 K^{*+} \times B b_1^-)$ ΔLUE $< 6.7 \times 10^{-6}$ 1 Assumes equal $\Gamma(K^+ \overline{K^0})/\Gamma_{\text{total}}$ ΔLUE | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Teach of the proof of the | /r /r |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B(b_1^- K^- K^{*0} \times B(b_1^- K^{*0} \times B(b_1^- K^- K^- K^- K^- K^- K^- K^- K^- K^- K$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Teasy of the following problem of the following pro | /r /r |
| 1 Assumes equal $\Gamma(b_1^+ K^{*0} \times B b_1^- K^{*0} \times B b_1^- K^{*0} \times B b_1^- K^- K^- K^- K^- K^- K^- K^- K^- K^- K$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Teach of the proof of the | /r /r |
| 1 Assumes equal | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Problem of the complete of the co | /r /r |
| 1 Assumes equal $(b_1^+ K^{*0} \times B(b_1^- MLUE) \times (5.9 \times 10^{-6}) \times (5.9 \times 10^{$ | $t \rightarrow \omega \pi^+)$ 0 0 0 0 0 0 0 0 0 0 | f B^+ and B^0 at the $T(4S)$. Image: Problem of the complete of the co | /r /r |

 B^{\pm}

| $\Gamma(K_S^0K_S^0\pi^+)/\Gamma_{\text{total}}$ Γ_{302}/Γ | $\Gamma(K^{*+}K^{+}\pi^{-})/\Gamma_{\text{total}}$ Γ_{312}/Γ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁶) CL% DO CUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| <0.51 90 ¹ AUBERT 09J BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | <6.1 90 ¹ AUBERT,B 060 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| <3.2 90 1 GARMASH 04 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$. |
| 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. | $\Gamma(K^+K^-K^+)/\Gamma_{\text{total}}$ Γ_{313}/Γ |
| | 33.7±2.2 OUR AVERAGE Error includes scale factor of 1.4. |
| $\Gamma(K^+K^-\pi^+)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | 35.2 \pm 0.9 \pm 1.6 1 AUBERT 060 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5.0 \pm 0.5 \pm 0.5 1 AUBERT 07BB BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $30.6\pm1.2\pm2.3$ 1 GARMASH 05 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <13 90 $\frac{1}{2}$ GARMASH 04 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $32.8\pm1.8\pm2.8$ $\frac{1}{2}$ GARMASH 04 BELL Repl. by GARMASH 05 $\frac{2}{2}$ AUBERT 03M BABR Repl. by AUBERT 060 |
| <pre>< 6.3 90 1,2 AUBERT 03M BABR Repl. by AUBERT 07BB </pre> <12 90 3 GARMASH 02 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | $35.3\pm3.7\pm4.5$ 3 GARMASH 02 BELL Repl. by GARMASH 04 |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | <200 90 4 ADAM 96D DLPH $e^+e^- \rightarrow Z$ <320 90 4 ABREU 95N DLPH Sup. by ADAM 96D |
| 2 Charm and charmonium contributions are subtracted, otherwise no assumptions about | <350 90 ALBRECHT 91E ARG $e^+e^- ightarrow \varUpsilon(4S)$ |
| intermediate resonances. 3 Uses a reference decay mode $B^+	o \overline D^0\pi^+$ and $\overline D^0	o K^+\pi^-$ with ${\sf B}(B^+	o$ | $\frac{1}{2}$ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\overline{D}{}^0\pi^+)\cdot B(\overline{D}{}^0\to K^+\pi^-) = (20.3\pm 2.0)\times 10^{-5}.$ | ² Assumes equal production of B^0 and B^+ at the $\Upsilon(4S)$; charm and charmonium contributions are subtracted, otherwise no assumptions about intermediate resonances. |
| $\Gamma(K^+K^-\pi^+ \text{ nonresonant})/\Gamma_{\text{total}}$ Γ_{304}/Γ | ³ Uses a reference decay mode $B^+ \to \overline{D}{}^0\pi^+$ and $\overline{D}{}^0 \to K^+\pi^-$ with $B(B^+ \to D^0\pi^+)$ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | $\overline{D}{}^0\pi^+)$ -B $(\overline{D}{}^0	o K^+\pi^-)=(20.3\pm 2.0)\times 10^{-5}$. ⁴ Assumes B^0 and B^- production fractions of 0.39, and B_5 production fraction of 0.12. |
| | |
| $\Gamma(K^+\overline{K}^*(892)^0)/\Gamma_{\text{total}}$ Γ_{305}/Γ | $\Gamma(K^+\phi)/\Gamma_{\text{total}}$ Γ_{314}/Γ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | <u>VALUE (units 10^{−6}) </u> |
| $<$ 1.1 90 1 AUBERT 07AR BABR $e^+e^- \rightarrow \Upsilon(4S)$ | 8.4 \pm 0.7 \pm 0.7 1 AUBERT 060 BABR $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 7.6 $\pm 1.3 \pm 0.6$ 2 ACOSTA 05J CDF $p\overline{p}$ at 1.96 TeV |
| <129 90 ABBIENDI 00B OPAL $e^+e^- \rightarrow Z$ <138 90 2 ABE 00C SLD $e^+e^- \rightarrow Z$ | $9.60\pm0.92^{+1.05}_{-0.85}$ 1 GARMASH 05 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| <138 90 2 ABE 00c SLD $e^+e^- \rightarrow Z$ < 5.3 90 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | 5.5 $^{+2.1}_{-1.8}$ \pm 0.6 1 BRIERE 01 CLE2 $^{+}$ e $^{-}$ \rightarrow γ (4 <i>S</i>) |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ullet $ullet$ $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ |
| 2 ABE 00c assumes B($Z ightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^0} = f_{B^+} =$ | $10.0 \ ^{+0.9}_{-0.8} \ \pm 0.5$ 1 AUBERT 04A BABR Repl. by AUBERT 060 |
| $(39.7 + \frac{1.8}{-2.2})\%$ and $f_{B_s} = (10.5 + \frac{1.8}{-2.2})\%$. | 9.4 ± 1.1 ± 0.7 1 CHEN 03B BELL Repl. by GARMASH 05 |
| $\Gamma(K^+\overline{K}_0^*(1430)^0)/\Gamma_{\text{total}}$ Γ_{306}/Γ | $14.6 {}^{+ 3.0}_{- 2.8} \pm 2.0$ 3 GARMASH 02 BELL Repl. by CHEN 03B |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | 7.7 $^{+1.6}_{-1.4}$ \pm 0.8 1 AUBERT 01D BABR $e^+e^- ightarrow ~ \varUpsilon(4.5)$ |
| <2.2 90 1 AUBERT 07AR BABR $e^+e^- \rightarrow r(4S)$ | <144 90 4 ABE 00c SLD $e^+e^- \rightarrow Z$ |
| 1 Assumes equal production of B^+ and B^0 at the $arangle (4S)$. | < 5 90 1 BERGFELD 98 CLE2 |
| $\Gamma(K^+K^+\pi^-)/\Gamma_{\text{total}}$ Γ_{307}/Γ | <pre><280 90 5 ADAM 96D DLPH $e^+e^- \rightarrow Z$ < 12 90 ASNER 96 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$</pre> |
| VALUE CL% DOCUMENT ID TECN COMMENT | <440 90 ⁶ ABREU 95N DLPH Sup. by ADAM 96D |
| <1.6 × 10 ⁻⁷ 90 1 AUBERT 08BE BABR $e^+e^- \rightarrow \Upsilon(4S)$ | <180 90 ALBRECHT 91B ARG $e^+e^- \rightarrow \Upsilon(4S)$ < 90 90 7 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $ \begin{array}{ccccccccccccccccccccccccccc$ |
| $<2.4\times10^{-6}$ 90 1 GARMASH 04 BELL e $^{+}$ e $^{-}$ \rightarrow $\varUpsilon(4S)$ $<1.3\times10^{-6}$ 90 2 AUBERT 03M BABR Repl. by AUBERT 08BE | $\frac{1}{2}$ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $<3.2 \times 10^{-6}$ 90 3 GARMASH 02 BELL $e^+e^- ightarrow 	ag{4.5}$ | ² Uses B($B^+ \to J/\psi K^+$) = $(1.00 \pm 0.04) \times 10^{-3}$ and B($J/\psi \to \mu^+ \mu^-$) = 0.0588 \pm 0.0010. |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 3 Uses a reference decay mode $B^+	o \overline{D}{}^0\pi^+$ and $\overline{D}{}^0	o K^+\pi^-$ with ${\sf B}(B^+	o$ |
| ² Assumes equal production of B^0 and B^+ at the $\Upsilon(4S)$; charm and charmonium contributions are subtracted, otherwise no assumptions about intermediate resonances. | $\overline{D}^0 \pi^+) \cdot \mathrm{B}(\overline{D}^0 \to K^+ \pi^-) = (20.3 \pm 2.0) \times 10^{-5}$. ⁴ ABE 00c assumes B($Z \to b \overline{b}$)=(21.7 ± 0.1)% and the B fractions $f_{R^0} = f_{R^+} = 10^{-5}$ |
| 3 Uses a reference decay mode $B^+	o \overline D^0\pi^+$ and $\overline D^0	o K^+\pi^-$ with ${\sf B}(B^+	o$ | (39.7 $^{+1.8}_{-2.2}$)% and $f_{B_c} = (10.5 ^{+1.8}_{-1.2})$ %. |
| $\overline{D}{}^0\pi^+)\cdot B(\overline{D}{}^0\to K^+\pi^-) = (20.3\pm 2.0)\times 10^{-5}.$ | ⁵ ADAM 96D assumes $f_{B^0} = f_{B^-} = 0.39$ and $f_{B_S} = 0.12$. |
| $\Gamma(K^+K^+\pi^-\text{nonresonant})/\Gamma_{\text{total}}$ Γ_{308}/Γ | ⁶ Assumes a B^0 , B^- production fraction of 0.39 and a B_s production fraction of 0.12. |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | 7 AVERY 89B reports $<$ 8 \times 10 $^{-5}$ assuming the \varUpsilon (45) decays 43% to $B^{0}\overline{B}{}^{0}$. We rescale to 50%. |
| <87.9 90 ABBIENDI 00B OPAL $e^+e^- 	oup Z$ | |
| $\Gamma(K^+ f_J(2220))/\Gamma_{\text{total}}$ Γ_{309}/Γ | $\Gamma(f_0(980) K^+ \times B(f_0(980) \rightarrow K^+ K^-))/\Gamma_{total}$ $\Gamma_{315}/\Gamma_{total}$ |
| VALUE (units 10 ⁻⁶) DO CUMENT ID TECN COMMENT | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| not seen 1 HUANG 03 BELL $e^+e^- ightarrow \varUpsilon(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. |
| ¹ No evidence is found for such decay and set a limit on B($B^+ 	o f_J(2220)) 	imes B(f_J(2220) 	o \phi \phi) < 1.2 	imes 10^{-6}$ at 90%CL where | $6.5\pm2.5\pm1.6$ 1 AUBERT 060 BABR $e^+e^- ightarrow$ $\Upsilon(4S)$ |
| the $f_J(2220)$ is a possible glueball state. | 1 Assumes equal production of B^+ and B^{0} at the \varUpsilon (45). |
| $\Gamma(K^{*+}\pi^+K^-)/\Gamma_{\text{total}}$ Γ_{310}/Γ | $\Gamma(a_2(1320)K^+ \times B(a_2(1320) \rightarrow K^+K^-))/\Gamma_{total}$ Γ_{316}/Γ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | VALUE CL% DOCUMENT ID TECN COMMENT |
| <11.8 90 1 AUBERT,B 060 BABR $e^+e^- \rightarrow r(4S)$ | <1.1 × 10 ⁻⁶ 90 ¹ GARMASH 05 BELL $e^+e^- \rightarrow \tau(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(K^*(892)^+ K^*(892)^0)/\Gamma_{\text{total}}$ Γ_{311}/Γ | $\Gamma(f'_{2}(1525)K^{+} \times B(f'_{2}(1525) \to K^{+}K^{-}))/\Gamma_{\text{total}}$ Γ_{317}/Γ |
| VALUE (units 10 ⁻⁶) CL% DO CUMENT ID TECN COMMENT | $\frac{VALUE}{4.9 \times 10^{-6}}$ 90 $\frac{DOCUMENT\ ID}{1\ GARMASH}$ 05 BELL $e^+e^- \rightarrow \Upsilon(4.5)$ |
| 1.2 \pm 0.5 \pm 0.1 AUBERT 09F BABR $e^+e^- ightarrow \Upsilon$ (4S) | 4.9 × 10 90 GARMASH US BELL $e^+e^- \rightarrow T(45)$ ¹ Assumes equal production of B^+ and B^0 at the $T(45)$. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| <71 90 1 GODANG 02 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ | $\Gamma(X_0(1550) K^+ \times B(X_0(1550) \to K^+ K^-))/\Gamma_{\text{total}} \qquad \Gamma_{318}/\Gamma$ |
| 1 Assumes a helicity 00 configuration. For a helicity 11 configuration, the limit decreases to 4.8×10^{-5} . | $X_0(1550)$ is a possible spin zero state near 1.55 GeV/ c^2 invariant mass of K^+K^- . VALUE (units 10^{-6}) DOCUMENT ID TECN COMMENT |
| 10 110 A 10 1 | 4.3 \pm 0.6 \pm 0.3 1 AUBERT 060 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| | $^{-}$ Assumes equal production of B^{+} and B^{0} at the $\varUpsilon(4S)$. |

 $^{^1}$ Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

 B^{\pm}

| $\Gamma(\phi(1680) K^+ \times B(\phi(1680)$ | | $\Gamma(\phi K_2^*(1770)^+)/\Gamma_{\text{total}}$ $\Gamma_{330}/\Gamma_{330}$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE CL% <0.8 × 10 ⁻⁶ 90 | $\frac{DOCUMENT\ ID}{1\ GARMASH}$ 05 BELL $e^+e^- ightarrow \varUpsilon(4S)$ | $\frac{VALUE \text{ (units }10^{-6})}{<15.0}$ $\frac{CL\%}{90}$ $\frac{DOCUMENT \text{ (ID}}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT}{1}$ $e^+e^- 	o T(4S)$ |
| ¹ Assumes equal production of | , | Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(f_0(1710)K^+ \times B(f_0(1710)$ | $) \rightarrow K^{+}K^{-}))/\Gamma_{\text{total}}$ Γ_{320}/Γ | $\Gamma(\phi K_2^*(1820)^+)/\Gamma_{\text{total}}$ |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| 1.7±1.0±0.3 | 1 AUBERT 060 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | <16.3 90 $^{-1}$ AUBERT 0881 BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| ¹ Assumes equal production of | | 1 Assumes equal production of B^+ and B^{0} at the \varUpsilon (45). |
| $\Gamma(K^+K^-K^+ \text{ nonresonant})$ | | $\Gamma(a_1^+K^{*0})/\Gamma_{\text{total}}$ $\Gamma_{332}/\Gamma_{\text{total}}$ |
| VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁶) <u>CL% DOCUMENT ID TECN COMMENT</u> |
| | Error includes scale factor of 3.3. | <3.6 90 1,2 DEL-AMO-SA101 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $50.0 \pm 6.0 \pm 4.0$ $24.0 \pm 1.5 + 2.6$ -6.0 | 1 AUBERT 060 BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 1 GARMASH 05 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | 1 Assumes B($a^\pm_1 	o \pi^\pm \pi^\mp \pi^\pm)=0.5$ 2 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. |
| | ng data for averages, fits, limits, etc. • • | |
| <38 90 | BERGFELD 96B CLE2 $e^+e^- ightarrow\varUpsilon(4S)$ | $\Gamma(K^+\phi\phi)/\Gamma_{	ext{total}}$ $\Gamma_{333}/\Gamma_{	ext{VALUE}}$ (units 10^{-6}) DOCUMENT ID TECH COMMENT |
| $^{ m 1}$ Assumes equal production of | B^+ and B^0 at the $\varUpsilon(4S)$. | 5.0±1.2 OUR AVERAGE Error includes scale factor of 2.3. |
| $\Gamma(K^*(892)^+K^+K^-)/\Gamma_{total}$ | Γ ₃₂₂ /Γ | $5.6\pm0.5\pm0.3$ |
| VALUE (units 10^{-6}) CL% | DO CUMENT ID TECN COMMENT | $2.6 ^{+}_{-0.9} ^{+} \pm 0.3$ 1 HUANG 03 BELL $e^+e^- ightarrow \gamma (45)$ |
| 36.2±3.3±3.6 • • We do not use the following | 1 AUBERT,B 06u BABR $e^+e^- 	o 	au(4S)$ ng data for averages, fits, limits, etc. $\bullet 	ext{ } \bullet 	ext{ } \bullet$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $7.5\pm1.0\pm0.7$ 1 AUBERT,BE 06H BABR Repl. by LEES 11A |
| <1600 90 | ALBRECHT 91E ARG $e^+e^- ightarrow \gamma(4S)$ | 1 Assumes equal production of B^0 and B^+ at the $\varUpsilon(45)$ and for a $\phi\phi$ invariant mas |
| ¹ Assumes equal production of | · , , | below 2.85 GeV/c^2 . |
| $\Gamma(K^*(892)^+\phi)/\Gamma_{\text{total}}$ | Г ₃₂₃ /Г | $\Gamma(\eta'\eta'K^+)/\Gamma_{\text{total}}$ $\Gamma_{334}/\Gamma_{\text{total}}$ |
| VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| | Error includes scale factor of 1.7. 1 AUBERT 07BA BABR $e^+e^- ightarrow \varUpsilon(4S)$ | <25 90 1 AUBERT,B 06P BABR $e^+e^- ightarrow 	au(4S)$ 1 Assumes equal production of B^+ and B^0 at the $	au(4S)$. |
| 0.4 0.= | 1 CHEN 03B BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | |
| | ng data for averages, fits, limits, etc. ● ● | $\Gamma(\omega\phi K^+)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{335}}/\Gamma_{	ext{VALUE (units }10^{-6})}$ CL% DOCUMENT ID TECH COMMENT |
| $12.7 + 2.2 \pm 1.1$ | ¹ AUBERT 03v BABR Repl. by AUBERT 07BA | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $9.7^{+4.2}_{-3.4}\pm 1.7$ | ¹ AUBERT 01D BABR Repl. by AUBERT 03v | 1 Assumes equal production of B^+ and B^{0} at the $ \Upsilon(4S).$ |
| | 1 BRIERE 01 CLE2 $e^+e^- ightarrow \gamma(4S)$ | $\Gamma(X(1812)K^+ \times B(X \to \omega \phi))/\Gamma_{\text{total}}$ $\Gamma_{336}/\Gamma_{336}$ |
| < 41 90 < 70 90 | 1 BERGFELD 98 CLE2 ASNER 96 CLE2 $e^{+}e^{-} \rightarrow \gamma(4S)$ | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| <1300 90 | ALBRECHT 91B ARG $e^+e^- ightarrow \varUpsilon(4S)$ | <0.32 90 1 LIU 99 BELL $e^{+}e^{-} \rightarrow r(4S)$ |
| ¹ Assumes equal production of | B^+ and B^0 at the $\varUpsilon(4S)$. | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(\phi(K\pi)_0^{*+})/\Gamma_{\text{total}}$ | Γ ₃₂₄ /Γ | $\Gamma(K^*(892)^+\gamma)/\Gamma_{\text{total}}$ |
| $(K\pi)_0^{*+}$ is the total S-wave | e composed of $K_0^st(1430)$ and nonresonant that are described | <u>VALUE (units 10⁻⁵) CL% DOCUMENT ID TECN COMMENT</u> 4.21±0.18 OUR AVERAGE |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | $4.22\pm0.14\pm0.16$ 1 AUBERT 09A0 BABR $e^+e^- ightarrow \Upsilon(4S)$ $4.25\pm0.31\pm0.24$ 2 NA KAO 04 BELL $e^+e^- ightarrow \Upsilon(4S)$ |
| 8.3±1.4±0.8 | 1 AUBERT 08BI BABR $e^{+}e^{-} ightarrow \gamma(45)$ | $4.25 \pm 0.31 \pm 0.24$ 2 NA KAO 04 BELL $e^+e^- \rightarrow \Upsilon(45)$ $3.76 \stackrel{+}{-} 0.89 \pm 0.28$ 2 COAN 00 CLE2 $e^+e^- \rightarrow \Upsilon(45)$ |
| ↓ Assumes equal production of | | 5.70 _ 0.83 ± 0.20 |
| | $^+B^+$ and 0 at the $^{\gamma}(4S)$. | |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}$ | Γ ₃₂₅ /Γ | • • • We do not use the following data for averages, fits, limits, etc. • • • $3.87\pm0.28\pm0.26$ 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) | Γ ₃₂₅ /Γ | • • • We do not use the following data for averages, fits, limits, etc. • • • $3.87 \pm 0.28 \pm 0.26 \qquad \qquad \begin{array}{ccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $3.87 \pm 0.28 \pm 0.26 \qquad \qquad 3 \text{ AUBERT,BE} \qquad 04\text{A} \qquad \text{BABR} \qquad \text{Repl. by AUBERT 09AO} \\ 3.83 \pm 0.62 \pm 0.22 \qquad \qquad 2 \text{ AUBERT} \qquad 02\text{C} \qquad \text{BABR} \qquad \text{Repl. by AUBERT,BE 04A} \\ 5.7 \ \pm 3.1 \ \pm 1.1 \qquad \qquad 4 \text{ AMMAR} \qquad 93 \qquad \text{CLE2} \qquad \text{Repl. by COAN 00} \\ < 55 \qquad \qquad 90 \qquad \qquad 5 \text{ ALBRECHT} \qquad 89\text{G} \qquad \text{ARG} \qquad e^+ e^- \rightarrow \qquad \varUpsilon(45)$ |
| $\frac{\Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\rm total}}{^{VALUE(\rm units10^{-6})}}$ 6.1 \pm 1.6 \pm 1.1 1 Assumes equal production of | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.87 \pm 0.28 \pm 0.26 \\ 3.83 \pm 0.62 \pm 0.22 \\ 2 \text{ AUBERT} \\ 5.7 \pm 3.1 \pm 1.1 \\ 4 \text{ AMMAR} \\ 93 \\ 5 \text{ AUBERTHSE} \\ 04A \text{ BABR} \\ \text{Repl. by AUBERT 09AO} \\ 02C \text{ BABR} \\ \text{Repl. by COAN 00} \\ 05C \text{ Sall } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C \text{ Repl. by COAN 00} \\ 05C \text{ Soll } 12C $ |
| $\frac{\Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\rm total}}{^{VALUE(\rm units10^{-6})}}$ 6.1 \pm 1.6 \pm 1.1 1 Assumes equal production of | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.87 \pm 0.28 \pm 0.26 \\ 3.83 \pm 0.62 \pm 0.22 \\ 2 \text{ AUBERT} \\ 5.7 \pm 3.1 \pm 1.1 \\ 4 \text{ AMMAR} \\ 93 \text{ CLE2} \\ 896 \text{ ARG} \\ e^+ e^- \to \Upsilon(4S) \\ < 55 \\ 90 \\ 5 \text{ AUBERCHT} \\ 896 \text{ CRG} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 897 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 90 \text{ AVERY} \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ < 180 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898 \\ 898$ |
| $\frac{\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}}{6.1\pm 1.6\pm 1.1}$ $\frac{1}{4} \text{ Assumes equal production of } \frac{\Gamma(\phi K_1(1400)^+)/\Gamma_{\text{total}}}{\sqrt{ALUE (\text{units } 10^{-6})}} \frac{cL\%}{90}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.87 \pm 0.28 \pm 0.26 \\ 3.83 \pm 0.62 \pm 0.22 \\ 2 \text{ AUBERT} \\ 5.7 \pm 3.1 \pm 1.1 \\ 4 \text{ AMMAR} \\ 93 \text{ CLE2} \\ 890 \\ 5 \text{ 5} \text{ AUBERCHT} \\ 896 \text{ AVERY} \\ 898 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 896 \text{ CLEO} \\ e^+ e^- \to \Upsilon(4S) \\ 89$ |
| $\frac{\Gamma\left(\phi K_1(1270)^+\right)/\Gamma_{\text{total}}}{6.1 \pm 1.6 \pm 1.1}$ $\frac{1}{4} \text{ Assumes equal production of } \Gamma\left(\phi K_1(1400)^+\right)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units } 10^{-6})}{4} \frac{CL\%}{90}$ $\bullet \bullet \text{We do not use the following states}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09AO 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04A 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 < 55 90 5 ALBRECHT 89G ARG $e^+e^- \to \Upsilon(45)$ < 55 90 5 AVERY 89B CLEO $e^+e^- \to \Upsilon(45)$ < 180 90 AVERY 87 CLEO $e^+e^- \to \Upsilon(45)$ < 1 Uses B($\Upsilon(4S) \to B^+B^-$) = (51.6 \pm 0.6)% and B($\Upsilon(4S) \to B^0\overline{B}^0$) = (48.4 \pm 0.6)% 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 3 Uses the production ratio of charged and neutral B from $\Upsilon(4S)$ decays R+ $^+$ 0 = 1.006 \pm 0.048 |
| $\frac{\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}}{6.1\pm 1.6\pm 1.1}$ $\frac{1}{4} \text{ Assumes equal production of } \frac{\Gamma(\phi K_1(1400)^+)/\Gamma_{\text{total}}}{\sqrt{ALUE (\text{units } 10^{-6})}} \frac{cL\%}{90}$ | Ta25/ Γ DOCUMENT ID 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(45)$ E^+ and E^0 at the E^0 and E^0 at the E^0 and E^0 at the E^0 are E^0 and E^0 are E^0 and E^0 are E | • • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.87 \pm 0.28 \pm 0.26 \\ 3.83 \pm 0.62 \pm 0.22 \\ 2 \text{ AUBERT} \\ 5.7 \pm 3.1 \pm 1.1 \\ 4 \text{ AMMAR} \\ 93 \text{ CLE2} \\ 8790 \\ 890 \text{ AVERY} \\ 890 \text{ CLEO } e^+e^- \to \Upsilon(4S) \\ 890 \text{ AVERY} \\ $ |
| $ \begin{array}{l} \Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \\ \hline 6.1 \pm 1.6 \pm 1.1 \\ \hline 1 \\ {\rm Assumes equal production of} \\ \Gamma\left(\phiK_1(1400)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \\ \hline < 3.2 \\ \hline 0 \\ \bullet \bullet \bullet {\rm We do not use the following of of the control of of the control o$ | Table | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09AO 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT 08 04. 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 \pm 55 90 5 AUBERCHT 89G ARG \pm 6 \pm 7 \pm 7 (4.5) \pm 8 \pm 90 AVERY 89B CLEO \pm 8 \pm 90 AVERY 87 CLEO \pm 90 AVERY 87 CLEO \pm 90 AVERY 87 CLEO \pm 90 AVERY 80 AVERY 8 |
| $ \begin{split} & \Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\text{total}} \\ & \frac{VALUE\{\text{units }10^{-6}\}}{6.1\pm1.6\pm1.1} \\ & \frac{1}{4}\text{ Assumes equal production of } \\ & \Gamma\left(\phiK_1(1400)^+\right)/\Gamma_{\text{total}} \\ & \frac{VALUE\{\text{units }10^{-6}\}}{4} & \frac{CL\%}{4} \\ & < & 3.2 & 90 \\ & \bullet & \bullet & \text{We do not use the followind } \\ & <1100 & 90 \\ & \frac{1}{4}\text{ Assumes equal production of } \\ & \Gamma\left(\phiK^*\{1410\}^+\right)/\Gamma_{\text{total}} \end{split} $ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09AO 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04A 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 \pm 55 90 5 ALBRECHT 89G ARG \pm 6 \pm 7 \pm 7 \pm 7 (4.5) \pm 8 \pm 8 CLEO \pm 8 \pm 9 CLEO \pm 9 \pm 9 AVERY 89B CLEO \pm 9 \pm 9 \pm 10 \pm 10 \pm 10 \pm 11 Uses B(\pm 14.5) \pm 11 Uses B(\pm 14.5) \pm 12 \pm 15 \pm 15 \pm 16.6)% and B(\pm 14.5) \pm 16 \pm 17 \pm 18 \pm 18 \pm 19 |
| $ \begin{array}{l} \Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \\ \hline 6.1 \pm 1.6 \pm 1.1 \\ \hline 1 \\ {\rm Assumes equal production of} \\ \Gamma\left(\phiK_1(1400)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \\ \hline < 3.2 \\ \hline 0 \\ \bullet \bullet \bullet {\rm We do not use the following of of the control of of the control o$ | Table | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04A 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 < 55 90 5 ALBRECHT 89G ARG $e^+e^- \to \Upsilon(4.5)$ < 55 90 5 AVERY 89B CLEO $e^+e^- \to \Upsilon(4.5)$ < 180 90 AVERY 87 CLEO $e^+e^- \to \Upsilon(4.5)$ 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4.5)$. 3 Uses the production ratio of charged and neutral B from $\Upsilon(4.5)$ decays $R^+/0 = 1.006 \pm 0.048$. 4 AMMAR 93 observed $A = 1.1 \pm 0.3$ events above background. 5 Assumes the $\Upsilon(4.5)$ decays 43% to $B^0 \overline{B}^0$. F(K1(1270)+ γ)/ Γ total $\frac{VALUE (units 10^{-5})}{4.3\pm0.9\pm0.9}$ $\frac{CL\%}{1}$ $\frac{DOCUMENT ID}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT}{e^+e^-} \to \Upsilon(4.5)$ |
| $ \begin{array}{lll} & \Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\text{total}} \\ & \frac{VALUE\{\text{units}\ 10^{-6}\}}{6.1\pm 1.6\pm 1.1} \\ & \frac{1}{4} \text{ Assumes equal production of } \\ & \Gamma\left(\phiK_1(1400)^+\right)/\Gamma_{\text{total}} \\ & \frac{VALUE\{\text{units}\ 10^{-6}\}}{2} & \frac{CL\%}{2} \\ & < & 3.2 & 90 \\ & \bullet & \bullet & \text{We do not use the following states} \\ & <1100 & 90 \\ & \frac{1}{4} \text{ Assumes equal production of } \\ & \Gamma\left(\phiK^*\{1410\}^+\right)/\Gamma_{\text{total}} \\ & \frac{VALUE\{\text{units}\ 10^{-6}\}}{2} & \frac{CL\%}{2} \\ \end{array} $ | Tays/ Γ DOCUMENT ID 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Fach 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Fach COMMENT 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Representation of the property | • • • We do not use the following data for averages, fits, limits, etc. • • • $3.87 \pm 0.28 \pm 0.26$ $3.87 \pm 0.28 \pm 0.26$ $3.83 \pm 0.62 \pm 0.22$ 2 AUBERT $5.7 \pm 3.1 \pm 1.1$ 4 AMMAR 93 CLE2 896 ARG 6.55 90 5 AUBERCHT 896 CLEO $6.7 \pm 0.7 \pm 0.$ |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) 6.1±1.6±1.1 ¹ Assumes equal production of $\Gamma(\phi K_1(1400)^+)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) C1% 3.2 90 • • • We do not use the following continuous of the following continuous of $\Gamma(\phi K^*(1410)^+)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) C1% C4.3 90 | Tays/ Γ DOCUMENT ID 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Fach 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Fach COMMENT 1 AUBERT 08BI BABR $e^+e^- \rightarrow \tau(4S)$ Representation of the property | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04A 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 \pm 55 90 5 ALBRECHT 89G ARG \pm 6 \pm 6 \pm 7 \pm 7(45) \pm 55 90 5 AVERY 89B CLEO \pm 6 \pm 7 \pm 7(45) \pm 10 Uses B(\pm 10 \pm 10 \pm 11 Uses B(\pm 11 Uses B(\pm 12 \pm 13 \pm 14 \pm 15 \pm 15 \pm 16 \pm 16 \pm 16 \pm 17 \pm 17 \pm 17 \pm 17 \pm 18 \pm 18 \pm 19 \pm 19 \pm 19 \pm 10 \pm 19 \pm 10 \pm 19 \pm 10 \pm 10 \pm 19 \pm 10 |
| $ \begin{array}{l} \Gamma\left(\phiK_1(1270)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \\ \hline 6.1 \pm 1.6 \pm 1.1 \\ \hline 1 \ {\rm Assumes \ equal \ production \ of} \\ \Gamma\left(\phiK_1(1400)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \qquad CL\% \\ \hline < 3.2 \qquad 90 \\ \bullet \bullet \bullet \ We \ {\rm do \ not \ use \ the \ following \ color \ of} \\ < 1100 \qquad 90 \\ \hline 1 \ {\rm Assumes \ equal \ production \ of} \\ \Gamma\left(\phiK^*(1410)^+\right)/\Gamma_{\rm total} \\ \hline NALUE (units 10^{-6}) \qquad CL\% \\ \hline < 4.3 \qquad 90 \\ \hline 1 \ {\rm Assumes \ equal \ production \ of} \\ \hline \end{array} $ | Table Tipe The Normal Series of the series | • • • We do not use the following data for averages, fits, limits, etc. • • • $3.87 \pm 0.28 \pm 0.26$ $3.83 \pm 0.62 \pm 0.22$ $2 \text{ AUBERT} \text{ O2C BABR Repl. by AUBERT 09AO}$ $3.63 \pm 0.62 \pm 0.22$ $2 \text{ AUBERT} \text{ O2C BABR Repl. by AUBERT 09AO}$ $5.7 \pm 3.1 \pm 1.1$ $4 \text{ AMMAR} \text{ 93 CLE2 Repl. by COAN 00}$ $< 55 \qquad 90 \qquad 5 \text{ ALBRECHT} \qquad 896 \text{ ARG } e^+e^- \to \Upsilon(4.5)$ $< 55 \qquad 90 \qquad 5 \text{ AVERY} \qquad 898 \text{ CLEO } e^+e^- \to \Upsilon(4.5)$ $< 180 \qquad 90 \qquad \text{AVERY} \qquad 87 \text{CLEO } e^+e^- \to \Upsilon(4.5)$ $^2 \text{ Assumes equal production of } B^+ \text{ and } B^0 \text{ at the } \Upsilon(4.5) \to B^0 \overline{B}^0) = (48.4 \pm 0.6)\%$ $^2 \text{ Assumes equal production ratio of charged and neutral B from } \Upsilon(4.5) \text{ decays } R^+/0 = 1.006 \pm 0.048.$ $^4 \text{ AMMAR 93 observed } 4.1 \pm 2.3 \text{ events above background.}$ $^5 \text{ Assumes the } \Upsilon(4.5) \text{ decays } 43\% \text{ to } B^0 \overline{B}^0.$ $\mathbf{\Gamma(K_1(1270)^+ \gamma)/\Gamma_{total}}$ $\mathbf{\Gamma(K_1(1270)^+ \gamma)/\Gamma_{total}}$ $\mathbf{\Gamma(M_1(1270)^+ \gamma)/\Gamma_{total}}$ |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 6.1±1.6±1.1 ¹ Assumes equal production of $\Gamma(\phi K_1(1400)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) CL% 3.2 90 • • • We do not use the following constant of the following | Table Tipe The substitute of | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04. 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 $<$ 55 90 5 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 55 90 5 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 180 90 AVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4.5)$. 3 Uses the production ratio of charged and neutral B from $\Upsilon(4.5)$ decays $R^+/0 = 1.006 \pm 0.048$. 4 AMMAR 93 observed 4.1 \pm 2.3 events above background. 5 Assumes the $\Upsilon(4.5)$ decays 43% to $B^0\overline{B}^0$. $\Gamma(K_1(1270)^+\gamma)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units }10^{-5})}{4.3 \pm 0.9 \pm 0.9}$ $\frac{CL\%}{1}$ $\frac{DOCUMENT \ ID}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT}{1}$ A338/II A3±0.9 \pm 0.9 90 1 NISHIDA 02 BELL Repl. by YANG 05 $<$ 730 90 2 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$. 4ABRECHT 89G Reports $<$ 0.0066 assuming the $\Upsilon(4.5)$ decays 45% to $B^0\overline{B}^0$. W |
| | Tays/Γ DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 OSBI BABR $e^+e^- \rightarrow r(4S)$ Factor Comment 1 AUBERT 2 AUGENT 4 AUBERT 4 AUBERT 4 AUBERT 5 AUGENT 6 AUGENT 7 AUBERT 6 AUGENT 7 AUBERT 8 AUBE | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09AO 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04/5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 \times 55 90 5 ALBRECHT 89G ARG $e^+e^- \to \tau(4.5)$ \times 55 90 5 AVERY 89B CLEO $e^+e^- \to \tau(4.5)$ \times 6.180 90 AVERY 87 CLEO $e^+e^- \to \tau(4.5)$ \times 1 Uses B($\tau(4.5) \to B^+B^-$) $= (51.6 \pm 0.6)\%$ and B($\tau(4.5) \to B^0\overline{B}^0$) $= (48.4 \pm 0.6)\%$ 2 Assumes equal production of B $^+$ and B 0 at the $\tau(4.5)$. 3 Uses the production ratio of charged and neutral B from $\tau(4.5)$ decays R $^+/^0$ $= 1.006 \pm 0.048$. 4 AMMAR 93 observed 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 43% to $\tau(4.5)$ $= 1.006 \pm 0.048$. For $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 8.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 4.1 \pm 2.3 events above background. 5 Assumes the $\tau(4.5)$ decays 6.1 \pm 2.3 events above background. 5 Assumes $\tau(4.5)$ decays 6.1 \pm 2.3 events above background. 5 Assumes $\tau(4.5)$ decays 6.1 \pm 2.3 events above background. 5 Assumes $\tau(4.5)$ de |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-6})$ 6.1±1.6±1.1 Assumes equal production of $\Gamma(\phi K_1(1400)^+)/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-6})$ 3.2 $VALUE \text{ (units } 10^{-6})$ $VALUE \text{ (units } 10^{-6})$ 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ 2.0 $VALUE \text{ (units } 10^{-6})$ 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ 7.0±1.3±0.9 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ 1 Assumes equal production of $VALUE \text{ (units } 10^{-6})$ | Tays/Γ DOCUMENT ID 1 AUBERT 08BI BABR $e^+e^- \rightarrow r(4S)$ Factor $e^+e^- \rightarrow r(4S)$ Representation 1 AUBERT 08BI BABR $e^+e^- \rightarrow r(4S)$ Representation 1 AUBERT 08BI BABR $e^+e^- \rightarrow r(4S)$ Factor $e^+e^- \rightarrow r(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04. 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 $<$ 55 90 5 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 55 90 5 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 180 90 AVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4.5)$. 3 Uses the production ratio of charged and neutral B from $\Upsilon(4.5)$ decays $R^+/0 = 1.006 \pm 0.048$. 4 AMMAR 93 observed 4.1 \pm 2.3 events above background. 5 Assumes the $\Upsilon(4.5)$ decays 43% to $B^0\overline{B}^0$. $\Gamma(K_1(1270)^+\gamma)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units }10^{-5})}{4.3 \pm 0.9 \pm 0.9}$ $\frac{CL\%}{1}$ $\frac{DOCUMENT \ ID}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT}{1}$ A338/II A3±0.9 \pm 0.9 90 1 NISHIDA 02 BELL Repl. by YANG 05 $<$ 730 90 2 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$. 4ABRECHT 89G Reports $<$ 0.0066 assuming the $\Upsilon(4.5)$ decays 45% to $B^0\overline{B}^0$. W |
| $\Gamma(\phi K_1(1270)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 6.1±1.6±1.1 ¹ Assumes equal production of $\Gamma(\phi K_1(1400)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) CL% 3.2 90 • • • We do not use the following continuous of $\Gamma(\phi K_1(1400)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 1 Assumes equal production of $\Gamma(\phi K^*(1410)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 1 Assumes equal production of $\Gamma(\phi K_0^*(1430)^+)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 7.0±1.3±0.9 | Tays/Γ DOCUMENT ID 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 OSBI BABR $e^+e^- \rightarrow r(4S)$ Factor Comment 1 AUBERT 2 AUGENT 4 AUBERT 4 AUBERT 4 AUBERT 5 AUGENT 6 AUGENT 7 AUBERT 6 AUGENT 7 AUBERT 8 AUBE | • • • We do not use the following data for averages, fits, limits, etc. • • • 3.87 \pm 0.28 \pm 0.26 3 AUBERT,BE 04A BABR Repl. by AUBERT 09A0 3.83 \pm 0.62 \pm 0.22 2 AUBERT 02C BABR Repl. by AUBERT,BE 04. 5.7 \pm 3.1 \pm 1.1 4 AMMAR 93 CLE2 Repl. by COAN 00 $<$ 55 90 5 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 55 90 5 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 180 90 AVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4.5)$ $<$ 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4.5)$. 3 Uses the production ratio of charged and neutral B from $\Upsilon(4.5)$ decays $R^+/0 = 1.006 \pm 0.048$. 4 AMMAR 93 observed 4.1 \pm 2.3 events above background. 5 Assumes the $\Upsilon(4.5)$ decays 43% to $B^0\overline{B}^0$. $\Gamma(K_1(1270)^+\gamma)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units }10^{-5})}{4.3 \pm 0.9 \pm 0.9}$ $\frac{CL\%}{1}$ $\frac{DOCUMENT \ ID}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT}{1}$ A338/II A3±0.9 \pm 0.9 90 1 NISHIDA 02 BELL Repl. by YANG 05 $<$ 730 90 2 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4.5)$. 4ABRECHT 89G Reports $<$ 0.0066 assuming the $\Upsilon(4.5)$ decays 45% to $B^0\overline{B}^0$. W |

ALBRECHT 91B ARG $e^+\,e^ightarrow~ \varUpsilon(4\,S)$

90

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

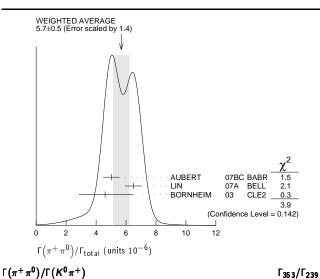
 1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^0 at the $\varUpsilon(4S)$.

Assumes equal potential of B^{-1} and B^{-1} at the T(4.5), decays 45% to $B^{0}\overline{B}{}^{0}$. We rescale to 50%.

 B^{\pm}

| $\Gamma(\eta K^+ \gamma)/\Gamma_{\text{total}}$ | | Γ ₃₃₉ /Γ | $\Gamma(K_2^*(1430)^+\gamma)/\Gamma_{\text{total}}$ | _ | Γ ₃₄₈ |
|------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------|-----------------------------------------------------------------|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁶) 7.9±0.9 OUR AVERAGE | DO CUMENT ID TECN | COMMENT | | <u>DO CUMENT ID</u> | TECN COMMENT |
| 7.7±1.0±0.4 | 1,2 AUBERT 09 BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | 1.45 ± 0.40 ± 0.15 • • • We do not use the fo | AUBERT,B | 04U BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $8.4 \pm 1.5 + 1.2 \\ -0.9$ | 2,3 NISHIDA 05 BELL | $e^+e^- \rightarrow \gamma(4S)$ | <140 90 | | 89G ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| 0.5 | wing data for averages, fits, limits, | , | ¹ Assumes equal production | | () |
| 0.0±1.3±0.5 | | Repl. by AUBERT 09 | | | he $\Upsilon(4S)$ decays 45% to $B^0\overline{B}^0$. |
| $^{1} m_{\eta K} < 3.25 \mathrm{GeV/c^{2}}$ | | | rescale to 50%. | _ | |
| ² Assumes equal production | of B^+ and B^0 at the $\Upsilon(4S)$. | | $\Gamma(K^*(1680)^+\gamma)/\Gamma_{\text{total}}$ | | Г349 |
| $^3 m_{\eta K} < 2.4 { m GeV/c^2}$ | | | <u>VALUE</u> <u>C</u> | | TECN COMMENT |
| $(\eta' K^+ \gamma) / \Gamma_{\text{total}}$ | | Γ ₃₄₀ /Γ | <0.0019 90 | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | \ / |
| (1 1 1) total (ALUE (units 10 ⁻⁶) | DO CUMENT ID TECN | COMMENT | ¹ ALBRECHT 89G report rescale to 50%. | s < 0.0017 assuming th | ne $\varUpsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. |
| .9 + 1.0 OUR AVERAGE | DOCUMENT ID TEST | COMMENT | | | - |
| | 1.2 | | $\Gamma(K_3^*(1780)^+\gamma)/\Gamma_{\text{total}}$ | | Г350 |
| 6±1.2±0.4 | | $e^+e^- \rightarrow \Upsilon(4S)$ | <u>VALUE (units 10⁻⁶) CI</u> | DOCUMENT 1,2 NISHIDA | $\begin{array}{ccc} ID & \underline{TECN} & \underline{COMMENT} \\ & 05 & \mathrm{BELL} & e^+e^- \rightarrow & \Upsilon(4S) \end{array}$ |
| $9^{+1.5}_{-1.2}\pm0.1$ | · | $e^+ e^- \rightarrow \Upsilon(45)$ | • • • We do not use the fo | | · , |
| Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | - | <5500 90 | | Γ 896 ARG $e^+e^- ightarrow \gamma(4S)$ |
| $\frac{2}{2} m_{\eta' K} < 3.4 \text{ GeV/c}^2$ | | _ | ¹ Assumes equal production | | |
| ³ Set the upper limit of 4.2 | $	imes$ 10^{-6} at 90% CL with $m_{\eta^\prime K} < 3$ | 3.25 GeV/c ² . | ² Uses B(K_3^* (1780) → η | | , |
| $(\phi K^+ \gamma)/\Gamma_{\text{total}}$ | | Γ ₃₄₁ /Γ | ³ ALBRECHT 89G reports | | $(4S)$ decays 45% to $B^0\overline{B}^0$. We reso |
| (ΦΛ · '/)/ · total LUE (units 10 ⁻⁶) | DO CUMENT ID TECN | COMMENT | to 50%. | | |
| | Error includes scale factor of 1.2. | | $\Gamma(K_4^*(2045)^+\gamma)/\Gamma_{\text{total}}$ | | Γ ₃₅₁ |
| $8 \pm 0.30 \pm 0.24$ | | $e^+e^- \rightarrow \Upsilon(4S)$ | <u>VALUE</u> <u>CI</u> | <u>DO CUMENT ID</u> | TECN COMMENT |
| • $\pm 0.6 \pm 0.4$ | ¹ AUBERT 07Q BABR wing data for averages, fits, limits, | $e^+e^- \rightarrow \Upsilon(4S)$ | <0.0099 90 | | 89G ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| \pm 0.9 \pm 0.4 | ¹ DRUTSKOY 04 BELL | | ALBRECHT 89G report rescale to 50%. | s < 0.0090 assuming th | he $\Upsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. |
| Assumes equal production | _ | | | | F |
| · · · | | F /F | $\Gamma(\rho^+ \gamma)/\Gamma_{\text{total}}$ | | Г352 |
| $(K^+\pi^-\pi^+\gamma)/\Gamma_{\text{total}}$ | | Γ ₃₄₂ /Γ | <u>VALUE (units 10⁻⁶) CL%</u> 0.98±0.25 OUR AVERA | | TECN COMMENT |
| LUE (units 10 ⁻⁵) | DOCUMENT ID TECN Error includes scale factor of 1.2. | COMMENT | $1.20 + 0.42 \pm 0.20$ | | 08вн BABR $e^+e^- ightarrow \gamma(4S)$ |
| 95 ± 0.13 ± 0.20 | | $e^+ e^- \rightarrow \gamma(4S)$ | 0.01 | | . , |
| $50 \pm 0.18 \pm 0.22$ | ^{2,3} YANG 05 BELL | , , | $0.87 + 0.29 + 0.09 \\ -0.27 - 0.11$ | | 08 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | wing data for averages, fits, limits, | etc. • • • | • • • We do not use the fo | | s, fits, limits, etc. • • • |
| $4 \pm 0.5 \begin{array}{c} +0.4 \\ -0.2 \end{array}$ | ^{2,4} NISHIDA 02 BELL | Repl. by YANG 05 | $1.10 {}^{+ 0.37}_{- 0.33} \pm 0.09$ | ¹ AUBERT (| O7L BABR Repl. by AUBERT 08B |
| $^{1} M_{K \pi \pi} < 1.8 \text{ GeV}/c^{2}$. | | | $\substack{0.55 + 0.42 + 0.09 \\ - 0.36 - 0.08}$ | ¹ MOHAPATRA (| 06 BELL Repl. by TANIGUCHI |
| ² Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | | $0.9 \ ^{+0.6}_{-0.5} \ \pm 0.1$ 90 | ¹ AUBERT (| DS BABR Repl. by AUBERT 07L |
| $^{3}M_{K\pi\pi}$ < 2.0 GeV/ c^{2} | | | - U.5 - < 2.2 90 | ¹ MOHAPATRA (| · · |
| 4 $M_{K \pi \pi} < 2.4 \text{ GeV}/c^{2}$. | | | < 2.1 90 | ¹ AUBERT (| 04c BABR $e^+e^- \rightarrow r(4S)$ |
| $(K^*(892)^0\pi^+\gamma)/\Gamma_{	ext{total}}$ | | Γ ₃₄₃ /Γ | <13 90 | | 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| LUE | DO CUMENT ID TECN | COMMENT | Assumes equal production | | 4 <i>S</i>). on was seen; the central value assur |
| $0.0^{+0.7}_{-0.6}\pm0.2)\times10^{-5}$ | 1,2 NISHIDA 02 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | no contamination. | sonant K $\pi\gamma$ contaminat | on was seen; the central value assur |
| ¹ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | | $\Gamma(\pi^+\pi^0)/\Gamma_{ m total}$ | | Г _{35.3} |
| 2 $M_{K \pi \pi} < 2.4 \text{ GeV}/c^{2}$ | | | VALUE (units 10 ⁻⁶) CL | % DOCUMENT ID | TECN COMMENT |
| $(K^+ ho^0 \gamma) / \Gamma_{ m total}$ | | Г ₃₄₄ /Г | 5.7 ±0.5 OUR AVE | | ale factor of 1.4. See the ideogram |
| LUE CL% | DO CUMENT ID TECN | COMMENT | below. $5.02 \pm 0.46 \pm 0.29$ | ¹ AUBERT | 07BC BABR $e^+e^- ightarrow \gamma(4S)$ |
| 2.0 × 10 ⁻⁵ 90 | | $e^+ e^- \rightarrow \gamma(4S)$ | $6.5 \pm 0.4 \pm 0.4$ | 1 LIN | 07A BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ¹ BORNHEIM | 03 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $M_{K\pi\pi} < 2.4 \text{ GeV}/c^2$ | | | | ollowing data for average | ` ' |
| $(K^+\pi^-\pi^+\gamma$ nonresonar | nt)/Γ _{total} | Γ ₃₄₅ /Γ | 5.8 ±0.6 ±0.4 | 1 AUBERT | 05L BABR Repl. by AUBERT 07 |
| LUE CL% | DOCUMENT ID TECN | COMMENT | $5.0 \pm 1.2 \pm 0.5$ | ¹ CHAO | 04 BELL Repl. by LIN 07A |
| 9.2 × 10 ⁻⁶ 90 | | $e^+ e^- \rightarrow \Upsilon(4S)$ | $5.5 \begin{array}{l} +1.0 \\ -1.9 \end{array} \pm 0.6$ | ¹ AUBERT | 03L BABR Repl. by AUBERT 05 |
| Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | | $7.4 \begin{array}{c} +2.3 \\ -2.2 \end{array} \pm 0.9$ | 1 CASEY | 02 BELL Repl. by CHAO 04 |
| $^{2}M_{K\pi\pi} < 2.4\mathrm{GeV}/c^{2}$ | | | < 13.4 90 | ¹ ABE | 01н BELL $e^+e^- ightarrow$ γ (4 S) |
| $(\kappa^0\pi^+\pi^0\gamma)/\Gamma_{ m total}$ | | Γ ₃₄₆ /Γ | < 9.6 90 | | 01E BABR $e^+e^- ightarrow \gamma(4S)$ |
| LUE (units 10 ⁻⁵) | DO CUMENT ID TECN | COMMENT | < 12.7 90 < 20 90 | | |
| 56±0.42±0.31 | 1,2 AUBERT 07R BABR | $e^+e^- ightarrow \gamma(4S)$ | | | HENNESSY 00 |
| $^{1} M_{K \pi \pi} < 1.8 \text{ GeV}/c^{2}$. | | | < 17 90 < 240 90 | | 96 CLE2 Repl. by GODANG 9 90B ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| | of B^+ and B^0 at the $\varUpsilon(4S)$. | | < 240 90 <2300 90 | | 87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| $(K_1(1400)^+\gamma)/\Gamma_{ m total}$ | | Г ₃₄₇ /Г | ¹ Assumes equal production | | , , |
| ALUE (units 10 ⁻⁵) CL% | DO CUMENT ID TECN | COMMENT | ² BEBEK 87 assume the | | |
| 1.5 90 | 1 YANG 05 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | | | |
| | wing data for averages, fits, limits, | | | | |
| | 1 NISHIDA 02 BELL | Repl. by YANG 05 | | | |
| | | e · e → 1(45) | | | |
| < 1.5 • • • We do not use the follo < 5.0 < 90 < 90 < 90 | wing data for averages, fits, limits, | etc. • • • | | | |

Γ₃₅₈/Γ



| $0.285 \pm 0.02 \pm 0.02$ | | LIN | 07A | BELL | $e^+e^- \to$ | T(45) |
|---------------------------------------------|------------|------------------|--------|--------|--------------|---------------------|
| $\Gamma(\pi^+\pi^+\pi^-)/\Gamma_{ m total}$ | | | | | | Г ₃₅₄ /Г |
| VALUE (units 10^{-6}) | L%_ | DOCUMENT ID | | TECN | COMMENT | |
| $15.2 \pm 0.6 ^{+1.3}_{-1.2}$ | 1 | AUBERT | 09L | BABR | $e^+e^- \to$ | Υ(4S) |
| Wo do not use the f | ollowing o | data for average | c fitc | limite | otc | |

DOCUMENT ID

TECN COMMENT

 We do not use the following data for averages, fits, limits, etc. 1 AUBERT B 056 BABR Rent by AUBERT 091

| $10.9\!\pm\!3.3\!\pm\!1.6$ | | ¹ AUBERT | 03м | BABR | Repl. by AUBERT 05 G |
|----------------------------|----|-----------------------|-----|------|-----------------------------------|
| <130 | 90 | ² ADAM | 96D | DLPH | $e^+ e^- \rightarrow Z$ |
| <220 | 90 | ³ ABREU | | | Sup. by ADAM 96D |
| <450 | 90 | ⁴ ALBRECHT | 90B | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| <190 | 90 | 5 BORTOLETT | O89 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| 1 | | 0 . | | | |

 1 Assumes equal production of B^0 and B^+ at the $\varUpsilon(4S);$ charm and charmonium contributions are subtracted, otherwise no assumptions about intermediate resonances.

 $^2\,\mathrm{ADA\,M}$ 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_S}=0.12$

 3 Assumes a B^0 , B^- production fraction of 0.39 and a $B_{\scriptscriptstyle S}$ production fraction of 0.12.

⁴ ALBRECHT 90B limit assumes equal production of $B^0 \overline{B}{}^0$ and $B^+ B^-$ at $\Upsilon(4S)$.

⁵ BORTOLETTO 89 reports $< 1.7 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$.

| $\Gamma(ho^0\pi^+)/\Gamma_{ m total}$ | Г ₃₅₅ / І |
|----------------------------------------|----------------------|
| · (P ··)/·total | . 300 / . |

| VALUE (units 10 ⁻⁶) <u>CL%</u> | DOCUMENT ID | | TE CN | COMMENT |
|--------------------------------------------|---------------------|-----|-------|--------------------------------------|
| 8.3±1.2 OUR AVERAGE | | | · · | |
| $8.1 \pm 0.7 {+1.3 \atop -1.6}$ | ¹ AUBERT | 09L | BABR | $e^+e^- ightarrow \varUpsilon(45)$ |
| $8.0^{+2.3}_{-2.0}\pm0.7$ | $^{ m 1}$ gordon | 02 | BELL | $e^+e^- ightarrow ~ \gamma(4S)$ |
| $10.4^{+3.3}_{-3.4}\pm 2.1$ | $^{ m 1}$ JESSOP | 00 | CLE2 | $e^+e^- ightarrow \varUpsilon(4S)$ |
| 100 1 1 11 6 11 | | | er | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 110 00 1101 01 | | .o G data ioi dicia | 500, | | .5, 616 |
|----------------------------------------|----|-----------------------|------|------|------------------------------------|
| $8.8 \pm 1.0 \substack{+0.6 \\ -0.9}$ | | ¹ AUBERT,B | 05 G | BABR | Repl. by AUBERT 09L |
| $9.5\pm 1.1\pm 0.9$ | | ¹ AUBERT | 04z | BABR | Repl. by AUBERT 05G |
| < 83 | 90 | ² ABE | 00c | SLD | $e^+ e^- \rightarrow Z$ |
| <160 | 90 | ³ ADAM | 96D | DLPH | $e^+ e^- \rightarrow Z$ |
| < 43 | 90 | ASNER | 96 | CLE2 | Repl. by JESSOP 00 |
| <260 | 90 | ⁴ ABREU | 95 N | DLPH | Sup. by ADAM 96D |
| <150 | 90 | ¹ ALBRECHT | 90в | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| <170 | 90 | 5 BORTOLETTO | 89 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| <230 | 90 | ⁵ BEBEK | 87 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 600 | 90 | GILES | 84 | CLEO | Repl. by BEBEK 87 |

 1 Assumes equal production of B^+ and B^0 at the arphi(4S).

²ABE 00c assumes B(Z \rightarrow $b\,\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^0} = f_{B^+} =$ $(39.7 + 1.8 \atop -2.2)\%$ and $f_{B_s} = (10.5 + 1.8 \atop -2.2)\%$.

 $^3\mathrm{ADAM}$ 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_S}=0.12.$

 4 Assumes a B^0 , B^- production fraction of 0.39 and a $B_{\rm S}$ production fraction of 0.12.

⁵ Papers assume the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}^0$. We rescale to 50%.

| $\left[\Gamma\left(K^*(892)^0\pi^+\right)+\Gamma\left(\rho^0\pi^+\right)\right]$ | $\pi^+)]/\Gamma_{total}$ | | | $(\Gamma_{264} + \Gamma_{355})/\Gamma$ |
|----------------------------------------------------------------------------------|--------------------------|-----|------|----------------------------------------|
| VALUE (units 10 ⁻⁶) | DO CUMENT ID | | TECN | COMMENT |
| $170^{+120}_{-20}\pm 20$ | 1 ADAM | 96D | DLPH | $e^+ e^- \rightarrow Z$ |

 $^{^{1}}$ ADAM 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_S}=0.12$.

| $\Gamma(\pi^+ f_0(980) \times B($ | f ₀ (980) → | $\pi^+\pi^-))/\Gamma_{ m total}$ | | | | Γ ₃₅₆ /Γ |
|---------------------------------------|------------------------|----------------------------------------|-------------|---------|----------------------|-----------------------------|
| VALUE (units 10^{-6}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| < 1.5 | 90 | ¹ AUBERT | 09L | BABR | $e^+e^- \rightarrow$ | Y(45) |
| ● ● We do not use | the following | ng data for averages | , fits, | limits, | etc. • • • | |
| < 3.0 | 90 | ¹ AUBERT,B | 05 G | BABR | Repl. by A | UBERT 09L |
| <140 | 90 | ² BORTOLETTO | 089 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| 1 Assumes equal pro | oduction of | ${\it B}^{+}$ and ${\it B}^{0}$ at the | r(45 | 5). | | |
| | | $< 1.2 	imes 10^{-4}$ assum | | | 5) decays 43 | % to $B^0 \overline{B}^0$. |
| We rescale to 50% | | | , | | | |

 $\Gamma(\pi^+ f_2(1270))/\Gamma_{\text{total}}$ Γ_{357}/Γ VALUE (units 10^{-6}) DO CUMENT ID TECN COMMENT ^{1,2} AUBERT 09L BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $\bullet~\bullet$ We do not use the following data for averages, fits, limits, etc. $\bullet~\bullet$

2,3 AUBERT,B 05G BABR Repl. by AUBERT 09L $4.1 \ \pm 1.3 \ \pm 0.1$ <240 ⁴ BORTOLETTO89 CLEO $e^+e^- \rightarrow \Upsilon(4S)$

¹ AUBERT 09L reports $[\Gamma(B^+ \to \pi^+ f_2(1270))/\Gamma_{\text{total}}] \times [B(f_2(1270) \to \pi^+ \pi^-)] =$ $(0.9\pm0.2\pm0.1_{-0.1}^{+0.3})\times10^{-6}$ which we divide by our best value $B(f_2(1270)\to\pi^+\pi^-)=(56.5_{-0.8}^{+1.6})\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 2 Assumes equal production of $\overset{\smile}{B}{}^+$ and B^0 at the $\varUpsilon(4S)$.

3 AUBERT,B 05G reports $\left[\Gamma\left(B^{+}\rightarrow\pi^{+}f_{2}(1270)\right)/\Gamma_{\mathsf{total}}\right]\times\left[B\left(f_{2}(1270)\rightarrow\pi^{+}\pi^{-}\right)\right]$ $= (2.3 \pm 0.6 \pm 0.4) \times 10^{-6}$ which we divide by our best value B($f_2(1270) \rightarrow \pi^+\pi^-$) = $(56.5 + 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 4 BORTOLETTO 89 reports $< 2.1 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}^0$.

 $\Gamma(
ho(1450)^0\pi^+ imes B(
ho^0 o \pi^+\pi^-))/\Gamma_{ ext{total}}$

VALUE (units 10⁻⁶) DO CUMENT ID TECN COMMENT $1.4 \pm 0.4 \, \substack{+0.5 \\ -0.8}$ $^{
m 1}$ AUBERT 09L BABR $e^+e^- \rightarrow \Upsilon(4S)$

• • • We do not use the following data for averages, fits, limits, etc. • • • 90

¹ AUBERT,B 05G BABR Repl. by AUBERT 09L ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

Γ₃₅₉/Γ $\Gamma(f_0(1370)\pi^+ \times B(f_0(1370) \to \pi^+\pi^-))/\Gamma_{\text{total}}$ DO CUMENT ID VALUE (units 10-6) CL% TECN COMMENT 1 AUBERT 90 09L BABR $e^+e^- \rightarrow$ • • We do not use the following data for averages, fits, limits, etc.

¹ AUBERT,B 05G BABR Repl. by AUBERT 09L 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(f_0(500)\pi^+ \times B(f_0(500) \rightarrow \pi^+\pi^-))/\Gamma_{\text{total}}$ Γ_{360}/Γ CL% DOCUMENT ID TECN COMMENT $^{-1}$ AUBERT,B 05G BABR $e^+e^- \rightarrow r(4S)$ 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(\pi^+\pi^-\pi^+ \text{ nonresonant})/\Gamma_{\text{total}}$ Γ_{361}/Γ VALUE (units 10-6) DOCUMENT ID

TECN COMMENT $5.3 \pm 0.7 ^{+1.3}_{-0.8}$ ¹ AUBERT 09L BABR $e^+e^- \rightarrow \Upsilon(4S)$

• • • We do not use the following data for averages, fits, limits, etc. • • • ¹ AUBERT,B 05G BABR Repl. by AUBERT 09L 90 < 4.6

BERGFELD 96B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 90 1 Assumes equal production of B^{+} and $B^{\,0}$ at the $\Upsilon(4S)$.

 $\Gamma(\pi^+\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_{362}/Γ DOCUMENT ID TECN COMMENT 1 ALBRECHT 90B ARG $e^{+}e^{-}
ightarrow \varUpsilon(4S)$

¹ ALBRECHT 90B limit assumes equal production of $B^0 \overline{B}{}^0$ and $B^+ B^-$ at $\Upsilon(4S)$.

 $\Gamma(\rho^+\pi^0)/\Gamma_{\rm total}$ Γ_{363}/Γ VALUE (units 10⁻⁶) DO CUMENT ID TECN COMMENT 10.9±1.4 OUR AVERAGE $^{\mathrm{1}}$ AUBERT $10.2\!\pm\!1.4\!\pm\!0.9$ 07x BABR $e^+e^- \rightarrow \Upsilon(4S)$ $13.2 \pm 2.3 ^{+1.4}_{-1.9}$ $^{\mathrm{1}}$ ZHANG 05A BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • ¹ AUBERT $10.9 \pm 1.9 \pm 1.9$ 04z BABR Repl. by AUBERT 07x 1,2 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ < 43

< 77 ASNER 96 CLE2 Repl. by JESSOP 00 < 550 90 1 ALBRECHT 90B ARG $e^{+}e^{-}
ightarrow \varUpsilon(4\,S)$

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 Assumes no nonresonant contributions of B^+ \to $~\pi^+$ π^0 π^0

 $\Gamma(\pi^+\pi^-\pi^+\pi^0)/\Gamma_{\text{total}}$ Γ_{364}/Γ DO CUMENT ID TECN COMMENT <4.0 × 10⁻³ 1 ALBRECHT 90B ARG $e^{+}e^{-}
ightarrow \varUpsilon (4S)$

 $^{^1}$ ALBRECHT 90B limit assumes equal production of $B^0\,\overline B{}^0$ and $B^+\,B^-$ at $\varUpsilon(4S)$

 1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^0 at the $\varUpsilon(4\mathcal{S}).$

 B^{\pm}

| = 1.2 ± 0.8 1.4 ± 0.4 Ve do not use = 1.9 ± 1.1 When the sequal profit is 1.9 ± 1.1 Hence the sequal profit is 1.9 ± 0.6 = | the following of the fo | ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT, 1 RICHICHI BEHRENS f B^+ and B^0 at | ale factor of 2.8 08AH BAB 07B BELL ages, fits, limit 05K BAB 04D BAB 00 CLE2 98 CLE2 the T(4S). Scale factor of: 09AV BABR N 06 BELL ages, fits, limit 07AE BABR 04D BABR 04D BABR 05K BABR 04D BABR 05K BABR 06K BABR 07AE BABR 00 CLE2 98 CLE2 the T(4S). | 8. R $e^+e^- \rightarrow $ L $e^+e^- \rightarrow $ S, etc. • • • • R Repl. by A BER 2 $e^+e^- \rightarrow $ 2 Repl. by R $\frac{COMMENT}{1.9}$ $e^+e^- \rightarrow $ Repl. by AUI | T(45) UBERT 08AH T,B 05K T(45) ICHICHI 00 \[\begin{align*} \Gamma_{373}/I \\ \Gamm |
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| =1.2±0.8 -1.4±0.4 Ve do not use =1.9±1.1 Immes equal pro | the following of the fo | 1 AUBERT 1 WANG ing data for aver 1 AUBERT,B 1 AUBERT,B 1 RICHICHI BEHRENS f B+ and B ⁰ at DOCUMENT ID Error includes: 1 AUBERT 1 SCHUEMAN ing data for aver 1 AUBERT 1 RICHICHI BEHRENS f B+ and B ⁰ at 1 AUBERT 1 AUBERT 1 RICHICHI BEHRENS f B+ and B ⁰ at 1 AUBERT 1 AUBERT 1 BEHRENS f B+ and B ⁰ at | 08AH BAB 07B BELL ages, fits, limit 05K BAB 04D BAB 00 CLE2 98 CLE2 the T(4S). TECN scale factor of: 09AV BABR 07AE | R $e^+e^- \rightarrow$ L $e^+e^- \rightarrow$ L $e^+e^- \rightarrow$ S, etc. • • • R Repl. by A BER' 2 $e^+e^- \rightarrow$ 2 Repl. by R $\frac{COMMENT}{1.9}.$ e+e- \rightarrow Repl. by AUI Repl. by | T(45) UBERT 08AH T,B 05K T(45) ICHICHI 00 F373/F F(45) BERT 09AV BERT 07AE BERT,B 05K F(45) F(45) F(45) F(45) F(45) UBERT 07A F(45) UBERT 07A EZ 10A T(45) UBERT 07E T(45) UBERT 07E T(45) |
| 1.4 ± 0.4 We do not use =1.9 ± 1.1 The sequal properties of the sequal properties of the sequal properties of the sequence | 90 90 90 duction of CL% VERAGE the following 90 90 90 duction of CL% the following 90 90 duction of | 1 WANG ing data for aver 1 AUBERT,B 1 AUBERT,B 1 RICHICHI BEHRENS f B+ and B ⁰ at DOCUMENT ID Error includes: 1 AUBERT 1 SCHUEMAN ing data for aver 1 AUBERT,B 1 AUBERT 1 RICHICHI BEHRENS f B+ and B ⁰ at 1 AUBERT 1 RICHICHI BEHRENS f B+ and B ⁰ at 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B+ and B ⁰ at | 07B BELL ages, fits, limit 05K BAB 04D BAB 00 CLE2 98 CLE2 the T(4S). 7 TECN scale factor of: 09AV BABR N 06 BELL ages, fits, limit 07AE BABR 05K BABR 01M BELL 01G BABR 00 CLE2 98 CLE2 the T(4S). 7 TECN TECN SCALE BABR N 07 BELL ages, fits, limit 07AE BABR 08 CLE2 THE T(4S). | L $e^+e^- \rightarrow$ s, etc. • • • R Repl. by A R Repl. by A R Repl. by R 2 Repl. by R COMMENT 1.9. $e^+e^- \rightarrow \gamma$ $e^+e^- \rightarrow \gamma$ $e^+e^- \rightarrow \gamma$ Repl. by AUI Repl. by AUI Repl. by AUI Repl. by AUI Repl. by B R Repl. by R COMMENT Repl. by R R R R R R R R R R R R R R R R R R R | T(45) UBERT 08AH T,B 05K T(45) ICHICHI 00 F373/F F(45) BERT 09AV BERT 07AE BERT,B 05K F(45) F(45) F(45) F(45) F(45) UBERT 07A F(45) UBERT 07A EZ 10A T(45) UBERT 07E T(45) UBERT 07E T(45) |
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| h)/Ftotal hits 10-6 h-1.9 ± 1.1 We do not use -3.1 + 2.3 -2.8 - 1.3 hits 10-6 hits 10-6 4 We do not use | 90 90 90 90 duction of | 1 ABE 1 AUBERT 1 RICHICHI BEHRENS f B+ and B ⁰ at DOCUMENT 1 DEL-AMO- ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B+ and B ⁰ at | 01M BELL 01G BABR 00 CLE2 98 CLE2 the T(45). ID TECN -SA10A BAB ages, fits, limit 07E BAB NN 07 BEL 8 04D BAB 00 CLE: 98 CLE: | $e^+e^- \rightarrow \gamma$ $e^+e^- \rightarrow \gamma$ $e^+e^- \rightarrow \gamma$ Repl. by RIC V COMMENT BR $e^+e^- \rightarrow \gamma$ SA NCH $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ $E^+e^- \rightarrow \gamma$ | Γ(45) Γ(45) Γ(45) HICHI 00 Γ374/I Γ(45) PEL-AMO- EZ 10A Γ(45) UBERT 07E Γ(45) UBERT 07E Γ(45) |
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| h)/Ftotal hits 10-6 h-1.9 ± 1.1 We do not use -3.1 + 2.3 -2.8 - 1.3 hits 10-6 hits 10-6 4 We do not use | 90 90 duction of <u>CL%</u> the following 90 90 90 duction of | 1 RICHICHI BEHRENS f B+ and B ⁰ at DOCUMENT 1 DEL-AMO- ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B+ and B ⁰ at | 00 CLE2 98 CLE2 the T(45). ***DD*** **DD*** * | $e^+e^- \rightarrow \gamma$ Repl. by RIC V <u>COMMENT</u> BR $e^+e^- \rightarrow \epsilon$ S, etc. • • • BR Repl. by E $e^+e^- \rightarrow \epsilon$ BR Repl. by A $e^+e^- \rightarrow \epsilon$ BR Repl. by A $e^+e^- \rightarrow \epsilon$ | T374/I T(4S) PEL-AMO- EZ 10A T(4S) UBERT 07E T(4S) UBERT 07E |
| h)/Ftotal hits 10-6 h-1.9 ± 1.1 We do not use -3.1 + 2.3 -2.8 - 1.3 hits 10-6 hits 10-6 4 We do not use | 90 duction of CL% the following 90 90 90 duction of | BEHRENS f B+ and B ⁰ at DOCUMENT DEL-AMO- ing data for aver AUBERT SCHUEMA AUBERT,E RICHICHI BEHRENS f B+ and B ⁰ at | 98 CLE2 the T(45). ID TECN -SA10A BAB ages, fits, limit 07E BAB NN 07 BEL 8 040 BAB 00 CLE: 98 CLE: | Repl. by RIC $\frac{V}{SR} e^+e^- \rightarrow SANCH$ L $e^+e^- \rightarrow SR$ Repl. by D RR Repl. by 2 RR Repl. by 2 | T374/I T(45) PEL-AMO- EZ 10A T(45) UBERT 07E T(45) UICHICHI 00 |
| h)/Ftotal hits 10-6 h-1.9 ± 1.1 We do not use -3.1 + 2.3 -2.8 - 1.3 hits 10-6 hits 10-6 4 We do not use | the following the following states of the following st | f B+ and B ⁰ at DOCUMENT DEL-A MO- ing data for aver AUBERT SCHUEMA AUBERT,E RICHICHI BEHRENS f B+ and B ⁰ at | ### T(45). #### TECN -SA10A BAB ages, fits, limit | V COMMENT BR $e^+e^- \rightarrow$ SS, etc. • • • BR Repl. by D $E^+e^- \rightarrow$ BR Repl. by A $E^+e^- \rightarrow$ BR Repl. by A | r(4S) DEL-AMO- EZ 10A $r(4S)$ UBERT 07E $r(4S)$ UBERT 000 UBERT 000 |
| h)/Ftotal hits 10-6 h-1.9 ± 1.1 We do not use -3.1 + 2.3 -2.8 - 1.3 hits 10-6 hits 10-6 4 We do not use | 90 90 90 90 90 duction of | DOCUMENT 1 DEL-A MO- ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B+ and B ⁰ at | ### TECN -SA10A BAB ages, fits, limit | BR $e^+e^- \rightarrow$ s, etc. • • • BR Repl. by E SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | τ(4S) DEL-AMO- EZ 10A τ(4S) UBERT 07E τ(4S) ICHICHI 00 |
| $\frac{1.9}{1.8}\pm 1.1$ We do not use $\frac{3.1+2.3}{2.8-1.3}$ Unumes equal pro)/\(\Gamma_{\text{total}}\) inits 10^{-6}) We do not use | the following the following specific sp | 1 DEL-AMO- ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B+ and B0 at | -SA10A BAB ages, fits, limit 07E BAB NN 07 BEL 3 04D BAB 00 CLE: 98 CLE: | BR $e^+e^- \rightarrow$ s, etc. • • • BR Repl. by E SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | τ(45) PEL-AMO- EZ 10A τ(45) UBERT 07E τ(45) ICHICHI 00 |
| Ve do not use $-3.1+2.3$ $2.8-1.3$ umes equal pro $\frac{1}{2}$ $\frac{1}$ | 90 90 90 90 duction of | ing data for aver 1 AUBERT 1 SCHUEMA 1 AUBERT, 1 RICHICHI BEHRENS f B^+ and B^0 at | orages, fits, limit 07E BAB NN 07 BEL 3 04D BAB 00 CLE: 98 CLE: | BR Repl. by D SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | PEL-AMO- EZ $10A$ $\Upsilon(4S)$ UBERT $07E$ $\Upsilon(4S)$ ICHICHI 00 |
| Ve do not use $-3.1+2.3$ $2.8-1.3$ umes equal pro $\frac{1}{2}$ $\frac{1}$ | 90 90 90 90 duction of | 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B and B 0 at | 07E BAB NN 07 BEL 3 04D BAB 00 CLE: 98 CLE: | BR Repl. by D SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | EZ 10A $\Upsilon(4S)$ UBERT 07E $\Upsilon(4S)$ |
| $-3.1+2.3$ 2.8 -1.3 umes equal pro)/ Γ total nits 10^{-6}) 4 We do not use | 90 90 90 90 duction of | 1 AUBERT 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B and B 0 at | 07E BAB NN 07 BEL 3 04D BAB 00 CLE: 98 CLE: | BR Repl. by D SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | EZ 10A $\Upsilon(4S)$ UBERT 07E $\Upsilon(4S)$ |
| umes equal pro)/Ftotal nits 10 ⁻⁶) 4 Ve do not use | 90 90 90 duction of | 1 SCHUEMA 1 AUBERT,E 1 RICHICHI BEHRENS f B^+ and B^0 at | NN 07 BEL 3 04D BAB 00 CLE: 98 CLE: | SANCH L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | EZ 10A $\Upsilon(4S)$ UBERT 07E $\Upsilon(4S)$ |
|)/Γ _{total} nits 10 ⁻⁶) 4 Ve do not use | 90 90 90 duction of | 1 AUBERT,E 1 RICHICHI BEHRENS f B^+ and B^0 at | 04D BAB 00 CLE: 98 CLE: | L $e^+e^- \rightarrow$ BR Repl. by A 2 $e^+e^- \rightarrow$ | Υ(45) UBERT 07E Υ(45) |
|)/Γ _{total} nits 10 ⁻⁶) 4 Ve do not use | 90 90 duction of | 1 RICHICHI BEHRENS f \mathcal{B}^+ and \mathcal{B}^0 at | 00 CLE: 98 CLE: | $e^+e^- \rightarrow$ | Υ(4 <i>S</i>) |
|)/Γ _{total} nits 10 ⁻⁶) 4 Ve do not use | 90 duction of | BEHRENS f B^+ and B^{0} at | 98 CLE: | | ICHICHI 00 |
|)/Γ _{total} nits 10 ⁻⁶) 4 Ve do not use | duction of | f B^+ and B^0 at | | 2 Repl. by R | |
|)/Γ _{total} nits 10 ⁻⁶) 4 Ve do not use | <u>CL%</u> | | the 1 (43). | | Γ /Γ |
| nits 10 ⁻⁶) 4 Ve do not use | | | | | Γ /Γ |
| nits 10 ⁻⁶) 4 Ve do not use | | | | | 375/ |
| 4 Ve do not use | | DOCUMENT I | D TECN | COMMENT | |
| Ve do not use | | 1 AUBERT,B | | $e^+e^- \rightarrow$ | T(45) |
| | | ing data for aver | | | . (/ |
| * | 90 | 1 AUBERT | 04A BABR | Repl. by AL | IRERT B 06 |
| | 90 | ¹ AUBERT | | $e^+e^- \rightarrow$ | |
| | 90 | ² ABE | 00c SLD | $e^+ e^- \rightarrow .$ | |
| | 90 | ¹ BERGFELD | 98 CLE2 | | |
| ımes equal pro | duction of | f B^+ and B^0 at | the $\Upsilon(4S)$. | | |
| 00c assume | $s B(Z \rightarrow$ | $b\overline{b}$ = (21.7 \pm | : 0.1)% and th | he B fractions | $f_{B^0} = f_{B^+} =$ |
| 7 + 1.8)% and | $f_{B_c} = (10.5)$ | $5 + \frac{1}{2} \cdot \frac{8}{2} \cdot $ | | | |
| | D _S | - 2.2 | | | |
| ,, | | | | | Γ ₃₇₆ /Ι |
| nits 10 ⁻⁰) | | . — | | _ | 00(+-) |
| N · | | | | | 1 (45) |
| Ve do not use | the follow | - | - | | |
| | at | | | 2 | |
| | | | ` ' | | |
| - | | , . | | | Γ ₃₇₇ /Ι |
| nits 10 ⁻⁶) | <u>CL%</u> | | | | Y(4C) |
| imes equal pro | | | | | . , |
| _ | | = | aa. D IIICSOIIS | 7 (45) | |
| - | . • | | | | Г378/ |
| nits 10 ⁻⁰) | | | | | |
| | | | | $R e^+e^- \rightarrow$ | Y(45) |
| umes equal pro | duction of | f B^+ and B^{0} at | the $\Upsilon(4S)$. | | |
| _+ _+ |) /E | | | | F , |
| ·π·π π | // total | | 15 | | Г379/ |
| | <u>CL%</u> | | | | |
| | | | | | . , |
| RECHT 90B I | imit assum | nes equal produc | tion of $B^0\overline{B}{}^0$ a | and ${\it B}^{+}{\it B}^{-}$ at | r(45). |
| | | | | | |
| | | | | | |
| | | | | | |
| | E 00c assume $7+\frac{1}{2}$, 2 % and $\frac{1}{2}$)/ Γ total units 10^{-6}) We do not use unuse equal properties 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 100 , 1 | E 00c assumes $B(Z \rightarrow 7, \frac{1}{2}, \frac{1}{2}, \frac{1}{2})$ % and $f_{B_S} = (10.7, \frac{1}{2}, \frac{1}{2})$ % where $f_{B_S} = (10.7, \frac{1}{2})$ % and $f_$ | E 00c assumes $B(Z \rightarrow b \bar{b}) = (21.7 \pm 1.7 \pm 1.8)$ % and $f_{B_S} = (10.5 \pm 1.8)$ %. 1) / \(\text{Total} \) We do not use the following data for averable unness equal production of B^+ and B^0 at $BBCFELI$ unness equal production of B^+ and B^0 at $BBCFELI$ unness equal production of B^+ and B^0 at $BBCFELI$ unness equal production of charged and new $BBCFELI$ unness equal production of charged and new $BBCFELI$ unness equal production of charged and new $BBCFELI$ unness equal production of B^+ and B^0 at $BBCFELI$ unness equal production of B^+ and B^0 at $BCCFELI$ unness equal production of B^+ and B^0 at $BCCFELI$ unness equal production of B^+ and B^0 at $BCCFELI$ unness equal production of B^+ and B^0 at $BCCFELI$ unness equal production of B^+ and B^0 at $BCCFELI$ unness equal production of B^+ and B^0 at $BCCCFELI$ unness equal production of B^+ and B^0 at $BCCCCCFELI$ unness equal production of B^+ and B^0 at $BCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC$ | E 00c assumes $B(Z \rightarrow b\overline{b}) = (21.7 \pm 0.1)\%$ and to $7 + \frac{11.8}{2.2}\%$ and $f_{B_3} = (10.5 + \frac{11.8}{2.2})\%$. The proof of the proo | E 00c assumes $B(Z \to b\overline{b}) = (21.7 \pm 0.1)\%$ and the B fractions $7 + \frac{1.8}{2.2}\%$ and $f_{B_S} = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$. The proof of $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 + \frac{1.8}{2.2})\%$ and $P_S = (10.5 +$ |

 B^{\pm}

| VALUE CL% | Γ ₃₈₀ /Γ DOCUMENT ID TECN COMMENT | $\Gamma(p\overline{p}\pi^+)/\Gamma_{\text{total}}$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <6.2 × 10 ⁻⁴ 90 | $\frac{DOCUMENT\ ID}{1}$ BORTOLETTO89 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | <u>VALUE (units 10⁻⁶) CL% DOCUMENT ID TECN COMMENT</u> 1.62± 0.20 OUR AVERAGE |
| | wing data for averages, fits, limits, etc. • • • | $1.60 ^{+}_{-}$ $\begin{array}{ccc} 0.22 \\ 0.19 \end{array} \pm $ 0.12 $$ $1,2,3$ WEI 08 BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| $<6.0 \times 10^{-4}$ 90 $<3.2 \times 10^{-3}$ 90 | 2 ALBRECHT 90B ARG $e^+e^- ightarrow \varUpsilon(4S)$ 1 BEBEK 87 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | $1.69\pm$ $0.29\pm$ 0.26 1 AUBERT 07AV BABR $e^{+}e^{-} ightarrow$ $\varUpsilon(4S)$ |
| | Section 2.1 Section 2.1 Section 2.1 Section 2.1 Section 2.1 Section 3.1 Secti | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| We rescale to 50%. | The sequal production of $B^0\overline{B}^0$ and B^+B^- at $\Upsilon(4S)$. | 3.06^{+}_{-} 0.73_{\pm} 0.37 1.3_{-} WANG 04 BELL Repl. by WEI 08 |
| | mes equal production of $B^{0}\overline{B}^{0}$ and $B^{+}B^{-}$ at $\Upsilon(4S)$. | < 3.7 90 1,2 ABE 02K BELL Repl. by WANG 0 <500 90 4 ABREU 95N DLPH Repl. by ADAM 9 |
| $\Gamma(ho^0 a_2(1320)^+)/\Gamma_{ m total}$ | Γ ₃₈₁ /Γ | <160 90 SBEBEK 89 CLEO $e^+e^- \rightarrow r(4s)$ |
| VALUE CL% | | 570 ± 150 ± 210 6 ALBRECHT 88F ARG $e^+e^- \rightarrow r(4S)$ |
| <7.2 × 10 ⁻⁴ 90 • • • We do not use the follo | 1 BORTOLETTO89 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ wing data for averages, fits, limits, etc. $ullet$ $ullet$ | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Explicitly vetoes resonant production of $p\overline{p}$ from Charmonium states. |
| $< 2.6 \times 10^{-3}$ 90 | 2 BEBEK 87 CLEO $e^+e^- ightarrow \gamma(4S)$ | ³ Also provides results with $m_{p\overline{p}} < 2.85 \text{ GeV/c}^2$ and angular asymmetry of $p\overline{p}$ system |
| ¹ BORTOLETTO 89 reports | $s < 6.3 	imes 10^{-4}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. | ⁴ Assumes a B^0 , B^- production fraction of 0.39 and a B_s production fraction of 0.1: |
| We rescale to 50%. 2 BEBEK 87reports < 2.3 × | 10^{-3} assuming the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}{}^0$. We rescale | 5 BEBEK 89 reports $<1.4\times10^{-4}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}^0$. We rest to 50%. 6 ALBRECHT 88F reports $(5.2\pm1.4\pm1.9)\times10^{-4}$ assuming the $\varUpsilon(4S)$ decays 45% |
| to 50%. | | ALBRECHT 88F reports $(5.2 \pm 1.4 \pm 1.9) \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 45% $B^0 \overline{B}{}^0$. We rescale to 50%. |
| $\Gamma(b_1^0\pi^+\times B(b_1^0\to\omega\pi^0))$ |)/Γ _{total} Γ ₃₈₂ /Γ | |
| VALUE (units 10^{-6}) | DOCUMENT ID TECN COMMENT | $\Gamma(\rho \overline{\rho} \pi^+ \text{nonresonant})/\Gamma_{\text{total}}$ |
| 6.7±1.7±1.0 | 1 AUBERT 07BI BABR $e^{+}e^{-} ightarrow$ $\varUpsilon(4S)$ | $\frac{VALUE (units 10^{-6})}{<53}$ $\frac{CL\%}{}$ $\frac{DOCUMENT ID}{}$ $\frac{TECN}{}$ $\frac{COMMENT}{}$ $+e^+e^-$ → $T(4S)$ |
| $^{ m 1}$ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | |
| $\Gamma(b_1^+\pi^0\times B(b_1^+\to\omega\pi^+)$ | Γ_{101} | Γ(ρρπ+π+π-)/Γ _{total} Γ ₃₉₃ <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> |
| VALUE (units 10^{-6}) CL% | | • • • We do not use the following data for averages, fits, limits, etc. • • |
| <3.3 90 | 1 AUBERT 08AG BABR $e^{+}e^{-} ightarrow~ arGamma(4S)$ | $<$ 5.2 $	imes$ 10 $^{-4}$ 90 1 ALBRECHT 88F ARG $e^{+}e^{-} ightarrow \varUpsilon$ (45) |
| $^{ m 1}$ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | 1 ALBRECHT 88F reports $<$ 4.7 \times 10 $^{-4}$ assuming the $\varUpsilon(4S)$ decays 45% to $B^0\overline{B}^0$. rescale to 50%. |
| $\Gamma(\pi^+\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma_1$ | rotal Γ ₃₈₄ /Γ | |
| VALUE CL% | | $\Gamma(p\overline{p}K^+)/\Gamma_{	ext{total}}$ |
| <6.3 × 10 ⁻³ 90 | ¹ ALBRECHT 90B ARG $e^+e^- \rightarrow \Upsilon(4S)$ | <u>VALUE (units 10⁻⁶)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 5.9 ±0.5 OUR AVERAGE Error includes scale factor of 1.5. |
| ¹ ALBRECHT 90B limit assu | imes equal production of $B^0\overline{B}{}^0$ and B^+B^- at \varUpsilon (45). | $5.54^{+0.27}_{-0.25}\pm0.36$ 1,2,3 WEI 08 BELL $e^+e^- ightarrow~\Upsilon(4S)$ |
| $\Gamma(b_1^+ \rho^0 \times B(b_1^+ \to \omega \pi^+))$ | Γ_{385}/Γ | 6.7 \pm 0.5 \pm 0.4 1,3 AUBERT,B 05L BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| VALUE CL% <5.2 × 10⁻⁶ 90 | DOCUMENT ID TECN COMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • |
| | . , | $4.59^{+0.38}_{-0.34}\pm0.50$ 1,2,3 WA NG 05A BELL Repl. by WEI 08 |
| | of B^+ and B^0 at the $\varUpsilon(4S)$. | $5.66^{+0.67}_{-0.57} \pm 0.62$ 1,2,3 WA NG 04 BELL Repl. by WA NG (|
| $\Gamma(b_1^0 \rho^+ \times B(b_1^0 \to \omega \pi^0))$ | | 4.3 $^{+1.1}_{-0.9}$ $^{\pm}$ 0.5 1,2 ABE 02K BELL Repl. by WANG (|
| <u>VALUE</u> <u>CL%</u> <3.3 × 10^{−6} 90 | 1 AUBERT 09AF BABR $e^+e^- ightarrow arphi(4S)$ | 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. |
| | of B^+ and B^0 at the $\Upsilon(4S)$. | 2 Explicitly vetoes resonant production of $p\overline{p}$ from Charmonium states. 3 Provides also results with $m_{p\overline{p}}<2$.85 GeV/c 2 and angular asymmetry of $p\overline{p}$ syste |
| Γ(a ₁ (1260) ⁺ a ₁ (1260) ⁰)/ | | |
| I (a1(1260)' a1(1260)')/ VALUE | Γ _{total} Γ ₃₈₆ /Γ . <u>DOCUMENT ID</u> <u>TECN COMMENT</u> | $\Gamma(\Theta(1710)^{++}\overline{p}\times B(\Theta(1710)^{++}\to pK^{+}))/\Gamma_{total}$ Γ_{399} |
| <1.3 × 10 ⁻² 90 | 1 ALBRECHT 90B ARG $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| ¹ ALBRECHT 90B limit assu | mes equal production of $B^0\overline{B}{}^0$ and B^+B^- at $\varUpsilon(4S)$. | <0.091 90 1 WANG 05A BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $\Gamma(h^+\pi^0)/\Gamma_{\rm total}$ | Г ₃₈₈ /Г | <0.1 90 $^{-1,2}$ AUBERT,B 05L BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $h^+ = K^+ \text{ or } \pi^+$ | . 3007 | $rac{1}{2}$ Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | ² Provides upper limits depending on the pentaquark masses between 1.43 to 2.0 GeV |
| 16 ⁺⁶ ±3.6 | GODANG 98 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(f_J(2220) K^+ \times B(f_J(2220) \to p\overline{p}))/\Gamma_{\text{total}}$ |
| $\Gamma(\omega h^+)/\Gamma_{ m total}$ | Г ₃₈₉ /Г | $\frac{VALUE \text{ (units } 10^{-6})}{\text{<0.41}}$ $\frac{CL\%}{90}$ $\frac{DOCUMENT \ ID}{1}$ $\frac{TECN}{8}$ $\frac{COMMENT}{1}$ $\frac{TECN}{90}$ $\frac{COMMENT}{1}$ |
| $h^+ = K^+ \text{ or } \pi^+$ | 1 389/1 | <0.41 90 1 WANG 05A BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| VALUE (units 10^{-6}) | DOCUMENT ID TECN COMMENT | |
| | | $\Gamma(ho\Lambda(1520))/\Gamma_{	ext{total}}$ $\Gamma_{	ext{39}};$ VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT |
| 13.8 ^{+2.7} OUR AVERAGE | | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | 1 LU 02 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $13.4 + \frac{3.3}{-2.9} \pm 1.1$ | | · · · · · · · · · · · · · · · · · · · |
| $13.4 + \frac{3.3}{-2.9} \pm 1.1$ $14.3 + \frac{3.6}{-3.2} \pm 2.0$ | 1 JESSOP 00 CLE2 $\mathrm{e^+e^-} ightarrow \ \varUpsilon(4.5)$ | |
| $13.4^{+3.3}_{-2.9} \pm 1.1$ $14.3^{+3.6}_{-3.2} \pm 2.0$ • • • We do not use the follo | 1 JESSOP 00 CLE2 $e^+e^- ightarrow 	au(4S)$ wing data for averages, fits, limits, etc. $ullet$ $ullet$ $ullet$ | |
| $13.4 + \frac{3.3}{2.9} \pm 1.1$ $14.3 + \frac{3.6}{3.2} \pm 2.0$ • • • We do not use the follo $25 + \frac{48}{7} \pm 3$ | 1 JESSOP 00 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ wing data for averages, fits, limits, etc. \bullet \bullet \bullet 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 | $\Gamma(p\overline{p}K^+ \text{ nonresonant})/\Gamma_{\text{total}}$ |
| $13.4^{+3.3}_{-2.9}\pm 1.1$ $14.3^{+3.6}_{-3.2}\pm 2.0$ • • • We do not use the follo $25^{+8}_{-7}\pm 3$ Assumes equal production | 1 JESSOP 00 CLE2 $e^+e^- \to \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. | $ \begin{array}{c ccccc} \hline \Gamma(p\overline{p}K^+ \text{ nonresonant})/\Gamma_{\text{total}} & & & & & & & & & & & & & & & & & & $ |
| $13.4^{+3.3}_{-2.9}\pm 1.1$ $14.3^{+3.6}_{-3.2}\pm 2.0$ • • • We do not use the follo $25^{+8}_{-7}\pm 3$ Assumes equal production | 1 JESSOP 00 CLE2 $e^+e^- \to \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. | $\Gamma(p \overline{p} K^+ \text{ nonresonant})/\Gamma_{	ext{total}}$ Γ_{398} <u>VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT</u> |
| $13.4 + \frac{3.3}{2.9} \pm 1.1$ $14.3 + \frac{3.3}{3.2} \pm 2.0$ • • • We do not use the follo $25 + \frac{8}{7} \pm 3$ ¹ Assumes equal production $\Gamma(h + X^0 \text{ (Fa milon))}/\Gamma_{\text{total}}$ WALUE (units 10^{-6}) | 1 JESSOP 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ wing data for averages, fits, limits, etc. \bullet \bullet \bullet 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 13.4 $^{+3.3}_{-2.9}\pm1.1$ 14.3 $^{+3.3}_{-3.2}\pm2.0$ • • • We do not use the follo 25 $^{+8}_{-7}\pm3$ 1 Assumes equal production $\Gamma(h^+X^0(\text{Fa milon}))/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) <49 90 | 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 DOCUMENT ID TECN COMMENT $\frac{DOCUMENT\ ID}{1\ AMMAR}$ 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $13.4 + \frac{3.3}{2.9} \pm 1.1$ $14.3 + \frac{3.6}{3.2} \pm 2.0$ • • • We do not use the follo $25 + \frac{8}{7} \pm 3$ Assumes equal production $\Gamma(h + \chi^0 \text{(Familon))} / \Gamma_{\text{total}}$ $\frac{\chi_{\text{CLWE (units }10^{-6})}}{49}$ $\frac{\zeta_{\text{LWE}}}{1}$ AMMAR 01B searched for | 1 JESSOP 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 DOCUMENT ID TECN COMMENT 1 AMMAR 01B CLE2 $e^+e^- 	oup \Upsilon(4S)$ the two-body decay of the B meson to a massless neutral | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 13.4 $ + \frac{3.3}{2.9} \pm 1.1$ 14.3 $ + \frac{3.6}{3.2} \pm 2.0$ • • • We do not use the follo 25 $ + \frac{8}{7} \pm 3$ 1 Assumes equal production $\Gamma(h + X^0 (Familon)) / \Gamma_{total}$ $VALUE (units 10^{-6}) 2.49 20 1 AMMAR 01B searched for feebly-interacting particle.$ | 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 DOCUMENT ID TECN COMMENT $\frac{DOCUMENT\ ID}{1\ AMMAR}$ 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 13.4 $ + \frac{3.3}{2.9} \pm 1.1$ 14.3 $ + \frac{3.6}{3.2} \pm 2.0$ • • • We do not use the follo 25 $ + \frac{8}{7} \pm 3$ 1 Assumes equal production $\Gamma(h + X^0 (Familon)) / \Gamma_{total}$ $VALUE (units 10^{-6}) 2.49 20 1 AMMAR 01B searched for feebly-interacting particle.$ | 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 AMMAR 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ the two-body decay of the B meson to a massless neutral χ^0 such as the familion, the Nambu-Goldstone boson associ- | |
| 13.4 $ + \frac{3.3}{2.9} \pm 1.1$ 14.3 $ + \frac{3.6}{3.2} \pm 2.0$ • • • We do not use the follo 25 $ + \frac{8}{7} \pm 3$ 1 Assumes equal production $\Gamma(h + X^0 (Familon)) / \Gamma_{total}$ $VALUE (units 10^{-6}) 2.49 20 1 AMMAR 01B searched for feebly-interacting particle.$ | 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 AMMAR 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ the two-body decay of the B meson to a massless neutral χ^0 such as the familion, the Nambu-Goldstone boson associ- | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 13.4 $^{+3.3}_{-2.9}\pm1.1$ 14.3 $^{+3.6}_{-3.2}\pm2.0$ • • • We do not use the follo 25 $^{+8}_{-7}\pm3$ 1 Assumes equal production $\Gamma(h^+X^0(\text{Familon}))/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-6})}{1 \text{ AMMAR }018 \text{ searched for feebly-interacting particle}}$ | 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ wing data for averages, fits, limits, etc. • • • 1 BERGFELD 98 CLE2 Repl. by JESSOP 00 of B^+ and B^0 at the $\Upsilon(4S)$. 1 AMMAR 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ the two-body decay of the B meson to a massless neutral χ^0 such as the familion, the Nambu-Goldstone boson associ- | |

| | $B(f_J(2220)\to \rho\overline{\rho}))/$ | /Γ _{total} | Γ ₄₀₀ /Γ | $\Gamma(\Lambda\overline{\Lambda}\pi^+)/\Gamma_{ m total}$ | | | Γ ₄₁₀ /Γ |
|--------------------------------------------------------------|-------------------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------|-------------------------------------------|------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁶) | CL%DOCUMEN | | OMMENT | VALUE (units 10 ⁻⁶) | | | COMMENT |
| <0.77 | 90 1 AUBERT oduction of 4 and 6 | | e ⁻ → T(45) | <0.94 • • • We do not use th | e following data for averag | | Repl. by CHANG 09 , etc. ● ● |
| | oduction of B - and B - a | at the 7 (43). | | <2.8 | 90 ² LEE | = | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $(\rho \overline{\Lambda})/\Gamma_{\text{total}}$ | | | Γ ₄₀₁ /Γ | 1 For $m_{\Lambda} \overline{\Lambda} < 2.85$ Ge | V/c^2 . | | |
| /ALUE (units 10 ⁻⁶) | CL% | | MMENT | | uction of ${\it B}^{+}$ and ${\it B}^{0}$ at t | he $\Upsilon(4S)$. | |
| < 0.32 | 90 ¹ TSAI | | $e^- \rightarrow r(4S)$ | $\Gamma(\Lambda \overline{\Lambda} K^+)/\Gamma_{\text{total}}$ | | | Γ ₄₁₁ /Γ |
| < 0.49 | the following data for av 90 1 CHANG | = | epl. by TSAI 07 | VALUE (units 10 ⁻⁶) | DO CUMENT IL |) TECN | COMMENT |
| < 1.5 | 90 ¹ BORNHE | | $e^- \rightarrow \Upsilon(4S)$ | $3.38^{+0.41}_{-0.36} \pm 0.41$ | 1,2 CHANG | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 2.2 | 90 ¹ ABE | 020 BELL e^+ | $e^- \rightarrow \Upsilon(4S)$ | | e following data for averag | | , |
| < 2.6 | 90 ¹ COAN | 99 CLE2 e+ | , , | | | | |
| <60 <93 | 90 ² AVERY 90 ³ ALBRECI | | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ | $2.91 {}^{+ 0.9}_{- 0.70} \pm 0.38$ | ² LEE | | Repl. by CHANG 09 |
| | oduction of B^+ and B^0 | | c , , (40) | $^{ m 1}$ Excluding charmoniu | um events in 2.85 $< m_{\Lambda \overline{\Lambda}}$ | < 3.128 GeV | $^{\prime}/\mathrm{c}^{2}$ and 3.315 $<$ $m_{\Lambda}\overline{\Lambda}$ $<$ |
| | $0.5 < 5 \times 10^{-5}$ assuming t | | to $B^0\overline{B}^0$. We rescale | 3.735 GeV/c ² . Meas | surements in various $m_{\Lambda \overline{\Lambda}}$ | bins are also r | reported. |
| to 50%. | eports $<$ 8.5 $	imes$ 10 $^{-5}$ ass | suming the $\Upsilon(AS)$ decay | vs 45% to 80 R 0 We | ² Assumes equal produ | uction of B^+ and B^0 at t | he $\Upsilon(4S)$. | |
| rescale to 50%. | cports < 0.5 × 10 833 | uning the 7 (45) decay | y3 43 /0 10 D D . VVC | $\Gamma(\Lambda \overline{\Lambda} K^{*+})/\Gamma_{\text{total}}$ | | | Γ ₄₁₂ /Γ |
| $(\rho \overline{\Lambda} \gamma) / \Gamma_{\text{total}}$ | | | Γ ₄₀₂ /Γ | VALUE (units 10 ⁻⁶) | DO CUMENT IL | TECN | COMMENT |
| (P11)/ 1 total (ALUE (units 10 ⁻⁶) | CL% DO CUMEN | IT ID TECN CO | ' 402/' DMMENT | $2.19^{+1.13}_{-0.88}\pm0.33$ | 1,2 chang | 09 BELL | $e^+e^- \rightarrow \gamma(4S)$ |
| | | ,,, | | ==== | | | , |
| $2.45 + 0.44 \pm 0.22$ | ¹ WANG | | $e^- \rightarrow \Upsilon(4S)$ | ¹ For $m_{\Lambda \overline{\Lambda}} < 2.85$ Ge ² | uction of B^+ and B^0 at t | ho Υ(15) | |
| | the following data for av | erages, fits, limits, etc. | • • • | | action of B. and B. at t | nc 7 (45). | |
| $2.16 {}^{+ 0.58}_{- 0.53} {}^{\pm 0.20}$ | 1 LEE | | epl. by WANG 07c | $\Gamma(\overline{\Delta}{}^0 p)/\Gamma_{\text{total}}$ | | | Γ ₄₁₃ /Γ |
| <3.9 | 90 ² EDWARD | | $e^- \rightarrow \gamma(4S)$ | VALUE (units 10 ⁻⁶) | <u>CL%</u> <u>DOCUMENT II</u> 90 ¹ WEI | | COMMENT |
| Assumes equal pro | duction of B^+ and B^0 a | at the $\Upsilon(4S)$. | | < 1.38 • • • We do not use th | 90 ^I WEI e following data for avera _i | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ² Corresponds to E_{γ} | $_{\gamma} > 1.5$ GeV. The limit c | hanges to 3.3×10^{-6} | for $E_{\gamma} > 2.0$ GeV. | <380 | _ | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $(\rho \overline{\Lambda} \pi^0)/\Gamma_{\text{total}}$ | | | Γ ₄₀₃ /Γ | 1 Assumes equal produ | uction of B^+ and B^0 at t | he $\Upsilon(4S)$. | * * |
| ALUE (units 10 ⁻⁶) | DO CUMEN | IT ID TECN CO | MMENT | ² BORTOLETTO 89 | reports $< 3.3 	imes 10^{-4}$ ass | uming the γ (4 | (15) decays 43% to $B^0 \overline{B}{}^0$. |
| $3.00^{+0.61}_{-0.53} \pm 0.33$ | 1 WANG | 07c BELL e^+ | $e^- \rightarrow \gamma(4S)$ | We rescale to 50%. | | | |
| 0.00 | | | - '('-') | $\Gamma(\Delta^{++}\overline{\rho})/\Gamma_{\text{total}}$ | | | Γ ₄₁₄ /Γ |
| | oduction of B^+ and B^0 a | at the T(45). | | VALUE (units 10 ⁻⁶) | CL% DOCUMENT IL | | COMMENT |
| $\Gamma(p\overline{\Sigma}(1385)^0)/\Gamma_{to}$ | otal | | Γ ₄₀₄ /Γ | < 0.14 | 90 ¹ WEI | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| /ALUE (units 10 ⁻⁶) | CL% DO CUMEN | | MMENT | | e following data for averag | - | |
| <0.47 | 90 ¹ WANG | 07c BELL e^+ | $e^- \rightarrow \gamma(4S)$ | <150 | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ¹ Assumes equal pro | oduction of ${\it B}^+$ and ${\it B}^0$ a | at the $\varUpsilon(4S)$. | | 2 BORTOLETTO 89 | uction of B^+ and B^0 at t reports $< 1.3 \times 10^{-4}$ ass | ne 1 (45). Uming the Υ (4 | (S) decays 43% to $B^0 \overline{B}^0$. |
| $(\Delta + \overline{\Lambda})/\Gamma_{\text{total}}$ | | | Γ ₄₀₅ /Γ | We rescale to 50%. | | | ,, |
| /ALUE (units 10 ⁻⁶) | CL% DO CUMEN | IT ID TECN CO | PMMENT | $\Gamma(D^+ \rho \overline{\rho})/\Gamma_{\text{total}}$ | | | Γ ₄₁₅ /Γ |
| <0.82 | 90 ¹ WANG | $07c$ BELL e^+ | e ⁻ → γ(4S) | VALUE | <u>CL%</u> <u>DO CUMENT IL</u> | | COMMENT |
| ¹ Assumes equal pro | duction of ${\it B}^+$ and ${\it B}^0$ a | at the $\Upsilon(4S)$. | | $<1.5 \times 10^{-5}$ | 90 ¹ ABE | | $e^+e^- ightarrow ~ \varUpsilon(45)$ |
| $\Gamma(p\overline{\Sigma}\gamma)/\Gamma_{total}$ | | | Γ ₄₀₆ /Γ | ¹ Assumes equal produ | uction of ${\it B}^+$ and ${\it B}^{0}$ at t | he $\Upsilon(4S)$. | |
| (P = 1)/ total (ALUE (units 10 ^{- 6}) | CL% DO CUMEN | IT ID TECN CO | ' 406 / ' DMMENT | $\Gamma(D^*(2010)^+ \rho \overline{\rho})/\Gamma_1$ | total | | Γ ₄₁₆ /Γ |
| <4.6 | 90 1 LEE | | e ⁻ → γ(45) | VALUE | CL% DOCUMENT IL | TECN | |
| - | the following data for av | | | <1.5 × 10 ⁻⁵ | 90 ¹ ABE | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| <7.9 | 90 ² EDWARD | OS 03 CLE2 e^+ | $e^- \rightarrow \gamma(4S)$ | ¹ Assumes equal produ | uction of ${\it B}^+$ and ${\it B}^{0}$ at t | he $\Upsilon(4S)$. | |
| | duction of ${\it B}^+$ and ${\it B}^0$ a | | | $\Gamma(\rho \overline{\Lambda}{}^{0} \overline{D}{}^{0})/\Gamma_{\text{total}}$ | | | Γ ₄₁₇ /Γ |
| 2 Corresponds to E_{γ} | $_{\gamma} > 1.5$ GeV. The limit c | thanges to 6.4 $	imes$ 10 $^{-6}$ | for $E_{\gamma} >$ 2.0 GeV. | VALUE (units 10 ⁻⁵) | DO CUMENT IL |) TECN | |
| $(\rho \overline{\Lambda} \pi^+ \pi^-)/\Gamma_{\text{tota}}$ | -1 | | Γ ₄₀₇ /Γ | $1.43 + 0.28 \pm 0.18$ | 1,2 CHEN | 11F BELL | $e^+e^- \rightarrow \gamma(4S)$ |
| /ALUE (units 10 ⁻⁶) | II CL% DOCUMEN | IT ID TECN CO | • | | (2.0.1.0.5% D/D) | | 89 \pm 0.05%, and B(D^0 \rightarrow |
| 5.92+0.88±0.69 | | 09c BELL e ⁺ | | $K^-\pi^+\pi^0) = 13.9$: | | $K \pi' = 3.$ | 89 \pm 0.05%, and $\mathrm{B}(D^{\circ} \rightarrow$ |
| | | | () | | uction of B^0 and B^+ from | upsilon(4S) o | lecays. |
| | the following data for av 90 ² ALBRECI | verages, fits, limits, etc. HT 88F ARG e ⁺ | | $\Gamma(p\overline{\Lambda}{}^{0}\overline{D}^{*}(2007)^{0})/\Gamma$ | - | | F /F |
| <200 | | | e → 1(45) | , | | | Γ ₄₁₈ /Γ |
| | oduction of B^+ and B^0 a eports $< 1.8 	imes 10^{-4}$ ass | | vs 45% to 80 R 0 We | <u>VALUE (units 10⁻⁵)</u> | | | $e^+e^- ightarrow \Upsilon(4S)$ |
| rescale to 50%. | cports < 1.0 × 10 433 | anning the 7 (40) decay | y5 45 /0 10 D D . 440 | | | | $B^+ \rightarrow \rho \overline{\Lambda}{}^0 \overline{D}{}^* (2007)^0)/$ |
| $(\rho \overline{\Lambda} \rho^0)/\Gamma_{\text{total}}$ | | | Γ ₄₀₈ /Γ | Γ] / [B(D*(200 | $0.7)^0 \rightarrow D^0 \pi^0$)1 assumir | urement of [1] ng B(D*(2007) | $0^0 \to D^0 \pi^0 = (61.9 \pm 0.00)$ |
| (ALUE (units 10 ⁻⁶) | DO CUMEN | IT ID TECN CO | · 408/· DMMENT | $(2.9) \times 10^{-2}$ | , | .8 5(5 (2001) | , , , , , , , (01.5 ± |
| .78 + 0.67 ± 0.60 | 1 CHEN | 09c BELL e ⁺ | | ² Uses B($\Lambda \rightarrow p\pi^-$) | $= 63.9 \pm 0.5\%$ and B(D | $0 \rightarrow K^- \pi^+)$ | $= 3.89 \pm 0.05\%$. |
| | | | € → 1(43) | ³ Assumes equal produ | uction of ${\it B}^{0}$ and ${\it B}^{+}$ fron | n Upsilon(4S) o | lecays. |
| ¹ Assumes equal pro | oduction of B^+ and B^0 a | at the $\varUpsilon(4S)$. | | $\Gamma(\overline{\Lambda}_c^- \rho \pi^+)/\Gamma_{\text{total}}$ | | | Γ ₄₁₉ /Γ |
| $(p\overline{\Lambda}f_2(1270))/\Gamma_{to}$ | otai | | Γ ₄₀₉ /Γ | VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN C | COMMENT |
| ALUE (units 10 ⁻⁶) | | IT ID TECN CO | MMENT | 2.8±0.8 OUR AVERAGE | <u> </u> | | |
| $0.03 + 0.77 \pm 0.27$ | 1 CHEN | 09c BELL e^+ | | $3.4 \pm 0.1 \pm 0.9$ | 1,2 AUBERT | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | | - ' (+0) | $2.0 \pm 0.3 \pm 0.5$ $2.4 \pm 0.6 \pm 0.6$ | 4 4 | 06A BELL ϵ 02 CLE2 ϵ | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| + Assumes equal pro | oduction of B^+ and B^0 a | at the T (45). | | | e following data for averag | | · / |
| | | | | $1.9 \pm 0.5 \pm 0.5$ | 1,5 GABYSHEV | 02 BELL F | Repl. by GABYSHEV 06A |
| | | | | $6.2^{+2.3}_{-2.0}\pm1.6$ | 1,6 _{FU} | 97 CLE2 F | Repl. by DYTMAN 02 |

 $\begin{array}{c} 1.9 \!\pm\! 0.5 \!\pm\! 0.5 \\ 6.2 \!+\! 2.3 \!\pm\! 1.6 \end{array}$

 1,6 $_{
m FU}$

97 CLE2 Repl. by DYTMAN 02

 Γ_{429}/Γ

| See key on p | oage 4. | 57 | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 Assumes equal pro 2 AUBERT 08BN re $\overline{\Lambda_{C}} p \pi^{+})/\Gamma_{\text{total}}$ 1 3 3 GABYSHEV 06A re $\overline{\Lambda_{C}} p \pi^{+})/\Gamma_{\text{total}}$ we rescale to our tis their experiments best value. | ports $(3.4 \pm \times [B(\Lambda_C^+ - E)] \times [B(\Lambda_C$ | $\begin{array}{c} = 0.1 \pm 0.9) \times 10 \\ \rightarrow p K^- \pi^+)] \text{ ass} \\ \pm 0.15 \pm 0.20) \times \\ p K^- \pi^+)] \text{ assur} \\ (\Lambda_C^+ \rightarrow p K^- \pi^+) \\ \text{ our second error} \\ (32) \times 10^{-4} \text{ from a} \end{array}$ | i^{-4} from a suming $B(A_c^{-4})$ from a ming $B(A_c^{+})$ = $(5.0 \pm i)$ is the system | $_{c}^{+} \rightarrow p K^{-} \pi^{-}$ a measurement $\rightarrow p K^{-} \pi^{+}) = 1.3) \times 10^{-2}$. Generatic error from the of $[\Gamma (B^{+} - B^{-})]$ | $^{+}$) = (5.0 \pm of [$\Gamma(B^{+} \rightarrow 0.05, \text{ which})$ Our first error om using our $\overline{\Lambda}_{C}^{-} p \pi^{+}$)/ |
| $\Gamma_{\text{total}}] \times [B(\Lambda_C^+ - \text{to our best value}]$ to our best value experiment's error 5 GABYSHEV 02 is $\overline{\Lambda}_C^- p \pi^+)/\Gamma_{\text{total}}]$ | ⁴ DYT MAN 02 reports $(2.4^{+0.63}_{-0.62}) \times 10^{-4}$ from a measurement of $[\Gamma(B^+ \to \overline{\Lambda}_c^- p \pi^+)/\Gamma_{\text{total}}] \times [B(\Lambda_c^+ \to p K^- \pi^+)]$ assuming $B(\Lambda_c^+ \to p K^- \pi^+) = 0.05$, which we rescale to our best value $B(\Lambda_c^+ \to p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. ⁵ GABYSHEV 02 reports $(1.87^{+0.54}_{-0.49}) \times 10^{-4}$ from a measurement of $[\Gamma(B^+ \to \overline{\Lambda}_c^- p \pi^+)/\Gamma_{\text{total}}] \times [B(\Lambda_c^+ \to p K^- \pi^+)]$ assuming $B(\Lambda_c^+ \to p K^- \pi^+) = 0.05$, which we rescale to our best value $B(\Lambda_c^+ \to p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our both value. | | | | |
| $\Gamma(\overline{\Lambda}_c^- \Delta(1232)^{++})$ | | A _C branching trac | tion. | | Γ ₄₂₀ /Γ |
| VALUE (units 10 ⁻⁵) | / ' total CL% | DO CUMENT ID | TECN | I COMMENT | |
| <1.9 | 90 | GABYSHEV | 06A BELL | $\frac{COMMENT}{e^+ e^-} \rightarrow$ | Υ(4S) |
| $\Gamma(\overline{\Lambda}_c^- \Delta_X (1600)^{++})$ VALUE (units 10^{-5}) |)/Γ _{total} | DOCUMENT ID 1 GABYSHEV | TECN | COMMENT | Γ ₄₂₁ /Γ |
| 5.9±1.2±1.5 | | | | | |
| 1 GABYSHEV 06A reports $(5.9\pm1.0\pm0.6)\times10^{-5}$ from a measurement of $[\Gamma(B^{+}\to \overline{\Lambda_{c}^{-}}\Delta\chi(1600)^{++})/\Gamma_{\text{total}}]\times[B(\Lambda_{c}^{+}\to\rhoK^{-}\pi^{+})]$ assuming $B(\Lambda_{c}^{+}\to\rhoK^{-}\pi^{+})=0.05$, which we rescale to our best value $B(\Lambda_{c}^{+}\to\rhoK^{-}\pi^{+})=(5.0\pm1.3)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | | | | | |
| $\Gamma(\overline{\Lambda}_c^- \Delta_X(2420)^{++})/\Gamma_{total}$ Γ_{422}/Γ VALUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | | | | | |
| VALUE (units 10 ⁻⁵) | | | | | |
| $4.7^{+1.1}_{-1.0}\pm1.2$ | | 1 GABYSHEV | | | ` ' |
| $\overline{\Lambda}_c^- \Delta_X (2420)^{++}$ 0.05, which we resour first error is from using our bes |)/F _{total}] × scale to our their experim | $[B(\Lambda_c^+ \rightarrow pK^-$ | $\pi^+)]$ assum | $ing B(\Lambda_c^+ \rightarrow$ | $p K^{-} \pi^{+}) =$ |

| 1 GABYSHEV 06A reports $(4.7^{+1.0}_{-0.9}\pm0.4)	imes10^{-5}$ from a measurement of [Γ $(B^{+} ightarrow$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\overline{\Lambda}_c^- \Delta_X(2420)^{++})/\Gamma_{	ext{total}}] \times [B(\Lambda_c^+ 	o p K^- \pi^+)] \text{ assuming } B(\Lambda_c^+ 	o p K^- \pi^+) =$ |
| 0.05, which we rescale to our best value B($\Lambda_c^+ \to p K^- \pi^+$) = $(5.0 \pm 1.3) \times 10^{-2}$. |
| Our first error is their experiment's error and our second error is the systematic error |
| from using our best value. |

 $\Gamma((\overline{\Lambda}_c^- p)_s \pi^+)/\Gamma_{\text{total}}$ Γ_{423}/Γ $(\overline{\Lambda}_c^- \rho)_s$ denotes a low-mass enhancement near 3.35 GeV/c².

DO CUMENT ID TECN COMMENT ¹ GABYSHEV 06A BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 GABYSHEV 06A reports (3.9 $^+_{-0.7}$ \pm 0.4) $\times\,10^{-5}$ from a measurement of [Γ (B $^+$ \rightarrow $(\overline{\Lambda}_c^- \, \rho)_s \, \pi^+ \big) / \Gamma_{\mathsf{total}} \big] \, \times \, [\mathsf{B}(\Lambda_c^+ \to \ \rho \, K^- \, \pi^+)] \, \, \mathsf{assuming} \, \, \mathsf{B}(\Lambda_c^+ \to \ \rho \, K^- \, \pi^+) \, = \, 0.05,$ which we rescale to our best value B($\Lambda_c^+ \to p \, K^- \pi^+$) = $(5.0 \pm 1.3) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\overline{\Sigma}_c(2520)^0 p)$ | Γ _{total} | | | Γ ₄₂₄ /Γ |
|-----------------------------------------|--------------------|-------------------------|----------------------|-------------------------------------|
| VALUE (units 10^{-5}) | CL% | DO CUMENT ID | TECN | COMMENT |
| <0.3 | 90 | ^{1,2} AUBERT | 08BN BAB | $R e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not us | se the foll | owing data for avera | ges, fits, lim | nits, etc. • • • |
| <2.7 | 90 | 1,2 GABYSHEV | 06A BELI | $e^+e^- \rightarrow \Upsilon(4S)$ |
| <4.6 | 90 | ^{1,2} GABYSHEV | 02 BELI | Repl. by GABYSHEV 06A |
| ¹ Assumes equal p | oroduction | of B^+ and B^0 at 1 | the $\Upsilon(4S)$. | |

| $\Gamma(\overline{\Sigma}_c(2520)^0 p)/\Gamma(\overline{\Lambda}_c(2520)^0 p)$ | $_{c}^{-}p\pi^{+})$ | | | | $\Gamma_{424}/\Gamma_{419}$ |
|--------------------------------------------------------------------------------|---------------------|-------------|-----------|---------|-----------------------------|
| VALUE (units 10^{-3}) | CL% | DOCUMENT ID | TECN | COMMENT | |
| _9 | 90 | ALIBERT | 08BN BABR | e+ e | $\Upsilon(AS)$ |

² Uses the value for $\Lambda_C \to pK^-\pi^+$ branching ratio (5.0 \pm 1.3)%.

 $\Gamma(\overline{\Sigma}_c(2800)^0 p)/\Gamma_{\rm total}$ Γ_{425}/Γ VALUE (units 10-5) DOCUMENT ID TECN COMMENT ¹ AUBERT 08BN BABR $e^+e^-
ightarrow \gamma(4S)$

 $^{1}\,\text{AUBERT 08BN reports}\,\,[\Gamma\big(B^{+}\,\rightarrow\,\,\overline{\Sigma}_{\it C}(2800)^{0}\,\rho\big)/\Gamma_{\rm total}]\,\,/\,\,[B(B^{+}\,\rightarrow\,\,\overline{\Lambda}_{\it C}^{-}\,\rho\,\pi^{+})]\,=\,$ $0.117 \pm 0.023 \pm 0.024$ which we multiply by our best value B($B^+ \rightarrow \overline{\Lambda}_c^- p \pi^+$) = (2.8 \pm 0.8) $\times\,10^{-4}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^0)/\Gamma_{\rm tot}$ | ai | | | | | Γ ₄₂₆ /Γ |
|--------------------------------------------------------------------|-----------|----------------------------------|----------|-----------|----------------------|---------------------|
| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $1.81 \pm 0.29 {}^{+ 0.52}_{- 0.50}$ | | $^{1,2}\mathrm{DYT}\mathrm{MAN}$ | 02 | CLE2 | $e^+e^- \to$ | Y(45) |
| • • • We do not use t | he follow | ing data for averag | es, fits | , limits, | etc. • • • | |
| <3.12 | 90 | ³ FU | 97 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| 1 Assumes equal proc | luction c | of B^+ and B^{0} at th | e Υ(4 | S). | | |

² DYT MAN 02 measurement uses B($\Lambda_c^- \to \overline{p} \, K^+ \pi^-$) = 5.0 \pm 1.3%. The second error includes the systematic and the uncertainty of the branching ratio.

 3 FU 97 uses PDG 96 values of Λ_C branching ratio.

| $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^+ \pi^-)/\Gamma_{\rm t}$ | otal | | | | | Γ ₄₂₇ /Γ |
|------------------------------------------------------------------------|---------|----------------------|---------|-----------|----------------------|---------------------|
| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $2.25 \pm 0.25 {}^{+ 0.63}_{- 0.61}$ | | 1,2 DYT MA N | 02 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not use the | followi | ing data for average | s, fits | , limits, | etc. • • • | |
| | | 2 | | | | |

<1.46 ³ FU 97 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 90

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

² DYT MAN 02 measurement uses B($\Lambda_c^- \to \overline{p} K^+ \pi^-$) = 5.0 \pm 1.3%. The second error includes the systematic and the uncertainty of the branching ratio.

 3 FU 97 uses PDG 96 values of Λ_C branching ratio.

 $\Gamma(\Lambda_c^+ \Lambda_c^- K^+)/\Gamma_{\text{total}}$

| $\Gamma(\overline{\Lambda}_c^- p \pi^+ \pi^+ \pi^-)$ | $\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₄₂₈ /Γ |
|------------------------------------------------------|----------------------------|---------------------------|----------|------|----------------------|---------------------|
| VALUE | CL% | DO CUMEN | T ID | TECN | COMMENT | |
| $<1.34 \times 10^{-2}$ | 90 | 1 FU | 97 | CLE2 | $e^+e^- \rightarrow$ | T(45) |
| ¹ FU 97 uses PDG | 96 values o | fΛ _C branching | g ratio. | | | |

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------------|-----|------|-----------------------------------|
| 8.7±3.5 OUR AVERAGE | | | | |
| $11 \pm 1 \pm 6$ | 1,2 AUBERT | 08н | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| 8 +1 +4 | 2,3 GABYSHEV | 06 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |

 1 AUBERT 08H reports (1.14 \pm 0.15 \pm 0.62) imes 10 $^{-3}$ from a measurement of [Γ ($B^+
ightarrow$ $\varLambda_c^+ \varLambda_c^- \, K^+) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(\varLambda_c^+ \to \, \rho \, K^- \, \pi^+)] \text{ assuming } \mathsf{B}(\varLambda_c^+ \to \, \rho \, K^- \, \pi^+) = (5.0 \pm 10)$ $1.3) \times 10^{-2}$

² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. ³ GABYSHEV 06 reports $(7.9^{+1.0}_{-0.9}\pm3.6)\times10^{-4}$ from a measurement of $[\Gamma(B^+\to 0.00)]$ $\Lambda_c^+\Lambda_c^-K^+)/\Gamma_{\mathsf{total}}]\times[\mathsf{B}(\Lambda_c^+\to\ \rho\,K^-\pi^+)]\ \mathsf{assuming}\ \mathsf{B}(\Lambda_c^+\to\ \rho\,K^-\pi^+)=(5.0\pm0.00)$ $1.3) \times 10^{-2}$

 $\Gamma(\overline{\Sigma}_c(2455)^0 p)/\Gamma_{\text{total}}$ Γ_{430}/Γ VALUE (units 10^{-5}) DO CUMENT ID TECN COMMENT

 1,2 GABYSHEV 06A BELL $e^+e^-
ightarrow \varUpsilon$ (45) $3.7 \pm 0.8 \pm 1.0$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 90 1,3 DYTMAN 02 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ <8 1,4 GABYSHEV 02 BELL Repl. by GABYSHEV 06A 90 < 9.3

 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$.

 2 GABYSHEV 06A reports (3.7 \pm 0.7 \pm 0.4) imes 10 $^{-5}$ from a measurement of [$\Gamma(B^+
ightarrow$ $\overline{\Sigma}_{\it C}(2455)^{\,0}\,p\big)/\Gamma_{\rm total}]\,\times[{\rm B}(\Lambda_{\it C}^{\,+}\to\,p\,{\it K}^-\,\pi^+)]\ {\rm assuming}\ {\rm B}(\Lambda_{\it C}^{\,+}\to\,p\,{\it K}^-\,\pi^+)=0.05,$ which we rescale to our best value B($\Lambda_c^+ \to \rho K^- \pi^+$) = (5.0 ± 1.3) × 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

 3 DYT MAN 02 measurement uses B($\Lambda_c^- o \overline{p}\, K^+ \pi^-$) = 5.0 \pm 1.3%. The second error includes the systematic and the uncertainty of the branching ratio.

 4 Uses the value for $\Lambda_C \to \ p \ K^- \, \pi^+$ branching ratio (5.0 \pm 1.3)%.

 $\Gamma(\overline{\Sigma}_c(2455)^0 p)/\Gamma(\overline{\Lambda}_c^- p \pi^+)$ $\Gamma_{430}/\Gamma_{419}$ DOCUMENT ID TECN COMMENT $^{
m 1}$ AUBERT $0.123 \pm 0.012 \pm 0.008$ 08BN BABR $e^+e^- \rightarrow \Upsilon(4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(\overline{\Sigma}_c(2455)^0 p \pi^0)/\Gamma_{\text{total}}$ Γ_{431}/Γ VALUE (units 10^{-4}) DO CUMENT ID TECN COMMENT

 $1.2 \, \overline{\rm DYT\,MA\,N}$ 02 CLE2 $e^+e^- \rightarrow \ \varUpsilon(4S)$ 1 DYTMAN 02 reports (4.4 \pm 1.4) \times 10 $^{-4}$ from a measurement of [$\Gamma(B^{+} \rightarrow$ $\overline{\Sigma}_{\it C}(2455)^{\it 0}\, p\, \pi^{\it 0})/\Gamma_{\it total}] \times [B(\varLambda_{\it C}^{\it +} \rightarrow p\, K^{\it -}\, \pi^{\it +})] \ \ {\rm assuming} \ \ B(\varLambda_{\it C}^{\it +} \rightarrow p\, K^{\it -}\, \pi^{\it +}) = 0$ 0.05, which we rescale to our best value B($\Lambda_c^+ \to \rho K^- \pi^+$) = (5.0 ± 1.3) × 10⁻². Our first error is their experiment's error and our second error is the systematic error

from using our best value. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(\overline{\Sigma}_c(2455)^0 p \pi^- \pi^+)/\Gamma_{\text{total}}$ Γ_{432}/Γ TECN COMMENT DOCUMENT ID $1.2 \overline{\text{DYTMAN}}$ 02 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 4.4 ± 1.3 ± 1.1 $^1\,\text{DYT\,MA\,N}$ 02 reports (4.4 \pm 1.3) \times 10 $^{-4}$ from a measurement of [\Gamma(B^+ \rightarrow $\overline{\Sigma}_{\mathcal{C}}(2455)^{0} p \pi^{-} \pi^{+}) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(\Lambda_{\mathcal{C}}^{+} \to p \, \mathsf{K}^{-} \pi^{+})] \text{ assuming } \mathsf{B}(\Lambda_{\mathcal{C}}^{+} \to p \, \mathsf{K}^{-} \pi^{+})$ = 0.05, which we rescale to our best value B($\Lambda_c^+ \to p \ K^- \pi^+$) = (5.0 \pm 1.3) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value

 $^2\,\mathrm{Assumes}\stackrel{\smile}{\mathrm{equal}}$ production of B^+ and $B^{\,0}$ at the $\varUpsilon(4S).$

 B^{\pm}

90 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

| | F(V++++\IF F IF |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\overline{\Sigma}_c(2455)^{}\rho\pi^+\pi^+)/\Gamma_{\text{total}}$ Γ_{433}/Γ VALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT | $\Gamma(K^+\ell^+\ell^-)/\Gamma_{	ext{total}}$ Test for $\Delta B{=}1$ weak neutral current. Allowed by higher-order electroweak interactions. |
| 2.8±1.0±0.7 | VALUE (units 10 ⁻⁷) 5.1±0.5 OUR AVERAGE |
| 1 DYTMAN 02 reports (2.8 \pm 1.0) $	imes$ 10 $^{-4}$ from a measurement of [Γ(B^+ $ ightarrow$ | 4.8 \pm 0.9 \pm 0.2 |
| $\overline{\Sigma}_{\it C}(2455)^{}\rho\pi^{+}\pi^{+})/\Gamma_{\sf total}]\times [{\sf B}(\Lambda_{\it C}^{+}\to\rho{\sf K}^{-}\pi^{+})]\ {\sf assuming}\ {\sf B}(\Lambda_{\it C}^{+}\to\rho{\sf K}^{-}\pi^{+})$ | $5.3 + 0.6 \pm 0.3$ 1 WEI $09 \text{A} \text{ BELL}$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| = 0.05, which we rescale to our best value B($\Lambda_c^+ \to p K^- \pi^+$) = (5.0 \pm 1.3) \times 10 ⁻² . Our first error is their experiment's error and our second error is the systematic error | • • • We do not use the following data for averages, fits, limits, etc. • • |
| Our first error is their experiment's error and our second error is the systematic error | |
| from using our best value. 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $3.8^{+~0.9}_{-~0.8}\pm0.2$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T |
| | $5.3^{+1.1}_{-1.0}\pm0.3$ 1 ISHIKAWA 03 BELL Repl. by WEI 09A |
| $\Gamma(\overline{\Lambda}_c(2593)^-/\overline{\Lambda}_c(2625)^-p\pi^+)/\Gamma_{\text{total}}$ Γ_{434}/Γ | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| VALUE CL% DOCUMENT ID TECN COMMENT $<1.9 \times 10^{-4}$ 90 1,2 DYTMAN 02 CLE2 $e^+e^- \rightarrow r(4.5)$ | |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $\Gamma(K^+e^+e^-)/\Gamma_{total}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher–order electroweak interactions. |
| ² DYT MAN 02 measurement uses B($\Lambda_C^- \to \overline{p} K^+ \pi^-$) = 5.0 \pm 1.3%. The second error | VALUE (units 10^{-7}) CL% DOCUMENT ID TECN COMMENT |
| includes the systematic and the uncertainty of the branching ratio. | 5.5 ± 0.7 OUR AVERAGE |
| $\Gamma(\Xi_c^0 \Lambda_c^+ \times B(\Xi_c^0 \to \Xi^+ \pi^-))/\Gamma_{\text{total}}$ Γ_{435}/Γ | $5.1 + 1.2 \pm 0.2$ 1 AUBERT 09T BABR $e^+e^- ightarrow \gamma(4S)$ |
| $VALUE$ (units 10^{-5}) DO CUMENT ID TECN COMMENT | $5.7^{+0.9}_{-0.8} \pm 0.3$ 1 WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| 3.0±1.1 OUR AVERAGE | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $2.5\pm0.9\pm0.6$ 08H BABR $e^+e^- ightarrow~ arGamma(4S)$ | . 1.2 |
| $5.6^{+1.9}_{-1.5}\pm1.9$ 2,3 CHISTOV 06A BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ | 1.1 |
| 1 AUBERT 08H reports $(2.51\pm0.89\pm0.61)	imes10^{-5}$ from a measurement of [Γ(B^+ $ ightarrow$ | $10.5 + \frac{2.5}{-2.2} \pm 0.7$ AUBERT 030 BABR Repl. by AUBERT,B 06J |
| $\overline{\Xi}_{c}^{0}\Lambda_{c}^{+} \times B(\overline{\Xi}_{c}^{0} \to \overline{\Xi}^{+}\pi^{-}))/\Gamma_{total}] \times [B(\Lambda_{c}^{+} \to p K^{-}\pi^{+})] \text{ assuming } B(\Lambda_{c}^{+} \to p K^{-}\pi^{+})]$ | $6.3 ^{+}_{-1.7} ^{1.9} \pm 0.3$ ² ISHIKAWA 03 BELL Repl. by WEI 09A |
| $p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$ | $<$ 14 90 1 ABE 02 BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $<$ 9 90 $\frac{1}{2}$ AUBERT 02L BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 3 CHISTOV 06A reports $(5.6^{+1.9}_{-1.5}\pm1.9)	imes10^{-5}$ from a measurement of $[\Gamma(B^+\to 1.9)]$ | $<$ 24 90 3 ANDERSON 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ $<$ 990 90 4 ALBRECHT 91E ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\overline{\Xi}_c^0 \Lambda_c^+ \times B(\overline{\Xi}_c^0 \to \overline{\Xi}^+ \pi^-))/\Gamma_{total}] \times [B(\Lambda_c^+ \to p K^- \pi^+)] \text{ assuming } B(\Lambda_c^+ \to p K^- \pi^+)$ | <68000 90 5 WEIR 90B MRK2 e^+e^- 29 GeV |
| $p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}.$ | $<$ 600 90 6 AVERY 89B CLEO $e^+e^- ightarrow \gamma(4S)$ |
| $\Gamma(\overline{\Xi_c^0}\Lambda_c^+ \times B(\overline{\Xi_c^0} \to \Lambda K^+ \pi^-))/\Gamma_{\text{total}}$ Γ_{436}/Γ | $<$ 2500 90 7 AVERY 87 CLEO $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| VALUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Assumes equal production of B^0 and B^+ at $\Upsilon(4S)$. The second error is a total of |
| 2.6±1.1 OUR AVERAGE Error includes scale factor of 1.1. | Assumes equal production of B^{α} and B^{β} at $I(45)$. The second error is a total of systematic uncertainties including model dependence. |
| $1.7\pm0.9\pm0.5$ 1.2 AUBERT 08H BABR $e^+e^- 	or \Upsilon(4S)$ | ³ The result is for di-lepton masses above 0.5 GeV. |
| $4.0^{+1.1}_{-0.9}\pm 1.3$ 2,3 CHISTOV 06A BELL $e^+e^- 	o 	ag{7}(4S)$ | 4 ALBRECHT 91E reports $<9.0\times10^{-5}$ assuming the $\varUpsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. We rescale to 50%. |
| 1 AUBERT 08H reports (1.70 \pm 0.93 \pm 0.53) $	imes$ 10 $^{-5}$ from a measurement of [Г (B^+ $ ightarrow$ | 5 WEIR 90B assumes B^{+} production cross section from LUND. |
| $\overline{\Xi}_c^0 \Lambda_c^+ \times B(\overline{\Xi}_c^0 \to \Lambda K^+ \pi^-))/\Gamma_{\text{total}} \times [B(\Lambda_c^+ \to \rho K^- \pi^+)] \text{ assuming } B(\Lambda_c^+ \to \rho K^- \pi^+)$ | 6 AVERY 89B reports $<$ 5 $	imes$ 10 $^{-5}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}^0$. We rescale to 50% |
| $p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 7 AVERY 87 reports $< 2.1 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 40% to $B^0 \overline{B}{}^0$. We rescale |
| Assumes equal production of B and B at the 7 (43). 3 CHISTOV 06A reports $(4.0^{+1.1}_{-0.9} \pm 1.3) \times 10^{-5}$ from a measurement of $[\Gamma(B^+ \to B^+)]$ | to 50%. |
| $\overline{\Xi}_c^0 \Lambda_c^+ \times B(\overline{\Xi}_c^0 \to \Lambda K^+ \pi^-))/\Gamma_{total}] \times [B(\Lambda_c^+ \to p K^- \pi^+)] \text{ assuming } B(\Lambda_c^+ \to p K^- \pi^+)$ | $\Gamma(K^+\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{443}/Γ |
| $p(K^-\pi^+) = (5.0 \pm 1.3) \times 10^{-2}$. | Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE (units 10^{-7}) CL% DOCUMENT ID TECN COMMENT |
| | VALUE (units 10 ⁻⁷) CL% DOCUMENT ID TECN COMMENT 4.8±0.4 OUR FIT |
| $\Gamma(\pi^+\ell^+\ell^-)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{437}}/\Gamma$ | 5.1 ^{+ 0.8} OUR AVERAGE |
| \sim 4.9 × 10 ⁻⁸ 90 1 WEI 08A BELL $e^+e^- \rightarrow r(4S)$ | 3 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $4.1^{+1.6}_{-1.5}\pm0.2$ 1 AUBERT 09T BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| $<$ 1.2 $	imes$ 10 $^{-7}$ 90 1 AUBERT 07AG BABR e^{+} e^{-} $ ightarrow$ \varUpsilon (4 S) | $5.3 {+ 0.8 \atop - 0.7} \pm 0.3$ WEI 09A BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $arphi(4S)$. | • • We do not use the following data for averages, fits, limits, etc. |
| $\Gamma(\pi^+ e^+ e^-)/\Gamma_{\text{total}}$ Γ_{438}/Γ | $3.1 ^{+1.5}_{-1.2} \pm 0.3$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T |
| Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. | 0.7+1.9±0.2 |
| VALUE CL% DOCUMENT ID TECN COMMENT | |
| $<$ 8.0 \times 10 ⁻⁸ 90 1 WEI 08A BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $4.5 {+ 1.4 \atop -1.2} \pm 0.3$ 2 ISHIKAWA 03 BELL Repl. by WEI 09A |
| • • We do not use the following data for averages, fits, limits, etc. • • | $9.8 {+ 4.6 \atop - 3.6} {\pm 1.6}$ 1 ABE 02 BELL Repl. by ISHIKAWA 03 |
| $<1.8 \times 10^{-7}$ 90 1 AUBERT 07AG BABR $e^+e^- 	o 	au(4S)$ $<3.9 \times 10^{-3}$ 90 2 WEIR 90B MRK2 e^+e^- 29 GeV | $<$ 12 90 1 AUBERT 02L BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $<$ 36.8 90 3 ANDERSON 01B CLE2 $e^+e^- \rightarrow \Upsilon(45)$ |
| 2 WEIR 90B assumes B^{+} production cross section from LUND. | < 52 |
| $\Gamma(\pi^+\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_{439}/Γ | $<$ 2400 90 GABRECHT 91E ARG $e^+e^- ightarrow \Upsilon(4S)$ |
| $(\pi^+ \mu^+ \mu^-)/\Gamma_{\text{total}}$ $\Gamma_{\text{439}}/\Gamma$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. | <64000 90 7 WEIR 90B MRK2 $e^{+}e^{-}$ 29 GeV |
| VALUE CL% DOCUMENT ID TECN COMMENT | <pre>< 1700</pre> |
| <6.9 × 10⁻⁸ 90 ¹ WEI 08A BELL e^+e^- → $\Upsilon(4S)$ | $<$ 3800 90 FAVERY 87 CLEO $e^+e^- ightarrow 7(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | ² Assumes equal production of B^0 and B^+ at the $T(45)$. The second error is a total of |
| $<2.8 \times 10^{-7}$ 90 1 AUBERT 07AG BABR $e^+e^- \rightarrow \Upsilon(4.5)$ $<9.1 \times 10^{-3}$ 90 2 WEIR 90B MRK2 e^+e^- 29 GeV | systematic uncertainties including model dependence. |
| 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. | The result is for di-lepton masses above 0.5 GeV. |
| 2 WEIR 90B assumes B^+ production cross section from LUND. | ⁴ AFFOLDER 99B measured relative to $B^+ \to J/\psi(1S) K^+$. ⁵ ABE 96L measured relative to $B^+ \to J/\psi(1S) K^+$ using PDG 94 branching ratios. |
| , | ⁶ ALBRECHT 91E reports $< 2.2 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 45% to $B^0 \overline{B}{}^0$. We |
| $\Gamma(\pi^+ \nu \overline{\nu})/\Gamma_{\text{total}}$ Γ_{440}/Γ | |
| | rescale to 50%. |
| Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> | |
| Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT (<1.0 × 10^-4 90 1 AUBERT 05H BABR $e^+e^- \rightarrow \Upsilon(4S)$ | rescale to 50%. 7 WEIR 908 assumes B^+ production cross section from LUND. 8 AVERY 89B reports $< 1.5 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. We rescale to 5.0%. |
| Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. <u>VALUE CL% DOCUMENT ID TECN COMMENT</u> | rescale to 50%. 7 WEIR 90B assumes B^+ production cross section from LUND. 8 AVERY 89B reports $< 1.5 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}{}^0$. We |

 B^{\pm}

| $\Gamma(K^+\mu^+\mu^-)/\Gamma(J/I)$ | , | | TE 611 6 | | ₃ /Γ ₁₈₅ | | ual production of <i>B</i> ual production of | | | e second erro | ris a total of |
|-------------------------------------------------------------------------------|-----------------------------------------------|-------------------------------|-------------------------------------------|------------------------------------------------------------------------|---------------------------------|--------------------------------------------------|-------------------------------------------------|-----------------------------------------|--------------------|------------------------------------------------------|-----------------------------|
| VALUE (units 10 ⁻³) 0.47±0.04 OUR FIT 0.46±0.04±0.02 | | CUMENT ID LTONEN 1 | | <u>ОММЕNТ</u> p at 1.96 TeV | i | systematic u 10 ^{—6} | ncertainties includi 91E reports < 1.1 | ng model depend | ence. The | 90% C.L. uppe | r limit is 2.2 × |
| • • • We do not use t $0.38 \pm 0.05 \pm 0.02$ | _ | ata for average LTONEN 1 | | etc. ● ● ● epl. by AALTONE | N. 1141 | rescale to 5 (| | × 10 - assumm | g the 1(43 | j decays 45 % | LO B - B We |
| $0.59 \pm 0.05 \pm 0.02$ $0.59 \pm 0.15 \pm 0.03$ | | | | epi. by AALTONE | | Γ(<i>K</i> *(892)+μ | $\mu^+ \mu^-)/\Gamma(J/\psi)$ | 1 <i>5) K</i> *(892)+ |) | | $\Gamma_{448}/\Gamma_{205}$ |
| $\Gamma(K^+ \overline{\nu} \nu) / \Gamma_{\text{total}}$ | | | | Г | 444/Γ | VALUE (units 10^{-3} |) | DOCUMENT ID | TEC | V COMMENT | |
| Test for $\Delta B = 1$ w VALUE CL% | | | | er electroweak intera | | 0.75±0.15 OUR 0.67±0.22±0.0 | | AALTONEN | 11AI CDF | p p at 1.90 | . TeV |
| <1.3 × 10 ⁻⁵ 90 | | | $\frac{COMMENT}{R}$ $e^+e^- \rightarrow$ | T(45) | | | | AALIONEN | TIAI CDI | pp at 1.50 | |
| • • • We do not use t | the following da | ata for average | es, fits, limits, | etc. • • • | - | $\Gamma(\pi^+ e^+ \mu^-)$ | / I total pton family numbe | r conservation. | | | Γ ₄₅₀ /Γ |
| $<1.4 \times 10^{-5}$ 90 $<5.2 \times 10^{-5}$ 90 | ¹ CHEN ¹ AUBERT | | $e^+e^- \rightarrow R e^+e^- \rightarrow$ | | | VALUE | <u>CL%</u> | DO CUMENT ID | TEC | | |
| $<2.4 \times 10^{-4}$ 90 | | | 2 e ⁺ e ⁻ → | | | <0.0064 | 90 | ¹ WEIR | | K2 e ⁺ e ⁻ 29 | GeV |
| ¹ Assumes equal prod | duction of B+ | and B^0 at the | e $\Upsilon(4S)$. | | | | ssumes B ⁺ produc | cross section | n from LON | ID. | |
| $\Gamma(\rho^+ \nu \overline{\nu}) / \Gamma_{\text{total}}$ | | | | | ₄₄₅ / Γ | $\Gamma(\pi^+ e^- \mu^+)$ Test of let | / I total pton family numbe | r conservation. | | | Γ ₄₅₁ /Γ |
| lest for $\Delta B = 1$ v VALUE | | rrent. Allowed DOCUMENT ID | | er electroweak inter COMMENT | action. | VALUE | <u>CL%</u> | DO CUMENT ID | - | V <u>COMMENT</u> | |
| <1.5 × 10 ⁻⁴ | | CHEN | | $e^+e^- ightarrow ~ \varUpsilon(4.5)$ |) | <0.0064 | 90 ssumes B ⁺ produc | ¹ WEIR | | K2 e ⁺ e ⁻ 29 | GeV |
| ¹ Assumes equal prod | | | | | | | | cross section | n from LON | ID. | |
| $\Gamma(K^*(892)^+\ell^+\ell^-)$ Test for $\Delta B=1$ w | /F _{total} | ront Allowed | hu himhar arda | T | 446/F | $\Gamma(\pi^+ e^{\pm} \mu^{\mp})$ | /F _{total} | DO CUMENT ID | TEC | V COMMENT | Γ ₄₅₂ /Γ |
| VALUE (units 10^{-7}) | | DO CUMENT ID | TECN | | actions. | <1.7 × 10 ⁻⁷ | 90 | 1 AUBERT | | $e^+e^- \rightarrow$ | Υ(45) |
| 12.9 ± 2.1 OUR AVE | | | | | | ¹ Assumes equ | ual production of B | $^{+}$ and 0 at the | e $\Upsilon(4S)$. | | , , |
| $14.0 + \frac{4.0}{3.7} \pm 0.9$ | | AUBERT | | $e^+ e^- \rightarrow \Upsilon(4S)$ | , | Γ(K+ e+ μ ⁻) | /Γ _{total} | | | | Γ ₄₅₃ /Γ |
| $12.4 + 2.3 \pm 1.3$ | | WEI | | $e^+ e^- \rightarrow \Upsilon(4S)$ |) | Test of le | pton family numbe | | | | |
| • • • We do not use t | | _ | | | | VALUE (units 10 ⁻⁷ |) <u>CL%</u> 90 | 1 AUBERT,B | 061 BAE | $\frac{V}{R} = \frac{COMMENT}{e^+e^-} \rightarrow$ | Υ(4.5) |
| $7.3 + 5.0 \pm 2.1$ | | AUBERT,B | | Repl. by AUBER | | - | ot use the following | | | | . (+3) |
| <22 ¹ Assumes equal prod | | ISHIKAWA | | $e^+ e^- \rightarrow \Upsilon(4S)$ |) | <8 | 90 | ¹ AUBERT | 02L BAE | R Repl. by | RT,B 06J |
| | | and D at the | : 1 (43). | - | . /- | $<\!6.4\ \times 10^4$ | 90 | ² WEIR | 90в MR | $K2 e^{+}e^{-}29$ | |
| $\Gamma(K^*(892)^+ \nu \overline{\nu})/\Gamma_t$ Test for $\Delta B = 1$ v | total weak neutral cu | rrent. Allowed | d by higher-ord | er electroweak inter | 449/ Г action | | ual production of B | | | _ | |
| <u>VALUE</u> <8 ×10 ^{−5} | | <i>DOCUMENT ID</i> AUBERT | | $e^+e^- \rightarrow \Upsilon(4S)$ | <u> </u> | | ssumes B ⁺ produc | tion cross sectio | n from LUN | ID. | |
| • • • We do not use t | | | | |) | $\Gamma(K^+e^-\mu^+)$ | /Γ_{total} pton family numbe | r conservation | | | Γ ₄₅₄ /Γ |
| $< 1.4 \times 10^{-4}$ | | CHEN | | $e^+ e^- \rightarrow \ \varUpsilon (4S)$ |) | VALUE (units 10 ⁻⁷ | | DO CUMENT ID | TEC | V COMMENT | |
| ¹ Assumes equal prod | duction of B ⁺ | and B^0 at the | e $\Upsilon(4S)$. | | | <1.3 | 90 | 1 AUBERT,B | | $e^+e^- \rightarrow$ | T(45) |
| $\Gamma(K^*(892)^+e^+e^-)$ |)/Γ _{total} | | har hilahan and a | | ₄₄₇ /Γ | • • • We do no $<6.4 \times 10^4$ | ot use the following 90 | ; data for average ² WEIR | | s, etc. • • • K2 e ⁺ e ⁻ 29 | CoV |
| VALUE (units 10^{-7}) | | DOCUMENT ID | | r electroweak intera | actions. | | Jal production of B | | | NZ E E 29 | Gev |
| 15.5 + 4.0 OUR A | AVERAGE | | | | | | ssumes B ⁺ produc | | | ID. | |
| $13.8 + 4.7 \pm 0.8$ | | AUBERT | 09⊤ BABR | $e^+e^- \rightarrow \gamma(4S)$ |) | Γ(K ⁺ e [±] μ [∓]) | /Γ _{total} | | | | Γ ₄₅₅ /Γ |
| $17.3 + 5.0 \pm 2.0$ | | WEI | | $e^+e^- \rightarrow \gamma(4S)$ | , | VALUE (units 10 ⁻⁷ | | DOCUMENT ID | TEC | | |
| • • • We do not use t | | | | | , | <0.91 | 90 | 1 AUBERT,B | | $e^+e^- \rightarrow$ | T(45) |
| $7.5{}^{+}_{-}{}^{7.6}_{6.5}{}^{\pm}3.8$ | | AUBERT,B | | Repl. by AUBER | Т 09т | • | ual production of B | ' [∓] and B ^o at th | e $\Upsilon(4S)$. | | |
| $\begin{array}{c} - 6.5 \\ - 2.0 \\ - 8.7 \\ \pm 2.8 \end{array}$ | | AUBERT | | $e^+e^- \rightarrow \gamma(4S)$ | | $\Gamma(K^+\mu^{\pm}\tau^{\mp})$ | /「_{total} pton family numbe | r concernation | | | Γ ₄₅₆ /Γ |
| < 46 | _ | ISHIKAWA | | $e^+e^- \rightarrow \Upsilon(4S)$ | • | VALUE (units 10 ⁻⁶ | | DO CUMENT ID | TEC | V COMMENT | |
| < 89 | 90 1 | ABE | 02 BELL | Repl. by ISHIKA | WA 03 | <77 | | ¹ AUBERT | | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| < 95 <6900 | | AUBERT ALBRECHT | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | | ¹ Uses a fully | reconstructed hadr | onic B decay as | a tag on th | e recoil side. | |
| 1 Assumes equal prod | duction of B+ | and B ⁰ at the | e Υ(45) | , | • | Γ(<i>K</i> *(892)+ 6 | $e^+\mu^-)/\Gamma_{ m total}$ | | | | Γ ₄₅₇ /Γ |
| ² Assumes equal pro- systematic uncertai | duction of B ^U inties including | and B ⁺ at | $\Upsilon(4S)$. The lence. | second error is a t | otal of | VALUE (units 10 ⁻⁷ | | DO CUMENT ID | | <u>COMMENT</u> | |
| ³ ALBRECHT 91E re | | | | decays 45% to $B^0\overline{B}$ | 3 ⁰ . We | <13 | 90 yal production of B | 1 AUBERT,B | | $e^+e^- \rightarrow$ | T(45) |
| rescale to 50%. | \ | | | _ | | | | i and Bractn | e 1 (45). | | |
| Γ(K*(892)+ μ + μ -) Test for $\Delta B = 1$ w |)/ˈtotai <i>v</i> eak neutral cur | rent. Allowed | by higher-orde | ler electroweak intera | ' ₄₄₈ /Γ actions. | Γ(K*(892)+ 6 | | DO 60145117 10 | 750 | | Γ ₄₅₈ /Γ |
| VALUE (units 10 ⁻⁷) | CL%_ | DO CUMENT ID | | COMMENT | | VALUE (units 10 ⁻⁷ |) <u>CL%</u> 90 | DOCUMENT ID AUBERT.B | | $\frac{V}{BR} \frac{COMMENT}{e^+e^-} \rightarrow$ | Υ(4.5) |
| 10.7± 2.2 OUR | | | | | | | ual production of B | _ ′ | | | . () |
| 11.6 + 3.1 OUR | | | | | | Γ(<i>K</i> *(892)+ 6 | | | , | | Γ450/Γ |
| $14.6 + 7.9 \pm 1.2$ | 1 | AUBERT | 09T BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |) | Test of le | pton family numbe | | | | Γ ₄₅₉ /Γ |
| $11.1 + 3.2 \pm 1.0$ | | WEI | | $e^+ e^- \rightarrow \gamma (4S)$ |) | <1.4 × 10 ⁻⁶ | <u>CL%</u> 90 | DOCUMENT ID AUBERT,B | | $\frac{V}{R} = \frac{COMMENT}{e^+e^-} \rightarrow$ | Υ(4 S) |
| • • • We do not use t | | | | | | | 90 ot use the following | | | | 1 (43) |
| $9.7 + 9.4 \pm 1.4$ | 1 | AUBERT,B | 06J BABR | Repl. by AUBER | Т 09т | $< 7.9 \times 10^{-6}$ | 90 | ¹ AUBERT | 02L BAE | R Repl. by | T D 04 - |
| $30.7^{+25.8}_{-17.8}\pm4.2$ | 1 | AUBERT | 03∪ BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |) | ¹ Assumes ear | ual production of B | $+$ and B^0 at the | e Υ(45). | AURE | RT,B 06J |
| $6.5 + 6.9 + 1.5 \\ -5.3 - 1.6$ | 2 | ISHIKAWA | 03 BELL | Repl. by WEI 09. | A | , issumes equ | F 3 0 0 1. 01 D | U U U U | . (). | | |
| < 39 | | ABE | | Repl. by ISHIKA | | | | | | | |
| < 170 <12000 | | AUBERT ALBRECHT | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | | | | | | | |
| \12000 | | | 712 /MG | 2 0 7 (43 | , | | | | | | |

 VALUE (units 10^{-6})
 CL%
 DOCUMENT ID
 TECN
 COMMENT

 <2.8 90
 1 EDWARDS
 02B
 CLE2
 $e^{+}e^{-} \rightarrow r(4S)$

 1 Assumes equal production of B^+ and B^0 at the arangle (4S).

| В | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|--------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|
| $\Gamma(\pi^-e^+e^+)/\Gamma_{total}$ Test of total lepton number conservation. | Γ ₄₆₀ /Γ | Γ(K*(892)- μ+ μ+ Test of total lep | -)/F _{total} ton number conservation. | Γ ₄₇₀ /Γ |
| VALUE CL% DOCUMENT ID TECN COMMENT | | VALUE (units 10 ⁻⁶) | CL% DOCUMENT ID TECN COMMEN | IT |
| \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | <i>Y</i> (4 <i>S</i>) | <8.3 1 Assumes equal pro | 90 1 EDWARDS 02B CLE2 e^+e^- duction of B^+ and B^0 at the $\varUpsilon(45)$. | → \(\mathcal{\gamma}(45) |
| <0.0039 90 ² WEIR 90B MRK2 e ⁺ e ⁻ 29 0 | GeV | $\Gamma(K^*(892)^-e^+\mu^+$ |)/r | Γ ₄₇₁ /Γ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$. 2 WEIR 90B assumes B^+ production cross section from LUND. | | Test of total lep | //'total ton number conservation. | 1471/1 |
| | | VALUE (units 10 ⁻⁶) | CL% DOCUMENT ID TECN COMMEN | |
| $(\pi^-\mu^+\mu^+)/\Gamma_{\text{total}}$ Test of total lepton number conservation. | Г ₄₆₁ /Г | <4.4 | 90 ¹ EDWARDS 02B CLE2 e ⁺ e ⁻ | → Υ(4S) |
| VALUE CL% DOCUMENT ID TECN COMMENT | | ¹ Assumes equal pro | duction of B^+ and B^0 at the \varUpsilon (45). | |
| 4.4×10^{-8} 90 AAIJ 12c LHCB pp at 7 Te • • • We do not use the following data for averages, fits, limits, etc. • • • | V | Γ(D ⁻ e ⁺ e ⁺)/Γ _{tot} | al <u>CL% DOCUMENT ID TECN COMMEN</u> | Γ ₄₇₂ /Γ |
| $<1.4 \times 10^{-6}$ 90 1 EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | | $< 2.6 \times 10^{-6}$ | 90 1 SEON 11 BELL e^+e^- | . , |
| $<9.1 \times 10^{-3}$ 90 2 WEIR 90B MRK2 e^+e^- 29 0 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 WEIR 90B assumes B^+ production cross section from LUND. | uev | | oduction of B^0 and B^+ from Upsilon(4S) decays and 3-body phase-space hypothesis for the signal dec | |
| | | $\Gamma(D^-e^+\mu^+)/\Gamma_{\rm tot}$ | al | Γ ₄₇₃ /Γ |
| $\Gamma(\pi^-e^+\mu^+)/\Gamma_{total}$ Test of total lepton number conservation. | Г ₄₆₂ /Г | VALUE | <u>CL% DOCUMENT ID TECN COMMEN</u> | IT |
| VALUE CL% DOCUMENT ID TECN COMMENT | | <1.8 × 10 ⁻⁶ | 90 1 SEON 11 BELL e^+e^- | . , |
| <1.3 \times 10⁻⁶ 90 ¹ EDWARDS 02B CLE2 $e^+e^- \rightarrow \bullet$ • • • We do not use the following data for averages, fits, limits, etc. • • • | Υ(4S) | · · | oduction of B^0 and B^+ from Upsilon(4S) decays and 3-body phase-space hypothesis for the signal dec | |
| < 0.0064 90 2 WEIR 90B MRK2 e^+e^- 29 e^- | GeV | $\Gamma(D^-\mu^+\mu^+)/\Gamma_{\text{tot}}$ | al | Γ ₄₇₄ /Γ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | VALUE | <u>CL%</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMEN</u> | IT |
| 2 WEIR 90B assumes B^+ production cross section from LUND. | | $<1.1 \times 10^{-6}$ | 90 1 SEON 11 BELL e^+e^- | . , |
| $\Gamma(ho^-e^+e^+)/\Gamma_{total}$ Test of total lepton number conservation. | Γ ₄₆₃ /Γ | | oduction of B^0 and B^+ from Upsilon(4S) decays and 3-body phase-space hypothesis for the signal dec | |
| VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT $<$ 2.6 90 1 EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | Υ(4 S) | $\Gamma(\Lambda^0 \mu^+)/\Gamma_{ m total}$ | | Γ ₄₇₅ /Γ |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 1 (43) | VALUE | CL%DOCUMENT IDTECN _COMMEN | IT |
| | | <6 × 10 ⁻⁸ | 90 1,2 DEL-AMO-SA11K BABR e^+e^- | . , |
| $\Gamma(\rho^-\mu^+\mu^+)/\Gamma_{\text{total}}$ Test of total lepton number conservation. | Г ₄₆₄ /Г | DEL-AMO-SANCH | HEZ 11K reports $< 6.1 \times 10^{-8}$ from a measureme | nt of $[\Gamma(B^+)]$ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | $\Lambda^{\circ} \mu^{+})/\Gamma_{\text{total}}] \times 2 \text{Hoss R}(\gamma(AS))$ | $[B(\Lambda \to p\pi^-)]$ assuming $B(\Lambda \to p\pi^-) = (63.9 \pm B^0 \overline{B}{}^0) = (51.6 \pm 0.6)\%$ and $B(\Upsilon(4S) \to B^+ B^-) = (63.9 \pm 0.6)\%$ | (40.4 0.6)% |
| <5.0 90 1 EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | Υ(4S) | | $B B = (51.0 \pm 0.0) \%$ and $B (7(43) \rightarrow B \cdot B) =$ | = (40.4 ± 0.0) /6. |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | $\Gamma(\Lambda^0 e^+)/\Gamma_{\rm total}$ | | Γ ₄₇₆ /Γ |
| $\Gamma(ho^-e^+\mu^+)/\Gamma_{ m total}$ | Γ ₄₆₅ /Γ | VALUE | CL% DOCUMENT ID TECN COMMEN | |
| Test of total lepton number conservation. | 1 465 / 1 | <3.2 × 10 ⁻⁸ | 90 1,2 DEL-AMO-SA11 κ BABR e^+e^- | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | | HEZ 11K reports $< 3.2 \times 10^{-8}$ from a measureme [B($\Lambda \to p\pi^-$)] assuming B($\Lambda \to p\pi^-$) = (63.9 \pm | |
| <3.3 90 ¹ EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | Y(45) | $\frac{2}{2}$ Uses B($\Upsilon(4S) \rightarrow$ | $B^0 \overline{B}^0$) = (51.6 ± 0.6)% and B($\Upsilon(4S) \rightarrow B^+B^-$) = | = (48.4 + 0.6)% |
| 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (45). | | | 5 5 7 = (61.6 ± 6.6) % and 5(7(16) 1 5 5 7 = | - (1011 ± 010) /01 |
| $\Gamma(K^-e^+e^+)/\Gamma_{\text{total}}$ | Γ ₄₆₆ /Γ | $\Gamma(\overline{\Lambda}{}^0\mu^+)/\Gamma_{total}$ | | Γ ₄₇₇ /Γ |
| Test of total lepton number conservation. | 4007 | <u>VALUE</u> <6 × 10−8 | $\frac{\text{CL\%}}{90}$ $\frac{\text{DOCUMENT ID}}{1,2}$ DEL-AMO-SA11K BABR e^+e^- | |
| VALUE CL% DOCUMENT ID TECN COMMENT $<1.0 \times 10^{-6}$ 90 1 EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | m(+c) | ****** | HEZ 11K reports $< 6.2 \times 10^{-8}$ from a measureme | |
| <1.0 \times 10 ⁻⁶ 90 ¹ EDWARDS 02B CLE2 $e^+e^- \rightarrow$ • • • We do not use the following data for averages, fits, limits, etc. • • | T(4S) | | [B($\Lambda \to p\pi^-$)] assuming B($\Lambda \to p\pi^-$) = (63.9 \pm | |
| < 0.0039 90 ² WEIR 90B MRK2 e^+e^- 29 (| GeV | | $B^0\overline{B^0}) = (51.6 \pm 0.6)\%$ and B($\Upsilon(4S) \rightarrow B^+B^-) = (60.5 \pm 0.6)\%$ | |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | | , , , , , , , , , , , , , , , , , , , , | |
| 2 WEIR 90B assumes B^+ production cross section from LUND. | | $\Gamma(\overline{\Lambda}^0 e^+)/\Gamma_{\text{total}}$ | | Γ ₄₇₈ /Γ |
| $\Gamma(K^-\mu^+\mu^+)/\Gamma_{\text{total}}$ | Γ ₄₆₇ /Γ | <u>∨ALUE</u> <8 × 10 ^{−8} | $\frac{\text{CL\%}}{90}$ $\frac{\text{DOCUMENT ID}}{1,2}$ $\frac{\text{TECN}}{\text{DEL-AMO-SA11K}}$ BABR e^+e^- | |
| Test of total lepton number conservation. | 1 467/1 | | HEZ 11K reports $< 8.1 \times 10^{-8}$ from a measureme | |
| VALUE CL% DOCUMENT ID TECN COMMENT | | 70 e+)/[1 × | [B($\Lambda \to p\pi^-$)] assuming B($\Lambda \to p\pi^-$) = (63.9 \pm | $(0.5) \times 10^{-2}$ |
| <4.1 × 10⁻⁸ 90 AAIJ 12c LHCB pp at 7 Te | V | ² Uses B($\Upsilon(4S) \rightarrow$ | $B^0\overline{B^0}) = (51.6 \pm 0.6)\%$ and B($\Upsilon(4S) \rightarrow B^+B^-) = (63.5 \pm 0.6)\%$ | = (48.4 ± 0.6)% |
| • • We do not use the following data for averages, fits, limits, etc. • • | | | | |
| $<1.8 \times 10^{-6}$ 90 1 EDWARDS 02B CLE2 e ⁺ e ⁻ \rightarrow $<9.1 \times 10^{-3}$ 90 2 WEIR 90B MRK2 e ⁺ e ⁻ 29 0 | \ / | | POLARIZATION IN B+ DECAY | |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | GC V | In decays inv | volving two vector mesons, one can distinguish amo | ong the |
| WEIR 90B assumes B^+ production cross section from LUND. | | states in which | ch meson polarizations are both longitudinal (L) or b | oth are |
| · | F /F | | d parallel (\parallel) or perpendicular (\perp) to each other w | |
| $\Gamma(K^-e^+\mu^+)/\Gamma_{\text{total}}$ Test of total lepton number conservation. | Γ ₄₆₈ /Γ | | L/Γ , Γ_{\perp}/Γ , and the relative phases ϕ_{\parallel} and ϕ_{\perp} . | |
| VALUE CL% DOCUMENT ID TECN COMMENT | | definitions in Particle Listir | the note on "Polarization in ${\it B}$ Decays" review in ${\it in}$ | ine Bř |
| <2.0 \times 10⁻⁶ 90 1 EDWARDS 02B CLE2 $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | Γ_L/Γ in $B^+	o \overline{D}$ | • | |
| <0.0064 90 ² WEIR 90B MRK2 e ⁺ e ⁻ 29 0 | GeV | VALUE 0.892±0.018±0.016 | | $\rightarrow \Upsilon(4S)$ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | | | → 1(43) |
| ² WEIR 90B assumes B^+ production cross section from LUND. $\Gamma(K^*(892)^-e^+e^+)/\Gamma_{\text{total}}$ | Γ ₄₆₉ /Γ | Γ_L/Γ in $B^+ \to \overline{D}$ | <u>DOCUMENT ID TECN COMMEN</u> | |
| Test of total lepton number conservation. | 407/ | $0.86 \pm 0.06 \pm 0.03$ | AUBERT 04K BABR e^+e^- | → Υ(4S) |

 $\Gamma_L/\Gamma \text{ in } B^+ \to \ J/\psi \, K^{*+}$

0.604±0.015±0.018

ITOH

| Γ_{\perp}/Γ in $B^+ \to J/\psi K^{*+}$ | DO CUMENT ID | | T. C. | | |
|---------------------------------------------------------------------------------------------|-----------------------|---------------|--------|------------------------------------------------|----------------|
| <u>VALUE</u> 0.180±0.014±0.010 | DOCUMENT ID | 05 | BELL | $e^+e^- \rightarrow$ | Υ(4S) |
| Γ_L/Γ in $B^+	o\omegaK^{*+}$ | | | | | |
| <u>VALUE</u> 0.41±0.18±0.05 | DOCUMENT ID AUBERT | 09н | | $e^+e^- \rightarrow$ | Υ(45) |
| Γ_L/Γ in $B^+ \rightarrow \omega K_2^*(1430)^+$ | | | | | , |
| VALUE | DOCUMENT ID | | | | m(+c) |
| 0.56±0.10±0.04 | AUBERT | 09H | вавк | e · e → | 1 (43) |
| Γ_L/Γ in $B^+ \to K^{*+} \overline{K}^{*0}$ | DOCUMENT ID | | TECN | COMMENT | |
| $0.75 {}^{+ 0.16}_{- 0.26} {}^{\pm 0.03}$ | ¹ AUBERT | 09F | BABR | $e^+e^- \to$ | Υ(4S) |
| 1 Assumes equal production of B° | $^+$ and B^0 at the | r(45 | 5). | | |
| Γ_L/Γ in $B^+ \rightarrow \phi K^*(892)^+$ | DOCUMENT ID | | TECN | COMMENT | |
| 0.50±0.05 OUR AVERAGE 0.49±0.05±0.03 | AUBERT | 07ва Е | BABR (| $e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| $0.52\pm0.08\pm0.03$ • • We do not use the following | CHEN | 05 A E | BELL | $e^+e^- \rightarrow$ | |
| 0.46±0.12±0.03 | AUBERT | | | | JBERT 07BA |
| Γ_{\perp}/Γ in $B^+	o \phi K^{*+}$ | | | | | |
| 0.20±0.05 OUR AVERAGE | DO CUMENT ID | | | COMMENT | |
| $0.21 \pm 0.05 \pm 0.02$ $0.19 \pm 0.08 \pm 0.02$ | AUBERT CHEN | | | $e^+e^- \rightarrow e^+e^- \rightarrow$ | |
| ϕ_{\parallel} in $B^+	o\phi K^{*+}$ | | | | | |
| VALUE (°) 2.34±0.18 OUR AVERAGE | DOCUMENT ID | | TECN | COMMENT | |
| 2.47±0.20±0.07 | AUBERT | 07ва | BABR | $e^+e^- \rightarrow$ | T(45) |
| $2.10 \pm 0.28 \pm 0.04$ | CHEN | | | $e^+ e^- \rightarrow$ | |
| ϕ_{\perp} in $B^+ \rightarrow \phi K^{*+}$ VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
| 2.58±0.17 OUR AVERAGE | | 07 | | | m(+c) |
| $2.69 \pm 0.20 \pm 0.03$ $2.31 \pm 0.30 \pm 0.07$ | AUBERT CHEN | | | $e^+ e^- \rightarrow e^+ e^- \rightarrow$ | |
| $\delta_0(B^+ \to \phi K^{*+})$ | | | | | |
| <u>VALUE (rad)</u> 3.07±0.18±0.06 | DOCUMENT ID AUBERT | | | $e^+e^- \rightarrow$ | Υ(Λ S) |
| $A_{CP}^0(B^+\to\phiK^{*+})$ | AODERT | OTBA | DADK | ¢ · ¢ → | 7 (43) |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.17±0.11±0.02 | AUBERT | 0 7 BA | BABR | e+ e− → | Υ(4S) |
| $A_{CP}^{\perp}(B^+ \rightarrow \phi K^{*+})$ VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.22±0.24±0.08 | AUBERT | 07ва | BABR | $e^+ e^- \rightarrow$ | Υ(4S) |
| $\Delta \phi_{\parallel}(B^+ \to \phi K^{*+})$ | | | | | |
| <u>VALUE</u> (rad) 0.07±0.20±0.05 | DOCUMENT ID AUBERT | | | $e^+e^- \rightarrow$ | Υ(45) |
| $\Delta\phi_{\perp}(B^+ \to \phi K^{*+})$ | | | | | |
| VALUE (rad) 0.19±0.20±0.07 | DOCUMENT ID | | | $\frac{\textit{COMMENT}}{e^+ e^- \rightarrow}$ | Υ(4 S) |
| $\Delta \delta_0(B^+ \to \phi K^{*+})$ | 71002111 | 0.0 | 57.51. | | , (10) |
| VALUE (rad) | DOCUMENT ID | | | | |
| 0.20±0.18±0.03 | AUBERT | 07BA | BABR | e ⁺ e [−] → | Υ(4S) |
| Γ_L/Γ in $B^+ \rightarrow \phi K_1(1270)^+$ | DO CUMENT ID | | TECN | COMMENT | |
| $0.46 + 0.12 + 0.06 \\ -0.13 - 0.07$ | AUBERT | 08ві | BABR | $e^+e^- \to$ | T(45) |
| Γ_L/Γ in $B^+ 	o \phi K_2^*(1430)^+$ | | | | | |
| 0.80 + 0.09 ± 0.03 | DOCUMENT ID AUBERT | | | $e^+e^- \rightarrow$ | Υ(45) |
| | | - 001 | | 1 | V 1 |
| $\begin{array}{ccc} \delta_0(B^+ \to \phi K_2^*(1430)^+) \\ \text{VALUE (rad)} \end{array}$ | DOCUMENT ID | | TECN | COMMENT | |
| 3.59±0.19±0.12 | AUBERT | | | $e^+e^- \rightarrow$ | Υ(4S) |
| $\Delta\delta_0(B^+\to \phi K_2^*(1430)^+)$ | | | | | |
| <u>VALUE</u> (rad) − 0.05 ± 0.19 ± 0.06 | DOCUMENT ID AUBERT | | | $\frac{\textit{COMMENT}}{e^+ e^- \rightarrow}$ | |
| _ | • | | | • | · / |

| VALUE <u>E</u> | OCUMENT ID | TECN COL | MMENT | |
|---------------------------------------------------------------|---------------------------------|---------------|--------------------------|----------------------------------|
| 0.78±0.12±0.03 | EL-AMO-SA11D | BABR e^+ | $e^- \rightarrow \gamma$ | 45) |
| • • • We do not use the | following data for av | erages, fits, | limits, etc. | • • • |
| $0.96^{+0.04}_{-0.15}\pm0.04$ A | UBERT 03v I | BABR Rep | ol. by DEL- | AMO-SANCHEZ 11D |
| $\Gamma_L/\Gamma(B^+ \to K^*(892))$ | | T 10 | TE 611 66 | |
| VALUE 0.48±0.08 OUR AVERAG | | 1 ID | TECN CC | OMMEN I |
| $0.52 \pm 0.10 \pm 0.04$ | AUBERT | ,B 06G | BABR e^+ | $+e^- \rightarrow r(4S)$ |
| $0.43 \pm 0.11 {}^{+\; 0.05}_{-\; 0.02}$ | ZHANG | | | $+e^- \rightarrow r(4S)$ |
| Γ_L/Γ in $B^+ 	o ho^+ ho^0$ | | | | |
| VALUE 0.950±0.016 OUR AVER/ | DOCUMENT ID | TECN | COMMENT | |
| 0.950±0.015±0.006 | AUBERT 0 | 9g BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.948 \pm 0.106 \pm 0.021$ | ZHANG 0 | | | |
| • • • We do not use the | following data for av | erages, fits, | limits, etc. | • • • |
| $0.905 \pm 0.042 ^{+ 0.023}_{- 0.027}$ | AUBERT,BE 0 | 6G BABR | Repl. by A | AUBERT 09G |
| $0.97 \ ^{+0.03}_{-0.07} \ \pm 0.04$ | AUBERT 0 | 3∨ BABR | Repl. by A | AUBERT,BE 06G |
| Γ_L/Γ in $B^+ 	o \omega ho^+$ | | | | |
| VALUE | DO CUMENT ID | | | |
| 0.90±0.05±0.03 • • • We do not use the | AUBERT following data for av | | | |
| $0.82 \pm 0.11 \pm 0.02$ | AUBERT,B | • | | |
| $0.88 + 0.12 \pm 0.03$ | | | | AUBERT,B 06T |
| 0.15 = 0.00 | 71002111 | 000 5/15 | it itepii by | 7,002,007 |
| Γ_L/Γ in $B^+ \rightarrow \rho \overline{\rho} K$ | *(892)+ | | | |
| VALUE | <u>DO CUMEN</u> | | TECN CC | |
| 0.32±0.17±0.09 | CHEN | 08c | BELL e | +e ⁻ → \(\gamma(45)\) |
| | <i>CP</i> VIOL | ATION | | |
| ${\it A_{CP}}$ is defined a | s | | | |

 Γ_L/Γ in $B^+ \to \,
ho^0\, K^*(892)^+$

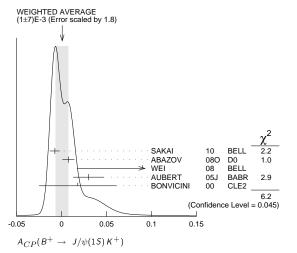
$$\frac{B(B^- \to \overline{f}) - B(B^+ \to f)}{B(B^- \to \overline{f}) + B(B^+ \to f)},$$

the $\it CP$ -violation charge asymmetry of exclusive $\it B^-$ and $\it B^+$ decay.

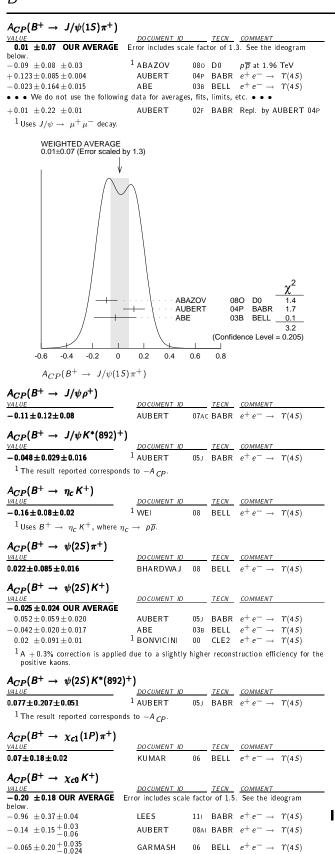
$A_{CP}(B^+\to~J/\psi(1S)\,K^+)$

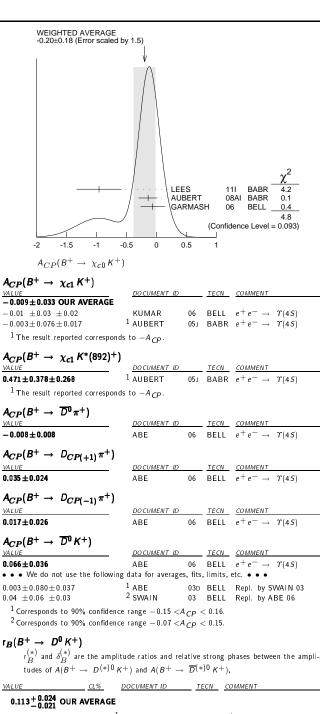
| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------|-----------------------------|----------|------------|-----------------------------------|
| (1 ±7)× See the ideogram below. | 10 ⁻³ OUR AVERAG | E E | rror inclu | ides scale factor of 1.8. |
| $-0.0076 \pm 0.0050 \pm 0.0022$ | SAKAI | 10 | BELL | $e^+e^- \rightarrow \gamma(4S)$ |
| $0.0075 \pm 0.0061 \pm 0.0030$ | $^{ m 1}$ ABAZOV | 080 | D0 | $p\overline{p}$ at 1.96 TeV |
| $0.09 \pm 0.07 \pm 0.02$ | ² WEI | 80 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.030 \pm 0.014 \pm 0.010$ | ³ AUBERT | 05 J | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.018 \pm 0.043 \pm 0.004$ | ⁴ BONVICINI | 00 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | ring data for average | s, fits, | limits, | etc. • • • |
| 0.03 ± 0.015 ± 0.006 | AUBERT | 04P | BABR | Repl. by AUBERT 05J |
| $-0.026 \pm 0.022 \pm 0.017$ | ABE | 03в | BELL | Repl. by SAKAI 10 |
| $0.003 \pm 0.030 \pm 0.004$ | AUBERT | 02F | BABR | Repl. by AUBERT 04P |
| 1 Uses $J/\psi ightarrow \mu^{+} \mu^{-}$ decay | i | | | |
| 2 Uses $B^+ \rightarrow J/\psi K^+$, whe | | | | |
| 3 The result reported correct | nda to A | | | |

 $^{^3}$ The result reported corresponds to $-A_{CP}$. 4 A + 0.3% correction is applied due to a slightly higher reconstruction efficiency for the positive kaons.



 B^{\pm}





0.113+0.024 OUR AVERAGE $0.096 \pm 0.029 \pm 0.006$ 1 DEL-AMO-SA...10F BABR $e^{+}\,e^{-}
ightarrow ~ \varUpsilon(4S)$ $0.095 \,{}^{+\, 0.051}_{-\, 0.041}$ 2 DEL-AMO-SA...10H BABR $e^+\,e^ightarrow~\varUpsilon$ (45) $0.160 + 0.040 + 0.051 \\ -0.038 - 0.015$ 3 POLUEKTOV 10 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • < 0.13 ⁴ LEES 11D BABR $e^+e^- \rightarrow \Upsilon(4S)$ 08AL BABR Repl. by DEL-AMO- $0.086 \pm 0.032 \pm 0.015$ ⁵ AUBERT SANCHEZ 10F 08 BELL $e^+e^-
ightarrow \Upsilon(4S)$ HORII $0.15\,9 \,{}^{+\, 0.054}_{-\, 0.050} \pm 0.050$ ⁶ POLUEKTOV 06 BELL Repl. by POLUEKTOV 10 ⁷ AUBERT,B 05Y BABR Repl. by AUBERT 08AL $0.12 \pm 0.08 \pm 0.05$ 1 Uses Dalitz plot analysis of $\overline{D}{}^0$ \rightarrow ~ $K\,^0_S\,\pi^+\,\pi^-$, $K\,^0_S\,K^+\,K^-$ decays from B^+ \rightarrow $D^{(*)} \, {\it K}^{(*)+}$ modes. The corresponding two standard deviation interval is 0.037 <² Uses the Cabibbo suppressed decay of $B^+ \to \overline{D} \, K^+$ followed by $\overline{D} \to K^- \pi^+$. 3 Uses Dalitz plot analysis of $\overline{D}^0 \to K_0^0 \pi^+ \pi^-$ decays from $B^+ \to D^0 K^+$ modes. The corresponding two standard deviation interval is 0.084 $< r_B < 0.239$.

⁴ Uses decays of neutral D to $K = \pi + \pi^0$.

| 5 Uses Dalitz plot analysis of $\overline{D}{}^0	o \kappa^0_S\pi^+\pi^-$ and $\overline{D}{}^0	o \kappa^0_S\kappa^+\kappa^-$ decays coming | $A_{CP}(B^+ \rightarrow [K^-\pi^+]_D\pi^+$ |) |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| from $B^{\pm} \to D(*)$ $K(*)^{\pm}$ modes. 6 Uses a Dalitz plot analysis of the $\overline{D}{}^0 \to K^0_{\S} \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ | VALUE 0.00±0.09 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| and DK*+ modes | $0.13 \pm 0.25 \pm 0.02$ | AALTONEN 11AJ CDF $p\overline{p}$ at 1.96 TeV |
| Uses a Dalitz analysis of neutral D decays to $K_S^0\pi^+\pi^-$ in the processes $B^\pm 	o$ | $-0.04\pm0.11{}^{+0.02}_{-0.01}$ | HORII 11 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $D^{(*)} K^{\pm}, D^* \rightarrow D \pi^0, D \gamma.$ | 0.03 ± 0.17 ± 0.04 | DEL-AMO-SA 10H BABR $e^+e^- \rightarrow \Upsilon(4S)$ ng data for averages, fits, limits, etc. • • • |
| $B(B^+ \to D^0 K^+)$ | $-0.02 + 0.15 \pm 0.04$ | HORII 08 BELL Repl. by HORII 11 |
| LUE (°) DOCUMENT ID TECN COMMENT 5 ±16 OUR AVERAGE | | • • |
| 9 $^{+19}_{-20}$ \pm 4 1 DEL-AMO-SA10F BABR $e^+e^- ightarrow \varUpsilon(4S)$ | $+0.30 {+0.29 \atop -0.25} \pm 0.06$ | SAIGO 05 BELL Repl. by HORII 08 |
| $6.7^{+13.0}_{-15.8}\pm23.2$ ² POLUEKTOV 10 BELL $e^+e^- \rightarrow r(4S)$ | $A_{CP}(B^+ \rightarrow [K^-\pi^+]_{(D\pi)})$ | π^+) |
| • We do not use the following data for averages, fits, limits, etc. • • | <u>VALUE</u> -0.09±0.27±0.05 | DOCUMENT ID TECN COMMENT |
| $^{+27}_{-30}~\pm~8$ 3 AUBERT 08AL BABR Repl. by DEL-A MO-SANCHEZ 10F | | DEL-AMO-SA10H BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $.7^{+19.0}_{-19.7} \pm 23.1$ ⁴ POLUEKTOV 06 BELL Repl. by POLUEKTOV 10 | $A_{CP}(B^+ \rightarrow [K^-\pi^+]_{(D\gamma)})$ | |
| 1 ±45 +23 5 AUBERT,B 05Y BABR Repl. by AUBERT 08AL | <u>VALUE</u> -0.65 ±0.55 ±0.22 | DEL-AMO-SA10H BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_0^0 \pi^+ \pi^-$, $K_0^0 K^+ K^-$ decays from $B^+ \to 1$ | | , , |
| D(*) $K(*)+$ modes. The corresponding two standard deviation interval is 75° < | $A_{CP}(B^+ \rightarrow [K^-\pi^+]_{(D\pi)})$ | M+) DOCUMENT ID TECN COMMENT |
| $\delta_R < 157^{\circ}$. | 0.77±0.35±0.12 | DEL-AMO-SA10H BABR $e^+e^- 	oup 	ag{(4.5)}$ |
| Uses Dalitz plot analysis of $\overline{D}{}^0 \to K_S^0 \pi^+ \pi^-$ decays from $B^+ \to D^0 K^+$ modes. The corresponding two standard deviation interval is $102.2^\circ < \delta_R < 162.3^\circ$. | $A_{CP}(B^+ \rightarrow [K^-\pi^+]_{(D\gamma)})$ | K +) |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming | $\frac{VALUE}{ACP(D_{\perp} \rightarrow [K_{\perp}, K_{\perp}](D_{\gamma})}$ | DOCUMENT ID TECN COMMENT |
| from $B^\pm\to D(*)K(*)\pm$ modes. Uses a Dalitz plot analysis of the $\overline D^0\to K^0_S\pi^+\pi^-$ decays; Combines the DK^+ , D^*K^+ | $0.36 \pm 0.94 + 0.25 \\ -0.41$ | DEL-AMO-SA10H BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| and DK*+ modes | $A_{CP}(B^+ \rightarrow [\pi^+\pi^-\pi^0]_D)$ | V+) |
| Uses a Dalitz analysis of neutral D decays to $K_S^0 \pi^+ \pi^-$ in the processes $B^\pm \to \pi^+ \pi^-$ | $A_{CP}(B^+ \rightarrow [\pi^+\pi^-\pi^-]D^+$ | DOCUMENT ID TECN COMMENT |
| $D^{(*)} K^{\pm}$, $D^* \rightarrow D \pi^0$, $D \gamma$. | $-0.02 \pm 0.15 \pm 0.03$ | $1 \overline{\text{AUBERT}}$ 07BJ $\overline{\text{BABR}}$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| $(B^+ \to DK^{*+})$ r_B and δ_B are the amplitude ratios and relative strong phases between the amplitudes | • • • We do not use the follows $-0.02 \pm 0.16 \pm 0.03$ | ng data for averages, fits, limits, etc. • • • AUBERT,B 05⊤ BABR Repl. by AUBERT 07E |
| of $A_{CP}(B^+ \to D K^{*+})$ and $A_{CP}(B^+ \to \overline{D} K^{*+})$, | | AOBERT, B 031 BABK Repl. by AOBERT 078 of $D^0 \rightarrow \pi^+\pi^-\pi^0$. Also reports the one-sigma region |
| LUE DOCUMENT ID TECN COMMENT | $0.06 < r_B < 0.78, -30^{\circ} < r_B$ | $\gamma <$ 76°, and $-27^{\circ} < \delta <$ 78°. |
| 34 ±0.09 OUR AVERAGE Error includes scale factor of 1.3. | $A_{CP}(B^+ \rightarrow D_{CP(+1)}K^+)$ |) |
| 1 ± 0.07 1 AUBERT 09AJ BABR $e^+e^- \rightarrow \Upsilon(4S)$ 64 $\pm 0.216 \pm 0.093$ 2 POLUEKTOV 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE | DOCUMENT ID TECN COMMENT |
| • We do not use the following data for averages, fits, limits, etc. • • • | 0.24±0.06 OUR AVERAGE Er 0.39±0.17±0.04 | ror includes scale factor of 1.1. AALTONEN 10A CDF pp at 1.96 TeV |
| 11 + 0.088 ± 0.042 3 AUBERT 08AL BABR REPL. by AUBERT 09AJ | $0.25 \pm 0.06 \pm 0.02$ | 1 DEL-A MO-SA10G BABR $e^{+}e^{-} ightarrow$ \varUpsilon (4 S) |
| | 0.06 ± 0.14 ± 0.05 | ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ ng data for averages, fits, limits, etc. $\bullet \bullet \bullet$ |
| Obtained by combining the GLW and ADS methods. The 2-sigma range corresponds to [0.17, 0.43]. | $0.27 \pm 0.09 \pm 0.04$ | AUBERT 08AA BABR Repl. by DEL-AMO- |
| Uses a Dalitz plot analysis of the $\overline{D}{}^0 	o K^0_S \pi^+ \pi^-$ decays; Combines the $D K^+$, $D^* K^+$ | $0.35 \pm 0.13 \pm 0.04$ | SANCHEZ 10g AUBERT 06J BABR Repl. by AUBERT 08AA |
| | | |
| and DK^{*+} modes. Uses Dalitz plot analysis of $\overline{D}^0 \to K_c^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_c^0 K^+ K^-$ decays coming | $0.07 \pm 0.17 \pm 0.06$ | AUBERT 04N BABR Repl. by AUBERT 06J |
| Uses Dalitz plot analysis of $\overline{D}{}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}{}^0 \to K_S^0 K^+ K^-$ decays coming | $0.07 \pm 0.17 \pm 0.06$ $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ | |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. | $0.29\pm0.26\pm0.05$ $0.06\pm0.19\pm0.04$ Reports the first evidence for | AUBERT 04N BABR Repl. by AUBERT 06J ² ABE 03D BELL Repl. by SWAIN 03 ³ SWAIN 03 BELL Repl. by ABE 06 |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. ($B^+ \to D K^{*+}$) UE (°) DOCUMENT ID TECH COMMENT | $\begin{array}{c} 0.29\pm0.26\pm0.05\\ 0.06\pm0.19\pm0.04\\ \hline 1 \text{ Reports the first evidence for}\\ \text{deviations.}\\ 2 \text{ Corresponds to } 90\% \text{ confiden} \end{array}$ | AUBERT 04N BABR Repl. by AUBERT 06J ABE 03D BELL Repl. by SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standards are range $-0.14 < A_{CP} < 0.73$. |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. ($B^+ \to D K^{*+}$) UE (°) $DOCUMENT\ ID$ TECN Error includes scale factor of 2.0. | $\begin{array}{c} 0.29\pm0.26\pm0.05\\ 0.06\pm0.19\pm0.04\\ \hline 1 \text{ Reports the first evidence for}\\ \text{deviations.}\\ 2 \text{ Corresponds to } 90\% \text{ confiden} \end{array}$ | AUBERT 04N BABR Repl. by AUBERT 06J ² ABE 03D BELL Repl. by SWAIN 03 ³ SWAIN 03 BELL Repl. by ABE 06 |
| Uses Dalitz plot analysis of $\overline{D}{}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}{}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D(*) K(*) \pm$ modes. (B+ \(\to D K^{*+} \) \(\frac{E(c)}{2} \) \(\frac{DOCUMENT ID}{2} \) \(\frac{TECN}{2} \) \(\frac{COMMENT}{2} \) \(\frac{1}{2} \) \(| 0.29±0.26±0.05 0.06±0.19±0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. ($B^+ \to D K^{*+}$) UE($^\circ$) ± 70 OUR AVERAGE Error includes scale factor of 2.0. $^{+39}_{-37} \pm 18$ 1 AUBERT 08AL BABR $e^+ e^- \to T(4S)$ $e^+ e^- \to T(4S)$ $e^+ e^- \to T(4S)$ | 0.29±0.26±0.05 0.06±0.19±0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider **ACP(B+ → D _{CP(-1)} K+ NALUE* | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D(*) K(*) \pm$ modes. ($B^+ \to DK^{*+}$) $U \in (\circ)$ $U \to (\circ)$ $U $ | 0.29±0.26±0.05 0.06±0.19±0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider **ACP(B+ → D _{CP(-1)} K+) **ALUE** -0.10±0.07 OUR AVERAGE | AUBERT 04N BABR Repl. by AUBERT 06J abE 03D BELL Repl. by SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standatice range $-0.14 < A_{CP} < 0.73$. ice range $-0.26 < A_{CP} < 0.38$. |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm \text{modes}$. ($B^+ \to D K^{*+}$) DOCUMENT ID TECN COMMENT ± 70 OUR AVERAGE Error includes scale factor of 2.0. 1 AUBERT 08AL BABR $e^+ e^- \to T(4S)$ 2 POLUEKTOV 06 BELL $e^+ e^- \to T(4S)$ Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming | 0.29 \pm 0.26 \pm 0.05 0.06 \pm 0.19 \pm 0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider ACP(B⁺ \rightarrow D_{CP(-1)} K⁺). <u>NALUE</u> -0.10 \pm 0.07 OUR AVERAGE -0.09 \pm 0.07 \pm 0.02 -0.12 \pm 0.14 \pm 0.05 | AUBERT 04N BABR Repl. by AUBERT 06J as BABR Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard range $-0.14 < A_{CP} < 0.73$. Receive range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. The standard range $-0.26 < A_{CP} < 0.38$. |
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| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm m$ modes. ($B^+ \to DK^{*+}$) UE (°) ± 70 OUR AVERAGE Error includes scale factor of 2.0. $+\frac{39}{37} \pm 18$ 1 AUBERT 08AL BABR $e^+e^- \to T(4S)$ 1.6 $\pm 20.2 \pm 49.4$ 2 POLUEKTOV 06 BELL $e^+e^- \to T(4S)$ Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm m$ modes. Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. Use $DK^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. | $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider $ACP(B^+ \rightarrow D_{CP(-1)}K^+)$ *** -0.10 ± 0.07 OUR AVERAGE -0.09 ± 0.07 ± 0.02 -0.12 ± 0.14 ± 0.05 • • • We do not use the followider of the confidence of th | AUBERT 04N BABR Repl. by AUBERT 06J 2 ABE 03D BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard rece range $-0.14 < A_{CP} < 0.73$. It can be a compared by ABE 06 2 Comment Delianation of the compared by ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ and Babra Repl. by DEL-AMO-SANCHEZ 106 AUBERT 06J BABR Repl. by AUBERT 08AA ABE 03D BELL Repl. by AUBERT 08AA ABE Repl. by AUBERT 08AA A |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm m$ modes. ($B^+ \to DK^{*+}$) $b \in (^\circ)$ $b \in ($ | $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider of the confidence of the corresponds to 90% confidence of the corresponds of the c | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D(*) K(*) \pm$ modes. ($B^+ \to DK^{*+}$) USE (*) $E^+ \to DK^{*+}$) USE (*) $E^+ \to DK^{*+}$ DOCUMENT ID $E^+ \to DK^{*+}$ Error includes scale factor of 2.0. 1 AUBERT 08AL BABR $e^+ e^- \to T(4S)$ 0.6 $\pm 20.2 \pm 49.4$ 2 POLUEKTOV 06 BELL $e^+ e^- \to T(4S)$ Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D(*) K(*) \pm$ modes. Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and $DK^* \to K_S^0 \pi^+ \pi^-$ decays; $DK^+ \to K_S^0 \pi^+ \pi^-$ decays; $DK^0 \to K_S^0 \pi^+ \pi^-$ decays; $DK^0 \to K_S^0 \pi^+ \pi^-$ decays | $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider of the corresponds of 90% confider of the corresponds of th | AUBERT 04N BABR Repl. by AUBERT 06J 2 ABE 03D BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard rece range $-0.14 < A_{CP} < 0.73$. It can be compared by a co |
| from $B^{\pm} \rightarrow D^{(*)} K^{(*)\pm}$ modes. $(B^{+} \rightarrow DK^{*+})$ $UE^{(\circ)}$ $\overline{L^{+70}}$ \overline{DUR} $\overline{L^{+70}}$ \overline{UE} $\overline{L^{+70}}$ | $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ 1 Reports the first evidence for deviations. 2 Corresponds to 90% confider 3 Corresponds to 90% confider 4 CP($B^+ \rightarrow D_{CP(-1)}K^+$). WALUE -0.10 ± 0.07 OUR AVERAGE $-0.09 \pm 0.07 \pm 0.02$ $-0.12 \pm 0.14 \pm 0.05$ • • We do not use the following $-0.09 \pm 0.09 \pm 0.02$ $-0.06 \pm 0.13 \pm 0.04$ $-0.22 \pm 0.24 \pm 0.04$ $-0.19 \pm 0.17 \pm 0.05$ 1 Corresponds to 90% confider 2 Corresponds to 90% confider | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm m$ modes. ($B^+ \to DK^{*+}$) USE (**) ± 70 OUR AVERAGE Error includes scale factor of 2.0. $+\frac{39}{37} \pm 18$ 1 AUBERT 08AL BABR $e^+ e^- \to T(4S)$ Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)} \pm m$ modes. Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the $D^- K^+ K^- K^+$ and $D^- K^+ K^- K^+ K^- K^+$ and $D^- K^+ K^- K^+ K^- K^+ K^- K^+$ and $D^- K^+ K^+ K^- K^- K^+ K^- K^- K^+ K^- K^- K^+ K^- K^- K^+ K^- K^- K^- K^- K^- K^- K^- K^- K^- K^-$ | 0.29±0.26±0.05 0.06±0.19±0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider ³ Corresponds to 90% confider $ACP(B^+ \rightarrow D_{CP(-1)}K^+)$ MALUE -0.10±0.07 OUR AVERAGE -0.09±0.07±0.02 -0.12±0.14±0.05 • • We do not use the followider of the f | AUBERT 04N BABR Repl. by AUBERT 06J 82 Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard regrange $-0.14 < A_{CP} < 0.73$. Receive range $-0.26 < A_{CP} < 0.38$. Repl. by ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ and ABE 08 ABBR Repl. by DEL-AMO-SANCHEZ 10G AUBERT 08AA BABR Repl. by AUBERT 08AA Repl. by ABE 06 Rep |
| 3 Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. 3 ($B^+ \to DK^{(*)} = DK^{(*)} K^{(*)\pm}$ modes. 4 $+ \frac{39}{-37} = 18$ 1 AUBERT 08AL BABR $e^+e^- \to T(4S)$ 2 POLUEKTOV 06 BELL $e^+e^- \to T(4S)$ 1 Uses Dalitz plot analysis of $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming from $B^\pm \to D^{(*)} K^{(*)\pm}$ modes. 2 Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. 2 Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. 2 Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. 2 Uses a Dalitz plot analysis of the $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays; Combines the DK^+ , D^*K^+ and DK^*+ modes. 3 DASE DALITY DOWN AVERAGE 3.086 DATONEN 11AJ CDF $p\overline{p}$ at 1.96 TeV 4.039 + 0.26 + 0.04 5.039 + 0.26 + 0.04 6.047 + 0.12 7 DEL-AMO-SA10H BABR $e^+e^- \to T(4S)$ 8 We do not use the following data for averages, fits, limits, etc. • • | $0.29 \pm 0.26 \pm 0.05$ $0.06 \pm 0.19 \pm 0.04$ 1 Reports the first evidence for deviations. 2 Corresponds to 90% confider 3 Corresponds to 90% confider 4 CP($B^+ \rightarrow D_{CP(-1)}K^+$). WALUE -0.10 ± 0.07 OUR AVERAGE $-0.09 \pm 0.07 \pm 0.02$ $-0.12 \pm 0.14 \pm 0.05$ • • We do not use the following $-0.09 \pm 0.09 \pm 0.02$ $-0.06 \pm 0.13 \pm 0.04$ $-0.22 \pm 0.24 \pm 0.04$ $-0.19 \pm 0.17 \pm 0.05$ 1 Corresponds to 90% confider 2 Corresponds to 90% confider | AUBERT 04N BABR Repl. by AUBERT 06J 2 ABE 03D BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard rece range $-0.14 < A_{CP} < 0.73$. It can be compared by a co |
| 3 Uses Dalitz plot analysis of $\overline{D}^0 \rightarrow K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \rightarrow K_S^0 K^+ K^-$ decays coming from $B^\pm \rightarrow D^{(*)} K^{(*)} \pm \text{modes}$. 3 ($B^+ \rightarrow D^+ K^* + D^+ $ | 0.29±0.26±0.05 0.06±0.19±0.04 ¹ Reports the first evidence for deviations. ² Corresponds to 90% confider of the property of the prope | AUBERT 04N BABR Repl. by AUBERT 06J 2 ABE 03D BELL Repl. by SWAIN 03 3 SWAIN 03 BELL Repl. by ABE 06 direct CP violation in $B \rightarrow D$ K decays with 3.6 standard recrange $-0.14 < A_{CP} < 0.73$. Recrange $-0.26 < A_{CP} < 0.38$. Repl. by ABE 06 DELLAMO-SA10G BABR $e^+e^- \rightarrow \Upsilon(4S)$ ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ and ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 08AA BABR Repl. by DEL-AMO-SANCHEZ 10G AUBERT 08J BABR Repl. by AUBERT 08AA 1 ABE 03D BELL Repl. by SWAIN 03 BELL Repl. by SWAIN 03 BELL Repl. by ABE 06 DELCE ABE 05 SWAIN 03 BELL Repl. by ABE 06 DELCE ABE 05 SWAIN 03 BELL Repl. by ABE 06 DELCE ABE 05 SWAIN 05 DELCE ABE 06 DELCE DELCE DELCE DELCE ABE 06 DELCE DEL |

 $A_{CP}(B^+ \to (D^*_{CP(-1)})^0 \pi^+)$

 -0.090 ± 0.051

DO CUMENT ID

TECN COMMENT

06 BELL $e^+e^- \rightarrow \Upsilon(4S)$

AUBERT,B 05v BABR Repl. by AUBERT 09AJ

 $-\,0.22\pm0.61\pm0.17$

 B^{\pm}

| $A_{CP}(B^+ \rightarrow D^{*0}K^+)$ VALUE | DOCUMENT ID TECN COMMENT |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| $egin{array}{lll} \textbf{0.07} & \pm \textbf{0.04} & \textbf{OUR AVERAGE} \\ \textbf{0.06} & \pm \textbf{0.04} & \pm \textbf{0.01} \\ \textbf{0.089} & \pm \textbf{0.086} \\ \end{array}$ | : AUBERT 088F BABR $e^+e^- ightarrow \varUpsilon(4S)$ ABE 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $_B^*(B^+ \rightarrow D^{*0}K^+)$ | |
| $r_D^{(*)}$ and $\delta_D^{(*)}$ are the am | plitude ratios and relative strong phases between the ampli- |
| tudes of $A(B^+ \rightarrow D^{(*)})$ | $D(K^+)$ and $A(B^+	o \overline{D}(*)^0K^+)$, |
| VALUE | DOCUMENT ID TECN COMMENT |
| 0.123+0.026 OUR AVERAGE | |
| $0.133 + 0.042 \pm 0.013$ | 1 DEL-AMO-SA10F BABR $e^{+}e^{-} ightarrow~ \varUpsilon(4S)$ |
| $0.096 + 0.035 \\ -0.051$ | 2 DEL-AMO-SA10H BABR $e^+e^- ightarrow~ \varUpsilon$ (4 S) |
| . 0 070 . 0 064 | 3 POLUEKTOV 10 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| | ing data for averages, fits, limits, etc. • • • |
| $0.135 \pm 0.050 \pm 0.012$ | ⁴ AUBERT 08AL BABR Repl. by DEL-AMO- SANCHEZ 10F |
| $0.175 + 0.108 \pm 0.050$ | POLUEKTOV 06 BELL Repl. by POLUEKTOV 10 |
| 0.17 ±0.10 ±0.04 | AUBERT,B 05 Y BABR Repl. by AUBERT 08AL |
| | of $\overline{D}{}^0$ \to $K_5^0\pi^+\pi^-$, $K_5^0K^+K^-$ decays from B^+ \to corresponding two standard deviation interval is 0.049 $<$ |
| 2 Uses the Cabibbo suppressed | If decay of $B^+	o \overline D^*K^+$ followed by $\overline D^*	o \overline D\pi^0$ or $\overline D\gamma$, |
| and $\overline{D} \rightarrow K^- \pi^+$ | |
| The corresponding two stand | $\overline{D}{}^0 \to K_S^0 \pi^+ \pi^-$ decays from $B^+ \to D^{*0} K^+$ modes. dard deviation interval is 0.061 $< r_B^* <$ 0.271. |
| ⁴ Uses Dalitz plot analysis of | $\overline{D}{}^0 	o \ {\it K}^0_{S} \pi^+ \pi^-$ and $\overline{D}{}^0 	o \ {\it K}^0_{S} {\it K}^+ {\it K}^-$ decays coming |
| from $B^{\pm} \rightarrow D^{(*)} K^{(*)\pm}$ n 5 Uses a Dalitz plot analysis of | nodes. the $\overline{D}{}^0	o K_S^0\pi^+\pi^-$ decays; Combines the D K^+ , D^*K^+ |
| and DK^{*+} modes. | |
| Uses a Dalitz analysis of r $D^{(*)} K^{\pm}, D^* \rightarrow D \pi^0, D \gamma$ | neutral D decays to $K^0_S\pi^+\pi^-$ in the processes $B^\pm	o$ |
| | γ . |
| $\delta_B^*(B^+	o D^{*0}K^+)$ VALUE $(^\circ)$ DOCUM | ENT ID TECN COMMENT |
| 300 ±30 OUR AVERAGE | Error includes scale factor of 1.7. |
| | MO-SA10F BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| -19.0 | EKTOV 10 BELL $e^+e^-	o \varUpsilon(4S)$ ring data for averages, fits, limits, etc. $ullet$ $ullet$ |
| 297 $\begin{array}{c} +27 \\ -29 \end{array}$ \pm 6.4 $\begin{array}{c} 3 \\ \end{array}$ AUBEF | |
| == | |
| - 35.1 | EKTOV 06 BELL Repl. by POLUEKTOV 10 |
| 296 ± 41 $^{+20}_{-19}$ 5 AUBER | · · |
| $D^{(*)} K^{(*)+}$ modes. The | of $\overline{D}{}^0 \to K_S^0 \pi^+ \pi^-$, $K_S^0 K^+ K^-$ decays from $B^+ \to \infty$ |
| $\delta_B^* < 322^\circ$. | $\overline{D}{}^0 	o \ {\cal K}^0_S \pi^+ \pi^-$ decays from $B^+ 	o D^* {\cal K}^+$ modes. The |
| | $B^+ \to K_S^+ \pi^+ \pi^-$ decays from $B^+ \to D^+ K^+$ modes. The deviation interval is $296.5^\circ < \delta_B^* < 382.7^\circ$. |
| ³ Uses Dalitz plot analysis of | $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ and $\overline{D}^0 \to K_S^0 K^+ K^-$ decays coming |
| from $B^{\pm} \rightarrow D^{(*)} K^{(*)\pm} n$ | nodes. the $\overline D^0	o K^0_{oldsymbol S}\pi^+\pi^-$ decays; Combines the DK^+ , D^*K^+ |
| and DK^{*+} modes | |
| ⁵ Uses a Dalitz analysis of r | neutral D decays to $K_S^0\pi^+\pi^-$ in the processes B^\pm $ ightarrow$ |
| $D^{(*)} K^{\pm}, D^* \rightarrow D \pi^0, D \gamma$ | у. |
| $A_{CP}(B^+ \to D_{CP(+1)}^{*0} K^+$ |) |
| VALUE | DOCUMENT ID TECN COMMENT |
| -0.12±0.08 OUR AVERAGE -0.11±0.09±0.01 | AUBERT 08BF BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| -0.20 ± 0.22 ± 0.04 | ABE 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | ing data for averages, fits, limits, etc. • • • |
| $-0.10 \pm 0.23 ^{+0.03}_{-0.04}$ | AUBERT 05N BABR Repl. by AUBERT 08BF |
| $A_{CP}(B^+ \rightarrow D^*_{CP(-1)}K^+)$ | |
| 0.07±0.10 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| $+0.06\pm0.10\pm0.02$ | AUBERT 08BF BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $+0.13\pm0.30\pm0.08$ | ABE 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $A_{CP}(B^+ \rightarrow D_{CP(+1)}K^*)$ | |
| ALUE | DOCUMENT ID TECN COMMENT |
| - 0.09 ± 0.13 ± 0.06 • • We do not use the follow | AUBERT 09AJ BABR $e^+e^- \rightarrow \Upsilon(4S)$ ing data for averages, fits, limits, etc. • • • |
| $-0.08 \pm 0.19 \pm 0.08$ | AUBERT,B 050 BABR Repl. by AUBERT 09AJ |

 $-0.08\pm0.19\pm0.08$ AUBERT,B 05U BABR Repl. by AUBERT 09AJ

| $A_{CP}(B^+ \rightarrow D_{CP(-1)}K^-)$ | *(892)+) | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|------------------------------------------------------|
| VALUE | | TECN COMMENT |
| -0.23±0.21±0.07 | | 9AJ BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • We do not use the following the fol | wing data for averages, t | fits, limits, etc. • • • |
| -0.26±0.40±0.12 | AUBERT,B 0 | 50 BABR Repl. by AUBERT 09AJ |
| $A_{CP}(B^+ \rightarrow D^{*+} \overline{D}^{*0})$ | DOCUMENT ID | TECNCOMMENT |
| $-0.15 \pm 0.11 \pm 0.02$ | | 6A BABR $e^+e^- 	o 	au(4S)$ |
| $A_{CP}(B^+ \rightarrow D^{*+} \overline{D}{}^0)$ | | |
| VALUE | DO CUMENT ID | TECN COMMENT |
| $-0.06 \pm 0.13 \pm 0.02$ | AUBERT,B 0 | 6A BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $A_{CP}(B^+ \rightarrow D^+ \overline{D}^{*0})$ | DO CUMENT ID | TECN COMMENT |
| $0.13 \pm 0.18 \pm 0.04$ | AUBERT,B 0 | 6A BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $A_{CP}(B^+ \rightarrow D^+ \overline{D}{}^0)$ | | |
| <u>VALUE</u> -0.03±0.07 OUR AVERAGE | DO CUMENT ID | TECN COMMENT |
| 0.00 ± 0.08 ± 0.02 | ADACHI 0 | 8 BELL $e^+e^- ightarrow \gamma(4S)$ |
| $-0.13\pm0.14\pm0.02$ | AUBERT,B 0 | 6A BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $A_{CP}(B^+ \rightarrow K_S^0 \pi^+)$ | | |
| VALUE 0.009±0.029 OUR AVERAGE | DOCUMENT ID Error includes scale | TECN COMMENT factor of 1.2 |
| 0.03 ±0.03 ±0.01 | LIN 07 | BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| $-0.029\pm0.039\pm0.010$ | 1 AUBERT,BE 06c | BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 0.18 ±0.24 | ² CHEN 00 | CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ |
| • • We do not use the following the fol | 2 | |
| $-0.09 \pm 0.05 \pm 0.01$ $0.05 \pm 0.05 \pm 0.01$ | AUBERT,BE 05E CHAO 05A | BABR Repl. by AUBERT, BE 06c BELL Repl. by LIN 07 |
| $-0.05 \pm 0.08 \pm 0.01$ | | BABR Repl. by AUBERT,BE 05E |
| $\begin{array}{cccc} 0.07 & +0.09 & +0.01 \\ -0.08 & -0.03 \end{array}$ | 6 UNNO 03 | BELL Repl. by CHAO 05A |
| $0.46 \pm 0.15 \pm 0.02$ | ⁷ CASEY 02 | BELL Repl. by UNNO 03 |
| $0.098 {}^{+\ 0.430 + 0.020}_{- 0.343 - 0.063}$ | ⁸ ABE 01к | BELL Repl. by CASEY 02 |
| -0.343 - 0.063 $-0.21 \pm 0.18 \pm 0.03$ | 9 AUBERT 01E | BABR Repl. by AUBERT 04M |
| $^{ m 1}$ Corresponds to 90% confid | | |
| ² Corresponds to 90% confid | lence range $-0.22 < A_{C}$ | p < 0.56. |
| ³ Corresponds to 90% confic | | |
| ⁴ Corresponds to a 90% CL | | CP < 0.13. |
| 5 90% CL interval $-$ 0.18 $<$ 6 Corresponds to 90% confid | | 0.22 |
| ⁷ Corresponds to 90% confic | | |
| ⁸ Corresponds to 90% confic | lence range $-0.53 < A_{C}$ | P < 0.82. |
| ⁹ Corresponds to 90% confic | lence range $-0.51 < A_{Cl}$ | p < 0.09. |
| $A_{CP}(B^+ \rightarrow K^+\pi^0)$ | | |
| 0.051 ± 0.025 OUR AVERAGE | <u>DO CUMENT ID</u> iE | TECN COMMENT |
| $0.07\ \pm0.03\ \pm0.01$ | LIN 08 | BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $0.030 \pm 0.039 \pm 0.010$ | 4 | C BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| -0.29 ± 0.23 • • • We do not use the following the following the following that the following the following that the following the following that the following the following the following that the following th | CHEN 00 Wing data for averages, 1 | CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| 0.06 ±0.06 ±0.01 | ² AUBERT 05L | BABR Repl. by AUBERT 07BC |
| $0.06 \pm 0.06 \pm 0.02$ | ² CHAO 05A | |
| $0.04 \pm 0.05 \pm 0.02$ | ³ CHAO 04B | |
| $-0.09 \pm 0.09 \pm 0.01$ $-0.02 \pm 0.19 \pm 0.02$ | ⁴ AUBERT 03L ⁵ CASEY 02 | BABR Repl. by AUBERT 05L BELL Repl. by CHAO 04B |
| $-0.059 + 0.222 + 0.055 \\ -0.196 - 0.017$ | | BELL Repl. by CASEY 02 |
| 0.003 - 0.196 - 0.017 $0.00 \pm 0.18 \pm 0.04$ | ⁷ AUBERT 01E | BABR Repl. by AUBERT 03L |
| 1 Corresponds to 90% confic | | |
| ² Corresponds to a 90% CL | interval of $-0.06 < A_{\rm c}$ | CD < 0.18. |
| ³ Corresponds to 90% CL in | terval of $-$ 0.05 $$ | > < 0.13. |
| ⁴ Corresponds to 90% confid | lence range $-0.24 < A_C$ | p < 0.06. |
| ⁵ Corresponds to 90% confic | | |
| ⁶ Corresponds to 90% confic ⁷ Corresponds to 90% confic | | |
| | .ccc runge - 0.30 \ACI | p < 10.00. |
| $A_{CP}(B^+ \rightarrow \eta' K^+)$ | | |
| VALUE | | ECN COMMENT |
| 0.013±0.017 OUR AVERAG | E | |
| VALUE | E | BABR $e^+e^- 	o 	au(4S)$ |
| 0.013±0.017 OUR AVERAG | AUBERT 09AV E SCHUEMANN 06 E | |

| • • • We do not use the following data for averages, fits, limits, etc. • • • | $A_{CP}(B^+ 	o 	ext{ } K^{*0}\pi^+)$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.010 ± 0.022 ± 0.006 AUBERT 07AE BABR Repl. by AUBERT 09AV | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> −0.04 ±0.09 OUR AVERAGE Error includes scale factor of 2.1 |
| 0.033±0.028±0.005 | 0.016 |
| 0.037±0.045±0.011 | |
| $-0.015\pm0.070\pm0.009$ ⁵ CHEN 02B BELL Repl. by SCHUEMANN 06 | $-0.149\pm0.064\pm0.022$ GARMASH 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $0.06 \pm 0.15 \pm 0.01$ ⁶ ABE 01M BELL Repl. by CHEN 02B | |
| $\frac{1}{2}$ Corresponds to 90% confidence range $-0.17 < A_{CP} < 0.23$. | $0.068 \pm 0.078 \stackrel{+ \; 0.070}{- \; 0.067}$ AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| 2 Corresponds to 90% confidence range $-0.012 < A_{CP} < 0.078$. | $A_{CP}(B^+ \to K^*(892)^+ \pi^0)$ |
| 3 Corresponds to 90% confidence range -0.04 $<\!A_{CP}\!<0.11.$ 4 Corresponds to 90% confidence range -0.28 $<\!A_{CP}\!<0.07.$ | $ACP(D \rightarrow V, (0.37), \mu_2)$ |
| Corresponds to 90% confidence range $-0.28 < A_{CP} < 0.07$. 5 Corresponds to 90% confidence range $-0.13 < A_{CP} < 0.10$. | $-0.06\pm0.24\pm0.04$ LEES 111 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 6 Corresponds to 90% confidence range $-0.20 < A_{CP} < 0.32$. | |
| - 01 | $0.04 \pm 0.29 \pm 0.05$ AUBERT 05x BABR Repl. by LEES 111 |
| $A_{CP}(B^+ \to \eta' K^*(892)^+)$ | A (D+ K++) |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> -0.26±0.27±0.02 DEL-AMO-SA10A BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $A_{CP}(B^+	o K^+\pi^-\pi^+)$ VALUE DOCUMENT ID TECK COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • | 0.038±0.022 OUR AVERAGE |
| -0.30 + 0.33 ± 0.02 1 AUBERT 07E BABR Repl. by DEL-AMO- | $0.028 \pm 0.020 \pm 0.023$ AUBERT 08AI BABR $e^+e^- ightarrow \varUpsilon(45)$ |
| -0.30 -0.37 ±0.02 - AOBERT 07E BABK REPL BY DEL-AMO- | $0.049\pm0.026\pm0.020$ GARMASH 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $^{ m 1}$ Reports $^{ m A}_{\it CP}$ with the opposite sign convention. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| A (D+ | -0.013±0.037±0.011 AUBERT,B 05 N BABR Repl. by AUBERT 08AI 0.01 ±0.07 ±0.03 AUBERT 03 M BABR Repl. by AUBERT,B 05 N |
| $A_{CP}(B^+	o\eta'K_0^*(1430)^+)$ VALUE DO CUMENT ID TECN COMMENT | |
| $0.06 \pm 0.20 \pm 0.02$ DEL-AMO-SA10A BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $A_{CP}(B^+ \to f_0(980) K^+)$ |
| | VALUE DOCUMENT IDTECNCOMMENT |
| $A_{CP}(B^+ \to \eta' K_2^*(1430)^+)$ | $-0.09 \begin{array}{l} +0.05 \\ -0.04 \end{array}$ OUR AVERAGE Error includes scale factor of 1.1. |
| VALUE DOCUMENT ID TECN COMMENT | 0.18 \pm 0.18 \pm 0.04 |
| 0.15 \pm 0.13 \pm 0.02 DEL-AMO-SA10A BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $-0.106\pm0.050 {+0.036 \atop -0.015}$ AUBERT 08AI BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $A_{CP}(B^+ \rightarrow \eta K^+)$ | $-0.31 \pm 0.25 \pm 0.08$ 2 AUBERT 060 BABR $e^+e^- \rightarrow \gamma(45)$ |
| VALUE <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $-0.077 \pm 0.065 + 0.046$ GARMASH 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| -0.37±0.08 OUR AVERAGE | |
| $-0.38 \pm 0.11 \pm 0.01$ HOI 12 BELL $e^+e^- 	oup 	au(4S)$ $-0.36 \pm 0.11 \pm 0.03$ AUBERT 09AV BABR $e^+e^- 	oup 	au(4S)$ | • • We do not use the following data for averages, fits, limits, etc. • • • |
| • • • We do not use the following data for averages, fits, limits, etc. • • | $0.088 \pm 0.095 \stackrel{+}{-} \stackrel{0.097}{-} 0.056$ AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| -0.22±0.11±0.01 AUBERT 07AE BABR Repl. by AUBERT 09AV | 1 Measured in $B^{+} ightarrow f_{0} K^{+}$ with $f_{0} ightarrow \pi^{0} \pi^{0}$ decay. |
| $-0.39\pm0.16\pm0.03$ CHANG 07B BELL Repl. by HOI 12 | ² Measured in the $B^+ \rightarrow K^+ K^- K^+$ decay. |
| -0.20±0.15±0.01 AUBERT,B 05κ BABR Repl. by AUBERT 07AE | $A_{CP}(B^+ \to f_2(1270) K^+)$ |
| -0.49±0.31±0.07 CHANG 05A BELL Repl. by CHANG 07B -0.52±0.24±0.01 AUBERT 04H BABR Repl. by AUBERT,B 05κ | VALUE DOCUMENT ID TECH COMMENT |
| | -0.68 + 0.19 OUR AVERAGE |
| $A_{CP}(B^+ \to \eta K^*(892)^+)$ | |
| VALUE DOCUMENT ID TECN COMMENT 0.02±0.06 OUR AVERAGE | $-0.85\pm0.22^{+0.26}_{-0.13}$ AUBERT 08AI BABR $e^+e^- ightarrow \gamma(4S)$ |
| $0.03\pm0.10\pm0.01$ WANG 07B BELL $e^+e^- ightarrow \varUpsilon(4S)$ | $-0.59\pm0.22\pm0.036$ GARMASH 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $0.01\pm0.08\pm0.02$ AUBERT,B 06H BABR $e^+e^- ightarrow \Upsilon(4S)$ | $A_{CP}(B^+ \to f_0(1500) K^+)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $\mathcal{ACP}(D \rightarrow 0)$ (1300) \mathcal{K}) VALUE DOCUMENT ID TECN COMMENT |
| 0.13±0.14±0.02 AUBERT,B 04D BABR Repl. by AUBERT,B 06H | 0.28 \pm 0.26 \pm 0.15 AUBERT 08AI BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $A_{CP}(B^+ \to \eta K_0^*(1430)^+)$ | 0.20 <u>10.20</u> <u>0.14</u> |
| VALUE DO CUMENT ID TECN COMMENT | $A_{CP}(B^+ \rightarrow \rho^0 K^+)$ |
| 0.05 \pm 0.13 \pm 0.02 AUBERT,B 06H BABR $e^+ e^- ightarrow ~ \varUpsilon(4S)$ | VALUE DO CUMENT ID TECN COMMENT |
| A (P+ V*(1420)+) | 0.37±0.10 OUR AVERAGE |
| $A_{CP}(B^+ 	o \eta K_2^*(1430)^+)$ VALUE DOCUMENT ID TECN COMMENT | $0.44\pm0.10^{+0.06}_{-0.14}$ AUBERT 08AI BABR $e^+e^- ightarrow \gamma(4S)$ |
| VALUE DOCUMENT ID TECN COMMENT -0.45 ± 0.30 ± 0.02 AUBERT,B 06H BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $0.30\pm0.11^{+0.11}_{-0.04}$ GARMASH 06 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| | • • We do not use the following data for averages, fits, limits, etc. • • • |
| $A_{CP}(B^+ \to \omega K^+)$ | |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.02±0.05 OUR AVERAGE | $0.32\pm0.13^{+0.10}_{-0.08}$ AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| $-0.01 \pm 0.07 \pm 0.01$ AUBERT 07AE BABR $e^+e^- ightarrow \Upsilon(4S)$ | $A_{CP}(B^+ \to K_0^*(1430)^0 \pi^+)$ |
| $0.05 \pm 0.08 \pm 0.01$ JEN 06 BELL $e^+e^- \rightarrow \tau(45)$ | NALUE DOCUMENT ID TECH COMMENT $ACP(D \rightarrow V_0(1430), y_{1,1})$ |
| | 0.055 ± 0.033 OUR AVERAGE |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 0.05 ± 0.09 ± 0.01 AUBERT.B 06E BABR Repl. by AUBERT 07AE | $0.032\pm0.035 {+0.034 \atop -0.028}$ AUBERT 08AI BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| 0.05 ± 0.09 ± 0.01 AUBERT,B 06E BABR Repl. by AUBERT 07AE -0.09 ± 0.17 ± 0.01 AUBERT 04H BABR Repl. by AUBERT,B 06E | . 0.029 |
| | |
| 0.06 + 0.21 + 0.01 | • • • We do not use the following data for averages, fits, limits, etc. |
| 0.06 + 0.21 ± 0.01 | 0.000 |
| $-0.21\pm0.28\pm0.03$ ² LU 02 BELL Repl. by WANG 04A | -0.064±0.032 ^{+0.023} -0.026 AUBERT,B 05N BABR Repl. by AUBERT 08AI |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04a 1 Corresponds to 90% CL interval 0.15 < A_{CP} <0.90 | |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04A 1 Corresponds to 90% CL interval 0.15 < $A_{CP}<0.90$ 2 Corresponds to 90% confidence range -0.70 < $A_{CP}<+0.38$. | $A_{CP}(B^+ \to K_2^*(1430)^0 \pi^+)$ |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04A 1 Corresponds to 90% CL interval $0.15 < A_{CP} < 0.90$ 2 Corresponds to 90% confidence range $-0.70 < A_{CP} < +0.38$. $A_{CP}(B^+ \to \omega K^{*+})$ | $A_{CP}(B^+ 	o K_2^*(1430)^0\pi^+)$ NALUE DOCUMENT ID TECN COMMENT |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04A 1 Corresponds to 90% CL interval $0.15 < A_{CP} < 0.90$ 2 Corresponds to 90% confidence range $-0.70 < A_{CP} < +0.38$. Acp (B ⁺ $\rightarrow \omega K^{*+}$) | $A_{CP}(B^+ \to K_2^*(1430)^0 \pi^+)$ |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04A 1 Corresponds to 90% CL interval $0.15 < A_{CP} < 0.90$ 2 Corresponds to 90% confidence range $-0.70 < A_{CP} < +0.38$. $A_{CP}(B^+ \to \omega K^{*+})$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $-0.21\pm0.28\pm0.03$ 2 LU 02 BELL Repl. by WANG 04A 1 Corresponds to 90% CL interval $0.15 < A_{CP} < 0.90$ 2 Corresponds to 90% confidence range $-0.70 < A_{CP} < +0.38$. $A_{CP}(B^+ \rightarrow \omega K^{*+})$ VALUE $D_{CP}(B^+ \rightarrow \omega K^{*+})$ AUBERT 09H BABR $e^+e^- \rightarrow \Upsilon(4S)$ $A_{CP}(B^+ \rightarrow \omega (K\pi)_0^{*+})$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

 B^{\pm}

| $A_{CP}(B^+ \rightarrow K^{*+}\pi^+\pi^-)$ | $A_{CP}(B^+ \to \phi K^*(892)^+)$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE DOCUMENT ID TECN COMMENT 0.07 \pm 0.07 \pm 0.04 AUBERT.B 0.00 BABR $e^+e^- ightarrow aisebox{9}{γ}(4S)$ | VALUE DOCUMENT ID TECN COMMENT -0.01 ± 0.08 OUR AVERAGE |
| $A_{CP}(B^+ 	o ho^0 K^*(892)^+)$ VALUE DOCUMENT ID TECN COMMENT | $0.00\pm0.09\pm0.04$ AUBERT 07BA BABR $e^+e^- 	o 	au(45)$ $-0.02\pm0.14\pm0.03$ 1 CHEN 05A BELL $e^+e^- 	o 	au(45)$ |
| 0.31 \pm 0.03 DEL-AMO-SA11D BABR $e^+e^- \rightarrow \Upsilon(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • • 0.16±0.17±0.03 AUBERT 03v BABR Repl. by AUBERT 07v |
| • • We do not use the following data for averages, fits, limits, etc. • • • | -0.13±0.29 ^{+0.08} _{-0.11} 2 CHEN 03B BELL Repl. by CHEN 05A |
| $0.20^{+0.32}_{-0.29}\pm0.04$ AUBERT 03V BABR Repl. by DEL-AMO-SANCHEZ 11D | $-0.43^{+0.36}_{-0.30}\pm0.06$ 3 AUBERT 02E BABR Repl. by AUBERT 03 |
| $A_{CP}(B^+ \to K^*(892)^+ f_0(980))$ VALUE DOCUMENT ID TECN COMMENT | 1 Corresponds to 90% confidence range -0.25 $<\!A_{CP}<0.22$. 2 Corresponds to 90% confidence range -0.64 $<\!A_{CP}<0.36$. |
| -0.15 ± 0.12 ± 0.03 DEL-A MO-SA11D BABR $e^+e^- \rightarrow \mathcal{T}(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | 3 Corresponds to 90% confidence range -0.88 <a <math="">_{CP} < 0.18. |
| -0.34 ± 0.21 ± 0.03 AUBERT,B 06G BABR Repl. by DEL-AMO-SANCHEZ 11D | $A_{CP}(B^+ \to \phi(K\pi)_0^{*+})$ |
| $A_{CP}(B^+ 	o a_1^+ K^0)$ | VALUE DOCUMENT ID TECN COMMENT 0.04±0.15±0.04 AUBERT 08BI BABR e^+e^- → $\Upsilon(4S)$ |
| | · / |
| +0.12±0.11±0.02 AUBERT 08F BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $A_{CP}(B^+	o\phi K_1(1270)^+)$ VALUE DOCUMENT ID TECN COMMENT |
| $A_{CP}(B^+ \to b_1^+ K^0)$ | $0.15 \pm 0.19 \pm 0.05$ AUBERT 08BI BABR $e^+e^- ightarrow \varUpsilon (4.5)$ |
| VALUEDO CUMENT IDTECNCOMMENT $-0.03 \pm 0.15 \pm 0.02$ AUBERT08AG BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $A_{CP}(B^+	o\phi K_2^*(1430)^+)$ VALUE DOCUMENT ID TECK COMMENT |
| $A_{CP}(B^+ \to K^*(892)^0 \rho^+)$ | -0.23 \pm 0.19 \pm 0.06 AUBERT 08BI BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $A_{CP}(B^+ \to K^+ \phi \phi)$ |
| -0.01 \pm 0.16 \pm 0.02 AUBERT,B 06G BABR $e^+e^- ightarrow \varUpsilon(4S)$ | VALUE DOCUMENT ID TECN COMMENT |
| $A_{CP}(\mathcal{B}^+	o b_1^0K^+)$ VALUE DOCUMENT ID TECN COMMENT | -0.10±0.08±0.02 |
| -0.46 \pm 0.20 \pm 0.02 AUBERT 07BI BABR $e^+e^- \rightarrow r(4S)$ | |
| $A_{CP}(B^+ \to K^0 K^+)$ | $A_{CP}(B^+	o K^+[\phi\phi]_{\eta_c})$ VALUE DOCUMENT ID TECH COMMENT |
| VALUE <u>DOCUMENT ID TECN COMMENT</u> 0.12±0.18 OUR AVERAGE | $1 = \frac{1}{1}$ LEES 11A BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.13 + 0.23 \pm 0.02$ LIN 07 BELL $e^+e^- ightarrow \varUpsilon(45)$ | $^{1}m_{\phi\phi}$ is consistent with $\eta_{ m C}$ mass [2.94, 3.02] GeV/c 2 . |
| $0.10\pm0.26\pm0.03$ 1 AUBERT,BE 06c BABR $e^{+}e^{-} ightarrow~\varUpsilon(4S)$ | $A_{CP}(B^+ 	o K^*(892)^+ \gamma)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 0.15 ± 0.33 ± 0.03 AUBERT, BE 05E BABR Repl. by | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> +0.018±0.028±0.007 AUBERT 09A0 BABR e^+e^- → $T(4.5)$ |
| AUBERT,BE 06c | |
| 1 Corresponds to 90% confidence range $-0.31 < A_{CP} < 0.54$. 2 Corresponds to 90% confidence range $-0.43 < A_{CP} < 0.68$. | $A_{CP}(B^+	o\eta K^+\gamma)$ VALUE DOCUMENT ID TECK COMMENT |
| $A_{CP}(B^+ \to K^+ K_S^0 K_S^0)$ | -0.12\pm0.07 OUR AVERAGE $-0.09\pm0.10\pm0.01$ 1 AUBERT 09 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| VALUE <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $-0.16\pm0.09\pm0.06$ Addition of Balk $e^+e^- \rightarrow \Upsilon(45)$ $-0.16\pm0.09\pm0.06$ 2 NISHIDA 05 BELL $e^+e^- \rightarrow \Upsilon(45)$ |
| -0.04 \pm 0.11 \pm 0.02 1 AUBERT,B 04V BABR $e^+e^- \rightarrow \Upsilon(4S)$ | • • We do not use the following data for averages, fits, limits, etc. • • |
| 1 Corresponds to 90% confidence range $-0.23~<~A_{CP}~<0.15$. | $-0.09\pm0.12\pm0.01$ 1 AUBERT,B 06M BABR Repl. by AUBERT 0 1 m_{\etaK} < 3.25 GeV/c 2 . |
| $A_{CP}(B^+ \to K^+ K^- \pi^+)$ | $\frac{m_{\eta K}}{2m_{\eta K}} < 2.4 \text{ GeV/c}^2$ |
| VALUE DOCUMENT ID TECN COMMENT 0.00±0.10±0.03 AUBERT 07BB BABR $e^+e^- 	o 	au(4S)$ | $A_{CP}(B^+ 	o \phi K^+ \gamma)$ |
| $A_{CP}(B^+ \to K^+ K^- K^+)$ | VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| VALUE DOCUMENT ID TECN COMMENT | -0.13\pm0.11 OUR AVERAGE Error includes scale factor of 1.1. -0.03 \pm 0.11 \pm 0.08 SAHOO 11A BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| -0.017±0.026±0.015 AUBERT 060 BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | $-0.26\pm0.14\pm0.05$ AUBERT 07Q BABR $e^+e^- ightarrow \gamma(4S)$ |
| 0.02 ±0.07 ±0.03 AUBERT 03M BABR Repl. by AUBERT 060 | $A_{CP}(B^+ \to \rho^+ \gamma)$ |
| $A_{CP}(B^+ \to \phi K^+)$ | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> $-0.11 \pm 0.32 \pm 0.09$ TANIGUCHI 08 BELL e^+e^- → $\Upsilon(4S)$ |
| VALUE | $A_{CP}(B^+ 	o \pi^+ \pi^0)$ |
| $0.00\pm0.08\pm0.02$ AUBERT 060 BABR $e^+e^- ightarrow$ $\varUpsilon(4S)$ | VALUE |
| $-0.07 \pm 0.17 + 0.03 - 0.02$ ACOSTA 05J CDF $p\overline{p}$ at 1.96 TeV | 0.06 \pm 0.05 OUR AVERAGE $0.07\pm0.06\pm0.01$ LIN 08 BELL $e^+e^- ightarrow \gamma(4S)$ |
| | $0.03\pm0.08\pm0.01$ AUBERT 07BC BABR $e^+e^- ightarrow \gamma(4S)$ |
| $0.01\pm0.12\pm0.05$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 0.04±0.09±0.01 | • • • We do not use the following data for averages, fits, limits, etc. • • • -0.01 ± 0.10 ± 0.02 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04 \pm 0.09 \pm 0.01 \qquad \qquad ^2 \text{ AUBERT} \qquad 04\text{A} \text{BABR} \text{Repl. by AUBERT 06o} \\ -0.05 \pm 0.20 \pm 0.03 \qquad \qquad ^3 \text{ AUBERT} \qquad 02\text{E} \text{BABR} e^+e^- \rightarrow \varUpsilon(4S)$ $^1 \text{ Corresponds to 90\% confidence range} -0.20 < A_{CP} < 0.22.$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04 \pm 0.09 \pm 0.01 \qquad \qquad 2 \qquad \text{AUBERT} \qquad 04 \text{A} \qquad \text{BABR} \qquad \text{Repl. by AUBERT 06o} \\ -0.05 \pm 0.20 \pm 0.03 \qquad \qquad 3 \qquad \text{AUBERT} \qquad 02 \text{E} \qquad \text{BABR} \qquad e^+ e^- \rightarrow \qquad \varUpsilon(4S)$ $\frac{1}{2} \text{ Corresponds to 90\% confidence range} \qquad -0.20 < A_{CP} < 0.22.$ $\frac{2}{2} \text{ Corresponds to 90\% confidence range} \qquad -0.10 < A_{CP} < 0.18.$ | $-0.01\pm0.10\pm0.02$ 1 AUBERT 05L BABR Repl. by AUBERT 07B 0.00 $\pm0.10\pm0.02$ 2 CHAO 05A BELL Repl. by CHAO 04B |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04 \pm 0.09 \pm 0.01 \qquad \qquad 2 \qquad \text{AUBERT} \qquad 04 \text{A} \qquad \text{BABR} \qquad \text{Repl. by AUBERT 06o} \\ -0.05 \pm 0.20 \pm 0.03 \qquad \qquad 3 \qquad \text{AUBERT} \qquad 02 \text{E} \qquad \text{BABR} \qquad e^+ e^- \rightarrow \mathcal{T}(4S) \\ 1 \qquad \text{Corresponds to 90\% confidence range} \qquad -0.20 < A_{CP} < 0.22. \\ 2 \qquad \text{Corresponds to 90\% confidence range} \qquad -0.10 < A_{CP} < 0.18. \\ 3 \qquad \text{Corresponds to 90\% confidence range} \qquad -0.37 < A_{CP} < 0.28. \\ \end{cases}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04\pm0.09\pm0.01 \qquad 2 \text{ AUBERT} \qquad 04\text{A} \text{BABR} \text{Repl. by AUBERT 06o} \\ -0.05\pm0.20\pm0.03 \qquad 3 \text{ AUBERT} \qquad 02\text{E} \text{BABR} e^+e^- \rightarrow r(4S) \\ \frac{1}{2} \text{ Corresponds to 90\% confidence range} -0.20 < A_{CP} < 0.22. \\ \frac{2}{2} \text{ Corresponds to 90\% confidence range} -0.10 < A_{CP} < 0.18. \\ \frac{3}{2} \text{ Corresponds to 90\% confidence range} -0.37 < A_{CP} < 0.28. \\ A_{CP}(B^+ \rightarrow X_0(1550)K^+)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04 \pm 0.09 \pm 0.01 \qquad 2 \text{ AUBERT} \qquad 04\text{A} \text{BABR} \text{Repl. by AUBERT} 06\text{O} \\ -0.05 \pm 0.20 \pm 0.03 \qquad 3 \text{AUBERT} \qquad 02\text{E} \text{BABR} e^+ e^- \rightarrow \tau (4S) \\ 1 \text{Corresponds to 90\% confidence range} -0.20 < A_{CP} < 0.22. \\ 2 \text{Corresponds to 90\% confidence range} -0.10 < A_{CP} < 0.18. \\ 3 \text{Corresponds to 90\% confidence range} -0.37 < A_{CP} < 0.28. \\ A_{CP}(B^+ \rightarrow X_0(1550)K^+) \\ VALUE \qquad DOCUMENT ID \qquad TECN \qquad COMMENT \\ -0.04 \pm 0.07 \pm 0.02 \qquad 1 \text{AUBERT} \qquad 06\text{O} \text{BABR} e^+ e^- \rightarrow \tau (4S)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.04 \pm 0.09 \pm 0.01 \qquad 2 \text{ AUBERT} \qquad 04\text{A} \text{BABR} \text{Repl. by AUBERT 06o} \\ -0.05 \pm 0.20 \pm 0.03 \qquad 3 \text{ AUBERT} \qquad 02\text{E} \text{BABR} \qquad e^+e^- \rightarrow r(4S) \\ 1 \text{ Corresponds to 90% confidence range} -0.20 < A_{CP} < 0.22. \\ 2 \text{ Corresponds to 90% confidence range} -0.10 < A_{CP} < 0.18. \\ 3 \text{ Corresponds to 90% confidence range} -0.37 < A_{CP} < 0.28. \\ A_{CP}(B^+ \rightarrow X_0(1550)K^+) \\ \frac{DOCUMENT \ ID}{1 \text{ AUBERT}} \qquad \frac{TECN}{060 \ \text{BABR}} \qquad \frac{COMMENT}{e^+e^- \rightarrow r(4S)} \\ 1 \text{ Measured in the } B^+ \rightarrow K^+K^-K^+ \text{ decay.}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • $0.04\pm0.09\pm0.01 \qquad \qquad 2 \text{ AUBERT} \qquad 04\text{A} \qquad \text{BABR} \qquad \text{Repl. by AUBERT} \qquad 06\text{O} \\ -0.05\pm0.20\pm0.03 \qquad \qquad 3 \text{ AUBERT} \qquad 02\text{E} \qquad \text{BABR} \qquad e^+e^- \rightarrow \gamma(4S) \\ \text{1 Corresponds to 90\% confidence range} -0.20 < A_{CP} < 0.22. \\ \text{2 Corresponds to 90\% confidence range} -0.10 < A_{CP} < 0.18. \\ \text{3 Corresponds to 90\% confidence range} -0.37 < A_{CP} < 0.28. \\ \text{4 ACP}(B^+ \rightarrow X_0(1550)K^+)$ $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

| $h_{CP}(B^+	o\pi^+\pi^-\pi^+)$ alue document id tech com | $A_{CP}(B^+	o\eta\pi^+)$ iment odd the decomposition of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment of the second comment in the second comment is a second comment in the second comment in the second comment is a second comment in the second comment in the second comment is a second comment in the second comment in the second comment is a second comment in the second comment in the second comment is a second comment in the second comment in the second comment is a second comment in the second comment |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $0.032 \pm 0.044 \stackrel{+}{-} 0.040$ AUBERT 09L BABR $e^+ \epsilon$ | -0.14±0.07 OUR AVERAGE Error includes scale factor of 1.4. |
| | $-0.19\pm0.06\pm0.01$ HOI 12 BELL $e^+e^- \rightarrow T(4S)$ |
| • • We do not use the following data for averages, fits, limits, etc. | |
| | 1. by AUBERT 09L • • • We do not use the following data for averages, fits, limits, etc. • • • 1. by AUBERT 05G -0.08+0.10+0.01 AUBERT 07∆F BARR Bend by AUBERT 09∆V |
| <u>.</u> | 1. by AUBERT 05G -0.08±0.10±0.01 AUBERT 07AE BABR Repl. by AUBERT 09AV -0.23±0.09±0.02 CHANG 07B BELL Repl. by HOI 12 |
| $c_P(B^+ 	o ho^0 \pi^+)$ | -0.13±0.12±0.01 AUBERT,B 05K BABR Repl. by AUBERT 07AE |
| <u>DOCUMENT ID TECN COMMEN</u> | 1T 0.07 ± 0.15 ± 0.03 CHANG 05A BELL Repl. by CHANG 07B |
| .18 $\pm 0.07 ^{+0.05}_{-0.15}$ AUBERT 09L BABR $e^+ e^-$ - | $	o$ $	au(4S)$ — 0.44 \pm 0.18 \pm 0.01 AUBERT 04H BABR Repl. by AUBERT,B 05K |
| We do not use the following data for averages, fits, limits, etc. | $A_{CP}(B^+ 	o \eta ho^+)$ |
| $0.074 \pm 0.120 ^{+0.035}_{-0.055}$ AUBERT,B 05G BABR Repl. by | TEN COMMENT |
| | 0.11 ± 0.11 OUR AVERAGE |
| .19 \pm 0.11 \pm 0.02 AUBERT 04z BABR Repl. by | 0.13±0.11±0.02 AOBERT COATIBABLE C → T (45) |
| $c_{P}(B^{+} \rightarrow f_{2}(1270)\pi^{+})$ | $-0.04 {+ 0.34 \pm 0.01} \pm 0.01$ WANG 07B BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| <u>DO CUMENT ID TECN COM</u> | |
| .41 $\pm 0.25 ^{+0.18}_{-0.15}$ AUBERT 09L BABR $e^+ \epsilon$ | $e^- ightarrow \gamma(4S)$ 0.02 \pm 0.18 \pm 0.02 AUBERT,B 05 κ BABR Repl. by AUBERT 08AF |
| • We do not use the following data for averages, fits, limits, etc. • | |
| 0 0 | $A_{CP}(B^+ \rightarrow \eta \pi^+)$ |
| $0.004 \pm 0.247 + 0.028 \atop -0.032$ AUBERT,B 05G BABR Repl | I. by AUBERT 09L VALUE DOCUMENT ID TECN COMMENT |
| ····- | 0.06±0.16 OUR AVERAGE |
| $_{CP}(B^+ \to \rho^0(1450)\pi^+)$ | $0.03\pm0.17\pm0.02$ AUBERT 09AV BABR $e^+e^- ightarrow \Upsilon(4S)$ |
| <u>DOCUMENT ID</u> <u>TECN</u> <u>COM</u> | MENT 0.20 $^{+0.37}_{-0.36}\pm$ 0.04 SCHUEMANN 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $0.06 \pm 0.28 ^{+0.23}_{-0.40}$ AUBERT 09L BABR $e^{+} \epsilon$ | |
| | $0.21\pm0.17\pm0.01$ AUBERT 07AE BABR Repl. by AUBERT 09AV |
| $_{CP}(B^+ \to f_0(1370)\pi^+)$ | $0.14\pm0.16\pm0.01$ AUBERT,B 05K BABR Repl. by AUBERT 07A |
| UE <u>DO CUMENT ID</u> <u>TECN</u> <u>COM</u> | $\frac{MENT}{m(AC)} \qquad \qquad A_{CP}(B^+ \to \eta' \rho^+)$ |
| 2±0.15±0.16 AUBERT 09L BABR e+ e | $e^- 	o 	au(4S)$ $ACP(B' 	o 	extbf{\eta} 	heta')$ |
| (P+ , -++ nonresonant) | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $_{CP}(B^+	o\pi^+\pi^-\pi^+ 	ext{ nonresonant})$ | $\bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc. } \bullet \bullet \bullet$ |
| | 1445557 - 07- 0455 0 1 1 551 440 |
| $.14\pm0.14^{+0.18}_{-0.08}$ AUBERT 09L BABR e^{+} ϵ | $e^- ightarrow ~ \gamma(4S)$ SANCHEZ 10A |
| 4-1 10 | $^{ m 1}$ Reports A_{CP} with the opposite sign convention. |
| $\nu_P(B^+ \to \rho^+ \pi^0)$ | |
| <u>DOCUMENT ID</u> <u>TECN</u> <u>COM</u> 1.02±0.11 OUR AVERAGE | $A_{CP}(B^+	o b_1^0\pi^+)$ |
| .02 \pm 0.11 OUR AVERAGE .01 \pm 0.13 \pm 0.02 AUBERT 07x BABR $e^+\epsilon$ | γ_{AUE} DOCUMENT ID TECN COMMENT |
| | +0.03±0.10±0.02 AUBERT UTBI BABR e e → 7(43) |
| $.06\pm0.17^{+0.04}_{-0.05}$ ZHA NG 05A BELL $e^+\epsilon$ | $e^- \to \Upsilon(4S)$ $A_{CP}(B^+ \to \rho \overline{\rho} \pi^+)$ |
| We do not use the following data for averages, fits, limits, etc. | VALUE DOCUMENT ID TECH COMMENT |
| 0.24 ± 0.16 ± 0.06 AUBERT 04z BABR Repl | I. by AUBERT 07X 0.00±0.04 OUR AVERAGE |
| $_{CP}(B^+ \to \rho^+ \rho^0)$ | $-0.02\pm0.05\pm0.02$ 1 WEI 08 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| $c_{\mathcal{P}}(\mathcal{B}^{	op} 	op ho^{	op})$.ue <u>DOCUMENT ID</u> TECN_COMMENT | $+0.04\pm0.07\pm0.04$ AUBERT 07AV BABR $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| 0.05 ±0.05 OUR AVERAGE | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $.054\pm0.055\pm0.010$ AUBERT 09G BABR $e^+e^- ightarrow$ | au(4S) |
| .00 \pm 0.22 \pm 0.03 ZHANG 03B BELL $e^+e^- \rightarrow$ | |
| • We do not use the following data for averages, fits, limits, etc. | • • • |
| .12 \pm 0.13 \pm 0.10 AUBERT,BE 06G BABR Repl. by A | Λ (D+ . n \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ |
| .19 ±0.23 ±0.03 AUBERT 03v BABR Repl. by A | AUBERT,BE 06G <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN COMMENT</u> |
| (D+ +) | -0.16±0.07 OUR AVERAGE |
| $p_P(B^+ \to \omega \pi^+)$ | $-0.17\pm0.10\pm0.02$ 1 WEI 08 BELL $e^+e^- ightarrow r(4S)$ |
| UE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> .04 ± 0.06 OUR AVERAGE | $-0.16 {}^{+0.07}_{-0.08} \pm 0.04$ 1 AUBERT,B 05L BABR $\mathrm{e^+e^-} ightarrow ~ \varUpsilon(4S)$ |
| $02\pm0.08\pm0.01$ AUBERT 07AE BABR $e^+e^- ightarrow$ | • • We do not use the following data for averages fits limits etc. • • • |
| $02\pm0.00\pm0.01$ AGBERT 07AE BABR e $^{+}$ e $^{-}$ \rightarrow $02\pm0.09\pm0.01$ JEN 06 BELL e^{+} e^{-} \rightarrow | |
| 34 ± 0.25 1 CHEN 00 CLE2 $e^+e^- \rightarrow$ | (45) |
| We do not use the following data for averages, fits, limits, etc. | • • • |
| $.01\pm0.10\pm0.01$ AUBERT,B 06E BABR Repl. by A | 4 (pt = (**(a.a.) t) |
| $.03\pm0.16\pm0.01$ AUBERT 04H BABR Repl. by A | AUBERT,B 06E <u>VALUE</u> <u>DOCUMENT ID TECN COMMENT</u> |
| $.50^{+0.23}_{-0.20} \pm 0.02$ WANG 04A BELL Repl. by J | IFN 0.6 0.21 ± 0.16 OUR AVERAGE Error includes scale factor of 1.4. |
| | $-0.01\pm0.19\pm0.02$ CHEN 08C BELL $e \mid e \rightarrow T(45)$ |
| $.01 + 0.29 \pm 0.03$ 3 AUBERT 02E BABR Repl. by A | AUBERT 04H $+0.32\pm0.13\pm0.05$ AUBERT 07AV BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| Corresponds to 90% confidence range $-0.75 < A_{CP} < 0.07$. | $A_{CP}(B^+ 	o p \overline{\Lambda} \gamma)$ |
| Corresponds to 90% CL interval -0.25< A_{CP} <0.41 | VALUE DOCUMENT ID TECH COMMENT |
| Corresponds to 90% confidence range $-0.50 < A_{CP} < 0.46$. | +0.17±0.16±0.05 WANG 07C BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| , , | <u>.</u> |
| $P(B^+ \to \omega \rho^+)$ | $A_{CP}(B^+	o p \overline{\Lambda}\pi^0)$ |
| r (| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| | 7/4C\ .00110471004 |
| <u>UE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> .20±0.09±0.02 AUBERT 09H BABR e^+e^- → | • = = |
| <u>UE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> .20±0.09±0.02 AUBERT 09H BABR e^+e^- → | • • • |
| <u>UE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> . 20±0.09±0.02 AUBERT 09H BABR $e^+e^- \rightarrow$ • We do not use the following data for averages, fits, limits, etc. • .04±0.18±0.02 AUBERT,B 06T BABR Repl. by A | AUBERT 09H $A_{CP}(B^+ 	o K^+ \ell^+ \ell^-)$ |
| <u>UE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> . 20 ± 0.09 ± 0.02 AUBERT 09H BABR $e^+e^- \rightarrow e^-$ • We do not use the following data for averages, fits, limits, etc. • 0.04 ± 0.18 ± 0.02 AUBERT, B 06T BABR Repl. by A | AUBERT 09H $A_{CP}(B^+	o K^+\ell^+\ell^-)$ AUBERT.B 06T $VALUE$ DOCUMENT ID TECH COMMENT |
| <u>UE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> . 20±0.09±0.02 AUBERT 09H BABR $e^+e^- \rightarrow$ • We do not use the following data for averages, fits, limits, etc. • .04±0.18±0.02 AUBERT,B 06T BABR Repl. by A | AUBERT 09H $A_{CP}(B^+ \to K^+ \ell^-)$ AUBERT, B 06T $VALUE - 0.01 \pm 0.09$ OUR AVERAGE Error includes scale factor of 1.1. |
| .20±0.09±0.02 AUBERT 09H BABR $e^+e^- \rightarrow$ • We do not use the following data for averages, fits, limits, etc. • .04±0.18±0.02 AUBERT,B 06T BABR Repl. by A | AUBERT 09H AUBERT, B 06T $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 1.00 ± 0.09 ± 0.02 AUBERT 09H BABR e^+e^- → We do not use the following data for averages, fits, limits, etc. • 0.04 ± 0.18 ± 0.02 AUBERT, B 06T BABR Repl. by A | AUBERT 09H $A_{CP}(B^+ \to K^+ \ell^-)$ AUBERT, B 06T $VALUE - 0.01 \pm 0.09$ OUR AVERAGE Error includes scale factor of 1.1. |

| $A_{CP}(B^+ \rightarrow K^+ e^+ e^-)$ | | $B(B^+ \to K^{*+}\ell^+\ell^-)$ (10) | $09 < q^2 < 12.86 \text{ GeV}^2/c^2$ | |
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| ALUE | DOCUMENT ID TECN COMMENT | $\frac{VALUE \text{ (units } 10^{-7}\text{)}}{\text{(units } 10^{-7}\text{)}}$ | DOCUMENT ID TECN | COMMENT |
| 0.14±0.14±0.03 | WEI 09A BELL $e^+e^- ightarrow \varUpsilon(4S)$ | $1.97 \pm 0.99 \pm 0.22$ | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| $_{CP}(B^+	o K^+\mu^+\mu^-)$ | DOCUMENT ID TECN COMMENT | $B(B^+ \to K^{*+} \ell^+ \ell^-)$ (14. | | |
| 0.05 ± 0.13 ± 0.03 | WEI 09A BELL $e^+e^- ightarrow angle \gamma(4S)$ | <u>VALUE</u> (units 10 ⁻⁷) 0.52±0.61±0.09 | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| $_{CP}(B^+ \rightarrow K^{*+}\ell^+\ell^-)$ | | $B(B^+ \to K^{*+} \ell^+ \ell^-)$ (16. | | pp at 1.50 TeV |
| <u>LUE</u> 0.09±0.14 OUR AVERAGE | DOCUMENT ID TECN COMMENT | $B(B' \rightarrow K^+ \ell' \ell' \ell')$ (16. VALUE (units 10^{-7}) | U < q- GeV-/C-) DOCUMENT ID TECN | COMMENT |
| 0.01 + 0.26 ± 0.02 | AUBERT 09T BABR $e^+e^- ightarrow \varUpsilon(4S)$ | 1.57±0.96±0.17 | AALTONEN 11AI CDF | p p at 1.96 TeV |
| $0.13 + 0.17 \pm 0.01$ $0.13 + 0.17 \pm 0.01$ | WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $B(B^+ \to K^{*+} \ell^+ \ell^-)$ (1.0 | $< q^2 < 6.0 \text{ GeV}^2/c^2$ | |
| | ng data for averages, fits, limits, etc. • • • | VALUE (units 10 ⁻⁷) | DO CUMENT ID TECN | COMMENT |
| $0.03 \pm 0.23 \pm 0.03$ | AUBERT,B 06J BABR Repl. by AUBERT 09T | $2.57 \pm 1.61 \pm 0.40$ | AALTONEN 11ai CDF | $p\overline{p}$ at 1.96 TeV |
| $_{CP}(B^+ \rightarrow K^*e^+e^-)$ | | $B(B^+ \to K^{*+}\ell^+\ell^-)$ (0.0) | | |
| LUE | DOCUMENT ID TECN COMMENT | <u>VALUE</u> (units 10 ⁻⁷) 2.01±1.39±0.27 | AALTONEN 11AI CDF | P at 1.96 TeV |
| $0.14^{+0.23}_{-0.22}\pm0.02$ | WEI 09A BELL $e^+ e^- ightarrow \varUpsilon(4S)$ | | | pp at 1.50 let |
| $_{CP}(B^+ \rightarrow K^* \mu^+ \mu^-)$ | | $B(B^+ \to K^+ \ell^+ \ell^-) (q^2 < VALUE (units 10^{-7})$ | DOCUMENT ID TECN | COMMENT |
| LUE | DOCUMENT ID TECN COMMENT | 0.36±0.11±0.03 | AALTONEN 11AI CDF | p p at 1.96 TeV |
| 0.12±0.24±0.02 | WEI 09A BELL $e^+e^- ightarrow \varUpsilon(4S)$ | $B(B^+ \to K^+ \ell^+ \ell^-) (2.0$ | $< q^2 < 4.3 \text{ GeV}^2/c^2$ | |
| $(B^+ \to D^{(*)}K^{(*)+})$ For angle $a(A_7)$ of the CK | (M unitarity triangle, see the review on "CP Violation" in | VALUE (units 10 ⁻⁷) | DO CUMENT ID TECN | COMMENT |
| the Reviews section. | | $0.80 \pm 0.15 \pm 0.05$ | AALTONEN 11ai CDF | p₱ at 1.96 TeV |
| ±10 OUR AVERAGE | OCUMENT ID TECN COMMENT | $B(B^+ \to K^+ \ell^+ \ell^-)$ (4.3) | | |
| | EL-AMO-SA10F BABR $e^+e^- ightarrow \varUpsilon(4S)$ | <u>VALUE (units 10⁻⁷)</u> 1.18±0.19±0.09 | DOCUMENT ID TECN AALTONEN 11AI CDF | COMMENT p p at 1.96 TeV |
| -11.0 | DLUEKTOV 10 BELL $e^+e^- 	o 	au(4S)$ | • | | ρραι 1.30 ΙΕΝ |
| | ng data for averages, fits, limits, etc. $ullet$ $ulle$ | $B(B^{+} \to K^{+} \ell^{+} \ell^{-}) (10.0)$ WALUE (units 10 ⁻⁷) | 19 < q ² < 12.86 GeV ² /c ²) DOCUMENT ID TECN | COMMENT |
| . 00 | JBERT 08AL BABR Repl. by DEL-AMO- | 0.68±0.12±0.05 | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| . 15 | SANCHEZ 10F DLUEKTOV 06 BELL Repl. by POLUEKTOV 10 | $B(B^+ \to K^+ \ell^+ \ell^-)$ (14.1 | $8 < q^2 < 16.0 \text{ GeV}^2/c^2$ | |
| == | | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| - 15 | • • | $0.53 \pm 0.10 \pm 0.03$ | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| -19 | DLUEKTOV 04 BELL Repl. by POLUEKTOV 06 | $B(B^+ \to K^+ \ell^+ \ell^-)$ (16.0 | | |
| | $^{1}\overline{D}{}^{0} \rightarrow K_{S}^{0}\pi^{+}\pi^{-}, K_{S}^{0}K^{+}K^{-}$ decays from $B^{+} \rightarrow K_{S}^{0}\pi^{+}\pi^{-}$ decays from $B^{+} \rightarrow K_{S}^{0}\pi^{+}\pi^{-}$ | $\frac{VALUE \text{ (units } 10^{-7})}{\textbf{0.48} \pm \textbf{0.11} \pm \textbf{0.03}}$ | DOCUMENT ID TECN AALTONEN 11AI CDF | COMMENT |
| $39^{\circ} < \gamma < 98^{\circ}$. CP conserva | the corresponding two standard deviation interval for γ is standard network that is the combined result is ruled out with a significance | | | p p at 1.96 TeV |
| of 3.5 standard deviations. ² Uses Dalitz plot analysis of \overline{L} | $\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ decays from $B^+ \to D^{(*)} K^+$ modes. | $B(B^+ \to K^+ \ell^+ \ell^-) (1.0)$ WALUE (units 10^{-7}) | < q ² < 6.0 GeV ² /c ²) DOCUMENT ID TECN | COMMENT |
| The corresponding two stone | lard deviation interval for γ is 54.2 $^\circ$ $< \gamma <$ 100.5 $^\circ$. CP | 1.41±0.20±0.10 | AALTONEN 11AI CDF | p p at 1.96 TeV |
| conservation in the combine | d result is ruled out with a significance of 3.5 standard | | | |
| conservation in the combined | d result is ruled out with a significance of 3.5 standard | | $< a^2 < 4.3 \text{ GeV}^2/c^2$ | |
| conservation in the combined deviations. Reports confidence intervals for parameters using $B^\pm \to D F$ | d result is ruled out with a significance of 3.5 standard for the CKM angle γ from the measured values of the GLW K^{\pm} decays with D mesons decaying to non- $CP(K\pi)$, CP - | $B(B^+ \to K^+ \ell^+ \ell^-) (0.0)$ WALUE (units 10^{-7}) | < q ² < 4.3 GeV ² /c ²) <u>DOCUMENT ID TECN</u> | COMMENT |
| conservation in the combined deviations. Reports confidence intervals f parameters using $B^\pm \to D P P$ even $(K^+K^-,\pi^+\pi^-)$, and | d result is ruled out with a significance of 3.5 standard for the CKM angle γ from the measured values of the GLW K^{\pm} decays with D mesons decaying to non- $CP(K\pi)$, CP - CP -odd $(K_0^0, \pi^0, K_0^0, \omega)$ states. | $B(B^+ \to K^+ \ell^+ \ell^-)$ (0.0 | | <u>СОММЕΝТ</u> р |
| conservation in the combine deviations. Reports confidence intervals f parameters using $B^{\pm} \rightarrow D P$ even $(K^+ K^-, \pi^+ \pi^-)$, and 4 Uses Dalitz plot analysis of \overline{L} from $B^{\pm} \rightarrow D^{(*)} K^{(*)\pm}$ ms | d result is ruled out with a significance of 3.5 standard for the CKM angle γ from the measured values of the GLW K^{\pm} decays with D mesons decaying to non- $CP(K\pi)$, CP - CP -odd $(K_0^S\pi^0, K_0^S\omega)$ states. $T^0 \to K_0^S\pi^+\pi^-$ and $T^0 \to K_0^SK^+K^-$ decays coming | $B(B^+ \to K^+ \ell^+ \ell^-)$ (0.0 <u>VALUE</u> (units 10 ⁻⁷) | DOCUMENT ID TECN AALTONEN 11AI CDF | |
| conservation in the combine deviations. 3 Reports confidence intervals f parameters using $B^{\pm} \rightarrow D \ \theta$ even $(K^+ K^-, \pi^+ \pi^-)$, and 4 Uses Dalitz plot analysis of \overline{L} from $B^{\pm} \rightarrow D^{(*)} K^{(*)\pm}$ mc $(2^{9}) < \infty < 122^{9}$ | d result is ruled out with a significance of 3.5 standard for the CKM angle γ from the measured values of the GLW K^\pm decays with D mesons decaying to non- $CP(K\pi)$, CP - CP -odd $(K_S^0\pi^0, K_S^0\omega)$ states. $T_S^0 \to K_S^0\pi^+\pi^-$ and $T_S^0 \to K_S^0\pi^+\pi^-$ decays coming odes. The corresponding two standard deviation interval is | $B(B^+ \to K^+ \ell^+ \ell^-)$ (0.0 <u>VALUE</u> (units 10 ⁻⁷) | DOCUMENT ID TECN AALTONEN 11AI CDF B [±] REFERENCES | ρ p at 1.96 TeV |
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| Published In B Decays, 2nd Edition, World Scientific, Singapore | | 4 D | PRL 72 3456 | F. Abe et al. | (CDF Collab.) |
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| Published In B Decays, 2nd Edition, World Scientific, Singapore | | 4 D | PL B335 526 | H. Albrecht et al. | (ARGUS Collab.) |
| Published In B Decays, 2nd Edition, World Scientific, Singapore | | 4 | PRL 73 3503 | M. Athanas et al. | (CLEO Collab.) |
| Published In B Decays, 2nd Edition, World Scientific, Singapore | | | PRL 74 3090 (erratum) | M. Athanas et al. | (CLEO Collab.) |
| Published In B Decays, 2nd Edition, World Scientific, Singapore | | 4 | PR D50 11/3 | L. Montanet et al. | (CERN, LBL, BOST+) |
| ABREU 93D ZPHY C57 181 P. Abreu et al. (DELPHI Collab.) ABREU 936 P. B312 253 P. Abreu et al. (DELPHI Collab.) ACTON 936 P. B312 253 P. Abreu et al. (DELPHI Collab.) ACTON 936 P. B312 253 P. Abreu et al. (OPAL Collab.) ALBRECHT 93E ZPHY C50 11 H. Albrecht et al. (ARGUS Collab.) ALEXANDER 93B P. B319 365 J. Alexander et al. (CLEO Collab.) ABMAR 93 PRL 71 674 R. Ammar et al. (CLEO Collab.) BUSKULC 93D P. B307 194 A. Bean et al. (CLEO Collab.) Also P. B325 537 (erratum) D. Buskulic et al. (ALEPH Collab.) ASO P. B325 537 (erratum) D. Buskulic et al. (ALEPH Collab.) SANGHERA 93 PR D47 791 D. Buskulic et al. (ALEPH Collab.) ALBRECHT 92C P. B277 195 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 92C P. B277 195 H. Albrecht et al. (ARGUS Collab.) BORTOLETTO 92 PR D45 21 D. Bortoletto et al. (ARGUS Collab.) BORTOLETTO 92 PR D45 21 D. Bortoletto et al. (ALEPH Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ALEPH Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ARGUS Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ARGUS Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ARGUS Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ARGUS Collab.) ALBRECHT 91C PL B295 396 D. Buskulic et al. (ARGUS Collab.) BEKKELMAN 91 ARNPS 41 1 K. Berkelmet al. (ARGUS Collab.) BEKKELMAN 91 ARNPS 41 1 K. Berkelmen, S. Stone (CORN, SYRA) "Decays of B Messors" FULTON 91 PR D43 651 R. Fulton et al. (ARGUS Collab.) | | | | | |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | ADDELL 03 | SD R Di | ZDUV CEZ 101 | D. Abrou of al | (DELBIII Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 20 | ZFR1 C37 101 | P. Abreu et al. | (DELPHI Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 30 | PL D312 233 | P.D. Acton at al | (OPAL Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3.0 | 7DUV C60 11 | L Albrocht at al | (APGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3 D | DI D210 265 | I. Alexander et al. | (CLEO Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3 | DDI 71 674 | D. Ammar et al. | (CLEO Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3 R | PRI 70 2681 | A Rean et al. | CLEO Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3 D | PI R307 194 | D. Buskulic et al. | (ALEPH Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 30 | PL B307 134 PL B325 537 (erratum) | D. Buskulic et al. | (ALEPH Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 3 | PR D47 701 | S Sanghera et al | (CLEO Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | PI B275 195 | H Albrecht et al | (ARGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | PI B277 209 | H Albrecht et al | (ARGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | 7PHY C54 1 | H Albrecht et al | (ARGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | PR D45 21 | D. Bortoletto et al | (CLEO Collab |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | PL B295 396 | D. Buskulic et al. | (ALEPH Collab) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | | PL B254 288 | H. Albrecht et al. | (ARGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | | 1 C | PL B255 297 | H. Albrecht et al. | (ARGUS Collab.) |
| FULLION 91 PR D43-651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241-278 H. Albrecht et al. (ARGUS Collab.) | ALBRECHT 91 | 1E | PL B262 148 | H. Albrecht et al. | (ARGUS Collab.) |
| FULLION 91 PR D43 651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241 278 H. Albrecht et al. (ARGUS Collab.) | BERKELMAN 91 | 1 | ARNPS 41 1 | K. Berkelman, S. Stone | `(CORN, SYRA) |
| FULLION 91 PR D43 651 R. Fulton et al. (CLEO Collab.) ALBRECHT 90B PL B241 278 H. Albrecht et al. (ARGUS Collab.) | "Decays of B | | so ns" | | |
| ALBRECHT 90B PL 8241 278 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 90J ZPHY C48 543 H. Albrecht et al. (ARGUS Collab.) ANTREASYAN 90B ZPHY C48 553 D. Antræsyan et al. (Crystal Ball Collab.) BORTOLETTO 90 PRL6 42 117 D. Bortoletto et al. (CLEO Collab.) Also PR D45 21 D. Bortoletto et al. (CLEO Collab.) WERR 90B PR D41 1384 A.J. Weir et al. (Mark II Collab.) ALBRECHT 89G PL 8223 370 P. Avery et al. (CLEO Collab.) BEBEK 89 PRL6 2 84 C. Bebek et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 86 C. Bebek et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 2436 D. Bortoletto et al. (CLEO Collab.) ALBRECHT 88F PL 8209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 88F PL 8215 424 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1229 C. Bebek et al. (CLEO Collab.) ALBRECHT 87 PR D36 1229 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) | FULTON 91 | 1 | PR D43 651 | R. Fulton et al. | (CLEO Collab.) |
| ALBRECHT 90J ZPHY C48 543 H. Albrecht et al. (ARGUS Collab.) BORTOLETTO 90 PRL 64 2117 D. Bortoletto et al. (Crystal Ball Collab.) AS0 PR D45 21 D. Bortoletto et al. (CLEC Collab.) WEIR 90B PR D41 1384 A.J. Weir et al. (Mark II Collab.) ALBRECHT 89G PL B223 470 P. Avery et al. (CLEC Collab.) BEBEK 99 PRL 62 8 C. Bebek et al. (CLEC Collab.) BEBEK 99 PRL 62 8 C. Bebek et al. (CLEC Collab.) BEBEK 98 PRL 62 8 D. Bortoletto et al. (CLEC Collab.) BEBEK 98 PRL 62 8 C. Bebek et al. (CLEC Collab.) ALBRECHT 88F PL B209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B199 451 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B199 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEC Collab.) BEBEK 87 PR D36 1229 C. Bebek et al. (CLEC Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEC Collab.) GLES 84 PR D30 2279 R. Giles et al. (CLEC Collab.) | ALBRECHT 90 | 0 B | PL B241 278 | H. Albrecht et al. | (ARGUS Collab.) |
| ANTREASYAN 90B ZPHY C48 553 D. Antreasyan et al. (Crystal Ball Collab.) BORTOLETTO 90 PRL6 42 2117 D. Bortoletto et al. (CLEO Collab.) ALBRECHT 896 PR D41 1384 A.J. Weir et al. (Mark II Collab.) ALBRECHT 896 PR D41 1384 A.J. Weir et al. (Mark II Collab.) ALBRECHT 897 PR D42 370 P. Avery et al. (CLEO Collab.) BEBEK 89 PRL6 28 C. Bebek et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 2436 D. Bortoletto et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 2436 D. Bortoletto et al. (CLEO Collab.) ALBRECHT 88F PL B209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B195 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B195 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B195 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1239 P. B183 429 P. Avery et al. (CLEO Collab.) ALBRECHT 87C PL B183 219 P. Avery et al. (CLEO Collab.) ALBRECH 86 PR D38 2279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D38 2279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D38 2279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D30 2279 R. Giles et al. (CLEO Collab.) | ALBRECHT 90 | 0 J | ZPHY C48 543 | H. Albrecht et al. | (ARGUS Collab.) |
| BORTOLETTO 90 | ANTREASYAN 90 | 0B | ZPHY C48 553 | D. Antreasyan et al. | (Crystal Ball Collab.) |
| Also PR D45 21 D. Bortoketto et al. (CLEO Collab.) WEIR 90B PR D41 1384 A.J. Weir et al. (Mark II Collab.) ALBRECHT 896 PL B229 304 H. Albrecht et al. (ARGUS Collab.) AVERY 89B PL B223 470 P. Avery et al. (CLEO Collab.) BEBEK 89 PRL 62 8 C. Bebek et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 2436 D. Bortoketto et al. (CLEO Collab.) ALBRECHT 88F PL B209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 88F PL B215 424 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B189 451 H. Albrecht et al. (ARGUS Collab.) AVERY 97 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) ALAM 86 PR D30 2279 R. Giles et al. (CLEO Collab.) | | 0 | PRL 64 2117 | D. Bortoletto et al. | (CLEO Collab.) |
| WEIR 90B PR D41 1384 A.J. Weir et al. (Mark II Collab.) | | | PR D45 21 | D. Bortoletto et al. | (CLEO Collab.) |
| ALBRECHT 896 PL 8229 304 H. Albrecht et al. (ARGUS Collab.) BEBEK 89 PRL 62 8 C. Bebek et al. (CLEO Collab.) BEBEK 89 PRL 62 8 C. Bebek et al. (CLEO Collab.) ALBRECHT 88F PL 8209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 88F PL 8209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL 8185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL 8185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL 8189 451 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL 8189 451 H. Albrecht et al. (ARGUS Collab.) BEBEK 97 PR D36 1289 C. Bebek et al. (CLEO Collab.) BEBEK 97 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) GLES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PR D41 1384 | A.J. Weir et al. | (Mark II Collab.) |
| AVERY 89B PL B223 470 P. Avery et al. CLEO Collab. BEBEK 89 PRL 62 8 C. Bebek et al. (CLEO Collab.) BORTOLETTO 89 PRL 62 2436 D. Bortoletto et al. (CLEO Collab.) ALBRECHT 88F PL B209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B185 218 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D30 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) PDG 86 PL 170B 1 M. Aguila-Benitez et al. (CERO, CT)+GIB. GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PL B229 304 | H. Albrecht et al. | (ARGUS Collab.) |
| BEBEK 89 PRL 52 8 C. Bebek et al. C. C. Gollab. | | | PL B223 470 | P. Avery et al. | (CLEO Collab.) |
| BORTOLETTO 89 | | | PRL 62 8 | C. Bebek et al. | (CLEO Collab.) |
| ALBRECHT 88F PL B209 119 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B189 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1229 P. Avery et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) GLEO Collab.) GLEO Collab.) | | | PRL 62 2436 | D. Bortoletto et al. | (CLEO Collab.) |
| ALBRECHT 87C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B195 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87D PL B199 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) PDG 86 PL 170B 1 M. Aguila-Benitez et al. (CERN, CIT+) GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PL B209 119 | H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECHT 87 C PL B185 218 H. Albrecht et al. (ARGUS Collab.) ALBRECHT 87 D PL B199 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) PDG 86 PL 170B 1 M. Aguila-Benitez et al. (CLEO Collab.) | | | PL B215 424 | H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECH 87D PL B199 451 H. Albrecht et al. (ARGUS Collab.) AVERY 87 PL B183 429 P. Avey et al. (CLEO Collab.) BEBEK 87 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) PDG 86 PL 170B 1 M. Agullar-Benitez et al. (CERN, CIT+) GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PL B185 218 | H. Albrecht et al. | (ARGUS Collab.) |
| AVERY 0/ Pt. B383 429 P. Avery et al. (CLEO Collab.) BEBEK 87 PR D36 1289 C. Bebek et al. (CLEO Collab.) ALAM 86 PR D34 3279 M.S. Alam et al. (CLEO Collab.) PDG 86 PL 170B 1 M. Aguila-Benitez et al. (CERO, CIT+) GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PL B199 451 | H. AIDTECHT et al. | (AKGUS COIIab.) |
| ALAM 86 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PL B183 429 | P. Avery et al. | (CLEO COllab.) |
| ALAM 09 FN D39 32/9 M.S. Aldill et al. (LEU Collab.) PDG 86 PL 170B 1 M. Aguila-Benitez et al. (CERN, CIT+) GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | | | PR D30 1207 | C. Devek et al. | (CLEO CONST.) |
| GILES 84 PR D30 2279 R. Giles et al. (CLEO Collab.) | ALAM 85 | | FR D34 32/7 | M. Aguilor Regiter et al | (CEEU COHAD.) |
| GLEO CONAD.) | | | PD D20 2270 | P. Glac at al | (CLEO COURT) |
| | GILES 64 | * | FR D30 2217 | N. Giles Et al. | (CLEO CONAD.) |

$$I(J^P) = \frac{1}{2}(0^-)$$

Quantum numbers not measured. Values shown are quark-model

See also the ${\it B}^{\pm}/{\it B}^{0}$ ADMIXTURE and ${\it B}^{\pm}/{\it B}^{0}/{\it B}_{\it S}^{\it 0}/\it b$ -baryon AD-MIXTURE sections.

See the Note "Production and Decay of b-flavored Hadrons" at the beginning of the \mathcal{B}^\pm Particle Listings and the Note on " \mathcal{B}^0 - $\overline{\mathcal{B}}^0$ Mixing" near the end of the \mathcal{B}^0 Particle Listings.

BO MASS

The fit uses $m_{B^+},\,(m_{B^0}-m_{B^+}),$ and m_{B^0} to determine $m_{B^+},\,m_{B^0},$ and the mass difference.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------|--------------------------|---------------------------|----------|-----------|-----------------------------------|
| 5279.58±0.17 OUR F | Т | | | | |
| 5279.55 ± 0.26 OUR A | VERAGE | | | | |
| $5279.58 \pm 0.15 \pm 0.28$ | | ¹ AAIJ | 12E | LHCB | pp at 7 TeV |
| $5279.63 \pm 0.53 \pm 0.33$ | | ² ACOSTA | 06 | CDF | $p\overline{p}$ at 1.96 TeV |
| $5279.1 \pm 0.7 \pm 0.3$ | 135 | ³ CSORNA | 00 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $5281.3 \pm 2.2 \pm 1.4$ | 51 | ABE | 96B | CDF | $p\overline{p}$ at 1.8 TeV |
| • • • We do not use | the followi | ng data for average | es, fits | , limits, | etc. • • • |
| 5279.2 ±0.54 ± 2.0 | 340 | ALAM | 94 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |
| 5278.0 ±0.4 ±2.0 | | BORTOLETT | O92 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $5279.6 \pm 0.7 \pm 2.0$ | 40 | ⁴ ALBRECHT | 90J | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5278.2 ±1.0 ±3.0 | 40 | ALBRECHT | 87c | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5279.5 ±1.6 ±3.0 | 7 | ⁵ ALBRECHT | 87D | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| 5280.6 ±0.8 ±2.0 | | BEBEK | 87 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| $1 \text{ Uses } B^0 \rightarrow J/\psi F$ | (⁰ fully red | constructed decays. | | | |
| ² Uses exclusively re | | | | 1/2/2 — | → u+u- decays |
| | | | | | ents and invariant masse |
| without beam cons | | iructed 133 b → | J/ψ | , NS EV | CIILS AIIU IIIVAIIAIIL IIIASS |
| | | 1580 for $\Upsilon(45)$ m | 366 | Sunarcar | les ALBRECHT 87c an |

 $^{^4}$ ALBRECHT 90J assumes 10580 for $\Upsilon(4S)$ mass. Supersedes ALBRECHT 87c and ALBRECHT 87D. 5 Found using fully reconstructed decays with $J/\psi.$ ALBRECHT 87D assume m $_{\Upsilon(4S)}=$

¹⁰⁵⁷⁷ MeV.

| VALUE (MeV) | | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|---|-------------|------|------|---------------------------------|
| 0.32±0.06 OUR FIT | | | | | |
| 0.32±0.05 OUR AVERAGE | | | | | |
| $0.20 \pm 0.17 \pm 0.11$ | 1 | AAIJ | 12E | LHCB | pp at 7 TeV |
| $0.33 \pm 0.05 \pm 0.03$ | | AUBERT | 08AF | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| $0.53 \pm 0.67 \pm 0.14$ | 3 | ACOSTA | 06 | CDF | $p\overline{p}$ at 1.96 TeV |
| $0.41 \pm 0.25 \pm 0.19$ | | ALAM | 94 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |
| $-0.4 \pm 0.6 \pm 0.5$ | | BORTOLETT | O92 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| $-0.9 \pm 1.2 \pm 0.5$ | | ALBRECHT | 90J | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| $2.0 \pm 1.1 \pm 0.3$ | 4 | BEBEK | 87 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |

 $^{^2}$ Uses the B -momentum distributions in the ${\rm e^+\,e^-}$ rest frame. 3 Uses exclusively reconstructed final states containing a $J/\psi\to~\mu^+\mu^-$ decays.

$m_{B_H^0} - m_{B_I^0}$

See the B^0 - \overline{B}^0 MIXING PARAMETERS section near the end of these B^0

B⁰ MEAN LIFE

See $B^{\pm}/B^0/B_c^0/b$ -baryon ADMIXTURE section for data on B-hadron mean life averaged over species of bottom particles.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors.

| VALUE (10 ⁻¹² s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------|---------|--------------------------|-------------|------------|------------------------------------|
| 1.519±0.007 OUR E | VALUATI | | | | |
| $1.507\pm0.010\pm0.008$ | | 1 AALTONEN | 11 | CDF | $\rho \overline{\rho}$ at 1.96 TeV |
| $1.414 \pm 0.018 \pm 0.034$ | | ² ABAZOV | 09E | D0 | $p\overline{p}$ at 1.96 TeV |
| $1.501 {}^{+ 0.078}_{- 0.074} {\pm} 0.050$ | | ³ ABAZOV | 07s | D0 | p p at 1.96 TeV |
| $1.504 \pm 0.013 ^{+0.018}_{-0.013}$ | | ⁴ AUBERT | 06 G | BABR | $e^+e^- ightarrow \gamma(4S)$ |
| $1.534 \pm 0.008 \pm 0.010$ | | ⁵ ABE | 05в | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.531\pm0.021\pm0.031$ | | ⁶ ABDALLAH | 04 E | DLPH | $e^+e^- \rightarrow Z$ |
| $1.523^{+0.024}_{-0.023}\pm0.022$ | | ⁷ AUBERT | 03c | BABR | $e^+e^- ightarrow \gamma(4S)$ |
| 1.533±0.034±0.038 | | ⁸ AUBERT | 03н | BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| $1.497 \pm 0.073 \pm 0.032$ | | ⁹ A COSTA | 02c | CDF | $p\overline{p}$ at 1.8 TeV |
| $1.529 \pm 0.012 \pm 0.029$ | | ¹⁰ AUBERT | 02н | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.546 \pm 0.032 \pm 0.022$ | | ¹¹ AUBERT | 01 F | BABR | $e^+e^- \rightarrow r(4S)$ |
| $1.541 \pm 0.028 \pm 0.023$ | | ¹⁰ ABBIENDI,G | 00в | OPAL | $e^+e^- \rightarrow Z$ |
| $1.518 \pm 0.053 \pm 0.034$ | | ¹² BARATE | 00R | ALEP | $e^+e^- \rightarrow Z$ |
| $1.523 \pm 0.057 \pm 0.053$ | | ¹³ ABBIENDI | 99 J | OPAL | $e^+e^- \rightarrow Z$ |
| $1.474 \pm 0.039 ^{+ 0.05 2}_{- 0.05 1}$ | | ¹² ABE | 98 Q | CDF | p p at 1.8 TeV |
| 1.52 ±0.06 ±0.04 | | ¹³ ACCIARRI | 98s | L3 | $e^+e^- \rightarrow Z$ |
| 1.64 ±0.08 ±0.08 | | 13 ABE | 97J | SLD | $e^+e^- \rightarrow Z$ |
| 1.532±0.041±0.040 | | ¹⁴ ABREU | 97F | DLPH | $e^+e^- \rightarrow Z$ |
| $1.25 {}^{+ 0.15}_{- 0.13} \pm 0.05$ | 121 | ⁹ BUSKULIC | 961 | ALEP | $e^+e^- ightarrow Z$ |
| $1.49 \begin{array}{c} +0.17 \\ -0.15 \end{array} \begin{array}{c} +0.08 \\ -0.06 \end{array}$ | | ¹⁵ BUSKULIC | 961 | ALEP | $e^+e^- ightarrow Z$ |
| $1.61 ^{+ 0.14}_{- 0.13} \pm 0.08$ | 1 | ^{2,16} ABREU | 95 Q | DLPH | $e^+e^-\to~Z$ |
| $1.63 \pm 0.14 \pm 0.13$ | | ¹⁷ ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| $1.53 \pm 0.12 \pm 0.08$ | 1 | ^{2,18} AKERS | 95 T | OPAL | $e^+e^- \rightarrow Z$ |
| • • • We do not use | | wing data for avera | ges, fi | ts, limits | s, etc. • • • |
| $1.524\pm0.030\pm0.016$ | | 3 ABULENCIA | 07A | CDF | Repl. by AALTONEN 11 |
| $1.473 + 0.052 \pm 0.023$ | | ² ABAZOV | 05 B | D0 | Repl. by ABAZOV 05W |
| $1.40 \ ^{+ 0.11}_{- 0.10} \ \pm 0.03$ | | ³ ABAZOV | 05 C | D0 | Repl. by ABAZOV 07s |
| $1.530 \pm 0.043 \pm 0.023$ | | ² ABAZOV | 05 W | D0 | Repl. by ABAZOV 09E |
| 1.54 ±0.05 ±0.02 | | ¹⁹ ACOSTA | 05 | CDF | Repl. by AALTONEN 11 |
| $1.554 \pm 0.030 \pm 0.019$ | | ¹¹ ABE | 02н | BELL | Repl. by ABE 05B |
| $1.58 \pm 0.09 \pm 0.02$ | | ⁹ ABE | 98B | CDF | Repl. by ACOSTA 02c |
| $1.54 \pm 0.08 \pm 0.06$ | | ¹² ABE | 96 c | CDF | Repl. by ABE 98Q |
| $1.55 \pm 0.06 \pm 0.03$ | | ²⁰ BUSKULIC | 96J | ALEP | $e^+e^- \rightarrow Z$ |
| $1.61 \pm 0.07 \pm 0.04$ | | ¹² BUSKULIC | 96 J | ALEP | Repl. by BARATE 00R |
| 1.62 ± 0.12 | | ²¹ ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| $1.57 \ \pm 0.18 \ \pm 0.08$ | 121 | ⁹ ABE | 94 D | CDF | Repl. by ABE 98B |
| $1.17 {}^{+ 0.29}_{- 0.23} \pm 0.16$ | 96 | ¹² ABREU | 93D | DLPH | Sup. by ABREU 95Q |
| 1.55 ±0.25 ±0.18 | 76 | ¹⁷ ABREU | 93 G | DLPH | Sup. by ADAM 95 |
| . 0 04 . 0 10 | | | | | |

78 12 ACTON

93c OPAL Sup. by AKERS 95T

 $1.51 \begin{array}{c} +0.24 \\ -0.23 \end{array} \begin{array}{c} +0.12 \\ -0.14 \end{array}$

| 1.52 | $^{+0.20}_{-0.18}$ | $^{+0.07}_{-0.13}$ | 77 | ¹² BUSKULIC | 93D | ALEP | Sup. by BUSKULIC 96J |
|------|--------------------|--------------------|----|------------------------|-----|------|------------------------------------------------------|
| 1.20 | $^{+0.52}_{-0.36}$ | $^{+0.16}_{-0.14}$ | 15 | ²² WAGNER | 90 | MRK2 | $E_{\mathrm{cm}}^{\mathit{ee}} = 29 \; \mathrm{GeV}$ |
| 0.82 | $^{+0.57}_{-0.37}$ | ±0.27 | | ²³ AVERILL | 89 | HRS | $E_{ m cm}^{\it ee}$ = 29 GeV |

¹ Measured mean life using fully reconstructed decays $(J/\psi K^{(*)})$.

 11 Events are selected in which one B meson is fully reconstructed while the second B meson is reconstructed inclusively.

 $^{12}\,\mathrm{Data}$ analyzed using $D\,/\,D^*\,\ell\,\mathrm{X}$ event vertices.

13 Data analyzed using charge of secondary vertex.

¹⁴ Data analyzed using inclusive $D/D^*\ell X$.

15 Measured mean life using partially reconstructed $D^{*-}\pi^+ X$ vertices. 16 ABREU 95Q assumes B($B^0 \to D^{**-}\ell^+\nu_\ell$) = 3.2 \pm 1.7%.

 17 Data analyzed using vertex-charge technique to tag B charge.

¹⁸ AKERS 95T assumes $B(B^0 \to D_s^{(*)}D^0(*))=5.0\pm0.9\%$ to find B^+/B^0 yield. ¹⁹ Measured using the time-dependent angular analysis of $B_d^0 \to J/\psi K^{*0}$ decays.

 20 Combined result of $D/D^*\ell x$ analysis, fully reconstructed $\ddot{\it B}$ analysis, and partially reconstructed $D^{*-}\pi^{+}X$ analysis.

21 Combined ABREU 95Q and ADAM 95 result. 22 WAGNER 90 tagged B^0 mesons by their decays into $D^{*-}e^+\nu$ and $D^{*-}\mu^+\nu$ where the D^{*-} is tagged by its decay into $\pi^{-}\overline{D}^{0}$.

²³ AVERILL 89 is an estimate of the B^0 mean lifetime assuming that $B^0 \to D^{*+} + X$

MEAN LIFE RATIO τ_{B^+}/τ_{B^0}

I

 au_{B^+}/ au_{B^0} (direct measurements) "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------|------------|-----------------------|-------------|-----------|-----------------------------------|
| 1.079±0.007 OUR EVA | LUATIO | | | | |
| $1.088 \pm 0.009 \pm 0.004$ | | 1 AALTONEN | 11 | CDF | $p\overline{p}$ at 1.96 TeV |
| $1.080 \pm 0.016 \pm 0.014$ | | ² ABAZOV | 05 D | D0 | $p\overline{p}$ at 1.96 TeV |
| $1.066 \pm 0.008 \pm 0.008$ | | ³ ABE | 05B | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.060 \pm 0.021 \pm 0.024$ | | 4 ABDALLAH | 04E | DLPH | $e^+e^- \rightarrow Z$ |
| $1.093 \pm 0.066 \pm 0.028$ | | ⁵ ACOSTA | 02c | CDF | $p\overline{p}$ at 1.8 TeV |
| $1.082 \pm 0.026 \pm 0.012$ | | ⁶ AUBERT | 01F | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.085 \pm 0.059 \pm 0.018$ | | ² BARATE | 00R | ALEP | $e^+e^- \rightarrow Z$ |
| $1.079 \pm 0.064 \pm 0.041$ | | ⁷ ABBIENDI | 991 | OPAL | $e^+e^- \rightarrow Z$ |
| $1.110 \pm 0.056 ^{+0.033}_{-0.030}$ | | ² ABE | 98Q | CDF | $ ho\overline{ ho}$ at 1.8 TeV |
| $1.09 \pm 0.07 \pm 0.03$ | | ⁷ ACCIARRI | 98s | L3 | $e^+e^- \rightarrow Z$ |
| $1.01 \pm 0.07 \pm 0.06$ | | ⁷ ABE | ر97 | SLD | $e^+e^- \rightarrow Z$ |
| $1.27 \ \substack{+0.23 \\ -0.19} \ \substack{+0.03 \\ -0.02}$ | | ⁵ BUSKULIC | 96J | ALEP | $e^+e^- ightarrow Z$ |
| $1.00 \ ^{+ 0.17}_{- 0.15} \ \pm 0.10$ | | ^{2,8} ABREU | 95 Q | DLPH | $e^+e^- ightarrow Z$ |
| $1.06 \ ^{+ 0.1 3}_{- 0.1 1}\ \pm 0.10$ | | ⁹ ADAM | 95 | DLPH | $e^+e^- ightarrow Z$ |
| $0.99 \pm 0.14 ^{+ 0.05}_{- 0.04}$ | | ^{2,10} AKERS | 95T | OPAL | $e^+e^- ightarrow Z$ |
| • • • We do not use to | ne followi | ng data for averag | es, fits | , limits, | etc. • • • |
| $1.091 \pm 0.023 \pm 0.014$ | | 6 ABE | 02н | BELL | Repl. by ABE 05B |
| $1.06 \pm 0.07 \pm 0.02$ | | ⁵ ABE | 98B | CDF | Repl. by ACOSTA 02c |
| $1.01 \pm 0.11 \pm 0.02$ | | ² ABE | 96c | CDF | Repl. by ABE 980 |
| $1.03 \pm 0.08 \pm 0.02$ | | 11 BUSKULIC | 96J | ALEP | $e^+e^- \rightarrow Z$ |
| $0.98 \pm 0.08 \pm 0.03$ | | ² BUSKULIC | 96J | ALEP | Repl. by BARATE 00R |
| $1.02 \pm 0.16 \pm 0.05$ | 269 | ⁵ ABE | 94D | CDF | Repl. by ABE 98B |
| $1.11 \ ^{+ 0.5 1}_{- 0.3 9}\ \pm 0.11$ | 188 | ² ABREU | 93D | DLPH | Sup. by ABREU 95Q |
| $1.01 \ ^{+ 0.29}_{- 0.22} \ \pm 0.12$ | 253 | ⁹ ABREU | 93 G | DLPH | Sup. by ADAM 95 |
| $1.0 {}^{+ 0.33}_{- 0.25} \ \pm 0.08$ | 130 | ACTON | 93 c | OPAL | Sup. by AKERS 95T |
| $0.96 \begin{array}{c} +0.19 \\ -0.15 \end{array} \begin{array}{c} +0.18 \\ -0.12 \end{array}$ | 154 | ² BUSKULIC | 93D | ALEP | Sup. by BUSKULIC 96J |

⁴ BEBEK 87 actually measure the difference between half of $E_{\rm cm}$ and the B^\pm or B^0 mass, so the $m_{B^0}-m_{B^\pm}$ is more accurate. Assume $m_{T(4S)}=10580$ MeV.

 $^{^2}$ Measured mean life using $B^0\to J/\psi\,K^{*0}$ decays. 3 Measured mean life using $B^0\to J/\psi\,K_{\rm S}$ decays.

 $^{^4}$ Measured using a simultaneous fit of the B^0 lifetime and $\overline{B}{}^0B^0$ oscillation frequency Δm_d in the partially reconstructed $B^0 \to D^{*-}\ell \nu$ decays.

⁵ Measurement performed using a combined fit of *CP*-violation, mixing and lifetimes.

 $^{^6}$ Measurement performed using an inclusive reconstruction and 8 flavor identification

⁷ AUBERT 03c uses a sample of approximately 14,000 exclusively reconstructed $B^0 \rightarrow$ $D^*(2010)^{-}\ell\nu$ and simultaneously measures the lifetime and oscillation frequency.

⁸ Measurement performed with decays $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*-}\rho^+$ using a partial reconstruction technique. 9 Measured mean life using fully reconstructed decays. 10 Data analyzed using partially reconstructed $\overline{B}^0 \to D^{*+} \ell^- \overline{\nu}$ decays.

- $\frac{1}{\cdot}$ Measured mean life using fully reconstructed decays ($J/\psi \, {\it K}^{\left(*\right)})$
- $^2\,\mathrm{Data}$ analyzed using $D\,/\,D^*\,\mu\mathrm{X}$ vertices.
- ³ Measurement performed using a combined fit of *CP*-violation, mixing and lifetimes.
- 4 Measurement performed using an inclusive reconstruction and B flavor identification
- ⁵ Measured using fully reconstructed decays.
- 6 Events are selected in which one B meson is fully reconstructed while the second B meson is reconstructed inclusively.
- 7 Data analyzed using charge of secondary vertex. 8 ABREU 95Q assumes B(B 0 \rightarrow D^{**-} ℓ^+ ν_ℓ) = 3.2 \pm 1.7%.
- 9 Data analyzed using vertex-charge technique to tag B charge. 10 AKERS 95T assumes B($B^0\to D_{\rm S}^{~(*)}D^0(*))=5.0\pm0.9\%$ to find B^+/B^0 yield.
- 11 Combined result of $D/D^*\ell {\rm X}$ analysis and fully reconstructed ${\it B}$ analysis.

1.076±0.034 OUR EVALUATION

 au_{B^+}/ au_{B^0} (inferred from branching fractions)

These measurements are inferred from the branching fractions for semileptonic decay or other spectator-dominated decays by assuming that the rates for such decays are equal for B^0 and B^+ . We do not use measurements which assume equal production of B^0 and B^+ because of the large uncertainty in the production ratio.

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) by taking into account correlations between measurements DO CUMENT ID

TECN COMMENT

| RAGE | | | | |
|--------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | URQUIJO | 07 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | AUBERT,B | 06Y | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| ne following | data for averages, f | its, li | nits, etc | . • • • |
| | ¹ ARTUSO | 97 | CLE2 | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| | ² JESSOP | 97 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | ³ ATHANAS | 94 | CLE2 | Sup. by ARTUSO 97 |
| | ⁴ ALBRECHT | 92c | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| 29 | ^{4,5} ALBRECHT | 92G | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | ⁴ FULTON | 91 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | ⁴ ALBRECHT | 89L | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
|) | ⁶ BEAN | 87B | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | ne following 29 | URQUIJO AUBERT,B ne following data for averages, f 1 ARTUSO 2 JESSOP 3 ATHANAS 4 ALBRECHT 29 4.5 ALBRECHT 4 FULTON 4 ALBRECHT | URQUIJO 07 AUBERT,B 06Y ne following data for averages, fits, lin 1 ARTUSO 97 2 JESSOP 97 3 ATHANAS 94 4 ALBRECHT 92C 29 4,5 ALBRECHT 92C 4 FULTON 91 4 ALBRECHT 89L | URQUIJO 07 BELL AUBERT,B 06Y BABR ne following data for averages, fits, limits, etc 1 ARTUSO 97 CLE2 2 JESSOP 97 CLE2 3 ATHANAS 94 CLE2 4 ALBRECHT 92c ARG 29 4.5 ALBRECHT 92c ARG 4 FULTON 91 CLEO 4 ALBRECHT 89L ARG |

- ¹ ARTUSO 97 uses partial reconstruction of $B \to D^* \ell \nu_{\ell}$ and independent of B^0 and
- ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.
- 3 ATHANAS 94 uses events tagged by fully reconstructed B^- decays and partially or fully reconstructed B^0 decays.
- ⁴ Assumes equal production of B^0 and B^+ .
 ⁵ ALBRECHT 92G data analyzed using $B \to D_S \overline{D}$, $D_S \overline{D}^*$, $D_S^* \overline{D}$, $D_S^* \overline{D}^*$ events.
- ⁶BEAN 87B assume the fraction of $B^0 \overline{B}{}^0$ events at the $\Upsilon(4S)$ is 0.41.

$\operatorname{sgn}(\operatorname{Re}(\lambda_{CP})) \Delta \Gamma_{B_d^0} / \Gamma_{B_d^0}$

 $\Gamma_{B^0_d}$ and $\Delta\Gamma_{B^0_d}$ are the decay rate average and difference between two B_d^0 CP eigenstates (light — heavy). The λ_{CP} characterizes B^0 and \overline{B}^0 decays to states of charmonium plus K_I^0 , see the review on "CP Violation" in the reviews section

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) by taking into account correlations between measurements.

| DO CUMENT ID | TECN | COMMENT | | | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|--|--|--|--|--|--|
| | | | | | | | | |
| data from the da | atablock that | follows this one. | | | | | | |
| ¹ HIGUCHI | 12 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | | | | | | |
| ² AUBERT,B | 04c BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ | | | | | | |
| ¹ Reports $-\Delta \Gamma_d/\Gamma_d$ using $B^0 \to J/\psi K^0_S$, $J/\psi K^0_L$, $D^-\pi^+$, $D^{*-}\pi^+$, $D^{*-}\rho^+$, and $D^{*-}\ell^+\nu$ decays. | | | | | | | | |
| | | | | | | | | |
| range [—0.084, 0 | .068]. | | | | | | | |
| | data from the diagram of the diagra | data from the datablock that HIGUCHI 12 BELL AUBERT,B 04c BABR | | | | | | |

$|\Delta \Gamma_{B_a^0}|/\Gamma_{B_a^0}$

<u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

```
^{1} ABDALLAH 03B DLPH e^{+}\,e^{-}
ightarrow~Z
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                ^{2,3} BEHRENS 00B CLE2 e^+\,e^-
ightarrow~\varUpsilon(45)
                         95
```

- $^1\,\mathrm{Using}$ the measured $\tau_{B^0}\!=\!1.55\,\pm\,0.03\,\mathrm{ps}.$
- $^2\,\text{BEHRENS}$ 00B uses high-momentum lepton tags and partially reconstructed $\overline{\mathcal{B}}{}^{\,0}\,\to\,$
- $D^{*+}\pi^-$, ρ^- decays to determine the flavor of the B meson. Assumes Δ_{md} =0.478 \pm 0.018 ps $^{-1}$ and τ_{B^0} =1.548 \pm 0.032 ps.

B⁰ DECAY MODES

 \overline{B}^0 modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing. Modes which do not identify the charge state of the B are listed in the B^\pm/B^0 ADMIXTURE

The branching fractions listed below assume 50% $B^0\,\overline B^0$ and 50% $B^+\,B^$ production at the $\Upsilon(4S)$. We have attempted to bring older measurements up to date by rescaling their assumed $\Upsilon(4S)$ production ratio to 50:50 and their assumed D, $D_{\rm S}$, D^* , and ψ branching ratios to current values whenever this would affect our averages and best limits significantly.

Indentation is used to indicate a subchannel of a previous reaction. All resonant subchannels have been corrected for resonance branching fractions to the final state so the sum of the subchannel branching fractions can exceed that of the final state.

For inclusive branching fractions, e.g., $B \rightarrow D^{\pm}$ anything, the values usually are multiplicities, not branching fractions. They can be greater

| | than one. | | |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|-----------------------------------|
| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
| Γ ₁ | $\ell^+ u_{\ell}$ anything | [a] (10.33± 0.28) % | |
| Γ ₂ | $e^+ \nu_e X_c$ | | |
| _ | D_{ℓ}^{+} | (10.1 ± 0.4) % | |
| Γ3 | $D\ell^+\nu_\ell$ anything | (9.2 ± 0.8) % | |
| Γ ₄ | $D^-\ell^+ u_\ell$ | [a] $(2.18 \pm 0.12) \%$ | |
| Γ_5 | $D^- 	au^+ u_	au$ | $(1.1 \pm 0.4)\%$ | |
| Γ_6 | $D^*(2010)^-\ell^+ u_\ell$ | [a] $(4.95 \pm 0.11) \%$ | |
| Γ_7 | $D^*(2010)^- \tau^+ \nu_{	au}$ | $(1.5 \pm 0.5)\%$ | S=1.4 |
| Γ ₈ | $\overline{D}{}^0\pi^-\ell^+ u_\ell$ | $(4.3\pm0.6)\times 1$ | 0-3 |
| Γ ₉ | $D_0^*(2400)^- \ell^+ \nu_\ell \times \\ B(D_0^{*-} \to \overline{D}{}^0 \pi^-)$ | $(3.0\ \pm\ 1.2\)\times 1$ | |
| Γ ₁₀ | $D_2^*(2460)^- \ell^+ \nu_\ell 	imes$ | $(1.21\pm0.33)\times 1$ | 0 ⁻³ S=1.8 |
| | $B(D_2^{*-} 	o \ \overline{D}{}^0\pi^-)$ | | |
| Γ_{11} | $\overline{D}^{(*)} n \pi \ell^{+} \overline{\nu_{\ell}} (n \geq 1)$ | $(2.3 \pm 0.5)\%$ | |
| Γ ₁₂ | $\overline{D}^{*0}\pi^-\ell^+\nu_\ell$ | (4.9 \pm 0.8) \times 1 | $^{0-3}$ |
| Γ13 | $D_1(2420)^{-}\ell^{+}\nu_{\ell}\times$ | (2.80 ± 0.28) × 1 | |
| . 13 | $\begin{array}{c} D_1(2420)^{-} \stackrel{\ell^+}{\ell^+} \nu_{\ell} \times \\ B(D_1^- \to \overline{D}^{*0} \pi^-) \end{array}$ | (=:== ::==) | |
| г | D'(2420) = (+ + + + + + + + + + + + + + + + + + | (21 00)1 | 0-3 |
| Γ ₁₄ | $D_1'(2430)^- \ell^+ \nu_\ell \times$ | $(3.1\ \pm\ 0.9\)\times 1$ | 0 0 |
| | $B(D_1'^- \to \overline{D}^{*0}\pi^-)$ | | |
| Γ ₁₅ | $D_2^*(2460)^- \ell^+ \nu_\ell \times \\ B(D_2^{*-} \to \overline{D}^{*0} \pi^-)$ | $(6.8\ \pm\ 1.2\)\times 1$ | 0-4 |
| Γ ₁₆ | $\rho^-\ell^+ u_\ell$ | [a] (2.34 ± 0.28) × 1 | 0-4 |
| Γ ₁₇ | $\pi^-\ell^+ u_\ell$ | [a] (1.44 ± 0.05) × 1 | |
| Γ ₁₈ | $\pi^-\mu^+ u_\mu$ | [0] (1 ± 0.00) × 1 | • |
| 10 | Inclusive | modes | |
| Γ ₁₉ | K^{\pm} anything | (78 ± 8)% | |
| Γ ₂₀ | D^0X | | |
| | $\frac{D}{D^0}X$ | (8.1 ± 1.5) % | |
| Γ ₂₁ | | (47.4 ± 2.8) % | |
| Γ ₂₂ | D+ X | < 3.9 % | CL=90% |
| Γ ₂₃ | D-X | $(36.9 \pm 3.3)\%$ | |
| Γ ₂₄ | $D_s^+ X$ | $(10.3 + 2.1 \atop -1.8)\%$ | |
| | $D_s^- X$ | < 2.6 % | CL=90% |
| | | | |
| Γ ₂₆ | $\Lambda_c^+ X$ | < 3.1 % | CL=90% |
| Γ_{27} | $\overline{\Lambda}_c^- X$ | $(5.0 \ \frac{+}{-} \ \frac{2.1}{1.5}) \%$ | |
| Γ ₂₈ | c X | (95 ± 5)% | |
| | cX | (24.6 ± 3.1) % | |
| Γ ₂₉ Γ ₃₀ | c cX | $(24.6 \pm 3.1)\%$ $(119 \pm 6)\%$ | |
| 1 30 | | | |
| _ | D, D*, or | | 2 |
| Γ_{31} | $D^-\pi^+$ | $(2.68 \pm 0.13) \times 1$ | |
| Γ_{32} | $D^-\rho^+$ | $(7.8 \pm 1.3) \times 1$ | $^{0}-^{3}$ |
| Γ_{33} | $D^-K^0\pi^+$ | $(4.9 \pm 0.9) \times 1$ | 0^{-4} |
| Γ_{34} | $D^-K^*(892)^+$ | $(4.5 \pm 0.7) \times 1$ | 0-4 |
| Γ ₃₅ | $D^-\omega\pi^+$ | $(2.8 \pm 0.6) \times 1$ | 0-3 |
| Г36 | D^-K^+ | (1.97 ± 0.21) × 1 | |
| Γ ₃₇ | $D = K + \overline{K}_0$ | < 3.1 × 1 | |
| Γ ₃₈ | $D^{-}K^{+}\overline{K}^{*}(892)^{0}$ | (8.8 ± 1.9)×1 | |
| Γ ₃₉ | $\overline{D}^0 \pi^+ \pi^-$ | (8.4 ± 0.9)×1 | |
| Γ ₄₀ | $D^*(2010)^-\pi^+$ | $(2.76 \pm 0.13) \times 1$ | |
| Γ ₄₁ | $D = (2010)^{-1} \pi^{-1}$ $D = \pi^{+1} \pi^{+1} \pi^{-1}$ | | |
| | | (6.4 ± 0.7) × 1 | |
| Γ ₄₂ | $(D^-\pi^+\pi^+\pi^-)$ nonresonant | (3.9 ± 1.9) × 1 | |
| 43 | $D^-\pi^+\rho^0$ | $(1.1 \pm 1.0) \times 1$ | |
| 1 | | | |

 $(6.0 \pm 3.3) \times 10^{-3}$

(1.5 ± 0.5) %

 $D^-a_1(1260)^+$

 $D^*(2010)^{-}\pi^+\pi^0$

 Γ_{44}

| Γ ₄₆ Γ ₄₇ | $D^*(2010)^- ho^+\ D^*(2010)^-K^+$ | (| $6.8 \pm 0.9 \times 10^{-3}$ $2.14 \pm 0.16 \times 10^{-4}$ | | Γ ₉₂ | $D^- D_{s1}(2536)^+ 	imes B(D_{s1}(2536)^+ 	o$ | (| $1.7 \ \pm \ 0.6 \) \times 10^{-4}$ | |
|------------------------------------|-----------------------------------------------|---|----------------------------------------------------------------|---------|---------------------------|-------------------------------------------------------------------|-----|------------------------------------------------------------------|--------|
| Γ ₄₈ | $D^*(2010)^- K^0 \pi^+$ | (| $3.0 \pm 0.8 \times 10^{-4}$ | | | $D^{*0}K^+$ | | | |
| Γ_{49} | $D^*(2010)^- K_*(892)^+$ | (| $3.3~\pm~0.6~)\times10^{-4}$ | | Γ ₉₃ | $D^- D_{s1} (2536)^+ \times$ | (| $2.6 \pm 1.1) \times 10^{-4}$ | |
| Γ ₅₀ | $D^*(2010)^{-}K^{+}\overline{K}^{0}$ | < | 4.7×10^{-4} | CL=90% | | $B(D_{s1}(2536)^+ \to 0.000)$ | | | |
| Γ ₅₁ | $D^*(2010)^- K^+ \overline{K}^*(892)^0$ | (| $1.29 \pm 0.33) \times 10^{-3}$ | | _ | $D^{*+}K^0$) | | 4 | |
| Γ ₅₂ | $D^*(2010)^-\pi^+\pi^+\pi^-$ | (| $7.0 \pm 0.8 \times 10^{-3}$ | S=1.3 | F ₉₄ | $D^*(2010)^- D_{s1}(2536)^+ \times D^{*0}(6536)^+$ | (| $5.0 \pm 1.4 \times 10^{-4}$ | |
| 53 | $(D^*(2010)^-\pi^+\pi^+\pi^-)$ non- | (| $0.0 \pm 2.5 \times 10^{-3}$ | | | $B(D_{s1}(2536)^+ \to D^{*0}K^+ + D^{*+}K^0)$ | | | |
| Γ ₅₄ | $D^*(2010)^-\pi^+ ho^0$ | (| $5.7 \pm 3.2) \times 10^{-3}$ | | г | | , | 22 11 10-4 | |
| Γ ₅₅ | $D^*(2010)^- a_1(1260)^+$ | (| 1.30 ± 0.27) % | | Γ ₉₅ | $D^*(2010)^- D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to$ | (| $3.3 \pm 1.1) \times 10^{-4}$ | |
| Γ ₅₆ | $D^*(2010)^-\pi^+\pi^+\pi^-\pi^0$ | ì | 1.76± 0.27) % | | | $D^{*0}K^+$ | | | |
| Γ ₅₇ | $D^{*-}3\pi^{+2}\pi^{-}$ | (| $4.7 \pm 0.9 \times 10^{-3}$ | | Γ ₉₆ | $D^{*-}D_{51}(2536)^{+} \times$ | - (| $5.0 \pm 1.7) \times 10^{-4}$ | |
| Γ ₅₈ | $\overline{D}^*(2010)^- \omega \pi^+$ | (| $2.89 \pm 0.30) \times 10^{-3}$ | | . 96 | $B(D_{s1}(2536)^+ \to$ | , | 3.0 ± 1.1 / × 10 | |
| Γ ₅₉ | $D_1(2430)^0 \omega \times$ | (| 4.1 \pm 1.6) \times 10 ⁻⁴ | | | $D^{*+}K^{0}$ | | | |
| | $B(D_1(2430)^0 \to D^{*-}\pi^+)$ | | _ | | Γ_{97} | $D^- D_{sJ}(2573)^+ \times$ | < | 1×10^{-4} | CL=90% |
| Γ ₆₀ | $\overline{D}^{**-}\pi^+$ | | $2.1 \pm 1.0 \times 10^{-3}$ | | | $B(D_{sJ}(2573)^+ \to D^0 K^+)$ | | | |
| Γ ₆₁ | $D_1(2420)^-\pi^+ \times B(D_1^- \to$ | (| 1.00^{+}_{-} $\stackrel{0.21}{0.25}$) $\times 10^{-4}$ | | Γ ₉₈ | $D^*(2010)^- D_{sJ}(2573)^+ \times$ | < | 2×10^{-4} | CL=90% |
| | $D^-\pi^+\pi^-)$ | | 0.23 | | _ | $B(D_{sJ}(2573)^+ \to D^0 K^+)$ | | _ | |
| Γ_{62} | $D_1(2420)^-\pi^+ \times B(D_1^- \to$ | < | 3.3×10^{-5} | CL=90% | Г99 | $D^+\pi^-$ | (| $7.8 \pm 1.4 \times 10^{-7}$ | |
| | $D^{*-}\pi^{+}\pi^{-}$ | | | | | $D_s^+\pi^-$ | (| $2.16 \pm 0.26) \times 10^{-5}$ | |
| Γ ₆₃ | $\overline{D}_{2}^{*}(2460)^{-}\pi^{+}\times$ | (| $2.15 \pm 0.35) \times 10^{-4}$ | | | $D_{s}^{*+}\pi^{-}$ | (| $2.1 \pm 0.4 \times 10^{-5}$ | S=1.4 |
| | $B(D_2^*(2460)^- \to D^0\pi^-)$ | | | | | $D_s^+ \rho^-$ | < | $2.4 	 \times 10^{-5}$ | CL=90% |
| Γ ₆₄ | $\overline{D}_{0}^{*}(2400) - \pi^{+} \times$ | (| $6.0 \pm 3.0 \times 10^{-5}$ | | Γ ₁₀₃ | $D_{s}^{*+}\rho^{-}$ | (| $4.1 \pm 1.3 \times 10^{-5}$ | |
| ٠. | $B(D_0^*(2400)^- \to D^0\pi^-)$ | | | | Γ ₁₀₄ | $D_s^+ a_0^-$ | < | 1.9 $\times 10^{-5}$ | CL=90% |
| Γ ₆₅ | $D_2^*(2460)^-\pi^+ \times B((D_2^*)^- \to$ | < | 2.4×10^{-5} | CL=90% | | $D_s^{*+} a_0^-$ | < | $3.6 	 \times 10^{-5}$ | CL=90% |
| 03 | $D^{*-}\pi^{+}\pi^{-}$ | | | | Γ ₁₀₆ | $D_s^+ a_1(1260)^-$ | < | 2.1×10^{-3} | CL=90% |
| Γ_{66} | $\overline{D}_{2}^{*}(2460)^{-}\rho^{+}$ | < | 4.9×10^{-3} | CL=90% | Γ ₁₀₇ | $D_s^{*+} a_1 (1260)^-$ | < | $1.7 	 \times 10^{-3}$ | CL=90% |
| Γ ₆₇ | $D^{\circ} \overline{D}{}^{\circ}$ | < | 4.3×10^{-5} | CL=90% | | $D_{s}^{+} a_{2}^{-}$ | < | 1.9×10^{-4} | CL=90% |
| Γ ₆₈ | $D^{*0}\overline{D}^{0}$ | < | 2.9×10^{-4} | CL=90% | | $D_s^{*+} a_2^{-}$ | < | 2.0×10^{-4} | CL=90% |
| Γ ₆₉ | $D^- D^+$ | (| $2.11 \pm 0.31) \times 10^{-4}$ | S=1.2 | Γ ₁₁₀ | $D_s^{\stackrel{3}{\sim}} K^{\stackrel{2}{+}}$ | (| $2.2 \pm 0.5) \times 10^{-5}$ | S=1.8 |
| Γ_{70} | $D^-D_s^+$ | (| $7.2 \pm 0.8 \times 10^{-3}$ | | | $D_s^{*-}K^+$ | i | $2.19 \pm 0.30) \times 10^{-5}$ | |
| Γ_{71} | $D^*(2010)^-D_s^+$ | (| $8.0 \pm 1.1) \times 10^{-3}$ | | Γ112 | $D_s^s K^*(892)^+$ | ì | | |
| Γ_{72} | $D^{-}D_{s}^{*+}$ | (| $7.4 \pm 1.6 \times 10^{-3}$ | | | = | | * | |
| Γ ₇₃ | $D^*(2010)^- D_s^{*+}$ | (| 1.77 ± 0.14) % | | | $D_s^{*-}K^*(892)^+$ | (| $3.2 \stackrel{+}{-} \stackrel{1.5}{1.3}) \times 10^{-5}$ | |
| Γ_{74} | $D_{s0}(2317)^{-}\ddot{K}^{+}	imes$ | (| 4.2 \pm 1.4) \times 10 ⁻⁵ | | 114 | $D_{s}^{-}\pi^{+}K^{0}$ | (| $1.10 \pm 0.33) \times 10^{-4}$ | |
| | $B(D_{s0}(2317)^- \to D_s^- \pi^0)$ | | | | Γ ₁₁₅ | $D_s^{*-}\pi^+ K^0$ | < | 1.10×10^{-4} | CL=90% |
| Γ ₇₅ | $D_{s0}(2317)^{-}\pi^{+}\times$ | < | $2.5 	 \times 10^{-5}$ | CL=90% | Γ ₁₁₆ | $D_s^- \pi^+ K^*(892)^0$ | < | 3.0×10^{-3} | CL=90% |
| | $B(D_{s0}(2317)^- \to D_s^- \pi^0)$ | | | | Γ ₁₁₇ | $D_s^{*-}\pi^+K^*(892)^0$ | < | 1.6×10^{-3} | CL=90% |
| Γ_{76} | $D_{sJ}(2457)^-K^+ \times$ | < | 9.4×10^{-6} | CL=90% | Γ ₁₁₈ | $\overline{D}_{0}^{0}K^{0}$ | (| $5.2 \pm 0.7) \times 10^{-5}$ | |
| | $B(D_{sJ}(2457)^- \to D_s^- \pi^0)$ | | | | | $\overline{D}^0 K^+ \pi^-$ | (| $8.8 \pm 1.7) \times 10^{-5}$ | |
| Γ ₇₇ | $D_{sJ}(2457)^-\pi^+ \times$ | < | 4.0×10^{-6} | CL=90% | Γ ₁₂₀ | | (| $4.2 \pm 0.6 \times 10^{-5}$ | |
| | $B(D_{sJ}(2457)^- \to D_s^- \pi^0)$ | | | | Γ ₁₂₁ | $D_2^*(2460)^- K^+ \times$ | (| $1.8 \pm 0.5 \times 10^{-5}$ | |
| Γ ₇₈ | $D_s^- D_s^+$ | < | 3.6×10^{-5} | CL=90% | _ | $B(D_2^*(2460)^- \to \overline{D}{}^0\pi^-)$ | | | |
| Γ ₇₉ | $D_{s}^{*-}D_{s}^{+}$ | < | 1.3 × 10 ⁻⁴ | CL=90% | Γ ₁₂₂ | $\overline{D}{}^0K^+\pi^-$ non-resonant | <, | 3.7×10^{-5} | CL=90% |
| Γ ₈₀ | $D_{s}^{*-}D_{s}^{*+}$ | < | 2.4 × 10 ⁻⁴ | CL=90% | 123 F | $\overline{D}^0 \pi^0$ $\overline{D}^0 \rho^0$ | (| $2.63 \pm 0.14) \times 10^{-4}$ $3.2 \pm 0.5) \times 10^{-4}$ | |
| | | | | | ' 124 | $\frac{\overline{D}}{\overline{D}}{}^{0} f_{2}$ | (| $1.2 \pm 0.4 \times 10^{-4}$ | |
| Γ ₈₁ | $D_{s0}(2317)^+D^-\times$ | (| $9.7 ^{+}_{-} \overset{4.0}{3.3}) \times 10^{-4}$ | S=1.5 | Γ _{1.26} | $\frac{\overline{D}}{\overline{D}}{}^{0}\eta$ | (| $2.36 \pm 0.32) \times 10^{-4}$ | S=2.5 |
| г | $B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)$ | | 9.5 × 10 ⁻⁴ | CL 000/ | F ₁₂₇ | $D^{\circ} \eta'$ | ì | $1.38 \pm 0.16) \times 10^{-4}$ | S=1.3 |
| 82 | $D_{s0}(2317)^+D^-\times$ | < | $9.5 	 \times 10^{-4}$ | CL=90% | Γ ₁₂₈ | $D^0\omega$ | į. | $2.53 \pm 0.16) \times 10^{-4}$ | |
| г | $B(D_{s0}(2317)^+ \to D_s^{*+} \gamma)$ | , | $1.5 \pm 0.6) \times 10^{-3}$ | | Γ129 | $D^{\circ}\phi$ | < | 1.16 $\times 10^{-5}$ | CL=90% |
| 83 | $D_{s0}(2317)^+ D^*(2010)^- \times$ | (| 1.5 ± 0.6) × 10 ⁻⁵ | | Γ130 | $D^{0} K^{+} \pi^{-}$ | (| $6 \pm 4) \times 10^{-6}$ | |
| F | $B(D_{s0}(2317)^+ \rightarrow D_s^+ \pi^0)$ | , | 3 - 1 - 1 - 3 | | Γ ₁₃₁ | $-D^{0}K^{*}(892)^{0}$ | < | 1.1 $\times 10^{-5}$ | CL=90% |
| 84 | $D_{sJ}(2457)^+D^-$ | , | $3.5 \pm 1.1 \times 10^{-3}$ | | Γ ₁₃₂ | $\overline{D}^{*0} \gamma$ | < , | 2.5×10^{-5} | CL=90% |
| Γ ₈₅ | $D_{sJ}(2457)^+ D^- \times$ | (| 6.5 | | l 133 | $\frac{\overline{D}^*(2007)^0}{\overline{D}^*(2007)^0}\pi^0$ | (| 2.2 ± 0.6) $\times 10^{-4}$ | S=2.6 |
| | $B(D_{sJ}(2457)^+ \to D_s^+ \gamma)$ | | | | l 134 | $\overline{D}^*(2007)^0 \rho^0 \over \overline{D}^*(2007)^0 \eta$ | | 5.1×10^{-4} | CL=90% |
| Γ ₈₆ | $D_{sJ}(2457)^+ D^- \times$ | < | $6.0 	 \times 10^{-4}$ | CL=90% | ! 135 Г | $\overline{D}^*(2007)^0\eta'$ | | 2.3 ± 0.6) × 10^{-4} 1.40 ± 0.22) × 10^{-4} | S=2.8 |
| | $B(D_{sJ}(2457)^+ \to D_s^{*+}\gamma)$ | | | | ' 136 F ₁₂₇ | $\underline{\underline{D}}^*(2007)^0\pi^+\pi^-$ | | $6.2 \pm 2.2 \times 10^{-4}$ | |
| Γ ₈₇ | $D_{sJ}(2457)^+D^- \times$ | < | 2.0×10^{-4} | CL=90% | Γ ₁₂₀ | $\underline{\underline{D}}^*(2007)^0 K^0$ | | $3.6 \pm 1.2 \times 10^{-5}$ | |
| | $B(D_{sJ}(2457)^+ 	o$ | | | | Γ139 | $\overline{D}^*(2007)^0 K^*(892)^0$ | | 6.9 × 10 ⁻⁵ | CL=90% |
| | $D_s^+ \pi^+ \pi^-)$ | | | | Γ ₁₄₀ | D*(2007) ⁰ K*(892) ⁰ | | 4.0 × 10 ⁻⁵ | CL=90% |
| Γ ₈₈ | $D_{sJ}(2457)^+D^- \times$ | < | $3.6 	 \times 10^{-4}$ | CL=90% | Γ ₁₄₁ | $D^*(2007)^0 \pi^+ \pi^+ \pi^- \pi^-$ | | $2.7~\pm~0.5~)\times10^{-3}$ | |
| | $B(D_{sJ}(2457)^+ \to D_s^+ \pi^0)$ | | | | Γ ₁₄₂ | $D^*(2010)^+ D^*(2010)^-$ | (| 8.2 \pm 0.9) \times 10 ⁻⁴ | |
| Γ ₈₉ | $D^*(2010)^- D_{sJ}(2457)^+$ | | 9.3 \pm 2.2) \times 10 ⁻³ | | Γ ₁₄₃ | $\overline{D}^*(2007)^0 \omega$ | | $3.6 \pm 1.1) \times 10^{-4}$ | S=3.1 |
| Γ_{90} | $D_{sJ}(2457)^+ D^*(2010) \times$ | (| $2.3 ^{+}_{-} \stackrel{0.9}{0.7}) \times 10^{-3}$ | | Γ ₁₄₄ | $D^*(2010)^+D^-$ | | $6.1 \pm 1.5 \times 10^{-4}$ | S=1.6 |
| | $B(D_{sJ}(2457)^+ 	o D_s^+ \gamma)$ | | | | l ₁₄₅ | $D^*(2007)^0 \overline{D}^*(2007)^0$ | | 9 × 10 ⁻⁵ | CL=90% |
| Γ_{91} | $D^-D_{c1}(2536)^+ \times$ | (| $2.8~\pm~0.7~)\times10^{-4}$ | | l 146 | $D^{-}D^{0}K^{+}$ $D^{-}D^{*}(2007)^{0}K^{+}$ | | $1.07 \pm 0.11) \times 10^{-3}$ | |
| | $B(D_{s1}(2536)^+ \rightarrow D^{*0}K^+$ | | | | ¹ 147 г | $D^*(2007)^{\circ}K^{+}$ $D^*(2010)^{-}D^{0}K^{+}$ | | $3.5 \pm 0.4 \times 10^{-3}$ $2.47 \pm 0.21 \times 10^{-3}$ | |
| | $+ D^{*+} K^{0}$ | | | | ' 148 Γ | $D^*(2010)^- D^*(2007)^0 K^+$ | | 1.06 ± 0.09) % | |
| | | | | | Γ ₁₅₀ | $D^{-}D^{+}K^{0}$ | | 7.5 \pm 1.7) \times 10 ⁻⁴ | |
| | | | | | . 130 | | ` | , | |

 B^0

| Γ ₁₅₁ | $D^*(2010)^- D^+ K^0 + \ D^- D^*(2010)^+ K^0$ | $(6.4\pm0.5)\times10^{-3}$ | | Γ ₂₁₁ | $\chi_{c1}(1P)K^*(892)^0$ | (| 2.22^{+}_{-} $\stackrel{0.40}{0.31}) \times 10^{-4}$ | S=1.6 |
|--------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------------|------------------|--------------------------------------|------------------------------------------------------------------------------------|-------|-----------------------------------------------------------------------|------------------|
| | $D^*(2010)^- D^*(2010)^+ K^0$ | $(8.1 \pm 0.7) \times 10^{-3}$ | | Γ ₂₁₂ | $X(4051)^{+}K^{-}\times B(X^{+}\to X^{+})$ | (| $3.0 \ ^{+}_{-} \ ^{4.0}_{1.8} \) \times 10^{-5}$ | |
| Γ ₁₅₃ | $D^{*-}D_{51}(2536)^+ 	imes B(D_{s1}(2536)^+ 	o D^{*+}K^0)$ | $(8.0 \pm 2.4) \times 10^{-4}$ | | Γ ₂₁₃ | $\chi_{c1} \pi^+)$ $X(4248)^+ K^- \times B(X^+ \rightarrow X^+)$ | (| 4.0 $^{+20.0}_{-1.0}$) $\times10^{-5}$ | |
| Γ _{15.4} | $\overline{D}{}^0D^0K^0$ | $(2.7 \pm 1.1) \times 10^{-4}$ | | | $\chi_{c1} \pi^+)$ | | | |
| Γ ₁₅₅ | $\overline{D}^{0}D^{*}(2007)^{0}K^{0} +$ | $(1.1 \pm 0.5) \times 10^{-3}$ | | | <i>K</i> or <i>K</i> * | | | |
| | $\overline{D}^*(2007)^0 D^0 K^0$ | | | Γ ₂₁₄ | K ⁺ π ⁻ | (| $1.94 \pm 0.06) \times 10^{-5}$ | |
| | | $(2.4 \pm 0.9) \times 10^{-3}$ | | l 215 | $K^0 \pi^0$ | (| $9.5 \pm 0.8 \times 10^{-6}$ | S=1.3 |
| Γ ₁₅₇ | $(\overline{D} + \overline{D}^*)(D + D^*)K$ | (3.68 ± 0.26) % | | l 216 | $\eta' K^0 \\ \eta' K^* (892)^0$ | (| $6.6 \pm 0.4 \times 10^{-5}$ $3.1 \pm 0.9 \times 10^{-6}$ | S=1.4 |
| | Charmonium mo | des | | Γ _{21.7} | $\eta' K_0^* (1430)^0$ | | $6.3 \pm 1.6 \times 10^{-6}$ | |
| Γ ₁₅₈ | $\eta_{c} K^{0}$ | $(8.3 \pm 1.2) \times 10^{-4}$ | | Γ _{21.0} | $\eta' K_2^* (1430)^0$ | | $1.37 \pm 0.32 \times 10^{-5}$ | |
| F15.9 | $n_c K^* (892)^0$ | ($6.4~\pm~0.9$) $\times10^{-4}$ | | | | | , | |
| Γ_{160} | $\eta_c(2S) K^{*0}$ | | CL=90% | | ηK^0 | | 1.23^{+}_{-} $\stackrel{0.27}{0.24}) \times 10^{-6}$ | |
| 161 | | 4 × 10 ⁻⁴ | CL=90% | Γ ₂₂₁ | $\eta K^*(892)^0$ | | $1.59 \pm 0.10) \times 10^{-5}$ | |
| | $J/\psi(1S) K^0$ | $(8.74 \pm 0.32) \times 10^{-4}$ | | I 222 | $\eta K_0^*(1430)^0$ | | $1.10 \pm 0.22) \times 10^{-5}$ | |
| _ | $J/\psi(1S) K^+ \pi^-$ $J/\psi(1S) K^*(892)^0$ | $(1.2 \pm 0.6) \times 10^{-3}$ $(1.34 \pm 0.06) \times 10^{-3}$ | | I 223 | $\eta K_{2}^{*}(1430)^{0}$ | | $9.6 \pm 2.1 \times 10^{-6}$ | |
| Ι ₁₆₄ Γ ₁₆₅ | $J/\psi(1S) \mathcal{H}_{S}^{(0S2)}$ | $(8 \pm 4) \times 10^{-5}$ | | I 224 | ωK^{0} $a_0(980)^0 K^0 \times B(a_0(980)^0 \rightarrow$ | | 5.0 ± 0.6) $\times 10^{-6}$ 7.8 $\times 10^{-6}$ | CL=90% |
| Γ166 | | $\begin{array}{ccc} 2.5 & \times 10^{-5} \end{array}$ | CL=90% | 1 225 | $\eta \pi^0$) $\times B(a_0(900) \rightarrow \eta \pi^0)$ | < | 7.8 × 10 - | CL=90% |
| Γ167 | $J/\psi(1S)\phi K^0$ | $(9.4 \pm 2.6) \times 10^{-5}$ | 02-7070 | Гээс | $b_1^0 \overset{\eta \pi}{K^0} \times B(b_1^0 \to \omega \pi^0)$ | _ | 7.8 $\times 10^{-6}$ | CL=90% |
| Γ ₁₆₈ | $J/\psi(1S)\omega K^0$ | $(2.3 \pm 0.4) \times 10^{-4}$ | | | $a_0(980)^{\pm} K^{\mp} \times B(a_0(980)^{\pm} \rightarrow$ | | 1.9 × 10 ⁻⁶ | CL=90% |
| Γ ₁₆₉ | $X(3872) K^0 \times B(X \rightarrow J/\psi \omega)$ | (6.0 ± 3.2) $\times 10^{-6}$ | | | $\eta \pi^{\pm}$) | - | | |
| Γ ₁₇₀ | | $(2.1 \pm 0.9) \times 10^{-5}$ | | | $b_1^- \dot{K}^+ \times B(b_1^- \rightarrow \omega \pi^-)$ | (| $7.4 \pm 1.4 \times 10^{-6}$ | |
| Γ ₁₇₁ | $J/\psi(1S) K(1270)^0$ | $(1.3 \pm 0.5) \times 10^{-3}$ | | Γ ₂₂₉ | $b_1^{ar{0}} K^{*0} 	imes B(b_1^{ar{0}} 	o \omega \pi^0)$ | < | $8.0 	 \times 10^{-6}$ | CL=90% |
| | $J/\psi(1S)\pi^0$ | $(1.76 \pm 0.16) \times 10^{-5}$ | S=1.1 | Γ ₂₃₀ | $b_1^- K^{*+} 	imes B(b_1^- 	o \ \omega \pi^-)$ | < | $5.0 	 \times 10^{-6}$ | CL=90% |
| | $J/\psi(1S) \eta$ $J/\psi(1S) \pi^+ \pi^-$ | $(9.5 \pm 1.9) \times 10^{-6}$ $(4.6 \pm 0.9) \times 10^{-5}$ | | Γ ₂₃₁ | $a_0(1450)^{\pm} K^{\mp} \times$ | < | 3.1×10^{-6} | CL=90% |
| Γ ₁₇₅ | | $(4.0 \pm 0.3) \times 10^{-5}$ | CL=90% | _ | $B(a_0(1450)^{\pm} \to \eta \pi^{\pm})$ | | r. | |
| Γ ₁₇₆ | $J/\psi(1S) f_2$ | | CL=90% | | $K_S^0 X^0$ (Familon) | | 5.3 × 10 ⁻⁵ | CL=90% |
| Γ ₁₇₇ | $J/\psi(1S)\rho^{0}$ | $(2.7 \pm 0.4) \times 10^{-5}$ | | I 233 | $\omega K^*(892)^0$ | | 2.0 ± 0.5) $\times 10^{-6}$ | |
| | $J/\psi(1S)\omega$ | | CL=90% | | $\omega (K\pi)_0^{*0}$ $\omega K_0^* (1430)^0$ | | $1.84 \pm 0.25) \times 10^{-5}$ $1.60 \pm 0.34) \times 10^{-5}$ | |
| Γ_{179} | | $9.4 	 \times 10^{-7}$ | CL=90% | г 235 Гала | $\omega K_0^* (1430)^0$ | | $1.00 \pm 0.34) \times 10$ $1.01 \pm 0.23) \times 10^{-5}$ | |
| 180 | | 6.3 × 10 ⁻⁵ | CL=90% | ' 236 Гоза | $\omega K_2^+(1450)$ $\omega K^+\pi^-$ nonresonant | (| $5.1 \pm 1.0 \times 10^{-6}$ | |
| Γ ₁₈₁ | | $(1.0 \pm 0.4) \times 10^{-3}$ $(5.4 \pm 3.0) \times 10^{-4}$ | | Γ ₂₃₈ | $K^+\pi^-\pi^0$ | ì | $3.78 \pm 0.32) \times 10^{-5}$ | |
| T ₁₈₃ | | $(8 \pm 4) \times 10^{-4}$ | | Γ ₂₃₉ | $K^+ ho^-$ | (| $7.0 \pm 0.9 \times 10^{-6}$ | |
| Γ ₁₈₄ | | $(6.6 \pm 2.2) \times 10^{-4}$ | | Γ ₂₄₀ | $K^{+} \rho (1450)^{-}$ | | $2.4 \pm 1.2 \times 10^{-6}$ | |
| Γ_{185} | $X(3872)^{-}K^{+}$ | 5×10^{-4} | CL=90% | Γ ₂₄₁ | | | $6 \pm 7) \times 10^{-7}$ | |
| Γ ₁₈₆ | $X(3872)^{-}K^{+} \times B(X(3872)^{-} \rightarrow [c] <$ | $4.2 	 \times 10^{-6}$ | CL=90% | Γ ₂₄₂ | $(K^+\pi^-\pi^0)$ non-resonant $(K\pi)_0^{*+}\pi^-	imes B((K\pi)_0^{*+} ightarrow$ | | 2.8 ± 0.6) $\times 10^{-6}$ 3.4 ± 0.5) $\times 10^{-5}$ | |
| Γ | $J/\psi(1S)\pi^{-}\pi^{0})$ $X(3872)K^{0}\times B(X \rightarrow$ | $(4.3 \pm 1.3) \times 10^{-6}$ | | T ₂₄₃ | $(K^+\pi^0)$ | (| 3.4 ± 0.5) × 10 | |
| ' 187 | $J/\psi \pi^+ \pi^-$) | (4.5 ± 1.5) × 10 | | Γ ₂₄₄ | $(K\pi)_0^{*0}\pi^0 \times B((K\pi)_0^{*0} \to$ | (| $8.6 \pm 1.7 \times 10^{-6}$ | |
| Γ ₁₈₈ | $X(3872) K^0 \times B(X \rightarrow J/\psi \gamma)$ | $2.4 	 \times 10^{-6}$ | CL=90% | | $K^+\pi^-$) | , | , | |
| Γ ₁₈₉ | $X(3872)K^*(892)^0 \times B(X \to $ | $\times 10^{-6}$ | CL=90% | Γ ₂₄₅ | $K_2^*(1430)^{0'}\pi^0$ | < | 4.0×10^{-6} | CL=90% |
| _ | $J/\psi\gamma$) | 6 | | Γ ₂₄₆ | $K^{*}(1680)^{0}\pi^{0}$ | | 7.5 $\times 10^{-6}$ | CL=90% |
| l 190 | 30 | $6.62 	 \times 10^{-6}$ $4.4 	 \times 10^{-6}$ | CL=90% CL=90% | Γ ₂₄₇ | $K_X^{*\dot{0}}\pi^0$ | | $6.1 \pm 1.6 \times 10^{-6}$ | |
| ' 191 | $\psi(2S)\gamma$ | . 4.4 × 10 | CL_90/0 | Γ ₂₄₈ | $K^0 \pi^+ \pi^-$ charmless | | $4.96 \pm 0.20) \times 10^{-5}$ | |
| Γ_{192} | $X(3872)K'^0 \times B(X \rightarrow$ | $(1.7 \pm 0.8) \times 10^{-4}$ | | Г ₂₄₉ | $K^0\pi^+\pi^-$ non-resonant | | 1.47^{+}_{-} $\stackrel{0.40}{0.26}$) $\times 10^{-5}$ | S=2.1 |
| | $D^0 \overline{D}{}^0 \pi^0$) | | | Γ _{25 0} | $K^0 \rho^0$ | (| $4.7 \pm 0.6 \times 10^{-6}$ | |
| | | (1.2 ± 0.4) $\times 10^{-4}$ | | Г ₂₅₁ | $K^*(892)^+\pi^- \ K^*_0(1430)^+\pi^-$ | (| $8.4 \pm 0.8 \times 10^{-6}$ | C 2.0 |
| Γ_{194} | | $(3.2 \ ^{+}_{-} \ ^{6.0}_{1.8} \) \times 10^{-5}$ | | Ι ₂₅₂ Γ ₂₅₃ | $K_0^{(1430)} \cdot \pi$ $K_x^{*+} \pi^-$ | | $3.3 \pm 0.7 \times 10^{-5}$ $5.1 \pm 1.6 \times 10^{-6}$ | S=2.0 |
| г | $\psi(2S)\pi^{\pm})$ $X(4430)^{\pm}K^{\mp}\times B(X^{\pm}\rightarrow$ | | CL 050/ | Γ ₂₅₄ | $K^*(1410)^+\pi^- \times$ | | 3.8 × 10 ⁻⁶ | CL=90% |
| 195 | $J/\psi \pi^{\pm})$ | 4 × 10 ⁻⁶ | CL=95% | . 234 | $B(K^*(1410)^+ \to K^0\pi^+)$ | • | | |
| Γ196 | | 8.3 × 10 ⁻⁷ | CL=90% | Γ ₂₅₅ | $f_0(980) K^0 \times B(f_0(980) \rightarrow$ | (| 7.0 \pm 0.9 $)\times10^{-6}$ | |
| Γ_{197} | $J/\psi(1S)\gamma$ | $1.6 	 \times 10^{-6}$ | CL=90% | | $\pi^+\pi^-)$ | | | |
| Γ ₁₉₈ | | $1.3 	 \times 10^{-5}$ | CL=90% | Γ _{25 6} | $f_2(1270) K^0$ | (| $2.7 \ ^{+}_{-} \ ^{1.3}_{1.2} \) \times 10^{-6}$ | |
| F ₁₉₉ | $\psi(2S)K^0$ | $(6.2 \pm 0.5) \times 10^{-4}$ | G. 000/ | Γ _{25 7} | $f_X(1300) K^0 \times B(f_X \rightarrow$ | (| $1.8 \pm 0.7) \times 10^{-6}$ | |
| I 200 Гааг | | $\begin{array}{ccc} 1.23 & \times 10^{-4} \\ 1.88 & \times 10^{-4} \end{array}$ | CL=90% CL=90% | _ | $\pi^{+}\pi^{-}$) | | , | |
| F202 | $\psi(2S)K^+\pi^-$ | $(5.7 \pm 0.4) \times 10^{-4}$ | CL=7070 | I 25 8 | $K^*(892)^0 \pi^{0'}$ $K^*(1430)^+ -^-$ | | 3.3 ± 0.6) $\times 10^{-6}$ | CL 000/ |
| Γ ₂₀₃ | $\psi(2S) K^*(892)^0$ | $(6.1 \pm 0.5) \times 10^{-4}$ | S=1.1 | г 25 9 Гала | $K_2^*(1430)^+\pi^-$ $K^*(1680)^+\pi^-$ | | 6×10^{-6} 1.0×10^{-5} | CL=90% CL=90% |
| | | $(1.4 \begin{array}{c} + & 0.6 \\ - & 0.5 \end{array}) \times 10^{-4}$ | | 1 260 F261 | $K^{+}\pi^{-}\pi^{+}\pi^{-}$ | [e] < | | CL=90% CL=90% |
| F205 | $\chi_{c0} K^*(892)^0$ | $(1.7 \pm 0.4) \times 10^{-4}$ | | Γ ₂₆₂ | $\rho^0 K^+ \pi^-$ | | $2.8 \pm 0.7 \times 10^{-6}$ | |
| Γ ₂₀₆ | $\chi_{c2}K^0$ | $1.5 	 \times 10^{-5}$ | CL=90% | Γ ₂₆₃ | $f_0(980) K^+ \pi^-$ | | $1.4 \ ^{+}_{-} \ ^{0.5}_{0.6} \) \times 10^{-6}$ | |
| I 207 | $\chi_{c2} K^* (892)^{\circ}$ | $(6.6 \pm 1.9) \times 10^{-5}$ | | Γ ₂₆₄ | $K^+\pi^-\pi^+\pi^-$ nonresonant | | 2.1 × 10 ⁻⁶ | CL=90% |
| Γ208 | $\chi_{c1}(1P)\pi^0$ | $(1.12\pm 0.28) \times 10^{-5}$ | | Γ ₂₆₅ | $K^*(892)^0\pi^+\pi^-$ | | $5.5 \pm 0.5 \times 10^{-5}$ | |
| I 209 Гана | $\chi_{c1}(1P)K^0$ | $(3.93 \pm 0.27) \times 10^{-4}$ $(3.8 \pm 0.4) \times 10^{-4}$ | | Γ ₂₆₆ | $K^*(892)^0 \rho^0$ | (| $3.4 \begin{array}{c} + & 1.7 \\ - & 1.3 \end{array}) \times 10^{-6}$ | S=1.8 |
| ' 210 | $\chi_{c1}(1P)K^{-}\pi^{+}$ | (3.0 ± 0.4) × 10 ' | | Γ ₂₆₇ | $K^*(892)^0 f_0(980)$ | | 2.2×10^{-6} | CL=90% |
| | | | | Γ ₂₆₈ | $K_1(1270)^+\pi^-$ | | 3.0 × 10 ⁻⁵ | CL=90% |
| | | | | 200 | | | | |

| Γ ₂₆₉ | $K_1(1400)^+\pi^-$ | < | | CL=90% | Γ ₃₃₈ | $\eta' f_0(980) \times B(f_0(980) \rightarrow -+)$ | < | 9 | $\times 10^{-7}$ | CL=90% |
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| Г ₂₇₀ | $a_1(1260)^- K^+ K^*(892)^+ \rho^-$ | [e] (| $\begin{array}{ccc} 1.6 & \pm & 0.4 &) \times 10^{-5} \\ 1.20 & \times 10^{-5} \end{array}$ | CL=90% | Гааа | ηho^0 | | 1.5 | $\times 10^{-6}$ | CL=90% |
| 1 271 F272 | $K_1(1400)^0 \rho^0$ | < | 3.0 × 10 ⁻³ | CL=90% | | $\eta f_0(980) \times B(f_0(980) \to$ | < | | × 10 ⁻⁷ | CL=90% |
| | K+ K- | < | 4.1 × 10 ⁻⁷ | CL=90% | - 540 | $\pi^{+}\pi^{-}$) | | • | | |
| | $K^0\overline{K}^0$ | | $9.6 {}^{+}_{-} {}^{2.0}_{1.8}) 	imes 10^{-7}$ | | Γ ₃₄₁ | , | (| 94 + | $^{4.0}_{3.1}$) $\times 10^{-7}$ | |
| | | , | _ | | | | | | | |
| l ₂₇₅ | $\frac{K^0 K^- \pi^+}{K^{*0} K^0 + K^{*0} \overline{K}^0}$ | (| $6.4 \pm 1.2 \times 10^{-6}$ 1.9×10^{-6} | | Γ ₃₄₂ | $\omega \eta'$ | (| 1.0 + | $_{0.4}^{0.5}$) $\times 10^{-6}$ | |
| I 276 | $K^+K^-\pi^0$ | < | $1.9 	 \times 10^{-6}$ $1.9 	 \times 10^{-5}$ | CL=90% | Γ ₃₄₃ | $\omega \rho^0$ | < | 1.6 | $\times 10^{-6}$ | CL=90% |
| Γ277 | $K_S^0 K_S^0 \pi^0$ | < | 9 × 10 ⁻⁷ | CL=90% | Γ ₃₄₄ | $\omega f_0(980) \times B(f_0(980) \rightarrow$ | < | 1.5 | $\times 10^{-6}$ | CL=90% |
| Γ ₂₇₉ | $K_{S}^{0}K_{S}^{0}\eta$ | < | 1.0 × 10 ⁻⁶ | CL=90% | | $\pi^+\pi^-)$ | | | | |
| Γ ₂₈₀ | $K_S^0 K_S^0 \eta'$ | < | 2.0 × 10 ⁻⁶ | CL=90% | | $\omega \omega$ | < | 4.0 | × 10 ⁻⁶ | CL=90% |
| | $K^0K^+K^-$ | (| E | | | $\phi \pi^0$ | < | 2.8 | × 10 ⁻⁷ | CL=90% |
| Γ ₂₈₂ | $K^0 \phi$ | (| . 12 | | Γ ₃₄₇ | | < | 5 5 | $\times 10^{-7} \times 10^{-7}$ | CL=90% CL=90% |
| | | | | | Г ₃₄₈ | $\phi \rho^0$ | < | 3.3 | × 10 × 10 ⁻⁷ | CL=90% |
| Γ ₂₈₃ | $K_S^0 K_S^0 K_S^0$ | (| 6.2 | S=1.3 | | $\phi f_0(980) \times B(f_0 \to \pi^+ \pi^-)$ | < | 3.8 | × 10 ⁻⁷ | CL=90% |
| Γ ₂₈₄ | $K_S^0 K_S^0 K_L^0$ | < | 1.6×10^{-5} | CL=90% | Γ ₃₅₁ | | < | 1.2 | $\times 10^{-6}$ | CL=90% |
| Γ_{285} | $K^*(892)^{0}K^{+}K^{-}$ | (| $2.75 \pm 0.26) \times 10^{-5}$ | | Γ _{35 2} | | < | 2 | $\times 10^{-7}$ | CL=90% |
| Γ_{286} | $K^*(892)^0 \phi$ | (| $9.8 \pm 0.6 \times 10^{-6}$ | | Γ _{35 3} | $a_0(980)^{\pm}\pi^{\mp} \times B(a_0(980)^{\pm} \to$ | < | 3.1 | $\times 10^{-6}$ | CL=90% |
| Γ ₂₈₇ | $K^+K^-\pi^+\pi^-$ nonresonant | < | 7.17 $\times 10^{-5}$ | CL=90% | | $\eta \pi^{\pm})$ | | | | |
| Γ ₂₈₈ | $K^*(892)^0 K^- \pi^+$ | (| _ | _ | Γ ₃₅₄ | $a_0(1450)^{\pm} \pi^{\mp} \times B(a_0(1450)^{\pm} \rightarrow$ | < | 2.3 | $\times 10^{-6}$ | CL=90% |
| I 289 | $K^*(892)^0 \overline{K}^*(892)^0$ | (| 8 ± 5) × 10 ⁻⁷ | S=2.2 | F | $\eta \pi^{\pm}$) | | 7.0 | | CI 0001 |
| | $K^+K^+\pi^-\pi^-$ nonresonant $K^*(892)^0K^+\pi^-$ | < | $6.0 	 \times 10^{-6}$ $2.2 	 \times 10^{-6}$ | CL=90% CL=90% | | $\pi^{+}\frac{1}{\pi^{-}\pi^{0}}$ $\rho^{0}\pi^{0}$ | < , | 7.2 | $\times 10^{-4}$ 0.5) $\times 10^{-6}$ | CL=90% |
| Γ ₂₉₁ Γ ₂₉₂ | $K^*(892)^0 K^*(892)^0$ | < | 2.2×10^{-7} | CL=90% CL=90% | Г _{35 6} Г _{35 7} | $\rho^{\pm}\pi^{\pm}$ | [h] (| | 0.5×10^{-5} 0.23×10^{-5} | |
| | $K^*(892)^+ K^*(892)^-$ | < | , | CL=90% | Гз5 7 Гз5 о | $\pi^{+}\pi^{-}\pi^{+}\pi^{-}$ | | 1.93 | × 10 ⁻⁵ | CL=90% |
| Γ ₂₉₄ | $K_1(1400)^0 \phi$ | < | | CL=90% | Γ _{35 9} | $\rho^0 \pi^+ \pi^-$ | < | 8.8 | × 10 ⁻⁶ | CL=90% |
| Γ ₂₉₅ | $\phi(K\pi)_0^{*0}$ | (| $4.3 \pm 0.7) \times 10^{-6}$ | | Γ ₃₆₀ | $\rho^0 \rho^0$ | (| 7.3 ± | $2.8) \times 10^{-7}$ | |
| Γ_{296} | $\phi (K\pi)_0^{*0} (1.60 < m_{K\pi} < 2.15)$ | [f] | 1.7×10^{-6} | CL=90% | Γ ₃₆₁ | $f_0(980)\pi^+\pi^-$ | < | 3.8 | $\times 10^{-6}$ | CL=90% |
| Γ_{297} | $K_0^*(1430)^{\bar{0}} K^- \pi^+$ | < | 3.18×10^{-5} | CL=90% | Γ ₃₆₂ | $\rho^0 f_0(980) \times B(f_0(980) \to$ | < | 3 | $\times 10^{-7}$ | CL=90% |
| Γ ₂₉₈ | $K_0^*(1430)^0 \overline{K}^*(892)^0$ | < | 3.3×10^{-6} | CL=90% | _ | $\pi^+\pi^-)$ | | | - | |
| Γ_{299} | $K_0^*(1430)^0 \overline{K}_0^*(1430)^0$ | < | 8.4×10^{-6} | CL=90% | Γ ₃₆₃ | $f_0(980) f_0(980) \times P_2(f_0(980)) \times P_2(f_0(980)) + P_2(f_0($ | < | 1 | × 10 ⁻⁷ | CL=90% |
| Γ_{300} | $K_0^*(1430)^0 \phi$ | (| $3.9 \pm 0.8 \times 10^{-6}$ | | Гаса | $B^2(f_0(980) \to \pi^+\pi^-)$ $f_0(980) f_0(980) \times B(f_0 \to$ | | 2.3 | × 10=7 | CL=90% |
| Γ_{301} | $K_0^*(1430)^0 K^*(892)^0$ | < | $1.7 	 \times 10^{-6}$ | CL=90% | 1 364 | $\pi^+\pi^-) \times B(f_0 \to K^+K^-)$ | | 2.3 | × 10 | CL _ 30 /0 |
| Γ_{302} | $K_0^*(1430)^0 K_0^*(1430)^0$ | < | $4.7 	 \times 10^{-6}$ | CL=90% | Γ ₃₆₅ | $a_1(1260)^{\mp}\pi^{\pm}$ | [h] (| 3.3 ± | $0.5) \times 10^{-5}$ | |
| Γ_{303} | $K^*(1680)^0 \phi$ | < | 3.5×10^{-6} | CL=90% | Г366 | $a_2(1320)^{\mp}\pi^{\pm}$ | [h] < | | $^{'} \times 10^{-4}$ | CL=90% |
| | $K^*(1780)^0 \phi$ | < | 2.7×10^{-6} | CL=90% | Γ ₃₆₇ | $\pi^{+} \frac{\pi^{-}}{\pi^{-}} \pi^{0} \pi^{0}$ | | 3.1 | $\times 10^{-3}$ | CL=90% |
| 305 | $K^*(2045)^0 \phi$ | < | $1.53 	 \times 10^{-5}$ | CL=90% | Γ ₃₆₈ | $\rho^+ \rho^-$ | (| $2.42\pm$ | $0.31) \times 10^{-5}$ | |
| | $K_2^*(1430)^0 \rho^0$ | < | 1.1 $\times 10^{-3}$ | CL=90% | Γ ₃₆₉ | a (10c0)U =U | | 1.1 | $\times 10^{-3}$ | CL=90% |
| | | | _ | | | $a_1(1260)^0\pi^0$ | < | 1.1 | | |
| Γ_{307} | $K_2^*(1430)^0 \phi$ | (| $7.5 \pm 1.0 \times 10^{-6}$ | | Γ ₃₇₀ | $\omega \pi^0$ | < | 5 | $\times 10^{-7}$ | CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ | $K_2^*(1430)^0 \phi \ K^0 \phi \phi$ | (| 7.5 \pm 1.0) \times 10 ⁻⁶ 4.5 \pm 0.9) \times 10 ⁻⁶ | CL 00% | Γ ₃₇₀ Γ ₃₇₁ | $\frac{\omega \pi^0}{\pi^+ \pi^+ \pi^- \pi^- \pi^0}$ | < < | 5 9.0 | $^{\times 10^{-7}}_{\times 10^{-3}}$ | CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ | $K_2^*(1430)^0 \phi$ $K^0 \phi \phi$ $\eta' \eta' K^0$ | ((< | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ | $\omega \pi^0 \\ \pi^+ \pi^+ \pi^- \pi^- \pi^0 \\ a_1 (1260)^+ \rho^-$ | < < < | 5 9.0 6.1 | $ \begin{array}{r} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \end{array} $ | CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0}$ $\eta K^{0} \gamma$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ | $\omega \pi^{0} \\ \pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0} \\ a_{1} (1260)^{+} \rho^{-} \\ a_{1} (1260)^{0} \rho^{0}$ | < < < | 5 9.0 6.1 2.4 | $\times 10^{-7}$ $\times 10^{-3}$ $\times 10^{-5}$ $\times 10^{-3}$ | CL=90% CL=90% |
| Γ_{307} Γ_{308} Γ_{309} Γ_{310} Γ_{311} | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0}$ $\eta K^{0} \gamma$ $\eta' K^{0} \gamma$ | (((< | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ Γ ₃₇₄ | $\begin{array}{c} \omega \pi^{0} \\ \pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0} \\ a_{1} (1260)^{+} \rho^{-} \\ a_{1} (1260)^{0} \rho^{0} \\ b_{1}^{\mp} \pi^{\pm} \times B (b_{1}^{\mp} \rightarrow \omega \pi^{\mp}) \end{array}$ | < < < (| 5 9.0 6.1 2.4 1.09 ± | $\begin{array}{c} \times10^{-7} \\ \times10^{-3} \\ \times10^{-5} \\ \times10^{-3} \\ 0.15)\times10^{-5} \end{array}$ | CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{0} \phi \gamma$ $K^{0} \phi \gamma$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ Γ ₃₇₄ Γ ₃₇₅ | $\begin{array}{c} \omega \pi^{0} \\ \pi^{+} \pi^{+} \pi^{-} \pi^{-} \pi^{0} \\ a_{1} (1260)^{+} \rho^{-} \\ a_{1} (1260)^{0} \rho^{0} \\ b_{1}^{\mp} \pi^{\pm} \times B (b_{1}^{\mp} \to \omega \pi^{\mp}) \\ b_{1}^{0} \pi^{0} \times B (b_{1}^{0} \to \omega \pi^{0}) \end{array}$ | < < < < < < < < < < < < < < < < < < < | 5 9.0 6.1 2.4 1.09± 1.9 | $\begin{array}{c} \times \ 10^{-7} \\ \times \ 10^{-3} \\ \times \ 10^{-5} \\ \times \ 10^{-3} \\ 0.15) \times \ 10^{-5} \\ \times \ 10^{-6} \end{array}$ | CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{0} \phi \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ | (< (| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | CL=90% | Γ ₃₇₀ Γ371 Γ372 Γ ₃₇₃ Γ ₃₇₄ Γ375 Γ ₃₇₆ | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\timesB(b_{1}^{\mp}\rightarrow\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\rightarrow\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{-}\rightarrow\omega\pi^{-}) \end{array}$ | < < < < < < < < < < < < < < < < < < < | $5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(1410) \gamma$ | ((((< | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ Γ ₃₇₄ Γ ₃₇₅ Γ ₃₇₆ | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\rightarrow\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\rightarrow\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{-}\rightarrow\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\rightarrow\omega\pi^{0}) \end{array}$ | < < < < < < < < < < < < < < < < < < < | $5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ Γ ₃₇₄ Γ ₃₇₅ Γ ₃₇₆ | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\timesB(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.9 1.4 3.4 3.0 | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ | $K_2^*(1430)^0 \phi$ $K^0 \phi \phi$ $\eta' \eta' K^0 \gamma$ $\eta' K^0 \gamma$ $\eta' K^0 \gamma$ $K^0 \phi \gamma$ $K^+ \pi^- \gamma$ $K^*(892)^0 \gamma$ $K^+ \pi^- \gamma$ nonresonant $K^*(892)^0 X(214) \times B(X \rightarrow$ | ((((< | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\timesB(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.9 1.4 3.4 3.0 | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ Γ ₃₁₇ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0}$ $\eta K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\timesB(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \end{array}$ | < < < < < < < < < < < < < < < < < < < | 5 9.0 6.1 2.4 1.09 ± 1.9 1.4 3.4 3.0 | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ Γ ₃₁₇ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0}$ $\eta K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{0} \gamma$ $K^{0} \phi \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(1410) \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm} \times B(b_{1}^{\mp} \to \omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0} \times B(b_{1}^{0} \to \omega\pi^{0}) \\ b_{1}^{-}\rho^{+} \times B(b_{1}^{-} \to \omega\pi^{-}) \\ b_{1}^{0}\rho^{0} \times B(b_{1}^{0} \to \omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-} \times \\ B^{2}(a_{1}^{+} \to 2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.9 1.4 3.4 3.0 1.18 ± | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ Γ ₃₁₇ Γ ₃₁₈ Γ ₃₁₉ Γ ₃₂₀ | $K_2^*(1430)^0 \phi$ $K^0 \phi \phi$ $\eta' \eta' K^0$ $\eta K^0 \gamma$ $\eta' K^0 \gamma$ $K^0 \phi \gamma$ $K^+ \pi^- \gamma$ $K^*(892)^0 \gamma$ $K^*(1410) \gamma$ $K^+ \pi^- \gamma$ nonresonant $K^*(892)^0 X(214) \times B(X \rightarrow \mu^+ \mu^-)$ $K^0 \pi^+ \pi^- \gamma$ $K^+ \pi^- \pi^0 \gamma$ $K_1(1270)^0 \gamma$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% | Γ ₃₇₀ Γ ₃₇₁ Γ ₃₇₂ Γ ₃₇₃ Γ ₃₇₄ Γ ₃₇₅ Γ ₃₇₇ Γ ₃₇₈ Γ ₃₇₉ | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm} \times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0} \times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+} \times B(b_{1}^{-}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0} \times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-} \times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \end{array}$ | <pre></pre> | 5 9.0 6.1 2.4 1.09 ± 1.9 1.4 3.4 3.0 1.18 ± | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ Γ ₃₁₇ Γ ₃₁₈ Γ ₃₁₉ Γ ₃₂₀ Γ ₃₂₁ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ $K^{0} \pi^{-} \gamma$ $K^{0} \pi^{-} \gamma$ $K^{0} \pi^{-} \gamma$ $K^{0} \pi^{-} \gamma$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \end{array}$ | <pre></pre> | 5 9.0 6.1 2.4 1.09 ± 1.4 3.4 3.0 1.18 ± 1.1 | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₃₀₇ Γ ₃₀₈ Γ ₃₀₉ Γ ₃₁₀ Γ ₃₁₁ Γ ₃₁₂ Γ ₃₁₃ Γ ₃₁₄ Γ ₃₁₅ Γ ₃₁₆ Γ ₃₁₇ Γ ₃₁₈ Γ ₃₁₉ Γ ₃₂₀ Γ ₃₂₁ Γ ₃₂₂ | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ $K_{1}^{0} (1270)^{0} \gamma$ $K_{1}^{0} (1400)^{0} \gamma$ $K_{2}^{*} (1430)^{0} \gamma$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho}\pi^{+}\pi^{-} \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.4 3.4 3.0 1.18 ± 1.1 | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-3}\\ \times10^{-3}\\ 0.15)\times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| F307 F308 F309 F310 F311 F312 F313 F314 F315 F316 F317 F318 F319 F320 F321 F322 F323 | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(1410) \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ $K^{+} \pi^{-} \pi^{0} \gamma$ $K_{1}(1270)^{0} \gamma$ $K_{1}(1400)^{0} \gamma$ $K_{2}^{*}(1430)^{0} \gamma$ $K^{*}(1680)^{0} \gamma$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F382 F383 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}\left(1260\right)^{0}\rho^{0} \\ b_{1}^{+}\pi^{+}\timesB(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{1}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}\left(1260\right)^{+}a_{1}\left(1260\right)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.4 3.4 3.0 1.18 ± 1.1 1.1 2.5 2.66 ± | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| F307 F308 F309 F310 F311 F312 F313 F314 F315 F316 F317 F318 F319 F320 F321 F322 F323 F324 | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(1410) \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ $K^{+} \pi^{-} \pi^{0} \gamma$ $K_{1}(1270)^{0} \gamma$ $K_{1}(1400)^{0} \gamma$ $K_{2}^{*}(1430)^{0} \gamma$ $K^{*}(1680)^{0} \gamma$ $K_{3}^{*}(1780)^{0} \gamma$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F382 F383 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho}\pi^{+}\pi^{-} \end{array}$ | < | 5 9.0 6.1 2.4 1.09 ± 1.4 3.4 3.0 1.18 ± 1.1 1.1 2.5 2.66 ± | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| F307 F308 F309 F310 F311 F312 F313 F314 F315 F316 F317 F318 F319 F320 F321 F322 F323 F324 | $K_{2}^{*}(1430)^{0} \phi$ $K^{0} \phi \phi$ $\eta' \eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $\eta' K^{0} \gamma$ $K^{+} \pi^{-} \gamma$ $K^{*}(892)^{0} \gamma$ $K^{*}(1410) \gamma$ $K^{+} \pi^{-} \gamma$ nonresonant $K^{*}(892)^{0} X (214) \times B(X \rightarrow \mu^{+} \mu^{-})$ $K^{0} \pi^{+} \pi^{-} \gamma$ $K^{+} \pi^{-} \pi^{0} \gamma$ $K_{1}(1270)^{0} \gamma$ $K_{1}(1400)^{0} \gamma$ $K_{2}^{*}(1430)^{0} \gamma$ $K^{*}(1680)^{0} \gamma$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F382 F383 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{1}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho}\\ \rho\overline{\rho}\pi^{+}\pi^{-}\\ \rho\overline{\rho}K^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to 0) \end{array}$ | <pre></pre> | 5 9.0 6.1 2.4 1.09 ± 1.4 3.4 3.0 1.18 ± 1.1 1.1 2.5 2.66 ± | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| F307 F308 F309 F310 F311 F312 F313 F314 F315 F316 F317 F318 F319 F320 F320 F321 F322 F323 F324 F325 | $\begin{array}{c} K_2^*(1430)^0\phi\\ K^0\phi\phi\\ \eta'\eta'K^0\gamma\\ \eta'K^0\gamma\\ \eta'K^0\gamma\\ K^+\pi^-\gamma\\ K^*(892)^0\gamma\\ K^*(1410)\gamma\\ K^+\pi^-\gamma \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Г370 Г371 Г372 Г373 Г374 Г375 Г376 Г377 Г380 Г380 Г381 Г382 Г383 Г384 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\eta^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{-}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho}\pi^{+}\pi^{-} \\ \rho\overline{\rho}K^{0} \\ \theta(1540)^{+}\overline{\rho}\times B(\theta(1540)^{+}\to\rho K^{0}_{S}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \end{array}$ | < | $5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \\ 0.31) \times 10^{-5} \\ \\ \% \\ \times 10^{-7} \\ \times 10^{-4} \\ 0.32) \times 10^{-6} \\ \times 10^{-8} \\ \times 10^{-7} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| \(\Gamma_{307}\) \(\Gamma_{308}\) \(\Gamma_{309}\) \(\Gamma_{310}\) \(\Gamma_{311}\) \(\Gamma_{312}\) \(\Gamma_{313}\) \(\Gamma_{313}\) \(\Gamma_{313}\) \(\Gamma_{314}\) \(\Gamma_{315}\) \(\Gamma_{320}\) \(\Gamma_{322}\) \(\Gamma_{323}\) \(\Gamma_{324}\) \(\Gamma_{325}\) \(\Gamma_{326}\) \(\Gam | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \eta' \eta' K^0 \gamma \\ \eta' K^0 \gamma \\ \eta' K^0 \gamma \\ K^0 \gamma \\ K^+ \alpha^- \gamma \\ K^*(892)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times \text{B} (X \rightarrow \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^1 (1270)^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K_2^*(1430)^0 \gamma \\ K^*(1680)^0 \gamma \\ K_3^* (1780)^0 \gamma \\ K_4^* (2045)^0 \gamma \\ \end{array}$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Г370 Г371 Г372 Г373 Г374 Г375 Г376 Г377 Г380 Г380 Г381 Г382 Г383 Г384 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\timesB(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \pi^{p}\kappa^{0} \\ \rho(1540)^{+}\overline{\rho}\timesB(\mathcal{O}(1540)^{+}\to\rho\kappa^{0}_{S}) \\ f_{J}(2220)K^{0}\timesB(f_{J}(2220)\to\infty) \end{array}$ | < | $5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-3} \\ 0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-3} \\ 0.31) \times 10^{-5} \\ \\ \% \\ \times 10^{-7} \\ \times 10^{-4} \\ 0.32) \times 10^{-6} \\ \times 10^{-8} \\ \times 10^{-7} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| \(\Gamma_{307}\) \(\Gamma_{308}\) \(\Gamma_{309}\) \(\Gamma_{310}\) \(\Gamma_{311}\) \(\Gamma_{312}\) \(\Gamma_{313}\) \(\Gamma_{313}\) \(\Gamma_{313}\) \(\Gamma_{314}\) \(\Gamma_{315}\) \(\Gamma_{320}\) \(\Gamma_{322}\) \(\Gamma_{323}\) \(\Gamma_{324}\) \(\Gamma_{325}\) \(\Gamma_{326}\) \(\Gam | $\begin{array}{c} K_2^*(1430)^0\phi\\ K^0\phi\phi\\ \eta'\eta'K^0\gamma\\ \eta'K^0\gamma\\ \eta'K^0\gamma\\ K^+\pi^-\gamma\\ K^*(892)^0\gamma\\ K^*(1410)\gamma\\ K^+\pi^-\gamma \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Г370 Г371 Г372 Г373 Г374 Г375 Г376 Г377 Г380 Г380 Г381 Г382 Г383 Г384 | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ \rho K^{0} \\ \mathcal{O}(1540)^{+}\overline{\rho}\times B(\mathcal{O}(1540)^{+}\to\rho K^{0}_{3}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ K^{*}(892)^{0} \\ \end{array}$ | <pre></pre> | $5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5$ | $\begin{array}{c} \times10^{-7}\\ \times10^{-3}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-5}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-6}\\ \times10^{-3}\\ 0.31)\times10^{-5}\\ \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| \(\Gamma_{307}\) \(\Gamma_{308}\) \(\Gamma_{309}\) \(\Gamma_{310}\) \(\Gamma_{311}\) \(\Gamma_{313}\) \(\Gamma_{315}\) \(\Gamma_{315}\) \(\Gamma_{316}\) \(\Gamma_{317}\) \(\Gamma_{316}\) \(\Gamma_{317}\) \(\Gamma_{320}\) \(\Gamma_{321}\) \(\Gamma_{322}\) \(\Gamma_{323}\) \(\Gamma_{325}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gamma_{326}\) \(\Gamma_{327}\) \(\Gam | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \eta' \eta' K^0 \gamma \\ \eta' K^0 \gamma \\ \eta' K^0 \gamma \\ \eta' K^0 \gamma \\ K^+ \pi^- \gamma \\ K^*(892)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times \text{B} (X \rightarrow \mu^+ \mu^-) \\ \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^+ \pi^- \pi^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K_2^* (1430)^0 \gamma \\ K^*_2 (1430)^0 \gamma \\ K^*_3 (1780)^0 \gamma \\ K^*_4 (2045)^0 \gamma \\ \end{array}$ Light unflavored $\begin{array}{c} \rho^0 \gamma \\ \rho^0 X (214) \times \text{B} (X \rightarrow \mu^+ \mu^-) \end{array}$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Гато Гатт Гата Гата Гата Гата Гата Гата | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{-}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho}\pi^{+}\pi^{-} \\ \rho\overline{\rho}K^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho K^{0}_{S}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho}K^{*}(892)^{0} \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ 4.5 \\ \\ 1.24 + \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.31) \times 10^{-5}$ $\%$ $\begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ 0.32) \times 10^{-6} \\ \times 10^{-7} \\ \end{array}$ $0.28) \times 10^{-6}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| \$\begin{align*} \Gamma_{307} & \Gamma_{308} & \Gamma_{309} & \Gamma_{310} & \Gamma_{311} & \Gamma_{314} & \Gamma_{315} & \Gamma_{316} & \Gamma_{317} & \Gamma_{316} & \Gamma_{317} & \Gamma_{316} & \Gamma_{317} & \Gamma_{320} & \Gamm | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \gamma' \gamma' K^0 \gamma \\ \gamma' K^0 \gamma \\ \gamma' K^0 \gamma \\ \kappa'' K^0 \gamma \\ K^+ \alpha \gamma \\ K^*(392)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times B (X \rightarrow \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^+ \pi^- \pi^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K^*_2 (1430)^0 \gamma \\ K^*_3 (1780)^0 \gamma \\ K^*_4 (2045)^0 \gamma \\ \\ \text{Light unflavored} \\ \rho^0 \gamma \\ \rho^0 X (214) \times B (X \rightarrow \mu^+ \mu^-) \\ \omega \gamma \end{array}$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Гато Гатт Гатт Гата Гата Гата Гата Гата | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{\mp}\pi^{\pm}\times B(b_{1}^{\mp}\to\omega\pi^{\mp}) \\ b_{0}^{1}\pi^{0}\times B(b_{1}^{1}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{-}\to\omega\pi^{-}) \\ b_{1}^{1}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \pi^{F}K^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho K_{S}^{0}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho}K^{*}(892)^{0} \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\Lambda}\pi^{-} \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.31) \times 10^{-5}$ $\%$ $\begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ 0.32) \times 10^{-6} \\ \times 10^{-7} \\ \end{array}$ $0.28) \times 10^{-6}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| F307 F308 F309 F310 F311 F311 F315 F316 F317 F318 F320 F320 F327 F328 F327 F328 F327 F328 F328 | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \gamma' \gamma' K^0 \\ \gamma K^0 \gamma \\ \gamma' K^0 \gamma \\ K^0 \phi \gamma \\ K^+ \pi^- \gamma \\ K^*(892)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times B(X \rightarrow \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^+ \pi^- \pi^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K_2^* (1430)^0 \gamma \\ K^*_3 (1780)^0 \gamma \\ K^*_3 (1780)^0 \gamma \\ K^*_4 (2045)^0 \gamma \\ \end{array}$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{\mp}) \\ b_{1}^{0}\eta^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ & \qquad | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.31) \times 10^{-5}$ $\%$ $\begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ \times 10^{-7} \\ \times 10^{-7} \\ \end{array}$ $0.28 \\ \times 10^{-7}$ $0.29) \times 10^{-6} \\ \times 10^{-7}$ | CL=90% |
| F307 F308 F309 F310 F311 F313 F314 F315 F316 F317 F318 F320 F321 F322 F323 F324 F325 F326 F327 F328 F329 F3300 F3301 F3301 F3301 F3311 | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \gamma' \gamma' K^0 \\ \gamma K^0 \gamma \\ \gamma' K^0 \gamma \\ K^0 \gamma \\ K^0 \phi \gamma \\ K^+ \pi^- \gamma \\ K^*(892)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times B(X \to \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^+ \pi^- \pi^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K_2^*(1430)^0 \gamma \\ K_3^* (1780)^0 \gamma \\ K_4^* (2045)^0 \gamma \\ \end{array}$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F389 F390 F390 F371 F371 F372 F373 F375 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{\mp}) \\ b_{1}^{0}\eta^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ \pi^{+}\pi^{-} \\ \rho\overline{\rho} \\ \mathcal{K}^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho \\ \rho\overline{\kappa}^{0} \\ f_{J}(2220) \\ K^{0}\times B(f_{J}(2220)\to\rho \\ \rho\overline{\rho} \\ \pi^{+}\pi^{-} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ f_{J}(2220) \\ K^{0}\times B(f_{J}(2220)\to\rho \\ \rho\overline{\rho} \\ \rho\overline{\lambda} \\ \pi^{-} \\ \rho\overline{\Sigma}(1385)^{-} \\ \Delta^{0}\overline{\lambda} \\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ 9.3 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-7} \\ \times 10^{-4} \\ 0.32) \times 10^{-6} \\ \times 10^{-7} \\ 0.28) \times 10^{-6} \\ \times 10^{-7} \\ 0.29) \times 10^{-6} \\ \times 10^{-7} \\ \times 10^{-$ | CL=90% |
| F307 F308 F309 F310 F311 F311 F315 F316 F317 F318 F320 F320 F327 F328 F327 F328 F327 F328 F328 | $\begin{array}{c} K_2^*(1430)^0 \phi \\ K^0 \phi \phi \\ \gamma' \gamma' K^0 \\ \gamma K^0 \gamma \\ \gamma' K^0 \gamma \\ K^0 \gamma \\ K^0 \phi \gamma \\ K^+ \pi^- \gamma \\ K^*(892)^0 \gamma \\ K^*(1410) \gamma \\ K^+ \pi^- \gamma \text{nonresonant} \\ K^*(892)^0 X (214) \times B(X \to \mu^+ \mu^-) \\ K^0 \pi^+ \pi^- \gamma \\ K^+ \pi^- \pi^0 \gamma \\ K_1 (1270)^0 \gamma \\ K_1 (1400)^0 \gamma \\ K_2^*(1430)^0 \gamma \\ K_3^* (1780)^0 \gamma \\ K_4^* (2045)^0 \gamma \\ \end{array}$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F389 F390 F391 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\timesB(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\timesB(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\timesB(b_{1}^{0}\to\omega\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho}\\ \rho\overline{\rho}\pi^{+}\pi^{-}\\ \rho\overline{\rho}K^{0}\\ \Theta(1540)^{+}\overline{\rho}\timesB(\Theta(1540)^{+}\to\rho K^{0}_{3}) \\ f_{J}(2220)K^{0}\timesB(f_{J}(2220)\to\rho \overline{\rho}\overline{\rho}K^{*}(892)^{0} \\ f_{J}(2220)K^{0}\timesB(f_{J}(2220)\to\rho \overline{\rho}\overline{\rho}\overline{\Lambda}\pi^{-}\\ \rho\overline{\lambda}(1385)^{-}\Delta^{0}\overline{\Lambda}\\ \rho\overline{\lambda}K^{-} \\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ 9.3 \\ 8.2 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-7} \\ \times$ | CL=90% |
| F307 F308 F309 F310 F311 F316 F316 F317 F318 F319 F320 F321 F322 F323 F324 F325 F326 F327 F328 F329 F330 F331 F333 F3331 F3333 F33 | $\begin{array}{c} \kappa_2^*(1430)^0 \phi \\ \kappa^0 \phi \phi \\ \gamma' \gamma' K^0 \gamma \\ \gamma' \kappa'^0 \gamma \\ \gamma' \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa^+ \kappa^- \gamma \\ \kappa^*(892)^0 \gamma \\ \kappa^*(1410) \gamma \\ \kappa^+ \pi^- \gamma \\ \text{nonresonant} \\ \kappa^*(892)^0 \chi(214) \times \text{B}(X \rightarrow \mu^+ \mu^-) \\ \kappa^0 \pi^+ \pi^- \gamma \\ \kappa^+ \pi^- \pi^0 \gamma \\ \kappa^1 (1270)^0 \gamma \\ \kappa^1 (1270)^0 \gamma \\ \kappa^1 (1400)^0 \gamma \\ \kappa^2 (1430)^0 \gamma \\ \kappa^3 (1780)^0 \gamma \\ \kappa^4 (2045)^0 \gamma \\ \end{array}$ Light unflavored $\begin{array}{c} \rho^0 \gamma \\ \rho^0 \chi(214) \times \text{B}(X \rightarrow \mu^+ \mu^-) \\ \omega \gamma \\ \pi^+ \pi^- \\ \pi^0 \pi^0 \\ \eta \pi^0 \\ \eta \eta^0 \\ \eta \eta^0 \end{array}$ | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F380 F381 F382 F383 F384 F385 F386 F387 F388 F389 F390 F391 F392 F393 F392 F392 F392 F392 F392 F392 F393 F395 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{+}\times B(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{-}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho}\\ \rho\overline{\rho}\\ \kappa^{0}\\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho\kappa^{0}_{3}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}\\ \rho\overline{\rho}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}\\ \rho\overline{\rho}\\ \pi^{-}\rho\overline{\rho}\\ (1385)^{-}\Delta^{0}\overline{\Lambda}\\ \rho\overline{\Lambda}\\ \kappa^{-}\rho\overline{\rho}\\ \sigma^{-}D \\ \rho\overline{\rho}\\ \sigma^{-}\\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ 4.5 \\ \\ 1.24 + \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ 9.3 \\ 8.2 \\ 3.8 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-3} \\ 0.31) \times 10^{-5} \\ \\ \begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ \times 10^{-7} \\ \times 10^{-7} \\ \times 10^{-7} \\ \end{array}$ $0.28) \times 10^{-6} \\ \times 10^{-7} \\ \times $ | CL=90% |
| F307 F308 F309 F310 F311 F316 F316 F317 F318 F319 F320 F321 F325 F326 F327 F328 F329 F333 F333 F3334 | $\begin{array}{c} \kappa_2^*(1430)^0 \phi \\ \kappa^0 \phi \phi \\ \gamma' \gamma' K^0 \gamma \\ \gamma' \kappa'^0 \gamma \\ \gamma' \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa'^0 \gamma \\ \kappa^+ \kappa^- \gamma \\ \kappa^*(892)^0 \gamma \\ \kappa^*(1410) \gamma \\ \kappa^+ \pi^- \gamma \\ \kappa^*(892)^0 X (214) \times \mathrm{B}(X \to \mu^+ \mu^-) \\ \kappa^0 \pi^+ \pi^- \gamma \\ \kappa^+ \pi^- \pi^0 \gamma \\ \kappa^1 (1270)^0 \gamma \\ \kappa^1 (1400)^0 \gamma \\ \kappa^2 (1430)^0 \gamma \\ \kappa^3 (1780)^0 \gamma \\ \kappa^4 (2045)^0 \gamma \\ \end{array}$ | (((((((((((((((((((| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.3 CL=90% CL=90% S=1.7 | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F389 F390 F391 F392 F393 F395 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho K_{0}^{0}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ K^{*}(892)^{0} \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ \lambda\pi^{-}\rho\overline{\lambda}(1385)^{-}\Delta^{0}\overline{\lambda} \\ \rho\overline{\lambda}K^{-}\rho\overline{\lambda}^{0}\pi^{-}\overline{\lambda}{\lambda} \\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ \\ 9.3 \\ 8.2 \\ 3.8 \\ 3.2 \\ \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-3} \\ 0.31) \times 10^{-5} \\ \\ \begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ \times 10^{-7} \\ \times 10^{-7} \\ \end{array}$ $0.28) \times 10^{-6} \\ \times 10^{-7} \\ 0.29) \times 10^{-6} \\ \times 10^{-7} \\ \times 10^{-7$ | CL=90% |
| F307 F308 F309 F310 F311 F312 F313 F316 F317 F316 F317 F318 F319 F320 F327 F328 F329 F330 F331 F332 F333 F334 F335 | $\begin{array}{c} \kappa_2^*(1430)^0 \phi \\ \kappa^0 \phi \phi \\ \eta' \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \kappa' \kappa^0 \gamma \\ \kappa^+ \kappa^- \gamma \\ \kappa^*(392)^0 \gamma \\ \kappa^*(1410) \gamma \\ \kappa^+ \pi^- \gamma & \text{nonresonant} \\ \kappa^*(392)^0 X(214) \times B(X \to \mu^+ \mu^-) \\ \kappa^0 \pi^+ \pi^- \gamma \\ \kappa^+ \pi^- \pi^0 \gamma \\ \kappa_1(1270)^0 \gamma \\ \kappa_1(1400)^0 \gamma \\ \kappa_2^*(1430)^0 \gamma \\ \kappa^*_2(1430)^0 \gamma \\ \kappa^*_3(1780)^0 \gamma \\ \kappa^*_4(2045)^0 \gamma \\ & \qquad | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% S=1.3 CL=90% CL=90% S=1.7 CL=90% | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F390 F391 F392 F393 F394 F394 F395 F396 F397 F398 F399 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ \kappa^{+} \\ \theta(1540)^{+}\overline{\rho}\times B(\theta(1540)^{+}\to\rho\kappa^{0}_{S}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ K^{*}(892)^{0} \\ f_{J}(2220)K^{*}_{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ \overline{\Lambda} \\ \pi^{-}\rho\overline{\lambda} \\ \rho\overline{\lambda} \\ \rho\overline{\lambda} \\ \kappa^{-}\rho\overline{\lambda} \\ \overline{\lambda} \\ \Lambda \\ \overline{\lambda} \\ \Lambda \\ K^{0} \\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 1.5 \\ \\ 3.14 \pm \\ 2.6 \\ \\ 9.3 \\ 8.2 \\ 3.8 \\ 3.2 \\ 4.8 \begin{array}{c} + \\ - \\ 4.8 \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-7} \\ \times 10^{-7} \\ 0.22) \times 10^{-6} \\ \times 10^{-7} \\ 0.29) \times 10^{-6} \\ \times 10^{-7} \\ 0.29) \times 10^{-6} \\ \times 10^{-7} \\ \times 10^{-$ | CL=90% |
| F307 F308 F309 F310 F312 F313 F316 F317 F318 F316 F317 F318 F326 F327 F328 F327 F328 F327 F328 F337 F338 F331 F335 | $\begin{array}{c} \kappa_2^*(1430)^0 \phi \\ \kappa^0 \phi \phi \\ \eta' \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \eta' \kappa^0 \gamma \\ \kappa' \kappa^0 \gamma \\ \kappa^+ \kappa^- \gamma \\ \kappa^*(392)^0 \gamma \\ \kappa^*(1410) \gamma \\ \kappa^+ \pi^- \gamma & \text{nonresonant} \\ \kappa^*(392)^0 X(214) \times B(X \to \mu^+ \mu^-) \\ \kappa^0 \pi^+ \pi^- \gamma \\ \kappa^+ \pi^- \pi^0 \gamma \\ \kappa_1(1270)^0 \gamma \\ \kappa_1(1400)^0 \gamma \\ \kappa_2^*(1430)^0 \gamma \\ \kappa^*_2(1430)^0 \gamma \\ \kappa^*_3(1780)^0 \gamma \\ \kappa^*_4(2045)^0 \gamma \\ & \qquad | (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=90% S=1.3 CL=90% CL=90% S=1.7 | F370 F371 F372 F373 F374 F375 F376 F377 F378 F379 F380 F381 F382 F383 F384 F385 F386 F387 F388 F390 F391 F392 F393 F394 F394 F395 F396 F397 F398 F399 F | $\begin{array}{c} \omega\pi^{0} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{0} \\ a_{1}(1260)^{+}\rho^{-} \\ a_{1}(1260)^{0}\rho^{0} \\ b_{1}^{+}\pi^{\pm}\times B(b_{1}^{+}\to\omega\pi^{+}) \\ b_{1}^{0}\pi^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{-}\rho^{+}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ b_{1}^{0}\rho^{0}\times B(b_{1}^{0}\to\omega\pi^{0}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-} \\ a_{1}(1260)^{+}a_{1}(1260)^{-}\times \\ B^{2}(a_{1}^{+}\to2\pi^{+}\pi^{-}) \\ \pi^{+}\pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \\ \mathbf{Baryon} \\ \rho\overline{\rho} \\ \rho\overline{\rho} \\ \pi^{+}\pi^{+}\pi^{-}\pi^{-}\pi^{-}\pi^{0} \\ \Theta(1540)^{+}\overline{\rho}\times B(\Theta(1540)^{+}\to\rho K_{0}^{0}) \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ K^{*}(892)^{0} \\ f_{J}(2220)K^{0}\times B(f_{J}(2220)\to\rho\overline{\rho}) \\ \rho\overline{\rho} \\ \lambda\pi^{-}\rho\overline{\lambda}(1385)^{-}\Delta^{0}\overline{\lambda} \\ \rho\overline{\lambda}K^{-}\rho\overline{\lambda}^{0}\pi^{-}\overline{\lambda}{\lambda} \\ \end{array}$ | <pre></pre> | $\begin{array}{c} 5 \\ 9.0 \\ 6.1 \\ 2.4 \\ 1.09 \pm \\ 1.9 \\ 1.4 \\ 3.4 \\ 3.0 \\ 1.18 \pm \\ 1.1 \\ \\ 1.1 \\ 2.5 \\ 2.66 \pm \\ 5 \\ \\ 4.5 \\ \\ 1.24 \begin{array}{c} + \\ - \\ 3 \\ 8.2 \\ 3.8 \\ 3.2 \\ 4.8 \begin{array}{c} + \\ - \\ 4.8 \end{array} \end{array}$ | $\begin{array}{c} \times 10^{-7} \\ \times 10^{-3} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-5} \\ \end{array}$ $0.15) \times 10^{-5} \\ \times 10^{-6} \\ \times 10^{-3} \\ 0.31) \times 10^{-5} \\ \\ \begin{array}{c} \times 10^{-7} \\ \times 10^{-4} \\ \times 10^{-7} \\ \times 10^{-7} \\ \end{array}$ $0.28) \times 10^{-6} \\ \times 10^{-7} \\ 0.29) \times 10^{-6} \\ \times 10^{-7} \\ \times 10^{-7$ | CL=90% |

 B^0

| Γ ₃₉₆ $\overline{\Lambda}\Lambda D^0$ | (| 1.1 + | $^{0.6}_{0.5}$) $\times 10^{-5}$ | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|------------|-----------------------------------|--------|
| $\Gamma_{397} \Delta^0 \overline{\Delta^0}$ | < | | × 10 ⁻³ | CL=90% |
| $\Gamma_{398} \underline{\Delta}^{++} \underline{\Delta}^{}$ | < | 1.1 | × 10 ⁻⁴ | CL=90% |
| Γ ₃₉₉ \overline{D}^{0} p \overline{p} | (| | $0.09) \times 10^{-4}$ | |
| $\Gamma_{400} D_{5} \overrightarrow{\Lambda} p$ | į (| | $0.9) \times 10^{-5}$ | |
| $\Gamma_{401} \overline{D}^* (2007)^0 p \overline{p}$ | (| | $0.13) \times 10^{-4}$ | |
| $\Gamma_{402} D^*(2010) - \rho \overline{n}$ | (| | $0.4) \times 10^{-3}$ | |
| $\Gamma_{403} D - p \overline{p} \pi^{+}$ | (| | $0.32) \times 10^{-4}$ | |
| $\Gamma_{404} D^*(2010)^- p \overline{p} \pi^+$ | (| | 0.5) $\times 10^{-4}$ | |
| $\Gamma_{405} \Theta_c \overline{p} \pi^+ \times B(\Theta_c \to D^- p)$ | < | 9 | $\times 10^{-6}$ | CL=90% |
| $\Gamma_{406} \ \underline{\Theta}_{c} \overline{p} \pi^{+} \times B(\Theta_{c} \to D^{*-} p)$ | < | 1.4 | $\times 10^{-5}$ | CL=90% |
| $\Gamma_{407} \ \overline{\Sigma}_c^{} \Delta^{++}$ | < | 1.0 | $\times 10^{-3}$ | CL=90% |
| $\Gamma_{408} \overline{\Lambda}_c^- p \pi^+ \pi^-$ | (| $1.3~\pm$ | $0.4) \times 10^{-3}$ | |
| $\Gamma_{409} \overline{\Lambda}_{c}^{-} p$ | (| $2.0~\pm$ | $0.4) \times 10^{-5}$ | |
| $\Gamma_{410} \frac{c}{\Lambda_c} p_{\pi}^0$ | (| 1.9 ± | $0.5) \times 10^{-4}$ | |
| $\Gamma_{411} \Sigma_{C}(2455)^{-} p$ | < | 3.0 | $\times 10^{-5}$ | |
| $\Gamma_{412} \overline{\Lambda}_c^{\circ} p \pi^+ \pi^- \pi^0$ | < | 5.07 | $\times 10^{-3}$ | CL=90% |
| $\Gamma_{413} \overline{\Lambda}_c^c p \pi^+ \pi^- \pi^+ \pi^-$ | < | 2.74 | $\times 10^{-3}$ | CL=90% |
| $\Gamma_{414} \overline{\Lambda_{c}} p \pi^{+} \pi^{-}$ | (| 1.12± | $0.32) \times 10^{-3}$ | |
| Γ_{415} $\overline{\Lambda}_c^- p \pi^+ \pi^- \text{(nonresonant)}$ | į. | | 1.9) × 10 ⁻⁴ | |
| $\Gamma_{416} = \frac{c}{\Sigma_c} (2520)^{} p \pi^+$ | ì | | $0.4) \times 10^{-4}$ | |
| $\Gamma_{417} = \frac{\Sigma_c(2520)^0 p \pi^-}{\Sigma_c(2520)^0 p \pi^-}$ | < | | × 10 ⁻⁵ | CL=90% |
| $\Gamma_{418}^{11} = \overline{\Sigma}_{c}(2455)^{0} p \pi^{-}$ | (| | $0.5) \times 10^{-4}$ | |
| Γ_{419} $\overline{\Sigma}_c(2455)^0 N^0 \times B(N^0 \rightarrow$ | į. | | $2.9) \times 10^{-5}$ | |
| $ ho \pi^-)$ | | | | |
| $\Gamma_{420} \overline{\Sigma}_{c}(2455)^{} p \pi^{+}$ | (| $2.2\ \pm$ | $0.7) \times 10^{-4}$ | |
| Γ_{421} $\Lambda_c^- p K^+ \pi^-$ | (| | $1.4) \times 10^{-5}$ | |
| $\Gamma_{422} \qquad \overline{\Sigma}_c(2455)^{} p K^+ \times$ | (| $1.1~\pm$ | $0.4) \times 10^{-5}$ | |
| $B(\overline{\Sigma}_c^{} \to \overline{\Lambda}_c^- \pi^-)$ | | | | |
| $\Gamma_{423} = \Lambda_{c}^{-} p K^{*} (892)^{0}$ | < | 2.42 | $\times 10^{-5}$ | CL=90% |
| $\Gamma_{424} \overline{\Lambda}_c^- \Lambda K^+$ | (| | $1.3) \times 10^{-5}$ | |
| $\Gamma_{425}^{\overline{425}} \overline{\Lambda_c^-} \Lambda_c^+$ | < | | × 10 ⁻⁵ | CL=90% |
| $\Gamma_{426} = \frac{7}{4} (2593)^{-} / \frac{7}{4} (2625)^{-} p$ | < | | $\times 10^{-4}$ | CL=90% |
| $ \Gamma_{426} \overline{A_c}(2593)^- / \overline{A_c}(2625)^- p \Gamma_{427} \overline{\Xi_c} A_c^+ \times B(\overline{\Xi_c} \rightarrow \overline{\Xi}^+ \pi^- \pi^-) $ | (| | 2.3) × 10 ⁻⁵ | S=1.9 |
| $\Gamma_{428} \Lambda_c^+ \Lambda_c^- K^0$ | (| | 3.2) × 10 ⁻⁴ | = |
| 420 °C °C °C | , | | | |
| | | | D | (0) |

Lepton Family number (LF) or Lepton number (L) or Baryon number (B)violating modes, or/and $\Delta B = 1$ weak neutral current (B1) modes

| Γ_{429} | $\gamma \gamma$ | B1 | < | 3.2 | $\times 10^{-7}$ | CL=90% |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| Γ_{430} | $e^+ e^-$ | B1 | < | 8.3 | $\times 10^{-8}$ | CL=90% |
| Γ_{431} | $e^+e^-\gamma$ | B1 | < | 1.2 | $\times 10^{-7}$ | CL=90% |
| Γ_{432} | $\mu^+\mu^-$ | B1 | < | 1.4 | $\times 10^{-9}$ | CL=90% |
| Γ_{433} | $\mu^+\mu^-\gamma$ | B1 | < | 1.6 | $\times 10^{-7}$ | CL=90% |
| Γ ₄₃₄ | $\tau^+\tau^-$ | B1 | < | 4.1 | $\times 10^{-3}$ | CL=90% |
| Γ_{435} | $\pi^{0}\ell^{+}\ell^{-}$ | B1 | < | 1.2 | $\times 10^{-7}$ | CL=90% |
| Γ ₄₃₆ | $\pi^{0} e^{+} e^{-}$ | B1 | < | 1.4 | × 10 ⁻⁷ | CL=90% |
| | $\pi^{0} \mu^{+} \mu^{-}$ | B1 | < | 1.8 | $\times 10^{-7}$ | CL=90% |
| Γ ₄₃₈ | $\pi^0 \nu \overline{\nu}$ | B1 | < | 2.2 | $\times 10^{-4}$ | CL=90% |
| Γ_{439} | $K^0 \ell^+ \ell^-$ | B1 | [a] (| 3.1 + (| $0.80.7 \times 10^{-7}$ | |
| Γ_{440} | $K^0 e^+ e^-$ | B1 | (| 1.6 + | $(0.8) \times 10^{-7}$ | |
| Γ_{441} | $K^0 \mu^+ \mu^-$ | B1 | (| 3.8 ± 0 | $0.8) \times 10^{-7}$ | |
| | $K^0 u \overline{ u}$ | B1 | < | 5.6 | $\times 10^{-5}$ | CL=90% |
| Γ_{443} | $\rho^0 \nu \overline{\nu}$ | B1 | < | 4.4 | $\times 10^{-4}$ | CL=90% |
| Γ444 | $K^*(892)^0 \ell^+ \ell^-$ | В1 | [a] (| 9.9 + | $(1.2) \times 10^{-7}$ | |
| | , , | | | | 1.1 / | |
| | $K^*(892)^0 e^+ e^-$ | В1 | (| | 0.19 0.17) × 10 ⁻⁶ | |
| | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ | B1 B1 | (| 1.03 + (| $0.19 \atop 0.17) \times 10^{-6} \atop 0.10) \times 10^{-6}$ | |
| Γ ₄₄₅ | $K^*(892)^0 e^+ e^-$ | | • | 1.03 + (| $0.19 \atop 0.17) \times 10^{-6} \atop 0.10) \times 10^{-6} \atop \times 10^{-4}$ | CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ | В1 | (| 1.03 + (1.06 ± (| $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\ 0.10 \\ \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \end{array}$ | CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ | B1 B1 | (| 1.03 + (1.06 ± (1.2 | $0.19 \\ 0.17) \times 10^{-6}$ $0.10) \times 10^{-6}$ $\times 10^{-4}$ $\times 10^{-5}$ $\times 10^{-8}$ | |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₄₉ Γ ₄₅₀ | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ | B1 B1 B1 | (< < | 1.03 + (1.06 ± (1.2) 5.8 | $0.19 \atop 0.17 \atop 0.17 \atop 0.10 \atop 0.10 \atop 0.10 \atop 0.10 \atop 0.10^{-6} \atop 0.10^{-4} \atop 0.10^{-5} \atop 0.10^{-8} \atop 0.10^{-7}$ | CL=90% CL=90% CL=90% |
| Γ_{445} Γ_{446} Γ_{447} Γ_{448} Γ_{449} Γ_{450} Γ_{451} | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^0 e^{\pm} \mu^{\mp}$ | B1 B1 B1 LF | (| 1.03 + (1.06 ± (1.2 5.8 6.4 | 0.19) $\times 10^{-6}$ 0.17) $\times 10^{-6}$ 0.10) $\times 10^{-6}$ $\times 10^{-4}$ $\times 10^{-5}$ $\times 10^{-8}$ $\times 10^{-7}$ $\times 10^{-7}$ | CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₄₉ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^0 e^{\pm} \mu^{\mp}$ $K^*(892)^0 e^+ \mu^-$ | B1 B1 B1 LF LF LF | (| 1.03 + (1.06 ± (1.2 5.8 6.4 1.4 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\ \end{array} \times 10^{-6} \\ 0.10) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-7} \\ \times 10^{-7} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₄₉ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ | $K^*(892)^0 e^+ e^-$ $K^*(892)^0 \mu^+ \mu^-$ $K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^0 e^{\pm} \mu^{\mp}$ $K^*(892)^0 e^+ \mu^-$ $K^*(892)^0 e^- \mu^+$ | B1 B1 B1 LF LF LF | (| 1.03 + (1.06 ± (1.2 5.8 6.4 1.4 2.7 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \end{array}$ | CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₄₉ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ | $K^*(892)^0 e^+ e^ K^*(892)^0 \mu^+ \mu^ K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^0 e^{\pm} \mu^{\mp}$ $K^*(892)^0 e^+ \mu^ K^*(892)^0 e^- \mu^+$ $K^*(892)^0 e^{\pm} \mu^{\mp}$ | B1 B1 B1 LF LF LF | (| 1.03 + 0 1.06 ± 0 1.2 5.8 6.4 1.4 2.7 5.3 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\ \times 10^{-6} \\ \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₄₉ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ | $K^*(892)^0 e^+ e^ K^*(892)^0 \mu^+ \mu^ K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^*(892)^0 e^+ \mu^ K^*(892)^0 e^- \mu^+$ $K^*(892)^0 e^+ \mu^{\mp}$ $e^{\pm} \tau^{\mp}$ | B1 B1 LF LF LF LF | (| 1.03 + (1.06 ± (1.2 5.8 6.4 1.4 2.7 5.3 3.4 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ Γ ₄₅₃ Γ ₄₅₄ Γ ₄₅₅ Γ ₄₅₆ | $K^*(892)^0 e^+ e^ K^*(892)^0 \mu^+ \mu^ K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu \overline{\tau}$ $\pi^0 e^{\pm} \mu^+$ $K^*(892)^0 e^+ \mu^ K^*(892)^0 e^- \mu^+$ $K^*(892)^0 e^+ \mu^ K^*(892)^0 e^+ \mu^ \mu^+ \tau^+$ | B1 B1 LF LF LF LF LF | (| 1.03 + 6 1.06 ± 6 1.2 5.8 6.4 1.4 2.7 5.3 3.4 5.8 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-5} \\ \times 10^{-5} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ Γ ₄₅₃ Γ ₄₅₄ Γ ₄₅₅ Γ ₄₅₆ Γ ₄₅₇ | $\begin{array}{c} K^*(892)^0 e^+ e^- \\ K^*(892)^0 \mu^+ \mu^- \\ K^*(892)^0 \nu \overline{\nu} \\ \phi \nu \overline{\nu} \\ e^\pm \mu^\mp \\ \pi^0 e^\pm \mu^\mp \\ K^*(892)^0 e^+ \mu^- \\ K^*(892)^0 e^- \mu^+ \\ K^*(892)^0 e^\pm \mu^\mp \\ e^\pm \tau^\mp \\ \text{invisible} \end{array}$ | B1 B1 LF LF LF LF LF LF | ((< < (h) < < < (h) | $1.03 \begin{array}{c} 1.03 \\ -6.06 \\ 1.06 \\ \pm 0.06 \\ 1.2 \\ 5.8 \\ 6.4 \\ 1.4 \\ 2.7 \\ 5.3 \\ 3.4 \\ 5.8 \\ 2.8 \\ \end{array}$ | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ Γ ₄₅₃ Γ ₄₅₄ Γ ₄₅₅ Γ ₄₅₆ | $K^*(892)^0 e^+ e^ K^*(892)^0 \mu^+ \mu^ K^*(892)^0 \nu \overline{\nu}$ $\phi \nu \overline{\nu}$ $e^{\pm} \mu^{\mp}$ $\pi^0 e^{\pm} \mu^{\mp}$ $K^*(892)^0 e^+ \mu^ K^*(892)^0 e^- \mu^+$ $K^*(892)^0 e^{\pm} \mu^{\mp}$ $e^{\pm} \tau^{\mp}$ invisible $\nu \overline{\nu} \gamma$ | B1 B1 LF LF LF LF LF LF | ((| 1.03 + (1.06 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-5} \\ $ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |
| Γ ₄₄₅ Γ ₄₄₆ Γ ₄₄₇ Γ ₄₄₈ Γ ₄₅₀ Γ ₄₅₁ Γ ₄₅₂ Γ ₄₅₃ Γ ₄₅₄ Γ ₄₅₅ Γ ₄₅₆ Γ ₄₅₇ | $\begin{array}{c} K^*(892)^0 e^+ e^- \\ K^*(892)^0 \mu^+ \mu^- \\ K^*(892)^0 \nu \overline{\nu} \\ \phi \nu \overline{\nu} \\ e^\pm \mu^\mp \\ \pi^0 e^\pm \mu^\mp \\ K^*(892)^0 e^+ \mu^- \\ K^*(892)^0 e^- \mu^+ \\ K^*(892)^0 e^\pm \mu^\mp \\ e^\pm \tau^\mp \\ \text{invisible} \end{array}$ | B1 B1 LF LF LF LF LF LF LF | ((| 1.03 + (1.06 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0.00 ± 0 | $\begin{array}{c} 0.19 \\ 0.17 \\ 0.17 \\) \times 10^{-6} \\ \times 10^{-4} \\ \times 10^{-5} \\ \times 10^{-8} \\ \times 10^{-7} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-5} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% |

- [a] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [b] \overline{D}^{**} represents an excited state with mass 2.2 < M < 2.8 GeV/c².
- $[c] X (3872)^+$ is a hypothetical charged partner of the X(3872).
- [d] Stands for the possible candidates of $K^*(1410)$, $K_0^*(1430)$ and $K_2^*(1430).$
- [e] ${\it B}^{0}$ and ${\it B}_{s}^{0}$ contributions not separated. Limit is on weighted average of the two decay rates.
- [f] This decay refers to the coherent sum of resonant and nonresonant ${\it J}^{\it P}$ = 0 $^+$ K π components with 1.60 < $m_{K\pi}$ < 2.15 GeV/c 2 .
- [g] X (214) is a hypothetical particle of mass 214 MeV/c² reported by the HyperCP experiment, Physical Review Letters 94 021801 (2005)
- [h] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [i] $\Theta(1540)^+$ denotes a possible narrow pentaquark state.

CONSTRAINED FIT INFORMATION

An overall fit to 20 branching ratios uses 56 measurements and one constraint to determine 14 parameters. The overall fit has a $\chi^2=$ 37.3 for 43 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta x_i\delta x_j\right>/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, x_i \equiv $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

| <i>x</i> ₇ | 8 | | | | | | | | | |
|-------------------------|-----------------------|-----------------------|------------------------|----------|------------------------|--------------|------------------|--------------|------------------|------|
| <i>x</i> ₃₁ | 0 | 0 | | | | | | | | |
| x_{41} | 0 | 0 | 43 | | | | | | | |
| <i>x</i> ₆₁ | 0 | 0 | 6 | 13 | | | | | | |
| <i>x</i> ₁₆₂ | 0 | 0 | 0 | 0 | 0 | | | | | |
| <i>x</i> ₁₆₄ | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| <i>x</i> ₁₉₉ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| x ₂₀₃ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | | |
| x ₂₁₄ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| X330 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| x ₄₄₁ | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 |
| <i>x</i> ₄₄₆ | 0 | 0 | 0 | 0 | 0 | 0 | 32 | 0 | 0 | 0 |
| | <i>x</i> ₆ | <i>x</i> ₇ | <i>x</i> ₃₁ | x_{41} | <i>x</i> ₆₁ | <i>X</i> 162 | X ₁₆₄ | <i>X</i> 199 | X ₂₀₃ | X214 |

| X ₄₄₆ | 0 | 0 |
|------------------|------|------|
| | X330 | X441 |

B⁰ BRANCHING RATIOS

For branching ratios in which the charge of the decaying B is not determined, see the B^\pm section.

 $\Gamma(\ell^+ \nu_\ell anything)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below. "OUR EVALUATION is all average using research values of the second The average and rescaling were performed by the Heavy Flavor Averaging Group (HEAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The aver-(HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. aging /rescaling procedure takes into account correlations between the measurements

| aging/rescaring procedur | e takes into account correlations between the measurements | ٥. |
|---------------------------------|----------------------------------------------------------------------|----|
| VALUE (units 10 ⁻²) | DOCUMENT ID TECN COMMENT | |
| 10.33±0.28 OUR EVALUATION | ON | |
| 10.14±0.30 OUR AVERAGE | Error includes scale factor of 1.1. | |
| $10.46 \pm 0.30 \pm 0.23$ | 1 URQUIJO 07 BELL $e^{+}e^{-} ightarrow$ \varUpsilon (4 S) | |
| $9.64 \pm 0.27 \pm 0.33$ | 2 AUBERT,B 06Y BABR $e^+e^- ightarrow arGamma(4S)$ | |
| $10.78 \pm 0.60 \pm 0.69$ | 3 ARTUSO 97 CLE2 $e^+e^- ightarrow \gamma(4S)$ | |
| $9.3 \pm 1.1 \pm 1.5$ | ALBRECHT 94 ARG $e^+e^- ightarrow \varUpsilon(4S)$ | |
| $9.9 \pm 3.0 \pm 0.9$ | HENDERSON 92 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | |
| | wing data for averages, fits, limits, etc. • • • | |
| $10.32 \pm 0.36 \pm 0.35$ | ⁴ OKABE 05 BELL Repl. by URQUIJO 07 | |
| $10.9 \pm 0.7 \pm 1.1$ | ATHANAS 94 CLE2 Sup. by ARTUSO 97 | |
| 4 | | |

- 1 URQUIJO 07 report a measurement of (9.80 \pm 0.29 \pm 0.21)% for the partial branching fraction of $B\to e\nu_e X_C$ decay with electron energy above 0.6 GeV. We converted the result to $B\to e\nu_e X$ branching fraction.
- $^2\, {\rm The\ measurements}$ are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame. The best precision on the ratio is achieved for a momentum threshold of 1.0 GeV: B($B^+
 ightharpoonup$ $e^{+} \nu_{e} X) / B(B^{0} \rightarrow e^{+} \nu_{e} X) = 1.074 \pm 0.041 \pm 0.026.$
- 3 ARTUSO 97 uses partial reconstruction of $B\to D^*\ell\nu_\ell$ and inclusive semileptonic branching ratio from BARISH 96B (0.1049 \pm 0.0017 \pm 0.0043).
- ⁴ The measurements are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame, and their ratio of B($B^+ \to e^+ \nu_e X$)/B($B^0 \to e^+ \nu_e X$) = 1.08 \pm 0.05 \pm 0.02.

| $\Gamma(e^+ u_e X_c) / \Gamma_{ m total}$ | | | | | Γ_2/Γ |
|------------------------------------------------------------------------------------------------------|------------------------------|--------|-----------|---------------|-------------------|
| VALUE (units 10 ⁻²) | DO CUMENT ID | | TECN | COMMENT | |
| 10.08±0.30±0.22 | ¹ URQUIJO | 07 | BELL | e^+e^- | $\Upsilon(4S)$ |
| 1 Measure the independent $\it E$ energies of 0.4 GeV. | $^{+}$ and 0 partial br | anchin | g fractio | ns with elect | ron threshold |
| $\Gammaig(oldsymbol{D^-\ell^+ u_\ell}ig)/\Gamma_{	ext{total}}$ ℓ denotes e or μ , not the | e sum. | | | | Γ4/Γ |

(HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|---------|-----------|------------------------------------|
| 0.0218±0.0012 OUR EVALUA | ΓΙΟΝ | | | |
| 0.0218±0.0012 OUR AVERAG | E | | | |
| $0.0221 \pm 0.0011 \pm 0.0011$ | $^{ m 1}$ AUBERT | 10 | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.0213 \pm 0.0012 \pm 0.0039$ | ABE | 02E | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.0209 \pm 0.0013 \pm 0.0018$ | ² BARTELT | 99 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.0235 \pm 0.0020 \pm 0.0044$ | ³ BUSKULIC | 97 | ALEP | $e^+e^- \rightarrow Z$ |
| | ing data for average | s, fits | , limits, | etc. • • • |
| $0.0221 \pm 0.0011 \pm 0.0012$ | ¹ AUBERT | 08Q | BABR | Repl. by AUBERT 10 |
| $0.0187 \pm 0.0015 \pm 0.0032$ | ⁴ ATHANAS | 97 | CLE2 | Repl. by BARTELT 99 |
| $0.018 \pm 0.006 \pm 0.003$ | ⁵ FULTON | 91 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.020\ \pm0.007\ \pm0.006$ | ⁶ ALBRECHT | 89J | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | | | | |

- $^{
 m 1}$ Uses a fully reconstructed B meson as a tag on the recoil side.
- ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.
- ³BUSKULIC 97 assumes fraction (B^+) = fraction (B^0) = (37.8 \pm 2.2)% and PDG 96 values for B lifetime and branching ratio of D^* and D decays.
- 4 ATHANAS 97 uses missing energy and missing momentum to reconstruct neutrino.
- 5 FULTON 91 assumes assuming equal production of B^0 and B^+ at the \varUpsilon (4S) and uses Mark III D and D^* branching ratios.
- 6 ALBRECHT 89J reports $0.018 \pm 0.006 \pm 0.005$. We rescale using the method described in STONE 94 but with the updated PDG 94 B($D^0
 ightarrow \kappa^- \pi^+$)

| $\Gamma(D^-\ell^+\nu_\ell)/\Gamma(\ell^+\nu_\ell$ a nything) |) | | | Γ_4/Γ_1 |
|--------------------------------------------------------------|-------------|------|---------|---------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT | |

 $0.230 \pm 0.011 \pm 0.011$ ¹ AUBERT BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^{
m 1}$ Uses a fully reconstructed B meson on the recoil side.

| $\Gamma igl(D^- \ell^+ u_\ell igr) / \Gamma igl(D \ell^+ u_\ell igr$ anyt | hing) | | | Γ_4/Γ_3 |
|-------------------------------------------------------------------------------|--------------|------|---------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |

 $0.215 \pm 0.016 \pm 0.013$ 1 AUBERT 07AN BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^{
m 1}$ Uses a fully reconstructed B meson on the recoil side.

| $\Gamma(D^- 	au^+ u_	au) / \Gamma_{	ext{total}}$ | | | | Γ ₅ /Γ |
|---------------------------------------------------|-----------------------------|-------------|------------|-------------------|
| VALUE (units 10 ⁻²) | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the foll | owing data for averages, fi | ts, limits, | etc. • • • | |
| | 1 | | | |

 $1.04 \pm 0.35 \pm 0.18$ [⊥] AUBERT 08N BABR Repl. by AUBERT 09s

 $^{
m 1}$ Uses a fully reconstructed B meson as a tag on the recoil side.

| $\Gamma(D^-\tau^+\nu_{	au})/\Gamma(D^-\ell^+\nu_{\ell})$ | | | | | Γ_5/Γ_4 |
|----------------------------------------------------------|--------------|-----|------|-----------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.489±0.165±0.069 | 1 AUBERT | 09s | BABR | $e^+ e^- \rightarrow$ | Y(45) |
| 1 | | | | | |

Uses a fully reconstructed B meson as a tag on the recoil side.

 $\Gamma(D^*(2010)^-\ell^+\nu_\ell)/\Gamma_{\mathrm{total}}$ Γ_6/Γ OUR EVALUATION is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group nts.

| | (HFAG) and are de | scribed at | nttp://www.siac.stai | ntora.eau | /xorg/ntag/. | ine av | |
|------------------------------|-------------------------|------------|------------------------|-----------|--------------|---------|--|
| | aging/rescaling proc | edure take | s into account correla | tions bet | ween the mea | suremen | |
| | VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | | |
| 0.0495±0.0011 OUR EVALUATION | | | | | | | |
| | 0.0511 ± 0.0023 OUR FIT | Error inc | ludes scale factor of | 1.6. | | | |

| 0.0511 ± 0.0023 OUR FIT En | ror includes scale facto | or of 1.6. | |
|----------------------------|------------------------------|-------------------|---------------------------------|
| 0.0509±0.0022 OUR AVERAG | iE Error includes sca | le factor of 1.6. | . See the ideogram |
| 0.0458 ± 0.0003 ± 0.0026 | ¹ DUNGEL | 10 BELL | $e^+e^- \rightarrow \gamma(45)$ |

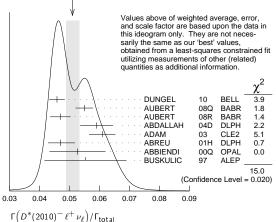
| 0.0430 ± 0.0003 ± 0.0020 | DONGLE | 10 | DLLL | e · e → | 1 (43) |
|----------------------------------------------|-----------------------|------|-----------|----------------------|----------------|
| $0.0549 \pm 0.0016 \pm 0.0025$ | ² AUBERT | 08Q | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0469 \pm 0.0004 \pm 0.0034$ | ³ AUBERT | 08R | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0590 \pm 0.0022 \pm 0.0050$ | ⁴ ABDALLAH | 04 D | DLPH | $e^+e^- \rightarrow$ | Z^0 |
| $0.0609 \pm 0.0019 \pm 0.0040$ | ⁵ ADAM | 03 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| $0.0470 \pm 0.0013 ^{+\ 0.0036}_{-\ 0.0031}$ | ⁶ ABREU | 01 н | DLPH | $e^+e^- \to$ | Z |
| $0.0526 \pm 0.0020 \pm 0.0046$ | ⁷ ABBIENDI | 00 Q | OPAL | e^+e^- | Ζ |
| $0.0553 \pm 0.0026 \pm 0.0052$ | ⁸ BUSKULIC | 97 | ALEP | $e^+e^- \rightarrow$ | Ζ |
| Me do not use the following | data for averages | fit. | limite of | | |

| $0.0333 \pm 0.0020 \pm 0.0032$ | | BOSKOLIC | 21 | ALLE | c · c → Z |
|------------------------------------------------|-----------|--------------------------|-------|-----------|-----------------------------------|
| ullet $ullet$ $ullet$ We do not use the | following | g data for averages, | fits, | limits, e | tc. • • • |
| $0.0490 \pm 0.0007 {}^{+\ 0.0036}_{-\ 0.0035}$ | | ⁴ AUBERT | 05 E | BABR | Repl. by AUBERT 08R |
| $0.0539 \pm 0.0011 \pm 0.0034$ | | ⁹ ABDALLAH | 04 D | DLPH | $e^+e^- \rightarrow Z^0$ |
| $0.0459 \pm 0.0023 \pm 0.0040$ | | ¹⁰ ABE | 02F | BELL | Repl. by DUNGEL 10 |
| $0.0609 \pm 0.0019 \pm 0.0040$ | | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.0508 \pm 0.0021 \pm 0.0066$ | | ¹² ACKERSTAFF | 97 G | OPAL | |
| | | | | | ENDI 00 o |
| $0.0552 \pm 0.0017 \pm 0.0068$ | | ¹³ ABREU | 96P | DLPH | Repl. by ABREU 01H |
| $0.0449 \pm 0.0032 \pm 0.0039$ | 376 | ¹⁴ BARISH | 95 | CLE2 | Repl. by ADAM 03 |
| $0.0518 \pm 0.0030 \pm 0.0062$ | 410 | ¹⁵ BUSKULIC | 95 N | ALEP | Sup. by BUSKULIC 97 |
| | | | | | |

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<sup>16</sup> ALBRECHT
0.045 \pm 0.003 \pm 0.004
0.047 \pm 0.005 \pm 0.005
                               235
                                        <sup>17</sup> ALBRECHT
                                                             93 ARG
                                        <sup>18</sup> SANGHERA
seen
                                                             93
                                                                    CLE2
                                                                             e^+e^- \rightarrow \Upsilon(4S)
                                        <sup>19</sup> ANTREASYAN 90B CBAL
0.070 \ \pm 0.018 \ \pm 0.014
                                        20 ALBRECHT 89c ARG
                                                                             e^+e^- \rightarrow \Upsilon(4S)
0.060 \pm 0.010 \pm 0.014
                                        <sup>21</sup> ALBRECHT
                                                             89J ARG
                                                                             e^+e^- \rightarrow \Upsilon(4S)
0.040\ \pm0.004\ \pm0.006
                                        ^{22}BORTOLETTO89B CLEO e^+e^- 
ightarrow \ \varUpsilon(4S)
                                       <sup>23</sup> ALBRECHT 87J ARG
0.070\ \pm 0.012\ \pm 0.019
```

- 1 Uses fully reconstructed $D^{*-}\,\ell^{+}\,\nu$ events $(\ell=e \text{ or }\mu).$
- 2 Uses a fully reconstructed B meson as a tag on the recoil side.
- 3 Measured using fully reconstructed D^* sample and a simultaneous fit to the Caprini-Lellouch-Neubert form factor parameters: $ho^2=1.191\pm0.048\pm0.028,\,R_1(1)=1.429\pm0.061\pm0.044,\,{\rm and}\,\,R_2(1)=0.827\pm0.038\pm0.022.$
- 4 Measured using fully reconstructed D^* sample
- ⁵ Uses the combined fit of both $B^0 \to D^*(2010)^- \ell \nu$ and $B^+ \to \overline{D}(2007)^0 \ell \nu$ samples.
- 6 ABREU 01H measured using about 5000 partial reconstructed D^* sample.
- ⁷ABBIENDI 00Q assumes the fraction B($b \rightarrow B^0$)= (39.7 $\frac{+1.8}{-2.2}$)%. This result is an average of two methods using exclusive and partial D^* reconstruction
- ⁸ BUSKULIC 97 assumes fraction $(B^+)=$ fraction $(B^0)=(37.8\pm2.2)\%$ and PDG 96 values for B lifetime and D^* and D branching fractions
- 9 Combines with previous partial reconstructed D^* measurement.
- 10 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.
- $^{11}\,\mathrm{The}$ results are based on the same analysis and data sample reported in ADAM 03.
- 12 ACKERSTAFF 97G assumes fraction $(B^+)=$ fraction $(B^0)=(37.8\pm2.2)\%$ and PDG 96 values for B lifetime and branching ratio of D^st and D decays
- 13 ABREU 96P result is the average of two methods using exclusive and partial D^{st} reconstruction.
- ¹⁴ BARISH 95 use B($D^0 \to K^-\pi^+$) = (3.91 \pm 0.08 \pm 0.17)% and B($D^{*+} \to D^0\pi^+$) $= (68.1 \pm 1.0 \pm 1.3)\%.$
- 15 BUSKULIC 95N assumes fraction $(B^+)=$ fraction $(B^0)=38.2\pm1.3\pm2.2\%$ and au_{R^0} $= 1.58 \pm 0.06$ ps. $\Gamma(D^{*-}\ell^{+}\nu_{\ell})/{
 m total} = [5.18 - 0.13({
 m fraction}(B^{0}) - 38.2) - 1.5(au_{B^{0}} - 2.18) + 1.5(1.8)$
- ¹⁶ ALBRECHT 94 assumes B($D^{*+} \rightarrow D^0 \pi^+$) = 68.1 \pm 1.0 \pm 1.3%. Uses partial reconstruction of D^{*+} and is independent of D^{0} branching ratios.
- TALBREATH 93 reports $0.052 \pm 0.005 \pm 0.006$. We rescale using the method described in STONE 94 but with the updated PDG 94 B($D^0 \rightarrow K^-\pi^+$). We have taken their average e and μ value. They also obtain $\alpha = 2*F^0/(\Gamma^- + \Gamma^+) 1 = 1.1 \pm 0.4 \pm 0.2$. $A_{AF}=3/4*(\Gamma^--\Gamma^+)/\Gamma=0.2\pm0.08\pm0.06$ and a value of $|V_{cb}|=0.036$ –0.045 depending on model assumptions.
- 18 Combining $\overline{D}^{*0}\ell^+\nu_\ell$ and $\overline{D}^{*-}\ell^+\nu_\ell$ SANGHERA 93 test V-A structure and fit the decay angular distributions to obtain $A_{FB}=3/4*(\Gamma^--\Gamma^+)/\Gamma=0.14\pm0.06\pm0.03$. Assuming a value of V_{CD} , they measure V_c , A_1 , and A_2 , the three form factors for the $D^*\ell
 u_\ell$ decay, where results are slightly dependent on model assumptions.
- 19 A NTREASYA N 90B is average over B and $\overline{D}^*(2010)$ charge states.
- 20 The measurement of ALBRECHT 89c suggests a D^* polarization γ_L/γ_T of 0.85 \pm 0.45. or $\alpha=0.7\pm0.9$.
- 21 ALBRECHT 89) is ALBRECHT 87) value rescaled using B($D^*(2010)^- \rightarrow D^0\pi^-$) = 0.57 \pm 0.04 \pm 0.04. Superseded by ALBRECHT 93.
- $0.57 \pm 0.04 \pm 0.04$. Supersected by ALDRECH 1 93. 22 We have taken average of the the BORTOLETTO 89B values for electrons and muons, $0.046 \pm 0.005 \pm 0.007$. We rescale using the method described in STONE 94 but with the updated PDG 94 B($D^0 \rightarrow K^-\pi^+$). The measurement suggests a D^* polarization parameter value $\alpha = 0.65 \pm 0.66 \pm 0.25$.
- 23 ALBRECHT 87J assume μ -e universality, the B($\varUpsilon(4S)
 ightarrow ~B^0 \, \overline{B}{}^0$) = 0.45, the B($D^0
 ightarrow$ $(K^-\pi^+)=(0.042\pm 0.004\pm 0.004)$, and the $B(D^*(2010)^-\to D^0\pi^-)=0.49\pm 0.08$. Superseded by ALBRECHT 891.

WEIGHTED AVERAGE 0.0509±0.0022 (Error scaled by 1.6)



 $\Gamma(D^*(2010)^-\ell^+\nu_\ell)/\Gamma(D\ell^+\nu_\ell \text{ a nything})$ Γ_6/Γ_3 DOCUMENT TECN COMMENT 1 AUBERT 0.537±0.031±0.036 07AN BABR $e^+e^- \rightarrow \Upsilon(4S)$

¹Uses a fully reconstructed B meson on the recoil side.

| $\Gamma(D^*(2010)^-\tau^+\nu_{	au})/\Gamma_{ m tc}$ | atal | Γ ₇ /Ι |
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| VALUE (units 10 ⁻²) | DO CUMENT ID TEC | • |
| 1.5 ±0.5 OUR FIT Error | includes scale factor of 1.4. | |
| $2.02^{+0.40}_{-0.37} \pm 0.37$ | ¹ MATYJA 07 BEI | LL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | lowing data for averages, fits, limi | its, etc. • • • |
| $1.11 \pm 0.51 \pm 0.06$ | ² AUBERT 08N BA | BR Repl. by AUBERT 09s |
| | the accompanying B meson. | |
| | I B meson as a tag on the recoil: | side. |
| $\Gamma(D^*(2010)^-\tau^+\nu_{\tau})/\Gamma($ | | Γ ₇ /Γ ₀ |
| 0.29 ±0.10 OUR FIT Err | DOCUMENT ID TEC or includes scale factor of 1.4. | CN COMMENT |
| $0.207 \pm 0.095 \pm 0.008$ | ¹ AUBERT 09s BA | BR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $^{ m 1}$ Uses a fully reconstructed | $oldsymbol{B}$ meson as a tag on the recoil : | side. |
| $\Gamma(\overline{D}{}^0\pi^-\ell^+\nu_\ell)/\Gamma_{total}$ | | Γ ₈ /Ι |
| VALUE (units 10 ⁻³) | DO CUMENT ID TECN | COMMENT |
| 4.3±0.6 OUR AVERAGE | 1 | n - m(+m) |
| $4.3 \pm 0.8 \pm 0.3$ $4.3 \pm 0.9 \pm 0.2$ | ¹ AUBERT 08Q BABF ^{1,2} LIVENTSEV 08 BELL | $e^+e^- ightarrow \gamma(4S) \ e^+e^- ightarrow \gamma(4S)$ |
| | lowing data for averages, fits, limi | |
| $3.4\pm1.0\pm0.2$ | ³ LIVENTSEV 05 BELL | |
| 1 Uses a fully reconstructed | 1 B meson as a tag on the recoil : $(4.2 \pm 0.7 \pm 0.6) \times 10^{-3}$ from | side. |
| $\overline{D}_{0}^{0} = 0 + 10$ /c 1 / [| $(4.2\pm0.7\pm0.6)	imes 10^{-5}$ from $(B(B^0	o D^-\ell^+ u_\ell)]$ assuming B(| a measurement of $[(B^{\circ} - (B^{\circ}) \rightarrow D^{\circ})] = (2.12 - (2.12))$ |
| 0.201×10^{-2} , which we r | escale to our best value $B(B^0 \rightarrow$ | $D^-\ell^+\nu_\ell = (2.18 \pm 0.12)$ |
| 10 ⁻² . Our first error is | their experiment's error and our s | second error is the systemati |
| error from using our best | value. $[\Gamma(B^0 \to \overline{D}^0 \pi^- \ell^+ \nu_\ell)/\Gamma_{\text{total}}]$ | |
| 0.15 ± 0.03 ± 0.03 which | we multiply by our best value B(| $/ [B(B^+ \rightarrow D^-\ell^+\nu_\ell)] =$ $B^+ \rightarrow \overline{D}^0 \ell^+\nu_\ell) = (2.26 \pm$ |
| $0.11) \times 10^{-2}$. Our first | error is their experiment's error | and our second error is th |
| systématic error from usi | ng our best value. | |
| $\Gamma(D_0^*(2400)^-\ell^+\nu_{\ell} \times B(\ell))$ | $D_0^{*-} \rightarrow \overline{D}{}^0\pi^-))/\Gamma_{\text{total}}$ | Г9/ |
| VALUE (units 10 ⁻³) | | CN COMMENT |
| 3.0 \pm 1.2 OUR AVERAGE E 4.4 \pm 0.8 \pm 0.6 | rror includes scale factor of 1.8. 1 AUBERT 08BL BA | BR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 2.0 ± 0.7 ± 0.5 | _ | LL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | B meson as a tag on the recoil: | side. |
| $\Gamma(D_2^*(2460)^-\ell^+\nu_{\ell} \times B(2460)^-\ell^+\nu_{\ell})$ | $D_a^{*-} \rightarrow \overline{D}{}^0\pi^-))/\Gamma_{total}$ | Γ ₁₀ / |
| VALUE (units 10 ⁻³) | | COMMENT |
| 1.21±0.33 OUR AVERAGE | Error includes scale factor of 1.8 | 3. |
| $1.10 \pm 0.17 \pm 0.08$ $2.2 \pm 0.4 \pm 0.4$ | | BR $e^+e^- \rightarrow \Upsilon(4S)$ LL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | all B semileptonic decays without | , , |
| | $B^0 \rightarrow \overline{D}_2^*(2460)^- \ell^+ \nu_\ell) \cdot B(\overline{D}_2^*)$ | |
| $(1.77 \pm 0.26 \pm 0.11) \times 10^{-1}$ | ⁻³ and the authors have provided u | s the individual measurement |
| 2 | | |
| Uses a fully reconstructed | B meson as a tag on the recoil B | side. |
| | | |
| $\Gamma(\overline{D}^{(*)} n \pi \ell^+ \nu_\ell (n \geq 1))$ |)/Γ(<i>Dℓ</i> +ν _ℓ anything) | Γ ₁₁ /Γ |
| $\Gamma(\overline{D}^{(*)} \cap \pi \ell^+ \nu_{\ell} (n \ge 1))$ $VALUE$ $0.248 \pm 0.032 \pm 0.030$ | $\frac{1}{\sqrt{\Gamma(D\ell^+\nu_\ell \text{anything})}} \frac{DOCUMENT ID}{1 \text{AUBERT} 07AN BA}$ | Г ₁₁ /Г |
| $\Gamma(\overline{D}^{(*)} \cap \pi\ell^+ \nu_\ell (n \ge 1))$ $VALUE$ 0.248±0.032±0.030 1 Uses a fully reconstructed |)/Γ(<i>Dℓ</i> +ν _ℓ anything) | Γ_{11}/Γ COMMENT BR $e^+e^- 	o 	au(45)$ |
| $ \begin{split} & \Gamma(\overline{D}^{(*)} \operatorname{n} \pi \ell^+ \nu_\ell (\operatorname{n} \geq 1)) \\ & \underbrace{\scriptscriptstyle{VALUE}} \\ & 0.248 \pm 0.032 \pm 0.030 \\ & 1 \text{ Uses a fully reconstructed} \\ & \Gamma(\overline{D}^{*0} \pi^- \ell^+ \nu_\ell) / \Gamma_{\text{total}} \end{split} $ | $0/\Gamma(D\ell^+ u_\ell$ anything) $0/\Gamma(D\ell^+ u_\ell$ anything) $0/\Gamma(D\ell^+ u_\ell)$ $0/\Gamma(D\ell^+ u$ | $rac{\Gamma_{11}/\Gamma}{RR} = \frac{COMMENT}{e^+e^- 	o \Upsilon(4S)}$ |
| | $\frac{1}{\sqrt{\Gamma(D\ell^+\nu_\ell \text{anything})}} \frac{DOCUMENT ID}{1 \text{AUBERT} 07AN BA}$ | $rac{\Gamma_{11}/\Gamma}{RR} = \frac{COMMENT}{e^+e^- 	o \Upsilon(4S)}$ |
| $ \begin{array}{l} \Gamma\left(\overline{D}^{(*)} \operatorname{n}\pi\ell^{+}\nu_{\ell} (\operatorname{n} \geq 1)\right) \\ \underline{VALUE} \\ 0.248 \pm 0.032 \pm 0.030 \\ 1 \text{ Uses a fully reconstructed} \\ \Gamma\left(\overline{D}^{*0}\pi^{-}\ell^{+}\nu_{\ell}\right)/\Gamma_{\text{total}} \\ \underline{VALUE} (\operatorname{units} 10^{-3}) \\ 4.9 \pm 0.8 \text{ OUR AVERAGE} \end{array} $ | $0/\Gamma(D\ell^+ u_\ell anything)$ $0/\Gamma(D\ell^+ u_\ell anythi$ | Γ_{11}/Γ BR $e^+e^- 	o 	au_{(45)}$ Γ_{12}/Γ Γ_{12}/Γ |
| | $0/\Gamma(D\ell^+\nu_\ell \text{ anything})$ | $\begin{array}{c c} & & \Gamma_{11}/\Gamma \\ \hline \text{BR} & \frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)} \\ \hline \\ R & e^+e^- \rightarrow \Upsilon(4S) \\ e^+e^- \rightarrow \Upsilon(4S) \\ e^+e^- \rightarrow \Upsilon(4S) \end{array}$ |
| $ \begin{array}{l} \Gamma\left(\overline{D}^{(*)} n \pi \ell^+ \nu_\ell (n \geq 1)\right) \\ \hline \nu_{ALUE} \\ 0.248 \pm 0.032 \pm 0.030 \\ 1 Uses a fully reconstructed \\ \Gamma\left(\overline{D}^{*0} \pi^- \ell^+ \nu_\ell\right) / \Gamma_{total} \\ \hline \nu_{ALUE} (units 10^{-3}) \\ 4.9 \pm 0.8 OUR AVERAGE \\ 4.8 \pm 0.8 \pm 0.4 \\ 5.8 \pm 2.2 \pm 0.3 \\ \bullet \bullet We do not use the fol \\ \hline \end{array} $ | $\rho/\Gamma(D\ell^+\nu_\ell \text{anything})$ $\rho/\Gamma(D\ell^+\nu_\ell $ | $\begin{array}{c c} & & \Gamma_{11}/\Gamma \\ \hline & & \underline{COMMENT} \\ BR & e^+e^- \rightarrow \Upsilon(4S) \\ \hline & & |
| | $0/\Gamma(D\ell^+\nu_\ell \text{ anything})$ | T11/ Γ BR $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ its, etc. • • Repl. by LIVENTSEV 08 |
| $ \begin{split} & \Gamma\left(\overline{D}^{(*)} \operatorname{n} \pi \ell^{+} \nu_{\ell} (\operatorname{n} \geq 1)\right) \\ & \frac{VALUE}{0.248 \pm 0.032 \pm 0.030} \\ & 1 \text{ Uses a fully reconstructed} \\ & \Gamma\left(\overline{D}^{*0} \pi^{-} \ell^{+} \nu_{\ell}\right) / \Gamma_{\text{total}} \\ & \frac{VALUE (\operatorname{units} 10^{-3})}{4.9 \pm 0.8} \operatorname{OUR} \text{ AVERAGE} \\ & 4.8 \pm 0.8 \pm 0.4 \\ & 5.8 \pm 2.2 \pm 0.3 \\ & \bullet \bullet \bullet \text{ We do not use the fol} \\ & 5.7 \pm 1.3 \pm 0.2 \\ & 1 \text{ Uses a fully reconstructed} \end{split} $ | 1 AUBERT 08Q BABELLIOWING DOWN 18 TECN 1 AUBERT 08Q BABELLIOWING GAT POR 19 TECN 1 AUBERT 08Q BABELLIOWING GAT POR 19 TECN 1 AUBERT 08 BELLIOWING GAT POR 19 TECN 3.4 LIVENTSEV 05 BELL | $\begin{array}{c c} & \Gamma_{11}/\Gamma \\ \hline \text{BR} & \frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)} \\ \hline & & \\ \hline$ |
| $ \begin{split} & \Gamma\left(\overline{D}^{(*)} \operatorname{n} \pi \ell^+ \nu_\ell (\operatorname{n} \geq 1)\right) \\ & \frac{VALUE}{0.248 \pm 0.032 \pm 0.030} \\ & 1 \operatorname{Uses} \text{ a fully reconstructed} \\ & \Gamma\left(\overline{D}^{*0} \pi^- \ell^+ \nu_\ell\right) / \Gamma_{\text{total}} \\ & \frac{VALUE \left(\operatorname{units} 10^{-3} \right)}{4.9 \pm 0.8} \operatorname{OUR} \text{ AVERAGE}} \\ & 4.8 \pm 0.8 \pm 0.4 \\ & 5.8 \pm 2.2 \pm 0.3 \\ & \bullet \bullet \text{ We do not use the fol} \\ & 5.7 \pm 1.3 \pm 0.2 \\ & 1 \operatorname{Uses} \text{ a fully reconstructed} \\ & 2 \operatorname{LIVENTSEV} \text{ 08 reports} \end{split} $ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | T11/ Γ BR $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ R $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ its, etc. • • • Repl. by LIVENTSEV 08 side. a measurement of $[\Gamma(B^0 - e^+)]$ |
| $ \begin{split} & \Gamma\left(\overline{D}^{(*)} \operatorname{n} \pi \ell^+ \nu_\ell (\operatorname{n} \geq 1)\right) \\ & \frac{VALUE}{0.248 \pm 0.032 \pm 0.030} \\ & 1 \operatorname{Uses} \text{ a fully reconstructed} \\ & \Gamma\left(\overline{D}^{*0} \pi^- \ell^+ \nu_\ell\right) / \Gamma_{\text{total}} \\ & \frac{VALUE}{4.9 \pm 0.8} \operatorname{OUR} \text{ AVERAGE} \\ & 4.9 \pm 0.8 \operatorname{OUR} \text{ AVERAGE} \\ & 4.8 \pm 0.8 \pm 0.4 \\ & 5.8 \pm 2.2 \pm 0.3 \\ & \bullet \bullet \text{ We do not use the fol} \\ & 5.7 \pm 1.3 \pm 0.2 \\ & 1 \operatorname{Uses} \text{ a fully reconstructed} \\ & \overline{D}^{*0} \pi^- \ell^+ \nu_\ell\right) / \Gamma_{\text{total}} / \end{aligned} $ | $\frac{1}{1} \frac{DOCUMENT\ ID}{AUBERT} \frac{TEO}{1000000000000000000000000000000000000$ | $\begin{array}{c c} \Gamma_{11}/\Gamma \\ \hline EN & \underline{COMMENT} \\ \hline BR & e^+e^- \rightarrow \Upsilon(4S) \\ \hline & \Gamma_{12}/\Gamma \\ \hline & COMMENT \\ \hline & e^+e^- \rightarrow \Upsilon(4S) \\ & e^+e^- \rightarrow \Upsilon(4S) \\ & e^+e^- \rightarrow \Upsilon(4S) \\ & \text{its, etc.} \bullet \bullet \bullet \\ \hline & \text{Repl. by LIVENTSEV 08} \\ & \text{side.} \\ & \text{a measurement of } \left[\Gamma(B^0 - E^0) - E^0 + V_F\right] = (2.123) \end{array}$ |
| $\Gamma(\overline{D}^{(*)} \operatorname{n}\pi\ell^+\nu_\ell(\operatorname{n} \geq 1))$ $VALUE$ 0.248±0.032±0.030 1 Uses a fully reconstructed $\Gamma(\overline{D}^{*0}\pi^-\ell^+\nu_\ell)/\Gamma_{\text{total}}$ 4.9±0.8 OUR AVERAGE 4.8±0.8±0.4 5.8±2.2±0.3 • • We do not use the fol 5.7±1.3±0.2 1 Uses a fully reconstructed $\Gamma(\operatorname{n}^{*0}\pi^-\ell^+\nu_\ell)/\Gamma_{\text{total}}/\Gamma_{\text{total}}$ $\Gamma(\operatorname{n}^{*0}\pi^-\ell^+\nu_\ell)/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{\text{total}}/\Gamma_{tot$ | $\frac{1}{1}\frac{DOCUMENT\ ID}{AUBERT} \qquad \frac{TECN}{O7AN\ BA}$ $\frac{DOCUMENT\ ID}{1}\frac{TECN}{AUBERT} \qquad 08Q BABF$ $\frac{1}{1}\frac{AUBERT}{AUBERT} \qquad 08Q BABF$ $\frac{1}{1}\frac{2}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}{1}\frac{1}\frac$ | $\begin{array}{c c} & \Gamma_{11}/\Gamma \\ \hline \text{BR} & \underline{comment} \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ & e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ & e^+e^- \rightarrow & \Upsilon(4S) \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \text{its, etc.} & \bullet & \bullet \\ \hline \\ \text{Repl. by LIVENTSEV 08} \\ \text{side.} \\ \text{a measurement of } \left[\Gamma(B^0 - \\ (B^0 \rightarrow D^-\ell^+\nu_\ell) = (2.12 \pm 0.12) \right] \\ \hline \\ & D^-\ell^+\nu_\ell) = (2.18 \pm 0.12) \end{array}$ |
| | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c c} & \Gamma_{11}/\Gamma \\ \hline \text{BR} & \underline{comment} \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ & e^+e^- \rightarrow & \Upsilon(4S) \\ \hline \\ & e^+e^- \rightarrow & \Upsilon(4S) \\ e^+e^- \rightarrow & \Upsilon(4S) \\ \text{its, etc.} & \bullet & \bullet \\ \hline \\ \text{Repl. by LIVENTSEV 08} \\ \text{side.} \\ \text{a measurement of } \left[\Gamma(B^0 - \\ (B^0 \rightarrow D^-\ell^+\nu_\ell) = (2.12 \pm 0.12) \right] \\ \hline \\ & D^-\ell^+\nu_\ell) = (2.18 \pm 0.12) \end{array}$ |

| $0.20) \times 10^{-2}$, which we res 10^{-2} . Our first error is the error from using our best v | scale to our best value leir experiment's erro | B(B ⁰ rand c | → D ⁻ our seco | nd error is t | $0.18\pm0.12)	imes$ the systematic |
|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|-------------------------|------------------------------|--------------------------------------------------|------------------------------------|
| 3 Excludes D*+ contribution 4 LIVENTSEV 05 | n to <i>D</i> π modes. reports ΓΓ <i>(B⁽</i> |) | \rightarrow | \overline{D}^* | $(0_{\pi} - \ell^{+} \nu_{\ell})$ |
| $\Gamma_{	ext{total}}]$ / $[B(B^+ 	o \overline{D}^*)]$ our best value $B(B^+ 	o \overline{D})$ their experiment's error an value. | $[2007)^{0} \ell^{+} \nu_{\ell}] = 0.1$ $[0.10] \times (2007)^{0} \ell^{+} \nu_{\ell} = 0.1$ | 0 ± 0. [5.70 ± | .02 ± 0. ± 0.19) : | $^{.01}$ which w $_{	imes}$ $^{.0}$ $^{-2}$. Ou | e multiply by r first error is |
| $\Gamma(D_1(2420)^-\ell^+\nu_\ell \times B(D))$ | $_{1}^{-} ightarrow\overline{D}^{st0}\pi^{-}))/\Gamma$ | total | | | Γ ₁₃ /Γ |
| | | | | | |
| VALUE (units 10^{-3}) | DO CUMENT ID | | TECN | COMMENT | |
| VALUE (units 10 ⁻³) 2.80±0.28 OUR AVERAGE | | | | | |
| | 1 AUBERT | 09Y | BABR | $e^+e^- \rightarrow$ | Υ(4S) |
| 2.80±0.28 OUR AVERAGE | 1 AUBERT | 09Y | BABR | $e^+e^- \rightarrow$ | Υ(4S) Υ(4S) |
| 2.80±0.28 OUR AVERAGE 2.78±0.24±0.25 | | 09Y | BABR | $e^+e^- \rightarrow$ | Υ(45) Υ(45) Υ(45) |

```
\Gamma(D_1'(2430)^-\ell^+\nu_\ell \times \mathsf{B}(D_1'^- \to \overline{D}^{*0}\pi^-))/\Gamma_{\mathsf{total}}
                                                                                                                \Gamma_{14}/\Gamma
                                                 DOCUMENT ID TECN COMMENT
                              CL%
                                               <sup>1</sup> AUBERT
                                                                       08BL BABR e^+e^- \rightarrow \Upsilon(4S)
  3.1 \pm 0.7 \pm 0.5
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                              ^{1} LIVENTSEV 08 BELL e^{+}e^{-} \rightarrow \ \varUpsilon(4S)
                                 90
< 5.0
   ^{\mathrm{1}} Uses a fully reconstructed ^{\mathrm{B}} meson as a tag on the recoil side.
```

| $\Gamma(D_2^*(2460)^-\ell^+\nu_\ell$ | $\times B(D_2^{*-}$ | $\rightarrow \overline{D}^{*0}\pi^{-}))/$ | Γ _{total} | | | Γ ₁₅ /Γ | |
|--------------------------------------|-----------------------|------------------------------------------------------|-----------------------|--------|----------------------|--------------------|---|
| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | TE | CN | COMMENT | | |
| 0.68 ± 0.12 OUR AV | /ERAGE | , | | | | | |
| $0.67 \pm 0.12 \pm 0.05$ | | ¹ AUBERT | | ABR | $e^+e^- \rightarrow$ | T(45) | |
| $0.7 \pm 0.2 \pm 0.2$ | | ² AUBERT | 08BL B | ABR | $e^+e^- \rightarrow$ | Y(45) | |
| • • • We do not use | the followi | ng data for average | s, fits, lin | nits, | etc. • • • | | |
| <3.0 | 90 | ² LIVENTSEV | 08 BI | ELL | $e^+e^- \rightarrow$ | Y(45) | |
| ¹ Uses a simultaneo | us fit of all | B semileptonic deci | ays withou | ıt ful | l reconstruct | ion of events. | ı |
| AUBERT 09Y rep | orts B(B ⁰ | $\rightarrow \overline{D}_{2}^{*}(2460)^{-}\ell^{+}$ | ν _θ) · Β(| D*(2 | 460) [−] → | $D(*)0\pi^{-}) =$ | |
| | ` 2 | Ζ' ' | e, (| ۷١ | , | , | |

 $(1.77\pm0.26\pm0.11)\times10^{-3}$ and the authors have provided us the individual measurement. 2 Uses a fully reconstructed B meson as a tag on the recoil side.

 $\Gamma(\rho^-\ell^+\nu_\ell)/\Gamma_{\rm total}$ $\ell=e$ or μ , not sum over e and μ modes.

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) by including both B^0 and B^+ decays. The average assumes equality of

the semileptonic decay width for these isospin conjugate states. DO CUMENT ID TECN COMMENT 2.34±0.15±0.24 OUR EVALUATION

| 2.07±0.34 OUR AVERAGE | Error includes sca | le fac | tor of 1. | 4. See the ideogram below. |
|--------------------------------------------------|------------------------|-------------|-----------|------------------------------------------------------------------------|
| $1.75 \pm 0.15 \pm 0.27$ | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $2.93 \pm 0.37 \pm 0.37$ | ² ADAM | 07 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| $2.17 \pm 0.54 \pm 0.32$ | ³ HOKUUE | 07 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ● ● We do not use the follow | wing data for avera | ges, fi | ts, limit | s, etc. • • • |
| $2.14 \pm 0.21 \pm 0.56$ | ¹ AUBERT,B | 05 o | BABR | Repl. by DEL-AMO- SANCHEZ 11c |
| $2.17 \pm 0.34 + 0.62 \\ -0.68$ | ⁴ ATHAR | 03 | CLE2 | Repl. by ADAM 07 |
| $3.29 \pm 0.42 \pm 0.72$ | ⁵ AUBERT | 03E | BABR | Repl. by AUBERT,B 050 |
| $2.57 \pm 0.29 {}^{+ 0.53}_{- 0.62}$ | ⁶ BEHRENS | 00 | CLE2 | Repl. by ADAM 07 |
| $2.69 \pm 0.41 {}^{+ 0.61}_{- 0.64}$ | ⁷ BEHRENS | 00 | CLE2 | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| $2.5 \pm 0.4 ^{+ 0.7}_{- 0.9}$ | ⁸ ALEXANDER | 96т | CLE2 | Repl. by BEHRENS 00 |
| <4.1 90 | ⁹ BEAN | 93B | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |

 $^{1}\mathit{B}^{+}$ and B^{0} decays combined assuming isospin symmetry. Systematic errors include both

experimental and form-factor uncertainties. 2 The B^0 and B^+ results are combined assuming the isospin, B lifetimes, and relative charged/neutral B production at the $\Upsilon(4S)$.

 $^3\,\mathrm{The\ signal\ events}$ are tagged by a second B meson reconstructed in the semileptonic mode $B \to D^{(*)} \ell \nu_{\ell}$.

ATHAR 03 reports systematic errors $^{+0.47}_{-0.50}$ \pm 0.41 \pm 0.01, which are experimental systematic, systematic due to residual form-factor uncertainties in the signal, and systematic tematic due to residual form-factor uncertainties in the cross-feed modes, respectively. We combine these in quadrature.

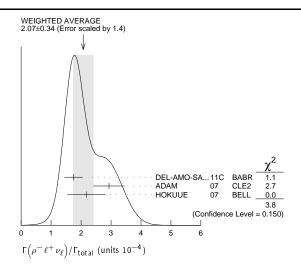
5 Uses isospin constraints and extrapolation to all electron energies according to five different form-factor calculations. The second error combines the systematic and theoretical uncertainties in quadrature.

⁶ Averaging with ALEXANDER 96T results including experimental and theoretical correlations considered, BEHRENS 00 reports systematic errors $^{+}_{-0.46}^{+0.33}\pm$ 0.41, where the

second error is theoretical model dependence. We combine these in quadrature. 7 BEHRENS 00 reports $^{+0.35}_{-0.40}\pm$ 0.50, where the second error is the theoretical model dependence. We combine these in quadrature. B^+ and B^0 decays combined using isospin symmetry: $\Gamma(B^0\to\rho^-\ell^+\nu)=2\Gamma(B^+\to\rho^0\ell^+\nu)\approx 2\Gamma(B^+\to\omega\ell^+\nu)$. No

isospin symmetry. If $\nu = \nu$ = 7, evidence for $\omega \ell \nu$ is reported. 8 ALEXANDER 96T reports $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where the second error is the theoretical model $^{+0.5}_{-0.7} \pm 0.5$ where $^{+0.5}_{-0.7} \pm 0.5$ decays combined using dependence. We combine these in quadrature. B^+ and B^0 decays combined using isospin symmetry: $\Gamma(B^0\to\rho^-\ell^+\nu)=2\Gamma(B^+\to\rho^0\ell^+\nu)\approx 2\Gamma(B^+\to\nu\ell^+\nu)$. No evidence for $\omega\ell\nu$ is reported.

⁹BEAN 93B limit set using ISGW Model. Using isospin and the quark model to combine $\Gamma(
ho^0\ell^+\nu_\ell)$ and $\Gamma(\omega\ell^+\nu_\ell)$ with this result, they obtain a limit <(1.6–2.7) \times 10⁻⁴ at 90% CL for $B^+ \to (\omega \text{ or } \rho^0) \ell^+ \nu_\ell$. The range corresponds to the ISGW, WSB, and KS models. An upper limit on $\left|V_{ub}/V_{cb}\right| <$ 0.08–0.13 at 90% CL is derived as well.



 $\Gamma(\pi^-\ell^+\nu_\ell)/\Gamma_{ ext{total}}$ "OUR EVALUATION" is provided by the Heavy Flavor Averaging Group (HFAG) the procedure is described at http://www.slac.stanford.edu/xorg/hfag/

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------------------------|------------------------------------------------------|--------------|------------------------------------------------------|
| 1.441 ± 0.052 OUR EVALUATIO | N | | |
| 1.44 ±0.05 OUR AVERAGE | | | |
| $1.41 \pm 0.05 \pm 0.07$ | ¹ DEL-AMO-SA11c | | |
| $1.42 \pm 0.05 \pm 0.08$ | ² DEL-AMO-SA11F | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.49 \pm 0.04 \pm 0.07$ | ² HA 11 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.54 \pm 0.17 \pm 0.09$ | | V BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.37 \pm 0.15 \pm 0.11$ | ^{3,4} ADAM 07 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.38 \pm 0.19 \pm 0.14$ | ⁵ HOKUUE 07 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | ng data for averages, fits | , limits, | etc. • • • |
| $1.46 \ \pm 0.07 \ \pm 0.08$ | ⁶ AUBERT 07J | BABR | Repl. by DEL-AMO- SANCHEZ 11F |
| $1.33 \pm 0.17 \pm 0.11$ | ⁷ AUBERT,B 06K | BABR | |
| $1.38 \pm 0.10 \pm 0.18$ | ⁸ AUBERT,B 05 o | BABR | Repl. by DEL-AMO- |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ⁹ ATHAR 03 ¹⁰ ALEXANDER 96T | CLE2 CLE2 | SANCHEZ 11c Repl. by ADAM 07 Repl. by ATHAR 03 |

 $^{\rm 1}\,{\rm Using}$ isospin relation, ${\it B}^{\,+}$ and ${\it B}^{\,0}$ branching fractions are combined

Uses the neutrino reconstruction technique. Assumes $B(\Upsilon(4S) \to B^+B^-) = (51.6 \pm 0.6)\%$ and $B(\Upsilon(4S) \to B^0\overline{B}^0) = (48.4 \pm 0.6)\%$. ³ The B^0 and B^+ results are combined assuming the isospin, B lifetimes, and relative charged/neutral B production at the $\Upsilon(4S)$.

⁴ Also report the rate for $q^2 > 16$ GeV² of $(0.41 \pm 0.08 \pm 0.04) \times 10^{-4}$ from which they obtain $|V_{ub}|=3.6\pm0.4\pm0.2^{+0.6}_{-0.4}$ (last error is from theory).

 $^{5}\,\mathrm{The}$ signal events are tagged by a second B meson reconstructed in the semileptonic mode $B \to D^{(*)} \ell \nu_{\ell}$.

⁶ The analysis uses events in which the signal B decays are reconstructed with an innovative loose neutrino reconstruction technique.

The signals are tagged by a second B meson reconstructed in a semileptonic or hadronic decay. The B^0 and B^+ results are combined assuming the isospin symmetry.

 $^8B^+$ and 0 decays combined assuming isospin symmetry. Systematic errors include both experimental and form-factor uncertainties.

PATHAR 03 reports systematic errors $0.11\pm0.01\pm0.07$, which are experimental systematic, systematic due to residual form-factor uncertainties in the signal, and systematic due to residual form-factor uncertainties in the cross-feed modes, respectively. We combine these in quadrature.

 10 ALEXA NDER 96T gives systematic errors $\pm 0.3\pm 0.2$ where the second error reflects the estimated model dependence. We combine these in quadrature. Assumes isospin symmetry: $\Gamma(B^0\to\pi^-\ell^+\nu)=2\times\Gamma(B^+\to\pi^0\ell^+\nu)$.

| $\Gamma(\pi^-\mu^+ u_\mu)/\Gamma_{ m total}$ | | | Γ_{18}/Γ |
|----------------------------------------------|-------------------------|--------------------------|----------------------|
| VALUE | DO CUMENT ID | <u>TECN</u> | |
| • • • We do not use the follow | wing data for averages, | fits, limits, etc. • • • | |
| seen | 1 ALBRECHT | 91c ARG | |

 1 In ALBRECHT 91c, one event is fully reconstructed providing evidence for the b
ightarrow u

| $\Gamma(K^{\pm}$ anything)/ Γ_{total} | | | | | Г19/Г |
|-----------------------------------------------------|--------------|-----|------|-----------------------|-------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.78±0.08 | 1 ALBRECHT | 96D | ARG | $e^+ e^- \rightarrow$ | Y(45) |
| ¹ Average multiplicity. | | | | | |

| $\Gamma(D^0X)/\Gamma_{\text{total}}$ | | | | Γ_{20}/Γ |
|--------------------------------------|--------------------------------|-----------|-------------|----------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| $0.081 \pm 0.014 \pm 0.005$ | ¹ AUBERT 07N | BABR | $e^+e^-\to$ | Y(45) |
| • • • We do not use the fol | lowing data for averages, fits | , limits, | etc. • • • | |

¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N $0.063 \pm 0.019 \pm 0.005$ $^1\,\rm Events$ are selected by completely reconstructing one B and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

| $\Gamma(\overline{D}{}^0X)/\Gamma_{\text{total}}$ | | | | Γ_{21}/Γ | | | |
|---------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------|------------------------|----------------------|--|--|--|
| VALUE | DO CUMENT ID | TECI | <u>COMMENT</u> | | | | |
| $0.474 \pm 0.020 {}^{+ 0.020}_{- 0.019}$ | ¹ AUBERT | 07n BAE | R $e^+e^- \rightarrow$ | T(45) | | | |
| • • • We do not use the follow | owing data for average | s, fits, limit | s, etc. • • • | | | | |
| $0.511 \pm 0.031 \pm 0.028$ | ¹ AUBERT,BE | 04B BAE | R Repl. by A | AUBERT 07N | | | |
| | ¹ Events are selected by completely reconstructing one B and searching for a reconstruction charmed particle in the rest of the event. The last error includes systematic and one particle in the rest of the event. | | | | | | |

| $\Gamma(D^0X)/[\Gamma(D^0X)+\Gamma(\overline{D}^0X)]$ | | | $\Gamma_{20}/(\Gamma_{20}+\Gamma_{21}$ | | | |
|-------------------------------------------------------|----------------|------|----------------------------------------|--|--|--|
| VALUE | DOCUMENT ID | TECN | COMMENT | | | |
| 0.146±0.022±0.006 | AUBERT 07N | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | | | |
| ullet $ullet$ We do not use the following | etc. • • • | | | | | |
| 0.110 ± 0.031 ± 0.008 | ALIBERT RE MAR | BABB | Rent by ALIBERT 07N | | | |

 $\Gamma(D+X)/\Gamma_{\text{total}}$ Γ_{22}/Γ VALUE CL% DO CUMENT ID TECN COMMENT $^{\mathrm{1}}$ AUBERT < 0.039 90 07N BABR $e^+e^- \rightarrow$ $\Upsilon(4S)$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $^{1}\,\mathrm{AUBERT,BE}-04\mathrm{B}$ BABR Repl. by AUBERT 07N 90

 1 Events are selected by completely reconstructing one ${\it B}$ and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

 $\Gamma(D^-X)/\Gamma_{\text{total}}$ Γ_{23}/Γ DOCUMENT ID $0.369 \pm 0.016 ^{+0.030}_{-0.027}$ $^{\mathrm{1}}$ AUBERT 07N BABR $e^+e^- \rightarrow$ \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

 $0.397 \pm 0.030 \,{}^{+\, 0.040}_{-\, 0.038}$ $^{
m 1}$ AUBERT,BE 04B BABR Repl. by AUBERT 07N

 $^{
m 1}$ Events are selected by completely reconstructing one B and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

 $\Gamma(D^+X)/[\Gamma(D^+X)+\Gamma(D^-X)]$ $\Gamma_{22}/(\Gamma_{22}+\Gamma_{23})$ VALUE DO CUMENT ID TECN COMMENT $0.058 \pm 0.028 \pm 0.006$ AUBERT 07N BABR $e^+e^- \rightarrow$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet AUBERT,BE 04B BABR Repl. by AUBERT 07N $0.055 \pm 0.040 \pm 0.006$

 $\Gamma(D_s^+ X)/\Gamma_{\text{total}}$ Γ_{24}/Γ $0.103\pm0.012^{+0.017}_{-0.014}$ ¹ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • •

 $0.109 \pm 0.021 + 0.039 \\ -0.024$ ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N $^{
m 1}$ Events are selected by completely reconstructing one B and searching for a reconstructed

charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

 $\Gamma(D_s^- X)/\Gamma_{\text{total}}$ Γ_{25}/Γ VALUE CL% DOCUMENT ID TECN COMMENT 1 AUBERT < 0.026 90 07N BABR $e^+e^- \rightarrow$ • • • We do not use the following data for averages, fits, limits, etc. • • • $^{1}\,\mathrm{AUBERT,BE}$ 04B BABR Repl. by AUBERT 07N 90

 $^{
m 1}$ Events are selected by completely reconstructing one ${\it B}$ and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties

 $\Gamma(D_s^+ X)/[\Gamma(D_s^+ X) + \Gamma(D_s^- X)]$ $\Gamma_{24}/(\Gamma_{24}+\Gamma_{25})$ DO CUMENT ID TECN_COMMENT 0.879±0.066±0.005 AUBERT 07N BABR $e^+e^- \rightarrow$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet $0.733 \pm 0.092 \pm 0.010$ AUBERT,BE 04B BABR Repl. by AUBERT 07N

 Γ_{26}/Γ $\Gamma(\Lambda_c^+ X)/\Gamma_{\text{total}}$ VALUE DOCUMENT ID TECN COMMENT < 0.031 90 ¹ AUBERT 07N BABR $e^+e^- \rightarrow$ • • • We do not use the following data for averages, fits, limits, etc. • • • $^{1}\,\mathrm{AUBERT,BE}$ 04B BABR Repl. by AUBERT 07N < 0.038 90

 $^{
m 1}$ Events are selected by completely reconstructing one B and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

 $\Gamma(\overline{\Lambda}_c^- X)/\Gamma_{\text{total}}$ Γ_{27}/Γ DOCUMENT ID TECN COMMENT $0.05 \pm 0.010 ^{+0.019}_{-0.011}$ ¹ AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $0.049 \pm 0.017 ^{\,+\, 0.018}_{\,-\, 0.011}$ ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N

 $^{^1\,\}rm Events$ are selected by completely reconstructing one B and searching for a reconstructed charmed particle in the rest of the event. The last error includes systematic and charm branching ratio uncertainties.

 $\Gamma(\Lambda_c^+X)/\big[\Gamma(\Lambda_c^+X)+\Gamma(\overline{\Lambda}_c^-X)\big]$

| $\Gamma(\Lambda_c^+ X)/[\Gamma(\Lambda_c^+ X) + \Gamma(\Lambda_c^+ X)]$ | - /- | $\Gamma(D^-\rho^+)/\Gamma_{ m total}$ | Γ ₃₂ /Γ |
|-------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $0.243 \begin{array}{l} + 0.119 \\ - 0.121 \\ \pm 0.003 \\ \end{array}$ | DOCUMENT ID TECN COMMENT AUBERT 07N BABR $e^+e^- \rightarrow \Upsilon(4S)$ | <u>VALUE</u> | |
| | AUBERT 07N BABR $e^+e^- 	o 	au(45)$ wing data for averages, fits, limits, etc. • • • | $0.0077 \pm 0.0013 \pm 0.0002$ 79 $0.009 \pm 0.005 \pm 0.003$ 9 | 1 ALAM 94 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 2 ALBRECHT 90J ARG $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| 0.286 ± 0.142 ± 0.007 | AUBERT,BE 04B BABR Repl. by AUBERT 07N | | g data for averages, fits, limits, etc. • • • |
| | | $0.022 \pm 0.012 \pm 0.009$ 6 | 2 ALBRECHT 88K ARG $e^+e^- ightarrow \varUpsilon(4S)$ |
| Γ(ՇX)/Γ _{total} | Γ ₂₈ /Γ DOCUMENT ID TECN COMMENT | | $(D^{-}\rho^{+})/\Gamma_{\text{total}}] \times [B(D^{+} \rightarrow K^{-}2\pi^{+})] = 0.000704 \pm 0.000704$ |
| 0.947±0.030+0.045 -0.040 | 1 AUBERT 07N BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | | e divide by our best value B($D^+ ightarrow K^-2\pi^+)=(9.13\pm r$ is their experiment's error and our second error is the |
| | wing data for averages, fits, limits, etc. • • | | r is their experiment's error and our second error is the r best value. Assumes equal production of B^+ and B^0 at |
| $1.039 \pm 0.051 + 0.063 \\ -0.058$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N | the $\Upsilon(4S)$. | $\overline{B}{}^0:B^+B^-$ production ratio is 45:55. Superseded by AL- |
| | | BRECHT 90J which assumes 5 | |
| | pletely reconstructing one ${\cal B}$ and searching for a reconstructed tof the event. The last error includes systematic and charm is. | $\Gamma(D^- K^0 \pi^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) | Γ ₃₃ /I |
| Γ(cX)/Γ _{total} | Γ ₂₉ /Γ | 4.9±0.7±0.5 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 0.246±0.024+0.021 -0.017 | 1 AUBERT 07N BABR $e^+e^- 	o 	au(45)$ | $^{ m 1}$ Assumes equal production of $^{ m 1}$ | B^+ and B^0 at the $\varUpsilon(4 S)$. |
| | wing data for averages, fits, limits, etc. • • • | $\Gamma(D^-K^*(892)^+)/\Gamma_{total}$ | Γ ₃₄ /Γ |
| $0.237 \pm 0.036 \stackrel{+}{-} 0.041 \\ -0.027$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N | <u>VALUE (units 10⁻⁴)</u> 4.5 ± 0.7 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| | | 4.6 ± 0.6 ± 0.5 | 1 AUBERT,BE 05B BABR $e^{+}e^{-} ightarrow$ \varUpsilon (4 S) |
| Events are selected by comp charmed particle in the res | pletely reconstructing one B and searching for a reconstructed to fithe event. The last error includes systematic and charm | $3.7 \pm 1.5 \pm 1.0$ | 1 MAHAPATRA 02 CLE2 $e^{+}e^{-} ightarrow$ $\varUpsilon(4S)$ |
| branching ratio uncertaintie | | $^{ m 1}$ Assumes equal production of ι | B^+ and B^{0} at the $\varUpsilon(4S)$. |
| Γ(σcX)/Γ _{total} | Γ ₃₀ /Γ | $\Gamma(D^-\omega\pi^+)/\Gamma_{total}$ | Γ ₃₅ /Γ |
| VALUE | DOCUMENT ID TECN COMMENT | VALUE | DOCUMENT ID TECN COMMENT 1 ALEXANDER 01B CLE2 $e^+e^- \rightarrow \Upsilon(4.5)$ |
| $1.193 \pm 0.030 + 0.053 \\ -0.049$ | 1 AUBERT 07N BABR $e^+e^- ightarrow \varUpsilon(4S)$ | 0.0028 ± 0.0005 ± 0.0004 | TALEXANDER 01B CLE2 $e^+e^- 	o 	au(45)$ B^+ and B^0 at the $\Upsilon(45)$. The signal is consistent with |
| | wing data for averages, fits, limits, etc. • • • | | eeded through the $ ho'^+$ resonance at mass 1349 \pm 25 \pm 16 |
| $1.276 \pm 0.062 ^{+ 0.088}_{- 0.074}$ | ¹ AUBERT,BE 04B BABR Repl. by AUBERT 07N | MeV and width 547 \pm 86 $^{+46}_{-45}$ | |
| 1 Events are selected by comp | pletely reconstructing one B and searching for a reconstructed tof the event. The last error includes systematic and charm | | |
| branching ratio uncertaintie | | $\Gamma(D^-K^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) | Γ36/I DOCUMENT ID TECN COMMENT |
| $\Gamma(D^-\pi^+)/\Gamma_{ m total}$ | Г ₃₁ /Г | 1.97±0.21 OUR AVERAGE | DOCOMENT ID TECH COMMENT |
| VALUE (units 10 ⁻³) EVTS | • | $2.01 \pm 0.18 \pm 0.14$ | 1 AAIJ 11F LHCB pp at 7 TeV 2 ABE 01i BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| 2.68±0.13 OUR FIT | | $1.8 \pm 0.4 \pm 0.1$ | Table 011 BELL $e^+e^- ightarrow I(45)$ 18 \pm 0.14) $	imes$ 10 ⁻⁴ from a measurement of $[\Gamma(B^0-$ |
| 2.68±0.13 OUR AVERAGE 2.55±0.05±0.16 | 1 AUBERT 07H BABR $e^+e^- ightarrow \ arphi(4S)$ | $D = K^+$)/ Γ 1 / $IR(R^0 \rightarrow$ | $[D^-\pi^+]$ assuming B($B^0 \rightarrow D^-\pi^+$) = (2.68 ± 0.13) × |
| $3.03 \pm 0.03 \pm 0.10$ $3.03 \pm 0.23 \pm 0.23$ | ² AUBERT,BE 06J BABR $e^+e^- \rightarrow \Upsilon(45)$ | 10-3 | |
| $2.68 \pm 0.12 \pm 0.24$ | ^{1,3} AHMED 02B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | ² ABE 01 reports $[\Gamma(B^0 \to D^-)]$ | $(K^+)/\Gamma_{ m total}]/[{\rm B}(B^0 	o D^-\pi^+)] = (6.8 \pm 1.5 \pm 0.7) \times 10^{-3} { m kpst}$ value ${\rm B}(B^0 	o D^-\pi^+) = (2.68 \pm 0.13) \times 10^{-3}$ |
| 2.7 ±0.6 ±0.5 4.8 ±1.1 ±1.1 | 4 BORTOLETTO92 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ 5 ALBRECHT 90J ARG $e^+e^- ightarrow \varUpsilon(4S)$ | Our first error is their experin | nent's error and our second error is the systematic erro |
| $5.1 \begin{array}{c} +2.8 \\ -2.5 \end{array} \begin{array}{c} +1.3 \\ -1.2 \end{array}$ | | from using our best value. | |
| | wing data for averages, fits, limits, etc. • • • | $\Gamma(D^-K^+\overline{K}^0)/\Gamma_{ m total}$ | Γ ₃₇ /Ι |
| $2.90 \pm 0.21 \pm 0.14$ | 1,7 AUBERT,B 040 BABR Repl. by AUBERT 07H | VALUE (units 10 ⁻⁴) CL% | DOCUMENT ID TECN COMMENT |
| $2.9 \pm 0.4 \pm 0.1$ 81 $3.1 \pm 1.3 \pm 1.0$ 7 | | <3.1 90 | 1 DRUTSKOY 02 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| | of B^+ and B^0 at the $\Upsilon(4S)$. | Assumes equal production of <i>I</i> | B^+ and B° at the $T(4S)$. |
| | od. Does not depend on $D^{'}$ branching fractions or B^{+}/B^{0} | $\Gamma(D^-K^+\overline{K}^*(892)^0)/\Gamma_{\text{total}}$ | Γ ₃₈ /Ι |
| production rates. 3 AHMED 02B reports an ac | dditional uncertainty on the branching ratios to account for | VALUE (units 10 ⁻⁴) | DOCUMENT ID TECN COMMENT |
| 4.5% uncertainty on relativ | e production of B^0 and B^+ , which is not included here. | 8.8 \pm 1.1 \pm 1.5 Assumes equal production of <i>I</i> | 1 DRUTSKOY 02 BELL $e^{+}e^{-} \rightarrow r$ (4 <i>S</i>) |
| ⁴ BORTOLETTO 92 assume Mark III branching fractions | es equal production of B^+ and B^0 at the $\varUpsilon(4S)$ and uses so for the D . | · | , , |
| ⁵ ALBRECHT 88K assumes i | $B^0\overline{B}{}^0$: B^+B^- production ratio is 45:55. Superseded by AL– | $\Gamma(\overline{D}{}^0\pi^+\pi^-)/\Gamma_{ m total}$ | Г ₃₉ /I |
| BRECHT 90J which assum 6 BEBEK 87 value has been | es 50:50. updated in BERKELMAN 91 to use same assumptions as | VALUE (units 10-4) CL% EVTS | DOCUMENT ID TECN COMMENT |
| noted for BORTOLETTO | 92. $(B^0 \to D^- \pi^+)/\Gamma_{\text{total}}] \times [B(D^+ \to K_{\frac{5}{2}}^0 \pi^+)] = (42.7 \pm$ | 8.4±0.4±0.8 • • • We do not use the followin: | ¹ KUZMIN 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ g data for averages, fits, limits, etc. • • • |
| 21 + 22) × 10-6 which | $(B^0 \rightarrow D^- \pi^+)/I_{\text{total}} \times [B(D^+ \rightarrow K_S^0 \pi^+)] = (42.7 \pm M_S^0 \pi^+)$ we divide by our best value $B(D^+ \rightarrow K_S^0 \pi^+) = (1.47 \pm M_S^0 \pi^+)$ | 8.0±0.6±1.5 | 1,2 SATPATHY 03 BELL Repl. by KUZMIN 07 |
| $0.07) \times 10^{-2}$. Our first ϵ | error is their experiment's error and our second error is the | < 16 90 | 1 ALAM 94 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| systematic error from using | our best value. | < 70 90 | 3 BORTOLETTO92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ 4 BEBEK 87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| $^{\circ}$ ALAM 94 reports [$\Gamma(B^{\circ} - 0.032 + 0.023) \times 10^{-3}$ | $D^-\pi^+)/\Gamma_{	ext{total}}] 	imes [B(D^+ 	o K^-2\pi^+)] = (0.265 \pm K^-2\pi^+)$ which we divide by our best value $B(D^+ 	o K^-2\pi^+) = K^-2\pi^+$ | $<$ 340 90 700 \pm 500 5 | ⁵ BEHRENDS 83 CLEO $e^+e^- \rightarrow \Upsilon(45)$ |
| $(9.13 \pm 0.19) \times 10^{-2}$. Or | in first error is their experiment's error and our second error | 1 Assumes equal production of ι | |
| | using our best value. Assumes equal production of ${\it B}^{+}$ and | ² No assumption about the inter ³ BORTOLETTO 92 assumes 6 | rmediate mechanism is made in the analysis. Equal production of ${\it B}^+$ and ${\it B}^0$ at the ${\it \Upsilon}(4{\it S})$ and use |
| $\Gamma(D^-\ell^+\nu_\ell)/\Gamma(D^-\pi^+)$ | Γ_4/Γ_{31} | | r the D . The product branching fraction into $D_0^*(2340)$ |
| VALUE | DOCUMENT ID TECN COMMENT | | π is < 0.0001 at 90% CL and into $D_2^*(2460)$ followed by |
| 9.9±1.0±0.9 | AALTONEN 09E CDF $ ho\overline{ ho}$ at 1.96 TeV | $D_2^*(2460) \to D^0 \pi \text{ is } < 0.000$ 4 BEREK 87 assume the $\Upsilon(45)$ |)4 at 90% CL.) decays 43% to $B^0\overline{B}{}^0$. We rescale to 50%. $B(D^0-$ |
| | | $K^-\pi^+$) = (4.2 ± 0.4 ± 0.4) | % and B($D^0 	o K^-\pi^+\pi^+\pi^-$) = $(9.1\pm0.8\pm0.8)\%$ |
| | | were used | imptions: B($D^0 \to K^-\pi^+$) = (0.042 ± 0.006 |
| | | and B($\Upsilon(4S) \rightarrow B^0 \overline{B}^0$) | = 50%. The product branching ratio is $B(B^0 -$ |
| | | $\overline{D}^0 \pi^+ \pi^-) B(\overline{D}^0 \to K^+ \pi^-)$ | $(0.39 \pm 0.26) \times 10^{-2}$ |
| | | $\overline{D}{}^0\pi^+\pi^-)B(\overline{D}{}^0\to K^+\pi^-)$ | $) = (0.39 \pm 0.26) \times 10^{-2}.$ |

 $\Gamma_{26}/(\Gamma_{26}+\Gamma_{27})$

 $\Gamma(D^-\rho^+)/\Gamma_{\text{total}}$

 Γ_{32}/Γ

 Γ_{47}/Γ

 Γ_{49}/Γ

| $(D^*(2010)^-\pi^+)/\Gamma_t$ | | | | | | Γ_{40}/Γ |
|--------------------------------|-----------|--------------------------|---------|------------|----------------------|----------------------|
| ALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.76±0.13 OUR AVER/ | AGE | 1 AUDEDT | 07 | DADD | .+ | 20(46) |
| $2.79 \pm 0.08 \pm 0.17$ | | 1 AUBERT | | | | |
| $2.7 \pm 0.4 \pm 0.1$ | | ^{2,3} AUBERT,BE | | | $e^+e^- \rightarrow$ | |
| $2.81 \pm 0.24 \pm 0.05$ | | ⁴ BRANDENB | | | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.6 \pm 0.3 \pm 0.4$ | 82 | ⁵ ALAM | | | $e^+e^- \rightarrow$ | |
| $3.37 \pm 0.96 \pm 0.02$ | | ⁶ BORTOLETT | O92 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.36 \pm 0.88 \pm 0.02$ | 12 | ⁷ ALBRECHT | 90J | | $e^+e^- \to$ | |
| $2.36^{+1.50}_{-1.10}\pm0.02$ | 5 | ⁸ BEBEK | 87 | CLEO | $e^+e^- \to$ | $\Upsilon(4S)$ |
| • • We do not use the | following | data for averages, fi | ts, lin | nits, etc. | • • • | |
| 0 ±4 ±1 | 8 | ⁹ AKERS | | | | |
| 2.7 ±1.4 ±1.0 | 5 | ¹⁰ ALBRECHT | 87c | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| 3.5 ±2 ±2 | | ¹¹ ALBRECHT | 86F | ARG | $e^+e^- \rightarrow$ | r(45) |
| 7 ±5 ±5 | 41 | ¹² GILES | | | | |

- ²AUBERT,BE 06J reports $[\Gamma(B^0 \to D^*(2010)^-\pi^+)/\Gamma_{\text{total}}] / [B(B^0 \to D^-\pi^+)] = 0.99 \pm 0.11 \pm 0.08$ which we multiply by our best value $B(B^0 \to D^-\pi^+) = (2.68 \pm 0.13) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- 3 Uses a missing-mass method. Does not depend on D branching fractions or B^+/B^0 production rates.
- ⁴ BRANDENBURG 98 assume equal production of B^+ and B^0 at $\Upsilon(4S)$ and use the D^* reconstruction technique. The first error is their experiment's error and the second error is the systematic error from the PDG 96 value of $B(D^* \to D\pi)$.
- 6 BORTOLETTO 92 reports $(4.0\pm 1.0\pm 0.7)\times 10^{-3}$ from a measurement of $[\Gamma(B^0\to D^*(2010)^-\pi^+)/\Gamma_{\rm total}]\times [B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm 0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm 0.5)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses MarkIII branching fractions for the D.
- ⁷ALBRECHT 90J reports $(2.8\pm0.9\pm0.6)\times10^{-3}$ from a measurement of $[\Gamma(B^0\to D^*(2010)^+\pi^+)/\Gamma_{\text{total}}]\times[B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and $B^0\to B^+$ and $B^0\to B^+$
- B^0 at the $\Upsilon(45)$ and uses MarkIII branching fractions for the D. 8 BEBEK 87 reports $(2.8^{+}1.5^{+}1.0^{-}0.6)\times 10^{-3}$ from a measurement of $[\Gamma(B^0\to D^*(2010)^-\pi^+)/\Gamma_{\rm total}]\times [B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Updated in BERKELMAN 91 to use same assumptions as noted for BORTOLETTO 92 and ALBRECHT 90J.
- 9 Assumes B($Z
 ightarrow b \overline{b}) = 0.217$ and 38% B_d production fraction.
- 10 ALBRECHT 87c use PDG 86 branching ratios for D and $D^*(2010)$ and assume $\mathrm{B}(\varUpsilon(4S)\to B^+B^-)=55\%$ and $\mathrm{B}(\varUpsilon(4S)\to B^0\overline{B^0})=45\%.$ Superseded by ALBRECHT 90J.
- 11 ALBRECHT 86F uses pseudomass that is independent of D^0 and D^+ branching ratios. 12 Assumes B(D^* (2010) $^+ \rightarrow D^0 \pi^+$) = 0.60 $^+$ 0.08. Assumes B(T^* (45) $\rightarrow B^0 \overline{B}{}^0$) = 0.40 \pm 0.02 Does not depend on D branching ratios.

| $\Gamma(D^*(2010)^-\ell^+\nu_\ell)/\Gamma(D^*(2010)^-\pi^+)$ | | | | | |
|--------------------------------------------------------------|-------------------------|-----|------|-------------------------|--------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $16.5 \pm 2.3 \pm 1.1$ | AALTONEN | 09E | CDF | $p\overline{p}$ at 1.96 | TeV |
| $\Gamma(D^-\pi^+\pi^+\pi^-)/\Gamma_{\text{total}}$ | | | | | Γ ₄₁ /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.0064±0.0007 OUR FIT | | | | | |
| $0.0080 \pm 0.0021 \pm 0.0014$ | ¹ BORTOLETTO | 92 | CLEO | $e^+e^ ightarrow$ | $\Upsilon(4S)$ |

 $^1\,\rm BORTOLETTO$ 92 assumes equal production of B^+ and B^0 at the $~\tau(4S)$ and uses Mark III branching fractions for the D.

| $\Gamma(D^-\pi^+\pi^+\pi^-)/\Gamma(D^-\pi^+)$ | | | | | Γ_{41}/Γ_{31} |
|-----------------------------------------------|--------------|-----|------|-------------|---------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 2.38±0.23 OUR FIT | | | | | |
| $2.38 \pm 0.11 \pm 0.21$ | AAIJ | 11E | LHCB | pp at 7 TeV | |

| $\Gamma((D^-\pi^+\pi^+\pi^-)$ nonresonant)/ $\Gamma_{ m total}$ | | | | Γ_{42}/Γ |
|-----------------------------------------------------------------|----------------|------|---------|----------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| 0.0039 + 0.0014 + 0.0013 | 1 BORTOLETTO92 | CLEO | e+ e- → | Y(45) |

 1 BORTOLETTO 92 assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$ and uses Mark III branching fractions for the D.

| $\Gamma(D^-\pi^+ ho^0)/\Gamma_{ m total}$ | | | | Γ_{43}/Γ |
|-------------------------------------------|---------------------------|------|-----------------------|----------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| 0.0011 ± 0.0009 ± 0.0004 | ¹ BORTOLETTO92 | CLEO | $e^+ e^- \rightarrow$ | T(45) |
| 4 | | | | |

 $^1\,\rm BORTOLETTO$ 92 assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$ and uses Mark III branching fractions for the D.

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\frac{\Gamma(D^-a_1(1260)^+)/\Gamma_{\text{total}}}{0.0060\pm0.0022\pm0.0024} \qquad \frac{DOCUMENT\ ID}{1\ \text{BORTOLETTO92}} \qquad \frac{TECN}{\text{CLEO}} \qquad \frac{COMMENT}{e^+e^- \rightarrow \ r(4.5)}
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 1 BORTOLETTO 92 assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$ and uses Mark III branching fractions for the D.

0.015 \pm 0.008 \pm 0.008 8 2 ALBRECHT 87c ARG $e^+e^- \rightarrow ~ \varUpsilon (4S)$

- 1 ALBRECHT 90J reports $0.018\pm0.004\pm0.005$ from a measurement of $[\Gamma(B^0\to D^*(2010)^-\pi^+\pi^0)/\Gamma_{total}]\times[B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(45)$ and uses Mark III branching fractions for the D.
- 2 ALBRECHT 87c use PDG 86 branching ratios for D and $D^*(2010)$ and assume B($\Upsilon(4S)\to B^+B^-)=55\%$ and B($\Upsilon(4S)\to B^0\overline{B}{}^0)=45\%$. Superseded by ALBRECHT 90J.

| $\Gamma(D^*(2010)^-\rho^+$ | [⊢])/Γ _{total} | | | | | Γ46/Γ |
|----------------------------|-----------------------------------|-----------------------|-----------|------------|----------------------|----------------|
| VALUE | EVTS | DOCUMENT IE |) | TECN | COMMENT | |
| 0.0068 ±0.0009 | OUR AVERAGE | | | | | |
| 0.0068 ±0.0003 = | ±0.0009 | ¹ CSORNA | | | | |
| 0.0160 ± 0.0113 = | ±0.0001 | ² BORTOLET | TO92 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.00589 \pm 0.00352 \pm$ | ±0.00004 19 | ³ ALBRECHT | 901 | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not ι | use the following | data for averages, | fits, lim | nits, etc. | • • • | |
| 0.0074 ±0.0010 = | ±0.0014 76 | ^{4,5} ALAM | 94 | CLE2 | $e^+e^- \to$ | Y(45) |
| 0.081 +0.029 | +0.059 | 6 CHEN | 85 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

- 1 Assumes equal production of B^0 and B^+ at the $\varUpsilon(4S)$ resonance. The second error combines the systematic and theoretical uncertainties in quadrature. CSORNA 03 includes data used in ALAM 94. A full angular fit to three complex helicity amplitudes is performed.
- 2 BORTOLETTO 92 reports 0.019 \pm 0.008 \pm 0.011 from a measurement of $[\Gamma(B^0\to D^*(2010)^-\rho^+)/\Gamma_{\rm total}]\times [B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(45)$ and uses Mark III branching fractions for the D.
- 3 ALBRECHT 9 DJ reports $0.007\pm0.003\pm0.003$ from a measurement of $[\Gamma(B^0\to D^*(2010)^-\rho^+)/\Gamma_{total}]\times [B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses Markill branching fractions for the D.
- ⁴ ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(45)$ and use the CLEOII $B(D^*(2010)^+ \to D^0 \, \pi^+)$ and absolute $B(D^0 \to K^- \pi^+)$ and the PDG 1992 $B(D^0 \to K^- \pi^+ \pi^0)/B(D^0 \to K^- \pi^+)$ and $B(D^0 \to K^- 2\pi^+ \pi^-)/B(D^0 \to K^- \pi^+)$.
- 5 This decay is nearly completely longitudinally polarized, $\Gamma_L/\Gamma=(93\pm5\pm5)\%,$ as expected from the factorization hypothesis (ROSNER 90). The nonresonant $\pi^+\pi^0$ contribution under the ρ^+ is less than 9% at 90% CL.
- on D branching ratios.

$\Gamma(D^*(2010)^-K^+)/\Gamma_{\text{total}}$

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT | |
|---------------------------------|---------------------|-----|------|-----------------------------------|---|
| 2.14±0.16 OUR AVERAGE | · | | | | Ī |
| $2.14 \pm 0.12 \pm 0.10$ | ¹ AUBERT | 06A | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $2.0 \pm 0.4 \pm 0.1$ | ² ABE | 011 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | |

¹ AUBERT 06A reports $[\Gamma(B^0 \to D^*(2010)^- K^+)/\Gamma_{\text{total}}] / [B(B^0 \to D^*(2010)^- \pi^+)]$ = 0.0776 ± 0.0034 ± 0.0029 which we multiply by our best value $B(B^0 \to D^*(2010)^- \pi^+) = (2.76 \pm 0.13) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

and our second error is the systematic error from using our best value. $^{2}\text{ABE 01: reports}\left[\Gamma(B^{0} \rightarrow D^{*}(2010)^{-}K^{+})/\Gamma_{\text{total}}\right]/\left[B(B^{0} \rightarrow D^{*}(2010)^{-}\pi^{+})\right] = 0.074 \pm 0.015 \pm 0.006$ which we multiply by our best value $B(B^{0} \rightarrow D^{*}(2010)^{-}\pi^{+}) = (2.76 \pm 0.13) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(D^*(2010)^-K^*(892)^+)/\Gamma_{total}$ VALUE (units 10^{-4}) DO CUMENT ID TECN CO.

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT | |
|---------------------------------|------------------------|----|------|----------------------|----------------|
| 3.3±0.6 OUR AVERAGE | | | | | |
| $3.2 \pm 0.6 \pm 0.3$ | ¹ AUBERT,BE | | | | |
| $3.8 \pm 1.3 \pm 0.8$ | ² MAHAPATRA | 02 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

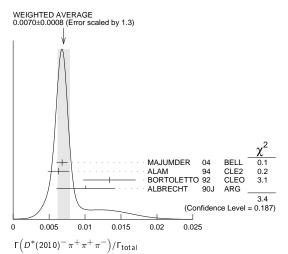
- 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (45).
- 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and an unpolarized final state.

 B^0

| Γ(D*(2010)-K+ | Κ ⁰)/Γ _{tota} | Ì | | | | Γ ₅₀ /Γ |
|--------------------------------------------------------------------|-------------------------------------------|----------------------------------------|-----|-------------|----------------------|----------------------|
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <4.7 | 90 | $^{ m 1}$ DRUTSKOY | 02 | BELL | e^+e^- | Y(45) |
| ¹ Assumes equal pro Γ(<i>D</i> *(2010) – <i>K</i> + | | | Υ(4 | S). | | Γ ₅₁ /Γ |
| VALUE (units 10 ⁻⁴) | | DOCUMENT ID | | TECN | COMMENT | |
| 12.9±2.2±2.5 | | ¹ DRUTSKOY | 02 | BELL | $e^+e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | oduction of | ${\it B}^{+}$ and ${\it B}^{0}$ at the | r(4 | S). | | |
| Γ(D*(2010)-π+π | $(\pi^+\pi^-)/\Gamma_t$ | otal | | | | Γ_{52}/Γ |

| , , | , | // | LOLGI | | | | | , |
|---------|-----------------|-----------------|---------|-----------------|----------|-----------|-----------------------|----------------|
| VALUE | | CL% | _ | DOCUMENT ID | | TECN | COMMENT | |
| 0.0070 | ±0.0008 | OUR AVE | RAGE | Error includes | scale f | actor of | 1.3. See th | e ideogram |
| below. | | | | | | | | |
| 0.0068 | 1 ± 0.00023 | 3 ± 0.00072 | 1 | MAJUMDER | 04 | BELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| 0.0063 | ±0.0010 | ±0.0011 | | ALAM | | | | |
| 0.0134 | ±0.0036 | ±0.0001 | 4 | BORTOLETT | O 92 | CLEO | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| 0.0101 | ±0.0041 | ±0.0001 | 5 | ALBRECHT | 90J | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • W | e do not u | se the follow | ing dat | a for averages, | fits, li | mits, etc | . • • • | |
| 0.033 | ±0.009 | ±0.016 | 6 | ALBRECHT | 87c | ARG | e^+e^- | $\Upsilon(4S)$ |
| < 0.042 | | 90 | 7 | BEBEK | 87 | CLEO | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |

- ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.
- ²ALAM 94 assume equal production of B^+ and B^0 at the $\Upsilon(45)$ and use the CLEOII $B(D^*(2010)^+ \rightarrow D^0\pi^+)$ and absolute $B(D^0 \rightarrow K^-\pi^+)$ and the PDG 1992 $B(D^0 \rightarrow K^-\pi^+\pi^0)/B(D^0 \rightarrow K^-\pi^+)$ and $B(D^0 \rightarrow K^-2\pi^+\pi^-)/B(D^0 \rightarrow K^-\pi^+)$.
- ³The three pion mass is required to be between 1.0 and 1.6 GeV consistent with an a_1 meson. (If this channel is dominated by a_1^+ , the branching ratio for $\overline{D}^{*-}a_1^+$ is twice that for $\overline{D}^{*-}\pi^+\pi^+\pi^-$.)
- 4 BORTOLETTO 92 reports 0.0159 \pm 0.0028 \pm 0.0037 from a measurement of $[\Gamma(B^0\to D^*(2010)^-\pi^+\pi^+\pi^-)/\Gamma_{\rm total}]\times [{\rm B}(D^*(2010)^+\to D^0\pi^+)]$ assuming ${\rm B}(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $[D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the T(4S) and uses Mark III branching fractions for the D
- 5 ALBRECHT 90J reports $0.012\pm0.003\pm0.004$ from a measurement of $[\Gamma(B^0\to D^*(2010)^-\pi^+\pi^+\pi^-)/\Gamma_{\text{total}}]\times[B(D^*(2010)^+\to D^0\pi^+)]$ assuming $B(D^*(2010)^+\to D^0\pi^+)=0.57\pm0.06$, which we rescale to our best value $B(D^*(2010)^+\to D^0\pi^+)=(67.7\pm0.5)\times10^{-2}$. Our first error is their experiment; error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the T(4S) and uses Mark III branching fractions for
- ⁶ ALBRECHT 87c use PDG 86 branching ratios for D and $D^*(2010)$ and assume $B(\Upsilon(4S) \rightarrow B^+B^-) = 55\%$ and $B(\Upsilon(4S) \rightarrow B^0\overline{B}{}^0) = 45\%$. Superseded by ALBRECHT 901
- 7 BEBEK 87 value has been updated in BERKELMAN 91 to use same assumptions as noted for BORTOLETTO 92.





 1 BORTOLETTO 92 assumes equal production of B^+ and B^0 at the $\varUpsilon(45)$ and uses Mark III branching fractions for the D and $D^*(2010)$.

| $\Gamma(D^*(2010)^-\pi^+\rho^0)/\Gamma_{\rm tota}$ | Ì | | | Γ_{54}/Γ |
|----------------------------------------------------|-----------------------------------------|--------------|-------------|-----------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| $0.00573 \pm 0.00317 \pm 0.00004$ | ¹ BORTOLETTO92 | CLEO | e^+e^- | T(45) |
| ¹ BORTOLETTO 92 reports | $0.0068 \pm 0.0032 \pm 0.0021$ | from a i | measurement | of $\Gamma(B^0 \rightarrow$ |
| $D^*(2010) = \pi^+ \rho^0 / \Gamma_{\text{total}}$ | $\times [B(D^*(2010)^+ \rightarrow D^0$ | $\pi^+)]$ as | suming B(D | *(2010)+ - |
| D0 -+) 0 57 1 0 06 wh | ich we receale to our best | value D | (D*(2010)+ | . n0_+1 |

^BORTOLETTO 92 reports 0.0068 \pm 0.0032 \pm 0.0021 from a measurement of $[\Gamma(B^0 \to D^*(2010)^-\pi^+\rho^0)/\Gamma_{\rm total}] \times [B(D^*(2010)^+ \to D^0\pi^+)]$ assuming $B(D^*(2010)^+ \to D^0\pi^+) = 0.57 \pm 0.06$, which we rescale to our best value $B(D^*(2010)^+ \to D^0\pi^+) = (67.7 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses Mark III branching fractions for the D.

| $\Gamma(D^*(2010)^-a_1(1260)^+)/$ | r _{total} | | | | Γ ₅₅ /Γ |
|-----------------------------------|-----------------------|--------|------|----------------------|--------------------|
| VALUE | DO CUMENT I | D | TECN | COMMENT | |
| 0.0130 ± 0.0027 OUR AVERAGE | | | | | |
| $0.0126 \pm 0.0020 \pm 0.0022$ | ^{1,2} ALAM | 94 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0152 \pm 0.0070 \pm 0.0001$ | ³ BORTOLET | T O 92 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

 1 ALAM 94 value is twice their $\Gamma(D^*(2010)^-\pi^+\pi^+\pi^-)/\Gamma_{\rm total}$ value based on their observation that the three pions are dominantly in the $a_1(1260)$ mass range 1.0 to 1.6 . GeV.

 2 ALAM 94 assume equal production of B^+ and B^0 at the $\varUpsilon(4S)$ and use the CLEOII B($D^*(2010)^+ \to D^0 \, \pi^+$) and absolute B($D^0 \to K^- \pi^+$) and the PDG 1992 B($D^0 \to K^- \pi^+ \pi^+)$)/B($D^0 \to K^- \pi^+$) and B($D^0 \to K^- \pi^+ \pi^-)$ /B($D^0 \to K^- \pi^+$). 3 BORTOLETTO 92 reports 0.018 \pm 0.006 \pm 0.006 from a measurement of $[\Gamma(B^0 \to D^*(2010)^- a_1(1260)^+)/\Gamma_{\rm total}] \times [B(D^*(2010)^+ \to D^0 \pi^+)]$ assuming B($D^*(2010)^+ \to D^0 \pi^+$) = 0.57 \pm 0.06, which we rescale to our best value B($D^*(2010)^+ \to D^0 \pi^+$) = (67.7 \pm 0.5) \times 10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes

equal production of B^+ and B^0 at the arphi(4S) and uses MarkIII branching fractions for

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S).$ The signal is consistent with all observed $\omega\pi^+$ having proceeded through the ρ'^+ resonance at mass 1349 \pm 25 $^{+10}_{-5}$ MeV and width 547 \pm 86 $^{+46}_{-45}$ MeV.

^2ALBRECHT 90J reports 0.041 \pm 0.015 \pm 0.016 from a measurement of [$\Gamma(B^0 \to D^*(2010)^-\pi^+\pi^+\pi^-\pi^0)/\Gamma_{total}$] \times [$B(D^*(2010)^+ \to D^0\pi^+)$] assuming $B(D^*(2010)^+ \to D^0\pi^+) = 0.57 \pm 0.06$, which we rescale to our best value $B(D^*(2010)^+ \to D^0\pi^+) = (67.7 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Gamma(4S)$ and uses Mark III branching fractions for the Γ

 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

 $^{-1}$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$.

²The signal is consistent with all observed $\omega\pi^+$ having proceeded through the ρ'^+ resonance at mass 1349 \pm 25 $^{+10}_{-5}$ MeV and width 547 \pm 86 $^{+46}_{-45}$ MeV.

$$\frac{\Gamma(D_1(2430)^0 \omega \times B(D_1(2430)^0 \to D^{*-}\pi^+))/\Gamma_{total}}{A.1 \pm 1.2 \pm 1.1} \frac{DOCUMENT\ ID}{1\ AUBERT} \frac{TECN}{06L} \frac{COMMENT}{e^+e^- \to \Upsilon(4S)}$$

 1 Obtained by fitting the events with cos $\theta_{D^*} < 0.5$ and scaling up the result by a factor of 4/3. No interference effects between $B^0 \to D_1' \omega$ and $D^* \omega \pi$ are assumed.

AUBERT.BE 06J reports $[\Gamma(B^0 \to D^{**-}\pi^+)/\Gamma_{\rm total}]/[B(B^0 \to D^-\pi^+)] = 0.77 \pm 0.22 \pm 0.29$ which we multiply by our best value $B(B^0 \to D^-\pi^+) = (2.68 \pm 0.13) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

eviation from some discontinuous value. 2 Uses a missing-mass method. Does not depend on D branching fractions or B^+/B^0 production rates.

 $^{^1}$ Assumes equal production of B^+ and $B^{\,0}$ at the $\, \varUpsilon$ (45).

| ALUE (units 10 ⁻²) .57 ^{+0.35} OUR FIT | | <u>DO CUMENT I</u> | | | | |
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| -0.40 -0.3 -1 ±0.5 +0.3 | | A A I I | 116 | LUCD | pp at 7 Te | - 1/ |
| .1 ±0.5 ±0.5 | | AAIJ | 111 | LHCB | ppat 1 ie | ev |
| $(D_1(2420)^-\pi^+\times 1)$ | | | | | | Γ ₆₂ /Γ |
| ALUE (units 10 ⁻⁴) | CL% | DOCUMENT I | ID | TECN | COMMENT | |
| <0.33 1 Assumes equal prod | | | | | $e^+e^- \rightarrow$ | T(45) |
| $(\overline{D}_2^*(2460)^-\pi^+\times 1)$ | | | | | | F /F |
| (D ₂ (2460) π· Χ I ALUE (units 10 ⁻⁴) | | - | | | COMMENT | Γ ₆₃ /Γ |
| 2.15 ± 0.17 ± 0.31 | | 1,2 KUZMIN | | | $e^+e^- \rightarrow$ | Υ(4S) |
| • We do not use the second secon | | | - | | | |
| <14.7 | | l ALAM | 94 | CLE2 | $e^+e^- \rightarrow$ | Υ(4 <i>S</i>) |
| ¹ Assumes equal prod ² Our second uncerta | | | | | s quoted in | the paper. |
| $(\overline{D}_0^*(2400)^-\pi^+\times$ | | | | | | Γ ₆₄ /Γ |
| ALUE (units 10 ⁻⁴) | ·- u (- | | | | <u>COMM</u> ENT | - 04/ |
| .60±0.13±0.27 | | 1,2 KUZMIN | | | $e^+ e^- \rightarrow$ | Υ(45) |
| Assumes equal prod | | | | | | |
| ² Our second uncerta | | | | | s quoted in | |
| $(D_2^*(2460)^-\pi^+\times$ | | | | | | Γ ₆₅ /Γ |
| ALUE (units 10 ⁻⁴) | 90 | DOCUMENT I | ID OF A | DELL | $e^+e^- \rightarrow$ | Y(45) |
| ¹ Assumes equal prod | | | | | e · e → | 7 (43) |
| $(\overline{D}_2^*(2460)^- \rho^+)/\Gamma$ | | D and D at 1 | tile 1 (4. | ٠,. | | E /E |
| 11/21/24601 0 1/1 | | | | | | |
| , - | total | DOCUMENT I | ID | TECN | COMMENT | Γ ₆₆ /Γ |
| ALUE <0.0049 1 ALAM 94 assumes absolute $B(D^0 \rightarrow$ | <u>CL%</u> 90 equal pro | duction of B^+ a | 94 nd <i>B</i> ⁰ a | CLE2 t the γ | $e^+e^- \rightarrow$ (4S) and us | r(4S) e the CLEOII |
| $\frac{\Delta L U E}{< 0.0049}$ 1 ALAM 94 assumes absolute $B(D^0 \rightarrow D^0)/\Gamma_{total}$ | $\frac{CL\%}{90}$ equal pro $K^-\pi^+)$ | 1 ALAM duction of B^+ a and $\mathrm{B}(D_2^*(2460)$ | 94 nd B^0 a $+ \rightarrow \mathcal{D}$ | CLE2 t the $ \Upsilon _0^0 \pi ^+)$: | $e^+e^- \rightarrow (4S)$ and us = 30%. | Υ(4S) |
| ALUE <0.0049 1 ALAM 94 assumes absolute $B(D^0 \rightarrow D^0)$ / Γ total ALUE (units 10^{-4}) | <u>CL%</u> 90 equal pro | 1 ALAM duction of $^{B+}$ a | 94 nd B^0 a $+ \rightarrow \mathcal{D}$ | CLE2 t the $ \Upsilon _0^0 \pi ^+)$: | $e^+e^- \rightarrow (4S)$ and us = 30%. | Τ(4 <i>S</i>) e the CLEOII |
| $ALU\overline{E}$ <0.0049 1 ALAM 94 assumes absolute B($D^0 \rightarrow C$) / Ftotal ALUE (units 10^{-4}) <0.43 | $\frac{CL\%}{90}$ equal pro $K^{-}\pi^{+})$ $\frac{CL\%}{90}$ | 1 ALAM duction of B^{+} a and B($D_{2}^{*}(2460)$ 1 ADACHI | 94 nd B^0 a $^+ \rightarrow D$ | CLE2 t the Υ $0^0\pi^+)$: | $e^+e^- \rightarrow$ (45) and us = 30%. | Τ(4 <i>S</i>) e the CLEOII |
| $\triangle LUE$ <0.0049 1 ALAM 94 assumes absolute B($D^0 \rightarrow (D^0 \overline{D}^0)$)/ Γ total ALUE (units 10^{-4}) <0.43 • • We do not use the conditions of the condition | $\frac{CL\%}{90}$ equal pro $K = \pi^{+}$) $\frac{CL\%}{90}$ ne followi | 1 ALAM duction of 8 + a and B(D_{2}^{*} (2460) 1 ADACHI ng data for avera 1 AUBERT,B | 94 nd B^0 a $^+$ \rightarrow $^ ^-$ 08 19es, fits 06A | CLE2 t the r , | $e^+e^- ightarrow e^+(4S)$ and us = 30%. $\frac{COMMENT}{e^+e^-} ightarrow etc. $ | T(4S) e the CLEOIII |
| ALUE $<$ 0.0049 1 ALAM 94 assumes absolute $B(D^0 \rightarrow D^0)/\Gamma$ total ALUE (units 10^{-4}) < 0.43 • • We do not use the $<$ 0.6 1 Assumes equal prod | $\frac{CL\%}{90}$ equal pro $K = \pi^{+}$) $\frac{CL\%}{90}$ ne followi | 1 ALAM duction of 8 + a and B(D_{2}^{*} (2460) 1 ADACHI ng data for avera 1 AUBERT,B | 94 nd B^0 a $^+$ \rightarrow $^ ^-$ 08 19es, fits 06A | CLE2 t the r , | $e^+e^- ightarrow e^+(4S)$ and us = 30%. $\frac{COMMENT}{e^+e^-} ightarrow etc. $ | $r(4S)$ e the CLEOIII $rac{\Gamma_{67}/\Gamma}{}$ |
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| ALUE $<$ 0.0049 1 ALAM 94 assumes absolute $B(D^0 \rightarrow (D^0 \overline{D}^0))/\Gamma$ total (ALUE (units $10^{-4})$ <0.43 • • We do not use the $<$ 0.6 1 Assumes equal prodes $(D^0 \overline{D}^0)/\Gamma$ total (ALUE (units $10^{-4})$ (2.9) | $\frac{cL\%}{90}$ equal pro $K^-\pi^+)$ $\frac{cL\%}{90}$ e following the following of the following o | 1 ALAM duction of 8 + a and 1 B(2 (2460) 2 ADACHI ng data for avera 1 AUBERT,B 1 B+ and 1 B0 at 1 AUBERT,B | 94 nd B^0 a A^0 a A^0 | CLE2 t the Υ $0^{0}\pi^{+})$ = TECN BELL, limits, BABR S). | $e^+e^- \rightarrow$ (45) and us $= 30\%$. $\frac{COMMENT}{e^+e^- \rightarrow}$ etc. • • • $e^+e^- \rightarrow$ | r(4S) e the CLEOII |
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| **ALUE** **C0.0049** 1 ALAM 94 assumes absolute $B(D^0 \rightarrow D^0)$ / Γ total (ALUE (units 10^{-4}) **C0.6** 1 Assumes equal prodiction of the sequence of | $\frac{cL\%}{90}$ equal pro $K = \pi^+$) $\frac{cL\%}{90}$ ue following $\frac{cL\%}{90}$ uction of $\frac{cL\%}{90}$ ERAGE 190 190 190 190 190 190 190 190 190 19 | 1 ALAM duction of B+ a and B(D*(2460) 1 ADACHI ng data for avera 1 AUBERT,B 1 B+ and B0 at 1 DOCUMENT I 1 AUBERT,B 1 B+ and B0 at 1 DOCUMENT I 1 AUBERT,B 1 B+ and B0 at 1 LIPELES BARATE ASNER 1 B+ and B0 at 1 LIPELES BARATE ASNER 1 B+ and B0 at 1 | 94 nd B^0 a $+ \rightarrow D$ 08 ID 08 Iges, fits 06A the $\Upsilon(4:3)$ Cale fact 07 06A Iges, fits 09 09 7 The T 01 05 06 07 06 08 08 09 08 09 09 09 00 00 00 | CLE2 t the T 00 π+) = TECN BELL limits, BABR BABR BABR S). TECN BELL LIMITE BABR CTECN BELL BABR BABR CTECN CTEC | $\begin{array}{c} e^+e^- \rightarrow \\ (4S) \text{ and us} \\ = 30\%. \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \end{array}$ | T(45) e the CLEOII F67/F T(45) F68/F T(45) F69/F T(45) |
| **ALUE** **C0.0049** 1 ALAM 94 assumes absolute $B(D^0 \rightarrow D^0)$ / Γ total ALUE (units 10^{-4}) **C0.43** • • We do not use the sum of t | $\frac{cL\%}{90}$ equal pro $K = \pi^+$) $\frac{cL\%}{90}$ ne followi $\frac{cL\%}{90}$ uction of $\frac{cL\%}{90}$ uction of $\frac{cL\%}{90}$ uction of | 1 ALAM duction of B+ a and B(D*2(2460) DOCUMENT I 1 ADACHI ng data for avera 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B I B+ and B ⁰ at the DOCUMENT I 2 Error includes so I FRATINA 1 AUBERT,B ng data for avera 1 MA JUMDEI 1 LIPELES BARATE ASNER B+ and B ⁰ at the SE DOCUMENT SE DOCUMENT SE DOCUMENT ADDRIVED 94 nd B^0 a $+ \rightarrow E$ 08 198 198 109 100 06A 100 100 100 100 100 100 | CLE2 t the Υ | $\begin{array}{c} e^+e^- \rightarrow \\ (45) \text{ and us} \\ = 30\%. \\ \\ \hline \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{etc.} \\ \bullet \bullet \bullet \\ \hline \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \hline \underline{COMMENT} \\ 2. \\ e^+e^- \rightarrow \\ \text{etc.} \\ \bullet \bullet \bullet \\ \hline e^+e^- \rightarrow \\ \text{etc.} \\ \bullet \bullet \bullet \bullet \\ \hline e^+e^- \rightarrow \\ \hline \end{array}$ | T(45) e the CLEOII Γ67/Γ T(45) Γ(45) Γ(45) Γ(45) Γ(45) T(45) |
| ALUE | 2 (L % 90 equal pro K - π +) - (C / 8 90 equal pro K - π +) - (C / 8 90 equal pro K - π +) - (C / 8 90 equal pro K - π +) - (C / 8 90 equal pro K - π +) - (C / 8 90 equal pro K - π +) - (C / 8 90 equal pro K + π + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 | 1 ALAM duction of B+ a and B(D*(2460)) DOCUMENT I 1 ADACHI ng data for avera 1 AUBERT,B B+ and B ⁰ at the second of the second | 94 nd B^0 a $+ \rightarrow E$ 08 198 198 198 198 198 198 198 | CLE2 t the Υ τ τ τ τ τ τ τ τ τ τ τ τ τ τ τ τ τ τ | $\begin{array}{c} e^+e^- \rightarrow \\ (4S) \text{ and us} \\ = 30\%. \\ \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \\ \frac{e^+e^-}{e^-} \rightarrow \\ \\ \frac{e^-}{e^-} \rightarrow \\ \\ \frac{e^+e^-}{e^-} \rightarrow \\ \\ \frac{e^+e^-}{e^-} \rightarrow \\ \\ \frac{e^-}{e^-} \rightarrow \\ \\ \frac{e^-}{$ | r(4S) e the CLEOII $r(4S)$ |
| ALUE ALUE ASSUMES ASSUMES ASSUME B($D^0 \rightarrow 0^0$) Ftotal ALUE (units 10^{-4}) <0.6 ASSUMES Equal Production ASSUMES Production ASSUMES Production ASSUMES Production Production ASSUMES Production Pr | 2 (L %) 90 equal pro (K - π +) 90 equal pro | 1 ALAM duction of B+ a and B(D*2(2460) DOCUMENT I 1 ADACHI ng data for avera 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B I B+ and B ⁰ at the DOCUMENT I 2 Error includes so I FRATINA 1 AUBERT,B ng data for avera 1 MA JUMDEI 1 LIPELES BARATE ASNER B+ and B ⁰ at the SE DOCUMENT SE DOCUMENT SE DOCUMENT ADDRIVED 94 nd B^0 a $+ \rightarrow D$ 08 gges, fits 06A the $\Upsilon(4:$ 07 06A gges, fits 07 06A gges, fits $= 0.00$ 7 $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ $=$ | CLE2 t the T TECN BELL limits, BABR BABR BABR Or of 1.2 BELL LLE2 ALEP CLE2 ALEP CLE3 ALEP CLE3 ALEP CLE4 ALEP CLE5 | $\begin{array}{c} e^+e^- \rightarrow \\ (4S) \text{ and us} \\ = 30\%. \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ e^+e^$ | T(45) e the CLEOII Γ67/Γ T(45) Γ(45) Γ(45) Γ(45) Γ(45) T(45) |
| ALUE $(ALUE)$ $(ALUE$ | $\frac{cL\%}{90}$ equal pro $K - \pi^+$) $\frac{cL\%}{90}$ ene following 90 equation of $\frac{cL\%}{90}$ | 1 ALAM duction of B+ a and B(D*(2460) DOCUMENT I 1 ADACHI ng data for avera 1 AUBERT,B 1 B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B 1 B+ and B ⁰ at the DOCUMENT I 1 AUBERT,B 1 FRATINA 1 AUBERT,B 1 G data for avera 1 MAJUMDEI 1 LIPELES BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 B+ and B ⁰ at the BARATE ASNER 1 ZUPANC 2 AUBER | 94 nd B^0 a B^0 a B^0 a 08 ges, fits 06A the $T(4:1)$ Cale fact 07 06A ges, fits R 05 09 97 the $T(4:1)$ Cale fact 07 06A 10 10 10 10 10 10 10 10 10 1 | CLE2 t the T TECN BELL limits, BABR S). TECN BELL BABR S). TECN TECN TECN TECN TECN TECN TECN TEC | $\begin{array}{c} e^+e^- \rightarrow \\ (45) \text{ and us} \\ = 30\%. \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{etc.} \bullet \bullet \\ e^+e^- \rightarrow \\ \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \frac{e^+e^- \rightarrow}{e^+e^- \rightarrow} \\ \\ \frac{e^-e^- \rightarrow}{e^-e^- \rightarrow$ | $T(4S)$ e the CLEOII $T67/\Gamma$ $T(4S)$ |

¹ ZUPANC 07 reports $(7.5\pm0.2\pm1.1)\times10^{-3}$ from a measurement of $[\Gamma(B^0\to D^-D_s^+)/$ $\Gamma_{
m total}] imes [B(D_S^+ o \phi \pi^+)]$ assuming $B(D_S^+ o \phi \pi^+) = (4.4 \pm 0.6) imes 10^{-2}$, which we rescale to our best value B($D_s^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best 2 AUBERT 06N reports (0.64 \pm 0.13 \pm 0.10) \times 10 $^{-2}$ from a measurement of [\Gamma(B 0 \rightarrow $D^-D_s^+)/\Gamma_{ ext{total}}] \times [B(D_s^+ o \phi \pi^+)]$ assuming $B(D_s^+ o \phi \pi^+) = 0.0462 \pm 0.0062$, which we rescale to our best value B($D_s^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using 3 GIBAUT 96 reports 0.0087 \pm 0.0024 \pm 0.0020 from a measurement of [$\Gamma(B^0
ightarrow$ $D^-D_S^+)/\Gamma_{\rm total}] \ \times \ [{\rm B}(D_S^+ \to \ \phi\pi^+)] \ \ {\rm assuming} \ \ {\rm B}(D_S^+ \to \ \phi\pi^+) \ = \ 0.035, \ {\rm which}$ we rescale to our best value B($D_s^+ o \phi \pi^+$) = (4.5 ± 0.4) × 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best 4 ALBRECHT 92G reports 0.017 \pm 0.013 \pm 0.006 from a measurement of $[\Gamma(B^0
ightarrow$ $(D^-D_S^+)/\Gamma_{ ext{total}} \times [B(D_S^+ o \phi \pi^+)]$ assuming $B(D_S^+ o \phi \pi^+) = 0.027$, which we rescale to our best value B($D_S^+ \to \phi \pi^+$) = (4.5 ± 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^+ branching ratios, e.g., B($D^+ \rightarrow \kappa^- 2\pi^+$) = 5 BORTOLETTO 92 reports 0.0080 \pm 0.0045 \pm 0.0030 from a measurement of [Γ(B^{0} \rightarrow $(D^-D_s^+)/\Gamma_{ ext{total}} \times [B(D_s^+ o \phi \pi^+)]$ assuming $B(D_s^+ o \phi \pi^+) = 0.030 \pm 0.011$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$ and uses Mark III

| $\Gamma(D^*(2010)^-D_s^+)/\Gamma_{\text{total}}$ | | | | | Γ ₇₁ /Γ |
|--------------------------------------------------|-----------------------|-----|------|-----------------------|--------------------|
| VALUE EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 0.0080 ± 0.0011 OUR AVERAGE | | | | | |
| $0.0073 \pm 0.0013 \pm 0.0007$ | ¹ AUBERT | 06N | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0083 \pm 0.0015 \pm 0.0007$ | ² AUBERT | 031 | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0088 \pm 0.0017 \pm 0.0008$ | ³ AHMED | 00в | CLE2 | $e^+e^- \rightarrow$ | T(45) |
| $0.008 \pm 0.006 \pm 0.001$ | ⁴ ALBRECHT | 92G | ARG | $e^+ e^- \rightarrow$ | Y(45) |

 6 BORTOLETTO 90 assume B($D_s
ightarrow \phi \pi^+) = 2\%$. Superseded by BORTOLETTO 92.

branching fractions for the D.

⁵ BORTOLETTO92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ 0.011 + 0.006 + 0.001 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

⁶ GIBAUT 96 CLE2 Repl. by AHMED 00B $0.0072 \pm 0.0022 \pm 0.0006$ GIBAUT 96 CLE2 Repl. by AHMED 7 BORTOLETTO90 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ 0.024 ± 0.014

 1 AUBERT 06N reports (0.71 \pm 0.13 \pm 0.09) imes 10 $^{-2}$ from a measurement of [$\Gamma(B^0
ightarrow$ $D^*(2010)^-D_s^+)/\Gamma_{ ext{total}}] \times [B(D_s^+ o \phi \pi^+)]$ assuming $B(D_s^+ o \phi \pi^+) = 0.0462 \pm 0.0462$ 0.0062, which we rescale to our best value B($D_s^+ o \phi \pi^+$) = (4.5 \pm 0.4) \times 10 $^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 2 AUBERT 031 reports 0.0103 \pm 0.0014 \pm 0.0013 from a measurement of [$\Gamma(B^0 \rightarrow$ $D^*(2010)^-D_S^+)/\Gamma_{ ext{total}}] \times [B(D_S^+ o \phi \pi^+)]$ assuming $B(D_S^+ o \phi \pi^+) = 0.036$, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

 3 AHMED 00B reports 0.0110 \pm 0.0018 \pm 0.0011 from a measurement of $[\Gamma(B^0
ightarrow$ $D^*(2010)^- D_s^+)/\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ assuming $B(D_s^+ \to \phi \pi^+) = 0.036$, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

 4 ALBRECHT 92G reports 0.014 \pm 0.010 \pm 0.003 from a measurement of [$\Gamma(B^0 \rightarrow$ $D^*(2010)^- D_s^+)/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ assuming } B(D_s^+ \to \phi \pi^+) = 0.027,$ which we rescale to our best value B($D_s^+ o \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^+ and $D^st(2010)^+$ branching ratios, e.g., B(D^0 - $K^-\pi^+) = 3.71 \pm 0.25\%$, B($D^+ \to K^-2\pi^+$) = 7.1 $\pm 1.0\%$, and B($D^*(2010)^+ \to K^-\pi^+$) $D^0\pi^+)=55\pm4\%$

 5 BORTOLETTO 92 reports 0.016 \pm 0.009 \pm 0.006 from a measurement of [Г(B 0 \rightarrow $D^*(2010)^-D_S^+)/\Gamma_{\mbox{total}}] \times [\mbox{B}(D_S^+ \rightarrow \ \phi \pi^+)] \mbox{ assuming B}(D_S^+ \rightarrow \ \phi \pi^+) = 0.030 \ \pm 0.000 \ \pm$ 0.011, which we rescale to our best value B($D_s^+ o \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$ and uses MarkIII branching fractions for the D and $D^*(2010)$.

 6 GIBAUT 96 reports 0.0093 \pm 0.0023 \pm 0.0016 from a measurement of [$\Gamma(B^0
ightarrow$ $D^*(2010)^-D_S^+)/\Gamma_{\mbox{total}}] \, \times \, [\mbox{B}(D_S^+ \, \rightarrow \, \phi \pi^+)] \, \mbox{ assuming } \, \mbox{B}(D_S^+ \, \rightarrow \, \phi \pi^+) \, = \, 0.035,$ which we rescale to our best value B($D_s^+ o \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

⁷BORTOLETTO 90 assume B($D_S \rightarrow \phi \pi^+$) = 2%. Superseded by BORTOLETTO 92.

| $\Gamma(D^-D_s^{*+})/\Gamma_{\text{total}}$ | | | | | Γ_{72}/Γ |
|---------------------------------------------|-----------------------|-----|------|----------------------|----------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.0074 ± 0.0016 OUR AVERAGE | | | | | |
| $0.0071 \pm 0.0016 \pm 0.0006$ | ¹ AUBERT | 06N | BABR | $e^+e^- \rightarrow$ | Y(45) |
| $0.0078 \pm 0.0032 \pm 0.0007$ | ² GIBAUT | 96 | CLE2 | $e^+e^- \rightarrow$ | Y(45) |
| $0.016 \pm 0.012 \pm 0.001$ | ³ ALBRECHT | 92G | ARG | $e^+e^- \rightarrow$ | r(45) |
| | | | | | |

 1 AUBERT 06N reports (0.69 \pm 0.16 \pm 0.09) $\times\,10^{-2}$ from a measurement of [Г(B 0 \rightarrow $D^-D_s^{*+})/\Gamma_{
m total}] imes [{
m B}(D_s^+ o\phi\pi^+)]$ assuming ${
m B}(D_s^+ o\phi\pi^+)=0.0462\pm0.0062$, which we rescale to our best value B($D_c^+ \rightarrow \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

 2 GIBAUT 96 reports 0.0100 \pm 0.0035 \pm 0.0022 from a measurement of [$\Gamma(B^0 \rightarrow$ $(D^-D_s^{*+})/\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ assuming $B(D_s^+ \to \phi \pi^+) = 0.035$, which we rescale to our best value B($D_s^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best

 3 ALBRECHT 92G reports 0.027 \pm 0.017 \pm 0.009 from a measurement of [$\Gamma(B^0
ightarrow$ $D^-D_s^{*+})/\Gamma_{
m total}] imes [{\sf B}(D_s^+ o \phi \pi^+)]$ assuming ${\sf B}(D_s^+ o \phi \pi^+) = 0.027$, which we rescale to our best value B($D_S^+ \to \phi \pi^+$) = (4.5 ± 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^+ branching ratios, e.g., B($D^+ \to K^- 2\pi^+$) = 7.7 \pm 1.0%.

$\Gamma(D^*(2010)^-D_*^{*+})/\Gamma_{total}$

Г73/Г

| (5 (1010) 5 // total | | | | | . 121 |
|-----------------------------------|-----------------------|----------|---------|-----------------------|----------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.0177±0.0014 OUR AVERAGE | | | | | |
| $0.0173 \pm 0.0018 \pm 0.0015$ | ¹ AUBERT | 06N | BABR | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0188 \pm 0.0009 \pm 0.0017$ | ² AUBERT | 05∨ | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.0158 \pm 0.0027 \pm 0.0014$ | ³ AUBERT | 031 | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.015 \pm 0.004 \pm 0.001$ | ⁴ AHMED | 00в | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.016 \pm 0.009 \pm 0.001$ | ⁵ ALBRECHT | 92G | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not use the following | g data for average | s, fits, | limits, | etc. • • • | |

⁶ GIBAUT 96 CLE2 Repl. by AHMED 00B $0.016\ \pm0.005\ \pm0.001$ $^1\,\text{AUBERT}$ 06N reports (1.68 \pm 0.21 \pm 0.19) \times 10 $^{-2}$ from a measurement of [\Gamma(B^0 \rightarrow

 $D^*(2010)^-D_S^{*+})/\Gamma_{\mbox{total}}] \times [B(D_S^+ \to \phi \pi^+)] \mbox{ assuming } B(D_S^+ \to \phi \pi^+) = 0.0462 \pm 0.0$ 0.0062, which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value.

² A partial reconstruction technique is used and the result is independent of the particle decay rate of D_S^+ meson. It also provides a model-independent determination of B(D_S^+ ightarrow $\phi \pi^+$) = (4.81 ± 0.52 ± 0.38)%.

 3 AUBERT 031 reports 0.0197 \pm 0.0015 \pm 0.0030 from a measurement of $[\Gamma(B^0
ightarrow$ $D^*(2010)^-D_{S}^{*+})/\Gamma_{\mathsf{total}}] \times [\mathsf{B}(D_{S}^+ \to \ \phi \pi^+)] \text{ assuming } \mathsf{B}(D_{S}^+ \to \ \phi \pi^+) = 0.036,$ which we rescale to our best value $B(D_5^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using

our best value. 4 AHMED 00B reports 0.0182 \pm 0.0037 \pm 0.0025 from a measurement of [$\Gamma(B^0 o$ $D^*(2010)^-D_S^{*+})/\Gamma_{\mbox{total}}] \times [\mbox{B}(D_S^+ \to \ \phi \pi^+)] \mbox{ assuming B}(D_S^+ \to \ \phi \pi^+) = 0.036,$ which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

 5 ALBRECHT 92G reports 0.026 \pm 0.014 \pm 0.006 from a measurement of [Г(B^{0} ightarrow $D^*(2010)^-\,D_S^{*+})/\Gamma_{\mbox{total}}]\,\times\,[\mbox{B}(D_S^+\,\to\,\,\phi\pi^+)]\,\,\mbox{assuming}\,\,\mbox{B}(D_S^+\,\to\,\,\phi\pi^+)\,=\,0.027,$ which we rescale to our best value B($D_c^+ \to \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes PDG 1990 D^+ and $D^*(2010)^+$ branching ratios, e.g., B(D^0 – $K^-\pi^+) = 3.71 \pm 0.25\%$, B($D^+ \to K^-2\pi^+$) = 7.1 $\pm 1.0\%$, and B($D^*(2010)^+ \to K^-\pi^+$) $D^0\pi^+)=55\pm4\%$

 6 GIBAUT 96 reports 0.0203 \pm 0.0050 \pm 0.0036 from a measurement of [Г (B^0 ightarrow $D^*(2010)^-D_s^{*+})/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ assuming } B(D_s^+ \to \phi \pi^+) = 0.035,$ which we rescale to our best value B($D_c^+ \rightarrow \phi \pi^+$) = (4.5 \pm 0.4) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using

$[\Gamma(D^*(2010)^-D_s^+) + \Gamma(D^*(2010)^-D_s^{*+})]/\Gamma_{\text{total}}$

 $(\Gamma_{71} + \Gamma_{73})/\Gamma$

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | TECN | COMMENT |
|--------------------------|------|---------------------------|------|------------------------------------|
| 2.5 ±0.4 OUR AVER | AGE | | | |
| $2.40 \pm 0.35 \pm 0.22$ | | | | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $3.3 \pm 0.9 \pm 0.3$ | 22 | ² BORTOLETTO90 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |

 1 AUBERT 031 reports (3.00 \pm 0.19 \pm 0.39) imes 10 $^{-2}$ from a measurement of [$\Gamma(B^0
ightarrow$ $D^*(2010)^-D_s^+) + \Gamma(B^0 \to D^*(2010)^-D_s^{*+}) \Big] / \Gamma_{\rm total}] \times [B(D_s^+ \to \phi \pi^+)]^{\rm Lassuming}$ $B(D_s^+ \to \phi \pi^+) = 0.036$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+) =$ $(4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $^2\,\text{BORTOLETTO}$ 90 reports $\overset{-}{(7.5~\pm~2.0)}\times10^{-2}$ from a measurement of [[$\Gamma(B^{\,0}\,\to\,$ $D^*(2010)^-\,D_s^+) + \Gamma\big(B^0\to\,D^*(2010)^-\,D_s^{*+}\big)\Big]/\Gamma_{\mathsf{total}}] \times [\mathsf{B}(D_s^+\to\,\phi\pi^+)] \; \mathsf{assuming}$ $B(D_s^+ \to \phi \pi^+) = 0.02$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+) =$ $(4.5 \stackrel{\circ}{\pm} 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D_{s0}(2317)^-K^+ \times B(D_{s0}(2317)^- \to D_s^-\pi^0))/\Gamma_{total}$

VALUE (units 10^{-5}) DOCUMENT ID TECN COMMENT $4.2^{+1.4}_{-1.3}\pm0.4$ 1 DRUTSKOY 05 BELL $e^{+}\,e^{-}
ightarrow \, \varUpsilon(4\,S)$ 1 DRUTSKOY 05 reports $(5.3^{+1.5}_{-1.3}\pm1.6) imes10^{-5}$ from a measurement of $[\Gamma(B^0
ightarrow$ $D_{s0}(2317)^- \, \text{K}^+ \times \, \text{B}(D_{s0}(2317)^- \to \, D_s^- \, \pi^0) \,) / \Gamma_{\text{total}}] \times [\text{B}(D_s^+ \to \, \phi \, \pi^+)] \, \text{assuming}$ $B(D_s^+ \to \phi \pi^+) = 0.036 \pm 0.009$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+)$ $=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D_{s0}(2317)^-\pi^+ \times B(D_{s0}(2317)^- \to D_s^-\pi^0))/\Gamma_{\text{total}}$ Γ_{75}/Γ CL% DO CUMENT ID TECN COMMENT 1 DRUTSKOY 05 BELL $e^{+}e^{-} ightarrow \gamma(4S)$ 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(D_{sJ}(2457)^-\pi^+ \times B(D_{sJ}(2457)^- \to D_s^-\pi^0))/\Gamma_{\text{total}}$ Γ_{77}/Γ DOCUMENT ID CL% TECN COMMENT 1 DRUTSKOY 05 BELL $e^{+}e^{-}
ightarrow \varUpsilon$ (4*S*) 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(D_s^-D_s^+)/\Gamma_{\text{total}}$ Γ_{78}/Γ DOCUMENT ID VALUE CL% TECN COMMENT $< 3.6 \times \overline{10^{-5}}$ $1 \overline{\text{ZUPANC}}$ 07 BELL $e^+e^- \rightarrow$ 9.0 • • • We do not use the following data for averages, fits, limits, etc. • • • <10 imes10 $^{-5}$ 90 1 AUBERT,BE 05F BABR $e^{+}e^{-}
ightarrow$ \varUpsilon (4S) 1 Assumes equal production of ${\it B}^+$ and ${\it B}^{\,0}$ at the ${\it \Upsilon}(4{\it S})$.

 $\Gamma(D_s^{*-}D_s^+)/\Gamma_{\text{total}}$ Γ_{79}/Γ CL% DOCUMENT ID TECN COMMENT $<1.3 \times 10^{-4}$ 1 AUBERT,BE 05F BABR $e^{+}e^{-}
ightarrow \gamma (4S)$ 90

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(D_s^{*-}D_s^{*+})/\Gamma_{\text{total}}$ Γ_{80}/Γ CL% DOCUMENT ID TECN COMMENT <2.4 × 10⁻⁴ 90 1 AUBERT,BE 05F BABR $e^{+}e^{-}
ightarrow \varUpsilon(4S)$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $\Gamma(D_{s0}(2317)^+D^-\times B(D_{s0}(2317)^+\to D_s^+\pi^0))/\Gamma_{total}$ Γ_{81}/Γ VALUE (units 10⁻³) DOCUMENT ID TECN COMMENT

 $0.97^{+0.40}_{-0.33}$ OUR AVERAGE Error includes scale factor of 1.5.

 $1.4 \ ^{+\ 0.5}_{-\ 0.4}\ \pm 0.1$ 1,2 AUBERT,B 04s BABR $e^+e^ightarrow$ \varUpsilon (4S) $0.69^{+0.29}_{-0.24} \pm 0.06$ ^{1,3} KROKOVNY 03B BELL $e^+e^- \rightarrow r(4S)$

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 AUBERT,B 04s reports (1.8 \pm 0.4 $^+_-$ 0.5) \times 10 $^{-3}$ from a measurement of [Γ(B^0 \rightarrow $D_{s0}(2317)^{+}\,D^{-}\times \,\mathrm{B}(D_{s0}(2317)^{+}\to\,D_{s}^{+}\,\pi^{0}))/\Gamma_{total}]\times [\mathrm{B}(D_{s}^{+}\to\,\phi\pi^{+})] \text{ assuming }$ $B(D_s^+ \to \phi \pi^+) = 0.036 \pm 0.009$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+)$ $=(4.5\pm0.4) imes10^{-2}$. Our first error is their experiment's error and our second error is

the systematic error from using our best value. 3 KROKOVNY 03B reports $(0.86^{+0.33}_{-0.26}\pm0.26)\times10^{-3}$ from a measurement of $[\Gamma(B^0\to 0.26)\times10^{-3}]$ $D_{s0}(2317)^+ \, D^- \times \, \mathrm{B}(D_{s0}(2317)^+ \, \to \, D_s^+ \, \pi^0)) / \Gamma_{\mathrm{total}}] \times [\mathrm{B}(D_s^+ \, \to \, \phi \pi^+)] \, \, \mathrm{assuming}$ B($D_s^+ \to \phi \pi^+$) = 0.036 \pm 0.009, which we rescale to our best value B($D_s^+ \to \phi \pi^+$) $= (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(D_{s0}(2317)^+ D^- \times B(D_{s0}(2317)^+ \to D_s^{*+} \gamma)) / \Gamma_{\text{total}}$

VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 90 ¹ KROKOVNY 03B BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

 $\Gamma(D_{s0}(2317)^+ D^*(2010)^- \times B(D_{s0}(2317)^+ \to D_s^+ \pi^0))/\Gamma_{\text{total}}$ Γ_{83}/Γ DOCUMENT ID TECN COMMENT VALUE (units 10^{-3}) 1 AUBERT,B 04s BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(D_{sJ}(2457)^+D^-)/\Gamma_{\text{total}}$ Γ84/Γ VALUE (units 10^{-3}) DO CUMENT ID TECN COMMENT 3.5 ±1.1 OUR AVERAGE $2.6 \pm 1.5 \pm 0.7$ ¹ AUBERT 06N BABR $e^+e^- \rightarrow \Upsilon(4S)$ $4.8^{\color{red}+2.2}_{-1.6}\!\pm\!1.1$ ^{2,3} AUBERT,B 04s BABR $e^+e^- \rightarrow \Upsilon(4S)$ $3.9^{+1.5}_{-1.3}\pm0.9$ 2,4 Krokovny 03b Bell $e^+e^- ightarrow ~ \varUpsilon(4\,{\it S})$

| ¹ Uses a missing-mass method ² Assumes equal production of ³ AUBERT,B 04s reports [Γ (| $^{:}B^{+}$ and B^{0} at the Υ (4 $B^{0} ightarrow D_{s,J}$ (2457) ^{+}D | ι <i>s</i>).) /Γ _{tot a} | $[B] \times [B]$ | 1(2460) ⁺ → |
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| $D_s^{*+} \pi^0$] = $(2.3 + 1.0 \pm 0.3)$ $D_s^{*+} \pi^0$) = $(48 \pm 11) \times 10^-$ | | | | |
| error is the systematic error f 4 KROKOVNY 03B reports [Γ | from using our best value | e | 1 [0/0 | (0460)± |
| $D_s^{*+} \pi^0$] = $(1.9 + 0.7 \pm 0.2)$ | $\times 10^{-3}$ which we divide t | tot/ / oy our bes | $_{ m al}$] $	imes$ [B($D_{ m S}$ st value B($D_{ m S}$ | $\frac{1}{1}(2460)^{+} \rightarrow \frac{1}{1}(2460)^{+} \rightarrow \frac{1}$ |
| $D_s^{*+}\pi^0)=(48\pm11)\times10^-$ error is the systematic error f | 2 . Our first error is their | experim | ent's error ar | nd our second |
| $\Gamma(D_{sJ}(2457)^+D^- \times B(D_{sJ})^{VALUE \text{ (units }10^{-3})}$ | $(2457)^+ \rightarrow D_s^+ \gamma))/$ DOCUMENT ID | | COMMENT | Г ₈₅ /Г |
| 0.65 + 0.17 OUR AVERAGE | | | | |
| $0.64 + 0.24 \pm 0.06$ | 1,2 AUBERT,B 04s | BABR | $e^+e^- ightarrow$ | Y(45) |
| $0.66^{+0.21}_{-0.19} \pm 0.06$ | 1,3 KROKOVNY 03B | BELL | $e^+e^- \to$ | Y(45) |
| ¹ Assumes equal production of ² AUBERT,B 04s reports (0.8 | $^{+}$ $^{+}$ and 0 at the $^{\circ}$ $^{(4)}$ $^{+}$ $^{-3}$ $^{+}$ $^{-3}$ $^{-3}$ $^{-3}$ | S). roman | neasurement | of $[\Gamma(B^0 \rightarrow$ |
| D_{sJ} (2457) $^+$ $D^ 	imes$ B(D_{sJ} (2 B(D_s^+ $ ightarrow$ $\phi\pi^+$) = 0.036 \pm | $(2457)^{\pm} \rightarrow D_s^{+} \gamma) / \Gamma_{tot}$ | $_{al}$ J \times [B) | $(D_S^+ \rightarrow \phi \pi$ | ±)] assuming |
| $= (4.5 \pm 0.4) \times 10^{-2}. \text{ Our f}$ the systematic error from usi 3 KROKOVNY 03B reports (0. | first error is their experin | nent's err | or and our s | econd error is |
| D_{sJ} (2457) $^+$ $D^ 	imes$ B(D_{sJ} (2 | $0.2 \pm 0.19 \pm 0.25) \times 10^{-1}$ $0.2457)^+ \rightarrow D_s^+ \gamma) / \Gamma_{tot}$ | al] × [B) | $(D_s^+ 	o \phi \pi)$ | †)] assuming |
| $B(D_s^+ \to \phi \pi^+) = 0.036 \pm$ | 0.009, which we rescale | to our be | st value B(<i>E</i> | $\rho_s^+ \rightarrow \phi \pi^+)$ |
| $= (4.5 \pm 0.4) 	imes 10^{-2}$. Our the systematic error from usi | | nent's err | or and our s | econd error is |
| $\Gamma(D_{sJ}(2457)^+D^- \times B(D_{sJ})$ | | | | Г ₈₆ /Г |
| <u>VALUE (units 10^{−3})</u> <u>CL%</u> <0.60 90 | DOCUMENT ID 1 KROKOVNY 03B | TECN BELL | $e^+e^- \rightarrow$ | Υ(4.5) |
| ¹ Assumes equal production of | | | | . () |
| $\Gamma(D_{sJ}(2457)^+D^- \times B(D_{sJ})$ | $(2457)^+ \to D_s^+ \pi^+ \pi^-$ | -))/Γ _t | otal | Γ ₈₇ /Γ |
| <u>VALUE (units 10⁻³)</u> <u>CL%</u> <0.20 90 | DOCUMENT ID 1 KROKOVNY 03B | TECN | COMMENT _ | m(+c) |
| <0.20 90 Assumes equal production of | | | e · e → | 1 (43) |
| $\Gamma(D_{sJ}(2457)^+D^- \times B(D_{sJ})$ | $(2457)^+ \rightarrow D_s^+ \pi^0)$ | /Γ _{total} | | Γ ₈₈ /Γ |
| <u>VALUE (units 10^{−3})</u> <u>CL%</u> <0.36 90 | DOCUMENT ID | TECN | COMMENT | |
| 40.36 90 90 1 Assumes equal production of | | | $e^+e^- \rightarrow$ | T(45) |
| $\Gamma(D^*(2010)^- D_{sJ}(2457)^+)$ | | , | | Γ ₈₉ /Γ |
| VALUE (units 10^{-3}) | DOCUMENT ID | TECN | COMMENT | |
| 9.3±2.2 OUR AVERAGE 8.8±2.0±1.4 | ¹ AUBERT 06N | BABR | $e^+e^ ightarrow$ | Y(45) |
| $11 \begin{array}{cc} +5 \\ -4 \end{array} \pm 3$ | ^{2,3} AUBERT,B 04s | BABR | $e^+e^- \to$ | Y(45) |
| ¹ Uses a missing-mass method ² AUBERT,B 04s reports | $\Gamma(B^0 \rightarrow D^*)$ | 2010) - E |) _{6.7} (2457) ⁺) | $1/\Gamma_{total}$ × |
| $[B(D_{s1}(2460)^+ \rightarrow D_s^{*+}\pi)]$ | $[0] = (5.5 \pm 1.2 + 2.2)$ $[0] = (5.5 \pm 1.2 + 2.2)$ | × 10 ⁻³ | which we | divide by our |
| best value $B(D_{s1}(2460)^+ - experiment's error and our se 3 Assumes equal production of$ | conderror is the systemates B^+ and B^0 at the $\Upsilon(4)$ | itic error (S). | from using o | ur best value. |
| $\Gamma(D_{sJ}(2457)^+D^*(2010)\times 10^{-3}$ | | | | Γ ₉₀ /Γ |
| VALUE (units 10 ⁻³) 2.3±0.3 ⁺ 0.6 | DOCUMENT ID 1 AUBERT,B 04s | | | Υ(4 C) |
| ¹ Assumes equal production of | | | e · e → | 1 (43) |
| $\Gamma(D^-D_{s1}(2536)^+ \times B(D_{s1}(2536)^+)$ | | + D*+ I | Κ ⁰))/Γ _{total} | _ ₉₂ +Г ₉₃)/Г |
| VALUE (units 10 ⁻⁴) | DOCUMENT ID | | | |
| VALUE (units 10 ⁻⁴) 2.75±0.62±0.36 | 1,2 AUSHEV 11 | BELL | $e^+ e^- \rightarrow$ | Y(45) |
| 1 Uses $\Gamma(D^*(2007)^0 \rightarrow D \Gamma(D_{s1}(2536)^+ \rightarrow D^*(2007)^2 + D^*(2007)^2$ Assumes equal production of | $(0.70^{\circ})^{\circ}$ / $\Gamma(D^*(2007)^{\circ})^{\circ}$ / $\Gamma(D_{s1}(2536)^{+})^{\circ}$ / $\Gamma(D_{s1}(2536)^{+})^{\circ}$ and D° at the $\Upsilon(4)^{\circ}$ | $\rightarrow D^0$ $\rightarrow D^*($ +S). | γ) = 1.74 2010) + K^0) | \pm 0.13 and $=$ 1.36 \pm 0.2. |
| $\Gamma(D^-D_{s1}(2536)^+ \times B(D_{s1})^+ \times B(D_{s$ | $(2536)^+ \rightarrow D^{*0} K^+)$ |)/F _{total} | | Г ₉₂ /Г |
| 1.71 ± 0.48 ± 0.32 | 1 AUBERT 08B | BABR | $e^+e^- \rightarrow$ | Υ(4S) |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

AUBERT

03x BABR Repl. by AUBERT 08B

90

<5

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\Gamma(D^-D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^{*+}K^0))/\Gamma_{total}
                                                                                                        \Gamma_{93}/\Gamma
VALUE (units 10^{-4})
                                            DOCUMENT ID TECN COMMENT
                                           <sup>1</sup> AUBERT 08B BABR e^+e^- \rightarrow \Upsilon(4S)
  <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(D^*(2010)^- D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^{*0}K^+ + D^{*+}K^0))/
                                                                                 \Gamma_{94}/\Gamma = (\Gamma_{95} + \Gamma_{96})/\Gamma
VALUE (units 10^{-4})
                                              DOCUMENT ID
                                                                        TECN COMMENT
                                        1,2 AUSHEV 11 BELL e^+e^- \rightarrow \Upsilon(4S)
5.01 \pm 1.21 \pm 0.70
  {}^{1}\, \text{Uses} \ \ \Gamma(D^{*}(2007)^{\,0} \ \to \ D^{\,0}_{\,\,}\pi^{\,0}) \ \ / \ \ \Gamma(D^{*}(2007)^{\,0} \ \to \ D^{\,0}_{\,\,}\gamma) \ \ = \ 1.74 \ \pm \ 0.13 \ \ \text{and}
    \Gamma(D_{s1}(2536)^+ \to D^*(2007)^0 K^+) / \Gamma(D_{s1}(2536)^+ \to D^*(2010)^+ K^0) = 1.36 \pm 0.2.
  <sup>2</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(D^*(2010)^- D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^{*0}K^+))/\Gamma_{\text{total}}
                                                                                                        Г95/Г
VALUE (units 10^{-4})
                                            DOCUMENT ID TECN COMMENT
                                           <sup>1</sup> AUBERT
                                                                 08B BABR e^+e^- \rightarrow \Upsilon(4S)
  3.32 \pm 0.88 \pm 0.66
\bullet \bullet We do not use the following data for averages, fits, limits, etc. 
 \bullet \bullet
                                       AUBERT 03x BABR Repl. by AUBERT 08B
  <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(D^{*-}D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \rightarrow D^{*+}K^0))/\Gamma_{total}
                                                                                                        \Gamma_{96}/\Gamma
VALUE (units 10^{-4})
                                             DOCUMENT ID
                                                                  TECN COMMENT
                                           1 AUBERT
5.00 \pm 1.51 \pm 0.67
                                                             08B BABR e^+e^- \rightarrow \Upsilon(4S)
   <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(D^-D_{sJ}(2573)^+ \times B(D_{sJ}(2573)^+ \to D^0K^+))/\Gamma_{\text{total}}
                                                                                                        \Gamma_{97}/\Gamma
                                              DOCUMENT ID TECN COMMENT
                                                                  03x BABR e^+e^- \rightarrow \Upsilon(4S)
                                              AUBERT
\Gamma(D^*(2010)^- D_{sJ}(2573)^+ \times B(D_{sJ}(2573)^+ \to D^0 K^+))/\Gamma_{\text{total}}
                                                                                                        \Gamma_{98}/\Gamma
VALUE (units 10<sup>-4</sup>) CL%
                                              DOCUMENT ID
                                                                 03x BABR e^+e^- \rightarrow \Upsilon(4S)
\Gamma(D^+\pi^-)/\Gamma_{\text{total}}
                                                                                                        Γ99/Γ
VALUE (units 10^{-7})
                                              DOCUMENT ID
                                                                    TECN COMMENT
                                        1.2 \overline{\mathrm{DAS}} 10 BELL e^+e^- \rightarrow \Upsilon(4S)
7.8 \pm 1.3 \pm 0.4
  ^{1}\,\mathrm{DAS} 10 reports [ \Gamma\left(B^{\,0}\,\rightarrow\,\,D^{\,+}\,\pi^{\,-}\right)/\Gamma_{\,total} ] / [ \mathrm{B}(B^{\,0}\,\rightarrow\,\,D^{\,-}\,\pi^{\,+}) ] = (2.92 \pm 0.38 \pm
    0.31) \times 10<sup>-4</sup> which we multiply by our best value B(B^0 \rightarrow D^-\pi^+) = (2.68 \pm 0.13) \times
             Our first error is their experiment's error and our second error is the systematic
    error from using our best value.
  ^2 Derived using \tan(\theta_C)~f_D/f_{D_S}~\sqrt{B(B^0\to D_S^+\pi^-)/B(B^0\to D^-\pi^+)} by assuming the flavor SU(3) symmetry, where \theta_C is the Cabibbo angle, f_D~(f_{D_S}) is the D~(D_S) meson
    decay constant.
\Gamma(D_s^+\pi^-)/\Gamma_{\text{total}}
                                                                                                       \Gamma_{100}/\Gamma
VALUE (units 10^{-6})
                                              DOCUMENT ID
                                                                      TECN COMMENT
      21.6±2.6 OUR AVERAGE
                                            ^{1} DAS
                                                                 10 BELL e^+e^- \rightarrow \Upsilon(4S)
      19.9\!\pm\!2.6\!\pm\!1.8
     25 \pm 4 \pm 2
                                           <sup>1</sup> AUBERT
                                                                  08AJ BABR e^+e^- \rightarrow \Upsilon(4S)
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                           <sup>2</sup> AUBERT
     14.0 \pm 3.5 \pm 1.3
                                                                 07κ BABR Repl. by AUBERT 08AJ
                                           <sup>3</sup> AUBERT
      25\phantom{0}\pm 9\phantom{0}\pm 2\phantom{0}
                                                                  03\text{D} BABR Repl. by AUBERT 07\kappa
     19 \begin{array}{cc} +9 \\ -7 \end{array} \pm 2
                                           ^4 KROKOVNY \phantom{0} 02 \phantom{0} BELL \phantom{0} Repl. by DAS 10
 < 220
                                           ^{5} ALEXANDER 93B CLE2 e^{+}e^{-} \rightarrow \Upsilon(4S)
                               90
                                           ^{6} BORTOLETTO90 CLEO e^{+}\,e^{-}
ightarrow \varUpsilon(4\,S)
 < 1300
                               90
   <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
  <sup>2</sup> AUBERT 07K reports [\Gamma(B^0 \to D_s^+\pi^-)/\Gamma_{
m total}] \times [B(D_s^+ \to \phi\pi^+)] = (0.63 \pm 0.15 \pm
    (0.05) \times 10^{-6} which we divide by our best value B(D_s^+ \rightarrow \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}.
    Our first error is their experiment's error and our second error is the systematic error
     from using our best value.
  0.21) \times 10^{-6} which we divide by our best value B(D_s^+ \rightarrow \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}.
     Our first error is their experiment's error and our second error is the systematic error
    from using our best value.
   <sup>4</sup> KROKOVNY 02 reports [\Gamma(B^0 \rightarrow D_S^+\pi^-)/\Gamma_{\text{total}}] \times [B(D_S^+ \rightarrow \phi\pi^+)] =
    (0.86^{+0.37}_{-0.30}\pm0.11)\times10^{-6} which we divide by our best value B(D_s^+\to\phi\pi^+) =
    (4.5\pm0.4)\times10^{-2}. Our first error is their experiment's error and our second error is
  the systematic error from using our best value. 

<sup>5</sup> ALEXANDER 93B reports < 270 \times 10^{-6} from a measurement of [\Gamma(B^0 \to D_s^+ \pi^-)/
    \Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] assuming B(D_s^+ \to \phi \pi^+) = 0.037, which we rescale to
    our best value B(D_s^+ \rightarrow \phi \pi^+) = 4.5 \times 10<sup>-2</sup>.
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 6 BORTOLETTO 90 assume B($D_S
ightarrow \, \phi \pi^+$) = 2%.

| $\left[\Gamma(D_s^+ \pi^-) + \Gamma(D_s^- K^+) \right] / \Gamma_{\text{total}} $ $\left(\Gamma_{100} + \Gamma_{110} \right) / \Gamma$ | $\Gamma(D_s^+ a_1(1260)^-)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{106}$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALUE CL% DOCUMENT ID TECN COMMENT | VALUE CL% DOCUMENT ID TECN COMMENT |
| <1.0 × 10⁻³ 90 1 ALBRECHT 93E ARG $e^+e^- \rightarrow \Upsilon(4S)$ 1 ALBRECHT 93E reports $< 1.7 \times 10^{-3}$ from a measurement of $\left[\left[\Gamma(B^0 \rightarrow D_s^+\pi^-) + \Gamma(B^0 \rightarrow D_s^-K^+)\right]/\Gamma_{\text{total}}\right] \times \left[B(D_s^+ \rightarrow \phi\pi^+)\right]$ assuming $B(D_s^+ \rightarrow \phi\pi^+) = 0.027$, which we rescale to our best value $B(D_s^+ \rightarrow \phi\pi^+) = 4.5 \times 10^{-2}$. | <2.1 × 10⁻³ 90 1 ALBRECHT 93E ARG $e^+e^- \rightarrow \Upsilon(4.5)$ 1 ALBRECHT 93E reports $< 3.5 \times 10^{-3}$ from a measurement of $[\Gamma(B^0 D_S^+ a_1(1260)^-)/\Gamma_{\text{total}}] \times [B(D_S^+ \rightarrow \phi \pi^+)]$ assuming $B(D_S^+ \rightarrow \phi \pi^+) = 0.02$ which we rescale to our best value $B(D_S^+ \rightarrow \phi \pi^+) = 4.5 \times 10^{-2}$. |
| $\Gamma(D_s^{*+}\pi^-)/\Gamma_{\text{total}}$ | $\Gamma(D_s^{*+}a_1(1260)^-)/\Gamma_{\text{total}}$ $\Gamma_{107/}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 2.9 \pm 0.7 \pm 0.3 | $\Gamma(D_s^+ a_2^-)/\Gamma_{total}$ $\Gamma_{108}/\Gamma_{total}$ Γ_{total} Γ_{to |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 AUBERT 07K reports [$\Gamma(B^0\to D_c^{*+}\pi^-)/\Gamma_{\rm total}]\times [B(D_c^+\to\phi\pi^+)]=(1.32\pm0.27\pm0.27\pm0.27)$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $0.15) \times 10^{-6}$ which we divide by our best value B($D_s^+ \to \phi \pi^+$) = $(4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(D_s^{*+}a_2^-)/\Gamma_{total}$ $\Gamma_{109}/\Gamma_{total}$ |
| 3 ALEXANDER 93B reports $<44\times10^{-5}$ from a measurement of $[\Gamma(B^0\to D_S^{*+}\pi^-)/\Gamma_{\rm total}]\times [B(D_S^+\to \phi\pi^+)]$ assuming $B(D_S^+\to \phi\pi^+)=0.037$, which we rescale to | |
| our best value $B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$. $ \Gamma(D_s^{*+} \pi^-) + \Gamma(D_s^{*-} K^+) / \Gamma_{\text{total}} $ | $\Gamma(D_s^-K^+)/\Gamma_{total}$ $\Gamma_{110}/\Gamma_{total}$ $\Gamma_{110}/\Gamma_{total}$ Γ_{total} |
| ALUE CL% DOCUMENT ID TECN COMMENT (7×10^{-4}) $(7 \times 10^{-$ | 22 \pm 5 OUR AVERAGE Error includes scale factor of 1.8. 19.1 \pm 2.4 \pm 1.7 1 DAS 10 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 29 \pm 4 \pm 2 1 AUBERT 08AJ BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • 27 \pm 5 \pm 2 2 AUBERT 07K BABR Repl. by AUBERT 08 26 \pm 10 \pm 2 3 AUBERT 03D BABR Repl. by AUBERT 07 36 \pm 11 \pm 3 4 KROKOVNY 02 BELL Repl. by DAS 10 |
| $\Gamma(D_s^+ ho^-)/\Gamma_{total}$ $\Gamma_{102}/\Gamma_{total}$ | $<$ 190 90 5 ALEXANDER 93B CLE2 $e^{+}e^{-} \rightarrow r$ (4 <i>S</i>) $<$ 1300 90 6 BORTOLETTO90 CLEO $e^{+}e^{-} \rightarrow r$ (4 <i>S</i>) |
| • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 AUBERT 07K reports $[\Gamma(B^0\to D_s^-K^+)/\Gamma_{\rm total}]\times [B(D_s^+\to\phi\pi^+)]=(1.21\pm0.17$ 0.11) $\times10^{-6}$ which we divide by our best value $B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^-$ Our first error is their experiment's error and our second error is the systematic error using our best value. 3 AUBERT 03D reports $[\Gamma(B^0\to D_s^-K^+)/\Gamma_{\rm total}]\times [B(D_s^+\to\phi\pi^+)]=(1.16\pm0.36$ 0.24) $\times10^{-6}$ which we divide by our best value $B(D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^-$ Our first error is their experiment's error and our second error is the systematic error musing our best value. 4 KROKOVNY 02 reports $[\Gamma(B^0\to D_s^-K^+)/\Gamma_{\rm total}]\times [B(D_s^+\to\phi\pi^+)]$ $(1.61\pm0.45\pm0.21)\times10^{-6}$ which we divide by our best value $B(D_s^+\to\phi\pi^+)$ $(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error the systematic error from using our best value. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | ⁵ ALEXANDER 93B reports $<$ 330 \times 10 ⁻⁶ from a measurement of [Γ($B^0 \to D_s^- K^+$ Γ _{total}] \times [B($D_s^+ \to \phi \pi^+$)] assuming B($D_s^+ \to \phi \pi^+$) = 0.037, which we rescale our best value B($D_s^+ \to \phi \pi^+$) = 4.5 \times 10 ⁻² . ⁶ BORTOLETTO 90 assume B($D_s \to \phi \pi^+$) = 2%. |
| • • We do not use the following data for averages, fits, limits, etc. • • • $<$ 150 90 2 ALBRECHT 93E ARG $e^+e^- \rightarrow r(4S)$ $<$ 60 90 3 ALEXANDER 93B CLE2 $e^+e^- \rightarrow r(4S)$ | $\Gamma(D_s^{*-}K^+)/\Gamma_{total}$ VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 ALBRECHT 93E reports $<2.5\times10^{-3}$ from a measurement of $[\Gamma(B^0\to D_S^{*+}\rho^-)/\Gamma_{\rm total}]\times[B(D_S^+\to \phi\pi^+)]$ assuming $B(D_S^+\to \phi\pi^+)=0.027$, which we rescale to | 2.19±0.30 OUR AVERAGE 2.02±0.33±0.22 1 JOSHI 10 BELL $e^+e^- \rightarrow r(4S)$ 2.4 ±0.4 ±0.2 1 AUBERT 08AJ BABR $e^+e^- \rightarrow r(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • |
| our best value $\bar{\mathrm{B}}(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$. 3 ALEXANDER 93B reports $< 7.4 \times 10^{-4}$ from a measurement of $[\Gamma(B^0 \to D_s^{*+} \rho^-)/\Gamma_{\mathrm{total}}] \times [\mathrm{B}(D_s^+ \to \phi \pi^+)]$ assuming $\mathrm{B}(D_s^+ \to \phi \pi^+) = 0.037$, which we rescale to our best value $\mathrm{B}(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$. | 2.2 \pm 0.6 \pm 0.2 2 AUBERT 07K BABR Repl. by AUBERT 08 < 2.5 90 AUBERT 03D BABR Repl. by AUBERT 07K SAUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBERT 08 AUBE |
| our best value $B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$. $\Gamma(D_s^+ a_0^-) / \Gamma_{total} \qquad \qquad \Gamma_{104} / \Gamma$ | Assumes equal production of B and B at the $I(45)$, 2 AUBERT 07K reports $[\Gamma(B^0 \to D_s^+ - K^+)/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] = (0.97 \pm 0.24 + 0.12) \times 10^{-6}$ which we divide by our best value $B(D_s^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-6}$. Our first error is their experiment's error and our second error is the systematic error. |

 Γ_{105}/Γ

 $\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)]$ assuming $B(D_s^+ \to \phi \pi^+) = 0.037$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$.

 1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^0 at the \varUpsilon (45).

90

1 AUBERT

 $\Gamma(D_s^{*+}a_0^-)/\Gamma_{\mathrm{total}}$

| $\Gamma(D_s^-K^*(892)^+)/\Gamma_{\text{total}}$ | | Γ_{112}/Γ | $\Gamma(\overline{D}^0 K^+ \pi^-)/\Gamma_{\text{total}}$ | | | | | Γ ₁₁₉ /Ι |
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| VALUE (units 10 ⁻⁵) CL% | 1 AUDERT ON BARR of a | 27(4.5) | <u>VALUE (units 10^{−6})</u> 88 ± 15 ± 9 | | DOCUMENT ID AUBERT | | $e^+e^- \rightarrow$ | Υ(45) |
| -0.9 | ¹ AUBERT 08AJ BABR $e^+e^- \rightarrow$ data for averages, fits, limits, etc. • • | T(45) | ¹ Assumes equal produ | | | | | , (10) |
| - | ² ALBRECHT 93E ARG $e^+e^- \rightarrow$ | T(45) | $\Gamma(\overline{D}^0 K^*(892)^0)/\Gamma_{to}$ | da. | | | | Γ ₁₂₀ /Ι |
| < 80 90 | 3 ALEXANDER 93B CLE2 $e^+e^- ightarrow$ | | VALUE (units 10 ⁻⁵) | DO | OCUMENT ID | TECN CO | OMMENT | - 1207 |
| ALBRECHT 025 reserve | | - | 4.2±0.6 OUR AVERAGE | | UBERT,B (|)6L BABR e ⁻ | + o= . ~(| 4.6) |
| | $4.6 	imes 10^{-3}$ from a measurement of $D_S^+ 	o \phi \pi^+)]$ assuming ${\sf B}(D_S^+ 	o \phi \pi^+)$ | | $4.0 \pm 0.7 \pm 0.3$ $4.8 + 1.1 \pm 0.5$ | | ROKOVNY (| | , | . , |
| which we rescale to our best val | lue B($D_s^+ \to \phi \pi^+$) = 4.5 × 10 ⁻² . | . , = 0.02., | • • • We do not use th | | | | , | ,43) |
| ³ ALEXANDER 93B reports < | $9.7 	imes 10^{-4}$ from a measurement of | of $[\Gamma(B^0 \rightarrow$ | $5.7\!\pm\!0.9\!\pm\!0.6$ | | |)6A BABR R | | ERT,B 06L |
| | $D_s^+ 	o \phi \pi^+)]$ assuming $B(D_s^+ 	o \phi \pi)$ | $\tau^{+}) = 0.037,$ | $^{ m 1}$ Assumes equal produ | uction of B^+ | \vdash and B^0 at th | e Υ(45). | | |
| which we rescale to our best val | lue B($D_S^+ \to \phi \pi^+$) = 4.5 × 10 ⁻² . | | $\Gamma(D_2^*(2460)^-K^+\times 1)$ | B(D*(2460 | $(D)^- \rightarrow \overline{D}{}^0 \pi^-$ | -))/Γ _{total} | | Γ ₁₂₁ / |
| $\Gamma(D_s^{*-}K^*(892)^+)/\Gamma_{\text{total}}$ | | Γ ₁₁₃ /Γ | VALUE (units 10 ⁻⁶) | | DOCUMENT ID AUBERT | 06A BABR | COMMENT | |
| VALUE (units 10 ⁻⁵) <u>CL%</u> | DOCUMENT ID TECN COMMENT | | 18.3±4.0±3.1 | | | | $e^+e^ \rightarrow$ | Y(45) |
| $3.2^{+1.4}_{-1.2}\pm0.4$ | 1 AUBERT 08AJ BABR $e^{+}e^{-} ightarrow$ | Y(45) | ¹ Assumes equal produ | | | e Υ(4S). | | |
| | data for averages, fits, limits, etc. • • • | | $\Gamma(\overline{D}{}^0K^+\pi^-$ non-reso | | | | | Γ ₁₂₂ / |
| | 2 ALBRECHT 93E ARG $e^+e^- \rightarrow$ 3 ALEXANDER 93B CLE2 $e^+e^- \rightarrow$ | | VALUE (units 10 ⁻⁶) | | DOCUMENT ID AUBERT | 06A BABR | | Υ(4 C) |
| $<$ 90 90 $^{-1}$ Assumes equal production of B^- | | . (45) | <37 1 Assumes equal produ | | | | e · e → | 1 (43) |
| ² ALBRECHT 93E reports < | $5.8 	imes 10^{-3}$ from a measurement of | | · | action of D | and D at th | c / (40). | | r . |
| $D_s^{*-} K^*(892)^+)/\Gamma_{total}] \times [B($ | $(D_s^+ 	o \phi \pi^+)$] assuming $B(D_s^+ 	o \phi \pi^+)$ | $\pi^+) = 0.027,$ | $\Gamma(\overline{D}{}^0\pi^0)/\Gamma_{	ext{total}}$ VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TECN | COMMENT | Г ₁₂₃ / |
| which we rescale to our best val | lue B($D_s^+ \to \phi \pi^+$) = 4.5 × 10 ⁻² . | | 2.63±0.14 OUR AVE | RAGE | | TECN | COMMENT | |
| D*- K*(892)+)/F 1 > FR/ | 11.0×10^{-4} from a measurement $(D_S^+ 	o \phi \pi^+)$] assuming B $(D_S^+ 	o \phi \pi^+)$ | or [ι(Β° → π ⁺) = 0.037 | $2.69 \pm 0.09 \pm 0.13$ $2.25 \pm 0.14 \pm 0.35$ | | ^l LEES ^l BLYTH | 11M BABR 06 BELL | $e^+e^- \rightarrow e^+e^- \rightarrow$ | . , |
| which we rescale to our best val | lue B($D_s^+ 	o \phi \pi^+$) = 4.5 \times 10 ⁻² . |) = 0.037, | $2.25 \pm 0.14 \pm 0.35$ $2.74 + 0.36 \pm 0.55$ | | COAN | 00 BELL 02 CLE2 | | |
| | S , , X 20 | | • • • We do not use th | | | | | , (40) |
| $\Gamma(D_s^-\pi^+K^0)/\Gamma_{\text{total}}$ | DO CUMENT ID | Γ ₁₁₄ /Γ | $2.9 \ \pm 0.2 \ \pm 0.3$ | 1 | AUBERT | 04B BABR | Repl. by LE | EES 11M |
| ALUE (units 10 ⁻⁴) CL% 1.10±0.26±0.20 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Υ(4.5) | $3.1 \pm 0.4 \pm 0.5$ < 1.2 | | L _{ABE} 2 NEMATI | 02J BELL 98 CLE2 | Repl. by Bl Repl. by Co | |
| | data for averages, fits, limits, etc. • • • | . (+5) | <1.2 <4.8 | | ALAM | | Repl. by N | |
| $\frac{1}{2}$ Assumes equal production of B^{-2} | $^+$ and B^0 at the \varUpsilon (45). × 10^{-3} from a measurement of [$\Gamma(B^0 ightarrow$ | $D_{s}^{-}\pi^{+}\kappa^{0})/$ | ² NEMATI 98 assumes values for D^0 , D^{*0} , | η , η' , and ω | branching fra | ctions. | | the CLEO |
| | ssuming B($D_S^+ 	o \phi \pi^+) =$ 0.027, which | | 3 ALAM 94 assume example B($D^0 ightarrow K$ and B($D^0 ightarrow K^-$ 2: | $(-\pi^+)$ and t | the PDG 1992 E | $B(D^0 \rightarrow K^-\pi)$ | $+ \pi^{0})/B(D^{0}$ | $\rightarrow K^-\pi^+$ |
| $\Gamma_{total}] \times [B(D_{S}^+ \to \phi \pi^+)] \text{ as }$ our best value $B(D_{S}^+ \to \phi \pi^+)$ | ssuming B($D_S^+ 	o \phi \pi^+) =$ 0.027, which | we rescale to | absolute B($D^0 	o K$ | $(-\pi^+)$ and t | the PDG 1992 E | $B(D^0 \rightarrow K^-\pi)$ | $^{+}\pi^{0})/B(D^{0}$ | Γ_{124} |
| $\Gamma_{	ext{total}} \times [B(D_s^+ 	o \phi \pi^+)] 	ext{ as our best value } B(D_s^+ 	o \phi \pi^+)$ $\Gamma(D_s^{*-} \pi^+ K^0) / \Gamma_{	ext{total}}$ | ssuming B($D_S^+ 	o \phi \pi^+) =$ 0.027, which | | absolute B($D^0 	o K$ and B($D^0 	o K^- 2$ $\Gamma(\overline{D}{}^0 \rho^0)/\Gamma_{\text{total}}$ <u>VALUE (units 10⁻⁴)</u> | (- π ⁺) and t (π ⁺ π ⁻)/B(I <u>CL%</u> | the PDG 1992 E $D^0	o K^-\pi^+$ | $B(D^0 \to K^- \pi^-)$. | -+ π ⁰)/B(D ⁰ | ⁰ → κ ⁻ π ⁺ |
| $ \begin{array}{ll} \Gamma_{\rm total}] \times [{\rm B}(D_s^+ \to \phi \pi^+)] \ {\rm as} \\ {\rm our \ best \ value \ B}(D_s^+ \to \phi \pi^+) \\ \hline \Gamma \big(D_s^{\star-} \pi^+ K^0\big) / \Gamma_{\rm total} \\ {\scriptstyle VALUE \ (units \ 10^{-4})} & \underline{CL\%} \\ < 1.10 & 90 \end{array} $ | ssuming B($D_s^+ 	o \phi \pi^+$) = 0.027, which $\phi = 4.5 \times 10^{-2}$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad \frac{TECN}{0.00000000000000000000000000000000000$ | we rescale to Γ ₁₁₅ /Γ | absolute B($D^0 \rightarrow K$ and B($D^0 \rightarrow K-2$) $\Gamma(\overline{D^0}\rho^0)/\Gamma_{\text{total}}$ $\frac{NALUE \text{ (units }10^{-4}\text{)}}{3.19\pm0.20\pm0.45}$ | $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ $(\pi^+\pi^-)$ | the PDG 1992 E $D^0 	o K^-\pi^+$ $\frac{DOCUMENT~ID}{2}$ KUZMIN | $\frac{3(D^0 \to K^- \pi)}{07}$ $\frac{TECN}{BELL}$ | $(+\pi^0)/B(D^0)$ $\frac{COMMENT}{e^+e^-} \rightarrow$ | ⁰ → κ ⁻ π ⁺ |
| $ \begin{array}{lll} & \Gamma_{\rm total}] \times [{\rm B}(D_s^+ \to \phi \pi^+)] \ {\rm as} \\ & {\rm our \ best \ value \ B}(D_s^+ \to \phi \pi^+) \\ & \Gamma \Big(D_s^{\star-} \pi^+ K^0\Big) / \Gamma_{\rm total} \\ & \frac{{\rm VALUE \ (units \ 10^{-4})}}{90} & \frac{{\rm CL\%}}{90} \\ & \bullet \bullet \bullet \ {\rm We \ do \ not \ use \ the \ following} \end{array} $ | ssuming B($D_s^+ \to \phi \pi^+$) = 0.027, which $\phi = 4.5 \times 10^{-2}$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad \frac{TECN}{086\ BABR} \qquad \frac{COMMENT}{e^+e^- \to 0}$ data for averages, fits, limits, etc. • • • | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ | absolute B($D^0 	o K$ and B($D^0 	o K^- 2$ $\Gamma(\overline{D}{}^0 \rho^0)/\Gamma_{\text{total}}$ <u>VALUE (units 10⁻⁴)</u> | $(-\pi^+)$ and the $(\pi^+\pi^-)$ /B($(\pi^+\pi^-)$) /B($(\pi^+\pi^-)$) /B($(\pi^+\pi^-)$) /B($(\pi^+\pi^-)$) and the $(\pi^+\pi^-)$ /B($(\pi^+\pi^-)$) /B(| the PDG 1992 E $D^0 	o K^-\pi^+$ $\frac{DOCUMENT~ID}{2}$ KUZMIN | $B(D^0 \to K^-\pi^-)$. TECN 07 BELL es, fits, limits, | $(+\pi^0)/B(D^0)$ $\frac{COMMENT}{e^+e^-} \rightarrow$ | $ \begin{array}{c} \Gamma_{124}/\\ \hline \Gamma_{(45)} \end{array} $ |
| | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $0 = 4.5 \times 10^{-2}$. $\frac{DOCUMENT\ ID}{1}$ AUBERT 08G BABR $e^+e^- \to 0$ data for averages, fits, limits, etc. • • • $0 \to 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ | absolute B($D^0 	o K$ and B($D^0 	o K^- 2$) $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-4})}{3.19 \pm 0.20 \pm 0.45}$ • • We do not use th 2.9 $\pm 1.0 \pm 0.4$ < 3.9 | $(-\pi^+)$ and the $(\pi^+\pi^-)/B(\mu^-)$ are following to $(\pi^+\pi^-)/B(\mu^-)$ and $(\pi^+\pi^-)/B(\mu^-)$ and $(\pi^+\pi^-)/B(\mu^-)$ are $(\pi^+\pi^-)/B(\mu^-)$ and | the PDG 1992 ED $^0 ightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2} KUZMIN$ data for averag SATPATHY | $B(D^0 \rightarrow K^-\pi^-)$. TECN 07 BELL es, fits, limits, 03 BELL 98 CLE2 | $\begin{array}{c} (-1)^{+} + \pi^{0})/B(D^{0}) \\ \hline (-1)^{-} + e^{-} \rightarrow \\ (-1)^{-} + e^$ | $0 ightarrow \kappa^- \pi^+ $ $\Gamma_{124}/$ $T(4S)$ UZMIN 07 $T(4S)$ |
| $ \begin{array}{lll} \Gamma_{\rm total}] \times [{\rm B}(D_s^+ \to \phi \pi^+)] \ {\rm as} \\ \ {\rm our} \ {\rm best} \ {\rm value} \ {\rm B}(D_s^+ \to \phi \pi^+)] \ {\rm as} \\ \ {\rm our} \ {\rm best} \ {\rm value} \ {\rm B}(D_s^+ \to \phi \pi^+)] \ {\rm as} \\ \ \Gamma\left(D_s^{*-}\pi^+ K^0\right)/\Gamma_{\rm total} \\ \ {\rm val} \ {\rm val} \ {\rm UE} \ ({\rm units} \ 10^{-4}) & {\rm CL\%} \\ \ {\rm < 1.10} & 90 \\ \ {\rm • \bullet \bullet } \ {\rm We} \ {\rm do \ not \ use \ the \ following} \\ \ {\rm < 25} & 90 \\ \ {\rm ^1Assumes \ equal \ production \ of \ } B^- \\ \ {\rm ^2ALBRECHT} \ {\rm 93E \ reports} \ {\rm < 4.2 \times 4.2 \times 4.2 \times 10^{-10}} \\ \ \ {\rm < 1.20} \\ \ \ {\rm < 1.20} \\ \ \ {\rm < 1.20} \\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $0 = 4.5 \times 10^{-2}$. $\frac{DOCUMENT\ ID}{1}$ AUBERT 08G BABR $e^+e^- \to 0$ data for averages, fits, limits, etc. • • • • $\frac{2}{1}$ ALBRECHT 93E ARG $e^+e^- \to 0$ and e^0 at the e^0 (45). e^0 (10) a measurement of e^0 (10) | we rescale to $\frac{\Gamma_{115}/\Gamma}{r(4s)}$ $\frac{r(4s)}{s^{*-}\pi^{+}\kappa^{0}}/$ | absolute B($D^0 \rightarrow K$ and B($D^0 \rightarrow K-2$) $\Gamma(\overline{D^0}\rho^0)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-4}\text{)}}{3.19\pm0.20\pm0.45}$ • • We do not use th 2.9 ±1.0 ±0.4 | $(T-\pi^+)$ and the $(T-\pi^+)$ and the $(T-\pi^+)$ | the PDG 1992 E $D^0 	o K^-\pi^+$ $\frac{DOCUMENT\ ID}{2} KUZMIN$ data for averag | $B(D^0 \rightarrow K^-\pi^-)$. TECN 07 BELL es, fits, limits, 03 BELL 98 CLE2 94 CLE2 | $\begin{array}{c} (-1.5) + \pi^{0} / \text{B} (D^{0}) | $0 \rightarrow \kappa^- \pi^+$ $\frac{\Gamma_{124}/\Gamma_{124}}{\Gamma_{124}/\Gamma_{124}}$ UZMIN 07 $\frac{\Gamma_{124}/\Gamma_{124}}{\Gamma_{124}/\Gamma_{124}}$ EMATI 98 |
| $\Gamma_{	ext{total}}] 	imes [B(D_S^+ 	o \phi \pi^+)]$ as our best value $B(D_S^+ 	o \phi \pi^+)]$ as our best value $B(D_S^+ 	o \phi \pi^+)$ $\Gamma(D_S^{*-}\pi^+ K^0)/\Gamma_{	ext{total}}$ $CL\%$ $< 1.10 	ext{2} 	ext{90}$ $< 1.40 	ext{90}$ $< 25 	ext{90}$ 1 Assumes equal production of $B^ ^2$ ALBRECHT 93E reports $< 4.2 	imes \Gamma_{	ext{total}}] 	imes [B(D_S^+ 	o \phi \pi^+)]$ as | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{cccc} & & & & & & \\ DOCUMENT & 1D & & & & \\ \hline & 1 & AUBERT & 086 & BABR & e^+e^- \to \\ & & & & \\ data & for averages, fits, limits, etc. & \bullet & \bullet \\ & 2 & ALBRECHT & 93E & ARG & e^+e^- \to \\ & + & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ 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| $ \begin{split} &\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ as } \\ &\text{our best value } B(D_s^+ \to \phi \pi^+) \\ &\Gamma(D_s^{\bullet-} \pi^+ K^0) / \Gamma_{\text{total}} \\ &\frac{CL\%}{C} \\ &< 1.10 & 90 \\ &\bullet \bullet \bullet \text{ We do not use the following} \\ &< 25 & 90 \\ &^1 \text{ Assumes equal production of } B^- \\ &^2 \text{ ALBRECHT 93E reports} < 4.2 \times \\ &\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] \text{ as } \\ &\text{our best value } B(D_s^+ \to \phi \pi^+) \end{aligned} $ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{cccc} & & & & & & \\ DOCUMENT & 1D & & & & \\ \hline & 1 & AUBERT & 086 & BABR & e^+e^- \to \\ & & & & \\ data & for averages, fits, limits, etc. & \bullet & \bullet \\ & 2 & ALBRECHT & 93E & ARG & e^+e^- \to \\ & + & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & \\ & & & \\ & & & \\ $ | we rescale to $\frac{\Gamma_{115}/\Gamma}{r(4s)}$ $\frac{r(4s)}{s^{*-}\pi^{+}\kappa^{0}}/$ | absolute $B(D^0 \to K \text{ and } B(D^0 \to K - 2)]$ $\Gamma(\overline{D^0} \rho^0) / \Gamma_{\text{total}}$ $MLUE \text{ (units } 10^{-4})$ $3.19 \pm 0.20 \pm 0.45$ • • • We do not use th $2.9 \pm 1.0 \pm 0.4$ < 3.9 < 5.5 < 6.0 < 27.0 1 Assumes equal produ 2 Our second uncertain 3 NEMATI 98 assumes | $(-\pi^+)$ and the $(\pi^+\pi^-)/B(i$ $(\pi^+\pi^-)/B($ | the PDG 1992 ED 00 \rightarrow $K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average LSATPATHY BORTOLETT $\stackrel{1}{\rightarrow}$ ALAM $\stackrel{1}{\rightarrow}$ BORTOLETT $\stackrel{1}{\rightarrow}$ ALBRECHT $\stackrel{1}{\rightarrow}$ and $\stackrel{1}{\rightarrow}$ 0 at systematics a section of B^+ as a section of B^+ as a section of B^+ as | $3(D^0 \rightarrow K^-\pi^-)$. 7 ECN 07 BELL es, fits, limits, 03 BELL 98 CLE2 94 CLE2 692 CLE0 88K ARG e $\Upsilon(4S)$. nd model error nd B^0 at the Υ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \end{array}$ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+ \\ \hline \Gamma_{124}/ \\ \hline \Gamma_{(4S)} \\ \\ \text{UZMIN 07} \\ \Gamma_{(4S)} \\ \text{EMATI 98} \\ \Gamma_{(4S)} \\ \Gamma_{(4S)} \\ \end{array}$ |
| $ \Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)] \text{ as } \\ \text{our best value } B(D_s^+ \to \phi \pi^+)] \text{ as } \\ Our best value B(D_s^+ \to \phi \pi^+)] \\ F(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}} \\ \frac{CL\%}{C} \times CL\% \\ C1.10 \qquad 90 \\ \bullet \bullet \bullet \text{ We do not use the following} \\ < 25 \qquad 90 \\ 1 \text{ Assumes equal production of } B^- \\ 2 \text{ ALBRECHT 93E reports } < 4.2 \times \\ \Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)] \text{ as } \\ our best value B(D_s^+ \to \phi \pi^+) \\ F(D_s^- \pi^+ K^*(892)^0)/\Gamma_{\text{total}} $ | ssuming $B(D_S^+ \to \phi \pi^+) = 0.027$, which $A_S^+ = 0.027$, which A | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\frac{\Upsilon(4S)}{S} = \frac{\Gamma(4S)}{S}$ $\frac{\Gamma(4S)}{S} = \frac{\Gamma(4S)}{S}$ we rescale to $\frac{\Gamma_{116}/\Gamma}{\Gamma(4S)}$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{total}$ $\frac{NALUE (units 10^{-4})}{3.19 \pm 0.20 \pm 0.45} • • • We do not use th 2.9 \pm 1.0 \pm 0.4 < 3.9 < 5.5 < 6.0 < 27.0 1 \text{ Assumes equal produ} 2 Our second uncertail 3 NEMATI 98 assumes values for D^0. 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TECN 07 BELL es, fits, limits, 03 BELL 98 CLE2 94 CLE2 692 CLEO 88K ARG e $\Upsilon(4S)$. nd model error at B^0 at the Υ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{(4S) and use} \end{array}$ | $0 \rightarrow K^-\pi^+$ $ \Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124$ |
| $ \begin{array}{c c} \Gamma_{\rm total} \times [{\rm B}(D_S^+ \to \phi \pi^+)] \text{ as } \\ \text{our best value B}(D_S^+ \to \phi \pi^+) \\ \hline \Gamma(D_S^{*-} \pi^+ K^0) / \Gamma_{\rm total} \\ \hline \times 1.10 & 90 \\ < 1.10 & 90 \\ < \cdot \bullet & \text{We do not use the following} \\ < 25 & 90 \\ \hline {}^1 \text{Assumes equal production of } B^- \\ {}^2 \text{ALBRECHT 93E reports} < 4.2 \times \\ \Gamma_{\rm total} \times [{\rm B}(D_S^+ \to \phi \pi^+)] \text{ as our best value B}(D_S^+ \to \phi \pi^+) \\ \hline \Gamma(D_S^- \pi^+ K^* (892)^0) / \Gamma_{\rm total} \\ \hline \times 1.00 \times 10^{-3} & 90 \\ \hline \end{array} $ | suming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$. Since $B_s = 0.027$, which $A_s = 0.$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\frac{\Upsilon(4S)}{S}$ $\frac{T(4S)}{S}$ we rescale to $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0}p^0)/\Gamma_{\text{total}}$ $\frac{NALUE \text{ (units }10^{-4}\text{)}}{3.19\pm0.20\pm0.45}$ • • • We do not use th $2.9 \pm 1.0 \pm 0.4$ < 3.9 < 5.5 < 6.0 < 27.0 ¹ Assumes equal produces a sum of the sum of | $(-\pi^+)$ and the $(\pi^+\pi^-)/B(i)$ is following to $(\pi^+\pi^-)/B(i)$ in $(\pi^+\pi^-)/B(i)$ in $(\pi^+\pi^-)/B(i)$ in $(\pi^+\pi^-)/B(i)$ in $(\pi^+\pi^-)/B(i)$ and $(\pi^+\pi^-)/B(i)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for averag $\frac{1}{3}$ SATPATHY $\frac{3}{4}$ NEMATI $\frac{1}{4}$ ALAM $\frac{5}{4}$ BORTOLETT $\frac{5}{4}$ ALBRECHT $\frac{1}{4}$ and $\frac{1}{4}$ and $\frac{1}{4}$ at the systematics a action of B^+ and B^0 at the systematics a function of B^+ and B^0 at the systematics a function of B^+ and B^0 branching fra the PDG 1992 E B^+ and the PDG 1992 E | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{(4S) and use} \end{array}$ | $0 \rightarrow K^-\pi^+$ $ \Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124$ |
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| $ \begin{array}{ll} \Gamma_{\rm total}] \times [{\rm B}(D_S^+ \to \phi \pi^+)] \ {\rm as} \\ \ {\rm our \ best \ value \ B}(D_S^+ \to \phi \pi^+)] \ {\rm as} \\ \ {\rm our \ best \ value \ B}(D_S^+ \to \phi \pi^+) \\ \hline -(D_S^* - \pi^+ K^0)/\Gamma_{\rm total} \\ \times 1.10 & 90 \\ \times 2 \times 1.10 $ | suming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$. Since $B_s = 0.027$, which $A_s = 0.$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ of $\Gamma(B^0 \rightarrow \pi^+) = 0.027$, | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0}p^0)/\Gamma_{\text{total}}$ $\underline{MALUE (units 10^{-4})} 3.19\pm0.20\pm0.45 • • • We do not use th 2.9 \pm1.0 \pm0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the second uncertain of the se$ | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(i)$ $(-\frac{CL\%}{\pi^+\pi^-})/B(i)$ The following of the following | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $DOCUMENT\ ID$ $C^2 KUZMIN$ data for average $C^3 KUZMIN$ $C^3 $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\frac{COMMENT}{e^+e^-} \rightarrow \text{etc.} \bullet \bullet \bullet$ Repl. by KI $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- ^- \rightarrow e^-e^- \rightarrow e^-$ | $0 \rightarrow K^-\pi^+$ $\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}$ $\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{$ |
| $\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ ($D_s^+ \to \Phi^+$) (| ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$. Since $B_s = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ we rescale to $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \rightarrow \pi^+) = 0.027$, Γ_{117}/Γ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{total}$ $\underline{MLUE (units 10^{-4})} 3.19\pm0.20\pm0.45 • • • We do not use th 2.9 \pm1.0 \pm0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the same of$ | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(i)$ $(-\frac{CL\%}{\pi^+\pi^-})/B(i)$ The following of the following | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $DOCUMENT\ ID$ $C^2 KUZMIN$ data for average $C^3 KUZMIN$ $C^3 $ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\frac{COMMENT}{e^+e^-} \rightarrow \text{etc.} \bullet \bullet \bullet$ Repl. by KI $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- ^- \rightarrow e^-e^- \rightarrow e^-$ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ \hline \Gamma_{124}/\\ |
| $\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ ($D_s^+ \to \Phi^+$) (| ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$. Since $B_s = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ we rescale to $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \rightarrow \pi^+) = 0.027$, Γ_{117}/Γ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $\underline{MALUE (units 10^{-4})} 3.19\pm0.20\pm0.45 • • • We do not use th 2.9 \pm1.0 \pm0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the sum of the s$ | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(i)$ $(-\frac{CL\%}{\pi^+\pi^-})/B(i)$ The following of the following | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average 4 SATPATHY 8 NEMATI 4 ALAM 5 BORTOLETT 5 ALBRECHT + and B^0 at the systematics a function of B^+ and the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ ual production to D^0 as assuming D^0 3 assuming D^0 3 assuming D^0 3 assuming D^0 | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi). \\ \hline & 7ECN \\ \hline 07 & BELL \\ \text{es, fits, limits,} \\ 98 & \text{CLE2} \\ 94 & \text{CLE2} \\ \text{TO92} & \text{CLEO} \\ 88K & \text{ARG} \\ \text{e} & \Upsilon(45). \\ \text{nd model error} \\ \text{nd model error} \\ \text{d} & B^0 \text{ at the } \Upsilon(50). \\ \text{d} & \text{Exp} & \text{Color} \\ \text{ether} & T(10). \\ \text{ether} & T(1$ | $+\pi^0)/B(D^0)$ $\frac{COMMENT}{e^+e^-} \rightarrow \text{etc.} \bullet \bullet \bullet$ Repl. by KI $e^+e^- \rightarrow \text{Repl.}$ by NI $e^+e^- \rightarrow \text{c}^+e^- \rightarrow \text{s}^-$ s quoted in the $\Gamma(4S)$ and use $\pi^0/B(D^0)$ at the $T(4S)$ and use $\pi^0/B(D^0)$ | $0 \rightarrow K^-\pi^+$ $ \Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124}/\Gamma_{124$ |
| $\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ $\Gamma(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}} \times (1.10) = 0$ 0 0 0 0 0 0 0 0 0 | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $\frac{\Gamma_{14S}}{\Gamma(4S)}$ $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$, $\frac{\Gamma_{117}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{total}$ $\underline{MLUE (units 10^{-4})} 3.19\pm0.20\pm0.45 • • • We do not use th 2.9 \pm1.0 \pm0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the same of$ | $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ $(-\pi^+)$ $(-\pi^+)$ $(-\pi^+)$ and the $(-\pi^+\pi^-)$ $(-\pi^+\pi^-)$ 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\frac{1}{2}(4S) & and use$ | $0 \rightarrow K^-\pi^+$ 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| $\Gamma_{\text{total}}] \times [B(D_S^+ \to \phi \pi^+)]$ as our best value $B(D_S^+ \to \phi \pi^+)]$ as our best value $B(D_S^+ \to \phi \pi^+)$ $\Gamma(D_S^* - \pi^+ K^0)/\Gamma_{\text{total}}$ $\times (LVE (\text{units } 10^{-4}))$ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $\frac{\Gamma_{14S}}{\Gamma(4S)}$ $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$, $\frac{\Gamma_{117}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{total}$ $\frac{NALUE (units 10^{-4})}{3.19 \pm 0.20 \pm 0.45} • • • We do not use th 2.9 \pm 1.0 \pm 0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the sum of the s$ | $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ $(-\pi^+)$ $(-\pi^+)$ and the $(-\pi^+\pi^-)$ $(-\pi^-\pi^-)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average $\frac{1}{2}$ SATPATHY $\frac{1}{3}$ NEMATI $\frac{1}{4}$ ALAM $\frac{1}{5}$ BORTOLETT $\frac{1}{5}$ ALBRECHT $\frac{1}{5}$ ALBRECHT $\frac{1}{5}$ and $\frac{1}{6}$ at the systematics a auction of B^+ and B^0 at the systematics a function of B^+ and B^0 at the pDG 1992 E $D^0 \rightarrow K^-\pi^+$ and production the PDG 3 assuming $B^0 \rightarrow K^-\pi^+$ and production $B^0 \rightarrow K^0 \rightarrow K^0$ and $B^0 \rightarrow K^0 \rightarrow K$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} (4S) & \text{And use} \\ +\pi^0)/B(D^0) \\ \hline \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} & \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \frac{1}{2}(4S) & \text{and use} \\ \frac{1}{2}(4S) & and use$ | $0 \rightarrow K^-\pi^+$ 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| $\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ ($D_s^* = \pi^+ K^0$)/ Γ_{total} ($D_s^* = \pi^+ K^0$)/ Γ_{total} ($D_s^* = 0$) $D_s^* = 0$ ($D_s^* = 0$)/ Γ_{total} ($D_s^* = 0$) ($D_s^* = 0$)/ Γ_{total} ($D_s^* = 0$)/ Γ_{total} ($D_s^* = 0$) ($D_s^* = 0$)/ Γ_{total} ($D_s^* = 0$) | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$. Simplifying the property of the | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $\frac{\Gamma_{14S}}{\Gamma(4S)}$ $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$, $\frac{\Gamma_{117}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{total}$ $2.9 \pm 1.0 \pm 0.4$ $3 \times 1.0 \pm 0.4$ $4 \times 1.0 \pm 0.4$ $5 \times 1.0 \pm 0.4$ $6 \times 1.0 \pm 0.4$ $1.0 \pm 0.18 \pm 0.38$ | $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ $(-\pi^+)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average 1 SATPATHY 3 NEMATI 4 ALAM 5 BORTOLETT 5 ALBRECHT 4 and B^0 at the systematics a lection of B^+ and b^0 pranching fraction of B^+ and the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ ual production the D . 03 assuming B | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} +\pi^0)/B(D^0) \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} & \bullet \bullet \bullet \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{f}(4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ of the } T(A) \\ \text{production rate} \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \hline \end{array}$ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ \hline \Gamma_{124}/\\ \hline \Gamma_{(4S)}\\ \hline \end{array}$ UZMIN 07 $\begin{array}{c} \gamma_{(4S)}\\ \gamma_{(4S)}\\ \gamma_{(4S)}\\ \gamma_{(4S)}\\ \gamma_{(4S)}\\ \end{array}$ the paper. e the PDG S the PDG S the CLEO $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ 4S) \text{ and use} \\ \hline \Gamma_{(4S)}\\ \hline \Gamma_{(4S)}\\ \hline \end{array}$ |
| $\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ ($(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}}$) $(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}}$ $(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}}$ $(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}}$ $(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}}$ $(D_s^* - \pi^+ K^0)$ as our best value $(D_s^+ \to \phi \pi^+)$ as our best value $(D_s^+ \to \phi \pi^+)$ $(D_s^- \pi^+ K^0)/\Gamma_{\text{total}}$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^- \to \Phi \pi^+)/\Gamma_{\text{total}}$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^- \to \Phi \pi^+)/\Gamma_{\text{total}}$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^- \to \Phi \pi^+)/\Gamma_{\text{total}}$ $(D_s^+ \to \Phi \pi^+)$ $(D_s^- \to \Phi \pi^+)/\Gamma_{\text{total}}$ $(D_s^+ \to \Phi \pi^+)$ $(D$ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(116/\Gamma)$ $T(4S)$ $T(117/\Gamma)$ $T(4S)$ $T($ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $2.9 \pm 1.0 \pm 0.4$ 2.9 ± 0.4 2.9 ± 0.4 4.1 ± 0.4 | $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ $(-\pi^+)$ $(-\pi^+)$ and the $(\pi^+\pi^-)$ $(-\pi^+)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average 1 SATPATHY 3 NEMATI 4 ALAM 5 BORTOLETT 5 ALBRECHT 4 and B^0 at the systematics a lection of B^+ and b^0 pranching fraction of B^+ and the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ ual production the D . 03 assuming B | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} +\pi^0)/B(D^0) \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} & \bullet \bullet \bullet \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{f}(4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ of the } T(A) \\ \text{production rate} \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \hline \end{array}$ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{125}/\\ |
| Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$) \sim 1.10 \sim • • We do not use the following \sim 2.5 90 \sim 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports $<$ 4.2 × Γ_{total}] × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] \sim 0.7 \sim 4.6 × 10 ⁻³ 90 \sim 1 ALBRECHT 93ε reports $<$ \sim | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $\Upsilon(4S)$ $\frac{\Gamma_{14S}}{\Gamma(4S)}$ $\frac{\Gamma_{116}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$, $\frac{\Gamma_{117}/\Gamma}{\Upsilon(4S)}$ of $\Gamma(B^0 \to \pi^+) = 0.027$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $2.9 \pm 1.0 \pm 0.4$ $3.9 + 0.5$ $4.0 + 0.5$ $2.9 + 0.5$ $2.9 + 0.5$ $4.0 + 0.5$ $2.9 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ 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| the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average 1 SATPATHY 3 NEMATI 4 ALAM 5 BORTOLETT 5 ALBRECHT 4 and B^0 at this systematics a suction of B^+ and B^0 by the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ ual production the D . 03 assuming B $\frac{DOCUMENT\ ID}{2}$ KUZMIN $\frac{DOCUMENT\ ID}{2}$ at this systematics a $\frac{DOCUMENT\ ID}{2}$ $\frac{DOCUMENT\ ID}{2}$ | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi \\ \hline & TECN \\ \hline & 07 & BELL \\ es, fits, limits, \\ 03 & BELL \\ 98 & CLE2 \\ 94 & CLE2 \\ \hline & 092 & CLE0 \\ 88K & ARG \\ e & \Upsilon(45). \\ & nd & model error \\ & nd & B^0 & at the & \Upsilon(45). \\ & B^0 & at the & \Upsilon(45). \\ & B^0 & at the & \Upsilon(45). \\ & of & B^+ & and & B^0 \\ \hline & 07 & BELL \\ e & \Upsilon(45). \\ & nd & model error \\ \hline \end{array}$ | $\begin{array}{c} +\pi^0)/B(D^0) \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} & \bullet \bullet \bullet \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{f}(4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ and use} \\ (4S) \text{ of the } T(A) \\ \text{production rate} \\ \hline \frac{COMMENT}{e^+e^-} \rightarrow \\ \hline \end{array}$ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{124}/\\ \hline \Gamma_{125}/\\ |
| Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as κ LUE (units 10^{-4}) κ Ct.% 1.10 90 2.5 90 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports < 4.2× Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^- \rightarrow \phi \pi^+$)] which we rescale to our best value B($D_s^- \rightarrow \Phi \pi^+$)] as our best value B($D_s^- \rightarrow \Phi \pi^+$)] ALBRECHT 93ε reports < $D_s^- \pi^+ K^*(892)^0$)/ Γ_{total} × [LOS ($D_s^- \rightarrow \Phi \pi^+$)] ALBRECHT 93ε reports < $D_s^- \rightarrow \Phi \pi^+$ × (892)0)/ Γ_{total} × [Which we rescale to our best value B($D_s^- \rightarrow \Phi \pi^+$)] as the contraction of $D_s^- \rightarrow \Phi \pi^+$ × (892)0)/ Γ_{total} × [LOS ($D_s^- \rightarrow \Phi \pi^+$) For total × (2±0.7 OUR AVERAGE | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $A_s = 0.027$, which $A_s = 0.027$ and $A_s = 0.027$, which $A_s = 0.027$ and $A_s = 0.027$, which $A_s = 0.027$ and $A_s = 0.027$, which $A_s = 0.027$ and $A_s = 0.02$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ $T(116/\Gamma)$ $T(4S)$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $2.9 \pm 1.0 \pm 0.4$ $3.19 \pm 0.20 \pm 0.45$ • • • We do not use the 2.9 $\pm 1.0 \pm 0.4$ 3.9 < 5.5 < 6.0 < 27.0 $1 \text{ Assumes equal produ}$ $2 \text{ Our second uncertain}$ $3 \text{ NEMATI 98 assumes}$ $values for D^0, D^{*0}, $ | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(i)$ $(-\frac{c \iota \%}{\pi^+\pi^-})/B(i)$ are following to $(-\frac{i}{2})$ are following to $(-\frac{i}{2})$ $(-\frac$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average L SATPATHY B NEMECHT 1 ALAM B BORTOLETT 2 ALAM 0 BORTOLETT 1 BORTOLETT 1 COUMENT 1 DOCUMENT 1 DOT includes scale 1 DOCUMENT 1 DOT includes scale 1 DOCUMENT 1 DOT includes scale 1 | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi \\ \hline & TECN \\ \hline & 07 & BELL \\ es, fits, limits, \\ 03 & BELL \\ 98 & CLE2 \\ 94 & CLE2 \\ \hline & 092 & CLE0 \\ 88k & ARG \\ e & T(45). \\ & 100 & 100 & 100 \\ \hline & 100 & 100 & 100 \\ & 100 & 100 & 100 \\ \hline & 100 & 1$ | $\begin{array}{c} (4S) & \text{on } (4S) & $ | $\begin{array}{c} 0 \longrightarrow K^-\pi^+\\ \hline \Gamma_{124}/\\ \hline \Gamma_{(45)}\\ \hline UZMIN 07\\ \Upsilon_{(45)}\\ EMATI 98\\ \Upsilon_{(45)}\\ \Upsilon_{(45)}\\ EMATI 98\\ \Upsilon_{(45)}\\ \Upsilon_{(45)}\\ E the CLEO \\ 0 \longrightarrow K^-\pi^+\\ \hline 45) and us atio is 45:5\\ \hline \Gamma_{125}/\\ \hline \Upsilon_{(45)}\\ \hline \Upsilon_{(45)}\\ \hline \end{array}$ |
| Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$) (Γ($D_s^* - \pi^+ K^0$)/ Γ_{total} $\xrightarrow{\text{CLW}}$ < 1.10 90 • • • We do not use the following <25 90 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports < 4.2× Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$) $\Gamma_s^{\text{(ALUE}}$ $\Gamma_s^{\text{(ALUE}}$ $\Gamma_s^{\text{(AS)}}$ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{ccccccccccccccccccccccccccccccccccc$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0} \rho^0)/\Gamma_{\text{total}}$ $2.9 \pm 1.0 \pm 0.4$ $3.9 + 0.5$ $4.0 + 0.5$ $2.9 + 0.5$ $2.9 + 0.5$ $4.0 + 0.5$ $2.9 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 + 0.5$ $4.0 +$ | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(i)$ $(\pi^+\pi^-)/B(i)$ 1,2 The following of t | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average 1 SATPATHY 3 NEMATI 4 ALAM 5 BORTOLETT 5 ALBRECHT 4 and B^0 at this systematics a suction of B^+ and B^0 by the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ ual production the D . 03 assuming B $\frac{DOCUMENT\ ID}{2}$ KUZMIN $\frac{DOCUMENT\ ID}{2}$ at this systematics a $\frac{DOCUMENT\ ID}{2}$ $\frac{DOCUMENT\ ID}{2}$ | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi \\ \hline \\ 3(D^0 \rightarrow K^-\pi \\ \hline \\ 07 \text{BELL} \\ \text{es, fits, limits,} \\ 98 \text{CLE2} \\ 94 \text{CLE2} \\ 94 \text{CLE2} \\ \hline \\ 092 \text{CLEO} \\ 88K \text{ARG} \\ \text{e} \Upsilon(45). \\ \text{nd} \text{model error} \\ \text{of} B^0 \text{at the } \Upsilon \\ 3(D^0 \rightarrow K^-\pi \\ 5). \\ \text{of} B^0 \cdot B^+ \text{and} B^0 \\ \hline \\ 0 \overline{B}^0 \cdot B^+ B^- \\ \text{e} \Upsilon(45). \\ \text{nd} \text{model error} \\ \hline \\ \text{e} \text{factor of } 2.5, \\ 11M \text{BABR} \\ \end{array}$ | $\begin{array}{c} (4S) & \text{on } (4S) & $ | $0 \rightarrow K^-\pi^-$ \[\text{F124/}{} \] \[\text{T(45)} \] UZMIN 07 \[\text{T(45)} \] EMATI 98 \[\text{T(45)} \] T(45) the paper. e the PDG of the CLEO of the CLEO of the CLEO of the Table of Table o |
| $\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ $\Gamma(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}} \times LUE (\text{units } 10^{-4}) \qquad CL\%$ < 1.10 90 • • We do not use the following <25 90 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports < 4.2× $\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ $\Gamma(D_s^- \pi^+ K^*(892)^0)/\Gamma_{\text{total}} \times LUE \times (-1.6 \times 10^{-3}) = 0$ 1 ALBRECHT 93ε reports < $D_s^- \pi^+ K^*(892)^0/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0)/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^* | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{ccccccccccccccccccccccccccccccccccc$ | 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| the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $D^0 \leftarrow K^-\pi^+$ $D^0 \rightarrow K^-\pi^+$ | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi \\ \hline & TECN \\ \hline 07 & BELL \\ es, fits, limits, \\ 03 & BELL \\ 98 & CLE2 \\ 94 & CLE2 \\ \hline 092 & CLE0 \\ 88K & ARG \\ e & \Upsilon(4S). \\ \hline nd & model error \\ nd & B^0 & \text{at the } \Upsilon \\ \hline ctions. \\ B^0 & \text{at the } \Upsilon \\ \hline of & B^+ & \text{and } B^0 \\ \hline 0 & \overline{B}^0 : B^+ & B^- \\ \hline \hline 07 & & \overline{BELL} \\ e & \Upsilon(4S). \\ \hline nd & model error \\ \hline e & factor & of 2.5. \\ \hline 11M & BABR \\ 06 & BELL \\ es, fits, limits, \\ \hline \end{array}$ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{(4S) and use} \\ +\pi^0)/\text{B}(D^0) \\ \text{0 at the } T(4D^0) \\ 0$ | $0 \rightarrow \kappa^- \pi^+$ 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| Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$) (Γ($D_s^* - \pi^+ K^0$)/ Γ_{total} $\xrightarrow{\text{CLW}}$ < 1.10 90 • • • We do not use the following <25 90 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports < 4.2× Γ_{total} × [B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$)] as our best value B($D_s^+ \rightarrow \phi \pi^+$) $\Gamma_s^{\text{(ALUE}}$ $\Gamma_s^{\text{(ALUE}}$ $\Gamma_s^{\text{(AS)}}$ | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{ccccccccccccccccccccccccccccccccccc$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ | absolute $B(D^0 \rightarrow K)$ and $B(D^0 \rightarrow K)$ and $B(D^0 \rightarrow K)$. Total MALUE (units 10^{-4}) 3.19 \pm 0.20 \pm 0.45 • • • We do not use the 2.9 \pm 1.0 \pm 0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the control of the co | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $\frac{DOCUMENT\ ID}{2}$ KUZMIN data for average $\frac{1}{2}$ SATPATHY $\frac{1}{3}$ NEMATI $\frac{1}{4}$ ALAM $\frac{1}{5}$ BORTOLETT $\frac{1}{5}$ ALBRECHT $\frac{1}{5}$ ALBRECH | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi). \\ \hline & TECN \\ \hline 07 & BELL \\ es, fits, limits, \\ 03 & BELL \\ 98 & CLE2 \\ 94 & CLE2 \\ 94 & CLE2 \\ \hline 092 & CLE0 \\ 88K & ARG \\ e & \Upsilon(4S). \\ \text{nd model error and } B^0 \text{ at the } \Upsilon(5G) \\ \text{ctions.} \\ B^0 & \text{at the } \Upsilon(5G) \\ B^0 & \text{of } B^+ \text{ and } B^0 \\ \hline 07 & BELL \\ e & \Upsilon(4S). \\ \text{nd model error of } 2.5. \\ 11M & BABR \\ 06 & BELL \\ \text{es, fits, limits,} \\ 04B & BABR \\ \end{array}$ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{C(4S) and use} \\ + \pi^0)/B(D^0) \\ \text{O at the } T(A^0) \\ \text{COMMENT} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \\ \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{s quoted in t} \\ \\ \text{Repl. by LE} \\ \text{Repl. by LE} \\ \end{array}$ | $0 \rightarrow K^-\pi^+$ $\Gamma_{124}/T_{(45)}$ UZMIN 07 $T_{(45)}$ EMATI 98 $T_{(45)}$ the paper. e the CLEO $0 \rightarrow K^-\pi^+$ $1 \rightarrow K^-\pi^+$ |
| $\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ $\Gamma(D_s^* - \pi^+ K^0)/\Gamma_{\text{total}} \times LUE (\text{units } 10^{-4}) \qquad CL\%$ < 1.10 90 • • We do not use the following <25 90 1 Assumes equal production of B^- 2 ALBRECHT 93ε reports < 4.2× $\Gamma_{\text{total}} \times [B(D_s^+ \to \phi \pi^+)]$ as our best value $B(D_s^+ \to \phi \pi^+)$ $\Gamma(D_s^- \pi^+ K^*(892)^0)/\Gamma_{\text{total}} \times LUE \times (-1.6 \times 10^{-3}) = 0$ 1 ALBRECHT 93ε reports < $D_s^- \pi^+ K^*(892)^0/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0)/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^*(892)^0]/\Gamma_{\text{total}} \times [E_s^- \pi^+ K^* | ssuming $B(D_s^+ \to \phi \pi^+) = 0.027$, which $b = 4.5 \times 10^{-2}$. $\begin{array}{ccccccccccccccccccccccccccccccccccc$ | we rescale to $\frac{\Gamma_{115}/\Gamma}{\Upsilon(4S)}$ $T(4S)$ | absolute $B(D^0 \rightarrow K$ and $B(D^0 \rightarrow K - 2)$ $\Gamma(\overline{D^0}\rho^0)/\Gamma_{\text{total}}$ $MALUE (\text{units }10^{-4})$ 3.19±0.20±0.45 • • • We do not use th 2.9 ±1.0 ±0.4 < 3.9 < 5.5 < 6.0 <27.0 1 Assumes equal production of the second uncertain of the seco | $(-\pi^+)$ and to $(\pi^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)/B(a^+\pi^-)$ | the PDG 1992 E $D^0 \rightarrow K^-\pi^+$ $D^0 \leftarrow K^-\pi^+$ $D^0 \rightarrow K^-\pi^+$ | $\begin{array}{c} 3(D^0 \rightarrow K^-\pi \\ \hline & TECN \\ \hline 07 & BELL \\ es, fits, limits, \\ 03 & BELL \\ 98 & CLE2 \\ 94 & CLE2 \\ 94 & CLE2 \\ \hline 092 & CLE0 \\ 88K & ARG \\ e & \Upsilon(4S). \\ \text{nd model error ond } B^0 \text{ at the } \Upsilon \text{ ctions.} \\ I & B^0 \text{ at the } \Upsilon \text{ ctions.} \\ I & B^0 \text{ at the } \Upsilon \text{ ctions.} \\ Of & B^+ \text{ and } B^0 \\ \hline 07 & BELL \\ e & \Upsilon(4S). \\ \text{nd model error of } 2.5. \\ \hline 11M & BABR \\ 06 & BELL \\ \text{es, fits, limits,} \\ 04B & BABR \\ 06B & BELL \\ \text{es, fits, limits,} \\ 04B & BABR \\ 02J & BELL \\ \end{array}$ | $\begin{array}{c} \frac{COMMENT}{e^+e^-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by KI} \\ e^+e^- \rightarrow \\ \text{Repl. by NI} \\ e^+e^- \rightarrow \\ \text{s quoted in t} \\ \text{(4S) and use} \\ +\pi^0)/\text{B}(D^0) \\ \text{0 at the } T(4D^0) \\ 0$ | $0 \rightarrow K^-\pi^+$ Γ_{124}/T $T(45)$ UZMIN 07 $T(45)$ EMATI 98 $T(45)$ the paper. e the CLEO $0 \rightarrow K^-\pi^+$ $45)$ and use atio is 45:5! Γ_{125}/T $T(45)$ the paper. Γ_{126}/T $T(45)$ EES 11M LYTH 06 |

| 19 | B^+ and B^0 at the $\Upsilon(4$ | S). | $\Gamma(\overline{D}^*(2007)^0\pi^0)/$ | Γ _{total} | | | | Γ ₁₃₃ /Γ |
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| 4 NEMATI 98 assumes equal pr values for D^{0} , D^{*0} , η , η' , an | roduction of B^{\pm} and B° | at the $\varUpsilon(4S)$ and use the PDG 96 | <u>VALUE (units 10⁻⁴)</u> 2.2 ±0.6 OUR AV | CL% | DO CUMENT ID | | | agram bolow |
| ³ ALAM 94 assume equal prod | luction of ${\it B}^{+}$ and ${\it B}^{0}$ a | t the $\Upsilon(4S)$ and use the CLEOII | $3.05 \pm 0.14 \pm 0.28$ | | 1 LEES | | R $e^+e^- \rightarrow$ | |
| absolute B($D^0 \rightarrow K^-\pi^+$) a | nd the PDG 1992 B(D^0 - | $\rightarrow K^{-}\pi^{+}\pi^{0})/B(D^{0} \rightarrow K^{-}\pi^{+})$ | $1.39 \pm 0.18 \pm 0.26$ | 1 | ¹ BLYTH | 06 BELL | $e^+e^- \rightarrow$ | r(45) |
| and B($D^0 \rightarrow K^- 2\pi^+ \pi^-$), | $/B(D^{\circ} \rightarrow K^{-}\pi^{+}).$ | | $2.20 + 0.59 \pm 0.79$ | 1 | ¹ COAN | 02 CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $\Gamma(\overline{D}{}^0\eta')/\Gamma_{total}$ | | Γ ₁₂₇ /Γ | ● ● We do not use | | | ges, fits, limits | , etc. • • • | |
| /ALUE (units 10 ⁻⁴) CL% 1.38±0.16 OUR AVERAGE | DOCUMENT ID | TECN COMMENT | $2.9 \pm 0.4 \pm 0.5$ | | ¹ AUBERT | | R Repl. by Li | EES 11M |
| 1.48 ± 0.13 ± 0.07 | | BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $2.7 \begin{array}{c} +0.8 \\ -0.7 \end{array} \begin{array}{c} +0.5 \\ -0.6 \end{array}$ | | 1 ABE | 02J BELL | | |
| $1.14 \pm 0.20 {}^{+ 0.10}_{- 0.13}$ | ¹ SCHUMANN 05 | BELL $e^+e^- \rightarrow \Upsilon(4S)$ | <4.4 <9.7 | | ² NEMATI ³ ALAM | 98 CLE2 94 CLE2 | !Repl.byC !Repl.byN | |
| ■ • • We do not use the following | ng data for averages, fits | , limits, etc. • • • | Assumes equal pro | | | | . Kepi. by N | LIVIATI 30 |
| $1.7 \pm 0.4 \pm 0.2$ | | BABR Repl. by LEES 11M | ² NEMATI 98 assun | nes equal produ | uction of ${\it B}^{+}$ a | and B^0 at the | $\Upsilon(4S)$ and us | e the PDG 96 |
| <9.4 90 <8.6 90 | ² NEMATI 98 ³ ALAM 94 | CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ CLE2 Repl. by NEMATI 98 | values for D ⁰ , D* | | | | Υ(4C) d | the CLEON |
| ¹ Assumes equal production of | | | 3 ALAM 94 assume B(D^* (2007) $^0 \rightarrow$ | | | | | |
| | | at the $\Upsilon(4S)$ and use the PDG 96 | $(\kappa - \pi + \pi^0)/B(D^0)$ | $0 \rightarrow \kappa - \pi^+$ | and $B(D^0 \rightarrow$ | $K^{-}2\pi^{+}\pi^{-}$ | $)/B(D^0 \rightarrow K$ | $-\pi+$). |
| values for D^0 , D^{*0} , η , η' , an | | | WEIGHTED | AVERAGE | | | | |
| | | at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ | 2.2±0.6 (Erro | or scaled by 2.6 | 6) | | | |
| and B($D^0 \rightarrow K^- 2\pi^+ \pi^-$) | $/B(D^0 \rightarrow K^-\pi^+).$ | $\dots $ | 1 | \downarrow | | | | |
| $(\overline{D}{}^0\eta')/\Gamma(\overline{D}{}^0\eta)$ | | $\Gamma_{127}/\Gamma_{126}$ | | Λ / / |) | | | |
| (D II) (D II) | DO CUMENT ID | TECN COMMENT | | \ | | | | |
| .54±0.07±0.01 | | $\overline{BABR} \ \overline{e^+ e^- \to \ \varUpsilon(4S)}$ | | | | | | |
| • • We do not use the following | = = | | | | | | | |
| 0.7 ±0.2 ±0.1 | AUBERT 04B | BABR Repl. by LEES 11M | | | | | | |
| $(\overline{\mathcal{D}}^0\omega)/\Gamma_{total}$ | | Γ ₁₂₈ /Γ | | \ / | | | | |
| (ALUE (units 10 ⁻⁴) CL% | DOCUMENT ID | TECN COMMENT | | \ / | | | | |
| 2.53 ± 0.16 OUR AVERAGE 2.57 ± 0.11 ± 0.14 | ¹ LEES 11M | BABR $e^+e^- \rightarrow \Upsilon(4S)$ | | \ / | | | | v^2 |
| $2.37 \pm 0.23 \pm 0.28$ | ¹ BLYTH 06 | | | \ | \ LE | EES | 11M BABR | 6.9 |
| • • We do not use the following | | | - | + \ \ / · · · | | | 06 BELL 02 CLE2 | 7.0 0.0 |
| $3.0 \pm 0.3 \pm 0.4$ | 1 AUBERT 04B | | | v | \ | | _ | 13.9 |
| $1.8 \pm 0.5 \stackrel{+0.4}{-0.3}$ | ¹ ABE 02J ² NEMATI 98 | BELL Repl. by BLYTH 06 | | | | (Confi | dence Level = | 0.0010) |
| <5.1 90 <6.3 90 | ² NEMATI 98 ³ ALAM 94 | CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ CLE2 Repl. by NEMATI 98 | 0 1 | 2 3 | 3 4 | 5 6 | | |
| | -10 | | E(<u>D</u> *(200 | -,0 0) | | | | |
| $^{ m 1}$ Assumes equal production of | | | I (D (200) | /) π)/I _{tota} | (units 10 ⁻⁴ |) | | |
| ² NEMATI 98 assumes equal pr | oduction of B^+ and B^0 | at the $\Upsilon(4S)$ and use the PDG 96 | | | (units 10 ⁻⁴ |) | | F /F |
| ² NEMATI 98 assumes equal pr values for D^0 , D^{*0} , η , η' , an | roduction of B^+ and $B^{ m 0}$ nd ω branching fractions. | at the $arphi(4S)$ and use the PDG 96 | $\Gamma(\overline{D}{}^0\pi^0)/\Gamma(\overline{D}{}^*(20$ | | | | COMMENT | Γ ₁₂₃ /Γ ₁₃₃ |
| ² NEMATI 98 assumes equal pr values for D^0 , D^{*0} , η , η' , an ³ ALAM 94 assume equal prod absolute $B(D^0 \to K^-\pi^+)$ a | roduction of B^+ and B^0 and ω branching fractions. Juction of B^+ and B^0 and the PDG 1992 B(D^0 - | at the $\Upsilon(4S)$ and use the PDG 96 | $\Gamma(\overline{D}^0\pi^0)/\Gamma(\overline{D}^*(2000000000000000000000000000000000000$ | 007) ⁰ π ⁰) | DOCUMENT ID | <u>TECN</u> | | Γ ₁₂₃ /Γ ₁₃₃ |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and ³ ALAM 94 assume equal prodabsolute $\mathrm{B}(D^0 \to K^-\pi^+)$ a and $\mathrm{B}(D^0 \to K^-2\pi^+\pi^-)$, | roduction of B^+ and B^0 and ω branching fractions. Juction of B^+ and B^0 and the PDG 1992 B(D^0 - | at the $\varUpsilon(4S)$ and use the PDG 96 It the $\varUpsilon(4S)$ and use the CLEOII | $\Gamma(\overline{D}^0\pi^0)/\Gamma(\overline{D}^*(2000000000000000000000000000000000000$ | 007) ⁰ π ⁰) | DO CUMENT ID | <u>тесм</u> 11м ВАВІ | $e^+e^- \rightarrow$ | Υ(4S) |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and ³ ALAM 94 assume equal prodabsolute $\mathrm{B}(D^0 \to K^-\pi^+)$ a and $\mathrm{B}(D^0 \to K^-2\pi^+\pi^-)$, | roduction of B^+ and B^0 and ω branching fractions. Juction of B^+ and B^0 and the PDG 1992 B(D^0 - | at the $\varUpsilon(4S)$ and use the PDG 96 It the $\varUpsilon(4S)$ and use the CLEOII | $\Gamma(\overline{D}^0\pi^0)/\Gamma(\overline{D}^*(2000000000000000000000000000000000000$ | 007) ⁰ π ⁰) | DOCUMENT ID LEES BLYTH | <u>тесм</u> 11м ВАВІ 06 ВЕЦІ | R $e^+e^- \rightarrow e^+e^- \rightarrow$ | |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$ / $\Gamma(D^0\phi)/\Gamma_{total}$ | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 B(D^0 - $K^-\pi^+$). | at the $\Upsilon(4S)$ and use the PDG 96 if the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/{\rm B}(D^0\to K^-\pi^+)$ | $\Gamma(\overline{D}^0\pi^0)/\Gamma(\overline{D}^*(2000000000000000000000000000000000000$ | 007) ⁰ π ⁰) | DOCUMENT ID LEES BLYTH | D TECN 11M BABI 06 BELL ges, fits, limits | R $e^+e^- \rightarrow e^+e^- \rightarrow$ | Υ(4S) Υ(4S) |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and ³ ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$ / $\Gamma(D^0\phi)/\Gamma_{total}$ VALUE (units 10^{-6}) 21.6 90 | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 B(D^0 - $K^-\pi^+$). $\frac{DOCUMENT\ ID}{1\ AUBERT}$ | at the $\Upsilon(4S)$ and use the PDG 96 at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/\mathrm{B}(D^0\to K^-\pi^+)$ $\frac{\tau_{129}/\Gamma}{\sigma_{\mathrm{BABR}}} \frac{c_{OMMENT}}{e^+e^-\to \Upsilon(4S)}$ | $\Gamma(D^0\pi^0)/\Gamma(D^*(2000000000000000000000000000000000000$ | $007)^0\pi^0$ | <u>DOCUMENT ID</u> LEES BLYTH data for averag | D TECN 11M BABI 06 BELL ges, fits, limits | R $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow$ | r(4 s) r(4 s) EES 11 m |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$) and $B(D^0 \to K^-\pi^+)$ and $B(D^0 \to K^-\pi^+)$. 1 (20%) 1 Assumes equal production of | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 B(D^0 - $K^-\pi^+$). $\frac{DOCUMENT\ ID}{1\ AUBERT}$ | at the $\Upsilon(4S)$ and use the PDG 96 at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/\mathrm{B}(D^0\to K^-\pi^+)$ $\frac{\tau_{129}/\Gamma}{\sigma_{\mathrm{BABR}}} \frac{c_{OMMENT}}{e^+e^-\to \Upsilon(4S)}$ | $\Gamma(\overline{D}^0\pi^0)/\Gamma(\overline{D}^*(2000000000000000000000000000000000000$ | $007)^0\pi^0$ | DOCUMENT ID LEES BLYTH data for averag AUBERT | 11M BAB 06 BELL ges, fits, limits 04B BABI | R $e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^+e^-$, etc. \bullet \bullet | Υ(4S) Υ(4S) |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$, $\Gamma(D^0\phi)/\Gamma_{\text{total}}$ (units 10^{-6}) $CL\%$ (11.6 90 1 Assumes equal production of | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 B(D^0 - $K^-\pi^+$). $\frac{DOCUMENT\ ID}{1\ AUBERT}$ | at the $\Upsilon(4S)$ and use the PDG 96 at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/\mathrm{B}(D^0\to K^-\pi^+)$ $\frac{\tau_{129}/\Gamma}{\sigma_{\mathrm{BABR}}} \frac{c_{OMMENT}}{e^+e^-\to \Upsilon(4S)}$ | $\Gamma(\overline{D^0}\pi^0)/\Gamma(\overline{D^*}(20)\pi^0)/\Gamma(\overline{D^*}(20)\pi^0)/\Gamma(\overline{D^*}(20)\pi^0)$ 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)/\Gamma(2007)^0\rho^0)$ | $(007)^0 \pi^0$ RAGE the following of t | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN | R $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow$ | Υ(4 <i>S</i>) Υ(4 <i>S</i>) ΕΕS 11M |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$, $\Gamma(D^0\phi)/\Gamma_{total}$ (11.6 90 Assumes equal production of $\Gamma(D^0K^+\pi^-)/\Gamma_{total}$ | roduction of B^+ and B^0 and ω branching fractions. Solution of B^+ and B^0 and the PDG 1992 $B(D^0 - K^-\pi^+)$. $\frac{DOCUMENT\ ID}{1\ AUBERT} 07ABB^+ \ and B^0 at the \Upsilon(4)$ | at the $\Upsilon(4S)$ and use the PDG 96 at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ $ \frac{\Gamma_{129}/\Gamma}{O BABR} \frac{COMMENT}{e^+e^-\to \Upsilon(4S)} S). $ | $\Gamma(D^0π^0)/\Gamma(D^*(20π^0)/\Gamma(D^*(20π^0))/\Gamma(D^*(20π^0))$ 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(D^*(2007)^0ρ^0)/\Gamma(2007)^0ρ^0/\Gamma(2007)^0ρ^0$ $\frac{VALUE}{< 5.1 × 10^{-4}}$ • • • We do not use | $(007)^0 \pi^0$ RAGE the following of t | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID SATPATHY data for average | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits | R $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^$ | T(4S) $T(4S)$ $T(4S)$ $T(4S)$ $T(4S)$ |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$, $\Gamma(D^0\phi)/\Gamma_{total}$ (21.6 90 1 Assumes equal production of $\Gamma(D^0K^+\pi^-)/\Gamma_{total}$ (ALUE (units 10^{-6}) CL% • • • We do not use the following summer of $\Gamma(D^0K^+\pi^-)/\Gamma_{total}$ (ALUE (units 10^{-6}) CL% • • • We do not use the following summer of $\Gamma(D^0K^+\pi^-)/\Gamma_{total}$ (ALUE (units 10^{-6}) CL% • • • We do not use the following summer of $\Gamma(D^0K^+\pi^-)/\Gamma_{total}$ | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $\mathbb{B}(D^0 - K^-\pi^+)$. $\frac{DOCUMENT\ ID}{B^+ and\ B^0}$ at the $\Upsilon(4-DOCUMENT\ ID)$ ng data for averages, fits | at the $\Upsilon(4S)$ and use the PDG 96 at the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ $\frac{\Gamma_{129}/\Gamma}{OBABR} \frac{COMMENT}{e^+e^-\to \Upsilon(4S)}$ S). Γ_{130}/Γ TECN COMMENT $= \frac{COMMENT}{OBABR}$ Timits, etc. • • • | $\Gamma(\overline{D^0}\pi^0)/\Gamma(\overline{D^*}(20))$ ALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(\overline{D^*}(2007)^0\rho^0)/1$ ALUE <5.1 × 10 ⁻⁴ • • We do not use <0.00056 | 007) ⁰ π ⁰) RAGE the following of t | DOCUMENT ID LEES BLYTH data for averag AUBERT DOCUMENT ID 1 SATPATHY data for averag 2 NEMATI | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits 98 CLE2 | R $e^+e^- \rightarrow$ $\cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot$ $\cdot \cdot $ | $T(4S)$ $T(4S)$ EES 11M Γ_{134}/Γ $T(4S)$ |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$, $T(D^0\phi)/\Gamma$ total V_{ALUE} (units 10^{-6}) V_{ALUE} (units V_{ALUE} (units V_{ALUE}) V_{ALUE} 0 V_{AL | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $B(D^0 - K^-\pi^+)$. $\frac{DOCUMENT\ ID}{AUBERT} 																																				$ | at the $\Upsilon(4S)$ and use the PDG 96 If the $\Upsilon(4S)$ and use the CLEOII $\rightarrow K^-\pi^+\pi^0)/B(D^0\rightarrow K^-\pi^+)$ The proof of the pro | $\Gamma(\overline{D^0}\pi^0)/\Gamma(\overline{D^*}(20))$ NALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(2007)^0\rho^0$ ×5.1 × 10 ⁻⁴ • • • We do not use <0.00056 <0.00017 | $\frac{1}{1}$ The following of the followin | DOCUMENT ID LEES BLYTH data for averag AUBERT DOCUMENT ID 1 SATPATHY data for averag 2 NEMATI 3 ALAM | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits 0 LE2 94 CLE2 | R $e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^- \rightarrow e^-e^$ | $T(4S)$ $T(4S)$ EES 11M Γ_{134}/Γ $T(4S)$ |
| ² NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-2\pi^+\pi^-)$, $\Gamma(D^0\phi)/\Gamma_{\rm total}$ (211.6 90 1 Assumes equal production of $\Gamma(D^0K^+\pi^-)/\Gamma_{\rm total}$ (21% • • • We do not use the following squares) 90 1 Assumes equal production of $\Gamma(D^0K^+\pi^-)$ (21% 1 Assumes) 90 1 Assumes equal production of $\Gamma(D^0K^+\pi^-)$ (31% 1 Assumes) 90 1 Assumes equal production of | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $B(D^0 - K^-\pi^+)$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 07AG$ $\frac{DOCUMENT\ ID}{1\ AUBERT}$ and B^0 at the $\Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ B^+ and B^0 at the $\Upsilon(4)$ | at the $\Upsilon(4S)$ and use the PDG 96 It the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ $= \frac{\Gamma_{129}/\Gamma}{OBABR} = \frac{COMMENT}{e^+e^-\to \Upsilon(4S)}$ S). Γ_{130}/Γ $= \frac{TECN}{TECN} = \frac{COMMENT}{TOMMENT}$ To BABR Repl. by AUBERT 09AE S). | $\Gamma(D^0\pi^0)/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/\Gamma(D^*(20^0\pi^0))/$ | $ \begin{array}{c c} \hline \text{RAGE} \\ \hline \text{the following} \\ \hline \hline \hline \textbf{Ftotal} \\ \hline \underline{\textbf{CL}\%} \\ 90 \\ \hline \text{the following} \\ 90 \\ \hline \text{oduction of } B^{-1} \\ \hline \text{mes equal production} \\ \hline \end{array} $ | DOCUMENT ID LEES BLYTH data for averag AUBERT DOCUMENT ID SATPATHY ATTEMPT AND ATTEMPT | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits 98 CLE2 94 CLE2 ene Y(4S). and B ⁰ at the | R $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ \downarrow , etc. $\bullet \bullet$ R Repl. by LI $\frac{COMMENT}{\downarrow}$ \downarrow , etc. $\bullet \bullet$ \downarrow , etc. $\bullet \bullet$ \downarrow Repl. by N | T(45) T(45) EES 11M Γ134/Γ T(45) T(45) EMATI 98 |
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Fig. COMMENT $S = \frac{\Gamma_{130}/\Gamma_{119}}{\Gamma_{130}/\Gamma_{119}}$ EBABR $e^+e^-\rightarrow \Upsilon(4S)$ | $\Gamma(\overline{D^0}\pi^0)/\Gamma(\overline{D^*}(20))$ MALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(\overline{D^*}(2007)^0\rho^0)/1$ MALUE <5.1 × 10 ⁻⁴ • • We do not use <0.00056 <0.00117 1 Assumes equal procaution of the property of the procaution of the property of the propert | the following Total CL% 90 conduction of B^{-1} mes equal product $D^0 \pi^0$) and all product $D^0 \pi^0$ 0 all all product $D^0 \pi^0$ 0 and all product $D^0 \pi^0$ 0 all all product D | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID 1 SATPATHY data for average 2 NEMATI 3 ALAM + and B ⁰ at the uction of B ⁺ and branching fraction of B ⁺ and brought Bly0 at the properties of B branching the boolute Bly0 are boolute Bly0 at the properties of B branching fraction of B ⁺ and branching the properties of B branching fraction of B branching the properties of B branching the B branching | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL 98 CLE2 94 CLE2 the $\Upsilon(4S)$. and B^0 at the actions. d B^0 at the T | R $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ R Repl. by LI $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ Repl. by N $e^+e^- \rightarrow$ Repl. by N | $T(4S)$ $T(4S)$ EES 11M T_{134}/I $T(4S)$ EMATI 98 The PDG 96 The CLEOI |
| 2 NEMATI 98 assumes equal pr values for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prod absolute $B(D^0 \rightarrow K^-\pi^+)$ a and $B(D^0 \rightarrow K^-\pi^+)$ a and $B(D^0 \rightarrow K^-2\pi^+\pi^-)$, $K^0 = K^0$. 1 Assumes equal production of $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K^0$. The $K^0 = K^0$ is $K^0 = K$ | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $\mathbb{B}(D^0 \to K^-\pi^+)$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 07A^{I}$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 09A$ $1\ Of \ 2.5 \ standard \ deviat$ | at the $\Upsilon(4S)$ and use the PDG 96 If the $\Upsilon(4S)$ and use the CLEOII $\rightarrow K^-\pi^+\pi^0)/B(D^0\rightarrow K^-\pi^+)$ Γ_{129}/Γ $TECN \qquad COMMENT \qquad OBABR \qquad e^+e^-\rightarrow \Upsilon(4S)$ S). Γ_{130}/Γ $TECN \qquad COMMENT \qquad OBABR \qquad OBA$ | $\Gamma(D^0\pi^0)/\Gamma(D^*(20))$ NALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(D^*(2007)^0\rho^0)/\Gamma(2007)^0\rho^0$ ×5.1 × 10 ⁻⁴ • • • We do not use <0.00056 <0.00117 1 Assumes equal processor of pooling and processor of pooling | the following the following $\frac{\Gamma_{\text{total}}}{CL\%}$ the following $\frac{\Gamma_{\text{total}}}{90}$ the following $\frac{90}{90}$ oduction of B^+ oduction of B^+ oduction of B^+ oduction of B^- | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID 1 SATPATHY data for average 2 NEMATI 3 ALAM + and B ⁰ at the uction of B ⁺ and branching fraction of B ⁺ and brought Bly0 at the properties of B branching the boolute Bly0 are boolute Bly0 at the properties of B branching fraction of B ⁺ and branching the properties of B branching fraction of B branching the properties of B branching the B branching | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL 98 CLE2 94 CLE2 the $\Upsilon(4S)$. and B^0 at the actions. d B^0 at the T | R $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ R Repl. by LI $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ Repl. by N $e^+e^- \rightarrow$ Repl. by N | T(45) T(45) T(45) T(45) T(45) EMATI 98 e the PDG 96 the CLEOI 992 B($D^0 - T^+$). |
| ² NEMATI 98 assumes equal pr values for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prod absolute $B(D^0 \rightarrow K^-\pi^+)$ a and $B(D^0 \rightarrow K^-\pi^+)$ a and $B(D^0 \rightarrow K^-2\pi^+\pi^-)$, $K^-(D^0\phi)/\Gamma$ total ALUE (units 10^{-6}) QL% $K^-(D^0\phi)/\Gamma$ total $K^-(D^0\phi)/\Gamma$ total $K^-(D^0\phi)/\Gamma$ total $K^-(D^0\phi)/\Gamma$ total $K^-(D^0\phi)/\Gamma$ total $K^-(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^-(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^-(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^-(D^0\phi)/\Gamma$ $K^+(D^0\phi)/\Gamma$ $K^-(D^0\phi)/\Gamma$ $K^-($ | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $\mathbb{B}(D^0 \to K^-\pi^+)$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 07A^{I}$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 09A$ $1\ Of \ 2.5 \ standard \ deviat$ | at the $\Upsilon(4S)$ and use the PDG 96 If the $\Upsilon(4S)$ and use the CLEOII $\rightarrow K^-\pi^+\pi^0)/B(D^0\rightarrow K^-\pi^+)$ Γ_{129}/Γ $TECN \qquad COMMENT$ o BABR $e^+e^-\rightarrow \Upsilon(4S)$ S). Γ_{130}/Γ $TECN \qquad COMMENT$ i, limits, etc. • • • BABR Repl. by AUBERT 09AE S). $\Gamma_{130}/\Gamma_{119}$ $TECN \qquad COMMENT$ E BABR $e^+e^-\rightarrow \Upsilon(4S)$ ions after combining results from | Γ($D^0\pi^0$)/Γ(D^* (20) MALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 Γ(D^* (2007) $^0\rho^0$)/Γ MALUE <5.1 × 10 ⁻⁴ • • • We do not use <0.00056 <0.00117 1 Assumes equal procaution of the control of the con | the following the following $\frac{\Gamma_{\text{total}}}{CL\%}$ the following $\frac{\Gamma_{\text{total}}}{90}$ the following $\frac{90}{90}$ oduction of B^+ oduction of B^+ oduction of B^+ oduction of B^- | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID 1 SATPATHY data for average 2 NEMATI 3 ALAM + and B ⁰ at the uction of B ⁺ and branching fraction of B ⁺ and brought Bly0 at the properties of B branching the boolute Bly0 are boolute Bly0 at the properties of B branching fraction of B ⁺ and branching the properties of B branching fraction of B branching the properties of B branching the B branching | 11M BABI 06 BELL ges, fits, limits 04B BABI 09 TECN 03 BELL ges, fits, limits 98 CLE2 94 CLE2 one $\Upsilon(4S)$. and B^0 at the actions. d B^0 at the $\Upsilon(4S)$ | R $e^+e^- \rightarrow c$, $e^+e^- \rightarrow c$, etc. $\bullet \bullet \bullet$ R Repl. by LI $\frac{COMMENT}{e^+e^- \rightarrow c}$ E, etc. $\bullet \bullet \bullet$ R Repl. by N $T(4S) \text{ and use}$ | $T(4S)$ $T(4S)$ EES 11M T_{134}/I $T(4S)$ EMATI 98 The PDG 96 The CLEOI |
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| the following the following of the following $\frac{CL\%}{90}$ conduction of B^+ mes equal production $\frac{CL\%}{100}$ and all $\frac{CL\%}{100}$ and all $\frac{CL\%}{100}$ and all $\frac{CL\%}{1000}$ and $\frac{CL\%}{10000}$ total $\frac{CL\%}{1000000000000000000000000000000000000$ | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID 1 SATPATHY data for average 2 NEMATI 3 ALAM + and B^0 at the auction of B^+ as B^0 branching fraction of B^+ and B^0 and $B(D^0 \to DOCUMENT ID)$ or includes scale | 11M BABI 06 BELL ges, fits, limits 04B BABI 03 BELL 90 03 BELL ges, fits, limits 94 CLE2 94 CLE2 94 CLE2 95 CLE2 96 CLE2 97 CLE2 98 CLE2 98 CLE2 98 CLE2 99 CLE2 100 MBO at the cartions. dd B^0 at the cartions. dd B^0 at the cartions. depends on $K^-\pi^+$ and $K^-2\pi^+\pi^-$ | R $e^+e^- \rightarrow e^- \rightarrow e^-$, etc. • • • R Repl. by LI $\frac{COMMENT}{e^+e^- \rightarrow e^-}$, etc. • • • Repl. by N $\Upsilon(4S) \text{ and use}$ | T(45) T(45) T(45) T(45) T(45) T(45) 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T_{135}/Γ |
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| 2 NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal production absolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a consider the second should be sufficiently and $ALUE$ (units 10^{-6}) and $ALUE$ (units 10^{-5}) and 10^{-5} | roduction of B^+ and B^0 and ω branching fractions. Luction of B^+ and B^0 and the PDG 1992 $\mathbb{B}(D^0 - K^-\pi^+)$. $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 07A^-$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 06A$ $B^+ \ and \ B^0 \ at \ the \ \Upsilon(4)$ $\frac{DOCUMENT\ ID}{1\ AUBERT} \qquad 09A$ $1\ O9A$ $2\ O9A$ $2\ O9A$ $2\ O9A$ $3\ O9A$ $3\ O9A$ $3\ O9A$ $3\ O9A$ $4\ O9A$ $4\ O9A$ $5\ O9A$ $6\ O9A$ $6\ O9A$ $6\ O9A$ $6\ O9A$ $6\ O9A$ $9\ $ | at the $\Upsilon(4S)$ and use the PDG 96 If the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ Fig. 129/F TECN COMMENT To BABR $e^+e^-\to \Upsilon(4S)$ S). Fig. 130/F TECN COMMENT To Imits, etc. • • • BABR Repl. by AUBERT 09AE S). Fig. 130/Fig. TECN COMMENT TECN COMMENT TECN COMMENT TECN COMMENT TECN COMMENT TECN COMMENT THE BABR $e^+e^-\to \Upsilon(4S)$ TO THE TECN COMMENT THE TECN CO | $\Gamma(\overline{D^0}\pi^0)/\Gamma(\overline{D}^*(20))$ NALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 $\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0\rho^0)/\Gamma(\overline{D^*}(2007)^0)/\Gamma(\overline{D^*}(2007)^0)/\Gamma(\overline{D^*}(2007)^0)/\Gamma(\overline{D^*}(2007)^0)/\Gamma(\overline$ | the following $\frac{CL\%}{90}$ The following $\frac{CL\%}{90}$ Oduction of $\frac{B}{100}$ The sequal product $\frac{D^0\pi^0}{1000}$ and $\frac{B}{10000}$ The following $\frac{B}{100000000000000000000000000000000000$ | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID SATPATHY data for average 2 NEMATI 3 ALAM and B^0 at the auction of B^+ and bosolute $B(D^0 \rightarrow D^0)$ DOCUMENT ID or includes scale 1 LEES | 11M BABI 06 BELL ges, fits, limits 04B BABI 03 BELL ges, fits, limits 98 CLE2 94 CLE2 94 CLE2 one $\Upsilon(4S)$. and B^0 at the actions. d B^0 at the $K^-\pi^+$) a $K^-\pi^+$) a $K^-2\pi^+\pi^-$ 12e factor of 2. | R $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ i, etc. •• R Repl. by LI $\frac{COMMENT}{e^+e^- \rightarrow}$ i , etc. •• i, etc. •• R Repl. by N T(4S) and use $T(4S) and use$ | T(45) T(45) T(45) T(45) T(45) EMATI 98 The CLEOI 992 B($D^0\pi^+$). T(45) |
| 2 NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η , and 3 ALAM 94 assume equal production by $B(D^0 \rightarrow K^-\pi^+)$ and $B(D^0 \rightarrow K^-2\pi^+\pi^-)$, D^0 and D^0 | roduction of B^+ and B^0 and ω branching fractions. We have the position of B^+ and B^0 and the position of B^+ and B^0 and the position of B^+ and B^0 and the position of B^+ and B^0 at the $T(4)$ and $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ | at the $\Upsilon(4S)$ and use the PDG 96 It the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ Fig. 129/ Γ TECN COMMENT Solution of BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 130/ Γ TECN COMMENT E BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 131/ Γ TECN COMMENT BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 131/ Γ TECN COMMENT BABR $e^+e^-\to \Upsilon(4S)$ Solution is etc. • • • • • • • • • • • • • • • • • • • | Γ($D^0\pi^0$)/Γ(D^* (20) NALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • • We do not use 1.0 ±0.1 ±0.2 Γ(\overline{D}^* (2007) $^0\rho^0$)/Γ NALUE <5.1 × 10 ⁻⁴ • • • We do not use <0.00056 <0.00117 1 Assumes equal procaution of the control | The following of the f | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID SATPATHY data for average 2 NEMATI 3 ALAM and B^0 at the auction of B^+ and bosolute $B(D^0 \rightarrow D^0)$ DOCUMENT ID or includes scale 1 LEES | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits 98 CLE2 94 CLE2 94 CLE2 one $\Upsilon(4S)$. ond B^0 at the actions. d B^0 at the actions. d E^0 at the action | R $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ i, etc. •• R Repl. by LI $\frac{COMMENT}{e^+e^- \rightarrow}$ i , etc. •• i, etc. •• R Repl. by N T(4S) and use $T(4S) and use$ | T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) |
| 2 NEMATI 98 assumes equal provalues for D^0 , D^{*0} , η , η' , and 3 ALAM 94 assume equal prodabsolute $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a and $B(D^0 \to K^-\pi^+)$ a form K^{ALUE} (units 10^{-6}) K^{-2} | roduction of B^+ and B^0 and ω branching fractions. We have the position of B^+ and B^0 and the position of B^+ and B^0 and the position of B^+ and B^0 and the position of B^+ and B^0 at the $T(4)$ and $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ are position of $T(4)$ and $T(4)$ are position of $T(4)$ | at the $\Upsilon(4S)$ and use the PDG 96 It the $\Upsilon(4S)$ and use the CLEOII $\to K^-\pi^+\pi^0)/B(D^0\to K^-\pi^+)$ Fig. 129/ Γ TECN COMMENT Solution of BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 130/ Γ TECN COMMENT E BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 131/ Γ TECN COMMENT BABR $e^+e^-\to \Upsilon(4S)$ Solution is after combining results from Fig. 131/ Γ TECN COMMENT BABR $e^+e^-\to \Upsilon(4S)$ Solution is etc. • • • • • • • • • • • • • • • • • • • | Γ($D^0\pi^0$)/Γ(D^* (20) NALUE 0.90±0.08 OUR AVE 0.88±0.05±0.06 1.62±0.23±0.35 • • We do not use 1.0 ±0.1 ±0.2 Γ(\overline{D}^* (2007) $^0\rho^0$)/Γ NALUE <5.1 × 10 ⁻⁴ • • We do not use <0.00056 <0.00117 1 Assumes equal proceed on the control of the control | the following of the f | DOCUMENT ID LEES BLYTH data for average AUBERT DOCUMENT ID SATPATHY data for average 2 NEMATI 3 ALAM + and B^0 at the uction of B^+ and boolute $B(D^0 - 1)$ and $B(D^0 - 1)$ DOCUMENT ID or includes scale 1 LEES 1 BLYTH data for average | 11M BABI 06 BELL ges, fits, limits 04B BABI 0 TECN 03 BELL ges, fits, limits 98 CLE2 94 CLE2 94 CLE2 one $\Upsilon(4S)$. ond B^0 at the actions. d B^0 at the actions. d E^0 at the action | R $e^+e^- \rightarrow$. R Repl. by LI $\begin{array}{c} \underline{COMMENT} \\ \cdot $ | T(4S) T(4S) T(4S) EES 11M T(4S) EMATI 98 The CLEOI 992 B($D^0 - T^+$). T(4S) T(4S) T(4S) T(4S) T(4S) T(4S) T(4S) |

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

¹ ARTUSO

90

90

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$

 1 AUBERT,B 05Q BABR $e^{+}e^{-}
ightarrow \varUpsilon(4S)$

 $^{^1}$ Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 NEMATI 98 assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$ and use the PDG 96 ² NEMATI 98 assumes equal production of B^+ and B^0 at the T(45) and use the PDG 96 values for D^0 , D^{*0} , η , η' , and ω branching fractions.

³ ALAM 94 assume equal production of B^+ and B^0 at the T(45) and use the CLEOII $B(D^*(2007)^0 \to D^0\pi^0)$ and absolute $B(D^0 \to K^-\pi^+)$ and the PDG 1992 $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$ and $B(D^0 \to K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$.

| $(\overline{D}^0 \eta)/\Gamma(\overline{D}^*(2007)^0 \eta)$ | | $\Gamma_{126}/\Gamma_{135}$ | Γ(D*(2010)+ D*(| (2010) ⁻)/l | | | | $\Gamma_{142}/\Gamma_{142}$ |
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| 4 <i>LUE</i> .99±0.10 OUR AVERAGE | DOCUMENT ID TECN COMMENT | | VALUE (units 10 ⁻⁴) 8.2±0.9 OUR A | <u>CL%</u> VERAGE | DO CUMENT ID | TECN | COMMENT | |
| $97 \pm 0.07 \pm 0.07$ | LEES 11M BABR $e^+e^- \rightarrow$ | | 8.1 ± 0.6 ± 1.0 | | ¹ AUBERT,B | 06A BABR | $e^+e^- \rightarrow \gamma(4S)$ |) |
| $27 \pm 0.29 \pm 0.25$ | BLYTH 06 BELL $e^+e^- \rightarrow$ | Y (45) | $8.1 \pm 0.8 \pm 1.1$ | | ¹ MIYAKE | 05 BELL | $e^+e^- \rightarrow \gamma(4S)$ |) |
| = | data for averages, fits, limits, etc. • • • | | $9.9 + \frac{4.2}{-3.3} \pm 1.2$ | | ¹ LIPELES | 00 CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |) |
| $9 \pm 0.2 \pm 0.1$ | AUBERT 04B BABR Repl. by L | LEES 11M | • • • We do not us | e the followin | ng data for aver | ages, fits, limit | s. etc. • • • | |
| $(\overline{D}^*(2007)^0\eta')/\Gamma(\overline{D}^*(2007)^0\eta')$ | ⁰ n) | $\Gamma_{136}/\Gamma_{135}$ | $8.3 \pm 1.6 \pm 1.2$ | | ² AUBERT | = | Repl. by AUBER | Т.В 06в |
| ALUE | DOCUMENT ID TECN COMMENT | 130/ 133 | $6.2 + 4.0 \pm 1.0$ | | ³ ARTUSO | 99 CLE2 | Repl. by LIPELES | |
| 61±0.14±0.02 | LEES 11M BABR $e^+e^- \rightarrow$ | Υ(4S) | =:- | | ⁴ BARATE | | · · | 3 00 |
| • • We do not use the following | data for averages, fits, limits, etc. • • • | • , - | <61 <22 | | 5 ASNER | 98Q ALEP 97 CLE2 | $e^+e^- \rightarrow Z$ Repl. by ARTUS | ∩ aa |
| $5 \pm 0.3 \pm 0.1$ | AUBERT 04B BABR Repl. by L | LEES 11M | ¹ Assumes equal p | | | | Kepi. by AKTOS | 0)) |
| $(\overline{D}^*(2007)^0\eta')/\Gamma_{\mathrm{total}}$ | | г /г | | | | | of the final states i | is 0.22 = |
| • | | Γ ₁₃₆ /Γ | 0.18 ± 0.03 | | | | | |
| 1.40 ± 0.22 OUR AVERAGE | DOCUMENT ID TECN COMMENT | | 3 ARTUSO 99 use | es B(↑ (4 <i>S</i>) − | $\rightarrow B^0B^0)=(48$ | ± 4)% | | 0 . 0 0 |
| | ¹ LEES 11M BABR $e^+e^- \rightarrow$ | $\Upsilon(4.5)$ | which correspond | de to a branci | hing ratio of (2 | $3+1.9 \pm 0.4$ | background of 0.1 | U ± U.U |
| | 1 SCHUMANN 05 BELL $e^{+}e^{-} ightarrow$ | . , | 5 A CNED 07 at CI | IEO observes | a 1 event with a | 3-1.2 ± 0.4) | ckground of 0.022 | . 0.01 |
| We do not use the following | data for averages, fits, limits, etc. • • • | | This corresponds | to a branchi | ing ratio of (5.3 | +7.1 + 1.0 | ckground of 0.022 ∠10-4 | ± 0.01 |
| 1.3 ±0.7 ±0.2 | ^{,2} AUBERT 04B BABR Repl. by L | LEES 11M | Tilla corresponda | s to a brancin | ing ratio of (5.5 | -3.7 ± 1.0) × | (10 . | |
| 14 90 | BRANDENB 98 CLE2 $e^+e^- ightarrow$ | Y(45) | $\Gamma(\overline{D}^*(2007)^0\omega)/$ | [total | | | | Γ ₁₄₃ / |
| | ³ NEMATI 98 CLE2 $e^+e^- \rightarrow$ | | VALUE (units 10 ⁻⁴) | CL% | DOCUMENT | ID TECI | | 1437 |
| | ⁴ ALAM 94 CLE2 Repl. by N | NEMATI 98 | 3.6 ±1.1 OUR | | | | | |
| $\frac{1}{2}$ Assumes equal production of B | | | $4.55 \pm 0.24 \pm 0.39$ | 9 | 1 LEES | 11M BAB | $R e^+e^- \rightarrow \Upsilon(4)$ | <i>(S</i>) |
| ² Reports an upper limit < 2.6 > 3 NEMATI 98 assumes equal prod | $	imes$ 10^{-4} at 90% CL. Duction of B^+ and B^0 at the $\varUpsilon(4S)$ and us | sa tha DDC 04 | $2.29 \pm 0.39 \pm 0.40$ | | ¹ BLYTH | 06 BEL | | S) |
| VALUES for D^0 , D^{*0} , η , η' , and | | 20 THE LDG 20 | | | | - | | |
| ALAM 94 assume equal produc | tion of B^+ and B^0 at the $\varUpsilon(4S)$ and use | se the CLEOII | 4.2 ±0.7 ±0.9 | 90 | 1 AUBERT | | R Repl. by LEES | |
| $B(D^*(2007)^0 \rightarrow D^0\pi^0)$ and a | absolute B($D^0 	o K^-\pi^+$) and the PDG 1 | 1992 B(D^0 → | < 7.9 | 90 | 1 ABE | 02J BEL | | |
| $K^-\pi^+\pi^0)/B(D^0 \to K^-\pi^+)$ |) and B($D^{0} \rightarrow K^{-}2\pi^{+}\pi^{-}$)/B($D^{0} \rightarrow K^{-}2\pi^{+}\pi^{-}$) | $K^{-}\pi^{+}$). | < 7.4 <21 | 90 90 | ² NEMATI ³ ALAM | | 2 $e^+e^- \rightarrow \Upsilon$ (4 2 Repl. by NEMA | |
| $\overline{D}^0 \eta') / \Gamma(\overline{D}^*(2007)^0 \eta')$ | | | | | | | ∠ Kepi. by N⊑ivi <i>F</i> | 111 90 |
| | DO CUMENT ID TECH COMMENT | $\Gamma_{127}/\Gamma_{136}$ | Assumes equal p | | | | r(4S) and use the | BDC |
| <u>∪E</u> 5 ±0.18±0. 06 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | values for D^0 , D | | | | : 1(45) and use the | FDG |
| | data for averages, fits, limits, etc. • • • | 1 (43) | 3 ALAM 94 assum | ne equal prod | uction of B ⁺ a | nd B^0 at the | arphi(4S) and use the | CLEC |
| $\pm 0.8 \pm 0.2$ | AUBERT 04B BABR Repl. by L | IEEC 1111 | $B(D^*(2007)^0 \rightarrow$ | $D^0\pi^0$) and | d absolute $B(D^0)$ | $\rightarrow K^-\pi^+$) | and the PDG 1992 | $B(D^0)$ |
| | AOBERT 048 BABK Kept. by L | TES IIM | | | | | $^{-})/B(D^{0} \rightarrow K^{-}\pi$ | |
| $\overline{D}^*(2007)^0 \pi^+ \pi^-) / \Gamma_{ m total}$ | | Γ ₁₃₇ /Γ | F/50 \/F/5*/a | \() \ | | | - | |
| LUE | DOCUMENT ID TECN COMMENT | | $\Gamma(\overline{D}^0\omega)/\Gamma(\overline{D}^*(20))$ | $007)^{\circ}\omega)$ | | | | 28/Γ ₁ 4 |
| 2±1.2±1.8) × 10 ⁻⁴ | ,2 SATPATHY 03 BELL $e^+e^- ightarrow$ | Y(45) | <u>VALUE</u> 0.58±0.06 OUR AVI | FRAGE | <u>DO CUMENT</u> | ID TECH | <u>COMMENT</u> | |
| $^{ m 1}$ Assumes equal production of B | $^+$ and B^0 at the $arphi(4S)$. | | $0.56 \pm 0.04 \pm 0.04$ | | LEES | 11M BAB | $R e^+e^- \rightarrow \gamma (4)$ | (5) |
| 2 No assumption about the interr | mediate mechanism is made in the analysis | ŝ. | $1.04 \pm 0.20 \pm 0.17$ | | BLYTH | 06 BEL | $L e^+e^- \rightarrow \Upsilon (4$ | <i>(S</i>) |
| S*(000=10::0\::= | | Γ /Γ | ● ● We do not use | e the followin | ng data for aver | ages, fits, limit | s, etc. • • • | |
| /J=(2007)♥ K ♥1/ | | | $0.7 \pm 0.1 \pm 0.1$ | | AUBERT | Mn DAD | | 11M |
| $D^*(2007)^0 K^0)/\Gamma_{\text{total}}$ | DOCUMENT ID TECH COMMENT | Γ ₁₃₈ /Γ | 0.7 ±0.1 ±0.1 | | AUDENT | U4B DAD | R Repl. by LEES | |
| .UE (units 10 ⁻⁵) <u>CL%</u> | DOCUMENT ID TECN COMMENT | | | ٠١/٦ | AUDLICI | U4B DAD | | Г |
| .UE (units 10 ⁻⁵) CL% 3.6±1.2±0.3 | 1 AUBERT,B 06L BABR $e^{+}e^{-} ightarrow$ | | Γ(D*(2010)+ D- | • | | | | Γ ₁₄₄ / |
| UE (units 10^{-5}) CL% 3.6±1.2±0.3 • We do not use the following | $\frac{1}{\text{AUBERT,B}} \qquad \text{O6L} \qquad \overline{\text{BABR}} \qquad e^+ \ e^- \rightarrow \\ \text{data for averages, fits, limits, etc.} \qquad \bullet \bullet$ | Υ(4S) | Γ(D*(2010)+ D- VALUE (units 10 ⁻⁴) | CL% | DOCUMENT II | O <u>TECN</u> | COMMENT | Γ ₁₄₄ / |
| UE (units 10^{-5}) CL% 2.6 ± 1.2 ± 0.3 • We do not use the following 0.6 90 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Υ(4S) | $\Gamma(D^*(2010)^+D^-)$ MALUE (units 10^{-4}) 6.1 ± 1.5 OUR AV | CL% | <u>DOCUMENT IL</u> rror includes sca | <u>TECN</u> le factor of 1.6 | COMMENT | |
| UE (units 10^{-5}) CL% 1.6±1.2±0.3 • We do not use the following | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Υ(4S) | Γ(D*(2010)+ D- VALUE (units 10 ⁻⁴) 6.1±1.5 OUR AV 5.7±0.7±0.7 | VERAGE Er | <u>DOCUMENT IL</u> rror includes sca ¹ AUBERT,B | D TECN le factor of 1.6 06A BABR | $\frac{COMMENT}{5.}$ $8 e^{+}e^{-} \rightarrow \Upsilon(45)$ | 5) |
| UE (units 10^{-5}) CL% .6±1.2±0.3 • We do not use the following .6 90 Assumes equal production of B | $\begin{array}{llllllllllllllllllllllllllllllllllll$ | Υ(4S) Υ(4S) | $\Gamma(D^*(2010)^+D^-$ $\frac{VALUE \text{ (units }10^{-4})}{6.1\pm1.5 \text{ OUR AV}}$ $5.7\pm0.7\pm0.7$ $11.7\pm2.6^{+2.2}_{-2.5}$ | CL% VERAGE Er | DOCUMENT IL rror includes sca 1 AUBERT,B 1,2 ABE | D TECN le factor of 1.6 06A BABR 02Q BELL | 5. $e^+e^- \rightarrow r(4S)$ $e^+e^- \rightarrow r(4S)$ | 5) |
| UE (units 10^{-5}) CL% .6±1.2±0.3 • We do not use the following .6 90 Assumes equal production of B | $\begin{array}{llllllllllllllllllllllllllllllllllll$ | · τ(4S) · τ(4S) · τ(139/Γ | $\Gamma(D^*(2010)^+D^-$ $\frac{VALUE \text{ (units }10^{-4})}{6.1\pm1.5 \text{ OUR AV}}$ $5.7\pm0.7\pm0.7$ $11.7\pm2.6^{+2.2}_{-2.5}$ • • • We do not use | CL% VERAGE Er | DOCUMENT IL rror includes sca ¹ AUBERT,B 1,2 ABE ng data for aver | D <u>TECN</u> le factor of 1.6 06A BABR 02Q BELL ages, fits, limit | 5. $e^+e^- \rightarrow r$ (4S s, etc. • • • | 5) |
| UE (units 10 ⁻⁵) .6±1.2±0.3 • We do not use the following .6 90 Assumes equal production of B 5*(2007) ⁰ K*(892) ⁰)/Γ _{total} UE .CL% | $\begin{array}{llllllllllllllllllllllllllllllllllll$ | Γ ₁₃₉ /Γ | $\Gamma(D^*(2010)^+D^-\frac{VALUE (units 10^{-4})}{6.1\pm1.5 \text{ OUR AV}}$ $5.7\pm0.7\pm0.7$ $11.7\pm2.6^{+2.2}_{-2.5}$ • • We do not us $8.8\pm1.0\pm1.3$ | CL%_VERAGE En | DOCUMENT IL rror includes sca ¹ AUBERT,B 1,2 ABE ng data for aver. ¹ AUBERT | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR | 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ s, etc. • • • | 5) 5) tt,B 0 |
| UE (units 10^{-5}) CL% 1.6±1.2±0.3 • We do not use the following 6 90 Assumes equal production of B $\overline{D}^*(2007)^0 K^*(892)^0 / \Gamma_{tota}$ UE 1.9 × 10^{-5} 90 | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow e^+ e^- \rightarrow e^- e^- \rightarrow e^- e^- \rightarrow e^- e^- \rightarrow e^- e^- e^- e^- \rightarrow e^- e^- e^- e^- e^- e^- e^- e^- e^- e^-$ | Γ ₁₃₉ /Γ | $\Gamma(D^*(2010)^+D^-$ $\frac{VALUE \text{ (units }10^{-4})}{6.1\pm1.5 \text{ OUR AV}}$ $5.7\pm0.7\pm0.7$ $11.7\pm2.6^{+2.2}_{-2.5}$ • • • We do not use | CL%_VERAGE En | DOCUMENT IL rror includes sca ¹ AUBERT,B 1,2 ABE ng data for aver | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR | 5. $e^+e^- \rightarrow r$ (4S s, etc. • • • | 5) 5) 8T,B 0 |
| ### Comparison of B Assumes equal production of B | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ at the $\Upsilon(4S)$. 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ at the $\Upsilon(4S)$. 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ at the $\Upsilon(4S)$. | Γ ₁₃₉ /Γ · Υ(4 <i>S</i>) | $\Gamma(D^*(2010)^+D^-\frac{VALUE (units 10^{-4})}{6.1\pm1.5 \text{ OUR AV}}$ $5.7\pm0.7\pm0.7$ $11.7\pm2.6^{+2.2}_{-2.5}$ • • We do not us $8.8\pm1.0\pm1.3$ | CL%_VERAGE En | DOCUMENT IL rror includes sca ¹ AUBERT,B 1,2 ABE ng data for aver. ¹ AUBERT | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL | 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ s, etc. • • • | 5) 5) RT,B 0 |
| UE (units 10^{-5}) CL% 1.6±1.2±0.3 • We do not use the following 1.6 90 Assumes equal production of B To (2007) K*(892) 0 / Γ tota 1.9 × 10 ⁻⁵ 90 Assumes equal production of B To (2007) K*(892) 0 / Γ tota To (2007) K*(892) 0 / Γ tota | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ | $\Gamma(D^*(2010)^+D^-\frac{VALUE\ (units\ 10^{-4})}{6.1\pm1.5\ OUR\ AV}$ $\frac{6.1\pm1.5\ OUR\ AV}{5.7\pm0.7\pm0.7}$ $11.7\pm2.6^{\pm}\frac{2.2}{2.5}$ • • • We do not use $8.8\pm1.0\pm1.3$ $14.8\pm3.8^{\pm}\frac{2.8}{3.1}$ | CL% VERAGE En 1 se the followin | DOCUMENT III Tror includes sca 1 AUBERT,B 1,2 ABE ng data for aver: 1 AUBERT 1,3 ABE | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL 00 CLE2 98Q ALEP | 5. $e^+e^- \rightarrow T(4S)$ 8. $e^+e^- \rightarrow T(4S)$ 8. $e^+e^- \rightarrow T(4S)$ 8. Repl. by AUBER $e^+e^- \rightarrow T(4S)$ $e^+e^- \rightarrow T(4S)$ $e^+e^- \rightarrow Z(4S)$ | 5) 8T,B 0 |
| WE (units 10^{-5}) CL% .6±1.2±0.3 • We do not use the following .6 90 Assumes equal production of B $\overline{D}^*(2007)^0 K^*(892)^0 / \Gamma_{tota}$ WE CL% 9 × 10^{-5} 90 Assumes equal production of B $\overline{D}^*(2007)^0 K^*(892)^0 / \Gamma_{tota}$ CL% | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ 1 KROKOVNY 03 BELL $e^+e^- \rightarrow$ 1 KROKOVNY 03 BELL $e^+e^- \rightarrow$ | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ | $ \begin{split} &\Gamma \big(D^* \big(2010 \big)^+ D^- \\ & \underbrace{^{VALUE} (\text{units } 10^{-4})}_{\textbf{5.7 \pm 0.7 \pm 0.7}} \\ & \underbrace{\textbf{6.1 \pm 1.5 OUR AV}}_{\textbf{5.7 \pm 0.7 \pm 0.7}} \\ & \underbrace{\textbf{11.7 \pm 2.6 + 2.2}}_{\textbf{2.5}} \\ \bullet \bullet \bullet \text{We do not us:}}_{\textbf{8.8 \pm 1.0 \pm 1.3}} \\ & \underbrace{\textbf{14.8 \pm 3.8 \pm 2.8}}_{\textbf{3.1}} \\ & < 6.3 \\ & < 56 \\ & < 18 \end{split} $ | CL% VERAGE En 1 see the followin 1 90 90 90 90 | DOCUMENT IL TOTO INCIDENCE SEARCH 1,2 ABE 1,2 ABE 1 AUBERT 1,3 ABE 1 LIPELES BARATE ASNER | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL 00 CLE2 98Q ALEP 97 CLE2 | 5. $e^+e^- \rightarrow \Upsilon(4S)$ 8. $e^+e^- \rightarrow \Upsilon(4S)$ 9. $e^+e^- \rightarrow \Upsilon(4S)$ 10. Repl. by AUBER 11. $e^+e^- \rightarrow \Upsilon(4S)$ 11. $e^+e^- \rightarrow \Upsilon(4S)$ 11. $e^+e^- \rightarrow \Upsilon(4S)$ | 5) 5) RT,B 0 |
| we (units 10^{-5}) CL% 1.6±1.2±0.3 • We do not use the following 1.6 Assumes equal production of B $(5^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ (9×10^{-5}) Assumes equal production of B $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ $(2^{+}(2007)^{0} K^{*}(892)^{0})/\Gamma_{tota}$ | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow e^+ e^- \rightarrow e^- e^- \rightarrow e^+ e^- \rightarrow e^+ e^- \rightarrow e^- e^- \rightarrow e^- e^- e^- \rightarrow e^- e^- e^- \rightarrow e^- e^- e^- \rightarrow e^- e^- e^- e^- \rightarrow e^- e^- e^- e^- e^- e^- e^- e^- e^- e^-$ | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ | $ \begin{split} &\Gamma \big(D^* \big(2010 \big)^+ D^- \\ & \underline{VALUE} (\text{units } 10^{-4}) \\ & \underline{6.1 \pm 1.5} \text{OUR AV} \\ & 5.7 \pm 0.7 \pm 0.7 \\ & 11.7 \pm 2.6 - \frac{2.2}{2.5} \\ \bullet & \bullet \text{We do not us:} \\ & 8.8 \pm 1.0 \pm 1.3 \\ & 14.8 \pm 3.8 + \frac{2.8}{3.1} \\ & < 6.3 \\ & < 56 \\ & < 18 \\ & 1 \text{Assumes equal p} \end{split} $ | CL% VERAGE En 1 see the followin 1 90 90 90 oroduction of | DOCUMENT IL TOTO INCIDENT SEA 1,2 ABE 1,2 ABE 1 AUBERT 1 AUBERT 1.3 ABE 1 LIPPLES BARATE ASNER B+ and B ⁰ at | Default of 1.6 o | 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ 8. Repl. by AUBER $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | 5) 5) RT,B 0 |
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| ## (units 10^{-5}) CL % 6±1.2±0.3 • We do not use the following 6 90 Assumes equal production of B 5*(2007) ⁰ K*(892) ⁰)/ Γ_{tota} ### (2007) Assumes equal production of B 0*(2007) ⁰ K*(892) ⁰)/ Γ_{tota} ### (2007) Assumes equal production of B 0*(2007) ⁰ K*(892) ⁰)/ Γ_{tota} ### (2007) Assumes equal production of B | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KOKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KOKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 DOCUMENT ID TECN $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ Γ ₁₄₀ /Γ | $ \begin{split} &\Gamma \big(D^* \big(2010 \big)^+ D^- \\ & \underline{ \text{NALUE (units } 10^{-4}) } \\ & \underline{ \text{6.1 \pm 1.5 OUR AV} } \\ & \underline{ \text{5.7 \pm 0.7 \pm 0.7} } \\ & 11.7 \pm 2.6 \stackrel{+}{-} \frac{2.2}{2.5} \\ \bullet & \bullet & \text{We do not us:} \\ & 8.8 \pm 1.0 \pm 1.3 \\ & 14.8 \pm 3.8 \stackrel{+}{-} \frac{2.8}{3.1} \\ & < 6.3 \\ & < 56 \\ & < 18 \\ & \text{1 Assumes equal p} \\ & \text{2 The measuremen} \\ & \text{3 The measuremen} \\ & \text{3 The measuremen} \\ \end{split} $ | CL% VERAGE En 1 se the followin 90 90 90 oroduction of the is performent is performent is performent. | DOCUMENT ILL rror includes sca 1 AUBERT,B 1,2 ABE Ing data for aver: 1,3 ABE 1 LIPELES BARATE AS NER B+ and B ⁰ at ed using a partie | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL 00 CLE2 98Q ALEP 97 CLE2 the \(^4S\)). constructed \(^D\) il reconstructiod | 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ 8. Repl. by AUBER $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | 5) 37,B 0 37,B 0 |
| 2E (units 10^{-5}) CL% 6±1.2±0.3 • We do not use the following 6 90 Assumes equal production of B 75*(2007) 0 K*(892) 0 / Γ tota 29 × 10 ⁻⁵ 90 Assumes equal production of B 7*(2007) K*(892) 0 / Γ tota 75*(2007) K*(892) 0 / Γ tota 75*(2007) 0 K*(892) 0 / Γ tota | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 1$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 1$ and B^0 at the $\Upsilon(4S)$. 1 $\frac{DOCUMENT\ ID}{1}$ $\frac{TECN}{1}$ $\frac{COMMENT\ 1}{1}$ $COMMENT\ $ | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ Γ ₁₄₁ /Γ | $ \begin{split} &\Gamma \big(D^* \big(2010 \big)^+ D^- \\ & \underbrace{^{VALUE} (\text{units } 10^{-4})}_{\text{5.1} \pm 1.5 \text{OUR AV}} \\ & \underbrace{5.7 \pm 0.7 \pm 0.7}_{\text{11.7} \pm 2.6 - 2.5} \\ & \bullet \bullet \text{We do not us} \\ & 8.8 \pm 1.0 \pm 1.3 \\ & 14.8 \pm 3.8 + 2.8 \\ & -3.1 \\ & < 6.3 \\ & < 56 \\ & < 18 \\ & 1 \text{Assumes equal p} \\ & 2 \text{The measuremen} \end{split} $ | CL% VERAGE En 1 se the followin 90 90 90 oroduction of the is performent is performent is performent. | DOCUMENT ILL rror includes sca 1 AUBERT,B 1,2 ABE Ing data for aver: 1,3 ABE 1 LIPELES BARATE AS NER B+ and B ⁰ at ed using a partie | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL 00 CLE2 98Q ALEP 97 CLE2 the \(^4S\)). constructed \(^D\) il reconstructiod | 5. COMMENT 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ 8. Repl. by AUBER $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ * and D^+ decays. | 5) 8T,B 0 5) 5) |
| ## (units 10^{-5}) CL % 6±1.2±0.3 • We do not use the following 6 90 Assumes equal production of B $5^*(2007)^0 K^*(892)^0 / \Gamma_{\text{tota}}$ J^{E} 90 Assumes equal production of B $J^*(2007)^0 K^*(892)^0 / \Gamma_{\text{tota}}$ J^{E} 10 Assumes equal production of B $J^*(2007)^0 K^*(892)^0 / \Gamma_{\text{tota}}$ 12 13 24 25 26 26 27 27 28 29 29 20 20 20 20 20 20 20 20 | 1 AUBERT,B 06L BABR $e^+e^- \rightarrow 0.00$ data for averages, fits, limits, etc. • • • 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KOKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KOKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 DOCUMENT ID TECN $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. 1 KROKOVNY 03 BELL $e^+e^- \rightarrow 0.00$ dat the $T(4S)$. | Γ ₁₃₉ /Γ Γ ₁₄₀ /Γ Γ ₁₄₁ /Γ | $ \begin{split} &\Gamma \big(D^* \big(2010 \big)^+ D^- \\ & \underline{ \text{VALUE (units } 10^{-4})} \\ & \underline{ \text{6.1} \pm 1.5 \text{ OUR AV}} \\ & \underline{ \text{5.7} \pm 0.7 \pm 0.7} \\ & \underline{ \text{11.7} \pm 2.6 - 2.5} \\ \bullet & \bullet & \text{We do not us:} \\ & \underline{ \text{8.8} \pm 1.0 \pm 1.3} \\ & \underline{ \text{14.8} \pm 3.8 + 2.8} \\ & \underline{ \text{6.3}} \\ & < \underline{ \text{6.3}} \\ & < \underline{ \text{56}} \\ & < \underline{ \text{18}} \\ & \\ & \text{1 Assumes equal p} \\ & \\ & \text{2 The measuremen} \\ & \\ & \text{3 The measuremen} \\ & \\ & \text{fully reconstructed} \end{split} $ | verage in the following set th | DOCUMENT IL TOTO INCIDENCE 1 AUBERT, B 1,2 ABE 1 AUBERT 1 AUBERT 1.3 ABE 1 LIPPLES BARATE ASNER B+ and B ⁰ at ed using fully ree ed using a partials as a cross che | D TECN le factor of 1.6 06A BABR 02Q BELL ages, fits, limit 03J BABR 02Q BELL 00 CLE2 98Q ALEP 97 CLE2 the \(^4S\)). constructed \(^D\) il reconstructiod | 5. COMMENT 5. $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ 8. Repl. by AUBER $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ * and D^+ decays. | 5) 8T,B 0 5) 5) 5) |
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| 3.46±0.18±0.37 1 DEL-AMO-SA118 BABR $e^+e^- \rightarrow T(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | - I | Tassumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma((\overline{D} + \overline{D}^*)(D + D^*)K)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units } 10^{-2})}{3.68 \pm 0.10 \pm 0.24}$ 1 DEL-AMO-SA118 BABR e^+ • • • We do not use the following data for averages, fits, limits, etc. 4.3 ±0.3 ±0.6 1 AUBERT 03x BABR Report e^+ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(\eta_c K^0)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units } 10^{-3})}{0.83 \pm 0.12 \text{ OUR AVERAGE}}$ 0.59 ±0.20 ±0.07 1.2 AUBERT 0.7AV BABR e^+ 0.91±0.15 ±0.08 1.3 AUBERT, B 0.4B BABR e^+ 1.09 ±0.55 ±0.33 4 EDWARDS 01 CLE2 e^+ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 2 AUBERT 07AV reports [Γ($B^0 \rightarrow \eta_c K^0$)/Γtotal] × [B(η_c (15) → $p\overline{p}$) = 0.05)×10 ±0 with we divide by our best value B(η_c (15) → $p\overline{p}$) = 0.059 ×10 ±0 with we divide by our best value B(η_c (15) → $p\overline{p}$) = 0.059 ×10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 ±0 × 10 × 1 | r = - r (4S) $r = - r (4S)$ |
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| Taksumes equal production of B^+ and B^0 at the $T(4S)$. | - I | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Γ_{157}/Γ $\stackrel{MMENT}{\bullet \bullet \bullet} \Gamma$ pl. by DEL-AMO-SANCHEZ 11B Γ_{158}/Γ $\stackrel{MMENT}{\bullet \bullet \bullet} \Gamma_{4S}$ $e^- \to \Upsilon(4S)$ $e^- \to \Gamma(4S)$ $(1.41 \pm 0.17) \times 10^{-3}$ systematic error from systematic error from the form of the following error of the following error of the following error of the following error form of the following error |
| 2.47 ± 0.10 ± 0.18 2.47 ± 0.10 ± 0.18 1 DEL-AMO-SA118 BABR $e^+e^- \rightarrow T(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • • • 3.1 $^+$ 0.4 1 AUBERT 03x BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. | - I | 3.68±0.10±0.24 • • • • We do not use the following data for averages, fits, limits, etc. 4.3 ±0.3 ±0.6 1 AUBERT 1 AUBERT 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. $T(\eta_c K^0)/\Gamma_{\text{total}}$ $MALUE (units 10^{-3})$ 0.83±0.12 OUR AVERAGE 0.59 $^+$ 0.29 $^+$ 0.07 1.2 AUBERT 0.7 AUBERT 0.7 AUBERT 0.7 AUBERT 0.7 BABR 0.9 1±0.15 $^+$ 0.08 1.3 AUBERT, B 0.4 BABR 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. 1 AUBERT 1 | MMENT $Te^- \rightarrow \Upsilon(4S)$ PI. by DEL-AMO-SANCHEZ 11B FISA/F MMENT T_{158}/F MMENT T_{158}/F |
| 247±0.10±0.18 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow T(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • • 3.1 $^{+0.4}_{-0.3}$ ± 0.4 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(D^*(2010)^- D^*(2007)^0 K^+)/\Gamma_{total}$ $\frac{VALUE (units 10^{-3})}{1 \text{ DEL-AMO-SA11B}} \frac{DOCUMENT ID}{1 \text{ DEL-AMO-SA11B}} \frac{TECN}{1 \text{ BABR}} \frac{COMMENT}{e^+e^- \rightarrow T(4S)}$ • • • We do not use the following data for averages, fits, limits, etc. • • • 11.8±1.0 ±1.7 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(D^-D^+K^0)/\Gamma_{total}$ 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow T(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | - I | 3.68±0.10±0.24 • • • • We do not use the following data for averages, fits, limits, etc. 4.3 ±0.3 ±0.6 1 AUBERT 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. $T(\eta_C K^0)/\Gamma_{\text{total}}$ MALUE (units 10 ⁻³) 0.59±0.12 OUR AVERAGE 0.59±0.19±0.07 1.2 AUBERT 0.7AV BABR e+ 0.91±0.15±0.07 1.3 AUBERT, 0.4B BABR e+ 1.23±0.23±0.41 1 FANG 0.3 BELL e+ 1.09±0.55±0.33 4 EDWARDS 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. 2 AUBERT 0.7AV reports $[\Gamma(B^0 \to \eta_C K^0)/\Gamma_{\text{total}}] \times [B(\eta_C(1S) \to \rho \overline{\rho}) = 0.05) \times 10^{-6}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.05 \times 10^{-6}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.0085 \pm 0.0071) \times 10^{-3}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.0085 \pm 0.0071) \times 10^{-3}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.0085 \pm 0.0071) \times 10^{-3}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.0085 \pm 0.0071) \times 10^{-3}$ which we divide by our best value $B(\eta_C(1S) \to \rho \overline{\rho}) = 0.0085 \pm 0.0071) \times 10^{-3}$ which we divide by our best value. 4 EDWARDS 01 assumes equal production of B^0 and B^+ at the $T(A)$ uncertainties (28.3)% from $B(J/\psi(1S) \to \gamma \eta_C)$ in those modes for. $T(\eta_C(K^0)/\Gamma(J/\psi(1S)K^0)) = 0.0085 \times 0.0085$ | From the content of |
| The same equal production of B^+ and B^0 at the $T(4S)$. | - I | 4.3 \pm 0.3 \pm 0.6 1 AUBERT 03X BABR Replacement 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(\eta_c K^0)/\Gamma_{\text{total}}$ **MALUE (units 10^{-3})** 0.83 \pm 0.12 OUR AVERAGE 0.59 \pm 0.20 \pm 0.07 1.2 AUBERT 07AV BABR e^+ 0.91 \pm 0.15 \pm 0.08 1.3 AUBERT,B 04B BABR e^+ 1.23 \pm 0.23 \pm 0.41 1 FANG 03 BELL e^+ 1.09 \pm 0.55 \pm 0.33 4 EDWARDS 01 CLE2 e^+ 1.4Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 AUBERT 07AV reports $[\Gamma(B^0 \to \eta_c K^0)/\Gamma_{\text{total}}] \times [B(\eta_c(1S) \to \eta_c K^0)/\Gamma_{tota$ | pl. by DEL-AMO-SANCHEZ 11B |
| $\Gamma(D^*(2010)^-D^*(2007)^0K^+)/\Gamma_{total}$ $\Gamma_{149}/\Gamma_{total}$ $\Gamma_{10.6\pm0.33\pm0.86}$ 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow T(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | - I | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{ll} \underline{MMENT} \\ & fe^- \to & \mathcal{T}(4S) \end{array}$ |
| 10.6±0.33±0.86 • • • We do not use the following data for averages, fits, limits, etc. • • • • • • 11.8±1.0 ±1.7 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 ASsumes equal production of B^+ and B^0 at the $T(4S)$. 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 ASSUMES equal production of B^+ and B^0 at the $T(4S)$. 1 DEL-AMO-SAN.11B BABR $e^+e^- \rightarrow T(4S)$ 1 DEL-AMO-SAN.11B BABR Repl. by DEL-AMO-SANCHEZ 11B 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SANCHEZ 11B | - I | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | MMENT $f e^- \rightarrow \Upsilon(4S)$ |
| 10.6±0.33±0.86 • • • We do not use the following data for averages, fits, limits, etc. • • • • • • 11.8±1.0 ±1.7 1 AUBERT | - - - 1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccc} re^- &\rightarrow & \varUpsilon(4S) \\ \end{array}$ |
| 11.8 \pm 1.0 \pm 1.7 1 AUBERT 03X BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 1 $T(D^-D^+K^0)/\Gamma_{total}$ 1 T_{total} 2 T_{total} 2 T_{total} 2 T_{total} 1 T_{total} 2 T_{total} 1 T_{total} 2 T_{total} 2 T_{total} 2 T_{total} 2 T_{total} 2 T_{total} 2 T_{total} 3 T_{total} 4 T_{total} 4 T_{total} 5 T_{total} 6 T_{total} | - - - 1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{l} re^- \to \ \Upsilon(4S) \\ re^- \to \ \Upsilon(4S) \\ \hline \rho \overline{\rho})] = (0.83 ^{+0.28}_{-0.26} \pm \\ (1.41 \pm 0.17) \times 10^{-3}. \\ \text{systematic error from} \\ \kappa \overline{\kappa} K]] = (0.0648 \pm \\ \eta_{\mathcal{C}}(1S) \to \kappa \overline{\kappa} \pi) = \\ \text{ad our second error is} \\ \Gamma(4S). \text{ The correlated have been accounted} \\ \hline \Gamma_{158}/\Gamma_{162} \\ \hline \kappa e^- \to \ \Upsilon(4S) \end{array}$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(D^-D^+K^0)/\Gamma_{total} \qquad \qquad \Gamma_{150}/\Gamma_{0.75\pm0.12\pm0.12} \qquad \qquad \Gamma_{1} \qquad \Gamma_{1} \qquad \Gamma_{1} \qquad \Gamma_{1} \qquad \qquad \Gamma_{1} \qquad \qquad \Gamma_{1} \qquad \Gamma_{1} \qquad \Gamma_{1} \qquad \qquad \Gamma_{1} \qquad$ | - - - 1 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{l} [\rho e^- \rightarrow ~ \Upsilon(4S)] \\ [\rho \overline{\rho}]] = (0.83^{+0.28}_{-0.26} \pm \\ (1.41 \pm 0.17) \times 10^{-3}. \\ [osystematic error from \\ [\kappa \overline{\kappa}\pi]] = (0.0648 \pm \\ \eta_{\mathcal{C}}(1S) \rightarrow ~ \kappa \overline{\kappa}\pi) = \\ [osystematic arror is] \\ [osystematic follows:] \\ [$ |
| | - - - 1 | $\begin{array}{llllllllllllllllllllllllllllllllllll$ | $[p\overline{p}]] = (0.83^{+}_{-}0.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28^{+}_{-}1.28$ |
| VALUE (units 10^{-3}) QLW DOCUMENT ID 0.75 ± 0.12 ± 0.12 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow T(4S)$ $<$ • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • Value (units 10^{-3}) 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT ID 1 DEL-AMO-SANCHEZ 11B 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow T(4S)$ Fig. 1/Fitcal Fig. 1/ | - - - 1 | $ ^{1}\text{Assumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \varUpsilon(4s). $ $ ^{2}\text{AUBERT 07AV reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \eta_{C}) \right] $ $ ^{2}\text{AUBERT 07AV reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \rho_{D}) \right] $ $ ^{2}\text{AUBERT B 04b reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \eta_{C}) \right] $ $ ^{3}\text{AUBERT B 04b reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \eta_{C}) \right] $ $ ^{2}\text{AUBERT B 04b reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \eta_{C}) \right] $ $ ^{2}\text{AUBERT B 04b reports} \left[\Gamma(B^{0} \to \eta_{C} K^{0}) / \Gamma_{\text{total}} \right] \times \left[B(\eta_{C}(1s) \to \eta_{C}) \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right] $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right) $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right) $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{+} \text{ at the } \Upsilon_{C} \right) $ $ ^{4}\text{EDVARDS 01 assumes equal production of } B^{0} \text{ and } B^{-} \text{ at the } \Upsilon_{C} \right) $ $ ^{4}EDVARDS 01 assumes equal pr$ | $\begin{array}{c} (1.41\pm0.17)\times 10^{-3}. \\ \text{systematic error from} \\ \left. K\overline{K}\pi\right)] = (0.0648\pm \eta_C(15) \rightarrow K\overline{K}\pi) = \\ \text{nd our second error is} \\ \Gamma(45). \text{ The correlated have been accounted} \\ \hline \Gamma_{158}/\Gamma_{162} \\ \hline \kappa e^- \rightarrow \Gamma(45) \end{array}$ |
| VALUE (units 10^{-3}) 6.41±0.36±0.39 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • 6.5 ±1.2 ±1.0 1 AUBERT 03x BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(D^*(2010)^- D^*(2010)^+ K^0)/\Gamma_{total}$ VALUE (units 10^{-3}) 8.1 ±0.7 OUR AVERAGE 8.26±0.43±0.67 6.8 ±0.8 ±1.4 1,2 DALSENO 07 BELL 1,2 AUBERT,B 06Q BABR 08BAR 08BAR 09BAR | Ī | $\begin{array}{ll} (7.2\pm0.6)\times10^{-2}. \text{ Our first error is their experiment's error and the systematic error from using our best value.} \\ ^{4}\text{EDWARDS oI assumes equal production of B^{0} and B^{+} at the Υ uncertainties (28.3)% from $B(J/\psi(1S)\to\gamma\eta_{\mathcal{C}})$ in those modes for.} \\ \hline \Gamma(\eta_{\mathcal{C}}K^{0})/\Gamma(J/\psi(1S)K^{0}) \\ \hline \frac{VALUE}{1.39\pm0.20\pm0.45} & \frac{DOCUMENT\ ID}{1\ AUBERT\ B} & \frac{TECN}{04B\ BABR} & \frac{COI}{e^{+}} \\ \hline ^{1}\text{ Uses BABAR measurement of } B(B^{0}\to J/\psiK^{0}) = (8.5\pm0.5\pm0.5) \end{array}$ | our second error is $\Gamma(45)$. The correlated have been accounted $\frac{\Gamma_{158}/\Gamma_{162}}{\Gamma_{158}}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • 6.5 $\pm 1.2 \pm 1.0$ | - - I | for. $ \Gamma(\eta_c K^0)/\Gamma(J/\psi(1S)K^0) $ $ \frac{VALUE}{1.39\pm0.20\pm0.45} $ $ \frac{DOCUMENT\ ID}{1\ AUBERT,B} $ | $\frac{\Gamma_{158}/\Gamma_{162}}{e^- \rightarrow \Upsilon(45)}$ |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(D^+(2010)^-D^+(2010)^+K^0)/\Gamma_{\rm total} \qquad \qquad \Gamma_{\rm 152}/\Gamma_{\rm 152}/\Gamma_{\rm 152}$ 8.1 ±0.7 OUR AVERAGE $8.26\pm0.43\pm0.67 \qquad 1 \ $ | Г - І | $ \begin{array}{c cccc} \underline{\textit{VALUE}} & \underline{\textit{DOCUMENT ID}} & \underline{\textit{TECN}} & \underline{\textit{COI}} \\ \textbf{1.39\pm0.20\pm0.45} & 1 & \text{AUBERT,B} & 048 & \text{BABR} & e^{\pm} \\ & 1 & \text{Uses BABAR measurement of B} (B^0 \rightarrow J/\psi K^0) = (8.5 \pm 0.5 \pm $ | $e^- 	o 	au(4S)$ |
| Γ(D^* (2010) − D^* (2010) + K^0)/Γ _{total} POCUMENT ID DOCUMENT ID TECN COMMENT TOTAL (Leginalis 10^{-3}) 1 DEL-AMO-SA11B BABR $e^+e^- 	o T(4S)$ 6.8 ± 0.8 ± 1.4 1,2 DALSENO 1,2 AUBERT, B 06Q BABR $e^+e^- 	o T(4S)$ 6.8 ± 0.8 ± 1.4 1,2 AUBERT, B 1,2 AUBERT, B 1,3 BABR Repl. by AUBERT, B 1,4 Sumes equal production of B^+ and B^0 at the $T(4S)$. The result is rescaled by a factor of 2 to convert from K^0 to K^0 . Γ(D^*-D_{s1} (2536) + × B(D_{s1} (2536) + → D^*+K^0))/Γ _{total} Γ153/Γ VALUE (units 10^{-4}) | г - І | 1.39 \pm 0.20 \pm 0.45 1 AUBERT,B 04B BABR e^+ 1 Uses BABAR measurement of B($B^0 \rightarrow J/\psi K^0$) = (8.5 \pm 0.5 \pm | e ⁻ → γ(4S) |
| VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 8.1 ±0.7 OUR AVERAGE 1 DEL-AMO-SA11B BABR $e^+e^- 	o T(4S)$ 8.2 ±0.43±0.67 1 DEL-AMO-SA11B BABR $e^+e^- 	o T(4S)$ 8.8 ±0.8 ±1.4 1,2 DALSENO 07 BELL $e^+e^- 	o T(4S)$ 8.8 ±0.8 ±1.4 1,2 AUBERT,B 06Q BABR $e^+e^- 	o T(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • 8.8 ±1.5 ±1.3 1 AUBERT 03X BABR Repl. by AUBERT,B 06Q 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 2 The result is rescaled by a factor of 2 to convert from K_S^0 to K^0 . Γ($D^*-D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^{*+}K^0))/\Gamma_{total}$ Γ153/Γ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT | - I | 1 Uses BABAR measurement of B($B^0 ightarrow ~J/\psi~{ m K}^0$) $=$ (8.5 \pm 0.5 \pm | , , |
| 8.1 ±0.7 OUR AVERAGE 8.26±0.43±0.67 1 DEL-AMO-SA11B BABR $e^+e^- 	oup 	au 	au 	au 	au 	au 	au 	au 	au 	au 	au$ | - I | | |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. The result is rescaled by a factor of 2 to convert from K_S^0 to K^0 . $\Gamma(D^{*-}D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \rightarrow D^{*+}K^0))/\Gamma_{total} \qquad \Gamma_{153}/\Gamma_{VALUE (units 10^{-4})} \qquad \qquad DOCUMENT ID \qquad TECN COMMENT$ | | 0.64±0.09 OUR AVERAGE 0.60±0.08±0.07 | . , |
| ² The result is rescaled by a factor of 2 to convert from K_S^0 to K^0 . $\Gamma(D^{*-}D_{s1}(2536)^+ \times B(D_{s1}(2536)^+ \to D^{*+}K^0))/\Gamma_{total} \qquad \Gamma_{153}/\Gamma_{VALUE (units 10^{-4})} \qquad DOCUMENT ID TECN COMMENT$ | | -0.21 | , |
| VALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT | | $1.62\pm0.32^{+0.55}_{-0.60}$ 4 FANG 03 BELL e^+ 1 AUBERT 08AB reports [$\Gamma(B^0 \to \eta_C K^*(892)^0)/\Gamma_{\rm total}$] / [B($B^+ - 0.06\pm0.05$ which we multiply by our best value B($B^+ \to \eta_C K^+$): Our first error is their experiment's error and our second error is the | $\rightarrow \eta_C K^+)] = 0.62 \pm $ = $(9.6 \pm 1.2) \times 10^{-4}$. |
| $7.6^{+4.8}_{-4.2} + 1.6_{-1.4}$ 1,2 DALSENO 07 BELL $e^+e^- 	o 	au(4.5)$ | - | using our best value. ² Uses the production ratio of $(B^+B^-)/(B^0\overline{B}^0)=1.026\pm0.032$ ³ AUBERT 07av reports $[\Gamma(B^0\to\eta_CK^*(892)^0)/\Gamma_{\rm total}]\times[B((1.03\pm0.27\pm0.27\pm0.17)\times10^{-6}$ which we divide by our best value | at $\Upsilon(4S)$. $(\eta_C(1S) \to p\overline{p})] = $ e $B(\eta_C(1S) \to p\overline{p})$ |
| 8.2 \pm 2.6 \pm 1.2 | | = $(1.41\pm0.17) \times 10^{-3}$. Our first error is their experiment's error is the systematic error from using our best value. ⁴ Assumes equal production of B^+ and B^0 at the $T(4S)$. | and our second error |
| $ \Gamma(\overline{D}^0 D^0 K^0) / \Gamma_{\text{total}} $ $ \Gamma_{154} / \Gamma_{\text{total}} $ | Γ | $\Gamma(\eta_c(2S)K^{*0})/\Gamma_{\rm total}$ | Γ ₁₆₀ /Γ |
| VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT | _ | <u>VALUE (units 10⁻⁴)</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COI</u> <3.9 90 ¹ AUBERT 08AB BABR e ⁺ | $\frac{MMENT}{e^- \rightarrow \Upsilon(4S)}$ |
| 0.27 \pm 0.10 \pm 0.05 1 DEL-AMO-SA11B BABR e^{+} e^{-} \rightarrow Υ (4.5) \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | I | 1 Uses the production ratio of $(B^+B^-)/(B^0\overline{B}^0)=1.026\pm0.032$ | · , |
| <1.4 90 1 AUBERT 03x BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. | | $\Gamma(B^0 	o h_c(1P) K^{*0}) / \Gamma_{ m total} 	imes \Gamma(h_c(1P) 	o \eta_c(1S) \gamma) / \Gamma_{ m tot} \Gamma_{161} / \Gamma_2$ | imes tal $	imes$ |
| $\left[\Gamma(\overline{D}^{0} D^{*}(2007)^{0} K^{0}) + \Gamma(\overline{D}^{*}(2007)^{0} D^{0} K^{0})\right]/\Gamma_{\text{total}}$ Γ_{155}/Γ_{0} | Γ | <u>VALUE (units 10⁻⁴)</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COM</u> <2.2 90 ¹ AUBERT 08AB BABR e ⁺ | MMENT |
| VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT | | 1 Uses the production ratio of $(B^+B^-)/(B^0\overline{B}^0) = 1.026 \pm 0.032$ | |
| 1.08 \pm 0.32 \pm 0.36 1 DEL-AMO-SA11B BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | I | $\Gamma(\eta_c K^*(892)^0)/\Gamma(\eta_c K^0)$ | Γ ₁₅₉ /Γ ₁₅₈ |
| <3.7 90 1 AUBERT 03x BABR Repl. by DEL-AMO-SANCHEZ 11B 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | VALUE DO CUMENT ID TECN COL | $e^- \rightarrow \Upsilon(4S)$ |

and B^0 at the $\Upsilon(4S)$.

VALUE (units 10⁻³)

1.34 ±0.06 OUR FIT

| $(J/\psi(1S)K^0)/\Gamma$ | total | | | | Γ ₁₆₂ /Γ |
|---------------------------------------------------------|------------------------|----------------------------------------------------|-------------------|-----------|----------------------------------------------------------------------------------------|
| ALUE (units 10^{-4}) | | DOCUMENT ID | | TECN | COMMENT |
| 8.74±0.32 OUR FI | | | | | |
| 8.71 ± 0.32 OUR AV | ERAGE | | | | |
| $8.6 \begin{array}{c} +1.3 \\ -1.2 \end{array} \pm 0.3$ | | ^{1,2} AUBERT | 07av | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $8.69 \pm 0.22 \pm 0.30$ | | ² AUBERT | 05 J | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $7.9 \pm 0.4 \pm 0.9$ | | ² ABE | 03в | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $9.5 \pm 0.8 \pm 0.6$ | | ² AVERY | 00 | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.5 \pm 2.3 \pm 1.7$ | | ³ ABE | | | ρ p at 1.8 TeV |
| $7.0 \pm 4.1 \pm 0.1$ | | 4 BORTOLETT | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $9.3 \pm 7.2 \pm 0.1$ | 2 | ⁵ ALBRECHT | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • We do not use | the following | - | fits, | limits, e | tc. • • • |
| $8.3 \pm 0.4 \pm 0.5$ | | ² AUBERT | 02 | BABR | Repl. by AUBERT 05J |
| 8.5 $^{+1.4}_{-1.2}$ ± 0.6 | | ² JESSOP | 97 | CLE2 | Repl. by AVERY 00 |
| $7.5 \pm 2.4 \pm 0.8$ | 10 | ⁴ ALAM | 94 | | Sup. by JESSOP 97 |
| 50 9 | 00 | ALAM | 86 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 1 AUBERT 07AV 1 (1.87 + 0.28 + 0. | eports $[\Gamma(B^0)]$ | $\rightarrow J/\psi(1S) K^0$ which we divide by | /Γ _{tot} | al] × [l | $B(J/\psi(1S) \rightarrow p\overline{p})] = B(J/\psi(1S) \rightarrow p\overline{p}) =$ |
| | | | | | r and our second error is |
| the systematic er | ror from using | scenoris then exp cour best value. | ermie | it s ello | r and our second error is |
| ² Assumes equal pi | oduction of E | 3 + and 0 at the | r(45 |). | |
| | | $\rightarrow J/\psi K^+) = (1$ | | | 10^{-3} |
| | | | | | asurement of $[\Gamma(B^0 ightarrow$ |
| $J/\psi(1S) K^0)/\Gamma_{t}$ | $\times 10^{\circ}$ | $\psi(1S) \rightarrow e^+e^-$ | l assu | ming B | $J/\psi(1S) \rightarrow e^+e^-) =$ |
| | | | | | $\rightarrow e^{+}e^{-}) = (5.94 \pm$ |
| | | | | | |

systematic error from using our best value. Assumes equal production of B^+ and B^0 at 5 ALBRECHT 90J reports (8 \pm 6 \pm 2) imes 10 $^{-4}$ from a measurement of [$\Gamma(B^{\,0}
ightarrow$ $\textit{J/}\psi(1\textit{S})\;\textit{K}^{0})/\Gamma_{\text{total}}]\;\times\; [\textit{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\;\;e^{+}\,e^{-})]\;\; \text{assuming}\;\; \textit{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\;\;e^{+}\,e^{-})$ = 0.069 \pm 0.009, which we rescale to our best value B(J/ ψ (1S) ightarrow e^+e^-) = $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+

 $\Gamma(J/\psi(1S) K^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{163}/Γ

EVTS

| VALUE (units 10 ⁻³) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|---------------------------------|---------------|----------|------------------------|---------|-----------|----------------------|----------------|
| 1.16±0.56±0.01 | | | ¹ BORTOLETT | O92 | CLEO | e^+e^- | Y(45) |
| • • • We do not u | se the follov | ving dat | a for averages, fits | , limit | s, etc. • | • • | |
| <1.3 | 90 | | ² ALBRECHT | 87D | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| < 6.3 | 90 | 2 | GILES | 84 | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(45)$ |

 $^1\,\text{BORTOLETTO}$ 92 reports (1.0 \pm 0.4 \pm 0.3) $\times 10^{-3}$ from a measurement of [Γ(B 0 \rightarrow $\textit{J/}\psi(1S)\;\textit{K}^{+}\;\pi^{-})/\Gamma_{\mbox{total}}] \times [\mbox{B}(\textit{J/}\psi(1S) \rightarrow \ e^{+}\;e^{-})] \; \mbox{assuming} \; \mbox{B}(\textit{J/}\psi(1S) \rightarrow \ e^{+}\;e^{-})$ = 0.069 \pm 0.009, which we rescale to our best value B($J/\psi(1S)
ightarrow e^+e^-$) = (5.94 \pm 0.06) $\times\,10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at

²ALBRECHT 87D assume $B^+B^-/B^0\overline{B}^0$ ratio is 55/45. $K\pi$ system is specifically selected as nonresonant.

| $\Gamma(1/\psi(15) K^*(892)^0) / \Gamma_{total}$ | Γ164/ | |
|--------------------------------------------------|-------|--|
| I (J/1b(15) K*(892)*)/I total | 164/ | |

DOCUMENT ID TECN COMMENT

| _ | 06 OUR AVER | AGE | | | | |
|------------------------------------------------|----------------------------|----------|-------------------------|---------|-----------|---------------------------------------------------|
| $1.30 \begin{array}{c} +0. \\ -0. \end{array}$ | $\frac{22}{21}$ ± 0.04 | | ^{1,2} AUBERT | 07AV | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.309 \pm 0.$ | 026 ± 0.077 | | ² AUBERT | 05 J | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.29 \pm 0.$ | 05 ± 0.13 | | ² ABE | 02N | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.74 \pm 0.$ | 20 ± 0.18 | | ³ ABE | 980 | CDF | <i>p</i> p 1.8 TeV |
| $1.32 \pm 0.$ | 17 ± 0.17 | | 4 JESSOP | 97 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.28 \pm 0.$ | 66 ± 0.01 | | ⁵ BORTOLETTO | 92 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| $1.28 \pm 0.$ | 60 ± 0.01 | 6 | ⁶ ALBRECHT | 90J | ARG | $e^+e^- \rightarrow \gamma(4S)$ |
| 4.07 ±1. | 82 ± 0.04 | 5 | ⁷ BEBEK | 87 | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| • • • We | e do not use the | followin | g data for averages | , fits, | limits, e | tc. • • • |
| 1.24 ±0. | 05 ± 0.09 | | ² AUBERT | 02 | BABR | Repl. by AUBERT 05J |
| $1.36 \pm 0.$ | 27 ± 0.22 | | ⁸ ABE | 96н | CDF | Sup. by ABE 980 |
| $1.69 \pm 0.$ | 31 ±0.18 | 29 | ⁹ ALAM | 94 | CLE2 | Sup. by JESSOP 97 |
| | | | ¹⁰ ALBRECHT | 94 G | ARG | $e^+ e^- \rightarrow \gamma(4S)$ |
| 4.0 ±0. | 30 | | ¹¹ ALBAJAR | 91E | UA1 | $E_{\text{cm}}^{p\overline{p}} = 630 \text{ GeV}$ |
| $3.3 \pm 0.$ | 18 | 5 | ¹² ALBRECHT | 87D | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $4.1 \pm 0.$ | 18 | 5 | ¹³ ALAM | 86 | CLEO | Repl. by BEBEK 87 |
| 1 | | 0 | | . 0. | | |

¹ AUBERT 07AV reports $[\Gamma(B^0 \to J/\psi(1S) K^*(892)^0)/\Gamma_{total}] \times [B(J/\psi(1S) \to p\overline{p})]$ = $(2.82 + 0.30 + 0.36) \times 10^{-6}$ which we divide by our best value B $(J/\psi(1S) \rightarrow p\overline{p}) =$ $(2.17\pm0.07)\times10^{-3}$. Our first error is their experiment's error and our second error is

the systematic error from using our best value. ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

ABE 980 reports $[B(B^0 \to J/\psi(1S)~K^*(892)^0]]/[B(B^+ \to J/\psi(1S)~K^+)] = 1.76 \pm 0.14 \pm 0.15$. We multiply by our best value $B(B^+ \to J/\psi(1S)~K^+) = (9.9 \pm 1.0) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 5 BORTOLETTO 92 reports (1.1 \pm 0.5 \pm 0.3) $\times 10^{-3}$ from a measurement of [Г(B 0 \rightarrow $\textit{J/}\psi(1\textit{S})\;\textit{K*}(892)^{\textstyle 0})/\Gamma_{\textstyle \text{total}}]\;\times\; [\textit{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\;\;e^{+}\,e^{-})]\;\; \text{assuming}\;\; \textit{B}(\textit{J/}\psi(1\textit{S})\;\rightarrow\;\;e^{+}\,e^{-})]$ $e^+\,e^-)=$ 0.069 \pm 0.009, which we rescale to our best value B $(J/\psi(1S)
ightarrow\,e^+\,e^-)=$ $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 6 ALBRECHT 9 0J reports $(1.1\pm0.5\pm0.2) imes10^{-3}$ from a measurement of $[\Gamma(B^0
ightarrow$ $J/\psi(1S)~K^*(892)^0)/\Gamma_{ ext{total}}]~\times~[\mathrm{B}(J/\psi(1S)~\to~e^+\,e^-)]$ assuming $\mathrm{B}(J/\psi(1S)~\to~e^+\,e^-)$ $e^+\,e^-)=$ 0.069 \pm 0.009, which we rescale to our best value B $(J/\psi(1S)
ightarrow\,e^+\,e^-)=$ $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 7 BEBEK 87 reports (3.5 \pm 1.6 \pm 0.3) imes 10 $^{-3}$ from a measurement of [$\Gamma(B^0
ightarrow$ $J/\psi(1S)~K^*(892)^0)/\Gamma_{ ext{total}}]~\times~[B(J/\psi(1S)~\to~e^+\,e^-)]$ assuming $B(J/\psi(1S)~\to~e^+\,e^-)$ $e^+e^-)=0.069\pm0.009$, which we rescale to our best value B $(J/\psi(1S)\to e^+e^-)=$ $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Updated in BORTOLETTO 92 to use the same assumptions.

⁸ ABE 96H assumes that B($B^+ \to J/\psi K^+$) = (1.02 ± 0.14) × 10⁻³.

⁹ The neutral and charged B events together are predominantly longitudinally polarized, $\Gamma_L/\Gamma=0.080\pm0.08\pm0.05$. This can be compared with a prediction using HQET, 0.73 (KRAMER 92). This polarization indicates that the $B \to \, \psi \, K^*$ decay is dominated by the $\mathit{CP} = -1$ CP eigenstate. Assumes equal production of B^+ and B^0 at the $\varUpsilon(4\mathit{S})$.

 $^{
m 10}$ ALBRECHT 94G measures the polarization in the vector-vector decay to be predominantly longitudinal, $\Gamma_{\slash\hspace{-0.4em}T}/\Gamma=0.03\pm0.16\pm0.15$ making the neutral decay a $\it CP$ eigenstate when the K^{*0} decays through $K_S^0 \pi^0$

¹¹ ALBAJAR 91E assumes B_d^0 production fraction of 36%.

 12 ALBRECHT 87D assume $B^+B^-/B^0\overline{B}^0$ ratio is 55 /45. Superseded by ALBRECHT 90J. 13 ALAM 86 assumes B^{\pm}/B^0 ratio is 60/40. The observation of the decay $B^+ \rightarrow$ $J/\psi\, K^*(892)^+$ (HAAS 85) has been retracted in this paper.

| $\Gamma(J/\psi(1S) K^*(892)^{\circ})/\Gamma(.$ | $J/\psi(1S)K^0$ | | | | $\Gamma_{164}/\Gamma_{162}$ |
|------------------------------------------------|-----------------|------|------|---------|-----------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 1.50±0.09 OUR AVERAGE | · | | | | |
| $1.51 \pm 0.05 \pm 0.08$ | ALIDEDT | 05.1 | BARR | a+a | $\Upsilon(AS)$ |

96Q CDF *p*p ABE $1.39 \pm 0.36 \pm 0.10$ • • • We do not use the following data for averages, fits, limits, etc. • • •

 $1.49 \pm 0.10 \pm 0.08$ ¹ AUBERT 02 BABR Repl. by AUBERT 05J

 1 Assumes equal production of \mathcal{B}^+ and $\mathcal{B}^{\,0}$ at the $\varUpsilon(4S)$.

$\Gamma(J/\psi(1S)\eta K_S^0)/\Gamma_{\text{total}}$ Γ_{165}/Γ

VALUE (units 10^{-5}) DO CUMENT ID TECN COMMENT ¹ AUBERT 8.4 ± 2.6 ± 2.7 04Y BABR $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

$\Gamma(J/\psi(1S)\eta'K_S^0)/\Gamma_{\text{total}}$

 Γ_{166}/Γ VALUE (units 10^{-5}) TECN COMMENT DOCUMENT ID CL% $^{1}\,\mathrm{XIE}$ < 2.5 90 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(J/\psi(1S)\omega K^0)/\Gamma_{\text{total}}$

VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT 1 DEL-AMO-SA...10B BABR $e^{+}\,e^{-}
ightarrow ~ \varUpsilon(4S)$ $2.3 \pm 0.3 \pm 0.3$

• • • We do not use the following data for averages, fits, limits, etc. • • • $^{\mathrm{1}}$ AUBERT $3.1 \pm 0.6 \pm 0.3$

08W BABR Repl. by DEL-AMO-SANCHEZ 10B 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

$\Gamma(X(3872)K^0 \times B(X \rightarrow J/\psi\omega))/\Gamma_{\text{total}}$

 Γ_{169}/Γ DOCUMENT ID TECN COMMENT

 Γ_{168}/Γ

VALUE (units 10-6) 1 DEL-AMO-SA...10B BABR $e^{+}e^{-}
ightarrow$ 6±3±1

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

$\Gamma(X(3915)K^0 \times B(X \rightarrow J/\psi\omega))/\Gamma_{\text{total}}$ Γ_{170}/Γ VALUE (units 10⁻⁵) DOCUMENT ID TECN COMMENT

 1 DEL-AMO-SA...10B BABR $e^{+}\,e^{-}
ightarrow ~ \varUpsilon(4S)$ $2.1 \pm 0.9 \pm 0.3$ • • • We do not use the following data for averages, fits, limits, etc. • • •

 $1.3^{+1.3}_{-1.1} \pm 0.2$ 1,2 AUBERT 08W BABR Repl. by DEL-AMO-SANCHEZ 10B

 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

 2 Corresponds to upper limit of 3.9×10^{-5} at 90% CL.

$\Gamma(J/\psi(1S)\phi K^0)/\Gamma_{\text{total}}$ Γ_{167}/Γ DOCUMENT ID TECN COMMENT

) × 10⁻⁵ OUR AVERAGE (9.4 ± 2.6) $\stackrel{\cdot}{(10.2\pm3.8\pm1.0)}\times10^{-5}$ ¹ AUBERT 030 BABR $e^+e^- \rightarrow \Upsilon(4S)$ $(8.8^{+3.5}_{-3.0}\pm1.3)\times10^{-5}$ 2 anastassov 00 CLE2 $e^+e^-
ightarrow \varUpsilon (4\,{\it S})$

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 2 A NASTASSOV 00 finds 10 events on a background of 0.5 \pm 0.2. Assumes equal production of B^0 and B^+ at the $\varUpsilon(4S)$, a uniform Dalitz plot distribution, isotropic $J/\psi(1S)$ and ϕ decays, and B($B^+ \rightarrow J/\psi(1S) \phi K^+$)= B($B^0 \rightarrow J/\psi(1S) \phi K^0$).

 $^{^4}$ Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$.

 1 Uses $B^0 o J/\psi(1S)$ K 0_S decay as a reference and B($B^0 o J/\psi(1S)$ K 0) $= 8.3 \times 10^{-4}$.

 B^0

| $\Gamma(J/\psi(1S) K(1270)^0)/\Gamma_{\text{total}}$ | Γ ₁₇₁ /Γ | $\Gamma(J/\psi(1S)K^*(89))$ | $(2)^+\pi^-)/\Gamma_{to}$ | tal | | | Γ ₁₈₃ /Γ |
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| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | | VALUE (units 10 ⁻⁴) | | DOCUMENT ID | TECN | | |
| 1.30 \pm 0.34 \pm 0.32 | () | 7.7 \pm 4.1 \pm 1.3 1 Uses $B^0 \rightarrow J/\psi$ | | ¹ AFFOLDER as a reference ar | 02B CDF and B($B^0 \rightarrow B$ | $p\overline{p}$ 1.8 TeV $I/\psi(1S) K^0$)= | |
| $B(B^+ \to J/\psi(1S) K^+) = (1.00 \pm 0.10) \times 10^{-3}$ | | Γ(<i>J/ψ</i> (1 <i>S</i>) <i>K</i> *(89 | 9 | | | | Г ₁₈₄ /Г |
| $\Gamma(J/\psi(1S)\pi^0)/\Gamma_{\text{total}}$ | Γ ₁₇₂ /Γ | VALUE (units 10^{-4}) | | DO CUMENT ID | | COMMENT | |
| <u>VALUE (units 10⁻⁵) </u> | | $6.6 \pm 1.9 \pm 1.1$ | | ¹ AFFOLDER | | <i>ρ</i> p 1.8 TeV | |
| $1.69\pm0.14\pm0.07$ 1 AUBERT 08AU BABR $e^{+}e^{-} ightarrow \Upsilon(4.69\pm0.14\pm0.07)$ | S) | ¹ Uses $B^0 \rightarrow J/$ | $\psi(1S) K^*(892)$ | ⁰ decay as a re | ference and | $B(B^0 \rightarrow J/$ | $\psi(1S) K^{0}) =$ |
| $2.3~\pm 0.5~\pm 0.2$ 1 ABE 03 B BELL e^{+} e^{-} $ ightarrow$ (4.5) | 5) | 12.4×10^{-4} | | | | | |
| $2.5 \ {}^{+1.1}_{-0.9} \ \pm 0.2$ 1 AVERY 00 CLE2 $e^+e^- ightarrow \ \varUpsilon(4.5)$ | S) | Γ(X (3872) ⁻ K ⁺) | | | | | Γ ₁₈₅ /Γ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | <u>∨ALUE</u> <5 × 10 ⁻⁴ | <u>CL%</u> 90 | DOCUMENT ID AUBERT | | $e^+e^- \rightarrow$ | 20(4.6) |
| $1.94\pm0.22\pm0.17$ 1 AUBERT,B 06B BABR Repl. by AUBER 2.0 ±0.6 ±0.2 1 AUBERT 02 BABR Repl. by AUBER | | ¹ Perform measure | | | | | |
| < 32 90 ² ACCIARRI 97c L3 | | | | = | | = | _ |
| < 5.8 90 BISHAI 96 CLE2 Sup. by AVERY <690 90 ¹ ALEXANDER 95 CLE2 Sup. by BISHAI | | Γ(X (3872) - K+ > | CL% | $\rightarrow J/\psi(15)$ | . , . | total COMMENT | Γ ₁₈₆ /Γ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 1 30 | <4.2 | | 2 CHOI | | $e^+e^- \rightarrow$ | Υ(4 S) |
| ² ACCIARRI 97c assumes B^0 production fraction (39.5 \pm 4.0%) and B_S (12. | $0 \pm 3.0\%$). | • • • We do not us | | | | | (43) |
| $\Gamma(J/\psi(1S)\eta)/\Gamma_{\text{total}}$ | Γ ₁₇₃ /Γ | <5.4 | 90 2, | ³ AUBERT | 05в BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $VALUE$ (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT | 11/3/1 | 1_2 Assumes $\pi^+\pi^0_2$ | | | | | |
| 9.5 \pm 1.7 \pm 0.8 1 CHANG 07A BELL $e^+e^- \rightarrow 7$ | Υ(4S) | ² Assumes equal p ³ The isovector- <i>X</i> | | | | at 1 × 10-4 | level |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | , | _ | | | | | |
| $<$ 27 90 1 AUBERT 030 BABR $e^{+}e^{-} \rightarrow 7$ $<$ 1200 90 2 ACCIARRI 97c L3 | r(45) | $\Gamma(X (3872) K^0 \times E^{0})$ | - | T'π))/Itot: DOCUMENT ID | | COMMENT | Γ ₁₈₇ /Γ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | 4.3±1.2±0.4 | <u>CL%</u> | ² CHOI | 11 BELL | $e^+e^- \rightarrow$ | T(45) |
| ² ACCIARRI 97c assumes B^0 production fraction (39.5 \pm 4.0%) and B_S (12. | 0 ± 3.0%). | • • • We do not us | | | | | . () |
| $\Gamma(J/\psi(1S)\pi^{+}\pi^{-})/\Gamma_{\text{total}}$ | Γ ₁₇₄ /Γ | < 6.0 | | ² AUBERT | | $e^+e^- \rightarrow$ | |
| VALUE DOCUMENT ID TECN COMMENT | 174/ | <10.3 | | 3 AUBERT | | Repl. by Al | |
| $ \frac{\text{(4.6\pm0.7\pm0.6)} \times 10^{-5}}{\text{1 AUBERT}} \qquad \text{03B} \qquad \overline{\text{BABR}} \qquad e^+e^- \rightarrow 7 $ | r(45) | 1 CHOI 11 reports $X(3872)~{\it K}^+ 	imes {\it B}$ | $[I (B^0 \rightarrow X)]$ | 8/2) K o × B(X | $\rightarrow J/\psi \pi^{+} \tau$ $\downarrow 0.14 \pm 0.04$ | τ¯))/I _{total}] Iwhich we mi | / [B(B⊤ → |
| 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4 S). | | best value $B(B^+)$ | $\rightarrow X(3872) K$ | $^+ \times B(X \rightarrow J)$ | $(\psi \pi^{+} \pi^{-})) =$ | $= (8.6 \pm 0.8)$ | $	imes 10^{-6}$. Our |
| $\Gamma(J/\psi(1S)\pi^+\pi^-$ nonresonant)/ Γ_{total} | Γ ₁₇₅ /Γ | first error is thei using our best va | | error and our se | cond error is | the systemat | ic error from |
| VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | 1137 | ² Assumes equal p | roduction of B^{-} | | | | |
| <1.2 90 1 AUBERT 07AC BABR $e^+e^- \rightarrow 7$ | r(45) | ³ The lower limit is | s also given to | be 1.34 × 10 ⁻⁶ | at 90% CL. | | |
| 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4 S). | | $\Gamma(X(3872) K^0 \times E$ | $3(X \to J/\psi \gamma)$ | /))/Γ _{total} | | | Γ ₁₈₈ /Γ |
| $\Gamma(J/\psi(1S)f_2)/\Gamma_{total}$ | Γ ₁₇₆ /Γ | VALUE (units 10^{-6}) | CL% | DOCUMENT ID | | | |
| VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | | <2.4 • • • We do not us | | ¹ BHARDWAJ | | | T(45) |
| <0.46 90 1 AUBERT 07AC BABR $e^+e^- \rightarrow 7$ | r(45) | <4.9 | _ | aata ioi avelage ² aubert | | e ⁺ e ⁻ → | $\Upsilon(AS)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | ¹ Assumes equal p | | | | | 7 (43) |
| $\Gamma(J/\psi(1S) ho^0)/\Gamma_{ m total}$ | Γ ₁₇₇ /Γ | 2 Uses B(Υ (4 S) $-$ | | | | $B^0 \overline{B}{}^0) = (4$ | $8.4 \pm 0.6)\%$ |
| VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | | Γ(X (3872) K*(89 | $2)^0 \times B(X \rightarrow$ | $J/\psi\gamma))/\Gamma_{tc}$ | tal | | Γ ₁₈₉ /Γ |
| 2.7\pm0.3\pm0.2 1 AUBERT 07AC BABR $e^+e^- \rightarrow r(4)$ | 4 <i>S</i>) | <u>VALUE (units 10⁻⁶)</u> | <u>CL%</u> | DO CUMENT ID | | COMMENT | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $1.6 \pm 0.6 \pm 0.4$ AUBERT 03B BABR Repl. by AUBE | ERT 0740 | <2.8 | | ¹ AUBERT | | $e^+e^- \rightarrow$ | · / |
| <25 90 BISHAI 96 CLE2 $e^+e^- \rightarrow \tau(4$ | | 1 Uses B(\varUpsilon (4 s) $-$ | $\rightarrow B^+B^-)=(5$ | 1.6 ± 0.6)% and | $B(\varUpsilon(4S) 	o$ | $B^0 \overline{B}{}^0) = (4$ | $8.4 \pm 0.6)\%$. |
| 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (45). | | $\Gamma(X(3872)K^0 \times E^{-1})$ | $3(X \to \psi(2S))$ | $)\gamma))/\Gamma_{ m total}$ | | | Γ ₁₉₀ /Γ |
| 5/1//46\ \/5 | Γ ₁₇₈ /Γ | VALUE (units 10 ⁻⁶) | <u>CL%</u> | DOCUMENT ID | | COMMENT | |
| $I(J/\psi(15)\omega)/I_{total}$ | | < 6.62 | | 1 | 11 DELL | $e^+e^ \rightarrow$ | T(45) |
| $I(J/\psi(15)\omega)/I$ total VALUE CL% DOCUMENT ID TECN COMMENT VALUE CL% DOCUMENT ID TECN COMMENT | . 1/0/. | • | | | | | |
| | | • • • We do not us | e the following | data for average | s, fits, limits, | etc. • • • | 20(4.6) |
| VALUE CL% DOCUMENT ID TECN COMMENT $< 2.7 \times 10^{-4}$ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 1$ | r(45) | • • • We do not us | e the following 90 | data for average ² AUBERT | s, fits, limits, 09B BABR | | Y(45) |
| VALUE CL% DOCUMENT ID TECN COMMENT $< 2.7 \times 10^{-4}$ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 1$ | | • • • We do not us | e the following 90 roduction of <i>B</i> - | data for average ² AUBERT ⁺ and <i>B</i> ⁰ at the | s, fits, limits, 09 B BABR $\Upsilon(4S)$. | etc. • • • • $e^+e^- \rightarrow$ | , , |
| VALUE CL% DOCUMENT ID TECN COMMENT <2.7 × 10 ⁻⁴ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 7$ $\Gamma(J/\psi(1S)\phi)/\Gamma_{total}$ VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT <0.94 | r(4 <i>S</i>) Γ ₁₇₉ /Γ | $\bullet \bullet \bullet$ We do not use <19 1 Assumes equal p 2 Uses B($\varUpsilon(4S)$ — | e the following 90 roduction of B^- $\rightarrow B^+B^-) = (5$ | data for average 2 AUBERT $^+$ and B^0 at the $^1.6 \pm 0.6)\%$ and | es, fits, limits, $09B$ BABR $\mathcal{T}(4S)$. I B($\mathcal{T}(4S)$ $ ightarrow$ | etc. • • • • $e^+e^- \rightarrow$ | 8.4 ± 0.6) % |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | r(4S) Γ ₁₇₉ /Γ r(4S) | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(\gamma(45)\) - \(\begin{align*} \begin{align*} al | e the following 90 roduction of B^- $\rightarrow B^+B^-) = (5$ 2) $^0 \times B(X \rightarrow $ | data for average 2 AUBERT $^+$ and B^0 at the $^1.6\pm0.6)\%$ and $\psi(2S)\gamma))/1$ | es, fits, limits, $09B BABR$ er $\Upsilon(4S)$. If $B(\Upsilon(4S) \rightarrow total)$ | etc. • • • $e^+e^- \rightarrow$ $B^0\overline{B}^0) = (4)$ | , , |
| VALUE CL% DOCUMENT ID TECN COMMENT $<2.7 \times 10^{-4}$ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 7$ $\Gamma(J/\psi(1S)\phi)/\Gamma_{total}$ VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT <0.94 90 1 LIU 081 BELL $e^+e^- \rightarrow 7$ <0.94 • • • We do not use the following data for averages, fits, limits, etc. • • • <9.2 90 1 AUBERT 030 BABR $e^+e^- \rightarrow 7$ | r(4S) Γ ₁₇₉ /Γ r(4S) | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(\gamma(4S)\) \(\begin{align*} \begin{align*} a | 90 roduction of B^{-} $B^{+}B^{-}$) = (5 2) $^{0} \times B(X \rightarrow CL\%)$ | data for average 2 AUBERT $^+$ and 0 at the 1 1 1 2 2 2 2 2 2 2 2 | es, fits, limits, one babbands (45) . If (45) \rightarrow total (76) | etc. • • • $e^+e^- \rightarrow B^0\overline{B}{}^0) = (4$ | 18.4 ± 0.6)%. Γ 191 /Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | r(4S) Γ ₁₇₉ /Γ r(4S) | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(\gamma(45)\) - \(\begin{align*} \begin{align*} al | e the following 90 roduction of B^- $\Rightarrow B^+B^-$) = (5 2) ⁰ × B($X \rightarrow CL\%$ 90 | data for average 2 AUBERT $^+$ and 0 at the 1 1 2 2 2 2 2 2 2 2 | es, fits, limits, one babble of $(4S)$. I B($T(4S)$) of total $TECN$ BABR | etc. • • • $e^{+}e^{-} \rightarrow$ $B^{0}\overline{B}^{0}) = (4$ $\overline{e^{+}e^{-}} \rightarrow$ | $\frac{18.4 \pm 0.6)\%}{\Gamma_{191}/\Gamma}$ |
| VALUE CL% DOCUMENT ID TECN COMMENT TO SITE OF A PARTICLE (Units 10^{-6}) $CL\%$ DOCUMENT ID TECN COMMENT TO SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID TECN COMMENT TO SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO $CL\%$ DOCUMENT ID SITE OF $e^+e^- \rightarrow 0$ TO e | r(4S) Γ ₁₇₉ /Γ r(4S) | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(T(4S) -) \(\begin{align*} \begin{align*} align* | e the following 90 roduction of B^- $\rightarrow B^+B^-$) = (5 2) $^0 \times B(X \rightarrow CL\%)$ $\rightarrow B^+B^-$) = (5 | data for average 2 AUBERT $^+$ and B at the 1 2 2 2 2 2 2 2 2 | es, fits, limits, one babble of $(4S)$. I B($T(4S)$) of total $TECN$ BABR | etc. • • • $e^{+}e^{-} \rightarrow$ $B^{0}\overline{B}^{0}) = (4$ $\overline{e^{+}e^{-}} \rightarrow$ | Γ_{191}/Γ Γ_{191}/Γ $\Gamma_{18.4 \pm 0.6)\%$. |
| VALUE COMMENT ID TECN COMMENT 10 TECN TECN TO TECN TECN TO TECN TECN TO TECN TECN TECN TECN TECN TECN TECN TECN | r(45) Γ ₁₇₉ /Γ r(45) Γ ₁₈₀ /Γ | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(\alpha(4S)\) — \(\begin{align*} \begin{align*} al | e the following 90 roduction of B^- $\rightarrow B^+B^-$) = (5 2) $^0 \times B(X \rightarrow CL\%)$ $\rightarrow B^+B^-$) = (5 | data for average 2 AUBERT $^+$ and 0 at the 1 .6. \pm 0.6)% and 0 $\psi(2S)\gamma)$ // 0 DOCUMENT ID 1 AUBERT 1 .1.6. \pm 0.6)% and 0 π^0) // Γ total | s, fits, limits, $\begin{array}{ccc} 098 & \text{BABR} \\ e & \varUpsilon(4S). \end{array}$ $\begin{array}{ccc} \text{IB}(\varUpsilon(4S) \rightarrow \\ & & \\ \hline & & \\ $ | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $B^{0}\overline{B}^{0}) = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $B^{0}\overline{B}^{0}) = (4)$ | $\frac{18.4 \pm 0.6)\%}{\Gamma_{191}/\Gamma}$ |
| VALUE CL% DOCUMENT ID TECN COMMENT <2.7 × 10 ⁻⁴ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 0$ \(\begin{array}{cccccccccccccccccccccccccccccccccccc | r(45) Γ ₁₇₉ /Γ r(45) Γ ₁₈₀ /Γ | • • • • We do not use <19 1 Assumes equal p 2 Uses B(\(\alpha(4S) - \) \(\begin{align*} \begin | e the following 90 roduction of B^{-} $B^{+}B^{-}) = (5$ $2)^{0} \times B(X \rightarrow \frac{CL\%}{90})$ $\Rightarrow B^{+}B^{-}) = (5$ $B(X \rightarrow D^{0}\overline{D})$ | data for average 2 AUBERT $^+$ and 0 at the $^{1.6} \pm 0.6)\%$ and 0 0 AUBERT 1 AUBERT 1 AUBERT 1 1 AUBERT 1 1 1 AUBERT 1 1 1 1 1 1 1 1 | s, fits, limits, observed by the set of the | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $B^{0}\overline{B}^{0}) = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $B^{0}\overline{B}^{0}) = (4)$ $\frac{COMMENT}{e^{-}e^{-}} \rightarrow$ $\frac{COMMENT}{e^{-}e^{-}} \rightarrow$ | Γ_{191}/Γ Γ_{191}/Γ Γ_{192}/Γ Γ_{192}/Γ |
| VALUE (units 10^{-6}) $CL\%$ DOCUMENT ID TECN COMMENT $CL\%$ $e^+e^- \rightarrow 0$ | r(45) Γ ₁₇₉ /Γ r(45) Γ ₁₈₀ /Γ | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(T(45) — F(X (3872) K*(89) MLUE (units 10^-6) <4.4 1 Uses B(T(45) — F(X (3872) K^0 × E MLUE (units 10^-4) 1.66±0.70+0.32 | roduction of $B^ \Rightarrow B^+B^-$) = (ξ $= \frac{cL\%}{90}$ $\Rightarrow B^+B^-$) = (ξ $= \frac{cL\%}{90}$ $\Rightarrow B^+B^-$) = (ξ $= \frac{cL\%}{90}$ | data for average 2 AUBERT $^+$ and 0 at the 1 .6 \pm 0.6)% and 0 1 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 1 AUBERT 1 1 1 AUBERT 1 1 1 AUBERT 1 1 1 1 1 1 1 1 | $\begin{array}{c} \text{09B BABR} \\ \text{2 } \varUpsilon(4S). \\ \text{1 B} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Γ_{191}/Γ $\Gamma_{(4S)}$ Γ_{192}/Γ $\Gamma_{(4S)}$ |
| VALUE (units 10^{-6}) $CL\%$ DOCUMENT ID TECN COMMENT $CL\%$ $e^+e^- \rightarrow 0$ | r(45) Γ ₁₇₉ /Γ r(45) Γ ₁₈₀ /Γ | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(\(T(4S) - \) \(T(X(3872) K^*(89) \) \(\text{MLUE} (units 10^{-6}) \) <4.4 1 Uses B(\(T(4S) - \) \(T(X(3872) K^0 \times \) \(\text{MLUE} (units 10^{-4}) \) 1.66\(\pm 0.37 \) 1 Measure the near | e the following 90 roduction of $B^ \mapsto B^+B^-$) = (ξ 2) 0 × B($X \rightarrow \frac{cL\%}{90}$ $\mapsto B^+B^-$) = (ξ 3) $(X \rightarrow D^{0}\overline{D})$ | data for average 2 AUBERT $^+$ and 0 at the 1 .6 \pm 0.6)% and 0 1 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 .1.6 \pm 0.6)% and 1 1 AUBERT 1 1 AUBERT 1 1 1 AUBERT 1 1 1 AUBERT 1 1 1 1 1 1 1 1 | $\begin{array}{c} \text{09B BABR} \\ \text{2 } \varUpsilon(4S). \\ \text{1 B} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Γ_{191}/Γ $\Gamma_{(4S)}$ Γ_{192}/Γ $\Gamma_{(4S)}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | r(4S) Γ ₁₇₉ /Γ r(4S) Γ(4S) Γ ₁₈₀ /Γ r(4S) | ••• We do not us: <19 1 Assumes equal p 2 Uses B(T(4S) — F(X(3872)K*(89) MALUE (units 10-6) <4.4 1 Uses B(T(4S) — F(X(3872)K0 × E MLUE (units 10-4) 1.66±0.70+0.32 1 Measure the near 0.7+0.3 ± 0.8 M | e the following 90 roduction of $B^ \mapsto B^+B^-$) = (ξ 2) 0 × B($X \rightarrow \frac{CL\%}{90}$ $\mapsto B^+B^-$) = (ξ 3($X \rightarrow D^0\overline{D}$ $\xrightarrow{C-}$ threshold enhance V/c^2 . | data for average 2 AUBERT $^+$ and 0 at the 1 .1.6 \pm 0.6)% and 0 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 0 π^0))/ Γ total 0 π^0))/ Γ total 0 π^0) occument 1 1 GOKHROO ncements in the | $\begin{array}{c} \text{09B BABR} \\ \text{2 } \varUpsilon(4S). \\ \text{1 B} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Γ_{191}/Γ $\Gamma_{(4S)}$ Γ_{192}/Γ $\Gamma_{(4S)}$ |
| <2.7 × 10 ⁻⁴ 90 BISHAI 96 CLE2 $e^+e^- → 7$ Γ($J/ψ(1S)φ)/Γ_{total}$ VALUE (units 10 ⁻⁶) 20 1 LIU 90 1 LIU 90 1 BISHAI 96 CLE2 $e^+e^- → 7$ 20 20 20 40.94 90 1 LIU 91 81 81 81 81 81 81 81 81 81 81 81 81 81 | Γ(45) Γ179/Γ Γ(45) Γ(45) Γ180/Γ Γ(45) Γ181/Γ | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(\(T(4S) - \) \(T(X(3872) K^*(89) \) \(\text{MLUE} (units 10^{-6}) \) <4.4 1 Uses B(\(T(4S) - \) \(T(X(3872) K^0 \times \) \(\text{MLUE} (units 10^{-4}) \) 1.66\(\pm 0.37 \) 1 Measure the near | e the following 90 roduction of $B^ \mapsto B^+B^-$) = (ξ 2) 0 × B($X \rightarrow \frac{CL\%}{90}$ $\mapsto B^+B^-$) = (ξ 3($X \rightarrow D^0\overline{D}$ $\xrightarrow{C-}$ threshold enhance V/c^2 . | data for average 2 AUBERT $^+$ and 0 at the 1 .1.6 \pm 0.6)% and 0 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 0 π^0))/ Γ total 0 π^0))/ Γ total 0 π^0) occument 1 1 GOKHROO ncements in the | $\begin{array}{c} \text{09B BABR} \\ \text{2 } \varUpsilon(4S). \\ \text{1 B} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | etc. \bullet \bullet $e^{+}e^{-} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ $e^{0}\overline{B}^{0} = (4)$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Γ_{191}/Γ $\Gamma_{(4S)}$ Γ_{192}/Γ $\Gamma_{(4S)}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | Γ(45) Γ179/Γ Γ(45) Γ(45) Γ180/Γ Γ(45) Γ181/Γ | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(T(4S) — F(X(3872) K*(89) MALUE (units 10-6) <4.4 1 Uses B(T(4S) — F(X(3872) K0 × E MALUE (units 10-4) 1.66±0.70±0.32 1 Measure the near 0.7±0.3 ± 0.8 M F(X(3872) K0 × E MALUE (units 10-4) | e the following 90 roduction of $B^ \mapsto B^+B^-$) = (ξ 2) 0 \times $B(X \to \frac{CL\%}{90})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ $B(X \to D^0\overline{D})$ $\mapsto B^+B^-$) = (ξ B^+B^-) = (ξ ξ B^+B^-) = (ξ ξ B^+B^-) = (ξ ξ ξ ξ ξ ξ ξ | data for average 2 AUBERT $^+$ and 0 at the 1 .1.6 \pm 0.6)% and 0 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 0 π^0))/ Γ total 0 π^0))/ Γ total 0 π^0) occument 1 1 GOKHROO ncements in the | $\begin{array}{c} \text{09B BABR} \\ \text{2 } \varUpsilon(4S). \\ \text{1 B} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \text{1 b} (\varUpsilon(4S) \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | etc. $\bullet \bullet \bullet$ $e + e - \rightarrow$ $B^0 \overline{B}{}^0) = (A^0 \overline{B}{}^0)$ | Γ_{191}/Γ $\Gamma_{(45)}$ Γ_{192}/Γ $\Gamma_{(45)}$ Γ_{192}/Γ $\Gamma_{(45)}$ ass $3875.2 \pm$ |
| VALUE CL% DOCUMENT ID TECN COMMENT $<2.7 \times 10^{-4}$ 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 7$ [** (J/\psi(15)\phi)/\psi(15)\phi)/\psi(150)\phi)/\psi(150)\phi) CL% DOCUMENT ID TECN COMMENT <0.94 90 1 LIU 081 BELL $e^+e^- \rightarrow 7$ <9.2 90 1 AUBERT 030 BABR $e^+e^- \rightarrow 7$ 1 Assumes equal production of B^+ and B^0 at the $T(45)$. $T(45)$. Image: Comment of the image of | Γ(45) Γ179/Γ Γ(45) Γ(45) Γ180/Γ Γ(45) Γ181/Γ | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(T(4S) — Γ(X(3872) K*(89) MALUE (units 10-6) <4.4 1 Uses B(T(4S) — Γ(X(3872) K ⁰ × E MALUE (units 10-4) 1.66±0.70±0.37 1 Measure the near 0.7±0.3 ±0.8 N Γ(X(3872) K ⁰ × E MALUE (units 10-4) 1.2±0.4 OUR AVI | reduction of B^{-} $B^{+}B^{-}$) = (E^{-} $B^{+}B^{-}$) = (E^{-} B^{-} | data for average 2 AUBERT $^+$ and 0 at the 1 .1.6 \pm 0.6)% and 0 1 AUBERT 1 AUBERT 1 AUBERT 1 .1.6 \pm 0.6)% and 0 π^0))/ Γ total 1 DOCUMENT ID 1 GOKHROO ncements in the 1 DOCUMENT ID 1 DOCUMENT ID 1 DOCUMENT ID 1 | s, fits, limits, observed by the set of the | etc. \bullet \bullet \bullet $e^+e^- \rightarrow \bullet$ $\bullet B^0\overline{B}^0) = (a^0 - a^0) | $68.4 \pm 0.6)\%$. Γ_{191}/Γ $\Upsilon(45)$ $88.4 \pm 0.6)\%$. Γ_{192}/Γ $\Upsilon(45)$ ass $3875.2 \pm \Gamma_{193}/\Gamma$ |
| VALUE (2.7×10^{-4}) 90 BISHAI 96 CLE2 $e^+e^- \rightarrow 7$ $\Gamma(J/\psi(1S)\phi)/\Gamma_{total}$ VALUE (units 10^{-6}) $CL\%$ DOCUMENT ID TECN COMMENT < 0.94 90 1 LIU 081 BELL $e^+e^- \rightarrow 7$ < 0.94 90 1 AUBERT 030 BABR $e^+e^- \rightarrow 7$ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(J/\psi(1S)\eta'(958))/\Gamma_{total}$ VALUE (units 10^{-5}) $CL\%$ DOCUMENT ID TECN COMMENT 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(J/\psi(1S)\eta'(958))/\Gamma_{total}$ VALUE (units 10^{-5}) $CL\%$ DOCUMENT ID TECN COMMENT 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. $\Gamma(J/\psi(1S)K^0\pi^+\pi^-)/\Gamma_{total}$ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT 1 ASSUMES 10^{-4} $10.3\pm 3.3\pm 1.5$ 1 AFFOLDER 02B CDF $p\overline{p}$ 1.8 TeV 1 Uses 10^{-4} $10.3\pm 3.3\pm 1.5$ 1 AFFOLDER 02B CDF 10^{-4} 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5 $10.$ | r(45) | • • • • We do not us: <19 1 Assumes equal p 2 Uses B(T(4S) — F(X(3872) K*(89) MALUE (units 10-6) <4.4 1 Uses B(T(4S) — F(X(3872) K0 × E MALUE (units 10-4) 1.66±0.70±0.32 1 Measure the near 0.7±0.3 ± 0.8 M F(X(3872) K0 × E MALUE (units 10-4) | reduction of B^{*} $B^{+}B^{-}$) = (\mathbb{E} 2) 0 × $\mathbf{B}(X \rightarrow 0)$ 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 × 0 | data for average 2 AUBERT $^+$ and 0 at the 1 c. 1 c. 1 c. 2 c. 2 c. 2 c. 2 dubert 1 dubert 1 dubert 1 c. 1 dubert 1 dubert 1 dubert 1 dubert 1 dubert 1 dubert 1 document 1 document 1 document 1 document 1 documents in the 1 comments in the 1 composite 1 dubert 2 dubert | s, fits, limits, 098 BABR $2 \Upsilon(4S)$. I B($\Upsilon(4S) \rightarrow 1$ TECN 098 BABR I B($\Upsilon(4S) \rightarrow 1$ TECN 06 BELL $(D^0 \overline{D}^0 \pi^0)$ $\frac{1}{2}$ TECN $\frac{1}{2}$ TECN $\frac{1}{2}$ BELL 1 | etc. $\bullet \bullet \bullet$ $e + e - \rightarrow$ $B^0 \overline{B}{}^0) = (A^0 \overline{B}{}^0)$ | $7(4S)$ $193/\Gamma$ $193/\Gamma$ |

 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S).$ 2 This result is equivalent to the the 90% CL upper limit of 4.37 \times 10 $^{-4}$

| 「(X (4430)± K∓ × /ALUE (units 10 ⁻⁵) | Б(Х − → <u>СL%_</u> | ψ(23)π-))/ <u>DOCUMENT II</u> | | TECN | COMMENT | Γ ₁₉₄ / |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| $3.2^{+1.8}_{-0.9}^{+5.3}_{-1.6}$ | | ¹ MIZUK | 09 | BELL | $e^+e^ \rightarrow$ | T(45) |
| • • We do not use | the followin | - | _ | | | |
| <3.1 | 95 | ¹ AUBERT ^{1,2} CHOI | 09A | A BABR BELL | | |
| $4.1 \pm 1.0 \pm 1.4$ 1 Assumes equal pro | duction of | | | | Repl. by N | MIZUK U9 |
| ² Establishes the X(| | | | | leeds confirm | nation. |
| (X (4430) ± K [∓] × | | = | | Ü | | _ |
| (A (4430) — A · X ALUE (units 10 ⁻⁵) | | DOCUMENT IL | | TECN | COMMENT | Γ ₁₉₅ / |
| <0.4 | <u>CL%</u> 95 | 1 AUBERT | 094 | | $e^+e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | duction of | _ | | | | 7 (43) |
| | | | (. | - /- | | - , |
| $(J/\psi(1S) p \overline{p})/\Gamma_{to}$ | otal <u>CL%_</u> | DO CUMENT IL | 7 | TECN | COMMENT | Γ ₁₉₆ / |
| <8.3 × 10 ⁻⁷ | 90 | 1 XIE | 05 | BELL | | Y(45) |
| • • We do not use | the followin | g data for averag | ges, fits | , limits, | | . , |
| $< 1.9 \times 10^{-6}$ | 90 | $^{ m 1}$ AUBERT | 03K | BABR | $e^+e^- \to$ | Y(45) |
| ¹ Assumes equal pro | duction of | \mathcal{B}^+ and \mathcal{B}^0 at t | he $\varUpsilon(4$ | S). | | |
| $(J/\psi(1S)\gamma)/\Gamma_{\rm tot}$ | al | | | | | Γ197/ |
| ALUE (units 10 ⁻⁶) | CL% | DOCUMENT II |) | TECN | COMMENT | 2317 |
| <1.6 | 90 | ¹ AUBERT,B | 04т | BABR | $e^+e^- \rightarrow$ | Y(45) |
| ¹ Assumes equal pro | duction of | ${\it B}^{+}$ and ${\it B}^{0}$ at t | he $\Upsilon(4)$ | S). | | |
| $(J/\psi(1S)\overline{D}^0)/\Gamma_{to}$ | ot al | | | | | Γ ₁₉₈ / |
| ALUE (units 10 ⁻⁵) | CL% | DO CUMENT IL |) | TECN | COMMENT | 1707 |
| <1.3 | 90 | 1 AUBERT | | BABR | | Y(45) |
| $\bullet~\bullet~$ We do not use | the followin | - | ges, fits | , limits, | etc. • • • | |
| <2.0 | 90 | ¹ ZHA NG | | BELL | $e^+ e^- \rightarrow$ | Y(45) |
| ¹ Assumes equal pro | duction of | ${\it B}^{+}$ and ${\it B}^{0}$ at t | he $\Upsilon(4)$ | S). | | |
| $(\psi(2S) K^0)/\Gamma_{\rm tota}$ | i | | | | | Γ199/ |
| ALUE (units 10 ⁻⁴) | CL% | DO CUMENT IL |) | TECN | COMMENT | |
| 6.2 ±0.5 OUR F | | | | | | |
| 6.2 ±0.6 OUR A 6.46±0.65±0.51 | VERAGE | ¹ AUBERT | 05 J | BABR | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| 6.7 ±1.1 | | ¹ ABE | 03в | | $e^+e^- \rightarrow$ | |
| $5.0 \pm 1.1 \pm 0.6$ | | ¹ RICHICHI | 01 | CLE2 | $e^+ e^- \rightarrow$ | Y(45) |
| We do not use | the followin | g data for averag | _ | | | UDEDT AF |
| 6.9 ±1.1 ±1.1 < 8 | 90 | 1 ALAM | 02 94 | BABR CLE2 | $e^+e^- \rightarrow$ | UBERT 05 J $\Upsilon(4S)$ |
| <15 | 90 | ¹ BORTOLET | | CLEO | $e^+e^ \rightarrow$ | |
| <28 | 90 | 1 ALBRECHT | 901 | ARG | $e^+e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | duction of | B ⁺ and B [∪] at t | he $\Upsilon(4)$ | S). | | |
| $(\psi(2S) K^0)/\Gamma(J/$ | $\psi(1S) K^0$ | ') | | | | Γ_{199}/Γ_{16} |
| ALUE | | DOCUMENT II |) | TECN | COMMENT | |
| .82±0.13±0.12 | | 1 AUBERT | 02 | BABR | $e^+ e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | | | he <i>T</i> (4 | 5). | | |
| $(\psi(3770) K^0 \times B($ | | | | | | Γ ₂₀₀ / |
| ALUE (units 10 ⁻⁴) <1.23 | CL% | DOCUMENT II |) | TECN | COMMENT | |
| | | | | | $e^+ e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | | | he $\Upsilon(4)$ | S). | | |
| $(\psi(3770) K^0 \times B($ | $\psi \rightarrow D^-$ | $D^+))/\Gamma_{total}$ | | | | Γ ₂₀₁ / |
| ALUE (units 10 ⁻⁴) <1.88 | CL% | DOCUMENT IL |) | TECN | COMMENT | |
| | | | | | $e^+e^- \rightarrow$ | T(45) |
| ¹ Assumes equal pro | duction of | \mathcal{B}^+ and \mathcal{B}^0 at t | he $\Upsilon(4)$ | S). | | |
| | - total | | | | | Γ ₂₀₂ / |
| $(\psi(2S) K^{+} \pi^{-})/\Gamma$ | | DOCUMENT II |) | TECN | COMMENT | • |
| · · · // | | DO COMENT II | | | | |
| 4LUE (units 10 ⁻⁴) 5.68±0.13±0.42 | <u>CL%</u> | ¹ MIZUK | 09 | RELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| 5.68±0.13±0.42 • • We do not use | CL%_ | ¹ MIZUK ig data for avera _l | ges, fits | , limits, | etc. • • • | |
| 5.68±0.13±0.42 • • We do not use | CL%_ the followin | ¹ MIZUK ig data for averaged ¹ ALBRECHT | ges, fits 90J | , limits, ARG | etc. • • • | |
| 5.68±0.13±0.42 • • We do not use | CL%_ the followin | ¹ MIZUK ig data for averaged ¹ ALBRECHT | ges, fits 90J | , limits, ARG | etc. • • • | |
| ### ALUE (units 10 ⁻⁴) 5.68±0.13±0.42 • • We do not use 10 1 Assumes equal pro | the followin 90 duction of | ¹ MIZUK ig data for averaged ¹ ALBRECHT | ges, fits 90J | , limits, ARG | etc. • • • | Y(45) |
| 5.68 ± 0.13 ± 0.42 • • We do not use <10 1 Assumes equal pro ((4(25) K*(892) ⁰) ALUE (units 10 ⁻⁴) | CL% the followin 90 duction of // Ttotal CL% | ¹ MIZUK g data for averag ¹ ALBRECHT B ⁺ and B ⁰ at t | ges, fits 90 J | , limits, ARG S). TECN | etc. • • • • $e^+e^- \rightarrow$ | Y(45) |
| 5.68 \pm 0.13 \pm 0.42 • • We do not use <10 1 Assumes equal pro (ψ (25) K^* (892) ⁰ ALUE (units 10 ⁻⁴) 6.1 \pm 0.5 OUR F | the following 90 duction of $\frac{CL\%}{T_{total}}$ | 1 MIZUK g data for average 1 ALBRECHT 1 B+ and 0 at t 1 DOCUMENT IE noludes scale fac | ges, fits 90 J he $\Upsilon(4)$ tor of 1 | , limits, ARG S). TECN .1. | etc. • • • • $e^+e^- \rightarrow$ $COMMENT$ | Y(45) |
| 5.68 \pm 0.13 \pm 0.42 • We do not use <10 1 Assumes equal pro $(\psi(25) K^{*}(892)^{0})^{4}$ ALUE (units 10 ⁻⁴) 6.1 \pm 0.5 OUR F 6.1 \pm 0.6 OUR A | the following 90 duction of $\frac{CL\%}{T_{total}}$ | MIZUK g data for average ALBRECHT B+ and B ⁰ at t DOCUMENT IE noludes scale fac Error includes sca | ges, fits $90\mathrm{J}$ he $\Upsilon(4)$ tor of 1 cale fact | ARG S). TECN 1. or of 1. | etc. \bullet \bullet \bullet $e^+e^- \rightarrow$ $\underline{COMMENT}$ | Υ(45) Γ ₂₀₃ / |
| 5.68 \pm 0.13 \pm 0.42 • • We do not use <10 1 Assumes equal pro (ψ (25) K^* (892)0 ALUE (units 10 ⁻⁴) 6.1 \pm 0.5 OUR F 6.1 \pm 0.6 OUR A 5.52 \pm 0.35 \pm 0.53 5.52 \pm 0.35 \pm 0.53 | the following 90 duction of $\frac{CL\%}{T_{total}}$ | MIZUK g data for averag ALBRECHT B+ and B ⁰ at t DOCUMENT IE ncludes scale fac Error includes sca MIZUK | ges, fits $90J$ he $\Upsilon(4)$ tor of 1 cale fact 09 | , limits, ARG S). TECN .1. tor of 1 BELL | etc. \bullet \bullet \bullet $e^+e^- \rightarrow$ $\frac{COMMENT}{e^+e^- \rightarrow}$ | r(4s) Γ203/ r(4s) |
| • • We do not use <10 1 Assumes equal pro (\psi(25) K*(892)^0) (\text{ALUE (units 10}^4) 6.1 \pm 0.5 OUR F 6.1 \pm 0.6 OUR A | the following 90 duction of $\frac{CL\%}{T_{total}}$ | MIZUK g data for average ALBRECHT B+ and B ⁰ at t DOCUMENT IE noludes scale fac Error includes sca | ges, fits $90J$ he $\Upsilon(4)$ tor of 1 cale fact 09 | , limits, ARG S). TECN 1. or of 1. BELL BABR | etc. \bullet \bullet \bullet $e^+e^- \rightarrow$ $\underline{COMMENT}$ | $\Upsilon(4S)$ $\Gamma_{203}/$ $\Upsilon(4S)$ $\Upsilon(4S)$ |

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\bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
                                                                   <sup>1</sup> ALAM 94 CLE2 Repl. by RICHICHI 01
 <19
                                                90
                                                                   <23
                                                90
    ^1 Assumes equal production of B^+ and B^0 at the \varUpsilon(4S).
    ^{2}\, {\rm ABE \ 980 \ reports} \ [{\rm B}(B^{\,0} \ \to \ \psi(2S) \ {\rm K}^{*}(892)^{\,0})]/[{\rm B}(B^{\,+} \ \to \ J/\psi(1S) \ {\rm K}^{+})] \ = 0.908 \ \pm 0.000  \ \pm 0.000        0.194\pm0.10. We multiply by our best value B(B^+\to J/\psi(1S)\,K^+)=(9.9\pm1.0)\times10^{-4}. Our first error is their experiment's error and our second error is the systematic error from
       using our best value.
\Gamma(\psi(2S)K^*(892)^0)/\Gamma(\psi(2S)K^0)
                                                                                                                                                        \Gamma_{203}/\Gamma_{199}
                                                                       DO CUMENT ID
                                                                                                           TECN COMMENT
0.99±0.10 OUR FIT
1.00 \pm 0.14 \pm 0.09
                                                                       AUBERT
                                                                                                      05J BABR e^+e^- \rightarrow \Upsilon(4S)
\Gamma(\chi_{c0}(1P)K^0)/\Gamma_{total}
VALUE (units 10^{-6})
                                                                       DO CUMENT ID
                                                                                                             TECN COMMENT
      142^{+55}_{-44}\!\pm\!22
                                                               ^{1,2} AUBERT
                                                                                                      09AU BABR e^+e^- \rightarrow \Upsilon(4S)
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                 90
                                                                    <sup>2</sup> GARMASH 07 BELL e^+e^- \rightarrow \Upsilon(4S)
 <1240
                                                 90
                                                                    <sup>1</sup> AUBERT
                                                                                                      05K BABR e^+e^- \rightarrow \Upsilon(4S)
                                                                    <sup>3</sup> EDWARDS 01 CLE2 e^+e^- \rightarrow \Upsilon(4S)
   ^1 Assumes equal production of B^+ and B^0 at the \varUpsilon(4S). ^2 Uses Dalitz plot analysis of the B^0\to K^0\pi^+\pi^- final state decays. ^3 EDWARDS 01 assumes equal production of B^0 and B^+ at the \varUpsilon(4S). The correlated
       uncertainties (28.3)% from B(J/\psi(1S) \rightarrow \gamma \eta_{\mathcal{C}}) in those modes have been accounted
\Gamma(\chi_{c0} K^*(892)^0)/\Gamma_{total}
                                                                                                                                                                \Gamma_{205}/\Gamma
VALUE (units 10<sup>-4</sup>)
                                                                     DOCUMENT ID
                                                                                                           TECN COMMENT
                                                                                                    08BD BABR e^+e^- \rightarrow \Upsilon(4S)
    1.7 \pm 0.3 \pm 0.2
                                                                 <sup>1</sup> AUBERT
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                               90
                                                                 <sup>1</sup> AUBERT 05K BABR Repl. by AUBERT 08BD
   <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(\chi_{c2}K^0)/\Gamma_{total}
                                                                                                                                                                \Gamma_{206}/\Gamma
                                                                     DOCUMENT ID
                                                                                                           TECN COMMENT
 <1.5 	imes \overline{10^{-5}}
                                                                 ^1 BHARDWAJ 11 BELL e^+\,e^-
ightarrow~\varUpsilon(4{\it S})
 • • • We do not use the following data for averages, fits, limits, etc. • • •
 < 2.8 \times 10^{-5}
                                                                 ^2 AUBERT 09B BABR e^+\,e^-
ightarrow~\varUpsilon(45)
                                           90
 <2.6 \times 10^{-5}
                                                                 ^{
m 1} soni
                                               90
                                                                                                   06 BELL Repl. by BHARDWAJ 11
 < 4.1 \times 10^{-5}
                                               90
                                                                 <sup>1</sup> AUBERT
                                                                                                  05κ BABR e^+e^- \rightarrow \Upsilon(4S)
    ^1 Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
    ^2 Uses \chi_{c1,2} \to J/\psi \gamma. Assumes B( \Upsilon(4S) \to B^+ B^-) = (51.6 \pm 0.6)% and B( \Upsilon(4S) \to B^+ B^-
       B^0 \overline{B}{}^0) = (48.4 \pm 0.6)\%.
\Gamma(\chi_{c2} K^*(892)^0)/\Gamma_{total}
                                                                                                                                                                \Gamma_{207}/\Gamma
VALUE (units 10^{-5}) CL\%
                                                                       DOCUMENT ID
                                                                                                             TECN COMMENT
                                                                   <sup>1</sup> AUBERT
    6.6 \pm 1.8 \pm 0.5
                                                                                                     09B BABR e^+e^- \rightarrow \Upsilon(4S)
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                 90
                                                                    <sup>2</sup> soni
                                                                                                     06 BELL e^+e^- \rightarrow \Upsilon(4S)
                                                                    <sup>2</sup> AUBERT
                                                                                                      05K BABR Repl. by AUBERT 09B
    ^{1} Uses \chi_{c1,2} \rightarrow ~J/\psi \gamma. Assumes B( \varUpsilon(4S) \rightarrow ~B^{+}~B^{-}) = (51.6 \pm 0.6)\% and B( \varUpsilon(4S) \rightarrow ~B^{+}~B^{-}) = (51.6 \pm 0.6)\% and B( \varUpsilon(4S) \rightarrow ~B^{+}~B^{-}) = (51.6 \pm 0.6)\%
       B^{0}\overline{B}^{0}) = (48.4 \pm 0.6)\%
    <sup>2</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(\chi_{c1}(1P)\pi^0)/\Gamma_{total}
                                                                                                                                                                \Gamma_{208}/\Gamma
VALUE (units 10^{-5})
                                                                       DOCUMENT ID TECN COMMENT
                                                                    <sup>1</sup> KUMAR
1.12±0.25±0.12
                                                                                                     08 BELL e^+e^- \rightarrow \Upsilon(4S)
    <sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(\chi_{c1}(1P)K^0)/\Gamma_{total}
                                                                                                                                                                \Gamma_{209}/\Gamma
VALUE (units 10<sup>-4</sup>)
                                                                     DOCUMENT ID
                                                                                                         TECN COMMENT
       3.93±0.27 OUR AVERAGE
       3.78^{\,+\,0.17}_{\,-\,0.16}\,\pm\,0.33
                                                                 ^{1} BHARDWAJ 11 BELL e^{+}e^{-} \rightarrow \Upsilon(4S)
      4.2 \ \pm 0.3 \ \pm 0.3
                                                                 <sup>2</sup> AUBERT
                                                                                                   09B BABR e^+e^- \rightarrow \Upsilon(4S)
      3.1 \  \, ^{+\, 1.5}_{-\, 1.1} \  \, \pm \, 0.1
                                                                 3 AVERY
                                                                                                   00 CLE2 e^+e^- \rightarrow \Upsilon(4S)
• • • We do not use the following data for averages, fits, limits, etc. • •
                                                                 1 SONI
      3.5\,1\pm0.33\pm0.45
                                                                                                  06 BELL Repl. by BHARDWAJ 11
                                                                 1 AUBERT
      4.53 \pm 0.41 \pm 0.51
                                                                                                   05 J BABR Repl. by AUBERT 09B
                                                                  <sup>4</sup> AUBERT
                                                                                                   02 BABR Repl. by AUBERT 05J
      4.3 \pm 1.4 \pm 0.2
                                                                 ^{
m 1} ALAM
                                               90
 <27
                                                                                                   94 CLE2 e^+e^- \rightarrow \Upsilon(4S)
```

| 1 Assumes equal production of B^+ and B^0 at the $arphi(4S)$. | • • • We do not u | se the follow | ring data for avera | ges, fi | ts, limit: | s, etc. • • • |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|----------------------------------------------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| ² Uses $\chi_{c1,2} \to J/\psi \gamma$. Assumes B($\Upsilon(4S) \to B^+ B^-$) = (51.6 \pm 0.6)% and B($\Upsilon(4S) \to$ | 18.5 ± 1.0 ± 0.7 | , | $^{ m 1}$ CHAO | 04 | BELL | Repl. by LIN 07A |
| $B^{0}\overline{B}^{0}) = (48.4 \pm 0.6)\%.$ | $17.9 \pm 0.9 \pm 0.7$ | , | ¹ AUBERT | 02Q | BABR | Repl. by AUBERT 07 |
| ³ AVERY 00 reports $(3.9^{+1.9}_{-1.3} \pm 0.4) \times 10^{-4}$ from a measurement of $[\Gamma(B^0 \rightarrow$ | $22.5 \pm 1.9 \pm 1.8$ | | ¹ CASEY | 02 | BELL | Repl. by CHAO 04 |
| | 19.3 + 3.4 + 1.5 -3.2 - 0.6 | | ¹ ABE | 01н | BELL | Repl. by CASEY 02 |
| $\chi_{\mathcal{C}1}(1P) K^0)/\Gamma_{\text{total}} \ \times \ [B(\chi_{\mathcal{C}1}(1P) \to \gamma J/\psi(1S))] \ \text{assuming} \ B(\chi_{\mathcal{C}1}(1P) \to \gamma J/\psi(1S)) = 0.273 \pm 0.016$, which we rescale to our best value $B(\chi_{\mathcal{C}1}(1P) \to \gamma J/\psi(1S))$ | 16.7± 1.6±1.3 | | ¹ AUBERT | 01E | BABR | Repl. by AUBERT 02 |
| $\gamma J/\psi(15)$) = $(34.4\pm1.5)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production | < 66 | 90 | ² ABE | 00c | SLD | $e^+e^- \rightarrow Z$ |
| of B^+ and B^0 at the $\Upsilon(4S)$. | $17.2 + 2.5 \pm 1.2$ | 2 | ¹ CRONIN-HEN | 00 | CLE2 | Repl. by BORNHEIM |
| ⁴ AUBERT 02 reports (5.4 \pm 1.4 \pm 1.1) \times 10 ⁻⁴ from a measurement of [$\Gamma(B^0 \rightarrow$ | 15 + 5. ±1.4 | | GODANG | 98 | CLE2 | Repl. by CRONIN- |
| $\chi_{c1}(1P)K^0)/\Gamma_{total}] 	imes [B(\chi_{c1}(1P) 	o 	\gamma J/\psi(1S))]$ assuming $B(\chi_{c1}(1P) 	o 	\gamma J/\psi(1S)) = 0.273 \pm 0.016$, which we rescale to our best value $B(\chi_{c1}(1P) 	o 	o 	o)$ | • | | GODANG | 70 | CLLZ | HENNESSY 00 |
| | $24 \begin{array}{c} +17 \\ -11 \end{array} \pm 2$ | | ³ ADAM | 96D | DLPH | $e^+e^- ightarrow Z$ |
| $\gamma J/\psi(15)$) = (34.4 \pm 1.5) \times 10 ⁻² . Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production | < 17 | 90 | ASNER | 96 | CLE2 | Sup. by ADAM 96D |
| of B^+ and B^0 at the $\Upsilon(4S)$. | < 30 | 90 | ⁴ BUSKULIC | | ALEP | |
| * * | < 90 | 90 90 | ⁵ ABREU ⁶ AKERS | | OPAL | Sup. by ADAM 96D |
| $(\chi_{c1}(1P)K^0)/\Gamma(J/\psi(1S)K^0)$ $\Gamma_{209}/\Gamma_{162}$ | < 81 < 26 | 90 | 7 BATTLE | | CLE2 | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| ALUE DOCUMENT ID TECN COMMENT 5.52 \pm 0.16 \pm 0.02 DABR $e^+e^- \rightarrow \Upsilon(4S)$ | <180 | 90 | ALBRECHT | | ARG | $e^+e^- \rightarrow r(4S)$ |
| | < 90 | 90 | ⁸ AVERY | | | $e^+e^- \rightarrow \dot{r(4S)}$ |
| ¹ AUBERT 02 reports $0.66 \pm 0.11 \pm 0.17$ from a measurement of $\left[\Gamma\left(B^0 \to \chi_{C1}(1P) K^0\right)\right]$ | <320 | 90 | AVERY | 87 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $ \begin{array}{ll} \Gamma(B^0 \to J/\psi(15) K^0)] \times [\mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))] \ \ \mathrm{Assuming} \ \ \mathrm{B}(\chi_{c1}(1P) \to \gamma J/\psi(1S))$ | ¹ Assumes equal | production o | of B^+ and B^{0} at t | he γ | (45). | |
| $\gamma J/\psi(1S))=(34.4\pm1.5)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production | | | | 0.1)% | and th | te B fractions $f_{B^0} = f_{B^0}$ |
| | (39.7 + 1.8)% a | nd $f_{B_c} = (10)$ | .5 ^{+ 1.8})%. | | | |
| of B^+ and B^0 at the $\varUpsilon(4S)$. | | | | f _B = | = 0.12. | Contributions from B^0 |
| $(\chi_{c1}(1P)K^-\pi^+)/\Gamma_{total}$ Γ_{210}/Γ | B _s decays cann | ot be separa | ted. Limits are given | ven fo | r the we | ighted average of the o |
| ALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT | rates for the tw | oneutral <i>B</i> | mesons. | fractio | ne for F | 0 , $^{+}$, $^{+}$, $^{-}$, $^{-}$ b baryons. |
| .83±0.10±0.39 1 MIZUK 08 BELL $e^+e^- \rightarrow r(4S)$ | | | | | | production fraction of |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | Contributions f | B^0 and | B ⁰ decays canno | ot be | separate | d. Limits are given fo |
| | weighted averag | ge of the dec | ay rates for the tw | vo neu | tral B n | nesons. |
| $(\chi_{c1}(1P)K^*(892)^0)/\Gamma_{total}$ Γ_{211}/Γ | ⁶ Assumes B(Z – | $\rightarrow b\overline{b} = 0.$ | 217 and $B_d^0(B_s^0)$ | fractio | on 39.5% | % (12%). |
| ALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT | | | production of BOT | \overline{B}^0 an | d <i>B</i> + <i>B</i> | $^-$ at $\varUpsilon(4S)$. |
| 2.22 $^{+0.40}_{-0.31}$ OUR AVERAGE Error includes scale factor of 1.6. | 8 Assumes the $ 	au$ | (4 <i>S</i>) decays | 43% to $B^{0}\overline{B}^{0}$. | | | |
| | $\Gamma(K^+\pi^-)/\Gamma(K^0)$ | 0 _π 0) | | | | Γ ₂₁₄ /Ι |
| 2.5 \pm 0.2 \pm 0.2 1 AUBERT 09B BABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE | , | DO CUMENT I | 'D | TECN | COMMENT |
| $1.73 ^{+}_{-}0.15 ^{+}_{-}0.34$ 2 MIZUK 08 BELL $e^{+}e^{-} \rightarrow \varUpsilon (45)$ | 2.16±0.16±0.16 | | LIN | | | $e^+e^- \rightarrow \gamma(4S)$ |
| • We do not use the following data for averages, fits, limits, etc. • • • | ● ● We do not u | se the follow | ing data for avera | ges, fi | ts, limit | s, etc. • • • |
| $3.14\pm0.34\pm0.72$ 2 SONI 06 BELL Repl. by MIZUK 08 | $1.20 {}^{+ 0.50}_{- 0.58} {}^{+ 0.22}_{- 0.32}$ | | ¹ ABE | 01 | н RFII | L Repl. by LIN 07A |
| 3.27±0.42±0.64 | | | | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ¹ Assumes equal | production o | of B^+ and B^0 at t | the γ | (45). | |
| 1 Uses $\chi_{c1,2} 	o J/\psi \gamma$. Assumes B($\Upsilon(4S) 	o B^+B^-) = (51.6 \pm 0.6)\%$ and B($\Upsilon(4S) 	o$ | $\left[\Gamma(K^{+}\pi^{-})+\Gamma($ | $(\pi^{+}\pi^{-})]/$ | Ftotal | | | $(\Gamma_{214} + \Gamma_{330})$ |
| $B^{0}\overline{B}^{0}) = (48.4 \pm 0.6)\%.$ | - ' | | | T ID | TE | ECN COMMENT |
| ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | <u>VALUE (units 10⁻⁶)</u> 19± 6 OUR AVER | AGE | | | | |
| 3 AUBERT 02 reports (4.8 \pm 1.4 \pm 0.9) $	imes$ 10 $^{-4}$ from a measurement of [$\Gamma(B^0 ightarrow$ | $28 + 15 \pm 20$ | | ¹ ADAM | | 96D D | LPH $e^+e^- \rightarrow Z$ |
| $\chi_{C1}(1P)K^*(892)^0)/\Gamma_{	ext{total}}] 	imes [B(\chi_{C1}(1P) 	o 	au J/\psi(1S))]$ assuming $B(\chi_{C1}(1P) 	o 	au J/\psi(1S)) = 0.273 \pm 0.016$, which we rescale to our best value $B(\chi_{C1}(1P) 	o 	o 	au J/\psi(1S))$ | | | | | | |
| | $18 \begin{array}{c} + & 6 + & 3 \\ - & 5 - & 4 \end{array}$ | 17. | | | | LE2 $e^+e^- \rightarrow \Upsilon(4.5)$ |
| $\gamma J/\psi(15)$) = $(34.4 \pm 1.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production | • • • We do not u | se the follow | ring data for avera | ges, fi | ts, limit | s, etc. • • • |
| of B^+ and B^0 at the $\Upsilon(4S)$. | $24 + \frac{8}{7} \pm 2$ | | ² BATTLE | | 93 CI | LE2 $e^+e^- \rightarrow \gamma$ (4.5 |
| 4 BORTOLETTO 92 assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | umas f | f 0.20 and | £ | 0.10 | Contributions from PO |
| (V/4051)± //- D/V± ±\\/5 | ADAM 900 ass | of he senara | $t_{B^-} = 0.39$ and | $^{I}B_{s}$ = | = U.12. r the we | Contributions from B^0 ighted average of the α |
| $(X(4051)^+ K^- \times B(X^+ \to \chi_{c1} \pi^+))/\Gamma_{total} \qquad \Gamma_{212}/\Gamma$ | rates for the tw | o neutral B | mesons. | | | |
| ALUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | ² BATTLE 93 ass | sumes equal | production of B^0 | B ^U an | d <i>B</i> + <i>B</i> | $^-$ at $\varUpsilon(4S)$. |
| $.0 \overset{+}{-} \overset{1.5}{0.8} \overset{+}{-} \overset{1.5}{1.6}$ MIZUK 08 BELL $e^+ e^- ightarrow \varUpsilon(4S)$ | $\Gamma(K^0\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₂₁ |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | TECN | |
| · · · · · · · · · · · · · · · · · · · | 9.5 ± 0.8 OUR A | | Error includes scal | e facto | | |
| | $8.7 \pm 0.5 \pm 0.6$ | | ¹ FUJIKAWA | | | $e^+e^- ightarrow \gamma(4S)$ |
| $(X(4248)^{+} K^{-} \times B(X^{+} \to \chi_{c1} \pi^{+}))/\Gamma_{total} \qquad \Gamma_{213}/\Gamma$ | 0.1 _ 0.0 _ 0.0 | | ¹ AUBERT | 08E | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ALUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | $10.3\pm0.7\pm0.6$ | | | | CLEO | $e^+e^- \rightarrow \gamma(4S)$ |
| ALUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | | | $^{ m 1}$ bornheim | 03 | CLE2 | C C / (45) |
| LLUE (units 10^{-5}) $0 + 2.3 + 19.7 \\ -0.9 - 0.5$ DOCUMENT ID TECN COMMENT $e^+e^- \rightarrow r(4S)$ | $10.3\pm0.7\pm0.6$ | se the follow | | | | . , |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $10.3 \pm 0.7 \pm 0.6 \\ 12.8 + 4.0 + 1.7 \\ -3.3 - 1.4$ | se the follow | ring data for avera $rac{1}{2}$ LIN | ges, fi | | . , |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $10.3 \pm 0.7 \pm 0.6$ $12.8 \stackrel{+}{+} 4.0 + 1.7$ -3.3 - 1.4 • • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ | se the follow | ring data for avera $rac{1}{4}$ LIN $rac{1}{4}$ AUBERT | ges, fi 07A 05 Y | ts, limit BELL BABR | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 |
| NLUE (units 10^{-5}) DOCUMENT ID TECN COMMENT $0^{+}2.3^{+}+19.7$ $1^{0}-0.3^{-}0.5^{-}$ MIZUK 08 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. $(\chi_{c1}(1P)K^{*}(892)^{0})/\Gamma(\chi_{c1}(1P)K^{0})$ TECN TOMMENT $\Gamma_{211}/\Gamma_{209}$ ALUE DOCUMENT ID TECN COMMENT | $10.3 \pm 0.7 \pm 0.6$ 12.8 + 4.0 + 1.7 -3.3 - 1.4 • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT | ges, fi 07A | ts, limit: BELL BABR BABR | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 |
| NLUE (units 10^{-5}) DOCUMENT ID 1 MIZUK 08 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 1 ($\chi_{c1}(1P)K^*(892)^0$)/ $\Gamma(\chi_{c1}(1P)K^0)$ 1 AUBERT 1 AUBERT 1 MIZUK 1 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 1 MIZUK 1 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $10.3 \pm 0.7 \pm 0.6$ $12.8 \stackrel{+}{+} 4.0 + 1.7$ -3.3 - 1.4 • • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ | se the follow | ring data for avera $rac{1}{4}$ LIN $rac{1}{4}$ AUBERT | ges, fi 07A 05 Y | ts, limit BELL BABR | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 |
| ALUE (units 10^{-5}) DOCUMENT ID TECN COMMENT $0^{+}2.3^{+}+19.7$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-$ | $10.3 \pm 0.7 \pm 0.6$ 12.8 + 4.0 + 1.7 -3.3 - 1.4 • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ $11.7 \pm 2.3 + 1.2$ -1.3 | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT | ges, fi 07А 05Ү 04м | ts, limits BELL BABR BABR BELL | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A |
| ALUE (units 10^{-5}) DOCUMENT ID TECN COMMENT 1 MIZUK 08 BELL $e^+e^- \rightarrow r(4S)$ 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. ($\chi_{c1}(1P)K^*(892)^0$)/ $\Gamma(\chi_{c1}(1P)K^0)$ TOUMENT TOUMEN | $10.3 \pm 0.7 \pm 0.6$ 12.8 + 4.0 + 1.7 -3.3 - 1.4 • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ $11.7 \pm 2.3 + 1.2$ $8.0 + 3.3 \pm 1.6$ | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO 1 CASEY | ges, fi 07A 05Y 04M 04 | ts, limits BELL BABR BABR BELL BELL | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A Repl. by CHAO 04 |
| ALUE (units 10^{-5}) DOCUMENT ID TECN COMMENT $0^{+}2.3^{+}+19.7$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-}0.5$ $1^{0}-0.9^{-$ | $10.3 \pm 0.7 \pm 0.6$ $12.8 + 4.0 + 1.7$ $- 3.3 - 1.4$ $- • • We do not u$ $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ $11.7 \pm 2.3 + 1.2$ $8.0 + 3.3 \pm 1.6$ $16.0 + 7.2 + 2.5 = 2.7$ | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO | ges, fi 07A 05 ү 04 м | ts, limits BELL BABR BABR BELL | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A |
| ALUE (units 10 ⁻⁵) DO CUMENT ID TECN COMMENT 1.0+2.3+19.7 1 MIZUK 08 BELL $e^+e^- \rightarrow \tau(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\tau(4S)$. ($\chi_{c1}(1P)K^*(892)^0$)/ $\Gamma(\chi_{c1}(1P)K^0)$ Tecn COMMENT ($\chi_{c1}(1P)K^*(892)^0$)/ $\Gamma(\chi_{c1}(1P)K^0)$ AUBERT Tecn COMMENT AUBERT Tecn COMMENT Tecn COMMENT AUBERT Tecn COMMENT Tecn C | $10.3 \pm 0.7 \pm 0.6$ 12.8 + 4.0 + 1.7 -3.3 - 1.4 • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ $11.7 \pm 2.3 + 1.2$ $8.0 + 3.3 \pm 1.6$ | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO 1 CASEY | ges, fi 07A 05Y 04M 04 | ts, limits BELL BABR BABR BELL BELL BELL | s, etc. • • • Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A Repl. by CHAO 04 |
| ALUE (units 10 ⁻⁵) DOCUMENT ID 1 MIZUK 08 BELL $e^+e^- \rightarrow r(4S)$ 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. 1 AUBERT 2 BARR 2 AUBERT 3 AUBERT 4 AUBERT 4 AUBERT 5 AUBERT 5 AUBERT 6 AUBE | 10.3 ± 0.7 ± 0.6 12.8 + 4.0 + 1.7 - 3.3 - 1.4 • • We do not u 9.2 ± 0.7 ± 0.6 11.4 ± 0.9 ± 0.6 11.4 ± 1.7 ± 0.8 11.7 ± 2.3 + 1.2 8.0 + 3.3 8.0 + 3.3 16.0 + 7.2 + 2.5 8.2 + 3.1 ± 1.2 | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO 1 CASEY 1 ABE 1 AUBERT | ges, fi 07A 05Y 04M 04 02 01H | ts, limits BELL BABR BABR BELL BELL BELL BABR | Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A Repl. by CHAO 04 Repl. by CASEY 02 Repl. by AUBERT 04 |
| ALUE (units 10^{-5}) DOCUMENT ID 1 MIZUK 08 BELL $e^+e^- \rightarrow r(4S)$ 1 Assumes equal production of B^+ and B^0 at the $r(4S)$. $r(\chi_{c1}(1P)K^*(892)^0)/\Gamma(\chi_{c1}(1P)K^0)$ AUBERT $r(\chi_{c1}(1P)K^*(892)^0)/\Gamma(\chi_{c1}(1P)K^0)$ $r(\chi_{c1}(1P)K^0)$ AUBERT $r(\chi_{c1}(1P)K^0)$ $r(\chi_$ | $10.3 \pm 0.7 \pm 0.6$ 12.8 + 4.0 + 1.7 -3.3 - 1.4 • • We do not u $9.2 \pm 0.7 \pm 0.6$ $11.4 \pm 0.9 \pm 0.6$ $11.4 \pm 1.7 \pm 0.8$ $11.7 \pm 2.3 + 1.2$ -3.1 ± 1.6 16.0 + 7.2 + 2.5 -5.9 - 2.7 $8.2 + 3.1 \pm 1.2$ 14.6 + 5.9 + 2.4 -5.1 - 3.3 | | Ing data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO 1 CASEY 1 ABE 1 AUBERT 1 CRONIN-HEN | ges, fi 07A 05 Y 04M 04 02 01H 01E 00 | ts, limits BELL BABR BABR BELL BELL BELL BABR CLE2 | Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A Repl. by CHAO 04 Repl. by CASEY 02 Repl. by AUBERT 04 Repl. by BORNHEIM |
| ALUE (units 10^{-5}) DOCUMENT ID TECN COMMENT 1.0+2.3+19.7 1 MIZUK 08 BELL $e^+e^- \rightarrow T(4S)$ 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 1 Assumes equal production of B^+ and B^0 at the $T(4S)$. 1 ASSUMES EQUAL POOLUMENT ID TECN COMMENT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 ASSUMES EQUAL POOLUMENT ID 1 ALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT | 10.3 ± 0.7 ± 0.6 12.8 + 4.0 + 1.7 - 3.3 - 1.4 • • We do not u 9.2 ± 0.7 ± 0.6 11.4 ± 0.9 ± 0.6 11.4 ± 1.7 ± 0.8 11.7 ± 2.3 + 1.2 8.0 + 3.3 8.0 + 3.3 16.0 + 7.2 + 2.5 8.2 + 3.1 ± 1.2 | se the follow | ring data for avera 1 LIN 1 AUBERT 1 AUBERT 1 CHAO 1 CASEY 1 ABE 1 AUBERT | ges, fi 07A 05Y 04M 04 02 01H | ts, limits BELL BABR BABR BELL BELL BELL BABR | Repl. by FUJIKAWA Repl. by AUBERT 08 Repl. by AUBERT 05 Repl. by LIN 07A Repl. by CHAO 04 Repl. by CASEY 02 Repl. by AUBERT 04 |

07B BABR $e^+e^- \rightarrow \Upsilon(4S)$ 07A BELL $e^+e^- \rightarrow \Upsilon(4S)$

 1 BORNHEIM 03 CLE2 $e^{+}\,e^{-}
ightarrow \, \varUpsilon(4\,S)$

 $19.1 \pm 0.6 \pm 0.6$ $19.9 \pm 0.4 \pm 0.8$ 18.0 + 2.3 + 1.2 2.1 - 0.9

1 LIN

 $^{^{1}}$ Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$.

 1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^0 at the $\varUpsilon(4\mathcal{S}).$

| | Γ ₂₁₆ /Γ | $\Gamma(\omega K^0)/\Gamma_{ m total}$ | Γ ₂₂₄ / |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁶) 66 + 4 OUR AVERAGE | <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> Error includes scale factor of 1.4. | <u>VALUE (units 10^{−6}) CL%</u> 5.0±0.6 OUR AVERAGE | DOCUMENT ID TECN COMMENT |
| 68.5 ± 2.2 ± 3.1 | 1 AUBERT 09AV BABR $e^{+}e^{-} ightarrow \gamma(4S)$ | 5.4 ± 0.8 ± 0.3 | 1 AUBERT 07AE BABR $e^{+}e^{-} ightarrow~ argamma(4S)$ |
| $58.9 + 3.6 \pm 4.3$ | 1 SCHUEMANN 06 BELL $e^{+}e^{-} ightarrow \varUpsilon (4S)$ | $4.4 + 0.8 \pm 0.4$ | 1 JEN 06 BELL $e^+e^- \rightarrow r(4S)$ |
| $89 \begin{array}{c} +18 \\ -16 \end{array} \pm 9$ | ¹ RICHICHI 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | $10.0^{+5.4}_{-4.2} \pm 1.4$ | 1 JESSOP 00 CLE2 $e^{+}e^{-} \rightarrow r(4S)$ |
| | owing data for averages, fits, limits, etc. • • • | 7.2 | ving data for averages, fits, limits, etc. • • |
| 66.6± 2.6±2.8 | ¹ AUBERT 07AE BABR Repl. by AUBERT 09AV | $6.2 \pm 1.0 \pm 0.4$ | AUBERT,B 06E BABR Repl. by AUBERT 07AE |
| $67.4 \pm 3.3 \pm 3.2$ | AUBERT 05M BABR AUBERT 07AE | $5.9^{+1.6}_{-1.3} \pm 0.5$ | ¹ AUBERT 04H BABR Repl. by AUBERT,B 06 |
| 60.6± 5.6±4.6 | AUBERT 03W BABR Repl. by AUBERT 05M | $4.0 + 1.9 \pm 0.5$ | ¹ WANG 04A BELL Repl. by JEN 06 |
| $55 \begin{array}{c} +19 \\ -16 \end{array} \pm 8$ | 1 ABE 01M BELL Repl. by SCHUEMANN 06 | <13 90 | ¹ AUBERT 01G BABR Repl. by AUBERT 04H |
| $\begin{array}{ccc} 42 & {}^{+13}_{-11} & \pm 4 \end{array}$ | AUBERT 01G BABR Repl. by AUBERT 03W | <57 90 | ¹ BERGFELD 98 CLE2 Repl. by JESSOP 00 |
| 47 $^{+27}_{-20}$ ± 9 | BEHRENS 98 CLE2 Repl. by RICHICHI 00 | $^{ m 1}$ Assumes equal production $^{ m c}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. |
| ¹ Assumes equal production | of B^+ and B^0 at the $\Upsilon(4S)$. | $\Gamma(a_0(980)^0 K^0 \times B(a_0(980)^0 K^0))$ | $0^0 \rightarrow \eta \pi^0$)/ Γ_{total} Γ_{225} |
| $\Gamma(\eta' K^*(892)^0)/\Gamma_{\text{total}}$ | Γ ₂₁₇ /Γ | <u>VALUE (units 10⁻⁶)</u> <u>CL%</u> | , |
| VALUE (units 10 ⁻⁶) CL% | | <7.8 90 | $rac{	extit{DOCUMENT ID}}{1	extit{ AUBERT,BE}} rac{	extit{TECN}}{04	extit{ BABR}} rac{	extit{comment}}{e^+e^- ightarrow 	ag{4S}}$ |
| 3.1 + 0.9 ± 0.3 | $\frac{1}{1}$ DEL-AMO-SA10A BABR $e^+e^- \rightarrow r(4S)$ | $^{ m 1}$ Assumes equal production $^{ m c}$ | of charged and neutral B mesons from $\varUpsilon(4S)$ decays. |
| | * * | $\Gamma(b_1^0 K^0 \times B(b_1^0 	o \omega \pi^0))$ | /Γ _{total} Γ ₂₂₆ / |
| • • • vve do not use the foll $3.8 \pm 1.1 \pm 0.5$ | owing data for averages, fits, limits, etc. • • • 1 AUBERT 07E BABR Repl. by DEL-AMO- | | |
| | SANCHEZ 104 | <u>VALUE (units 10^{−6}) CL%</u> <7.8 90 | 1 AUBERT 08AG BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| < 2.6 90 < 7.6 90 | 1 SCHUEMANN 07 BELL $e^+e^- ightarrow ^{TA(S)}$ 1 AUBERT,B 04D BABR Repl. by AUBERT 07E | $^{ m 1}$ Assumes equal production $_{ m c}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. |
| <24 90 | 1 RICHICHI 00 CLE2 $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | $\Gamma(a_0(980)^{\pm}K^{\mp}\times B(a_0(980)^{\pm}K^{\mp})$ | $0)^{\pm} ightarrow \eta \pi^{\pm}))/\Gamma_{	ext{total}}$ $\Gamma_{227}/$ |
| <39 90 | BEHRENS 98 CLE2 Repl. by RICHICHI 00 | VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN COMMENT |
| ¹ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | <1.9 90 | 1 AUBERT 07Y BABR $e^+e^- 	o 	au(4S)$ |
| $\Gamma(\eta' K_0^* (1430)^0) / \Gamma_{\text{total}}$ | Γ ₂₁₈ /Γ | ● We do not use the follow | ving data for averages, fits, limits, etc. • • • |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | <2.1 90 | ¹ AUBERT,BE 04 BABR Repl. by AUBERT 07 |
| 6.3±1.3±0.9 | 1 DEL-AMO-SA10A BABR $e^{+}e^{-} ightarrow~ \varUpsilon(4S)$ | $^{ m 1}$ Assumes equal production $_{ m c}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. |
| ¹ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | $\Gamma(b_1^-K^+\times B(b_1^-\to\omega\pi^-)$ |))/Γ _{total} Γ ₂₂₈ / |
| $\Gamma(\eta' K_2^*(1430)^0)/\Gamma_{\text{total}}$ | Γ ₂₁₉ /Γ | VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT | 7.4±1.0±1.0 | 1 AUBERT 07BI BABR $e^{+}e^{-} ightarrow \gamma(4S)$ |
| 13.7+3.0 ±1.2 | 1 DEL-AMO-SA10A BABR $e^{+}e^{-} ightarrow \gamma(4S)$ | $^{ m 1}$ Assumes equal production $_{ m C}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. |
| -2.9 | | | |
| 1. | s p ± 1 p 0 m(. s) | $\Gamma(h \cup K^{*0} \times B(h \cup \to \omega \pi^{0}))$ | 1/1 |
| ¹ Assumes equal production | of B^+ and B^0 at the $\varUpsilon(4S)$. | $\Gamma(b_1^0 K^{*0} \times B(b_1^0 \to \omega \pi^0))$ VALUE CLY |)/F _{total} F ₂₂₉ / DOCUMENT ID TECN COMMENT |
| 1 Assumes equal production $\Gamma(\eta K^0)/\Gamma_{	ext{total}}$ | of \mathcal{B}^+ and \mathcal{B}^0 at the \varUpsilon (45). $ \Gamma_{220}/\Gamma $ | $ \frac{\Gamma(b_1^0 K^{*0} \times B(b_1^0 \to \omega \pi^0))}{\langle 8.0 \times 10^{-6} \rangle} $ | |
| $\Gamma(\eta K^0)/\Gamma_{\text{total}}$ | | VALUE CL% | $1 \ { m DOCUMENT\ ID} \ { m OPAF\ BABR} \ { m e^+e^-} ightarrow { m T}(4S)$ |
| $\Gamma(\eta K^0)/\Gamma_{\text{total}}$ | Γ ₂₂₀ /Γ | VALUE CL% <8.0 × 10 ⁻⁶ 90 1 Assumes equal production of the second control of the second c | $\frac{DOCUMENT\ ID}{1}$ AUBERT 09AF BABR $e^+e^- ightarrow \varUpsilon(4S)$ of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $\Gamma(\eta K^0)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-6}\text{)}}{1.23 \stackrel{+}{-} 0.27} \text{ OUR AVERAGE}$ | F ₂₂₀ /F DOCUMENT ID TECN COMMENT SE | <u>VALUE</u> <u>CL%</u> <8.0 × 10 ^{−6} 90 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \frac{\Gamma\left(\etaK^{0}\right)/\Gamma_{\text{total}}}{1.23 + 0.27} \frac{\text{CL}\%}{0.24} \\ 1.27 + 0.39 \pm 0.08 $ | Γ_{220}/Γ | VALUE CL% <8.0 × 10 ⁻⁶ 90 1 Assumes equal production of the second control of the second c | $\frac{DOCUMENT\ ID}{1}$ AUBERT 09AF BABR $e^+e^- ightarrow \varUpsilon(4S)$ of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $ \frac{\Gamma(\eta \text{K}^0)/\Gamma_{\text{total}}}{1.23 \overset{+}{-} 0.27} \text{OUR AVERAC} \\ 1.27 \overset{+}{-} 0.29 & 0.08 \\ 1.15 \overset{+}{-} 0.38 \overset{+}{-} 0.09 \\ $ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} \underline{\text{WALUE}} & \underline{\text{CLW}} \\ < 8.0 \times 10^{-6} & 90 \\ \\ \text{1 Assumes equal production of} \\ \Gamma(b_1^- K^{*+} \times B(b_1^- \to \omega \pi^-)) \\ \underline{\text{WALUE}} & \underline{\text{CLW}} \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c c} \Gamma(\eta K^0)/\Gamma_{\text{total}} \\ \hline 1.23 \substack{+0.27 \\ -0.24} \text{ OUR AVERAC} \\ 1.27 \substack{+0.33 \\ -0.29} \pm 0.08 \\ 1.15 \substack{+0.43 \\ -0.38} \pm 0.09 \\ \bullet \bullet \bullet \text{ We do not use the foll} \end{array} $ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c c} \underline{\text{WLUE}} & \underline{\text{CL\%}} \\ \hline < 8.0 \times 10^{-6} & 90 \\ \\ ^{1} \text{ Assumes equal production of } \\ \hline \Gamma \left(b_{1}^{-} K^{*+} \times \text{B} \left(b_{1}^{-} \rightarrow \omega \pi^{-} \frac{\text{CL\%}}{\text{S.0}} \times 10^{-6} \right) \\ \\ \hline < 5.0 \times 10^{-6} & 90 \\ \\ ^{1} \text{ Assumes equal production of } \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{lll} \Gamma \left(\eta K^0 \right) / \Gamma_{\text{total}} \\ & \underline{\text{VALUE (units } 10^{-6})} & \underline{\text{CL\%}} \\ \hline \textbf{1.23} & \underline{\textbf{0.24}} & \text{OUR AVERAC} \\ 1.27 & \underline{\textbf{0.23}} & \underline{\textbf{0.08}} \\ 1.27 & \underline{\textbf{0.03}} & \underline{\textbf{0.08}} \\ 1.15 & \underline{\textbf{0.13}} & \underline{\textbf{0.09}} \\ \bullet & \bullet & \text{We do not use the foll} \\ < 1.9 & 90 \end{array} $ | TECN COMMENT DOCUMENT ID TECN COMMENT 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT OPAN BABR $e^+e^- \rightarrow \Upsilon(4S)$ Diving data for averages, fits, limits, etc. • • • 1 CHANG OTB BELL Repl. by HOI 12 | $\begin{array}{c} \underline{\text{WALUE}} & \underline{\text{CLW}} \\ < 8.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(b_1^- K^{*+} \times \text{B}(b_1^- \to \omega \pi^- \times 10^{-6}) \right) \\ \underline{\text{MALUE}} & \underline{\text{CLW}} \\ < 5.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(a_0(1450)^{\pm} K^{\mp} \times \text{B}(a_0(1450)^{\pm} K^{\pm}) \right) \\ \underline{\text{MALUE}} & \underline{\text{CLW}} \\ \\ < 5.0 \times 10^{-6} & 90 \\ \underline{\text{MALUE}} & \underline{\text{CLW}} \\ \\ = 1 \text{ Assumes equal production of} \\ \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c c} \Gamma(\eta K^0)/\Gamma_{total} \\ \hline \nu_{ALUE (units 10^{-6})} & \underline{CL\%} \\ \hline 1.23 & 0.27 \text{OUR AVERAC} \\ \hline 1.27 & 0.29 & 0.08 \\ \hline 1.15 & 0.43 & 0.09 \\ \bullet & \bullet & \text{We do not use the foll} \\ \end{array} $ | TECN COMMENT DOCUMENT ID TECN COMMENT THOI 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 1 O9AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ Dowing data for averages, fits, limits, etc. • • • 1 CHANG 1 CHANG 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT,B 1 AUBERT,B 06V BABR 1 O5K BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\begin{array}{c c} \underline{\text{WLUE}} & \underline{\text{CL\%}} \\ \hline < 8.0 \times 10^{-6} & 90 \\ \\ ^{1} \text{ Assumes equal production of } \\ \hline \Gamma \left(b_{1}^{-} K^{*+} \times \text{B} \left(b_{1}^{-} \rightarrow \omega \pi^{-} \frac{\text{CL\%}}{\text{S.0}} \times 10^{-6} \right) \\ \\ \hline < 5.0 \times 10^{-6} & 90 \\ \\ ^{1} \text{ Assumes equal production of } \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c c} \Gamma(\eta K^0)/\Gamma_{\text{total}} \\ \hline \nu_{ALUE (\text{units} 10^{-6})} & c.t.\% \\ \hline 1.23 \stackrel{+}{-} 0.27 \text{OUR AVERAGE} \\ \hline 1.27 \stackrel{+}{-} 0.32 \pm 0.08 \\ \hline 1.15 \stackrel{+}{-} 0.38 \pm 0.09 \\ \bullet \bullet \bullet \text{ We do not use the foll} \\ \hline < 1.9 & 90 \\ < 2.9 & 90 \\ < 2.5 & 90 \\ < 2.0 & 90 \end{array} $ | TECN COMMENT DOCUMENT ID TECN COMMENT TECN TECN COMMENT 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT,B 06V BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05K BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B | ASSUMES EQUAL PRODUCTION OF $(b_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(b_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(b_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(b_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(c_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(c_1^-K^{*+}\times B(b_1^-\to \omega\pi^-))$ $(c_1^-K^{*+}\times B(a_0^-(1-b_1^-K^+))$ $(c_1^-K^{*+}\times B(a_0^-(1-b_1^-K^+))$ $(c_1^-K^{*+}\times B(a_0^-(1-b_1^-K^+))$ $(c_1^-K^{*+}\times B(a_0^-(1-b_1^-K^+))$ $(c_1^-K^{*+}\times B(a_0^-(1-b_1^-K^+))$ $(c_1^-K^-K^-)$ $(c_1^-K^-K^-K^-K^-K^-K^-K^-K^-K^-K^-K^-K^-K^$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $Γ(η κ0)/Γtotal$ $VALUE (units 10-6)$ $CL\%$ 1.23 $^+0.27$ OUR AVERACE 1.27 $^+0.33$ ± 0.08 1.15 $^+0.43$ ± 0.09 • • • We do not use the foll < 1.9 < 2.9 < 90 < 2.5 90 < 5.2 90 | TECN COMMENT DOCUMENT ID TECN COMMENT TECN TECN COMMENT 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ Dowing data for averages, fits, limits, etc. • • • 1 CHANG 1 AUBERT,B 06V BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT,B 1 AUBERT,B 05K BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B 1 AUBERT,B 05A BELL Repl. by AUBERT,B 05K Repl. by AUBERT,B 05K | $\begin{array}{c} \underline{\text{WALUE}} & \underline{\text{CLW}} \\ < 8.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(b_1^- K^{*+} \times \text{B}(b_1^- \to \omega \pi^- \text{WALUE})\right) \\ < 5.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(a_0(1450)^{\pm} K^{\mp} \times \text{B}(a_0(1450)^{\pm} \text{WALUE})\right) \\ < 3.1 & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $Γ(η K^0)/Γ_{total}$ $VALUE (units 10^{-6})$ $CL\%$ 1.23 $\stackrel{•}{=}$ 0.27 OUR AVERACE 1.27 $\stackrel{•}{=}$ 0.33 ± 0.08 1.15 $\stackrel{•}{=}$ 0.38 ± 0.09 • • • We do not use the foll < 1.9 < 2.9 < 2.9 < 2.5 < 90 < 2.0 90 | TECN COMMENT DOCUMENT ID TECN COMMENT TECN TECN COMMENT 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT,B 06V BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05K BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B | **NLUE** CL%** <pre> <8.0 \times 10^{-6}</pre> | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c cccc} \Gamma(\eta K^0)/\Gamma_{total} & & & \\ \hline 1.23 & + 0.27 & \text{OUR AVERAC} \\ \hline 1.23 & + 0.27 & \text{OUR AVERAC} \\ \hline 1.27 & + 0.33 & \pm 0.09 \\ \hline 1.15 & + 0.43 & \pm 0.09 \\ \hline \bullet & \bullet & \text{We do not use the foll} \\ \hline < 1.9 & 90 \\ < 2.9 & 90 \\ < 2.5 & 90 \\ < 2.0 & 90 \\ < 2.2 & 90 \\ < 9.3 & 90 \\ < 33 & 90 \\ \end{array} $ | Tech Document ID Tech Comment IHOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ THOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ THOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ Dowing data for averages, fits, limits, etc. • • 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT, B 06V BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, B 05K BABR $e^+e^- 	oup \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B 1 AUBERT 04H BABR Repl. by AUBERT, B 05K 1 RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ | $\begin{array}{c} \underline{\text{WALUE}} & \underline{\text{CLW}} \\ < 8.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(b_1^- K^{*+} \times \text{B}(b_1^- \to \omega \pi^- \text{WALUE})\right) \\ < 5.0 \times 10^{-6} & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \Gamma\left(a_0(1450)^{\pm} K^{\mp} \times \text{B}(a_0(1450)^{\pm} \text{WALUE})\right) \\ < 3.1 & 90 \\ \\ 1 \text{ Assumes equal production of} \\ \end{array}$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $Γ(η κ0)/Γ_{total}$ 1.23 $^+$ 0.27 OUR AVERACE 1.27 $^+$ 0.33 $^+$ 0.09 • • • We do not use the following solution of th | THO IS BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 HOI 12 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT,B 06V BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B 1 AUBERT,B 05K BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by OHANG 07B 1 AUBERT 04H BABR Repl. by AUBERT,B 05K 1 RICHICHI 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $\Upsilon(4S)$. | $ \begin{array}{c} \underline{\text{WALUE}} & \underline{\text{CLW}} \\ < 8.0 \times 10^{-6} & 90 \\ 1 \text{ Assumes equal production of } \\ \Gamma\left(b_1^- K^{*+} \times B(b_1^- \to \omega \pi^- K^- K^{*+} \times B(b_1^- \to \omega \pi^- K^- K^- K^- K^- K^- K^- K^- K^- K^- K$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c c} \Gamma(\eta K^0)/\Gamma_{\text{total}} \\ \hline \nu_{ALUE(\text{units}10^{-6})} & c.t.\% \\ \hline 1.23 & + 0.27 & \text{OUR AVERAC} \\ \hline 1.27 & + 0.33 & + 0.09 \\ \hline 1.15 & + 0.43 & + 0.09 \\ \hline \bullet & \bullet & \text{We do not use the foll} \\ \hline < 2.9 & 90 \\ < 2.5 & 90 \\ < 2.5 & 90 \\ < 2.0 & 90 \\ < 2.2 & 90 \\ < 3.3 & 90 \\ \end{array} $ | Tech | **NLUE** CL** <8.0 × 10^-6 90 1 Assumes equal production of the production of th | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| $Γ(η κ^0)/Γ_{total}$ $VALUE (units 10^{-6})$ $CL\%$ 1.23 + 0.27 OUR AVERACO 1.27 + 0.33 + 0.09 • • • We do not use the foll < 1.9 90 < 2.9 90 < 2.5 90 < 2.0 90 < 3.3 90 1 Assumes equal production $Γ(η κ^*(892)^0)/Γ_{total}$ $VALUE (units 10^{-6})$ 15.9 ± 1.0 OUR AVERAGE 15.2 ± 1.2 ± 1.0 16.5 ± 1.1 ± 0.8 13.8 + 5.5 ± 1.6 • • • We do not use the foll 18.6 ± 2.3 ± 1.2 < 30 90 | THE PROOF OF THE | **Note * | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $Γ(η κ^0)/Γ_{total}$ $VALUE (units 10^{-6})$ $CL\%$ 1.23 + 0.27 OUR AVERACE 1.27 + 0.33 ± 0.08 1.15 + 0.38 ± 0.09 • • • We do not use the following | THOM IS BELL $e^+e^- 	oup \Upsilon(4S)$ I HOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ I AUBERT 09AV BABR $e^+e^- 	oup \Upsilon(4S)$ Owing data for averages, fits, limits, etc. • • • I CHANG 07B BELL Repl. by HOI 12 I AUBERT,B 06V BABR $e^+e^- 	oup \Upsilon(4S)$ I CHANG 05A BELL Repl. by CHANG 07B I AUBERT, B 05K BABR $e^+e^- 	oup \Upsilon(4S)$ I CHANG 05A BELL Repl. by AUBERT,B 05K I RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. F221/ Γ DOCUMENT ID TECN COMMENT I WANG 07B BELL $e^+e^- 	oup \Upsilon(4S)$ I RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ I RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ Owing data for averages, fits, limits, etc. • • • I AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. | **NLUE** CL%** **N.UE** Cunits 10^{-6} CL%* **N.UE** (units 10^{-6}) CL%* **N.U | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| $\Gamma(\eta K^0)/\Gamma_{\text{total}}$ 1.23 $\stackrel{+}{-}0.27$ OUR AVERAGE 1.27 $\stackrel{+}{-}0.33 \pm 0.08$ 1.15 $\stackrel{+}{-}0.38 \pm 0.09$ • • • We do not use the foll < 1.9 90 < 2.9 90 < 2.5 90 < 2.0 90 < 5.2 90 < 5.2 90 < 33 90 1 Assumes equal production $\Gamma(\eta K^*(892)^0)/\Gamma_{\text{total}}$ VALUE (units 10 $\stackrel{-}{-}6$) • • • We do not use the foll 18.6 $\pm 2.3 \pm 1.2$ <30 90 1 Assumes equal production $\Gamma(\eta K^*(1430)^0)/\Gamma_{\text{total}}$ | THE DOCUMENT ID DOCUMENT ID TECN COMMENT TECN COMMENT 1 HOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- 	oup \Upsilon(4S)$ Dowing data for averages, fits, limits, etc. • • • 1 CHANG 07B BELL Repl. by HOI 12 1 AUBERT,B 06V BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT,B 05K BABR $e^+e^- 	oup \Upsilon(4S)$ 1 CHANG 05A BELL Repl. by CHANG 07B 1 AUBERT 04H BABR Repl. by AUBERT,B 05K BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. F221/ Γ DOCUMENT ID TECN COMMENT 1 RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ Dowing data for averages, fits, limits, etc. • • 1 AUBERT,B 04D BABR Repl. by AUBERT,B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. | **Note * | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\eta K^0)/\Gamma_{total}$ 1.23 $\stackrel{+}{=}0.27$ OUR AVERAGE 1.27 $\stackrel{+}{=}0.33 \pm 0.08$ 1.15 $\stackrel{+}{=}0.33 \pm 0.09$ • • • We do not use the foll < 1.9 90 < 2.9 90 < 2.5 90 < 2.0 90 < 5.2 90 < 5.2 90 1 Assumes equal production $\Gamma(\eta K^*(892)^0)/\Gamma_{total}$ $VALUE$ (units 10^{-6}) 1.8.6 $\pm 2.3 \pm 1.2$ < 30 90 1 Assumes equal production 18.6 $\pm 2.3 \pm 1.2$ < 30 90 1 Assumes equal production $\Gamma(\eta K^*(1430)^0)/\Gamma_{total}$ | THE PROOF OF THE | **Note **Comparison of the searched for feebly-interacting particle X and X are with a spontaneously of the searched X and X are with a spontaneously of the searched X and X are the searched X and X are the searched for feebly-interacting particle X at the search X and X are the search of X and X a | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\eta K^0)/\Gamma_{\text{total}}$ 1.23 + 0.27 OUR AVERAGE 1.27 + 0.33 ± 0.09 • • • We do not use the foll < 1.9 90 < 2.9 90 < 2.5 90 < 2.0 90 < 5.2 90 < 3.3 90 1 Assumes equal production $\Gamma(\eta K^*(892)^0)/\Gamma_{\text{total}}$ VALUE (units 10 - 6) 1.5. ± 1.1 ± 0.8 13.8 + 5.5 ± 1.6 • • • We do not use the foll 18.6 ± 2.3 ± 1.2 < 30 90 1 Assumes equal production $\Gamma(\eta K^*_0(1430)^0)/\Gamma_{\text{total}}$ VALUE (units 10 - 6) 1 Assumes equal production $\Gamma(\eta K^*_0(1430)^0)/\Gamma_{\text{total}}$ | THE PROOF OF THE PROOF OF THE PROOF OF BH AND BOTTOM TO TECN COMMENT 1 HOI 12 BELL $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT 09AV BABR $e^+e^- 	oup \Upsilon(4S)$ 2 AUBERT, B 06V BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, B 06V BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, B 05K BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, B 05K BABR $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, D 05A BELL Repl. by CHANG 07B 1 AUBERT 04H BABR Repl. by AUBERT, B 05K 1 RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. F221/F DOCUMENT ID TECN COMMENT 1 WANG 07B BELL $e^+e^- 	oup \Upsilon(4S)$ 1 RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ 1 RICHICHI 00 CLE2 $e^+e^- 	oup \Upsilon(4S)$ 1 AUBERT, B 06H BABR $e^+e^- 	oup \Upsilon(4S)$ 2 DOWING data for averages, fits, limits, etc. • • • 1 AUBERT, B 04D BABR Repl. by AUBERT, B 06H BEHRENS 98 CLE2 Repl. by RICHICHI 00 of B^+ and B^0 at the $T(4S)$. F222/F DOCUMENT ID TECN COMMENT 1 AUBERT, B 06H BABR $e^+e^- 	oup \Upsilon(4S)$ of B^+ and B^0 at the $T(4S)$. | **Note * | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\eta K^0)/\Gamma_{total}$ 1.23 $\stackrel{+}{=}0.27$ OUR AVERAGE 1.27 $\stackrel{+}{=}0.33 \pm 0.08$ 1.15 $\stackrel{+}{=}0.33 \pm 0.09$ • • • We do not use the foll < 1.9 90 < 2.9 90 < 2.5 90 < 2.0 90 < 5.2 90 < 5.2 90 1 Assumes equal production $\Gamma(\eta K^*(892)^0)/\Gamma_{total}$ $VALUE$ (units 10^{-6}) 1.8.6 $\pm 2.3 \pm 1.2$ < 30 90 1 Assumes equal production 18.6 $\pm 2.3 \pm 1.2$ < 30 90 1 Assumes equal production $\Gamma(\eta K^*(1430)^0)/\Gamma_{total}$ | THE PROOF OF THE | **Note **Comparison of the searched for feebly-interacting particle X and X are with a spontaneously of the searched X and X are with a spontaneously of the searched X and X are the searched X and X are the searched for feebly-interacting particle X at the search X and X are the search of X and X a | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Uses Dalitz plot analysis of $B^0\to~K^+\pi^-\pi^0$ decays.

 B^0

| $\Gamma(\omega K_0^*(1430)^0)/\Gamma_{\text{total}}$ | Γ ₂₃₅ /Γ | $\Gamma((K\pi)_0^{*0}\pi^0 \times B((K\pi)_0^{*0} -$ | $\rightarrow K^{+}\pi^{-}))/\Gamma_{\text{total}}$ | Γ ₂₄₄ /Γ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻⁶) DOCUMENT ID | TECN COMMENT | $(K\pi)^{*0}_0$ is the total S-way | ve composed of $K_0^st(1430)$ and no | nresonant that are described |
| | 09н BABR $e^+e^- ightarrow$ \varUpsilon (4 S) | using LASS shape. VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN | V COMMENT |
| 1 Assumes equal production of B^{+} and B^{0} at the $^{\prime}$ | $\Upsilon(4S)$. | 8.6±1.1±1.3 | | $\frac{e^+e^-}{} \rightarrow \Upsilon(4S)$ |
| $\Gamma(\omega K_2^*(1430)^0)/\Gamma_{\text{total}}$ | Γ ₂₃₆ /Γ | | wing data for averages, fits, limit | , , |
| VALUE (units 10 ⁻⁶) DOCUMENT ID | TECN COMMENT | | | |
| | 09н BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $8.7 + 1.1 + 2.8 \\ -0.9 - 2.6$ | • | R Repl. by LEES 11 |
| 1 Assumes equal production of B^{+} and B^{0} at the | | Assumes equal production | | |
| | | ² Uses Dalitz plot analysis of | $B^0 \rightarrow K^+\pi^-\pi^0$ decays. | |
| $\Gamma(\omega K^+\pi^- \text{ nonresonant})/\Gamma_{\text{total}}$ | Г ₂₃₇ /Г | $\Gamma(K_2^*(1430)^0\pi^0)/\Gamma_{\mathrm{total}}$ | | Γ ₂₄₅ /Γ |
| VALUE (units 10 ⁻⁶) DOCUMENT ID | TECN COMMENT | VALUE (units 10 ⁻⁶) CL% | DO CUMENT ID TECN | • |
| | 08 BELL $e^+e^- ightarrow \varUpsilon(4S)$ | <4.0 90 | 1 AUBERT 08AQ BAB | $e^+e^- \rightarrow r(4S)$ |
| 1 Assumes equal production of B^{+} and B^{0} at the 2 For the $K\pi$ mass range 0.755–1.250 GeV/c ² , exc | | $^{ m 1}$ Assumes equal production $^{ m 1}$ | of B^+ and B^0 at the $\varUpsilon(4S)$. | |
| - · · · · · · · · · · · · · · · · · · · | - ' ' | $\Gamma(K^*(1680)^0\pi^0)/\Gamma_{ m total}$ | | F /F |
| $\Gamma(K^+\pi^-\pi^0)/\Gamma_{\text{total}}$ | Γ ₂₃₈ /Γ | | | Γ ₂₄₆ /Γ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID | TECN COMMENT | VALUE (units 10 ⁻⁶) CL% <7.5 90 | | $rac{COMMENT}{GR} ightarrow rac{COMMENT}{e^+e^- ightarrow \Upsilon(4S)}$ |
| 37.8 \pm 3.2 OUR AVERAGE 38.5 \pm 1.0 \pm 3.9 1,2 LEES | 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | = | | SR e e e → 1 (43) |
| | 04 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | · · · | of B^+ and B^0 at the $\varUpsilon(4S)$. | |
| • • • We do not use the following data for averages, | (/ | $\Gamma(K_X^{*0}\pi^0)/\Gamma_{ m total}$ | | Γ ₂₄₇ /Γ |
| | | K_X^{*0} stands for the possi | ble candidates of $K^*(1410)$, K_0^* | (1430) and K_2^* (1430). |
| -1.5 | 08AQ BABR Repl. by LEES 11 | VALUE (units 10 ⁻⁶) | DO CUMENT ID TECH | <u>COMMENT</u> |
| | 02 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ | $6.1^{+1.6+0.5}_{-1.5-0.6}$ | ¹ CHANG 04 BEL | L $e^+e^- \rightarrow \Upsilon(4S)$ |
| ¹ Assumes equal production of B^+ and B^0 at the ² | | | of B^+ and B^0 at the $\varUpsilon(4S)$. | , |
| ² Uses Dalitz plot analysis of $B^0 	o K^+\pi^-\pi^0$ dec | cays. | | | |
| $\Gamma(K^+ ho^-)/\Gamma_{\text{total}}$ | Γ ₂₃₉ /Γ | $\Gamma(K^0\pi^+\pi^- \text{ charmless})/\Gamma_t$ | | Γ ₂₄₈ /Γ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID | TECN COMMENT | VALUE (units 10 ⁻⁶) CL% | DOCUMENT ID TECN | COMMENT |
| 7.0±0.9 OUR AVERAGE | | 49.6± 2.0 OUR AVERAGE 50.2± 1.5±1.8 | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $6.6 \pm 0.5 \pm 0.8$ 1,2 LEES 11 | · / | $47.5 \pm 2.4 \pm 3.7$ | ² GARMASH 07 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 15.1 + 3.4 + 2.4 1 CHANG 04 | BELL $e^+e^- ightarrow \varUpsilon(4S)$ | $50 \begin{array}{c} +10 \\ -9 \end{array} \pm 7$ | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| \bullet \bullet \bullet We do not use the following data for averages, | fits, limits, etc. • • • | | wing data for averages, fits, limit | , , |
| $8.0^{+0.8}_{-1.3} \pm 0.6$ 1 AUBERT 08A | Q BABR Repl. by LEES 11 | 43.0± 2.3±2.3 | | Repl. by AUBERT 09AU |
| 112 | BABR Repl. by AUBERT 08AQ | 43.0± 2.3±2.3 43.7± 3.8±3.4 | | Repl. by AUBERT 061 |
| | • • | 45.4± 5.2±5.9 | | Repl. by GARMASH 07 |
| <pre><32 90 1 JESSOP 00 <35 90 ASNER 96</pre> | | <440 90 | ALBRECHT 91E ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 1 Assumes equal production of B^{+} and B^{0} at the | . , | | of B^+ and B^0 at the $\varUpsilon(4S)$. | |
| 2 Uses Dalitz plot analysis of $B^0 \rightarrow K^+\pi^-\pi^0$ dec | | ² Uses Dalitz plot analysis of | the $B^0 ightarrow \ K^0 \pi^+ \pi^-$ final stat | te decays. |
| · | • | $\Gamma(K^0\pi^+\pi^-$ non-resonant) | /F _{total} | Γ ₂₄₉ /Γ |
| $\Gamma(K^+\rho(1450)^-)/\Gamma_{\text{total}}$ | Γ ₂₄₀ /Γ | VALUE (units 10 ⁻⁶) | DOCUMENT ID TECH | • |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID | TECN COMMENT | 14.7 + 4.0 OUR AVERAGE E | rror includes scale factor of 2.1 | |
| 2.4±1.0±0.6 • • • We do not use the following data for averages, | 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | | | |
| | 08AQ BABR Repl. by LEES 11 | $11.1^{+2.5}_{-1.0}\pm0.9$ | ¹ AUBERT 09AU BAB | SR $e^+e^- 	o 	au(4S)$ |
| ¹ Assumes equal production of B^+ and B^0 at the | | $19.9 \pm 2.5 + 1.7 \\ -2.0$ | ² GARMASH 07 BEL | L $e^+e^- \rightarrow \Upsilon(4S)$ |
| ² Uses Dalitz plot analysis of $B^0 \rightarrow K^+\pi^-\pi^0$ dec | | =:- | of B^+ and B^0 at the $\varUpsilon(4S)$. | , , |
| | _ | | of B^+ and B^0 at the $I(4S)$. The $B^0 	o K^0 \pi^+ \pi^-$ final stat | |
| $\Gamma(K^+\rho(1700)^-)/\Gamma_{\text{total}}$ | E /E | oses Santz plot analysis of | 3 | re decays. |
| | Γ ₂₄₁ /Γ | | | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID | TECN COMMENT | $\Gamma(K^0 ho^0)/\Gamma_{ m total}$ | | |
| 0.6±0.6±0.4 1,2 LEES | $\frac{\text{TECN}}{\text{11}} \frac{\text{COMMENT}}{\text{BABR}} \frac{c \rightarrow r(4S)}{e^+ e^- \rightarrow r(4S)}$ | VALUE (units 10^{-6}) CL% | | |
| 0.6±0.6±0.4 1,2 LEES • • • We do not use the following data for averages, | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | VALUE (units 10 ⁻⁶) CL% 4.7±0.6 OUR AVERAG | E_ | Γ ₂₅₀ /Γ |
| | $ \begin{array}{c c} \underline{\textit{TECN}} & \underline{\textit{COMMENT}} \\ 11 & BABR & e^+ e^- \to & \varUpsilon(4S) \\ fits, limits, etc. & \bullet & \bullet \\ 08AQ BABR & Repl. by LEES & 11 \\ \end{array} $ | $\frac{\text{VALUE (units }10^{-6})}{\textbf{4.7 \pm 0.6 OUR AVERAG}} \underbrace{\text{CL\%}}_{4.4 \ -0.6} \pm 0.3}$ | E_ | Γ ₂₅₀ /Γ |
| 0.6±0.6±0.4 • • • We do not use the following data for averages, <1.1 90 ¹ AUBERT ¹ Assumes equal production of B+ and B⁰ at the | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. | VALUE (units 10 ⁻⁶) CL% 4.7±0.6 OUR AVERAG | 1 AUBERT 09AU BABR | Γ ₂₅₀ /Γ |
| $\begin{array}{c} \textbf{0.6\pm0.6\pm0.4} & 1.2 \text{ LEES} \\ \bullet \bullet \bullet \text{ We do not use the following data for averages,} \\ <1.1 & 90 & ^1 \text{ AUBERT} \\ ^1 \text{ Assumes equal production of } B^+ \text{ and } B^0 \text{ at the } 2 \text{ Uses Dalitz plot analysis of } B^0 \to K^+\pi^-\pi^0 \text{ dec} \end{array}$ | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. | $\frac{\text{VALUE (units } 10^{-6})}{\text{4.7 \pm 0.6 OUR AVERAG}} \xrightarrow{\text{CL}\%} \\ 4.4 \xrightarrow{+0.7} \pm 0.3 \\ 6.1 \pm 1.0 \xrightarrow{+1.1} \\ 6.1 \pm 1.0 \xrightarrow{+1.1}$ | 1 AUBERT 09AU BABR | $ \frac{\text{COMMENT}}{e^+e^- \rightarrow \text{ $\Upsilon(45)$}} $ $ e^+e^- \rightarrow \text{ $\Upsilon(45)$} $ |
| 0.6±0.6±0.4 • • • We do not use the following data for averages, <1.1 90 ¹ AUBERT ¹ Assumes equal production of B+ and B⁰ at the | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. | $\frac{\text{VALUE (units } 10^{-6})}{\textbf{4.7 \pm 0.6 OUR AVERAG}} \xrightarrow{\text{CL}\%} \\ \textbf{4.4 + 0.7 \pm 0.8} \\ \textbf{4.4 + 0.7 \pm 0.3} \\ \textbf{6.1 \pm 1.0 + 1.1} \\ \textbf{1.1.2}$ | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit | $ \frac{\text{COMMENT}}{e^+e^- \rightarrow \text{ $\Upsilon(45)$}} $ $ e^+e^- \rightarrow \text{ $\Upsilon(45)$} $ |
| 0.6±0.6±0.4 1,2 LEES • • • We do not use the following data for averages, <1.1 90 1 AUBERT 1 Assumes equal production of B^+ and B^0 at the 2 Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ dec $\Gamma((K^+\pi^-\pi^0) \text{ non-resonant})/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) CL% DOCUMENT ID | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. cays. | $\frac{\text{VALUE (units }10^{-6})}{\textbf{4.7 \pm 0.6 OUR AVERAG}}$ $4.4 + 0.7 \pm 0.6 \pm 0.3$ $6.1 \pm 1.0 + 1.1$ • • We do not use the follow $4.9 \pm 0.8 \pm 0.9$ < 39 90 | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit 1 AUBERT 07F BABR ASNER 96 CLEO | $\frac{\text{COMMENT}}{e^+e^- \rightarrow \ \Upsilon(4S)}$ $e^+e^- \rightarrow \ \Upsilon(4S)$ s, etc. • • • Repl. by AUBERT 09AU $e^+e^- \rightarrow \ \Upsilon(4S)$ |
| 0.6 \pm 0.6 \pm 0.4 1,2 LEES • • • We do not use the following data for averages, <1.1 90 1 AUBERT 1 Assumes equal production of B^+ and B^0 at the 2 Uses Dalitz plot analysis of $B^0 \rightarrow K^+\pi^-\pi^0$ dec $\Gamma((K^+\pi^-\pi^0) \text{ non-resonant})/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) 2.8 \pm 0.5 \pm 0.4 1,2 LEES | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. ays. F242/ Γ TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $ \begin{array}{c} \underline{\text{VALUE (units } 10^{-6})} & \underline{\text{CL\%}} \\ \textbf{4.7 \pm 0.6 OUR AVERAG} \\ \textbf{4.4 } & -0.6 \pm 0.3 \\ \textbf{6.1 \pm 1.0 } & -1.1 \\ \textbf{ • • • We do not use the follow} \\ \textbf{4.9 \pm 0.8 \pm 0.9} \\ \textbf{< 39} & \textbf{90} \\ \textbf{< 320} & \textbf{90} \end{array} $ | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit 1 AUBERT 07F BABR ASNER 96 CLEO ALBRECHT 91B ARG | $\begin{array}{c} \Gamma_{250}/\Gamma \\ \hline comment \\ e^+e^- \rightarrow \Upsilon(45) \\ e^+e^- \rightarrow \Upsilon(45) \\ \text{s, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT 09AU} \\ e^+e^- \rightarrow \Upsilon(45) \\ e^+e^- \rightarrow \Upsilon(45) \end{array}$ |
| 0.6±0.6±0.4 1,2 LEES • • • We do not use the following data for averages, <1.1 90 1 AUBERT 1 Assumes equal production of B^+ and B^0 at the 2 Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ dec $\Gamma((K^+\pi^-\pi^0) \text{ non-resonant})/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) 2.8±0.5±0.4 1,2 LEES • • • We do not use the following data for averages, | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. Lays. Frace COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit 1 AUBERT 07F BABR ASNER 96 CLEO ALBRECHT 91B ARG 3 AVERY 89B CLEO | $\begin{array}{c} \Gamma_{250}/\Gamma \\ \hline comment \\ e^+e^- \rightarrow \ \Upsilon(45) \\ e^+e^- \rightarrow \ \Upsilon(45) \\ \text{s, etc.} \bullet \bullet \\ \text{Repl. by AUBERT 09AU} \\ e^+e^- \rightarrow \ \Upsilon(45) \\ e^+e^- \rightarrow \ \Upsilon(45) \\ e^+e^- \rightarrow \ \Upsilon(45) \end{array}$ |
| 0.6±0.6±0.4 1,2 LEES • • • We do not use the following data for averages, <1.1 90 1 AUBERT 1 Assumes equal production of B^+ and B^0 at the 2 Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ dec $\Gamma((K^+\pi^-\pi^0) \text{ non-resonant})/\Gamma_{\text{total}}$ MALUE (units 10 ⁻⁶) 2.8±0.5±0.4 1,2 LEES • • • We do not use the following data for averages, 4.4±0.9±0.5 1 AUBERT | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. cays. Frace COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit 1 AUBERT 07F BABR ASNER 96 CLEO ALBRECHT 91B ARG 3 AVERY 89B CLEO 4 AVERY 87 CLEO | $\begin{array}{c} \Gamma_{250}/\Gamma \\ \hline comment \\ e^+e^- \rightarrow \ \varUpsilon(45) \\ e^+e^- \rightarrow \ \varUpsilon(45) \\ \text{s, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT 09AU} \\ e^+e^- \rightarrow \ \varUpsilon(45) \\ e^+e^- \rightarrow \ \varUpsilon(45) \\ \end{array}$ |
| 0.6±0.6±0.4 1.2 LEES • • • We do not use the following data for averages, <1.1 90 1 AUBERT 1 Assumes equal production of B^+ and B^0 at the 2 Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ dec $\Gamma((K^+\pi^-\pi^0) \text{ non-resonant})/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁶) 2.8±0.5±0.4 1.2 LEES • • • We do not use the following data for averages, 4.4±0.9±0.5 1 AUBERT <9.4 90 1 CHANG | TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • • 08AQ BABR Repl. by LEES 11 $\Upsilon(4S)$. cays. Factor TECN COMMENT 11 BABR $e^+e^- \rightarrow \Upsilon(4S)$ fits, limits, etc. • • 08AQ BABR Repl. by LEES 11 04 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | | 1 AUBERT 09AU BABR 2 GARMASH 07 BELL wing data for averages, fits, limit 1 AUBERT 07F BABR ASNER 96 CLEO ALBRECHT 91B ARG 3 AVERY 89B CLEO 4 AVERY 87 CLEO of B+ and B 0 at the T(4.5). | $\begin{array}{c} \Gamma_{250}/\Gamma \\ \hline comment \\ e^{+}e^{-} \rightarrow \ \varUpsilon(4S) \\ e^{+}e^{-} \rightarrow \ \varUpsilon(4S) \\ \text{s, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT 09AU} \\ e^{+}e^{-} \rightarrow \ \varUpsilon(4S) \\ \end{array}$ |
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| $12.6 ^{+2.7}_{-1.6} \pm 0.9$ 1,2 AUBERT 08AQ BABR Repl. by LEES : | VALUE (units 10 ⁻⁶ | | DO CUMENT ID | TECN COMMENT | 20() |
| 11.0±1.5±0.71 | < 6 • • • We do no | 90 t use the followin | ¹ GARMASH 07 g data for averages, fits, | BELL $e^+e^- \rightarrow$ | T(45) |
| $12.9\pm2.4\pm1.4$ ZAUBERT,B 040 BABR Repl. by AUBER | | | | BABR $e^+e^- \rightarrow$ | Y(45) |
| $14.8 + 4.6 + 2.8 \\ -4.4 - 1.3$ 2 CHANG 04 BELL Repl. by GARM | | 90 | ³ GARMASH 04 | BELL Repl. by G | |
| $<$ 72 90 ASNER 96 CLE2 $e^+e^- ightarrow arUpsilon(4$ | <2600 | 90 | | ARG $e^+e^- \rightarrow$ | |
| <pre><620 90 ALBRECHT 91B ARG $e^+e^- \rightarrow \Upsilon(4$ <380 90 4AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4$</pre> | ¹ GARMASH | 07 reports B(B ^U | $\rightarrow K_2^*(1430)^+\pi^-)\times B($ | $(K_2^{*+} \rightarrow K^0 \pi^+) \leftarrow$ | < 2.1 × 10 ⁻ |
| <560 90 SAVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4)$ | | | compute B($B^0 \rightarrow K_2^*$ (| | ne PDG valu |
| 1 Uses Dalitz plot analysis of $B^0 	o K^+\pi^-\pi^0$ decays. | | | $	imes 10^{-2}$ and 2/3 for the $^0 ightarrow \ 	imes ^+ \pi^- \pi^0$ decays. | | |
| Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 3 Assumes equ | al production of | B^+ and B^0 at the $\Upsilon(4.5)$ | 5). | |
| ³ Uses Dalitz plot analysis of the $B^0 \to K^0 \pi^+ \pi^-$ final state decays. ⁴ AVERY 89B reports < 4.4 × 10 ⁻⁴ assuming the $\Upsilon(4S)$ decays 43% to $B^0 T_0$ | . We Γ (K*(1680) + | π ⁻)/Γ | | | Γ ₂₆₀ / |
| rescale to 50%. 5 AVERY 87 reports $< 7 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 40% to $B^0 \overline{B}{}^0$. We | • | • | DO CUMENT ID | TECN COMMENT | ' 260/ |
| The second of t | <10 | 90 | , | ${\text{BELL}} e^+ e^- \rightarrow$ | Y(45) |
| $\Gamma(K_0^*(1430)^+\pi^-)/\Gamma_{\text{total}}$ | • • • We do no | | g data for averages, fits, | | |
| VALUE (units 10 ⁻⁶) DOCUMENT ID TECN COMMENT | <25 | | | BABR $e^+e^- \rightarrow$ | |
| 33 ±7 OUR AVERAGE Error includes scale factor of 2.0. | | | $\rightarrow K^*(1680)^+\pi^-)\times B($ | | |
| $29.9^{+2.3}_{-1.7}\pm3.6$ 1,2 AUBERT 09AU BABR $e^+e^- ightarrow$ \varUpsilon (4 | | | compute B($B^0 \rightarrow K^*$ (: 10^{-2} and 2/3 for the F | | ie PDG vaiu |
| $49.7\pm3.8^{+6.8}_{-8.2}$ 2 GARMASH 07 BELL $e^+e^- \rightarrow \Upsilon(4$ | ² Uses Dalitz | olot analysis of B | $^{0} \rightarrow \ \ \mathit{K}^{+} \pi^{-} \pi^{0} decays.$ | | |
| $^{-6.2}$ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ³ Assumes equ | al production of | B^+ and B^0 at the \varUpsilon (4.5 | 5). | |
| ² Uses Dalitz plot analysis of the $B^0 	o K^0 \pi^+ \pi^-$ final state decays. | $\Gamma(K^+\pi^-\pi^+\tau)$ | r ⁻)/Γ _{total} | | | Γ ₂₆₁ /Ι |
| | VALUE | | DOCUMENT ID | TECN COMMENT | |
| K_{χ}^{*+} stands for the possible candidates of $K^{*}(1410)$, $K_{0}^{*}(1430)$ and $K_{2}^{*}(1430)$ | \ <u></u> | 90 | | DLPH $e^+e^- \rightarrow$ | Z |
| κ_{χ} stands for the possible california to κ (1410), κ_0 (1430) and κ_2 (142 VALUE (units 10^{-6}) DOCUMENT ID TECN COMMENT | $<2.1 \times 10^{-4}$ | 90 | g data for averages, fits, ² ABREU 95N | DLPH Sup. by Al | DAM 96D |
| 5.1 \pm 1.5 \pm 0.6 1 CHANG 04 BELL $e^+e^- \rightarrow \gamma$ (4 | | | | | |
| | B _S decays c | $B_0 = B_0$ | $f_{B^-}=0.39$ and $f_{B_S}=0$ d. Limits are given for t | he weighted average | of the decay |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | rates for the | two neutral R m | esons. on_fraction of 0.39 and a | | |
| $\Gamma(K^*(1410)^+\pi^- \times B(K^*(1410)^+ \to K^0\pi^+))/\Gamma_{total}$ | 54/Γ Contribution | s from B^0 and B | $\frac{30}{s}$ decays cannot be sep | parated. Limits are | given for th |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | weighted ave | rage of the decay | rates for the two neutra | al B mesons. | |
| <3.8 90 1 GARMASH 07 BELL $e^{+}e^{-} \rightarrow \Upsilon(4)$ | $\Gamma(\rho^0 K^+ \pi^-)$ | Γ _{total} | | | Γ ₂₆₂ /Ι |
| 1 Uses Dalitz plot analysis of the ${\it B}^{0} ightarrow {\it K}^{0} \pi^+ \pi^-$ final state decays. | VALUE (units 10 ⁻⁶ | | DOCUMENT ID | TECN COMMENT | |
| $\Gamma(f_0(980) K^0 \times B(f_0(980) \to \pi^+\pi^-)) / \Gamma_{\text{total}}$ | ₅₅ /Γ 2.8±0.5±0.5 | | 1,2 KYEONG 09 | $\rm BELL~e^+e^- \rightarrow$ | Y(45) |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | Assumes equ | al production of | B^+ and B^0 at the $\Upsilon(45)$ | 5). | |
| 7.0\pm0.9 OUR AVERAGE 6.9 \pm 0.8 \pm 0.6 1 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4S)$ | ² Required 0.7 | $5 < m_{K^+\pi^-} <$ | 1.20 GeV/c². | | |
| 7.6 \pm 1.7 \pm 0.9 2 GARMASH 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | Γ(f ₀ (980) K+ | π^-)/ $\Gamma_{ m total}$ | | | Γ ₂₆₃ /Γ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE (units 10 ⁻⁶ | | DOCUMENT ID | TECN COMMENT | |
| 5.5±0.7±0.6 1 AUBERT 061 BABR Repl. by AUBERT | 9AU 1.4±0.4+0.3 | | 1,2 KYEONG 09 | BELL $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $<$ 360 90 3 AVERY 89B CLEO $e^+e^- ightarrow 	ag{7}(45)$ | • | al production of | B^+ and B^0 at the $\Upsilon(4.5)$ | 5) | |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ² Required 0.7 | 5 < m _{K+K-} < | 1.2 GeV/c ² . | - ,. | |
| ² Uses Dalitz plot analysis of the $B^0 \to K^0 \pi^+ \pi^-$ final state decays. ³ AVERY 89B reports $< 4.2 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0 T_0$ | | | | | - /r |
| rescale to 50%. | VALUE | r nonresonant | // total DOCUMENT ID | TECN COMMENT | Γ264/Γ |
| $\Gamma(f_2(1270)K^0)/\Gamma_{\text{total}}$ | | 90 | 1,2 KYEONG 09 | $\overline{\text{BELL}} \overline{e^+e^-} \rightarrow$ | Y(45) |
| 1 (72(141V) /\ J/I total | ₅₆ /Γ <2.1 × 10 ⁻⁶ | | | | |
| | ¹ Assumes equ | al production of | B^+ and B^0 at the \varUpsilon (4.5 | 5). | |
| VALUE (units 10 ⁻⁶) CL% DO CUMENT ID TECN COMMENT | ¹ Assumes equ | al production of | B^+ and B^0 at the $\Upsilon(4.5)$ 1.42 and 0.75 $< m_{K^+\pi^-}^-$ | 5). _ < 1.20 GeV/c ² . | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 | al production of $5 < m_{\pi^+\pi^-} < 3$ | B^+ and B^0 at the \varUpsilon (48) 1.42 and 0.75 $< m_{K^+\pi^-}^-$ | 5). _ < 1.20 GeV/c ² . | Гэ с г /Г |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | 1 Assumes equ ² Required 0.5 $\Gamma(K^*(892)^0\pi$ | al production of $5 < m_{\pi^+\pi^-} < 3 + \pi^-)/\Gamma_{\text{total}}$ | 1.42 and 0.75 $< m_{K^+\pi^-}$ | _ < 1.20 GeV/c ² . | Γ ₂₆₅ /[|
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ ² Required 0.5 \[\begin{align*} \begin{align*} \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | al production of $5 < m_{\pi^+\pi^-} < 1$ $+\pi^-)/\Gamma_{	ext{total}}$ | 1.42 and 0.75 $< m_{K^+\pi^-}$ | 5). $_{-}$ < 1.20 GeV/ c^{2} . TECN COMMENT BABR $e^{+}e^{-} \rightarrow$ | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{MLUE \text{ (units }10^{-6})}{54.5 \pm 2.9 \pm 10^{-6}}$ $\bullet \bullet \bullet$ We do no | al production of $5 < m_{\pi^+\pi^-} < \frac{1}{2}$ $+\pi^-)/\Gamma_{\text{total}}$ 4.3 | 1.42 and 0.75 $< m_{K^+\pi^-}$ | $_{-}$ < 1.20 GeV/c ² . $\frac{TECN}{BABR}$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{MLUE \text{ (units }10^{-6})}{54.5 \pm 2.9 \pm 0.0}$ $\frac{10^{-6}}{10^{-6}}$ | al production of $5 < m_{\pi^+\pi^-} < 2$ $+ \pi^-)/\Gamma_{\rm total}$ $- \frac{CL\%}{4.3}$ t use the following | .42 and 0.75 $< m_{K^+\pi^-}$ $\frac{_{DOCUMENT\ ID}}{_{1}}$ AUBERT 07As g data for averages, fits, | $_{-}$ < 1.20 GeV/c ² . $\frac{TECN}{BABR}$ $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | Υ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{MLUE \text{ (units }10^{-6})}{54.5 \pm 2.9 \pm 10^{-6}}$ $\bullet \bullet \bullet$ We do no | al production of $5 < m_{\pi^+\pi^-} < 2$ $+ \pi^-)/\Gamma_{\rm total}$ $- \frac{CL\%}{4.3}$ t use the following | .42 and 0.75 $< m_{K^+\pi^-}$ $\frac{_{DOCUMENT\ ID}}{_{1}}$ AUBERT 07As g data for averages, fits, | $ \begin{array}{ccc} & < 1.20 \text{ GeV/c}^2. \\ \hline & & \\ \hline & \\ \hline & & \\ \hline & \\ \hline & & \\ $ | γ(4S) γ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{MLUE \text{ (units }10^{-6})}{54.5 \pm 2.9 \pm 2}$ 10^{-6} • • • We do not value $4.5 + \frac{1}{-1}.\frac{1}{0} + \frac{1}{-1}$ < 1400 1 Assumes equ | al production of $5 < m_{\pi^+\pi^-} < 1$ $+\pi^-)/\Gamma$ total $\frac{cL\%}{4.3}$ t use the followin 0.9 1.6 90 al production of | 1.42 and 0.75 < m _{K+π} - DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1.2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the Υ(45) | $ \begin{array}{ccc} -< 1.20 \ \mbox{GeV/c}^2. \\ \hline \underline{TECN} & \underline{COMMENT} \\ \mbox{BABR} & e^+e^- \rightarrow \\ \mbox{limits, etc.} & \bullet & \bullet \\ \mbox{BELL} & e^+e^- \rightarrow \\ \mbox{ARG} & e^+e^- \rightarrow \\ \end{array} $ | τ(4S) τ(4S) |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{MLUE \text{ (units }10^{-6})}{54.5 \pm 2.9 \pm 2}$ 10^{-6} • • • We do not value $4.5 + \frac{1}{-1}.\frac{1}{0} + \frac{1}{-1}$ < 1400 1 Assumes equ | al production of $5 < m_{\pi^+\pi^-} < 1$ $+ \pi^-)/\Gamma_{\rm total}$ CL% 4.3 t use the followin 0.9 1.6 | 1.42 and 0.75 < m _{K+π} - DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1.2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the Υ(45) | $ \begin{array}{ccc} -< 1.20 \ \mbox{GeV/c}^2. \\ \hline \underline{TECN} & \underline{COMMENT} \\ \mbox{BABR} & e^+e^- \rightarrow \\ \mbox{limits, etc.} & \bullet & \bullet \\ \mbox{BELL} & e^+e^- \rightarrow \\ \mbox{ARG} & e^+e^- \rightarrow \\ \end{array} $ | γ(4S) γ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ π | al production of $5 < m_{\pi^+\pi^-} < 3$ $+$ $+$ $-$)/ $\Gamma_{\rm total}$ $ CL\%$ 4.3 t use the followin 0.9 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ | 1.42 and 0.75 < m _{K+π} - DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1.2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the Υ(45) | $ \begin{array}{ccc} -< 1.20 \ \mbox{GeV/c}^2. \\ \hline \underline{TECN} & \underline{COMMENT} \\ \mbox{BABR} & e^+e^- \rightarrow \\ \mbox{limits, etc.} & \bullet & \bullet \\ \mbox{BELL} & e^+e^- \rightarrow \\ \mbox{ARG} & e^+e^- \rightarrow \\ \end{array} $ | Υ(4S) Υ(4S) Υ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0\pi)$ $\frac{VALUE (units 10^{-6})}{54.5 \pm 2.9 \pm}$ 10 ⁻⁶ ••• We do not value $4.5 + \frac{1.1}{-1.0} + \frac{1.1}{-1.0}$ < 1400 $1 Assumes equ 2 Required 0.5 \Gamma(K^*(892)^0\rho)$ | al production of $5 < m_{\pi^+\pi^-} < 3$ and $5 < m_{\pi^+\pi^-} < 3$ and $5 < m_{\pi^+\pi^-} < 3$ and $6 < 3$ a | 1.42 and 0.75 < m _{K+π} - DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1.2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the Υ(45) | $ \begin{array}{ccc} -< 1.20 \ \mbox{GeV/c}^2. \\ \hline \underline{TECN} & \underline{COMMENT} \\ \mbox{BABR} & e^+e^- \rightarrow \\ \mbox{limits, etc.} & \bullet & \bullet \\ \mbox{BELL} & e^+e^- \rightarrow \\ \mbox{ARG} & e^+e^- \rightarrow \\ \end{array} $ | Υ(4S) Υ(4S) Υ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0 \pi)$ $\frac{MLUE \text{ (units } 10^{-6})}{54.5 \pm 2.9 \pm 2}$ 10^{-6} ••• We do not value $4.5 + \frac{1}{1}.1 + \frac{1}{1}.0 - \frac{1}{2}$ < 1400 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0 \rho)$ $\frac{MLUE \text{ (units } 10^{-6})}{14.1 + \frac{1}{1}.0 - \frac{1}{2}}$ | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma$ total $-2 \le 0$ $\times 1$ | 1.42 and 0.75 $< m_{K^+\pi^-}$ DOCUMENT ID 1 AUBERT 07AS g data for averages, fits, 1.2 KYEONG 09 ALBRECHT 91E B^+ and B^0 at the $\Upsilon(4S)$ $1.42 \text{ GeV}/\text{c}^2$. | $ \begin{array}{ccc} -< 1.20 \; {\rm GeV/c^2}. \\ \\ \hline {\it TECN} & {\it COMMENT} \\ \\ {\it BABR} & e^+e^- \rightarrow \\ \\ {\it BELL} & e^+e^- \rightarrow \\ \\ {\it ARG} & e^+e^- \rightarrow \\ \\ {\it S}). \\ \\ \hline {\it TECN} & {\it COMMENT} \\ \\ \end{array} $ | Υ(4S) Υ(4S) Υ(4S) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0 \pi)$ MLUE (units 10^{-6}) 54.5 ± 2.9 ± 10^{-6} • • • We do not value $4.5 + \frac{1}{1}.1 + \frac{1}{1}.0 - \frac{1}{2}$ <1400 1 Assumes equ 2 Required 0.5 $\Gamma(K^*(892)^0 \rho)$ MLUE (units 10^{-6} 58/Γ $3.4 + \frac{1}{1}.7 \text{ O}$ | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma_{\rm total}$ $- \frac{CL\%}{4.3}$ t use the following 0.9 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $- \frac{CL\%}{4.3}$ JYR AVERAGE | 1.42 and 0.75 $< m_{K^+\pi^-}$ DOCUMENT ID 1 AUBERT 07AS g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B^+ and B^0 at the $\Upsilon(4S^0)$ 1.42 GeV/ c^2 . | $\begin{array}{ccc} -< 1.20 \; \mathrm{GeV/c^2}. \\ & \underline{TECN} & \underline{COMMENT} \\ \mathrm{BABR} & e^+e^- \rightarrow \\ \mathrm{limits}, \; \mathrm{etc.} & \bullet \bullet \bullet \\ \mathrm{BELL} & e^+e^- \rightarrow \\ \mathrm{ARG} & e^+e^- \rightarrow \\ \mathrm{5}). \\ & \underline{TECN} & \underline{COMMENT} \\ \mathrm{r} \; \; \mathrm{of} \; 1.8. \end{array}$ | τ(45) τ(45) τ(45) |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 \[\begin{align*} \begin{align*} \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma_{\text{total}}$ $- \frac{CL\%}{4.3}$ t use the following 0.9 1.6 90 all production of $5 < m_{\pi^+\pi^-} < 3$ $- \frac{CL\%}{4.3}$ JIR AVERAGE Eq. 9.5 | 1.42 and 0.75 $< m_{K^+\pi^-}$ DOCUMENT ID 1 AUBERT 07AS g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B+ and B^0 at the $\Upsilon(4S)$ L.42 GeV/ c^2 . DOCUMENT ID Error includes scale factor 1 KYEONG 09 | $\begin{array}{ccc} -< 1.20 \text{ GeV/c}^2. \\ \hline \frac{TECN}{BABR} & \frac{COMMENT}{e^+e^- \rightarrow} \\ \text{limits, etc.} & \bullet & \bullet \\ \text{BELL} & e^+e^- \rightarrow \\ \text{ARG} & e^+e^- \rightarrow \\ \text{5}). \\ \hline \frac{TECN}{COMMENT} \\ \text{r of } 1.8. \\ \text{BELL} & e^+e^- \rightarrow \\ \end{array}$ | τ(45) τ(45) τ(45) Γ266/Ι |
| VALUE (units 10^{-6}) 2.7 $^+$ 1.0 $^+$ 2.9 1 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4^-)$ • • • We do not use the following data for averages, fits, limits, etc. <2.5 90 2 GARMASH 07 BELL $e^+e^- \rightarrow \Upsilon(4^-)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 GARMASH 07 reports $B(B^0 \rightarrow f_2(1270) K^0) \times B(f_2(1270) \rightarrow \pi^+\pi^-) < 1.4$ using Dalitz plot analysis. We compute $B(B^0 \rightarrow f_2(1270) K^0)$ using the PE $B(f_2(1270) \rightarrow \pi\pi) = 84.8 \times 10^{-2}$ and 2/3 for the $\pi^+\pi^-$ fraction. $F(f_X(1300) K^0 \times B(f_X \rightarrow \pi^+\pi^-))/\Gamma_{total}$ VALUE (units 10^{-6}) 1 AUBERT 0 9AU BABR $e^+e^- \rightarrow \Upsilon(4^-)$ 1 ASSUMES equal production of B^+ and B^0 at the $\Upsilon(4S)$. $F(K^*(892)^0\pi^0)/\Gamma_{total}$ | 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ π ΔΕΕΕ (units 10 ⁻⁶ 54.5 ± 2.9 ± 10 ⁻⁶ value 4.5 + 1.1 + -1.0 - <1400 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ ρ ΔΕΕΕ (units 10 ⁻⁶ 3.4 + 1.7 2.1 + 0.7 5.6 ± 0.9 ± 1 | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma_{\rm total}$ CL% 4.3 4.3 4.3 4.3 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $0 < m_{\pi^+\pi^-} < 3$ JR AVERAGE E.9 1.9 1.5 1.3 | 1.42 and 0.75 < m _{K+π} - DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the Υ(45 1.42 GeV/c ² . DOCUMENT ID Error includes scale factor 1 KYEONG 09 1 AUBERT, B 066 | $-< 1.20 \text{ GeV/c}^2.$ $\frac{TECN}{BABR} e^+e^- \rightarrow \text{limits, etc.} \bullet \bullet$ $BELL e^+e^- \rightarrow ARG e^+e^- \rightarrow 5).$ $\frac{TECN}{TCO} \frac{COMMENT}{COMMENT}$ $\text{r of } 1.8.$ $BELL e^+e^- \rightarrow BABR e^+e^- \rightarrow BABR e^+e^- \rightarrow COMMENT$ | τ(45) τ(45) τ(45) Γ266/Ι |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equived 0.5 Γ(K*(892) ⁰ π MLUE (units 10 ⁻⁶ 54.5 ± 2.9 ± • • • We do no 2 Required 0.5 57/Γ 1 Assumes equived 0.5 Γ(K*(892) ⁰ ρ MLUE (units 10 ⁻⁶ 54.5 ± 1.1 ± 2.1 ± 0.5 Γ(K*(892) ⁰ ρ MLUE (units 10 ⁻⁶ 5.6 ± 0.9 ± 1 • • • We do no 2 Negurired 0.5 - 1.3 Or 1.3 | al production of $5 < m_{\pi^+\pi^-} < 3$ $+$ $+$ $-$)/ Γ total $ CL\%$ 4.3 4.3 4.3 4.3 4.9 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $ -$ | DOCUMENT ID 1 AUBERT 07AS g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the \(\gamma(4.5)\) (4.2 GeV/c ² . DOCUMENT ID Error includes scale factor 1 KYEONG 09 1 AUBERT,B 06G g data for averages, fits, | $-< 1.20 \text{ GeV/c}^2.$ $\frac{TECN}{BABR} e^+e^- \rightarrow \text{limits, etc.} \bullet \bullet \bullet$ $BELL e^+e^- \rightarrow ARG e^+e^- \rightarrow 5).$ $\frac{TECN}{TCO} \frac{COMMENT}{COMMENT}$ of 1.8. $\frac{ELL}{BABR} e^+e^- \rightarrow \frac{BABR}{e^+e^-} \rightarrow \frac{BABR}{e^-} \rightarrow \frac{BABR}{e^+} \rightarrow \frac{BABR}{e^-} $ | τ(45) τ(45) τ(45) Γ266/Ι |
| VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT 2.7 ± 0.8 ± 0.9 1 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4-1.0) = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.$ | 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ π MALUE (units 10 ⁻⁶ 54.5±2.9± • • • We do not 4.5 + 1.1 + <1400 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ ρ MALUE (units 10 ⁻⁶ 3.4 + 1.7 5.6±0.9±1 • • We do not < 34 | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma_{\rm total}$ CL% 4.3 4.3 4.3 4.3 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $0 < m_{\pi^+\pi^-} < 3$ JR AVERAGE E.9 1.9 1.5 1.3 | DOCUMENT ID 1 AUBERT 07AS g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the T(4542 GeV/c ² . DOCUMENT ID Error includes scale factor 1 KYEONG 09 1 AUBERT,B 06G g data for averages, fits, 2 GODANG 02 | $-< 1.20 \text{ GeV/c}^2.$ $\frac{TECN}{BABR} e^+e^- \rightarrow \text{limits, etc.} \bullet \bullet \bullet$ $BELL e^+e^- \rightarrow \text{ARG} e^+e^- \rightarrow \text{55}.$ $\frac{TECN}{OMMENT} \text{ of } 1.8.$ $BELL e^+e^- \rightarrow \text{limits, etc.} \bullet \bullet$ $CLE2 e^+e^- \rightarrow \text{CLE2} e^+e^- \rightarrow \text{CLE2}$ | τ(45) τ(45) τ(45) Γ266/Γ τ(45) τ(45) |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ π MALUE (units 10 ⁻⁶ 54.5±2.9± 10 ⁻⁶ • • • We do no 4.5 + 1.1 + <1400 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ ρ MALUE (units 10 ⁻⁶ 3.4 + 1.3 O 5.6±0.9±1 • • We do no < 34 <286 6460 | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma$ total $CL\%$ 4.3 t use the followin 0.9 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ $- 2$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{cccc} -< 1.20 \text{ GeV/c}^2. \\ \hline TECN & COMMENT \\ BABR & e^+e^- \rightarrow \\ BELL & e^+e^- \rightarrow \\ ARG & e^+e^- \rightarrow \\ 5). \\ \hline TECN & COMMENT \\ TO & 1.8. \\ \hline BELL & e^+e^- \rightarrow \\ BABR & e^+e^- \rightarrow \\ Ilmits, etc. & \bullet \bullet \\ CLE2 & e^+e^- \rightarrow \\ SLD & e^+e^- \rightarrow \\ ARG & e^+e^- \rightarrow \\ \end{array}$ | T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) |
| VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT 2.7 ± 0.8 ± 0.9 1 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4-1.0) = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.0 = 1.$ | 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ π MALUE (units 10 ⁻⁶ 54.5±2.9± 10 ⁻⁶ • • • We do no 4.5 + 1.1 + <1400 1 Assumes equ 2 Required 0.5 Γ(Κ*(892) ⁰ ρ MALUE (units 10 ⁻⁶ 3.4 + 1.3 O 5.6±0.9±1 • • We do no < 34 <286 6460 | al production of $5 < m_{\pi^+\pi^-} < 3$ $+ \pi^-)/\Gamma_{\rm total}$ $- \frac{cL\%}{4.3}$ t use the followin 0.9 1.6 90 al production of $5 < m_{\pi^+\pi^-} < 3$ $- \frac{cL\%}{2}$ JR AVERAGE E 1.9 .5 .3 t use the followin 90 90 | DOCUMENT ID 1 AUBERT 07As g data for averages, fits, 1,2 KYEONG 09 ALBRECHT 91E B+ and B ⁰ at the \(\gamma(4.42\) GeV/c ² . DOCUMENT ID Error includes scale factor 1 KYEONG 09 1 AUBERT,B 06G g data for averages, fits, 2 GODANG 02 3 ABE 00C ALBRECHT 91B 4 AVERY 89B | $\begin{array}{cccc} -< 1.20 \text{ GeV/c}^2. \\ \hline {\it TECN} & {\it COMMENT} \\ \hline {\it BABR} & e^+e^- \rightarrow \\ \hline {\it Ilmits}, \text{ etc.} & \bullet & \bullet \\ \hline {\it BELL} & e^+e^- \rightarrow \\ \hline {\it SS}). \\ \hline {\it TECN} & {\it COMMENT} \\ {\it Tof 1.8}. \\ \hline {\it BELL} & e^+e^- \rightarrow \\ \hline {\it BABR} & e^+e^- \rightarrow \\ \hline {\it BABR} & e^+e^- \rightarrow \\ \hline {\it CLE2} & e^+e^- \rightarrow \\ \hline {\it SLD} & e^+e^- \rightarrow \\ \hline {\it SLD} & e^+e^- \rightarrow \\ \hline \end{array}$ | T(4S) |

| B^0 | |
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| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. ² Assumes a helicity 00 configuration. For a helicity 11 configuration, the limit decreases to 2.4×10^{-5} . ³ ABE 00c assumes B($Z \to b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^0} = f_{B^+} = (39.7 + \frac{1.8}{2.2})\%$ and $f_{B_S} = (10.5 + \frac{1.8}{2.2})\%$. ⁴ AVERY 89B reports $< 6.7 \times 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0\overline{B}^0$. We rescale to 50%. ⁵ AVERY 87 reports $< 1.2 \times 10^{-3}$ assuming the $\Upsilon(4S)$ decays 40% to $B^0\overline{B}^0$. We rescale to 50%. | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Obtains this result from $B(K^+K^-)/B(K^+\pi^-)=0.020\pm0.008\pm0.006$, assuming $B(B^0\to K^+\pi^-)=(19.4\pm0.6)\times10^{-6}$. 3 ABULENCIA, A 06D obtains this from $\Gamma(K^+K^-)/\Gamma(K^+\pi^-)<0.10$ at 90% CL, as suming $B(B^0\to K^+\pi^-)=(18.9\pm0.7)\times10^{-6}$. 4 ABE 00c assumes $B(Z\to b\overline{b})=(21.7\pm0.1)\%$ and the B fractions $f_{B^0}=f_{B^+}=(39.7^{+1.8}_{-2.2})\%$ and $f_{B_S}=(10.5^{+1.8}_{-1.8})\%$. 5 ADAM 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_S}=0.12$. Contributions from B^0 and B_S decays cannot be separated. Limits are given for the weighted average of the decay the factor of the temporate B_S decays cannot be separated. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | rates for the two neutral B mesons. ⁶ BUSKULIC 96V assumes PDG 96 production fractions for B^0 , B^+ , B_{ς} , b baryons. ⁷ Assumes a B^0 , B^- production fraction of 0.39 and a B_{ς} production fraction of 0.12 Contributions from B^0 and B_{ς}^0 decays cannot be separated. Limits are given for th weighted average of the decay rates for the two neutral B mesons. |
| < 4.3 90 1 AUBERT,B 066 BABR $e^+e^- \rightarrow \mathcal{T}(4S)$ <170 90 2 AVERY 89B CLEO $e^+e^- \rightarrow \mathcal{T}(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\mathcal{T}(4S)$. | weighted average of the decay rates for the two heutral B mesons. $\Gamma(K^0\overline{K^0})/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT |
| 2 AVERY 89B reports $<2.0\times10^{-4}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}{}^0.$ We rescale to 50%. | 0.96+0.20 OUR AVERAGE |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $0.87 + 0.25 \pm 0.09$ 1 LIN 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ $1.08 \pm 0.28 \pm 0.11$ 1 AUBERT,BE 06c BABR $e^+e^- \rightarrow \Upsilon(4S)$ •• • We do not use the following data for averages, fits, limits, etc. •• • $0.8 \pm 0.3 \pm 0.9$ 1 ABE 05G BELL Repl. by LIN 07 |
| $\Gamma(K_1(1400)^+\pi^-)/\Gamma_{total}$ $VALUE$ $CL\%$ C | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • < 1.1 \times 10 ⁻³ 90 ALBRECHT 91B ARG $e^+e^- \rightarrow \tau(4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\tau(4S)$. | < 3.3 90 1 BORNHEIM 03 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(45)$ < 4.1 90 1 CASEY 02 BELL $e^{+}e^{-} \rightarrow \Upsilon(45)$ < 17 90 GODANG 98 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(45)$ 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(45)$. |
| $\Gamma(a_1(1260)^-K^+)/\Gamma_{\text{total}}$ Γ_{270}/Γ | $\Gamma(K^0K^-\pi^+)/\Gamma_{\text{total}}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Assumes a_1^\pm decays only to 3π and $B(a_1^\pm\to\pi^\pm\pi^\pm\pi^\pm)=0.5.$ 3 ADAM 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_S}=0.12.$ Contributions from B^0 and B_S decays cannot be separated. Limits are given for the weighted average of the decay rates for the two neutral B mesons | ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $ \left[\Gamma(\overline{K^{*0}} K^0) + \Gamma(K^{*0} \overline{K^0}) \right] / \Gamma_{\text{total}} \qquad \qquad \Gamma_{\text{276}} / \Gamma_{2$ |
| rates for the two neutral B mesons. Assumes a B^0 , B^- production fraction of 0.39 and a $B_{\rm S}$ production fraction of 0.12. Contributions from B^0 and $B^0_{\rm S}$ decays cannot be separated. Limits are given for the weighted average of the decay rates for the two neutral B mesons. | 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $\Gamma(K^*(892)^+ \rho^-)/\Gamma_{total}$ $\Gamma_{271}/\Gamma_{VALUE\ (units\ 10^{-6})}$ CL% DOCUMENT ID TECN COMMENT | $\frac{\Gamma(K^{+}K^{-}\pi^{0})/\Gamma_{\text{total}}}{\text{<19 \times 10^{-6}}} \underbrace{\begin{array}{c} \text{CL\%} \\ 90 \end{array} \underbrace{\begin{array}{c} \text{DOCUMENT ID} \\ 1 \text{ ECKHART} \end{array}}_{\text{ECKHART}} \underbrace{\begin{array}{c} \text{TECN} \\ \text{CLE2} \end{array}}_{\text{e}^{+}e^{-} \rightarrow T(4S)}$ |
| <12.0 90 ¹ AUBERT,B 06G BABR $e^+e^- \rightarrow \Upsilon(4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(K_S^0 K_S^0 \pi^0) / \Gamma_{\text{total}}$ VALUE (1% DOCUMENT ID TECN COMMENT) |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | <0.9 × 10⁻⁶ 90 1 AUBERT 09AD BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(K^+K^-)/\Gamma_{total}$ Γ_{273}/Γ | $\Gamma(K_S^0K_S^0\eta)/\Gamma_{	ext{total}}$ $\Gamma_{279}/\Gamma_{	ext{279}}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $<1.0 \times 10^{-6}$ 90 1 AUBERT 09AD BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| (0.7) 90 2 AALTONEN 09c CDF $\rho \overline{\rho}$ at 1.96 TeV co.5 90 1 AUBERT 07a BABR $e^+e^- \rightarrow \tau(4.5)$ | $\Gamma(K_0^0K_0^0\eta')/\Gamma_{	ext{total}}$ $\Gamma_{	ext{280}}/\Gamma_{	ext{LUE}}$ $\Gamma_{	ext{CL}\%}$ DOCUMENT ID TECK COMMENT |
| < 1.8 90 3 ABULENCIA,A 06D CDF Repl. by AALTONEN 09C < 0.37 90 ABE 05G BELL Repl. by LIN 07 < 0.7 90 CHAO 04 BELL $e^+e^- \rightarrow \gamma(4S)$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| < 0.8 90 1 BORNHEIM 03 CLE2 $e^{+}e^{-} \rightarrow \Upsilon(4S)$ < 0.6 90 1 AUBERT 020 BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$ < 0.9 90 1 CASEY 02 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ < 2.7 90 1 ABE 01H BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ | Γ(K ⁰ K+ K ⁻)/Γ _{total} VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT 24.7 ± 2.3 OUR AVERAGE COMMENT CO |
| <pre>< 2.7 90</pre> | 23.8 \pm 2.0 \pm 1.6 1 AUBERT,B 04v BABR $e^+e^- \rightarrow \Upsilon(4S)$ 28.3 \pm 3.3 \pm 4.0 1 GARMASH 04 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $<$ 4.3 90 GODANG 98 CLE2 Repl. by CRONIN-HENNESSY 00 $<$ 46 5 ADAM 96D DLPH $e^+e^- \rightarrow Z$ $<$ 4 90 ASNER 96 CLE2 Repl. by GODANG 98 | <1300 90 ALBRECHT 91E ARG $e^+e^- ightarrow \varUpsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $<$ 4 90 ASNER 96 CLE2 REPL. by GODANG 98 $<$ 18 90 6 BUSKULIC 96V ALEP $e^+e^- \rightarrow Z$ | |

| | | | | Γ ₂₈₂ /Γ | Γ(K*(892) ⁰ K ⁻ τ | r+)/Γ _{total} | | | | Γ ₂₈₈ , |
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| VALUE (units 10 ⁻⁶) | CL% DO CUMENT | ID TECN | COMMENT | | VALUE (units 10 ⁻⁶) 4.5 ±1.3 OUR AV | ERAGE | DO CUMENT IL | TECN | <u>COMMENT</u> | |
| 8.6+1.3 OUR AV | 'ERAGE | | | | $2.11 + 5.63 + 4.85 \\ -5.26 - 4.75$ | | ^{1,2} CHIANG | 10 BELI | L $e^+e^- \rightarrow$ | T(45) |
| $8.4 {}^{+ 1.5}_{- 1.3} {}^{\pm} 0.5$ | $^{ m 1}$ AUBERT | 04A BAB | R $e^+e^- \rightarrow \Upsilon(4.5)$ | S) | -5.26 - 4.75 $4.6 \pm 1.1 \pm 0.8$ | | ² AUBERT | | R $e^+e^ \rightarrow$ | Υ(4 <i>S</i>) |
| $9.0^{+2.2}_{-1.8}\pm0.7$ | $^{ m 1}$ CHEN | 03в BELL | $e^+e^- ightarrow \gamma (4.5)$ | S) | $^{ m 1}$ Measured in the | range 0.7< <i>n</i> | $n_{m{K}\pi} < 1.7$ and c | orrected usin | g PS assumpt | ion for the f |
| | ne following data for avera | ages, fits, limits | s, etc. • • • | | $K\pi$ mass range. 90% CL. | The quoted i | result is equivaler | t to the uppe | er limit of < 1 | 3.9×10^{-6} |
| $8.1^{+3.1}_{-2.5}\pm0.8$ | ¹ AUBERT | 01D BAB | R $e^+e^- \rightarrow \Upsilon(4.5)$ | S) | ² Assumes equal p | production of | \mathcal{B}^+ and \mathcal{B}^0 at ti | ne $\varUpsilon(4S)$. | | |
| < 12.3 | 90 ¹ BRIERE | 01 CLE2 | | 5) | Γ(<i>K</i> *(892) ⁰ <i>K</i> *(8 | 392) ⁰)/Γ _{tot} , | ıİ | | | Γ ₂₈₉ , |
| < 31 < 88 | 90 ¹ BERGFELD 90 ASNER | 98 CLE2 96 CLE2 | | 5) | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT IE | | COMMENT | |
| < 720 | 90 ALBRECHT | | , | , | | | Error includes s | | | / |
| < 420 | 90 ² AVERY 90 ³ AVERY | | $e^+e^- \rightarrow \gamma(45)$ | | 0.26 + 0.33 + 0. -0.29 - 0. | | 1,2 CHIANG | 10 BELI | L e ⁺ e [−] → | T(45) |
| <1000 1 Assumes equal prod | uction of B^+ and B^0 at | | O $e^+e^- \rightarrow \Upsilon(4.5)$ | او | $1.28 ^{+0.35}_{-0.30} \pm 0.$ | | ² AUBERT | | $R e^+e^- \rightarrow$ | T(45) |
| ² AVERY 89B reports | $s < 4.9 \times 10^{-4}$ assuming | g the $\Upsilon(4S)$ d | lecays 43% to $B^0\overline{B}$ | 3 0. We | | | g data for averag | | | 201 - 21 |
| rescale to 50% | $< 1.3 	imes 10^{-3}$ assuming the | | | | < 22 <469 | 90 90 | ³ GODANG ⁴ ABE | 02 CLE: 00c SLD | $e^+e^- \rightarrow e^+e^- \rightarrow$ | |
| to 50%. | | , , | | • | $^{ m 1}$ Measured in the | range 0.7< <i>n</i> | $n_{K\pi} < 1.7$ and c | orrected using | g PS assumpt | ion for the f |
| $\Gamma(K_S^0 K_S^0 K_S^0)/\Gamma_{	ext{total}}$ | I | | Ī | Γ ₂₈₃ /Γ | $K\pi$ mass range. | The quoted | result is equivale | nt to the upp | er limit of $\stackrel{\cdot}{<}$ | 0.8×10^{-6} |
| VALUE (units 10 ⁻⁶) | <u>DO CUMENT</u> | ID TECN | COMMENT | | 90% CL. 2 Assumes equal p | production of | B^+ and B^{0} at ti | ne $\Upsilon(4S)$. | | |
| $6.2^{+1.2}_{-1.1}$ OUR AVERAG | iE Error includes scale fa | actor of 1.3. | | | 3 Assumes a helic to 1.9 \times 10 $^{-5}$. | ity 00 configu | ration. For a heli | city 11 config | guration, the | limit decrea |
| $6.9 + 0.9 \pm 0.6$ | ¹ AUBERT,B | | R $e^+e^- \rightarrow \Upsilon(4.5)$ | S) | 4 ABE 00c assun | nes B($Z \rightarrow$ | $b\overline{b})=(21.7 \pm 0)$ | 0.1)% and th | ne B fraction | is $f_{\mathbf{R}^0} = f_{\mathbf{R}^+}$ |
| $4.2 + 1.6 \pm 0.8$ | ¹ GARMASH | | L $e^+e^- \rightarrow r(4.5)$ | , | (39.7 ^{+ 1.8} _{- 2.2})% ar | | | | | 5 6. |
| 1.5 | | | L e e → 7(43 | 3) | $\Gamma(K^+K^+\pi^-\pi^-$ | nonreconani | -) /Γ | | | Гааа |
| | uction of B^+ and B^0 at | the $T(4S)$. | | | VALUE (units 10 ⁻⁶) | CL% | L)/'total DOCUMENT IE |) TECA | I COMMENT | Г290, |
| $\Gamma(K_S^0 K_S^0 K_L^0) / \Gamma_{total}$ | | | | Г ₂₈₄ /Г | <6.0 | 90 | 1 CHIANG | 10 BELI | $e^+e^- \rightarrow$ | r(45) |
| VALUE (units 10 ⁻⁶) | <u>CL%</u> <u>DOCUMENT</u> 90 ¹ AUBERT.B | | R $e^+e^- \rightarrow \Upsilon(4.5)$ | <u> </u> | ¹ Assumes equal p | production of | ${\it B}^+$ and ${\it B}^{0}$ at ti | ne $\Upsilon(4S)$. | | • |
| <16 | uction of B^+ and B^0 at | | $R e^+e^- \rightarrow T(4S)$ | 5) | Γ(<i>K</i> *(892) ⁰ <i>K</i> + ₇ |) /г | | | | Гооз |
| | | ine 1 (43). | <u>-</u> | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT IE |) TECN | I COMMENT | Γ ₂₉₁ |
| Γ(K*(892) ⁰ K+ K ⁻) | | | | Γ ₂₈₅ /Γ | <2.2 | 90 | 1 AUBERT | | $\frac{e^+e^-}{}$ | Υ(4S) |
| VALUE (units 10 ⁻⁶) 27.5±1.3±2.2 | <u>CL%</u> <u>DO CUMENT</u> 1 AUBERT | | R $e^+e^- \rightarrow \Upsilon(4.5)$ | <u> </u> | ● ● We do not us | | | | | |
| | ne following data for avera | | , | ٠, | <7.6 | 90 | 1 CHIANG | | $L e^+e^- \rightarrow$ | T(45) |
| <610 | 90 ALBRECHT | Γ 91E ARG | $e^+e^- ightarrow ~ \gamma(4.5)$ | S) | 1 Assumes equal p | | | ne $\Upsilon(4S)$. | | |
| 1 Assumes equal prod | uction of ${\it B}^{+}$ and ${\it B}^{0}$ at | the $\Upsilon(4S)$. | | | Γ(K*(892) ⁰ K*(8 | 392) ⁰)/Γ _{tot a} | ıl | | | Γ 29 2. |
| Assumes equal plou | | | | Γοος /Γ | | 61.0/ | DO CUMENT IE | | | |
| • • | al | | I | Γ ₂₈₆ /Γ | VALUE (units 10 ⁻⁶) | <u>CL%</u> | | | | Y(45) |
| $\Gamma(K^*(892)^0\phi)/\Gamma_{	ext{tota}}$ | CL% DOCUMENT ID | TECN | <u>COMMENT</u> | 286/1 | < 0.2 • • • We do not us | 90 | 1 CHIANG | 10 BELI | $e^+e^- \rightarrow$ | T(45) |
| $\Gamma(K^*(892)^0 \phi)/\Gamma_{\text{tota}}$ $\frac{VALUE \text{ (units } 10^{-6}\text{)}}{9.8 \pm 0.6 \text{ OUR AVE}}$ | CL% DOCUMENT ID | TECN 08BG BABR | COMMENT | | < 0.2 | 90 se the followin | 1 CHIANG g data for averag | 10 BELI es, fits, limit: | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ | , |
| Γ(K*(892) ⁰ φ)/Γ _{tota} VALUE (units 10 ⁻⁶) 9.8±0.6 OUR AVE 9.7±0.5±0.5 | CL% DOCUMENT ID | | COMMENT | | < 0.2 • • • We do not us < 0.41 < 37 | 90 se the followin 90 90 | 1 CHIANG g data for averag ¹ AUBERT ² GODANG | 10 BELI ges, fits, limits 081 BAB 02 CLE2 | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ | T(45) |
| $\Gamma(K^*(892)^0\phi)/\Gamma_{\text{total}}$ $VALUE$ (units 10^{-6}) 9.8 ± 0.6 OUR AVE $9.7\pm0.5\pm0.5$ 10.0+1.6+0.7 -1.5-0.8 | CL% DOCUMENT ID ERAGE 1 AUBERT | 08BG BABR 03B BELL | $\begin{array}{ccc} \underline{\textit{COMMENT}} \\ e^{+} e^{-} & & \mathcal{T}(4S) \\ e^{+} e^{-} & & \mathcal{T}(4S) \end{array}$ | - 286/1 | < 0.2 • • • We do not us < 0.41 <37 1 Assumes equal p | 90 se the followin 90 90 oroduction of | $rac{1}{CHIANG}$ g data for average $rac{1}{2}$ AUBERT $rac{2}{3}$ GODANG B^+ and B^0 at ti | 10 BELI ges, fits, limits 08 BAB 02 CLE2 ne $\Upsilon(4S)$. | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ | τ(45) τ(45) |
| $ \begin{array}{l} \Gamma\left(K^{\star}(892)^{0}\phi\right)/\Gamma_{\textrm{total}} \\ VALUE \; (units \; 10^{-6}) \\ \textbf{9.8\pm0.6} \; \textrm{OUR AVE} \\ 9.7\pm0.5\pm0.5 \\ 10.0^{+}1.6+0.7 \\ 10.0^{+}1.5-0.8 \\ 11.5^{+}4.5^{+}1.8 \\ -3.7^{-}1.7 \end{array} $ | CL% DOCUMENT ID ERAGE 1 AUBERT 1 CHEN | 08BG BABR 03B BELL 01 CLE2 | $\begin{array}{l} \underline{\text{COMMENT}} \\ e^+ e^- \rightarrow & \varUpsilon(4S) \\ e^+ e^- \rightarrow & \varUpsilon(4S) \\ e^+ e^- \rightarrow & \varUpsilon(4S) \end{array}$ | - 286/1 | < 0.2 • • • We do not us < 0.41 < 37 | 90 se the followin 90 90 oroduction of | $rac{1}{CHIANG}$ g data for average $rac{1}{2}$ AUBERT $rac{2}{3}$ GODANG B^+ and B^0 at ti | 10 BELI ges, fits, limits 08 BAB 02 CLE2 ne $\Upsilon(4S)$. | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ | τ(45) τ(45) |
| $ \begin{array}{l} \Gamma\left(K^{\star}(892)^{0}\phi\right)/\Gamma_{\textrm{total}} \\ VALUE \; (units \; 10^{-6}) \\ \textbf{9.8\pm0.6} \; \textrm{OUR AVE} \\ 9.7\pm0.5\pm0.5 \\ 10.0^{+}1.6+0.7 \\ 10.0^{+}1.5-0.8 \\ 11.5^{+}4.5^{+}1.8 \\ -3.7^{-}1.7 \end{array} $ | CL% ERAGE 1 AUBERT 1 CHEN 1 BRIERE ne following data for avera | 08BG BABR 03B BELL 01 CLE2 ages, fits, limits | $\begin{array}{l} \underline{\text{COMMENT}} \\ e^+ e^- \rightarrow & \varUpsilon(4S) \\ e^+ e^- \rightarrow & \varUpsilon(4S) \\ e^+ e^- \rightarrow & \varUpsilon(4S) \end{array}$ | <u> </u> | 0.2 • • We do not us 0.41 <37 1 Assumes equal properties a helic to 2.9 x 10⁻⁵. | 90 se the followin 90 90 oroduction of ity 00 configu | 1 CHIANG g data for averag 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli | 10 BELI ges, fits, limits 08 BAB 02 CLE2 ne $\Upsilon(4S)$. | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ | $\Gamma(4S)$ $\Gamma(4S)$ limit decreas |
| Γ (K^* (892) ⁰ φ)/Γ total VALUE (units 10 ⁻⁶) 9.8±0.6 OUR AVE 9.7±0.5±0.5 10.0+1.6+0.7 -1.5-0.8 11.5+4.5+1.8 • • We do not use th 9.2±0.7±0.6 9.2±0.9±0.5 | CLW DOCUMENT ID TRAGE 1 AUBERT 1 CHEN 1 BRIERE The following data for avera 1 AUBERT 1 AUBERT 1 AUBERT, B | 08BG BABR 03B BELL 01 CLE2 ages, fits, limits 07D BABR 04W BABR | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \to \Upsilon(4S) \\ e^+ e^- \to \Upsilon(4S) \\ e^+ e^- \to \Upsilon(4S) \\ \text{s, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \end{array}$ | 08BG 07D | < 0.2 • • • We do not us < 0.41 <37 1 Assumes equal properties a helic to 2.9 × 10⁻⁵. √ (K*(892) + K*(| 90 se the followin 90 90 oroduction of ity 00 configu | 1 CHIANG g data for averag 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli | 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 BELI 10 | L $e^+e^- \rightarrow$ s, etc. \bullet \bullet \bullet R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ guration, the | $\Gamma(4S)$ $\Gamma(4S)$ limit decrease Γ_{293} |
| $\Gamma(K^*(892)^0 \phi)/\Gamma_{\text{total}}$ $9.8\pm 0.6 \text{ OUR AVE}$ $9.7\pm 0.5\pm 0.5$ $10.0^{+}1.6+0.7$ $-1.5-0.8$ $11.5^{+}4.5+1.8$ $11.5^{+}3.7-1.7$ • • • We do not use the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the expression of the 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of the expression of the expression of the expression of the expression of | CLW DOCUMENT ID TRAGE 1 AUBERT 1 CHEN 1 BRIERE The following data for avera 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT | 08BG BABR 03B BELL 01 CLE2 ages, fits, limits 07D BABR 04W BABR 03V BABR | $\begin{array}{l} \underline{COMMENT} \\ e^+ e^- \to \Upsilon(4S) \\ e^+ e^- \to \Upsilon(4S) \\ e^+ e^- \to \Upsilon(4S) \\ \text{s, etc.} \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \end{array}$ | 08BG 07D ,B 04W | < 0.2 • • • We do not us < 0.41 <37 ¹ Assumes equal part of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of 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City 11 config | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ guration, the | T(4S) T(4S) limit decrease |
| $\Gamma\left(K^*(892)^0\phi\right)/\Gamma_{\text{tot}}$ $\frac{VALUE\ (\text{units }10^{-6})}{9.8\pm0.6\ \text{OUR\ AVE}}$ $9.7\pm0.5\pm0.5$ $10.0^{+1.6+0.7}.5-0.8$ $11.5^{+4.5}+1.8$ $-3.7-1.7$ • • • We do not use the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the 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| $ \begin{split} & \Gamma\left(K^{*}(892)^{0} \phi\right) / \Gamma_{\text{total}} \\ & \frac{VALUE \ (\text{units} \ 10^{-6})}{9.8 \pm 0.6 \ \text{OUR AVE}} \\ & 9.7 \pm 0.5 \pm 0.5 \\ & 10.0 + 1.6 + 0.7 \\ & -1.5 - 0.8 \\ & 11.5 + 4.5 + 1.8 \\ & 11.5 + 4.5 + 1.8 \\ & 11.5 + 4.5 + 1.8 \\ & 11.5 + 2.7 - 1.7 \\ & \bullet \bullet \text{We do not use th}} \\ & 9.2 \pm 0.7 \pm 0.6 \\ & 9.2 \pm 0.9 \pm 0.5 \\ & 11.2 \pm 1.3 \pm 0.8 \\ & 8.7 + 2.5 \\ & -2.1 \pm 1.1 \\ & < 384 \\ & < 21 \\ & < 43 \end{split} $ | CLW ERAGE 1 AUBERT 1 CHEN 1 BRIERE 1 AUBERT 1 AUBERT, B 1 AUBERT, B 1 AUBERT 1 AUBERT 1 AUBERT 2 AUBERT 1 AUBERT 3 AUBERT 4 AUBERT 6 AUBERT 6 AUBERT 7 AUBERT 8 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT 9 AUBERT | 0886 BABR 038 BELL 01 CLE2 ages, fits, limits 07D BABR 04W BABR 03V BABR 01D BABR 00C SLD 98 CLE2 | $\begin{array}{c} \underline{COMMENT} \\ e^+e^- \to & \varUpsilon(4S) \\ e^+e^- \to & \varUpsilon(4S) \\ e^+e^- \to & \varUpsilon(4S) \\ \text{S, etc.} \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ e^+e^- \to & Z \\ e^+e^- \to & \varUpsilon(4S) \end{array}$ | 08BG 07D ,B 04W | < 0.2 • • • We do not us < 0.41 <37 ¹ Assumes equal p ² Assumes a helic to 2.9 × 10 ⁻⁵ Γ(K*(892)* K*(<u>VALUE (units 10⁻⁶)</u> < 2.0 • • • We do not us <141 ¹ Assumes equal p | 90 90 90 90 90 90 90 90 90 90 90 90 90 9 | 1 CHIANG g data for average 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli tal DOCUMENT II 1 AUBERT g data for average 2 GODANG B+ and B ⁰ at ti | 10 BELI 10 BELI 10 BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 CLE: 11 CONTROL TECA 12 CLE: 13 CLE: 14 CLE: 15 CLE: 16 T(45). | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ guration, the L COMMENT R $e^+e^- \rightarrow$ s, etc. • • • 2 $e^+e^- \rightarrow$ | $T(4S)$ $T(4S)$ Ilimit decreas Γ_{293} $T(4S)$ |
| $ \begin{split} &\Gamma\left(K^{+}(892)^{0}\phi\right)/\Gamma_{\text{tot}};\\ &\frac{VALUE\left(\text{units}\ 10^{-6}\right)}{9.8\pm0.6\text{OURAVE}}\\ &9.7\pm0.5\pm0.5\\ &10.0^{+1.6}\pm0.7\\ &11.5^{+}\pm0.8\\ &11.5^{+}\pm0.8\\ &11.5^{+}\pm0.8\\ &11.5^{+}\pm0.8\\ &11.5^{+}\pm0.8\\ &11.2^{+}\pm0.7\\ &\bullet \bullet \text{We do not use th}\\ &9.2\pm0.7\pm0.6\\ &9.2\pm0.9\pm0.5\\ &11.2\pm1.3\pm0.8\\ &8.7^{+}\pm0.7\\ &2.1\\ &434\\ &<21\\ &<43\\ &<320 \end{split} $ | CLW CRAGE 1 AUBERT 1 CHEN 1 BRIERE 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 AUBERT 1 A | 0886 BABR 038 BELL 01 CLE2 ages, fits, limits 07D BABR 04W BABR 03W BABR 01D BABR 01D BABR 00C SLD 98 CLE2 91B ARG | $\begin{array}{l} e^+e^- \to ~ \Upsilon(45) \\ e^+e^- \to ~ \Upsilon(45) \\ e^+e^- \to ~ \Upsilon(45) \\ \text{s, etc.} ~ \bullet ~ \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{e}^+e^- \to ~ Z \\ \end{array}$ | 08BG 07D ,B 04W | < 0.2 • • • We do not us < 0.41 <37 1 Assumes equal p 2 Assumes a helic to 2.9 × 10 ⁻⁵ (K*(892) + K*(| 90 90 90 90 90 90 90 90 90 90 90 90 90 9 | 1 CHIANG g data for average 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli tal DOCUMENT II 1 AUBERT g data for average 2 GODANG B+ and B ⁰ at ti | 10 BELI 10 BELI 10 BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 CLE: 11 CONTROL TECA 12 CLE: 13 CLE: 14 CLE: 15 CLE: 16 T(45). | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ guration, the L COMMENT R $e^+e^- \rightarrow$ s, etc. • • • 2 $e^+e^- \rightarrow$ | $T(4S)$ $T(4S)$ Ilimit decreas Γ_{293} $T(4S)$ |
| $ \begin{split} & \Gamma\left(K^*(892)^0 \phi\right) / \Gamma_{\text{total}} \\ & \frac{VALUE \ (\text{units}\ 10^{-6})}{9.8 \pm 0.6 \ \text{OUR}\ \text{AVE}} \\ & 9.7 \pm 0.5 \pm 0.5 \\ & 9.7 \pm 0.5 \pm 0.5 \\ & 10.0^{+}1.6 + 0.7 \\ & -1.5 - 0.8 \\ & 11.5^{+}4.5 + 1.8 \\ & 11.5^{+}4.5 + 1.8 \\ & 11.5^{+}3.7 - 1.7 \\ & \bullet \bullet \text{We do not use th}} \\ & 9.2 \pm 0.7 \pm 0.6 \\ & 9.2 \pm 0.9 \pm 0.5 \\ & 11.2 \pm 1.3 \pm 0.8 \\ & 8.7 + 2.5 \\ & 2.1 \\ & < 43 \\ & < 21 \\ & < 43 \\ & < 320 \\ & < 380 \\ & < 380 \\ & < 380 \end{split} $ | DOCUMENT ID | 08BG BABR 03B BELL 01 CLE2 ages, fits, limits 070 BABR 04w BABR 03v BABR 01D BABR 00c SLD 98 CLE2 96 CLE2 96 CLE2 91B ARG 89B CLEO 87 CLEO | $\begin{array}{c} \text{COMMENT} \\ e^+e^- \to ~\Upsilon(4S) \\ e^+e^- \to ~\Upsilon(4S) \\ e^+e^- \to ~\Upsilon(4S) \\ \text{s, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ e^+e^- \to ~Z \\ e^+e^- \to ~\Upsilon(4S) \\ e^+e^- \to ~\Upsilon(4S) \end{array}$ | 08BG 07D ,B 04W | < 0.2 • • • We do not us < 0.41 <37 ¹ Assumes equal properties a helic to 2.9 × 10−5 < (K*(892)* K*(MALUE (units 10−6)) < 2.0 • • We do not us < 141 ¹ Assumes equal properties a helic to 8.9 × 10−5 | 90 90 90 90 90 90 90 90 90 90 90 90 90 9 | 1 CHIANG g data for average 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli tal DOCUMENT II 1 AUBERT g data for average 2 GODANG B+ and B ⁰ at ti | 10 BELI 10 BELI 10 BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 TECA 10 BAP BAB 10 CLE: 10 CLE: 11 CONTROL TECA 12 CLE: 13 CLE: 14 CLE: 15 CLE: 16 T(45). | L $e^+e^- \rightarrow$ s, etc. • • • R $e^+e^- \rightarrow$ 2 $e^+e^- \rightarrow$ guration, the L COMMENT R $e^+e^- \rightarrow$ s, etc. • • • 2 $e^+e^- \rightarrow$ | r(4S) $r(4S)$ Ilimit decreas $r(4S)$ $r(4S)$ $r(4S)$ Ilimit decreas |
| Γ (K*(892) ⁰ φ)/ Γ total Γ (K*(892) ⁰ γ)/ Γ total Γ (white Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0) Γ (0 | DOCUMENT ID | 0886 BABR 038 BELL 01 CLE2 ages, fits, limits 07D BABR 03V BABR 03V BABR 01D BABR 01C SLD 98 CLE2 91B ARG 89B CLE0 87 CLEO | $\begin{array}{c} \text{COMMENT} \\ e^+e^- \to & \varUpsilon(45) \\ e^+e^- \to & \varUpsilon(45) \\ e^+e^- \to & \varUpsilon(45) \\ \text{S, etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{Repl. by AUBERT} \\ \text{epl. by AUBERT} \\ e^+e^- \to & Z \\ e^+e^- \to & \varUpsilon(45) \\ e^+e^- \to & \varUpsilon(45) \\ e^+e^- \to & \varUpsilon(45) \\ e^+e^- \to & \varUpsilon(45) \end{array}$ | 08BG 07D ,B 04W | < 0.2 • • • • We do not us < 0.41 <37 ¹ Assumes equal p ² Assumes a helic to 2.9 × 10 ⁻⁵ . Γ(Κ*(892)* K*(MALUE (units 10 ⁻⁶) < 2.0 • • • We do not us <141 ¹ Assumes equal p ² Assumes a helic to 8.9 × 10 ⁻⁵ . Γ(Κ₁(1400)° φ)/ MALUE | 90 90 90 90 90 90 90 90 90 90 90 90 90 9 | 1 CHIANG g data for average 1 AUBERT 2 GODANG B+ and B ⁰ at ti ration. For a heli tal DOCUMENT II 1 AUBERT g data for average 2 GODANG B+ and B ⁰ at ti | 10 BELI 10 BELI 10 BAB 10 CLE: 10 CITY 11 CONFIG | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $T(4S)$ $T(4S)$ Ilimit decreas Γ_{293} $T(4S)$ |
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| Γ(K^* (892) ⁰ φ)/Γtotal NALUE (units 10 ⁻⁶) 9.8±0.6 OUR AVE 9.7±0.5±0.5 10.0+1.6+0.7 -1.5-0.8 11.5+4.5+1.8 1.5+4.5+1.8 • • • We do not use the 9.2±0.7±0.6 9.2±0.9±0.5 11.2±1.3±0.8 8.7+2.5±1.1 <384 < 21 < 43 < 320 < 380 < 380 1 Assumes equal prod 2 ABE 00c assumes (39.7+1.8)% and f, 3 AVERY 89B reports rescale to 50%. 4 AVERY 87 reports to 50%. 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 1 Assumes equal production of B^+ and B^0 at the arGamma(4S).

 B^0

 $4.1^{\,+\,1.7}_{\,-\,1.4}\,\pm\,0.4$

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| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | VALUE (units 10^{-6}) CL | <u>DOCUMENT ID TECN COMMENT</u> |
| <31.8 90 1,2 CHIANG 10 BELL $e^+e^- \rightarrow$ | Y(45) | <31 90 | 1 AUBERT,B 06P BABR $e^{+}e^{-} ightarrow$ \varUpsilon (4 S) |
| $^{-1}$ Measured in the range 0.7< $m_{K\pi} <$ 1.7 and corrected using PS assumption | on for the full | $^{ m 1}$ Assumes equal productio | n of B^+ and B^{0} at the $\varUpsilon(4S)$. |
| $K\pi$ mass range. 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | $\Gamma(\eta K^0 \gamma)/\Gamma_{ m total}$ | Г310 |
| | • | VALUE (units 10 ⁻⁶) | DOCUMENT ID TECN COMMENT |
| $\Gamma(K_0^*(1430)^0\overline{K}^*(892)^0)/\Gamma_{\text{total}}$ | Γ ₂₉₈ /Γ | 7.6±1.8 OUR AVERAGE | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | $7.1^{+2.1}_{-2.0}\pm0.4$ | 1,2 AUBERT 09 BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| <3.3 90 1,2 CHIANG 10 BELL $e^+e^- \rightarrow$ | . , _ | $8.7 + 3.1 + 1.9 \\ -2.7 - 1.6$ | 2,3 NISHIDA 05 BELL $e^+e^- ightarrow \gamma(4S)$ |
| 1 Measured in the range 0.7< m $_{K\pi} <$ 1.7 and corrected using PS assumptio $K\pi$ mass range. | on for the full | | lowing data for averages, fits, limits, etc. • • • |
| 2 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | $11.3 + 2.8 \pm 0.6$ | 1,2 AUBERT,B 06M BABR Repl. by AUBERT 09 |
| $\Gamma(K_0^*(1430)^0\overline{K_0^*}(1430)^0)/\Gamma_{\text{total}}$ | Г299/Г | =:- | AODERT, B OOM BABIC Rept. by AODERT O. |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | 1 299/1 | $\frac{1}{2} m_{\eta K} < 3.25 \text{ GeV/c}^2$ | |
| <8.4 90 1,2 CHIANG 10 BELL $e^+e^- \rightarrow$ | Υ(45) | 2 Assumes equal production 3 $m_{nK}^{}$ $< 2.4 \text{ GeV/c}^{2}$ | n of B^+ and B^0 at the $\varUpsilon(4S)$. |
| 1 Measured in the range 0.7< $m_{\mbox{\it K}\pi} <$ 1.7 and corrected using PS assumptio | . , | ., | |
| $K\pi$ mass range. | | $\Gamma(\eta' K^0 \gamma) / \Gamma_{ m total}$ | Γ ₃₁₁ |
| 2 Assumes equal production of B^+ and B^0 at the \varUpsilon (45). | ı | VALUE (units 10^{-6}) CL | |
| $\Gamma(K_0^*(1430)^0\phi)/\Gamma_{\text{total}}$ | Г ₃₀₀ /Г | <6.4 90 | 1,2 WEDD 10 BELL $e^+e^- ightarrow r$ (4 <i>S</i>) lowing data for averages, fits, limits, etc. • • • |
| VALUE (units 10 ⁻⁶) DOCUMENT ID TECN COMMENT | | <6.6 90 | |
| 3.9 \pm 0.5 \pm 0.6 1 AUBERT 08BG BABR $e^+e^- \rightarrow \gamma$ | (45) | | n of B^+ and B^0 at the $\Upsilon(4S)$. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | DEDT ASP | $\frac{2}{m_{n'K}}$ < 3.4 GeV/c ² . | 5. 5 and 5 at the 1 (45). |
| 4.6 \pm 0.7 \pm 0.6 | | $\frac{\eta}{m_{\eta'K}}^{K} < 3.25 \text{ GeV/c}^2$ | |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | , | |
| 2 Observed 181 \pm 17 events with statistical significance greater than 10 σ . | | $\Gamma(K^0\phi\gamma)/\Gamma_{ m total}$ | Γ ₃₁₂ |
| $\Gamma(K_0^*(1430)^0K^*(892)^0)/\Gamma_{\text{total}}$ | Γ ₃₀₁ /Γ | VALUE (units 10^{-6}) CL | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | . 3017. | 2.74 ± 0.60 ± 0.32 | 1 SAHOO 11A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. • • |
| <1.7 90 1 CHIANG 10 BELL $e^+e^- \rightarrow$ | Υ(4S) | <2.7 90 | 1 AUBERT 070 BABR $e^{+}e^{-} ightarrow \gamma(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | Ī | <8.3 90 | |
| F (1/2 / 1 4 2 0) 1 | - /- | ¹ Assumes equal productio | n of B^+ and B^0 at $\varUpsilon(4S)$. |
| $\Gamma(K_0^*(1430)^0 K_0^*(1430)^0)/\Gamma_{\text{total}}$ | Γ ₃₀₂ /Γ | $\Gamma(K^+\pi^-\gamma)/\Gamma_{ m total}$ | Г ₃₁₃ |
| VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT <4.7 90 1 CHIANG 10 BELL $e^+e^- \rightarrow$ | Υ(4 S) | VALUE | DOCUMENT ID TECN COMMENT |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 7 (43) | $(4.6^{+1.3}_{-1.2}^{+0.5}) \times 10^{-6}$ | |
| | • | | n of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $\Gamma(K^*(1680)^0 \phi)/\Gamma_{\text{total}}$ | Г ₃₀₃ /Г | 2 1.25 GeV/ c^2 < $M_{K\pi}$ < | n of B^+ and B^+ at the $T(4S)$. 1.6 GeV/ c^2 |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | | |
| <3.5 90 ¹ AUBERT 07A0 BABR $e^+e^- \rightarrow$ | T(4S) | $\Gamma(K^*(892)^0\gamma)/\Gamma_{total}$ | Г ₃₁₄ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | <u>VALUE (units 10⁻⁶)</u> <u>CL%</u> 43.3± 1.5 OUR AVER / | DOCUMENT ID TECN COMMENT AGE |
| $\Gamma(K^*(1780)^0 \phi)/\Gamma_{\text{total}}$ | Γ ₃₀₄ /Γ | 44.7± 1.0±1.6 | 1 AUBERT 09AO BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | $40.1 \pm\ 2.1 \pm 1.7$ | ² NAKAO 04 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| <2.7 90 ¹ AUBERT 07AO BABR $e^+e^- \rightarrow$ | T(45) | $45.5 {+\atop -} {7.2\atop 6.8} {\pm} 3.4$ | 3 COAN 00 CLE2 $e^+e^- ightarrow~\varUpsilon(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the \varUpsilon (4 S). | | ● ● We do not use the following | lowing data for averages, fits, limits, etc. • • • |
| $\Gamma(K^*(2045)^0 \phi)/\Gamma_{\text{total}}$ | Γ ₃₀₅ /Γ | 39.2± 2.0±2.4 | 4 AUBERT,BE 04A BABR Repl. by AUBERT 09AO |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | < 110 90 $42.3 \pm 4.0 \pm 2.2$ | ACOSTA 02G CDF pp at 1.8 TeV 2 AUBERT 02C BABR Repl. by AUBERT,BE 0 |
| <15.3 90 1 AUBERT 07A0 BABR $e^{+}e^{-} \rightarrow$ | T(45) | < 210 90 | 5 ADAM 96D DLPH $e^{+}e^{-} ightarrow Z$ |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | | $40 \pm 17 \pm 8$ < 420 90 | 6 AMMAR 93 CLE2 Repl. by COAN 00 ALBRECHT 89G ARG $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\Gamma(K_2^*(1430)^0 \rho^0)/\Gamma_{\text{total}}$ | Г ₃₀₆ /Г | < 240 90 | 7 AVERY 89B CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | . | <2100 90 | AVERY 87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| <1.1 x 10³ 90 ALBRECHT 91B ARG $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | $\frac{1}{2} \text{ Uses B}(\Upsilon(4S) \to B^+ B^-)$ | $(-) = (51.6 \pm 0.6)\%$ and B($\Upsilon(4S) \rightarrow B^0 \overline{B}{}^0) = (48.4 \pm 0.6)$ |
| $\Gamma(K_2^*(1430)^0\phi)/\Gamma_{\text{total}}$ | Γ ₃₀₇ /Γ | | n of B^+ and B^0 at the $arphi(4S)$. n of B^+ and B^0 at the $arphi(4S)$. No evidence for a nonresona |
| $VALUE$ (units 10^{-6}) $CL\%$ $DOCUMENT ID$ $TECN$ $COMMENT$ | . 201/, | | n of B^+ and B^+ at the $T(4S)$. No evidence for a nonreson: seen; the central value assumes no contamination. |
| 7.5 \pm 0.9 \pm 0.5 1 AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon$ | (4S) | ⁴ Uses the production ratio | of charged and neutral B from $\varUpsilon(4S)$ decays $R^{+/0}=1.006$ |
| | . / | $^{0.048}$. 5 ADAM 96D assumes f_{P0} | $= f_{R^-} = 0.39$ and $f_{B_c} = 0.12$. |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | | | $B^ B_S$ 5 ± 2.8 events above background. |
| $7.8\pm1.1\pm0.6$ AUBERT 07D BABR Repl. by AUE | | - A WINAR 93 Observed 6.0 | |
| 7.8 \pm 1.1 \pm 0.6 | BERT 07D | ⁷ AVERY 89B reports < 2 | $2.8 	imes 10^{-4}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0\overline{B}{}^0$. |
| 7.8 \pm 1.1 \pm 0.6 seen 2 AUBERT, 07b BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Repl. by AUE and 07c BABR Rep | BERT 07D | 7 AVERY 89B reports < 2 rescale to 50%. | $2.8 	imes 10^{-4}$ assuming the $\Upsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. |
| 7.8 \pm 1.1 \pm 0.6 | BERT 07D (4 <i>S</i>) | 7 AVERY 89B reports < 2 rescale to 50%. $\Gamma(K^*(1410)\gamma)/\Gamma_{total}$ | $2.8 	imes 10^{-4}$ assuming the $\varUpsilon(4S)$ decays 43% to $B^0 \overline{B}{}^0$. \\ \begin{align*} \Gamma_{315} & & & & & & & & & & & & & & & & & & & |
| 7.8 \pm 1.1 \pm 0.6 | BERT 07D (4 <i>S</i>) | ⁷ AVERY 89B reports < 2 rescale to 50%. Γ(Κ*(1410) γ)/Γ _{total} <u>VALUE</u> <u>CL</u> | $2.8 	imes 10^{-4}$ assuming the $T(4S)$ decays 43% to $B^0 \overline{B}^0$. $$^{\circ}$ |
| 7.8 \pm 1.1 \pm 0.6 1 AUBERT 07D BABR Repl. by AUE seen 2 AUBERT,B 04W BABR Repl. by AUE (1400 90 ALBRECHT 91B ARG $e^+e^- \rightarrow \Upsilon$ 1 Assumes equal production of B^+ and B^0 at the Υ (4 S). 2 The angular distribution of $B \rightarrow \phi K^*$ (1430) provides evidence with static cance of 3.2 σ . | BERT 07D (4 <i>5</i>) istical signifi- | ⁷ AVERY 89B reports < 2 rescale to 50%. $\Gamma(K^*(1410)\gamma)/\Gamma_{total}$ $\frac{VALUE}{<1.3 \times 10^{-4}}$ 90 | 2.8×10^{-4} assuming the $T(4S)$ decays 43% to $B^0\overline{B}^0$. The sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of the sum of t |
| 7.8 \pm 1.1 \pm 0.6 1 AUBERT 07D BABR Repl. by AUE seen 2 AUBERT,B 04W BABR Repl. by AUE (1400 90 ALBRECHT 91B ARG $e^+e^- \rightarrow r$ 1 Assumes equal production of B^+ and B^0 at the r (4 s). 2 The angular distribution of $B \rightarrow \phi K^*$ (1430) provides evidence with stati | BERT 07D (4 <i>S</i>) | ⁷ AVERY 89B reports < 2 rescale to 50%. $\Gamma(K^*(1410)\gamma)/\Gamma_{total}$ $\frac{VALUE}{<1.3 \times 10^{-4}}$ 90 | 2.8 $	imes$ 10 ⁻⁴ assuming the $T(4S)$ decays 43% to $B^0\overline{B}^0$. The sum of B^0 at the $T(4S)$ decays 43% to $B^0\overline{B}^0$. The sum of B^0 at the $T(4S)$. |

<2.6 × 10⁻⁶

¹ AUBERT,BE 06H BABR Repl. by LEES 11A

 1 Assumes equal production of B^0 and B^+ at the $\varUpsilon(4S)$ and for a $\phi\phi$ invariant mass below 2.85 GeV/c².

90 1,2 NISHIDA

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4{\rm S}).$ 2 1.25 GeV/ c^2 < $M_{K\pi}$ < 1.6 GeV/ c^2

02 BELL $e^+e^- \rightarrow \Upsilon(4S)$

| $\Gamma(K^*(892)^0X(214)\times B(X\to \mu^+\mu^-))/\Gamma_{\text{total}}$ Γ_{317}/Γ | $\Gamma(ho^0\gamma)/\Gamma_{ m total}$ | | Γ ₃₂₆ / |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|---------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| X(214) is a hypothetical particle of mass 214 MeV/c ² reported by the HyperCP | VALUE (units 10 ⁻⁶) CL% | DO CUMENT ID | TECN COMMENT |
| experiment (PARK 05) | 0.86±0.15 OUR AVERA | | |
| 4LUE (units 10 ⁻⁸) CL% DOCUMENT ID TECN COMMENT | $0.97^{+0.24}_{-0.22}\pm0.06$ | ¹ AUBERT 0 | 8BH BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| (2.26 90 1,2 HYUN 10 BELL $e^+e^- \rightarrow r(4S)$ | $0.78 {}^{+ 0.17}_{- 0.16} {}^{+ 0.09}_{- 0.10}$ | ¹ TANIGUCHI 0 | 8 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Based on scalar nature of X particle. With a vector X assumption, the upper limit is | - 0.16 - 0.10 • • • We do not use the fo | llowing data for averages | s, fits, limits, etc. • • • |
| 2.27×10^{-8} . | $0.79^{+0.22}_{-0.20}\pm0.06$ | ¹ AUBERT 0 | 7L BABR Repl. by AUBERT 08вн |
| $(K^0\pi^+\pi^-\gamma)/\Gamma_{	ext{total}}$ Γ_{318}/Γ | | | |
| LUE (units 10 ⁻⁵) DOCUMENT ID TECN COMMENT | $\begin{array}{c} 1.25 + 0.37 + 0.07 \\ -0.33 - 0.06 \end{array}$ | 1 MOHAPATRA 0 | , , |
| 5±0.22 OUR AVERAGE | $0.0 \pm 0.2 \pm 0.1$ 90 < 0.8 90 | ¹ AUBERT 0 ¹ MOHAPATRA 0 | BABR Repl. by AUBERT 07L BELL $e^+e^- ightarrow \gamma(4S)$ |
| $0.05\pm0.21\pm0.12$ 0.07 R BABR $e^+e^- \rightarrow \Upsilon(4.5)$ | < 1.2 90 | ¹ AUBERT 0 | 4c BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 10 \pm 0.4 \pm 0.3 2,3 YANG 05 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | <17 90 | | 0 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $^1M_{K\pi\pi} < 1.8$ GeV/ c^2 . 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | $^{ m 1}$ Assumes equal production | on of B^+ and B^0 at the | $\Upsilon(4S)$. |
| Assumes equal production of B^{-1} and B^{-1} at the $T(43)$. | $\Gamma(\rho^0 X(214) \times B(X \to \mu))$ | $(\mu^+ \mu^-))/\Gamma_{\text{total}}$ | Г ₃₂₇ / |
| | X(214) is a hypothe | tical particle of mass 2 | $^{\rm L4}$ MeV/c $^{ m 2}$ reported by the HyperC |
| $(K^+\pi^-\pi^0\gamma)/\Gamma_{\text{total}}$ Γ_{319}/Γ | experiment (PARK 05 VALUE (units 10 ⁻⁸) CL | .% DOCUMENT ID | TECN COMMENT |
| LUE (units 10^{-5})DOCUMENT IDTECNCOMMENT $07\pm0.22\pm0.31$ $1,2$ AUBERT07RBABR $e^+e^- \rightarrow \Upsilon(4S)$ | <1.73 90 | | $\frac{10}{10} \frac{\text{BELL}}{\text{BELL}} \frac{e^+e^- \rightarrow \Upsilon(4S)}{e^+e^- \rightarrow \Upsilon(4S)}$ |
| $^{1}M_{K\pi\pi} < 1.8 \text{ GeV}/c^{2}.$ | ¹ Assumes equal production | | \ / |
| $^{10}K\pi\pi$ 1.3 GeV/C: Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ² The result is the same f | or a scalar or vector X p | article. |
| | $\Gamma(\rho^0\gamma)/\Gamma(K^*(892)^0\gamma)$ | | Γοος /Γος |
| $(K_1(1270)^0\gamma)/\Gamma_{	ext{total}}$ Γ_{320}/Γ | $VALUE$ (units 10^{-2}) | DOCUMENT ID | Γ326/Γ31 ΤΕCN COMMENT |
| ALUE (units 10^{-5}) CL% DOCUMENT ID TECN COMMENT 5.8 90 1 YANG 05 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | 2.06 + 0.45 + 0.14 - 0.43 - 0.16 | | 08 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| • We do not use the following data for averages, fits, limits, etc. | $\frac{2.06}{-}0.43 - 0.16$ | TANIGUCHI | 08 BELL e e → 7(43) |
| 700 90 2 ALBRECHT 89G ARG $e^+e^- ightarrow~ \varUpsilon(4S)$ | $\Gamma(\omega\gamma)/\Gamma_{ m total}$ | | Γ ₃₂₈ / |
| 1 Assumes equal production of B^+ and B^0 at the $arGamma(4S)$. | VALUE (units 10 ⁻⁶) CL% | DO CUMENT ID | TECN COMMENT |
| 2 ALBRECHT 89G reports <0.0078 assuming the $\Upsilon(4S)$ decays 45% to $B^0\overline{B}{}^0.$ We rescale to 50%. | 0.44 + 0.18 OUR AVERA | GE | |
| | | _ | BH BABR $e^+e^- ightarrow \gamma(45)$ |
| $(K_1(1400)^0\gamma)/\Gamma_{\text{total}}$ Γ_{321}/Γ | $0.50 + 0.27 \pm 0.09$ | | , , |
| ALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | $0.40 {}^{+ 0.19}_{- 0.17} {}^{+ 0.13}$ | | BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| 1.2 90 ¹ YANG 05 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • | • • • We do not use the fo | llowing data for averages | s, fits, limits, etc. • • • |
| 430 90 ² ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4S)$ | $0.40 {}^{+ 0.24}_{- 0.20} {}^{\pm 0.05}$ | ¹ AUBERT 07L | BABR Repl. by AUBERT 08BH |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | $0.56 + 0.34 + 0.05 \\ -0.27 - 0.10$ | ¹ MOHAPATRA 06 | BELL Repl. by TANIGUCHI 08 |
| 2 ALBRECHT 89G reports < 0.0048 assuming the $\Upsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. We | <1.0 90 | 1 AUBERT 05 | BABR Repl. by AUBERT 07L |
| rescale to 50%. | <0.8 90 | 1 MOHAPATRA 05 | BELL Repl. by MOHAPATRA 06 |
| $(K_2^*(1430)^0\gamma)/\Gamma_{\text{total}}$ Γ_{322}/Γ | <1.0 90 <9.2 90 | | BABR $e^+e^- \rightarrow \Upsilon(4S)$ CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| NLUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | ¹ Assumes equal production | | , , |
| 1.24 ± 0.24 OUR AVERAGE 1.22 \pm 0.25 \pm 0.10 1 AUBERT,B 040 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(\phi\gamma)/\Gamma_{ m total}$ | | Γ/ |
| 1.3 \pm 0.5 \pm 0.1 1 NISHIDA 02 BELL $e^+e^- ightarrow \gamma(4S)$ | | .% DOCUMENT ID | Γ ₃₂₉ / TECN COMMENT |
| • • We do not use the following data for averages, fits, limits, etc. • • • | <8.5 × 10 ⁻⁷ 90 | _ | 05C BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 40 90 2 ALBRECHT 89G ARG $e^+e^- \rightarrow \Upsilon(4S)$ | ● ● We do not use the for | llowing data for averages | |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 ALBRECHT 896 reports $<4.4\times10^{-4}$ assuming the $\varUpsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. We | $< 0.33 \times 10^{-5}$ 90 | | 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| rescale to 50%. | ¹ Assumes equal production | on of B^+ and B^0 at the | $\Upsilon(4S)$. |
| $(K^*(1680)^0\gamma)/\Gamma_{\text{total}}$ Γ_{323}/Γ | $\Gamma(\pi^+\pi^-)/\Gamma_{ m total}$ | | Γ ₃₃₀ / |
| (N (1999) 7)/ TOTAL 1323/ 1 | VALUE (units 10^{-6}) CL% | DOCUMENT ID | TECN COMMENT |
| (0.0020 $\overline{}$ 90 $\overline{}$ ALBRECHT 89G $\overline{}$ ARG $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $\overline{}$ $$ | 5.15±0.22 OUR FIT 5.18±0.24 OUR AVER | AGE | |
| 1 ALBRECHT 89G reports $<$ 0.0022 assuming the \varUpsilon (4 <i>S</i>) decays 45% to $B^0\overline{B}^0$. We | 5.5 ±0.4 ±0.3 | ¹ AUBERT (| D7B BABR $e^+e^- ightarrow \gamma(4S)$ |
| rescale to 50%. | $5.1 \pm 0.2 \pm 0.2$ | ¹ LIN (| D7A BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\left(K_3^*(1780)^0\gamma\right)/\Gamma_{\text{total}}$ Γ_{324}/Γ | $\begin{array}{cccc} 4.5 & +1.4 & +0.5 \\ & -1.2 & -0.4 \end{array}$ | ¹ BORNHEIM (| O3 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| NLUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | • • • We do not use the fo | | |
| < 83 90 1,2 NISHIDA 05 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $4.4 \pm 0.6 \pm 0.3$ $4.7 \pm 0.6 \pm 0.2$ | | 04 BELL Repl. by LIN 07A 02Q BABR Repl. by AUBERT 07B |
| • • We do not use the following data for averages, fits, limits, etc. • • • $(10000 	 90 	 ^3 \text{ ALBRECHT} 	 896 \text{ ARG} 	 e^+ e^- \rightarrow \Upsilon(45)$ | $4.7 \pm 0.6 \pm 0.2$ $5.4 \pm 1.2 \pm 0.5$ | 4 | D2 BELL Repl. by CHAO 04 |
| 10000 90 3 ALBRECHT 89G ARG $e^+e^- ightarrow \varUpsilon(4S)$ 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | $5.6 \begin{array}{c} +2.3 \\ -2.0 \end{array} \begin{array}{c} +0.4 \\ -0.5 \end{array}$ | ¹ ABE | D1н BELL Repl. by CASEY 02 |
| 2 Uses B($K_3^*(1780) \rightarrow \eta K$) = $0.11_{-0.04}^{+0.05}$. | $4.1 \pm 1.0 \pm 0.7$ | ¹ AUBERT (| DIE BABR Repl. by AUBERT 02Q |
| ³ ALBRECHT 89G reports < 0.011 assuming the $\Upsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. We rescale | < 67 90 | | 00c SLD $e^+e^- \rightarrow Z$ |
| to 50%. | $\begin{array}{cc} 4.3 & +1.6 \\ -1.4 & \pm 0.5 \end{array}$ | 1 CRONIN-HEN | |
| $(K_4^*(2045)^0 \gamma)/\Gamma_{\text{total}}$ Γ_{325}/Γ | < 15 90 | GODANG | 98 CLE2 Repl. by CRONIN- HENNESSY 00 |
| LUECL%DOCUMENT IDTECNCOMMENT | < 45 90 | | 96D DLPH $e^+e^-	o Z$ |
| 0.0043 90 1 ALBRECHT 89G ARG $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | < 20 90 < 41 90 | | 96 CLE2 Repl. by GODANG 98 96V ALEP $e^+e^- \rightarrow Z$ |
| 1 ALBRECHT 89G reports < 0.0048 assuming the $\Upsilon(4S)$ decays 45% to $B^{0}\overline{B}^{0}$. We | < 41 90 < 55 90 | - | 96∨ ALEP $e^+e^- \rightarrow Z$ 95N DLPH Sup. by ADAM 96D |
| rescale to 50%. | < 47 90 | 6 AKERS | 04L OPAL $e^+e^- ightarrow Z$ |
| | < 29 90 | ¹ BATTLE | O3 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | 1 ALBBECUT | 00p ABC s+ ~(.c) |
| | <130 90 | _ | 90B ARG $e^+e^- \rightarrow \Upsilon(4S)$ 39 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | 7 BORTOLETTO | . , |

| ¹ Assumes equal pr | roduction o | of B^+ and B^0 at t | the $\Upsilon(4S)$. | | | $\Gamma(\eta'\eta')/\Gamma_{ m total}$ | | | | | Γ ₃₃₅ /Γ |
|-------------------------------------------------------------------|------------------------|---------------------------------------------|-----------------------------|------------------------------------------------------------------------|-------------|-------------------------------------------|----------------------------|------------------------------------------------|---------------------|--------------------------------------------------------|-----------------------------|
| ² ABE 00c assum | nes B(Z - | $\rightarrow b\overline{b}$)=(21.7 \pm | 0.1)% and the | B fractions $f_{R^0} = f_{R^0}$ | += | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | |
| (39.7 + 1.8)% and | | | | 5 5 | | < 1.7 | | 1 AUBERT | 09AV BAB | $e^+e^- \rightarrow$ | T(45) |
| ³ ADAM 96D assur | $mes f_{-0} =$ | $f_{-} = 0.39$ and | $f_D = 0.12$. | | | | | | | | |
| 4 BUSKILLO 06V | occumes Di | DC 06 production | fractions for P | $^{)}$, B^{+} , B_{S} , b baryons. | | < 6.5 | | 1 SCHUEMANN | | $e^+e^- \rightarrow$ | |
| | | | | | 2 | < 2.4 | | ¹ AUBERT,B | | | AUBERT 09AV |
| Assumes a Bo, E | y produc | tion traction of U.3 | 9 and a B _S pro | duction fraction of 0.12 | 2. | <10 | | ¹ AUBERT,B | | | AUBERT,B 06v |
| ⁶ Assumes B($Z \rightarrow$ | | | | | | <47 | 90 | BEHRENS | | $e^+e^- \rightarrow$ | |
| ⁷ Paper assumes th | he $\Upsilon(4S)$ (| decays 43% to B ⁰ | B ⁰ . We rescale | to 50%. | | ¹ Assumes equal p | roduction of | B^+ and B^0 at t | he $\Upsilon(4S)$. | | |
| $\Gamma(\pi^+\pi^-)/\Gamma(K^+\pi^+)$ | π-) | | | Γ ₃₃₀ /Γ ₂ | 014 | | | | (/. | | |
| VALUE | , | DO CUMENT ID | TECN CO | MMENT | £1 7 | $\Gamma(\eta'\eta)/\Gamma_{ m total}$ | | | | | Г336/Г |
| 0.265 ± 0.013 OUR F | -IT | | | | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | |
| $0.259 \pm 0.017 \pm 0.016$ | i | AALTONEN 1 | 1n CDF ρ \overline{p} | at 1.96 TeV | | < 1.2 | 90 | ¹ AUBERT | 08AH BAB | $R e^+e^- \rightarrow$ | r(45) |
| | e the follov | ving data for avera | ges, fits, limits, | etc. • • • | | ● ● We do not us | e the followin | ng data for avera | ges, fits, lim | its, etc. • • | • ` ' |
| $0.21\ \pm0.05\ \pm0.03$ | | ABULENCIA,A 0 | 6D CDF Re | pl. by AALTONEN 11N | I | < 4.5 | 90 | 1 SCHUEMANN | L 07 BEL | $L e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| | | | | | | < 1.7 | 90 | ¹ AUBERT | | | AUBERT 08AH |
| $\Gamma(\pi^0\pi^0)/\Gamma_{ m total}$ | | | | Г ₃₃₁ | _/Г | < 4.6 | 90 | ¹ AUBERT,B | | $R e^+e^- \rightarrow$ | |
| VALUE (units 10 ⁻⁶) | CL% | DOCUMENT IL | TECN | COMMENT | | <27 | 90 | BEHRENS | 98 CLE | $e^+e^- \rightarrow$ | r(45) |
| 1.62±0.31 OUR | AVERAGE | | | | | ¹ Assumes equal p | roduction of | B^+ and B^0 at t | he $\Upsilon(4S)$. | | |
| $1.47 \pm 0.25 \pm 0.12$ | 2 | ¹ AUBERT | 07BC BABR | $e^+ e^- ightarrow \varUpsilon$ (45) | | | | | , , | | |
| $2.3 \begin{array}{c} + 0.4 & + 0.2 \\ - 0.5 & - 0.3 \end{array}$ | | $^{ m 1}$ CHAO | 05 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | | $\Gamma(\eta' ho^0)/\Gamma_{ m total}$ | | | | | Γ ₃₃₇ /Γ |
| • • • We do not use | e the follow | vinα data for avera | aes fits limits | etc • • • | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT I | D TE | CN COMMEN | IT |
| | | AUBERT | • | | 7n.c | < 1.3 | 90 | ¹ SCHUEMAN | IN 07 BE | LL e^+e^- | → Υ(4S) |
| $1.17 \pm 0.32 \pm 0.10$ < 3.6 | 90 | 1 AUBERT | | Repl. by AUBERT 07 $e^+e^- \rightarrow \Upsilon(4S)$ | IBC | ● ● We do not us | e the followin | ng data for avera | ges, fits, lim | its, etc. • • | • |
| 2.1 ±0.6 ±0.3 | 90 | 1 AUBERT | | Repl. by AUBERT 05 | Ši. | < 2.8 | 90 | 1 DEL-AMO-S | - SA 10a BA | BR e+e- | $\rightarrow \Upsilon(4.5)$ |
| < 4.4 | 90 | ¹ BORNHEIM | | $e^+e^- \rightarrow \Upsilon(4S)$ | ,_ | < 3.7 | 90 | AUBERT | | BR Repl. by | |
| 1.7 ±0.6 ±0.2 | | 1 LEE | 03 BELL | Repl. by CHAO 05 | | | 0.0 | 1 | 04- 04 | | CHEZ 10A |
| < 5.7 | 90 | ¹ ASNER | 02 CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ | | < 4.3 <12 | 90 90 | ¹ AUBERT,B ¹ RICHICHI | | .вк кері. by Е2 <i>е⁺е[—] -</i> | y AUBERT 07E |
| < 6.4 | 90 | ¹ CASEY | 02 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | | <23 | 90 | BEHRENS | | | → 7(43) y RICHICHI 00 |
| < 9.3 | 90 | GODANG | 98 CLE2 | | | | | | | LZ Repl. b | , memem oo |
| < 9.1 | 90 | ASNER | | Repl. by GODANG 9 | 8 | ¹ Assumes equal p | roduction of | B and B at t | ne / (45). | | |
| <60 | 90 | ² ACCIARRI | 95H L3 | $e^+ e^- \rightarrow Z$ | | $\Gamma(\eta' f_0(980) \times B($ | $f_0(980) \rightarrow 0$ | $\pi^+\pi^-))/\Gamma_{tot}$ | a.i | | Г338/Г |
| ¹ Assumes equal pr | | | | | | VALUE (units 10 ⁻⁶) | CL% | DOCUMENT I | | CN COMMEN | • |
| ² ACCIARRI 95н а | issumes f _B | $_0=39.5\pm4.0$ an | d $f_{B_s} = 12.0 \pm $ | = 3.0%. | | <0.9 | 90 | 1 DEL-AMO-S | | | |
| | | | | _ | | • • • We do not us | | | | | |
| $\Gamma(\eta\pi^0)/\Gamma_{ m total}$ | | | | Γ ₃₃₂ | <u>:</u> /Γ | | | = | - | | |
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | | <1.5 | 90 | AUBERT | U/E BA | BR Repl. by، SAN | CHEZ 10A |
| < 1.5 | 90 | ¹ AUBERT | 08AH BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | | ¹ Assumes equal p | roduction of | B^+ and B^0 at t | he $\Upsilon(4S)$. | 5, | |
| | e the follov | ving data for avera | ges, fits, limits, | etc. • • • | | , , | | | (/. | | |
| < 1.3 | 90 | ¹ AUBERT | 06w BABR | Repl. by AUBERT 08A | VН | $\Gamma(\eta ho^0)/\Gamma_{ m total}$ | | | | | Γ ₃₃₉ /Γ |
| < 2.5 | 90 | $^{ m 1}$ CHANG | 05 A BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT I | D TE | CN COMMEN | IT. |
| < 2.5 | 90 | ¹ AUBERT,B | 04D BABR | Repl. by AUBERT 06v | V | < 1.5 | 90 | 1 AUBERT | | BR e+e- | |
| < 2.9 | 90 | ¹ RICHICHI | | $e^+e^- \rightarrow \Upsilon(4S)$ | | | | | | | |
| < 8 | 90 | BEHRENS | | Repl. by RICHICHI 00 | | < 1.9 | 90 | ¹ WANG | - | LL e+e- | |
| < 250 | 90 90 | ² ACCIARRI | 95н L3 90в ARG | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow \Upsilon(4S)$ | | < 1.5 | 90 | 1 AUBERT,B | | | y AUBERT 07Y |
| <1800 | | 1 ALBRECHT | | e · e → 1(45) | | <10 | 90 | ¹ RICHICHÍ | | | $\rightarrow \Upsilon(4S)$ |
| Assumes equal pr | | | | 0.00/ | | <13 | 90 | BEHRENS | 98 CL | E2 Repl. by | y RICHICHI 00 |
| ² ACCIARRI 95н а | issumes ¹ B | ₀ = 39.5 ± 4.0 an | a $t_{B_S} = 12.0 \pm $ | ± 3.0%. | | ¹ Assumes equal p | roduction of | B^+ and B^0 at t | he $\Upsilon(4S)$. | | |
| $\Gamma(\eta\eta)/\Gamma_{ m total}$ | | | | Г ₃₃₃ | ./г | | | | . , | | |
| | | | | | 17' | $\Gamma(\eta f_0(980) \times B(f_0(980))$ | $_0(980) \rightarrow \tau$ | τ˙π¯))/I _{tota} | I | | Г ₃₄₀ /Г |
| VALUE (units 10 ⁻⁶) | <u>CL%</u> | DO CUMENT II | | | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT I | D TE | CN COMMEN | IT |
| < 1.0 | 90 | 1 AUBERT | | $e^+e^- \rightarrow \Upsilon(4S)$ | | <0.4 | 90 | ¹ AUBERT | 07Y BA | BR e^+e^- | → Υ(45) |
| • • • We do not use | | | | | _ | ¹ Assumes equal p | roduction of | B^+ and B^0 at t | he $\Upsilon(4S)$. | | |
| < 1.8 | 90 | ¹ AUBERT,B ¹ CHANG | | Repl. by AUBERT 0 | 9AV | | | | | | |
| < 2.0 | 90 | | | $e^+e^- \rightarrow \Upsilon(4S)$ | | $\Gamma(\omega\eta)/\Gamma_{ m total}$ | | | | | Γ ₃₄₁ /Γ |
| < 2.8 | 90 90 | ¹ AUBERT,B BEHRENS | 98 CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | |
| < 18 <410 | 90 | ² ACCIARRI | 95 CLE2 | $e^+e^- \rightarrow Z$ | | $0.94 + 0.35 \pm 0.09 $ | 9 | ¹ AUBERT | 09AV BAB | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| | | | | e · e → Z | | | | | | | , , |
| Assumes equal pr | | | | 2.00/ | | • • • We do not us | | 2 | - | | |
| ² ACCIARRI 95н а | issumes 1 _B | ₀ = 39.5 ± 4.0 an | a $r_{B_S} = 12.0 \pm $ | ± 3.0%. | | < 1.9 | | I AUBERT,B | | | AUBERT 09AV |
| $\Gamma(\eta'\pi^0)/\Gamma_{ m total}$ | | | | Г ₃₃₄ | /г | $4.0 \ ^{+1.3}_{-1.2} \ \pm 0.4$ | | ¹ AUBERT,B | 04x BAB | R Repl. by A | AUBERT,Β 05κ |
| | | | | | ·/ · | <12 | 90 | ¹ BERGFELD | 98 CLE2 | 2 | |
| VALUE (units 10 ⁻⁶) 1.2±0.6 OUR AV | CL% CEDACE | DOCUMENT ID | | COMMENT | | ¹ Assumes equal p | | | he $\Upsilon(4S)$ | | |
| 0.9 ± 0.4 ± 0.1 | PERMUE | Error includes scale 1 AUBERT | | $e^+e^- \rightarrow \gamma(4S)$ | | | 21 | _ 300 | (). | | |
| $0.9 \pm 0.4 \pm 0.1$ $2.8 \pm 1.0 \pm 0.3$ | | | OUMH DABK | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | | $\Gamma(\omega\eta')/\Gamma_{ m total}$ | | | | | Γ 34 2/Γ |
| | e the follow | | | | | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT I | D TE | CN COMMEN | IT |
| | 101101 | _ | = | | | $1.01 + 0.46 \pm 0.09$ | | 1 AUBERT | DOM/ DA | BR e+e- | γ(45) |
| $0.8 {}^{+ 0.8}_{- 0.6} {}^{\pm 0.1}$ | | ¹ AUBERT | 06w BABR | Repl. by AUBERT 08A | ЛН | | | | | | , , |
| $1.0^{+1.4}_{-1.0}\pm0.8$ | 90 | ¹ AUBERT,B | 04D BARR | Repl. by AUBERT 06v | v | | | | | | |
| | | | | | • | < 2.2 | 90 | 1 SCHUEMAN | | | |
| < 5.7 <11 | 90 90 | ¹ RICHICHI BEHRENS | | $e^+e^- \rightarrow \Upsilon(4S)$ Repl. by RICHICHI 00 | | < 2.8 | 90 | 1 AUBERT,B | | BR e ⁺ e ⁻ | → Υ(45) |
| | | | | repi. by Rienieni 00 | | <60 | 90 | 1 BERGFELD | 98 CL | E2 | |
| ¹ Assumes equal pr | roduction o | or B⊓ and B° at t | ne T (45). | | | ¹ Assumes equal p | roduction of | \mathcal{B}^+ and \mathcal{B}^0 at t | he $\Upsilon(4S)$. | | |
| | | | | | | | | | | | |

 2 ADAM 96D assumes $f_{B^0}=f_{B^-}=0.39$ and $f_{B_s}=0.12$.

³ Assumes a B^0 , B^- production fraction of 0.39 and a B_s production fraction of 0.12.

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(\omega ho^0)/\Gamma_{ m total}$ | | | Г ₃₄₃ /Г | $\Gamma(\phi\phi)/\Gamma_{ m total}$ | | | | | Γ ₃₅₂ / |
|----------------------------------------------|---------------------|--------------------------------------------------------|----------------------------------------------------------------------------|--------------------------------------------------------|-------------------------|---------------------------------------------|----------------------|-------------------------------------------|------------------------|
| VALUE (units 10 ⁻⁶) | CL% | DOCUMENT ID T | ECN COMMENT | VALUE | CL% | DO CUMENT ID | TEC | | |
| < 1.6 | 90 | | ABR $e^+e^- ightarrow \varUpsilon(4S)$ | <2 ×10 ⁻⁷ • • • We do not us | 90 | | | $3R e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| | | ing data for averages, fits | | <1.5 × 10 ⁻⁶ | 90 | | | | IDEDT 0000 |
| < 1.5 < 3.3 | 90 90 | | ABR Repl. by AUBERT 09H ABR Repl. by AUBERT,B 06T | <3.21 × 10 ⁻⁴ | 90 | | 04x BAI 00c SLE | BR Repl. by AU $e^+e^- \rightarrow$ | |
| <11 | 90 | ¹ BERGFELD 98 C | | <1.2 × 10 ⁻⁵ | 90 | 4 | 98 CLE | | 4 |
| | | f B^+ and B^0 at the $\Upsilon(4)$ | | $< 3.9 \times 10^{-5}$ | 90 | | | $e^+e^- \rightarrow$ | Υ(4S) |
| | | , | • | ¹ Assumes equal ₁ | production of | B^+ and B^0 at the | · \(\gamma(45). | | |
| $\Gamma(\omega f_0(980) \times B(a))$ | | , | Г ₃₄₄ /Г | ² ABE 00c assur | $mes B(Z \rightarrow$ | $b\overline{b}) = (21.7 \pm 0.1)$ | 1)% and | the B fraction | is $f_{B^0} = f_{B^+}$ |
| VALUE (units 10 ⁻⁶) | CL%_ | DO CUMENT ID | TECN COMMENT | (39.7 $^{+}_{-}$ $^{1.8}_{2.2}$)% a | nd $f_{B_s} = (10.5)$ | $5 + 1.8 \atop - 2.2$)%. | | | |
| <1.5 | 90 | ¹ AUBERT 09н ing data for averages, fits | BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(a_0(980)^{\pm}\pi^{\mp}\times$ | D(= (000) | ±±\\/r | | | F / |
| <1.5 | 90 | | BABR Repl. by AUBERT 09H | | | | | | Г ₃₅₃ / |
| | | f B^+ and B^0 at the Υ (4 | | VALUE (units 10 ⁻⁶) | <u>CL%</u> 90 | DOCUMENT ID 1 AUBERT | | ABR $e^+e^- \rightarrow$ | Y(4.5) |
| | oroduction c | I B - allu B - at the 1 (4 | • | • • • We do not us | | | | | 1 (43) |
| $\Gamma(\omega\omega)/\Gamma_{\text{total}}$ | | | Г ₃₄₅ /Г | <5.1 | 90 | ¹ AUBERT,BE | | | AUBERT 07Y |
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN COMMENT | | | B^+ and B^0 at the | | | |
| < 4.0 | 90 | · · | BABR $e^+e^- \rightarrow \Upsilon(4S)$ | | | | | | |
| | | ing data for averages, fits | | $\Gamma(a_0(1450)^{\pm}\pi^{\mp}$ | \times B(a_0 (14) | $(50)^{\pm} \rightarrow \eta \pi^{\pm})$ | | | Γ ₃₅₄ / |
| <19 | 90 | | CLE2 | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | | COMMENT | |
| ¹ Assumes equal p | production o | f B^+ and B^0 at the \varUpsilon (4 | S). | <2.3 | 90 | 1 AUBERT | | ABR $e^+e^ \rightarrow$ | $\Upsilon(4S)$ |
| $\Gamma(\phi\pi^0)/\Gamma_{\rm total}$ | | | Г ₃₄₆ /Г | ¹ Assumes equal ₁ | production of | B^+ and B^0 at the | · \(\gamma(45). | | |
| VALUE (units 10 ⁻⁶) | CL% | DOCUMENT ID | TECN COMMENT | $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{to}$ | otai | | | | Γ ₃₅₅ / |
| <0.28 | 90 | ¹ AUBERT,B 06c | BABR $e^+e^- \rightarrow r(4S)$ | VALUE | <u>CL%</u> | DO CUMENT ID | | ECN COMMENT | |
| ● ● We do not us | se the follow | ing data for averages, fits | , limits, etc. • • • | $< 7.2 \times 10^{-4}$ | 90 | $^{ m 1}$ ALBRECHT | 90в A | RG $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| <1.0 | 90 | | BABR Repl. by AUBERT,B 06c | ¹ ALBRECHT 90 | 3 limit assum | es equal production | of $B^0\overline{B}$ | 0 and $_{B}^{+}$ $_{B}^{-}$ a | t γ(45). |
| <5 | 90 | ¹ BERGFELD 98 | | $\Gamma(ho^0\pi^0)/\Gamma_{ m total}$ | | | | | Г356/ |
| ¹ Assumes equal p | production o | f B^+ and B^0 at the \varUpsilon (4 | S). | VALUE (units 10 ⁻⁶) | 61.0/ | DO CUMENT ID | - | ECN COMMENT | 1356/ |
| $\Gamma(\phi\eta)/\Gamma_{\rm total}$ | | | Γ ₃₄₇ /Γ | 2.0 ±0.5 OU | <u>CL%</u> R AVERAGE | | | ECN <u>COMMENT</u> | |
| VALUE (units 10-6) | CL% | DOCUMENT ID T | ECN COMMENT | 3.0 ±0.5 ±0. | | ^{1,2} KUSAKA | 08 B | ELL $e^+e^ \rightarrow$ | $\Upsilon(4S)$ |
| <0.5 | 90 | 1 AUBERT 09AV B | ABR $e^+e^- \rightarrow \Upsilon(4S)$ | $1.4 \pm 0.6 \pm 0.$ | | ¹ AUBERT | 04z B | ABR $e^+e^ \rightarrow$ | $\Upsilon(4S)$ |
| | se the follow | ing data for averages, fits | , limits, etc. • • • | $1.6 \begin{array}{c} +2.0 \\ -1.4 \end{array} \pm 0.$ | 8 | ¹ JESSOP | 00 C | LEO $e^+e^ \rightarrow$ | $\Upsilon(4S)$ |
| < 0.6 | 90 | | ABR Repl. by AUBERT 09AV | | se the followi | ng data for average | s, fits, lir | nits, etc. • • • | |
| <1.0 <9 | 90 90 | | ABR Repl. by AUBERT,B 06∨ LE2 | 3.12 + 0.88 + 0.00 + 0.00 = 0.00 = 0.00 | 60 | ¹ DRAGIC | 06 B | ELL Repl. by | KUSAKA 08 |
| | | f B^+ and B^0 at the Υ (4 | | $5.1 \pm 1.6 \pm 0.$ | | DRAGIC | | ELL Repl. by I | |
| - Assumes equal p | oroduction c | TB and B at the 1 (4 | 3). | < 5.3 | 90 | ¹ GORDON | | ELL Repl. by I | |
| $\Gamma(\phi\eta')/\Gamma_{\rm total}$ | | | Г ₃₄₈ /Г | < 24 | 90 | ASNER | | LEO Repl. by | |
| VALUE (units 10 ⁻⁶) | CL% | | ECN COMMENT | <400 | 90 | 1 ALBRECHT | 90B A | RG $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| < 0.5 | 90 | ¹ SCHUEMANN 07 B | | | | B^+ and B^0 at the | | . (1.450 | /1570 |
| • • • We do not us | | ing data for averages, fits | | resonances. | measureme | nt that excludes co | ntributio | ns from $ ho$ (1450 |) and ρ(1570 |
| < 1.1 | 90 | | ABR $e^+e^- \rightarrow \Upsilon(4S)$ | F(= +)/F | | | | | - , |
| < 1.0 < 4.5 | 90 90 | | ABR Repl. by AUBERT 09AV ABR Repl. by AUBERT,B 06V | $\Gamma(ho^{\mp}\pi^{\pm})/\Gamma_{total}$ | | | | | Г357/ |
| <31 | 90 | | LE2 | VALUE (units 10 ⁻⁶) 23.0±2.3 OUR | AVEDAGE | DOCUMENT ID | <u>TE</u> | COMMENT | |
| ¹ Assumes equal p | oroduction c | f B^+ and B^0 at the \varUpsilon (4 | S). | 22.6±1.1±4.4 | | 1,2 KUSAKA | 08 BI | ELL $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $\Gamma(\phi ho^0)/\Gamma_{ m total}$ | | | Г ₃₄₉ /Г | $22.6 \pm 1.8 \pm 2.2$ | | ¹ AUBERT | | ABR $e^+e^- \rightarrow$ | |
| | 51.0/ | 0.0 000 000 00 | | $27.6 + 8.4 \pm 4.2$ | | ¹ JESSOP | 00 CI | .E2 $e^+e^ \rightarrow$ | $\Upsilon(4S)$ |
| VALUE (units 10 ⁻⁶) | <u>CL%</u> | DOCUMENT ID 1 AUBERT 08B | TECN COMMENT | • • • We do not us | | ng data for average | s, fits, lir | nits, etc. • • • | |
| < 0.33 • • • We do not us | 90 se the follow | ing data for averages, fits | KBABR $e^+e^- ightarrow \varUpsilon(4S)$. limits, etc. $ullet$ $ullet$ | $20.8 + 6.0 + 2.8 \\ -6.3 - 3.1$ | | 1 GORDON | | ELL Repl. by k | CIISAKA NO |
| <156 | 90 | • | SLD $e^+e^- \rightarrow Z$ | | | | | | |
| < 13 | 90 | | CLE2 | < 88 < 520 | 90 90 | A SNER ¹ ALBRECHT | 96 CL 90B AI | .E2 Repl. by J RG $e^+e^- \rightarrow$ | |
| ¹ Assumes equal p | production c | f B^+ and B^0 at the \varUpsilon (4 | S). | <5200 | 90 | ³ BEBEK | | .EO $e^+e^- \rightarrow$ | |
| ² ABE 00c assun | nes B(Z $-$ | $b\overline{b}) = (21.7 \pm 0.1)\%$ | and the B fractions $f_{B^0} = f_{B^+} =$ | ¹ Assumes equal i | production of | B^+ and B^0 at the | r(45). | | |
| (39.7 + 1.8)% ar | | | - 5 | ² This is the first | | nt that excludes co | | ns from $ ho(1450$ | and $ ho(1570$ |
| | , | | - /- | resonances. 3 BEBEK 87 repo | rts < 6.1 × 10 | 0^{-3} assuming the γ | (45) de≀ | avs 43% to B ⁰ 7 | 30. We rescal |
| $\Gamma(\phi f_0(980) \times B(t))$ | | , | Γ ₃₅₀ /Γ | to 50%. | | | , , | ,,, | |
| VALUE (units 10 ⁻⁶) | <u>CL%</u> | | TECN COMMENT | $\Gamma(\pi^+\pi^-\pi^+\pi^-)$ | /F | | | | Г358/ |
| <0.38 | 90 | | KBABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE | /' total CL% | DO CUMENT ID | 7 | ECN <u>COMMENT</u> | 1358/ |
| ¹ Assumes equal p | production c | f B^+ and B^0 at the \varUpsilon (4 | S). | <19.3 × 10 ⁻⁶ | 90 | 1 CHIANG | | ELL $e^+e^- \rightarrow$ | Υ(4S) |
| $\Gamma(\phi\omega)/\Gamma_{ m total}$ | | | Γ ₃₅₁ /Γ | • • • We do not u | | | | | . () |
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN COMMENT | $< 23.1 \times 10^{-6}$ | 90 | ¹ AUBERT | | ABR $e^+e^- \rightarrow$ | Y(45) |
| | | | BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $< 2.3 \times 10^{-4}$ | 90 | ² ADAM | 96D D | LPH $e^+e^ \rightarrow$ | |
| < 1.2 | 90 | AUDERI,D UUI | DADN C C → 1(43) | | | | | | |
| < 1.2 | | ing data for averages, fits | | $< 2.8 \times 10^{-4} $ $< 6.7 \times 10^{-4}$ | 90 90 | ³ ABREU ¹ ALBRECHT | | LPH Sup. by A RG $e^+e^- \rightarrow$ | |

 B^0

| $\Gamma(ho^0 \pi^+ \pi^-)/\Gamma_{ m total}$ | Γ ₃₅₉ /Γ | $\Gamma(\rho^+\rho^-)/\Gamma_{\text{total}}$ Γ_{368}/Γ |
|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | " 359/" % DOCUMENT ID TECN COMMENT | '\(\(P\cdot P\)\'\)\'\total '368\'\ \(\frac{VALUE\(\text{units}\10^{-6}\)\)\(\cdot CL\%\)\(\text{DOCUMENT\ID\)\(\text{TECN\\}\)\(\cdot COMMENT\)\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ |
| < 8.8 90 | | 24.2±3.1 OUR AVERAGE |
| - | illowing data for averages, fits, limits, etc. • • • | $25.5\pm2.1^{+3.6}_{-3.9}$ 1 AUBERT 07BF BABR $e^+e^- ightarrow$ \varUpsilon (45) |
| <12.0 90 | 1 CHIANG 08 BELL $e^{+}e^{-} ightarrow~ arGamma(4S)$ | 22.8 \pm 3.8 \pm 2.3 |
| ¹ Assumes equal production | on of B^+ and B^0 at the $\varUpsilon(4S)$. | |
| $\Gamma(ho^0 ho^0)/\Gamma_{ m total}$ | Г ₃₆₀ /Г | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ' (<i>P P) </i> ' total VALUE (units 10 ⁻⁶) CL | | $25 \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 0.73±0.28 OUR AVER | | 30 ±4 ±5 1,2 AUBERT,B 04R BABR Repl. by AUBERT 07BF |
| $0.92 \pm 0.32 \pm 0.14$ | 1 AUBERT 08BB BABR $e^{+}e^{-} ightarrow~ \varUpsilon(4S)$ | <2200 90 1 ALBRECHT 90B ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.4 \pm 0.4 \begin{array}{c} + 0.2 \\ - 0.3 \end{array}$ | 1 CHIANG 08 BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. 2 The quoted result is obtained after combining with AUBERT 04G result by AUBERT 04R |
| | ollowing data for averages, fits, limits, etc. • • • | alone gives $(33 \pm 4 \pm 5) \times 10^{-6}$. |
| $1.07 \pm 0.33 \pm 0.19$ | AUBERT 07G BABR Repl. by AUBERT 08BB | $\Gamma(a_1(1260)^0\pi^0)/\Gamma_{\text{total}}$ Γ_{369}/Γ |
| < 1.1 90 | | Γ(a ₁ (1260) ^u π ^u)/Γ _{total} Γ ₃₆₉ /Γ VALUE CL% DOCUMENT ID TECN COMMENT |
| < 2.1 90 < 18 90 | | <1.1 × 10 ⁻³ 90 1 ALBRECHT 90B ARG $e^+e^- \rightarrow r(4S)$ |
| <136 90 | 3 | 1 ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at $\varUpsilon(4S)$. |
| <280 90 | | |
| <290 90 <430 90 | | |
| • | on of B^+ and B^0 at the $\Upsilon(4S)$. | $\frac{VALUE \text{ (units } 10^{-6})}{\text{< 0.5}}$ $\frac{CL\%}{90}$ $\frac{DOCUMENT ID}{1}$ $\frac{TECN}{0}$ $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ |
| | on or B ' and B at the 1(45). onfiguration. For a helicity 11 configuration, the limit decreases | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| to 1.4 × 10 ⁻⁵ | · · · | $<$ 2.0 90 $^{-1}$ JEN 06 BELL $e^+e^- ightarrow \gamma(4S)$ |
| | $P \rightarrow b \overline{b} = (21.7 \pm 0.1)\%$ and the B fractions $f_{B^0} = f_{B^+} = (40.7 \pm 1.8)\%$ | < 1.2 90 ¹ AUBERT,B 04D BABR Repl. by AUBERT 08AH |
| $(39.7 + 1.8)\%$ and $f_{B_s} =$ | $(10.5 \pm \frac{1}{2} \pm \frac{1}{2})\%$. S) decays 43% to $B^0 \overline{B}^0$. We rescale to 50%. | $<$ 1.9 90 1 WANG 04A BELL $e^+e^- ightarrow \varUpsilon(4S)$ $<$ 3 90 1 AUBERT 01G BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| * | , · · · | $<$ 5.5 90 1 JESSOP 00 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(f_0(980)\pi^+\pi^-)/\Gamma_{\text{tota}}$ | Γ ₃₆₁ /Γ | < 14 90 $\frac{1}{2}$ BERGFELD 98 CLE2 Repl. by JESSOP 00 |
| VALUE (units 10^{-6}) CL | <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | <460 90 2 ALBRECHT 90B ARG $e^+e^- ightarrow r(4S)$ |
| <3.8 90 | | ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| ¹ Assumes equal production | on of B^+ and B^0 at the $\varUpsilon(4S)$. | 2 ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at $\varUpsilon(4S)$. |
| $\Gamma(\rho^0 f_0(980) \times B(f_0(980))$ | $(1) \rightarrow \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{362}/Γ | $\Gamma(\pi^+\pi^+\pi^-\pi^-\pi^0)/\Gamma_{\text{total}}$ Γ_{371}/Γ |
| VALUE (units 10^{-6}) CL% | • | VALUE CL% DOCUMENT ID TECN COMMENT |
| <0.3 90 | $1 \overline{CHIANG}$ 08 \overline{BELL} $e^+e^- \to \varUpsilon(4S)$ | <9.0 × 10⁻³ 90 ¹ ALBRECHT 90B ARG $e^+e^- → \Upsilon(4S)$ |
| • • • We do not use the fo | ollowing data for averages, fits, limits, etc. • • • | 1 ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at \varUpsilon (4S). |
| < 0.40 90 | 1 AUBERT 08BB BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(a_1(1260)^+ \rho^-)/\Gamma_{\text{total}}$ Γ_{372}/Γ |
| <0.53 90 | AUBERT 07G BABR Repl. by AUBERT 08BB | VALUE (units 10 ⁻⁶) CL% DO CUMENT ID TECN COMMENT |
| | on of B^+ and B^0 at the $\varUpsilon(4S)$. | < 61 90 1,2 AUBERT,B 060 BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\Gamma(f_0(980) f_0(980) \times B^2($ | $f_0(980) \rightarrow \pi^+\pi^-))/\Gamma_{\text{total}}$ Γ_{363}/Γ | • • • We do not use the following data for averages, fits, limits, etc. • • |
| VALUE (units 10^{-6}) CL% | - , | <3400 90 ¹ ALBRECHT 90B ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| <0.1 90 | 1 CHIANG 08 BELL $e^+e^- ightarrow \varUpsilon(4S)$ sllowing data for averages, fits, limits, etc. $ullet$ $ullet$ $ullet$ | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Assumes $a_1(1260)$ decays only to 3π and B($a_1^\pm	o\pi^\pm\pi^\mp\pi^\pm)=0.5$. |
| <0.19 90 | 1 AUBERT 08BB BABR $e^{+}e^{-} ightarrow \gamma(4S)$ | - |
| <0.16 90 | $^{-}$ AUBERT 08BB ABR Repl. by AUBERT 08BB | $\Gamma(a_1(1260)^0 \rho^0)/\Gamma_{\text{total}}$ Γ_{373}/Γ |
| ¹ Assumes equal production | on of B^+ and B^0 at the $\varUpsilon(4S)$. | VALUE CL% DOCUMENT ID TECN COMMENT |
| | , | <2.4 × 10⁻³ 90 ¹ ALBRECHT 90B ARG $e^+e^- \rightarrow r(4S)$ |
| | $_0 \rightarrow \pi^+\pi^-) \times B(f_0 \rightarrow K^+K^-))/\Gamma_{\text{total}}$ Γ_{364}/Γ | 1 ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at \varUpsilon (4S). |
| <0.23 90 | $\frac{.\%}{1}$ DOCUMENT ID TECN COMMENT ${1}$ AUBERT 08BK BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(b_1^{\mp}\pi^{\pm} \times B(b_1^{\mp} \to \omega\pi^{\mp}))/\Gamma_{total}$ Γ_{374}/Γ |
| | on of B^+ and B^0 at the $\Upsilon(4S)$. | VALUE (units 10 ⁻⁶) DO CUMENT ID TECN COMMENT |
| | | 10.9\pm1.2\pm0.9 1 AUBERT 07BI BABR $e^+e^- ightarrow \ \varUpsilon(4S)$ |
| $\Gamma(a_1(1260)^{\mp}\pi^{\pm})/\Gamma_{\text{tota}}$ | | 1 Assumes equal production of B^+ and B^{0} at the $ \varUpsilon(4S).$ |
| VALUE (units 10 ⁻⁶) CL | | $\Gamma(b_1^0\pi^0 \times B(b_1^0 	o \omega\pi^0))/\Gamma_{total}$ Γ_{375}/Γ |
| 33.2±3.8±3.0 | 1,2 AUBERT 06v BABR $e^+e^- 	o 	au(4S)$ sollowing data for averages, fits, limits, etc. \bullet \bullet | VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT |
| < 630 90 | • | <1.9 90 1 AUBERT 08AG BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| < 490 90 | | ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| <1000 90 | | |
| | on of B^+ and B^0 at the $\varUpsilon(4S)$. | $\Gamma(b_1^-\rho^+\times B(b_1^-\to\omega\pi^-))/\Gamma_{total} \qquad \qquad \Gamma_{376}/\Gamma$ |
| 2 Assumes $a_1(1260)$ decay | ys only to 3π and $\mathrm{B}(a_1^\pm \to \pi^\pm \pi^\mp \pi^\pm) = 0.5$. | VALUE CL% DOCUMENT ID TECN COMMENT $<1.4 \times 10^{-6}$ 90 1 AUBERT 09AF BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5 Paper assumes the $ \Upsilon (4 $ | S) decays 43% to $B^0 = \overline{B}^0$. We rescale to 50%. | 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| $\Gamma(a_2(1320)^{\mp}\pi^{\pm})/\Gamma_{\text{tota}}$ | Γ ₃₆₆ /Γ | |
| VALUE CL | .% DOCUMENT ID TECN COMMENT | $\Gamma(b_1^0 \rho^0 \times B(b_1^0 \to \omega \pi^0)) / \Gamma_{total}$ Γ_{377} / Γ |
| • | 0 1 BORTOLETTO89 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | ollowing data for averages, fits, limits, etc. • • • | |
| | 1 BEBEK 87 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ | 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. |
| $^{	t L}$ Paper assumes the $\varUpsilon(4)$ | S) decays 43% to $B^0\overline{B}{}^0$. We rescale to 50%. | $\Gamma(\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-)/\Gamma_{\text{total}}$ |
| $\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{\rm total}$ | Γ ₃₆₇ /Γ | VALUE CL% DOCUMENT ID TECN COMMENT |
| VALUE CL | .% | <3.0 × 10⁻³ 90 ¹ ALBRECHT 90B ARG e^+e^- → $\Upsilon(4S)$ |
| <3.1 × 10 ⁻³ 90 | | 1 ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at \varUpsilon (45). |
| ¹ ALBRECHT 90B limit a | ssumes equal production of $B^0\overline{B}{}^0$ and B^+B^- at $\varUpsilon(4S)$. | |
| | | |

 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $(a_1(1260)^+ a_1(1260)^- \times B^2(a_1^+ \to 2\pi^+\pi^-))/\Gamma_{\text{total}}$ | Γ ₃₇₉ /Γ | Γ(ρ ρ Κ*(892) ⁰)/Γ | | | | | Г ₃₈₆ /Г |
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| ALUE (units 10 ⁻⁶) | $e^+e^- 	o 	au(4S)$ | VALUE (units 10 ⁻⁶) 1.24 + 0.28 OUR AV | <u>CL%_</u> /ERAGE | DO CUMENT ID | TECN | COMMENT | |
| • • We do not use the following data for averages, fits, limits, etc | | | | | | | |
| <6000 90 ¹ ALBRECHT 90B ARG e | | $1.18 + 0.29 \pm 0.11$ | j | ^{1,2} CHEN | | e+e- → | |
| (2800 90 ² BORTOLETTO89 CLEO e | e ⁺ e ⁻ → T(4S) | $1.47 \pm 0.45 \pm 0.40$ | 45 - 6-11 | ² AUBERT | | ≥ e+e- → | Y(45) |
| 1 Assumes equal production of $B^0\overline{B}^0$ and B^+B^- at $\varUpsilon(4S)$. 2 BORTOLETTO 89 reports $<3.2\times10^{-3}$ assuming the $\varUpsilon(4S)$. We rescale to 50%. | decays 43% to $B^0\overline{B}^0$. | • • • We do not use <7.6 | 90 | ² WA NG | 04 BELL | $e^+e^-\to$ | T(45) |
| $(\pi^+\pi^+\pi^+\pi^-\pi^-\pi^-\pi^0)/\Gamma_{	ext{total}}$ | Γ ₃₈₀ /Γ | 1 Explicitly vetoes re 2 Assumes equal pro | | | | n states. | |
| <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>C</u> <1.1 × 10 ^{−2} 90 ¹ ALBRECHT 90B ARG e | $e^+e^- 	o 	au(4S)$ | $\Gamma(f_J(2220)K_0^*\times B)$ | (f _J (2220) - | $\rightarrow \rho \overline{p}))/\Gamma_{\text{total}}$ | | | Γ ₃₈₇ /Ι |
| $^{-1}$ ALBRECHT 90B limit assumes equal production of $B^0\overline{B}{}^0$ and B^0 | | <u>VALUE</u> (units 10 ⁻⁶) | CL% | DO CUMENT ID | | COMMENT | |
| | | <0.15 | 90 | 1 AUBERT | | $e^+e^- \rightarrow$ | T(45) |
| $(\rho \overline{\rho})/\Gamma_{\text{total}}$ | Г ₃₈₁ /Г | ¹ Assumes equal pro | duction of E | 3^+ and B^0 at the | $\Upsilon(4S)$. | | |
| | COMMENT | $\Gamma(p \overline{\Lambda} \pi^-)/\Gamma_{\text{total}}$ | | | | | Γ388/I |
| • • We do not use the following data for averages, fits, limits, etc. | $e^+e^- \rightarrow r(4S)$ | VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | · |
| | $e^+e^- \rightarrow r(4S)$ | 3.14±0.29 OUR | | 1 | | | , -, |
| < 0.27 90 ¹ AUBERT 040 BABR e | | $3.07 \pm 0.31 \pm 0.23$ | | 1 AUBERT | | R e ⁺ e [−] → | . , |
| < 1.4 90 $\frac{1}{2}$ BORNHEIM 03 CLE2 <i>e</i> | $e^+e^- \rightarrow \Upsilon(4S)$ | $3.23 { + 0.33 \atop - 0.29 } \pm 0.29$ | | ¹ WANG | | $e^+e^- \rightarrow$ | Υ(4S) |
| | $e^+e^- \rightarrow \Upsilon(4S)$ | • • • We do not use | - | g data for average | s, fits, limits | , etc. • • • | |
| < 7.0 90 ¹ COAN 99 CLE2 <i>e</i> < 18 90 ² BUSKULIC 96V ALEP <i>e</i> | $e^+ e^- \rightarrow \Upsilon(4S)$ $e^+ e^- \rightarrow Z$ | $2.62 + 0.44 \pm 0.31$ | 1 | ^{1,2} WA NG | 05A BELL | Repl. by V | VANG 07c |
| • | Sup. by ADAM 96D | $3.97 + 1.00 \pm 0.56$ | | ¹ WANG | 03 BELL | Repl. by V | VANG 05A |
| | $e^+e^- \rightarrow \gamma(4S)$ | < 13 | 90 | ¹ COAN | | e+e- → | |
| | $e^+ e^- ightarrow ~ \varUpsilon(4S) \ e^+ e^- ightarrow ~ \varUpsilon(4S)$ | <180 | 90 | ³ ALBRECHT | | $e^+e^ \rightarrow$ | |
| 1 Assumes equal production of B^+ and B^0 at the $\varUpsilon(4S)$. | 7 (43) | ¹ Assumes equal pro | duction of E | S^+ and B^{0} at the | $\Upsilon(4S)$. | | |
| ² BUSKULIC 96V assumes PDG 96 production fractions for B^0 , E^0 | B ⁺ . B _a . b baryons. | ² Provides also resul | | | | | |
| ³ Assumes a B^0 , B^- production fraction of 0.39 and a B_S produc | | 3 ALBRECHT 88F r | eports < 2.0 | $	imes 10^{-4}$ assuming | the $\Upsilon(4S)$ | decays 45% t | о В ⁰ В ⁰ . W |
| ⁴ Paper assumes the $\Upsilon(4S)$ decays 43% to $B^{0}\overline{B}{}^{0}$. We rescale to | 50%. | rescale to 50%. | | | | | |
| 5 ALBRECHT 88F reports $< 1.3 \times 10^{-4}$ assuming the $\varUpsilon(4S)$ dec | ays 45% to $B^0\overline{B}{}^0$. We | $\Gamma(p\overline{\Sigma}(1385)^-)/\Gamma_{tot}$ | otal | | | | Г ₃₈₉ / |
| rescale to 50%. | | VALUE (units 10^{-6}) | CL% | DO CUMENT ID | TECN | | |
| $(\rho \overline{\rho} \pi^+ \pi^-)/\Gamma_{\text{total}}$ | Γ ₃₈₂ /Γ | <0.26 | 90 | ¹ WANG | | $e^+e^- \rightarrow$ | Y(45) |
| | | | | | | | |
| | COMMENT | $^{ m 1}$ Assumes equal pro | duction of E | B^+ and B^0 at the | $\Upsilon(4S)$. | | |
| <2.5 90 ¹ BEBEK 89 CLEO <i>e</i> | $e^+e^- \rightarrow \gamma(4S)$ | | duction of E | $^{ m H}$ and $^{ m B}$ at the | Υ(45). | | Γ ₃₉₀ /Ι |
| • • We do not use the following data for averages, fits, limits, etc. | $e^+e^- \rightarrow \Upsilon(4S)$ | ¹ Assumes equal pro $\Gamma(\Delta^{0} \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE (units 10^{-6})$ | duction of E | 3+ and B ⁰ at the | $\Upsilon(4S)$. | COMMENT | Γ ₃₉₀ /Ι |
| \$\ \begin{align*} \cdot 2.5 & 90 & 1 \\ \begin{align*} \text{BBBEK} & 89 & \text{CLEO} & \\ \end{align*} \\ \begin{align*} \cdot \text{BBBEK} & 89 & \text{CLEO} & \\ \end{align*} \\ \end{align*} \\ \end{align*} \\ \end{align*} \\ \text{ClEO} & \\ \end{align*} \\ \end{align*} \\ \end{align*} \\ \text{OLPH} & \text{SI} \\ \end{align*} \\ \end{align*} \\ \text{DLPH} & \text{SI} \\ \end{align*} \\ \end | $e^+e^- ightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D | $\Gamma(\Delta^0 \overline{A})/\Gamma_{total}$ | | | TECN | $\frac{\textit{COMMENT}}{e^+e^- \rightarrow}$ | |
| | $e^+e^- 	o 	au(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- 	o 	au(4S)$ | $\Gamma(\Delta^0 \overline{\lambda})/\Gamma_{\text{total}}$ VALUE (units 10^{-6}) | <u>CL%_</u> 90 | DOCUMENT ID WANG | 07c BELL | | |
| <2.5 90 1 BEBEK 89 CLEO e • • We do not use the following data for averages, fits, limits, etc <9.5 90 2 ABREU 95N DLPH 5 5.4 \pm 1.8 \pm 2.0 3 ALBRECHT 88F ARG e 1 BEBEK 89 reports < 2.9 × 10 ⁻⁴ assuming the Υ (4 S) decays 43% to 50%. | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale | $ \Gamma(\Delta^{0} \overline{\Lambda})/\Gamma_{\text{total}} $ $ \underline{VALUE (\text{units } 10^{-6})} $ < 0.93 1 Assumes equal pro | <u>CL%_</u> 90 | DOCUMENT ID WANG | 07c BELL | | r(45) |
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| \$\ \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-6}\text{)}$ <0.93 ¹ Assumes equal pro $\Gamma(p \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-6}\text{)}$ <0.82 | 2L% 90 duction of E | $\frac{DOCUMENT\ ID}{1\ WANG}$ and B^0 at the $\frac{DOCUMENT\ ID}{1\ WANG}$ | 7 TECN 07 BELL 7 (45). 7 TECN 03 BELL | $e^+e^- \rightarrow$ | Υ(4 <i>S</i>) |
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| \$\ \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ ~ 0.93 1 Assumes equal pro $\Gamma(p\overline{\Lambda}K^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro ~ 0.82 1 Assumes equal pro $\sim \Gamma(p\overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ | CL% 90 duction of E CL% 90 duction of E | $\begin{array}{c} \underline{DOCUMENT\ ID} \\ 1\ WANG \\ 3+\ \text{and}\ B^{0}\ \text{at the} \\ \\ \underline{DOCUMENT\ ID} \\ 1\ WANG \\ 3+\ \text{and}\ B^{0}\ \text{at the} \end{array}$ | 07c BELL (4s). 7(4s). 03 BELL (4s). | $e^+e^- \rightarrow \frac{\text{COMMENT}}{e^+e^- \rightarrow}$ | τ(4S) Γ ₃₉₁ /Ι |
| \$\$\cdot \cdot \text{\$\text{\$\cdot \cdot \ | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ ~ 0.93 1 Assumes equal pro $\Gamma(\rho \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\rho \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\rho \overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ ~ 0.82 | CL% 90 duction of E CL% 90 duction of E | $\frac{DOCUMENT\ ID}{1\ WANG}$ $3^{+}\ and\ B^{0}\ at\ the}$ $\frac{DOCUMENT\ ID}{1\ WANG}$ $3^{+}\ and\ B^{0}\ at\ the}$ $\frac{DOCUMENT\ ID}{1\ DOCUMENT\ ID}$ | 07c BELL **T(45).** 03 BELL **T(45).** | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \hline \\ \frac{COMMENT}{e^-} \end{array}$ | τ(4 <i>s</i>) Γ ₃₉₁ /Ι τ(4 <i>s</i>) |
| \$\text{\$<\char{e}\$}\$ \text{\$\char{e}\$}\$ \text{\$\text{\$\text{\$W}\$}\$ do not use the following data for averages, fits, limits, etc. \$\(\char{e}\) \text{\$<\char{e}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\char{e}\$}\$ \$\char{ | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-6})}{\text{<} 0.93}$ 1 Assumes equal pro $\Gamma(p \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-6})}{\text{<} 0.82}$ 1 Assumes equal pro $\Gamma(p \overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ $\frac{VALUE}{\text{<} 3.8 \times 10^{-6}}$ | 2L% 90 duction of E 2L% 90 duction of E 2L% | $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ | 07c BELL (45). 1ECN 03 BELL (45). 1ECN 03 BELL | $e^+e^- \rightarrow \frac{\text{COMMENT}}{e^+e^- \rightarrow}$ | τ(4 <i>s</i>) Γ ₃₉₁ /1 τ(4 <i>s</i>) |
| \$\text{\$<\char{e}\$}\$ \text{\$\char{e}\$}\$ \text{\$\text{\$\text{\$W}\$}\$ do not use the following data for averages, fits, limits, etc. \$\(\char{e}\) \text{\$<\char{e}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\text{\$\char{e}\$}\$}\$ \text{\$\char{e}\$}\$ \$\char{ | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. Farally Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6}\text{)}$ < 0.93 1 Assumes equal pro $\Gamma(p\overline{\Lambda}K^-)/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6}\text{)}$ < 0.82 1 Assumes equal pro $\Gamma(p\overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ $VALUE$ < 3.8 × 10 ⁻⁶ 1 Assumes equal pro | 2L% 90 duction of E 2L% 90 duction of E 2L% | $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ | 07c BELL (45). 1ECN 03 BELL (45). 1ECN 03 BELL | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \hline \\ \frac{COMMENT}{e^-} \end{array}$ | τ(4 <i>s</i>) Γ ₃₉₁ /1 τ(4 <i>s</i>) |
| \$\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \(\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \) \$\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \) \$\cdot \cdot \cdot \cdot \text{A} \text{L} \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. \[\begin{align*} \Gamma_{383}/\Gamma_{283}/\Gamma_{283}/\Gamma_{283}/\Gamma_{283}/\Gamma_{283}/\Gamma_{283}/\Gamma_{283}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{2833}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{28333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{283333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{2833333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{28333333}/\Gamma_{2833333333}/\Gamma_{2833333333}/\Gamma_{28333333333}/\Gamma_{28333333333333333333333333333333333333 | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-6})}{\text{<} 0.93}$ 1 Assumes equal pro $\Gamma(p \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units } 10^{-6})}{\text{<} 0.82}$ 1 Assumes equal pro $\Gamma(p \overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ $\frac{VALUE}{\text{<} 3.8 \times 10^{-6}}$ | 2L% 90 duction of E 2L% 90 duction of E 2L% | $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ $3+\ and\ B^0\ at\ the$ $\frac{DOCUMENT\ ID}{1\ WANG}$ | 07c BELL (45). 1ECN 03 BELL (45). 1ECN 03 BELL | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow} \\ \\ \hline \\ \frac{COMMENT}{e^-} \end{array}$ | τ(4S) Γ ₃₉₁ /Ι τ(4S) Γ ₃₉₂ /Ι τ(4S) |
| \$\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \(\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \) \$\cdot \cdot \cdot \text{We do not use the following data for averages, fits, limits, etc.} \) \$\cdot \cdot | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. Fab. F | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ ~ 0.93 1 Assumes equal pro $\Gamma(p\overline{\Lambda}K^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(p\overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(p\overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro ~ 0.82 1 Assumes equal pro ~ 0.82 1 Assumes equal pro ~ 0.82 | CL% 90 duction of E CL% 90 duction of E CL% 90 duction of E | DOCUMENT ID 1 WANG 3+ and B ⁰ at the | 07c BELL (45). 03 BELL (45). 03 BELL (45). 03 BELL (45). | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ \end{array}$ | Γ ₃₉₁ /Ι Γ ₃₉₂ /Ι Γ ₃₉₃ /Ι |
| • • We do not use the following data for averages, fits, limits, etc. e9.5 90 2 ABREU 95N DLPH S 5.4±1.8±2.0 3 ALBRECHT 88F ARG e 1 BEBEK 89 reports < 2.9×10^{-4} assuming the $\Upsilon(4S)$ decays 43% to 50%. 2 Assumes a B^0 , B^- production fraction of 0.39 and a B_S production fraction of 0.39 and a B_S production fraction of 0.49 and the $\Upsilon(4S)$ we rescale to 50%. 2 Assumes to 50%. 2 Appendix 2 ABRECHT 88F reports 6.0 ± 2.0 ± 2.2 assuming the $\Upsilon(4S)$ where scale to 50%. 2 ADRECHT 88F reports 6.0 ± 2.0 ± 2.2 assuming the $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ and $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are $\Upsilon(4S)$ are | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Repl. by CHEN 08c Repl. by WANG 05A | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ ~ 0.93 1 Assumes equal pro $\Gamma(\rho \overline{\Lambda} K^-)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\rho \overline{\Lambda} \Gamma_0)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\rho \overline{\Lambda} \Gamma_0)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\Lambda \Lambda)/\Gamma_{\text{total}}$ ~ 0.82 1 Assumes equal pro $\Gamma(\overline{\Lambda} \Lambda)/\Gamma_{\text{total}}$ ~ 0.82 | 21% 90 duction of E 21% 90 duction of E 21% 90 duction of E | DOCUMENT ID 1 WANG 3+ and B ⁰ at the 1 WANG 3+ and B ⁰ at the 1 WANG 3+ and B ⁰ at the DOCUMENT ID 1 WANG 3+ and B ⁰ at the | 07c BELL 7(45). 17ECN 03 BELL 7(45). 17ECN 03 BELL 7(45). 17ECN 03 BELL 7(45). | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \underline{} \\ e^+e^- \rightarrow \\ \\ \underline{} \\ e^+e^- \rightarrow \\ \\ \underline{} \\ e^+e^- \rightarrow \\ \\ \underline{} \\ e^+e^- \rightarrow \\ \\ \end{array}$ | τ(45) Γ ₃₉₁ /Ι τ(45) Γ ₃₉₂ /Ι τ(45) |
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We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Repl. by CHEN 08c Repl. by WANG 05A Repl. by WANG 04 tates. tes and pK^0 production | $ \begin{split} &\Gamma(\Delta^0\overline{\Lambda})/\Gamma_{\text{total}} \\ &\stackrel{\text{VALUE (units }10^{-6})}{<0.93} \\ &1 \text{ Assumes equal pro} \\ &\Gamma(\rho\overline{\Lambda}K^-)/\Gamma_{\text{total}} \\ &\stackrel{\text{VALUE (units }10^{-6})}{<0.82} \\ &1 \text{ Assumes equal pro} \\ &\Gamma(\rho\overline{\Sigma}^0\pi^-)/\Gamma_{\text{total}} \\ &\stackrel{\text{VALUE}}{<3.8\times10^{-6}} \\ &1 \text{ Assumes equal pro} \\ &\Gamma(\overline{\Lambda}\Lambda)/\Gamma_{\text{total}} \\ &\stackrel{\text{VALUE (units }10^{-6})}{<0.32} \\ &\bullet \bullet \text{ VVe do not use} \\ &<0.69 \\ &<1.2 \\ &<1.0 \\ &<3.9 \end{split} $ | CL% 90 duction of E CL% 90 duction of E CL% 90 duction of E CL% 90 the following 90 90 90 | DOCUMENT ID 1 WANG 3+ and B ⁰ at the DOCUMENT ID 1 WANG 3+ and B ⁰ at the 1 WANG 3+ and B ⁰ at the 1 TSAI 3 data for average 1 CHANG 1 BORNHEIM 1 ABE 1 COAN | 07c BELL (45). 03 BELL (45). 03 BELL (45). 7(45). 7ECN 07 BELL s, fits, limits 05 BELL 03 CLE2 020 BELL 99 CLE2 | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^+e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline \\ e^-e^- \rightarrow \\ \hline $ | T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) THANG 05 |
| \$\ \cdot \cdot \text{VE do not use the following data for averages, fits, limits, etc. } \ \cdot \cdot \text{VE do not use the following data for averages, fits, limits, etc. } \ \cdot \cdot \cdot \cdot \text{VE do not use the following data for averages, fits, limits, etc. } \ \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \c | $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Sup. by ADAM 96D $e^+e^- \rightarrow \Upsilon(4S)$ % to $B^0\overline{B}^0$. We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Repl. by CHEN 08c Repl. by WANG 05A Repl. by WANG 04 tates. tes and pK^0 production | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ 20 20 3 1 Assumes equal pro $\Gamma(p\overline{\Lambda}K^-)/\Gamma_{\text{total}}$ 20 20 3 1 Assumes equal pro $\Gamma(p\overline{\Lambda})/\Gamma_{\text{total}}$ 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 20 | CL% 90 duction of E CL% 90 duction of E CL% 90 duction of E CL% 90 the following 90 90 90 | DOCUMENT ID 1 WANG 3+ and B ⁰ at the DOCUMENT ID 1 WANG 3+ and B ⁰ at the 1 WANG 3+ and B ⁰ at the 1 TSAI 3 data for average 1 CHANG 1 BORNHEIM 1 ABE 1 COAN | 07c BELL (45). 03 BELL (45). 03 BELL (45). 7(45). 7ECN 07 BELL s, fits, limits 05 BELL 03 CLE2 020 BELL 99 CLE2 | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \hline \\ \frac{COMMENT}{e^{+}e^{-}} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ \hline \\ \text{Repl. by T} \\ e^{+}e^{-} \rightarrow \\ \text{Repl. by C} \\ \end{array}$ | T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) T(45) THANG 05 |
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We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Repl. by CHEN 08C Repl. by WANG 05A Repl. by WANG 04 cates. tes and pK^0 production symmetry of $p\overline{p}$ system. F384/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • $e^+e^- \rightarrow \Upsilon(4S)$ | Γ($\Delta^0 \overline{\Lambda}$)/ Γ_{total} 24LUE (units 10^{-6}) <0.93 1 Assumes equal pro Γ($p\overline{\Lambda}$ K^-)/ Γ_{total} 24LUE (units 10^{-6}) <0.82 1 Assumes equal pro Γ($p\overline{\Sigma}^0 \pi^-$)/ Γ_{total} 24LUE <3.8 × 10^{-6} 1 Assumes equal pro Γ($\overline{\Lambda}\Lambda$)/ Γ_{total} 24LUE (units 10^{-6}) <0.32 • • • We do not use <0.69 <1.2 <1.0 <3.9 1 Assumes equal pro Γ($\overline{\Lambda}\Lambda$ K^0)/ Γ_{total} 24LUE (units 10^{-6}) 4.76 + 0.84 + 0.61 1 Excluding charmon 3.735 GeV/ c^2 . 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We rescale ction fraction of 0.12. decays 45% to $B^0\overline{B}^0$. F383/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • Repl. by CHEN 08C Repl. by WANG 05A Repl. by WANG 04 Lates. tes and pK^0 production symmetry of $p\overline{p}$ system. F384/F COMMENT $e^+e^- \rightarrow \Upsilon(4S)$ c. • • • | $\Gamma(\Delta^0 \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6})$ <0.93 1 Assumes equal pro $\Gamma(p\overline{\Lambda}K^-)/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6})$ <0.82 1 Assumes equal pro $\Gamma(p\overline{\Sigma}^0 \pi^-)/\Gamma_{\text{total}}$ $VALUE$ <3.8 × 10 ⁻⁶ 1 Assumes equal pro $\Gamma(\overline{\Lambda}\Lambda)/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6})$ <0.32 ••• We do not use <0.69 <1.2 <1.0 <3.9 1 Assumes equal pro $\Gamma(\overline{\Lambda}\Lambda K^0)/\Gamma_{\text{total}}$ $VALUE \text{ (units 10}^{-6})$ 4.76+0.68 4.76+0.68 1 Excluding charmon 3.735 GeV/c ² . 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 $^{^{1}}$ Excluding charmonium events in 2.85 $< m_{A\overline{A}} < 3.128~{\rm GeV/c^2}$ and 3.315 $< m_{A\overline{A}} < 3.735~{\rm GeV/c^2}$. Measurements in various $m_{A\overline{A}}$ bins are also reported. 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(45)$.

 B^0

| | | Γ ₃₉₆ /Γ | $\Gamma(\overline{\Lambda}_c^- p \pi^+ \pi^-)/\Gamma_{\text{total}}$ | | | Γ ₄₀₈ /Ι |
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| VALUE (units 10 ⁻⁵) | DOCUMENT ID TECN COMMEN | | VALUE (units 10 ⁻³) 1.3 ±0.4 OUR AVERAGE | <u>DOCUMENT ID</u> | TECN COMMENT | |
| $1.05 + 0.57 \pm 0.14$ | ¹ CHANG 09 BELL e ⁺ e ⁻ - | → Υ(4S) | $\begin{array}{ccc} & -0.3 & \pm 0.4 \\ 1.7 & -0.2 & \pm 0.4 \end{array}$ | 1 DYTMAN | 02 CLE2 $e^+e^- \rightarrow$ | T(45) |
| $^{ m 1}$ Assumes equal production $^{ m c}$ | f B^+ and B^0 at the \varUpsilon (4 S). | | -0.2 $1.10 \pm 0.20 \pm 0.29$ | ² GABYSHEV | 02 BELL $e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| $\Gamma(\Delta^0 \overline{\Delta}{}^0)/\Gamma_{ m total}$ | | Γ ₃₉₇ /Γ | | following data for average | s, fits, limits, etc. • • • | () |
| ALUE CL% | DOCUMENT ID TECN COMMEN | Τ | $1.33^{+0.46}_{-0.42}\pm 0.37$ | ³ FU | 97 CLE2 Repl. by D' | YTMAN 02 |
| <0.0015 90 | ¹ BORTOLETTO89 CLEO e ⁺ e ⁻ - | . , | | s (1.67 + 0.27) × 10-3 | from a measurement o | f ΓΓ(R ⁰ _ |
| ¹ BORTOLETTO 89 reports to 50%. | $<$ 0.0018 assuming $ \varUpsilon(4S) $ decays 43% to $ B^{ 0} $ | \overline{B}^{0} . We rescale | | | assuming $B(\Lambda_C^+ \to p K^-$ | |
| | | | which we rescale to ou | $\wedge [B(X_C \rightarrow PX \times Y)]$ or best value $B(A^+ \rightarrow PX \times Y)$ | $(-\pi^{+}) = (5.0 \pm 1.3) \times 10^{-}$ | -2 Our firs |
| $\Gamma(\Delta^{++}\overline{\Delta}^{})/\Gamma_{\text{total}}$ | DO CUMENT 10 TEST COMMEN | Г ₃₉₈ /Г | error is their experime | ent's error and our second | $(\pi^+)=(5.0\pm 1.3)	imes 10^{-6}$ error is the systematic error | or from using |
| <u>/ALUE</u> <u>CL%</u> <1.1 × 10⁻⁴ 90 | $\frac{DOCUMENT\ ID}{1}$ BORTOLETTO89 CLEO e^+e^- | | our best value | | from a measurement o | |
| | $< 1.3 	imes 10^{-4}$ assuming $\varUpsilon(45)$ decays 43% | . , | | | assuming $B(\Lambda_c^+ \to p K^-)$ | |
| rescale to 50%. | | | which we rescale to ou | ir best value $B(\Lambda_c^+ \to pK)$ | $(\pi - \pi^+) = (5.0 \pm 1.3) 	imes 10^{-6}$ error is the systematic error | -2. Our firs |
| $\Gamma(\overline{D}^0 p \overline{p}) / \Gamma_{\text{total}}$ | | Г399/Г | error is their experime our best value. | ent's error and our second | error is the systematic erro | or from using |
| /ALUE (units 10 ⁻⁴) | DOCUMENT IDTECNCOMMEN: | • | ³ FU 97 uses PDG 96 v | alues of Λ_{C} branching frac | tion. | |
| 1.14±0.09 OUR AVERAGE | 1 | | | | | F / |
| 1.13±0.06±0.08 1.18±0.15±0.16 | 1 AUBERT,B 06s BABR $e^{+}e^{-}$ – 1 ABE 02w BELL $e^{+}e^{-}$ – | | $\Gamma(\overline{\Lambda}_c^- p)/\Gamma_{\text{total}}$ | GLAY DOGUMENT ID | TE 01 001111511T | Γ ₄₀₉ /Ι |
| ¹ Assumes equal production of | | 7 (45) | VALUE (units 10 ⁻⁵) C | <u>CL%</u> <u>DOCUMENT ID</u> RAGE | TECN COMMENT | |
| | . 5 and 5 at the 1 (45). | | $1.9 \pm 0.2 \pm 0.5$ | ^{1,2} AUBERT | 08BN BABR $e^+e^- ightarrow 1$ | · / |
| $\Gamma(D_s^-\overline{\Lambda} ho)/\Gamma_{ m total}$ | | Γ ₄₀₀ /Γ | $2.19^{+0.56}_{-0.49}\pm0.65$ | $^{1,3}\mathrm{GABYSHEV}$ | 03 BELL $e^+e^- ightarrow 1$ | r(45) |
| /ALUE (units 10 ⁻⁵) | $1,2$ MEDVEDEVA 07 BELL e^+e^- | <u> </u> | • • • We do not use the | following data for average | s, fits, limits, etc. • • • | |
| 2.8±0.8±0.3 | | → I(45) | $2.10 {}^{+ 0.67}_{- 0.55} {}^{+ 0.77}_{- 0.46}$ | 1,4 AUBERT | 07AV BABR Repl. by AU | BERT 08BN |
| ¹ Assumes equal production of 2 MEDVEDEVA 07 reports (2 | f B^{\pm} and B^{0} at the $\varUpsilon(4S)$. $9\pm0.7\pm0.5\pm0.4)\!	imes\!10^{-5}$ from a measurem | ent of $\Gamma(B^0 \rightarrow$ | | | 02 CLE2 $e^+e^- \rightarrow 1$ | |
| | $\rightarrow \phi \pi^+)$] assuming B($D_s^+ \rightarrow \phi \pi^+$) = (4.4) | | | | 02 BELL $e^+e^- \rightarrow 1$ | . , |
| which we rescale to our bes | t value B($D_c^+ \rightarrow \phi \pi^+$) = (4.5 ± 0.4) × 1 | .0 ^{−2} . Our first | · · | | 97 CLE2 $e^+e^- \rightarrow 1$ | (45) |
| error is their experiment's e | t value B($D_S^+	o\phi\pi^+)=(4.5\pm0.4)	imes 1$ rror and our second error is the systematic ϵ | error from using | | ction of B^+ and B^0 at the s $(1.89 \pm 0.21 \pm 0.49) \times 1$ | : $\varUpsilon(4S)$. 10^{-5} from a measurement | of [F (R 0 - |
| our best value. | | | | | g B($\Lambda_c^+ \rightarrow p K^- \pi^+$) = (| |
| Γ(<u>D</u> *(2007) ⁰ ρ̄)/Γ _{total} | | Γ ₄₀₁ /Γ | 310 ⁻² | . /1 | | , . |
| /ALUE (units 10 ⁻⁴) | DOCUMENT ID TECN COMMEN | T | The second error for | GABYSHEV 03 includes | the systematic and the en | for of Λ_C – |
| 1.01±0.10±0.09 | 1 AUBERT,B 06s BABR $e^{+}e^{-}$ – | $\rightarrow \Upsilon(4S)$ | pre n accay branc | ning fraction. $\rightarrow p K^- \pi^+$ branching ra | | |
| $1.20 + 0.33 \pm 0.21$ | 1 ABE 02W BELL $e^{+}e^{-}$ – | . , | | | $^{+}\pi^{-})=5.0\pm1.3\%$. The | second erro |
| 1 Assumes equal production of | | , | includes the systemati | ic and the uncertainty of tl | he branching ratio. | |
| | TB: and B at the T(43). | | YFU 97 uses PDG 96 V | alues of Λ_C branching ratio | 0. | |
| $\Gamma(D^*(2010)^- \rho \overline{n})/\Gamma_{\text{total}}$ | | Γ ₄₀₂ /Γ | $\Gamma(\overline{\Lambda}_c^- ho \pi^0)/\Gamma_{ m total}$ | | | Γ ₄₁₀ /Ι |
| /ALUE (units 10 ⁻⁴) | DOCUMENT ID TECN COMMEN | | VALUE (units 10^{-4}) | CL% DO CUMENT ID | TECN COMMENT | |
| $14.5 + \frac{3.4}{3.0} \pm 2.7$ | | → Υ(4S) | $1.9 \pm 0.2 \pm 0.5$ | 1,2 AUBERT | 10. DADD 1 - | $\Upsilon(AC)$ |
| -3.0 +2.7 | 1 ANDERSON 01 CLE2 $e^{+}e^{-}$ - | | | 6.00 1 4.1 6 | 10H BABR $e^+e^- \rightarrow$ | 1 (43) |
| ¹ Assumes equal production c | | | • • • We do not use the | following data for average | s, fits, limits, etc. • • • | , |
| ¹ Assumes equal production of | | Γ403/Γ | • • • We do not use the <5.9 | 90 ³ FU | s, fits, limits, etc. \bullet \bullet \bullet 97 CLE2 $e^+e^- \rightarrow$ | Υ(4S) |
| •.• | f \mathcal{B}^+ and \mathcal{B}^0 at the \varUpsilon (45). | Γ ₄₀₃ /Γ | \bullet \bullet We do not use the $<$ 5.9 1 AUBERT 10H reports | 90 3 FU $(1.94\pm0.17\pm0.52)	imes 1$ | s, fits, limits, etc. $ullet$ $ullet$ 97 CLE2 $e^+e^- ightarrow 0^{-4}$ from a measurement | $\Upsilon(4S)$ of $[\Gamma(B^0-$ |
| 1 Assumes equal production of $(D^{-} p \overline{p} \pi^{+})/\Gamma_{	ext{total}}$ | f \mathcal{B}^+ and \mathcal{B}^0 at the \varUpsilon (45). | T | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_C^- p \pi^0 / \Gamma_{\text{total}} \times [$ | 90 3 FU $(1.94\pm0.17\pm0.52)	imes 1$ | s, fits, limits, etc. \bullet \bullet \bullet 97 CLE2 $e^+e^- \rightarrow$ | $\Upsilon(4S)$ of $[\Gamma(B^0-$ |
| 1 Assumes equal production of $(D^{-} \rho \overline{\rho} \pi^{+})/\Gamma_{	ext{total}}$ | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{_{DOCUMENT\ ID}}{^1\ \text{AUBERT}, \text{B}} \begin{array}{ccc} & \underline{^{TECN}} & \underline{^{COMMEN}} \\ & & & \\ \end{array}$ | T | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\text{total}}] \times [$ 1.3) \times 10 ⁻² . ² Assumes equal produc | 90 3 FU $(1.94\pm0.17\pm0.52)\times 1$ $\mathbb{B}(\Lambda_C^+\to\rhoK^-\pi^+)]$ ass tion of B^+ and B^0 at the | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$ 0^{-4} from a measurement uming B($\Lambda_C^+ \rightarrow \rho K^- \pi^-$ | $\Upsilon(4S)$ of $[\Gamma(B^0-$ |
| Assumes equal production of $(D^-p\overline{p}\pi^+)/\Gamma_{total}$ ALUE (units 10^{-4}) 3.38±0.14±0.29 | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{68} \qquad \frac{COMMEN}{8BABR} \qquad e^+e^ G^-$ of B^+ and B^0 at the $\Upsilon(4S)$. | $T \rightarrow \Upsilon(4S)$ | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\text{total}}] \times [$ 1.3) \times 10 ⁻² . ² Assumes equal produc | 90 3 FU $_{(1.94~\pm~0.17~\pm~0.5~2)~\times~1}$ B($\Lambda_{c}^{+}~\rightarrow~\rho~K^{-}\pi^{+}$)] ass | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$ 0^{-4} from a measurement uming B($\Lambda_C^+ \rightarrow \rho K^- \pi^-$ | $\Upsilon(4S)$ of $[\Gamma(B^0-$ |
| Assumes equal production of $(D^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ $ALUE$ (units 10^{-4}) 3.38±0.14±0.29 Assumes equal production of $(D^*(2010)^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ | if B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{06S} \qquad \frac{COMMEN}{BABR} \qquad e^+e^ G^-$ if B^+ and B^0 at the $\Upsilon(4S)$. | $rac{T}{T} \rightarrow r(4S)$ | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\rm total}] \times [1.3) \times 10^{-2}.$ ² Assumes equal produc ³ FU 97 uses PDG 96 v | 90 3 FU $(1.94\pm0.17\pm0.52)\times 1$ $\mathrm{B}(\Lambda_c^+\to pK^-\pi^+)]$ ass tion of B^+ and B^0 at the alues of Λ_C branching ratio | s, fits, limits, etc. \bullet \bullet \bullet 97 CLE2 $e^+e^- \rightarrow 0^{-4}$ from a measurement uming $\mathrm{B}(\Lambda_c^+ \rightarrow pK^-\pi^-)$ $\Upsilon(4S)$. | $\Upsilon(4S)$ of $[\Gamma(B^0 - 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.$ |
| Assumes equal production of $\Gamma(D^-\rho \overline{p}\pi^+)/\Gamma_{\text{total}}$ (ALUE (units 10^{-4}) 3.38±0.14±0.29 1 Assumes equal production of $\Gamma(D^*(2010)^-\rho \overline{p}\pi^+)/\Gamma_{\text{total}}$ (ALUE (units 10^{-4}) 5.0 ±0.5 OUR AVERAGE | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{6S} \qquad \frac{COMMEN}{6}$ f B^+ and B^0 at the $\Upsilon(4S)$. | 7 γ (45) Γ ₄₀₄ /Γ | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\text{total}}] \times [$ 1.3) \times 10 ⁻² . ² Assumes equal produc | 90 3 FU $(1.94\pm0.17\pm0.52)\times 1$ $\mathrm{B}(\Lambda_c^+\to pK^-\pi^+)]$ ass tion of B^+ and B^0 at the alues of Λ_C branching ratio | s, fits, limits, etc. \bullet \bullet \bullet 97 CLE2 $e^+e^- \rightarrow 0^{-4}$ from a measurement uming $\mathrm{B}(\Lambda_c^+ \rightarrow pK^-\pi^-)$ $\Upsilon(4S)$. | $\Upsilon(4S)$ of $[\Gamma(B^0 - 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.0 \pm 5.$ |
| 1 Assumes equal production of $\Gamma(D^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ $\frac{(ALUE (units 10^{-4})}{3.38\pm0.14\pm0.29}$ 1 Assumes equal production of $\Gamma(D^*(2010)^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ $\frac{(ALUE (units 10^{-4})}{3.0\pm0.5}$ 0.0 ±0.5 OUR AVERAGE $\frac{1}{3.81\pm0.22\pm0.44}$ | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{6B} \qquad \frac{COMMEN}{e^+e^-} - \frac{1}{6B}$ If B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{6B} \qquad \frac{COMMEN}{6B}$ | $ \begin{array}{ccc} & & & & & \\ & & & & & \\ & & & & & \\ & & & &$ | • • • We do not use the <5.9 ¹ AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\text{total}}] \times [1.3) \times 10^{-2}.$ ² Assumes equal produc 3 FU 97 uses PDG 96 v $\Gamma(\Sigma_c(2455)^- \rho)/\Gamma_{\text{total}}$ **MLUE (units 10^-6)* <30 | 90 3 FU $ (1.94 \pm 0.17 \pm 0.52) \times 1 \\ B(\Lambda_c^+ \to p K^- \pi^+)] \text{ ass} $ tion of B^+ and B^0 at the values of Λ_C branching ratio $ \frac{B}{A} = \frac{DOCUMENT ID}{A A} $ $\frac{DOCUMENT ID}{A A} $ | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$.0 ⁻⁴ from a measurement uming $B(\Lambda_C^+ \rightarrow pK^-\pi^-)$. $\Upsilon(45)$. 0. $\frac{TECN}{10H} \frac{TECN}{BABR} \frac{COMMENT}{e^+e^- \rightarrow}$ | $\Upsilon(4S)$ of $[\Gamma(B^0 - 1)]$ \uparrow $= (5.0 \pm 1)$ \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow |
| Assumes equal production of $\Gamma(D^-\rho \overline{p}\pi^+)/\Gamma_{\text{total}}$ (ALUE (units 10^{-4}) 3.38±0.14±0.29 1 Assumes equal production of $\Gamma(D^*(2010)^-\rho \overline{p}\pi^+)/\Gamma_{\text{total}}$ (ALUE (units 10^{-4}) 5.0 ±0.5 OUR AVERAGE | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad \frac{TECN}{6S} \qquad \frac{COMMEN}{6}$ f B^+ and B^0 at the $\Upsilon(4S)$. | $ \begin{array}{ccc} & & & & & \\ & & & & & \\ & & & & & \\ & & & &$ | • • • We do not use the <5.9 $1 \text{ AUBERT 10H reports}$ $\overline{\Lambda}_c^- \rho \pi^0)/\Gamma_{\text{total}}] \times [1.3) \times 10^{-2}.$ $2 \text{ Assumes equal produc}$ $3 \text{ FU 97 uses PDG 96 v}$ $\Gamma(\Sigma_c(2455)^- \rho)/\Gamma_{\text{total}}$ $\frac{1}{2} \text{ AUBERT 10H reports}$ | 90 3 FU $(1.94 \pm 0.17 \pm 0.52) \times 1$ $B(\Lambda_c^+ \to p K^- \pi^+)] \text{ ass}$ $\text{ation of } B^+ \text{ and } B^0 \text{ at the alues of } \Lambda_C \text{ branching ratio}$ $\frac{\text{al}}{1.2 \text{ AUBERT}}$ $\text{5} [\Gamma(B^0 \to \Sigma_C (2455)^- p)]$ | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$.0 ⁻⁴ from a measurement uming $B(\Lambda_C^+ \rightarrow pK^-\pi^-)$. $\Upsilon(45)$. o. $\frac{TECN}{10H} \frac{COMMENT}{BABR} \frac{COMMENT}{e^+e^- \rightarrow}$.)/ Γ_{total}] $\times [B(\Lambda_C^+ \rightarrow pK^-)]$ | $T(4S)$ of $[\Gamma(B^0 - 1)]$ $T(4S)$ $T(4S)$ |
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| Assumes equal production of $\Gamma(D^-p\bar{p}\pi^+)/\Gamma_{\text{total}}$ $ALUE (units 10^{-4})$ $A.3.38 \pm 0.14 \pm 0.29$ Assumes equal production of $\Gamma(D^*(2010)^-p\bar{p}\pi^+)/\Gamma_{\text{total}}$ $ALUE (units 10^{-4})$ $ALUE (units 10^{-4})$ $ALUE (units 10^{-4})$ $ALUE (units 10^{-4})$ $ASsumes equal production of \Gamma(D^*(2010)^-p\bar{p}\pi^+)/\Gamma_{\text{total}} ASSUMES equal production of \Gamma(D^-p\bar{p}\pi^+)/\Gamma_{\text{total}} | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} = 06S BABR e^+e^ 6$ f B^+ and B^0 at the $\Upsilon(4S)$. II $\frac{DOCUMENT\ ID}{1\ AUBERT,B} = 06S BABR e^+e^ 6$ f B^+ and B^0 at the $T(4S)$. D))/ Γ total $\frac{DOCUMENT\ ID}{1\ AUBERT,B} = 06S BABR e^+e^ 6$ f B^+ and B^0 at the $T(4S)$. P))/ Γ total $\frac{DOCUMENT\ ID}{1\ AUBERT,B} = 06S BABR e^+e^ 6$ f B^+ and B^0 at the $T(4S)$. P)/ Γ total $\frac{DOCUMENT\ ID}{1\ AUBERT,B} = 06S BABR e^+e^ 6$ f B^+ and B^0 at the $T(4S)$. | $ \begin{array}{ccc} & & & & & & & & & & & & & & & & & & &$ | • • • We do not use the <5.9 1 AUBERT 10H reports $\overline{\mathcal{T}_c} \rho \pi^0$)/ Γ_{total}] × [1.3) × 10 ⁻² . 2 Assumes equal produc 3 FU 97 uses PDG 96 v $\Gamma(\Sigma_c(2455)^- \rho)/\Gamma_{\text{total}}$ $\frac{VALUE}{\sqrt{30}}$ 1 AUBERT 10H reports 1.5 × 10 ⁻⁶ which we 2 Assumes equal produc $\Gamma(\overline{\mathcal{T}_c} \rho \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\mathcal{T}_c} \rho \pi^+ \pi^- \pi^+ \pi^-)$ $\frac{VALUE}{\sqrt{30}}$ 2.74 × 10 ⁻³ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\mathcal{T}_c} \rho \pi^+ \pi^-)/\Gamma_{\text{total}}$ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\mathcal{T}_c} \rho \pi^+ \pi^-)/\Gamma_{\text{total}}$ 1 FU 97 uses PDG 96 v | 90 3 FU $(1.94 \pm 0.17 \pm 0.52) \times 1$ $B(\Lambda_c^+ \to p K^- \pi^+)]$ assistion of B^+ and B^0 at the alues of Λ_C branching ratio 1.2 $\frac{DOCUMENT ID}{AUBERT}$ 1.2 $\frac{AUBERT}{AUBERT}$ divide by our best value B strong of B^+ and B^0 at the $\frac{AUBERT}{AUBERT}$ $\frac{DOCUMENT ID}{AUBERT}$ | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$.0 ⁻⁴ from a measurement uming $B(\Lambda_C^+ \rightarrow pK^-\pi^-)$. $\Upsilon(45)$. 5. 10H BABR $e^+e^- \rightarrow$.)/ Γ_{total}] \times [$B(\Lambda_C^+ \rightarrow pK^-\pi^+)$. $\Upsilon(45)$. 7 CLE2 $e^+e^- \rightarrow$. $\Upsilon(45)$. | $T(4S)$ of $[\Gamma(B^0 - K^0)]$ $T(4S)$ |
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| Assumes equal production of $\Gamma(D^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ ALUE (units 10^{-4}) 1 Assumes equal production of $\Gamma(D^*(2010)^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ 3.38 ± 0.14 ± 0.29 1 Assumes equal production of $\Gamma(D^*(2010)^-p\overline{p}\pi^+)/\Gamma_{\text{total}}$ 3.0 ± 0.5 OUR AVERAGE 1.81 ± 0.22 ± 0.44 5.5 ± 1.3 ± 1.0 1 Assumes equal production of $\Gamma(D^*(p\overline{p}\pi^+) \times B(D^*(p^-p^-p^-p^-p^-p^-p^-p^-p^-p^-p^-p^-p^-p$ | f B^+ and B^0 at the $\Upsilon(4S)$. $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad 06S BABR e^+e^- = 6$ f B^+ and B^0 at the $\Upsilon(4S)$. II $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad 06S BABR e^+e^- = 6$ $1\ ANDERSON \qquad 01 \qquad CLE2 \qquad e^+e^- = 6$ f B^+ and B^0 at the $\Upsilon(4S)$. D))/\(\Gamma_1\) Total $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad 06S BABR e^+e^- = 6$ f B^+ and B^0 at the $\Upsilon(4S)$. P))/\(\Gamma_1\) Total $\frac{DOCUMENT\ ID}{1\ AUBERT,B} \qquad 06S BABR e^+e^- = 6$ f B^+ and B^0 at the $T(4S)$. DOCUMENT \(ID \) 1 AUBERT,B 06S BABR e^+e^- = 6 f B^+ and B^0 at the $T(4S)$. DOCUMENT \(ID \) 1 PROCARIO 94 CLE2 e^+e^- = 6 0012 from a measurement of \([\Gamma_1\((B^0 \to \mathbb{\Sigma_2} \)] Suming \(B(A_c^+ \to \rho K^- \pi^+) = 0.043, whice | $ \begin{array}{ccc} & & & & & & & & & & & & & & & & & & &$ | • • • We do not use the <5.9 1 AUBERT 10H reports $\overline{\Lambda}_c^- \rho \pi^0$)/ Γ_{total}] × [1.3) × 10 ⁻² . 2 Assumes equal produc 3 FU 97 uses PDG 96 v $\Gamma(\Sigma_c(2455)^- \rho)/\Gamma_{\text{total}}$ **AUBERT 10H reports 1.5 × 10 ⁻⁶ which we 2 Assumes equal produc $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ **IFU 97 uses PDG 96 v $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^- \pi^+ \pi^-)$ **ALUE** **2.74 × 10 ⁻³ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^- \pi^+ \pi^-)$ **ALUE** **2.74 × 10 ⁻³ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^-)/\Gamma_{\text{total}}$ **ALUE** **2.74 × 10 ⁻³ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^-)/\Gamma_{\text{total}}$ **ALUE** **2.74 × 10 ⁻³ 1 FU 97 uses PDG 96 v $\Gamma(\overline{\Lambda}_c^- \rho \pi^+ \pi^-)/\Gamma_{\text{total}}$ **ALUE** **2.74 × 10 ⁻³ 1 Assumes equal produc 2 PARK 07 reports (1 | 90 3 FU $(1.94 \pm 0.17 \pm 0.52) \times 1$ $B(\Lambda_c^+ \to p K^- \pi^+)]$ assistion of B^+ and B^0 at the values of Λ_c branching ratio A_c branching ratio | s, fits, limits, etc. $\bullet \bullet \bullet$ 97 CLE2 $e^+e^- \rightarrow$.0 ⁻⁴ from a measurement uming $B(\Lambda_c^+ \rightarrow pK^-\pi^-)$. $\Upsilon(45)$. o. $\frac{TECN}{10H} \frac{COMMENT}{BABR} \frac{COMMENT}{e^+e^- \rightarrow}$.) $/\Gamma_{\text{Total}}] \times [B(\Lambda_c^+ \rightarrow pK^-\pi^+) = 5.0$. $\Upsilon(45)$. $\frac{TECN}{97} \frac{COMMENT}{CLE2} \frac{COMMENT}{e^+e^- \rightarrow}$ o. $\frac{TECN}{97} \frac{COMMENT}{CLE2} \frac{COMMENT}{e^+e^- \rightarrow}$ o. | $T(4S)$ of $[\Gamma(B^0 - 1)]$ $T(4S)$ |

 Γ_{427}/Γ

08H BABR $e^+e^- \rightarrow \Upsilon(4S)$

06A BELL $e^+e^- \rightarrow \Upsilon(4S)$

| $\Gamma(\overline{\Lambda}_c^- p \pi^+ \pi^- \text{(nonres)})$ | · · · · · · · · · · · · · · · · · · · |
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| VALUE (units 10 ⁻⁴) | DOCUMENT ID TECN COMMENT |
| 5.4 ± 0.4 ± 1.9 | 1,2 PARK 07 BELL $e^+e^- ightarrow \varUpsilon(45)$ ction of B^+ and B^0 at the $\varUpsilon(45)$. |
| | 6.4 \pm 0.4 \pm 1.9) \times 10 ⁻⁴ from a measurement of [$\Gamma(B^0$ – |
| | $[B(\Lambda_C^+ \to pK^-\pi^+)]$ assuming $B(\Lambda_C^+ \to pK^-\pi^+)$ |
| $pK^{-}\pi^{+}) = (5.0 \pm$ | |
| $(\overline{\Sigma}_c(2520)^{}\rho\pi^+)$ |)/F _{total} F ₄₁₆ /I |
| /ALUE (units 10 ⁻⁴) | DOCUMENT ID TECN COMMENT |
| .2±0.1±0.4 | $1.2 \overline{PARK}$ 07 \overline{BELL} $e^+ e^- 	o 	 \varUpsilon(4S)$ |
| | e following data for averages, fits, limits, etc. • • • |
| .6 ± 0.6 ± 0.4 | 3 GABYSHEV 02 BELL Repl. by PARK 07 |
| | ction of B^+ and B^0 at the $\Upsilon(4S)$. 1.2 \pm 0.1 \pm 0.4) $	imes$ 10 $^{-4}$ from a measurement of [$\Gamma(B^0$ $-$ |
| | $\Gamma_{\text{total}} \times [B(\Lambda_c^+ \to p K^- \pi^+)] \text{ assuming } B(\Lambda_c^+ \to p K^- \pi^+)$ |
| $= (5.0 \pm 1.3) \times 10^{-1}$ | ·2 _. |
| ³ GABYSHEV 02 rep | orts $(1.63 {+ 0.64 \atop - 0.58}) 	imes 10^{-4}$ from a measurement of $[\Gamma(B^0 ightharpoonup]$ |
| $\overline{\Sigma}_{c}(2520)^{}\rho\pi^{+})$ | $[\Gamma_{total}] \times [B(\Lambda_c^+ \to p K^- \pi^+)]$ assuming $B(\Lambda_c^+ \to p K^- \pi^+)$ |
| = 0.05, which we res | scale to our best value B($\Lambda_c^+ 	o p K^- \pi^+$) = $(5.0 \pm 1.3) 	imes 10^{-2}$ cir experiment's error and our second error is the systematic error |
| from using our best v | |
| $(\Sigma_c(2520)^0 p\pi^-)/$ | Γ _{total} Γ ₄₁₇ /Γ |
| ALUE | <u>CL%</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| <0.38 × 10 ⁻⁴ | 90 1 PARK 07 BELL $e^+e^- 	o 	au(4S)$ |
| • • vve do not use the $<1.21 \times 10^{-4}$ | e following data for averages, fits, limits, etc. • • • 90 ^{1,2} GABYSHEV 02 BELL Repl. by PARK 07 |
| | ction of B^+ and B^0 at the $\Upsilon(4S)$. |
| | ction of B and B at the 1 (45). |
| ² Uses the value for Λ_{ℓ} | $_{2} \rightarrow pK^{-}\pi^{+}$ branching ratio (5.0 \pm 1.3)%. |
| 2 Uses the value for Λ_c | $\varepsilon \to \rho K^- \pi^+$ branching ratio (5.0 ± 1.3)%. |
| ² Uses the value for Λ_c $(\Sigma_c (2455)^0 N^0 \times B)$ | $(N^0 	o p\pi^-))/\Gamma_{\text{total}}$ $\Gamma_{419}/\Gamma_{419}$ |
| ² Uses the value for Λ_c $(\Sigma_c (2455)^0 N^0 \times B)$ N^0 is the $N(1440)$ | $(N^0 	o p\pi^-))/\Gamma_{ m total}$ $\Gamma_{ m 419}/\Gamma_{ m P_{11}}$ or $N(1535)~S_{ m 11}$ or an admixture of the two baryonic states. |
| Uses the value for Λ_c $(\sum_{c} (2455)^0 N^0 \times B$ $N^0 \text{ is the } N(1440)$ $NLUE \text{ (units } 10^{-4})$ | $(N^0 	o p\pi^-))/\Gamma_{\text{total}}$ $\Gamma_{419}/\Gamma_{419}$ |
| ² Uses the value for Λ_{c} $(\Sigma_{c}(2455)^{0} N^{0} \times B)$ N^{0} is the $N(1440)$ $N^{0} \times 10^{-4}$ $N^{0} \times 10^{-4}$ | $(N^0 ightarrow p\pi^-))/\Gamma_{	ext{total}}$ $\Gamma_{	ext{419}}/\Gamma_{	ext{419}}/\Gamma_{	ext{11}}$ or an admixture of the two baryonic states. $\frac{DOCUMENT\ ID}{1.2\ KI\ M}$ $\frac{TECN}{08}$ $\frac{COMMENT}{e^+e^- ightarrow r(4S)}$ ction of B^+ and B^0 at the $r(4S)$. |
| ² Uses the value for Λ_c $(\Sigma_c(2455)^0 N^0 \times B$ N^0 is the $N(1440)$ $MLUE$ (units 10^{-4}) $1.80\pm0.15\pm0.25$ ¹ Assumes equal produce $1.80\pm0.15\pm0.25$ ² KIM 08 reports (0. | $(N^0 	o p\pi^-))/\Gamma_{	ext{total}}$ $\Gamma_{	ext{419}}/\Gamma_{	ext{419}}$ P_{11} or $N(1535)$ S_{11} or an admixture of the two baryonic states. $\begin{array}{c} DOCUMENT\ ID \\ \hline 1.2\ KIM \\ \end{array}$ 08 BELL $\begin{array}{c} COMMENT \\ e^+e^- \\ \hline \end{array}$ $T(45)$ ction of B^+ and B^0 at the $T(45)$. 80 \pm 0.15 \pm 0.25) \times 10 ⁻⁴ from a measurement of $\Gamma(B^0 	o \pi^-)$ |
| ² Uses the value for Λ_c : $(\Sigma_c(2455)^0 N^0 \times B N^0$ is the $N(1440)$ $MLUE$ (units 10^{-4}). $80\pm0.15\pm0.25$ ¹ Assumes equal produce $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ 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$10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ $10\pm0.15\pm0.25$ | $ \begin{array}{c c} (\textbf{N}^{\textbf{0}} \rightarrow \textbf{p} \pi^{-}))/\Gamma_{\textbf{total}} & 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| ² Uses the value for Λ_c (Σ_c (2455) 0 $N^0 \times B$ N^0 is the N (1440) ALUE (units 10 ⁻⁴) .80±0.15±0.25 ¹ Assumes equal produ ² KIM 08 reports (0. Σ_c (2455) 0 $N^0 \times B$ (I I I I I I I I I I | $ \begin{array}{c} (N^0 \to p\pi^-))/\Gamma_{\rm total} & \Gamma_{419}/\Gamma_{\rm P11} \text{ or } N(1535) \ S_{11} \text{ or an admixture of the two baryonic states.} \\ \hline P_{11} \text{ or } N(1535) \ S_{11} \text{ or an admixture of the two baryonic states.} \\ \hline P_{12} \text{ KIM} & 08 & \text{BELL} & \frac{COMMENT}{e^+e^- \to T(4S)} \\ \hline S_{12} \text{ KIM} & 08 & \text{BELL} & \frac{e^+e^- \to T(4S)}{e^+e^- \to T(4S)} \\ \hline S_{13} \text{ or } 0.15 \pm 0.25) \times 10^{-4} \text{ from a measurement of } [\Gamma(B^0 \to V^0 \to p\pi^-))/\Gamma_{\rm total}] \times [B(\Lambda_c^+ \to pK^-\pi^+)] \text{ assuming } B(\Lambda_c^+ \to I^0) \\ \hline S_{13} \text{ or } 1.2 \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{148}/\Gamma_0 \text{ or } I^0 \text{ park} \\ \hline S_{148}/\Gamma_0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} \\ \hline S_{15} \text{ park} & \text{or } I^0 \text{ park} \\ \hline S_{15} \text{ park} & $ |
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| ² Uses the value for Λ_c ($\Sigma_c(2455)^0 N^0 \times B$ N^0 is the $N(1440)$ N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the | $ \begin{array}{c} (N^0 \to p\pi^-))/\Gamma_{\rm total} & \Gamma_{419}/\Gamma_{\rm P11} & N(1535) \ S_{11} \ {\rm or} \ {\rm an \ admixture \ of \ the \ two \ baryonic \ states.} \\ \hline N(1535) \ S_{11} \ {\rm or \ an \ admixture \ of \ the \ two \ baryonic \ states.} \\ \hline N(1535) \ S_{11} \ {\rm or \ an \ admixture \ of \ the \ two \ baryonic \ states.} \\ \hline N(1535) \ S_{11} \ {\rm or \ an \ ameasurement \ of \ } \\ \hline N(1535) \ S_{11} \ {\rm or \ and \ } BELL \ e^+e^- \to T(4S) \\ \hline N(1535) \ S_{11} \ {\rm or \ } S_{11} \ {\rm or \ } S_{12} \ {\rm or \ } S_{11} \ {\rm or \ } S_{12} \ {\rm or \ } S_{12} \ {\rm or \ } S_{13} |
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| ² Uses the value for Λ_{c} : $(\Sigma_{c}(2455)^{0}N^{0} \times B N^{0})$ is the $N(1440)$ N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is the N^{0} is | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 2 Uses the value for Λ_{c} (Σ_{c} (2455) 0 N^{0} × B N^{0} is the N (1440) N^{0} LIVE (units 10-4) 1.80±0.15±0.25 1 Assumes equal production of Σ_{c} (2455) 0 N^{0} × B(I_{p} K^{-} π^{+}) = (5.0 ± $\frac{1}{2}$ Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} | $ \begin{array}{c} (\textbf{N^0} \rightarrow \textbf{p}\pi^-))/\Gamma_{\textbf{total}} & \Gamma_{\textbf{419}}/\Gamma_{\textbf{P}1} \\ P_{11} \text{ or } N(1535) \ S_{11} \text{ or an admixture of the two baryonic states.} \\ \hline P_{12} \text{ or } N(1535) \ S_{11} \text{ or an admixture of the two baryonic states.} \\ \hline P_{12} \text{ KIM} & 08 & \text{BELL} & e^+e^- \rightarrow r(4S) \\ \hline P_{13} \text{ or } 1.2 \text{ KIM} & 08 & \text{BELL} & e^+e^- \rightarrow r(4S) \\ \hline S_{10} \pm 0.15 \pm 0.25) \times 10^{-4} \text{ from a measurement of } [\Gamma(B^0 \rightarrow V^0 \rightarrow p\pi^-))/\Gamma_{\textbf{total}}] \times [B(\Lambda_C^+ \rightarrow pK^-\pi^+)] \text{ assuming } B(\Lambda_C^+ \rightarrow I^-) \\ \hline P_{13} \times 10^{-2}. & \hline P_{13} \text{ assuming } I^- \\ \hline P_{148}/\Gamma_{13} & \hline P_{148}/\Gamma_{13} \\ \hline P_{15} \text{ pARK} & 07 & \text{BELL} & e^+e^- \rightarrow r(4S) \\ \hline S_{15} \text{ pOCUMENT } ID & \underline{TECN} & \underline{COMMENT} \\ \hline P_{15} \text{ pARK} & 07 & \underline{BELL} & e^+e^- \rightarrow r(4S) \\ \hline P_{15} \text{ as DYTMAN} & 02 & \underline{CLE2} & e^+e^- \rightarrow r(4S) \\ \hline P_{15} \text{ as DYTMAN} & 02 & \underline{CLE2} & e^+e^- \rightarrow r(4S) \\ \hline P_{15} \text{ as Initial states} & \underline{P}_{15} \text{ as Initial states} \\ \hline P_{15} \text{ pARK} & 07 & \underline{BELL} & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{BELL} & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{BELL} & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 & \underline{P}_{15} \text{ pARK} & 07 \\ \hline P_{15} \text{ pARK} & 07 $ |
| 2 Uses the value for Λ_{c} (Σ_{c} (2455) 0 N^{0} × B N^{0} is the N (1440) N^{0} LIVE (units 10-4) 1.80±0.15±0.25 1 Assumes equal production of Σ_{c} (2455) 0 N^{0} × B(I_{p} K^{-} π^{+}) = (5.0 ± $\frac{1}{2}$ Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} (2455) $\frac{1}{2}$ Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} (2455) Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} Σ_{c} | $ \begin{array}{c} (\textbf{N}^{0} \rightarrow \textbf{p}\pi^{-}))/\Gamma_{\text{total}} & \Gamma_{\textbf{419}}/\Gamma_{\textbf{P}1} & \Gamma_{\textbf{V}19}/\Gamma_{\textbf{I}} & \Gamma_{\textbf{V}19}/\Gamma_{\textbf{I}} & \Gamma_{\textbf{I}} |
| 2 Uses the value for Λ_{c} $(\sum_{c} (2455)^{0} N^{0} \times B N^{0} \text{ is the } N(1440) \times LUE \text{ (units }10^{-4})$ 1.80±0.15±0.25 1 Assumes equal production of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of th | $ (N^0 \to p\pi^-))/\Gamma_{\rm total} \qquad \qquad \Gamma_{419}/\Gamma_{\rm P11} = N(1535) S_{11} {\rm or} {\rm an \ admixture \ of \ the \ two \ baryonic \ states.} $ $ \frac{DOCUMENT ID}{1.2 {\rm KIM}} \qquad 08 \qquad {\rm BELL} \qquad \frac{COMMENT}{e^+e^- \to r(4S)} $ $ 80 \pm 0.15 \pm 0.25) \times 10^{-4} {\rm from \ ameasurement \ of \ } [\Gamma(B^0 \to V^0 \to p\pi^-))/\Gamma_{\rm total}] \times [B(\Lambda_c^+ \to p K^-\pi^+)] {\rm assuming \ } B(\Lambda_c^+ \to I^0) {\rm assum$ |
| ² Uses the value for Λ_c ($\Sigma_c(2455)^0$ $N^0 \times B$ N^0 is the $N(1440)$ N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 in N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 in N^0 is the N^0 is the N^0 in N^0 is the N^0 in N^0 is the N^0 in N^0 in N^0 is the N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in N^0 in | $ (N^0 \to p\pi^-))/\Gamma_{\rm total} \qquad \qquad \Gamma_{419}/\Gamma_{\rm P11} \text{ or } N(1535) \ S_{11} \text{ or an admixture of the two baryonic states.} $ $ \frac{DOCUMENT ID}{1.2 \text{ KIM}} \qquad 08 \qquad \text{BELL} \qquad e^+e^- \to T(4S) $ ction of B^+ and B^0 at the $T(4S)$. $80 \pm 0.15 \pm 0.25) \times 10^{-4}$ from a measurement of $[\Gamma(B^0 \to V^0 \to p\pi^-))/\Gamma_{\rm total}] \times [B(\Lambda_C^+ \to pK^-\pi^+)]$ assuming $B(\Lambda_C^+ \to 1.3) \times 10^{-2}$. $ \frac{CMMENT ID}{1.2 \text{ PARK}} \qquad 07 \qquad \text{BELL} \qquad e^+e^- \to T(4S) $ e following data for averages, fits, limits, etc. ••• • • • • • • • • • • • • • • • • • |
| ² Uses the value for Λ_c $(\Sigma_c(2455)^0 N^0 \times B N^0)$ is the $N(1440)$ N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the form using our best N^0 is the N^0 is the form using our best N^0 is the N^0 is the N^0 is the form using our best N^0 is the N^0 is the N^0 is the form using our best N^0 is the N^0 is the N^0 is the form using our best N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the form using our best N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the | $ \begin{array}{c} (N^0 \to p\pi^-))/\Gamma_{\rm total} & \Gamma_{419}/\Gamma_{\rm P11} & N(1535) S_{11} {\rm or} {\rm an admixture of the two baryonic states.} \\ \hline P_{11} & ON(1535) S_{11} {\rm or} {\rm an admixture of the two baryonic states.} \\ \hline P_{12} & N(1535) S_{11} {\rm or} {\rm an admixture of the two baryonic states.} \\ \hline P_{12} & N(100) & ELL & e^+e^- \to T(4S) \\ \hline S_0 & \pm 0.15 \pm 0.25) \times 10^{-4} {\rm from a measurement of } [\Gamma(B^0 \to V^0 \to p\pi^-))/\Gamma_{\rm total}] \times [B(\Lambda_C^+ \to pK^-\pi^+)] {\rm assuming B}(\Lambda_C^+ \to I^0) \\ \hline P_{13} & N(10^{-2}) & I & I & I \\ \hline I_{13} & I & I & I \\ \hline I_{13} & I & I & I \\ \hline I_{13} & I & I & I \\ \hline I_{13} & I & I & I \\ \hline I_{14} & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & I & I \\ \hline I_{15} & $ |
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| 2 Uses the value for Λ_c ($\Sigma_c(2455)^0$ $N^0 \times B$ N^0 is the $N(1440)$ N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N^0 is the N | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 2 Uses the value for Λ_{c} (Σ_{c} (2455) 0 N^{0} × B N^{0} is the N (1440) 0 LUE (units 10-4) 1 LOB 0.15 ± 0.25 1 Assumes equal production 2 KIM 08 reports (0. Σ_{c} (2455) 0 N^{0} × B(I $pK^{-}\pi^{+}$) = (5.0 ± 1 (Σ_{c} (2455) 0 $p\pi^{-}$)/ 1 LUE (units 10-4) 1 .5±0.5 OUR AVERAGE 1 4±0.2±0.4 1 .0±0.4 1 Assumes equal production 2 PARK 07 reports (Σ_{c} (2455) 0 $p\pi^{-}$)/ 1 (5.0 ± 1.3) × 10-2 2 .3 DYTMAN 02 reports (1.3 ± 0.5 × 1.3 × 10-2 2 .005, which we rescand Our first error is the from using our best 1 4 GABYSHEV 02 reports (2455) 0 $p\pi^{-}$)/ 1 1 0.05, which we rescand Our first error is the from using our best 1 (Σ_{c} (2455) 0 $p\pi^{-}$)/ 1 1 0.05, which we rescand Our first error is the from using our best 1 (Σ_{c} (2455) $^{-}$ $p\pi^{+}$) 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

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^1 Assumes equal production of B^+ and B^0 at the \varUpsilon(45). ^2 PARK 07 reports (2.1 \pm 0.2 \pm 0.6) \times 10 ^{-4} from a measurement of [Γ (B^0 \rightarrow
     \overline{\Sigma}_{\it C}({\it 2455})^{--}\,\rho\,\pi^+)/\Gamma_{\sf total}]\,\times\,[{\it B}(\Lambda_{\it C}^+\,\to\,\,\rho\,{\it K}^-\,\pi^+)]\,\,{\it assuming}\,\,{\it B}(\Lambda_{\it C}^+\,\to\,\,\rho\,{\it K}^-\,\pi^+)
      = (5.0 \pm 1.3) \times 10^{-2}
    ^3 DYTMAN 02 reports (3.7 \pm 1.1) 	imes 10^{-4} from a measurement of [\Gamma(B^0 
ightarrow
     \overline{\Sigma}_{\mathcal{C}}(2455)^{--}\rho\pi^{+})/\Gamma_{\mathsf{total}}] \times [\mathsf{B}(\Lambda_{\mathcal{C}}^{+} \to \rho \, \mathsf{K}^{-}\pi^{+})] \text{ assuming } \mathsf{B}(\Lambda_{\mathcal{C}}^{+} \to \rho \, \mathsf{K}^{-}\pi^{+})
      = 0.05, which we rescale to our best value B(\Lambda_c^+ \to p \, K^- \, \pi^+) = (5.0 \pm 1.3) \times 10<sup>-2</sup>
      Our first error is their experiment's error and our second error is the systematic error
      from using our best value.
    ^4 GABYSHEV 02 reports (2.38^{+~0.75}_{-~0.69}) \times 10^{-4} from a measurement of [Γ(B^0 \rightarrow
     \begin{array}{l} \overline{\Sigma}_{\mathcal{C}}(2455)^{--}\rho\pi^+)/\Gamma_{\mathsf{total}}] \times [\mathsf{B}(\Lambda_{\mathcal{C}}^+ \to \ \rho\, \mathsf{K}^-\pi^+)] \ \text{assuming } \mathsf{B}(\Lambda_{\mathcal{C}}^+ \to \ \rho\, \mathsf{K}^-\pi^+) \\ = 0.05, \text{ which we rescale to our best value } \mathsf{B}(\Lambda_{\mathcal{C}}^+ \to \ \rho\, \mathsf{K}^-\pi^+) = (5.0 \pm 1.3) \times 10^{-2}. \end{array}
      Our first error is their experiment's error and our second error is the systematic error
     from using our best value.
\Gamma(\Lambda_c^- \rho K^+ \pi^-)/\Gamma_{\text{total}}
                                                                                                                                \Gamma_{421}/\Gamma
VALUE (units 10<sup>-5</sup>)
                                                         DOCUMENT ID TECN COMMENT
                                                  1.2 \, \overline{\text{AUBERT}} 09AG BABR e^+e^- 
ightarrow \gamma (4S)
   ^1 AUBERT 09AG reports (4.33 \pm 0.82 \pm 0.33 \pm 1.13) 	imes 10^{-5} from a measurement of
      \begin{split} & [\Gamma(B^0 \to \Lambda_c^- \rho \, K^+ \pi^-) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(\Lambda_c^+ \to \rho \, K^- \pi^+)] \text{ assuming } \mathsf{B}(\Lambda_c^+ \to \rho \, K^- \pi^+) \\ & = (5.0 \pm 1.3) \times 10^{-2}. \end{split} 
   <sup>2</sup>Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma\big(\overline{\Sigma}_c(2455)^{--}\,p\,K^+\times \mathsf{B}(\overline{\Sigma}_c^{\,--}\to \overline{\varLambda}_c^-\,\pi^-)\,\big)/\Gamma_{\mathsf{total}}
                                                                                                                                \Gamma_{422}/\Gamma
^1 AUBERT 09AG reports (1.11 \pm 0.30 \pm 0.09 \pm 0.29) 	imes 10^{-5} from a measurement of
     [\Gamma\big(B^0\to \overline{\Sigma}_c(\text{2455})^{--}\,\rho\,\text{K}^+\times\text{B}(\overline{\Sigma}_c^{--}\to \overline{\Lambda}_c^-\,\pi^-)\,\big)/\Gamma_{\text{total}}]\times[\text{B}(\Lambda_c^+\to \rho\,\text{K}^-\pi^+)]
     assuming B(\Lambda_c^+ \to p \, K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}.
    <sup>2</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(\Lambda_c^- p K^*(892)^0)/\Gamma_{\text{total}}
                                                                                                                                \Gamma_{423}/\Gamma
<u>VALUE (units 10<sup>-5</sup>)</u> <u>CL%</u>
                                                        DOCUMENT ID TECN COMMENT
                                                 1 \overline{\sf AUBERT} 09AG BABR e^+e^- 	o 	au(4S)
                                      90
   ^1 Assumes equal production of \mathcal{B}^+ and \mathcal{B}^{\,0} at the \varUpsilon(4\mathcal{S}).
\Gamma(\overline{\Lambda}_c^- \Lambda K^+)/\Gamma_{\text{total}}
                                                                                                                                \Gamma_{424}/\Gamma
VALUE (units 10^{-5})
                                                         DOCUMENT ID TECN COMMENT
                                                  1,2 LEES
3.8 \pm 0.8 \pm 1.0
                                                                                 11F BABR e^+e^- \rightarrow \Upsilon(4S)
    ^{1} Assumes equal production of B^{0} and B^{+} from Upsilon(4S) decays.
    ^2 LEES 11F reports (3.8 \pm 0.8 \pm 0.2 \pm 1.0) \times 10 ^{-5} from a measurement of [Г (B ^0 \rightarrow
     \overline{\varLambda}_{c}^{-}\varLambda\,K^{+})/\Gamma_{\mathsf{total}}] \ / \ [\mathsf{B}(\varLambda_{c}^{+} \ \rightarrow \ \rho\,K^{-}\pi^{+})] \ / \ [\mathsf{B}(\varLambda \ \rightarrow \ \rho\,\pi^{-})] \ \mathsf{assuming} \ \mathsf{B}(\varLambda_{c}^{+} \ \rightarrow \ \rho\,\pi^{-})]
      p \ K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}, B(\Lambda \to p \pi^-) = (63.9 \pm 0.5) \times 10^{-2}. The reported
      uncertainties are statistical, systematic, and \overline{\Lambda}_{c}^{-} branching fraction uncertainty.
                                                                                                                                \Gamma_{425}/\Gamma
\Gamma(\overline{\Lambda}_c^- \Lambda_c^+)/\Gamma_{\text{total}}
<u>VALUE (units 10<sup>−5</sup>)</u> <u>CL%</u>
<6.2 90
                                                 ^1 Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
\Gamma(\overline{\Lambda}_c(2593)^- / \overline{\Lambda}_c(2625)^- p) / \Gamma_{\mathsf{total}}
                                                                                                                                \Gamma_{426}/\Gamma
<sup>1</sup> Assumes equal production of B^+ and B^0 at the \Upsilon(4S).
   ^2 DYT MA N 02 measurement uses B( \Lambda_c^- \to \overline{p} \, K^+ \pi^-) = 5.0 \pm 1.3\% . The second error
     includes the systematic and the uncertainty of the branching ratio.
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 $\Gamma(\overline{\Xi}_c^- \Lambda_c^+ \times \mathsf{B}(\overline{\Xi}_c^- \to \overline{\Xi}^+ \pi^- \pi^-))/\Gamma_{\mathsf{total}}$

 $p K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$

 $p \, K^- \pi^+) = (5.0 \pm 1.3) \times 10^{-2}$

 $9.3^{+3.7}_{-2.8}\pm3.1$

2.2\pm2.3 OUR AVERAGE Error includes scale factor of 1.9. 1.5 \pm 1.1 \pm 0.4 1,2 AUBERT 08H BA

DO CUMENT ID

 2,3 CHISTOV

 $^1\,\text{AUBERT}$ 08H reports (1.5 \pm 1.07 \pm 0.44) $\times\,10^{-5}$ from a measurement of [Г(B 0 \rightarrow $\overline{\overline{z}}_c^- \Lambda_c^+ \times \mathsf{B}(\overline{\overline{z}}_c^- \to \overline{\overline{z}}^+ \pi^- \pi^-)) / \Gamma_{\mathsf{total}}] \times [\mathsf{B}(\Lambda_c^+ \to p \, K^- \pi^+)] \text{ assuming } \mathsf{B}(\Lambda_c^+ \to p \, K^- \pi^+)]$

Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 3 CHISTOV 06A reports (9.3 $^{+3.7}_{-2.8}~\pm~3.1)~\times~10^{-5}~$ from a measurement of [Γ($B^0~\to~$ $\overline{\Xi}_{c}^{-}\Lambda_{c}^{+}\times B(\overline{\Xi}_{c}^{-}\to \overline{\Xi}^{+}\pi^{-}\pi^{-})\,)/\Gamma_{\mathsf{total}}]\times [B(\Lambda_{c}^{+}\to p\,K^{-}\pi^{+})] \; \mathsf{assuming} \; B(\Lambda_{c}^{+}\to p\,K^{-}\pi^{+})$

 B^0

| $\Gamma(\Lambda_c^+\Lambda_c^-K^0)/\Gamma_{\text{total}}$ Γ_{428}/Γ | $ \begin{array}{l} 1 \text{ Uses B}(B^+ \to J/\psi K^+ \to \ \mu^+ \mu^- K^+) = (6.0 \pm 0.2) \times 10^{-5}. \\ 2 \text{ Uses B}(B^+ \to J/\psi K^+ \to \ \mu^+ \mu^- K^+) = (6.01 \pm 0.21) \times 10^{-5} \text{ and B}(B^0 \to \ K^+ \pi^-) \end{array} $ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻⁴) 5.4±3.2 OUR AVERAGE | $0 \sec B(B^{*} \rightarrow J) \psi K^{*} \rightarrow \mu^{*} \mu^{*} K^{*}) = (0.01 \pm 0.21) \times 10^{-3} \text{ and } B(B^{*} \rightarrow K^{*} \pi^{*})$ $= (1.94 \pm 0.06) \times 10^{-5} \text{ for normalization.}$ |
| $3.8 \pm 3.1 \pm 2.1$ | 3 Uses B production ratio f($\overline{b} 	o B^+$)/f($\overline{b} 	o B^0_s$) = 3.71 \pm 0.47 and three normalization |
| 8 $\stackrel{+3}{-2}$ ± 4 2,3 GABYSHEV 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | modes. 4 Uses B($B^+ \to J/\psi K^+ \to \mu^+ \mu^- K^+) = (6.01 \pm 0.21) \times 10^{-5}$. |
| $^{-2}$ AUBERT 08H reports (0.38 \pm 0.31 \pm 0.21) $	imes$ 10 $^{-3}$ from a measurement of [$\Gamma(B^0 	o$ | 5 Uses B($B^+ \rightarrow J/\psi K^+$) B($J/\psi \rightarrow \mu^+ \mu^-$) = (5.94 ± 0.21) × 10 ⁻⁵ . |
| AGBERT of reports $(0.38 \pm 0.51 \pm 0.21) \times 10^{-9}$ from a measurement of $[1.68 \rightarrow A_c^+ A_c^- K^0)/\Gamma_{\text{total}}] \times [B(A_c^+ \rightarrow p K^- \pi^+)]$ assuming $B(A_c^+ \rightarrow p K^- \pi^+) = (5.0 \pm 0.51)$ | 6 Assumes equal production of B^+ and B^0 at the \varUpsilon (45). |
| $(3.0 \pm 1.3) \times 10^{-2}$. | 7 Uses B($B^+ \to J/\psi K^+$) B($J/\psi \to \mu^+ \mu^-$) = (5.88 ± 0.26) × 10 ⁻⁵ . |
| ² Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | ⁸ Assumes production cross-section $\sigma(B_S)/\sigma(B^+)=0.100/0.391$ and the CDF measured value of $\sigma(B^+)=3.6\pm0.6~\mu b$. |
| 3 GABYSHEV 06 reports $(7.9^{+2.9}_{-2.3}\pm4.3)	imes10^{-4}$ from a measurement of $[\Gamma(B^0 ightarrow$ | 9 ABE 98 assumes production of $\sigma(B^0)=\sigma(B^+)$ and $\sigma(B_s)/\sigma(B^0)=1/3$. They nor- |
| $\Lambda_c^+ \Lambda_c^- K^0)/\Gamma_{\text{total}} \times [B(\Lambda_c^+ \to p K^- \pi^+)]$ assuming $B(\Lambda_c^+ \to p K^- \pi^+) = (5.0 \pm 1)$ | malize to their measured $\sigma(B^0, \rho_T(B) > 6, y < 1.0) = 2.39 \pm 0.32 \pm 0.44 \mu b$. |
| $1.3) \times 10^{-2}$. | 10 ACCIARRI 97B assume PDG 96 production fractions for B^+ , B^0 , B_s , and Λ_b |
| $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{429}/Γ | 11 ABE 96L assumes equal B^0 and B^+ production. They normalize to their measured |
| Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | $\sigma(B^+, p_T(B)) > 6 \text{ GeV}/c, y < 1) = 2.39 \pm 0.54 \mu\text{b}.$ |
| VALUE CL% DOCUMENT ID TECN COMMENT | $^{12}B^0$ and 08_S are not separated. 13 Obtained from unseparated 08_S and $^08_S^0$ measurement by assuming a $^08_S^0$ ratio 2:1. |
| <3.2 \times 10 ⁻⁷ 90 1 DEL-AMO-SA. 11A BABR $e^+e^- \rightarrow \Upsilon(4S)$ | 14 AVERY 89B reports $< 5 \times 10^{-3}$ assuming the $\Upsilon(45)$ decays 43% to $B^0 \overline{B}^0$. We rescale |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $<6.2 \times 10^{-7}$ 90 1 VILLA 06 BELL $e^+e^- \rightarrow \Upsilon(4.5)$ | to E00/ |
| $<6.2 \times 10^{-7}$ 90 | 15 ALBRECHT 87D reports $<5\times10^{-5}$ assuming the $\varUpsilon(4S)$ decays 45% to $B^0\overline{B}{}^0$. We rescale to 50%. |
| $<3.9 \times 10^{-5}$ 90 2 ACCIARRI 951 L3 $e^+e^- \rightarrow Z$ | 16 AVERY 87 reports $<$ 9 $	imes$ 10 $^{-5}$ assuming the $ \Upsilon(4S)$ decays 40% to $ B^0 \overline{B}{}^0 $. We rescale |
| ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | to 50%. |
| 2 ACCIARRI 951 assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_s}=12.0\pm3.0\%$. | $\Gamma(\mu^+\mu^-\gamma)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{433}}/\Gamma$ |
| $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ Γ_{430}/Γ | Test for $\Delta B{=}1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DO CUMENT ID TECN COMMENT |
| Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | $<1.6 \times 10^{-7}$ 90 AUBERT 08C BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| VALUE CL% DOCUMENT ID TECN COMMENT | |
| < 8.3 \times 10 ⁻⁸ 90 AALTONEN 09P CDF $p\overline{p}$ at 1.96 TeV • • • We do not use the following data for averages, fits, limits, etc. • • | $\Gamma(\tau^+\tau^-)/\Gamma_{	ext{total}}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. |
| $<$ 11.3 \times 10 ⁻⁸ 90 1 AUBERT 08P BABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE CL% DOCUMENT ID TECN COMMENT |
| $< 6.1 \times 10^{-8}$ 90 1 AUBERT 05w BABR Repl. by AUBERT 08P | <4.1 \times 10 ⁻³ 90 1 AUBERT 06s BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $< 1.9 \times 10^{-7}$ 90 $\frac{1}{2}$ CHANG 03 BELL $e^+e^- ightarrow \Upsilon(45)$ | 1 Assumes equal production of B^+ and B^{0} at the $\varUpsilon(4S)$. |
| $< 8.3 \times 10^{-7}$ 90 ¹ BERGFELD 00B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ | $\Gamma(\pi^0\ell^+\ell^-)/\Gamma_{	ext{total}}$ Γ_{435}/Γ |
| $< 1.4 \times 10^{-5}$ 90 2 ACCIARRI 97B L3 $e^+e^- \rightarrow Z$ $< 5.9 \times 10^{-6}$ 90 AMMAR 94 CLE2 Repl. by BERGFELD 00B | VALUECL%DOCUMENT IDTECN _COMMENT |
| $< 2.6 \times 10^{-5}$ 90 3 AVERY 89B CLEO $e^+e^- \rightarrow r(4S)$ | <1.2 × 10 ⁻⁷ 90 1 AUBERT 07AG BABR $e^+e^- \rightarrow r(4S)$ |
| $<$ 7.6 $	imes$ 10 $^{-5}$ 90 4 ALBRECHT 87D ARG $e^+e^- ightarrow \varUpsilon(4S)$ | ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ |
| $<$ 6.4 \times 10 ⁻⁵ 90 ⁵ AVERY 87 CLEO $e^+e^- \rightarrow \varUpsilon(4S)$ $<$ 3 \times 10 ⁻⁴ 90 GILES 84 CLEO Repl. by AVERY 87 | $<$ 1.5 $	imes$ 10 $^{-7}$ 90 1 WEI 08A BELL $e^{+}e^{-} ightarrow 	au$ (4 $^{\circ}$) |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | 1 Assumes equal production of ${\it B}^+$ and ${\it B}^{0}$ at the $ {\it \Upsilon}(4S)$. |
| ² ACCIARRI 97B assume PDG 96 production fractions for B^+ , B^0 , B_S , and Λ_b . | $\Gamma(\pi^0 u \overline{ u}) / \Gamma_{	ext{total}}$ |
| 3 AVERY 89B reports $< 3 \times 10^{-5}$ assuming the $~ \gamma(4S)$ decays 43% to $B^0 \overline{B}{}^0$. We rescale | Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interaction. |
| to 50%. 4 ALBRECHT 87D reports $<$ 8.5 $	imes$ 10 $^{-5}$ assuming the $ \varUpsilon(4S)$ decays 45% to $ B^{0} \overline{B}{}^{0} $ We | VALUE CL% DOCUMENT ID TECN COMMENT $<2.2 \times 10^{-4}$ 90 THEN 07D BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| rescale to 50% | <2.2 \times 10 ⁻⁴ 90 ¹ CHEN 07D BELL $e^+e^- \rightarrow \Upsilon(4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. |
| 5 AVERY 87 reports $<$ 8 \times 10 $^{-5}$ assuming the $\varUpsilon(45)$ decays 40% to $B^0\overline{B}{}^0$. We rescale to 50%. | |
| | $\Gamma(\pi^0 e^+ e^-)/\Gamma_{\text{total}}$ Γ_{436}/Γ |
| $\Gamma(e^+e^-\gamma)/\Gamma_{total}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | VALUE CL% DOCUMENT ID TECN COMMENT |
| VALUE CLY DOCUMENT ID TECN COMMENT | <1.4 × 10 ⁻⁷ 90 ¹ AUBERT 07AG BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| <1.2 × 10 ⁻⁷ 90 AUBERT 08C BABR $e^+e^- \rightarrow \Upsilon(4S)$ | • • We do not use the following data for averages fits limits etc. • • • |
| <1.2 × 10 ⁻⁷ 90 AUBERT 08c BABR $e^+e^- \rightarrow \Upsilon(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $\sim 2.3 \times 10^{-7}$ 90 1 WEL 080 RELL $a + a = - \infty (4.5)$ |
| | $<$ $2.3 	imes 10^{-7}$ 90 1 WEI 08A BELL $e^{+}e^{-} ightarrow 	au(4S)$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ $\Gamma_{\text{432}}/\Gamma$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | $<$ 2.3×10^{-7} 90 1 WEI 08A BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 1 Assumes equal production of B^{+} and B^{0} at the $\Upsilon(4S)$. |
| $\Gamma(\mu^+\mu^-)/\Gamma_{	ext{total}}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | <2.3 \times 10 ⁻⁷ 90 ¹ WEI 08A BELL $e^+e^- \rightarrow \Upsilon(4S)$ ¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{\rm total}$ Γ_{437}/Γ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT 7 A 7 TEV CHATRCHYAN12A CMS Pp at 7 TeV | $<2.3 \times 10^{-7}$ 90 1 WEI 08A BELL $e^+e^- 	o 	au(4S)$ 1 Assumes equal production of B^+ and B^0 at the $	au(4S)$. $\Gamma(\pi^0 \mu^+ \mu^-)/\Gamma_{\rm total} \qquad \qquad \Gamma_{437}/\Gamma_{\rm tot$ |
| | $<2.3 \times 10^{-7}$ 90 1 WEI 08A BELL $e^+e^- 	o 	au(4S)$ 1 Assumes equal production of B^+ and B^0 at the $	au(4S)$. $\Gamma(\pi^0\mu^+\mu^-)/\Gamma_{\text{total}}$ $\frac{\Gamma(\pi^0\mu^+\mu^-)}{\Delta LUE}$ $\frac{CL\%}{\Delta LUE}$ $\frac{DOCUMENT\ ID}{\Delta LUE}$ $\frac{TECN}{\Delta LUE}$ $\frac{COMMENT}{\Delta LUE}$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT 7 A 7 TEV CHATRCHYAN12A CMS pp at 7 TeV | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{total}$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT COMMENT COMMENT COMMENT Pp at 7 TeV • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| T($\mu^+\mu^-$)/ Γ_{total} Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. WALUE CL% DOCUMENT ID TECN COMMENT Pp at 7 TeV COMMENT COMMENT LECHOP Pp at 7 TeV COMMENT COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP COMMENT COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP COMMENT COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP COMMENT LECHOP COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP COMMENT LECHOP Pp at 7 TeV COMMENT LECHOP LECHOP COMMENT LECHOP COMMENT LECHOP LECHOP COMMENT LECHOP LECHOP LECHOP COMMENT LECHOP | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| T($\mu^+\mu^-$)/ Γ_{total} Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **NALUE** **CL\(\frac{CL\(\)}{DOCUMENT ID} \) **O** We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| T($\mu^+\mu^-$)/ Γ_{total} Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. **Test for $\Delta B=1$ weak interactions. **Test for $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ we at $\Delta B=1$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| T($\mu^+\mu^-$)/ Γ_{total} Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. ALLUE CL% DOCUMENT ID TECN COMMENT C | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. ALLUE CL% DOCUMENT ID TECN COMMENT Pp at 7 TeV 1 CHATRCHYAN12A CMS Pp at 7 TeV 1 CHATRCHYAN12A CMS Pp at 7 TeV 2.2.6 × 10 ⁻⁹ 90 2 AAIJ 12A LHCB Pp at 7 TeV 2.1.2 × 10 ⁻⁸ 90 3 AAIJ 11B LHCB Repl. by AAIJ 12A 4.5.0 × 10 ⁻⁹ 90 4 AALTONEN 11AG CDF Pp at 1.96 TeV 2.7.2 × 10 ⁻⁸ 90 1 CHATRCHYAN11T CMS Repl. by CHATRCHYAN 12A CS.0 × 10 ⁻⁹ 90 4 AALTONEN 1 CHATRCHYAN11T CMS Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CS.2 × 10 ⁻⁸ 90 6 AUBERT 08P BABR e ⁺ e ⁻ → T(4S) 3.9 × 10 ⁻⁸ 90 6 AUBERT OSW BABR e ⁺ e ⁻ → T(4S) CS.5 × 10 ⁻⁷ 90 8 ACOSTA 040 CDF Pp at 1.96 TeV ACTONEN 08I CDF Repl. by AALTONEN 08I CDF Repl. by AALTONEN 08I CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 08I CDF CDF CDF CDF CDF CDF CDF CD | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE 100 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. ALLUE CL% DOCUMENT ID TECN COMMENT TECN COMMENT OWNED 1 CHATRCHYAN12A CMS Pp at 7 TeV 1 CHATRCHYAN12A CMS Pp at 7 TeV 2.2 6 × 10 - 9 90 2 AAIJ 12A LHCB Repl. by AAIJ 12A LHCB Repl. by AAIJ 12A LHCB Repl. by CHATRCHYAN 12A CS.0 × 10 - 9 90 4 AALTONEN 11AG CDF Pp at 1.96 TeV C3.7 × 10 - 9 90 1 CHATRCHYAN11T CMS Repl. by CHATRCHYAN 12A CS.2 × 10 - 8 90 5 AALTONEN 13A CS.2 × 10 - 8 90 6 AUBERT 08P BABR CF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CS.2 × 10 - 8 90 6 AUBERT 08P BABR CF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CS.2 × 10 - 8 90 6 AUBERT 08P BABR CF Repl. by AALTONEN 18B CS.2 × 10 - 8 90 6 AUBERT 08P BABR CF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF Repl. by AALTONEN 18B CS.2 × 10 - 8 OF OF OF OF OF OF OF OF OF O | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. ALLUE CL% DOCUMENT ID TECN COMMENT CO | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. Allowed by pap 1 7 ReV occombents. Allowed by pap 1 7 ReV occombents. Allowed by pap 1 1 194 Vev occombents. Allowed by pap 1 1 196 Vev occombents. Allowed by pap 1 1 196 Vev occombents. Allowed by pap 1 1 196 Vev occombents. Allowed by pap 1 1 196 Vev occombents. Allowed by higher-order electroweak interactions. Allowed by pap 1 1 196 Vev occombents. Allowed by higher-order electroweak interactions. Allowed by higher-order electrowe by pap 1 7 TeV occombents. Allowed by higher-order electrowe by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occombents. Allowed by pap 1 7 TeV occ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT Pp at 7 TeV 2.6 × 10 ⁻⁹ 90 1 CHATRCHYAN12a CMS pp at 7 TeV 2.6 × 10 ⁻⁹ 90 2 AAIJ 12a LHCB pp at 7 TeV 2.1 × 10 ⁻⁸ 90 3 AAIJ 11b LHCB Repl. by AAIJ 12a CSSN Pp at 1.96 TeV Repl. by AAITONEN 11ac CDF Repl. by AAITONEN 11ac CSSN × 10 ⁻⁹ 90 1 CHATRCHYAN11T CMS Repl. by CHATRCHYAN 12a CSSN × 10 ⁻⁹ 90 5 AALTONEN 11ac CDF Repl. by AALTONEN 11ac CDF Repl. by AALTONEN 11ac CSSN × 10 ⁻⁸ 90 6 AUBERT 08b BABR e+e-→ T(4S) 3.9 × 10 ⁻⁸ 90 6 AUBERT 05b BABR e+e-→ T(4S) 3.5 × 10 ⁻⁷ 90 6 AUBERT 05b BABR e+e-→ T(4S) CSSN × 10 ⁻⁷ 90 6 CHANG 3 BELL e+e-→ T(4S) CSSN × 10 ⁻⁷ 90 6 BERGFELD 00b CLE2 e+e-→ T(4S) CSSN × 10 ⁻⁷ 90 6 BERGFELD 00b CLE2 e+e-→ T(4S) CSSN × 10 ⁻⁵ 90 ABBOTT 98b DO pp 1.8 TeV CSSN × 10 ⁻⁵ 90 10 ACCIARRI 97b 11 ABE 96c CDF Repl. by ABE 98 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Γ(μ ⁺ μ ⁻)/Γtotal Test for Δβ=1 weak neutral current. Allowed by higher-order electroweak interactions. VALUE CL% DOCUMENT ID TECN COMMENT TECN COMMENT Pp at 7 TeV 1.2 × 10 ⁻⁹ 90 2 AAIJ 1 2A LHCB Pp at 7 TeV 2.2 × 10 ⁻⁸ 90 3 AAIJ 11B 4 LHCB Repl. by AAIJ 12A C1.2 × 10 ⁻⁹ 90 4 AALTONEN 11AG CDF Pp at 1.96 TeV 3.7 × 10 ⁻⁹ 90 1 CHATRCHYAN11T CMS Repl. by CHATRCHYAN 12A C5.0 × 10 ⁻⁹ 90 1 CHATRCHYAN11T CMS Repl. by CHATRCHYAN 11A C5.2 × 10 ⁻⁸ 90 5 AALTONEN 1 CHATRCHYAN 11T CMS Repl. by AALTONEN 11AG CDF Repl. by AALTONEN 11AG CDF C1.2 × 10 ⁻⁸ 90 6 AUBERT C3.9 × 10 ⁻⁸ 90 7 ABULENCIA C3.9 × 10 ⁻⁸ 90 6 AUBERT C3.9 × 10 ⁻⁸ 90 6 AUBERT C4.6 × 10 ⁻⁷ 90 6 CHANG C5.2 × 10 ⁻⁸ 90 6 CHANG C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ 90 C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ C6.1 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ C7.0 × 10 ⁻⁷ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| T(μ+μ−)/Γtotal Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. Allowed DOCUMENT ID TECN COMMENT | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Test for $\Delta B = 1$ weak neutral current. Allowed by higher-order electroweak interactions. VALUE $CL\%$ DOCUMENT ID TECN COMMENT $CL\%$ Pp at 7 TeV $CL\%$ Ved on not use the following data for averages, fits, limits, etc. • • • $CL\%$ Value $CL\%$ 90 $CL\%$ 2 AAIJ 12A LHCB pp at 7 TeV $CL\%$ 1.2 × 10 ⁻⁹ 90 $CL\%$ 3 AAIJ 11B LHCB Repl. by AAIJ 12A $CL\%$ 8 Repl. by CHATRCHYAN 11B LHCB Repl. by CHATRCHYAN 12A $CL\%$ 8 Repl. by CHATRCHYAN 11B $CL\%$ 8 Repl. by CHATRCHYAN 11B $CL\%$ 8 Repl. by CHATRCHYAN 11B $CL\%$ 8 Repl. by CHATRCHYAN 11AG CDF $CL\%$ 8 Repl. by CHATRCHYAN 11AG CDF $CL\%$ 1.5 × 10 ⁻⁸ 90 $CL\%$ 4 AALTONEN 081 CDF Repl. by AALTONEN 11AG CDF $CL\%$ 8 Repl. by CHATRCHYAN 11AG CDF $CL\%$ 8 Repl. by CHATRCHYAN 12A $CL\%$ 1.5 × 10 ⁻⁸ 90 $CL\%$ 1 ABBERT 08P BABR $CL\%$ 2 Repl. by AALTONEN 081 $CL\%$ 1 ABBORT 08B BABR $CL\%$ 2 Repl. by AALTONEN 081 $CL\%$ 1 ABBORT 08B BABR $CL\%$ 2 Repl. by AALTONEN 081 $CL\%$ 1 ABBORT 08B BCL $CL\%$ 2 Repl. by AALTONEN 081 $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 08B CDF $CL\%$ 1 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBORT 09B CDF $CL\%$ 2 ABBOR 09F ABF 09F ABF 09F ABF 09F ABF 09F ABF 09F ABF 09F ABF 09F ABF 09F ABBORT 09B DDF 09F 09F 09F 09F 09F 09F 09F 09F 09F 09 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 1 Assumes equal production of B^0 and B^+ at $\varUpsilon(4S)$.

 $8.1^{+2.1}_{-1.9}\pm0.9$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T

¹ ISHIKAWA 03 BELL Repl. by WEI 09A

| | neutral current. Allowe | , 0 | | | $8{=}1$ weak neutr | | = | der electroweak intera | 445 /Γ ctions. |
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| VALUE (units 10 ⁻⁷) | | D TECN C | COMMENT | VALUE (units 10 ⁻⁷) | | <u>DO CUMENT</u> | ID TECN | COMMENT | |
| $1.6^{+1.0}_{-0.8}$ OUR AV | ERAGE | | | 10.3 + 1.9 O | UR AVERAGE | | | | |
| $0.8 {}^{+ 1.5}_{- 1.2} {}^{\pm} 0.1$ | $^{ m 1}$ AUBERT | 09т BABR <i>e</i> | $e^+e^- \rightarrow \gamma(4S)$ | $8.6^{+2.6}_{-2.4}\pm$ | 0.5 | $^{ m 1}$ AUBERT | 09т ВАВ | R $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $2.0^{+1.4}_{-1.0}\pm0.1$ | ¹ WEI | 09A BELL e | $e^+e^- \rightarrow \gamma(4S)$ | $11.8 + 2.7 \pm 0$ | 0.9 | ¹ WEI | 09A BELI | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| | following data for avera | nges, fits, limits, etc | c. • • • | - 2.2 • • • We do not | | ing data for aver | ages, fits, limits | s, etc. • • • | |
| $1.3^{+1.6}_{-1.1}\pm0.2$ | ¹ AUBERT,B | 06J BABR R | Repl. by AUBERT 09T | $10.4^{+3.3}_{-2.9}\pm$ | | ¹ AUBERT.B | = | R Repl. by AUBERT | Г 09т |
| -1.1 $-2.1 + 2.3 \pm 0.8$ | 1 AUBERT | | $e^+e^- \rightarrow r(4S)$ | $11.1^{+5.6}_{-4.7}\pm$ | | 1 AUBERT | | R $e^+e^- ightarrow \gamma(4S)$ | |
| = | 90 ² ISHIKAWA | | $e^+e^- \rightarrow \Upsilon(4S)$ | < 24 | 90 | 2 ISHIKAWA | | $e^+e^- ightarrow \gamma(45)$ | |
| | 90 ¹ ABE | | Repl. by ISHIKAWA 03 | < 64 | 90 | 1 ABE | | Repl. by ISHIKAV | |
| | 90 ¹ AUBERT 90 ³ ANDERSON | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | < 67 | 90 | ¹ AUBERT | | $R e^+e^- \rightarrow \Upsilon(4S)$ | |
| | 90 ³ ANDERSON 90 ALBRECHT | | $e^+e^- \rightarrow r(4S)$ $e^+e^- \rightarrow r(4S)$ | <2900 1 a | 90 | ALBRECH | | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| < 5200 | 90 ⁴ AVERY | 87 CLEO e | $e^+e^- \rightarrow \Upsilon(4S)$ | Assumes equa 2 Assumes equa | al production o | fB^+ and B^0 at fB^0 and B^+ at | the $T(4S)$. $\Upsilon(4S)$. | | |
| ¹ Assumes equal product ² Assumes equal product ³ The result is for di-lep | tion of B^0 and B^+ at | $\Upsilon(4S)$. | | Γ(<i>K</i> *(892) ⁰ μ ⁻ | $+\mu^-)/\Gamma_{\rm total}$ | | | Γ, der electroweak intera | 446/F |
| ⁴ AVERY 87 reports < 6 | $.5 	imes 10^{-4}$ assuming the | $\mathcal{T}(4S)$ decays 40% | % to $B^0\overline{B}^0$. We rescale | $VALUE$ (units 10^{-7}) | CL% | DO CUMENT ID | - | COMMENT | |
| to 50%. | | | | 10.6±1.0 O | | | | | |
| $\Gamma(K^0\nu\overline{\nu})/\Gamma_{\text{total}}$ | In a contract contract of the Attraction | and have been to be | Γ ₄₄₂ /Γ | 11.1 + 1.8 O | UR AVERAGE | | | | |
| | k neutral current. Allow <u>CL%</u> <u>DOCUMENT I</u> | vea by nigher-order of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the contract of the con | | $13.5 + 4.0 \pm 13.5 + 4.0 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13.5 \pm 13$ | 1.0 | ¹ AUBERT | 09T BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| | | SA10Q BABR <i>e</i> | | 10.6 + 1.9 ± | 0.7 | ¹ WEI | 09A BELL | $e^+e^- \rightarrow r(4S)$ | |
| • • We do not use the | - | = | | - 1.4 • • • We do not | | ing data for aver | ages, fits, limits | s, etc. • • • | |
| $<1.6 \times 10^{-4}$ Assumes equal product | 90 ¹ CHEN | | $e^+e^- \rightarrow \gamma(4S)$ | $8.7^{+3.8}_{-3.3}\pm$ | | ¹ AUBERT,B | = | Repl. by AUBERT (|)9т |
| | tion of B + and B * at 1 | the 1 (45). | | 8.6 + 7.9 ± | | ¹ AUBERT | | Repl. by AUBERT, | |
| $\Gamma(\rho^0 \nu \overline{\nu})/\Gamma_{\text{total}}$ | k neutral current. Allow | and by higher order | Γ ₄₄₃ /Γ | 0.0 | | | | , , , | 3 001 |
| VALUE TWEE | CL% DO CUMENT I | D TECN C | COMMENT | $13.3^{+4.2}_{-3.7}\pm$ | | ² ISHIKAWA | | Repl. by WEI 09A | |
| - | 90 ¹ CHEN | | $e^+e^- \rightarrow \Upsilon(4S)$ | < 42 < 33 | 90 90 | ¹ ABE AUBERT | | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ | |
| ¹ Assumes equal product | tion of ${\it B}^+$ and ${\it B}^0$ at 1 | the $\varUpsilon(4S)$. | | < 40 | 90 | ³ AFFOLDER | 99B CDF | $p\overline{p}$ at 1.8 TeV | |
| $\Gamma(K^0\mu^+\mu^-)/\Gamma_{\text{total}}$ | | | Γ ₄₄₁ /Γ | < 250 | 90 | ⁴ ABE | 96L CDF | Repl. by AFFOLDE | ₹ 99в |
| Test for $\Delta B = 1$ weak | neutral current. Allowe | | | < 230 | 90 | ⁵ ALBAJAR | 91c UA1 | $E_{\rm cm}^{p\overline{p}}$ = 630 GeV | |
| | <u>DO CUMENT ID</u> | TECN CON | MMENT | <3400 | 90 | ALBRECHT | 91E ARG | $e^+e^- \rightarrow \gamma(4S)$ | |
| | | 091 BABR e ⁺ | $e^- \rightarrow \Upsilon(45)$ | ¹ Assumes equa ² Assumes equ systematic un ³ AFFOLDER 9 ⁴ ABE 96L mea | al production of al production of neertainties incl 99B measured r usured relative to | of B^+ and B^0 at of B^0 and B^+ auding model depelative to $B^0 \rightarrow$ | the $\Upsilon(4S)$. The endence. $J/\psi(1S)K^*(8)$ | e second error is a to | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | RAGE 1 AUBERT 1 WEI | 09т ВАВК e^+ | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ | ¹ Assumes equa ² Assumes equa systematic un ³ AFFOLDER ⁶ ⁴ ABE 96L mea ⁵ ALBAJAR 91 | al production of al production of acertainties incl 99B measured r asured relative to LC assumes 36% | f B^+ and B^0 at of B^0 and B^+ ; uding model depelative to $B^0 	o D$ of $D^0 	o D$ quarks give | the $\Upsilon(4S)$. The endence. $J/\psi(1S)K^*(8)$ Using B^0 mesons. | e second error is a to 392) ⁰ . ng PDG 94 branching | ratios |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | RAGE 1 AUBERT 1 WEI | 09T BABR e ⁺ 09A BELL e ⁺ 1ges, fits, limits, etc | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ | 1 Assumes equal 2 Assumes equal 2 Assumes equal systematic un 3 AFFOLDER 9 4 ABE 96L mea 5 ALBAJAR 91 T(K*(892) ⁰ \$\mu^{-4}\$ | al production of al production of acertainties incl 99B measured r asured relative to LC assumes 36% | f B^+ and B^0 at of B^0 and B^+ : uding model depelative to $B^0 \rightarrow J/\psi(1S)$ of \overline{b} quarks give | the $\Upsilon(4S)$. The endence. $J/\psi(1S)$ $K^*(892)^0$ using B^0 mesons. | e second error is a to 1992) ⁰ . ng PDG 94 branching F446 , | ratios |
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| $\begin{array}{c} \text{ALUE (units } 10^{-7}) & \text{CL} \\ \textbf{3.8 \pm 0.8 } & \textbf{OUR FIT} \\ \textbf{4.5 \pm 1.0} & \textbf{OUR AVEF} \\ \textbf{4.9 \pm 2.9} & \pm 0.3 \\ \textbf{4.4 \pm 1.3} & \pm 0.3 \\ \textbf{\bullet \bullet We do not use the} \\ \textbf{5.9 \pm 3.3} & \pm 0.7 \\ \end{array}$ | 1 AUBERT 1 WEI following data for avera | 09T BABR e^+ 09A BELL e^+ 1ges, fits, limits, et e | $e^- 	o 	au(45)$ $e^- 	o 	au(45)$ c. •• pl. by AUBERT 09T pl. by AUBERT,B 06J | 1 Assumes equi 2 Assumes equi systematic un 3 AFFOLDER 9: 4 ABE 961 mea 5 ALBAJAR 91 \(\mathbb{\text{\(K^*(892)^0}\)\mu^{\pm}}\) \(\mathbb{MLUE\)\(\text{\(units 10^{-3}\)}\) \(\mathbb{0.79\pm 0.07\)\(\mathbb{OUR}\) | al production of all production of all production of all production of acceptainties included management of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the same of the s | f B^+ and B^0 at of B^0 and B^+ ; uding model depelative to $B^0 \rightarrow J/\psi(1S)$ of \overline{b} quarks give $\psi(1S)$ $K^*(892)^0$ | the $\Upsilon(4S)$. at $\Upsilon(4S)$. The endence. $J/\psi(1S)K^*(8)U$ using U and U U U U U U U U U U | e second error is a to $392)^0$. ng PDG 94 branching F446. COMMENT $p\overline{p}$ at 1.96 TeV | ratios |
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| 74.10E (units 10^{-7}) CL 3.8 ± 0.8 OUR FIT 4.5 ± 1.2 OUR AVEF 4.9 ± 0.3 ± 0.3 4.4 ± 1.3 ± 0.3 • • • We do not use the 5.9 ± 0.3 ± 0.7 1.63 ± 0.63 ± 0.7 1.63 ± 0.63 ± 0.14 5.6 ± 0.9 ± 0.5 | AAGE 1 AUBERT 1 WEI following data for avera 1 AUBERT,B 1 AUBERT 2 ISHIKAWA 1 ABE AUBERT | 09T BABR e ⁺ 09A BELL e ⁺ 1ges, fits, limits, etc 06J BABR Rep 03U BABR Rep 03 BELL Rep | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ C. • • • pl. by AUBERT 09T pl. by AUBERT,B 06J pl. by WEI 09A pl. by ISHIKAWA 03 | 1 Assumes equipments assumes equipments assumes equipments and a systematic un 3 AFFOLDER % 4 ABE 96L mea 5 ALBAJAR 91 Γ(Κ*(892) ⁰ μ ⁺¹ MALUE (units 10 ⁻³) 0.79±0.07 OUR 0.77±0.08±0.03 • • • We do not 0.80±0.10±0.06 0.61±0.23±0.07 | al production of all production of all production of all production of all productions of all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions | f B^+ and B^0 at of B^0 and B^+ ; uding model depelative to $B^0 \rightarrow J/\psi(1S)$ of \overline{b} quarks give $\psi(1S)$ $K^*(892)^0$ AALTONEN ing data for aver | the $\Upsilon(45)$. at $\Upsilon(45)$. 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The constant of E^0 mesons are solutions. | e second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a to a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second error is a second err | ratios /Γ₁₆₄ |
| $ \begin{array}{c cccc} & \text{VALUE (units } 10^{-7}) & \text{CL} \\ \hline \textbf{3.8} & \pm 0.8 & \text{OUR FIT} \\ \textbf{4.5} & \pm 1.2 & \text{OUR AVEF} \\ \textbf{4.9} & + 2.9 & \pm 0.3 \\ \textbf{4.4} & + \frac{1}{1.1} & \pm 0.3 \\ \bullet & \bullet & \text{We do not use the} \\ \hline \textbf{5.9} & + \frac{3.3}{2.6} & \pm 0.7 \\ \textbf{1.63} & \pm 0.7 \\ \textbf{1.63} & \pm 0.82 & \pm 0.14 \\ \textbf{5.6} & - \frac{2.9}{2.3} & \pm 0.5 \\ \textbf{<33} & & 90 \\ \textbf{<66.4} & & 90 \\ \textbf{<5200} & & 90 \\ \end{array} $ | RAGE 1 AUBERT 1 WEI following data for avera 1 AUBERT,B 1 AUBERT 2 ISHIKAWA 1 ABE AUBERT 3 ANDERSON ALBRECHT | 09T BABR e+ 09A BELL e+ 19ges, fits, limits, etc 06J BABR Rep 03U BABR Rep 03 BELL Rep 02L BABR e+ 01B CLE2 e+ 91E ARG e+ | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ c. • • • pl. by AUBERT 09T pl. by AUBERT,B 06J pl. by WEI 09A pl. by ISHIKAWA 03 $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ | 1 Assumes equ: 2 Assumes equ systematic un 3 AFFOLDER 9 4 ABE 96L mea 5 ALBAJAR 91 Γ(K*(892) ⁰ μ [±] MALUE (units 10 ⁻³) 0.79±0.07 OUR 0.77±0.08±0.03 • • • We do not 0.80±0.10±0.06 0.61±0.23±0.07 Γ(K*(892) ⁰ ν̄ | al production of all production of all production of all production of all productions of all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions are all productions | f B^+ and B^0 at of B^0 and B^+ ; uding model depelative to $B^0 \rightarrow J/\psi(1S)$ of \overline{D} quarks give $\psi(1S)$ $K^*(892)^0$ AALTONEN AALTONEN AALTONEN | the $\Upsilon(4S)$. at $\Upsilon(4S)$. The endence. $J/\psi(1S) K^*(4S)$ using $J/\psi(1S) K^*(8S)^0$ using $J/\psi(1S) K^*(8S)^0$ using $J/\psi(1S) K^*(8S)^0$ mesons. TECN 11AI CDF ages, fits, limits 11L CDF 09B CDF | FA46, COMMENT PP at 1.96 TeV s, etc. • • • Repl. by AALTONEN F. | ratios. /Γ ₁₆₄ Ν 11ΑΙ Ν 11L |
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| $^{\mathrm{1}}$ Assumes equal production of $\mathit{B}^{\mathrm{+}}$ and | or averages, fits, limits, etc. • • • |
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| | P^0 at the $\Upsilon(AS)$ |
| | B at the 1 (43). |
| $\Gamma(K^*(892)^0 e^+ \mu^-)/\Gamma_{\text{total}}$ | Γ ₄₅₂ /Γ |
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| <5.3 90 ¹ AUB | |
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| $<1.1 \times 10^{-4}$ 90 BORN | HEIM 04 CLE2 $e^+e^- ightarrow \varUpsilon(4S)$ |
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| . // 13101 | vation. Allowed by higher-order electroweak inter- |
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| Test of lepton family number conservance actions. 22.2 × 10 ⁻⁵ 90 1 AUBER • • We do not use the following data for $<3.8 \times 10^{-5}$ 90 BORNI $<8.3 \times 10^{-4}$ 90 AMMA 1 Assumes equal production of B^+ and Γ (invisible)/ Γ total | RT 08AD BABR $e^+e^- 	o 	au(4S)$ or averages, fits, limits, etc. $\bullet \bullet \bullet$ HEIM 04 CLE2 $e^+e^- 	o 	au(4S)$ R 94 CLE2 Repl. by BORNHEIM 04 B^0 at the $	au(4S)$. |
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| Test of lepton family number conservancions. 2.2 × 10 ⁻⁵ 90 1 AUBER 2.8 × 10 ⁻⁵ 90 BORNIV 2.8 × 10 ⁻⁴ 90 AMMA 1 Assumes equal production of B^+ and $\Gamma \text{ (invisible)}/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-5}\text{)}}{2}$ 1 Uses the fully reconstructed $B^0 \rightarrow D$ $\Gamma (\nu \nu \gamma)/\Gamma_{\text{total}}$ | RT 08AD BABR $e^+e^- 	o 	au(4S)$ or averages, fits, limits, etc. $\bullet 	extbf{ } \bullet$ 07 ALEL MARINE PROBLEM 04 CLE2 $e^+e^- 	o 	au(4S)$ R 94 CLE2 Repl. by BORNHEIM 04 B0 at the $	au(4S)$. |
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\Gamma(\Lambda_c^+ \mu^-)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                                                                                                             \Gamma_{459}/\Gamma
                                                                                                                                                                                  DOCUMENT ID
                                                                                                                                                                                                                                                                                      TECN COMMENT
    <1.8 \times 10^{-6}
                                                                                                                                                             1.2 \, \overline{\text{DEL-AMO-SA...11}}K BABR e^+ \, e^- 
ightarrow ~ \varUpsilon(4\, S)
            ^1 DEL-AMO-SANCHEZ 11K reports < 180 \times 10^{-8} from a measurement of [\Gamma(B^0 
ightarrow
                   \Lambda_{C}^{+}\,\mu^{-})/\Gamma_{\text{total}}]\,\times\,[B(\Lambda_{C}^{+}\,\rightarrow\,\,p\,K^{-}\,\pi^{+})]\,\,\text{assuming}\,\,B(\Lambda_{C}^{+}\,\rightarrow\,\,p\,K^{-}\,\pi^{+})\,=\,(5.0\,\pm\,0.06)
          <sup>2</sup> Uses B(\Upsilon(4S) \to B^0 \overline{B}{}^0) = (51.6 ± 0.6)% and B(\Upsilon(4S) \to B^+ B^-) = (48.4 ± 0.6)%.
\Gamma(\Lambda_c^+ e^-)/\Gamma_{\text{total}}
                                                                                                                                                                                  DOCUMENT ID
                                                                                                                                                                                                                                                                                      TECN COMMENT
                                                                                                                                                          1.2 DEL-AMO-SA...11K BABR e^+e^- 
ightarrow \gamma (4S)
          ^1\,\text{DEL-AMO-SANCHEZ} 11K reports < 520 \times 10 ^{-8} from a measurement of [Г (B^0 \rightarrow
                   \Lambda_c^+ \, e^-)/\Gamma_{\text{total}}] \times [B(\Lambda_c^+ \to p \, K^- \, \pi^+)] assuming B(\Lambda_c^+ \to p \, K^- \, \pi^+) = (5.0 \pm 1.0 \pm
                 1.3) \times 10^{-}
            <sup>2</sup> Uses B( \Upsilon(4S) \to B^0 \overline{B}{}^0) = (51.6 ± 0.6)% and B( \Upsilon(4S) \to B^+ B^-) = (48.4 ± 0.6)%.
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POLARIZATION IN B DECAYS

Revised February 2012 by A. V. Gritsan (Johns Hopkins University) and J. G. Smith (University of Colorado at Boulder).

We review the notation used in polarization measurements in particle production and decay, with a particular emphasis on the B decays and the CP-violating observables in polarization measurements. We look at several examples of vector-vector and vector-tensor B meson decays, while more details about the theory and experimental results in B decays can be found in a separate mini-review [1] in this Review.

Figure 1 illustrates angular observables in an example of the sequential process $ab \to X \to P_1P_2 \to (p_{11}p_{12})(p_{21}p_{22})$ [2]. The angular distributions are of particular interest because they are sensitive to spin correlations and reveal properties of particles and their interactions, such as quantum numbers and couplings. In the case of a spin-zero particle X, such as Bmeson or a Higgs boson, there are no spin correlations in the production mechanism and the decay chain is to be analyzed. The angular distribution of decay products can be expressed as a function of three helicity angles which describe the alignment of the particles in the decay chain. The analyzer of the Bdaughter polarization is normally chosen for two-body decays, as the direction of the daughters in the center-of-mass of the parent $(e.g., \rho \to 2\pi)$ [3], and for three-body decays as the normal to the decay plane (e.g., $\omega \to 3\pi$) [4]. An equivalent set of transversity angles is sometimes used in polarization analyses [5]. The differential decay width depends on complex amplitudes $A_{\lambda_1\lambda_2}$, corresponding to the X-daughter helicity states λ_i .

In the case of a spin-zero B-meson decay, its daughter helicities are constrained to $\lambda_1=\lambda_2=\lambda$. Therefore we simplify amplitude notation as A_λ . Moreover, most B-decay polarization analyses are limited to the case when the spin of one of the B-meson daughters is 1. In that case, there are only three independent amplitudes corresponding to $\lambda=0$ or ± 1 [6], where the last two can be expressed in terms of parity-even and parity-odd amplitudes $A_{\parallel,\perp}=(A_{+1}\pm A_{-1})/\sqrt{2}$. The overall decay amplitude involves three complex terms proportional to the above amplitudes and the Wigner d functions of helicity angles. The exact angular dependence would depend on the quantum numbers of the B-meson daughters and of their decay products, and can be found in the literature [6,7]. The

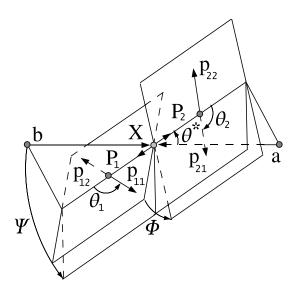


Figure 1: Definition of the production and helicity angles in the sequential process $ab \to X \to P_1P_2 \to (p_{11}p_{12})(p_{21}p_{22})$. The three helicity angles include θ_1 and θ_2 , defined in the rest frame of the two daughters P_1 and P_2 , and Φ , defined in the X frame as the angle between the two decay planes. The two production angles θ^* and Ψ are defined in the X frame, where Ψ is the angle between the production plane and the average of the two decay planes.

differential decay rate would involve six real quantities α_i , including interference terms,

$$\frac{d\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2 d\Phi} = \sum_i \alpha_i f_i (\cos\theta_1, \cos\theta_2, \Phi), \quad (1)$$

where each $f_i(\cos \theta_1, \cos \theta_2, \Phi)$ has unique angular dependence specific to particle quantum numbers, and the α_i parameters are defined as:

$$\alpha_1 = \frac{|A_0|^2}{\sum |A_1|^2} = f_L \,, \tag{2}$$

$$\alpha_2 = \frac{|A_{\parallel}|^2 + |A_{\perp}|^2}{\sum |A_{\lambda}|^2} = (1 - f_L), \qquad (3)$$

$$\alpha_3 = \frac{|A_{\parallel}|^2 - |A_{\perp}|^2}{\sum |A_{\lambda}|^2} = (1 - f_L - 2f_{\perp}), \tag{4}$$

$$\alpha_4 = \frac{\Im m(A_{\perp}A_{\parallel}^*)}{\Sigma |A_{\lambda}|^2} = \sqrt{f_{\perp}(1 - f_L - f_{\perp})} \sin(\phi_{\perp} - \phi_{\parallel}), \quad (5)$$

$$\alpha_5 = \frac{\Re e(A_{\parallel} A_0^*)}{\Sigma |A_{\lambda}|^2} = \sqrt{f_L \left(1 - f_L - f_{\perp}\right)} \cos(\phi_{\parallel}), \qquad (6)$$

$$\alpha_6 = \frac{\Im m(A_\perp A_0^*)}{\Sigma |A_\lambda|^2} = \sqrt{f_\perp f_L} \sin(\phi_\perp), \qquad (7)$$

where the amplitudes have been expressed with the help of polarization parameters f_L , f_\perp , ϕ_\parallel , and ϕ_\perp defined in Table 1. Note that the terms proportional to $\Re e(A_\perp A_\parallel^*)$, $\Im m(A_\parallel A_0^*)$, and $\Re e(A_\perp A_0^*)$ are absent in Eqs. (2-7). However, these terms may appear for some three-body decays of a B-meson daughter, see Ref. 7.

Table 1: Rate, polarization, and CP-asymmetry parameters defined for the B-meson decays to mesons with non-zero spin. Numerical examples are shown for the $B^0 \to \varphi K^*(892)^0$ decay. The first six parameters are defined under the assumption of no CP violation in decay, while they are averaged between the \overline{B} and B parameters in general. The last six parameters involve differences between the \overline{B} and B meson decay parameters. The phase convention δ_0 is chosen with respect to a single A_{00} amplitude from a reference B decay mode, which is $B^0 \to \varphi K_0^*(1430)^0$ for numerical results.

| parameter | definition | average |
|--------------------------|---------------------------------------------------------------|--------------------------------|
| \mathcal{B} | $\Gamma/\Gamma_{\rm total}$ | $(9.8 \pm 0.6) \times 10^{-6}$ |
| f_L | $ A_0 ^2/\Sigma A_\lambda ^2$ | 0.480 ± 0.030 |
| f_{\perp} | $ A_{\perp} ^2/\Sigma A_{\lambda} ^2$ | 0.24 ± 0.05 |
| $\phi_{\parallel}-\pi$ | $arg(A_{\parallel}/A_0) - \pi$ | -0.74 ± 0.13 |
| $\phi_{\perp} - \pi$ | $arg(A_{\perp}/A_0) - \pi$ | -0.75 ± 0.13 |
| $\delta_0 - \pi$ | $\arg(A_{00}/A_0) - \pi$ | -0.32 ± 0.17 |
| A_{CP} | $(\bar{\Gamma} - \Gamma)/(\bar{\Gamma} + \Gamma)$ | $+0.01 \pm 0.05$ |
| A_{CP}^0 | $(\bar{f_L}-f_L)/(\bar{f_L}+f_L)$ | $+0.04\pm0.06$ |
| A_{CP}^{\perp} | $(\bar{f}_{\perp} - f_{\perp})/(\bar{f}_{\perp} + f_{\perp})$ | -0.11 ± 0.12 |
| $\Delta\phi_{\parallel}$ | $(ar{\phi_{\parallel}} - \phi_{\parallel})/2$ | $+0.11 \pm 0.22$ |
| $\Delta\phi_{\perp}$ | $(\bar{\phi_{\perp}} - \phi_{\perp} - \pi)/2$ | $+0.08 \pm 0.22$ |
| $\Delta \delta_0$ | $(\bar{\delta_0} - \delta_0)/2$ | $+0.27 \pm 0.16$ |

Overall, six real parameters describe three complex amplitudes A_0 , A_{\parallel} , and A_{\perp} . These could be chosen to be the four polarization parameters f_L , f_{\perp} , ϕ_{\parallel} , and ϕ_{\perp} , one overall size normalization, such as decay rate Γ , or branching fraction \mathcal{B} , and one overall phase δ_0 . The phase convention is arbitrary for an isolated B decay mode. However, for several B decays, the relative phase could produce meaningful and observable effects through interference with other B decays with the same final states, such as for $B \to VK_J^*$ with $J=0,1,2,3,4,\ldots$ The phase could be referenced to the single $B \to VK_0^*$ amplitude A_{00} in such a case, as shown in Table 1. Here V stands for any spin-one vector meson.

Moreover, CP violation can be tested in the angular distribution of the decay as the difference between the B and \overline{B} . Each of the six real parameters describing the three complex amplitudes would have a counterpart CP-asymmetry term, corresponding to three direct-CP asymmetries in three amplitudes, and three CP-violating phase differences, equivalent to the phase measurements from the mixing-induced CP asymmetries in the time evolution of B-decays [1]. In Table 1 and Ref. 8, these are chosen to be the direct-CP asymmetries in the overall decay rate \mathcal{A}_{CP} , in the f_L fraction \mathcal{A}_{CP}^0 , and in the f_\perp fraction \mathcal{A}_{CP}^1 , and three weak phase differences:

$$\Delta \phi_{\parallel} = \frac{1}{2} \arg(\bar{A}_{\parallel} A_0 / A_{\parallel} \bar{A}_0),$$
 (8)

$$\Delta \phi_{\perp} = \frac{1}{2} \arg(\bar{A}_{\perp} A_0 / A_{\perp} \bar{A}_0) - \frac{\pi}{2}, \qquad (9)$$

 B^0

$$\Delta \delta_0 = \frac{1}{2} \arg(\bar{A}_{00} A_0 / A_{00} \bar{A}_0). \tag{10}$$

The $\frac{\pi}{2}$ term in Eq. (9) reflects the fact that A_{\perp} and \bar{A}_{\perp} differ in phase by π if CP is conserved. The two parameters $\Delta\phi_{\parallel}$ and $\Delta\phi_{\perp}$ are equivalent to triple-product asymmetries constructed from the vectors describing the decay angular distribution [9]. The CP-violating phase difference in the reference decay mode [8] is, in the Wolfenstein CKM quark-mixing phase convention,

$$\Delta\phi_{00} = \frac{1}{2}\arg(A_{00}/\bar{A}_{00}). \tag{11}$$

This can be measured only together with the mixing-induced phase difference for some of the neutral *B*-meson decays similar to other mixing-induced *CP* asymmetry measurements [1].

It may not always be possible to have a phase-reference decay mode which would define δ_0 and $\Delta\delta_0$ parameters. In that case, it may be possible to define the phase difference directly similarly to Eq. (11):

$$\Delta \phi_0 = \frac{1}{2} \arg(A_0/\bar{A}_0) \,.$$
 (12)

One can measure the angles of the CKM unitarity triangle, assuming Standard Model contributions to the $\Delta\phi_0$ and B-mixing phases. Examples include measurements of $\beta=\phi_1$ with $B\to J/\psi K^*$ and $\alpha=\phi_2$ with $B\to\rho\rho$.

Most of the B decays that arise from tree-level $b \rightarrow c$ transitions have the amplitude hierarchy $|A_0| > |A_+| > |A_-|$ which is expected from analyses based on quark-helicity conservation [10]. The larger the mass of the vector-meson daughters, the weaker the inequality. The B meson decays to heavy vector particles with charm, such as $B \to J/\psi K^*$, $\psi(2S)K^*$, $\chi_{c1}K^*$, $D^*\rho$, D^*K^* , D^*D^* , and $D^*D^*_s$, show a substantial fraction of the amplitudes corresponding to transverse polarization of the vector mesons $(A_{\pm 1})$, in agreement with the factorization prediction. The detailed amplitude analysis of the $B \to J/\psi K^*$ decays has been performed by the BABAR [11], Belle [12], CDF [13], CLEO [14], and D0 [15] collaborations. Most analyses are performed under the assumption of the absence of direct CP violation. The parameter values are given in the particle listing of this Review. The difference between the strong phases ϕ_{\parallel} and ϕ_{\perp} deviates significantly from zero. The recent measurements [11,12] of CP-violating terms similar to those in $B \to \varphi K^*$ [8] shown in Table 1 are consistent with zero.

In addition, the mixing-induced CP-violating asymmetry is measured in the $B^0 \to J/\psi K^{*0}$ decay [1,11,12] where angular analysis allows one to separate CP-eigenstate amplitudes. This allows one to resolve the sign ambiguity of the $\cos 2\beta$ ($\cos 2\phi_1$) term that appears in the time-dependent angular distribution due to interference of parity-even and parity-odd terms. This analysis relies on the knowledge of discrete ambiguities in the strong phases ϕ_{\parallel} and ϕ_{\perp} , as discussed below. The BABAR experiment used a method based on the dependence on the $K\pi$ invariant mass of the interference between the S- and P-waves to resolve the discrete ambiguity in the determination of the

strong phases $(\phi_{\parallel}, \phi_{\perp})$ in $B \to J/\psi K^*$ decays [11]. The result is in agreement with the amplitude hierarchy expectation [10]. The CDF [16], D0 [17], and LHCb [18] experiments have studied the $B_s^0 \to J/\psi \varphi$ decay and provided the lifetime, polarization, and phase measurements.

The amplitude hierarchy $|A_0| \gg |A_+| \gg |A_-|$ was expected in B decays to light vector particles in both penguin transitions [19,20] and tree-level transitions [10]. There is confirmation by the BABAR and Belle experiments of predominantly longitudinal polarization in the tree-level $b \to u$ transition, such as $B^0 \to \rho^+ \rho^-$ [21], $B^+ \to \rho^0 \rho^+$ [22], and $B^+ \to \omega \rho^+$ [23]; this is consistent with the analysis of the quark helicity conservation [10]. Because the longitudinal amplitude dominates the decay, a detailed amplitude analysis is not possible with current B samples, and limits on the transverse amplitude fraction are obtained. The fraction of transverse polarization is large in decays to heavier mesons such as $B^0 \to a_1(1260)^+ a_1(1260)^-$ [24]. Only limits have been set for $B^0 \to \omega \rho^0, \omega \omega$ [23]; there is some evidence for $B^0 \to \rho^0 \rho^0$ [25] decays. The small values for these branching fractions indicates that $b \to d$ penguin pollution is small in the charmless, strangeless vector-vector B decays.

The interest in the polarization and CP-asymmetry measurements in penguin transition, such as $b \rightarrow s$ decays $B \to \varphi K^*, \ \rho K^*, \ \omega K^*, \ {\rm or} \ B^0_s \to \varphi \varphi, \ {\rm and} \ b \to d \ {\rm decay}$ $B \to K^*K^*$, is motivated by their potential sensitivity to physics beyond the Standard Model. The decay amplitudes for $B \to \varphi K^*$ have been measured by the BABAR and Belle experiments [8,26,27]. The fractions of longitudinal polarization are $f_L = 0.50 \pm 0.05$ for the $B^+ \rightarrow \varphi K^{*+}$ decay and $f_L = 0.48 \pm 0.03$ for the $B^0 \to \varphi K^{*0}$ decay. These indicate significant departure from the naive expectation of predominant longitudinal polarization, suggesting other contributions to the decay amplitude, previously neglected, either within the Standard Model, such as penguin annihilation [28] or QCD rescattering [29], or from physics beyond the Standard Model [30]. The complete set of twelve amplitude parameters measured in the $B^0 \to \varphi K^{*0}$ decay is given in Table 1. Several other parameters could be constructed from the above twelve parameters, as suggested in Ref. 31.

The discrete ambiguity in the phase $(\phi_{\parallel}, \phi_{\perp}, \Delta\phi_{\parallel}, \Delta\phi_{\perp})$ measurements has been resolved by BABAR in favor of $|A_{+}| \gg |A_{-}|$ through interference between the S- and P-waves of $K\pi$. The search for vector-tensor and vector-axial vector $B \to \varphi K_{J}^{(*)}$ decays with J=1,2,3,4 revealed a large fraction of longitudinal polarization in the decay $B \to \varphi K_{2}^{*}(1430)$ with $f_{L}=0.90_{-0.07}^{+0.06}$ [8,32], but large contribution of transverse amplitude in $B \to \varphi K_{1}(1270)$ with $f_{L}=0.46_{-0.15}^{+0.13}$ [33].

Like $B \to \varphi K^*$, the decays $B \to \rho K^*$ and $B \to \omega K^*$ may be sensitive to New Physics. Measurements of the longitudinal polarization fraction in $B^+ \to \rho^0 K^{*0}$, $B^+ \to \rho^+ K^{*0}$ [34] and in both vector-vector and vector-tensor final states of $B \to \omega K_J^*$ [23] reveal a large fraction of transverse polarization, indicating an anomaly similar to $B \to \varphi K^*$ except for a different

pattern in vector-tensor final states. A large transverse polarization is also observed in the $B^0_s \to \varphi \varphi$ decays by CDF [37] and $B^0_s \to K^{*0} \bar{K}^{*0}$ decays by LHCb [36]. At the same time, first measurement of the polarization in the $b \to d$ penguin decays $B \to K^* \bar{K}^*$ indicates a large fraction of longitudinal polarization [35]. The polarization pattern in penguin-dominated B-meson decays is not fully understood [28,29,30].

The three-body semileptonic B-meson decays, such as $B \to V\ell_1\ell_2$, share many features with the two-body $B \to VV$ decays. Their differential decay width can be parameterized with the two helicity angles defined in the V and $(\ell_1\ell_2)$ frames and with the azimuthal angle, as defined in Fig. 1. However, since the $(\ell_1\ell_2)$ pair does not come from an on-shell particle, the angular distribution is unique to each point in the dilepton mass $m_{\ell\ell}$ spectrum. The polarization measurements as a function of $m_{\ell\ell}$ provide complementary information on physics beyond the Standard Model, as discussed for $B \to K^*\ell^+\ell^-$ decay in Ref. 38. The current data in this mode has been analyzed by the BABAR, Belle, and CDF experiments [39].

The examples of the angular distributions and observables in $B \to K^* \ell^+ \ell^-$ are discussed in Ref. 38. Typically two angular observables have been measured in this decay in certain ranges of the dilepton mass $m_{\ell\ell}$ [39]. One parameter is the fraction of longitudinal polarization F_L , which is determined by the K^* angular distribution and is similar to f_L defined for exclusive two-body decays. The other parameter is the forward-backward asymmetry of the lepton pair A_{FB} , which is the asymmetry of the decay rate with positive and negative values of $\cos \theta_1$.

In summary, there has been considerable recent interest in the polarization measurements of B-meson decays because they reveal both weak- and strong-interaction dynamics [28–30,40]. New measurements will further elucidate the pattern of spin alignment measurements in rare B decays, and further test the Standard Model and strong interaction dynamics, including the non-factorizable contributions to the B-decay amplitudes.

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POLARIZATION IN BO DECAY

In decays involving two vector mesons, one can distinguish among the states in which meson polarizations are both longitudinal (L) or both are transverse and parallel (||) or perpendicular (\perp) to each other with the parameters Γ_L/Γ , Γ_\perp/Γ , and the relative phases ϕ_\parallel and ϕ_\perp . See the definitions in the note on "Polarization in B Decays" review in the $B^{\,0}$

Γ_L/Γ in $B^0 \rightarrow J/\psi(1S) K^*(892)^0$

| VALUE | EVTS | DO CUMENT ID | TE | ECNCOMMENT |
|---------------------------------------|------------|-----------------------|------------|---------------------------------------|
| 0.570±0.008 OUR AV | /ERAGE | | | |
| $0.587\pm0.011\pm0.013$ | | ¹ ABAZOV | 09E D | 0 $p\overline{p}$ at 1.96 TeV |
| $0.556 \pm 0.009 \pm 0.010$ | | ² AUBERT | 07AD BA | ABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.562\pm0.026\pm0.018$ | | ACOSTA | 05 CI | DF $p\overline{p}$ at 1.96 TeV |
| $0.574\pm0.012\pm0.009$ | | ITOH | 05 BI | ELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.59 \pm 0.06 \pm 0.01$ | | ³ AFFOLDER | 00n CI | DF $p\overline{p}$ at 1.8 TeV |
| $0.52 \pm 0.07 \pm 0.04$ | | ⁴ JESSOP | 97 CI | LE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.65 \pm 0.10 \pm 0.04$ | 65 | ABE | 95 z CI | DF ρ p at 1.8 TeV |
| $0.97 \pm 0.16 \pm 0.15$ | 13 | ⁵ ALBRECHT | 94 G A I | RG $e^+e^- \rightarrow \Upsilon(4S)$ |
| ● ● We do not use | the follow | ing data for averag | ges, fits, | limits, etc. • • • |
| $0.566\pm0.012\pm0.005$ | | ² AUBERT | 05 P B | ABR Repl. by AUBERT 07AD |
| $0.62 \pm 0.02 \pm 0.03$ | | ⁶ ABE | 02N BI | ELL Repl. by ITOH 05 |
| $0.597\pm0.028\pm0.024$ | | ⁷ AUBERT | 01H B/ | ABR Repl. by AUBERT 07AD |
| $0.80\ \pm0.08\ \pm0.05$ | 42 | ⁵ ALAM | 94 CI | LE2 Sup. by JESSOP 97 |
| | | | | |

- 1 Measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^0 \to J/\psi \, K^{*0}$ and $B_s^0 \to J/\psi \, \phi$.
- ² Obtained by combining the B^0 and B^+ modes.
- a AFFOLDER 00x measurements are based on 190 B^0 candidates obtained from a data sample of 89 pb $^{-1}$. The *P*-wave fraction is found to be $0.13^{+0.12}_{-0.09} \pm 0.06$.
- 4 JESSOP 97 is the average over a mixture of $B^{\,0}$ and B^+ decays. The P-wave fraction
- is found to be 0.16 \pm 0.08 \pm 0.04. 5 Averaged over an admixture of B^0 and B^+ decays.
- 6 Averaged over an admixture of B^0 and B^+ decays and the P wave fraction is (19 \pm 2 \pm
- 7 Averaged over an admixture of B^0 and B^- decays and the P wave fraction is (16.0 \pm 3.2 \pm 1.4) \times 10 $^{-2}$.

Γ_{\perp}/Γ in $B^0 \rightarrow J/\psi K^{*0}$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------------|---------------------|-----------------|------------------------------------|
| 0.219±0.010 OUR AVERAGE | Error includes scal | e factor of 1.2 | |
| $0.230 \pm 0.013 \pm 0.025$ | $^{ m 1}$ abazov | 09E D0 | $p\overline{p}$ at 1.96 TeV |
| $0.233 \pm 0.010 \pm 0.005$ | ² AUBERT | 07AD BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.215 \pm 0.032 \pm 0.006$ | ACOSTA | 05 CDF | $p\overline{p}$ at 1.96 TeV |
| $0.195 \pm 0.012 \pm 0.008$ | IT OH | 05 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |

 $^{^{}m 1}$ Measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^{\,0} \to J/\psi\, K^{*0}$ and $B_s^{\,0} \to J/\psi\, \phi$

| $\phi_{ }$ in $B^0 \rightarrow J/\psi K$ |
|-------------------------------------------|
|-------------------------------------------|

| VALUE (rad) | DO CUMENT ID | TECN | COMMENT |
|---------------------------|----------------------|----------------|---------------------------------|
| -2.86±0.11 OUR AVERAGE | Error includes scale | factor of 1.5. | |
| $-2.69 \pm 0.08 \pm 0.11$ | ¹ ABAZOV | 09E D0 | $p\overline{p}$ at 1.96 TeV |
| $-2.93 \pm 0.08 \pm 0.04$ | ² AUBERT | 07AD BABR | $e^+e^- \rightarrow \gamma(4S)$ |

 $^{^{1}}$ Obtained $\phi_{||}$ as $\delta_{2}-\delta_{1}$, assuming they are uncorrelated.

ϕ_{\perp} in $B^0 \rightarrow J/\psi K^{*0}$

| , | , | | | | |
|---------------------------|-------------|--------------------------|-------------|---------------------------------------|--|
| VALUE (rad) | | DO CUMENT ID | TECN | COMMENT | |
| 3.01 ± 0.14 OUR AV | ERAGE | Error includes scale fac | tor of 2.9. | | |
| $3.21 \pm 0.06 \pm 0.06$ | | ABAZOV | 09E D0 | $p\overline{p}$ at 1.96 TeV | |
| $2.91 \pm 0.05 \pm 0.03$ | | ¹ AUBERT | 07AD BABR | $e^+e^- ightarrow ~ \varUpsilon(4S)$ | |
| $^{ m 1}$ Obtained by con | nbining the | B^0 and B^+ modes. | | | |

$\Gamma_{I}/\Gamma \text{ in } B^{0} \rightarrow \psi(2S) K^{*}(892)^{0}$

| $I_{L/1} III D $ | - , | | | | |
|---------------------------------------------------|-----------------------|------|------|---------------------------------|---|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| 0.46 ±0.04 OUR AVERAGE | | | | | |
| $0.448 {}^{+ 0.040 + 0.040}_{- 0.027 - 0.053}$ | MIZUK | 09 | BELL | $e^+e^- ightarrow \gamma (45)$ |) |
| $0.48 \pm 0.05 \pm 0.02$ | ¹ AUBERT | 07AE | BABR | $e^+e^- \rightarrow \gamma(4S)$ |) |
| $0.45 \pm 0.11 \pm 0.04$ | ² RICHICHI | 01 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |) |

 $^{^1}$ Obtained by combining the B^0 and B^+ modes. ²Averages between charged and neutral B mesons.

Γ_{\perp}/Γ in $B^0 \rightarrow \psi(2S) K^{*0}$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|--------------------------|-------------------------|-------|-----------------------------------|
| $0.30 \pm 0.06 \pm 0.02$ | ¹ AUBERT 07A | DBABR | $e^+e^- \rightarrow \Upsilon(4S)$ |

 $^{^{1}}$ Obtained by combining the $B^{\,0}$ and $B^{\,+}$ modes.

ϕ_{\parallel} in $B^0 \rightarrow \psi(2S) K^{*0}$

| VALUE (rad) | DO CUMENT ID | TECN | COMMENT |
|------------------------|--------------|-----------|-----------------------------------|
| $-2.8 \pm 0.4 \pm 0.1$ | 1 AUBERT | 07AD BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |

 $^{^{1}}$ Obtained by combining the B^{0} and B^{+} modes.

ϕ_{\perp} in $B^0 \rightarrow \psi(2S) K^{*0}$

| VALUE (rad) | DO CUMENT ID | TECN | COMMENT | |
|-----------------|--------------|-----------|---------------------------------|--|
| 2.8 ± 0.3 ± 0.1 | 1 AUBERT | 07AD BABR | $e^+e^- \rightarrow \gamma(45)$ | |

 $^{^{1}}$ Obtained by combining the B^{0} and B^{+} modes

Γ_L/Γ in $B^0 \rightarrow \chi_{c1} K^*(892)^0$

| $0.83 \buildrel {+0.06 \atop -0.08}$ OUR AVERAGE | Error includes scale | facto | or of 1.3. | | |
|---------------------------------------------------------|----------------------|-------|------------|----------------------|----------------|
| $0.947 {}^{+ 0.038}_{- 0.048} {}^{+ 0.046}_{- 0.099}$ | MIZUK | 80 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

DOCUMENT ID

TECN COMMENT

 $0.77 \ \pm 0.07 \ \pm 0.04$ 07AD BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 Obtained by combining the \mathcal{B}^{0} and \mathcal{B}^{+} modes

Γ_{\perp}/Γ in $B^0 \rightarrow \chi_{c1} K^*(892)^0$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|----------------|--------------|-----------|-----------------------------------|
| 0.03±0.04±0.02 | 1 AUBERT | 07AD BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |

 $^{^{1}}$ Obtained by combining the $B^{\,0}$ and $B^{\,+}$ modes.

$\phi_{||}$ in $B^0 \to \chi_{c1} K^*(892)^0$

| 0.0+0.3+0.1 1 AUBERT 07AD | BARR | $e^+e^- \rightarrow \gamma(45)$ | |
|---------------------------|------|---------------------------------|--|
| VALUE (rad) DOCUMENT ID | TECN | COMMENT | |

 $^{^{1}\,\}mathrm{Obtained}$ by combining the $B^{\,0}\,$ and $B^{\,+}\,$ modes.

Γ_L/Γ in $B^0 \rightarrow D_s^{*+}D^{*-}$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------------|------------------------|---------|---------------------------------|
| 0.52 ±0.05 OUR AVERAGE | | | |
| $0.519 \pm 0.050 \pm 0.028$ | ¹ AUBERT 0: | 3ı BABR | $e^+e^- \rightarrow \gamma(4S)$ |
| $0.506 \pm 0.139 \pm 0.036$ | AHMED 0 | OB CLE2 | $e^+e^- \rightarrow \gamma(45)$ |

¹ Measurement performed using partial reconstruction of D^{*-} decay.

| VALUE | EVIS | DOCUMENT II | υ | IECN | COMMENT | |
|--------------------------|-------------|----------------|------------|---------|-----------------------------|-----|
| 0.885 ± 0.016 ± 0.012 | | CSORNA | 03 | CLE2 | $e^+e^- \rightarrow \gamma$ | 45) |
| • • • We do not use th | e following | data for avera | ges, fits, | limits, | etc. • • • | |
| $0.93 \pm 0.05 \pm 0.05$ | 76 | ALAM | 94 | CLE2 | $e^+e^- \rightarrow \gamma$ | 4S) |

| I_L/I in $B^0 	o D_S^{*+} ho^-$ | | | | |
|------------------------------------|---------------------|-----------|---------------------------------|--|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| $0.84^{+0.26}_{-0.26} \pm 0.13$ | ¹ AUBERT | 08AL BABR | $e^+e^- \rightarrow \gamma(4S)$ | |

 $^{^1}$ Assumes equal production of B^+ and B^0 at the \varUpsilon (4S).

Γ_L/Γ in $B^0 \rightarrow D_s^{*+} K^{*-}$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-------------------------------|--------------|------|---------------------------------|
| $0.92^{+0.37}_{-0.31}\pm0.07$ | 1 AUBERT 08A | BABR | $e^+e^- \rightarrow \gamma(4S)$ |

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

² Obtained by combining the B^0 and B^+ modes.

² Obtained by combining the B^0 and B^+ modes.

| LUE DOCUMENT ID TECN COMMENT | $\delta_0(B^0	o\phi K^{ullet 0})$ VALUE (rad) DOCUMENT ID TECN COMMENT | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 57±0.08±0.02 MIYAKE 05 BELL $e^+e^- ightarrow \Upsilon(4S)$ | 2.82\pm0.15\pm0.09 AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4.5)$ | 5) |
| $_{\perp}/\Gamma$ in $B^0 \to D^{*+}D^{*-}$ | • • • We do not use the following data for averages, fits, limits, etc. • • • | , |
| L/I III $B^z \to D^z \cdot D^z$ | 2.78±0.17±0.09 AUBERT 07D BABR Repl. by AUBER | RT 08 |
| 150±0.025 OUR AVERAGE | A_{CP}^0 in $B^0	o \phi K^{*0}$ | |
| $158\pm0.028\pm0.006$ AUBERT 09C BABR $e^+e^- 	o 	ag{7(4S)}$ | VALUE DOCUMENT ID TECH COMMENT | |
| 1.25 \pm 0.043 \pm 0.023 VERVINK 09 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • We do not use the following data for averages, fits, limits, etc. • • • | 0.04 ± 0.06 OUR AVERAGE | ۵. |
| .43±0.034±0.008 AUBERT 07во ВАВК Repl. by AUBERT 09с | $0.01\pm0.07\pm0.02$ AUBERT 08BG BABR $e^+e^- ightarrow \varUpsilon(4S)$ $0.13\pm0.12\pm0.04$ 1 CHEN 05A BELL $e^+e^- ightarrow \varUpsilon(4S)$ | , |
| .25 ± 0.044 ± 0.007 AUBERT,BE 05A BABR Repl. by AUBERT 07B0 | • • • We do not use the following data for averages, fits, limits, etc. • • • | , |
| .9 ±0.08 ±0.01 MIYAKE 05 BELL Repl. by VERVINK 09 063±0.055±0.009 AUBERT 03Q BABR Repl. by AUBERT,BE 05A | $-0.03\pm0.08\pm0.02$ AUBERT 07D BABR Repl. by AUBER | RT 08 |
| | $-0.06\pm0.10\pm0.01$ AUBERT,B 04W BABR Repl. by AUBER | |
| c/Γ in $B^0	o \overline D^{*0}\omega$ | $^{ m 1}$ This quantity was recalculated by the BELLE authors from numbers in the origin | inal pa |
| <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 65 \pm 0.047 \pm 0.015 LEES 11M BABR $e^+e^- \rightarrow \Upsilon(4S)$ | A_{CP}^{\perp} in $B^0	o\phi K^{*0}$ | |
| · · · · · · · · · · · · · · · · · · · | VALUE DOCUMENT ID TECN COMMENT -0.11±0.12 OUR AVERAGE | |
| / Γ in $B^0 	o D^{*-}\omega \pi^+$ | -0.01 ± 0.12 OOR AVERAGE $-0.04\pm0.15\pm0.06$ AUBERT 08BG BABR $e^+e^- ightarrow \gamma(45)$ | 5) |
| <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 54±0.042±0.016 1 AUBERT 06L BABR e^+e^- → $\Upsilon(4S)$ | $-0.20\pm0.18\pm0.04$ 1 CHEN 05A BELL $e^+e^- ightarrow \gamma(4S)$ | , |
| Invariant mass of the $[\omega\pi]$ system is restricted in the region 1.1 and 1.9 GeV. | ullet $ullet$ $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | |
| | -0.03±0.16±0.05 AUBERT 07D BABR Repl. by AUBERT | |
| /F in $B^0 	o \omega K^{*0}$ | $-0.10\pm0.24\pm0.05$ AUBERT,B 04W BABR Repl. by AUBER 1 This quantity was recalculated by the BELLE authors from numbers in the origin | |
| UE DOCUMENT ID TECN COMMENT 9±0.13 OUR AVERAGE | _ | шаг ра |
| $2\pm0.14\pm0.02$ AUBERT 09H BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ | $\Delta\phi_{\parallel}$ in $B^0	o \phi K^{*0}$ | |
| $6\pm0.29^{+0.18}_{-0.08}$ GOLDENZWE08 BELL $e^+e^- ightarrow \varUpsilon(4S)$ | VALUE (rad) DOCUMENT ID TECN COMMENT 0.11 ± 0.22 OUR AVERAGE Error includes scale factor of 1.7. | |
| | 0.11 \pm 0.22 OUR AVERAGE Error includes scale factor of 1.7. 0.22 \pm 0.12 \pm 0.08 AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4.5)$ | S) |
| /F in $B^0 	o \omega K_2^* (1430)^0$ | $-0.32\pm0.27\pm0.07$ 1 CHEN 05A BELL $e^+e^- ightarrow 	ag{4.5}$ | |
| LUE DOCUMENT ID TECN COMMENT 15 \pm 0.12 \pm 0.02 AUBERT 09H BABR $e^+e^- ightarrow $ | • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| | 0.24±0.14±0.08 AUBERT 07D BABR Repl. by AUBER | |
| /Γ in $B^0 	o 	extit{K*}^0 \overline{K}^{*0}$ | $0.27 + 0.20 \pm 0.05$ AUBERT,B 04w BABR Repl. by AUBER | RT 07 |
| .UE DOCUMENT ID TECNCOMMENT | $^{ m 1}$ This quantity was recalculated by the BELLE authors from numbers in the origin | inal pa |
| $0 + 0.10 \pm 0.06$ AUBERT 081 BABR $e^+ e^- \rightarrow \Upsilon(4S)$ | $\Delta\phi_{\perp}$ in $B^0	o\phi K^{*0}$ | |
| /Γ in $B^0 	o \phi K^*(892)^0$ | VALUE (rad) DO CUMENT ID TECN COMMENT | |
| LUE DOCUMENT ID TECN COMMENT | 0.08±0.22 OUR AVERAGE Error includes scale factor of 1.7. | |
| 80±0.030 OUR AVERAGE | $0.21 \pm 0.13 \pm 0.08$ AUBERT 08BG BABR $e^+e^- 	ou 	ag{4.5}$ $-0.30 \pm 0.25 \pm 0.06$ 1 CHEN 05A BELL $e^+e^- 	ou 	ag{4.5}$ | , |
| 94±0.034±0.013 AUBERT 08BG BABR $e^+e^- \to \Upsilon(4S)$ 5 ±0.05 ±0.02 CHEN 05A BELL $e^+e^- \to \Upsilon(4S)$ | • • • We do not use the following data for averages, fits, limits, etc. • • • | ٥, |
| • • We do not use the following data for averages, fits, limits, etc. • • | 0.19±0.15±0.08 AUBERT 07D BABR Repl. by AUBER | RT 08 |
| $06\pm0.040\pm0.015$ AUBERT 07D BABR Repl. by AUBERT 08BG | 0.36 ± 0.25 ± 0.05 AUBERT,B 04W BABR Repl. by AUBER | |
| $2 \pm 0.05 \pm 0.02$ 1 AUBERT,B 04w BABR Repl. by AUBERT 07D | $^{ m 1}$ This quantity was recalculated by the BELLE authors from numbers in the origin | inal pa |
| 5 ±0.07 ±0.09 AURERT DAVE DADE DAN BUALDEDT DAMA | | |
| | $\Delta \delta_0(B^0 	o \phi K^{*0})$ | |
| $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A | VALUE (rad) DO CUMENT ID TECN COMMENT | |
| $\pm 1.10\pm0.00\pm0.04$ CHEN 03B BELL Repl. by CHEN 05A ± 1.00 CHEN 05A dubert, B 04W also measures the fraction of parity-odd transverse contribution f $_{\perp}=0.22\pm0.05\pm0.02$ and the phases of the parity-even and parity-odd transverse amplitudes | VALUE (rad)DO CUMENT IDTECNCOMMENT $0.27 \pm 0.14 \pm 0.08$ AUBERT08 bg BABR $e^+e^- \rightarrow \Upsilon(4S)$ | S) |
| $\pm 1.\pm 0.10\pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A 1 AUBERT,B 04W also measures the fraction of parity-odd transverse contribution f $_\perp=0.22\pm 0.05\pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A AUBERT,B 04W also measures the fraction of parity-odd transverse contribution f $_{\perp}=0.22\pm 0.05\pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. L/ Γ in $B^0 \to \phi K^{*0}$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A 1 AUBERT,B 04w also measures the fraction of parity-odd transverse contribution $f_{\perp}=0.22\pm0.05\pm0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. $\int \Gamma \ln B^{0} \rightarrow \phi K^{*0}$ LUE DOCUMENT ID TECN COMMENT | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A AUBERT, B 04w also measures the fraction of parity-odd transverse contribution $f_{\perp} = 0.22 \pm 0.05 \pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. A Fin $B^0 \rightarrow \phi K^{*0}$ UE DOCUMENT ID TECN COMMENT Fror includes scale factor of 1.5. | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , RT 08 |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A AUBERT,B 04w also measures the fraction of parity-odd transverse contribution $f_{\perp} = 0.22 \pm 0.05 \pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. // Fin $B^0 \rightarrow \phi K^{*0}$ LUE A ± 0.05 OUR AVERAGE Error includes scale factor of 1.5. 12 $\pm 0.032 \pm 0.013$ AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | , RT 08 |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A AUBERT, B 04w also measures the fraction of parity-odd transverse contribution $f_{\perp} = 0.22 \pm 0.05 \pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. // Γ in $B^0 \rightarrow \phi K^{*0}$ // Ψ 4 ± 0.05 OUR AVERAGE Error includes scale factor of 1.5. AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(45)$ 1 $\pm 0.05 \pm 0.02$ 1 CHEN 05A BELL $e^+e^- \rightarrow \Upsilon(45)$ | $VALUE$ (rad) 0.27±0.14±0.08 • • We do not use the following data for averages, fits, limits, etc. • • • 0.21±0.17±0.08 Δφ ₀₀ ($B^0 \rightarrow \phi K_0^*$ (1430) ⁰) $VALUE$ (rad) 0.28±0.42±0.04 $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) $VALUE$ (rad) | , RT 08 |
| 1 $\pm 0.10 \pm 0.04$ CHEN 03B BELL Repl. by CHEN 05A AUBERT,B 04W also measures the fraction of parity-odd transverse contribution $f_{\perp} = 0.22 \pm 0.05 \pm 0.02$ and the phases of the parity-even and parity-odd transverse amplitudes relative to the longitudinal amplitude. A Fin B ⁰ $\rightarrow \phi K^{+0}$ B DOCUMENT ID TECN COMMENT TECN COMMENT 1 $\pm 0.032 \pm 0.013$ AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4S)$ 1 $\pm 0.06 \pm 0.02$ 1 CHEN 05A BELL $e^+e^- \rightarrow \Upsilon(4S)$ • We do not use the following data for averages, fits, limits, etc. • • | $VALUE$ (rad) DOCUMENT ID TECN COMMENT 10.27±0.14±0.08 AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4.5)$ 0.21±0.17±0.08 AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT 07D BABR Repl. by AUBERT | RT 08 |
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 B^0

| $\delta_0(B^0 \to \phi K_2^*(1430)^0)$ | | |
|-------------------------------------------------------------------------------|-----------------------|---------------------------------------------------------------------------|
| · | DOCUMENT ID | |
| $3.41 \pm 0.13 \pm 0.13$ • • • We do not use the following | | GBABR $e^+e^- ightarrow \varUpsilon(4S)$ ts, limits, etc. $ullet$ $ullet$ |
| $3.54 {}^{+\; 0.12}_{-\; 0.14} \pm 0.06$ | AUBERT 07D | BABR Repl. by AUBERT 08BG |
| A_{CP}^{0} in $B^{0} \rightarrow \phi K_{2}^{*}(1430)^{0}$ | | |
| VALUE | DOCUMENT ID | TECN COMMENT |
| $-0.05 \pm 0.06 \pm 0.01$ | AUBERT 08 | BG BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $\Delta\phi_{\parallel}(B^0\to \phi K_2^*(1430)^0)$ | | |
| VALUE (rad) | | TECN COMMENT |
| $-1.00 \pm 0.38 \pm 0.09$ | AUBERT 08 | BG BABR $e^+e^- ightarrow \gamma(4S)$ |
| $\Delta \delta_0 \text{ in } B^0 \rightarrow \phi K_2^* (1430)^0$ VALUE (rad) | DOCUMENT ID | TECN COMMENT |
| 0.11±0.13±0.06 | | TECN COMMENT BG BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| | ACDENT 00 | DO DADA C : C → 1(43) |
| Γ_L/Γ in $B^0 	o K^*(892)^0 ho^0$ | DOCUMENT ID | TECN COMMENT |
| $0.57 \pm 0.09 \pm 0.08$ | AUBERT,B 06 | G BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| Γ_L/Γ in $B^0 \to \rho^+ \rho^-$ | DOCUMENT ID | TECN COMMENT |
| 0.977+0.028 OUR AVERAGE | | |
| $0.992 \pm 0.024 ^{+0.026}_{-0.013}$ | AUBERT 07B | FBABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| $0.941^{+0.034}_{-0.040}\pm 0.030$ | SOMOV 06 | BELL $e^+e^- ightarrow \Upsilon(4S)$ |
| • • We do not use the following | data for averages, fi | ts, limits, etc. • • • |
| $0.978 \pm 0.014 ^{+ 0.021}_{- 0.029}$ | AUBERT,B 05 c | BABR Repl. by AUBERT 07BF |
| $0.98 \ ^{+0.02}_{-0.08} \ \pm 0.03$ | AUBERT 04G | BABR Repl. by AUBERT,B 04R |
| $0.99 \ \pm 0.03 \ ^{+ \ 0.04}_{- \ 0.03}$ | AUBERT,B 04R | BABR Repl. by AUBERT,B 05c |
| Γ_L/Γ in $B^0 	o ho^0 ho^0$ | DO CUMENT 1D | TECH COMMENT |
| | DOCUMENT ID | |
| -0.14 | | BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| • • We do not use the following | = | |
| | | BABR Repl. by AUBERT 08BB |
| Γ_L/Γ in $B^0 \rightarrow a_1(1260)^+ a_1(1260)^+$ | | |
| $0.31 \pm 0.22 \pm 0.10$ | AUBERT 09 | ALBABR $e^+e^- ightarrow~\varUpsilon(4S)$ |
| Γ_L/Γ in $B^0 \to p \overline{p} K^*(892)^0$ | | |
| VALUE 1.01±0.13±0.03 | DOCUMENT ID CHEN 08 | TECN COMMENT C BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | CITEIN UO | C DELL C. C → 1(43) |
| Γ_L/Γ in $B^0 \rightarrow \Lambda \overline{\Lambda} K^*(892)^0$ | DOCUMENT ID | TECN COMMENT |
| $0.60 \pm 0.22 \pm 0.08$ | CHANG 09 | BELL $e^+e^- \rightarrow \Upsilon(4S)$ |

$B^0-\overline{B}^0$ MIXING

Updated April 2012 by O. Schneider (Ecole Polytechnique Fédérale de Lausanne).

There are two neutral $B^0-\overline{B}^0$ meson systems, $B^0_d-\overline{B}^0_d$ and $B^0_s-\overline{B}^0_s$ (generically denoted $B^0_q-\overline{B}^0_q$, q=s,d), which exhibit particle-antiparticle mixing [1]. This mixing phenomenon is described in Ref. 2. In the following, we adopt the notation introduced in Ref. 2, and assume CPT conservation throughout. In each system, the light (L) and heavy (H) mass eigenstates,

$$|B_{\rm L,H}\rangle = p|B_q^0\rangle \pm q|\overline{B}_q^0\rangle,$$
 (1)

have a mass difference $\Delta m_q = m_{\rm H} - m_{\rm L} > 0$, and a total decay width difference $\Delta \Gamma_q = \Gamma_{\rm L} - \Gamma_{\rm H}$. In the absence of CP violation in the mixing, |q/p| = 1, these differences are given by $\Delta m_q = 2|M_{12}|$ and $|\Delta \Gamma_q| = 2|\Gamma_{12}|$, where M_{12} and Γ_{12} are the

off-diagonal elements of the mass and decay matrices [2]. The evolution of a pure $|B_q^0\rangle$ or $|\overline{B}_q^0\rangle$ state at t=0 is given by

$$|B_q^0(t)\rangle = g_+(t) |B_q^0\rangle + \frac{q}{p} g_-(t) |\overline{B}_q^0\rangle \,, \tag{2}$$

$$|\overline{B}_{q}^{0}(t)\rangle = g_{+}(t)|\overline{B}_{q}^{0}\rangle + \frac{p}{a}g_{-}(t)|B_{q}^{0}\rangle, \qquad (3)$$

which means that the flavor states remain unchanged (+) or oscillate into each other (-) with time-dependent probabilities proportional to

$$|g_{\pm}(t)|^2 = \frac{e^{-\Gamma_q t}}{2} \left[\cosh\left(\frac{\Delta\Gamma_q}{2}t\right) \pm \cos(\Delta m_q t) \right],$$
 (4)

where $\Gamma_q = (\Gamma_{\rm H} + \Gamma_{\rm L})/2$. In the absence of CP violation, the time-integrated mixing probability $\int |g_-(t)|^2 dt/(\int |g_-(t)|^2 dt + \int |g_+(t)|^2 dt)$ is given by

$$\chi_q = \frac{x_q^2 + y_q^2}{2(x_q^2 + 1)}, \quad \text{where} \quad x_q = \frac{\Delta m_q}{\Gamma_q}, \quad y_q = \frac{\Delta \Gamma_q}{2\Gamma_q}.$$
 (5)

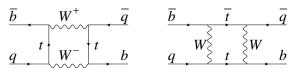


Figure 1: Dominant box diagrams for the $B_q^0 \to \overline{B}_q^0$ transitions (q = d or s). Similar diagrams exist where one or both t quarks are replaced with c or u quarks.

Standard Model predictions and phenomenology

In the Standard Model, the transitions $B_q^0 \to \overline{B}_q^0$ and $\overline{B}_q^0 \to B_q^0$ are due to the weak interaction. They are described, at the lowest order, by box diagrams involving two W bosons and two up-type quarks (see Fig. 1), as is the case for $K^0 - \overline{K}^0$ mixing. However, the long range interactions arising from intermediate virtual states are negligible for the neutral B meson systems, because the large B mass is off the region of hadronic resonances. The calculation of the dispersive and absorptive parts of the box diagrams yields the following predictions for the off-diagonal element of the mass and decay matrices [3],

$$\begin{split} M_{12} &= -\frac{G_F^2 m_W^2 \eta_B m_{B_q} B_{B_q} f_{B_q}^2}{12 \pi^2} \, S_0(m_t^2 / m_W^2) \, (V_{tq}^* V_{tb})^2 \,, \qquad (6) \\ \Gamma_{12} &= \frac{G_F^2 m_b^2 \eta_B' m_{B_q} B_{B_q} f_{B_q}^2}{8 \pi} \\ &\quad \times \left[(V_{tq}^* V_{tb})^2 + V_{tq}^* V_{tb} V_{cq}^* V_{cb} \, \mathcal{O} \left(\frac{m_c^2}{m_b^2} \right) \right. \\ &\quad \left. + (V_{cq}^* V_{cb})^2 \, \mathcal{O} \left(\frac{m_c^4}{m_b^4} \right) \right] \,, \end{split}$$

where G_F is the Fermi constant, m_W the W boson mass, and m_i the mass of quark i; m_{B_q} , f_{B_q} and B_{B_q} are the B_q^0 mass, weak decay constant and bag parameter, respectively. The known function $S_0(x_t)$ can be approximated very well by $0.784 \, x_t^{0.76} \, [4]$, and V_{ij} are the elements of the CKM matrix [5].

The QCD corrections η_B and η_B' are of order unity. The only non-negligible contributions to M_{12} are from box diagrams involving two top quarks. The phases of M_{12} and Γ_{12} satisfy

$$\phi_M - \phi_\Gamma = \pi + \mathcal{O}\left(\frac{m_c^2}{m_b^2}\right), \tag{8}$$

implying that the mass eigenstates have mass and width differences of opposite signs. This means that, like in the $K^0 - \overline{K}{}^0$ system, the heavy state is expected to have a smaller decay width than that of the light state: $\Gamma_{\rm H} < \Gamma_{\rm L}$. Hence, $\Delta \Gamma = \Gamma_{\rm L} - \Gamma_{\rm H}$ is expected to be positive in the Standard Model.

Furthermore, the quantity

$$\left| \frac{\Gamma_{12}}{M_{12}} \right| \simeq \frac{3\pi}{2} \frac{m_b^2}{m_W^2} \frac{1}{S_0(m_t^2/m_W^2)} \sim \mathcal{O}\left(\frac{m_b^2}{m_t^2}\right)$$
 (9)

is small, and a power expansion of $|q/p|^2$ yields

$$\left|\frac{q}{p}\right|^2 = 1 + \left|\frac{\Gamma_{12}}{M_{12}}\right| \sin(\phi_M - \phi_\Gamma) + \mathcal{O}\left(\left|\frac{\Gamma_{12}}{M_{12}}\right|^2\right). \tag{10}$$

Therefore, considering both Eqs. (8) and (9), the CP-violating parameter

$$1 - \left| \frac{q}{p} \right|^2 \simeq \operatorname{Im} \left(\frac{\Gamma_{12}}{M_{12}} \right) \tag{11}$$

is expected to be very small: $\sim \mathcal{O}(10^{-3})$ for the $B_d^0 - \overline{B}_d^0$ system and $\lesssim \mathcal{O}(10^{-4})$ for the $B_s^0 - \overline{B}_s^0$ system [6].

In the approximation of negligible CP violation in mixing, the ratio $\Delta\Gamma_q/\Delta m_q$ is equal to the small quantity $|\Gamma_{12}/M_{12}|$ of Eq. (9); it is hence independent of CKM matrix elements, *i.e.*, the same for the $B_d^0-\overline{B}_d^0$ and $B_s^0-\overline{B}_s^0$ systems. Calculations [7] yield $\sim 5\times 10^{-3}$ with a $\sim 20\%$ uncertainty. Given the published experimental knowledge [8] on the mixing parameter x_q

$$\begin{cases} x_d = 0.770 \pm 0.008 & (B_d^0 - \overline{B}_d^0 \text{ system}) \\ x_s = 26.49 \pm 0.29 & (B_o^0 - \overline{B}_o^0 \text{ system}) \end{cases} , \tag{12}$$

the Standard Model thus predicts that $\Delta\Gamma_d/\Gamma_d$ is very small (below 1%), but $\Delta\Gamma_s/\Gamma_s$ considerably larger (\sim 10%). These width differences are caused by the existence of final states to which both the B_q^0 and \overline{B}_q^0 mesons can decay. Such decays involve $b \to c\overline{c}q$ quark-level transitions, which are Cabibbosuppressed if q=d and Cabibbo-allowed if q=s.

A complete set of Standard Model predictions for all mixing parameters in both the $B_d^0 - \overline{B}_d^0$ and $B_s^0 - \overline{B}_s^0$ systems can be found in Ref. 7.

$\label{lem:experimental} Experimental \ issues \ and \ methods \ for \ oscillation \ analyses$

Time-integrated measurements of B^0 – \overline{B}^0 mixing were published for the first time in 1987 by UA1 [9] and ARGUS [10], and since then by many other experiments. These measurements are typically based on counting same-sign and opposite-sign lepton pairs from the semileptonic decay of the produced $b\overline{b}$ pairs. Such analyses cannot easily separate the contributions from the different b-hadron species, therefore, the clean environment of $\Upsilon(4S)$ machines (where only B_d^0 and charged B_u mesons are produced) is in principle best suited to measure χ_d .

However, better sensitivity is obtained from time-dependent analyses aiming at the direct measurement of the oscillation frequencies Δm_d and Δm_s , from the proper time distributions of B_d^0 or B_s^0 candidates identified through their decay in (mostly) flavor-specific modes, and suitably tagged as mixed or unmixed. This is particularly true for the $B_s^0 - \overline{B}_s^0$ system, where the large value of x_s implies maximal mixing, i.e., $\chi_s \simeq 1/2$. In such analyses, the B_d^0 or B_s^0 mesons are either fully reconstructed, partially reconstructed from a charm meson, selected from a lepton with the characteristics of a $b \to \ell^-$ decay, or selected from a reconstructed displaced vertex. At high-energy colliders (LEP, SLC, Tevatron, LHC), the proper time $t = \frac{m_B}{L}$ is measured from the distance L between the production vertex and the B decay vertex, and from an estimate of the Bmomentum p. At asymmetric B factories (KEKB, PEP-II), producing $e^+e^- \to \Upsilon(4S) \to B_d^0 \overline{B}_d^0$ events with a boost $\beta \gamma$ (=0.425, 0.55), the proper time difference between the two B candidates is estimated as $\Delta t \simeq \frac{\Delta z}{\beta \gamma c}$, where Δz is the spatial separation between the two B decay vertices along the boost direction. In all cases, the good resolution needed on the vertex positions is obtained with silicon detectors.

The average statistical significance \mathcal{S} of a B_d^0 or B_s^0 oscillation signal can be approximated as [11]

$$S \approx \sqrt{N/2} f_{\text{sig}} (1 - 2\eta) e^{-(\Delta m \sigma_t)^2/2}, \qquad (13)$$

where N is the number of selected and tagged candidates, $f_{\rm sig}$ is the fraction of signal in that sample, η is the total mistag probability, and σ_t is the resolution on proper time (or proper time difference). The quantity \mathcal{S} decreases very quickly as Δm increases; this dependence is controlled by σ_t , which is therefore a critical parameter for Δm_s analyses. At high-energy colliders, the proper time resolution $\sigma_t \sim \frac{m_B}{\langle p \rangle} \sigma_L \oplus t \frac{\sigma_p}{p}$ includes a constant contribution due to the decay length resolution σ_L (typically 0.04–0.3 ps), and a term due to the relative momentum resolution σ_p/p (typically 10–20% for partially reconstructed decays), which increases with proper time. At B factories, the boost of the B mesons is estimated from the known beam energies, and the term due to the spatial resolution dominates (typically 1–1.5 ps because of the much smaller B boost).

In order to tag a B candidate as mixed or unmixed, it is necessary to determine its flavor both in the initial state and in the final state. The initial and final state mistag probabilities, η_i and η_f , degrade \mathcal{S} by a total factor $(1-2\eta)=(1-2\eta_i)(1-2\eta_f)$. In lepton-based analyses, the final state is tagged by the charge of the lepton from $b \to \ell^-$ decays; the largest contribution to η_f is then due to $\overline{b} \to \overline{c} \to \ell^-$ decays. Alternatively, the charge of a reconstructed charm meson $(D^{*-}$ from B_d^0 or D_s^- from B_s^0), or that of a kaon hypothesized to come from a $b \to c \to s$ decay [12], can be used. For fully-inclusive analyses based on topological vertexing, final-state tagging techniques include jetcharge [13] and charge-dipole [14,15] methods. At high-energy colliders, the methods to tag the initial state (i.e., the state at production), can be divided into two groups: the ones that tag

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the initial charge of the \overline{b} quark contained in the B candidate itself (same-side tag), and the ones that tag the initial charge of the other b quark produced in the event (opposite-side tag). On the same side, the sign of a charged pion or kaon from the primary vertex is correlated with the production state of the B_d^0 or B_s^0 if that particle is a decay product of a B^{**} state or the first in the fragmentation chain [16,17]. Jet- and vertexcharge techniques work on both sides and on the opposite side, respectively. Finally, the charge of a lepton from $b \to \ell^-$ or of a kaon from $b \to c \to s$ can be used as opposite side tags, keeping in mind that their performance is degraded due to integrated mixing. At SLC, the beam polarization produced a sizeable forward-backward asymmetry in the $Z \to b\overline{b}$ decays, and provided another very interesting and effective initial state tag based on the polar angle of the B candidate [14]. Initial state tags have also been combined to reach $\eta_i \sim 26\%$ at LEP [17,18], or even 22% at SLD [14] with full efficiency. In the case $\eta_f = 0$, this corresponds to an effective tagging efficiency $Q = \epsilon D^2 = \epsilon (1 - 2\eta)^2$, where ϵ is the tagging efficiency, in the range 23 - 31%. The equivalent figure achieved by CDF during Tevatron Run I was $\sim 3.5\%$ [19], reflecting the fact that tagging is more difficult at hadron colliders. The current CDF and DØ analyses of Tevatron Run II data reach $\epsilon D^2 = (1.8 \pm 0.1)\%$ [20] and $(2.5 \pm 0.2)\%$ [21] for opposite-side tagging, while same-side kaon tagging (for B_s^0 analyses) is contributing an additional 3.7-4.8% at CDF [20], and pushes the combined performance to $(4.7 \pm 0.5)\%$ at DØ [22]. LHCb, operating in the forward region at the LHC where the environment is different in terms of track multiplicity and b-hadron production kinematics, has reported $\epsilon D^2 = (2.10 \pm 0.25)\%$ [23] for opposite-side tagging and $(1.3 \pm 0.4)\%$ [24] for same-side kaon tagging.

At B factories, the flavor of a B_d^0 meson at production cannot be determined, since the two neutral B mesons produced in a $\Upsilon(4S)$ decay evolve in a coherent P-wave state where they keep opposite flavors at any time. However, as soon as one of them decays, the other follows a time-evolution given by Eqs. (2) or (3), where t is replaced with Δt (which will take negative values half of the time). Hence, the "initial state" tag of a B can be taken as the final-state tag of the other B. Effective tagging efficiencies Q of 30% are achieved by BaBar and Belle [25], using different techniques including $b \to \ell^-$ and $b \to c \to s$ tags. It is worth noting that, in this case, mixing of the other B (i.e., the coherent mixing occurring before the first B decay) does not contribute to the mistag probability.

In the absence of experimental observation of a decaywidth difference, oscillation analyses typically neglected $\Delta\Gamma$ in Eq. (4), and described the data with the physics functions $\Gamma e^{-\Gamma t} (1 \pm \cos(\Delta m t))/2$ (high-energy colliders) or $\Gamma e^{-\Gamma |\Delta t|} (1 \pm \cos(\Delta m \Delta t))/4$ (asymmetric $\Upsilon(4S)$ machines). As can be seen from Eq. (4), a non-zero value of $\Delta\Gamma$ would effectively reduce the oscillation amplitude with a small time-dependent factor that would be very difficult to distinguish from time resolution effects. Measurements of Δm are usually extracted from the data using a maximum likelihood fit.

Δm_d and $\Delta \Gamma_d$ measurements

Many $B_d^0 - \overline{B}_d^0$ oscillations analyses have been published [26] by the ALEPH [27], DELPHI [15,28], L3 [29], OPAL [30,31] BaBar [32], Belle [33], CDF [16], DØ [21], and LHCb [34] collaborations. Although a variety of different techniques have been used, the individual Δm_d results obtained at high-energy colliders have remarkably similar precision. Their average is compatible with the recent and more precise measurements from asymmetric B factories. The systematic uncertainties are not negligible; they are often dominated by sample composition, mistag probability, or b-hadron lifetime contributions. Before being combined, the measurements are adjusted on the basis of a common set of input values, including the b-hadron lifetimes and fractions published in this Review. Some measurements are statistically correlated. Systematic correlations arise both from common physics sources (fragmentation fractions, lifetimes, branching ratios of b hadrons), and from purely experimental or algorithmic effects (efficiency, resolution, tagging, background description). Combining all published measurements [15,16,21,27-34] and accounting for all identified correlations yields $\Delta m_d = 0.507 \pm 0.003 \text{(stat)} \pm 0.003 \text{(syst)} \text{ ps}^{-1}$ [8], a result dominated by the B factories.

On the other hand, ARGUS and CLEO have published time-integrated measurements [35–37], which average to $\chi_d=0.182\pm0.015$. Following Ref. 37, the width difference $\Delta\Gamma_d$ could in principle be extracted from the measured value of Γ_d and the above averages for Δm_d and χ_d (see Eq. (5)), provided that $\Delta\Gamma_d$ has a negligible impact on the Δm_d measurements. However, direct time-dependent studies published by DELPHI [15], BaBar [38] and Belle [39] provide stronger constraints, which can be combined to yield [8]

$$sign(Re\lambda_{CP})\Delta\Gamma_{d}/\Gamma_{d} = 0.015 \pm 0.018$$
,

where $sign(Re\lambda_{CP}) = +1$ is expected in the Standard Model.

Assuming $\Delta\Gamma_d=0$ and no CP violation in mixing, and using the measured B_d^0 lifetime of 1.519 ± 0.007 ps, the Δm_d and χ_d results are combined to yield the world average

$$\Delta m_d = 0.507 \pm 0.004 \text{ ps}^{-1}$$
 (14)

or, equivalently,

$$\chi_d = 0.1862 \pm 0.0023 \,. \tag{15}$$

This Δm_d value provides an estimate of $2|M_{12}|$, and can be used with Eq. (6) to extract $|V_{td}|$ within the Standard Model [40]. The main experimental uncertainties on the result come from m_t and Δm_d , but are completely negligible with respect to the uncertainty due to the hadronic matrix element $f_{B_d}\sqrt{B_{B_d}} = 211 \pm 12$ MeV obtained from lattice QCD calculations [41].

Δm_s and $\Delta \Gamma_s$ measurements

After many years of intense search at LEP and SLC, $B_s^0 - \overline{B}_s^0$ oscillations were first observed in 2006 by CDF using 1 fb⁻¹ of Tevatron Run II data [20]. A year later DØ reported an independent preliminary evidence using 2.4 fb⁻¹ of data [46]. Recently LHCb obtained the most precise results

using 0.036 fb⁻¹ [34] and 0.34 fb⁻¹ [24] of data collected at the LHC in 2010 and 2011, respectively. While the average of the published measurements of Δm_s [20,34] is

$$\Delta m_s = 17.69 \pm 0.08 \text{ ps}^{-1},$$
 (16)

including also the preliminary LHCb measurement [24] and taking systematic correlations into account yields

$$\Delta m_s = 17.719 \pm 0.036(\text{stat}) \pm 0.023(\text{syst}) \text{ ps}^{-1}$$
. (17)

The information on $|V_{ts}|$ obtained in the framework of the Standard Model is hampered by the hadronic uncertainty, as in the B_d^0 case. However, several uncertainties cancel in the frequency ratio

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \xi^2 \left| \frac{V_{ts}}{V_{td}} \right|^2 \,, \tag{18}$$

where $\xi = (f_{B_s}\sqrt{B_{B_s}})/(f_{B_d}\sqrt{B_{B_d}}) = 1.237 \pm 0.032$ is an SU(3) flavor-symmetry breaking factor obtained from lattice QCD calculations [41]. Using the measurements of Eqs. (14) and (16), one can extract

$$\left| \frac{V_{td}}{V_{ts}} \right| = 0.2111 \pm 0.0010 \text{(exp)} \pm 0.0055 \text{(lattice)},$$
 (19)

in good agreement with (but much more precise than) the value obtained from the ratio of the $b \to d\gamma$ and $b \to s\gamma$ transition rates observed at the B factories [40].

The CKM matrix can be constrained using experimental results on observables such as Δm_d , Δm_s , $|V_{ub}/V_{cb}|$, ϵ_K , and $\sin(2\beta)$ together with theoretical inputs and unitarity conditions [40,47,48]. The constraint from our knowledge on the ratio $\Delta m_s/\Delta m_d$ is more effective in limiting the position of the apex of the CKM unitarity triangle than the one obtained from the Δm_d measurements alone, due to the reduced hadronic uncertainty in Eq. (18). We also note that the measured value of Δm_s is consistent with the Standard Model prediction obtained from CKM fits where no experimental information on Δm_s is used, e.g., $19.0 \pm 1.5 \text{ ps}^{-1}$ [47] or $18.1^{+2.2}_{-2.1} \text{ ps}^{-1}$ [48].

Information on $\Delta\Gamma_s$ can be obtained from the study of the proper time distribution of untagged B_s^0 samples [49]. In the case of an inclusive B_s^0 selection [50], or a semileptonic (or flavor-specific) B_s^0 decay selection [18,51], both the shortand long-lived components are present, and the proper time distribution is a superposition of two exponentials with decay constants $\Gamma_{L,H} = \Gamma_s \pm \Delta \Gamma_s/2$. In principle, this provides sensitivity to both Γ_s and $(\Delta \Gamma_s/\Gamma_s)^2$. Ignoring $\Delta \Gamma_s$ and fitting for a single exponential leads to an estimate of Γ_s with a relative bias proportional to $(\Delta \Gamma_s/\Gamma_s)^2$. An alternative approach, which is directly sensitive to first order in $\Delta\Gamma_s/\Gamma_s$, is to determine the effective lifetime of untagged B_s^0 candidates decaying to (fairly pure) CP eigenstates; measurements exist for $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ [52], $B_s^0 \to K^+ K^-$ [53], and $B_s^0 \to J/\psi f_0(980)$ [54]. The extraction of $1/\Gamma_s$ and $\Delta\Gamma_s$ from such measurements, discussed in detail in Ref. [55], requires additional information in the form of theoretical assumptions

or external inputs on weak phases and hadronic parameters. In what follows, only the effective lifetimes from the decays to the pure CP eigenstates K^+K^- and $J/\psi f_0(980)$ will be used, under the assumption that these decays are dominated by a single weak phase.

The best sensitivity to $1/\Gamma_s$ and $\Delta\Gamma_s$ is achieved by the recent time-dependent measurements of the $B_s^0 \to J/\psi \phi$ decay rates performed at CDF [56,57], DØ [58] and LHCb [59,60], where the CP-even and CP-odd amplitudes are separated statistically through a full angular analysis. In particular LHCb obtained the first observation of a non-zero value of $\Delta\Gamma_s$ [60]. These studies use both untagged and tagged B_s^0 candidates and are optimized for the measurement of the CP-violating phase ϕ_s , defined as the weak phase difference between the $B_s^0 - \overline{B}_s^0$ mixing amplitude and the $b \to c\overline{c}s$ decay amplitude. The Standard Model prediction for ϕ_s , if Penguin pollution is neglected, is equal to $-2\beta_s = -2\arg(-(V_{ts}V_{th}^*)/(V_{cs}V_{ch}^*)) =$ $-0.0363^{\,+0.0016}_{\,-0.0015}$ [48]. With a Gaussian constraint on ϕ_s to this Standard Model expectation, a combination [8] of the published $B_s^0 \to J/\psi \phi$ analyses [56,58,59] and of the lifetime measurements with flavor-specific [18,51] and pure CP [53,54] final states yields

$$\Delta\Gamma_s = +0.100 \pm 0.013 \text{ ps}^{-1}$$
 and $1/\Gamma_s = 1.497 \pm 0.015 \text{ ps}$, (20)

or, equivalently,

$$1/\Gamma_{\rm L} = 1.393 \pm 0.019 \ {\rm ps}$$
 and $1/\Gamma_{\rm H} = 1.618 \pm 0.024 \ {\rm ps} \, ,$ (21)

in good agreement with the Standard Model prediction $\Delta\Gamma_s = 0.087 \pm 0.021~{\rm ps}^{-1}$ [7].

The positive sign of $\Delta\Gamma_s$ is due to the constraint applied on ϕ_s . In absence of such constraint, there would be two mirror solutions related by the transformation $(\Delta\Gamma_s,\phi_s)\to (-\Delta\Gamma_s,\pi-\phi_s)$. Recently the LHCb collaboration analyzed the $B^0_s\to J/\psi K^+K^-$ decay, considering that the K^+K^- system can be in a P-wave or S-wave state, and measured the dependence of the strong phase difference between the P-wave and S-wave amplitudes as a function of the K^+K^- invariant mass [61]. This allowed, for the first time, the unambiguous determination of the sign of $\Delta\Gamma_s$, which was found to be positive at the 4.7 σ level.

Independent estimates of $\Delta\Gamma_s/\Gamma_s$ obtained from measurements of the $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ branching fractions [52,62] are no longer included in the average, since they are based on the questionable [7] assumption that these decays account for all CP-even final states.

Average b-hadron mixing probability and b-hadron production fractions at high energy

Mixing measurements can significantly improve our knowledge on the fractions f_u , f_d , f_s , and f_{baryon} , defined as the fractions of B_u , B_d^0 , B_s^0 , and b-baryons in an unbiased sample of weakly decaying b hadrons produced in high-energy collisions.

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Indeed, time-integrated mixing analyses using lepton pairs from $b\bar{b}$ events at high energy measure the quantity

$$\overline{\chi} = f_d' \chi_d + f_s' \chi_s \,, \tag{22}$$

where f'_d and f'_s are the fractions of B^0_d and B^0_s hadrons in a sample of semileptonic b-hadron decays. Assuming that all b hadrons have the same semileptonic decay width implies $f'_q = f_q/(\Gamma_q \tau_b)$ (q = s, d), where τ_b is the average b-hadron lifetime. Hence $\overline{\chi}$ measurements performed at LEP [63] and Tevatron [64,65,66], together with the χ_d average of Eq. (15) and the very good approximation $\chi_s = 1/2$ (in fact $\chi_s = 0.499292 \pm 0.000016$ from Eqs. (5), (16) and (20)), provide constraints on the fractions f_d and f_s . In what follows, we use the preliminary $\overline{\chi}$ result from CDF [65] instead of the published one [64]. Averages based on published data only can be found in the full listings of this Review.

The LEP experiments have measured $\mathcal{B}(\bar{b} \to B_s^0) \times \mathcal{B}(B_s^0 \to B_s^0)$ $D_s^-\ell^+\nu_\ell X)$ [67], $\mathcal{B}(b\to\Lambda_b^0)\times\mathcal{B}(\Lambda_b^0\to\Lambda_c^+\ell^-\overline{\nu}_\ell X)$ [68], and $\mathcal{B}(b \to \Xi_b^-) \times \mathcal{B}(\Xi_b^- \to \Xi^- \ell^- \overline{\nu}_\ell X)$ [69] from partially reconstructed final states including a lepton, f_{baryon} from protons identified in b events [70], and the production rate of charged b hadrons [71]. The b-hadron fraction ratios measured at CDF are based on double semileptonic $K^*\mu\mu$ and $\phi\mu\mu$ final states [72] and lepton-charm final states [73]; in addition CDF and DØ have both measured strange b-baryon production [74]. On the other hand, fraction ratios have been studied by LHCb using fully reconstructed hadronic B_s^0 and B_d^0 decays [75], as well as semileptonic decays [76]. Both CDF and LHCb observe that the ratio $f_{\Lambda_i^0}/(f_u+f_d)$ decreases with the transverse momentum of the lepton+charm system, indicating that the b-hadron fractions are not the same in different environments. We therefore provide sets of fractions separately for LEP and Tevatron (and no complete set for LHCb, where strange bbaryon production has not been measured yet). A combination of all the available information under the constraints $f_u = f_d$, $f_u + f_d + f_s + f_{\text{baryon}} = 1$, and Eq. (22), yields the averages shown in Table 1.

Table 1: $\overline{\chi}$ and b-hadron fractions (see text).

| | in Z decays [8] | at Tevatron [8] | at LHCb [76] |
|-------------------|---------------------|-------------------|---------------------------|
| $\overline{\chi}$ | 0.1259 ± 0.0042 | 0.127 ± 0.008 | |
| $f_u = f_d$ | 0.403 ± 0.009 | 0.330 ± 0.030 | |
| f_s | 0.103 ± 0.009 | 0.103 ± 0.012 | |
| $f_{ m baryon}$ | 0.090 ± 0.015 | 0.236 ± 0.067 | |
| f_s/f_d | 0.256 ± 0.025 | 0.311 ± 0.037 | $0.267^{+0.021}_{-0.020}$ |

$CP\mbox{-}violation\ studies$

Evidence for CP violation in $B_q^0 - \overline{B}_q^0$ mixing has been searched for, both with flavor-specific and inclusive B_q^0 decays, in samples where the initial flavor state is tagged, usually with a lepton from the other b-hadron in the event. In the

case of semileptonic (or other flavor-specific) decays, where the final-state tag is also available, the following asymmetry [2]

$$\mathcal{A}_{\mathrm{SL}}^{q} = \frac{N(\overline{B}_{q}^{0}(t) \to \ell^{+}\nu_{\ell}X) - N(B_{q}^{0}(t) \to \ell^{-}\overline{\nu}_{\ell}X)}{N(\overline{B}_{q}^{0}(t) \to \ell^{+}\nu_{\ell}X) + N(B_{q}^{0}(t) \to \ell^{-}\overline{\nu}_{\ell}X)} \simeq 1 - |q/p|_{q}^{2}$$

$$\tag{23}$$

has been measured either in time-integrated analyses at CLEO [37,77], CDF [78] and DØ [79], or in time-dependent analyses at LEP [31,80], BaBar [38,81], Belle [82] and DØ [83]. In the inclusive case, also investigated at LEP [80,84], no final-state tag is used, and the asymmetry [85]

$$\frac{N(B_q^0(t) \to \text{all}) - N(\overline{B}_q^0(t) \to \text{all})}{N(B_q^0(t) \to \text{all}) + N(\overline{B}_q^0(t) \to \text{all})}$$

$$\simeq \mathcal{A}_{\text{SL}}^q \left[\frac{x_q}{2} \sin(\Delta m_q t) - \sin^2\left(\frac{\Delta m_q t}{2}\right) \right] \tag{24}$$

must be measured as a function of the proper time to extract information on ${\cal CP}$ violation.

The DØ collaboration measures a like-sign dimuon charge asymmetry in semileptonic b decays that deviates by $3.9\,\sigma$ from the Standard Model prediction [79]. In all other cases, asymmetries compatible with zero (and the Standard Model) have been found, with a precision limited by the available statistics. Most of the analyses at high energy don't disentangle the B^0_d and B^0_s contributions, and either quote a mean asymmetry or a measurement of $\mathcal{A}^d_{\rm SL}$ assuming $\mathcal{A}^s_{\rm SL}=0$: we no longer include these in the average. An exception is the latest dimuon DØ analysis [79], which separates the two contributions by exploiting their dependence on the muon impact parameter cut. The resulting measurements of $\mathcal{A}^d_{\rm SL}$ and $\mathcal{A}^s_{\rm SL}$ are then both compatible with the Standard Model. They are also correlated. We therefore perform a two-dimensional average of all published measurements [37,38,77,79,81–83] and obtain [8]

$$\mathcal{A}_{SL}^d = -0.0033 \pm 0.0033$$
, or $|q/p|_d = 1.0017 \pm 0.0017$, (25)

$$\mathcal{A}_{SL}^{s} = -0.0105 \pm 0.0064$$
, or $|q/p|_{s} = 1.0052 \pm 0.0032$, (26)

with a correlation coefficient of -0.57 between $\mathcal{A}_{\mathrm{SL}}^d$ and $\mathcal{A}_{\mathrm{SL}}^s$. These results show no evidence of CP violation and don't constrain yet the Standard Model.

CP violation induced by $B_s^0 - \overline{B}_s^0$ mixing in $b \to c\bar{c}s$ decays has been a field of very active study in the past couple of years. In addition to the previously mentioned $B_s^0 \to J/\psi \phi$ studies, the recently observed CP-odd decay mode $B_s^0 \to J/\psi f_0(980)$, $f_0(980) \to \pi^+\pi^-$ has also been analyzed by LHCb to measure ϕ_s , without the need for an angular analysis [86]. A two-dimensional fit [8] of all published analyses [56,58,59,86] in the $(\phi_s, \Delta\Gamma_s)$ plane, shown on Fig. 2, yields $\phi_s = -0.14^{+0.16}_{-0.11}$. This is consistent with the Standard Model expectation, although with a large uncertainty. The fit is then repeated, but using the external constraint provided by the measured semileptonic asymmetry of Eq. (26), which depends on $\Delta\Gamma_s$ and on the mixing phase difference $\phi_M - \phi_\Gamma - \pi = \arg(-M_{12}/\Gamma_{12})$ of Eq. (8). Since New Physics is expected to affect $\arg(-M_{12}/\Gamma_{12})$

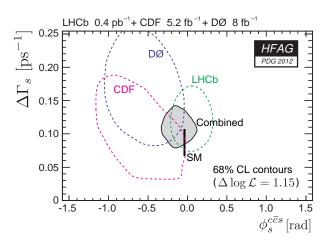


Figure 2: 68% CL contours in the $(\phi_s, \Delta\Gamma_s)$ plane, showing the measurements from CDF [56], DØ [58] and LHCb [59,86], with their combination [8]. The unphysical mirror solution with $\Delta\Gamma_s < 0$ [61] is not shown. The thin rectangle represents the Standard Model predictions of ϕ_s [48] and $\Delta\Gamma_s$ [7].

and ϕ_s in the same way, the constraint is implemented under the assumption that a new phase in B_s^0 mixing would not change the difference $\arg(-M_{12}/\Gamma_{12}) - \phi_s$ from its Standard Model value [7]. The result is [8]

$$\phi_s = -0.17^{+0.14}_{-0.11}, \tag{27}$$

still not showing any sign of CP violation or New Physics. The precision on this average will soon improve significantly. Indeed it does not include yet the preliminary updates of CDF [57] and LHCb [60], nor a new preliminary LHCb measurement using $B_s^0 \to J/\psi \pi^+ \pi^-$ decays [87]. The LHCb preliminary combined value is $\phi_s = -0.002 \pm 0.083 ({\rm stat}) \pm 0.027 ({\rm syst})$ [60].

Summary

 $B^0-\overline{B}^0$ mixing has been and still is a field of intense study. While relatively little experimental progress was achieved in the B_d^0 sector during the past years, impressive new B_s^0 results became available from CDF, DØ and LHCb. The mass difference in the $B_s^0 - \overline{B}_s^0$ system is now known to a relative precision which is significantly better than that in the B_d^0 \overline{B}_d^0 system. The non-zero decay width difference in the $B_s^0 - \overline{B}_s^0$ system is now firmly established, with a relative difference of $(15 \pm 2)\%$. Its sign has been determined: the heavy state of the $B_s^0 - \overline{B}_s^0$ system lives longer than the light state. In contrast, the relative decay width difference in the $B_d^0 - \overline{B}_d^0$ system, $(1.5 \pm 1.8)\%$, is still consistent with zero. CP violation in mixing has not been observed yet, with precisions on the semileptonic asymmetries below 1%. A quantum step has been achieved in the measurement of the mixing-induced phase ϕ_s in B_s^0 decays proceeding through the $b \to c\bar{c}s$ transition, with a Gaussian uncertainty reaching the 0.1 radian level. Despite these significant improvements, all observations remain consistent with the Standard Model expectations.

However, the measurements where New Physics might show up are still statistically limited. More results are expected in the future, especially from LHCb in the B_s^0 sector, with promising prospects for the investigation of the CP-violating phase $\arg(-M_{12}/\Gamma_{12})$ and an expected uncertainty on ϕ_s of ~ 0.05 radian by the time of the next edition of this *Review*.

Mixing studies have clearly reached the stage of precision measurements, where much effort is needed, both on the experimental and theoretical sides, in particular to further reduce the hadronic uncertainties of lattice QCD calculations. In the long term, a stringent check of the consistency of the B_d^0 and B_s^0 mixing amplitudes (magnitudes and phases) with all other measured flavor-physics observables will be possible within the Standard Model, leading to very tight limits on (or otherwise a long-awaited surprize about) New Physics.

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B⁰-B⁰ MIXING PARAMETERS

For a discussion of $B^0-\overline{B}^0$ mixing see the note on " $B^0-\overline{B}^0$ Mixing" in the B^0 Particle Listings above.

 χ_d is a measure of the time-integrated $B^0 extstyle - \overline{B}{}^0$ mixing probability that a produced $B^0(\overline{B}^0)$ decays as a $\overline{B}^0(B^0)$. Mixing violates $\Delta B \neq 2$ rule.

$$\chi_d = \frac{x_d^2}{2(1+x_d^2)}$$

$$x_d = \frac{\Delta m_{B^0}}{\Gamma_{B^0}} = (m_{B^0_H} - m_{B^0_L}) \ \tau_{B^0} \ ,$$

where H, L stand for heavy and light states of two B^0 CP eigenstates and $\tau_{B^0}=\frac{1}{0.5(\Gamma_{B^0_H}+\Gamma_{B^0_L})}$.

This B^0 - \overline{B}^0 mixing parameter is the probability (integrated over time) that a produced B^0 (or \overline{B}^0) decays as a \overline{B}^0 (or B^0), e.g. for inclusive lepton decays $\chi_d = \Gamma(B^0 \to \ell^- X \text{ (via } \overline{B}^0))/\Gamma(B^0 \to \ell^\pm X)$

$$\chi_d = \Gamma(B^0 \to \ell^- X \text{ (via } \overline{B}^0)) / \Gamma(B^0 \to \ell^{\pm} X)$$

$$= \Gamma(\overline{B}^0 \to \ell^+ X \text{ (via } B^0)) / \Gamma(\overline{B}^0 \to \ell^{\pm} X)$$

 $\begin{array}{l} \chi_{\overline{G}} = \Gamma(\overline{B}^0 \to \ell^+ X \text{ (via } B^0))/\Gamma(\overline{B}^0 \to \ell^\pm X) \\ \text{Where experiments have measured the parameter } r = \chi/(1-\chi), \text{ we have converted to} \end{array}$ χ . Mixing violates the $\Delta B \neq 2$ rule.

Note that the measurement of χ at energies higher than the $\varUpsilon(4S)$ have not separated χ_d from χ_S where the subscripts indicate $B^0(\overline{b}d)$ or $B_S^0(\overline{b}s)$. They are listed in the $B^{\pm}/B^0/B_S^0/b$ -baryon ADMIXTURE section.

The experiments at $\Upsilon(4S)$ make an assumption about the $B^0\overline{B}{}^0$ fraction and about the ratio of the B^\pm and B^0 semileptonic branching ratios (usually that it equals one).

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements, includes χ_d calculated from Δm_{B^0} and au_{B^0} .

TECN COMMENT DOCUMENT ID 0.1862±0.0023 OUR EVALUATION 0.182 ±0.015 OUR AVERAGE $^{\mathrm{1}}$ BEHRENS $0.198 \pm 0.013 \pm 0.014$ 00B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ $^2\,\text{ALBRECHT}$ 94 ARG $e^+e^- \rightarrow \Upsilon(4S)$ 0.16 + 0.04 + 0.0493 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ ³BARTELT $0.149 \pm 0.023 \pm 0.022$ ⁴ ALBRECHT 92L ARG $e^+e^- ightarrow \varUpsilon(4S)$ 0.171 + 0.048 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| 0.20 | ± 0.13 | ± 0.12 | | ⁵ A LB RE CHT | 96D | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
|--------|--------------------|------------|----|--------------------------|-----|-------|------------------------------------------|
| 0.19 | ±0.07 | ± 0.09 | | ⁶ A LB RE CHT | 96D | ARG | $e^+ e^- \rightarrow \ \varUpsilon(4S)$ |
| 0.24 | ±0.12 | | | ⁷ ELSEN | 90 | JA DE | e^+e^- 35–44 GeV |
| 0.158 | $+0.052 \\ -0.059$ | | | ARTUSO | 89 | CLEO | $e^+e^- ightarrow ~ \varUpsilon(45)$ |
| 0.17 | ±0.05 | | | ⁸ A LB RE CHT | 87ı | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| < 0.19 | | | 90 | ⁹ B EA N | 87в | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| < 0.27 | | | 90 | ¹⁰ AVERY | 84 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | | | | | | | |

¹BEHRENS 00B uses high-momentum lepton tags and partially reconstructed \overline{B}^0 \rightarrow $D^{*+}\pi^-$, ρ^- decays to determine the flavor of the B meson.

 2 ALBRECHT 94 reports $\it r$ =0.194 \pm 0.062 \pm 0.054. We convert to $\it \chi$ for comparison. Uses tagged events (lepton + pion from D^*).

 3 BARTELT 93 analysis performed using tagged events (lepton+pion from D^*). Using dilepton events they obtain 0.157 \pm 0.016 $^+_{-}0.028$

⁴ ALBRECHT 92L is a combined measurement employing several lepton-based techniques. It uses all previous ARGUS data in addition to new data and therefore supersedes ALBRECHT 87i. A value of $r=20.6\pm7.0\%$ is directly measured. The value can be used to measure $x=\Delta M/\Gamma=0.72\pm0.15$ for the B_d meson. Assumes $f_{+-}/f_0=1.0\pm0.05$ and uses $\tau_{B^{\pm}}/\tau_{B^0} = (0.95 \pm 0.14) (f_{+-}/f_0)$

5 Uses D^{*+} K^{\pm} correlations. 6 Uses $(D^{*+}\ell^{-})$ K^{\pm} correlations.

 $^{7}\,\mathrm{These}$ experiments see a combination of B_{S} and B_{d} mesons.

⁸ ALBRECHT 871 is inclusive measurement with like-sign dileptons, with tagged *B* decays plus leptons, and one fully reconstructed event. Measures r=0.21 \pm 0.08. We convert to χ for comparison. Superseded by ALBRECHT 92L.

 9 BEAN 87B measured $r < \,$ 0.24; we converted to χ

 10 Same-sign dilepton events. Limit assumes semileptonic BR for ${\it B}^{+}$ and ${\it B}^{\,0}$ equal. If $B^0/B^{\pm^{\circ}}$ ratio <0.58, no limit exists. The limit was corrected in BEAN 87B from r < 0.30 to r < 0.37. We converted this limit to χ

$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L}$

 $\Delta m_{B^0}^{-}$ is a measure of 2π times the $B^0 {\ensuremath{-}} \overline B^0$ oscillation frequency in time-dependent mixing experiments.

The second "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/.The averaging/rescaling procedure takes into account correlations between the mea-

The first "OUR EVALUATION", also provided by the HFAG, includes Δm_d calculated from χ_d measured at $\Upsilon(4S)$.

 B^0

| $\frac{\textit{VALUE}(10^{12}\;\hbar\;\text{s}^{-1})}{\textbf{0.507}\!\pm\!\textbf{0.004}\;\text{OUR}\;\text{EVAL}}$ | <u>DOCUMENT ID</u> UATION First | | TECN | COMMENT |
|----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|-------------------|-----------------|---------------------------------------------------------------------|
| 0.507±0.004 OUR EVAL | UATION Second | | | |
| $0.499 \pm 0.032 \pm 0.003$ | 1 AAIJ | 121 | LHCB | pp at 7 TeV |
| $0.506 \pm 0.020 \pm 0.016$ | ² ABAZOV | 06W | | p p at 1.96 TeV |
| $0.511 \pm 0.007 {}^{+ 0.007}_{- 0.006}$ | 3 AUBERT | 06G | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.511 \pm 0.005 \pm 0.006$ | ⁴ ABE ⁵ ABDALLAH | 05B | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.531 \pm 0.025 \pm 0.007$ $0.503 \pm 0.008 \pm 0.010$ | 6 HASTINGS | 03в 03 | DLPH BELL | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.509 \pm 0.017 \pm 0.020$ | ⁷ ZHENG | 03 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.516 \pm 0.016 \pm 0.010$ | 8 AUBERT | 021 | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| 0.493±0.012±0.009 | 9 AUBERT | 02J | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.497 \pm 0.024 \pm 0.025$ $0.503 \pm 0.064 \pm 0.071$ | ¹⁰ ABBIENDI,G ¹¹ ABE | 00в 99к | OPAL CDF | $e^+ e^- \rightarrow Z$ $p\overline{p}$ at 1.8 TeV |
| $0.500 \pm 0.052 \pm 0.043$ | 12 ABE | 99Q | CDF | ρ p at 1.8 TeV |
| $0.516 \pm 0.099 + 0.029 \\ -0.035$ | ¹³ AFFOLDER | 99c | CDF | $p\overline{p}$ at 1.8 TeV |
| $0.471 {}^{+ 0.078}_{- 0.068} {}^{+ 0.033}_{- 0.034}$ | ¹⁴ ABE | 98c | CDF | $p\overline{p}$ at 1.8 TeV |
| 0.471 - 0.068 - 0.034 $0.458 \pm 0.046 \pm 0.032$ | ¹⁵ ACCIARRI | 98D | L3 | $e^+e^- \rightarrow Z$ |
| $0.438 \pm 0.048 \pm 0.032$ $0.437 \pm 0.043 \pm 0.044$ | 16 ACCIARRI | 98D | L3 | $e^+e^- \rightarrow Z$ |
| $0.472 \pm 0.049 \pm 0.053$ | ¹⁷ ACCIARRI | 98D | L3 | $e^+e^- \rightarrow Z$ |
| $0.523\pm0.072\pm0.043$ | 18 ABREU | 97N | DLPH | $e^+e^- \rightarrow Z$ |
| 0.493±0.042±0.027 | 16 ABREU | 97N | DLPH | $e^+e^- \rightarrow Z$ |
| $0.499 \pm 0.053 \pm 0.015$ $0.480 \pm 0.040 \pm 0.051$ | ¹⁹ ABREU ¹⁵ ABREU | 97n 97n | DLPH DLPH | $e^+ e^- \rightarrow Z$ $e^+ e^- \rightarrow Z$ |
| $0.444 \pm 0.029 \pm 0.020$ | 16 ACKERSTAFF | | OPAL | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow Z$ |
| 0.01. | | | | |
| $0.430 \pm 0.043 ^{+\ 0.028}_{-\ 0.030}$ | ¹⁵ ACKERSTAFF | 97∨ | OPAL | $e^+e^- \rightarrow Z$ |
| $0.482 \pm 0.044 \pm 0.024$ | ²⁰ BUSKULIC | 97D | ALEP | $e^+e^- \rightarrow Z$ |
| 0.404 ± 0.045 ± 0.027 | ¹⁶ BUSKULIC ¹⁵ BUSKULIC | 97D | ALEP ALEP | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow Z$ |
| $0.452 \pm 0.039 \pm 0.044$ $0.539 \pm 0.060 \pm 0.024$ | ²¹ ALEXANDER | 97D 96∨ | OPAL | $e^+ e^- \rightarrow Z$ $e^+ e^- \rightarrow Z$ |
| $0.567 \pm 0.089 + 0.029 \\ -0.023$ | 22 ALEXANDER | 96v | OPAL | $e^+e^- \rightarrow Z$ |
| • • • We do not use the | | | | |
| 0.492±0.018±0.013 | 23 AUBERT | 03c | BABR | Repl. by AUBERT 066 |
| $0.516 \pm 0.016 \pm 0.010$ | 24 AUBERT | 02N | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.494 \pm 0.012 \pm 0.015$ | ²⁵ HARA | 02 | BELL | Repl. by ABE 05B |
| $0.528\pm0.017\pm0.011$ | ²⁶ TOMURA | 02 | BELL | Repl. by ABE 05B |
| $0.463 \pm 0.008 \pm 0.016$ $0.444 \pm 0.028 \pm 0.028$ | ⁹ ABE ²⁷ ACCIARRI | 01D 98D | BELL L3 | Repl. by HASTINGS 03 $e^+e^- \rightarrow Z$ |
| 0.497±0.035 | 28 ABREU | 97N | DLPH | $e^+e^- \rightarrow Z$ |
| $0.467 \pm 0.022 + 0.017 \\ -0.015$ | ²⁹ ACKERSTAFF | | OPAL | $e^+e^- \rightarrow Z$ |
| 0.446±0.032 | ³⁰ BUSKULIC | 97D | ALEP | $e^+e^- \rightarrow Z$ |
| $0.531 + 0.050 \pm 0.078$ | ³¹ ABREU | 96Q | DLPH | Sup. by ABREU 97N |
| | | | | |
| $0.496 ^{+\ 0.055}_{-\ 0.051} \pm 0.043$ | ¹⁵ ACCIARRI | 96E | L3 | Repl. by ACCIARRI 98D |
| $0.548 \pm 0.050 + 0.023 \\ -0.019$ | ³² ALEXANDER | 96∨ | OPAL | $e^+ e^- \rightarrow Z$ |
| 0.496 ± 0.046 | ³³ AKERS | 95 J | OPAL | Repl. by ACKERSTAFF 97v |
| $0.462 { + 0.040 + 0.052 \atop - 0.053 - 0.035 }$ | ¹⁵ AKERS | 95 J | OPAL | Repl. by ACKERSTAFF 97v |
| 0.50 ±0.12 ±0.06 | 18 ABREU | 94м | DLPH | Sup. by ABREU 97N |
| $0.508 \pm 0.075 \pm 0.025$ | 21 AKERS | 94c | OPAL | Repl. by ALEXANDER 96v |
| $0.57 \pm 0.11 \pm 0.02$ $0.50 + 0.07 + 0.11$ $0.50 + 0.06 - 0.10$ | 22 AKERS | 94н | | Repl. by ALEXANDER 96v |
| -0.00 -0.10 | ¹⁵ BUSKULIC | 94B | ALEP | Sup. by BUSKULIC 97D |
| $0.52 \begin{array}{c} +0.10 & +0.04 \\ -0.11 & -0.03 \end{array}$ | ²² BUSKULIC | 93ĸ | ALEP | Sup. by BUSKULIC 97D |
| 1 Measured using B^{0} $-$ | D-π+ | | | |
| ² Uses opposite-side fla | | → D(| *) μν,, λ | |
| ³ Measured using a sim | ultaneous fit of the | B ⁰ li | fetime a | nd $\overline{B}^0 B^0$ oscillation frequency |
| Δm_d in the partially | reconstructed $B^0 ightarrow$ | D^{*-} | $\ell \nu$ deca | ays. |
| 4 Measurement perform | ed using a combined | fit of | CP-viol | ation, mixing and lifetimes. |
| Structed vertex was re | | epton | were rei | moved and an inclusively recon- |
| ⁶ HASTINGS 03 measu | rement based on th | e tim | e evolut | ion of dilepton events. It also |
| reports $f_+/f_0 = 1.01$ | \pm 0.03 \pm 0.09 and 0 | CPT v | iolation | parameters in $B^0 - \overline{B}{}^0$ mixing. |
| ⁷ ZHENG 03 data anal | yzed using partially | recons | structed | $\overline{B}{}^0 	o D^{*-}\pi^+$ decay and a companying B decay. |
| 8 Uses a tagged sample | of fully-reconstructed | n noi d neut | ral Bole | companying B decay. |
| ⁹ Measured based on th | e time evolution of d | ilepto | n events | in $\Upsilon(4S)$ decays. |
| ¹⁰ Data analyzed using p | artially reconstructed | \overline{B}^0 | → D*+ | $\ell^-\overline{ u}$ decay and a combination |
| of flavor tags from the 11 Uses di-muon events. | e rest of the event. | | | |
| ^{1∠} Uses jet-charge and le | pton-flavor tagging. | | | |
| 13 Uses $\ell^- D^{*+} - \ell$ even | ts. | | | |
| 14 Uses π - B in the same 15 Uses ℓ - ℓ . | side. | | | |
| ¹ Uses ℓ-Q _{hem} . | | | | |
| 17 Uses ℓ - ℓ with impact 18 Uses $D^{*\pm}$ - $Q_{\rm hem}$ | parameters. | | | |
| uses D·+-Q _{hem} . | | | | |

¹⁹Uses $\pi_s^{\pm}\ell$ - Q_{hem} 20 Uses $D^* \pm -\ell/Q_{\text{hem}}$

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<sup>21</sup> Uses D^{*\pm}\ell-Q_{\text{hem}}
 22 Uses D^*\pm\ell. 23 AUBERT 03c uses a sample of approximately 14,000 exclusively reconstructed B^0 \to
    D^*(2010)^-\ell
u and simultaneously measures the lifetime and oscillation frequency.
 24 AUBERT 02N result based on the same analysis and data sample reported in
 AUBERT 021. 25 Uses a tagged sample of B^0 decays reconstructed in the mode B^0 \to D^*\ell\nu.
 ^{26} Uses a tagged sample of fully-reconstructed hadronic B^0 decays at \varUpsilon(4S).
 ^{27} ACCIARRI 98D combines results from \ell-\ell, \ell-Q_{hem}, and \ell-\ell with impact parameters.
 ^{28} \rm ABREU 97N combines results from D^{*\pm} - Q_{\rm hem} , \ell - Q_{\rm hem} , \pi_S^{\pm} \ell - Q_{\rm hem} , and \ell - \ell
 ^{29} ACKERSTAFF 97v combines results from \ell-\ell, \ell-Q_{\mathrm{hem}}, D^*-\ell, and D^{*\pm}-Q_{\mathrm{hem}}
 30 BUSKULIC 97D combines results from D^{*\pm}-\ell/Q_{\mathrm{hem}}, \ell-Q_{\mathrm{hem}}, and \ell-\ell.
 31 ABREU 96Q analysis performed using lepton, kaon, and jet-charge tags. 32 ALEXANDER 96V combines results from D^{*\pm}-\ell and D^{*\pm}\ell-\ellhem.
 ^{33} A KERS 95J combines results from charge measurement, D^{*\pm}\ell^-Q_{
m hem} and \ell^-\ell.
\mathbf{x}_d = \Delta m_{B^0} / \Gamma_{B^0}
The second "OUR EVALUATION" is an average using rescaled values of the data
       listed below. The average and rescaling were performed by the Heavy Flavor Aver-
       aging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the mea-
       The first "OUR EVALUATION", also provided by the HFAG, includes \chi_d measured
       at \Upsilon(4S).
0.770±0.008 OUR EVALUATION First
0.770±0.008 OUR EVALUATION Second
\operatorname{Re}(\lambda_{CP} / |\lambda_{CP}|) \operatorname{Re}(z)
       The \lambda_{CP} characterizes B^0 and \overline{B}{}^0 decays to states of charmonium plus K_I^0. Param-
       eter z is used to describe CPT violation in mixing, see the review on "CP Violation"
       in the reviews section.
                                             DO CUMENT ID
VALUE
                                                                      TECN COMMENT
                                           1 \overline{\text{AUBERT,B}} 04c BABR e^+e^- \rightarrow \Upsilon(4S)
0.014 \pm 0.035 \pm 0.034
  ^{1}\,\mathrm{Corresponds} to 90% confidence range [-0.072, 0.101].
\Delta\Gamma Re(z)
                                             DOCUMENT ID
                                                                       TECN COMMENT
-0.0071 \pm 0.0039 \pm 0.0020
                                             AUBERT
                                                                06T BABR e^+e^- \rightarrow \Upsilon(4S)
Re(z)
_{\it VALUE~(units~10^{-2})}
                                             DO CUMENT ID
                                                                     TECN COMMENT
                                          ^{1} HIGUCHI 12 BELL e^{+}e^{-} 
ightarrow \varUpsilon(4S)
1.9± 3.7±3.3
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                          <sup>2</sup> HA STINGS 03 BELL Repl. by HIGUCHI 12
0 \pm 12 \pm 1
  <sup>1</sup> Measured using B^0 \rightarrow J/\psi K_S^0, J/\psi K_J^0, D^-\pi^+, D^{*-}\pi^+, D^{*-}\rho^+, and D^{*-}\ell^+\nu
  <sup>2</sup> Measured using inclusive dilepton events from B^0 decay.
lm(z)
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| VALUE (units 10 ⁻²) | DO CUMENT ID | | TECN | COMMENT | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------|--------------|-----------------------------------|--|--|
| -0.8 ±0.4 OUR AVERAGE | · | | | | | |
| $-0.57 \pm 0.33 \pm 0.33$ | | | | $e^+e^- \rightarrow \Upsilon(4S)$ | | |
| $-1.39 \pm 0.73 \pm 0.32$ | ² AUBERT | 06т | BABR | $e^+e^- \rightarrow \gamma(4S)$ | | |
| | | | | | | |
| $3.8 \pm 2.9 \pm 2.5$ | ³ AUBERT,B | 04c | BABR | Repl. by AUBERT 06T | | |
| -3 ± 1 ± 3 | 4 HA STINGS | 03 | BELL | Repl. by HIGUCHI 12 | | |
| 1 Measured using $B^0\to J/\psiK^0_{\rm S}$, $J/\psiK^0_{\rm L}$, $D^-\pi^+$, $D^{*-}\pi^+$, $D^{*-}\rho^+$, and $D^{*-}\ell^+\nu$ decays. | | | | | | |
| 2 Assuming $\Delta\Gamma=0$, the result | becomes $Im(z) =$ | -0.0 | $037 \pm 0.$ | 0046. | | |

 $^{^3}$ Corresponds to 90% confidence range [-0.028, 0.104].

CP VIOLATION PARAMETERS

$\operatorname{Re}(\epsilon_{B^0})/(1+|\epsilon_{B^0}|^2)$

CP impurity in B_d^0 system. It is obtained from either $a_{\ell\ell}$, the charge asymmetry in like-sign dilepton events or a_{cp} , the time-dependent asymmetry of inclusive B^0 and $\overline{B}^{\,0}$ decays.

The second "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements. It assumes there is no CP violation in B_S mixing.

The first "OUR EVALUATION", also provided by the HFAG, uses the measurements from B-factories only.

⁴ Measured using inclusive dilepton events from B^0 decay.

 $-0.06 \pm 0.09 \begin{array}{c} +0.01 \\ -0.02 \end{array}$

 $-\,0.19\ \pm0.10\ \pm0.03$

 $0.044 + 0.186 + 0.018 \\ -0.167 - 0.021$

⁷ CASEY

9 AUBERT

8 ARE

02 BELL Repl. by CHAO 04B

01K BELL Repl. by CASEY 02

01E BABR Repl. by AUBERT 02Q

| 0.8 ± 0.8 OUR EVAI | | | TECN | COMMENT |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| 0.0± 0.9 OUR AVE | RAGE | | | |
| - 0.3± 1.3 | 1 ABAZOV | 110 | D0 | p p at 1.96 TeV |
| $0.4\pm 1.3\pm 0.9$ - $0.3\pm 2.0\pm 2.1$ | ² AUBERT ³ NAKANO | 06T | BABR BELL | $e^+e^- \rightarrow \Upsilon(4S)$ $e^+e^- \rightarrow \Upsilon(4S)$ |
| - 0.3 ± 2.0 ± 2.1 1.2 ± 2.9 ± 3.6 | 4 AUBERT | 06 02κ | | $e^+e^- \rightarrow T(45)$ $e^+e^- \rightarrow T(45)$ |
| - 3.2± 6.5 | ⁵ BARATE | | ALEP | $e^+e^- \rightarrow Z$ |
| $3.5 \pm 10.3 \pm 1.5$ | ⁶ JAFFE | 01 | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $1.2\!\pm\!13.8\!\pm\!3.2$ | ⁷ ABBIENDI | 991 | OPAL | $e^+e^- \rightarrow Z$ |
| 2 ± 7 ±3 | ⁸ ACKERSTAF | | | |
| | following data for averag | | | |
| $-2.3\pm 1.1\pm 0.8$ $-14.7\pm 6.7\pm 5.7$ | ⁹ ABAZOV ¹⁰ AUBERT,B | 06s 04c | D0 DADD | Repl. by ABAZOV 11U Repl. by AUBERT 06T |
| 4 ±18 ±3 | 11 BEHRENS | 00B | CLE2 | Repl. by JAFFE 01 |
| 45 | ¹² BARTELT | 93 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |
| Uses the dimuon charg | e asymmetry with differ | ent imp | act par | ameters from which it re- |
| ports $A_{SL}^d = (-1.2 \pm$ | $5.2) \times 10^{-3}$. | | | |
| ² AUBERT 06T reports | $q/p -1=(-0.8\pm2.7\pm1)$ | .9)×10 | ⁻³ . We | convert to $(1- q/p ^2)/4$. |
| Uses the charge asymr 0.0040 ± 0.0043 . | metry in like-sign dilepto | on event | s and r | eports $ q/p = 1.0005 \pm$ |
| AUBERT 02K uses the | charge asymmetry in lil | ke-sign c | ilepton | events. |
| BARATE 01D measure | ed by investigating time | -depend | ent asy | mmetries in semileptonic |
| and fully inclusive B_d^0 | decays. | | | |
| $^{ m 0}$ JAFFE 01 finds $a_{\ell\ell}$ BEHRENS 00B indepen | = 0.013 ± 0.050 ± | U.005 a | nd com | nbines with the previous |
| Data analyzed using t | he time-dependent asvn | nmetry | of inclu | sive B^0 decay. The pro- |
| duction flavor of B^0 m | esons is determined usi | | | charge and the charge of |
| secondary vertex in the | opposite hemisphere | on = | | ho charge |
| sample of R ⁰ decays de | unies or I and is based fined by lepton and Ω_1 | tage | uring t | he charge asymmetry in a |
| $-0.006 \pm 0.010 \pm 0.0$ | 06 is found. The indirect | t CPT | riolation | is not invoked, $\mathrm{Re}(\epsilon_B) = 1$ n parameter is determined |
| to $Im(\delta B) = -0.020 =$ | \pm 0.016 \pm 0.006. | | | |
| | e asymmetry. ./nl — 1 029 ± 0 013 ± 0 | 011 and | we con | verted it to $(1- q/p ^2)/4$. |
| | | | | ally reconstructed $\overline{B}^0 \rightarrow$ |
| $D^{*+}\pi^{-}$. ρ^{-} decays to | determine the flavor o | f the B | neson. | - |
| 2 BARTELT 93 finds a_ℓ | $\ell = 0.031 \pm 0.096 \pm 0$ | .032 wh | ich corr | esponds to $\left a_{\ell\ell} ight < 0.18$, |
| which yields the above | $ \operatorname{Re}(\epsilon_{B^0})/(1+ \epsilon_{B^0} ^2 .$ | | | |
| T/CP | | | | |
| $A_{T/CP}$ is defined as | 5 | | | |
| | | | | |
| , | . 0a)a (0a. 0 a)a | र छन | | |
| , | $P(\overline{B}^0 \to B^0) - P(B^0 \to B^0)$ | $\overline{B^0}$, | | |
| , | $\frac{P(\overline{B}^0 \to B^0) - P(B^0 \to B^0)}{P(\overline{B}^0 \to B^0) + P(B^0 \to B^0)}$ | | | |
| , the <i>CPT</i> invariant as | | | ı proba | bilities P $(\overline{B}^0	o\ B^0)$ and |
| the CPT invariant as $P(B^0 	o \overline{B}^0)$. | | scillatio | | bilities $P(\overline{\mathcal{B}}^{0} \to \mathcal{B}^{0})$ and |
| the $	extit{CPT}$ invariant as $P(B^0	o \overline{B}^0).$ | ymmetry between the o | scillatio | TECN | COMMENT |
| the CPT invariant as $P(B^0 \rightarrow \overline{B}^0)$. | ymmetry between the o <u>DOCUMENT ID</u> 1 AUBERT | scillation 02K | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. UE UE 05 \pm 0.012 \pm 0.014 AUBERT 02K uses the | DOCUMENT ID 1 AUBERT charge asymmetry in lil | scillation 02K | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. UE UE 05 \pm 0.012 \pm 0.014 AUBERT 02K uses the | DOCUMENT ID 1 AUBERT charge asymmetry in lil | scillation 02K | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the ${\it CPT}$ invariant as ${\it P}({\it B}^0 	o \overline{\it B}^0)$. 15 ±0.012±0.014 AUBERT 02 ${\it K}$ uses the ${\it P}({\it B}^0 	o D^*(2010)$ | DOCUMENT ID 1 AUBERT charge asymmetry in iii)+ D-) | scillation 02K ke-sign o | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. UE 05 \pm 0.012 \pm 0.014 AUBERT 02 κ uses the $P(B^0 \to D^*(2010), A_{CP})$ is defined as | DOCUMENT ID 1 AUBERT charge asymmetry in iii)+ D-) | scillation 02K ke-sign o | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. OS $\pm 0.012 \pm 0.014$ AUBERT 02K uses the $CP(B^0 \to D^*(2010))$ A CP is defined as | DOCUMENT ID 1 AUBERT charge asymmetry in lil | scillation 02K ke-sign o | <i>TECN</i> BABR | $e^+e^- ightarrow \gamma(4S)$ |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. WE 15±0.012±0.014 AUBERT 02k uses the $P(B^0 \to D^*(2010) A_{CP})$ is defined as | ymmetry between the o $\frac{DOCUMENTID}{1\mathrm{AUBERT}}$ charge asymmetry in iii $\mathbf{J}^{+}\mathbf{D}^{-}\mathbf{J}$ $B(\overline{B}^{0}\rightarrow\overline{t})-B(B^{0}\rightarrow t$ $B(\overline{B}^{0}\rightarrow\overline{t})+B(B^{0}\rightarrow t$ | Scillation 02k ke-sign c | TECN BABR ilepton | $\frac{\textit{COMMENT}}{e^+e^-\rightarrow\Upsilon(4S)}$ events. |
| the CPT invariant as $\Pr(B^0 \to \overline{B}^0)$. v_E 05 \pm 0.012 \pm 0.014 AUBERT 02K uses the $\Pr(B^0 \to D^*(2010))$ A_{CP} is defined as the $P_{CP}(B^0 \to D^*(2010))$ | ymmetry between the or $\frac{DOCUMENT\ ID}{1\ AUBERT}$ charge asymmetry in lill $ +D^- $ $B(\overline{B^0} \to \overline{f}) - B(B^0 \to f)$ $B(B^0 \to f)$ asymmetry of exclusions as $B(B^0 \to f)$ | scillation 02k ke-sign c | TECN BABR ilepton | $\begin{array}{c} \underline{\textit{COMMENT}} \\ e^+e^- \to \mathcal{T}(4S) \\ \text{events.} \end{array}$ dec ay. |
| the CPT invariant as $P(B^0 \to \overline{B}^0)$. UE 05 \pm 0.012 \pm 0.014 AUBERT 02K uses the $\mathit{CP}(B^0 \to D^*(2010))$ A_{CP} is defined as the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ characteristic of the $\mathit{CP-violation}$ | pymmetry between the of $\frac{DOCUMENT\ IC}{1\ AUBERT}$ charge asymmetry in IIII $\frac{1}{1} + \frac{1}{1} + \frac{1}{1} + \frac{1}{1}$ $\frac{B(\overline{B}^0 \to \overline{f}) - B(B^0 \to f}{1} + B(B^0 \to f)$ rge asymmetry of exclusing a symmetry of exclusions. | 02K ke-sign c | $\frac{TECN}{BABR}$ ilepton and \overline{B}^0 | $comment$ $e^+e^- 	o 	au(4S)$ events. decay. $comment$ |
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\underline{COMMENT} \\ e^+e^- \to r(4S) \\ \text{events.} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ |

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^{1} Corresponds to 90% confidence range -0.30 < A_{CP} < 0.22.
  ^2 Corresponds to a 90% CL interval of -0.15 < A_{CP} < -0.03.
  <sup>3</sup> Based on a total signal yield of N(K^-\pi^+) + N(K^+\pi^-) = 1606 \pm 51 events.
  ^4 CHAO 04B reports significance of 3.9 standard deviation for deviation of A_{CP} from zero.
  ^{5} Corresponds to 90% confidence range -0.21 <\!\!A_{\mbox{\it CP}} < 0.07.
  ^6 Corresponds to 90% confidence range -0.188 < \stackrel{-}{A_{CP}} < -0.016.
  ^7 Corresponds to 90% confidence range -0.21 <A _{CP}^{-2} <+0.09
  ^{8} Corresponds to 90% confidence range -0.25 < A_{CP} < 0.37.
  ^{9} Corresponds to 90% confidence range -0.35 < A_{CP} < -0.03.
A_{CP}(B^0 \to \eta' K^*(892)^0)
                                         DOCUMENT ID TECN COMMENT
0.02 \pm 0.23 \pm 0.02
                                         DEL-AMO-SA...10A BABR e^+e^- 
ightarrow ~ \varUpsilon(4S)
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
0.08 \pm 0.25 \pm 0.02
                                      <sup>1</sup> AUBERT 07E BABR Repl. by DEL-AMO-
  ^1Reports A_{CP} with the opposite sign convention.
A_{CP}(B^0 \rightarrow \eta' K_0^* (1430)^0)
                                         DOCUMENT ID
                                                               TECN COMMENT
-0.19±0.17±0.02
                                         DEL-AMO-SA...10A BABR e^+e^- \rightarrow \Upsilon(4S)
A_{CP}(B^0 \rightarrow \eta' K_2^*(1430)^0)
                                         DOCUMENT ID
                                                              TECN COMMENT
0.14±0.18±0.02
                                         DEL-AMO-SA...10A BABR e^+e^- 
ightarrow \varUpsilon(4S)
A_{CP}(B^0 \to \eta K^*(892)^0)
                                      DOCUMENT ID TECN COMMENT
0.19±0.05 OUR AVERAGE
0.17 \pm 0.08 \pm 0.01
                                                       07B BELL e^+e^- \rightarrow \Upsilon(4S)
                                      AUBERT,B 06H BABR e^+e^- \rightarrow \Upsilon(4S)
0.21 \pm 0.06 \pm 0.02
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
0.02 \pm 0.11 \pm 0.02
                                      AUBERT.B 04D BABR Repl. by AUBERT.B 06H
A_{CP}(B^0 \rightarrow \eta K_0^*(1430)^0)
                                         DOCUMENT ID
                                                                TECN_COMMENT
0.06±0.13±0.02
                                         AUBERT,B 06H BABR e^+e^-
ightarrow \Upsilon(4S)
A_{CP}(B^0 \rightarrow \eta K_2^*(1430)^0)
                                         DOCUMENT ID
                                                                TECN COMMENT
-0.07 \pm 0.19 \pm 0.02
                                         AUBERT.B
                                                         06н BABR e^+e^- 
ightarrow \varUpsilon (4S)
A_{CP}(B^0 \rightarrow b_1 K^+)
                                                              TECN COMMENT
-0.07 \pm 0.12 \pm 0.02
                                         AUBERT
                                                          07BI BABR e^+e^- \rightarrow \Upsilon(4S)
A_{CP}(B^0 \rightarrow \omega K^{*0})
                                         DOCUMENT ID
                                                                TECN COMMENT
0.45 \pm 0.25 \pm 0.02
                                                          09н BABR e^+e^- 
ightarrow \varUpsilon (4S)
                                         AUBERT
A_{CP}(B^0 \rightarrow \omega(K\pi)_0^{*0})
                                         DOCUMENT ID
                                                              TECN COMMENT
-0.07 \pm 0.09 \pm 0.02
                                                          09н BABR e^+e^- \rightarrow \Upsilon(4S)
A_{CP}(B^0 \to \omega K_2^*(1430)^0)
                                         DOCUMENT ID
                                                              TECN COMMENT
-0.37 \pm 0.17 \pm 0.02
                                         AUBERT
                                                          09н BABR e^+e^- \rightarrow \Upsilon(4S)
A_{CP}(B^0 \rightarrow K^+\pi^-\pi^0)
                                         DOCUMENT ID
                                                            TECN COMMENT
  0 ± 6 OUR AVERAGE
-3.0^{\,+}_{\,-}\,{}^{4.5}_{5.1}\,{\pm}5.5
                                       <sup>1</sup> AUBERT
                                                          08AQ BABR e^+e^- \rightarrow \Upsilon(4S)
                                       <sup>2</sup> CHANG
  7 \pm 11 \pm 1
                                                          04 BELL e^+e^- \rightarrow \Upsilon(4S)
  ^1 Uses Dalitz plot analysis of B^0\to K^+\pi^-\pi^0 decays. ^2 Corresponds to 90% confidence range -0.12 < A^{CP} < 0.26
A_{CP}(B^0 \rightarrow \rho^- K^+)
0.20±0.11 OUR AVERAGE
                                    DOCUMENT ID TECN COMMENT
  0.20 \pm 0.09 \pm 0.08
                                   ^{1}\,\mathrm{LEES}
                                                     11 BABR e^+e^- \rightarrow \Upsilon(4S)
  0.22 \,{}^{+\; 0.22 \, + \; 0.06}_{-\; 0.23 \, - \; 0.02}
                                   <sup>2</sup> CHANG
                                                     04 BELL e^+e^- \rightarrow \Upsilon(4S)
• • • We do not use the following data for averages, fits, limits, etc. • • •
  0.11 \, {}^{+\; 0.14}_{-\; 0.15} \pm 0.07
                                   <sup>1</sup> AUBERT
                                                     08AQ BABR Repl. by LEES 11
                                  <sup>3</sup> AUBERT
-0.28 \pm 0.17 \pm 0.08
                                                  03T BABR Repl. by AUBERT 08AQ
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 1 Uses Dalitz plot analysis of $B^0\to K^+\pi^-\pi^0$ decays. 2 Corresponds to 90% confidence range $-0.18~<~A_{CP}~<0.64$

 $^1\, {\rm Uses}$ Dalitz plot analysis of ${\it B}^{\, 0} \, \rightarrow \, {\it K}^+ \, \pi^- \, \pi^0$ decays.

DOCUMENT ID

LEES

11 BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^3\,\mathrm{The}$ result reported corresponds to $-A_{CP}$.

 $A_{CP}(B^0 \to \rho(1450)^- K^+)$

 B^0

| VALUE DO CUMENT ID TECN COMMENT | $A_{CP}(B^0	o a_1^-K^+)$ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| -0.36±0.57±0.23 11 BABR e^+e^- → $\Upsilon(4S)$ | -0.16±0.12±0.01 AUBERT 08F BABR $e^+e^- ightarrow 	au(4S)$ |
| ¹ Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ decays. | $A_{CP}(B^0 \rightarrow K^0 K^0)$ |
| $A_{CP}(B^0	o K^+\pi^-\pi^0$ nonresonant) ALUE DOCUMENT ID TECH COMMENT | VALUE DO CUMENT ID TECN COMMENT |
| 10.10±0.16±0.08 1 LEES 11 BABR $e^+e^- \rightarrow r(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | - $-0.58^{+0.73}_{-0.66}\pm0.04$ LIN 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| | $A_{CP}(B^0	o K^*(892)^0\phi)$ VALUE DOCUMENT ID TECH COMMENT |
| -0.27 -0.10 | 0.01 ± 0.05 OUR AVERAGE |
| ¹ Uses Dalitz plot analysis of $B^0 \to K^+\pi^-\pi^0$ decays. The quoted value is only for the flat part of the non-resonant component. | e $0.01\pm0.06\pm0.03$ AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4S)$ $0.02\pm0.09\pm0.02$ 1 CHEN 05A BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $A_{CP}(B^0	o K^0\pi^+\pi^-)$ TALUE DOCUMENT ID TECH COMMENT | -0.03 ± 0.07 ± 0.03 AUBERT 07D BABR Repl. by AUBERT 08B |
| -0.01 \pm 0.05 \pm 0.01 1 AUBERT 09AU BABR $e^+e^- ightarrow \gamma(4S)$ | $-$ 0.01 \pm 0.09 \pm 0.02 AUBERT,B 04 $_{ m W}$ BABR Repl. by AUBERT 07D |
| 1 Uses Dalitz plot analysis of $B^0 	o 	extit{K}^0 \pi^+ \pi^-$ decays and the first of two equivalen | $0.04\pm0.12\pm0.02$ AUBERT 03V BABR Repl. by AUBERT 04W $0.07\pm0.15 + 0.05$ 2 CHEN 03B BELL Repl. by CHEN 05A |
| solutions is used. | $0.07\pm0.15^{+0.05}_{-0.03}$ 2 CHEN 03B BELL Repl. by CHEN 05A $0.00\pm0.27\pm0.03$ 3 AUBERT 02E BABR Repl. by AUBERT 03V |
| $A_{CP}(B^0 \to K^*(892)^+\pi^-)$ | $\frac{1}{2}$ Corresponds to 90% confidence range $-0.14 < A_{CP} < 0.17$. |
| VALUE DOCUMENT ID TECN COMMENT − 0.22±0.06 OUR AVERAGE | Corresponds to 90% confidence range $-0.18 < A_{CP} < 0.33$. |
| $-0.29\pm0.11\pm0.02$ ¹ LEES 11 BABR $e^+e^- ightarrow \varUpsilon(4S)$ | 3 Corresponds to 90% confidence range $-0.44 < A_{CP} < 0.44$. |
| $-0.21 \pm 0.10 \pm 0.02$ 2,3 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $A_{CP}(B^0 \to K^*(892)^0 K^- \pi^+)$ |
| $-0.21 \pm 0.11 \pm 0.07$ ⁴ DALSENO 09 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE DOCUMENT ID TECN COMMENT |
| $0.26 + 0.33 + 0.10 \atop -0.34 + 0.08$ 5 EISENSTEIN 03 CLE2 $e^+e^- ightarrow \varUpsilon(45)$ | $+$ 0.22 \pm 0.33 \pm 0.20 AUBERT 07AS BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $A_{CP}(B^0 \to \phi(K\pi)_0^{*0})$ |
| -0.19 ^{+0.20} _{-0.15} ±0.04 | VALUE DOCUMENT ID TECN COMMENT |
| -0.11±0.14±0.05 | 0.20\pm0.14\pm0.06 AUBERT 08BG BABR $e^+e^- 	o 	au(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 1 Uses Dalitz plot analysis of $B^0 ightarrow \kappa^+ \pi^- \pi^0$ decays. | $0.17\pm0.15\pm0.03$ AUBERT 07D BABR Repl. by AUBERT 08B |
| ² Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays. | $A_{CP}(B^0 \to \phi K_2^*(1430)^0)$ |
| 3 The first of two equivalent solutions is used. 4 Uses Dalitz plot analysis of $B^0 	o 	ext{ } K^0 \pi^+ \pi^-$ decays and the first of two consisten | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| solutions that may be preferred | -0.08±0.12±0.05 AUBERT 08BG BABR $e^+e^- 	o 	au(4S)$ |
| 5 Corresponds to 90% confidence range $-0.31 <$ A $_{CP} < 0.78$. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $A_{CP}(B^0 \to (K\pi)_0^{*+}\pi^-)$ | $-0.12\pm0.14\pm0.04$ AUBERT 07D BABR Repl. by AUBERT 08B |
| VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $A_{CP}(B^0 \to K^*(892)^0 \gamma)$ |
| 0.09\pm0.07 OUR AVERAGE $0.07\pm0.14\pm0.01$ 1 LEES 11 BABR $e^+e^- ightarrow \varUpsilon(4S)$ | VALUE DOCUMENT ID TECN COMMENT -0.016 \pm 0.022 \pm 0.007 AUBERT 09A0 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.09\pm0.07\pm0.03$ 2 AUBERT 09AU BABR $e^+e^- \rightarrow r(45)$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| | $A_{CP}(B^0 \to K_2^*(1430)^0 \gamma)$ |
| | VALUE DO CUMENT IDTECNCOMMENT |
| $0.17^{+0.11}_{-0.16}\pm0.22$ 1 AUBERT 08AQ BABR Repl. by LEES 11 1 Uses Dalitz plot analysis of $B^0	o K^+\pi^-\pi^0$ decays. | $\frac{VALUE}{-0.08\pm0.15\pm0.01}$ $\frac{DOCUMENT\ ID}{AUBERT,B}$ $\frac{TECN}{04U}$ $\frac{COMMENT}{BABR}$ e^+e^- → $r(4S)$ |
| $0.17^{+0.11}_{-0.16}\pm0.22$ 1 AUBERT 08AQ BABR Repl. by LEES 11 1 Uses Dalitz plot analysis of $B^{0}\to K^{+}\pi^{-}\pi^{0}$ decays. 2 Uses Dalitz plot analysis of $B^{0}\to K^{0}\pi^{+}\pi^{-}$ decays and the first of two equivalen | th the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of the second state of th |
| $0.17^{+0.11}_{-0.16}\pm0.22$ 1 AUBERT 08AQ BABR Repl. by LEES 11 1 Uses Dalitz plot analysis of $B^0\to K^+\pi^-\pi^0$ decays. 2 Uses Dalitz plot analysis of $B^0\to K^0\pi^+\pi^-$ decays and the first of two equivalen solutions is used. | $\frac{VALUE}{-0.08\pm0.15\pm0.01}$ $\frac{DOCUMENT~ID}{AUBERT,B}$ $\frac{TECN}{04U}$ $\frac{COMMENT}{BABR}$ $e^+e^- → \Upsilon(4S)$ |
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| $^{0.17}_{-0.16}^{+0.11}_{+0.22}$ 1 AUBERT 08AQ BABR Repl. by LEES 11 1 Uses Dalitz plot analysis of 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 $^$ | TECN COMMENT -0.08 ± 0.15 ± 0.01 ACP(B ⁰ $\rightarrow \rho^+ \pi^-$) MALUE 0.08 ± 0.12 OUR AVERAGE Error includes scale factor of 2.0. -0.03 ± 0.07 ± 0.04 ••• We do not use the following data for averages, fits, limits, etc. 1 THE result reported corresponds to $-A_{CP}$. ACP(B ⁰ $\rightarrow \rho^- \pi^+$) MALUE -0.13 ± 0.08 ± 0.03 1 AUBERT 0.14 ± 0.05 -0.02 ± 0.16 + 0.05 0.18 ± 0.08 ± 0.03 1 AUBERT 0.15 ± 0.08 -0.02 ± 0.16 + 0.05 0.18 ± 0.08 ± 0.03 1 AUBERT 0.17 ± 0.07 0.18 ± 0.08 ± 0.03 1 AUBERT 0.08 ± 0.16 ± 0.09 0.08 ± 0.16 ± 0.09 0.08 ± 0.16 ± 0.09 0.08 ± 0.16 ± 0.01 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.08 ± 0.10 ± 0.09 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0.10 ± 0.00 0 |
| $^{0.17}_{-0.16}^{+0.11}\pm0.22$ 1 AUBERT 08AQ BABR Repl. by LEES 11 1 Uses Dalitz plot analysis of B^{0} \rightarrow $K^{+}\pi^{-}\pi^{0}$ decays. 2 Uses Dalitz plot analysis of B^{0} \rightarrow $K^{0}\pi^{+}\pi^{-}$ decays and the first of two equivalen solutions is used. 4 ACP(B^{0} \rightarrow ($K\pi$) $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{*0}$ $_{0}^{$ | The result reported corresponds to $-A_{CP}$. ACP(B ⁰ $\rightarrow \rho^+\pi^-$) MALUE 0.08 \pm 0.12 OUR AVERAGE Error includes scale factor of 2.0. -0.03 \pm 0.07 \pm 0.04 **No Medical States and the following data for averages, fits, limits, etc. • • • -0.02 \pm 0.16 \pm 0.05 -0.18 \pm 0.08 \pm 0.03 1 AUBERT 0.18 \pm 0.87 \pm 0.07 1 The result reported corresponds to $-A_{CP}$. ACP(B ⁰ $\rightarrow \rho^-\pi^+$) MALUE -0.16 \pm 0.29 OUR AVERAGE From includes scale factor of 2.0. -0.02 \pm 0.16 \pm 0.05 -0.02 \pm 0.16 \pm 0.05 -0.08 \pm 0.08 \pm 0.03 1 AUBERT 03T BABR Repl. by KUSAKA 07 1 The result reported corresponds to $-A_{CP}$. ACP(B ⁰ $\rightarrow \rho^-\pi^+$) MALUE -0.16 \pm 0.23 OUR AVERAGE Error includes scale factor of 1.7. -0.37 \pm 0.16 \pm 0.09 AUBERT 07AA BABR $e^+e^- \rightarrow \Upsilon(4S)$ 0.08 \pm 0.16 \pm 0.11 KUSAKA 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ 0.08 \pm 0.16 \pm 0.11 KUSAKA 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • -0.53 \pm 0.29 \pm 0.09 WANG 05 BELL Repl. by KUSAKA 07 ACP(B ⁰ $\rightarrow a_1(1260)^{\pm}\pi^+$) MALUE -0.07 \pm 0.07 \pm 0.02 AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\begin{array}{c} 1.7 + 0.11 \\ -0.16 \pm 0.22 \\ 1 \text{ USES Dalitz plot analysis of } B^0 \rightarrow K^+\pi^-\pi^0 \text{ decays.} \\ 2 \text{ USES Dalitz plot analysis of } B^0 \rightarrow K^0\pi^+\pi^- \text{ decays and the first of two equivalen solutions is used.} \\ \hline A_{CP}(B^0 \rightarrow (K\pi)_0^{*0}\pi^0) \\ \hline MALUE \\ \hline -0.15 \pm 0.10 \pm 0.04 \\ \bullet \bullet \bullet \text{ We do not use the following data for averages, fits, limits, etc.} \bullet \bullet \bullet \\ \hline -0.22 \pm 0.12 \pm 0.30 \\ 1 \text{ USES Dalitz plot analysis of } B^0 \rightarrow K^+\pi^-\pi^0 \text{ decays.} \\ \hline A_{CP}(B^0 \rightarrow K^{*0}\pi^0) \\ \hline MALUE \\ \hline -0.15 \pm 0.12 \pm 0.04 \\ \hline 1 \text{ USES Dalitz plot analysis of } B^0 \rightarrow K^+\pi^-\pi^0 \text{ decays.} \\ \hline A_{CP}(B^0 \rightarrow K^{*0}\pi^0) \\ \hline MALUE \\ \hline -0.09 \pm 0.21 \pm 0.09 \\ \hline 1 \text{ USES Dalitz plot analysis of } B^0 \rightarrow K^+\pi^-\pi^0 \text{ decays.} \\ \hline A_{CP}(B^0 \rightarrow K^*(892)^0\pi^+\pi^-) \\ \hline MALUE \\ \hline +0.07 \pm 0.04 \pm 0.03 \\ \hline A_{CP}(B^0 \rightarrow K^*(892)^0\rho^0) \\ \hline MALUE \\ \hline -0.09 \pm 0.19 \pm 0.02 \\ \hline AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ DOG BABR \\ e^+e^- \rightarrow T(4S) \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ DOG BABR \\ \hline DOCUMENT \\ DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ BABR \\ e^+e^- \rightarrow T(4S) \\ \hline DOCUMENT ID \\ AUBERT \\ \hline DOCUMENT ID \\ BABR \\ \hline DOCUMENT \\ DOCUMENT ID \\ BABR \\ DOCUMENT \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DOCUMENT ID \\ DO$ | The result reported corresponds to $-A_{CP}$. ACP($B^0 	o \rho^+ \pi^-$) MALUE 0.08 ± 0.12 OUR AVERAGE 0.02 ± 0.08 ± 0.04 0.02 ± 0.08 ± 0.04 0.02 ± 0.08 ± 0.04 0.02 ± 0.08 ± 0.04 0.02 ± 0.08 ± 0.04 0.08 ± 0.05 0.09 ± 0.004 0.000 ± 0.004 0.000 ± 0.004 0.000 ± 0.005 0.000 ± 0.004 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0.000 ± 0.005 0 |

| MALUE — 0.76±0.14 OUR AVERAGE — 0.76±0.16 ± 0.03 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • $ -0.66 \pm 0.19 \pm 0.04 \qquad 1 \text{ AUBERT} \qquad 0780 \text{ BABR} \qquad \text{Repl. by AUBERT 09c} \\ -0.75 \pm 0.56 \pm 0.12 \qquad \qquad \text{MIYAKE} \qquad 05 \qquad \text{BELL} \qquad \text{Repl. by VERVINK 09} \\ 0.06 \pm 0.37 \pm 0.13 \qquad 2 \text{ AUBERT} \qquad 03Q \qquad \text{BABR} \qquad \text{Repl. by AUBERT 07Bo} \\ 1 \text{ Assumes both } \textit{CP}\text{-even and } \textit{CP}\text{-odd states having the } \textit{CP} \text{ asymmetry.} \\ 2 \text{ AUBERT 03Q reports} \lambda = 0.75 \pm 0.19 \pm 0.02 \text{ and } \text{Im}(\lambda) = 0.05 \pm 0.29 \pm 0.10. \text{W} \\ \end{aligned} $ |
| • • • We do not use the following data for averages, fits, limits, etc. -0.66±0.19±0.04 -0.75±0.55±0.12 MIYAKE 05 BELL Repl. by VERVINK 09 0.06±0.37±0.13 2 AUBERT 03Q BABR Repl. by VERVINK 09 1 Assumes both CP-even and CP-odd states having the CP asymmetry. 2 AUBERT 03Q reports \(\begin{array}{c} \ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $0.06\pm0.37\pm0.13$ 2 AUBERT 03Q BABR Repl. by AUBERT 07BO 1 Assumes both CP -even and CP -odd states having the CP asymmetry. 2 AUBERT 03Q reports $ \lambda $ = 0.75 \pm 0.19 \pm 0.02 and $ m(\lambda)$ = 0.05 \pm 0.29 \pm 0.10. W |
| 1 Assumes both <i>CP</i> -even and <i>CP</i> -odd states having the <i>CP</i> asymmetry. 2 AUBERT 03Q reports $ \lambda {=}0.75\pm0.19\pm0.02$ and ${\rm Im}(\lambda){=}0.05\pm0.29\pm0.10$. W |
| ² AUBERT 03Q reports $ \lambda $ =0.75 \pm 0.19 \pm 0.02 and Im(λ)=0.05 \pm 0.29 \pm 0.10. V |
| convert them to 5 and 6 parameters taking into account contractions. |
| c (D) D++ D+-) |
| C_+ ($B^0 \to D^{*+}D^{*-}$) See the note in the $C_{\pi\pi}$ datablock, but for CP even final state. |
| VALUEDO CUMENT IDTECNCOMMENT $0.00 \pm 0.12 \pm 0.02$ AUBERT09cBABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $-0.05\pm0.14\pm0.02$ AUBERT 07B0 BABR Repl. by AUBERT 09c |
| +0.06±0.17±0.03 ¹ AUBERT,BE 05A BABR Repl. by AUBERT 07Bo |
| 1 AUBERT,BE 05A reports a $\it CP$ -odd fraction R $_\perp =$ 0.125 \pm 0.044 \pm 0.007. |
| $S_{+} (B^{0} \rightarrow D^{*+}D^{*-})$ |
| See the note in the $s_{\pi\pi}$ datablock, but for <i>CP</i> even final state. |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| -0.76±0.16±0.04 AUBERT 09c BABR e^+e^- → $\Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • |
| -0.72±0.19±0.05 AUBERT 07Bo BABR Repl. by AUBERT 09c |
| $-0.75\pm0.25\pm0.03$ 1 AUBERT,BE 05A BABR Repl. by AUBERT 07BC |
| 1 AUBERT,BE 05A reports a <i>CP</i> -odd fraction R $_{\perp}=$ 0.125 \pm 0.044 \pm 0.007. |
| $C_{-}(B^{0} \rightarrow D^{*+}D^{*-})$ |
| See the note in the $C_{\pi\pi}$ datablock, but for CP odd final state. |
| VALUE DOCUMENT ID TECN COMMENT |
| +0.41±0.49±0.08 AUBERT 09c BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| +0.23±0.67±0.10 AUBERT 07B0 BABR Repl. by AUBERT 09c |
| $-0.20\pm0.96\pm0.11$ AGBERT OF BOBABR Repl. by AGBERT OF AGBERT OF BOBABR Repl. by AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUBERT AUB |
| 1 AUBERT,BE 05A reports a <i>CP</i> -odd fraction R $_{\parallel}$ $=$ 0.125 \pm 0.044 \pm 0.007. |
| $S_{-} (B^0 \rightarrow D^{*+}D^{*-})$ |
| See the note in the $S_{\pi\pi}$ datablock, but for <i>CP</i> odd final state. |
| VALUE DO CUMENT ID TECN COMMENT |
| −1.80±0.70±0.16 AUBERT 09c BABR $e^+e^- 	o 	au(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 1 AUBERT,BE 05A reports a <i>CP</i> -odd fraction R $_{1}$ = 0.125 \pm 0.044 \pm 0.007. |
| _ |
| $C(B^0 \to D^*(2010)^+ D^*(2010)^- K_0^0)$ |
| VALUEDOCUMENT IDTECNCOMMENT $0.01 \pm 0.28 \pm 0.09$ 1 DALSENO07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| Reports value of A which is equal to $-C$. |
| |
| $S\left(B^0 	o D^*(2010)^+ D^*(2010)^- K_S^0\right)$ VALUE DOCUMENT ID TECN COMMENT |
| |
| $0.06^{+0.45}_{-0.44} \pm 0.06$ 1 DALSENO 07 BELL $e^{+}e^{-} \rightarrow r(4S)$ |
| ¹ This value includes an unknown CP dilution factor D due to possible contributions fro intermediate resonances and different partial waves. |
| $C_{D^+D^-}$ ($B^0 	o D^+D^-$) |
| VALUE DOCUMENT ID TECN COMMENT |
| −0.5 ±0.4 OUR AVERAGE Error includes scale factor of 2.5. |
| $-0.07\pm0.23\pm0.03$ AUBERT 09c BABR $e^+e^- ightarrow \Upsilon(4S)$ $-0.91\pm0.23\pm0.06$ 1 FRATINA 07 BELL $e^+e^- ightarrow \Upsilon(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |
| +0.11±0.22±0.07 AUBERT 07AI BABR Repl. by AUBERT 09 +0.11±0.35±0.06 AUBERT,B 05z BABR Repl. by AUBERT 07 |
| The paper reports A , which is equal to $-C$. |
| |
| $S_{D^+D^-}(B^0\to D^+D^-)$ |
| <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> — 0.87±0.26 OUR AVERAGE |
| $-0.63\pm0.36\pm0.05$ AUBERT 09c BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $-1.13\pm0.37\pm0.09$ FRATINA 07 BELL $e^+e^- \rightarrow r(4S)$ |
| · · |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $-0.54 \pm 0.34 \pm 0.06$ AUBERT 07AI BABR Repl. by AUBERT 09 |
| |

 B^0

 $-\,0.13\pm0.32^{\,+\,0.06}_{\,-\,0.09}$

| $C_{J/\psi(1S)\pi^0}~(B^0 ightarrow$. | $J/\psi(1S)\pi^0$) |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>/ALUE</u> -0.13±0.13 OUR AVER | |
| -0.13±0.13 OUR AVER -0.20±0.19±0.03 | AUBERT 08AU BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| $-0.08 \pm 0.16 \pm 0.05$ | 1 LEE 08A BELL $e^+e^- \rightarrow \Upsilon(45)$ |
| | following data for averages, fits, limits, etc. • • • |
| $-0.21 \pm 0.26 \pm 0.06$ | AUBERT,B 06B BABR Repl. by AUBERT 08AU |
| $0.01 \pm 0.29 \pm 0.03$ | ¹ KATAOKA 04 BELL Repl. by LEE 08A |
| $0.38 \pm 0.41 \pm 0.09$ | AUBERT 03N BABR Repl. by AUBERT,B 06B |
| ¹ BELLE Collab. quote | s $A_{J/\psi\pi^0}$ which is equal to $-{\cal C}_{J/\psi\pi^0}$. |
| $S_{J/\psi(1S)\pi^0}~(B^0	o J)$ | $J/\psi(1S)\pi^0)$ |
| ALUE | DOCUMENT ID TECN COMMENT |
| -0.94 ± 0.29 OUR AVER | |
| $-1.23 \pm 0.21 \pm 0.04$ $-0.65 \pm 0.21 \pm 0.05$ | AUBERT 08AU BABR $e^+e^- ightarrow \varUpsilon(4S)$ LEE 08A BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| | following data for averages, fits, limits, etc. • • |
| $-0.68 \pm 0.30 \pm 0.04$ | AUBERT,B 06B BABR Repl. by AUBERT 08AU |
| $-0.72 \pm 0.42 \pm 0.09$ | KATAOKA 04 BELL Repl. by LEE 08A |
| $0.05\pm0.49\pm0.16$ | AUBERT 03N BABR Repl. by AUBERT,B 06B |
| $C_{D_{C}^{(*)},h^0}(B^0\to D_C^{(*)})$ | $\frac{h^0}{2}h^0$ |
| DCP HI C | P , DOCUMENT ID TECN COMMENT |
| -0.23±0.16±0.04 | AUBERT 07AJ BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| . (. | |
| $S_{D_{CP}^{(*)}h^0}(B^0 \to D_{C}^{(*)})$ | ['] P μ _ο) |
| ALUE | DOCUMENT ID TECN COMMENT |
| -0.56±0.23±0.05 | AUBERT 07AJ BABR $e^+ e^- ightarrow \varUpsilon(4S)$ |
| $C_{K^0\pi^0}$ $(B^0\to K^0\pi^0)$ | |
| <u>0.00±0.13 OUR AVER</u> | AGE Error includes scale factor of 1.4. |
| $-0.14 \pm 0.13 \pm 0.06$ | 1 FUJIKAWA 10A BELL $e^{+}e^{-} ightarrow~\varUpsilon$ (4 S) |
| $+0.13\pm0.13\pm0.03$ | AUBERT 091 BABR $e^+e^- ightarrow~\varUpsilon(4S)$ |
| • • We do not use the | following data for averages, fits, limits, etc. ● ● |
| $+0.24 \pm 0.15 \pm 0.03$ | AUBERT 08E BABR Repl. by AUBERT 091 |
| $+0.05 \pm 0.14 \pm 0.05$ $+0.06 \pm 0.18 \pm 0.03$ | ¹ CHAO 07 BELL Repl. by FUJIKAWA 10A AUBERT 05Y BABR Repl. by AUBERT 08E |
| $-0.16 \pm 0.29 \pm 0.05$ | 1,2 CHAO 05A BELL Repl. by AGBERT 05E |
| $+0.11 \pm 0.20 \pm 0.09$ | ¹ CHEN 05B BELL Repl. by CHAO 07 |
| $-0.03 \pm 0.36 \pm 0.11$ | ¹ AUBERT 04m BABR Repl. by AUBERT,B 04m |
| $+0.40 + 0.27 \pm 0.09$ | ³ AUBERT,B 04M BABR Repl. by AUBERT 05Y |
| 1 Reports A which is eq | ual to -C. |
| | $_{5}$ CL interval of $-0.33 < A_{CP} < 0.64$. |
| ³ Based on a total sign | al yield of 122 \pm 16 events. |
| $S_{K^0\pi^0} (B^0 \rightarrow K^0\pi^0)$ |) |
| /ALUE | DO CUMENT ID TECN COMMENT |
| 0.58±0.17 OUR AVER | |
| 0.67 ± 0.31 ± 0.08 | FUJIKAWA 10A BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| $+0.55 \pm 0.20 \pm 0.03$ | AUBERT 091 BABR $e^+e^- \rightarrow \Upsilon(4S)$ following data for averages, fits, limits, etc. • • |
| $+0.40\pm0.23\pm0.03$ | AUBERT 08E BABR Repl. by AUBERT 091 |
| + 0.40 ± 0.23 ± 0.03 + 0.33 ± 0.35 ± 0.08 | CHAO 07 BELL Repl. by FUJIKAWA 10A |
| $+0.35 \pm 0.35 \pm 0.04$ | AUBERT 05Y BABR Repl. by AUBERT 08E |
| | , , |
| $+0.32\pm0.61\pm0.13$ | CHEN 05B BELL Repl. by CHAO 07 |
| $+0.48 + 0.38 \pm 0.06$ | ¹ AUBERT,B 04M BABR Repl. by AUBERT 05Y |
| $^{ m 1}$ Based on a total sign | al yield of 122 \pm 16 events. |
| $C_{\eta'(958) K_S^0} (B^0 \rightarrow \eta)$ | ′(958) K ⁰ ₅) |
| See updated measu | rements in C_{n',K^0} |
| /ALUE | DO CUMENT ID TECN COMMENT |
| -0.04 ± 0.20 OUR AVER | The state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the s |
| $-0.21 \pm 0.10 \pm 0.02$ | AUBERT 05M BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| 0.19 ± 0.11 ± 0.05 | 1 CHEN 05B BELL $e^{+}e^{-} \rightarrow \ \varUpsilon(4S)$ following data for averages, fits, limits, etc. • • • |
| | 1 |
| $-0.26 \pm 0.22 \pm 0.03$ | |
| $0.01 \pm 0.10 \pm 0.04$ | * ABE USH BELL REDI. DV CHEN USR |
| $0.01 \pm 0.16 \pm 0.04$ $0.10 \pm 0.22 \pm 0.04$ | ¹ ABE 03H BELL Repl. by CHEN 05B AUBERT 03W BABR Repl. by AUBERT 05 |

 $^{
m 1}$ CHEN

 $^{1}\, \rm BELLE$ Collab. quotes ${\it A}_{\eta'(958)\, K_{S}^{0}}$ which is equal to $-{\it C}_{\eta'(958)\, K_{S}^{0}}.$

02B BELL Repl. by ABE 03c

| 0.30 ± 0.14 ± 0.02 + 0.65 ± 0.18 ± 0.04 • • • We do not use the following of 0.71 ± 0.37 + 0.05 0.04 ± 0.27 ± 0.05 0.02 ± 0.34 ± 0.03 0.28 ± 0.55 + 0.07 C _{η'} κ ⁰ (B ⁰ → η' κ ⁰) ν _α LUE - 0.05 ± 0.05 OUR AVERAGE - 0.08 ± 0.06 ± 0.02 0.01 ± 0.07 ± 0.05 1 The mixing-induced CP violation deviations in this b → s penguing 2. The paper reports A, which is equal to the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of t | S _T /K ⁰ <u>DOCUMENT ID</u> rincludes scale AUBERT CHEN lata for averages ABE AUBERT CHEN DOCUMENT ID AUBERT CHEN lata for averages AUBERT CHEN AUBERT CHEN lata for averages AUBERT is reported with dominated mo ual to —C. DOCUMENT ID AUBERT CHEN AUBERT AUBERT CHEN lata for averages AUBERT is reported with | 05M 05B 05B 03C 03C 03H 03W 02B 09I 07 5, fits, 07A a sig 06. | BABR BELL BELL BABR BELL TECN BABR BELL TECN BABR BELL BABR BELL BABR BELL BIMITS, BABR BABR BABR BABR BABR BABR BABR BAB | Repl. by ABE 03H Repl. by CHEN 051 Repl. by AUBERT Repl. by ABE 03C $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ etc. • • • Repl. by AUBERT e of more than 5 stan $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ etc. • • • Repl. by AUBERT e of more than 5 stan $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ etc. • • • Repl. by AUBERT e of more than 5 stan |
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| +0.65 ± 0.18 ± 0.04 • • • We do not use the following of $0.71 \pm 0.37 + 0.05$ $0.71 \pm 0.37 + 0.05$ $0.43 \pm 0.27 \pm 0.05$ $0.02 \pm 0.34 \pm 0.03$ $0.28 \pm 0.55 + 0.07$ -0.08 C _{1/7} K0 (B ⁰ → η' K ⁰) WALUE -0.05 ± 0.05 OUR AVERAGE -0.08 ± 0.06 ± 0.02 0.01 ± 0.07 ± 0.05 • • • We do not use the following of one of the deviations in this $b \rightarrow s$ penguing 2 The paper reports A, which is equal to the deviations in this $b \rightarrow s$ penguing 2 The paper reports A, which is equal to the deviations in this $b \rightarrow s$ penguing 2 The paper reports A, which is equal to the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the deviation of the | CHEN lata for averages ABE ABE AUBERT CHEN DOCUMENT ID lata for averages AUBERT is reported with a dominated moual to —C. DOCUMENT ID AUBERT CHEN lata for averages AUBERT is reported with a dominated moual to —C. | 05B 07B 03C 03H 03W 02B 09I 07 07A a sig 07A a sig 07A a sig | BELL limits, BELL BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL limits, BABR BELL li | $e^+e^- 	o 	au(45)$ etc. • • • Repl. by ABE 03H Repl. by CHEN 05I Repl. by AUBERT Repl. by ABE 03C $\frac{COMMENT}{e^+e^- 	o 	au(45)}$ etc. • • • Repl. by AUBERT e of more than 5 stan $\frac{COMMENT}{e^+e^- 	o 	au(45)}$ etc. • • • Repl. by AUBERT e of more than 5 stan $\frac{COMMENT}{e^+e^- 	o 	au(45)}$ etc. • • • Repl. by AUBERT e of more than 5 stan |
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| deviations in this $b \rightarrow s$ penguin 2 The paper reports A , which is equal S_{η',K^0} ($B^0 \rightarrow \eta',K^0$) WALUE 0.60 ± 0.07 OUR AVERAGE + 0.57 ± 0.08 ± 0.02 0.64 ± 0.10 ± 0.04 • • We do not use the following of 0.58 ± 0.10 ± 0.03 1 The mixing-induced CP violation deviations in this $b \rightarrow s$ penguin C_{ω,K^0_S} ($B^0 \rightarrow \omega K^0_S$) WALUE - 0.30 ± 0.28 OUR AVERAGE Erro - 0.52 ± 0.22 ± 0.03 + 0.09 ± 0.29 ± 0.06 | DOCUMENT ID AUBERT CHEN lata for averages AUBERT is reported with dominated mo | 09i 07 s, fits, 07A a sig de. | TECN BABR BELL , limits, BABR enificance | $\begin{array}{c} \underline{COMMENT} \\ e^+e^- \to & \varUpsilon(4.5) \\ e^+e^- \to & \varUpsilon(4.5) \\ \text{etc.} \bullet \bullet \bullet \\ \text{Repl. by AUBERT} \\ \text{e of more than 5 stan} \end{array}$ |
| S_{η',K^0} ($B^0 \to \eta',K^0$) $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ $V_{\lambda U,UE}$ | AUBERT CHEN lata for averages AUBERT is reported with dominated mo | 07 s, fits, 07A a sig de. | BABR BELL limits, BABR nificance | $e^+e^- \rightarrow \Upsilon(45)$ $e^+e^- \rightarrow \Upsilon(45)$ etc. • • • Repl. by AUBERT e of more than 5 star |
| WLUE 0.60 ± 0.07 OUR AVERAGE + 0.57 ± 0.08 ± 0.02 0.64 ± 0.10 ± 0.04 • • • We do not use the following of 0.58 ± 0.10 ± 0.03 1 The mixing-induced CP violation deviations in this $b \to s$ penguin $C_{\omega K_S^0} (B^0 \to \omega K_S^0)$ WALUE - 0.30 ± 0.28 OUR AVERAGE = 0.52 ± 0.22 ± 0.03 + 0.09 ± 0.29 ± 0.06 | AUBERT CHEN lata for averages AUBERT is reported with n dominated mo | 07 s, fits, 07A a sig de. | BABR BELL limits, BABR nificance | $e^+e^- \rightarrow \Upsilon(45)$ $e^+e^- \rightarrow \Upsilon(45)$ etc. • • • Repl. by AUBERT e of more than 5 star |
| $+0.57 \pm 0.08 \pm 0.02$ $0.64 \pm 0.10 \pm 0.04$ • • • We do not use the following of 0.58 ± 0.10 ± 0.03 1 The mixing-induced <i>CP</i> violation deviations in this <i>b</i> → <i>s</i> penguin $C_{\omega K_S^0} (B^0 \rightarrow \omega K_S^0)$ MALUE -0.30 ± 0.28 OUR AVERAGE Erro -0.52 ± 0.22 ± 0.03 +0.09 ± 0.29 ± 0.06 | CHEN lata for averages AUBERT is reported with n dominated mo | 07 s, fits, 07A a sig de. | BELL , limits, BABR mificance | $e^+e^- 	o \hat{\Upsilon}(45)$ etc. • • • Repl. by AUBERT e of more than 5 star |
| 0.64 \pm 0.10 \pm 0.04 1 • • • We do not use the following of 0.58 \pm 0.10 \pm 0.03 1 The mixing-induced CP violation deviations in this $b \rightarrow s$ pengular $C_{\omega K_S^0}$ ($B^0 \rightarrow \omega K_S^0$) VALUE -0.30 \pm 0.28 OUR AVERAGE Erro -0.52 \pm 0.22 \pm 0.03 \pm 0.09 \pm 0.29 \pm 0.06 1 | CHEN lata for averages AUBERT is reported with n dominated mo | 07 s, fits, 07A a sig de. | BELL , limits, BABR mificance | $e^+e^- 	o \hat{\Upsilon}(45)$ etc. • • • Repl. by AUBERT e of more than 5 star |
| • • • We do not use the following of $0.58\pm0.10\pm0.03$ 1 The mixing-induced CP violation deviations in this $b\to s$ penguin $C_{\omega K_S^0}$ ($B^0\to \omega K_S^0$) WALUE - 0.30 ± 0.28 OUR AVERAGE $0.52\pm0.22\pm0.03$ $0.09\pm0.29\pm0.06$ 1 | lata for averages AUBERT is reported with a dominated mo DOCUMENT ID r includes scale | o, fits, 07A a sig de | limits, BABR inificance | etc. • • • Repl. by AUBERT e of more than 5 star |
| $\begin{array}{c} 0.58 \pm 0.10 \pm 0.03 & 1 \\ {}^{1} \text{ The mixing-induced } \textit{CP} \text{ violation} \\ \text{ deviations in this } b \rightarrow s \text{ penguin} \\ \textit{C}_{\omega \textit{K}_{S}^{0}} \left(\textit{B}^{0} \rightarrow \omega \textit{K}_{S}^{0} \right) \\ \underbrace{\textit{VALUE}}_{\textbf{0.30} \pm 0.28 \text{ OUR AVERAGE}} \\ -0.52 \pm 0.22 \pm 0.03 \\ +0.09 \pm 0.29 \pm 0.06 & 1 \end{array} \text{ Erro}$ | AUBERT is reported with n dominated mo | 07A asig de. | BABR nificance | Repl. by AUBERT e of more than 5 stan |
| deviations in this $b \rightarrow s$ penguli $C_{\omega K_S^0}(B^0 \rightarrow \omega K_S^0)$ $\frac{VALUE}{-0.30 \pm 0.28 \text{ OUR AVERAGE}} \text{Erro}$ $-0.52 \stackrel{+}{_{-}} 0.22 \stackrel{+}{_{-}} 0.23$ $+0.09 \pm 0.29 \pm 0.06$ | n dominated mo <u>DOCUMENT ID</u> r includes scale | de. | <u>TECN</u> | |
| deviations in this $b \rightarrow s$ penguli $C_{\omega K_S^0}(B^0 \rightarrow \omega K_S^0)$ $\frac{VALUE}{-0.30 \pm 0.28 \text{ OUR AVERAGE}} \text{Erro}$ $-0.52 \stackrel{+}{_{-}} 0.22 \stackrel{+}{_{-}} 0.23$ $+0.09 \pm 0.29 \pm 0.06$ | n dominated mo <u>DOCUMENT ID</u> r includes scale | de. | <u>TECN</u> | |
| WALUE -0.30±0.28 OUR AVERAGE -0.52±0.20 -0.52±0.03 +0.09±0.29±0.06 1 | r includes scale | | | COMMENT |
| WALUE -0.30±0.28 OUR AVERAGE -0.52±0.20 -0.52±0.03 +0.09±0.29±0.06 1 | r includes scale | | | COMMENT |
| -0.30 ± 0.28 OUR AVERAGE Erro $-$ 0.52 $^{+}_{-}$ 0.22 ± 0.03 +0.09 ± 0.29 ± 0.06 11 | r includes scale | | | COMMENT |
| $+0.09\pm0.29\pm0.06$ 1 | AUBERT | | 01 1.6. | |
| $+0.09\pm0.29\pm0.06$ 1 | | 09ı | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ◆ We do not use the following d | CHAO | 07 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | lata for averages | , fits, | limits, | etc. • • • |
| $-0.55 + 0.28 \pm 0.03$ | AUBERT,B | 06E | BABR | Repl. by AUBERT |
| | CHEN | 05в | BELL | Repl. by CHAO 07 |
| 1 Belle Collab. quotes $^{A}_{\omegaK^0_S}$ which | th is equal to — | C ω K ⁰ | i · | |
| $S_{\omega K_S^0}(B^0 \to \omega K_S^0)$ | | | | |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.43 ± 0.24 OUR AVERAGE | | | | |
| $+0.55 + 0.26 \pm 0.02$ | AUBERT | 091 | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $+0.11\pm0.46\pm0.07$ | CHAO | 07 | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • We do not use the following d | lata for averages | , tits, | , Iimits, | etc. • • • |
| $+0.51^{+0.35}_{-0.39}\pm0.02$ | AUBERT,B | 06E | BABR | Repl. by AUBERT |
| $+0.76\pm0.65{}^{+0.13}_{-0.16}$ | CHEN | 05в | BELL | Repl. by CHAO 07 |
| $C(B^0 \rightarrow K_S^0 \pi^0 \pi^0)$ | DOCUMENT IS | | TECN | COMMENT |
| VALUE 0.23±0.52±0.13 | DOCUMENT ID AUBERT | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | ~ · M () | , 5,1011 | - 0 / (40) |
| $S(B^0 \to K_S^0 \pi^0 \pi^0)$ | | | | |
| <u>VALUE</u> 0.72±0.71±0.08 | DOCUMENT ID AUBERT | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | MUDEKI | UIAG | YBABK | e · e → 1(45) |
| $C_{ ho^0 K_S^0} (B^0 ightarrow ho^0 K_S^0)$ | CUMENT ID | TFO | SN CO | MMENT |
| -0.04±0.20 OUR AVERAGE | | 120 | | |
| | BERT 09≜ LSENO 09 | | | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ |

¹ Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays and the first of two equivalent solutions is used. 2 Quotes $A_{\rho^0(KS)^0}$ which is equal to $-C_{\rho^0 K^0_S}$. 3 Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays and the first of two consistent solutions that may be preferred.

| $S_{\rho^0 K_S^0}(B^0 \to \rho^0 K_S^0)$ | $C_{K^0\pi^+\pi^-}(B^0\to K^0\pi^+\pi^-)$ nonresonant) |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE DOCUMENT ID TECN COMMENT | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| .50 ⁺ 0.17 OUR AVERAGE | 1 Uses Dalitz plot analysis of $B^0 	o \ \kappa^0 \pi^+ \pi^-$ decays and the first of two equivalent |
| $.35 ^{+0.26}_{-0.31} \pm 0.07$ 1 AUBERT 09AU BABR $e^+e^- ightarrow \varUpsilon(4S)$ | solutions is used. |
| $64^{+0.19}_{-0.25}\pm0.13$ 2 DALSENO 09 BELL $e^+e^- ightarrow \gamma(4S)$ | $C_{\mathcal{K}_S^0 \mathcal{K}_S^0} (B^0 \to \mathcal{K}_S^0 \mathcal{K}_S^0)$ |
| \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.0 ±0.4 OUR AVERAGE Error includes scale factor of 1.4. |
| .20 \pm 0.52 \pm 0.24 AUBERT 07F BABR Repl. by AUBERT 09AU 1 Uses Dalitz plot analysis of $B^{0} \rightarrow K^{0}\pi^{+}\pi^{-}$ decays and the first of two equivalent | $+0.38\pm0.38\pm0.05$ 1 NA KAHAMA 08 BELL $e^+e^- ightarrow~arGamma(4S)$ |
| solutions is used. | $-0.40\pm0.41\pm0.06$ AUBERT,BE 06c BABR $e^+e^- ightarrow \gamma(4S)$ |
| 2 Uses Dalitz plot analysis of ${\cal B}^0 \to {\cal K}^0 \pi^+ \pi^-$ decays and the first of two consistent solutions that may be preferred. | 1 Reports $^AK^0_SK^0_S$ which equals to $^{-C}K^0_SK^0_S$. |
| $f_{6(980) K_{5}^{0}}(B^{0} \rightarrow f_{0}(980) K_{5}^{0})$ | $S_{K_S^0 K_S^0} (B^0 \to K_S^0 K_S^0)$ |
| ALUE DOCUMENT ID TECN COMMENT | VALUE DOCUMENT ID TECN COMMENT — 0.8 ±0.5 OUR AVERAGE |
| 0.14 \pm 0.17 OUR AVERAGE 0.30 \pm 0.29 \pm 0.14 1,2 NAKAHAMA 10 BELL $e^+e^- \to \ \varUpsilon(4S)$ | -0.8 ± 0.9 OUR AVERAGE $-0.38 \pm 0.69 \pm 0.09$ NA KAHAMA 08 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $0.08\pm0.19\pm0.05$ 3 AUBERT 09AU BABR $e^+e^- ightarrow \gamma(4S)$ | $-1.28 + 0.80 + 0.11$ AUBERT,BE 06c BABR $e^+e^- 	o T(4S)$ |
| • • We do not use the following data for averages, fits, limits, etc. • • | |
| -0.06±0.17±0.11 | $C_{K^+K^-K^0_S}(B^0 \to K^+K^-K^0_S \text{ nonresonant})$ |
| -0.15 ± 0.15 ± 0.07 | UALUE DOCUMENT ID TECN COMMENT 0.09 ±0.09 OUR AVERAGE |
| 1 Quotes $A_{f_0(980)}K_S^0$ which is equal to $-C_{f_0(980)}K_S^0$. | $0.14 \pm 0.11 \pm 0.09$ 1.2 NAKAHAMA 10 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| $f_0(980) K_S^o$ $f_0(980) K_S^o$ ² Uses Dalitz plot analysis of $B^0 \to K_S^0 K^+ K^-$ decays and the first of four consistent | $0.054\pm0.102\pm0.060$ 1,3 AUBERT 07AX BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| solutions that may be preferred. | 0.09 \pm 0.10 \pm 0.05 1.3 CHAO 07 BELL Repl. by NAKAHAMA 10 |
| 3 Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays and the first of two equivalent solutions is used. | 0.10 \pm 0.14 \pm 0.04 |
| ⁴ Uses Dalitz plot analysis of $B^0 \to \kappa^0 \pi^+ \pi^-$ decays and the first of two consistent solutions that may be preferred. | -0.10 ±0.19 ±0.10 3 AUBERT,B 04V BABR Repl. by AUBERT 05T |
| $f_0(980) K_S^0 (B^0 \to f_0(980) K_S^0)$ | $0.40~\pm0.33~{+0.28 \atop -0.10}$ 1 ABE 03с BELL Repl. by ABE 03н |
| ALUE DOCUMENT ID TECN COMMENT | $0.17 \pm 0.16 \pm 0.04$ $1,3$ ABE 03H BELL Repl. by CHEN 05B |
| 0.73 ± 0.27 OUR AVERAGE Error includes scale factor of 1.6. | ¹ Quotes $A_{K+K-K_S^0}$ which is equal to $-C_{K+K-K_S^0}$ |
| $0.96 + 0.21 \pm 0.04 \pm 0.04$ AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4S)$ | 2 Uses Dalitz plot analysis of $B^0 	o 	extit{K}^0_S 	extit{K}^+$ decays and the first of four consister solutions that may be preferred. |
| | 3 Excludes the events from $B^0 	o \phi K^0_S$ decay. The results are derived from a combined |
| $-0.43^{+0.22}_{-0.20}\pm0.14$ 2 DALSENO 09 BELL $e^+e^- \rightarrow \Upsilon(4S)$ •• • We do not use the following data for averages, fits, limits, etc. ••• | sample of $\mathit{K}^+\mathit{K}^-\mathit{K}^0_{S}$ and $\mathit{K}^+\mathit{K}^-\mathit{K}^{0}_{\mathit{L}}$ decays. |
| $-0.25\pm0.26\pm0.10$ 3 AUBERT 07AX BABR Repl. by AUBERT 09AU | $S_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0)$ nonresonant) |
| +0.18±0.23±0.11 CHAO 07 BELL Repl. by DALSENO 09 +0.47±0.41±0.08 CHEN 05B BELL Repl. by CHAO 07 | VALUE DOCUMENT ID TECN COMMENT |
| 1 Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays and the first of two equivalent | -0.74 $^{+0.12}_{-0.10}$ OUR AVERAGE |
| solutions is used. 2 Uses Dalitz plot analysis of $B^0 \to K^0 \pi^+ \pi^-$ decays and the first of two consistent | $-0.764\pm0.111 {}^{+0.071}_{-0.040}$ 1,2 AUBERT 07AX BABR $e^+e^- ightarrow \varUpsilon$ (4S) |
| solutions that may be preferred. | $-0.68 \pm 0.15 \stackrel{+0.21}{-0.13}$ CHAO 07 BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| 3 Reports eta_{eff} . We quote ${\it S}$ obtained from epaps: E-PRLTAO-99-076741. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $S_{\underline{f}_2(1270) K_S^0} (B^0 \to f_2(1270) K_S^0)$ | -0.42 ±0.17 ±0.03 |
| ALUE DOCUMENT ID TECN COMMENT -0.48 \pm 0.52 \pm 0.12 1 AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4.5)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 1 Uses Dalitz plot analysis of $B^0 	o K^0 \pi^+ \pi^-$ decays and the first of two equivalent | $-0.49 \pm 0.43 \pm 0.11$ ABE 03C BELL Repl. by ABE 03H $-0.51 \pm 0.26 \pm 0.05$ 1.5 ABE 03H BELL Repl. by CHEN 05B |
| solutions is used. | ¹ Excludes events from $B^0 \to \phi K_S^0$ decay. The results are derived from a combine |
| | |
| $f_{5(1270)} K_{5}^{0} (B^{0} \rightarrow f_{2}(1270) K_{5}^{0})$ | sample of $K^+ K^- K^0_S$ and $K^+ K^- K^0_L$ decays. |
| ALUE <u>DOCUMENT ID TECN COMMENT</u> | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. Reports eta_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. |
| ALUE <u>DOCUMENT ID TECN COMMENT</u> | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. ² Reports β_{eff} . We quote <i>S</i> obtained from epaps: E-PRLTAO-99-076741. ³ The measured <i>CP</i> -even final states fraction is $0.89\pm0.08\pm0.06$. ⁴ The measured <i>CP</i> -even final states fraction is $0.98\pm0.15\pm0.04$. |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 09AU BABR $e^+e^- ightarrow \Upsilon(45)$ 1 Uses Dalitz plot analysis of $B^0 ightarrow K^0 \pi^+ \pi^-$ decays and the first of two equivalent | sample of $K^+K^-K_0^S$ and $K^+K^-K_0^L$ decays. ² Reports β_{eff} . We quote <i>S</i> obtained from epaps: E-PRLTAO-99-076741. ³ The measured <i>CP</i> -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. ⁴ The measured <i>CP</i> -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. ⁵ The measured <i>CP</i> -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. |
| ALUE DOCUMENT ID TECN COMMENT 1.28 $^+$ 0.35 $^+$ 0.40 $^+$ 0.11 1 AUBERT 09AU BABR $e^+e^- 	oup \Upsilon(4S)$ 1 Uses Dalitz plot analysis of $B^0 	oup \kappa^0 \pi^+ \pi^-$ decays and the first of two equivalent solutions is used. | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. ² Reports β_{eff} . We quote <i>S</i> obtained from epaps: E-PRLTAO-99-076741. ³ The measured <i>CP</i> -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. ⁴ The measured <i>CP</i> -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. ⁵ The measured <i>CP</i> -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. $C_{K^+K^-K^0_S}$ ($B^0 \rightarrow K^+K^-K^0_S$ inclusive) |
| ALUE DOCUMENT ID TECN COMMENT 1.28 $+ 0.35 \pm 0.11$ 1 AUBERT 1 AUBERT 1 Uses Dalitz plot analysis of $B^0 \rightarrow K^0 \pi^+ \pi^-$ decays and the first of two equivalent solutions is used. 5 $f_X(1300) K_S^0$ ($B^0 \rightarrow f_X(1300) K_S^0$) | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. ² Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. ³ The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. ⁴ The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. ⁵ The measured CP -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. $C_{K^+K^-K^0_S}$ ($B^0 \rightarrow K^+K^-K^0_S$ inclusive) |
| ALUE DOCUMENT ID TECN COMMENT 1.28 $^+$ 0.35 $^+$ 0.11 1 AUBERT 09AU BABR $e^+e^- 	oup \Upsilon(45)$ 1 Uses Dalitz plot analysis of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used. 6 $f_X(1300) K_S^0 (B^0 	oup f_X(1300) K_S^0)$ | sample of $K^+K^-K_S^0$ and $K^+K^-K_L^0$ decays. ² Reports β_{eff} . We quote 5 obtained from epaps: E-PRLTAO-99-076741. ³ The measured <i>CP</i> -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. ⁴ The measured <i>CP</i> -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. ⁵ The measured <i>CP</i> -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. $C_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0 \text{ inclusive})$ VALUE 0.015 $\pm 0.077 \pm 0.053$ 1, 2 AUBERT 1, 2 AUBERT 1 Measured using full Dalitz plot fit including ϕ component. |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 09AU BABR $e^+e^- ightharpoonup \Upsilon(4.5)$ 1 Uses Dalitz plot analysis of $B^0 ightharpoonup K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used. 5 $f_X(1300) K_S^0$ ($B^0 ightharpoonup f_X(1300) K_S^0$) ALUE DOCUMENT ID TECN COMMENT | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. $C_{K^+K^-K^0_S}(B^0 \to K^+K^-K^0_S \text{ inclusive})$ VALUE 0.015 $\pm 0.077 \pm 0.053$ 1, 2 AUBERT 1, 2 AUBERT 1, 3 AUBERT 1, 4 AUBERT 1, 5 AUBERT 1, 6 AUBERT 1, 6 AUBERT 1, 7 AUBERT 2 The results are derived from a combined sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 1 | sample of $K^+K^-K^0_S$ and $K^+K^-K^0_L$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is 0.98 ± 0.06 . 6 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 8 The measured CP -even final states fraction is 0.98 ± 0.06 . 9 The measured CP -even final states fraction is 0.98 ± 0.06 . 9 The measured CP -even final states fraction is 0.98 ± 0.06 . 9 The measured CP -even final states fraction is 0.98 ± 0.06 . 1 The measured CP -even final states fraction is 0.98 ± 0.06 . 1 The measured CP -even final states fraction is 0.98 ± 0.06 . 1 The measured CP -even final states fraction is 0.98 ± 0.06 . 1 The measured CP -even final states fraction is 0.98 ± 0.08 . 2 The measured CP -even final states fraction is 0.98 ± 0.08 . 2 The measured CP -even final states fraction is 0.98 ± 0.08 . 2 The measured CP -even final states fraction is 0.98 ± 0.08 . 2 The measured CP -even final states fraction is 0.98 ± 0.08 . 3 The measured CP -even final states fraction is 0.98 ± 0 |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 2 AUMENT AUBERT | sample of $K^+K^-K_0^S$ and $K^+K^-K_L^0$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is 0.98 ± 0.06 . 6 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 7 The measured CP -even final states fraction is 0.98 ± 0.06 . 8 The measured CP -even final states fraction is 0.98 ± 0.06 . 9 The measured CP -even final states fraction is 0.98 ± 0.06 . 1 Measured CP -even final states fraction is 0.98 ± 0.06 . 1 Measured CP -even final states fraction is 0.98 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 1 Measured CP -even final states fraction is 0.99 ± 0.06 . 2 The measured CP -even final states fraction is 0.99 ± 0.06 . 2 The measured CP -even final states fraction is 0.99 ± 0.06 . 2 The measured CP -even final s |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 1 | sample of $K^+K^-K_S^0$ and $K^+K^-K_L^0$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. The measured using full Dalitz plot fit including CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP or CP |
| ALUE DOCUMENT ID TECN COMMENT 1 AUBERT 2 AUMENT AUBERT | sample of $K^+K^-K_S^0$ and $K^+K^-K_L^0$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $1.03 \pm 0.15 \pm 0.05$. $C_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0 \text{ inclusive})$ MALUE DOCUMENT ID 1 Measured using full Dalitz plot fit including ϕ component. 2 The results are derived from a combined sample of $K^+K^-K_S^0$ and $K^+K^-K_L^0$ decays $S_{K^+K^-K_S^0}(B^0 \to K^+K^-K_S^0 \text{ inclusive})$ MALUE O.647 $\pm 0.116 \pm 0.040$ 1 Measured using full Dalitz plot fit including ϕ component. $C_{\phi K_S^0}(B^0 \to \phi K_S^0)$ |
| 1 AUBERT 09AU BABR $e^+e^- 	oup T(4S)$ 1 Uses Dalitz plot analysis of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used. 1 Uses Dalitz plot analysis of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used. 1 AUBERT 09AU BABR $e^+e^- 	oup T(4S)$ 1 Uses Dalitz plot analysis of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used. 1 AUBERT 09AU BABR $e^+e^- 	oup T(4S)$ 1 Uses Dalitz plot analysis of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ decays and the first of two equivalent of $B^0 	oup K^0\pi^+\pi^-$ | sample of $K^+K^-K_S^0$ and $K^+K^-K_L^0$ decays. 2 Reports β_{eff} . We quote S obtained from epaps: E-PRLTAO-99-076741. 3 The measured CP -even final states fraction is $0.89 \pm 0.08 \pm 0.06$. 4 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. 5 The measured CP -even final states fraction is $0.98 \pm 0.15 \pm 0.04$. TECN COMMENT 1 Measured using full Dalitz plot fit including ϕ component. 1 AUBERT 07AX BABR CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE CP -EVALUE |

 1 Uses Dalitz plot analysis of $B^0\to K^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used.

 B^0

| • • • We do not use the following data for averages, fits, limits, etc. • • • | $C_{K^*(892)^0\gamma}(B^0 \to K^*(892)^0\gamma)$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $-0.07 \pm 0.15 \pm 0.05$ 1,3 CHEN 07 BELL Repl. by NAKAHAMA 10 | · · · |
| $-0.07 \pm 0.13 \pm 0.05$ 3 AUBERT 05T BABR Repl. by AUBERT 07AX | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> — 0.04 ± 0.16 OUR AVERAGE Error includes scale factor of 1.2. |
| -0.08 ± 0.22 ± 0.09 1,3 CHEN 05 B BELL Repl. by CHEN 07 | $-0.14\pm0.16\pm0.03$ 1 AUBERT 08BA BABR $e^{+}e^{-} ightarrow$ $\varUpsilon(4S)$ |
| $0.01\pm0.33\pm0.10$ 3 AUBERT,B 04G BABR Repl. by AUBERT 05T | $+0.20\pm0.24\pm0.05$ 1,2 USHIRODA 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| 0.56±0.41±0.16 | • • We do not use the following data for averages, fits, limits, etc. |
| 0.15 ± 0.29 ± 0.07 | -0.40±0.23±0.03 AUBERT,B 05P BABR Repl. by AUBERT 08BA -0.57±0.32±0.09 ³ AUBERT,B 04Z BABR Repl. by AUBERT,B 05P |
| 1 Quotes $A_{\phi K_{\mathcal{S}}^{0}}$ which is equal to $-\mathcal{C}_{\phi K_{\mathcal{S}}^{0}}$. | |
| ² Uses Dalitz plot analysis of $B^0 \to K_S^0 K^+ K^-$ decays and the first of four consistent | 1 Requires 0.8 $<$ $M_{K_{S}^{0}\pi^{0}}$ $<$ 1.0 GeV/ c^{2} . |
| solutions that may be preferred. 3 Result combines ${\cal B}$ -meson final states ϕK^0_S and ϕK^0_L by assuming $S_{\phiK^0_S}=-S_{\phiK^0_L}$ | 2 Reports value of A which is equal to $-C$. 3 Based on a total signal of 105 ± 14 events with $K^*(892)^0	o K_S^0\pi^0$ only. |
| $S_{\phi K_S^0} (B^0 \to \phi K_S^0)$ | $S_{K^*(892)^0\gamma}(B^0 \to K^*(892)^0\gamma)$ |
| VALUE DOCUMENT ID TECN COMMENT | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> — 0.15 ± 0.22 OUR AVERAGE |
| 0.39±0.17 OUR AVERAGE 0.21±0.26±0.11 | -0.03 ± 0.22 OOR AVERAGE $-0.03\pm0.29\pm0.03$ 1 AUBERT 08BA BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| 0.21 \pm 0.26 \pm 0.11 | $-0.32 + \frac{0.36}{0.33} \pm 0.05$ 1 USHIRODA 06 BELL $e^+e^- \rightarrow r(45)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.50 ± 0.25 + 0.07 1 AUBERT 05T BABR Repl. by AUBERT 07AX | -0.21±0.40±0.05 AUBERT,B 05P BABR Repl. by AUBERT 08BA |
| 0.08±0.33±0.09 | $-0.79 {+0.63 \atop -0.50} \pm 0.10$ 2 USHIRODA 05 BELL Repl. by USHIRODA 06 |
| $0.47\pm0.34 {+0.08 \atop -0.06}$ 1 AUBERT,B 04G BABR Repl. by AUBERT 05T | $0.25\pm0.63\pm0.14$ 3 AUBERT,B 04z BABR Repl. by AUBERT,B 05P |
| $-0.73\pm0.64\pm0.22$ ABE 03c BELL Repl. by ABE 03H | 1 Requires $0.8 < M_{K_{c}^{0}\pi^{0}} < 1.0 \; {\rm GeV/c^{2}}.$ |
| $-0.96\pm0.50^{+0.09}_{-0.11}$ ABE 03н BELL Repl. by CHEN 05в | 2 Assumes $C(B^{0} \to K^{*}(892)^{0} \gamma) = 0$. |
| 1 Result combines B -meson final states $\phi K^0_{\mathcal{S}}$ and ϕK^0_{L} by assuming $S_{\phi K^0_{S}} = -S_{\phi K^0_{I}}$ | ³ Based on a total signal of 105 ± 14 events with $K^*(892)^0 \rightarrow K_5^0 \pi^0$ only. |
| 2 Reports eta_{eff} . We quote s obtained from epaps: E-PRLTAO-99-076741. | $C_{\eta K^0 \gamma} (B^0 \to \eta K^0 \gamma)$ |
| $C_{K_S K_S K_S}(B^0 \to K_S K_S K_S)$ | <u>NALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> $-0.32 \pm 0.40 \pm 0.07$ ¹ AUBERT 09 BABR $e^+e^- \rightarrow r(4S)$ |
| -0.15 ± 0.16 OUR AVERAGE Error includes scale factor of 1.1. | $1 m_{nK} < 3.25 \text{ GeV/c}^2$. |
| $+0.02\pm0.21\pm0.05$ AUBERT 07AT BABR $e^+e^- 	o 	au(4S)$ $-0.31\pm0.20\pm0.07$ 1 CHEN 07 BELL $e^+e^- 	o 	au(4S)$ | 7 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $S_{\eta K^0 \gamma} (B^0 	o \eta K^0 \gamma)$ MALUE DOCUMENT ID TECH COMMENT |
| $-0.34 {+ 0.28 \pm 0.05}$ AUBERT,B 05 BABR Repl. by AUBERT 07AT | -0.18$^{+}$0.49$^{+}$0.12 1 AUBERT 09 BABR $e^{+}e^{-} \rightarrow \Upsilon(4S)$ |
| $-0.54\pm0.34\pm0.09$ 1 SUMISAWA 05 BELL Repl. by CHEN 07 | 4.15 |
| 1 Belle Collab. quotes $A_{K_SK_SK_S}$ which is equal to $-C_{K_SK_SK_S}$. | $^{1} m_{\eta K} < 3.25 \mathrm{GeV/c^2}$. |
| | C - (B0 , K0 da) |
| $S_{K_SK_S}(B^0 \to K_SK_SK_S)$ | $C_{K^0\phi\gamma} (B^0	o K^0\phi\gamma)$ VALUE DOCUMENT ID TECH COMMENT |
| VALUE DOCUMENT ID TECN COMMENT -0.4 +0.5 OUR AVERAGE Error includes scale factor of 2.5 | |
| -0.4 \pm0.5 OUR AVERAGE Error includes scale factor of 2.5. -0.71 \pm 0.24 \pm 0.04 AUBERT 07AT BABR $e^+e^- \rightarrow \Upsilon(4S)$ | -0.35 ± 0.58 $\stackrel{+}{-}$ 0.23 1 SAHOO 11A BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.30 \pm 0.32 \pm 0.08$ CHEN 07 BELL $e^+e^- \rightarrow \Upsilon(45)$ | 1 Reports value of A , which is equal to $-\mathcal{C}$. |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| | $S_{K^0\phi\gamma} (B^0 \to K^0\phi\gamma)$ |
| -0.71 + 0.38 ± 0.04 AUBERT,B 05 BABR Repl. by AUBERT 07AT | VALUEDOCUMENT IDTECNCOMMENT |
| $1.26 \pm 0.68 \pm 0.20$ SUMISAWA 05 BELL Repl. by CHEN 07. | $0.74 + 0.72 + 0.10 \ -1.05 - 0.24$ SAHOO 11A BELL $e^+e^- 	o 	au(45)$ |
| $C_{K_S^0\pi^0\gamma}(B^0\to K_S^0\pi^0\gamma)$ | |
| VALUE DOCUMENT ID TECN COMMENT | $C(B^0 \to K_S^0 \rho^0 \gamma)$ |
| + 0.36 ± 0.33 ± 0.04 1 AUBERT 08BA BABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE DOCUMENT ID TECN COMMENT |
| • • We do not use the following data for averages, fits, limits, etc. • • | -0.05 ± 0.18 ± 0.06 1,2 LI 08F BELL e^+e^- → $T(4S)$ |
| $+0.20\pm0.20\pm0.06$ 2,3 USHIRODA 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | 1 Requires M $_{K_c^0\pi^+\pi^-}<$ 1.8 GeV/c 2 and 0.6 $<$ M $_{\pi^+\pi^-}<$ 0.9 GeV/c 2 . |
| $-1.0~\pm 0.5~\pm 0.2$ AUBERT,B 05P BABR Repl. by AUBERT 08BA | ² Reports value of $A_{ m eff}$ which is equal to $-$ <i>C</i> , and includes the non-resonant $\pi^+\pi^-$ |
| $-0.03\pm0.34\pm0.11$ 3 USHIRODA 05 BELL Repl. by USHIRODA 06 | contribution in the $ ho^0$ region. |
| ¹ Requires $1.1 < M_{K_c^0 \pi^0} < 1.8 \text{ GeV/c}^2$. | · |
| ^{$N_{\tilde{S}}$ π^{0}} ² Requires $M_{K_{\tilde{S}}^{0}\pi^{0}} < 1.8 \text{ GeV/c}^{2}$. | $S(B^0 	o K^0_S ho^0 \gamma)$ VALUE DOCUMENT ID TECH COMMENT |
| ³ Reports $A_{K_0^0\pi^0\gamma}$, which is $-C_{K_0^0\pi^0\gamma}$. | +0.11±0.33 ⁺ 0.05 1 LI 08F BELL $e^+e^- \rightarrow r(4S)$ |
| $K_{S}^{0}\pi^{0}\gamma^{\prime}$ | -0.07 |
| $S_{\kappa_{\mathcal{Q}}^0\pi^0\gamma}(B^0 \to K_{\mathcal{S}}^0\pi^0\gamma)$ | 1 Requires M $_{K_{S}^{0}\pi^{+}\pi^{-}}<$ 1.8 GeV/c 2 . |
| VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | $C(B^0 \to \rho^0 \gamma)$ |
| -0.78±0.59±0.09 1 AUBERT 08BA BABR $e^+e^- ightarrow \Upsilon(4S)$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $-0.10\pm0.31\pm0.07$ 2 USHIRODA 06 BELL $e^+e^- ightarrow \varUpsilon(4S)$ | 1 Reports value of A which is equal to $-C$. |
| $\pm 0.9 \pm 1.0 \pm 0.2$ AUBERT,B 05P BABR Repl. by AUBERT 08BA | |
| $-0.58 {+0.46 \pm 0.11}$ USHIRODA 05 BELL Repl. by USHIRODA 06 | $S(B^0 \to \rho^0 \gamma)$ |
| $^{-0.30}$ Requires $1.1 < M_{K_{\odot}^{0}\pi^{0}} < 1.8 \text{ GeV/c}^{2}$. | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> -0.83 ± 0.65 ± 0.18 USHIRODA 08 BELL e^+e^- → $\Upsilon(4S)$ |
| ² Requires $M_{K_{\zeta}^0\pi^0} < 1.8 \text{ GeV/c}^2$. | $C_{\pi\pi} (B^0 \to \pi^+\pi^-)$ |
| n _S n- | $C_{\pi\pi}$ is defined as $(1- \lambda ^2)/(1+ \lambda ^2)$, where the quantity $\lambda=q/p~\overline{A}_f/A_f$ is a phas convention independent observable quantity for the final state f . For details, see the review on "CP Violation" in the Reviews section. |
| | VALUE DOCUMENT ID TECN COMMENT |

| - 0.09 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 - 2.00 | • • • We do not use the f $-0.56 \pm 0.12 \pm 0.06$ | ollowing data for averages, fits, limits, etc. • • • 1 ABE 05D BELL Repl. by ISHINO 07 | $\Delta S_{ ho\pi}(m{B^0}	om{ ho^+\pi^-})$ $\Delta S_{ ho\pi}$ is related to the strong phase difference between the amplitudes contributing |
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---------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| | | | |
| -0.91 ± 0.92 ± 1.00 | | 1 | -0.05 ± 0.10 OUR AVERAGE |
| - 0.35 = 0.45 = 0.45 | $-0.94^{+0.31}_{-0.25}\pm0.09$ | ¹ ABE 02M BELL Repl. by ABE 03G | |
| -0.00.4.0.2.0.00 AUDIECT | $-0.25 + 0.45 \pm 0.14$ | ² AUBERT 02D BABR Repl. by AUBERT 02Q | |
| Piper person depth of the provision of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the cont | | ³ AUBERT 02Q BABR Repl. by AUBERT,BE 05 | |
| \$\(\chi \) \chi \) \chi \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ | 1 Paper reports $A_{\pi\pi}$ wh | ch equals to $-C_{\pi\pi}$. | |
| S _{art} (β ⁰ → π ⁴ π) S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x ²), see the role in 10 C _{art} distribute above S _{art} = 3mA/(1- x | | | <i>r</i> :- |
| Seg = 20 mill (1-1) ²), see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) and (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed above (1-1) ² see the face in the Copy distributed | Corresponds to 90% co | nfidence range $-0.72 < C_{\pi\pi} < 0.12$. | <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.3 ±0.4 OUR AVERAGE |
| *** We do not use the following state for provinging | | | $-0.10\pm0.40\pm0.53$ AUBERT 07AA BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| 0.00000000000000000000000000000000000 | $S_{\pi\pi} = 2 \operatorname{Im} \lambda / (1 + \lambda)$ | $^{[2)}$), see the note in the $\mathcal{C}_{\pi\pi}$ datablock above. | |
| -0.03 ± 111,0.03 ADEEDT OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(45) OF DELL (= = -7.7(| | | |
| -0.6.1 = 0.0.0.6.14 -0.6.7 = 0.6.16.2.6.2.6 -0.6.7 = 0.6.16.2.6.2.6 -0.6.7 = 0.6.16.2.6.2.6 -0.6.7 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2.6 -0.6.2 = 0.6.16.2.6.2 -0.6.2 = 0.6.16.2.6 -0.6.2 = 0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 = 0.6.2.6.2.6 -0.6.2 | _ | | |
| - 6.7 ± 0.15 ± 0.05 | | | · Quotes A $_{ ho^0\pi^0}$ which is equal to $-{\cal C}_{ ho^0\pi^0}$. |
| $\frac{\sin(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\sin(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\sin(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\sin(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} = \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)} + \frac{\cos(x)}{\cos(x)$ | | 4 | $S_{\rho 0,\pi^0} (B^0 \to \rho^0 \pi^0)$ |
| 1.001.02 ± 0.007 | | , , | VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| -1.21±1.03±1.05 ABE 02M BELL Right by ABE 031.21±1.03±1.01 3 ABE 02M BELL Right by ABERT 020 00±1.03±1.01 3 AUBERT 070 BABR Right by ABERT 020 00±1.03±1.01 3 AUBERT 070 BABR Right by ABERT 020 00±1.03±1.01 3 AUBERT 070 BABR Right by ABERT 020 00±1.03±1.01 1 AUBERT 020 00±1.01 1 | | | |
| - 0.31 ± 0.37 ± 0.38 ± 0.38 | $-1.23 \pm 0.41 + 0.08$ | ABE 03G BELL Repl. by ABE 04E. | |
| $\begin{array}{c} 0.03 \pm \frac{6.57}{6.59} \pm 0.11 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 3.4 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.02 \pm 0.05 \\ 0.0$ | | ABE 02M BELL Repl. by ABE 03G | $C (R^0 \rightarrow 2.(1260) + \pi^{-1})$ |
| 0.01±0.31±0.09 AUBERT 0.20 BABR Rep. by AUBERT 10.25 BABR Rep. by AUBERT 0.74 BABR t^+e^- — T[45] BLILE Collab curves $A_{p,q}$ which is considered to the CP-conserving case, $C_{q,q} = S_{p,q} = S_{p,$ | | | |
| | | | |
| $ \frac{3}{C} \text{ cort size of C-conserving case, } C_{eff} = S_{eff} = 0. \text{ at the } 52 \text{ signs level} $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.98 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.98 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.98 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.58 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.58 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.58 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.58 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 39% confidence range} = 0.58 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 30 WARAGO to 50 ELL } \text{ of } c - 7 / (4.5) $ $ \frac{3}{C} \text{ corresponds to 2.90\% C.L interval of } 0.38 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 2.90\% C.L interval of } 0.38 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 2.90\% C.L interval of } 0.38 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 2.90\% C.L interval of } 0.38 c.S_{eff} < 0.58. $ $ \frac{3}{C} \text{ corresponds to 2.90\% C.L interval of } 0.38 c.S_{eff} < 0.588 c.S_{$ | | | $S (R^0 \rightarrow 2.(1260) + \pi^-)$ |
| \$\$ \frac{\chicker_{\text{constant}}{\chicker_{\text{constant}}} = 0.954 \chicker_{\text{size}} < 0.951 \\ \frac{\chicker_{\text{constant}}{\chicker_{\text{constant}}}}{\text{Constant}} = 0.054 \chicker_{\text{size}} \\ \frac{\chicker_{\text{constant}}}{\text{Constant}} = 0.044 \chicker_{\text{constant}} \\ \frac{\chicker_{\text{constant}}}{\text{Constant}} = 0.044 \chicker_{\text{constant}} \\ \frac{\chicker_{\text{constant}}}{\text{constant}} = 0.044 \chicker_{\text{constant}} \\ \frac{\chicker_{\text{constant}}}{\text{constant}}} = 0.044 \chicker_{\text{constant}} \\ \text{constant}} 0.044 \chicker_{\text | ² Rule out the <i>CP</i> -conser | ving case, $C_{\pi\pi} = S_{\pi\pi} = 0$, at the 5.2 sigma level. | |
| | ³ Corresponds to 90% co | nfidence range $-0.89 < S_{\pi\pi} < 0.85$. | |
| $ \begin{array}{c c c c c c c c c c c c c c c c c c c $ | ⁴ Corresponds to 90% co | nfidence range $-0.54 < \! S_{\pi\pi} < 0.58$. | $\Lambda C (R^0 \rightarrow a_c(1260) + \pi^-)$ |
| $-0.49\pm0.30 \text{ OUR AVERAGE} \\ -0.49\pm0.35\pm0.05 \text{ AUBERT } 0\text{ Tree BABR } e^+e^- \rightarrow T(45) \\ -0.49\pm0.35\pm0.05 \text{ AUBERT } 1\text{ CHANO } 0\text{ BELL } e^+e^- \rightarrow T(45) \\ -0.49\pm0.52\pm0.17 1\text{ CHANO } 0\text{ BELL } e^+e^- \rightarrow T(45) \\ -0.12\pm0.52\pm0.07 1\text{ CHANO } 0\text{ SELL } e^+e^- \rightarrow T(45) \\ -0.12\pm0.52\pm0.07 2\text{ AUBERT } 0\text{ SL BABR Repl. by AUBERT } 0\text{ AUBERT } 0\text{ SL BABR Repl. by AUBERT } 0\text{ AUBERT } 0\text{ SL BABR Repl. by AUBERT } 0\text{ AUBERT } 0\text{ SL BABR Repl. by AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0\text{ AUBERT } 0 AUBERT $ | $C_{-0} = (B^0 \to \pi^0 \pi^0)$ | | ΔC_{\bullet} describes the asymmetry between the rates $\Gamma(B^0 \to a^+ \pi^-) + \Gamma(\overline{B}^0 \to a^+ \pi^-)$ |
| $-0.4 \pm 0.3 \pm 0.06$ $-0.4 \pm 0.3 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.05$ $-0.4 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0.0 \pm 0$ | VALUE | | |
| 0.44 ± 0.53 ± 0.17 1 CHAO 65 BELL e+ e − 7(45) ••• We do not use the following data for averages, fits, limits, etc. ••• -0.12 ± 0.54 ± 0.05 ± 0.07 BELLE Collab quotes A _{D = 0} which is equal to −C _{D = 0} = 1 -0.47 ± 0.05 ± 0.07 ± 0.07 BELLE Collab quotes A _{D = 0} which is equal to −C _{D = 0} = 1 -0.48 ∈ A _{D = 0} which is equal to −C _{D = 0} = 1 -0.41 ± 0.04 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 -0.13 ± 0.07 ± 0.05 ± 0.05 -0.13 ± 0.07 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 ± 0.05 | | | |
| • • • • • • • • • • • • • • • • • • • | | | 0.26 \pm 0.15 \pm 0.07 AUBERT 070 BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| 1 BELLE Callab. quotes A _{D = 0} which is equal to - C _{D = D} - 2 corresponds to a 90% CL interval of - 0.88 < A _C P < 0.64. Comparison | | | $\Delta S_{2,\pi} (B^0 \to a_1(1260)^+\pi^-)$ |
| 1 BELLE Coilab. quotes A _{ab = 0} which is equal to - C _{ab = 0} b. Walk (MEC | | | $\Delta S_{a_1\pi}$ is related to the strong phase difference between the amplitudes contributing |
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| MILUE DOCUMENT D TECN COMMENT COMMENT STEN COMMENT COMMEN | $C (R^0 \rightarrow c^+ \sigma^-)$ | - | |
| 0.01 ±0.04 DUR AVERAGE Error includes scale factor of 1.9. 0.15 ±0.09 ±0.05 AUBERT 707AB BABR $e^+e^- \rightarrow T(45)$ 0.13 ±0.09 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.25 ±0.17 ±0.02 WARG 0 BELL Repl. by KUSAKA 07 0.36 ±0.18 ±0.04 AUBERT 031 BABR Repl. by AUBERT 07AA BABR $e^+e^- \rightarrow T(45)$ 0.36 ±0.18 ±0.04 AUBERT 031 BABR Repl. by AUBERT 07AA BABR $e^+e^- \rightarrow T(45)$ 0.36 ±0.18 ±0.04 AUBERT 031 BABR Repl. by AUBERT 07AA BABR $e^+e^- \rightarrow T(45)$ 0.36 ±0.18 ±0.04 AUBERT 031 BABR Repl. by AUBERT 07AA BABR $e^+e^- \rightarrow T(45)$ 0.06 ±0.13 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.06 ±0.13 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.19 ±0.24 ±0.03 AUBERT 031 BABR Repl. by AUBERT 07AA AC _{pπ} (B ⁰ → ρ ⁺ π ⁻) ΔC _{pπ} describes the asymmetry between the rates $\Gamma(B^0 \rightarrow \rho^+\pi^-)$ AUCE 0.37 ±0.06 OUR AVERAGE 0.39 ±0.01 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.36 ±0.13 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.36 ±0.13 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.36 ±0.13 ±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ 0.36 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.15 ±0.05 COMMENT 10 TECN COMMENT 0.16 ±0.15 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.13 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0.05 ±0.05 COMMENT 10 TECN COMMENT 0.17 ±0. | $C_{\rho\pi} (B \rightarrow P^{\cdot} \pi)$ | DOCUMENT ID TECN COMMENT | |
| 0.15 ± 0.09 ± 0.05 | _ | GE Error includes scale factor of 1.9. | |
| • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | | | , |
| 0.25 ± 0.17 ± 0.02 | | · , | |
| $S_{\rho\pi}(B^0 \to \rho^+\pi^-)$ | $0.25 \pm 0.17 \pm 0.02$ | WANG 05 BELL Repl by KUSAKA 07 | |
| $S_{\rho\pi}\left(B^{0} \rightarrow \rho^{+}\pi^{-}\right) \\ \frac{VALUE}{VALUE} \\ 0.01 \pm 0.09 \text{ OUMRNT} D \\ 0.02 0.01 \pm 0.09 O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O $ | 0.00 | · | , |
| VALUE DOCUMENT ID TECN COMMENT 0.01±0.09 OUR AVERAGE 0.03±0.11±0.04 AUBERT 07AB BABR $e^+e^- \rightarrow T(4S)$ 0.06±0.13±0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(4S)$ 0.02±0.11±0.04 AUBERT 07AB BABR $e^+e^- \rightarrow T(4S)$ 0.03±0.12±0.08 WANG 05 BELL Repl. by KUSAKA 07 0.19±0.24±0.03 AUBERT 03 BABR Repl. by AUBERT 07AA ΔCρπ (B ⁰ → ρ ⁺ π ⁻) ΔCρπ describes the asymmetry between the rates Γ(B ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ π ⁻) + Γ(B̄ ⁰ → ρ ⁺ | | NODEKT SON BROKEN SY NODEKT SINK | $C_{\rho^0\rho^0}(B^0 \to \rho^0\rho^0)$ |
| 0.01 \pm 0.09 OUR AVERAGE -0.03 \pm 0.11 \pm 0.04 AUBERT 07AA BABR $e^+e^- \rightarrow T(45)$ 0.06 \pm 0.13 \pm 0.05 • • We do not use the following data for averages, fits, limits, etc. • • • -0.28 \pm 0.23 \pm 0.10 0.19 \pm 0.24 \pm 0.03 AUBERT 03T BABR Repl. by AUBERT 07AA $ \Delta C_{\rho \pi} \left(B^0 \rightarrow \rho^+ \pi^-\right) $ -0.28 \pm 0.23 \pm 0.09 -0.37 \pm 0.08 OUR AVERAGE 0.33 \pm 0.09 \pm 0.05 AUBERT 07AB BABR $e^+e^- \rightarrow T(45)$ 0.36 \pm 0.11 \pm 0.05 • • We do not use the following data for averages, fits, limits, etc. • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | $S_{\rho\pi} (B^0 \rightarrow \rho^+\pi^-)$ | DOCUMENT ID TECH COMMENT | |
| 0.66 \pm 0.13 \pm 0.05 KUSAKA 07 BELL $e^+e^- \rightarrow T(45)$ • • We do not use the following data for averages, fits, limits, etc. • • • 0.28 \pm 0.23 $^+$ 0.10 0.19 \pm 0.24 \pm 0.03 AUBERT 037 BABR Repl. by AUBERT 07AA $ C_{\rho\rho} \left(B^0 \rightarrow \rho^+ \pi^-\right) $ $ C_{\rho\rho} \left(B^0 \rightarrow \rho^+ \pi^-\right) $ $ C_{\rho\pi} \left(B^0 \rightarrow \rho^+ \pi^-$ | 0.01 ± 0.09 OUR AVERA | | _ |
| • • We do not use the following data for averages, fits, limits, etc. • • • 0.3 $\pm 0.7 \pm 0.2$ AUBERT 08B BABR $e^+e^- \rightarrow T(4S)$ 0.0 $\pm 0.24 \pm 0.03$ AUBERT 03T BABR Repl. by AUBERT 07AA $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ ($C^0 \rightarrow C^0 \rightarrow$ | | | rr |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | |
| 0.19 \pm 0.24 \pm 0.03 AUBERT 0.3T BABR Repl. by AUBERT 0.7AA $C_{\rho\pi}$ ($B^0 \rightarrow \rho^+\pi^-$) $C_{\rho\pi}$ (describes the asymmetry between the rates $\Gamma(B^0 \rightarrow \rho^+\pi^-) + \Gamma(\overline{B}^0 \rightarrow \rho^+\pi^-$ | | | |
| | | • • | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | AUBERT UST BABK REPT. DY AUBERT UTAA | -0.05 ± 0.13 OUR AVERAGE |
| AC ρ_{π} describes the asymmetry between the falles $T(B^0 \to \rho^+\pi^+) + T(B^0 \to \rho^+\pi^-)$. MLUE DOCUMENT ID TECN COMMENT 0.37±0.08 OUR AVERAGE 0.39±0.09±0.09 AUBERT 07AA BABR $e^+e^- \to T(4S)$ 0.36±0.10±0.05 KUSAKA 07 BELL $e^+e^- \to T(4S)$ 0.38±0.18±0.09 AUBERT 07AB AUBERT 07AB 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. Specified by AUBERT 07AB 2.28±0.18±0.09 AUBERT 07AB AUBERT 07AB 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. Specified by AUBERT 07AB 2.28±0.18±0.09 AUBERT 07AB AUBERT 07AB 3 BABR Repl. by AUBERT 07AB 5 PA BABR Repl. by AUBERT 07AB 5 PA BABR Repl. by AUBERT 07AB 5 PA BABR Repl. by AUBERT 07AB 6 0.19±0.30±0.08 6 0.08±0.41±0.09 COMMENT 1D TECN COMMENT TEC | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\Delta C_{ ho\pi}$ describes the | asymmetry between the rates $\Gamma(B^0 \to \rho^+ \pi^-) + \Gamma(\overline{B}^0 \to \rho^+ \pi^-)$ | |
| 0.37 ± 0.08 OUR AVERAGE 0.39 ± 0.09 0.36 ± 0.10 ± 0.05 0.36 ± 0.10 ± 0.05 0.36 ± 0.10 ± 0.05 0.38 ± 0.18 $_{-0.04}^{+0.02}$ 0.28 $_{-0.19}^{+0.18}$ 0.39 ± 0.04 0.28 $_{-0.19}^{+0.18}$ 0.30 ± 0.04 0.28 $_{-0.19}^{+0.18}$ 0.30 ± 0.04 0.28 $_{-0.19}^{+0.18}$ 0.30 ± 0.04 0.28 $_{-0.19}^{+0.18}$ 0.30 ± 0.04 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.30 ± 0.05 0.05 0.05 0.05 0.05 0.05 0.07 ± 0.05 0.06 ± 0.17 ± 0.27 ± 0.14 0.06 ± 0.17 ± 0.05 0.19 ± 0.30 ± 0.08 0.19 ± 0.30 ± 0.08 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.41 ± 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 ± 0.41 ± 0.09 0.08 | $ ho^-\pi^+)$ and $\Gamma(B^0-M)$ | $\rho^-\pi^+) + \Gamma(B^0 \to \rho^+\pi^-).$ DOCUMENT ID TECH COMMENT | $-0.00\pm0.30\pm0.09$ 1 SOMOV 06 BELL Repl. by SOMOV 07 |
| 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. 1 BELLE Collab. quotes A_{CP} which is equal to $-C$. 2 S _{PP} ($B^0 \rightarrow P^+P^-$) 3 8 ± 0.18 $^+$ 0.02 | | | |
| **Spp ($B^0 \rightarrow \rho^+ \rho^-$) 0.38 ± 0.18 $^+_{-0.02}$ WANG 05 BELL Repl. by KUSAKA 07 0.28 $^+_{-0.19}$ ± 0.04 AUBERT 07AA **AUBERT 03T BABR Repl. by AUBERT 07AA **AUBERT 07AB BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **AUBERT 07BF BABR $e^+e^- \rightarrow r(4S)$ **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 ± 0.41 ± 0.09 **O.08 | | · , | |
| 0.38 ± 0.18 $_{-0.04}^{+0.02}$ WANG 05 BELL Repl. by KUSAKA 07 $\frac{NALUE}{-0.06 \pm 0.17 \text{ OUR AVERAGE}}$ 0.28 $_{-0.19}^{+0.18}$ AUBERT 03T BABR Repl. by AUBERT 07AA $\frac{NALUE}{-0.06 \pm 0.17 \text{ OUR AVERAGE}}$ 0.19 ± 0.30 ± 0.08 SOMOV 07 BELL $e^+e^- \rightarrow r(4S)$ 0.19 ± 0.30 ± 0.08 SOMOV 07 BELL $e^+e^- \rightarrow r(4S)$ 0.08 ± 0.41 ± 0.09 SOMOV 06 BELL Repl. by SOMOV 07 BELL $e^+e^- \rightarrow r(4S)$ 0.08 ± 0.41 ± 0.09 SOMOV 06 BELL Repl. by SOMOV 07 BELL $e^+e^- \rightarrow r(4S)$ 0.08 ± 0.41 ± 0.09 SOMOV 06 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 BELL Repl. by SOMOV 07 B | | | 0.1 |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | | ** |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | · · | |
| $0.19\pm0.30\pm0.08$ SOMOV 07 BELL $e^+e^- \rightarrow \tau(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • $0.08\pm0.41\pm0.09$ SOMOV 06 BELL Repl. by SOMOV 07 $-0.33\pm0.24^{+0.08}_{-0.14}$ AUBERT, B 05c BABR Repl. by AUBERT 07bF | $0.28 + 0.18 \pm 0.04$ | AUBERT 03T BABR Repl. by AUBERT 07AA | $-0.17\pm0.20^{+0.05}_{-0.06}$ AUBERT 07BF BABR $e^+e^- ightarrow \gamma(4S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $0.08 \pm 0.41 \pm 0.09 \qquad \qquad \text{SOMOV} \qquad 06 \qquad \text{BELL} \qquad \text{Repl. by SOMOV} \qquad 07 \\ -0.33 \pm 0.24 {}^{+0.08}_{-0.14} \qquad \qquad \qquad \text{AUBERT,B} \qquad 05 \text{C} \qquad \text{BABR} \qquad \text{Repl. by AUBERT} \qquad 07 \text{BABR} \qquad 07 \text{C} \qquad 07 \text{C} \qquad 07 \text{BABR} \qquad 07 $ | | | |
| $-0.33\pm0.24^{+0.08}_{-0.14}$ AUBERT,B 05c BABR Repl. by AUBERT 07BF | | | • • We do not use the following data for averages, fits, limits, etc. |
| | | | |
| -0.42±0.42±0.14 AUBERT,B 04R BABR Repl. by AUBERT,B 05c | | | |
| | | | −0.42±0.42±0.14 AUBERT,B 05c |

 R^0

| $ \lambda (B^0 \to J/$ | ψ K*(892) ⁰) | | | | |
|------------------------------------------------------------------------------------------|--------------------------|---------------------------------|---------|-----------|---------------------------------------|
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
| < 0.25 | 95 | $^{ m 1}$ AUBERT,B | 04н | BABR | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| $^{ m 1}$ Uses the mea | sured cosine co | efficients C and \overline{C} | and as | sumes | p = 1. |
| $\cos 2\beta \ (B^0 \rightarrow \beta \ (\phi_1) \text{ is or } \\ \text{in the Review}$ | ne of the angles | | | , see the | review on "CP" Violat |
| | AVERAGE Er | ror includes scale f | actor c | of 1.6. | |
| $2.72^{+0.50}_{-0.79} \pm 0.27$ | | ¹ AUBERT | 05 P | BABR | $e^+e^- ightarrow \varUpsilon(4S)$ |
| $0.87 \pm 0.74 \pm 0.12$ | | ² IT ОН | 05 | BELL | $e^+ e^- \rightarrow \gamma(4S)$ |

| The measureme | ent is | obtain | ed wher | sin | 2β | is fixed | to | 0.726 | and | the | sign | of | cos | 2β | is |
|------------------|--------|---------|----------|-----|----------|----------|----|-------|-----|-----|------|----|-----|----------|----|
| positive with 86 | % со | nfidenc | e level. | | | | | | | | _ | | | | |
|) | | | | | | | | | | | | | | | |

² The measurement is obtained with sin 2β fixed to 0.731.

$\cos 2\beta (B^0 \to [K_S^0 \pi^+ \pi^-]_{\Omega(*)} h^0)$

| VALUE | DOCUMENT ID | TECN | COMMENT | | | |
|--------------------------------------|-------------------------------------|-----------|---------------------------------------|--|--|--|
| 1.0 + 0.6 OUR AVERAGE | Error includes scale factor of 1.8. | | | | | |
| $0.42 \pm 0.49 \pm 0.16$ | ¹ AUBERT | 07вн BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ | | | |
| $1.87 + 0.40 + 0.22 \\ -0.53 - 0.32$ | ² KROKOVNY | 06 BELL | $e^+e^- ightarrow ~ \varUpsilon(4S)$ | | | |

 $^{^{}m 1}$ AUBERT 07BH evaluates the likelihoods for the positive and negative solutions assuming $\sin(2~eta_{eff})=0.678.$ It quotes L $_+$ / (L $_+$ + L $_-$) =0.86 corresponding to a likelihood ratio of $L_{+}/L_{-}=6.14$ in favor of the positive solution.

 2 KROKOVNY 06 evaluates the likelihoods for the positive and negative solutions assuming $\sin(2~\beta_{eff})=0.689.$ It quotes L $_+$ / (L $_+$ + L $_-$) = 0.983 corresponding to a likelihood ratio of L $_+$ /L $_-$ = 57.8 in favor of the positive solution.

(S₊ + S₋)/2 ($B^0 \rightarrow D^{*-}\pi^+$) S_± = $-\frac{2Im(\lambda_\pm)}{1+|\lambda_\pm|^2}$ where λ_+ and λ_- are defined in the C_{$\pi\pi$} datablock above for $B^0 \rightarrow D^{*-}\pi^+$ and $\overline{B}^0 \rightarrow D^{*+}\pi^-$.

| VALUE | DOCUMENT ID | | TECN | COMMENT | | | | |
|--------------------------------|-------------------------|-------|-----------|-----------------------------------|--|--|--|--|
| -0.039±0.011 OUR AVERAGE | | | | | | | | |
| $-0.046\pm0.013\pm0.015$ | ¹ BAHINIPATI | 11 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | | | | |
| $-0.040 \pm 0.023 \pm 0.010$ | ² AUBERT | 06Y | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | | | | |
| $-0.034 \pm 0.014 \pm 0.009$ | ¹ AUBERT | 05 z | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | | | | |
| • • • We do not use the follow | wing data for ave | ages, | fits, lim | its, etc. • • • | | | | |
| $-0.039\pm0.020\pm0.013$ | ³ RONGA | 06 | BELL | Repl. by BAHINIPATI 11 | | | | |
| $-0.030 \pm 0.028 \pm 0.018$ | ¹ GERSHON | 05 | BELL | Repl. by RONGA 06 | | | | |
| $-0.068 \pm 0.038 \pm 0.020$ | ² AUBERT | 04∨ | BABR | Repl. by AUBERT 06Y | | | | |
| $-0.063 \pm 0.024 \pm 0.014$ | ¹ AUBERT | 04 W | BABR | Repl. by AUBERT 05z | | | | |
| $0.060 \pm 0.040 \pm 0.019$ | ² SARANGI | 04 | BELL | Repl. by RONGA 06 | | | | |

¹ Uses partially reconstructed $B^0 \rightarrow D^{*\pm} \pi^{\mp}$ decays.

3 Combines the results from fully reconstructed and partially reconstructed $D^*\pi$ events by taking weighted averages. Assumes that systematic errors from physics parameters and fit biases in the two measurements are 100% correlated.

$(S_- - S_+)/2 (B^0 \rightarrow D^{*-}\pi^+)$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------------|--------|-----------|-----------------------------------|
| -0.009±0.015 OUR AVERA | GE | | | |
| $-0.015\pm0.013\pm0.015$ | ¹ BAHINIPATI | 11 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.049 \pm 0.042 \pm 0.015$ | ² AUBERT | 06Y | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $-0.019\pm0.022\pm0.013$ | ¹ AUBERT | 05 z | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the following | owing data for ave | rages, | fits, lim | its, etc. • • • |
| $-0.011 \pm 0.020 \pm 0.013$ | ³ RONGA | 06 | BELL | Repl. by BAHINIPATI 11 |
| $-0.005 \pm 0.028 \pm 0.018$ | ¹ GERSHON | 05 | BELL | Repl. by RONGA 06 |
| $0.031 \pm 0.070 \pm 0.033$ | ² AUBERT | 04∨ | BABR | Repl. by AUBERT 06Y |
| $-0.004\pm0.037\pm0.014$ | 1 AUBERT | 04W | BABR | Repl. by AUBERT 05z |
| $0.049 \pm 0.040 \pm 0.019$ | ² sarangi | 04 | BELL | Repl. by RONGA 06 |
| 1 | _0 _++ ¬ | | | |

 $^{^1}$ Uses partially reconstructed $B^0 o D^{*\pm}\pi^{\mp}$ decays.

$(S_{+} + S_{-})/2 (B^{0} \rightarrow D^{-}\pi^{+})$ DOCUMENT ID

| -0.046 ± 0.023 OUR AVERAGE | | | | |
|-----------------------------------|----------------------|-----------|---------|------------------------------------|
| $-0.010\pm0.023\pm0.07$ | ¹ AUBERT | 06Y | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $-0.050\pm0.021\pm0.012$ | ² RONGA | 06 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the following | ig data for averag | es, fits, | limits, | etc. • • • |
| $-0.022 \pm 0.038 \pm 0.020$ | ¹ AUBERT | 04∨ | BABR | Repl. by AUBERT 06Y |
| $-0.062\pm0.037\pm0.018$ | ¹ SARANGI | 04 | BELL | Repl. by RONGA 06 |
| | | | | |

 $^{^1}$ Uses fully reconstructed $B^0 \to D^\pm \pi^\mp$ decays. ² Combines the results from fully reconstructed and partially reconstructed $D\pi$ events by taking weighted averages. Assumes that systematic errors from physics parameters and fit biases in the two measurements are 100% correlated.

| $(S_{-} - S_{+})$ | /2 | $(B^0 \rightarrow$ | $D^{-}\pi^{+}$ |
|-------------------|----|--------------------|----------------|
|-------------------|----|--------------------|----------------|

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|----------------------|-----------|---------|-----------------------------------|
| -0.022±0.021 OUR AVERAGE | | | | |
| $-0.033 \pm 0.042 \pm 0.012$ | ¹ AUBERT | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $-0.019 \pm 0.021 \pm 0.012$ | ² RONGA | 06 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do not use the follow | ing data for averag | es, fits, | limits, | etc. • • • |
| $0.025 \pm 0.068 \pm 0.033$ | $^{ m 1}$ AUBERT | 04∨ | BABR | Repl. by AUBERT 06Y |
| $-0.025 \pm 0.037 \pm 0.018$ | ¹ SARANGI | 04 | BELL | Repl. by RONGA 06 |
| 10 | _+ + . | | | |

 $^{^{}m L}$ Uses fully reconstructed $B^0 o D^\pm\pi^\mp$ decays.

$(S_{+} + S_{-})/2 (B^{0} \rightarrow D^{-} \rho^{+})$

| VALUE | DOCUMENT ID TECN COMMENT | |
|------------------------------|----------------------------------------------------------------------------------------------------------------|------------|
| $-0.024 \pm 0.031 \pm 0.009$ | $1 \frac{1}{\text{AUBERT}} \frac{1}{\text{OGY}} \frac{1}{\text{BABR}} \frac{1}{e^+e^-} \rightarrow \gamma(4S)$ | <i>i</i>) |

¹ Uses fully reconstructed $B^0 \rightarrow D^- \rho^+$ decays.

$$(S_- - S_+)/2 (B^0 \rightarrow D^- \rho^+)$$

| (0_ 0+)/- (0 / 0 | r 1 | |
|------------------------------|--------------|------------------------------------------------------------|
| VALUE | DO CUMENT ID | TECN COMMENT |
| $-0.098 \pm 0.055 \pm 0.018$ | 1 AUBERT 06Y | $\overline{\text{BABR}}$ $e^+e^- \rightarrow \Upsilon(4S)$ |

¹ Uses fully reconstructed $B^0 \rightarrow D^- \rho^+$ decays.

$$C_{\eta_c \, K_S^0} \, (B^0 \rightarrow \, \eta_c \, K_S^0)$$

| VALUE | DOCUMENT ID | TECN | COMMENT |
|-------------------|-------------|----------|---------------------------------|
| 0.080±0.124±0.029 | AUBERT | 09к BABR | $e^+e^- \rightarrow \gamma(4S)$ |

$$S_{\eta_c\,K^0_S}\left(B^0\to\;\eta_c\,K^0_S\right)$$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------|--------------|----------|---------------------------------|
| 0.925 ± 0.160 ± 0.057 | AUBERT | 09K BABR | $e^+e^- \rightarrow \gamma(4S)$ |

DOCUMENT ID

$$C_{c \, \overline{c} \, K^{(*)0}} \, (B^0 \rightarrow c \, \overline{c} \, K^{(*)0})$$

 $C_{c \in K(*)0}$ $(B^0 \to c \in K(*)0)$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group $(HFAG) \ and \ are \ described \ at \ http://www.slac.stanford.edu/xorg/hfag/. \ The \ average of the average of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanford of the stanfor$ aging/rescaling procedure takes into account correlations between the measurements.

TECN COMMENT

0.5 ± 1.7 OUR EVALUATION 0.1 ± 1.8 OUR AVERAGE

| $-29 \begin{array}{c} +53 \\ -44 \end{array} \pm 6$ | $^{ m 1}$ AUBERT | 09AU BABR | $e^+e^- \to$ | r(45) |
|-----------------------------------------------------|---------------------|-----------|----------------------|----------------|
| $2.4 \pm 2.0 \pm 1.6$ | ² AUBERT | 09k BABR | $e^+e^-\to$ | $\Upsilon(4S)$ |
| $-4 \pm 7 \pm 5$ | ³ SAHOO | 08 BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| _ 18+ 21+14 | 4 CHEN | 07 RELL | a+ a | 2(15) |

| 4.9 ± 2.3 ± 1.8 | ² AUBERT | 07AY BABR | Repl. by AUBERT 09K |
|-----------------------|---------------------|-----------|----------------------|
| - 0.7 ± 4.1 ± 3.3 | ⁵ ABE | 05B BELL | Repl. by CHEN 07 |
| $5.1 \pm 3.2 \pm 1.4$ | ⁶ AUBERT | 05 F BABR | Repl. by AUBERT 07AY |
| $5.1 \pm 5.1 \pm 2.6$ | ⁷ ABE | 02z BELL | Repl. by ABE 05B |
| 5.3 ± 5.4 ± 3.2 | ⁸ AUBERT | 02P BABR | Repl. by AUBERT 05F |

 $^{^1}$ Uses Dalitz plot analysis of $B^0 \to \kappa^0 \, \pi^+ \, \pi^-$ decays and the first of two equivalent

solutions is used. ² Measurement based on $B^0 \to c\overline{c}K^{(*)0}$ decays.

Reports value of A of $B^0 o \psi(2S) K^0$ which is equal to -C. 4 Reports value of A of $B^0 o J/\psi K^0$ which is equal to -C.

 5 Measurement based on $152 \times 10^{6}~B\overline{B}$ pairs.

⁶ Measurement based on 227 \times 10⁶ $B\overline{B}$ pairs.

 7 Measured with both $\eta_f=\pm 1$ samples.

 $^{8}\,\mathrm{Me}\,\mathrm{asured}$ with the high purity of $\eta_{f}\,=\,-1$ samples.

For a discussion of CP violation, see the review on "CP Violation" in the Reviews section. $\sin(2\beta)$ is a measure of the *CP*-violating amplitude in the $B^0_d \to J/\psi(1S) \, K^0_S$

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The aver-ALUE DOCUMENT ID TECN COMMENT

0.679±0.020 OUR EVALUATION aging/rescaling procedure takes into account correlations between the measurements.

0 671 ±0 022 OHP AVERAGE

| U.U/I I U.UZZ OUN AVENAGE | | | | | |
|----------------------------------------------------|-------------------------|--------------|------|-------------------------|----------------|
| $-0.69 \pm 0.52 \pm 0.08$ | ¹ AUBERT | 09 AU | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.687 \pm 0.028 \pm 0.012$ | ² AUBERT | 09K | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.72 \pm 0.09 \pm 0.03$ | ³ SAHOO | 80 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.642 \pm 0.031 \pm 0.017$ | CHEN | | | e^+e^- | |
| $1.56 \pm 0.42 \pm 0.21$ | ⁴ AUBERT | 04R | BABR | $e^+e^- \rightarrow$ | $\Upsilon(45)$ |
| $0.79 \begin{array}{l} +0.41 \\ -0.44 \end{array}$ | ⁵ AFFOLDER | 00c | CDF | ρ p at 1.8 ¬ | ГеV |
| $0.84 \ ^{+\ 0.82}_{-1.04} \ \pm 0.16$ | ⁶ BARATE | 00Q | ALEP | $e^+e^- \to$ | Ζ |
| $3.2 {}^{+ 1.8}_{- 2.0} \pm 0.5$ | ⁷ ACKERSTAFF | 98z | OPAL | $e^+e^- \rightarrow$ | Z |

² Uses fully reconstructed $B^0 \rightarrow D^{*\pm} \pi^{\mp}$ decays.

²Uses fully reconstructed $B^0 \rightarrow D^{*\pm}\pi^{\mp}$ decays.

 $^{^3}$ Combines the results from fully reconstructed and partially reconstructed $D^*\pi$ events by taking weighted averages. Assumes that systematic errors from physics parameters and fit biases in the two measurements are 100% correlated.

 $^{^2}$ Combines the results from fully reconstructed and partially reconstructed $D\,\pi$ events by taking weighted averages. Assumes that systematic errors from physics parameters and fit biases in the two measurements are 100% correlated.

| • • • We do not use the follo | wing data for avera | ges, fits, limits | s, etc. • • • |
|-------------------------------------------------------------------------|----------------------|-------------------|-----------------------------------|
| $0.714 \pm 0.032 \pm 0.018$ | ² AUBERT | 07AY BABR | Repl. by AUBERT 09K |
| $0.728 \pm 0.056 \pm 0.023$ | ⁸ ABE | 05B BELL | Repl. by CHEN 07 |
| $0.722 \pm 0.040 \pm 0.023$ | ⁹ AUBERT | 05F BABR | Repl. by AUBERT 07AY |
| $0.99 \pm 0.14 \pm 0.06$ | ¹⁰ ABE | 02U BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.719 \pm 0.074 \pm 0.035$ | ¹¹ ABE | 02z BELL | Repl. by ABE 05B |
| $0.59 \pm 0.14 \pm 0.05$ | ¹² AUBERT | 02N BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.741 \pm 0.067 \pm 0.034$ | ¹³ AUBERT | 02P BABR | Repl. by AUBERT 05F |
| $\begin{array}{cccc} 0.58 & +0.32 & +0.09 \\ -0.34 & -0.10 \end{array}$ | ABASHIAN | 01 BELL | Repl. by ABE 01G |
| $0.99 \pm 0.14 \pm 0.06$ | ¹⁴ ABE | 01G BELL | Repl. by ABE 02z |
| $0.34 \pm 0.20 \pm 0.05$ | AUBERT | 01 BABR | Repl. by AUBERT 01B |
| $0.59 \pm 0.14 \pm 0.05$ | ¹⁴ AUBERT | 01B BABR | Repl. by AUBERT 02P |
| $1.8 \pm 1.1 \pm 0.3$ | ¹⁵ ABE | 98u CDF | Repl. by AFFOLDER 00c |
| 4 | 0 0 . | | |

- 1 Uses Dalitz plot analysis of $B^0 o \kappa^0 \pi^+ \pi^-$ decays and the first of two equivalent 2 Measurement based on $B^0 \to c\overline{c} K^{(*)0}$ decays.
- 3 Based on $B^0 o \psi(2S) \, K_S^0$ decays.
- 4 Measurement in which the J/ψ decays to hadrons or to muons that do not satisfy the
- standard identification criteria. 5 AFFOLDER 00c uses about 400 $B^0\to J/\psi(15)\,K_S^0$ events. The production flavor of ${\it B}^{\,0}$ was determined using three tagging algorithms: a same-side tag, a jet-charge tag, and a soft-lepton tag.
- ⁶BARATE 00Q uses 23 candidates for $B^0 \rightarrow J/\psi(1S) K_S^0$ decays. A combination of jet-charge, vertex-charge, and same-side tagging techniques were used to determine the
- 7 ACKERSTAFF 98z uses 24 candidates for $B_d^0 o J/\psi(1S) K_S^0$ decay. A combination of jet-charge and vertex-charge techniques were used to tag the B_d^0 production flavor.
- 8 Measurement based on 152×10^{6} $B\overline{B}$ pairs.
- ⁹ Measurement based on 227 \times 10⁶ $B\overline{B}$ pairs.
- 10 ABE 02 $_{\rm U}$ result is based on the same analysis and data sample reported in ABE 01G. 11 ABE 02 $_{\rm U}$ result is based on 85 \times 10 6 $B\overline{B}$ pairs.

- 11 ABE 022 result is based on 85 × 10 o BB pairs. 12 AUBERT 02N result based on the same analysis and data sample reported in AUBERT 01B. 13 AUBERT 02P result is based on 88 × 10 6 BB pairs. 14 First observation of CP violation in B0 meson system. 15 ABE 98U uses 198 \pm 17 B $_d^0 \rightarrow J/\psi(15)$ K0 events. The production flavor of B0 was determined using the same side tagging technique.

 $C_{J/\psi(nS)\,K^0}(B^0 o J/\psi(nS)\,K^0)$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

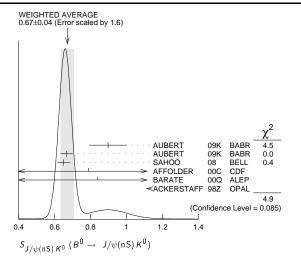
| VALUE (units 10 ⁻²) | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------------------------------|----------------------|-----|------|-----------------------|----------------|
| 0.5 ± 2.0 OUR EVALUATION | | | | | |
| 0.0±1.8 OUR AVERAGE | | | | | |
| $+8.9\pm7.6\pm2.0$ | ¹ AUBERT | 09K | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $+1.6\pm2.3\pm1.8$ | AUBERT | 09K | BABR | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| -4 ±7 ±5 | ^{1,2} sahoo | 80 | BELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| $-1.8 \pm 2.1 \pm 1.4$ | ² CHEN | 07 | BELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| ¹ Based on $B^0 \rightarrow \psi(2S) K_S^0$ | decavs. | | | | |

²The paper reports A, which is equal to -C.

 $S_{J/\psi(nS)} K^0 \ (B^0 o J/\psi(nS) K^0)$ "OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group $(HFAG) \ and \ are \ described \ at \ http://www.slac.stanford.edu/xorg/hfag/. \ The \ averaging/rescaling \ procedure \ takes \ into \ account \ correlations \ between \ the \ measurements.$

| VALUE | DO CUMENT ID | TECN | COMMENT |
|----------------------------------------------------|-------------------------|------------------|------------------------------------|
| 0.676±0.021 OUR EVALUATI | ON | | |
| 0.67 ±0.04 OUR AVERAGE | Error includes scale | factor of 1.6. | See the ideogram below |
| $0.897 \pm 0.100 \pm 0.036$ | ¹ AUBERT | 09к BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.666 \pm 0.031 \pm 0.013$ | AUBERT | 09κ BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.650 \pm 0.029 \pm 0.018$ | ² sahoo | 08 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.79 \begin{array}{c} +0.41 \\ -0.44 \end{array}$ | ³ AFFOLDER | 00c CDF | $p\overline{p}$ at 1.8 TeV |
| $0.84 \ ^{+ 0.82}_{- 1.04} \ \pm 0.16$ | ⁴ BARATE | 00Q ALEP | $e^+e^- ightarrow ~Z$ |
| $3.2 {}^{+ 1.8}_{- 2.0} \pm 0.5$ | ⁵ ACKERSTAFF | 98z OPAL | $e^+e^- ightarrow ~Z$ |
| • • • We do not use the follow | ving data for averages | s, fits, limits, | etc. • • • |
| $0.72 \ \pm 0.09 \ \pm 0.03$ | ¹ SAHOO | 08 BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.642 \pm 0.031 \pm 0.017$ | CHEN | 07 BELL | $e^+e^- \rightarrow \Upsilon(4.5)$ |

- 1 Based on $B^0 o \psi(2S) \, K^0_S$ decays.
- 2 Combined result of CHEN 07 and SAHOO 08. 3 AFFOLDER 00c uses about 400 $B^0\to J/\psi(1S)\,K_S^0$ events. The production flavor of ${\it B}^{\,0}$ was determined using three tagging algorithms: a same-side tag, a jet-charge tag, and a soft-lepton tag.
- 4 BARATE 00Q uses 2 3 candidates for $B^0 o J/\psi(1S)\,K_S^0$ decays. A combination of jet-charge, vertex-charge, and same-side tagging techniques were used to determine the B^0 production flavor.
- 5 ACKERSTAFF 98z uses 24 candidates for $B^0_d \to J/\psi(1S)\,K^0_S$ decay. A combination of jet-charge and vertex-charge techniques were used to tag the $B_d^{\,0}$ production flavor.



$C_{J/\psi K^{*0}} (B^0 \to J/\psi K^{*0})$

| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
|---------------------------------------------------------|------------------------------------|-----|------|----------------------|-------|--|
| $0.025 \pm 0.083 \pm 0.054$ | ¹ AUBERT | 09K | BABR | $e^+e^- \rightarrow$ | T(45) | |
| ¹ Based on $B^0 \rightarrow J/\psi K^{*0}$, | $K^{*0} \rightarrow K_s^0 \pi^0$. | | | | | |

$S_{J/\psi \, K^{*0}} \; (B^0 \to \; J/\psi \, K^{*0})$

DOCUMENT ID TECN COMMENT 1,2 AUBERT 0.601 ± 0.239 ± 0.087 09K BABR $e^+e^- \rightarrow \Upsilon(4S)$

- ¹ Based on $B^0 \rightarrow J/\psi K^{*0}$, $K^{*0} \rightarrow K_S^0 \pi^0$.
- $^2\, {\rm This}~ {\it S}_{J/\psi~K^{*0}}$ value has been corrected for the dilution of the $\sin(\Delta {\rm M}~\Delta t)$ coefficient of the $\stackrel{J/\psi}{CP}$ asymmetry by a factor of $1-R_{\perp}$, which arises from the mixture of CP-even and CP-odd B decay amplitudes

$C_{\chi_{c0} \, K_S^0} \, (B^0 \rightarrow \, \chi_{c0} \, K_S^0)$

DO CUMENT ID $-0.29 + 0.53 \pm 0.06$ ¹ AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4S)$

 1 Uses Dalitz plot analysis of $B^0\to \kappa^0\pi^+\pi^-$ decays and the first of two equivalent solutions is used.

$S_{\chi_{c0}\,K_S^0}\,(B^0\to\,\chi_{c0}\,K_S^0)$

DOCUMENT ID $-0.69 \pm 0.52 \pm 0.08$ ¹ AUBERT 09AU BABR $e^+e^- \rightarrow \Upsilon(4S)$

 1 Uses Dalitz plot analysis of $B^0 \to \kappa^0 \pi^+ \pi^-$ decays and the first of two equivalent solutions is used

$C_{\chi_{c1} \, K_S^0} \, (B^0 \to \chi_{c1} \, K_S^0)$

0.129±0.109±0.025

0.614±0.160±0.040

DOCUMENT IE TECN COMMENT AUBERT 09K BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $S_{\chi_{c1}K_S^0}(B^0\to\chi_{c1}K_S^0)$

DOCUMENT ID TECN COMMENT AUBERT 09κ BABR $e^+e^- \rightarrow \Upsilon(4S)$

$\sin(2\beta_{\rm eff})(B^0 \to \phi K^0)$

DOCUMENT ID TECN COMMENT $0.22 \pm 0.27 \pm 0.12$ 07AX BABR $e^+e^- \rightarrow \Upsilon(4S)$ AUBERT

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $0.50 \pm 0.25 \, {}^{+\; 0.07}_{-\; 0.04}$ ¹ AUBERT 05T BABR Repl. by AUBERT 07AX

 1 Obtained by constraining $\mathit{C}=0$.

$\sin(2\beta_{\rm eff})(B^0 \to \phi K_0^*(1430)^0)$

DOCUMENT ID VALUE TECN_COMMENT 0.97 + 0.03 $^{\mathrm{1}}$ AUBERT 08BG BABR $e^+e^- \rightarrow \Upsilon(4S)$

 1 Measured using the *CP*-violation phase difference $\Delta\phi_{00}$ between the B and \overline{B} decay

$\sin(2\beta_{\rm eff})(B^0\to~K^+\,K^-\,K^0_S)$

DOCUMENT ID TECN COMMENT $0.77 \pm 0.11 + 0.07 \\ -0.04$ AUBERT 07AX BABR $e^+e^-
ightarrow \gamma(4S)$

- ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
- ¹ AUBERT $0.55 \pm 0.22 \pm 0.12$ 05T BABR Repl. by AUBERT 07AX
 - 1 Obtained by constraining $\mathit{C}=0.$

1.429±0.061±0.044 AUBERT 08R BABR Repl. by AUBERT 09A

 $^1\, {\rm Uses}$ fully reconstructed $\, D^{*-}\, \ell^+\, \nu$ events ($\ell = e \,\, {\rm or} \,\, \mu).$

AUBERT,B 06Z BABR Repl. by AUBERT 08R

| sin (2.8. \/ 1.80 . 1.4 | 0_+1 60) | D (5 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | | |
|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------------|
| $sin(2\beta_{eff})(B^0 \rightarrow [K])$ | ${}^{\circ}_{S}\pi^{+}\pi^{-}]_{D(*)}h^{\circ})$ DOCUMENT ID TECN COMMENT | R_2 (form factor ratio \sim A | A ₂ /A ₁) DOCUMENT ID TECN | COMMENT |
| VALUE 0.45±0.28 OUR AVERA | | | Error includes scale factor of 1.9 | |
| $0.29 \pm 0.34 \pm 0.06$ | AUBERT 07BH BABR $e^+e^- ightarrow~ \varUpsilon$ (4 S) | $0.864 \pm 0.024 \pm 0.008$ | ¹ DUNGEL 10 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $.78 \pm 0.44 \pm 0.22$ | KROKOVNY 06 BELL $e^+e^- ightarrow~\varUpsilon(4S)$ | $0.66 \pm 0.05 \pm 0.09$ | | $e^+e^- \rightarrow \gamma(4S)$ |
| $\lambda (B^0 \rightarrow [K_S^0 \pi^+ \tau])$ | 1 h ⁰) | $0.71 \pm 0.22 \pm 0.07$ | · | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ALUE | ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' | | ing data for averages, fits, limits, | |
| .01±0.08±0.02 | AUBERT 07BH BABR $e^+e^- ightarrow \varUpsilon(4S)$ | $0.827 \pm 0.038 \pm 0.022$ $0.885 \pm 0.040 \pm 0.026$ | | Repl. by AUBERT 09 Repl. by AUBERT 08 |
| | NOBERT OTHER E C 7 (43) | 1 Uses fully reconstructed D^{*-} | · | noph by noblen of |
| $\sin(2\beta + \gamma)$ | | • | $\epsilon = \nu$ events ($\epsilon = \epsilon$ or μ). | |
| eta (ϕ_1) and γ (ϕ_1) Violation" in the R | 3) are angles of CKM unitarity triangle, see the review on "CP | $ ho_{A_1}^2$ (form factor slope) | | |
| ALUE | <u>CL% DOCUMENT ID TECN COMMENT</u> | VALUE | DO CUMENT ID TECN | COMMENT |
| >0.40 | 90 1 AUBERT 06Y BABR $e^{+}e^{-} ightarrow \varUpsilon(4S)$ | 1.204±0.031 OUR AVERAGE 1.214±0.034±0.009 | ¹ DUNGEL 10 BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • We do not use the | e following data for averages, fits, limits, etc. • • • | $1.22 \pm 0.02 \pm 0.07$ | | $e^+e^- \rightarrow r(45)$ |
| >0.13 | 95 ² RONGA 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | 0.91 ±0.15 ±0.06 | | $e^+e^- \rightarrow \gamma(4S)$ |
| >0.07 >0.35 | 95 2 RONGA 06 BELL $e^+e^- \rightarrow r(4S)$ 90 3 AUBERT 05z BABR $e^+e^- \rightarrow r(4S)$ | ● ● We do not use the follow | ing data for averages, fits, limits, | etc. • • • |
| >0.69 | 68 4 AUBERT 04V BABR $e^+e^- \rightarrow \Upsilon(4S)$ | $1.191 \pm 0.048 \pm 0.028$ | | Repl. by AUBERT 09 |
| >0.58 | 95 ⁵ AUBERT 04w BABR Repl. by AUBERT 05 z | $1.145 \pm 0.059 \pm 0.046$ | | Repl. by AUBERT 08 |
| ¹ Uses fully reconstruc | ted $B^0	o D^{(*)\pm}\pi^\mp$ and $D^\pm ho^\mp$ decays and some theoretical | $^{ m I}$ Uses fully reconstructed D^{*-} | $^-\ell^+ u$ events ($\ell=e$ or μ). | |
| assumptions. | (.) | | | (.)0 . |
| | from fully reconstructed and partially reconstructed $D^{(*)}\pi$ events overages. Assumes that systematic errors from physics parameters | PARTIAL BRANCI | HING FRACTIONS IN B ⁰ - | → K(*) ⁰ ℓ+ℓ ⁻ |
| and fit biases in the t | two measurements are 100% correlated. Enter $B^0 \to D^{*\pm}\pi^{\mp}$ decays and some theoretical assumptions. | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (q ² < | (2.0 GeV ² /c ²) | |
| Uses partially reconst | tructed $B^0 \to D^{*\pm} \pi^+$ decays and some theoretical assumptions. | VALUE (units 10^{-7}) | DOCUMENT ID TECN | COMMENT |
| such as the SU(3) sy | ted $B^0 	o D^{(*)\pm}\pi^{\mp}$ decays and some theoretical assumptions, mmetry relation. | 1.80±0.36±0.11 | AALTONEN 11AI CDF | ρ p at 1.96 TeV |
| ⁵ Combining this meas | urement with the results from AUBERT 04v for fully reconstructed | D/D0 (**0 (+ (-) / 0.0 | 2 . 4.2 (-2) | |
| | and some theoretical assumptions, such as the $\mathop{SU}(3)$ symmetry | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (2.0 | | |
| relation. | | VALUE (units 10 ⁻⁷) 0.84±0.28±0.06 | DOCUMENT ID TECN AALTONEN 11ai CDF | COMMENT |
| $\beta + \gamma$ | | U.84±U.28±U.06 | AALTONEN TIAL COF | p p at 1.96 TeV |
| ALUE (°) | DOCUMENT ID TECN COMMENT | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (4.3 | $< q^2 < 8.68 \text{ GeV}^2/c^2$ | |
| 3±53±20 | 1 AUBERT 08AC BABR $e^{+}e^{-} ightarrow~ \varUpsilon(45)$ | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| ¹ Used a time-depende | ant Dalitz-plot analysis of $B^0 	o D^\mp K^0 \pi^\pm$ assuming the ratio of | $1.73 \pm 0.43 \pm 0.15$ | AALTONEN 11AI CDF | ρ p at 1.96 TeV |
| the $b \rightarrow u$ and $b \rightarrow$ | c decay amplitudes to be 0.3. | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (10.0) | 0 - a ² - 12 96 Ca\(\frac{2}{a}\(\frac{2}{a}\) | |
| $\gamma(B^0 \to D^0 K^{*0})$ | | | | |
| ALUE (°) | DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁷) 1.77±0.36±0.12 | DOCUMENT ID TECN AALTONEN 11AI CDF | <u>COMMENT</u> p p at 1.96 TeV |
| 62±56 | 1 AUBERT 09R BABR $e^{+}e^{-} ightarrow~\varUpsilon$ (45) | | | pp at 1.50 TeV |
| ¹ Uses Dalitz plot ana | lysis of $D^0 	o 	extit{K}^0_S \pi^+ \pi^-$ decays coming from $B^0 	o 	extit{D}^0 	extit{K}^{*0}$ | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (14.13) | $8 < q^2 < 16.0 \text{ GeV}^2/c^2$ | |
| modes. The correspo is implied. | inding 95% CL interval is 77 $^{\circ}<\gamma<$ 247 $^{\circ}.$ A 180 degree ambiguity | VALUE (units 10^{-7}) | DOCUMENT ID TECN | COMMENT |
| is implied. | | $1.34 \pm 0.26 \pm 0.08$ | AALTONEN 11AL CDF | ρ p at 1.96 TeV |
| ν | | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (16.0) | $< a^2 \text{ GeV}^2/c^2$ | |
| For angle $\alpha(\phi_2)$ o the reviews section | f the CKM unitarity triangle, see the review on "CP violation" in | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| | | 0.97±0.26±0.07 | AALTONEN 11AI CDF | p p at 1.96 TeV |
| ALUE (°) 90 ± 5 OUR AVER | | 0 | 2 2 - 2 - | • • |
| 79 ± 7 ±11 | 1 AUBERT 10D BABR $e^{+}e^{-} ightarrow~\varUpsilon(4S)$ | $B(B^0 \to K^{*0}\ell^+\ell^-)$ (1.0 < | | |
| 92.4 ⁺ 6.0 - 6.5 | ² AUBERT 09G BABR $e^+e^- \rightarrow r(4S)$ | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| - 6.5 88 ±17 | ³ SOMOV 06 BELL $e^+e^- \rightarrow \Upsilon(4S)$ | $1.42 \pm 0.41 \pm 0.12$ | AALTONEN 11AL CDF | $p\overline{p}$ at 1.96 TeV |
| | e following data for averages, fits, limits, etc. • • • | $B(B^0 \to K^{*0}\ell^+\ell^-) (0.0 < 0.0)$ | $< q^2 < 4.3 \text{ GeV}^2/c^2$ | |
| 78.6± 7.3 | ⁴ AUBERT 070 BABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| 00 ±13 | ⁵ AUBERT,B 05 c BABR Repl. by AUBERT 09 g | 2.60±0.45±0.17 | AALTONEN 11AI CDF | ρ p at 1.96 TeV |
| 02 $^{+16}_{-12}$ ± 14 | ⁶ AUBERT,B 04r BABR Repl. by AUBERT,B 05c | D(D) (() (+ (-) (2) | 0 0 0 1/2 / 2) | |
| | time dependent analysis of RO (1360) ± -∓ and branching | $B(B^0\to K^0\ell^+\ell^-)\ (\mathfrak{q}^2<$ | • • | |
| fraction measuremen | time dependent analysis of $B^0	o a_1(1260)^\pm\pi^\mp$ and branching ts of $B	o a_1(1260)$ K and $B	o K_1\pi$. | VALUE (units 10 ⁻⁷) 0.31±0.37±0.02 | DOCUMENT ID TECN | COMMENT |
| ² Based on the favored | $B \rightarrow \rho \rho$ isospin method. | | AALTONEN 11AI CDF | p p at 1.96 TeV |
| ³ Obtained using isosp | oin relation and selecting a solution closest to the CKM best fit | $B(B^0 \to K^0 \ell^+ \ell^-)$ (2.0 < | $q^2 < 4.3 \text{ GeV}^2/c^2$ | |
| 4 The angle of the 90% CL | allowed interval is 59° $<\phi_2$ ($\equiv lpha >< 115$ °. Tained using the measured <i>CP</i> parameters of $B^0 ightarrow a_1(1260)^\pm \pi^\mp$ | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |
| and choosing one of | the four solutions that is compatible with the result of SM-based | $0.93 \pm 0.49 \pm 0.07$ | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| fits. | oin relation and selecting a solution closest to the CKM best fit | $B(B^0 \to K^0 \ell^+ \ell^-)$ (4.3 < | $a^2 < 9.69 \text{ GeV}^2/c^2$ | |
| average; 90% CL allo | owed interval is $79^\circ < lpha < 123^\circ$. | | | COMMENT |
| ⁶ Obtained from the m | easured CP parameters of the longitudinal polarization by selecting | VALUE (units 10 ⁻⁷) 0.66±0.51±0.05 | DOCUMENT ID TECN AALTONEN 11AI CDF | <u>COMMENT</u> pp at 1.96 TeV |
| the solution closest to | o the CKM best fit central value of $lpha=95^\circ$ – 98° . | | | ρρ αι 1.70 ΙΕΥ |
| | $B^0 	o D^{*-} \ell^+ u_\ell$ FORM FACTORS | $B(B^0 \to K^0 \ell^+ \ell^-)$ (10.09) | $< q^2 < 12.86 \text{ GeV}^2/c^2)$ | |
| | → U t·V[FORM FACTORS | VALUE (units 10 ⁻⁷) | DO CUMENT ID TECN | COMMENT |
| ${\it R}_{1}$ (form factor ra | | $-0.03 \pm 0.22 \pm 0.01$ | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV |
| ALUE | DOCUMENT ID TECN COMMENT | $B(B^0 \to K^0 \ell^+ \ell^-)$ (14.18) | $\sim a^2 \sim 16.0 \text{ GeV}^2/c^2$ | |
| .41 ±0.04 OUR AVER .401±0.034±0.018 | TAGE 1 DUNGEL 10 BELL $e^+e^- ightarrow \gamma(4S)$ | | • | COMMENT |
| .56 ±0.07 ±0.15 | AUBERT 09A BABR $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) 0.73±0.26±0.06 | AALTONEN 11AI CDF | COMMENT |
| .18 ±0.30 ±0.12 | DUBOSCQ 96 CLE2 $e^+e^- \rightarrow r(4s)$ | | | $p\overline{p}$ at 1.96 TeV |
| • • We do not use the | e following data for averages, fits, limits, etc. • • • | $B(B^0 \to K^0 \ell^+ \ell^-)$ (16.0 · | $< q^2 \text{ GeV}^2/c^2$) | |
| $1.429 \pm 0.061 \pm 0.044$ | AUBERT 08R BABR Repl. by AUBERT 09A | VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | COMMENT |

VALUE (units 10^{-7})

0.21±0.18±0.16

DOCUMENT ID

| $B(B^0 \to K^0 \ell^+ \ell^-) (1.0$ | $< a^2 < 6.0 \text{ GeV}^2/c^2$ | | AUBERT 08E PR D77 012003 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------|---------------------------------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------|
| VALUE (units 10^{-7}) | | COMMENT | AUBERT 08F PRL 100 051803 AUBERT 08G PRL 100 171803 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| 0.98±0.61±0.08 | AALTONEN 11AI CDF | p p at 1.96 TeV | AUBERT 08H PR D77 031101R AUBERT 08I PRL 100 081801 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| $B(B^0 \to K^0 \ell^+ \ell^-) (0.0$ | $< a^2 < 4.3 \text{ GeV}^2/c^2$ | | AUBERT 08N PRL 100 021801 Also PR D79 092002 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| VALUE (units 10 ⁻⁷) | | COMMENT | AUBERT 08P PR D77 032007 AUBERT 08Q PRL 100 151802 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| 1.27±0.62±0.10 | AALTONEN 11AI CDF | <u>p</u> at 1.96 TeV | AUBERT 08 PR D77 032002 AUBERT 08 W PRL 101 082001 | B. Aubert et al. B. Aubert et al. B. Aubert et al. | (BABAR Collab.) |
| | | | AUBERT 08Y PR D77 111101R | B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| | B ⁰ REFERENCES | | CHEN 08C PRL 100 251801 CHIANG 08 PR D78 111102R CHOI 08 PRL 100 142001 | JH. Chen et al. C.C. Chiang et al. | (BELLE COllab.) (BELLE COllab.) (BELLE COllab.) |
| AAU 12A PL B708 55 | R. Aaij et al. | (LHCb Collab.) | GOLDENZWE08 PRL 101 231801 | SK. Choi et al. P. Goldenzweig et al. H.O. Kim et al. | (BELLE COllab.) (BELLE Collab.) (BELLE Collab.) |
| AAIJ 12E PL B708 241 AAIJ 12I PL B709 177 | 'R. Aaij et al. | (LHCb Collab.) (LHCb Collab.) | KUMAR 08 PR D78 091104R | R. Kumar et al. | (BELLE Collab.) |
| CHATRCHYAN 12A JHEP 1204 0 | 105 T. Higuchi [´] et al. | (CMS Collab.) | KUSAKA 08 PR D77 072001 | A. Kusaka et al. | (BELLE Collab.) |
| HIGUCHI 12 PR D85 0711 | | (BELLE Collab.) | LEE 08A PR D77 071101R | S.E. Lee et al. | (BELLE Collab.) |
| HOI 12 PRL 108 0313 | R. Aaii et al. | (BELLE Collab.) | LI 08F PRL 101 251601 | J. Li et al. | (BELLE Collab.) |
| AAIJ 11B PL B699 330 | | (LHCb Collab.) | LIN 08 NAT 452 332 | SW. Lin et al. | (BELLE Collab.) |
| AAIJ 11E PR D84 0920 | 801 R. Aaij et al. | (LHCb Collab.) | LIU 081 PR D78 011106R | Y. Liu et al. | (BELLE Collab.) |
| AAIJ 11F PRL 107 2113 | | (LHCb Collab.) | LIVENTSEV 08 PR D77 091503R | D. Liventsev et al. | (BELLE Collab.) |
| AALTONEN 11 PRL 106 121: | 801 T. Aaltonen et al. | `(CDF Collab.) | MIZUK 08 PR D78 072004 | R. Mizuk et al. | (BELLE Collab.) |
| AALTONEN 11AG PRL 107 191: | | (CDF Collab.) | NAKAHAMA 08 PRL 100 121601 | Y. Nakahama et al. | (BELLE Collab.) |
| AALTONEN 11AI PRL 107 2013 | 903 (errat) T. Aaltonen et al. | (CDF Collab.) | SAHOO 08 PR D77 091103R | H. Sahoo et al. | (BELLE Collab.) |
| | 802 T. Aaltonen et al. | (CDF Collab.) | TANIGUCHI 08 PRL 101 111801 | N. Taniguchi et al. | (BELLE Collab.) |
| AALTONEN 11L PRL 106 1613 | 802 T. Aaltonen et al. | (CDF Collab.) | UCHIDA 08 PR D77 051101R | Y. Uchida <i>et al.</i> | (BELLE Collab.) |
| AALTONEN 11N PRL 106 1813 | | (CDF Collab.) | USHIRODA 08 PRL 100 021602 | Y. Ushiroda <i>et al.</i> | (BELLE Collab.) |
| ABAZOV 11U PR D84 0520 | 102 T. Aushev et al. | (DO Collab.) | WEI 08A PR D78 011101R | JT. Wei et al. | (BELLE Collab.) |
| AUSHEV 11 PR D83 0511 | | (BELLE Collab.) | ABAZOV 07S PRL 99 142001 | V.M. Abazov et al. | (DO Collab.) |
| BAHINIPATI 11 PR D84 0211 | 101 S. Bahinipati <i>et al.</i> | (BELLE Collab.) | ABULENCIA 07A PRL 98 122001 | A. Abulencia <i>et al.</i> | (FNAL CDF Collab.) |
| BHARDWAJ 11 PRL 107 0913 | 803 V. Bhardwaj <i>et al.</i> | (BELLE Collab.) | ADAM 07 PRL 99 041802 | N.E. Adam <i>et al.</i> | (CLEO Collab.) |
| CHATRCHYAN 11T PRL 107 1917 | 802 S. Chatrchyan et al. | (CMS Collab.) | Also PR D76 012007 | D.M. Asner et al. | (CLEO Collab.) |
| CHOI 11 PR D84 0520 | | (BELLE Collab.) | AUBERT 07A PRL 98 031801 | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 11A PR D83 0320 | DO 6 P. del Amo Sanchez et al. | (BABAR Collab.) | AUBERT 07AA PR D76 012004 | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 11B PR D83 0320 | | (BABAR Collab.) | AUBERT 07AC PR D76 031101R | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 11C PR D83 0320 | DO7 P. del Amo Sanchez et al. | (BABAR Collab.) | AUBERT 07AD PR D76 031102R | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 11F PR D83 0520 | | (BABAR Collab.) | AUBERT 07AE PR D76 031103R | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 11K PR D83 0911 | 101 P. del Amo Sanchez et al. | (BABAR Collab.) | AUBERT 07AF PRL 99 021603 | B. Aubert et al. | (BABAR Collab.) |
| HA 11 PR D83 0711 | | (BELLE Collab.) | AUBERT 07AG PRL 99 051801 | B. Aubert et al. | (BABAR Collab.) |
| LEES 11 PR D83 1120 | D10 J.P. Lees et al. | (BABAR Collab.) | AUBERT 07AI PRL 99 071801 | B. Aubert et al. | (BABAR Collab.) |
| LEES 11A PR D84 0120 | | (BABAR Collab.) | AUBERT 07AJ PRL 99 081801 | B. Aubert et al. | (BABAR Collab.) |
| LEES 11F PR D84 0711 | 102 J.P. Lees et al. | (BABAR Collab.) | AUBERT 07AN PR D76 051101R | B. Aubert et al. | (BABAR Collab.) |
| LEES 11M PR D84 1120 | | (BABAR Collab.) | AUBERT 07AO PR D76 051103R | B. Aubert et al. | (BABAR Collab.) |
| SAHOO 11A PR D84 0711 | 101 H. Sahoo et al. | (BELLE Collab.) | AUBERT 07AQ PR D76 071101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 10 PRL 104 0113 | | (BABAR Collab.) | AUBERT 07AS PR D76 071104R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 10D PR D81 0520 | DO9 B. Aubert et al. | (BABAR Collab.) | AUBERT 07AT PR D76 091101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 10H PR D82 0311 | | (BABAR Collab.) | AUBERT 07AV PR D76 092004 | B. Aubert et al. | (BABAR Collab.) |
| AUSHEV 10 PR D81 0311 | 103R T. Aushev et al. | (BELLE Collab.) | AUBERT 07AX PRL 99 161802 | B. Aubert et al. | (BABAR Collab.) |
| CHIANG 10 PR D81 0711 | | (BELLE Collab.) | AUBERT 07AY PRL 99 171803 | B. Aubert et al. | (BABAR Collab.) |
| DAS 10 PR D82 0511 | 103R A. Das et al. | (BELLE Collab.) | AUBERT 07B PR D75 012008 | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 10A PR D82 0115 | | (BABAR Collab.) | AUBERT 07BC PR D76 091102R | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 10B PR D82 0111 | 101R P. del Amo Sanchez <i>et al.</i> | (BABAR Collab.) | AUBERT 07BF PR D76 052007 | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 10E PR D82 0311 | | (BABAR Collab.) | AUBERT 07BH PRL 99 231802 | B. Aubert et al. | (BABAR Collab.) |
| DEL-AMO-SA 10 Q PR D82 1120 | DO2 P. del Amo Sanchez et al. | (BABAR Collab.) | AUBERT 07BI PRL 99 241803 | B. Aubert et al. | (BABAR Collab.) |
| DUNGEL 10 PR D82 1120 | | (BELLE Collab.) | AUBERT 07BO PR D76 111102R | B. Aubert et al. | (BABAR Collab.) |
| FUJIKAWA 10A PR D81 0111 | 101R M. Fujikawa et al. | (BELLE Collab.) | AUBERT 07D PRL 98 051801 | B. Aubert et al. | (BABAR Collab.) |
| HYUN 10 PRL 105 091 | | (BELLE Collab.) | AUBERT 07E PRL 98 051802 | B. Aubert et al. | (BABAR Collab.) |
| JOSHI 10 PR D81 0311 | 101R N.J. Joshi et al. | (BELLE Collab.) | AUBERT 07F PRL 98 051803 | B. Aubert et al. | (BABAR Collab.) |
| NAKAHAMA 10 PR D82 0730 | | (BELLE Collab.) | AUBERT 07G PRL 98 111801 | B. Aubert et al. | (BABAR Collab.) |
| WEDD 10 PR D81 1111 AALTONEN 09B PR D79 0111 | 104R R. Wedd et al. | (BELLE Collab.) (BELLE Collab.) (CDF Collab.) | AUBERT 07H PR D75 031101R AUBERT 07J PRL 98 091801 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| AALTONEN 09C PRL 103 031: AALTONEN 09E PR D79 0320 | 801 T. Aaltonen et al. | (CDF Collab.) (CDF Collab.) (CDF Collab.) | AUBERT 07K PRL 98 081801 AUBERT 07L PRL 98 151802 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| AALTONEN 09P PRL 102 2013 | 801 T. Aaltonen et al. | (CDF Collab.) (DF Collab.) (D0 Collab.) | AUBERT 07N PR D75 072002 AUBERT 07O PRL 98 181803 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| AUBERT 09 PR D79 0111 | 102R B. Aubert et al. | (BABAR Collab.) | AUBERT 07Q PR D75 051102R AUBERT 07R PRL 98 211804 | B. Aubert et al. B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| AUBERT 09A PR D79 0120 AUBERT 09AA PR D79 1120 | 001 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | Also PRL 100 189903E | B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| AUBERT 09AC PR D79 1120 AUBERT 09AD PR D80 0111 AUBERT 09AE PR D80 0311 | 101R B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | AUBERT 07Y PR D75 111102R | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) |
| AUBERT 09AF PR D80 0511 | 101R B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | CHANG 07A PRL 98 131803 CHANG 07B PR D75 071104R CHAO 07 PR D76 091103R | MC. Chang et al. P. Chang et al. | (BELLE Collab.) |
| AUBERT 09AG PR D80 0511 AUBERT 09AL PR D80 0920 | 007 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | CHEN 07 PR 0/8 091103R CHEN 07 PRL 98 031802 CHEN 07D PRL 99 221802 | Y. Chao et al. KF. Chen et al. KF. Chen et al. | (BELLE Collab.) (BELLE Collab.) |
| AUBERT 09A0 PRL 103 211: AUBERT 09AU PR D80 1120 | 001 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | DALSENO 07 PR D76 072004 | J. Dalseno et al. S. Fratina et al. | (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) |
| AUBERT 09AV PR D80 1120 AUBERT 09B PRL 102 1321 AUBERT 09C PR D79 0320 | 001 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) (BABAR Collab.) | FRATINA 07 PRL 98 221802 GARMASH 07 PR D75 012006 HOKUUE 07 PL B648 139 | A. Garmash et al. T. Hokuue et al. | (BELLE Collab.) (BELLE Collab.) |
| AUBERT 09G PRL 102 1413 | 802 B. Aubert et al. | (BABAR Collab.) | ISHINO 07 PRL 98 211801 KUSAKA 07 PRL 98 221602 | H. Ishino et al. A. Kusaka et al. | (BELLE COllab.) (BELLE COllab.) |
| AUBERT 091 PR D79 0520 | DO3 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) (BABAR Collab.) | Also PR D77 072001 KUZMIN 07 PR D76 012006 | A. Kusaka et al. | (BELLE COllab.) (BELLE COllab.) |
| AUBERT 09K PR D79 0720 AUBERT 09R PR D79 0720 | DO3 B. Aubert et al. | (BABAR Collab.) | LIN 07 PRL 98 181804 | A. Kuzmin et al. SW. Lin et al. | (BELLE Collab.) |
| AUBERT 09S PR D79 0920 AUBERT 09T PRL 102 091 | 002 B. Aubert <i>et al.</i> 803 B. Aubert <i>et al.</i> ment No. E-PRLTAO-102-060910 | (BABAR Collab.) (BABAR Collab.) | LIN 07A PRL 99 121601 MATYJA 07 PRL 99 191807 MEDVEDEVA 07 PR D76 051102R | SW. Lin et al. A. Matyja et al. | (BELLE Collab.) (BELLE Collab.) |
| AUBERT 09Y PRL 103 0513 | 803 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | PARK 07 PR D75 011101R | T. Medvedeva et al. K.S. Park et al. | (BELLE Collab.) (BELLE Collab.) |
| CHANG 09 PR D79 0520 | 004 J. Dalseno <i>et al.</i> | (BELLE Collab.) | SCHUEMANN 07 PR D75 092002 | J. Schuemann et al. | (BELLE Collab.) |
| DALSENO 09 PR D79 0720 | | (BELLE Collab.) | SOMOV 07 PR D76 011104R | A. Somov et al. | (BELLE Collab.) |
| KYEONG 09 PR D80 0511 | 104R R. Mizuk et al. | (BELLE Collab.) | TSAI 07 PR D75 111101R | YT. Tsai et al. | (BELLE Collab.) |
| MIZUK 09 PR D80 0311 | | (BELLE Collab.) | URQUIJO 07 PR D75 032001 | P. Urquijo et al. | (BELLE Collab.) |
| VERVINK 09 PR D80 1111 | 801 JT. Wei et al. | (BELLE Collab.) | WANG 07B PR D75 092005 | C.H. Wang et al. | (BELLE Collab.) |
| WEI 09A PRL 103 1713 | | (BELLE Collab.) | WANG 07C PR D76 052004 | MZ. Wang et al. | (BELLE Collab.) |
| AALTONEN 081 PRL 100 1013 | | (BELLE Collab.) (CDF Collab.) | XIE 07 PR D75 017101 ZUPANC 07 PR D75 091102R | Q.L. Xie et al. A. Zupanc et al. V.M. Abazov et al. | (BELLE Collab.) (BELLE Collab.) |
| ADACHI 08 PR D77 0911 AUBERT 08AB PR D78 0120 | DO 6 B. Aubert et al. | (BÈLLE Collab.) (BABAR Collab.) | ABAZOV 06S PR D74 092001 ABAZOV 06W PR D74 112002 ABULENCIA,A 06D PRL 97 211802 | V.M. Abazov et al. | ` (DO Collab.) (DO Collab.) (CDF Collab.) |
| AUBERT 08AC PR D77 0711 AUBERT 08AD PR D77 0911 | 104R B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) | ACOSTA 06 PRL 96 202001 | A. Abulencia <i>et al.</i> D. Acosta <i>et al.</i> | (CDF Collab.) |
| AUBERT 08AF PR D78 0111 | 104R B. Aubert et al. | (BABAR Collab.) | AUBERT 06 PR D73 011101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08AG PR D78 0111 | | (BABAR Collab.) | AUBERT 06A PRL 96 011803 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08AH PR D78 0111 | DOS B. Aubert et al. | (BABAR Collab.) | AUBERT 06E PRL 96 052002 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08AJ PR D78 0320 | | (BABAR Collab.) | AUBERT 06G PR D73 012004 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08AP PR D78 0511 | 103R B. Aubert et al. | (BABAR Collab.) | AUBERT 06I PR D73 031101R | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08AQ PR D78 0520 | 105 B. Aubert et al. | (BABAR Collab.) | AUBERT 06L PR D74 012001 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08AU PRL 101 021: | 801 B. Aubert et al. | (BABAR Collab.) | AUBERT 06N PR D74 031103R | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08AV PRL 101 081: | 801 B. Aubert et al. | (BABAR Collab.) | AUBERT 06S PRL 96 241802 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
| AUBERT 08B PR D77 0111 | 102R B. Aubert et al. | (BABAR Collab.) | AUBERT 06T PRL 96 251802 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BA PR D78 0711 | 102R B. Aubert et al. | | AUBERT 06V PRL 97 051802 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BB PR D78 0711 AUBERT 08BC PR D78 0720 | 104R B. Aubert et al. 1007 B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) (BABAR Collab.) | AUBERT 06W PR D73 071102R AUBERT 06X PR D73 071103R | B. Aubert <i>et al.</i> B. Aubert <i>et al.</i> | (BABAR Collab.) (BABAR Collab.) |
| AUBERT 08BD PR D78 0911 | 101R B. Aubert et al. | (BABAR Collab.) | AUBERT 06Y PR D73 111101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BG PR D78 0920 | | (BABAR Collab.) | AUBERT,B 06A PR D73 112004 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BH PR D78 1120 | 001 B. Aubert et al. | (BABAR Collab.) | AUBERT,B 06B PR D74 011101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BK PRL 101 201: | | (BABAR Collab.) | AUBERT,B 06C PR D74 011102R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BL PRL 101 261: | 802 B. Aubert et al. | (BABAR Collab.) | AUBERT,B 06E PR D74 011106R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08BN PR D78 1120 | | (BABAR Collab.) | AUBERT.B 06G PRL 97 201801 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT 08C PR D77 0111 | 104R B. Aubert et al. | (BABAR Collab.) | AUBERT B 06H PRL 97 201802 | B. Aubert et al. | (BABAR Collab.) |
| | | | | | |

 B^0

Meson Particle Listings B^0 , B^{\pm}/B^0 ADMIXTURE

| ABE (| 01K 01L 01M 01H | PR D64 071101 PRL 87 161601 PL B517 309 PL B510 55 | K. Abe et al. K. Abe et al. K. Abe et al. P. Abreu et al. | (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) (DELPHI Collab.) |
|--------------------------------------------------------|------------------------------------|---------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| ANDERSON (| 01B 01 01B | PR D64 092001 PRL 87 271801 PRL 86 2732 PRL 87 181803 | J.P. Alexander et al. R. Ammar et al. S. Anderson et al. S. Anderson et al. | (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) |
| AUBERT (AUBERT (AUBERT (| 01E | PRL 87 091801 PRL 87 151801 PRL 87 151802 | B. Aubert et al. B. Aubert et al. B. Aubert et al. B. Aubert et al. B. Aubert et al. | (BaBar Collab.) (BaBar Collab.) (BaBar Collab.) (BaBar Collab.) |
| AUBERT (AUBERT (AUBERT (| 01F 01G 01H 01I | PRL 87 241803 | B. Aubert et al. B. Aubert et al. B. Aubert et al. B. Aubert et al. R. Barate et al. | (BaBar Collab.) (BaBar Collab.) (BaBar Collab.) (BaBar Collab.) (ALEPH Collab.) |
| BRIERE (EDWARDS (JAFFE (| 01 01 01 01 | PRL 86 3718 PRL 86 30 | R.A. Biere et al. K.W. Edwards et al. D. Jaffe et al. S.J. Richichi et al. G. Abbiendi et al. | (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) |
| ABBIENDI (ABBIENDI,G (ABE (| 00 Q | PL B493 266 | G. Abbiendi et al. G. Abbiendi et al. K. Abe et al. T. Affolder et al. | (OPAL Collab.) (OPAL Collab.) (SLD Collab.) |
| AFFOLDER (AHMED (ANASTASSOV (| 00 N 00 B | PRL 85 4668 PR D62 112003 PRL 84 1393 PRL 84 4292 | T. Affolder et al. S. Ahmed et al. A. Anastassov et al. M. Artuso et al. | (CDF Collab.) (CDF Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |
| BARATE (BARATE (BEHRENS (| 00 00 Q 00 R 00 | PR D62 051101 PL B492 259 PL B492 275 PR D61 052001 | P. Avery et al. R. Barate et al. R. Barate et al. B.H. Behrens et al. | (CLEO COllab.) (ALEPH COllab.) (ALEPH COllab.) (CLEO COllab.) |
| BERGFELD (CHEN (COAN (| 00 B 00 B 00 00 | PRL 84 5283 | B.H. Behrens et al. T. Bergfeld et al. S. Chen et al. T.E. Coan et al. | (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |
| LIPELES (| | PR D61 111101 PRL 85 2881 PR D62 032005 | D. Cronin-Hennessy et al. S.E. Csorna et al. C.P. Jessop et al. E. Lipeles et al. S.J. Richichi et al. | (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |
| ABBIENDI ! ABE ABE | 99J 99K 99Q 99B | EPJ C12 609 PR D60 051101 PR D60 072003 | G. Abbiendi <i>et al.</i> F. Abe <i>et al.</i> F. Abe <i>et al.</i> | (OPAL Collab.) (CDF Collab.) (CDF Collab.) |
| AFFOLDER ARTUSO BARTELT COAN | 99 C 99 99 99 | PR D60 112004 PRL 82 3020 PRL 82 3746 PR D59 111101 | T. Affolder et al. T. Affolder et al. M. Artuso et al. J. Bartelt et al. T.E. Coan et al. | (CDF Collab.) (CDF Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |
| ABE ABE ABE | 98 B 98 98 B 98 C | PR D57 R3811 PR D57 5382 PRL 80 2057 | B. Abbott et al. F. Abe et al. F. Abe et al. F. Abe et al. | (DO Collab.) (CDF Collab.) (CDF Collab.) (CDF Collab.) (CDF Collab.) |
| ABE ABE | 98 O 98 Q 98 U 98 V | PR D58 072001 PR D58 092002 PRL 81 5513 | F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. | (CDF Collab.) (CDF Collab.) (CDF Collab.) (CDF Collab.) |
| ACCIARRI ' ACCIARRI ' ACKERSTAFF ' | 98 D 98 S | EPJ C5 195 | M. Acciarri et al. M. Acciarri et al. K. Ackerstaff et al. R. Barate et al. | (L3 COllab.) (L3 Collab.) (OPAL COllab.) (ALEPH COllab.) |
| BERGFELD ! BRANDENB ! GODANG ! | 98 98 98 98 98 | PRL 80 3710 PRL 81 272 PRL 80 2762 PRL 80 3456 PR D57 5363 | B.H. Behrens et al. T. Bergfeld et al. G. Brandenbrug et al. R. Godang et al. | (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |
| ABE S ABREU S Also | 97 J 97 F 97 N | PRL 79 590 ZPHY C74 19 ZPHY C75 579 (erratum | B. Nemati et al. K. Abe et al. P. Abreu et al. P. Abreu et al. P. Abreu et al. | (CLEO Collab.) (SLD Collab.) (DELPHI Collab.) (DELPHI Collab.) (DELPHI Collab.) |
| ACCIARRI (ACCIARRI ACKERSTAFF (ACKERSTAFF (| 97 B 97 C 97 G 97 U | PL B391 474 PL B391 481 PL B395 128 ZPHY C76 401 | M. Acciarri et al. M. Acciarri et al. K. Ackerstaff et al. K. Ackerstaff et al. | (L3 Collab.) (L3 Collab.) (OPAL Collab.) (OPAL Collab.) |
| ARTUSO S ASNER ATHANAS | 97 V 97 97 97 97 | ZPHY C76 417 PL B399 321 PRL 79 799 PRL 79 2208 PL B395 373 | K. Ackerstaff et al. M. Artuso et al. D. Asner et al. M. Athanas et al. D. Buskulic et al. | (OPAL Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (ALEPH Collab.) |
| BUSKULIC FU JESSOP | 97 D 97 97 97 96 B | ZPHY C75 397 PRL 79 3125 | D. Buskulic et al. X. Fu et al. | (ALEPH Collab.) (CLEO Collab.) (CLEO Collab.) (CDE Collab.) |
| ABE ABE | 96 L 96 Q | PRL 76 4462 PRL 76 2015 PRL 76 4675 PR D54 6596 | F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. | (CDF Collab.) (CDF Collab.) (CDF Collab.) (CDF Collab.) |
| ACCIARRI ' | 96 Q 96 E 96 D | ZPHY C71 539 ZPHY C72 17 PL B383 487 ZPHY C72 207 PL B374 256 | C.P. Jessop et al. F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. F. Abe et al. P. Abreu et al. M. Acciarri et al. M. Acciarri et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. | (DELPHI Collab.) (DELPHI Collab.) (L3 Collab.) (DELPHI Collab.) (ARGUS Collab.) |
| ALEXANDER ALEXANDER AS NER BARISH | 96T 96V 96 96B | ZPHY C72 377 PR D53 1039 PRL 76 1570 | G. Alexander et al. D.M. Asner et al. B.C. Barish et al. | (CLEO COllab.) (OPAL Collab.) (CLEO Collab.) (CLEO Collab.) |
| BUSKULIC BUSKULIC DUBOSCQ | 96 J | ZPHY C71 31 PL B384 471 | M. Bishai et al. D. Buskulic et al. D. Buskulic et al. J.E. Duboscq et al. D. Gibaut et al. | (CLEO Collab.) (ALEPH Collab.) (ALEPH Collab.) (CLEO Collab.) (CLEO Collab.) |
| PDG ABE ABREU ABREU | 96 95 Z 95 N 95 Q | PR D5/L 1 | R. M. Barnett et al. F. Abe et al. P. Abreu et al. P. Abreu et al. M. Acciarri et al. | (CDF Collab.) (DELPHI Collab.) (DELPHI Collab.) |
| ACCIARRI ADAM AKERS | 95 H 95 I 95 95 J 95 T | PL B363 137 | M. Acciarri et al. M. Acciarri et al. W. Adam et al. R. Akers et al. R. Akers et al. J. Alexander et al. | (L3 Collab.) (L3 Collab.) (DELPHI Collab.) (OPAL Collab.) |
| ALEXANDER Also BARISH BUSKULIC | 95 95 95 N | PL B347 469 (erratum) PR D51 1014 PL B359 236 | J. Alexander et al. B.C. Barish et al. D. Buskulic et al. | (OPAL Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (ALEPH Collab.) |
| ABE ABREU AKERS AKERS | | PRL 72 3456 PL B338 409 PL B327 411 PL B336 585 | F. Abe et al. P. Abreu et al. R. Akers et al. R. Akers et al. R. Akers et al. | `(CDF Collab.) (DELPHI Collab.) (OPAL Collab.) (OPAL Collab.) (OPAL Collab.) |
| | 94 J 94 L | | R. Akers et al. | (OPAL Collab.) |

| ALAM ALBRECHT ALBRECHT AMMAR ATHANAS AISO BUS KULIC PDG PROCARIO STONE | 94 94 94 G 94 94 94 94 B 94 94 94 | PR D50 43 PL B324 249 PL B340 217 PR D49 5701 PRL 73 3503 PRL 74 3090 (erratum) PL B322 441 PR D50 1173 PRL 73 1472 HEPSY 93-11 | M.S. Alam et al. H. Albrecht et al. H. Albrecht et al. R. Ammar et al. M. Athanas et al. M. Athanas et al. D. Buskulic et al. L. Montanet et al. M. Procario et al. S. Stone | (CLEO Collab.) (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (ALEPH Collab.) (CERN, LBL, BOST+) (CLEO Collab.) |
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| ABREU ACTON ALBRECHT ALBRECHT ALBRECHT ALEXANDER AMMAR BARTELT BEAN BUS KULIC AISO BUS KULIC SANGHERA ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT | 93D 93G 93C 93E 93B 93 93 93 93 93 93 93 D 93K 93 92C 92G 92L | ZPHY C57 181 PL B312 253 PL B307 247 ZPHY C57 533 ZPHY C65 533 ZPHY C60 11 PL B319 365 PRL 71 674 PRL 71 1892 PRL 71 2681 PL B307 194 PL B325 537 (erratum) PL B325 537 91 PL B275 195 ZPHY C54 1 ZPHY C54 1 ZPHY C54 1 | M.S. Alam et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. R. Ammar et al. M. Athanas et al. M. Athanas et al. M. Athanas et al. D. Buskulic et al. L. Montanet et al. M. Procario et al. S. Stone Scientific, Singapore P. Abreu et al. P.D. Acton et al. P.D. Acton et al. H. Albrecht et al. H. Albrecht et al. J. Alexander et al. J. E. Bartelt et al. M. Battle et al. D. Buskulic et al. D. Buskulic et al. S. Sanghera et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. S. Sanghera et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. | (DELPHI Collab.) (DELPHI Collab.) (OPAL Collab.) (ARGUS Collab.) (ALEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (ALEO Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) (ALEPH Collab.) |
| BORTOLETTO HENDERS ON KRAMER ALBAJAR ALBAJAR ALBRECHT ALBRECHT ALBRECHT BERKELMAN "Decays of FILITON | 92 92 92 91C 91E 91B 91C 91E 91 B Me | PR D45 21 PR D45 2212 PL B279 181 PL B262 163 PL B273 540 PL B255 297 PL B262 148 ARNPS 41 1 Sons" | D. Bortoletto et al. S. Henderson et al. G. Kramer, W.F. Palmer C. Albajar et al. C. Albajar et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. B. K. Berkelman, S. Stone R. Eulton et al. | (CLEO Collab.) (CLEO Collab.) (HAMB, OSU) (UA1 Collab.) (UA1 Collab.) (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) (CORN, SYRA) |
| ALBRECHT ALBRECHT ANTREASYAN BORTOLETTO ELSEN | 90 B 90 J 90 B 90 90 | PL B241 278 ZPHY C48 543 ZPHY C48 553 PRL 64 2117 ZPHY C46 349 | H. Albrecht et al. H. Albrecht et al. D. Antreasyan et al. D. Bortoletto et al. E. Elsen et al. | (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) (Crystal Ball Collab.) (CLEO Collab.) (JADE Collab.) |
| WAGNER WAGNER ALBRECHT ALBRECHT ALBRECHT AVERIL AVERY BEBEK BORTOLETTO ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT ALBRECHT BEBEK ALAM ALBRECHT BEBEK BEHRENDS | 90 89 C 89 G 89 G 89 G 89 G 89 B 89 B 89 B 88 F 87 C 87 C 87 D 87 B 87 B 87 B 87 B 86 B 86 B 85 B 86 B 87 B 88 B 88 B 87 B 88 B 87 B 88 B 88 | PR D42 3732 PRL 64 1095 PL B219 121 PL B229 304 PL B229 375 PR D39 123 PR D39 123 PR D39 123 PR B223 470 PRL 62 2436 PRL 62 2436 PRL 63 1667 PRL 63 1667 PR B209 119 PL B215 424 PL B185 218 PL B199 451 PL B192 245 PL B197 452 PL B197 452 PL B183 429 PRL 58 183 PR D36 1289 PR D36 1289 PR D36 1289 PR D36 1289 PR D36 1299 PR D37 1298 PR D37 1298 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D38 1299 PR D39 1298 PR D36 1299 PR D30 2279 PRL 50 881 | R. Autherent et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. D. Antrasyan et al. D. Antrasyan et al. D. Esten et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. D. Antrasyan et al. D. Averill et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. D. Bortoletto et al. D. Bortoletto et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. | (Mark II Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (AR GUS Collab.) (AR GUS Collab.) (AR GUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) |

B^{\pm}/B^{0} ADMIXTURE

B DECAY MODES

The branching fraction measurements are for an admixture of B mesons at the $\Upsilon(4S)$. The values quoted assume that $B(\varUpsilon(4S) \to B\overline{B}) = 100\%$.

For inclusive branching fractions, e.g., $B \to D^\pm$ anything, the treatment of multiple D's in the final state must be defined. One possibility would be to count the number of events with one-or-more D's and divide by the total number of B's. Another possibility would be to count the total number of D's and divide by the total number of B's, which is the definition of average multiplicity. The two definitions are identical if only one D is allowed in the final state. Even though the "one-or-more" definition seems sensible, for practical reasons inclusive branching fractions are almost always measured using the multiplicity definition. For heavy final state particles, authors call their results inclusive branching fractions while for light particles some authors call their results multiplicities. In the B sections, we list all results as inclusive branching fractions, adopting a multiplicity definition. This means that inclusive branching fractions can exceed 100% and that inclusive partial widths can exceed total widths, just as inclusive cross sections can exceed total cross sections.

 $\overline{{\it B}}$ modes are charge conjugates of the modes below. Reactions indicate the weak decay vertex and do not include mixing.

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| | | | | | K or | K* modes | i | |
|-----------------|-----------------------------------------------------------------------------|------------------------------|------------------------------------|------------------------------------|------------------------------------------------------------------------|------------|------------------------------------------------------|------------------------------------|
| | | | Scale factor/ | Γ ₅₈ | K^\pm anything | | |) % |
| | Mode | Fraction (Γ_i/Γ) | Confidence level | Γ ₅₉ | K^+ anything | | (66 ± 5 |) % |
| | | V 11 7 | | Γ ₆₀ | K^- anything | | (13 ± 4 |) % |
| | Semileptonic and | d leptonic modes | | Γ ₆₁ | K^0/\overline{K}^0 anything | [e] | (64 ± 4 |) % |
| Γ_1 | $e^+ u_e$ anything | [a] (10.72 ± 0.13 |) % | Γ ₆₂ | $K^*(892)^{\pm}$ anything | | (18 ± 6 |) % |
| Γ_2^- | $\overline{p} e^+ \nu_e$ anything | < 5.9 | $\times 10^{-4} \text{ CL} = 90\%$ | Γ ₆₃ | $K^*(892)^0 / \overline{K}^*(892)^0$ anything | [e] | (14.6 ± 2.6 |) % |
| Γ3 | $\mu^+ \nu_\mu$ a nything | [a] (10.72 ± 0.13 |) % | Γ ₆₄ | $K^*(892)\gamma$ | | | $) \times 10^{-5}$ |
| Γ ₄ | $\ell^+ u_\ell$ anything | $[a,b]$ (10.72 \pm 0.13 |) % | | $\eta K \gamma$ | | (8.5 + 1.8 |)×10 ⁻⁶ |
| Γ ₅ | $D^-\ell^+\nu_\ell$ anything | [b] (2.8 ± 0.9 | * | Γ ₆₅ | • | | 0.5 - 1.6 | * |
| Γ ₆ | $\overline{D}^0 \ell^+ \nu_\ell$ anything | [b] (7.2 ± 1.4 | * | Γ ₆₆ | $K_1(1400)\gamma$ | < | | $\times10^{-4}$ CL=90% |
| Γ ₇ | $\frac{\overline{D}}{D}\ell\nu_{\ell}$ | (2.39 ± 0.12 | | Γ ₆₇ | $K_2^*(1430)\gamma$ | | $(1.7 \begin{array}{c} + 0.6 \\ - 0.5 \end{array} $ | $) \times 10^{-5}$ |
| Γ ₈ | $D\tau^+ u_{	au}$ | (8.6 ± 2.7 | | Γ ₆₈ | $K_2(1770)\gamma$ | < | | $\times 10^{-3} \text{ CL} = 90\%$ |
| Г | $D^{*-}\ell^{+} u_{\ell}$ anything | [c] (6.7 ± 1.3 | , | Γ ₆₉ | $K_3^*(1780)\gamma$ | < | | $\times 10^{-5} \text{ CL} = 90\%$ |
| Γ ₁₀ | $D^{*0}\ell^+\nu_\ell$ a nything | [6] (6.1 ± 1.0 | , | | 3. | | | ×10 - CL=90% ×10-3 CL=90% |
| Γ ₁₁ | $D^* \tau^+ u_{	au}$ | (1.62 ± 0.33) |) % | Γ ₇₀ | $K_4^*(2045)\gamma$ | < | 1.0 | |
| Γ ₁₂ | $\overline{D}^{**}\ell^+\nu_{\ell}$ | $[b,d]$ (2.7 \pm 0.7 | , | Γ ₇₁ | $K\eta'(958)$ | | (8.3 ± 1.1 | |
| Γ ₁₃ | \overline{D}_1 (2420) ℓ^+ ν_ℓ anything | (3.8 ± 1.3 | · _ | Γ ₇₂ | $K^*(892)\eta'(958)$ | | (4.1 ± 1.1) | |
| Γ ₁₄ | $D\pi \ell^+ \nu_\ell$ a nything + | (2.6 ± 0.5 | * | Γ ₇₃ | $K\eta$ | < | | $\times 10^{-6} \text{ CL} = 90\%$ |
| ' 14 | $D^*\pi\ell^+ u_\ell$ anything | (2.0 ± 0.5 |) /0 3=1.3 | Γ ₇₄ | $K^*(892)\eta$ | | (1.8 ± 0.5) | |
| Γ ₁₅ | $D\pi\ell^+\nu_\ell$ a nything | (1.5 ± 0.6) |) % | Γ ₇₅ | $\underline{K} \phi \phi$ | | (2.3 ± 0.9) | |
| Γ ₁₆ | $D^*\pi\ell^+ u_\ell$ anything | (1.9 ± 0.4 | * | Γ ₇₆ | $\overline{\underline{b}} \rightarrow \overline{\underline{s}} \gamma$ | | (3.53 ± 0.24) | |
| Γ ₁₇ | $\overline{D}_{2}^{*}(2460)\ell^{+}\nu_{\ell}$ anything | (4.4 ± 1.6 | * | Γ ₇₇ | $\overline{b} \rightarrow \overline{d} \gamma$ | | (9.2 ± 3.0) | * |
| Γ ₁₈ | $D^{*-}\pi^+\ell^+\nu_\ell$ a nything | (1.00 ± 0.34 | , | Γ ₇₈ | $\overline{b} ightarrow \overline{s}$ gluon | < | | % CL=90% |
| | $D_s^-\ell^+\nu_\ell$ anything | | ×10 ⁻³ CL=90% | Γ_{79} | η anything | | $(2.6 + 0.5 \\ -0.8$ | $) \times 10^{-4}$ |
| Γ ₁₉ | | [b] < 7 | | Γ ₈₀ | η' anything | | (4.2 ± 0.9 | |
| Γ ₂₀ | $D_s^-\ell^+\nu_\ell K^+$ a nything | [b] < 5 | $\times 10^{-3} \text{ CL} = 90\%$ | | K ⁺ gluon (charmless) | | 1.87 | ×10 ⁻⁴ CL=90% |
| Γ ₂₁ | $D_s^-\ell^+ u_\ell K^0$ anything | [b] < 7 | $\times 10^{-3} \text{ CL} = 90\%$ | Г ₈₁ | K^0 gluon (charmless) | _ | (1.9 ± 0.7 | |
| Γ ₂₂ | $\ell^+ u_\ell^-$ charm | (10.51 ± 0.13) |) % | Γ ₈₂ | A gluon (charmess) | | (1.9 ± 0.7 |) × 10 · |
| Γ ₂₃ | $X_{u} \ell^{+} \nu_{\ell}$ | (2.08 ± 0.30) | | | Light unflavo | red meso | n modes | |
| Γ ₂₄ | $K^+\ell^+ u_\ell$ anything | [b] (6.2 \pm 0.5 |) % | Γ ₈₃ | $\rho\gamma$ | | (1.39 ± 0.25) | $) \times 10^{-6}$ S=1.2 |
| Γ ₂₅ | $K^-\ell^+ u_\ell$ anything | $[b]$ (10 \pm 4 | $) \times 10^{-3}$ | Γ ₈₄ | $\rho/\omega\gamma$ | | (1.30 ± 0.23 | |
| Γ ₂₆ | $K^0/\overline{K}{}^0\ell^+ u_\ell$ a nything | [b] (4.5 \pm 0.5 |) % | Γ ₈₅ | π^{\pm} anything | [e,h] | |) % |
| | 5.5 | | | Γ ₈₆ | π^0 anything | | |) % |
| _ | D, D* , or | - | | Γ ₈₇ | η anything | | (17.6 ± 1.6) | * |
| Γ ₂₇ | D^{\pm}_{0} anything | (23.7 ± 1.3) | * | Γ ₈₈ | ρ^0 anything | | • |) % |
| Γ ₂₈ | $D^0/\overline{D}{}^0$ anything | (62.7 ± 2.9) | * | Γ ₈₉ | ω anything | | 81 | % CL=90% |
| Γ ₂₉ | $D^*(2010)^{\pm}$ a nything | (22.5 ± 1.5) | | Γ ₉₀ | ϕ anything | | (3.43 ± 0.12 | |
| Γ ₃₀ | $D^*(2007)^0$ anything | (26.0 ± 2.7) |) % | Γ ₉₁ | φ K*(892) | < | * | ×10 ⁻⁵ CL=90% |
| Γ ₃₁ | D_s^\pm anything | [e] (8.3 \pm 0.8 |) % | | $\overline{b} \rightarrow \overline{d} \text{ gluon}$ | | 2.2 | × 10 CL=30/0 |
| Γ ₃₂ | $D_s^{*\pm}$ anything | (6.3 ± 1.0) |) % | г ₉₂ Г ₉₃ | π^+ gluon (charmless) | | (3.7 ± 0.8 | $) \sim 10^{-4}$ |
| Γ ₃₃ | $D_{\varepsilon}^{*\pm} \overline{D}(*)$ | (3.4 ± 0.6) |) % | 1 93 | " graon (enarmicos) | | (3.7 ± 0.0 | , ~ 10 |
| Γ ₃₄ | $\overline{D}^{s}D_{s0}(2317)$ | , | , | | | on modes | | |
| Γ ₃₅ | $\frac{D}{D}D_{s,I}(2457)$ | | | Γ_{94} | $\Lambda_c^+ / \overline{\Lambda}_c^-$ anything | | (4.5 ± 1.2) |) % |
| | $D^{(*)}\overline{D}^{(*)}K^0 + D^{(*)}\overline{D}^{(*)}K^{\pm}$ | |) 0/ | Γ_{95} | Λ_c^+ anything | | | |
| Γ ₃₆ | DODONK* + DODONK+ | [e, f] (7.1 $+$ 2.7 $-$ 1.7 |) % | Г ₉₆ | $\overline{\Lambda}_{c}^{-}$ anything | | | |
| Γ ₃₇ | $b \rightarrow c \overline{c} s$ | (22 ± 4) |) % | . 96 Г ₉₇ | $\frac{\Lambda_c}{\Lambda_c}e^+$ a nything | < | 1.1 | $\times 10^{-3} \text{ CL} = 90\%$ |
| Γ ₃₈ | $D_s^{(*)}\overline{D}^{(*)}$ | $[e, f]$ (3.9 \pm 0.4 | | | | | | |
| Γ ₃₉ | $D^*D^*(2010)^{\pm}$ | [e] < 5.9 | $\times 10^{-3} \text{ CL} = 90\%$ | Γ ₉₈ | <u>⊼</u> _c panything | | (2.6 ± 0.8) | * |
| Γ_{40} | $DD^*(2010)^{\pm} + D^*D^{\pm}$ | [e] < 5.5 | $\times 10^{-3} \text{ CL} = 90\%$ | | $\overline{\Lambda}_c^-$ p e^+ $ u_e$ | < | 1.0 | $\times 10^{-3} \text{ CL} = 90\%$ |
| Γ ₄₁ | D D [±] | [e] < 3.1 | $\times 10^{-3} \text{ CL} = 90\%$ | Γ_{100} | $\overline{\Sigma}_c^{}$ a nything | | (4.2 ± 2.4) | |
| Γ ₄₂ | $D_s^{(*)\pm}\overline{D}^{(*)}X(n\pi^{\pm})$ | [e,f] (9 + 5 - 4 |) % | Γ_{101} | $\overline{\Sigma}_{c}^{-}$ anything | < | 9.6 | $\times10^{-3}$ CL=90% |
| | | | | Γ_{102} | $\overline{\Sigma}_{c}^{\delta}$ anything | | (4.6 ± 2.4) | |
| Γ ₄₃ | $D^*(2010)\gamma$ | < 1.1 | $\times 10^{-3} \text{ CL} = 90\%$ | F ₁₀₃ | $\overline{\Sigma}_{C}^{0} N(N = p \text{ or } n)$ | | 1.5 | |
| Γ ₄₄ | $D_s^+ \pi^-$, $D_s^{*+} \pi^-$, $D_s^+ \rho^-$, | [e] < 4 | ×10 ⁻⁴ CL=90% | F ₁₀₄ | Ξ_c^0 anything | | | $) \times 10^{-4}$ S=1.1 |
| | $D_s^{*+} ho^-$, $D_s^+\pi^0$, $D_s^{*+}\pi^0$, | | | . 104 | $\times B(\Xi_c^0 \to \Xi^-\pi^+)$ | | , 0.50 | , |
| | $D_{s}^{+}\eta$, $D_{s}^{*+}\eta$, $D_{s}^{+}\rho^{0}$, | | | | = | | | |
| | $D_s^{*+}\rho^0$, $D_s^+\omega$, $D_s^{*+}\omega$ | | | Γ_{105} | Ξ_c^+ anything | | $(4.5 + 1.3 \\ -1.2$ | $) \times 10^{-4}$ |
| lг | D_s ρ , D_s ω , D_s ω $D_{s1}(2536)^+$ anything | < 9.5 | $\times 10^{-3} \text{ CL} = 90\%$ | | \times B($\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$) | | | |
| 「 ₄₅ | DSI(2000) anything | 7.5 | A 10 CL = 7U70 | Γ106 | p/\overline{p} anything | [e] | (8.0 ± 0.4) |) % |
| I | Charmonio | um modes | | F ₁₀₇ | p/\overline{p} (direct) anything | | (5.5 ± 0.5 | |
| Γ_{46} | $J/\psi(1S)$ anything | (1.094 ± 0.032) |) % S=1.1 | F100 | Λ/Λ anything | | (4.0 ± 0.5 | |
| Γ_{47} | $J/\psi(1S)$ (direct) anything | (7.8 ± 0.4) | $) \times 10^{-3}$ S=1.1 | Γ108 | <u>∧</u> anything | [0] | (4.0 ± 0.5 |) /0 |
| Γ ₄₈ | $\psi(2S)$ a nything | (3.07 ± 0.21) | $) \times 10^{-3}$ | Γ110 | 7anything √ | | | |
| Γ ₄₉ | $\chi_{c1}(1P)$ a nything | (3.86 ± 0.27 | $) \times 10^{-3}$ | L*** | $\Xi^-/\overline{\Xi}^+$ anything | [6] | (2.7 ± 0.6 | $) \times 10^{-3}$ |
| Γ ₅₀ | $\chi_{c1}(1P)$ (direct) anything | (3.22 ± 0.25 | | | baryons anything | | (6.8 ± 0.6) | |
| Γ ₅₁ | $\chi_{c2}(1P)$ a nything | (1.3 ± 0.4 | | | ppanything | | (2.47 ± 0.23 | * |
| Γ ₅₂ | $\chi_{c2}(1P)$ (direct) anything | (1.65 ± 0.31 | | · 113 | $\Lambda \overline{p} / \overline{\Lambda} p$ anything | | (2.47 ± 0.23) | |
| Γ ₅₃ | $\eta_{c}(1S)$ anything | < 9 | ×10 ⁻³ CL=90% | | $\Lambda \overline{\Lambda}$ anything | | 5 | ×10 ⁻³ CL=90% |
| Γ ₅₄ | $KX(3872) \times B(X \rightarrow D^0 \overline{D}{}^0 \pi^0)$ | (1.2 ± 0.4 | | 115 ا | | | | |
| Γ ₅₅ | $KX(3872) \times B(X \rightarrow$ | (8.0 ± 2.2 |) × 10 ⁻⁵ | | Lepton Family numbe | | | or |
| | $\stackrel{\sim}{D}^{*0} \stackrel{\circ}{D^0})$ | , | | | $\Delta B=1$ weak neut | ral curren | t (<i>B1</i>) modes | |
| Γ_{56} | $KX(3940) \times B(X \rightarrow D^{*0}D^0)$ | < 6.7 | $\times 10^{-5} \text{ CL} = 90\%$ | Γ ₁₁₆ | $s e^+ e^-$ | | (4.7 ± 1.3) | |
| Γ ₅₇ | $KX(3915) \times B(X \rightarrow \omega J/\psi)$ | [g] (7.1 ± 3.4 | | Γ ₁₁₇ | $s \mu^+ \mu^-$ | | (4.3 ± 1.2 | |
| 31 | , , , , , , , , , , , , , , , , , , , , | .51 (= | * | Γ ₁₁₈ | $s\ell^+\ell^-$ | | (4.5 ± 1.0) | |
| | | | | Γ ₁₁₉ | $\pi \ell^+ \ell^-$ | | 6.2 | $\times 10^{-8} \text{ CL} = 90\%$ |
| | | | | Γ ₁₂₀ | $K e^+ e^-$ | | (4.4 ± 0.6) | $) \times 10^{-7}$ |
| | | | | | | | | |

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| Γ_{121} | $K^*(892) e^+ e^-$ | В1 | (| 1.19 | \pm | 0.20 |) × 1 | $^{0}-^{6}$ | S=1.2 |
|----------------|------------------------------|----|-------|------|-------|------|------------|-------------|--------|
| Γ_{122} | $K\mu^+\mu^-$ | B1 | (| 4.4 | \pm | 0.4 |) × 1 | $^{0}-^{7}$ | |
| Γ_{123} | $K^*(892)\mu^+\mu^-$ | B1 | (| 1.06 | \pm | 0.09 |) × 1 | $^{0-6}$ | |
| Γ_{124} | $K\ell^+\ell^-$ | B1 | (| 4.5 | \pm | 0.4 |) × 1 | $^{0}-^{7}$ | |
| Γ_{125} | $K^*(892)\ell^+\ell^-$ | B1 | (| 1.08 | \pm | 0.11 |) × 1 | $^{0-6}$ | |
| Γ_{126} | Kν ν | B1 | < | 1.4 | | | $\times 1$ | $^{0-5}$ | CL=90% |
| | $K^* \nu \overline{\nu}$ | B1 | < | 8 | | | $\times 1$ | 0^{-5} | CL=90% |
| Γ_{128} | $s e^{\pm} \mu^{\mp}$ | LF | [e] < | 2.2 | | | $\times 1$ | $^{0}^{-5}$ | CL=90% |
| | $\pi e^{\pm} \mu^{\mp}$ | LF | < | 9.2 | | | | | CL=90% |
| | $\rho e^{\pm} \mu^{\mp}$ | LF | < | 3.2 | | | | | CL=90% |
| | $K e^{\pm} \mu^{\mp}$ | LF | < | 3.8 | | | $\times 1$ | 0-8 | CL=90% |
| Γ_{132} | $K^*(892) e^{\pm} \mu^{\mp}$ | LF | < | 5.1 | | | $\times 1$ | 0^{-7} | CL=90% |
| | | | | | | | | | |

- [a] These values are model dependent.
- [b] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [c] Here "anything" means at least one particle observed.
- [d] D^{**} stands for the sum of the $D(1 \, {}^{1}P_{1})$, $D(1 \, {}^{3}P_{0})$, $D(1 \, {}^{3}P_{1})$, $D(1 \, {}^{3}P_{2})$, $D(2^{1}S_{0})$, and $D(2^{1}S_{1})$ resonances.
- [e] The value is for the sum of the charge states or particle/antiparticle states indicated.
- $[f] D^{(*)} \overline{D}^{(*)}$ stands for the sum of $D^* \overline{D}^*$, $D^* \overline{D}$, $D \overline{D}^*$, and $D \overline{D}$.
- [g] X (3915) denotes a near-threshold enhancement in the ω J/ψ mass spec-
- [h] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.

B±/B0 ADMIXTURE BRANCHING RATIOS

$\Gamma(e^+\nu_e$ a nything)/ Γ_{total}

 Γ_1/Γ

These branching fraction values are model dependent.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

07 BELL $e^+e^- \rightarrow \Upsilon(4S)$

<u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

¹ URQUIJO

0.1072 + 0.0013 OUR EVALUATION

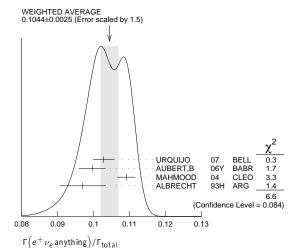
 $0.1028 \pm 0.0018 \pm 0.0024$

 0.1044 ± 0.0025 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram

| $0.0996 \pm 0.0019 \pm 0.0032$ | ² AUBERT,B | 06Y | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
|----------------------------------------|----------------------------|---------|------------|------------------------------------|
| $0.1091 \pm 0.0009 \pm 0.0024$ | ³ MAHMOOD | 04 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.097 \pm 0.005 \pm 0.004$ | ⁴ ALBRECHT | 93H | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| ullet $ullet$ We do not use the follow | wing data for avera | ges, fi | ts, limits | s, etc. • • • |
| $0.1085 \pm 0.0021 \pm 0.0036$ | ⁵ OKABE | 05 | BELL | Repl. by URQUIJO 07 |
| $0.1083 \pm 0.0016 \pm 0.0006$ | ⁶ AUBERT | 04x | BABR | Repl. by AUBERT,B 06Y |
| $0.1036 \pm 0.0006 \pm 0.0023$ | ⁷ AUBERT,B | 04A | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.1087 \pm 0.0018 \pm 0.0030$ | ⁸ AUBERT | 03 | BABR | Repl. by AUBERT 04x |
| $0.109 \pm 0.0012 \pm 0.0049$ | ⁹ ABE | 02Y | BELL | Repl. by OKABE 05 |
| $0.1049 \pm 0.0017 \pm 0.0043$ | ¹⁰ BARISH | 96B | CLE2 | Repl. by MAHMOOD 04 |
| $0.100 \pm 0.004 \pm 0.003$ | ¹¹ YA NA GISAWA | 91 | CSB2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.103 \pm 0.006 \pm 0.002$ | 12 ALBRECHT | 90H | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.117 \pm 0.004 \pm 0.010$ | ¹³ WACHS | 89 | CBAL | Direct e at $\Upsilon(4S)$ |
| $0.120 \pm 0.007 \pm 0.005$ | CHEN | 84 | CLEO | Direct e at $\Upsilon(4S)$ |
| $0.132 \pm 0.008 \pm 0.014$ | 14 KLOPEEN | 83B | CUSB | Direct e at $\Upsilon(4S)$ |

- 1 URQUIJO 07 report a measurement of (10.07 \pm 0.18 \pm 0.21)% for the partial branching fraction of $B\to e\nu_e X_c$ decay with electron energy above 0.6 GeV. We converted the result to $B\to e\nu_e X$ branching fraction.
- 2 The measurements are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame. The best precision on the ratio is achieved for a momentum threshold of 1.0 GeV: B($B^+
 ightarrow$ $e^+ \nu_e X$) / B($B^0 \rightarrow e^+ \nu_e X$) = 1.074 ± 0.041 ± 0.026.
- 3 Uses charge and angular correlations in $\varUpsilon(4S)$ events with a high-momentum lepton and
- All BRECHT 93H analysis performed using tagged semileptonic decays of the B. This technique is almost model independent for the lepton branching ratio.
- ⁵ The measurements are obtained for charged and neutral B mesons partial rates of semileptonic decay to electrons with momentum above 0.6 GeV/c in the B rest frame, and their ratio of B(B⁺ $\rightarrow e^+ \nu_e X)/B(B^0 \rightarrow e^+ \nu_e X) = 1.08 \pm 0.05 \pm 0.02$.
- 6 The semileptonic branching ratio, $|V_{cb}|$ and other heavy-quark parameters are determined from a simultaneous fit to moments of the hadronic-mass and lepton-energy dis-
- 7 Uses the high-momentum lepton tag method and requires the electron energy above 0.6
- 8 Uses the high-momentum lepton tag method. They also report $|V_{C\,D}|=0.0423$ \pm $0.0007(exp) \pm 0.0020(theo.)$
- 9 Uses the high-momentum lepton tag method. ABE 02Y also reports $|V_{C\,D}|=0.0408\pm0.0010(\exp)\pm0.0025(theo.)$. The second error is due to uncertainties of theoretical
- 10 BARISH 96B analysis performed using tagged semileptonic decays of the B. This technique is almost model independent for the lepton branching ratio.

- 11 YA NA GISAWA 91 also measures an average semileptonic branching ratio at the $\varUpsilon(5S)$ of 9.6–10.5% depending on assumptions about the relative production of different ${\cal B}$ meson species
- 12 ALBRECHT 90H uses the model of ALTARELLI 82 to correct over all lepton momenta. 0.099 \pm 0.006 is obtained using ISGUR 89B
- 13 Using data above p(e)=2.4 GeV, WACHS 89 determine $\sigma(B\to e\nu {\rm up})/\sigma(B\to e\nu {\rm charm})<0.065$ at 90% CL.
- ¹⁴ Ratio $\sigma(b \rightarrow e \nu up)/\sigma(b \rightarrow e \nu charm) < 0.055$ at CL = 90%



| $\Gamma(\overline{p}e^+\nu_e$ ar | $_{ m iything})/\Gamma_{ m total}$ | | | | | Γ, | 2/Γ |
|----------------------------------|------------------------------------|--------------------|-----------|---------|----------------------|----------------|-----|
| VALUE | | DO CUMENT ID | | TECN | COMMENT | | |
| <5.9 × 10 | 9 0 | ¹ ADAM | 03B | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |
| • • • We do | not use the followin | g data for average | es, fits, | limits, | etc. • • • | | |
| < 0.0016 | 90 | ALBRECHT | 90н | ARG | $e^+e^- \to$ | $\Upsilon(4S)$ | |
| ¹ Based on | V-A model. | | | | | | |

 $\Gamma \big(\mu^+ \nu_\mu \text{anything} \big) / \Gamma_{\text{total}}$ These branching fraction values are model dependent.

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DOCUMENT ID The data in this block is included in the average printed for a previous datablock

0.1072 ± 0.0013 OUR EVALUATION

• • • We do not use the following data for averages, fits, limits, etc. • • •

| $0.100 \ \pm 0.006 \ \pm 0.002$ | ¹ ALBRECHT | 90н | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
|---------------------------------|-----------------------|-----|------|----------------------|----------------|
| $0.108 \ \pm 0.006 \ \pm 0.01$ | CHEN | 84 | CLEO | Direct μ at | $\Upsilon(4S)$ |
| $0.112 \pm 0.009 \pm 0.01$ | LEV MA N | 84 | CUSB | Direct μ at | $\Upsilon(4S)$ |

 1 ALBRECHT 90H uses the model of ALTARELLI 82 to correct over all lepton momenta. 0.097 \pm 0.006 is obtained using ISGUR 89B.

$\Gamma(\ell^+ \nu_\ell \text{ a nything})/\Gamma_{\text{total}}$

 Γ_4/Γ

 Γ_3/Γ

These branching fraction values are model dependent.

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DO CUMENT ID TECN COMMENT

0.1072±0.0013 OUR EVALUATION

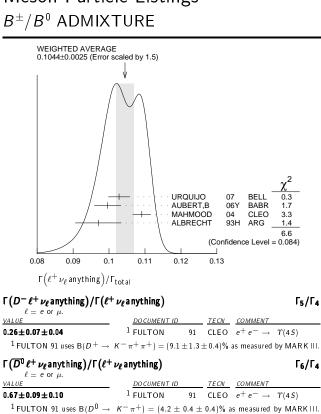
0.1044 ± 0.0025 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 1.5. See the ideogram below

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $0.108\ \pm0.002\ \pm0.0056$ ¹ HENDERSON 92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$

 1 HENDERSON 92 measurement employs e and μ . The systematic error contains 0.004 in quadrature from model dependence. The authors average a variation of the Isgur, Scora, Grinstein, and Wise model with that of the Altarelli-Cabibbo-Corbò-Maiani-Martinelli model for semileptonic decays to correct the acceptance.

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE



| $\ell = e \text{ or } \mu$ | - 2 7 6 / | | | | . 0, |
|----------------------------|---------------------|----|------|------------------------------|------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.67±0.09±0.10 | ¹ FULTON | 91 | CLEO | $e^+ e^- \rightarrow \gamma$ | (45) |

 $^1\, {\rm FULTON}$ 91 uses B(D $^0 \rightarrow \ \ K^-\, \pi^+) = (4.2 \pm 0.4 \pm 0.4)\%$ as measured by MARK III.

$\Gamma(\overline{D}\ell\nu_{\ell})/\Gamma(\ell^+\nu_{\ell} \text{anything})$ DOCUMENT ID TECN COMMENT $0.223 \pm 0.006 \pm 0.009$ ¹ AUBERT 10 BABR $e^+e^- \rightarrow \Upsilon(4S)$

¹Uses a fully reconstructed B meson as a tag on the recoil side.

| $\Gamma(D	au^+ u_	au)/\Gamma_{ m total}$ | | | | Г ₈ /Г |
|------------------------------------------|--------------|-------|-------------|-------------------|
| VALUE (units 10 ⁻²) | DO CUMENT ID | TE | ECN COMMENT | |
| 0.86+0.24+0.12 | 1 ALIBERT | OSN B | ABR a+a- | Y(45) |

 $^{
m 1}$ Uses a fully reconstructed B meson as a tag on the recoil side.

| $\Gamma(D^{*-}\ell^+ u_\ell$ anything)/ $\Gamma_{ m total}$ | | | | | ٦/و٦ |
|-------------------------------------------------------------|----------------------|---------|---------|---------------------------|------|
| VALUE (units 10 ⁻²) | DO CUMENT ID | | TECN | COMMENT | |
| $0.67 \pm 0.08 \pm 0.10$ | ABDALLAH | 04D | DLPH | $e^+ e^- \rightarrow Z^0$ | |
| | g data for averages, | , fits, | limits, | etc. • • • | |

 $0.6 \pm 0.3 \pm 0.1$ 1 BARISH 95 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 1 BARISH 95 use B($D^{0} \rightarrow \kappa^{-}$ $(\pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$ and $B(D^{*+} \rightarrow D^0 \pi^+)$ $= (68.1 \pm 1.0 \pm 1.3)\%$

 $\Gamma(D^{*0}\ell^+
u_\ell$ a nything)/ $\Gamma_{
m total}$ Γ_{10}/Γ VALUE (units 10^{-2}) DOCUMENT ID TECN COMMENT

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet¹ BARISH 95 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 1 BARISH 95 use B(D 0 \rightarrow $~K^{-}\,\pi^{+})=(3.91\pm0.08\pm0.17)\%,~B(D^{*+}\rightarrow~D^{0}\,\pi^{+})=(68.1\pm1.0\pm1.3)\%,~B(D^{*0}\rightarrow~D^{0}\,\pi^{0})=(63.6\pm2.3\pm3.3)\%.$

 $\Gamma(D^*\tau^+\nu_{ au})/\Gamma_{ ext{total}}$ Γ_{11}/Γ VALUE (units 10^{-2}) DOCUMENT ID TECN COMMENT ¹ AUBERT $1.62 \pm 0.31 \pm 0.11$ 08N BABR $e^+e^- \rightarrow \Upsilon(4S)$

 $^{
m 1}$ Uses a fully reconstructed $\it B$ meson as a tag on the recoil side. The results are normalized to the B^+ decay rate.

 $D^{**} \text{ stands for the sum of the } D(1\,{}^{1}\!P_{1}), \ D(1\,{}^{3}\!P_{0}), \ D(1\,{}^{3}\!P_{1}), \ D(1\,{}^{3}\!P_{2}), \ D(2\,{}^{1}\!S_{0}),$ and ${\it D}(2\,{}^1\!S_1)$ resonances. $\ell=e$ or μ , not sum over e and μ modes. CL% EVTS DO CUMENT ID TECN COMMENT 1 ALBRECHT 93 ARG e^{+} e^{-} $0.027 \pm 0.005 \pm 0.005$ 63

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet² BARISH 95 95 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$

 $^{
m 1}$ ALBRECHT 93 assumes the GISW model to correct for unseen modes. Using the BHKT model, the result becomes 0.023 \pm 0.006 \pm 0.004. Assumes B($D^{8+} \rightarrow D^0 \pi^+$) = 68.1%, B($D^0 \rightarrow K^- \pi^+$) = 3.65%, B($D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$) = 7.5%. We have taken their average e and μ value.

²BARISH 95 use $B(D^0 \rightarrow K^-\pi^+) = (3.91 \pm 0.08 \pm 0.17)\%$, assume all nonresonant channels are zero, and use GISW model for relative abundances of D^{**} states.

| $I(D_1(2420)\ell^*\nu_{\ell}a$ | nytning)/i total | | 113/1 |
|---------------------------------------|-------------------------------|-------------------------------|----------|
| VALUE | DO CUMENT ID | TECN COMMENT | |
| 0.0038±0.0013 OUR | AVERAGE Error includes so | cale factor of 2.4. | |
| 0.0033 ± 0.0006 | $^{ m 1}$ abazov | 050 D0 p p at 1.90 | |
| 0.0074 ± 0.0016 | ² BUSKULIC | 97B ALEP $e^+e^- \rightarrow$ | Z |
| ● ● We do not use | the following data for averag | es, fits, limits, etc. • • • | |
| seen | ³ BUSKULIC | 95B ALEP Repl. by | IIIC 97p |

¹ Assumes B($D_1 \to D^*\pi$) = 1, B($D_1 \to D^*\pi^{\pm}$) = 2/3, and B($b \to B$) =0.397. 2 BUSKULIC 97B assumes B(D1(2420) \to $D^*\pi)$ = 1, B(D1(2420) \to $D^*\pi^\pm)$ = 2/3, and B(b \to B) = 0.378 \pm 0.022.

 3 BUSKULIC 95B reports $f_B \times {\sf B}(B o \overline{D}_1(2420)^0 \ell^+ \nu_\ell$ anything) $\times {\sf B}(\overline{D}_1(2420)^0 o 2420)^0$ $\overline{D}^*(2010)^-\pi^+)=(2.04\pm0.58\pm0.34)10^{-3}$, where f_B is the production fraction for a single B charge state.

$\left[\Gamma(D\pi\ell^+\nu_\ell \text{anything}) + \Gamma(D^*\pi\ell^+\nu_\ell \text{anything})\right]/\Gamma_{\text{total}}$ Γ_{14}/Γ

DO CUMENT ID COMMENT 0.026 ±0.005 OUR AVERAGE Error includes scale factor of 1.5 $0.0340 \pm 0.0052 \pm 0.0032$ ¹ ABREU 00R DLPH e^+ ² BUSKULIC 97B ALEP $e^+e^- \rightarrow Z$

 $^{
m 1}$ Assumes no contribution from $B_{
m S}$ and b baryons. Further assumes contributions from single pion $(D\,\pi\,{\rm and}\,\,D^*\,\pi)$ states only, allowing isospin conservation to relate the relative π^0 and π^+ rates. ² BUSKULIC 97B assumes B($b \rightarrow B$) = 0.378 \pm 0.022 and uses isospin invariance by

assuming that all observed $D^0\pi^+$, $D^{*0}\pi^+$, $D^+\pi^-$, and $D^{*+}\pi^-$ are from D^{**} states. A correction has been applied to account for the production of B_b^0 and A_b^0 .

$\Gamma(D\pi\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{total}}$ Γ_{15}/Γ DOCUMENT ID VALUE TECN COMMENT 0.0154 ± 0.0061 ABREU 00R DLPH $e^+e^- \rightarrow Z$

 $\Gamma(D^*\pi\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{total}}$ Γ_{16}/Γ <u>VALUE</u> DOCUMENT ID TECN COMMENT

 0.0186 ± 0.0038 00R DLPH $e^+e^- \rightarrow Z$ ABREU

$\Gamma(\overline{D}_2^*(2460)\ell^+\nu_\ell \text{ a nything})/\Gamma_{\text{total}}$ Γ_{17}/Γ DOCUMENT ID TECN COMMENT 0.0044±0.0016 1 ABAZOV 050 D0 pp at 1.96 TeV • • • We do not use the following data for averages, fits, limits, etc. • • •

² BUSKULIC < 0.0065 95 97B ALEP $e^+e^- \rightarrow Z$ ³ BUSKULIC 95B ALEP $e^+e^ightarrow Z$

¹ Assumes B $(D_2^* \to D^* \pi^{\pm}) = 0.30 \pm 0.06$ and B $(b \to B) = 0.397$.

²A revised number based on BUSKULIC 97B which assumes B($D_2^*(2460) \rightarrow D^*\pi^{\pm}$) = 0.20 and B($b \rightarrow B$) = 0.378 \pm 0.022.

³BUSKULIC 95B reports $f_B \times \overline{B(B \to \overline{D}_2^*(2460)^0} \ell^+ \nu_\ell \text{ anything}) \times \overline{B(\overline{D}_2^*(2460)^0} \to \overline{D}_2^*(2460)^0$ $\overline{D}^*(2010)^-\pi^+) \stackrel{-}{\le} 0.81 \stackrel{-}{\times} 10^{-3}$ at CL=95%, where f_B is the production fraction for a single B charge state

$\Gamma(B \rightarrow \overline{D}_{2}^{*}(2460) \ell^{+} \nu_{\ell} anything) \times B(D_{2}^{*}(2460) \rightarrow D^{*-} \pi^{+})$

 $\overline{\Gamma(B \to \overline{D}_1(2420) \ell^+ \nu_\ell \, anything)} \times B(\overline{D}_1(2420) \to D^{*-} \pi^+)$ DOCUMENT ID $0.39 \pm 0.09 \pm 0.12$ ABAZOV 050 D0 $p\overline{p}$ at 1.96 TeV

$\Gamma \Big(D^{*-} \pi^+ \ell^+ \nu_\ell \text{ anything} \Big) / \Gamma_{\text{total}}$ Includes resonant and nonresonant contributions.

<u>VALUE</u> (units 10⁻³) DO CUMENT ID TECN COMMENT $^{
m 1}$ BUSKULIC 95B ALEP $e^+e^- o Z$

 1 BUSKULIC 95B reports $\mathit{f}_{B}\,\times\,\mathsf{B}(B\,\to\,\,\overline{D}^{*}(2010)^{-}\,\pi^{+}\,\ell^{+}\,\nu_{\ell}\,\mathsf{anything})\,=\,(\,3.7\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0\,\pm\,1.0$ $0.7)10^{-3}$. Above value assumes $f_B = 0.37 \pm 0.03$.

 Γ_{18}/Γ

$\Gamma(D_s^-\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{total}}$ Γ_{19}/Γ DOCUMENT ID TECN COMMENT CL% $< 7 \times 10^{-3}$ 1 ALBRECHT 93E ARG $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 90

 $^1\, {\rm ALBRECHT}$ 93E reports < 0.012 from a measurement of [$\Gamma \left(B \to \ D_{_S}^- \ell^+ \nu_\ell \, {\rm anything} \right)/$ $\Gamma_{
m total}] imes [{
m B}(D_{
m S}^+ o \phi \pi^+)]$ assuming ${
m B}(D_{
m S}^+ o \phi \pi^+) = 0.027$, which we rescale to our best value B($D_S^+ \rightarrow \phi \pi^+$) = 4.5 \times 10 $^{-2}$.

$\Gamma(D_s^-\ell^+\nu_\ell K^+ \text{ anything})/\Gamma_{\text{total}}$ Γ_{20}/Γ CL% VALUE DOCUMENT ID TECN COMMENT

<5 × 10⁻³ 90 ¹ ALBRECHT 93E ARG $e^+e^- \rightarrow \Upsilon(4S)$ ¹ALBRECHT reports < 0.008 from a measurement of $[\Gamma(B \rightarrow D_s^- \ell^+ \nu_\ell K^+ \text{ anything})/\Gamma_{\text{total}}] \times$

 $[B(D_S^+ \to \phi \pi^+)]$ assuming $B(D_S^+ \to \phi \pi^+) = 0.027$, which we rescale to our best value $B(D_s^+ \to \phi \pi^+) = 4.5 \times 10^{-2}$.

$\Gamma(D_s^-\ell^+\nu_\ell K^0 \text{ anything})/\Gamma_{\text{total}}$ Γ_{21}/Γ VALUE DOCUMENT ID TECN COMMENT

<7 × 10⁻³ $^{
m 1}$ ALBRECHT 90 93E ARG $e^+e^-
ightarrow \varUpsilon(4S)$ ¹ALBRECHT 93E reports < 0.012 a measurement of $[\Gamma(B \to D_S^- \ell^+ \nu_\ell K^0 \text{ anything})/\Gamma_{\text{total}}] \times [B(D_S^+ \to \phi \pi^+)]$ assuming B($D_s^+ \to \phi \pi^+$) = 0.027, which we rescale to our best value B($D_s^+ \to \phi \pi^+$) $= 4.5 \times 10^{-2}$

0.1061 + 0.0016 + 0.0006

$\Gamma(\ell^+ \nu_\ell \, charm)/\Gamma_{total}$ "OUR EVALUATION" is an average using rescaled values of the data listed below.

The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

0.1051±0.0013 OUR EVALUATION 0.1058±0.0015 OUR AVERAGE ¹ AUBERT $0.1064 \pm 0.0017 \pm 0.0006$ 10A BABR $e^+e^-
ightarrow \gamma(4S)$ ² URQUIJO 07 BELL $e^+e^- \rightarrow \Upsilon(4S)$ $0.1044 \pm 0.0019 \pm 0.0022$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

3 AUBERT 1 Obtained from a combined fit to the moments of observed spectra in inclusive B
ightharpoonup $X_{\mathcal{C}} \ell^+ \nu_{\ell}$ decay.

04x BABR Repl. by AUBERT 10A

- ² Measured the independent B^+ and B^0 partial branching fractions with electron energy
- above 0.4 GeV. 3 The semileptonic branching ratio, $|V_{Cb}|$ and other heavy-quark parameters are determined from a simultaneous fit to moments of the hadronic-mass and lepton-energy distribution.

aging/rescaling procedure takes into account correlations between the measurements.

| VALUE (units 10 ⁻³) | DO CUMENT ID | TE | CN COMMENT | r |
|-------------------------------------|------------------------|--------------|------------------------------------|--------------|
| 2.08 ±0.30 OUR EVALUAT | ON | | | |
| 2.33 ±0.22 OUR AVERAGE | | | | |
| $2.27 \pm 0.26 ^{+ 0.37}_{- 0.33}$ | ¹ AUBERT | 06н ВА | BR e ⁺ e ⁻ - | → Υ(4S) |
| $2.53 \pm 0.24 \pm 0.24$ | ² AUBERT,B | 05x BA | BR e+e | → Υ(4S) |
| $2.80 \pm 0.52 \pm 0.41$ | ³ LIMOSA NI | 05 BE | LL e^+e^- – | → Υ(4S) |
| $1.77 \pm 0.29 \pm 0.38$ | 4 BORNHEIM | 02 CL | E2 $e^{+}e^{-}$ - | → Υ(4S) |
| | wing data for avera | ges, fits, l | imits, etc. • • | • |
| $1.963\!\pm\!0.173\!\pm\!0.159$ | ⁵ URQUIJO | 10 BE | LL e ⁺ e ⁻ - | → Υ(4S) |
| | ⁶ AUBERT | 08AS BA | BR e ⁺ e ⁻ - | γ(4S) |
| $2.24 \pm 0.27 \pm 0.47$ | ^{7,8} AUBERT | 04ı BA | BR Repl. by | AUBERT,B 05X |

- 1 Obtained from the partial rate $\Delta B = (0.572 \pm 0.041 \pm 0.065) \times 10^{-3}$ for the electron momentum interval of 2.0-2.6 GeV/c based on BLNP method.
- 2 Determined from the partial rate $\Delta \vec{B} = (4.41 \pm 0.42 \pm 0.42) \times 10^{-4}$ measured for electron energy > 2 GeV and hadronic mass squared < 3.5 GeV², and calculated acceptance 0.174 in that region. The V_{ub} is measured as $(4.41\pm0.30^{+0.65}_{-0.47}\pm0.28)\times10^{-3}$.
- 3 Uses electrons in the momentum interval 1.9–2.6 GeV/c in the center-of-mass frame. The V_{ub} is found to be (5.08 \pm 0.47 $^+_{-0.48}$) \times 10 $^{-3}$.
- 4 BORNHEIM 02 uses the observed yield of leptons from semileptonic B decays in the end-point momentum interval 2.2–2.6 GeV/c with recent CLEO-2 data on $B\to X_S\gamma$. The V_{ub} is found to be (4.08 \pm 0.34 \pm 0.53) imes 10 $^{-3}$.
- 5 Uses a multivariate analysis method and requires lepton momentum in the B rest frame, $\mathbf{p}_l^{*B} > 1.0 \text{ GeV/c}.$
- $^6\,{\rm Me}_{\rm asures}$ several partial branching fractions in different phase space regions. The most precise result is obtained in the region for hadronic mass ${\rm M}_X < 1.55~{\rm GeV/c^2}$, and is $\Delta {\rm B} = (1.18 \pm 0.09 \pm 0.07) \times 10^{-3}$. The corresponding $|V_{ub}|$ from the BLNP method $\Delta B = (1.10 \pm 0.39 \pm 0.37) \times 10^{-3}$, where the last uncertainty comes from the theoretical prediction of the partial rate in the given phase-space region.
- ⁷ Used BaBar measurement of Semileptonic branching fraction B($B \to X \ell \nu_{\ell}$) = (10.87 \pm 0.18 ± 0.30)% to convert the ratio of rates to branching fraction.
- $^{8}\,\mathrm{The\;third\;error\;includes\;the\;systematics\;and\;theoretical\;errors\;summed\;in\;quadrature.}$

$\Gamma(X_{ij}\ell^+\nu_{\ell})/\Gamma(\ell^+\nu_{\ell} \text{ anything})$

 Γ_{23}/Γ_{4}

 ℓ denotes e or μ , not the sum. These experiments measure this ratio in very limited momentum intervals.

| VALUE (BIRES 10 | CL/0 LV13 | DOCUMENTID | | ILCIV | COMMENT |
|-----------------|----------------------|-----------------------|-----------|----------|------------------------------------|
| 2.06 ± 0.25 ± 0 |).42 | 1 AUBERT | 041 | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| • • • We do no | ot use the following | data for averages, fi | its, limi | ts, etc. | • • • |
| | | ² ALBRECHT | 94 c | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | 107 | | | CLE2 | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | 77 | ⁴ ALBRECHT | 91c | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | 41 | ⁵ ALBRECHT | 90 | ARG | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| | 76 | | 90 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| <4.0 | 90 | ⁷ BEHRENDS | 87 | CLEO | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| <4.0 | 90 | CHEN | 84 | CLEO | Direct e at $\Upsilon(4S)$ |
| < 5.5 | 90 | KLOPEEN | 83B | CUSB | Direct e at $\Upsilon(4S)$ |

- $^{
 m 1}$ The third error includes the systematics and theoretical errors summed in quadrature.
- ²ALBRECHT 94c find $\Gamma(b \rightarrow c)/\Gamma(b \rightarrow all) = 0.99 \pm 0.02 \pm 0.04$.
- 3 BARTELT 93B (CLEO II) measures an excess of 107 \pm 15 \pm 11 leptons in the lepton momentum interval 2.3–2.6 GeV/c which is attributed to $b\to~u\ell\nu_\ell$. This corresponds to a model-dependent partial branching ratio $\Delta B_{u\,b}$ between $(1.15\pm0.16\pm0.15)\times10^{-4}$, as evaluated using the KS model (KOERNER 88), and (1.54 \pm 0.22 \pm 0.20) imes 10^{-4} using the ACCMM model (ARTUSO 93). The corresponding values of $|V_{UB}|/|V_{CB}|$ are 0.056 \pm 0.006 and 0.076 \pm 0.008, respectively. ⁴ ALBRECHT 91c result supersedes ALBRECHT 90. Two events are fully reconstructed
- providing evidence for the $b \to u$ transition. Using the model of ALTARELLI 82, they obtain $|V_{ub}/V_{cb}| = 0.11 \pm 0.012$ from 77 leptons in the 2.3–2.6 GeV momentum range.

- 5 ALBRECHT 90 observes 41 \pm 10 excess e and μ (lepton) events in the momentum interval $\rho=2.3-2.6$ GeV signaling the presence of the $b \to u$ transition. The events correspond to a model-dependent measurement of $\left|V_{U\,D}/V_{C\,D}\right|=0.10\pm0.01$.
- 6 FULTON 90 observe 76 \pm 20 excess e and μ (lepton) events in the momentum interval p=2.4–2.6 GeV signaling the presence of the $b\to u$ transition. The average branching ratio, $(1.8\,\pm\,0.4\,\pm\,0.3)\,\times\,10^{-4}$, corresponds to a model-dependent measurement of approximately $|V_{ub}/V_{cb}|=0.1$ using B(b $\rightarrow c\ell\nu$) = 10.2 \pm 0.2 \pm 0.7%.
- 7 The quoted possible limits range from 0.018 to 0.04 for the ratio, depending on which model or momentum range is chosen. We select the most conservative limit they have calculated. This corresponds to a limit on $|v_{u\,b}|/|v_{c\,b}|<0.20$. While the endpoint technique employed is more robust than their previous results in CHEN 84, these results do not provide a numerical improvement in the limit.

$\Gamma(K^+\ell^+\nu_\ell \text{ anything})/\Gamma(\ell^+\nu_\ell \text{ anything})$

 Γ_{24}/Γ_4

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|-------------------|-----|------|-----------------------------------|
| 0.58 ±0.05 OUR AVERAGE | | | | |
| $0.594 \pm 0.021 \pm 0.056$ | ALBRECHT | 94c | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.54 \pm 0.07 \pm 0.06$ | ¹ ALAM | 87в | CLEO | $e^+e^- ightarrow \gamma(4S)$ |

 $^{
m 1}$ ALAM 87B measurement relies on lepton-kaon correlations.

$\Gamma(K^-\ell^+ u_\ell$ anything)/ $\Gamma(\ell^+ u_\ell$ anything)

 Γ_{25}/Γ_4

| ϵ denotes ϵ or μ , not the sum | 11. | | | | |
|------------------------------------------------------|-------------------|------|------|----------------------|-------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.092±0.035 OUR AVERAGE | | | | | |
| $0.086 \pm 0.011 \pm 0.044$ | ALBRECHT | 94 c | ARG | $e^+e^- \rightarrow$ | Y(45) |
| $0.10 \pm 0.05 \pm 0.02$ | ¹ ALAM | 87B | CLEO | $e^+e^- \rightarrow$ | Y(45) |

¹ ALAM 87B measurement relies on lepton-kaon correlations.

$\Gamma(K^0/\overline{K}^0\ell^+\nu_\ell$ anything)/ $\Gamma(\ell^+\nu_\ell$ anything)

 Γ_{26}/Γ_{4}

| aum. Sum over K°ar | nd Kostates | i, |
|--------------------|-------------|-----------------------------------|
| DO CUMENT ID | TECN | COMMENT |
| | | |
| | 94c ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ² ALAM | 87B CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ |
| | DOCUMENT ID | ¹ ALBRECHT 94c ARG |

- ¹ ALBRECHT 94c assume a K^0/\overline{K}^0 multiplicity twice that of K^0_S
- ²ALAM 87B measurement relies on lepton-kaon correlations.

$\langle n_c \rangle$

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|------------------------|--------------|-----------|----------------------|----------------|
| 1.10±0.05 | 1 GIBBONS | 97B | CLE2 | $e^+e^- \rightarrow$ | Y(45) |
| • • • We do not use the fol | lowing data for averag | es, fits, | , limits, | etc. • • • | |
| $0.98 \pm 0.16 \pm 0.12$ | ² ALAM | 8 7 B | CLEO | $e^+e^- \to$ | $\Upsilon(4S)$ |

- ¹ GIBBONS 97B from charm counting using B($D_s^+ \to \phi \pi$) = 0.036 \pm 0.009 and B($\Lambda_c^+ \to \phi \pi$) $pK^{-}\pi^{+}) = 0.044 \pm 0.006.$
- From the difference between K^- and K^+ widths. ALAM 87B measurement relies on lepton-kaon correlations. It does not consider the possibility of $B\overline{B}$ mixing. We have thus removed it from the average.

$\Gamma(D^{\pm} \text{ anything})/\Gamma_{\text{total}}$

 Γ_{27}/Γ

| VALUE | EVIS DOCUMENT ID | | CN COMM | ENI | |
|-----------------------------|-----------------------------|----------|----------------|-----------|--|
| 0.237±0.013 OUR AV | ERAGE | | | | |
| $0.237 \pm 0.013 \pm 0.005$ | ¹ GIBBONS | | | | |
| $0.25 \pm 0.04 \pm 0.01$ | ² BORTOLETTO | | | | |
| $0.229 \pm 0.053 \pm 0.005$ | ³ ALBRECHT | 91 H A F | $RG = e^+e^-$ | - → Υ(4S) | |
| • • • We do not use t | he following data for aver- | ges, fit | s, limits, etc | . • • • | |

 $0.208\pm0.049\pm0.004$ 20k 4 BORTOLETTO87 CLEO Sup. by BORTOLETTO 92

- 1 GIBBONS 97B reports $[\Gamma(B\rightarrow~D^{\pm}\,{\rm anything})/\Gamma_{\rm total}]\,\times\,[B(D^{+}\rightarrow~K^{-}\,2\pi^{+})]\,=\,$ 0.0216 \pm 0.0008 \pm 0.00082 which we divide by our best value B($D^+
 ightarrow K^- 2\pi^+$) =
- $(9.13\pm0.19)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 2 BORTOLETTO 92 reports $[\Gamma(B\to D^\pm {\rm anything})/\Gamma_{{\rm total}}] \times [B(D^+\to K^-2\pi^+)] =$
- 0.0226 \pm 0.0030 \pm 0.0018 which we divide by our best value B($D^+ \rightarrow K^- 2\pi^+$) = (9.13 \pm 0.19) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. 3 ALBRECHT 91H reports [$\Gamma(B \rightarrow D^\pm \text{anything})/\Gamma_{\text{total}}$] \times [B($D^+ \rightarrow K^- 2\pi^+$)] =
- $0.0209\pm0.0027\pm0.0040$ which we divide by our best value B($D^+\to K^-2\pi^+$) = $(9.13\pm0.19)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- ⁴ BORTOLETTO 87 reports $[\Gamma(B \rightarrow D^{\pm} \text{ anything})/\Gamma_{\text{total}}] \times [B(D^{+} \rightarrow K^{-}2\pi^{+})]$ = 0.019 \pm 0.004 \pm 0.002 which we divide by our best value $B(D^+ \to K^- 2\pi^+) = (9.13 \pm 0.19) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D^0/\overline{D}^0 \text{ a nything})/\Gamma_{\text{total}}$

 Γ_{28}/Γ

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|----------|-----------------------|---------|-------------|-------------------------------------------|
| 0.627±0.029 OUR AVI | ERAGE | Error includes | scale f | factor of | $1.3. \ \text{See the ideogram below}.$ |
| $0.648 \pm 0.025 {}^{+ 0.007}_{- 0.008}$ | | $^{ m 1}$ GIBBONS | 97в | CLE2 | $e^+e^- ightarrow \gamma(4S)$ |
| $0.60 \pm 0.05 \pm 0.01$ | | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.50 \ \pm 0.08 \ \pm 0.01$ | | ³ ALBRECHT | 91 H | ARG | $e^+e^- \rightarrow \Upsilon(4S)$ |
| ● ● We do not use t | he follo | wing data for av | erages, | , fits, lim | nits, etc. • • • |
| $0.54 \pm 0.07 \pm 0.01$ | | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.62 \ \pm 0.19 \ \pm 0.01$ | | ⁵ GREEN | 83 | CLEO | Repl. by BORTOLETTO 87 |

Meson Particle Listings B^{\pm}/B^{0} ADMIXTURE

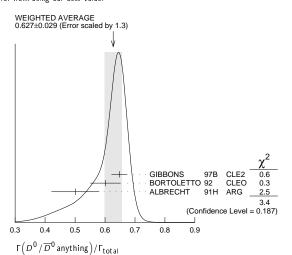
 1 GIBBONS 97B reports $[\Gamma(B\to D^0/\overline{D}^0\,\text{anything})/\Gamma_{total}]\times [B(D^0\to K^-\pi^+)]=0.0251\pm0.0006\pm0.00075$ which we divide by our best value $B(D^0\to K^-\pi^+)=(3.88\pm0.05)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. 2 BORTOLETTO 92 reports $[\Gamma(B\to D^0/\overline{D}^0\,\text{anything})/\Gamma_{total}]\times [B(D^0\to K^-\pi^+)]$

^2BORTOLETTO 92 reports $[\Gamma(B \to D^0/\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}] \times [B(D^0 \to K^-\pi^+)] = 0.0233 \pm 0.0012 \pm 0.0014$ which we divide by our best value $B(D^0 \to K^-\pi^+) = (3.88 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. ^3ALBRECHT 91H reports $[\Gamma(B \to D^0/\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}] \times [B(D^0 \to K^-\pi^+)]$

³ALBRECHT 91H reports $[\Gamma(B \to D^0/\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}] \times [B(D^0 \to K^-\pi^+)] = 0.0194 \pm 0.0015 \pm 0.0025$ which we divide by our best value $B(D^0 \to K^-\pi^+) = (3.88 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

the systematic error from using our best value. 4 BORTOLETTO 87 reports $[\Gamma(B \to D^0/\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}] \times [B(D^0 \to K^-\pi^+)]$ = 0.0210 ± 0.0015 ± 0.0021 which we divide by our best value $B(D^0 \to K^-\pi^+) = (3.88 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

the systematic error from using our best value. ⁵ GREEN 83 reports [$\Gamma(B \to D^0/\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}$] × [$B(D^0 \to K^-\pi^+)$] = 0.024 ± 0.006 ± 0.004 which we divide by our best value $B(D^0 \to K^-\pi^+)$ = (3.88 ± 0.05) × 10^{-2} . Our first error is their experiment's error and our second error is the systematic error from using our best value.



| $\Gamma(D^*(2010)^{\pm} \text{ anything})/\Gamma_{\text{total}}$ | | | | | | | |
|------------------------------------------------------------------|--------|--------------|-----|------|----------|--|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| 0.225 ±0.015 OUR A | VERAGE | | | | | | |
| 0.047 0.010 0.01 | | 1 CIDDONG | 075 | CLEO | -+ x(4C) | | |

• • • We do not use the following data for averages, fits, limits, etc. • •

0.27 ± 0.06 $^{+0.08}_{-0.06}$ 510 6 CSORNA 85 CLEO Repl. by BORTOLETTO 87

 1 GIBBONS 97B reports B($B\to D^*(2010)^+$ anything) = 0.239 \pm 0.015 \pm 0.014 \pm 0.009 using CLEO measured D and D^* branching fractions. We rescale to our PDG 96 values of D and D^* branching ratios. Our first error is their experiment's error and our second error is the systematic error from using our best value.

²ALBRECHT 96D reports $B(B\to D^*(2010)^+$ anything) 0.196 ± 0.019 using CLEO measured $B(D^*(2010)^+\to D^0\pi^+)=0.681\pm0.01\pm0.013,\ B(D^0\to K^-\pi^+)=0.0401\pm0.0014,\ B(D^0\to K^-\pi^+\pi^+\pi^-)=0.081\pm0.005$., We rescale to our PDG 96 values of D and D^* branching ratios. Our first error is their experiment's error and our second error is the systematic error from using our best value.

second error is the systematic error from using our best value. ³ BORTOLETTO 92 reports B($B \to D^*(2010)^+$ anything) = 0.25 \pm 0.03 \pm 0.04 using MARKII B($D^*(2010)^+ \to D^0\pi^+$) = 0.57 \pm 0.06 and B($D^0 \to K^-\pi^+$) = 0.042 \pm 0.008. We rescale to our PDG 96 values of D and D^* branching ratios. Our first error is their experiment's error and our second error is the systematic error from using our best value.

4 ALBRECHT 91H reports 0.348 \pm 0.060 \pm 0.035 from a measurement of [$\Gamma(B \to D^*(2010)^\pm \text{anything})/\Gamma_{\text{total}}$] \times [$B(D^*(2010)^+ \to D^0\pi^+)$] assuming $B(D^*(2010)^+ \to D^0\pi^+)$ = 0.55 \pm 0.04, which we rescale to our best value $B(D^*(2010)^+ \to D^0\pi^+)$ = (67.7 \pm 0.5) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value. Uses the PDG 90 $B(D^0 \to K^-\pi^+)$ = 0.0371 \pm 0.0025.

 5 BORTOLETTO 87 uses old MARK III (BALTRUSAITIS 86E) branching ratios B($D^0\to K^-\pi^+)=0.056\pm0.004\pm0.003$ and also assumes B($D^*(2010)^+\to D^0\pi^+)=0.60^{+0.08}_{-0.15}$. The product branching ratio for B($B\to D^*(2010)^+)$ B($D^*(2010)^+\to D^0\pi^+)$ is $0.13\pm0.02\pm0.012$. Superseded by BORTOLETTO 92.

 6 V-A momentum spectrum used to extrapolate below p=1 GeV. We correct the value assuming B($D^0\to K^-\pi^+)=0.042\pm0.006$ and B($D^{*+}\to D^0\pi^+)=0.6\pm0.08$. The product branching fraction is B($B\to D^{*+}X$)·B($D^{*+}\to \pi^+D^0$)·B($D^0\to K^-\pi^+$) = (68 \pm 15 \pm 9) \times 10 $^{-4}$.

| $\Gamma(D^*(2007)^0 \text{ anything})/\Gamma_{tot}$ | tal | | | | Г30/Г |
|-----------------------------------------------------|-------------------|-----|------|----------------------|-------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.260 \pm 0.023 \pm 0.015$ | $^{ m 1}$ GIBBONS | 97в | CLE2 | $e^+e^- \rightarrow$ | Y(45) |

¹ GIBBONS 97B reports B($B \to D^*(2007)^0$ anything) 0.247 \pm 0.012 \pm 0.018 \pm 0.018 using CLEO measured D and D^* branching fractions. We rescale to our PDG 96 values of D and D^* branching ratios. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(D_s^{\pm} \text{ anything})/\Gamma$ | total | | | | Г ₃₁ /Г |
|---------------------------------------------|--------|-------------|------|---------|--------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 0.083 ± 0.008 OUR A | VERAGE | · · | | | |

 1 ARTUSO 05B reports 0.0905 \pm 0.0025 \pm 0.0140 from a measurement of $[\Gamma(B\to D_s^\pm \, {\rm anything})/\Gamma_{\rm total}] \times [B(D_s^+\to \phi\pi^+)]$ assuming $B(D_s^+\to \phi\pi^+)=(4.4\pm0.5)\times 10^{-2}$, which we rescale to our best value $B(D_s^+\to \phi\pi^+)=(4.5\pm0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 2 AUBERT 02g reports $[\Gamma(B\to D_s^\pm \text{ anything})/\Gamma_{\text{total}}] \times [B(D_s^+\to \phi\pi^+)] = 0.00393 \pm 0.00007 \pm 0.00021$ which we divide by our best value $B(D_s^+\to \phi\pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 3 ALBRECHT 92g reports [$\Gamma(B \to D_S^\pm \, anything)/\Gamma_{total}] \times [B(D_S^+ \to \phi \pi^+)] = 0.00292 \pm 0.00039 \pm 0.00031$ which we divide by our best value $B(D_S^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁴ BORTOLETTO 90 reports $[\Gamma(B\to D_s^\pm \text{ anything})/\Gamma_{\text{total}}] \times [B(D_s^+\to \phi\pi^+)] = 0.00306 \pm 0.00047$ which we divide by our best value $B(D_s^+\to \phi\pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁵ HAAS 86 reports $[\Gamma(B \to D_s^\pm \text{anything})/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi \pi^+)] = 0.0038 \pm 0.0010$ which we divide by our best value $B(D_s^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $64 \pm 22\%$ decays are 2-body. ⁶ GIBAUT 96 reports 0.1211 \pm 0.0039 \pm 0.0088 from a measurement of $[\Gamma(B \to 0.0039 \pm 0.0088)]$

⁶ GIBAUT 96 reports $0.1211 \pm 0.0039 \pm 0.0088$ from a measurement of $[\Gamma(B \to D_s^\pm \text{ anything})/\Gamma_{\text{total}}] \times [B(D_s^+ \to \phi\pi^+)]$ assuming $B(D_s^+ \to \phi\pi^+) = 0.035$, which we rescale to our best value $B(D_s^+ \to \phi\pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value

 7 ALBRECHT 87H reports [\Gamma ($B\to D_S^\pm$ anything)/ $\Gamma_{\rm total}]\times [B(D_S^+\to\phi\pi^+)]=0.0042\pm0.0009\pm0.0006$ which we divide by our best value $B(D_S^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. 46 \pm 16% of $B\to D_S$ X decays are 2-body. Superseded by ALBRECHT 92G.

 1 AUBERT 02g reports $[\Gamma(B\to D_S^{*\pm} \, {\rm anything})/\Gamma_{\rm total}] \times [B(D_S^+ \to \phi \pi^+)] = 0.00284 \pm 0.00029 \pm 0.00025$ which we divide by our best value $B(D_S^+ \to \phi \pi^+) = (4.5 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D_s^{*\pm}\overline{D}^{(*)})/\Gamma(D_s^{*\pm}$ a nything) Γ_{33}/Γ_{32}

<u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> **0.533\pm0.037\pm0.037 AUBERT 02G BABR e^+e^- \rightarrow r(4S)**

¹ The product branching ratio for B(B $\to \overline{D}D_{S0}(2317)^+) \times B(D_{S0}(2317)^+ \to D_S\pi^0)$ is measured to be $(8.5 + \frac{2.1}{1.9} \pm 2.6) \times 10^{-4}$.

$\Gamma(\overline{D}D_{sJ}(2457))/\Gamma_{total}$ ALUE DOCUMENT ID TECN COMMENT

 $D_s^{*+}\pi^0, D_s^+\gamma)$ are measured to be $(17.8^{+}_{-3.9}^{+4.5} \pm 5.3) \times 10^{-4}$ and $(6.7^{+1.3}_{-1.2} \pm 2.0) \times 10^{-4}$, respectively.

 $\frac{\left[\Gamma\left(D^{(*)}\overline{D^{(*)}}K^{0}\right) + \Gamma\left(D^{(*)}\overline{D^{(*)}}K^{\pm}\right)\right]/\Gamma_{\text{total}}}{\frac{DOCUMENT ID}{1}} \underbrace{\frac{TECN}{TECN}} \underbrace{\frac{COMMENT}{COMMENT}} \Gamma36/\Gamma$ $0.071 \pm \frac{0.025}{0.025} \pm \frac{0.010}{0.000}$ $1 \text{ BARATE} \qquad 98Q \quad \text{ALEP} \quad e^{+}e^{-} \rightarrow Z$

 $^{^{}m 1}$ The systematic error includes the uncertainties due to the charm branching ratios.

 3 BALEST 95s assume $6(\chi_{C1}(IP)\to J/\psi(1S)\,\gamma)=(27.3\pm1.6)\times10^{-2}$, the PDG 1994 value. Fit to ψ -photon invariant mass distribution allows for a $\chi_{C1}(IP)$ and a $\chi_{C2}(IP)$

 $^4 \, {\rm ALBRECHT}$ 92E assumes no $\chi_{{\cal C}2}(1P)$ production.

 $1.4 \begin{array}{c} +0.6 \\ -0.5 \end{array}$

 $1.1 \quad \pm 0.21 \ \pm 0.23$

7

46

⁷HAAS

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| $\Gamma(b \to c \overline{c} s) / \Gamma_{\text{tot}}$ | ıl | | | Г ₃₇ /Г | ¹ AUBERT 03F also reports the momentum distribution and helicity of $J/\psi \to \ell^+\ell^-$ in |
|--------------------------------------------------------------------|-------------------------|------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | | DOCUMENT ID | TECN COMMENT | 2(- 5) | the $~\Upsilon(4S)$ center-of-mass frame. 2 MASCHMANN 90 reports $(1.12\pm0.33\pm0.25)\times10^{-2}$ from a measurement of [$\Gamma(B-1)$] |
| 0.219±0.037 | | | CLE2 $e^+e^- \rightarrow \gamma$ | (45) | $J/\psi(1S)$ anything) $/\Gamma_{total}] \times [B(J/\psi(1S) \to e^+e^-)]$ assuming $B(J/\psi(1S) \to e^+e^-)$ |
| ¹ COAN 98 uses <i>D</i> - | -ℓ correlatior | 1. | | | = 0.069 \pm 0.009, which we rescale to our best value B($J/\psi(1S) \rightarrow e^+e^-$) = (5.94 \pm |
| $\Gamma(D_s^{(*)}\overline{D}^{(*)})/\Gamma(s)$ | D_a^\pm a nythir | ng) | | Γ_{38}/Γ_{31} | $0.06) 	imes 10^{-2}$. Our first error is their experiment's error and our second error is the |
| Sum over mode | | • | | | systematic error from using our best value. |
| 0.469±0.017 OUR A | VERAGE | DO CUMENT ID | TECN COMMENT | | ³ ALBRECHT 87D reports $(1.07 \pm 0.16 \pm 0.22) \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.07)] \times 10^{-2}$ from a measurement o |
| $0.464 \pm 0.013 \pm 0.015$ | | AUBERT 02G | BABR $e^+e^- \rightarrow \gamma$ | (45) | $J/\psi(1S)$ anything) $/\Gamma_{\text{total}}] \times [B(J/\psi(1S) \to e^+ e^-)]$ assuming $B(J/\psi(1S) \to e^+ e^-)$ = 0.069 \pm 0.009, which we rescale to our best value $B(J/\psi(1S) \to e^+ e^-)$ = (5.94 \pm |
| $0.56 \begin{array}{l} +0.21 & +0.09 \\ -0.15 & -0.08 \end{array}$ | | ¹ BARATE 980 | ALEP $e^+e^- \rightarrow Z$ | | $0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is th |
| $0.457 \pm 0.019 \pm 0.037$ | | • | CLE2 $e^+e^- \rightarrow \gamma$ | | systematic error from using our best value. ALBRECHT 87D find the branching ratio fo |
| $0.437 \pm 0.019 \pm 0.037$ $0.58 \pm 0.07 \pm 0.09$ | | | ARG $e^+e^- \rightarrow \gamma$ | · / | J/ψ not from $\psi(2S)$ to be 0.0081 \pm 0.0023. |
| 0.56 ±0.10 | | | CLEO $e^+e^- \rightarrow \gamma$ | | ⁴ ALAM 86 reports $(1.09 \pm 0.16 \pm 0.21) \times 10^{-2}$ from a measurement of $[\Gamma(B - 1.01)] \times 10^{-2}$ |
| | asures R/R | $\rightarrow D_S(*)\overline{D}(*) = 0.05$ | 6 + 0.021 + 0.009 + 0. | 019 011, where | $J/\psi(1S)$ anything)/ Γ_{total}] \times [B($J/\psi(1S) \rightarrow \mu^+\mu^-$)] assuming B($J/\psi(1S) \rightarrow \mu^+\mu^-$) |
| the third error re | sults from t | he uncertainty on the dif | — 0.015 — 0.008 — 0. Iferent D branching ra | 011, where atios and is | $\mu^+\mu^-)=0.074\pm0.012$, which we rescale to our best value B($J/\psi(1S)\to\mu^+\mu^-=(5.93\pm0.06)\times10^{-2}$. Our first error is their experiment's error and our second error |
| | | on B($D_s^+ \rightarrow \phi \pi^+$). We | | | is the systematic error from using our best value. |
| | | anything)= 0.1 ± 0.025 . | ` , | | 5 BALEST 95B reports $(1.12\pm0.04\pm0.06)	imes10^{-2}$ from a measurement of [Г $(B$ – |
| F (D* D* (0010)+) | /= | | | F /F | $J/\psi(1S)$ anything) $/\Gamma_{	ext{total}}] 	imes [B(J/\psi(1S) ightarrow e^+ e^-)]$ assuming $B(J/\psi(1S) ightarrow e^+ e^-)$ |
| $\Gamma(D^*D^*(2010)^{\pm})$ | / I total | | | Г39/Г | = 0.0599 \pm 0.0025, which we rescale to our best value B($J/\psi(1S) ightarrow e^+e^-$) = |
| VALUE | <u>CL%</u> | | TECN COMMENT | | $(5.94 \pm 0.06) \times 10^{-2}$. Our first error is their experiment's error and our second error is |
| $< 5.9 \times 10^{-3}$ | 90 | BARATE 98Q | ALEP $e^+e^- \rightarrow Z$ | | the systematic error from using our best value. They measure $J/\psi(1S) \rightarrow e^+e^-$ and |
| $[\Gamma(DD^*(2010)^{\pm})$ | + Γ(D* D | ±)]/Γ _{total} | | Γ_{40}/Γ | $\mu^+\mu^-$ and use PDG 1994 values for the branching fractions. The rescaling is the sam for either mode so we use e^+e^- . |
| VALUE | | | TECN COMMENT | | ⁶ Statistical and systematic errors were added in quadrature. ALBRECHT 85H also repor |
| <5.5 × 10 ⁻³ | 90 | | ALEP $e^+e^- \rightarrow Z$ | | a CL $=$ 90% limit of 0.007 for $B ightarrow J/\psi(1S)+$ X where m_{X} $<$ 1 GeV. |
| | | • | | | ⁷ Dimuon and dielectron events used. |
| $\Gamma(DD^{\pm})/\Gamma_{\text{total}}$ | | | | Γ_{41}/Γ | $\Gamma(J/\psi(1S))$ (direct) anything) Γ_{total} Γ_{47}/Γ_{47} |
| VALUE | <u>CL%</u> | | TECN COMMENT | | VALUE <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| $< 3.1 \times 10^{-3}$ | 90 | BARATE 98Q | ALEP $e^+e^- \rightarrow Z$ | | 0.0078 ±0.0004 OUR AVERAGE Error includes scale factor of 1.1. |
| $\Gamma(D_s^{(*)}\pm \overline{D}^{(*)}X)$ | nπ±1)/Γ. | -4-1 | | Γ_{42}/Γ | $0.00740 \pm 0.00023 \pm 0.00043$ |
| VALUE | /// | | TECN COMMENT | .427. | $0.00813 \pm 0.00017 \pm 0.00037$ 2 ANDERSON 02 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| | | | ALEP $e^+e^- \rightarrow Z$ | - | _ |
| $\substack{0.094 + 0.040 + 0.034 \\ - 0.031 - 0.024}$ | | - BARAIE 98Q | ALEP e e - Z | | $0.0080~\pm 0.0008$ 3 BALEST 95B CLE2 $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| ¹ The systematic er | ror includes | the uncertainties due to t | the charm branching (| ratios. | 1_2 AUBERT 03F also reports the helicity of $J/\psi 	o \ell^+\ell^-$ produced directly in B decay. |
| $\Gamma(D^*(2010)\gamma)/\Gamma_{to}$ | | | | г /г | 2 Also reports the measurement of $J/\psi ightarrow \ell^+ \ell^-$ polarization produced directly from decay. |
| $I(D, (2010)\lambda)/I^{4}$ | otal | DOCUMENT ID | TECN COMMENT | Г43/Г | BALEST 95B assume PDG 1994 values for sub-mode branching ratios. $J/\psi(1S)$ meson |
| <1.1 × 10 ⁻³ | 90 | | CBAL $e^+e^- \rightarrow \gamma$ | 2(45) | are reconstructed in $J/\psi(1S) \to e^+e^-$ and $J/\psi(1S) \to \mu^+\mu^-$. The $B \to J/\psi(1S)$ |
| _ | | | | . , | branching ratio contains $J/\psi(1S)$ mesons directly from B decays and also from feeddow |
| | | inclusive process $B(b \rightarrow 02-2045 \text{ MeV}, \text{independent})$ | | | through $\psi(2S)\to J/\psi(1S)$, $\chi_{C1}(1P)\to J/\psi(1S)$, or $\chi_{C2}(1P)\to J/\psi(1S)$. Usin the measured inclusive rates, BALEST 95B corrects for the feeddown and finds the $B-$ |
| hadronization. | | | | | $J/\psi(1S)$ (direct) X branching ratio. |
| Γ(D+π- D*+π- | D+ o- | $D_s^{*+} ho^-$, $D_s^+\pi^0$, D_s^{*-} | + π ⁰ D+ π D*+ τ | D+ a0 | $\Gamma(\psi(2S))$ anything) Γ_{total} |
| | | | x, D_s, η, D_s, η | | $\Gamma(\psi(2S))$ anything)/ $\Gamma_{	ext{total}}$ value evts document id tech comment |
| $D_s^{*+} \rho^0$, $D_s^+ \omega$, D_s^0 Sum over mode | s Θ)/Itot | al | | Γ ₄₄ /Γ | 0.00307±0.00021 OUR AVERAGE |
| VALUE | <u>CL%</u> | DO CUMENT ID | TECN COMMENT | | $0.00297\pm0.00020\pm0.00020$ AUBERT 03F BABR $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| $<4 \times 10^{-4}$ | 90 | ¹ ALEXANDER 93B | CLE2 $e^+ e^- \rightarrow \gamma$ | (45) | $0.00316\pm0.00014\pm0.00028$ 1 ANDERSON 02 CLE2 $e^+e^- ightarrow$ $\varUpsilon(4S)$ |
| ¹ ALEXANDER 93i | B reports < | 4.8×10^{-4} from a mea | asurement of $\Gamma(B -$ | $D^+\pi^-$ | 0.0046 \pm 0.0017 \pm 0.0011 8 ALBRECHT 87D ARG $e^+e^- ightarrow \varUpsilon(4S)$ |
| | | , $D_s^+ \pi^0$, $D_s^{*+} \pi^0$, D_s^- | | | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| | | | | | 0.0034 \pm 0.0004 \pm 0.0003 240 ² BALEST 95B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| $D_s \omega, D_s \omega)/1$ | totall × [| $B(D_s^+ \to \phi \pi^+)]$ assum | $\log B(D_s \rightarrow \phi \pi)$ |) = 0.037, | 1 Also reports the measurement of $\psi(2S) 	o \ell^+\ell^-$ polarization produced directly from |
| which we rescale t | o our best v | value B($D_s^+ \rightarrow \phi \pi^+$) = | 4.5 × 10 2. This bran | iching ratio | B decay. |
| limit provides a m | iodel-depend | ent upper limit $ V_{ub} / V_{ub} $ | ⁄ _{C b} < 0.16 at CL=9 | 0%. | ² BALEST 95B assume PDG 1994 values for sub mode branching ratios. They find B($B = \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times \frac{1}{2}(35) \times $ |
| $\Gamma(D_{s1}(2536)^{+} \text{ any}$ | thing)/[| ıtal | | Γ ₄₅ /Γ | $\psi(25)$ X, $\psi(25) \rightarrow \ell^+\ell^-) = 0.30 \pm 0.05 \pm 0.04$ and B($B \rightarrow \psi(25)$ X, $\psi(25) - J/\psi(15) \pi^+\pi^-) = 0.37 \pm 0.05 \pm 0.05$. Weighted average is quoted for B($B \rightarrow \psi(25)$ X) |
| | | P-wave D_S^+ meson with . | $J^{P} = 1^{+}$ | | |
| VALUE VALUE | CL% | | | | $\Gamma(\chi_{c1}(1P) \text{ a nything})/\Gamma_{	ext{total}}$ $\Gamma_{49}/\Gamma_{	ext{total}}$ |
| <0.0095 | 90 | ¹ BISHAI 98 | $\begin{array}{ccc} \underline{\textit{TECN}} & \underline{\textit{COMMENT}} \\ \text{CLE2} & e^+ e^- \rightarrow & \varUpsilon \end{array}$ | (4.5) | VALUEEVTS DOCUMENT ID TECN COMMENT |
| | | | | | 0.00386±0.00027 OUR AVERAGE |
| Assuming racionz | ation, the de | ecay constant $f_{D_{s1}^+}$ is at b | cast a factor of 2.5 th | nes smaller | 0.00367 \pm 0.00035 \pm 0.00044 AUBERT 03F BABR $e^+e^- \rightarrow \Upsilon(4S)$ 0.00363 \pm 0.00022 \pm 0.00034 ¹ ABE 02L BELL $e^+e^- \rightarrow \Upsilon(4S)$ |
| than $f_{D_s^+}$. | | | | | $0.00363 \pm 0.00022 \pm 0.00034$ |
| , | | | | | • • • We do not use the following data for averages, fits, limits, etc. • • |
| $\Gamma(J/\psi(1S))$ anythin | $_{ig})/\Gamma_{total}$ | | | Γ ₄₆ /Γ | $0.00329\pm0.00035\pm0.00014$ 2 CHEN 01 CLE2 $e^+e^- ightarrow 	au(45)$ |
| VALUE (units 10 ⁻²) | EVTS | | TECN COMMENT | | $0.00329 \pm 0.00035 \pm 0.00014$ CHEN 01 CLE2 $e^+e^- \rightarrow I(45)$ 0.0040 $\pm 0.0006 \pm 0.0004$ 112 3 BALEST 95B CLE2 Repl. by CHEN 01 |
| 1.094±0.032 OUR A | VERAGE E | error includes scale factor | | _ | $0.0105 \pm 0.0035 \pm 0.0025$ 4 ALBRECHT 92E ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| $1.057 \pm 0.012 \pm 0.040$ | | | BABR $e^+e^- \rightarrow \gamma$ | | 1 ABE 02L uses PDG 01 values for B $(J/\psi(1S) ightarrow \ell^+\ell^-)$ and B $(\chi_{c1,c2} ightarrow J/\psi(1S) \gamma_{c2})$ |
| $1.121 \pm 0.013 \pm 0.042$ | 67 | | CLE2 $e^+e^- \rightarrow r_0$ | · , | ² CHEN 01 reports 0.00414 \pm 0.00031 \pm 0.00040 from a measurement of $\Gamma(B-C)$ |
| $1.30 \pm 0.45 \pm 0.01$ | 27 | | CBAL $e^+e^- \rightarrow \Upsilon_1$ | | |
| $1.24 \pm 0.27 \pm 0.01$ | 120 | ³ ALBRECHT 87D A ⁴ ALAM 86 0 | | | $\chi_{C1}(1P)$ anything) $/\Gamma_{total}] \times [B(\chi_{C1}(1P) 	o 	\gamma J/\psi(1S))]$ assuming $B(\chi_{C1}(1P) 	o 	\gamma J/\psi(1S))] = 0.273 \pm 0.016$, which we rescale to our best value $B(\chi_{C1}(1P) 	o 	au)$ |
| 1.36 ± 0.24 ± 0.01 | 52 the followin | g data for averages, fits, | CLEO $e^+e^- \rightarrow r_0$ | (43) | $\gamma J/\psi(1S)) = (34.4 \pm 1.5) \times 10^{-2}$. Our first error is their experiment's error and our |
| | | - | | (46) | $\gamma J/\psi(1S))=(34.4\pm1.5)	imes10^{-2}$. Our first error is their experiment's error and ou second error is the systematic error from using our best value. Assumes equal productio |
| $1.13 \pm 0.06 \pm 0.01$ $1.4 + 0.6$ | 1489 | _ | CLE2 $e^+e^- \rightarrow r_0$ | ` ' | of B^+ and B^0 at the $\Upsilon(4S)$. |
| | 7 | ⁶ ALBRECHT 85H A | ARG $e^+e^- ightarrow \gamma$ | (AC) | 3 BALEST 95B assume B($\chi_{c1}(1P) \rightarrow J/\psi(1S)\gamma$) = $(27.3 \pm 1.6) \times 10^{-2}$, the PDG 1994 |

 6 ALBRECHT 85H ARG $e^+\,e^ightarrow~ \varUpsilon(4S)$

85 CLEO Repl. by ALAM 86

Meson Particle Listings B^{\pm}/B^{0} ADMIXTURE

| $\Gamma(\chi_{c1}(1P)(\text{direct}) \text{ anything})/\Gamma_{\text{total}}$ | | | | | | | |
|-------------------------------------------------------------------------------|---------------------|---------|-----------|-----------------------|----------------|--|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | | |
| 0.00322±0.00025 OUR AVERAGE | | | | | | | |
| $0.00341 \pm 0.00035 \pm 0.00042$ | AUBERT | | | $e^+ e^- \rightarrow$ | | | |
| $0.00332 \pm 0.00022 \pm 0.00034$ | ¹ ABE | 02L | BELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ | | |
| $0.0030 \pm 0.0004 \pm 0.0001$ | ² CHEN | 01 | CLE2 | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | | |
| | g data for average | s, fits | , limits, | etc. • • • | | | |
| 0.0037 ± 0.0007 | ³ BALEST | 95B | CLE2 | Repl. by C | HEN 01 | | |

 1 ABE 02L uses PDG 01 values for ${\rm B}(J/\psi(1{\rm S})\to~\ell^+\,\ell^-)$ and ${\rm B}(\chi_{c1,c2}\to~J/\psi(1{\rm S})\,\gamma).$

 3 BALEST 95B assume PDG 1994 values. $J/\psi(1S)$ mesons are reconstructed in the e^+e^- and $\mu^+\mu^-$ modes. The $B\to\chi_{c1}(1P){\rm X}$ branching ratio contains $\chi_{c1}(1P)$ mesons directly from B decays and also from feeddown through $\psi(2{\rm S})\to\chi_{c1}(1P)\gamma.$ Using the measured inclusive rates, BALEST 95B corrects for the feeddown and finds the $B\to\chi_{c1}(1P)$ (direct) X branching ratio.

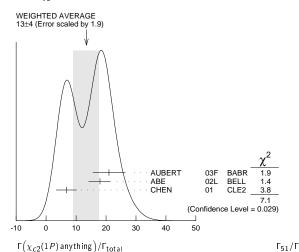
$\Gamma(\chi_{c2}(1P) \text{ a nything})/\Gamma_{\text{total}}$

 Γ_{51}/Γ

| VALUE (units 10^{-4}) | CL% EV | TS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------|---------|---------------------|-----------|---------|------------------------------------------------------------|
| 13 ±4 OUR | AVERAG | E Erro | or includes scale | factor | of 1.9. | See the ideogram below. |
| $21.0 \pm 4.5 \pm 3.1$ | | | AUBERT | 03F | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $18.0 + 2.3 \pm 2.6$ | | | ¹ ABE | 02L | BELL | $e^+ e^- \rightarrow ~ $ |
| $6.8 \pm 3.4 \pm 0.3$ | | | ² CHEN | 01 | CLE2 | $e^+ e^- ightarrow ~ \varUpsilon (4S)$ |
| ● ● We do not | use the fo | llowing | data for average | es, fits, | limits, | etc. • • • |
| <38 | 90 | 35 | ³ BALEST | 95B | CLE2 | Repl. by CHEN 01 |

 1 ABE 02L uses PDG 01 values for B $(J/\psi(1S)
ightarrow \ell^+\ell^-)$ and B $(\chi_{c1},_{c2}
ightarrow J/\psi(1S)\gamma)$.

 $^{^3}$ BALEST 95B assume B($\chi_{c2}(1P) \to J/\psi(1S)\,\gamma) = (13.5 \pm 1.1) \times 10^{-2}$, the PDG 1994 value. $J/\psi(1S)$ mesons are reconstructed in the $e^+\,e^-$ and $\mu^+\mu^-$ modes, and PDG 1994 branching fractions are used. If interpreted as signal, the 35 ± 13 events correspond to B($B \to \chi_{c2}(1P)\,\rm X) = (0.25 \pm 0.10 \pm 0.03) \times 10^{-2}$.



| $\Gamma(\chi_{c2}(1P)(ext{direct}) 	ext{ anything})/\Gamma_{	ext{total}}$ | | | | | | | | |
|----------------------------------------------------------------------------|------------------|-----|------|-----------------------|-------|--|--|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | | | |
| 0.00165 ± 0.00031 OUR AVERAGE | | | | | | | | |
| $0.00190 \pm 0.00045 \pm 0.00029$ | AUBERT | 03F | BABR | $e^+ e^- \rightarrow$ | Y(45) | | | |
| $0.00153 + 0.00023 \pm 0.00027$ | ¹ ABE | 02L | BELL | $e^+e^- \to$ | Y(45) | | | |

 1 ABE 02L uses PDG 01 values for ${\rm B}(J/\psi(1S)\,\rightarrow\,\ell^+\,\ell^-)$ and ${\rm B}(\chi_{c1,c2}\,\rightarrow\,J/\psi(1S)\,\gamma).$

| $\Gammaig(\eta_c(1S))$ anything | $/\Gamma_{total}$ | | | | | Γ_{53}/Γ |
|---------------------------------|-------------------|--------------|------|------|---------|----------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| < 0.009 | 90 | 1 BALEST | 95 B | CLE2 | e+e | $\Upsilon(4.5)$ |

 $^{^1}$ BALEST 95B assume PDG 1994 values for sub mode branching ratios. $J/\psi(1S)$ mesons are reconstructed in $J/\psi(1S)\to e^+\,e^-$ and $J/\psi(1S)\to \mu^+\,\mu^-$. Search region 2960 $<\!m_{\eta_c(1S)}<\!3010$ MeV/ $\!c^2$.

| $\Gamma(KX(3872) \times B(X$ | $A \to D^0 \overline{L}$ | $(\overline{\mathcal{D}}^0\pi^0))/\Gamma_{total}$ | | | | Г ₅₄ /Г |
|-------------------------------------------------------|--------------------------|---------------------------------------------------|---------------------|------------------------------------|----------------------|--------------------|
| VALUE (units 10^{-4}) | | DO CUMENT ID | | TECN | COMMENT | |
| $1.22 \pm 0.31 + 0.23 \\ -0.30$ | | $^{ m 1}$ GOKHROO | 06 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| 1 Measure the near-t $0.7^{+0.3}_{-1.6}\pm 0.8$ Me | | hancements in the | e (D ⁰ 7 | $\overline{\mathcal{D}}^0\pi^0)$ s | ystem at a n | nass 3875.2 \pm |
| $\Gamma(KX(3872) \times B(X$ | $T \to D^{*0}$ | $D^0))/\Gamma_{\rm total}$ | | | | Γ ₅₅ /Γ |
| VALUE (units 10 ⁻⁴) | | DO CUMENT ID | | TECN | COMMENT | |
| $0.80 \pm 0.20 \pm 0.10$ | | AUSHEV | 10 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| $\Gamma(KX(3940) \times B(X))$ | $J \to D^{*0}$ | $D^0))/\Gamma_{\rm total}$ | | | | Γ ₅₆ /Γ |
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.67 | 90 | AUSHEV | 10 | BELL | $e^+e^- \rightarrow$ | Y(45) |
| $\Gamma(KX(3915) \times B(X$ | $J \to \omega J/2$ | $\psi))/\Gamma_{\mathrm{total}}$ | | | | Γ ₅₇ /Γ |
| VALUE (units 10^{-5}) | | DO CUMENT ID | | TECN | COMMENT | |
| 7.1 ±1.3 ± 3.1 | | $^{ m 1}$ CHOI | 05 | BELL | $e^+e^- \to$ | Y(45) |

.1±1.3±3.1 1 CHOI 05 BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ 1 CHOI 05 reports the observation of a near-threshold enhancement in the $\omega J/\psi$ mass spectrum in exclusive $B \rightarrow K \omega J/\psi$. The new state, denoted as X(3915), is measured to have a mass of $3943 \pm 11 \pm 13 \text{ GeV}/c^2$ and a width $\Gamma = 87 \pm 22 \pm 26 \text{ MeV}$.

| $\Gamma(K^{\pm}$ anything)/ Γ_{total} | | | | | Γ ₅₈ /Γ |
|----------------------------------------------|-------------------------|-----------|---------|----------------------|--------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.789±0.025 OUR AVERAG | E | | | | |
| $0.82 \pm 0.01 \pm 0.05$ | ALBRECHT | 94c | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.775 \pm 0.015 \pm 0.025$ | ¹ ALBRECHT | 931 | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.85 \pm 0.07 \pm 0.09$ | ALAM | 87B | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| • • • We do not use the fol | lowing data for average | es, fits, | limits, | etc. • • • | |
| seen | ² BRODY | | | $e^+e^- \rightarrow$ | |
| seen | ³ GIA NNI NI | 82 | CUSB | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

 1 ALBRECHT 931 value is not independent of the sum of $B\to K^+$ anything and $B\to K^-$ anything ALBRECHT 94c values.

² Assuming $\Upsilon(4S) \to B\overline{B}$, a total of $3.38 \pm 0.34 \pm 0.68$ kaons per $\Upsilon(4S)$ decay is found (the second error is systematic). In the context of the standard B-decay model, this leads to a value for (b-quark $\to c$ -quark)/(b-quark \to all) of $1.09 \pm 0.33 \pm 0.13$.

 3 GIANNINI 82 at CESR-CUSB observed $1.58\pm0.35~K^0$ per hadronic event much higher than 0.82 ± 0.10 below threshold. Consistent with predominant $b\to cX$ decay.

| $\Gamma(K^+ \text{ anything})/\Gamma_{\text{total}}$ | | | | | Γ59/Γ |
|------------------------------------------------------|-----------------------|----------|---------|----------------------|----------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.66 ±0.05 | $^{ m 1}$ ALBRECHT | 94 c | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| | wing data for average | s, fits, | limits, | etc. • • • | |
| $0.620 \pm 0.013 \pm 0.038$ | ² ALBRECHT | | | | |
| $0.66\ \pm0.05\ \pm0.07$ | ² ALAM | 87в | CLEO | $e^+e^- \rightarrow$ | Y(45) |

 1 Measurement relies on lepton-kaon correlations. It is for the weak decay vertex and does not include mixing of the neutral B meson. Mixing effects were corrected for by assuming a mixing parameter r of (18.1 \pm 4.3)%.

 $^{^2}$ Measurement relies on lepton-kaon correlations. It includes production through mixing of the neutral ${\it B}$ meson.

| ı | 「(K—anything)/Γ _{total} | | | | | Γ ₆₀ | ۱/Г |
|---|----------------------------------|-----------------------|----------|---------|----------------------|-----------------|-----|
| 1 | ALUE | DO CUMENT ID | | TECN | COMMENT | | |
| (| 0.13 ±0.04 | ¹ ALBRECHT | 94c | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |
| • | • • We do not use the follow | ving data for average | s, fits, | limits, | etc. • • • | | |
| (| $0.165 \pm 0.011 \pm 0.036$ | ² ALBRECHT | | | | | |
| 0 | $0.19 \pm 0.05 \pm 0.02$ | ² ALAM | 87в | CLEO | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ | |

 1 Measurement relies on lepton-kaon correlations. It is for the weak decay vertex and does not include mixing of the neutral B meson. Mixing effects were corrected for by assuming a mixing parameter r of (18.1 \pm 4.3)%.

2 Measurement relies on lepton-kaon correlations. It includes production through mixing of the neutral *B* meson

| $\Gamma(K^0/\overline{K}^0 \text{ anything})/\Gamma_{\text{tot}}$ | al | | | | Γ_{61}/Γ |
|-------------------------------------------------------------------|---------------------------------------|------|------------------|----------------------|----------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.64 ±0.04 OUR AVERAGE | | | | | |
| $0.642 \pm 0.010 \pm 0.042$ | ¹ ALBRECHT | 94 c | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $0.63 \pm 0.06 \pm 0.06$ | ALAM | 87в | CLEO | $e^+e^- \rightarrow$ | Y(45) |
| ¹ ALBRECHT 94c assume | a K^0/\overline{K}^0 multiplicity t | wice | that of <i>I</i> | $\langle {}^0_S.$ | |
| $\Gamma(K^*(892)^{\pm} \text{ anything})/\Gamma_1$ | total | | | | Γ ₆₂ /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.182 \pm 0.054 \pm 0.024$ | ALBRECHT | 94J | ARG | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| | | | | | |

 $^{^2}$ CHEN 01 reports 0.00383 \pm 0.00031 \pm 0.00040 from a measurement of $[\Gamma(B\to\chi_{c1}(1P)(\text{direct})\ \text{anything})/\Gamma_{\text{total}}]\times [B(\chi_{c1}(1P)\to \gamma J/\psi(1S))]$ assuming $B(\chi_{c1}(1P)\to \gamma J/\psi(1S))]=0.273 \pm 0.016,$ which we rescale to our best value $B(\chi_{c1}(1P)\to \gamma J/\psi(1S))=(34.4\pm 1.5)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

²CHEN 01 reports $(9.8\pm4.8\pm1.5)\times10^{-4}$ from a measurement of $[\Gamma(B\to\chi_{C2}(1P)\text{ anything})/\Gamma_{\text{total}}]\times[B(\chi_{C2}(1P)\to\gamma J/\psi(1S))]$ assuming $B(\chi_{C2}(1P)\to\gamma J/\psi(1S))=0.135\pm0.011$, which we rescale to our best value $B(\chi_{C2}(1P)\to\gamma J/\psi(1S))=(19.5\pm0.8)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Assumes equal production of B^+ and B^0 at the T(4S).

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| $\Gamma(K^*(892)\gamma)/\Gamma_{\text{total}}$ | | | | | Г ₆₄ /Г | $\Gamma(K\phi\phi)/\Gamma_{\text{total}}$ | | | | Γ ₇₅ /Γ |
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| VALUE (units 10 ⁻⁵) 4.24±0.54±0.32 | | OAN 00 | | $e^+e^- \rightarrow$ | T(45) | VALUE (units 10 ⁻⁶) | DOCUMENT ID 1 HUANG | 03 BELL | $e^+e^- \rightarrow 1$ | Y(4.6) |
| • • • We do not use the | e following dat | a for averages, fits | , limits, e | | | 2.3 + 0.9 ± 0.3 | uction of charged and neutra | | | ` ' |
| <150 < 24 | | ESIAK 92 LBRECHT 88H | | $e^+ e^- \rightarrow e^+ e^- \rightarrow$ | $\Upsilon(4S)$ $\Upsilon(4S)$ | $\Gamma(\overline{b} \to \overline{s}\gamma)/\Gamma_{\text{total}}$ | action of charged and neutra | ai <i>D</i> ilicsoli pai | rs and isospin | Γ ₇₆ /Γ |
| $^{1}\mathrm{An}$ average of $\mathrm{B}(B^{+})$ | | | | | surements re- | $VALUE$ (units 10^{-4}) | DO CUMENT ID | TECN COM | MENT | 176/1 |
| ported in COAN 00 I ² LESIAK 92 set a lim | it on the inclu | sive process B(b - | $\rightarrow s\gamma) <$ | 2.8×10^{-3} | ³ at 90% CL | 3.53±0.24 OUR AVERA | AGE | | | |
| for the range of mas hadronization. | sses of 892–204 | 15 MeV, independe | ent of ass | sumptions a | bout s-quark | $3.47 \pm 0.15 \pm 0.40$ $3.91 \pm 0.91 \pm 0.64$ | ^{1,2} LIMOSANI 09 ^{2,3} AUBERT 080 | BELL e⊤e BABR e+e | $e^- \rightarrow r(4S)$ $e^- \rightarrow r(4S)$ | |
| $\Gamma(\eta K \gamma)/\Gamma_{\text{total}}$ | | | | | Г ₆₅ /Г | $3.92 \pm 0.31 \pm 0.47$ | _ | BABR e+ | $e^- \rightarrow r(45)$ |) |
| VALUE (units 10 ⁻⁶) | D | OCUMENT ID | TECN | COMMENT | . 65 / . | $3.49 \pm 0.20 + 0.59 \\ -0.46$ | | BABR e+ | $e^- \rightarrow r(4S)$ |) |
| $3.5 \pm 1.3 ^{+1.2}_{-0.9}$ | 1 N | ISHIDA 05 | BELL | $e^+e^- \rightarrow$ | Υ(4S) | $3.36 \pm 0.53 { + 0.65 \atop -0.68 }$ | 0 - | BELL e+ | $e^- \rightarrow \gamma(4S)$ | |
| $m_{\eta K} < 2.4 \text{ GeV/c}^2$ | 2 | | | | | 3.29±0.44±0.29 • • • We do not use th | ^{2,7} CHEN 01c ne following data for average | CLE2 e+e s. fits. limits. | |) |
| , | | | | | г., /г | $2.30 \pm 0.08 \pm 0.30$ | 8 DEL-AMO-SA10M | BABR e+ | $e^- \rightarrow \gamma(4S)$ |) |
| $\Gamma(K_1(1400)\gamma)/\Gamma_{total}$ | | OCUMENT ID | TECN | COMMENT | Γ ₆₆ /Γ | $4.3 \pm 0.3 \pm 0.7$ | 9 AUBERT 090 | 9 | I. by DEL-AM ANCHEZ 10M | vI |
| <12.7 × 10 ⁻⁵ | 90 ¹ C | OAN 00 | | | T(45) | $3.50 \pm 0.32 \pm 0.31$ $2.32 \pm 0.57 \pm 0.35$ | ^{2,10} KOPPENBURG 04 ALAM 95 | | I. by LIMOSA I. by CHEN 0 | |
| • • • We do not use the $< 1.6 \times 10^{-3}$ | | = | | tc. • • • $e^+e^- \rightarrow$ | T(45) | | eported is (3.45 \pm 0.15 \pm 0. | | - | |
| $< 1.6 \times 10$ $< 4.1 \times 10^{-4}$ | | LBRECHT 88H | | $e^+e^- \rightarrow$ | . , | | $_{_{/}}>$ 1.6 GeV using the metho | d of hep-ph/0 | 507253 (avera | age of three |
| Assumes equal produ | | | | | 3 | theoretical models). ³ Uses a fully reconstru | ucted B meson as a tag on th | e recoil side. T | he measureme | ent reported |
| ² LESIAK 92 set a lim for the range of mas | | | | | | | .60) \times 10 ⁻⁴ for $E_{\gamma} >$ 1.9 G | | | |
| hadronization. | | | | | | | eported is $(3.67\pm0.29\pm0.8)$ eported is $(3.27\pm0.18^{+0.5}_{-0.4})$ | | | |
| $\Gamma(K_2^*(1430)\gamma)/\Gamma_{total}$ | | | | | Γ ₆₇ /Γ | ABE 01F reports the | eir systematic errors (± 0.42) | $^{+0.50}_{-0.54}$) $\times 10^{-1}$ | $\frac{1}{2}$, where the s | second erro |
| ALUE (units 10 ⁻⁵) | | OCUMENT ID | TECN | COMMENT | | is due to the theoret | tical uncertainty. We combin | ne them in qua | drature. | |
| $1.66 + 0.59 \pm 0.13$ • • We do not use the | | | | e ⁺ e [−] → | T(45) | 7 The measurement re 8 Measured using sum | eported is $(3.21\pm0.43 {+0.3} \atop -0.2$ ns of seven exclusive final s | $(\bar{9}) \times 10^{-7}$ for tates $B \rightarrow 2$ | $E_{\gamma} > 2.0 \text{ Ge}$ Where | X , is |
| <83 | = | = | | $e^+e^- \rightarrow$ | T(45) | nonstrange (strange) |) charmless hadronic system | in mass range | 0.5-2.0 GeV | /c ² . |
| $^{ m 1}$ COAN 00 obtains a fi | | | | | | ⁹ Measured using sum | ns of seven exclusive final s | tates $B \rightarrow \lambda$ | $\zeta_{d(s)}\gamma$ where | $X_{d(s)}$ is |
| $K^*(1410)$ yielded a r | | | | | | nonstrange (strange) |) charmless hadronic system eported is (3.55 \pm 0.32 \pm 0. | in mass range 32.0×10^{-4} for | 0.6-1.8 GeV | /c ² . eV |
| (= .= -,) | iate consistent | with o, the central | i value ass | | intanination. | ** The measurement re | | | | |
| | | with o, the central | i value ass | 3411105 110 00 | Г ₆₈ /Г | | eported is (3.55 ± 0.32 ± 0. | , | 7 | |
| $\frac{(K_2(1770)\gamma)}{\Gamma_{\text{total}}}$ <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas | I _ <u>CL%</u> <u>D</u> 90 ¹ Li iit on the inclu | DCUMENT ID ESIAK 92 sive process B(b - | $\frac{TECN}{CBAL}$ $\rightarrow s\gamma) <$ | $\frac{COMMENT}{e^+ e^- \rightarrow}$ 2.8×10^{-3} | Γ ₆₈ /Γ (4.5) 3 at 90% CL | $\frac{\Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma_{\text{total}}}{\frac{VALUE \text{ (units } 10^{-6})}{9.2 \pm 2.0 \pm 2.3}}$ • • • We do not use the | DOCUMENT ID TECN DEL-AMO-SA10M BABR e following data for average | $\frac{COMMENT}{e^+e^- \rightarrow e^+, \text{ fits, limits, } e^+}$ | Υ(4S) | Γ ₇₇ / |
| $(K_2(1770)\gamma)/\Gamma_{\text{total}}$ (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE) (ALUE | 1 <u>CL%</u> <u>D</u> 90 ¹ Li nit on the inclu sses of 892–204 | DCUMENT ID ESIAK 92 sive process B(b - | $\frac{TECN}{CBAL}$ $\rightarrow s\gamma) <$ | $\frac{COMMENT}{e^+ e^- \rightarrow}$ 2.8×10^{-3} | Γ ₆₈ /Γ (4.5) 3 at 90% CL | $ \begin{array}{c c} \Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{\text{total}} \\ \underline{MLUE (\text{units} 10^{-6})} \\ \hline \textbf{9.2\pm2.0\pm2.3} & 1 \\ \bullet \bullet \bullet \text{ We do not use th} \\ 14 & \pm 5 & \pm 4 \\ 1 \text{ Measured using sum} \end{array} $ | DOCUMENT ID TECN DEL-AMO-SA10M BABF e following data for average AUBERT 09U BABF ns of seven exclusive final s | $\frac{COMMENT}{e^+e^- \rightarrow}$ s, fits, limits, $\frac{1}{2}$ R Repl. by D states $B \rightarrow 2$ | $\Upsilon(4S)$ etc. $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ | $oxed{ egin{array}{c} oxed{ eta_{777}} }$ JCHEZ 10r $oxed{ X_{d(s)} }$ is |
| $\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}$ VALUE $V.1.2 \times 10^{-3}$ Γ LESIAK 92 set a limfor the range of mashadronization. $\Gamma(K_3^*(1780)\gamma)/\Gamma_{\text{total}}$ $\Gamma(K_4UE)$ VALUE | $\begin{array}{cccc} & & & & & & \\ & \underline{CL\%} & & & \underline{DC} \\ & 90 & & 1 & \underline{LI} \\ & & \text{tit on the incluses} \\ & & \text{sses of } 892-204 \\ & & \underline{I} \\ & & \underline{CL\%} & & \underline{DC} \\ & & & 90 & & 1 & \underline{N} \end{array}$ | ESIAK 92 Sive process B(b – 15 MeV, independent 10 DECUMENT 10 SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIGNAL OF SIG | $\frac{TECN}{\text{CBAL}}$ $\Rightarrow s\gamma) < \text{ent of ass}$ $\frac{TECN}{\text{BELL}}$ | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \end{array}$ | Γ ₆₈ /Γ Γ(45) 3 at 90% CL bout s-quark | $ \begin{array}{c} \Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{\text{total}} \\ \underline{^{NLUE(\text{units}10^{-6})}} \\ \hline \textbf{9.2\pm2.0\pm2.3} & 1 \\ \bullet \bullet \bullet \text{ We do not use th} \\ 14 & \pm 5 & \pm 4 \\ 1 \text{ Measured using sum} \\ \text{nonstrange (strange)} \end{array} $ | DOCUMENT ID TECN DEL-AMO-SA10M BABF ne following data for average AUBERT 09U BABF | $\begin{array}{c} \underline{COMMENT} \\ R & e^+e^- \rightarrow \\ R & \text{s. fits, limits, s.} \\ R & \text{Repl. by D} \\ R & \text{tates } B \rightarrow P \\ R & \text{in mass range} \end{array}$ | $\Upsilon(4S)$ etc. • • • EL-A MO-SA N $d_{d(s)}\gamma$ where $0.5-2.0~{\rm GeV}$ | ${\sf \Gamma_{77}}/$ ICHEZ 10 ${\sf I}$ ${\sf X}_{d(s)}$ is ${\sf /c^2}.$ |
| $\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}$ $ALUE$ <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas hadronization. $\Gamma(K_3^*(1780)\gamma)/\Gamma_{\text{total}}$ $ALUE$ <3.7 × 10 ⁻⁵ • • We do not use the | $\begin{array}{cccc} & \underline{CL\%} & \underline{D} \\ \underline{00} & 1 & \underline{L} \\ \underline{00} & 1 & \underline{L} \\ \underline{0} & \underline{0} \\ \underline{0} &$ | ESIAK 92 Sive process B(b – 15 MeV, independent 10 DCUMENT 10 USHIDA 05 a for averages, fits | $TECN$ CBAL $\rightarrow s\gamma) < 0$ ent of ass $TECN$ BELL , limits, e | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{tt.} \bullet \bullet \end{array}$ | Γ ₆₈ /Γ | $ \begin{array}{c} \Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total} \\ \underline{^{MLUE(units10^{-6})}} \\ \hline 9.2 \pm 2.0 \pm 2.3 \\ \hline 1 \bullet \bullet \bullet \text{ We do not use th} \\ 14 \pm 5 \pm 4 \\ \hline 1 \text{ Measured using sum} \\ \text{nonstrange (strange)} \\ 2 \text{ Measured using sum} \\ \text{nonstrange (strange)} \\ \end{array} $ | DOCUMENT ID 1 DEL-AMO-SA10M BABI ne following data for average 2 AUBERT 09U BABI ns of seven exclusive final s) charmless hadronic system ns of seven exclusive final s) charmless hadronic system | $\begin{array}{c} COMMENT \\ R & e^+ e^- \rightarrow \\ R & \text{s. fits, limits, on} \\ R & \text{Repl. by D} \\ R & \text{tates } B \rightarrow P \\ R & \text{in mass range} \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text{tates } B \rightarrow P \\ R & \text$ | $T(45)$ etc. • • • EL-AMO-SAN $d_{(s)}\gamma$ where 0.5 – 2.0 GeV $d_{(s)}\gamma$ where | ICHEZ 10 $X_{d(s)}$ is $/c^2$. $X_{d(s)}$ is |
| $\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}$ ΛLUE <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas hadronization. $\Gamma(K_3^*(1780)\gamma)/\Gamma_{\text{total}}$ ΛLUE <3.7 × 10 ⁻⁵ • • • We do not use the 4.0×10^{-3} | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ESIAK 92 Sive process B(b – 15 MeV, independent 10 COUMENT 10 ISHIDA 05 a for averages, fits LBRECHT 88H | $TECN$ CBAL $\rightarrow s\gamma) < 0$ ent of ass $TECN$ BELL , limits, e | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \end{array}$ | Γ ₆₈ /Γ | $ \begin{array}{c c} \Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma_{\text{total}} \\ \hline \underline{^{NALUE}(\text{units } 10^{-6})} \\ \hline 9.2 \pm 2.0 \pm 2.3 & 1 \\ \bullet \bullet \bullet \text{ We do not use th} \\ 14 & \pm 5 & \pm 4 \\ 1 & \text{Measured using sum} \\ \text{nonstrange (strange)} \\ 2 & \text{Measured using sum} \\ \text{nonstrange (strange)} \\ \Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma(\overline{b} \to 0) \end{array} $ | DOCUMENT ID 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 09U BABF ns of seven exclusive final s) charmless hadronic system ns of seven exclusive final s) charmless hadronic system s of seven exclusive final s | $\frac{COMMENT}{e^+e^- \rightarrow s}, \text{ fits, limits, }, \\ \text{R Repl. by D} \\ \text{tates } B \rightarrow \mathcal{D} \\ \text{in mass range} \\ \text{tates } B \rightarrow \mathcal{D} \\ \text{in mass range} \\ \text{on mass range} \\ $ | $\Upsilon(4S)$ etc. $\bullet \bullet \bullet$ EL-AMO-SAN $\zeta_{d(s)}\gamma$ where $0.5-2.0$ GeV $\zeta_{d(s)}\gamma$ where $0.6-1.8$ GeV | ICHEZ 10 $X_{d(s)}$ is $/\mathrm{c}^2$ $X_{d(s)}$ is $/\mathrm{c}^2$. |
| $\frac{\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}}{ALUE}$ <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas hadronization. $\frac{\Gamma(K_3^*(1780)\gamma)}{\Gamma_{\text{total}}}$ $\frac{\Lambda LUE}{ALUE}$ <3.7 × 10 ⁻⁵ • • We do not use the <3.0 × 10 ⁻³ ¹ Uses B($K_3^*(1780)$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ESIAK 92 sive process B(b – 15 MeV, independent 10 COUMENT 10 ISHIDA 05 a for averages, fits LBRECHT 88H | $TECN$ CBAL $\rightarrow s\gamma) < 0$ ent of ass $TECN$ BELL , limits, e | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{tt.} \bullet \bullet \end{array}$ | Γ ₆₈ /Γ | $ \begin{array}{c} \Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total} \\ \underline{^{MLUE(units10^{-6})}} \\ \hline 9.2 \pm 2.0 \pm 2.3 \\ \hline 1 \bullet \bullet \bullet \text{ We do not use th} \\ 14 \pm 5 \pm 4 \\ \hline 1 \text{ Measured using sum} \\ \text{nonstrange (strange)} \\ 2 \text{ Measured using sum} \\ \text{nonstrange (strange)} \\ \end{array} $ | DOCUMENT ID 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 09U BABF ns of seven exclusive final s) charmless hadronic system ns of seven exclusive final s) charmless hadronic system (3 5γ) | $\begin{array}{c} \underline{COMMENT} \\ R \ e^+e^- \rightarrow \\ S, \ \text{fits, limits,} \\ R \ \text{Repl. by D} \\ \text{tot mass range} \\ \text{totage} \ B \rightarrow D \\ \text{in mass range} \\ \text{in mass range} \\ \\ \underline{TECN} \end{array}$ | $\Upsilon(4S)$ etc. • • • EL-A MO-SA N $\langle d(s) \gamma \rangle$ where 0.5–2.0 GeV $\langle d(s) \gamma \rangle$ where 0.6–1.8 GeV | $\Gamma_{77}/$ JICHEZ 101 $X_{d(s)}$ is $/c^2$. $X_{d(s)}$ is Γ_{77}/Γ_7 |
| $\frac{\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}}{ALUE}$ <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas hadronization. $\frac{\Gamma(K_3^*(1780)\gamma)}{\Gamma_{\text{total}}}$ $\frac{\Lambda LUE}{ALUE}$ < 3.0 × 10 ⁻³ ¹ Uses $B(K_3^*(1780) \rightarrow \Gamma_{\text{total}})$ $\frac{\Gamma(K_4^*(2045)\gamma)}{\Gamma_{\text{total}}}$ | $\begin{array}{cccc} & & & & \underline{D} \\ -\underline{CL\%} & & \underline{D} \\ 90 & & 1 \\ 1 \\ \text{init on the inclusions of } 892-204 \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & 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ARG \end{array}$ | $\begin{array}{c} \underline{COMMENT} \\ e^+ e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+ e^- \rightarrow \\ \text{tt.} \bullet \bullet \end{array}$ | Γ ₆₈ /Γ | $\Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-6})}{9.2 \pm 2.0 \pm 2.3}$ 1 ••• We do not use the 14 ± 5 ± 4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma(\overline{b} \to \overline{d}\gamma)/\Gamma(\overline{b} \to \overline{d}\gamma)$ $\frac{VALUE}{0.040 \pm 0.009 \pm 0.010}$ ••• We do not use the | DOCUMENT ID 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 2 O9U BABF ns of seven exclusive final s 3 charmless hadronic system ns of seven exclusive final s 3 charmless hadronic system 1 DEL-AMO-SA ne following data for average | $ \frac{COMMENT}{R} \stackrel{e^+e^-}{=} \rightarrow \\ s, \text{ fits, limits, } s, \\ 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| $\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}$ ΛLUE <1.2 × 10 ⁻³ ¹ LESIAK 92 set a lim for the range of mas hadronization. $\Gamma(K_3^*(1780)\gamma)/\Gamma_{\text{total}}$ <1.3.7 × 10 ⁻⁵ • • • We do not use the $\langle 3.0 \times 10^{-3}$ ¹ Uses B($K_3^*(1780) \rightarrow \Gamma(K_4^*(2045)\gamma)/\Gamma_{\text{total}}$ ΛLUE <1.0 × 10 ⁻³ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ESIAK 92 sive process B(b – 15 MeV, independent 10 SHIDA 05 a for averages, fits LBRECHT 88H + 0.05 -0.04 DOUMENT ID SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 -0.04 SHIDA 05 | $\begin{array}{c} -\frac{TECN}{\text{CBAL}} \\ \text{CBAL} \\ \rightarrow s\gamma) < \\ \text{ent of ass} \\ -\frac{TECN}{\text{BELL}} \\ \text{, limits, e} \\ \text{ARG} \\ \hline \\ -\frac{TECN}{\text{CBAL}} \end{array}$ | $\begin{array}{c} \underline{COMMENT} \\ e^+e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \\ \\ \end{array}$ | Γ68 Γ Γ(45) 3 at 90% CL bout s-quark Γ69 Γ Γ(45) Γ70 Γ Γ(45) | $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total}$ $VALUE (units 10^{-6})$ 9.2±2.0±2.3 1 • • • We do not use the 14 ±5 ±4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow VALUE)$ 0.040±0.009±0.010 • • • We do not use the 0.033±0.013±0.009 | DOCUMENT ID 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 2 OPU BABF ns of seven exclusive final s considerable of the seven exclusive final s considerable of the seven exclusive final s considerable of the seven exclusive final s considerable of the 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\underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | T(45) 3 at 90% CL bout s-quark T(45) T(45) T(45) T(45) 3 at 90% CL bout s-quark Γ(45) T(45) T | $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total}$ VALUE (units 10 ⁻⁶) 9.2±2.0±2.3 1 • • • We do not use th 14 ±5 ±4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow \overline{d}\gamma)$ VALUE 0.040±0.009±0.010 • • • We do not use th 0.033±0.013±0.009 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) 7 ($\overline{b} \rightarrow \overline{s}gluon$)/ Γ_{tot} VALUE <0.068 90 • • • We do not use th <0.08 | DOCUMENT ID 1 DEL-AMO-SA10M BABF ne following data for average 2 AUBERT 1 DEL-AMO-SA10M BABF ne following data for 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$\begin{array}{c} -\frac{TECN}{\text{CBAL}} \\ \rightarrow s\gamma) < \text{ent of ass} \\ -\frac{TECN}{\text{BELL}}, \text{ limits, e} \\ +\text{ARG} \\ -\frac{TECN}{\text{CBAL}} \\ \rightarrow s\gamma) < \text{ent of ass} \\ -\frac{TECN}{\text{CLE2}} \\ S). \\ -\frac{TECN}{\text{BABR}}, \text{ limits, e} \\ +\text{CLE2} \\ \end{array}$ | $\begin{array}{c} \underline{COMMENT} \\ e^+e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \text{tc.} \bullet \bullet \bullet \\ e^+e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | T ₆₈ /Γ T ₍₄₅₎ 3 at 90% CL bout s-quark F ₆₉ /Γ T ₍₄₅₎ $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total}$ NALUE (units 10 ⁻⁶) 9.2±2.0±2.3 • • • We do not use the 14 ±5 ±4 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DOCUMENT ID UBERT 07E a for averages, fits CHICHI 00 nd B ⁰ at the T(4. | $\begin{array}{c} -\frac{TECN}{\text{CBAL}} \\ \rightarrow s\gamma) < \text{ent of ass} \\ \\ -\frac{TECN}{\text{BELL}}, \text{ limits, e} \\ +\frac{TECN}{\text{CBAL}} \\ \rightarrow s\gamma) < \text{ent of ass} \\ \\ -\frac{TECN}{\text{CLE2}} \\ S). \\ \\ -\frac{TECN}{\text{BABR}}, \text{ limits, e} \\ -\frac{CLE2}{S}. \\ \\ -\frac{TECN}{\text{CLE2}} \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{\text{CLE2}} \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ -\frac{TECN}{S}. \\ \\ 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| $\Gamma(K_2(1770)\gamma)/\Gamma_{\text{total}}$ Λ_{ALUE} <1.2 × 10 ⁻³ 1 LESIAK 92 set a lim for the range of mas hadronization. $\Gamma(K_3^*(1780)\gamma)/\Gamma_{\text{total}}$ Λ_{ALUE} <3.7 × 10 ⁻⁵ • • We do not use the <3.0 × 10 ⁻³ 1 Uses $B(K_3^*(1780) \rightarrow)/\Gamma_{\text{total}}$ Λ_{ALUE} <1.0 × 10 ⁻³ 1 LESIAK 92 set a lim for the range of mas hadronization. $\Gamma(K_1^*(958))/\Gamma_{\text{total}}$ Λ_{ALUE} (8.3 + 0.9 ± 0.7) × 10 ⁻⁵ 1 Assumes equal produ $\Gamma(K^*(992)\eta'(958))/\Lambda_{ALUE}$ (units 10 ⁻⁶) 4.1 + 1.0 ± 0.5 • • We do not use the <22 1 Assumes equal produ $\Gamma(K_1^*(N)/\Gamma_{\text{total}})/\Gamma_{\text{total}}$ <2.2 1 Assumes equal produ | Inition the inclusives of 892–204 Inition the inclusives of 892–204 Inition the inclusives of 892–204 Inition the inclusives of 892–204 Inition the inclusives of 892–204 Inition of B^+ and B^- and | ESIAK 92 Sive process B(b – 15 MeV, independent 10 MeV, independent 10 MeV, independent 10 MeV, independent 10 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\underline{COMMENT} \\ e^+e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \\ \underline{COMMENT} \\ e^+e^- \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | T ₆₈ /Γ T ₍₄₅₎ 3 at 90% CL bout s-quark F ₆₉ /Γ T ₍₄₅₎ $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total}$ MALUE (units 10 ⁻⁶) 9.2±2.0±2.3 1 • • • We do not use the 14 ±5 ±4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow MLUE)$ 0.040±0.009±0.010 • • • We do not use the 0.033±0.013±0.009 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) 7 ($\overline{b} \rightarrow \overline{s}$ gluon)/ Γ_{tot} MLUE <0.068 • • • We do not use the 0.08 1 COAN 98 uses D-0.02 ALBRECHT 95b us for charmless B dec 1f interpreted as b − quoted above. 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\overline{d}\gamma)/\Gamma_{total}$ MALUE (units 10 ⁻⁶) 9.2±2.0±2.3 1 • • • We do not use the 14 ±5 ±4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} \rightarrow MLUE)$ 0.040±0.009±0.010 • • • We do not use the 0.033±0.013±0.009 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) 7 ($\overline{b} \rightarrow \overline{s}$ gluon)/ Γ_{tot} MLUE <0.068 • • • We do not use the 0.08 1 COAN 98 uses D-0.02 ALBRECHT 95b us for charmless B dec 1f interpreted as b − quoted above. Resulted 1.030+0.044 2.61±0.30+0.444 2.61±0.30+0.444 2.61±0.30+0.444 2.61±0.30−0.744 | DOCUMENT ID 1 DEL-AMO-SA10M BABI ne following data for average 2 AUBERT 1 DEL-AMO-SA10M BABI ne following data for average 2 AUBERT 2 DOCUMENT ID 1 DEL-AMO-SA The following data for average 2 AUBERT 1 DEL-AMO-SA The following data for average 2 AUBERT The sof seven exclusive final selection of seven exclusive final | COMMENT R e ⁺ e ⁻ → S, fits, limits, R Repl. by D in mass range states R → R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in mass range R in 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\underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \text{CLE2} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \underline{\textit{CLE2}} \\ \underline{\textit{S}}). \\ \underline{\textit{TECN}} \\ \underline{\textit{CN}} \\ \underline{\textit{CLE2}} \\ \underline{\textit{CN}} | $\begin{array}{c} \underline{COMMENT} \\ e^+e^- \rightarrow \\ 2.8 \times 10^{-5} \\ \text{sumptions a} \\ \\ \hline \\ comment \\ e^+e^- \rightarrow \\ \\ comment \\ e^+e^- \rightarrow \\ \\ comment \\ e^+e^- \rightarrow \\ \\ comment \\ e^+e^- \rightarrow \\ \\ \hline \\ comment \\ e^+e^- \rightarrow \\ \\ \hline \\ comment \\ e^+e^- \rightarrow \\ \\ \hline \\ comment \\ e^+e^- \rightarrow \\ \\ \hline \\ comment \\ e^+e^- \rightarrow \\ \\ \hline \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ 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comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment \\ \\ comment $ | T ₆₈ /Γ T ₍₄₅₎ 3 at 90% CL bout s-quark F ₆₉ /Γ T ₍₄₅₎ $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma_{total}$ MALUE (units 10 ⁻⁶) 9.2±2.0±2.3 1 • • • We do not use the 14 ±5 ±4 1 Measured using sum nonstrange (strange) 2 Measured using sum nonstrange (strange) 1 Measured using sum nonstrange (strange) $\Gamma(\overline{b} \rightarrow \overline{d}\gamma)/\Gamma(\overline{b} $ | DOCUMENT ID 1 DEL-AMO-SA10M BABI ne following data for average 2 AUBERT 1 DEL-AMO-SA10M BABI ne following data for average 2 AUBERT 2 DOCUMENT ID 1 DEL-AMO-SA The following data for average 2 AUBERT The sof seven exclusive final separate for average 2 AUBERT The sof seven 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Γ_{77}/Γ_{1} Γ_{74}/Γ_{1} Γ_{74}/Γ_{1} Γ_{78}/Γ_{1} Γ_{78}/Γ_{1} Γ_{79}/Γ_{1} $\Gamma_{$ |

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| B+/B° ADMIX I URE | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| $\Gamma(η'$ anything)/ $\Gamma_{ m total}$ | Γ ₈₀ /Γ | $\Gamma(\pi^{\pm}$ anything)/ $\Gamma_{	ext{total}}$ | | Г85/Г |
| <u>VALUE (units 10^{−4})</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COM</u> 4.2±0.9 OUR AVERAGE | IMENT | <u>VALUE</u> 3.585 ±0.025 ±0.070 | DOCUMENT ID TECN 1 ALBRECHT 931 ARG | $\frac{COMMENT}{e^+e^- \rightarrow \Upsilon(4S)}$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $e^- \rightarrow \Upsilon(4S)$ $e^- \rightarrow \Upsilon(4S)$ | | from K_S^0 and Λ decays. If in | ` ' |
| • • • We do not use the following data for averages, fits, limits, etc. • $6.2\pm1.6\pm1.3 \atop 2.0$ 3 BROWDER 98 CLE2 e^+e^- | $e^- 	o 	au(4S)$ | Γ (π⁰ anything)/Γ_{total} | DOCUMENT ID TECN | Г ₈₆ /Г |
| $^{-2.0}$ AUBERT,B 04F reports branching ratio $B \rightarrow \eta' X_S$ for high models. | | 2.35 ± 0.02 ± 0.11 | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 2.0 and 2.7 GeV/c in the $\Upsilon(4S)$ center-of-mass frame. X_S repres consisting of a kaon and zero to four pions. | ents a recoil system | | with no corrections from decays | |
| 2 BONVICINI 03 observed a signal of 61.2 \pm 13.9 events in $B 	o \eta$ high momentum η' between 2.0 and 2.7 GeV/ c in the $\mathcal{T}(4S)$ center- | -of-mass frame. The | Γ(η a nything)/Γ _{total} | DOCUMENT ID TECN | Г ₈₇ /Г |
| X_{nc} denotes "charmless" hadronic states recoiling against η' . The sest systematic and background subtraction uncertainties in quadrature. 3 BROWDER 98 observed a signal of 39.0 \pm 11.6 events in high mor | | 0.176±0.011±0.012 | KUBOTA 96 CLE2 | $e^+e^- 	o 	au(4S)$ |
| production between 2.0 and 2.7 GeV/ c . The branching fraction is pretation of $b \rightarrow sg$, where the last error includes additional unce | based on the inter- | $\Gamma(ho^0$ anything)/ $\Gamma_{ m total}$ | DOCUMENT ID TECN | Г ₈₈ /Г <u>соммент</u> |
| color-suppressed $b 	o backgrounds$. | | $0.208 \pm 0.042 \pm 0.032$ | ALBRECHT 94J ARG | $e^+e^- ightarrow \gamma(4S)$ |
| \(\begin{align*} \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \begin{align*} \Gamma(\beta + \beta + \begin{align*} \Gamma(\beta + \beta + \beta + \begin{align*} \Gamma(\beta + \beta + | Г₈₁/Г _{ІМЕΝТ} | $\Gamma(\omega \text{ anything})/\Gamma_{\text{total}}$ | 00.000.000.00 | Г ₈₉ /Г |
| <1.87 90 1 DEL-AMO-SA11 BABR e+ e | $e^- \rightarrow r(4S)$ | <u>VALUE</u> <u>CL%</u> <0.81 90 | ALBRECHT 94J ARG | |
| $^{1}B \rightarrow K^{+}X$ with $m_{X} < 1.69$ GeV/c ² . | | $\Gamma(\phi \text{ anything})/\Gamma_{	ext{total}}$ | | Г ₉₀ /Г |
| $\Gamma(K^0$ gluon (charmless))/ Γ_{total} | Γ ₈₂ /Γ | <u>VALUE</u> 0.0343 ± 0.0012 OUR AVERAGE | DOCUMENT ID TECN | <u>COMMENT</u> |
| VALUE (units 10^{-4}) DOCUMENT ID TECN COM 1.95 ± 0.51 ± 0.50 1 DEL-AMO-SA11 BABR e^{\pm} e^{\pm} | - | $0.0353 \pm 0.0005 \pm 0.0030$ $0.0341 \pm 0.0006 \pm 0.0012$ | HUANG 07 CLEC AUBERT 04s BABI | $e^+e^- \rightarrow \Upsilon(4S)$ R $e^+e^- \rightarrow \Upsilon(4S)$ |
| 5.15 | e → 1(43) | $0.0341 \pm 0.0000 \pm 0.0012$ $0.0390 \pm 0.0030 \pm 0.0035$ | ALBRECHT 94J ARG | . ' ' |
| $^1B \rightarrow K^0X$ with $m_{\chi} < 1.69$ GeV/c ² . | | $0.023 \pm 0.006 \pm 0.005$ | BORTOLETTO86 CLEC | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(ho\gamma)/\Gamma_{	ext{total}}$ | Г ₈₃ /Г | $\Gamma(\phi K^*(892))/\Gamma_{\text{total}}$ | | Γ ₉₁ /Γ |
| <u>VALUE (units 10⁻⁶)</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMM</u> 1.39 ± 0.25 OUR AVERAGE Error includes scale factor of 1.2. | MENT | <u>VALUE</u> <u>CL%</u> <2.2 × 10^{−5} 90 | DOCUMENT ID TECN BERGFELD 98 CLE2 | |
| $1.73 ^{+\; 0.34}_{-\; 0.32} \pm 0.17$ | $^- \rightarrow \gamma_{(4S)}$ | ¹ Assumes equal production of | | |
| $1.21 + 0.24 \pm 0.12$ 1.2 ± 0.12 1.2 ± 0.12 TANIGUCHI 08 BELL e^+e^- | $- \rightarrow r(45)$ | $\Gamma(\pi^+ \text{ gluon (charmless))}/\Gamma_{\text{t}}$ | | Г93/Г |
| • • • We do not use the following data for averages, fits, limits, etc. | * * | VALUE (units 10 ⁻⁴) | OTAL DO CUMENT ID TECN | |
| $1.36^{+0.29}_{-0.27} \pm 0.10$ 1,3 AUBERT 07L BABR Repl. | by AUBERT 08вн | $3.72^{+0.50}_{-0.47}\pm0.59$ | ¹ DEL-AMO-SA11 BABI | $e^+e^- \rightarrow r(4S)$ |
| < 1.9 90 1,3 AUBERT 04c BABR Repl. | • | $^{1}B \rightarrow \pi^{+}X$ with $m_{X} < 1.73$ | L GeV/c ² . | |
| <14 90 1.4 COAN 00 CLE2 e^+e^- 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. 2 Assumes $\Gamma(B \to \rho \gamma) = \Gamma(B^+ \to \rho^+ \gamma) = 2 \Gamma(B^0 \to \rho^0 \gamma)$ and | , , | $\Gamma(\Lambda_c^+ \ / \ \overline{\Lambda}_c^- \ { m anything}) / \Gamma_{ m total}$ | | Г ₉₄ /Г |
| Assumes $\Gamma(B \to \rho\gamma) = \Gamma(B^+ \to \rho^+\gamma) = 2 \Gamma(B^- \to \rho^+\gamma)$ and $\tau_{B^+}/\tau_{B^0} = 1.071 \pm 0.009$. 3 Assumes $\Gamma(B \to \rho\gamma) = \Gamma(B^+ \to \rho^+\gamma) = 2 \Gamma(B^0 \to \rho^0\gamma)$ and | | 0.045 ± 0.003 ± 0.012 | | $e^+e^- ightarrow \gamma(4S)$ |
| Assumes $\Gamma(B \to \rho \gamma) = \Gamma(B \to \rho \gamma) = 2\Gamma(B \to \rho \gamma)$ and $\tau_{B^+}/\tau_{B^0} = 1.083 \pm 0.017$. | uses merime ratio of | • • • We do not use the followi $0.064 \pm 0.008 \pm 0.008$ | | s, etc. $ullet$ $ullet$ $ullet$ $ullet$ $e^+e^- ightarrow arGamma(4.5)$ |
| ⁴ COAN 00 reports B($B \to \rho \gamma$)/B($B \to K^*(892) \gamma$) < 0.32 at 90 the central value of B($B \to K^*(892) \gamma$)=(4.24 ± 0.54 ± 0.32) × 1 | 0% CL and scaled by 10^{-5} . | 0.14 ±0.09 <0.112 90 | 3 ALBRECHT 88E ARG | |
| $\Gamma(ho\gamma)/\Gamma(K^*(892)\gamma)$ YALUE (units 10^{-2}) DOCUMENT ID TECN COM | Γ ₈₃ /Γ ₆₄ | | $5 \pm 0.003 \pm 0.012$ from a $\times [B(\Lambda_C^+ \rightarrow p K^- \pi^+)]$ assum | |
| 3.02+0.60+0.26 TANIGUCHI 08 BELL e+e | | $(5.0 \pm 1.3) \times 10^{-2}$ | ed from lepton baryon correlati | - |
| $\Gamma(\rho/\omega\gamma)/\Gamma_{\rm total}$ | Г ₈₄ /Г | baryons in ${\it B}^{0}$ and ${\it B}^{\pm}$ decay | rare Λ _C . | |
| VALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMM | • | | $(B \to \Lambda_C^+ X) \cdot B(\Lambda_C^+ \to p K^- \pi^-)$ = $(2.2 \pm 1.0)\%$ from ABRAMS | |
| 1.30 ± 0.23 OUR AVERAGE Error includes scale factor of 1.2. 1.63 $^{+}_{-0.28}$ ± 0.16 | $\rightarrow \Upsilon(AS)$ | ⁴ Assuming all baryons result | from charmed baryons, ALAM | 86 conclude the branching |
| $1.14 \pm 0.20 \pm 0.10$ 1.3 TANIGUCHI 08 BELL e^+e^- | ` , | fraction is 7.4 \pm 2.9%. The $\Gamma(\Lambda_c^+$ anything)/ $\Gamma(\overline{\Lambda}_c^-$ anyth | limit given above is model indep ing) | pendent. Г95/Г96 |
| \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet | • • • | VALUE | DOCUMENT ID TECN | COMMENT |
| $1.25 + 0.25 \pm 0.09$ 4 AUBERT 07L BABR Repl. | by AUBERT 08вн | 0.19±0.13±0.04 | | $e^+e^- \rightarrow r(4S)$ |
| 1.32 + 0.34 + 0.10 4 MOHA PATRA 06 BELL Repl. | - | _ | nentum lepton tag ($P_\ell > 1.4$ Ge $-$ | |
| 0.6 \pm 0.3 \pm 0.1 | | $\Gamma(\overline{\Lambda}_c^- e^+ \text{ anything})/\Gamma(\Lambda_c^+ / NALUE)$ | ⊼ canything) <u>DOCUMENT ID</u> <u>TECN</u> | Г97/Г94 <u>соммент</u> |
| ¹ Assumes $\Gamma(B \to \rho \gamma) = \Gamma(B^+ \to \rho^+ \gamma) = 2 \Gamma(B^0 \to \rho^0 \gamma)$ and | uses lifetime ratio of | <0.025 90 | ¹ LEES 12 BABI | $e^+e^- \rightarrow \gamma(4S)$ |
| $	au_{B^+}/	au_{B^0}=1.071\pm0.009.$ 2 Also reports $ V_{td}/V_{ts} =0.233 {+0.025 + 0.022 \over -0.024 - 0.021}.$ | | • • • We do not use the followi < 0.05 90 | ng data for averages, fits, limits ² BONVICINI 98 CLE2 | |
| ³ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. ⁴ Assumes $\Gamma(B \to \rho \gamma) = \Gamma(B^+ \to \rho^+ \gamma) = 2 \Gamma(B^0 \to \rho^0 \gamma)$ and | uses lifetime ratio of | $^{1}_{ m 0}$ Uses the full reconstruction $^{\circ}_{ m 0}$ | FRONVICINI 98 CLE2 of the recoiling B in a hadronic from with momentum above 0.6 | decay as a tag. |
| $\tau_{B^+}/\tau_{B^0} = 1.083 \pm 0.017.$ | e /e | $\Gamma(\overline{\Lambda}_c^-e^+ { m anything})/\Gamma(\overline{\Lambda}_c^- { m an})$ | | Γ ₉₇ /Γ ₉₆ |
| $\Gamma(ho/\omega\gamma)/\Gamma(K^*(892)\gamma)$ VALUE (units 10^{-2}) CL% DOCUMENT ID TECN COMM | Γ ₈₄ /Γ ₆₄ | <u>VALUE</u> <u>CL%</u> <0.035 90 | , | R $e^+e^- \rightarrow \Upsilon(4S)$ |
| 2.84±0.50+0.29 1 TANIGUCHI 08 BELL e+e- | | | of the recoiling B in a hadronic | . , |
| • • We do not use the following data for averages, fits, limits, etc. | · / | $\Gamma(\overline{\Lambda}_c^- panything)/\Gamma(\Lambda_c^+ / \overline{\Lambda}_c^-)$ | - | Г98/Г94 |
| <3.5 90 MOHAPATRA 05 BELL Repl. | by TANIGUCHI 08 | VALUE | DO CUMENT ID TECN | COMMENT |
| 1 Also reports $ V_{td} /V_{ts} =0.195^{+0.020}_{-0.019}\pm0.015$. | | $0.57 \pm 0.05 \pm 0.05$ | BONVICINI 98 CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| $\Gamma(\overline{\Lambda}_c^- p e^+ \nu_e) / \Gamma(\overline{\Lambda}_c^- p)$ | | D ===: | co | Г99/Г98 | 1 ACKERSTAFF 97N assumes E and $B_{ m s}$. | $B(b \to B) = 0.868$ | \pm 0.041, <i>i.e.</i> , an admixture of B^0 , B^\pm , |
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| <0.04 1 BONVICINI 98 uses th | | 98 CLE2 | | (45) | ² ALAM 83B reported their | e consistent with eq | \pm 0.007 \pm 0.004. Values are for qual yields of p and \overline{p} . Using assumed |
| $\Gamma(\overline{\Sigma}_c^{} \text{ a nything})/\Gamma_{\text{tot}}$ | tal | | | Γ ₁₀₀ /Γ | $\Gamma(\Lambda \text{anything})/\Gamma(\overline{\Lambda} \text{anything})$ |) | Γ ₁₀₉ /Γ ₁₁₀ |
| VALUE <u>8</u> 0.0042±0.0021±0.0011 | | D TECN | | (A.C.) | <u>VALUE</u> 0.43±0.09±0.07 | DOCUMENT ID 1 AMMAR | 97 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| ¹ PROCARIO 94 report | | | | | ¹ AMMAR 97 uses a high-mom | | • ' ' |
| | 0.00007 which we divid | | | | $\Gamma(\Xi^-/\overline{\Xi}^+ \text{a nything})/\Gamma_{\text{total}}$ | | Γ ₁₁₁ /Γ |
| $= (5.0 \pm 1.3) \times 10^{-2}$ | . Our first error is their | experiment's er | ror and our seco | ond error is | VALUE EVT: | S DOCUMENT | |
| | om using our best value | h. | | | 0.0027 ± 0.0006 OUR AVERAGE 0.0027 ± 0.0005 ± 0.0004 147 | | D 92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Gamma(\Sigma_c^- \text{ a nything})/\Gamma_{\text{total}}$ | I CL% DOCUMENT I | D TECN | COMMENT | Γ ₁₀₁ /Γ | 0.0028 ± 0.0014 54 | | . , |
| | <u>CL%</u> <u>DOCUMENT I</u> 90 ¹ PROCARIO | 94 CLE2 | $e^+e^- \rightarrow \gamma$ | (45) | $\Gamma(\text{baryons a nything})/\Gamma_{\text{total}}$ | | Γ ₁₁₂ /Γ |
| ¹ PROCARIO 94 report | s $[\Gamma(B \rightarrow \overline{\Sigma}_c^-)]$ anythi | $^{\rm ng)}/\Gamma_{\rm total}] \times$ | $[B(\Lambda_c^+ \to p K$ | $(-\pi^+)]$ | VALUE 0.068±0.005±0.003 | | 920 ARG $e^+e^- ightarrow \varUpsilon(4S)$ |
| 0.00048 which we divi | de by our best value B(| $\Lambda_c^+ \to p K^- \pi$ | $^{+}) = 5.0 \times 10^{-}$ | -2. | • • • We do not use the following | | |
| $\Gamma(\overline{\Sigma_c^0} \text{ a nything})/\Gamma_{\text{total}}$ | | | | Γ_{102}/Γ | 0.076 ± 0.014 | | 89к ARG $e^+e^- ightarrow \varUpsilon (4S)$ |
| VALUE 0.0046 ± 0.0021 ± 0.0012 | | D TECN | c+ c- r | (4 C) | * ALBRECHT 920 result is fron lations, and various lepton-bar | n simultaneous analy ryon and lepton-bary | ysis of p and Λ yields, $p\overline{p}$ and $\Lambda\overline{p}$ corre- yon-antibaryon correlations. Supersedes |
| ¹ PROCARIO 94 report | | | | | ALBRECHT 89K. ² ALBRECHT 89K obtain this r | result by adding thei | ir their measurements (5.5 \pm 1.6)% for |
| | 0.00007 which we divid | | | | urrect protons and (4.2 ± 0.5 | 5 ± 0.6) % 101 111Clu | sive Λ production. They then assume in also. Since each B decay has two |
| $= (5.0 \pm 1.3) \times 10^{-2}$ | . Our first error is their om using our best value | experiment's er | ror and our seco | ond error is | baryons, they divide by 2 to c | | |
| _ | Ü | t. | | | Γ(pp̄anything)/Γ _{total} | _ | Γ ₁₁₃ /Γ |
| $\Gamma\left(\sum_{c}^{0} N\left(N = p \text{ or } n\right)\right) / VALUE$ | total | D TECN | COMMENT | Γ ₁₀₃ /Γ | Includes p and \overline{p} from Λ are <u>VALUE</u> <u>EVTS</u> | nd A decay. <u>DOCUMENT ID</u> | |
| <1.5 × 10 ⁻³ | 90 ¹ PROCARIO | 94 CLE2 | $e^+e^- \rightarrow \gamma$ | (45) | 0.0247±0.0023 OUR AVERAGE 0.024 ±0.001 ±0.004 | CRAWEORD | 92 CLEO $e^+e^- ightarrow \varUpsilon(45)$ |
| ¹ PROCARIO 94 report | | | | | $0.024 \pm 0.001 \pm 0.004$ $0.025 \pm 0.002 \pm 0.002$ 918 | | 89K ARG $e^+e^- \rightarrow \Upsilon(4S)$ |
| | $\rightarrow p K^- \pi^+)$] assuming | | | , which we | Γ(ρ p anything)/Γ(ρ/ p anytl | hing) | Γ ₁₁₃ /Γ ₁₀₆ |
| rescale to our best val | ue B($\Lambda_C^+ \to p K^- \pi^+$) | $= 5.0 \times 10^{-2}$ | | | Includes p and \overline{p} from Λ ar | nd ∏ decay. | |
| $\Gamma(\Xi_c^0 \text{ anything } \times B(\Xi_c^0))$ | $(c \to \Xi^- \pi^+))/\Gamma_{ m tota}$ | ıl | | Γ ₁₀₄ /Γ | <u>VALUE</u> • • We do not use the following | | TECN COMMENT i, fits, limits, etc. • • • |
| VALUE (units 10 ⁻³) 0.193±0.030 OUR AVERA | DOCUMENT I | | COMMENT | | $0.30 \pm 0.02 \pm 0.05$ | - | 92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
| | | | | | 0.30±0.02±0.03 | 0.0.00 | |
| $0.211 \pm 0.019 \pm 0.025$ | ¹ AUBERT,B | | $e^+e^- ightarrow ~ \gamma$ | (45) | 1 CRAWFORD 92 value is not | | |
| $0.211 \pm 0.019 \pm 0.025$ $0.144 \pm 0.048 \pm 0.021$ | ¹ AUBERT,B ² BARISH | 05м BABR 97 CLE2 | $e^+e^- \rightarrow \Upsilon$ $e^+e^- \rightarrow \Upsilon$ | | | | $r \Gamma(p\overline{p} \text{ anything})/\Gamma_{	ext{total}}$ value. |
| $0.211 \pm 0.019 \pm 0.025$ $0.144 \pm 0.048 \pm 0.021$ The yield is obtained b | 1 AUBERT,B 2 BARISH by requiring the momen | 05м BABR 97 CLE2 | $e^+e^- \rightarrow \Upsilon$ $e^+e^- \rightarrow \Upsilon$ | | 1 CRAWFORD 92 value is not $\Gamma(\Lambda \overline{p}/\overline{\Lambda} p a n y thing)/\Gamma_{total}$ Includes p and \overline{p} from Λ are | independent of their \overline{A} decay. | $(\Gamma(p\overline{p})^{\overline{p}})/\Gamma_{	ext{total}}$ value. $\Gamma_{	ext{114}}/\Gamma_{	ext{114}}$ |
| $\begin{array}{c} 0.211 \pm 0.019 \pm 0.025 \\ 0.144 \pm 0.048 \pm 0.021 \\ \\ {}^{1}\text{The yield is obtained t} \\ {}^{2}\text{BARISH 97 find 79} \pm \end{array}$ | $ \begin{array}{c} 1 \text{ AUBERT,B} \\ 2 \text{ BARISH} \\ \text{oy requiring the moment} \\ 27 \ \Xi_C^0 \text{ events.} \end{array} $ | 05м BABR 97 CLE2 tum P < 2.15 С | $e^+e^- \rightarrow \Upsilon$ $e^+e^- \rightarrow \Upsilon$ | (4 <i>5</i>) | 1 CRAWFORD 92 value is not $ \Gamma(\Lambda \overline{p}/\overline{\Lambda} \rho \text{anything})/\Gamma_{\text{total}} $ Includes p and \overline{p} from Λ at $ \frac{VALUE}{0.025 \pm 0.004 \text{ OUR AVERAGE}} $ | independent of their nd \overline{A} decay. <u>DOCUMENT ID</u> | r Γ(ρ̄p̄anything)/Γ _{total} value. Γ ₁₁₄ /Γ |
| $\begin{array}{l} 0.211\pm 0.019\pm 0.025 \\ 0.144\pm 0.048\pm 0.021 \\ \end{array}$ The yield is obtained to 2 BARISH 97 find 79 \pm | ¹ AUBERT,B ² BARISH by requiring the momen 27 \equiv_c^0 events. $\Xi_c^+ \to \Xi^- \pi^+ \pi^+))/$ | 05M BABR 97 CLE2 tum P $<$ 2.15 C | $e^{+}e^{-} \rightarrow \Upsilon$ $e^{+}e^{-} \rightarrow \Upsilon$ GeV/c. | | 1 CRAWFORD 92 value is not Γ(Λ̄p/Āρanything)/Γ _{total} Includes p and p̄ from Λ an VALUE EVTS | independent of their nd \$\overline{A}\$ decay. **DOCUMENT ID** **CRAWFORD** | $(\Gamma(ho\overline{ ho}) = \Gamma(ho\overline{ ho}) = \Gamma(ho\overline{ ho}) = \Gamma(ho\overline{ ho})$ represents the second value. |
| 0.211 \pm 0.019 \pm 0.025 0.144 \pm 0.048 \pm 0.021 ¹ The yield is obtained to a BARISH 97 find 79 \pm $\Gamma\left(\Xi_{c}^{+} \text{anything} \times \text{B}(\Xi_{c}^{-})\right)$ WALUE (units 10 ⁻³) | 1 AUBERT,B 2 BARISH by requiring the momen 27 $= \frac{1}{c}$ events. $= \frac{1}{c} \rightarrow \frac{1}{c} - \frac{1}{c} + \frac{1}{c} + \frac{1}{c}$ | 05M BABR 97 CLE2 tum P < 2.15 C Γ _{total} Δ ΤΕCN | $e^+e^- ightarrow \gamma$ $e^+e^- ightarrow \gamma$ GeV/c. | Γ ₁₀₅ /Γ | 1 CRAWFORD 92 value is not $ \Gamma(\Lambda \overline{p}/\overline{\Lambda}p anything)/\Gamma_{total} $ Includes p and \overline{p} from Λ at $ \underbrace{EVTS}_{0.025 \pm 0.004 OUR AVERAGE}_{0.029 \pm 0.005 \pm 0.005} $ 0.023 $\pm 0.004 \pm 0.003$ 165 | independent of their nd \$\overline{T}\$ decay. \$\overline{DOCUMENT ID}\$ CRAWFORD ALBRECHT | $\Gamma(ho\overline{ ho}$ anything)/ $\Gamma_{ m total}$ value. $\Gamma_{ m 114}/\Gamma_{ m TECN}$ $\Gamma_{ m COMMENT}$ 92 CLEO $e^+e^- ightarrow \Upsilon(4S)$ 89K ARG $e^+e^- ightarrow \Upsilon(4S)$ |
| 0.211 \pm 0.019 \pm 0.025 0.144 \pm 0.048 \pm 0.021 ¹ The yield is obtained to a BARISH 97 find 79 \pm $\Gamma(\Xi_c^+ \text{anything} \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) \times \text{B}(\Xi_c^+ \text{anything}) $ | 1 AUBERT,B 2 BARISH 2y requiring the momen: 27 \equiv_c^0 events. $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+))/$ DOCUMENT 1 1 BARISH | 05M BABR 97 CLE2 tum P < 2.15 C Γ _{total} Δ ΤΕCN | $e^{+}e^{-} \rightarrow \Upsilon$ $e^{+}e^{-} \rightarrow \Upsilon$ GeV/c. | Γ ₁₀₅ /Γ | 1 CRAWFORD 92 value is not $\Gamma(\Lambda \overline{p}/\overline{\Lambda}panything)/\Gamma_{total}$ Includes p and \overline{p} from Λ at $\frac{MLUE}{0.025\pm0.004} \frac{EVTS}{0.023\pm0.005\pm0.005}$ $0.023\pm0.004\pm0.003$ $\Gamma(\Lambda \overline{p}/\overline{\Lambda}panything)/\Gamma(\Lambda/\overline{\Lambda})$ Includes p and \overline{p} from Λ at | independent of their and \$\overline{A}\$ decay. \[\textit{DOCUMENT ID} \\ CRAWFORD \\ ALBRECHT \[\textit{Ianything} \) and \$\overline{A}\$ decay. | TECN COMMENT 92 CLEO $e^+e^- ightarrow \Upsilon(45)$ 89K ARG $e^+e^- ightarrow \Upsilon(45)$ |
| 0.211 \pm 0.019 \pm 0.025 0.144 \pm 0.048 \pm 0.021 ¹ The yield is obtained the partial part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part | 1 AUBERT,B 2 BARISH Dy requiring the momen: 27 \equiv_{c}^{0} events. Et $\rightarrow \Xi^{-}\pi^{+}\pi^{+}$))/ DOCUMENT II 1 BARISH E 28 \equiv_{c}^{+} events. | 05M BABR 97 CLE2 tum P < 2.15 C Γ _{total} Δ ΤΕCN | $e^+e^- ightarrow \gamma$ $e^+e^- ightarrow \gamma$ GeV/c. | Γ ₁₀₅ /Γ | 1 CRAWFORD 92 value is not $\Gamma(\Lambda \overline{p}/\overline{\Lambda}p \text{ anything})/\Gamma_{\text{total}}$ Includes p and \overline{p} from Λ at $\frac{EVTS}{0.025 \pm 0.004} \text{ OUR AVERAGE}$ $0.029 \pm 0.005 \pm 0.003$ $0.023 \pm 0.004 \pm 0.003$ 165 $\Gamma(\Lambda \overline{p}/\overline{\Lambda}p \text{ anything})/\Gamma(\Lambda/\overline{\Lambda})$ Includes p and \overline{p} from Λ at $\frac{VALUE}{N}$ | independent of their A decay. DOCUMENT ID CRAWFORD ALBRECHT Sanything) and A decay. DOCUMENT ID | r $\Gamma(p\overline{p}$ anything)/ $\Gamma_{	ext{total}}$ value. F114/ Γ TECN COMMENT 92 CLEO $e^+e^- 	oup \Upsilon(45)$ 89K ARG $e^+e^- 	oup \Upsilon(45)$ F114/ $\Gamma_{	ext{108}}$ |
| 0.211±0.019±0.025 0.144±0.048±0.021 ¹ The yield is obtained the description of the yield is obtained the description of the yield is obtained the description of the yield is obtained the yield is obtained the yield is obtained the yield is obtained the yield is obtained the yield is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained the yield is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it is obtained to yield it yield it is obtained to yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it yield it | $\begin{array}{c} 1 \text{ AUBERT,B} \\ 2 \text{ BARISH} \\ \text{ Dy requiring the moment} \\ 27 = \frac{1}{c} \text{ events.} \\ \\ E \xrightarrow{\textbf{c}} \Rightarrow \overline{\textbf{z}} - \pi + \pi + \mathbf{y}) / \\ \underline{DOCUMENT \ I} \\ 1 \text{ BARISH} \\ \\ E \text{ 28 } = \frac{1}{c} \text{ events.} \\ \end{array}$ | 05M BABR 97 CLE2 tum P < 2.15 C Γ _{total} Δ ΤΕCN | $e^+e^- ightarrow \gamma$ $e^+e^- ightarrow \gamma$ GeV/c. | Γ ₁₀₅ /Γ | 1 CRAWFORD 92 value is not $\Gamma(\Lambda \overline{p}/\overline{\Lambda}panything)/\Gamma_{total}$ Includes p and \overline{p} from Λ at $\frac{MLUE}{0.025\pm0.004} \frac{EVTS}{0.023\pm0.005\pm0.005}$ $0.023\pm0.004\pm0.003$ $\Gamma(\Lambda \overline{p}/\overline{\Lambda}panything)/\Gamma(\Lambda/\overline{\Lambda})$ Includes p and \overline{p} from Λ at | independent of their A decay. DOCUMENT ID CRAWFORD ALBRECHT Canything A decay. DOCUMENT ID ng data for averages | r $\Gamma(p\overline{p}$ anything)/ $\Gamma_{	ext{total}}$ value. F114/ Γ TECN COMMENT 92 CLEO $e^+e^- 	oup \Upsilon(45)$ 89K ARG $e^+e^- 	oup \Upsilon(45)$ F114/ $\Gamma_{	ext{108}}$ |
| 0.211±0.019±0.025 0.144±0.048±0.021 ¹ The yield is obtained to 2 BARISH 97 find 79± $\Gamma(\Xi_{c}^{+} \text{anything} \times B(\Xi_{c}^{-} \text{base})$ 0.453±0.096±0.085 ¹ BARISH 97 find 125± $\Gamma(p/\overline{p} \text{anything})/\Gamma_{\text{total}}$ Includes p and \overline{p} find 125± | 1 AUBERT,B 2 BARISH 27 \equiv_{c}^{0} events. $E_{c}^{+} \rightarrow E_{c}^{-} \pi^{+} \pi^{+}))/$ 1 BARISH E 28 \equiv_{c}^{+} events. 1 but A and \overline{A} decay. DOCUMENT \overline{A} DOCUMENT \overline{A} DOCUMENT \overline{A} | 05M BABR 97 CLE2 tum P < 2.15 C | $e^+e^- ightarrow \gamma$ $e^+e^- ightarrow \gamma$ GeV/c. | Γ ₁₀₅ /Γ | 1 CRAWFORD 92 value is not \[\begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \beg | independent of their A decay. DOCUMENT ID CRAWFORD ALBRECHT Canything A decay. DOCUMENT ID OCUMENT ID A data for averages 1 CRAWFORD alue is no | True $(p\overline{p}$ anything)/ Γ_{total} value. Find/ Γ TECN COMMENT 92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ 89k ARG $e^+e^- \rightarrow \Upsilon(4S)$ Find/ Γ_{108} TECN COMMENT 1, fits, limits, etc. • • • 92 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ |
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| 0.211±0.019±0.025 0.144±0.048±0.021 ¹ The yield is obtained to 2 BARISH 97 find 79 ± 「(=; anything × B(=; anything × B(=; anything) / Figure 1.005 ¹ BARISH 97 find 125 ± □(p/panything) / Fiotal includes p and p from the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the properties of the 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CRAWFORD 48 ALBRECHT CRAWFORD 48 ALBRECHT CRA | 95M BABR 97 CLE2 tum P < 2.15 C Total | $\begin{array}{c} e^+e^- \to & \Upsilon \\ e^+e^- \to & \Upsilon \\ \text{SeV/c.} \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \to & \Upsilon} \\ \\ e^+e^- \to & \Upsilon \\ \\ e^+e^- \to & \Upsilon \\ \\ e^+e^- \to & \Upsilon \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ \hline \\ COMMENT \\ \\ e^+e^- \to & \Upsilon \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT 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DOCUMENT ID CRAWFORD ALBRECHT Canything and A decay. DOCUMENT ID Ind A decay. DOCUMENT ID Ind A decay. DOCUMENT ID CRAWFORD Ind A decay. DOCUMENT ID CRAWFORD Ind A decay. DOCUMENT ID CRAWFORD Ind A decay. Ind A decay. DOCUMENT ID INVASA KI 2 AUBERT, B Ind A data for averages 2 KANEKO GLENN BEBEK | TECN COMMENT TECN COMMENT 92 CLEO $e^+e^- 	o r(4S)$ 89K ARG $e^+e^- 	o r(4S)$ T114/ Γ_{108} TECN COMMENT 7114/ Γ_{108} TECN COMMENT 7115/ Γ_{108} TECN COMMENT 92 CLEO $e^+e^- 	o r(4S)$ 93 of independent of their 94 CLEO $e^+e^- 	o r(4S)$ 95 T15/ Γ_{108} 715/ Γ_{108} 715/ Γ_{108} 716, fits, limits, etc. •• 96 CLEO $e^+e^- 	o r(4S)$ 716, fits, limits, etc. •• 97 CLEO $e^+e^- 	o r(4S)$ 716/ Γ_{108} |

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| $\Gamma(s\mu^+\mu^-)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{117}}/\Gamma$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions | | $$\Gamma_{122}/\Gamma_{}$$ neutral current. Allowed by higher-order electroweak interactions |
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| tions. VALUE (units 10 ⁻⁶) <u>CL% DOCUMENT ID TECN COMMENT</u> | tions. <u>VALUE</u> (units 10 ⁻⁷) | DOCUMENT ID TECN COMMENT |
| 4.3 \pm1.2 OUR AVERAGE 4.13 \pm 1.05 $\stackrel{+}{-}$ 0.81 $\stackrel{1}{-}$ 1 IWASAKI 05 BELL $e^+e^- \rightarrow \gamma$ (4 S) | 4.4 ± 0.4 OUR AVERAGE 4.2 ± 0.4 ± 0.2 | AALTONEN 11AI CDF pp at 1.96 TeV |
| 4.13 \pm 1.00 \pm 0.81 | $4.1^{+1.3}_{-1.2} \pm 0.2$ | 1 AUBERT 09T BABR $e^+e^- ightarrow \varUpsilon(4S)$ |
| • • We do not use the following data for averages, fits, limits, etc. • • | $5.0 \pm 0.6 \pm 0.3$ | 1 WEI 09A BELL $e^{+}e^{-} ightarrow$ \varUpsilon (4 S) |
| 7.9 $\pm 2.1 \substack{+2.1 \\ -1.5}$ KANEKO 03 BELL Repl. by IWASAKI 05 | | lowing data for averages, fits, limits, etc. • • • |
| $<$ 58 90 GLENN 98 CLEO $e^+e^- ightarrow \varUpsilon(4S)$ | $3.5 + 1.3 \pm 0.3$ | ¹ AUBERT,В 06л BABR Repl. by AUBERT 09т |
| <17000 90 CHADWICK 81 CLEO $e^+e^- ightarrow 	ag{45}$ | $4.5 + 2.3 \pm 0.4$ | ¹ AUBERT 030 BABR Repl. by AUBERT,B 06J |
| ¹ Requires $M_{\ell^+\ell^-} > 0.2 \text{ GeV}/c^2$. | $4.8^{+1.2}_{-1.1} \pm 0.4$ | ^{1,2} SHIKAWA 03 BELL Repl. by WEI 09A |
| $[\Gamma(se^+e^-) + \Gamma(s\mu^+\mu^-)]/\Gamma_{total}$ $(\Gamma_{116}+\Gamma_{117})/\Gamma$ Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interac- | 9.9+4.0+1.3 -3.2-1.0 | ABE 02 BELL Repl. by ISHIKAWA 03 of B^+ and B^0 at the $\Upsilon(4S)$. |
| tions. VALUE <u>CL% DOCUMENT ID TECN COMMENT</u> | | al of systematic uncertainties including model dependence. |
| <4.2 \times 10 ⁻⁵ 90 GLENN 98 CLEO $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(K\mu^+\mu^-)/\Gamma(Ke^+e^-)$ | Γ ₁₂₂ /Γ ₁₂₀ |
| • • We do not use the following data for averages, fits, limits, etc. • • • <0.0024 90 ¹ BEAN 87 CLEO Repl. by GLENN 98 | VALUE | DOCUMENT ID TECN COMMENT |
| <0.0062 90 ² AVERY 84 CLEO Repl. by BEAN 87 | 1.02±0.18 OUR AVERAGE | AUDEDT 00- DARD + - W(4.6) |
| ¹ BEAN 87 reports $[(\mu^+ \mu^-)+(e^+e^-)]/2$ and we converted it. | $0.96^{+0.44}_{-0.34} \pm 0.05$ $1.03 \pm 0.19 \pm 0.06$ | AUBERT 09T BABR $e^+e^- ightarrow \varUpsilon(4S)$ WEI 09A BELL $e^+e^- ightarrow \varUpsilon(4S)$ |
| ² Determine ratio of B^+ to B^0 semileptonic decays to be in the range 0.25–2.9. | | lowing data for averages, fits, limits, etc. \bullet \bullet |
| $\Gamma(s\ell^+\ell^-)/\Gamma_{	ext{total}}$ Test for $\Delta B=1$ weak neutral current. | $1.06 \pm 0.48 \pm 0.08$ | AUBERT,B 06J BABR Repl. by AUBERT 09T |
| VALUE (units 10 ⁻⁶) 9.5 ±1.0 OUR AVERAGE | $\Gamma(K^*(892)\mu^+\mu^-)/\Gamma_{	ext{tota}}$ Test for $\Delta B=1$ weak | Γ ₁₂₃ /Γ neutral current. Allowed by higher-order electroweak interac |
| $4.11\pm0.83^{+0.85}_{-0.81}$ 1 IWASAKI 05 BELL $e^+e^- ightarrow$ $\varUpsilon(4S)$ | tions. <u>VALUE (units 10⁻⁷) CL%</u> | DOCUMENT ID TECN COMMENT |
| 5.6 ± 1.5 ± 1.3 2 AUBERT,B 041 BABR $e^+e^- \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | 10.6±0.9 OUR AVERAGE | |
| 9 | $10.1 \pm 1.0 \pm 0.5$ | AALTONEN 11AI CDF $p\overline{p}$ at 1.96 TeV |
| 6.1 $\pm 1.4 \stackrel{+1.4}{-1.1}$ 2 KANEKO 03 BELL Repl. by IWASAKI 05 | $13.5 + 3.5 \pm 1.0$ | 1 AUBERT 09T BABR $e^+e^- ightarrow~ \varUpsilon(4S)$ |
| ¹ Requires $M_{\ell^+\ell^-} > 0.2 \text{ GeV}/c^2$. | $11.0 + 1.6 \pm 0.8$ | 1 WEI 09A BELL $e^{+}e^{-} ightarrow \varUpsilon(4S)$ |
| ² Requires $M_{e^+e^-} > 0.2 \text{ GeV}/c^2$. | | lowing data for averages, fits, limits, etc. • • • |
| $\Gamma(\pi\ell^+\ell^-)/\Gamma_{total}$ Γ_{119}/Γ | $8.8 ^{+\ 3.5}_{-\ 3.0} \pm 1.2$ | ¹ AUBERT,B 06J BABR Repl. by AUBERT 09T |
| VALUE CL% DOCUMENT ID TECN COMMENT | $12.7 + {7.6 \atop -6.1} \pm 1.6$ | ¹ AUBERT 030 BABR Repl. by AUBERT,B 06J |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $11.7 + \frac{3.6}{-3.1} \pm 1.0$ | ² ISHIKAWA 03 BELL Repl. by WEI 09A |
| $<$ 9.1 $	imes$ 10 ⁻⁸ 90 1 AUBERT 07AG BABR $e^+e^- ightarrow~\Upsilon(4{\mbox{S}})$ | <31 90 | ABE 02 BELL Repl. by ISHIKAWA 03 |
| 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. $\Gamma(Ke^+e^-)/\Gamma_{\rm total} \qquad \qquad \Gamma_{120}/\Gamma$ | ² Assumes equal productio | n of B^+ and B^0 at the $\varUpsilon(4S)$. n of B^0 and B^+ at $\varUpsilon(4S)$. The second error is a total o ncluding model dependence. |
| Test for $\Delta B=1$ weak neutral current. Allowed by higher-order electroweak interactions. | $\Gamma(K^*(892)\mu^+\mu^-)/\Gamma(K^*)$ | |
| VALUE (units $10^{-\ell}$) CL% DOCUMENT ID TECN COMMENT 4.4±0.6 OUR AVERAGE | 0.92±0.21 OUR AVERAGE | Error includes scale factor of 1.2. |
| $3.9 ^{+~0.9}_{-~0.8} \pm 0.2$ 1 AUBERT 09T BABR $e^+ e^- ightarrow ~ \varUpsilon (45)$ | $1.37 + 0.53 \pm 0.09$ | AUBERT 09T BABR $e^+e^- ightarrow~\varUpsilon(4S)$ |
| 0.00 | $0.83 \pm 0.17 \pm 0.08$ | MEI + - 20/46) |
| $4.8 {+ 0.8 \atop - 0.7} {\pm 0.3}$ 1 WEI 09A BELL $e^+e^- ightarrow \Upsilon(4S)$ | Mo do not use the fell | WEI 09A BELL $e^+e^- 	o 	au(4S)$ |
| $4.8^{+0.0}_{-0.7} \pm 0.3$ 1 WEI 09A BELL $e^{+}e^{-} \rightarrow \Upsilon(4S)$ • • • We do not use the following data for averages, fits, limits, etc. • • • | | lowing data for averages, fits, limits, etc. • • • |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $0.91 \pm 0.45 \pm 0.06$ | lowing data for averages, fits, limits, etc. • • • AUBERT,B 06J BABR Repl. by AUBERT 09T |
| • • We do not use the following data for averages, fits, limits, etc. • • • $3.3 ^{+0.9}_{-0.8} \pm 0.2 \qquad \qquad ^{1} \text{ AUBERT,B} \qquad \text{06J} \text{BABR} \text{Repl. by AUBERT 09T} \\ 7.4 ^{+1.8}_{-1.6} \pm 0.5 \qquad \qquad ^{1} \text{ AUBERT} \qquad \text{03U} \text{BABR} \text{Repl. by AUBERT,B 06J}$ | $0.91 \pm 0.45 \pm 0.06$ $\Gamma(K\ell^+\ell^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak tions. | lowing data for averages, fits, limits, etc. • • • AUBERT,B 06J BABR Repl. by AUBERT 09T \[\begin{align*} \Gamma_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{124444}/\limits_{124444}/\limits_{124444}/\limits_{124444}/\limits_{124444 |
| • • We do not use the following data for averages, fits, limits, etc. • • • $3.3 ^{+0.9}_{-0.8} \pm 0.2 \qquad \qquad ^{1}_{-0.8} \pm 0.2 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad$ | $0.91\pm0.45\pm0.06$ $\Gamma\big(K\ell^+\ell^-\big)/\Gamma_{	ext{total}}$ Test for $\Delta B=1$ weak | lowing data for averages, fits, limits, etc. • • • AUBERT,B 06J BABR Repl. by AUBERT 09T \[\begin{align*} \Gamma_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{124}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{1244}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{12444}/\limits_{124444}/\limits_{124444}/\limits_{124444}/\limits_{124444}/\limits_{1244 |
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| • • We do not use the following data for averages, fits, limits, etc. • • • $3.3^{+0.9}_{-0.8} \pm 0.2 \qquad \qquad ^{1}_{-0.8} \pm 0.2 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.5 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad ^{1}_{-0.8} \pm 0.3 \qquad $ | $\begin{array}{l} 0.91\pm0.45\pm0.06 \\ \hline \Gamma(\textit{K}\ell^+\ell^-)/\Gamma_{\rm total} \\ \text{Test for } \Delta B = 1 \text{ weak tions.} \\ \hline \textit{4.5}\pm0.4 \text{ OUR AVERAGE} \\ 3.9\pm0.7\pm0.2 \\ 4.8\pm0.5 \\ -0.4\pm0.3 \\ \hline \bullet \bullet \text{ We do not use the foll} \\ 3.4\pm0.7\pm0.2 \\ \hline \end{array}$ | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $3.3^{+0.9}_{-0.8} \pm 0.2$ $1 \text{ AUBERT,B} \qquad 06 \text{J} \text{BABR} \text{Repl. by AUBERT 09T}$ $7.4^{+1.8}_{-1.6} \pm 0.5$ $1 \text{ AUBERT} \qquad 03 \text{U} \text{BABR} \text{Repl. by AUBERT,B} 06 \text{J}$ $4.8^{+1.5}_{-1.3} \pm 0.3$ $1.^{2} \text{ ISHIKAWA} \qquad 03 \text{BELL} \text{Repl. by WEI 09A}$ $<13 \qquad 90 \qquad \text{ABE} \qquad 02 \text{BELL} \text{Repl. by ISHIKAWA} 03$ $1 \text{ Assumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \Upsilon(4S).$ $2 \text{ The second error is a total of systematic uncertainties including model dependence.}}$ $\Gamma(K^{*}(892) e^{+} e^{-})/\Gamma_{\text{total}}$ Γ_{121}/Γ $\Gamma_{\text{Test for } \Delta B} = 1 \text{ weak neutral current. Allowed by higher-order electroweak interactions.}$ $VALUE (with 10^{-7}) \qquad CL\% \qquad DOCUMENT ID \qquad TECN COMMENT$ | 0.91 \pm 0.45 \pm 0.06 $\Gamma(K\ell^+\ell^-)/\Gamma_{total}$ Test for $\Delta B = 1$ weak tions. **MALUE (units 10^{-7}) CL% 4.5 \pm 0.4 OUR AVERAGE 3.9 \pm 0.7 \pm 0.2 4.8 \pm 0.4 \pm 0.3 • • • We do not use the foll 3.4 \pm 0.7 \pm 0.2 6.5 \pm 1.4 \pm 0.4 | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $3.3_{-0.8}^{+0.9} \pm 0.2$ $1^{1} \text{ AUBERT,B} \qquad 0.6 \text{J} \qquad \text{BABR} \qquad \text{Repl. by AUBERT 09T}$ $7.4_{-1.6}^{+1.8} \pm 0.5$ $1^{1} \text{ AUBERT} \qquad 0.3 \text{U} \qquad \text{BABR} \qquad \text{Repl. by AUBERT,B 06J}$ $4.8_{-1.3}^{+1.5} \pm 0.3$ $1.^{1} \text{ ISHIKAWA} \qquad 0.3 \qquad \text{BELL} \qquad \text{Repl. by WEI 09A}$ $<13 \qquad 90 \qquad \text{ABE} \qquad 0.2 \qquad \text{BELL} \qquad \text{Repl. by ISHIKAWA 03}$ $1^{1} \text{ Assumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \Upsilon(4S).$ $2^{1} \text{ The second error is a total of systematic uncertainties including model dependence.}}$ $\Gamma(K^{*}(892) e^{+} e^{-})/\Gamma_{\text{total}}$ $\text{Test for } \Delta B = 1 \text{ weak neutral current. Allowed by higher-order electroweak interactions.}}$ $\frac{VALUE (units 10^{-7})}{11.9 \pm 2.0 \text{ OUR AVERAGE}} \qquad \frac{DOCUMENT ID}{\text{Error includes scale factor of } 1.2.$ | $\begin{array}{l} 0.91\pm0.45\pm0.06 \\ \hline \Gamma(\textit{K}\ell^+\ell^-)/\Gamma_{\rm total} \\ \text{Test for } \Delta B = 1 \text{ weak tions.} \\ \hline \textit{4.5}\pm0.4 \text{ OUR AVERAGE} \\ 3.9\pm0.7\pm0.2 \\ 4.8\pm0.5 \\ -0.4\pm0.3 \\ \hline \bullet \bullet \text{ We do not use the foll} \\ 3.4\pm0.7\pm0.2 \\ \hline \end{array}$ | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT,B 06J BABR Repl. by AUBERT 09T |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $3.3_{-0.8}^{+0.9} \pm 0.2 \qquad 1 \text{ AUBERT,B} \qquad 06J \text{BABR} \text{Repl. by AUBERT 09T} \\ 7.4_{-1.6}^{+1.8} \pm 0.5 \qquad 1 \text{ AUBERT} \qquad 03U \text{BABR} \text{Repl. by AUBERT,B} 06J \\ 4.8_{-1.3}^{+1.5} \pm 0.3 \qquad 1.2 \text{ISHIKAWA} \qquad 03 \text{BELL} \text{Repl. by WEI 09A} \\ <13 \qquad 90 \qquad \text{ABE} \qquad 02 \text{BELL} \text{Repl. by ISHIKAWA} 03 \\ 1 \text{ Assumes equal production of } B^+ \text{ and } B^0 \text{ at the } \Upsilon(4S). \\ 2 \text{ The second error is a total of systematic uncertainties including model dependence.}} \\ \Gamma(K^*(892)e^+e^-)/\Gamma_{\text{total}} \qquad \Gamma_{121}/\Gamma \\ \text{Test for } \Delta B = 1 \text{weak neutral current.} \text{Allowed by higher-order electroweak interactions.} \\ \frac{VALUE(\text{units }10^{-7})}{11.9\pm 2.0 \text{ OUR AVERAGE}} \frac{DOCUMENT ID}{Error includes scale factor of 1.2.} \\ 9.9_{-2.1}^{+2.3} \pm 0.6 \qquad 1 \text{AUBERT} \qquad 09T \text{BABR} e^+e^- \rightarrow \Upsilon(4S)$ | 0.91 \pm 0.45 \pm 0.06 $\Gamma(K\ell^+\ell^-)/\Gamma_{total}$ Test for $\Delta B = 1$ weak tions. **MALUE (units 10^{-7}) CL% 4.5 \pm 0.4 OUR AVERAGE 3.9 \pm 0.7 \pm 0.2 4.8 \pm 0.4 \pm 0.3 • • • We do not use the foll 3.4 \pm 0.7 \pm 0.2 6.5 \pm 1.4 \pm 0.4 | lowing data for averages, fits, limits, etc. • • • AUBERT, B 06J BABR Repl. by AUBERT 09T |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $3.3_{-0.8}^{+0.9} \pm 0.2$ $1^{1} \text{ AUBERT,B} \qquad 0.6 \text{J} \qquad \text{BABR} \qquad \text{Repl. by AUBERT 09T}$ $7.4_{-1.6}^{+1.8} \pm 0.5$ $1^{1} \text{ AUBERT} \qquad 0.3 \text{U} \qquad \text{BABR} \qquad \text{Repl. by AUBERT,B 06J}$ $4.8_{-1.3}^{+1.5} \pm 0.3$ $1.^{1} \text{ ISHIKAWA} \qquad 0.3 \qquad \text{BELL} \qquad \text{Repl. by WEI 09A}$ $<13 \qquad 90 \qquad \text{ABE} \qquad 0.2 \qquad \text{BELL} \qquad \text{Repl. by ISHIKAWA 03}$ $1^{1} \text{ Assumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \Upsilon(4S).$ $2^{1} \text{ The second error is a total of systematic uncertainties including model dependence.}}$ $\Gamma(K^{*}(892) e^{+} e^{-})/\Gamma_{\text{total}}$ $\text{Test for } \Delta B = 1 \text{ weak neutral current. Allowed by higher-order electroweak interactions.}}$ $\frac{VALUE (units 10^{-7})}{11.9 \pm 2.0 \text{ OUR AVERAGE}} \qquad \frac{DOCUMENT ID}{\text{Error includes scale factor of } 1.2.$ | 0.91 \pm 0.45 \pm 0.06 $\Gamma(K \ell^+ \ell^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak tions. **MALUE* (units 10^{-7}) 4.5 \pm 0.4 OUR AVERAGE 3.9 \pm 0.7 \pm 0.3 • • • We do not use the foll 3.4 \pm 0.7 \pm 0.2 6.5 \pm 1.4 \pm 0.4 4.8 \pm 0.9 \pm 0.3 7.5 \pm 2.5 \pm 0.6 < 5.1 | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet$ 1 AUBERT, 06J BABR Repl. by AUBERT 09T 2 AUBERT 03U BABR Repl. by AUBERT, 09T 3 ISHIKAWA 03 BELL Repl. by WEI 09A 4 ABE 02 BELL Repl. by ISHIKAWA 03 1 AUBERT 02L BABR $e^+e^- \rightarrow \Upsilon(4S)$ |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $3.3_{-0.8}^{+0.9} \pm 0.2 \qquad 1 \text{ AUBERT,B} \qquad 06J \text{BABR} \text{Repl. by AUBERT 09T} \\ 7.4_{-1.6}^{+1.8} \pm 0.5 \qquad 1 \text{ AUBERT} \qquad 03U \text{BABR} \text{Repl. by AUBERT,B} 06J \\ 4.8_{-1.3}^{+1.5} \pm 0.3 \qquad 1.2 \text{ISHIKAWA} \qquad 03 \text{BELL} \text{Repl. by WEI 09A} \\ <13 \qquad 90 \qquad \text{ABE} \qquad 02 \text{BELL} \text{Repl. by ISHIKAWA} 03 \\ 1 \text{ Assumes equal production of } B^+ \text{ and } B^0 \text{ at the } \Upsilon(4S). \\ 2 \text{ The second error is a total of systematic uncertainties including model dependence.}} \\ \Gamma(K^*(892)e^+e^-)/\Gamma_{\text{total}} \qquad \Gamma_{121}/\Gamma \\ \text{Test for } \Delta B = 1 \text{weak neutral current.} \text{Allowed by higher-order electroweak interactions.} \\ \frac{VALUE(\text{units }10^{-7})}{11.9\pm 2.0 \text{ OUR AVERAGE}} \frac{DOCUMENT ID}{Error includes scale factor of 1.2.} \\ 9.9_{-2.1}^{+2.3} \pm 0.6 \qquad 1 \text{AUBERT} \qquad 09T \text{BABR} e^+e^- \rightarrow \Upsilon(4S)$ | 0.91 \pm 0.45 \pm 0.06 $\Gamma(K\ell^+\ell^-)/\Gamma_{total}$ Test for $\Delta B = 1$ weak tions. **MALUE (units 10^{-7}) 4.5 \pm 0.4 OUR AVERAGE 3.9 \pm 0.7 \pm 0.3 • • • We do not use the foll 3.4 \pm 0.7 \pm 0.2 6.5 \pm 1.4 \pm 0.4 4.8 \pm 1.0 \pm 0.3 7.5 \pm 2.5 \pm 0.6 < 5.1 90 <17 | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet$ 1 AUBERT, 06J BABR Repl. by AUBERT 09T 2 AUBERT 03U BABR Repl. by AUBERT, 09T 3 ISHIKAWA 03 BELL Repl. by WEI 09A 4 ABE 02 BELL Repl. by ISHIKAWA 03 1 AUBERT 02L BABR $e^+e^- \rightarrow \Upsilon(4S)$ 5 ANDERSON 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ |
| *• • We do not use the following data for averages, fits, limits, etc. • • • $ 3.3 + 0.9 \pm 0.2 $ $1 \text{ AUBERT,B} \qquad 06J \text{BABR} \text{Repl. by AUBERT 09T} $ $7.4 + 1.8 \pm 0.5 $ $4.8 + 1.5 \pm 0.3 $ $1.2 \text{ ISHIKAWA} \qquad 03 \text{BELL} \text{Repl. by WEI 09A} $ $<13 \qquad 90 \qquad \text{ABE} \qquad 02 \text{BELL} \text{Repl. by ISHIKAWA 03} $ $^{1} \text{ Assumes equal production of } B^{+} \text{ and } B^{0} \text{ at the } \Upsilon(4S). $ $^{2} \text{ The second error is a total of systematic uncertainties including model dependence.} $ $T(K^{*}(892)e^{+}e^{-})/\Gamma_{\text{total}} $ $Test \text{ for } \Delta B = 1 \text{ weak neutral current. Allowed by higher-order electroweak interactions.} $ $\frac{\text{MALUE} (\text{units } 10^{-7}) \qquad \text{CL\%} \qquad \underline{DOCUMENT ID} \qquad \underline{TECN} \qquad \underline{COMMENT} $ $11.9 \pm 2.0 \text{ OUR AVERAGE} \qquad \text{Error includes scale factor of } 1.2. $ $9.9 + \frac{2.3}{2.1} \pm 0.6 \qquad 1 \text{ AUBERT} \qquad 09T \text{ BABR } e^{+}e^{-} \rightarrow \Upsilon(4S) $ $13.9 + \frac{2.3}{2.0} \pm 1.2 \qquad 1 \text{ WEI} \qquad 09A \text{ BELL} \qquad e^{+}e^{-} \rightarrow \Upsilon(4S)$ | 0.91 \pm 0.45 \pm 0.06 $\Gamma(K \ell^+ \ell^-)/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ weak tions. **MALUE (units 10^{-7}) 4.5 \pm 0.4 OUR AVERAGE 3.9 \pm 0.7 \pm 0.3 • • • We do not use the foll 3.4 \pm 0.7 \pm 0.2 6.5 \pm 1.4 \pm 0.4 4.8 \pm 1.0 \pm 0.3 7.5 \pm 2.1 \pm 0.6 < 5.1 90 1 Assumes egual production | lowing data for averages, fits, limits, etc. • • • AUBERT, B 06J BABR Repl. by AUBERT 09T |
| • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.3_{-0.8}^{+0.9} \pm 0.2 $ | 0.91 ± 0.45 ± 0.06 $\Gamma(K \ell^+ \ell^-)/\Gamma_{total}$ Test for $\Delta B = 1$ weak tions. MALUE (units 10^{-7}) 4.5 ± 0.4 OUR AVERAGE 3.9 ± 0.7 ± 0.2 4.8 + 0.5 ± 0.3 • • • We do not use the foll 3.4 ± 0.7 ± 0.2 6.5 + 1.4 ± 0.4 4.8 + 1.0 ± 0.3 7.5 + 2.5 ± 0.6 < 5.1 90 1 Assumes equal production 2 Assumes equal production 2 Assumes all four $B \rightarrow K$ 3 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assumes equal production 2 Assume | lowing data for averages, fits, limits, etc. • • • AUBERT,B 06J BABR Repl. by AUBERT 09T |
| • • We do not use the following data for averages, fits, limits, etc. • • • $ 3.3_{-0.8}^{+0.9} \pm 0.2 $ | 0.91 ± 0.45 ± 0.06 $\Gamma(K \ell^+ \ell^-)/\Gamma_{total}$ Test for $\Delta B = 1$ weak tions. MALUE (units 10^{-7}) 4.5 ± 0.4 OUR AVERAGE 3.9 ± 0.7 ± 0.2 4.8 + 0.5 ± 0.3 • • • We do not use the foll 3.4 ± 0.7 ± 0.2 6.5 + 1.4 ± 0.4 4.8 + 1.0 + 0.3 7.5 + 2.5 ± 0.6 < 5.1 90 1 Assumes equal production 2 Assumes equal production 2 Assumes equal production lepton universality for $B - C$ | lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ AUBERT,B 06J BABR Repl. by AUBERT 09T F124/I neutral current. Allowed by higher-order electroweak interact DOCUMENT ID TECN COMMENT 1 AUBERT 09T BABR $e^+e^- \rightarrow \Upsilon(4S)$ WEI 09A BELL $e^+e^- \rightarrow \Upsilon(4S)$ lowing data for averages, fits, limits, etc. $\bullet \bullet \bullet$ 1 AUBERT, B 06J BABR Repl. by AUBERT 09T 2 AUBERT 03U BABR Repl. by AUBERT, B 06J 3 ISHIKAWA 03 BELL Repl. by WEI 09A 4 ABE 02 BELL Repl. by ISHIKAWA 03 1 AUBERT 02L BABR $e^+e^- \rightarrow \Upsilon(4S)$ 5 ANDERSON 01B CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ 1 of B^+ and B^0 at the $\Upsilon(4S)$. 1 of B^+ and B^0 at the $T(4S)$. |

ABE 02 BELL Repl. by ISHIKAWA 03 1 Assumes equal production of B^+ and B^0 at the $\Upsilon(45)$. 2 Assumes equal production of B^0 and B^+ at $\Upsilon(45)$. The second error is a total of systematic uncertainties including model dependence.

¹ Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

| $\Gamma(K^*(892)\ell^+\ell^-)$ Test for ΔB |)/Γ_{total} = 1 weak neutral current | . Allowed by high | | Γ ₁₂₅ /Γ interac- | 4 | CP VIOLATIO | ON | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------------|----------------|
| tions. | | _ | | | A_{CP} is defined as | | | | |
| VALUE (units 10 ⁻⁷) 10.8±1.1 OUR A | <u>CL%</u> <u>DOCUMEN</u> VERAGE | IT ID TECN | <u>COMMENT</u> | | $\frac{B}{D}$ | $(\overline{B} \to \overline{f}) - B(B \to f)$ $(\overline{B} \to \overline{f}) + B(B \to f)$ | , | | |
| $11.1 {}^{+ 1.9}_{- 1.8} \!\pm\! 0.7$ | ¹ AUBERT | 09т ВАВ | R $e^+e^- ightarrow$ $\gamma(4S)$ |) | the <i>CP-</i> violation charge | | | I B ⁰ decay. | |
| $10.7^{+1.1}_{-1.0}\pm0.9$ | WEI | 09A BEL | L $e^+e^- ightarrow \gamma (4S)$ |) | $A_{CP}(B \rightarrow K^*(892)\gamma)$ | | | | |
| • • We do not us | se the following data for a | averages, fits, lim | ts, etc. • • • | | $A_{CP}(B \rightarrow K^*(892)\gamma)$ VALUE | DOCUMENT ID | TECN CO | MMENT | |
| $7.8^{+1.9}_{-1.7}\pm 1.1$ | ¹ AUBERT | ,B 06J BAB | R Repl. by AUBER | Т 09т | -0.003±0.017 OUR AVERAGE | | | | -\ |
| $8.8 + \frac{3.3}{-2.9} \pm 1.0$ | ² AUBERT | . 03U BAB | R Repl. by AUBER | T,B 06J | $-0.015 \pm 0.044 \pm 0.012$ 2 | NA KAO 04 | oBABR e∃ BELL e∃ | $e^- \rightarrow \gamma(4)$ $e^- \rightarrow \gamma(4)$ | , |
| $11.5 + 2.6 \pm 0.8$ | ³ ISHIKAW | /A 03 BEL | L Repl. by WEI 09 | A | $+0.08 \pm 0.13 \pm 0.03$ 2 • • We do not use the follow | | | $e^- \rightarrow \gamma(4)$ | 5) |
| <31 <33 | 90 ^{1,4} AUBERT 90 ⁵ ANDERS | | R Repl. by AUBER $e^+e^- 	o 	au(4S)$ | | $-0.013\pm0.036\pm0.010$ 3 | AUBERT,BE 04A | BABR Re | | |
| ² Assumes the p $K^*(892) e^+ e^-$ ³ Assumes equal p lepton universali error is total sys ⁴ For averaging I $B(B \rightarrow K^*(892))$ | production of B^+ and B^C partial width ratio of μ partial width ratio of μ production rate for charge ty for $B \to K\ell^+\ell^-$, and stematic uncertainties incl: $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^+\mu^-$ and $K^*(892)\mu^-$ | electron and mu $^-$) = 1.33. and neutral B m $B(B \rightarrow K^*(892)$ uding model deper $(892)e^+e^-$ mo $(92)\mu^+\mu^-)=1$. | eson pairs, isospin in $\mu^+\mu^-)=1.33$. Thendence. des, AUBERT 02L | variance, e second | 1 Corresponds to a 90% CL in 2 Assumes equal production o 3 Corresponds to a 90% CL al 4 A 90% CL range is -0.170 $A_{CP}(b \rightarrow s \gamma)$ MALUE -0.008 ± 0.029 OUR AVERAGE $-0.011 \pm 0.030 \pm 0.014$ | f B^+ and B^0 at the lowed region, -0.07 $< A_{CP} < 0.082$. | Υ(45). 4 < A _{CP} | $< 0.049.$ $\frac{COMMENT}{e^+e^- \rightarrow}$ | Y(4S) |
| $(K \nu \overline{\nu})/\Gamma_{\text{total}}$ | | | | Γ ₁₂₆ /Γ | $+0.002\pm0.050\pm0.030$ | ² NISHIDA | | $e^+e^- \rightarrow$ | r(45) |
| Test for $\Delta B =$ | =1 weak neutral current. | | | 120/1 | • • We do not use the follow | - | | | LIDEDT AC |
| <1.4 × 10 ⁻⁵ | <u>сь%</u> <u>досимя</u> 90 ¹ DEL-AI | | BR $e^+e^- \rightarrow \Upsilon(4)$ | <u>c)</u> | $+0.025 \pm 0.050 \pm 0.015$ | ³ AUBERT,B | | Repl. by A | |
| - | production of B^+ and B^0 | • | BK e¹e → I(4 | 5) [| ¹ Uses a sum of exclusively red 0.6 and 2.8 GeV/c ² . | constructed $B \rightarrow X$ | s decay mod | ies, with X_S i | mass betwe |
| $(K^* \nu \overline{\nu})/\Gamma_{\text{total}}$ Test for $\Delta B = ALUE$ (units 10^{-5}) | =1 weak neutral current. CL% DOCUME | ENT ID TEG | | Γ ₁₂₇ /Γ | 2 This measurement is perform corresponds to $-0.093 < \lambda^3$ Corresponds to $-0.06 < A_0$ | A_{CP} $<$ 0.096 at 90 | 1% CL. | _s less than 2. | 1 GeV, wh |
| <8 | 90 AUBER | | BR $e^+e^- \rightarrow \gamma(4)$ | S) | $A_{CP}(b ightarrow (s+d)\gamma)$ | DO CUMENT ID | TECN | COMMENT | |
| $\Gamma(se^{\pm}\mu^{\mp})/\Gamma_{	ext{tota}}$ Test for lepto teractions. | nl n family number conserv <u>CL% DOCUME</u> | | / higher-order electro | Г ₁₂₈ /Г weak in- | $egin{array}{cccccccccccccccccccccccccccccccccccc$ | 1 AUBERT AUBERT,BE 2 COAN | 06в BABF | $\begin{array}{c} & e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \end{array}$ | r(45) |
| <2.2 × 10 ⁻⁵ | 90 GLENN | 98 CLI | $e^+e^- \rightarrow r(4)$ | S) | $^{ m 1}$ Uses a fully reconstructed $\it B$ | meson as a tag on t | he recoil side | . Requires E, | γ > 2.2 Ge |
| $\Gamma(\pi e^{\pm} \mu^{\mp})/\Gamma_{\text{tota}}$ | | | | Γ ₁₂₉ /Γ | 2 Corresponds to $-0.27 < A_{C_1}$ | $_{P} <$ 0.10 at 90% CL | | | |
| | al ı family number conserva | ion. | | 129/1 | $A_{CP}(B \to X_s \ell^+ \ell^-)$ | | | | |
| VALUE | CL% DO CUME | NT ID TEC | | | $ACP(D \rightarrow X_S \ell \cdot \ell)$ | DO CUMENT ID | TECN | COMMENT | |
| <9.2 × 10 ⁻⁸ | 90 ¹ AUBER | | BR $e^+e^- ightarrow \gamma(4)$ | S) | $-0.22 \pm 0.26 \pm 0.02$ | 1 AUBERT,B | 04ı BABF | $e^+e^- \rightarrow$ | T(45) |
| $<1.6 \times 10^{-6}$ | se the following data for $^{\circ}$ 90 $^{-1}$ EDWAF production of B^+ and B^0 | RDS 02B CLI | E2 $e^+e^- \rightarrow \Upsilon(4)$ | S) | 1 The final state flavor is dete $= \kappa_S^0$, $\kappa_S^0 \pi^0$ or $\kappa_S^0 \pi^+ \pi^-$ | | and pion cha | rges where m | odes with . |
| Γ(- a±∓) /Γ | | , | | Г /Г | $A_{CP}(B \rightarrow K^* e^+ e^-)$ | | | | |
| | ı family number conserva | | | Γ ₁₃₀ /Γ | <u>VALUE</u> −0.18±0.15±0.01 | <u>DOCUMENT ID</u> WEI | 09A BELL | $e^+e^- \rightarrow$ | Υ(45) |
| <3.2 × 10 ⁻⁶ | 90 ¹ EDWAF | RDS 02B CLI | | S) | $A_{CP}(B \rightarrow K^* \mu^+ \mu^-)$ | | 03.1. 0222 | | . () |
| ¹ Assumes equal p | production of B^+ and B^0 | at the $T(4S)$. | | | <u>VALUE</u> | DOCUMENT ID | TECN | | 20(4.6) |
| $\Gamma(K e^{\pm} \mu^{\mp})/\Gamma_{tot}$ Test of lepton | al family number conserva | ion. | | Γ ₁₃₁ /Γ | $-0.03 \pm 0.13 \pm 0.02$ $A_{CP}(B \rightarrow K^* \ell^+ \ell^-)$ | WEI | U9A BELL | e ⁺ e [−] → | 1 (45) |
| VALUE (units 10^{-7}) | CL% DOCUME | | COMMENT | | VALUE | DO CUMENT ID | TECN | COMMENT | |
| < 0.38 | 90 ¹ AUBER | | BR $e^+e^- ightarrow \gamma(4)$ | S) | -0.07±0.08 OUR AVERAGE | | | - | |
| | se the following data for a | • | | _, | $+0.01{}^{+0.16}_{-0.15}{}^{\pm0.01}$ | AUBERT | 09T BABE | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| <16 | 90 ¹ EDWAF | | $E2 e^+ e^- \rightarrow \Upsilon(4)$ | S) | $-0.10\pm0.10\pm0.01$ | WEI | 09A BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| | production of B^+ and B^0 | at the $\Upsilon(4S)$. | | F /F | $A_{CP}(B \rightarrow \eta \text{ anything})$ | DO CHASET IS | TE 011 | CO**** | |
| • | family number conserva | | | Γ ₁₃₂ /Γ | $-0.13 \pm 0.04 + 0.02 \\ -0.03$ | DOCUMENT ID 1 NISHIMURA | | $e^+e^- \rightarrow$ | Υ(4S) |
| VALUE (units 10 ⁻⁷) < 5.1 | 90 ¹ AUBER | T,B 06J BA | BR $e^+e^- \rightarrow r(4)$ | <i>S</i>) | $^{-}$ Uses $B \rightarrow ~\eta X_S$ with 0.4 $<$ | $m_{\chi_{\rm S}} < 2.6~{ m GeV/c^2}$ | | | |
| | se the following data for : | • | | | | | | | |
| <62 | 90 ¹ EDWAF | DC 000 CLI | $e^+e^- \rightarrow \Upsilon(4)$ | C) | P∩I | ARIZATION IN | M DECAV | | |

In decays involving two vector mesons, one can distinguish among the states in which meson polarizations are both longitudinal (£) or both are transverse and parallel (\parallel) or perpendicular (\perp) to each other with the parameters $\Gamma_L/\Gamma,\,\Gamma_\perp/\Gamma,$ and the relative phases ϕ_\parallel and $\phi_\perp.$ See the definitions in the note on "Polarization in B Decays" review in the B^0 Particle Listings.

 $^{^{1}}$ Results with different \mathbf{q}^{2} cuts are also reported.

Meson Particle Listings B^{\pm}/B^{0} ADMIXTURE

| $E_L(B \to K^* \ell^+ \ell^-) (m_{\ell\ell} < 1)$ | | TE 641 | CO.4445WT | $B(B \to K^* \ell^+ \ell^-)$ (4.3 < | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|-------------------|---------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|----------------------------------|----------------|------------------------------------------------------------------|
| .35±0.16±0.04 | DOCUMENT ID AUBERT 09N | TECN BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) 1.60±0.35 OUR AVERAGE | DO CUMENT ID | - | TECN | COMMENT |
| $L(B \rightarrow K^*\ell^+\ell^-) (m_{\ell\ell} > 1)$ | 3.2 GeV/c ²) | <u>TECN</u> | COMMENT | $1.72 \pm 0.41 \pm 0.14$ $1.37 \stackrel{+}{-} 0.47 \pm 0.39$ | AALTONEN WEI | | | $p\overline{p}$ at 1.96 TeV $e^+e^- \rightarrow \Upsilon(4S)$ |
| 71 + 0.20 ± 0.04 | | | $e^+e^- \rightarrow \Upsilon(4S)$ | • • • We do not use the follow | = | _ | | |
| | 2 C 2 (2) | | | 1.69±0.57±0.15 | AALTONEN | | | Repl. by AALTONEN 1 |
| $L(B \rightarrow K^*\ell^+\ell^-) (q^2 < 2.0)$ $LUE \longrightarrow LUE$ $LUE \longrightarrow LUE$ $LUE \longrightarrow LUE$ | DOCUMENT ID | TECN | COMMENT | $B(B \to K^* \ell^+ \ell^-)$ (10.09) <u>VALUE</u> (units 10 ⁻⁷) 1.95 ± 0.28 OUR AVERAGE | < q ² < 12.86 | | TECN | COMMENT |
| $3 + 0.32 \pm 0.07$ | AALTONEN 11L | CDF | $p\overline{p}$ at 1.96 TeV | $1.77 \pm 0.34 \pm 0.11$ | AALTONEN | 11AI | CDF | $p\overline{p}$ at 1.96 TeV |
| $9 { + 0.21 \atop - 0.18 } \pm 0.02$ | WEI 09A | BELL | $e^+ e^- ightarrow ~ \varUpsilon(45)$ | $2.24 + 0.44 \pm 0.19$ | WEI | | | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $(B \rightarrow K^*\ell^+\ell^-)$ (2.0 < q ² | 2 < 4.3 GeV ² /c ²) | TECN | COMMENT | • • • We do not use the follow $1.97 \pm 0.47 \pm 0.17$ | AALTONEN | 11L | CDF | ts, etc. • • • Repl. by AALTONEN 1 |
| 0±0.20 OUR AVERAGE | | | | $B(B \to K^* \ell^+ \ell^-)$ (14.18 | - | | | |
| $10 + 0.32 \pm 0.08$ $71 \pm 0.24 \pm 0.05$ | | CDF | $p\overline{p}$ at 1.96 TeV $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) 1.14±0.19 OUR AVERAGE | DO CUMENT ID | | TECN | COMMENT |
| | | BLLL | e e → 7(43) | $1.21 \pm 0.24 \pm 0.07$ | AALTONEN | 11AI | | p p at 1.96 TeV |
| $L(B \rightarrow K^*\ell^+\ell^-)$ (4.3 < q ² | - < 8.6 GeV-/c-) DOCUMENT ID | TECN | COMMENT | $1.05 + 0.29 \pm 0.08$ • • • We do not use the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following th | WEI wing data for ave | | | $e^+e^- \rightarrow r(4S)$ |
| 74+0.15 OUR AVERAGE | | | | $1.51 \pm 0.36 \pm 0.13$ | = | - | | Repl. by AALTONEN 1 |
| $2 + 0.19 \pm 0.07$ | AALTONEN 11L | CDF | ρ p at 1.96 TeV | $B(B \to K^* \ell^+ \ell^-) (16.0$ | $< q^2 \text{ GeV}^2/c^2$ |) | | |
| $4 + 0.23 \pm 0.07$ $4 - 0.24 \pm 0.07$ | | | $e^+e^- \rightarrow \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) | DO CUMENT ID | | TECN | COMMENT |
| 0.21 | | | · / | 1.3 ±0.6 OUR AVERAGE 0.88±0.22±0.05 | Error includes sca AALTONEN | | | <i>p</i> |
| $L(B \rightarrow K^*\ell^+\ell^-)$ (10.09 < | q ² < 12.86 GeV ² | / c²) | COMMENT | $2.04 ^{+\ 0.27}_{-\ 0.24} \pm 0.16$ | WEI | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| 23±0.12 OUR AVERAGE | | | | • • • We do not use the follow | - | - | | |
| $31 + 0.19 \pm 0.02$ | | CDF | ρ p at 1.96 TeV | $1.35 \pm 0.37 \pm 0.12$ | AALTONEN | | CDF | Repl. by AALTONEN 1 |
| $7^{+0.17}_{-0.15}\pm0.03$ | WEI 09A | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ | $B(B \to K^* \ell^+ \ell^-) \ (1.0 < 1.0)$ | - | | TECN | COMMENT |
| $(B \to K^* \ell^+ \ell^-) (14.18 <$ | | | | VALUE (units 10 ⁻⁷) 1.48±0.30 OUR AVERAGE | DO CUMENT ID | | TECN | COMMENT |
| D.34±0.31 OUR AVERAGE Erro | DOCUMENT ID or includes scale facto | TECN r of 2.1. | COMMENT | $1.48 \pm 0.39 \pm 0.12$ | AALTONEN | | | p p at 1.96 TeV |
| $0.55 + 0.17 \pm 0.02$ | | CDF | $p\overline{p}$ at 1.96 TeV | $1.49 + 0.45 \pm 0.12$ • • • We do not use the follow | WEI wing data for ave | | | $e^+e^- ightarrow \gamma(4S)$ |
| $0.15 + 0.27 \pm 0.07$ | WEI 09A | BELL | $e^+ e^- ightarrow \varUpsilon(4S)$ | $1.60 \pm 0.54 \pm 0.14$ | AALTONEN | _ | | Repl. by AALTONEN 1 |
| $L(B \to K^* \ell^+ \ell^-) \ (16.0 < \epsilon)$ | n ² GeV ² /c ² \ | | | $B(B \to K^*\ell^+\ell^-) (0.0 <$ | $q^2 < 4.3 \text{ GeV}$ | / ² /c ²) | | |
| LUE | DOCUMENT ID | TECN | COMMENT | VALUE (units 10^{-7}) | DO CUMENT ID | | TECN | COMMENT |
| 11 ^{+0.12} OUR AVERAGE | | | | 2.53±0.43±0.15 • • • We do not use the follow | | | | $p\overline{p}$ at 1.96 TeV ts, etc. \bullet \bullet |
| $9^{+0.18}_{-0.14} \pm 0.03$ | AALTONEN 11L | CDF | $p\overline{p}$ at 1.96 TeV | $1.98 \pm 0.55 \pm 0.18$ | AALTONEN | _ | | Repl. by AALTONEN 1 |
| $2 + 0.15 \\ -0.13 \pm 0.02$ | WEI 09A | BELL | $e^+ e^- ightarrow \varUpsilon(4S)$ | $B(B \rightarrow K\ell^+\ell^-) (q^2 < 2)$ | | | | |
| $_L(B \rightarrow K^*\ell^+\ell^-) \ (1.0 < q^2)$ | 2 < 6.0 GeV 2 /c 2) | | | VALUE (units 10 ⁻⁷) 0.46±0.22 OUR AVERAGE | <u>DOCUMENT ID</u> Error includes sca | | TECN of 2.4 | COMMENT |
| 60±0.18 OUR AVERAGE | DOCUMENT ID | TECN | COMMENT | $0.33 \pm 0.10 \pm 0.02$ | AALTONEN | 11AI | CDF | $p\overline{p}$ at 1.96 TeV |
| 50+0.27 -0.30 ± 0.03 | AALTONEN 11L | CDF | ρ p at 1.96 TeV | $0.81 + 0.18 \pm 0.05$ | WEI | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| -0.30 $57 \pm 0.23 \pm 0.05$ | | | $e^+e^- \rightarrow \Upsilon(4S)$ | • • • We do not use the follow $0.38 \pm 0.16 \pm 0.03$ | wing data for ave AALTONEN | _ | | |
| $L(B \to K^* \ell^+ \ell^-) \ (0.0 < q^2)$ | 2 < 4.3 GeV 2 /c 2) | | | $B(B \to K\ell^+\ell^-) (2.0 <$ | | | | , , |
| LÜE | DO CUMENT ID | TECN | COMMENT | VALUE (units 10 ⁻⁷) | DO CUMENT ID | <u> </u> | TECN | COMMENT |
| $17 + 0.23 \pm 0.03$ | AALTONEN 11L | CDF | <i>p</i> | 0.61 ± 0.15 OUR AVERAGE 0.77 $\pm 0.14 \pm 0.05$ | Error includes sca AALTONEN | le factor 11AI | | ρ p at 1.96 TeV |
| PARTIAL BRANCHI | NG FRACTIONS | N B - | K(*) f+ f- | $0.46 + 0.14 \pm 0.03$ | WEI | 09A | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $(B \rightarrow K^* \ell^+ \ell^-) (q^2 < 2.0)$ | | | | • • • We do not use the follow | = | _ | | |
| | | ECN_C | DMMENT | $0.58 \pm 0.19 \pm 0.04$ | AALTONEN | | CDF | Repl. by AALTONEN 1 |
| 1±0.26 OUR AVERAGE | | | | $B(B \to K\ell^+\ell^-) (4.3 <$ | • | | | |
| . 0.40 | ALTONEN 11ALC VEI 09A B | | $\overline{\sigma}$ at 1.96 TeV $+e^- ightarrow ~ \Upsilon(4S)$ | VALUE (units 10 ⁻⁷) 1.03±0.13 OUR AVERAGE | DO CUMENT ID | | TECN | COMMENT |
| • We do not use the following | | | * * | $1.05 \pm 0.17 \pm 0.07$ | AALTONEN | 11AI | | p p at 1.96 TeV |
| 8±0.40±0.09 A | ALTONEN 11L C | DF R | epl. by AALTONEN 11AI | $1.00^{+0.19}_{-0.18} \pm 0.06$ | WEI | | | $e^+e^- 	o 	au(4S)$ |
| $B \to K^* \ell^+ \ell^-) (2.0 < q^2)$ | $< 4.3 \text{ GeV}^2/\text{c}^2$) | | | • • • We do not use the follow $0.93 \pm 0.25 \pm 0.06$ | Wing data for ave | _ | | ts, etc. • • • Repl. by AALTONEN 1 |
| | | ECN C | DMMENT | $B(B \to K\ell^+\ell^-) (10.09$ | | | | , , |
| | | | | $\frac{D(B \to K\ell^{-}\ell^{-})}{VALUE(units10^{-7})}$ | DOCUMENT ID | | TECN | COMMENT |
| 84±0.20 OUR AVERAGE | ALTONEN 11AL C | DF p | o at 1.96 TeV | VALUE (BILLS 10) | DO COMENT ID | | ILCIV | COMMENT |
| 84±0.20 OUR AVERAGE 82±0.26±0.06 A | | | e^{-} at 1.96 TeV $e^{-} ightarrow ~ \varUpsilon(4S)$ | 0.50±0.09 OUR AVERAGE | ' | | | |
| 84 ± 0.20 OUR AVERAGE $82 \pm 0.26 \pm 0.06 \qquad \qquad A$ $86 \frac{+ 0.31}{0.27} \pm 0.07 \qquad \qquad W$ • • We do not use the following | VEI 09A B data for averages, fits | ELL e | $^+e^- \rightarrow ~ \gamma(4S)$ | | AALTONEN WEI | 11AI 09A | CDF | $p\overline{p}$ at 1.96 TeV $e^+e^- \rightarrow \Upsilon(4S)$ |

| $B(B \to K\ell^+\ell^-)$ (14.18) VALUE (units 10 ⁻⁷) | DOCUMENT ID | TEC | N CO | MMENT | |
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| 0.49 + 0.08 OUR AVERAGE | | | | | |
| $0.52 \pm 0.09 \pm 0.03$ | AALTONEN | 11ai CDI | F p | at 1.96 TeV | |
| $0.38 + 0.19 \pm 0.02$ | | 09A BEL | | $e^- \rightarrow \Upsilon(4S)$ | |
| \bullet • We do not use the follo $0.38 \pm 0.12 \pm 0.03$ | | ges, fits, l 11L CDI | | tc. ● ● ● pl. by AALTONE! | d 11aı |
| | | IIL CD | i ite | pi. by AALTONLI | M IIMI |
| $B(B \rightarrow K\ell^+\ell^-)$ (16.0 < ALUE (units 10^{-7}) | c q2 GeV2/c2) DOCUMENT ID | TEC | N CO | MMENT | |
| 0.49±0.24 OUR AVERAGE | Error includes scale | TEC factor of | | WINENT | |
| $0.38 \pm 0.09 \pm 0.02$ | | 11AL CDI | | at 1.96 TeV | |
| $0.98 ^{+0.20}_{-0.18} \pm 0.06$ • • We do not use the follo | | 09A BEL res fits I | | $e^- \rightarrow \Upsilon(4S)$ | |
| $0.35 \pm 0.13 \pm 0.02$ | | 11L CDI | | pl. by AALTONE! | N 11AI |
| $B(B \rightarrow K\ell^+\ell^-) (1.0 <$ | $q^2 < 6.0 \text{ GeV}^2/c$ | : ²) | | | |
| ALUE (units 10^{-7}) | DOCUMENT ID | TEC | N CO | MMENT | |
| 32±0.15 OUR AVERAGE 29±0.18±0.08 | AALTONEN : | 11ai CDI | F D | at 1.96 TeV | |
| $.36 + 0.23 \pm 0.08$ | | 09A BEL | | $e^- \rightarrow \Upsilon(4S)$ | |
| • • We do not use the follo | - | ges, fits, l | | | |
| $.01\pm0.26\pm0.07$ | AALTONEN | 11L CDI | F Re | pl. by AALTONE! | V 11AI |
| $3(B \rightarrow K\ell^+\ell^-) (0.0 <$ | | - | | | |
| /ALUE (units 10 ⁻⁷) | DOCUMENT ID AALTONEN | TEC 11AI CDI | | mmENT at 1.96 TeV | |
| • • We do not use the follo | | | | | |
| $.96 \pm 0.25 \pm 0.06$ | AALTONEN | 11L CDI | F Re | pl. by AALTONE! | V 11AI |
| where $s=q^2/m_B^2$, an flight direction of the addition, the fraction the relative contribution $B \to K\ell^+\ell^-$, can be added to the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second se | of longitudinal pola on from scalar and p | the lepto d in the rization l oseudosca | on with dileptor ${\sf F}_L$ of talent | respect to the rest frame. In the K^* and F_S , guin amplitudes | |
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| where $\mathbf{s} = \mathbf{q}^2/m_B^2$, an flight direction of the addition, the fraction the relative contribution $B \to Ke^+\ell^-$, cadecay products. 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In he K^* and F_S , guin amplitudes stribution of its $\frac{COMMENT}{e^+e^- \to r(4S)}$ the $e^+e^- \to r(4S)$ of the q^2 bins for considering $p_{\overline{p}}$ at 1.96 TeV $e^+e^- \to r(4S)$ | $s \theta > 0$ |
| where $\mathbf{s} = \mathbf{q}^2/m_B^2$, an flight direction of the addition, the fraction the relative contribution $B \to Ke^+\ell^-$, cadecay products. 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AFB($B \to K^* \ell^+ \ell^-$) (q ² ALUE CL% 0.50 ± 0.15 ± 0.02 • • We do not use the followood on the selection of the addition of the contribution of the | $A_{FB}(s) = \frac{N(\cos\theta)}{N(\cos\theta)}$ d θ is the angle of θ meson, measured of longitudinal polar on from scalar and ϕ and be measured from θ and θ measured from θ and θ measured from θ and θ measured from θ and θ measured from θ measured from θ and θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured from θ measured | the leptod in the distribution of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod of the leptod | on with dileptor FL of the large per gular dileptor BELL imits, e. 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| where $s = q^2/m_B^2$, an flight direction of the addition, the fraction the relative contribution $B \to Ke^+\ell^-$, codecay products. 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In he K^* and F_S , guin amplitudes stribution of its $\frac{COMMENT}{e^+e^- \to r(4S)}$ the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ of the $e^+e^- \to r(4S)$ | $s \theta > 0$ |

| $A_{FB}(B \rightarrow K^*\ell^+\ell^-)$ (14.18 | | | | |
|------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|--------------------------------|-------------------|--------------------------------------------------------------------------------|
| | DO CUMENT ID | | <u>TECN</u> | COMMENT |
| 0.53 ^{+ 0.13} OUR AVERAGE | | | | |
| 0.42±0.16±0.09 | AALTONEN | 11L | CDF | p p at 1.96 TeV |
| $0.70 + 0.16 \pm 0.10$ | WEI | 09A | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $A_{FB}(B \rightarrow K^* \ell^+ \ell^-) (16.0)$ | < q ² GeV ² /c ² | | <u>TECN</u> | COMMENT |
| 0.67 ^{+0.10} OUR AVERAGE | | | | |
| $0.70 {}^{+ 0.16}_{- 0.25} \pm 0.10$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $0.66^{+0.11}_{-0.16}\pm0.04$ | WEI | 09A | BELL | $e^+e^- ightarrow \gamma(4S)$ |
| $A_{FB}(B 	o K^*\ell^+\ell^-)$ (1.0 < | < q ² < 6.0 GeV | / ² /c ² |) TECN | COMMENT |
| 0.32±0.23 OUR AVERAGE | | | | |
| $0.43 + 0.36 \pm 0.06$ | AALTONEN | 11L | CDF | p p at 1.96 TeV |
| $0.26 + 0.27 \pm 0.07$ | WEI | 09A | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $A_{FB}(B 	o K^*\ell^+\ell^-) (0.0 	ext{ <}$ | q ² < 4.3 GeV | / ² /c ² | <u>TECN</u> | COMMENT |
| $0.21 + 0.31 \pm 0.05$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $A_{FB}(B \rightarrow K^* \ell^+ \ell^-) (m_{\ell\ell})$ | < 2.5 GeV/c ² |) | TECN | COMMENT |
| $0.24^{+0.18}_{-0.23} \pm 0.05$ | AUBERT | 09n | BABR | |
| $\Lambda_{FB}(B \to K^*\ell^+\ell^-) (m_{\ell\ell})$ | > 3.2 GeV/c ² |) | TECN | COMMENT |
| $0.76 + 0.52 \pm 0.07$ | AUBERT | 09N | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Lambda_{FB}(B \to K\ell^+\ell^-) (q^2 > 0)$ | | | TECN | COMMENT |
| 0.11±0.12 OUR AVERAGE | DO CUMENT ID | | TECN | COMMENT |
| $0.15 + 0.21 \pm 0.08$ | ¹ AUBERT,B | 06J | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $^{1.10\pm0.14\pm0.01}$ Results with different q 2 cuts 2 Using an unbinned max. likelihand $\cos\theta<0$. | | 06 $_c$ distr | BELL ibution i | ${ m e^+e^-} ightarrow~\Upsilon(45)$ n five ${ m q}^2$ bins for $\cos	heta >0$ |
| $\Lambda_{FB}(B	o K\ell^+\ell^-)$ (q ² < 2 | 2.0 GeV ² /c ²) | | <u>TECN</u> | COMMENT |
| -0.02±0.26 OUR AVERAGE | | | | |
| $-0.15 + 0.46 \pm 0.08$ | AALTONEN | 11L | CDF | p p at 1.96 TeV |
| $0.06 + 0.32 \pm 0.02$ | WEI | 09A | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Lambda_{FB}(B \to K\ell^+\ell^-)$ (2.0 < | $q^2 < 4.3 \text{ GeV}^2$ | ² /c ²) | TECN | COMMENT |
| 0.2 ±0.6 OUR AVERAGE Er | ror includes scale | facto | of 2.2. | COMMENT |
| $0.72 + 0.40 \pm 0.07$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $-0.43 + 0.38 \pm 0.09$ | WEI | 09A | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Lambda_{FB}(B \to K\ell^+\ell^-)$ (4.3 < | q ² < 8.6 GeV ² | | TECN | COMMENT |
| -0.20 + 0.10 OUR AVERAGE | | | | |
| $-0.20 + 0.17 \pm 0.03$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| -0.20 $-0.20 + 0.12 \pm 0.03$ | WEI | 09A | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Lambda_{FB}(B \rightarrow K\ell^+\ell^-)$ (10.09) | | | | |
| -0.15 + 0.13 OUR AVERAGE | DOCUMENT ID | | TECN | COMMENT |
| $-0.10 + 0.17 \pm 0.07$ | AALTONEN | 110 | CDF | p p at 1.96 TeV |
| -0.15 ± 0.07 $-0.21 \pm 0.17 \pm 0.06$ | | | | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $\Lambda_{FB}(B \to K\ell^+\ell^-)$ (14.18) | | | | COMMENT |
| 0.03 ^{+0.27} OUR AVERAGE | <u>DO CUMENT ID</u> | | I E CIV | COMMENT |
| $0.03 + 0.49 \pm 0.04$ | AALTONEN | 11ı | CDF | p p at 1.96 TeV |
| $0.04 + 0.32 \pm 0.05$ | | | | |
| 1.04 : 5.55 ± 0.05 | WEI | 09A | RFLL | $e^+e^- \rightarrow \Upsilon(4S)$ |

Meson Particle Listings B^{\pm}/B^0 ADMIXTURE

| $A_{FB}(B \rightarrow K\ell^+\ell^-)$ (1 | $6.0 < q^2 \text{ GeV}^2/c^2$ | | TECN | COMMENT |
|----------------------------------------------|---------------------------------|-------------------|------|---------------------------------------|
| 0.03 ⁺ 0.10 OUR AVERAGE | | | | |
| $0.07^{+0.30}_{-0.23} \pm 0.02$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $0.02 {}^{+ 0.11}_{- 0.08} \pm 0.02$ | WEI | 09A | BELL | $e^+e^- ightarrow ~ \gamma(4S)$ |
| $A_{FB}(B \rightarrow K\ell^+\ell^-)$ (1 | $0.0 < q^2 < 6.0 \text{ GeV}^2$ | /c ²) | | |
| <u>VALUE</u> -0.01 ± 0.13 OUR AVERAG | DO CUMENT ID | | TECN | COMMENT |
| 0.08 + 0.27 ± 0.07 | | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $-0.04^{+0.13}_{-0.16}\pm0.05$ | WEI | 09A | BELL | $e^+e^- ightarrow ~ \Upsilon(45)$ |
| $A_{FB}(B \rightarrow K\ell^+\ell^-)$ (0 | $0.0 < q^2 < 4.3 \text{ GeV}^2$ | /c ²) | | |
| VALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT |
| $0.36^{+0.24}_{-0.26} \pm 0.06$ | AALTONEN | 11L | CDF | $p\overline{p}$ at 1.96 TeV |
| $F_S(B \to K\ell^+\ell^-)$ (q ² | $> 0.1 \text{ GeV}^2/c^2)$ | | | |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $0.81 + 0.58 \pm 0.46$ | ¹ AUBERT,B | ر96 | BABR | $e^+e^- ightarrow ~ \varUpsilon(45)$ |
| $^{ m 1}$ Results with different q $^{ m 2}$ | cuts are also reported. | | | |
| | ICOCDINI ACVAM | | | |

ISOSPIN ASYMMETRY

 Δ_{0-} is defined as

$$\frac{\Gamma(B^0 \to f_d) - \Gamma(B^+ \to f_u)}{\Gamma(B^0 \to f) + \Gamma(B^+ \to f)}$$

the isospin asymmetry of inclusive neutral and charged B decay.

$\Delta_{0-}(B(B \rightarrow X_s \gamma))$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|------|------|------------------------------------|
| -0.01 ±0.06 OUR AVERAGE | | | | |
| $-0.06 \pm 0.15 \pm 0.07$ | ^{1,2} AUBERT | 080 | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $-0.006\pm0.058\pm0.026$ | AUBERT,B | 05 R | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| 1 The result is for F > 2.2 Gr | ٠.٧ | | | |

$\Delta_{0+}(B \rightarrow K^*(892)\gamma)$

 Δ_{0+} describes the isospin asymmetry between $\Gamma(B^0 o K^*(892)^0\gamma)$ and $\Gamma(B^+ o$

| VALUE | DO CUMENT ID | TECN | COMMENT | | | | |
|-----------------------------|------------------------|----------|-----------------------------------------|--|--|--|--|
| 0.052±0.026 OUR AVERAGE | | | | | | | |
| $0.066 \pm 0.021 \pm 0.022$ | ¹ AUBERT | | $e^+e^- ightarrow \gamma(4S)$ | | | | |
| $0.012 \pm 0.044 \pm 0.026$ | NAKAO | 04 BELL | $e^+ e^- ightarrow \varUpsilon(4S)$ | | | | |
| | | | | | | | |
| $0.050 \pm 0.045 \pm 0.037$ | ² AUBERT,BE | 04A BABF | Repl. by AUBERT 09AO | | | | |

 1 Uses the production ratio of charged and neutral B from $\varUpsilon(45)$ decays and the lifetime ratio $\tau_{B^+}/\tau_{B^0}=1.071\pm0.009.$ The 90% CL interval is $0.017<~\Delta_{0+}<0.116$

² Uses the production ratio of charged and neutral B from $\Upsilon(4S)$ decays R^{+/0} = 1.006 \pm 0.048 and the lifetime ratio of τ_{B^+} / τ_{B^0} = 1.083 \pm 0.017. The 90% CL interval is $-0.046 < \Delta_{0+} < 0.146.$

$\Delta_{\rho\gamma} = \Gamma(B^+ \to \rho^+ \gamma) / (2 \cdot \Gamma(B^0 \to \rho^0 \gamma)) - 1$

| VALUE | DOCUMENT ID | TECIV | COMMENT |
|--------------------------------------------|-------------|-----------|---------------------------------------|
| -0.46 ± 0.17 OUR AVERAGE | | | |
| $-0.43{}^{+0.25}_{-0.22}{\pm}0.10$ | AUBERT | 08вн BABR | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |
| $-0.48 {}^{+ 0.21 + 0.08}_{- 0.19 - 0.09}$ | TANIGUCHI | 08 BELL | $e^+e^- ightarrow ~ \varUpsilon(4S)$ |

DOCUMENT ID TECN COMMENT

$\Delta_{0-}(B(B \rightarrow K\ell^+\ell^-))$

| $-0.40^{+0.34}_{-0.30}$ OUR AVERAGE | Error includes scale factor of 1.9. | | | | | |
|-------------------------------------|-------------------------------------|-----|------|--------------|-------|--|
| $-1.43 ^{+ 0.56}_{- 0.85} \pm 0.05$ | 1,2 AUBERT | 09т | BABR | $e^+e^- \to$ | T(45) | |
| $-0.31^{+0.17}_{-0.14}\pm0.08$ | 3 WEI | 09A | BELL | $e^+e^- \to$ | Y(45) | |

 $^{^{1}\, {}m For} \,\, 0.1 < m_{
ho + \,
ho -}^{2} < 7.02 \,\, {
m GeV}^{2}/{
m c}^{4}.$

$\Delta_{0-}(B(B \rightarrow K^*\ell^+\ell^-))$

| -U-(U(D / N & C)) | | | | | | |
|--------------------------------------------------------------------------|----------------------|-------------|------|--------------|----------------|--|
| VALUE | DO CUMENT ID | | ECN_ | COMMENT | | |
| -0.44 ± 0.13 OUR AVERAGE | Error includes scale | e factor of | 1.1. | | | |
| $-0.56^{+0.17}_{-0.15}\pm0.03$ | 1,2 AUBERT | 09т В | ABR | $e^+e^-\to$ | $\Upsilon(4S)$ | |
| $-0.29\pm0.16\pm0.09$ | 3 WEI | 09A BI | ELL | $e^+e^- \to$ | Y(45) | |
| $^{1}For0.1 < m_{_{arrho+_{arrho-}}}^{2} < 7.02GeV^{2}/c^{4}.$ | | | | | | |
| 2 Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$. | | | | | | |
| 3 For $q^{2} < 8.68 \text{ GeV}^{2}/c^{2}$ | | | | | | |

 $[\]Delta_{0-}(B(B \to K^{(*)}\ell^+\ell^-))$

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|------------------------------------|----------------------|--------|---------|----------------------|----------------|
| -0.45 ± 0.17 OUR AVERAGE | Error includes scale | factor | of 1.7. | | |
| $-0.64 + 0.15 \pm 0.03$ | 1,2 aubert | 09т | BABR | $e^+e^- \to$ | $\Upsilon(4S)$ |
| $-0.30{}^{+0.12}_{-0.11}{\pm}0.08$ | ³ WEI | 09A | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| | _ | | | | |

 $^{^{1}\, {\}rm For} \,\, 0.1 < m_{\,\ell^{+}\,\ell^{-}}^{\,2} < 7.02 \,\, {\rm GeV}^{2}/{\rm c}^{4}$

$B \rightarrow X_c \ell \nu$ HADRONIC MASS MOMENTS

$\langle M_X^2 - \overline{M}_D^2 \rangle$ (First Moments)

| VALUE (GeV ²) | DO CUMENT ID | | TECN | COMMENT | | | |
|-----------------------------|---------------------|------|------|-----------------------------------|--|--|--|
| 0.36 ±0.08 OUR AVERAGE | Error includes scal | | | | | | |
| $0.467 \pm 0.038 \pm 0.068$ | | | | $p\overline{p}$ at 1.96 TeV | | | |
| $0.293 \pm 0.012 \pm 0.058$ | ² CSORNA | 04 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ | | | |
| | | | | | | | |
| $0.251 \pm 0.023 \pm 0.062$ | 3 CRONIN-HEI | N01B | CLE2 | $e^+e^- ightarrow \gamma(4S)$ | | | |

 $^{^{1}}$ Moments are measured with a minimum lepton momentum of 0.7 GeV/c in the B rest

$\langle M_X^2 \rangle$ (First Moments)

| VALUE (GeV ²) | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|-----------------------|----|------|-----------------------------------|--|
| 4.156±0.029 OUR AVERAGE | | | | | |
| $4.144 \pm 0.028 \pm 0.022$ | | | | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $4.18 \pm 0.04 \pm 0.03$ | ¹ AUBERT,B | 04 | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| | | | | | |

 $^{^{1}}$ The leptons are required to have $E_{\ell} > 1.5~{
m GeV}/c$.

$\langle (M_X^2 - \overline{M}_X^2)^2 \rangle$ (Second Moments)

| 1, V V, 1 | • | | | | |
|-----------------------------------|-------------------------|---------|-----------|-----------------------------------|--|
| VALUE (GeV ⁴) | DO CUMENT ID | | TECN | COMMENT | |
| 0.55 ±0.08 OUR AVERAGE | | | | | |
| $0.515 \pm 0.061 \pm 0.064$ | ¹ SCHWA NDA | 07 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $0.629 \pm 0.031 \pm 0.143$ | ² CSORNA | 04 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| • • • We do not use the following | owing data for average | s, fits | , limits, | etc. • • • | |
| $1.05 \pm 0.26 \pm 0.13$ | ³ ACOSTA | 05 F | CDF | p p at 1.96 TeV | |
| $0.576 \pm 0.048 \pm 0.168$ | ¹ CRONIN-HEN | 01в | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ | |

 $^{^1\,\}mathrm{The}$ leptons are required to have $E_\ell > 1.5\,\,\mathrm{GeV}/\mathit{c}.$

$\langle (M_X^2 - \overline{M}_D^2)^2 \rangle$ (Second Moments)

| VALUE (GeV ⁴) | DOCUMENT ID | TECN | COMMENT | | | | |
|-----------------------------------------------------------------|----------------------------|------|-----------------------------------|--|--|--|--|
| $0.639 \pm 0.056 \pm 0.178$ | ¹ CRONIN-HEN01B | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ | | | | |
| ¹ The leptons are required to have $F_a > 1.5$ GeV/c | | | | | | | |

The leptons are required to have $E_\ell > 1.5~{
m GeV}/c$.

$B \rightarrow X_c \ell \nu$ LEPTON MOMENTUM MOMENTS

$R_0 \left(\Gamma_{E_I > 1.7 GeV} / \Gamma_{E_I > 1.5 GeV} \right)$

| O (D[/1.7GeV / D[/1.5GeV | , | | |
|--------------------------------|--------------|------|---------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| $0.6187 \pm 0.0014 \pm 0.0016$ | MAHMOOD 03 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ |
| | | | |

 $^{^{1}\,\}mathrm{The}$ leptons are required to have $\mathrm{E}_{l}>$ 1.5 GeV in the B rest frame.

$R_1 \left(\langle E_l \rangle_{E_l > 1.5 GeV} \right)$

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------|-----------------------|---------|----------|-----------------------------------|--|
| 1.7797 ± 0.0018 OUR AVERAGE | Error includes sca | ale fac | or of 1. | 8. See the ideogram | |
| below. | | | | _ | |
| $1.7743 \pm 0.0019 \pm 0.0014$ | | | | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $1.7792 \pm 0.0021 \pm 0.0027$ | ² mah mood | 04 | CLEO | $e^+e^- \rightarrow \Upsilon(4S)$ | |
| $1.7810 \pm 0.0007 \pm 0.0009$ | ³ MAH MOOD | 03 | CLE2 | $e^+e^- \rightarrow \gamma(4S)$ | |

 $^{^1}$ The leptons are required to have E $_l>1.5$ GeV in the B rest frame. The result with $_2$ E $_l>0.6$ GeV is also given.

 $^{^{2}\,\}mbox{Uses}$ a fully reconstructed $\it B$ meson as a tag on the recoil side.

²Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $^{^{3}}$ For $q^{2} < 8.68 \; GeV^{2}/c^{2}$

²Assumes equal production of B^+ and B^0 at the $\Upsilon(4S)$.

 $^{^3}$ For q $^2 < 8.68 \; \text{GeV}^2/\text{c}^2$

frame; 2 Uses minimum lepton energy of 1.5 GeV and also reports moments with E $_{\ell}~>$ 1.0 GeV.

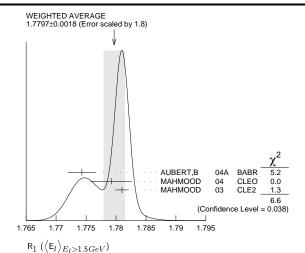
 $^{^3}$ The leptons are required to have $P_\ell > 1.5~{
m GeV}/c$.

 $^{^2}$ Uses minimum lepton energy of 1.5 GeV and also reports moments with $E_\ell >$ 1.0 GeV.

 $^{^3}$ Moments are measured with a minimum lepton momentum of 0.7 GeV/c in the $\it B$ rest

 $^{^2}$ Uses E $_e>1.5$ GeV and also reports moments with other minimum minimum E $_e$ conditions, as low as E $_e>0.6$ GeV.

 $^{^3}$ The leptons are required to have $\mathsf{E}_l > 1.5$ GeV in the B rest frame.



$\mathsf{R}_2~(\langle \mathsf{E}_l^2 - \overline{E}_l^2 \rangle_{E_l > 1.5 GeV})$

VALUE (10⁻³ GeV²) 30.8±0.8 OUR AVERAGE

 $30.3 \pm 0.9 \pm 0.5$ $31.6 \pm 0.8 \pm 1.0$

| DOCUMENT ID | TECN | COMMENT | | | |
|-----------------------|------|---------|----------------------|-------|--|
| ¹ AUBERT,B | 04A | BABR | $e^+e^- \rightarrow$ | T(45) | |
| ² MAHMOOD | | | $e^+e^- \to$ | | |

- 1 The leptons are required to have E $_l~>1.5$ GeV in the B rest frame. The result with ${\rm E}_l~>0.6~{
 m GeV}$ is also given.
- 2 Uses ${\rm E}_e>$ 1.5 GeV and also reports moments with other minimum minimum ${\rm E}_e$ conditions, as low as ${\rm E}_e>$ 0.6 GeV.

$\frac{\mathsf{R_3}\; (\langle \mathsf{E}_{l}^3 - \overline{E}_{l}^3 \rangle_{E_l > 1.5 GeV})}{{}^{\mathit{VALUE}\; (10^{-3}\;\; \mathrm{GeV}^3)}}$

2.12±0.47±0.20

DOCUMENT ID TECN COMMENT 1 AUBERT,B 04A BABR $e^{+}e^{-}
ightarrow \varUpsilon (4S)$

$B \rightarrow X_s \gamma$ PHOTON ENERGY MOMENTS

$\langle E_{\gamma} \rangle$

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|--------------------------|-----|------|-----------------------|----------------|
| 2.306±0.014 OUR AVERAGE | | | | | |
| $2.311 \pm 0.009 \pm 0.015$ | ¹ LIMOSANI | 09 | BELL | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.289 \pm 0.058 \pm 0.027$ | ^{1,2} AUBERT | 080 | BABR | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.309 \pm 0.023 \pm 0.023$ | ^{1,3} SCHWA NDA | 80 | BELL | $e^+ e^- \rightarrow$ | $\Upsilon(4S)$ |
| $2.288 \pm 0.025 \pm 0.023$ | 1 AUBERT.BE | 06B | BABR | $e^+e^- \rightarrow$ | $\Upsilon(4S)$ |

 $^{^1\,\}mathrm{The}$ result is for E $_{\gamma}~>$ 1.9 GeV.

$\langle E_{\gamma}^2 \rangle - \langle E_{\gamma} \rangle^2$

| VALUE (10 ⁻² GeV ²) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------|--------------------------|-----|------|----------------------------------------|
| 2.99±0.28 OUR AVERAGE | | | | |
| $3.02 \pm 0.19 \pm 0.30$ | ¹ LIMOSANI | 09 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $3.34 \pm 1.24 \pm 0.62$ | ^{1,2} AUBERT | 080 | BABR | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $2.17 \pm 0.60 \pm 0.55$ | ^{1,3} SCHWA NDA | 80 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $3.28 \pm 0.40 \pm 0.43$ | ¹ AUBERT,BE | 06в | BABR | $e^+ e^- ightarrow \varUpsilon(4S)$ |

 $^{^1\,\}mathrm{The}$ result is for $E_{\,\gamma}>$ 1.9 GeV.

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| | 01 00 R | Unofficial 2001 WWW ed PL B475 407 | ition P. Abreu <i>et al.</i> | (DELPHI Collab.) |
| COAN | 00 | PRL 84 5283 | T.E. Coan et al. | (CLEO Collab.) |
| | 00 | PRL 85 520 | S.J. Richichi et al. | (CLEO Collab.) |
| | 98 Q 98 | EPJ C4 387 PRL 81 272 | R. Barate et al. T. Bergfeld et al. | (ALEPH Collab.) (CLEO Collab.) |
| BISHAI | 98 | PR D57 3847 | M. Bishai et al. | (CLEO Collab.) |
| | 98 98 | PR D57 6604 PRL 81 1786 | G. Bonvicini et al. T.E. Browder et al. | (CLEO Collab.) (CLEO Collab.) |
| | 98 | PRL 80 1150 | T.E. Coan et al. | (CLEO Collab.) |
| GLENN | 98 97 N | PRL 80 2289 ZPHY C74 423 | S. Glenn et al. K. Ackerstaff et al. | (CLEO Collab.) (OPAL Collab.) |
| | 97 N | | R. Ammar et al. | (CLEO Collab.) |
| BARISH | 97 | PRL 79 3599 | B. Barish et al. | (CLEO Collab.) |
| | 97 B 97 B | ZPHY C73 601 PR D56 3783 | D. Buskulic et al. I. Gibbons et al. | (ALEPH Collab.) (CLEO Collab.) |
| ALBRECHT | 96 D | PL B374 256 | L. Gibbons et al. H. Albrecht et al. | `(CLEO Collab.) (ARGUS Collab.) |
| | | PRL 76 1570 | B.C. Barish et al. | (CLEO Collab.) |
| | 96 96 | | D. Gibaut et al. Y. Kuhota et al. | (CLEO Collab.) (CLEO Collab.) |
| PDG | 96 | | Y. Kubota et al. R. M. Barnett et al. | |
| | 95 95 D | PRL 74 2885 PL B353 554 | M.S. Alam et al. H. Albrecht et al. | (CLEO Collab.) (ARGUS Collab.) |
| BALEST | 95 B | | R. Balest et al. | (CLEO Collab.) |
| | 95 95 B | PR D51 1014 | B.C. Barish et al. | (CLEO Collab.) |
| | 95 B 94 C | PL B345 103 ZPHY C62 371 | D. Buskulic et al. H. Albrecht et al. | (ALEPH Collab.) (ARGUS Collab.) |
| ALBRECHT | 94 J | ZPHY C62 371 ZPHY C61 1 | H. Albrecht et al. | (ARGUS Collab.) (ARGUS Collab.) |
| | 94 93 | PRL 73 1472 | M. Procario et al. H. Albrecht et al. | (CLEO Collab.) (ARGUS Collab.) |
| ALBRECHT | 93 E | ZPHY C60 11 | H. Albrecht et al. | (ARGUS Collab) |
| ALBRECHT | 93 H | PL B318 397 | H. Albrecht et al. | (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) |
| | 93 I 93 B | | H. Albrecht et al. J. Alexander et al. | (AKGUS Collab.) (CLEO Collab |
| ARTUSO | 93 | PL B311 307 | M. Artuso | (SYRA) |
| | 93 B 92 E | PRL 71 4111 PL B277 209 | J.E. Bartelt <i>et al.</i> H. Albrecht <i>et al.</i> | (CLEO Collab.) (ARGUS Collab.) |
| ALBRECHT | 92 G | ZPHY C54 1 ZPHY C56 1 | H. Albrecht et al. H. Albrecht et al. | (ARGUS Collab.) |
| ALBRECHT | 92 O | ZPHY C56 1 | H. Albrecht et al. | (ARGUS Collab.) (ARGUS Collab.) |
| BORTOLETTO CRAWFORD | 92 92 | | D. Bortoletto et al. G. Crawford et al. | (CLEO Collab.) (CLEO Collab.) |
| HENDERS ON | 92 | PR D45 2212 | S. Henderson et al. | (CLEO Collab.) |
| | 92 91 C | ZPHY C55 33 PL B255 297 | T. Lesiak <i>et al.</i> H. Albrecht <i>et al.</i> | (Crystal Ball Collab.) (ARGUS Collab.) |
| | 91H | ZPHY C52 353 | H. Albrecht et al. | (ARGUS Collab.) (ARGUS Collab.) |
| | | | | |

 $^{^{1}}$ The leptons are required to have E $_{L} > 1.5$ GeV in the B rest frame. The result with

 $^{^2}$ Uses a fully reconstructed B meson as a tag on the recoil side. 3 Results for different E_γ threshold values are also measured.

 $^{^{2}}$ Uses a fully reconstructed \it{B} meson as a tag on the recoil side.

 $^{^3\,\}mathrm{Results}$ for different $E_{\,\gamma}$ threshold values are also measured.

B^\pm/B^0 ADMIXTURE, $B^\pm/B^0/B_s^0/b$ -baryon ADMIXTURE

| BORTOLETTO 9: AISO FULLTON 9: MAS CHMANN 9: POF 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CHMANN 9: MAS CH | 100H 00H 000 0009KB 88H 877F7777766666H 8333B 833B | PR D43 651 PRL 66 2436 PRL 66 2436 PRL 66 2436 PRL 8249 359 PRL 64 2117 PR D45 21 PRL 64 16 ZPHY C46 555 PL 8239 1 ZPHY C42 519 PR D39 799 ZPHY C42 533 PL 8210 263 PL 8210 263 PL 8210 263 PL 8210 263 PL 8210 728 ZPHY C38 511 PRL 59 22 PRL 58 1814 PRL 59 22 PRL 58 1814 PR 1819 451 PR D33 3533 PRL 59 407 PR D35 19 PR D36 3533 PRL 59 407 PR D36 3539 PRL 59 1084 PRL 58 119 PRL 58 2140 PRL 56 800 PRL 56 800 PRL 56 119 PRL 58 1240 PRL 58 1240 PRL 58 1240 PRL 58 129 PRL 58 129 PRL 58 129 PRL 59 129 PRL 59 129 PRL 59 129 PRL 59 129 PRL 59 129 PRL 51 1419 PRL 51 1419 PRL 51 1419 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 147 PRL 51 | R. Fulton et al. C. Yanagisawa et al. H. Albrecht et al. H. Albrecht et al. D. Bortoletto et al. D. Bortoletto et al. D. Bortoletto et al. W.S. Maschmann et al. J.J. Hernandez et al. H. Albrecht et al. K. Wachs et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. H. Albrecht et al. M.S. Alam et al. M.S. Alam et al. M.S. Alam et al. M.S. Alam et al. M.S. Alam et al. M.S. Alam et al. H. Albrecht et al. J. Bortoletto et al. J. Haas et al. D. Bortoletto et al. J. Haas et al. H. Albrecht et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Haas et al. J. Gmen et al. G. Klopfenstein et al. G. Altarelli et al. A. D. Brody et al. | (CLEO Collab.) (CUSB II (COllab.) (ARGUS COllab.) (ARGUS COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (Crystal Ball Collab.) (TNTO, CIT) (Crystal Ball Collab.) (ARGUS Collab.) (ARGUS Collab.) (ARGUS Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) (CLEO COllab.) 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| KLOPFEN 83 | 3B | PL 130B 444 | C. Klopfenstein et al. | (CUSB Collab.) |
| BRODY 83 GIANNINI 83 | | PRL 48 1070 NP B206 1 | A.D. Brody et al. G. Giannini et al. | |
| BEBEK 8: | | PRL 46 84 | C. Bebek et al. | (CLEO Collab.) |
| CHADWICK 8: | | PRL 46 88 | K. Chadwick et al. | (CLEO Collab.) |
| ABRAMS 80 | 0 | PRL 44 10 | G.S. Abrams et al. | (SLAC, LBL) |

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE MEAN LIFE

Each measurement of the B mean life is an average over an admixture of various bottom mesons and baryons which decay weakly. Different techniques emphasize different admixtures of produced particles, which could result in a different B mean life.

"OUR EVALUATION" is an average using rescaled values of the The average and rescaling were performed by data listed below. the Heavy Flavor Averaging Group (HFAG) and are described at $http://www.slac.stanford.edu/xorg/hfag/. \ \ The \ averaging/rescaling \ pro-prosphere and the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of t$ cedure takes into account correlations between the measurements and asymmetric lifetime errors, but ignores the small differences due to dif-

| | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|-----------|-------------------------|-------------|------------|----------------------------------------|
| 1.568±0.009 OUR E | VALUATI | | | | |
| $1.570\pm0.005\pm0.008$ | | ¹ ABDALLAH | 04E | DLPH | $e^+e^- \rightarrow Z$ |
| $1.533\pm0.015{}^{+0.035}_{-0.031}$ | | ² ABE | 98B | CDF | $p\overline{p}$ at 1.8 TeV |
| $1.549\!\pm\!0.009\!\pm\!0.015$ | | ³ ACCIARRI | 98 | L3 | $e^+ e^- ightarrow Z$ |
| $1.611 \pm 0.010 \pm 0.027$ | | ⁴ ACKERSTAFF | 97F | OPAL | $e^+e^- \rightarrow Z$ |
| $1.582\pm0.011\pm0.027$ | | ⁴ ABREU | 96E | DLPH | |
| $1.533\pm0.013\pm0.022$ | 19.8k | ⁵ BUSKULIC | 96F | ALEP | $e^+e^- \rightarrow Z$ |
| $1.564\pm0.030\pm0.036$ | | ⁶ ABE,K | 95B | SLD | $e^+e^- \rightarrow Z$ |
| $1.542\pm0.021\pm0.045$ | | ⁷ ABREU | 94L | DLPH | |
| $1.523\pm0.034\pm0.038$ | 5372 | ⁸ ACTON | 93L | OPAL | |
| $1.511\pm0.022\pm0.078$ | | ⁹ BUSKULIC | 930 | ALEP | $e^+e^- \rightarrow Z$ |
| • • • We do not use | the follo | • | ges, f | its, limit | |
| $1.575\pm0.010\pm0.026$ | | ¹⁰ ABREU | 96E | DLPH | $e^+e^- \rightarrow Z$ |
| $1.50 ^{+ 0.24}_{- 0.21} \pm 0.03$ | | ¹¹ ABREU | 94P | DLPH | $e^+e^- ightarrow ~Z$ |
| $1.46 \ \pm 0.06 \ \pm 0.06$ | 5344 | ¹² ABE | 93J | CDF | Repl. by ABE 98B |
| $1.23 ^{+ 0.14}_{- 0.13} \pm 0.15$ | 188 | ¹³ ABREU | 93D | DLPH | Sup. by ABREU 94L |
| $1.49 \ \pm 0.11 \ \pm 0.12$ | 25 3 | ¹⁴ ABREU | 93G | DLPH | Sup. by ABREU 94L |
| $1.51 ^{+ 0.16}_{- 0.14} \pm 0.11$ | 130 | ¹⁵ ACTON | 93c | OPAL | $e^+ e^- ightarrow Z$ |
| $1.535\pm0.035\pm0.028$ | 7357 | ⁸ ADRIANI | 93ĸ | L3 | Repl. by ACCIARRI 98 |
| 1.28 ± 0.10 | | 16 ABREU | 92 | DLPH | Sup. by ABREU 94L |
| $1.37 \pm 0.07 \pm 0.06$ | 1354 | 17 ACTON | 92 | OPAL | Sup. by ACTON 93L |
| $1.49 \pm 0.03 \pm 0.06$ | | ¹⁸ BUSKULIC | 92F | ALEP | Sup. by BUSKULIC 96F |
| $1.35 {}^{+ 0.19}_{- 0.17} \pm 0.05$ | | ¹⁹ BUSKULIC | 92G | ALEP | $e^+ e^- \rightarrow Z$ |
| $1.32 \ \pm 0.08 \ \pm 0.09$ | 1386 | ²⁰ adeva | 91H | L3 | Sup. by ADRIANI 93K |
| $1.32 ^{+ 0.31}_{- 0.25} \pm 0.15$ | 37 | ²¹ ALEXANDER | 91 G | OPAL | $e^+ e^- ightarrow Z$ |
| $1.29 \ \pm 0.06 \ \pm 0.10$ | 2973 | ²² DECAMP | 91c | ALEP | Sup. by BUSKULIC 92F |
| $1.36 \begin{array}{c} +0.25 \\ -0.23 \end{array}$ | | ²³ HAGEMANN | 90 | JADE | E ^{ee} _{cm} = 35 GeV |
| 1.13 ±0.15 | | ²⁴ LYONS | 90 | RVUE | |
| $1.35 \pm 0.10 \pm 0.24$ | | BRAUNSCH | 89в | TASS | E ^{ee} _{cm} = 35 GeV |
| | | | | | |

| 0.98 | $\pm0.12\ \pm0.13$ | | ONG | 89 | MRK2 | $E_{ m cm}^{\it ee}=$ 29 GeV |
|------|------------------------------------|-----|--------------------|----|------|------------------------------------------|
| 1.17 | $^{+0.27}_{-0.22}^{+0.17}_{-0.16}$ | | KLEM | 88 | DLCO | $E_{\mathrm{cm}}^{\mathit{ee}} =$ 29 GeV |
| 1.29 | $\pm0.20\ \pm0.21$ | | ²⁵ ASH | 87 | MAC | $E_{ m cm}^{\it ee}=$ 29 GeV |
| 1.02 | +0.42 | 301 | ²⁶ BROM | 87 | HRS | $E_{cm}^{ee} = 29 \text{ GeV}$ |

 $^{^{}m 1}$ Measurement performed using an inclusive reconstruction and B flavor identification technique

CHARGED b-HADRON ADMIXTURE MEAN LIFE

| VALUE (10 ⁻¹² s) | DO CUMENT IL |) | TECN | COMMENT |
|---------------------------------------|----------------------|---------|----------|--------------------------|
| 1.72±0.08±0.06 | 27 ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| ²⁷ ADAM 95 data analyzed u | sing vertex-charge t | echniqu | e to tag | <i>b</i> -hadron charge. |

NEUTRAL b-HADRON ADMIXTURE MEAN LIFE

| VALUE (10 ⁻¹² s) | DO CUMENT I | 'D | TECN | COMMENT |
|-----------------------------|---------------------|----------|----------|------------------------|
| 1.58±0.11±0.09 | 28 ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| 28 ADAM 95 data analyzed us | ing vertex-charge t | techniqu | e to tag | b-hadron charge |

MEAN LIFE RATIO $au_{ ext{charged }b- ext{hadron}}/ au_{ ext{neutral }b- ext{hadron}}$

| VALUE | <u>DO CUMENT</u> | · ID | TECN | COMMENT |
|---------------------------------|--------------------|------|------|------------------------|
| $1.09^{+0.11}_{-0.10} \pm 0.08$ | ²⁹ ADAM | 95 | DLPH | $e^+e^- \rightarrow Z$ |
| 29 . 5 | | | | |

²⁹ ADAM 95 data analyzed using vertex-charge technique to tag b-hadron charge.

$|\Delta \tau_b|/\tau_{b,\overline{b}}$

 $au_{b,\overline{b}}$ and $|\Delta au_b|$ are the mean life average and difference between b and \overline{b} hadrons.

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|------------------------------|--------------|-----|------|------------------------|--|
| $-0.001 \pm 0.012 \pm 0.008$ | 30 ABBIENDI | 99J | OPAL | $e^+e^- \rightarrow Z$ | |
| | | | | | |

 $^{^{}m 30}$ Data analyzed using both the jet charge and the charge of secondary vertex in the opposite hemisphere

 $^{^2}$ Measured using inclusive $J/\psi(1{\rm S}) \to ~\mu^+\,\mu^-$ vertex.

³ ACCIARRI 98 uses inclusively reconstructed secondary vertex and lepton impact param-

eter.

4 ACKERSTAFF 97F uses inclusively reconstructed secondary vertices.

⁵ BUSKULIC 96F analyzed using 3D impact parameter.

⁶ ABE,K 95B uses an inclusive topological technique.

⁷ABREU 94L uses charged particle impact parameters. Their result from inclusively reconstructed secondary vertices is superseded by ABREU 96E.

 $^{^8}$ ACTON 93L and ADRIA NI 93K analyzed using lepton (e and μ) impact parameter at Z. ⁹BUSKULIC 930 analyzed using dipole method.

¹⁰ Combines ABREU 96E secondary vertex result with ABREU 94L impact parameter result.

 $^{^{11}}$ From proper time distribution of $b
ightarrow \ J/\psi(1{\cal S})$ anything.

 $^{^{12}}$ ABE 93J analyzed using $J/\psi(1S)
ightarrow \mu\mu$ vertices.

 $^{^{13}}$ ABREU 93D data analyzed using $D/D^*\ell$ anything event vertices.

 $^{^{\}rm 14}\,{\sf ABREU}$ 93G data analyzed using charged and neutral vertices.

 $^{^{15}}$ ACTON 93c analysed using $D/D*\ell$ anything event vertices.

¹⁶ ABREU 92 is combined result of muon and hadron impact parameter analyses. Hadron tracks gave $(12.7 \pm 0.4 \pm 1.2) \times 10^{-13}$ s for an admixture of B species weighted by production fraction and mean charge multiplicity, while muon tracks gave (13.0 \pm 1.0 \pm 0.8) imes $10^{-13}\,\mathrm{s}$ for an admixture weighted by production fraction and semileptonic branching

¹⁷ ACTON 92 is combined result of muon and electron impact parameter analyses.

 $^{^{18}\,\}mathrm{BUSKULIC}$ 92F uses the lepton impact parameter distribution for data from the 1991

 $^{^{19}}$ BUSKULIC 92G use $J/\psi(1S)$ tags to measure the average b lifetime. This is comparable to other methods only if the $J/\psi(1S)$ branching fractions of the different b-flavored

hadrons are in the same ratio. 20 Using $Z \to e^+ X$ or $\mu^+ X$, ADEVA 91H determined the average lifetime for an admixture of B hadrons from the impact parameter distribution of the lepton. 21 Using $Z \to J/\psi(1S) X$, $J/\psi(1S) \to \ell^+ \ell^-$, ALEXANDER 91G determined the average

lifetime for an admixture of B hadrons from the decay point of the $J/\psi(1S)$

²² Using $Z \to e X$ or μX , DECA MP 91c determines the average lifetime for an admixture of ${\it B}$ hadrons from the signed impact parameter distribution of the lepton.

²³ HAGEMANN 90 uses electrons and muons in an impact parameter analysis.

²⁴ LYONS 90 combine the results of the B lifetime measurements of ONG 89, BRAUN-SCHWEIG 89B, KLEM 88, and ASH 87, and JADE data by private communication. They use statistical techniques which include variation of the error with the mean life, and possible correlations between the systematic errors. This result is not independent of the measured results used in our average.

 $^{^{25}}$ We have combined an overall scale error of 15% in quadrature with the systematic error of \pm 0.7 to obtain \pm 2.1 systematic error.

 $^{^{}m 26}$ Statistical and systematic errors were combined by BROM 87

b PRODUCTION FRACTIONS AND DECAY MODES

The branching fraction measurements are for an admixture of B mesons and baryons at energies above the $\varUpsilon(4S)$. Only the highest energy results (LHC, LEP, Tevatron, $Sp\,\overline{p}S$) are used in the branching fraction averages. In the following, we assume that the production fractions are the same at the LHC, LEP, and at the Tevatron.

For inclusive branching fractions, e.g., $B
ightarrow D^{\pm}$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

The modes below are listed for a \overline{b} initial state. b modes are their charge conjugates. Reactions indicate the weak decay vertex and do not include mixing.

Scale factor / Mode Fraction (Γ_i/Γ) Confidence level

PRODUCTION FRACTIONS

The production fractions for weakly decaying b-hadrons at high energy have been calculated from the best values of mean lives, mixing parameters, and branching fractions in this edition by the Heavy Flavor Averaging Group (HFAG) as described in the note " B^0 – \overline{B}^0 Mixing" in the B^0 Particle Listings. The production fractions in b-hadronic Z decay or $p\overline{p}$ collisions at the Tevatron are also listed at the end of the section. Values assume

$$\begin{array}{ll} \mathsf{B}(\overline{b} \to B^+) = \mathsf{B}(\overline{b} \to B^0) \\ \mathsf{B}(\overline{b} \to B^+) + \mathsf{B}(\overline{b} \to B^0) + \mathsf{B}(\overline{b} \to B^0) + \mathsf{B}(b \to b\text{-baryon}) = 100 \ \%. \end{array}$$

The correlation coefficients between production fractions are also re-

 $cor(B_c^0, b\text{-baryon}) = -0.277$ $cor(B_5^0, B^{\pm}=B^0) = -0.119$ cor(b-baryon, $B^{\pm}=B^{0})=-0.921$.

The notation for production fractions varies in the literature $(f_d,\ d_{B^0},$ $f(b \to \overline{B}{}^0)$, ${
m Br}(b \to \overline{B}{}^0))$. We use our own branching fraction notation here, $B(\overline{b} \rightarrow B^0)$.

Note these production fractions are b-hadronization fractions, not the conventional branching fractions of b-quark to a B-hadron, which may have considerable dependence on the initial and final state kinematic and production environment.

| | B^+ | (| 40.1 | \pm | 0.8) % |
|----------------|-----------------|-----|------|-------|----------|
| | B_{\perp}^{0} | (| 40.1 | \pm | 0.8) % |
| Γ ₃ | B_s^0 | (| 10.5 | \pm | 0.6) % |
| Г | h harvon | - / | 0.2 | - 1 | 1 6 \ 0/ |

DECAY MODES

Semileptonic and leptonic modes

| Γ_5 | u anything | (| 23.1 ± | 1.5) % | |
|-----------------|-----------------------------------------------------------------|---------|------------|-----------------------------------|--------|
| Γ_6 | $\ell^+ u_\ell$ a nything | [a] (| 10.69± | 0.22) % | |
| Γ ₇ | $e^+ u_e^{}$ anything | (| $10.86\pm$ | 0.35) % | |
| Γ8 | $\mu^+ u_\mu$ anything | (| 10.95 + | 0.29 0.25) % | |
| Г9 | $D^-\ell^+ u_\ell$ anything | [a] (| $2.27\pm$ | 0.35) % | S=1.7 |
| Γ_{10} | $D^-\pi^+\ell^+ u_\ell$ a nything | (| 4.9 \pm | $1.9) \times 10^{-3}$ | |
| Γ_{11} | $D^-\pi^-\ell^+ u_\ell$ a nything | (| $2.6~\pm$ | $1.6) \times 10^{-3}$ | |
| Γ_{12} | $\overline{D}{}^0\underline{\ell}^+$ ν_ℓ anything | [a] (| $6.84\pm$ | 0.35) % | |
| Γ_{13} | $\overline{D}{}^0\pi^-\ell^+ u_\ell$ anything | (| $1.07\pm$ | 0.27) % | |
| Γ_{14} | $\overline{D}{}^0\pi^+\ell^+ u_\ell$ anything | (| $2.3~\pm$ | $1.6) \times 10^{-3}$ | |
| Γ_{15} | $D^{*-}\ell^+ u_\ell$ a nything | | $2.75\pm$ | | |
| Γ_{16} | $D^{*-}\pi^-\ell^+ u_\ell$ anything | | | 7)×10 ⁻⁴ | |
| Γ_{17} | $D^{*-}\pi^{+}\ell^{+}\nu_{\ell}$ anything | (| | $1.0) \times 10^{-3}$ | |
| Γ_{18} | $\overline{D}^0_j\ell^+ u_\ell$ anything $	imes$ | [a,b] (| $2.6 \pm$ | $0.9) \times 10^{-3}$ | |
| | $B(\overline{D}_j^0 	o D^{*+}\pi^-)$ | | | | |
| Γ_{19} | $D_i^-\ell^+ u_\ell$ anything $	imes$ | [a,b] (| $7.0 \pm$ | $2.3) \times 10^{-3}$ | |
| | $B(D_j^- 	o D^0\pi^-)$ | | | | |
| Γ_{20} | \overline{D}_2^* $(2460)^0$ ℓ^+ $ u_\ell$ a nything | < | 1.4 | $\times 10^{-3}$ | CL=90% |
| | $\times B(\overline{D}_{2}^{*}(2460)^{0} \rightarrow$ | | | | |
| | $D^{*-}\pi^{+}$ | | | | |
| Γ_{21} | $D_2^*(2460)^-\ell^+ u_\ell$ anything | (| 4.2 + | $^{1.5}_{1.8}$) $\times 10^{-3}$ | |
| | \times B($D_2^*(2460)^- \rightarrow$ | | | 1.0 | |
| | $D^0 \pi^-)^2$ | | | | |
| Γ_{22} | $\overline{D}_2^st (2460)^{\acute{0}} \ell^+ u_\ell$ a nything | (| 1.6 ± | $0.8) \times 10^{-3}$ | |
| | $\times B(\overline{D}_2^*(2460)^0 \rightarrow$ | , | | * | |
| | $D^-\pi^+$ | | | | |
| Γ ₂₃ | | | | | |

```
	au^+\,
u_	au anything
\Gamma_{24}
                                                                (2.41 \pm 0.23)\%
           D^{st-	au}
u_{	au} a nything
                                                                   9 \pm 4 ) \times 10<sup>-3</sup>
\Gamma_{25}
        \overline{c} \rightarrow \ell^- \overline{
u}_\ell a nything
                                                              ( 8.02 ± 0.19) %
Γ<sub>26</sub>
\Gamma_{27}
        c \rightarrow \ell^+ \nu anything
                                                               (1.6 + 0.4 - 0.5) %
                             Charmed meson and baryon modes
        \overline{D}{}^0 a nything
                                                               ( 59.8 \pm 2.9 ) %
         D^0 D_s^{\pm} anything
                                                         [c] (9.1 + 4.0 )\%
         D^{\mp}D_{s}^{\pm} anything
                                                         [c] (4.0 + 2.3 \times 1.8)
        \overline{D}{}^0 D^0 anything
                                                         [c] (5.1 + 2.0)\%
\Gamma_{32}
        D^0 D^{\pm} anything
                                                         [c] (2.7 + 1.8 \atop -1.6)\%
        D^{\pm}\,D^{\mp} a nything
                                                                                   \times 10^{-3} CL=90%
                                                         [c] < 9
\Gamma_{33}
        D^0 anything
\Gamma_{34}
\Gamma_{35}
        D<sup>+</sup> anything
        D^- anything
                                                               (23.3 \pm 1.7)\%
Γ<sub>36</sub>
Γ<sub>37</sub>
        D^*(2010)^+ anything
                                                               (17.3 \pm 2.0)\%
\Gamma_{38}
        D_1 (2420)^0 a nything
                                                               (5.0 \pm 1.5)\%
        D^*(2010)^{\mp}D_s^{\pm} anything
                                                         [c] (3.3 + 1.6 )\%
        D^{0}D^{*}(2010)^{\pm} anything
                                                         [c] (3.0 + 1.1 \atop -0.9)\%
                                                         [c] (2.5 + 1.2)\%
        D^*(2010)^{\pm}D^{\mp} anything
        D^*(2010)^{\pm} D^*(2010)^{\mp} anything
                                                        [c] (1.2 \pm 0.4)\%
                                                               (\begin{array}{ccc} 10 & \begin{array}{c} +11 \\ -10 \end{array} \end{array}) \ \%
\Gamma_{43}
\Gamma_{44}
        D_2^*(2460)^0 anything
                                                                (4.7 \pm 2.7)\%
        D_s^- anything
\Gamma_{45}
                                                               (14.7 \pm 2.1)\%
        D_s^+ anything
\Gamma_{46}
                                                               (10.1 \pm 3.1)\%
        \Lambda_c^{+} anything
\Gamma_{47}
                                                               (9.7 \pm 2.9)\%
\Gamma_{48}
        \overline{c}/c anything
                                                        [d] (116.2 \pm 3.2)\%
                                       Charmonium modes
\Gamma_{49}
        J/\psi(1S) anything
                                                                (1.16 \pm 0.10) \%
\Gamma_{50}
         \psi(2S) anything
                                                                (4.8 \pm 2.4) \times 10^{-3}
        \chi_{c1}(1P) anything
\Gamma_{51}
                                                                (1.4 \pm 0.4)\%
                                           K or K* modes
\Gamma_{52}
        \overline{s}\gamma
                                                               (3.1 \pm 1.1) \times 10^{-4}
\Gamma_{53}
        \overline{S}\overline{\nu}\nu
                                                              < 6.4
                                                                                  \times 10^{-4}
                                                                                                CL=90%
        \mathcal{K}^\pmanything
                                                               (74 ± 6)%
\Gamma_{54}
         K_S^0 anything
                                                               (29.0 \pm 2.9)\%
\Gamma_{55}
                                              Pion modes
\Gamma_{5\,6}
        \pi^{\pm} anything
                                                               (397 \pm 21) \%
        \pi^0 anything
                                                         [d]
                                                              (278 ±60 )%
        \phianything
                                                                (2.82 \pm 0.23) \%
                                            Baryon modes
        p/\overline{p} anything
                                                               (13.1 \pm 1.1)\%
                                             Other modes
        charged anything
                                                               (497 ± 7 ) %
                                                               (1.7 \ ^{+} \ ^{1.0} _{-}) \times 10^{-5}
\Gamma_{61}
        hadron+ hadron-
\Gamma_{62}
        charmless
                                                                  7 \pm 21 ) \times 10^{-3}
                                            Baryon modes
\Gamma_{63}
        \Lambda/\overline{\Lambda} anything
                                                                 5.9 ± 0.6)%
        b-baryon anything
                                                                ( 10.2 \pm 2.8 ) %
                        \Delta B = 1 weak neutral current (B1) modes
```

B1 [a] An ℓ indicates an e or a μ mode, not a sum over these modes.

R1

В1

 Γ_{65} e^+e^- anything

 $\mu^+\mu^-$ anything

 $u \overline{
u}$ anything

 Γ_{66}

- [b] D_i represents an unresolved mixture of pseudoscalar and tensor D^{**} (Pwave) states.
- [c] The value is for the sum of the charge states or particle/antiparticle
- [d] Inclusive branching fractions have a multiplicity definition and can be greater than 100%.

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE BRANCHING RATIOS

 $\Gamma(B^+)/\Gamma_{total} \qquad \qquad \Gamma_1/\Gamma_{total} \qquad \qquad \Gamma_1/\Gamma_{$ http://www.slac.stanford.edu/xorg/hfag/.

| VALUE | DO CUMENT ID | TECN | COMMENT |
|--------------------------------|------------------------|----------|------------------------|
| 0.401 ±0.008 OUR EVALUAT | ION | | |
| $0.4099 \pm 0.0082 \pm 0.0111$ | ³¹ abdallah | 03k DLPH | $e^+e^- \rightarrow Z$ |

 $^{
m 31}$ The analysis is based on a neural network, to estimate the charge of the weakly-decaying bhadron by distinguishing its decay products from particles produced at the primary

| $\Gamma(B^+)/\Gamma(B^0)$ | | | | | Γ_1/Γ_2 |
|------------------------------------------|-------------|-----|------|-----------------------------|---------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| $1.054 \pm 0.018 ^{+\ 0.062}_{-\ 0.074}$ | AALTONEN | 08N | CDF | $p\overline{p}$ at 1.96 TeV | |

 $\Gamma(B_s^0)/[\Gamma(B^+)+\Gamma(B^0)]$ $\Gamma_3/(\Gamma_1+\Gamma_2)$ DO CUMENT IE 0.131 ±0.008 OUR EVALUATION 0.134 ±0.008 OUR AVERAGE $0.134 \ \pm 0.004 \ ^{+\ 0.011}_{-\ 0.010}$ 12J LHCB pp at 7 TeV $^{33}\,\mathrm{AAIJ}$ $0.1\,265 \pm 0.0\,085 \pm 0.0131$ 11F LHCB pp at 7 TeV $0.128 \ ^{+\ 0.011}_{-\ 0.010}\ \pm 0.011$ ³⁴ AALTONEN 08N CDF ³⁵ AFFOLDER $0.213\ \pm0.068$ 00E CDF $p\overline{p}$ at 1.8 TeV $\begin{array}{cccc} 0.21 & \pm 0.036 & ^{+}0.038 \\ -0.030 & \end{array}$

 32 Measured using b-hadron semileptonic decays and assuming isospin symmetry.

36 ARE

 33 AAIJ 11F measured $f_s/f_d=0.253\pm0.017\pm0.017\pm0.020$, where the errors are statistical, systematic, and theoretical. We divide their value by 2. Our second error

99P CDF

pp at 1.8 TeV

 Γ_5/Γ

combines systematic and theoretical uncertainties.
34 AALTONEN 08N reports $\left[\Gamma(\overline{b} \to B_s^0)/\left[\Gamma(\overline{b} \to B^+) + \Gamma(\overline{b} \to B^0)\right]\right] \times \left[B(D_s^+ \to B_s^0)/\left[\Gamma(\overline{b} \to B^+) + \Gamma(\overline{b} \to B^0)\right]\right]$ $\phi\pi^+)]=(5.76\pm0.18^{+0.45}_{-0.42})\times10^{-3}$ which we divide by our best value B($D_s^+\to\phi\pi^+)=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 35 AFFOLDER 00 E uses several electron-charm final states in $b \to ce^-$ X. 36 ABE 99 P uses the numbers of $K^*(892)^0$, $K^*(892)^+$, and $\phi(1020)$ events produced in association with the double semileptonic decays $b \to c \mu^- X$ with $c \to s \mu^+ X$.

| $\Gamma(b\text{-baryon})/[\Gamma(B^+)+\Gamma(B^+)]$ | 3 ⁰)] | | | $\Gamma_4/(\Gamma_1+\Gamma_2)$ |
|-------------------------------------------------------------|-------------------------|-----|------|--------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.116±0.022 OUR EVALUATIO | N | | | - |
| 0.30 ±0.06 OUR AVERAGE | | | | |
| $0.305 \pm 0.010 \pm 0.081$ | ³⁷ AAIJ | 12J | LHCB | pp at 7 TeV |
| $0.31 \pm 0.11 \begin{array}{c} +0.12 \\ -0.08 \end{array}$ | ³⁸ AALT ONEN | 09E | CDF | $p\overline{p}$ at 1.8 TeV |

 $0.28 \ ^{+\, 0.11}_{-\, 0.09} \ \pm 0.07$ ³⁹ AALTONEN 08N CDF $p\overline{p}$ at 1.96 TeV

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 40 AFFOLDER 00E CDF $p\overline{p}$ at 1.8 TeV 0.118 ± 0.042

 37 Measured the ratio to be (0.404 \pm 0.017 \pm 0.027 \pm 0.105) \times [1 - (0.031 \pm 0.004 \pm 0.003)×P $_T$] using b-hadron semileptonic decays where the P $_T$ is the momentum of charmed hadron-muon pair in GeV/c. We quote their weighted average value where the second error combines systematic and the error on $B(\Lambda_c^+ \to p K^- \pi^+)$.

 $^{38}\mathrm{Errata}$ to the measurement reported in AFFOLDER OOE using the p_T spectra from fully reconstructed B^0 and Λ_b decays.

³⁹ AALTONEN 08N reports $[\Gamma(\overline{b} \to b\text{-baryon})/[\Gamma(\overline{b} \to B^+) + \Gamma(\overline{b} \to B^0)]] \times [B(\Lambda_c^+ \to b^+)]$ $p\ K^-\ \pi^+)]=(14.1\pm0.6^{+5.3}_{-4.4})\times10^{-3}$ which we divide by our best value $B(\Lambda_c^+\to p\ K^-\ \pi^+)=(5.0\pm1.3)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

40 AFFOLDER 00E uses several electron-charm final states in $b
ightarrow ce^- X$.

| $\Gamma(\nu_{anything})/\Gamma_{total}$ | | | | |
|-----------------------------------------|----------------|-----|------|-------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.2308±0.0077±0.0124 | 41,42 ACCIARRI | 96c | L3 | $e^+ e^- \rightarrow Z$ |

 41 ACCIARRI 96c assumes relative b semileptonic decay rates $e:\mu: au$ of 1:1:0.25. Based on missing-energy spectrum

 42 Assumes Standard Model value for R_B .

 $\Gamma(\ell^+ \nu_\ell a \, \text{nything})/\Gamma_{total}$ "OUR EVALUATION" is an average of the data listed below, excluding all asymmetry

measurements, performed by the LEP Electroweak Working Group as described in the "Note on the Z boson" in the Z Particle Listings.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|------------------------|-----|------|--------------------------|
| 0.1069±0.0022 OUR EVALUA | | | | |
| 0.1064 ± 0.0016 OUR AVERA | GE | | | |
| $0.1070\pm0.0010\pm0.0035$ | ⁴³ HEISTER | 02G | ALEP | $e^+ e^- \rightarrow Z$ |
| $0.1070 \pm 0.0008 {}^{+ 0.0037}_{- 0.0049}$ | ⁴⁴ ABREU | 01L | DLPH | $e^+e^-\to~Z$ |
| $0.1083 \pm 0.0010 {}^{+\ 0.0028}_{-\ 0.0024}$ | ⁴⁵ ABBIENDI | 00E | OPAL | $e^+ e^- ightarrow Z$ |
| $0.1016 \pm 0.0013 \pm 0.0030$ | ⁴⁶ ACCIARRI | 00 | L3 | $e^+ e^- \rightarrow Z$ |
| $0.1085 \pm 0.0012 \pm 0.0047$ | 47,48 ACCIARRI | 96c | 1.3 | $e^+e^- \rightarrow 7$ |

• • We do not use the following data for averages, fits, limits, etc.

⁴⁹ ABREU $0.1106 \pm 0.0039 \pm 0.0022$ 95D DLPH $e^+e^- \rightarrow Z$ ⁵⁰ BUSKULIC $0.114 \ \pm 0.003 \ \pm 0.004$ 94G ALEP $e^+e^- \rightarrow Z$ ⁵¹ ABREU $0.100 \ \pm 0.007 \ \pm 0.007$ 93C DLPH $e^+e^-
ightarrow Z$ ⁵² AKERS 93B OPAL Repl. by ABBI-ENDI 00E $0.105 \pm 0.006 \pm 0.005$

 $^{
m 43}$ Uses the combination of lepton transverse momentum spectrum and the correlation between the charge of the lepton and opposite jet charge. The first error is statistic and the second error is the total systematic error including the modeling.

44 The experimental systematic and model uncertainties are combined in quadrature.

45 ABBIENDI 00E result is determined by comparing the distribution of several kinematic

variables of leptonic events in a lifetime tagged $\ddot{Z} \to b \, \bar{b}$ sample using artificial neural network techniques. The first error is statistic; the second error is the total systematic

⁴⁶ ACCIARRI 00 result obtained from a combined fit of $R_b = \Gamma(Z \to b \, \overline{b})/\Gamma(Z \to \text{hadrons})$

and B($b \to \ell \nu X$), using double-tagging method. 47 ACCIARRI 96c result obtained by a fit to the single lepton spectrum

 49 ASBINED Standard Model value for R_B . 49 ASBINED 95D give systematic errors ± 0.0019 (model) and 0.0012 (R_c). We combine these in quadrature.

This value is from a global fit to the lepton p

these in quadrature. So BUSKULIC 946 uses e and μ events. This value is from a global fit to the lepton p and p_T (relative to jet) spectra which also determines the b and c production fractions, the fragmentation functions, and the forward-backward asymmetries. This branching ratio depends primarily on the ratio of dileptons to single leptons at high p_T . But the lower p_T portion of the lepton spectrum is included in the global fit to reduce the model dependence. The model dependence is ± 0.0026 and is included in the systematic error.

dependence. The incode dependence is ± 0.0020 and is incoded in ± 0.002 and ± 0.002 and ± 0.002 and ± 0.007 ± 0.007 . So patial 0.100 $\pm 0.007 \pm 0.007$.

| SEAKERS 93 | B analysis p | erforme | d using sing | le and dilepto | n events. | | |
|---------------------------------------------------------|-------------------------|----------|-----------------------|------------------|------------|------------------------------------------------------|-------------------|
| $\Gamma(e^+ u_e { m a} { m nyt}$ | , . | | | | | | Γ ₇ /Γ |
| <i>VALUE</i> 0.1086 ± 0.003 | | EVTS | <u>DOCUM</u> | ENT ID | TECN | COMMENT | |
| 0.1086 ± 0.003 | 5 OUR AVE | RAGE | | | | | |
| 0.1078 ± 0.000 | $8 + 0.0050 \\ -0.0046$ | | ⁵³ ABBIE | NDI 00E | OPAL | $e^+e^-\to~Z$ | |
| 0.1089 ± 0.002 | 0 ± 0.0051 | į | ^{4,55} ACCIA | RRI 96c | L3 | $e^+ e^- \rightarrow Z$ | |
| 0.107 ± 0.015 | ± 0.007 | 260 | ⁵⁶ ABREU | J 93c | DLPH | $e^+ e^- \rightarrow Z$ | |
| 0.138 ±0.032 | ± 0.008 | | ⁵⁷ ADEV | A 91c | L3 | $e^+ e^- \rightarrow Z$ | |
| • • • We do | not use the | followin | g data for a | verages, fits, l | imits, etc | . • • • | |
| 0.086 ±0.027 | ±0.008 | | ⁵⁸ ABE | 93E | VNS | $E_{cm}^{ee} = 58 \text{ GeV}$ | |
| $0.109 \begin{array}{l} +0.014 \\ -0.013 \end{array}$ | ±0.0055 | 2719 | ⁵⁹ AKER | 5 93в | OPAL | Repl. by ABBI- ENDI 00E | |
| 0.111 ± 0.028 | ±0.026 | | BEHRI | END 90D | CELL | | |
| 0.150 ± 0.011 | ±0.022 | | BEHRI | END 90D | CELL | $E_{cm}^{ee} = 35 \text{ GeV}$ | |
| 0.112 ± 0.009 | ±0.011 | | ONG | 88 | MRK2 | $E_{\mathrm{CM}}^{\mathit{ee}} = 29 \; \mathrm{GeV}$ | |
| $0.149 \begin{array}{l} + 0.022 \\ - 0.019 \end{array}$ | | | PAL | 86 | DLCO | $E_{\mathrm{cm}}^{\mathit{ee}} = 29~\mathrm{GeV}$ | |
| 0.110 ±0.018 | ±0.010 | | AIHAR | :A 85 | TPC | $E_{\text{cm}}^{\textit{ee}} = 29 \text{ GeV}$ | |
| 0.111 ± 0.034 | ±0.040 | | ALTH | OFF 84J | TA SS | $E_{\rm cm}^{ee} = 34.6 {\rm Ge}^{1}$ | V |
| 0.146 ± 0.028 | | | KOOP | 84 | DLCO | Repl. by PAL 8 | 6 |
| 0.116 ± 0.021 | ±0.017 | | NELSC | N 83 | MRK2 | Eee 29 GeV | |
| | | | | | | | |

 $^{53}ABBIENDI~00E$ result is determined by comparing the distribution of several kinematic variables of leptonic events in a lifetime tagged $Z \to b \, \overline{b}$ sample using artificial neural network techniques. The first error is statistic; the second error is the total systematic

54 ACCIARRI 96c result obtained by a fit to the single lepton spectrum

 55 Assumes Standard Model value for R_B .

⁵⁵ Assumes Standard Model value for R_B .

⁵⁶ ABREU 93c event count includes ee events. Combining ee, $\mu\mu$, and $e\mu$ events, they obtain 0.100 ± 0.007 ± 0.007.

⁵⁷ ADEVA 91c measure the average B(b → eX) branching ratio using single and double tagged b enhanced Z events. Combining e and μ results, they obtain 0.113 ± 0.010 ± 0.006. Constraining the initial number of b quarks by the Standard Model prediction (378 ± 3 MeV) for the decay of the Z into $b\bar{b}$, the electron result gives 0.112 ± 0.004 ± 0.006. They obtain 0.119 ± 0.003 ± 0.006 when e and μ results are combined. Used to 0.006. They obtain 0.119 ± 0.005 \pm 0.006 when ϵ and μ results are combined. Used to measure the $b\bar{b}$ width itself, this electron result gives 370 \pm 12 \pm 24 MeV and combined with the muon result gives 385 \pm 7 \pm 22 MeV. 58 ABE 93E experiment also measures forward-backward asymmetries and fragmentation

functions for b and c.

59 AKERS 93B analysis performed using single and dilepton events.

 $\Gamma(\mu^+\nu_\mu \text{ a nything})/\Gamma_{\text{total}}$ Γ_8/Γ DOCUMENT ID TECN COMMENT 0.1095 + 0.0029 OUR AVERAGE

| - 0.0023 | • | | | | | |
|----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|------------|-----------------------------------------------|
| 5 ± 0.0008 | $^{+0.0034}_{-0.0027}$ | | ⁶⁰ ABBIENDI | 00E | OPAL | $e^+e^- ightarrow ~Z$ |
| 2 ± 0.0015 | ± 0.0059 | | | 96c | L3 | $e^+e^- ightarrow ~Z$ |
| ±0.012 | ±0.007 | 656 | | 93c | DLPH | $e^+ e^- \rightarrow Z$ |
| | | | | | | |
| We do n | ot use the | followin | ng data for averages, | fits, li | mits, etc | S. • • • |
| ±0.006 | ±0.007 | | ⁶² UENO | 96 | AMY | e^+e^- at 57.9 GeV |
| $^{+0.010}_{-0.009}$ | ±0.0055 | 4248 | ⁶⁵ AKERS | 93B | OPAL | Repl. by ABBI- ENDI 00E |
| ±0.023 | ±0.016 | | BEHREND | 90D | CELL | E ee = 43 GeV |
| ±0.010 | ±0.016 | | BEHREND | 90D | CELL | E ^{ee} _{cm} = 35 GeV |
| ±0.012 | ±0.010 | | ONG | 88 | MRK2 | <i>E</i> ^{ee} _{cm} = 29 GeV |
| ±0.016 | ±0.015 | | BARTEL | 87 | JADE | E ^{ee} _{cm} = 34.6 GeV |
| ±0.018 | ±0.025 | | BARTEL | 85 J | JADE | Repl. by BARTEL 87 |
| ±0.028 | ±0.010 | | ALTHOFF | 84 G | TASS | E ^{ee} _{cm} = 34.5 GeV |
| ±0.015 | ±0.013 | | ADEVA | 83в | MRKJ | E ^{ee} _{cm} = 33–38.5 GeV |
| | \$\pmu 0.0008\$ \$\pmu 0.0012\$ \$\pmu 0.012\$ \$\pmu 0.012\$ \$\pmu 0.006\$ \$\pmu 0.006\$ \$\pm 0.009\$ \$\pm 0.023\$ \$\pm 0.010\$ \$\pm 0.012\$ \$\pm 0.016\$ \$\pm 0.018\$ \$\pm 0.028\$ | $\pm0.006\ \pm 0.007$ | $\begin{array}{c} \pm 0.0008 + 0.0034 \\ \pm 0.0008 + 0.0027 \\ \pm 0.0015 \pm 0.0059 \\ \pm 0.012 \pm 0.007 \\ \pm 0.012 \pm 0.006 \\ \text{We do not use the followir} \\ \pm 0.006 \pm 0.007 \\ - 0.009 \pm 0.0055 \\ \pm 0.023 \pm 0.016 \\ \pm 0.010 \pm 0.016 \\ \pm 0.010 \pm 0.016 \\ \pm 0.012 \pm 0.010 \\ \pm 0.016 \pm 0.015 \\ \pm 0.018 \pm 0.025 \\ \pm 0.028 \pm 0.010 \\ \end{array}$ | ## 0.0008 + 0.0034 | ## 10.0008 | ## 10.0008 |

FERNANDEZ 83D MAC $E_{cm}^{ee} = 29 \text{ GeV}$

62 Assumes Standard Model value for R_B .

| tagged b enhanced Z events. | rage B(b → eX) Combining e and | brancl | hing rati | o using sing | gle and | d double |
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| tagged D entanted 2 events. 0.006. Constraining the initia (378±3 MeV) for the decay of They obtain 0.119±0.003±0 the $b\overline{b}$ width itself, this muon electron result gives 385±7: | al number of <u>b</u> q the Z into bb, the).006 when e and n result gives 394 | uarks t e muon μresul | y the S result gi ts are co | tandard Moves $0.123\pm$ | del pr 0.003 ed to | ediction ±0.006. measure |
| ⁶⁵ AKERS 93B analysis performe | | d dilept | on even | ts. | | |
| $(D^-\ell^+\nu_\ell$ anything)/ Γ_{total} | DO CUMENT ID | | TECN | COMMENT | | Г9/Г |
| .0227±0.0035 OUR AVERAGE | Error includes so | cale fac | tor of 1 | 7. | | |
| $0.0272 \pm 0.0028 \pm 0.0018$ $0.0199 \pm 0.0026 \pm 0.0004$ | ⁶⁶ ABREU ⁶⁷ AKERS | 95 Q | OPAL | $e^+e^- \rightarrow e^+e^- \rightarrow$ | Z | |
| 66 ABREU 00R reports their expethe first error is statistical, the to the <i>D</i> branching fraction. V 67 AKERS 95Q reports $[\Gamma(\overline{b})]$ | : second is system Ve combine first 1 | atic, an | nd the th quadratu | nird isthe u rre. | ncert a | inty due |
| $(1.82\pm0.20\pm0.12)\times10^{-3}$ $(9.13\pm0.19)\times10^{-2}$. Our fit the systematic error from usin | which we divide b rst error is their e | v our l | oest valu | $e B(D^+ \rightarrow$ | κ- | $2\pi^{+}) =$ |
| $\Gammaig(D^-\pi^+\ell^+ u_\ell$ a nything $ig)/\Gamma_{	ext{to}}$ | ntal DOCUMENT ID | | TECN | COMMENT | | Γ_{10}/Γ |
| 0.0049±0.0018±0.0007 | ABREU | | | $e^+e^- \rightarrow$ | Ζ | |
| $\Gamma(D^-\pi^-\ell^+ u_\ell$ a nything $)/\Gamma_{ m to}$ | 4-1 | | | | | Γ ₁₁ /Γ |
| VALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT | | . 11/, |
| $0.0026 \pm 0.0015 \pm 0.0004$ | ABREU | 00R | DLPH | $e^+ e^- \rightarrow$ | Ζ | |
| $\Gamma(\overline{\mathcal{D}}^0\ell^+ u_\ell$ anything)/ $\Gamma_{	ext{total}}$ | DO CUMENT ID | | <u>TECN</u> | COMMENT | | Γ ₁₂ /Γ |
| 0.0684±0.0035 OUR AVERAGE | | | | | 7 | |
| 0.0704 ± 0.0040 ± 0.0017 0.065 ± 0.006 ± 0.001 | ⁶⁸ ABREU ⁶⁹ AKERS | | DLPH OPAL | $e^+e^- \rightarrow e^+e^- \rightarrow$ | | |
| 68 ABREU 00R reports their expe the first error is statistical, the | eriment's uncertai | nties ± | 0.0034 | ± 0.0036 ± | 0.001 | 7, where |
| 69 A KERS 95Q reports [$\Gamma(\overline{b} \to (2.52 \pm 0.14 \pm 0.17) \times 10^{-3}$ (3.88 ± 0.05) $\times 10^{-2}$. Our fix | which we divide | by our | hest va | D / D 0 | . v- | L \ |
| the systematic error from usin | g our best value. | | | | | l error is |
| the systematic error from usin $\Gamma(\overline{\mathcal{D}}{}^0\pi^-\ell^+ u_\ell$ anything $)/\Gamma_{ m tot}$ | g our best value. | xperim | | | | |
| the systematic error from usin $\Gamma(\overline{\mathcal{D}}^0\pi^-\ell^+ u_\ell$ anything)/ $\Gamma_{	ext{tot}}$ | g our best value. :al | xperim | ent's err | or and ours | second | l error is |
| the systematic error from usin $\Gamma(\overline{D}^0\pi^-\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{tot}}$ $\frac{(\Delta L U E)}{(\Delta L U E)} = 0.0015 \pm 0.0011$ $\Gamma(\overline{D}^0\pi^+\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{tot}}$ | g our best value. al DOCUMENT ID ABREU | xperim 00R | ent's err <u>TECN</u> DLPH | or and our s $\frac{COMMENT}{e^+ e^- \rightarrow}$ | second | l error is |
| the systematic error from usin $\Gamma(\overline{D^0}\pi^-\ell^+\nu_\ell$ anything)/ $\Gamma_{\rm tot}$ $VALUE$ 0.0107 \pm 0.0025 \pm 0.0011 $\Gamma(\overline{D^0}\pi^+\ell^+\nu_\ell$ anything)/ $\Gamma_{\rm tot}$ $VALUE$ | g our best value. al DOCUMENT ID ABREU | xperim 00r | ent's err <u>TECN</u> | or and our s | z Z | Γ ₁₃ /Γ |
| the systematic error from usin $\Gamma(\overline{D}^0\pi^-\ell^+\nu_\ell$ anything)/ $\Gamma_{\rm tot}$ $\rho_{\rm ALUE}$ 0.0107 \pm 0.0025 \pm 0.0011 $\Gamma(\overline{D}^0\pi^+\ell^+\nu_\ell$ anything)/ $\Gamma_{\rm tot}$ 0.0023 \pm 0.0015 \pm 0.0004 $\Gamma(D^{*-}\ell^+\nu_\ell$ anything)/ $\Gamma_{\rm total}$ | g our best value. al DOCUMENT ID ABREU al DOCUMENT ID ABREU | oor 00R | TECN DLPH TECN DLPH | or and our s $\frac{COMMENT}{e^{+}e^{-}\rightarrow}$ $\frac{COMMENT}{e^{+}e^{-}\rightarrow}$ | z Z | Γ ₁₃ /Γ |
| the systematic error from usin $\Gamma(\overline{D}^0\pi^-\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $0.0107\pm0.0025\pm0.0011$ $\Gamma(\overline{D}^0\pi^+\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $0.0023\pm0.0015\pm0.0004$ $\Gamma(D^{*-}\ell^+\nu_\ell \text{anything})/\Gamma_{\text{total}}$ 0.0025 ± 0.0019 OUR AVERAGE | g our best value. al DOCUMENT ID ABREU COLUMENT ID ABREU DOCUMENT ID | oor 00r 00r | TECN DLPH TECN DLPH TECN DLPH | or and our some of the comment $e^+e^- \rightarrow \frac{COMMENT}{e^+e^- \rightarrow \frac{COMMENT}{e^+e^-}}$ | z Z | Γ_{13}/Γ Γ_{14}/Γ |
| the systematic error from usin $(D^0\pi^-\ell^+\nu_\ell)$ anything)/ $\Gamma_{\rm tot}$ $(D^0\pi^+\ell^+\nu_\ell)$ $(D^0\pi^+\nu_\ell)$ | g our best value. al DOCUMENT ID ABREU al DOCUMENT ID ABREU | OOR OOR | TECN DLPH TECN DLPH TECN DLPH | or and our s $\frac{COMMENT}{e^{+}e^{-}\rightarrow}$ $\frac{COMMENT}{e^{+}e^{-}\rightarrow}$ | z Z | Γ_{13}/Γ Γ_{14}/Γ |
| the systematic error from usin $\Gamma(\overline{D}^0\pi^-\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $VALUE$ 0.0107 \pm 0.0025 \pm 0.0011 $\Gamma(\overline{D}^0\pi^+\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $VALUE$ 0.0023 \pm 0.0015 \pm 0.0004 $\Gamma(D^*-\ell^+\nu_\ell \text{anything})/\Gamma_{\text{total}}$ $VALUE$ 0.00275 \pm 0.0019 OUR AVERAGE 0.0275 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 $VALUE$ 0.0276 \pm 0.0027 \pm 0.0011 | g our best value. (a) DOCUMENT ID ABREU DOCUMENT ID ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO ABREU TO | 00R 00R 00R 95Q nties ± | TECN DLPH TECN DLPH TECN DLPH OPAL c0.0017: dd the th | or and our state of the comment $e^+e^- \rightarrow \frac{COMMENT}{e^+e^- \rightarrow \frac{COMMENT}{e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- ^- \rightarrow e^-e^- | Z Z Z Z O.0000 | Γ_{13}/Γ Γ_{14}/Γ Γ_{15}/Γ Γ_{9} , where inty due |
| the systematic error from usin $\Gamma(D^0\pi^-\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $\Delta \ell \cup \ell = 0.0107 \pm 0.0025 \pm 0.0011$ $\Gamma(D^0\pi^+\ell^+\nu_\ell \text{anything})/\Gamma_{\text{tot}}$ $\Delta \ell \cup \ell = 0.0023 \pm 0.0015 \pm 0.0004$ $\Gamma(D^{*-}\ell^+\nu_\ell \text{anything})/\Gamma_{\text{total}}$ $\Delta \ell \cup \ell = 0.0023 \pm 0.0019$ OUR AVERAGE 0.0275 ± 0.0019 OUR AVERAGE $0.0275 \pm 0.0021 \pm 0.0009$ $0.0275 \pm 0.0027 \pm 0.0011$ 0.0275 ± 0.0027 | g our best value. (a) $DOCUMENT ID$ ABREU (a) $DOCUMENT ID$ ABREU 70 ABREU 71 AKERS eriment's uncertaint second is system (second is system). We combine first in $D^* \ell^+ \nu_\ell X$ × B(| 00R 00R 00R static, and it is in the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the | TECN DLPH TECN DLPH TECN DLPH ODAL CO.0017: and the the quadratus $D^0 \pi^-$ | or and our state of the comment $e^+e^- \rightarrow \frac{COMMENT}{e^+e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^+e^- \rightarrow e^-e^- \rightarrow e^-$ | Z Z Z Z O.0000 ncerta | Γ_{13}/Γ Γ_{14}/Γ Γ_{15}/Γ 9, where inty due $(-\pi^+)$ |
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 60 ABBIENDI 00E result is determined by comparing the distribution of several kinematic variables of leptonic events in a lifetime tagged $Z \to b \, \overline{b}$ sample using artificial neural network techniques. The first error is statistic; the second error is the total systematic

 63 ABREU 93c event count includes $\mu\mu$ events. Combining ee, $\mu\mu$, and e μ events, they

error. 61 ACCIARRI 96c result obtained by a fit to the single lepton spectrum.

| $\Gamma(D_j^-\ell^+ u_\ell)$ anything $	imes$ B | $(D_i^- \rightarrow D^0\pi^-))/$ | Γ _{total} | | | Γ19/Γ |
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| D _j represents an unres | | | and ter | nsor D** (P-w | ave) states. |
| VALUE (units 10^{-3}) | DO CUMENT IE |) | TECN | COMMENT | |
| $7.0 \pm 1.9 ^{+1.2}_{-1.3}$ | AKERS | 95 Q | OPAL | $e^+e^- \rightarrow Z$ | • |
| $\Gamma(\overline{D}_2^*(2460)^0\ell^+ u_\ell$ anythi | $\log 	imes B(\overline{D}_2^*(2460))$ | 0 → D | *-π ⁺) |))/F _{total} | Γ ₂₀ /Γ |
| VALUE (units 10^{-3}) CLS | <u>DOCUMENT IL</u> |) | TECN | COMMENT | |
| <1.4 90 | ABBIENDI | | | $e^+e^- \rightarrow Z$ | • |
| $\Gamma(D_2^*(2460)^-\ell^+ u_\ell$ a nyth | $\log \times B(D_2^*(2460))$ | _ → ı | $D^0\pi^-$ |)/Γ _{total} | Γ_{21}/Γ |
| VALUE (units 10 ⁻³) | DO CUMENT IL |) | TECN | COMMENT | |
| $4.2 \pm 1.3 ^{+\ 0.7}_{-\ 1.2}$ | AKERS | 95 Q | OPAL | $e^+e^- \rightarrow Z$ | |
| $\Gamma(\overline{D}_2^*(2460)^0\ell^+ u_\ell$ anythi | $\log \times B(\overline{D}_2^*(2460))$ | 0 → D |)-π+)) | /Γ _{total} | Γ ₂₂ /Γ |
| VALUE (units 10 ⁻³) | DO CUMENT IL | | | COMMENT | |
| 1.6±0.7±0.3 | AKERS | 95 Q | OPAL | $e^+e^- \rightarrow Z$ | • |
| Heavy Flavour Steering tions between the mea WALUE 0.00171±0.00052 OUR EVA 0.0017 ±0.0004 OUR AVE | surements | - | | | |
| 0.0017 ± 0.0004 COR AVE $0.00163 \pm 0.00053 + 0.00055$ $0.00163 \pm 0.00053 + 0.00062$ | ⁷² ABBIENDI | 01R | OPAL | $e^+e^- \rightarrow Z$ | |
| $0.00157 \pm 0.00035 \pm 0.00055$ | ⁷³ ABREU | | DLPH | | |
| $0.00173 \pm 0.00055 \pm 0.00055$ | ⁷⁴ BARATE | 99G | ALEP | $e^+e^- \rightarrow Z$ | • |
| $0.0033 \pm 0.0010 \pm 0.0017$ | ⁷⁵ ACCIARRI | 98к | L3 | $e^+e^- \rightarrow Z$ | |
| 0.0033 $\pm 0.0010 \pm 0.0017$ 72 Obtained from the best to $X_U \ell \nu$ neutral network ou 73 ABREU 00D result obtain depleted samples and the $\tau_b = 1.564 \pm 0.014$ ps. 74 Uses lifetime tagged $b \overline{b}$ s | 75 ACCIARRI fit of the MC simulat tput distributions. fied from a fit to the n fir lepton spectra, and firmale. | 98k ed even umbers I assum | L3 ts to th of decaying $ V_C $ | $e^+e^- ightarrow Z$ e data based o ys in $b ightarrow u$ e | on the $b ightharpoonup$ nriched and |
| 0.0033 $\pm 0.0010 \pm 0.0017$ 72 Obtained from the best $X_{\mu} \ell \nu$ neutral network out 73 ABREU 00D result obtain depleted samples and the $\tau_{b} = 1.564 \pm 0.014$ ps. 74 Uses lifetime tagged $b \overline{D}$ s 75 ACCIARRI 98K assumes | 75 ACCIARRI fit of the MC simulat tput distributions. fied from a fit to the n fir lepton spectra, and firmale. | 98k ed even umbers I assum | L3 ts to th of decaying $ V_C $ | $e^+e^- ightarrow Z$ e data based o ys in $b ightarrow u$ e | on the $b ightharpoonup$ nriched and 0.0033 and |
| 0.0033 \pm 0.0010 \pm 0.0017 72 Obtained from the best $X_{\mu} \ell \nu$ neutral network ou 73 ABREU 00D results obtain depleted samples and the $\tau_b = 1.564 \pm 0.014$ ps. 75 ACCIARRI 98K assumes $\Gamma(\tau^+ \nu_\tau \text{ a nything})/\Gamma_{\text{total}}$ | 75 ACCIARRI fit of the MC simulat tput distributions. Head from a fit to the neitrepton spectra, and sample. $R_b=0.2174\pm0.000$ | 98K ed even umbers I assum 9 at Z o | L3 ts to th of decaring $ V_C $ | $e^+e^- \rightarrow Z$ e data based of the data based of the data based of the data by $b = 0.0384 \pm 10^{-2}$ | on the $b ightharpoonup$ nriched and 0.0033 and |
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| 0.0033 \pm 0.0010 \pm 0.0017 72 Obtained from the best $X_{y} \ell \nu$ neutral network our $X_{3} \ell \nu$ neutral network of $X_{3} \ell \nu$ neutral network of $X_{3} \ell \nu$ neutral network of $X_{3} \ell \nu$ neutral network of $X_{3} \ell \nu$ neutral network of $X_{3} \ell \nu$ neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral neutral | 75 ACCIARRI fit of the MC simulat that distributions. It is defined a fit to the noir lepton spectra, and sample. 85 DOCUMENT II 76 ABBIENDI 77 BARATE 78 ABREU 79,80 ACCIARRI 2 81 ACCIARRI 10wing data for average and substitution of the sample. Since the sample walled from missing evalue for R_B . In gragged $b\overline{b}$ events in granged $b\overline{b}$ events in granged because in granged because of the sample o | 98k ed even umbers l assum 9 at Z of 01Q 01E 00c 96c 94c 94c ges, fits 95 93B ue. e used. ithout i nergy sq at the 2 | L3 ts to th of decay. TECN OPAL ALEP DLPH L3 L3 L3 L3 Limits, ALEP dentifyin obectrum. $TECN$ TECN TECN TECN TECN TECN TECN | $e^+e^- 	o 	ext{ } 	e$ | on the $b \rightarrow$ nriched and 0.0033 and $\lceil \frac{724}{\Gamma} \rceil$ RATE 01E SKULIC 95 |
| 0.0033 \pm 0.0010 \pm 0.0017 72 Obtained from the best $X_{u} \ell \nu$ neutral network ou T^3 ABREU 00D result obtain depleted samples and the $\tau_b = 1.564 \pm 0.014$ ps. 74 Uses lifetime tagged $b D = 0.000$ for $D = 0.000$ | 75 ACCIARRI fit of the MC simulat that distributions. It is defined a fit to the noir lepton spectra, and sample. 86 ABBIENDI 77 BARATE 78 ABBIENDI 77 BARATE 78 ABREU 79,80 ACCIARRI 2 81 ACCIARRI 2 81 ACCIARRI 3 BUSKULIC BUSKULIC 6 BUSKULIC 6 BUSKULIC 6 BUSKULIC 6 BUSKULIC 7 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC 8 BUSKULIC | 98k ed even umbers l assumm 9 at Z of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the s | L3 ts to th of decay. TECN OPAL ALEP DLPH L3 L3 L3 L3 Limits, ALEP dentifyin obectrum. $TECN$ TECN TECN TECN TECN TECN TECN | $e^+e^- 	o Z$ e data based of ys in $b 	o u$ e $b = 0.0384 \pm 0$ $\frac{COMMENT}{e^+e^- 	o Z}$ $e^+e^- 	o Z$ $e^+e^- 	o Z$ $e^+e^- 	o Z$ $e^+e^- 	o Z$ etc. • • • Repl. by BAI Repl. by BU: | on the $b \rightarrow$ nriched and 0.0033 and $\lceil \frac{724}{\Gamma} \rceil$ RATE 01E SKULIC 95 |
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0.0802±0.0019 OUR EVALUATION 0.0817 ± 0.0020 OUR AVERAGE $0.0818 \pm 0.0015 \, {}^{+\, 0.0024}_{-\, 0.0026}$

 $0.0798 \pm 0.0022 ^{\,+\, 0.0025}_{\,-\, 0.0029}$

 $0.0840 \pm 0.0016 \, {}^{+\ 0.0039}_{-\ 0.0036}$

 $0.0770 \pm 0.0097 \pm 0.0046$

 $\begin{array}{cccc} 0.082 & \pm 0.003 & \pm 0.012 \\ 0.077 & \pm 0.004 & \pm 0.007 \end{array}$

84 HEISTER

⁸⁵ ABREU

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ⁸⁷ ABREU

⁸⁶ ABBIENDI

88 BUSKULIC 89 AKERS

02G ALEP $e^+e^-
ightarrow Z$

01L DLPH $e^+e^-
ightarrow Z$

00E OPAL $e^+e^- \rightarrow Z$

95D DLPH $e^+e^- \rightarrow Z$

936 OPAL Repl. by ABBI-ENDI 00E

$B^{\pm}/B^{0}/B_{c}^{0}/b$ -baryon ADMIXTURE

| | pton transverse momentum spectrum and the c pton and opposite jet charge. The first error is sta | orrelation | $\Gamma(D^*(2010)^+ \text{ anything})/\Gamma_{\text{tot}}$ | | | Г ₃₇ /Г |
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| the second error is the total | systematic error including the modeling. and model uncertainties are combined in quadrat | | | 100 ACKERSTAFF 98E OF | PAL $e^+e^- \rightarrow Z$ | |
| 86 ABBIENDI 00E result is det | ermined by comparing the distribution of several lin a lifetime tagged $Z 	o b \overline{b}$ sample using artific | kinem atic | 100 Uses lepton tags to select Z - | | | |
| network techniques. The fir | st error is statistic; the second error is the total s | ystem at ic | $\Gamma(D_1(2420)^0 \text{ anything})/\Gamma_{\text{tota}}$ | | COMMENT | Γ ₃₈ /Γ |
| ⁸⁷ ABREU 95D give systemation | c errors ±0.0033 (model) and 0.0032 ($R_{\it C}$). We esult is from the same global fit as their $\Gamma(\overline{b} ightarrow$ | | | 101 ACKERSTAFF 97W OF | | |
| data. | μ events. This value is from the same global fi | | 101 ACKERSTAFF 97W assume $\Gamma_{b\overline{b}}/\Gamma_{ m hadrons}=0.216$ at Z | $B(D_2^*(2460)^0 \to D^*$ | $^{+}\pi^{-}) = 0.21 \pm 0$ |).04 and |
| $\Gamma(\overline{b} \rightarrow \ell^+ \nu_{\ell} \text{ anything}) / \Gamma_{to}$ | | as then | $\Gamma(D^*(2010)^{\mp}D_s^{\pm} \text{ a nything})/$ | | | Г ₃₉ /Г |
| $\Gamma(c \to \ell^+ \nu a \text{nything}) / \Gamma_{\text{tota}}$ | | Γ ₂₇ /Γ | VALUE | DOCUMENT ID TE | COMMENT | |
| <u>VALUE</u> | DOCUMENT ID TECN COMMENT | | $0.033 \begin{array}{l} + 0.010 \\ - 0.009 \\ - 0.009 \\ \end{array}$ | • | EP $e^+e^- \rightarrow Z$ | |
| $0.0161 \pm 0.0020 + 0.0034$ | 90 ABREU 01L DLPH $e^+e^- 	o Z$ | | $\Gamma(D^0D^*(2010)^{\pm} \text{ anything})/1$ | | charm branching rati | |
| $\Gamma(\overline{D}^0 \text{ anything})/\Gamma_{\text{total}}$ | and model uncertainties are combined in quadrat | _ | VALUE | | COMMENT | Γ ₄₀ /Γ |
| VALUE VALUE | DOCUMENT ID TECN COMMENT | Γ ₂₈ /Γ | $0.030 + 0.009 + 0.007 \\ -0.008 - 0.005$ | ¹⁰³ BARATE 98Q AL | $EP e^+ e^- \to \; Z$ | |
| $0.598 \pm 0.029 {}^{+ 0.007}_{- 0.008}$ | 91 BUSKULIC 96Y ALEP $e^+e^- ightarrow~Z$ | | ¹⁰³ The systematic error includes | | charm branching rati | ios. |
| 91 BUSKULIC 96Y reports 0. | 605 \pm 0.024 \pm 0.016 from a measurement of $D^0 \to K^-\pi^+)$] assuming B($D^0 \to K^-\pi^+$) = | $[\Gamma(\overline{b} \rightarrow 0.0202)]$ | Γ(<i>D</i> *(2010) [±] <i>D</i> [∓] a nything)/ | | ECN COMMENT | Γ_{41}/Γ |
| which we rescale to our bes | t value B($D^0 ightarrow K^-\pi^+$) $= (3.88 \pm 0.05) 	imes 10$ | ı−2. Our | | | $\frac{COMMENT}{COMMENT}$ $\frac{COMMENT}{COMMENT}$ | |
| first error is their experimen using our best value. | it's error and our second error is the systematic e | rror from | 104 The systematic error includes | the uncertainties due to the | e charm branching rat | ios. |
| $\Gamma(D^0D_s^{\pm} \text{ a nything})/\Gamma_{	ext{total}}$ | | Γ ₂₉ /Γ | Γ(<i>D</i> *(2010) [±] <i>D</i> *(2010) [∓] any | | | Γ ₄₂ /Γ |
| VALUE 0.091 + 0.020 + 0.034 - 0.018 - 0.022 | $\frac{DOCUMENT\ ID}{92}$ BARATE 98Q ALEP $e^+e^- ightarrow Z$ | | VALUE | <u>DOCUMENT ID TE</u> | COMMENT | |
| | The sthe uncertainties due to the charm branching rate. | ilos | -0.003 | * | $EP e^+e^- \rightarrow Z$ | |
| $\Gamma(D^{\mp}D_s^{\pm} \text{ anything})/\Gamma_{\text{total}}$ | is the uncertainties due to the chain branching rai | Γ ₃₀ /Γ | 105 The systematic error includes | the uncertainties due to the | charm branching rati | |
| VALUE | DOCUMENT ID TECN COMMENT | | Γ(D̄ Danything)/Γ _{total} | DOCUMENT ID TE | COMMENT | Γ ₄₃ /Γ |
| $\begin{array}{l} 0.040 + 0.017 + 0.016 \\ -0.014 - 0.011 \end{array}$ | 93 BARATE 98 Q ALEP $e^+e^- 	o Z$ | | $0.10 \pm 0.032 + 0.107 \\ -0.095$ | ¹⁰⁶ ABBIENDI 041 OF | PAL $e^+e^- \rightarrow Z$ | |
| | s the uncertainties due to the charm branching ra | ios. | 106 Measurement performed using dates. | g an inclusive identification o | of B mesons and the t | D candi- |
| $\left[\Gamma(D^0 D_s^{\pm} \text{ anything}) + \Gamma(D_s)\right]$ | $\mathcal{F}D_s^{\pm}$ a nything)]/ Γ_{total} (Γ_{29} + | ⊦Γ ₃₀)/Γ | Γ(D ₂ *(2460) ⁰ a nything)/Γ _{tota} | | | Γ ₄₄ /Γ |
| 0.131 + 0.026 + 0.048 - 0.022 - 0.031 | 94 BARATE 98Q ALEP $e^+e^- \rightarrow Z$ | | VALUE | DOCUMENT ID TE | COMMENT | - 44/- |
| | s the uncertainties due to the charm branching rai | ios. | 0.047±0.024±0.013 ¹⁰⁷ ACKERSTAFF 97W assume | 107 ACKERSTAFF 97w OF | | 04 and |
| $\Gamma(\overline{D}^0 D^0 \text{ anything})/\Gamma_{\text{total}}$ | | Г ₃₁ /Г | $\Gamma_{b\overline{b}}/\Gamma_{hadrons} = 0.216 \text{ at } Z$ | decay. | , = 0.21 ± 0 | |
| VALUE 0.016+0.012 | DOCUMENT ID TECN COMMENT | | $\Gamma(D_s^-$ anything)/ $\Gamma_{ m total}$ | | | Г ₄₅ /Г |
| $0.051 + 0.016 + 0.012 \\ -0.014 - 0.011$ | 95 BARATE 98Q ALEP $e^+e^- ightarrow Z$ | | VALUE | DO CUMENT ID TE | CN COMMENT | |
| 95 The systematic error include | s the uncertainties due to the charm branching rat | ios | $0.147 \pm 0.017 \pm 0.013$ | ¹⁰⁸ BUSKULIC 96Y AL | .EP $e^+e^- \rightarrow Z$ | |
| | s the uncertainties due to the charm branching ra | | ¹⁰⁸ BUSKULIC 96Y reports 0.18 | | a measurement of | |
| $\Gamma(D^0 D^{\pm} \text{ a nything})/\Gamma_{\text{total}}$ | s the uncertainties due to the charm branching rat DOCUMENT ID TECN COMMENT | rios. Γ ₃₂ /Γ | 108 BUSKULIC 96Y reports 0.18 D_s^- anything)/ $\Gamma_{ m total}$] \times [B(E | $83 \pm 0.019 \pm 0.009$ from $Q_S^+ ightarrow \left(\phi \pi^+ ight)$] assuming B(I | a measurement of $D_S^+ 	o \phi \pi^+) = 0.03$ | 36, which |
| $\Gamma(D^0 D^{\pm} \text{ a nything})/\Gamma_{\text{total}}$ | - | | $108\mathrm{BUSKULIC}$ 96Y reports 0.14 D_S^- anything)/ Γ_total] \times [B(L we rescale to our best value E their experiment's error and o | $83 \pm 0.019 \pm 0.009$ from $D_s^+ \rightarrow \phi \pi^+)$] assuming B($B_s^+ \rightarrow \phi \pi^+) = (4.5 \pm 0.00)$ | a measurement of $D_S^+ \to \phi \pi^+) = 0.03$ $0.4) \times 10^{-2}$. Our first | 36, which sterror is |
| $\Gamma(D^0 D^{\pm} \text{ a nything})/\Gamma_{\text{total}}$ $\frac{\text{MALUE}}{0.027 \pm 0.015 \pm 0.010}$ 96 The systematic error include | $\frac{DOCUMENT\ ID}{96\ BARATE}$ $98Q\ ALEP\ e^+e^-	o Z$ is the uncertainties due to the charm branching rate | Γ ₃₂ /Γ | $108\mathrm{BUSKULIC}$ 96Y reports 0.14 D_s^- anything)/ Γ_total] × [B(L we rescale to our best value E their experiment's error and o value. | $83 \pm 0.019 \pm 0.009$ from $D_s^+ \rightarrow \phi \pi^+)$] assuming B($B_s^+ \rightarrow \phi \pi^+) = (4.5 \pm 0.00)$ | a measurement of $D_S^+ \to \phi \pi^+) = 0.03$ $0.4) \times 10^{-2}$. Our first | 36, which st error is our best |
| $\Gamma(D^0 D^{\pm} \text{ a nything})/\Gamma_{\text{total}}$ $MLUE$ $0.027 + 0.015 + 0.010$ $0.027 + 0.013 - 0.009$ | $\frac{DOCUMENT\ ID}{96\ BARATE}$ 98Q ALEP $e^+e^-	o Z$ as the uncertainties due to the charm branching rather $0\ D^\pm$ anything)]/ $\Gamma_{	ext{total}}$ ($\Gamma_{	ext{31}}$ - | Γ ₃₂ /Γ | 108 BUSKULIC 96Y reports 0.14 D_s^- anything)/ Γ_{total}] × [B(E_s^-) we rescale to our best value E their experiment's error and o value. $\Gamma(D_s^+ \text{ anything})/\Gamma_{\text{total}}$ MALUE | $83 \pm 0.019 \pm 0.009$ from $0.5^+ \rightarrow \phi \pi^+)]$ assuming B(I assuming B(I assuming B) assuming B(I are second error is the system $\frac{DOCUMENT\ ID}{IE}$ | a measurement of $D_S^+ \to \phi \pi^+) = 0.03$ $0.4) \times 10^{-2}$. Our first | 36, which sterror is |
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| $ \begin{split} & \Gamma(D^0 D^{\pm} \text{a nything}) / \Gamma_{\text{total}} \\ & \frac{VALUE}{0.027 + 0.015 + 0.010} \\ & 96 \text{The systematic error include} \\ & \left[\Gamma(\overline{D^0} D^0 \text{a nything}) + \Gamma(D^0 D^0 \text{a nything}) \right] \\ & \frac{VALUE}{0.078 + 0.020 + 0.018} \\ & 97 \text{The systematic error include} \\ & \Gamma(D^{\pm} D^{\mp} \text{anything}) / \Gamma_{\text{total}} \\ & \frac{VALUE}{0.018 - 0.016} \\ & \frac{CL\%}{0.018 - 0.016} \\$ | POCUMENT ID 96 BARATE 98Q ALEP $e^+e^- \rightarrow Z$ 15 the uncertainties due to the charm branching rate 16 D^\pm anything)]/ Γ_{total} (Γ_{31} + 17 D^\pm COMMENT 97 BARATE 98Q ALEP $e^+e^- \rightarrow Z$ 18 the uncertainties due to the charm branching rate 18 D^\pm COMMENT 19 D^\pm ALEP 19 D^\pm COMMENT 10 D^\pm ALEP 10 D^\pm COMMENT 11 D^\pm COMMENT 12 D^\pm COMMENT 13 D^\pm COMMENT 15 D^\pm COMMENT 16 D^\pm COMMENT | Γ ₃₂ /Γ cios | 108 BUSKULIC 96Y reports 0.14 $D_s^- \text{ anything} / \Gamma_{\text{total}}] \times [\text{B(}D_s)] \times [$ | $83 \pm 0.019 \pm 0.009$ from $9^+_S \rightarrow \phi \pi^+)]$ assuming B($I^S \rightarrow \phi \pi^+)$ assuming B($I^S \rightarrow \phi \pi^+)$ = (4.5 $\pm 0^S \rightarrow \phi \pi$ | a measurement of $D_s^+ 	o \phi \pi^+) = 0.03$ $0.4) 	imes 10^{-2}$. Our first natic error from using $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ cluding the branching $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ a measurement of $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ | 36, which sterror is our best $\frac{\Gamma_{46}/\Gamma}{\Gamma_{47}/\Gamma}$ fractions $\frac{\Gamma_{47}/\Gamma}{\Gamma_{60}}$ $\Gamma_{60} = 0.044,$ |
| $ \begin{split} &\Gamma(D^0 D^{\pm} \text{a nything})/\Gamma_{\text{total}} \\ &\frac{VALUE}{0.027 + 0.015 + 0.010} \\ &96 \text{The systematic error include} \\ & [\Gamma(\overline{D^0} D^0 \text{a nything}) + \Gamma(D^0 D^0 \text{a nything}) \\ &\frac{VALUE}{0.078 + 0.020 + 0.018} \\ &97 \text{The systematic error include} \\ &\frac{97}{1000000000000000000000000000000000000$ | POCUMENT ID PROPERTY ID PROPERTY ID PROPERTY ID PROPERTY ID PROCUMENT ID BARATE PROCUMENT ID BOCUMENT ID BOC | Γ ₃₂ /Γ cios Γ ₃₂ /Γ Γ ₃₅ /Γ | 108 BUSKULIC 96Y reports 0.14 $D_s^- \text{ anything} / \Gamma_{\text{total}}] \times [\text{B(}D_s)] \times [$ | $83 \pm 0.019 \pm 0.009$ from $9^+_S \rightarrow \phi \pi^+)]$ assuming B($I^S \rightarrow \phi \pi^+)$ assuming B($I^S \rightarrow \phi \pi^+)$ = (4.5 $\pm 0^S \rightarrow \phi \pi$ | a measurement of $D_s^+ 	o \phi \pi^+) = 0.03$ $0.4) 	imes 10^{-2}$. Our first natic error from using $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ cluding the branching $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ a measurement of $\frac{ECN}{ECN} = \frac{COMMENT}{e^+e^- 	o Z}$ | 36, which sterror is our best $\frac{\Gamma_{46}/\Gamma}{\Gamma_{47}/\Gamma}$ fractions $\frac{\Gamma_{47}/\Gamma}{\Gamma_{60}}$ $\Gamma_{60} = 0.044,$ |
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Γ_{33}/Γ $+\Gamma_{35}/\Gamma$ fractions Γ_{36}/Γ Γ_{36}/Γ | 108 BUSKULIC 96Y reports 0.14 D_s^- anything)/ Γ_{total} × [B(L we rescale to our best value E their experiment's error and o value. $\Gamma(D_s^+$ anything)/ Γ_{total} NALUE 0.101±0.010±0.029 109 The second error is the total o used in the measurement. $\Gamma(b \to \Lambda_c^+$ anything)/ Γ_{total} NALUE 0.097±0.013±0.025 110 BUSKULIC 96Y reports 0.1: Λ_c^+ anything)/ Γ_{total} WALUE 0.1097±0.013±0.025 $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × reports 0.1: $\Gamma(c)$ × repor | $83 \pm 0.019 \pm 0.009$ from $b_s^+ \rightarrow \phi \pi^+)]$ assuming B(I $3(D_s^+ \rightarrow \phi \pi^+) = (4.5 \pm 0)$ ur second error is the system $\frac{DOCUMENT\ ID}{109\ ABDALLAH} \qquad \frac{TE}{110\ BUSKULIC} \qquad \frac{TE}{96Y} \qquad AL \\ \frac{DOCUMENT\ ID}{110\ BUSKULIC} \qquad \frac{TE}{96Y} \qquad AL \\ \frac{DOCUMENT\ ID}{110\ BUSKULIC} \qquad \frac{TE}{96Y} \qquad AL \\ \frac{DOCUMENT\ ID}{110\ BUSKULIC} \qquad \frac{TE}{110\ BUSKULIC} \qquad \frac{TE}{111\ ABBIENDI} \qquad 041 \qquad OF$ | a measurement of $D_s^+ \to \phi \pi^+) = 0.03$ $0.4) \times 10^{-2}$. 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| | pocument ID 96 BARATE 98 Q ALEP $e^+e^- \rightarrow Z$ so the uncertainties due to the charm branching rate 97 D= anything)]/ Γ_{total} DOCUMENT ID 98 BARATE 98 Q ALEP $e^+e^- \rightarrow Z$ So the uncertainties due to the charm branching rate DOCUMENT ID BARATE 98 Q ALEP $e^+e^- \rightarrow Z$ So the uncertainties due to the charm branching rate $\frac{DOCUMENT\ ID}{BARATE}$ $\frac{TECN}{98 Q}$ $\frac{COMMENT}{ALEP}$ $\frac{COMMENT}{e^+e^- \rightarrow Z}$ $\frac{DOCUMENT\ ID}{98 ABDALLAH}$ 03E $\frac{DOCUMENT\ ID}{98 ABDALLAH}$ 03E $\frac{DOCUMENT\ ID}{98 ABDALLAH}$ 03E $\frac{DOCUMENT\ ID}{SOCUMENT\ ID}$ $\frac{TECN}{SOCUMENT}$ $\frac{COMMENT}{SOCUMENT}$ 99 BUSKULIC 96Y ALEP $e^+e^- \rightarrow Z$ | Γ_{32}/Γ tios. $+\Gamma_{32}/\Gamma$ tios. Γ_{33}/Γ $+\Gamma_{35}/\Gamma$ fractions Γ_{36}/Γ Γ_{36}/Γ Γ_{36}/Γ Γ_{36}/Γ | 108 BUSKULIC 96Y reports 0.14 D_s^- anything)/ Γ_{total} × [B(L we rescale to our best value E their experiment's error and o value. $\Gamma(D_s^+$ anything)/ Γ_{total} NALUE 0.101±0.010±0.029 109 The second error is the total o used in the measurement. $\Gamma(b \to \Lambda_c^+$ anything)/ Γ_{total} NALUE 0.097±0.013±0.025 110 BUSKULIC 96Y reports 0.11 Λ_c^+ anything)/ Γ_{total} WALUE which we rescale to our best v error is their experiment's error our best value. $\Gamma(\overline{C}/c$ anything)/ Γ_{total} NALUE 1.162±0.032 OUR AVERAGE 1.12 $^+$ 0.11 $^-$ 0.10 1.166±0.031±0.080 1.147±0.041 | $83 \pm 0.019 \pm 0.009$ from 0.000^{+} from 0.0000^{+} from 0.0000^{+} from 0.00000^{+} from $0.00000000000000000000000000000000000$ | a measurement of $D_s^+ \rightarrow \phi \pi^+) = 0.03$ $0.4) \times 10^{-2}$. Our first natic error from using $\frac{ECN}{ECN} = \frac{COMMENT}{ECN}$ LPH $e^+e^- \rightarrow Z$ cluding the branching $\frac{ECN}{ECN} = \frac{COMMENT}{ECN}$ a measurement of $\frac{ECN}{ECN} = \frac{ECN}{ECN} $ | 36, which at error is our best $ \frac{\Gamma_{46}/\Gamma}{\Gamma_{46}/\Gamma} $ fractions $ \frac{\Gamma_{47}/\Gamma}{\Gamma_{47}/\Gamma} $ [$\Gamma(b \rightarrow 0.044, 0.045)$ Our first om using |

| ¹¹¹ Measurement performe | ed using an | inclusive identif | fication of | B mesons | and the | D candi- |
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| dates. 112 Evaluated via summat | | | | | | |
| TT ABREU 98D results a | ire extracted | I from a fit to | the <i>b-</i> tag | gging proba | ability dis | stribution |
| based on the impact p | | production frac | tions for | R ⁰ R+ F | R h han | ons and |
| PDG 96 branching rati | | | | | | |
| and A_C branching ratio | os, corrected | t to include incl | lusive $\Xi_{\mathcal{C}}$ | and charm | onium. | - |
| $\Gamma(J/\psi(1S) {\sf anything}) /$ | Γ _{total} | | | | | Γ_{49}/Γ |
| VALUE (units 10 ⁻²) | CL% EVTS | DOCUME | NT ID | TECN | COMMEN | IT |
| 1.16±0.10 OUR AVERA | AGE | 115 | | | | _ |
| $1.12 \pm 0.12 \pm 0.10$ $1.16 \pm 0.16 \pm 0.14$ | 121 | ¹¹⁵ ABREU ¹¹⁶ ADRIAN | 94 JI 93 | | | \rightarrow Z \rightarrow Z |
| $1.21 \pm 0.13 \pm 0.08$ | | BUSKUL | | 2G ALEP | | $\rightarrow Z$ |
| • • • We do not use the | following da | _ | | ts, etc. • • | • • | |
| 1.3 ±0.2 ±0.2 | 00 | 117 ADRIAN | | | e+ e | |
| <4.9 | 90 | MATTE | | | $E_{\rm cm}^{ee} = 2$ | |
| 115 ABREU 94P is an inc e^+e^- and $\mu^+\mu^-$ cha | | | | | Uses J/v | <i>p</i> (13) → |
| 116 ADRIANI 93J is an in | | | | | Uses J/ | $\psi(1S) \rightarrow$ |
| $\mu^{+}\mu^{-}$ and $J/\psi(1S)$ - | $\rightarrow e^+e^-$ | hannels. | B | | | |
| 117 ADRIANI 92 measuren 0.3) \times 10 ⁻³ which is u | ment is an in used to extra | iclusive result to act the <i>b</i> -hadroi | orB(Z → n.contribu | $J/\psi(1S)$ ition to J/ϵ | $X) = (4.1$ $\psi(1S)$ pro | \pm 0.7 \pm |
| | | | | , | , , , , , | |
| $\Gamma(\psi(2S))$ anything Γ_{to} | | DOCUMENT ID | TEC | N СОММІ | ENT | Γ ₅₀ /Γ |
| 0.0048±0.0022±0.0010 | | ABREU | 94P DLF | | → Z | |
| ¹¹⁸ ABREU 94P is an inc | | | | | | |
| $J/\psi(1S) \pi^{+} \pi^{-}$, $J/\psi($ | $(1S) \rightarrow \mu^{+}$ | μ^- channels. | Assumes | $\Gamma(Z \to b\overline{b})$ | $\overline{O})/\Gamma_{hadro}$ | $_{on} = 0.22.$ |
| $\Gamma(\chi_{c1}(1P) \text{ a nything})/1$ | Γ _{total} | | | | | Γ_{51}/Γ |
| VALUE | EVTS | DO CUMENT ID | <u>TE</u> | CN COMI | 1ENT | |
| 0.014 ±0.004 OUR AVE | | ABREU | 94P DL | DII .+ | - 7 | |
| $0.0111 + 0.0057 \pm 0.0005$ | | ADRIANI | | | $\stackrel{-}{\rightarrow} Z$ $\stackrel{-}{\rightarrow} Z$ | |
| 0.019 $\pm 0.007 \pm 0.001$ 119 ABREU 94P reports | | | 93J L3 | measurem | | IE / 15 . |
| $v_{-1}(1P)$ anything) $/\Gamma_{\bullet}$. | . 0.014 ± 1 × [B/ | 0.000 - 0.002 | | | | |
| $\chi_{\mathcal{C}1}(1P)$ anything) $/\Gamma_{\mathrm{to}}$ $\gamma J/\psi(1S)) = 0.273$ | ± 0.016, v | vhich we resca | le to our | best valu | ie B (χ_{c1}) | (1P) → |
| $\gamma J/\psi(1S))=(34.4 \pm 0.00)$ our second error is the | | | | | | error and |
| | | | | value Ass | II mes no | |
| and $I(Z \rightarrow DD)/I_{had}$ | $d_{\text{ron}} = 0.22$. | | | | | $\chi_{C2}(1P)$ |
| and $\Gamma(Z \rightarrow bb)/\Gamma_{had}$ 120 ADRIANI 93J reports | $d_{ron} = 0.22.$ s 0.024 ± | 0.009 ± 0.002 | 2 from a | measurer | nent of | $\chi_{C2}(1P)$ $[\Gamma(\overline{b} \rightarrow$ |
| 120 ADRIANI 931 reports | $d_{ron} = 0.22.$ s 0.024 ± | 0.009 ± 0.002 | 2 from a | measurer | nent of | $\chi_{C2}(1P)$ $[\Gamma(\overline{b} \rightarrow$ |
| 120 ADRIANI 93J reports $\chi_{C1}(1P)$ anything) $/\Gamma_{tc}$ $\gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S)) = (34.4 \pm 0.000)$ | $_{ m dron} = 0.22.$ s $0.024 \pm 0.016, \ v \pm 1.5) 	imes 10$ | 0.009 ± 0.002 $(\chi_{C1}(1P) \rightarrow 0.002)$ which we rescand 0.002 | 2 from a $\gamma J/\psi(1S)$ le to our error is | measurer))] assumir best valu their exper | nent of $\log B(\chi_{c1})$ ie $B(\chi_{c1})$ | $\chi_{c2}(1P)$ $[\Gamma(\overline{b} \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow 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| 120 ADRIANI 93J reports $\chi_{C1}(1P)$ anything) / Γ_{t} $\gamma J/\psi(1S)$) = 0.273 $\gamma J/\psi(1S)$) = 0.34.4 = our second error is the $\Gamma(\chi_{C1}(1P)$ anything) / $\frac{1}{2}$ | $d 	ext{ron} = 0.22.$ $s = 0.024 \pm 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, | 0.009 ± 0.002 $\chi_{C1}(1P) \rightarrow 0.002$ which we resca 0^{-2} . Our first error from using 0.002 anything) DOCUMENT ID that for averages, | 2 from a $\gamma J/\psi(1S)$ le to our error is g our bes | measurer ())] assumir best valu their exper t value. N COMMI ts, etc. • • | nent of $\log B(\chi_{C1})$ in $B(\chi_{C1})$ iment's ϵ | $\chi_{C2}(1P)$ $[\Gamma(\overline{b} \rightarrow (1P) \rightarrow (1P) \rightarrow error and$ |
| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / $[t_t, \gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S) = (34.4 \pm 0.00)$ our second error is the $\Gamma(\chi_{c1}(1P)$ anything) / $[VALUE]$ • • • We do not use the 1.92 ± 0.82 | $d_{ron} = 0.22$. $s = 0.024 \pm 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 0.016$, $v = 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N COMMI ts, etc. • • e^+e^- | nent of $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ | $\chi_{C2}(1P)$ $[\Gamma(\overline{b} \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow \text{error and}]$ |
| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / Γ_{t} $\gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S)) = (33.4 \pm 0.00)$ our second error is the $\Gamma(\chi_{c1}(1P) \text{ anything})/U$ VALUE E | $d_{\text{ron}} = 0.22.$ $d_{\text{ron}} = 0.22.$ $d_{\text{ron}} = 0.024 \pm 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ d_{r | 0.009 ± 0.002 $(X_{C1}(1P) \rightarrow (X_{C1}(1P) | 2 from a $\gamma J/\psi(1S)$ le to our error is g our bes $\frac{TEC}{\gamma}$, fits, limit 93J L3 | measurer))] assumir best valu their exper t value. N COMMI ts, etc. • • e+e- ecays at th | nent of $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ | $\chi_{C2}(1P)$ $[\Gamma(\overline{b} \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow \text{error and}]$ |
| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / $[t_t \gamma J/\psi(15)) = 0.273$ $\gamma J/\psi(15) = (34.4 \pm 0.4)$ our second error is the $\Gamma(\chi_{c1}(1P) \text{ anything}) / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / [t_t \psi(1P) \text{ anything}] / $ | $d_{\text{ron}} = 0.22.$ $d_{\text{ron}} = 0.22.$ $d_{\text{ron}} = 0.024 \pm 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ v}$ $d_{\text{ron}} = 0.016, \text{ 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| 120 ADRIANI 93J reports $\chi_{C1}(1P)$ anything) / Γ_{t} , $\gamma J/\psi(1S)$) = 0.273 $\gamma J/\psi(1S)$) = 0.34.4 \pm our second error is the $\Gamma(\chi_{C1}(1P)$ anything) / $\frac{VALUE}{2}$ • • • We do not use the 1.92 \pm 0.82 \pm 121 ADRIANI 93J is a ratio $J/\psi(1S) \rightarrow \mu^+\mu^-$ or $\Gamma(\overline{s}\gamma)/\Gamma_{total}$ | $d_{ron} = 0.22$. $s = 0.024 \pm 0$ $d_{ron} = 0.24 \pm 0.016$, $s = 0.016$, $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.016$. $s = 0.01$ | (0.009 ± 0.002) $(X_{C1}(1P) \rightarrow (X_{C1}(1P) | 2 from a $\gamma J/\psi(1S)$ le to our error is g our besing $\gamma J/\psi(1S)$ le to find $\gamma J/\psi(1S)$ le to our error is $\gamma J/\psi(1S)$ fits, limited $\gamma J/\psi(1S)$ from $\gamma J/\psi(1S)$ from $\gamma J/\psi(1S)$ from $\gamma J/\psi(1S)$ | measurer best valutheir expert t value. 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| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / $[t_t, \gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S) = (34.4 \pm 0.4)$ our second error is the $\Gamma(\chi_{c1}(1P)$ anything) / $[t_t, \psi_{LUE}]$ \bullet \bullet We do not use the 1.92 ± 0.82 121 ADRIANI 93J is a ratic $J/\psi(1S) \rightarrow \mu^+ \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot J/\psi(1S) \rightarrow \mu^- \cot $ | $_{\rm dron}$ = 0.22. $_{\rm s}$ = 0.024 $_{\rm t}$ $_{\rm otal}$ $_{\rm l}$ $_{\rm s}$ $_{\rm t}$ $_{\rm l}$ | $(X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_$ | 2 from a $\gamma J/\psi(15)$ le to our error is g our bes $\frac{TEC}{\gamma}$, fits, limit 93J L3 from b d tics cance $\frac{TEC}{\gamma}$ 98I ALE | measurer (i))] assuming best value their expert value. 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| 120 ADRIANI 93J reports $\chi_{c1}(1P) \text{ anything} / \Gamma_{t}$ $\gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S)) = (334.4 \pm 0)$ our second error is the $\Gamma(\chi_{c1}(1P) \text{ anything}) / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ $\psi(1P) \text{ anything} / \Gamma_{t}$ | dron = 0.22. s 0.024 ± 0.016 , s 0.024 ± 0.016 , b 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v 0.016 , v | 0.009 ± 0.002 $\chi_{C1}(1P) \rightarrow V_{C1}(1P) \rightarrow V_{C1}(1P) \rightarrow V_{C1}(1P)$ $V_{C1}(1P) \rightarrow V_{C1}(1P)$ | 2 from a $\gamma J/\psi(1S)$ le to our error is g our bess $\frac{TEC}{3}$, fits, limi 93J L3 from b d tics cance $\frac{TEC}{3}$ 8 ALE, fits, limi | measurer (i)] assumin best valu their expert value. N COMMMI ts, etc. • • • • e- ecays at th . N COMMMI P e+e- ts, etc. • • • - ts, etc. • • • | nent of $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ in $B(x_{C1})$ 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| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / $[t_1, \gamma J/\psi(1S)) = 0.273$ $\gamma J/\psi(1S) = (34.4 \pm 0.00)$ our second error is the $\Gamma(\chi_{c1}(1P)$ anything) / $[t_1, t_2]$ $\psi(1S) = (4.00)$ $\psi(1S) = $ | dron = 0.22. s 0.024 ± 0.016 , s 0.024 ± 0.016 , v 0.016 , v | $(X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_$ | 2 from a $\gamma J/\psi(1S)$ le to our error is g our bes $\frac{TEC}{f}$, fits, limi 93J L3 tics cance $\frac{TEC}{f}$ 98I ALE, fits, limi 96D DLF | measurer (i)] assumin best value their expert value. N COMMI ts, etc. • • • • • • • • • • • • • • • • • • • | nent of $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log B(\chi_{C1})$ in $\log 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| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / Γ_{t} $\gamma J/\psi(1S)$) = 0.273 $\gamma J/\psi(1S)$) = (34.4 \pm our second error is the $\Gamma(\chi_{c1}(1P) \text{ anything})/\Gamma_{t}$ χ_{LUE} \bullet • We do not use the 1.92 \pm 0.82 121 ADRIANI 93J is a ratio $J/\psi(1S) \rightarrow \mu^{+}\mu^{-}$ or $\Gamma(\overline{s}\gamma)/\Gamma_{\text{total}}$ χ_{LUE} (units 10^{-4}) $3.11\pm0.80\pm0.72$ • • • We do not use the < 5.4 <12 122 BARATE 98I uses lifet 123 ADAM 96D assumes f_{t} 124 ADRIANI 93L result is $\Gamma(\overline{s}\nu\nu)/\Gamma_{\text{total}}$ | dron = 0.22. s 0.024 ± 0 total \times [B(\pm 0.016, \times 1.5) \times 10 systematic Γ (J/ψ (1S \pm 1.5) \times 10 systematic Γ (J/ψ (1S \pm 1.21 \pm 1.21 \pm 2.2 following data total since $\frac{CL\%}{2}$ 122 following data $\frac{CL\%}{2}$ 122 following data $\frac{CL\%}{2}$ 123 \pm 126 following data $\frac{CL\%}{2}$ 127 following data $\frac{CL\%}{2}$ 128 for $\frac{CL\%}{2}$ 129 for $\frac{CL\%}{2}$ 127 for $\frac{CL\%}{2}$ 127 for $\frac{CL\%}{2}$ 128 for $\frac{CL\%}{2}$ 129 for $\frac{CL\%}{2}$ 120 for $\frac{CL\%}{2}$ 130 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 131 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 133 for $\frac{CL\%}{2}$ 132 for $\frac{CL\%}{2}$ 133 for $\frac{CL\%}{2}$ 133 for $\frac{CL\%}{2}$ 133 for $\frac{CL\%}{2}$ 134 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 135 for $\frac{CL\%}{2}$ 136 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for $\frac{CL\%}{2}$ 137 for C | (0.009 ± 0.002) $(X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_{C1}(1P)$ $(X_{C1}(1P) \rightarrow X_{C1}(1P) \rightarrow X_{C1}(1P)$ | 2 from a $\gamma J/\psi(15)$ le to our error is g our bes' $\frac{TEC}{\gamma}$, fits, limi 93. L3. From b d tics cance $\frac{TEC}{\gamma}$ 981 ALE, limi 960 DLF 931. 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| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / Γ_{t} $\gamma_{J}/\psi(1S)$) = 0.273 $\gamma_{J}/\psi(1S)$) = 0.273 our second error is the $\Gamma(\chi_{c1}(1P)$ anything) / $\frac{VALUE}{VALUE}$ E • • We do not use the 1.92 \pm 0.82 121 ADRIANI 93J is a ratio $\frac{1}{J}/\psi(1S) \rightarrow \mu^{+}\mu^{-}$ or $\frac{\Gamma(\overline{s}\gamma)}{\Gamma(total)}$ 3.11 \pm 0.80 \pm 0.72 • • • We do not use the < 5.4 <12 122 BARATE 98I uses lifet 123 ADAM 96D assumes f 124 ADRIANI 93L result is $\frac{\Gamma(\overline{s}\overline{\nu}\nu)}{\Gamma(\overline{s}\overline{\nu}\nu)}$ / $\frac{\Gamma(\overline{s}\overline{\nu}\nu)}{\Gamma(\overline{s}\overline{\nu}\nu)}$ / $\frac{\Gamma(\overline{s}\overline{\nu}\nu)}{\Gamma(\overline{s}\overline{\nu}\nu)}$ / $\frac{\Gamma(\overline{s}\overline{\nu}\nu)}{\Gamma(\overline{s}\overline{\nu}\nu)}$ | dron = 0.22. s 0.024 ± 0.016 , s 0.024 ± 0.016 , $[B \times 0.016] \times [B \times $ | (0.009 ± 0.002) $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X_{C1}(1P) \rightarrow 0.002)$ $(X$ | 2 from a $\gamma J/\psi(15)$ le to our error is g our bess g our error is g our bess g our error is g our | measurer (i) j] assumin best value their expert value. 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N COMMI EP e+e- SPH e+e- e+e- (i) N COMMI EP e+e- (ii) COMMI EP e+e- (iii) COMMI EP e+e- | nent of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the probability of the | $\chi_{c2}(1P)$ $[\Gamma(\overline{b} \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P) \rightarrow (1P)$ Γ_{51}/Γ_{49} Γ_{52}/Γ |
| 120 ADRIANI 93J reports $\chi_{c1}(1P)$ anything) / Γ_{t} $\gamma J/\psi(15)$) = 0.273 $\gamma J/\psi(15)$) = 0.34.4 \pm our second error is the $\Gamma(\chi_{c1}(1P)$ anything) / $\frac{VALUE}{VALUE}$ $=$ • • We do not use the 1.92 \pm 0.82 121 ADRIANI 93J is a ratio $J/\psi(1S) \rightarrow \mu^+\mu^-$ or $\Gamma(\overline{s}\gamma)/\Gamma$ total $\frac{VALUE}{VALUE}$ (units 10^{-4}) 3.11 \pm 0.80 \pm 0.72 • • • We do not use the $<$ 5.4 $<$ 12 122 BARATE 98I uses lifet 123 ADA M 96D assumes f 124 ADRIANI 93L result is $\Gamma(\overline{s}\overline{v}\nu)/\Gamma$ total $\frac{VALUE}{VALUE}$ $<$ 6.4 \times 10 ⁻⁴ 125 The energy-flow and D $\Gamma(K^{\pm}$ anything) / Γ total $\frac{VALUE}{VALUE}$ | dron = 0.22. s 0.024 ± 0.016 , s 0.024 ± 0.016 , v 121×180 , systematic F(J/ ψ (1S systematic T121, 211, o of inclusive channel since $\frac{CL\%}{122}$ following days $\frac{CL\%}{122}$ following days $\frac{CL\%}{122}$ for $\frac{CL\%}{122}$ for $\frac{CL\%}{122}$ for $\frac{CL\%}{122}$ 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| 120 ADRIANI 93J reports $\chi_{C1}(1P)$ anything) / Γ_{t} $\gamma J/\psi(1S)$ 0.273 $\gamma J/\psi(1S)$ 0.273 $\gamma J/\psi(1S)$ 0.44 = our second error is the $\Gamma(\chi_{C1}(1P)$ anything) / Γ_{t} χ_{LUE} • • We do not use the 1.92±0.82 121 ADRIANI 93J is a ratic $J/\psi(1S) \rightarrow \mu^{\pm}\mu^{-}$ or $\Gamma(\overline{s}\gamma)/\Gamma$ total $\Gamma(\overline{s}\gamma)/\Gamma$ total $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ total $\Gamma(\overline{s}\gamma)/\Gamma$ total $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ $\Gamma(\overline{s}\gamma)/\Gamma$ 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| 120 ADRIANI 93J reports $\chi_{C1}(IP)$ anything) / I_{L} $\gamma J/\psi(1S)$ 0.273 $\gamma J/\psi(1S)$ 0.273 $\gamma J/\psi(1S)$ 0.44 \pm our second error is the $\Gamma(\chi_{C1}(IP)$ anything) / I_{L} ψ_{L} ψ | dron = 0.22. s 0.024 ± 0.016 , s 0.024 ± 0.016 , s 0.014 ± 0.016 , systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) = 0.016$, systematic $\mathbf{\Gamma}(J/\psi\{1S\}) 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| $\Gamma(\pi^0 \text{anything})/\Gamma_{\text{total}}$ | | | | | | Γ ₅₇ /Γ |
|-----------------------------------------------------------------------------------|----------------------------|-----------------------------------------------|---------------|---------------------------------------------|-------------------------------------------------------------------|-----------------------------------|
| VALUE 2.78±0.15±0.60 | | ADAM | 96 | TECN DLPH | $e^+e^- \rightarrow 7$ | |
| 126 ADAM 96 measureme | | | | | | s in 7 → |
| bb events. | ant obtained | i nom a ni to ti | пстар | nuity uis | tribution of w | |
| $\Gamma(\phi \text{ anything})/\Gamma_{\text{total}}$ | | DOCUMENT ID | | TECN | COMMENT | Γ ₅₈ /Γ |
| 0.0282±0.0013±0.0019 | | ABBIENDI | 00z | OPAL | $e^+e^- \rightarrow Z$ | |
| $\Gamma(p/\overline{p}anything)/\Gamma_{tot}$ | al | | | | | Г59/Г |
| 0.131±0.011 OUR AVER | AGE | DO CUMENT ID | | TECN | COMMENT | |
| $0.131 \pm 0.004 \pm 0.011$ $0.141 \pm 0.018 \pm 0.056$ | | BARATE ABREU | 98∨ 95∈ | ALEP DLPH | $\begin{array}{ccc} e^+e^- \to & Z \\ e^+e^- \to & Z \end{array}$ | |
| Γ(charged anything)/ | Γ _{total} | DOCUMENT ID | | <u>TECN</u> | COMMENT | Γ ₆₀ /Γ |
| 4.97±0.03±0.06 | 127 | ABREU | 98H | DLPH | $e^+e^- \rightarrow Z$ | |
| • • • We do not use the | | | s, fits, | limits, e | etc. • • • | |
| $5.84 \pm 0.04 \pm 0.38$ | | ABREU | 95 C | DLPH | Repl. by ABRI | EU 98H |
| 127 ABREU 98H measure | ment exclud | les the contribut | tion f | rom K ⁰ | and Λ decay. | |
| Γ(hadron+ hadron-), | /Γ _{total} | | | | | Γ_{61}/Γ |
| VALUE (units 10 ⁻⁵) | | DOCUMENT ID | | TECN | COMMENT | |
| $1.7^{+1.0}_{-0.7}\pm0.2$ | 128,129 | BUSKULIC | 96v | ALEP | $e^+e^- \rightarrow Z$ | |
| 128 BUSKULIC 96v assur 129 Average branching from hadrons, weighted by | action of w | eakly decaying . | B had | Irons int | o two long-live | |
| Γ (charmless)/ Γ total | | | | | | Γ_{62}/Γ |
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| 0.007±0.021 130 ABREU 98D results ar on the impact parame been subtracted. | e extracted | ABREU from a fit to the pected hidden c | b-t ag | DLPH ging pro contribu | $e^+e^- ightarrow~Z$ bability distribut tion of 0.026 \pm | ion based 0.004 has |
| $\Gamma(\Lambda/\overline{\Lambda}\text{anything})/\Gamma_{\text{tot}}$ | al | | | | | Г ₆₃ /Г |
| VALUE 0.059 ±0.006 OUR AVI | EDAGE | DOCUMENT ID | | TECN | COMMENT | |
| 0.0587 ± 0.0046 ± 0.0048 0.059 ± 0.007 ± 0.009 | ERAGE | ACKERSTAFF ABREU | 97N 95 ⊂ | OPAL DLPH | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow Z$ | |
| Γ(b-baryon a nything) | /F | | | | | Γ ₆₄ /Γ |
| VALUE | / · tota | DOCUMENT ID | | TECN | COMMENT | . 64/. |
| $0.102 \pm 0.007 \pm 0.027$ | | BARATE | 98∨ | ALEP | $e^+e^- \rightarrow Z$ | |
| 131 BARATE 98v assume | $s B(B_S \rightarrow$ | $pX) = 8 \pm 4\%$ | and | B(b-barg | $yon \rightarrow pX) =$ | 58 ± 6%. |
| $\Gamma(\mu^+\mu^-$ a nything)/ Γ_1 | total | | | | | Γ ₆₆ /Γ |
| Test for $\Delta B = 1$ w | | current. DOCUMENT ID | | TECN | COMMENT | |
| <3.2 ×10 ⁻⁴ | 90 | ABBOTT | 98B | D0 | p | |
| • • • We do not use the | | | | | | |
| $< 5.0 \times 10^{-5}$ | 90 132 | ALBAJAR | 91 C | UA1 | $E_{\rm CM}^{p\overline{p}}=$ 630 Ge | |
| < 0.02 | 95 | ALTHOFF | 84 G | TASS | $E_{\rm cm}^{ee}=34.5~{\rm Ge}$ | eV |
| < 0.007 | 95 | ADEVA | 83 | | $E_{\rm cm}^{ee} = 30-38$ | GeV |
| < 0.007 | 95 | BARTEL | 83B | JA DE | $E_{cm}^{ee} = 33-37$ | |
| 132 Both ABBOTT 98B a was overestimated by | and GLENN a large fact | l 98 claim that t tor. | the ef | ficiency | quoted in ALB <i>F</i> | AJAR 91c |
| $[\Gamma(e^+e^-\text{ anything}) + \\ \text{Test for } \Delta B = 1 \text{ w}$ | eak neutral | current. | | TECN | • | +Γ ₆₆)/Γ |
| • • We do not use the | CL% following d | DOCUMENT ID lata for averages | | | | |
| < 0.008 | 90 | MATTEUZZI | 83 | | E ^{ee} _{cm} = 29 GeV | , |
| $\Gamma(\nu \overline{\nu}$ anything)/ Γ_{total} | | | | | | Γ ₆₇ /Γ |
| VALUE | | DO CUMENT ID | | | COMMENT | |
| • • • We do not use the | _ | _ | | | | |
| <3.9 × 10 ⁻⁴ | | GROSSMAN | 96 | | $e^+e^- \rightarrow Z$ | 1 |
| $^{133}\mathrm{GROSSMAN}$ 96 limit $< 1.8 \times 10^{-3}$ at CL= | ıs derived f =90% using | rom the ALEPH conservative sir | BUS nplify | KULIC 9 ing assui | 5 limit B(B+ - mptions. | $\rightarrow \tau^+ \nu_{\tau}$) |
| | | AT HIGH ENI | | | | |
| For a discussion | of $B - \overline{B}$ mi | xing, see the no | te on | "B ⁰ − B ⁰ | Mixing" in the | • |

 χ_{b} is the average $B \text{-} \overline{B}$ mixing parameter at high-energy $\chi_{b} = f'_{d} \chi_{d} + f'_{S} \chi_{S}$ where f'_{d} and f'_{S} are the fractions of B^{0} and B^{0}_{S} hadrons in an unbiased sample of semileptonic b-hadron decays.

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at $http://www.slac.stanford.edu/xorg/hfag/. \ \ The \ averaging/rescaling \ pro-prosphere and the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of t$ cedure takes into account correlations between the measurements

| | EVTS | DOCUMENT ID | | TE CN | COMMENT |
|--------------------------------------------------------------------------------------------|--------------------|-------------------------|-------------|------------|-------------------------------------------|
| 0.1284 ± 0.0069 OUR EVAL | | | | | |
| 0.129 ±0.004 OUR AVER | | 14 | | | |
| $0.132 \pm 0.001 \pm 0.024$ | | 34 ABAZOV | 06s | D0 | $p\overline{p}$ at 1.96 TeV |
| $0.152 \pm 0.007 \pm 0.011$ | 11 | ³⁵ ACOSTA | 04A | CDF | p p at 1.8 TeV |
| $0.1312 \pm 0.0049 \pm 0.0042$ | 14 | ³⁶ ABBIENDI | 03P | OPAL | $e^+e^- \rightarrow Z$ |
| $0.127 \pm 0.013 \pm 0.006$ | | 37 ABREU | 01L | DLPH | $e^+e^- \rightarrow Z$ |
| $0.1192 \pm 0.0068 \pm 0.0051$ | | ³⁸ ACCIARRI | 99D | L3 | $e^+e^- \rightarrow Z$ |
| $0.121 \pm 0.016 \pm 0.006$ | | ³⁹ ABREU | 94) | DLPH | $e^+e^- \rightarrow Z$ |
| $0.114 \pm 0.014 \pm 0.008$ | | ^{l0} BUSKULIC | 94G | ALEP | $e^+e^- \rightarrow Z$ |
| 0.129 ± 0.022 | 14 | ^{l1} BUSKULIC | 92B | ALEP | $e^+ e^- \rightarrow Z$ |
| | | 12 ABE | 91G | CDF | ρ ρ 1.8 TeV |
| $0.148 \pm 0.029 \pm 0.017$ | | ¹³ ALBAJAR | 91D | UA1 | ρ p 630 GeV |
| • • • We do not use the fo | | | fits, I | imits, etc | C. • • • |
| $0.131\ \pm0.020\ \pm0.016$ | | ¹⁴ ABE | 971 | CDF | Repl. by ACOSTA 04A |
| $0.1107 \pm 0.0062 \pm 0.0055$ | 14 | ¹⁵ ALEXANDER | 96 | OPAL | Rep. by ABBI- ENDI 03P |
| $0.136 \ \pm 0.037 \ \pm 0.040$ | | ¹⁶ UENO | 96 | AMY | e ⁺ e ⁻ at 57.9 GeV |
| $0.144 \ \pm 0.014 \ ^{+\ 0.017}_{-\ 0.011}$ | | ¹⁷ ABREU | 94F | DLPH | Sup. by ABREU 94J |
| 0.131 ± 0.014 | 14 | ^{I8} ABREU | 94」 | DLPH | $e^+ e^- \rightarrow Z$ |
| $0.123\ \pm0.012\ \pm0.008$ | | ACCIARRI | 94D | L3 | Repl. by ACCIA- RRI 99D |
| $0.157 \pm 0.020 \pm 0.032$ | | ¹⁹ ALBAJAR | 94 | UA1 | $\sqrt{s} = 630 \text{ GeV}$ |
| $0.121 \ ^{+\ 0.044}_{-\ 0.040} \ \pm 0.017$ | 1665 ¹⁵ | ⁶⁰ ABREU | 93c | DLPH | Sup. by ABREU 94J |
| $0.143 \ ^{+\ 0.022}_{-\ 0.021}\ \pm 0.007$ | 15 | ¹ AKERS | 93B | OPAL | Sup. by ALEXAN- DER 96 |
| $0.145 \ ^{+\ 0.041}_{-\ 0.035} \ \pm 0.018$ | 15 | ⁵² ACTON | 92c | OPAL | $e^+ e^- \rightarrow Z$ |
| $0.121 \ \pm 0.017 \ \pm 0.006$ | 15 | ³ ADEVA | 92 c | L3 | Sup. by ACCIA- RRI 94D |
| $\begin{array}{ccc} 0.132 & \pm 0.22 & \begin{array}{c} + 0.015 \\ - 0.012 \end{array}$ | 823 15 | ⁶⁴ DECAMP | 91 | ALEP | $e^+ e^- ightarrow Z$ |
| $0.178 \ ^{+\ 0.049}_{-\ 0.040}\ \pm 0.020$ | | ⁵⁵ ADEVA | 90P | L3 | $e^+e^-\to~Z$ |
| $0.17 {}^{+}0.15 \\ -0.08$ | 156,15 | ⁷ WEIR | 90 | MRK2 | $\mathrm{e^{+}e^{-}}$ 29 GeV |
| $\begin{array}{cc} 0.21 & +0.29 \\ -0.15 \end{array}$ | | ⁶ BAND | 88 | MAC | $E_{ m cm}^{\it ee}=$ 29 GeV |
| >0.02 at 90% CL | 15 | ⁶ BAND | 88 | MAC | $E_{\rm cm}^{ee} = 29 \; {\rm GeV}$ |
| $0.121\ \pm0.047$ | 156,15 | ⁸ ALBAJAR | 87c | UA1 | Repl. by ALBA- |
| <0.12 at 90% CL | | ⁹ SCHAAD | 85 | | JAR 91D Eee = 29 GeV |
| 134 Uses the dimuon charge | as ym me | ry Averaged ove | rthe | mix of b | -flavored hadrons |

- 135 Measurement performed using events containing a dimuon or an e/μ pair.
- 136 The average B mixing parameter is determined simultaneously with b and c forwardbackward asymmetries in the fit.
- 137 The experimental systematic and model uncertainties are combined in quadrature.
- 138 ACCIARRI 99D uses maximum-likelihood fits to extract χ_b as well as the A^b_{FB} in Z
 ightharpoonup $b\,\overline{b}$ events containing prompt leptons.
- 139 This ABREU 941 result is from 5182ℓℓ and 279 Λℓ events. The systematic error includes 0.004 for model dependence.
- $^{140}\,\mathrm{BUSKULIC}$ 94G data analyzed using $e\,e,\,e\,\mu$, and $\mu\,\mu$ events.
- $^{141}\,\mathrm{BUSKULIC}$ 92B uses a jet charge technique combined with electrons and muons.
- $^{142}\,\mathrm{ABE}$ 91G measurement of χ is done with $e\,\mu$ and $e\,e$ events.
- $^{143}\mathrm{ALBAJAR}$ 91D measurement of χ is done with dimuons.
- 144 Uses di-muon events.
- 145 ALEXANDER 96 uses a maximum likelihood fit to simultaneously extract χ as well as the forward-backward asymmetries in $e^+e^- \rightarrow Z \rightarrow b\overline{b}$ and $c\overline{c}$.
- 146 UENO 96 extracted χ from the energy dependence of the forward-backward asymmetry.
- 147 ABREU 94F uses the average electric charge sum of the jets recoiling against a b-quark jet tagged by a high p_T muon. The result is for $\overline{\chi}=f_d\chi_d+0.9f_s\chi_s$
- 148 This ABREU 941 result combines $\ell\ell$, $\hbar\ell$, and jet-charge ℓ (ABREU 94F) analyses. It is for $\overline{\chi}=\mathit{f_d}\chi_d+0.96\mathit{f_S}\chi_S$
- 149 ALBAJAR 94 uses dimuon events. Not independent of ALBAJAR 91D.
- $^{150}\mathrm{ABREU}$ 93c data analyzed using ee, $e\mu$, and $\mu\mu$ events.
- 151 AKERS 93B analysis performed using dilepton events.
- $^{152}\mathrm{ACTON}$ 92c uses electrons and muons. Superseded by AKERS 93B.
- $^{153}_{154}$ ADEVA 92c uses electrons and muons.
- 154 DECAMP 91 done with opposite and like-sign dileptons. Superseded by BUSKULIC 92B.
- 155 ADEVA 90P measurement uses e.e, $\mu\mu$, and $e\mu$ events from 118k events at the ZSuperseded by ADEVA 92c.
- 156 These experiments are not in the average because the combination of B_{S} and B_{d} mesons which they see could differ from those at higher energy.
- 157 The WEIR 90 measurement supersedes the limit obtained in SCHAAD 85. The 90% CL are 0.06 and 0.38. 158 ALBAJAR 87c measured $\chi=(\overline{\cal B}^0\to {\cal B}^0\to \mu^+{\rm X})$ divided by the average production
- weighted semileptonic branching fraction for B hadrons at 546 and 630 GeV
- 159 Limit is average probability for hadron containing B quark to produce a positive lepton.

CP VIOLATION PARAMETERS in semileptonic b-hadron decays.

 $7.5)\times10^{-3}$

 $\operatorname{Re}(\epsilon_b)/(1+|\epsilon_b|^2)$

| VALUE (units 10 ⁻³) | DO CUMENT IE |) | TECN | COMMENT |
|---------------------------------------------|----------------------------------|-----------------|-----------------|----------------------------------------------|
| $-1.97 \pm 0.43 \pm 0.23$ | ¹⁶⁰ ABAZOV | 11∪ | D0 | $p\overline{p}$ at 1.96 TeV |
| ● ● We do not use the f | ollowing data for averag | ges, fits, | limits, | etc. • • • |
| $-2.39 \pm 0.63 \pm 0.37$ | ¹⁶¹ ABAZOV | 10н | D0 | Repl. by ABAZOV 110 |
| 160 ABAZOV 110 reports a | measurement of like-s | ign dim | uon cha | irge asymmetry of $A^b_{SL}=$ |
| $(-7.87 \pm 1.72 \pm 0.93)$ | $	imes 10^{-3}$ in semileptoni | c <i>b-</i> had | ron dec | ays. |
| 161 ABAZOV 10H reports | a measurement of | like-sign | dimud | on charge asymmetry of |
| $A_{SL}^{b} = (-9.57 \pm 2.51 \pm$ | $\pm1.46)	imes10^{-3}$ in semil | eptonic | <i>b</i> -hadro | on decays. Using the mea- |
| sured production ratio | of B_d^0 and B_s^0 , and the | as ym m | etry of I | $B_d^0 A_{SL}^d = (-4.7 \pm 4.6) \times$ |
| | | | | for B_{c}^{0} as $A_{CT}^{s} = (-14.6 \pm$ |

B-HADRON PRODUCTION FRACTIONS IN HADRONIC Z DECAY

The production fractions of b-hadrons in hadronic Z decays have been calculated using the best values of mean lives, mixing parameters and branching fractions in this edition by the Heavy Flavor Averaging Group (HFAG) (see http://www.slac.stanford.edu/xorg/hfag/).

The values reported below assume: $f(\overline{b} \rightarrow B^+) = f(\overline{b} \rightarrow B^0)$

$$f(\overline{b} \to B^+) = f(\overline{b} \to B^0)$$

$$f(\overline{b} \to B^+) + f(\overline{b} \to B^0) + f(\overline{b} \to B^0) + f(b \to b\text{-baryon}) = 1$$

The values are:
$$f(\overline{b} \to B^+) = f(\overline{b} \to B^0) = 0.403 \pm 0.009$$

 $f(\overline{b} \to B_s^0) = 0.103 \pm 0.009$

 $f(b \rightarrow b\text{-baryon}) = 0.090 \pm 0.015$ and their correlation coefficients are: $cor(B_S^0, b\text{-baryon}) = +0.036$

 $cor(B_{c}^{0}, B^{+}=B^{0}) = -0.522$

the note "The Z boson").

cor(b-baryon, $B^+ = B^0) = -0.871$ as obtained using a time-integrated mixing parameter $\overline{\chi}=0.1259\pm0.0042$ given by a fit to heavy quark quantities with asymmetries removed (see

B-HADRON PRODUCTION FRACTIONS IN pp COLLISIONS AT Tevatron

The production fractions for b-hadrons in $p\overline{p}$ collisions at the Tevatron have been calculated from the best values of mean lifetimes, mixing parameters, and branching fractions in this edition by the Heavy Flavor Averaging Group (HFAG) (see http://www.slac.stanford.edu/xorg/hfag/).

The values reported below assume:

$$\begin{array}{ll} f(\overline{b} \rightarrow B^{'+}) = f(\overline{b} \rightarrow B^0) \\ f(\overline{b} \rightarrow B^+) + f(\overline{b} \rightarrow B^0) + f(\overline{b} \rightarrow B^0_S) + f(b \rightarrow b\text{-baryon}) = 1 \end{array}$$

The values are: $f(\overline{b} \rightarrow B^+) = f(\overline{b} \rightarrow B^0) = 0.339 \pm 0.031$

 $f(\overline{b} \rightarrow B_s^0) = 0.111 \pm 0.014$

 $f(b \rightarrow b\text{-baryon}) = 0.212 \pm 0.069$ and their correlation coefficients are: $cor(B_S^0, b\text{-baryon}) = -0.581$

 $cor(B_0^0, B^+ = B^0) = +0.425$

cor(b-baryon, $B^+ = B^0) = -0.984$

as obtained with the Tevatron average of time-integrated mixing parameter

$B^{\pm}/B^{0}/B_{s}^{0}/b$ -baryon ADMIXTURE REFERENCES

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V_{cb} and V_{ub} CKM Matrix Elements

OMITTED FROM SUMMARY TABLE

DETERMINATION OF V_{cb} AND V_{ub}

Updated February 2012 by R. Kowalewski (Univ. of Victoria, Canada) and T. Mannel (Univ. of Siegen, Germany)

INTRODUCTION

Precision determinations of $|V_{ub}|$ and $|V_{cb}|$ are central to testing the CKM sector of the Standard Model, and complement the measurements of CP asymmetries in B decays. The length of the side of the unitarity triangle opposite the well-measured angle β is proportional to the ratio $|V_{ub}|/|V_{cb}|$, making its determination a high priority of the heavy-flavor physics program.

The semileptonic transitions $b\to c\ell\overline{\nu}_\ell$ and $b\to u\ell\overline{\nu}_\ell$ provide two avenues for determining these CKM matrix elements, namely through inclusive and exclusive final states. The experimental and theoretical techniques underlying these two avenues are independent, providing a crucial cross-check on our understanding. Recent measurements and calculations are reflected in the values quoted in this article, which is an update on the previous review [1]. The leptonic decay $B^-\to \tau\overline{\nu}$ can also be used to extract $|V_{ub}|$, but we do not use this information at present since none of the current experimental measurements have a significance above 3.6σ .

The theory underlying the determination of $|V_{qb}|$ is mature, in particular for $|V_{cb}|$. Most of the theoretical approaches use the fact that the mass m_b of the b quark is large compared to the scale $\Lambda_{\rm QCD}$ that determines low-energy hadronic physics. The basis for precise calculations is a systematic expansion in powers of Λ/m_b , where $\Lambda \sim 500-700$ MeV is a hadronic scale of the order of $\Lambda_{\rm QCD}$, using effective-field-theory methods to separate non-perturbative from perturbative contributions. The expansion in Λ/m_b and α_s works well enough to enable a precision determination of $|V_{cb}|$ and $|V_{ub}|$ in semileptonic decays.

The large data samples available at the B factories enable analyses where one B meson from an $\Upsilon(4S)$ decay is fully reconstructed, allowing a recoiling semileptonic B decay to be studied with high purity. Improved knowledge of $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays allows partial rates for $\overline{B} \to X_u \ell \overline{\nu}_\ell$ transitions to be measured in regions previously considered inaccessible, increasing the acceptance for $\overline{B} \to X_u \ell \overline{\nu}_\ell$ transitions and reducing theoretical uncertainties.

Experimental measurements of the exclusive $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ decay are quite precise, and recent improvements in the theoretical calculation of the form factor normalization have enabled a determination of $|V_{ub}|$ from this decay with an uncertainty below 10%

Throughout this review the numerical results quoted are based on the methods of the Heavy Flavor Averaging Group [2].

V_{cb} and V_{ub} CKM Matrix Elements

DETERMINATION OF $|V_{cb}|$

Summary: The determination of $|V_{cb}|$ from $\overline{B} \to D^*\ell\overline{\nu}_{\ell}$ decays is currently at a relative precision of about 2%. The main limitation is the knowledge of the form factor near the maximum momentum transfer to the leptons. For the $\overline{B} \to D\ell\overline{\nu}_{\ell}$ channel experimental measurements have recently been substantially improved, allowing this channel to provide a meaningful cross-check on $\overline{B} \to D^*\ell\overline{\nu}_{\ell}$.

Determinations of $|V_{cb}|$ from inclusive decays are currently below 2% relative uncertainty. The limitations arise mainly from our ignorance of higher-order perturbative and non-perturbative corrections.

The values obtained from inclusive and exclusive determinations are marginally consistent with each other:

$$|V_{cb}| = (41.9 \pm 0.7) \times 10^{-3} \text{ (inclusive)}$$
 (1)

$$|V_{cb}| = (39.6 \pm 0.9) \times 10^{-3} \text{ (exclusive)}.$$
 (2)

An average of the above gives $|V_{cb}| = (40.9 \pm 0.6) \times 10^{-3}$, with $p(\chi^2) = 0.04$. Scaling the error by $\sqrt{\chi^2/1} = 2.0$ we quote

$$|V_{cb}| = (40.9 \pm 1.1) \times 10^{-3}$$
 (3)

$|V_{cb}|$ from exclusive decays

Exclusive determinations of $|V_{cb}|$ are based on a study of semileptonic B decays into the ground state charmed mesons D and D^* . The main uncertainties in this approach stem from our ignorance of the form factors describing the $B \to D$ and $B \to D^*$ transitions. However, in the limit of infinite bottom and charm quark masses only a single form factor appears, the Isgur-Wise function [3], which depends on the product of the four-velocities v and v' of the initial and final-state hadrons.

The extraction of $|V_{cb}|$ is based on the distribution of the variable $w \equiv v \cdot v'$, which corresponds to the energy of the final state $D^{(*)}$ meson in the rest frame of the decay. Heavy Quark Symmetry (HQS) [3,4] predicts the normalization of the rate at w = 1, the point of maximum momentum transfer to the leptons, and $|V_{cb}|$ is obtained from an extrapolation of the measured spectrum to w = 1. This extrapolation relies on a parametrization of the form factor, as explained below.

A precise determination requires corrections to the HQS prediction for the normalization as well as some information on the slope of the form factors near the point w=1, since the phase space vanishes there. The corrections to the HQS prediction due to finite quark masses are given in terms of the symmetry-breaking parameter

$$\frac{1}{\mu} = \frac{1}{m_c} - \frac{1}{m_b},$$

which is essentially $1/m_c$ for realistic quark masses. HQS ensures that those matrix elements that correspond to the currents that generate the HQS are normalized at w=1; as a result, some of the form factors either vanish or are normalized to unity at w=1. Due to Luke's Theorem [5] (which is an application of the Ademollo-Gatto theorem [6] to heavy

quarks), the leading correction to those form factors normalized due to HQS is quadratic in $1/\mu$, while for the form factors that vanish in the infinite mass limit the corrections are in general linear in $1/m_c$ and $1/m_b$. Thus we have, using the definitions as in Eq. (2.84) of Ref. [7]

$$h_i(1) = 1 + \mathcal{O}(1/\mu^2)$$
 for $i = +, V, A_1, A_3$,
 $h_i(1) = \mathcal{O}(1/m_c, 1/m_b)$ for $i = -, A_2$. (4)

In addition to these corrections, there are perturbatively calculable radiative corrections from QCD and QED, which will be discussed in the relevant sections. Both - radiative corrections as well as $1/m_{b,c}$ corrections - are considered in the framework of Heavy Quark Effective Theory (HQET) [8], which provides for a systematic expansion.

$$\overline{B} \to D^* \ell \overline{\nu}_{\ell}$$

The decay rate for $\overline{B} \to D^* \ell \overline{\nu}_{\ell}$ is given by

$$\frac{d\Gamma}{dw}(\overline{B} \to D^* \ell \overline{\nu}_{\ell}) = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 m_{D^*}^3 (w^2 - 1)^{1/2} P(w) (\eta_{\rm em} \mathcal{F}(w))^2.$$
(5)

where P(w) is a phase space factor with $P(1) = 12(m_B - m_{D^*})^2$ and $\mathcal{F}(w)$ is dominated by the axial vector form factor h_{A_1} as $w \to 1$. Furthermore, $\eta_{\rm em} = 1.007$ accounts for the electroweak corrections to the four-fermion operator mediating the semileptonic decay [11]. In the infinite-mass limit, the HQS normalization gives $\mathcal{F}(1) = 1$.

The form factor $\mathcal{F}(w)$ must be parametrized to perform an extrapolation to the zero-recoil point. A frequently used one-parameter form motivated by analyticity and unitarity is [9,10]

$$\mathcal{F}(w) = \eta_{\mathcal{A}} \left[1 + \delta_{1/m^2} + \cdots \right]$$
$$\left[1 - 8\rho_{\mathcal{A}1}^2 z + (53\rho_{\mathcal{A}1}^2 - 15)z^2 - (231\rho_{\mathcal{A}1}^2 - 91)z^3 \right]$$
(6)

with $z=(\sqrt{w+1}-\sqrt{2})/(\sqrt{w+1}+\sqrt{2})$ originating from a conformal transformation. The parameter $\rho_{\rm A1}^2$ is the slope of the form factor at w=1. The factor $\eta_{\rm A}$ is the QCD short-distance radiative correction [12] to the form factor

$$\eta_{\rm A} = 0.960 \pm 0.007,\tag{7}$$

and δ_{1/m^2} comes from non-perturbative $1/m^2$ corrections.

Improved lattice simulations that include effects from finite quark masses are used to calculate the deviation of $\mathcal{F}(1)$ from unity. A recent calculation gives

$$\mathcal{F}(1) = 0.902 \pm 0.017,\tag{8}$$

where the factor $\eta_{\rm em}$ has been divided out from the value quoted in Ref. [13] and the errors have been added in quadrature. The leading uncertainties are due to heavy-quark discretization and chiral extrapolation errors.

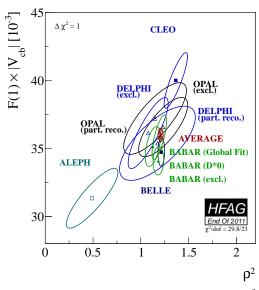


Figure 1: Measurements of $|V_{cb}|\mathcal{F}(1)$ vs. $\rho_{A_1}^2$ are shown as $\Delta \chi^2 = 1$ ellipses.

Non-lattice estimates based on sum rules for the form factor tend to yield lower values for $\mathcal{F}(1)$ [14,15,16]. Omitting the contributions from excited states, the sum rules indicate that $\mathcal{F}(1) < 0.93$. Including an estimate for the contribution of the excited states yields $\mathcal{F}(1) = 0.86 \pm 0.01 \pm 0.02$ [16]. where the second uncertainty originates from the estimate for the excited states.

Many experiments [17–25] have measured the differential rate as a function of w. Fig. 1 shows corresponding values of $\mathcal{F}(1) |V_{cb}|$ and $\rho_{A_1}^2$ (as defined in Ref. [10]) . These measurements are input to a four-dimensional fit [26] for $\mathcal{F}(1)|V_{cb}|$, $\rho_{A_1}^2$ and the form factor ratios $R_1 \propto A_2/A_1$ and $R_2 \propto V/A_1$. The leading sources of uncertainty on $\mathcal{F}(1) |V_{cb}|$ are due to detection efficiencies and $D^{(*)}$ decay branching fractions, while for $\rho_{A_1}^2$ the uncertainties in R_1 and R_2 still dominate. Recent BABAR measurements, one using $\overline{B}^0 \to D^{*0}\ell\overline{\nu}_\ell$ decays [23] and the other using a global fit to $\overline{B} \to D\ell\overline{\nu}_\ell X$ decays [24] are completely insensitive to uncertainties related to the reconstruction of the charged pion from $D^* \to D\pi$ decays; both measurements agree with the average given below.

The fit gives $\mathcal{F}(1) |V_{cb}| = (36.0 \pm 0.5) \times 10^{-3}$ with a *p*-value of 0.15. Along with the lattice value given above for $\mathcal{F}(1)$ this yields

$$|V_{cb}| = (39.6 \pm 0.6_{\text{exp}} \pm 0.8_{\text{theo}}) \times 10^{-3} \quad (\overline{B} \to D^* \ell \overline{\nu}_{\ell}, \text{ LQCD}).$$
(9)

The value of $\mathcal{F}(1)$ obtained from QCD sum rules results in a larger value for $|V_{cb}|$:

$$|V_{cb}| = (41.6 \pm 0.6_{\text{exp}} \pm 1.9_{\text{theo}}) \times 10^{-3} \quad (\overline{B} \to D^* \ell \overline{\nu}_{\ell}, \text{ SR}).$$
 (10)

$$\overline{B} \to D \ell \overline{
u}_{\ell}$$

The differential rate for $\overline{B} \to D\ell \overline{\nu}_{\ell}$ is given by

$$\frac{d\Gamma}{dw}(\overline{B} \to D\ell \overline{\nu}_{\ell}) = \frac{G_F^2}{48\pi^3} |V_{cb}|^2 (m_B + m_D)^2 m_D^3 (w^2 - 1)^{3/2} (\eta_{\rm em} \mathcal{G}(w))^2. \quad (11)$$

The form factor is

$$G(w) = h_{+}(w) - \frac{m_B - m_D}{m_B + m_D} h_{-}(w), \tag{12}$$

where h_+ is normalized to unity in the infinite-mass limit due to HQS and h_- vanishes in the heavy-mass limit. Thus

$$\mathcal{G}(1) = 1 + \mathcal{O}\left(\frac{m_B - m_D}{m_B + m_D} \frac{1}{m_c}\right) \tag{13}$$

and the corrections to the HQET predictions are parametrically larger than was the case for $\overline{B} \to D^* \ell \overline{\nu}_{\ell}$.

In order to get a more precise prediction for the form factor $\mathcal{G}(1)$ the heavy-quark expansion can be supplemented by additional assumptions. It has been argued in Ref. [27] that in a limit in which the kinetic energy μ_{π}^2 is equal to the chromomagnetic moment μ_G^2 (these quantities are discussed below in more detail) one may obtain the value

$$G(1) = 1.04 \pm 0.01_{\text{power}} \pm 0.01_{\text{pert}}.$$
 (14)

Lattice calculations including effects beyond the heavy mass limit have become available, and hence the fact that deviations from the HQET predictions are parametrically larger than in the case $\overline{B} \to D^* \ell \overline{\nu}_{\ell}$ is irrelevant. These unquenched calculations quote a value (preliminary, from 2005) [28]

$$\mathcal{G}(1) = 1.074 \pm 0.018 \pm 0.016.$$
 (15)

The measurements of $\overline{B} \to D\ell\overline{\nu}_{\ell}$ have improved substantially in the last few years. The new measurements [24,29] are consistent with previous measurements [17,30,31] but significantly more precise. The average of these inputs [26] gives $\mathcal{G}(1)|V_{cb}|=(42.6\pm0.7\pm1.4)\times10^{-3}$. Using the value given in Eq. (15) for $\mathcal{G}(1)$, accounting for the electroweak correction and conservatively adding the theory uncertainties linearly results in

$$|V_{cb}| = (39.4 \pm 1.4 \pm 1.3) \times 10^{-3} \quad (\overline{B} \to D\ell \overline{\nu}_{\ell}, \text{ LQCD}), (16)$$

where the first uncertainty is from experiment and the second from theory.

Using the non-lattice estimate from Eq. (14) one finds $|V_{cb}|=(40.7\pm1.5\pm0.8)\times10^{-3}$.

Measuring the differential rate at w=1 is more difficult in $\overline{B} \to D\ell\overline{\nu}_\ell$ decays than in $\overline{B} \to D^*\ell\overline{\nu}_\ell$ decays, since the rate is smaller and the background from mis-reconstructed $\overline{B} \to D^*\ell\overline{\nu}_\ell$ decays is significant; this is reflected in the larger experimental uncertainty. The B factories address these limitations by studying decays recoiling against fully reconstructed B mesons or doing a global fit to $\overline{B} \to X_c\ell\overline{\nu}_\ell$ decays. Theoretical input

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on the shape of the w spectrum in $\overline{B} \to D\ell\overline{\nu}_{\ell}$ is valuable, as precise measurements of the total rate are easier; recent measurements [24,29] of $\mathcal{B}(\overline{B} \to D\ell\overline{\nu}_{\ell})$ have uncertainties of $\sim 5\%$.

The determinations from $\overline{B} \to D^* \ell \overline{\nu}_{\ell}$ and $\overline{B} \to D \ell \overline{\nu}_{\ell}$ decays are consistent, and their uncertainties are largely uncorrelated. Averaging these two lattice-based results gives

$$|V_{cb}| = (39.6 \pm 0.9) \times 10^{-3}$$
 (exclusive). (17)

Prospects for Lattice determinations of the $B \to D^{(*)}$ form factors

Lattice determinations of the $B \to D^{(*)}$ form factors naturally build in heavy-quark symmetries, so all uncertainties scale with the deviation of the form factor from unity [32,33]. In combination with unquenched calculations, i.e. calculations with realistic sea quarks, one obtains quite precise calculations of the form factors, now at the 2% level. The dominant uncertainties are due to the chiral extrapolation from the light quark masses used in the numerical lattice computation to realistic up and down quark masses, and to discretization errors. These sources of uncertainty will be reduced with larger lattice sizes and smaller lattice spacings.

A further ongoing development is the extension of these calculations to nonzero recoil. Such calculations are especially helpful for avoiding the $w \to 1$ extrapolation in $B \to D$.

Decays to Excited D Meson States

Above the ground state D and D^* mesons lie four positiveparity states with one unit of orbital angular momentum, generically denoted as D^{**} . In the heavy mass limit they form two spin symmetry doublets with $j_{\ell} = 1/2$ and $j_{\ell} = 3/2$, where j_{ℓ} is the total angular momentum of the light degrees of freedom. The doublet with $j_{\ell} = 3/2$ is expected to be narrow while the states with $j_{\ell} = 1/2$ should be broad, consistent with experimental measurements. Furthermore, one expects that in the heavy mass limit $\Gamma(B \to D^{**}(j_{\ell} = 3/2)\ell\bar{\nu}) \gg \Gamma(B \to D^{**}(j_{\ell} = 3/2)\ell\bar{\nu})$ $D^{**}(j_{\ell}=1/2)\ell\bar{\nu})$ [34,35,36]. Measurements indicate that this expectation may be violated, although the experimental situation is not clear. BELLE [37] and BABAR [38] report different results for the broad states and the experiments do not have the sensitivity to identify the spin-parity of these states. It has been suggested that decays to radially excited charm mesons may play a role in this puzzle [39]. If a violation is confirmed, it may indicate substantial mixing between the two spin symmetry doublets, which can occur due to terms of order $1/m_c$. However, the impact on the exclusive $|V_{cb}|$ determination is expected to be small, since the zero-recoil point is protected against corrections of order $1/m_c$ by Luke's theorem.

$|V_{cb}|$ from inclusive decays

At present the most precise determinations of $|V_{cb}|$ come from inclusive decays. The method is based on a measurement of the total semileptonic decay rate, together with the leptonic energy and the hadronic invariant mass spectra of inclusive semileptonic decays. The total decay rate can be calculated quite reliably in terms of non-perturbative parameters that can be extracted from the information contained in the spectra.

Inclusive semileptonic rate

The theoretical foundation for the calculation of the total semileptonic rate is the Operator Product Expansion (OPE) which yields the Heavy Quark Expansion (HQE), a systematic expansion in inverse powers of the b-quark mass [40,41]. The validity of the OPE is proven in the deep Euclidean region for the momenta (which is satisfied, e.g., in deep inelastic scattering), but its application to heavy-quark decays requires a continuation to time-like momenta $p_B^2 = M_B^2$, where possible contributions which are exponentially damped in the Euclidean region could become oscillatory. The validity of the OPE for inclusive decays is equivalent to the assumption of partonhadron duality, hereafter referred to simply as duality, and possible oscillatory contributions would be an indication of duality violation.

Duality-violating effects are hard to quantify. In practice, they would appear as unnaturally large coefficents of higher order terms in the 1/m expansion [42]. The description of ~ 60 measurements in terms of ~ 6 free parameters in global fits to $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays provides a non-trivial testing ground for the HQE predictions. Present fits include terms up to order $1/m_b^3$, the coefficients of which have sizes as expected a priori by theory and are in quantitative agreement with extractions from other observables. The consistency of the data with these OPE fits will be discussed later; no indication is found that terms of order $1/m_b^4$ or higher are large, and there is no evidence for duality violations in the data. Thus duality or, likewise, the validity of the OPE, is assumed in the analysis, and no further uncertainty is assigned to potential duality violations.

The OPE result for the total rate can be written schematically (the details of the expression can be found, e.g., in Ref. [43]) as

$$\Gamma = |V_{cb}|^2 \hat{\Gamma}_0 m_b^5(\mu) (1 + A_{\text{ew}}) \times \left[z_0^{(0)}(r) + \frac{\alpha_s(\mu)}{\pi} z_0^{(1)}(r) + \left(\frac{\alpha_s(\mu)}{\pi} \right)^2 z_0^{(2)}(r) + \cdots \right. \\ + \frac{\mu_{\pi}^2}{m_b^2} \left(z_2^{(0)}(r) + \frac{\alpha_s(\mu)}{\pi} z_2^{(1)}(r) + \cdots \right) \\ + \frac{\mu_G^2}{m_b^2} \left(y_2^{(0)}(r) + \frac{\alpha_s(\mu)}{\pi} y_2^{(1)}(r) + \cdots \right) \\ + \frac{\rho_{\text{DS}}^3}{m_b^3} \left(z_3^{(0)}(r) + \frac{\alpha_s(\mu)}{\pi} z_3^{(1)}(r) + \cdots \right) \\ + \frac{\rho_{\text{LS}}^3}{m_b^3} \left(y_3^{(0)}(r) + \frac{\alpha_s(\mu)}{\pi} y_3^{(1)}(r) + \cdots \right) \\ + z_4 \left(r, \frac{s_i}{m_b^4}, \frac{\alpha_s(\mu)}{\pi} \right) + \dots \right]$$

$$(18)$$

where $A_{\rm ew}$ denotes the electroweak corrections, r is the ratio m_c/m_b and the y_i and z_i are known functions which appear in the perturbative expansion of the different orders of the heavy mass expansion. A similar expansion can be set up for

moments of the distributions of charged-lepton energy, hadronic invariant mass and hadronic energy.

This expression is known up to order $1/m_b^5$, where the terms of order $1/m_b^n$ with n>2 have been computed only at tree level [44,45,46,47]. The leading term is the parton model, which is known completely to order α_s and α_s^2 [48–50], and the terms of order $\alpha_s^{n+1}\beta_0^n$ (where β_0 is the first coefficient of the QCD β function, $\beta_0 = (33 - 2n_f)/3$) have been included by the usual BLM procedure [43,51,52]. Furthermore, the corrections of order $\alpha_s\mu_\pi^2/m_b^2$ have been computed [53].

Starting at order $1/m_b^3$ contributions with an infrared sensitivity to the charm mass m_c appear [46,54,112]. At order $1/m_b^3$ this "intrinsic charm" contribution is a $\log(m_c)$ in the coefficient of the Darwin term ρ_D^3 . At higher orders, terms such as $1/m_b^3 \times 1/m_c^2$ and $\alpha_s(m_c)1/m_b^3 \times 1/m_c$ appear, which are comparable in size to the contributions of order $1/m_b^4$

The HQE parameters are given in terms of forward matrix elements; the parameters entering the expansion for orders up to $1/m_b^3$ are

$$\overline{\Lambda} = M_B - m_b ,$$

$$\mu_{\pi}^2 = -\langle B|\overline{b}(iD_{\perp})^2b|B\rangle ,$$

$$\mu_G^2 = \langle B|\overline{b}(iD_{\perp}^{\mu})(iD_{\perp}^{\nu})\sigma_{\mu\nu}b|B\rangle ,$$

$$\rho_D^3 = \langle B|\overline{b}(iD_{\perp\mu})(ivD)(iD_{\perp}^{\nu})b|B\rangle ,$$

$$\rho_{\rm LS}^3 = \langle B|\overline{b}(iD_{\perp}^{\mu})(ivD)(iD_{\perp}^{\nu})\sigma_{\mu\nu}b|B\rangle .$$
(19)

The hadronic parameters of the orders $1/m_b^4$ and $1/m_b^5$ can be found in Ref. [47] while the five hadronic parameters s_i of the order $1/m_b^4$ can be found in Ref. [45]; these have not yet been included in the fits. The non-perturbative matrix elements depend on the renormalization scale μ , on the chosen renormalization scheme and on the quark mass m_b , and may eventually be calculated in Lattice QCD. The rates and the spectra depend strongly on m_b (or equivalently on $\overline{\Lambda}$), which makes the discussion of renormalization issues mandatory.

Using the pole mass definition for the heavy quark masses, it is well known that the corresponding perturbative series of decay rates does not converge very well, making a precision determination of $|V_{cb}|$ in such a scheme impossible. The solution to this problem is to choose an appropriate "short-distance" mass definition. Frequently used mass definitions are the kinetic scheme [14], or the 1S scheme [56]. Both of these schemes have been applied to semileptonic $b \to c$ transitions, yielding comparable results and uncertainties.

The 1S scheme eliminates the b quark pole mass by relating it to the perturbative expression for the mass of the 1S state of the Υ system. The physical mass of the $\Upsilon(1S)$ contains non-perturbative contributions, which have been estimated in Ref. [57]. These non-perturbative contributions are small; nevertheless, the best determination of the b quark mass in the 1S scheme is obtained from sum rules for $e^+e^- \to b\bar{b}$ [58].

Alternatively one may use a short-distance mass definition such as the $\overline{\rm MS}$ mass $m_b^{\overline{\rm MS}}(m_b)$. However, it has been argued that the scale m_b is unnaturally high for B decays, while

for smaller scales $\mu \sim 1 \, \text{GeV} \, m_b^{\overline{\text{MS}}}(\mu)$ is under poor control. For this reason the so-called "kinetic mass" $m_b^{\text{kin}}(\mu)$, has been proposed. It is the mass entering the non-relativistic expression for the kinetic energy of a heavy quark, and is defined using heavy-quark sum rules [14].

The HQE parameters also depend on the renormalization scale and scheme. The matrix elements given in Eq. (19) are defined with the full QCD fields and states, which is the definition frequently used in the kinetic scheme. Sometimes slightly different parameters λ_1 and λ_2 are used, which are defined in the infinite mass limit. The relation between these parameters is

$$\overline{\Lambda}_{\text{HQET}} = \lim_{m_b \to \infty} \overline{\Lambda}, \quad -\lambda_1 = \lim_{m_b \to \infty} \mu_{\pi}^2,
\lambda_2 = \lim_{m_b \to \infty} \mu_G^2, \quad \rho_1 = \lim_{m_b \to \infty} \rho_D^3,
\rho_2 = \lim_{m_b \to \infty} \rho_{LS}^3.$$
(20)

Defining the kinetic energy and the chromomagnetic moment in the infinite-mass limit (as, e.g., in the 1S scheme) requires that $1/m_b$ corrections to the matrix elements defined in Eq. (19) be taken into account once one goes beyond order $1/m_b^2$. As a result, additional quantities $\mathcal{T}_1 \cdots \mathcal{T}_4$ appear at order $1/m_b^3$. However, these quantities are correlated such that the total number of non-perturbative parameters to order $1/m_b^3$ is the same as in the scheme where m_b is kept finite in the matrix elements which define the non-perturbative parameters. A detailed discussion of these issues can be found in Ref. [59].

In order to define the HQE parameters properly one must adopt a renormalization scheme, as was done for the heavy quark mass. Since all these parameters can again be determined by heavy-quark sum rules, one may adopt a scheme similar to the kinetic scheme for the quark mass. The HQE parameters in the kinetic scheme depend on powers of the renormalization scale μ , and the above relations are valid in the limit $\mu \to 0$, leaving only logarithms of μ .

Some of these parameters also appear in the relation for the heavy hadron masses. The quantity $\overline{\Lambda}$ is determined once a definition is specified for the quark mass. The parameter μ_G^2 can be extracted from the mass splitting in the lowest spin-symmetry doublet of heavy mesons [60]

$$\mu_G^2(\mu) = \frac{3}{4} C_G(\mu, m_b) (M_{B^*}^2 - M_B^2), \tag{21}$$

where $C_G(\mu, m_b)$ is a perturbatively-computable coefficient which depends on the scheme. In the kinetic scheme we have

$$\mu_G^2(1\text{GeV}) = 0.35_{-0.02}^{+0.03} \,\text{GeV}^2.$$
 (22)

Determination of HQE Parameters and $|V_{cb}|$

Several experiments have measured moments in $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays [61–69] as a function of the minimum lepton momentum. The measurements of the moments of the electron energy spectrum (0th-3rd) and of the squared hadronic mass spectrum (0th-2nd) have statistical uncertainties that are roughly equal

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to their systematic uncertainties. They can be improved with more data and significant effort. The sets of moments measured by each experiment have strong correlations; the full statistical and systematic correlation matrices are required to allow these to be used in a global fit. Measurements of photon energy moments $(0^{\text{th}}-2^{\text{nd}})$ in $B \to X_s \gamma$ decays [70–74] as a function of the minimum accepted photon energy are still primarily statistics limited.

Global fits to the full set of moments [69,71,75–78] have been performed in the 1S and kinetic schemes. The semileptonic moments alone determine a linear combination of m_b and m_c very accurately but leave the orthogonal combination poorly determined [79]; additional input is required to allow a precise determination of m_b . This additional information can come from the radiative $B \to X_s \gamma$ moments, which provide complementary information on m_b and μ_π^2 , or from precise determinations of the charm quark mass [80,81]. The values obtained in the kinetic scheme fits [77] with these two constraints are consistent. Based on the charm quark mass constraint [80], $m_c^{\overline{\rm MS}}(3\,{\rm GeV}) = 0.998 \pm 0.029\,{\rm GeV}$,

$$|V_{cb}| = (41.88 \pm 0.44 \pm 0.59) \times 10^{-3}$$
 (23)

$$m_h^{\text{kin}} = 4.560 \pm 0.023 \,\text{GeV}$$
 (24)

$$\mu_{\pi}^{2}(\text{kin}) = 0.453 \pm 0.036 \,\text{GeV}^{2},$$
(25)

where the first error on $|V_{cb}|$ includes experimental and theoretical uncertainties and the second error is from the estimated accuracy of the HQE for the total semileptonic rate.

Theoretical uncertainties are estimated and included in performing the fits. The $\chi^2/{\rm dof}$ is substantially below unity in all fits, suggesting that the theoretical uncertainties may be overestimated. In any case, the low χ^2 shows no evidence for duality violations at a significant level. Similar values for the parameters are obtained when only experimental uncertainties are used in the fits. If the photon energy spectrum moments from $\overline{B} \to X_s \gamma$ are used in place of the constraint on the charm quark mass, the results change by only small amounts, e.g., $m_b^{\rm kin}$ increases to $4.574 \pm 0.032 \,{\rm GeV}$. The mass in the $\overline{\rm MS}$ scheme corresponding to Eq. (24) is $m_b^{\overline{\rm MS}} = 4.19 \pm 0.04 \,{\rm GeV}$, which can be compared with a recent value obtained using relativistic sum rules [82], $m_b^{\overline{\rm MS}} = 4.163 \pm 0.016 \,{\rm GeV}$, and provides a non-trivial cross-check.

A fit to the same moments in the 1S scheme gives [78]

$$|V_{cb}| = (41.96 \pm 0.45 \pm 0.07) \times 10^{-3}$$
 (26)

$$m_b^{1S} = 4.691 \pm 0.037 \,\text{GeV}$$
 (27)

$$\lambda_1(1S) = -0.362 \pm 0.067 \,\text{GeV}^2,$$
 (28)

where the last error on $|V_{cb}|$ is due to the uncertainties in the B meson lifetimes. This fit uses semileptonic and radiative moments and constrains the chromomagnetic operator using the mass difference between the D and D^* mesons. This independent fit gives consistent results for $|V_{cb}|$ and, after translation to a common renormalization scheme, for m_b and μ^2

The precision of the global fit results can be further improved. Some of the measurements, in particular of the $\overline{B} \to X_s \gamma$ photon energy spectrum, can be improved by using the full B-factory data sets. Improvements can be made in the theory by calculating higher order perturbative corrections to the coefficients of the HQE parameters, in particular the still missing $\alpha_s \mu_G^2$ corrections, which are presently only known for $B \to X_s \gamma$ [84]. The inclusion of still higher order moments may improve the sensitivity of the fits to higher order terms in the HQE.

Determination of $|V_{ub}|$

Summary: The determination of $|V_{ub}|$ is the focus of significant experimental and theoretical work. The determinations based on inclusive semileptonic decays using different calculational ansätze are consistent. The largest parametric uncertainty comes from the error on m_b . Significant progress has been made in determinations of $|V_{ub}|$ from $\overline{B} \to \pi \ell \overline{\nu}_\ell$ decays by using combined fits to theory and experimental data as a function of q^2 . Further improvements in the form factor normalization are needed to improve the precision.

The values obtained from inclusive and exclusive determinations are

$$|V_{ub}| = (4.41 \pm 0.15 + 0.15 + 0.15) \times 10^{-3}$$
 (inclusive), (29)

$$|V_{ub}| = (3.23 \pm 0.31) \times 10^{-3}$$
 (exclusive). (30)

The two determinations are independent, and the dominant uncertainties are on multiplicative factors. The inclusive and exclusive values are weighted by their relative errors and the uncertainties are treated as normally distributed. The resulting average has $p(\chi^2) = 0.01$, so we scale the error by $\sqrt{\chi^2/1} = 2.6$ to find

$$|V_{ub}| = (4.15 \pm 0.49) \times 10^{-3}.$$
 (31)

Given the poor consistency between the two determinations, this average should be treated with caution.

$|V_{ub}|$ from inclusive decays

The theoretical description of inclusive $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays is based on the Heavy Quark Expansion, as for $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays, and leads to a predicted total decay rate with uncertainties below 5% [85,86]. Unfortunately, the total decay rate is hard to measure due to the large background from CKMfavored $\overline{B} \to X_c \ell \overline{\nu}_{\ell}$ transitions. Technically, the calculation of the partial decay rate in regions of phase space where $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays are suppressed is different from what has been described above, since it requires the introduction of a non-perturbative distribution function, the "shape function" (SF) [87,88]. Due to this, the theoretical input for the extraction on V_{ub} from inclusive decays is more challenging. The shape function becomes important when the light-cone momentum component $P_{+} \equiv E_{X} - |P_{X}|$ is not large compared to Λ_{QCD} . This additional difficulty can be addressed in two complementary ways. The leading shape function can either be measured in the radiative decay $\overline{B} \to X_s \gamma$, or be modeled with

constraints on the 0th-2nd moments, and the results applied to the calculation of the $\overline{B} \to X_u \ell \overline{\nu}_\ell$ partial decay rate [89–91]; in such an approach the largest challenges are for the theory. Alternatively, measurements of $\overline{B} \to X_u \ell \overline{\nu}_\ell$ partial decay rates can be extended further into the $\overline{B} \to X_c \ell \overline{\nu}_\ell$ -allowed region, enabling a simplified theoretical (pure HQE) treatment [92] but requiring precise experimental knowledge of the $\overline{B} \to X_c \ell \overline{\nu}_\ell$ background.

The shape function is a universal property of B mesons at leading order. It has been recognized for many years [87,88] that the leading SF can be measured in $\overline{B} \to X_s \gamma$ decays. However, sub-leading shape functions [93-98] arise at each order in $1/m_b$, and differ in semileptonic and radiative B decays. The form of the SFs cannot be calculated from first principles. Prescriptions that relate directly the partial rates for $\overline{B} \to X_s \gamma$ and $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ decays and thereby avoid any parameterization of the leading SF are available [99–102]; uncertainties due to sub-leading SFs remain in these approaches. Existing measurements have tended to use parameterizations of the leading SF that respect constraints on the zeroth, first and second moments. At leading order the first and second moments are equal to $\overline{\Lambda} = M_B - m_b$ and μ_{π}^2 , respectively. The relations between SF moments and the non-perturbative parameters of the HQE are known to second order in α_s [103]. As a result, measurements of HQE parameters from global fits to $\overline{B} \to X_c \ell \overline{\nu}_\ell$ and $\overline{B} \to X_s \gamma$ moments can be used to constrain the SF moments, as well as provide accurate values of m_b and other parameters for use in determining $|V_{ub}|$. The possibility of measuring these HQE parameters directly from moments in $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays has been explored [104], but the experimental precision achievable there is not competitive with other approaches.

A recent development is to use appropriate basis functions to approximate the shape function, thereby also including the known short-distance contributions as well as the renormalization properties of the SF [105], in order to allow a global fit of all inclusive B meson decay data.

The calculations that are used for the fits performed by HFAG are documented in Refs. [89] (BLNP), [106] (GGOU), [107] (DGE) and [92] (BLL).

The calculations start from the triple diffential rate using the variables

$$P_l = M_B - 2E_l, \quad P_- = E_X + |\vec{P}_X|, \quad P_+ = E_X - |\vec{P}_X| \quad (32)$$

for which the differential rate becomes

$$\frac{d^{3}\Gamma}{dP_{+}dP_{-}dP_{l}} = \frac{G_{F}^{2}|V_{ub}|^{2}}{16\pi^{2}}(M_{B} - P_{+})$$

$$\left\{ (P_{-} - P_{l})(M_{B} - P_{-} + P_{l} - P_{+})\mathcal{F}_{1} + (M_{B} - P_{-})(P_{-} - P_{+})\mathcal{F}_{2} + (P_{-} - P_{l})(P_{l} - P_{+})\mathcal{F}_{3} \right\}.$$
(33)

The "structure functions" \mathcal{F}_i can be calculated using factorization theorems that have been proven to subleading order in the $1/m_b$ expansion.

The BLNP [89] calculation uses these factorization theorems to write the \mathcal{F}_i in terms of perturbatively calculable hard coefficients H and jet functions J, which are convolved with the (soft) light-cone distribution functions S, the shape functions of the B meson. The BLNP calculation has been updated to include the full $\mathcal{O}(\alpha_S^2)$ contributions [108].

The leading order term in the $1/m_b$ expansion of the \mathcal{F}_i contains a single non-perturbative function and is calculated to subleading order in α_s , while at subleading order in the $1/m_b$ expansion there are several independent non-perturbative functions which have been calculated only at tree level in the α_s expansion.

To extract the non-perturbative input one can study the photon energy spectrum in $B \to X_s \gamma$ [91]. This spectrum is known at a similar accuracy as the P_+ spectrum in $B \to X_u \ell \overline{\nu}_\ell$. Going to subleading order in the $1/m_b$ expansion requires the modeling of subleading SFs, a large variety of which were studied in Ref. [89].

A distinct approach (GGOU) [106] uses a hard, Wilsonian cut-off that matches the definition of the kinetic mass. The non-perturbative input is similar to what is used in BLNP, but the shape functions are defined differently. In particular, they are defined at finite m_b and depend on the light-cone component k_+ of the b quark momentum and on the momentum transfer q^2 to the leptons. These functions include sub-leading effects to all orders; as a result they are non-universal, with one shape function corresponding to each structure function in Eq. (33). Their k_+ moments can be computed in the OPE and related to observables and to the shape functions defined in Ref. [89].

Going to subleading order in α_s requires the definition of a renormalization scheme for the HQE parameters and for the SF. It has been noted that the relation between the moments of the SF and the forward matrix elements of local operators is plagued by ultraviolet problems which require additional renormalization. A possible scheme for improving this behavior has been suggested in Refs. [89,91], which introduce a particular definition of the quark mass (the so-called shape function scheme) based on the first moment of the measured spectrum. Likewise, the HQE parameters can be defined from measured moments of spectra, corresponding to moments of the SF.

One can also attempt to calculate the SF by using additional assumptions. One possible approach (DGE) is the so-called "dressed gluon exponentiation" [107], where the perturbative result is continued into the infrared regime using the renormalon structure obtained in the large β_0 limit, where β_0 has been defined following Eq. (18).

While attempts to quantify the SF are important, the impact of uncertainties in the SF is significantly reduced in some recent measurements that cover a larger portion of the $\overline{B} \to X_u \ell \overline{\nu}_\ell$ phase space. Several measurements using a combination of cuts on the leptonic momentum transfer q^2 and the hadronic invariant mass m_X as suggested in Ref. [109] have been made. Measurements of the electron spectrum in

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 $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays have been made down to momenta of 1.9 GeV or even lower, where SF uncertainties are not dominant. Of course, determining $\overline{B} \to X_u \ell \overline{\nu}_\ell$ partial rates in charm-dominated regions can bring in a strong dependence on the modeling of the $\overline{B} \to X_u \ell \overline{\nu}_\ell$ spectrum, which is problematic. The measurements quoted below have used a variety of functional forms to parameterize the leading SF; in no case does this lead to more than a 2% uncertainty on $|V_{ub}|$.

Weak Annihilation [110,111,106] (WA) can in principle contribute significantly in the restricted region (at high q^2) accepted by measurements of $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays. An estimate [92] based on leptonic D_s decays [111,112] leads to a $\sim 2\%$ uncertainty on the total $\overline{B} \to X_u \ell \overline{\nu}_\ell$ rate from the $\Upsilon(4S)$. The differential spectrum from WA decays is not well known, but they are expected to contribute predominantly at high q^2 . More recent investigations of WA [112,113,114] confirm that WA is a small effect, but may become a significant source of uncertainty for $|V_{ub}|$ measurements that only accept a small fraction, f_u , of the full $\overline{B} \to X_u \ell \overline{\nu}_\ell$ phase space. Modeldependent limits on WA were determined in Ref. [115], where the CLEO data were fitted to combinations of WA models and a spectator $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ component and background. More direct experimental constraints [116] on WA have recently been made by comparing the $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decay rates of charged and neutral B mesons. However, these constraints are not sensitive to the isoscalar contribution to WA. The sensitivity of $|V_{ub}|$ determinations to WA can also be reduced by removing the region at high q^2 in those measurements where q^2 is determined.

Measurements

We summarize the measurements used in the determination of $|V_{ub}|$ below. Given the improved precision and more rigorous theoretical interpretation of the recent measurements, earlier determinations [117–120] will not be further considered in this review.

Inclusive electron momentum measurements [121–123] reconstruct a single charged electron to determine a partial decay rate for $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ near the kinematic endpoint. This results in a high $\mathcal{O}(50\%)$ selection efficiency and only modest sensitivity to the modeling of detector response. The decay rate can be cleanly extracted for $E_e > 2.3 \,\text{GeV}$, but this is deep in the SF region, where theoretical uncertainties are large. Measurements down to 2.0 or 1.9 GeV exist, but have low (< 1/10) signal-to-background (S/B) ratio, making the control of the $\overline{B} \to X_c \ell \overline{\nu}_{\ell}$ background a crucial point. In these analyses the inclusive electron momentum spectrum from $B\overline{B}$ events is determined by subtracting the $e^+e^- \rightarrow q\bar{q}$ continuum background using data samples collected just below $B\overline{B}$ threshold. The continuum-subtracted spectrum is fitted to a combination of a model $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ spectrum and several components $(D\ell\overline{\nu}_{\ell}, D^*\ell\overline{\nu}_{\ell}, ...)$ of the $\overline{B} \to X_c\ell\overline{\nu}_{\ell}$ background. The resulting $|V_{ub}|$ values for various E_e cuts are given in Table 1. The leading uncertainty at the lower lepton momentum cuts comes from the $\overline{B} \to X_c \ell \overline{\nu}_{\ell}$ background. Prospects for

reducing further the lepton momentum cut are improving in light of better knowledge of the semileptonic decays to higher mass $X_c\ell\overline{\nu}$ states [124,37]. The determination of $|V_{ub}|$ from these measurements is discussed below.

An untagged "neutrino reconstruction" measurement [125] from BABAR uses a combination [126] of a high-energy electron with a measurement of the missing momentum vector. This allows a much higher S/B ~ 0.7 at the same E_e cut and a $\mathcal{O}(5\%)$ selection efficiency, but at the cost of a smaller accepted phase space for $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays and uncertainties associated with the determination of the missing momentum. A control sample of $\Upsilon(4S) \to B\overline{B}$ decays where one B is reconstructed as $\overline{B} \to D^0(X) e \overline{\nu}$ with $D^0 \to K^- \pi^+$ is used to reduce uncertainties from detector and background modeling. The corresponding values for $|V_{ub}|$ are given in Table 1.

The large samples accumulated at the B factories allow studies in which one B meson is fully reconstructed and the recoiling B decays semileptonically [127–130]. ments can fully reconstruct a "tag" B candidate in about 0.5%(0.3%) of $B^+B^ (B^0\overline{B}^0)$ events. An electron or muon with center-of-mass momentum above 1.0 GeV is required amongst the charged tracks not assigned to the tag B and the remaining particles are assigned to the X_u system. The full set of kinematic properties $(E_{\ell}, m_X, q^2, etc.)$ are available for studying the semileptonically decaying B, making possible selections that accept up to 70% of the full $\overline{B} \to X_u \ell \overline{\nu}_\ell$ rate. Despite requirements (e.g. on the square of the missing mass) aimed at rejecting events with additional missing particles, undetected or mis-measured particles from $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decay (e.g., K_L^0 and additional neutrinos) remain an important source of uncertainty. Measurements with the largest kinematic acceptance (i.e. $E_{\ell} > 1 \, \mathrm{GeV}$) lead to the smallest theoretical and overall uncertainties on $|V_{ub}|$.

BABAR [127] and BELLE [128,129] have measured partial rates with cuts on m_X , m_X and q^2 , and P_+ based on large samples of $B\overline{B}$ events. Correlations amongst these related partial rates are taken into account in the average given in Table 1. In each case the experimental systematics have significant contributions from the modeling of $\overline{B} \to X_u \ell \overline{\nu}_\ell$ and $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays and from the detector response to charged particles, photons and neutral hadrons.

Determination of $|V_{ub}|$

The determination of $|V_{ub}|$ from the measured partial rates requires input from theory. The BLNP, GGOU and DGE calculations described previously are used to determine $|V_{ub}|$ from all measured partial $\overline{B} \to X_u \ell \overline{\nu}_\ell$ rates; the values [26] are given in Table 1. The m_b input values used are derived from the fitted value in equation Eq. (24): $m_b^{SF} = 4.588 \pm 0.025$ GeV for BLNP, $m_b^{\rm kin} = 4.560 \pm 0.023$ GeV for GGOU, and $m_b^{\overline{MS}} = 4.194 \pm 0.043$ GeV for DGE. The larger uncertainties on m_b^{SF} and $m_b^{\overline{MS}}$ reflect the effect of scheme translations, which are done at fixed-order in α_s .

As an illustration of the relative sizes of the uncertainties entering $|V_{ub}|$ we give the error breakdown for the GGOU average: statistical—2.0%; experimental—1.7%; $\overline{B} \to X_c \ell \overline{\nu}_\ell$ modeling—1.3%; $\overline{B} \to X_u \ell \overline{\nu}_\ell$ modeling—1.9%; HQE parameters —1.9%; higher-order corrections—1.4%; q^2 modeling—1.3%; Weak Annihilation— $^{+0}_{-1.9}$ %; SF form—0.2%. The uncertainty on m_b dominates the uncertainty on $|V_{ub}|$ from HQE parameters, but no longer dominates the overall uncertainty.

The correlations amongst the multiple BABAR recoil-based measurements [127] are fully accounted for in the average. The statistical correlations amongst the other measurements used in the average are tiny (due to small overlaps among signal events and large differences in S/B ratios) and have been ignored. Correlated systematic and theoretical errors are taken into account, both within an experiment and between experiments.

Table 1: $|V_{ub}|$ (in units of 10^{-5}) from inclusive $\overline{B} \to X_u \ell \overline{\nu}_\ell$ measurements. The first uncertainty on $|V_{ub}|$ is experimental, while the second includes both theoretical and HQE parameter uncertainties. The values are listed in order of increasing f_u (0.19 to 0.90); those below the horizontal bar are based on recoil methods.

| Ref. | cut | BLNP | GGOU | DGE |
|-------------------------------------------|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| [125] [123] | $E_e > 2.1$ E_e - q^2 $E_e > 2.0$ $E_e > 1.9$ | $\begin{array}{c} 419 \pm 49 \substack{+\ 26}{-\ 34} \\ 466 \pm 31 \substack{+\ 31}{-\ 36} \\ 448 \pm 25 \substack{+\ 27}{-\ 28} \\ 488 \pm 45 \substack{+\ 24}{-\ 27} \end{array}$ | $393 \pm 46 \stackrel{+}{_{-}} \stackrel{22}{_{-}} 29$ not avail. $429 \pm 24 \stackrel{+}{_{-}} \stackrel{18}{_{-}} 24$ $475 \pm 44 \stackrel{+}{_{-}} \stackrel{17}{_{-}} 22$ | $382 \pm 45 \stackrel{+}{} \stackrel{23}{} \atop 432 \pm 29 \stackrel{+}{} \stackrel{24}{} \atop 29} \atop 428 \pm 24 \stackrel{+}{} \stackrel{22}{} \atop 479 \pm 44 \stackrel{+}{} \stackrel{21}{} \atop -24}$ |
| [127] [127] [127] [127] [129] | $m_X - q^2$ P_+ m_X $E_e > 1$ $E_e > 1$ | $\begin{array}{c} 425 \pm 23 \begin{array}{c} + 23 \\ - 25 \end{array} \\ 402 \pm 25 \begin{array}{c} + 24 \\ - 23 \end{array} \\ 397 \pm 22 \pm 20 \\ 428 \pm 24 \begin{array}{c} + 18 \\ - 20 \\ 447 \pm 27 \begin{array}{c} + 19 \\ - 21 \end{array} \end{array}$ | $\begin{array}{c} 417 \pm 22 \stackrel{+}{_{-}} \stackrel{22}{_{-}} \\ 375 \pm 23 \stackrel{+}{_{-}} \stackrel{30}{_{-}} \\ 394 \pm 22 \stackrel{+}{_{-}} \stackrel{16}{_{-}} \\ 435 \pm 24 \stackrel{+}{_{-}} \stackrel{9}{_{-}} \\ 454 \pm 27 \stackrel{+}{_{-}} \stackrel{10}{_{-}} \end{array}$ | $\begin{array}{c} 419 \pm 22 \stackrel{+}{\underset{19}{-}} \stackrel{18}{\underset{19}{-}} \\ 410 \pm 25 \stackrel{+}{\underset{28}{-}} \stackrel{37}{\underset{29}{-}} \\ 416 \pm 23 \stackrel{+}{\underset{20}{-}} \stackrel{26}{\underset{20}{-}} \\ 440 \pm 24 \stackrel{+}{\underset{13}{-}} \stackrel{12}{\underset{13}{-}} \\ 460 \pm 27 \stackrel{+}{\underset{-}{-}} \stackrel{11}{\underset{13}{-}} \end{array}$ |
| | | $440 \pm 15 {}^{+}_{-} {}^{19}_{21}$ | $439 \pm 15 {}^{+}_{-} {}^{12}_{14}$ | $445 \pm 15 {}^{+}_{-} {}^{15}_{16}$ |

The theoretical calculations produce very similar results for $|V_{ub}|$; the standard deviation of the theory predictions for the endpoint rate is 4.6%, for the m_X - q^2 rate is 2.2%, and for the $E_e > 1$ GeV rate is 0.8%. The $|V_{ub}|$ values do not show a marked trend versus the kinematic acceptance, f_u , for $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays. The p-values of the averages are in the range 30-50%, indicating that the ratios of calculated partial widths in the different phase space regions are in good agreement with ratios of measured partial branching fractions.

A recent calculation [108] at NNLO accuracy of the leading term in the partial rate for kinematically restrictive cuts (e.g. near the electron endpoint energy) shows a surprisingly large change from the NLO calculation used in the BLNP method, increasing $|V_{ub}|$ by up to $\sim 8\%$ for some measurements. These updated calculations are not reflected in the BLNP values shown in Table 1. In the GGOU and the DGE approaches the inclusion of the dominant $\alpha_s^2\beta_0$ contributions do not suggest large α_s^2 corrections in these methods.

All calculations yield compatible $|V_{ub}|$ values and similar error estimates. We take the arithmetic mean of the values and errors to find

$$|V_{ub}| = (4.41 \pm 0.15_{\text{exp}} ^{+0.15}_{-0.17 \text{ th}}) \times 10^{-3}$$
 (inclusive). (34)

As was the case with $|V_{cb}|$, it is hard to assign an uncertainty to $|V_{ub}|$ for possible duality violations. However, theoretical arguments suggest that duality should hold even better in $b \to u\ell \overline{\nu}_\ell$ than in $b \to c\ell \overline{\nu}_\ell$ [42]. In any case, unless duality violations are much larger in $\overline{B} \to X_u\ell \overline{\nu}_\ell$ decays than in $\overline{B} \to X_c\ell \overline{\nu}_\ell$ decays, the precision of the $|V_{ub}|$ determination is not yet at the level where duality violations are likely to be significant.

Hadronization uncertainties also impact the $|V_{ub}|$ determination. The theoretical expressions are valid at the parton level and do not incorporate any resonant structure (e.g. $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$); this must be added "by hand" to the simulated $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ event samples, since the detailed final state multiplicity and structure impacts the estimates of experimental acceptance and efficiency. The experiments have adopted procedures to input resonant structure while preserving the appropriate behavior in the kinematic variables averaged over the sample. The resulting uncertainties have been estimated to be $\sim 1\text{-}2\%$ on $|V_{ub}|$.

A separate class of analyses follows the strategy discussed in Refs. [99–102], where integrals of differential distributions in $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays are compared with corresponding integrals in $\overline{B} \to X_s \gamma$ decays to extract $|V_{ub}|$, thereby eliminating the need to model the leading shape function. A study [132] using the measured BABAR electron spectrum in $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays provides $|V_{ub}|$ determinations using all available "SF-free" calculations; the resulting $|V_{ub}|$ values have total uncertainties of $\sim 12\%$ and are compatible with the average quoted above.

The BLL [109] calculation can be used for measurements [128,130,131] with cuts on m_X and q^2 . Using the same HQE parameter input as above yields a $|V_{ub}|$ value of $(4.62 \pm 0.20 \pm 0.29) \times 10^{-3}$, which is about 7% higher than the values obtained from the calculations used in Table 1 for these measurements.

Status and outlook

At present, as indicated by the average given above, the uncertainty on $|V_{ub}|$ from inclusive decays is at the 5% level. Are these uncertainties justified? The uncertainty on m_b was discussed in detail above. The uncertainties quoted in the calculations due to matching scales, higher order corrections, etc., are at the few percent level on $|V_{ub}|$. While these uncertainties are inherently difficult to quantify, the calculations take different approaches yet produce similar estimates. Experimental uncertainties have been assessed independently by BaBar and Belle. An important common source of uncertainty comes from modelling the $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays. Better measurements of these exclusive decays would be helpful in this regard, as would improved knowledge of the main $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays.

V_{cb} and V_{ub} CKM Matrix Elements

$|V_{ub}|$ from exclusive decays

Exclusive charmless semileptonic decays offer a complementary means of determining $|V_{ub}|$. For the experiments, the specification of the final state provides better background rejection, but the lower branching fraction reflects itself in lower yields compared with inclusive decays. For theory, the calculation of the form factors for $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays is challenging, but brings in a different set of uncertainties from those encountered in inclusive decays. In this review we focus on $\overline{B} \to \pi \ell \overline{\nu}_\ell$, as it is the most promising mode for both experiment and theory, and recent improvements have been made in both areas. Measurements of other exclusive states can be found in Refs. [135–140,154].

 $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ form factor calculations The relevant form factors for the decay $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ are usually defined as

$$\langle \pi(p_{\pi})|V^{\mu}|B(p_B)\rangle = \tag{35}$$

$$f_{+}(q^2)\left[p_B^{\mu}+p_\pi^{\mu}-\frac{m_B^2-m_\pi^2}{q^2}q^{\mu}\right]+f_0(q^2)\frac{m_B^2-m_\pi^2}{q^2}q^{\mu}$$

in terms of which the rate becomes (in the limit $m_{\ell} \to 0$)

$$\frac{d\Gamma}{da^2} = \frac{G_F^2 |V_{ub}|^2}{24\pi^3} |p_{\pi}|^3 |f_+(q^2)|^2, \tag{36}$$

where p_{π} is the momentum of pion in the B meson rest frame.

Currently available non-perturbative methods for the calculation of the form factors include lattice QCD (LQCD) and light-cone sum rules (LCSR). The two methods are complementary in phase space, since the lattice calculation is restricted to the kinematical range of high momentum transfer q^2 to the leptons, to avoid large discretization errors, while light-cone sum rules provide information near $q^2 = 0$. Interpolations between these two regions can be constrained by unitarity and analyticity.

Unquenched simulations, for which quark loop effects in the QCD vacuum are fully incorporated, have become quite common, and the first results based on these simulations for the $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ form factors have been obtained by the Fermilab/MILC collaboration [141] and the HPQCD collaboration [142]. The two calculations differ in the way the b quark is simulated, with HPQCD using nonrelativistic QCD and Fermilab/MILC the so-called Fermilab heavy-quark method; they agree within the quoted errors.

In order to obtain the partially-integrated differential rate, the BK parameterization [143]

$$f_{+}(q^{2}) = \frac{c_{B}(1 - \alpha_{B})}{(1 - \tilde{q}^{2})(1 - \alpha_{B}\tilde{q}^{2})},$$
(37)

$$f_0(q^2) = \frac{c_B(1 - \alpha_B)}{(1 - \tilde{q}^2/\beta_B)},\tag{38}$$

with $\tilde{q}^2 \equiv q^2/m_{B^*}^2$ has been used frequently to extrapolate to small values of q^2 . It includes the leading pole contribution from B^* , and higher poles are modeled by a single pole. The heavy-quark scaling is satisfied if the parameters c_B , α_B and β_B scale appropriately. However, the BK parameterization should

be used with some caution, since it is not consistent with SCET [144]. More recently, analyticity and unitarity bounds have been employed to constrain the form factors. Making use of the heavy-quark limit, stringent constraints on the shape of the form factor can be derived [144], and the conformal mapping of the kinematical variables onto the complex unit disc yields a rapidly converging series in this variable. The use of lattice data in combination with a data point at small q^2 from SCET or sum rules provides a stringent constraint on the shape of the form factor [145]. The form factor parametrization given in Ref. [145] has been applied to the extraction of $|V_{ub}|$ from $B \to \pi \ell \bar{\nu}_{\ell}$ using lattice data in Ref. [141].

Much work remains to be done, since the current combined statistical plus systematic errors in the lattice results are still at the $\sim 10\%$ level on $|V_{ub}|$ and need to be reduced. Reduction of errors to the ~ 5 -6% level for $|V_{ub}|$ will be feasible within the next few years, with the inclusion of numerical data at lighter pion masses and finer lattice spacings, as well as possibly two-loop or nonperturbative matching between lattice and continuum heavy-to-light current operators.

Another established non-perturbative approach to obtain the form factors is through Light-Cone QCD Sum Rules (LCSR), where the heavy mass limit has been discussed from the point of view of SCET in Ref. [147]. The sum-rule approach provides an approximation for the product $f_B f_+(q^2)$, valid in the region $0 < q^2 < \sim 12 \text{ GeV}^2$. The determination of $f_+(q^2)$ itself requires knowledge of the decay constant f_B , which usually is obtained by replacing f_B by its two-point QCD (SVZ) sum rule [148] in terms of perturbative and condensate contributions. The advantage of this procedure is the approximate cancellation of various theoretical uncertainties in the ratio $(f_B f_+)/(f_B)$. The LCSR for $f_B f_+$ is based on the lightcone OPE of the relevant vacuum-to-pion correlation function, calculated in full QCD at finite b-quark mass. The resulting expressions actually comprise a triple expansion: in the twist tof the operators near the light-cone, in α_s , and in the deviation of the pion distribution amplitudes from their asymptotic form, which is fixed from conformal symmetry.

There are multiple sources of uncertainties in the LCSR calculation, which are discussed in Refs. [149,150]. Currently, a total uncertainty slightly larger than 10% on $|V_{ub}|$ is extracted from a LCSR calculation of

$$\Delta\zeta(0, q_{max}^2) = \frac{G_F^2}{24\pi^3} \int_0^{q_{max}^2} dq^2 \, p_\pi^3 |f_+(q^2)|^2$$

$$= \frac{1}{|V_{ub}|^2 \tau_{B_0}} \int_0^{q_{max}^2} dq^2 \, \frac{d\mathcal{B}(B \to \pi \ell \nu)}{dq^2} \qquad (39)$$

which turn out to be [151]

$$\Delta \zeta(0, 12 \,\text{GeV}^2) = 4.59^{+1.00}_{-0.85} \,\text{ps}^{-1}.$$
 (40)

It is interesting to note that the results from the LQCD and LCSR are consistent with each other when either the

BK parameterization or parametrizations based on conformal mappings [145,146] are used to relate them. This increases confidence in the theoretical predictions for the rate of $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$. This is complementary to the lattice results at large values of q^2 , and the results from LCSR smoothly extrapolate the lattice data to small values of q^2 .

An alternative determination of $|V_{ub}|$ has been proposed by several authors [152,153] based on a model-independent relation between rare decays such as $\overline{B} \to K^* \ell^+ \ell^-$ and $\overline{B} \to \rho \ell \overline{\nu}_\ell$. However, it requires a precise measurement of the $\overline{B} \to K^* \ell^+ \ell^-$ decay, which is a task for ultra-high-rate experiments.

$\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ measurements

The $\overline{B} \to \pi \ell \overline{\nu}_\ell$ measurements fall into two broad classes: untagged, in which case the reconstruction of the missing momentum of the event serves as an estimator for the unseen neutrino, and tagged, in which the second B meson in the event is fully reconstructed in either a hadronic or semileptonic decay mode. The tagged measurements have high and uniform acceptance, S/B as high as 10, but low statistics. The untagged measurements have somewhat higher background levels (S/B < 1) and make slightly more restrictive kinematic cuts, but have adequate statistics to measure the q^2 dependence of the form factor.

Table 2: Total and partial branching fractions for $\overline{B}{}^0 \to \pi^+ \ell^- \overline{\nu}_\ell$, scaled to a common set of external inputs. The uncertainties are from statistics and systematics. Measurements of $\mathcal{B}(B^- \to \pi^0 \ell^- \overline{\nu}_\ell)$ have been multiplied by a factor $2\tau_{B^0}/\tau_{B^+}$ to obtain the values below.

| | $\mathcal{B} \times 10^4$ | $\mathcal{B}(q^2 > 16) \times 10^4$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CLEO π^+, π^0 [139] BABAR π^+, π^0 [140] BABAR π^+ [154] BELLE π^+, π^0 [155] | $\begin{aligned} 1.38 &\pm 0.15 \pm 0.11 \\ 1.41 &\pm 0.05 \pm 0.08 \\ 1.42 &\pm 0.05 \pm 0.07 \\ 1.49 &\pm 0.04 \pm 0.07 \end{aligned}$ | $0.41 \pm 0.08 \pm 0.04 0.32 \pm 0.02 \pm 0.03 0.33 \pm 0.03 \pm 0.03 0.40 \pm 0.02 \pm 0.02$ |
| BELLE SL π^+ [156] BELLE SL π^0 [156] BELLE had π^+ [157] BELLE had π^0 [157] BABAR SL π^+ [158] BABAR SL π^0 [158] BABAR had π^+ [159] BABAR had π^0 [159] | $\begin{array}{c} 1.42 \pm 0.19 \pm 0.15 \\ 1.41 \pm 0.26 \pm 0.15 \\ 1.12 \pm 0.18 \pm 0.05 \\ 1.22 \pm 0.22 \pm 0.05 \\ 1.39 \pm 0.21 \pm 0.08 \\ 1.78 \pm 0.28 \pm 0.15 \\ 1.07 \pm 0.27 \pm 0.19 \\ 1.52 \pm 0.41 \pm 0.30 \end{array}$ | $\begin{array}{c} 0.37 \pm 0.10 \pm 0.04 \\ 0.36 \pm 0.15 \pm 0.04 \\ 0.26 \pm 0.08 \pm 0.01 \\ 0.41 \pm 0.11 \pm 0.02 \\ 0.46 \pm 0.13 \pm 0.03 \\ 0.44 \pm 0.17 \pm 0.06 \\ 0.65 \pm 0.20 \pm 0.13 \\ 0.48 \pm 0.22 \pm 0.12 \end{array}$ |
| Average | $1.42 \pm 0.03 \pm 0.04$ | $0.37 \pm 0.01 \pm 0.02$ |

CLEO has analyzed $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ and $\overline{B} \to \rho \ell \overline{\nu}_{\ell}$ using an untagged analysis [139]. Similar analyses have been done at BABAR [140,154] and BELLE [155]. The leading systematic uncertainties in the untagged $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ analyses are associated with modeling the missing momentum reconstruction, with backgrounds from $\overline{B} \to X_u \ell \overline{\nu}_{\ell}$ decays and $e^+e^- \to q\overline{q}$ continuum events, and with varying the form factor for the $\overline{B} \to \rho \ell \overline{\nu}_{\ell}$ decay. The values obtained for the full and partial

branching fractions [26] are listed in Table 2 above the horizontal line. These BABAR and BELLE measurements provide the differential $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ rate versus q^2 , shown in Fig. 2, which is used in the determination of $|V_{ub}|$ discussed below.

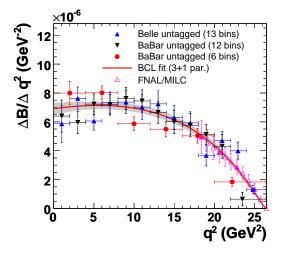


Figure 2: The untagged measurements of the differential $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ branching fraction versus q^2 that are used together with lattice calculations in the determination of $|V_{ub}|$.

Analyses [156,158] based on reconstructing a B in the $\overline{D}^{(*)}\ell^+\nu_\ell$ decay mode and looking for a $\overline{B}\to\pi\ell\overline{\nu}_\ell$ or $\overline{B}\to\rho\ell\overline{\nu}_\ell$ decay amongst the remaining particles in the event make use of the fact that the B and \overline{B} are back-to-back in the $\Upsilon(4S)$ frame to construct a discriminant variable that provides a signal-to-noise ratio above unity for all q^2 bins. A related technique was discussed in Ref. [161]. BABAR [158] and BELLE [157] have also used their samples of B mesons reconstructed in hadronic decay modes to measure exclusive charmless semileptonic decays giving very clean but low-yield samples. The resulting full and partial branching fractions are given in Table 2. The averages take account of correlations and common systematic uncertainties, and have $p(\chi^2) > 0.5$ in each case.

 $|V_{ub}|$ can be obtained from the average $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ branching fraction and the measured q^2 spectrum. Using the average [26] of partial branching fractions in the $q^2 < 12 \,\text{GeV}^2$ region, $(0.81 \pm 0.02 \pm 0.03) \times 10^{-4}$, along with an LCSR calculation of the theoretical rate [151] gives

$$|V_{ub}| = (3.40 \pm 0.07_{\text{exp}}^{+0.37}_{-0.32 \text{ theo}}) \times 10^{-3} \text{ (LCSR}, q^2 < 12 \text{ GeV}^2).$$
(41)

Fits to the measured q^2 spectrum using a theoretically motivated parameterization (e.g. "BCL" from Ref. [146]) remove most of the model dependence from theoretical uncertainties in the shape of the spectrum. Recent determinations [26,141] of $|V_{ub}|$ from $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ decays have used simultaneous fits (see

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also Refs. [162]) to the experimental partial rate and lattice points versus q^2 . A fit [26] to the untagged measurements incorporates the full statistical and systematic uncertainties in the measured spectrum and uses four lattice points in the region $q^2 > 16 \, \text{GeV}^2$, taking into account their correlations. The fit, shown in Fig. 2, has $p(\chi^2) = 2.2\%$. If the tagged measurements, which are less consistent in the $q^2 < 8 \, \text{GeV}^2$ region, are included, the fit gives $p(\chi^2) < 0.01\%$. We quote the result from the untagged measurements and add the difference (0.09×10^{-3}) between the $|V_{ub}|$ values from the two fits as an additional uncertainty to find

$$|V_{ub}| = (3.23 \pm 0.31) \times 10^{-3}$$
 (exclusive). (42)

The largest contributions to the uncertainty come from lattice systematic and statistical errors, which will be further improved in the future.

Conclusion

The study of semileptonic B meson decays continues to be an active area for both theory and experiment. Substantial progress has been made in the application of HQE calculations to inclusive decays, where fits to moments of $\overline{B} \to X_c \ell \overline{\nu}_\ell$ decays provide precise values for $|V_{cb}|$ and, in conjunction with $B \to X_s \gamma$ decays or input on m_c , provide precise and consistent values for m_b . The values from the inclusive and exclusive $|V_{cb}|$ determinations are in reasonable agreement.

Continued improvements in measurements of inclusive $\overline{B} \to X_u \ell \overline{\nu}_\ell$ decays, along with additional theoretical studies of higher order contributions and improved knowledge of m_b , have strengthened our determination of $|V_{ub}|$. Further progress in this area is possible, but will require better theoretical control over higher order terms, and improved experimental knowledge of the $\overline{B} \to X_c \ell \overline{\nu}_\ell$ background.

Progress in both $b \to u$ and $b \to c$ exclusive channels depends crucially on progress in lattice calculations. Here the prospects are good, since unquenched calculations are now available for the semileptonic form factors discussed here, as well as for other hadronic weak matrix elements needed to obtain the elements and phase of the CKM matrix [163,164]. Projections for future uncertainties from lattice calculations can be found in Ref. [165].

The measurements of the $\overline{B} \to \pi \ell \overline{\nu}_{\ell}$ branching fraction have uncertainties below 4%, and the measured q^2 dependence is reasonably precise. Reducing the theoretical uncertainties to a comparable level will require significant effort, but is clearly vital.

The difference between the values for $|V_{ub}|$ obtained from inclusive and exclusive decays has persisted for many years, despite significant improvements in both theory and experiment for both methods. How to reconcile these results remains an intriguing puzzle.

Both $|V_{cb}|$ and $|V_{ub}|$ are indispensable inputs into unitarity triangle fits. In particular, knowing $|V_{ub}|$ with good precision allows a test of CKM unitarity in the most direct way, by

comparing the length of the $|V_{ub}|$ side of the unitarity triangle with the measurement of $\sin(2\beta)$. This comparison of a "tree" process $(b \to u)$ with a "loop-induced" process $(B^0 - \overline{B}^0)$ mixing) provides sensitivity to possible contributions from new physics. While the effort required to further improve our knowledge of these CKM matrix elements is large, it is well motivated.

The authors would like to acknowledge helpful input from C. Bozzi, J. Dingfelder, P. Gambino, A. Kronfeld, V. Luth, F. Muheim, C. Schwanda, P. Urquijo and R. Van de Water.

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Vcb MEASUREMENTS

For the discussion of $V_{\mathcal{C}\mathcal{D}}$ measurements, which is not repeated here, see the review on "Determination of $|V_{CD}|$ and $|V_{UD}|$."

The CKM matrix element $|V_{cb}|$ can be determined by studying the rate of the semileptonic decay $B o D^{(*)} \ell
u$ as a function of the recoil kinematics of $D^{(*)}$ mesons. Taking advantage of theoretical constraints on the normalization and a linear ω dependence of the form factors $(F(\omega),~G(\omega))$ provided by Heavy Quark Effective Theory (HQET), the $|V_{cb}| \times F(\omega)$ and $ho^2~(a^2)$ can be simultaneously extracted from data, where ω is the scalar product of the two-meson four velocities, F(1) is the form factor at zero recoil $(\omega=1)$ and ρ^2 is the slope, sometimes denoted as a^2 . Using the theoretical input of F(1), a value of $\left|V_{CD}\right|$ can be obtained.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements

$\left|V_{cb}\right|\times F(1) \; (\text{from} \; B^0 \to \; D^{*-}\ell^+\nu)$

TECN COMMENT DOCUMENT ID

0.03590 \pm 0.00045 OUR EVALUATION with ρ^2 =1.207 \pm 0.026 and a correlation 0.32. The fitted χ^2 is 29.7 for 23 degrees of freedom.

0.0360 ±0.0009 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram

| $0.0346 \pm 0.0002 \pm 0.0010$ | 1 | DUNGEL | 10 | BELL | $e^+e^- \rightarrow \Upsilon(4S)$ |
|--------------------------------------------------|----------|-----------------|--------|------------|-----------------------------------|
| $0.0359 \pm 0.0002 \pm 0.0012$ | 2 | AUBERT | 09A | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.0359 \pm 0.0006 \pm 0.0014$ | 3 | AUBERT | 08AT | BABR | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.0392 \pm 0.0018 \pm 0.0023$ | 4 | ABDALLAH | 04D | DLPH | $e^+e^- \rightarrow Z^0$ |
| $0.0431 \pm 0.0013 \pm 0.0018$ | 5 | ADAM | 03 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.0355 \ \pm 0.0014 \ ^{+ 0.0023}_{- 0.0024}$ | 6 | ABREU | 01н | DLPH | $e^+ e^- \rightarrow Z$ |
| $0.0371 \pm 0.0010 \pm 0.0020$ | 7 | ABBIENDI | 00Q | OPAL | $e^+e^- \rightarrow Z$ |
| $0.0319 \pm 0.0018 \pm 0.0019$ | 8 | BUSKULIC | 97 | ALEP | $e^+ e^- \rightarrow Z$ |
| ullet $ullet$ We do not use the f | ollowing | data for averag | es, fi | ts, limits | s, etc. • • • |
| $0.0344 \pm 0.0003 \pm 0.0011$ | 9 | AUBERT | 08R | BABR | Repl. by AUBERT 09A |
| $0.0355 \pm 0.0003 \pm 0.0016$ | 10 | AUBERT | 05 E | BABR | Repl. by AUBERT 08R |
| $0.0377 \pm 0.0011 \pm 0.0019$ | | ABDALLAH | 04D | DLPH | $e^+e^- \rightarrow Z^0$ |
| $0.0354 \pm 0.0019 \pm 0.0018$ | | ABE | 02F | BELL | Repl. by DUNGEL 10 |
| $0.0431\ \pm0.0013\ \pm0.0018$ | 13 | BRIERE | 02 | CLE2 | $e^+e^- \rightarrow \Upsilon(4S)$ |
| $0.0328 \pm 0.0019 \pm 0.0022$ | | ACKERSTAFF | 97G | OPAL | Repl. by ABBIENDI 00Q |
| $0.0350 \pm 0.0019 \pm 0.0023$ | | ABREU | 96P | DLPH | Repl. by ABREU 01H |
| $0.0351 \pm 0.0019 \pm 0.0020$ | 15 | BARISH | 95 | CLE2 | Repl. by ADAM 03 |
| $0.0314 \pm 0.0023 \pm 0.0025$ | | BUSKULIC | 95 N | ALEP | Repl. by BUSKULIC 97 |
| | | | | | |

¹ Uses fully reconstructed $D^{*-}\ell^+\nu$ events $(\ell=e \text{ or } \mu)$.

² Obtained from a global fit to $B \to D^{(*)}\ell\nu_\ell$ events, with reconstructed $D^0\ell$ and $D^+\ell$ final states and $ho^2=1.22\pm0.02\pm0.07$.

 3 Measured using the dependence of $B^- o D^{*0} e^- \overline{
u}_e$ decay differential rate and the form factor description by CAPRINI 98 with $ho^2=1.16\pm0.06\pm0.08$.

 4 Measurement using fully reconstructed D^* sample with a $\rho^2=1.32\pm0.15\pm0.33$. 5 Average of the $B^0\to \ D^*(2010)^-\ell^+\nu$ and $B^+\to \ \overline{D}^*(2007))\,\ell^+\nu$ modes with $\rho^2=1.61\pm0.09\pm0.21$ and $f_{+-}=0.521\pm0.012$.

 6 ABREU 01H measured using about 5000 partial reconstructed D^* sample with a $ho^2 = 1.34 \pm 0.14 ^{+~0.24}_{-~0.22}$

 7 ABBIENDI 00Q: measured using both inclusively and exclusively reconstructed $D^{*\pm}$ samples with a ρ^2 =1.21 \pm 0.12 \pm 0.20. The statistical and systematic correlations between $|V_{cb}| \times F(1)$ and ρ^2 are 0.90 and 0.54 respectively.

 8 BUSKULIC 97: measured using exclusively reconstructed $D^{*\pm}$ with a a^2 =0.31 \pm 0.17 \pm

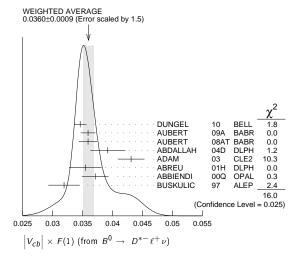
 $_{0}$ 0.08. The statistical correlation is 0.92. $_{0}^{9}$ Measured using fully reconstructed D^{\ast} sample and a simultaneous fit to the Caprini-Lellouch-Neubert form factor parameters: $\rho^2=1.191\pm0.048\pm0.028$, $R_1(1)=1.429\pm0.061\pm0.044$, and $R_2(1)=0.827\pm0.038\pm0.022$.

10 Measurement using fully reconstructed D^* sample with a $\rho^2=1.29\pm0.03\pm0.27.$ 11 Combines with previous partial reconstructed D^* measurement with a $\rho^2=1.39\pm0.10\pm0.10$

10.35. The Measured using exclusive $B^0 \to D^*(892)^- e^+ \nu$ decays with $\rho^2 = 1.35 \pm 0.17 \pm 0.19$ and a correlation of 0.91. The SBRIERE 02 result is based on the same analysis and data sample reported in ADAM 03.

 14 ABREU 96P: measured using both inclusively and exclusively reconstructed $\mathit{D}^{*\pm}$ samples.

 15 BARISH 95: measured using both exclusive reconstructed $B^0 o D^{*-} \ell^+
u$ and $B^+ o$ $D^{*0}\ell^+\nu$ samples. They report their experiment's uncertainties $\pm 0.0019 \pm 0.0018 \pm 0.0008$, where the first error is statistical, the second is systematic, and the third is the uncertainty in the lifetimes. We combine the last two in quadrature.



$|V_{cb}| \times G(1) \text{ (from } B \rightarrow D^- \ell^+ \nu)$

DOCUMENT ID TECN COMMENT **0.04264 \pm 0.00153 OUR EVALUATION** with ρ^2 =1.186 \pm 0.054 and a correlation 0.83.

The fitted χ^2 is 0.5 for 8 degrees of freedom.

0.0421 ±0.0016 OUR AVERAGE 16 AUBERT $0.0423 \pm 0.0019 \pm 0.0014$ 10 BABR $e^+e^- \rightarrow \Upsilon(4S)$ 17 AUBERT 09A BABR $e^+e^- \rightarrow r(4S)$ $0.0431\ \pm0.0008\ \pm0.0023$ ¹⁸ ABE 02E BELL $e^+e^- \rightarrow \Upsilon(4S)$ $0.0411 \ \pm 0.0044 \ \pm 0.0052$ ¹⁹ BARTELT $0.0416 \pm 0.0047 \pm 0.0037$ 99 CLE2 $e^+e^- \rightarrow \Upsilon(4S)$ $^{20}\,\mathrm{BUSKULIC}$ $0.0278 \pm 0.0068 \pm 0.0065$ 97 ALEP $e^+e^- \rightarrow Z$

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

 $0.0337 \ \pm 0.0044 \ ^{+ \ 0.0072}_{- \ 0.0049}$ ²¹ ATHANAS 97 CLE2 Repl. by BARTELT 99

 16 Obtained from a fit to the combined $B o \, \overline{D} \ell^+
u_\ell$ sample in which a hadronic decay of

the second B meson is fully reconstructed and $\rho^2=1.20\pm0.09\pm0.04.$ 17 Obtained from a global fit to $B\to~D^{(*)}\ell\,\nu_\ell$ events, with reconstructed $D^0\,\ell$ and $D^+\,\ell$ final states and $ho^2=1.20\pm0.04\pm0.07$.

18 Using the missing energy and momentum to extract kinematic information about the undetected neutrino in the $B^0 \rightarrow D^- \ell^+ \nu$ decay.

¹⁹BARTELT 99: measured using both exclusive reconstructed $B^0 \to D^- \ell^+ \nu$ and $B^+ \to D^- \ell^+ \nu$ $D^0\ell^+
u$ samples.

 20 BUSKULIC 97: measured using exclusively reconstructed D^{\pm} with a $a^2 = -0.05 \pm 0.53 \pm 0.00$

0.38. The statistical correlation is 0.99. 21 ATHANAS 97: measured using both exclusive reconstructed $B^0 \to D^- \ell^+ \nu$ and $B^+ \to D^+ \ell^+ \nu$ $D^0\ell^+\nu$ samples with a ρ^2 =0.59 \pm 0.22 \pm 0.12 \pm 0.59. They report their experiment's uncertainties $\pm 0.0044 \pm 0.0048 ^{+0.0053}_{-0.0012}$, where the first error is statistical, the second is systematic, and the third is the uncertainty due to the form factor model variations. We combine the last two in quadrature.

Vub MEASUREMENTS

For the discussion of V_{ub} measurements, which is not repeated here, see the review on "Determination of $|V_{CD}|$ and $|V_{UD}|$."

The CKM matrix element $|V_{UD}|$ can be determined by studying the rate of the charmless semileptonic decay $b \to u \ell \nu$. The relevant branching ratio measurements based on exclusive and inclusive decays can be found in the B Listings, and are not repeated here.

Vcb and Vub CKM Matrix Elements REFERENCES

| AUBERT | 10 | PRL 104 011802 | B. Aubert et al. | (BABAR | Collab.) |
|------------|------|----------------|-------------------------------------|---------|----------|
| DUNGEL | 10 | PR D82 112007 | W. Dungel et al. | (BELLE | Collab.) |
| AUBERT | 09A | PR D79 012002 | B. Aubert et al. | (BABAR | Collab.) |
| AUBERT | 08AT | PRL 100 231803 | B. Aubert et al. | (BABAR | Collab.) |
| AUBERT | 08 R | PR D77 032002 | B. Aubert et al. | (BABAR | Collab.) |
| AUBERT | 05 E | PR D71 051502R | B. Aubert et al. | (BABAR | Collab.) |
| ABDALLAH | 04 D | EPJ C33 213 | J. Abdallah et al. | (DELPHI | Collab.) |
| ADAM | 03 | PR D67 032001 | N.E. Adam et al. | (CLEO | Collab.) |
| ABE | 02 E | PL B526 258 | K. Abe et al. | (BELLE | Collab.) |
| ABE | 02 F | PL B526 247 | K. Abe et al. | (BELLE | Collab.) |
| BRIERE | 02 | PRL 89 081803 | R. Briere et al. | (CLEO | Collab.) |
| ABREU | 01H | PL B510 55 | P. Abreu et al. | (DELPHI | Collab.) |
| ABBIENDI | 00 Q | PL B482 15 | G. Abbiendi et al. | (OPAL | Collab.) |
| BARTELT | 99 | PRL 82 3746 | J. Bartelt et al. | (CLEO | Collab.) |
| CAPRINI | 98 | NP B530 153 | I. Caprini, L. Lellouch, M. Neubert | (BCIP, | CERN) |
| ACKERSTAFF | 97 G | PL B395 128 | K. Ackerstaff et al. | (ÖPAL | Collab.) |
| ATHANAS | 97 | PRL 79 2208 | M. Athanas et al. | (CLEO | Collab.) |
| BUS KULIC | 97 | PL B395 373 | D. Buskulic et al. | (ALEPH | |
| ABREU | 96 P | ZPHY C71 539 | P. Abreu et al. | (DELPHI | Collab.) |
| BARISH | 95 | PR D51 1014 | B.C. Barish et al. | | Collab.) |
| BUS KULIC | 95 N | PL B359 236 | D. Buskulic et al. | (ÀLEPH | Collab.) |
| | | | | | |

 B^* , B_i^* (5732), B_1 (5721)⁰



$$I(J^P) = \frac{1}{2}(1^-)$$

 $\emph{I},\ \emph{J},\ \emph{P}$ need confirmation. Quantum numbers shown are quark-model predictions.

B* MASS

From mass difference below and the average of our B masses $(m_{B^\pm} + m_{B^0})/2.$

VALUE (MeV)

5325.2±0.4 OUR FIT

DO CUMENT ID

$m_{B*} - m_B$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|---------------|-------------------------|----------|---------|-------------------------------------------------|
| 45.78±0.35 OUR FIT | | | | | |
| 45.78±0.35 OUR AV | ERAGE | | | | |
| $46.2 \pm 0.3 \pm 0.8$ | | ¹ ACKERSTAFF | 97м | OPAL | $e^+ e^- \rightarrow Z$ |
| $45.3\ \pm0.35\pm0.87$ | 4227 | $^{ m 1}$ BUSKULIC | 96D | ALEP | E ^{ee} _{cm} = 88-94 GeV |
| $45.5\ \pm0.3\ \pm0.8$ | | ¹ ABREU | 95 R | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 46.3 ±1.9 | 1378 | | | | E ^{ee} _{cm} = 88-94 GeV |
| $46.4 \pm 0.3 \pm 0.8$ | | | | | $e^+ e^- \rightarrow \gamma X$ |
| 45.6 ±0.8 | | ² WU | 91 | CSB2 | $e^+e^- \rightarrow \gamma X$, $\gamma \ell X$ |
| 45.4 ±1.0 | | 3 LEE-FRANZII | VI 90 | CSB2 | $e^+e^- \rightarrow \gamma(5S)$ |
| ullet $ullet$ We do not use | the following | ng data for average | es, fits | limits, | etc. • • • |
| 52 ± 2 ± 4 | 1400 | ⁴ HAN | 85 | CUSB | $e^+ e^- ightarrow \gamma e X$ |
| 1 | | | | | |

 $^{^{1}}u$, d, s flavor averaged.

 $^{^4}$ HAN 85 is for $E_{\rm cm}=$ 10.6–11.2 GeV, giving an admixture of B^0 , B^+ , and $B_{\rm S}$.

| (m) | B*+ - | m _{B+}) |) – (| (m _{B*0} | - | m_{B^0} |
|-----|-------|-------------------|-------|-------------------|---|-----------|
|-----|-------|-------------------|-------|-------------------|---|-----------|

| VALUE (MeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------|-----|-------------|------|------|-----------------|
| <6 | 95 | ABREU | 95 R | DLPH | Eee = 88-94 GeV |

B* DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------|------------------------------|
| Γ ₁ | $B\gamma$ | dominant |

B* REFERENCES

| ACKERSTAFF | 97 M | ZPHY C74 413 | K. Ackerstaff et al. | (OPAL Collab.) |
|--------------|------|--------------|------------------------|-------------------------|
| BUSKULIC | 96 D | ZPHY C69 393 | D. Buskulic et al. | (ALEPH Collab.) |
| ABREU | 95 R | ZPHY C68 353 | P. Abreu et al. | (DELPHI Collab.) |
| A CCIARRI | 95 B | PL B345 589 | M. Acciarri et al. | ` (L3 Collab.) |
| AKERIB | 91 | PRL 67 1692 | D.S. Akerib et al. | (CLEO Collab.) |
| WU | 91 | PL B273 177 | Q.W. Wu et al. | (CÙSB II Collab.) |
| LEE-FRANZINI | 90 | PRL 65 2947 | J. Lee-Franzini et al. | (CUSB II Collab.) |
| HAN | 85 | PRL 55 36 | K. Han et al. | (COLU, LSÚ, MPIM, STON) |



$$I(J^P) = ?(?^?)$$

 $I, J, P \text{ need confirmation.}$

OMITTED FROM SUMMARY TABLE

Signal can be interpreted as stemming from several narrow and broad resonances. Needs confirmation.

B*(5732) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | TE | COMMENT | |
|--------------------------------------|----------------|-----------------------|---------------|--------------------------------------------------|-----|
| 5698± 8 OUR AVE | RAGE Error | includes scale fac | tor of 1.2 | <u>.</u> | |
| 5710 ± 20 | | ¹ AFFOLDER | 01F CI | DF $p\overline{p}$ at 1.8 TeV | |
| $5695 + 17 \\ -19$ | | ² BARATE | 98L A | EP $e^+e^- 	o Z$ | |
| $5704 \pm 4 \pm 10$ | 1944 | ³ BUSKULIC | 96D A | EP $E_{\rm cm}^{ee} = 88-94$ | GeV |
| $5732 \pm 5 \pm 20$ | 2157 | ABREU | 95B D | LPH <i>E</i> ^{ee} _{cm} = 88-94 | GeV |
| 5681 ± 11 | 1738 | AKERS | 95E O | PAL $E_{cm}^{ee} = 88-94$ | GeV |
| ● ● We do not us | e the followin | g data for average | es, fits, lir | nits, etc. • • • | |
| 5713± 2 | | ⁴ ACCIARRI | 99N L3 | $e^+e^- \rightarrow Z$ | |

¹ AFFOLDER 01F uses the reconstructed B meson through semileptonic decay channels. The fraction of light B mesons that are produced at L=1 B^{**} states is measured to be 0.28 + 0.06 + 0.03.

 2 BARATE 98L uses fully reconstructed B mesons to search for B^{**} production in the $B\,\pi^\pm$ system. In the framework of heavy quark symmetry (HQS), they also measured the mass of B_2^* to be $5739^{+1}_{-11}^{+1}^{-4}_{-4}$ MeV/c² and the relative production rate of B(b \rightarrow B_2^* \rightarrow $B^{(*)}_{-1}^{+1}\pi)B(b$ \rightarrow $B_{u,d}^{+})=(31\pm9^{+6}_{-5})\%$.

 3 Using $m_{B\,\pi} - m_B = 424 \pm 4 \pm 10$ MeV.

 4 ACCIARRI 99N uses inclusive reconstructed B mesons to search for B^{**} production in the $B^{(*)}\pi^\pm$ system. In the framework of HQET, they measured the mass of B_1^* and B_2^* to be $5670\pm10\pm13$ MeV and $5768\pm5\pm6$ with the $B(b\to B^{**})=(32\pm3\pm6)\times10^{-2}$. They also reported the evidence for the existence of an excited B-meson state or mixture of states in the region 5.9–6.0 GeV.

B*(5732) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|------|--------------|------|------|-------------------------------------------|
| 128±18 OUR AVE | RAGE | | | | |
| 145 ± 28 | 2157 | ABREU | 95 B | DLPH | E ^{ee} _{cm} = 88-94 GeV |
| 116 ± 24 | 1738 | AKERS | 95 E | OPAL | E ^{ee} _{cm} = 88-94 GeV |

B*(5732) DECAY MODES

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|------------|-----------------|--------------------------------------|
| Γ_1 | $B^*\pi + B\pi$ | dominant |
| Γ_2 | $B^*\pi(X)$ | [a] (85 ± 29) % |

[a] X refers to decay modes with or without additional accompanying decay particles.

B*(5732) BRANCHING RATIOS

X refers to decay modes with or without additional accompanying decay particles.

| $\Gamma(B^*\pi(X))/\Gamma_{total}$ | | | | | Γ_2/Γ |
|------------------------------------|--------------|-----|------|-----------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.85 + 0.26 \pm 0.12$ | ABBIENDI | 02E | OPAL | $e^+e^- ightarrow Z$ | |

B*(5732) REFERENCES

| ABBIENDI | 02 E | EPJ C23 437 | G. Abbiendi et al. | (OPAL Collab.) |
|-----------|------|---------------|--------------------|------------------|
| AFFOLDER | 01F | PR D64 072002 | T. Affolder et al. | `(CDF Collab.) |
| ACCIARRI | 99 N | PL B465 323 | M. Acciarri et al. | (L3 Collab.) |
| BARATE | 98 L | PL B425 215 | R. Barate et al. | (ALEPH Collab.) |
| BUS KULIC | 96 D | ZPHY C69 393 | D. Buskulic et al. | (ALEPH Collab.) |
| ABREU | 95 B | PL B345 598 | P. Abreu et al. | (DELPHI Collab.) |
| AKERS | 95 E | ZPHY C66 19 | R. Akers et al. | `(OPAL Collab.) |

 $B_1(5721)^0$

$$I(J^P) = \frac{1}{2}(1^+)$$
 Status: ***

I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

B1 (5721) MASS

OUR FIT uses m_{B^+} and $m_{B^0_1}-m_{B^+}$ to determine $m_{B_1(5721)^0}.$

5723.5 ± 2.0 OUR FIT Error includes scale factor of 1.1.

$m_{B_1^0} - m_{B^+}$

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------|--------------------------|--------------|-----------------------------|
| 444.3 ± 2.0 OUR FIT Error | includes scale factor of | | |
| 444.2±2.3 OUR AVERAGE | Error includes scale fa | ctor of 1.3. | |
| $446.2 + 1.9 + 1.0 \\ -2.1 - 1.2$ | $^{ m 1}$ aaltonen | 09D CDF | $p\overline{p}$ at 1.96 TeV |
| $441.5\pm 2.4\pm 1.3$ | ABAZOV | 07T D0 | p p at 1.96 TeV |
| 1 Observed in $B_1^0 	o B^{*+}$ | π^- | | |

B₁(5721)0 DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------|------------------------------|
| Γ ₁ | $B^{*+}\pi^-$ | dominant |

²These papers report E_{γ} in the B^* center of mass. The $m_{B^*}-m_B$ is 0.2 MeV higher. $E_{\rm cm}=10.61$ –10.7 GeV. Admixture of B^0 and B^+ mesons, but not B_s .

 $^{^3}$ LEE-FRANZINI 90 value is for an admixture of B^0 and B^+ . They measure 46.7 \pm 0.4 \pm 0.2 MeV for an admixture of B^0 , B^+ , and B_S , and use the shape of the photon line to separate the above value.

B₁(5721)⁰ BRANCHING RATIOS

| $\Gamma(B^{*+}\pi^{-})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|-------------------------------|--------------|--------------------|-----------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| dominant | AALTONEN | 09D | CDF | p p at 1.96 TeV | |
| dominant | ² ABAZOV | 07T | D0 | $p\overline{p}$ at 1.96 TeV | |
| 2 Observed in $B_1^0 	o B^{*+} \pi^{-1}$ | with $B^{*+} \rightarrow B^+$ | γ and | I B ⁺ → | $J/\psi\pi^+$ | |

B₁(5721) REFERENCES

 AALTONEN
 09D
 PRL 102 102003
 T. Aaltonen et al.
 (CDF Collab.

 ABAZOV
 07T
 PRL 99 172001
 V.M. Abazov et al.
 (D0 Collab.



 $I(J^P) = \frac{1}{2}(2^+)$ Status: *** I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

$B_2^*(5747)^0$ MASS

OUR FIT uses m_{B^+} , $m_{B^0_1}-m_{B^+}$, and $m_{B^{*0}_2}-m_{B^0_1}$ to determine $m_{B^*_2(5747)^0}$. The -0.659 correlation between statistical uncertainties of $m_{B^0_1}-m_{B^+}$ and $m_{B^{*0}_2}-m_{B^0_1}$ measurements reported by ABAZOV 07T is taken into account.

| VALUE (MeV) | DO CUMENT ID |
|----------------|-------------------------------------|
| 5743±5 OUR FIT | Error includes scale factor of 2.9. |

B₂*(5747)0 WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------------------------------------------------------|--------------|---------|----------------------------|
| $\begin{array}{c} 22.7 + 3.8 + 3.2 \\ 22.7 - 3.2 - 10.2 \end{array}$ | AALTONEN (| 09D CDF | p p at 1.96 TeV |

| $m_{B_{2}^{*0}}$ | - | $m_{B_1^0}$ |
|------------------|---|-------------|
|------------------|---|-------------|

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------------------------------|------------------------------------|-------------|-----------------------------|
| 19 ±6 OUR FIT Error inclu | ides scale factor of 3 | 3. 0. | |
| 19 ±6 OUR AVERAGE Err | or includes scale fac | tor of 2.8. | |
| $14.9 + 2.2 + 1.2 \\ -2.5 - 1.4$ | $^{ m 1}$ aaltonen | 09D CDF | p p at 1.96 TeV |
| $26.2 \pm 3.1 \pm 0.9$ | $^{ m 1}$ ABAZOV | 07T D0 | $p\overline{p}$ at 1.96 TeV |
| ¹ Observed in $B_2^{*0} \rightarrow B^{*+} \pi$ | $-$ and $B_2^{*0} \rightarrow B^+$ | π^- . | |

B*(5747)0 DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------|------------------------------|
| Γ ₁ | $B^+\pi^-$ | dominant |
| Γ_2 | $B^{*+}\pi^-$ | dominant |

B*(5747) BRANCHING RATIOS

| $\Gamma(B^+\pi^-)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|----------------------------------------------------------------------------|---------------------------|------------------|-----------|-------------------------------------|----------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| dominant | AALTONEN | 09D | CDF | $p\overline{p}$ at 1.96 TeV | |
| dominant | ABAZOV | 07T | D0 | p p at 1.96 TeV | |
| $\Gamma(B^{*+}\pi^-)/\Gamma_{\rm total}$ | | | | | Γ_2/Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| dominant | AALTONEN | 09D | CDF | $p\overline{p}$ at 1.96 TeV | |
| dominant | ABAZOV | 07T | D0 | $p\overline{p}$ at 1.96 TeV | |
| $\Gamma(B^{*+}\pi^-)/\Gamma(B^+\pi^-)$ | | | | | Γ_2/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $1.10 \pm 0.42 \pm 0.31$ | ² ABAZOV | 07T | D0 | $p\overline{p}$ at 1.96 TeV | |
| ² Converted from measured ra = $0.475 \pm 0.095 \pm 0.069$. | atio of R = B(B_2^{*0} | → B ³ | *+ \pi^-) | $/ B(B_2^{*0} \rightarrow B^{(*)})$ |)+ _{\pi} -) |

B*(5747)0 REFERENCES

 AALTONEN
 09D
 PRL 102 102003
 T. Aaltonen et al.
 (CDF Collab.)

 ABAZOV
 07T
 PRL 99 172001
 V.M. Abazov et al.
 (D0 Collab.)

BOTTOM, STRANGE MESONS $(B = \pm 1, S = \mp 1)$

 $B_s^0 = s\overline{b}, \overline{B}_s^0 = \overline{s}b,$ similarly for B_s^* 's



$$I(J^P) = 0(0^-)$$

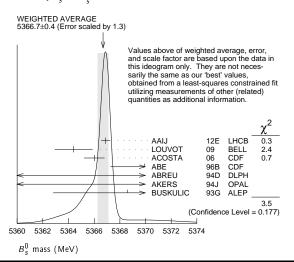
I, J, P need confirmation. Quantum numbers shown are quarkmodel predictions.

BO MASS

| VALUE (MeV) | VTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------|----------|---------------------|---------|--------------|----------------------------------|
| 5366.77 ± 0.24 OUR FIT | | · | | | |
| 5366.7 ± 0.4 OUR AVE | RAGE | | ile fac | tor of 1.3 | . See the ideogram |
| $5366.90 \pm\ 0.28 \pm 0.23$ | | ¹ AAIJ | 12E | LHCB | pp at 7 TeV |
| $5364.4 \pm 1.3 \pm 0.7$ | | LOUVOT | 09 | BELL | $e^+ e^- \rightarrow \gamma(5S)$ |
| $5366.01 \pm 0.73 \pm 0.33$ | | ² ACOSTA | 06 | CDF | p p at 1.96 TeV |
| $5369.9 \pm 2.3 \pm 1.3$ | 32 | ³ ABE | 96B | CDF | p p at 1.8 TeV |
| 5374 ± 16 ± 2 | 3 | ABREU | 94D | DLPH | $e^+ e^- \rightarrow Z$ |
| 5359 ±19 ±7 | 1 | ³ AKERS | 94J | OPAL | $e^+ e^- \rightarrow Z$ |
| $5368.6 \pm 5.6 \pm 1.5$ | 2 | BUSKULIC | 93G | ALEP | $e^+ e^- \rightarrow Z$ |
| ullet $ullet$ $ullet$ We do not use the | followin | g data for average | s, fits | , limits, et | .c. • • • |
| 5370 \pm 1 \pm 3 | | DRUTSKOY | 07A | BELL | Repl. by LOUVOT 09 |
| 5370 ±40 | 6 | ⁴ AKERS | 94J | OPAL | $e^+ e^- \rightarrow Z$ |
| $5383.3 \pm 4.5 \pm 5.0$ | 14 | ABE | 93F | CDF | Repl. by ABE 96B |

¹Uses $B_s^0 \rightarrow J/\psi \phi$ fully reconstructed decays.

⁴ From the decay $B_S \rightarrow D_S^- \pi^+$



$m_{B_c^0} - m_B$

 m_B is the average of our B masses $(m_{B^\pm} + m_{B^0})/2$.

| | | | _ | | |
|-------------------------------|----------------------|---------------------|-----------|----------|-------------------------------------------|
| VALUE (MeV) | CL% | DO CUMENT IL |) | TECN | COMMENT |
| 87.35 ± 0.23 OUR FI | т — | | | | |
| 87.34 ± 0.29 OUR A | VERAGE | | | | |
| $87.42 \pm 0.30 \pm 0.09$ | | ¹ AAIJ | 12E | LHCB | ρρ at 7 TeV ρ ρ at 1.96 TeV |
| $86.64 \pm 0.80 \pm 0.08$ | | ² ACOSTA | 06 | CDF | $p\overline{p}$ at 1.96 TeV |
| • • • We use the fo | ollowing data f | or averages but | not for | fits. • | • • |
| 89.7 ±2.7 ±1.2 | | ABE | 96B | CDF | $p\overline{p}$ at 1.8 TeV |
| | e the following | data for averag | ges, fits | limits, | etc. • • • |
| 80 to 130 | 68 | LEE-FRANZ | INI 90 | CSB2 | $e^+ e^- \rightarrow \gamma(5S)$ |
| $^{ m 1}$ The reported res | ult is $m_{B_s^0}$ – | $m_{B^+} = 87.52$ | ± 0.30 : | ± 0.12 M | MeV. We convert it to the |
| mass difference v | | | | | |
| ² The reported res | ult is m_{D0} — | $m_{D0} = 86.38$ | ± 0.90 : | ± 0.06 № | MeV. We convert it to the |
| mass difference v | | | | | |

$m_{B_{sH}^0} - m_{B_{sL}^0}$

See the $B_S^0 - \overline{B}_S^0$ MIXING section near the end of these B_S^0 Listings.

BO MEAN LIFE

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors.

First "OUR EVALUATION" is an average of 1 / [0.5 ($\Gamma_{B^0_{sL}} + \Gamma_{B^0_{sH}}$)]. The Second "OUR EVALUATION" is the average of $B_s \xrightarrow{} D_s X$ data

| VALUE (10 ⁻¹² | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|--------------------|-------------|-----------------------------------|-------------|-----------|------------------------------|
| 1.497±0.01 | | | | | | |
| 1.466±0.03 1.518±0.04 | | | l Second ¹ AALTONEN | 11 40 | CDF | p p at 1.96 TeV |
| | | | ² ABAZOV | | | • • |
| 1.398±0.04 | | | | 06∨ | DU | $p\overline{p}$ at 1.96 TeV |
| $1.42 \begin{array}{l} +0.14 \\ -0.13 \end{array}$ | ±0.03 | | ³ ABREU | 00Y | DLPH | $e^+e^- \rightarrow Z$ |
| $1.53 \begin{array}{l} +0.16 \\ -0.15 \end{array}$ | ±0.07 | | ⁴ ABREU,P | 00 G | DLPH | $e^+e^-\to~Z$ |
| 1.36 ±0.09 | $^{+0.06}_{-0.05}$ | | ⁵ ABE | 99D | CDF | $p\overline{p}$ at 1.8 TeV |
| $1.72 \begin{array}{l} +0.20 \\ -0.19 \end{array}$ | $^{+0.18}_{-0.17}$ | | ⁶ ACKERSTAFF | 98F | OPAL | $e^+e^- \rightarrow Z$ |
| $1.50 \begin{array}{l} +0.16 \\ -0.15 \end{array}$ | ±0.04 | | ⁵ ACKERSTAFF | 98 G | OPAL | $e^+e^-\to~Z$ |
| 1.47 ±0.14 | | | ⁴ BARATE | 98c | ALEP | $e^+e^- \rightarrow Z$ |
| $1.54 \begin{array}{l} +0.14 \\ -0.13 \end{array}$ | ±0.04 | | ⁵ BUSKULIC | 96м | ALEP | $e^+e^- ightarrow Z$ |
| | | he followin | g data for averag | es, fit | s, limits | , etc. • • • |
| 1.51 ±0.11 | | | ⁷ BARATE | 98c | ALEP | $e^+e^- ightarrow Z$ |
| $1.56 \begin{array}{l} +0.29 \\ -0.26 \end{array}$ | $^{+0.08}_{-0.07}$ | | ⁵ ABREU | 96F | DLPH | Repl. by ABREU 00Y |
| $1.65 \begin{array}{l} +0.34 \\ -0.31 \end{array}$ | ±0.12 | | ⁴ ABREU | 96F | DLPH | Repl. by ABREU 00Y |
| 1.76 ±0.20 | $^{+0.15}_{-0.10}$ | | ⁸ ABREU | 96F | DLPH | Repl. by ABREU 00Y |
| 1.60 ±0.26 | $^{+0.13}_{-0.15}$ | | ⁹ ABREU | 96F | DLPH | Repl. by ABREU,P 000 |
| 1.67 ± 0.14 | | 1 | ⁰ ABREU | 96F | DLPH | $e^+e^- \rightarrow Z$ |
| $1.61 \begin{array}{l} +0.30 \\ -0.29 \end{array}$ | $^{+0.18}_{-0.16}$ | 90 | ⁴ BUSKULIC | 96E | ALEP | Repl. by BARATE 980 |
| $1.42 \begin{array}{l} +0.27 \\ -0.23 \end{array}$ | ±0.11 | 76 | ⁵ ABE | 95 R | CDF | Repl. by ABE 99D |
| $1.74 \begin{array}{l} +1.08 \\ -0.69 \end{array}$ | ±0.07 | 8 1 | ¹ ABE | 95 R | CDF | Sup. by ABE 96N |
| $1.54 \begin{array}{l} +0.25 \\ -0.21 \end{array}$ | ±0.06 | 79 | ⁵ AKERS | 95 G | OPAL | Repl. by ACKER- STAFF 986 |
| $1.59 \begin{array}{l} +0.17 \\ -0.15 \end{array}$ | ±0.03 | 134 | ⁵ BUSKULIC | 95 o | ALEP | Sup. by BUSKULIC 96 |
| 0.96 ±0.37 | | 41 1 | ² ABREU | 94 E | DLPH | Sup. by ABREU 96F |
| $1.92 \begin{array}{l} +0.45 \\ -0.35 \end{array}$ | ±0.04 | 31 | ⁵ BUSKULIC | 94 c | ALEP | Sup. by BUSKULIC 95 |
| $1.13 \begin{array}{c} +0.35 \\ -0.26 \end{array}$ | ± 0.09 | 22 | ⁵ ACTON | 93н | OPAL | Sup. by AKERS 95G |

 $^{^1}$ AALTONEN 11AP combines the fully reconstructed $B_s^0
ightarrow D_s^- \pi^+$ decays and partially reconstructed $B_s^0 \rightarrow D_s X$ decays.

ı

B_s MEAN LIFE (Flavor specific)

| <u>VALUE (10⁻¹² s)</u> 1.463±0.032 OUR EVALUATION | DO CUMENT ID | | <u>TECN</u> | COMMENT | - |
|------------------------------------------------------------------------|---------------------|------|-------------|-----------------------------|---|
| 1.456±0.031 OUR AVERAGE | | | | | |
| $1.518 \pm 0.041 \pm 0.027$ | $^{ m 1}$ aaltonen | 11AP | CDF | $p\overline{p}$ at 1.96 TeV | |
| $1.398 \pm 0.044 ^{+ 0.028}_{- 0.025}$ | ² ABAZOV | 06∨ | D0 | $p\overline{p}$ at 1.96 TeV | |
| $1.42 \begin{array}{c} +0.14 \\ -0.13 \end{array} \pm 0.03$ | ³ ABREU | 00Y | DLPH | $e^+e^- \rightarrow Z$ | |

 $^{^2}$ Uses exclusively reconstructed final states containing a $J/\psi \to ~\mu^+\,\mu^-$ decays.

 $^{^3\,{\}rm From}$ the decay $B_S^{}\,\rightarrow\,J/\psi(1S)\,\phi.$

² Measured using $D_S \mu^+$ vertices.

³Uses $D_s^-\ell^+$, and $\phi\ell^+$ vertices.

 $^{^{4}}$ Measured using D_{S} hadron vertices.

⁵ Measured using $D_s^-\ell^+$ vertices.

 $^{^6}$ ACKERSTAFF 98F use fully reconstructed $D_S^- o \phi \pi^-$ and $D_S^- o K^{*0} \, K^-$ in the inclusive B_s^0 decay.

⁷ Combined results from $D_s^-\ell^+$ and D_s hadron.

 $^{^8}$ Measured using $\phi\ell$ vertices.

⁹ Measured using inclusive D_S vertices.

 $^{^{10}}$ Combined result for the four ABREU 96F methods. 11 Exclusive reconstruction of $B_S \to ~\psi \, \phi$

 $^{^{12} \}rm ABREU$ 94c uses the flight-distance distribution of D_S vertices, ϕ -lepton vertices, and $D_S \, \mu$ vertices.

| $1.36 \pm 0.09 ^{+ 0.06}_{- 0.05}$ | ⁴ ABE | 99D | CDF | $p\overline{p}$ at 1.8 TeV |
|--------------------------------------|-------------------------|-----|------|----------------------------|
| $1.50 \ ^{+0.16}_{-0.15} \ \pm 0.04$ | ⁴ ACKERSTAFF | 98G | OPAL | $e^+e^- \to ~Z$ |
| $1.54 \ ^{+0.14}_{-0.13} \ \pm 0.04$ | ⁴ BUSKULIC | 96м | ALEP | $e^+e^- ightarrow ~Z$ |

- 1 AALTONEN 11AP combines the fully reconstructed $B_s^0\to D_s^-\pi^+$ decays and partially reconstructed $B_s^0\to D_s^-X$ decays.
- ² Measured using $D_s^- \mu^+$ vertices.
- 3 Uses $D_s^-\ell^+$, and $^3\ell^+$ vertices.
- ⁴ Measured using $D_s^-\ell^+$ vertices.

B_s^0 MEAN LIFE $(B_S \rightarrow J/\psi \phi)$

| VALUE (10 ⁻¹² s) | DO CUMENT IE |) | TECN | COMMENT | |
|-----------------------------------------------------------------------------------------|---------------------|----------|----------|-----------------------------------------|--|
| 1.429±0.088 OUR EVALU | JATION | | | | |
| 1.42 +0.08 OUR AVER | AGE | | | | |
| $1.444 + 0.098 \pm 0.020$ | ¹ ABAZOV | 05в | D0 | p p at 1.96 TeV | |
| $1.40 \ ^{+ 0.15}_{- 0.13} \ \pm 0.02$ | ² ACOSTA | 05 | CDF | ρ p at 1.96 TeV | |
| $1.34 \ ^{+ 0.23}_{- 0.19} \ \pm 0.05$ | ² ABE | 98в | CDF | ρ p at 1.8 TeV | |
| • • • We do not use the | following data for | average | s, fits, | limits, etc. • • • | |
| $1.39 \ ^{+ 0.13}_{- 0.16} \ ^{+ 0.01}_{- 0.02}$ | ² ABAZOV | 05W | D0 | $p\overline{p}$ at 1.96 TeV | |
| $1.34 \begin{array}{l} +0.23 \\ -0.19 \end{array} \pm 0.05$ | ³ ABE | 96N | CDF | Repl. by ABE 98B | |
| 1 Measured using fully reconstructed $B_{_S} ightarrow \; J/\psi(1S) \phi$ decays. | | | | | |
| ² Measured using the tir | ne-dependent angu | ılar ana | lysis of | $B_s^0 \rightarrow J/\psi \phi$ decays. | |
| 3 ABE 96N uses 58 \pm 12 | | | | | |

$au_{B_c^0}/ au_{B^0}$ MEAN LIFE RATIO

$au_{B^0_-}/ au_{B^0}$ (direct measurements)

| VALUE | DO CUMENT IE | TECN | COMMENT | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|-------------------------------------------|-----------------------------------|--|--|
| $1.052 \pm 0.061 \pm 0.015$ | | | $p\overline{p}$ at 1.96 TeV | | |
| • • • We do not use the foll | owing data for averag | es, fits, limits | , etc. • • • | | |
| $0.980 {}^{+ 0.076}_{- 0.071} {}^{\pm 0.003}$ | ² ABAZOV | 05B D0 | Repl. by ABAZOV 05 w | | |
| $0.91\ \pm0.09\ \pm0.003$ | ³ ABAZOV | 05w D0 | Repl. by ABAZOV 09E | | |
| 1 Measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^0\to J/\psiK^{*0}$ and $B_s^0\to J/\psi\phi.$ | | | | | |
| ² Measured mean life ratio ³ Measured using the time- | using fully reconstruc dependent angular an | ted decays. alysis of $B_{_{S}}^{0}$ - | $ ightarrow$ $J/\psi\phi$ decays. | | |

Bo MEAN LIFE

 B_{sH}^{0} is the heavy mass state of two B_{s}^{0} CP eigenstates.

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) using the constraint of the flavor-specific lifetime average in a way similar to $\Delta\Gamma_{B^0}/\Gamma_{B^0_0}$.

TECN COMMENT

DOCUMENT ID

| 1.618±0.024 OUR EVALU | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|------------------|-----------------------------|--|
| | $^{ m 1}$ aaltonen | 12D CDF | $p\overline{p}$ at 1.96 TeV | |
| $1.70 \begin{array}{l} +0.12 \\ -0.11 \end{array} \pm 0.03$ | ² AALTONEN | 11AB CDF | $p\overline{p}$ at 1.96 TeV | |
| • • • We do not use the t | ollowing data for ave | rages, fits, lim | its, etc. • • • | |
| $1.613 {}^{+ 0.123}_{- 0.113}$ | ^{3,4} AALTONEN | 08J CDF | Repl. by AALTONEN 12D | |
| $1.58 \ \begin{array}{c} +0.39 \\ -0.42 \end{array} \begin{array}{c} +0.01 \\ -0.02 \end{array}$ | ⁴ ABAZOV | 05w D0 | Repl. by ABAZOV 08AM | |
| $2.07 \ ^{+0.58}_{-0.46} \ \pm 0.03$ | ⁴ A COSTA | 05 CDF | Repl. by AALTONEN 08J | |
| 1 Uses the time-dependent angular analysis of $B_S^{0}\to J/\psi\phi$ decays and assuming CP-violating angle $\beta_S(B^{0}\to J/\psi\phi)=0.02.$ | | | | |
| 2 Measured using $J/\psi f_0(980)$, a pure $C\!P$ odd final state. | | | | |
| 3 Obtained from $\Delta\Gamma_s$ and Γ_s fit with a correlation of 0.6. | | | | |
| 4 Measured using the time-dependent angular analysis of $B_{ m S}^0 ightarrow J/\psi \phi$ decays. | | | | |
| | | | , | |

Bo MEAN LIFE

 $B_{sL}^{\,0}$ is the light mass state of two $B_{\,s}^{\,0}$ CP eigenstates.

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) using the constraint of the flavor-specific lifetime average in a way similar to $\Delta\Gamma_{B_{S}^{0}}/\Gamma_{B_{S}^{0}}$.

| VALUE (10 ⁻¹² s) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------|-----------------------|-----|------|-----------------------------|
| 1.393±0.019 OUR EVALUATION | ON | | | |
| $1.440 \pm 0.096 \pm 0.009$ | 1 AAIJ | 12 | LHCB | pp at 7 TeV |
| | ² AALTONEN | 12D | CDF | $p\overline{p}$ at 1.96 TeV |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| $1.437 + 0.054 \\ -0.047$ | 3,4 AALTONEN | 08J CDF | Repl. by AALTONEN 12D |
|------------------------------------------------------------------------------------------------|---------------------|----------|-------------------------|
| $1.24 \begin{array}{l} +0.14 \\ -0.11 \end{array} \begin{array}{l} +0.01 \\ -0.02 \end{array}$ | ⁴ ABAZOV | 05w D0 | Repl. by ABAZOV 08AM |
| $1.05 \ ^{+0.16}_{-0.13} \ \pm 0.02$ | ⁴ ACOSTA | 05 CDF | Repl. by AALTONEN 08J |
| $1.27 \pm 0.33 \pm 0.08$ | ⁵ BARATE | 00k ALEP | $e^+ e^- \rightarrow Z$ |

 1 Measured using decays $B_{s}^{\,0} \rightarrow K^{+}K^{-}$.

- ² Uses the time-dependent angular analysis of $B_s^0 \to J/\psi \phi$ decays and assuming *CP*-violating angle $\beta_s(B^0 \to J/\psi \phi) = 0.02$.
- 3 Obtained from $\Delta\Gamma_s$ and Γ_s fit with a correlation of 0.6.
- 4 Measured using the time-dependent angular analysis of $B_{\,\rm S}^{\,0} \to \, J/\psi\,\phi$ decays.
- ⁵ Uses $\phi \phi$ correlations from $B_S^0 \to D_S^{(*)+} D_S^{(*)-}$.

$\Delta \Gamma_{B_c^0}/\Gamma_{B_c^0}$

 $\Gamma_{B^0_s}$ and $\Delta\Gamma_{B^0_s}$ are the decay rate average and difference between two B^0_s CP eigenstates (light — heavy).

"OUR EVALUATION" is an average of all available B_S flavor-specific lifetime measurements with the $\Delta\Gamma_{B_2^0}/\Gamma_S$ analyses performed by the Heavy

Flavor Averaging Group (HFAG) as described in our "Review on B- \overline{B} Mixing" in the B^0 Section of these Listings.

| VALUE | <u>L%_ DOCUMENT ID</u> | | TECN | COMMENT |
|-------------------------|-------------------------|-------|------------|-----------------------------|
| 0.150±0.020 OUR EV | LUATION | | | |
| | ¹ AAIJ | 12D | LHCB | pp at 7 TeV |
| | ² AALTONEN | 12D | CDF | $p\overline{p}$ at 1.96 TeV |
| | ³ ABAZOV | 12D | D0 | $p\overline{p}$ at 1.96 TeV |
| • • • We do not use the | following data for aver | ages, | fits, limi | ts, etc. • • • |

| $0.147 { + 0.036 + 0.042 \atop - 0.030 - 0.041 }$ | ⁴ ESEN | 10 BELL | $e^+ e^- \rightarrow \Upsilon(5S)$ |
|----------------------------------------------------|------------------------|----------|------------------------------------|
| $0.116^{+0.09}_{-0.10}\ \pm 0.010$ | ⁵ AALTONEN | 08J CDF | Repl. by AALTONEN 12D |
| $\substack{0.24 & +0.28 & +0.03 \\ -0.38 & -0.04}$ | ^{5,6} ABAZOV | 05w D0 | Repl. by ABAZOV 08AM |
| $0.65 \ ^{+ 0.25}_{- 0.33} \ \pm 0.01$ | ⁵ ACOSTA | 05 CDF | Repl. by AALTONEN 08J |
| < 0.46 95 | | 00Y DLPH | $e^+e^- \rightarrow Z$ |
| < 0.69 95 | ⁸ ABREU,P | 00G DLPH | $e^+ e^- \rightarrow Z$ |
| < 0.83 95 | | 99D CDF | ρ p at 1.8 TeV |
| < 0.67 95 | ¹⁰ ACCIARRI | 98s L3 | $e^+ e^- \rightarrow Z$ |
| 2 | | | |

 $^{-1}$ Measured using the time-dependent angular analysis of $B_{_S}^{\,0}
ightarrow \, J/\psi\,\phi$ decays.

 2 Uses the time-dependent angular analysis of $B_s^0 \to J/\psi \, \phi$ decays and assuming CP-violating angle $\beta_s(B^0 \to J/\psi \, \phi) = 0.02.$

 3 Measured using fully reconstructed $B_S \to J/\psi \, \phi$ decays.

⁴ Assumes *CP* violation is negligible.

 5 Measured using the time-dependent angular analysis of $B_s^0 \to J/\psi \phi$ decays.

 $^6\, \text{Uses} \, \left| \text{A}_{\,0} \right|^2 - \left| \text{A}_{\,\parallel} \right|^2 = 0.355 \, \pm \, 0.066 \, \, \text{from ACOSTA} \, \, 05.$

⁷Uses $D_s^-\ell^+$, and $\phi\ell^+$ vertices.

 8 Measured using D_S hadron vertices.

 9 ABE 99D assumes $\tau_{{\cal B}_c^0} = 1.55\,\pm\,0.05$ ps.

 10 ACCIARRI 98s assumes $\tau_{B_c^0} = 1.49 \pm 0.06$ ps and PDG 98 values of b production fraction.

$\Delta \Gamma_{R}$

"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) using the constraint of the flavor-specific lifetime average in a way similar to $\Delta\Gamma_{B_{0}^{0}}/\Gamma_{B_{0}^{0}}$.

| VALUE (10 ¹² s ⁻¹) | DO CUMENT ID | TECN | COMMENT |
|-------------------------------------------------------------|-------------------------|-----------------|-----------------------------|
| 0.100±0.013 OUR EVALU | ATION | | |
| 0.109±0.022 OUR AVERA | GE | | |
| $0.123 \pm 0.029 \pm 0.011$ | 1 aaij | 12D LHCE | 3 pp at 7 TeV |
| $0.075 \pm 0.035 \pm 0.006$ | ² AALTONEN | 12D CDF | $p\overline{p}$ at 1.96 TeV |
| $0.163 + 0.065 \\ -0.064$ | ^{3,4} ABAZOV | 12D D0 | $p\overline{p}$ at 1.96 TeV |
| ● ● We do not use the f | following data for aver | ages, fits, lin | nits, etc. • • • |
| $0.085 {}^{+ 0.072}_{- 0.078} \pm 0.001$ | ⁵ ABAZOV | 09E D0 | Repl. by ABAZOV 08AM |
| $0.076 {}^{+ 0.059}_{- 0.063} \pm 0.006$ | ⁶ AALTONEN | 08J CDF | Repl. by AALTONEN 12D |
| $0.19 \ \pm 0.07 \ ^{+ 0.02}_{- 0.01}$ | 4,7 ABAZOV | 08am D 0 | Repl. by ABAZOV 12D |
| $0.12 \ ^{+ 0.08}_{- 0.10} \ \pm 0.02$ | 6,8 ABAZOV | 07 D0 | Repl. by ABAZOV 07N |
| 0.13 ± 0.09 | ⁹ ABAZOV | 07N D0 | Repl. by ABAZOV 09E |
| $0.47 \begin{array}{c} +0.19 \\ -0.24 \end{array} \pm 0.01$ | ⁶ ACOSTA | 05 CDF | Repl. by AALTONEN 08J |

B_s^0

- 1 Measured using the time-dependent angular analysis of $B_{\,S}^{\,0} \rightarrow \,\, J/\psi\,\phi$ decays.
- 2 Uses the time-dependent angular analysis of B $^0_{\rm S} \rightarrow ~J/\psi \, \phi$ decays and assuming CPviolating angle $\beta_{\rm S}(B^0 \to J/\psi \phi) = 0.02$.
- $^3\,\mbox{The error includes}$ both statistical and systematic uncertainties.
- 4 Measured using fully reconstructed $B_{S}\,\rightarrow\,J/\psi\,\phi$ decays.
- Measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^0 \to J/\psi \, K^{*0}$ and $B_s^0 \to J/\psi \, \phi$.
- 6 Measured using the time-dependent angular analysis of $B_S^0
 ightarrow J/\psi\,\phi$ decays and assuming *CP*-violating phase $\phi_s=0.$ 7 Obtaines 90% CL interval $-0.06 < \Delta\Gamma_s < 0.30.$
- $^8\,\mathrm{ABAZOV}$ 07 reports 0.17 \pm 0.09 \pm 0.02 with $\mathit{CP}\text{-violating phase}$ $\phi_{_S}$ as a free parameter.
- 9 Combines D^0 measurements of time-dependent angular distributions in $B^0_s
 ightarrow J/\psi \phi$ and charge asymmetry in semileptonic decays. There is a 4-fold ambiguity in the solution.

$\Delta\Gamma_s^{CP} / \Gamma_s$

 Γ_s and $\Delta\Gamma_s^{CP}$ are the decay rate average and difference between even, $\Gamma_s^{CP-even}$, and odd, Γ_s^{CP-odd} , CP eigenstates.

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------------------|------------------|----------------------------------------------|---------|-----------|---------------------------------------------------------|
| • • • We do not use the | following | data for averages | , fits, | limits, e | etc. • • • |
| $\begin{array}{c} 0.072 \pm 0.021 \pm 0.022 \\ > 0.012 \end{array}$ | | ¹ ABAZOV ¹ AALTONEN | | | $p\overline{p}$ at 1.96 TeV $p\overline{p}$ at 1.96 TeV |
| $0.079^{+\ 0.038\ +\ 0.031}_{-\ 0.035\ -\ 0.030}$ | | ¹ ABAZOV | 07Y | D0 | Repl. by ABAZOV 091 |
| $0.25 \begin{array}{c} +0.21 \\ -0.14 \end{array}$ | | ² BARATE | 00K | ALEP | $e^+e^- ightarrow ~Z$ |
| 1 Accumes 2 B/B0 | $D^{(*)}D^{(*)}$ |) ~ ∧Γ <i>CP</i> / Γ | | | |

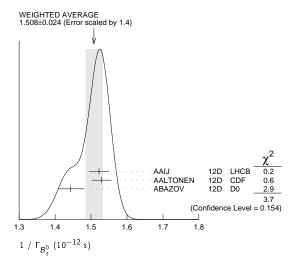
"OUR EVALUATION" has been obtained by the Heavy Flavor Averaging Group (HFAG) using the constraint of the flavor-specific lifetime average in a way similar to $\Delta\Gamma_{B_c^0}/\Gamma_{B_c^0}$.

| VALUE (10 ** S) | DOCUMENT ID | TECN | COMMENT |
|-------------------------------|-------------------------|------------------|------------------------------|
| 1.497±0.015 OUR EVALUAT | ION | | |
| 1.508±0.024 OUR AVERAGE | Error includes so | ale factor of 1 | L.4. See the ideogram below. |
| $1.522\pm0.021\pm0.019$ | ¹ AAIJ | | pp at 7 TeV |
| $1.529 \pm 0.025 \pm 0.012$ | ² AALTONEN | 12D CDF | $p\overline{p}$ at 1.96 TeV |
| $1.443 + 0.038 \\ -0.035$ | $^{2,3}\mathrm{ABAZOV}$ | 12D D0 | $p\overline{p}$ at 1.96 TeV |
| • • • We do not use the follo | owing data for aver | ages, fits, limi | ts. etc. • • • |

² ABAZOV 09E D0 $1.487 \pm 0.060 \pm 0.028$ Repl. by ABAZOV 08AM ² AALTONEN 08J CDF $1.52\ \pm0.04\ \pm0.02$ Repl. by AALTONEN 12D ² ABAZOV $1.52\ \pm0.05\ \pm0.01$ 08am D0 Repl. by ABAZOV 12D

- $^1\,\rm AAIJ~12D$ reports average deacy width of B_s^0 , $\Gamma_{B_s^0}=0.657\pm0.009\pm0.008~\rm ps^{-1}~that$ we converted to $1/\Gamma_{B_c^0}$
- ² Measured using the time-dependent angular analysis of $B_S^0 o J/\psi \phi$ decays.

 $^{^3\,\}mbox{The error includes both statistical and systematic uncertainties.}$



BO DECAY MODES

These branching fractions all scale with B($\overline{b} \to B_c^0$).

The branching fraction B(B $_S^0 \to D_S^- \ell^+ \nu_\ell$ anything) is not a pure measurement since the measured product branching fraction $B(\overline{b} \to B_s^0) \times$ $\mathsf{B}(B_s^0\to\ D_s^-\ell^+\nu_\ell \mathrm{anything}) \ \mathrm{was} \ \mathrm{used} \ \mathrm{to} \ \mathrm{determine} \ \mathsf{B}(\overline{b}\to\ B_s^0), \ \mathrm{as}$ described in the note on " $B^0-\overline{B}^0$ Mixing"

For inclusive branching fractions, e.g., $B\to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater

| | Mode | F | raction (| Γ _i /Γ) | Confidence | level |
|-----------------|-------------------------------------------------------------------------------------------------------------------|------|-----------|----------------------------------------|------------------|-------|
| Γ_1 | D_s^- anything | | (93 | ±25)% | | |
| Γ_2^- | $\ell \nu_{\ell} X$ | | | ± 2.7) % | | |
| Γ_3^- | $D_{s}^{-}\ell^{+}\nu_{\ell}$ anything | [a] | | ± 2.4) % | | |
| Γ_4 | $D_{s1}(2536)^- \mu^+ \nu_{\mu}$, | | (2.5 | ± 0.7) × 1 | 10 | |
| • | $D_{s1}^- \rightarrow D^{*-}K_S^0$ | | | | | |
| Γ ₅ | $D_{s1}(2536)^{-}X \mu^{+} \nu,$ $D_{s1}^{-} \rightarrow \overline{D}^{0} K^{+}$ | | (4.3 | ± 1.7) × 1 | 10-3 | |
| Γ ₆ | $D_{s1} \rightarrow D K$ $D_{s2}(2573)^{-} X \mu^{+} \nu$, $D_{s2}^{-} \rightarrow \overline{D}^{0} K^{+}$ | | (2.6 | ± 1.2) × 1 | 10-3 | |
| Γ_7 | | | (2 2 | | 3 | |
| | $D_s^- \pi^+$ | | | ± 0.4) × 1 | | |
| L ⁸ | $D_s^- \rho^+$ | | | ± 1.7) × 1 | | |
| Γ9 | $D_{s}^{-}\pi^{+}\pi^{+}\pi^{-}$ | | | ± 1.2) × 1 | | |
| Γ_{10} | $D_{s}^{\mp} K^{\pm}$ | | | ± 0.6)×1 | | |
| Γ_{11} | $D_s^+ D_s^-$ | | (5.3 | \pm 0.9) \times 3 | 10^{-3} | |
| Γ_{12} | $D_{s}^{*-}\pi^{+}$ | | (2.1 | \pm 0.6) \times 3 | 10-3 | |
| Γ_{13} | $D^{*-} \rho^{+}$ | | (1.03 | ± 0.26) % | | |
| Γ_{14} | $D_{s}^{*+}D_{s}^{-}+D_{s}^{*-}D_{s}^{+}$ | | (1.24 | ± 0.21) % | | |
| Γ ₁₅ | $D_{c}^{*+}D_{c}^{*-}$ | | (1.88 | ± 0.34) % | | |
| Γ ₁₆ | $D_{s}^{(*)+}D_{s}^{(*)-}$ | | (4.5 | ± 1.4) % | | |
| Γ ₁₇ | $\overline{D}^{0} \overline{K}^{*} (892)^{0}$ | | | ± 1.4)×1 | 10-4 | |
| | | | | | | |
| Γ ₁₈ | $J/\psi(1S)\phi$ | | | + 0.28 - 0.23) × | | |
| Γ ₁₉ | $J/\psi(1S)\pi^0$ | | < 1.2 | | 10-3 | 90% |
| Γ ₂₀ | $J/\psi(1S)\eta$ | | | + 1.3 - 1.0) × | | |
| Γ ₂₁ | $J/\psi(1S) K^0$ | | | ± 0.8)×1 | | |
| Γ ₂₂ | $J/\psi(1S)K^{*0}$ | | | ± 4)×1 | | |
| Γ ₂₃ | $J/\psi(1S)\eta'$ | | | + 1.0 - 0.9) × | | |
| Γ ₂₄ | $J/\psi(1S) f_0(980)$, $f_0 ightarrow$ | | | + 0.35 - 0.28) × 3 | | |
| Γ ₂₅ | $J/\psi(1S) f_0(1370), f_0 \rightarrow \pi^+ \pi^-$ | | | ± 1.4) × 1 | | |
| Γ ₂₆ | $\psi(2S)\phi$ | | (5.7 | + 1.8 - 1.6)×: | 10^{-4} | |
| Γ ₂₇ | $\pi^{+} \pi^{-}$ | | < 1.2 | | 10^{-6} | 90% |
| Γ ₂₈ | $\pi^{0} \pi^{0}$ | | < 2.1 | | 10-4 | 90% |
| Γ ₂₉ | $\eta\pi^0$ | | < 1.0 | | 10-3 | 90% |
| Γ ₃₀ | $\eta \eta$ | | < 1.5 | | ₁₀ -3 | 90% |
| Γ ₃₁ | $\rho^{0} \rho^{0}$ | | < 3.20 | | 10-4 | 90% |
| Γ ₃₂ | $\phi \rho^0$ | | < 6.17 | | 10^{-4} | 90% |
| Γ ₃₃ | $\phi\phi$ | | (1.9 | $^{+}_{-}$ $^{0.6}_{0.5}$) \times 3 | 10^{-5} | |
| Γ_{34} | $\pi^+ K^-$ | | (5.3 | ± 1.0) × 3 | 10^{-6} | |
| Γ ₃₅ | $K^+ K^-$ | | (2.64 | ± 0.28) × 1 | 10^{-5} | |
| Γ_{36} | $K^0\overline{K}^0$ | | < 6.6 | × | 10 ⁻⁵ | 90% |
| Γ ₃₇ | $\overline{K}^*(892)^0 \rho^0$ | | < 7.67 | | 10^{-4} | 90% |
| Γ ₃₈ | $\overline{K}^*(892)^0 K^*(892)^0$ | | | ± 0.7)×1 | 10-5 | |
| Γ ₃₉ | $\phi K^*(892)^0$ | | < 1.013 | | 10-3 | 90% |
| Γ ₄₀ | р <u></u> | | < 5.9 | | 10-5 | 90% |
| Γ ₄₁ | $\gamma \gamma$ | B1 - | < 8.7 | | 10-6 | 90% |
| Γ_{42} | $\phi\gamma$ | | (5.7 | + 2.2 - 1.9)× | 10 ⁻⁵ | |

Lepton Family number (LF) violating modes or $\Delta B = 1$ weak neutral current (B1) modes

| | | | (/ | | |
|---------------|---------------------------------|----|-------------|----------------------------------|-----|
| Γ_{43} | $\mu^+ \mu^-$ | В1 | < 6.4 | $\times 10^{-9}$ | 90% |
| Γ_{44} | $e^+ e^-$ | B1 | < 2.8 | $\times 10^{-7}$ | 90% |
| Γ_{45} | $e^{\pm}\mu^{\mp}$ | LF | [b] < 2.0 | $\times 10^{-7}$ | 90% |
| Γ_{46} | $\phi(\textrm{1020})\mu^+\mu^-$ | B1 | (1.23 $^+$ | $^{0.40}_{0.34}) \times 10^{-6}$ | |
| Γ_{47} | $\phi u \overline{ u}$ | B1 | < 5.4 | $\times 10^{-3}$ | 90% |

- [a] Not a pure measurement. See note at head of B_{ε}^{0} Decay Modes.
- [b] The value is for the sum of the charge states or particle/antiparticle states indicated.

CONSTRAINED FIT INFORMATION

An overall fit to 8 branching ratios uses 11 measurements and one constraint to determine 6 parameters. The overall fit has a $\chi^2 =$ 1.5 for 6 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

| <i>x</i> ₉ | 46 | | | |
|-------------------------------------------------------|----------------|----|-------------------------|------------------|
| <i>x</i> ₁₀ | 48 | 22 | | |
| x ₁₀ x ₁₈ x ₂₄ | 0 | 0 | 0 | |
| x ₂₄ | 0 | 0 | 0 | 94 |
| | X ₇ | Χq | <i>X</i> _{1.0} | X _{1.8} |

BO BRANCHING RATIOS

$\Gamma(D_s^- \text{ a nything})/\Gamma_{\text{total}}$

 Γ_1/Γ

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|-----------------------|-----|------|------------------------------------|
| 0.93±0.25 OUR AVE | RAGE | | | | |
| $0.91 \pm 0.18 \pm 0.41$ | | | 07 | BELL | $e^+ e^- \rightarrow \Upsilon(4S)$ |
| $0.81 \pm 0.24 \pm 0.22$ | 90 | ² BUSKULIC | 96E | ALEP | $e^+ e^- \rightarrow Z$ |
| $1.56 \pm 0.58 \pm 0.44$ | 147 | ³ ACTON | 92N | OPAL | $e^+ e^- \rightarrow Z$ |

 1 The extraction of this result takes into account the correlation between the measurements of B($\varUpsilon(5S)\to \ D_5X)$ and B($\varUpsilon(5S)\to \ D^0X).$

²BUSKULIC 96E separate $c\overline{c}$ and $b\overline{b}$ sources of D_s^+ mesons using a lifetime tag, subtract generic $\overline{b} \to W^+ \to D_S^+$ events, and obtain $B(\overline{b} \to B_S^0) \times B(B_S^0 \to D_S^-$ anything) = 0.088 ± 0.020 ± 0.020 assuming B($D_S \rightarrow \phi \pi$) = (3.5 ± 0.4) × 10⁻² and PDG 1934 values for the relative partial widths to other D_S channels. We evaluate using our current values B($\overline{b} \to B_S^0$) = 0.107 \pm 0.014 and B($D_S \to \phi \pi$) = 0.036 \pm 0.009. Our first error is their experiment's and our second error is that due to $B(\overline{b}\to B_s^0)$ and $B(D_s\to B_s^0)$ $\phi\pi$).

 3 ACTON 92N assume that excess of 147 \pm 48 D_s^0 events over that expected from B^0 , B^+ , and $c\,\overline{c}$ is all from B^0_S decay. The product branching fraction is measured to be $\mathsf{B}(\overline{b}\to \mathsf{B}_s^0)\mathsf{B}(\mathsf{B}_s^0\to \mathsf{D}_s^- \mathsf{anything})\times \mathsf{B}(\mathsf{D}_s^-\to \phi\pi^-) = (5.9\pm1.9\pm1.1)\times 10^{-3}.$ We evaluate using our current values B($\overline{b} \to B_s^0$) = 0.107 \pm 0.014 and B($D_s \to \phi \pi$) $= 0.036 \pm 0.009$. Our first error is their experiment's and our second error is that due to $B(\overline{b} \to B_s^0)$ and $B(D_s \to \phi \pi)$.

| $\Gamma(\ell u_{\ell} X) / \Gamma_{	ext{total}}$ | | | | | Γ_2/Γ |
|---------------------------------------------------|-------------------|-----|------|----------|-------------------|
| VALUE (units 10^{-2}) | DO CUMENT ID | | TECN | COMMENT | |
| $9.5 + 2.5 + 1.1 \\ -2.0 - 1.9$ | ¹ LEES | 12A | BABR | e^+e^- | |

 $^{1}\,\mathrm{The}$ measurement corresponds to a branching fraction where the lepton originates from bottom decay and is the average between the electron and muon branching fractions. LEES 12A uses the correlation of the production of ϕ mesons in association with a lepton in $e^+\,e^-$ data taken at center-of-mass energies between 10.54 and 11.2 GeV.

 $\Gamma(D_s^-\ell^+\nu_\ell \text{ anything})/\Gamma_{\text{total}}$

The values and averages in this section serve only to show what values result if one assumes our $\mathsf{B}(\overline{b} \to B_0^S)$. They cannot be thought of as measurements since the underlying product branching fractions were also used to determine $B(\overline{b} \to B_s^0)$ as described in the note on "Production and Decay of b-Flavored Hadrons."

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------------|-----------------------|-------------|-----------|--------------------------|
| 0.079±0.024 OUR AVE | RAGE | | | | |
| $0.076 \pm 0.012 \pm 0.021$ | 134 | $^{ m 1}$ BUSKULIC | 95 o | ALEP | $e^+ e^- \rightarrow Z$ |
| $0.107 \pm 0.043 \pm 0.029$ | | ² ABREU | 92M | DLPH | $e^+ e^- \rightarrow Z$ |
| $0.103 \pm 0.036 \pm 0.028$ | 18 | ³ ACTON | 92N | OPAL | $e^+ e^- \rightarrow Z$ |
| • • • We do not use th | e followir | ng data for average | es, fits, | , limits, | etc. • • • |
| $0.13 \pm 0.04 \pm 0.04$ | 27 | ⁴ BUSKULIC | 92E | ALEP | $e^+ e^- ightarrow Z$ |

 1 BUSKULIC 950 use $D_{_S}\ell$ correlations. The measured product branching ratio is B(\overline{b} ightarrow $B_S) imes {\sf B}(B_S o D_S^- \ell^+ \nu_\ell \, {\sf anything}) = (0.82 \pm 0.09 {+ 0.13 \atop - 0.14}) \% \, {\sf assuming} \, \, {\sf B}(D_S o \phi \pi)$ = $(3.5 \pm 0.4) \times 10^{-2}$ and PDG 1994 values for the relative partial widths to the six other D_S channels used in this analysis. Combined with results from $\varUpsilon(4S)$ experiments this can be used to extract B($\overline{b} \to B_S$) = (11.0 \pm 1.2 $^{+2.5}_{-2.6}$)%. We evaluate using our current values B($\overline{b} \to B_s^0$) = 0.107 \pm 0.014 and B($D_s \to \phi \pi$) = 0.036 \pm 0.009. Our first error is their experiment's and our second error is that due to B($\overline{b} \to B_c^0$) and

²ABREU 92M measured muons only and obtained product branching ratio B($Z \rightarrow b$ or $\overline{b}) \times \mathsf{B}(\overline{b} \to \ B_S) \times \mathsf{B}(B_S \to \ D_S \, \mu^+ \, \nu_\mu \, \mathsf{anything}) \times \mathsf{B}(D_S \to \ \phi \, \pi) = (18 \pm 8) \times 10^{-5}.$ We evaluate using our current values $B(\overline{b}\to B_s^0)=0.107\pm0.014$ and $B(D_s\to\phi\pi)=0.036\pm0.009$. Our first error is their experiment's and our second error is that due

to $B(\overline{b}\to B^0_s)$ and $B(D_s\to \phi\pi)$. We use $B(Z\to b\text{ or }\overline{b})=2B(Z\to b\overline{b})=$ $2 \times (0.2212 \pm 0.0019)$. 3 ACTON 92N is measured using $D_{_S}
ightarrow \phi \pi^+$ and $K^*(892)^0 \, K^+$ events. The product branching fraction measured is measured to be B($\overline{b} \to B_s^0$)B($B_s^0 \to D_s^- \ell^+ \nu_\ell$ anything)

 \times B $(D_c^- \to \phi \pi^-) = (3.9 \pm 1.1 \pm 0.8) \times 10^{-4}$. We evaluate using our current values $B(\overline{b} \to B_s^0) = 0.107 \pm 0.014$ and $B(D_S \to \phi \pi) = 0.036 \pm 0.009$. Our first error is their experiment's and our second error is that due to $B(\overline{b} \to B_s^0)$ and $B(D_s \to \phi \pi)$. 4 BUSKULIC 92E is measured using $D_S \to \phi \pi^+$ and $K^*(892)^0 K^+$ events. They use $2.7\pm0.7\%$ for the $\phi\pi^+$ branching fraction. The average product branching fraction is measured to be B($\overline{b}\to B_s^0$)B(B $_s^0\to D_s^-\ell^+\nu_\ell$ anything) =0.020 \pm 0.0055 $_-^0$ 0.006. We evaluate using our current values B($\overline{b}\to B_S^0$) = 0.107 \pm 0.014 and B($D_S\to\phi\pi$) = 0.036 \pm 0.009. Our first error is their experiment's and our second error is that due to $B(\overline{b} \to B_s^0)$ and $B(D_s \to \phi \pi)$. Superseded by BUSKULIC 95 o.

 $\Gamma(D_{s1}(2536)^-\mu^+\nu_{\mu},\ D_{s1}^- o D^{*-}K_S^0)/\Gamma_{total}$ Γ_4/Γ VALUE (units 10^{-3}) TECN COMMENT ¹ ABAZOV 09G D0 ρp at 1.96 TeV $2.5 \pm 0.7 \pm 0.1$

 $^1\,\mathrm{ABAZOV}$ 09G reports $[\Gamma(B_S^0\to\ D_{S1}(2536)^-\,\mu^+\,\nu_\mu,\ D_{S1}^-\to\ D^{*-}\,K_S^0)/\Gamma_{\mathrm{total}}]\,\times\,$ $[B(\overline{b} \to B_s^0)] = (2.66 \pm 0.52 \pm 0.45) \times 10^{-4}$ which we divide by our best value $B(\overline{b} \to B_s^0)$ B_s^0) = $(10.5 \pm 0.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(D_{s1}(2536)^- X \mu^+ \nu, D_{s1}^- \to \overline{D}{}^0 K^+) / \Gamma(D_s^- \ell^+ \nu_\ell \text{ anything})$ Γ_5/Γ_3 TECN COMMENT

11A LHCB pp at 7 TeV 5.4±1.2±0.5 AAIJ

 $\Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \rightarrow \overline{D}^0 K^+) / \Gamma(D_s^- \ell^+ \nu_\ell \text{ anything})$ Γ_6/Γ_3 DOCUMENT ID TECN COMMENT 11A LHCB pp at 7 TeV $3.3 \pm 1.0 \pm 0.4$

 $\Gamma(D_{s1}(2536)^- X \mu^+ \nu, D_{s1}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s2}^- \to \overline{D}{}^0 K^+) / \Gamma(D_{s2}(2573)^- X \mu^+ \nu, D_{s$ $\overline{D^0}K^+$ Γ_5/Γ_6 DO CUMENT ID TECN COMMENT

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet1 AAIJ $0.61 \pm 0.14 \pm 0.05$ 11A LHCB pp at 7 TeV

 $^{1}\,\mathrm{Not}$ independent of other AAIJ $11\mathrm{A}$ measurements

 Γ_7/Γ $\Gamma(D_s^-\pi^+)/\Gamma_{\text{total}}$ VALUE (units 10-3) DOCUMENT ID TECN COMMENT 3.2±0.4 OUR FIT

3.3±0.5 OUR AVERAGE

 $^{1}\,\mathrm{LOUVOT}$ $3.6 \pm 0.5 \pm 0.5$ 09 BELL $e^+e^- \rightarrow r(5.5)$ 2 ABULENCIA 07c CDF $p\overline{p}$ at 1.96 TeV $3.0 \pm 0.7 \pm 0.1$

• • We do not use the following data for averages, fits, limits, etc.

DRUTSKOY 07A BELL Repl. by LOUVOT 09 $6.8 \pm 2.2 \pm 1.6$ ³ ABULENCIA 06J CDF Repl. by ABULENCIA 07c ⁴ AKERS 94J OPAL $e^+\,e^ightarrow~Z$ <130 93G ALEP $e^+\,e^ightarrow~Z$ seen BUSKULIC

 $\begin{array}{l} ^{1}\text{LOUVOT 09 reports } (3.67^{+0.35}_{-0.33}^{+0.65}_{-0.645}) \times 10^{-3} \text{ from a measurement of } [\Gamma(\mathcal{B}_{5}^{0} \to \mathcal{D}_{s}^{-+})/\Gamma_{\text{total}}] \times [B(\varUpsilon(10860) \to \mathcal{B}_{s}^{(*)}\overline{\mathcal{B}_{s}^{(*)}})] \text{ assuming B} (\varUpsilon(10860) \to \mathcal{B}_{5}^{(*)}\overline{\mathcal{B}_{s}^{(*)}}) \\ \end{array}$ = $(19.5 \pm 2.6) \times 10^{-2}$, which we rescale to our best value B($\Upsilon(10860) \rightarrow B_s^{(*)} \overline{B}_s^{(*)}$) = $(19.9 \pm 3.0) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

²ABULENCIA 07c reports $[\Gamma(B_s^0 \rightarrow D_s^- \pi^+)/\Gamma_{total}]$ / $[B(B^0 \rightarrow D^- \pi^+)] = 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1.13 \pm 1$ 0.08 ± 0.23 which we multiply by our best value B(B $^0\to D^-\pi^+$) = (2.68 \pm 0.13) imes 10^{-3} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

³ ABULENCIA 06J reports $[\Gamma(B_s^0 \rightarrow D_s^- \pi^+)/\Gamma_{total}] / [B(B^0 \rightarrow D^- \pi^+)] = 1.32 \pm 1.32$ 0.18 \pm 0.38 which we multiply by our best value B($B^0
ightarrow D^-\pi^+$) = (2.68 \pm 0.13) imes 10^{-3} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁴ AKERS 94) sees ≤ 6 events and measures the limit on the product branching fraction $f(\overline{b} \to B_s^0) \cdot B(B_s^0 \to D_s^- \pi^+) < 1.3\%$ at CL = 90%. We divide by our current value $B(\overline{b} \rightarrow B_s^0) = 0.105.$

 $\Gamma(D_s^-\rho^+)/\Gamma_{\text{total}}$ Γ_8/Γ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT $7.4 \pm 1.4 \pm 1.0$ ¹ LOUVOT 10 BELL $e^+e^- \rightarrow r(5S)$

 $^{1}\operatorname{LOUVOT\ 10\ reports}\ [\Gamma\left(B\begin{smallmatrix}0\\s\end{smallmatrix}\to\ D_{s}^{-}\ \rho^{+}\right)/\Gamma_{\mathsf{total}}]\ /\ [B(B_{s}^{0}\to\ D_{s}^{-}\pi^{+})] = 2.3\pm0.4\pm0.2$ which we multiply by our best value B($B_s^0 \to D_s^- \pi^+$) = $(3.2 \pm 0.4) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 B^{0}

<121

| $(D_s^-\pi^+\pi^+\pi^-)/\Gamma_{total}$ | DO CUMENT ID | TECN | COMMENT | Г9/Г |
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| 5±1.2 OUR FIT .7±1.5±0.7 | | c CDF | | eV |
| 1 ABULENCIA 07c reports | | | /Γ _{total}] / | |
| $D^-\pi^+\pi^+\pi^-)] = 1.05 \pm 0$ | 0.10 ± 0.22 which we r | | | |
| $D^-\pi^+\pi^+\pi^-)=(6.4\pm0.$ our second error is the system | 7) $	imes$ 10^{-3} . Our first ϵ | error is the our best va | eir experiment' alue. | 's error and |
| $(D_s^-\pi^+\pi^+\pi^-)/\Gamma(D_s^-\pi^+)$ |) DOCUMENT ID | <u>TECN</u> | <u>COMMENT</u> | Γ ₉ /Γ ₇ |
| 04±0.35 OUR FIT 01±0.37±0.20 | | | pp at 7 TeV | |
| $(D_s^{\mp} K^{\pm})/\Gamma_{\text{total}}$ | | | | Γ ₁₀ /Γ |
| ALUE (units 10 ⁻⁴) 9±0.6 OUR FIT | DO CUMENT ID | TECN | COMMENT | |
| $4^{+1.2}_{-1.0}\pm0.4$ | ¹ LOUVOT 09 | BELL | $e^+ e^- \rightarrow 7$ | ^(5 S) |
| $^1\text{LOUVOT}$ 09 reports (2.4 $^+$ | $^{1.2}_{1.0} \pm 0.42) \times 10^{-4}$ | from a m | easurement of | $[\Gamma(B_s^0)]$ |
| $D_s^{\mp} K^{\pm})/\Gamma_{\text{total}}] \times [B(\Upsilon(108))]$ | $B60) ightarrow B_S^{(*)} \overline{B}_S^{(*)})]$ as | ssuming B(| $\Upsilon(10860) \rightarrow$ | $B_s^{(*)} \overline{B}_s^{(*)}$ |
| $= (19.5 \pm 2.6) \times 10^{-2}$, whic = $(19.9 \pm 3.0) \times 10^{-2}$. Our is the systematic error from u | first error is their exp | | | |
| $(D_s^{\pm} K^{\pm})/\Gamma(D_s^{-} \pi^{+})$ | | | | Γ ₁₀ /Γ ₇ |
| 092±0.018 OUR FIT | DO CUMENT ID | TECN | COMMENT | |
| .097±0.018±0.009 | AALTONEN 09 | AQ CDF | p p at 1.96 T | eV |
| $(D_s^+ D_s^-)/\Gamma_{\text{total}}$ | DOCUMENT IS | TECN - | 24445N7 | Γ ₁₁ /Γ |
| 1.00 (units 10 ⁻³) CL% 5.3±0.9 OUR AVERAGE | | | OMMENT | |
| | _ | | o at 1.96 TeV + -= ∞(5. | c) |
| $10.3 + 3.9 + 2.6 \\ -3.2 - 2.5$ • • We do not use the following | | | $^+e^- ightarrow~\gamma$ (5) etc. • • • |) |
| _ | | | erc. • • • epl. by AALT(| NEN 12c |
| | ONEN OUF | | | |
| 67 90 | DRUTSKOY 07A | | epl. by ESEN | |
| 1 AALTONEN 12C reports ($f_{\mathrm{S}}/$ | f_d) (B($B_s^0 \rightarrow D_s^+ D_s^-$ | BELL R | epl. by ESEN $\rightarrow D^-D_S^+))$ | 10 = 0.183 ± |
| 1 AALTONEN 12c reports ($f_S/$ 0.021 \pm 0.017. We multiply t | f_d) (B($B_s^0 	o D_s^+ D_s^-$) his result by our best v | BELL Road $)$ $/$ $B(B^0)$ alue of $B(B^0)$ | epl. by ESEN $\rightarrow D^-D_s^+))$ $B^0 \rightarrow D^-D_s^+$ | 10 = 0.183 ± -) = (7.2 ± |
| $^1\mathrm{AALTONEN}$ 12c reports ($\mathit{f_s/}$ 0.021 \pm 0.017. We multiply t | f_d) (B($B_s^0 	o D_s^+ D_s^-$) his result by our best v | BELL Road $)$ $/$ $B(B^0)$ alue of $B(B^0)$ | epl. by ESEN $\rightarrow D^-D_s^+))$ $B^0 \rightarrow D^-D_s^+$ | 10 = 0.183 ± -) = (7.2 ± |
| 1 AALTONEN 12c reports $(f_{\rm S}/$ 0.021 \pm 0.017. We multiply t 0.8) \times 10 ⁻³ and divide by or Our first quoted uncertainty if the systematic uncertainty from | (f_d) (B($B_s^0 \rightarrow D_s^+ D_s^-$) his result by our best vur best value of f_s/f_d , s the combined experiment using out best value | BELL Ref. $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = 1/2$ $A = $ | epl. by ESEN $ \rightarrow D^-D_S^+)) \\ B^0 \rightarrow D^-D_S^+ \\ 2 f_S/f_d = 0.13 \\ \text{ertainty and of} $ | $0 = 0.183 \pm 0.083$ $0 = 0.183 \pm 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ |
| 1 AALTONEN 12c reports $(f_{\rm S}/$ 0.021 \pm 0.017. We multiply t 0.8) \times 10 $^{-3}$ and divide by or Our first quoted uncertainty if the systematic uncertainty for 2 Uses $\varUpsilon(10860)$ \rightarrow $B_{\rm S}^*\overline{B}_{\rm S}^*$ as | f_d) (B(B $_S^0 	o D_S^+ D_S^-$) his result by our best value of f_S/f_d , s the combined experirom using out best value suming B($\Upsilon(10860)$ $-$ | BELL Ref. $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A = 1$ $A $ | epl. by ESEN $ \rightarrow D^-D_s^+)) $ $ B^0 \rightarrow D^-D_s^+ $ $ C_{f_g}/f_{d_g} = 0.13 $ ertainty and out $ C_{f_g}^*) = (19.3 \pm 0.13) $ | $0 = 0.183 \pm 0.083$ $0 = 0.183 \pm 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ $0 = 0.008$ |
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| 1 AALTONEN 12c reports (f_s) 0.021 ± 0.017. We multiply t 0.8) × 10 ⁻³ and divide by or our first quoted uncertainty if the systematic uncertainty for 2 Uses $\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*$ as $\Gamma(\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*) / \Gamma(3^3$ AALTONEN 08r reports $\Gamma(3^3$ AALTONEN 08r reports $\Gamma(3^4, -0.44)$ which we multiply our first error is their experimusing our best value. ($D_s^* - \pi^+$)/ Γ_{total} MUE (units 10 ⁻³) 1±0.5±0.3 | (f_{d}) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) is result by our best value of f_{s}/f_{d} , s the combined experirom using out best value suming B($T(10860) \rightarrow B_{s}^{(*)}B_{s}^{0}$)/ $(B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-})/\Gamma$ by our best value B(B_{s}^{0}) ent's error and our second $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 | BELL R. 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| 1 AALTONEN 12c reports (f_s/c_s) 0.021 \pm 0.017. We multiply t 0.8) \times 10 ⁻³ and divide by or our first quoted uncertainty if the systematic uncertainty for 2 Uses $\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*$ as $\Gamma(\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*) / \Gamma(3^3$ AALTONEN 08r reports $\Gamma(1.44^{+0.48}_{-0.44})$ which we multiply our first error is their experimusing our best value. $(D_s^* \pi^+)/\Gamma_{\rm total}$ | (f_{d}) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) is result by our best value of f_{s}/f_{d} , s the combined experirom using out best value suming B($T(10860) \rightarrow B_{s}^{(*)}B_{s}^{0}$)/ $(B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-})/\Gamma$ by our best value B(B_{s}^{0}) ent's error and our second $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 | BELL R. 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| 1 AALTONEN 12c reports $(f_s/0.021\pm0.017)$. 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| 1 AALTONEN 12c reports (f_s) 0.021 \pm 0.017. We multiply t 0.8) \times 10 ⁻³ and divide by or our first quoted uncertainty if the systematic uncertainty for 2 Uses $\Gamma(10860) \rightarrow B_s^* \overline{B}_s^*$ as $\Gamma(\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*) / \Gamma(3)$ 3 AALTONEN 08r reports $\Gamma(3)$ 1.44 $^{+0.48}_{-0.44}$ which we multiply our first error is their experimusing our best value. ($D_s^* - T_s^*$)/ Γ total 1.40.5 \pm 0.3 1 LOUVOT 10 reports $\Gamma(B_s^0 - 0.07)$ which we multiply by our first error is their experiment using our best value. ($D_s^* - T_s^*$)/ Γ total | (f_{d}) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) (B($B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-}$) is result by our best value of f_{s}/f_{d} , s the combined experirom using out best value suming B($T(10860) \rightarrow B_{s}^{(*)}B_{s}^{0}$)/ $(B_{s}^{0} \rightarrow D_{s}^{+}D_{s}^{-})/\Gamma$ by our best value B(B_{s}^{0}) ent's error and our second $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 17 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 18 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 10 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 $\frac{DOCUMENT\ ID}{1\ DOUVOT}$ 19 | BELL R. 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| 1 AALTONEN 12c reports (f_s) 0.021 ± 0.017. We multiply t 0.8) × 10 ⁻³ and divide by or our first quoted uncertainty if the systematic uncertainty for 2 Uses $\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*$ as $\Gamma(\Upsilon(10860) \rightarrow B_s^* \overline{B}_s^*) / \Gamma(3)$ 3 AALTONEN 08r reports $\Gamma(4.4^+ 0.48^+)$ which we multiply our first error is their experimusing our best value. ($D_s^* - T^*$)/ Γ total 1.40.40 (units 10 ⁻³) 1.40.50 ± 0.3 1.40.90 To reports $\Gamma(B_s^0 - 0.07^+)$ which we multiply by our first error is their experiment using our best value. 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DRUTSKOY 07A BELL Repl. by ESEN 10

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<sup>1</sup> AALTONEN 12C reports (f_S/f_d) (B(B_S^0 \rightarrow D_S^{*+}D_S^- + D_S^{*-}D_S^+) / B(B^0 \rightarrow D_S^{*+}D_S^-)
             (D^-D_s^+)) = 0.424 \pm 0.046 \pm 0.035. We multiply this result by our best value of
            B(B^0 \to D^-D_s^+) = (7.2 \pm 0.8) \times 10^{-3} and divide by our best value of f_s/f_d, where
            1/2\ f_{\rm S}/f_{\rm d}=0.131 \times 0.008. Our first quoted uncertainty is the combined experiment's uncertainty and our second is the systematic uncertainty from using out best values.
         <sup>2</sup>Uses \Upsilon(10860) \to B_S^* \overline{B}_S^* assuming B(\Upsilon(10860) \to B_S^{(*)} \overline{B}_S^{(*)}) = (19.3 ± 2.9)% and
            \Gamma(\Upsilon(10860) \to B_s^* \overline{B}_s^*) / \Gamma(\Upsilon(10860) \to B_s^{(*)} \overline{B}_s^{(*)}) = (90.1^{+3.8}_{-4.0})\%.
\Gamma(D_s^{*+}D_s^{*-})/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                          \Gamma_{15}/\Gamma
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ho\,\overline{
ho} at 1.96 TeV
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            30.8 + 12.2 + 8.5 \\ -10.4 - 8.6
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                                                                                                                                                                      10 BELL e^+e^- \rightarrow \gamma(5S)
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                                                                                                     DRUTSKOY 07A BELL Repl. by ESEN 10
        ^{1}\, {\rm AALT\,ONE\,N\,} \, 12c \; {\rm reports} \; (f_{S}/f_{d}) \; ({\rm B}(B_{S}^{\,0} \to \, D_{S}^{\,*+}D_{S}^{\,*-}) \; / \; {\rm B}(B^{\,0} \to \, D^{\,-}D_{S}^{\,+})) = 0.654 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.00 \, \pm 0.0
            0.072 \pm 0.065. We multiply this result by our best value of B(B^0 \rightarrow D^- D_c^+) = (7.2 \pm
            0.8)\times 10^{-3} and divide by our best value of f_s/f_d, where 1/2 f_s/f_d = 0.131\pm 0.008. Our first quoted uncertainty is the combined experiment's uncertainty and our second is
            the systematic uncertainty from using out best values.
        <sup>2</sup> Uses \Upsilon(10860) \to B_S^* \overline{B}_S^* assuming B(\Upsilon(10860) \to B_S^{(*)} \overline{B}_S^{(*)}) = (19.3 ± 2.9)% and
            \Gamma(\Upsilon(10860) \to B_S^* \overline{B}_S^*) \ / \ \Gamma(\Upsilon(10860) \to B_S^{(*)} \overline{B}_S^{(*)}) = (90.1^{+3.8}_{-4.0})\%.
\Gamma(D_s^{(*)+}D_s^{(*)-})/\Gamma_{total} \\ \text{"OUR EVALUATION" is an average using rescaled values of the data listed below.}
                   (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The aver-
                    aging/rescaling\ procedure\ takes\ into\ account\ correlations\ between\ the\ measurements.
                                                                                                                      DO CUMENT ID
                                                                                                                                                                                    TECN COMMENT
    4.5 ±1.4 OUR EVALUATION
    3.7 \pm0.6 OUR AVERAGE
     3.5 \pm 0.4 \pm 0.4
                                                                                                                <sup>1</sup> AALTONEN 12c CDF p\overline{p} at 1.96 TeV
    6.85 + 1.53 + 1.79 \\ -1.30 - 1.80
                                                                                                          ^{2,3}\,\text{ESEN}
                                                                                                                                                                        10 BELL e^+e^- \rightarrow \Upsilon(5S)
                                                                                                                ^{4} ABAZOV
    3.5 \pm 1.0 \pm 1.1
                                                                                                                                                                        09ı D0
                                                                                                          <sup>5,6</sup> BARATE
14 \pm 6 \pm 3
                                                                                                                                                                        00K ALEP e^+e^- \rightarrow Z
\bullet \bullet \,\bullet We do not use the following data for averages, fits, limits, etc. \,\bullet \,\bullet
    3.9 \begin{array}{c} +1.9 \\ -1.7 \end{array} \begin{array}{c} +1.6 \\ -1.5 \end{array}
                                                                                                                <sup>4</sup> ABAZOV
                                                                                                                                                                        07Y D0 Repl. by ABAZOV 09i
                                                                                                                                                                        98Q ALEP e^+e^- 
ightarrow {\it Z}
 < 0.218
                                                                                 90
                                                                                                                      BARATE
       ^{1}\,\text{AALTONEN 12c reports}\,\,(f_{S}/f_{d})\,\,(\text{B}(B_{S}^{\,0}\,\rightarrow\,\,D_{S}^{\,(*)+}\,D_{S}^{\,(*)-})\,\,/\,\,\text{B}(B^{\,0}\,\rightarrow\,\,D^{\,-}\,D_{S}^{\,+}))=
            1.261 \pm 0.095 \pm 0.112. We multiply this result by our best value of B(B^0 \rightarrow D^- D_s^+)
       (7.2\pm0.8)\times10^{-3} and divide by our best value of f_s/f_d, where 1/2~f_s/f_d=0.131\pm0.008. Our first quoted uncertainty is the combined experiment's uncertainty and our second is the systematic uncertainty from using out best values. 2 Sum of exclusive B_S\to D_S^+D_S^-, B_S\to D_S^{*\pm}D_S^{\mp} and B_S\to D_S^{*+}D_S^{*-}.
         ^3\,\text{Uses}\ \ \varUpsilon(10860) \ \rightarrow\ B_{\,S}^{\,\ast}\,\overline{B}_{\,S}^{\,\ast}\ \text{assuming}\ \text{B}(\ \varUpsilon(10860) \ \rightarrow\ B_{\,S}^{\,(\ast)}\,\overline{B}_{\,S}^{\,(\ast)}) = (19.3\pm2.9)\%\ \text{and}
            \Gamma(\Upsilon(10860) \to B_S^* \overline{B}_S^*) / \Gamma(\Upsilon(10860) \to B_S^{(*)} \overline{B}_S^{(*)}) = (90.1^{+3.8}_{-4.0})\%.
         <sup>4</sup> Uses the final states where D_s^+ \to \phi \pi^+ and D_s^- \to \phi \mu^- \overline{\nu}_{\mu}.
         ^{5} \ \text{Reports B}(B_{s}^{0} (\text{short}) \to D_{s}^{\binom{3}{s}} D_{s}^{(*)}) = (0.23 \pm 0.10 \pm 0.05) \cdot [0.17/\text{B}(D_{s} \to \phi \chi)]^{2} \\ \text{assuming B}(B_{s}^{0} \to B_{s}^{0} (\text{short})) = 50\%. \ \ \text{We use our best value of B}(D_{s} \to \phi \chi) = (0.23 \pm 0.10 \pm 0.05) \cdot [0.17/\text{B}(D_{s} \to \phi \chi)]^{2} 
            15.7 \pm 1.0\% to obtain the quoted result.
        <sup>6</sup> Uses \phi\phi correlations from B_s^0({
m short}) \to D_s^{(*)+} D_s^{(*)-}.
\Gamma(\overline{D}{}^{0}\overline{K}^{*}(892)^{0})/\Gamma_{total}
                                                                                                                                                                                                                                                                          \Gamma_{17}/\Gamma
VALUE (units 10^{-4})
                                                                                                                      DO CUMENT ID
                                                                                                                                                                                TECN COMMENT
                                                                                                               1 AAIJ
                                                                                                                                                                       11D LHCB pp at 7 TeV
4.7 \pm 1.2 \pm 0.7
        ^1 AAIJ 11D reports [ \Gamma \left(B_s^0 \to \, \overline{D}^0 \, \overline{K}^* (892)^0 \right) / \Gamma_{\mbox{total}} ] \, / \, \left[ B(B^0 \to \, \overline{D}^0 \, \rho^0) \right] = 1.48 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.34 \pm 0.
            0.19 which we multiply by our best value B(B^0\to \overline{D}^0\rho^0) = (3.2\pm0.5)\times 10^{-4}. Our first error is their experiment's error and our second error is the systematic error from
             using our best value.
\Gamma(J/\psi(1S)\phi)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                          \Gamma_{18}/\Gamma
VALUE (units 10-3)
                                                                                                                                                                                         TECN COMMENT
                                                                                                                      DO CUMENT ID
```

1.09 + 0.28 OUR FIT

 $1.4 \pm 0.4 \pm 0.1$

<6

seen

¹ ABE

² AKERS

⁴ ACTON

³ABE

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

1

960 CDF pp

94J OPAL $e^+e^ightarrow Z$

93F CDF ρp at 1.8 TeV

92N OPAL Sup. by AKERS 94J

| $^{1} \text{ABE 96Q reports } [\Gamma(B_{s}^{0} \to J/\psi(1S)\phi)/\Gamma_{\text{total}}] \times [\Gamma(\overline{b} \to B_{s}^{0})/\big[\Gamma(\overline{b} \to B^{+}) + \Gamma(\overline{b} \to B^{+})] \times [\Gamma(\overline{b} \to B^{+})]$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| B^0] = $(0.185 \pm 0.055 \pm 0.020) \times 10^{-3}$ which we divide by our best value $\Gamma(\overline{b} \to B_s^0)/$ |
| $\left[\Gamma(\overline{b}\to B^+) + \Gamma(\overline{b}\to B^0)\right] = 0.131 \pm 0.008$. Our first error is their experiment's |
| error and our second error is the systematic error from using our best value. |
| ² AKERS 94J sees one event and measures the limit on the product branching fraction |
| $f(\overline{b}\to B^0_S)\cdot \mathrm{B}(B^0_S\to J/\psi(1S)\phi)<7	imes10^{-4}$ at CL = 90%. We divide by $\mathrm{B}(\overline{b}\to 10^{-4})$ |
| B_s^0) = 0.112. |

 3 ABE 93F measured using $J/\psi(1S) \to \mu^+ \mu^-$ and $\phi \to K^+ K^-$.

⁴ In ACTON 92N a limit on the product branching fraction is measured to be $f(\overline{b} \to B_S^0) \cdot B(B_S^0 \to J/\psi(1S) \phi) \leq 0.22 \times 10^{-2}$.

 $\Gamma(J/\psi(1S)\pi^0)/\Gamma_{\text{total}}$ Γ_{19}/Γ DO CUMENT ID TECN <1.2 × 10⁻³ ¹ ACCIARRI 97c L3 90

 $^{1}\,\mathrm{ACCIARRI}$ 97c assumes $B^{\,0}$ production fraction (39.5 \pm 4.0%) and $B_{\,\mathrm{S}}$ (12.0 \pm 3.0%).

| $\Gamma(J/\psi(1S)\eta)/\Gamma_{\text{total}}$ | | | | | | Γ_{20}/Γ |
|------------------------------------------------|-------------|------------------|----------|-----------|--------------|----------------------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $5.10 \pm 0.50 + 1.17 \\ -0.83$ | | 1 LI | 12 | BELL | $e^+e^- \to$ | $\Upsilon(4S)$ |
| • • • We do not use the | e following | data for average | es, fits | , limits, | etc. • • • | |
| | | 2 | | | | |

I

VALUE (units 10^{-6})

<38 ² ACCIARRI 97c L3 1 Observed for the first time with significances over 10 σ . The second error are total

systematic uncertainties including the error on $N(B_c^{(*)}\overline{B}_c^{(*)})$. ²ACCIARRI 97c assumes B^0 production fraction (39.5 \pm 4.0%) and B_s (12.0 \pm 3.0%).

 $\Gamma(J/\psi(1S) K^0)/\Gamma_{\text{total}}$ Γ_{21}/Γ

VALUE (units 10^{-5}) DO CUMENT ID TECN COMMENT 1 AALTONEN 11A CDF $\overline{p}\overline{p}$ at 1.96 TeV $3.6 \pm 0.7 \pm 0.3$

 $^{1}\,\text{AALT\,ONEN\,\,11A\,\,reports\,\,} [\Gamma\big(B_{\,\,S}^{\,0}\,\,\rightarrow\,\,\, J/\psi(1S)\,\,\text{K}^{\,0}\big)/\Gamma_{total}]\,\,\times\,\, [B(\overline{b}\,\,\rightarrow\,\,\,B_{\,\,S}^{\,0})]\,\,/\,\, [B(\overline{b}\,\,\rightarrow\,\,\,B_{\,\,S}^{\,0})]$ $[B^0]$] / $[B(B^0 \to J/\psi(1S) K^0)] = 0.0109 \pm 0.0019 \pm 0.0011$ which we multiply or divide by our best values B($\overline{b} \to B_s^0$) = (10.5 ± 0.6)×10⁻², B($\overline{b} \to B^0$) = (40.1 ± 0.8)×10⁻², $B(B^0 \to J/\psi(15)\, K^0) = {}^{6/7.4} \pm 0.32) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best values.

 $\Gamma(J/\psi(1S) K^{*0})/\Gamma_{\text{total}}$ Γ_{22}/Γ VALUE (units 10-5) DOCUMENT ID TECN COMMENT ¹ AALTONEN 11A CDF $p\overline{p}$ at 1.96 TeV 9±4±1

 $^{1}\,\text{AALT\,ONEN\,\,11A\,\,reports}\,\, [\Gamma \left(B_{\,\,S}^{\,\,0}\,\rightarrow\,\,\,J/\psi(1S)\,K^{*\,0}\right)/\Gamma_{\text{total}}\,]\,\,\times\,\, [B(\overline{b}\,\rightarrow\,\,B_{\,\,S}^{\,\,0})]\,\,/\,\, [B(\overline{b}\,\rightarrow\,\,B_{\,\,S}^{\,\,0})]\,\,/\,\, [B(\overline{b}\,\rightarrow\,\,B_{\,\,S}^{\,\,0})]$ $[B^0]/[B(B^0 \to J/\psi(15) \, K^*(892)^0]] = 0.0168 \pm 0.0024 \pm 0.0068$ which we multiply or divide by our best values $B(\overline{b} \to B_S^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}, \, B(\overline{b} \to B^0) = (10.5 \pm 0.6) \times 10^{-2}$ $(40.1 \pm 0.8) \times 10^{-2}$, B($B^0 \rightarrow J/\psi(1S) K^*(892)^0$) = $(1.34 \pm 0.06) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best values.

| $\Gammaig(J/\psi(1S)\eta'ig)/\Gamma_{	ext{total}}$ | | | | | Γ_{23}/Γ |
|----------------------------------------------------|---------|-------|------|---------------------|----------------------|
| VALUE (units 10 ⁻⁴) | DOCUMEN | IT ID | TECN | COMMENT | |
| $3.71 \pm 0.61 + 0.85$ | 1 LI | 12 | BELL | $e^+e^ \rightarrow$ | Y(45) |

 1 Observed for the first time with significances over 10 $\sigma.$ The second error are total systematic uncertainties including the error on N($\mathcal{B}_{S}^{(*)}\overline{\mathcal{B}}_{S}^{(*)}).$

| $\Gamma(J/\psi(1S)\eta)/\Gamma(J/\psi(1S)\eta')$ |) | | | | Γ_{20}/Γ_{23} |
|--------------------------------------------------|----------------------------|----|------|--------------|---------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.73 \pm 0.14 \pm 0.02$ | LI | 12 | BELL | $e^+e^- \to$ | Y(45) |
| $\Gamma(J/\psi(1S) f_0(980), f_0 \to \pi^+$ | $\pi^-)/\Gamma_{ m total}$ | | | | Γ ₂₄ /Γ |
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT | |
| 1.36 ^{+0.35} _{-0.28} OUR FIT | | | | | |

1.16 + 0.31 + 0.30-0.19 - 0.251 LI11 BELL $e^+e^- \rightarrow \gamma(5S)$

 $^{
m 1}$ The second error includes both the detector systematic and the uncertainty in the number of produced $Y(5S) \rightarrow B_c^{(*)} \overline{B}_c^{(*)}$ pairs.

| $\Gamma(J/\psi(1S) f_0(980), f_0 \to s$ | Γ_{24}/Γ_{1} | 8 | | | |
|-----------------------------------------|--------------------------|------|------|-----------------------------|---|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.125 ±0.010 OUR FIT | <u> </u> | | | | _ |
| 0.126±0.010 OUR AVERAGE | | | | | |
| $0.135 \pm 0.036 \pm 0.001$ | $^{ m 1}$ abazov | 12c | D0 | $p\overline{p}$ at 1.96 TeV | |
| $0.123^{+0.026}_{-0.022}\pm 0.001$ | ² AAIJ | 11 | LHCB | pp at 7 TeV | |
| $0.126 \pm 0.012 \pm 0.001$ | ³ AALTONEN | 11AE | CDF | $p\overline{p}$ at 1.96 TeV | |

¹ ABAZOV 12c reports $\left[\Gamma\left(B_S^0 \to J/\psi(1S) f_0(980), f_0 \to \pi^+\pi^-\right)/\Gamma\left(B_S^0 \to J/\psi(1S) \phi\right)\right]$ / $[B(\phi(1020) \rightarrow K^+K^-)] = 0.275 \pm 0.041 \pm 0.061$ which we multiply by our best value / $[0(01020) \rightarrow K^+K^-] = (48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

2 AAIJ 11 reports $[\Gamma(B_s^0 \to J/\psi(1s)\,f_0(980),\ f_0 \to \pi^+\pi^-)/\Gamma(B_s^0 \to J/\psi(1s)\,\phi)]/$ $[B(\phi(1020) \to K^+K^-)] = 0.252^{+}_{-}0.046^{+}_{-}0.027^{-}_{-}$ which we multiply by our best value $B(\phi(1020) \to K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}_{-}$ Our first error is their experiment's error and our second error is the systematic error from using our best value. 3 AALTONEN 11AB reports $[\Gamma(B_s^0 \to J/\psi(1s)\,f_0(980),\ f_0 \to \pi^+\pi^-)/\Gamma(B_s^0 \to J/\psi(1s)\,f_0(980),\ f_0 \to J/\psi(1s)\,f$

ply by our best value B($\phi(1020) \rightarrow K^+K^-$) = (48.9 \pm 0.5) \times 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best

 $\Gamma(J/\psi(1S)\,f_0(1370),\,f_0 o\pi^+\pi^-)/\Gamma_{
m total}$ Γ_{25}/Γ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT 0.34 + 0.11 + 0.085-0.14 - 0.054 1_{11} 11 BELL $e^+e^- \rightarrow \gamma(5S)$

 ${\bf 1}$ The second error includes both the detector systematic and the uncertainty in the number of produced $Y(5S) \rightarrow B_s^{(*)} \overline{B}_s^{(*)}$ pairs.

 Γ_{26}/Γ $\Gamma(\psi(2S)\phi)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) DOCUMENT ID EVTS TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet BUSKULIC 93G ALEP $e^+e^- \rightarrow Z$

 $\Gamma(\psi(2S)\phi)/\Gamma(J/\psi(1S)\phi)$ Γ_{26}/Γ_{18} DO CUMENT ID TECN COMMENT 0.53±0.10 OUR AVERAGE $0.53 \pm 0.10 \pm 0.09$ ABAZOV $p\overline{p}$ at 1.96 TeV

 $0.52 \pm 0.13 \pm 0.07$ ABULENCIA 06N CDF $p\overline{p}$ at 1.96 TeV $\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{27}/Γ

DO CUMENT ID

 1 AALTONEN 09c CDF $p\overline{p}$ at 1.96 TeV 90 • • • We do not use the following data for averages, fits, limits, etc. • • • ² PENG 10 BELL $e^+e^- \rightarrow \gamma(5S)$ < 12 90 ³ ABULENCIA,A 06D CDF Repl. by AALTONEN 09c < 1.7 90 ⁴ ABE <232 90 00c SLD $e^+e^- \rightarrow Z$

TECN_COMMENT

 5 BUSKULIC 96V ALEP $e^{+}e^{-}
ightarrow Z$ <170 90 1 Obtains this result from $(f_s/f_d)\cdot {\rm B}(B_s\to~\pi^+\pi^-)/{\rm B}(B^0\to~K^+\pi^-)=0.007$ \pm 0.004 \pm 0.005, assuming $f_s/f_d=$ 0.276 \pm 0.034 and B($B^0\to K^+\pi^-$) = (19.4 \pm

²Uses $\Upsilon(10860) \to B_s^* \overline{B}_s^*$ and assumes B($\Upsilon(10860) \to B_s^{(*)} \overline{B}_s^{(*)}$) = (19.3 ± 2.9)% and $\Gamma(\Upsilon(10860) \to B_s^*\overline{B}_s^*) / \Gamma(\Upsilon(10860) \to B_s^{(*)}\overline{B}_s^{(*)}) = (90.1^{+3.8}_{-4.0})\%.$

³ ABULENCIA, A 06D obtains this from B($B_S \to \pi^+ \pi^-$) / B($B_S \to K^+ K^-$) < 0.05 at 90% CL, assuming B($B_S \to K^+ K^-$) = (33 ± 6 ± 7) × 10⁻⁶. ⁴ ABE 00c assumes B($Z \to b \overline{b}$)=(21.7 ± 0.1)% and the B fractions $f_{B^0} = f_{B^+} = f_{B^0} =$

 $(39.7 + 1.8 \atop -2.2)\%$ and $f_{B_s} = (10.5 + 1.8 \atop -2.2)\%$.

⁵ BUSKULIC 96V assumes PDG 96 production fractions for B^0 , B^+ , B_s , b baryons.

| $\Gamma(\pi^0\pi^0)/\Gamma_{ m total}$ | | | | | | Γ ₂₈ /Γ |
|----------------------------------------|-----|--------------|------|------|------------------------|--------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $<2.1 \times 10^{-4}$ | 90 | 1 ACCIARRI | 95 H | L3 | $e^+e^- \rightarrow Z$ | |

 $^{1}\,\mathrm{ACCIARRI}$ 95 H assumes $\mathit{f}_{B^{\,0}}=$ 39.5 \pm 4.0 and $\mathit{f}_{B_{\,\mathrm{S}}}=$ 12.0 \pm 3.0%.

 $\Gamma(\eta\pi^0)/\Gamma_{\text{total}}$ Γ_{29}/Γ DOCUMENT ID $<1.0 \times 10^{-3}$ 90 ¹ ACCIARRI 95H L3 $e^+e^- \rightarrow Z$ 1 ACCIARRI 95H assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_S}=12.0\pm3.0\%$.

 Γ_{30}/Γ $\Gamma(\eta\eta)/\Gamma_{\text{total}}$ DO CUMENT ID TECN COMMENT <1.5 × 10⁻³ 1 ACCIARRI 95H L3 $e^{+}e^{-} \rightarrow Z$ 90 1 ACCIARRI 95H assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_S}=12.0\pm3.0\%$.

 $\Gamma(\rho^0 \rho^0)/\Gamma_{\text{total}}$ Γ_{31}/Γ CL% DOCUMENT ID TECN COMMENT <3.20 × 10⁻⁴ 1 ABE 90 00c SLD $e^+e^- \rightarrow Z$

¹ ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^0} = f_{B^+} =$ $(39.7 + 1.8 \atop -2.2)\%$ and $f_{B_c} = (10.5 + 1.8 \atop -2.2)\%$.

 $\Gamma(\phi \rho^0)/\Gamma_{\rm total}$ Γ_{32}/Γ TECN COMMENT $<6.17 \times 10^{-4}$ ¹ ABE 00c SLD $e^+e^- \rightarrow Z$ 90 $^1\,{\rm ABE}$ 00c assumes B(Z \rightarrow $b\,\overline{b})\!=\!(21.7\,\pm\,0.1)\%$ and the B fractions $f_{B^0}\!=\!f_{B^+}\!=\!$

 $(39.7 + \frac{1}{2}.\frac{8}{2})\%$ and $f_{B_c} = (10.5 + \frac{1}{2}.\frac{8}{2})\%$.

 B_s^0

| $\Gamma(\phi\phi)/\Gamma_{ m total}$ $\Gamma_{ m 33}/\Gamma$ | $\Gamma(\overline{K}^*(892)^0 \rho^0)/\Gamma_{total}$ Γ_{37}/Γ_{100} |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALUE (units 10 ⁻⁶) CL% DO CUMENT ID TECN COMMENT | VALUE CL% DOCUMENT ID TECN COMMENT |
| 19±3 $^{+5}_{-4}$ 1 AALTONEN 11AN CDF $p\bar{p}$ at 1.96 TeV | 1 ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^{0}} = f_{B^{+}} = f_{B^{+}}$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | $(39.7 + \frac{1.8}{-2.2})\%$ and $f_{B_s} = (10.5 + \frac{1.8}{-2.2})\%$. |
| $14 + \frac{6}{5} \pm 6$ 2 ACOSTA 05J CDF Repl. by AALTONEN 11AN | |
| <1183 90 ³ ABE 00¢ SLD $e^+e^- \to Z$ | $\Gamma(\overline{K}^*(892)^0 K^*(892)^0)/\Gamma_{\text{total}}$ Γ_{38}/Γ_{38} |
| ¹ AALTONEN 11AN reports $\left[\Gamma\left(B_s^0 \to \phi\phi\right)/\Gamma_{\text{total}}\right]/\left[B\left(B_s^0 \to J/\psi(1S)\phi\right)\right] = (1.78 \pm 1.00)$ | <u>VALUE (units 10⁻⁵)</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.81±0.46±0.56 ¹ AAIJ 12F LHCB pp at 7 TeV |
| $0.14 \pm 0.20) \times 10^{-2}$ which we multiply by our best value B($B_s^0 \rightarrow J/\psi(15) \phi$) = | 2.81±0.46±0.56 ¹ AAIJ 12F LHCB pp at 7 TeV • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(1.09^{+0.28}_{-0.23}) \times 10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | <168.1 90 2 ABE 00c SLD $e^+e^- \rightarrow Z$ |
| 2 Uses B($B^0 \to J/\psi \phi$) = $(1.38 \pm 0.49) \times 10^{-3}$ and production cross-section ratio of | ¹ Uses $B^0 \rightarrow J/\psi K^{*0}$ for normalization and assumes $B(B^0 \rightarrow J/\psi K^{*0})$ $B(J/\psi -$ |
| $\sigma(B_S)/\sigma(B^0) = 0.26 \pm 0.04.$ | $\mu^+\mu^-)$ B($K^{*0}\to K^+\pi^-)=(1.33\pm0.06)\times10^{-3}$ and $f_s/f_d=0.253\pm0.031$. The second quoted error is total uncertainty including the error of 0.34 on f_s/f_d . |
| ³ ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B^0} = f_{B^+} =$ | second quoted error is total uncertainty including the error of 0.34 on $t_{\rm S}/t_{\rm d}$. ² ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 ± 0.1)% and the B fractions $t_{\rm B0}$ = $t_{\rm B+}$ = |
| $(39.7 + \frac{1.8}{2.2})\%$ and $f_{B_3} = (10.5 + \frac{1.8}{2.2})\%$. | (39.7 $\frac{1.8}{2}$)% and $f_{B_c} = (10.5 + \frac{1.8}{2})$ %. |
| $\Gamma(\pi^+ K^-)/\Gamma_{\text{total}}$ Γ_{34}/Γ | , |
| /ALUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | $\Gamma(\phi K^*(892)^0)/\Gamma_{\text{total}}$ $\Gamma_{39}/\Gamma_{\text{total}}$ |
| 5.3±0.9±0.4 | VALUE CL% DOCUMENT ID TECN COMMENT |
| • • We do not use the following data for averages, fits, limits, etc. • • • | <10.13 × 10⁻⁴ 90 ¹ ABE 00¢ SLD $e^+e^- \rightarrow Z$ |
| < 26 90 $\frac{2}{9}$ PENG 10 BELL $e^+e^- \rightarrow \Upsilon(5.5)$ < 5.6 90 $\frac{3}{9}$ ABULENCIA,A 06D CDF Repl. by AALTONEN 09c | ¹ ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{B0} = f_{B+} = (39.7 + \frac{1.8}{2.2})$ % and $f_{B_s} = (10.5 + \frac{1.8}{2.2})$ %. |
| < 3.6 90 ABBLENCIA, A 060 CDF REPL. By AALTONEN 09C <261 90 4 ABE 00C SLD $e^+e^- \rightarrow Z$ | $B_s = (10.5 - 2.2)^{70}$ dilu $B_s = (10.5 - 2.2)^{70}$. |
| <210 90 5 BUSKULIC 96v ALEP $e^{+}e^{-} ightarrow$ Z | $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ $\Gamma_{40}/\Gamma_{\text{total}}$ |
| <260 90 ⁶ AKERS 94L OPAL $e^+e^- \rightarrow Z$ | Test for $\Delta B{=}1$ weak neutral current. Allowed by higher-order electroweak interactions VALUE CL% DOCUMENT ID TECN COMMENT |
| ¹ AALTONEN 09c reports $[\Gamma(B_s^0 \to \pi^+ K^-)/\Gamma_{\text{total}}] / [B(B^0 \to K^+ \pi^-)] \times [B(\overline{b} \to R^0)] / (F_0/\overline{b}) = 0.031 + 0.032 + 0.003$ | $<$ 5.9 × 10 ⁻⁵ 90 1 BUSKULIC 96V ALEP $e^+e^- \rightarrow Z$ |
| $B_s^0)]/[B(\overline{b}\to B^0)] = 0.071\pm0.010\pm0.007$ which we multiply or divide by our best values $B(B^0\to K^+\pi^-) = (1.94\pm0.06)\times10^{-5}$, $B(\overline{b}\to B_s^0) = (10.5\pm0.6)\times10^{-2}$, | ¹ BUSKULIC 96v assumes PDG 96 production fractions for B^0 , B^+ , B_s , b baryons. |
| Values B(B \rightarrow K $^{\circ}\pi$) = (1.34 \pm 0.00) × 10 $^{\circ}$, B(B \rightarrow B $_{S}$) = (10.3 \pm 0.0) × 10 $^{\circ}$, B($\overline{b} \rightarrow$ B 0) = (40.1 \pm 0.8) × 10 $^{-2}$. Our first error is their experiment's error and our | |
| second error is the systematic error from using our best values. | $\lceil (\gamma \gamma) / \Gamma_{	ext{total}} brace$ Test for $\Delta B = 1$ weak neutral current. |
| ² Uses $\Upsilon(10860) \to B_S^* \overline{B}_S^*$ and assumes B($\Upsilon(10860) \to B_S^{(*)} \overline{B}_S^{(*)}$) = (19.3 ± 2.9)% | VALUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT |
| and $\Gamma(\Upsilon(10860) \to B_s^* \overline{B}_s^*) / \Gamma(\Upsilon(10860) \to B_s^{(*)} \overline{B}_s^{(*)}) = (90.1 + \frac{3.8}{-4.0})\%.$ | < 8.7 90 1 WICHT 08A BELL $e^+e^- ightarrow \gamma(5S)$ |
| ³ ABULENCIA,A 06D obtains this from (f_s/f_d) (B($B_s \rightarrow \pi^+ K^-$) / B($B^0 \rightarrow K^+ \pi^-$)) | • • • We do not use the following data for averages, fits, limits, etc. • • • • < 53 90 DRUTSKOY 07A BELL Repl. by WICHT 08A |
| $<$ 0.08 at 90% CL, assuming $f_{\rm S}/f_d=0.260\pm0.039$ and B($B^0\to K^+\pi^-)=(18.9\pm0.7)\times10^{-6}$. | < 148 90 2 ACCIARRI 951 L3 $e^+e^- \rightarrow Z$ |
| ⁴ ABE 00c assumes B($Z \rightarrow b\overline{b}$)=(21.7 \pm 0.1)% and the B fractions $f_{R^0} = f_{R^+} =$ | ¹ Assumes $\Upsilon(5S) \to B_S^* \overline{B}_S^* = (19.5 + \frac{3.0}{2.3})\%$. |
| | |
| | 2 ACCIARRI 951 assumes $f_{R^0}=39.5\pm4.0$ and $f_{B_c}=12.0\pm3.0\%$. |
| $(39.7^{+}_{-2.2}^{+1.8})\%$ and $f_{B_S}=(10.5^{+}_{-2.2}^{+1.8})\%$. ⁵ BUSKULIC 96v assumes PDG 96 production fractions for B^0 , B^+ , B_S , b baryons. | 2 ACCIARRI 951 assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_S}=12.0\pm3.0\%$. |
| $(39.7 + \frac{1.8}{2.2})\%$ and $f_{B_5} = (10.5 + \frac{1.8}{2.2})\%$. | 2 ACCIARRI 951 assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_S}=12.0\pm3.0\%$. $\Gamma(\phi\gamma)/\Gamma_{\rm total}$ |
| $ \begin{array}{l} (39.7 ^{+}1.8_{0})\% \text{ and } f_{B_{S}} = (10.5 ^{+}1.8_{0})\%. \\ 5 \text{ BUSKULIC 96v assumes PDG 96 production fractions for } B^{0}, B^{+}, B_{S}, b \text{ baryons.} \\ 6 \text{ Assumes B}(Z \rightarrow b \overline{b}) = 0.217 \text{ and } B^{0}_{d} \left(B^{0}_{S}\right) \text{ fraction } 39.5\% \ (12\%). \end{array} $ | 2 ACCIARRI 951 assumes $f_{B^0}=39.5\pm4.0$ and $f_{B_S}=12.0\pm3.0\%$. $ \Gamma(\phi\gamma)/\Gamma_{\rm total} $ $ \Gamma_{\rm 42/I} $ $ \frac{VALUE (\rm units 10^{-6}) \qquad CL\% \qquad DOCUMENT ID \qquad TECN \qquad COMMENT }{}$ |
| $ (39.7^{+}1.8_{-})\% \text{ and } f_{B_s} = (10.5^{+}1.8_{-})\%. $ $ ^{5} \text{ BUSKULIC 96v assumes PDG 96 production fractions for } B^{0}, B^{+}, B_{s}, b \text{ baryons.} $ $ ^{6} \text{ Assumes B}(Z \rightarrow b \overline{b}) = 0.217 \text{ and } B^{0}_{d} (B^{0}_{s}) \text{ fraction } 39.5\% (12\%). $ $ ^{7} (K^{+} K^{-})/\Gamma_{\text{total}} $ $ ^{7} \text{ (MLUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT } COMMENT \(D \) COMMENT$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(39.7 + \frac{1}{2}.8)\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.8)\%.$ $^5 \text{ BUSKULIC 96V assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.}$ $^6 \text{ Assumes } B(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_s) \text{ fraction 39.5\% (12\%).}$ $\frac{(K^+ K^-)}{f_{\text{total}}} \frac{CL\%}{26.4 \pm 2.8 \text{ OUR AVERAGE}} \frac{DOCUMENT \ ID}{DOCUMENT \ ID} \frac{TECN}{2000 \text{ COMMENT}} \frac{COMMENT}{2000 \text{ COMMENT}}$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{c} (39.7 + \frac{1}{2}.\frac{8}{2})\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.\frac{8}{2})\%. \\ 5 \text{ BUSKULIC 96V assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.} \\ 6 \text{ Assumes B}(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_S) \text{ fraction 39.5\% (12\%).} \\ \hline F(K^+ K^-)/\Gamma_{\text{total}} & \Gamma_{35}/\Gamma_{26.4 \pm 2.8 \text{ OUR AVERAGE}} \\ \hline 26.4 \pm 2.8 \text{ OUR AVERAGE} \\ 25.8 \pm 2.2 \pm 1.7 & 1 \text{ AALTONEN 11N CDF} & p \overline{p} \text{ at 1.96 TeV} \\ \hline \end{array} $ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(39.7 \stackrel{+}{-} \stackrel{1}{-} \stackrel{1}{.8})\% \text{ and } f_{B_S} = (10.5 \stackrel{+}{-} \stackrel{1}{-} \stackrel{1}{.8})\%.$ $^5 \text{ BUSKULIC 96v assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.}$ $^6 \text{ Assumes } B(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_S) \text{ fraction 39.5\% (12\%).}$ $\frac{(K^+ K^-)/\Gamma_{\text{total}}}{(E_{\text{total}} \text{ total})} \frac{DOCUMENT 1D}{DOCUMENT 1D} \frac{TECN}{TECN} \frac{COMMENT}{TECN}$ $\frac{26.4 \pm 2.8 \text{ OUR AVERAGE}}{25.8 \pm 2.2 \pm 1.7} \frac{1}{20.2 \pm 1.7} \text{ AALTONEN } 11\text{ N CDF } p \overline{p} \text{ at } 1.96 \text{ TeV}$ $38 \stackrel{+}{-} \frac{10}{9} \pm 7 \qquad 2 \text{ PENG} \qquad 10 \text{BELL} e^+ e^- \to T(5S)$ $0.9 \bullet \text{ We do not use the following data for averages, fits, limits, etc.} \bullet \bullet \bullet$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $(39.7 \overset{+}{-}\overset{1}{2}\overset{.8}{.})\% \text{ and } f_{B_S} = (10.5 \overset{+}{-}\overset{1}{2}\overset{.8}{.})\%.$ $^5 \text{ BUSKULC 96v assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.}$ $^6 \text{ Assumes B}(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_s) \text{ fraction } 39.5\% (12\%).$ $(K^+K^-)/\Gamma_{\text{total}} \qquad \qquad \Gamma_{35}/\Gamma_{\text{CL}\%} \qquad \qquad \Gamma_{35}/\Gamma_{\text{CL}} \qquad \qquad \Gamma_{35}/\Gamma_$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{c} (39.7 + \frac{1}{2}.8)\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.8)\%. \\ 5 \text{ BUSKULIC 96v assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.} \\ 6 \text{ Assumes } B(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_s) \text{ fraction 39.5\% (12\%).} \\ \hline \textbf{C(K^+ K^-)/\Gamma total} & \textbf{\Gamma_{35}/\Gamma} \\ \hline \textbf{C(K^+ K^-)/\Gamma total} & \textbf{DOCUMENT 1D} & \textbf{TECN} & \textbf{COMMENT} \\ \hline \textbf{26.44 2.8 OUR AVERAGE} \\ \hline 25.8 \pm 2.2 \pm 1.7 & 1 \text{ AALTONEN } 11\text{ N CDF } p \overline{p} \text{ at } 1.96 \text{ TeV} \\ \hline 38 + \frac{10}{9} \pm 7 & 2 \text{ PENG} & 10 \text{ BELL } e^+e^- \to r(5S) \\ \hline \textbf{33 } \pm 6 \pm 7 & 3 \text{ ABULENCIA, A 06b CDF } \text{ Repl. by AALTONEN 11N} \\ \hline \textbf{283} & 90 & 4 \text{ ABE} & 00\text{C SLD } e^+e^- \to Z \\ \hline \textbf{2400} & 90 & 5 \text{ BUSKULIC 96V ALEP } e^+e^- \to Z \\ \hline \textbf{2140} & 90 & 6 \text{ AKERS} & 94\text{ LOPAL } e^+e^- \to Z \\ \hline \textbf{1 AALTONEN 11N reports } (f_S/f_d) (B(B^0_S \to K^+K^-)) + B(B^0 \to K^+\pi^-)) = 0.347 \pm 1.96 \\ \hline \textbf{1 ABLTONEN 11N reports } (f_S/f_d) (B(B^0_S \to K^+K^-)) + B(B^0 \to K^+\pi^-)) = 0.347 \pm 1.96 \\ \hline \textbf{2 Note of the sum of the production of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{1 AALTONEN 11N reports } (f_S/f_d) (B(B^0_S \to K^+K^-)) + B(B^0 \to K^+\pi^-)) = 0.347 \pm 1.96 \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline \textbf{2 Note of the production fractions for B^0, B^+, B_S, b baryons.} \\ \hline 2 Note of the production fractions for B^0, B^0, B^0, B^0, B^0, B^0, B^0, B^0,$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{c} (39.7 + \frac{1}{2}.\frac{8}{2})\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.\frac{8}{2})\%. \\ 5 \text{ BUSKULIC 96V assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.} \\ 6 \text{ Assumes B}(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_s) \text{ fraction 39.5\% (12\%).} \\ \hline \textbf{C(K^+ K^-)/\Gamma total} \\ \hline \textbf{C(K^+ K^-)/\Gamma total} \\ \hline \textbf{C(L\%)} \\ \hline \textbf{26.4 \pm 2.8 \text{ OUR AVERAGE}} \\ \hline 25.8 \pm 2.2 \pm 1.7 \\ 38 + \frac{10}{9} \pm 7 \\ \hline \textbf{2PENG} \\ \hline \textbf{10} \\ \hline \textbf{BELL} \\ \hline \textbf{e}^+ e^- \to \textbf{T(5.5)} \\ \hline \textbf{33} \\ \pm 6 \\ \pm 7 \\ \hline \textbf{3} \\ \hline \textbf{3} \\ \hline \textbf{ABULENCIA, A} \\ \hline \textbf{36} \\ \hline \textbf{26} \\ \hline \textbf{29} \\ \hline \textbf{90} \\ \hline \textbf{3} \\ \hline \textbf{3} \\ \hline \textbf{BUSKULIC 96V ALEP} \\ \hline \textbf{6} \\ \hline \textbf{6} \\ \hline \textbf{735/\Gamma} \\ \hline \textbf{10} \\ \hline$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $\begin{array}{c} (39.7 + \frac{1}{2}.8)\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.8)\%. \\ 5 \text{ BUSKULIC 96V assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.} \\ 6 \text{ Assumes B}(Z \to b \overline{b}) = 0.217 \text{ and } B^0_d (B^0_s) \text{ fraction 39.5\% (12\%).} \\ \hline F(K^+ K^-)/\Gamma_{\text{total}} & & & & & & & & & & & & & & & & & & $ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| $\begin{array}{c} (39.7 + \frac{1}{2}.8)\% \text{ and } f_{B_S} = (10.5 + \frac{1}{2}.8)\%. \\ 5 \text{ BUSKULIC 96V assumes PDG 96 production fractions for } B^0, B^+, B_S, b \text{ baryons.} \\ 6 \text{ Assumes } B(Z \to b \overline{b}) = 0.217 \text{ and } B_d^0 (B_S^0) \text{ fraction } 39.5\% (12\%). \\ \hline C(K^+ K^-)/\Gamma \text{total} & & & & & & & & & & & & & & & & & & &$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| ⁶ Uses <i>B</i> production ra | atio $f(\overline{b} \rightarrow B^+)$ | $/f(\overline{b} \rightarrow B^0)$ | = 3.86 | \pm 0.59, and the | number of |
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| $B^+ \rightarrow J/\psi K^+$ dec 7 Uses B production ra | ays. | | | | |
| $B^+ \rightarrow J/\psi K^+ \text{ dec.}$ | avs. | | | | ilumber of |
| ⁸ Assumes production | cross-section $\sigma(B)$ | $_{\rm S})/\sigma(B^+) =$ | 0.270 ± | 0.034. | |
| 9 Assumes production of | ross section $\sigma(B^+)$ | $)/\sigma(B_S)=3.$ | $.71 \pm 0.4$ | 11 and B($B^+ 	o J$ | $1/\psi K^+ \rightarrow$ |
| $\mu^+\mu^-$ K $^+$) = (5.88 10 Assumes production of | \pm 0.26) \times 10 ⁻⁵ . | $1/\sigma(R^{+}) =$ | 0.100/0 | 391 and the CDE | measured |
| value of $\sigma(B^+)=3$. | $6 \pm 0.6 \ \mu b$. | | | | |
| ¹¹ ABE 98 assumes pro | duction of $\sigma(B^0)$ | | | | |
| malize to their measu ¹² ACCIARRI 97B assun | | | | | |
| ¹³ ABE 96L assumes <i>B</i> | B^+/B_c production | ratio 3/1 | They n | ormalize to their | b. me asured |
| $\sigma(B^+, \rho_T(B) > 6 \text{ Ge}$ | | | | | |
| $(e^+ e^-)/\Gamma_{\text{total}}$ | | | | | Γ44/Γ |
| Test for $\Delta B = 1$ w | | nt. | T.C. | | - 44 / - |
| 4LUE <2.8 × 10 ⁻⁷ | | | P CDF | <u>COMMENT</u> pp at 1.96 Te | |
| • We do not use the | | | | | • |
| $< 5.4 \times 10^{-5}$ | 90 ¹ ACCI | | в L3 | $e^+e^- ightarrow ~Z$ | |
| ¹ ACCIARRI 97B assun | ne PDG 96 produc | ction fractions | for <i>B</i> [⊢] | $^-$, B^0 , B_s , and Λ | b· |
| $(e^{\pm}\mu^{\mp})/\Gamma_{ m total}$ | | | | | Γ ₄₅ /Γ |
| Test of lepton fam | | | | | |
| <2.0 × 10 ⁻⁷ 90 | | <i>NT ID</i> NEN 09P | | pp at 1.96 TeV | |
| • We do not use the | | | | | |
| $<6.1 \times 10^{-6}$ 90 | | 98∨ | | Repl. by AALTO | NEN 09P |
| $<4.1 \times 10^{-5}$ 90 | | | | $e^+e^- \rightarrow Z$ | |
| ¹ ACCIARRI 97B assun | | ction tractions | S TOT B | , B° , B_S , and A_S | b. |
| $(\phi(1020)\mu^+\mu^-)/\Gamma_1$ Test for $\Delta B=1$ w | otal | n+ | | | Γ ₄₆ /Γ |
| ALUE TEST FOR $\Delta B = 1$ W | <u>CL%</u> <u>DOCU</u> | III. IMENT ID | ΤΕCΛ | <u>COMMENT</u> | |
| We do not use the | | _ | | | |
| $< 3.2 \times 10^{-6} $ $< 4.7 \times 10^{-5}$ | 90 ¹ ABA: 90 ACO: | | G D0 D CDF | | |
| ¹ Uses B($B_s^0 \rightarrow J/\psi \phi$ | | 5177 02 | D CDI | pp ut 1.0 10 v | |
| ` 5 | | | | | Γ ₄₆ /Γ ₁₈ |
| $(\phi(1020)\mu^{+}\mu^{-})/\Gamma$ | | NT ID | TECN | COMMENT | . 40/ - 10 |
| • | | | | COMMENT | |
| 1.13±0.19±0.07 | <u>DOCUME</u> AALTOI | NEN 11AI | CDF | $p\overline{p}$ at 1.96 TeV | |
| ALUE (units 10 ⁻³) 1.13±0.19±0.07 • • We do not use the | % <u>DOCUME</u> AALTON e following data fo | NEN 11AI or averages, fi | CDF ts, limit: | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet | |
| 1.13 \pm 0.19 \pm 0.07 • • We do not use the 1.11 \pm 0.25 \pm 0.09 | <u>%</u> <u>DOCUME</u> AALTON e following data fo AALTON | NEN 11AI or averages, fi NEN 11L | CDF ts, limit: CDF | $p\overline{p}$ at 1.96 TeV s, etc. • • • Repl. by AALTO | |
| ALUE (units 10^{-3}) CL 1.13±0.19±0.07 • • We do not use the 1.11±0.25±0.09 <2.3 90 | % <u>DOCUME</u> AALTON e following data for AALTON | NEN 11AI or averages, fi NEN 11L | CDF ts, limit: CDF | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet | NEN 11L |
| ALUE (units 10 ⁻³) CL 1.13±0.19±0.07 • • We do not use the 1.11±0.25±0.09 <2.3 90 • $(\phi \nu \overline{\nu})/\Gamma_{\text{total}}$ | M DOCUME. AALTOP Following data for AALTOP AALTOP | NEN 11AI or averages, fi NEN 11L (NEN 09B | CDF ts, limit: CDF | $p\overline{p}$ at 1.96 TeV s, etc. • • • Repl. by AALTO | |
| 1.13 ± 0.19 ± 0.07 • • We do not use the 1.11 ± 0.25 ± 0.09 < 2.3 90 $(\phi \nu \overline{\nu})/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ was the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and t | M DOCUME. AALTOP Following data for AALTOP AALTOP AALTOP Weak neutral currect CL% DOCUME. | NEN 11AI or averages, fi NEN 11L ^o NEN 09B nt. <i>IMENT ID</i> | CDF ts, limit: CDF CDF | pp at 1.96 TeV s, etc. • • • Repl. by AALTO Repl. by AALTO | NEN 11L |
| 1.13 ± 0.19 ± 0.07 • We do not use the 1.11 ± 0.25 ± 0.09 (22.3 90 $(\phi \nu \overline{\nu})/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ was 4.4UE | M DOCUME. AALTOI a following data for AALTOI AALTOI AALTOI ALTOI CLM DOCU 1 ADA | NEN 11AI or averages, fi NEN 11L o NEN 09B nt. or MENT ID M 96 | CDF ts, limits CDF CDF | $p\overline{p}$ at 1.96 TeV 5, etc. • • • Repl. by AALTO Repl. by AALTO | NEN 11L |
| ALUE (units 10^{-3}) CL 1.13±0.19±0.07 • We do not use the 1.11±0.25±0.09 <2.3 90 $(\phi \nu \overline{\nu})/\Gamma_{\text{total}}$ Test for $\Delta B = 1$ was the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of th | M DOCUME. AALTOI a following data for AALTOI AALTOI AALTOI ALTOI CLM DOCU 1 ADA | NEN 11AI or averages, fi NEN 11L o NEN 09B nt. or MENT ID M 96 | CDF ts, limits CDF CDF | pp at 1.96 TeV s, etc. • • • Repl. by AALTO Repl. by AALTO | NEN 11L |
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| ALUE (units 10^{-3}) CL 1.13±0.19±0.07 • • We do not use the 1.11±0.25±0.09 (2.3 96 ($\phi \nu \overline{\nu}$)/ Γ total Test for $\Delta B = 1$ w ALUE 5.4 × 10 ⁻³ 1 ADAM 96D assumes 1./ Γ in $B_s^0 \rightarrow D_s^* \rho^0$ ALUE 0.05±0.08±0.03 -0.10±0.04 | $ \begin{array}{ccc} \frac{\%}{\%} & \underline{\textit{DOCUME}}, \\ & & & & & & \\ & & & & & \\ & & & & & $ | NEN 11AI or averages, finen 11L on NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the Nen 19B on the | CDF ts, limits CDF TECN D DLP 0.12. DECA | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet \bullet Repl. by AALTO Repl. by AALTO H $e^+e^- \to Z$ | NEN 11L |
| 1.13 \pm 0.19 \pm 0.07 • We do not use the 1.11 \pm 0.25 \pm 0.09 ($\phi \nu p$)/ Γ total Test for $\Delta B = 1$ was 1.40 M 96D assumes 1.1/ Γ in $B_s^0 \rightarrow D_s^* \rho^0$ ΔLUE 1.1/ Γ in $B_s^0 \rightarrow J/\psi$ 1.1/ Γ in $B_s^0 \rightarrow J/\psi$ | $\begin{array}{ccc} \frac{\%}{\%} & \underline{\textit{DOCUME}}, \\ & & & & & & \\ & & & & & \\ & & & & & $ | NEN 11AI or averages, finen 11L on NEN 09B on the NEN 11L on NEN 09B on the NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of NEN 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of Nen 11B of | CDF ts, limit: CDF CDF TECA D DLP 0.12. DECA BELI | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet Repl. by AALTO Repl. by AALTO $\frac{d}{dt} = \frac{COMMENT}{e^+e^- \to Z}$ | NEN 11L |
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| ALUE (units 10^{-3}) CL/ Γ in $B_s^0 \rightarrow D_s^* \rho^{ALUE}$ L/ Γ in $B_s^0 \rightarrow J/\psi$ ALUE (LIFE AND AVEF. 5.24 ± 0.015 OUR AVEF. 5.24 ± 0.015 OUR AVEF. 5.24 ± 0.015 OUR AVEF. 5.24 ± 0.015 + 0.015 OUR AVEF. 5.24 ± 0.013 ± 0.015 | $\begin{array}{ccc} & & & & & & & & & \\ & & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & \\ & & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ &$ | NEN 11AI or averages, fit nen 11L on NEN 11L on NEN 19B on NEN 19B on NEN 19B on NEN 19B on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12D on NEN 12 | CDF ts, limit: CDF CDF TECA D DLP 0.12. DECA BELI TECN tor of 1. CDF | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet \bullet Repl. by AALTO Repl. by AALTO $\frac{d}{dt} = \frac{COMMENT}{e^+e^- \rightarrow Z}$ $\frac{COMMENT}{e^+e^- \rightarrow T}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ 2. | NEN 11L |
| ALUE (units 10^{-3}) CL 1.13±0.19±0.07 • • We do not use the 1.11±0.25±0.09 (2.3) 90 ($\phi \nu \overline{\nu}$)/ Γ total Test for $\Delta B = 1$ w ALUE (5.4 × 10 ⁻³ 1 ADAM 96D assumes 1./ Γ in $B_s^0 \rightarrow D_s^* \rho$ ALUE 0.5±0.08±0.03 ($\mu \nu \overline{\nu}$)/ $\nu \nu \nu$ ($\nu \nu \overline{\nu}$)/ $\nu \nu$ ($\nu \nu \nu \nu$)/ $\nu \nu$ 1 ADAM 96D assumes | $\begin{array}{ccc} \frac{\%}{A} & \underline{\textit{DOCUME}}, \\ & \text{AALTOI} \\ & \text{e following data fo}, \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOI} \\ & \text{AALTOIN } \\ & AALTOIN$ | NEN 11AI or averages, finen 11L on NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the NEN 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the Neu 19B on the | CDF ts, limits CDF TECA D DLP 0.12. DECA BELI TECN TO DD TO DD TO DD TO DD TO DD TO DD TO DD | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet \bullet Repl. by AALTO Repl. by AALTO $\frac{d}{dt} = \frac{COMMENT}{e^+e^- \rightarrow Z}$ $\frac{d}{dt} = \frac{COMMENT}{e^+e^- \rightarrow Z}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2$ | NEN 11L |
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DECA BELI TECN CDF CDF CDF CDF CDF CDF CDF CDF CDF CDF | $p\overline{p}$ at 1.96 TeV s, etc. \bullet \bullet \bullet Repl. by AALTO Repl. by AALTO $\frac{COMMENT}{E}$ H $e^+e^- \rightarrow Z$ $\frac{COMMENT}{E}$ L $e^+e^- \rightarrow T$ $\frac{COMMENT}{E}$ 2. $p\overline{p}$ at 1.96 TeV $p\overline{p}$ at 1.8 TeV $p\overline{p}$ at 1.8 TeV s, etc. \bullet \bullet \bullet Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO Repl. by AALTO R | NEN 11L |

 2 The error includes both statistical and systematic uncertainties. 3 AFFOLDER 00N measurements are based on 40 B_s^0 candidates obtained from a data sample of 89 pb $^{-1}$. The *P*-wave fraction is found to be 0.23 \pm 0.19 \pm 0.04. 4 Measured the angular and lifetime parameters for the time-dependent angular untagged decays $B_d^0 \rightarrow J/\psi \, K^{*0}$ and $B_s^0 \rightarrow J/\psi \, \phi$.

| Γ_{\perp}/Γ in $B_s^0 \to J/\psi(1S)$ | Φ <u>DO CUMENT ID</u> | | TECN | COMMENT |
|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|---------------------|----------------------|--------------------------------------------|
| 0.231 ± 0.016 OUR AVERAGE | | | | |
| $0.231 \pm 0.014 \pm 0.015$ | $^{ m 1}$ aaltonen | 12D (| CDF | p p at 1.96 TeV |
| $0.231 {}^{+ 0.024}_{- 0.030}$ | ^{1,2} ABAZOV | 12D [| D0 | p p at 1.96 TeV |
| • • • We do not use the follo | wing data for avera | ges, fits | , limits, | etc. • • • |
| $0.244 \pm 0.032 \pm 0.014$ | ³ ABAZOV | 09E I | D0 | Repl. by ABAZOV 12D |
| $0.239 \pm 0.029 \pm 0.011$ | $^{ m 1}$ aaltonen | | | Repl. by AALTONEN 121 |
| $0.125 \pm 0.069 \pm 0.002$ | ACOSTA | | | Repl. by AALTONEN 08. |
| ¹ Measured using the time-d | ependent angular a | nalysis | of B_s^0 – | \rightarrow $J/\psi\phi$ decays. |
| 2 The error includes both sta 3 Measured the angular and decays $B_d^0 	oup J/\psi K^{*0}$ a | lifetime parameters | atic und for the | ertaintie time-de | es. :pendent angular untagged |
| ϕ_{\parallel} in ${\cal B}^0_s ightarrow \; J/\psi(1S) \phi$ | | | | |
| VALUE (rad) | . 1 ABAZOV | D | TECN | COMMENT |
| 3.15 ± 0.22 • • • We do not use the follo | * ABAZOV wing data for avera | 12D ges, fits | D0 s, limits, | $p\overline{p}$ at 1.96 TeV etc. • • • |
| $2.72^{+1.12}_{-0.27} \pm 0.26$ | ABAZOV | 09E | D0 | Repl. by ABAZOV 12D |
| $^{ m 1}$ The error includes both sta | ntistical and system | atic unc | ertaintie | es. |
| Γ_L/Γ in $B_s^0 	o \phi \phi$ | DO CUMENT | | TECN | COMMENT |
| VALUE 0.348±0.041±0.021 | . <u>DOCUMENT I</u> AALTONEN | | <u>TECN</u> N CDF | |
| Γ_{\perp}/Γ in $B^0_s 	o \phi \phi$ | | | | pp at 1130 101 |
| VALUE | DO CUMENT I | | TECN | COMMENT |
| $0.365 \pm 0.044 \pm 0.027$ | AALTONEN | 11A | N CDF | $p\overline{p}$ at 1.96 TeV |
| ϕ_{\parallel} in $B_s^0 	o \phi \phi$ | | | | |
| VALUE (rad) | DO CUMENT I | D | TECN | COMMENT |
| $2.71^{+0.31}_{-0.36} \pm 0.22$ | ¹ AALTONEN | 11A | n CDF | ρ ρ at 1.96 TeV |
| ¹ AALTONEN 11AN quotes the smaller solution. | $\cos\phi_{\parallel} = -0.91 \begin{array}{c} +0 \\ -0 \end{array}$ | $^{15}_{13} \pm 0$ | .09 whic | th we convert to ϕ_{\parallel} taking |
| Γ_L/Γ in $B_s^0 \to K^{*0}\overline{K}^{*0}$ | 0.000 | | T. C | |
| VALUE 0.31±0.12±0.04 | . <u>DOCUMENT I</u> AAIJ | | | pp at 7 TeV |
| | 71/113 | 141 | LITCD | pp ut 1 100 |
| Γ_{\perp}/Γ in $B_s^0 \to K^{*0} \overline{K}^{*0}$ | <u>DOCUMENT I</u> | D | TECN | <u>COMMENT</u> |
| $0.38 \pm 0.11 \pm 0.04$ | AAIJ | 12F | LHCB | ρρ at 7 TeV |
| | $B_s^0 - \overline{B}_s^0$ MIX | ING | | |
| For a discussion of B_{i}^{0} | $\frac{1}{2} - \overline{B}_{S}^{0}$ mixing see the | note o | n "B ⁰ -ī | $\overline{3}^0$ Mixing" in the |
| B ⁰ Particle Listings a | | | | |

 χ_S is a measure of the time-integrated $B_S^0 \overline{B}_S^0$ mixing probability that produced $B_S^0 (\overline{B}_S^0)$ decays as a $\overline{B}_S^0 (B_S^0)$. Mixing violates $\Delta B \neq 2$ rule.

$$\chi_s = \frac{x_s^2}{2(1+x_s^2)}$$

$$x_{s} = \frac{\Delta m_{B_{s}^{0}}}{\Gamma_{B_{s}^{0}}} = (m_{B_{sH}^{0}} - m_{B_{sL}^{0}}) \tau_{B_{s}^{0}},$$

where H, L stand for heavy and light states of two B_s^0 CP eigenstates and $\tau_{B_s^0} = \frac{1}{0.5(\Gamma_{B_s^0 H}^0 + \Gamma_{B_s^0 L}^0)}$.

$\Delta m_{B_s^0} = m_{B_{sH}^0} - m_{B_{sL}^0}$

's "sH"'sL $\Delta m_{B_s^0}$ is a measure of 2π times the B_s^0 - \overline{B}_s^0 oscillation frequency in time-dependent mixing experiments.

"OUR EVALUATION" is provided by the Heavy Flavor Averaging Group (HFAG) by taking into account correlations between measurements.

| VALUE (10 ¹² ħ s ⁻¹) | CL% | | TECN | COMMENT | |
|---------------------------------------------|---------------|-------|------|-------------|--|
| 17.69±0.08 OUR E | VALUATION | | | | |
| 17.69±0.08 OUR A | VERAGE | | | | |
| $17.63 \pm 0.11 \pm 0.02$ | 1 AAIJ | 121 | LHCB | pp at 7 TeV | |
| $1777 \pm 0.10 \pm 0.07$ | 2 ariii encia | A 06c | CDE | n | |

| • | • | • | We do | not | use | the | following | data | for | averages, | fits, | limits, | etc. | • | • | • | |
|---|---|---|-------|-----|-----|-----|-----------|------|-----|-----------|-------|---------|------|---|---|---|--|
| | | | | | | | | | | | | | | | | | |

| • | • • vvc do not usc | the folk | Jwille data for aver | agcs, | 1113, 11111 | 113, CtC. • • • |
|---|--------------------------------|----------|--------------------------|-------|-------------|------------------------------------|
| | 17-21 | 90 | ³ ABAZOV | 06в | D0 | $\rho \overline{\rho}$ at 1.96 TeV |
| | $17.31^{+0.33}_{-0.18}\pm0.07$ | | ⁴ ABULENCIA | 06 Q | CDF | Repl. by ABULEN- CIA,A 06G_ |
| 2 | > 8.0 | 95 | ⁵ ABDALLAH | 04 J | DLPH | $e^+e^- \rightarrow Z^0$ |
| 2 | > 4.9 | 95 | ⁶ ABDALLAH | 04 J | DLPH | $e^+e^- \rightarrow Z^0$ |
| 2 | > 8.5 | 95 | ⁷ ABDALLAH | 04 J | DLPH | $e^+e^- \rightarrow Z^0$ |
| 2 | > 5.0 | 95 | ⁸ ABDALLAH | 03в | DLPH | $e^+e^- \rightarrow Z$ |
| 2 | >10.3 | 95 | ⁹ ABE | 03 | SLD | $e^+e^- \rightarrow Z$ |
| 2 | >10.9 | 95 | ¹⁰ HEISTER | 03E | ALEP | $e^+e^- \rightarrow Z$ |
| 2 | > 5.3 | 95 | ¹¹ ABE | 02v | SLD | $e^+e^- \rightarrow Z$ |
| 2 | > 1.0 | 95 | ¹² ABBIENDI | 01 D | OPAL | $e^+e^- \rightarrow Z$ |
| 2 | > 7.4 | 95 | ¹³ ABREU | 00Y | DLPH | Repl. by ABDALLAH 04J |
| 2 | > 4.0 | 95 | ¹⁴ ABREU,P | 00 G | DLPH | $e^+e^- \rightarrow Z$ |
| 2 | > 5.2 | 95 | ¹⁵ ABBIENDI | 99s | OPAL | $e^+e^- \rightarrow Z$ |
| < | <96 | 95 | ¹⁶ ABE | 99D | CDF | ρ p at 1.8 TeV |
| 2 | > 5.8 | 95 | ¹⁷ ABE | 99 J | CDF | ρ p at 1.8 TeV |
| 2 | > 9.6 | 95 | ¹⁸ BARATE | 99 J | ALEP | $e^+e^- 	o Z$ |
| 2 | > 7.9 | 95 | ¹⁹ BARATE | 98 c | ALEP | Repl. by BARATE 99J |
| 2 | > 3.1 | 95 | ²⁰ ACKERSTAFF | | OPAL | Repl. by ABBIENDI 99s |
| | > 2.2 | 95 | ²¹ ACKERSTAFF | 97∨ | OPAL | Repl. by ABBIENDI 99s |
| | > 6.5 | 95 | ²² ADAM | 97 | DLPH | Repl. by ABREU 00Y |
| | > 6.6 | 95 | ²³ BUSKULIC | | ALEP | Repl. by BARATE 980 |
| | > 2.2 | 95 | ²¹ AKERS | 95 J | OPAL | Sup. by ACKERSTAFF 97V |
| | > 5.7 | 95 | ²⁴ BUSKULIC | 95 J | ALEP | $e^+e^- \rightarrow Z$ |
| 2 | > 1.8 | 95 | ²¹ BUSKULIC | 94B | ALEP | $e^+e^- \rightarrow Z$ |
| | | | | | | |

- ¹ Measured using $B_S^0 \rightarrow D_S^- \pi^+$ and $D_S^- \pi^+ \pi^- \pi^+$ decays.
- 2 Significance of oscillation signal is 5.4 $\sigma.$ Also reports $|V_{td}|/|V_{ts}|=0.2060$ \pm
- 3 A likelihood scan over the oscillation frequency, $\Delta m_{_S}$, gives a most probable value of 19 ps $^{-1}$ and a range of 17< $\Delta m_s <$ 21 (ps $^{-1}$) at 90% C.L. assuming Gaussian uncertainties. Also excludes $\Delta m_s < \!\! 14.8~\mathrm{ps}^{-1}$ at 95% C.L
- 4 Significance of oscillation signal is 0.2%. Also reported the value $\left|V_{\,td}\right|$ / $\left|V_{\,ts}\right|$ = $0.208 + 0.001 + 0.008 \\ -0.002 - 0.006$
- 5 Uses leptons emitted with large momentum transverse to a jet and improved techniques for vertexing and flavor-tagging.
- $^{6}\,\mathrm{Updates}$ of $\overset{\smile}{D}_{S}\text{-lepton}$ analysis.
- 7 Combined results from all Delphi analyses.
- $8\,\mbox{Events}$ with a high transverse momentum lepton were removed and an inclusively reconstructed vertex was required.
- and tertiary vertices originating from the $B \to D$ decay chain. The analysis excludes $\Delta m_S < 4.9 \, \mathrm{ps}^{-1}$ and $7.9 < \Delta m_S < 10.3 \, \mathrm{ps}^{-1}$.
- 10 Three analyses based on complementary event selections: (1) fully-reconstructed hadronic decays; (2) semileptonic decays with $D_{\rm S}$ exclusively reconstructed; (3) inclusive semileptonic decays
- $^{11}\,\mathrm{ABE}$ 02v uses exclusively reconstructed D_s^- mesons and excludes $\Delta m_s < \!\! 1.4\,\mathrm{ps}^{-1}$ and $2.4 < \, \Delta m_{\,S} <$ 5.3 ps $^{-1}\,$ at 95%CL.
- 12 Uses fully or partially reconstructed $D_{\rm S}\ell$ vertices and a mixing tag as a flavor tagging.
- 13 Replaced by ABDALLAH 04A. Uses $D_s^-\ell^+$, and $\phi\ell^+$ vertices, and a multi-variable discriminant as a flavor tagging.
- 14 Uses inclusive D_S vertices and fully reconstructed B_S decays and a multi-variable discriminant as a flavor tagging.
- 15 Uses $\ell ext{-}Q_{ ext{hem}}$ and $\ell ext{-}\ell ext{.}$
- 16 ABE 99D assumes $\tau_{B_{s}^{0}}=1.55\,\pm\,0.05$ ps and $\Delta\Gamma/\Delta \textit{m}=\,(5.6\,\pm\,2.6)\times10^{-3}.$
- $^{17} \mathrm{ABE}$ 99J uses ϕ $\ell\text{-}\ell$ correlation.
- 18 BARATE 99J uses combination of an inclusive lepton and D_s^- -based analyses.
- 19 BARATE 98c combines results from $D_s h$ - $\ell/Q_{
 m hem}$, $D_s h$ -K in the same side, $D_s \ell$ - $\ell/Q_{\mbox{\scriptsize hem}}$ and $D_S\,\ell ext{-}K$ in the same side.
- ²⁰ Uses ℓ-Q_{hem}
- 21 Uses ℓ - ℓ . 22 ADAM 97 combines results from $D_S\ell$ - $Q_{\rm hem}$, ℓ - $Q_{\rm hem}$, and ℓ - ℓ .
- 23 BUSKULIC 96M uses $D_{\scriptscriptstyle S}$ lepton correlations and lepton, kaon, and jet charge tags.
- 24 BUSKULIC 95J uses $\ell\text{-}Q_{\text{hem}}$. They find $\Delta m_S>5.6$ [> 6.1] for $\textit{f}_{\text{S}}{=}10\%$ [12%]. We interpolate to our central value $\textit{f}_{\text{S}}{=}10.5\%$.

$x_s = \Delta m_{B_s^0} / \Gamma_{B_s^0}$

This is derived by the Heavy Flavor Averaging Group (HFAG) from the results on $\Delta m_{B_0^0}$ and "OUR EVALUATION" of the B_0^0 mean lifetime.

26.49±0.29 OUR EVALUATION

DO CUMENT ID

This is a $B_s^0 - \overline{B}_s^0$ integrated mixing parameter derived from x_s above and OUR EVAL-UATION of $\Delta \Gamma_{B_0} / \Gamma_{B_0}$

0.499292±0.000016 OUR EVALUATION

DO CUMENT ID

CP VIOLATION PARAMETERS in B

$\operatorname{Re}(\epsilon_{B_s^0}) / (1 + |\epsilon_{B_s^0}|^2)$

CP impurity in B_s^0 system.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/scaling procedure takes into account correlation between the measurements. The value has been obtained from a 2D fit of the B_d and B_s asymmetries, which includes the B_s measurements listed below and the B factory average for the B_d .

| VALUE (units 10^{-3}) | DO CUMENT IE |) | TECN | COMMENT |
|--------------------------------|---------------------|------------|---------|-----------------------------|
| -2.6±1.6 OUR EVALUATION | | | | |
| -2.2±2.0 OUR AVERAGE Er | | | | |
| -4.5 ± 2.7 | $^{ m 1}$ ABAZOV | | D0 | $p\overline{p}$ at 1.96 TeV |
| $-0.4\pm2.3\pm0.4$ | ² ABAZOV | 10E | D0 | $p\overline{p}$ at 1.96 TeV |
| • • • We do not use the follow | ing data for avera | ges, fits, | limits, | etc. • • • |
| _36+19 | 3 ABAZOV | 1.0H | D0 | Rent by ABAZOV 11II |

⁴ ABAZOV $6.1 \pm 4.8 \pm 0.9$ 07A D0 Repl. by ABAZOV 10E 1 Uses the dimuon charge asymmetry with different impact parameters from which it reports $A_{SL}^s = (-18.1 \pm 10.6) \times 10^{-3}$.

 2 ABAZOV 10E reports a measurement of flavor-specific asymmetry in $B^0_{(s)}
ightarrow \mu^+ \, D^{*-}_{(s)} X$ decays with a decay-time analysis including initial-state flavor tagging, A $_{SL}^{s}$ =(-1.7 \pm $9.1^{+1.4}_{-1.5}) imes 10^{-3}$ which is approximately equal to 4 imes Re($\epsilon_{B^0_-}$) / (1 + $|\epsilon_{B^0_-}|^2$).

 3 ABAZOV 10H reports a measurement of like-sign dimuon charge asymmetry of $A_{SL}^b=(-9.57\pm2.51\pm1.46)\times10^{-3}$ in semileptonic b-hadron decays. Using the measurement sured production ratio of B_d^0 and B_s^0 , and the asymmetry of B_d^0 A_{SL}^0 =(-4.7 \pm 4.6) \times 10⁻³ measured from B-factories, they obtain the asymmetry for B_s^0 .

⁴ The first direct measurement of the time integrated flavor untagged charge asymmetry in semileptonic B_s^0 decays is reported as $2 \mathrm{xA}_{SL}^s (\mathrm{untagged}) = \mathrm{A}_{SL}^s = (2.45 \pm 1.93 \pm$ $0.35) \times 10^{-2}$.

CP Violation phase β_s

 $-2eta_s$ is the weak phase difference between B^0_s mixing amplitude and the B^0_s ightarrow $J/\psi\,\phi$ decay amplitude. The Standard Model value of β_{S} is $\arg(-\frac{V_{tS}V_{tb}^{*}}{V_{cS}V_{cb}^{*}})$.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at $http://www.slac.stanford.edu/xorg/hfag/. \ \ The \ averaging/scaling$ procedure takes into account correlation between the measurements.

DO CUMENT ID

0.08 + 0.05 OUR EVALUATION

0.02 ±0.11 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram

| DCIOW. | | | | |
|------------------------------|-------------------------|-----|------|------------------------------------|
| $0.22 \pm 0.22 \pm 0.01$ | ¹ AAIJ | 12B | LHCB | pp at 7 TeV |
| $-0.075 \pm 0.09 \pm 0.03$ | ² aaij | 12D | LHCB | pp at 7 TeV |
| | ³ AALTONEN | 12D | CDF | $p\overline{p}$ at 1.96 TeV |
| $0.275 {}^{+ 0.18}_{- 0.19}$ | ^{4,5,6} ABAZOV | 12D | D0 | $\rho \overline{\rho}$ at 1.96 TeV |

• • We do not use the following data for averages, fits, limits, etc. • •

| | 0 | 0 | · · |
|-------------------------------------------------------------------------|-----------------------|----------|-----------------------|
| | ⁷ AALTONEN | 08G CDF | Repl. by AALTONEN 12D |
| $\begin{array}{cccc} 0.28 & +0.12 & +0.04 \\ -0.15 & -0.01 \end{array}$ | ^{5,8} ABAZOV | 08AM D 0 | Repl. by ABAZOV 12D |
| $0.395 \pm 0.280 {}^{+ 0.005}_{- 0.070}$ | ^{6,9} ABAZOV | 07 D0 | Repl. by ABAZOV 07N |
| 0.35 + 0.20 | 6,10 ABAZOV | 07n D0 | Repl. by ABAZOV 08AM |

 1 Reports $\phi_{\it S}=-$ 2 $\beta_{\it S}=-$ 0.44 \pm 0.44 \pm 0.02 that was measured using a time-dependent fit to $B_s^0 \rightarrow J/\psi f_0(980)$ decays.

 2 Reports $\phi_S=-2$ $eta_S=0.15\pm0.18\pm0.06$ that was measured using a time-dependent angular analysis of $B_s^0 \to J/\psi \phi$ decays.

 3 Reports 0.02 < ϕ_S < 0.52 or 1.08 < ϕ_S < 1.55 at 68% C.L. confidence regions in the two-dimensional space of ϕ_s and $\Delta\Gamma_{B^0_s}$ from $B^0_s \to J/\psi \phi$ decays.

⁴ The error includes both statistical and systematic uncertainties

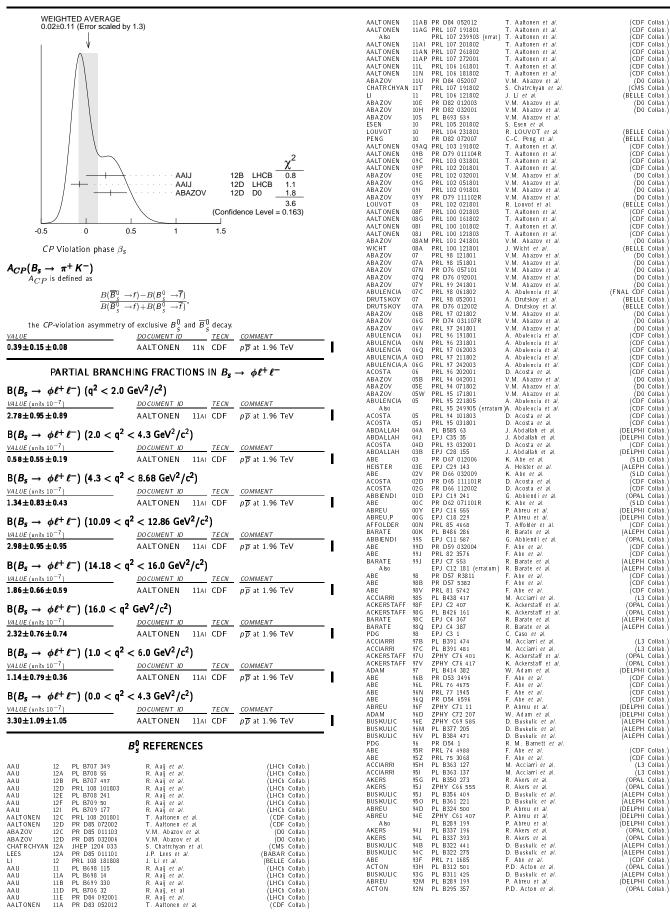
 5 Measured using fully reconstructed $B_{S} \rightarrow J/\psi \phi$ decays.

⁶ Reports ϕ_s which equals to $-2\beta_s$.

 $^7\,\mathrm{Reports}$ 0.32 $<2\beta_\mathrm{S}<$ 2.82 at 68% C.L. and confidence regions in the two-dimensional space of $2\beta_s$ and $\Delta\Gamma$ from the first measurement of $B_s^0 \to J/\psi \phi$ decays using flavor tagging. The probability of a deviation from SM prediction as large as the level of observed data is 15%. 8 Reports $\phi_S=-2$ β_S and obtains 90% CL interval -0.03 < β_S < 0.60.

⁹The first direct measurement of the *CP*-violating mixing phase is reported from the time-dependent analysis of flavor untagged $B_s^0 \rightarrow J/\psi \phi$ decays.

 $^{
m 10}$ Combines D0 collaboration measurements of time-dependent angular distributions in $B^0_s o J/\psi \, \phi$ and charge asymmetry in semileptonic decays. There is a 4-fold ambiguity in the solution.



PL B311 425 PL B289 199 PL B295 357

D. Buskulic et al. P. Abreu et al.

P.D. Acton et al.

(ALEPH Collab (DELPHI Collab

(OPAL Collab.

BUS KULIC

 B_s^0 , B_s^* , $B_{s1}(5830)^0$, $B_{s2}^*(5840)^0$, $B_{sJ}^*(5850)$

BUSKULIC 92E PL B294 145 LEE-FRANZINI 90 PRL 65 2947 D. Buskulic et al. J. Lee-Franzini et al. (ALEPH Collab. (CUSB II Collab.



VALUE (MeV)

$$I(J^P) = 0(1^-)$$

TECN COMMENT

 ${\it I},~{\it J},~{\it P}$ need confirmation. Quantum numbers shown are quark-model predictions.

B* MASS

DO CUMENT ID

From mass difference below and the B_c^0 mass

| 5415.4 + 2.4 OUR FIT Error | includes scale factor of | of 3.0. | |
|-----------------------------------------------------|--------------------------|-----------------|----------------------------------|
| 5415.8±1.5 OUR AVERAGE | Error includes scale t | factor of 2.6. | |
| $5416.4 \pm 0.4 \pm 0.5$ | | | $e^+ e^- \rightarrow \gamma(5S)$ |
| $5411.7 \pm 1.6 \pm 0.6$ | ¹ AQUINES | 06 CLEC | $e^+e^- \rightarrow \gamma(5S)$ |
| ● ● We do not use the following | owing data for average | s, fits, limits | , etc. • • • |
| 5418 ±1 ±3 | DRUTSKOY | 07A BELL | Repl. by LOUVOT 09 |
| 5414 ±1 ±3 | ² BONVICINI | 06 CLEC | $e^+e^- \rightarrow \gamma(5S)$ |

1 Utilized the beam constrained invariant mass peak positions for B^{\ast} and B_{8}^{\ast} to extract the measurement.

²Uses 14 candidates consistent with B_s decays into final states with a J/ψ and a $D_s^{(*)}$

$m_{B_s^*} - m_{B_s}$

VALUE (MeV)

DOCUMENT ID TECN COMMENT

48.7⁺2.3 OUR FIT Error includes scale factor of 2.8.

46.1±1.5 OUR AVERAGE

| $45.7 \pm 1.7 \pm 0.7$ | ³ AQUINES | 06 | CLEO | $e^+e^- \rightarrow \gamma(5.5)$ | 5) |
|-----------------------------------|----------------------|---------|---------|----------------------------------|------|
| 47.0 ± 2.6 | 4 LEE-FRANZINI | 90 | CSB2 | $e^+e^- \rightarrow \gamma(5.5)$ | 5) |
| • • • We do not use the following | data for averages | , fits, | limits, | etc. • • • | |
| 48 +1 +3 | 5 BONVICINI | 06 | CLEO | Real by AOIIIN | FS (|

 3 Utilized the beam constrained invariant mass peak positions for B^* and B_S^* to extract the measurement.

4 LEE-FRANZINI 90 measure 46.7 \pm 0.4 \pm 0.2 MeV for an admixture of B^0 , B^+ , and B_S . They use the shape of the photon line to separate the above value for B_S .

⁵ Uses 14 candidates consistent with B_{S} decays into final states with a J/ψ and a $D_{S}^{(*)}$

$|(m_{B_c^*} - m_{B_c}) - (m_{B^*} - m_{B})|$

<u>VALUE (MeV)</u> <u>CL%</u> **<6** 95

 DOCUMENT ID
 TECN
 COMMENT

 ABREU
 95r
 DLPH
 E em = 88-94 GeV

B* DECAY MODES

Mode Fraction (Γ_i/Γ) $\Gamma_1 \qquad B_{\rm S} \, \gamma$ dominant

B* REFERENCES

| A QUINES BONVICINI | 07 A 06 06 | PRL 102 021801 PR D76 012002 PRL 96 152001 PRL 96 022002 | R. Louvot et al. A. Drutskoy et al. O. Aquines et al. G. Bonvicini et al. | (BELLE Collab.) (BELLE Collab.) (CLEO Collab.) (CLEO Collab.) |
|-----------------------|------------------|-------------------------------------------------------------------|------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| ABREU LEE-FRANZINI | 95 R | ZPHY C68 353 | P. Abreu <i>et al.</i> J. Lee-Franzini <i>et al.</i> | (DELPHI Collab.) (CUSB II Collab.) |

 $B_{s1}(5830)^0$

 $I(J^P) = O(1^+)$ Status: ***

I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

B_{s1} (5830)0 MASS

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------|----------------|------|----------------------------|
| 5829.4±0.7 | 1 AALTONEN 08K | CDF | p p at 1.96 TeV |

 1 Uses two-body decays into K^- and B^+ mesons reconstructed as $B^+\to J/\psi\,K^+$, $J/\psi\to \mu^+\mu^-$ or $B^+\to \overline{D}{}^0\pi^+$, $\overline{D}{}^0\to K^+\pi^-$.

 $m_{B_{s1}^0} - m_{B^{*+}}$

<u>VALUE (MeV)</u> <u>DOCUME</u> **504.41 ± 0.21 ± 0.14** 2 AALTO

DOCUMENT ID TECN COMMENT

2 AALTONEN 08K CDF pp at 1.96 TeV

 2 Uses two-body decays into K^- and B^+ mesons reconstructed as $B^+\to J/\psi\,K^+$, $J/\psi\to~\mu^+\,\mu^-$ or $B^+\to~\overline{D}^0\,\pi^+$, $\overline{D}^0\to~K^+\,\pi^-$.

$B_{s1}(5830)^0$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------|------------------------------|
| $\overline{\Gamma_1}$ | B*+ K- | dominant |

B_{s1} (5830)0 BRANCHING RATIOS

B_{s1} (5830)⁰ REFERENCES

ALTONEN 08K PRL 100 082001

T. Aaltonen et al.

CDE Collab)

 $B_{s2}^*(5840)^0$

$$I(J^P) = 0(2^+)$$
 Status: ***

I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

B*2(5840)0 MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------|---------------------|-----|------|-----------------------------|
| 5839.7±0.6 OUR AVERAGE | | | | |
| 5839.7 ± 0.7 | $^{ m 1}$ AALTONEN | 08ĸ | CDF | $p\overline{p}$ at 1.96 TeV |
| $5839.6\pm1.1\pm0.7$ | ² ABAZOV | 08E | D0 | $p\overline{p}$ at 1.96 TeV |

 1 Uses two-body decays into K^- and B^+ mesons reconstructed as $B^+\to J/\psi\,K^+$, $J/\psi\to~\mu^+\mu^-$ or $B^+\to~\overline{D}^0\,\pi^+$, $\overline{D}^0\to~K^+\pi^-$.

 2 Observed in *0 50 $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^{+1}$ $^$

$m_{B_{s2}^{*0}} - m_{B_{s1}^{0}}$

 VALUE (MeV)
 DOCUMENT ID
 TECN
 COMMENT

 10.5 ± 0.6
 3 AALTONEN
 08 K
 CDF
 $p\overline{p}$ at 1.96 TeV

 3 Uses two-body decays into K^- and B^+ mesons reconstructed as $B^+\to J/\psi\,K^+$, $J/\psi\to\mu^+\mu^-$ or $B^+\to\overline{D}^0\,\pi^+$, $\overline{D}^0\to K^+\pi^-$.

B* (5840)0 DECAY MODES

Mode Fraction (Γ_i/Γ) $\Gamma_1 \qquad B^+K^- \qquad \qquad \text{dominant}$

$B_{s2}^*(5840)^0$ BRANCHING RATIOS

$B_{52}^*(5840)^0$ REFERENCES

 AALTONEN
 08K
 PRL 100 082001
 T. Aaltonen et al.
 (CDF Collab.)

 ABAZOV
 08E
 PRL 100 082002
 V.M. Abazov et al.
 (D0 Collab.)

 $B_{sJ}^{*}(5850)$

 $I(J^P) = ?(?^?)$ I, J, P need confirmation.

OMITTED FROM SUMMARY TABLE

Signal can be interpreted as coming from $\overline{\it b}\,{\it s}$ states. Needs confirmation.

$B_{sJ}^{*}(5850)$ MASS

 VALUE (MeV)
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 5853±15
 141
 AKERS
 95E
 OPAL
 $E_{\rm CM}^{\rm eff} = 88-94$ GeV

$B_{s,I}^{*}(5850)$ WIDTH

 VALUE (MeV)
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 47±22
 141
 AKERS
 95E
 OPAL
 E^{ee}_{CM} = 88-94 GeV

B_{sJ}^* (5850) REFERENCES

AKERS 95E ZPHY C66 19 R. Akers et al. (OPAL Collab.)

Meson Particle Listings B_c^{\pm} , Heavy Quarkonium Spectroscopy

BOTTOM, CHARMED MESONS

$(B=C=\pm 1)$

 $B_c^+ = c \overline{b}, B_c^- = \overline{c} b$, similarly for B_c^* 's



$$I(J^P) = 0(0^-)$$

I, J, P need confirmation.

Quantum numbers shown are quark-model predictions.

BE MASS

| VALUE (GeV) | DOCUMENT ID | TECN | COMMENT |
|--------------------------------------------------|-------------------------|-----------------|-----------------------------|
| 6.277 ±0.006 OUR AVERAGE | Error includes | scale factor of | of 1.6. |
| | | | <i>p</i> at 1.96 TeV |
| | | 08T D0 | $p\overline{p}$ at 1.96 TeV |
| $6.4 \pm 0.39 \pm 0.13$ | ² ABE | 98M CDF | $p\overline{p}$ at 1.8 TeV |
| ● ● We do not use the follow | ing data for avera | iges, fits, lim | its, etc. • • • |
| $6.2857 \pm 0.0053 \pm 0.0012$ | ¹ ABULENCIA | 06c CDF | Repl. by AALTONEN 08M |
| 6.32 ± 0.06 | ³ ACKERSTAFF | | |

 $^{^1}$ Measured using a fully reconstructed decay mode of $B_{\it C} \, \rightarrow \, J/\psi \, \pi.$

B_c^{\pm} MEAN LIFE

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements.

| VALUE (10 ⁻¹² s) | DOCUMENT ID | | TECN | COMMENT | | | |
|---------------------------------------------------------|------------------------|-----|------|-------------------------------|--|--|--|
| 0.453±0.041 OUR EVALUATION 0.45 ±0.04 OUR AVERAGE | | | | | | | |
| $0.448 {}^{+ 0.038}_{- 0.036} {\pm} 0.032$ | ⁴ ABAZOV | 09н | D0 | $p\overline{p}$ at 1.96 TeV | | | |
| $0.463^{+0.073}_{-0.065}\pm 0.036$ | ⁵ ABULENCIA | 060 | CDF | $p\overline{p}$ at 1.96 TeV | | | |
| $0.46 \ ^{+ 0.18}_{- 0.16} \ \pm 0.03$ | ⁵ ABE | 98м | CDF | <i>p</i> p 1.8 TeV | | | |
| The lifetime is measured from the 1/2/11 decay vertices | | | | | | | |

The lifetime is measured from the $J/\psi \mu$ decay vertices. The lifetime is measured from the $J/\psi e$ decay vertices.

B_c^+ DECAY MODES \times B($\overline{b} \rightarrow B_c$)

 B_c^- modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|------------|---------------------------------------------------------------------------------------------|------------------------------|---------------------|
| | The following quantities are not pr $\Gamma_{\hat{I}}/\Gamma\times B(\overline{b}\to B_C).$ | ure branching ratios; rather | the fraction |
| Γ_1 | $J/\psi(1S)\ell^+ u_\ell$ anything | $(5.2 + 2.4) \times 10$ | ₎ -5 |
| Γ_2 | $J/\psi(1S)\pi^+$ | < 8.2 × 10 | ₀ -5 90% |
| Γ_3 | $J/\psi(1S) \pi^{+} \pi^{+} \pi^{-}$ | < 5.7 × 10 |) ⁻⁴ 90% |
| Γ_4 | $J/\psi(1S) a_1(1260)$ | < 1.2 × 10 | 90% |
| Γ_5 | $D^*(2010)^+ \overline{D}{}^0$ | < 6.2 × 10 | ₀ -3 90% |

B+ BRANCHING RATIOS

| $\Gamma(J/\psi(1S)\ell^+\nu_\ell$ anything)/ $\Gamma_{\mathrm{total}} \times \mathrm{B}(\overline{b} \to B_c)$ | | | | | | $\Gamma_1/\Gamma \times B$ |
|----------------------------------------------------------------------------------------------------------------|----------------|----------------------------------------------------------------------|---------|---------|-------------------------------|----------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT | |
| $(5.2^{+2.4}_{-2.1}) \times 10^{-5}$ | | ⁶ ABE | 98м | CDF | <i>p</i> p 1.8 TeV | |
| • • • We do not use the | ne following | g data for averages | , fits, | limits, | etc. • • • | |
| < 1.6 | 90 90 90 | ⁷ ACKERSTAFF ⁸ ABREU ⁹ BARATE | 97E | DLPH | $e^+e^- ightarrow~Z$ | |

6 ABE 98M result is derived from the measurement of $[\sigma(B_C)\times \mathsf{B}(B_C\to J/\psi(1S)\,\ell\nu_\ell)]/[\sigma(B^+)\times \mathsf{B}(B^+\to J/\psi(1S)\,\kappa^+)]=0.132^{+0.041}_{-0.037}(\mathrm{stat})\pm 0.031(\mathrm{sys})^{+0.032}_{-0.020}(\mathrm{lifetime})$ by using PDG 98 values of $\mathsf{B}(b\to B^+)$ and $\mathsf{B}(B^+\to J/\psi(1S)\,\kappa^+).$ 7 ACKERSTAFF 980 reports $\mathsf{B}(Z\to B_C\mathrm{X})/\mathsf{B}(Z\to q\,q)\times \mathsf{B}(B_C\to J/\psi(1S)\,\ell\nu_\ell)<6.95\times 10^{-5}$ at 90%CL. We rescale to our PDG 98 values of $\mathsf{B}(Z\to b\,\overline{b}).$

 8 ABREU 97E value listed is for an assumed $\tau_{B_C}=0.4$ ps and improves to 1.6×10^{-4} for $\tau_{B_C}=1.4$ ps.

 9 BARATE 97H reports B($Z\to B_c$ X)/B($Z\to q\,q$)·B($B_c\to J/\psi(1S)\,\ell\nu_\ell)<5.2\times10^{-5}$ at 90%CL. We rescale to our PDG 96 values of B($Z\to b\,\overline{b}$). A $B_c^+\to J/\psi(1S)\,\mu^+\nu_\mu$ candidate event is found, compared to all the known background sources 2×10^{-3} , which gives $m_{B_C}=5.96^{+0.25}_{-0.19}$ GeV and $\tau_{B_C}=1.77\pm0.17\,\mathrm{ps}.$

| VALUE | <u>CL%</u> | DO CUMENT IE | I | TECN | COMMENT | | |
|-----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------|--------------------------------------------------------------------|-----------------------------------------------------------------------------------|-------------------------------|---------------|
| $< 8.2 \times 10^{-5}$ | 90 | ¹⁰ BARATE | 97н | ALEP | $e^+e^- \rightarrow Z$ | 7 | |
| • • • We do not u | se the follow | ing data for averag | es, fits | , limits, | etc. • • • | | |
| $< 2.4 \times 10^{-4}$ | | ¹¹ ACKERSTAF | | | | | |
| | | 12 ABREU | | | | 7 | |
| $< 2.0 \times 10^{-5}$ | 95 | ¹³ ABE | 96R | CDF | <i>p</i> p 1.8 TeV | | |
| 11 ACKERSTAFF $^{1.06\times10^{-4}}_{12}~{\rm ABREU~97E~val}$ $\tau_{B_{\mathcal{C}}}=1.4~{\rm ps.}$ | rescale to ou 980 reports 90%CL. We ue listed is fo | r PDG 96 values of $B(Z \rightarrow B_C X)/B$ rescale to our PD or an assumed τ_{B_C} | $f B(Z)$ $(Z \rightarrow G 98 v)$ $= 0.4$ | $ ightarrow b \overline{b})$. $q q) 	imes B$ alues of ps and in | $B(B_C \rightarrow J/\psi)$ $B(Z \rightarrow b\overline{b})$ mproves to 2.7 | $(1S) \pi^{+} \times 10^{-4}$ |)< for |
| ¹³ ABE 96R repor | $B(b \rightarrow$ | $B_c X)/B(b \rightarrow B^-$ | [⊢] X)⋅B(| $B_c^+ \rightarrow$ | $J/\psi(1S) \pi^+$ |)/B(<i>B</i> + | \rightarrow |
| $J/\psi(1S) K^{+})$ < | < 0.053 at 9 | 5%CL for $\tau_{B_c} =$ | 0.8 ps. | lt chan | ges from 0.15 | to 0.04 | for |
| 0.17 ps $<	au_{B_{\mathcal{C}}}<$ | 1.6 ps. We | rescale to our PDG $) = 0.00101 \pm 0.0$ | 96 valu | | | | |
| -/ | | | | | | | |

| $\Gamma(J/\psi(1S)\pi^+\pi^+\pi^-)/\Gamma_{total}	imesB(\overline{b}	o B_c)$ | | | | | $\Gamma_3/\Gamma \times B$ | |
|------------------------------------------------------------------------------|-----|---------------------|-----|------|----------------------------|---|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <5.7 × 10 ⁻⁴ | 90 | ¹⁴ ABREU | 97E | DLPH | e^+e^- | Z |

 $^{14}\,\mathrm{ABREU}$ 97E value listed is independent of 0.4 ps $<\tau_{B_{\mathrm{C}}}<1.4\,\mathrm{ps}.$

 $< 5.29 \times 10^{-4}$ at 90%CL. We rescale to our PDG 98 values of B($Z \to b\overline{b}$). $\Gamma(D^*(2010)^+ \overline{D}^0) / \Gamma_{\text{total}} \times B(\overline{b} \to B_c)$

| $I(D(2010) \cdot D)$ | //'total ヘロ | $(v \rightarrow D_C)$ | | | | 15/1 2 0 |
|-----------------------------|---------------|-----------------------------------|------------------|--------------------|----------------------------|----------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $<6.2 \times 10^{-3}$ | 90 | ¹⁶ BARATE | 98Q | ALEP | $e^+e^- \rightarrow Z$ | |
| ¹⁶ BARATE 98Q re | ports B(Z – | $\rightarrow B_C X) \times B(B_C$ | → D* | (2010) | $+ \overline{D}^0$) < 1.9 | $	imes$ 10^{-3} at |
| 90%CL. We resc | ale to our PD | G 98 values of B | $(Z \rightarrow$ | $b\overline{b}$). | | |

B REFERENCES

| ABAZOV AALTONEN ABAZOV ABULENCIA ABULENCIA ABE | 09 H 08 M 08 T 06 C 06 O 98 M | PRL 102 092001 PRL 100 182002 PRL 101 012001 PRL 96 082002 PRL 97 012002 PRL 81 2432 | V.M. Abazov et al. T. Aaltonen et al. V.M. Abazov et al. A. Abulencia et al. A. Abulencia et al. F. Abe et al. | (D0 Collab.) (CDF Collab.) (D0 Collab.) (CDF Collab.) (CDF Collab.) (CDF Collab.) |
|---------------------------------------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| A Iso | | PR D58 112004 | F. Abe et al. | (CDF Collab.) |
| ACKERSTAFF | 98 O | PL B420 157 | K. Ackerstaff et al. | (ÒPAL Collab.) |
| BARATE | 98 Q | EPJ C4 387 | R. Barate et al. | (ALEPH Collab.) |
| PDG | 98 | EPJ C3 1 | C. Caso et al. | , , |
| ABREU | 97 E | PL B398 207 | P. Abreu et al. | (DELPHI Collab.) |
| BARATE | 97 H | PL B402 213 | R. Barate et al. | (ALEPH Collab.) |
| ABE | 96 R | PRL 77 5176 | F. Abe et al. | (CDF Collab.) |
| PDG | 96 | PR D54 1 | R. M. Barnett et al. | |

DEVELOPMENTS IN HEAVY QUARKONIUM SPECTROSCOPY

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A golden age for heavy quarkonium physics dawned a decade ago, initiated by the confluence of exciting advances in quantum chromodynamics (QCD) and an explosion of related experimental activity. The subsequent broad spectrum of breakthroughs, surprises, and continuing puzzles had not been anticipated. In that period, the BESII program concluded only

² ABE 98M observed 20.4 $^{+}_{-5.5}$ events in the $B_c^+ \to J/\psi(1s) \ell \nu_\ell$ with a significance of > 4.8 standard deviations. The mass value is estimated from $m(J/\psi(1S)\,\ell)$.

 $^{^3}$ ACKERSTAFF 980 observed 2 candidate events in the $B_C\to J/\psi(1S)\,\pi^+$ channel with an estimated background of 0.63 \pm 0.20 events.

Heavy Quarkonium Spectroscopy

to give birth to BESIII; the *B*-factories and CLEO-c flourished; quarkonium production and polarization measurements at HERA and the Tevatron matured; and heavy-ion collisions at RHIC opened a window on the deconfinement regime. For an extensive presentation of the status of heavy quarkonium physics, the reader is referred to several reviews [1–7], the last of which covers developments through the middle of 2010, and which supplies some tabular information and phrasing reproduced here (with kind permission, copyright 2011, Springer). This note focuses solely on experimental developments in heavy quarkonium spectroscopy, and in particular on those too recent to have been included in Ref. 7.

Table 1 lists properties of newly observed conventional heavy quarkonium states, where "newly" is interpreted to mean within the past decade. The h_c is the 1P_1 state of charmonium, singlet partner of the long-known χ_{cJ} triplet 3P_J . The $\eta_c(2S)$ is the first excited state of the pseudoscalar ground state $\eta_c(1S)$, lying just below the mass of its vector counterpart, $\psi(2S)$. The state originally dubbed Z(3930) is now regarded by many as the first observed 2P state of χ_{cJ} , the $\chi_{c2}(2P)$. The first B-meson seen that contains charm is the B_c^+ . The ground state of bottomonium is the $\eta_b(1S)$, recently confirmed with a second observation of more than 5σ significance. The $\Upsilon(1D)$ is the lowest-lying D-wave triplet of the $b\bar{b}$ system.

Table 1: New conventional states in the $c\bar{c}$, $b\bar{c}$, and $b\bar{b}$ regions, ordered by mass. Masses m and widths Γ represent the weighted averages from the listed sources. Quoted uncertainties reflect quadrature summation from individual experiments. In the Process column, the decay mode of the new state claimed is indicated in parentheses. Ellipses (...) indicate inclusively selected event topologies; i.e., additional particles not required by the Experiments to be present. A question mark (?) indicates an unmeasured value. For each Experiment a citation is given, as well as the statistical significance in number of standard deviations (#σ), or "(np)" for "not provided". The Year column gives the date of first measurement cited. The Status column indicates that the state has been observed by at most one (NC!-needs confirmation) or at least two independent experiments with significance of >5σ (OK). The state labelled $\chi_{c2}(2P)$ has previously been called Z(3930). See also the reviews in [1–7]. Adapted from [7] with kind permission, copyright (2011), Springer.

| State | $m \; (\mathrm{MeV})$ | $\Gamma \; ({\rm MeV})$ | J^{PC} | Process (mode) | Experiment $(\#\sigma)$ | Year | Status |
|--------------------|-------------------------|-------------------------|----------|---------------------------------------------------------------------|----------------------------------------------|------|--------|
| $h_c(1P)$ | 3525.41 ± 0.16 | <1 | 1+- | $\psi(2S) \to \pi^0 \left(\gamma \eta_c(1S) \right)$ | CLEO [8–10] (13.2) | 2004 | OK |
| | | | | $\psi(2S) \to \pi^0 (\gamma)$ | CLEO [8–10] (10), BES [11] (19) | | |
| | | | | $p\bar{p} \to (\gamma \eta_c) \to (\gamma \gamma \gamma)$ | E835 [12] (3.1) | | |
| | | | | $\psi(2S) \to \pi^0 (\ldots)$ | BESIII [11] (9.5) | | |
| $\eta_c(2S)$ | 3638.9 ± 1.3 | 10 ± 4 | 0-+ | $B \to K (K^0_S K^- \pi^+)$ | Belle $[13,14]$ (6.0) | 2002 | OK |
| | | | | $e^+e^- \to e^+e^- (K_S^0K^-\pi^+)$ | BABAR [15,16] (7.8), | | |
| | | | | | CLEO [17] (6.5), Belle [18] (6) | | |
| | | | | $e^+e^- \to J/\psi (\ldots)$ | BABAR [19] (np), Belle [20] (8.1) | | |
| $\chi_{c2}(2P)$ | 3927.2 ± 2.6 | 24 ± 6 | 2^{++} | $e^+e^- \to e^+e^-(D\bar{D})$ | Belle [21] (5.3) , BABAR $[22,23]$ (5.8) | 2005 | OK |
| B_c^+ | 6277 ± 6 | - | 0- | $\bar{p}p \to (\pi^+ J/\psi)$ | CDF [24,25] (8.0), D0 [26] (5.2) | 2007 | OK |
| $\eta_b(1S)$ | 9395.8 ± 3.0 | $12.4^{+12.7}_{-5.7}$ | 0_{-+} | $\Upsilon(3S) \to \gamma()$ | BABAR [27] (10), CLEO [28] (4.0) | 2008 | OK |
| | | | | $\Upsilon(2S) \to \gamma (\ldots)$ | BABAR [29] (3.0) | | |
| | | | | $\Upsilon(5S) \to \pi^+ \pi^- \gamma (\dots)$ | Belle [30] (14) | | |
| $h_b(1P)$ | 9898.6 ± 1.4 | ? | 1^{+-} | $\Upsilon(5S) \to \pi^+\pi^- ()$ | Belle $[31,30]$ (5.5) | 2011 | NC! |
| | | | | $\Upsilon(3S) \to \pi^0 (\ldots)$ | BABAR [32] (3.0) | | |
| $\Upsilon(1^3D_2)$ | 10163.7 ± 1.4 | ? | $2^{}$ | $\Upsilon(3S) \to \gamma \gamma (\gamma \gamma \Upsilon(1S))$ | CLEO [33] (10.2) | 2004 | OK |
| | | | | $\Upsilon(3S) \to \gamma\gamma \left(\pi^+\pi^-\Upsilon(1S)\right)$ | BABAR [34] (5.8) | | |
| | | | | $\Upsilon(5S) \to \pi^+\pi^- ()$ | Belle [31] (2.4) | | |
| $h_b(2P)$ | $10259.8_{-1.2}^{+1.5}$ | ? | 1^{+-} | $\Upsilon(5S) \to \pi^+\pi^-()$ | Belle [31] (11.2) | 2011 | NC! |
| $\chi_{bJ}(3P)$ | 10530 ± 10 | ? | ? | $pp \to (\gamma \mu^+ \mu^-)$ | ATLAS [35] (>6) | 2011 | NC! |

Both the $h_b(1P)$, the bottomonium counterpart of $h_c(1P)$, and the next excited state, $h_b(2P)$, were very recently observed by Belle [31], as described further below, in dipion transitions from either the $\Upsilon(5S)$ or $Y_b(10888)$. All fit into their respective spectroscopies roughly where expected. Their exact masses, production mechanisms, and decay modes provide guidance to their descriptions within QCD. The $h_b(nP)$ states still need experimental confirmation at the 5σ level, as does the $\chi_{bJ}(3P)$ triplet.

Correspondingly, the menagerie of new, heavy-quarkoniumlike unanticipated states* is shown in Table 2; notice that just a handful have been experimentally confirmed. None can unambiguously be assigned a place in the hierarchy of charmonia or bottomonia; neither do any have a universally accepted unconventional origin. The X(3872) occupies a unique niche among the unexplained states as both the first and the most intriguing. It is, by now, widely studied, yet its interpretation demands much more experimental attention. The Y(4260) and Y(4360)are vector states decaying to $\pi^+\pi^-J/\psi$ and $\pi^+\pi^-\psi(2S)$, respectively, yet, unlike most conventional vector charmonia, do not correspond to enhancements in the e^+e^- hadronic cross section. The three Z_c^+ and two Z_b^+ states, each decaying to a charged pion and conventional heavy quarkonium state, would be manifestly exotic, but remain unconfirmed. Final states of the type $\Upsilon(nS)\pi^+\pi^-$ from e^+e^- collisions acquired near the $\Upsilon(5S)$ have a lineshape differing somewhat from that of multi-hadronic events, which suggested a new state $Y_b(10888)$, distinct from $\Upsilon(5S)$, which could be analogous to Y(4260). The nature of $Y_b(10888)$, if it does mimic the behavior of the charmonium-region Y's, could help to explain the observed (and otherwise unexpected) high rate of dipion transitions to $\Upsilon(nS)$ and $h_b(nP)$ seen in the e^+e^- collisions near the $\Upsilon(5S)$. It could also provide insight into the Z_b^+ states, which appear to be intermediate resonances in the dipion transitions.

BABAR [71,59] has searched for the three Z_c^{\pm} states in the charmonium mass region seen by Belle, and failed to observe any significant signals. The approach taken in searching for $B \to Z^{\pm}K \to (c\bar{c})K\pi$, where $(c\bar{c})$ is $\psi(2S)$ or χ_{c1} , is to first fit the data for all reasonable $K\pi$ mass or angular structure, having demonstrated that the presence of one or more Z's cannot be accommodated by this procedure. After doing so, the finding is that some of what might be the Belle excess of events above Belle background gets absorbed into the $K\pi$ structure of the BABAR background. As shown in Table 2, where Belle observes signals of significances 5.0σ , 5.0σ , and 6.4σ for $Z_1(4050)^+$, $Z_2(4250)^+$, and $Z(4430)^+$, respectively, BABAR reports 1.1σ , 2.0σ , and 2.4σ effects, setting upper limits on product branching fractions that are not inconsistent with Belle's measured rates, leaving the situation unresolved.

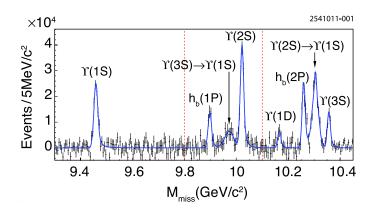


Figure 1: From Belle [31], the mass recoiling against $\pi^+\pi^-$ pairs, $M_{\rm miss}$, in e^+e^- collision data taken near the peak of the $\Upsilon(5S)$ (points with error bars). The smooth combinatoric and $K_S^0 \to \pi^+\pi^-$ background contributions have already been subtracted. The fit to the various labeled signal contributions overlaid (curve). Adapted from [31] with kind permission, copyright (2011) The American Physical Society.

Although $\eta_c(2S)$ measurements began to converge on a mass and width nearly a decade ago, refinements are still in progress. In particular, Belle [14] has revisited its analysis of $B \to K\eta_c(2S)$, $\eta_c(2S) \to KK\pi$ decays with more data and methods that account for interference between the above decay chain, an equivalent one with the $\eta_c(1S)$ instead, and one with no intermediate resonance. The net effect of this interference is far from trivial; it shifts the apparent mass by $\sim +10$ MeV and blows up the apparent width by a factor of six. The updated $\eta_c(2S)$ mass and width are in better accordance with other measurements than the previous treatment [13] not including interference. Complementing this measurement in B-decay, BABAR [15] updated their previous [16] $\eta_c(2S)$ mass and width measurements in two-photon production, where interference effects, judging from studies of $\eta_c(1S)$, appear to be small. In combination, precision on the $\eta_c(2S)$ mass has improved dramatically.

New results on η_b , h_b , and Z_b^+ mostly come from Belle, all from analyses of 121.4 fb⁻¹ of e^+e^- collision data collected near the peak of the $\Upsilon(5S)$ resonance. They also appear in the same types of decay chains: $\Upsilon(5S) \to \pi^- Z_b^+$, $Z_b^+ \to \pi^+ (b\bar{b})$, and, when the $b\bar{b}$ forms an $h_b(1P)$, frequently $h_b(1P) \to \gamma \eta_b$.

Previous unsuccessful searches for h_b focused on what was considered the most easily detected production mechanism, $\Upsilon(3S) \to \pi^0 h_b(1P)$. In early 2011 BABAR presented marginal evidence for this transition at the 3σ level, at a mass near that expected for zero hyperfine splitting.

^{*} For consistency with the literature, we preserve the use of X, Y, Z, and G, contrary to the practice of the PDG, which exclusively uses X for unidentified states.

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Table 2: As in Table 1, but for new unconventional states in the $c\bar{c}$ and $b\bar{b}$ regions, ordered by mass. For X(3872), the values given are based only upon decays to $\pi^+\pi^-J/\psi$. X(3945) and Y(3940) have been subsumed under X(3915) due to compatible properties. The state known as Z(3930) appears as the $\chi_{c2}(2P)$ in Table 1. In some cases experiment still allows two J^{PC} values, in which case both appear. See also the reviews in [1-7]. Adapted from [7] with kind permission, copyright (2011), Springer.

| State | m (MeV) | Γ (MeV) | J^{PC} | Process (mode) | Experiment $(\#\sigma)$ | Year S | Status |
|----------------|-----------------------------------------|-----------------------------------------|------------|-------------------------------------------------------------|----------------------------------------|--------|--------|
| X(3872) | 3871.68 ± 0.17 | < 1.2 | 1++/2-+ | $B \to K (\pi^+ \pi^- J/\psi)$ | Belle [36,37] (12.8), BABAR [38] (8.6) | 2003 | OK |
| | | | | $p\bar{p} \to (\pi^+\pi^- J/\psi) + \dots$ | CDF [39-41] (np), D0 [42] (5.2) | | |
| | | | | $B \to K \left(\omega J/\psi\right)$ | Belle [43] (4.3), BABAR [23] (4.0) | | |
| | | | | $B \to K(D^{*0}\overline{D}^0)$ | Belle [44,45] (6.4), BABAR [46] (4.9) | | |
| | | | | $B \to K \left(\gamma J/\psi \right)$ | Belle [47] (4.0), BABAR [48,49] (3.6) | | |
| | | | | $B \to K(\gamma \psi(2S))$ | BABAR [49] (3.5), Belle [47] (0.4) | | |
| | | . 10 | . 0. | $pp \to (\pi^+\pi^-J/\psi) + \dots$ | LHCb [50] (np) | | |
| X(3915) | 3917.4 ± 2.7 | 28^{+10}_{-9} | $0/2^{?+}$ | $B \to K(\omega J/\psi)$ | Belle [51] (8.1), BABAR [52] (19) | 2004 | OK |
| | | . 07 | 0 | $e^+e^- \rightarrow e^+e^- \left(\omega J/\psi\right)$ | Belle [53] (7.7), BABAR [23] (np) | | |
| X(3940) | 3942^{+9}_{-8} | 37^{+27}_{-17} | ??+ | $e^+e^- \to J/\psi (D\overline{D}^*)$ | Belle $[54]$ (6.0) | 2007 | NC! |
| | | | | $e^+e^- \to J/\psi (\underline{\dots})$ | Belle [20] (5.0) | | |
| G(3900) | 3943 ± 21 | 52 ± 11 | 1 | $e^+e^- \to \gamma (D\overline{D})$ | BABAR [55] (np), Belle [56] (np) | 2007 | OK |
| Y(4008) | 4008^{+121}_{-49} | 226 ± 97 | 1 | $e^+e^- \to \gamma(\pi^+\pi^-J/\psi)$ | Belle [57] (7.4) | 2007 | NC! |
| $Z_1(4050)^+$ | 4051_{-43}^{+24} | 82^{+51}_{-55} 15^{+11}_{-7} | ? | $B \to K \left(\pi^+ \chi_{c1}(1P) \right)$ | Belle [58] (5.0), BABAR [59] (1.1) | 2008 | NC! |
| Y(4140) | 4143.4 ± 3.0 | 15^{+11}_{-17} | ??+ | $B \to K \left(\phi J/\psi \right)$ | CDF $[60,61]$ (5.0) | 2009 | NC! |
| X(4160) | $4156_{-25}^{+29} \\ 4248_{-45}^{+185}$ | $139_{-65}^{+113} 177_{-72}^{+321}$ | ??+ | $e^+e^- \to J/\psi (D\overline{D}^*)$ | Belle [54] (5.5) | 2007 | NC! |
| $Z_2(4250)^+$ | 4248^{+185}_{-45} | 177^{+321}_{-72} | ? | $B \to K \left(\pi^+ \chi_{c1}(1P) \right)$ | Belle [58] (5.0), BABAR [59] (2.0) | 2008 | NC! |
| Y(4260) | 4263^{+8}_{-9} | 95 ± 14 | 1 | $e^+e^- \to \gamma \left(\pi^+\pi^-J/\psi\right)$ | BABAR $[62,63]$ (8.0) | 2005 | OK |
| | | | | | CLEO [64] (5.4), Belle [57] (15) | | |
| | | | | $e^+e^- \rightarrow (\pi^+\pi^-J/\psi)$ | CLEO [65] (11) | | |
| | 194 | + 22 | - 2 1 | $e^+e^- \to (\pi^0\pi^0 J/\psi)$ | CLEO $[65]$ (5.1) | | |
| Y(4274) | $4274.4^{+8.4}_{-6.7}$ | 32^{+22}_{-15} $13.3^{+18.4}_{-10.0}$ | ??+ | $B \to K \left(\phi J/\psi \right)$ | CDF [61] (3.1) | 2010 | NC! |
| X(4350) | $4350.6^{+4.6}_{-5.1}$ | $13.3^{+18.4}_{-10.0}$ | $0/2^{++}$ | $e^+e^- \rightarrow e^+e^- \left(\phi J/\psi\right)$ | Belle [66] (3.2) | 2009 | NC! |
| Y(4360) | 4361 ± 13 | 74 ± 18 | 1 | $e^+e^- \to \gamma \left(\pi^+\pi^-\psi(2S)\right)$ | | 2007 | OK |
| $Z(4430)^+$ | 4443^{+24}_{-18} | 107^{+113}_{-171} | ? | $B \to K \left(\pi^+ \psi(2S) \right)$ | Belle [69,70] (6.4), BABAR [71] (2.4) | 2007 | NC! |
| X(4630) | 4634_{-11}^{+19} | 92^{+41}_{-32} | 1 | $e^+e^- \to \gamma \left(\Lambda_c^+\Lambda_c^-\right)$ | Belle [72] (8.2) | 2007 | NC! |
| Y(4660) | 4664±12 | 48±15 | 1 | $e^+e^- \rightarrow \gamma \left(\pi^+\pi^-\psi(2S)\right)$ | | 2007 | NC! |
| $Z_b(10610)^+$ | | 18.4 ± 2.4 | | $\Upsilon(5S) \to \pi^-(\pi^+[b\bar{b}])$ | Belle [73,74] (16) | 2011 | NC! |
| $Z_b(10650)^+$ | | 11.5 ± 2.2 | | $\Upsilon(5S) \to \pi^-(\pi^+[bb])$ | Belle [73,74] (16) | 2011 | NC! |
| $Y_b(10888)$ | 10888.4 ± 3.0 | $30.7^{+8.9}_{-7.7}$ | 1 | $e^+e^- \to (\pi^+\pi^-\Upsilon(nS))$ | Belle $[75,76]$ (2.0) | 2010 | NC! |

The Belle h_b discovery analysis [31] selects hadronic events and looks for peaks in the mass recoiling against $\pi^+\pi^-$ pairs, the spectrum for which, after subtraction of smooth combinatoric and $K_S^0 \to \pi^+\pi^-$ backgrounds, appears in Fig. 1. Prominent and unmistakable $h_b(1P)$ and $h_b(2P)$ peaks are present. This search was directly inspired by a new CLEO result [77], which found the surprisingly copious transitions $\psi(4160) \rightarrow \pi^+\pi^-h_c(1P)$ and an indication that $Y(4260) \to \pi^+\pi^- h_c(1P)$ occurs at a comparable rate as the signature mode, $Y(4260) \to \pi^+\pi^- J/\psi$. The presence of $\Upsilon(nS)$ peaks in Fig. 1 at rates two orders of magnitude larger than expected for transitions requiring a heavy-quark spin-flip, along with separate studies with exclusive decays $\Upsilon(nS) \to \mu^+\mu^-$, allow precise calibration of the $\pi^+\pi^-$ recoil mass spectrum and very accurate measurements of $h_b(1P)$ and $h_b(2P)$ masses. Both corresponding hyperfine splittings are consistent with zero

within an uncertainty of about 1.5 MeV (lowered to ± 1.1 MeV for $h_b(1P)$ in Ref. 30). Belle soon noticed that, for events in the peaks of Fig. 1, there seemed to be two intermediate charged states nearby. For example, Fig. 2 shows a Dalitz plot for events restricted to the $\Upsilon(2S)$ region of $\pi^+\pi^-$ recoil mass. The two bands observed in the maximum of the two $M[\pi^{\pm}\Upsilon(2S)]^2$ values also appear for $\Upsilon(1S)$, $\Upsilon(3S)$, $h_b(1P)$, and $h_b(2P)$ samples, but do not appear in the respective $[b\bar{b}]$ sidebands. Belle fits all subsamples to resonant plus non-resonant amplitudes, allowing for interference (notably, between $\pi^- Z_b^+$ and $\pi^+ Z_b^-$), and finds consistent pairs of Z_h^+ masses for all bottomonium transitions, and comparable strengths of the two states. Angular analysis favors a $J^P = 1^+$ assignment for both Z_b^+ states, which must also have negative G-parity. Transitions through Z_h^+ to the $h_b(nP)$ saturate the observed $\pi^+\pi^-h_b(nP)$ cross sections. The two masses of Z_b^+ states are just a few MeV above the $B^*\bar{B}$

and $B^*\bar{B}^*$ thresholds, respectively. The Z_b^+ cannot be simple mesons because they are charged and have $b\bar{b}$ content.

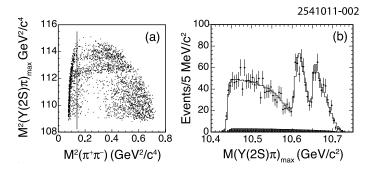


Figure 2: From Belle [74] e^+e^- collision data taken near the peak of the $\Upsilon(5S)$ for events with a $\pi^+\pi^-$ -missing mass consistent with a $\Upsilon(nS)2$, (a) the maximum of the two possible single π^\pm -missing-mass-squared combinations vs. the $\pi^+\pi^-$ -mass-squared; and (b) projection of the maximum of the two possible single π^\pm -missing-mass combinations (points with error bars) overlaid with a fit (curve). Events to the left of the vertical line in (a) are excluded from further analysis. The two horizontal stripes in (a) and two peaks in (b) correspond to the two Z_b^+ states. Adapted from [74] with kind permission, copyright (2011) The American Physical Society.

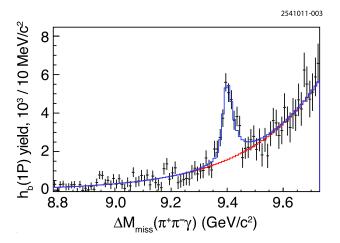


Figure 3: From Belle [30] e^+e^- collision data taken near the peak of the $\Upsilon(5S)$, the $h_b(1P)$ event yield vs. the mass recoiling against the $\pi^+\pi^-\gamma$ (corrected for misreconstructed $\pi^+\pi^-$), where the $h_b(1P)$ yield is obtained by fitting the mass recoiling against the $\pi^+\pi^-$ (points with error bars). The fit results (solid histograms) for signal plus background and background alone are superimposed. Adapted from [30] with kind permission, copyright (2011) The American Physical Society.

The third Belle result to flow from these data is confirmation of the $\eta_b(1S)$ and measurement of the $h_b(1P) \to \gamma \eta_b(1S)$ branching fraction, expected to be several tens of percent. To accomplish this, events with the $\pi^+\pi^-$ recoil mass in the $h_b(1P)$ mass window and a radiative photon candidate are selected, and the $\pi^+\pi^-\gamma$ recoil mass queried for correlation with non-zero $h_b(1P)$ population in the $\pi^+\pi^-$ missing mass spectrun, as shown in Fig. 3. A clear peak is observed, corresponding to the $\eta_b(1S)$. A fit is performed to extract the $\eta_b(1S)$ mass, and first measurements of its width and the branching fraction for $h_b(1P) \to \gamma \eta_b(1S)$ (the latter of which is $(49.8 \pm 6.8^{+10.9}_{-5.2})\%$). The mass determination has comparable uncertainty to and a larger central value (by 10 MeV, or 2.4σ) than the average of previous measurements, thereby reducing the new world average hyperfine splitting by nearly 5 MeV, as shown in Table 3.

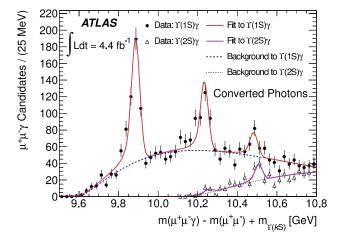


Figure 4: From ATLAS [35] pp collision data (points with error bars) taken at $\sqrt{s}=7$ TeV, the effective mass of $\chi_{bJ}(1P,2P,3P) \rightarrow \gamma \Upsilon(1S,2S)$ candidates in which $\Upsilon(1S,2S) \rightarrow \mu^+\mu^-$ and the photon is reconstructed as an e^+e^- conversion in the tracking system. Fits (smooth curves) show significant signals for each triplet (merged-J) on top of a smooth background. From [35] with kind permission, copyright (2012) The American Physical Society.

The $\chi_{bJ}(nP)$ states have recently been observed at the LHC by ATLAS [35] for n=1,2,3, although in each case the three J states are not distinguished from one another. Events are sought which have both a photon and an $\Upsilon(1S,2S) \to \mu^+\mu^-$ candidate which together form a mass in the χ_b region. Observation of all three J-merged peaks is seen at significance in excess of 6σ for both unconverted and converted photons. The mass plot for converted photons, which provide better mass resolution, is shown in Fig. 4. This marks the first observation of the $\chi_{bJ}(3P)$ triplet, quite near the expected mass.

Heavy Quarkonium Spectroscopy

Table 3: Measured $\eta_b(1S)$ masses and hyperfine splittings, by experiment and production mechanism.

| $m(\eta_b)$ | Δm_{hf} | Process | Ref. $(\chi^2/\text{d.o.f.})$ |
|---------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------------------------|-------------------------------|
| $9394.2^{+4.8}_{-4.9}\pm 2.0$ | 4.0 | $\Upsilon(nS)2 \to \gamma \eta_b$ | BABAR [29] |
| $9388.9^{+3.1}_{-2.3}\pm 2.7$ $9391.8\pm 6.6\pm 2.0$ | $71.4^{+2.3}_{-3.1} \pm 2.7$ $68.5 \pm 6.6 \pm 2.0$ | $\Upsilon(nS)3 \to \gamma \eta_b$ $\Upsilon(nS)3 \to \gamma \eta_b$ | BABAR [27] CLEO [28] |
| 9391.0 ± 2.8 | 69.3 ± 2.9 | Above [7] | $Avg^a (0.6/2)$ |
| $9401.0 \pm 1.9^{+1.4}_{-2.4}$ 9395.8 ± 3.0 | $59.3 \pm 1.9_{-1.4}^{+2.4}$ 64.5 ± 3.0 | $h_b(1P) \to \gamma \eta_b$ All | Belle [30] $Avg^a (6.1/3)$ |

^a An inverse-square-error-weighted average of the individual measurements appearing above, for which all statistical and systematic errors were combined in quadrature without accounting for any possible correlations between them. The uncertainty on this average is inflated by the multiplicative factor S if $S^2 \equiv \chi^2/\text{d.o.f.} > 1$.

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Meson Particle Listings Heavy Quarkonium Spectroscopy

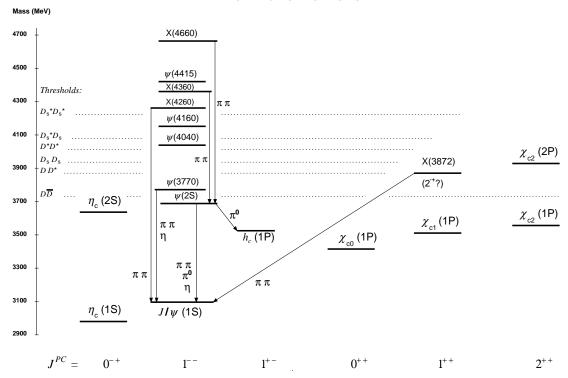
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Charmonium, $\eta_c(1S)$

cc MESONS

THE CHARMONIUM SYSTEM



The level scheme of the $c\overline{c}$ states showing experimentally established states with solid lines. Singlet states are called η_c and h_c , triplet states ψ and χ_{cJ} , and unassigned charmonium-like states X. In parentheses it is sufficient to give the radial quantum number and the orbital angular momentum to specify the states with all their quantum numbers. Only observed hadronic transitions are shown; the single photon transitions $\psi(nS) \to \gamma \eta_c(mP)$, $\psi(nS) \to \gamma \chi_{cJ}(mP)$, and $\chi_{cJ}(1P) \to \gamma J/\psi$ are omitted for clarity.

 $\eta_c(1S)$

$$I^G(J^{PC}) = 0^+(0^{-+})$$

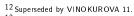
$\eta_c(1S)$ MASS

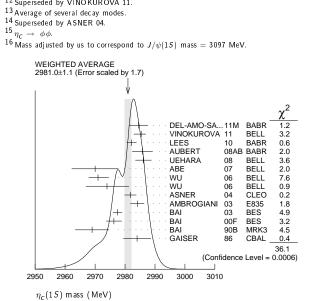
| VALUE (MeV) | EVTS | DOCUMENT ID | TEC | |
|---------------------------------|--------|-------------------------|-------------|--------------------------------------------------------------------------------|
| 2981.0± 1.1 OUR A | /ERAGE | Error includes sca | le factor o | f 1.7. See the ideogram below. |
| $2984.5 \pm \ 0.8 \pm \ 3.1$ | 11k | DEL-AMO-SA | | $R \gamma \gamma \rightarrow K^+ K^- \pi^+ \pi^- \pi^0$ |
| 2985.4 \pm 1.5 $^{+}_{-}$ 2.0 | 920 | ¹ VINOKUROVA | 11 BEL | $L B^{\pm} \rightarrow \ K^{\pm} (K_S^0 K^{\pm} \pi^{\mp})$ |
| 2982.2± 0.4± 1.6 | 14k | ² LEES | 10 BAB | R $10.6 e^{+}e^{-} \xrightarrow{0} K^{\pm} \pi^{\mp}$ |
| 2985.8± 1.5± 3.1 | 0.9k | AUBERT | 08AB BAB | $R B \rightarrow \eta_C(1S) K^{(*)} \rightarrow K \overline{K}_{\pi} K^{(*)}$ |
| 2986.1 ± 1.0 ± 2.5 | 7.5k | UEHARA | 08 BEL | $\gamma \gamma \rightarrow \eta_C \rightarrow \text{hadrons}$ |
| $2970~\pm~5~\pm~6$ | 501 | ³ ABE | 07 BEL | $L e^+e^- \rightarrow J/\psi(c\overline{c})$ |
| 2971 \pm 3 $^{+}$ 2 | 195 | WU | 06 BEL | $B^+ \rightarrow p \overline{p} K^+$ |
| 2974 \pm 7 $^{+}$ 2 | 20 | WU | 06 BEL | $L B^+ \to \Lambda \overline{\Lambda} K^+$ |
| 2981.8 \pm 1.3 \pm 1.5 | 592 | ASNER | 04 CLE | O $\gamma\gamma \rightarrow \eta_C \rightarrow K_S^0 K^{\pm}\pi^{\mp}$ |
| 2984.1 ± 2.1 ± 1.0 | 190 | ⁴ AMBROGIANI | 03 E835 | $\overline{p}p \rightarrow \eta_C \rightarrow \gamma\gamma$ |
| $2977.5 \pm 1.0 \pm 1.2$ | 5 | ,6 BAI | 03 BES | $J/\psi \rightarrow \gamma \eta_C$ |
| 2976.3± 2.3± 1.2 | 6,7 | 7,8 BAI | 00F BES | |
| 2969 \pm 4 \pm 4 | 80 | ⁶ BAI | 90B MR | |
| 2984 \pm 2.3 \pm 4.0 | | ⁶ GAISER | 86 CBA | $L J/\psi \to \gamma X, \ \psi(2S) \to \gamma X$ |

• • • We do not use the following data for averages, fits, limits, etc. • • • 9 DEL-AMO-SA...11M BABR $\gamma\gamma
ightarrow \kappa_S^0 \, \kappa^{\pm} \, \pi^{\mp}$ $2982.5 \pm \ 0.4 \pm \ 1.4$ 12k ⁶ MITCHELL CLEO $e^+e^- \rightarrow$ 2982.2 ± 0.6 09 06E BABR $B^{\pm} \rightarrow K^{\pm} X_{c} \overline{c}$ $^{10}\,\mathrm{AUBERT}$ 2982 ± 5 270 ¹¹ AUBERT $2982.5 \pm 1.1 \pm 0.9$ 2.5k 04D BABR $\gamma \gamma \rightarrow \eta_C(1S)$ 12 FA NG $2979.6 \pm \ 2.3 \pm \ 1.6$ 180 03 BELL $B \rightarrow \eta_C K$ 140 6,7,13 BAI $2976.6 \pm 2.9 \pm 1.3$ 00F BES ¹⁴ BRANDENB... 2980.4 ± 2.3 ± 0.6 00B CLE2 7,13 _{BAI} $2975.8 \pm \ 3.9 \pm \ 1.2$ 99B BES Sup. by BAI 00F $2999\ \pm\ 8$ ABREU $e^+e^- \rightarrow e^+e^-$ +hadrons $2988.3 + 3.3 \\ - 3.1$ $\overline{p}p \rightarrow \gamma \gamma$ ARMSTRONG 95F E760 91 DM2 $J/\psi \rightarrow \eta_C$ 2974.4± 1.9 6,13 BISELLO ⁶ BAI 90B MRK3 $J/\psi \rightarrow \gamma K^+ K^- K^0_S K^0_I$ $2956 \pm 12 \pm 12$ 2982.6 + 2.7BAGLIN 87в $\mathsf{SPEC} \quad \overline{p} \, p \, \to \, \, \gamma \gamma$ 6,13 BALTRUSAIT...86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ 2980.2 ± 1.6 6,15 BALTRUSAIT...84 $2976\ \pm\ 8$ MRK3 $J/\psi \rightarrow 2\phi\gamma$ 16 HIMEL $2982\ \pm\ 8$ 80в MRK2 e^+e^- ¹⁶ PARTRIDGE 80B CBAL $2980\ \pm\ 9$ 1 Accounts for interference with non-resonant continuum. 2 Taking into account interference with the non-resonant $J^P=0$ — amplitude 3 From a fit of the J/ψ recoil mass spectrum. Supersedes ABE,K 02 and ABE 04G. 4 Using mass of $\psi(2S)=3686.00$ MeV. ⁵ From a simultaneous fit of five decay modes of the η_C . 6 MITCHELL 09 observes a significant asymmetry in the lineshapes of $\psi(2S) \to \gamma \eta_{\mathcal{C}}$ and $J/\psi \to \gamma \eta_{\mathcal{C}}$ transitions. If ignored, this asymmetry could lead to significant bias whenever the mass and width are measured in $\psi(2S)$ or J/ψ radiative decays. $^7\,\mathrm{Using}$ an η_{C} width of 13.2 MeV. ⁸ Weighted average of the $\psi(2S)$ and $J/\psi(1S)$ samples. ⁹ Not independent from the measurements reported by LEES 10.

 $^{10}\,\mathrm{From}$ the fit of the kaon momentum spectrum. Systematic errors not evaluated.

 $^{11}\,\mathrm{Superseded}$ by LEES 10.





$\eta_c(1S)$ WIDTH

| VALUE (MeV) | CL% EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| 29.7± 1.0 OUR 29.7± 2.1 OUR | | includes scale facto | vr of | مم ۸ ۲ | the ideogram below. |
| 36.2± 2.8±3.0 | 11k | DEL-AMO-SA | | | $\gamma\gamma \rightarrow$ |
| | | | | | $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ |
| $35.1 \pm 3.1 + 1.0 \\ -1.6$ | 920 | ¹⁷ VINOKUROVA | 11 | BELL | $B^{\pm}_{K^{\pm}(K^{0}_{S}K^{\pm}\pi^{\mp})}$ |
| $31.7 \pm 1.2 \pm 0.8$ | 14k | ¹⁸ LEES | 10 | BABR | $^{10.6}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{\overset{o}{\kappa_{S}}}\overset{\rightarrow}{\kappa^{\pm}}_{\pi^{\mp}}$ |
| $36.3^{+}_{-}\ \ \overset{3.7}{3.6}\pm4.4$ | 921 ± 32 | AUBERT | 08AB | BABR | $B \to \eta_{C}(1S) K^{(*)} \to K \overline{K} \pi K^{(*)}$ |
| $28.1 \pm \ 3.2 \pm 2.2$ | 7.5k | UEHARA | 80 | BELL | $ \begin{array}{ccc} K & \pi & K & \pi & K & \uparrow \\ \gamma & \gamma & \rightarrow & \eta_C & \rightarrow \\ & \text{hadrons} \end{array} $ |
| 48 $^{+}_{-}$ $^{8}_{7}$ ± 5 | 195 | WU | 06 | BELL | $B^+ \rightarrow p \overline{p} K^+$ |
| 40 ±19 ±5 | 20 | WU | 06 | BELL | $B^+ \rightarrow \Lambda \overline{\Lambda} K^+$ |
| 24.8± 3.4±3.5 | 592 | ASNER | 04 | CLEO | $\begin{array}{ccc} \gamma \gamma \rightarrow & \eta_{\rm C} \rightarrow \\ \kappa_{\rm S}^0 \kappa^{\pm} \pi^{\mp} \end{array}$ |
| $20.4 + 7.7 \pm 2.0$ | 190 | AMBROGIANI | 03 | E835 | $\overline{p}p \rightarrow \eta_C \rightarrow \gamma\gamma$ |
| 17.0± 3.7±7.4 | | ¹⁹ BAI | 03 | BES | $J/\psi \rightarrow \gamma \eta_C$ |
| 11.0± 8.1±4.1 | | ²⁰ BAI | 00F | BES | $J/\psi \to \gamma \eta_{\mathcal{C}}$ and $\psi(2S) \to \gamma \eta_{\mathcal{C}}$ |
| $23.9 {}^{+12.6}_{-7.1}$ | | ARMSTRONG | 95 F | E760 | $\overline{p}p \rightarrow \gamma \gamma$ |
| $7.0 \frac{+}{-} \begin{array}{c} 7.5 \\ 7.0 \end{array}$ | 12 | BAGLIN | 87в | SPEC | $\overline{p}p \rightarrow \gamma \gamma$ |
| $10.1 {}^{+ 33.0}_{- 8.2}$ | 23 | ²¹ BALTRUSAIT | .86 | MRK3 | $J/\psi \rightarrow \gamma \rho \overline{\rho}$ |
| 11.5 ± 4.5 | | GAISER | 86 | CBAL | $J/\psi \to \gamma X, \ \psi(2S) \to \gamma X$ |
| • • • We do not | use the following | data for averages, | fits, li | mits, etc | |
| $32.1\!\pm\ 1.1\!\pm\!1.3$ | 12k | ²² DEL-AMO-SA | 11 M | BABR | $\gamma \gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| $34.3 \pm 2.3 \pm 0.9$ | 2547 ± 90 | ²³ AUBERT | 04 D | BABR | $\gamma \gamma \rightarrow \eta_C(1S) \rightarrow$ |
| 29 ± 8 ±6 | 182 ± 25 | ²⁴ FA NG | 03 | BELL | $B \rightarrow \eta_C K$ |
| $27.0 \pm 5.8 \pm 1.4$ | | ²⁵ BRANDENB | 00в | CLE2 | $\begin{array}{c} \gamma\gamma \to \eta_C \to \\ \kappa^{\pm} \kappa_S^0 \pi^{\mp} \end{array}$ |
| < 40 | 90 18 | HIMEL | 80в | MRK2 | e^+e^- |
| < 20 | 90 | PARTRIDGE | 80B | CBAL | e+ e- |
| ¹⁸ Taking into a ¹⁹ From a simuli ²⁰ From a fit to a ²¹ Positive and a ²² Not independ | ccount interference taneous fit of five o the 4-prong invaria negative errors corr ent from the meas | on-resonant conting with the non-resonant characteristic with the non-resonant mass in $\psi(2S)$ — espond to 90% corurements reported | nant $\eta_{\mathcal{C}}$ $ ightarrow \gamma \eta$ nfiden | _C and $J_{/}$ ce level. | $/\psi(1S) ightarrow \gamma \eta_C$ decays. |
| 23 Superseded by | y LEES 10. y VINOKUROVA 1 | | | | I |
| ²⁵ Superseded by | y ASNER 04. | | | | - |

| | and so this id sarily obtain utilizir | s above of weigh cale factor are ba leogram only. The the same as our ned from a least-sing measurements ities as additiona | sed up ey are 'best' v squares of oth | not nec ralues, s constra er (relat | data in es- ained fit |
|-----------------|---------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|----------------------------------------------|-----------------------------|
| Λ. | | DEL AMO CA | 4414 | DADD. | χ^2 |
| | | DEL-AMO-SA VINOKUROVA | | BABR BELL | 2.5 2.4 |
| T | | LEES | 10 | BABR | 1.9 |
| | | AUBERT | | BABR | 1.3 |
| 41 | | UEHARA | 08 | BELL | 0.2 |
| | | · WU | 06 | BELL | 4.5 |
| | | WÜ | 06 | BELL | |
| <u> </u> | | ASNER | 04 | CLEO | 1.0 |
| | | AMBROGIANI | 03 | E835 | 1.4 |
| <u> </u> | | BAI | 03 | BES | 2.4 |
| | | BAI | 00F | BES | 4.2 |
| -++- | | ARMSTRONG | 95F | E760 | 0.3 |
| <u> </u> | | BAGLIN | 87B | SPEC | 9.2 |
| | | BALTRUSAIT | 86 | MRK3 | |
| + -/ | | GAISER | 86 | CBAL | 16.4 |
| | | | | | 47.7 |
| | | (Conf | dence | Level < | 0.0001) |
| | 4 | | | | , |
| -20 0 20 40 | 60 | 80 100 | | | |
| | | | | | |

$\eta_c(1S)$ DECAY MODES

| | Mode | Fraction (Γ_{j} | /Γ) Confid | dence level |
|-----------------|----------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------|-------------|
| | Decays involv | ing hadronic resonan | ces | |
| Γ_1 | $\eta'(958) \pi \pi$ | (4.1 ±1.3 | 7)% | |
| Γ_2 | ho ho | (1.8 ± 0.5) | 5)% | |
| Гз | $K^*(892)^0 K^- \pi^+ + \text{c.c.}$ | (2.0 ±0.7 | 7)% | |
| Γ_4 | $K^*(892)\overline{K}^*(892)$ $K^{*0}\overline{K}^{*0}\pi^+\pi^-$ | (6.8 ±1.3 | $3) \times 10^{-3}$ | |
| Γ_5 | $K^{*0}\overline{K}^{*0}\pi^{+}\pi^{-}$ | (1.1 ± 0.5) | 5)% | |
| Γ ₆ | $\phi K^+ K^-$ | (2.9 ±1.4 | $1) \times 10^{-3}$ | |
| | $\phi\phi$ | (1.94 ± 0.3) | $30) \times 10^{-3}$ | |
| Γ ₈ | $\phi 2(\pi^{+}\pi^{-})$ | < 3.5 | $\times 10^{-3}$ | 90% |
| Γ9 | $a_0(980) \pi$ | < 2 | % | 90% |
| Γ_{10} | $a_2(1320)\pi$ | < 2 | % | 90% |
| Γ_{11} | $K^*(892)\overline{K} + \text{c.c.}$ | < 1.28 | % | 90% |
| Γ_{12} | $f_2(1270)\eta$ | < 1.1 | % | 90% |
| Γ_{13} | $\omega \omega$ | < 3.1 | $\times 10^{-3}$ | 90% |
| | $\omega \phi$ | < 1.7 | | 90% |
| 15 | $f_2(1270) f_2(1270)$ | | $5) \times 10^{-3}$ | |
| 16 | $f_2(1270) f_2'(1525)$ | (9.3 ±3. | $1) \times 10^{-3}$ | |
| | Decays | into stable hadrons | | |
| | $K\overline{K}\pi$ | (7.2 ±0.6 | 5)% | |
| 18 | $\eta\pi^+\pi^-$ | (4.9 ±1.8 | 3)% | |
| T ₁₉ | $K^{+}K^{-}\pi^{+}\pi^{-}$ | (6.1 ±1.2 | $(2) \times 10^{-3}$ | |
| 20 | $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ | (3.4 ±0.6 | 5)% | |
| 21 | $K^{+}K^{-}2(\pi^{+}\pi^{-})$ | (7.1 ± 2.9 | $9) \times 10^{-3}$ | |
| 22 | $2(K^{+}K^{-})$ | $(1.34 \pm 0.3$ | $32) \times 10^{-3}$ | |
| 23 | $2(\pi^{+}\pi^{-})$ | (8.6 ±1.3 | $3) \times 10^{-3}$ | |
| 24 | $3(\pi^{+}\pi^{-})$ | (1.5 ± 0.5) | | |
| 25 | p p | (1.41 ± 0.1) | $17) \times 10^{-3}$ | |
| 26 | $\Lambda \overline{\Lambda}$ | (9.4 ± 3.2 | $2) \times 10^{-4}$ | |
| 27 | $K\overline{K}\eta$ | < 3.1 | % | 90% |
| T ₂₈ | $\pi^+ \pi^- \rho \overline{\rho}$ | < 1.2 | % | 90% |
| | Ra | diative decays | | |
| 29 | $\gamma\gamma$ | • | $16) \times 10^{-4}$ | |
| 2) | | ` | , | |
| | | ugation (<i>C</i>), Parity (<i>F</i> umber (<i>LF</i>) violating (| | |
| 30 | $\pi^+\pi^-$ | P,CP < 1.1 | × 10 ⁻⁴ | 90% |
| Γ ₃₁ | $\pi^0 \pi^0$ | P, CP < 3.5 | × 10 ⁻⁵ | 90% |
| | K+ K- | P.CP < 6 | | 90% |

P, CP < 6

P,CP < 3.1

Γ₃₂ K⁺K⁻

 $\Gamma_{33} \quad K_S^0 K_S^0$

 $\times\,10^{\,-4}$

 $\times\,10^{-4}$

90%

90%

 $\eta_c(1S)$

CONSTRAINED FIT INFORMATION

An overall fit to the total width, 8 combinations of partial widths obtained from integrated cross section, and 14 branching ratios uses 73 measurements and one constraint to determine 11 parameters. The overall fit has a $\chi^2=$ 136.4 for 63 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta p_i \delta p_j \rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| <i>x</i> ₇ | 15 | | | | | | | | |
|------------------------|-------|-----------------------|------------------------|------------------------|------------------------|-----------------|-----|-----------------|-----|
| <i>x</i> ₁₅ | 5 | 6 | | | | | | | |
| <i>x</i> ₁₇ | 28 | 35 | 10 | | | | | | |
| <i>x</i> ₁₉ | 15 | 17 | 5 | 32 | | | | | |
| x ₂₂ | 12 | 14 | 4 | 31 | 14 | | | | |
| x ₂₃ | 18 | 20 | 6 | 38 | 20 | 16 | | | |
| x ₂₅ | 20 | 23 | 7 | 46 | 23 | 19 | 26 | | |
| x ₂₉ | -33 | -39 | -12 | -72 | -38 | -31 | -45 | -56 | |
| Γ | -3 | -3 | -1 | -6 | -3 | -3 | -4 | 10 | -31 |
| | x_4 | <i>x</i> ₇ | <i>x</i> ₁₅ | <i>x</i> ₁₇ | <i>x</i> ₁₉ | x ₂₂ | X23 | X ₂₅ | X29 |

| | Mode | Rate (MeV) |
|-----------------|-------------------------------|---------------------|
| Γ ₄ | $K^*(892)\overline{K}^*(892)$ | 0.20 ±0.04 |
| Γ_7 | $\phi \phi$ | 0.058 ± 0.009 |
| Γ_{15} | $f_2(1270) f_2(1270)$ | 0.29 ±0.07 |
| Γ_{17} | $K\overline{K}\pi$ | 2.12 ± 0.19 |
| Γ_{19} | $K^+ K^- \pi^+ \pi^-$ | 0.180 ± 0.035 |
| | $2(K^{+}K^{-})$ | 0.040 ±0.009 |
| Γ_{23} | $2(\pi^+\pi^-)$ | 0.25 ± 0.04 |
| Γ_{25} | $p\overline{p}$ | 0.042 ± 0.005 |
| Γ ₂₉ | $\gamma \gamma$ | 0.0053 ± 0.0005 |

$\eta_c(1S)$ PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | | | | | Γ29 |
|------------------------|------|--------------|------|---------|-----|
| VALUE (keV) | FVTS | DO CUMENT ID | TECN | COMMENT | |

| | 5.3± | : 0.5 O | UR I | FΙΤ | | _ | | | | | | | | | |
|---|------|---------|------|-------|-----|-----------|------|-----|-----------|-------|---------|------|---|---|---|
| , | | We do | not | use t | the | following | data | for | averages, | fits, | limits, | etc. | • | • | • |

| 5.2± 1.2 | 273 ± 43^{-2} | 26,27 AUBERT | 06E BABR | $B^{\pm} \rightarrow K^{\pm} X_{C} \overline{C}$ |
|----------------------------------------------|-------------------|--------------------------|----------|------------------------------------------------------------------------|
| $5.5 \pm 1.2 \pm 1.8$ | 157 ± 33 | ²⁸ KUO | 05 BELL | $\gamma \gamma \rightarrow p \overline{p}$ |
| $7.4 \pm 0.4 \pm 2.3$ | | ²⁹ ASNER | 04 CLEO | $\gamma \gamma \rightarrow \eta_C \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| $13.9 \pm\ 2.0 \pm\ 3.0$ | 41 | ³⁰ ABDALLAH | 03J DLPH | $\gamma \gamma \rightarrow \eta_C$ |
| $3.8 + 1.1 + 1.9 \\ -1.0 - 1.0$ | 190 | ³¹ AMBROGIANI | | $\overline{p} p \to \ \eta_C \to \ \gamma \gamma$ |
| $7.6 \pm~0.8 \pm~2.3$ | 2 | | 00B CLE2 | $\gamma \gamma \rightarrow \eta_C \rightarrow K^{\pm} K_S^0 \pi^{\mp}$ |
| $6.9 \pm 1.7 \pm 2.1$ | 76 | ³³ ACCIARRI | | $e^+ e^- \rightarrow e^+ e^- \eta_C$ |
| $27\pm 16\pm 10$ | 5 | ²⁹ SHIRAI | 98 A MY | 58 e ⁺ e ⁻ |
| $6.7^{+}_{-}{}^{2.4}_{1.7}\pm2.3$ | | ²⁸ ARMSTRONG | | $\overline{p}p \rightarrow \gamma \gamma$ |
| 11.3 ± 4.2 | | | 94H ARG | $e^+ e^- \rightarrow e^+ e^- \eta_C$ |
| $8.0 \pm 2.3 \pm 2.4$ | 17 | ³⁵ ADRIANI | 93N L3 | $e^+ e^- \rightarrow e^+ e^- \eta_C$ |
| $5.9^{+}_{-}{}^{2.1}_{1.8}\pm1.9$ | | ³¹ CHEN | 90в CLEO | $e^+e^-\rightarrowe^+e^-\eta_C$ |
| $6.4 + 5.0 \\ - 3.4$ | | ³⁶ AIHARA | 88D TPC | $e^+e^- ightarrowe^+e^-{\rm X}$ |
| 4.3^{+}_{-} $\overset{3.4}{3.7}$ \pm 2.4 | | ²⁸ BAGLIN | 87B SPEC | $\overline{\rho} \rho \rightarrow \gamma \gamma$ |
| 28 ± 15 | 2 | ^{29,37} BERGER | 86 PLUT | $\gamma \gamma \rightarrow K \overline{K} \pi$ |

 26 Calculated by us using $\Gamma(\eta_C\to K\overline{K}\pi)\times \Gamma(\eta_C\to \gamma\gamma)\ /\Gamma=0.44\pm0.05$ keV from PDG 06 and B($\eta_C\to K\overline{K}\pi)=(8.5\pm1.8)\%$ from AUBERT 06E.

- 27 Systematic errors not evaluated.
- 28 Normalized to B($\eta_C \rightarrow p\overline{p}$)= $(1.3 \pm 0.4) \times 10^{-3}$. 29 Normalized to B($\eta_C \rightarrow \kappa^{\pm} \kappa_S^0 \pi^{\mp}$).
- $^{30}\,\mathrm{Average}$ of $\mathrm{K}_{S}^{0}\,\mathrm{K}^{\pm}\pi^{\mp}$, $\pi^{+}\,\pi^{-}\,\mathrm{K}^{+}\,\mathrm{K}^{-}$, and $2(\,\mathrm{K}^{+}\,\mathrm{K}^{-})$ decay modes.
- 31 Normalized to the sum of B($\eta_c \to \kappa^\pm \kappa_S^0 \pi^\mp$), B($\eta_c \to \kappa^+ \kappa^- \pi^+ \pi^-$), and B($\eta_c \to \kappa^+ \kappa^- \pi^+ \pi^-$), and B($\eta_c \to \kappa^+ \kappa^- \pi^+ \pi^-$), and B($\eta_c \to \kappa^+ \kappa^- \pi^+ \pi^-$). $2\pi^{+} 2\pi^{-}$).
- 32 Superseded by ASNER 04.
- $^{
 m 33}$ Normalized to the sum of 9 branching ratios.
- 34 Normalized to the sum of B($\eta_C \to K^\pm K_S^0 \pi^\mp$), B($\eta_C \to \phi \phi$) $K^+ K^- \pi^+ \pi^-$), and $B(\eta_C \rightarrow 2\pi^+ 2\pi^-)$.
- 35 Superseded by ACCIARRI 99T.
- ³⁶ Normalized to the sum of B($\eta_C \to K^\pm K^0_S \pi^\mp$), B($\eta_C \to 2K^+ 2K^-$), B($\eta_C \to K^\pm K^0_S \pi^\mp$) $K^+ K^- \pi^+ \pi^-$), and $B(\eta_C \rightarrow 2\pi^+ 2\pi^-)$.
- $^{\rm 37}\,\text{Re-evaluated}$ by AIHARA 88D.

| $\Gamma(K\overline{K}\pi) \times \Gamma(\gamma)$ | | . , . | Γ(i)Γ(<i>γγ</i>)/Γ(| | • | Γ ₁₇ Γ ₂₉ / |
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| VALUE (keV) | CL% EVTS | | DOCUMENT ID | | TECN | COMMENT |
| 0.377±0.021 OUR F 0.407±0.027 OUR A | | Error in | ncludes scale fa | ctor | of 1.2 | |
| $0.374 \pm 0.009 \pm 0.031$ | | | LEES | 10 | BABR | $^{10.6}_{e^{+}e^{-}}\overset{e^{+}e^{-}}{_{6}\overset{O}{\kappa}}\overset{K^{\pm}}{_{6}}^{\pi^{\mp}}$ |
| 0.407±0.022±0.028 | 2 | 39,40 | A SNER | 04 | CLEO | |
| 0.407 ± 0.022 ± 0.020 | , | | N SINEK | 0.1 | CLLO | $\gamma \gamma \rightarrow \eta_C \rightarrow \kappa_S^0 \kappa^{\pm} \pi^{\mp}$ |
| $0.60 \pm 0.12 \pm 0.09$ | 41 | | ABDALLAH | 03J | DLPH | $\gamma \gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| $1.47 \pm 0.87 \pm 0.27$ | | 40 | SHIRAI | 98 | AMY | $\gamma \gamma \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow \eta_C \rightarrow 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| 0.84 ±0.21 | | 40 | ALBRECHT | 944 | ARG | $K^{\pm} K^0_S \pi^{\mp}$ $\gamma \gamma \rightarrow K^{\pm} K^0_S \pi^{\mp}$ |
| 0.60 +0.23 | | | CHEN | | CLEO | |
| -0.20 $1.06 \pm 0.41 \pm 0.27$ | 11 | | BRAUNSCH | | TASS | $\gamma \gamma \to \kappa \overline{\kappa} \pi$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 7 | | BERGER | 86 | PLUT | $\gamma \gamma \rightarrow K \overline{K} \pi$ |
| - 0.45 - • • • We do not us | e the follow | | | | | • • |
| 0.386±0.008±0.021 | | 42 | DEL_AMO_SA | 11 _M | BABB | $\sim \sim \kappa^0 \kappa^{\pm} \pi^{\mp}$ |
| $0.418 \pm 0.044 \pm 0.022$ | 2 | 40,43 | BRANDENB | 00в | CLE2 | $ \begin{array}{ccc} \gamma\gamma & \rightarrow & \eta_C \rightarrow \\ & & \kappa^{\pm} & \kappa^0_{S} & \pi^{\mp} \end{array} $ |
| -0.63 | O.F. | 40 | DELIDEND | 00 | CELL | $K^{\pm} K_S^0 \pi^{\mp}$ $\gamma \gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ |
| < 0.63 < 4.4 | 95 95 | | BEHREND ALTHOFF | | CELL TASS | |
| 38 From the correct | | | | 038 | 1733 | $II \rightarrow KKK$ |
| ³⁹ Calculated by us | from the v | alue rep | orted in ASNE | R 04 | that as | ssumes $B(\eta_C \to K\overline{K}\tau)$ |
| $= 5.5 \pm 1.7\%$ 40 We have multipli | $ied K^{\pm} K_{0}^{0}$ | π∓ mea | surement by 3 | to o | btain <i>K</i> | \overline{K}_{π} |
| ⁴¹ Calculated by us | s from the | value r | eported in AB | DAL | LAH 03 | BJ, which uses $B(\eta_{\mathcal{C}}$ - |
| $K_S^0 K^{\pm} \pi^{\mp}) = ($ | $1.5 \pm 0.4)$ % | 6. | | | | |
| 42 Not independent | | neasuren | nents reported | by LI | EES 10. | |
| ⁴³ Superseded by A | | | | | | |
| $\Gamma(K^+K^-\pi^+\pi^-)$ | $\times \Gamma(\gamma \gamma)$ | | | | | Γ ₁₉ Γ ₂₉ / |
| VALUE (eV) | EVT | S I | DOCUMENT ID | | TECN | COMMENT |
| 32 + 6 OUR F | T | | JOCOMENT ID | | | |
| 32 ± 6 OUR F 27 ± 6 OUR A | T VERAGE | | JOSEPH IN | | | |
| 27 ± 6 OUR A 25.7± 3.2± 4.9 | AVERAGE 2019 ± 24 | 8 (| JEHARA | 08 | BELL | |
| 27 ± 6 OUR A 25.7± 3.2± 4.9 280 ±100 ±60 | AVERAGE 2019 ± 24: 4: | 8 U 2 44 A | JEHARA ABDALLAH | 08 03J | BELL DLPH | $\gamma \gamma \rightarrow \pi^+ \pi^- K^+ K^-$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 2019 ± 244 41 13.9 ± 6.0 | 8 U 2 44 A | JEHARA ABDALLAH ALBRECHT | 08 03Ј 94н | BELL DLPH ARG | $\gamma \gamma \rightarrow \pi^+ \pi^- K^+ K^- \gamma \gamma \rightarrow \pi^+ \pi^- K^+ K^-$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | AVERAGE 2019 ± 248 45 13.9 ± 6.0 s from the | 8 l 2 44 / 6 / | JEHARA ABDALLAH ALBRECHT | 08 03Ј 94н | BELL DLPH ARG | $\gamma \gamma \rightarrow \pi^+ \pi^- K^+ K^- \gamma \gamma \rightarrow \pi^+ \pi^- K^+ K^-$ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by us $\pi^{+}\pi^{-}K^{+}K^{-}$ | AVERAGE 2019 ± 240 400 13.9 ± 6.00 s from the 1000 ± 0.00 1000 ± 0.00 | 8 l 2 44 / 6 / value r 0.7)%. | JEHARA ABDALLAH ALBRECHT eported in AB | 08 03Ј 94н | BELL DLPH ARG | $\gamma\gamma \to \pi^+\pi^- K^+ K^- \gamma\gamma \to \pi^+\pi^- K^+ K^- \gamma\gamma \to \pi^+\pi^- K^+ K^- K^- K^- K^- K^- K^- K^- K^- K^- K^-$ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 \pm 4 Calculated by \pm 2 \pm 4 \pm 4 Calculated \pm 5 \pm 6 Circle (K+K- \pm 7+ \pm 7- \pm 7 | AVERAGE 2019 ± 240 400 13.9 ± 6.00 s from the 1000 ± 0.00 1000 ± 0.00 | 8 (2 ⁴⁴ / ₄ 6 / ₄ value r 0.7)%. | JEHARA ABDALLAH ALBRECHT eported in AB | 08 03J 94H DAL | BELL DLPH ARG LAH 03 | $\gamma\gamma \to \pi^+\pi^-K^+K^ \gamma\gamma \to \pi^+\pi^-K^+K^-$ SJ, which uses B(η_C - |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by \pm \pm 7 \pm 7 \pm 8 \pm 7 \pm 9 \pm 10 \pm | AVERAGE 2019 ± 248 43.9 ± 6.0 s from the $= (2.0 \pm 0)$ $\pi^{0}) \times \Gamma(4)$ $EVTS$ | 8 U 2 44 μ 6 A value r 0.7)%. γγ)/Γ ₁ <u>DO</u> | JEHARA ABDALLAH ALBRECHT eported in AB | 08 03J 94H DAL | BELL DLPH ARG LAH 03 TECN imits, el | $\gamma\gamma \to \pi^+\pi^-K^+K^ \gamma\gamma \to \pi^+\pi^-K^+K^-$ SJ, which uses B(η_C - |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by U: $\pi^{+}\pi^{-}K^{+}K^{-})$ $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-})$ VALUE (keV) | AVERAGE $2019 \pm 24 = 4$ $4:$ 13.9 ± 6.0 s from the $= (2.0 \pm 0)$ $\pi^{0}) \times \Gamma(\frac{EVTS}{E})$ e the follow | 8 U 2 44 μ 6 A value r 0.7)%. γγ)/Γ ₁ <u>DO</u> | JEHARA ABDALLAH ALBRECHT eported in AB total | 08 03J 94H DAL | BELL DLPH ARG LAH 03 TECN imits, el | $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{-}K^{-}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K$ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 1.00 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}$ WLUE (keV) \bullet • • We do not us 0.190 \pm 0.006 \pm 0.028 | AVERAGE $2019 \pm 24:$ $4:$ $13.9 \pm 6.$ Is from the $= (2.0 \pm 0)$ $EVTS$ $= \text{the follow}$ $11k$ | 8 l ₂ 44 μ 6 μ value r 0.7)%. γγ)/Γ ₁ <u>DC</u> ing data | JEHARA ABDALLAH ALBRECHT eported in AB total DCUMENT ID for averages, : EL-AMO-SA1 | 08 03J 94Н DAL | BELL DLPH ARG LAH 03 TECN imits, et | $\begin{array}{c} \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \text{U, which uses B}(\eta_{C}^{-}-K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-$ |
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| 27 \pm 6 OUR μ 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by \pm $\pi^{+}\pi^{-}K^{+}K^{-})$ $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}K^{+}K^{-})$ \bullet • • We do not us 0.190 \pm 0.006 \pm 0.028 45 Not independent $\Gamma(K^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)$ | AVERAGE 2019 ± 244 $4:$ $13.9 \pm 6.$ $5 = (2.0 \pm 0)$ $\frac{EVTS}{6} = \text{the follow}$ $3 = 11k$ from other $(2)) \times \Gamma($ | 8 1 2 44 46 6 7 7 7 7 7 7 7 7 | JEHARA ABDALLAH ALBRECHT eported in AB total DOUMENT ID of or averages, EL-AMO-SA1 ements reporte | 08 03J 94Н DAL | BELL DLPH ARG LAH 03 TECN imits, et BABR DEL-AM | $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}$ $\gamma\gamma \rightarrow K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 1.00 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}K^{-})$ VALUE (keV) 45 Not independent $\Gamma(K^{*}(892)\overline{K}^{*}(89)$ VALUE (keV) | EVERAGE 2019 ± 24 $4:$ $13.9 \pm 6.$ s from the $= (2.0 \pm 0)$ $\pi^{0}) \times \Gamma($ $EVTS$ e the follow $3 11k$ from other | 8 1 2 44 46 6 7 7 7 7 7 7 7 7 | JEHARA ABDALLAH ALBRECHT eported in AB total COUMENT ID of or averages, EL-AMO-SA1 ements reporte | 08 03J 94Н DAL | BELL DLPH ARG LAH 03 TECN imits, et | $\gamma\gamma \rightarrow \pi^+\pi^-K^+K^ \gamma\gamma \rightarrow \pi^+\pi^-K^+K^-$ is, which uses B(η_C - $\Gamma_{20}\Gamma_{29}/\Gamma_{29}/\Gamma_{20}$ $\frac{COMMENT}{\Gamma_{20}}\Gamma_{20}/\Gamma_{20}$ $\frac{COMMENT}{\Gamma_{20}}\Gamma_{20}/\Gamma_{20}/\Gamma_{20}$ $\frac{COMMENT}{\Gamma_{20}}\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma_{20}/\Gamma$ |
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| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 1.00 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\pi^{-}(K^{+}K^{-}\pi^{+}\pi^{-}K^{-}K^{-})$ $\pi^{-}(K^{+}K^{-}\pi^{+}\pi^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K$ | AVERAGE 2019 ± 24 $4:$ $13.9 \pm 6.$ s from the $= (2.0 \pm 0)$ $EVTS$ e the follow a $11k$ from other $(2) \times \Gamma(\frac{EVT}{882 \pm 11!}$ $882 \pm 11!$ | 8 | JEHARA ABDALLAH ALBRECHT eported in AB total COUMENT ID for averages, EL-AMO-SA1 ements reporte total DOCUMENT ID JEHARA | 08 03J 94H DAL | BELL DLPH ARG LAH 03 TECN imits, et BABR DEL-AN TECN BELL | $\begin{array}{c} \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \kappa^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}\\ \gamma\gamma\rightarrow \kappa^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma\rightarrow \pi^{+}\pi^{-}K^{-}\\ \gamma\gamma\rightarrow \pi^{-}K^{-}\\ \gamma\gamma\rightarrow \pi^{-}K^{-}\\ \gamma\gamma\rightarrow \pi^{-}K^{-}\\ \gamma\gamma\rightarrow \pi^{-}K^{-}\\ \gamma\gamma\rightarrow $ |
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| AVERAGE 2019 ± 241 4: $13.9 \pm 6.$ s from the $= (2.0 \pm 0)$ EVT $= \text{the follow}$ 3: $11k$ from other $(22) \times \Gamma(\frac{EVT}{128 \pm 20}) \times \Gamma(\frac{EVT}{128 \pm 20})$ $\Gamma(\gamma \gamma)/\Gamma_{1}$ | 8 L Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value r Value 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| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}K^{-})$ $\bullet \bullet \bullet \text{We do not us}$ 0.190 \pm 0.006 \pm 0.028 45 Not independent $\Gamma(K^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)$ 36 \pm 6 OUR FIT 32.4 \pm 4.2 \pm 5.8 $\Gamma(f_{2}(1270)f'_{2}(1522)$ $VALUE(eV)$ 49 \pm 9 \pm 13 $\Gamma(2(K^{+}K^{-})) \times VALUE(eV)$ 7.0 \pm 1.6 OUR FIT 5.8 \pm 1.9 OUR AV | EVERAGE $2019 \pm 24:$ $4:$ $13.9 \pm 6.$ s from the $= (2.0 \pm 0)$ $EVTS$ $= \text{ the follow}$ $3: 11k$ from other $20) \times \Gamma(\frac{EVTS}{EVT}$ $882 \pm 11:$ $25) \times \Gamma(\frac{EVT}{1128 \pm 20:}$ $\Gamma(\gamma \gamma)/\Gamma_{\frac{EVT}{EV}}$ VERAGE | 8 United States 8×10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} 10^{-2} $10^{$ | JEHARA ABDALLAH ALBRECHT eported in AB total DOUMENT ID for averages, EL-AMO-SA1 ements reporte total JEHARA total JUHARA DOCUMENT ID JEHARA | 08 03J 94H DAL fits, I 1M I 08 | BELL DLPH ARG LAH 03 TECN BELL TECN BELL TECN TECN | $\begin{array}{c} \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \text{is, which uses } B(\eta_{C}^{-}-K^{-}K^{-}K^{-}K^{-}K^{-}K^{-}K^{-$ |
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Is from the = (2.0 ± 0) $\frac{EVTS}{2}$ e the follow 3: 11k from other 22)) × $\Gamma(\frac{EVTS}{2}$ 882 ± 11: 25)) × $\Gamma(\frac{EVT}{2}$ $\frac{EVT}{2}$ $\frac{EVT}{2}$ 7 $\frac{EVT}{2}$ | 8 L 2 44 $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Value r $/$ Valu | JEHARA ABDALLAH ALBRECHT eported in AB COMENT ID of or averages, EL-AMO-SA1 ements reporte total DOCUMENT ID JEHARA LOCUMENT ID JEHARA | 08 03J 94H DAL DAL 11M I 08 | BELL DLPH ARG LAH 03 TECN imits, et BABR DEL-AN TECN BELL TECN TECN 8 BELL | $\begin{array}{c} \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \text{is, which uses } B(\eta_{C} \rightarrow K^{-})\\ \text{is, which uses } B(\eta_{C} \rightarrow K^{-}$ |
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| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}K^{-})$ \leftarrow • • We do not us 0.190 \pm 0.006 \pm 0.026 45 Not independent $\Gamma(K^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)$ 36 \pm 6 OUR FIT 32.4 \pm 4.2 \pm 5.8 $\Gamma(f_{2}(1270)f_{2}^{*}(15222)$ $\Gamma(K^{*}K^{-})$ $\Gamma(K^{*}$ | AVERAGE 2019 ± 24: 4: 13.9 ± 6. s from the = (2.0 ± 0) $\frac{EVTS}{2}$ e the follow 3 11k from other 22)) × $\Gamma(\frac{EVT}{2}$ 1128 ± 20: $\Gamma(\gamma\gamma)/\Gamma_1$ $\frac{EVT}{2}$ T VERAGE 216 ± 9.1 ± 3: from the | 8 1 2 44 $/$ value remarks $\gamma \gamma \rangle / \Gamma_1 \frac{1}{DC}$ measur $\gamma \gamma \rangle / \Gamma_1 \frac{1}{C}$ $\frac{S}{6}$ 1 $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{S}{1}$ $\frac{1}{(\gamma \gamma)} / \frac{S}{1}$ $\frac{S}{1}$ | JEHARA ABDALLAH ALBRECHT eported in AB total COUMENT ID of or averages, EL-A MO-SA1 ements reporte total DOCUMENT ID JEHARA DOCUMENT ID JEHARA LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LOCAL LO | 08 03J 94H DAL fits, I 1M I d in | BELL DLPH ARG LAH 03 TECN BELL TECN BELL TECN BELL ABBELL | $\begin{array}{c} \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \text{is, which uses } B(\eta_{C} - \frac{1}{2}), \\ \text{is, which uses } B(\eta_{C} - $ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 \pm 4 Calculated by us $\pi^+\pi^-K^+K^-$) $\Gamma(K^+K^-\pi^+\pi^-K^-)$ \leftarrow • • • We do not us 0.190 \pm 0.006 \pm 0.028 \pm 5 Not independent $\Gamma(K^*(892)\overline{K}^*(892)\overline{K}^*(892)\overline{K}^*(892)$ \leftarrow • • \leftarrow 10 OUR FIT 32.4 \pm 4.2 \pm 5.8 \rightarrow 6 OUR FIT 32.4 \pm 4.2 \pm 5.8 \rightarrow 7 ($f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ $f_2(1270)f_2'(1524)$ $=$ 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LAH 03 TECN BELL TECN BELL TECN BELL ABBELL | $\begin{array}{c} \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \Sigma, \text{ which uses } B(\eta_{C} - \frac{1}{2}), \\ \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, \Sigma, $ |
| 27 \pm 6 OUR A 25.7 \pm 3.2 \pm 4.9 280 \pm 100 \pm 60 170 \pm 80 \pm 20 44 Calculated by u: $\pi^{+}\pi^{-}K^{+}K^{-}$) $\Gamma(K^{+}K^{-}\pi^{+}\pi^{-}K^{-})$ \leftarrow • • We do not us 0.190 \pm 0.006 \pm 0.026 45 Not independent $\Gamma(K^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)\overline{K}^{*}(892)$ 36 \pm 6 OUR FIT 32.4 \pm 4.2 \pm 5.8 $\Gamma(f_{2}(1270)f_{2}^{*}(15222)$ $\Gamma(K^{*}K^{-})$ $\Gamma(K^{*}$ | AVERAGE 2019 ± 24: 4: 13.9 ± 6. s from the = (2.0 ± 0 EVTS e the follow 3: 11k from other 22) × $\Gamma($ EVT 1128 ± 20: $\Gamma(\gamma\gamma)/\Gamma_{E}$ VERAGE 216 ± 9.1 ± : s from the e: 1. ± 1.2)% | 8 L 4 2 44 4 4 4 4 4 5 4 6 4 4 7 4 4 5 6 6 6 4 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 $^{$ | JEHARA ABDALLAH ALBRECHT eported in AB total DOUMENT ID of raverages, EL-AMO-SA1 ements reporte total DOCUMENT ID JEHARA DOCUMENT ID JEHARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LIEBARA LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY LOCALITY L | 08 03J 94H DAL fits, I 1M I d in | BELL DLPH ARG LAH 03 TECN BELL TECN BELL TECN BELL ABBELL | $\begin{array}{c} \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \gamma\gamma \rightarrow \pi^{+}\pi^{-}K^{+}K^{-}\\ \text{IJ}, \text{ which uses } B(\eta_{C} \rightarrow K^{-})\\ \text{IJ}, \text{ which uses }$ |

 $6.8 \pm 1.2 \pm 1.3$

VALUE (eV)

45 ± 6 OUR FIT

40.7± 3.7± 5.3

 $180 \pm 70 \pm 20$

 $\Gamma(2(\pi^+\pi^-)) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$

42 ± 6 OUR AVERAGE

 132 ± 23

 5381 ± 492

 21.4 ± 8.6

UEHARA

DOCUMENT ID

08 BELL $\gamma \gamma \rightarrow 2(K^+K^-)$

TECN COMMENT

UEHARA 08 BELL $\gamma\gamma \to 2(\pi^+\pi^-)$ ALBRECHT 94H ARG $\gamma\gamma \to 2(\pi^+\pi^-)$

 $\Gamma_{23}\Gamma_{29}/\Gamma$

Meson Particle Listings $\eta_c(1S)$

| $\Gamma(ho ho)	imes\Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ VALUE (eV) CL% EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\phi 2(\pi^+\pi^-))/\Gamma_{\text{total}}$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | <u>VALUE (units 10⁻⁴) CL% DOCUMENT ID</u> <35 90 ⁵² ABLIKIM |
| <39 90 < 1556 UEHARA 08 BELL $\gamma\gamma 	o 2(\pi^+\pi^-)$ | $\Gamma(a_0(980)\pi)/\Gamma_{\text{total}}$ |
| $\Gamma(f_2(1270)f_2(1270)) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_{15}\Gamma_{29}/\Gamma$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <0.02 90 ^{49,53} BALTRUSAIT |
| 11 ± 13 OUR FIT $19\pm17\pm12$ 1182 ± 766 UEHARA 08 BELL $\gamma\gamma\to 2(\pi^+\pi^-)$ | $\Gamma(a_2(1320)\pi)/\Gamma_{\text{total}}$ |
| $\Gamma(\rho \overline{\rho}) \times \Gamma(\gamma \gamma)/\Gamma_{\text{total}}$ $\Gamma_{25}\Gamma_{29}/\Gamma$ | VALUE CL% DO CUMENT ID |
| ALUE(eV) EVTS DOCUMENTID TECN COMMENT | <0.02 90 ⁴⁹ BALTRUSAIT |
| .4 ±0.8 OUR FIT .20±1.53 ± 0.67 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 1.53 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 .20 ± 0.75 | Γ(K*(892)K+ c.c.)/Γ _{total} NALUE <u>CL*</u> DO CUMENT ID |
| • • We do not use the following data for averages, fits, limits, etc. | <0.0128 90 BISELLO <0.0132 90 ⁴⁹ BISELLO |
| 6 $^{+1.3}_{-1.1}$ ± 0.4 190 48 AMBROGIANI 03 E835 $\overline{p}p ightarrow \gamma \gamma$ | $\Gamma(f_2(1270)\eta)/\Gamma_{\text{total}}$ |
| $0.1 \begin{array}{c} +2.9 \\ -2.0 \end{array}$ 48 ARMSTRONG 95F E760 $\overline{p}p \rightarrow \gamma\gamma$ | VALUE CL% DO CUMENT ID |
| 48 Not independent from the $\Gamma_{\gamma\gamma}$ reported by the same experiment. | <0.011 90 ⁴⁹ BALTRUSAIT |
| $\eta_c(1S)$ BRANCHING RATIOS | Γ(ωω)/Γ _{total} VALUE CL% DOCUMENT ID |
| HADRONIC DECAYS | <0.0031 90 49 BALTRUSAIT86 • • • We do not use the following data for average |
| $(\eta'(958)\pi\pi)/\Gamma_{total}$ Γ_1/Γ | <0.0063 90 ⁴⁹ ABLIKIM 05 L |
| ALUE EVTS DOCUMENT ID TECN COMMENT 1.041 \pm 0.017 BALTRUSAIT86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ | <0.0063 49 BISELLO 91 |
| $(ho ho)/\Gamma_{ m total}$ Γ_2/Γ | $\Gamma(\omega\phi)/\Gamma_{ m total}$ |
| ALUE (units 10 ⁻³) CL% EVTS DOCUMENT ID TECN COMMENT 8 ± 5 OUR AVERAGE | <u>VALUE</u> <u>CL%</u> <u>DOCUMENT ID</u> <0.0017 90 ⁴⁹ ABLIKIM 05L |
| $2.6\pm$ 3.8 ± 5.1 72 ⁴⁹ ABLIKIM 05L BES2 $J/\psi ightarrow$ | $\Gamma(f_2(1270) f_2(1270)) / \Gamma_{\text{total}}$ |
| $\pi^{+}\pi^{-}\pi^{+}\pi^{-}\gamma$ 6.0± 2.4±8.8 113 49 BISELLO 91 DM2 $J/\psi \to \gamma \rho^{0} \rho^{0}$ | VALUE (units 10^{-2}) EVTS DOCUMENT |
| 3.6 \pm 10.6 \pm 8.2 32 ⁴⁹ BISELLO 91 DM2 $J/\psi \rightarrow \gamma \rho^+ \rho^-$ • • We do not use the following data for averages, fits, limits, etc. • • • | 0.97±0.25 OUR FIT 0.76±0.25 ± 0.18 91.2 ± 19.8 54 ABLIKIM |
| 14 90 49 BALTRUSAIT86 MRK3 $J/\psi \rightarrow \eta_{\rm C} \gamma$ | 5127 |
| $(K^*(892)^0 K^- \pi^+ + \text{c.c.})/\Gamma_{\text{total}}$ Γ_3/Γ | $\Gamma(KK\pi)/\Gamma_{\text{total}}$ VALUE (units 10^{-2}) CL% EVTS DOCUME |
| ALUE EVTS DOCUMENT ID TECN COMMENT .02 \pm 0.007 63 49 BALTRUSAIT86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ | 7.2 ±0.6 OUR FIT 6.1 ±0.8 OUR AVERAGE |
| $(K^*(892)\overline{K}^*(892))/\Gamma_{\text{total}}$ Γ_4/Γ | 8.5 ±1.8 55 AUBER |
| ALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT 88±13 OUR FIT | |
| 91±26 OUR AVERAGE | 6.90±1.42±1.32 33 ⁴⁹ BISELL |
| $82\pm28\pm27$ 14 49 BISELLO 91 DM2 $e^+e^- \rightarrow$ | 5.43±0.94±0.94 68 ⁴⁹ BISELL |
| γ K ⁺ K ⁻ $\pi^+\pi^-$ 90±50 9 49 BALTRUSAIT86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ | 4.8 ±1.7 95 ^{49,56} BALTR |
| $(K^{*0}\overline{K}^{*0}\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_5/Γ | $16.1 \begin{tabular}{ll} +9.2 & 57 \ HIMEL \\ \bullet \bullet \bullet \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ |
| ALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT 12 \pm 47 \pm 26 45 50 ABLIKIM 06A BES2 $J/\psi \rightarrow K^{*0} \overline{K}^{*0} \pi^{+} \pi^{-} \gamma$ | < 10.7 90 49 PARTR |
| $(\phi K^+ K^-)/\Gamma_{\text{total}} \qquad \qquad \Gamma_6/\Gamma$ | $\Gamma(\eta\pi^+\pi^-)/\Gamma_{ m total}$ |
| 4LUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | VALUE EVTS DOCUMENT ID 0.049±0.018 OUR EVALUATION |
| 9+0.9 ±1.1 14.1+4.4 51 HUANG 03 BELL $B^+ \rightarrow (\phi K^+ K^-) K^+$ | 0.047±0.015 OUR AVERAGE 0.054±0.020 75 ⁴⁹ BALTRUSAIT |
| $(\phi\phi)/\Gamma_{total}$ Γ_{7}/Γ | 0.037±0.013±0.020 18 ⁴⁹ PARTRIDGE |
| 4.0 UE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT 9.4± 3.0 OUR FIT | $\Gamma(K^+K^-\pi^+\pi^-)/\Gamma_{\text{total}}$ |
| 0 ± 5 OUR AVERAGE | <u>VALUE EVTS</u> <u>DOCUMENT ID</u> 0.0061±0.0012 OUR FIT |
| 5.3 \pm 5.1 \pm 9.1 72 ⁴⁹ ABLIKIM 05L BES2 $J/\psi \to K^+K^-K^+K^-\gamma$ 6 \pm 9 357 \pm 64 ⁴⁹ BAI 04 BES $J/\psi \to \gamma K^+K^-K^+K^-$ | 0.0142±0.0033 OUR AVERAGE 0.012 ±0.004 413 ± 54 ⁴⁹ BAI |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 0.021 ±0.007 110 ⁴⁹ BALTRUSAIT |
| 0 $^{+18}_{-12}$ ± 10 5 $^{49}_{}$ BISELLO 91 DM2 $J/\psi \to \gamma K^+ K^- K_0^5 K_L^0$ 4 ± 18 ± 24 80 $^{49}_{}$ BAI 908 MRK3 $J/\psi \to \gamma K^+ K^- K^+ K^-$ | 0.014 + 0.022 57 HIMEL |
| 7 ± 21 ± 24 49 BAI 908 MRK3 $J/\psi \rightarrow \gamma K^+ K^- K_S^0 K_L^0$ • • We do not use the following data for averages, fits, limits, etc. • • • | $\Gamma(K^+K^-\pi^+\pi^-\pi^0)/\Gamma(K\overline{K}\pi)$ VALUE EVTS DOCUMENT ID |
| 8 + $\frac{8}{6}$ + 7 7.0+ $\frac{2.0}{-2.3}$ 51 HUANG 03 BELL $B^+ \rightarrow (\phi \phi)$ K^+ | 0.477±0.017±0.070 11k 58 DEL-A MO-SA |
| - 6 $ -2.3$ | $\Gamma(K^+K^-2(\pi^+\pi^-))/\Gamma_{	ext{total}}$ |
| ·/ + 1 / F / V \overline{\sigma} - 1 | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID |
| | 71 ± 22 ± 16 100 59 A D L IZINA 00: |
| ALUE EVTS DOCUMENT ID TECN COMMENT 1.027±0.004 OUR FIT | 71±23±16 100 ⁵⁹ ABLIKIM 06A |
| V //. V | 71±23±16 100 ⁵⁹ ABLIKIM 06A |

 Γ_8/Γ TECN COMMENT 06A BES2 $J/\psi
ightarrow \overline{\phi 2(\pi^+\pi^-)\gamma}$ $\frac{D}{D}$ $\frac{TECN}{MRK3}$ $\frac{COMMENT}{J/\psi
ightarrow \eta_C \gamma}$ Γ_{10}/Γ T...86 MRK3 $J/\psi
ightarrow \eta_{\it C} \gamma$ Γ_{11}/Γ TECN COMMENT 91 DM2 $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ 91 DM2 $J/\psi \rightarrow \gamma K^{+} K^{-} \pi^{0}$ Γ_{12}/Γ $\frac{D}{\text{IT...86}}$ $\frac{TECN}{\text{MRK3}}$ $\frac{COMMENT}{J/\psi
ightarrow \eta_{\text{C}} \gamma}$ Γ_{13}/Γ TECN COMMENT MRK3 $J/\psi
ightarrow \eta_{\it C} \gamma$ ges, fits, limits, etc. 🔹 🔹 🔹 BES2 $J/\psi \rightarrow$ $\begin{array}{ccc} & & & \\ & \pi^+\pi^-\pi^0\,\pi^+\pi^-\pi^0\,\gamma \\ \\ {\rm DM2} & & J/\psi \,\rightarrow\, \gamma\omega\omega \end{array}$ Γ_{14}/Γ TECN COMMENT

5L BES2 $J/\psi \rightarrow \pi^+\pi^-\pi^0 K^+K^-\gamma$ Γ_{15}/Γ IT ID TECN COMMENT 04m BES $J/\psi
ightarrow \gamma 2\pi^+ \, 2\pi^ \Gamma_{17}/\Gamma$ MENT ID TECN COMMENT 06E BABR $B^{\pm} \rightarrow K^{\pm} X_{C\overline{C}}$ 04 BES $J/\psi \rightarrow \gamma K^{\pm} \pi^{\mp} K_S^0$ 91 DM2 $J/\psi
ightarrow$ 91 DM2 $J/\psi \rightarrow$ RUSAIT...86 MRK3 $J/\psi
ightarrow \eta_{\it C} \, \gamma$ 80в MRK2 $\psi(2S)
ightarrow \eta_{\it C} \gamma$ ges, fits, limits, etc. • • • RIDGE 80B CBAL $J/\psi
ightarrow \eta_{\it C} \gamma$ Γ_{18}/Γ TECN COMMENT IT...86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ E 80B CBAL $J/\psi \rightarrow \eta \pi^+ \pi^- \gamma$ Γ_{19}/Γ TECN COMMENT 04 BES $J/\psi \rightarrow \gamma K^+ K^- \pi^+ \pi^-$.86 MRK3 $J/\psi \rightarrow \eta_C \gamma$ 80B MRK2 $\psi(2S) \rightarrow \eta_{\it C} \, \gamma$ Γ_{20}/Γ_{17} TECN COMMENT .11M BABR $\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$ TECN COMMENT 5A BES2 $J/\psi \rightarrow K^+ K^- 2(\pi^+ \pi^-) \gamma$

 $\eta_c(1S)$

| 「(2(K+K ⁻))/「 _{tota} /ALUE (units 10 ⁻³) | EVTS DOCUMENT ID TECN COMMEN | Γ ₂₂ /Γ _≀ |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| 1.34 ± 0.32 OUR FIT | 2 Do commen | · <u>·</u> |
| • • We do not use the | e following data for averages, fits, limits, etc. • • | • |
| $1.4 {}^{+}_{-} {}^{0.5}_{0.4} \pm 0.6$ | $5^{+4.6}_{-3.0}$ 51 HUANG 03 BELL $B^+ \rightarrow$ | 2(K+K-)K+ |
| 1 ±10 ±6 | | K+K-K+K- |
| (0/14± 14=1) 15/14 | _ | - /- |
| '(2(K+K-))/Γ(K' ALUE | • | Γ ₂₂ /Γ ₁₇ |
| .019±0.004 OUR FIT | <u>EVTS DOCUMENT ID TECN COMMEN</u> | 11 |
| .024±0.007 OUR AVE | | |
| $.023 \pm 0.007 \pm 0.006$ | AUBERT,B 04B BABR B^{\pm} \rightarrow | ,,, |
| $.026^{+0.009}_{-0.007}\pm0.007$ | 15 ⁵¹ HUANG 03 BELL B^{\pm} \rightarrow | $\kappa^{\pm}(2K^+2K^-)$ |
| (2(-+)) /F | | Г /Г |
| $\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ (ALUE (units 10^{-2}) | EVTS DOCUMENT ID TECN COM | Γ ₂₃ /Γ |
| .86±0.13 OUR FIT | <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COM</u> | MENI |
| .15 ± 0.26 OUR AVER | | |
| .0 ± 0.5 | | $\rightarrow \gamma 2(\pi^+\pi^-)$ |
| .05 ± 0.17 ± 0.34 .3 ± 0.6 | 137 49 BISELLO 91 DM2 J/ψ 25 49 BALTRUSAIT86 MRK3 J/ψ | $\rightarrow \gamma 2\pi^+ 2\pi^-$ $\rightarrow n \gamma$ |
| .0 +1.5 | 57 HIMEL 80B MRK2 $\psi(2)$ | |
| 1.0 | Σ σου πιτίτε φ(ε. | · / · · · · · · · · · · · · · · · · · · |
| $(\phi K^+ K^-)/\Gamma (K \overline{K})$ | π) | Γ_6/Γ_{17} |
| ALUE | <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMME</u> | |
| $.052^{+0.016}_{-0.014} \pm 0.014$ | 7 51 HUANG 03 BELL B^{\pm} $ ightarrow$ | $K^{\pm}\phi\phi$ |
| | | - 1- |
| $(3(\pi^+\pi^-))/\Gamma_{\text{total}}$ | | Γ ₂₄ /Γ |
| ALUE (units 10 ⁻⁴) | EVTS DOCUMENT ID TECN COMME | |
| 52±33±35 | 479 61 ABLIKIM 06A BES2 $J/\psi ightarrow$ | $3(\pi^+\pi^-)\gamma$ |
| $(p\overline{p})/\Gamma_{\text{total}}$ | | Γ ₂₅ /Γ |
| ALUE (units 10 ⁻⁴) | EVTS DOCUMENT ID TECN COMMEN | IT . |
| 4.1± 1.7 OUR FIT | C.F. | |
| 2.5 ± 3.2 OUR AVER. 5 ± 6 21 | \pm 33 49 BAI 04 BES $J/\psi ightarrow$ | γ p D |
| 0 ± 3 ±4 | 18 ⁴⁹ BISELLO 91 DM2 $J/\psi \rightarrow$ | |
| 1 ± 6 | 23 49 BALTRUSAIT86 MRK3 $J/\psi ightarrow$ | $\eta_C \gamma$ |
| 9 +29 -15 | 57 HIMEL 80B MRK2 $\psi(2S)$ - | $\rightarrow \eta_C \gamma$ |
| • • We do not use the | e following data for averages, fits, limits, etc. $ullet$ | • |
| 4.8^{+}_{-} $\begin{array}{c} 2.0 \\ 2.4 \\ \end{array} \pm 1.8$ | 195 62 WU 06 BELL B^+ \rightarrow | $p\overline{p}K^+$ |
| | | |
| $\Gamma(p\overline{p})/\Gamma(K\overline{K}\pi)$ | | Γ_{25}/Γ_{17} |
| ALUE 0.0197±0.0022 OUR F | <u>EVTS DOCUMENT ID TECN COMME</u> T | <u>NT</u> |
| 0.021 ±0.002 +0.004 -0.006 | 195 51 WU 06 BELL $B^\pm ightarrow$ | κ± ο ο |
| .021 ±0.002 -0.006 | 193 WO 00 BELL B | $\kappa - \rho \rho$ |
| $(p\overline{p})/\Gamma_{\text{total}} \times \Gamma(q)$ | $\phi)/\Gamma_{\text{total}}$ | $\Gamma_{25}/\Gamma \times \Gamma_7/\Gamma$ |
| ALUE (units 10 ⁻⁵) | DOCUMENT ID TECN COMME | NT |
| .27±0.06 OUR FIT | | |
| .0 +3.5 -3.2 | BAGLIN 89 SPEC $\overline{p}p \rightarrow$ | K+K-K+K- |
| · (4 4) / F | | F /F |
| (ΛΛ̄)/Γ _{total} | | Γ ₂₆ /Γ |
| ALUE (units 10 ⁻⁴) CL% | <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMME</u> e following data for averages, fits, limits, etc. • • | <u>N I</u> |
| | | · - ! |
| $9.9 + 2.7 \pm 1.2$ | 20 63 WU 06 BELL B^+ \rightarrow | |
| <20 90 | ⁴⁹ BISELLO 91 DM2 <i>e</i> ⁺ <i>e</i> ⁻ | $\rightarrow \gamma \Lambda \overline{\Lambda}$ |
| $(\Lambda \overline{\Lambda})/\Gamma(\rho \overline{\rho})$ | | Γ_{26}/Γ_{25} |
| ALUE | DOCUMENT ID TECN COMMEN | |
| $0.67^{+0.19}_{-0.16}\pm0.12$ | $^{64}\mathrm{WU}$ 06 BELL B^{+} \rightarrow | $p\overline{p}K^+, \Lambda\overline{\Lambda}K^+$ |
| | - | |
| $(K\overline{K}\eta)/\Gamma_{\text{total}}$ | | Γ ₂₇ /Γ |
| ALUE | CL% DOCUMENT ID TECN COMME | |
| <0.031 | 90 49 BALTRUSAIT86 MRK3 J/ψ $ ightarrow$ | $\eta_C \gamma$ |
| $(\pi^+\pi^-\rho\overline{\rho})/\Gamma_{\rm total}$ | | Γ ₂₈ /Γ |
| , rr//:wid | | |
| ALUE | CL% DO CUMENT ID TECN COMME | NT |

- 49 The quoted branching ratios use B($J/\psi(1S) \to \gamma \eta_{\rm C}(1S)) = 0.0127 \pm 0.0036$. Where relevant, the error in this branching ratio is treated as a common systematic in computing
- $^{\rm averages.}$ 50 ABLIKIM 06A reports [$\Gamma(\eta_C(1S) \to K^{*0} \overline{K}^{*0} \pi^+ \pi^-)/\Gamma_{\rm total}$] \times [B ($J/\psi(1S) \to \gamma\eta_C(1S)$)] = (1.91 ± 0.64 ± 0.48) × 10^{-4} which we divide by our best value B ($J/\psi(1S) \to \gamma\eta_C(1S)$)] = (1.91 ± 0.64 ± 0.48) × 10^{-4} which we divide by our best value B ($J/\psi(1S) \to \gamma\eta_C(1S)$) $\gamma \eta_{\rm C}(1S) = (1.7 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second
- $\eta_{RC}(13)=(1.1\pm0.4)$ ATO . Our instantial states where Experiments early and our section error is the systematic error from using our best value. 51 Using B($B^+\to \eta_C$ K $^+$) = $(1.25\pm0.12^+0.10^-)$ $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^{-3}$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 03 and B($\eta_C\to 10^-$) $\times 10^-$ from FANG 04 $\times 10^-$ f $K\overline{K}\pi$) = $(5.5 \pm 1.7) \times 10^{-2}$.
- $^{52} \text{ABLIKIM 06A reports} \left[\Gamma \left(\eta_{\mathcal{C}}(1S) \rightarrow \ \phi 2(\pi^{+}\pi^{-}) \right) / \Gamma_{\text{total}} \right] \times \left[\text{B}(\textit{J}/\psi(1S) \rightarrow \ \gamma \eta_{\mathcal{C}}(1S)) \right]$ < 0.603 imes 10⁻⁴ which we divide by our best value B $(J/\psi(1S)
 ightarrow \gamma\eta_{\it C}(1S)) = 1.7 <math> imes$ 10^{-2}
- ⁵³We are assuming B($a_0(980) \rightarrow \eta \pi$) >0.5.
- ⁵⁴ ABLIKIM 04M reports $[\Gamma(\eta_C(1S) \rightarrow \eta_A) > 0.3.$ $\uparrow \eta_C(1270) f_2(1270))/\Gamma_{total}] \times [B(J/\psi(1S) \rightarrow \eta_C(1S))] = (1.3 \pm 0.3 \stackrel{+}{_{-}} 0.3) \times 10^{-4}$ which we divide by our best value $B(J/\psi(1S) \rightarrow \eta_C(1S))] = (1.3 \pm 0.3 \stackrel{+}{_{-}} 0.3) \times 10^{-4}$ $\gamma \eta_c(15)$) = $(1.7 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- 55 Determined from the ratio of $B(B^\pm\to K^\pm\eta_C)$ B($\eta_C\to K\overline{K}\pi)=(7.4\pm0.5\pm0.7)\times 10^{-5}$ reported in AUBERT,B 04B and B($B^\pm\to K^\pm\eta_C)=(8.7\pm1.5)\times 10^{-3}$ reported in AUBERT 06E. So Average from $K^+K^-\pi^0$ and $K^\pm K^0_S \pi^\mp$ decay channels.
- ⁵⁷ Estimated using B($\psi(2S) \rightarrow \gamma \eta_{C}(1S)$) = 0.0028 \pm 0.0006
- ⁵⁸We have multiplied the value of $\Gamma(K^+ K^- \pi^+ \pi^- \pi^0)/\Gamma(K^0_S K^\pm \pi^\mp)$ reported in DEL-
- AMO-SANCHEZ 11M by a factor 1/3 to obtain $\Gamma(K^+K^-\pi^+\pi^-\pi^0)/\Gamma(K\overline{K}\pi)$. Not independent from other measurements reported in DEL-A MO-SANCHEZ 11M. 59 ABLIKIM 06A reports $[\Gamma(\eta_c(1s) \to K^+K^-2(\pi^+\pi^-))/\Gamma_{\text{total}}] \times [B(J/\psi(1s) \to \gamma\eta_c(1s))] = (1.21\pm0.32\pm0.24)\times10^{-4}$ which we divide by our best value $B(J/\psi(1s) \to \gamma\eta_c(1s))$ $\gamma\eta_c(1S)=(1.7\pm0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- 60 Normalized to the sum of B(η_{c} $\xrightarrow{}$ K^{\pm} K^{0}_{S} $\pi^{\mp}),$ B(η_{c} \rightarrow $\phi\phi),$ B(η_{c} \rightarrow ${\it K}^+ \, {\it K}^- \, \pi^+ \, \pi^-)$, and ${\it B}(\eta_{\it C} \rightarrow \, 2\pi^+ \, 2\pi^-)$.
- 61 ABLIKIM 06A reports $[\Gamma(\eta_C(1S) \to 3(\pi^+\pi^-))/\Gamma_{\text{total}}] \times [B(J/\psi(1S) \to \gamma\eta_C(1S))] = (2.59 \pm 0.32 \pm 0.47) \times 10^{-4}$ which we divide by our best value $B(J/\psi(1S) \to \gamma\eta_C(1S)) = (1.7 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- ⁶² WU 06 reports $[\Gamma(\eta_C(1S)
 ightarrow
 ho \overline{
 ho})/\Gamma_{ ext{total}}] \times [B(B^+
 ightarrow \eta_C K^+)] = (1.42 \pm 0.11 ^{+0.16}_{-0.20}) \times 10^{-10}$ 10^{-6} which we divide by our best value B($B^+ \to \eta_c \, K^+$) = $(9.6 \pm 1.2) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- 63 WU 06 reports $\left[\Gamma(\eta_c(1S) \rightarrow \Lambda \overline{\Lambda})/\Gamma_{\text{total}}\right] \times \left[B(B^+ \rightarrow \eta_c K^+)\right] =$ $(0.95 + 0.25 + 0.08) \times 10^{-6}$ which we divide by our best value B($B^+ \rightarrow \eta_c K^+$) = $(9.6 \pm 1.2) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
- ⁶⁴ Not independent from other $\eta_C \to \Lambda \overline{\Lambda}$, $p\overline{p}$ branching ratios reported by WU 06.

| | R/ | ADIATIVE DEC | AYS | | <u>—</u> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|-----------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ | | | | | Γ ₂₉ /Γ |
| VALUE (units 10^{-4}) | CL% EVTS | DOCUMENT ID | | TECN | COMMENT |
| | $1.2 + 2.8 \\ -1.1$ | ⁶⁵ ADAMS data for averages, | | | $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ |
| $2.3 ^{+1.0}_{-0.8} \pm 0.3$ | 13 | 66 WICHT | 80 | BELL | $B^{\pm} \rightarrow K^{\pm} \gamma \gamma$ |
| $2.80^{+0.67}_{-0.58}\pm1.0$ | | 67 ARMSTRONG | 95F | E760 | $\overline{p} p \to \gamma \gamma$ |
| < 9 | 90 | ⁶⁸ BISELLO | 91 | DM2 | $J/\psi \rightarrow \gamma \gamma \gamma$ |
| 6 $^{+4}_{-3}$ ± 4 | | ⁶⁷ BAGLIN | 87в | SPEC | $\overline{p} p \rightarrow \gamma \gamma$ |
| < 18 | 90 | ⁶⁹ BLOOM | 83 | CBAL | $J/\psi \rightarrow \eta_C \gamma$ |
| (2.4 + 1.1 ± 0. = (1.7 ± 0.4) the systematic 66 WICHT 08 (2.2 + 0.9 + 0.4 (9.6 ± 1.2) v. is the systematic 67 Not independe experiment. 68 The quoted br relevant, the er averages. | $3) \times 10^{-6}$ which $\times 10^{-2}$. Our first error from using reports $\left[\Gamma\left(\eta_C(1, \frac{1}{2})\right) \times 10^{-7}\right]$ which 10^{-4} . Our firstic error from usint from the value anching ratios us for in this branch | th we divide by our sterror is their experience our best value. S) $\rightarrow \gamma \gamma / / \Gamma_{\rm to}$ the we divide by out terror is their exping our best value. The sees of the total and the second of the second output the second of the second output the second of the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the second output the secon | best erime $_{\mathrm{tal}}$] r best erime $_{\mathrm{two-p}}$ | value By nt's error × [B() it value ent's error hoton w | $\begin{array}{ll} (1S) & \rightarrow & \gamma \eta_{C}(1S))] = \\ (J/\psi(1S) & \rightarrow & \gamma \eta_{C}(1S)) \\ \gamma & \text{and our second error is} \\ (B^{+} & \rightarrow & \eta_{C} \ K^{+})] = \\ (B(B^{+} & \rightarrow & \eta_{C} \ K^{+}) = \\ \gamma & \text{or and our second error} \\ \gamma & \text{otherwise} \\ \gamma &$ |

 $\Gamma(\gamma\gamma)/\Gamma(K\overline{K}\pi)$ Γ_{29}/Γ_{17} EVTS VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 2.5 ± 0.4 OUR FIT ⁷⁰ WICHT 08 BELL $B^{\pm}
ightarrow K^{\pm} \gamma \gamma$

⁷⁰ Using B($B^+ \to \eta_C K^+$) = $(1.25 \pm 0.12 + 0.12 + 0.10 \times 10^{-3} \text{ from FANG 03 and B}(\eta_C \to 0.12 + 0.12 \times 10^{-3}) \times 10^{-3} \text{ from FANG 03 and B}(\eta_C \to 0.12 + 0.12 \times 10^{-3}) \times 10^{-3} \text{ from FANG 03 and B}(\eta_C \to 0.12 + 0.12 \times 10^{-3}) \times 10^{-3} \text{ from FANG 03 and B}(\eta_C \to 0.12 + 0.12 \times 10^{-3}) \times 10^{-3} \text{ from FANG 03 and B}(\eta_C \to 0.12 + 0.12 \times 10^{-3}) \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^{-3} \times 10^$ $K\overline{K}\pi$) = $(5.5 \pm 1.7) \times 10^{-2}$.

| $\Gamma(p\overline{p})/\Gamma_{\text{total}} \times \Gamma(\gamma)$ | $(\gamma)/\Gamma_{\rm tot}$ | al | | $\Gamma_{25}/\Gamma \times \Gamma_{29}/\Gamma$ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| /ALUE (units 10 ⁻⁶) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 0.250±0.026 OUR FIT | | | | |
| 0.26 ±0.05 OUR AVE | | Error includes scale facto | | |
| $0.224 + 0.038 \pm 0.020$ | 190 | AMBROGIANI 03 | E835 | $\overline{p}p \rightarrow \eta_C \rightarrow \gamma \gamma$ |
| $0.336 {}^{+ 0.080}_{- 0.070}$ | | ARMSTRONG 95F | E760 | $\overline{p}p \rightarrow \gamma \gamma$ |
| 0.68 + 0.42 - 0.31 | 12 | BAGLIN 87B | SPEC | $\overline{p}p \rightarrow \gamma \gamma$ |
| | Charge | conjugation (<i>C</i>), Par | rity (D) | |
| | | ily number (<i>LF</i>) viol | | |
| $(\pi^+\pi^-)/\Gamma_{ m total}$ | | ., | | г _{зо} /г |
| (" ")/ · total (ALUE (units 10 ⁻⁵) | CL% | DOCUMENT ID | TECN | |
| <11 | 90 | 71 ABLIKIM 11G | | |
| | 6.11 | | | |
| • • • We do not use ti | ie tollowin | g data for averages, fits | , limits, | etc. • • • |
| • • • We do not use th <60 | 90 | - | | etc. • • • $J/\psi \rightarrow \pi^+\pi^-\gamma$ |
| <60 ⁷¹ ABLIKIM 11G repo | 90 rts $[\Gamma(\eta_C)]$ | 72 ABLIKIM 06B 1S) $\rightarrow \pi^+\pi^-)/\Gamma_{\text{total}}$ | BES2 | $J/\psi \rightarrow \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \rightarrow \gamma\eta_{\bar{c}}(1S))$ |
| $^{<60}$ 71 ABLIKIM 11 $_{ m G}$ repo $< 1.82{	imes}10^{-6}$ whic | 90 $ \text{rts } [\Gamma \big(\eta_C (\mathbf{r}) \big)] $ the we divide | 72 ABLIKIM 06B $^{1S)} ightarrow \pi^+ \pi^-)/\Gamma_{	ext{tota}}$ e by our best value B($^{J/}$ | $egin{array}{l} BES2 \ al \] 	imes [B \ \psi(1S) \ - \ \end{array}$ | $J/\psi \rightarrow \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \rightarrow \gamma\eta_{c}(1S))$ $\rightarrow \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ |
| $^{<60}$ 71 ABLIKIM 11G repo $^{<1.82	imes10^{-6}}$ whic 72 ABLIKIM 06B repo | 90 rts $[\Gamma(\eta_C)]$ th we divid rts $[\Gamma(\eta_C)]$ | 72 ABLIKIM 06B 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ e by our best value B($^{J/}$ 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ | $egin{array}{l} BES2 \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \ \psi(1\mathcal{S}) - \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \end{array}$ | $J/\psi \rightarrow \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \rightarrow \gamma\eta_{C}(1S))$ $\rightarrow \gamma\eta_{C}(1S)) = 1.7 \times 10^{-2}$ $(J/\psi(1S) \rightarrow \gamma\eta_{C}(1S))$ |
| $^{<60}$ 71 ABLIKIM 11 $_{ m C}$ repo $^{<1.82	imes10^{-6}}$ whic | 90 rts $[\Gamma(\eta_C)]$ th we divid rts $[\Gamma(\eta_C)]$ | 72 ABLIKIM 06B 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ e by our best value B($^{J/}$ 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ | $egin{array}{l} BES2 \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \ \psi(1\mathcal{S}) - \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \end{array}$ | $J/\psi \rightarrow \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \rightarrow \gamma\eta_{c}(1S))$ $\rightarrow \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ |
| $^{<60}$ 71 ABLIKIM 11G repo $^{<1.82 \times 10^{-6}}$ whice 72 ABLIKIM 06B repo $^{<1.1 \times 10^{-5}}$ which | 90 rts $[\Gamma(\eta_C)]$ th we divid rts $[\Gamma(\eta_C)]$ | 72 ABLIKIM 06B 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ e by our best value B($^{J/}$ 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ | $egin{array}{l} BES2 \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \ \psi(1\mathcal{S}) - \ a_{B} \end{bmatrix} 	imes egin{array}{l} B \end{array}$ | $J/\psi \rightarrow \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \rightarrow \gamma\eta_{C}(1S))$ $\rightarrow \gamma\eta_{C}(1S)) = 1.7 \times 10^{-2}$ $(J/\psi(1S) \rightarrow \gamma\eta_{C}(1S))$ |
| $^{<60}$ 71 ABLIKIM 11 $_{ m C}$ repo $^{<1.82	imes10^{-6}}$ whic | 90 rts $[\Gamma(\eta_C)]$ th we divid rts $[\Gamma(\eta_C)]$ | $72\mathrm{ABLIKIM}$ 06B $15) ightarrow \pi^+\pi^-)/\Gamma_{\mathrm{tota}}$ e by our best value $\mathrm{B}(J/15) ightarrow \pi^+\pi^-)/\Gamma_{\mathrm{tota}}$ by our best value $\mathrm{B}(J/\tau)$ | $egin{array}{l} BES2 \\ Bi \end{bmatrix} 	imes egin{array}{l} B \\ \psi(1S) - Bi \end{bmatrix} 	imes egin{array}{l} B \\ \psi(1S) - Bi \end{bmatrix} \end{array}$ | $J/\psi \to \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \to \gamma\eta_{c}(1S))$ $\to \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ $(J/\psi(1S) \to \gamma\eta_{c}(1S))$ $\to \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ |
| <60 71 ABLIKIM 11g repo $< 1.82 \times 10^{-6}$ whice 72 ABLIKIM 06B repo $< 1.1 \times 10^{-5}$ which $= (\pi^0 \pi^0) / \Gamma_{\text{total}}$ VALUE (units 10^{-5}) | 90 rts $[\Gamma(\eta_C)]$ th we dividerts $[\Gamma(\eta_C)]$ n we divide | 72 ABLIKIM 06B 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ e by our best value B($^{J/}$ 15 $\rightarrow \pi^{+}\pi^{-})/\Gamma_{\rm tota}$ | $egin{array}{l} BES2 \\ Bi \end{bmatrix} 	imes egin{array}{l} B \\ \psi(1S) - Bi \end{bmatrix} 	imes egin{array}{l} B \\ \psi(1S) - Bi \end{bmatrix} \end{array}$ | $J/\psi \to \pi^{+}\pi^{-}\gamma$ $(J/\psi(1S) \to \gamma\eta_{c}(1S))$ $\to \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ $(J/\psi(1S) \to \gamma\eta_{c}(1S))$ $\to \gamma\eta_{c}(1S)) = 1.7 \times 10^{-2}$ |
| <60 71 ABLIKIM 11G repo < 1.82×10^{-6} whice 72 ABLIKIM 06B repo < 1.1×10^{-5} whice ($0^{0}0^{0}$)/ $\Gamma_{\mathbf{total}}$ ALUE (units 10^{-5}) < 3.5 | 90 In this interpolation of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of | $72\mathrm{ABLIKIM}$ 06B $15) ightarrow \pi^+\pi^-)/\Gamma_{\mathrm{tota}}$ e by our best value $\mathrm{B}(J/15) ightarrow \pi^+\pi^-)/\Gamma_{\mathrm{tota}}$ by our best value $\mathrm{B}(J/\tau)$ | BES2 $\begin{array}{l} \text{BES2} \\ \psi(1S) = \\ \psi(1S) = \\ \psi(1S) = \\ \end{array}$ $\begin{array}{l} \text{TECN} \\ \text{BES3} \end{array}$ | $\begin{array}{ccc} J/\psi \rightarrow & \pi^{+}\pi^{-}\gamma \\ (J/\psi(1S) \rightarrow & \gamma\eta_{c}(1S)) \\ \rightarrow & \gamma\eta_{c}(1S)) = 1.7\times10^{-2} \\ (J/\psi(1S) \rightarrow & \gamma\eta_{c}(1S)) \\ \rightarrow & \gamma\eta_{c}(1S)) = 1.7\times10^{-2} \\ & & \Gamma_{31}/\Gamma \\ \hline & \frac{COMMENT}{J/\psi \rightarrow & \gamma\pi^{0}\pi^{0}} \end{array}$ |
| <00 71 ABLIKIM 11G repo < 1.82×10 ⁻⁶ whice 72 ABLIKIM 06B repo < 1.1×10 ⁻⁵ whice - (π ⁰ π ⁰)/Γtotal ALUE (units 10 ⁻⁵) < 3.5 | 90 In this interpolation of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of | 72 ABLIKIM 06B $15) \rightarrow \pi^+\pi^-)/\Gamma_{	ext{tota}}$ e by our best value B($J/\tau_{	ext{tota}}$) by our best value B($J/\tau_{	ext{tota}}$) by our best value B($J/\tau_{	ext{tota}}$) by our best value B($J/\tau_{	ext{tota}}$) $\frac{DOCUMENT\ ID}{73\ ABLIKIM}$ 11G g data for averages, fits | BES2 $\frac{1}{ A } \times [B] \times [B]$ $\psi(1S) \rightarrow [B]$ $\psi(1S) \rightarrow [B]$ $\frac{TECN}{BES3}$ i, limits, | $\begin{array}{ccc} J/\psi \rightarrow & \pi^{+}\pi^{-}\gamma \\ (J/\psi(1S) \rightarrow & \gamma\eta_{c}(1S)) \\ \rightarrow & \gamma\eta_{c}(1S)) = 1.7\times10^{-2} \\ (J/\psi(1S) \rightarrow & \gamma\eta_{c}(1S)) \\ \rightarrow & \gamma\eta_{c}(1S)) = 1.7\times10^{-2} \\ & & \Gamma_{31}/\Gamma \\ \hline & \frac{COMMENT}{J/\psi \rightarrow & \gamma\pi^{0}\pi^{0}} \end{array}$ |

| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | | | | | | Г ₃₂ /Г |
|---------------------------------------------------------|----------------------------------------------------|--------------------------------------------------------|----------------------------|------------------------------------------|----------------------------------------|-----------------------|
| VALUE (units 10^{-5}) | CL% | DOCUMENT ID | TE | CN C | OMMENT | |
| <60 | 90 75 | ABLIKIM 0 | 6в ВЕ | ES2 J | $I/\psi \rightarrow K^+$ | $\kappa^-\gamma$ |
| 75 ABLIKIM 06B report $< 0.96 	imes 10^{-5}$ which | s $[\Gammaig(\eta_{\mathcal{C}}(1S))]$ we divide b | $\rightarrow K^+ K^-)/\Gamma_1$ y our best value B(| $\frac{total}{J/\psi(15)}$ | \times [B(J S) $\rightarrow \gamma$ | $/\psi(1S) \rightarrow \eta_C(1S) = 1$ | $\gamma \eta_C(1S))]$ |

 $\Gamma(K_S^0 K_S^0)/\Gamma_{\text{total}}$ Γ_{33}/Γ DO CUMENT ID TECN COMMENT

 $76 \overline{\mathsf{ABLIKIM}} \qquad 06 \overline{\mathsf{BES2}} \qquad J/\psi \rightarrow \ \kappa_S^0 \ \kappa_S^0 \ \gamma$ <31 $^{76} \text{ABLIKIM 06B reports } [\Gamma \left(\eta_{\mathcal{C}}(1S) \ \rightarrow \ \kappa_S^0 \ \kappa_S^0 \right) / \Gamma_{\text{total}}] \ \times \left[\text{B}(J/\psi(1S) \ \rightarrow \ \gamma \eta_{\mathcal{C}}(1S)) \right]$ $<0.53\times10^{-5}$ which we divide by our best value B $(J/\psi(1S)
ightarrow \gamma\eta_{C}(1S))=1.7\times10^{-2}.$

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|---------------------------------------------------------|--------------------------------------------|------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
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$J/\psi(1S)$

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

$J/\psi(1S)$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|--------------------------------|------------|--------------------------|----------------|------------------------------------------|
| 3096.916±0.011 OUR AV | ERAGE | | | |
| $3096.917 \pm 0.010 \pm 0.007$ | | AULCHENKO (| 3 KEDR | $e^+e^- ightarrow hadrons$ |
| 3096.89 ±0.09 | 502 | | | $e^+e^- ightarrow hadrons$ |
| $3096.91 \pm 0.03 \pm 0.01$ | | ² ARMSTRONG 9 | 93B E760 | $\overline{p}p \rightarrow e^+e^-$ |
| $3096.95 \pm 0.1 \pm 0.3$ | 193 | BAGLIN 8 | 37 SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| | ollowing d | lata for averages, fits | , limits, etc. | • • • |
| 3097.5 ±0.3 | | GRIBUSHIN 9 | 96 FMPS | $515 \pi^- \text{Be} \rightarrow 2\mu X$ |
| 3098.4 ±2.0 | 38k | LEMOIGNE 8 | 32 GOLI | 185 π^- Be \rightarrow |
| | | 3 ZHOLENTZ 8 | | $^{\gamma\mu^+\mu^-}_{e^+e^-}$ A |
| 3096.93 ±0.09 | 502 | ³ ZHOLENTZ 8 | 30 REDE | e+ e- |
| 3097.0 ±1 | | ⁴ BRANDELIK 7 | 79c DASP | e^+e^- |
| 4 | | | | |

- 1 Reanalysis of ZHOLENTZ 80 using new electron mass (COHEN 87) and radiative corrections (KURAEV 85). 2 Mass central value and systematic error recalculated by us according to Eq. (16) in ARMSTRONG 938, using the value for the $\psi(25)$ mass from AULCHENKO 03.
- ³ Superseded by ARTAMONOV 00.

Mode

 $^4\,{\rm From}$ a simultaneous fit to $e^+\,e^-$, $\mu^+\,\mu^-$ and hadronic channels assuming $\Gamma(e^+\,e^-)$ $=\Gamma(\mu^+\mu^-).$

$J/\psi(1S)$ WIDTH

| VALUE (keV) | <u>EVT</u> S | DOCUMENT ID | | TECN | COMMENT |
|-----------------------|--------------|---------------------------------------|---------|-----------------|---------------------------------------------------------|
| 92.9± 2.8 OU | R AVERA | GE Error include | s scal | e factor | of 1.1. |
| 96.1 ± 3.2 | 13k | ⁵ ADAMS | 06A | CLEO | $e^+e^- \rightarrow \mu^+\mu^-\gamma$ |
| 84.4± 8.9 | | | | BES | |
| $91 \ \pm 11 \ \pm 6$ | | ⁶ ARMSTRONG | 93B | E760 | $\overline{p}p \rightarrow e^+e^-$ |
| $85.5 + 6.1 \\ - 5.8$ | | ⁷ HSUEH | 92 | RVUE | See $	au$ mini-review |
| • • • We do n | ot use the | following data fo | r ave | ages, fit | s, limits, etc. • • • |
| 94.1 ± 2.7 | | | | | 3.097 $e^+e^- \rightarrow \ e^+e^-$, $\ \mu^+\mu^-$ |
| 93.7± 3.5 | 7.8k | ⁵ AUBERT | 04 | BABR | $e^+e^- \rightarrow \mu^+\mu^-\gamma$ |
| | | the reported val $B(\mu^+\mu^-)=(5.9$ | | | $^-$)×B($\mu^+\mu^-$) using B(e^+e^-) = |
| | | | | | ANDREOTTI 07 in its Ref. [4]. |
| | | | | | 5, BOYARSKI 75, ESPOSITO 75B, |
| BRANDELI | | FIVIAIN 92, DALL | /IIVI-C | ELIO 75 | 5, BOTAKSKI 75, ESPOSITO 758, |
| 8 Assuming F | (e+e-) | $= \Gamma(\mu^+\mu^-)$ and | using | $\Gamma(e^+e^-$ | $^{-}$)/ $\Gamma_{\text{total}} = (5.94 \pm 0.06)\%$. |
| | , | (, , , | | , | " total (, |

$J/\psi(1S)$ DECAY MODES

Fraction (Γ_i/Γ)

Scale factor/

Confidence level

| $\overline{\Gamma_1}$ | hadrons | (87.7 ±0.5) % | |
|-----------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------|-----|
| Γ_2 | virtual $\gamma ightarrow $ hadrons | $(13.50 \pm 0.30) \%$ | |
| | ggg | $(64.1 \pm 1.0) \%$ | |
| | $\gamma g g$ | (8.8 ±1.1) % | |
| | e+ e- | (5.94 ±0.06) % | |
| Γ ₆ | $e^+e^-\gamma$ | [a] $(8.8 \pm 1.4) \times 10^{-3}$ | |
| Γ ₇ | $\mu^+\mu^-$ | $(5.93 \pm 0.06)\%$ | |
| | Decays involving had | dronic resonances | |
| | $ ho\pi$ | (1.69 ± 0.15) % S=2 | .4 |
| Γ_9 | $ ho^0\pi^0$ | $(5.6 \pm 0.7) \times 10^{-3}$ | |
| | $a_2(1320) \rho$ | (1.09 ± 0.22) % | |
| Γ_{11} | $\omega \pi^+ \pi^+ \pi^- \pi^-$ | $(8.5 \pm 3.4) \times 10^{-3}$ | |
| | $\omega \pi^+ \pi^- \pi^0$ | $(4.0 \pm 0.7) \times 10^{-3}$ | |
| | $\omega \pi^+ \pi^-$ | $(8.6 \pm 0.7) \times 10^{-3}$ S=1 | . 1 |
| Γ_{14} | $\omega f_2(1270)$ | $(4.3 \pm 0.6) \times 10^{-3}$ | |
| 15 | $K^*(892)^0 \overline{K}^*(892)^0$ | $(2.3 \pm 0.7) \times 10^{-4}$ | |
| Γ_{16} | $K^*(892)^{\pm}\overline{K}^*(892)^{\mp}$ | $(1.00 \begin{array}{c} +0.22 \\ -0.40 \end{array}) \times 10^{-3}$ | |
| | $K^*(892)^{\pm}\overline{K}^*(800)^{\mp}$ | $(1.1 ^{+ 1.0}_{- 0.6}) \times 10^{-3}$ | |
| Γ ₁₈ | $\eta K^*(892)^0 \overline{K}^*(892)^0$ | $(1.15 \pm 0.26) \times 10^{-3}$ | |
| Γ_{19} | $K^*(892)^0 \overline{K}_2^*(1430)^0 + \text{c.c.}$ | $(6.0 \pm 0.6) \times 10^{-3}$ | |
| Γ_{20} | $K^*(892)^0 \overline{K}_2(1770)^0 + \text{c.c.} \rightarrow$ | $(6.9 \pm 0.9) \times 10^{-4}$ | |
| Γ ₂₁ | $K^*(892)^0 K^- \pi^+ + \text{c.c.}$ $\omega K^*(892) \overline{K} + \text{c.c.}$ | $(6.1 \pm 0.9) \times 10^{-3}$ | |

$J/\psi(1S)$

| Γ ₂₂ | $K^{+}\overline{K}^{*}(892)^{-}+\text{ c.c.}$ | (5.12 : | $\pm 0.30) \times 10^{-3}$ | | Γ ₉₀ | $\pi^+ \pi^- K^+ K^-$ | | $(6.6 \pm 0.5) \times 10^{-3}$ | |
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| Γ ₂₃ | $K^+\overline{K}^*(892)^- + \text{c.c.} \rightarrow K^+K^-\pi^0$ | (1.97 : | ± 0.20) $\times 10^{-3}$ | | | $\pi^{+} \pi^{-} K^{+} K^{-} \eta$ $\pi^{0} \pi^{0} K^{+} K^{-}$ | | $(1.84 \pm 0.28) \times 10^{-3}$ $(2.45 \pm 0.31) \times 10^{-3}$ | |
| Γ ₂₄ | $K^+K^*(892)^- + \text{c.c.} \rightarrow$ | (3.0 : | ± 0.4) $\times 10^{-3}$ | | Г ₉₂ Г ₉₃ | $K\overline{K}\pi$ | | $(6.1 \pm 1.0) \times 10^{-3}$ | |
| Γ ₂₅ | $K^0 K^{\pm} \pi^{\mp}$ $K^0 \overline{K}^* (892)^0 + \text{c.c.}$ | (4.39 - | $\pm 0.31) \times 10^{-3}$ | | Γ ₉₄ | $2(\pi^{+}\pi^{-})$ | - | $(3.55 \pm 0.23) \times 10^{-3}$ | |
| Γ ₂₆ | $K^{0}\overline{K}^{*}(892)^{0} + \text{c.c.} \rightarrow$ | , | ± 0.4) $\times 10^{-3}$ | | Γ ₉₅ Γ ₉₆ | $3(\pi^+\pi^-)$ $2(\pi^+\pi^-\pi^0)$ | | $(4.3 \pm 0.4) \times 10^{-3}$ $(1.62 \pm 0.21)\%$ | |
| Γ ₂₇ | $K^0 K^{\pm} \pi^{\mp} \ K_1 (1400)^{\pm} K^{\mp}$ | (3.8 : | ±1.4)×10 ⁻³ | | . 96 Г ₉₇ | $2(\pi^{+}\pi^{-})\eta$ | | $(2.29 \pm 0.24) \times 10^{-3}$ | |
| Γ ₂₈ | $\overline{K}^*(892)^0 K^+ \pi^- + \text{c.c.}$ | seen | 11.4 / / 10 | | Г ₉₈ | $3(\pi^+\pi^-)\eta$ | | $(7.2 \pm 1.5) \times 10^{-4}$ | |
| Γ ₂₉ | $\omega \pi^0 \pi^0$ $b_1 (1235)^{\pm} \pi^{\mp}$ | * | ± 0.8) $\times 10^{-3}$ ± 0.5) $\times 10^{-3}$ | | Г ₉₉ Г ₁₀₀ | $ \rho \overline{p} $ $ \rho \overline{p} \pi^0 $ | | $(2.17 \pm 0.07) \times 10^{-3}$ $(1.19 \pm 0.08) \times 10^{-3}$ | S=1.1 |
| Γ ₃₀ Γ ₃₁ | $\omega K^{\pm} K_{S}^{0} \pi^{\mp}$ | | ± 0.5) $\times 10^{-3}$ | | Γ ₁₀₁ | $p \overline{p} \pi^+ \pi^-$ | | $(6.0 \pm 0.5) \times 10^{-3}$ | S=1.3 |
| Γ ₃₂ | $b_1(1235)^0\pi^0$ | · · | ± 0.6) $\times 10^{-3}$ | | I ₁₀₂ | $ \rho \overline{p} \pi^+ \pi^- \pi^0 $ $ \rho \overline{p} \eta $ | [c] | $(2.3 \pm 0.9) \times 10^{-3}$ $(2.00 \pm 0.12) \times 10^{-3}$ | S=1.9 |
| Γ ₃₃ | $\eta \overset{\leftarrow}{K}^{\pm} \overset{\circ}{K} \overset{\circ}{S} \pi^{\mp}$ $\phi \overset{\leftarrow}{K}^* (892) \overset{\leftarrow}{K} + \text{c.c.}$ | | ± 0.4) $\times 10^{-3}$ | | | $p \overline{p} \rho$ | < | 3.1 × 10 ⁻⁴ | CL=90% |
| Г ₃₄ Г ₃₅ | $\omega K \overline{K}$ | | ± 0.23) $\times 10^{-3}$ ± 0.32) $\times 10^{-3}$ | | | $p \overline{p} \omega$ | | $(1.10 \pm 0.15) \times 10^{-3}$ | S=1.3 |
| Γ ₃₆ | $\omega f_0(1710) \rightarrow \omega K \overline{K}$ | (4.8 | ± 1.1) $\times 10^{-4}$ | | | ρ <u>ρ</u> η'(958) ρ <u>ρ</u> φ | | $(2.1 \pm 0.4) \times 10^{-4}$ $(4.5 \pm 1.5) \times 10^{-5}$ | |
| Γ ₃₇ | $\phi 2(\pi^+ \pi^-) \ \Delta (1232)^{++} \overline{p} \pi^-$ | , | ± 0.23) $\times 10^{-3}$ ± 0.5) $\times 10^{-3}$ | | Γ ₁₀₈ | n n | | $(2.2 \pm 0.4) \times 10^{-3}$ | |
| Г ₃₈ Г ₃₉ | $\omega \eta$ | | ± 0.20) $\times 10^{-3}$ | S=1.6 | Γ ₁₀₉ | $n \overline{n} \pi^+ \pi^-$ $\Sigma^+ \overline{\Sigma}^-$ | | $(4 \pm 4) \times 10^{-3}$ $(1.50 \pm 0.24) \times 10^{-3}$ | |
| Γ_{40} | $\phi K \overline{K}$ | | $\pm 0.24) \times 10^{-3}$ | S=1.5 | Γ111 | $\Sigma^0 \overline{\Sigma}{}^0$ | | $(1.50 \pm 0.24) \times 10^{-3}$ | |
| Γ ₄₁ Γ ₄₂ | $ \phi f_0(1710) \to \phi K \overline{K} \phi f_2(1270) $ | | ± 0.6) $\times 10^{-4}$ ± 1.3) $\times 10^{-4}$ | | Γ_{112} | $2(\pi^{+}\pi^{-})K^{+}K^{-}$ | | $(4.7 \pm 0.7) \times 10^{-3}$ | S=1.3 |
| Γ ₄₃ | $\Delta(1232)^{++}\overline{\Delta}(1232)^{}$ | · · | ± 0.29) $\times 10^{-3}$ | | Г ₁₁₃ | $p \overline{n} \pi^ n N(1440)$ | | $(2.12 \pm 0.09) \times 10^{-3}$ seen | |
| Γ ₄₄ | $\Sigma (1385)^{-} \overline{\Sigma} (1385)^{+} $ (or c.c.) | | $\pm 0.13) \times 10^{-3}$ | | Γ ₁₁₅ | n N(1520) | | seen | |
| Γ ₄₅ Γ ₄₆ | $\phi f_2'(1525) \\ \phi \pi^+ \pi^-$ | | ± 4) × 10 ⁻⁴ ± 0.9) × 10 ⁻⁴ | S=2.7 S=1.2 | Γ ₁₁₆ | n N(1535) | | seen | |
| Γ ₄₇ | $\phi \pi^0 \pi^0$ | | ± 1.6) $\times 10^{-4}$ | 3_1.2 | Γ ₁₁₇ Γ ₁₁₈ | <u>=- =+</u> | | $(8.5 \pm 1.6) \times 10^{-4}$ $(1.61 \pm 0.15) \times 10^{-3}$ | S=1.5 S=1.9 |
| Γ ₄₈ | $\phi K^{\pm} K_S^0 \pi^{\mp}$ | | ± 0.8) $\times 10^{-4}$ | | Γ ₁₁₉ | $\Lambda \overline{\Sigma}^- \pi^+$ (or c.c.) | | $(8.3 \pm 0.7) \times 10^{-4}$ | S=1.7 |
| Γ ₄₉ | $\omega f_1(1420)$ $\phi \eta$ | | ± 2.4) $\times 10^{-4}$ ± 0.8) $\times 10^{-4}$ | S=1.5 | Γ ₁₂₀ | $pK^{-}\overline{\Lambda}$ | | $(8.9 \pm 1.6) \times 10^{-4}$ | |
| Γ ₅₀ Γ ₅₁ | <u>=</u> 0 <u>=</u> 0 | , | $\pm 0.80 \times 10^{-3}$ | 3=1.3 | Г ₁₂₁ | $ \begin{array}{c} 2(K^+K^-) \\ pK^-\overline{\Sigma}^0 \end{array} $ | | $(7.6 \pm 0.9) \times 10^{-4}$ $(2.9 \pm 0.8) \times 10^{-4}$ | |
| Γ ₅₂ | $\Xi(1530)^{-}\overline{\Xi}^{+}$ | | ± 1.5) $\times 10^{-4}$ | | Γ_{123} | K^+K^- | i | $(2.37 \pm 0.31) \times 10^{-4}$ | |
| Γ ₅₃ Γ ₅₄ | $ \begin{array}{l} \rho \overset{\cdot}{K} - \overline{\Sigma} (1385)^0 \\ \omega \pi^0 \end{array} $ | * | ± 3.2) $\times 10^{-4}$ ± 0.5) $\times 10^{-4}$ | S=1.4 | Γ ₁₂₄ | $K_{\underline{S}}^{0} K_{\underline{L}}^{0}$ | | $(1.46 \pm 0.26) \times 10^{-4}$ | S=2.7 |
| Γ ₅₅ | $\phi \eta'(958)$ | | ± 0.7) $\times 10^{-4}$ | S=2.1 | Γ ₁₂₆ | $\Lambda \overline{\Lambda} \eta^{-1}$ $\Lambda \overline{\Lambda} \pi^{0}$ | < | $(2.6 \pm 0.7) \times 10^{-4}$ 6.4×10^{-5} | CL=90% |
| Γ ₅₆ | $\phi f_0(980)$ | (3.2 : | ± 0.9) $\times 10^{-4}$ | S=1.9 | F _{1.27} | $\overline{\Lambda} n K_S^0 + \text{c.c.}$ | | $(6.5 \pm 1.1) \times 10^{-4}$ | |
| | | | | | . 121 | 7111115 | | | |
| Γ ₅₇ Γ ₅₈ | $\phi f_0(980) \to \phi \pi^+ \pi^- \\ \phi f_0(980) \to \phi \pi^0 \pi^0$ | | ± 0.4) $\times 10^{-4}$ ± 0.7) $\times 10^{-4}$ | | Γ ₁₂₈ | $\pi^+\pi^-$ | | $(1.47 \pm 0.23) \times 10^{-4}$ | CL 000/ |
| Ι ₅₇ Γ ₅₈ Γ ₅₉ | $ \begin{array}{c} \phi f_0(980) \rightarrow \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \rightarrow \eta \phi \pi^+ \pi^- \end{array} $ | (1.7 : | ± 0.7) $\times 10^{-4}$ ± 1.0) $\times 10^{-4}$ | | Γ ₁₂₈ Γ ₁₂₉ | $\pi^+ \pi^ \Lambda \overline{\Sigma} + \text{c.c.}$ | < | $(1.47 \pm 0.23) \times 10^{-4}$ 1.5×10^{-4} | CL=90% CL=95% |
| Γ ₅₈ Γ ₅₉ Γ ₆₀ | $\phi f_0(980) \rightarrow \phi \pi^0 \pi^0$ $\eta \phi f_0(980) \rightarrow \eta \phi \pi^+ \pi^-$ $\phi a_0(980)^0 \rightarrow \phi \eta \pi^0$ | (1.7 : (3.2 : (5 : : | ± 0.7) $\times 10^{-4}$ ± 1.0) $\times 10^{-4}$ ± 4) $\times 10^{-6}$ | | Γ ₁₂₈ Γ ₁₂₉ | $\pi^+ \pi^-$ $\Lambda \overline{\Sigma} + \text{c.c.}$ $K_S^0 K_S^0$ | < | $ \begin{array}{cccc} (& 1.47 & \pm 0.23 &) \times 10^{-4} \\ & 1.5 & & \times 10^{-4} \\ & 1 & & \times 10^{-6} \end{array} $ | CL=90% CL=95% |
| Γ ₅₈ Γ ₅₉ Γ ₆₀ Γ ₆₁ | $ \begin{array}{c} \phi f_0(980) \rightarrow \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \rightarrow \eta \phi \pi^+ \pi^- \end{array} $ | (1.7 = (3.2 = (5 = (3.2 = (| ± 0.7) $\times 10^{-4}$ ± 1.0) $\times 10^{-4}$ | | Γ ₁₂₈ Γ ₁₂₉ | $\pi^+\pi^-$ $\Lambda\overline{\Sigma} + {\rm c.c.}$ $K_S^0K_S^0$ Radiative | < < e decays | $ \begin{array}{cccc} (\ 1.47\ \pm0.23\)\times10^{-4} \\ 1.5 & \times10^{-4} \\ 1 & \times10^{-6} \end{array} $ | |
| Γ_{58} Γ_{59} Γ_{60} Γ_{61} Γ_{62} Γ_{63} | $ \begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \phi \eta \pi^0 \\ \Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ \phi f_1(1285) \end{array} $ | (1.7 : (3.2 : (5 : : (3.2 : : (5 : : (3.2 : : (5 : : (3.2 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 : : (2.6 | $\begin{array}{lll} \pm 0.7 &) \times 10^{-4} \\ \pm 1.0 &) \times 10^{-4} \\ \pm 4 &) \times 10^{-6} \\ \pm 1.4 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \end{array}$ | S=1.1 | Γ_{128} Γ_{129} Γ_{130} Γ_{131} Γ_{132} | $\pi^+\pi^-$ $ \Lambda \overline{\Sigma} + {\rm c.c.} \\ {\cal K}^0_S \; {\cal K}^0_S $ Radiative 3γ 4γ | < e decays | $ \begin{array}{cccc} (\ 1.47\ \pm 0.23\)\times 10^{-4} \\ 1.5 & \times 10^{-4} \\ 1 & \times 10^{-6} \\ \\ \textbf{S} \\ (\ 1.2\ \pm 0.4\)\times 10^{-5} \\ 9 & \times 10^{-6} \end{array} $ | CL=95% CL=90% |
| Γ_{58} Γ_{59} Γ_{60} Γ_{61} Γ_{62} Γ_{63} Γ_{64} | $\begin{array}{l} \phi f_{0}(980) \to \phi \pi^{0} \pi^{0} \\ \eta \phi f_{0}(980) \to \eta \phi \pi^{+} \pi^{-} \\ \phi a_{0}(980)^{0} \to \phi \eta \pi^{0} \\ \Xi(1530)^{0} \overline{\Xi}^{0} \\ \Sigma(1385)^{-} \overline{\Sigma}^{+} \text{ (or c.c.)} \\ \phi f_{1}(1285) \\ \eta \pi^{+} \pi^{-} \end{array}$ | (1.7 : (3.2 : (5 : : (3.2 : : (5 : : (3.2 : : (5 : : (3.1 : : (2.6 : : (4.0 : : (4.0 : : (5 :)))))) | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 | Γ ₁₂₈ Γ ₁₂₉ Γ ₁₃₀ Γ ₁₃₁ Γ ₁₃₂ Γ ₁₃₃ | $\pi^+\pi^-$ $ \Lambda \overline{\Sigma} + {\rm c.c.} \\ K_S^0K_S^0 $ Radiative 3γ 4γ 5γ | <pre>< decays </pre> | $ \begin{array}{ccccc} (\ 1.47\ \pm 0.23\)\times 10^{-4} \\ 1.5 & \times 10^{-4} \\ 1 & \times 10^{-6} \\ \\ \mathbf{S} \\ (\ 1.2\ \pm 0.4\)\times 10^{-5} \\ 9 & \times 10^{-6} \\ 1.5 & \times 10^{-5} \end{array} $ | CL=95% CL=90% CL=90% |
| Γ_{58} Γ_{59} Γ_{60} Γ_{61} Γ_{62} Γ_{63} | $ \begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \phi \eta \pi^0 \\ \Xi(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ \phi f_1(1285) \end{array} $ | (1.7 : (3.2 : (5 : : (3.2 : (5 : : (3.2 : (5 : (4.0 : (4.0 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.9 | $\begin{array}{lll} \pm 0.7 &) \times 10^{-4} \\ \pm 1.0 &) \times 10^{-4} \\ \pm 4 &) \times 10^{-6} \\ \pm 1.4 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \\ \pm 0.5 &) \times 10^{-4} \end{array}$ | S=1.1 | Γ_{128} Γ_{129} Γ_{130} Γ_{131} Γ_{132} Γ_{133} Γ_{134} | $\pi^+\pi^ \Lambda \overline{\Sigma}$ + c.c. $K_S^0 K_S^0$ Radiative 3γ 4γ 5γ $\gamma \eta_c(1S)$ | < de decays | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% |
| Γ_{58} Γ_{59} Γ_{60} Γ_{61} Γ_{62} Γ_{63} Γ_{64} Γ_{65} Γ_{66} Γ_{67} | $\begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \phi \eta \pi^0 \\ \overline{\Xi}(1530)^0 \overline{\Xi}^0 \\ \Sigma (1385)^- \overline{\Sigma}^+ \text{ (or c.c.)} \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \end{array}$ | (1.7 : (3.2 : (5 : : (3.2 : : (5 : : (3.2 : : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.4 : (1.2 : (1.4 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 | Γ ₁₂₈ Γ ₁₂₉ Γ ₁₃₀ Γ ₁₃₁ Γ ₁₃₂ Γ ₁₃₃ Γ ₁₃₄ Γ ₁₃₅ | $\begin{array}{c} \pi^+\pi^-\\ \Lambda\overline{\Sigma} + \mathrm{c.c.}\\ K_S^0K_S^0 \end{array}$ Radiative $\begin{array}{c} 3\gamma\\ 4\gamma\\ 5\gamma\\ \gamma\eta_c(1S)\\ \end{array}$ $\gamma\eta_c(1S) \to 3\gamma$ | < decays | $ \begin{array}{ccccc} (\ 1.47\ \pm 0.23\)\times 10^{-4} \\ 1.5 & \times 10^{-4} \\ 1 & \times 10^{-6} \\ \hline \textbf{S} \\ (\ 1.2\ \pm 0.4\)\times 10^{-5} \\ 9 & \times 10^{-6} \\ 1.5 & \times 10^{-5} \\ (\ 1.7\ \pm 0.4\)\% \\ (\ 1.2\ \pm \frac{2.7}{1.1}\)\times 10^{-6} \\ \end{array} $ | CL=95% CL=90% CL=90% |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ | $\begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \phi \eta \pi^0 \\ \overline{\Xi}(1530)^0 \overline{\Xi}^0 \\ \Sigma (1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \end{array}$ | (1.7 : (3.2 : (5 : : (3.2 : : (5 : : (3.2 : : (1.4 : : (1.05 : (1.93 : (1.4 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.0 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | Γ ₁₂₈ Γ ₁₂₉ Γ ₁₃₀ Γ ₁₃₁ Γ ₁₃₂ Γ ₁₃₃ Γ ₁₃₄ Γ ₁₃₅ Γ ₁₃₆ | $\begin{array}{c} \pi^+\pi^-\\ \Lambda\overline{\Sigma} + \text{c.c.}\\ K_S^0K_S^0 \end{array}$ Radiative $\begin{array}{c} 3\gamma\\ 4\gamma\\ 5\gamma\\ \gamma\eta_c(1S)\\ \gamma\eta_c(1S) \to 3\gamma\\ \gamma\pi^+\pi^-2\pi^0\\ \gamma\eta\pi\pi \end{array}$ | <pre>< decays e decays </pre> | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ | $\begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \phi \eta \pi^0 \\ \overline{\Xi}(1530)^0 \overline{\overline{\Xi}}^0 \\ \Sigma (1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \\ a_2(1320)^\pm \pi^\mp \\ K K_2^*(1430) + \text{c.c.} \end{array}$ | (1.7 : (3.2 : (5 : : (3.2 : : (5 : : (3.2 : : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.4 : (1.2 : (1.4 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.4 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (1.2 : (| $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-6} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \times 10^{-3} \end{array}$ | S=1.1 CL=90% CL=90% | Γ ₁₂₈ Γ ₁₂₉ Γ ₁₃₀ Γ ₁₃₁ Γ ₁₃₂ Γ ₁₃₃ Γ ₁₃₄ Γ ₁₃₅ Γ ₁₃₆ Γ ₁₃₇ Γ ₁₃₇ | $\begin{array}{c} \pi^+\pi^-\\ \Lambda\overline{\Sigma} + \mathrm{c.c.}\\ K_S^0K_S^0 \end{array} \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad $ | < | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ F ₆₉ F ₇₀ F ₇₁ | $\begin{array}{l} \phi \ f_0(980) \to \phi \pi^0 \pi^0 \\ \eta \phi f_0(980) \to \eta \phi \pi^+ \pi^- \\ \phi a_0(980)^0 \to \eta \phi \pi^0 \\ \Xi (1530)^0 \overline{\Xi}^0 \\ \Sigma (1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho \eta'(958) \\ a_2(1320)^{\pm} \pi^{\mp} \\ K \overline{K}_2^* (1430) + \text{c.c.} \\ K_1(1270)^{\pm} K^{\mp} \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : | $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-6} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \end{array}$ | CL=90% CL=90% CL=90% | Γ ₁₂₈ Γ ₁₂₉ Γ ₁₃₀ Γ ₁₃₁ Γ ₁₃₂ Γ ₁₃₃ Γ ₁₃₄ Γ ₁₃₅ Γ ₁₃₆ Γ ₁₃₇ Γ ₁₃₈ Γ ₁₃₉ Γ ₁₄₀ | $\begin{array}{c} \pi^+\pi^-\\ \Lambda\overline{\Sigma} + \text{c.c.}\\ K_S^0K_S^0\\ \hline \\ & \text{Radiative}\\ 3\gamma\\ 4\gamma\\ 5\gamma\\ \gamma\eta_c(1S)\\ \gamma\eta_c(1S) \rightarrow 3\gamma\\ \gamma\pi^+\pi^-2\pi^0\\ \gamma\eta_\pi\pi\\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^-\\ \gamma\eta(1405/1475) \rightarrow \gamma K\overline{K}\pi\\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^0\\ \end{array}$ | <pre></pre> | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ F ₆₉ F ₇₀ F ₇₁ F ₇₂ | $\begin{array}{l} \phi \ f_0(980) \rightarrow \phi \ \pi^0 \ \pi^0 \\ \eta \phi \ f_0(980) \rightarrow \phi \ \eta \phi \pi^+ \pi^- \\ \phi \ a_0(980)^0 \rightarrow \phi \eta \pi^0 \\ \equiv (1530)^0 \ \overline{\equiv}^0 \\ \Sigma \ (1385)^- \ \overline{\Sigma}^+ \ (\text{or c.c.}) \\ \phi \ f_1(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \ \eta'(958) \\ \omega \ f_0(980) \\ \rho \eta'(958) \\ \omega \ f_2(1320)^\pm \pi^\mp \\ K \ K_2^* (1430)^+ \ C.c. \\ K_1(1270)^\pm K^\mp \\ K_2^* (1430)^0 \ \overline{K}_2^* (1430)^0 \end{array}$ | (1.7 : (3.2 : (5 :) (3.2 : (5 :) (3.2 :) (1.4 :) (1.93 : (1.82 : (1.4 :) (1.05 : (1.05 :) (1.05 :) (3.0 < 3.0 < 2.9 | $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-6} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.21) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \end{array}$ | CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F140 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | <pre></pre> | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.6 S=1.8 |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ F ₇₀ F ₇₁ F ₇₂ F ₇₃ F ₇₄ | $\begin{array}{l} \phif_0(980) \to \phi\pi^0\pi^0 \\ \eta\phif_0(980) \to \eta\phi\pi^+\pi^- \\ \phia_0(980)^0 \to \eta\eta\pi^0 \\ \equiv (1530)^0\overline{\equiv}^0 \\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.}) \\ \phif_1(1285) \\ \eta\pi^+\pi^- \\ \rho\eta \\ \omega\eta'(958) \\ \omegaf_0(980) \\ \rho\eta'(958) \\ a_2(1320)^\pm\pi^\mp \\ K\overline{K}_2^*(1430)^+\text{c.c.} \\ K_1(1270)^\pmK^\mp \\ K_2^*(1430)^0\overline{K}_2^*(1430)^0 \\ \phi\pi^0 \\ \phi\eta(1405) \to \phi\eta\pi\pi \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (1.4 : 3.2 : (1.4 : 3.2 : (1.4 : 3.2 : (1.05 : (1.05 : (1.05 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : | $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-6} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F141 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | <pre></pre> | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ F ₆₉ F ₇₀ F ₇₁ F ₇₂ F ₇₃ F ₇₄ F ₇₅ | $\begin{array}{l} \phif_0(980) \to \phi\pi^0\pi^0 \\ \eta\phif_0(980) \to \eta\phi\pi^+\pi^- \\ \phia_0(980)^0 \to \eta\eta\pi^0 \\ \equiv (1530)^0\overline{\equiv}^0 \\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.}) \\ \phif_1(1285) \\ \eta\pi^+\pi^- \\ \rho\eta \\ \omega\eta'(958) \\ \omegaf_0(980) \\ \rho\eta'(958) \\ a_2(1320)^\pm\pi^\mp \\ K\overline{K}_2^*(1430)^+\text{c.c.} \\ K_1(1270)^\pmK^\mp \\ K_2^*(1430)^0\overline{K}_2^*(1430)^0 \\ \phi\pi^0 \\ \phi\eta(1405) \to \phi\eta\pi\pi \\ \omegaf_2'(1525) \end{array}$ | (1.7 : (3.2 : (5 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : | $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.7) \times 10^{-4} \\ \pm 0.7) \times 10^{-4} \\ \pm 0.7) \times 10^{-4} \\ \pm 0.8) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-3} \\ \times 10^{-4} \\ \times 10^{-4} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F140 F141 F142 F143 F144 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda \overline{\Sigma} + \text{c.c.} \\ K_{S}^{0} K_{S}^{0} \end{array} \\ \hline \text{Radiative} \\ 3\gamma \\ 4\gamma \\ 5\gamma \\ \gamma \eta_{c}(1S) \\ \gamma \eta_{c}(1S) \rightarrow 3\gamma \\ \gamma \pi^{+}\pi^{-}2\pi^{0} \\ \gamma \eta \pi \pi \\ \gamma \eta(1405/1475) \rightarrow \gamma K \overline{K} \pi \\ \gamma \eta(1405/1475) \rightarrow \gamma \gamma K \overline{K} \pi \\ \gamma \eta(1405/1475) \rightarrow \gamma \gamma \rho^{0} \\ \gamma \eta(1405/1475) \rightarrow \gamma \gamma \rho \phi \\ \gamma \eta \eta \rho \omega \end{array}$ | c c c c c c c c | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% |
| F ₅₈ F ₅₉ F ₆₀ F ₆₁ F ₆₂ F ₆₃ F ₆₄ F ₆₅ F ₆₆ F ₆₇ F ₆₈ F ₇₀ F ₇₁ F ₇₂ F ₇₃ F ₇₄ | $\begin{array}{l} \phif_0(980) \to \phi\pi^0\pi^0 \\ \eta\phif_0(980) \to \eta\phi\pi^+\pi^- \\ \phia_0(980)^0 \to \eta\eta\pi^0 \\ \equiv (1530)^0\overline{\equiv}^0 \\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.}) \\ \phif_1(1285) \\ \eta\pi^+\pi^- \\ \rho\eta \\ \omega\eta'(958) \\ \omegaf_0(980) \\ \rho\eta'(958) \\ a_2(1320)^\pm\pi^\mp \\ K\overline{K}_2^*(1430)^+\text{c.c.} \\ K_1(1270)^\pmK^\mp \\ K_2^*(1430)^0\overline{K}_2^*(1430)^0 \\ \phi\pi^0 \\ \phi\eta(1405) \to \phi\eta\pi\pi \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (1.4 : 3.2 : (1.4 : 3.2 : (1.4 : 3.2 : (1.05 : (1.05 : (1.05 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : (3.0 : | $\begin{array}{c} \pm 0.7) \times 10^{-4} \\ \pm 1.0) \times 10^{-4} \\ \pm 4) \times 10^{-6} \\ \pm 1.4) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 1.7) \times 10^{-4} \\ \pm 0.23) \times 10^{-4} \\ \pm 0.5) \times 10^{-4} \\ \pm 0.18) \times 10^{-4} \\ \times 10^{-3} \\ \times 10^{-6} \\ \times 10^{-4} \end{array}$ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | Γ128 Γ129 Γ130 Γ131 Γ132 Γ133 Γ134 Γ137 Γ138 Γ137 Γ140 Γ141 Γ142 Γ143 Γ144 Γ144 | $\begin{array}{c} \pi^+\pi^-\\ \Lambda\overline{\Sigma} + \text{c.c.}\\ K_S^0K_S^0\\ \hline \\ & \text{Radiative}\\ 3\gamma\\ 4\gamma\\ 5\gamma\\ \gamma\eta_c(1S)\\ \gamma\eta_c(1S) \rightarrow 3\gamma\\ \gamma\pi^+\pi^-2\pi^0\\ \gamma\eta\pi\pi\\ \gamma\eta_2(1870) \rightarrow \gamma\eta\pi^+\pi^-\\ \gamma\eta(1405/1475) \rightarrow \gamma\kappa\overline{K}\pi\\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^0\\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho^0\\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho\\ \gamma\eta(1405/1475) \rightarrow \gamma\gamma\rho\\ \gamma\rho\rho\\ \gamma\rho\rho\\ \gamma\rho\rho\\ \gamma\rho\phi\\ \end{array}$ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F68 F69 F70 F71 F72 F73 F74 F75 | $\begin{array}{l} \phif_0(980) \to \phi\pi^0\pi^0\\ \eta\phif_0(980) \to \eta\phi\pi^+\pi^-\\ \phia_0(980)^0 \to \eta\phi\pi^+\pi^-\\ \phia_0(980)^0 \to \phi\eta\pi^0\\ \equiv (1530)^0\overline{\equiv}^0\\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.})\\ \phif_1(1285)\\ \eta\pi^+\pi^-\\ \rho\eta\\ \omega\eta'(958)\\ \omegaf_0(980)\\ \rho\eta'(958)\\ a_2(1320)^\pm\pi^\mp\\ K\overline{K}_2^*(1430)^+\text{c.c.}\\ K_1(1270)^\pmK^\mp\\ K_2^*(1430)^0\overline{K}_2^*(1430)^0\\ \phi\pi^0\\ \phi\eta(1405) \to \phi\eta\pi\pi\\ \omegaf_2'(1525)\\ \eta\phi(2170) \to\\ \etaK^*(892)^0\overline{K}^*(892)^0\\ \Sigma(1385)^0\overline{\Lambda} \end{array}$ | (1.7 : (3.2 : (5 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda \overline{\Sigma} + \text{c.c.} \\ K_{S}^{0} K_{S}^{0} \end{array} \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F70 F71 F72 F73 F74 F75 F76 | $\begin{array}{l} \phi f_0(980) \to \phi \pi^0 \pi^0 \\ \eta\phi f_0(980) \to \eta \phi\pi^+\pi^- \\ \phi a_0(980)^0 \to \eta \eta\pi^0 \\ \equiv (1530)^0 \overline{\equiv}^0 \\ \Sigma (1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi f_1(1285) \\ \eta \pi^+\pi^- \\ \rho\eta \\ \omega \eta'(958) \\ \omega f_0(980) \\ \rho\eta'(958) \\ \omega f_0(980) \\ \rho\eta'(958) \\ a_2(1320)^\pm \pi^\mp \\ K \overline{K}_2^*(1430)^+ \text{c.c.} \\ K_1(1270)^\pm K^\mp \\ K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ \phi \pi^0 \\ \phi \eta(1405) \to \phi \eta\pi \pi \\ \omega f_2'(1525) \\ \eta \phi (2170) \to \\ \eta K^*(892)^0 \overline{K}^*(892)^0 \\ \Sigma (1385)^0 \overline{\Lambda} \\ \Delta(1232)^+ \overline{\rho} \end{array}$ | (1.7 : (3.2 : (5 : 2 : 2) (1.8 : 2 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1) (1.05 : 1 | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 F147 F148 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda \overline{\Sigma} + \text{c.c.} \\ K_{S}^{0} K_{S}^{0} \end{array} \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | c c c c c c c c | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F68 F70 F71 F72 F73 F74 F75 F76 | $\begin{array}{l} \phif_0(980) \to \phi\pi^0\pi^0\\ \eta\phif_0(980) \to \eta\phi\pi^+\pi^-\\ \phia_0(980)^0 \to \eta\phi\pi^+\pi^-\\ \phia_0(980)^0 \to \phi\eta\pi^0\\ \equiv (1530)^0\overline{\equiv}^0\\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.})\\ \phif_1(1285)\\ \eta\pi^+\pi^-\\ \rho\eta\\ \omega\eta'(958)\\ \omegaf_0(980)\\ \rho\eta'(958)\\ a_2(1320)^\pm\pi^\mp\\ K\overline{K}_2^*(1430)^+\text{c.c.}\\ K_1(1270)^\pmK^\mp\\ K_2^*(1430)^0\overline{K}_2^*(1430)^0\\ \phi\pi^0\\ \phi\eta(1405) \to \phi\eta\pi\pi\\ \omegaf_2'(1525)\\ \eta\phi(2170) \to\\ \etaK^*(892)^0\overline{K}^*(892)^0\\ \Sigma(1385)^0\overline{\Lambda} \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (1.4 : (1.93 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.0 | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±1.7) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 F147 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda \overline{\Sigma} + \text{c.c.} \\ K_{S}^{0} K_{S}^{0} \end{array} \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | c c c c c c c c | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F70 F71 F72 F73 F74 F75 F76 | $\begin{array}{ll} \phi_{\tilde{h}}(980) \to \phi\pi^0\pi^0 \\ \eta\phi_{\tilde{h}}(980) \to \eta\phi\pi^+\pi^- \\ \phi_{\tilde{a}_0}(980)^0 \to \eta\eta\pi^0 \\ & \equiv (1530)^0 \stackrel{\Xi}{=} 0 \\ & \sum (1385)^- \stackrel{\Xi}{\Sigma}^+ (\text{or c.c.}) \\ \phi_{\tilde{h}}(1285) \\ \eta\pi^+\pi^- \\ \rho\eta \\ \omega\eta'(958) \\ \omega_{\tilde{h}_0}(980) \\ \rho\eta'(958) \\ a_2(1320)^{\pm}\pi^{\mp} \\ K\stackrel{K}{K}_2^*(1430)^+ \text{c.c.} \\ K_1(1270)^{\pm}K^{\mp} \\ K^*_2(1430)^0 \stackrel{K}{K}_2^*(1430)^0 \\ \phi\pi^0 \\ \phi\eta(1405) \to \phi\eta\pi\pi \\ \omega f_2'(1525) \\ \eta\phi(2170) \to \\ \eta K^*(892)^0 \stackrel{K}{K}^*(892)^0 \\ \Sigma(1385)^0 \stackrel{\Lambda}{\Lambda} \\ \Delta(1232)^+ \stackrel{\Xi}{P} \\ \Theta(1540) \stackrel{\Xi}{\Theta}(1540) \to \\ K^0_S p K^- \overline{\eta} + \text{c.c.} \\ \Theta(1540) K^- \overline{\eta} \to K^0_S p K^- \overline{\eta} \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁶ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.17) × 10 ⁻⁴ ±0.23) × 10 ⁻⁴ ±0.21) × 10 ⁻⁴ ±0.18) × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F140 F141 F142 F143 F144 F145 F146 F147 F148 F149 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | [d] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 |
| Г ₅₈ Г ₅₉ Г ₆₀ Г ₆₁ Г ₆₂ Г ₆₃ Г ₆₄ Г ₆₅ Г ₆₆ Г ₆₇ Г ₇₀ Г ₇₁ Г ₇₂ Г ₇₃ Г ₇₄ Г ₇₅ Г ₇₆ Г ₇₇ Г ₇₈ Г ₇₉ Г ₈₀ Г ₈₁ | $\begin{array}{c} \phi_{f_0}(980) \to \phi \pi^0 \pi^0 \\ \eta \phi_{f_0}(980) \to \eta \phi \pi^+ \pi^- \\ \phi_{a_0}(980)^0 \to \phi \eta \pi^0 \\ \overline{\Xi}(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi_{f_1}(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega_{f_0}(980) \\ \rho \eta'(958) \\ a_2(1320)^{\pm} \pi^{\mp} \\ K \overline{K}_2^*(1430)^+ K^{\mp} \\ K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ \phi \pi^0 \\ \phi \eta(1405) \to \phi \eta \pi \pi \\ \omega f_2'(1525) \\ \eta \phi(2170) \to \\ \eta K^*(892)^0 \overline{K}^*(892)^0 \\ \Sigma(1385)^0 \overline{\Lambda} \\ \Delta(1232)^+ \overline{\rho} \\ \Theta(1540) \overline{\Theta}(1540) \to \\ K_0^S p K^- \overline{n} + \text{c.c.} \\ \Theta(1540) K_0^S \overline{p} \to K_0^S p K^- \overline{n} \\ \Theta(1540) K_0^S \overline{p} \to K_0^S \overline{p} K^+ n \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.7) × 10 ⁻⁴ ±0.8) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F140 F141 F142 F143 F144 F145 F146 F147 F148 F149 F150 F151 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | [d] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 |
| F58 F59 F60 F61 F65 F66 F67 F70 F75 F76 F77 F78 F79 F80 F81 F82 $\begin{array}{c} \phi_{f_0}(980) \to \phi\pi^0\pi^0\\ \eta\phi_{f_0}(980) \to \eta\phi\pi^+\pi^-\\ \phi_{a_0}(980)^0 \to \eta\eta\pi^0\\ \equiv (1530)^0 \overline{\equiv}^0\\ \Sigma(1385)^- \overline{\Sigma}^+ (\text{or c.c.})\\ \phi_{f_1}(1285)\\ \eta\pi^+\pi^-\\ \rho\eta\\ \omega\eta'(958)\\ \omega_{f_0}(980)\\ \rho\eta'(958)\\ \omega_{f_0}(980)\\ \rho\eta'(958)\\ a_2(1320)^\pm\pi^\mp\\ KK_2^*(1430)^+ K_2^\mp\\ KK_2^*(1430)^0 \overline{K}_2^* (1430)^0\\ \phi\pi^0\\ \phi\pi^0\\ \phi\pi^0\\ \phi\pi^0(1405) \to \phi\eta\pi\pi\\ \omega_{f_2}(1525)\\ \eta\phi(2170) \to\\ \eta K^*(892)^0 \overline{K}^*(892)^0\\ \Sigma(1385)^0 \overline{\Lambda}\\ \Delta(1232)^+ \overline{\rho}\\ \Theta(1540) \overline{\Theta}(1540) \to\\ K_0^S \ p K^- \overline{\eta} + \text{c.c.}\\ \Theta(1540) K^- \overline{\eta} \to K_0^S \ \overline{\rho} K^+ \overline{\eta}\\ \overline{\Theta}(1540) K^- \overline{\eta} \to K_0^S \ \overline{\rho} K^+ \overline{\eta}\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \overline{\Theta}(1540) K^+ \eta \to K_0^S \ \overline{\rho} K^+ \eta\\ \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 | ±0.7) × 10-4 ±1.0) × 10-4 ±4) × 10-6 ±1.4) × 10-4 ±0.5) × 10-4 ±0.5) × 10-4 ±0.21) × 10-4 ±0.21) × 10-4 ±0.18) × 10-4 × 10-3 × 10-3 × 10-3 × 10-4 × 10-4 × 10-4 × 10-4 × 10-5 × 10-5 × 10-5 × 10-5 | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 F147 F148 F149 F150 F151 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda \overline{\Sigma} + \text{c.c.} \\ K_{S}^{0} K_{S}^{0} \end{array} \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | [d] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 |
| Г ₅₈ Г ₅₉ Г ₆₀ Г ₆₁ Г ₆₂ Г ₆₃ Г ₆₄ Г ₆₅ Г ₆₆ Г ₆₇ Г ₇₀ Г ₇₁ Г ₇₂ Г ₇₃ Г ₇₄ Г ₇₅ Г ₇₆ Г ₇₇ Г ₇₈ Г ₇₉ Г ₈₀ Г ₈₁ | $\begin{array}{c} \phi_{f_0}(980) \to \phi \pi^0 \pi^0 \\ \eta \phi_{f_0}(980) \to \eta \phi \pi^+ \pi^- \\ \phi_{a_0}(980)^0 \to \phi \eta \pi^0 \\ \overline{\Xi}(1530)^0 \overline{\Xi}^0 \\ \Sigma(1385)^- \overline{\Sigma}^+ (\text{or c.c.}) \\ \phi_{f_1}(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega_{f_0}(980) \\ \rho \eta'(958) \\ a_2(1320)^{\pm} \pi^{\mp} \\ K \overline{K}_2^*(1430)^+ K^{\mp} \\ K_2^*(1430)^0 \overline{K}_2^*(1430)^0 \\ \phi \pi^0 \\ \phi \eta(1405) \to \phi \eta \pi \pi \\ \omega f_2'(1525) \\ \eta \phi(2170) \to \\ \eta K^*(892)^0 \overline{K}^*(892)^0 \\ \Sigma(1385)^0 \overline{\Lambda} \\ \Delta(1232)^+ \overline{\rho} \\ \Theta(1540) \overline{\Theta}(1540) \to \\ K_0^S p K^- \overline{n} + \text{c.c.} \\ \Theta(1540) K_0^S \overline{p} \to K_0^S p K^- \overline{n} \\ \Theta(1540) K_0^S \overline{p} \to K_0^S \overline{p} K^+ n \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 | ±0.7) × 10 ⁻⁴ ±1.0) × 10 ⁻⁴ ±4) × 10 ⁻⁶ ±1.4) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.5) × 10 ⁻⁴ ±0.7) × 10 ⁻⁴ ±0.8) × 10 ⁻⁴ ±0.18) × 10 ⁻⁴ × 10 ⁻³ × 10 ⁻³ × 10 ⁻³ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁴ × 10 ⁻⁵ × 10 ⁻⁵ | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 F147 F148 F149 F150 F151 F152 F153 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | c c c c c c c c c c | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F68 F69 F70 F71 F72 F73 F74 F75 F76 F77 F78 F79 F80 F81 F82 F83 | $\begin{array}{c} \phi_{\tilde{K}}(980) \to \phi\pi^0\pi^0\\ \eta\phi_{\tilde{K}}(980) \to \phi\pi^0\pi^0\\ \eta\phi_{\tilde{K}}(980) \to \eta\phi\pi^+\pi^-\\ \phi_{\tilde{d}_0}(980)^0 \to \phi\eta\pi^0\\ \equiv (1530)^0 \overline{\equiv}^0\\ \Sigma(1385)^-\overline{\Sigma}^+(\text{or c.c.})\\ \phi_{\tilde{K}}(1285)\\ \eta\pi^+\pi^-\\ \rho\eta\\ \omega\eta'(958)\\ \omega_{\tilde{K}}(980)\\ \rho\eta'(958)\\ \omega_{\tilde{K}}(980)\\ \rho\eta'(958)\\ a_2(1320)^{\pm}\pi^{\mp}\\ K_{\tilde{K}}^*(1430)^{+}\text{c.c.}\\ K_1(1270)^{\pm}K^{\mp}\\ K_{\tilde{K}}^*(1430)^0\overline{K}_2^*(1430)^0\\ \phi\pi^0\\ \phi\eta(1405) \to \phi\eta\pi\pi\\ \omega f_2'(1525)\\ \eta\phi(2170) \to\\ \etaK^*(892)^0\overline{K}^*(892)^0\\ \Sigma(1385)^0\overline{\Lambda}\\ \Delta(1232)^+\overline{p}\\ \Theta(1540)\overline{\Theta}(1540) \to\\ K_S^0pK^-\overline{n}+\text{c.c.}\\ \Theta(1540)K^0_S\overline{p}\to K_S^0\overline{p}K^+n\\ \overline{\Theta}(1540)K^0_S\overline{p}\to K_S^0\overline{p}K^+n\\ \overline{\Theta}(1540)K^0_S\overline{p}\to K_S^0\overline{p}K^-\overline{n}\\ \Sigma^0\overline{\Lambda}\\ \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 4.0 : (1.93 : (1.82 : (1.4 : (1.05 : (1.93 : (1.4 : (1.05 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : 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| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F68 F69 F70 F71 F72 F73 F74 F75 F76 F77 F78 F79 F80 F81 F82 F83 | $\begin{array}{c} \phi_{1} \hat{b}_{0} (980) \rightarrow \phi \pi^{0} \pi^{0} \\ \eta \phi_{1} (980) \rightarrow \phi \eta \pi^{0} \pi^{0} \\ \eta \phi_{1} (980) \rightarrow \eta \phi \pi^{+} \pi^{-} \\ \phi_{2} (980)^{0} \rightarrow \phi \eta \pi^{0} \\ \equiv (1530)^{0} \overline{\equiv}^{0} \\ \Sigma (1385)^{-} \overline{\Sigma}^{+} (\text{or c.c.}) \\ \phi_{1} (1285) \\ \eta \pi^{+} \pi^{-} \\ \rho \eta \\ \omega \eta' (958) \\ \omega_{1} (980) \\ \rho \eta' (958) \\ a_{2} (1320)^{\pm} \pi^{\mp} \\ K K_{2}^{*} (1430) + \text{c.c.} \\ K_{1} (1270)^{\pm} K^{\mp} \\ K_{2}^{*} (1430)^{0} \overline{K}_{2}^{*} (1430)^{0} \\ \phi \pi^{0} \\ \phi \eta (1405) \rightarrow \phi \eta \pi \pi \\ \omega f_{2}^{*} (1525) \\ \eta \phi (2170) \rightarrow \\ \eta K^{*} (892)^{0} \overline{K}^{*} (892)^{0} \\ \Sigma (1385)^{0} \overline{\Lambda} \\ \Delta (1232)^{+} \overline{p} \\ \Theta (1540) \overline{\Theta} (1540) \rightarrow \\ K_{0}^{0} p K^{-} \overline{n} + \text{c.c.} \\ \Theta (1540) K_{0}^{0} \overline{p} \rightarrow K_{0}^{0} \overline{p} K^{+} n \\ \overline{\Theta} (1540) K_{0}^{0} \overline{p} \rightarrow K_{0}^{0} \overline{p} K^{+} n \\ \overline{\Theta} (1540) K_{0}^{0} \overline{p} \rightarrow K_{0}^{0} \overline{p} K^{-} \overline{n} \\ \Sigma^{0} \overline{\Lambda} \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 4.0 : (1.93 : (1.82 : (1.4 : (1.05 : (1.93 : (1.82 : (1.4 : (1.05 : (1.93 : (1.82 : (1.4 : (1.05 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : (1.93 : | ±0.7) × 10-4 ±1.0) × 10-4 ±4) × 10-6 ±1.4) × 10-4 ±0.5) × 10-4 ±0.5) × 10-4 ±0.7) × 10-4 ±0.8) × 10-4 ±0.18) × 10-4 × 10-3 × 10-3 × 10-3 × 10-4 × 10-4 × 10-4 × 10-4 × 10-5 × 10-5 × 10-5 × 10-5 × 10-5 × 10-5 × 10-5 | CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% CL=90% | F128 F129 F130 F131 F132 F133 F134 F135 F136 F137 F138 F139 F140 F141 F142 F143 F144 F145 F146 F147 F148 F149 F150 F151 F152 F153 F154 | $\begin{array}{c} \pi^{+}\pi^{-} \\ \Lambda\overline{\Sigma} + \text{c.c.} \\ K_{S}^{0}K_{S}^{0} \end{array} \\ & \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | [d] | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | CL=95% CL=90% CL=90% S=1.6 S=1.8 CL=95% CL=90% CL=90% S=1.1 S=1.9 |
| F58 F59 F60 F61 F65 F66 F67 F68 F70 F71 F75 F76 F77 F78 F79 F80 F81 F82 F83 F84 F85 F86 $φ_{f_0}(980) \rightarrow φ\pi^0\pi^0$ $ηφ_{f_0}(980) \rightarrow φ\pi^0\pi^0$ $ηφ_{f_0}(980) \rightarrow φ\eta\pi^0$ $\equiv (1530)^0 \equiv 0$ $\Sigma (1385)^- \overline{\Sigma}^+ \text{ (or c.c.)}$ $φ_{f_1}(1285)$ $η\pi^+\pi^ ρη$ $ωη'(958)$ $ω_{f_0}(980)$ $ρη'(958)$ $ω_{f_0}(130)^+ \pi^+$ $K_{f_0}^*(1430)^0 \overline{K_0}^*(1430)^0$ $φ\pi^0$ $φη(1405) \rightarrow φηππ$ $ω_{f_0}(1525)$ $ηφ(2170) \rightarrow ηK^*(892)^0 \overline{K}^*(892)^0$ $\Sigma (1385)^0 \overline{Λ}$ $\Delta (1232)^+ \overline{ρ}$ $\Theta (1540) \overline{Θ}(1540) \rightarrow K_0^S \overline{ρ} K^- \overline{η}$ $\Theta (1540) \overline{K}^0 \overline{ρ} \rightarrow K_0^S \overline{ρ} K^+ \overline{η}$ $\overline{Θ}(1540) \overline{K}^0 \overline{ρ} \rightarrow K_0^S \overline{ρ} K^+ \overline{η}$ $\overline{Θ}(1540) \overline{K}^0 \overline{ρ} \rightarrow K_0^S \overline{ρ} K^- \overline{η}$ $\overline{Θ}(1540) 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| Г ₅₈ Г ₅₉ Г ₆₀ Г ₆₁ Г ₆₂ Г ₆₃ Г ₆₄ Г ₆₅ Г ₆₆ Г ₆₇ Г ₇₀ Г ₇₁ Г ₇₂ Г ₇₃ Г ₇₄ Г ₇₅ Г ₇₆ Г ₇₇ Г ₇₈ Г ₇₉ Г ₈₀ Г ₈₁ Г ₈₂ Г ₈₃ Г ₈₄ | $\begin{array}{c} \phi_{\tilde{K}}(980) \to \phi\pi^0\pi^0\\ \eta\phi_{\tilde{K}}(980) \to \phi\pi^0\pi^0\\ \eta\phi_{\tilde{K}}(980) \to \eta\phi\pi^+\pi^-\\ \phi_{\tilde{A}_0}(980)^0 \to \phi\eta\pi^0\\ \equiv (1530)^0 \stackrel{\Xi_0}{\equiv}^0\\ \Sigma(1385)^- \stackrel{\Xi_1}{\Sigma^+} (\text{or c.c.})\\ \phi_{\tilde{K}_1}(1285)\\ \eta\pi^+\pi^-\\ \rho\eta\\ \omega\eta'(958)\\ \omega_{\tilde{K}_0}(980)\\ \rho\eta'(958)\\ \omega_{\tilde{K}_0}(980)\\ \rho\eta'(958)\\ a_2(1320)^{\pm}\pi^{\mp}\\ K_{\tilde{K}_1}^*(1430)^{+}\text{c.c.}\\ K_1(1270)^{\pm}K^{\mp}\\ K_{\tilde{K}_1}^*(1430)^0 \stackrel{K}{K}_2^*(1430)^0\\ \phi\pi^0\\ \phi\eta(1405) \to \phi\eta\pi\pi\\ \omega f_2'(1525)\\ \eta\phi(2170) \to\\ \eta K^*(892)^0 \stackrel{K}{K}^*(892)^0\\ \Sigma(1385)^0 \stackrel{\Lambda}{\Lambda}\\ \Delta(1232)^+ \stackrel{\Xi}{p}\\ \Theta(1540) \stackrel{K}{\Theta}(1540) \to\\ K_0^S p K^- \stackrel{\Xi}{\eta} + \text{c.c.}\\ \Theta(1540) K_0^S \stackrel{\Xi}{p} \to K_0^S \stackrel{\Xi}{p} K^+ n\\ \stackrel{\Xi}{\Theta}(1540) K_0^S \stackrel{\Xi}{p} \to K_0^S \stackrel{\Xi}{p} K^+ n\\ \stackrel{\Xi}{\Phi}(1540) K_0^S \stackrel{\Xi}{p} \to K_0^S \stackrel{\Xi}{p} K^+ n\\ \stackrel{\Xi}{\Theta}(1540) K_0^S$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (3.2 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : (3.4 : 3.2 : 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CL=90% CL=90% S=1.1 S=1.9 |
| F58 F59 F60 F61 F62 F63 F64 F65 F66 F67 F70 F71 F72 F73 F74 F75 F76 F77 F88 F79 F80 F81 F82 F83 F84 | $\begin{array}{c} \phi_{\tilde{k}}(980) \to \phi \pi^0 \pi^0 \\ \eta \phi_{f_0}(980) \to \eta \phi \pi^+ \pi^- \\ \phi_{a_0}(980) \to \eta \eta \pi^0 \\ \equiv (1530)^0 \stackrel{\Xi}{=} 0 \\ \Sigma (1385)^- \stackrel{\Sigma}{\Sigma}^+ (\text{or c.c.}) \\ \phi_{f_1}(1285) \\ \eta \pi^+ \pi^- \\ \rho \eta \\ \omega \eta'(958) \\ \omega_{f_0}(980) \\ \rho \eta'(958) \\ \omega_{f_0}(980) \\ \rho \eta'(958) \\ \omega_{f_2}(1320)^\pm \pi^\mp \\ K^*_{\chi}(1430)^+ \text{c.c.} \\ K_1(1270)^\pm K^\mp \\ K^*_{\chi}(1430)^0 \stackrel{K}{K}^*_{\chi}(1430)^0 \\ \phi \pi^0 \\ \phi \eta(1405) \to \phi \eta \pi \pi \\ \omega f_2'(1525) \\ \eta \phi(2170) \to \\ \eta K^*_{\chi}(892)^0 \stackrel{K}{K}^*_{\chi}(892)^0 \\ \Sigma (1385)^0 \stackrel{K}{\Lambda} \\ \Delta (1232)^+ \stackrel{E}{p} \\ \Theta(1540) \stackrel{E}{K}_0 \stackrel{E}{p} \to K^0_{S} \stackrel{E}{p} K^+ n \\ \Theta(1540) \stackrel{E}{K}_0 \stackrel{E}{p} \to K^0_{S} \stackrel{E}{p} K^+ n \\ \stackrel{E}{\Theta}(1540) \stackrel{E}{K}_0 \stackrel{E}{p} \to K^0_{S} \stackrel{E}{p} K^- \stackrel{E}{n} \\ \Sigma^0 \stackrel{E}{\Lambda} \end{array}$ | (1.7 : (3.2 : (5 : 3.2 : (5 : 3.2 : (5 : 3.2 : (6.4 : 3.2 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.4 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.1 : (1.05 : (1.05 : (1.1 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 : (1.05 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Meson Particle Listings $J/\psi(1S)$

| $\Gamma_{161} \gamma f_1(1510) \rightarrow \gamma \eta \pi^+ \pi^-$ | | (| 4.5 | ±1.2 |) × | 10-4 | |
|---------------------------------------------------------------------------|--------------|-----|--------|--------------------|------|-----------|-------------|
| $\Gamma_{162} \gamma f'_{2}(1525)$ | | (| 4.5 | $^{+0.7}_{-0.4}$ | | 10-4 | |
| $\Gamma_{163} \gamma f_2(1640) \rightarrow \gamma \omega \omega$ | | • | 2.8 | -0.4 ±1.8 | | 10-4 | |
| $\Gamma_{164} \gamma f_2(1910) \rightarrow \gamma \omega \omega$ | | , | 2.0 | ±1.4 | | 10-4 | |
| $\Gamma_{165} \gamma f_2(1950) \rightarrow$ | | | 7.0 | ±2.2 | | 10-4 | |
| $\gamma K^*(892) \overline{K}^*(892)$ | | , | | | , | | |
| $\Gamma_{166} \gamma K^{*}(892) \overline{K}^{*}(892)$ | | (| 4.0 | ± 1.3 |) × | 10^{-3} | |
| $\Gamma_{167} \gamma \phi \phi$ | | (| 4.0 | ± 1.2 | | 10^{-4} | S=2.1 |
| Γ ₁₆₈ γρ <u></u> ρ | | (| 3.8 | ± 1.0 | | 10^{-4} | |
| $\Gamma_{169} \gamma \eta(2225)$ | | (| 3.3 | ±0.5 | | 10^{-4} | |
| $\Gamma_{170} \gamma \eta (1760) \rightarrow \gamma \rho^0 \rho^0$ | | | 1.3 | ± 0.9 |) × | 10^{-4} | |
| $\Gamma_{171} \gamma \eta(1760) \rightarrow \gamma \omega \omega$ | | | | ± 0.33 |) × | 10-3 | |
| $\Gamma_{172} \ \gamma X(1835) \rightarrow \ \gamma \pi^+ \pi^- \eta'$ | | (| 2.6 | ± 0.4 | | 10-4 | |
| $\Gamma_{173} \gamma X(1835) \rightarrow \gamma p \overline{p}$ | | (| 7.5 | $^{+1.9}_{-0.9}$ |) × | 10-5 | |
| $\Gamma_{174} \ \gamma(K\overline{K}\pi) \ [J^{PC} = 0^{-+}]$ | | (| 7 | ± 4 | | 10^{-4} | S=2.1 |
| Γ_{175} $\gamma \pi^0$ | | (| 3.49 | $^{+0.33}_{-0.30}$ |) × | 10-5 | |
| $\Gamma_{176} \ \gamma p \overline{p} \pi^+ \pi^-$ | | < | 7.9 | | × | 10^{-4} | CL=90% |
| Γ ₁₇₇ γΛΛ | | < | 1.3 | | × | 10^{-4} | CL=90% |
| $\Gamma_{178} \gamma f_0(2200)$ | | | | | | 2 | |
| $\Gamma_{179} \gamma f_J(2220)$ | | | 2.50 | | | | CL = 99.9% |
| $\Gamma_{180} \gamma f_J(2220) \rightarrow \gamma \pi \pi_{\underline{}}$ | | | 8 | ± 4 | | 10-5 | |
| $\Gamma_{181} \gamma f_J(2220) \rightarrow \gamma K K$ | | | 3.6 | | | 10-5 | |
| $\Gamma_{182} \gamma f_J(2220) \rightarrow \gamma p \overline{p}$ | | | 1.5 | ±0.8 | | 10-5 | |
| $\Gamma_{183} \gamma f_0(1500)$ | | | | ± 0.32 | | | G1 000/ |
| Γ_{184} $\gamma A \rightarrow \gamma$ invisible | [e] | < | 6.3 | | × | 10-6 | CL=90% |
| \ | Veak decays | i | | | | | |
| $\Gamma_{185}~~D^-e^+ u_e^{}+{ m c.c.}$ | | < | 1.2 | | × | 10^{-5} | CL=90% |
| $\Gamma_{186} \ \overline{D}{}^0 e^+ e^- + \text{c.c.}$ | | < | 1.1 | | × | 10^{-5} | CL=90% |
| $\Gamma_{187} \ D_s^- e^+ u_e + { m c.c.}$ | | < | 3.6 | | × | 10^{-5} | CL=90% |
| $\Gamma_{188} D^{-} \pi^{+} + \text{c.c.}$ | | < | 7.5 | | × | 10^{-5} | CL=90% |
| $\Gamma_{189}^{100} \overline{D}^0 \overline{K}^0 + \text{c.c.}$ | | < | 1.7 | | × | 10^{-4} | CL=90% |
| $\Gamma_{190} \ D_s^- \pi^+ + \text{c.c.}$ | | < | 1.3 | | × | 10^{-4} | CL=90% |
| Charge conji | unation (C) | D | arity | (D) | | | |
| Lepton Family n | umber (IF) | , r | olatir | (r). Ig mod | es | | |
| Γ_{191} $\gamma\gamma$ | | < | | | | 10-6 | CL=90% |
| $\Gamma_{192}^{191} e^{\pm} \mu^{\mp}$ | | | 1.1 | | | 10-6 | CL=90% |
| $\Gamma_{193} e^{\pm} \tau^{\mp}$ | | | 8.3 | | | 10-6 | CL=90% |
| $\Gamma_{194}^{193} \mu^{\pm} \tau^{\mp}$ | | | 2.0 | | | 10^{-6} | CL=90% |
| | Other decays | | | | | | |
| Γ_{195} invisible | = | | 7 | | ~ | 10-4 | CL=90% |
| . 133 | | ` | • | | ^ | | SE-70/0 |
| [a] For $E_{\gamma} > 100$ MeV. | | | | | | | |
| [b] The value is for the sum | of the char | ge | state | es or i | arti | cle/a | ntiparticle |
| states indicated. | | J - | | [| | ., = | r |

- states indicated.
- [c] Includes $p\overline{p}\pi^+\pi^-\gamma$ and excludes $p\overline{p}\eta$, $p\overline{p}\omega$, $p\overline{p}\eta'$.
- [d] See the "Note on the $\eta(1405)$ " in the $\eta(1405)$ Particle Listings.
- [e] For a narrow state A with mass less than 960 MeV.

| $J/\psi(15)$ | PARTIAL | WIDTHS |
|--------------|---------|---------------|
| 2/4(20) | | |

| Γ(hadrons) | | | | | | Γ1 |
|-----------------------------------|-------------------|--------------------------|-----------|---------|------------------------------------------|----------------|
| VALUE (keV) | | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the followin | ng data for average | es, fits, | limits, | etc. • • • | |
| 74.1 ± 8.1 | | BAI | 95B | BES | $e^+ e^-$ | |
| 59 ±24 | | BALDINI | 75 | FRAG | e^+e^- | |
| 59 ±14 | | BOYARSKI | 75 | MRK1 | e^+e^- | |
| 50 ±25 | | ESPOSITO | 75B | FRAM | e^+e^- | |
| Γ(e ⁺ e ⁻) | | | | | | Γ ₅ |
| VALUE (keV) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 5.55±0.14±0.02 | OUR EVALUA | TION | | | | |
| ullet $ullet$ We do not | use the following | ng data for average | es, fits, | limits, | etc. • • • | |
| 5.71 ± 0.16 | 13k | ⁹ ADAMS | 06A | CLEO | $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$ | |
| 5.57 ± 0.19 | 7.8k | ⁹ AUBERT | 04 | BABR | $e^+e^- \rightarrow \mu^+\mu^-\gamma$ | |
| 5.14 ± 0.39 | | BAI | 95B | BES | e^+e^- | |
| $5.36 {}^{+ 0.29}_{- 0.28}$ | | ¹⁰ HSUEH | 92 | RVUE | See $	au$ mini-review | |
| 4.72 ± 0.35 | | ALEXANDER | 89 | RVUE | See γ mini-review | |
| 4.4 ±0.6 | | ¹⁰ BRA NDELIK | 79C | DASP | e^+e^- | |
| 4.6 ±0.8 | | ¹¹ BALDINI | 75 | FRAG | e^+e^- | |
| 4.8 ±0.6 | | BOYARSKI | 75 | MRK1 | e^+e^- | |
| 4.6 ±1.0 | | ESPOSITO | 75B | FRAM | e^+e^- | |

| ⁹ Calculated by us from the reported | values of $\Gamma(e^+e^-)\times B(\mu^+)$ | μ^-) using B($\mu^+\mu^-$) = |
|-------------------------------------------------|-------------------------------------------|-------------------------------------|
| $(5.93 \pm 0.06)\%$. | | |

 $^{10}\,{\rm From}$ a simultaneous fit to $e^+\,e^-$, $\mu^+\,\mu^-$, and hadronic channels assuming $\Gamma(e^+\,e^-)$

11 Assuming equal partial widths for e^+e^- and $\mu^+\mu^-$.

| $\Gamma(\mu^+\mu^-)$ | | | | | | Γ ₇ |
|------------------------|------------------|--------------------|----------|-----------|------------|----------------|
| VALUE (keV) | | DO CUMENT ID | | TECN | COMMENT | |
| | se the following | g data for average | es, fits | , limits, | etc. • • • | |
| 5.13 ± 0.52 | | BAI | 95B | BES | e^+e^- | |
| 4.8 ± 0.6 | | BOYARSKI | 75 | MRK1 | e^+e^- | |
| 5 ±1 | | ESPOSITO | 75B | FRAM | e^+e^- | |
| $\Gamma(\gamma\gamma)$ | | | | | | Γ191 |
| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT | |
| <5.4 | 90 | BRANDELIK | 79C | DASP | e^+e^- | |

$J/\psi(1S) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

This combination of a partial width with the partial width into e^+e^- and with the total width is obtained from the integrated cross section into channel in the e^+e^- annihilation.

| VALUE (keV) | DOCUMENT ID TECN COMMENT | |
|--------------------|--------------------------------------------------------------|--|
| • • • We do not us | se the following data for averages, fits, limits, etc. • • • | |
| 4 ± 0.8 | 12 BALDINI 75 FRAG e^+e^- | |
| 3.9 ± 0.8 | ¹² ESPOSITO 75B FRAM e ⁺ e− | |

| $\Gamma(e^+e^-) \times \Gamma(e^+e^-)/\Gamma_t$ | otal | | | Γ ₅ Γ ₅ /Γ |
|-------------------------------------------------|------------------------|----------|-----------|----------------------------------|
| VALUE (eV) | DOCUMENT ID | | TECN | COMMENT |
| 332.3± 6.4±4.8 | ANASHIN | 10 | KEDR | 3.097 $e^+e^- ightarrow~e^+e^-$ |
| | wing data for averag | es, fits | , limits, | etc. • • • |
| 350 ± 20 | BRANDELIK | 79C | DASP | e^+e^- |
| 320 ± 70 | 13 BALDINI | | | |
| 340 ± 90 | ¹³ ESPOSITO | 75B | FRAM | e^+e^- |
| 360 ±100 | ¹³ FORD | 75 | SPEC | e^+e^- |

 $^{13}\mathrm{Data}$ redundant with branching ratios or partial widths above.

| $\Gamma(\mu^+\mu^-) \times \Gamma(e$ | + e ⁻)/Γ _{to} | tai | | | $\Gamma_7\Gamma_5/\Gamma$ |
|---------------------------------------|------------------------------------|------------------------|-----------|-----------|------------------------------------------|
| VALUE (eV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 334 ± 5 OUR A\ | /ERAGE | | | | |
| $331.8 \pm 5.2 \pm 6.3$ | | ANASHIN | 10 | KEDR | 3.097 $e^+ e^- \rightarrow \mu^+ \mu^-$ |
| $338.4 \pm 5.8 \pm 7.1$ | 13k | ADAMS | 06A | CLEO | $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$ |
| $330.1 \pm 7.7 \pm 7.3$ | 7.8k | AUBERT | 04 | BABR | $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$ |
| ● ● We do not use | ethe follow | ng data for averag | ges, fits | , limits, | etc. • • • |
| 510 ±90 | | DASP | 75 | DASP | e^+e^- |
| 380 ±50 | | ¹⁴ ESPOSITO | 75B | FRAM | e^+e^- |

 $^{14}\,\mathrm{Data}$ redundant with branching ratios or partial widths above.

| $\Gamma(\omega\pi^+\pi^-\pi^0)$ | × Γ(e+ 6 | e ⁻)/Γ _{total} | | | | $\Gamma_{12}\Gamma_{5}/\Gamma_{12}$ |
|---------------------------------|----------|-------------------------------------|-----|------|---------------------------|-------------------------------------|
| $VALUE~(10^{-2}~keV)$ | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 2.2±0.3±0.2 | 170 | AUBERT | 06D | BABR | $10.6 e^+e^- \rightarrow$ | $\omega \pi^+ \pi^- \pi^0 \gamma$ |

| $\Gamma(\omega\pi^+\pi^-)\times\Gamma$ | (e+ e-) |)/Γ _{total} | | | $\Gamma_{13}\Gamma_{5}/\Gamma$ |
|----------------------------------------|---------|----------------------|-----------|--------------------------|---------------------------------|
| VALUE (eV) | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 53.6±5.0±0.4 | 788 | ¹⁵ AUBERT | 07AU BABR | 10.6 $e^+e^ \rightarrow$ | $_{\omega\pi^{+}\pi^{-}\gamma}$ |

 $^{15}\, {\rm AUBERT}$ 07AU reports [$\Gamma \left(J/\psi(1{\rm S}) \ \rightarrow \ \omega\,\pi^+\,\pi^- \right) \ \times \ \Gamma \left(J/\psi(1{\rm S}) \ \rightarrow \ e^+\,e^- \right)/\Gamma_{
m total}$] $\times \left[\mathsf{B}(\omega(782) \to \pi^+\pi^-\pi^0) \right] = 47.8 \pm 3.1 \pm 3.2 \,\, \mathsf{eV} \,\, \mathsf{which} \,\, \mathsf{we} \,\, \mathsf{divide} \,\, \mathsf{by} \,\, \mathsf{our} \,\, \mathsf{best} \,\, \mathsf{value} \,\, \mathsf{B}(\omega(782) \to \pi^+\pi^-\pi^0) = (89.2 \pm 0.7) \times 10^{-2}. \,\, \mathsf{Our} \,\, \mathsf{first} \,\, \mathsf{error} \,\, \mathsf{is} \,\, \mathsf{their} \,\, \mathsf{experiment's} \,\, \mathsf{error} \,\, \mathsf{and} \,\, \mathsf{our} \,\, \mathsf{second} \,\, \mathsf{error} \,\, \mathsf{is} \,\, \mathsf{the} \,\, \mathsf{systematic} \,\, \mathsf{error} \,\, \mathsf{from} \,\, \mathsf{using} \,\, \mathsf{our} \,\, \mathsf{best} \,\, \mathsf{value}.$

| Γ(<i>K</i> *(892) ^υ | $K_2^*(1430)^0 +$ | c.c.) $\times \Gamma(e^+e^-)$ | :⁻)/Γ _{tα} | otal Γ19Γ5/Γ |
|--------------------------------------------------|--------------------------------------|------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| VALUE (eV) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 33±4±1 | $317 \pm 23 ^{16,17}$ | AUBERT 07AK | BABR | 10.6 $e^+e^- \rightarrow \pi^+\pi^-K^+K^-\gamma$ |
| ¹⁶ Dividing b ¹⁷ AUBERT | y 2/3 to take in 07ΑΚ reports [Γ(| to account that B $(J/\psi(1S) ightarrow K^*($ | (<i>K</i> * ⁰ → 892) ⁰ K | $K^{+}\pi^{-}) = 2/3.$ *\frac{1}{2}(1430)^{0} + c.c.\rightarrow \Gamma(J/\psi(1S) \rightarrow \Gamma(J/\psi(1S)) |
| our best v | ralue B(<i>K</i> *(1430 | $(0) \rightarrow K\pi) = (49)$ | 9.9 ± 1. | \pm 1.1 \pm 1.4 eV which we divide by 2) \times 10 $^{-2}$. Our first error is their atic error from using our best value. |

experiment's error and our second error is the systematic error from using our best value.
$$\Gamma\left(K^*(892)^0\overline{K}_2(1770)^0 + \text{c.c.} \rightarrow K^*(892)^0K^-\pi^+ + \text{c.c.}\right) \times \Gamma\left(e^+e^-\right) / \Gamma_{\text{total}}$$

$$\frac{VALUE \text{ (eV)}}{13.8 \pm 0.4 \pm 0.3} \quad \frac{EVTS}{110 \pm 14} \quad \frac{DOCUMENT \text{ ID}}{18} \quad \frac{TECN}{BABR} \quad \frac{COMMENT}{10.6} \quad e^+e^- \rightarrow \pi^+\pi^-K^+K^-\gamma$$

$$\frac{18}{18} \text{ Dividing by } 2/3 \text{ to take into account that } \text{B}(K^{*0} \rightarrow K^+\pi^-) = 2/3.$$

 $\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{22}\Gamma_5/\Gamma$ VALUE (eV) DOCUMENT ID TECN COMMENT

08s BABR 10.6 $e^+e^- \to K^+K^*(892)^- \gamma$

AUBERT

29.0±1.7±1.3

1/2/1(15)

| $\frac{\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.} \to K^+K^-\pi^0) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}}{\Gamma_{23}\Gamma_5/\Gamma}$ | $\Gamma(\eta \pi^+ \pi^-) \times \Gamma(e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_{64}\Gamma_{5}/\Gamma$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (eV) EVTSDOCUMENT_IDTECNCOMMENT | VALUE (eV) EVTS DOCUMENT ID TECN COMMENT |
| 10.96 \pm 0.85 \pm 0.70 155 AUBERT 08s BABR 10.6 $e^+e^- \rightarrow \kappa^+\kappa^-\pi^0\gamma$ | 2.24±0.98±0.03 9 ²⁸ AUBERT 07AU BABR 10.6 $e^+e^- \to \eta \pi^+ \pi^- \gamma$ 28 AUBERT 07AU reports $[\Gamma(J/\psi(1S) \to \eta \pi^+ \pi^-) \times \Gamma(J/\psi(1S) \to e^+e^-)/\Gamma_{\text{total}}] \times$ |
| $\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.} \rightarrow K^0K^\pm\pi^\mp) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | $[B(\eta \to \pi^+ \pi^- \pi^0)] = 0.51 \pm 0.22 \pm 0.03$ eV which we divide by our best value $B(\eta \to \pi^+ \pi^- \pi^0)$ |
| 16.76±1.70±1.00 89 AUBERT 088 BABR $10.6 e^+ e^- \rightarrow K_S^0 K^{\pm} \pi^{\mp} \gamma$ | $\pi^+\pi^-\pi^0$) = $(22.74\pm0.28)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\Gamma(K^0\overline{K}^*(892)^0 + \text{c.c.}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{25}\Gamma_5/\Gamma_{\text{VALUE (eV)}}$ DOCUMENT ID TECN COMMENT | $\frac{\Gamma(K^*(892)^0\overline{K}^*(892)^0)}{E^{VTS}} \times \frac{\Gamma(e^+e^-)/\Gamma_{total}}{I^{ECN}} \times \frac{\Gamma_{15}\Gamma_5/\Gamma_5}{\Gamma_{15}\Gamma_5/\Gamma_5}$ |
| 26.6±2.5±1.5 AUBERT 08s BABR $10.6 e^+ e^- \rightarrow \kappa^0 \overline{\kappa}^* (892)^0 \gamma$ | 1.28±0.40±0.11 25 ± 8 29 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^-K^+K^-\gamma$ |
| $\Gamma(K^0\overline{K}^*(892)^0 + \text{c.c.} \to K^0K^\pm\pi^\mp) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{26}\Gamma_5/\Gamma$ | ²⁹ Dividing by $(2/3)^2$ to take twice into account that B($K^{*0} \rightarrow K^+\pi^-$) = 2/3. |
| VALUE (eV)EVTSDOCUMENT IDTECNCOMMENT17.70±1.70±1.70±1.9094AUBERT08sBABR $10.6 e^+e^- \rightarrow K_c^0 K^{\pm} \pi^{\mp} \gamma$ | $\Gamma(\phi f_2(1270)) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_{42}\Gamma_5/\Gamma_{total}$ $\Gamma_{42}\Gamma_5/\Gamma_{total}$ $\Gamma_{42}\Gamma_5/\Gamma_{total}$ $\Gamma_{42}\Gamma_5/\Gamma_{total}$ $\Gamma_{42}\Gamma_5/\Gamma_{total}$ |
| $\Gamma(\omega K \overline{K}) \times \Gamma(e^+ e^-) / \Gamma_{\text{total}}$ $\Gamma_{35} \Gamma_5 / \Gamma$ | 4.0±0.7±0.1 44 ± 7 30,31 AUBERT 07AK BABR 10.6 $e^+e^- 	o \pi^+\pi^- K^+ K^- \gamma$ |
| VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | 30 Using B($\phi \to (K+K)^-$) = (49.3 ± 0.6)%. 31 AUBERT 074K reports [$\Gamma(1/b)(1.5) \to \phi(6/1.270)$) × $\Gamma(1/b)(1.5) \to e^+e^-$)/ $\Gamma_1 \to 0$ |
| 3.70±1.98±0.03 24 ¹⁹ AUBERT 07AU BABR 10.6 $e^+e^- \to \omega K^+ K^- \gamma$ | 31 AUBERT 07AK reports $[\Gamma(J/\psi(1S) \rightarrow \phi f_2(1270)) \times \Gamma(J/\psi(1S) \rightarrow e^+e^-)/\Gamma_{\text{total}} \times [B(f_2(1270) \rightarrow \pi\pi)] = 3.41 \pm 0.55 \pm 0.28$ eV which we divide by our best value |
| ¹⁹ AUBERT 07AU reports $[\Gamma(J/\psi(1S) \to \omega K \overline{K}) \times \Gamma(J/\psi(1S) \to e^+e^-)/\Gamma_{\text{total}}] \times [B(\omega(782) \to \pi^+\pi^-\pi^0)] = 3.3 \pm 1.3 \pm 1.2$ eV which we divide by our best value | B($f_2(1270) \to \pi\pi$) = $(84.8^{+2.4}_{-1.2}) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $B(\omega(782) \to \pi^+\pi^-\pi^0) = (89.2 \pm 0.7) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(2(\pi^+\pi^-)\pi^0) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{85}\Gamma_5/\Gamma_{65}$ |
| $\Gamma(\phi 2(\pi^+\pi^-)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{37}\Gamma_5/\Gamma$ | VALUE (eV) EVTS DOCUMENT ID TECN COMMENT |
| VALUE (10 ⁻² keV) EVTS DOCUMENT ID TECN COMMENT | 303±5±18 4990 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\pi^0 \gamma$ |
| 0.96±0.19±0.01 35 20 AUBERT 06D BABR 10.6 e^+e^- → $\phi 2(\pi^+\pi^-)\gamma$ | $\Gamma(\pi^+\pi^-\pi^0) \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{87}\Gamma_5/\Gamma_{	ext{VALUE (keV)}}$ |
| 20 AUBERT 06D reports $[\Gamma(J/\psi(1S) \to \phi 2(\pi^+\pi^-)) \times \Gamma(J/\psi(1S) \to e^+e^-)/\Gamma_{\rm total}] \times [B(\phi(1020) \to K^+K^-)] = (0.47 \pm 0.09 \pm 0.03) \times 10^{-2}$ keV which we divide by | 0.122 \pm 0.005 \pm 0.008 AUBERT,B 04N BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma$ |
| our best value B($\phi(1020) \to K^+K^-$) = (48.9 \pm 0.5) \times 10 ⁻² . Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(\pi^+\pi^-\pi^0K^+K^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{88}\Gamma_5/\Gamma_{68}$ |
| $\Gamma(\phi\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{46}\Gamma_5/\Gamma$ | 107.0 \pm 4.3 \pm 6.4 768 AUBERT 07AU BABR 10.6 e+e $^ \rightarrow$ K+K $^ \pi$ + π - π 0 0 |
| VALUE (eV) EVTS DOCUMENT ID TECN COMMENT 4.8 ± 0.4 OUR AVERAGE | |
| $4.52 \pm 0.48 \pm 0.04$ 254 ± 23 21 SHEN | $\Gamma(\pi^+\pi^-K^+K^-) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_{90}\Gamma_5/\Gamma_{total}$ $\Gamma_{90}\Gamma_5/\Gamma_{total}$ $\Gamma_{90}\Gamma_5/\Gamma_{total}$ $\Gamma_{90}\Gamma_5/\Gamma_{total}$ $\Gamma_{90}\Gamma_5/\Gamma_{total}$ |
| 5.33 \pm 0.71 \pm 0.05 103 22 AUBERT,BE 06D BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ | 36.3±1.3±2.1 1586±58 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^- K^+ K^- \gamma$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ²¹ SHEN 09 reports 4.50 \pm 0.41 \pm 0.26 eV from a measurement of $[\Gamma(J/\psi(1S) \rightarrow \phi\pi^+\pi^-) \times \Gamma(J/\psi(1S) \rightarrow e^+e^-)/\Gamma_{\text{total}}] \times [B(\phi(1020) \rightarrow K^+K^-)]$ assuming | 33.6 \pm 2.7 \pm 2.7 233 ³² AUBERT 05D BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ |
| $B(\phi(1020)	o K^+K^-)=(49.2\pm0.6)	imes10^{-2}$, which we rescale to our best value | 32 Superseded by AUBERT 07AK. |
| $B(\phi(1020) \rightarrow K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(\pi^+\pi^-K^+K^-\eta) 	imes \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{91}\Gamma_5/\Gamma_{	ext{VALUE}}$ $\Gamma_{91}\Gamma_5/\Gamma_{	ext{VALUE}}$ |
| ²² AUBERT,BE 06D reports $[\Gamma(J/\psi(1S) \rightarrow \phi \pi^+ \pi^-) \times \Gamma(J/\psi(1S) \rightarrow e^+ e^-)/\Gamma_{\text{total}}] \times [B(\phi(1020) \rightarrow K^+ K^-)] = 2.61 \pm 0.30 \pm 0.18$ eV which we divide by our best value | 25.9±3.9±0.1 73 ³³ AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\eta\gamma$ |
| $B(\phi(1020) \rightarrow K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's | ³³ AUBERT 07AU reports $[\Gamma(J/\psi(1S) \to \pi^+\pi^-K^+K^-\eta) \times \Gamma(J/\psi(1S) \to e^+e^-)$, $\Gamma_{\text{total}}] \times [B(\eta \to 2\gamma)] = 10.2 \pm 1.3 \pm 0.8$ eV which we divide by our best value $B(\eta \to 2\gamma)$ |
| error and our second error is the systematic error from using our best value. $\Gamma(A = 0 - 0) = \Gamma(A = 0 - 0)$ | 2γ) = $(39.31\pm0.20)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\Gamma(\phi\pi^0\pi^0) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_{47}\Gamma_5/\Gamma$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\pi^0\pi^0K^+K^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{92}\Gamma_5/\Gamma$ |
| 3.15 ± 0.88 ± 0.03 23 AUBERT, BE 06D BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^0\pi^0\gamma$ | VALUE (eV) EVTS DOCUMENT ID TECN COMMENT |
| ²³ AUBERT,BE 06D reports $[\Gamma(J/\psi(1S) \rightarrow \phi\pi^0\pi^0) \times \Gamma(J/\psi(1S) \rightarrow e^+e^-)/\Gamma_{\text{total}}] \times [B(\phi(1020) \rightarrow K^+K^-)] = 1.54 \pm 0.40 \pm 0.16$ eV which we divide by our best value | 13.6±1.1±1.3 203 ± 16 AUBERT 07AK BABR $10.6 e^+ e^- \rightarrow \pi^0 \pi^0 K^+ K^- \gamma$ |
| $B(\phi(1020) \to K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(2(\pi^+\pi^-)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{94}\Gamma_{5}/\Gamma_{10}$ |
| $\Gamma(\phi\eta) \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{50}}\Gamma_{	ext{5}}/\Gamma$ | $\frac{VALUE\ (eV)}{19.5 \pm 1.4 \pm 1.3}$ $\frac{EVTS}{270}$ $\frac{DOCUMENT\ ID}{AUBERT}$ $\frac{TECN}{05D}$ BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\gamma$ |
| VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(3(\pi^+\pi^-)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{95}\Gamma_5/\Gamma_{95}$ |
| 6.1±2.7±0.4 6 ²⁴ AUBERT 07AU BABR 10.6 $e^+e^- 	o \phi \eta \gamma$ | VALUE (10 ⁻² keV) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| 24 AUBERT 07AU quotes $\Gamma_{ee}^{J/\psi}\cdot {\rm B}(J/\psi\to\phi\eta)\cdot {\rm B}(\phi\to {\rm K}^+{\rm K}^-)\cdot {\rm B}(\eta\to3\pi)=0.84\pm0.37\pm0.05~{\rm eV}$ | 2.37±0.16±0.14 496 AUBERT 06D BABR $10.6 \ e^+e^- \rightarrow 3(\pi^+\pi^-) \gamma$ |
| $\Gamma(\phi f_0(980) \rightarrow \phi \pi^+ \pi^-) \times \Gamma(e^+ e^-)/\Gamma_{\text{total}}$ $\Gamma_{57}\Gamma_5/\Gamma$ | $\Gamma(2(\pi^+\pi^-\pi^0)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{96}\Gamma_5/\Gamma_{96}$ |
| VALUE (eV) EVTS DOCUMENT ID TECN COMMENT 1.21±0.23 OUR AVERAGE Error includes scale factor of 1.2. | $\frac{VALUE (10^{-2} \text{ keV})}{8.9 \pm 0.5 \pm 1.0}$ $\frac{EVTS}{761}$ $\frac{DOCUMENT ID}{AUBERT}$ $\frac{TECN}{060}$ $\frac{COMMENT}{8BABR}$ $10.6 e^+e^- → 2(π^+π^-π^0)γ$ |
| $1.48\pm0.27\pm0.09$ 60 ±11 25 SHEN 09 BELL $10.6~e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$ $1.02\pm0.24\pm0.01$ 20 ±5 26 AUBERT 07AK BABR $10.6~e^+e^- \rightarrow \pi^+\pi^-K^+K^-\gamma$ | $\Gamma(2(\pi^+\pi^-)\eta) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{97}\Gamma_{5}/\Gamma_{10}$ |
| 25 Multiplied by 2/3 to take into account the $\phi\pi^+\pi^-$ mode only. Using B($\phi\to K^+K^-$) | VALUE (eV) EVTS DOCUMENT ID TECN COMMENT |
| = (49.2 \pm 0.6)%. ²⁶ AUBERT 07AK reports $[\Gamma(J/\psi(1S) \rightarrow \phi f_0(980) \rightarrow \phi \pi^+ \pi^-) \times \Gamma(J/\psi(1S) \rightarrow$ | 13.1±2.4±0.1 85 34 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\eta\gamma$ 34 AUBERT 07AU reports $\Gamma(1/2b(15) \rightarrow 2(\pi^+\pi^-)\eta) \times \Gamma(1/2b(15) \rightarrow e^+e^-)/\Gamma_1$ |
| $e^+e^-)/\Gamma_{	ext{total}}]	imes [B(\phi(1020)	o \ \mathit{K}^+\mathit{K}^-)] = 0.50\pm0.11\pm0.04\mathrm{eV}$ which we divide | ³⁴ AUBERT 07AU reports $[\Gamma(J/\psi(1S) \to 2(\pi^+\pi^-)\eta) \times \Gamma(J/\psi(1S) \to e^+e^-)/\Gamma_{\text{total}} \times [B(\eta \to 2\gamma)] = 5.16 \pm 0.85 \pm 0.39 \text{ eV}$ which we divide by our best value $B(\eta \to 2\gamma) = 0.00 \times 10^{-2} \text{ cm}^{-2}$ |
| by our best value B($\phi(1020) \to K^+K^-$) = $(48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best | $2\gamma)=(39.31\pm0.20)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| value. | $\Gamma(p\overline{p}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{99}\Gamma_5/\Gamma_{00}$ |
| $ \Gamma(\phi f_0(980) \to \phi \pi^0 \pi^0) \times \Gamma(e^+ e^-)/\Gamma_{\text{total}} $ $ \Gamma_{58}\Gamma_5/\Gamma_{\text{VALUE (eV)}} $ $ EVTS DOCUMENT ID TECN COMMENT $ | VALUE (eV) EVTS DOCUMENT ID TECN COMMENT 11.6±0.9 OUR AVERAGE Error includes scale factor of 1.2. |
| 0.96 \pm 0.40 \pm 0.01 7.0 \pm 2.8 27 AUBERT 07AK BABR 10.6 $e^+e^- \to \pi^0\pi^0$ $K^+K^-\gamma$ | 12.0 \pm 0.6 \pm 0.5 438 AUBERT 06B $e^+e^- \rightarrow p\overline{p}\gamma$ 9.7 \pm 1.7 35 ARMSTRONG 93B E760 $\overline{p}p \rightarrow e^+e^-$ |
| ²⁷ AUBERT 07AK reports $[\Gamma(J/\psi(1S) \rightarrow \phi f_0(980) \rightarrow \phi \pi^0 \pi^0) \times \Gamma(J/\psi(1S) \rightarrow e^+ e^-)/\Gamma_{\text{total}}] \times [B(\phi(1020) \rightarrow K^+ K^-)] = 0.47 \pm 0.19 \pm 0.05$ eV which we divide by our | 35 Using $\Gamma_{\text{total}} = 85.5 ^{+6.1}_{-5.8}$ MeV. |
| best value B($\phi(1020) \rightarrow K^+K^-$) = (48.9 ± 0.5) × 10 ⁻² . Our first error is their experiment's error and our second error is the systematic error from using our best value. | ····· |

²⁷ AUBERT 07AK reports $[\Gamma(J/\psi(1S) \rightarrow \phi f_0(980) \rightarrow \phi \pi^0 \pi^0) \times \Gamma(J/\psi(1S) \rightarrow e^+ e^-)/$ $\Gamma_{\text{total}}] imes [B(\phi(1020) o K^+K^-)] = 0.47 \pm 0.19 \pm 0.05 \, \text{eV}$ which we divide by our best value $B(\phi(1020) o K^+K^-) = (48.9 \pm 0.5) imes 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\Sigma^0\overline{\Sigma}{}^0) \times \Gamma($ | $(e^+e^-)/\Gamma_1$ | | | | | Γ ₁₁₁ Γ ₅ /Γ |
|--------------------------------------------------------|-------------------------------------|-----------------------------------|---------|--------|---------------------------------------------------------------------|-------------------------------------------------------------|
| VALUE (eV) | | DOCUMENT ID | TE | CN CO | OMMENT | |
| $6.4 \pm 1.2 \pm 0.6$ | | AUBERT | 07BD BA | ABR 10 |).6 e ⁺ e ⁻ - | $\rightarrow \Sigma^0 \overline{\Sigma}^0 \gamma$ |
| $\Gamma \big(2(\pi^+\pi^-) K^+$ | <i>K</i> −) × Г | $(e^+ e^-)/\Gamma_{\text{total}}$ | | | | $\Gamma_{112}\Gamma_{5}/\Gamma$ |
| <i>VALUE</i> (10 ⁻² keV) | EVTS | DO CUMENT | ID | TECN | COMMENT | |
| 2.75 ± 0.23 ± 0.17 | 205 | AUBERT | 06D | BABR | 10.6 e ⁺ e ⁻ K ⁺ K ⁻ | $\stackrel{-}{\underset{2(\pi^+\pi^-)\gamma}{\rightarrow}}$ |
| $\Gamma(\Lambda\overline{\Lambda}) \times \Gamma(e^+$ | e ⁻)/Γ _{total} | | . 10 | TECN | COMMENT | Γ ₁₁₈ Γ ₅ /Γ |
| VALUE (eV) | | | | | COMMENT | |
| $10.7 \pm 0.9 \pm 0.7$ | | AUBERT | 07вс | BABR | 10.6 e ⁺ e | $^- \rightarrow \Lambda \Lambda \gamma$ |
| Γ(2(K+K-)) × | • | • |) TECN | і сом | IMENT | Γ ₁₂₁ Γ ₅ /Γ |
| 4.11±0.39±0.30 • • • We do not u | | | | | | 2(K+K-)γ |
| $4.0~\pm 0.7~\pm 0.6$ 36 Superseded by | 38 | ³⁶ AUBERT | • | | | $2(K^+K^-)\gamma$ |

$J/\psi(1S)$ BRANCHING RATIOS

For the first four branching ratios, see also the partial widths, and (partial widths) $imes \Gamma (e^+ \, e^-) / \Gamma_{ ext{total}}$ above.

| VALUE | | | TECN | COMMENT | |
|------------------------------------------------|--------------------------------|----------|-----------|------------|------|
| 0.877±0.005 OUR AV | ERAGE | | | | |
| 0.878 ± 0.005 | BAI | 95B | BES | e^+e^- | |
| 0.86 ± 0.02 | BOYARSKI | 75 | MRK1 | e^+e^- | |
| $\Gamma(\text{virtual}\gamma 	o \text{hadro})$ | ons)/F _{total} | | | | Γ2/Γ |
| VALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT | |
| 0.135 ± 0.003 | 37,38 SETH | 04 | RVUE | e^+e^- | |
| • • • We do not use t | the following data for average | es, fits | , limits, | etc. • • • | |
| $0.17\ \pm0.02$ | 37 BOYARSKI | 75 | MRK1 | e^+e^- | |

 $\Gamma(\text{hadrons})/\Gamma_{\text{total}}$

 $37\,lncluded$ in $\Gamma(hadrons)/\Gamma_{total}$. 38 Using B($J/\psi \rightarrow \ell^+\ell^-)=(5.90\pm0.09)\%$ from RPP-2002 and R $=2.28\pm0.04$ determined by a fit to data from BAI 00 and BAI 02c.

| $\Gamma(ggg)/\Gamma_{\text{total}}$ | | | | | | Г3/Г |
|-------------------------------------|----------|-------------------------------------|------|---------|--------------------------------|-------------------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 64.1±1.0 | 6 M | 39 BESSON | 08 | CLEO | $\psi(2S) \rightarrow \pi^{+}$ | π^- + hadrons |
| ³⁹ Calculated usin | g the va | lue $\Gamma(\gamma g g)/\Gamma(g g$ | g) = | 0.137 ± | 0.001 ± 0.016 | \pm 0.004 from |

BESSON 08 and the PDG 08 values of B($\ell^+\ell^-$), B(virtual γ \rightarrow hadrons), and B($\gamma \gamma_C$). The statistical error is negligible and the systematic error is partially correlated with that of $\Gamma(\gamma gg)/\Gamma_{\rm total}$ measurement of BESSON 08.

| $\Gamma(\gamma g g)/\Gamma_{\text{total}}$ | | | | | | Γ4/Γ |
|--------------------------------------------|----------|-----------------------------------------------------|------------------|---------|------------------------------------|--------------------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 8.79±1.05 | 200 k | ⁴⁰ BESSON | 08 | CLEO | $\psi(2S) \rightarrow \pi^+ \pi^-$ | γ + hadrons |
| 40 Calculated usin | or the v | alue $\Gamma(\sim \sigma, \sigma) / \Gamma(\sigma)$ | $\sigma\sigma$) | - 0 137 | + 0.001 + 0.016 | + 0.004 from |

calculated using the value $\Gamma(\gamma gg)/\Gamma(ggg)=0.137\pm0.001\pm0.016\pm0.004$ from BESSON 08 and the value of $\Gamma(ggg)/\Gamma_{total}$. The statistical error is negligible and the systematic error is partially correlated with that of $\Gamma(ggg)/\Gamma_{total}$ measurement of BESSON 08.

| $\Gamma(\gamma g g)/\Gamma(g g g)$ | | | | | Γ ₄ /Γ | 3 |
|-------------------------------------------------------------------------------------|--------|-------------------------|------|------|-------------------------------------------|---|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $13.7 \pm 0.1 \pm 0.7$ | 6 M | BESSON | 80 | CLEO | $\psi(2S) \to \pi^+\pi^-J/\psi$ | |
| $\Gamma(e^+e^-)/\Gamma_{\rm total}$ | | | | | Γ ₅ / | Γ |
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 5.94 ±0.06 OUR AV | /ERAGE | | | | | |
| $5.945 \pm 0.067 \pm 0.042$ | 15 k | LI | 05 C | CLEO | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ | |
| $5.90 \pm 0.05 \pm 0.10$ | | BAI | 98D | BES | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ | |
| 6.09 ± 0.33 | | BAI | 95B | BES | e^+e^- | |
| $5.92 \pm 0.15 \pm 0.20$ | | COFFMAN | 92 | MRK3 | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ | |
| 6.9 ± 0.9 | | BOYARSKI | 75 | MRK1 | e^+e^- | |
| $\Gamma(e^+e^-\gamma)/\Gamma_{\rm total}$ | | | | | Γ ₆ / | Γ |
| VALUE (units 10 ⁻³) | | DOCUMENT ID | | TECN | COMMENT | |
| 8.8 \pm 1.3 \pm 0.4 All For $E_{\gamma} >$ 100 MeV | eV. | ⁴¹ ARMSTRONG | 96 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ | |
| $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ | | | | | Γ ₇ / | Γ |
| VALUE (units 10 ⁻²) | FVTS | DOCUMENT ID | | TECN | COMMENT | |

| $\Gamma(\mu^+\mu^-)/\Gamma_{ m total}$ | | | | | Γ ₇ /Γ |
|----------------------------------------|-------|--------------|------|-------|-------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 5.93 ±0.06 OUR AV | ERAGE | | | | |
| $5.960 \pm 0.065 \pm 0.050$ | 17k | LI | | | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ |
| $5.84 \pm 0.06 \pm 0.10$ | | BAI | 98D | BES | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ |
| 6.08 ± 0.33 | | BAI | 95 B | BES | e^+e^- |
| $5.90 \pm 0.15 \pm 0.19$ | | COFFMAN | 92 | MR K3 | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ |
| 6.9 ±0.9 | | BOYARSKI | 75 | MRK1 | e ⁺ e ⁻ |
| | | | | | |

| Γ(e+ e-)/Γ(μ+ μ- VALUE | , DOCUMENT ID | | TECN | Γ ₅ /Γ ₇ |
|-----------------------------|-----------------------|--------|-----------|--------------------------------------------------------------------------|
| 0.998±0.012 OUR AV | | | 1201 | COMMENT |
| $1.002 \pm 0.021 \pm 0.013$ | ⁴² ANASHIN | 10 | KEDR | $3.097 \ e^{+} \ e^{-} \rightarrow \ e^{+} \ e^{-}, \ \mu^{+} \ \mu^{-}$ |
| $0.997 \pm 0.012 \pm 0.006$ | LI | 05 C | CLEO | $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ |
| • • • We do not use t | the following data f | or ave | ages, fit | s, limits, etc. • • • |
| 1.00 ±0.07 | BAI | 95 B | BES | e^+e^- |
| 1.00 ±0.05 | BOYARSKI | 75 | MRK1 | e^+e^- |
| 0.91 ±0.15 | ESPOSITO | 75 B | FRAM | e^+e^- |
| | FORD | 75 | SPEC | a+ a- |

HADRONIC DECAYS

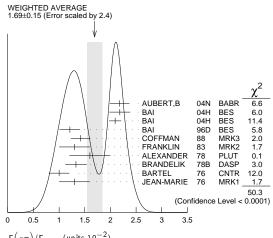
| $\Gamma(\rho\pi)/\Gamma_{\rm tot}$ | :al | | | | | Γ ₈ /Γ |
|------------------------------------|------------------|--------------|-------------------|-------|------------|--------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 |)-2) EVT: | 5 | DOCUMENT ID | | TECN | COMMENT |
| 1.69 ±0.15 | OUR AVERAG | E Err | or includes scale | facto | or of 2.4. | See the ideogram below. |
| 2.18 ± 0.19 | | 43,44 | AUBERT,B | 04N | BABR | $^{10.6}_{\pi^{+}\pi^{-}\pi^{0}}^{\sigma^{-}\sigma^{-}\sigma^{-}\sigma^{-}\sigma^{-}\sigma^{-}\sigma^{-}\sigma^{-$ |
| 2.184 ± 0.005 | ± 0.201 220k | 44,45 | BAI | 04н | BES | $e^+e^- \rightarrow J/\psi \rightarrow \pi^+\pi^-\pi^0$ |
| 2.091 ± 0.021 | ±0.116 | 44,46 | BAI | 04н | BES | $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ |
| 1.21 ± 0.20 | | | BAI | 96D | BES | $e^+ e^- \rightarrow \rho \pi$ |
| 1.42 ± 0.01 | ± 0.19 | | COFFMAN | 88 | MRK3 | e^+e^- |
| 1.3 ± 0.3 | 150 | | FRANKLIN | 83 | MRK2 | e^+e^- |
| 1.6 ± 0.4 | 183 | | ALEXANDER | 78 | PLUT | e^+e^- |
| 1.33 ± 0.21 | | | BRANDELIK | 78B | DASP | e^+e^- |
| 1.0 ± 0.2 | 543 | | BARTEL | 76 | CNTR | e^+e^- |
| 1.3 ± 0.3 | 153 | | JEAN-MARIE | 76 | MRK1 | e^+e^- |
| 4.2 | | | . 0 | | | |

- 43 From the ratio of $\Gamma(e^+\,e^-)$ B($\pi^+\,\pi^-\,\pi^0$) and $\Gamma(e^+\,e^-)$ B($\mu^+\,\mu^-)$ (AUBERT 04).
- 44 Not independent of their B($\pi^+\pi^-\pi^0$).

0.40±0.06±0.04 170

 Γ_1/Γ

45 From $J/\psi \to \pi^+\pi^-\pi^0$ events directly, 46 Obtained comparing the rates for $\pi^+\pi^-\pi^0$ and $\mu^+\mu^-$, using J/ψ events produced via $\psi(2S) \to \pi^+\pi^-J/\psi$ and with B $(J/\psi \to \mu^+\mu^-) = 5.88 \pm 0.10\%$.



| $\Gamma(\rho^0\pi^0)/\Gamma(\rho\pi)$ VALUE | | DO CUMENT IL | 9 | TECN | COMMENT | γا/و۲ |
|---------------------------------------------|----------------------|--------------------|----------|-----------|----------------------------------|---------------------------|
| 0.328±0.005±0.02 | 7 | COFFMAN | 88 | MRK | 3 e+e- | |
| ● ● We do not us | e the follow | ing data for avera | ges, fit | s, limits | , etc. • • • | |
| 0.35 ±0.08 | | ALEXANDE | R 78 | PLUT | - e+e- | |
| 0.32 ±0.08 | | BRANDELIK | 781 | B DASF | e+e- | |
| 0.39 ±0.11 | | BARTEL | 76 | CNT | Re^+e^- | |
| 0.37 ± 0.09 | | JEAN-MARI | E 76 | MRK | $1 e^{+}e^{-}$ | |
| $\Gamma(a_2(1320)\rho)/\Gamma_{\rm t}$ | otal | | | | | Γ ₁₀ /Ι |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 10.9±2.2 OUR AVE | RAGE | | | | | |
| $11.7 \pm 0.7 \pm 2.5$ | 75 84 | AUGUSTIN | 89 | DM2 | $J/\psi \rightarrow \rho^0 \rho$ | \pm_{π} \mp |
| 8.4 ± 4.5 | 36 | VANNUCCI | 77 | MRK1 | $e^+e^- \rightarrow 2$ | $(\pi^{+}\pi^{-})\pi^{0}$ |
| $\Gamma(\omega\pi^+\pi^+\pi^-\pi^-$ |)/F _{total} | | | | | Γ ₁₁ /Ι |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 85 ± 34 | 140 | VA NNU CCI | 77 | MRK1 | $e^+e^- ightarrow 3$ | $(\pi^{+}\pi^{-})\pi^{0}$ |

06D BABR 10.6 $e^+e^- \rightarrow \omega \pi^+\pi^-\pi^0 \gamma$

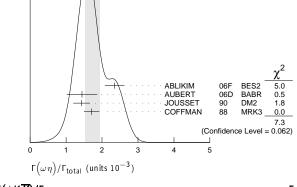
47 AUBERT

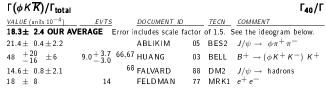
47 Using $\Gamma(J/\psi \to e^+e^-) = 5.52 \pm 0.14 \pm 0.04$ keV.

$J/\psi(1S)$

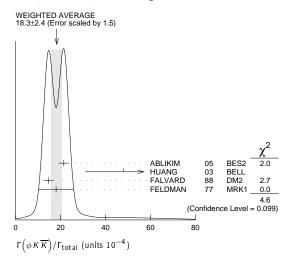
| $\Gamma(\omega\pi^+\pi^-)/\Gamma_{	ext{total}}$ | $\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.} \to K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_{23}/Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 8.6±0.7 OUR AVERAGE Error includes scale factor of 1.1. | <u>VALUE (units 10⁻³)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 1.97±0.20±0.05 155 ⁵³ AUBERT 08S BABR 10.6 e ⁺ e ⁻ → K ⁺ K ⁻ π ⁰ γ |
| 9.7 \pm 0.6 \pm 0.6 788 48 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow \omega \pi^+\pi^-\gamma$ | |
| 7.0 \pm 1.6 18058 AUGUSTIN 89 DM2 $J/\psi ightarrow 2(\pi^+\pi^-)\pi^0$ | ⁵³ AUBERT 08s reports $[\Gamma(J/\psi(1S) \to K^+ \overline{K}^*(892)^- + c.c. \to K^+ K^- \pi^0)/\Gamma_{\text{total}}] > [\Gamma(J/\psi(1S) \to e^+ e^-)] = (10.96 \pm 0.85 \pm 0.70) \times 10^{-3}$ keV which we divide by ou |
| 7.8 \pm 1.6 215 BURMESTER 77D PLUT e^+e^- | |
| 6.8 ± 1.9 348 VANNUCCI 77 MRK1 $e^+e^- 	o 2(\pi^+\pi^-)\pi^0$ | best value $\Gamma(J/\psi(1S) \to e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| ⁴⁸ AUBERT 07AU quotes $\Gamma^{J/\psi}_{ee}\cdot {\rm B}(J/\psi \to \omega \pi^+\pi^-)\cdot {\rm B}(\omega \to 3\pi) = 47.8\pm 3.1\pm 3.2{\rm eV}.$ | $\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.} \rightarrow K^0K^{\pm}\pi^{\mp})/\Gamma_{\text{total}}$ Γ_{24}/Γ |
| $\Gamma(\omega f_2(1270))/\Gamma_{\text{total}}$ Γ_{14}/Γ | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻³) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 4.3±0.6 OUR AVERAGE | 3.0±0.4±0.1 89 ⁵⁴ AUBERT 08S BABR 10.6 $e^+e^- \to K_S^0 K^{\pm} \pi^{\mp} \gamma$ |
| $4.3 \pm 0.2 \pm 0.6$ 5860 AUGUSTIN 89 DM2 e^+e^- | ⁵⁴ AUBERT 08s reports [Γ ($J/\psi(1S) \rightarrow K^+\overline{K}^*(892)^- + c.c. \rightarrow K^0 K^\pm \pi^\mp)/\Gamma_{total}$] × [Γ ($J/\psi(1S) \rightarrow e^+e^-$)] = (16.76 ± 1.70 ± 1.00) × 10 ⁻³ keV which we divide by our |
| 4.0 \pm 1.6 70 BURMESTER 77D PLUT e^+e^- | best value $\Gamma(J/\psi(1S) \rightarrow e^+e^-)$ = $(16.76 \pm 1.70 \pm 1.00) \times 10^-$ keV which we divide by our best value $\Gamma(J/\psi(1S) \rightarrow e^+e^-)$ = $5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their |
| • • We do not use the following data for averages, fits, limits, etc. | experiment's error and our second error is the systematic error from using our best value. |
| 1.9 ± 0.8 81 VANNUCCI 77 MRK1 $e^+e^- ightarrow 2(\pi^+\pi^-)\pi^0$ | F(K0K*(000)0) /F |
| $\Gamma(K^*(892)^0 \overline{K}^*(892)^0) / \Gamma_{\text{total}}$ Γ_{15} / Γ | $\Gamma(K^0\overline{K}^*(892)^0 + c.c.)/\Gamma_{total}$ VALUE (units 10^{-3}) EVTS DOCUMENT ID TECH COMMENT |
| VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 4.39±0.31 OUR AVERAGE |
| 2.3±0.7±0.1 25 ± 8 49 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow$ | 4.8 \pm 0.5 \pm 0.1 55 AUBERT 08s BABR 10.6 e^+ $e^ \rightarrow$ |
| $\pi^+\pi^-$ K $^+$ K $^-\gamma$ | $K^{0}\overline{K}^{*}(892)^{0}\gamma$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $3.96 \pm 0.15 \pm 0.60$ 1192 JOUSSET 90 DM2 $J/\psi \rightarrow {\rm hadrons}$ $4.33 \pm 0.12 \pm 0.45$ COFFMAN 88 MRK3 $J/\psi \rightarrow K^{\pm} K_0^{\rm C} \pi^{\mp}$ |
| <5 90 VANNUCCI 77 MRK1 $e^+e^- \rightarrow \pi^+\pi^-K^+K^-$ | 4.33±0.12±0.45 COFFMAN 86 MIRKS $J/\psi \rightarrow \Lambda + \Lambda \xi \pi^{+}$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| ⁴⁹ AUBERT 07ΑΚ reports $[\Gamma(J/\psi(1S) \rightarrow K^*(892)^0 \overline{K}^*(892)^0)/\Gamma_{total}] \times [\Gamma(J/\psi(1S) \rightarrow K^*(892)^0)/\Gamma_{total}]$ | 2.7 \pm 0.6 45 VANNUCCI 77 MRK1 $J/\psi \rightarrow K^{\pm}K_{S}^{0}\pi^{\mp}$ |
| $e^+e^-)]=(1.28\pm0.40\pm0.11)	imes10^{-3}$ keV which we divide by our best value | |
| $\Gamma(J/\psi(1S) \rightarrow e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. | ⁵⁵ AUBERT 08s reports $[\Gamma(J/\psi(1S) \to K^0\overline{K}^*(892)^0 + \text{c.c.})/\Gamma_{\text{total}}] \times [\Gamma(J/\psi(1S) \to e^+e^-)] = (26.6 \pm 2.5 \pm 1.5) \times 10^{-3} \text{ keV which we divide by our best value } \Gamma(J/\psi(1S) \to e^+e^-)]$ |
| | $e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our |
| $\Gamma(K^*(892)^{\pm}\overline{K}^*(892)^{\mp})/\Gamma_{\text{total}}$ Γ_{16}/Γ | second error is the systematic error from using our best value. |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(K^0\overline{K}^*(892)^0 + \text{c.c.})/\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.})$ Γ_{25}/Γ_{22} |
| 1.00±0.19 $^{+0.11}_{-0.32}$ 323 ABLIKIM 10E BES2 $J/\psi \to K^{\pm} K_S^0 \pi^{\mp} \pi^0$ | VALUE DOCUMENT ID TECH COMMENT |
| $\Gamma(K^*(892)^{\pm}\overline{K}^*(800)^{\mp})/\Gamma_{\text{total}}$ Γ_{17}/Γ | 0.82±0.05±0.09 COFFMAN 88 MRK3 J/ψ → $K\overline{K}^*(892)$ +c.c. |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(K^0\overline{K}^*(892)^0 + \text{c.c.} \rightarrow K^0K^{\pm}\pi^{\mp})/\Gamma_{\text{total}}$ Γ_{26}/Γ |
| 1.09±0.18 $^{+0.94}_{-0.54}$ 655 ABLIKIM 10E BES2 $J/\psi \to \kappa^{\pm} \kappa_S^0 \pi^{\mp} \pi^0$ | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| $\frac{1.07\pm0.10}{-0.54} = 0.53 \qquad \text{ADEINION} \qquad \frac{100}{100} = \frac{52}{5} = \frac{5}{7} = \frac{7}{4} = \frac{1}{100} = $ | 3.2±0.4±0.1 94 56 AUBERT 08S BABR 10.6 $e^+e^- \rightarrow \kappa_S^0 K^{\pm} \pi^{\mp} \gamma$ |
| $\Gamma(\eta K^*(892)^0 \overline{K}^*(892)^0)/\Gamma_{\text{total}}$ Γ_{18}/Γ | ⁵⁶ AUBERT 08s reports $[\Gamma(J/\psi(1S) \rightarrow K^0 \overline{K}^*(892)^0 + \text{c.c.} \rightarrow K^0 K^{\pm} \pi^{\mp})/\Gamma_{\text{total}}] \times$ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $[\Gamma(J/\psi(1S) \to e^+e^-)] = (17.70 \pm 1.70 \pm 1.00) \times 10^{-3}$ keV which we divide by our |
| 1.15 ± 0.13 ± 0.22 209 ABLIKIM 10c BES2 $J/\psi \to \eta K^+ \pi^- K^- \pi^+$ | best value $\Gamma(J/\psi(1S) ightarrow e^+ e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their |
| | |
| E/(/*/coo\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\ | experiment's error and our second error is the systematic error from using our best value. |
| · | - |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | experiment's error and our second error is the systematic error from using our best value. $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0±0.6 OUR AVERAGE | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{\text{total}}$ Γ_{27}/Γ |
| VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 OUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ _{\pi}^+$ $_{\pi}^ _{K}^+$ $_{K}^ _{\gamma}^-$ | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 DUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 e ⁺ e [−] → $\pi^+\pi^-K^+K^-\gamma$ 6.7 ± 2.6 40 VA NNUCCI 77 MRK1 $e^+e^- \to \pi^+\pi^-K^+K^-$ 50 Using B(K_2^* (1430) $^0 \to K\pi$) = (49.9 ± 1.2)%. | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ $NALUE (units 10^{-3})$ 3.8±0.8±1.2 57 BA 99c BES e+e- 57 Assuming B($K_1(1400) \rightarrow K^*\pi$)=0.94 ± 0.06 $\Gamma(\overline{K}^*(892)^0K^+\pi^- + c.c.)/\Gamma_{total}$ Γ ₂₈ /Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ $VALUE (units 10^{-3})$ 3.8±0.8±1.2 57 Assuming B($K_1(1400)$ → $K^*π$)=0.94 ± 0.06 $\Gamma(\overline{K}^*(892)^0K^+π^- + c.c.)/\Gamma_{total}$ $DOCUMENT ID$ $TECN$ $e^+e^ F_{28}/\Gamma$ F_{28}/Γ |
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| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 OUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ π^+π^-K^+K^-$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- \to π^+π^-K^+K^-$ 50 Using B($K_2^*(1430)^0 \to Kπ$) = (49.9 ± 1.2)%. 51 AUBERT 07AK reports [Γ($J/ψ(1S) \to K^*(892)^0 \overline{K}_2^*(1430)^0 + \text{c.c.})/Γ_{total}$] × [Γ($J/ψ(1S) \to e^+e^-$)] = (32.9 ± 2.3 ± 2.7) × 10 ⁻³ keV which we divide by our best value Γ($J/ψ(1S) \to e^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($ωK^*(892)\overline{K}$ + c.c.)/Γ _{total} | $ \Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total} $ $ \Gamma_{27}/\Gamma_{total} $ $ \Gamma_{27}/\Gamma_{total} $ $ \Gamma_{27}/\Gamma_{total} $ $ \Gamma_{27}/\Gamma_{total} $ $ \Gamma_{28}/\Gamma_{total} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18} $ $ \Gamma_{28}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_$ |
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| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 DUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ \pi^+\pi^-K^+K^-\gamma$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- \to \pi^+\pi^-K^+K^-$ 50 Using B($K_2^*(1430)^0 \to K\pi$) = (49.9 ± 1.2)%. 51 AUBERT 07AK reports $[\Gamma(J/\psi(1S) \to K^*(892)^0 \overline{K}_2^*(1430)^0 + c.c.)/\Gamma_{\text{total}}] \times [\Gamma(J/\psi(1S) \to e^+e^-)] = (32.9 ± 2.3 ± 2.7) \times 10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(1S) \to e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(\omega K^*(892) \overline{K} + c.c.)/\Gamma_{\text{total}}$ $VALUE (units 10^{-4}) \qquad EVTS$ 61 ± 9 OUR AVERAGE | $ \Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total} $ $ \Gamma_{27}/\Gamma_{NALUE (units 10^{-3})} $ $ \frac{DOCUMENT \ ID}{57 \ BAI} $ $ 99c \ BES $ $ e^+e^- $ $ 57 Assuming \ B(K_1(1400) \rightarrow K^*\pi) = 0.94 \pm 0.06 $ $ \Gamma(\overline{K}^*(892)^0 K^+\pi^- + c.c.)/\Gamma_{total} $ $ \frac{DOCUMENT \ ID}{58 \ ABLIKIM} $ $ \frac{TECN}{06c \ BES2} \frac{COMMENT}{J/\psi \rightarrow \overline{K}^*(892)^0 K^+\pi^-} $ $ \frac{58 \ A \ K_0^*(800) \ is \ observed \ by \ ABLIKIM \ 06c \ in \ the \ K^+\pi^- \ mass \ spectrum \ of \ the \ \overline{K}^*(892)^0 K^+\pi^- \ final \ state \ against \ the \ \overline{K}^*(892). \ A \ corresponding \ branching \ fraction \ of \ the \ J/\psi(15) \ is \ not \ presented. $ $ \Gamma(\omega\pi^0\pi^0)/\Gamma_{total} $ $ \Gamma_{29}/\Gamma_{WALUE \ (units 10^{-3})} $ $ \frac{EVTS}{DOCUMENT \ ID} $ $ \frac{TECN}{TECN} \frac{COMMENT}{COMMENT} $ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 OUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ \pi^+\pi^-K^+K^-$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- \to \pi^+\pi^-K^+K^-$ 50 Using B($K_2^*(1430)^0 \to K\pi$) = (49.9 ± 1.2)%. 51 AUBERT 07AK reports [Γ($J/ψ(15) \to K^*(892)^0\overline{K_2^*}(1430)^0 + \text{c.c.})/\Gamma_{\text{total}}$] × [Γ($J/ψ(15) \to e^+e^-$)] = (32.9 ± 2.3 ± 2.7) × 10 ⁻³ keV which we divide by our best value Γ($J/ψ(15) \to e^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($L/ψ(15) \to E^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($L/ψ(15) \to E^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($L/ψ(15) \to E^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($L/ψ(15) \to E^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. Γ($L/ψ(15) \to E^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $ \Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total} $ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 DUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ π^+π^-K^+K^-$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- → π^+π^-K^+K^-$ 50 Using B($K_2^*(1430)^0 → Kπ) = (49.9 ± 1.2) %$. 51 AUBERT 07AK reports [Γ($J/ψ(1S) → K^*(892)^0\overline{K}_2^*(1430)^0 + \text{c.c.})/Γ_{total}] × [Γ(J/ψ(1S) → e^+e^-)] = (32.9 ± 2.3 ± 2.7) × 10-3 keV which we divide by our best value Γ(J/ψ(1S) → e^+e^-) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. F(WK^*(892)\overline{K} + \text{c.c.})/\Gamma_{total} F21/Γ VALUE (units 10-4) EVTS 61 ± 9 OUR AVERAGE 62.0 ± 6.8 ± 10.6 899 ± 98 ABLIKIM 08E BES2 J/ψ → ωK_0^0K^\pm π^\mp 65.3 ± 10.2 ± 13.5 176 ± 28 ABLIKIM 08E BES2 J/ψ → ωK_0^0K^\pm π^\mp$ | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ $NALUE (units 10^{-3})$ $NALUE (units 10^{-3})$ $NAUE (units 1$ |
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| ### Proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of th | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total} \qquad \qquad \Gamma_{27}/\Gamma$ $\frac{NLUE (units 10^{-3})}{3.8\pm0.8\pm1.2} \qquad \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $57 \text{ Assuming B}(K_1(1400) \rightarrow K^*\pi) = 0.94 \pm 0.06$ $\Gamma(\overline{K}^*(892)^0K^+\pi^- + c.c.)/\Gamma_{total} \qquad \qquad \Gamma_{28}/\Gamma$ $\frac{NLUE}{NLUE} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $\frac{NLUE}{NLUE} \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $\frac{58}{3} A K_0^*(800) \text{ is observed by ABLIKIM} \qquad 06c \text{ BES2} \qquad J/\psi \rightarrow \overline{K}^*(892)^0K^+\pi^-$ $58A K_0^*(800) \text{ is observed by ABLIKIM} \qquad 06c \text{ in the } K^+\pi^- \text{ mass spectrum of the } K^*(892)^0K^+\pi^- \text{ final state against the } \overline{K}^*(892). \text{ A corresponding branching fraction of the } J/\psi(15) \text{ is not presented.}$ $\Gamma(\omega\pi^0\pi^0)/\Gamma_{total} \qquad \Gamma_{29}/\Gamma$ $\frac{NLUE (units 10^{-3})}{3.4\pm0.3\pm0.7} \qquad EVTS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $\frac{NLUE (units 10^{-4})}{30\pm50 \text{ UR AVERAGE}} \qquad VTS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $30\pm50 \text{ UR AVERAGE}$ $31\pm6 \qquad 4600 \qquad AUGUSTIN \qquad 89 \qquad DM2 \qquad J/\psi \rightarrow 2(\pi^+\pi^-)\pi^0$ $29\pm7 \qquad 87 \qquad BURMESTER \qquad 77D \qquad PLUT \qquad e^+e^-$ $\Gamma(\omega K^{\pm}K_0^0\pi^{\mp})/\Gamma_{total} \qquad \Gamma_{31}/\Gamma$ $\frac{NLUE (units 10^{-4})}{30\pm50 \text{ UR AVERAGE}} \qquad EVTS \qquad DOCUMENT ID \qquad TECN \qquad COMMENT$ $30\pm50 \text{ UR AVERAGE}$ |
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| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 OUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^ \pi^+\pi^-K^+K^-\gamma$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- \to \pi^+\pi^-K^+K^-$ 50 Using B($K_2^*(1430)^0 \to K\pi) = (49.9 ± 1.2)\%$. 51 AUBERT 07AK reports [Γ($J/\psi(1S) \to K^*(892)^0\overline{K}_2^*(1430)^0 + \text{c.c.})/\Gamma_{\text{total}}] × [Γ(J/\psi(1S) \to e^+e^-)] = (32.9 ± 2.3 ± 2.7) × 10-3 keV which we divide by our best value Γ(J/\psi(1S) \to e^+e^-) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. F(WK^*(892)\overline{K} + \text{c.c.})/\Gamma_{\text{total}} F21/Γ VALUE (units 10-4) EVTS 60.2 ± 6.8 ± 10.6 899 ± 98 ABLIKIM 08ε BES2 J/\psi \to \omega K_0^0 K^\pm \pi^\mp 61. ± 9 OUR AVERAGE 62.0 ± 6.8 ± 10.6 899 ± 98 ABLIKIM 08ε BES2 J/\psi \to \omega K_0^0 K^\pm \pi^\mp 65.3 ± 10.2 ± 13.5 176 ± 28 ABLIKIM 08ε BES2 J/\psi \to \omega K_0^0 K^\pm \pi^\mp 65.3 ± 10.2 ± 13.5 176 ± 28 ABLIKIM 08ε BES2 J/\psi \to \omega K_0^0 K^\pm \pi^\mp 65.3 ± 10.2 ± 13.5 176 ± 28 ABLIKIM 08ε BES2 J/\psi \to \omega K_0^0 K^\pm \pi^\mp 65.2 ± 0.4 ± 0.1 BECKER 87 MRK3 e^+e^- \to \text{hadrons} F(K^+\overline{K}^*(892)^- + \text{c.c.})/Ftotal VALUE (units 10-3) EVTS 5.12±0.30 OUR AVERAGE 5.2 ± 0.4 ± 0.1 52 AUBERT 08 BABR 10.6 e^+e^- \to K^+ K^+ (892)^- \gamma 4.57±0.17±0.70 2285 JOUSSET 90 DM2 J/\psi \to \text{hadrons} 5.26±0.13±0.53 COFFMAN 88 MRK3 J/\psi \to K^\pm K_0^- K^\mp K_0^- K^+ K^- \pi^0 3.2 ± 0.6 48 VANNUCCI 77 MRK1 J/\psi \to K^\pm K_0^- K^\mp K_0^- K^+ K^- K_0^- K^- K_0^- K^+ K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^- K_0^- K^-$ | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ T_{27}/Γ $T_{3.8\pm0.8\pm1.2}$ $T_{3.8\pm1.2}$ $T_{$ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT 6.0 ± 0.6 DUR AVERAGE 5.9 ± 0.6 ± 0.2 317 ± 23 50,51 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^- K^+ K^- \gamma$ 6.7 ± 2.6 40 VANNUCCI 77 MRK1 $e^+e^- \rightarrow \pi^+\pi^- K^+ K^-$ 50 Using B($K_2^*(1430)^0 \rightarrow K\pi)$ = (49.9 ± 1.2)%. 51 AUBERT 07AK reports [Γ($J/\psi(1S) \rightarrow K^*(892)^0 \overline{K}_2^*(1430)^0 + \text{c.c.})/\Gamma_{\text{total}}$] × [Γ($J/\psi(1S) \rightarrow e^+e^-$)] = (32.9 ± 2.3 ± 2.7) × 10 ⁻³ keV which we divide by our best value Γ($J/\psi(1S) \rightarrow e^+e^-$) = 5.55 ± 0.14 ± 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. F($WK^*(892)\overline{K} + \text{c.c.})/\Gamma_{\text{total}}$ F21/Γ VALUE (units 10 ⁻⁴) EVTS 60.2 ± 0.8 ± 10.6 899 ± 98 ABLIKIM 08E BES2 $J/\psi \rightarrow \omega K_0^0 K^\pm \pi^\mp$ 61. ± 9 OUR AVERAGE 62.0 ± 6.8 ± 10.6 899 ± 98 ABLIKIM 08E BES2 $J/\psi \rightarrow \omega K_0^0 K^\pm \pi^\mp$ 65.3 ± 10.2 ± 13.5 176 ± 28 ABLIKIM 08E BES2 $J/\psi \rightarrow \omega K_0^0 K^\pm \pi^\mp$ 65.3 ± 14 ± 14 530 ± 140 BECKER 87 MRK3 $e^+e^- \rightarrow \text{hadrons}$ F($K^+\overline{K}^*(892)^- + \text{c.c.})/\Gamma_{\text{total}}$ VALUE (units 10 ⁻³) EVTS 512±0.30 OUR AVERAGE 5.2 ± 0.4 ± 0.1 52 AUBERT 08S BABR 10.6 $e^+e^- \rightarrow K^+ K^- \pi^0$ 4.57±0.17±0.70 2285 JOUSSET 90 DM2 $J/\psi \rightarrow \text{hadrons}$ 5.26±0.13±0.53 COFFMAN 88 MRK3 $J/\psi \rightarrow K^\pm K_0^0 \pi^\mp$ 4.57±0.17±0.70 2285 JOUSSET 90 DM2 $J/\psi \rightarrow \text{hadrons}$ 6. • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{total}$ T_{27}/Γ $T_{MLUE\ (units\ 10^{-3})}$ T_{12}/Γ T_{27}/Γ T_{28}/Γ |
| ### Proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of the proof of th | |

| · (φΛ (032)Λ | + c.c.)/Γ _{total} | | | Г ₃₄ / |
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| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 21.8±2.3 OUR A | /ERAGE | | | |
| $20.8 \pm 2.7 \pm 3.9$ | 195 ± 25 | ABLIKIM | 08E BES2 | $J/\psi \rightarrow \phi K_S^0 K^{\pm} \pi^{\mp}$ |
| 29.6±3.7±4.7 | 238 ± 30 | ABLIKIM | 08E BES2 | $J/\psi \rightarrow \phi K^+ K^- \pi^0$ |
| $20.7 \pm 2.4 \pm 3.0$ | | FALVARD | 88 DM2 | $J/\psi ightarrow { m hadrons}$ |
| 20 ±3 ±3 | 155 ± 20 | BECKER | 87 MRK3 | $e^+e^-	o$ hadrons |
| (ω <i>κ Ҡ</i>)/Γ _{tota} | | | | Γ ₃₅ / |
| /ALUE (units 10 ⁻⁴) 1 7.0± 3.2 OUR A | | DOCUMENT ID | TECN CO | OMMENT |
| 3.6± 5.0±1.0 | | AUBERT 0 | 7ΔII BARR 10 | 0.6 $e^+e^- \rightarrow \omega K^+ K^-$ |
| 19.8± 2.1±3.9 | | | | $\psi \to hadrons$ |
| .6 ±10 | | FELDMAN 7 | , | |
| | | | | |
| 59 AUBERT 07AL | J quotes $\Gamma_{ee}^{3/\Psi} \cdot B$ | $(J/\psi \rightarrow \omega K^{+})$ | K^-) $\cdot B(\eta \rightarrow$ | $3\pi) = 3.3 \pm 1.3 \pm 0.2$ eV |
| Addition of ω | K^+ K^- and ω K^0 | K ⁰ branching | ratios. | |
| $(\omega f_0(1710) \rightarrow$ | $\omega K \overline{K})/\Gamma_{total}$ | | | Γ ₃₆ / |
| ALUE (units 10 ⁻⁴) | ,. | DO CUMENT ID | TECN | COMMENT |
| .8±1.1±0.3 | 61,6 | FALVARD | 88 DM2 | |
| | own branching fra | | | , , |
| | $(1710) \rightarrow K^+ K$ | | | ranching ratios. |
| $(\phi_2(\pi^+\pi^-))$ | | | | Γ ₃₇ / |
| 'ALUE (units 10 ⁻⁴) 6.6±2.3 OUR A | | UMENT ID | TECN COM | MENT |
| $7.3 \pm 3.3 \pm 1.2$ | 35 ⁶³ AUE | BERT 06D | BABR 10.6 | $e^{+}e^{-} \rightarrow \phi 2(\pi^{+}\pi^{-})$ |
| $6.0 \pm 1.0 \pm 3.0$ | | VARD 88 | | → hadrons |
| 63 Hsin σ Γ(1/2/2 - | $\rightarrow e^{+}e^{-}) = 5.5$ | 2 ± 0.14 ± 0.0 | 4 keV. | |
| O3111g 1 (3/φ | , | | | |
| ¯(∆(1232)++7 | | | | Г ₃₈ / |
| (∆(1232) ++ 7 ⁄ALUE (units 10 ⁻³) | | DOCUMENT ID | | Г ₃₈ / |
| (Δ(1232) ⁺⁺ 7 ALUE (units 10 ⁻³) | $(5\pi^-)/\Gamma_{total}$ | | <u>TECN</u> | |
| $\Gamma(\Delta(1232)^{++}7)$ $\Delta(LUE) \text{ (units } 10^{-3})$ $1.58\pm0.23\pm0.40$ $\Gamma(\omega\eta)/\Gamma_{	ext{total}}$ | 5π ⁻)/Γ _{total} | DOCUMENT ID | <u>TECN</u> | COMMENT |
| $\Gamma(\Delta(1232)^{++}\Gamma_{\Delta LUE \text{ (units }10^{-3})}^{-1})$ $.58\pm0.23\pm0.40$ $\Gamma(\omega\eta)/\Gamma_{\text{total}}^{-1}$ $\Gamma(\Delta LUE \text{ (units }10^{-3})$ | 5π ⁻)/Γ _{total} EVTS 332 | DOCUMENT ID EATON | ###################################### | COMMENT e+e- rag/ |
| $\Gamma(\Delta(1232)^{++}7)$ $ALUE$ (units 10^{-3}) $1.58\pm0.23\pm0.40$ $\Gamma(\omega\eta)/\Gamma_{\text{total}}$ $ALUE$ (units 10^{-3}) 1.74 ± 0.20 OUF | 7π ⁻)/Γ _{total} EVTS 332 RAVERAGE En | DOCUMENT ID EATON DOCUMENT ID ror includes scal | 84 MRK2 TECN TECN e factor of 1.6 | $\frac{COMMENT}{e^+e^-}$ $\frac{COMMENT}{comment}$ See the ideogram below |
| $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(126)^{++}7)$ $(\Delta(126)^{++}7)$ $(\Delta(126)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}$ | 7π ⁻)/Γ _{total} EVTS 332 RAVERAGE 5k 6 | DOCUMENT ID EATON DOCUMENT ID ror includes scal | ### TECN ARK 2 TECN ### TECN ### TECN ### TECN ### O6F BES2 | $\frac{COMMENT}{e+e-}$ $\frac{COMMENT}{See the ideogram below}$ $J/\psi ightarrow \omega \eta$ |
| $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(128)^{++}7)$ $(\Delta(128)^{++}7)$ $(\Delta(1232)^{++}7)$ $(\Delta(1232)^{++$ | 7π ⁻)/Γ _{total} EVTS 332 RAVERAGE 5k 66 4 13 | DOCUMENT ID EATON DOCUMENT ID ror includes scal 4 ABLIKIM 55 AUBERT | 84 MRK: TECN TECN e factor of 1.6 06F BES2 06D BABR | $\frac{\textit{COMMENT}}{e^+e^-}$ F39/ $\frac{\textit{COMMENT}}{J/\psi \to \omega\eta}$ 10.6 $e^+e^- \to \omega\eta\gamma$ |
| $(\Delta(1232)^{++}$ $\tau_{ALUE (units 10^{-3})}$.58±0.23±0.40 $(\omega \eta)/\Gamma_{total}$.74 ±0.20 OUF .352±0.273 .44 ±0.40 ±0.1.43 ±0.10 ±0.2 | 5π ⁻)/Γ _{total} EVTS 332 R AVERAGE 5k 4 13 21 378 | DOCUMENT ID EATON DOCUMENT ID TO includes scal A ABLIKIM S AUBERT JOUSSET | 84 MRK: TECN TECN TECN 6 factor of 1.6 06F BES2 06D BABR 90 DM2 | COMMENT $\frac{COMMENT}{e^+e^-}$ See the ideogram below $J/\psi \to \omega \eta$ $10.6 \ e^+e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ |
| $(\Delta(1232)^{++}$ $\tau_{ALUE (units 10^{-3})}$.58±0.23±0.40 $(\omega \eta)/\Gamma_{total}$.74 ±0.20 OUF .352±0.273 .44 ±0.40 ±0.1 .43 ±0.10 ±0.2 .71 ±0.08 ±0.2 | 5π ⁻)/Γ _{total} EVTS 332 R AVERAGE 5k 64 13 21 378 | DOCUMENT ID EATON DOCUMENT ID TO Includes scal 44 ABLIKIM 55 AUBERT JOUSSET COFFMAN | 84 MRK2 84 TECN TECN 6 factor of 1.6 06F BES2 06D BABR 90 DM2 88 MRK3 | COMMENT e^+e^- $\frac{COMMENT}{I}$ See the ideogram below $J/\psi \rightarrow \omega \eta$ $10.6 e^+e^- \rightarrow \omega \eta \gamma$ $J/\psi \rightarrow \text{hadrons}$ $g^+e^- \rightarrow 3\pi \eta$ |
| $(\Delta(1232)^{++}$ $\tau_{\Delta LUE (units 10^{-3})}$.58±0.23±0.40 $(\omega \eta)/\Gamma_{\text{total}}$.352±0.27 OUF .352±0.273 .44 ±0.40 ±0.1 .43 ±0.10 ±0.2 .71 ±0.08 ±0.2 64 Using B(η \to | 5π ⁻)/Γ _{total} EVTS 332 R AVERAGE 5k 64 13 21 378 20 2γ) = (39.43 ± | DOCUMENT ID EATON DOCUMENT ID TO includes scal 44 ABLIKIM 55 AUBERT JOUSSET COFFMAN = 0.26)%, B(η - | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABR 90 DM2 88 MRKS $\pi^+\pi^-\pi^0$ | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
| $(\Delta(1232)^{++}$ $\tau_{ALUE (units 10^{-3})}$ 1.58±0.23±0.40 $(\omega \eta)/\Gamma_{total}$ 1.74±0.20 OUF 1.2352±0.273 1.44±0.40±0.10±0.2 1.43±0.10±0.2 1.64 Using B($\eta \rightarrow \pi^+\pi^-\gamma$) = 4 | 5π ⁻)/Γ _{total} EVTS 332 R AVERAGE 5k 64 13 21 378 | $\frac{DOCUMENT\ ID}{EATON}$ $\frac{DOCUMENT\ ID}{EATON}$ $\frac{DOCUMENT\ ID}{EATON}$ or includes scal 64 ABLIKIM 55 AUBERT JOUSSET COFFMA N = 0.26)%, B(η - η - η + η d B(ω - η + η | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
| $(\Delta(1232)^{++}$ τ ΔLUE (units 10^{-3}) .58±0.23±0.40 $(\omega \eta)$ / Total ΔLUE (units 10^{-3}) .74 ±0.20 OUF .2552±0.273 .44 ±0.40 ±0.1 .43 ±0.10 ±0.2 .71 ±0.08 ±0.2 64 Using B($\eta \rightarrow \pi^+\pi^-\gamma$) = 4 65 Using Γ(J/ψ - | $\frac{5\pi^{-})/\Gamma_{\text{total}}}{\frac{EVTS}{332}}$ R AVERAGE 5k 4 13 21 378 20 2 γ) = (39.43 \pm 0.11%, and | $\frac{DOCUMENT\ ID}{EATON}$ $\frac{DOCUMENT\ ID}{EATON}$ $\frac{DOCUMENT\ ID}{EATON}$ or includes scal 64 ABLIKIM 55 AUBERT JOUSSET COFFMA N = 0.26)%, B(η - η - η + η d B(ω - η + η | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
| $(\Delta(1232)^{++}7_{\text{ALUE (units }10^{-3})}$.58±0.23±0.40 $(\omega\eta)/\Gamma_{\text{total}}$.74 ±0.20 OUF. 352±0.273 .44 ±0.40 ±0.1 .43 ±0.10 ±0.2 .71 ±0.08 ±0.2 64 Using B($\eta \rightarrow \pi^{+}\pi^{-}\gamma$) = 4 65 Using Γ(J/ψ - | $\frac{EVTS}{332}$ RAVERAGE Ending State 1 13 18 18 18 18 18 18 18 18 18 18 18 18 18 | DOCUMENT ID EATON DOCUMENT ID TO Includes Scal 34 ABLIKIM 55 AUBERT JOUSSET COFFMAN $= 0.26$)%, $B(\eta - 4)$ $= 0.00$, $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
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4)$ $= 0.00$, $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
| $(\Delta(1232)^{++}7$ (Δ(1232) ⁺⁺ 7 (Δ(1232) ⁺⁺ 7 (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{tota} | $\frac{EVTS}{332}$ RAVERAGE Errors $\frac{EVTS}{332}$ $\frac{EVTS}{332}$ RAVERAGE Errors $\frac{5k}{4}$ $\frac{6k}{21}$ $\frac{378}{20}$ $\frac{2\gamma}{68 \pm 0.11\%}$, and $\frac{6k}{20}$ $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} $ | DOCUMENT ID EATON DOCUMENT ID TO Includes Scal 34 ABLIKIM 55 AUBERT JOUSSET COFFMAN $= 0.26$)%, $B(\eta - 4)$ $= 0.00$, $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |
| $(\Delta(1232)^{++}7$ (Δ(1232) ⁺⁺ 7 (Δ(1232) ⁺⁺ 7 (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{total} (Δ(μ)/Γ _{tota} | $\frac{EVTS}{332}$ RAVERAGE Errors $\frac{EVTS}{332}$ $\frac{EVTS}{332}$ RAVERAGE Errors $\frac{5k}{4}$ $\frac{6k}{21}$ $\frac{378}{20}$ $\frac{2\gamma}{68 \pm 0.11\%}$, and $\frac{6k}{20}$ $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} \pm 0.51\%$, and $\frac{6k}{20} $ | DOCUMENT ID EATON DOCUMENT ID TO Includes Scal 34 ABLIKIM 55 AUBERT JOUSSET COFFMAN $= 0.26$)%, $B(\eta - 4)$ $= 0.00$, $= 0.00$ $= 0.00$ $= 0.00$ $= 0.00$ | 84 $\frac{TECN}{MRKS}$ e factor of 1.6 06F BES2 06D BABF 90 DM2 88 MRKS $\rightarrow \pi^{+}\pi^{-}\pi^{0}$ $\rightarrow \pi^{0}$ = (89.1 | COMMENT $2 \ e^+ e^-$ $739/$ COMMENT $5 \ \text{See the ideogram below}$ $J/\psi \to \omega \eta$ $10.6 \ e^+ e^- \to \omega \eta \gamma$ $J/\psi \to \text{hadrons}$ $6 \ e^+ e^- \to 3\pi \eta$ $9 \ = 22.6 \ \pm 0.4\%, \ B(\eta \to 0.4\%)$ |





 66 We have multiplied K^+ K^- measurement by 2 to obtain $K\,\overline{K}.$ 67 Using B($B^+\to J/\psi\,K^+)=(1.01\pm0.05)\times10^{-3}.$ 68 Addition of $\phi\,K^+$ K^- and $\phi\,K^0\,\overline{K}^0$ branching ratios.



| $\Gamma(\phi f_0(1710) \to \phi K \overline{K})/\Gamma_{\text{total}}$ | | | | | | |
|------------------------------------------------------------------------|------------------------|----|------|------------------------------|--|--|
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | TECN | COMMENT | | |
| 3.6±0.2±0.6 | 69,70 FALVARD | 88 | DM2 | $J/\psi ightarrow $ hadrons | | |
| ⁶⁹ Including interference with | f ₂ (1525). | | | | | |

⁷⁰ Includes unknown branching fraction $f_0(1710) \rightarrow K\overline{K}$.

F(↓€ (1270\) /F

| VALUE (units 10 ⁻³) CL 0.72±0.13±0.02 | | 71,72 ALIBERT | 07416 | TECN | COMMENT |
|------------------------------------------------------|--------|------------------------|-------|------|-------------------------------------------------------------------------------------|
| 0.72±0.13±0.02 | 44 ± 7 | 71,72 ALIBERT | 07416 | | |
| | | NOBERT | UTAK | BABK | $10.6 \begin{array}{l} e^+e^- \rightarrow \\ \pi^+\pi^- K^+ K^- \gamma \end{array}$ |
| • • • We do not use | | ving data for averages | | | |
| < 0.45 90 | | FALVARD | 88 | DM2 | $J/\psi ightarrow $ hadrons |
| < 0.37 90 | | VA N N U C C I | 77 | MRK1 | $e^+e^- \rightarrow K^+K^-$ |

 $= (4.02 \pm 0.65 \pm 0.33) imes 10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(1S)
ightharpoons 10^{-3}$ $e^+\,e^-) = 5.55\,\pm\,0.14\,\pm\,0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT IE |) | TECN | сомме | V <i>T</i> | |
|-------------------------------------------------------------|------------------------|-----------------------------------------------------|------|------|----------------------|---------------|--------------------|
| 1.10±0.09±0.28 | 233 | EATON | 84 | MRK2 | e+e- | | |
| Γ (Σ(1385) – <u>Σ</u> (| 1385) ⁺ (or | ·c.c.))/r _{total} | | | | | Γ ₄₄ /Γ |
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID |) | TECN | COMMEN | T | |
| 1.03±0.13 OUR A | VERAGE | | | | | | |
| $1.00 \pm 0.04 \pm 0.21$ | 631 ± 25 | HENRARD | 87 | DM2 | e^+e^- - | → Σ *- | |
| $1.19 \pm 0.04 \pm 0.25$ | 754 ± 27 | HENRARD | 87 | DM2 | e^+e^- - | → Σ *+ | |
| $0.86 \pm 0.18 \pm 0.22$ | 56 | EATON | 84 | MRK2 | e^+e^- - | → Σ *- | |
| $1.03 \pm 0.24 \pm 0.25$ | 68 | EATON | 84 | MRK2 | $e^+ e^-$ - | → Σ *+ | |
| $\Gamma(\phi f_2'(1525))/I$ | - total | | | | | | Γ ₄₅ /Γ |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT | - | |
| | | rror includes scale fa | | | | | |
| $12.3 \pm 0.6 \pm 2.0$ | 7 | ^{3,74} FALVARD | | | | | |
| 4.8 ± 1.8 | 46 | ⁷³ GIDAL | 81 | MRK2 | $J/\psi \rightarrow$ | κ+ κ- | κ+ κ− |
| ⁷³ Re-evaluated u ⁷⁴ Including interf | | $525) \rightarrow K\overline{K}) = 0.$ $f_0(1710).$ | 713. | | | | |
| Γ(φπ+ π ⁻)/Γ. | | | | | | | Γ44 /Γ |

| $\Gamma(\phi\pi^+\pi^-)/\Gamma_{to}$ | tal | | | | Γ ₄₆ /Γ |
|------------------------------------------------|------|-------------------------------------|-----|------|--------------------------------------------------------------------|
| VALUE (units 10^{-3}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.94±0.09 OUR A | | | | | |
| 0.96 ± 0.13 | 103 | ⁷⁵ AUBERT,BE | 06D | BABR | 10.6 $e^+e^- \to K^+K^-\pi^+\pi^-\gamma$ |
| $1.09 \pm 0.02 \pm 0.13$ | | ABLIKIM | 05 | BES2 | $J/\psi \rightarrow \phi \pi^{+} \pi^{-}$ |
| $0.78 \pm 0.03 \pm 0.12$ | | FALVARD | 88 | DM2 | $J/\psi ightarrow $ hadrons |
| $2.1\ \pm0.9$ | 23 | FELDMAN | 77 | MRK1 | e^+e^- |
| | | ERT,BE 06D meas = (2.61 ± 0.30 ± | | | $\rightarrow e^+e^-) \times B(J/\psi \rightarrow \phi \pi^+\pi^-)$ |
| $\Gamma(\phi\pi^0\pi^0)/\Gamma_{\text{total}}$ | | , | | | Γ47/Γ |

 $\underline{\mathit{VALUE}\,(units\,10^{-3})}$ $\underline{\mathit{EVTS}}$ DOCUMENT ID TECN COMMENT 23 ⁷⁶ AUBERT,BE 06D BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^0\pi^0\gamma$ 76 Derived by us. AUBERT,BE 06D measures $\Gamma(J/\psi\to~e^+\,e^-)\times {\rm B}(J/\psi\to~\phi\pi^0\,\pi^0\,)$ \times $B(\phi \to K^+K^-) = (1.54 \pm 0.40 \pm 0.16) \text{ eV}$

$J/\psi(1S)$

 $0.538 \pm 0.012 \pm 0.065$ 2090

222

⁷⁸ Using B($\omega \to \pi^+ \pi^- \pi^0$) = (89.1 ± 0.7)%.

 $0.360 \pm 0.028 \pm 0.054$

 $0.482 \pm 0.019 \pm 0.064$

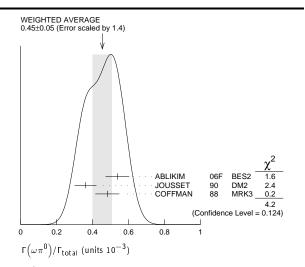
| $\Gamma(\phi K^{\pm} K_S^0 \pi^{\mp})$ | | | | | | Γ ₄₈ /Γ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|-----------------|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 7.2±0.8 OUR AVE 7.4±0.6±1.4 | 227 ± 19 | ABLIKIM | 08F | BES2 | $e^+e^- ightarrow~J$ | /2/2 |
| $7.4 \pm 0.0 \pm 1.4$ $7.4 \pm 0.9 \pm 1.1$ | 221 117 | FALVARD | 88 | DM2 | $J/\psi ightarrow {\sf had}$ | |
| $7 \pm 0.6 \pm 1.0$ | 163 ± 15 | BECKER | 87 | MRK3 | $e^+e^- ightarrow h$ | adrons |
| Γ(ω f ₁ (1420))/Γ | total | | | | | Γ ₄₉ /Γ |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TE CN | COMMENT | |
| $6.8^{+1.9}_{-1.6}\pm 1.7$ | $111 + 31 \\ -26$ | BECKER | 87 | MRK3 | $e^+e^- ightarrow$ h | adrons |
| $\Gamma(\phi\eta)/\Gamma_{ m total}$ | | | | | | Γ ₅₀ /Γ |
| VALUE (units 10 ⁻³) | EVTS | DOCUMENT ID | | | COMMENT | |
| 0.75 ±0.08 OUR | | rror includes scal | | | | |
| $1.4 \pm 0.6 \pm 0.1$ $0.898 \pm 0.024 \pm 0.03$ | | ⁷ AUBERT ABLIKIM | | | 10.6 e^+e^- – $e^+e^- \rightarrow J_f$ | |
| 0.64 ±0.04 ±0.1 | | JOUSSET | | DM2 | $J/\psi \rightarrow hadr$ | Ψ → Haur ons |
| $0.661 \pm 0.045 \pm 0.0$ | | COFFMAN | | MRK3 | $e^+e^- \rightarrow K$ | $+ \kappa - \eta$ |
| ⁷⁷ AUBERT 07AU 0.84 ± 0.37 ± | quotes $\Gamma_{ee}^{J/\psi}$ 0.05 eV. | $\cdot \ B(J/\psi \ 	o \ \phi \eta$ |) · B(| $\phi \rightarrow h$ | (+ κ−) · Β(| $\eta \rightarrow \gamma \gamma =$ |
| WEIGHT | ED AVERAGE | | | | | |
| 0.75±0.08 | 8 (Error scaled b | y 1.5) | | | | |
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| | <u> </u> | | JBERT | | 7AU BABR | 2.6 |
| | /—— T | | BLIKIM DUSSE | | 05B BES2 00 DM2 | 0.9 |
| | / | | DFFM/ | | 88 MRK3_ | 1.0 |
| | | \ | | | | |
| | | \ | | (Confi | dence I evel – | 4.4 0.109) |
| | | | | (Confi | dence Level = | |
| 0 | 0.5 | 1 1.5 | | (Confi | dence Level = | |
| | Γ _{total} (units 1 | 1 1.5 | | | dence Level = | |
| $\Gamma(\Xi^0\overline{\Xi^0})/\Gamma_{\rm total}$ | Γ _{total} (units 1 | 1 1.5 0 ⁻³) | | 2 | | 0.109) |
| Γ (Ξ⁰ Ξ⁰)/Γ_{total} VALUE (units 10 ⁻³) | Γ _{total} (units 1 | 1 1.5 0 ⁻³) | | 2 TECN | <u>COMMENT</u> | 0.109) Γ ₅₁ /Γ |
| $\Gamma(\Xi^0\overline{\Xi^0})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-3}\text{)}$ $1.20\pm0.12\pm0.21$ | Γ _{total} (units 1 I EVTS 206 | 1 1.5 0 ⁻³) | | 2 | | 0.109) Γ ₅₁ /Ι |
| $\Gamma(\Xi^{0}\overline{\Xi^{0}})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-3}\text{)}$ $1.20\pm0.12\pm0.21$ $\Gamma(\Xi(1530)-\overline{\Xi}+1)$ | Γ_{total} (units 1 $\frac{EVTS}{206}$ | 1 1.5 0 ⁻³) | 080 | 2 TECN BES2 | $\frac{\textit{COMMENT}}{e^+e^-\to}$ | 0.109) Γ ₅₁ /Ι |
| $\Gamma(\Xi^{0}\overline{\Xi^{0}})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-3}\text{)}$ $1.20\pm0.12\pm0.21$ $\Gamma(\Xi(1530)^{-}\overline{\Xi^{+}})$ $VALUE \text{ (units } 10^{-3}\text{)}$ | Γ_{total} (units 1 $\frac{EVTS}{206}$ -)/ Γ_{total} $\frac{EVTS}{2}$ | 1 1.5 0 ⁻³) DOCUMENT ID ABLIKIM | 080 | 2 TECN BES2 | $\frac{\textit{COMMENT}}{e^+e^-} \rightarrow$ | 0.109) Г ₅₁ /Г |
| $\Gamma\left(\Xi^{0}\overline{\Xi^{0}}\right)/\Gamma_{\text{total}}$ $VALUE (units 10^{-3})$ $1.20\pm0.12\pm0.21$ $\Gamma\left(\Xi\left(1530\right)-\overline{\Xi}^{+}\right)$ $VALUE (units 10^{-3})$ $0.59\pm0.09\pm0.12$ | $ \frac{\Gamma_{\text{total}} \text{ (units 1)}}{206} $ $ \frac{EVTS}{206} $ $ \frac{-)/\Gamma_{\text{total}}}{-\frac{EVTS}{75 \pm 11}} $ | 1 1.5 0 ⁻³) | 080 | 2 TECN BES2 | $\frac{\textit{COMMENT}}{e^+e^-\to}$ | 0.109) Γ ₅₁ /Γ |
| $\Gamma(\Xi^{0}\overline{\Xi^{0}})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-3}\text{)}$ $1.20\pm0.12\pm0.21$ $\Gamma(\Xi(1530)^{-}\overline{\Xi^{+}})$ $VALUE \text{ (units } 10^{-3}\text{)}$ | $ \frac{\Gamma_{\text{total}} \text{ (units 1)}}{206} $ $ \frac{EVTS}{206} $ $ \frac{-)/\Gamma_{\text{total}}}{-\frac{EVTS}{75 \pm 11}} $ | 1 1.5 0 ⁻³) DOCUMENT ID ABLIKIM | 080 | 2 TECN BES2 | $\frac{\textit{COMMENT}}{e^+e^-} \rightarrow$ | 0.109) Γ ₅₁ /Γ |
| $\Gamma\left(\Xi^{0}\overline{\Xi^{0}}\right)/\Gamma_{\text{total}}$ $VALUE (units 10^{-3})$ $1.20\pm0.12\pm0.21$ $\Gamma\left(\Xi\left(1530\right)-\overline{\Xi}^{+}\right)$ $VALUE (units 10^{-3})$ $0.59\pm0.09\pm0.12$ | $\Gamma_{\text{total}} \text{ (units 1)}$ $\frac{EVTS}{206}$ $\frac{-)/\Gamma_{\text{total}}}{-\frac{EVTS}{75 \pm 11}}$ | 1 1.5 0 ⁻³) DOCUMENT ID ABLIKIM | 080 | 2 TECN BES2 TECN DM2 | $\frac{\textit{COMMENT}}{e^+e^-} \rightarrow$ | 0.109) Γ ₅₁ / Γ ₅₂ / Γ ₅ |
| $\Gamma(\Xi^{0}\Xi^{0})/\Gamma_{\text{total}}$ $VALUE \text{ (units }10^{-3})$ $1.20\pm0.12\pm0.21$ $\Gamma(\Xi(1530)-\Xi^{+}$ $VALUE \text{ (units }10^{-3})$ $0.59\pm0.09\pm0.12$ $\Gamma(\rho K^{-}\overline{\Sigma}(1385)$ | $\Gamma_{\text{total}} \text{ (units 1)}$ $\frac{EVTS}{206}$ $\frac{-)/\Gamma_{\text{total}}}{-\frac{EVTS}{75 \pm 11}}$ | 1 1.5 0 ⁻³) DOCUMENT ID ABLIKIM DOCUMENT ID HENRARD | 080 | Z TECN BES2 TECN DM2 | $\begin{array}{c} \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ \\ \underline{\text{COMMENT}} \\ e^+e^- \end{array}$ | 0.109) Γ ₅₁ / Γ ₅₂ / Γ ₅ |
| $\Gamma(\equiv^0 \equiv^0)/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-3})$ $1.20\pm 0.12\pm 0.21$ $\Gamma(\equiv (1530) = \equiv^+$ $VALUE \text{ (units } 10^{-3})$ $0.59\pm 0.09\pm 0.12$ $\Gamma(pK = \Xi(1385)$ $VALUE \text{ (units } 10^{-3})$ $VALUE \text{ (units } 10^{-3})$ | $\Gamma_{\text{total}} \text{ (units 1)}$ $\frac{EVTS}{206}$ $\frac{EVTS}{75 \pm 11}$ $\frac{EVTS}{75 \pm 11}$ $\frac{EVTS}{75 \pm 11}$ | 1 1.5 0-3) DOCUMENT ID ABLIKIM DOCUMENT ID HENRARD | 080 | Z TECN BES2 TECN DM2 | $\begin{array}{c} \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ e^+e^- \\ \underline{\text{COMMENT}} \end{array}$ | 0.109) Γ ₅₁ / Ι Γ ₅₂ / Ι |

78 ABLIKIM

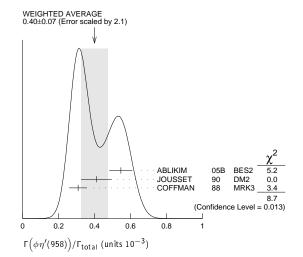
JOUSSET

COFFMAN

 $\begin{array}{lll} \text{06F} & \text{BES2} & J/\psi \to \omega \pi^0 \\ \text{90} & \text{DM2} & J/\psi \to \text{hadrons} \\ \text{88} & \text{MRK3} & e^+ \, e^- \to \pi^0 \, \pi^+ \, \pi^- \, \pi^0 \end{array}$



 $\Gamma(\phi\eta'(958))/\Gamma_{
m total}$ Γ_{55}/Γ $0.546 \pm 0.031 \pm 0.056$ ABLIKIM 05B BES2 $e^+ e^-
ightarrow J/\psi
ightarrow {
m hadr}$ $0.41 \ \pm 0.03 \ \pm 0.08$ JOUSSET 90 DM2 $J/\psi \rightarrow \text{hadrons}$ $0.308 \pm 0.034 \pm 0.036$ COFFMAN 88 MRK3 $e^+e^- \rightarrow K^+K^-\eta'$ • • • We do not use the following data for averages, fits, limits, etc. • • • < 1.3 90 VANNUCCI 77 MRK1 e^+e^-



| $\Gamma(\phi f_0(980))/\Gamma_{to}$ | tal | | | | | Γ ₅ | 6/Г |
|-------------------------------------|------------------------|-----------------------|----------|--------|------------------------|----------------|-----|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT IL |) | TECN | COMMENT | | |
| 3.2 ± 0.9 OUR AVE | RAGE En | or includes scale f | factor o | f 1.9. | | | |
| $4.6 \pm 0.4 \pm 0.8$ | | ⁷⁹ FALVARD | 88 | DM2 | $J/\psi \rightarrow h$ | adrons | |
| 2.6 ± 0.6 | 50 | ⁷⁹ GIDAL | 81 | MRK2 | $J/\psi \rightarrow F$ | K + K - K + | ĸ- |
| 79 Assuming B(f_0 (| 980) $\rightarrow \pi$ | π) = 0.78. | | | | | |

| ⁷⁹ Assuming B(f ₀ (980 | $) \rightarrow \pi \pi) =$ | 0.78. | | | | |
|-----------------------------------------------|----------------------------|--------------|------|------|------------------------------------------------|---|
| $\Gamma(\phi f_0(980) \rightarrow \phi \pi^+$ | π^-)/ Γ_{tota} | ıİ | | | Γ ₅₇ / | Γ |
| VALUE (units 10 ⁻³) | | | | TECN | COMMENT | |
| $0.182 \pm 0.042 \pm 0.005$ | 19.5 ± 4.5 | 80,81 AUBERT | 07ak | BABR | $10.6 e^{+}e^{-} \rightarrow K^{+}K^{-}\gamma$ | |
| ⁸⁰ Using B($\phi \rightarrow K^+$ | | | | · . | | |

 81 AUBERT 07AK reports $[\Gamma(J/\psi(1S)\to\phi\,f_0(980)\to\phi\,\pi^+\,\pi^-)/\Gamma_{\rm total}]\times[\Gamma(J/\psi(1S)\to e^+\,e^-)]=(1.01\pm0.22\pm0.08)\times10^{-3}\,$ keV which we divide by our best value $\Gamma(J/\psi(1S)\to e^+\,e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\phi f_0(980) \rightarrow \phi \pi^0$ | $\pi^0)/\Gamma_{ m tota}$ | ĺ | | Γ ₅₈ /Γ |
|-----------------------------------------------|---------------------------|-----------------|---------|----------------------------------------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 0.171±0.073±0.004 | 7.0 ± 2.8 | 82,83 AUBERT 07 | AK BABR | $10.6 e^{+}_{\pi} 0^{-}_{\pi} 0^{+}_{K} e^{-}_{K} \rightarrow$ |

 $^{^{82}}$ Using B($\phi\to K^+K^-)=(49.3\pm0.6)\%.$ 83 AUBERT 07AK reports [\Gamma ($J/\psi(1S)\to\phi\,f_0(980)\to\phi\,\pi^0\,\pi^0)/\Gamma_{total}]\times [\Gamma(J/\psi(1S)\to e^+e^-)]=(0.95\pm0.39\pm0.10)\times10^{-3}\,$ keV which we divide by our best value $\Gamma(J/\psi(1S)\to e^+e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

Meson Particle Listings $J/\psi(1S)$

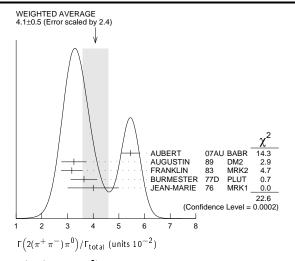
| $\Gamma(\eta\phi f_0(980) 	o \eta\phi\pi^+\pi^-)/\Gamma_{	ext{total}}$ | $/\Gamma$ $\Gamma(K_2^*(1430)^0 \overline{K}_2^*(1430)^0)/\Gamma_{\text{total}}$ Γ_{72}/Γ_{72} |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT |
| .23±0.75±0.73 52 ABLIKIM 08F BES $J/\psi \to \eta \phi f_0(980)$ | <29 90 VANNUCCI 77 MRK1 $e^+e^{\rightarrow}_{\pi^+\pi^-}_{\kappa^+\kappa^-}$ |
| $\Gamma(\phi a_0(980)^0 	o \phi \eta \pi^0)/\Gamma_{\text{total}}$ | |
| ALUE (units 10 ⁻⁶) DOCUMENT ID TECN COMMENT | ' (Ψ')/'total '' '' '' '' '' '' '' '' '' '' '' '' '' |
| 0 ±2.7±2.5 84 ABLIKIM 11D BES3 $J/\psi ightarrow \phi \eta \pi^0$ | <6.4 90 ABLIKIM $05B$ BES2 $e^{+}e^{-} \rightarrow J/\psi \rightarrow \phi\gamma\gamma$ |
| 34 Assuming $a_0(980)-f_0(980)$ mixing and isospin breaking via γ^* and K^*K loops. | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(\Xi(1530)^0\overline{\Xi}^0)/\Gamma_{\text{total}}$ Γ_{61} | / Γ <6.8 90 COFFMAN 88 MRK3 $e^+e^- ightarrow$ $K^+K^-\pi^0$ |
| ALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\phi\eta(1405) 	o \phi\eta\pi\pi)/\Gamma_{\text{total}}$ |
| 32±0.12±0.07 24 ± 9 HENRARD 87 DM2 e^+e^- | VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT |
| $(\Sigma(1385)^{-}\overline{\Sigma}^{+} \text{ (or c.c.)})/\Gamma_{\text{total}}$ | /Γ <2.5 90 90 FALVARD 88 DM2 $J/\psi ightarrow$ hadrons |
| ALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT | 90 Includes unknown branching fraction $\eta(1405) ightarrow \eta \pi \pi$. |
| .31±0.05 OUR AVERAGE | $\Gamma(\omega f_2'(1525))/\Gamma_{total}$ Γ ₇₅ / |
| $30\pm0.03\pm0.07$ 74 \pm 8 HENRARD 87 DM2 $e^+e^- \to \Sigma^{*-}$ $34\pm0.04\pm0.07$ 77 \pm 9 HENRARD 87 DM2 $e^+e^- \to \Sigma^{*+}$ | VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT |
| $29\pm0.11\pm0.10$ 26 EATON 84 MRK2 $e^+e^- \rightarrow \Sigma^{*-}$ | <2.2 90 91 VANNUCCI 77 MRK1 $e^+e^- ightarrow \pi^+\pi^-\pi^0$ K^+K^- |
| $31\pm0.11\pm0.11$ 28 EATON 84 MRK2 $e^+e^- ightarrow\Sigma^{*+}$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(\phi f_1(1285))/\Gamma_{\text{total}}$ Γ_{63} | <2.8 90 91 FALVARD 88 DM2 $J/\psi \rightarrow$ hadrons |
| 4LUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | 91 Re-evaluated assuming B($f_2'(1525) \rightarrow K\overline{K}$) = 0.713. |
| 6±0.5 OUR AVERAGE Error includes scale factor of 1.1. | $\Gamma(\eta\phi(2170) \to \eta K^*(892)^0 \overline{K}^*(892)^0) / \Gamma_{\text{total}}$ $\Gamma_{76}/\Gamma_{76}/\Gamma_{76}$ |
| .2 \pm 0.6 \pm 0.4 J/ ψ \rightarrow ϕ 2 (π^+ π^-) .1 \pm 0.5 \pm 0.4 25 85 JOUSSET 90 DM2 J/ ψ \rightarrow ϕ η π^+ π^- | VALUE (units 10 ⁻⁴) <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| $1\pm0.5\pm0.4$ 25 85 JOUSSET 90 DM2 $J/\psi \rightarrow \phi \eta \pi^+ \pi^-$ • • We do not use the following data for averages, fits, limits, etc. • • • | <2.52 90 ABLIKIM 10c BES2 $J/\psi \rightarrow \eta K^+\pi^-K^-\pi^+$ |
| $6\pm0.2\pm0.1$ 16 ± 6 BECKER 87 MRK3 $J/\psi ightarrow \phi K \overline{K} \pi$ | $\Gamma(\Sigma(1385)^{0}\overline{\Lambda})/\Gamma_{\text{total}}$ $\Gamma_{77}/$ |
| 95 We attribute to the $f_1(1285)$ the signal observed in the $\pi^+\pi^-\eta$ invariant mass di | |
| bution at 1297 MeV. | <0.2 90 HENRARD 87 DM2 e ⁺ e ⁻ |
| $(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ | /F = (A(1000)+=)/F |
| LUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\Delta(1232)^+ \overline{p})/\Gamma_{\text{total}}$ Γ_{78}/Γ_{78} |
| 40\pm0.17\pm0.03 9 ⁸⁶ AUBERT 07AU BABR 10.6 $e^+e^- ightarrow~\eta\pi^+\pi^-$ | γ VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT <0.1 90 HENRARD 87 DM2 e ⁺ e ⁻ |
| 36 AUBERT 07AU quotes $\Gamma^{J/\psi}_{ee}\cdot$ B $(J/\psi	o\eta\pi^+\pi^-)\cdot$ B $(\eta	o3\pi)=0.51\pm0.22\pm0.03$ | eV. |
| | $\Gamma(\Theta(1540)\Theta(1540) \rightarrow K_S^c \rho K^- \pi + c.c.)/\Gamma_{total}$ Γ_{79}/Γ_{100} |
| $(ho\eta)/\Gamma_{total}$ | |
| LUE (units 10 ⁻³) | <1.1 90 BAI 04G BES2 e^+e^- |
| $194\pm0.017\pm0.029$ 299 JOUSSET 90 DM2 $J/\psi ightarrow$ hadrons | $\Gamma(\Theta(1540) K^- \pi \to K_S^0 \rho K^- \pi) / \Gamma_{\text{total}}$ $\Gamma_{80} / \Gamma_{80} |
| 193 \pm 0.013 \pm 0.029 COFFMAN 88 MRK3 $e^+e^- ightarrow \pi^+\pi^-\eta$ | VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT |
| $(\omega \eta'(958))/\Gamma_{\text{total}}$ | /Γ <2.1 90 BAI 04G BES2 e ⁺ e ⁻ |
| ALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\Theta(1540)K_S^0 \overline{p} \to K_S^0 \overline{p} K^+ n) / \Gamma_{\text{total}} $ $\Gamma_{81} / \Gamma_{81} |
| .182±0.021 OUR AVERAGE | VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT |
| 226 \pm 0.043 218 ⁸⁷ ABLIKIM 06F BES2 $J/\psi 	o \omega \eta'$ | <1.6 90 BAI 046 BES2 e ⁺ e ⁻ |
| 18 $^{+0.10}_{-0.08}$ ± 0.03 6 JOUSSET 90 DM2 $J/\psi ightarrow$ hadrons | |
| 166 \pm 0.017 \pm 0.019 COFFMAN 88 MRK3 $e^+e^- ightarrow 3\pi\eta'$ | $\Gamma(\overline{\Theta}(1540)K^{+} n \to K_{5}^{0} \overline{p} K^{+} n) / \Gamma_{\text{total}} $ $\Gamma_{82} / \Gamma_{82} / $ |
| ³⁷ Using B($\eta' \to \pi^+\pi^-\eta$) = (44.3 ± 1.5)%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) = 29.5 ± 1.0%, B($\eta' \to \pi^+\pi^-\gamma$) | |
| $2\gamma)=39.43\pm0.26\%$, and B $(\omega	o\pi^+\pi^-\pi^0)=(89.1\pm0.7)\%$. | |
| $(\omega f_0(980))/\Gamma_{\text{total}}$ | $/\Gamma$ $\Gamma(\overline{\Theta}(1540) K_S^0 \rho \to K_S^0 \rho K^- \overline{n}) / \Gamma_{\text{total}}$ Γ_{83}/Γ_{83} |
| NLUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁵) CL% DO CUMENT ID TECN COMMENT |
| 41±0.27±0.47 88 AUGUSTIN 89 DM2 $J/\psi \to 2(\pi^+\pi^-)\pi^{38}$ | 90 BAI 04G BES2 e ⁺ e ⁻ |
| 38 Assuming B $(f_0(980) \to \pi\pi) = 0.78$. | $\Gamma(\Sigma^0 \overline{\Lambda})/\Gamma_{total}$ Γ_{84}/Γ_{100} |
| $(\rho\eta'(958))/\Gamma_{\text{total}}$ Γ_{66} | |
| ALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | <pre><0.9 90 HENRARD 87 DM2 e⁺e⁻</pre> |
| 105±0.018 OUR AVERAGE | STABLE HADRONS |
| $083\pm0.030\pm0.012$ 19 JOUSSET 90 DM2 $J/\psi ightarrow hadrons$ $114\pm0.014\pm0.016$ COFFMAN 88 MRK3 $J/\psi ightarrow \pi^+\pi^-\eta'$ | |
| | $\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma_{\text{total}}$ |
| $(a_2(1320)^{\pm}\pi^{\mp})/\Gamma_{\text{total}}$ | |
| LUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | 4.1 \pm 0.5 OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below. $5.46\pm0.34\pm0.14$ 4990 92 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\pi^0$. |
| 90 BRAUNSCH 76 DASP e ⁺ e ⁻ | 3.25 ± 0.49 46055 AUGUSTIN 89 DM2 $J/\psi 	o 2(\pi^+\pi^-)\pi^0$ |
| $(K\overline{K}_2^*(1430) + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{70} | / Γ 3.17±0.42 147 FRANKLIN 83 MRK2 $e^+e^- \rightarrow$ hadrons |
| LUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | 3.64 ± 0.52 1500 BURMESTER 77D PLUT e^+e^- 4 ±1 675 JEAN-MARIE 76 MRK1 e^+e^- |
| 40 90 VANNUCCI 77 MRK1 $e^+e^- ightarrow \mathcal{K}^0\overline{\mathcal{K}}_2^{*0}$ | 92 AUBERT 07AU reports $[\Gamma(J/\psi(1S) \rightarrow 2(\pi^+\pi^-)\pi^0)/\Gamma_{\text{total}}] \times [\Gamma(J/\psi(1S) - 2\pi^+\pi^-)\pi^0)/\Gamma_{\text{total}}]$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | e^+e^-] = 0.303 ± 0.005 ± 0.018 keV which we divide by our best value $\Gamma(J/\psi(1S) - e^+e^-)$ |
| 66 90 BRAUNSCH 76 DASP $e^+e^- ightarrow \kappa^\pm\overline{\kappa}_2^{*\mp}$ | $(e^+e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our |
| $(K_1(1270)^{\pm}K^{\mp})/\Gamma_{\text{total}}$ Γ_{77} | second error is the systematic error from using our best value. |
| (() ,, //.total , 1.2) | <i>i</i> · |

89 BAI

 $^{89}\,\mathrm{Assuming}~\mathrm{B}(\,\mathrm{K}_{1}(1270)\,\rightarrow\,\,\mathrm{K}\,\rho){=}\,\mathrm{0.42}\,\pm\,\mathrm{0.06}$

TECN COMMENT 99c BES e+e-

$J/\psi(1S)$



| $\Gamma(\omega\pi^+\pi^-)/\Gamma(2(\pi^+\pi^-)\pi^0)$ | ⁰) | | Γ_{13}/Γ_{85} |
|-------------------------------------------------------|-----------------------------|-----------------------|---------------------------|
| VALUE | DO CUMENT ID | TECN COMMENT | |
| • • • We do not use the follow | ing data for averages, fit | s, limits, etc. • • • | |
| 0.3 | ⁹³ JEAN-MARIE 76 | MRK1 e^+e^- | |

 93 Final state $(\pi^+\pi^-)\pi^0$ under the assumption that $\pi\pi$ is isospin 0. = (= (| _ > 0) (=

| $\Gamma(3(\pi^+\pi^-)\pi^0)/$ | Γ _{total} | | | | | Γ ₈₆ /Γ |
|-------------------------------|--------------------|--------------|----|------|--------------|--------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.029±0.006 OUR | AVERAGE | | | | | |
| 0.028 ± 0.009 | 11 | FRANKLIN | 83 | MRK2 | $e^+e^- \to$ | hadrons |
| 0.029 ± 0.007 | 181 | JEAN-MARIE | 76 | MRK1 | e^+e^- | |

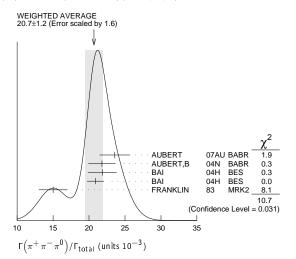
 $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\rm total}$ Γ_{87}/Γ DOCUMENT ID EVTS TECN COMMENT 20.7 ±1.2 OUR AVERAGE Error includes scale factor of 1.6. See the ideogram below. ⁹⁴ AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow J/\psi \pi^+\pi^- \gamma$ 23.6 ±2.1 ±0.5 256 95,96 AUBERT,B 04N BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma$ 21.8 ± 1.9 220k 96,97 BAI $21.84 \pm 0.05 \pm 2.01$ 04H BES e⁺e⁻ 96,98 BAI 04H BES $20.91 \pm 0.21 \pm 1.16$ FRANKLIN 83 MRK2 e^+e^- 168 15 + 2

 $^{94}\,\mathrm{AUBERT}$ 07AU reports $[\Gamma\big(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,\pi^0\big)/\Gamma_{\mathsf{total}}]~\times~[\Gamma\big(\psi(2S)~\rightarrow~\pi^+\,\pi^-\,\pi^0)]$ $J/\psi(1S)\,\pi^+\,\pi^-\big)\times\Gamma\big(\psi(2S)\to\,e^+\,e^-\big)/\Gamma_{\mbox{total}}\big]=(18.6\pm1.2\pm1.1)\times10^{-3}\;\mbox{keV which}$ we divide by our best value $\Gamma(\psi(2S) \to J/\psi(1S) \pi^+ \pi^-) \times \Gamma(\psi(2S) \to e^+ e^-)$ $\Gamma_{total}=0.789\pm0.015$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 95 From the ratio of $\Gamma(e^+\,e^-)$ B $(\pi^+\,\pi^-\,\pi^0)$ and $\Gamma(e^+\,e^-)$ B $(\mu^+\,\mu^-)$ (AUBERT 04).

 96 Mostly $\rho\pi$, see also $\rho\pi$ subsection. 97 From $J/\psi\to~\pi^+\pi^-\pi^0$ events directly.

 98 Obtained comparing the rates for $\pi^+\pi^-\pi^0$ and $\mu^+\mu^-$, using J/ψ events produced via $\psi(2S) \rightarrow \pi^{+} \pi^{-} J/\psi$ and with $B(J/\psi \rightarrow \mu^{+} \mu^{-}) = 5.88 \pm 0.10\%$.



```
\Gamma(\pi^+\pi^-\pi^0K^+K^-)/\Gamma_{\text{total}}
                                                                                                                                                                                                                      Γ<sub>88</sub>/Γ
                                                                                               DOCUMENT ID
                                                                 EVTS
                                                                                                                                                     TECN COMMENT
1.79±0.29 OUR AVERAGE Error includes scale factor of 2.2.
                                                                                                                                      07AU BABR 10.6 e^+e^- \rightarrow \kappa^+\kappa^-\pi^+\pi^-\pi^0\gamma
                                                                                      <sup>99</sup> AUBERT
                                                                 768
                                                                   309
                                                                                               VANNUCCI 77 MRK1 e<sup>+</sup>e<sup>-</sup>
  ^{99}\mathrm{AUBERT} 07AU reports [\Gamma \big(J/\psi(1\mathrm{S}) \ \rightarrow \ \pi^+\,\pi^-\,\pi^0\,\mathrm{K}^+\,\mathrm{K}^-\big)/\Gamma_{\mathrm{total}}] \ \times \ [\Gamma \big(J/\psi(1\mathrm{S}) \ \rightarrow \ \pi^+\,\pi^-\,\pi^0\,\mathrm{K}^+\,\mathrm{K}^-\big)/\Gamma_{\mathrm{total}}]
          e^+\,e^-)]= 0.1070\pm0.0043\pm0.0064 keV which we divide by our best value \Gamma(J/\psi(1S)
ightarrow
          e^+\,e^-) = 5.55\,\pm\,0.14\,\pm\,0.02 keV. Our first error is their experiment's error and our
          second error is the systematic error from using our best value.
\Gamma(4(\pi^+\pi^-)\pi^0)/\Gamma_{\rm total}
                                                                                                                                                                                                                      \Gamma_{89}/\Gamma
VALUE (units 10^{-4})
                                                          EVTS
                                                                                                                                                   TECN COMMENT
                                                                                               DOCUMENT ID
90±30
                                                                    13
                                                                                               JEAN-MARIE 76 MRK1 e+e-
\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}
                                                                                                                                                                                                                      \Gamma_{90}/\Gamma
VALUE (units 10^{-3}) EVTS
                                                                             DOCUMENT ID TECN COMMENT
 6.6±0.5 OUR AVERAGE
                                                1.6k ^{100} AUBERT 07AK BABR 10.6 e^+e^-
ightarrow\pi^+\pi^- K ^+ K ^-\gamma
6.5 \pm 0.4 \pm 0.2
                                                  205
                                                                            VANNUCCI 77 MRK1 e+e-
ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet
                                              233 ^{101} AUBERT 05D BABR 10.6 e^+\,e^-
ightarrow~ K^+\,K^-\,\pi^+\,\pi^-\,\gamma
<sup>100</sup> AUBERT 07AK reports [\Gamma(J/\psi(1S) \rightarrow \pi^+\pi^-K^+K^-)/\Gamma_{total}] \times [\Gamma(J/\psi(1S) \rightarrow \pi^+\pi^-K^+K^-)/\Gamma_{total}]
         [e^+e^-]=(36.3\pm1.3\pm2.1)\times10^{-3} keV which we divide by our best value \Gamma(J/\psi(1S)\to 0)
          e^+\,e^-) = 5.55\,\pm\,0.14\,\pm\,0.02 keV. Our first error is their experiment's error and our
          second error is the systematic error from using our best value.
^{101} Superseded by AUBERT 07AK. AUBERT 05D reports [\Gamma(J/\psi(1S) \to \pi^+\pi^-K^+K^-)/
         \Gamma_{\text{total}}] \times [\Gamma(J/\psi(1S) \rightarrow e^+e^-)] = (33.6 \pm 2.7 \pm 2.7) \times 10^{-3} \text{ keV} which we divide
         by our best value \Gamma(J/\psi(1S) \to e^+e^-) = 5.55 \pm 0.14 \pm 0.02 keV. Our first error is their experiment's error and our second error is the systematic error from using our best
\Gamma(\pi^+\pi^-K^+K^-\eta)/\Gamma_{\text{total}}
                                                                                                                                                                                                                      \Gamma_{91}/\Gamma
VALUE (units 10^{-3})
                                                                                               DO CUMENT ID
                                                                                                                                                    TECN COMMENT
                                                                                                                                      07AU BABR 10.6 e^+ e^-_{K^+K^-\pi^+\pi^-\eta\gamma}
1.84 \pm 0.28 \pm 0.05
                                                                                  <sup>102</sup> AUBERT
                                                                      73
102\,{\rm AUBERT~07AU~reports}~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^+\,\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^+\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\,K^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)~\rightarrow~\pi^-\eta\right)/\Gamma_{\mbox{total}}\right] ~\times~ \left[\Gamma\left(J/\psi(1S)
          [e^+e^-]=(10.2\pm1.3\pm0.8)\times10^{-3} keV which we divide by our best value \Gamma(J/\psi(1S)\to e^+e^-)=(10.2\pm1.3\pm0.8)\times10^{-3}
                              = 5.55 \pm 0.14 \pm 0.02 keV. Our first error is their experiment's error and our
          second error is the systematic error from using our best value.
\Gamma(\pi^0\pi^0K^+K^-)/\Gamma_{
m total}
VALUE (units 10<sup>-3</sup>)
                                                      EVTS
                                                                                    DOCUMENT ID TECN COMMENT
2.45 ± 0.31 ± 0.06 203 ± 16 ^{103} AUBERT 07AK BABR ^{10.6} ^{e^+} ^{e^-} ^{-} ^{-} ^{-} ^{-} ^{-} ^{-}
^{103} \, {\rm AUBERT} \, 07AK reports [\Gamma (J/\psi (1{\rm S}) \, \to \, \pi^0 \, \pi^0 \, K^+ \, K^-)/\Gamma_{\rm total}] \, \times \, [\Gamma (J/\psi (1{\rm S}) \, \to \, \pi^0 \, \pi^0 \, K^+ \, K^-)/\Gamma_{\rm total}]
          e^+e^-)] = (13.6\pm1.1\pm1.3)\times10^{-3} keV which we divide by our best value \Gamma(J/\psi(1S)\to 0)
          e^+e^-) = 5.55 \pm 0.14 \pm 0.02 keV. Our first error is their experiment's error and our
          second error is the systematic error from using our best value.
\Gamma(K\overline{K}\pi)/\Gamma_{\text{total}}
                                                                                                                                                                                                                      \Gamma_{93}/\Gamma
 VALUE (units 10 -4
                                                                 EVTS
                                                                                               DOCUMENT ID
                                                                                                                                                    TECN COMMENT
61 ±10 OUR AVERAGE
55.2 \pm 12.0
                                                                                               FRANKLIN
                                                                                                                                                   MRK1 e^+e^- \rightarrow K_s^0 K^{\pm}\pi^{\mp}
78.0 \pm 21.0
                                                                   126
\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}
                                                                                                                                                                                                                      Γ94/Γ
                                                                                  DOCUMENT ID
                                                                                                                                    TECN COMMENT
3.55 ± 0.23 OUR AVERAGE
3.53±0.12±0.29 1107 104 ABLIKIM
                                                                                                                            05H BES2 e^+e^- 
ightarrow \psi(2S) 
ightarrow
                                                                                                                                                                      J/\psi\,\pi^+\,\pi^-, J/\psi\,\to
                                                                                                                                                                      2(\pi^{+}\pi^{-})
                                                      270 <sup>105</sup> AUBERT
                                                                                                                          05D BABR 10.6 e^+e^- \rightarrow 2(\pi^+\pi^-)\gamma
3.51 \pm 0.34 \pm 0.09
                                                                                 JEAN-MARIE 76 MRK1 e+e-
```

 $^{104}\,\mathrm{Computed}$ using $\mathrm{B}(\mathrm{J/\psi}\rightarrow~\mu^{+}\,\mu^{-})=$ 0.0588 \pm 0.0010.

496 ¹⁰⁶ AUBERT

32 $^{106}\,\mathrm{Using}\;\Gamma(J/\psi \,
ightarrow \, e^+\,e^-) = 5.52 \pm 0.14 \, \pm 0.04 \; \mathrm{keV}.$

1.62±0.09±0.19 761 107 AUBERT

 107 Using $\Gamma(J/\psi
ightarrow e^+\,e^-) = 5.52 \pm 0.14 \pm 0.04$ keV.

 $\Gamma(3(\pi^+\pi^-))/\Gamma_{\text{total}}$

43 ± 4 OUR AVERAGE

 $\Gamma(2(\pi^+\pi^-\pi^0))/\Gamma_{\text{total}}$

 $\underbrace{\textit{VALUE}\,(\text{units}\,10^{-2})}_{\textit{EVTS}}$

VALUE (units 10-

 $43.0 \pm 2.9 \pm 2.8$

 $^{105}\,\mathrm{AUBERT}$ 05D reports $\left[\Gamma\left(J/\psi(1\mathrm{S})\,\rightarrow\,\,2(\pi^+\,\pi^-)\right)/\Gamma_{\mbox{total}}\right]\,\times\,\left[\Gamma\left(J/\psi(1\mathrm{S})\,\rightarrow\,\,e^+\,e^-\right)\right]$ $=(19.5\pm1.4\pm1.3) imes10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(1S)
ightarrow$

 $e^+\,e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

DOCUMENT ID TECN COMMENT

JEAN-MARIE 76 MRK1 e^+e^-

DOCUMENT ID TECN COMMENT

06D BABR 10.6 $e^+e^- \rightarrow 3(\pi^+\pi^-)\gamma$

06D BABR 10.6 $e^+e^- \to 2(\pi^+\pi^-\pi^0)\gamma$

Γ95/Γ

 Γ_{96}/Γ

 Γ_{111}/Γ

 $3.36 \pm 0.65 \pm 0.28$

 $1.6\ \pm0.6$

Including $p\overline{p}\pi^+\pi^-\gamma$ and excluding ω , η , η' <u>VALUE</u> (units 10^{-3})
<u>EVTS</u>
<u>DOCUMENT ID</u>

364

39

2.3 ±0.9 OUR AVERAGE Error includes scale factor of 1.9.

DO CUMENT ID

EATON

PERUZZI

Meson Particle Listings $J/\psi(1S)$

080 BES2 $e^+e^- o J/\psi$

 $\begin{array}{lll} & 07 \text{BD BABR} & 10.6 \ e^+ \, e^- \to \ \Sigma^0 \, \overline{\Sigma}{}^0 \, \gamma \\ 06 & \text{BES2} & J/\psi \to \ \Sigma^0 \, \overline{\Sigma}{}^0 \\ 87 & \text{DM2} & e^+ \, e^- \to \ \Sigma^0 \, \overline{\Sigma}{}^0 \\ 84 & \text{MRK2} & e^+ \, e^- \to \ \Sigma^0 \, \overline{\Sigma}{}^0 \\ \end{array}$

78 MRK1 $e^+e^- \rightarrow \Sigma^0 \overline{\Sigma}{}^0$

81 BONA $e^+e^- \rightarrow \Sigma^+\overline{\Sigma}^-$

DOCUMENT ID TECN COMMENT

| $\Gamma(2(\pi^+\pi^-)\eta)/\Gamma_0$ | total | | | | Г97/Г | $\Gamma(ho\overline{ ho}\eta)/\Gamma_{ m total}$ | | | | | Γ ₁₀₃ /Γ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻³) | EVTS DO | CUMENT ID | TECN CO | PMMENT | | VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 2.29±0.24 OUR AV 2.35±0.39±0.20 | | JBERT 07AU | u DADD 10 | .6 $e^+e^- \rightarrow 2$ | (=+==) no | 2.00±0.12 OUR AVE | | ¹¹ ABLIKIM | 09 BES2 | e+e- | |
| $2.26 \pm 0.08 \pm 0.27$ 4 | | | | $e^- \rightarrow 2(\pi^+)$ | | $2.03 \pm 0.13 \pm 0.15$ | 826 | EATON | | e+e- | |
| 108 AUBERT 07AU 0 | guotes Γ ^J /ψ | B(I/a) → 2(π+ | - (π -) n) .B(a | a → ~~l − 5 | 16 + 0.85 + | 2.5 ± 1.2 | | BRANDELIK | 79C DASP | | |
| 0.39 eV. | quotes i ee | $-B(J/\psi \rightarrow Z(\pi))$ | π)η) ·Β(1 | $\eta \rightarrow \gamma \gamma \gamma \gamma = 5$. | 10 ± 0.03 ± | 2.3 ±0.4 | 197 | PERUZZI | | e+e- | |
| $\Gamma(3(\pi^+\pi^-)\eta)/\Gamma_0$ | | | | | Г ₉₈ /Г | 111 From the combina | tion of $p\overline{p}\eta$ | $\rightarrow p\overline{p}\gamma\gamma$ and $p\overline{p}$ | $\overline{p} \eta \rightarrow p \overline{p} \pi^+$ | π [—] π ^U chann | iels. |
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | TECN | I COMMENT | 198/1 | $\Gamma(p\overline{p} ho)/\Gamma_{ m total}$ | | | | | Γ_{104}/Γ |
| 7.24±0.96±1.11 | 616 | ABLIKIM | | $e^+e^- \rightarrow$ | $3(\pi^{+}\pi^{-})n$ | VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | TECN | COMMENT | |
| | 010 | ADEII(IIII | 000 010 | 2 0 0 7 | , , , | <0.31 | 90 | EATON | 84 MRK2 | $e^+e^- \rightarrow 1$ | had rons γ |
| $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ | | | | | Г99/Г | $\Gamma(p\overline{p}\omega)/\Gamma_{ m total}$ | | | | | Γ ₁₀₅ /Γ |
| VALUE (units 10 ⁻³) 2.17±0.07 OUR AV | EVTS | DO CUMENT ID | TECN | COMMENT | | VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | COMMENT | . 103/. |
| 2.18±0.16±0.07 | | 109 WU | 06 BELI | $B^+ \rightarrow p \overline{p}$ | κ+ | 1.10±0.15 OUR AVE | | | | | am below. |
| $2.26 \pm 0.01 \pm 0.14$ | 63316 | BAI | 04E BES | | | $0.98 \pm 0.03 \pm 0.14$ | 2449 | ABLIKIM | | e+ e- | |
| 1.97 ± 0.22 | 99 | BALDINI | 98 FEN | | | $1.10 \pm 0.17 \pm 0.18$ | 486 | EATON | | ! e+e− + − | |
| $1.91 \pm 0.04 \pm 0.30$ | | PALLIN | 87 DM2 | | | 1.6 ±0.3 | 77 | PERUZZI | 78 MRK1 | e+e- | |
| 2.16±0.07±0.15 2.5 ±0.4 | 1420 133 | EATON BRANDELIK | 84 MR M 790 DAS | (2 e+e- P e+e- | | WEIGHTED | | | | | |
| 2.5 ±0.4 2.0 ±0.5 | 133 | BESCH | | Pe'e IAe ⁺ e ⁻ | | | rror scaled by | y 1.3) | | | |
| 2.2 ±0.2 | 331 | ¹¹⁰ PERUZZI | | (1 e ⁺ e ⁻ | | ı | \downarrow | | | | |
| • • • We do not us | | | es, fits, limit | s, etc. • • • | | | \wedge | | | | |
| 2.0 ±0.3 | 48 | ANTONELLI | | C e ⁺ e ⁻ | | | / \ | | | | |
| 109 WU 06 reports | $\Gamma(J/\psi(1S) -$ | $\rightarrow p \overline{p})/\Gamma_{total} \times$ | (B(B+ → | $J/\psi(1S) K^{+}$ |] = (2.21 ± | | / \ | | | | |
| 109 WU 06 reports $_{0.13~\pm~0.10)~	imes}$ | 10-6 which | we divide by our | best value E | $B(B^+ \rightarrow J/\psi)$ | $(15)K^{+}) =$ | | / \ | | | | |
| (1.016 ± 0.033) | $\times 10^{-3}$. Our | first error is their | experiment' | 's error and our | second error | | | | | | |
| is the systematic 110 Assuming angula | error from us | sing our best value | e. | | | | | | | | |
| | ar distribution | $(1+\cos^{2}\theta).$ | | | | | | | | | |
| $\Gamma(p\overline{p}\pi^0)/\Gamma_{\rm total}$ | | | | | Г ₁₀₀ /Г | | \ | | | | |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TECN | COMMENT | | | / | | | | 0 |
| | | | | | | | 1 | | | | 2 |
| | | or includes scale fa | | | | | | | | _ | χ ² |
| $1.33 \pm 0.02 \pm 0.11$ | 11 k | ABLIKIM | 09в BES | | <u> </u> | | | | | 08 BES2 84 MRK2 | χ ² 0.7 |
| 1.19±0.08 OUR AV 1.33±0.02±0.11 1.13±0.09±0.09 | | ABLIKIM EATON | 09в BES: 84 MR <i>I</i> | (2 e ⁺ e ⁻ | | | | EAT | ON 8 | 08 BES2 84 MRK2 78 MRK1 _ | χ ² 0.7 0.0 2.8 |
| $1.33 \pm 0.02 \pm 0.11$ $1.13 \pm 0.09 \pm 0.09$ 1.4 ± 0.4 | 11k 685 | ABLIKIM EATON BRANDELIK | 09B BES: 84 MR k 79C DAS | (2 e ⁺ e ⁻ P e ⁺ e ⁻ | | | | EAT | ON 8 RUZZI 7 | 34 MRK2 '8 MRK1 _ | 0.0 2.8 3.5 |
| $1.33 \pm 0.02 \pm 0.11$ $1.13 \pm 0.09 \pm 0.09$ 1.4 ± 0.4 1.00 ± 0.15 | 11 k 685 109 | ABLIKIM EATON | 09B BES: 84 MR k 79C DAS | (2 e ⁺ e ⁻ | | | | EAT | ON 8 RUZZI 7 | 4 MRK2 | 0.0 2.8 3.5 |
| $1.33 \pm 0.02 \pm 0.11$ $1.13 \pm 0.09 \pm 0.09$ 1.4 ± 0.4 1.00 ± 0.15 $\Gamma(p\overline{p}\pi^+\pi^-)/\Gamma_{to}$ | 11 k 685 109 | ABLIKIM EATON BRANDELIK | 09B BES: 84 MR k 79C DAS 78 MR k | (2 e ⁺ e ⁻ P e ⁺ e ⁻ (1 e ⁺ e ⁻ | Γ ₁₀₁ /Γ | 0 0.5 | 1 | PEF | ON 8 RUZZI 7 | 34 MRK2 '8 MRK1 _ | 0.0 2.8 3.5 |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10 ⁻³) | 11k 685 109 Pta l | ABLIKIM EATON BRANDELIK PERUZZI | 09B BES: 84 MR k 79C DAS 78 MR k | (2 e+e- P e+e- (1 e+e- | | | | PEF | ON 8 RUZZI 7 (Confi | 34 MRK2 '8 MRK1 _ | 0.0 2.8 3.5 |
| $\begin{array}{l} 1.33 \pm 0.02 \pm 0.11 \\ 1.13 \pm 0.09 \pm 0.09 \\ 1.4 \pm 0.4 \\ 1.00 \pm 0.15 \\ \hline \Gamma \left(p \overline{p} \pi^+ \pi^- \right) / \Gamma_{to} \\ \frac{VALUE \ (units \ 10^{-3})}{6.0 \ \pm 0.5 \ \ OUR \ AV} \end{array}$ | 11k 685 109 otal <u>EVTS</u> ERAGE Erro | ABLIKIM EATON BRANDELIK PERUZZI <u>DOCUMENT ID</u> or includes scale fa | 09B BES: 84 MR k 79C DAS 78 MR k TECA | $\begin{array}{cccc} \text{(2)} & e^+ e^- \\ \text{P} & e^+ e^- \\ \text{(1)} & e^+ e^- \\ \end{array}$ | | | 1 total (units | PEF | ON 8 RUZZI 7 (Confi | 34 MRK2 '8 MRK1 _ | 0.0 2.8 3.5 |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma \left(p \overline{p} \pi^{+} \pi^{-} \right) / \Gamma_{to}$ VALUE (units 10 ⁻³) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 | 11k 685 109 ota l <u>EVTS</u> 'ERAGE Erro 1435 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID or includes scale fa | 998 BES: 84 MR M 79C DAS 78 MR M actor of 1.3. 84 MR M | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\Big(p\overline{p}\omega\Big)/\Gamma$ | total (units | PEF | ON 8 RUZZI 7 (Confi | 34 MRK2 '8 MRK1 _ | 0.0 2.8 3.5 0.176) |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma\left(p\overline{p}\pi^{+}\pi^{-}\right)/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 | 11k 685 109 otal <u>EVTS</u> ERAGE Erro | ABLIKIM EATON BRANDELIK PERUZZI <u>DOCUMENT ID</u> or includes scale fa | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccc} \text{(2)} & e^+ e^- \\ \text{P} & e^+ e^- \\ \text{(1)} & e^+ e^- \\ \end{array}$ | | | total (units | PEF | ON 8 RUZZI 7 (Confi | 44 MRK2 8 MRK1 _ dence Level = | 0.0 2.8 3.5 0.176) |
| $1.33\pm0.02\pm0.11$ $1.13\pm0.09\pm0.09$ 1.4 ±0.4 1.00 ± 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 ±0.5 OUR AV 6.46 $\pm0.17\pm0.43$ 3.8 ±1.6 5.5 ±0.6 | 11k 685 109 otal <i>EVTS</i> ERAGE Erro 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DOCUMENT ID or includes scale fa EATON BESCH | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\eta'(958)\right)/\Gamma_{tol}$ $\frac{\text{VALUE (units 10}^{-3})}{0.21 \pm 0.04 \text{ OUR AV}}$ | tal EVTS | 1.5 2 2 10 ⁻³) | ON 8 RUZZI 7 (Confi 2.5 3 | 44 MRK2 8 MRK1 _ dence Level = | 0.0 2.8 3.5 0.176) |
| $1.33\pm0.02\pm0.11$ $1.13\pm0.09\pm0.09$ 1.4 ± 0.4 1.00 ± 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 ± 0.5 OUR AV $6.46\pm0.17\pm0.43$ 3.8 ± 1.6 5.5 ± 0.6 WEIGHTEI | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma(p \overline{p} \omega)/\Gamma$ $\Gamma(p \overline{p} \eta'(958))/\Gamma_{tol}$ $VALUE (units 10^{-3})$ $0.21 \pm 0.04 OUR AV$ $0.200 \pm 0.023 \pm 0.028$ | tal EVTS /ERAGE 265 ± 31 | 112 ABLIKIM | ON 8 RUZZI 7 (Confi | 44 MRK2 8 MRK1 _ dence Level = CN COMMEN S2 e+e- | 0.0 2.8 3.5 0.176) |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma\left(p\overline{p}\pi^{+}\pi^{-}\right)/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 5.5 \pm 0.6 | 11k 685 109 otal <i>EVTS</i> ERAGE Erro 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma(p \overline{p} \omega)/\Gamma$ $\Gamma(p \overline{p} \eta'(958))/\Gamma_{tol}$ <u>VALUE (units 10^3)</u> 0.21 ±0.04 OUR AN 0.200±0.023±0.028 0.68 ±0.23 ±0.17 | tal EVTS /ERAGE 265 ± 31 19 | 11.5 2 2 10 ⁻³) DOCUMENT 112 ABLIKIM EATON | ON 8 RUZZI 7 (Confi 1.5 3 ID TE 09 BE 84 MI | 144 MRK2 18 MRK1 _ dence Level = CN | 0.0 2.8 3.5 0.176) |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma\left(p\overline{p}\pi^{+}\pi^{-}\right)/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 5.5 \pm 0.6 | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\eta'(958)\right)/\Gamma_{tol}$ $VALUE\ (units\ 10^{-3})$ $0.21\ \pm0.04\ OUR\ AV$ $0.200\pm0.023\pm0.028$ $0.68\ \pm0.23\ \pm0.17$ $1.8\ \pm0.6$ | EVTS /ERAGE 265 ± 31 19 19 | DOCUMENT 112 ABLIKIM EATON PERUZZI | ON 8 RUZZI 7 (Confi 1 2.5 3 ID 7 09 BE 84 MI 78 MI | MRK2 8 MRK1 _ dence Level = | 0.0 2.8 3.5 0.176) Γ ₁₀₆ /Γ |
| $1.33\pm0.02\pm0.11$ $1.13\pm0.09\pm0.09$ 1.4 ± 0.4 1.00 ± 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 ± 0.5 OUR AV $6.46\pm0.17\pm0.43$ 3.8 ± 1.6 5.5 ± 0.6 WEIGHTEI | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\eta'(958)\right)/\Gamma_{tot}$ 0.21 ± 0.04 OUR AV 0.200 $\pm 0.023\pm 0.028$ 0.68 ± 0.23 ± 0.17 1.8 ± 0.6 112 From the combina | EVTS /ERAGE 265 ± 31 19 19 | DOCUMENT 112 ABLIKIM EATON PERUZZI | ON 8 RUZZI 7 (Confi 1 2.5 3 ID 7 09 BE 84 MI 78 MI | MRK2 8 MRK1 _ dence Level = | 0.0 2.8 3.5 0.176) Γ ₁₀₆ /Γ |
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& & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & \\ & & & \\ & & \\ & & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & 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$\frac{D}{2}$ $\frac{D}{2}$ $\frac{D}{2}$ $\frac{D}{2}$ $\frac{D}{2}$ $\frac{D}{2}$ | 44 MRK2 78 MRK1 _ dence Level = $\frac{CN}{R}$ $\frac{COMMEN}{R}$ $\frac{CS}{R}$ $\frac{e^+e^-}{e^+e^-}$ $\frac{R}{R}$ $\frac{e^+e^-}{PP}\gamma \rho^0$ chan | 0.0 2.8 3.5 0.176) \(\sigma_T\) |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10 ⁻³) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 5.5 \pm 0.6 | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega'\right)/\Gamma_{\text{tol}}$ $VALUE (units 10^{-3})$ $0.21 \pm 0.04 \text{OUR AV}$ $0.200 \pm 0.023 \pm 0.028$ $0.68 \pm 0.23 \pm 0.17$ 1.8 ± 0.6 $112 \text{ From the combina}$ $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ $0.45 \pm 0.13 \pm 0.07$ | EVTS /ERAGE 265 ± 31 19 19 | $\begin{array}{c c} & \text{EAT} \\ & \text{PEF} \\ \hline \\ 1.5 & 2 & 2 \\ \hline \\ 10^{-3}) \\ \hline \\ & \underline{DOCUMENT} \\ 112 \text{ ABLIKIM} \\ \text{EATON} \\ \text{PERUZZI} \\ \hline \\ & \rightarrow p\overline{p}\pi^+\pi^-\eta \\ \hline \\ & \underline{DOCUMENT\ ID} \\ \end{array}$ | FON 8 RUZZI 7 (Confi | 44 MRK2 8 MRK1 _ dence Level = $\frac{CN}{N}$ COMMEN $\frac{COMMEN}{N}$ $\frac{COMMEN}{N}$ $\frac{COMMENT}{N}$ | 0.0 2.8 3.5 0.176) \[\Gamma_{106} / \Gamma_{\text{T}} \] \[\Gamma_{107} / \Gamma_{\text{drons}} \] |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma\left(p\overline{p}\pi^{+}\pi^{-}\right)/\Gamma_{to}$ VALUE (units 10^{-3}) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 5.5 \pm 0.6 | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma(p \overline{p} \omega)/\Gamma$ $\Gamma(p \overline{p} \eta'(958))/\Gamma_{total}$ $VALUE (units 10^{-3})$ $0.21 \pm 0.04 OUR AV$ $0.200 \pm 0.023 \pm 0.028$ $0.68 \pm 0.23 \pm 0.17$ 1.8 ± 0.6 $112 From the combina$ $\Gamma(p \overline{p} \phi)/\Gamma_{total}$ $VALUE (units 10^{-4})$ $0.45 \pm 0.13 \pm 0.07$ $\Gamma(n \overline{n})/\Gamma_{total}$ | total (units $EVTS$ /ERAGE 265 ± 31 19 19 | $\begin{array}{ccc} & \text{EAT} \\ & \text{PEF} \\ & & \text{PEF} \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & $ | FON ERUZZI 7 (Confi 2.5 3 1D TE 09 BE 84 MI 78 MI and $p\overline{p}\eta' \rightarrow$ 88 DM2 | 44 MRK2 78 MRK1 _ dence Level = $\frac{CN}{2}$ COMMEN $\frac{CN}{2}$ $\frac{COMMEN}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ | 0.0 2.8 3.5 0.176) \[\begin{align*} \Gamma_{106} / \Gamma \] \[\text{ranels.} \] \[\Gamma_{107} / \Gamma \] \[\text{drons} \] |
| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma(p\overline{p}\pi^{+}\pi^{-})/\Gamma_{to}$ VALUE (units 10 ⁻³) 6.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 5.5 \pm 0.6 | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $O.21\pm0.04OURAN$ $0.202\pm0.023\pm0.028$ $0.68\pm0.23\pm0.17$ 1.8 ± 0.6 $1.12Fromthecombina$ $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{total}$ $MLUE(units10^{-4})$ $0.45\pm0.13\pm0.07$ $\Gamma\left(n\overline{n}\right)/\Gamma_{total}$ $MLUE(units10^{-2})$ | total (units $EVTS$ FRAGE 265 \pm 31 19 19 Ition of $p\overline{p}\eta'$ | $\begin{array}{c c} & \text{EAT} \\ & \text{PEF} \\ \hline \\ 1.5 & 2 & 2 \\ \hline \\ 10^{-3}) \\ \hline \\ & \underline{DOCUMENT} \\ 112 \text{ ABLIKIM} \\ \text{EATON} \\ \text{PERUZZI} \\ \hline \\ & \rightarrow p\overline{p}\pi^+\pi^-\eta \\ \hline \\ & \underline{DOCUMENT\ ID} \\ \end{array}$ | FON 8 RUZZI 7 (Confi | 44 MRK2 78 MRK1 _ dence Level = $\frac{CN}{2}$ COMMEN $\frac{CN}{2}$ $\frac{COMMEN}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ | 0.0 2.8 3.5 0.176) \(\sigma_T\) |
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| 1.33 \pm 0.02 \pm 0.11 1.13 \pm 0.09 \pm 0.09 1.4 \pm 0.4 1.00 \pm 0.15 $\Gamma(p\bar{p}\pi^{+}\pi^{-})/\Gamma_{to}$ **CALUE (units 10 ⁻³) 5.0 \pm 0.5 OUR AV 6.46 \pm 0.17 \pm 0.43 3.8 \pm 1.6 **WEIGHTE! | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DO CUMENT ID OF INCludes scale fa EATON BESCH PERUZZI | 09B BES: 84 MR k 79c DAS 78 MR k 200 TECN actor of 1.3. 84 MR k 81 BON | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $O.21\pm0.04OURAN$ $0.202\pm0.023\pm0.028$ $0.68\pm0.23\pm0.17$ 1.8 ± 0.6 $1.12Fromthecombina$ $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{total}$ $MLUE(units10^{-4})$ $0.45\pm0.13\pm0.07$ $\Gamma\left(n\overline{n}\right)/\Gamma_{total}$ $MLUE(units10^{-2})$ | total (units $EVTS$ FRAGE 265 \pm 31 19 19 Ition of $p\overline{p}\eta'$ | $\begin{array}{ccc} & \text{EAT} \\ & \text{PEF} \\ & & \text{PEF} \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & $ | FON ERUZZI 7 (Confi 3 1D TE 09 BE 84 MI 78 MI 78 MI and $p\overline{p}\eta' \rightarrow$ 88 DM2 7ECN 98 FENI | 44 MRK2 78 MRK1 _ dence Level = $\frac{CN}{2}$ COMMEN $\frac{CN}{2}$ $\frac{COMMEN}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ | 0.0 2.8 3.5 0.176) Γ ₁₀₆ /Γ |
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| 1.33±0.02±0.11 1.13±0.09±0.09 1.4 ±0.4 1.00±0.15 「(ppπ+π-)/Γ _{to} F(punts 10 ⁻³) 5.0 ±0.5 OUR AV 5.6 ±0.5 OUR AV 5.5 ±0.6 WEIGHTE 6.0±0.5 (Ei | 11k 685 109 Potal EVTS ERAGE Error 1435 48 533 | ABLIKIM EATON BRANDELIK PERUZZI DOCUMENT ID OF includes scale fa EATON BESCH PERUZZI 1.3) | 09B BES: 84 MR k 79C DAS 78 MR k actor of 1.3. 84 MR k 81 BON 78 MR k TFON SSCH RUZZI (Cor | (2 e ⁺ e ⁻ P e ⁺ e ⁻ (1 e ⁺ e ⁻ (1 e ⁺ e ⁻ | χ ² 1.0 1.9 0.7 3.6 | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\eta'\left(958\right)\right)/\Gamma_{tot}$ $VALUE (units 10^{-3})$ 0.21 ± 0.04 OUR AN 0.200 $\pm 0.023\pm 0.028$ 0.68 $\pm 0.23\pm 0.17$ 1.8 ± 0.6 112 From the combina $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{total}$ $VALUE (units 10^{-4})$ 0.45 $\pm 0.13\pm 0.07$ $\Gamma\left(n\overline{n}\right)/\Gamma_{total}$ $VALUE (units 10^{-2})$ 0.22 ± 0.04 OUR AN 0.231 ± 0.049 0.18 ± 0.09 • • • We do not use 0.190 ± 0.055 $\Gamma\left(n\overline{n}\pi^+\pi^-\right)/\Gamma_{total}$ | Lettal (units Lettal EVTS VERAGE 265 ± 31 19 19 Ition of $p\overline{p}\eta'$ Lettal (units EVTS 79 Lettal (units Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (units) Lettal (unit | DOCUMENT ID BALDINI BESCH g data for averages ANTONELLI | FON ERUZZI 8 FRUZZI 7 (Confi | MRK2 MRK1 _ dence Level = $\frac{CN}{28} \frac{COMMEN}{MRK1}$ $\frac{COMMENT}{J/\psi \rightarrow \text{had}}$ $\frac{COMMENT}{J/\psi \rightarrow \text{had}}$ $\frac{COMMENT}{e^+e^-}$ e^+e^- etc. • • • • • • • • • • • • • • • • • • • | 0.0 2.8 3.5 0.176) Γ ₁₀₆ /Γ στ πnels. Γ ₁₀₇ /Γ |
| 1.33±0.02±0.11 1.13±0.09±0.09 1.4 ±0.4 1.00±0.15 Γ(ppπ+π-)/Γ _{to} F(units 10 ⁻³) 5.0 ±0.5 OUR AV 4.64±0.17±0.43 3.8 ±1.6 6.0±0.5 (Ei | 11k 685 109 otalEVTS 'ERAGE Error 1435 48 533 D AVERAGE rror scaled by | ABLIKIM EATON BRANDELIK PERUZZI DOCUMENT ID OF includes scale fa EATON BESCH PERUZZI 1.3) LAMBER PERUZZI 6 8 | 09B BES: 84 MR k 79C DAS 78 MR k actor of 1.3. 84 MR k 81 BON 78 MR k TECN 18CH 18CH 18CH 18CH 18CH 18CH 18CH 18CH | (2 e ⁺ e ⁻ P e ⁺ e ⁻ (1 e ⁺ e ⁻ (1 e ⁺ e ⁻ | χ ² 1.0 1.9 0.7 3.6 | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega'\right)/\Gamma_{\text{tot}}$ $\frac{VALUE \text{ (units }10^{-3}\text{)}}{0.21 \pm 0.04 \text{ OUR AV}}$ $0.20 \pm 0.023 \pm 0.028$ $0.68 \pm 0.23 \pm 0.17$ 1.8 ± 0.6 $112 \text{ From the combina}$ $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-4}\text{)}}{0.45 \pm 0.13 \pm 0.07}$ $\Gamma\left(n\overline{n}\right)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-2}\text{)}}{0.22 \pm 0.04 \text{ OUR AV}}$ 0.231 ± 0.049 0.18 ± 0.09 •• • We do not use 0.190 ± 0.055 $\Gamma\left(n\overline{n}\pi^{+}\pi^{-}\right)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-3}\text{)}}{0.24 \pm 0.04}$ 0.18 ± 0.09 •• • We do not use 0.190 ± 0.055 | total (units Lettal EVTS /ERAGE 265 ± 31 19 19 tion of ppη' /ERAGE 79 the following 40 LEVTS | $\begin{array}{ccc} & \text{EAT} \\ & \text{PEF} \\ & & \text{PEF} \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & $ | FON ERUZZI 8 FRUZZI 7 (Confi | MRK2 WRK1 dence Level = $\frac{CN}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ $\frac{COMMENT}{2}$ | 0.0 2.8 3.5 0.176) Γ106/Γ ντ Γ107/Γ drons Γ108/Γ |
| 1.33±0.02±0.11 1.13±0.09±0.09 1.4 ±0.4 1.00±0.15 Γ(ρρπ+π-)/Γτο VALUE (units 10 ⁻³) 6.0 ±0.5 OUR AV 6.46±0.17±0.43 3.8 ±1.6 5.5 ±0.6 WEIGHTE! 6.0±0.5 (En | 11k 685 109 otalEVTS FERAGE Error 1435 48 533 D AVERAGE rror scaled by | ABLIKIM EATON BRANDELIK PERUZZI DOCUMENT ID OF includes scale fa EATON BESCH PERUZZI 1.3) LAMBER PERUZZI 6 8 | 09B BES: 84 MR k 79C DAS 78 MR k actor of 1.3. 84 MR k 81 BON 78 MR k TECN 18CH 18CH 18CH 18CH 18CH 18CH 18CH 18CH | (2 e ⁺ e ⁻ P e ⁺ e ⁻ (1 e ⁺ e ⁻ (1 e ⁺ e ⁻ | χ ² 1.0 1.9 0.7 3.6 | $\Gamma\left(p\overline{p}\omega\right)/\Gamma$ $\Gamma\left(p\overline{p}\omega\right)/\Gamma_{\text{tot}}$ $\frac{VALUE (\text{units}10^{-3})}{0.21\pm0.04\text{ OUR AN}}$ $0.20\pm0.023\pm0.028$ $0.68\pm0.23\pm0.17$ 1.8 ± 0.6 $112\text{From the combina}$ $\Gamma\left(p\overline{p}\phi\right)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units}10^{-4})}{0.45\pm0.13\pm0.07}$ $\Gamma\left(n\overline{n}\right)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units}10^{-2})}{0.22\pm0.04\text{ OUR AN}}$ 0.231 ± 0.049 0.18 ± 0.09 ••• We do not use 0.190 ± 0.055 $\Gamma\left(n\overline{n}\pi^{+}\pi^{-}\right)/\Gamma_{\text{total}}$ $\frac{VALUE (\text{units}10^{-3})}{VALUE (\text{units}10^{-3})}$ | total (units Lettal EVTS /ERAGE 265 ± 31 19 19 tion of ppη' /ERAGE 79 the following 40 LEVTS | $\begin{array}{ccc} & \text{EAT} \\ & \text{PEF} \\ & & \text{PEF} \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & $ | FON ERUZZI 8 FRUZZI 7 (Confi | MRK2 NRK1 _ dence Level = $\frac{CN}{I}$ COMMENT $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ $\frac{COMMENT}{I}$ | 0.0 2.8 3.5 0.176) Γ ₁₀₆ /Γ στ πnels. Γ ₁₀₇ /Γ |

TECN COMMENT

84 MRK2 e⁺e⁻

78 MRK1 e⁺e⁻

 $1.5\,0\!\pm\!0.10\!\pm\!0.22$

 $\Gamma(\Sigma^0\overline{\Sigma^0})/\Gamma_{total}$

 $1.15 \pm 0.24 \pm 0.03$ $1.33 \pm 0.04 \pm 0.11$

 $1.06 \pm 0.04 \pm 0.23$

 $1.58 \pm 0.16 \pm 0.25$

 1.3 ± 0.4

 $2.4\ \pm2.6$

WALUE (units 10⁻³) EV 1.29±0.09 OUR AVERAGE

399

EVTS

1779

90

52

3

 884 ± 30

ABLIKIM

 $^{113}\,\mathrm{AUBERT}$

ABLIKIM

PALLIN

EATON PERUZZI

BESCH

• • • We do not use the following data for averages, fits, limits, etc. • •

$J/\psi(1S)$

 $\Gamma(n\overline{n}\pi^{-})/\Gamma$

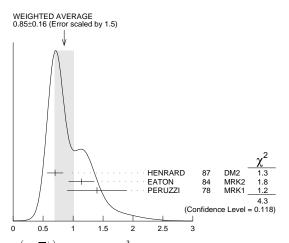
 113 AUBERT 07BD reports $[\Gamma\left(J/\psi(15)\to \Sigma^0\overline{\Sigma}^0\right)/\Gamma_{\rm total}]\times [\Gamma\left(J/\psi(15)\to e^+e^-\right)]= (6.4\pm1.2\pm0.6)\times10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(15)\to e^+e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(2(\pi^{+}\pi^{-})K^{+}I)$ | K−)/Γ _{to} | tal | | | Γ ₁₁₂ /Γ |
|-------------------------------------------|---------------------|-----------------------|---------|------|-------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 47 ± 7 OUR AV | | | | | |
| 49.8± 4.2±3.4 | 205 | ¹¹⁴ AUBERT | 06D | BABR | $^{10.6}_{\omega} {^{e^+}\kappa^-}_{K^-} _{2(\pi^+\pi^-)\gamma}$ |
| 31 ±13 | 30 | VANNUCCI | 77 | MRK1 | e^+e^- |
| 114 Using $\Gamma(J/\psi ightarrow$ | $e^{+}e^{-})$ | $= 5.52\pm0.14\pm0$ | .04 ke' | V. | |

Γ112/F

| '(P'''')/'total | | | | | ' 113/' |
|---------------------------------|------|--------------|-----|------|---------------------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 2.12±0.09 OUR AVE | RAGE | | | | |
| $2.36 \pm 0.02 \pm 0.21$ | 59k | ABLIKIM | 06K | BES2 | $J/\psi \rightarrow p \pi^{-} \overline{n}$ |
| $2.47 \pm 0.02 \pm 0.24$ | 55 k | ABLIKIM | 06K | BES2 | $J/\psi \rightarrow \overline{p}\pi^+ n$ |
| $2.02 \pm 0.07 \pm 0.16$ | 1288 | EATON | 84 | MRK2 | $e^+ e^- \rightarrow \rho \pi^-$ |
| $1.93 \pm 0.07 \pm 0.16$ | 1191 | EATON | 84 | MRK2 | $e^+ e^- \rightarrow \overline{p} \pi^+$ |
| 1.7 ± 0.7 | 32 | BESCH | 81 | BONA | $e^+ e^- \rightarrow p \pi^-$ |
| 1.6 ± 1.2 | 5 | BESCH | 81 | BONA | $e^+e^- \rightarrow \overline{p}\pi^+$ |
| 2.16 ± 0.29 | 194 | PERUZZI | 78 | MRK1 | $e^+ e^- \rightarrow \rho \pi^-$ |
| 2.04 ± 0.27 | 204 | PERUZZI | 78 | MRK1 | $e^+ e^- \rightarrow \overline{p} \pi^+$ |
| | | | | | |

| $\Gamma(\Xi^{-}\overline{\Xi}^{+})/\Gamma_{tota}$ | .l | | | | | Γ_{117}/Γ |
|---------------------------------------------------|--------------------|--------------------|-------|---------|----------------------------|-----------------------|
| VALUE (units 10^{-3}) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 0.85 ± 0.16 OUR AV | /ERAGE Erro | r includes scale f | actor | of 1.5. | See the ideogr | am below. |
| $0.70 \pm 0.06 \pm 0.12$ | 132 ± 11 | HENRARD | 87 | DM2 | $e^+ e^- ightarrow \Xi$ | - <u>F</u> + |
| $1.14 \pm 0.08 \pm 0.20$ | 194 | EATON | 84 | MRK2 | $e^+e^- \rightarrow \Xi$ | <u>-</u> <u>∓</u> + |
| 1.4 ± 0.5 | 51 | PERUZZI | 78 | MRK1 | $e^+e^- \rightarrow =$ | - = + |



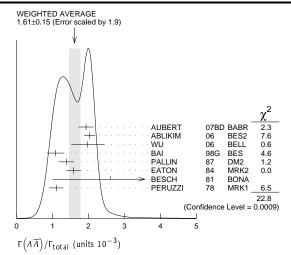
 $\Gamma(\Xi^{-}\overline{\Xi}^{+})/\Gamma_{total}$ (units 10^{-3})

| $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ | | | | | Γ ₁₁₈ /Γ |
|------------------------------------------------------------|-----------|-----------------------|------------|----------|-------------------------------------------------------------|
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | T | ECN | COMMENT |
| 1.61±0.15 OUR AVE | RAGE Erro | or includes scale f | actor of 1 | .9. Se | e the ideogram below. |
| $1.93 \pm 0.21 \pm 0.05$ | | ¹¹⁵ AUBERT | 07BD B. | ABR | 10.6 $e^+e^- \rightarrow \Lambda \overline{\Lambda} \gamma$ |
| $2.03 \pm 0.03 \pm 0.15$ | 8887 | ABLIKIM | 06 B | ES2 | $J/\psi \rightarrow \Lambda \overline{\Lambda}$ |
| $2.0 \ ^{+ 0.5}_{- 0.4} \ \pm 0.1$ | 46 | ¹¹⁶ WU | 06 B | ELL | $B^+ \rightarrow \Lambda \overline{\Lambda} K^+$ |
| $1.08 \pm 0.06 \pm 0.24$ | 631 | BAI | 98G B | ES | e+ e- |
| $1.38 \pm 0.05 \pm 0.20$ | 1847 | PALLIN | 87 D | M2 | e+ e- |
| $1.58\pm0.08\pm0.19$ | 365 | EATON | 84 M | IRK2 | e^+e^- |
| 2.6 ± 1.6 | 5 | BESCH | 81 B | ONA | e^+e^- |
| 1.1 ± 0.2 | 196 | PERUZZI | 78 M | IRK1 | e+ e- |
| 115 AUDEDT 0700 | [5/1] | / //16\ 44\ | /r 1 | . r= (, | / //1.6\ -+ -=\1 |

115 AUBERT 07BD reports $[\Gamma(J/\psi(1S) \to \Lambda\overline{\Lambda})/\Gamma_{\text{total}}] \times [\Gamma(J/\psi(1S) \to e^+e^-)] = (10.7 \pm 0.9 \pm 0.7) \times 10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(1S) \to e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

116 WU 06 reports $[\Gamma(J/\psi(1S) \to \Lambda\overline{\Lambda})/\Gamma_{\text{total}}] \times [B(B^+ \to J/\psi(1S) K^+)] = (2.00 \pm 0.34 \pm 0.34) \times 10^{-6}$ with the wide between the BCB $+ (J/\psi(1S) K^+)$

 $(2.00 + 0.34 \pm 0.34) \times 10^{-6}$ which we divide by our best value B(B+ \rightarrow $J/\psi(1S)$ K+) $=(1.016\pm0.033)\times10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.



| $\Gamma(\Lambda \overline{\Lambda})/\Gamma(\rho \overline{\rho})$ | | | | Γ ₁₁₈ /Γ ₉₉ |
|-------------------------------------------------------------------|------------------------------------------------------------------|-------|-----------|--------------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| $0.90^{+0.15}_{-0.14}\pm0.10$ | $^{117}\mathrm{WU}$ | 06 | BELL | $B^+ \to p \overline{p} K^+, \Lambda \overline{\Lambda} K^+$ |
| $^{117}\mathrm{Not}$ independent of oth | ner $J/\psi \to \Lambda \overline{\Lambda}$, $p \overline{p}$ b | ranch | ing ratio | s reported by WU 06. |

| $\Gamma(\Lambda \overline{\Sigma}^- \pi^+ \text{ (or c.c.)}$ | $)/\Gamma_{total}$ | | | | | Γ ₁₁₉ /Γ |
|--------------------------------------------------------------|--------------------|------------------------|-------|---------|----------------------|-----------------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 0.83 ±0.07 OUR AV | | | actor | of 1.2. | | |
| $0.770 \pm 0.051 \pm 0.083$ | | | 07н | BES2 | $e^+e^- \rightarrow$ | $\Lambda \Sigma^{+} \pi^{-}$ |
| $0.747 \pm 0.056 \pm 0.076$ | 254 | ¹¹⁸ ABLIKIM | 07н | BES2 | $e^+e^- \rightarrow$ | $\Lambda \overline{\Sigma}^- \pi^+$ |
| $0.90\ \pm0.06\ \pm0.16$ | 225 ± 15 | HENRARD | 87 | DM2 | $e^+e^- \rightarrow$ | $\overline{\Lambda} \Sigma^{+} \pi^{-}$ |
| $1.11 \pm 0.06 \pm 0.20$ | 342 ± 18 | HENRARD | 87 | DM2 | $e^+e^- \rightarrow$ | $\Lambda \overline{\Sigma}^- \pi^+$ |
| $1.53 \pm 0.17 \pm 0.38$ | 135 | EATON | 84 | MRK2 | $e^+e^- \rightarrow$ | $\Lambda \Sigma^{+} \pi^{-}$ |
| $1.38 \pm 0.21 \pm 0.35$ | 118 | EATON | 84 | MRK2 | $e^+e^- \rightarrow$ | $\Lambda \overline{\Sigma}^- \pi^+$ |

 $\Gamma(pK^-\overline{\Lambda})/\Gamma_{\text{total}}$ Γ_{120}/Γ VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT

¹¹⁸ Using B($\Lambda \rightarrow \pi^- p$) = 63.9% and B($\Sigma^+ \rightarrow \pi^0 p$) = 51.6%.

MRK2 $e^+e^ 0.89 \pm 0.07 \pm 0.14$ 307 EATON $\Gamma(2(K^+K^-))/\Gamma_{\text{total}}$ Γ_{121}/Γ DOCUMENT ID TECN COMMENT 0.76±0.09 OUR AVERAGE

 $0.74 \pm 0.09 \pm 0.02$ 156 \pm 15 119 AUBERT 07AK BABR 10.6 $e^+e^-
ightarrow 2(K^+K^-)\gamma$ 1.4 $^{+0.5}_{-0.4}$ ± 0.2 11.0 $^{+4.3}_{-3.5}$ 120 HUANG 03 BELL $B^+ \rightarrow 2(K^+K^-)K^+$ 0.7 ±0.3 VANNUCCI 77 MRK1 e+e-

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $0.72 \pm 0.17 \pm 0.02$ 38 121 AUBERT 05D BABR 10.6 $e^+e^- \rightarrow 2(K^+K^-)\gamma$

 $^{119} \, {\rm AUBERT} \,\, 07 \\ {\rm AK} \,\, {\rm reports} \,\, [\Gamma \left(J/\psi(1S) \,\rightarrow\, \, 2(K^+ \,\, K^-)\right)/\Gamma_{\mbox{total}}] \,\times\, [\Gamma \left(J/\psi(1S) \,\rightarrow\, \, e^+ \,e^-\right)]$ $= (4.11 \pm 0.39 \pm 0.30) \times 10^{-3}$ keV which we divide by our best value $\Gamma(J/\psi(1S) \rightarrow$ $e^+e^-)=5.55\pm0.14\pm0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. 120 Using B($B^+ \to J/\psi \, K^+$) = $(1.01\pm0.05) \times 10^{-3}$.

121 Superseded by AUBERT 07AK. AUBERT 05D reports $[\Gamma(J/\psi(1S) \rightarrow 2(K^+K^-))/$ $\Gamma_{
m total}] imes [\Gamma igl(J/\psi(1S)
ightarrow \ e^+ \, e^- igr)] = (4.0 \pm 0.7 \pm 0.6) imes 10^{-3} \ {
m keV}$ which we divide by our best value $\Gamma(J/\psi(1S) \to e^+e^-) = 5.55 \pm 0.14 \pm 0.02$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best

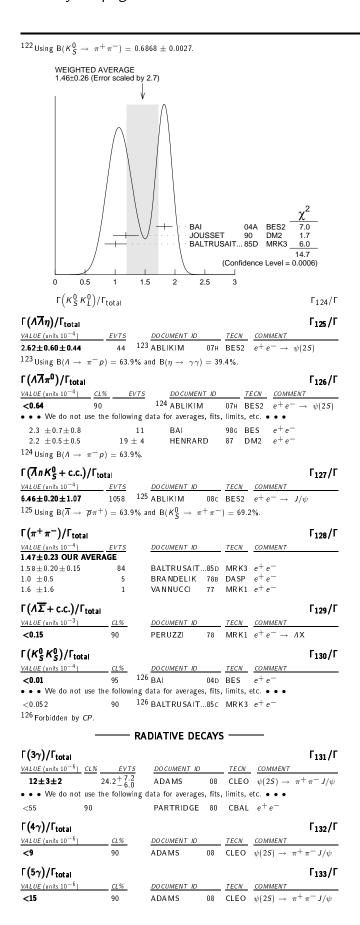
| $\Gamma(ho K^- \overline{\Sigma}{}^0) / \Gamma_{ m total}$ | | | | | | Γ ₁₂₂ /Γ |
|-------------------------------------------------------------|------|--------------|------|------|----------|---------------------|
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $0.29 \pm 0.06 \pm 0.05$ | 90 | EATON | 84 | MRK2 | e^+e^- | |
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | | | | | | Γ ₁₂₃ /Γ |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.37±0.31 OUR AVERA | \GE | | | | | |
| $2.39 \pm 0.24 \pm 0.22$ | 107 | BALTRUSAIT. | 85 D | MRK3 | e^+e^- | |
| $2.2\ \pm0.9$ | 6 | BRANDELIK | 79C | DASP | e^+e^- | |

| $\Gamma(K_S^0 K_L^0)/\Gamma_{\text{tota}}$ | I | | | | Γ ₁₂₄ , | / [|
|--------------------------------------------|-------------|--------------------|-------|-------|----------------------------------------------|------------|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT IL |) | TECN | COMMENT | |
| 1.46±0.26 OUR A | VERAGE Erro | or includes scale | | | See the ideogram below. | |
| $1.82 \pm 0.04 \pm 0.13$ | 2155 ± 45 | ¹²² BAI | 04A | BES2 | $J/\psi \rightarrow K_S^0 K_L^0 \rightarrow$ | |
| | | | | | $\pi^+\pi^-\chi$ | |
| $1.18 \pm 0.12 \pm 0.18$ | | JOUSSET | 90 | DM2 | $J/\psi ightarrow$ hadrons | |
| $1.01 \pm 0.16 \pm 0.09$ | 74 | BALTRUSAI | T85 D | MR K3 | ₃ e ⁺ e [−] | |

 Γ_{134}/Γ

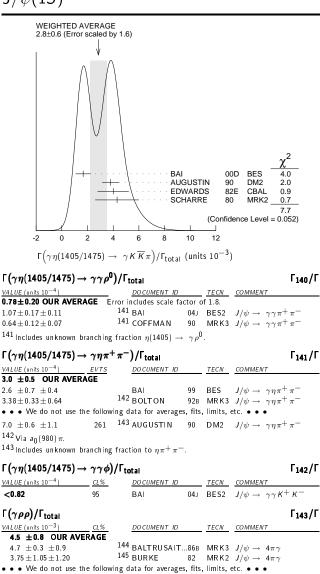
Meson Particle Listings $J/\psi(1S)$

 $\Gamma(\gamma \eta_c(1S))/\Gamma_{\text{total}}$



| | | | | | 134/ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻²) 1.7 ±0.4 OUR AVE | EVTS | DOCUMENT includes scale f | | TECN | COMMENT |
| $2.06 \pm 0.32 \pm 0.03$ | INAGE LITO | 127 MITCHELL | | | $e^+e^- \rightarrow \gamma X$ |
| 1.27±0.36 | | GAISER | . 86 | | |
| • • • We do not use | the following | | | | , , , |
| 0.79±0.20 | 273 ± 43 | 128 AUBERT | | | $R B^{\pm} \rightarrow K^{\pm} X_{C} \overline{C}$ |
| 0.79±0.20 seen | 213 ± 43 16 | | | | $3 J/\psi \rightarrow 2\phi\gamma$ |
| | | | | | rom a measurement |
| | | | | | |
| $[\Gamma(J/\psi(1S)] \rightarrow$ | $\gamma \eta_c(15))/1$ | total] \times [B(ψ | (25) - | → J/≀ | $\psi(1S) \pi^+ \pi^-)$] assuming |
| $B(\psi(2S) \rightarrow J/$ | $\psi(1S)\pi^+\pi^-$ |) = (35.04 ± 0 | .07 ± 1 | 0.77) × | 10^{-2} , which we resca |
| is their experime | $B(\psi(2S) \rightarrow 0$ | $J/\psi(15)\pi^+\pi^-$ |) = (33 risthe | .b ± 0.4 | $1)	imes 10^{-2}$. Our first erratic atic error from using o |
| best value | | | | | |
| ¹²⁸ Calculated by the | authors using | an average of B | $(J/\psi$ - | $\rightarrow \gamma \eta_C$ | \times B($\eta_{\it C} \rightarrow {\it K} \overline{\it K} \pi$) fro |
| BALTRUSAITIS | 86, BISELLO | 91, BAI 04 and | $B(\eta_C -$ | → KK | π) = (8.5 ± 1.8)% fro |
| AUBERT 06E. | | | | | |
| $\Gamma(\gamma \eta_c(1S) \rightarrow 3\gamma)$ |)/Γ _{total} | | | | Γ ₁₃₅ / |
| VALUE (units 10 ⁻⁶) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| | 2 8 | | | | |
| $1.2^{+2.7}_{-1.1}$ ± 0.3 | $1.2^{+2.8}_{-1.1}$ | ADAMS | 80 | CLEO | $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ |
| $\Gamma(\gamma\pi^+\pi^-2\pi^0)/\Gamma$ | | | | | Γ ₁₃₆ / |
| . , | total | DO CULTERIT := | | TE C** | • |
| VALUE (units 10 ⁻³) 8.3±0.2±3.1 | | DOCUMENT ID PRAITRISAIS | | TECN | COMMENT |
| | | - BALIRUSAH | 86B | WKK3 | $J/\psi ightarrow 4\pi\gamma$ |
| 129 $^{4\pi}$ mass less than | 1 2.0 GeV. | | | | |
| $\Gamma(\gamma\eta\pi\pi)/\Gamma_{total}$ | | | | | Γ ₁₃₇ / |
| VALUE (units 10 ⁻³) | | DO CUMENT ID | | TECN | COMMENT |
| 6.1 ±1.0 OUR AVE | RAGE | DOCOMENT ID | | TECN | COMMENT |
| 5.85 ± 0.3 ± 1.05 | 13 | ³⁰ EDWARDS | 83в | CBAL | $J/\psi \rightarrow \eta \pi^+ \pi^-$ |
| 7.8 ±1.2±2.4 | 13 | ³⁰ EDWARDS | 83B | CBAL | |
| 130 Broad enhanceme | | | | | , , , , , , , , , , , , , , , , , , , , |
| | | | | | |
| $\Gamma(\gamma \eta_2(1870) \rightarrow \gamma$ | $(\eta \pi^+ \pi^-)/\Gamma$ | total | | | Γ ₁₃₈ / |
| VALUE (units 10 ⁻⁴) | • | DOCUMENT ID | | TECN | COMMENT |
| | | DOCUMENT ID | | 1 | |
| | | BAI | 99 | BES | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 6.2±2.2±0.9 | —————————————————————————————————————— | BAI | 99 | | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ | $\rightarrow \gamma K \overline{K} \pi$ | BAI)/Γ _{total} | | BES | $J/\psi \rightarrow \gamma \eta \pi^+ \pi^ \Gamma_{139}/$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)_{VALUE\ (units\ 10^{-3})}$ | | BAI // T _{total} DOCUMENT ID | | BES TECN | $J/\psi ightarrow \gamma \eta \pi^+ \pi^ \Gamma_{139}/COMMENT$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)^{3})$ VALUE (units 10^{-3}) 2.8 \pm 0.6 OUR AVE | RAGE Error | BAI // Total DOCUMENT ID includes scale f | actor of | BES TECN 1.6. S | $J/\psi ightarrow \gamma \eta \pi^+ \pi^ \Gamma_{139/}$ $COMMENT$ ee the ideogram below. |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475))$ MALUE (units 10^{-3}) 2.8 \pm 0.6 OUR AVE $1.66\pm0.1 \pm 0.58$ | ERAGE Error | BAI //F _{total} DOCUMENT ID includes scale f 32 BAI | actor of | ### BES TECN F 1.6. So BES | $J/\psi ightarrow \gamma \eta \pi^+ \pi^-$ $\frac{\Gamma_{139}/}{COMMENT}$ the the ideogram below. $J/\psi ightarrow \gamma K^\pm K_S^0 \pi^\mp$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ VALUE (units 10^{-3}) 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 | ERAGE Error 131,13 | BAI //F _{total} DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN | actor of 00D 90 | TECN f 1.6. So BES DM2 | |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 | ERAGE Error 131,13 13 | BAI //Ftotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS | actor of 00D 90 82E | TECN f 1.6. So BES DM2 CBAL | $ \begin{array}{c} \overline{J/\psi \rightarrow \gamma \eta \pi^+ \pi^-} \\ \hline \Gamma_{139/} \\ \underline{COMMENT} \\ \text{ee the ideogram below.} \\ J/\psi \rightarrow \gamma K^{\pm} K^0_S \pi^{\mp} \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \end{array} $ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ VALUE (units 10^{-3}) 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 | ERAGE Error 131,1: 13 13 133,1: | BAI // Ttotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE | actor of 00D 90 82E 80 | TECN f 1.6. So BES DM2 CBAL MRK2 | $\begin{array}{c} \hline J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139}/\\ \hline comment \\ \text{ee the ideogram below.} \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • • We do not use | ERAGE Error 131,1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1: 1 | BAI // Ttotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag | actor of 00D 90 82E 80 es, fits, | TECN f 1.6. So BES DM2 CBAL MRK2 limits, | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139}/\\ \underline{COMMENT}\\ \text{ee the ideogram below.} \\ J/\psi \rightarrow \gamma K^{\pm} K^0_S \pi^{\mp} \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ \text{etc.} \bullet \bullet \bullet \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 | ERAGE Error 131,13 13 133,13 e the following 133,135,13 | BAI // Ttotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN | actor of 00D 90 82E 80 es, fits, | TECN f 1.6. So BES DM2 CBAL MRK2 limits, | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+\pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K_S^0 \pi^\mp \\ J/\psi \rightarrow \gamma K K \pi \\ J/\psi \rightarrow K^+K^-\pi^0 \gamma \\ e^+e^- \\ etc. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K K \pi \\ \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 | ERAGE Error 131,1: 1: 133,1: e the following 133,135,1: 133,137,1: | BAI //Ftotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 44 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN | actor of 00D 90 82E 80 es, fits, | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 | $ \begin{array}{c} J/\psi \to \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \to \gamma K^\pm K_S^0 \pi^\mp \\ J/\psi \to \gamma K \overline{K} \pi \\ J/\psi \to K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \to \gamma K \overline{K} \pi \\ J/\psi \to \gamma K \overline{K} \pi \\ J/\psi \to \gamma K \overline{K} \pi \\ \end{array} $ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 | ERAGE Error 131,13 13 133,13 e the following 133,135,13 | BAI //Ftotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 44 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN | actor of 00D 90 82E 80 es, fits, | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+\pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K_S^0 \pi^\mp \\ J/\psi \rightarrow \gamma K K \pi \\ J/\psi \rightarrow K^+K^-\pi^0 \gamma \\ e^+e^- \\ etc. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K K \pi \\ \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $\times_{ALUE (units 10^{-3})}$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 | ERAGE Error 131,1: 1: 133,1: 133,1: 133,135,1: 133,137,1: 133,136,1: | DOCUMENT ID DOCUMENT ID I includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 44 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI | actor of 00D 90 82E 80 es, fits, 92 92 | TECN F1.6. So BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 | $\begin{array}{c} \hline J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \hline \\ COMMENT \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm \kappa^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow K^+ \kappa^- \pi^0 \gamma \\ e^+ e^- \\ \text{etc.} \bullet \bullet \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^S K^- \pi^\mp \\ \hline \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $VALUE (units 10^{-3}) 2.8 \pm0.6 OUR AVE 1.66\pm0.1 \pm0.58 3.8 \pm0.3 \pm0.6 4.0 \pm0.7 \pm1.0 4.3 \pm1.7 • • • We do not use 1.78\pm0.21\pm0.33 0.83\pm0.13 \pm0.18 0.66\pm0.17 \pm0.24 1.03 \pm0.18 1.03 \pm0.18 0.19 \pm0.21$ | ERAGE Error 131,1: 1: 133,1: 1: 133,1: 2: the following 133,135,1: 133,136,1: 133,138,14 | BAI // Ftotal DOCUMENT ID 10 28 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI | actor of 00D 90 82E 80 es, fits, 92 92 90c | BES TECN f 1.6. So BES DM2 CBAL Imits, DM2 DM2 DM2 MRK3 | $ \begin{array}{c} \hline J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \hline \Gamma_{139}/\\ \hline \hline COMMENT \\ \text{eee the ideogram below.} \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ \text{etc.} \bullet \bullet \bullet \\ \hline J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \end{array} $ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.15 1.03 \pm 0.21 | FRAGE Error 131,1: 1: 133,1: 1: 133,135,1: 133,135,1: 133,136,1: 133,138,14: the $J/\psi(1S)$ of the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138,14: the Error 131,138, | BAI // Total DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 40 BAI cadiative transitie | actor of 00D 90 82E 80 es, fits, 92 92 90c | BES TECN f 1.6. So BES DM2 CBAL Imits, DM2 DM2 DM2 MRK3 | $\begin{array}{c} \hline J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \hline \\ COMMENT \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm \kappa^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow K^+ \kappa^- \pi^0 \gamma \\ e^+ e^- \\ \text{etc.} \bullet \bullet \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^- \overline{\kappa} \pi \\ J/\psi \rightarrow \gamma K^S K^- \pi^\mp \\ \hline \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma \eta(1405/1475)$ $\times \Lambda LUE \text{ (units } 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.15 1.03 \pm 0.21 \pm 0.26 0.16 \pm 0.115 1.03 \pm 0.21 \pm 0.26 1.11 Interference with around 1800 is (6) | FRAGE Error 131,13 13,13 13,13 13,13 13,13 13,13 13,13 13,13 13 \pm the $J/\psi(1S)$ \pm 0.01 \pm 0.01 \pm | BAI // Ftotal DOCUMENT ID Includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 44 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 40 BAI adiative transiti 0.05) × 10-3. | actor of 00D 90 82E 80 es, fits, 92 92 90c 90c | TECN f 1.6. So BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma \eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.16 \pm 0.15 1.03 \pm 0.21 \pm 0.39 131 Interference with around 1800 is (0.132 Interference with reference with results of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction o | ERAGE Error 131,13 13,13 13,13 13,13 13,13 13,13 1,13 13,13 1,15 13,13 1,15 \pm the $J/\psi(1S)$ 0.15 \pm 0.01 \pm $J/\psi 	o 	extstyle 	o$ $\pi f_1(1S)$ | BAI // Ftotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 44 SCHARRE data for averag 56 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI radiative transiti 0.05) × 10 ⁻³ . 1420) is (-0.03 | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.15 1.03 \pm 0.21 \pm 0.26 1.10 \pm 0.19 131 Interference with around 1800 is (C132 Interference with 133 Includes unknown | FRAGE Error 131,13 13,13 13 13 13 13 13 13 13 13 13 13 13 13 1 | BAI // Ftotal DOCUMENT ID includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI radiative transitic 0.05) × 10 ⁻³ . 1420) is (-0.03 | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ **MALUE (units 10^{-3}) 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.38 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 1.03 \pm 0.21 \pm 0.39 1.13 \pm 1.17 1.03 \pm 0.21 \pm 0.26 1.03 \pm 0.21 \pm 0.39 1.14 \pm 0.26 1.03 \pm 0.21 \pm 0.26 1.03 \pm 0.21 \pm 0.26 1.03 \pm 0.21 \pm 0.26 1.03 \pm 0.21 \pm 0.26 1.03 \pm 0.21 \pm 0.26 1.04 \pm 0.27 1.05 \pm 0.27 1.07 1.08 \pm 0.29 1.09 1.09 1.09 1.09 1.09 1.09 1.09 1.0 | FRAGE Error 131,1: 1: 1: 1: 1: 1: 1: 1: 1: 1: | BAI | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma n(1405/1475)$ $2.8 \pm 0.6 \text{ OUR AVE}$ 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 1.03 \pm 0.18 -0.19 131 Interference with around 1800 is (0 132 interference with 133 includes unknown 134 Corrected for spir 135 From fit to the a, | FRAGE Error 131,1: 1: 1: 1: 1: 1: 1: 1: 1: 1: | BAI | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2±2.2±0.9 Γ(γη(1405/1475) 2.8 ±0.6 OUR AVE 1.66±0.1 ±0.58 3.8 ±0.3 ±0.6 4.0 ±0.7 ±1.0 4.3 ±1.7 • • • We do not use 1.78±0.21±0.33 0.83±0.13±0.18 0.66±0.17+0.24 0.16±0.15 1.03±0.21±0.26 0.18±0.19 131 Interference with 133 Includes unknown 134 Corrected for spir 135 From fit to the a_1 136 $a_0(980)$ π mode. | FRAGE Error 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 14 the $J/\psi(1S)$ $\psi \to \gamma f_1(1S)$ | BAI // Ftotal DOCUMENT ID Includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI radiative transitic 0.05) × 10-3. 1420) is (-0.03 action η(1405) - sis for η(1405). + partial wave. | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma \eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.17 \pm 0.24 1.03 \pm 0.18 \pm 0.19 131 Interference with around 1800 is (C 132 Interference with around 1800 is (C 133 Includes unknown 134 Corrected for spir 135 From fit to the a_1 136 $a_0(980) \pi$ mode. 137 From fit to the a_1 | FRAGE Error 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 14 the $J/\psi(1S)$ $\psi \to \gamma f_1(1S)$ | BAI // Ftotal DOCUMENT ID Includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI radiative transitic 0.05) × 10-3. 1420) is (-0.03 action η(1405) - sis for η(1405). + partial wave. | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
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| 6.2 \pm 2.2 \pm 0.9 $\Gamma(\gamma\eta(1405/1475)$ $VALUE (units 10^{-3})$ 2.8 \pm 0.6 OUR AVE 1.66 \pm 0.1 \pm 0.58 3.8 \pm 0.3 \pm 0.6 4.0 \pm 0.7 \pm 1.0 4.3 \pm 1.7 • • • We do not use 1.78 \pm 0.21 \pm 0.33 0.83 \pm 0.13 \pm 0.18 0.66 \pm 0.17 \pm 0.24 0.16 \pm 0.15 1.03 \pm 0.21 \pm 0.29 131 Interference with around 1800 is (C 132 Interference with 133 Includes unknown 134 Corrected for spin 135 From fit to the a_1 136 $a_0(980) \pi$ mode. 137 From fit to the K 137 From fit to the K 138 K^*K mode | FRAGE Error 131,13 131,13 131,13 131,13 131,13 131,13 131,13 131,13 14 the $J/\psi(1S)$ 0.15 \pm 0.01 \pm $J/\psi \rightarrow \gamma f_1(1S)$ 0.16 \pm 0.17 \pm 0.18 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm 0.19 \pm | BAI // Ftotal DOCUMENT ID Includes scale f 32 BAI 33 AUGUSTIN 33 EDWARDS 34 SCHARRE data for averag 36 AUGUSTIN 38 AUGUSTIN 39 BAI 10 BAI radiative transitic 0.05) × 10-3. 1420) is (-0.03 iction η(1405) - issis for η(1405). + partial wave. | actor of 00D 90 82E 80 es, fits, 92 90c 90c on to th | TECN f 1.6. S BES DM2 CBAL MRK2 limits, DM2 DM2 MRK3 MRK3 e broad \pm 0.01 | $\begin{array}{c} J/\psi \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{139/} \\ \hline \\ comment \\ ee the ideogram below. \\ J/\psi \rightarrow \gamma K^\pm K^0_S \pi^\mp \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow K^+ K^- \pi^0 \gamma \\ e^+ e^- \\ etet. \bullet \bullet \bullet \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K \overline{K} \pi \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp \\ K \overline{K} \pi \text{ pseudoscalar sta} \end{array}$ |
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$J/\psi(1S)$



| $144~4\pi$ mass less than 2.0 GeV. $145~4\pi$ mass less than 2.0 GeV. We have multiplied $2\rho^0$ measurement by 3 to obtain 2ρ . $146~4\pi$ mass in the range 2.0–25 GeV. | | | | | | | | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------|-----|------|--------------|---------------------|--|--|--|
| $\Gamma(\gamma \rho \omega)/\Gamma_{\rm total}$ | | | | | | Γ ₁₄₄ /Γ | | | |
| VALUE (units 10^{-4}) | CL% | DOCUMENT ID | | TECN | COMMENT | | | | |
| <5.4 | 90 | ABLIKIM | 08A | BES2 | $e^+e^- \to$ | J/ψ | | | |
| $\Gamma(\gamma ho\phi)/\Gamma_{ m total}$ | | | | | | Γ ₁₄₅ /Γ | | | |
| VALUE (units 10^{-5}) | CL% | DO CUMENT ID | | TECN | COMMENT | | | | |

ABLIKIM

89B

 $J/\psi \rightarrow 4\pi\gamma$

08A BES2 $e^+\,e^ightarrow~J/\psi$

76 CNTR $e^+e^- \rightarrow 2\gamma\rho$

90 ¹⁴⁶ BISELLO

2.4 + 0.7

57

| $\Gamma(\gamma\eta'(958))/\Gamma_{to}$ | tal | | | | Γ ₁₄₆ /Γ |
|----------------------------------------|-----------------|-----------------------|----------|------------|----------------------------------------------------------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 5.16±0.15 OUR AV | ERAGE Err | or includes scale | factor | of 1.1. | |
| $4.86 \pm 0.23 \pm 0.08$ | 14 | ¹⁷ ABLIKIM | 11 | BES3 | $J/\psi \rightarrow \eta' \gamma$ |
| $5.24 \pm 0.12 \pm 0.11$ | | PEDLAR | 09 | CLE3 | $J/\psi \rightarrow \eta' \gamma$ |
| 5.55 ± 0.44 | 35k | ABLIKIM | 06E | BES2 | $J/\psi \rightarrow \eta' \gamma$ |
| • • • We do not u | se the followir | ng data for averag | ges, fit | ts, limits | , etc. • • • |
| $4.50\pm0.14\pm0.53$ | | BOLTON | 92B | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta$, $\eta \rightarrow$ |
| $4.30 \pm 0.31 \pm 0.71$ | | BOLTON | 92B | MRK3 | $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta, \eta \rightarrow \pi^+ \pi^- \pi^0$ |
| $4.04 \pm 0.16 \pm 0.85$ | 622 | AUGUSTIN | 90 | DM2 | $J/\psi \xrightarrow{\pi^+\pi^-} \gamma \eta \pi^+ \pi^-$ |
| $4.39 \pm 0.09 \pm 0.66$ | 2420 | AUGUSTIN | 90 | DM2 | $J/\psi \rightarrow \gamma \gamma \pi^{+} \pi^{-}$ |
| $4.1 \ \pm 0.3 \ \pm 0.6$ | | BLOOM | 83 | CBAL | $e^+ e^- ightarrow 3 \gamma +$ |
| 2.9 ±1.1 | 6 | BRANDELIK | 79 C | DASP | hadrons $e^+e^- \rightarrow 3\gamma$ |

BARTEL

 147 ABLIKIM 11 reports (4.84 \pm 0.03 \pm 0.24) $\times 10^{-3}$ from a measurement of [Γ($J/\psi(1S)$ \rightarrow $\gamma\eta'(958))/\Gamma_{\mathsf{total}}] \ / \ [\mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ [\mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\pi^-\eta)] \ / \ \mathsf{B}(\eta \to \ 2\gamma)] \ \mathsf{Assuming} \ \mathsf{B}(\eta'(958) \to \ \pi^+\eta)$ $\pi^+\pi^-\eta)=(43.2\pm0.7)\times 10^{-2}, B(\eta\to2\gamma)=(39.31\pm0.20)\times 10^{-2}, which we rescale to our best values <math>B(\eta'(958)\to\pi^+\pi^-\eta)=(43.4\pm0.7)\times 10^{-2}, B(\eta\to2\gamma)=(43.4\pm0.7)\times 1$

research to one observables $(\eta/30) = \eta/\eta/\eta = (3.34 \pm 0.7) \times 10^{-1}$, $(\eta/30) = \eta/\eta/\eta = (3.34 \pm 0.7) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best values. $\Gamma(\gamma 2\pi^+ 2\pi^-)/\Gamma_{\text{total}}$ DO CUMENT ID VALUE (units 10-3 TECN COMMENT 2.8 ±0.5 OUR AVERAGE Error includes scale factor of 1.9. See the ideogram below. 148 BISELLO 89B DM2 $J/\psi \rightarrow 4\pi\gamma$ 89B DM2 $J/\psi \rightarrow 4\pi\gamma$ 432+014+073¹⁴⁹ BISELLO $2.08 \pm 0.13 \pm 0.35$ 149 BALTRUSAIT...868 MRK3 $J/\psi
ightarrow 4\pi\gamma$ $3.05 \pm 0.08 \pm 0.45$ ¹⁵⁰ BURKE $4.85 \pm 0.45 \pm 1.20$ 82 MRK2 e⁺e⁻ $148~4\pi$ mass less than 3.0 GeV. $149~4\pi$ mass less than 2.0 GeV. $150~4\pi$ mass less than 2.5 GeV. WEIGHTED AVERAGE 2.8±0.5 (Error scaled by 1.9) BISELLO BISELLO 89B BALTRUSAIT... 86B DM2 BURKE 82 MRK2 (Confidence Level = 0.013) 4 10 $\Gamma(\gamma 2\pi^+ 2\pi^-)/\Gamma_{\text{total}} \text{ (units } 10^{-3})$ $\Gamma(\gamma f_2(1270) f_2(1270))/\Gamma_{\text{total}}$ Γ_{148}/Γ VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT 04M BES $J/\psi \rightarrow \gamma 2\pi^+ 2\pi^-$ ABLIKIM Γ_{149}/Γ $\Gamma(\gamma f_2(1270) f_2(1270) \text{ (non resonant)})/\Gamma_{\text{total}}$ DO CUMENT ID TECN COMMENT 151 ABLIKIM 8.2±0.8±1.7 04M BES $J/\psi
ightarrow \gamma 2\pi^+ 2\pi^ ^{151}\,\mathrm{Subtracting}$ contribution from intermediate $\eta_{C}(1S)$ decays. $\Gamma(\gamma K^+ K^- \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{150}/Γ VALUE (units 10^{-3}) EVTSDOCUMENT ID TECN COMMENT 00B BES $J/\psi \rightarrow \gamma K^+ K^0 \pi^+ \pi^ 2.1 \pm 0.1 \pm 0.6$ 1516 BAI $\Gamma(\gamma f_4(2050))/\Gamma_{\text{total}}$ Γ_{151}/Γ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 152 BALTRUSAIT...87 MRK3 $J/\psi \rightarrow \gamma \pi^+ \pi^ ^{152}\,\mathrm{Assuming}$ branching fraction $\mathit{f}_{4}(2050)\,\rightarrow\,\,\pi\,\pi/$ total $=\,0.167.$ $\Gamma(\gamma\omega\omega)/\Gamma_{\text{total}}$ Γ_{152}/Γ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 1.61±0.33 OUR AVERAGE $6.0 \pm 4.8 \pm 1.8$ 08A BES2 $J/\psi \rightarrow \gamma \omega \pi^+ \pi^ 1.41 \pm 0.2 \ \pm 0.42 \ 120 \pm 17$ BISELLO 87 SPEC e^+e^- , hadrons γ BALTRUSAIT...85c MRK3 $e^+e^- \rightarrow \text{hadrons} \gamma$ $1.76\pm0.09\pm0.45$ $\Gamma(\gamma\eta(1405/1475) \rightarrow \gamma\rho^0\rho^0)/\Gamma_{\text{total}}$ DOCUMENT ID

1.7 ±0.4 OUR AVERAGE Error includes scale factor of 1.3.

BUGG

153,154 BISELLO

 2.1 ± 0.4

 1.36 ± 0.38

 $^{\rm 153}\,{\rm Estimated}$ by us from various fits. 154 Includes unknown branching fraction to $ho^0
ho^0$. TECN COMMENT

89B DM2 $J/\psi
ightarrow 4\pi\gamma$

95 MRK3 $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$

 167 Included unknown branching fraction $f_1(1420)
ightarrow \kappa \overline{\kappa} \pi.$ 168 From fit to the $K^{*}(892)\, K\, \stackrel{-}{1}\, ^{+}\, +\, {
m partial}$ wave.

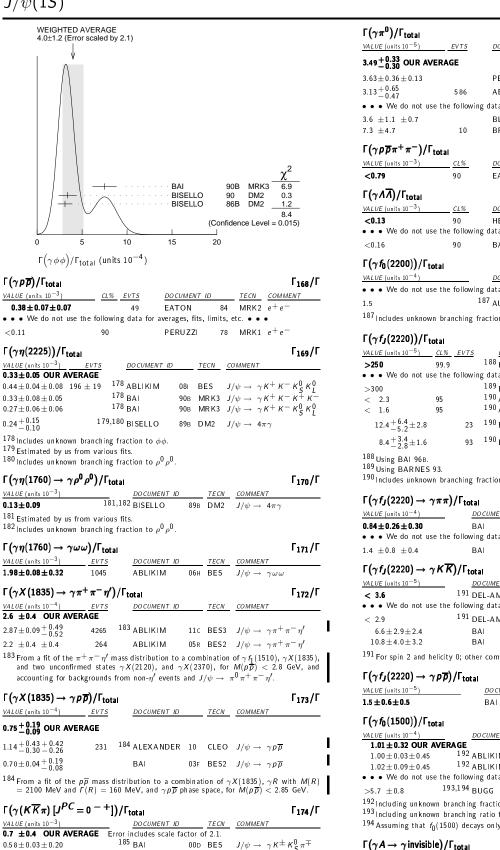
Meson Particle Listings $J/\psi(1S)$

| $\Gamma(\gamma f_2(1270))/\Gamma_{\text{total}}$ Γ_{154}/Γ | $\Gamma(\gamma f_1(1285))/\Gamma_{\text{total}}$ Γ_{160}/Γ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) DOCUMENT ID TECH COMMENT |
| 1.43±0.11 OUR AVERAGE | 0.61 ±0.08 OUR AVERAGE |
| $1.62 \pm 0.26 ^{+~0.02}_{-~0.05}$ 155 ABLIKIM 06V BES2 $e^+ e^- 	o J/\psi 	o \gamma \pi^+ \pi^-$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| $1.42\pm0.21^{+0.02}_{-0.04}$ 156 ABLIKIM 06V BES2 $e^+e^- ightarrow~J/\psi ightarrow~\gamma\pi^0\pi^0$ | 0.45 \pm 0.09 \pm 0.17 171 BAI 99 BES $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| $1.33\pm0.05\pm0.20$ 157 AUGUSTIN 87 DM2 $J/\psi ightarrow \gamma\pi^+\pi^-$ | $0.625 \pm 0.063 \pm 0.103$ 172 BOLTON 92 MRK3 $J/\psi 	o \gamma f_1(1285)$ |
| 1.36 \pm 0.09 \pm 0.23 | $0.70~\pm0.08~\pm0.16$ $173~{	t BOLTON}$ 928 MRK3 $J/\psi ightarrow \gamma\eta\pi^+\pi^-$ |
| $1.48\pm0.25\pm0.30$ 178 EDWARDS 82B CBAL $e^+e^- \rightarrow 2\pi^0\gamma$ 2.0 ±0.7 35 ALEXANDER 78 PLUT e^+e^- | $169 \text{ Assuming B}(f_1(1285) \to \rho^0 \gamma) = 0.055 \pm 0.013.$ |
| 1.2 \pm 0.6 30 158 BRANDELIK 78B DASP $e^+e^- \rightarrow \pi^+\pi^-\gamma$ | 1^{70} Assuming $\Gamma(f_1(1285) \to K\overline{K}\pi)/\Gamma_{	ext{total}} = 0.090 \pm 0.004.$ 1^{71} Assuming $\Gamma(f_1(1285) \to \eta\pi\pi)/\Gamma_{	ext{total}} = 0.5 \pm 0.18.$ |
| ABLIKIM 06v reports $\left[\Gamma\left(J/\psi(1S) \rightarrow \gamma f_2(1270)\right)/\Gamma_{total}\right] \times \left[B(f_2(1270) \rightarrow \pi\pi)\right] =$ | 172 Obtained summing the sequential decay channels |
| $(1.371\pm0.010\pm0.222)	imes10^{-3}$ which we divide by our best value B $(f_2(1270)	o\pi\pi)$ | $B(J/\psi \to \gamma f_1(1285), f_1(1285) \to \pi \pi \pi \pi) = (1.44 \pm 0.39 \pm 0.27) \times 10^{-4};$ |
| = $(84.8 \pm \frac{2.4}{1.2}) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $B(J/\psi \to \gamma f_1(1285), f_1(1285) \to a_0(980) \pi, a_0(980) \to \eta \pi) = (3.90 \pm 0.42 \pm 0.87) \times 10^{-4};$ |
| the systematic error from using our best value. $(156 \mathrm{ABLiKIM} 06 \mathrm{V} \mathrm{reports} [\Gamma(J/\psi(1S) 	o \gamma f_2(1270)) / \Gamma_{total}] \times [\mathrm{B}(f_2(1270) 	o \pi \pi)] = 0.56 \mathrm{ABLiKIM} (150 \mathrm{ABLiKIM} 150 \mathrm{ABLIKM} | $B(J/\psi \to \gamma f_1(1285), f_1(1285) \to a_0(980)\pi, a_0(980) \to K\overline{K}) = (0.66 \pm 0.26 \pm 0.26)\pi$ |
| $(1.200\pm0.027\pm0.174)	imes10^{-3}$ which we divide by our best value B $(f_2(1270) ightarrow\pi\pi)$ | 0.29) $\times 10^{-4}$; B($J/\psi \to \gamma f_1(1285), f_1(1285) \to \gamma \rho^0$) = $(0.25 \pm 0.07 \pm 0.03) \times 10^{-4}$. |
| = $(84.8 + 2.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is | 173 Using B($f_1(1285) \rightarrow a_0(980) \pi$) = 0.37, and including unknown branching ratio for |
| the systematic error from using our best value. 157 Estimated using B $(f_2(1270) 	o \pi\pi)$ =0.843 \pm 0.012. The errors do not contain the | $a_0(980) \rightarrow \eta \pi$. |
| uncertainty in the $f_2(1270)$ decay. | $\Gamma(\gamma f_1(1510) \rightarrow \gamma \eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ |
| ¹⁵⁸ Restated by us to take account of spread of E1, M2, E3 transitions. | VALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT |
| $\Gamma(\gamma f_0(1710) \to \gamma K \overline{K})/\Gamma_{\text{total}}$ Γ_{155}/Γ | 4.5 ± 1.0 ± 0.7 BAI 99 BES $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ |
| ALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT | $\Gamma(\gamma f_2'(1525))/\Gamma_{total}$ $\Gamma_{162}/\Gamma_{162}$ |
| 8.5 $\frac{+}{0.9}$ OUR AVERAGE Error includes scale factor of 1.2. | VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT |
| 9.62 ± 029 $^{+3.51}_{-1.86}$ 159 BAI 03G BES $J/\psi ightarrow \gamma K\overline{K}$ | 4.5 +0.7 OUR AVERAGE |
| 5.0 \pm 0.8 $^{+1.8}_{-0.4}$ 160,161 BAI 96c BES $J/\psi \rightarrow \gamma K^+ K^-$ | |
| 4.64 | $3.85\pm0.17^{+1.91}_{-0.73}$ 174 BAI 03G BES $J/\psi ightarrow \gamma K \overline{K}$ |
| 9.2 \pm 1.4 \pm 1.4 | 3.6 $\pm 0.4 ^{+1.4}_{-0.4}$ BAI 96c BES $J/\psi ightarrow \gamma {\it K}^+ {\it K}^-$ |
| 9.6 \pm 1.2 \pm 1.8 161 BALTRUSAIT87 MRK3 $J/\psi ightarrow \gamma K^+ K^-$ | 5.6 $\pm 1.4 \pm 0.9$ 174 AUGUSTIN 88 DM2 $J/\psi \rightarrow \gamma K^+ K^-$ |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | 4.5 \pm 0.4 \pm 0.9 174 AUGUSTIN 88 DM2 $J/\psi \rightarrow \gamma K_S^0 K_S^0$ |
| $1.6~\pm~0.2^{+~0.6}_{-~0.2}$ $161,162$ BAI 96c BES $J/\psi ightarrow~\gamma~K^+~K^-$ | 6.8 \pm 1.6 \pm 1.4 174 BALTRUSAIT87 MRK3 $J/\psi \rightarrow \gamma K^+ K^-$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $<$ 0.8 90 $\frac{163}{164}$ BISELLO 89B $J/\psi ightarrow 4\pi\gamma$ | <3.4 90 4 175 BRANDELIK 79C DASP $e^+e^- ightarrow \pi^+\pi^-\gamma$ |
| $1.6\pm0.4\pm0.3$ 164 BALTRUSAIT87 MRK3 $J/\psi \to \gamma\pi^+\pi^ 165$ EDWARDS 82D CBAL $e^+e^-\to\eta\eta\gamma$ | <2.3 90 3 ALEXANDER 78 PLUT $e^+e^- ightarrow K^+K^-\gamma$ |
| 3.8 \pm 1.6 POWARDS 82D CBAL $e^+e^- \to \eta\eta\gamma$ 159 Includes unknown branching ratio to K^+K^- or K^0_S K^0_S . | $174 \text{ Using B}(f_2'(1525) \to K\overline{K}) = 0.888.$ |
| 160 Assuming $J^P = 2^+$ for $f_0(1710)$. | 175 Assuming isotropic production and decay of the $f_2^\prime(1525)$ and isospin. |
| 61 Includes unknown branching fraction to K^+K^- or K^0_S K^0_S . We have multiplied K^+K^- | $\Gamma(\gamma f_2(1640) \rightarrow \gamma \omega \omega)/\Gamma_{\text{total}}$ |
| measurement by 2, and $K_S^0 K_S^0$ by 4 to obtain $K\overline{K}$ result. | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| 62 Assuming $J^P = 0^+$ for $f_0(1710)$. | 0.28\pm0.05\pm0.17 141 ABLIKIM 06H BES $J/\psi ightarrow \gamma \omega \omega$ |
| 63 includes unknown branching fraction to $ ho^0 ho^0$. 64 includes unknown branching fraction to $\pi^+\pi^-$. | $\Gamma(\gamma f_2(1910) \rightarrow \gamma \omega \omega)/\Gamma_{\text{total}}$ $\Gamma_{164}/\Gamma_{164}$ |
| Includes unknown branching fraction to $\pi^+\pi^-$. | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma(\gamma f_0(1710) \to \gamma \pi \pi)/\Gamma_{\text{total}}$ Γ_{156}/Γ | 0.20\pm0.04\pm0.13 151 ABLIKIM 06H BES $J/\psi ightarrow \gamma \omega \omega$ |
| (/-UC (units 10 ⁻⁴) DO CUMENT ID TECN COMMENT | $\Gamma(\gamma f_2(1950) \rightarrow \gamma K^*(892) \overline{K}^*(892)) / \Gamma_{\text{total}}$ $\Gamma_{165} / \Gamma_{165} |
| .0 ±1.0 OUR AVERAGE | $(7/2(1930) \rightarrow 7/(1932)/(1932))/(1932)/(1932)$ $VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT$ |
| .96 \pm 0.06 \pm 1.12 | 0.7 \pm 0.1 \pm 0.2 BAI 00B BES $J/\psi \rightarrow \gamma K^+ K^0 \pi^+ \pi^-$ |
| $1.99\pm0.15\pm2.64$ 1.66 ABLIKIM 06v BES2 $e^+e^- 	o J/\psi 	o \gamma \pi^0 \pi^0$ | |
| .5 $\pm 1.6~\pm 0.8$ BAI 98H BES $J/\psi ightarrow \gamma \pi^0 \pi^0$ | $\Gamma(\gamma K^*(892)\overline{K}^*(892))/\Gamma_{\text{total}}$ $\Gamma_{166}/\Gamma_{166}$ |
| 66 Including unknown branching fraction to $\pi\pi$. | $\frac{VALUE \text{ (units } 10^{-3})}{4.0 ± 0.3 ± 1.3}$ $\frac{EVTS}{320}$ $\frac{DOCUMENT ID}{176 BAI}$ $\frac{TECN}{00B}$ $\frac{COMMENT}{DES}$ $\frac{COMMENT}{J/ψ → γK^+K^0π^+π^-}$ |
| $\Gamma(\gamma f_0(1710) \rightarrow \gamma \omega \omega)/\Gamma_{total}$ Γ_{157}/Γ | 4.0 ± 0.3 ± 1.3 5.20 $^{-1.6}$ BAI 008 BES $J/\psi \rightarrow \gamma K^+ K^+ \pi^+ \pi^-$ 176 Summed over all charges. |
| $(7,0(17.10) \rightarrow 7000)/1 \text{ total}$ (ALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT | |
| 2000 ± 0.08 180 ABLIKIM 06H BES $J/\psi 	o \gamma \omega \omega$ | $\Gamma(\gamma\phi\phi)/\Gamma_{\text{total}}$ $\Gamma_{167}/\Gamma_{167}$ |
| | <u>VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT</u> 4.0±1.2 OUR AVERAGE Error includes scale factor of 2.1. See the ideogram below. |
| Γ ₁₅₈ /Γ | $7.5\pm0.6\pm1.2$ 168 BAI 90B MRK3 $J/\psi ightarrow \gamma$ 4 K |
| ALUE (units 10 ⁻³) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> .104±0.034 OUR AVERAGE | $3.4\pm0.8\pm0.6$ 33 ± 7 177 BISELLO 90 DM2 $J/\psi \rightarrow \gamma K^+ K^- K_S^0 K_L^0$ |
| $1.01\pm0.029\pm0.022$ PEDLAR 09 CLE3 $J/\psi ightarrow~\eta\gamma$ | $3.1\pm0.7\pm0.4$ 177 BISELLO 86B DM2 $J/\psi \rightarrow \gamma K^+ K^- K^+$ |
| .123 \pm 0.089 | $^{177}\phi\phi$ mass less than 2.9 GeV, $\eta_{\it C}$ excluded. |
| 1.88 ± 0.08 ± 0.11 BLOOM 83 CBAL e^+e^- | |
| 1.82 ± 0.10 BRANDELIK 79C DASP e^+e^- | |
| .3 \pm 0.4 21 BARTEL 77 CNTR e^+e^- | |
| $(\gamma f_1(1420) \rightarrow \gamma K \overline{K} \pi) / \Gamma_{\text{total}}$ Γ_{159} / Γ | |
| ALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | |
| .79±0.13 OUR AVERAGE | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| | |
| 187±0 1/1±0.14 10/ DAI and MDD 2 //-/ DU DT ± | |
| $0.87\pm0.14^{+0.14}_{-0.11}$ 167 BAI 90c MRK3 $J/\psi \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}$ | |

$J/\psi(1S)$

 $2.1 \pm 0.1 \pm 0.7$

 $^{185}\,\mathrm{For}$ a broad structure around 1800 MeV. $^{186}\,\mathrm{For}$ a broad structure around 2040 MeV.



00D BES $J/\psi \rightarrow \gamma K^{\pm} K_{S}^{0} \pi^{\mp}$

 Γ_{175}/Γ TECN COMMENT PEDLAR 09 CLE3 $J/\psi \rightarrow \pi^0 \gamma$ 06E BES2 $J/\psi \rightarrow \pi^0 \gamma$ ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet83 CBAL e+e-BLOOM BRANDELIK 79C DASP $e^+e^ \Gamma_{176}/\Gamma$ DO CUMENT ID TECN COMMENT EATON 84 MRK2 e+e- Γ_{177}/Γ DOCUMENT ID TECN COMMENT HENRARD 87 DM2 e+eullet ullet We do not use the following data for averages, fits, limits, etc. ullet ulletBAI 986 BES e+e- Γ_{178}/Γ DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • ¹⁸⁷ AUGUSTIN 88 DM2 $J/\psi \rightarrow \gamma \kappa_S^0 \kappa_S^0$ 187 Includes unknown branching fraction to $K_S^0 K_S^0$. Γ_{179}/Γ DOCUMENT ID TECN COMMENT 188 HASAN 96 SPEC $\overline{p}p \rightarrow \pi^+\pi^ \bullet$ \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 23 190 BALTRUSAIT...86D MRK3 $J/\psi \rightarrow \gamma K_S^0 K_S^0$ 93 190 BALTRUSAIT...86D MRK3 $J/\psi
ightarrow \gamma \, {\it K}^+ \, {\it K}^-$ ¹⁹⁰ Includes unknown branching fraction to K^+K^- or $K^0_SK^0_S$. Γ_{180}/Γ DO CUMENT ID TECN COMMENT 96B BES $e^+e^- \rightarrow J/\psi \rightarrow \gamma \pi^+\pi^-$ • • • We do not use the following data for averages, fits, limits, etc. • • • 98H BES $J/\psi
ightarrow \gamma \pi^0 \pi^0$ Γ_{181}/Γ DOCUMENT ID TECN COMMENT 191 DEL-AMO-SA...100 BABR $e^+e^- o ext{ } J/\psi o au$ K $^+$ K $^-$ • • • We do not use the following data for averages, fits, limits, etc. • • • 191 DEL-AMO-SA...100 BABR $e^+\,e^ightarrow~J/\psi
ightarrow~\gamma\,\kappa_S^0\,\kappa_S^0$ 96B BES $e^+e^- \rightarrow J/\psi \rightarrow \gamma K^+K^-$ 96B BES $e^+e^- \rightarrow J/\psi \rightarrow \gamma K_S^0 K_S^0$ $^{191}\mathrm{For}$ spin 2 and helicity 0; other combinations lead to more stringent upper limits. Γ_{182}/Γ DOCUMENT ID TECN COMMENT 96B BES $e^+e^- \rightarrow J/\psi \rightarrow \gamma p \overline{p}$ BAI Γ_{183}/Γ DOCUMENT ID TECN COMMENT ¹⁹² ABLIKIM 06v BES2 $e^+\,e^ightarrow~J/\psi
ightarrow~\gamma\,\pi^+\pi^-$ ¹⁹² ABLIKIM 06V BES2 $e^+e^- \rightarrow J/\psi \rightarrow \gamma\pi^0\pi^0$ ● • We do not use the following data for averages, fits, limits, etc. ^{193,194} BUGG 95 MRK3 $J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^ ^{192} {\rm Including}$ unknown branching fraction to $\pi \, \pi.$ 193 Including unknown branching ratio for $f_0(1500) \rightarrow \pi^+\pi^-\pi^+\pi^-$. $^{194}\,\mathrm{Assuming}$ that $f_0(1500)$ decays only to two S-wave dipions. $\Gamma(\gamma A \rightarrow \gamma \text{invisible})/\Gamma_{\text{total}}$ Γ_{184}/Γ (narrow state A with m_A < 960 MeV) VALUE (units 10-6) CL% DOCUMENT ID TECN COMMENT 90 ¹⁹⁵ INSLER 10 CLEO $e^+e^ightarrow\pi^+\pi^-J/\psi$ 195 The limit varies with mass m_A of a narrow state A and is 4.3 $\times\,10^{-6}$ for $m_A=0$ MeV, reaches its largest value of 6.3 $\times\,10^{-6}$ at $m_A=500$ MeV, and is 3.6 $\times\,10^{-6}$ at $m_A=600$ MeV,

| | | · WEAK DECAYS · | | _ | AUBERT | 07AU | PR D76 092005 | B. Aubert et al. | (BABAR Collab.) |
|---------------------------------------------------------------------------------------|-------------------------------------|-------------------------------------------------------------|-------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|--------------------|-------------------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------|
| $\Gamma(D^-e^+\nu_e + \text{c.c.})/$ | /Ftotal | | | Γ ₁₈₅ /Γ | Also AUBERT | | PR D76 092006 | (errat.) B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| VALUE (units 10 ⁻⁵) | CL%_ | DOCUMENT ID | TECN | | ABLIKIM ABLIKIM | 06 C | PL B632 181 PL B633 681 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| <1.2 | 90 | | BES2 | $e^+ e^- \rightarrow J/\psi$ | ABLIKIM ABLIKIM | 06E 06F | PR D73 052008 PR D73 052007 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| $\Gamma(\overline{D}{}^0 e^+ e^- + \text{c.c.})/$ | /г | | | Γ ₁₈₆ /Γ | ABLIKIM ABLIKIM | 06H 06K | PR D73 112007 PRL 97 062001 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES2 Collab.) |
| VALUE (units 10 ⁻⁵) | | DOCUMENT ID | TECN | COMMENT | ABLIKIM ABLIKIM | 06 M | PL B639 418 PL B642 441 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| <1.1 | 90 | | | $e^+e^- \rightarrow J/\psi$ | ADAMS AUBERT | 06A 06B | PR D73 051103R PR D73 012005 | B. Aubert et al. | (CLEO Collab.) (BABAR Collab.) |
| $\Gamma(D_s^-e^+\nu_e$ + c.c.)/ | /F | | | г /г | AUBERT AUBERT | 06 D | PR D73 052003 PRL 96 052002 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| $\frac{VALUE \text{ (units } 10^{-5}\text{)}}{VALUE \text{ (units } 10^{-5}\text{)}}$ | | DOCUMENT ID | TECN | Γ ₁₈₇ /Γ | AUBERT,BE WU ABLIKIM | 06 D 06 05 | PR D74 091103R PRL 97 162003 PL B607 243 | B. Aubert <i>et al.</i> CH. Wu <i>et al.</i> M. Ablikim <i>et al.</i> | (BABAR Collab.) (BELLE Collab.) |
| <3.6 | 90 1 | | | $e^+e^- \rightarrow J/\psi$ | ABLIKIM ABLIKIM | 05 B 05 C | PR D71 032003 PL B610 192 | M. Ablikim et al. M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) (BES Collab.) |
| 196 Using B($D_s^- \rightarrow \phi$ | $\pi^{-}) = 4.4$ | ± 0.5 %. | | | ABLIKIM ABLIKIM | 05 H 05 R | PR D72 012002 PRL 95 262001 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| 5 | | | | F /F | AUBERT | 05 D 05 C | PR D71 052001 PR D71 111103 | B. Aubert et al. Z. Li et al. | (BABAR Collab.) (CLEO Collab.) |
| $\Gamma(D^-\pi^+ + \text{c.c.})/\Gamma_b$ | otal <u>CL%</u> | DO CUMENT ID | TECN | Γ ₁₈₈ /Γ | ABLIKIM ABLIKIM | 04 04 M | PL B598 172 PR D70 112008 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| <7.5 × 10 ⁻⁵ | 90 | | | $e^+e^- \rightarrow J/\psi$ | AUBERT AUBERT,B | 04 04 N | PR D69 011103 PR D70 072004 | B. Aubert <i>et al.</i> B. Aubert <i>et al.</i> | (BaBar Collab.) (BABAR Collab.) |
| $\Gamma(\overline{D}^0\overline{K}^0 + \text{c.c.})/\Gamma_{\text{to}}$ | | | | Γ ₁₈₉ /Γ | BAI BAI | 04 04 A | PL B578 16 PR D69 012003 | J.Z. Bai et al. J.Z. Bai et al. | ` (BES Collab.) (BES Collab.) |
| | otal <u>CL%</u> | DOCUMENT ID | TECN | | BAI BAI | 04 D 04 E | PL B589 7 PL B591 42 | J.Z. Baietal. J.Z. Baietal. | (BES Collab.) (BES Collab.) |
| <u>∨ALUE</u> <1.7 × 10 ⁻⁴ | 90 | | | $e^+ e^- \rightarrow J/\psi$ | BAI BAI | 04 G 04 H | PR D70 012004 PR D70 012005 | J.Z. Baietal. J.Z. Baietal. | (BES Collab.) (BES Collab.) |
| $\Gamma(D_s^-\pi^+ + \text{c.c.})/\Gamma_t$ | | | | Γ ₁₉₀ /Γ | BAI SETH | 04 J 04 | PL B594 47 PR D69 097503 | J.Z. Bai <i>et al.</i> K.K. Seth | (BES Collab.) |
| VALUE <1.3 × 10 ⁻⁴ | .OLAI <u>CL%</u> | DOCUMENT ID | TECN | COMMENT | AULCHENKO BAI | 03 03 D | PL B573 63 PL B561 49 | V.M. Aulchenko et al. J.Z. Baiet al. | (KEDR Collab.) (BES Collab.) |
| $<1.3 \times 10^{-4}$ | 90 | ABLIKIM 08J | BES2 | $e^+ e^- ightarrow \; J/\psi$ | BAI BAI | 03 F 03 G | PRL 91 022001 PR D68 052003 | J.Z. Bai et al. J.Z. Bai et al. | (BÉS II Collab.) (BES Collab.) |
| $\Gamma(\gamma\gamma)/\Gamma_{total}$ | | | | Γ ₁₉₁ /Γ | HUANG BAI ARTAMONOV | 03 02 C | PRL 91 241802 PRL 88 101802 PL B474 427 | HC. Huang et al. J.Z. Bai et al. | (BÈLLE Collab.) (BES Collab.) |
| VALUE (units 10 ⁻⁵) | CL% | DO CUMENT ID | TECN | COMMENT | ARTAMONOV BAI BAI | 00 00 00 B | PL B474 427 PRL 84 594 PL B472 200 | A.S. Artamonov et al. J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| < 0.5 | 90 | | | $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ | BAI BAI | 00 D 99 | PL B476 25 PL B446 356 | J.Z. Bai et al. J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) (BES Collab.) |
| • • • We do not use t | | | | etc. $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ulle$ | BAI BAI | 99 C 98 D | PRL 83 1918 PR D58 092006 | J.Z. Bai et al. J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| <16 < 2.2 | 90 ¹ | | | $\psi(2S) \rightarrow K^+ \gamma \gamma$ $\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$ | BAI BAI | 98 G 98 H | PL B424 213 PRL 81 1179 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| < 50 | 90 | BARTEL 77 | CNTR | e+ e- | BALDINI ARMSTRONG | 98 | PL B444 111 PR D54 7067 | R. Baldini et al. T.A. Armstrong et al. | (FENICE Collab.) (E760 Collab.) |
| ¹⁹⁷ WICHT 08 reports | $[\Gamma(J/\psi(1S)]$ | $\rightarrow \gamma \gamma)/\Gamma_{total} \times [B]$ | (B ⁺ → | $J/\psi(15) \ K^+)] < 0.16 \times$ | BAI BAI | 96 B 96 C | PRL 76 3502 PRL 77 3959 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| | | best value B($B^+ 	o J$ | | | BAI GRIBUSHIN | 96 D 96 | PR D54 1221 PR D53 4723 | J.Z. Bai et al. A. Gribushin et al. | (BES Collab.) (E672 Collab., E706 Collab.) |
| LEPTON | FAMILY | NUMBER (LF) VI | OLATIN | IG MODES —— | HASAN BAI | 96 95 B | PL B388 376 PL B355 374 | A. Hasan, D.V. Bugg J.Z. Bai <i>et al</i> . | (BRUN, LOQM) (BES Collab.) |
| $\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{ m total}$ | | | | Γ ₁₉₂ /Γ | BUGG ANTONELLI | 95 93 | PL B353 378 PL B301 317 | D.V. Bugg <i>et al.</i> A. Antonelli <i>et al.</i> | (LOQM, PNPI, WASH) (FENICE COllab.) |
| VALUE (units 10 ⁻⁶) | CL% | DOCUMENT ID | TECN | COMMENT | ARMSTRONG BARNES | 93 | PR D47 772 PL B309 469 | T.A. Armstrong et al. P.D. Barnes et al. | (FNÀL E760 Collab.) (PS 185 Collab.) |
| <1.1 | 90 | BAI 03D | BES | $e^+ e^- 	o J/\psi$ | AUGUSTIN BOLTON | 92 92 | PR D46 1951 PL B278 495 | J.E. Augustin, G. Cosme T. Bolton <i>et al</i> . | (Mark III Collab.) |
| $\Gamma(e^{\pm}	au^{\mp})/\Gamma_{ m total}$ | | | | Γ ₁₉₃ /Γ | BOLT ON COFFMAN | 92 B 92 | PRL 69 1328 PRL 68 282 | T. Bolton et al. D.M. Coffman et al. | (Mark III Collab.) (Mark III Collab.) |
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | HSUEH BISELLO | 92 91 | PR D45 R2181 NP B350 1 | S. Hsueh, S. Palestini D. Bisello <i>et al</i> . | (FNAL, TORI) (DM2 Collab.) |
| <8.3 | 90 | ABLIKIM 04 | BES | $e^+ e^- 	o J/\psi$ | AUGUSTIN BAI BAI | 90 90 B 90 C | PR D42 10 PRL 65 1309 PRL 65 2507 | J.E. Augustin et al. Z. Bai et al. Z. Bai et al. | (DM2 Collab.) (Mark III Collab.) (Mark III Collab.) |
| $\Gamma(\mu^{\pm} 	au^{\mp})/\Gamma_{ m total}$ | | | | Г ₁₉₄ /Г | BISELLO COFFMAN | 90 90 | PL B241 617 PR D41 1410 | D. Bisello et al. D.M. Coffman et al. | (Mark III Collab.) (DM2 Collab.) (Mark III Collab.) |
| VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TECN | COMMENT | JOUSSET ALEXANDER | 90 89 | PR D41 1389 NP B320 45 | J. Jousset <i>et al.</i> J.P. Alexander <i>et al.</i> | (DM2 Collab.) (LBL, MICH, SLAC) |
| <2.0 | 90 | ABLIKIM 04 | BES | $e^+ e^- 	o J/\psi$ | AUGUSTIN BISELLO | 89 89B | NP B320 1 PR D39 701 | J.E. Augustin, G. Cosme G. Busetto <i>et al.</i> | (DM2 Collab.) (DM2 Collab.) |
| | | OTHER DECAYS | | _ | AUGUSTIN COFFMAN | 88 88 | PRL 60 2238 PR D38 2695 | J.E. Augustin et al. D.M. Coffman et al. | (DM2 Collab.) (Mark III Collab.) |
| $\Gamma(\text{invisible})/\Gamma(\mu^+\mu$ | ·-) | | | Γ ₁₉₅ /Γ ₇ | FALVARD AUGUSTIN | 88 87 | PR D38 2706 ZPHY C36 369 | A. Falvard <i>et al.</i> J.E. Augustin et al. | (CLER, FRAS, LALO+) (LALO, CLER, FRAS+) |
| VALUE | <u>CL%</u> | DOCUMENT ID | TECN | COMMENT | BA GLIN BA LT RUS AIT . | 87 | NP B286 592 PR D35 2077 | C. Baglin <i>et al.</i> R.M. Baltrusaitis <i>et al.</i> | (LAPP, ČERN, GENO, LYON+) (Mark III Collab.) |
| <1.2 × 10 ⁻² | 90 | ABLIKIM 08G | BES2 | $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ | BECKER BISELLO | 87 87 | PRL 59 186 PL B192 239 | J.J. Becker <i>et al.</i> D. Bisello <i>et al.</i> E.R. Cohen, B.N. Taylor | (Mark III Collab.) (PADO, CLER, FRAS+) |
| | - 1/ | ψ(1S) REFERENCI | FS | | COHEN HENRARD | 87 87 | RMP 59 1121 NP B292 670 | P. Henrard et al. | (CLER, FRAS, LALO+) |
| | | | | | PALLIN BALT RUS AIT. | . 86 | NP B292 653 PR D33 629 | D. Pallin et al. R.M. Baltrusaitis et al. | (CLER, FRAS, LALO, PADO) (Mark III Collab.) |
| ABLIKIM 11C PRL | 083 012003 106 072002 | M. Ablikim et al. M. Ablikim et al. | | (BES III Collab.) (BES III Collab.) | BALTRUSAIT. BALTRUSAIT. | 86 D | PR D33 1222 PRL 56 107 | R.M. Baltrusaitis <i>et al.</i> R.M. Baltrusaitis D. Bisello <i>et al.</i> | (Mark III Collab.) (CIT, UCSC, ILL, SLAC+) |
| ABLIKIM 10C PL B | 083 032003 685 27 | M. Ablikim <i>et al.</i> M. Ablikim <i>et al.</i> | | (BES III Collab.) (BES II Collab.) | BISELLO GAISER | 86B 86 | PL B179 294 PR D34 711 | J. Gaiser et al. | (DM2 Collab.) (Crystal Ball Collab.) |
| ALEXANDER 10 PR D | 693 88 082 092002 | M. Ablikim <i>et al.</i> J.P. Alexander <i>et al.</i> | | (BES II Collab.) (CLEO Collab.) | BALTRUSAIT. BALTRUSAIT. | 85 D | PRL 55 1723 PR D32 566 | R.M. Baltrusaitis et al. R.M. Baltrusaitis et al. | (CIT, UCSC+) (CIT, UCSC+) |
| DEL-AMO-SA 100 PRL | 685 134 105 172001 | V.V. Anashin <i>et al.</i> P. del Amo Sanchez | et al. | (KEDR Collab.) (BABAR Collab.) | KURAEV BALTRUSAIT. | 85 84 | SJNP 41 466 Translated from Y PRL 52 2126 | E.A. Kuraev, V.S. Fadin AF 41 733. R.M. Baltrusaitis <i>et al.</i> | ` (NOVO) (CIT, UCSC+) |
| ABLIKIM 09 PL B | 081 091101R 676 25 | J. Insler et al. M. Ablikim et al. | | (CLEO Collab.) (BES Collab.) | EAT ON BLOOM | 84 | PR D29 804 ARNS 33 143 | M.W. Eaton et al. E.D. Bloom. C. Peck | (LBL, SLAC) |
| MITCHELL 09 PRL | 080 052004 102 011801 | M. Ablikim et al. R.E. Mitchell et al. | | (BES2 Collab.) (CLEO Collab.) | EDWARDS FRANKLIN | 83 B 83 | PRL 51 859 PRL 51 963 | C. Edwards et al. M.E.B. Franklin et al. | (SLAC, CIT) (CIT, HARV, PRIN+) (LBL, SLAC) |
| SHEN 09 PR D | 079 111101 080 031101R C53 15 | T.K. Pedlar et al. C.P. Shen et al. M. Ablikim et al. | | (CLEO Collab.) (BELLE Collab.) (BES Collab.) | BURKE EDWARDS | 82 82 B | PRL 49 632 PR D25 3065 | D.L. Burke et al. C. Edwards et al. | (LBL, SLAC) (CIT, HARV, PRIN+) |
| ABLIKIM 08A PR D | 077 012001 659 789 | M. Ablikim et al. M. Ablikim et al. | | (BES Collab.) (BES Collab.) | EDWARDS Also | 82 D | PRL 48 458 ARNS 33 143 | C. Edwards <i>et al.</i> E.D. Bloom, C. Peck | (CIT, HARV, PRIN+) (SLAC, CIT) |
| ABLIKIM 08E PR D |)77 032005 100 102003 | M. Ablikim et al. M. Ablikim et al. | | (BES Collab.) (BES Collab.) | EDWARDS LEMOIGNE | 82 E 82 | PRL 49 259 PL 113B 509 | C. Edwards <i>et al.</i> Y. Lemoigne <i>et al.</i> | (CIT, HARV, PRIN+) (SACL, LOIC, SHMP+) |
| ABLIKIM 08G PRL | 100 192001 100 192001 | M. Ablikim et al. M. Ablikim et al. | | (BES Collab.) (BES Collab.) | BESCH GIDAL | 81 81 | ZPHY C8 1 PL 107B 153 | H.J. Besch et al. G. Gidal et al. | (BONN, DESY, MANZ) (SLAC, LBL) |
| ABLIKIM 08J PL B | 663 297 078 092005 | M. Ablikim et al. M. Ablikim et al. | | (BES Collab.) (BES Collab.) | PARTRIDGE SCHARRE | 80 80 | PRL 44 712 PL 97B 329 | R. Partridge et al. D.L. Scharre et al. | (CIT, HARV, PRIN+) (SLAC LBL) |
| ADAMS 08 PRL | 101 101801)77 092002 | G.S. Adams et al. B. Aubert et al. | | (CLEO Collab.) (BABAR Collab.) | ZHOLENT Z Also | 80 | PL 96B 214 SJNP 34 814 | A.A. Zholents et al. A.A. Zholents et al. | (NOVO) (NOVO) |
| BESS ON 08 PR D PDG 08 PL B | 078 032012 667 1 | D. Besson et al. C. Amsler et al. | | (CLEO Collab.) (PDG Collab.) | BRANDELIK | 79 C | Translated from Y ZPHY C1 233 | R. Brandelik <i>et al</i> . | (DASP Collab.) |
| WICHT 08 PL B ABLIKIM 07H PR D | 662 323 076 092003 | J. Wicht et al. M. Ablikim et al. | | (BÉLLE Collab.) (BES Collab.) | ALEXANDER BESCH | 78 78 78 B | PL 72B 493 PL 78B 347 | G. Alexander <i>et al.</i> H.J. Besch <i>et al.</i> B. Brandelik <i>et al.</i> | (DESY, HAMB, SIEG+) (BONN, DESY, MANZ) |
| ABLIKIM 07J PR D ANDREOTTI 07 PL B |)76 117101 654 74 | M. Ablikim <i>et al.</i> M. Andreotti <i>et al.</i> | | (BES Collab.) (Femilab E835 Collab.) | BRANDELIK PERUZZI BARTEL | 78 B 78 77 | PL 74B 292 PR D17 2901 PL 66B 489 | R. Brandelik et al. I. Peruzzi et al. W. Bartel et al. | (DASP Collab.) (SLAC, LBL) (DESY, HEIDP) |
| AUBERT 07AK PR D | | B. Aubert et al. | | ` (BABAR Collab.) | DARIEL | " | r L VOD 489 | w. Dallel et al. | (DEST, HEIDP) |

$J/\psi(1S)$, Branching Ratios of ψ 's and χ 's, $\chi_{c0}(1P)$

| BURMESTER | 77 D | PL 72B 135 | J. Burmester et al. | (DESY, HAMB, SIEG+) |
|-------------|------|--------------|-------------------------|---------------------|
| FELDMAN | 77 | PRPL 33C 285 | G.J. Feldman, M.L. Perl | (LBL, SLAC) |
| VANNUCCI | 77 | PR D15 1814 | F. Vannucci et al. | (SLAC, LBL) |
| BARTEL | 76 | PL 64B 483 | W. Bartel et al. | (DÈSY, HEIDP) |
| BRAUNSCH | 76 | PL 63B 487 | W. Braunschweig et al. | (DASP Collab.) |
| JEAN-MARIE | 76 | PRL 36 291 | B. Jean-Marie et al. | `(SLAC, LBL)IG |
| BALDINI | 75 | PL 58B 471 | R. Baldini-Celio et al. | (FRAS, ROMA) |
| BOYARSKI | 75 | PRL 34 1357 | A.M. Boyarski et al. | ` (SLAC, LBL) JPC |
| DASP | 75 | PL 56B 491 | W. Braunschweig et al. | (DASP Collab.) |
| ES POS IT O | 75 B | LNC 14 73 | B. Esposito et al. | (FRAS, NAPL, PADO+) |
| FORD | 75 | PRL 34 604 | R.L. Ford et al. | (SLAC, PENN) |

BRANCHING RATIOS OF $\psi(2S)$ AND $\chi_{c0,1,2}$

Updated May 2012 by J.J. Hernández-Rey (IFIC, Valencia), S. Navas (University of Granada), and C. Patrignani (INFN, Genova)

Since 2002, the treatment of the branching ratios of the $\psi(2S)$ and $\chi_{c0,1,2}$ has undergone an important restructuring.

When measuring a branching ratio experimentally, it is not always possible to normalize the number of events observed in the corresponding decay mode to the total number of particles produced. Therefore, the experimenters sometimes report the number of observed decays with respect to another decay mode of the same or another particle in the relevant decay chain. This is actually equivalent to measuring combinations of branching fractions of several decay modes.

To extract the branching ratio of a given decay mode, the collaborations use some previously reported measurements of the required branching ratios. However, the values are frequently taken from the Review of Particle Physics (RPP), which in turn uses the branching ratio reported by the experiment in the following edition, giving rise either to correlations or to plain vicious circles Ref. 1, Ref. 2 as discussed in more detail in earlier editions of this mini-review.

The way to avoid these dependencies and correlations is to extract the branching ratios through a fit that uses the truly measured combinations of branching fractions and partial widths. This fit, in fact, should involve decays from the four concerned particles, $\psi(2S)$, χ_{c0} , χ_{c1} , and χ_{c2} , and occasionally some combinations of branching ratios of more than one of them. This is what is done since the 2002 edition [3].

The PDG policy is to quote the results of the collaborations in a manner as close as possible to what appears in their original publications. However, in order to avoid the problems mentioned above, we had in some cases to work out the values originally measured, using the number of events and detection efficiencies given by the collaborations, or rescaling back the published results. The information was sometimes spread over several articles, and some articles referred to papers still unpublished, which in turn contained the relevant numbers in footnotes.

Even though the experimental collaborations are entitled to extract whatever branching ratios they consider appropriate by using other published results, we would like to encourage them to also quote explicitly in their articles the actual quantities measured, so that they can be used directly in averages and fits of different experimental determinations.

To inform the reader how we computed some of the values used in this edition of RPP, we use footnotes to indicate the branching ratios actually given by the experiments and the quantities they use to derive them from the true combination of branching ratios actually measured.

None of the branching ratios of the $\chi_{c0,1,2}$ are measured independently of the $\psi(2S)$ radiative decays. We tried to identify those branching ratios which can be correlated in a non-trivial way, and although we cannot preclude the existence of other cases, we are confident that the most relevant correlations have already been removed. Nevertheless, correlations in the errors of different quantities measured by the same experiment have not been taken into account.

FIT INFORMATION

This is an overall fit to 4 total widths, 1 partial width, 25 combinations of partial widths, 7 branching ratios, and 77 combinations of branching ratios. Of the latter 57 involve decays of more than one particle.

The overall fit uses 223 measurements to determine 49 parameters and has a χ^2 of 312.2 for 174 degrees of freedom.

The relatively high χ^2 of the fit, 1.8 per d.o.f., can be traced back to a few specific discrepancies in the data. No rescaling of errors has been applied.

In the listing we provide the correlation coefficients $<\delta x_i \delta x_i>/(\delta x_i \cdot \delta x_i)$, in percent, from the fit to the corresponding parameter x_i .

References

- 1. Y.F. Gu and X.H. Li, Phys. Lett. **B449**, 361 (1999).
- C. Patrignani, Phys. Rev. **D64**, 034017 (2001).
- Particle Data Group, K.Hagiwara et al., Phys. Rev. D68, 010001 (2002).

$$\chi_{c0}(1P)$$

$$I^{G}(J^{PC}) = 0^{+}(0^{+})$$

| | | $\chi_{c0}(1P)$ MA | SS | | |
|--------------------------------------------|--------------|-------------------------|----------|------------|-----------------------------------------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 3414.75 ± 0.31 OUR | AVERAGE | | | | |
| $3414.2 \pm 0.5 \pm 2.3$ | 5.4k | UEHARA | 80 | BELL | $\gamma \gamma \rightarrow \chi_{c0} \rightarrow hadrons$ |
| 3406 \pm 7 \pm 6 | 230 | ¹ ABE | 07 | BELL | $e^+ e^- \rightarrow J/\psi(c\overline{c})$ |
| $3414.21 \pm 0.39 \pm 0.27$ | | ABLIKIM | 05 G | BES2 | $\psi(2S) \rightarrow \gamma \chi_{C0}$ |
| $3414.7 \ \ ^{+}_{-} \ \ 0.7 \ \ \pm 0.2$ | | ² ANDREOTTI | 03 | E835 | $\overline{p}p \rightarrow \chi_{c0} \rightarrow \pi^0\pi^0$ |
| $3415.5 \pm 0.4 \pm 0.4$ | 392 | ³ BAGNASCO | 02 | E835 | $\overline{p}p \rightarrow \chi_{C0} \rightarrow J/\psi \gamma$ |
| 3417.4 $^{+}_{-}$ $^{1.8}_{1.9}$ ± 0.2 | | ² AMBROGIANI | 99B | E835 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| $3414.1 \pm 0.6 \pm 0.8$ | | BAI | 99B | BES | $\psi(2S) \rightarrow \gamma X$ |
| $3417.8 \pm 0.4 \pm 4$ | | ² GAISER | | | |
| 3416 \pm 3 \pm 4 | | ⁴ TANENBAUM | 78 | MRK1 | e^+e^- |
| ● ● We do not use | the followin | ng data for average | es, fits | s, limits, | etc. • • • |
| 3416.5 ± 3.0 | | EISENSTEIN | 01 | CLE2 | $e^+e^- \rightarrow e^+e^-\chi_{c0}$ |
| 3422 ± 10 | | ⁴ BARTEL | 78B | CNTR | $e^+ e^- \rightarrow J/\psi 2\gamma$ |
| 3415 ± 9 | | ⁴ BIDDICK | 77 | CNTR | $e^+ e^- \rightarrow \gamma X$ |
| ¹ From a fit of the . | I/ψ recoil r | nass spectrum. Su | perse | des ABE | K 02 and ABE 04G. |

$\chi_{c0}(1P)$ WIDTH

| VALUE (MeV) 10.4±0.6 OUR FIT | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|----------|---------------------|---------|--------|--------------------------------------------------------------|
| 10.5 ± 0.8 OUR AVER | AGE Erro | r includes scale fa | ctor of | f 1.1. | |
| $10.6\!\pm\!1.9\!\pm\!2.6$ | 5.4k | UEHARA | 80 | BELL | $\gamma \gamma ightarrow \chi_{c0} ightarrow { m hadrons}$ |
| $12.6 {}^{+ 1.5}_{- 1.6} {}^{+ 0.9}_{- 1.1}$ | | ABLIKIM | 05 G | BES2 | $\psi(2S) \rightarrow \gamma \chi_{C0}$ |
| $8.6 + 1.7 \pm 0.1$ | | ANDREOTTI | 03 | E835 | $\overline{p}p \rightarrow \chi_{c0} \rightarrow \pi^0\pi^0$ |

²Using mass of $\psi(2S) = 3686.0$ MeV.

³ Recalculated by ANDREOTTI 05A, using the value of $\psi(2S)$ mass from AULCHENKO 03 Mass value shifted by us by amount appropriate for $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.

 $\chi_{c0}(1P)$

| 9.7 ± 1.0 | 392 | ⁵ BAGNASCO | 02 | E835 | $\overline{p}p \rightarrow \chi_{C0} \rightarrow J/\psi \gamma$ |
|--------------------------------|-----------|-----------------------|-----|------|-----------------------------------------------------------------|
| $16.6^{+5.2}_{-3.7}\pm0.1$ | | AMBROGIANI | 99B | E835 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| $14.3\!\pm\!2.0\!\pm\!3.0$ | | BAI | 981 | BES | $\psi(2S) \rightarrow \gamma \pi^{+} \pi^{-}$ |
| $13.5 \pm 3.3 \pm 4.2$ | | GAISER | 86 | CBAL | $\psi(2S) \rightarrow \gamma X, \gamma \pi^0 \pi^0$ |
| ⁵ Recalculated by A | ANDREOTTI | 05A. | | | |
| | | | | | |

$\chi_{c0}(1P)$ DECAY MODES

Scale factor/

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------|----------------------|
| | Hadronic | decays | |
| Γ_1 | $2(\pi^{+}\pi^{-})$ | (2.26 ± 0.19) % | |
| Γ ₂ | $\rho^0 \pi^+ \pi^-$ | $(8.8 \pm 2.8) \times 10$ | -3 |
| Γ3 | $\rho^0 \rho^0$ | (0.0 12.0) × 10 | |
| Γ ₄ | $f_0(980) f_0(980)$ | $(6.7 \pm 2.1) \times 10$ | -4 |
| Γ ₅ | $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ | (3.4 ± 0.4) % | |
| Γ ₆ | $ ho^{+} \pi^{-} \pi^{0} + \text{c.c.}$ | (2.9 ± 0.4) % | |
| Γ ₇ | $4\pi^{0}$ | $(3.3 \pm 0.4) \times 10$ | -3 |
| Γ8 | $\pi^+\pi^-$ K $^+$ K $^-$ | (1.79 ± 0.15) % | |
| Γ9 | $K_0^*(1430)^0\overline{K}_0^*(1430)^0 ightarrow \pi^+\pi^-K^+K^-$ | $(9.9 \ ^{+}_{-}\overset{4}{2}.\overset{0}{9}\) \times 10$ | -4 |
| Γ ₁₀ | $K_0^*(1430)^0\overline{K}_2^*(1430)^0 + \text{c.c.} \rightarrow \pi^+\pi^-K^+K^-$ | $(8.1 \begin{array}{c} +2.0 \\ -2.4 \end{array}) \times 10$ | -4 |
| Γ ₁₁ | $K_1(1270)^+ K^- + \text{c.c.} \rightarrow \pi^+ \pi^- K^+ K^-$ | $(6.3~\pm1.9~)\times10$ | -3 |
| Γ ₁₂ | $K_1(1400)^+ K^- + \text{c.c.} \rightarrow \pi^+ \pi^- K^+ K^-$ | < 2.7 × 10 | -3 CL=90% |
| Γ ₁₃ | $f_0(980) f_0(980)$ | $(1.6 \begin{array}{c} +1.1 \\ -0.9 \end{array}) \times 10$ | |
| Γ ₁₄ | $f_0(980) f_0(2200)$ | $(8.0 \begin{array}{c} +2.0 \\ -2.5 \end{array}) \times 10$ | -4 |
| Γ_{15} | $f_0(1370) f_0(1370)$ | < 2.8 × 10 | |
| Γ_{16} | $f_0(1370) f_0(1500)$ | < 1.7 × 10 | -4 CL=90% |
| Γ_{17} | $f_0(1370) f_0(1710)$ | $(6.8 \begin{array}{c} +4.0 \\ -2.4 \end{array}) \times 10$ | -4 |
| Γ ₁₈ | $f_0(1500) f_0(1370)$ | < 1.3 × 10 | |
| Γ ₁₉ | $f_0(1500) f_0(1500)$ | < 5 × 10 | |
| Γ ₂₀ | $f_0(1500) f_0(1710)$ | < 7 × 10 | ⁻⁵ CL=90% |
| Γ_{21} | $K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | (1.13 ± 0.27) % | _ |
| Γ ₂₂ | $K^{+} K^{-} \pi^{0} \pi^{0}$ | $(5.6~\pm 0.9~)\times 10$ | -3 |
| Γ ₂₃ | $K^{+}\pi^{-}K^{0}\pi^{0} + \text{c.c.}$ | (2.52 ± 0.34) % | |
| Γ ₂₄ | $ ho^+$ $K^ K^0$ + c.c. K^* (892) $^ K^+$ π^0 $ ightarrow$ | (1.22±0.21) % | -3 |
| Г ₂₅ | $K^{+}\pi^{-}K^{0}\pi^{0}$ + c.c. | (4.7 ±1.2) × 10 | _ |
| Γ ₂₆ | $K_S^0 K_S^0 \pi^+ \pi^-$ | $(5.8 \pm 1.1) \times 10$ | |
| Γ ₂₇ | $K^+ K^- \eta \pi^0 = 3(\pi^+ \pi^-)$ | $(3.0 \pm 0.7) \times 10$ | • |
| Γ ₂₈ Γ ₂₉ | $K + K^* (892)^0 \pi^- + \text{c.c.}$ | $(1.20 \pm 0.18) \%$ $(7.3 \pm 1.6) \times 10$ | -3 |
| Γ ₃₀ | $K^*(892)^0 \overline{K}^*(892)^0$ | $(1.7 \pm 0.6) \times 10$ | |
| Γ ₃₁ | $\pi\pi$ | $(8.5 \pm 0.4) \times 10$ | -3 |
| Γ ₃₂ | $\pi^0 \eta$ | < 1.8 × 10 | |
| Γ_{33} | $\pi^0 \eta'$ | < 1.1 \times 10 | -3 |
| Γ ₃₄ | $\eta\eta_{}$ | $(3.03 \pm 0.21) \times 10$ | -3 |
| Γ ₃₅ | $\eta \eta'$ | < 2.4 × 10 | |
| Γ ₃₆ | $\eta'\eta'$ | $(2.02\pm 0.22)\times 10$ | |
| Γ ₃₇ | $\omega \omega$ | $(9.8 \pm 1.1) \times 10$ | |
| Г ₃₈ | $^{\omega\phi}_{	extsf{K}^{+}	extsf{K}^{-}}$ | $(1.19 \pm 0.22) \times 10$ $(6.06 \pm 0.35) \times 10$ | |
| Γ ₃₉ Γ ₄₀ | $K_S^0 K_S^0$ | $(3.14 \pm 0.18) \times 10$ | |
| Γ ₄₁ | $\pi^+\pi^-\eta$ | < 2.0 × 10 | |
| Γ ₄₂ | $\pi^+\pi^-\eta'$ | < 4 × 10 | |
| Γ ₄₃ | $\frac{1}{K^0}K^+\pi^- + \text{c.c.}$ | < 1.0 × 10 | |
| Γ ₄₄ | $K^+ K^- \pi^0$ | < 6 × 10 | |
| Γ_{45} | $K^+K^-\eta$ | $< 2.3 \times 10$ | ⁻⁴ CL=90% |
| Γ_{46} | $K^{+} K^{-} K^{0}_{S} K^{0}_{S}$ $K^{+} K^{-} K^{+} K^{-}$ | $(1.4~\pm 0.5~)\times 10$ | -3 |
| Γ_{47} | | $(2.79 \pm 0.29) \times 10$ | |
| Γ ₄₈ | $K^+K^-\phi$ | (9.8 ± 2.5) $\times 10$ | |
| Γ ₄₉ | $\phi \phi = \frac{1}{2}$ | $(8.2 \pm 0.8) \times 10$ | |
| Γ ₅₀ | ρ <u>ρ</u> | $(2.23 \pm 0.13) \times 10$ | |
| Γ ₅₁ | $p \frac{\overline{p}}{\overline{p}} \pi^0$ | $(7.0 \pm 0.7) \times 10$ $(3.6 \pm 0.4) \times 10$ | |
| Γ ₅₂ Γ ₅₃ | p p η p p ω | $(5.3 \pm 0.4) \times 10$ $(5.3 \pm 0.6) \times 10$ | -4 |
| Γ ₅₄ | $p \overline{p} \phi$ | $(6.1 \pm 1.5) \times 10$ | |
| Γ ₅₅ | $p \overline{p} \pi^+ \pi^-$ | $(2.1 \pm 0.7) \times 10$ | |
| Γ ₅₆ | $p \overline{p} \pi^0 \pi^0$ | $(1.05 \pm 0.28) \times 10$ | |
| Γ ₅₇ | $p\overline{p}K^+K^-$ (non-resonant) | $(1.23\pm 0.27)\times 10$ | |
| | | | |

| Γ ₅₉ Γ ₆₀ Γ ₆₁ Γ ₆₂ Γ ₆₃ Γ ₆₄ Γ ₆₅ Γ ₆₆ | $ \begin{array}{c} p \overline{p} K_S^0 K_S^0 \\ p \overline{n} \pi^- \\ \Lambda \overline{\Lambda} \\ \Lambda \overline{\Lambda} + \pi^- \\ K^+ \overline{p} \Lambda + \text{c.c.} \\ K^+ p \Lambda (1520) + \text{c.c.} \\ \Lambda (1520) \overline{\Lambda} (1520) \\ \Sigma^0 \overline{\Sigma}^0 \\ \Sigma^+ \overline{\Sigma}^- \\ \Xi^0 \overline{\Xi}^0 \\ \Xi^- \overline{\Xi}^+ + \end{array} $ | < 8.8 | CL=90% |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|--------|
| . 00 | | • | |
| | | Radiative decays | |
| Γ ₆₉ | $\gamma J/\psi(1S)$ | (1.17 ± 0.08) % | |
| Γ ₇₀ | $\gamma \rho^0$ | $< 9 \times 10^{-6}$ | CL=90% |
| Γ ₇₁ | | $< 8 \times 10^{-6}$ | CL=90% |
| Γ_{72} | $\gamma \phi$ | $< 6 \times 10^{-6}$ | CL=90% |
| Γ ₇₃ | $\gamma \gamma$ | $(2.23 \pm 0.17) \times 10^{-4}$ | |

CONSTRAINED FIT INFORMATION

A multiparticle fit to $\chi_{c1}(1P)$, $\chi_{c0}(1P)$, $\chi_{c2}(1P)$, and $\psi(2S)$ with 4 total widths, a partial width, 25 combinations of partial widths obtained from integrated cross section, and 84 branching ratios uses 223 measurements to determine 49 parameters. The overall fit has a $\chi^2=312.2$ for 174 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta \rho_i \delta \rho_j \right\rangle / (\delta \rho_i \cdot \delta \rho_j)$, in percent, from the fit to parameters ρ_i , including the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$.

| | i | | | | | | | | | |
|------------------------|-------|-------|-----------------------|-----------------|------------------------|-----------------|------------------------|------------------------|-----------------|------------------------|
| <i>x</i> ₂ | 26 | | | | | | | | | |
| <i>x</i> ₈ | 20 | 5 | | | | | | | | |
| <i>x</i> ₂₉ | 9 | 2 | 30 | | | | | | | |
| <i>x</i> ₃₁ | 22 | 6 | 23 | 8 | | | | | | |
| x ₃₄ | 13 | 3 | 14 | 5 | 28 | | | | | |
| <i>X</i> 39 | 20 | 5 | 20 | 7 | 36 | 23 | | | | |
| <i>x</i> ₄₀ | 22 | 6 | 22 | 8 | 35 | 22 | 30 | | | |
| X47 | 13 | 3 | 12 | 5 | 19 | 12 | 16 | 17 | | |
| <i>x</i> ₄₉ | 11 | 3 | 11 | 4 | 20 | 13 | 17 | 17 | 9 | |
| <i>X</i> 50 | 2 | 1 | 2 | 1 | -6 | -7 | 2 | 2 | 1 | 1 |
| <i>x</i> ₆₀ | 8 | 2 | 9 | 3 | 17 | 11 | 15 | 14 | 8 | 8 |
| <i>x</i> 69 | 2 | 1 | 3 | 1 | 13 | 10 | 8 | 6 | 4 | 4 |
| <i>x</i> ₇₃ | -26 | -7 | -18 | -10 | -9 | -4 | -10 | -15 | -9 | -5 |
| Γ | -14 | -4 | -12 | -6 | -12 | -8 | -11 | -13 | -7 | <u>-6</u> |
| | x_1 | x_2 | <i>x</i> ₈ | x ₂₉ | <i>x</i> ₃₁ | x ₃₄ | <i>x</i> ₃₉ | <i>x</i> ₄₀ | x ₄₇ | <i>x</i> ₄₉ |
| ı | ı | | | | | | | | | |

| <i>x</i> ₆₀ | 1 | | | |
|------------------------|------|-----|------|-----|
| <i>x</i> ₆₉ | -46 | 4 | | |
| <i>x</i> ₇₃ | -6 | -3 | 11 | |
| Γ | 3 | -5 | -10 | -57 |
| | Xs.o | Xen | X6.9 | X73 |

$\chi_{c0}(1P)$ PARTIAL WIDTHS

| $\Gamma(p\overline{p}) \times \Gamma(\gammaJ/\psi$ | (1 <i>S</i>))/Γ _{to} | tal | | Γ ₅₀ Γ ₆₉ /Γ |
|----------------------------------------------------|--------------------------------|-------------------------------------|--------------|-----------------------------------------------------------------|
| VALUE (eV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 27.1± 2.4 OUR FIT | | | | |
| • • • We do not use | the followin | ig data for averages, f | its, limits, | etc. • • • |
| $26.6\!\pm\ 2.6\!\pm\!1.4$ | 392 | 6,7 BAGNASCO 0 | 2 E835 | $\overline{p}p \rightarrow \chi_{c0} \rightarrow J/\psi \gamma$ |
| $48.7 {}^{+ 11.3}_{- 8.9} \pm 2.4$ | | ^{6,7} AMBROGIANI 9 | 9в Е835 | $\overline{p}p \rightarrow \gamma J/\psi$ |
| ⁶ Calculated by us i | using $B(J/\psi)$ | $e(1S) \rightarrow e^{+}e^{-}) = 0$ | .0593 ± 0 | .0010. |

Valculated by us using B($J/\psi(1S) \rightarrow e^+e^-$) = 0.0593 ± 0.0010. 7 Values in $(\Gamma(\rho\overline{\rho}) \times \Gamma(\gamma J/\psi(1S))/\Gamma_{\text{total}})$ and $(\Gamma(\rho\overline{\rho})/\Gamma_{\text{total}} \times \Gamma(\gamma J/\psi(1S))/\Gamma_{\text{total}})$ are not independent. The latter is used in the fit since it is less correlated to the total width.

$\chi_{c0}(1P) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)$ | γ)/Γ _{total} | | | Γ ₃₁ Γ ₇₃ /Ι |
|----------------------------------------------|-----------------------|-------------------------|---------|--------------------------------------------|
| VALUE (eV) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 19.7± 1.4 OUR I 23 ± 5 OUR / | | | · · | |
| $29.7^{+17.4}_{-12.0}\pm4.8$ | $103 + 60 \\ -42$ | ⁸ UEHARA | 09 BELL | 10.6 $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$ |
| $22.7\!\pm\ 3.2\!\pm\!3.5$ | 129 ± 18 | ⁹ NA KA ZAWA | 05 BELL | 10.6 $e^+e^- \to e^+e^- \to e^+e^-$ |

 $\chi_{c0}(1P)$

| 8 We multiplied the measurement by 3 to convert from $\pi^0\pi^0$ to $\pi\pi.$ Interference with the continuum included. | $\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{	ext{total}}$ VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9 We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. | 3.4 ± 0.4 ± 0.1 1751.4 12 HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h$ |
| $\Gamma(\eta\eta)	imes\Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_{34}\Gamma_{73}/\Gamma$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | ¹² HE 08B reports 3.54 ± 0.10 ± 0.43 ± 0.18 % from a measurement of [Γ($\chi_{C0}(1P)$ - $\pi^+\pi^-\pi^0\pi^0$)/Γ _{total}] × [Β($\psi(2S) \to \gamma\chi_{C0}(1P)$)] assuming B($\psi(2S) \to \gamma\chi_{C0}(1P)$): |
| 9.4 \pm 2.3 \pm 1.2 22 10 UEHARA 10A BELL 10.6 $e^+e^- \rightarrow e^+e^-\eta\eta$ 10 Interference with the continuum not included. | $(9.22\pm0.11\pm0.46)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C0}(1P))=(9.68\pm0.31)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\Gamma(K^+K^-) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_{39}\Gamma_{73}/\Gamma$ | Fig. ($\rho^+ \pi^- \pi^0 + \text{c.c.}$)/ Γ_{total} |
| <u>VALUE (eV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 14.0±1.1 OUR FIT | VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| 14.3\pm1.6\pm2.3 153 \pm 17 NAKAZAVVA 05 BELL 10.6 $e^+e^- \rightarrow e^+e^- + K^-$ | 2.9 ± 0.4 ± 0.1 1358.5 $^{13}, ^{14}$ HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h$ 13 HE 08B reports 3.04 ± 0.18 ± 0.42 ± 0.16 % from a measurement of $[\Gamma(\chi_{C0}(1P)$ - |
| $\Gamma(K_S^0 K_S^0) \times \Gamma(\gamma \gamma)/\Gamma_{\text{total}}$ $\Gamma_{40}\Gamma_{73}/\Gamma_{\text{ALUE (eV)}}$ $\Gamma_{40}\Gamma_{73}/\Gamma_{\text{DOCUMENT ID}}$ $\Gamma_{40}\Gamma_{73}/\Gamma_{\text{DOCUMENT ID}}$ | $\rho^+ \pi^- \pi^0 + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(25) \to \gamma \chi_{C0}(1P))]$ assuming $B(\psi(25) \to \gamma \chi_{C0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(25) \to \gamma \chi_{C0}(1P))$ |
| 2.3 ±0.5 OUR FIT 2.00±0.65±0.71 134±12 CHEN 07B BELL $e^+e^- \rightarrow e^+e^- \chi_{c0}$ | $\gamma\chi_{C0}(1P))=(9.68\pm0.31)	imes10^{-2}.$ Our first error is their experiment's error and ot second error is the systematic error from using our best value. ¹⁴ Calculated by us. We have added the values from HE 08B for $\rho^+\pi^-\pi^0$ and $\rho^-\pi^+\pi^0$ |
| $\Gamma(2(\pi^+\pi^-))	imes\Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_1\Gamma_{73}/\Gamma$ (ALUE (eV) EVTS DOCUMENT ID TECN COMMENT | decays assuming uncorrelated statistical and fully correlated systematic uncertainties. |
| 52 ± 4 OUR FIT | $\Gamma(4\pi^0)/\Gamma_{total}$ NALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT |
| 49 ±10 OUR AVERAGE Error includes scale factor of 1.8. 44.7 \pm 3.6 \pm 4.9 3.6k UEHARA 08 BELL $\gamma\gamma \rightarrow \chi_{C0} \rightarrow 2(\pi^+\pi^-)$ | 3.3±0.4±0.1 3296 15 ABLIKIM 11A BES3 $e^+e^- 	o \psi(2s) 	o \gamma \chi_{cl}$ |
| 75 \pm 13 \pm 8 EISENSTEIN 01 CLE2 $\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-} \chi_{c0}$ | ¹⁵ ABLIKIM 11A reports $(3.34 \pm 0.06 \pm 0.44) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{CO}(1P) - 4-0)/\Gamma(1P)]$ for $\Gamma(\chi_{CO}(1P) - 4-0)/\Gamma(1P)$ for $\Gamma(\chi_{CO}(1P) - 4-0)/\Gamma(1P)$ for $\Gamma(\chi_{CO}(1P) - 4-0)/\Gamma(1P)$ |
| $\Gamma(ho^0 ho^0)	imes\Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_3\Gamma_{73}/\Gamma$ VALUE (eV) CL% EVTS DOCUMENT ID TECN COMMENT | $4\pi^0)/\Gamma_{	ext{total}} \times [B(\psi(2S) 	o \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) 	o \gamma \chi_{c0}(1P)) = (9.62 	o 0.31) 	imes 10^{-2}$, which we rescale to our best value $B(\psi(2S) 	o \gamma \chi_{c0}(1P)) = (9.68 	o 0.31) 	imes 10^{-2}$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $0.31) 	imes 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| <12 90 <252 UEHARA 08 BELL $\gamma\gamma \to \chi_{c0} \to 2(\pi^+\pi^-)$ | $\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ |
| $\Gamma(\pi^+\pi^-K^+K^-)	imes\Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_8\Gamma_{73}/\Gamma$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) DOCUMENT ID |
| 11 ±4 OUR FIT | 17.9±1.5 OUR FIT |
| 18.8 \pm 3.7 \pm 4.7 1.7k UEHARA 08 BELL $\gamma\gamma \rightarrow \chi_{c0} \rightarrow K^+K^-\pi^+\pi^-$ | $\Gamma(K^+\overline{K}^*(892)^0\pi^- + \text{c.c.})/\Gamma(\pi^+\pi^-K^+K^-)$ VALUE DOCUMENT ID TECH COMMENT |
| $\Gamma(K^+K^-\pi^+\pi^-\pi^0) 	imes \Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_{21}\Gamma_{73}/\Gamma$ ALUE (eV) EVTS DOCUMENT ID TECH COMMENT | 0.41 \pm 0.09 OUR FIT 0.41 \pm 0.10 Tanenbaum 78 MrK1 $\psi(2S) ightarrow \gamma \chi_{c0}$ |
| 1094 DEL-AMO-SA11M BABR $\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$ | $\Gamma(K_0^*(1430)^0\overline{K}_0^*(1430)^0 \to \pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ $\Gamma_9/\Gamma_{\text{total}}$ |
| $\Gamma(K^+\overline{K}^*(892)^0\pi^- + \text{c.c.}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_{29}\Gamma_{73}/\Gamma$ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| ALUE (eV)EVTS DOCUMENT ID TECN COMMENT | 9.9+3.6 ± 0.3 83 16 ABLIKIM 05 Q BES2 $\psi(2S) \to \gamma \pi^+ \pi^- K^+ K^-$ |
| 16.7 \pm 6.1 \pm 3.0 495 \pm 182 UEHARA 08 BELL $\gamma\gamma \rightarrow \chi_{c0} \rightarrow K^+K^-\pi^+\pi^-$ | 16 ABLIKIM 05Q reports $(10.44 \pm 2.37^{+3.05}_{-1.90}) \times 10^{-4}$ from a measurement of |
| $\Gamma(K^*(892)^0\overline{K}^*(892)^0) \times \Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_{30}\Gamma_{73}/\Gamma_{	ext{VALUE}(eV)}$ $\Gamma_{30}\Gamma_{73}/\Gamma_{30}\Gamma_{73}/\Gamma_{30}$ | $ \begin{array}{lll} [\Gamma(\chi_{C0}(1P) \to \ \ K_0^*(1430)^0 \ \overline{K}_0^*(1430)^0 \to \ \pi^+\pi^- \ K^+ K^-)/\Gamma_{\rm total}] \times [B(\psi(2S) \to \gamma\chi_{C0}(1P))] \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ $ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | we rescale to our best value $B(\psi(2S) \to \gamma \chi_{CO}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our fireror is their experiment's error and our second error is the systematic error from usin |
| <6 90 <148 UEHARA 08 BELL $\gamma\gamma \rightarrow \chi_{c0} \rightarrow K^+K^-\pi^+\pi^-$ | our best value. |
| $\Gamma(K^+K^-K^+K^-) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(K_0^*(1430)^0\overline{K}_2^*(1430)^0 + \text{c.c.} \rightarrow \pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ $\Gamma_{10}/\Gamma_{\text{VALUE (units }10^{-4})}$ EVTS DOCUMENT ID TECN COMMENT |
| 6.4 \pm 0.7 OUR FIT 7.9 \pm 1.1 215 \pm 36 UEHARA 08 BELL $\gamma\gamma \to \chi_{c0} \to 2(K^+K^-)$ | 8.1 ⁺ 2.0 ⁺ 2.3 62 17 ABLIKIM 05 Q BES2 $\psi(2S) \rightarrow \gamma \pi^{+} \pi^{-} K^{+} K^{-}$ |
| $\Gamma(\phi\phi) \times \Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{49}}\Gamma_{	ext{73}}/\Gamma$ | 17 ABLIKIM 05 $_{\mathrm{Q}}$ reports $(8.49\pm1.66^{+1.32}_{-1.99})\times10^{-4}$ from a measurement of $[\Gamma(\chi_{c0}(1P)-\kappa_0^*(1430)^0\overline{\kappa}_2^*(1430)^0+\mathrm{c.c.}\to\pi^+\pi^-K^+K^-)/\Gamma_{\mathrm{total}}]\times[\mathrm{B}(\psi(2S)\to\gamma\chi_{c0}(1P)-\chi_{c0}^*)]$ |
| VALUE (eV) EVTS DOCUMENT ID TECN COMMENT 1.89±0.22 OUR FIT | assuming B($\psi(2S) \to \gamma \chi_{c0}(1P)$) = $(9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we resca |
| 2.3 ±0.9 ±0.4 23.6 ± 9.6 UEHARA 08 BELL $\gamma \gamma \to \chi_{c0} \to 2(K^+K^-)$ | to our best value $B(\psi(2S) \to \gamma \chi_{CO}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error their experiment's error and our second error is the systematic error from using our best |
| $\chi_{c0}(1P)$ BRANCHING RATIOS | value. |
| HADRONIC DECAYS | $\Gamma(K_1(1270)^+K^- + c.c. \rightarrow \pi^+\pi^-K^+K^-)/\Gamma_{total}$ VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ Γ_1/Γ | 6.3±1.9±0.2 68 18 ABLIKIM 05 Q BES2 $\psi(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^-$ |
| <u>VALUE</u> <u>DOCUMENT ID</u> 0.0226±0.0019 OUR FIT | ¹⁸ ABLIKIM 05 Q reports $(6.66 \pm 1.31 + 1.60) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c0}(1P) - \chi_{c0}(1P) + \chi_{c0}(1P)] \times [\Gamma(\chi_{c0}(1P) + \chi_{c0}(1P)] \times $ |
| $\Gamma(\rho^0\pi^+\pi^-)/\Gamma(2(\pi^+\pi^-))$ Γ_2/Γ_1 | ${\it K}_1(1270)^+{\it K}^- + {\rm c.c.} 	o \pi^+\pi^-{\it K}^+{\it K}^-)/\Gamma_{{ m total}}] 	imes [{\it B}(\psi(2S) 	o \gamma\chi_{{\it C}0}(1P))]$ assuming ${\it B}(\psi(2S) 	o \gamma\chi_{{\it C}0}(1P)) = (9.22 \pm 0.11 \pm 0.46) 	imes 10^{-2}$, which we rescale to our properties of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the contraction of the |
| VALUE DOCUMENT ID TECN COMMENT 0.39±0.12 OUR FIT | best value B($\psi(2s) \to \gamma \chi_{c0}(1P)$) = $(9.68 \pm 0.31) \times 10^{-2}$. Our first error is the experiment's error and our second error is the systematic error from using our best value. |
| D.39\pm0.12 TANENBAUM 78 MRK1 ψ (2S) $ ightarrow$ $\gamma \chi_{c0}$ | The measurement assumes B($\mathit{K}_1(1270) ightarrow ~\mathit{K} ho(770)) = 42 \pm 6\%.$ |
| $\Gamma(ho^0\pi^+\pi^-)/\Gamma_{	ext{total}}$ Γ2/Γ VALUE DOCUMENT ID | $\Gamma(K_1(1400)^+ K^- + \text{c.c.} \to \pi^+ \pi^- K^+ K^-) / \Gamma_{\text{total}}$ $\Gamma_{12} / \Gamma_{\text{total}} = \Gamma_{12} / \Gamma_{\text{total}}$ |
| 0.0088±0.0028 OUR FIT | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| Γ(f ₀ (980) f ₀ (980))/Γ _{total} Γ ₄ /Γ | 19 ABLIKIM 05Q reports $<$ 2.85 $	imes$ 10^{-3} from a measurement of [$\Gamma(\chi_{c0}(1P)$ - |
| VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT $0.00000000000000000000000000000000000$ | $K_1(1400)^+K^- + \text{c.c.} \rightarrow \pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))]$ as suming $B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to |
| 11 ABLIKIM 04G reports $[\Gamma(\chi_{c0}(1P) \rightarrow f_0(980)f_0(980))/\Gamma_{total}] \times [B(\psi(2S) \rightarrow f_0(980))/\Gamma_{total}]$ | our best value B($\psi(25) \to \gamma \chi_{C0}(1P)$) = 9.68 \times 10 ⁻² . The measurement assume B($K_1(1400) \to K^*(892) \pi$) = 94 ± 6%. |
| $\gamma \chi_{c0}(1P))]=(6.5\pm1.6\pm1.3)\times 10^{-5}$ which we divide by our best value $\mathrm{B}(\psi(25)\to\gamma\chi_{c0}(1P))=(9.68\pm0.31)\times 10^{-2}$. Our first error is their experiment's error and our | $D(\Lambda_1(1400) \to \Lambda (032)\pi) = 34 \pm 0\%.$ |
| $\gamma \chi_{c0}(1P)$) = (9.68 \pm 0.31) \times 10 $^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | |

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| (- () - () / () - () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () / () | ₁₃ /Γ | $\Gamma(K^+K^-\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_{22}/Γ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 5) → 2S) → | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| is identified via decay to $\pi^+\pi^-$ while the other via K^+K^- decay. $\Gamma(f_0(980) f_0(2200))/\Gamma_{total}$ | 1 ₄ /Γ | $\Gamma(K^+\pi^-K^0\pi^0 + \text{c.c.})/\Gamma_{\text{total}}$ VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | $ \begin{array}{c} K^{-} \\ P) \rightarrow \\ S) \rightarrow \end{array} $ | 2.52 ± 0.33 ± 0.08 401.7 29 HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0$ 29 HE 08B reports 2.64 ± 0.15 ± 0.31 ± 0.14 % from a measurement of $[\Gamma(\chi_{C0}(1P) \rightarrow K^+\pi^- K^0\pi^0 + c.c.)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(\rho^+ K^- K^0 + c.c.)/\Gamma_{total}$ |
| tified via $f_0(980) \rightarrow \pi^+\pi^-$ and $f_0(2200) \rightarrow K^+K^-$ decays. | ideli- | VALUE (%) EVTS DOCUMENT ID TECH COMMENT |
| $\begin{array}{l lllllllllllllllllllllllllllllllllll$ | $\begin{array}{ccc} P) & \rightarrow & \\ P) & \rightarrow & \\ PS) & \rightarrow & \end{array}$ | 1.22 \pm 0.21 \pm 0.04 179.7 30 HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0$ h^0 30 HE 08B reports 1.28 \pm 0.16 \pm 0.15 \pm 0.07 % from a measurement of $[\Gamma(\chi_{C0}(1P) \rightarrow \rho^+ K^- K^0 + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K^*(892)^- K^+ \pi^0 \rightarrow K^+ \pi^- K^0 \pi^0 + \text{c.c.})/\Gamma_{\text{total}}$ |
| while the other via K^+K^- decay. Both branching fractions for these f_0 decays an plicitly included in the quoted result. | | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | 5) → 5) → | 31 HE 08B reports $0.49\pm0.10\pm0.07\pm0.03$ % from a measurement of $[\Gamma(\chi_{C0}(1P)\to K^*(892)^-K^+\pi^0\to K^+\pi^-K^0\pi^0+c.c.)/\Gamma_{total}] \times [B(\psi(2S)\to \gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C0}(1P))=(9.22\pm0.11\pm0.46)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to \gamma\chi_{C0}(1P))=(9.68\pm0.31)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K_5^0K_5^0\pi^+\pi^-)/\Gamma_{total}$ |
| $\gamma \chi_{c0}(1P))=9.68 \times 10^{-2}$. The f_0 mesons are identified via $f_0(1370) \to \pi^+\pi^-$ | | , - |
| · · | licitly 17 /Γ | $\gamma \chi_{c0}(1P))]=(0.558\pm0.051\pm0.089)	imes10^{-3}$ which we divide by our best value |
| included in the quoted result. | 1 ₁₇ /Γ | 5.8±1.1±0.2 $152\pm14 3^2 \text{ ABLIKIM} 050 \text{ BES2} \psi(2S) \rightarrow \gamma \chi_{C0}$ $3^2 \text{ ABLIKIM} 050 \text{ reports } \left[\Gamma(\chi_{C0}(1P) \rightarrow K_S^0 K_S^0 \pi^+ \pi^-) / \Gamma_{\text{total}} \right] \times \left[B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) \right] = (0.558\pm0.051\pm0.089) \times 10^{-3} \text{ which we divide by our best value}$ $B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.68\pm0.31) \times 10^{-2}. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value}.$ |
| included in the quoted result. | Signature of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the | 5.8±1.1±0.2 152 ± 14 32 ABLIKIM 050 BES2 $\psi(2S) \rightarrow \gamma \chi_{C0}$ 32 ABLIKIM 050 reports $[\Gamma(\chi_{C0}(1P) \rightarrow K_S^0 K_S^0 \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))] = (0.558 \pm 0.051 \pm 0.089) \times 10^{-3}$ which we divide by our best value |
| included in the quoted result. | Significantly $F(S) \rightarrow F(S) \rightarrow$ | 32 ABLIKIM 050 reports $[\Gamma(\chi_{c0}(1P) \rightarrow K_S^0 K_S^0 \pi^+ \pi^-)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma\chi_{c0})]$ $\gamma\chi_{c0}(1P))] = (0.558 \pm 0.051 \pm 0.089) \times 10^{-3}$ which we divide by our best value $B(\psi(2S) \rightarrow \gamma\chi_{c0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K^+ K^- \eta \pi^0)/\Gamma_{total} \qquad \qquad \Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_{27}/\Gamma_$ |
| included in the quoted result. | Solicitly 17/ Γ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| included in the quoted result. | Solicitly $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F(T)$ $F(T) = F$ | 32 ABLIKIM 050 reports $[\Gamma(\chi_{C0}(1P) \rightarrow K_S^0 K_S^0 \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C0})]$ 32 ABLIKIM 050 reports $[\Gamma(\chi_{C0}(1P) \rightarrow K_S^0 K_S^0 \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))] = (0.558 \pm 0.051 \pm 0.089) \times 10^{-3}$ which we divide by our best value $B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $ \Gamma(K^+ K^- \eta \pi^0)/\Gamma_{\text{total}} \qquad \qquad \frac{FVTS}{33 \text{ HE}} \qquad \frac{DOCUMENT \ ID}{0.30 \pm 0.07 \pm 0.01} \qquad \frac{TECN}{56.4} \qquad \frac{COMMENT}{33 \text{ HE}} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad \frac{COMMENT}{66.4} \qquad COME$ |
| included in the quoted result. | Solicitly 17/ Γ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ $K = K$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |

27 ABLIKIM 05Q reports < 0.73 × 10⁻⁴ from a measurement of $[\Gamma(\chi_{C0}(1P) \rightarrow f_0(1500) f_0(1710))/\Gamma_{total}]$ × $[B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))$] = $(9.22\pm0.11\pm0.46)\times10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))$ = 9.68×10^{-2} . The f_0 mesons are identified via $f_0(1500) \rightarrow \pi^+\pi^-$ and $f_0(1710) \rightarrow K^+K^-$ decays. Both branching fractions for these f_0 decays are implicitly included in the quoted result.

 $\begin{array}{l} \gamma \chi_{C0}(1P))] = (0.168 \pm 0.035 \pm 0.047) \times 10^{-3} \text{ which we divide by our best value} \\ \mathrm{B}(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}. \text{ Our first error is their experiment's} \\ \mathrm{error and our second error is the systematic error from using our best value}. \\ \mathrm{36 \, Assumes} \, \mathrm{B}(K^*(892)^0 \rightarrow K^-\pi^+) = 2/3. \\ \mathrm{37 \, ABLIKIM \, 04H \, reports} \, [\Gamma(\chi_{C0}(1P) \rightarrow K^*(892)^0 \overline{K}^*(892)^0) / \Gamma_{\mathrm{total}}] \times [\mathrm{B}(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))] = (1.53 \pm 0.29 \pm 0.26) \times 10^{-4} \text{ which we divide by our best value} \, \mathrm{B}(\psi(2S) \rightarrow \gamma \chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value.} \end{array}$

 $\chi_{c0}(1P)$

| $\Gamma(\pi\pi)/\Gamma_{ m total}$ $\Gamma_{ m 31}/\Gamma$ | $\Gamma(K_S^0 K_S^0)/\Gamma(\pi\pi)$ Γ_{40}/Γ_{31} |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>VALUE (units 10⁻³)</u> <u>DOCUMENT ID</u> 8.5 ± 0.4 OUR FIT | VALUE DOCUMENT ID TECN COMMENT 0.369±0.022 OUR FIT |
| $\Gamma(\eta\eta)/\Gamma_{ m total}$ $\Gamma_{ m 34}/\Gamma$ | • • • We do not use the following data for averages, fits, limits, etc. • • • $0.31 \pm 0.05 \pm 0.05 \qquad \qquad ^{46,47} \text{ CHEN} \qquad \qquad 078 \text{BELL} e^+e^- \rightarrow e^+e^- \chi_{C0}$ |
| VALUE (units 10 ⁻³) DOCUMENT ID | 46 Using $\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\rm total}$ from the $\pi^+\pi^-$ measurement of NAKAZAWA 05 rescaled |
| 3.03±0.21 OUR FIT | by $3/2$ to convert to $\pi\pi$. 47 Not independent from other measurements. |
| $\Gamma(\eta\eta)/\Gamma(\pi\pi)$ Γ_{34}/Γ_{31} | $\Gamma(K_S^0 K_S^0)/\Gamma(K^+ K^-)$ Γ_{40}/Γ_{39} |
| 0.356±0.025 OUR FIT • • • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE DOCUMENT ID TECN COMMENT 0.519±0.035 OUR FIT |
| 0.26 $\pm 0.09 \ ^{+0.03}_{-0.02}$ 38 ANDREOTTI 05c E835 $\overline{p}p \rightarrow 2$ mesons | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.24 ± 0.10 ± 0.08 38 BAI 03C BES $\psi(2S) \rightarrow 5\gamma$ | 0.49 $\pm 0.07 \pm 0.08$ 48,49 CHEN 07B BELL $e^+e^- \rightarrow e^+e^- \chi_{c0}$ |
| 38 We have multiplied $\pi^0\pi^0$ measurement by 3 to obtain $\pi\pi$. | 48 Using $\Gamma(K^+K^-)~\times~\Gamma(\gamma\gamma)/\Gamma_{total}$ from NAKAZAWA 05. 49 Not independent from other measurements. |
| $\Gamma(\eta\eta')/\Gamma_{	ext{total}}$ | $\Gamma(\pi^+\pi^-\eta)/\Gamma_{	ext{total}}$ Γ_{41}/Γ |
| VALUE (units 10^{-3}) CL% EVTS DOCUMENT ID TECN COMMENT <0.24 90 35 \pm 13 39 ASNER 09 CLEO $\psi(2S) \rightarrow \gamma \eta' \eta$ | VALUE (units 10^{-3}) <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> <0.20 90 ⁵⁰ ATHAR 07 CLEO $\psi(25) \rightarrow \gamma h^+ h^- h^0$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| <0.5 90 40 ADAMS 07 CLEO $\psi(2S) \rightarrow \gamma \chi_{c0}$ 39 ASNER 00 reports < 0.25 × 10 ⁻³ from a measurement of [F(χ_{c} $\chi(1P) \rightarrow \chi \chi \chi')/\Gamma$] | <1.0 90 51 ABLIKIM 06R BES2 $\psi(2S) ightarrow \gamma \chi_{c0}$ |
| $^{39}\text{ASNER}$ 09 reports $<0.25\times10^{-3}$ from a measurement of $[\Gamma(\chi_{C0}(1P)\to\eta\eta')/\Gamma_{\text{total}}]\times[B(\psi(2S)\to\gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C0}(1P))=(9.22\pm0.11\pm0.46)\times10^{-3}$ | 50 ATHAR 07 reports $<$ 0.21 \times 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c0}(1P) \rightarrow \ \pi^+\pi^-\eta)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \ \gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S) \rightarrow \ \gamma\chi_{c0}(1P))=(9.22 \pm 1.00)$ |
| 10^{-2} , which we rescale to our best value B($\psi(2S) \to \gamma \chi_{c0}(1P)$) = 9.68×10^{-2} . 40 Superseded by ASNER 09. ADAMS 07 reports $< 0.5 \times 10^{-3}$ from a measurement | $0.11\pm0.46) \times 10^{-2}$, which we rescale to our best value B $(\psi(2S) \to \gamma \chi_{C0}(1P))=9.68 \times 10^{-2}$. |
| of $[\Gamma(\chi_{C0}(1P) \to \eta \eta')/\Gamma_{total}] \times [B(\psi(2S) \to \gamma \chi_{C0}(1P))]$ assuming $B(\psi(2S) \to \eta \eta')/\Gamma_{total}$ | ⁵¹ ABLIKIM 06R reports $< 1.1 \times 10^{-3}$ from a measurement of $[\Gamma(v_{-9}(1P) \rightarrow \pi^+\pi^- p)]$ |
| $\gamma \chi_{C0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value B $(\psi(2S) \to \gamma \chi_{C0}(1P)) = 9.68 \times 10^{-2}$. | Γ_{total} \times $\mathrm{B}(\psi(2\mathrm{S}) \to \gamma \chi_{c0}(1P))$ assuming $\mathrm{B}(\psi(2\mathrm{S}) \to \gamma \chi_{c0}(1P))$ = (9.2 ± 0.4) / \times 10^{-2} , which we rescale to our best value $\mathrm{B}(\psi(2\mathrm{S}) \to \gamma \chi_{c0}(1P))$ = 9.68×10^{-2} . |
| $\Gamma(\eta'\eta')/\Gamma_{\text{total}}$ Γ_{36}/Γ | $\Gamma(\pi^+\pi^-\eta')/\Gamma_{	ext{total}}$ Γ_{42}/Γ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| 2.02±0.21±0.06 0.4k 41 ASNER 09 CLEO $\psi(2S) \rightarrow \gamma \eta' \eta'$ • • • We do not use the following data for averages, fits, limits, etc. • • • | <0.4 90 ⁵² ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ |
| 1.6 ± 0.4 ± 0.1 23 ⁴² ADAMS 07 CLEO $\psi(2S) \rightarrow \gamma \chi_{CO}$ | 52 ATHAR 07 reports $<$ 0.38 \times 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c0}(1P) \to \pi^+\pi^-\eta')/\Gamma_{total}] \times [B(\psi(2S) \to \gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c0}(1P)) = (9.22 \pm 1)$ |
| ⁴¹ ASNER 09 reports $(2.12 \pm 0.13 \pm 0.21) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c0}(1P) \rightarrow 1/2)]$ | $0.11\pm0.46)\times10^{-2}$, which we rescale to our best value B($\psi(2S)\to\gamma\chi_{c0}(1P)$) = 9.68×10^{-2} . |
| $\eta'\eta')/\Gamma_{\text{total}} \times [\mathrm{B}(\psi(2S) \to \gamma\chi_{c0}(1P))]$ assuming $\mathrm{B}(\psi(2S) \to \gamma\chi_{c0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $\mathrm{B}(\psi(2S) \to \gamma\chi_{c0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$ | $\Gamma(\overline{K}^0K^+\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{43}/Γ |
| $(9.68\pm0.31)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| ⁴² Superseded by ASNER 09. ADAMS 07 reports $(1.7 \pm 0.4 \pm 0.2) \times 10^{-3}$ from a | <0.10 90 53 ATHAR 07 CLEO $\psi(25) \to \gamma h^+ h^- h^0$ |
| measurement of $[\Gamma(\chi_{c0}(1P) \to \eta' \eta')/\Gamma_{total}] \times [B(\psi(2S) \to \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c0}(1P)) = 0.0922 \pm 0.0011 \pm 0.0046$, which we rescale to our | • • • We do not use the following data for averages, fits, limits, etc. • • • <0.7 90 54,55 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C0}$ |
| best value B($\psi(2s) \to \gamma \chi_{C0}(1P)$) = $(9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | <0.7 90 55,56 BAI 998 BES $\psi(2S) ightarrow \gamma \chi_{c0}$ |
| $\Gamma(\omega\omega)/\Gamma_{ m total}$ $\Gamma_{ m 37}/\Gamma$ | ⁵³ ATHAR 07 reports $< 0.10 \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C0}(1P) \to \overline{K}^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{C0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{C0}(1P)) = (9.22 \pm \text{c.c.})/\Gamma_{\text{total}}]$ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | 0.11 \pm 0.46) \times 10 ⁻² , which we rescale to our best value B($\psi(2S) \to \gamma \chi_{C0}(1P)$) = 9.68 \times 10 ⁻² . |
| 0.98\pm0.11 OUR AVERAGE 0.94 \pm 0.11 \pm 0.03 991 ⁴³ ABLIKIM 11 κ BES3 $\psi(2S) \rightarrow \gamma$ hadrons | 54 ABLIKIM 06R reports $<$ 0.70 $	imes$ 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c0}(1P) ightarrow$ |
| 2.2 \pm 0.7 \pm 0.1 38.1 \pm 9.6 ⁴⁴ ABLIKIM 05N BES2 $\psi(2s) \rightarrow \gamma \chi_{c0} \rightarrow \gamma 6\pi$ | \overline{K}^0 $K^+\pi^-+$ c.c.)/ $\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c0}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{c0}(1P))$ |
| ⁴³ ABLIKIM 11K reports $(0.95\pm0.03\pm0.11)\times10^{-3}$ from a measurement of $[\Gamma(\chi_{c0}(1P)\to\omega\omega)/\Gamma_{total}]\times[B(\psi(2S)\to\gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{c0}(1P))=(9.62\pm0.01)$ | $\gamma \chi_{c0}(1P)) = 9.68 \times 10^{-2}$. |
| $0.31) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \to \gamma \chi_{c0}(1P)$) = (9.68 \pm 0.31) $\times 10^{-2}$. Our first error is their experiment's error and our second error is the | ⁵⁵ We have multiplied the $K_5^0 K^+\pi^-$ measurement by a factor of 2 to convert to $K^0 K^+\pi^-$. |
| systematic error from using our best value. | 56 Rescaled by us using B($\psi(2S)$ $ ightarrow$ $\gamma\chi_{c0}$)= (9.4 \pm 0.4)% and B($\psi(2S)$ $ ightarrow$ |
| ⁴⁴ ABLIKIM 05N reports $[\Gamma(\chi_{C0}(1P) \rightarrow \omega\omega)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))] = (0.212 \pm 0.053 \pm 0.037) \times 10^{-3}$ which we divide by our best value $B(\psi(2S) \rightarrow \omega\omega)/\Gamma_{\text{total}}$ | $J/\psi(1S) \pi^{+} \pi^{-}) = (32.6 \pm 0.5)\%.$ |
| $\gamma \chi_{c0}(1P))=(9.68\pm0.31)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(K^+K^-\pi^0)/\Gamma_{	ext{total}}$ VALUE (units 10^{-3}) CL% DOCUMENT ID TECN COMMENT |
| $\Gamma(\omega\phi)/\Gamma_{ m total}$ $\Gamma_{ m 38}/\Gamma$ | <0.06 90 57 ATHAR 07 CLEO $\psi(2S) \rightarrow \gamma h^+ h^- h^0$ |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | 57 ATHAR 07 reports $<$ 0.06 \times 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c0}(1P) \rightarrow K^+K^-\pi^0)/\Gamma_{total}] \times$ [B($\psi(2S) \rightarrow \gamma\chi_{c0}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma\chi_{c0}(1P)$) = (9.22 \pm 0.11 \pm |
| 1.19\pm0.22\pm0.04 76 ⁴⁵ ABLIKIM 11K BES3 $\psi(2S) \rightarrow \gamma$ hadrons ⁴⁵ ABLIKIM 11K reports $(1.2\pm0.1\pm0.2)\times10^{-4}$ from a measurement of $\Gamma(\chi_{CO}(1P)\rightarrow 1)$ | 1 total) $1 (0.10^{+0.3}) \rightarrow \gamma \chi_{c0}(11)$) assuming $B(\psi(25)) \rightarrow \gamma \chi_{c0}(11)$) = $(5.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(25)) \rightarrow \gamma \chi_{c0}(11)$) = 9.68×10^{-2} . |
| $(\omega \phi)/\Gamma_{\text{total}} \times [B(\psi(2S) \to \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c0}(1P)) = (9.62 \pm 1)$ | $\Gamma(K^+K^-\eta)/\Gamma_{\text{total}}$ Γ_{45}/Γ |
| $0.31) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \to \gamma \chi_{c0}(1P)$) = (9.68 \pm 0.31) $\times 10^{-2}$. Our first error is their experiment's error and our second error is the | $\frac{VALUE \text{ (units }10^{-3})}{<0.23}$ $\frac{CL\%}{90}$ $\frac{DOCUMENT ID}{58 \text{ ATHAR}}$ $\frac{TECN}{07}$ $\frac{COMMENT}{\sqrt{(2S)}} \rightarrow \gamma h^+ h^- h^0}$ |
| systematic error from using our best value. | |
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ Γ_{39}/Γ | ⁵⁸ ATHAR 07 reports $<$ 0.24 \times 10 ⁻³ from a measurement of $[\Gamma(\chi_{C0}(1P) \to K^+K^-\eta)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{C0}(1P)) = (9.22 \pm 0.22)$ |
| <u>VALUE (units 10⁻³)</u> <u>DOCUMENT ID</u> 6.06±0.35 OUR FIT | 0.11 \pm 0.46) \times 10 $^{-2}$, which we rescale to our best value B($\psi(2S) \to \gamma \chi_{C0}(1P))=9.68 \times 10^{-2}$. |
| $\Gamma(K_S^0 K_S^0)/\Gamma_{\text{total}}$ Γ_{40}/Γ | $\Gamma(K^+K^-K^0_SK^0_S)/\Gamma_{\text{total}}$ Γ_{46}/Γ |
| VALUE (units 10 ⁻³) DOCUMENT ID | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| 3.14±0.18 OUR FIT | 1.43±0.48±0.05 16.8±4.8 ⁵⁹ ABLIKIM 050 BES2 $\psi(2S) \rightarrow \gamma \chi_{C0}$ 59 ABLIKIM 050 reports $[\Gamma(\chi_{C0}(1P) \rightarrow K^+K^-K_0^0K_0^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow K^+K^-K_0^0K_0^0)/\Gamma_{\text{total}}]$ |
| | $\gamma \chi_{C0}(1P))] = (0.138 \pm 0.039 \pm 0.025) 	imes 10^{-3}$ which we divide by our best value |
| | $B(\bar{\psi}(2S) 	o \gamma \chi_{C0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| | , , |

 Γ_{64}/Γ

COMMENT

Meson Particle Listings

 $\chi_{c0}(1P)$

| $\Gamma(K^+K^-K^+K^-)/\Gamma_{total}$ Γ_{47}/Γ | $\Gamma(p\overline{p}\pi^0\pi^0)/\Gamma_{ m total}$ $\Gamma_{ m 56}/\Gamma_{ m 10}$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻³) DO CUMENT ID | VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| 2.79±0.29 OUR FIT | 0.105 ± 0.028 ± 0.003 39.5 ⁶⁸ HE 08B CLEO $e^+e^- \rightarrow \gamma h^+h^-h^0h^1$ |
| $\Gamma(K^+K^-\phi)/\Gamma_{\text{total}}$ Γ_{48}/Γ | ⁶⁸ HE 08B reports 0.11 \pm 0.02 \pm 0.02 \pm 0.01 % from a measurement of $[\Gamma(\chi_{C0}(1P)-\rho \overline{p}\pi^0\pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{C0}(1P))$: |
| ALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $(9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{c0}(1P)$ |
| 1.98±0.25±0.03 38 60 ABLIKIM 06T BES2 $\psi(2S)$ → $\gamma 2K^{+}2K^{-}$ | $= (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error |
| 60 ABLIKIM 06T reports $(1.03\pm0.22\pm0.15) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c0}(1P) \to 10^{-3})]$ | is the systematic error from using our best value. |
| $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4)^{+}$ $(8.4$ | $\Gamma(p\overline{p}K^+K^-(\text{non-resonant}))/\Gamma_{\text{total}}$ $\Gamma_{57}/$ |
| $(9.8 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| the systematic error from using our best value. | 1.23±0.26±0.04 48 ± 8 ⁶⁹ ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$ |
| $\Gamma_{(\phi\phi)}/\Gamma_{\text{total}}$ Γ_{49}/Γ_{0} | 69 ABLIKIM 11F reports $(1.24\pm0.20\pm0.18)	imes10^{-4}$ from a measurement of [Γ $(\chi_{c0}(1P)-1.00)$] |
| (ALUE (units 10^{-3}) DOCUMENT ID | $p\overline{p}K^+K^-$ (non-resonant)) $/\Gamma_{	ext{total}}] \times [B(\psi(2S) \to \gamma \chi_{C0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{C0}(1P)) = (9.62 \pm 0.31) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{C0}(1P))$ |
| 0.82±0.08 OUR FIT | $\gamma \chi_{C0}(1P)) = (9.62 \pm 0.31) \times 10^{-2}$, which we rescale to our best value B($\psi(2S)$ - |
| F/- = \/F | $\gamma\chi_{\rm C0}(1P))=(9.68\pm0.31)\times10^{-2}$. Our first error is their experiment's error and ous econd error is the systematic error from using our best value. |
| $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ Γ_{50}/Γ | $\Gamma(p\overline{p}K_S^0K_S^0)/\Gamma_{\text{total}}$ Γ_{58}/Γ_{58} |
| ALUE (units 10 ⁻⁴) DO CUMENT ID .23±0.13 OUR FIT | 1 9 97 |
| | VALUE (units 10^{-4})CL%DOCUMENT IDTECNCOMMENT<8.8 |
| $\Gamma(p\overline{p}\pi^0)/\Gamma_{\text{total}}$ Γ_{51}/Γ_{10} | 70 Using B($\psi(25) \to \chi_{c0} \gamma$) = (9.2 ± 0.5)% |
| ALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | |
| 1.70\pm0.07 OUR AVERAGE Error includes scale factor of 1.2. 1.74 \pm 0.06 \pm 0.02 $\frac{61}{}$ ONYISI $\frac{10}{}$ CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ | $\Gamma(ho \overline{n} \pi^-)/\Gamma_{ m total}$ |
| $0.56\pm0.12\pm0.02$ GV1131 10 CEE3 $\psi(2S) \rightarrow \gamma pp X$ $0.56\pm0.12\pm0.02$ 62 ATHAR 07 CLEO $\psi(2S) \rightarrow \gamma h^+ h^- h^0$ | VALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT |
| 61 ONYISI 10 reports (7.76 \pm 0.37 \pm 0.51 \pm 0.39) \times 10 $^{-4}$ from a measurement of | 11.4\pm3.1\pm0.4 71 ABLIKIM 061 BES2 $\psi(2S) \rightarrow \gamma p \pi^- X$ |
| $[\Gamma(\chi_{c0}(1P) \to p\overline{p}\pi^0)/\Gamma_{total}] \times [B(\psi(2S) \to \gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c0}(1P))$ | 71 ABLIKIM 06I reports $[\Gamma(\chi_{C0}(1P) \rightarrow p \overline{n} \pi^-)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))] = (1.10 \pm 0.24 \pm 0.18) \times 10^{-4}$ which we divide by our best value $B(\psi(2S) \rightarrow \gamma \chi_{C0}(1P))$ |
| $\gamma \chi_{c0}(1P)) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{c0}(1P)) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our | $(1.10 \pm 0.24 \pm 0.18) \times 10^{-2}$ Which we divide by our best value $B(\psi(25) \to \gamma \chi_{c0}(1P))$ = $(9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error |
| $\gamma\chi_{C0}(1P)$] = $(9.86\pm0.31)\times10^{-3}$. Our list error is their experiment's error and our second error is the systematic error from using our best value. 62 ATHAR 07 reports $(0.59\pm0.10\pm0.08)\times10^{-3}$ from a measurement of $[\Gamma(\chi_{C0}(1P)\to 0.08)\times10^{-3}]$ | is the systematic error from using our best value. |
| | $\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ $\Gamma_{60}/\Gamma_{\text{total}}$ |
| $p\overline{p}\pi^0$)/ Γ_{total}] \times [B($\psi(2S) \rightarrow \gamma \chi_{c0}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma \chi_{c0}(1P)$) = $(9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{c0}(1P)$) | VALUE (units 10 ⁻⁴) DOCUMENT ID |
| $(9.22\pm0.11\pm0.46)\times 10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C0}(1P))=(9.68\pm0.31)\times 10^{-2}$. Our first error is their experiment's error and our second error | 3.3±0.4 OUR FIT |
| is the systematic error from using our best value. | F(47 + -)/F |
| $\Gamma(p\overline{p}\eta)/\Gamma_{\text{total}}$ Γ_{52}/Γ | $\Gamma(\Lambda \overline{\Lambda} \pi^+ \pi^-)/\Gamma_{\text{total}}$ |
| ' (PP')) ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 0.36±0.04 OUR AVERAGE | <4.0 90 $^{\prime 2}$ ABLIKIM 06D BES2 $\psi(2S) \rightarrow \chi_{c0} \gamma$ 72 Using B $(\psi(2S) \rightarrow \chi_{c0} \gamma) = (9.2 \pm 0.5)\%$ |
| $0.36\pm0.04\pm0.01$ 63 ONYISI 10 CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ | |
| $0.37\pm0.11\pm0.01$ 64 ATHAR 07 CLEO $\psi(2S) ightarrow \gamma h^+ h^- h^0$ | $\Gamma(K^+ \overline{p} \Lambda + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{62}/Γ_{62} |
| ⁶³ ONYISI 10 reports $(3.73\pm0.38\pm0.28\pm0.19)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{c0}(1P)\to p\overline{p}\eta)/\Gamma_{\text{total}}]\times[B(\psi(2S)\to \gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{c0}(1P))$ | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| $\gamma \chi_{C0}(1P) = (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$) | 1.02±0.19±0.03 73 ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ |
| $\sim \sim c(1P)$) - (9.68 + 0.31) $\times 10^{-2}$ Our first error is their experiment's error and our | 73 ATHAR 07 reports $(1.07\pm0.17\pm0.12)	imes10^{-3}$ from a measurement of [Γ $(\chi_{c0}(1P)$ – |
| 7.001) 7.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 1.001 $1.$ | $\begin{array}{l} \textit{K}^+ \overline{p} \textit{\Lambda} + \text{c.c.}) / \Gamma_{\text{total}}] \times \left[\textit{B}(\psi(2S) \rightarrow \gamma \chi_{c0}(1P)) \right] \text{ assuming } \textit{B}(\psi(2S) \rightarrow \gamma \chi_{c0}(1P)) : \\ (9.22 \pm 0.11 \pm 0.46) \times 10^{-2}, \text{ which we rescale to our best value } \textit{B}(\psi(2S) \rightarrow \gamma \chi_{c0}(1P)) : \\ \end{cases}$ |
| $\rho \overline{\rho} \eta / \Gamma_{\text{total}} \times [B(\psi(2S) \to \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c0}(1P)) = (9.22 \pm 1.00)$ | $(9.22\pm0.11\pm0.46) \times 10^{-2}$, which we rescale to our best value $B(\psi(25) \to \gamma \chi_{c0}(1P))$ = $(9.68\pm0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error |
| 0.11 ± 0.46) $\times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{CO}(1P)$) = | is the systematic error from using our best value. |
| $(9.68 \pm 0.31) 	imes 10^{-2}$. Our first error is their experiment's error and our second error is | $\Gamma(K^+ p \Lambda(1520) + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{63}/Γ_{63} |
| the systematic error from using our best value. | VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma(p\overline{p}\omega)/\Gamma_{\text{total}}$ Γ_{53}/Γ | 3.0±0.8±0.1 62 ± 12 74 ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$ |
| /ALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | 74 ABLIKIM 11F reports $(3.00\pm0.58\pm0.50)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{C0}(1P)-10.000)]$ |
| 0.53 \pm 0.06 \pm 0.02 65 ONYISI 10 CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ | $K^+ \rho \Lambda(1520) + \text{c.c.}/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{c0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{c0}(1P))$ |
| 65 ONYISI 10 reports (5.57 \pm 0.48 \pm 0.42 \pm 0.14) \times 10 $^{-4}$ from a measurement of | $\gamma \chi_{c0}(1P)$) = $(9.62\pm0.31)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)-\gamma\chi_{c0}(1P))$ = $(9.68\pm0.31)\times10^{-2}$. Our first error is their experiment's error and our |
| $[\Gamma(\chi_{c0}(1P) \rightarrow p\overline{\rho}\omega)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma\chi_{c0}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{c0}(1P))$ | $\gamma \chi_{c0}(1P) = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and or |
| $\gamma \chi_{C0}(1P))=(9.22\pm0.11\pm0.46)\times 10^{-2}$, which we rescale to our best value ${\sf B}(\psi(2S)\to 0.01)$ | second error is the systematic error from using our best value. |

 Γ_{54}/Γ

 $4.2 \pm 0.7 \pm 0.1$

| $\Gamma(\Lambda(1520)\overline{\Lambda}(1520))$ | 0))/Γ _{total} | | | | |
|-------------------------------------------------|------------------------|--------------|-----|------|--|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | |
| 3.2±1.2±0.1 | 28 ± 10 | 75 ABLIKIM | 11F | BES3 | |

 $\psi(2S) \rightarrow \gamma \rho \overline{\rho} K^+ K^ ^{75}$ ABLIKIM 11F reports $(3.18\pm1.11\pm0.53)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{C0}(1P)\to\Lambda(1520)/\Gamma(1520))/\Gamma_{total}]\times[B(\psi(2S)\to\gamma\chi_{C0}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C0}(1P))=(9.62\pm0.31)\times10^{-2},$ which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C0}(1P))=(9.68\pm0.31)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(\Sigma^0\overline{\Sigma^0})/\Gamma_{total}$ Γ_{65}/Γ VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT 78 ± 10 76 NAIK 08 CLEO $\psi(2S) \rightarrow \gamma \Sigma^{0} \overline{\Sigma^{0}}$

 76 NAIK 08 reports (4.41 \pm 0.56 \pm 0.47) $\times\,10^{-4}$ from a measurement of [Г ($\chi_{C0}(1P)$ \to $\Sigma^0\overline{\Sigma}^0)/\Gamma_{\mathsf{total}}] \times [\mathsf{B}(\psi(2\mathcal{S}) \ \to \ \gamma\chi_{\mathcal{C}0}(1P))] \ \mathsf{assuming} \ \mathsf{B}(\psi(2\mathcal{S}) \ \to \ \gamma\chi_{\mathcal{C}0}(1P)) =$ $(9.22\pm0.11\pm0.46)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{c0}(1P))$ $= (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

ABELIAN IT reports $(6.12\pm 1.10\pm 0.60) \times 10^{-2}$ from a measurement of $[\chi_{CO}(1P) \to p \bar{p}\phi)/\Gamma_{\rm total}] \times [B(\psi(2S) \to \gamma \chi_{CO}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{CO}(1P)) = (9.62\pm 0.31) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{CO}(1P)) = (9.68\pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(\rho \overline{\rho} \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{55}/Γ
 VALUE (units 10⁻³)
 DO CUMENT ID
 TECN
 COMMENT

 2.1 ±0.7
 OUR EVALUATION
 Error includes scale factor of 1.4. Treating systematic
 2.1 ±1.0 OUR AVERAGE Error includes scale factor of 2.0. 1.57±0.21±0.53 67 BAI 99B BES $\psi(2S) \rightarrow \gamma \chi_{c0}$ 99B BES 67 TANENBAUM 78 MRK1 $\psi(2s)
ightarrow \gamma \chi_{c0}$ $4.20\!\pm\!1.15\pm0.18$ 67 Rescaled by us using B($\psi(2S)$ ightarrow $\gamma\chi_{c0}$)= (9.4 \pm 0.4)% and B($\psi(2S)$ ightarrow $J/\psi(1S) \pi^+ \pi^-) = (32.6 \pm 0.5)\%$

 $\chi_{\mathcal{L}_0(1P)} = (9.68 \pm 0.31) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁶⁶ ABLIKIM 11F reports (6.12 \pm 1.18 \pm 0.86) \times 10 $^{-5}$ from a measurement of [$\Gamma(\chi_{C0}(1P) \to$

DOCUMENT ID TECN COMMENT

42 \pm 8 66 ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$

 $\Gamma(p\overline{p}\phi)/\Gamma_{\text{total}}$

VALUE (units 10^{-5})

 $6.1 \pm 1.4 \pm 0.2$

EVTS

 $\chi_{c0}(1P)$

| $\Gamma(\Sigma^{+}\overline{\Sigma}^{-})/\Gamma_{\text{total}}$ | Г ₆₆ /Г | $\Gamma(\gamma\omega)/\Gamma_{\text{total}}$ | Γ ₇₁ /Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) EVTS DOCUMEN 3.1±0.7±0.1 39 ± 7 77 NAIK 77 NAIK 08 reports (3.25 ± 0.57 ± 0.43) × 10 | 08 CLEO $\psi(2S) \to \gamma \Sigma^+ \overline{\Sigma}^-$ | • • We do not use the following data for averages, fits, lim | TECN COMMENT CLEO $\psi(2S) \rightarrow \gamma \gamma \omega$ its, etc. • • • BES3 $\psi(2S) \rightarrow \gamma \gamma \omega$ |
| $\Sigma^+\overline{\Sigma}^-)/\Gamma_{	ext{total}}] 	imes [B(\psi(25) 	o 	au_{\infty}0(1.6) \times 10^{-2}], which we rescal = (9.68 \pm 0.31) 	imes 10^{-2}. Our first error is t is the systematic error from using our best v$ | le to our best value B $(\psi(2S) ightarrow \gamma \chi_{C0}(1P))$ heir experiment's error and our second error | ⁸⁵ BENNETT 08A reports $< 8.8 \times 10^{-6}$ from a measurem $\Gamma_{\text{total}}] \times [B(\psi(25) \to \gamma \chi_{C0}(1P))]$ assuming $B(\psi(25) \to 10^{-2}$, which we rescale to our best value $B(\psi(25) \to \gamma)$ | ent of $[\Gamma(\chi_{C0}(1P) \rightarrow \gamma\omega)/$ $\rightarrow \gamma\chi_{C0}(1P)) = (9.2 \pm 0.4) \times $ $\chi_{C0}(1P)) = 9.68 \times 10^{-2}$. |
| Γ(Ξ ⁰ Ξ ⁰)/Γ _{total} VALUE (units 10 ⁻⁴) EVTS DOCUMEN | Γ ₆₇ /Γ | ⁸⁶ ABLIKIM 11E reports $<$ 12.9×10 ⁻⁶ from a measurement of \times [B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$) which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$). | of $[\Gamma(\chi_{c0}(1P) \rightarrow \gamma \omega)/\Gamma_{total}]$ $(1P)) = (9.62 \pm 0.31) \times 10^{-2},$ |
| 3.2 \pm 0.8 \pm 0.1 23.3 \pm 4.9 ⁷⁸ NAIK 78 NAIK 08 reports $(3.34\pm0.70\pm0.48)\times10$ | 08 CLEO $\psi(2S) \rightarrow \gamma \equiv 0 \equiv 0$ | $\Gamma(\gamma\phi)/\Gamma_{ m total}$ | Γ ₇₂ /Γ |
| $\equiv 0 \ \equiv 0 \) / \Gamma_{\text{total}} \times [B(\psi(2s) \rightarrow \gamma \chi_{\text{co}}(1R)] \times [B(\psi(2s) \rightarrow \gamma \chi_{\text{co}}(1R)] \times [9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescal $= (9.68 \pm 0.31) \times 10^{-2}$. Our first error is t is the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from using our best we have the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the systematic error from the | P))] assuming $\mathrm{B}(\psi(2S) \to \gamma \chi_{c0}(1P)) =$ leto our best value $\mathrm{B}(\psi(2S) \to \gamma \chi_{c0}(1P))$ heir experiment's error and our second error | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\frac{\mathit{TECN}}{CLEO} \; \; \frac{\mathit{COMMENT}}{\psi(2S) ightarrow \gamma \gamma \phi}$ |
| $\Gamma(\Xi^-\overline{\Xi}^+)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) CL% EVTS DOCUME | Γ ₆₈ /Γ | 87 BENNETT 08A reports $<$ 6.4 \times 10 $^{-6}$ from a measurem $\Gamma_{	ext{total}}] 	imes [\mathrm{B}(\psi(2S) 	o \gamma_{\chi_C0}(1P))]$ assuming $\mathrm{B}(\psi(2S) -$ | ent of $[\Gamma(\chi_{c0}(1P) \rightarrow \gamma\phi)/$ $\gamma\chi_{c0}(1P)) = (9.2 \pm 0.4) \times$ |
| | rages, fits, limits, etc. \bullet \bullet \bullet M 06D BES2 $\psi(2S) \rightarrow \gamma \Xi^{+} \overline{\Xi}^{-}$ | 10^{-2} , which we rescale to our best value B($\psi(2S) \rightarrow \gamma$: 88 ABLIKIM 11E reports $< 16.2 \times 10^{-6}$ from a measurement of \times [B($\psi(2S) \rightarrow \gamma \chi_{CO}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma \chi_{CO}(1P)$) which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{CO}(1P)$) | of $[\Gamma(\chi_{c0}(1P) \rightarrow \gamma \phi)/\Gamma_{total}]$ $[1P)) = (9.62 \pm 0.31) \times 10^{-2},$ |
| 79 NAIK 08 reports $(5.14 \pm 0.60 \pm 0.47) \times 10$ $\Xi^- \overline{\Xi}^+)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{c0})]$ $(9.22 \pm 0.11 \pm 0.46) \times 10^{-2}$, which we rescal | P))] assuming B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$) = | $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ | ,, Г ₇₃ /Г си соммент |
| = $(9.68 \pm 0.31) \times 10^{-2}$. Our first error is t is the systematic error from using our best v B0 Using B($\psi(2S) \rightarrow \chi_{C0} \gamma$) = $(9.2 \pm 0.5)\%$ | heir experiment's error and our second error | 2.23±0.17 OUR FIT • • We do not use the following data for averages, fits, lim | nits, etc. • • • |
| | F /F F /F | | LL $B^{\pm} \rightarrow K^{\pm} \gamma \gamma$ |
| $\Gamma(\rho \overline{\rho})/\Gamma_{\text{total}} \times \Gamma(\pi \pi)/\Gamma_{\text{total}}$ VALUE (units 10 ⁻⁷) DOCUMENT | $\Gamma_{50}/\Gamma 	imes \Gamma_{31}/\Gamma$ TECN COMMENT | 89 WICHT 08 reports $[\Gamma(\chi_{C0}(1P)	o\gamma\gamma)/\Gamma_{	ext{total}}]	imes [B(B^+10^{-6}$ which we divide by our best value $B(B^+	o\chi_{C0}(1P))$ | $\rightarrow \chi_{c0}(1P) \ K^{+}) = 1.34 \times 10^{-4}$ |
| 19.0±1.4 OUR FIT 15.3±2.4±0.8 81 ANDREOT | FTI 03 E835 $\overline{p}p ightarrow \chi_{c0} ightarrow \pi^0 \pi^0$ | $\Gamma(\gamma\gamma)/\Gamma(\gamma J/\psi(1S))$ | Γ ₇₃ /Γ ₆₉ |
| 81 We have multiplied B($p\overline{p}$)·B($\pi^0\pi^0$) measur | | VALUE (units 10 ⁻²) DOCUMENT ID TECN | COMMENT |
| $\Gamma(\rho \overline{\rho})/\Gamma_{\text{total}} \times \Gamma(\pi^0 \eta)/\Gamma_{\text{total}}$ | $\Gamma_{50}/\Gamma \times \Gamma_{32}/\Gamma$ | 1.90±0.19 OUR FIT 2.0 ±0.4 OUR AVERAGE | |
| VALUE (units 10 ⁻⁷) DOCUMENT | | . 0.1 | $p\overline{p} \rightarrow \chi_{c0} \rightarrow \gamma\gamma$ |
| | FTI 05C E835 $\overline{p}p \rightarrow \pi^0 \eta$ | 1.45 ± 0.74 91 AMBROGIANI 00B E835 | $\overline{p} p 	o \chi_{c2} 	o \gamma \gamma, \gamma J/\psi$ |
| $\Gamma(p\overline{p})/\Gamma_{\text{total}} \times \Gamma(\pi^0 \eta')/\Gamma_{\text{total}}$ VALUE (units 10^{-7}) DOCUMENT | Γ ₅₀ /Γ × Γ ₃₃ /Γ | 90 The values of $\mathrm{B}(p\overline{p})\mathrm{B}(\gamma\gamma)$ and $\mathrm{B}(\gamma\gamma)\mathrm{B}(\gamma J/\psi)$ measure independent. The latter is used in the fit because of smal 91 Calculated by us using $\mathrm{B}(J/\psi(1S) \to e^+e^-) = 0.0593$ | ler systematics. |
| <2.5 ANDREOT | TTI 05C E835 $\overline{p}p ightarrow \pi^0 \eta$ | $\Gamma(p\overline{p})/\Gamma_{ m total} 	imes \Gamma(\gamma J/\psi(1S))/\Gamma_{ m total}$ | $\Gamma_{50}/\Gamma \times \Gamma_{69}/\Gamma$ |
| $\Gamma(p\overline{p})/\Gamma_{	ext{total}} 	imes \Gamma(\eta\eta)/\Gamma_{	ext{total}}$ | $\Gamma_{50}/\Gamma \times \Gamma_{34}/\Gamma$ | VALUE (units 10 ⁻⁷) EVTS DOCUMENT ID T | ECN COMMENT |
| <u>VALUE (units 10⁻⁷)</u> <u>DOCUMENT</u> 6.8 ± 0.6 OUR FIT | ID TECN COMMENT | 26.2±1.7 OUR FIT 28.2±2.1 OUR AVERAGE | |
| | FTI 05c E835 $\overline{p} p ightarrow \eta \eta$ | 28.0±1.9±1.3 392 92,93,94 BAGNASCO 02 E 29.3+5.7 ±1.5 89 92,93 AMBROGIANI 99B | 835 $\overline{p}p \rightarrow \chi_{c0} \rightarrow J/\psi \gamma$ $\overline{p}p \rightarrow \chi_{c0} \rightarrow J/\psi \gamma$ |
| $\Gamma(\rho \overline{\rho})/\Gamma_{\text{total}} \times \Gamma(\eta \eta')/\Gamma_{\text{total}}$ <u>VALUE (units 10⁻⁶)</u> <u>DOCUMENT</u> | $\Gamma_{50}/\Gamma 	imes \Gamma_{35}/\Gamma$ | 92 Values in $(\Gamma(\rho\overline{\rho}) \times \Gamma(\gamma J/\psi(1S))/\Gamma_{\mbox{total}})$ and $(\Gamma(\rho\overline{\rho})/\Gamma_{\mbox{total}})$ are not independent. The latter is used in the fit since it width. | |
| • • We do not use the following data for ave | _ | 93 Calculated by us using B $(J/\psi(15) ightarrow e^+ e^-) = 0.0593$ 94 Recalculated by ANDREOTTI 05A. | ± 0.0010. |
| 2.1 + 2.3 ANDREOT | FTI 05C E835 $\overline{p}p ightarrow \pi^0 \eta$ | | $\Gamma_{50}/\Gamma \times \Gamma_{73}/\Gamma$ |
| RADIATIVE | DECAYS —— | $\Gamma(\rho\overline{\rho})/\Gamma_{	ext{total}} \times \Gamma(\gamma\gamma)/\Gamma_{	ext{total}}$ VALUE (units 10^{-8}) DOCUMENT ID TE | I 50/I X I 73/I CN COMMENT |
| $\lceil \left(\gamma J/\psi(1S) \right) / \Gamma_{total}$ | Γ ₆₉ /Γ | 5.0 ±0.5 OUR FIT | |
| VALUE (units 10 ⁻⁴) DOCUMENT ID | TECN COMMENT | • • • We do not use the following data for averages, fits, lim | |
| 117± 8 OUR FIT • • • We do not use the following data for ave | rages, fits, limits, etc. ● ● | $6.52 \pm 1.18 ^{+0.48}_{-0.72}$ 95 ANDREOTTI 04 E8 | == |
| $200\pm20\pm20$ 82 ADAM 82 Uses B($\psi(2S) \rightarrow \gamma \chi_{c0} \rightarrow \gamma \gamma J/\psi$) from | 05A CLEO $e^+e^- ightarrow\psi(2S) ightarrow\gamma\chi_{C0}$ | 95 The values of $\mathrm{B}(p\overline{p})\mathrm{B}(\gamma\gamma)$ and $\mathrm{B}(\gamma\gamma)\mathrm{B}(\gamma J/\psi)$ measure independent. The latter is used in the fit because of smal | ler systematics. |
| ATHAR 04. | | $\chi_{c0}(1P)$ CROSS-PARTICLE BRANCHI | NG RATIOS |
| $\Gamma(\gamma \rho^0)/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-6}\text{)}$ $VALUE $ | F70/F SENT ID TECN COMMENT ETT 08A CLEO $\psi(2S) 	o \gamma \gamma \rho^0$ | $\Gamma(\chi_{c0}(1P) \to p\overline{p})/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma\chi_{c0}(1P))$ | $\Gamma_{50}/\Gamma 	imes \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| • • • We do not use the following data for ave | rages, fits, limits, etc. • • • | <u>VALUE (units 10⁻⁶) </u> | OMMENT |
| <10 90 6 ± 12 ⁸⁴ ABLIK | | 23.7±1.8 OUR AVERAGE | , <u> </u> |
| $^{83} \text{BENNETT}$ 08A reports $< 9.6 \times 10^{-6}$ from $\Gamma_{\text{total}}] \times [\text{B}(\psi(2\text{S}) \rightarrow \gamma \chi_{\text{C}0}(1P))]$ assuming | a measurement of $[\Gamma(\chi_{C0}(1P)	o \gamma ho^0)/\log B(\psi(2S)	o \gamma\chi_{C0}(1P))=(9.2\pm0.4)	imes$ | $23.7 \pm 1.4 \pm 1.4$ 383 ± 22 96 NAIK 08 CLEO ψ $23.6 + \frac{3}{3}.7 \pm 3.4$ $89.5 + \frac{14}{13}$ BAI 04F BES ψ | $(2S) \rightarrow \gamma p \overline{p}$ $(2S) \rightarrow \gamma \chi_{C0}(1P) \rightarrow \gamma \overline{p} p$ |
| 10 ⁻² , which we rescale to our best value B | $(\psi(2S) \rightarrow \gamma \chi_{c0}(1P)) = 9.68 \times 10^{-2}$. | | |
| 84 ABLIKIM 11E reports $<10.5\times10^{-6}$ from $\Gamma_{\rm tot \bar{a}_l}]\times [{\rm B}(\psi(25)\to\gamma\chi_{{\cal C}0}(1P))]$ assumin; 10^{-2} , which we rescale to our best value B | a measurement of $[\Gamma(\chi_{c0}(1P) \to \gamma_P^{\rm U})/g \ B(\psi(2S) \to \gamma\chi_{c0}(1P)) = (9.62 \pm 0.31) \times (\psi(2S) \to \gamma\chi_{c0}(1P)) = 9.68 \times 10^{-2}.$ | 96 Calculated by us. NAIK 08 reports B($\chi^0_c \to p \overline{p}$) = (25. using B($\psi(2S) \to \gamma \chi^0_c$) = (9.22 \pm 0.11 \pm 0.46)%. | $\pm 1.5 \pm 1.5 \pm 1.3) \times 10^{-9}$ |
| | | | |

| $J/\psi(1S)\pi^{+}\pi^{-}$ $\Gamma_{50}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ | $\Gamma(\chi_{c0}(1P) \to \pi\pi)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c0}(1P))/\Gamma_{\text{total}}$ $\Gamma_{31}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| <u>VALUE (units 10−5)</u> <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 6.4±0.4 OUR FIT | <u>VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT</u> 8.25 ± 0.29 OUR FIT |
| 4.6±1.9 97 BAI 98I BES $\psi(2S) \rightarrow \gamma \chi_{c0} \rightarrow \gamma \overline{\rho} p$ | 8.80±0.34 OUR AVERAGE |
| 97 Calculated by us. The value for B($\chi_{C0} \to p\overline{p}$) reported in BAI 981 is derived using | $9.11\pm0.08\pm0.65$ 17k 107 ABLIKIM 10A BES3 $e^+e^- ightarrow\psi(2S) ightarrow\gamma\chi_{c0}$ |
| B($\psi(2S) \to \gamma \chi_{CO}$) = (9.3 ± 0.8)% and B($\psi(2S) \to J/\psi(1S) \pi^+ \pi^-$) = (32.4 ± 2.6)% [BAI 98b]. | $\begin{array}{llllllllllllllllllllllllllllllllllll$ |
| $\Gamma(\chi_{c0}(1P) \to \Lambda \overline{\Lambda})/\Gamma_{\rm total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma_{\rm total} $ $\Gamma_{60}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ | 107 Calculated by us. ABLIKIM 10a reports B($\chi_{C0} \to \pi^0 \pi^0) = (3.23 \pm 0.03 \pm 0.23 \pm 0.14) \times 10^{-3}$ using B($\psi(25) \to \gamma \chi_{C0}) = (9.4 \pm 0.4)\%$. We have multiplied the $\pi^0 \pi^0$ measurement by 3 to obtain $\pi\pi$. |
| VALUE (units 10 ⁻⁶) EVTS DOCUMENT ID TECN COMMENT | 108 Calculated by us. ASNER 09 reports B($\chi_{c0} ightarrow \pi^+\pi^-$) = (6.37 \pm 0.08 \pm 0.31 \pm |
| 32 ±4 OUR FIT | 0.32) $	imes$ 10 $^{-3}$ using B $(\psi(2S) 	o \gamma \chi_{c0}) = (9.22 \pm 0.11 \pm 0.46)\%$. We have multiplied |
| $\begin{array}{llllllllllllllllllllllllllllllllllll$ | the $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. $^{109} \text{ Calculated by us. ASNER 09 reports B}(\chi_{c0}\to\pi^0\pi^0)=(2.94\pm0.07\pm0.32\pm0.15)\times 10^{-3} \text{ using B}(\psi(2S)\to\gamma\chi_{c0})=(9.22\pm0.11\pm0.46)\%. We have multiplied the }\pi^0\pi^0$ measurement by 3 to obtain $\pi\pi$. |
| $\Gamma(\chi_{c0}(1P) \to \Lambda \overline{\Lambda})/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma(\psi(2S) \to \chi_{c0}(1P))$ | $\Gamma(\chi_{c0}(1P) \to \pi\pi)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma\chi_{c0}(1P))/\Gamma(\psi(2S) \to \gamma\chi_{c0}(1P))$ |
| $J/\psi(1S)\pi^{+}\pi^{-})$ $\Gamma_{60}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ | $J/\psi(1S)\pi^{+}\pi^{-}$) $\Gamma_{31}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 9.5±1.1 OUR FIT | 24.5±0.9 OUR FIT |
| 13.0 $^{+3.6}_{-3.5}\pm 2.5$ 15.2 $^{+4.2}_{-4.0}$ 99 BAI 03E BES $\psi(2S) \to \gamma \Lambda \overline{\Lambda}$ | 20.7±1.7 OUR AVERAGE |
| ⁹⁹ BAI 03E reports [B($\chi_c^0 \to \Lambda \overline{\Lambda}$) B($\psi(2S) \to \gamma \chi_c^0$) / B($\psi(2S) \to J/\psi \pi^+ \pi^-$)] × | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| [B ² ($\Lambda \to \pi^- p$) / B($J/\psi \to p\overline{p}$)] = (2.45 $^+$ 0.68 $^+$ 0.46)%. We calculate from this | 110 We have multiplied $\pi^0\pi^0$ measurement by 3 to obtain $\pi\pi$. |
| measurement the presented value using B($\Lambda \to \pi^- p$) = (63.9 \pm 0.5)% and B($J/\psi \to p\overline{p}$) = (2.17 \pm 0.07) \times 10 ⁻³ . | 111 Calculated by us. The value for $B(\chi_{CO} \to \pi^+\pi^-)$ reported in BAI 98I is derived using $B(\psi' \to \gamma \chi_{CO}) = (9.3 \pm 0.8)\%$ and $B(\psi' \to J/\psi \pi^+\pi^-) = (32.4 \pm 2.6)\%$ [BAI 98D]. We have multiplied $\pi^+\pi^-$ measurement by $3/2$ to obtain $\pi\pi$. |
| $\Gamma(\chi_{c0}(1P) \to \gamma J/\psi(1S))/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma_{total}$ | $\Gamma(\chi_{c0}(1P) 	o \eta \eta)/\Gamma_{total} 	imes \Gamma(\psi(2S) 	o \gamma \chi_{c0}(1P))/\Gamma_{total}$ |
| $\Gamma_{69}/\Gamma \times \Gamma_{109}^{(25)}/\Gamma^{\psi(25)}$ | $\Gamma_{34}/\Gamma \times \Gamma_{109}^{\psi(25)}/\Gamma_{109}^{\psi(25)}$ |
| <u>VALUE (units 10−2)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.113±0.008 OUR FIT | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 0.073±0.018 OUR AVERAGE | 2.93±0.18 OUR FIT |
| 0.069 ± 0.018 100 OREGLIA 82 CBAL $\psi(2S) ightarrow \gamma \chi_{CO}$ | 3.12±0.19 OUR AVERAGE |
| 0.4 \pm 0.3 101 BRA NDELIK 79B DASP $\psi(2S) \rightarrow \gamma \chi_{CO}$ 0.16 \pm 0.11 101 BARTEL 78B CNTR $\psi(2S) \rightarrow \gamma \chi_{CO}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| 0.16 \pm 0.11 | • • • We do not use the following data for averages, fits, limits, etc. • • |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | $2.86\pm0.46\pm0.37$ 48 114 ADAMS 07 CLEO $\psi(2S) ightarrow \gamma \chi_{CO}$ |
| $0.125\pm0.007\pm0.013$ 560 103 MENDEZ 08 CLEO $\psi(2S) ightarrow \gamma \chi_{C0}$ | $^{-112}$ Calculated by us. ABLIKIM 10A reports B($\chi_{c0} ightarrow \eta \eta$) = (3.44 \pm 0.10 \pm 0.24 \pm 0.13) $	imes$ |
| $0.18 \pm 0.01 \pm 0.02$ 172 104 ADAM 05A CLEO Repl. by MENDEZ 08 | $10^{-3} \text{ using B}(\psi(2S) \rightarrow \gamma \chi_{C0}) = (9.4 \pm 0.4)\%.$ |
| 100 Recalculated by us using B $(J/\psi(1S) ightarrow ~\ell^+\ell^-) = 0.1181 \pm 0.0020.$ | 113 Calculated by us. A SNER 09 reports B($\chi_{c0} \to \eta \eta$) = (3.18 ± 0.13 ± 0.31 ± 0.16)×10 ⁻³ using B($\psi(25) \to \gamma \chi_{c0}$) = (9.22 ± 0.11 ± 0.46)%. |
| 101 Recalculated by us using B $(J/\psi(1S) ightarrow \mu^+\mu^-)=0.0588\pm0.0010$. | using B($\psi(2S) \rightarrow \gamma \chi_{c0}$) = (9.22 ± 0.11 ± 0.46)%. |
| 102 Assumes isotropic gamma distribution. | 114 Superseded by ASNER 09. Calculated by us. The value of B($\chi_{c0}(1P) \to \eta \eta$) reported by ADAMS 07 was derived using B($\psi(2S) \to \gamma \chi_{c0}(1P)$) = (9.22 \pm 0.11 \pm 0.46)% |
| 103 Not independent from other measurements of MENDEZ 08. 104 Not independent from other values reported by ADAM 05A. | (ATHAR 04). |
| | $\Gamma(\chi_{c0}(1P) 	o \eta \eta)/\Gamma_{total} 	imes \Gamma(\psi(2S) 	o \gamma \chi_{c0}(1P))/\Gamma(\psi(2S) 	o$ |
| $\Gamma(\chi_{c0}(1P) \to \gamma J/\psi(1S))/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))$ | $ \chi_{c0}(1r) \rightarrow \eta \eta \eta \rangle \text{total} \times \psi(23) \rightarrow \chi_{c0}(1r) \rangle \psi(23) \rightarrow \psi(25) \psi(25) \rangle |
| $J/\psi(1S)$ anything) $\Gamma_{69}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{9}^{\psi(2S)}$ | $J/\psi(1S)\pi^{+}\pi^{-})$ $\Gamma_{34}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| $\Gamma_{69}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{9}^{\psi(2S)} = \Gamma_{69}/\Gamma \times \Gamma_{109}^{\psi(2S)}/(\Gamma_{11}^{\psi(2S)} + \Gamma_{12}^{\psi(2S)} + \Gamma_{13}^{\psi(2S)} + \Gamma$ | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| $\begin{array}{c} 0.344\Gamma_{110}^{\psi(2S)} + 0.195\Gamma_{111}^{\psi(2S)} \end{array})$ | 0.87 \pm 0.05 OUR FIT 0.578 \pm 0.241 \pm 0.158 BAI 03C BES $\psi(2S) \rightarrow \gamma \eta \eta$ |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\chi_{c0}(1P)	o K^+K^-)/\Gamma_{ m total} 	imes \Gamma(\psi(2S)	o \gamma\chi_{c0}(1P))/\Gamma_{ m total}$ |
| 0.191±0.014 OUR FIT | $\Gamma_{39}/\Gamma 	imes \Gamma_{109}^{\psi(25)}/\Gamma^{\psi(25)}$ |
| | |
| $0.201\pm0.011\pm0.021$ 560 105 MENDEZ 08 CLEO $\psi(2S) ightarrow \gamma \chi_{CO}$ | <u>VALUE (units 10⁻⁴) </u> |
| $0.31~\pm0.02~\pm0.03$ 172 ADAM 05A CLEO Repl. by MENDEZ 08 | 5.97±0.07±0.32 8.1k 115 ASNER 09 CLEO $\psi(2S) \rightarrow \gamma K^+ K^-$ |
| 105 Not independent from other measurements of MENDEZ 08. | 115 Calculated by us. ASNER 09 reports B($\chi_{C0} ightarrow ~K^+K^-) = (6.47 \pm 0.08 \pm 0.35 \pm 0.08)$ |
| [(a, -(1P) \ \alpha \ \ \ \ \ \ \ \ \ \ | $0.32) \times 10^{-3}$ using B($\psi(2S) \rightarrow \gamma \chi_{C0}$) = $(9.22 \pm 0.11 \pm 0.46)\%$. |
| $\Gamma(\chi_{c0}(1P) \to \gamma J/\psi(1S))/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma(\psi(2S) \to \chi_{c0}(1P))$ | |
| $J/\psi(1S)\pi^{+}\pi^{-}$ | $\Gamma(\chi_{c0}(1P) \to K^+K^-)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma\chi_{c0}(1P))/\Gamma(\psi(2S) \to \psi(2S))$ |
| VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT | $J/\psi(1S)\pi^+\pi^-)$ $\Gamma_{39}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| 0.338±0.024 OUR FIT 0.358±0.020±0.037 560 MENDEZ 08 CLEO $\psi(2S) \rightarrow \gamma \chi_{c0}$ | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| 0.358 \pm 0.020 \pm 0.037 | 1.75±0.09 OUR FIT |
| $0.55 \pm 0.04 \pm 0.06$ 172 106 ADAM 05A CLEO Repl. by MENDEZ 08 | 1.63±0.10±0.15 774 ± 38 116 BAI 981 BES $\psi(2S) \rightarrow \gamma K^+ K^-$ |
| 106 Not independent from other values reported by ADAM 05A. | ¹¹⁶ Calculated by us. The value for B($\chi_{c0} ightarrow K^+K^-$) reported by BAI 98I is derived using |
| | $B(\psi(2S) \to \gamma \chi_{C0}) = (9.3 \pm 0.8)\%$ and $B(\psi(2S) \to J/\psi \pi^+ \pi^-) = (32.4 \pm 2.6)\%$ [BAI 98D]. |
| $\Gamma(\chi_{c0}(1P) \to \gamma \gamma)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P))/\Gamma_{total}$ | |
| $\Gamma_{73}/\Gamma 	imes \Gamma_{109}^{\psi(2S)}/\Gamma_{\psi(2S)}^{\psi(2S)}$ | $\Gamma(\chi_{c0}(1P) \to K_S^0 K_S^0) / \Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c0}(1P)) / \Gamma_{\text{total}}$ |
| VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | $\Gamma_{40}/\Gamma 	imes \Gamma_{109}^{\psi(25)}/\Gamma^{\psi(25)}$ |
| 2.16±0.19 OUR FIT | VALUE (units 10 ⁻⁴) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| 2.21±0.33 OUR AVERAGE | 3.04±0.15 OUR FIT |
| $2.17\pm0.32\pm0.10$ 207 ± 31 ECKLUND 08A CLEO $\psi(2S) \rightarrow \gamma \chi_{c0} \rightarrow 3\gamma$ | 3.18±0.17 OUR AVERAGE |
| 3.7 $\pm 1.8~\pm 1.0$ LEE 85 CBAL $\psi(2S) ightarrow \gamma \chi_{C0}$ | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| | |
| | 117 Calculated by us. ASNER 09 reports B($\chi_{c0} ightarrow ~\kappa_S^0 ~\kappa_S^0$) $= (3.49 \pm 0.08 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm 0.18 \pm $ |
| | Calculated by us. AsNER 09 leptons $B(\chi_{c0} \rightarrow \chi_{s} \chi_{s}) = (3.49 \pm 0.00 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0.10 \pm 0$ |
| | 0.17) $\times 10^{-3}$ using B($\psi(2S) \rightarrow \gamma \chi_{C0}$) = (9.22 ± 0.11 ± 0.46)%. |

 $\chi_{c0}(1P)$, $\chi_{c1}(1P)$

2.35 ± 0.23 OUR FIT $2.6 \pm 1.0 \pm 1.1$

126 BAI

126 Calculated by us. The value of B($\chi_{c0} \rightarrow \phi \phi$) reported by BAI 99B was derived using B($\psi(25) \rightarrow \gamma \chi_{c0}(1P)$) = (9.3 ± 0.8)% and B($\psi(25) \rightarrow J/\psi \pi^+ \pi^-$) = (32.4 ± 2.6)% [BAI 98b].

99B BES $\psi(2S) \rightarrow \gamma 2K^+ 2K^-$

| $\Gamma(\chi_{c0}(1P) \to K_S^0 K_S^0)/\Gamma_{\text{total}}$ $J/\psi(1S) \pi^+ \pi^-)$ | $\times \Gamma(\psi(2S) \to \gamma \chi$ | $(c_0(1P))/\Gamma(\psi(2S) \to \Gamma_{40}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)})$ |
|----------------------------------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) | DOCUMENT ID | TECN COMMENT |
| 9.1 ± 0.5 OUR FIT 5.6 ± 0.8 ± 1.3 | .8 BAI 99B | BES $\psi(2S) \rightarrow \gamma K_S^0 K_S^0$ |
| $^{118}\mathrm{Calculated}$ by us. The value of E | $B(\chi_{c0} \rightarrow K_S^0 K_S^0)$ rep | orted by BAI 99в was derived using |
| | |) $\rightarrow J/\psi \pi^+ \pi^-$) = (32.4 ± 2.6)% |
| $\Gamma(\chi_{c0}(1P) \rightarrow 2(\pi^+\pi^-))/\Gamma_{tot}$ | $_{\rm cal}$ $	imes$ $\Gamma(\psi(2S) ightarrow c$ | $\gamma \chi_{c0}(1P))/\Gamma(\psi(2S) \rightarrow$ |
| $J/\psi(1S)\pi^+\pi^-)$ | , | $\Gamma_1/\Gamma \times \Gamma_{109}^{\psi(25)}/\Gamma_{11}^{\psi(25)}$ |
| VALUE (units 10 ⁻³) | DOCUMENT ID | TECN COMMENT |
| 6.5 ± 0.5 OUR FIT | | |
| | cludes scale factor of .9 BAI 99B | |
| 9.3 ± 0.9 | TANENBAUM 78 | MRK1 $\psi(2S) \rightarrow \gamma \chi_{C0}$ |
| $^{119}\mathrm{Calculated}$ by us. The value for l | | |
| $B(\psi(2S) \to \gamma \chi_{C0}) = (9.3 \pm 0.$ [BAI 98D]. | 8)% and B $(\psi(2S) ightarrow$ | $J/\psi(15) \pi^+ \pi^-) = (32.4 \pm 2.6)\%$ |
| 120 The value B($\psi(1S) \rightarrow \gamma \chi_{C0}$) | $\times B(\chi_{c0} \rightarrow 2\pi^{+} 2\pi^{-})$ |) reported in TANENBAUM 78 is |
| Calculated by us using $B(J/\psi(1$ | $(5) \rightarrow \ell^+\ell^-) = 0.13$ | |
| $\Gamma(\chi_{c0}(1P) \rightarrow \pi^+\pi^-K^+K^-)$ | $/\Gamma_{\text{total}} \times \Gamma(\psi(2S))$ | $) ightarrow \gamma \chi_{c0}(1P))/\Gamma_{ m total}$ |
| | | $\Gamma_8/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| VALUE (units 10^{-3}) | DOCUMENT ID | TECN COMMENT |
| 1.73±0.13 OUR FIT 1.64±0.05±0.2 | ABLIKIM 05 Q | BES2 $\psi(2S) \rightarrow \gamma \chi_{C0}$ |
| $\Gamma(\chi_{c0}(1P) \rightarrow \pi^+\pi^-K^+K^-)$ | /Faces × F(1/25) | $\rightarrow \gamma \gamma_{-0}(1P))/\Gamma(\psi(2S) \rightarrow$ |
| $J/\psi(1S)\pi^+\pi^-)$ | / · total × · (4(25) | $\Gamma_8/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| $VALUE$ (units 10^{-3}) | DO CUMENT ID | === == |
| 5.2 ±0.4 OUR FIT | DO CUMENT ID | TECN COMMENT |
| | includes scale factor | of 2.3. |
| 4.22±0.20±0.97 | BAI 99B | BES $\psi(2S) \rightarrow \gamma \chi_{c0}$ |
| | TANENBAUM 78 | |
| ^{121}The reported value is derived u (4.6 \pm 0.7)%. Calculated by us | | |
| $\Gamma(\chi_{c0}(1P) \rightarrow K^+K^-K^+K^-$ | $)/\Gamma_{\rm total} \times \Gamma(\psi(25))$ | $5) \rightarrow \gamma \chi_{c0}(1P))/\Gamma_{\text{total}}$ $\Gamma_{47}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID | TECN COMMENT |
| 2.70±0.27 OUR FIT |)2 A DI IIKINA | DECO ((05) 0K±0K= |
| | | BES2 $\psi(2S) \rightarrow \gamma 2K^+ 2K^-$ |
| 122 Calculated by us. The value of derived using B $(\psi(2S) ightarrow \gamma \chi_C$ | | |
| $\Gamma(\chi_{c0}(1P) \rightarrow K^+K^-K^+K^-$ | $)/\Gamma_{\mathrm{total}} \times \Gamma(\psi(25))$ | $(5) \rightarrow \gamma \chi_{c0}(1P))/$ |
| $\Gamma(\psi(2S) \to J/\psi(1S)\pi^+\pi^-)$ | | $\Gamma_{47}/\Gamma \times \Gamma_{109}^{\psi(25)}/\Gamma_{11}^{\psi(25)}$ |
| VALUE (units 10^{-4}) | DOCUMENT ID | TECN COMMENT |
| 8.0±0.8 OUR FIT 6.1±0.8±0.9 | ²³ BAI 99B | BES $\psi(2S) \rightarrow \gamma 2K^{+} 2K^{-}$ |
| 123 Calculated by us. The value of | | |
| using B($\psi(2S) \rightarrow \gamma \chi_{C0}(1P)$) : 2.6)% [BAI 98D]. | $= (9.3 \pm 0.8)\%$ and B(| $(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-) = (32.4 \pm$ |
| $\Gamma(\chi_{c0}(1P) 	o \phi \phi)/\Gamma_{total} 	imes \Gamma$ | $(\psi(2S) \rightarrow \gamma \chi_{c0}(1))$ | 1 <i>P</i>))/Γ _{total} |
| | | $\Gamma_{49}/\Gamma 	imes \Gamma_{109}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID | TECN COMMENT |
| 0.79±0.08 OUR FIT 0.78±0.08 OUR AVERAGE | | |
| 0.77±0.03±0.08 612 12 | ²⁴ ABLIKIM 11K ²⁵ ABLIKIM 06T | |
| 124 Calculated by us. The value of using $B(\psi(2S) \rightarrow \gamma \chi_{CO}(1P))$ | $B(\chi_{C0} \to \phi \phi)$ report = (9.62 ± 0.31)%. | rted by ABLIKIM 11K was derived |
| 125 Calculated by us. The value of using $\mathrm{B}(\psi(2S) \to \gamma \chi_{c0}(1P))$ | $B(\chi_{C0} \rightarrow \phi \phi)$ report $= (9.2 \pm 0.4)\%$ | rted by ABLIKIM 06T was derived |
| $\Gamma(\chi_{c0}(1P) \to \phi\phi)/\Gamma_{\rm total} \times \Gamma$ | | $(P))/\Gamma(\psi(2S) \rightarrow$ |
| $J/\psi(1S)\pi^+\pi^-$ | | $\Gamma_{49}/\Gamma \times \Gamma_{109}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| VALUE (units 10 ⁻⁴) | DOCUMENT ID | TECN COMMENT |

$\chi_{c0}(1P)$ REFERENCES

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|---------------------------------------------------------------------------------------|------------------------------------------------------------|-------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ECKLUND HE | 08 A 08 B | PR D78 091501R PR D78 092004 | K.M. Ecklund et al. Q. He et al. | (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) (BELLE Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (CLEO Collab.) (FNAL E335 Collab.) (BELLE Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BES Collab.) |
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| AULCHENKO | 03 | PL B573 63 | V.M. Aulchenko et al. | (KEDR Collab.) |
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| EISENSTEIN | 01 | PRL 87 061801 | B.I. Eisenstein <i>et al.</i> | ` (CLEO Collab.) |
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| AM BROGIANI BAI | 0.0 D | PRL 83 2902 PR D60 072001 PR D58 092006 | M. Ambrogiani et al. | (ČLEO Collab.) (BES Collab.) (FNAL E835 Collab.) (KEDR Collab.) (BES Collab.) (BES Collab.) (BES Collab.) (BELE Collab.) (FNAL E835 Collab.) (FNAL E835 Collab.) (BES Collab.) (BES Collab.) (BES Collab.) |
| BAI | 98 D | PR D58 092006 | J.Z. Bai et al. | (BES Collab.) |
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| BAI BAI GAISER LEE OREGUIA | 85 | SLAC 282 PR D25 2259 NP B160 426 | K.A. Lee | (SLAC) (SLAC, CIT, HARV+) |
| BRANDFIIK | 79B | NP B160 426 | R Brandelik et al. | (DASP Collab.) |
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$\chi_{c1}(\overline{1P})$

$$I^{G}(J^{PC}) = 0^{+}(1^{+})$$

See the Review on " $\psi(2S)$ and χ_C branching ratios" before the $\chi_{C0}(1P)$ Listings.

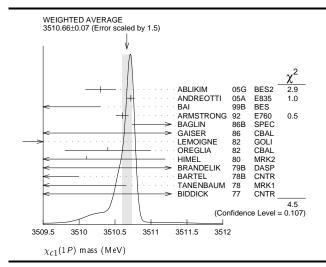
$\chi_{c1}(1P)$ MASS

| VALUE (N | leV) | | | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|-----------------------|---------|--------|-------------|-----------|------|-------------------|-------------|-----------|---------------------------------------------|
| 3510.66 below. | ± | 0.07 | OUR A | VERAGE | Err | or includes scale | facto | or of 1.5 | . See the ideogram |
| 3510.30 | \pm | 0.14 | ±0.16 | | | ABLIKIM | 05 G | BES2 | $\psi(2S) \rightarrow \gamma \chi_{C1}$ |
| 3510.719 | θ± | 0.051 | ± 0.019 | | | ANDREOTTI | 05 A | E835 | $p \overline{p} \rightarrow e^+ e^- \gamma$ |
| 3509.4 | \pm | 0.9 | | | | BAI | 99B | BES | $\psi(2S) \rightarrow \gamma X$ |
| 3510.60 | \pm | 0.087 | ± 0.019 | 513 | 1 | ARMSTRONG | 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| 3511.3 | \pm | 0.4 | ± 0.4 | 30 | | BAGLIN | 86B | SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| 3512.3 | \pm | 0.3 | ± 4.0 | | | GAISER | 86 | CBAL | $\psi(2S) \rightarrow \gamma X$ |
| 3507.4 | \pm | 1.7 | | 91 | 3 | LEMOIGNE | 82 | GOLI | 185 π^{-} Be → |
| | | | | | | | | | $\gamma \mu^+ \mu^- A$ |
| 3510.4 | ± | 0.6 | | | | OREGLIA | 82 | CBAL | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3510.1 | \pm | 1.1 | | 254 | 4 | HIMEL | 80 | MRK2 | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3509 | ± 1 | l 1 | | 21 | | BRANDELIK | 79B | DASP | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3507 | \pm | 3 | | | 4 | BARTEL | 78B | CNTR | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3505.0 | \pm | 4 | ± 4 | | 4,5 | TANENBAUM | 78 | MRK1 | e^+e^- |
| 3513 | \pm | 7 | | 367 | 4 | BIDDICK | 77 | CNTR | $\psi(2S) \rightarrow \gamma X$ |
| • • • V | Ve d | lo not | use the | following | data | for averages, fit | s, lim | its, etc. | • • • |
| 3500 | ± 1 | L O | | 40 | | TANENBAUM | 75 | MRK1 | Hadrons γ |

 $[\]frac{1}{2}$ Recalculated by ANDREOTTI 05A, using the value of $\psi(2S)$ mass from AULCHENKO 03.

² Using mass of $\psi(2S)=3686.0$ MeV. ³ $J/\psi(1S)$ mass constrained to 3097 MeV.

of Very Mass constants to 307 MeV. A Mass value shifted by us by amount appropriate for $\psi(2s)$ mass = 3686 MeV and $J/\psi(1s)$ mass = 3097 MeV. From a simultaneous fit to radiative and hadronic decay channels.



$\chi_{c1}(1P)$ WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------|----------------|--------------|--------------------|-------------|--------|------------------------------------------|
| 0.86 ±0.05 OL | JR FIT | | | | | |
| 0.88 ±0.05 OL | IR AVERAGE | • | | | | |
| $1.39 \begin{array}{c} +0.40 \\ -0.38 \end{array} \begin{array}{c} +0 \\ -0 \end{array}$ | .26 .77 | | ABLIKIM | 05 G | BES2 | $\psi(2S) \to \gamma \chi_{c1}$ |
| $0.876 \pm 0.045 \pm 0$ | .026 | | | | | $p\overline{p} \rightarrow e^+e^-\gamma$ |
| $0.87 \pm 0.11 \pm 0$ | .08 | 513 | ARMSTRONG | 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| • • • We do not u | ise the follow | ing data for | averages, fits, li | mits, | etc. • | • • |
| <1.3 | 95 | | BAGLIN | 86в | SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| <3.8 | 90 | | GAISER | 86 | CBAL | $\psi(2S) \rightarrow \gamma X$ |
| ⁶ Recalculated by | ANDREOT | TI 05A. | | | | |

$\chi_{c1}(1P)$ DECAY MODES

Scale factor/

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-------------------------------------------------------------|------------------------------|-------------------------|
| | Hadronic o | decays | _ |
| Γ_1 | $3(\pi^{+}\pi^{-})$ | (5.8 ±1.4)× | 10 ⁻³ S=1.2 |
| Γ_2^- | $2(\pi^{+}\pi^{-})$ $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ | (7.6 \pm 2.6) \times | 10-3 |
| Γ3 | $\pi^{+}\pi^{-}\pi^{0}\pi^{0}$ | (1.26±0.17) % | |
| Γ_4 | $ ho^+ \pi^- \pi^0 + \text{c.c.}$ | (1.53±0.26) % | |
| Γ_5 | $\rho^0 \frac{\pi}{\pi^+ \pi^-}$ | (3.9 ± 3.5) \times | $_{10}^{-3}$ |
| Γ ₆ | $4\pi^0$ | (5.7 \pm 0.8) $	imes$ | 10^{-4} |
| Γ_7 | $\pi^+\pi^-K^+K^-$ | (4.5 ± 1.0) $	imes$ | |
| Γ8 | $K^{+} K^{-} \pi^{0} \pi^{0}$ | (1.18 ± 0.29) $	imes$ | 10-3 |
| | $K^{+}\pi^{-}K^{0}\pi^{0}$ + c.c. | (9.0 ± 1.5) \times | |
| Γ_{10} | $\rho^{+} K^{-} K^{0} + \text{c.c.}$ | (5.3 ± 1.3) $	imes$ | |
| Γ_{11} | $K^*(892)^0 K^0 \pi^0 \rightarrow$ | (2.5 ± 0.7) $	imes$ | 10^{-3} |
| _ | $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ | | 2 |
| Γ_{12} | $K^{+}K^{-}\eta\pi^{0}$ | (1.2 \pm 0.4) \times | 10-3 |
| Γ ₁₃ | $\pi^+\pi^-K^0_SK^0_S$ | (7.2 \pm 3.1) $	imes$ | |
| Γ ₁₄ | $K^+K^-\eta$ | (3.3 ± 1.0) \times | |
| Γ ₁₅ | $K^0K^+\pi^- + c.c.$ | (7.3 \pm 0.6) $	imes$ | |
| Γ ₁₆ | $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ | (1.0 \pm 0.4) \times | |
| Γ ₁₇ | $K^*(892)^+K^- + \text{c.c.}$ | (1.5 \pm 0.7) $	imes$ | |
| Γ ₁₈ | $K_J^*(1430)^0 \overline{K}^0 + \text{c.c.} \rightarrow$ | < 8 × | 10 ⁻⁴ CL=90% |
| | $K_S^0 K^+ \pi^- + \text{ c.c.}$ | | |
| Γ_{19} | $K_J^*(1430)^+ K^- + \text{c.c.} \rightarrow$ | < 2.3 × | 10 ^{−3} CL=90% |
| | $K_S^0 K^+ \pi^- + \text{c.c.}$ | | |
| Γ_{20} | $K^{+} K^{-} \pi^{0}$ | $(~1.91\pm0.26)~\times$ | 10-3 |
| Γ ₂₁ | $\eta \pi^+ \pi^-$ | (5.0 \pm 0.5) \times | 10-3 |
| Γ_{22} | $a_0(980)^+\pi^- + \text{c.c.} \rightarrow \eta \pi^+\pi^-$ | (1.9 ± 0.7) $	imes$ | |
| Γ_{23} | $f_2(1270) \eta$ | (2.8 \pm 0.8) \times | 10 |
| Γ ₂₄ | $\pi^+\pi^-\eta'$ | (2.4 ± 0.5) \times | |
| Γ ₂₅ | $\pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$ | < 6 × | 10 ⁻⁶ CL=90% |
| Γ_{26} | $K^{+}\overline{K}^{*}(892)^{0}\pi^{-}+$ c.c. | (3.2 \pm 2.1) \times | |
| Γ ₂₇ | $K^*(892)^0 \overline{K}^*(892)^0$ | (1.5 ± 0.4) $	imes$ | |
| Γ ₂₈ | $K^+K^-K^0_SK^0_S$ | | 10 ⁻⁴ CL=90% |
| Γ_{29} | $K^+ K^- K^+ K^-$ | (5.6 ± 1.2) $	imes$ | 10-4 |
| Γ_{30} | $K^+ K^- \phi$ | (4.3 ± 1.6) $	imes$ | 10^{-4} |
| Γ_{31} | $\omega \omega$ | (6.0 ± 0.7) \times | 10-4 |
| Γ_{32} | $\omega \phi$ | (2.2 ±0.6) \times | |
| Γ_{33} | $\phi\phi$ | (4.4 \pm 0.6) $	imes$ | 10^{-4} |

| | $ \rho \overline{\rho} $ $ \rho \overline{\rho} \pi^0 $ | $(7.3 \pm 0.4) \times 10^{-5}$ $(1.64 \pm 0.20) \times 10^{-4}$ | | | |
|------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|--------|--|--|
| Γ_{36} | $p \overline{p} \eta$ | $(1.53\pm0.26)\times10^{-4}$ | | | |
| Γ_{37} | $p \overline{p} \omega$ | $(2.24\pm0.33)\times10^{-4}$ | | | |
| | р р ф | $< 1.8 \times 10^{-5}$ | CL=90% | | |
| Γ_{39} | $p \overline{p} \pi^+ \pi^-$ | $(5.0 \pm 1.9) \times 10^{-4}$ | | | |
| Γ_{40} | $\rho \overline{\rho} \pi^0 \pi^0$ | | | | |
| Γ_{41} | $p\overline{p}K^+K^-$ (non-resonant) | $(1.34 \pm 0.24) \times 10^{-4}$ | | | |
| Γ_{42} | $p\overline{p}K_S^0K_S^0$ | $< 4.5 \times 10^{-4}$ | CL=90% | | |
| Γ_{43} | $\Lambda \overline{\Lambda}$ | $(1.18\pm0.19)\times10^{-4}$ | | | |
| | $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | $< 1.5 \times 10^{-3}$ | CL=90% | | |
| | $K^+ \overline{\rho} \Lambda$ | $(3.2 \pm 1.0) \times 10^{-4}$ | | | |
| | $K^{+} \rho \Lambda(1520) + \text{c.c.}$ | $(1.8 \pm 0.5) \times 10^{-4}$ | | | |
| Γ_{47} | $\Lambda(1520) \overline{\Lambda}(1520)$ | $< 1.0 \times 10^{-4}$ | CL=90% | | |
| Γ_{48} | $\sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{j=1}^{n} \sum_{j=1}^{n} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{j$ | $< 4 \times 10^{-5}$ | CL=90% | | |
| Γ_{49} | $\Sigma + \overline{\Sigma} -$ | $< 6 \times 10^{-5}$ | CL=90% | | |
| Γ_{50} | $\equiv 0 \equiv 0$ | $< 6 \times 10^{-5}$ | CL=90% | | |
| Γ_{51} | <u>=-=</u> + | $(8.4 \pm 2.3) \times 10^{-5}$ | | | |
| Γ_{52} | $\pi^{+}\pi^{-} + K^{+}K^{-}$ | $< 2.1 \times 10^{-3}$ | | | |
| Γ_{53} | $K_S^0 K_S^0$ | $< 6 \times 10^{-5}$ | CL=90% | | |
| Radiative decays | | | | | |

| | $\gamma J/\psi(1S)$ | (34.4 ±1.5) % |
|-----------------|---------------------|--------------------------------|
| Γ_{55} | $\gamma \rho^0$ | $(2.28\pm0.19)\times10^{-4}$ |
| Γ_{56} | $\gamma \omega$ | $(7.1 \pm 0.9) \times 10^{-5}$ |
| Γ ₅₇ | $\gamma \phi$ | $(2.6 \pm 0.6) \times 10^{-5}$ |
| Γ_{58} | $\gamma \gamma$ | |

CONSTRAINED FIT INFORMATION

A multiparticle fit to $\chi_{c1}(1P)$, $\chi_{c0}(1P)$, $\chi_{c2}(1P)$, and $\psi(2S)$ with 4 total widths, a partial width, 25 combinations of partial widths obtained from integrated cross section, and 84 branching ratios uses 223 measurements to determine 49 parameters. The overall fit has a $\chi^2=312.2$ for 174 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta p_i \delta p_j \right\rangle / (\delta p_i \cdot \delta p_j)$, in percent, from the fit to parameters p_i , including the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$.

$\chi_{c1}(1P)$ PARTIAL WIDTHS

- χ_{c1} (1P) Γ(i)Γ(γ J/ψ (1S))/Γ(total) -

| $\Gamma(p\overline{p}) \times \Gamma(\gamma J/\psi(15))$ | S))/Γ _{total} | | | Г34 Г54/Г |
|----------------------------------------------------------|----------------------------------------|--------|----------|---------------------------------------------|
| VALUE (eV) | DOCUMENT ID | | TECN | COMMENT |
| 21.7±0.8 OUR FIT | <u> </u> | | | |
| 21.4±0.9 OUR AVERAG | E | | | |
| $21.5 \pm 0.5 \pm 0.8$ | | | | $p \overline{p} \rightarrow e^+ e^- \gamma$ |
| $21.4 \pm 1.5 \pm 2.2$ | ^{7,8} ARMSTRONG | 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| $19.9^{+4.4}_{-4.0}$ | ⁷ BAGLIN | 86в | SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| ⁷ Calculated by us usin | $g B(J/\psi(1S) \rightarrow e^+e^-) =$ | = 0.05 | 593 ± 0. | .0010. |
| ⁸ Recalculated by AND | | | | |

$\chi_{c1}(1P)$ BRANCHING RATIOS

— HADRONIC DECAYS —

| $\Gamma(3(\pi^+\pi^-))/\Gamma_{ m total}$ | | | | Γ_1/Γ |
|---------------------------------------------|--------------------------------------------------|-------------|-----------------------------------------|-------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TECN | COMMENT | |
| 5.8±1.4 OUR EVALUATION error as correlated. | Error includes scale fac | tor of 1.2. | Treating systemat | ic |
| 5.8±1.1 OUR AVERAGE | | | | |
| $5.4 \pm 0.7 \pm 0.9$ | ⁹ BAI 99 | в BES | $\psi(2S) \rightarrow \gamma \chi_{C1}$ | |
| $16.0 \pm 5.9 \pm 0.8$ | ⁹ BAI 99 ⁹ TANENBAUM 78 | MRK1 | $\psi(2S) \rightarrow \gamma \chi_{c1}$ | |
| ⁹ Rescaled by us using B(| | | | s) → |
| $J/\psi(15) \pi^+ \pi^-) = (32.6 \pm$ | ± 0.5)%. | | | |

 $^{19}\,{\rm HE}$ 08B reports 0.54 \pm 0.11 \pm 0.07 \pm 0.03 % from a measurement of [$\Gamma(\chi_{c1}(1P)$ \rightarrow

 $\begin{array}{lll} \gamma_{c} + \kappa^{-} \kappa^{0} + \text{c.c.}) / \Gamma_{\text{total}} & \times \left[\text{B}(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) \right] & \text{assuming B}(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) \\ & \gamma_{c1}(1P)) = (9.07 \pm 0.11 \pm 0.54) \times 10^{-2}, \text{ which we rescale to our best value B}(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) \\ & \gamma_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}. & \text{Our first error is their experiment's error and our second error is the systematic error from using our best value.} \end{array}$

(1 D)

| $\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ Γ_2/Γ | $\Gamma(K^*(892)^0 K^0 \pi^0 \to K^+ \pi^- K^0 \pi^0 + c.c.) / \Gamma_{total}$ Γ_{11} / Γ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | VALUE (%) EVTS DOCUMENT ID TECN COMMENT |
| 7.6±2.6 OUR EVALUATION Treating systematic error as correlated. 8 ±4 OUR AVERAGE Error includes scale factor of 1.5. | 0.25 \pm 0.07 \pm 0.01 |
| $4.6\pm2.1\pm2.6$ 10 BAI 99B BES $\psi(2S) \rightarrow \gamma \chi_{c1}$ | $K^*(892)^0$ K^0 $\pi^0 \to K^+\pi^ K^0$ π^0 + c.c.)/ Γ_{total}] \times [B($\psi(2S) \to \gamma \chi_{C1}(1P)$)] assum- |
| 12.5 \pm 4.2 \pm 0.6 10 TANENBAUM 78 MRK1 $\psi(2S) ightarrow \gamma \chi_{C1}$ | ing B($\psi(2S) \rightarrow \gamma \chi_{c1}(1P)$) = $(9.07 \pm 0.11 \pm 0.54) \times 10^{-2}$, which we rescale to our best |
| 10 Rescaled by us using B $(\psi(2S) \rightarrow \gamma \chi_{C1}) = (8.8 \pm 0.4)\%$ and B $(\psi(2S) \rightarrow J/\psi(1S) \pi^+ \pi^-) = (32.6 \pm 0.5)\%$. | value $\mathrm{B}(\psi(2s) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\Gamma(\pi^+\pi^-\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_3/Γ | $\Gamma(K^+K^-\eta\pi^0)/\Gamma_{\text{total}}$ Γ_{12}/Γ |
| $\frac{VALUE(\%)}{1.26 \pm 0.16 \pm 0.05}$ $\frac{EVTS}{604.7}$ $\frac{DOCUMENT ID}{11 HE}$ $\frac{TECN}{088}$ CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0$ | VALUE (%) EVTS DO CUMENT ID TECN COMMENT |
| | 0.118±0.036±0.005 141.3 21 HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0 h^0$ $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0 h^0$ 141.3 $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0 h^0$ 141.3 $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0 h^0$ 151.4 HE 08B reports 0.12 ± 0.03 ± 0.02 ± 0.01 % from a measurement of [Γ (χ _{C1} (1P) → 1P) h^0 h^0 h^0 h^0 h^0 h^0 h^0 h^0 h^0 h^0 |
| ¹¹ HE 08B reports 1.28 \pm 0.06 \pm 0.15 \pm 0.08 % from a measurement of $[\Gamma(\chi_{c1}(1P) \to \pi^+\pi^-\pi^0\pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c1}(1P)) =$ | $K^+K^-n\pi^0$ / [++++] \times [B($\psi(2S) \to \gamma \gamma_{c1}(1P)$)] assuming B($\psi(2S) \to \gamma \gamma_{c1}(1P)$) |
| π π π π π π π π π π | $K^+K^-\eta\pi^0)/\Gamma_{	ext{total}}] 	imes [B(\psi(25)	o \gamma\chi_{c1}(1P))]$ assuming $B(\psi(25)	o \gamma\chi_{c1}(1P))=(9.07\pm0.11\pm0.54)\times 10^{-2}$, which we rescale to our best value $B(\psi(2S)	o \gamma\chi_{c1}(1P))=(9.07\pm0.11\pm0.54)\times 10^{-2}$ |
| $= (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is | = $(9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| the systematic error from using our best value. | |
| $\Gamma(\rho^+\pi^-\pi^0 + \text{c.c.})/\Gamma_{\text{total}}$ Γ_4/Γ | $\Gamma(\pi^+\pi^-K_S^0K_S^0)/\Gamma_{\text{total}}$ Γ_{13}/Γ |
| VALUE (%)EVTSDO CUMENT_IDTECNCOMMENT | MLUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT7.2±3.1±0.3 19.8 ± 7.7 22 ABLIKIM050 BES2 $\psi(2S) \rightarrow \chi_{c1} \gamma$ |
| | 7.2\pm3.1\pm0.3 19.8 \pm 7.7 ²² ABLIKIM 050 BES2 $\psi(2S) \rightarrow \chi_{c1} \gamma$ |
| 12 HE 08B reports 1.56 \pm 0.13 \pm 0.22 \pm 0.10 $\%$ from a measurement of [$\Gamma(\chi_{c1}(1P) \rightarrow$ | ²² ABLIKIM 050 reports $[\Gamma(\chi_{c1}(1P) \rightarrow \pi^+\pi^-K_S^0K_S^0)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \pi^+\pi^-K_S^0K_S^0)/\Gamma_{total}]$ |
| $\rho^+\pi^-\pi^0$ + c.c.)/ Γ_{total} × [B($\psi(2S) \rightarrow \gamma \chi_{c1}(1P)$)] assuming B($\psi(2S) \rightarrow (2S) \rightarrow (2S)$) | $\gamma \chi_{c1}(1P)$] = $(0.67 \pm 0.26 \pm 0.11) \times 10^{-4}$ which we divide by our best value B($\psi(2S) \rightarrow \infty$), $(1P) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our |
| $\gamma \chi_{c1}(1P) = (9.07 \pm 0.11 \pm 0.54) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{c1}(1P) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our | $\gamma\chi_{c1}(1P))=(9.2\pm0.4)	imes10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\gamma\chi_{c1}(1P))=(9.2\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(K^+K^-\eta)/\Gamma_{\text{total}}$ Γ_{14}/Γ |
| 13 Calculated by us. We have added the values from HE 08B for $\rho^+\pi^-\pi^0$ and $\rho^-\pi^+\pi^0$ decays assuming uncorrelated statistical and fully correlated systematic uncertainties. | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| | 0.33±0.10±0.01 23 ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ |
| $\Gamma(\rho^0 \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_5/Γ | 23 ATHAR 07 reports $(0.34\pm0.10\pm0.04) 	imes 10^{-3}$ from a measurement of [$\Gamma(\chi_{C1}(1P) ightarrow$ |
| VALUE (units 10^{-4})DOCUMENT IDTECNCOMMENT39±35 1^4 TANENBAUM 78MRK1 $\psi(2S) \rightarrow \gamma \chi_{C1}$ | $K^+K^-\eta)/\Gamma_{	ext{total}}$ \times [B($\psi(2S) 	o \gamma \chi_{C1}(1P)$)] assuming B($\psi(2S) 	o \gamma \chi_{C1}(1P)$) = 0.0907 \pm 0.0011 \pm 0.0054, which we rescale to our best value B($\psi(2S) 	o \gamma \chi_{C1}(1P)$) |
| 14 Estimated using $B(\psi(2S) \to \gamma \chi_{C1}(1P)) = 0.087$. The errors do not contain the | = $(9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is |
| uncertainty in the $\psi(2S) \to \gamma \chi_{C1}(1P)) = 0.087$. The errors do not contain the | the systematic error from using our best value. |
| $\Gamma(4\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ | $\Gamma(K^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{15}/Γ |
| VALUE (units 10^{-3})EVTSDOCUMENT IDTECNCOMMENT0.57 \pm 0.03 \pm 0.08608 15 ABLIKIM11ABES3 $e^+e^- \rightarrow \psi(2S) \rightarrow \gamma \chi_{c1}$ | <u>VALUE (units 10⁻³)</u> <u>DO CUMENT ID</u> 7.3±0.6 OUR FIT |
| | |
| ¹⁵ ABLIKIM 11A reports $(0.57\pm0.03\pm0.08)\times10^{-3}$ from a measurement of $[\Gamma(\chi_{c1}(1P)\to 0)]$ | $\Gamma(K^*(892)^0\overline{K}^0 + c.c.)/\Gamma_{total}$ Γ_{16}/Γ |
| $4\pi^0)/\Gamma_{\rm total}]\times [{\sf B}(\psi(2S)\to\gamma\chi_{c1}(1P))]$ assuming ${\sf B}(\psi(2S)\to\gamma\chi_{c1}(1P))=(9.2\pm0.4)\times10^{-2}$. | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| • | 1.03\pm0.38\pm0.04 22 ²⁴ ABLIKIM 06R BES2 $\psi(25) \rightarrow \gamma \chi_{C1}$ 24 ABLIKIM 06R reports $(1.1 \pm 0.4 \pm 0.1) \times 10^{-3}$ from a measurement of $\Gamma(\chi_{C1}(1P) \rightarrow 0.1)$ |
| $\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_7/Γ | $K^*(892)^0 \overline{K}^0 + \text{c.c.} / \Gamma_{\text{total}} \times [B(\psi(2S) \rightarrow \gamma_{Xc1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma_{Xc1}(1P))$ |
| VALUE (units 10 ⁻³) 4.5 ± 1.0 OUR EVALUATION DOCUMENT ID TECN COMMENT Treating systematic error as correlated. | $\gamma \chi_{c1}(1P))=(8.7\pm0.4)\times 10^{-2}$, which we rescale to our best value B($\psi(2S)\to$ |
| 4.5 ± 0.9 OUR AVERAGE | $\gamma\chi_{c1}(1P))=(8.7\pm0.4)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{c1}(1P))=(9.2\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| 4.2 \pm 0.4 \pm 0.9 16 BAI 99B BES $\psi(2S) ightarrow \gamma \chi_{c1}$ | |
| 7.3 \pm 3.0 \pm 0.4 16 TANENBAUM 78 MRK1 $\psi(2s) \rightarrow \gamma \chi_{C1}$ | $\Gamma(K^*(892)^+K^- + c.c.)/\Gamma_{total}$ Γ_{17}/Γ |
| | |
| 16 Rescaled by us using B($\psi(25)\to\gamma\chi_{C1})=(8.8\pm0.4)\%$ and B($\psi(25)\to J/\psi(15)\pi^+\pi^-)=(32.6\pm0.5)\%.$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $J/\psi(1S) \pi^+ \pi^-) = (32.6 \pm 0.5)\%.$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow 0.2) \times 10^{-3}]$ |
| $J/\psi(1S) \pi^+ \pi^-) = (32.6 \pm 0.5)\%$. $\Gamma(K^+ K^- \pi^0 \pi^0)/\Gamma_{total}$ VALUE (%) FOR DOCUMENT ID TECH COMMENT | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \chi_{C1}(1P))]$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(25) \rightarrow \gamma \chi_{c1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow \kappa^*(892)^+ \kappa^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(25) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K_1^*(1430)^0 \overline{K}^0 + \text{c.c.} \rightarrow K_5^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}}$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K_J^*(1430)^0 \overline{K^0} + \text{c.c.} \rightarrow K_J^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}} \qquad \Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}/\Gamma_{18}$ |
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| $ \Gamma(K^+K^-\pi^0\pi^0)/\Gamma_{\text{total}} $ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + c.c.)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K_{\bullet}^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_{\bullet}^0 K^+ \pi^- + c.c.)/\Gamma_{total} \qquad \Gamma_{18}/\Gamma$ MLUE (units 10 ⁻³) 20.8 90 26 ABLIKIM 06R 90 26 ABLIKIM 06R 90 27 ABLIKIM 06R 90 27 ABLIKIM 06R 90 28 ES2 90 29 MEMEN 10 MEMEN 11 MEMEN 12 MEMEN 13 MEMEN 14 MEMEN 15 MEMEN 16 MEMEN 17 MEMEN 17 MEMEN 18 MEMEN 19 MEMEN 19 MEMEN 19 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 11 MEMEN 11 MEMEN 11 MEMEN 11 MEMEN 12 MEMEN 13 MEMEN 14 MEMEN 15 MEMEN 16 MEMEN 17 MEMEN 18 MEMEN 19 MEMEN 19 MEMEN 19 MEMEN 19 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 MEMEN 10 M |
| $\begin{split} &J/\psi(15)\pi^+\pi^-) = (32.6\pm0.5)\%. \\ & \Gamma\left(K^+K^-\pi^0\pi^0\right)/\Gamma_{total} & \Gamma_8/\Gamma_{total} & \Gamma_8/\Gamma_{t$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(25) \rightarrow \gamma \chi_{C1}$ 25 ABLIKIM 06R reports $(1.6 \pm 0.7 \pm 0.2) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + c.c.)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K^*_{\bullet}(1430)^0 \overline{K}^0 + c.c. \rightarrow K^0_{\bullet} K^+ \pi^- + c.c.)/\Gamma_{total} \qquad \Gamma_{18}/\Gamma$ MALUE (units 10 ⁻³) 20.8 90 26 ABLIKIM 06R BES2 0.9 × 10 ⁻³ from a measurement of $[\Gamma(\chi_{C1}(1P) \rightarrow K^*_{J}(1430)^0 \overline{K}^0 + c.c. \rightarrow K^0_{\bullet} K^+ \pi^- + c.c.)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = 9.2 \times 10^{-2}$. $\Gamma(K^*_{\bullet}(1430)^+ K^- + c.c. \rightarrow K^0_{\bullet} K^+ \pi^- + c.c.)/\Gamma_{total}$ Γ_{19}/Γ 19/Γ 19/Γ 10/10/10/10/10/10/10/10/10/10/10/10/10/1 |
| $\begin{split} &J/\psi(1S)\pi^{+}\pi^{-}) = (32.6\pm0.5)\%. \\ & \Gamma\left(K^{+}K^{-}\pi^{0}\pi^{0}\right)/\Gamma_{\text{total}} & \Gamma_{8}/\Gamma_{\text{NALUE}(\%)} & \frac{EVTS}{45.1} & \frac{DOCUMENT\ ID}{17\ \text{HE}} & 08B\ \text{CLEO}\ e^{+}e^{-} \to \gamma h^{+}h^{-}h^{0}h^{0} \\ & 17\ \text{HE} & 08B\ \text{reports}\ 0.12\pm0.02\pm0.02\pm0.01\ \%\ \text{from a measurement of}\ [\Gamma(\chi_{C1}(1P)\to K^{+}K^{-}\pi^{0}\pi^{0})/\Gamma_{\text{total}}] \times [B(\psi(2S)\to\gamma\chi_{C1}(1P))] & \text{assuming B}(\psi(2S)\to\gamma\chi_{C1}(1P)) \\ & = (9.07\pm0.11\pm0.54)\times10^{-2}, \text{ which we rescale to our best value B}(\psi(2S)\to\gamma\chi_{C1}(1P)) \\ & = (9.07\pm0.11\pm0.54)\times10^{-2}. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value.} \\ & \Gamma\left(K^{+}\pi^{-}K^{0}\pi^{0} + \text{C.C.}\right)/\Gamma_{\text{total}} & \Gamma_{9}/\Gamma_{\text{NALUE}(\%)} & EVTS & DOCUMENT\ ID & TECN & COMMENT \\ \hline 0.90\pm0.14\pm0.03 & 141.3 & 18\ \text{HE} & 08B\ \text{CLEO} & e^{+}e^{-}\to\gamma h^{+}h^{-}h^{0}h^{0} \\ \hline 18\ \text{HE} & 08B\ \text{reports} & 0.92\pm0.09\pm0.11\pm0.06\ \% \text{ from a measurement of } [\Gamma(\chi_{C1}(1P)\to K^{+}\pi^{-}K^{0}\pi^{0} + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S)\to\gamma\chi_{C1}(1P))] & \text{assuming B}(\psi(2S)\to\gamma\chi_{C1}(1P)) = (9.07\pm0.11\pm0.54)\times10^{-2}, \text{ which we rescale to our best value B}(\psi(2S)\to\gamma\chi_{C1}(1P)) = (9.2\pm0.4)\times10^{-2}. \text{ Our first error is their experiment's error and our second error is the systematic error from using our best value.} \\ & \Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10}/\Gamma_{10$ | 1.5 ± 0.7 ± 0.1 27 25 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}(1P) \rightarrow K^*(892)^+ K^- + \text{c.c.}/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $F(K_s^*(1430)^0 \overline{K}^0 + \text{c.c.} \rightarrow K_s^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}}$ F_{18}/Γ $\frac{VMLUE (units 10^{-3})}{\sqrt{2}} \times \frac{CL^*}{\sqrt{2}} \times \frac{DOCUMENT \ ID}{\sqrt{2}} \times \frac{COMMENT}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times \frac{2}{\sqrt{2}} \times $ |
| $\begin{split} &J/\psi(15)\pi^+\pi^-) = (32.6\pm0.5)\%. \\ & \Gamma(K^+K^-\pi^0\pi^0)/\Gamma_{total} & \Gamma_8/\Gamma_{total} & \Gamma_8/\Gamma_{tot$ | 1.5 ± 0.7 ± 0.1 27 28 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{c1}$ 28 ABLIKIM 29 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{c1}$ 29 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{c1}$ 20 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{c1}$ 20 $K^*(892)^+ K^- + c.c.)/\Gamma_{total}$ 20 $\chi_{c1}(1P) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 10 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 11 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 12 ABLIKIM 13 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 14 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 15 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 16 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 17 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 18 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 19 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 19 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 10 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 10 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 10 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 11 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 12 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 13 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 14 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 15 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.)/\Gamma_{total}$ 16 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.$ 17 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.$ 18 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.$ 19 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.$ 19 $K^*(1430)^0 \overline{K}^0 + c.c. \rightarrow K_0^0 K^+ \pi^- + c.c.$ 19 $K^*(1430)^0 \overline{K}^0 + c.c.$ 10 $K^*(1430)^0 \overline{K}^0 + c.c.$ 11 $K^*(1430)^0 \overline{K}^0 + $ |

 $1.91 \pm 0.25 \pm 0.07$ $^{28}\,\rm ATHAR~07$ reports (1.95 $\pm~0.16~\pm~0.23)\times10^{-3}$ from a measurement of [Γ ($\chi_{c1}(1P)~\rightarrow$ $\begin{array}{l} K^+K^-\pi^0)/\Gamma_{\text{total}}]\times [\mathsf{B}(\psi(2S)\to\gamma\chi_{c1}(1P))] \text{ assuming } \mathsf{B}(\psi(2S)\to\gamma\chi_{c1}(1P))=\\ 0.0907\pm0.0011\pm0.0054, \text{ which we rescale to our best value } \mathsf{B}(\psi(2S)\to\gamma\chi_{c1}(1P)) \end{array}$ = $(9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 Γ_{20}/Γ

 $\Gamma(K^+K^-\pi^0)/\Gamma_{\rm total}$

VALUE (units 10^{-3})

DOCUMENT ID

VALUE (units 10⁻³) 0.56±0.12 OUR FIT

Meson Particle Listings

 $\chi_{c1}(1P)$

| | $\chi_{c1}(1P)$ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{21}/Γ | $\Gamma(K^+K^-\phi)/\Gamma_{\text{total}}$ Γ_{30}/Γ |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| 5.0±0.5 OUR AVERAGE $4.9\pm0.5\pm0.2$ 29 ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ | 0.43±0.16±0.02 17 ³⁹ ABLIKIM 06T BES2 $\psi(2S)$ → $\gamma 2K^{+}2K^{-}$ |
| 4.9 \pm 0.5 \pm 0.2 222 30 ABLIKIM 06 RBES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ | 39 ABLIKIM 06T reports $(0.46\pm0.16\pm0.06) \times 10^{-3}$ from a measurement of [Г $(\chi_{c1}(1P) ightarrow 10^{-3})$ |
| ²⁹ ATHAR 07 reports $(5.0 \pm 0.3 \pm 0.5) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c1}(1P) \rightarrow$ | $(K^+ K^- \phi)/\Gamma_{total} \times [B(\psi(2S) \to \gamma \chi_{\mathcal{C}1}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{\mathcal{C}1}(1P)) = 0$ |
| | $(8.7\pm0.4)	imes10^{-2}$, which we rescale to our best value B($\psi(2S)	o \gamma\chi_{c1}(1P)$) = |
| $\eta\pi^+\pi^-)/\Gamma_{	ext{total}}] 	imes [B(\psi(2S)	o \gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S)	o \gamma\chi_{c1}(1P))=0.0907\pm0.0011\pm0.0054$, which we rescale to our best value $B(\psi(2S)	o \gamma\chi_{c1}(1P))$ | $(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our second error is |
| $= (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is | the systematic error from using our best value. |
| the systematic error from using our best value. | $\Gamma(\omega\omega)/\Gamma_{	ext{total}}$ Γ_{31}/Γ |
| 30 ABLIKIM 06R reports $(5.9\pm0.7\pm0.8) 	imes 10^{-3}$ from a measurement of $[\Gamma(\chi_{c1}(1P) ightarrow$ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| $\eta \pi^+ \pi^-)/\Gamma_{total}] \times [B(\psi(2S) \to \ \gamma \chi_{\mathcal{C}1}(1P))] \ assuming \ B(\psi(2S) \to \ \gamma \chi_{\mathcal{C}1}(1P)) = 0$ | 6.0 \pm 0.3 \pm 0.7 597 ⁴⁰ ABLIKIM 11K BES3 $\psi(2S) \rightarrow \gamma$ hadrons |
| $(8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value B $(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) =$ | 40 ABLIKIM 11K reports $(6.0\pm0.3\pm0.7)\times10^{-4}$ from a measurement of $\Gamma(\chi_{c1}(1P)\to$ |
| $(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our second error is | $\omega\omega)/\Gamma_{\text{total}}$ \times [B($\psi(2S) \rightarrow \gamma\chi_{c1}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma\chi_{c1}(1P)$) = (9.2 ± |
| the systematic error from using our best value. | $0.4) \times 10^{-2}$. |
| $\Gamma(a_0(980)^+\pi^- + \text{c.c.} \rightarrow \eta\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{22}/Γ | , |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(\omega \phi)/\Gamma_{\text{total}}$ Γ_{32}/Γ |
| 1.9 \pm 0.7 \pm 0.1 58 31 ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{c1}$ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 31 ABLIKIM 06R reports $(2.0 \pm 0.5 \pm 0.5) \times 10^{-3}$ from a measurement of $[\Gamma(\chi_{c1}(1P) \rightarrow$ | 0.22\pm0.06\pm0.02 |
| $a_0(980)^+\pi^-+$ c.c. $\rightarrow \eta\pi^+\pi^-)/\Gamma_{\text{total}} \times \left[\mathbb{B}(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))\right]$ assuming | ⁴¹ ABLIKIM 11K reports $(0.22\pm0.06\pm0.02)\times10^{-4}$ from a measurement of $\Gamma(\chi_{C1}(1P)\to$ |
| $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value | $\omega\phi)/\Gamma_{total} \times [B(\psi(2S) \to \gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c1}(1P)) = (9.2 \pm 1)$ |
| | $0.4) \times 10^{-2}$. |
| $B(\psi(2S) \to \gamma \chi_{C1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | |
| Γ(f (1070) _m) /Γ | $\Gamma(\phi\phi)/\Gamma_{ m total}$ |
| $\Gamma(f_2(1270)\eta)/\Gamma_{\text{total}}$ Γ_{23}/Γ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT | 4.4 \pm 0.3 \pm 0.5 366 ⁴² ABLIKIM 11K BES3 $\psi(2S) ightarrow \gamma$ hadrons |
| 2.8 ± 0.8 ± 0.1 53 ³² ABLIKIM 06R BES2 $\psi(2S) \rightarrow \gamma \chi_{C1}$ | ⁴² ABLIKIM 11K reports $(4.4 \pm 0.3 \pm 0.5) \times 10^{-4}$ from a measurement of $\Gamma(\chi_{C1}(1P) \rightarrow$ |
| 32 ABLIKIM 06R reports (3.0 \pm 0.7 \pm 0.5) $	imes$ 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c1}(1P) ightarrow$ | $\phi \phi)/\Gamma_{total} \times [B(\psi(2S) \to \gamma \chi_{\mathcal{C}1}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{\mathcal{C}1}(1P)) = (9.2 \pm 1.0)$ |
| $f_2(1270) \eta)/\Gamma_{total} \propto [B(\psi(2S) \to \gamma \chi_{c1}(1P))] \text{ assuming } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = 0$ | $0.4) \times 10^{-2}$. |
| $(8.7 \pm 0.4) \times 10^{-2}$, which we rescale to our best value B $(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) =$ | F/ =\ /F |
| $(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ Γ_{34}/Γ |
| the systematic error from using our best value. | VALUE (units 10 ⁻⁴) DOCUMENT ID |
| $\Gamma(\pi^+\pi^-\eta')/\Gamma_{\text{total}}$ Γ_{24}/Γ | 0.73±0.04 OUR FIT |
| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | $\Gamma(\rho \overline{\rho} \pi^0)/\Gamma_{\text{total}}$ Γ_{35}/Γ |
| 2.4 ± 0.5 ± 0.1 33 ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| 33 ATHAR 07 reports (2.4 \pm 0.4 \pm 0.3) $	imes$ 10 $^{-3}$ from a measurement of [$\Gamma(\chi_{c1}(1P) ightarrow$ | 0.164±0.020 OUR AVERAGE |
| $\pi^+\pi^-\eta')/\Gamma_{\text{total}}]\times [B(\psi(2S)\to\gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{c1}(1P))=0.0907\pm0.0011\pm0.0054$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{c1}(1P))$ | $0.172\pm0.020\pm0.007$ 43 ONYISI 10 CLE3 $\psi(2S) ightarrow \gamma p \overline{p} X$ |
| | $0.118\pm0.049\pm0.005$ 44 ATHAR 07 CLEO $\psi(2S) ightarrow \gamma h^+ h^- h^0$ |
| $=(9.2\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | 43 ONYISI 10 reports (1.75 \pm 0.16 \pm 0.13 \pm 0.11) $	imes$ 10 $^{-4}$ from a measurement of |
| the systematic error from using our best value. | $[\Gamma(\chi_{c1}(1P) \to \ p \overline{p} \pi^0)/\Gamma_{total}] \times [B(\psi(2S) \to \ \gamma \chi_{c1}(1P))] \ assuming \ B(\psi(2S) \to \ \gamma \chi_{c1}(1P))$ |
| $\Gamma(\pi^0 f_0(980) \to \pi^0 \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{25}/Γ | $\gamma\chi_{\mathcal{C}1}(1P))=(9.07\pm0.11\pm0.54)	imes10^{-2}$, which we rescale to our best value B $(\psi(2S) ightarrow$ |
| VALUE CL% DO CUMENT ID TECN COMMENT | $\gamma\chi_{C1}(1P))=(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\overline{\text{<6} \times 10^{-6}}$ 90 34 ABLIKIM 11D BES3 $\psi(2S) \rightarrow \gamma \pi^0 \pi^+ \pi^-$ | second error is the systematic error from using our best value. 44 ATHAR 07 reports $(1.2\pm0.5\pm0.1)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{c1}(1P)\to$ |
| 34 ABLIKIM 11D reports $[\Gamma(\chi_{c1}(1P) \to \pi^0 f_0(980) \to \pi^0 \pi^+ \pi^-)/\Gamma_{total}] \times [B(\psi(2S) \to 0]$ | $p\overline{p}\pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{c1}(1P)) =$ |
| $\gamma \chi_{c1}(1P))] < 6.0 \times 10^{-7}$ which we divide by our best value $\mathrm{B}(\psi(2S) 	o \gamma \chi_{c1}(1P))$ | $(9.07 \pm 0.11 \pm 0.54) \times 10^{-2}$, which we rescale to our best value B($\psi(25) \rightarrow \gamma \chi_{c1}(1P)$) |
| $=9.2 \times 10^{-2}$ | $(9.07 \pm 0.11 \pm 0.54) \times 10^{-2}$, which we rescale to our best value $B(\psi(23) \to \gamma \chi_{c1}(1P))$ = $(9.2 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is |
| = (| the systematic error from using our best value. |
| $\Gamma(K^+\overline{K}^*(892)^0\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{26}/Γ | |
| VALUE (units 10 ⁻⁴) DO CUMENT ID TECN COMMENT | $\Gamma(p\overline{p}\eta)/\Gamma_{\text{total}}$ Γ_{36}/Γ |
| 32±21 35 TANENBAUM 78 MRK1 $\psi(2S) ightarrow \gamma \chi_{C1}$ | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| ³⁵ Estimated using B($\psi(2S) \to \gamma \chi_{C1}(1P)$) = 0.087. The errors do not contain the | 0.153±0.026±0.006 45 ONYISI 10 CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ |
| uncertainty in the $\psi(2S)$ decay. | • • We do not use the following data for averages, fits, limits, etc. |
| $\Gamma(K^*(892)^0\overline{K}^*(892)^0)/\Gamma_{\text{total}}$ Γ_{27}/Γ | <0.16 90 46 ATHAR 07 CLEO $\psi(2S) ightarrow \gamma h^+ h^- h^0$ |
| | 45 ONYISI 10 reports $(1.56\pm0.22\pm0.14\pm0.10)	imes10^{-4}$ from a measurement of |
| | $[\Gamma\big(\chi_{C1}(1P) \ \to \ \rho \overline{p} \eta\big) / \Gamma_{total}] \ \times \ [B(\psi(2S) \ \to \ \gamma \chi_{C1}(1P))] \ assuming \ B(\psi(2S) \ \to \ \gamma \chi_{C1}(1P))]$ |
| | $\gamma\chi_{c1}(1P))=(9.07\pm0.11\pm0.54)\times10^{-2}$, which we rescale to our best value B $(\psi(2S)\to 0.01\pm0.01)$ |
| ³⁶ ABLIKIM 04H reports $[\Gamma(\chi_{c1}(1P) \to K^*(892)^0 \overline{K}^*(892)^0)/\Gamma_{total}] \times [B(\psi(2S) \to K^*(892)^0]/\Gamma_{total}] \times [B(\psi(2S) \to K^*(892)^0]/\Gamma_{total}]$ | $\gamma\chi_{c1}(1P))=(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\gamma \chi_{c1}(1P))] = (1.40 \pm 0.27 \pm 0.22) \times 10^{-4}$ which we divide by our best value B($\psi(2S) \rightarrow (1P)$) | second error is the systematic error from using our dest value. 46 ATHAR 07 reports $< 0.16 \times 10^{-3}$ from a massivement of $ \Gamma /2 \times (10^{-3}) = 0.75$. |
| $\gamma\chi_{c1}(1P))=(9.2\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | 46 ATHAR 07 reports $<0.16\times10^{-3}$ from a measurement of $[\Gamma(\chi_{C1}(1P)\to p\overline{p}\eta)/\Gamma_{\text{total}}]\times[B(\psi(2S)\to\gamma\chi_{C1}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C1}(1P))=(9.07\pm0.11\pm0.54)\times10^{-3}$ |
| 37 Assumes B($K^*(892)^0 \rightarrow K^-\pi^+$) = 2/3. | 10^{-2} , which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{c1}(1P)$) = 9.2 × 10 ⁻² . |
| | |
| $\Gamma(K^+K^-K_S^0K_S^0)/\Gamma_{\text{total}}$ Γ_{28}/Γ | $\Gamma(p\overline{p}\omega)/\Gamma_{total}$ Γ_{37}/Γ |
| VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| <5 90 3.2 \pm 2.4 38 ABLIKIM 050 BES2 $\psi(2S) \rightarrow \chi_{C1} \gamma$ | 0.224 \pm 0.032 \pm 0.009 |
| ³⁸ ABLIKIM 050 reports $[\Gamma(\chi_{c1}(1P) \rightarrow K^+ K^- K^0_S K^0_S)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow K^+ K^- K^0_S K^0_S)/\Gamma_{total}]$ | 47 ONYISI 10 reports (2.28 \pm 0.28 \pm 0.16 \pm 0.14) $	imes$ 10 $^{-4}$ from a measurement of |
| $\gamma \chi_{c1}(1P))] < 4.2 \times 10^{-5}$ which we divide by our best value $B(\psi(2S) \to \gamma \chi_{c1}(1P))$ | $[\Gamma(\chi_{c1}(1P) \rightarrow p\overline{p}\omega)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))$ |
| $= 9.2 \times 10^{-2}.$ | $\gamma\chi_{{\cal C}1}(1P))=(9.07\pm0.11\pm0.54)\times10^{-2}$, which we rescale to our best value B $(\psi(2S)\to 0.01\pm0.01)$ |
| | $\gamma \chi_{c1}(1P))=(9.2\pm0.4)	imes10^{-2}$. Our first error is their experiment's error and our |
| $\Gamma(K^+K^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{29}/Γ | second error is the systematic error from using our best value. |
| VALUE (units 10 ⁻³) DOCUMENT ID | |

| $\Gamma(p\overline{p}\phi)/\Gamma_{ m total}$ | | | | | Г ₃₈ , | /Г |
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| VALUE (units 10 ⁻⁵) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.8 | 90 | ⁴⁸ ABLIKIM | 11F | BES3 | $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K$ | - |
| 48 ABLIKIM 11F re $\Gamma_{	ext{total}}$ $] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2))] \times [B(\psi(2)$ | ports < 1.83 S) $\rightarrow \gamma \chi_{C}$ | $2	imes10^{-5}$ from a r $_1(1P))]$ assuming E | measur $3(\psi(25))$ | ement of γ | of $[\Gamma(\chi_{c1}(1P) \to p\overline{p}\phi \chi_{c1}(1P)) = (9.2 \pm 0.4)$ |)/ × |

$\chi_{c1}(1P)$

 $\Gamma(\Sigma^{+}\overline{\Sigma}^{-})/\Gamma_{\text{total}}$

 9.2×10^{-2}

VALUE (units 10^{-4}) CL%

EVTS

90 4.3 ± 2.3 58 NAIK

DO CUMENT ID

 58 NAIK 08 reports $<0.65\times 10^{-4}$ from a measurement of $[\Gamma(\chi_{C1}(1P)\to \Sigma^+\overline{\Sigma}^-)/\Gamma_{\rm total}]\times [B(\psi(2S)\to \gamma\chi_{C1}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C1}(1P))=(9.07\pm 1)$

 $0.11\pm0.54)\times10^{-2}$, which we rescale to our best value B($\psi(2S)\to\gamma\chi_{c1}(1P)$) =

| $\Gamma(ho\overline{ ho}\pi^+\pi^-)/\Gamma_{total}$ | | | Г39/Г |
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| VALUE (units 10 ⁻³) 0.50±0.19 OUR EVALUATIO | <u>DOCUMENT ID</u> Treating systematic en | TECN COMMENT or as correlated. | IT |
| 0.50±0.19 OUR AVERAGE | 49.544 | DEG ((00) | |
| 0.46±0.12±0.15 08±0.77±0.05 | ⁴⁹ BAI 99B ⁴⁹ TANENBAUM 78 | BES $\psi(2S)$ - MRK1 $\psi(2S)$ - | $\gamma \chi_{c1}$ |
| ⁴⁹ Rescaled by us using E | | (8.8 ± 0.4)% ar | |
| $J/\psi(1S) \pi^{+} \pi^{-}) = (32.6)$ | | . – / | (/(/ |
| $\Gamma(ho\overline{ ho}\pi^0\pi^0)/\Gamma_{ m total}$ | | | Γ ₄₀ /Γ |
| VALUE (%) CL% < 0.05 90 | DOCUMENT ID T | CLEO $e^+e^- \rightarrow$ | $_{\gamma h^{+} h^{-} h^{0} h^{0}}$ |
| 50 HE 08B reports $<$ 0.05 % [B($\psi(2S) \rightarrow \gamma \chi_{C1}(1P)$)] | from a measurement of Γ (assuming Γ) our best value Γ | $(\chi_{C1}(1P) \rightarrow p\overline{p}\pi_{C1}(1P)) = (9.07 \pm 0.07)$ | $^{0.0}\pi^{0})/\Gamma_{\text{total}} \times 0.11 \pm 0.54) \times$ |
| Γ(ρρΚ+ K-(non-resona | nt))/Γ _{total} | | Γ ₄₁ /Γ |
| VALUE (units 10 ⁻⁴) EVTS | | | |
| 1.35 ± 0.15 ± 0.19 82 ± 9 | | | $\rightarrow \gamma p \overline{p} K^+ K^-$ |
| ⁵¹ ABLIKIM 11F reports (1.39) $p\overline{p} K^+ K^- (\text{non-resonant})$ $\gamma \chi_{c1}(1P)) = (9.2 \pm 0.4)$ | $)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \cdot)]$ | | |
| $\Gamma(p\overline{p}K_S^0K_S^0)/\Gamma_{\text{total}}$ | | | Γ ₄₂ /Γ |
| VALUE (units 10 ⁻⁴) CL% <4.5 90 | DO CUMENT ID | TECN COMMEN | |
| <4.5 90 52 Using B($\psi(2S) \rightarrow \chi_{c1} \gamma$) | | BES2 $\psi(2S)$ - | $\rightarrow \gamma \chi_{c1}$ |
| $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ | | | Г ₄₃ /Г |
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | .437. |
| 1.18±0.19 OUR FIT | DO COMENT ID | _ | |
| $\Gamma(\Lambda \overline{\Lambda} \pi^+ \pi^-)/\Gamma_{ m total}$ | | | Γ ₄₄ /Γ |
| VALUE (units 10^{-3}) CL% | DO CUMENT ID | TECN COMMEN | |
| <1.5 90 | | BES2 $\psi(2S)$ - | $\rightarrow \gamma \chi_{c1}$ |
| ⁵³ Using B($\psi(2S) \rightarrow \chi_{c1} \gamma$) | $(9.1 \pm 0.6)\%$. | | |
| Γ(<i>K</i> + ¬Λ)/Γ _{total} | | | Γ ₄₅ /Γ |
| VALUE (units 10 ⁻³) | - 4 | TECN COMMEN | |
| 0.32±0.09±0.01 | ⁵⁴ ATHAR 07 | / / / | |
| 54 ATHAR 07 reports (0.33 ± | $\pm 0.09 \pm 0.04) \times 10^{-3}$ from | a measurement o | $f[\Gamma(\chi_{c1}(1P) \rightarrow (1P))]$ |
| $0.0907 \pm 0.0011 \pm 0.0054$ | $(25) ightarrow \gamma \chi_{C1}(1P))]$ assul, which we rescale to our b | ming $B(\psi(2S) ightarrow 0$ est value $B(\psi(2S)$ | $\gamma \chi_{c1}(1P)) = $ $\rightarrow \gamma \chi_{c1}(1P))$ |
| $-(9.2 + 0.4) \times 10^{-2}$ O | ur first error is their experin | nent's error and ou | r second error is |
| | using our best value. | | |
| the systematic error from | | | Γ46/Γ |
| the systematic error from $\Gamma(K^+ p \Lambda(1520) + c.c.)/\Gamma$ | | | 70, |
| the systematic error from $\Gamma(K^+ \rho \Lambda(1520) + \text{c.c.})/\Gamma$ VALUE (units 10^{-4}) EVTS | DOCUMENT ID | | |
| the systematic error from $\Gamma(K^+ p \Lambda(1520) + \text{c.c.})/\Gamma(K^+ p \Lambda(1520) + $ | DOCUMENT ID 55 ABLIKIM 11F | BES3 $\psi(2S)$ - | $\rightarrow \gamma p \overline{p} K^+ K^-$ |
| the systematic error from $\Gamma(K^+ p \Lambda(1520) + \text{c.c.})/\Gamma(K^+ p \Lambda(1520) + $ | $\begin{array}{c} 5 \\ 5 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\$ | BES3 $\psi(2S)$ -n a measurement of | $\uparrow \gamma p \overline{p} K^+ K^-$ $f [\Gamma(\chi_{c1}(1P) \rightarrow$ |
| the systematic error from $\Gamma(K^+ p \Lambda (1520) + c.c.) / \Gamma$ VALUE (units 10^{-4}) 1.8 ± 0.4 ± 0.3 55 ABLIKIM 11F reports (1.8) | $\begin{array}{lll} 5 & \underline{DOCUMENT\ ID} \\ 55 & ABLIKIM & 11F \\ 1 \pm 0.38 \pm 0.28) \times 10^{-4} \text{ fror } \\ \text{otal} & \times & [B(\psi(2S) \rightarrow \gamma)] \end{array}$ | BES3 $\psi(2S)$ -n a measurement of | $\uparrow \gamma p \overline{p} K^+ K^-$ $f [\Gamma(\chi_{c1}(1P) \rightarrow$ |
| the systematic error from | $\begin{array}{lll} & & \underline{\text{DOCUMENT ID}} \\ 55 & \underline{\text{ABLIKIM}} & \underline{11} \\ 1 \pm 0.38 \pm 0.28) \times 10^{-4} & \text{fror} \\ \underline{\text{otal}} & \times & \underline{\text{[B}(\psi(2S))} & \rightarrow & \gamma; \\ \times & 10^{-2}. & & & \\ & \underline{\text{I}} \end{array}$ | BES3 $\overline{\psi(2S)}$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ - $\psi(2S)$ | $\begin{array}{ccc} \rightarrow & \gamma p \overline{p} K^+ K^- \\ \text{f} \left[\Gamma \left(\chi_{C1}(1P) \rightarrow \right. \\ \text{ng} & \text{B}(\psi(2S) \rightarrow \right. \end{array} \right.$ |
| the systematic error from | $\begin{array}{c} 5 & \underline{\textit{DOCUMENT ID}} \\ 55 & \underline{\textit{ABLIKIM}} & 11 \text{F} \\ 1 \pm 0.38 \pm 0.28) \times 10^{-4} \text{ fror} \\ \text{otal} & \times [\text{B}(\psi(2S)) \rightarrow \gamma; \\ \times 10^{-2}. \\ \end{array}$ | BES3 $\psi(2S)$ - n a measurement c $\chi_{C1}(1P))]$ assumi | |
| the systematic error from | $\begin{array}{c} 5 & \underline{\textit{DOCUMENT ID}} \\ 55 & \underline{\textit{ABLIKIM}} & 11 \\ 1 \pm 0.38 \pm 0.28) \times 10^{-4} & \text{fror} \\ \text{otal}] \times [B(\psi(2S) \rightarrow \gamma)] \\ \times 10^{-2}. \\ \\ \textbf{al} \\ & \underline{\textit{DOCUMENT ID}} \\ 56 & \underline{\textit{ABLIKIM}} & 11 \\ 56 & \underline{\textit{ABLIKIM}} & 11 \\ \times [B(\psi(2S) \rightarrow \gamma)\chi] \\ \times [B(\psi(2S) \rightarrow \gamma) \end{array}$ | BES3 $\psi(2S)$ - n a measurement of $\chi_{C1}(1P)$] assuming $\frac{TECN}{BES3} \frac{COMMER}{\psi(2S)}$ - measurement of | |
| the systematic error from | $\begin{array}{c} 5 & \underline{\textit{DOCUMENT ID}} \\ 55 & \underline{\textit{ABLIKIM}} & 11 \\ 1 \pm 0.38 \pm 0.28) \times 10^{-4} & \text{fror} \\ \text{otal}] \times [B(\psi(2S) \rightarrow \gamma)] \\ \times 10^{-2}. \\ \\ \textbf{al} \\ & \underline{\textit{DOCUMENT ID}} \\ 56 & \underline{\textit{ABLIKIM}} & 11 \\ 56 & \underline{\textit{ABLIKIM}} & 11 \\ \times [B(\psi(2S) \rightarrow \gamma)\chi] \\ \times [B(\psi(2S) \rightarrow \gamma) \end{array}$ | BES3 $\psi(2S)$ - n a measurement of $\chi_{C1}(1P)$] assuming $\frac{TECN}{BES3} \frac{COMMER}{\psi(2S)}$ - measurement of | |
| the systematic error from | $\begin{array}{c} \frac{DOCUMENT\ ID}{55\ ABLIKIM} & 11F\\ 1\pm 0.38\pm 0.28)\times 10^{-4}\ from\\ \frac{1}{61} \times 10^{-2}. & \\ \frac{DOCUMENT\ ID}{56\ ABLIKIM} & 11F\\ \times 1.00\times 10^{-4}\ from\ a\\ \times [B(\psi(2S)) \to \gamma\chi_{C}] \end{array}$ | BES3 $\psi(2S)$ - m a measurement of $\chi_{C1}(1P)$] assuming $\frac{TECN}{BES3} \frac{COMMEN}{\psi(2S)}$ - measurement of $\chi_{C1}(1P)$] assuming assuming assuming $\chi_{C1}(1P)$ | $\begin{array}{c} \rightarrow \ \gamma p \overline{p} K^+ K^- \\ \text{f} [\Gamma(\chi_{c1}(1P) \rightarrow \\ \text{ng B}(\psi(2S) \rightarrow \\ \end{array}]$ $\begin{array}{c} \Gamma_{47}/\Gamma \\ \rightarrow \ \gamma p \overline{p} K^+ K^- \\ [\Gamma(\chi_{c1}(1P) \rightarrow \\ \text{g B}(\psi(2S) \rightarrow \\ \end{array}]$ |
| the systematic error from | $\begin{array}{c} 5 \\ 5 \\ 5 \\ 5 \\ 6 \\ 6 \\ 7 \\ 7 \\ 8 \\ 1 \\ 1 \\ 1 \\ 2 \\ 1 \\ 1 \\ 2 \\ 3 \\ 1 \\ 2 \\ 3 \\ 2 \\ 3 \\ 3 \\ 2 \\ 3 \\ 3 \\ 2 \\ 3 \\ 3$ | BES3 $\psi(2S)$ - n a measurement of $\chi_{C1}(1P)$] assuming $\psi(2S)$ - measurement of $\chi_{C1}(1P)$] assuming $\chi_{C1}(1P)$] assuming $\chi_{C1}(1P)$ | $\begin{array}{c} \rightarrow \ \gamma p \overline{p} K^+ K^- \\ \text{f} [\Gamma(\chi_{c1}(1P) \rightarrow \\ \text{ng B}(\psi(2S) \rightarrow \\ \end{array}]$ $\begin{array}{c} \Gamma_{47}/\Gamma \\ \rightarrow \ \gamma p \overline{p} K^+ K^- \\ [\Gamma(\chi_{c1}(1P) \rightarrow \\ \text{g B}(\psi(2S) \rightarrow \\ \end{array}]$ |

```
\Gamma(\Xi^0\overline{\Xi^0})/\Gamma_{total}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{50}/\Gamma
VALUE (units 10^{-4}) CL%
                                                                                                                                                       DO CUMENT ID
                                                                                                                                                                                                                                         TECN COMMENT
                                                                                                       EVTS
                                                                    90 1.7 \pm 2.4 59 NAIK
                                                                                                                                                                                                                  08 CLEO \psi(2S) \rightarrow \gamma \Xi^0 \overline{\Xi}{}^0
   ^{59} NAIK 08 reports <0.60\times10^{-4} from a measurement of [\Gamma(\chi_{C1}(1P)\to\overline{\Xi}^0\,\overline{\Xi}^0)/\Gamma_{total}\times[B(\psi(2S)\to\gamma\chi_{C1}(1P))] assuming B(\psi(2S)\to\gamma\chi_{C1}(1P))=(9.07\pm0.11\pm0.54)\times
               10^{-2}, which we rescale to our best value B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = 9.2 \times 10^{-2}.
\Gamma(\Xi^{-}\overline{\Xi}^{+})/\Gamma_{total}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{51}/\Gamma
VALUE (units 10^{-4}) CL%
                                                                                                           EVTS
                                                                                                                                                            DOCUMENT ID
                                                                                                                                                                                                                                         TECN COMMENT
                                                                                                                                                60 NAIK 08 CLEO \psi(2S) \rightarrow \gamma \Xi^{+} \overline{\Xi}^{-}
0.84 ± 0.22 ± 0.03 16.4 ± 4.3
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                                                                                                                               61 ABLIKIM 06D BES2 \psi(2S) 
ightarrow \gamma \chi_{\it C1}
                                                       90
    ^{60} NAIK 08 reports (0.86 \pm 0.22 \pm 0.08) \times 10 ^{-4} from a measurement of [\Gamma(\chi_{C1}(1P) \rightarrow
                \Xi^- \, \overline{\Xi}{}^+)/\Gamma_{\mathsf{total}}] \, \times \, [\mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P))] \, \, \mathsf{assuming} \, \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(1P)) \, = \, \mathsf{B}(\psi(2S) \, \to \, \gamma \chi_{\mathcal{C}1}(
              (9.07\pm0.11\pm0.54)\times10^{-2}, which we rescale to our best value B(\psi(2S)\to\gamma\chi_{c1}(1P))
               = (9.2 \pm 0.4) \times 10^{-2}. Our first error is their experiment's error and our second error is
                  he systematic error from using our best value.
     61 Using B(\psi(2S) \rightarrow \chi_{c1} \gamma) (9.1 \pm 0.6)%.
  [\Gamma(\pi^+\pi^-) + \Gamma(K^+K^-)]/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{52}/\Gamma
VALUE (units 10<sup>-4</sup>) CL%
                                                                                                                                  • • • We do not use the following data for averages, fits, limits, etc. • • •
                                                                                                                            ^{62} BRANDELIK 79B DASP \psi(2S) 
ightarrow \gamma \chi_{c1}
                                                                                                 90
    ^{62} Estimated using B(\psi(2S)\to\gamma\chi_{C1}(1P))=0.087. The errors do not contain the uncertainty in the \psi(2S) decay.
\Gamma(K_S^0 K_S^0)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{53}/\Gamma
VALUE \ (units \ 10^{-4})
                                                                                                                                              DO CUMENT ID TECN COMMENT
                                                                                                                                  <sup>63</sup> ABLIKIM
                                                                                                                                                                                                         050 BES2 \psi(2S) \rightarrow \chi_{c1} \gamma
    <0.6
                                                                                                  90
    <sup>63</sup>ABLIKIM 050 reports [\Gamma(\chi_{c1}(1P) \rightarrow K_S^0 K_S^0)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P))]
               <0.6\times10^{-5} which we divide by our best value B(\psi(2S) 
ightarrow \gamma\chi_{C1}(1P))=9.2\times10^{-2}.
                                                                                                                     - RADIATIVE DECAYS -
\Gamma(\gamma J/\psi(1S))/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{54}/\Gamma
                                                                                                                       DOCUMENT ID
                                                                                                                                                                                             TECN COMMENT
0.344 ± 0.015 OUR FIT
 <sup>64</sup> ADAM
0.379 \pm 0.008 \pm 0.021
                                                                                                                                                                              05A CLEO e^+\,e^-
ightarrow\,\psi(2S)
ightarrow\,\gamma\chi_{C1}
     64 Uses \mathbb{B}(\psi(2S) \to \gamma \chi_{c1} \to \gamma \gamma J/\psi) from ADAM 05A and \mathbb{B}(\psi(2S) \to \gamma \chi_{c1}) from
\Gamma(\gamma \rho^0)/\Gamma_{\rm total}
                                                                                                                                                           DOCUMENT ID
                                                                                                                                                                                                                                     TECN COMMENT
228±19 OUR AVERAGE
                                                                                                                                                 65 ABLIKIM
                                                                                                                                                                                                                        11E BES3 \psi(2S) \rightarrow \gamma \gamma \rho^0
 228+13+22
                                                                                            432 + 25
                                                                                                                                                <sup>66</sup>BENNETT
                                                                                                                                                                                                                 08A CLEO \psi(2S) \rightarrow \gamma \gamma \rho^0
229 \pm 25 \pm 9
                                                                                           186 \pm 15
     ^{65} ABLIKIM 11E reports (228 \pm 13 \pm 22) 	imes 10 ^{-6} from a measurement of [F (\chi_{C1}(1P) 
ightarrow
              \gamma \rho^0)/\Gamma_{\text{total}}] × [B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P))] assuming B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (9.2 \pm 1.0)
     <sup>66</sup>BENNETT 08A reports (243 \pm 19 \pm 22) \times 10 ^{-6} from a measurement of [\Gamma(\chi_{c1}(1P) \rightarrow
                \gamma \rho^0)/\Gamma_{\text{tot}_{\mbox{\footnotesize{\bf Q}}}l}] \times [\text{B}(\psi(2S) \to \ \gamma \chi_{c1}(1P))] \text{ assuming } \text{B}(\psi(2S) \to \ \gamma \chi_{c1}(1P)) = (8.7 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0 \pm 1.0
                                                            , which we rescale to our best value B(\psi(2S) 
ightarrow \gamma \chi_{\mathcal{C}1}(1P)) = (9.2 \pm 0.4) 	imes
              10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value.
\Gamma(\gamma\omega)/\Gamma_{\text{total}}
                                                                                                                                                                                                                                                                                                                                 \Gamma_{56}/\Gamma
 VALUE (units 10<sup>-6</sup>)
71± 9 OUR AVERAGE
                                                                                                             EVTS
                                                                                                                                                                                                                                       TECN COMMENT
                                                                                                                                                 <sup>67</sup> ABLIKIM
                                                                                                                                                                                                                         11E BES3 \psi(2S) \rightarrow \gamma \gamma \omega
70 + 7 + 7
                                                                                           136 \pm 14
                                                                                                                                               68 BENNETT
                                                                                                   39 + 7
                                                                                                                                                                                                                    08A CLEO \psi(2S) \rightarrow \gamma \gamma \omega
  78 + 18 + 3
    ^{67} ABLIKIM 11E reports (69.7\pm7.2\pm6.6)\times10^{-6} from a measurement of [F (\chi_{c1}(1P)\to
              \gamma \omega)/\Gamma_{\mathsf{total}} \times [\mathsf{B}(\psi(2S) \to \gamma \chi_{c1}(1P))] assuming \mathsf{B}(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 1)
     ^{68}BENNETT 08A reports (83 \pm 15 \pm 12) 	imes 10^{-6} from a measurement of [\Gamma(\chi_{c1}(1P) 
ightarrow
              \frac{\gamma\omega}{10^{-1}} |X_{\text{total}}| \times |B(\psi(2S) \to \gamma \chi_{c1}(1P))| \text{ assuming } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (8.7 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale } B(\psi(2S) \to \gamma \chi_{c1}(1P)) = (9.2 \pm 0.4) \times 10^{-2}, \text{ which we rescale }
```

which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{c1}(1P)$) = 9.2×10^{-2} .

 10^{-2} . Our first error is their experiment's error and our second error is the systematic

error from using our best value.

 Γ_{49}/Γ

TECN COMMENT

08 CLEO $\psi(2S) \rightarrow \gamma \Sigma^{+} \overline{\Sigma}^{-}$

<u>VALUE (units 10^{−2})</u> <u>EVTS</u> **5.34±0.12 OUR FIT**

 $\frac{\textit{VALUE} \, (\text{units} \, 10^{-2})}{\textbf{9.46} \pm \textbf{0.23} \, \, \textbf{OUR FIT}} = \frac{\textit{EVTS}}{}$

 $10.15 \pm 0.28 \; \text{OUR AVERAGE}$

 $12.6\ \pm0.3\ \pm3.8$ 8.5 ± 2.1

 $10.17 \pm 0.07 \pm 0.27 \hspace{1.5cm} 24.9k$

DO CUMENT ID TECN COMMENT

DOCUMENT ID TECN COMMENT

 $\begin{array}{ccc} \text{08} & \text{CLEO} & \psi(2\text{S}) \rightarrow & \gamma \chi_{c1} \\ \text{04B} & \text{BES} & \psi(2\text{S}) \rightarrow & J/\psi X \\ \text{80} & \text{MRK2} & \psi(2\text{S}) \rightarrow & \gamma \chi_{c1} \\ \end{array}$

 $\begin{array}{l} \Gamma\big(\chi_{c1}(1P) \to \gamma J/\psi(1S)\big)/\Gamma_{\text{total}} \, \times \, \Gamma\big(\psi(2S) \to \gamma \chi_{c1}(1P)\big)/\Gamma\big(\psi(2S) \to J/\psi(1S) \, \pi^+ \, \pi^-\big) \\ \end{array}$

MENDEZ

81 ABLIKIM 82 HIMEL

 \bullet • • We do not use the following data for averages, fits, limits, etc. • • • 10.24 ± 0.17 ± 0.23 3.7k 83 ADAM 05A CLEO Repl. by MENDEZ 08

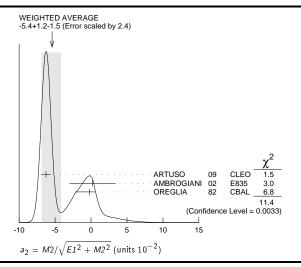
 $^{80}\,\mathrm{Not}$ independent from other measurements of MENDEZ 08.

3k

| | $\chi_{c1}(1P)$ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 81 From a fit to the J/ψ recoil mass spectra. 82 The value for $B(\psi(2S) \to \gamma \chi_{c1}) \times B(\chi_{c1} \to \gamma J/\psi(1S))$ quoted in HIMEL 80 is derived using $B(\psi(2S) \to J/\psi(1S)\pi^+\pi^-) = (33\pm 3)\%$ and $B(J/\psi(1S) \to \ell^+\ell^-) = 0.138\pm 0.018$. Calculated by us using $B(J/\psi(1S) \to \ell^+\ell^-) = 0.1181\pm 0.0020$. 83 Not independent from other values reported by ADAM 05A. |
| 71 Estimated using B($\psi(2S)\to\gamma\chi_{c1}(1P)$) = 0.087. The errors do not contain the uncertainty in the $\psi(2S)$ decay. | $\Gamma(\chi_{c1}(1P) \to K^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c1}(1P))/\Gamma_{\text{total}} \\ \Gamma_{15}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | MALUE (units 10 ⁻⁴) 6.8 ± 0.5 OUR FIT 7.2 ± 0.6 OUR AVERAGE 7.3 ± 0.5 ± 0.5 84 ATHAR 7 CLEO $\psi(2S) \rightarrow \gamma \kappa_S^0 K^+ \pi^-$ 7.0 ± 0.5 ± 0.9 85 ABLIKIM 86 BES2 $\psi(2S) \rightarrow \gamma \kappa_{c1}$ 84 Calculated by us. The value of $B(\chi_{c1} \rightarrow K^0 K^+ \pi^- + \text{c.c.})$ reported by ATHAR 07 was derived using $B(\psi(2S) \rightarrow \gamma \chi_{c1}(1P)) = (9.07 \pm 0.11 \pm 0.54)\%$. 85 Calculated by us. ABLIKIM 06R reports $B(\chi_{c1} \rightarrow K_S^0 K^+ \pi^-) = (4.0 \pm 0.3 \pm 0.5) \times 10^{-3}$. We use $B(\psi(2S) \rightarrow \gamma \chi_{c1}) = (8.7 \pm 0.4) \times 10^{-2}$. $\Gamma(\chi_{c1}(1P) \rightarrow K^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \gamma \chi_{c1}(1P))/$ |
| $\Gamma(\chi_{c1}(1P) \to \Lambda \overline{\Lambda})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c1}(1P))/\Gamma_{\text{total}} \Gamma_{43}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma^{\psi(2S)}$ | $\Gamma(\psi(2S) \rightarrow J/\psi(1S) \pi^+ \pi^-)$ $\Gamma_{15}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 20.1±1.6 OUR FIT 13.2±2.4±3.2 86 BAI 998 BES $\psi(2S) \rightarrow \gamma K_S^0 K^+ \pi^-$ 86 Calculated by us. The value of B($\chi_{C1} \rightarrow K_S^0 K^+ \pi^-$) reported by BAI 998 was derived using B($\psi(2S) \rightarrow \gamma \chi_{C1}(1P)$) = (8.7 ± 0.8)% and B($\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$) = (32.4 ± 2.6)% [BAI 980]. |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| ⁷⁴ BAI 03E reports [$B(\chi_{C1} \to \Lambda \overline{\Lambda})$ $B(\psi(2S) \to \gamma \chi_{C1})$ / $B(\psi(2S) \to J/\psi \pi^+ \pi^-)$] × [$B^2(\Lambda \to \pi^- \rho)$ / $B(J/\psi \to \rho \overline{\rho})$] = (1.33 $^{+0.52}_{-0.46} \pm 0.25$)%. We calculate from this measurement the presented value using $B(\Lambda \to \pi^- \rho)$ = (63.9 ± 0.5)% and $B(J/\psi \to \rho \overline{\rho})$ = (2.17 ± 0.07) × 10 ⁻³ . | 87 Calculated by us. The value of $B(\chi_{C1} \rightarrow 2K^+2K^-)$ reported by ABLIKIM 06T was derived using $B(\psi(2S) \rightarrow \gamma\chi_{C1}(1P)) = (8.7 \pm 0.8)\%$. $\Gamma(\chi_{C1}(1P) \rightarrow K^+K^-K^+K^-)/\Gamma_{total} \times \Gamma(\psi(2S) \rightarrow \gamma\chi_{C1}(1P))/\Gamma(\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-)$ $\Gamma_{29}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | MALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT III 1.54 ± 0.31 OUR FIT 1.13 ± 0.40 ± 0.29 88 BAI 998 BES $\psi(2S) \rightarrow \gamma K^+ K^+ K^- K^-$ 88 Calculated by us. The value of $B(\chi_{C1} \rightarrow 2K^+ 2K^-)$ reported by BAI 998 was derived using $B(\psi(2S) \rightarrow \gamma \chi_{C1}(1P)) = (8.7 \pm 0.8)\%$ and $B(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-) = (32.4 \pm 2.6)\%$ [BAI 98D]. $F(\chi_{C1}(1P) \rightarrow P\overline{P})/\Gamma_{\text{total}} \times F(\psi(2S) \rightarrow \gamma \chi_{C1}(1P))/\Gamma_{\text{total}}$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| ⁷⁸ Not independent from other measurements of MENDEZ 08. ⁷⁹ Not independent from other values reported by ADAM 05A. | MULTIPOLE AMPLITUDES IN $\chi_{c1}(1P) ightarrow \gamma J/\psi(1S)$ |
| $ \begin{array}{l} \Gamma(\chi_{c1}(1P) \to \gamma J/\psi(1S))/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c1}(1P))/\Gamma(\psi(2S) \to J/\psi(1S)) \\ J/\psi(1S) \text{anything}) & \Gamma_{54}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma_{9}^{\psi(2S)} \\ \Gamma_{54}/\Gamma \times \Gamma_{110}^{\psi(2S)}/\Gamma_{9}^{\psi(2S)} = \Gamma_{54}/\Gamma \times \Gamma_{110}^{\psi(2S)}/(\Gamma_{11}^{\psi(2S)} + \Gamma_{12}^{\psi(2S)} + \Gamma_{13}^{\psi(2S)} +$ | $a_2 = M2/\sqrt{E1^2 + M2^2}$ Magnetic quadrupole fractional transition amplitude MALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT -5.4 $^{+1.2}_{-1.5}$ OUR AVERAGE Error includes scale factor of 2.4. See the ideogram below. |
| $0.344\Gamma_{110}^{\psi(25)} + 0.195\Gamma_{111}^{\psi(25)})$ | $-6.26\pm0.63\pm0.24$ 39k ARTUSO 09 CLEO $\psi(25) 	o \gamma \gamma \ell^+ \ell^-$ 0.2 $\pm3.2 \pm0.4$ 2090 AMBROGIANI 02 E835 $p\overline{p} 	o \chi_{c1} 	o J/\psi \gamma$ |

| 42 - MZ/VLI | T 1712 1V | iagiictic quaui | upo | ic ii acci | onal transition amplitude |
|--------------------------------------------------|-----------|------------------|-------|------------|--------------------------------------------------------------------------|
| $VALUE$ (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $-5.4 \ ^{+1.2}_{-1.5}$ OUR A | VERAGE | Error includes s | scale | factor of | 2.4. See the ideogram below. |
| $-6.26\pm0.63\pm0.24$ | 39k | ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $0.2 \pm 3.2 \pm 0.4$ | 2090 | AMBROGIANI | 02 | E835 | $p\overline{p} \rightarrow \chi_{c1} \rightarrow J/\psi \gamma$ |
| $-0.2 \begin{array}{c} +0.8 \\ -2.0 \end{array}$ | 921 | OREGLIA | 82 | CBAL | $\psi(2S) \rightarrow \chi_{c1} \gamma \rightarrow J/\psi \gamma \gamma$ |

 $\chi_{c1}(1P)$, $h_{c}(1P)$



MULTIPOLE AMPLITUDES IN $\psi(2S) ightarrow \gamma \chi_{c1}(1S)$ RADIATIVE DECAY

$b_2 = M2/\sqrt{E1^2 + M2^2}$ Magnetic quadrupole fractional transition amplitude

| VALUE (units 10-2) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|------|--------------|----|------|--------------------------------------------------------|
| 2.9 ±0.8 OUR AVER | AGE | | | | |
| $2.76 \pm 0.73 \pm 0.23$ | 39k | ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $7.7 \begin{array}{c} +5.0 \\ -4.5 \end{array}$ | 921 | OREGLIA | 82 | CBAL | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |

MULTIPOLE AMPLITUDE RATIOS IN RADIATIVE DECAYS $\psi(2S) \rightarrow \gamma \chi_{c1}(1S)$ and $\chi_{c1} \rightarrow \gamma J/\psi(1S)$

a2/b2 Magnetic quadrupole transition amplitude ratio

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|------|--------------|----|------|----------------------------------------------------|
| -2.27 + 0.57 -0.99 | 39k | 90 ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |

 90 Statistical and systematic errors combined. Not independent of $a_2(\chi_{c1})$ and $b_2(\chi_{c1})$ values from ARTUSO 09.

$\chi_{c1}(1P)$ REFERENCES

| ADDITION | 11A | PR D83 012006 | M. Abillion of all | (DEC III Collab.) |
|------------|------|------------------|------------------------------|------------------------|
| ABLIKIM | | | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM | 11 D | PR D83 032003 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM | 11 E | PR D83 112005 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM | 11F | PR D83 112009 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM | 11K | PRL 107 092001 | M. Ablikim et al. | (BES III Collab.) |
| ONYISI | 10 | PR D82 011103R | P.U.E. Onyisi et al. | (CLEO Collab.) |
| ARTUSO | 0.9 | PR D80 112003 | M. Artuso et al. | (CLEO Collab.) |
| BENNETT | 08A | PRL 101 151801 | J.V. Bennett et al. | CLEO Collab. |
| ECKLUND | 08 A | PR D78 091501R | K.M. Ecklund et al. | (CLEO Collab.) |
| HE | 08 B | PR D78 092004 | Q. He et al. | CLEO Collab. |
| MENDEZ | 08 | PR D78 011102R | H. Mendez et al. | (CLEO Collab.) |
| NAIK | 08 | PR D78 031101R | P. Naik et al. | (CLEO Collab.) |
| ATHAR | 07 | PR D75 032002 | S.B. Athar et al. | (CLEO Collab.) |
| | 06 D | | | |
| ABLIKIM | | PR D73 052006 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM | 06R | PR D74 072001 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM | 06T | PL B642 197 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM | 05 G | PR D71 092002 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM | 05 O | PL B630 21 | M. Ablikim et al. | (BES Collab.) |
| ADAM | 05 A | PRL 94 232002 | N.E. Adam et al. | (CLEO Collab.) |
| ANDREOTTI | 05 A | NP B717 34 | M. Andreotti <i>et al</i> . | (FNAL E835 Collab.) |
| ABLIKIM | 04B | PR D70 012003 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM | 04 H | PR D70 092003 | M. Ablikim et al. | (BES Collab.) |
| ATHAR | 04 | PR D70 112002 | S.B. Athar et al. | (ČLEO Collab.) |
| BAI | 04 F | PR D69 092001 | J.Z. Bai et al. | (BES Collab.) |
| BAI | 041 | PR D70 012006 | J.Z. Bai et al. | (BES Collab.) |
| AULCHENKO | 03 | PL B573 63 | V.M. Aulchenko et al. | (KEDR Collab.) |
| BAI | 03 E | PR D67 112001 | J.Z. Bai et al. | (BES Collab.) |
| AMBROGIANI | 02 | PR D65 052002 | M. Ambrogiani et al. | (FNAL E835 Collab.) |
| BAI | 99B | PR D60 072001 | J.Z. Bai et al. | (BES Collab.) |
| BAI | 98 D | PR D58 092006 | J.Z. Bai et al. | (BES Collab.) |
| BAI | 981 | PRL 81 3091 | J.Z. Bai et al. | (BES Collab.) |
| | | | | |
| ARMSTRONG | 92 | NP B373 35 | T.A. Armstrong et al. | (FNAL, FERR, GENO+) |
| A Iso | | PRL 68 1468 | T.A. Armstrong et al. | (FNAL, FERR, GENO+) |
| BAGLIN | 86B | PL B172 455 | | I, GENO, LYON, OSLO+) |
| GA IS ER | 86 | PR D34 711 | J. Gaiser et al. | (Crystal Ball Collab.) |
| LEMOIGNE | 82 | PL 113B 509 | Y. Lemoigne et al. | (SACL, LOIC, SHMP+) |
| OREGLIA | 82 | PR D25 2259 | M.J. Oreglia et al. | (SLAC, CIT, HARV+) |
| A Iso | | Private Comm. | M.J. Oreglia | (EFI) |
| HIMEL | 80 | PRL 44 920 | T. Himel et al. | (LBL, SLAC) |
| A Iso | | Private Comm. | G. Trilling | (LBL, UCB) |
| BRANDELIK | 79B | NP B160 426 | R. Brandelik et al. | (DASP Collab.) |
| BARTEL | 78 B | PL 79B 492 | W. Bartel et al. | (DESY, HEIDP) |
| TANENBAUM | 78 | PR D17 1731 | W.M. Tanenbaum et al. | `(SLAC, LBL) |
| Also | | Private Comm. | G. Trilling | (LBL, UCB) |
| BIDDICK | 77 | PRL 38 1324 | C.J. Biddick et al. | (UCSD, UMD, PAVI+) |
| FELDMAN | 77 | PRPL 33 C 285 | G.J. Feldman, M.L. Perl | (LBL, SLAC) |
| YAMADA | 77 | Hamburg Conf. 69 | S. Yamada | (DASP Collab.) |
| WHITAKER | 76 | PRL 37 1596 | J.S. Whitaker et al. | (SLAC, LBL) |
| TANENBAUM | 75 | PRL 35 1323 | W.M. Tanenbaum et al. | (LBL, SLAC) |
| TANENBAUM | 15 | FRE 30 1023 | vv.ivi. Tallelibaulii et al. | (LBL, SLAC) |



$$I^G(J^{PC}) = ??(1 + -)$$

Quantum numbers are quark model prediction, C = - established

$h_c(1P)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|---------------------------------------|--------------|------------------------|---------------|-------------------------------------------------|---|
| 3525.41 ± 0.16 OUR A | VERAGE | Error includes scale | factor of 1. | 2. | _ |
| $3525.40\pm0.13\pm0.18$ | 3679 | ABLIKIM | 10B BES3 | $\psi(2S) \rightarrow \pi^0 \gamma \eta_C$ | ı |
| $3525.20\pm0.18\pm0.12$ | 1282 | ¹ DOBBS | 08A CLEO | $\psi(2S) \rightarrow \pi^0 \eta_C \gamma$ | |
| $3525.8 \pm 0.2 \pm 0.2$ | 13 | ANDREOTTI | 05 B E 835 | $\overline{p}p \rightarrow \eta_C \gamma$ | |
| ● ● We do not use | the followin | g data for averages, | fits, limits, | etc. • • • | |
| 3525.6 ± 0.5 | 92 + 23 | ADAMS | 09 CLEO | $\psi(2S) \rightarrow 2(\pi^{+}\pi^{-}\pi^{0})$ | |
| $3524.4 \pm 0.6 \pm 0.4$ | 168 ± 40 | | | $\psi(2S) \rightarrow \pi^0 \eta_C \gamma$ | |
| 3527 ±8 | 42 | ANTONIAZZI | 94 E705 | 300 π^{\pm} , ρ Li \rightarrow | |
| | | ³ ARMSTRONG | | $J/\psi \pi^0 X$ | |
| $3526.28 \pm 0.18 \pm 0.19$ | 59 | ³ ARMSTRONG | 92D E760 | $\overline{\rho} \rho \rightarrow J/\psi \pi^0$ | |
| $3525.4 \pm 0.8 \pm 0.4$ | 5 | BAGLIN | 86 SPEC | $\overline{p}p \rightarrow J/\psi X$ | |
| 1 | | | | | |

- 1 Combination of exclusive and inclusive analyses for the reaction $\psi(2S)
 ightarrow ~\pi^0\,h_C
 ightarrow$ $\pi^0\,\eta_{
 m C}\,\gamma$. This result is the average of DOBBS 08A and ROSNER 05.
- ² Superseded by DOBBS 08A.

 $\Gamma(J/\psi(1S)\pi\pi)/\Gamma(J/\psi(1S)\pi^0)$

and Systematic error recalculated by us according to Eq. (16) in ARMSTRONG 93B, using the value for the $\psi(2S)$ mass from AULCHENKO 03.

$h_c(1P)$ WIDTH

| VALUE (MeV) | CL% | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------|--------|-----------------|-----|----------------|-----|------|-------------------------------------------------------------------------|
| <1 | | 13 | | ANDREOTTI | 05в | E835 | $\overline{p}p \rightarrow \eta_C \gamma$ |
| • • • We do not | use th | ie followii | | | | | |
| <1.44 | 90 | 3679 | 4 | ABLIKIM | 10B | BES3 | $\psi(2S) \to \pi^0 \gamma \eta_C$ $\overline{\rho} p \to J/\psi \pi^0$ |
| <1.1 | 90 | 59 | | ARMSTRONG | 92D | E760 | $\overline{p}p \rightarrow J/\psi \pi^0$ |
| ⁴ The central va | lue is | $\Gamma = 0.73$ | ± 0 | .45 ± 0.28 MeV | /. | | |

$h_c(1P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------------------------------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $J/\psi(1S)\pi^0$ | |
| Γ_2 | $J/\psi(1S)\pi\pi$ | not seen |
| Γ_3 | ρ <u></u> | |
| Γ_4 | $ \begin{array}{l} \rho \overline{\rho} \\ \eta_c(1S) \gamma \\ \pi^+ \pi^- \pi^0 \end{array} $ | (51 ±6) % |
| Γ_5 | $\pi^{+} \pi^{-} \pi^{0}$ | $< 2.2 \times 10^{-3}$ |
| Γ_6 | $2\pi^{+}2\pi^{-}\pi^{0}$ | $(2.2^{+0.8}_{-0.7})$ % |
| Γ_7 | $3\pi^{+}3\pi^{-}\pi^{0}$ | < 2.9 % |

hc(1P) PARTIAL WIDTHS

$h_c(1P) \Gamma(i)\Gamma(\overline{p}p)/\Gamma(total)$

| $\Gamma(\eta_c(1S)\gamma) \times 1$ | $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ | | | | | $\Gamma_4\Gamma_3/\Gamma_3$ |
|-------------------------------------|-----------------------------------------------|------------------------|----------|---------|-------------------------------------------|-----------------------------|
| VALUE (eV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not u | se the following | g data for average | s, fits, | limits, | etc. • • • | |
| 12.0 ± 4.5 | 13 | ⁵ ANDREOTTI | 05в | E835 | $\overline{p}p \rightarrow \eta_C \gamma$ | |
| ⁵ Assuming $\Gamma = 3$ | 1 MeV | | | | | |

hc(1P) BRANCHING RATIOS

 Γ_2/Γ_1

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT | • |
|-------------------------------------------|-------------|--------------------|----------|--------------------------------------------------------------|-------------------|
| <0.18 | 90 | ARMSTRONG 92 | 2D E760 | $\overline{p}p \rightarrow J/\psi \pi^0$ | |
| $\Gamma(\eta_c(1S)\gamma)/\Gamma_{total}$ | | | | | Γ_4/Γ |
| $VALUE$ (units 10^{-2}) | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 51 ± 6 OUR AVERA | AGE | | | | |
| 54.3 ± 6.7 ± 5.2 | 3679 | ABLIKIM | 10B BES3 | $\psi(2S) \rightarrow \pi^0$ | $\gamma \eta_c$ |
| $48 \pm 6 \pm 7$ | | ⁶ DOBBS | 08A CLEC | $\psi(2S) \rightarrow \pi^0$ $\psi(2S) \rightarrow \pi^0$ | $\eta_{c}\gamma$ |
| • • • We do not use th | e following | | | | |
| 48 \pm 6 \pm 7 | 1282 | ⁷ DOBBS | 08A CLEC | $\psi(2S) \rightarrow \pi^0$ | $\eta_{c} \gamma$ |

⁸ ROSNER 05 CLEO $\psi(2S) \rightarrow \pi^0 \eta_C \gamma$ ⁶ Average of DOBBS 08A and ROSNER 05. DOBBS 08A reports $[\Gamma(h_c(1P) \to \eta_c(1S)\gamma)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \pi^0 h_c(1P))] = (4.16 \pm 0.30 \pm 0.37) \times 10^{-4}$ which we divide by our best value $B(\psi(2S) \to \pi^0 h_c(1P)) = (8.6 \pm 1.3) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. ⁷ DOBBS 08A reports $[\Gamma(h_c(1P) \to \eta_c(1S)\gamma)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \pi^0 h_c(1P))] = (4.19 \pm 0.32 \pm 0.45) \times 10^{-4}$ which we divide by our best value $B(\psi(2S) \to \pi^0 h_c(1P)) = (8.6 \pm 1.3) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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the systematic error from using our best value. ⁸ ROSNER 05 reports $[\Gamma(h_{\mathcal{C}}(1P) \rightarrow \eta_{\mathcal{C}}(1S)\gamma)/\Gamma_{\mathsf{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_{\mathcal{C}}(1P))] =$ $(4.0\pm0.8\pm0.7) imes10^{-4}$ which we divide by our best value B $(\psi(2S)
ightarrow\pi^0\,h_C(1P))$ $= (8.6 \pm 1.3) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

Confidence level

| $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$ | | | | | Г ₅ /Г |
|-------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|------|-----------------------------|-----------------------|
| VALUE (units 10^{-3}) | DO CUMENT | ID | TECN | COMMENT | |
| <2.2 | 9 ADAMS | 09 | CLEO | $\psi(2S) \rightarrow \tau$ | $\pi^0 \gamma \eta_C$ |
| 0 | and the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second s | ο. | | | 0 |

 9 ADAMS 09 reports $[\Gamma(h_C(1P)\to~\pi^+\pi^-\pi^0)/\Gamma_{\rm total}]\times [B(\psi(2S)\to~\pi^0\,h_C(1P))]<<0.19\times10^{-5}$ which we divide by our best value $B(\psi(2S)\to~\pi^0\,h_C(1P))=8.6\times10^{-4}$.

 $^{10}\,\text{ADAMS}\,\,\text{09 reports}\,\,[\Gamma\big(h_{\mathcal{C}}(1P)\,\rightarrow\,2\pi^{+}\,2\pi^{-}\,\pi^{0}\big)/\Gamma_{\text{total}}]\times[\mathrm{B}(\psi(2S)\,\rightarrow\,\pi^{0}\,h_{\mathcal{C}}(1P))]=$ $(1.88 ^{\,+\, 0.48} _{\,-\, 0.45} ^{\,+\, 0.47}) \times 10^{-5} \,\, {\rm which \ we \ divide \ by \ our \ best \ value \ B}(\psi(2S) \to \,\, \pi^0 \,h_C(1P))$ = $(8.6 \pm 1.3) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(3\pi^+3\pi^-\pi^0)/\Gamma_{ m total}$ | | | | | Γ_7/Γ |
|-----------------------------------------------|----------|----|------|------------------------------|-------------------|
| VALUE (units 10 ⁻²) | DOCUMENT | ID | TECN | COMMENT | |
| <2.9 | 11 ADAMS | 09 | CLEO | $\psi(2S) \rightarrow \pi^0$ | $\gamma \eta_c$ |

 11 ADAMS 09 reports [$\Gamma(h_C(1P)\to 3\pi^+\,3\pi^-\,\pi^0)/\Gamma_{\mbox{total}}]\times [B(\psi(2S)\to \pi^0\,h_C(1P))]$ $<2.5\times 10^{-5}$ which we divide by our best value $B(\psi(2S)\to \pi^0\,h_C(1P))=8.6\times 10^{-4}$.

$\begin{array}{c} <2.5\times10 & \text{which is 2.5.} \end{array}$ $\Gamma\big(h_c(1P)\to\eta_c(1S)\gamma\big)/\Gamma_{\text{total}} \times \Gamma\big(\psi(2S)\to\pi^0\,h_c(1P)\big)/\Gamma_{\text{total}}$ $\Gamma_4/\Gamma\times\Gamma_{15}^{\psi(2S)}/\Gamma^{\psi(2S)}$

| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|-----------------------|-----|------|--------------------------------------------|
| 4.3 ±0.4 OUR AVER | AGE | | | | |
| $4.58\pm0.40\pm0.50$ | 3679 | ¹² ABLIKIM | 10B | BES3 | $\psi(2S) \rightarrow \pi^0 \gamma X$ |
| $4.16 \pm 0.30 \pm 0.37$ | 1430 | ¹³ DOBBS | 08A | CLEO | $\psi(2S) \rightarrow \pi^0 \gamma \eta_C$ |

 $^{12}\,\mathrm{Not}$ independent of other branching fractions in ABLIKIM 10B.

13 Not independent of other branching fractions in DOBBS 08A.

$h_c(1P)$ REFERENCES

| ABLIKIM ADAMS | 10 B 09 | PRL 104 132002 PR D80 051106 | M. Ablikim et al. G.S. Adams et al. | (BES III Collab.) (CLEO Collab.) |
|------------------|------------|---------------------------------|----------------------------------------|-------------------------------------|
| DOBBS | 08A | PRL 101 182003 | S. Dobbs et al. | (CLEO Collab.) |
| ANDREOTTI | 05 B | PR D72 032001 | M. Andreotti et al. | (FNAL E835 Collab.) |
| ROSNER | 05 | PRL 95 102003 | J.L. Rosner et al. | (CLEO Collab.) |
| AULCHENKO | 03 | PL B573 63 | V.M. Aulchenko <i>et al.</i> | (KEDR Collab.) |
| ANTONIAZZI | 94 | PR D50 4258 | L. Antoniazzi et al. | (E705 Collab.) |
| ARMSTRONG | 93 B | PR D47 772 | T.A. Armstrong et al. | (FNAL E760 Collab.) |
| ARMSTRONG | 92 D | PRL 69 2337 | T.A. Armstrong et al. | (FNAL, FERR, GENO+) |
| BAGLIN | 86 | PL B171 135 | C. Baglin et al. | (LAPP CERN TORL STRB+) |



$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

See the Review on " $\psi(2S)$ and $\chi_{\mathcal{C}}$ branching ratios" before the $\chi_{c0}(1P)$ Listings.

$\chi_{c2}(1P)$ MASS

| VALUE (N | leV) | | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------|-------------|---------------|-----------|--------------------------|--------|-----------|---------------------------------------------|
| 3556.20 | ± 0.09 | OUR A | VERAGE | | | | |
| 3555.3 | \pm 0.6 | ± 2.2 | 2.5k | UEHARA | 80 | BELL | $\gamma \gamma \rightarrow hadrons$ |
| 3555.70 | \pm 0.59 | ± 0.39 | | ABLIKIM | 05 G | BES2 | $\psi(2S) \rightarrow \gamma \chi_{C2}$ |
| 3556.173 | 3± 0.123 | 3 ± 0.020 | | ANDREOTTI | 05 A | E835 | $p \overline{p} \rightarrow e^+ e^- \gamma$ |
| 3559.9 | ± 2.9 | | | EISENSTEIN | 01 | CLE2 | $e^+e^- \rightarrow$ |
| | | | | | | | $e^+e^-\chi_{c2}$ |
| 3556.4 | ± 0.7 | | | BAI | 99B | BES | $\psi(2S) \rightarrow \gamma X$ |
| 3556.22 | \pm 0.131 | 1 ± 0.020 | 585 | ¹ ARMSTRONG | 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| 3556.9 | \pm 0.4 | ± 0.5 | 50 | BAGLIN | 86B | SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| 3557.8 | \pm 0.2 | ± 4 | | ² GAISER | 86 | CBAL | $\psi(2S) \rightarrow \gamma X$ |
| 3553.4 | \pm 2.2 | | 66 | ³ LEMOIGNE | 82 | GOLI | 185 π^- Be \rightarrow |
| | | | | | | | $\gamma \mu^+ \mu^-$ A |
| 3555.9 | ± 0.7 | | | 4 OREGLIA | 82 | CBAL | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3557 | \pm 1.5 | | 69 | ⁵ HIMEL | 80 | MRK2 | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3551 | ± 11 | | 15 | BRANDELIK | 79B | DASP | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3553 | ± 4 | | | ⁵ BARTEL | 78B | CNTR | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 3553 | ± 4 | ± 4 | | ^{5,6} TANENBAUM | 78 | MRK1 | e^+e^- |
| 3563 | ± 7 | | 360 | ⁵ BIDDICK | 77 | CNTR | $e^+e^- \rightarrow \gamma X$ |
| • • • V | Ve do not | use the | following | data for averages, fit | s, lim | its, etc. | • • • |
| 3543 | ± 10 | | 4 | WHITAKER | 76 | MRK1 | $e^+e^- \rightarrow J/\psi 2\gamma$ |

 1 Recalculated by ANDREOTTI 05A, using the value of $\psi(2S)$ mass from AULCHENKO 03.

 $^3J/\psi(1S)$ mass constrained to 3097 MeV.

$\chi_{c2}(1P)$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|--------|------------------------|-----|------|----------------------------------------------|
| 1.98 ±0.11 OUR FIT 1.95 ±0.13 OUR AVI | | | | | |
| 1.915 ±0.188±0.013 | RAGE | | | | $p \overline{p} \rightarrow e^+ e^- \gamma$ |
| $1.96 \pm 0.17 \pm 0.07$ | 585 | ⁷ ARMSTRONG | 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| $\begin{array}{cc} 2.6 & +1.4 \\ -1.0 \end{array}$ | 50 | BAGLIN | 86B | SPEC | $\overline{p} p \rightarrow e^+ e^- X$ |
| $\begin{array}{ccc} 2.8 & +2.1 \\ -2.0 \end{array}$ | | ⁸ GAISER | 86 | CBAL | $\psi(2S) \rightarrow \gamma X$ |
| 7 Recalculated by A N | DREOTT | Π 05 Δ | | | |

Mode

$\chi_{c2}(1P)$ DECAY MODES

Fraction (Γ_i/Γ)

| | Mode | Fraction (1 ;/1) | Confidence level |
|-----------------|-------------------------------------------------------|-----------------------------------|---------------------|
| | Hadroni | c decays | |
| Γ ₁ | $2(\pi^{+}\pi^{-})$ | (1.10±0.11) % | |
| Γ_2 | , | (– / | |
| Γ ₃ | $^{ ho ho}_{\pi^+ \pi^- \pi^0 \pi^0}$ | (2.00±0.26) % | |
| Γ ₄ | $\rho^{+} \pi^{-} \pi^{0} + \text{c.c.}$ | (2.4 ±0.4) % | |
| Γ ₅ | $4\pi^0$ | $(1.21 \pm 0.17) \times 10$ | -3 |
| Γ ₆ | $K^{+}K^{-}\pi^{0}\pi^{0}$ | (2.2 ±0.5) × 10 | |
| Γ ₇ | $K^{+}\pi^{-}K^{0}\pi^{0}$ + c.c. | (1.51±0.22) % | |
| Γ ₈ | $\rho^{+} K^{-} K^{0} + \text{c.c.}$ | (4.5 ±1.4) × 10 | _3 |
| Г9 | $K^*(892)^0 K^+ \pi^- \rightarrow$ | (3.2 ±0.9) × 10 | _ |
| . 9 | $K^{+}\pi^{-}K^{0}\pi^{0} + c.c.$ | (512 2513) / 21 | |
| Γ_{10} | $K^*(892)^0 K^0 \pi^0 \to$ | $(4.2 \pm 0.9) \times 10$ | ₁ -3 |
| | $K^{+}\pi^{-}K^{0}\pi^{0}+\text{c.c.}$ | | |
| Γ_{11} | $K^*(892)^- K^+_0 \pi^0_0 \to$ | (4.1 ± 0.9) $\times 10$ | ₁ -3 |
| | $K^{+}\pi^{-}K^{0}\pi^{0}+c.c.$ | | |
| Γ_{12} | $K^*(892)^+K^0\pi^- \rightarrow$ | $(3.2 \pm 0.9) \times 10$ | ,-3 |
| | $K^{+}\pi^{-}K^{0}\pi^{0}$ + c.c. | | |
| Γ_{13} | $K^+K^-\eta\pi^0$ | ($1.4~\pm0.5$) \times 10 | _j -3 |
| Γ_{14} | $K^{+}K^{-}\pi^{+}\pi^{-}$ | $(9.1 \pm 1.1) \times 10$ | _j —3 |
| Γ_{15} | $K^{+} \frac{K^{-} \pi^{+} \pi^{-} \pi^{0}}{\pi^{0}}$ | (1.3 ± 0.4) % | |
| Γ_{16} | $K^{+}\overline{K}^{*}(892)^{0}\pi^{-}+\text{c.c.}$ | (2.3 ± 1.2) \times 10 | |
| Γ_{17} | $K^*(892)^0 \overline{K}^*(892)^0$ | $(2.5 \pm 0.5) \times 10$ | |
| Γ_{18} | $3(\pi^{+}\pi^{-})$ | ($8.6~\pm1.8~) \times 10$ | |
| Γ_{19} | $\phi\phi$ | $(1.14 \pm 0.12) \times 10$ | ₎ —3 |
| Γ_{20} | $\omega \omega$ | $(9.2 \pm 1.1) \times 10$ | _j -4 |
| Γ_{21} | $\omega \phi$ | | |
| Γ_{22} | $\pi\pi$ | $(2.43\pm0.13)\times10$ | ₎ —3 |
| Γ_{23} | $ ho^0\pi^+\pi^-$ | $(4.0 \pm 1.7) \times 10$ | |
| Γ_{24} | $\pi^+\pi^-\eta$ | $(5.2 \pm 1.4) \times 10$ | _j -4 |
| Γ ₂₅ | $\pi^+\pi^-\eta'$ | $(5.5 \pm 2.0) \times 10$ | _j -4 |
| Γ_{26} | $\eta\eta$ | (5.9 ± 0.5) $\times 10$ | ₎ -4 |
| Γ ₂₇ | K^+K^- | $(1.09\pm0.08)\times10$ | _j —3 |
| Γ ₂₈ | $K_S^0 K_S^0$ | (5.8 ± 0.5) $\times 10$ | |
| Γ_{29} | $\overline{K}^{0}K^{+}\pi^{-}+\text{c.c.}$ | $(1.40 \pm 0.20) \times 10$ | _j —3 |
| Γ_{30} | $K^+K^-\pi^0$ | (3.3 ± 0.8) $\times 10$ | _J -4 |
| Γ_{31} | $K^+K^-\eta$ | < 3.5 × 10 |) ⁻⁴ 90% |
| Γ_{32} | $\eta\eta'$ | < 6 × 10 | ₎ -5 90% |
| Γ_{33} | $\eta'\eta'$ | < 1.1 × 10 | |
| Γ ₃₄ | $\pi^{+}\pi^{-}K_{S}^{0}K_{S}^{0}$ | $(2.4 \pm 0.6) \times 10$ | _j —3 |
| Γ ₃₅ | $K^{+} K^{-} K^{0}_{S} K^{0}_{S}$ | < 4 × 10 |) ⁻⁴ 90% |
| Γ ₃₆ | $K^+ K^- K^+ K^-$ | $(1.78 \pm 0.22) \times 10$ | ₁ -3 |
| Γ ₃₇ | $K^+K^-\phi$ | $(1.55 \pm 0.33) \times 10$ | |
| Γ ₃₈ | ρ p | (7.2 ±0.4)×10 | |
| Γ ₃₉ | $p \overline{p} \pi^0$ | $(5.1 \pm 0.5) \times 10$ | ₀ -4 |
| Γ ₄₀ | p p η | (1.90±0.28) × 10 | |
| _ | $p \overline{p} \omega$ | (3.9 ±0.5) × 10 | |
| Γ_{42} | p p φ | (3.0 ±1.0)×10 | ₎ —5 |
| Γ ₄₃ | $p \overline{p} \pi^+ \pi^-$ | (1.32±0.34) × 10 | |
| Γ ₄₄ | $p \overline{p} \pi^0 \pi^0$ | (8.6 ±2.6) × 10 | |
| Γ ₄₅ | $p \overline{p} K^+ K^-$ (non-resonant) | (2.1 ±0.4) × 10 | ₎ -4 |
| Γ ₄₆ | $p\overline{p}K_S^0K_S^0$ | < 7.9 × 10 |) ⁻⁴ 90% |
| Γ ₄₇ | $p \overline{n} \pi^-$ | $(1.1 \pm 0.4) \times 10$ | |
| Γ ₄₈ | $\Lambda \overline{\Lambda}$ | $(1.86 \pm 0.27) \times 10^{-10}$ | |
| Γ ₄₉ | $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | < 3.5 × 10 | , -3 90% |
| Γ ₅₀ | $K^+ \overline{p} \Lambda + \text{c.c.}$ | (9.1 ±1.8) × 10 | |
| Γ ₅₁ | $K^{+} p \Lambda(1520) + \text{c.c.}$ | $(3.1 \pm 0.7) \times 10$ | |
| Γ ₅₂ | $\Lambda(1520) \overline{\Lambda}(1520)$ | (5.1 ±1.6) × 10 | |
| Γ ₅₃ | $\Sigma^0 \overline{\Sigma^0}$ | < 8 ×10 | |
| Γ ₅₄ | $\Sigma + \overline{\Sigma} -$ | < 7 × 10 | j−5 90% |
| 54 | | | /0 |

 $^{^2}$ Using mass of $\psi(2S)=3686.0\,\,{
m MeV}.$

 $^{^4}_-$ Assuming $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.

⁵ Mass value shifted by us by amount appropriate for $\psi(25)$ mass = 3686 MeV and $J/\psi(15)$ mass = 3097 MeV.

 $^{^{\}rm 6}\,{\rm From}$ a simultaneous fit to radiative and hadronic decay channels.

⁸Errors correspond to 90% confidence level; authors give only width range.

$\chi_{c2}(1P)$

 $\Gamma_{55} = \Xi^0 \overline{\Xi}^0$

| | <u> </u> | (1.55 ± 0.3 | $(55) \times 10^{-4}$ | |
|-----------------|------------------------------------|------------------|-----------------------|-----|
| Γ_{57} | $J/\psi(1S) \pi^+ \pi^- \pi^0$ | < 1.5 | % | 90% |
| | | Radiative decays | | |
| Γ_{58} | $\gamma J/\psi(1S) \gamma \rho^0$ | (19.5 ±0.8 | 3)% | |
| Γ_{59} | $\gamma \rho^0$ | < 2.1 | $\times 10^{-5}$ | 90% |
| Γ ₆₀ | $\gamma \omega$ | < 6 | $\times 10^{-6}$ | 90% |
| Γ_{61} | $\gamma \phi$ | < 8 | $\times 10^{-6}$ | 90% |
| Γ ₆₂ | $\gamma \gamma$ | (2.59±0.1 | $(6) \times 10^{-4}$ | |
| | | | | |

< 1.1

 $\times\,10^{-4}$

90%

CONSTRAINED FIT INFORMATION

A multiparticle fit to $\chi_{c1}(1P),~\chi_{c0}(1P),~\chi_{c2}(1P),~$ and $\psi(2S)$ with 4 total widths, a partial width, 25 combinations of partial widths obtained from integrated cross section, and 84 branching ratios uses 223 measurements to determine 49 parameters. The overall fit has a $\chi^2=312.2$ for 174 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta \rho_i \delta \rho_j \right\rangle / (\delta \rho_i \cdot \delta \rho_j)$, in percent, from the fit to parameters ρ_i , including the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$.

| <i>x</i> ₁₄ | 17 | | | | | | | | | |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-----------------|------------------------|------------------------|-----------------|
| <i>x</i> ₁₆ | 4 | 22 | | | | | | | | |
| <i>x</i> ₁₇ | 10 | 8 | 2 | | | | | | | |
| <i>X</i> ₁₉ | 12 | 11 | 2 | 6 | | | | | | |
| x ₂₂ | 23 | 20 | 4 | 12 | 27 | | | | | |
| <i>x</i> ₂₃ | 20 | 4 | 1 | 2 | 3 | 5 | | | | |
| <i>X</i> 26 | 13 | 12 | 3 | 7 | 17 | 32 | 3 | | | |
| <i>x</i> ₂₇ | 18 | 16 | 3 | 9 | 20 | 39 | 4 | 24 | | |
| <i>x</i> ₂₈ | 17 | 15 | 3 | 9 | 18 | 34 | 4 | 21 | 25 | |
| <i>x</i> ₂₉ | 9 | 8 | 2 | 5 | 10 | 19 | 2 | 12 | 14 | 13 |
| X36 | 12 | 10 | 2 | 6 | 11 | 22 | 3 | 13 | 16 | 14 |
| X38 | 7 | 6 | 1 | 4 | 1 | 1 | 2 | 0 | 1 | 2 |
| x ₄₈ | 8 | 7 | 2 | 4 | 10 | 20 | 2 | 12 | 14 | 13 |
| X ₅₈ | 28 | 24 | 5 | 14 | 30 | 59 | 6 | 36 | 44 | 39 |
| <i>x</i> ₆₂ | -18 | -15 | -3 | -9 | 1 | 3 | -5 | 3 | 0 | -2 |
| Γ | -25 | -21 | -5 | -13 | -19 | -36 | -6 | -21 | -27 | -25 |
| | x_1 | <i>x</i> ₁₄ | <i>X</i> ₁₆ | <i>x</i> ₁₇ | <i>x</i> ₁₉ | <i>x</i> ₂₂ | x ₂₃ | <i>x</i> ₂₆ | <i>x</i> ₂₇ | x ₂₈ |
| <i>x</i> ₃₆ | 8 | | | | | | | | | |
| X38 | 1 | 2 | | | | | | | | |
| X48 | 7 | 8 | 0 | | | | | | | |
| <i>X</i> ₅₈ | 21 | 25 | -11 | 22 | | | | | | |
| x ₆₂ | 0 | -3 | 27 | 2 | 9 | | | | | |
| Γ | -13 | -17 | -50 | -13 | -49 | -48 | | | | |
| | <i>x</i> ₂₉ | x ₃₆ | <i>x</i> 38 | <i>x</i> ₄₈ | <i>x</i> ₅₈ | x ₆₂ | | | | |

$\chi_{c2}(1P)$ PARTIAL WIDTHS

$\chi_{c2}(1P) \Gamma(i)\Gamma(\gamma J/\psi(1S))/\Gamma(total)$

| $\Gamma(p\overline{p}) \times \Gamma(\gamma J/\psi(1S))/$ | $\Gamma_{	ext{total}}$ | | Γ ₃₈ Γ ₅₈ /Γ |
|-------------------------------------------------------------------------------|----------------------------------------------------|---------|---------------------------------------------|
| VALUE (eV) | DO CUMENT ID | TECN | COMMENT |
| 27.7±1.4 OUR FIT | | | |
| 27.5 ± 1.5 OUR AVERAGE | | | |
| $27.0 \pm 1.5 \pm 1.1$ | ⁹ ANDREOTTI 05A | E835 | $p \overline{p} \rightarrow e^+ e^- \gamma$ |
| $27.7 \pm 1.5 \pm 2.0$ | 9,10 ARMSTRONG 92 | E760 | $\overline{p}p \rightarrow e^+e^-\gamma$ |
| 36 ±8 | ⁹ BAGLIN 86B | SPEC | $\overline{p}p \rightarrow e^+e^-X$ |
| $^9\mathrm{Calculated}$ by us using B($^{10}\mathrm{Recalculated}$ by ANDREC | $J/\psi(1S) ightarrow e^+ e^-) = 0.0$ TTI 05A. | 593 ± 0 | .0010. |

| $\Gamma(\gamma\gamma) \times \Gamma(\gamma)$ | $1/\psi(15))/1$ | total | | Γ ₆₂ Γ ₅₈ /Γ |
|----------------------------------------------|-----------------|---------------------------|----------|---------------------------------------|
| VALUE (eV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 100 ± 6 OUR FI | T | | | |
| 117± 10 OUR A | /ERAGE | | | |
| 111 ± 12 ± 9 | 147 ± 15 | ¹¹ DOBBS | 06 CLE3 | 10.4 $e^+e^- \rightarrow$ |
| | | | | $e^+e^-\chi_{c2}$ |
| $114 \pm 11 \pm 9$ | 136 ± 13.3 | 11,12 ABE | 02T BELL | $e^+e^- \rightarrow e^+e^- \chi_{c2}$ |
| $139 \pm 55 \pm 21$ | | ^{11,13} ACCIARRI | 99E L3 | $e^+e^- \rightarrow e^+e^-\chi_{c2}$ |
| $242 \pm 65 \pm 51$ | | ^{11,14} ACKER,K | 98 OPAL | $e^+e^- \rightarrow e^+e^-\chi_{C2}$ |
| 150± 42± 36 | | 11,15 DOMINICK | 94 CLE2 | $e^+e^- \rightarrow e^+e^-\chi_{c2}$ |
| $470 \pm 240 \pm 120$ | | 11,16 BAUER | 93 TPC | $e^+e^- \rightarrow e^+e^- \chi_{c2}$ |
| | | | | |

 11 Calculated by us using B($J/\psi \to \ell^+\ell^-$) = 0.1187 \pm 0.0008. 12 All systematic errors added in quadrature.

13 The value for $\Gamma(\chi_{C2} \to \gamma \gamma)$ reported in ACCIARRI 99E is derived using B($\chi_{C2} \to \gamma \gamma$)/ $(15) \times B(J/\psi(15)) \to \ell^+\ell^-) = 0.0162 \pm 0.0014$.

¹⁴ The value for $\Gamma(\chi_{c2} \to \gamma \gamma)$ reported in ACKERSTAFF, K 98 is derived using B($\chi_{c2} \to \gamma J/\psi(1s)$) = 0.135 \pm 0.011 and B($J/\psi(1s) \to \ell^+\ell^-$) = 0.1203 \pm 0.0038.

15 The value for $\Gamma(\chi_{c2} \to \gamma \gamma)$ reported in DOMINICK 94 is derived using $B(\chi_{c2} \to \gamma J/\psi(1S)) = 0.135 \pm 0.011$, $B(J/\psi(1S) \to e^+e^-) = 0.0627 \pm 0.0020$, and $B(J/\psi(1S) \to \mu^+\mu^-) = 0.0597 \pm 0.0025$.

 16 The value for $\Gamma(\chi_{C2}\to \gamma\gamma)$ reported in BAUER 93 is derived using B($\chi_{C2}\to \gamma J/\psi(1S))=0.135\pm0.011,\ B(J/\psi(1S)\to e^+e^-)=0.0627\pm0.0020,\ and\ B(J/\psi(1S)\to \mu^+\mu^-)=0.0597\pm0.0025.$

$\chi_{c2}(1P) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)$ |)/F _{total} | | | Γ ₂₂ Γ ₆₂ / | Γ |
|----------------------------------------------|----------------------|------------------------|---------|--------------------------------------------|---|
| VALUE (eV) | EVTS | DOCUMENT ID | TECN | COMMENT | |
| 1.24±0.08 OUR F | IT | | <u></u> | | |
| 1.18±0.25 OUR A | VERAGE | | | | |
| | | | | 10.6 $e^+e^- \rightarrow e^+e^-\pi^0\pi^0$ | |
| $1.14 \pm 0.21 \pm 0.17$ | 54 ± 10 | ¹⁸ NAKAZAWA | 05 BELL | 10.6 $e^+e^- \rightarrow$ | |
| | | | | a+ a- m+ m- | |

 17 We multiplied the measurement by 3 to convert from $\pi^0\pi^0$ to $\pi\pi$. Interference with

the continuum included. 18 We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$.

| $\Gamma(\eta\eta) \times \Gamma(\gamma\gamma)/$ | Γ _{total} | | | | | $\Gamma_{26}\Gamma_{62}/\Gamma$ |
|-------------------------------------------------|--------------------|----------------------|-----|------|--------------------------|---------------------------------|
| VALUE (eV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $0.53 \pm 0.22 \pm 0.09$ | 8 | ¹⁹ UEHARA | 10A | BELL | 10.6 $e^+e^ \rightarrow$ | $e^+e^-\eta\eta$ |
| ¹⁹ Interference with | the cont | inuum not included. | | | | |

 $\frac{\Gamma(\rho^0\pi^+\pi^-)\times\Gamma(\gamma\gamma)/\Gamma_{\text{total}}}{\frac{\text{VALUE}\,(\text{eV}\,)}{2.0\pm0.9\,\,\text{OUR}\,\,\text{FIT}}} \xrightarrow{\text{EVTS}} \frac{\text{DOCUMENT ID}}{\frac{\text{DOCUMENT ID}}{\text{TECN}}} \xrightarrow{\text{TECN}} \frac{\text{COMMENT}}{\text{COMMENT}}$

2.0±0.9 OUR FIT 3.2±1.9±0.5 986±578 UEHARA 08 BELL $\gamma\gamma \to \chi_{c2} \to 2(\pi^+\pi^-)$ $\Gamma(\rho\rho) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ $\Gamma_2\Gamma_{62}/\Gamma$

7.8 90 <598 OEHARA 08 BELL $\gamma \gamma \rightarrow \chi_{C2} \rightarrow 2(\pi^+\pi^-)$ $\Gamma(K^+K^-\pi^+\pi^-) \times \Gamma(\gamma \gamma)/\Gamma_{total} \qquad \qquad \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma_{14}\Gamma_{62}/\Gamma_{total} = \Gamma$

4.42±0.42±0.53 780 ± 74 UEHARA 08 BELL $\gamma \gamma \rightarrow \chi_{c2} \rightarrow K^+ K^- \pi^+ \pi^-$

 $\chi_{c2}(1P)$

| $\Gamma(\phi\phi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ VALUE (eV) EVTS | DOCUMENT ID | TE | ON COMMENT | Γ ₁₉ Γ ₆₂ /Γ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------|------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| 0.58±0.06 OUR FIT 0.58±0.18±0.16 26.5±8.1 | | | | $c2 \rightarrow 2(K^+K^-)$ |
| Xc2 | (1 <i>P</i>) BRANCH | NG RA | TIOS | |
| | HADRONIC D | ECAYS | . —— | |
| $\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ $\frac{VALUE}{0.0110 \pm 0.0011}$ OUR FIT | <u>DO CUMENT I</u> | D | | Γ ₁ /Γ |
| $\Gamma(ho^0\pi^+\pi^-)/\Gamma(2(\pi^+\pi^-))$ VALUE 0.36±0.15 OUR FIT | <u>DO CUMENT</u> | | TECN COMM | |
| 0.31 \pm 0.17 $\Gamma(\pi^{+}\pi^{-}\pi^{0}\pi^{0})/\Gamma_{\text{total}}$ VALUE (%) EVTS | | | MRK1 $\psi(2S)$ | Гз/Г |
| $\begin{array}{c} \underline{\text{VALUE}(\%)} & \underline{\text{EVTS}} \\ \textbf{2.00\pm0.25\pm0.08} & 903.5 \\ 21 \text{ HE 0Bs reports } 1.87 \pm 0.0 \\ \pi^+\pi^-\pi^0\pi^0)/\Gamma_{\text{total}}] \times [\text{B} \\ (9.33\pm0.14\pm0.61)\times10^{-2} \\ = (8.72\pm0.34)\times10^{-2}. \end{array}$ | $7\pm0.22\pm0.13$ $(\psi(2S) ightarrow\gamma\chi_{C2})$, which we rescale | % from a 1P))] assi to our be eir experii | measurement u ming $\mathrm{B}(\psi(2S))$ est value $\mathrm{B}(\psi(2S))$ | $0 \rightarrow \gamma \chi_{C2}(1P)) = 2S \rightarrow \gamma \chi_{C2}(1P)$ |

 22 HE 08B reports $2.23\pm0.11\pm0.32\pm0.16$ % from a measurement of $[\Gamma(\chi_{C2}(1P)\to\rho^+\pi^-\pi^0+c.c.)/\Gamma_{\rm total}]\times[B(\psi(2S)\to\gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

²³ Calculated by us. We have added the values from HE 08B for $\rho^+\pi^-\pi^0$ and $\rho^-\pi^+\pi^0$ decays assuming uncorrelated statistical and fully correlated systematic uncertainties.

0.35) \times 10 $^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{c2}(1P)) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. $\Gamma(K^{+}K^{-}\pi^{0}\pi^{0})/\Gamma_{total}$ VALUE (%)

EVTS

DOCUMENT ID

TECN

COMMENT

 26 HE 08B reports $1.41\pm0.11\pm0.16\pm0.10$ % from a measurement of $[\Gamma(\chi_{C2}(1P)\to K^+\pi^-\,K^0\pi^0+c.c.)/\Gamma_{total}]\times[B(\psi(2S)\to \gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 27 HE 08B reports $0.42\pm0.11\pm0.06\pm0.03$ % from a measurement of $[\Gamma(\chi_{c2}(1P)\to\rho^+\,K^-\,K^0+~c.c.)/\Gamma_{\rm total}]\times[B(\psi(2S)\to~\gamma\chi_{c2}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{c2}(1P))=(9.33\pm0.14\pm0.61)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{c2}(1P))=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 28 HE 08B reports $0.30\pm0.07\pm0.04\pm0.02$ % from a measurement of $[\Gamma(\chi_{C2}(1P)\to K^*(892)^0\,K^+\pi^-\to K^+\pi^-\,K^0\pi^0+{\rm c.c.})/\Gamma_{\rm total}]\times [B(\psi(2S)\to \gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times 10^{-2}$, which we rescale to our best value $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(8.72\pm0.34)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(K^*(892)^0 K^0 \pi^0$ | $\rightarrow K^{+}$ | $\pi^- K^0 \pi^0 +$ | - c.c.)/Γ _{tota} | ai | | Γ_{10}/Γ |
|--------------------------------------------------------------------------------------|--------------------------------------|---------------------------------|------------------------------|-----------------------|-----------------------------------------|--------------------------------------|
| VALUE (%) | EVTS | DO CUM. | ENT ID | TECN | COMMENT | |
| $0.42 \pm 0.09 \pm 0.02$ | 63.0 | ²⁹ HE | 08в | CLEO | $e^+e^- \to$ | $_{\gammah^+h^-h^0h^0}$ |
| ²⁹ HE 08B reports 0 κ*(892) ⁰ κ ⁰ π ⁰ | $\rightarrow K^+\pi^-$ | $- \kappa^0 \pi^0 + c$ | .c.)/F _{total}) | < [Β(ψ(2 | $(2S) \rightarrow \gamma \chi_{C}$ | 2(1P))] assum- |
| ing B $(\psi(2S) \rightarrow$ | | | | | | |
| best value $B(\psi(2$ experiment's error | $S) \rightarrow \gamma$ rand our S | $\chi_{C2}(1P)) =$ second error | (8.72 ± 0.3) is the system | $4) 	imes 10^{\circ}$ | ^{—2} . Our fir r from using | st error is their our best value. |

 $\Gamma(K^*(892)^- K^+ \pi^0 \to K^+ \pi^- K^0 \pi^0 + \text{c.c.})/\Gamma_{\text{total}} \qquad \Gamma_{11}/\Gamma_{\text{total}} \qquad$

0.41 \pm 0.09 \pm 0.02 51.1 30 HE 08B CLEO e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0 30 HE 08B reports 0.38 \pm 0.07 \pm 0.04 \pm 0.03 % from a measurement of $[\Gamma(\chi_{C2}(1P) \rightarrow V)]$

 30 HE 08B reports $0.38\pm0.07\pm0.04\pm0.03$ % from a measurement of $[\Gamma(\chi_{C2}(1P)\to K^*(892)^-K^+\pi^0\to K^+\pi^-K^0\pi^0+\mathrm{c.c.})/\Gamma_{total}]\times[B(\psi(2S)\to \gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times10^{-2},$ which we rescale to our best value $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(8.72\pm0.34)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

 31 HE 08B reports 0.30 \pm 0.07 \pm 0.04 \pm 0.02 % from a measurement of $[\Gamma(\chi_{C2}(1P)\to K^*(892)^+ \, K^0 \, \pi^- \to K^+ \pi^- \, K^0 \, \pi^0 + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S)\to \gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(9.33\pm 0.14\pm 0.61)\times 10^{-2},$ which we rescale to our best value $B(\psi(2S)\to \gamma\chi_{C2}(1P))=(8.72\pm 0.34)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

 32 HE 08B reports $0.13\pm0.04\pm0.02\pm0.01$ % from a measurement of $[\Gamma(\chi_{C2}(1P)\to K^+K^-\eta\pi^0)/\Gamma_{\rm total}]\times [B(\psi(2S)\to\gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times 10^{-2},$ which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(8.72\pm0.34)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\frac{\Gamma(K^+K^-\pi^+\pi^-)/\Gamma_{\text{total}}}{\text{9.1 \pm 1.1 OUR FIT}} \qquad \frac{\text{DOCUMENT ID}}{\text{DOCUMENT ID}}$

 $\Gamma(K^+\overline{K}^*(892)^0\pi^- + \text{c.c.})/\Gamma_{\text{total}}$

<u>VALUE (units 10⁻⁴)</u> <u>DOCUMENT ID</u>

23±12 OUR FIT

 $\Gamma(K^*(892)^0\overline{K}^*(892)^0)/\Gamma_{total}$ VALUE (units 10^{-3})

DOCUMENT ID

 VALUE (units 10⁻³)
 DOCUMENT ID

 2.5 ± 0.5 OUR FIT

 $\Gamma(3(\pi^+\pi^-))/\Gamma_{total}$ Γ_{18}/Γ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT

8.6±1.8 OUR EVALUATION 8.6±1.8 OUR AVERAGE8.6±0.9±1.6
8.7±5.9±0.4

Treating systematic error as correlated.

Treating systematic error as correlated.

BES $\psi(25) \rightarrow \gamma \chi_{C2}$ MRK1 $\psi(25) \rightarrow \gamma \chi_{C2}$

 33 Rescaled by us using B($\psi(25) \to \gamma \chi_{C2}) = (8.3 \pm 0.4)\%$ and B($\psi(25) \to J/\psi(1S) \, \pi^+ \, \pi^-) = (32.6 \pm 0.5)\%$. Multiplied by a factor of 2 to convert from $K_S^0 \, K^+ \, \pi^-$ to $K^0 \, K^+ \, \pi^-$ decay.

 $\Gamma(\phi\phi)/\Gamma_{total}$ $\Gamma_{19}/\Gamma_{VALUE\,(units\,10^{-3})}$ DOCUMENT ID

1.14±0.12 OUR FIT

 $\Gamma(\omega\omega)/\Gamma_{
m total}$ Γ_{20}/Γ

 VALUE (units 10⁻³)
 EVTS
 DOCUMENT ID
 TECN
 COMMENT

 0.9±0.11
 0.04
 762
 34 ABLIKIM
 11k BES3
 ψ(2S) → γ hadrons

 1.9±0.6±0.1
 2.77±7.4
 35 ABLIKIM
 0.5N BES2
 ψ(2S) → γ γ α → γ 6π

1.09 ± 0.6 ± 0.1 27.7 ± 7.4 35 ABLIKIM 05N BES2 $\psi(25) \rightarrow \gamma \chi_{c2} \rightarrow \gamma 6\pi$ 34 ABLIKIM 11κ reports (8.9 ± 0.3 ± 1.1) × 10⁻⁴ from a measurement of [Γ($\chi_{c2}(1P) \rightarrow \omega \omega$)/[rota]] × [B[$\psi(2S) \rightarrow \gamma \chi_{c2}(1P)$] assuming B[$\psi(2S) \rightarrow \gamma \chi_{c2}(1P)$] = (8.74 ±

"ABLIKIM 11k reports $(8.9\pm0.3\pm1.1)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{C2}(1P)\to\omega\omega)/\Gamma_{\rm total}]\times[B(\psi(2S)\to\gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(8.74\pm0.35)\times10^{-2}$, which we rescale to our best value $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

35 ABLIKIM 05N reports $[\Gamma(\chi_{c2}(1P) \to \omega\omega)/\Gamma_{total}] \times [B(\psi(2S) \to \gamma\chi_{c2}(1P))] = (0.165 \pm 0.044 \pm 0.032) \times 10^{-3}$ which we divide by our best value $B(\psi(2S) \to \gamma\chi_{c2}(1P)) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\chi_{c2}(1P)$

| $\Gamma(\omega\phi)/\Gamma_{ m total}$ | | Γ ₂₁ /Γ | $\Gamma(K^+K^-\eta)/\Gamma_{total}$ | Г ₃₁ /Г |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁵) CL% DC | CUMENT ID TECN | COMMENT | VALUE (units 10 ⁻³) CL% DOCUMENT ID | TECN COMMENT |
| <2.0 90 36 AE $_{36}$ ABLIKIM 11 κ reports < 2 × 10 $^{-5}$ f × $[{\rm B}(\psi(25) \to \gamma \chi_{\rm C2}(1P))]$ assuming which we rescale to our best value E | rom a measurement of [Γ () $	ext{ng B}(\psi(2S) ightarrow \gamma \chi_{C2}(1P)$ | $) = (8.74 \pm 0.35) \times 10^{-2},$ | <0.35 90 ⁴⁵ ATHAR 0 45 ATHAR 0 7 reports $< 0.33 \times 10^{-3}$ from a measure $\Gamma_{\text{total}} \times \text{B}(\psi(2S) \rightarrow \gamma \chi_{\text{C2}}(1P)) $ assuming B $0.14 \pm 0.61) \times 10^{-2}$, which we rescale to our be 8.72×10^{-2} . | $\gamma(\psi(2S) \rightarrow \gamma \chi_{C2}(1P)) = (9.33 \pm$ |
| $\Gamma(\pi\pi)/\Gamma_{total}$ | | Γ ₂₂ /Γ | $\Gamma(\eta\eta')/\Gamma_{\text{total}}$ | Г ₃₂ /Г |
| VALUE (units 10 ⁻³) <u>DC</u> 2.43±0.13 OUR FIT | CUMENT ID | | <u>VALUE (units 10⁻⁴)</u> <u>CL%</u> <u>EVTS</u> <u>DOCUMENT ID</u> <0.6 90 3.3 ± 8.0 46 ASNER | $\begin{array}{ccc} & \underline{TECN} & \underline{COMMENT} \\ & 09 & \text{CLEO} & \psi(2S) \rightarrow \gamma \eta \eta' \end{array}$ |
| $\Gamma(ho^0\pi^+\pi^-)/\Gamma_{ m total}$ | | Γ ₂₃ /Γ | • • We do not use the following data for averages, | fits, limits, etc. • • • |
| <u>VALUE (units 10⁻⁴)</u> <u>DC</u> 40±17 OUR FIT | CUMENT ID | | <2.5 90 47 ADAMS 46 ASNER 09 reports $<$ 0.6 \times 10 ⁻⁴ from a measureme [B($\psi(2S) \rightarrow \gamma \chi_{C2}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma$ | 07 CLEO $\psi(2S) \rightarrow \gamma \chi_{C2}$ ent of $[\Gamma(\chi_{C2}(1P) \rightarrow \eta \eta')/\Gamma_{\text{total}}] \times$ |
| $\Gamma(\pi^+\pi^-\eta)/\Gamma_{\text{total}}$ VALUE (units 10^{-3}) CL% DC | CUMENT ID TECN | Г ₂₄ /Г | 10^{-2} , which we rescale to our best value B($\psi(2S)$ 47 Superseded by ASNER 09. ADAMS 07 reports - | $ \rightarrow \gamma \chi_{\rm C2}(1P)) = 8.72 \times 10^{-2}. $ < 2.3 × 10 ⁻⁴ from a measurement |
| 0.52±0.14±0.02 37 AT • • • We do not use the following data | HAR 07 CLEO for averages, fits, limits, | | of $[\Gamma(\chi_{c2}(1P) \to \eta \eta')/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{c2}(1P)) = 0.0933 \pm 0.0014 \pm 0.0061$, which we $\gamma \chi_{c2}(1P)) = 8.72 \times 10^{-2}$. | $\gamma\chi_{C2}(1P))]$ assuming $\mathrm{B}(\psi(2S) ightarrow \mathrm{rescale}$ to our best value $\mathrm{B}(\psi(2S) ightarrow$ |
| $^{37}\text{ATHAR}$ 07 reports ($\text{0.49}\pm\text{0.12}\pm\text{0}$ | $.06) 	imes 10^{-3}$ from a measu | | $\Gamma(\eta'\eta')/\Gamma_{total}$ | Г ₃₃ /Г |
| $\begin{array}{ll} \pi^+\pi^-\eta)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to (9.33\pm0.14\pm0.61)\times 10^{-2}, \text{ which } v = (8.72\pm0.34)\times 10^{-2}. \text{ Our first } \epsilon \\ = (8.72\pm0.34)\times 10^{-2}. \text{ Our first } \epsilon \\ \text{is the systematic error from using or } 38\text{ABLIKIM 06R reports} < 1.7\times 10^{-3} \\ \Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{c2}(1P))] \\ 10^{-2}, \text{ which we rescale to our best} \\ \Gamma\left(\pi^+\pi^-\eta'\right)/\Gamma_{\text{total}} \\ \text{VALUE (units } 10^{-3}) \end{array}$ | we rescale to our best valuerror is their experiment's ir best value. From a measurement of [I assuming $\mathrm{B}(\psi(2\mathrm{S}) 	o \gamma \mathrm{value} \ \mathrm{B}(\psi(2\mathrm{S}) 	o \gamma \chi_{c2})$ | e B($\psi(2S) \to \gamma \chi_{C2}(1P)$) error and our second error | VALUE (units 10^{-4}) CL% EVTS 48 ASNER • • • We do not use the following data for averages, <3.3 90 49 ADAMS 48 ASNER 09 reports < 1.0×10^{-4} from a measurem × [B(ψ(2S) → $\gamma \chi_{c2}(1P)$)] assuming B(ψ(2S) → 10^{-2} , which we rescale to our best value B(ψ(2S) 49 Superseded by ASNER 09. ADAMS 07 reports of [Γ($\chi_{c2}(1P)$) = $0.0933 \pm 0.0014 \pm 0.0061$, which we | 07 CLEO $\psi(2\mathrm{S}) \rightarrow \gamma \chi_{c2}$ ent of $[\Gamma(\chi_{c2}(1P) \rightarrow \eta'\eta')/\Gamma_{\mathrm{total}}]$ $\gamma \chi_{c2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times \rightarrow \gamma \chi_{c2}(1P)) = 8.72 \times 10^{-2}.$ $< 3.1 \times 10^{-4}$ from a measurement |
| 0.55±0.20±0.02 39 AT | | $\overline{\psi(2S) \rightarrow \gamma h^+ h^- h^0}$ | $\gamma \chi_{C2}(17) = 0.0335 \pm 0.0014 \pm 0.0001$, which we $\gamma \chi_{C2}(1P)) = 8.72 \times 10^{-2}$. | rescale to our best value $B(\psi(25) \rightarrow$ |
| $\pi^+\pi^-\eta')/\Gamma_{\text{total}} \times [B(\psi(25) \rightarrow (9.33 \pm 0.14 \pm 0.61) \times 10^{-2}]$, which $v = (8.72 \pm 0.34) \times 10^{-2}$. Our first e is the systematic error from using of $\Gamma(\eta\eta)/\Gamma_{\text{total}}$ NALUE (units 10^{-4}) DC $S.9 \pm 0.5$ OUR FIT | we rescale to our best valu error is their experiment's | $e B(\psi(2S) \rightarrow \gamma \chi_{C2}(1P))$ | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 050 BES2 $\psi(2S) \rightarrow \gamma \chi_{C2}$ $-K_S^0 K_S^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \text{which we divide by our best value}]$ Our first error is their experiment's |
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | | Г ₂₇ /Г | $\Gamma(K^+K^-K^0_5K^0_5)/\Gamma_{total}$ VALUE (units 10^{-4}) CL% EVTS DOCUMENT II | Γ ₃₅ /Γ |
| 1.09±0.08 OUR FIT $\Gamma(K_S^0 K_S^0)/\Gamma_{\text{total}}$ | CUMENT ID | Γ ₂₈ /Γ | $\mathbf{<4}$ 90 2.3 ± 2.2 51 ABLIKIM $\mathbf{^{51}}$ ABLIKIM 050 reports $\mathbf{[\Gamma(\chi_{C2}(1P) \rightarrow K^+K^-) \gamma_{C2}(1P))]} < 3.5 \times 10^{-5}$ which we divide by our property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of | 050 BES2 $e^+e^- \rightarrow \chi_{C2} \gamma$ $- \kappa_S^0 \kappa_S^0)/\Gamma_{\text{total}}] \times [B(\psi(2S)] \rightarrow$ |
| | CUMENT ID | 25, | $= 8.72 \times 10^{-2}$. | |
| $\Gamma(K_S^0 K_S^0)/\Gamma(\pi\pi)$ | | Γ ₂₈ /Γ ₂₂ | $\Gamma(K^+K^-K^+K^-)/\Gamma_{\text{total}}$ <u>VALUE (units 10⁻³)</u> <u>DOCUMENT ID</u> | Г ₃₆ /Г — |
| | CUMENT ID TECN | COMMENT | 1.78 \pm 0.22 OUR FIT $\Gamma(K^+K^-\phi)/\Gamma_{ m total}$ | Г ₃₇ /Г |
| • • We do not use the following data | - | | $VALUE$ (units 10^{-3}) EVTS DOCUMENT ID | TECN COMMENT |
| $\begin{array}{ll} 0.27 \;\; \pm 0.07 \;\; \pm 0.04 & 40,41 \;\; \mathrm{CH} \\ ^{40} \mathrm{Using} \; \Gamma(\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\mathrm{total}} \;\; \mathrm{from} \; \mathrm{th} \\ \;\; \mathrm{by} \;\; 3/2 \; \mathrm{to} \;\; \mathrm{convert} \;\; \mathrm{to} \;\; \pi\pi. \\ ^{41} \;\; \mathrm{Not} \;\; \mathrm{independent} \;\; \mathrm{from} \;\; \mathrm{other} \;\; \mathrm{measur} \end{array}$ | he $\pi^+\pi^-$ measurement o | $e^+e^- ightarrowe^+e^-\chi_{C2}$ f NA KA ZAWA 05 rescaled | | GET BES2 $\psi(2S) \rightarrow \gamma 2K^{+} 2K^{-}$ From a measurement of $[\Gamma(\chi_{C2}(1P) \rightarrow \chi_{C2}(1P))]$ The suming $[\Psi(2S) \rightarrow \chi_{C2}(1P)] = \chi_{C2}(1P)$ |
| | CUMENT ID TECN | Γ ₂₈ /Γ ₂₇ <u>COMMENT</u> | $(8.72 \pm 0.4) \times 10^{-2}$. Our first error is their experthe systematic error from using our best value. | riment's error and our second error is |
| 0.53±0.05 OUR FIT • • • We do not use the following data | | | Γ(pp̄)/Γ _{total} <u>VALUE</u> (units 10 ⁻⁴) <u>DOCUMENT ID</u> | Г ₃₈ /Г |
| $0.70\pm0.21\pm0.12$ 42,43 CF 42 Using $\Gamma(K^+K^-)$ \times $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ | from NAKAZAWA 05. | $e^+e^- \rightarrow e^+e^-\chi_{C2}$ | 0.72±0.04 OUR FIT | |
| 43 Not independent from other measur $\Gamma(K^+K^-\pi^0)/\Gamma_{	ext{total}}$ | ements. | Γ ₃₀ /Γ | $\Gamma(ho \overline{ ho} \pi^0)/\Gamma_{	ext{total}}$ VALUE (units 10^{-3}) DOCUMENT ID | Г ₃₉ /Г тесм <u>сомме</u> нт |
| VALUE (units 10 ⁻³) DC | | COMMENT | | 0 CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ |
| $\begin{array}{ll} \textbf{0.33\pm0.08\pm0.01} & 44 \text{ AT} \\ 44 \text{ ATHAR 07 reports } (0.31\pm0.07\pm0 \\ \kappa^+ \ \kappa^- \pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to (9.33\pm0.14\pm0.61)\times10^{-2}, \text{ which } v = (8.72\pm0.34)\times10^{-2}. \text{ Our first } e \text{ is the systematic error from using ot} \end{array}$ | $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.04) \times 10^{-3}$ from a measure $(0.0$ | $(\psi(2S) \rightarrow \gamma \chi_{C2}(1P)) =$ e B $(\psi(2S) \rightarrow \gamma \chi_{C2}(1P))$ | 0.47 \pm 0.10 \pm 0.02 54 ATHAR 0 53 ONYISI 10 reports $(4.83 \pm 0.25 \pm 0.35 \pm 0.31)$ $[\Gamma(\chi_{c2}(1P) \rightarrow p \overline{p} \pi^0)/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \chi_{c2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2}$, which we $\gamma_{c2}(1P) = (8.72 \pm 0.34) \times 10^{-2}$. Our first errosecond error is the systematic error from using our 54 ATHAR 07 reports $(0.44 \pm 0.08 \pm 0.05) \times 10^{-3}$ from $p \overline{p} \pi^0 / \Gamma_{total} \times [B(\psi(2S) \rightarrow \chi_{c2}(1P))]$ ass | $\begin{array}{l} \gamma\chi_{C2}(1P))] \ \ \text{assuming} \ \ \mathbf{B}(\psi(2S) \to \\ \ \ \text{erescale to our best value} \ \ \mathbf{B}(\psi(2S) \to \\ \ \ \text{or is their experiment's error and our best value.} \end{array}$ |

 $p \overline{p} \pi^0 / \Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{c2}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{c2}(1P)) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 73 Uses B($\psi(2S)\to \gamma\chi_{C2}\to \gamma\gamma J/\psi)$ from ADAM 05A and B($\psi(2S)\to \gamma\chi_{C2})$ from ATHAR 04.

 $v_{\alpha}(1P)$

| | $\chi_{c2}(1P)$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\rho \overline{\rho} \eta)/\Gamma_{\text{total}}$ Γ_{40}/Γ | $\Gamma(\Lambda \overline{\Lambda} \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{49}/Γ |
| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT |
| 0.190 ± 0.028 OUR AVERAGE 0.188 ± 0.028 ± 0.007 55 ONYISI 10 CLE3 $\psi(2S) \to \gamma \rho \overline{\rho} X$ | <3.5 90 ⁶⁴ ABLIKIM 06D BES2 $\psi(2S) \rightarrow \chi_{C2} \gamma$ |
| $0.20 \pm 0.08 \pm 0.01$ 56 ATHAR 67 CLEO $\psi(2S) \rightarrow \gamma h^{+} h^{-} h^{0}$ | ⁶⁴ Using B($\psi(2S) \to \chi_{C2} \gamma$) = (9.3 ± 0.6)%. |
| 55 ONYISI 10 reports (1.76 \pm 0.23 \pm 0.14 \pm 0.11) $	imes$ 10 $^{-4}$ from a measurement of | $\Gamma(K^+ \overline{p} \Lambda + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{50}/Γ |
| $ \begin{array}{l} [\Gamma(\chi_{C2}(1P) \to \rho \overline{\rho} \eta)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{C2}(1P))] \text{ assuming } B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value } B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-2} \text{, which we rescale to our best value} B(\psi(2S) \to \gamma \chi_$ | VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT |
| $\gamma \chi_{c2}(1P) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our | 0.91±0.17±0.04 65 ATHAR 07 CLEO $\psi(2S) \to \gamma h^+ h^- h^0$ |
| $\gamma \chi_{C2}(1P) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. ⁵⁶ ATHAR 07 reports $(0.19 \pm 0.07 \pm 0.02) \times 10^{-3}$ from a measurement of $\Gamma(\chi_{C2}(1P) \rightarrow 0.02) \times 10^{-3}$ | ⁶⁵ ATHAR 07 reports $(0.85 \pm 0.14 \pm 0.10) \times 10^{-3}$ from a measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$)] from the measurement of [Γ ($\chi_{c2}(1P) \rightarrow 0.10 \times 10^{-3}$). |
| $\rho \overline{\rho} \eta / \Gamma_{\text{total}} \times [B(\psi(2S) \rightarrow \gamma \chi_{C2}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{C2}(1P)) = (9.33 \pm 1)$ | $K^+ \overline{p} \Lambda + \text{c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma \chi_{c2}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma \chi_{c2}(1P))$ = $(9.33 \pm 0.14 \pm 0.61) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \rightarrow 0.01)$ |
| $0.14 \pm 0.61) \times 10^{-2}$, which we rescale to our best value B($\psi(2S) \rightarrow \gamma \chi_{C2}(1P)$) = | $\gamma \chi_{c2}(1P)) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and |
| $(8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | our second error is the systematic error from using our best value. |
| | $\Gamma(K^+ p \Lambda(1520) + c.c.)/\Gamma_{total}$ $\Gamma_{51}/\Gamma_{total}$ |
| $\Gammaig(ar{ ho}ar{ ho}ig)ig/\Gamma_{	ext{total}}$ $\Gamma_{	ext{41}}/\Gamma$ VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10^{-3}) DOCUMENT ID TECN COMMENT 0.39 \pm 0.05 \pm 0.02 57 ONYISI 10 CLE3 $\psi(2S) \rightarrow \gamma p \overline{p} X$ | 3.1 \pm 0.7 \pm 0.1 79 \pm 13 ⁶⁶ ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$ ⁶⁶ ABLIKIM 11F reports $(3.06 \pm 0.50 \pm 0.54) \times 10^{-4}$ from a measurement of [$\Gamma(\chi_{CZ}(1P) \rightarrow 0.50 \pm 0.54) \times 10^{-4}$] |
| 57 ONYISI 10 reports (3.68 \pm 0.35 \pm 0.26 \pm 0.24) \times 10 ⁻⁴ from a measurement of | $K^+p\Lambda(1520)+\text{ c.c.})/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{c2}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{c2}(1P))$ |
| $[\Gamma(\chi_{c2}(1P) \to p\overline{p}\omega)/\Gamma_{total}] \times [B(\psi(2S) \to \gamma\chi_{c2}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c2}(1P))$ | $\gamma\chi_{c2}(1P))=(8.74\pm0.35)	imes10^{-2}$, which we rescale to our best value B $(\psi(2S) ightarrow$ |
| $\gamma\chi_{c2}(1P))=(9.33\pm0.14\pm0.61)\times10^{-2}$, which we rescale to our best value B($\psi(2S)\to\gamma\chi_{c2}(1P))=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our | $\gamma\chi_{C2}(1P))=(8.72\pm0.34)	imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\gamma \chi_{c2}(1P)) = (6.72 \pm 0.34) \times 10^{-1}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | |
| $\Gamma(p\overline{p}\phi)/\Gamma_{\text{total}}$ Γ_{42}/Γ | $\Gamma(\Lambda(1520)\overline{\Lambda}(1520))/\Gamma_{\text{total}}$ Γ_{52}/Γ |
| VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT5.1±1.6±0.229 ± 767 ABLIKIM11FBES3 $\psi(2S) \rightarrow \gamma p \bar{p} K^+ K^-$ |
| 3.0±0.9±0.1 24 ± 7 58 ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$ | 67 ABLIKIM 11F reports $(5.05 \pm 1.29 \pm 0.93) \times 10^{-4}$ from a measurement of |
| ⁵⁸ ABLIKIM 11F reports $(3.04\pm0.85\pm0.43)\times10^{-5}$ from a measurement of $\Gamma(\chi_{c2}(1P)\to 1.00)$ | $[\Gamma(\chi_{C2}(1P) \rightarrow \Lambda(1520)\overline{\Lambda}(1520))/\Gamma_{total}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C2}(1P))]$ assuming |
| $ ho \overline{ ho} \phi / \Gamma_{	ext{total}} brace \times [B(\psi(2S) 	o \gamma \chi_{C2}(1P))]$ assuming $B(\psi(2S) 	o \gamma \chi_{C2}(1P)) = (8.74 \pm 0.35) 	imes 10^{-2}$, which we rescale to our best value $B(\psi(2S) 	o \gamma \chi_{C2}(1P)) = (8.72 \pm 0.35) 	imes 10^{-2}$. | $B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.74 \pm 0.35) \times 10^{-2}$, which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.72 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's |
| 0.34) \times 10^{-2} . Our first error is their experiment's error and our second error is the | $\theta(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.72 \pm 0.34) \times 10^{-4}$. Our first error is their experiment s error and our second error is the systematic error from using our best value. |
| systematic error from using our best value. | $\Gamma(\Sigma^0\overline{\Sigma^0})/\Gamma_{\text{total}}$ Γ_{53}/Γ |
| $\Gamma(\rho \overline{\rho} \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{43}/Γ | VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | <0.8 90 7.5 \pm 3.4 68 NAIK 08 CLEO $\psi(2S) \rightarrow \gamma \Sigma^0 \overline{\Sigma}^0$ |
| 1.32±0.34 OUR EVALUATION Treating systematic error as correlated. 1.3 ±0.4 OUR AVERAGE Error includes scale factor of 1.3. | 68 NAIK 08 reports $<$ 0.75 $\times 10^{-4}$ from a measurement of $[\Gamma(\chi_{C2}(1P) \to \Sigma^0 \overline{\Sigma}^0)/\Gamma_{total}] \times [B(\psi(2S) \to \gamma \chi_{C2}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (9.33 \pm 0.14 \pm 0.61) \times 10^{-10}$ |
| $1.17\pm0.19\pm0.30$ 59 BAI 99B BES $\psi(2S) ightarrow \gamma \chi_{C2}$ | \times [B($\psi(2S) \to \gamma \chi_{C2}(1P)$)] assuming B($\psi(2S) \to \gamma \chi_{C2}(1P)$) = (9.33 ± 0.14 ± 0.61)× 10 ⁻² , which we rescale to our best value B($\psi(2S) \to \gamma \chi_{C2}(1P)$) = 8.72 × 10 ⁻² . |
| $2.64\pm1.03\pm0.14$ 59 TANENBAUM 78 MRK1 $\psi(25) ightarrow \gamma \chi_{C2}$ | |
| 59 Rescaled by us using B($\psi(2S) \rightarrow \gamma \chi_{C2}$)= (8.3 \pm 0.4)% and B($\psi(2S) \rightarrow J/\psi(1S) \pi^+\pi^-$) = (32.6 \pm 0.5)%. Multiplied by a factor of 2 to convert from | $\Gamma(\Sigma^{+}\overline{\Sigma}^{-})/\Gamma_{\text{total}}$ Γ_{54}/Γ |
| $K_0^0 K^+ \pi^-$ to $K^0 K^+ \pi^-$ decay. | VALUE (units 10^{-4}) CL% EVTS DOCUMENT ID TECN COMMENT <0.7 90 4.0 \pm 3.5 69 NAIK 08 CLEO $\psi(2S) \rightarrow \gamma \Sigma^{+} \overline{\Sigma}^{-}$ |
| r/==-0-0\/r | - ' ' ' |
| $\Gamma(ho\overline{ ho}\pi^0\pi^0)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{44}}/\Gamma$ VALUE (%) EVTS DOCUMENT ID TECN COMMENT | 69 NAIK 08 reports $<$ 0.67 \times 10 ⁻⁴ from a measurement of $[\Gamma(\chi_{C2}(1P) \rightarrow \Sigma^+\overline{\Sigma}^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S) \rightarrow \gamma\chi_{C2}(1P)) = (9.33 \pm 1.0)$ |
| 0.086 \pm 0.026 \pm 0.003 29.2 ⁶⁰ HE 08B CLEO $e^+e^- \rightarrow \gamma h^+ h^- h^0 h^0$ | 0.14 \pm 0.61) \times 10 $^{-2}$, which we rescale to our best value B($\psi(2S)\to~\gamma\chi_{C2}(1P))=8.72\times10^{-2}$. |
| $^{60}\mathrm{HE}$ 08B reports 0.08 \pm 0.02 \pm 0.01 \pm 0.01 % from a measurement of [$\Gamma(\chi_{c2}(1P)$ \rightarrow | |
| $p\overline{p}\pi^0\pi^0)/\Gamma_{\text{total}} \times [B(\psi(2S) \to \gamma\chi_{c2}(1P))]$ assuming $B(\psi(2S) \to \gamma\chi_{c2}(1P)) = 0$ | $\Gamma(\equiv^0\equiv^0)/\Gamma_{\text{total}}$ Γ_{55}/Γ |
| $(9.33\pm0.14\pm0.61)\times10^{-2}$, which we rescale to our best value B($\psi(2S)\to\gamma\chi_{C2}(1P)$) = $(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| is the systematic error from using our best value. | <1.1 90 2.9 \pm 1.7 'O NAIK 08 CLEO $\psi(25) \rightarrow \gamma \Xi^0 \Xi^0$ 70 NAIK 08 reports < 1.06 × 10 ⁻⁴ from a measurement of $\Gamma(\gamma) = (1P) \rightarrow \Xi^0 \Xi^0$ / Γ |
| $\Gamma(p\overline{p}K^+K^-(\text{non-resonant}))/\Gamma_{\text{total}}$ Γ_{45}/Γ | 70 NAIK 08 reports $<1.06\times10^{-4}$ from a measurement of $[\Gamma(\chi_{C2}(1P)\to\Xi^0\overline{\Xi^0})/\Gamma_{\rm total}]\times[B(\psi(2S)\to\gamma\chi_{C2}(1P))]$ assuming $B(\psi(2S)\to\gamma\chi_{C2}(1P))=(9.33\pm0.14\pm0.61)\times$ |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | 10^{-2} , which we rescale to our best value B $(\psi(2S) ightarrow \gamma \chi_{C2}(1P)) = 8.72 	imes 10^{-2}$. |
| 2.09 ± 0.35 ± 0.08 131 ± 12 61 ABLIKIM 11F BES3 $\psi(2S) \rightarrow \gamma p \overline{p} K^+ K^-$ | $\Gamma(\Xi^{-}\overline{\Xi}^{+})/\Gamma_{\text{total}}$ Γ_{56}/Γ |
| ⁶¹ ABLIKIM 11F reports $(2.08\pm0.19\pm0.30)\times10^{-4}$ from a measurement of $[\Gamma(\chi_{C2}(1P)\to -1)]$ | VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT |
| $p\overline{p}$ K^+ K^- (non-resonant))/ Γ_{total}] \times [B($\psi(2S) \to \gamma \chi_{C2}(1P)$)] assuming B($\psi(2S) \to \gamma \chi_{C2}(1P)$) = (8.74 \pm 0.35) \times 10 ⁻² , which we rescale to our best value B($\psi(2S) \to \gamma \chi_{C2}(1P)$) | 1.55 \pm 0.34 \pm 0.06 |
| $\chi_{C2}(17) = (6.74 \pm 0.34) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | • • • We do not use the following data for averages, fits, limits, etc. • • • < 3.7 90 72 ABLIKIM 06D BES2 $\psi(2S) \rightarrow \chi_{C2} \gamma$ |
| second error is the systematic error from using our best value. | 71 NAIK 08 reports $(1.45 \pm 0.30 \pm 0.15) \times 10^{-4}$ from a measurement of $[\Gamma(\chi_{c2}(1P) \rightarrow \chi_{c2})]$ |
| $\Gamma(p\overline{p}K_S^0K_S^0)/\Gamma_{\text{total}}$ Γ_{46}/Γ | $\Xi^-\overline{\Xi}^+)/\Gamma_{\text{total}} \times [B(\psi(2S) \to \gamma \chi_{c2}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{c2}(1P)) =$ |
| VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | $(9.33\pm0.14\pm0.61)	imes10^{-2}$, which we rescale to our best value B $(\psi(2S) ightarrow\gamma\chi_{c2}(1P))$ |
| <7.9 90 62 ABLIKIM 06D BES2 $\psi(2s) \rightarrow \chi_{c2} \gamma$ | $=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| ⁶² Using B($\psi(25) \rightarrow \chi_{\mathcal{C}2} \gamma$) = (9.3 \pm 0.6)%. | ⁷² Using B($\psi(2S) \to \chi_{C2} \gamma$) = (9.3 ± 0.6)%. |
| $\Gamma(p\overline{n}\pi^-)/\Gamma_{total}$ Γ_{47}/Γ | $\Gamma(J/\psi(1S)\pi^{+}\pi^{-}\pi^{0})/\Gamma_{\text{total}}$ Γ_{57}/Γ |
| /ALUE (units 10 ⁻⁴) DOCUMENT ID TECN COMMENT | <u>VALUE CL% DO CUMENT ID TECN COMMENT</u> |
| 11.1±3.8±0.4 63 ABLIKIM 061 BES2 $\psi(2S) \to \gamma p \pi^- X$ | <0.015 90 BARATE 81 SPEC 190 GeV π^- Be $ ightarrow 2\pi 2\mu$ |
| ⁶³ ABLIKIM 06i reports $[\Gamma(\chi_{C2}(1P) \to \rho \overline{n} \pi^-)/\Gamma_{\text{total}}] \times [B(\psi(2S) \to \gamma \chi_{C2}(1P))] = (0.97 \pm 0.20 \pm 0.26) \times 10^{-4}$ which we divide by our best value $B(\psi(2S) \to \gamma \chi_{C2}(1P))$ | RADIATIVE DECAYS |
| $=(8.72\pm0.34)\times10^{-2}$. Our first error is their experiment's error and our second error | $\Gamma(\gamma J/\psi(1S))/\Gamma_{\text{total}}$ Γ_{58}/Γ |
| is the systematic error from using our best value. | VALUE DOCUMENT ID TECN COMMENT |
| $\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ Γ_{48}/Γ | 0.195 ± 0.008 OUR FIT • • • We do not use the following data for averages, fits, limits, etc. • • • |
| VALUE (units 10 ⁻⁴) DO CUMENT ID | 0.199 \pm 0.005 \pm 0.012 73 ADAM 05A CLEO $e^+e^- ightarrow \psi(2S) ightarrow \gamma \chi_{C2}$ |
| 1.00±0.27 OUR FIT | 73 Uses B($\psi(2S) \to \gamma \chi_{C2} \to \gamma \gamma J/\psi$) from ADAM 05A and B($\psi(2S) \to \gamma \chi_{C2}$) from |

$\chi_{c2}(1P)$

| $(\gamma \rho^0)/\Gamma_{\text{total}}$ Γ_{59}/Γ | $\Gamma(\chi_{c2}(1P) \to \rho \overline{\rho})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}$ |
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| ALUE (units 10^{-6}) CL% EVTS DOCUMENT ID TECN COMMENT (21 90 13 ± 11 74 ABLIKIM 11E BES3 $\psi(2S) \rightarrow \gamma\gamma\rho^0$ | $\Gamma_{38}/\Gamma 	imes \Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | <u>VALUE (units 10^{−6}) </u> |
| (50) 90 17.2 \pm 6.8 ⁷⁵ BENNETT 08A CLEO $\psi(2S) ightarrow \gamma \gamma ho^0$ | 6.7±1.1 OUR AVERAGE Error includes scale factor of 1.5. |
| 74 ABLIKIM 11E reports $< 20.8 	imes 10^{-6}$ from a measurement of $[\Gamma(\chi_{c2}(1P) 	o \gamma ho^0)/$ | $7.2 \pm 0.7 \pm 0.4$ 121 ± 12 ⁸³ NAIK 08 CLEO $\psi(2S) \rightarrow \gamma \rho \overline{\rho}$ |
| $ \begin{array}{l} \lceil total \rceil \times \lceil B(\psi(2S) \to \gamma \chi_{C2}(1P)) \rceil \text{ assuming B}(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.74 \pm 0.35) \times \\ 10^{-2}, \text{ which we rescale to our best value B}(\psi(2S) \to \gamma \chi_{C2}(1P)) = 8.72 \times 10^{-2}. \end{array} $ | $4.4^{+1.6}_{-1.4}\pm 0.6$ $14.3^{+5.2}_{-4.7}$ BAI 04F BES $\psi(2S) 	o \gamma \chi_{c2}(1P) 	o \gamma \overline{p} p$ |
| ⁷⁵ BENNETT 08A reports $<$ 50 \times 10 ⁻⁶ from a measurement of $[\Gamma(\chi_{C2}(1P) \to \gamma_P ^0)/\Gamma_{\text{tot}_{\bar{q}}}] \times [B(\psi(2S) \to \gamma_{C2}(1P))]$ assuming $B(\psi(2S) \to \gamma_{C2}(1P)) = (8.1 \pm 0.4) \times 10^{-6}$ | ⁸³ Calculated by us. NAIK 08 reports ${\sf B}(\chi_{C2} \to \rho \overline{\rho}) = (7.7 \pm 0.8 \pm 0.4 \pm 0.5) \times 10^{-10}$ using ${\sf B}(\psi(25) \to \gamma \chi_{C2}) = (9.33 \pm 0.14 \pm 0.61)\%$. |
| 10^{-2} , which we rescale to our best value B $(\psi(2S) \to \gamma \chi_{C2}(1P)) = 8.72 \times 10^{-2}$. | $\Gamma(\chi_{c2}(1P) 	o \Lambda \overline{\Lambda})/\Gamma_{total} 	imes \Gamma(\psi(2S) 	o \gamma \chi_{c2}(1P))/\Gamma_{total}$ |
| $(\gamma\omega)/\Gamma_{	ext{total}}$ LUE (units 10^{-6}) CL% EVTS DOCUMENT ID TECN COMMENT | $\Gamma_{48}/\Gamma 	imes \Gamma_{48}^{\psi(25)}/\Gamma_{\psi(25)}^{\psi(25)}$ VALUE (units 10^{-6}) EVTS DOCUMENT ID TECN COMMENT |
| 26 90 1 ± 6 76 ABLIKIM 11E BES3 $\psi(2S) \rightarrow \gamma\gamma\omega$ | 16.3±2.3 OUR FIT |
| | 15.9 \pm 2.1 \pm 1.0 71 \pm 9 ⁸⁴ NAIK 08 CLEO $\psi(2S) \rightarrow \gamma \Lambda \overline{\Lambda}$ |
| 77 90 0.0 \pm 1.8 77 BENNETT 08A CLEO $\psi(2S) ightarrow \gamma \gamma \omega$ | ⁸⁴ Calculated by us. NAIK 08 reports B($\chi_{C2} \to \Lambda \overline{\Lambda}$) = (17.0 \pm 2.2 \pm 1.1 \pm 1.1) \times 10 $^-$ using B(ψ (2S) $\to \gamma \chi_{C2}$) = (9.33 \pm 0.14 \pm 0.61)%. |
| ⁷⁶ ABLIKIM 11E reports $< 6.1 \times 10^{-6}$ from a measurement of $[\Gamma(\chi_{c2}(1P) \to \gamma \omega)/\Gamma_{\text{total}}]$ | |
| $\times \left[B(\psi(2S) \to \gamma \chi_{C2}(1P)) \right] \text{ assuming } B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.74 \pm 0.35) \times 10^{-2},$ which we rescale to our best value $B(\psi(2S) \to \gamma \chi_{C2}(1P)) = 8.72 \times 10^{-2}.$ | $\Gamma(\chi_{c2}(1P) \to \Lambda \overline{\Lambda})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma(\psi(2S) \to \psi(2S))$ |
| ⁷⁷ BENNETT 08A reports $< 7.0 \times 10^{-6}$ from a measurement of $[\Gamma(\chi_{c2}(1P) \rightarrow \gamma \omega)/$ | $J/\psi(1S)\pi^{+}\pi^{-}$ |
| $\lceil total \rceil \times [B(\psi(2S) \to \gamma \chi_{\mathcal{C}2}(1P))]$ assuming $B(\psi(2S) \to \gamma \chi_{\mathcal{C}2}(1P)) = (8.1 \pm 0.4) \times 10^{-10}$ | VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT |
| 10^{-2} , which we rescale to our best value B $(\psi(2S) \to \gamma \chi_{C2}(1P)) = 8.72 \times 10^{-2}$. | 4.8±0.7 OUR FIT |
| $(\gamma \phi)/\Gamma_{\text{total}}$ Γ_{61}/Γ | 7.1 $ + \frac{3.1}{2.9} \pm 1.3$ 8.3 $ + \frac{3.7}{3.4}$ 85 BAI 03E BES $\psi(2S) \to \gamma \Lambda \overline{\Lambda}$ |
| ALUE (units 10 ⁻⁶) CL% EVTS DOCUMENT ID TECN COMMENT | ⁸⁵ BAI 03E reports [$B(\chi_{c2} \rightarrow \Lambda \overline{\Lambda}) B(\psi(2S) \rightarrow \gamma \chi_{c2}) / B(\psi(2S) \rightarrow J/\psi \pi^+ \pi^-)$] |
| 8 90 5 \pm 5 78 ABLIKIM 11E BES3 $\psi(2S) \rightarrow \gamma \gamma \phi$ | $[B^2(\Lambda 	o \ \pi^- p) \ / \ B(J/\psi 	o \ p \overline{p}) \] = (1.33 ^{+0.59}_{-0.55} \pm 0.25)\%.$ We calculate from th |
| • • We do not use the following data for averages, fits, limits, etc. • • • $(12 	 90 	 1.3 \pm 2.5 	 79 	 BENNETT 	 08A 	 CLEO 	 \psi(2S) 	o \gamma\gamma\phi$ | measurement the presented value using B($\Lambda \to \pi^- p$) = (63.9 \pm 0.5)% and B(J/ψ - $p\overline{p}$) = (2.17 \pm 0.07) \times 10 ⁻³ . |
| 1.3 ± 2.5 | |
| × [B($\psi(2S) \rightarrow \gamma \chi_{C2}(1P)$)] assuming B($\psi(2S) \rightarrow \gamma \chi_{C2}(1P)$) = $(8.74 \pm 0.35) \times 10^{-2}$, | $\Gamma(\chi_{c2}(1P) \to \pi\pi)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma_{\text{total}}$ |
| which we rescale to our best value B($\psi(2S) \to \gamma \chi_{C2}(1P)$) = 8.72 \times 10 ⁻² . | $\Gamma_{22}/\Gamma 	imes \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ |
| ⁷⁹ BENNETT 08A reports $<$ 13 $	imes$ 10 $^{-6}$ from a measurement of [$\Gamma(\chi_{c2}(1P)	o\gamma\phi)/\Gamma_{	ext{total}}$] | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| $\times \left[\mathbb{B}(\psi(2S) \to \gamma \chi_{C2}(1P)) \right] \text{ assuming } \mathbb{B}(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.1 \pm 0.4) \times 10^{-2},$ which we would be say both when $\mathbb{B}(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.1 \pm 0.4) \times 10^{-2},$ | 2.11±0.08 OUR FIT 2.17±0.09 OUR AVERAGE |
| which we rescale to our best value B($\psi(2S) \to \gamma \chi_{c2}(1P)$) = 8.72 \times 10 $^{-2}$. | $2.19\pm0.05\pm0.15$ 4.5k 86 ABLIKIM 10A BES3 $e^+e^- ightarrow \psi(2S) ightarrow \gamma\chi_{C}$ |
| $(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{62}/Γ | $2.23\pm0.06\pm0.10$ 2.5 k 87 ASNER 09 CLEO $\psi(2S) ightarrow \gamma\pi^+\pi^-$ |
| ALUE (units 10 ⁻⁴) DOCUMENT ID | 1.90 \pm 0.08 \pm 0.20 0.8k ⁸⁸ ASNER 09 CLEO $\psi(2S) \rightarrow \gamma \pi^0 \pi^0$ |
| 59±0.16 OUR FIT | ⁸⁶ Calculated by us. ABLIKIM 10A reports $B(\chi_{C2} \to \pi^0 \pi^0) = (0.88 \pm 0.02 \pm 0.06 \pm 0.04) \times 10^{-3}$ using $B(\psi(2S) \to \gamma\chi_{C2}) = (8.3 \pm 0.4)\%$. We have multiplied the $\pi^0 \pi$ |
| $(\gamma\gamma)/\Gamma(\gamma J/\psi(1S))$ Γ_{62}/Γ_{58} | measurement by 3 to obtain $\pi\pi$. |
| ALUE (units 10 ⁻³) DOCUMENT ID TECN COMMENT | 87 Calculated by us. ASNER 09 reports B($\chi_{c2} \to \pi^+\pi^-$) = (1.59 ± 0.04 ± 0.07 : |
| 33±0.09 OUR FIT 99±0.18 80 AMBROGIANI 00B E835 $\overline{p}p \to \chi_{C2} \to \gamma\gamma, \gamma J/\psi$ | $0.10) \times 10^{-3}$ using B($\psi(2S) \to \gamma \chi_{C2})=(9.33\pm0.14\pm0.61)\%$. We have multiplie the $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. |
| 80 Calculated by us using B $(J/\psi(1S) \rightarrow e^+e^-) = 0.0593 \pm 0.0010$. | 88 Calculated by us. ASNER 09 reports B($\chi_{c2} \rightarrow \pi^0 \pi^0$) = (0.68 \pm 0.03 \pm 0.07 \pm 0.04) |
| | 10^{-3} using B $(\psi(2S) ightarrow \gamma \chi_{C2}) = (9.33 \pm 0.14 \pm 0.61)\%$. We have multiplied the |
| $(\gamma\gamma)/\Gamma_{	ext{total}} \times \Gamma(p\overline{p})/\Gamma_{	ext{total}}$ $\Gamma_{62}/\Gamma \times \Gamma_{38}/\Gamma$ ALUE (units 10^{-8}) $\Gamma_{62}/\Gamma \times \Gamma_{38}/\Gamma$ $\Gamma_{62}/\Gamma \times \Gamma_{38}/\Gamma$ | $\pi^0\pi^0$ measurement by 3 to obtain $\pi\pi$. |
| ALUE (units 10 ^{−8}) <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 86±0.18 OUR FIT | $\Gamma(\chi_{c2}(1P) 	o \pi\pi)/\Gamma_{	ext{total}} 	imes \Gamma(\psi(2S) 	o \gamma\chi_{c2}(1P))/\Gamma(\psi(2S) 	o$ |
| 7 ±0.4 OUR AVERAGE | $J/\psi(1S)\pi^{+}\pi^{-}$) $\Gamma_{22}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ |
| 60 \pm 0.42 ARMSTRONG 93 E760 $\overline{p}p \rightarrow \gamma \gamma X$ 9 \pm 4.5 BAGLIN 87B SPEC $\overline{p}p \rightarrow \gamma \gamma X$ | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| | 0.629±0.024 OUR FIT |
| $\chi_{c2}(1P)$ CROSS-PARTICLE BRANCHING RATIOS | 0.54 ±0.06 OUR AVERAGE $0.66 \pm 0.18 \pm 0.37$ 21 ± 6 ⁸⁹ BAI $03c$ BES $\psi(2S) \rightarrow \gamma \pi^0 \pi^0$ |
| | $0.54 \pm 0.05 \pm 0.04$ 185 ± 16 90 BAI 98 BES $\psi(2S) \rightarrow \gamma \pi^+ \pi^-$ |
| $(\gamma_{\circ 2}(1P) \rightarrow K^+K^-\pi^+\pi^-)/\Gamma_{\bullet \bullet \bullet \bullet} \times \Gamma(\mathfrak{h}(2S) \rightarrow \sim \gamma_{\circ \bullet}(1P))/\Gamma(\mathfrak{h}(2S) \rightarrow$ | 89 We have multiplied $\pi^0\pi^0$ measurement by 3 to obtain $\pi\pi$. |
| $(\chi_{c2}(1P) \to K^+K^-\pi^+\pi^-)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma(\psi(2S) \to \chi_{c2}(1P))/\Gamma(\psi(2S) \to \chi_{c2}(1P))/\Gamma(\psi(2S))$ | |
| $/\psi(1S)\pi^{+}\pi^{-}$ $\Gamma_{14}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ | 90 Calculated by us. The value for B $(\chi_{c2} ightarrow \pi^+ \pi^-)$ reported by BAI 981 is derived usin |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 90 Calculated by us. The value for B($\chi_{c2} \rightarrow \pi^+\pi^-$) reported by BAI 981 is derived usin B($\psi(2S) \rightarrow \gamma \chi_{c2}$) = (7.8 \pm 0.8)% and B($\psi(2S) \rightarrow J/\psi \pi^+\pi^-$) = (32.4 \pm 2.6) |
| $/\psi(1S)\pi^+\pi^-$) $\Gamma_{14}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ ALUE (units 10^{-3}) $DOCUMENT ID$ $TECN$ $COMMENT$ $COMMENT$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ $TECN$ TE | 90 Calculated by us. The value for B($\chi_{c2} \to \pi^+\pi^-$) reported by BAI 981 is derived usin B($\psi(25) \to \gamma \chi_{c2}$) = (7.8 \pm 0.8)% and B($\psi(25) \to J/\psi \pi^+\pi^-$) = (32.4 \pm 2.6) [BAI 980]. We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. |
| / $\psi(1S)\pi^+\pi^-$) $\Gamma_{14}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}$ ALUE (units 10^{-3}) 36 ± 0.27 OUR FIT 5 ±0.9 OUR AVERAGE Error includes scale factor of 2.3. 90 $\pm0.14\pm0.44$ BAI 998 BES $\psi(2S) \rightarrow \gamma \chi_{C2}$ | ⁹⁰ Calculated by us. The value for $B(\chi_{C2} \to \pi^+\pi^-)$ reported by BAI 981 is derived usin $B(\psi(2S) \to \gamma\chi_{C2}) = (7.8 \pm 0.8)\%$ and $B(\psi(2S) \to J/\psi\pi^+\pi^-) = (32.4 \pm 2.6)$ [BAI 98D]. We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. $\Gamma(\chi_{C2}(1P) \to \eta\eta)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma\chi_{C2}(1P))/\Gamma_{total}$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | ⁹⁰ Calculated by us. The value for $B(\chi_{C2} \to \pi^+\pi^-)$ reported by BAI 981 is derived usin $B(\psi(2S) \to \gamma\chi_{C2}) = (7.8 \pm 0.8)\%$ and $B(\psi(2S) \to J/\psi\pi^+\pi^-) = (32.4 \pm 2.6)$ [BAI 98D]. We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. $\Gamma(\chi_{C2}(1P) \to \eta\eta)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma\chi_{C2}(1P))/\Gamma_{total}$ |
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| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 90 Calculated by us. The value for $B(\chi_{C2} \to \pi^+\pi^-)$ reported by BAI 981 is derived usin $B(\psi(2S) \to \gamma\chi_{C2}) = (7.8 \pm 0.8)\%$ and $B(\psi(2S) \to J/\psi\pi^+\pi^-) = (32.4 \pm 2.6)$ [BAI 98D]. We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. $ \Gamma(\chi_{C2}(1P) \to \eta\eta)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{C2}(1P))/\Gamma_{\text{total}} $ $ \Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{111}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}} = \frac{\Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S)}}{\Gamma_{26}/\Gamma \times \Gamma_{26}^{\psi(2S$ |
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| $/\psi(15)\pi^{+}\pi^{-}$) $/\psi(15)\pi^{+}\pi^{-}$) $/\psi(15)\pi^{+}\pi^{-}$) $/\psi(15)\pi^{+}\pi^{-}$) $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ $/(14)/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}/\Gamma_{111}^{\psi(25)}$ | 90 Calculated by us. 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| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $ \begin{array}{c} ^{90} \text{ Calculated by us. The value for B}(\chi_{c2} \to \pi^+\pi^-) \text{ reported by BAI 98I is derived usin} \\ \text{B}(\psi(25) \to \gamma\chi_{c2}) = (7.8 \pm 0.8)\% \text{ and B}(\psi(25) \to J/\psi\pi^+\pi^-) = (32.4 \pm 2.6) \\ \text{[BAI 98D]. We have multiplied } \pi^+\pi^- \text{ measurement by } 3/2 \text{ to obtain } \pi\pi. \\ \hline {\Gamma(\chi_{c2}(1P) \to \eta\eta)/\Gamma_{\text{total}}} \times {\Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma_{\text{total}}} \\ \hline {\Gamma_{26}/\Gamma} \times {\Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)}} \\ \hline \frac{VALUE \text{ (units }10^{-4})}{0.52 \pm 0.04} \times \frac{CL\%}{0.00000000000000000000000000000000000$ |
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| $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$) $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\pi^{-}$ $/\psi(1S)\pi^{+}\Psi^{-}$ $/\psi$ | 90 Calculated by us. The value for B($\chi_{c2} \rightarrow \pi^+\pi^-$) reported by BAI 981 is derived usin B($\psi(2S) \rightarrow \gamma \chi_{c2}$) = (7.8 ± 0.8)% and B($\psi(2S) \rightarrow J/\psi \pi^+\pi^-$) = (32.4 ± 2.6) [BAI 98D]. We have multiplied $\pi^+\pi^-$ measurement by 3/2 to obtain $\pi\pi$. $\Gamma(\chi_{c2}(1P) \rightarrow \eta \eta)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \gamma \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi_{c2}(1P))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \chi$ |

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\Gamma(\chi_{c2}(1P) \to K^+K^-)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                              \Gamma_{27}/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma^{\psi(25)}
                                                                                       TECN COMMENT
 9.5 ± 0.6 OUR FIT
                                                   93 ASNER
                                                                               09 CLEO \psi(2S) \rightarrow \gamma K^+ K^-
10.5 \pm 0.3 \pm 0.6
  ^{93} Calculated by us. ASNER 09 reports B( \chi_{\it C2} \rightarrow~{\it K^+ K^-}) = (1.13 \pm 0.03 \pm 0.06 \pm
      0.07) \times 10^{-3} using B(\psi(2S) \rightarrow \gamma \chi_{c2}) = (9.33 \pm 0.14 \pm 0.61)%.
\Gamma\big(\chi_{c2}(1P)\to \,K^+\,K^-\big)/\Gamma_{\rm total}\,\times\,\Gamma\big(\psi(2S)\to\gamma\,\chi_{c2}(1P)\big)/\Gamma\big(\psi(2S)\to
                                                                                              \Gamma_{27}/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{11}^{\psi(25)}
J/\psi(1S)\pi^+\pi^-
                                                                                          TECN COMMENT
VALUE (units 10<sup>-3</sup>)
0.283±0.017 OUR FIT
                                                           DOCUMENT ID
                                                      <sup>94</sup> BAI
0.190 \pm 0.034 \pm 0.019 115 ± 13
                                                                                   98I BES \psi(2S) \rightarrow \gamma K^+ K^-
  ^{94} Calculated by us. The value for B( \chi_{c2} \rightarrow \ \ K^+ \ K^-) reported by BAI 98I is derived using
      B(\psi(2S) \to \gamma \chi_{C2}) = (7.8 \pm 0.8)\% and B(\psi(2S) \to J/\psi \pi^+ \pi^-) = (32.4 \pm 2.6)\%
      [BAI 98b].
\Gamma(\chi_{c2}(1P) \to K_S^0 K_S^0)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                              \Gamma_{28}/\Gamma\times\Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)}
VALUE (units 10<sup>-5</sup>)
5.1 ±0.4 OUR FIT
                                                           DOCUMENT ID
                                                                                           TECN COMMENT
5.0 ±0.4 OUR AVERAGE
                                                                                   09 CLEO \psi(2S) \rightarrow \gamma K_S^0 K_S^0
4.9 \pm 0.3 \pm 0.3
                                                                                  050 BES2 \psi(2S) \rightarrow \gamma K_S^0 K_S^0
                                                           ABLIKIM
5.72 \pm 0.76 \pm 0.63
                                             65
  ^{95} Calculated by us. ASNER 09 reports B( \chi_{c2} \rightarrow ~K_S^0~K_S^0) = (0.53 \pm 0.03 \pm 0.03 \pm
      0.03) \times\,10^{-3} using B(\psi(2\mathrm{S})\to~\gamma\chi_{\mathrm{C2}})= (9.33 \pm 0.14 \pm 0.61)%
\Gamma(\chi_{c2}(1P) \to K_S^0 K_S^0)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))
                                                                                              \Gamma_{28}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}
J/\psi(1S)\pi^+\pi^-
                                                                                       TECN COMMENT
                                                       DOCUMENT ID
15.0±1.1 OUR FIT
                                                                               99B BES \psi(2S) \rightarrow \gamma K_S^0 K_S^0
14.7±4.1±3.3
  ^{96} Calculated by us. The value of B(\chi_{c2} 
ightarrow \, K_S^0 \, K_S^0) reported by BAI 99B was derived using
      {\sf B}(\psi(2S) \to \gamma \chi_{\it C2}(1P)) = (7.8 \pm 0.8)\% and {\sf B}(\psi(2S) \to J/\psi \pi^+ \pi^-) = (32.4 \pm 2.6)\%
\Gamma(\chi_{c2}(1P) \to \overline{K}^0 K^+ \pi^- + \text{c.c.})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                              \Gamma_{29}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)}
                                                                                        TECN COMMENT
                                                       DOCUMENT ID
1.22±0.17 OUR FIT
1.15 ± 0.18 OUR AVERAGE
                                                   ^{97}\,\mathrm{ATHAR}
1.21 \pm 0.19 \pm 0.09
                                        37
                                                                               07 CLEO \psi(2S) \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}
                                                   98 ABLIKIM
                                                                               06R BES2 \psi(2S) \rightarrow \gamma K_S^0 K^{\pm} \pi^{\mp}
                                        28
  ^{97} Calculated by us. ATHAR 07 reports B( \chi_{C2} \rightarrow ~\overline{K}^0~K^+~\pi^- + ~{\rm c.c.})~=~(1.3~\pm~0.2~\pm~0.2~\pm~0.2)
     0.1 \pm 0.1) \times 10^{-3} using B(\psi(2S) \rightarrow \gamma \chi_{c2}) = (9.33 \pm 0.14 \pm 0.61)%.
  <sup>98</sup> Calculated by us. ABLIKIM 06R reports B(\chi_{C2} \to \ K_S^0 \ K^\pm \pi^\mp) = (0.6 \pm 0.2 \pm 0.1) 	imes
     10^{-3} using B(\psi(2S)\to\gamma\chi_{C2})=(8.1\pm0.6)\% . We have multiplied by 2 to obtain \overline{K}^0\,K^+\pi^-+\text{c.c.} from K_S^0\,K^\pm\pi^\mp .
\Gamma(\chi_{c2}(1P) \to 2(\pi^+\pi^-))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))
                                                                                                \Gamma_1/\Gamma\times\Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}
J/\psi(1S)\pi^{+}\pi^{-}
                                                       DOCUMENT ID
                                                                                       TECN COMMENT
2.86±0.27 OUR FIT
3.1 ±1.0 OUR AVERAGE Error includes scale factor of 2.5. 2.3 ±0.1 ±0.5 99 BAI 99B BES
                                                                              99B BES
                                                 ^{100} Tanenbaum 78 MRK1 \psi(2S) 
ightarrow \gamma \chi_{c2}
  ^{99} Calculated by us. The value for B(\chi_{C2} 
ightarrow 2\pi^+ 2\pi^-) reported in BAI 99B is derived using
     B(\psi(2S) \to \gamma \chi_{C2}) = (7.8 \pm 0.8)\% and B(\psi(2S) \to J/\psi(1S) \pi^+ \pi^-) = (32.4 \pm 2.6)\%
100 The value for B(\psi(2S) \to \gamma \chi_{C2}) \times B(\chi_{C2} \to 2\pi^+\pi^-) reported in TANENBAUM 78 is derived using B(\psi(2S) \to J/\psi(1S) \pi^+\pi^-) \times B(J/\psi(1S) \ell^+\ell^-) = (4.6 \pm 0.7)\%. Calculated by us using B(J/\psi(1S) \to \ell^+\ell^-) = 0.1181 \pm 0.0020.
\Gamma(\chi_{c2}(1P) \to K^+K^-K^+K^-)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                              \Gamma_{36}/\Gamma\times\Gamma_{111}^{\psi(25)}/\Gamma^{\psi(25)}
                                                                                       TECN COMMENT
                                                       DOCUMENT ID
1.55 ± 0.19 OUR FIT
                                       160 <sup>101</sup> ABLIKIM
1.76 \pm 0.16 \pm 0.24
                                                                               06T BES2 \psi(2S) \rightarrow \gamma 2K^{+}2K^{-}
^{101} Calculated by us. The value of B(\chi_{C2} \to 2K^+2K^-) reported by ABLIKIM 06T was derived using B(\psi(2S) \to ~\gamma \chi_{C2}(1P)) = (8.1 \pm 0.4)\%.
\Gamma(\chi_{c2}(1P) \to K^+K^-K^+K^-)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma\chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                              \Gamma_{36}/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{11}^{\psi(25)}
\Gamma(\psi(2S) \to J/\psi(1S)\pi^+\pi^-)
VALUE (units 10<sup>-4</sup>)
4.6±0.6 OUR FIT
                                                                               99B BES \psi(2S) \rightarrow \gamma 2K^+ 2K^-
3.6 \pm 0.6 \pm 0.6
^{102} Calculated by us. The value of B(\chi_{c2} \to 2K^+2K^-) reported by BAI 99B was derived
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using B($\psi(2S) \to \gamma \chi_{C2}(1P)$) = (7.8 \pm 0.8)% and B($\psi(2S) \to J/\psi \, \pi^+ \, \pi^-$) = (32.4 \pm

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\chi_{c2}(1P)
\Gamma(\chi_{c2}(1P) \to \phi \phi)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                      \Gamma_{19}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma^{\psi(2S)}
                                                                                TECN COMMENT
VALUE (units 10-4)
                                  EVTS
                                                  DOCUMENT ID
1.00±0.10 OUR FIT

      0.98±0.13 OUR AVERAGE
      Error includes scale factor of 1.3.

      0.94±0.03±0.10
      849
      103 ABLIKIM
      11K
      BES

                                                                        11K BES3 \psi(2S) \rightarrow \gamma hadrons
                                     41 104 ABLIKIM
                                                                        06T BES2 \psi(2S) \rightarrow \gamma 2K^{+} 2K^{-}
^{103} Calculated by us. The value of B( \chi_{C2} \rightarrow ~\phi \phi) requising B( \psi(2S) \rightarrow ~\gamma \chi_{C2}(1P)) = (8.74 \pm 0.35)\% .
                                                                \phi\phi) reported by ABLIKIM 11K was derived
104 Calculated by us. The value of B(\chi_{C2} \to \phi \phi) reported by ABLIKIM 06T was derived using B(\psi(2S) \to \gamma \chi_{C2}(1P)) = (8.1 ± 0.4)%.
\Gamma(\chi_{c2}(1P) \to \phi \phi)/\Gamma_{total} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))
                                                                                      \Gamma_{19}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{11}^{\psi(2S)}
J/\psi(1S)\pi^{+}\pi^{-}
                                                  DOCUMENT ID
VALUE (units 10^{-4}
                                                                               TECN COMMENT
2.96±0.29 OUR FIT
                                            <sup>105</sup> BAI
4.8 ±1.3 ±1.3
                                                                         99B BES \psi(2S) \rightarrow \gamma 2K^{+} 2K^{-}
^{105} Calculated by us. The value of B(\chi_{c2} 
ightarrow \phi \phi) reported by BAI 99B was derived using
     \mathsf{B}(\psi(2S) \to \gamma \chi_{\mathcal{C}2}(1P)) = (7.8 \pm 0.8)\% \text{ and } \mathsf{B}(\psi(2S) \to J/\psi \, \pi^+ \, \pi^-) = (32.4 \pm 2.6)\%
\Gamma(\chi_{c2}(1P) \to \gamma J/\psi(1S))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}
                                                                                      \Gamma_{58}/\Gamma \times \Gamma_{111}^{\psi(25)}/\Gamma_{\psi(25)}
VALUE (units 10^{-2})
                                                                                TECN COMMENT
                                                  DOCUMENT ID
                                  EVTS
1.70±0.04 OUR FIT
1.34 \pm 0.14 OUR AVERAGE Error includes scale factor of 1.9. See the ideogram below.
1.62 \pm 0.04 \pm 0.12
                                  5.8k
                                                  BAI
                                                                        04I BES2 \psi(2S) \rightarrow J/\psi \gamma \gamma
                                                   GAISER
0.99 \pm 0.10 \pm 0.08
                                                                         86
                                                                               CBAL
                                                                                         \psi(2S) \rightarrow \gamma X
                                             106 OREGLIA
                                                                                           \psi(2S) \rightarrow \gamma \chi_{C2}
                                                                               CBAL
1.47 \pm 0.17
                                                                        82
                                             107 BRANDELIK 79B DASP
1.8\ \pm0.5
                                                                                           \psi(2S) \rightarrow \gamma \chi_{C2}
                                             107 BARTEL
1.2\ \pm0.2
                                                                        78B CNTR
                                                                                           \psi(2S) \to \ \gamma \chi_{c2}
                                             <sup>108</sup> BIDDICK
2.2 \pm 1.2
                                                                        77
                                                                               CNTR e^+e^- \rightarrow \gamma X
                                             106 WHITAKER
                                                                               MRK1
                                                                        76
\bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet
                                 12.4k 109 MENDEZ
                                                                       08 CLEO \psi(2S) \to \gamma \chi_{C2} 05A CLEO Repl. by MENDEZ 08
1.95 \pm 0.02 \pm 0.07
                                  1.9k 110 ADAM
1.85 \pm 0.04 \pm 0.07
^{106} Recalculated by us using B(J/\psi(1S) 
ightarrow \ell^+\ell^-) = 0.1181 \pm 0.0020.
^{107} Recalculated by us using B(J/\psi(1S) \rightarrow \mu^+\mu^-) = 0.0588 \pm 0.0010.
^{108}\,\mathrm{Assumes} isotropic gamma distribution.
^{109}\,\mathrm{Not} independent from other measurements of MENDEZ 08.
^{110}\,\mathrm{Not} independent from other values reported by ADAM 05 A.
             WEIGHTED AVERAGE
1.34±0.14 (Error scaled by 1.9)
                                                         Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not neces-
                                                         sarily the same as our 'best' values, obtained from a least-squares constrained fit
                                                         utilizing measurements of other (related)
                                                         quantities as additional information.
                                                                                                             <u>ለ</u>
5.0
                                                                 BAI
                                                                                       041
                                                                                               BES2
                                                                 GAISER
OREGLIA
                                                                                       86
82
                                                                                               CBAL
CBAL
                                                                                                             0.6
                                                                 BRANDELIK
BARTEL
                                                                                               DASP
CNTR
                                                                                       79B
                                                                                       78B
                                                                                                             0.5
                                                                  BIDDICK
                                                                                                CNTR
                                                                  WHITAKER
                                                                                               MRK1
                                                                                       76
                                                                              (Confidence Level =
                                                                                                         0.0064)
              \Gamma(\chi_{c2}(1P) \to \gamma J/\psi(1S))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}} (units
\Gamma(\chi_{c2}(1P) 	o \gamma J/\psi(1S))/\Gamma_{total} \times \Gamma(\psi(2S) 	o \gamma \chi_{c2}(1P))/\Gamma(\psi(2S) 	o
       J/\psi(1S) a nything)
        0.344\Gamma_{110}^{\psi(2S)} + 0.195\Gamma_{111}^{\psi(2S)}
<u>VALUE (units</u> 10<sup>-2</sup>)
                                                  DO CUMENT ID
                                                                             TECN COMMENT
2.86±0.07 OUR FIT
• • • We do not use the following data for averages, fits, limits, etc. • • •
                                            <sup>111</sup> MENDEZ
                                                                        08 CLEO \psi(2S) \rightarrow \gamma \chi_{C2}
                                 12.4k
                                                                        05A CLEO Repl. by MENDEZ 08
                                                  ADAM
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 $^{111}\,\mathrm{Not}$ independent from other measurements of MENDEZ 08.

$\chi_{c2}(1P)$

$\Gamma(\chi_{c2}(1P) \to \gamma J/\psi(1S))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))$ $\Gamma_{58}/\Gamma\times\overset{\stackrel{}{\Gamma}}{\Gamma}{}^{\psi(25)}_{111}/\Gamma^{\psi(25)}_{11}$ $J/\psi(1S)\pi^{+}\pi^{-}$ VALUE (units 10-2) 5.07±0.13 OUR FIT 5.53±0.17 OUR AVERAGE 08 CLEO $\psi(2S) \rightarrow \gamma \chi_{C2}$ 04B BES $\psi(2S) \rightarrow J/\psi X$ $5.56 \pm 0.05 \pm 0.16$ 12.4k MENDEZ 112 ABLIKIM 1.3k $^{113}\,\mathrm{HIMEL}$ 80 MRK2 $\psi(25) \rightarrow \gamma \chi_{C2}$ • • • We do not use the following data for averages, fits, limits, etc. • • 1.9k 114 ADAM $5.52 \pm 0.13 \pm 0.13$ 05A CLEO Repl. by MENDEZ 08 $^{112}{ m From}$ a fit to the J/ψ recoil mass spectra. 113 The value for B($\psi(2S)~\rightarrow~\gamma\chi_{\rm C2})\times$ B($\chi_{\rm C2}~\rightarrow~\gamma J/\psi(1S))$ reported in HIMEL 80 is derived using B($\psi(2S) \rightarrow J/\psi(1S) \, \pi^+ \, \pi^-$) = (33 \pm 3)% and B($J/\psi(1S) \rightarrow \ell^+ \ell^-$) = 0.138 \pm 0.018. Calculated by us using B($J/\psi(1S) ightarrow \ell^+\ell^-$) = (0.1181 \pm 0.0020). $^{114}\,\mathrm{Not}$ independent from other values reported by ADAM 05A.

$\Gamma(\chi_{c2}(1P) \to \gamma \gamma)/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \to \gamma \chi_{c2}(1P))/\Gamma_{\text{total}}$ $\Gamma_{62}/\Gamma \times \Gamma_{111}^{\psi(2S)}/\Gamma_{\psi(2S)}$

| | | | | | , 111 , |
|---------------------------------|------------|--------------|-----|------|-------------------------------------------------------------|
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID |) | TECN | COMMENT |
| 2.26±0.16 OUR FI | Т | | | | |
| 2.73±0.32 OUR AV | 'ERAGE | | | | |
| $2.68 \pm 0.28 \pm 0.15$ | 333 ± 35 | ECKLUND | 08A | CLEO | $\psi(2S) \rightarrow \gamma \chi_{C2} \rightarrow 3\gamma$ |
| $7.0 \pm 2.1 \pm 2.0$ | | LEE | 85 | CBAL | $\psi(2S) \rightarrow \gamma \chi_{c2}$ |

MULTIPOLE AMPLITUDES IN $\chi_{c2}(1P) ightarrow \gamma J/\psi(1S)$ RADIATIVE DECAY

$a_2 = M2/\sqrt{E1^2 + M2^2 + E3^2}$ Magnetic quadrupole fractional transition amplitude

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|---------------------|------------------------------------------|------|-----------|-----------------------------------------------------------------|
| -10.0 ± 1.5 OUR | AVERAGE | | | | |
| | | | | | $\psi(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $-9.3^{+3.9}_{-4.1}\pm0.6$ | 5.9k ¹³ | ¹⁶ AMBROGIANI | 02 | E835 | $\rho \overline{\rho} \to \ \chi_{c2} \to \ J/\psi \gamma$ |
| -14 \pm 6 | 1.9k ¹ | ¹⁶ ARMSTRONG | 93E | E760 | $p\overline{p} \rightarrow \chi_{c2} \rightarrow J/\psi \gamma$ |
| $-33.3^{+11.6}_{-29.2}$ | 441 1 | ¹⁶ OREGLIA | 82 | CBAL | $\psi(2S) \to \chi_{c1} \gamma \to J/\psi \gamma \gamma$ |
| | | | | | |
| $-\ 7.9\!\pm\ 1.9\!\pm\!0.3$ | 19.8k ¹³ | ¹⁷ ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| ¹¹⁵ From a fit with | floating N | $^{\prime\prime}2$ amplitudes $a_2^{}$ a | nd b | 2, and fi | xed E3 amplitudes $a_3 = b_3 = 0$. |

 $^{^{115}}$ From a fit with floating $\it M2$ amplitudes $\it a_2$ and $\it b_2$, and fixed $\it E3$ amplitudes $\it a_3=\it b_3=\it 0.116$ Assuming $\it a_3=\it 0.$

$a_3 = E3/\sqrt{E1^2 + M2^2 + E3^2}$ Electric octupole fractional transition amplitude

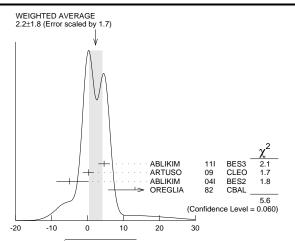
| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | TECN | COMMENT | | |
|----------------------------------------------------------------------------------------------------|---------------------|-------------------------|------|-------------------------------------------------------------|--|--|
| 1.6±1.3 OUR AVERA | GE | · | | | | |
| $1.7 \pm 1.4 \pm 0.3$ | 19.8k ¹¹ | ¹⁸ ARTUSO 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ | | |
| $2.0^{+5.5}_{-4.4}\pm0.9$ | 5908 | AMBROGIANI 02 | E835 | $\rho \overline{\rho} \to \ \chi_{C2} \to \ J/\psi \gamma$ | | |
| 0 +6 -5 | 1904 | ARMSTRONG 93 | E760 | $\rho \overline{p} \to \ \chi_{c2} \to \ J/\psi \gamma$ | | |
| 118 From a fit with floating $M2$ and $E3$ amplitudes a_2 , b_2 , and a_3 , and b_3 . | | | | | | |

MULTIPOLE AMPLITUDES IN $\psi(2S) ightarrow \gamma \chi_{c2}(1P)$ RADIATIVE DECAY

$b_2 = M2/\sqrt{E1^2 + M2^2 + E3^2}$ Magnetic quadrupole fractional transition amplitude

| umphicade | | | | | |
|---------------------------|-----------|------------------------|-------|-----------|---------------------------------------------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | 1 | TECN | COMMENT |
| 2.2±1.8 OUR | AVERAG | E Error includes | scale | factor c | f 1.7. See the ideogram below. |
| $4.6\pm1.0\pm1.3$ | 13.8k | | | BES3 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^-, \gamma K^+ K^-$ |
| $0.2\pm 1.5\pm 0.4$ | 19.8k | ¹²⁰ ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $-5.1^{+5.4}_{-3.6}$ | 721 | ¹¹⁹ ABLIKIM | 041 | BES2 | $\psi(2S) ightarrow \gamma \pi^+ \pi^-$, $\gamma \mathrm{K}^+ \mathrm{K}^-$ |
| $13.2 {}^{+ 9.8}_{- 7.5}$ | 441 | ¹²¹ OREGLIA | 82 | CBAL | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| • • • We do not | use the f | ollowing data for a | verag | es, fits, | limits, etc. • • • |
| $1.0\pm 1.3\pm 0.3$ | 19.8k | ¹²¹ ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| 440 | | | | | |

 $^{^{119}\}mathrm{From}$ a fit with floating $\mathit{M2}$ and $\mathit{E3}$ amplitudes b_2 and b_3 .



 $b_2=M2/\sqrt{E1^2+M2^2+E3^2}$ Magnetic quadrupole fractional transition mplitude (units 10^{-2})

$b_3 = E_3/\sqrt{E_1^2 + M_2^2 + E_3^2}$ Electric octupole fractional transition amplitude

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | 1 | TECN | COMMENT |
|--------------------------|--------|------------------------|-----|------|-----------------------------------------------------------------------------|
| -0.3±1.0 OUR A | VERAGE | | | | |
| $1.5 \pm 0.8 \pm 1.8$ | 13.8k | ¹²² ABLIKIM | 11) | BES3 | $\psi(2S) \rightarrow \gamma \pi^+ \pi^-, \gamma K^+ K^-$ |
| $-0.8\pm1.2\pm0.2$ | 19.8k | ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| $-2.7^{+4.3}_{-2.9}$ | 721 | 122 ABLIKIM | 041 | BES2 | $\psi(2S) ightarrow \ \gamma \pi^+ \pi^-$, $\gamma {\it K}^+ {\it K}^-$ |
| 100 | | | | | |

122 From a fit with floating M2 and E3 amplitudes b_2 and b_3 .

MULTIPOLE AMPLITUDE RATIOS IN RADIATIVE DECAYS $\psi(2S) o \gamma \chi_{c2}(1P)$ and $\chi_{c2} o \gamma J/\psi(1S)$

b_2/a_2 Magnetic quadrupole transition amplitude ratio

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-------|--------------|----|------|----------------------------------------------------|
| -11 ⁺¹⁴ -15 | 19.8k | 123 ARTUSO | 09 | CLEO | $\psi(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |

¹²³ Statistical and systematic errors combined. From a fit with floating M2 amplitudes a_2 and b_2 , and fixed E3 amplitudes $a_3 = b_3 = 0$. Not independent of values for $a_2(\chi_{C2}(1P))$ and $b_2(\chi_{C2}(1P))$ from ARTUSO 09.

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| | | | | (-220 combo.) |

 $^{^{117}}$ From a fit with floating $\it M2$ and $\it E3$ amplitudes $\it a_2,\,\it b_2,\,\it and\,\it a_3,\,\it and\,\it b_3.$

¹²⁰ From a fit with floating M2 and E3 amplitudes a_2 , b_2 , and a_3 , and b_3 .

¹²¹ From a fit with floating M2 amplitudes a_2 and b_2 , and fixed E3 amplitudes $a_3 = b_3 = 0$.

| / [] / [] | $\chi_{c2}($ | 1P | η_c | (2S) |) |
|-------------|--------------|----|----------|------|---|
|-------------|--------------|----|----------|------|---|

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| | | | | . , |

$\eta_c(2S)$

$$I^{G}(J^{PC}) = 0^{+}(0^{-+})$$

Quantum numbers are quark model predictions.

$\eta_c(2S)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|--------------------------|---------------|---------------------------------------------------------------------------------|--|
| 3638.9±1.3 OUR A | | | | | |
| $3638.5 \pm 1.5 \pm 0.8$ | 624 | ¹ DEL-AMO-SA. | .11м ВАВ | $R \gamma \gamma \rightarrow K_S^0 K^{\pm} \pi^{\mp}$ | |
| $3640.5 \pm 3.2 \pm 2.5$ | 1201 | | | $R \gamma \gamma \to K^+ K^- \pi^+ \pi^- \pi^0$ | |
| $3636.1 + 3.9 + 0.7 \\ -4.2 - 2.0$ | 128 | ² VINOKUROVA | 11 BELI | $B^{\pm} \rightarrow K^{\pm}(K_S^0 K^{\pm} \pi^{\mp})$ | |
| $3626\pm 5\pm 6$ | 311 | ³ ABE | 07 BELI | $e^+e^- \rightarrow J/\psi(c\overline{c})$ | |
| $3645.0 \pm 5.5 {}^{+ 4.9}_{- 7.8}$ | 121 ± 27 | AUBERT | 05c BAB | $R e^+ e^- \rightarrow J/\psi c \overline{c}$ | |
| $3642.9 \pm 3.1 \pm 1.5$ | 61 | ASNER | 04 CLE | $0 \gamma \gamma \rightarrow \ \eta_c \rightarrow \ K_S^0 \ K^{\pm} \pi^{\mp}$ | |
| • • • We do not u | se the follow | ing data for avera | ges, fits, li | mits, etc. • • • | |
| 3639 ± 7 | 98 ± 52 | ⁴ AUBERT | 06E BAB | $R B^{\pm} \rightarrow K^{\pm} X_{C\overline{C}}$ | |
| $3630.8 \pm 3.4 \pm 1.0$ | 112 ± 24 | | 04D BAB | $R \gamma \gamma \rightarrow \eta_C(2S) \rightarrow K \overline{K} \pi$ | |
| $3654 \pm 6 \pm 8$ | 39 ± 11 | ⁶ CHOI | 02 BELI | $B \rightarrow KK_SK^-\pi^+$ | |
| 3594 ±5 | | ⁷ EDWARDS | 82c CBA | $L e^+ e^- \rightarrow \gamma X$ | |
| l Ignoring possible interference with continuum. Accounts for interference with non-resonant continuum. From a fit of the J/ψ recoil mass spectrum. Supersedes ABE,K 02 and ABE 04c. From the fit of the kaon momentum spectrum. Systematic errors not evaluated. Superseded by DEL-AMO-SANCHEZ 11M. Superseded by VINOKUROVA 11. Assuming mass of $\psi(25)=3686$ MeV. | | | | | |

$\eta_c(2S)$ WIDTH

| VALUE (MeV) | CL% EVTS | DOCUMENT ID | TECN | COMMENT | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------------------|-----------|---------------------------------------------------------------------------------------------------------|--|--|
| 10 ± 4 OUR | AVERAGE | | | | | |
| $13.4 \pm \ 4.6 \pm 3.2$ | 624 | ⁸ DEL-AMO-SA | 11M BABR | $\gamma \gamma \rightarrow \kappa_S^0 \kappa^{\pm} \pi^{\mp}$ | | |
| $\begin{array}{ccc} 6.6 + & 8.4 + 2.6 \\ - & 5.1 - 0.9 \end{array}$ | 128 | ⁹ VINOKUROVA | 11 BELL | $B^{\pm}_{\overrightarrow{K^{\pm}}(K_S^0K^{\pm}\pi^{\mp})}$ | | |
| $6.3 \pm 12.4 \pm 4.0$ | 61 | ASNER | 04 CLEO | $ \begin{array}{ccc} \gamma\gamma \to & \eta_C \to \\ \kappa_S^0 & \kappa^{\pm} \pi^{\mp} \end{array} $ | | |
| • • • We do not u | se the following | data for averages, | | | | |
| <23 | 90 98 ± 52 | ¹⁰ AUBERT | 06E BABR | $B^{\pm} \rightarrow K^{\pm}X_{C}\overline{C}$ | | |
| 22 ± 14 | | AUBERT | 05 € BABR | $e^+e^- \rightarrow J/\psi c \overline{c}$ | | |
| $17.0 \pm 8.3 \pm 2.5$ | 112 ± 24 | ¹¹ AUBERT | 04D BABR | $\gamma \gamma \rightarrow \eta_C(2S) \rightarrow K\overline{K}\pi$ | | |
| < 55 | 90 39 ± 11 | ¹² CHOI | 02 BELL | $B \xrightarrow{K} K_S K^- \pi^+$ | | |
| <8.0 | 95 | ¹³ EDWARDS | 82c CBAL | $e^+e^- \rightarrow \gamma X$ | | |
| 8 Ignoring possible interference with continuum. 9 Accounts for interference with non-resonant continuum. 10 From the fit of the kaon momentum spectrum. Systematic errors not evaluated. 11 Superseded by DEL-AMO-SANCHEZ 11M. 12 For a mass value of 3654 \pm 6 MeV. Superseded by VINOKUROVA 11. 13 For a mass value of 3594 \pm 5 MeV | | | | | | |

$\eta_c(2S)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|---------------------------------------|------------------------------|------------------|
| $\overline{\Gamma_1}$ | hadrons | not seen | |
| Γ_2 | $K\overline{K}\pi$ | (1.9 ± 1.2) % | |
| Γ_3 | $2\pi^{+} 2\pi^{-}$ | not seen | |
| Γ_4 | $ ho^0 ho^0$ | not seen | |
| Γ_5 | $3\pi^{+} 3\pi^{-}$ | not seen | |
| Γ_6 | $K^{+}K^{-}\pi^{+}\pi^{-}$ | not seen | |
| Γ_7 | $K^{*0}\overline{K}^{*0}$ | not seen | |
| Γ ₈ | $K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | (1.4 ± 1.0) % | |
| Γ۸ | $K + K - 2\pi + 2\pi -$ | not seen | |

| | $K_S^0 K^- 2\pi^+ \pi^- + \text{c.c.}$ | not seen | | |
|-----------------|----------------------------------------|----------|------------------|-----|
| Γ_{11} | $2K^{+}2K^{-}$ | not seen | | |
| Γ_{12} | $\phi\phi$ | not seen | | |
| Γ_{13} | p p | | | |
| | $\gamma \gamma$ | < 5 | $\times 10^{-4}$ | 90% |
| Γ_{15} | $\pi^+\pi^-\eta$ | not seen | | |
| | $\pi^+\pi^-\eta'$ | not seen | | |
| | $K^+K^-\eta$ | not seen | | |
| Γ ₁₈ | $\pi^+ \pi^- \eta_c(1S)$ | not seen | | |

$\eta_c(2S)$ PARTIAL WIDTHS

| $\Gamma(\gamma\gamma)$ | Γ ₁₄ |
|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (keV) | DOCUMENT ID TECN COMMENT |
| • • • We do | not use the following data for averages, fits, limits, etc. ● ● |
| $1.3\!\pm\!0.6$ | 14 ASNER 04 CLEO $\gamma\gamma ightarrow \eta_{ m c} ightarrow \kappa_{ m S}^{ m 0} \kappa^{\pm} \pi^{\mp}$ |
| $B(\eta_{C}(1S))$ the branch | sure $\Gamma(\eta_C(2S)\gamma\gamma)$ B $(\eta_C(2S)\to K\overline{K}\pi)=(0.18\pm0.05\pm0.02)$ $\Gamma(\eta_C(1S)\gamma\gamma)\to K\overline{K}\pi)$. The value for $\Gamma(\eta_C(2S)\to \gamma\gamma)$ is derived assuming that sing fractions for $\eta_C(2S)$ and $\eta_C(1S)$ decays to $K_SK\pi$ are equal and using $\to \gamma\gamma)=7.4\pm0.4\pm2.3$ keV. |

| | | $η_c$ (2S) Γ(i)Γ | (γγ)/I | 「(tota | 1) | |
|-------------------------|-----------------------------------------------------------------------|----------------------------------------------|----------------|----------------|---------------------------------------------------------------------------------------------|--------------------------------------------|
| Γ(2π+2π- |) × Γ(<i>γγ</i>)/ | T _{total} | | TECN | COMMENT | Γ ₃ Γ ₁₄ /Γ |
| <6.5 | | | | | $\gamma \gamma \rightarrow \eta_C(2S)$ | → 2(π ⁺ π ⁻) |
| | $\langle \Gamma(\gamma\gamma)/\Gamma_{\text{tot}} \over \frac{EV}{2}$ | | NT ID | 1 | TECN <u>COMMENT</u> | $\Gamma_2\Gamma_{14}/\Gamma$ |
| 41±4±6 | 62 | 24 15 DEL-AN | ЛО-SA. | 11м Е | $\begin{array}{ccc} FECN & \underline{COMMENT} \\ BABR & \gamma \gamma \to & K \end{array}$ | ⁰ κ [±] π [∓] |
| ¹⁵ Not indep | endent from ot | her measuremen | ts repor | ted in I | DEL-A MO-SA NC | HEZ 11м. |
| • | +π ⁻) × Γ(| γγ)/Γ _{total} CUMENT ID | TECN | COM | IMENT | Γ ₆ Γ ₁₄ /Γ |
| <5.0 | 90 UE | HARA 08 | BELL | $\gamma\gamma$ | $\rightarrow \eta_C(2S) \rightarrow K$ | $+K^{-}\pi^{+}\pi^{-}$ |
| • | $+\pi^-\pi^0)\times$ | $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ | r ID | TE | CN COMMENT | Γ ₈ Γ ₁₄ /Γ |
| 30±6±5 | 1201 | 16 DEL-AMO |) CA 1: | | | |
| 30±0±3 | 1201 | DLL-AIVIC | <i>)</i> -энт. | IM BA | BR $\gamma \gamma \rightarrow K^{\top}$ | $K^{-}\pi^{+}\pi^{-}\pi^{0}$ |
| | | | | | BR $\gamma\gamma \to K^+$ DEL-AMO-SANC | |
| ¹⁶ Not indep | | her measuremen | ts repor | ted in I | | |

$\eta_c(2S) \; \Gamma(\mathrm{i})\Gamma(\gamma\gamma)/\Gamma^2(\mathrm{total})$

| A <i>LUE</i> (units 10 ⁻⁸) | CL% | DO CUMENT ID | TECN | COMMENT |
|----------------------------------------|-----------------------------------|--------------------------------------------------------------------------------|---------------|--------------------------------------------------|
| < 5.6 | ₉₀ 17,18 | ^{,19} AMBROGIANI 0 | 1 E835 | $\overline{\rho} \rho \rightarrow \gamma \gamma$ |
| • • We do not | use the followin | g data for averages, | fits, limits, | etc. • • • |
| < 8.0 | 9017,18 | , ²⁰ AMBROGIANI 0 , ²⁰ AMBROGIANI 0 | 1 E835 | $\overline{\rho} \rho \rightarrow \gamma \gamma$ |
| <12.0 | 90 18 | ^{,20} ambrogiani 0 | 1 E835 | $\overline{p}p \rightarrow \gamma \gamma$ |
| 18 For a total w 19 For the reson | idth Γ=5 MeV. ance mass region | f of ARMSTRONG 9 $3589-3599 \text{ MeV}/c^2$ $3575-3660 \text{ MeV}/c^2$ | | AMBROGIANI 01 analysis |

$\eta_c(2S)$ BRANCHING RATIOS

| $\Gamma(\text{hadrons})/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|-----------------|-----------------------------------------|-------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| not seen | ABREU | 980 DLPH | $e^+ e^- \rightarrow e^+ e^-$ | - + hadrons |
| ● ● We do not use the | following data for av | erages, fits, l | limits, etc. • • • | |
| seen | ²¹ EDWARDS | 82c CBAL | $e^+e^- ightarrow \gamma {\sf X}$ | |
| ²¹ For a mass value of 3 | 594 ± 5 MeV | | | |
| $\Gamma(K\overline{K}\pi)/\Gamma_{total}$ | | | | Γ ₂ /Γ |
| VALUE (units 10^{-2}) EV | TS DOCUMENT ID | TECN | COMMENT | |
| 1.9±0.4±1.1 59±1 | 2 ²² AUBERT | 08AB BAB | $R B \rightarrow \overline{\eta_c(2S)}$ | $K \rightarrow \overline{K} \overline{K} \pi K$ |
| • • • We do not use the | | | | |
| seen 39 ± 1 | 1 ²³ CHOI | 02 BELL | $B \rightarrow KK_SK$ | $-\pi^+$ |
| ²² Derived from a meas $[B(B^+ \rightarrow \eta_C K^+) + \eta_C(25) K^+) = (3.4 \pm 0.77 + 0.56) \times (6.88 \pm 0.77 + 0.66) \times (23)$ For a mass value of 3 | $	imes$ B $(\eta_C ightarrow K \overline{K} \pi)]$ \pm 1.8) $	imes$ 10 $^{-4}$, and $	imes$ 10 $^{-5}$ | = (9.6 + 2.0) | \pm 2.5)% and us | sing B(B^+ \rightarrow |

 $\eta_c(2S)$, $\psi(2S)$

| $\Gamma(2\pi^+2\pi^-)/\Gamma_{tot}$ | ai | | | | | Гз/Г |
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| /ALUE | | <u>DO CUMENT ID</u> UEHARA | 08 | TECN BELL | | C) |
| | | UEHAKA | 00 | DELL | $\gamma \gamma \rightarrow \eta_C(2)$ | _ |
| $\Gamma(ho^0 ho^0)/\Gamma_{ m total}$ | | DO CUMENT ID | | TECN | COMMENT | Γ ₄ /Γ |
| ot seen | | ABLIKIM | 11н | BES3 | $\psi(2S) \rightarrow \gamma$ | $2\pi^{+} 2\pi^{-}$ |
| $\Gamma(K^+ K^- \pi^+ \pi^-)$ |)/Γ _{total} | | | | | Γ_6/Γ |
| ALUE | | DO CUMENT ID | | | COMMENT | |
| ot seen | <u>.</u> | UEHARA | 80 | BELL | $\gamma \gamma \rightarrow \eta_C(2)$ | 5) |
| Γ (K+ K-π+π- 1 VALUE | π ^υ)/Γ(<i>ΚΤ</i> Κ | π) <u>DOCUMENT ID</u> | 7 | ECN / | COMMENT | Γ_8/Γ_2 |
| 0.73±0.17±0.17 | 1201 2 | DEL-AMO-SA | .11M E | BABR ~ | $\gamma \gamma \rightarrow K^+ K^-$ | $-\pi^{+}\pi^{-}\pi^{0}$ |
| ²⁴ We have multipli | | | | | | |
| | | ctor 1/3 to obta urements reported | | | | |
| $-(K^{*0}\overline{K}^{*0})/\Gamma_{\text{tota}}$ | | | | | | Γ ₇ /Γ |
| /ALUE | | OCUMENT ID | TEC | N CON | MENT | |
| ot seen | А | BLIKIM 11 | н ВЕ | $\psi(2)$ | $(2S) \rightarrow \gamma K^{+} I$ | $\kappa^-\pi^+\pi^-$ |
| Γ(2 <i>K</i> +2 <i>K</i> -)/Γ _{to} | otal | | | | | Γ_{11}/Γ |
| <i>VALUE</i> n ot seen | | <u>DO CUMENT ID</u> UEHARA | 08 | TECN BELL | | <u>s)</u> |
| F(+ 4) /F | | | | | 77 761- | |
| Γ (φφ)/Γ_{total} ⁄ALUE | | OCUMENT ID | TEC | N CON | | Γ ₁₂ /Γ |
| ot seen | А | BLIKIM 11 | н ВЕ | $\psi(2)$ | $(2S) \rightarrow \gamma K^{+} I$ | K-K+K- |
| $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ | | | | | | Γ ₁₄ /Γ |
| /ALUE <5 × 10 ⁻⁴ | <u>CL%</u> | 25 WICHT | | | COMMENT D+ V+ | |
| <5 × 10 ⁻⁴ • • • We do not us | 90 e the followin | | 08 es, fits | BELL , limits, | $B^{\pm} \rightarrow K^{\pm}$ etc. • • • | $\gamma\gamma$ |
| not seen | | AMBROGIAI | VI 01 | E835 | $\overline{p}p \rightarrow \gamma \gamma$ | |
| | | | | | | |
| ²⁵ WICHT 08 report which we divide | by our best v | alue B($B^+ 	o \eta$ | 85 E [B(B ⁻¹ C (2S) I | $(+) \rightarrow \eta_c$ (+) = 0 (+) | 3.4 × 10 ⁻⁴ . | |
| ²⁵ WICHT 08 report which we divide | ts $[\Gamma(\eta_C(2S))]$ by our best v | $ ightarrow \gamma \gamma)/\Gamma_{	ext{total}}] ightarrow alue B(B^+ ightarrow \eta$ | 85 E [B(B ⁻¹ C (2S) I | $\begin{array}{c} + \rightarrow \eta_c \\ < + \rangle = 1 \\ \hline \\ \text{CHING} \\ c (2S) \end{array}$ | $(2S) K^+)] < 3.4 \times 10^{-4}$ RATIOS | 0.18×10 ⁻⁶ |
| ²⁵ WICHT 08 reporting which we divide $\eta_c(2S) \rightarrow 2\pi^+$ | ts $[\Gamma(\eta_C(2S))]$ by our best v | $ ightarrow \gamma \gamma)/\lceil t_{	ext{total}} \rceil ightarrow \gamma \gamma)/\lceil t_{	ext{total}} \rceil ightarrow \gamma$ $ ightarrow PARTICLE B$ $ ightarrow \Gamma (\psi(2S)) ightarrow 0$ $ ightarrow DOCUMENT ID$ | 85 $\langle [B(B^{+})]^{C}(2S) H$ RANC $\rightarrow \gamma \eta$ | $\begin{array}{c} + \rightarrow \eta_c \\ + \rightarrow = 1 \\ \hline \\ \text{HING} \\ c \\ (2S) \end{array}$ | $(2S) K^+)] < 3.4 \times 10^{-4}$ | 0.18×10 ⁻⁶ |
| 25 WICHT 08 report which we divide $\eta_c(2)$ $\Gamma(\eta_c(2S) \rightarrow 2\pi^+)$ (41.6×10^{-6}) | ts $[\Gamma(\eta_C(2S))]$ by our best v 2S) CROSS $2\pi^-)/\Gamma_{\text{tot}}$ | $ ightarrow \gamma \gamma)/\lceil t_{\text{total}} \rceil ightarrow \gamma \gamma)/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma$ | 85 $ \begin{array}{c} (B(B^{+})) \\ (C(2S)) \\ (C$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ (+) = 1 \\ \hline \text{HING} \\ c(2S)) \\ I \\ \hline \frac{TECN}{CLEO} \end{array}$ | $\begin{array}{l} (2S) \ K^+)] < \\ 3.4 \times 10^{-4}. \end{array}$ $\begin{array}{l} \textbf{RATIOS} \\ / \Gamma_{\textbf{total}} \\ \textbf{73} / \Gamma \times \Gamma_{113}^{\psi(2)} \\ \psi(2S) \rightarrow \gamma \end{array}$ | 5)/Γψ(25) 2π+2π- |
| ²⁵ WICHT 08 reporting the position of the position with the divide $\eta_c(25) = 2\pi^+$ WALUE | ts $[\Gamma(\eta_C(2S))]$ by our best v 2S) CROSS $2\pi^-)/\Gamma_{\text{tot}}$ $\frac{CL\%}{90}$ 2S)) = 14 Me | $ ightarrow \gamma \gamma)/\lceil t_{\text{total}} \rceil ightarrow \gamma \gamma)/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \gamma \rangle/\lceil t_{\text{total}} \rceil ightarrow \gamma$ $ ightarrow \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma \gamma$ | 85 $ \begin{array}{c} (B(B^{+})) \\ (C(2S)) \\ (C$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ (+) = 1 \\ \hline \text{HING} \\ c(2S)) \\ I \\ \hline \frac{TECN}{CLEO} \end{array}$ | $\begin{array}{l} (2S) \ K^+)] < \\ 3.4 \times 10^{-4}. \end{array}$ $\begin{array}{l} \textbf{RATIOS} \\ / \Gamma_{\textbf{total}} \\ \textbf{73} / \Gamma \times \Gamma_{113}^{\psi(2)} \\ \psi(2S) \rightarrow \gamma \end{array}$ | 5)/Γψ(25) 2π+2π- |
| 25 WICHT 08 report which we divide $\eta_{c}(25) \rightarrow 2\pi^{+}$ $(14.6 \times 10^{-6}) \times 10^{-6}$ 26 Assuming $\Gamma(\eta_{c}(25)) \times 10^{-6}$ of limits on widt | ts $[\Gamma(\eta_C(2S))]$ by our best v 2S) CROSS $2\pi^-)/\Gamma_{\text{tot}}$; $\frac{cL\%}{90}$ 2S)) = 14 Meh. | $\gamma \gamma)/\Gamma_{\text{total}}] \times \text{alue B}(B^+ \to \eta)$ -PARTICLE B al $\times \Gamma(\psi(2S))$ DOCUMENT ID 26 CRONIN-HE V. CRONIN-HE | 85 $ \begin{array}{c} (B(B^{+} + C(2S))) \\ (B(2S) + C(2S)) $ | $\begin{array}{c} + \rightarrow \eta_C \\ (+) = \vdots \\ \text{HING} \\ c(2S)) \\ \frac{TECN}{\text{CLEO}} \\ \text{Cleo} \\ \text{Cleo} \end{array}$ | $\begin{array}{l} (2S) \ K^+)] < \\ 3.4 \times 10^{-4}. \end{array}$ RATIOS $\begin{array}{l} /\Gamma_{\text{total}} \\ 7_3 /\Gamma \times \Gamma_{113}^{\psi(2)} \\ \frac{COMMENT}{\psi(2S)} \to \gamma \end{array}$ es the analytic | 5)/Γψ(25) 2π+2π- |
| 25 WICHT 08 report which we divide $\eta_c(25) \rightarrow 2\pi^+$ $(ALUE) = (24.6 \times 10^{-6})^{26}$ Assuming $\Gamma(\eta_c(25) \rightarrow \rho^0 \rho^0)$ | ts $[\Gamma(\eta_c(2S))]$ by our best v 2S) CROSS $2\pi^-$)/ Γ_{tot} : $\frac{cL\%}{90}$ $(2S)$) = 14 Meh. | $\gamma \gamma)/\Gamma_{\text{total}}] \times$ alue B($B^+ \rightarrow \eta$) -PARTICLE B $\gamma \gamma | 85 $\langle [B(B^{+})] \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ (+) = 1 \\ \hline \\ \text{HING} \\ \\ c(2S)) \\ \\ \frac{TECN}{\text{CLEO}} \\ (10 \text{ give} \\ 5)) / \Gamma_{\text{tc}} \end{array}$ | $\begin{array}{l} (2S) \ K^+)] < \\ 3.4 \times 10^{-4}. \end{array}$ RATIOS $\begin{array}{l} \Gamma_3/\Gamma \times \Gamma_{113}^{\psi(2)} \\ (2S) \rightarrow \gamma \\ \text{es the analytic} \end{array}$ | 0.18×10^{-6} $\frac{\text{S}}{\text{F}} / \text{F} \psi(25)$ $\frac{2\pi^{+} 2\pi^{-}}{\text{dependence}}$ |
| which we divide $\eta_c(2S) \to 2\pi^+$ VALUE <14.6 × 10 ⁻⁶ 26 Assuming $\Gamma(\eta_c(2S) \to \rho^0 \rho^0)$ | ts $[\Gamma(\eta_c(2S))]$ by our best v 2S) CROSS $2\pi^-$)/ Γ_{tot} : $\frac{cL\%}{90}$ $(2S)$) = 14 Meh. | $\gamma \gamma)/\Gamma_{\text{total}}] \times$ alue B($B^+ \rightarrow \eta$) -PARTICLE B $\gamma \gamma | 85 $\langle [B(B^{+})] \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle \rangle$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ (+) = 1 \\ \hline \\ \text{HING} \\ \\ c(2S)) \\ \\ \frac{TECN}{\text{CLEO}} \\ (10 \text{ give} \\ 5)) / \Gamma_{\text{tc}} \end{array}$ | $(2S) K^+]] < 3.4 \times 10^{-4}$. RATIOS /\(\Gamma_{\text{total}} \frac{\psi_0^{\psi_2}}{\Gamma_{\text{total}} \frac{\psi_0^{\psi_2}}{\psi_2}} \frac{\psi_0^{\psi_2}}{\psi_2} \frac{\psi_2^{\psi_2}}{\psi_2} \psi_2^ | 0.18×10^{-6} $(S)_{\Gamma} \psi(2S)$ $(2\pi^+ 2\pi^-)$ $(E)_{\Gamma} \psi(2S)$ |
| 25 WICHT 08 report which we divide $\eta_c(25) \rightarrow 2\pi^+$ $\langle 14.6 \times 10^{-6} \rangle = 26 \text{ Assuming } \Gamma(\eta_c(25) \rightarrow \rho^0 \rho^0)$ $\langle 14.0 \times 10^{-6} \rangle = 26 \text{ Assuming } \Gamma(\eta_c(25) \rightarrow \rho^0 \rho^0)$ $\langle 12.7 \times 10^{-7} \rangle = 26 \text{ MALUE}$ | ts $[\Gamma(\eta_{C}(2S))]$ by our best v 2S) CROSS $\frac{2\pi^{-}}{1}/\Gamma_{\text{total}}$ $\frac{CL\%}{90}$ $\frac{CL\%}{90}$ | $\gamma \gamma)/\Gamma_{\rm total}] \times \Gamma \gamma \gamma)/\Gamma_{\rm total}] \times \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma \Gamma $ | 85 $\langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B(B^{+})] \rangle \langle [B$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - \rightarrow \eta_{c} \\ - 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| 25 WICHT 08 report which we divide $\eta_c(2s) \rightarrow 2\pi^+$ $\langle 14.6 \times 10^{-6} \rangle$ 26 Assuming $\Gamma(\eta_c(2s) \rightarrow \rho^0 \rho^0)$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ | ts $[\Gamma(\eta_{C}(2S))]$ by our best v 2S) CROSS $2\pi^{-}$ $/\Gamma_{total}$ $\frac{CL\%}{90}$ 2S)) = 14 Me h. $\frac{CL\%}{90}$ $\frac{CL\%}{90}$ | $\gamma \gamma)/\Gamma_{\text{total}}] \times \gamma 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| 25 WICHT 08 report which we divide $\eta_c(2S) \rightarrow 2\pi^+$ $\langle 14.6 \times 10^{-6} \rangle$ 26 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 14.6 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ $\langle 16.7 \times 10^{-7} \rangle$ | ts $[\Gamma(\eta_{C}(2S))]$ by our best v 2S) CROSS $2\pi^{-}$ $/\Gamma_{total}$ $\frac{CL\%}{90}$ 2S)) = 14 Me h. $\frac{CL\%}{90}$ $\frac{CL\%}{90}$ | $\gamma \gamma)/\Gamma_{\text{total}}] \times \gamma 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$\begin{array}{l} (2S) \ K^+)] < \\ 3.4 \times 10^{-4}. \end{array}$ RATIOS $\begin{array}{l} /\Gamma_{\text{total}} \\ 7_3 / \Gamma \times \Gamma_{113} \\ \hline 20MMENT \\ \psi(2S) \rightarrow \gamma \end{array}$ es the analytic $\begin{array}{l} (4) \Gamma_4 / \Gamma \times \Gamma_{113} \\ \hline 20MMENT \\ \psi(2S) \rightarrow \gamma \end{array}$ $\begin{array}{l} (4) \Gamma_4 / \Gamma \times \Gamma_{113} \\ \hline 20MMENT \\ \psi(2S) \rightarrow \gamma \end{array}$ $\begin{array}{l} /\Gamma_{\text{total}} \\ /\Gamma_{\text{total}} \end{array}$ | $5)/\Gamma\psi(25)$ $2\pi^{+}2\pi^{-}$ dependence $5)/\Gamma\psi(25)$ $2\pi^{+}2\pi^{-}$ |
| 25 WICHT 08 report which we divide $\eta_c(2S) \rightarrow 2\pi^+$ $<14.6 \times 10^{-6}$ 26 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ VALUE $<12.7 \times 10^{-7}$ $\Gamma(\eta_c(2S) \rightarrow 3\pi^+$ VALUE $<13.2 \times 10^{-6}$ | ts $[\Gamma(\eta_{C}(2S))]$ by our best v 2S) CROSS $2\pi^{-}$ $/\Gamma_{tota}$ 2S) $= 14$ Meh. 0) $/\Gamma_{total} \times$ $= \frac{ct\%}{90}$ $= 3\pi^{-}$ $/\Gamma_{total}$ | $\gamma \gamma)/\Gamma_{\text{total}} \times \gamma \gamma)/\Gamma_{\text{total}} \times \gamma \gamma)/\Gamma_{\text{total}} \times \gamma$ PARTICLE B $\gamma \gamma | 85 $(B(B^{+})^{-})^{-}$ RANC $\rightarrow \gamma \eta$ NN10 $(\eta \eta_{c}(2S)^{-})^{-}$ 11H $\rightarrow \gamma \eta$ $(TE)^{-}$ CL | $\begin{array}{c} + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow \eta_{c} \\ + \rightarrow 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| 25 WICHT 08 report which we divide $\eta_c(2)$ $\Gamma(\eta_c(2S) \to 2\pi^+)$ $(ALUE)$ $\sim 14.6 \times 10^{-6}$ 26 Assuming $\Gamma(\eta_c(2S) \to \rho^0 \rho^0)$ $(ALUE)$ $\sim 12.7 \times 10^{-7}$ $\Gamma(\eta_c(2S) \to 3\pi^+)$ $\sim 13.2 \times 10^{-6}$ 27 Assuming $\Gamma(\eta_c(2S) \to 6\pi^+)$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 10^{-6}$ $\sim 13.2 \times 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CRONIN-HEN10 | 85 RANC $C(2S)I$ RANC $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ $T(2S)I$ | $\begin{array}{c} + \rightarrow \eta_{c} \\ (X^{+}) = \vdots \\ \end{array}$ $\begin{array}{c} + \rightarrow \eta_{c} \\ (X^{+}) = \vdots \\ \end{array}$ $\begin{array}{c} - 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| 25 WICHT 08 report which we divide $\eta_c(2S) \rightarrow 2\pi^+$ $\langle 14.6 \times 10^{-6} \rangle$ 26 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ $\langle 12.7 \times 10^{-7} \rangle$ $\langle 12.7 \times 10^{-7} \rangle$ $\langle 13.2 \times 10^{-6} \rangle$ 27 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ $\langle 13.2 \times 10^{-6} \rangle$ 27 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ $\langle 13.2 \times 10^{-6} \rangle$ 28 Assuming $\Gamma(\eta_c(2S) \rightarrow \rho^0 \rho^0)$ | ts $[\Gamma(\eta_{C}(2S))$ by our best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume best volume 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| E/ (0.5) 1/4 | - K- 0 + 0 | -> /= | F(/ (0.5) | (2.51) | |
|------------------------------------------------------------------------|-------------------------------------------------|--------------------------------------|------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------|
| $\Gamma(\eta_c(2S) \to K^+$ | K = 2π = 2 | π^-)/l _{total} > | < 1 (ψ(2S) - | $ ightarrow \gamma \eta_c(2S))/$ $\Gamma_0/\Gamma 	imes \Gamma$ | $\psi^{(2S)}/\Gamma^{\psi(2S)}$ |
| VALUE | | DOCUMENT ID | TECN | | 113 / |
| <9.7 × 10 ⁻⁶ 30 Assuming $\Gamma(\eta_C)$ of limits on wide | (2S)) = 14 N | CRONIN-HEN MeV. CRONIN- | | $\psi(2S) \rightarrow \gamma K$ 0 gives the anal | |
| $\Gamma(\eta_c(2S) \to K_S^0$ | $K^-2\pi^+\pi$ | - + c.c.)/Γ _{to} | $_{\rm tal} \times \Gamma(\psi)$ | $2S) \rightarrow \gamma \eta_c(2)$ | <i>S</i>))/ |
| Γ _{total} | | ,, | | $\Gamma_{10}/\Gamma \times \Gamma$ | $\frac{\psi(2S)}{113} / \Gamma \psi(2S)$ |
| <u>VALUE</u> <u>C</u> <15.2 × 10 ^{−6} 9 | | UMENT ID ONIN-HEN10 | | $\gamma K_S^0 \rightarrow \gamma K_S^0 K_S^0$ | $-2\pi^{+}\pi^{-}+c.c.$ |
| 31 Assuming $\Gamma(\eta_{C}$ | (2S)) = 14 N | | | 9 | |
| of limits on wid $\Gamma(\eta_c(2S) \to \phi\phi$ | lth. | | | | |
| (100) // | ,, 1011 | • | , | $\Gamma_{12}/\Gamma \times \Gamma$ | $_{113}^{\psi(2S)}/\Gamma^{\psi(2S)}$ |
| <7.8 × 10 ⁻⁷ | | ABLIKIM | 11H BES3 | $\psi(2S) \rightarrow \gamma F$ | (+ K - K + K - |
| $\Gamma(\eta_c(2S) \to \pi^+$ | π ⁻ n) /Γ | | | , , , | |
| VALUE | // // to | <u>DOCUMEN</u> | | | $\frac{\psi(2S)}{113} / \Gamma^{\psi(2S)}$ |
| <4.3 × 10 ⁻⁶ | 90 | 32 CRONIN | | LEO $\psi(2S)$ — | |
| 32 Assuming $\Gamma(\eta_C$ of limits on wid | (25)) = 14 M lth. | vleV. CRONIN- | HENNESSY 1 | 0 gives the anal | ytic dependence |
| $\Gamma(\eta_c(2S) \to \pi^+$ | | $_{\rm stal} \times \Gamma(\psi(2$ | $S) \rightarrow \gamma \eta_c (2)$ | 2S))/Γ _{total} | |
| (, | , , , | | , , , , , , | $\Gamma_{16}/\Gamma \times \Gamma$ | $\frac{\psi(2S)}{113}/\Gamma^{\psi(2S)}$ |
| VALUE <14.2 × 10 ⁻⁶ | <u>CL%</u> 90 | DO CUMEN | | LEO $\psi(2S)$ — | T |
| 33 Assuming $\Gamma(\eta_C)$ | | | | | |
| of limits on wid | ith. | | | | |
| $\Gamma(\eta_c(2S) \to K^+$ | $(K^-\eta)/\Gamma_{\rm to}$ | $_{ m otal}$ $	imes$ $\Gamma(\psi(2$ | $(2S) \rightarrow \gamma \eta_c$ | 25))/F _{total} | ψ(25) 113 /Γψ(25) |
| VALUE | <u>CL%</u> | <u>DO CUMEN</u> | | I17/IXI <u>ECN</u> <u>COMMEN</u> | 113 // (/ |
| <5.9 × 10 ⁻⁶ | 90 | 34 CRONIN | | LEO $\psi(2S)$ — | |
| 34 Assuming $\Gamma(\eta_C)$ of limits on wid | (2S))=14 Nith. | vleV. CRONIN- | HENNESSY 1 | 0 gives the anal | ytic dependence |
| $\Gamma \big(\eta_c(2S) \to \pi^+$ | $\pi^- \eta_c(1S)$ | $)/\Gamma_{total} \times \Gamma$ | $(\psi(2S) \rightarrow 0$ | $\gamma \eta_c(2S))/\Gamma_{to}$ | otal |
| VALUE | CL W | DO CUMENT UP | TECN | | $_{113}^{\psi(25)}/\Gamma^{\psi(25)}$ |
| <1.7 × 10 ⁻⁴ | 90 3 | DOCUMENT ID 5 CRONIN-HEI | | $\psi(2S) \rightarrow \gamma$ | $\pi^+\pi^-\eta_c(1S)$ |
| 35 Assuming $\Gamma(\eta_C)$ | (2S)) = 14 M | vleV. CRONIN- | HENNESSY 1 | 0 gives the anal | ytic dependence |
| Of Hillies of Wile | | (a.C) DEE | EDENCES | | |
| | | $\eta_c(2S)$ REF | EKENCES | | |
| DEL-AMO-SA 11M | PR D84 091102 PR D84 012004 | P. del A | kim et al. imo Sanchez et | al. (B) | ES III Collab.) NBAR Collab.) |
| CRONIN-HEN 10 | PL B706 139 PR D81 052002 PR D78 012006 | D. Cron | kurova et al. in-Hennessey et :rt et al. | al. (B | ELLE Collab.) CLEO Collab.) NBAR Collab.) |
| UEHARA 08 I WICHT 08 I | EPJ C53 1 PL B662 323 | S. Ueha J. Wichi | ra et al. t et al. | (B (B | ELLE Collab.) ELLE Collab.) |
| AUBERT 06E I | PRL 98 082001 PRL 96 052002 | B. Aube | rt et al. | (BA | ELLE Collab.) |
| ABE 04G I | PR D72 031101 PR D70 071102 PRL 92 142001 | K. Abe | | `(B | NBAR Collab.) ELLE Collab.) ELEO Collab.) |
| AUBERT 04D I ABE,K 02 I | PRL 92 142002 PRL 89 142001 | B. Aube K. Abe | rt et al. | (B) (B | NBAR Collab.) ELLE Collab.) |
| AMBROGIANI 01 I | PRL 89 102001 PR D64 052003 | M. Amb | noi et al. progiani et al. | (FNAL | ELLE Collab.) E835 Collab.) |
| ARMSTRONG 95F I | PL B441 479 PR D52 4839 SLAC 282 | P. Abrei T.A. Ar R.A. Lei | m strong et al. | | LPHI Collab.) RR, GENO+) (SLAC) |
| | PRL 48 70 | | ards et al. | (CIT, H | ARV, PRIN+) |
| $\psi(2S)$ | | | $I^{G}(J^{PC})$ | = 0-(1 | |
| | Review on | "g/y(25) and | v branchine | g ratios" befo | re the |
| $\chi_{c0}(1P)$ | | $\psi(z \sigma)$ and ; | AC DIAIICIIIII | Siatios Delo | c inc |
| | | | | | |

3686.109+0.012 OUR FIT
3686.108+0.011 OUR AVERAGE

AAIJ

 $m_{\psi(3770)} - m_{\psi(2S)}$

VALUE (MeV)

 $3686.12 \pm 0.06 \pm 0.10$

 $\psi(2S)$ MASS

OUR FIT includes measurements of $m_{\psi(25)}$, $m_{\psi(3770)}$, and

DOCUMENT ID TECN COMMENT

12H LHCB $p\,p
ightarrow \,J/\psi\,\pi^+\,\pi^-\,X$

| | | | | | | $\psi(23)$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| | | | Гаа | <u>=-</u> = + | $(1.8 \pm 0.6) \times 10^{-4}$ | S=2.8 |
| | 114±0.007 ⁺ 0.011 1AI | NASHIN 12 KEDR $e^+e^- \rightarrow \text{hadrons}$ | Г ₃₀ Г ₃₁ | = 0 = 0 | $(2.8 \pm 0.9) \times 10^{-4}$ | 3-2.0 |
| | | JLCHENKO 03 KEDR $e^+e^- \rightarrow \text{hadrons}$ | Γ ₃₂ | $\Xi(1530)^0\overline{\Xi}(1530)^0$ | < 8.1 × 10 ⁻⁵ | CL=90% |
| | | RTAMONOV 00 OLYA $e^+e^- \rightarrow \text{hadrons}$ | Γ ₃₃ | $\Omega - \overline{\Omega} +$ | $< 7.3 \times 10^{-5}$ | CL=90% |
| | | RMSTRONG 93B E760 $\overline{p}p \rightarrow e^+e^-$ | Γ ₃₄ | $\pi^0 p \overline{p}$ | $(1.50\pm0.08)\times10^{-4}$ | S=1.1 |
| | We do not use the following data t | _ | Γ ₃₅ | $N_1^*(1440)\overline{p} \rightarrow \pi^0 p\overline{p}$ | $(8.1 \pm 0.8) \times 10^{-5}$ | |
| | | HOLENTZ 80 OLYA e ⁺ e ⁻ | Г ₃₆ | $\pi^0 f_0(2100) \rightarrow \pi^0 p \overline{p}$ | $(1.1 \pm 0.4) \times 10^{-5}$ | |
| + F | rom the scans in 2004 and 2006. All $+0.002$ MeV, where the third is | NASHIN 12 reports the value 3686.114 \pm 0.007 \pm uncertainty is due to assumptions on the interfer- | Γ ₃₇ | $\eta p \overline{p}$ | $(5.7 \pm 0.6) \times 10^{-5}$ $(1.2 \pm 0.4) \times 10^{-5}$ | |
| er | 0.011 ± 0.012 MeV, where the third to | onic continuum. We combined the two systematic | Г ₃₈ Г ₃₉ | $\eta f_0(2100) \rightarrow \eta p \overline{p}$ $N^*(1535) \overline{p} \rightarrow \eta p \overline{p}$ | $(4.4 \pm 0.7) \times 10^{-5}$ | |
| uı | ncertainties. | | Γ ₄₀ | $\omega p \overline{p}$ | $(6.9 \pm 2.1) \times 10^{-5}$ | |
| − R re | eanalysis of ZHOLENTZ 80 using n ctions (KURAEV 85). | ew electron mass (COHEN 87) and radiative cor- | Γ ₄₁ | $\phi p \overline{p}$ | < 2.4 × 10 ⁻⁵ | CL=90% |
| 3 N | lass central value and systematic e | error recalculated by us according to Eq. (16) in | Γ ₄₂ | $\pi^+\pi^-\rho\overline{\rho}$ | $(6.0 \pm 0.4) \times 10^{-4}$ | |
| | RMSTRONG 93B, using the value for uperseded by ARTAMONOV 00. | or the $J/\psi(1S)$ mass from AULCHENKO 03. | Γ ₄₃ | $p \overline{n} \pi^-$ or c.c. | $(2.48\pm0.17)\times10^{-4}$ | |
| . 2 | perseded by ARTAMONOV 00. | | Γ ₄₄ | $\rho \overline{n} \pi^- \pi^0$ | $(3.2 \pm 0.7) \times 10^{-4}$ | |
| | m _{w(25} | $-m_{J/\psi(1S)}$ | Γ ₄₅ | $2(\pi^{+}\pi^{-}\pi^{0})$ | $(4.8 \pm 1.5) \times 10^{-3}$ | |
| | • | | Γ ₄₆ | $\eta \pi^+ \pi^- \ \eta \pi^+ \pi^- \pi^0$ | < 1.6 × 10 ⁻⁴ | CL=90% |
| | : (MeV) <u>DOCUM.</u> 88±0.028 OUR AVERAGE | ENT ID TECN COMMENT | Γ ₄₇ Γ ₄₈ | $\eta \pi^{+} \pi^{-} \pi^{-}$ $2(\pi^{+} \pi^{-}) \eta$ | $(9.5 \pm 1.7) \times 10^{-4}$ $(1.2 \pm 0.6) \times 10^{-3}$ | |
| | _ | ENKO 03 KEDR $e^+e^- \rightarrow \text{hadrons}$ | Γ ₄₉ | $\eta' \pi^{+} \pi^{-} \pi^{0}$ | $(4.5 \pm 2.1) \times 10^{-4}$ | |
| 589.7 | ± 1.2 LEMOI | | Γ ₅₀ | $\omega \pi^+ \pi^-$ | $(7.3 \pm 1.2) \times 10^{-4}$ | S=2.1 |
| | 7 ±0.13 ⁵ ZHOLE | | Γ ₅₁ | $b_1^{\pm}\pi^{\mp}$ | $(4.0 \pm 0.6) \times 10^{-4}$ | S=1.1 |
| 588.7 • • • | ± 0.8 LUTH We do not use the following data t | 75 MRK1 For averages, fits, limits, etc. • • • | Γ ₅₂ | $b_{1}^{0}\pi^{0}$ | $(2.4 \pm 0.6) \times 10^{-4}$ | |
| 588 | ± 1 BAI | 98E BES e ⁺ e ⁻ | Γ ₅₃ | $\omega f_2(1270)$ | $(2.2 \pm 0.4) \times 10^{-4}$ | |
| | edundant with data in mass above. | 700 DES C C | Γ ₅₄ | $\pi^+\pi^-K^+K^-$ | $(7.5 \pm 0.9) \times 10^{-4}$ | S=1.9 |
| 6 S | ystematic errors not evaluated. | | [₅₅ | $\rho^0 K^+ K^-$ | $(2.2 \pm 0.4) \times 10^{-4}$ | |
| | | | Γ ₅₆ | $K^*(892)^0 \overline{K}_2^*(1430)^0$ | $(1.9 \pm 0.5) \times 10^{-4}$ | |
| | $\psi(2$ | S) WIDTH | Γ ₅₇ Γ ₅₈ | $K^{+} K^{-} \pi^{+} \pi^{-} \eta$ $K^{+} K^{-} 2(\pi^{+} \pi^{-}) \pi^{0}$ | $(1.3 \pm 0.7) \times 10^{-3}$ $(1.00\pm 0.31) \times 10^{-3}$ | |
| VALUE | (keV) EVTS DOC | UMENT ID TECN COMMENT | Γ ₅₉ | $K + K - 2(\pi + \pi)^{\pi}$ $K + K - 2(\pi + \pi)^{\pi}$ | $(1.00\pm0.31)\times10^{-3}$ | |
| | 9 OUR FIT | | Γ ₆₀ | $K_1(1270)^{\pm}K^{\mp}$ | $(1.00\pm0.28)\times10^{-3}$ | |
| | 16 OUR AVERAGE | .IKIM 08B BES2 $e^+e^- \rightarrow \text{hadrons}$ | Γ ₆₁ | $K_S^0 K_S^0 \pi^+ \pi^-$ | $(2.2 \pm 0.4) \times 10^{-4}$ | |
| | | JIKIM 08B BES2 $e^+e^- ightarrow hadrons$ DREOTTI 07 E835 $p\overline{p} ightarrow e^+e^-, J/\psi X$ | Γ ₆₂ | $\rho^0 p \overline{p}$ | $(5.0 \pm 2.2) \times 10^{-5}$ | |
| | 58± 2 ABL | IKIM 06L BES2 $e^+e^- ightarrow$ hadrons | Γ ₆₃ | $K^{+}\overline{K}^{*}(892)^{0}\pi^{-}+\text{ c.c.}$ | $(6.7 \pm 2.5) \times 10^{-4}$ | |
| 264± | | 02B BES2 e^+e^- | Γ ₆₄ | $2(\pi^{+}\pi^{-})$ | $(2.4 \pm 0.6) \times 10^{-4}$ | S=2.2 |
| | | MSTRONG 93B E760 $\overline{p}p \rightarrow e^+e^-$ | Γ ₆₅ | $\rho^0 \pi^+ \pi^-$ | $(2.2 \pm 0.6) \times 10^{-4}$ | S=1.4 |
| ′ F | rom a simultaneous fit to the hadror _ + F = + F = and lepton universality | ic and $\mu^+\mu^-$ cross section, assuming $\Gamma=\Gamma_h+$. Does not include vacuum polarization correction. | Γ ₆₆ | $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ $\omega f_{0}(1710) \rightarrow \omega K^{+}K^{-}$ | $(1.26\pm0.09) \times 10^{-3}$ $(5.9 \pm 2.2) \times 10^{-5}$ | |
| | | eevaluated by ANDREOTTI 07 in its Ref. [4]. | Γ ₆₇ Γ ₆₈ | $K^*(892)^0 K^- \pi^+ \pi^0 + \text{c.c.}$ | $(8.6 \pm 2.2) \times 10^{-4}$ | |
| | | | Γ ₆₉ | $K^*(892)^+K^-\pi^+\pi^- + \text{c.c.}$ | $(9.6 \pm 2.8) \times 10^{-4}$ | |
| | $\psi(2S)$ D | ECAY MODES | Γ ₇₀ | $K^*(892)^+ K^- \rho^0 + \text{c.c.}$ | | |
| | | | ' 70 | | $(7.3 \pm 2.6) \times 10^{-4}$ | |
| | | Scale factor/ | Γ ₇₁ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ | $(6.1 \pm 1.8) \times 10^{-4}$ | |
| | Mode | Scale factor/ Fraction (Γ_j/Γ) Confidence level | Γ ₇₁ Γ ₇₂ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ | $(6.1 \pm 1.8) \times 10^{-4}$ < 1.3 $\times 10^{-4}$ | CL=90% |
| Γ_1 | Mode hadrons | Fraction (Γ_i/Γ) Confidence level $(97.85\pm0.13)~\%$ | Γ ₇₁ Γ ₇₂ Γ ₇₃ | $K^*(892)^0 K^- \rho^+ + \text{ c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ | $(6.1 \pm 1.8) \times 10^{-4}$ $< 1.3 \times 10^{-4}$ $(1.85 \pm 0.25) \times 10^{-4}$ | S=1.1 |
| Γ2 | $\begin{array}{c} hadrons \\ virtual \gamma \to hadrons \end{array}$ | Fraction (Γ_{j}/Γ) Confidence level (97.85 \pm 0.13) % (1.73 \pm 0.14) % S=1.5 | Γ ₇₁ Γ ₇₂ Γ ₇₃ Γ ₇₄ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| Γ ₂ Γ ₃ | $\begin{array}{ll} hadrons \\ virtual \gamma \to hadrons \\ \mathcal{G} \mathcal{G} \mathcal{G} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 \pm 0.13) % (1.73 \pm 0.14) % S=1.5 (10.6 \pm 1.6) % | Γ ₇₁ Γ ₇₂ Γ ₇₃ Γ ₇₄ Γ ₇₅ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 |
| Γ ₂ Γ ₃ Γ ₄ | $\begin{array}{ll} hadrons \\ virtual \gamma \longrightarrow hadrons \\ ggg \\ \gamma gg \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 $(10.6\ \pm1.6\)$ % (1.03 ± 0.29) % | Γ ₇₁ Γ ₇₂ Γ ₇₃ Γ ₇₄ Γ ₇₅ Γ ₇₆ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ | $\begin{array}{ll} hadrons \\ virtual \gamma \to hadrons \\ ggg \\ \gamma gg \\ light \ hadrons \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % | Γ ₇₁ Γ ₇₂ Γ ₇₃ Γ ₇₄ Γ ₇₅ Γ ₇₆ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ | $\begin{array}{l} hadrons \\ virtual \gamma \to hadrons \\ \mathcal{E} \mathcal{E} \\ \gamma \mathcal{E} \mathcal{E} \\ light \ hadrons \\ e^+ e^- \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73 \pm 0.17) \times 10^{-3}$ | Γ ₇₁ Γ ₇₂ Γ ₇₃ Γ ₇₄ Γ ₇₅ Γ ₇₆ Γ ₇₇ Γ ₇₈ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_5^0 K_0^1$ $\pi^+ \pi^- \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ <\ 1.3\ \ \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \end{array} $ | S=1.1 S=2.8 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ | $\begin{array}{ll} hadrons \\ virtual \gamma \to hadrons \\ ggg \\ \gamma gg \\ light \ hadrons \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % | 771 772 773 774 775 776 777 778 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_S K^0_L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ <\ 1.3\ \ \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ \end{array} $ | S=1.1 S=2.8 S=1.4 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ | $\begin{array}{l} \text{hadrons} \\ \text{virtual} \gamma \to \text{hadrons} \\ \textit{ggg} \\ \gamma \textit{gg} \\ \text{light hadrons} \\ e^+ e^- \\ \mu^+ \mu^- \\ \tau^+ \tau^- \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ | 71 72 73 74 75 76 777 78 79 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_S K^0_L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ <\ 1.3\ \ \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \end{array} $ | S=1.1 S=2.8 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ | $\begin{array}{ll} {\rm hadrons} & \\ {\rm virtual} \gamma \to {\rm hadrons} \\ {\it ggg} \\ {\it rgg} \\ {\rm light \; hadrons} \\ {\it e^+e^-} \\ {\it \mu^+\mu^-} \\ {\it \tau^+\tau^-} \\ \\ & {\rm Decays \; into \; \it J} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ | 771 772 773 774 775 776 777 78 779 780 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_L^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 S=2.8 S=1.4 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \text{$g\hspace{0.1em}g\hspace{0.1em}g\hspace{0.1em}g} \\ \text{$\gamma\hspace{0.1em}g\hspace{0.1em}g\hspace{0.1em}g} \\ \text{light hadrons} \\ e^+e^-\\ \mu^+\mu^-\\ \tau^+\tau^- \\ \hline \text{ Decays into } J \\ J/\psi(1S) \text{ anything} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ / $\psi(15)$ and anything (59.5 ± 0.8) % | 771 772 773 774 775 776 777 78 779 780 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_S K^0_L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ <\ 1.3\ \ \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ | $\begin{array}{ll} {\rm hadrons} & \\ {\rm virtual} \gamma \to {\rm hadrons} \\ {\it ggg} \\ {\it rgg} \\ {\rm light \; hadrons} \\ {\it e^+e^-} \\ {\it \mu^+\mu^-} \\ {\it \tau^+\tau^-} \\ \\ & {\rm Decays \; into \; \it J} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ | 771 772 773 774 775 776 777 78 779 780 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_L^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% |
| $ \Gamma_{2}^{-1} $ $ \Gamma_{3}^{-1} $ $ \Gamma_{4}^{-1} $ $ \Gamma_{5}^{-1} $ $ \Gamma_{6}^{-1} $ $ \Gamma_{7}^{-1} $ $ \Gamma_{10}^{-1} $ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \textit{ggg} \\ \textit{ggg} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \hline \textbf{Decays into } \textit{J} \\ \textit{J}/\psi(1S) \text{ anything} \\ \textit{J}/\psi(1S) \text{ neutrals} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ / $\psi(1S)$ and anything (59.5 ± 0.8) % (24.6 ± 0.4) % | F ₇₁ F ₇₂ F ₇₃ F ₇₄ F ₇₅ F ₇₆ F ₇₇ F ₇₈ F ₇₉ F ₈₀ F ₈₁ F ₈₂ F ₈₃ | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_0^S K_0^L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% |
| $ \Gamma_{2} $ $ \Gamma_{3} $ $ \Gamma_{4} $ $ \Gamma_{5} $ $ \Gamma_{6} $ $ \Gamma_{7} $ $ \Gamma_{8} $ $ \Gamma_{10} $ $ \Gamma_{11} $ $ \Gamma_{12} $ | hadrons $\begin{array}{l} \text{virtual} \gamma \to \text{ hadrons} \\ \mathcal{B}\mathcal{B}\mathcal{B} \\ \gamma \mathcal{B}\mathcal{B} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ / ψ (15) and anything (59.5 ± 0.8) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % | 71 72 73 74 75 76 777 78 79 80 81 82 83 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_S K^0_L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1}.^{2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| $ \Gamma_{2}^{2} $ $ \Gamma_{3}^{4} $ $ \Gamma_{5}^{6} $ $ \Gamma_{7}^{7} $ $ \Gamma_{8}^{10} $ $ \Gamma_{11}^{11} $ $ \Gamma_{12}^{12} $ $ \Gamma_{13}^{13} $ | hadrons $\begin{array}{l} \text{virtual} \gamma \to \text{ hadrons} \\ \mathcal{E}\mathcal{E}\mathcal{E} \\ \gamma \mathcal{E}\mathcal{E} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \begin{array}{l} Decays \text{ into } J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^+\pi^- \\ J/\psi(1S) \pi^0\pi^0 \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ / ψ (15) and anything (59.5 ± 0.8) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % | 71 72 73 74 75 76 777 78 79 80 81 82 83 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_0^S K_0^L$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% |
| $ \Gamma_{2}^{2} $ $ \Gamma_{3}^{4} $ $ \Gamma_{5}^{6} $ $ \Gamma_{7}^{7} $ $ \Gamma_{8}^{10} $ $ \Gamma_{11}^{11} $ $ \Gamma_{12}^{12} $ $ \Gamma_{13}^{13} $ | hadrons $\begin{array}{l} \text{virtual} \gamma \to \text{ hadrons} \\ \textit{ggg} \\ \textit{ggg} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \textbf{Decays into } \textit{J} \\ \textit{J}/\psi(1S) \text{ anything} \\ \textit{J}/\psi(1S) \text{ neutrals} \\ \textit{J}/\psi(1S) \pi^0\pi^0 \\ \textit{J}/\psi(1S) \eta \\ \textit{J}/\psi(1S) \pi^0 \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (24.6 ± 0.4) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % $(1.30\pm0.10)\times10^{-3}$ S=1.4 | F71 F72 F73 F74 F75 F76 F77 F78 F80 F81 F82 F83 F84 F85 F86 F87 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_5^0 K_1^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^+$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^0 \overline{K}^0 + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ | hadrons $\begin{array}{l} \text{virtual} \gamma \to \text{ hadrons} \\ \mathcal{B}\mathcal{B}\mathcal{B} \\ \gamma \mathcal{B}\mathcal{B} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \\ Decays into \ J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0\pi^0 \\ J/\psi(1S) \pi^0 \\ J/\psi(1S) \eta \\ J/\psi(1S) \eta \\ \hline \\ Hadi \\ \pi^0h_{\mathcal{B}}(1P) \\ \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ / ψ (15) and anything (59.5 ± 0.8) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % | 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_L^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $\phi K^+ K^-$ $\phi K^+ K^-$ | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \mathcal{S}\mathcal{S}\mathcal{S} \\ \gamma \mathcal{S}\mathcal{S} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \begin{array}{l} Decays \text{ into } J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0 \pi^0 \\ J/\psi(1S) \pi^0 \\ J/\psi(1S) \pi^0 \\ \hline \end{array} \\ \\ \begin{array}{l} Hadi \\ \pi^0h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (17.75 ± 0.34) % (17.75 ± 0.34) % (17.75 ± 0.34) % $(13.0\pm0.10)\times10^{-3}$ S=1.4 conic decays $(8.6\pm1.3)\times10^{-4}$ $(3.5\pm1.6)\times10^{-3}$ | F71 F72 F73 F74 F75 F76 F77 F88 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F89 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_0^1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ $\phi K^+ K^-$ $2(K^+ K^-) \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1}.2\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ Γ ₁₅ Γ ₁₆ Γ ₁₇ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \mathcal{E}\mathcal{E}\mathcal{E} \\ \gamma\mathcal{E}\mathcal{E} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \\ Decays into \ J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S)\pi^0\pi^0 \\ J/\psi(1S)\pi^0 \\ J/\psi(1S)\pi^0 \\ \hline \\ Hadi \\ \pi^0h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (24.6 ± 0.4) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (17.75 ± 0.34) % $(1.30\pm0.10)\times10^{-3}$ S=1.4 conic decays $(8.6\pm1.3)\times10^{-4}$ $(3.5\pm1.6)\times10^{-3}$ $(2.9\pm1.0)\times10^{-3}$ S=4.6 | 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $p \overline{p} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_L^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $\phi K^+ K^-$ $\phi K^+ K^-$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-4} \\ <\ 2.96\ \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-1.8}\)\times 10^{-5} \\ \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| \[\begin{aligned} \Gamma_2 \\ \Gamma_3 \\ \Gamma_4 \\ \Gamma_5 \\ \Gamma_6 \\ \Gamma_7 \\ \Gamma_8 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ \Gamma_1 \\ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \mathcal{S}\mathcal{S}\mathcal{S} \\ \gamma \mathcal{S}\mathcal{S} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \hline \\ & \textbf{Decays into} \textbf{\textit{J}} \\ J/\psi(1S)\text{anything} \\ J/\psi(1S)\text{neutrals} \\ J/\psi(1S)\pi^0\pi^0 \\ J/\psi(1S)\pi^0 \\ \pi^0J/\psi(1S)\pi^0 \\ \hline \\ & \textbf{\textit{Hadi}} \\ \pi^0h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ \rhoa_2(1320) \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (3.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (17.75 ± 0.34) % (3.28 ± 0.07) % $(1.30\pm0.10)\times10^{-3}$ S=1.4 conic decays $(8.6\pm1.3)\times10^{-4}$ $(3.5\pm1.6)\times10^{-3}$ $(2.9\pm1.0)\times10^{-3}$ S=4.6 $(2.6\pm0.9)\times10^{-4}$ | F71 F72 F73 F74 F75 F76 F77 F88 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F89 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_S^0 K_0^1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ $\phi K^+ K^-$ $2(K^+ K^-) \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1}.2\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \end{array} $ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₇ Γ ₈ Γ ₉ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ Γ ₁₅ Γ ₁₆ Γ ₁₇ Γ ₁₈ Γ ₁₉ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \textit{ggg} \\ \textit{ggg} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \\ \textbf{Decays into } \textbf{\textit{J}} \\ \textit{J}/\psi(1S) \text{ anything} \\ \textit{J}/\psi(1S) \text{ neutrals} \\ \textit{J}/\psi(1S) \pi^0\pi^0 \\ \textit{J}/\psi(1S) \pi^0\pi^0 \\ \textit{J}/\psi(1S) \pi^0 \\ \text{\textit{J}}/\psi(1S) \pi^0 \\ \\ \textbf{\textit{Hadr}} \\ \pi^0 h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ \rho a_2(1320) \\ p\overline{p} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (24.6 ± 0.4) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % $(1.30\pm0.10)\times10^{-3}$ S=1.4 Fonic decays $ \begin{array}{c} (8.6\pm1.3)\times10^{-4}\\ (3.5\pm1.6)\times10^{-3}\\ (2.9\pm1.0)\times10^{-3}\\ (2.6\pm0.9)\times10^{-4}\\ (2.76\pm0.12)\times10^{-4}\\ (2.76\pm0.12)\times10^{-4} \end{array} $ | \(\frac{7}{71}\) \(\frac{7}{72}\) \(\frac{7}{73}\) \(\frac{7}{74}\) \(\frac{7}{75}\) \(\frac{7}{76}\) \(\frac{7}{78}\) \(\frac{8}{79}\) \(\frac{8}{83}\) \(\frac{8}{84}\) \(\frac{8}{87}\) \(\frac{8}{88}\) \(\frac{8}{89}\) \(\frac{7}{90}\) | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_5 K^0_1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ $\phi K^+ K^-$ $2(K^+ K^-) \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-4} \\ <\ 2.96 \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-0.8}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ Γ ₁₅ Γ ₁₆ Γ ₁₇ Γ ₁₈ Γ ₁₉ Γ ₂₀ | hadrons $\begin{array}{l} \text{virtual} \gamma \to \text{ hadrons} \\ \textit{ggg} \\ \textit{ggg} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \\ \textbf{Decays into } \textbf{\textit{J}} \\ \textit{\textit{J}}/\psi(1S) \text{ anything} \\ \textit{\textit{J}}/\psi(1S) \text{ neutrals} \\ \textit{\textit{J}}/\psi(1S) \pi^0 \pi^0 \\ \textit{\textit{J}}/\psi(1S) \pi^0 \\ \textit{\textit{J}}/\psi(1S) \pi^0 \\ \\ \hline \\ \textbf{\textit{Hadr}} \\ \pi^0h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ \rho a_2(1320) \\ p\overline{\rho} \\ \Delta^{++}\overline{\Delta}^{} \\ \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $(4.6\pm0.$ | F71 F72 F73 F74 F75 F76 F77 F78 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F89 F90 F91 F92 | $\begin{array}{l} K^*(892)^0 K^- \rho^+ + \mathrm{c.c.} \\ \eta K^+ K^- \\ \omega K^+ K^- \\ 3(\pi^+ \pi^-) \\ \rho \overline{p} \pi^+ \pi^- \pi^0 \\ K^+ K^- \\ K^0_5 K^0_1 \\ \pi^+ \pi^- \pi^0 \\ \rho(2150) \pi \to \pi^+ \pi^- \pi^0 \\ \rho(770) \pi \to \pi^+ \pi^- \pi^0 \\ \pi^+ \pi^- \\ K_1(1400)^\pm K^\mp \\ K^+ K^- \pi^0 \\ K^+ \overline{K}^*(892)^- + \mathrm{c.c.} \\ K^*(892)^0 \overline{K}^0 + \mathrm{c.c.} \\ \phi \pi^+ \pi^- \\ \phi f_0(980) \to \pi^+ \pi^- \\ 2(K^+ K^-) \\ \phi K^+ K^- \\ 2(K^+ K^-) \pi^0 \\ \phi \eta' \\ \omega \eta' \end{array}$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-0.8}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.2\ ^{+2.5}_{-2.1}\)\times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ Γ ₉ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ Γ ₁₇ Γ ₁₈ Γ ₁₉ Γ ₂₀ Γ ₂₁ | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{ hadrons} \\ \textit{ggg} \\ \textit{ggg} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \\ \textbf{Decays into } \textbf{\textit{J}} \\ \textit{J}/\psi(1S) \text{ anything} \\ \textit{J}/\psi(1S) \text{ neutrals} \\ \textit{J}/\psi(1S) \pi^0\pi^0 \\ \textit{J}/\psi(1S) \pi^0\pi^0 \\ \textit{J}/\psi(1S) \pi^0 \\ \text{\textit{J}}/\psi(1S) \pi^0 \\ \\ \textbf{\textit{Hadr}} \\ \pi^0 h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ \rho a_2(1320) \\ p\overline{p} \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (24.6 ± 0.4) % (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % $(1.30\pm0.10)\times10^{-3}$ S=1.4 conic decays $(8.6\pm1.3)\times10^{-4}$ $(3.5\pm1.6)\times10^{-3}$ $(2.9\pm1.0)\times10^{-3}$ S=4.6 $(2.6\pm0.9)\times10^{-4}$ $(2.6\pm0.9)\times10^{-4}$ $(2.76\pm0.12)\times10^{-4}$ $(2.76\pm0.12)\times10^{-4}$ $(1.28\pm0.35)\times10^{-4}$ <1.2 <1.2 | F71 F72 F73 F74 F75 F76 F77 F78 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F90 F91 F92 F93 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K_0^* K_0^1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ $\phi K^+ K^-$ $2(K^+ K^-) \pi^0$ $\phi \eta$ $\phi \eta'$ $\omega \eta'$ $\omega \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-0.8}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.2\ ^{+2.5}_{-2.1}\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ2 Γ3 Γ4 Γ5 Γ6 Γ7 Γ8 Γ10 Γ11 Γ12 Γ13 Γ14 Γ15 Γ16 Γ17 Γ18 Γ19 Γ20 Γ21 Γ22 | hadrons $\begin{array}{l} \text{virtual}\gamma \to \text{hadrons} \\ \mathcal{B}\mathcal{B}\mathcal{B} \\ \gamma \mathcal{B}\mathcal{B} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % (7.7 ± 0.8) × 10 $^{-3}$ (3.0 ± 0.4) × 10 $^{-3}$ (3.0 ± 0.4) × 10 $^{-3}$ (24.6 ± 0.4) % (33.6 ± 0.4) % (17.75 ± 0.34) % (3.28 ± 0.07) % (1.30 ± 0.10) × 10 $^{-3}$ S=1.4 conic decays (8.6 ± 1.3) × 10 $^{-4}$ (3.5 ± 1.6) × 10 $^{-3}$ (2.9 ± 1.0) × 10 $^{-3}$ S=4.6 (2.6 ± 0.9) × 10 $^{-4}$ (2.76 ± 0.12) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.28 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1.29 ± 0.35) × 10 $^{-4}$ (1. | \(\frac{7}{71}\) \(\frac{7}{72}\) \(\frac{7}{73}\) \(\frac{7}{74}\) \(\frac{7}{75}\) \(\frac{7}{76}\) \(\frac{7}{77}\) \(\frac{7}{78}\) \(\frac{7}{79}\) \(\frac{80}{81}\) \(\frac{82}{83}\) \(\frac{83}{84}\) \(\frac{85}{87}\) \(\frac{86}{87}\) \(\frac{86}{90}\) \(\frac{791}{91}\) \(\frac{792}{93}\) \(\frac{794}{94}\) | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^ \omega K^+ K^ 3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^ K_0^* K_0^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^ K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^ \phi f_0(980) \to \pi^+ \pi^ 2(K^+ K^-)$ $\phi K^+ K^ 2(K^+ K^-)$ $\phi \eta'$ $\omega \eta'$ $\omega \eta'$ $\omega \pi^0$ $\rho \eta'$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1}.^{2})\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ < 3.1 & \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1}.^{0})\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.2\ ^{+2.5})\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 1.9\ ^{+1.7})\times 10^{-5} \\ (\ 1.9\ ^{+1.7})\times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% |
| Γ2 Γ3 Γ4 Γ5 Γ6 Γ7 Γ8 Γ9 Γ10 Γ11 Γ12 Γ13 Γ14 Γ15 Γ16 Γ17 Γ18 Γ19 Γ20 Γ21 Γ22 Γ23 | hadrons $ \begin{array}{l} \text{virtual} \gamma \rightarrow \text{ hadrons} \\ \mathcal{B}\mathcal{B}\mathcal{B} \\ \gamma \mathcal{B}\mathcal{B} \\ \text{light hadrons} \\ e^+ e^- \\ \mu^+ \mu^- \\ \tau^+ \tau^- \\ \\ \hline $ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $(4.6\pm0.$ | F71 F72 F73 F74 F75 F76 F77 F78 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F90 F91 F92 F93 F94 F95 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^ \omega K^+ K^ 3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^ K_0^* K_0^0$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^ K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^ \phi f_0(980) \to \pi^+ \pi^ 2(K^+ K^-)$ $\phi K^+ K^ 2(K^+ K^-) \pi^0$ $\phi \eta'$ $\omega \eta'$ $\omega \pi^0$ $\rho \eta'$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1}.^{2})\times 10^{-4} \\ (\ 1.9\ ^{+1}.^{2})\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-4} \\ < 2.96 & \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7})\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 1.10\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-0.8})\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.2\ ^{+2.5}_{-2.1})\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 1.9\ ^{+1.7}_{-1.2})\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% S=1.7 S=1.1 |
| Γ2 Γ3 Γ4 Γ5 Γ6 Γ7 Γ8 Γ9 Γ10 Γ11 Γ12 Γ13 Γ14 Γ15 Γ16 Γ17 Γ18 Γ19 Γ20 Γ21 Γ22 Γ22 Γ22 Γ22 Γ22 Γ22 Γ22 | hadrons $\begin{array}{l} \text{virtual} \gamma \rightarrow \text{ hadrons} \\ \mathcal{S}\mathcal{S}\mathcal{S} \\ \gamma \mathcal{S}\mathcal{S} \\ \text{light hadrons} \\ e^+e^- \\ \mu^+\mu^- \\ \tau^+\tau^- \\ \hline \\ & \textbf{Decays into } J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0\pi^0 \\ J/\psi(1S) \pi^0\pi^0 \\ J/\psi(1S) \pi^0 \\ \hline \\ & J/\psi(1S) \pi^0 \\ \hline \\ & Hading \\ \pi^0 h_c(1P) \\ 3(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ 2(\pi^+\pi^-)\pi^0 \\ \rho a_2(1320) \\ \rho \overline{\rho} \\ \Delta^++\overline{\Delta} \\ \Lambda \overline{\Lambda}\pi^0 \\ \Lambda \overline{\Lambda}\eta \\ \Lambda \overline{\rho}K^+ \\ \Lambda \overline{\rho}K^+\pi^+\pi^- \\ \Lambda \overline{\Lambda}\pi^+\pi^- \\ \hline \end{array}$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $(4.6\pm0.$ | F71 F72 F73 F74 F75 F76 F77 F88 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F89 F90 F91 F92 F93 F94 F95 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^-$ $\omega K^+ K^-$ $3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^-$ $K^0_5 K^0_1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^-$ $K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^-$ $\phi f_0(980) \to \pi^+ \pi^-$ $2(K^+ K^-)$ $\phi K^+ K^-$ $2(K^+ K^-)$ $\phi \eta'$ $\omega \eta'$ $\omega \pi^0$ $\rho \eta'$ $\rho \eta$ $\omega \eta$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-4} \\ (\ 7.3\ \pm 0.7\)\times 10^{-4} \\ (\ 6.3\ \pm 0.7\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}_{-0.4}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-4} \\ <\ 2.96\ \times 10^{-5} \\ (\ 1.7\ ^{+0.8}_{-0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 7.0\ \pm 1.6\)\times 10^{-5} \\ (\ 1.0\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}_{-0.8}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ <\ 2.1\ \times 10^{-5} \\ <\ 2.1\ \times 10^{-5} \\ \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% S=1.7 S=1.1 CL=90% |
| $ \Gamma_{2}^{-} $ $ \Gamma_{3}^{-} $ $ \Gamma_{4}^{-} $ $ \Gamma_{5}^{-} $ $ \Gamma_{6}^{-} $ $ \Gamma_{7}^{-} $ $ \Gamma_{8}^{-} $ $ \Gamma_{11}^{-} $ $ \Gamma_{12}^{-} $ $ \Gamma_{11}^{-} $ $ \Gamma_{12}^{-} $ $ \Gamma_{13}^{-} $ $ \Gamma_{14}^{-} $ $ \Gamma_{15}^{-} $ $ \Gamma_{16}^{-} $ $ \Gamma_{17}^{-} $ $ \Gamma_{18}^{-} $ $ \Gamma_{19}^{-} $ $ \Gamma_{20}^{-} $ $ \Gamma_{21}^{-} $ $ \Gamma_{22}^{-} $ $ \Gamma_{23}^{-} $ $ \Gamma_{23}^{-} $ $ \Gamma_{24}^{-} $ $ \Gamma_{25}^{-} $ $ \Gamma_{26}^{-} $ | hadrons $\begin{array}{l} \text{virtual} \gamma \rightarrow \text{ hadrons} \\ \mathcal{E}\mathcal{E}\mathcal{E} \\ \gamma \mathcal{E}\mathcal{E} \\ \gamma \mathcal{E}\mathcal{E} \\ \text{light hadrons} \\ e^+ e^- \\ \mu^+ \mu^- \\ \tau^+ \tau^- \\ \hline \\ & \textbf{Decays into } \textbf{\textit{J}} \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0 \pi^0 \\ J/\psi(1S) \pi^0 \\ J/\psi(1S) \eta \\ J/\psi(1S) \eta \\ J/\psi(1S) \pi^0 \\ \hline \\ & \textbf{\textit{Hadr}} \\ \pi^0 h_c(1P) \\ 3(\pi^+ \pi^-) \pi^0 \\ 2(\pi^+ \pi^-) \pi^0 \\ 2(\pi^+ \pi^-) \pi^0 \\ \rho a_2(1320) \\ p\overline{p} \\ \Delta^{++} \overline{\Delta} - \\ \Lambda \overline{\Lambda} \pi^0 \\ \Lambda \overline{\rho} K^+ \\ \Lambda \overline{\rho} K^+ \\ \Lambda \overline{\rho} K^+ \\ \pi^- K^+ \pi^- \\ \Lambda \overline{\Lambda} \pi^+ \pi^- \\ \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^-$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $($ | F71 F72 F73 F74 F75 F76 F77 F88 F79 F80 F81 F82 F83 F84 F85 F86 F87 F88 F89 F90 F91 F92 F93 F94 F95 F96 F97 F98 | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^ \omega K^+ K^ 3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^ K^0_5 K^0_1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^ K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^ \phi f_0(980) \to \pi^+ \pi^ 2(K^+ K^-)$ $\phi K^+ K^ 2(K^+ K^-) \pi^0$ $\phi \eta'$ $\omega \eta'$ $\omega \eta'$ $\omega \eta'$ $\phi \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.9\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 1.0\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 0.6\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 1$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% S=1.7 S=1.1 CL=90% CL=90% |
| Γ ₂ Γ ₃ Γ ₄ Γ ₅ Γ ₆ Γ ₇ Γ ₈ Γ ₉ Γ ₁₀ Γ ₁₁ Γ ₁₂ Γ ₁₃ Γ ₁₄ Γ ₁₅ Γ ₁₆ Γ ₁₇ Γ ₁₈ Γ ₁₉ Γ ₂₀ Γ ₂₁ Γ ₂₂ Γ ₂₃ Γ ₂₄ Γ ₂₅ Γ ₂₆ Γ ₂₇ | hadrons $\begin{array}{l} \text{virtual} \gamma \rightarrow \text{ hadrons} \\ \mathcal{B}\mathcal{B}\mathcal{B} \\ \gamma \mathcal{B}\mathcal{B} \\ \text{light hadrons} \\ e^+ e^- \\ \mu^+ \mu^- \\ \tau^+ \tau^- \\ \\ \hline \\ Decays into \ J \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0 \pi^0 \\ J/\psi(1S) \pi^0 \\ J/\psi(1S) \eta \\ J/\psi(1S) \eta \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ J/\psi(1S) \eta \\ O \\ O \\ O \\ O \\ O \\ O \\ O \\ O \\ O \\$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $($ | \(\frac{7}{71}\) \(\frac{7}{72}\) \(\frac{7}{73}\) \(\frac{7}{74}\) \(\frac{7}{75}\) \(\frac{7}{76}\) \(\frac{7}{77}\) \(\frac{7}{78}\) \(\frac{7}{79}\) \(\frac{8}{80}\) \(\frac{8}{81}\) \(\frac{8}{82}\) \(\frac{8}{83}\) \(\frac{8}{84}\) \(\frac{8}{87}\) \(\frac{8}{88}\) \(\frac{8}{90}\) \(\frac{7}{91}\) \(\frac{7}{92}\) \(\frac{7}{93}\) \(\frac{7}{94}\) \(\frac{7}{95}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^ \omega K^+ K^ 3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^ K^0 S K^0 \pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^ K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^ \phi f_0(980) \to \pi^+ \pi^ 2(K^+ K^-)$ $\phi K^+ K^ 2(K^+ K^-)$ $\phi \eta'$ $\omega \eta'$ $\omega \eta'$ $\omega \pi^0$ $\rho \eta'$ $\rho \eta$ $\omega \eta$ $\phi \pi^0$ $\eta_c \pi^+ \pi^- \pi^0$ $\eta_c \pi^+ \pi^- \pi^0$ $\eta_c \pi^+ \pi^- \pi^0$ $\eta_c \pi^+ K^-$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.9\ ^{+0.7}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 1.0\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.2\ ^{+2.5}\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ <\ 4\ \times 10^{-6} \\ <\ 1.0\ \times 10^{-3} \end{array}$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% CL=90% S=1.7 S=1.1 CL=90% |
| Γ ₃ Γ ₄ | hadrons $\begin{array}{l} \text{virtual} \gamma \rightarrow \text{ hadrons} \\ \mathcal{E}\mathcal{E}\mathcal{E} \\ \gamma \mathcal{E}\mathcal{E} \\ \gamma \mathcal{E}\mathcal{E} \\ \text{light hadrons} \\ e^+ e^- \\ \mu^+ \mu^- \\ \tau^+ \tau^- \\ \hline \\ & \textbf{Decays into } \textbf{\textit{J}} \\ J/\psi(1S) \text{ anything} \\ J/\psi(1S) \text{ neutrals} \\ J/\psi(1S) \pi^0 \pi^0 \\ J/\psi(1S) \pi^0 \\ J/\psi(1S) \eta \\ J/\psi(1S) \eta \\ J/\psi(1S) \pi^0 \\ \hline \\ & \textbf{\textit{Hadr}} \\ \pi^0 h_c(1P) \\ 3(\pi^+ \pi^-) \pi^0 \\ 2(\pi^+ \pi^-) \pi^0 \\ 2(\pi^+ \pi^-) \pi^0 \\ \rho a_2(1320) \\ p\overline{p} \\ \Delta^{++} \overline{\Delta} - \\ \Lambda \overline{\Lambda} \pi^0 \\ \Lambda \overline{\rho} K^+ \\ \Lambda \overline{\rho} K^+ \\ \Lambda \overline{\rho} K^+ \\ \pi^- K^+ \pi^- \\ \Lambda \overline{\Lambda} \pi^+ \pi^- \\ \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^- \Pi^-$ | Fraction (Γ_i/Γ) Confidence level (97.85 ± 0.13) % (1.73 ± 0.14) % S=1.5 (10.6 ± 1.6) % (1.03 ± 0.29) % (15.4 ± 1.5) % $(7.73\pm0.17)\times10^{-3}$ $(7.7\pm0.8)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ $(3.0\pm0.4)\times10^{-3}$ (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % (4.6 ± 0.4) % $($ | \(\frac{7}{71}\) \(\frac{7}{72}\) \(\frac{7}{73}\) \(\frac{7}{74}\) \(\frac{7}{75}\) \(\frac{7}{76}\) \(\frac{7}{77}\) \(\frac{7}{78}\) \(\frac{7}{79}\) \(\frac{8}{80}\) \(\frac{8}{81}\) \(\frac{8}{82}\) \(\frac{8}{83}\) \(\frac{8}{84}\) \(\frac{8}{87}\) \(\frac{8}{88}\) \(\frac{8}{90}\) \(\frac{7}{91}\) \(\frac{7}{92}\) \(\frac{7}{93}\) \(\frac{7}{94}\) \(\frac{7}{95}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) \(\frac{7}{99}\) | $K^*(892)^0 K^- \rho^+ + \text{c.c.}$ $\eta K^+ K^ \omega K^+ K^ 3(\pi^+ \pi^-)$ $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ $K^+ K^ K^0_5 K^0_1$ $\pi^+ \pi^- \pi^0$ $\rho(2150) \pi \to \pi^+ \pi^- \pi^0$ $\rho(770) \pi \to \pi^+ \pi^- \pi^0$ $\pi^+ \pi^ K_1(1400)^{\pm} K^{\mp}$ $K^+ K^- \pi^0$ $K^+ \overline{K}^*(892)^- + \text{c.c.}$ $\phi \pi^+ \pi^ \phi f_0(980) \to \pi^+ \pi^ 2(K^+ K^-)$ $\phi K^+ K^ 2(K^+ K^-) \pi^0$ $\phi \eta'$ $\omega \eta'$ $\omega \eta'$ $\omega \eta'$ $\phi \pi^0$ | $ \begin{array}{c} (\ 6.1\ \pm 1.8\)\times 10^{-4} \\ < 1.3 & \times 10^{-4} \\ (\ 1.85\pm 0.25)\times 10^{-4} \\ (\ 3.5\ \pm 2.0\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 5.4\ \pm 0.5\)\times 10^{-5} \\ (\ 1.68\pm 0.26)\times 10^{-4} \\ (\ 1.9\ ^{+1.2}\)\times 10^{-4} \\ (\ 3.2\ \pm 1.2\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 8\ \pm 5\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.7\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.9\ ^{+0.8}\)\times 10^{-5} \\ (\ 1.09\pm 0.20)\times 10^{-4} \\ (\ 1.17\pm 0.29)\times 10^{-4} \\ (\ 6.8\ \pm 2.5\)\times 10^{-5} \\ (\ 6.0\ \pm 1.4\)\times 10^{-5} \\ (\ 1.0\pm 0.28)\times 10^{-4} \\ (\ 2.8\ ^{+1.0}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.1\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 2.2\ \pm 0.6\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 1.6\)\times 10^{-5} \\ (\ 3.1\ \pm 0.6\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 10^{-5} \\ (\ 3.1\ \times 10^{-5}\)\times 1$ | S=1.1 S=2.8 S=1.4 S=1.8 CL=90% S=1.7 S=1.1 CL=90% CL=90% |

$\psi(2S)$

| $\Gamma_{102} \phi f'_{2}(152)$ | 5) | | ± 1.6) $\times 10^{-5}$ | |
|-----------------------------------------------------|---------------------------------------------------------------|---------|------------------------------|---------|
| | $K^{-}\overline{n}$ + c.c. | < 8.8 | ×10 ⁻⁶ | CL=90% |
| $\Gamma_{104} \Theta(1540)$ | $K^{-}\overline{n} \rightarrow K_{S}^{0} p K^{-}\overline{n}$ | < 1.0 | $\times 10^{-5}$ | CL=90% |
| $\Gamma_{105} \Theta(1540)$ | $K_c^0 \overline{p} \rightarrow K_c^0 \overline{p} K^+ n$ | < 7.0 | $\times 10^{-6}$ | CL=90% |
| $\Gamma_{106} \overline{\Theta}(1540)$ | $K^{+} n \rightarrow K_{S}^{0} \overline{p} K^{+} n$ | < 2.6 | $\times 10^{-5}$ | CL=90% |
| | $K_S^0 p \rightarrow K_S^{0} p K^{-} \overline{n}$ | < 6.0 | $\times 10^{-6}$ | CL=90% |
| $\Gamma_{108} \ K_S^0 K_S^0$ | | < 4.6 | ×10 ⁻⁶ | 02-3070 |
| 10855 | Radiativ | | 7.10 | |
| $\Gamma_{109} \gamma \chi_{c0} (1P)$ | | - | ±0.31) % | |
| $\Gamma_{110} \gamma \chi_{c1} (1P)$ | | | ±0.4)% | |
| $\Gamma_{111} \gamma \chi_{c2} (1P)$ |)) | | ± 0.34) % | |
| $\Gamma_{112} \gamma \eta_c(1S)$ |) | | ± 0.5) $\times 10^{-3}$ | S=1.3 |
| $\Gamma_{113} \gamma \eta_{c}(2S)$ | | < 8 | ×10 ⁻⁴ | CL=90% |
| $\Gamma_{114}^{113} \gamma_{\pi}^{0}$ | | | ±0.4)×10-6 | CL=3076 |
| $\Gamma_{115} \gamma \eta'(958)$ | | | $\pm 0.06) \times 10^{-4}$ | |
| $\Gamma_{116} \gamma f_2 (1270)$ | | | $\pm 0.4 \times 10^{-4}$ | |
| $\Gamma_{117} \gamma f_0(1710)$ | | (2.1 | 10.4 / / 10 | |
| | $(10) \rightarrow \gamma \pi \pi$ | (30 | $\pm 1.3) \times 10^{-5}$ | |
| $\Gamma_{119} \qquad \gamma f_0(17)$ | $(10) \rightarrow \gamma K \overline{K}$ | | ± 1.6) $\times 10^{-5}$ | |
| $\Gamma_{120} \gamma \gamma$ | 10) / //// | < 1.4 | | CL=90% |
| $\Gamma_{121} \gamma \eta$ | | | ±0.5)×10-6 | CL=3070 |
| $\Gamma_{122} \gamma \eta \pi^{+} \pi^{-}$ | - | | ± 2.1) $\times 10^{-4}$ | |
| $\Gamma_{123} \gamma \eta (1405)$ | | (0 | 12.1 / / 10 | |
| | $(05) \rightarrow \gamma K \overline{K} \pi$ | < 9 | $\times 10^{-5}$ | CL=90% |
| $\Gamma_{125} \qquad \gamma \eta (14)$ | $05) \rightarrow \eta \pi^+ \pi^-$ | | ±2.5) × 10 ⁻⁵ | 02-3070 |
| $\Gamma_{126} \gamma \eta (1475)$ | | (| | |
| | $(75) \rightarrow K\overline{K}\pi$ | < 1.4 | $\times 10^{-4}$ | CL=90% |
| $\Gamma_{128} \qquad \gamma \eta (14)$ | 75) $\rightarrow \eta \pi^+ \pi^-$ | < 8.8 | ×10 ⁻⁵ | CL=90% |
| $\Gamma_{129} \gamma_2(\pi^+\pi^-)$ | | | $\pm 0.6) \times 10^{-4}$ | ,• |
| | π^{-} + c.c. | | ±0.9)×10-4 | |
| $\Gamma_{131}^{130} \gamma K^{*0} \overline{K}^{*}$ | 0 | | ±0.7)×10-4 | |
| | π^{-} + c.c. | | ± 0.5) $\times 10^{-4}$ | |
| Γ_{133} $\gamma K^+ K^-$ | | | ± 0.5) $\times 10^{-4}$ | |
| $\Gamma_{134} \gamma p \overline{p}$ | | | ± 0.5) $\times 10^{-5}$ | S=2.0 |
| | $(50) \rightarrow \gamma p \overline{p}$ | | $\pm 0.22) \times 10^{-5}$ | |
| | $(50) \rightarrow \gamma p \overline{p}$ | | $\pm 1.8) \times 10^{-6}$ | |
| | $(35) \rightarrow \gamma p \overline{p}$ | < 1.6 | ×10 ⁻⁶ | CL=90% |
| Γ_{138} $\gamma X \rightarrow$ | | [a] < 2 | $\times 10^{-6}$ | CL=90% |
| $\Gamma_{139} \gamma \pi^{+} \pi^{-} \mu$ | | | ± 1.4) $\times 10^{-5}$ | , |
| $\Gamma_{140} \gamma_{2}(\pi^{+}\pi^{-})$ | | < 2.2 | ×10 ⁻⁴ | CL=90% |
| $\Gamma_{141}^{140} \gamma_{3}(\pi^{+}\pi^{-})$ | | < 1.7 | $\times 10^{-4}$ | CL=90% |
| $\Gamma_{142} \gamma K^+ K^-$ | | < 4 | ×10 ⁻⁵ | CL=90% |
| 1-14 / | | • | | , , |

[a] For a narrow resonance in the range 2.2 < M(X) < 2.8 GeV.

CONSTRAINED FIT INFORMATION

A multiparticle fit to $\chi_{c1}(1P),\ \chi_{c0}(1P),\ \chi_{c2}(1P),\$ and $\psi(2S)$ with 4 total widths, a partial width, 25 combinations of partial widths obtained from integrated cross section, and 84 branching ratios uses 223 measurements to determine 49 parameters. The overall fit has a $\chi^2=312.2$ for 174 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta \rho_i \delta \rho_j \right\rangle / (\delta \rho_i \cdot \delta \rho_j)$, in percent, from the fit to parameters ρ_i , including the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\rm total}$.

| <i>x</i> ₇ | 5 | | | | | | | | | |
|-------------------------|-----------------------|-----------------------|-----------------------|----------|------------------------|------------------------|------------------------|-------------------------|-------------------------|-------------------------|
| <i>x</i> ₈ | 1 | 0 | | | | | | | | |
| <i>x</i> ₁₁ | 44 | 12 | 3 | | | | | | | |
| <i>x</i> ₁₂ | 39 | 8 | 2 | 64 | | | | | | |
| <i>X</i> 13 | 27 | 7 | 2 | 57 | 35 | | | | | |
| <i>X</i> 19 | 2 | 1 | 0 | 7 | 5 | 4 | | | | |
| <i>x</i> ₁₀₉ | 2 | 1 | 0 | 4 | 3 | 2 | 0 | | | |
| x ₁₁₀ | 2 | 1 | 0 | 5 | 2 | 3 | 0 | 0 | | |
| x ₁₁₁ | 3 | 1 | 0 | 6 | 4 | 4 | 0 | 0 | 0 | |
| Γ | - 79 | -6 | -2 | -52 | -46 | -32 | -10 | -2 | -3 | -3 |
| | <i>x</i> ₆ | <i>x</i> ₇ | <i>x</i> ₈ | x_{11} | <i>x</i> ₁₂ | <i>x</i> ₁₃ | <i>x</i> ₁₉ | <i>x</i> ₁₀₉ | <i>x</i> ₁₁₀ | <i>x</i> ₁₁₁ |

$\psi(2S)$ PARTIAL WIDTHS

T(hadrons)

| i (nadrons) | | | | | י 1 |
|-------------------------------------------------------------------------|------------------------------|---------|-----------|---------------------------------------|------------|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use the following | ng data for average | s, fits | , limits, | etc. • • • | |
| 258±26 | BAI | 02в | BES2 | e^+e^- | |
| 224±56 | LUTH | 75 | MRK1 | e^+e^- | |
| Γ(e ⁺ e ⁻) | | | | | Γ6 |
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| 2.35 ±0.04 OUR FIT | | | | | |
| 2.33 ±0.07 OUR AVERAGE | | | | | |
| $2.338 \pm 0.037 \pm 0.096$ | ABLIKIM | 08B | BES2 | $e^+e^-	o$ hadrons | |
| $2.330 \pm 0.036 \pm 0.110$ | ABLIKIM | 06L | BES2 | $e^+e^- ightarrow hadrons$ | |
| 2.44 ±0.21 | ⁹ BAI | 02B | BES2 | e^+e^- | |
| 2.14 ±0.21 | ALEXANDER | 89 | RVUE | See γ mini-review | |
| • • • We do not use the following | ng data for average | s, fits | , limits, | etc. • • • | |
| 2.0 ±0.3 | BRANDELIK | 79C | DA SP | e^+e^- | |
| 2.1 ±0.3 | ¹⁰ LUTH | 75 | MRK1 | e^+e^- | |
| ⁹ From a simultaneous fit to e^+ $\Gamma_{\tau}/0.38847$. | $^+e^-$, $\mu^+\mu^-$, and | hadro | nic chan | nel, assuming $\Gamma_e = \Gamma_\mu$ | <i>u</i> = |
| ¹⁰ From a simultaneous fit to e | $^+e^-$, $\mu^+\mu^-$, and | hadro | onic cha | nnels assuming $\Gamma(e^+e^-)$ | e-) |

¹⁰ From a simultaneous fit to e^+e^- , $\mu^+\mu^-$, and hadronic channels assuming $\Gamma(e^+e^-)$ = $\Gamma(\mu^+\mu^-)$.

| $\Gamma(\gamma\gamma)$ | | | | | | Γ ₁₂₀ |
|------------------------|-----|--------------|-----|------|----------|------------------|
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <43 | 90 | BRANDELIK | 79C | DASP | e^+e^- | |

$\psi(2S) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

This combination of a partial width with the partial width into $e^+\,e^-$ and with the total width is obtained from the integrated cross section into channel(i) in the $e^+\,e^-$ annihilation. We list only data that have not been used to determine the partial width $\Gamma(i)$ or the branching ratio $\Gamma(i)/total$.

 11 ANASHIN 12 reports the value 2.233 \pm 0.015 \pm 0.037 \pm 0.020 keV, where the third uncertainty is due to assumptions on the interference between the resonance and hadronic continuum. We combined the two systematic uncertainties.

 $\Gamma(J/\psi(1S)\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{11}\Gamma_6/\Gamma_{\text{NALUE}(keV)}$ $\Gamma_{12}\Gamma_{13}\Gamma_{14}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_{15}\Gamma_$

0.82 ±0.04 OUR AVERAGE Error includes scale factor of 1.6. See the ideogram below. 0.852±0.010±0.026 19.5 k±243 ADAM 06 CLEO 3.773 $e^+e^- \rightarrow \gamma \psi(2S)$ 0.76 ±0.05 ±0.01 544 13 AUBERT 05D BABR 10.6 $e^+e^- \rightarrow \pi^+\pi^-\mu^+\mu^-\gamma$ 0.68 ±0.09 14 BAI 98E BES e^+e^-

 13 AUBERT 05D reports $[\Gamma(\psi(2S)\to J/\psi(1S)\pi^+\pi^-)\times\Gamma(\psi(2S)\to e^+e^-)/\Gamma_{total}]\times[B(J/\psi(1S)\to \mu^+\mu^-)]=0.0450\pm0.0018\pm0.0022$ keV which we divide by our best value $B(J/\psi(1S)\to \mu^+\mu^-)=(5.93\pm0.06)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

14 The value of $\Gamma(e^+e^-)$ quoted in BAI 98E is derived using $B(\psi(2S) \to J/\psi(1S) \, \pi^+\pi^-) = (32.4 \pm 2.6) \times 10^{-2}$ and $B(J/\psi(1S) \to \ell^+\ell^-) = 0.1203 \pm 0.0038$. Recalculated by us using $B(J/\psi(1S) \to \ell^+\ell^-) = 0.1181 \pm 0.0020$.

 15 AUBERT 07Au reports $[\Gamma\left(\psi(2S)\to J/\psi(1S)\,\pi^+\pi^-\right)\times\Gamma\left(\psi(2S)\to e^+e^-\right)/\Gamma_{\text{total}}]\times[B(J/\psi(1S)\to \pi^+\pi^-\pi^0)]=0.0186\pm0.0012\pm0.0011$ keV which we divide by our best value $B(J/\psi(1S)\to \pi^+\pi^-\pi^0)=(2.07\pm0.12)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value

 $\psi(2S)$

| | $\psi(25)$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| WEIGHTED AVERAGE 0.82±0.04 (Error scaled by 1.6) | $\Gamma(2(\pi^+\pi^-)\pi^0) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{17}\Gamma_6/\Gamma$ |
| | <u>VALUE (eV)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 29.7\pm2.2\pm1.8 410 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\pi^0\gamma$ |
| Values above of weighted average, error, and scale factor are based upon the data in this ideogram only. They are not neces- | $\Gamma(\omega\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{50}\Gamma_{6}/\Gamma$ |
| sarily the same as our 'best' values, obtained from a least-squares constrained fit | VALUE (eV)EVTSDOCUMENT IDTECNCOMMENT3.01 \pm 0.84 \pm 0.023719 AUBERT07AU BABR $10.6 e^+e^- \rightarrow \omega \pi^+\pi^- \gamma$ |
| utilizing measurements of other (related) quantities as additional information. | 19 AUBERT 07AU reports $[\Gamma(\psi(2S) \to \omega \pi^+ \pi^-) \times \Gamma(\psi(2S) \to e^+ e^-)/\Gamma_{\text{total}}] \times [B(\omega(782) \to \pi^+ \pi^- \pi^0)] = 2.69 \pm 0.73 \pm 0.16$ eV which we divide by our best value $B(\omega(782) \to \pi^+ \pi^- \pi^0) = (89.2 \pm 0.7) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| χ^2 | $\Gamma(2(\pi^+\pi^-)\eta) \times \Gamma(e^+e^-)/\Gamma_{total}$ $\Gamma_{48}\Gamma_6/\Gamma_{total}$ $\Gamma_{48}\Gamma_6/\Gamma_{total}$ $\Gamma_{48}\Gamma_6/\Gamma_{total}$ $\Gamma_{48}\Gamma_6/\Gamma_{total}$ $\Gamma_{48}\Gamma_6/\Gamma_{total}$ |
| ADAM 06 CLEO 1.4 AUBERT 05D BABR 1.5 BAI 98E BES 2.4 5.3 (Confidence Level = 0.070) | 2.87 ± 1.41 ± 0.01 16 20 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\eta\gamma$ 20 AUBERT 07AU reports $[\Gamma(\psi(2S)\rightarrow 2(\pi^+\pi^-)\eta)\times\Gamma(\psi(2S)\rightarrow e^+e^-)/\Gamma_{total}]\times[B(\eta\rightarrow 2\gamma)]=1.13\pm0.55\pm0.08$ eV which we divide by our best value $B(\eta\rightarrow 2\gamma)=(39.31\pm0.20)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| 0.4 0.6 0.8 1 1.2 1.4 $\Gamma \left(J/\psi (1S) \pi^+ \pi^- \right) \times \Gamma \left(e^+ e^- \right) / \Gamma_{total} \; (keV)$ | $\Gamma(K^+K^-\pi^+\pi^-\pi^0) \times \Gamma(e^+e^-)/\Gamma_{total}$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT |
| | 4.4±1.3±0.3 32 AUBERT 07AU BABR $10.6 e^+ e^- \rightarrow K^+ K^- \pi^+ \pi^- \pi^0 \gamma$ |
| | $\Gamma(K^+K^-\pi^+\pi^-\eta) \times \Gamma(e^+e^-)/\Gamma_{	ext{total}}$ VALUE (eV) EVTS DO CUMENT ID TECH COMMENT |
| 0.411 ± 0.008 ± 0.018 3.6k ± 96 ADAM 06 CLEO 3.773 $e^+e^- \to \gamma \psi(25)$ | 3.05 ± 1.80 ± 0.02 7 21 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\eta\gamma$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 21 AUBERT 07AU reports $[\Gamma(\psi(2S)\to K^+K^-\pi^+\pi^-\eta)\times\Gamma(\psi(2S)\to e^+e^-)/\Gamma_{total}]\times[B(\eta\to 2\gamma)]=1.2\pm0.7\pm0.1$ eV which we divide by our best value $B(\eta\to 2\gamma)=(39.31\pm0.20)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| 87 \pm 9 OUR AVERAGE 83 \pm 25 \pm 5 14 16 AUBERT 07AU BABR 10.6 $e^+e^{\ J/\psi\pi^+\pi^-\pi^0\gamma}$ | $\psi(2S)$ BRANCHING RATIOS |
| 88 \pm 6 \pm 7 291 \pm 24 ADAM 06 CLEO 3.773 $e^{+}e^{-} \to \gamma \psi(2S)$ | F/badvara)/F |
| 16 AUBERT 07AU quotes $\Gamma_{ee}^{\psi(2S)}\cdot \mathrm{B}(\psi(2S)\to J/\psi\eta)\cdot \mathrm{B}(J/\psi\to \mu^+\mu^-)\cdot \mathrm{B}(\eta\to \pi^+\pi^-\pi^0)=1.11\pm0.33\pm0.07~\mathrm{eV}.$ | Γ(hadrons)/Γ _{total} Γ ₁ /Γ <u>VALUE</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| | 0.9785±0.0013 OUR AVERAGE 0.9779±0.0015 |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 0.981 ± 0.003 22 LUTH 75 MRK1 $e^+e^ 22$ Includes cascade decay into $J/\psi(1S)$. |
| | $\Gamma(\text{virtual}\gamma 	o \text{hadrons})/\Gamma_{	ext{total}}$ Γ_2/Γ |
| $\frac{\Gamma(p\overline{p}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}}{VALUE(e^\vee)} = \frac{VALUE(e^\vee)}{0.647 \pm 0.028 \text{ OUR FIT}} = \frac{DOCUMENT \ ID}{DOCUMENT \ ID} = \frac{TECN}{TECN} = \frac{COMMENT}{TECN}$ | VALUE DO CUMENT ID TECN COMMENT 0.0173±0.0014 OUR AVERAGE Error includes scale factor of 1.5. |
| 0.59 ±0.05 OUR AVERAGE | 0.0166 ± 0.0010 $23,24$ SETH 04 RVUE $e^+e^ 0.0199 \pm 0.0019$ 23 BAI 02B BES2 e^+e^- |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | • • • We do not use the following data for averages, fits, limits, etc. • • |
| $\Gamma(\Lambda\overline{\Lambda}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{26}\Gamma_6/\Gamma$ | $0.029~\pm0.004$ $23~{ m LUTH}$ 75 MRK1 $e^+e^ 23~{ m Included~in~\Gamma(hadrons)/\Gamma_{total}}.$ |
| VALUE (eV) DOCUMENT ID TECN COMMENT | 24 Using B($\psi(2S) \rightarrow \ell^{\pm}\ell^{-}$) = (0.73 ± 0.04)% from RPP-2002 and R = 2.28 ± 0.04 determined by a fit to data from BAI 00 and BAI 02c. |
| 1.5\pm0.4\pm0.1 AUBERT 07BD BABR 10.6 $e^+e^- \rightarrow \Lambda \overline{\Lambda} \gamma$ | • |
| $\Gamma(2(\pi^+\pi^-\pi^0)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ VALUE (eV) EVTS DOCUMENT ID TECN COMMENT | $\Gamma(ggg)/\Gamma_{total}$ VALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT |
| 11.2±3.3±1.3 43 AUBERT 06D BABR 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-\pi^0)\gamma$ | 10.58 ± 1.62 2.9 M 25 LIBBY 09 CLEO $\psi(2S) ightarrow$ hadrons |
| $\Gamma(K^+K^-2(\pi^+\pi^-)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $VALUE (eV)$ $EVTS$ $DOCUMENT ID$ $TECN$ $COMMENT$ | 25 Calculated using $\Gamma(\gamma gg)/\Gamma(ggg)=0.097\pm0.026\pm0.016$ from LiBBY 09, $B(\psi(2S)\to XJ/\psi)$ relative and absolute branching fractions from MENDEZ 08, $B(\psi(2S)\to \gamma\eta_C)$ from MITCHELL 09, and $B(\psi(2S)\to virtual\ \gamma\to hadrons),\ B(\psi(2S)\to \gamma\chi_{c,I}),$ and |
| 4.4±2.1±0.3 26 AUBERT 06D BABR 10.6 $e^+e^- \rightarrow K^+K^-2(\pi^+\pi^-)\gamma$ | ${\sf B}(\psi(2S)	o \ell^+\ell^-)$ from PDG 08. The statistical error is negligible and the systematic error is largely uncorrelated with that of $\Gamma(\gamma gg)/\Gamma_{\sf total}$ LIBBY 09 measurement. |
| $\Gamma(\pi^+\pi^-K^+K^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{54}\Gamma_6/\Gamma$ | $\Gamma(\gamma gg)/\Gamma_{\text{total}}$ Γ_4/Γ |
| VALUE (eV)EVTS DOCUMENT IDTECNCOMMENT | VALUE (units 10^{-2})EVTSDOCUMENT IDTECNCOMMENT1.025 \pm 0.288200 k 26 LIBBY09CLEO ψ (25) $\rightarrow \gamma$ + hadrons |
| 2.56 \pm 0.42 \pm 0.16 85 AUBERT 07AK BABR 10.6 $e^+e^- \to \pi^+\pi^- K^+ K^- \gamma$ $\Gamma(\phi f_0(980) \to \pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ $\Gamma_{87}\Gamma_6/\Gamma$ | 26 Calculated using $\Gamma(\gamma gg)/\Gamma(ggg) = 0.097 \pm 0.026 \pm 0.016$ from LIBBY 09. The statistical error is negligible and the systematic error is largely uncorrelated with that of |
| $\frac{VALUE (eV)}{0.347 \pm 0.169 \pm 0.003}$ 6 ± 3 $\frac{DOCUMENT ID}{17}$ $\frac{TECN}{AUBERT}$ 07AK BABR 10.6 e ⁺ e ⁻ → | $\Gamma(ggg)/\Gamma_{	ext{total}}$ LIBBY 09 measurement. $\Gamma(\gamma ggg)/\Gamma(ggg) \qquad \qquad \Gamma_4/\Gamma_3$ |
| $\pi^+\pi^-K^+K^-\gamma$ 17 AUBERT 07AK reports $[\Gamma(\psi(2S) 	o \phi f_0(980) 	o \pi^+\pi^-) 	imes \Gamma(\psi(2S) 	o e^+e^-)/$ | VALUE (units 10 ⁻²) EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma_{\text{total}}] \times [B(\phi(1020) \to K^+K^-)] = 0.17 \pm 0.08 \pm 0.02 \text{ eV}$ which we divide by our best value $B(\phi(1020) \to K^+K^-) = (48.9 \pm 0.5) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. | 9.7 \pm 2.6 \pm 1.6 |
| experiment's error and our second error is the systematic error from using our best value. $\Gamma(\phi\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\rm total}$ | NALUE DOCUMENT ID TECN COMMENT 0.154 \pm 0.015 27 MENDEZ 08 CLEO $e^+e^- \rightarrow \psi(25)$ |
| VALUE (eV)EVTSDOCUMENT IDTECNCOMMENT | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| 0.57±0.23±0.01 10 ¹⁸ AUBERT,BE 06D BABR 10.6 e^+e^- → $K^+K^-\pi^+\pi^-\gamma$ | 0.169 ± 0.026 28 ADAM 05 A CLEO $e^+e^- ightarrow \psi(2S)$ |
| ¹⁸ AUBERT,BE 06D reports $[\Gamma(\psi(2S) \rightarrow \phi\pi^+\pi^-) \times \Gamma(\psi(2S) \rightarrow e^+e^-)/\Gamma_{\text{total}}] \times$ | ²⁷ Uses B($\psi(2S) \rightarrow J/\psi X$) from MENDEZ 08 and other branching fractions from PDG 07. |

 ψ (2S)

| $\Gamma(e^+e^-)/\Gamma_{\rm total}$ | | Γ ₆ /Γ | $\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma_{\text{total}}$ | DO CUMENT ID | TECN | COMMENT | Γ_{11}/Γ |
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| VALUE (units 10 ⁻⁴) 77.3± 1.7 OUR FIT | DOCUMENT ID TECN COMMENT | | <u>VALUE</u> <u>EVTS</u> 0.336 ±0.004 OUR FIT | DO CUMENT ID | <u>TECN</u> | COMMENT | |
| | g data for averages, fits, limits, etc. • • • | | 0.343 ±0.011 OUR AVERAGE | Error includes scale | | | |
| 88 ±13 | 29 FELDMAN 77 RVUE e^+e^- | | $0.3504 \pm 0.0007 \pm 0.0077$ 565k 0.323 ± 0.014 | | 8 CLEO 2B BES2 | $\psi(2S) \rightarrow \ell^+$ | $\ell^{-}\pi^{+}\pi^{-}$ |
| ²⁹ From an overall fit assuming e | equal partial widths for e^+e^- and $\mu^+\mu^-$. Fo | or a mea- | 0.32 ± 0.04 | | | $e^+e^- \rightarrow J_I$ | $/_{\psi \pi^{+} \pi^{-}}$ |
| | entry $\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ below. Includes L | | • • • We do not use the followin $0.3354 \pm 0.0014 \pm 0.0110$ 60k | ng data for averages, | fits, limits, | | |
| $\Gamma(\mu^+\mu^-)/\Gamma_{ m total}$ | | Γ_7/Γ | ³³ Not independent from other v | values reported by AE | AM 05 A. | | |
| VALUE (units 10 ⁻⁴) | DO CUMENT ID | | $\Gamma(e^+e^-)/\Gamma(J/\psi(1S)\pi^+\pi^-$ | -) | | | Γ6/Γ11 |
| 77±8 OUR FIT | | | VALUE | DO CUMENT ID | TECN | COMMENT | . 6/ . 11 |
| $\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ | | Γ_7/Γ_6 | 0.0230 ± 0.0005 OUR FIT | 34 | 0- DADD | + - | |
| VALUE | DOCUMENT ID TECN COMMENT | | 0.0252±0.0028±0.0011 | | 2B BABR | e⊤ e⁻ | |
| 1.00±0.11 OUR FIT | g data for averages, fits, limits, etc. • • • | | 34 Using B $(J/\psi(1S) \rightarrow e^+e^-$ |) = 0.0593 ± 0.0010 | | | |
| 0.89±0.16 | BOYARSKI 75c MRK1 e^+e^- | | $\Gamma(\mu^+\mu^-)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ | | | | Γ_7/Γ_{11} |
| | | | <u>VALUE</u> 0.0229±0.0025 OUR FIT | DO CUMENT ID | TECN | COMMENT | |
| $\Gamma(au^+	au^-)/\Gamma_{	ext{total}}$ | | Г ₈ /Г | 0.0224±0.0029 OUR AVERAGE | | | | |
| VALUE (units 10 ⁻⁴) 30 ±4 OUR FIT | DO CUMENT ID TECN COMMENT | | $0.0216 \pm 0.0026 \pm 0.0014$ | | 2B BABR | | |
| 30.8±2.1±3.8 | 30 ABLIKIM 06w BES $e^+e^- ightarrow \psi(2)$ | 25) | $0.0327 \pm 0.0077 \pm 0.0072$ | 35 GRIBUSHIN 9 | | 515 π ⁻ Be - | $\rightarrow 2\mu X$ |
| | of B $(\psi(2S) ightarrow$ hadrons $)=0.9810\pm0.0030$ to | | ³⁵ Using B($J/\psi(1S) \rightarrow \mu^+\mu^-$ | $() = 0.0588 \pm 0.0010$ | | | |
| the total number of $\psi(2S)$ eve | ents. | | $\Gamma(au^+	au^-)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ | -) | | | Γ_8/Γ_{11} |
| DECAYS IN | TO $J/\psi(1S)$ and anything $\overline{}$ | _ | VALUE (units 10 ⁻³) | DOCUMENT ID | TECN | COMMENT | |
| $\Gamma(J/\psi(1S)$ anything $)/\Gamma_{ m total}$ | ,,,, | Γ. /Γ | 9.0 ±1.1 OUR FIT 8.73±1.39±1.57 | BAI (| 2 BES | e+e- | |
| VALUE | DOCUMENT ID TECN COMMENT | Г9/Г | | | 2 BL3 | e · e | |
| 0.5 95 ± 0.008 OUR FIT | | | $\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ | | | | Γ_{11}/Γ_{9} |
| 0.55 ±0.07 OUR AVERAGE 0.51 ±0.12 | BRANDELIK 79C DASP $e^+e^- ightarrow\mu$ | .+ v | VALUE EVTS 0.5646±0.0026 OUR FIT | DO CUMENT ID | TECN | COMMENT | |
| 0.57 ±0.08 | ABRAMS 75B MRK1 $e^+e^- \rightarrow \mu$ | | 0.554 ±0.008 OUR AVERAGE | Error includes scale | factor of 1 | .3. See the ide | eogram |
| • • • We do not use the following | g data for averages, fits, limits, etc. • • • | | below. 0.5604 ± 0.0009 ± 0.0062 565k | MENDEZ 0 | 8 CLEO | $\psi(2S) \rightarrow \ell^{+}$ | ρ-π+π- |
| $0.6254 \pm 0.0016 \pm 0.0155$ 1.1M | 31 MENDEZ 08 CLEO $\psi(2S) ightarrow \ell^{-1}$ | | $0.525 \pm 0.009 \pm 0.022$ 4k | ANDREOTTI (| | $\psi(2S) \rightarrow J/$ | |
| $0.5950 \pm 0.0015 \pm 0.0190$ 151k | ADAM 05A CLEO Repl. by ME | NDEZ 08 | $0.536 \pm 0.007 \pm 0.016$ $20k^{-36}$ 0.496 ± 0.037 | | 4B BES | $\psi(2S) \rightarrow J/$ | |
| 21 | | | | | | | |
| 31 Not independent from other m | leasurements of MENDEZ 08. | | | ARMSTRONG 9 ng data for averages. | | |) |
| $\Gammaig(e^+e^-ig)/\Gammaig(J/\psi(1S)$ anythin | ng) | | ● We do not use the following | ng data for averages, | fits, limits, | etc. • • • | |
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| $\Gamma\left(e^{+}e^{-}\right)/\Gamma\left(J/\psi(1S) \text{ anythin} \\ \Gamma_{6}/\Gamma_{9} = \Gamma_{6}/\Gamma_{6}/\Gamma_{6} \\ \frac{VALUE \text{ (units }10^{-2})}{1.299\pm0.026 \text{ OUR FIT}} \\ \frac{EVTS}{1.28\pm0.04 \text{ OUR AVERAGE}} \\ \frac{1.22\pm0.02\pm0.05}{1.28\pm0.03\pm0.02} \\ \frac{1.28\pm0.03\pm0.02}{1.44\pm0.08\pm0.02} \\ \frac{32}{32} \text{ Using B}(J/\psi(1S) \rightarrow e^{+}e^{-}) \\ \text{WEIGHTED AVERAGE} \\ \frac{1.28\pm0.04}{1.28\pm0.04} \text{ (Error scaled b} \\ \frac{1}{32} \\ \frac{1.2}{32} \\ \frac{1.2}{32} \\ \frac{1.2}{32} \\ \frac{1.2}{32} \\ \frac{1.4}{32} \\ $ | $\begin{array}{c} \text{Ng} \\ \text{Fil} + \text{Fil} + \text{Fil} + 0.344 \text{Fill} + 0.195 \text{Fill} \\ \underline{pocument\ id} \\ \underline{pocument\ id} \\ \text{Tror includes scale factor of } 1.6. \text{ See the ideogra} \\ 32 \text{ ANDREOTTI} \\ 05 \text{ E835} \\ \underline{pp} \rightarrow \psi(2:32) \\ 32 \text{ AMBROGIA NI} \\ 00A \text{ E835} \\ \underline{pp} \rightarrow \psi(2:32) \\ 32 \text{ ARMSTRONG} \\ 97 \text{ E760} \\ \underline{pp} \rightarrow \psi(2:32) \\ 20.0593 \pm 0.0010. \\ \text{Ny} \\ 1.6) \\ \text{Values above of weighted average, error, and scale factor are based upon the data this ideogram only. They are not necessarily the same as our 'best' values, obtained from a least-squares constrained utilizing measurements of other (related) quantities as additional information. \\ \text{ANDREOTTI} \\ 05 \text{ E835} \\ 1. \\ \text{AMBROGIANI} \\ \text{O0A} \\ \text{E835} \\ \text{O.} \\ \text{ARMSTRONG} \\ \text{O7} \\ \text{E835} \\ \text{O.} \\ \text{ARMSTRONG} \\ \text{O7} \\ \text{E835} \\ \text{O.} \\ \text{ARMSTRONG} \\ \text{O7} \\ \text{E835} \\ \text{O.} \\ \text{ARMSTRONG} \\ \text{O7} \\ \text{E835} \\ \text{O.} \\ \text{ARMSTRONG} \\ \text{O7} \\ \text{E760} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{I.6} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ \text{O.} \\ 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| $\Gamma\left(e^{+}e^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \\ \Gamma_{6}/\Gamma_{9} = \Gamma_{6}/\Gamma_{6}/\Gamma_{6} \\ \Gamma_{6}/\Gamma_{9} = \Gamma_{6}/\Gamma_{6}/\Gamma_{6}/\Gamma_{6}/\Gamma_{6} \\ \Gamma_{1299\pm0.026} \text{ OUR FIT} \\ 1.28 \pm 0.04 \text{ OUR AVERAGE } \\ 1.22 \pm 0.02 \pm 0.05 5097 \pm 73 \\ 1.28 \pm 0.03 \pm 0.02 \\ 1.44 \pm 0.08 \pm 0.02 \\ 32 \text{ Using B}(J/\psi(1S) \rightarrow e^{+}e^{-}) \\ \text{WEIGHTED AVERAGE} \\ 1.28\pm0.04 \text{ (Error scaled b} \\ 1.28\pm0.04 \text{ (Fror Scaled b}) \\ \\ \Gamma\left(e^{+}e^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \\ \Gamma\left(\mu^{+}\mu^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \right) \\ \Gamma\left(\mu^{+}\mu^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \\ \Gamma\left(\mu^{+}\mu^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \right) \\ \Gamma\left(\mu^{+}\mu^{-}\right)/\Gamma\left(J/\psi(1S)\text{ anythin} \\ \Gamma\left(\mu^{+}\mu^{-}\right)/\Gamma\left(J/\psi(1S)\text{ 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They are not necessarily the same as our best Values, obtained from a least-squares constrained utilizing measurements of other (related) quantities as additional information. ANDREOTTI 05 E835 $\rho \overline{\rho} \rightarrow \psi(2: e^+e^-)$ $e^+e^ \rho \overline{\rho} \rightarrow \psi(2: e^+e^-)$ $e^+e^ \rho \overline{\rho} \rightarrow \psi(2: e^+e^-)$ $e^+e^ e^+e^ e^ $ | (5) → (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) $($ | • • • We do not use the followin 0.5637 \pm 0.0027 \pm 0.0046 60k 36 From a fit to the J/ψ recoil 137 ABLIKIM 04B quotes $B(\psi(25))$ WEIGHTED AVERAGE 0.554 \pm 0.008 (Error scale 0.554 \pm 0.008 (Error scale 0.554 \pm 0.008 (Error scale 0.70) $\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma$ $\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma_{11} = (0.9761)$ $\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma_{12}$ 0.731 \pm 0.008 OUR FIT 0.73 \pm 0.09 $\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma_{13}$ $EVTS$ 0.1775 \pm 0.0034 OUR FIT 0.0769 \pm 0.0034 0.0053 61k 0.1652 \pm 0.0014 \pm 0.0058 13.4k | ng data for averages, ADAM (mass spectra. $5) \rightarrow J/\psi X$) / B(ψ (ed by 1.3) Values above and scale fact this ideogram starily the sar obtained from utilizing mean expectation of the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same and the same | e of weighte tor are bas to only. 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(5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) (5) $($ | • • • We do not use the followin 0.5637 \pm 0.0027 \pm 0.0046 60k 36 From a fit to the J/ψ recoil 137 ABLIKIM 04B quotes $B(\psi(25))$ WEIGHTED AVERAGE 0.554 \pm 0.008 (Error scale 0.554 \pm 0.008 (Error scale 0.554 \pm 0.008 (Error scale 0.574 \pm 0.008 OUR FIT 0.73 \pm 0.09 $\Gamma(J/\psi(15)\pi^0\pi^0)/\Gamma_{\text{total}}$ EVTS 0.1775 \pm 0.0034 OUR FIT 0.70 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 0.00761 \pm 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of weighte tor are bas to only. The ne as our bas and ditional in the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface of the surface | etc. • • • Repl. by MEI Repl. by MEI $(\psi \pi^+ \pi^-)$. And average, errued upon the day are not neces est' values, uares constrain of other (related information.) By CLEO By CLEO By CLEO By E835 By E760 COMMENT e^+e^- etc. • • • O $\psi(25) \rightarrow$ | NDEZ 08 or, ta in $\frac{\chi^2}{1.5}$ ned fit $\frac{\chi^2}{1.5}$ 1.1 3.6 0.168) Γ_{11}/Γ_9 Γ_{12}/Γ $\ell^+\ell^-2\pi^0$ |

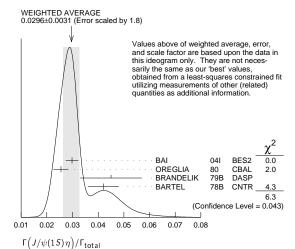
³⁹ Not independent from other values reported by ADAM 05A.

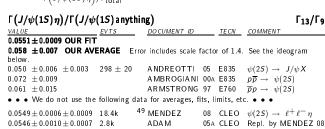
| $\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma(S)$ | $J/\psi(1S)$ and | ything) | | | Γ ₁₂ /Γ ₉ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|---------------------------------------------------------------|----------|----------|---------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.2982±0.0032 OUR FIT | | | | | |
| 0.320 ±0.012 OUR AVI | | | | | |
| $0.300 \pm 0.008 \pm 0.022$ | 1655 ± 44 | ANDREOTTI | | E835 | $\psi(2S) \rightarrow J/\psi X$ |
| $0.328 \pm 0.013 \pm 0.008$ | | AMBROGIAN | | | $p\overline{p} \rightarrow \psi(2S)$ |
| 0.323 ±0.033 | | ARMSTRONG | | | $\overline{\rho}\rho \rightarrow \psi(2S)$ |
| • • • We do not use the | following dat | a for averages, | tits, li | mits, et | C. • • • |
| $0.2829 \pm 0.0012 \pm 0.0056$ | 61k | MENDEZ | 80 | CLEO | $\psi(2S) \rightarrow \ell^+ \ell^- 2\pi^0$ |
| $0.2776 \pm 0.0025 \pm 0.0043$ | 13.4k | ADAM | 05 A | CLEO | Repl. by MENDEZ 08 |
| $\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma(S)$ | | π ⁻) DOCUMENT ID | | TECN | Γ ₁₂ /Γ ₁₁ |
| 0.528 ±0.008 OUR FIT | | | | | |
| 0.513 ±0.022 OUR AVI | ERAGE Erro | r includes scale | facto | | _ |
| $0.5047\pm0.0022\pm0.0102$ | | MENDEZ | 80 | | $\psi(2S) \rightarrow \ell^+\ell^-2\pi^0$ |
| $0.570 \pm 0.009 \pm 0.026$ | | ABLIKIM | | | $\psi(2S) \rightarrow J/\psi X$ |
| • • • We do not use the | following dat | a for averages, | fits, li | mits, et | C. • • • |
| $0.4924\pm0.0047\pm0.0086$ | 73k ^{41,42} | ADAM | 05A | CLEO | Repl. by MENDEZ 08 |
| $0.571 \pm 0.018 \pm 0.044$ | 43 | ANDREOTTI | 05 | E835 | $\psi(2S) \rightarrow J/\psi X$ |
| 0.53 ± 0.06 | | TANENBAUM | 76 | MR K1 | e^+e^- |
| 0.64 ± 0.15 | 44 | HILGER | 75 | SPEC | e^+e^- |
| 40 From a fit to the J/ψ 41 Not independent from 42 Using 13,217 $J/\psi\pi^0$ 43 Not independent from 44 Ignoring the $J/\psi(15)$ | other values π^0 and 60,010 other values | reported by AD 0 $J/\psi \pi^+ \pi^-$ ev reported by AD | ents. | | j. |

| $\Gamma(J/\psi(1S)\eta)/\Gamma_{total}$ | | | | | Γ ₁₃ /Γ |
|-------------------------------------------------|-----------|-------------------------|----------|-----------|---------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.0328 ± 0.0007 OUR FIT | | | | | |
| 0.0296 ± 0.0031 OUR AVE | RAGE | Error includes scale | facto | r of 1.8. | See the ideogram |
| below. | | | | | |
| $0.0298 \pm 0.0009 \pm 0.0023$ | 5.7k | BAI | 041 | BES2 | $\psi(2S) \rightarrow J/\psi \gamma \gamma$ |
| 0.0255 ± 0.0029 | 386 | ⁴⁵ OREGLIA | 80 | CBAL | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 0.045 ± 0.012 | 17 | ⁴⁶ BRANDELIK | 79B | DASP | $e^+e^- \rightarrow J/\psi 2\gamma$ |
| 0.042 ± 0.006 | 164 | ⁴⁶ BARTEL | 78B | CNTR | e^+e^- |
| \bullet \bullet \bullet We do not use the | following | g data for averages, | fits, li | mits, etc | i. • • • |
| $0.0343 \pm 0.0004 \pm 0.0009$ | 18.4k | ⁴⁷ MENDEZ | 08 | CLEO | $\psi(2S) \rightarrow \ell^+ \ell^- \eta$ |
| $0.0325 \pm 0.0006 \pm 0.0011$ | 2.8k | ⁴⁸ ADAM | | CLEO | Repl. by MENDEZ 08 |
| 0.043 ± 0.008 | 44 | TANENBAUM | 76 | MRK1 | e^+e^- |

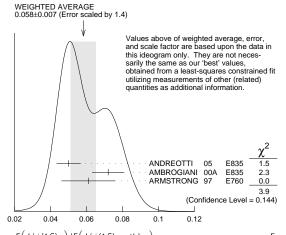
 $^{^{45}}$ Recalculated by us using B($J/\psi(1S)
ightarrow \ell^+\ell^-) = 0.1181 \pm 0.0020$.

 $^{^{\}mbox{\sc 48}}$ Not independent from other values reported by ADAM 05A.





 $^{
m 49}\,{\rm Not}$ independent from other measurements of MENDEZ 08.



 $\Gamma(J/\psi(1S)\eta)/\Gamma(J/\psi(1S))$ anything Γ_{13}/Γ_{9}

| $\Gamma(J/\psi(1S)\eta)/\Gamma(J/\psi)$ | $(15)\pi^{+}$ | π^-) | | | Γ_{13}/Γ_{11} |
|-----------------------------------------|---------------|-----------------------|---------|-----------|---------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.0976 ± 0.0016 OUR FIT | T | | | | |
| 0.0979 ± 0.0018 OUR AV | ERAGE | | | | |
| $0.0979 \pm 0.0010 \pm 0.0015$ | 18.4k | MENDEZ | 08 | CLEO | $\psi(2S) \rightarrow \ell^{+}\ell^{-}\eta$ |
| $0.098 \pm 0.005 \pm 0.010$ | 2k | ⁵⁰ ABLIKIM | 04B | BES | $\psi(2S) \rightarrow J/\psi X$ |
| 0.091 ± 0.021 | | ⁵¹ HIMEL | 80 | MRK2 | $e^+e^- \rightarrow \psi(2S)X$ |
| • • • We do not use the | following | g data for averages, | fits, I | imits, et | c. • • • |
| $0.0968 \pm 0.0019 \pm 0.0013$ | 2.8k | ⁵² ADAM | 05 A | CLEO | Repl. by MENDEZ 08 |
| $0.095 \pm 0.007 \pm 0.007$ | | | | | $\psi(2S) \rightarrow J/\psi X$ |
| 50 From a fit to the J/η | b recoil m | ass spectra. | | | |
| | | | | | |

⁵¹ The value for B($\psi(2S) \to J/\psi(1s) \eta$) reported in HIMEL 80 is derived using B($\psi(2S)$) \to $J/\psi(1S)\,\pi^+\,\pi^-)=(33\pm3))\%$ and B $(J/\psi(1S)\to\ell^+\ell^-)=0.138\pm0.018.$ Calculated by us using B($J/\psi(1S) \rightarrow \ell^+\ell^-$) = (0.1181 \pm 0.0020).

52 Not independent from other values reported by ADAM 05A

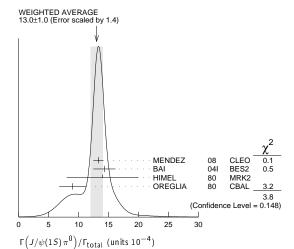
 $^{53}\,\mathrm{Not}$ independent from other values reported by ANDREOTTI 05

$\Gamma(J/\psi(1S)\pi^0)/\Gamma_{\rm total}$

 Γ_{14}/Γ

| VALUE (units 10^{-4}) | EVTS | DO CUMENT IL |) | TECN | COMMENT |
|--------------------------------|---------------|-----------------------|-----------|-----------|--------------------------------------------------|
| 13.0±1.0 OUR AVER | AGE Error | includes scale fa | ctor of | 1.4. See | the ideogram below. |
| $13.3 \!\pm\! 0.8 \!\pm\! 0.3$ | 530 | MENDEZ | 08 | CLEO | $\psi(2S) \rightarrow \ell^{+} \ell^{-} 2\gamma$ |
| $14.3 \pm 1.4 \pm 1.2$ | 280 | BAI | 041 | BES2 | $\psi(2S) \rightarrow J/\psi \gamma \gamma$ |
| 14 ±6 | 7 | | 80 | MRK2 | e^+e^- |
| $9 \pm 2 \pm 1$ | 23 | ⁵⁴ OREGLIA | 80 | CBAL | $\psi(2S) \rightarrow J/\psi 2\gamma$ |
| • • • We do not use | the following | data for averag | es, fits, | limits, e | tc. • • • |
| $13 \pm 1 \pm 1$ | 88 | ADAM | 05 A | CLEO | Repl. by MENDEZ 08 |
| | | | | | |

 54 Recalculated by us using B $(J/\psi(1S)
ightarrow ~\ell^+\ell^-) = 0.1181 \pm 0.0020.$



 $\Gamma(J/\psi(1S)\pi^0)/\Gamma(J/\psi(1S) \text{ anything})$ $\Gamma_{14}/\Gamma_9 = \Gamma_{14}/(\Gamma_{11} + \Gamma_{12} + \Gamma_{13} + 0.344\Gamma_{110} + 0.195\Gamma_{111})$

| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------|----------------------|-------|-----------|-------------------------------------------|
| ullet $ullet$ We do not use the | following | g data for averages, | fits, | limits, e | tc. • • • |
| $0.213 \pm 0.012 \pm 0.003$ | 527 | ⁵⁵ MENDEZ | 08 | CLEO | $e^+e^- \rightarrow J/\psi \gamma \gamma$ |
| $0.22\ \pm0.02\ \pm0.01$ | | ⁵⁶ ADAM | 05 A | CLEO | $e^+e^- \rightarrow \psi(2S) \rightarrow$ |
| | | | | | $J/\psi \gamma \gamma$ |

⁴⁶ Recalculated by us using B($J/\psi(1S) \rightarrow \mu^+\mu^-$) = 0.0588 \pm 0.0010.

⁴⁷ Not independent from other measurements of MENDEZ 08.

$\psi(2S)$

 55 Not independent from other values reported by MENDEZ 08. Supersedes ADAM 05A. 56 Not independent from other values reported by ADAM 05A.

| $\Gamma(J/\psi(1S)\pi^0)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ | | | | | | | | |
|--------------------------------------------------------|--------------|----------------------|--------------|---------|----------------------|------------------------|--|--|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | T | ECN | COMMENT | | | |
| • • • We do not use th | ne following | g data for average | s, fits, lim | nits, e | tc. • • • | | | |
| $0.380 \pm 0.022 \pm 0.005$ | 527 | ⁵⁷ MENDEZ | 08 C | LEO | e^+e^- | $J/\psi \gamma \gamma$ | | |
| $0.39 \ \pm 0.04 \ \pm 0.01$ | | ⁵⁸ ADAM | | | $e^+e^- \rightarrow$ | | | |

 57 Not independent from other values reported by MENDEZ 08. Supersedes ADAM 05A.

 $^{58}\,\mathrm{Not}$ independent from other values reported by ADAM $05\,\mathrm{A}.$

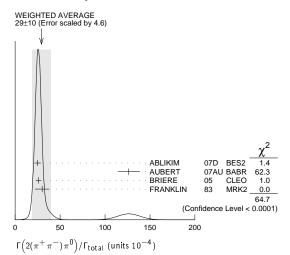
- HADRONIC DECAYS -

| $\Gamma(\pi^0 h_c(1P))/\Gamma$ | Γ _{total} | | | | | Γ ₁₅ /Γ |
|--------------------------------|------------------------|-----------------------|----------------------|-----------|------------------------|-------------------------------|
| VALUE (units 10^{-4}) | EVTS | DOCUMENT ID |) | TE CN | COMMENT | |
| 8.6 ± 1.3 OUR AV | ERAGE | | | | | |
| $9.0\pm 1.5\pm 1.3$ | 3k | ⁵⁹ GE | | | | π^0 anything |
| $8.4\pm1.3\pm1.0$ | 11k | ABLIKIM | 10B | BES3 | $\psi(2S) \rightarrow$ | $\pi^0 h_c$ |
| • • • We do not | use the follow | ing data for avera | ges, fits | , limits, | etc. • • • | - |
| seen | $92 + 23 \\ -22$ | ADAMS | | | | $^{2\pi^{+}2\pi^{-}2\pi^{0}}$ |
| seen | 1 282 | DOBBS | 08A | CLEO | $\psi(2S) \rightarrow$ | $\pi^0 \eta_C \gamma$ |
| seen | 168 ± 40 | ROSNER | 05 | CLEO | $\psi(2S) \rightarrow$ | $\pi^0 \eta_C \gamma$ |
| ⁵⁹ Assuming a w | idth $\Gamma(h_C(1P))$ | $=$ 0.86 MeV \equiv | Γ ₀ , a n | ne asured | dependenc | e of the central |

 59 Assuming a width $\Gamma(h_{\mathcal{C}}(1P))=0.86$ MeV $\equiv \varGamma_0$, a measured dependence of the central value of $B=(7.6+1.4~\times~\Gamma(h_{\mathcal{C}}(1P)/\Gamma_0)~\times~10^{-4}$, and with a systematic error that accounts for the width variation range 0.43-1.29 MeV.

| $\Gamma\big(2(\pi^+\pi^-)\pi^0\big)/ $ | T _{total} | | | | Γ ₁₇ /Γ |
|----------------------------------------|--------------------|----------------------|--------------|--------|----------------------------------------------------|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 29 ±10 OUR AV | /ERAGE | Error includes | scale | factor | of 4.6. See the ideogram below. |
| $24.9 \pm 0.7 \pm 3.6$ | 2173 | ABLIKIM | 07D | BES2 | $e^+ e^- \rightarrow \psi(2S)$ |
| $127 \pm 12 \pm 2$ | 410 | ⁶⁰ AUBERT | 07 AU | BABR | 10.6 $e^+e^- \rightarrow 2(\pi^+\pi^-)\pi^0\gamma$ |
| $26.1 \pm 0.7 \pm 3.0$ | 1703 | BRIERE | 05 | CLEO | $e^+e^- \rightarrow \psi(2S) \rightarrow$ |
| | | | | | $2(\pi^{+}\pi^{-})\pi^{0}$ |
| 30 + 8 | 42 | FRANKLIN | 83 | MRK2 | e+ e- |

 60 AUBERT 07AU reports $[\Gamma(\psi(2S)\to 2(\pi^+\pi^-)\pi^0)/\Gamma_{\rm total}]\times [\Gamma(\psi(2S)\to e^+e^-)]=(297\pm22\pm18)\times 10^{-4}$ keV which we divide by our best value $\Gamma(\psi(2S)\to e^+e^-)=2.35\pm0.04$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

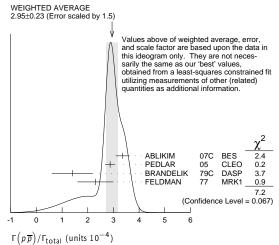


| $\Gamma(\rho a_2(132$ | 20))/Γ _{total} | | | | Г ₁₈ /Г |
|-------------------------------------|-------------------------|---------------------|-----------------------|---------------------------|--------------------------------------|
| VALUE (units 1 | 0 ⁻⁴) CL% | EVTS DOCUM | MENT ID TECH | <u>COMMENT</u> | |
| 2.55 ± 0.73 ± | 0.47 112 | ± 31 BAI | 04c BES | $2 \psi(2S) \rightarrow$ | $2(\pi^{+}\pi^{-})\pi^{0}$ |
| • • • We d | o not use the fo | ollowing data for a | averages, fits, limit | s, etc. • • • | |
| <2.3 | 90 | BAI | 98J BES | $e^+ e^-$ | |
| $\Gamma(p\overline{p})/\Gamma_{to}$ | tal | | | | Γ19/Γ |
| VALUE (units 1 | 0^{-4}) EVT. | <u>DOCUMEN</u> | T ID TECN | COMMENT | |
| 2.76±0.12 | OUR FIT | | | | |
| 2.95 ± 0.23 | OUR AVERAGE | Error includes s | scale factor of 1.5. | See the ideo | gram below. |
| $3.36 \pm 0.09 \pm$ | 0.25 1618 | B ABLIKIM | 07c BES | $e^+e^- \rightarrow$ | $\psi(2S) \rightarrow p\overline{p}$ |
| $2.87 \pm 0.12 \pm$ | 0.15 55 | 7 PEDLAR | 05 CLEO | $e^+e^- \rightarrow$ | $\psi(2S) \rightarrow p\overline{p}$ |
| 14 +08 | , | I BRANDE | IIK 70C DASP | a+a | 4/2C) . no |

FELDMAN

 $2.3\ \pm0.7$

77 MRK1 $e^+e^- \rightarrow \psi(2S) \rightarrow p\overline{p}$



| (FF) | total | , | | | | |
|--------------------------------------------|-------------------------------|--------------------------------------|---------|---------|----------------------------|--------------------------------------|
| $\Gamma(p\overline{p})/\Gamma(J/\psi(1))$ | l <i>S</i>) π ⁺ 1 | π-) | | | | Γ_{19}/Γ_{11} |
| VALUE (units 10^{-4}) | | DO CUMENT | ID | TEC | <u>COMMENT</u> | |
| 8.2 ±0.4 OUR F 6.98±0.49±0.97 | ΊΤ | BAI | 01 | BES | $e^+e^- \rightarrow$ | $\psi(2S) \rightarrow p\overline{p}$ |
| $\Gamma(\Delta^{++}\overline{\Delta}^{})/$ | Γ _{tot al} | | | | | Γ_{20}/Γ |
| VALUE (units 10^{-5}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 12.8±1.0±3.4 | 157 | 61 BAI | 01 I | BES | $e^+e^- ightarrow \psi($ | 25) → |
| ⁶¹ Estimated usin | g B(ψ(2 | $S) \rightarrow J/\psi \pi^+ \pi^-)$ | = 0.310 | 0.0 ± 0 | 28. | |

| $\Gamma(\Lambda \overline{\Lambda} \pi^0)/\Gamma_{ m total}$ | | | | | | Γ ₂₁ /Γ |
|--------------------------------------------------------------|-------------|------------------------------------|------|-------|----------------------|--------------------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.2 | 90 | 62 ABLIKIM | 07н | BES2 | $e^+e^- \rightarrow$ | $\psi(2S)$ |
| 62 Using B($\Lambda \to \pi^-$ | (-p) = 63.9 | 9% and B $(\eta 	o \gamma \gamma)$ | = 39 | 9.4%. | | |

| $\Gamma(\Lambda \overline{\Lambda} \eta)/\Gamma_{\text{total}}$ | | | | | | | Γ_{22}/Γ |
|-----------------------------------------------------------------|----------|-----|-------------|-----|------|----------|----------------------|
| VALUE (units 10^{-4}) | CL% | | DOCUMENT ID | | TECN | COMMENT | |
| <0.49 | 90 | 63 | ABLIKIM | 07н | BES2 | e^+e^- | $\psi(2S)$ |
| ⁶³ Using B($\Lambda \rightarrow \pi^- p$) |) = 63.9 | 9%. | | | | | |

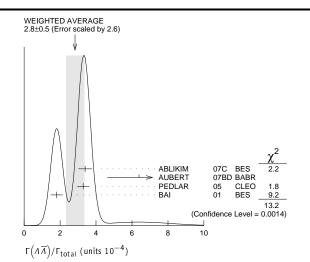
| $\Gamma(\Lambda \overline{p} K^+)/\Gamma_{\text{total}}$ | | | | | Γ ₂₃ /Γ |
|----------------------------------------------------------|------|--------------|----|------|-------------------------------------------|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.0±0.1±0.1 | 74.0 | BRIERE | 05 | CLEO | $e^+e^- \rightarrow \psi(2S) \rightarrow$ |
| | | | | | $p \overline{p} K^+ \pi^-$ |

| $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ | Γ ₂₆ /Γ |
|------------------------------------------------------------|--------------------|
| | |

| VALUE (units 10 ⁻⁴) CL% EVTS | DO CUMENT | ID TECN | COMMENT |
|------------------------------------------|----------------------|----------------|----------------------------------------------------|
| 2.8 ±0.5 OUR AVERAGE | Error includes | scale factor o | of 2.6. See the ideogram below. |
| $3.39 \pm 0.20 \pm 0.32$ 337 | ABLIKIM | 07c BES | $e^+e^- ightarrow \psi(2S) ightarrow { m hadrons}$ |
| $6.4 \pm 1.8 \pm 0.1$ | ⁶⁴ AUBERT | 07BD BABI | R 10.6 e^+e^- → $Λ \overline{\Lambda} \gamma$ |
| | PEDLAR | 05 CLE | $e^+e^- ightarrow \psi(2S) ightarrow { m hadrons}$ |
| $1.81 \pm 0.20 \pm 0.27$ 80 | 65 BAI | 01 BES | $e^+e^- ightarrow\psi(2S) ightarrow$ hadrons |
| | owing data for | averages, fits | . limits, etc. • • • |

< 4 90 FELDMAN 77 MRK1 $e^+e^- \rightarrow \psi(2S) \rightarrow$ hadrons ⁶⁴ AUBERT 07BD reports $[\Gamma(\psi(2S) \rightarrow \Lambda \overline{\Lambda})/\Gamma_{\text{total}}] \times [\Gamma(\psi(2S) \rightarrow e^+e^-)] = (15 \pm 4 \pm 1) \times 10^{-4}$ keV which we divide by our best value $\Gamma(\psi(2S) \rightarrow e^+e^-) = 2.35 \pm 0.04$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁶⁵ Estimated using B($\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$)= 0.310 \pm 0.028.

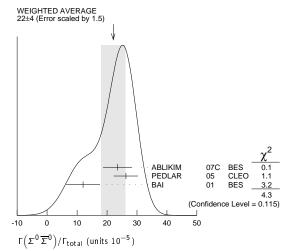


$\Gamma(\Sigma^{+}\overline{\Sigma}^{-})/\Gamma_{total}$ Γ_{27}/Γ VALUE (units 10^{-5}) EVTS DOCUMENT ID TECN COMMENT

25.7±4.4±6.8 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow \text{hadrons}$ PEDLAR

 $\Gamma(\Sigma^0 \overline{\Sigma^0})/\Gamma_{total}$ Γ_{28}/Γ DOCUMENT ID TECN COMMENT 22 ±4 OUR AVERAGE Error includes scale factor of 1.5. See the ideogram below. ABLIKIM 07c BES $e^+e^-
ightarrow \psi(2S)
ightarrow hadrons$ PEDLAR 05 CLEO $e^+e^-
ightarrow \psi(2S)
ightarrow hadrons$ $23.5 \pm 3.6 \pm 3.2$ 59 $26.3 \pm 3.5 \pm 2.1$ 66 _{BAI} 8 01 BES $e^+e^-
ightarrow \psi(2S)
ightarrow ext{hadrons}$

 $66\,{\rm Estimated}$ using B($\psi(2S)\,\rightarrow\,$ $J/\psi\,\pi^+\,\pi^-)\!=\,0.310\,\pm\,0.028.$



| $\Gamma(\Sigma(1385)^+\overline{\Sigma}(1385)^-)/\Gamma_{\text{total}}$ | | | | | | |
|-------------------------------------------------------------------------|------|--------------|----|------|------------|--|
| VALUE (units 10^{-5}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 11 1 2 1 2 | 1.4 | 67 BAL | 01 | DEC | a+ a=/(25) | |

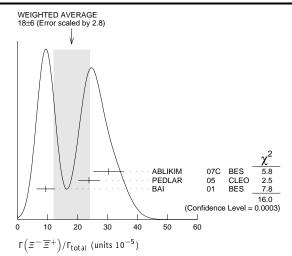
hadrons

⁶⁷Estimated using B($\psi(2S) \rightarrow J/\psi \pi^+ \pi^-$)= 0.310 \pm 0.028.

$\Gamma(\Xi^{-}\overline{\Xi}^{+})/\Gamma_{total}$ Γ_{30}/Γ

| VALUE (units 10 ⁻⁵ |) CL% EVTS | DO CUMENT | ID | TECN | COMMENT |
|-------------------------------|----------------|-------------------|-------|--------------|-------------------------------------------------------------|
| 18 ±6 OU | R AVERAGE | Error includes | | | 2.8. See the ideogram below. |
| $30.3 \pm 4.0 \pm 3.$ | 2 67 | ABLIKIM | 07c | BES | $e^+e^- ightarrow \; \psi(2S) ightarrow \; {\sf hadrons}$ |
| $23.8 \pm 3.0 \pm 2.$ | 1 63 | PEDLAR | 05 | CLEO | $e^+e^- ightarrow\psi(2S) ightarrow$ hadrons |
| $9.4 \pm 2.7 \pm 1.$ | 5 12 | ⁶⁸ BAI | 01 | BES | $e^+e^- ightarrow\psi(2S) ightarrow$ hadrons |
| • • • We do no | t use the foll | owing data for a | verag | es, fits, li | mits, etc. • • • |
| <20 | 90 | FELDMAN | 77 | MRK1 | $e^+e^- ightarrow \; \psi(2S) ightarrow \; {\sf hadrons}$ |

 $^{68}\, {\rm Estimated}$ using B($\psi(2{\rm S}) \,\rightarrow\, J/\psi\, \pi^+\, \pi^-) =\, 0.310\,\pm\,0.028.$



| $\Gamma(\Xi^0\overline{\Xi}^0)/\Gamma_{\mathrm{total}}$ | ļ | | | | | Г ₃₁ /Г |
|---------------------------------------------------------|------|--------------|----|------|--------------------------------------------|--------------------|
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 27.5 ± 6.4 ± 6.1 | 19 | PEDLAR | 05 | CLEO | $e^+ e^- \rightarrow \psi(2S) \rightarrow$ | |
| | | | | | hadrons | |

| I (= (1530) = (1530)) / I total | | | | | | 1 32/1 |
|----------------------------------|-------------|--------------------|-------|------------|---------------------------|----------------------------|
| VALUE (units 10 | -5) CL% | DO CUMENT II |) | TECN | COMMENT | |
| < 8.1 | 90 | 69 BAI | 01 | BES | $e^+e^- \rightarrow \psi$ | $(2S) \rightarrow hadrons$ |
| ● ● We do | not use the | following data for | avera | ges, fits, | limits, etc. • • | • |
| <32 | 90 | PEDLAR | 05 | CLEO | $e^+e^- \rightarrow \psi$ | $(2S) \rightarrow hadrons$ |

 $^{69}\,{\rm Estimated}$ using B($\psi(2S)\,\rightarrow\,$ $J/\psi\,\pi^+\,\pi^-$)= 0.310 \pm 0.028. $\Gamma(\Omega^{-}\overline{\Omega}^{+})/\Gamma_{total}$ Γ_{33}/Γ VALUE (units 10^{-5}) CL% DOCUMENT ID < 7.3 70 BAI $\overline{01}$ $\overline{\sf BES}$ $e^+\,e^ightarrow\,\psi(2S)
ightarrow\,{\sf hadrons}$ 90

• • • We do not use the following data for averages, fits, limits, etc. • • • 90 PEDLAR 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow \text{hadrons}$

 $^{70}\,{\rm Estimated}$ using B($\psi(2{\rm S})\,\rightarrow\,J/\psi\,\pi^+\,\pi^-)\!=\,0.310\,\pm\,0.028.$

| Γ(π ⁰ ρ ρ)/Ι | T _{total} | | | | Γ ₃₄ /Γ |
|-------------------------------------|-------------------------------|--------------------------------|--------------|-----------------------------------|--------------------|
| VALUE (units 10 |) ⁻⁴) EVTS | DO CUMENT | IDTECN | COMMENT | |
| 1.50 ± 0.08 C | OUR AVERAGE Er | or includes scale fa | ctor of 1.1. | | |
| $1.54 \pm 0.06 \pm$ | 0.06 948 | | | $0 \psi(2S) \rightarrow \pi^0 p$ | |
| $1.32 \pm 0.10 \pm$ | $0.15 \qquad 256 \pm 18$ | ⁷¹ ABLIKIM | 05E BES2 | $e^+e^- \rightarrow \psi(2)$ | S) → |
| | | | | $p\overline{p}\gamma\gamma$ | |
| 1.4 ± 0.5 | 9 | FRANKLIN | 83 MRK | (2 e ⁺ e ⁻ | |
| ⁷¹ Compute | d using B $(\pi^0 	o \gamma)$ | γ) = (98.80 \pm 0.03 | 3)%. | | |

 $\Gamma(N_1^*(1440)\overline{p} \to \pi^0 p \overline{p})/\Gamma_{\text{total}}$ Γ_{35}/Γ VALUE (units 10⁻⁵) DO CUMENT ID TECN COMMENT

 $72 \overline{\mathsf{ALEXANDER}} \ 10 \ \overline{\mathsf{CLEO}} \ \overline{\psi(2S)} o \ \pi^0 p \overline{p}$ 474 ⁷² From a fit of the $p\overline{p}$ and $p\pi^0$ mass distributions to a combination of $N_1^*(1440)\overline{p}$, π^0 $f_0(2100)$, and two other broad, unestablished resonances.

 $\Gamma(\pi^0\,f_0(2100)\to\pi^0\,\rho\,\overline{\rho})/\Gamma_{total}$ Γ_{36}/Γ VALUE (units 10^{-5}) EVTS DOCUMENT ID TECN COMMENT 73 ALEXANDER 10 CLEO $\psi(2S) \rightarrow \pi^0 \rho \overline{\rho}$ ⁷³ From a fit of the $p\overline{p}$ and $p\pi^0$ mass distributions to a combination of $N_1^*(1440)\overline{p}$, $\pi^0 f_0(2100)$, and two other broad, unestablished resonances.

| $\Gamma(\eta \rho \overline{\rho})/\Gamma_{\text{total}}$ | | | | Γ ₃₇ /Γ |
|-----------------------------------------------------------|--------------|-----------------------|----------|----------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁵) | EVTS | DOCUMENT ID | TECN | COMMENT |
| 5.7±0.6 OUR AVER | AGE | · | | |
| $5.6 \pm 0.6 \pm 0.3$ | 154 | ALEXANDER | 10 CLEO | $\psi(2S) \rightarrow \eta p \overline{p}$ |
| $5.8\!\pm\!1.1\!\pm\!0.7$ | 44.8 ± 8.5 | ⁷⁴ ABLIKIM | 05E BES2 | $e^+e^- \rightarrow \psi(2S) \rightarrow p \overline{p} \gamma \gamma$ |
| 8 ±3 ±3 | 9.8 | BRIERE | 05 CLEO | $e^+e^- \rightarrow \psi(2S) \rightarrow p \overline{p} \pi^+ \pi^- \pi^0$ |
| 7.4 | | | | |

⁷⁴ Computed using B($\eta \rightarrow \gamma \gamma$) = (39.43 ± 0.26)%.

[(maa] /[

| $\Gamma(\eta f_0(2100) \rightarrow \eta \rho)$ | ρ)/Γ _{tota} | ıl | | Г38/Г |
|------------------------------------------------|----------------------|----------------------------|-------------|-----------------------------------------------|
| VALUE (units 10^{-5}) | EVTS | DO CUMENT ID | TECN | COMMENT |
| $1.2 \pm 0.4 \pm 0.1$ | 31 | ⁷⁵ ALEXANDER 10 | CLEO | $\psi(2S) \rightarrow \eta p \overline{p}$ |
| ⁷⁵ From a fit of the $p\bar{p}$ | and $p\eta$ d | distributions to a combi | nation of N | *(1535) \overline{p} and ηf_0 (2100). |

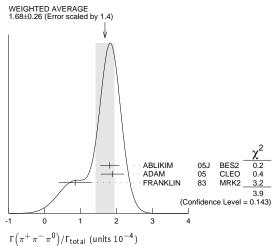
 ψ (2*S*)

| $ \Gamma(N^*(1535)\overline{p} \to \eta p \overline{p})/\Gamma_{\text{total}} $ | 83 AUBERT 07AU quotes $\Gamma^{\psi(2S)}_{ee}\cdot$ B($\psi(2S)\to\omega\pi^+\pi^-$) \cdot B($\omega\to3\pi$) = 2.69 \pm 0.73 \pm 0.16 eV. |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4.4 \pm 0.6 \pm 0.3 123 76 ALEXANDER 10 CLEO $\psi(2S) \rightarrow \eta p \overline{p}$ | 84 Normalized to B($\psi(2S) \to J/\psi \pi^+ \pi^-$) = 0.305 \pm 0.016. |
| ⁷⁶ From a fit of the $p\overline{p}$ and $p\eta$ distributions to a combination of $N^*(1535)\overline{p}$ and $\eta f_0(2100)$. | WEIGHTED AVERAGE 7.3±1.2 (Error scaled by 2.1) |
| $\Gamma(\omega p \overline{p})/\Gamma_{\text{total}}$ Γ_{40}/Γ | V |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | |
| 0.69\pm0.21 OUR AVERAGE 0.6 \pm 0.2 \pm 0.2 21.2 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow$ | |
| $p \overline{p} \pi^+ \pi^- \pi^0$ 0.8 ±0.3 ±0.1 14.9 ± 0.1 ⁷⁷ BAI 03B BES $\psi(2S) \rightarrow p \overline{p} \pi^+ \pi^- \pi^0$ | |
| 77 Normalized to B($\psi(25) \to J/\psi \pi^+ \pi^-$) = 0.305 ± 0.016. | |
| $\Gamma(\phi \rho \overline{\rho})/\Gamma_{\text{total}}$ Γ_{41}/Γ | \wedge |
| VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | |
| <0.24 90 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow p\overline{p}K^+K^-$ | χ^2 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | AUBERT 07AU BABR 4.6 |
| <0.26 90 ⁷⁸ BAI 03B BES $\psi(2S) \to K^+K^-p\overline{p}$ 78 Normalized to B $(\psi(2S) \to J/\psi\pi^+\pi^-) = 0.305 \pm 0.016$. | + \\ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ |
| | 13.7 (Confidence Level = 0.0034) |
| $\Gamma(\pi^+\pi^- ho\overline{ ho})/\Gamma_{	ext{total}}$ $\Gamma_{	ext{42}}/\Gamma$ VALUE (units $10^{-4})$ EVTS DOCUMENT ID TECN COMMENT | 0 5 10 15 20 25 |
| 6.0±0.4 OUR AVERAGE | $\Gamma(\omega\pi^+\pi^-)/\Gamma_{ m total}$ (units 10^{-4}) |
| $5.9\pm0.2\pm0.4$ 904.5 BRIERE 05 CLEO $e^+e^- 	o \psi(25) 	o p\overline{p}\pi^+\pi^-$ | |
| 8 ± 2 79 TANENBAUM 78 MRK1 e^+e^- | $\Gamma(b_{f 1}^{\pm}\pi^{\mp})/\Gamma_{	ext{total}}$ $\Gamma_{f 51}/\Gamma_{	ext{51}}$ VALUE (units $10^{-4})$ EVTS DOCUMENT ID TECN COMMENT |
| ⁷⁹ Assuming entirely strong decay. | 4.0 ±0.6 OUR AVERAGE Error includes scale factor of 1.1. |
| Γ (ρππ $^-$ or c.c.)/ Γ _{total} VALUE (units 10 $^{-4}$) EVTS DOCUMENT ID TECN COMMENT | 5.1 \pm 0.6 \pm 0.8 202 ABLIKIM 07D BES2 $e^+e^- \rightarrow \psi(2S)$ 4.18 $^+$ 0.43 $_{-}$ 0.42 $_{-}$ 0.92 170 ADAM 05 CLEO $e^+e^- \rightarrow \psi(2S)$ |
| 2.48±0.17 OUR AVERAGE | $3.2 \pm 0.6 \pm 0.5$ 61 ± 11 $85,86$ BAI 03 B BES $\psi(25) \rightarrow 2(\pi^{+}\pi^{-})\pi$ |
| $2.45 \pm 0.11 \pm 0.21$ 851 ABLIKIM 061 BES2 $e^+e^- \to p\pi^- X$ 2.52 \pm 0.12 \pm 0.22 849 ABLIKIM 061 BES2 $e^+e^- \to \overline{p}\pi^+ X$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| | 5.2 \pm 0.8 \pm 1.0 85 BAI 99c BES Repl. by BAI 03B 85 Assuming B($b_1 \to \omega \pi$)=1. |
| $\Gamma(ho\pi\pi^-\pi^0)/\Gamma_{	ext{total}}$ VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT | 86 Normalized to B($\psi(2S) \to J/\psi \pi^+ \pi^-$) = 0.305 ± 0.016. |
| 3.18 \pm 0.50 \pm 0.50 135 \pm 21 ABLIKIM 061 BES2 $e^+e^- 	op p\pi^-\pi^0 X$ | $\Gamma(b_1^0\pi^0)/\Gamma_{	ext{total}}$ $\Gamma_{52}/\Gamma_{	ext{total}}$ |
| $\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}$ Γ_{46}/Γ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| VALUE (units 10 ⁻⁴) CL% DO CUMENT ID TECN COMMENT | 2.35 $^{+0.47}_{-0.42}$ $^{+0.40}$ 45 ADAM 05 CLEO $e^+e^- \rightarrow \psi(2S)$ |
| <1.6 90 BRIERE 05 CLEO $e^+e^- 	o \psi(2S) 	o 2(\pi^+\pi^-)\pi^0$ | $\Gamma(\omega f_2(1270))/\Gamma_{\text{total}}$ Γ_{53}/Γ_{53} |
| $\Gamma(\eta \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ $\Gamma_{47}/\Gamma_{\text{total}}$ | VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT 2.2 ±0.4 OUR AVERAGE |
| '\'\'\' \'\'\'\'\'\\\\\\\\\\\\\\\\\\\\ | 2.3 \pm 0.5 \pm 0.4 57 ABLIKIM 07D BES2 $e^+e^- ightarrow \psi(2S)$ |
| 9.5 \pm 0.7 \pm 1.5 80 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow \text{hadr}$ | $2.05\pm0.41\pm0.38$ 62 ± 12 BAI 04c BES2 $\psi(2S) \rightarrow 2(\pi^+\pi^-)\pi$ ••• We do not use the following data for averages, fits, limits, etc. ••• |
| ● We do not use the following data for averages, fits, limits, etc. | $<$ 1.5 90 87 BAI 03B BES $\psi(2S) \rightarrow 2(\pi^+\pi^-)\pi$ $<$ 1.7 90 BAI 98J BES Repl. by BAI 03B |
| 10.3 \pm 0.8 \pm 1.4 201.7 81 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow \eta 3\pi(\eta \rightarrow \gamma \gamma)$ | <1.7 90 BAI 98J BES Repl. by BAI 03B 87 Normalized to B $(\psi(2S) ightarrow J/\psi \pi^+\pi^-)=0.305\pm0.016.$ |
| 8.1 \pm 1.4 \pm 1.6 50.0 ⁸¹ BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow \eta 3\pi(\eta \rightarrow 3\pi)$ | $\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ |
| 80 Average of $\eta ightarrow \gamma \gamma$ and $\eta ightarrow 3\pi$. | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT |
| 81 Not independent from other values reported by BRIERE 05. | 7.5\pm0.9 OUR AVERAGE Error includes scale factor of 1.9. 10.9 \pm 1.9 \pm 0.2 85 88 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow$ |
| $\Gamma(2(\pi^+\pi^-)\eta)/\Gamma_{	ext{total}}$ $\Gamma_{48}/\Gamma_{	ext{VALUE (units }10^{-3})}$ EVTS DOCUMENT ID TECN COMMENT | $\pi^+\pi^ K^+$ $K^-\gamma$ 7.1 \pm 0.3 \pm 0.4 817.2 BRIERE 05 CLEO e^+ $e^ \rightarrow$ $\psi(2S)$ \rightarrow |
| 1.2 \pm 0.6 \pm 0.1 16 82 AUBERT 07AU BABR 10.6 e $^+$ e $^- 	o 2(\pi^+\pi^-)\eta\gamma$ | $\kappa^+ \kappa^- \pi^+ \pi^-$ |
| ⁸² AUBERT 07AU quotes $\Gamma^{\psi(2S)}_{ee}\cdot \mathrm{B}(\psi(2S)\to 2(\pi^+\pi)\eta)\cdot \mathrm{B}(\eta\to\gamma\gamma)=1.2\pm0.7\pm0.1\mathrm{eV}$ | 16 ± 4 89 TANENBAUM 78 MRK1 e^+e^- 88 AUBERT 07AK reports $\left[\Gamma\left(\psi(2S)\right] \rightarrow \pi^+\pi^-K^+K^-\right)/\Gamma_{total}\right] \times \left[\Gamma\left(\psi(2S)\right] \rightarrow e^+e^-\right)$ |
| $\Gamma(\eta'\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$ Γ_{49}/Γ | $=(2.56\pm0.42\pm0.16)	imes10^{-3}$ keV which we divide by our best value $\Gamma(\psi(2S)$ – |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | $e^+e^-)=2.35\pm0.04$ keV. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| 4.5 \pm 1.6 \pm 1.3 BRIERE 05 CLEO $e^+e^- ightarrow \psi(2S) ightarrow hadr$ | 89 Assuming entirely strong decay. |
| $\Gamma(\omega\pi^+\pi^-)/\Gamma_{	ext{total}}$ | $\Gamma(\rho^0 K^+ K^-)/\Gamma_{\text{total}}$ |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 7.3±1.2 OUR AVERAGE Error includes scale factor of 2.1. See the ideogram below. $8.4\pm0.5\pm1.2$ 386 ABLIKIM 07D BES2 $e^+e^- \rightarrow \psi(2S)$ | $\kappa^+\kappa^-\pi^+\pi^-$ |
| 12.2 \pm 2.2 \pm 0.7 37 83 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow \omega \pi^+\pi^-\gamma$ | $\Gamma(K^*(892)^0 \overline{K}_2^*(1430)^0) / \Gamma_{\text{total}}$ $\Gamma_{56} / \Gamma_{56} $ |
| 8.2 \pm 0.5 \pm 0.7 391 BRIERE 05 CLEO $e^+e^- \to \psi(2S) \to 2(\pi^+\pi^-)\pi^0$ | VALUE (units 10^{-4}) CL% EVTS DOCUMENT ID TECN COMMENT 1.86 \pm 0.32 \pm 0.43 93 \pm 16 BAI 04c $\psi(2S) \rightarrow K^+K^-\pi^+\pi^-$ |
| $4.8 \pm 0.6 \pm 0.7$ 100 ± 22 ⁸⁴ BAI 03B BES $\psi(2S) \rightarrow 2(\pi^+ \pi^-)\pi^0$ | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| | <1.2 90 BAI 98J BES e ⁺ e ⁻ |
| | $\Gamma(K^+K^-\pi^+\pi^-\eta)/\Gamma_{\text{total}}$ |
| | VALUE (units 10 ⁻³) EVTS DOCUMENT ID TECN COMMENT |
| | 1.3±0.7±0.1 7 90 AUBERT 07AU BABR 10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\eta$ |

 ψ (2S)

| | _)π ⁰)/Γ _{tot} ; | | | | | Γ ₅₈ /Ι |
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| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $0.0\pm 2.5\pm 1.8$ | 65 | ABLIKIM | 07D | BES2 | $e^+e^- \rightarrow v$ | ψ(2 <i>S</i>) |
| $(K_1(1270)^{\pm}K^{\mp})$ |)/Γ _{total} | | | | | Γ ₆₀ /Ι |
| /ALUE (units 10 ⁻⁴) | | DO CUMENT ID | | TECN | COMMENT | |
| 0.0±1.8±2.1 | | ⁹¹ BAI | 99c | BES | e^+e^- | |
| 91 Assuming B(K_1 (| $1270) \rightarrow K \rho$ | o)=0.42 ± 0.06 | | | | |
| $(K_5^0 K_5^0 \pi^+ \pi^-)$ | /Γ _{total} | | | | | Γ ₆₁ /Ι |
| ALUE (units 10 ⁻⁴) | EVT: | | | TEC | | |
| $2.20 \pm 0.25 \pm 0.37$ | 83 ± 9 |) ABLIKIM | (| 050 BES | 52 e ⁺ e ⁻ - | → ψ(2S) |
| $(\rho^0 p \overline{p})/\Gamma_{\text{total}}$ | | | | | | Γ ₆₂ /Ι |
| /ALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $0.5 \pm 0.1 \pm 0.2$ | 61.1 | BRIERE | 05 | CLEO | $e^+e^- \rightarrow e^- <i>b</i> (2 <i>S</i>) → |
| -(v+ v *(000)0 - | \ / [| | | | $pp\pi \cdot \pi$ | F /1 |
| $(K^{+}\overline{K}^{*}(892)^{0}\pi$ | + c.c.)/I | | | T | | Γ ₆₃ /Ι |
| ALUE (units 10 ⁻⁴) 5.7 ± 2.5 | | DOCUMENT ID | 70 | TECN MD K 1 | e+e- | |
| _ | | TANENBAUM | 18 | INKK1 | e · e | |
| $(2(\pi^+\pi^-))/\Gamma_{\text{tot}}$ | tal | | | | | Γ ₆₄ /Ι |
| /ALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.4 ± 0.6 OUR AVER $2.2 \pm 0.2 \pm 0.2$ | AGE Errori 308 | ncludes scale facto BRIERE | or of 2. 05 | .2. CLEO | a+ c- | h(25) |
| 2 £ U.2 ± U.2 | 308 | DRIEKE | US | CLEU | $e^+e^- \rightarrow e^+$ $2(\pi^+\pi^-)$ | |
| .5 ± 1.0 | | TA NE NBAUM | 78 | MRK1 | e^+e^- | , |
| $(ho^0 \pi^+ \pi^-)/\Gamma_{\rm tot}$ | al | | | | | Γ ₆₅ /I |
| (P | ai EVTS | DO CUMENT ID | | TECN | COMMENT | . 02 / 1 |
| 2.2±0.6 OUR AVER | | ncludes scale facto | _ | - | | |
| $0.0 \pm 0.2 \pm 0.4$ | 285.5 | BRIERE | 05 | CLEO | $e^+e^- \rightarrow e^-$ | |
| .2±1.5 | | TA NE NBAUM | 78 | MRK1 | $e^{+}e^{-}$ | , |
| $K^{+}K^{-}\pi^{+}\pi^{-}\tau$ | τ ⁰)/Γ | | | | | Γ ₆₆ /Ι |
| /ALUE (units 10^{-4}) EV | • | CUMENT ID | TECN | COMN | 1ENT | . 00/ |
| 12.6±0.9 OUR AVE | | COMENT ID | TECH | CONTR | ILIVI | |
| $8.7 \pm 5.7 \pm 0.3$ | 32 ⁹² AU | BERT 07AU | BABR | 10.6 | $e^{+}_{K}e^{-}_{\pi^{+}\pi^{-}}$ | 0 |
| | | | | | | |
| 1.7±1.0±1.5 | 597 AR | LIKIM 066 | BES2 | ψ(2.S | $(\kappa \pi'\pi) \rightarrow \kappa^+\kappa^-$ | $\frac{\pi}{\pi} + \frac{\gamma}{\pi} - \pi^0$ |
| | | LIKIM 06G IERE 05 | BES2 CLEO | $\psi(2S)$ e^+e^- | $) \rightarrow K^+ K^-$ $\rightarrow \psi(2S)$ | $\pi^+\pi^-\pi^0$ \rightarrow |
| $2.7 \pm 0.5 \pm 1.0$ 71 | 1.6 BR | IERE 05 | CLEO | ψ(2S e ⁺ e ⁻ K | $\begin{array}{ccc}) \rightarrow & K^{+} K^{-} \\ \stackrel{-}{\rightarrow} & \psi(2S) \\ ^{+} K^{-} \pi^{+} \pi^{-} \end{array}$ | $\begin{array}{c} + \pi + \pi - \pi^0 \\ \rightarrow \\ \pi^0 \end{array}$ |
| 2.7±0.5±1.0 71 92AUBERT 07AU | 1.6 BR reports $[\Gamma(\psi)]$ | IERE 05 $(2S) \rightarrow K^+ K^-$ | CLEO ${\pi^{+}\pi}$ | $\psi(2S)$ $e^+e^ K^ (\tau^-\pi^0)$ | $) ightarrow K^+ K^- ightharpoonup \psi(2S) ightharpoonup ightharpoonup ightharpoonup \psi(2S) ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup ightharpoonup i$ | $\begin{array}{c} + \pi + \pi - \pi^0 \\ \rightarrow \\ \pi^0 \end{array}$ $(\psi(2S) - \psi(2S))$ |
| $2.7 \pm 0.5 \pm 1.0$ 71 92 AUBERT 07 AU $e^+ e^-)] = (44 = 0.00)$ | 1.6 BR reports $[\Gamma(\psi \pm 13 \pm 3) \times 1]$ | IERE 05 $(2S) \rightarrow K^+ K^-$ $10^{-4} \text{ keV which where } K^-$ | CLEO ${\pi}+_{\pi}$ ve divid | $\psi(2S)$ $e^+e^-K^ (\pi^-\pi^0)/K^-$ de by o | $0 \rightarrow K^{+}K^{-} \rightarrow \psi(2S) + K^{-}\pi^{+}\pi^{-}$ $\Gamma_{\text{total}} \times [0]$ | $\begin{array}{ccc} & \pi^+ \pi^- \pi^0 \\ \rightarrow & \pi^0 \\ \hline & \Gamma(\psi(2S) & - \\ & \Gamma(\psi(2S) & - \end{array}$ |
| $2.7 \pm 0.5 \pm 1.0$ 71 92 AUBERT 07 AU $e^+ e^-)] = (44 \pm e^+ e^-) = 2.35 \pm 0.00$ | 1.6 BR reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV}]$ | IERE 05 $(2S) \rightarrow K^+ K^-$ | CLEO ${\pi}+_{\pi}$ ve divid | $\psi(2S)$ $e^+e^-K^ (\pi^-\pi^0)/K^-$ de by o | $0 \rightarrow K^{+}K^{-} \rightarrow \psi(2S) + K^{-}\pi^{+}\pi^{-}$ $\Gamma_{\text{total}} \times [0]$ | $\begin{array}{ccc} & \pi^{+} \pi^{-} \pi^{0} \\ \rightarrow & \pi^{0} \\ \hline & \Gamma(\psi(2S) & - \\ & \Gamma(\psi(2S) & - \end{array}$ |
| $2.7 \pm 0.5 \pm 1.0$ 71 92 AUBERT 07AU $e^+e^-)] = (44 \pm 1.00)$ $e^+e^-) = 2.35 \pm 1.00$ error is the system | reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV.}]$ | IERE 05 $(25) \rightarrow K^+ K^-$ $10^{-4} \text{ keV which w}$ Our first error is tom using our best | CLEO ${\pi}+_{\pi}$ ve divid | $\psi(2S)$ $e^+e^-K^ (\pi^-\pi^0)/K^-$ de by o | $0 \rightarrow K^{+}K^{-} \rightarrow \psi(2S) + K^{-}\pi^{+}\pi^{-}$ $\Gamma_{\text{total}} \times [0]$ | $\begin{array}{ccc} & \pi^{+} \pi^{-} \pi^{0} \\ \rightarrow & \pi^{0} \\ \hline & \Gamma(\psi(2S) & - \\ & \Gamma(\psi(2S) & - \end{array}$ |
| $(2.7\pm0.5\pm1.0)$ 71 (92) AUBERT 07AU (e^+e^-)] = (44 ± 0.00) = (44 ± 0.00) = 2.35 error is the system (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = (40) = $($ | reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV}]$ matic error from $(K^+K^-)/\Gamma$ | IERE 05 $(25) \rightarrow K^+ K^-$ $10^{-4} \text{ keV which w}$ Our first error is tom using our best | CLEO ${\pi}+_{\pi}$ ve divid | $\psi(2S)$ $e^+e^ K^0$ $(r^-\pi^0)/V$ $(r^-\pi^0)$ $(r^-\pi^0)$ | $0 \rightarrow K^{+}K^{-} \rightarrow \psi(2S) + K^{-}\pi^{+}\pi^{-}$ $\Gamma_{\text{total}} \times [0]$ | $\begin{array}{ccc} \pi^+\pi^-\pi^0 \\ \rightarrow & \pi^0 \\ \hline \Gamma(\psi(2S) & - \\ \Gamma(\psi(2S) & - \\ \text{our second} \end{array}$ |
| 2.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-] = (44 \pm e^+e^-) = 2.35 \pm error is the syster (ω f ₀ (1710) $\rightarrow \omega$ ALUE (units 10 ⁻⁵) | reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV}]$ matic error from $F(K^+ K^-)/\Gamma$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which v})$ Our first error is toom using our best total $(000000000000000000000000000000000000$ | CLEO ${\pi} +_{\pi}$ we divide their expension value. | $\psi(2S)$ $e^+e^ K^ (T^-\pi^0)$ f f f f f f f f f f | $() \rightarrow K^+ K^- \rightarrow \psi(2S) + K^- \pi^+ \pi^ () \vdash \Gamma_{\text{total}}] \times [U]$ If best value at's error and U $MMENT$ $(S) \rightarrow U$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ \hline \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67}/\Gamma_{0} \\ \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-] = (44 \pm e^+e^-) = 2.35 \pm error is the syster (ω f ₀ (1710) $\rightarrow \omega$ | reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV}]$ matic error from $F(K^+ K^-)/\Gamma$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which v})$ Our first error is toom using our best total $(000000000000000000000000000000000000$ | CLEO ${\pi^{+}\pi}$ we divide their expenses value. | $\psi(2S)$ $e^+e^ K^ (T^-\pi^0)$ f f f f f f f f f f | $) \rightarrow K^{+}K^{-} \rightarrow \psi(2S) + K^{-}\pi^{+}\pi^{-}$ $\vdash_{\text{total}} \times [l_{\text{ur}} \text{ best value}] \times [l_{\text{ur}} \text{ best value}]$ and $\vdash_{\text{total}} \times [l_{\text{ur}} \text{ best value}]$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ \hline \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67}/\Gamma_{0} \\ \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ ω | 1.6 BR reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV}. 0]$ matic error fro $g(K^+K^-)/\Gamma$ $\frac{EVTS}{19}$ $\frac{D}{A}$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which v})$ Our first error is tom using our best total OCUMENT ID BLIKIM 060 | CLEO ${\pi^{+}\pi}$ we divide their expenses value. | $\psi(2S)$ $e^+e^ K^ (T^-\pi^0)$ f f f f f f f f f f | $() \rightarrow K^+ K^- \rightarrow \psi(2S) + K^- \pi^+ \pi^ () \vdash \Gamma_{\text{total}}] \times [U]$ If best value at's error and U $MMENT$ $(S) \rightarrow U$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ \hline \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67}/\Gamma \\ \hline - \\ \pi^{0} \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 \pm e^+e^-) = 2.35 \pm error is (1170) $\rightarrow \omega$ ΔLUE (units 10 ⁻⁵) \pm 1.9 \pm 2.0 \pm 0.9 1.9 \pm 2.0 \pm 0.9 | reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV.} c$ matic error from $F(K^+K^-)/\Gamma(EVTS)$ $F(K^+K^-)/\Gamma(EVTS)$ $F(K^+K^-)/\Gamma(EVTS)$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which v})$ Our first error is tom using our best total OCUMENT ID BLIKIM 060 | CLEO $- \frac{1}{\pi} + \frac{1}{\pi}$ we divide their expenses value. $\frac{TECP}{E}$ is BES | $\psi(2S) = \psi(2S) | $() \rightarrow K^+ K^- \rightarrow \psi(2S) + K^- \pi^+ \pi^ () \vdash \Gamma_{\text{total}}] \times [U]$ If best value at's error and U $MMENT$ $(S) \rightarrow U$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ \hline \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67}/\Gamma \\ \hline - \\ \pi^{0} \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ (ALUE (units 10 ⁻⁵) i.9 \pm 2.0 \pm 0.9 (K^* (892) 0 $K^-\pi$ (ALUE (units 10 ⁻⁴) | reports $[\Gamma(\psi)]$ $\pm 13 \pm 3) \times 1$ ± 0.04 keV. \odot matic error from $(F, K^+, K^-)/\Gamma$ $\frac{EVTS}{19}$ $\frac{D}{A}$ $\frac{EVTS}{19}$ $\frac{D}{A}$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which w})$ Our first error is tom using our best total OCUMENT ID (0 COMENT ID) (0 COMENT ID) | CLEO $- \frac{1}{\pi} + \frac{1}{\pi}$ we divide their expenses value. $\frac{TECP}{E}$ is BES | $\begin{array}{c} \psi(2S \\ e^{+}e^{-} \\ K \\ \tau^{-}\pi^{0})/de \end{array}$ $\begin{array}{c} K \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\$ | $\begin{array}{ll} () & \rightarrow & K^+ K^- \\ - & \rightarrow & \psi(2S) \\ + & K^- \pi^+ \pi^- \\ \Gamma_{\text{total}}] & \times [1] \\ \text{ur best value} \\ \text{nt's error and} \\ \text{otherwise} \\ MENT \\ S) & \rightarrow \\ K^+ K^- \pi^+ \pi \\ \\ MMENT \\ S) & \rightarrow \\ \end{array}$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ - (\psi(2S) - \\ \Gamma(\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67}/I \\ - \pi^{0} \\ \hline \Gamma_{68}/I \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster $\Gamma(\omega f_0(1710) \rightarrow \omega)$ ΔLUE (units 10^{-5}) 5.9 \pm 2.0 \pm 0.9 $\Gamma(K^*(892)^0 K^-\pi)$ ΔLUE (units 10^{-4}) | reports $[\Gamma(\psi)]$ $\pm 13 \pm 3) \times 1$ ± 0.04 keV. \odot matic error from $(F, K^+, K^-)/\Gamma$ $\frac{EVTS}{19}$ $\frac{D}{A}$ $\frac{EVTS}{19}$ $\frac{D}{A}$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which w})$ Our first error is tom using our best total OCUMENT ID BLIKIM 060)/\(\Gamma\) | CLEO $-\frac{\pi}{\pi} + \frac{\pi}{\pi}$ we divide their expenses value. $\frac{TECR}{\pi}$ $\frac{TECR}{\pi}$ | $\begin{array}{c} \psi(2S \\ e^{+}e^{-} \\ K \\ \tau^{-}\pi^{0})/de \end{array}$ $\begin{array}{c} K \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\ \psi(2S \\$ | $\begin{array}{l}) \rightarrow K^{+}K^{-} \\ \rightarrow \psi(2S) \\ +K^{-}\pi^{+}\pi^{-} \\ \text{Total}] \times [\text{If best value at's error and} \\ \text{MMENT} \\ S) \rightarrow \\ K^{+}K^{-}\pi^{+}\pi \\ \text{MMENT} \end{array}$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ - (\psi(2S) - \Gamma(\psi(2S) - $ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster $\Gamma(\omega f_0(1710) \rightarrow \omega)$ $\Delta ALUE$ (units 10^{-5}) $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow \omega$ $\Delta E_0(1710) \rightarrow 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\text{ur best value} \\ \text{nt's error and} \\ \text{otherwise} \\ MENT \\ S) & \rightarrow \\ K^+ K^- \pi^+ \pi \\ \\ MMENT \\ S) & \rightarrow \\ \end{array}$ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ - (\psi(2S) - \\ - (\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67} / I \\ - \pi^{0} \\ \hline \Gamma_{68} / I \\ - \pi^{0} \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster $\Gamma(\omega f_0(1710) \rightarrow \omega$ $\Delta ALUE$ (units 10^{-5}) $\Gamma(K^*(892)^0 K^-\pi$ $\Delta ALUE$ (units 10^{-4}) 3.6 \pm 1.3 \pm 1.8 $\Gamma(K^*(892)^+ K^-\pi$ | 1.6 BR reports $[\Gamma(\psi + 13 \pm 3) \times 1]$ ± 0.04 keV. 0 matic error from $(F + K^-)/\Gamma$ $\frac{EVTS}{19}$ $\frac{D}{A}$ $\frac{EVTS}{238}$ $\frac{D}{A}$ $\frac{EVTS}{238}$ $\frac{D}{A}$ | IERE 05 $(25) \rightarrow K^+ K$ $(0^{-4} \text{ keV which w})$ Our first error is tom using our best total OCUMENT ID BLIKIM 066 $(0.0000000000000000000000000000000000$ | CLEO $-\pi + \pi$ we divide their exvalue. $-\underline{TECR}$ is BES $-\underline{TECR}$ is BES | $\begin{array}{c} \psi(2S \\ e^+ e^- \\ K \\ \tau^- \pi^0)/de \text{ by or operimen} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{$ | $\begin{array}{l} () \rightarrow K^{+}K^{-} \\ \rightarrow \psi(2S) \\ + K - \pi + \pi^{-} \\ \text{Total}] \times [\text{If best value at's error and} \\ If the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the standard of the $ | $\begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi^{0} \\ - (\psi(2S) - \\ - (\psi(2S) - \\ \text{our second} \\ \hline \Gamma_{67} / I \\ - \pi^{0} \\ \hline \Gamma_{68} / I \\ - \pi^{0} \end{array}$ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ $(ALUE (units 10^{-5})$ $i.9 \pm$ 2.0 \pm 0.9 $(K^*(892)^0 K^-\pi)$ $(ALUE (units 10^{-4})$ $(ALUE (units 10^{-4})$ $(ALUE (units 10^{-4})$ | 1.6 BR reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV} \cdot 0]$ matic error from $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ | IERE 05 $(2S) \rightarrow K^+K$ $10^{-4} \text{ keV which wood ur first error is toom using our best}$ Total OCUMENT ID BLIKIM 06c)/\Gamma_total OCUMENT ID BLIKIM 06c c)/\Gamma_total OCUMENT ID | CLEO $-\pi + \pi$ we divide their exvalue. $-\underline{TECR}$ is BES $-\underline{TECR}$ is BES | $\begin{array}{c} \psi(2S \\ e^+e^- \\ K \\ \tau^-\pi^0)/de \text{ by or sperimen} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} $ | $\begin{array}{l} () \longrightarrow K^{+} K^{-} \\ - \longrightarrow \psi(2S) \\ + K^{-} \pi^{+} \pi^{-} \\ - & \downarrow \psi(2S) \\ + & \downarrow K^{-} \pi^{+} \pi^{-} \\ \text{Total}] \times [\mathbb{I} \\ \text{Iur best value} \\ \text{int's error and} \\ \text{Int's error and} \\ \\ \frac{MMENT}{S}) \longrightarrow \\ K^{+} K^{-} \pi^{+} \pi \\ \\ \frac{MMENT}{S}) \longrightarrow \\ \frac{MMENT}{S} \longrightarrow \\ \\ \frac{MMENT}{S} \longrightarrow \\ \\ \frac{MMENT}{S} \longrightarrow \\ \\ \end{array}$ | $ \begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi \\ \pi^{0} \end{array} $ $ \begin{array}{c} \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ 0 \text{ our second} \end{array} $ $ \begin{array}{c} \Gamma_{67}/I \\ -\pi^{0} \\ \Gamma_{68}/I \\ -\pi^{0} \end{array} $ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 = e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ $(ALUE (units 10^{-5})$ $i.9 \pm$ 2.0 \pm 0.9 $(K^*(892)^0 K^-\pi)$ $(ALUE (units 10^{-4})$ $(ALUE (units 10^{-4})$ $(ALUE (units 10^{-4})$ | 1.6 BR reports $[\Gamma(\psi \pm 13 \pm 3) \times 1 \pm 0.04 \text{ keV} \cdot 0]$ matic error from $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ $D(K^+K^-)/\Gamma(EVTS)$ | IERE 05 (225) → K+K 10 ⁻⁴ keV which w Our first error is t om using our best total OCUMENT ID BLIKIM 06cc)/ \(\begin{align*} \text{Ftotal} \\ \text{OCUMENT ID} \\ \text{BLIKIM} \\ \text{OCCUMENT ID} \\ \text{COUMENT ID} | CLEO $-\pi^+\pi^-$ we divide their ex- $-\frac{TECN}{8}$ is BES $-\frac{TECN}{8}$ | $\begin{array}{c} \psi(2S \\ e^+e^- \\ K \\ \tau^-\pi^0)/de \text{ by or sperimen} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{CON}{\psi(2)} \\ \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} \frac{V}{2} $ | $\begin{array}{l} () \rightarrow K + K - \pi \\ \rightarrow \psi(2S) \\ + K - \pi + \pi - \pi \\ - \nabla \cot \alpha] \times [1] \\ \text{ur best value} \\ \text{nt's error and} \\ \frac{MMENT}{S}) \rightarrow \\ K + K - \pi + \pi \\ \frac{MMENT}{S}) \rightarrow \\ K + K - \pi + \pi \\ \frac{MMENT}{S} \rightarrow \\ K + K - \pi + \pi \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ \frac{MMENT}{S} \rightarrow \\ $ | $ \begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi \\ \pi^{0} \end{array} $ $ \begin{array}{c} \Gamma(\psi(2S) - \\ \Gamma(\psi(2S) - \\ 0 \text{ our second} \end{array} $ $ \begin{array}{c} \Gamma_{67}/I \\ -\pi^{0} \\ \Gamma_{68}/I \\ -\pi^{0} \end{array} $ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 e^+e^-) = 2.35 error is the syster $C_0 = C_0 = C_0 = C_0$ $C_0 = C_0 = C_0 = C_0$ $C_0 = C_0 = C_0 = C_0$ $C_0 = C_0 = C_0 = C_0$ $C_0 $ | 1.6 BR reports $[\Gamma(\psi + 13 \pm 3) \times 1]$ ± 0.04 keV. 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\longrightarrow \psi(2S) \\ + K^{-} \pi^{+} \pi^{-} \\ - & \downarrow \psi(2S) \\ + & \downarrow K^{-} \pi^{+} \pi^{-} \\ \text{Total}] \times [\mathbb{I} \\ \text{Iur best value} \\ \text{int's error and} \\ \text{Int's error and} \\ \\ \frac{MMENT}{S}) \longrightarrow \\ K^{+} K^{-} \pi^{+} \pi \\ \\ \frac{MMENT}{S}) \longrightarrow \\ \frac{MMENT}{S} \longrightarrow \\ \\ \frac{MMENT}{S} \longrightarrow \\ \\ \frac{MMENT}{S} \longrightarrow \\ \\ \end{array}$ | $ \begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi 0 \\ - (\psi(2S) - \\ - (\psi(2S) - \\ \text{our second} \end{array} $ $ \begin{array}{c} \Gamma_{67}/I \\ - \pi^{0} \\ \Gamma_{68}/I \\ - \pi^{0} \\ \Gamma_{69}/I \\ - \pi^{0} $ |
| 12.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 \pm e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ $(ALUE (units 10^{-5})$ $1.9 \pm$ 2.0 \pm 0.9 $(K^*(892)^0 K^-\pi)$ $(ALUE (units 10^{-4})$ $1.6 \pm$ 1.3 \pm 1.8 $(K^*(892)^+ K^-\pi)$ $(ALUE (units 10^{-4})$ $1.6 \pm$ 2.2 \pm 1.7 | 1.6 BR reports $[\Gamma(\psi + 13 \pm 3) \times 1]$ ± 0.04 keV. 0 matic error fro $(FK + K^-)/\Gamma$ $\frac{EVTS}{19}$ $\frac{D}{A}$ $+ \pi^0 + \text{c.c.}$ $\frac{EVTS}{238}$ $\frac{D}{A}$ $+ \pi^- + \text{c.c.}$ $\frac{EVTS}{133}$ $\frac{D}{A}$ | IERE 05 (225) K+K 10-4 keV which w 100 ur first error is t 100 ur first error is t 100 ur first error is t 100 ur first error is t 100 ur first error is t 100 ur first error is t 100 ur first 100 ur f | CLEO $-\pi + \pi$ ve divide their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their e | $\begin{array}{c} \psi\left(2S\\ e^{+}e^{-}\\ \end{array}\right) \\ \psi\left(2S\\ \end{array}$ $\begin{array}{c} \kappa\\ K\\ K\\ K\\ \end{array}$ $\begin{array}{c} K\\ K\\ K\\ \end{array}$ $\begin{array}{c} \kappa\\ V\\ 2\\ \end{array}$ $\begin{array}{c} \frac{CON}{2}\\ \psi\left(2S\\ \end{array}$ $\begin{array}{c} \frac{CON}{2}\\ \psi\left(2S\\ \end{array}\right) \\ \begin{array}{c} \frac{CON}{2}\\ \end{array}$ | $\begin{array}{l} () \rightarrow K + K - \pi - \psi(2S) \\ \rightarrow \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \pi + \pi - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + K - \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S) \\ + \psi(2S$ | $ \begin{array}{c} \pi + \pi - \pi^{0} \\ \rightarrow \\ \pi 0 \\ - (\psi(2S) - \\ - (\psi(2S) - \\ \text{our second} \end{array} $ $ \begin{array}{c} \Gamma_{67}/I \\ - \pi^{0} \\ \Gamma_{68}/I \\ - \pi^{0} \\ \Gamma_{69}/I \\ - \pi^{0} $ |
| 2.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 \pm e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ ALUE (units 10 ⁻⁵) 9. \pm 2.0 \pm 0.9 (K^* (892) 0 $K^-\pi$ ALUE (units 10 ⁻⁴) 1.6 \pm 1.3 \pm 1.8 (K^* (892) $^+$ $K^-\pi$ ALUE (units 10 ⁻⁴) 1.6 \pm 2.2 \pm 1.7 (K^* (892) $^+$ $K^-\pi$ ALUE (units 10 ⁻⁴) | 1.6 BR reports $[\Gamma(\psi + 13 \pm 3) \times 1]$ ± 0.04 keV. 0 matic error fro $(FK + K^-)/\Gamma$ $EVTS$ 19 A $+\pi^0 + c.c.$ $EVTS$ 238 A $+\pi^- + c.c$ $EVTS$ 133 A $+\pi^0 + c.c.$ $EVTS$ 133 A | IERE 05 (25) → K+K 10-4 keV which w Our first error is t om using our best total OCUMENT ID BLIKIM 06c (25) / Ftotal OCUMENT ID BLIKIM 06c (26) / Ftotal OCUMENT ID BLIKIM 06c (27) / Ftotal OCUMENT ID OCUMENT ID | CLEO $-\pi + \pi$ ve divide their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their expension of their e | $\begin{array}{c} \psi\left(2S\\ e^+e^-\\ e^-\\ K\\ K\\ K\\ -\pi^0\right)/\right)\\ \psi\left(2\\ \psi$ | $\begin{array}{l} () \rightarrow K + K - 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| 2.7 \pm 0.5 \pm 1.0 71 92 AUBERT 07AU e^+e^-)] = (44 \pm e^+e^-) = 2.35 error is the syster (ω f ₀ (1710) $\rightarrow \omega$ ALUE (units 10 ⁻⁵) 1.9 \pm 2.0 \pm 0.9 (K^* (892) 0 $K^-\pi$ ALUE (units 10 ⁻⁴) 1.6 \pm 1.3 \pm 1.8 (K^* (892) $+$ $K^-\pi$ ALUE (units 10 ⁻⁴) 1.6 \pm 2.2 \pm 1.7 (K^* (892) $+$ $K^-\pi$ ALUE (units 10 ⁻⁴) 1.3 \pm 2.2 \pm 1.4 (K^* (892) 0 $K^-\pi$ ALUE (units 10 ⁻⁴) | 1.6 BR reports $[\Gamma (\psi + 13 \pm 3) \times 1]$ $\pm 13 \pm 3) \times 1$ $\pm 0.04 \text{ keV. 6}$ matic error fro $p(K+K^-)/\Gamma$ $\frac{EVTS}{19}$ A $+\pi^0 + \text{c.c.}$ $\frac{EVTS}{238}$ A $r^+\pi^- + \text{c.c.}$ $\frac{EVTS}{133}$ A $p^0 + \text{c.c.}/\Gamma$ $\frac{EVTS}{78}$ A $\frac{D}{A}$ $\frac{EVTS}{78}$ A $\frac{D}{A}$ | IERE 05 (25) → K+K 10-4 keV which w Our first error is t om using our best total OCUMENT ID BLIKIM 066 C.)/Ftotal OCUMENT ID BLIKIM 066 C.)/Ftotal OCUMENT ID BLIKIM 066 C.)/Ftotal OCUMENT ID BLIKIM 066 Total OCUMENT ID BLIKIM 066 | CLEO $-\pi + \pi$ ve divide heaveless. TECO BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ BES $-\frac{TECO}{1}$ | $\begin{array}{c} \psi(2S) \\ e^+e^- \\ e^- \\ K \\ K \\ K \\ -\pi^0)/) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\ \psi(2) \\$ | $\begin{array}{l}) \rightarrow K + K - \\ \rightarrow \psi(2S) \\ + K - \pi + \pi - \\ \hline (\text{Total}) \times [\text{I} \text{II} \text{r best value} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{III} \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ \text{r solution} \\ r solut$ | $ \begin{array}{ccc} \pi^{+}\pi^{-}\pi^{0} & \xrightarrow{\pi^{0}} \\ & \xrightarrow{\pi^{0}} \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - \\ & (\psi(2S) - 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| | | | | Ψ(| 23) |
|----------------------------------------------------|------------------------------|-------------------------------|--------------|-----------------------------------------------------------------------------------------------------|----------------------|
| Γ(ω K ⁺ K ⁻)/Γ _t | | | | | Г ₇₃ /Г |
| VALUE (units 10 ⁻⁴) | EVTS | DOCUMENT ID | | COMMENT | |
| 1.85 ± 0.25 OUR A | | or includes scale fa | | , | |
| $2.38 \pm 0.37 \pm 0.29$ | 78 | ABLIKIM | 06G BES | | _ 0 |
| $1.9 \ \pm 0.3 \ \pm 0.3$ | 76.8 | BRIERE | 05 CLE | $e^{+} e^{-} \xrightarrow{\kappa^{+} \pi^{-} \pi^{+} \pi} \psi(2S)$ | - π ⁰ |
| $1.5 \ \pm 0.3 \ \pm 0.2$ | 23.0 ± 5.2 | ⁹³ BAI | 03в BES | $ \begin{array}{c} K^{+} K^{-} \pi^{+} \pi \\ \psi(2S) \to \\ K^{+} K^{-} \pi^{+} \pi \end{array} $ | |
| ⁹³ Normalized to | $B(\psi(2S) \rightarrow J_s$ | $/\psi \pi^+ \pi^-) = 0.30$ | 5 ± 0.016. | $K^+K^-\pi^+\pi^-$ | π° |
| $\Gamma(3(\pi^+\pi^-))/\Gamma_1$ | otal | | | | Γ ₇₄ /Γ |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 3.5 ±2.0 OUR A | VERAGE Erro | or includes scale fa | ctor of 2.8. | | |
| $5.45 \pm 0.42 \pm 0.87$ | 671 | ABLIKIM | 05н BES | $e^+e^- \rightarrow \psi(2S)$ $3(\pi^+\pi^-)$ |) → |
| 1.5 ±1.0 | | ⁹⁴ TANENBAUM | 78 MR K | | |
| ⁹⁴ Assuming entir | ely strong deca | y. | | | |
| $\Gamma(ho\overline{ ho}\pi^+\pi^-\pi^0)$ | /Γ _{total} | | | | Γ_{75}/Γ |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| $7.3 \pm 0.4 \pm 0.6$ | 434.9 | BRIERE | 05 CLE | | `) → |
| | | | | $\rho \overline{\rho} \pi^+ \pi^- \pi^0$ | |
| $\Gamma(K^+K^-)/\Gamma_{\text{tot}}$ | al | | | | Γ ₇₆ /Γ |
| VALUE (units 10 ⁻⁵) | <u>CL%</u> | DOCUMENT ID | TECN | COMMENT | |
| 6.3 ± 0.7 OUR | AVERAGE | | | 1 | |
| $6.3 \pm 0.6 \pm 0.3$ | | DOBBS | 06A CLEC | | |
| 10 ±7 | | BRANDELIK | 79C DASI | | |
| • • • We do not u | | | | | |
| < 5 | 90 | FELD MA N | 77 MRK | 1 e ⁺ e ⁻ | |
| $\Gamma(K_S^0 K_L^0)/\Gamma_{\text{tota}}$ | | | | | Γ ₇₇ /Γ |
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 5.4 ±0.5 OUR A | VERAGE | | | | |
| $5.8 \pm 0.8 \pm 0.4$ | 156 14 | DOBBS 95 BAI | 06A CLEC |) e⊤e⁻ > ((06) ((0)) | ٠0 |
| $5.24 \pm 0.47 \pm 0.48$ | 156 ± 14 | 30 BAI | 04B BES | ' ' ' | Ľ → |
| 95 Using B(K_S^0 $-$ | $\pi^{+}\pi^{-}) = 0$ | .6860 ± 0.0027. | | $\pi^+\pi^-X$ | |
| $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\rm t}$ | otal | | | | Γ ₇₈ /Γ |
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT | ID TE | CN COMMENT | |
| | | | | See the ideogram b | elow. |
| $1.81 \pm 0.18 \pm 0.19$ | | ⁹⁶ ABLIKIM | | S2 $e^+e^- \rightarrow \psi(2)$ | |
| $1.88 ^{+ 0.16}_{- 0.15} \pm 0.28$ | 194 | A D A M | | EO $e^+e^- \rightarrow \psi(2)$ | |
| 0.85 ± 0.46 | 4 | | | $1K2 e^+e^- \rightarrow had$ | |
| | - | FRANKLIN | 83 IVIF | ik∠ e e → nad | rons |
| ⁹⁶ From a PW an | alysis of $\psi(2S)$ | $\rightarrow \pi^+\pi^-\pi^0$ | | | |
| WEIGHT | ED AVERAGE | w 4 4) | | | |
| 1.06±0.26 | 6 (Error scaled b | Jy 1.4) | | | |
| | | V | | | |
| | | /\ | | | |



 ψ (2S)

| | | — |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| $\Gamma(ho(770)\pi 	o \pi^+\pi^-\pi^0)/\Gamma_{total}$ | $\Gamma(2(K^+K^-))/\Gamma_{\text{total}}$ | 8/Г |
| VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT | VALUE (units 10 ⁻⁴) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | _ |
| 0.32±0.12 OUR AVERAGE Error includes scale factor of 1.8. | 0.6±0.1±0.1 59.2 BRIERE 05 CLEO $e^+e^- ightarrow \psi(2S)$ | → |
| $0.51\pm0.07\pm0.11$ 98 ABLIKIM 05J BES2 $\psi(25) \rightarrow \rho(770) \pi \rightarrow \pi^+\pi^-\pi^0$ | 2(K ⁺ K ⁻) | |
| $0.24^{+0.08}_{-0.07}\pm0.02$ 22 ADAM 05 CLEO $e^{+}e^{-} \rightarrow \psi(2S)$ | $\Gamma(\phi K^+ K^-)/\Gamma_{\text{total}}$ | ٦/و |
| • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | |
| <0.83 90 1 FRANKLIN 83 MRK2 e ⁺ e ⁻ | 0.70±0.16 OUR AVERAGE | |
| <10 90 BARTEL 76 CNTR e^+e^- | 0.8 \pm 0.2 \pm 0.1 36.8 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) - 2(K^+K^-)$ | * |
| <10 90 ⁹⁹ ABRAMS 75 MRK1 e ⁺ e ⁻ | $0.6 \pm 0.2 \pm 0.1$ 16.1 ± 5.0 107 BAI 03B BES $\psi(2S) \rightarrow 2(K^+K^-)$ | -) |
| 98 From a PW analysis of $\psi(2S) \to \pi^+\pi^-\pi^0$. | 107 Normalized to B $(\psi(2S) ightarrow J/\psi\pi^+\pi^-)=0.305\pm 0.016.$ | |
| | | ο/Г |
| $\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ | VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | ייי |
| VALUE (units 10 ⁻⁵) CL% DO CUMENT ID TECN COMMENT | 1.1 \pm 0.2 \pm 0.2 44.7 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S)$ | _ |
| 8 ±5 BRANDELIK 79C DASP e ⁺ e ⁻ | 2(K^+K^-) π^0 | , |
| • • • We do not use the following data for averages, fits, limits, etc. • • | Γ(Δm)/Γ | . /г |
| <pre><2.1 90 DOBBS 06A CLEO $e^+e^- 	oup \psi(2S)$ <5 90 FELDMAN 77 MRK1 e^+e^-</pre> | · · · · - | 1/Γ |
| | | — |
| $\Gamma(K_1(1400)^{\pm}K^{\mp})/\Gamma_{\text{total}}$ Γ_{82}/Γ | $2.8^{+1.0}_{-0.8}$ OUR AVERAGE | |
| VALUE (units 10 ⁻⁴) CL% DOCUMENT ID TECN COMMENT | $2.0 {+} {1.5 \atop -1.1} \pm 0.4$ 6 ADAM 05 CLEO $e^+e^- ightarrow \psi(2S)$ | |
| <3.1 90 ¹⁰⁰ BAI 99c BES e ⁺ e ⁻ | $3.3\pm1.1\pm0.5$ 17 ABLIKIM 04к BES $e^+e^- ightarrow \psi(2S)$ | |
| 100 Assuming B($K_1(1400) \rightarrow K^*\pi$)=0.94 \pm 0.06 | $\Gamma(\phi\eta')/\Gamma_{total}$ | 2/Γ |
| $\Gamma(K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_{83}/Γ | $(\Psi')''$ total $VALUE$ (units 10^{-5}) EVTS DOCUMENT ID TECN COMMENT | 2/' |
| VALUE (units 10 ⁻⁵) CL% EVTS DOCUMENT ID TECN COMMENT | 3.1 \pm 1.4 \pm 0.7 8 108 ABLIKIM 04K BES $e^+e^- \rightarrow \psi(2S)$ | |
| <2.96 90 1 FRANKLIN 83 MRK2 $e^+e^- ightarrow$ hadrons | 108 Calculated combining $\eta' ightarrow \gamma ho$ and $\eta \pi^+ \pi^-$ channels. | |
| $\Gamma(K^+\overline{K}^*(892)^- + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{84}/Γ | | /г |
| VALUE (units 10 ⁻⁵) CL% EVTS DOCUMENT ID TECN COMMENT | | 3/Г |
| | VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | — |
| $1.7_{-0.7}^{+0.8}$ Our average | $3.2^{+2.4}_{-2.0}\pm 0.7$ 4 109 ABLIKIM 04K BES $e^+e^- 	o \psi(2S)$ | |
| $2.9 + 1.3 \pm 0.4$ 9.6 ± 4.2 ABLIKIM 051 BES2 $e^+e^- ightarrow \psi(25)$ | 109 Calculated combining $\eta^\prime ightarrow \ \gamma ho$ and $\eta \pi^+ \pi^-$ channels. | |
| $1.3 + 1.0 \pm 0.3$ 7 ADAM 05 CLEO $e^+ e^- ightarrow \psi(2S)$ | $\Gamma(\omega\pi^0)/\Gamma_{ m total}$ | 4/Γ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | VALUE (units 10 ⁻⁵) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | ", |
| <5.4 90 FRANKLIN 83 MRK2 $e^+e^- \rightarrow \text{hadrons}$ | 2.1 ±0.6 OUR AVERAGE | |
| | $2.5 \ ^{+1.2}_{-1.0} \ \pm 0.2$ 14 ADAM 05 CLEO $e^+e^- ightarrow \psi(2S)$ | |
| $\Gamma(K^*(892)^0\overline{K}^0 + \text{c.c.})/\Gamma_{\text{total}}$ Γ_{85}/Γ | $1.87 ^{+0.68}_{-0.62} \pm 0.28$ 14 ABLIKIM 04L BES $e^+e^- ightarrow \psi(2S)$ | |
| <u>VALUE (units 10^{−5}) EVTS DOCUMENT ID TECN COMMENT</u> 10.9±2.0 OUR AVERAGE | | |
| $13.3^{+2.4}_{-2.8}\pm 1.7$ 65.6 \pm 9.0 ABLIKIM 051 BES2 $e^+e^- 	o \psi(25)$ | $\Gamma(ho\eta')/\Gamma_{ m total}$ | ₅ /Γ |
| | VALUE (units 10 ⁻⁵) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | |
| $9.2^{+2.7}_{-2.2}\pm 0.9$ 25 ADAM 05 CLEO $e^+e^- 	o \psi(2S)$ | 1.87$^{+1.64}_{-1.11}\pm 0.33$ 2 ABLIKIM 04L BES $e^{+}e^{-} ightarrow \psi(2S)$ | |
| $\Gamma(K^{+}\overline{K}^{*}(892)^{-} + \text{c.c.})/\Gamma(K^{*}(892)^{0}\overline{K}^{0} + \text{c.c.})$ Γ_{84}/Γ_{85} | F(am) /F | /г |
| VALUE DOCUMENT ID TECN COMMENT | V ., | ₆ /Γ |
| 0.16±0.06 OUR AVERAGE | <u>VALUE (units 10⁻⁵)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 2.2 ±0.6 OUR AVERAGE Error includes scale factor of 1.1. | — |
| $0.22^{+0.10}_{-0.14}$ ABLIKIM 051 BES2 $e^+e^- ightarrow \psi(25)$ | 3.0 $^{+1.1}_{-0.9}$ \pm 0.2 18 ADAM 05 CLEO $e^+e^- \to \psi(2S)$ | |
| $0.14 ^{+0.08}_{-0.06}$ ADAM 05 CLEO $e^+ e^- ightarrow \psi(2S)$ | | |
| | $1.78 ^{+}_{-}0.62 ^{+} \pm 0.17$ 13 ABLIKIM 04L BES $e^{+}e^{-} ightarrow \psi(2S)$ | |
| $\Gamma(\phi\pi^+\pi^-)/\Gamma_{ m total}$ | $\Gamma(\omega\eta)/\Gamma_{ m total}$ | 7/Г |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT 1.17±0.29 OUR AVERAGE Error includes scale factor of 1.7. | VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | |
| 2.43 \pm 0.95 \pm 0.04 10 \pm $\frac{1}{4}$ 01,102 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow$ | <1.1 90 ADAM 05 CLEO $e^+e^- \rightarrow \psi(2S)$ | |
| $\pi^+\pi^-{}_{	extsf{K}}^+{}_{	extsf{K}}^-{}_{\gamma}$ | | |
| 0.9 \pm 0.2 \pm 0.1 47.6 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S) \rightarrow K^+K^-\pi^+\pi^-$ | $<$ 3.1 90 ABLIKIM 04K BES $e^+e^- ightarrow \psi(2S)$ | |
| 1.5 $\pm 0.2 \pm 0.2$ 51.5 ± 8.3 103 BAI 03B BES $\psi(2S) \to K^+ K^- \pi^+ \pi^-$ | $\Gamma(\phi\pi^0)/\Gamma_{ m total}$ | 8/Г |
| ¹⁰¹ AUBERT 07AK reports $[\Gamma(\psi(2S) \rightarrow \phi \pi^+ \pi^-)/\Gamma_{total}] \times [\Gamma(\psi(2S) \rightarrow e^+ e^-)] =$ | VALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | |
| $(0.57\pm0.22\pm0.04)\times10^{-3}$ keV which we divide by our best value $\Gamma(\psi(2S)\to e^+e^-)=2.35\pm0.04$ keV. Our first error is their experiment's error and our second error is the | <0.4 90 ABLIKIM 04K BES $e^+e^- ightarrow \psi(2S)$ | |
| systematic error from using our best value. | • • • We do not use the following data for averages, fits, limits, etc. • • • | |
| 102 Using B($\phi \to K^+K^-$) = (49.3 ± 0.6)%. 103 Normalized to B($\psi(2S) \to J/\psi \pi^+\pi^-$) = 0.305 ± 0.016. | <0.7 90 ADAM 05 CLEO $e^+e^- ightarrow \psi(2S)$ | |
| | $\Gamma(\eta_c\pi^+\pi^-\pi^0)/\Gamma_{ m total}$ | 9/Γ |
| $\Gamma(\phi f_0(980) \to \pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_{87}/Γ | VALUE (units 10 ⁻³) CL% DOCUMENT ID TECN COMMENT | |
| VALUE (units 10 ⁻⁴) EVTS DOCUMENT ID TECN COMMENT | <1.0 90 PEDLAR 07 CLEO $e^+e^- ightarrow \psi(2S)$ | |
| 0.68\pm0.25 OUR AVERAGE Error includes scale factor of 1.1. 1.45 \pm 0.70 \pm 0.03 6 \pm $\frac{1}{3}$ 04,105 AUBERT 07AK BABR 10.6 $e^+e^- \rightarrow$ | $\Gamma(p\overline{p}K^+K^-)/\Gamma_{\text{total}}$ | η/Г |
| $\pi^+\pi^-\kappa^+\kappa^-\gamma$ | VALUE (units 10 ⁻⁵) EVTS DOCUMENT ID TECN COMMENT | ٠,, |
| 0.6 \pm 0.2 \pm 0.1 18.4 \pm 6.4 ¹⁰⁶ BAI 03B BES $\psi(2S) \rightarrow K^+K^-\pi^+\pi^-$ | 2.7 ± 0.6 ± 0.4 30.1 BRIERE 05 CLEO $e^+e^- \rightarrow \psi(2S)$ | → |
| 104 AUBERT 07AK reports $[\Gamma(\psi(2S) \rightarrow \phi f_0(980) \rightarrow \pi^+\pi^-)/\Gamma_{\text{total}}] \times [\Gamma(\psi(2S) \rightarrow \pi^+\pi^-)]$ | $p\overline{p} K^+ K^-$ | |
| $e^+e^-)]=(0.34\pm0.16\pm0.04)\times10^{-3}$ keV which we divide by our best value $\Gamma(\psi(2S)\to e^+e^-)=2.35\pm0.04$ keV. Our first error is their experiment's error and our second | $\Gamma(\overline{\Lambda}nK_S^0 + \text{c.c.})/\Gamma_{\text{total}}$ | 1/Г |
| error is the systematic error from using our best value. | $VALUE$ (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT | ٠,٠ |
| 105 Using B($\phi \to K^+K^-$) = (49.3 ± 0.6)%. | 0.81 \pm 0.11 \pm 0.14 50 110 ABLIKIM 08C BES2 $e^+e^- \rightarrow J/\psi$ | |
| 106 Normalized to B($\psi(2S) \to J/\psi \pi^+ \pi^-) = 0.305 \pm 0.016$. | 110 Using B($\overline{\Lambda} \to \overline{p}\pi^+$) = 63.9% and B($K_S^0 \to \pi^+\pi^-$) = 69.2%. | |
| | · , · , · · , · · · , · · · · · / · · · · | |

 $\psi(2S)$

| $(\phi f_2'(1525))/\Gamma_{	ext{total}}$ | Γ ₁₀₂ /Γ | $\Gamma(\gamma \chi_{c0}(1P))/\Gamma(\gamma \chi_{c2}(1P))$ Γ_{109}/Γ_{11} |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALUE (units 10^{-4}) CL% EVTS DOCUMENT ID TECN COMMENT 44±0.12±0.11 20 ± 6 BAI 04c $\psi(2S) \rightarrow$ • We do not use the following data for averages, fits, limits, etc. • • • | 2(K+K-) | • • • We do not use the following data for averages, fits, limits, etc. • • • $0.99\pm0.02\pm0.08$ |
| | → 2(K+K-) | 120 Not independent from ATHAR 04 measurements of B $(\gamma \chi_{cJ})$. |
| $(\Theta(1540)\overline{\Theta}(1540) \rightarrow K_S^0 p K^- \overline{n} + c.c.)/\Gamma_{total}$ | Γ ₁₀₃ /Γ | $\Gamma(\gamma \eta_c(1S))/\Gamma_{\text{total}}$ $\Gamma_{112}/\Gamma_{\text{total}}$ |
| ALUE (units 10 ⁻⁵) CL% DO CUMENT ID TECN COMMENT | | <u>VALUE (units 10⁻²)</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> 0.34 ±0.05 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below |
| <0.88 90 BAI 04G BES2 e ⁺ e ⁻ | | $0.432 \pm 0.016 \pm 0.060$ MITCHELL 09 CLEO $e^+e^- ightarrow \gamma X$ |
| $(\Theta(1540)K^{-}\overline{n} \to K_{5}^{0} p K^{-}\overline{n})/\Gamma_{\text{total}}$ | Γ ₁₀₄ /Γ | 0.32 \pm 0.04 \pm 0.06 2560 121 ATHAR 04 CLEO $e^+e^- \rightarrow \gamma X$ 0.28 \pm 0.06 122 GAISER 86 CBAL $e^+e^- \rightarrow \gamma X$ |
| ALUE (units 10^{-5}) CL% DOCUMENT ID TECN COMMENT <1.0 90 BAI 046 BES2 e^+e^- | | 121 ATHAR 04 used $\Gamma_{\eta_c(1S)}=24.8\pm4.9$ MeV to obtain this result. |
| $(\Theta(1540)K_S^0 \overline{p} \to K_S^0 \overline{p} K^+ n)/\Gamma_{\text{total}}$ | Γ ₁₀₅ /Γ | 122 GAISER 86 used $\Gamma_{\eta_c(1S)}^{\infty}=11.5\pm4.5$ MeV to obtain this result. |
| ALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | | WEIGHTED AVERAGE 0.34±0.05 (Error scaled by 1.3) |
| <0.70 90 BAI 04G BES2 e ⁺ e ⁻ | | , |
| $(\overline{\Theta}(1540)K^+ n \to K_S^0 \overline{p}K^+ n)/\Gamma_{\text{total}}$ | Γ ₁₀₆ /Γ | |
| ALUE (units 10^{-5}) CL% DOCUMENT ID TECN COMMENT < 2.6 90 BAI 04G BES2 e^+e^- | | |
| $(\overline{\Theta}(1540)K_S^0 p \to K_S^0 p K^{-} \overline{n})/\Gamma_{\text{total}}$ | Γ ₁₀₇ /Γ | |
| ALUE (units 10 ⁻⁵) CL% DOCUMENT ID TECN COMMENT | | |
| <0.60 90 BAI 046 BES2 e^+e^- | | |
| $(\kappa_S^0 \kappa_S^0)/\Gamma_{\text{total}}$ | Γ ₁₀₈ /Γ | |
| ALUE (units 10^{-4}) CO.046 $ \frac{DOCUMENT\ ID}{111} \text{ BAI} \qquad 04D \text{ BES} \qquad e^+e^- $ | | χ^2 |
| 1 Forbidden by <i>CP</i> . | | MITCHELL 09 CLEO 2.0 ATHAR 04 CLEO 0.1 |
| RADIATIVE DECAYS | | GAISER 86 CBAL 1.2 3.3 |
| $(\gamma \chi_{c0}(1P))/\Gamma_{total}$ | Γ ₁₀₉ /Γ | (Confidence Level = 0.196) |
| LUE (units 10⁻²) EVTS DOCUMENT ID TECN COMMENT 68±0.31 OUR FIT COMMENT COMMENT | | 0 0.2 0.4 0.6 0.8 1 |
| 2 ±0.4 OUR AVERAGE | | $\Gammaig(\gamma\eta_c(1S)ig)/\Gamma_{total}$ (units 10^{-2}) |
| $22\pm0.11\pm0.46$ 72600 ATHAR 04 CLEO $e^+e^-\to$ 9 $\pm0.5~\pm0.8$ 112 GAISER 86 CBAL $e^+e^-\to$ | γX γX | $\Gamma(\gamma \eta_c(2S))/\Gamma_{total}$ Γ_{113} |
| .2 \pm 2.3 | γX | VALUECL%DOCUMENT IDTECNCOMMENT $<8 \times 10^{-4}$ 90 123 CRONIN-HEN10CLEO $\psi(2S) \rightarrow \gamma K \overline{K} \pi$ |
| 12 Angular distribution $(1+\cos^2\theta)$ assumed. | | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $(\gamma \chi_{c1}(1P))/\Gamma_{total}$ | Γ ₁₁₀ /Γ | $<2\times10^{-3}$ 90 ATHAR 04 CLEO $e^+e^-\to\gamma X$ 0.2–1.3 \times 10 ⁻² 95 EDWARDS 82c CBAL $e^+e^-\to\gamma X$ |
| ALUE (units 10^{-2}) EVTS DOCUMENT ID TECN COMMENT 2 ± 0.4 OUR FIT | | 123 CRONIN-HENNESSY 10 reports $\left[\Gamma\left(\psi(2S)\to \gamma\eta_{\mathcal{C}}(2S)\right)/\Gamma_{\text{total}}\right]\times\left[B(\eta_{\mathcal{C}}(2S)\to \kappa\overline{\kappa}\pi)\right]<14.5\times10^{-6}$ which we divide by our best value $B(\eta_{\mathcal{C}}(2S)\to \kappa\overline{\kappa}\pi)$ |
| .9 ±0.5 OUR AVERAGE | | 1.9×10^{-2} . This measurement assumes $\Gamma(\eta_C(2S)) = 14$ MeV. CRONIN-HENNESSY |
| .07 \pm 0.11 \pm 0.54 76700 ATHAR 04 CLEO $e^+e^- \rightarrow$.0 \pm 0.5 \pm 0.7 113 GAISER 86 CBAL $e^+e^- \rightarrow$ | , | gives the analytic dependence of limits on width. |
| .1 ± 1.9 | γX | $\Gamma(\gamma\pi^0)/\Gamma_{	ext{total}}$ $\Gamma_{	ext{114}}$ VALUE (units 10^{-6}) CL% EVTS DOCUMENT ID TECN COMMENT |
| 13 Angular distribution (1 $-$ 0.189 $\cos^2	heta$) assumed. 14 Valid for isotropic distribution of the photon. | | 1.58\pm0.40\pm0.13 37 ABLIKIM 10F BES3 $\psi(2S) ightarrow \gamma \pi^0$ |
| $(\gamma \chi_{c2}(1P))/\Gamma_{total}$ | Г ₁₁₁ /Г | • • • We do not use the following data for averages, fits, limits, etc. • • • < 5 90 PEDLAR 09 CLE3 $\psi(2S) \rightarrow \gamma X$ |
| ALUE (units 10 ⁻²) <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | | <5400 95 124 LIBERMAN 75 SPEC e ⁺ e ⁻ <1 x 10 ⁴ 90 WIIK 75 DASP e ⁺ e ⁻ |
| .8 ±0.5 OUR AVERAGE Error includes scale factor of 1.1. | | $<$ 1 \times 10 4 90 VIIIK 15 DASP e i e 124 Restated by us using B($\psi(2S) \rightarrow \mu^{+}\mu^{-}$) = 0.0077. |
| $.33\pm0.14\pm0.61$ 79300 ATHAR 04 CLEO $e^+e^- \rightarrow$.0 ±0.5 ±0.7 115 GAISER 86 CBAL $e^+e^- \rightarrow$ | γX | $\Gamma(\gamma\eta'(958))/\Gamma_{\text{total}}$ |
| 0.0 ± 2.0 116 BIDDICK 77 CNTR $e^+e^- ightarrow$ | γX | VALUE (units 10 ⁻⁴) CL% EVTS DOCUMENT ID TECN COMMENT 1.23±0.06 OUR AVERAGE |
| 15 Angular distribution $(1-0.052\cos^2	heta)$ assumed. 16 Valid for isotropic distribution of the photon. | | $1.26\pm0.03\pm0.08$ 2226 $^{1}2^{5}$ ABLIKIM 10F BES3 $\psi(2S) ightarrow 3\gamma\pi^{+}\pi^{-}$ |
| $\Gamma(\gamma \chi_{c0}(1P)) + \Gamma(\gamma \chi_{c1}(1P)) + \Gamma(\gamma \chi_{c2}(1P))]/\Gamma_{\text{total}}$ | | $2\gamma\pi^+\pi^-$ 1.19 \pm 0.08 \pm 0.03 PEDLAR 09 CLE3 $\psi(2S) ightarrow \gamma X$ |
| | ₁₀ +Γ ₁₁₁)/Γ | 1.24 ± 0.27 ± 0.15 23 ABLIKIM 06R BES2 $e^{\frac{1}{2}}e^{\frac{2}{2}} \rightarrow \psi(25)$ 1.54 ± 0.31 ± 0.20 \sim 43 BAI 98F BES $\psi(25) \rightarrow \pi^{+}\pi^{-}2^{-}$ |
| • • We do not use the following data for averages, fits, limits, etc. • • • | | $\pi^+\pi^-3\gamma$ |
| $7.6\pm0.3\pm2.0$ 117 ATHAR 04 CLEO $e^+e^- \rightarrow$ | γX | • • • We do not use the following data for averages, fits, limits, etc. • • • < 60 90 126 BRAUNSCH 77 DASP e^+e^- |
| 17 Not independent from ATHAR 04 measurements of B $(\gamma\chi_{cJ})$. | | $<$ 11 90 127 BARTEL 76 CNTR $^{+}$ $^{-}$ |
| $(\gamma \chi_{c0}(1P))/\Gamma(\gamma \chi_{c1}(1P))$ ALUE DOCUMENT ID TECN COMMENT | $\Gamma_{109}/\Gamma_{110}$ | 125 Combining the results from $\eta'\to\pi^+\pi^-\eta$ and $\eta'\to\pi^+\pi^-\gamma$ decay modes. 126 Restated by us using total decay width 228 keV. |
| \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet | | 127 The value is normalized to the branching ratio for $\Gamma(J/\psi(1S)\eta)/\Gamma_{	ext{total}}$. |
| $.02\pm0.01\pm0.07$ 118 ATHAR 04 CLEO $e^+e^- \rightarrow$ | γX | $\Gamma(\gamma f_2(1270))/\Gamma_{\text{total}}$ |
| 18 Not independent from ATHAR 04 measurements of B $(\gamma\chi_{cJ})$. | - /- | VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT2.12 \pm 0.19 \pm 0.32 128 ,129 BAI03c BES $\psi(2S) \rightarrow \gamma \pi \pi$ |
| $\Gamma(\gamma\chi_{c2}(1P))/\Gamma(\gamma\chi_{c1}(1P))$ ALUE DOCUMENT ID TECN COMMENT | $\Gamma_{111}/\Gamma_{110}$ | • • • We do not use the following data for averages, fits, limits, etc. • • |
| | | $2.08 \pm 0.19 \pm 0.33$ 200.6 ± 18.8 128 BAI $03c$ BES $\psi(2S) 	o \gamma \pi^+ \pi^-$ |
| $ullet$ • We do not use the following data for averages, fits, limits, etc. $ullet$ • • • $0.3\pm0.02\pm0.03$ 119 ATHAR 04 CLEO $e^+e^-\to$ | | $2.90\pm1.08\pm1.07$ 29.9 ± 11.1 128 BAI 03c BES $\psi(2S) \rightarrow \gamma\pi^0\pi^0$ 128 Normalized to B $(\psi(2S) \rightarrow J/\psi\pi^+\pi^-) = 0.305\pm0.016$. |

 $\psi(2S)$

| $\Gamma(\gamma f_0(1710) \rightarrow \gamma \pi \pi)$ | • | ENT ID TECH | Γ ₁₁₈ /Γ | $\Gamma(\gamma f_2(1950) \rightarrow \gamma f_2(1950) $ | (PP̄)/Γ _{total} | DOCUMENT ID | TECN | Г13 |
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| $VALUE \text{ (units } 10^{-4})$ EV $0.301 \pm 0.041 \pm 0.124$ 35 130 Normalized to B(ψ (2) | | 03c BES | $\frac{\text{COMMENT}}{\psi(2S) \rightarrow \gamma \pi^+ \pi^-}$ | VALUE (units 10 ⁻⁵) 1.2±0.2±0.1 136 From a fit of the | e p p mass distr | 36 ALEXANDER 10 ribution to a combina | CLEO of γf | $\frac{COMMENT}{\psi(2S) \to \gamma p \overline{p}}$ $p(1950), \gamma f_2(2150),$ |
| $\Gamma(\gamma f_0(1710) \rightarrow \gamma K \overline{K})$ | ₹)/Γ _{total} | | Γ ₁₁₉ /Γ | $\gamma p \overline{ ho}$ phase space $\pi^0 p \overline{ ho}$ and contin | e, for $M(p\overline{p} < 2)$ | 2.85 GeV, and account | ting for bac | kgrounds from $\psi(25)$ |
| $(ALUE \text{ (units } 10^{-4}))$ CL: $(D.604 \pm 0.090 \pm 0.132)$ • • • We do not use the | 39.6 ± 5.9 31,132 BAI | 03c BES ψ | $\psi(2S) \rightarrow \gamma K^+ K^-$ | $\Gamma(\gamma f_2(2150) \rightarrow \gamma)$ VALUE (units 10^{-5}) | / ρ ̄ ̄ ̄) / Γ _{total} | DO CUMENT ID | TECN | Γ ₁₃ |
| | $6.8 \pm 3.1^{31,132}\mathrm{BAI}$ | | $\psi(2S) \rightarrow \gamma K_S^0 K_S^0$ | 0.72±0.18±0.03 | | 37 ALEXANDER 10 | | |
| 31 Includes unknown bra $^{K^+}$ $^-$ result by a fa | anching fractions to K^+ actor of 2 and the $K^0_SK^0_S$ | K^- or $K^0_S K^0_S$. We | have multiplied the | 137 From a fit of the $\gamma ho \overline{ ho}$ phase space $\pi^0 ho \overline{ ho}$ and contin | | ribution to a combina 2.85 GeV, and account | ntion of γf_2 ting for back | $_2$ (1950), γ $_2$ (2150), Ekgrounds from ψ (25 |
| $^{132}_{132}$ Normalized to $^{132}_{132}$ Normalized to $^{132}_{132}$ | $(S) \rightarrow J/\psi \pi^+ \pi^-) = 0$ | $.305\pm0.016.$ | | $\Gamma(\gamma X(1835) \rightarrow \gamma$ | • | | | Г ₁₃ |
| $\Gamma(\gamma\eta)/\Gamma_{	ext{total}_{j}}$ | | | Γ ₁₂₁ /Γ | VALUE (units 10 ⁻⁶) <1.6 | <u>CL%</u> 90 | DOCUMENT ID ALEXANDER 10 | | $\psi(2S) \rightarrow \gamma p \overline{p}$ |
| /ALUE (units 10 ⁻⁶) CI 1.38±0.48±0.09 | 13 133 ABLIKIM | 1 10F BES3 ψ(2 | $\frac{MMENT}{2(S) \rightarrow \gamma \pi^{+} \pi^{-} \pi^{0}}, \blacksquare$ | | | data for averages, fit | s, limits, e | |
| • • • We do not use the | = | | • • • | $\Gamma(\gamma X \to \gamma \rho \overline{\rho})/\Gamma$ | - total | e range 2.2 < <i>M(X)</i> | < 2.9 Ca) | , Г ₁₃ |
| < 90 90 | | , , | $(25) \rightarrow \pi^+\pi^- 3\gamma$ | VALUE (units 10 ⁻⁶) | CL%_ | DOCUMENT ID | | COMMENT |
| <200 90 | | | | <2 | 90 | ALEXANDER 10 | CLEO | $\psi(2S) \rightarrow \gamma p \overline{p}$ |
| .33 Combining the results | s from $\eta \to \pi^+\pi^-\pi^0$ a | and $\eta ightarrow 3\pi^{0}$ decay r | nodes. | $\Gamma(\gamma \pi^+ \pi^- \rho \overline{\rho})/\Gamma$ | total | | | Г ₁₃ |
| $\lceil (\gamma \eta \pi^+ \pi^-) / \lceil_{total} \rceil$ | | | Γ ₁₂₂ /Γ | VALUE (units 10 ⁻⁵) | EVTS | DOCUMENT ID | TECN | COMMENT |
| | EVTS DOCUMENT I | | IMENT . | $2.8 \pm 1.2 \pm 0.7$ | 17 | ABLIKIM 070 | D BES2 | $e^+e^- \rightarrow \psi(2S)$ |
| 3.71±1.25±1.64 | 418 ABLIKIM | 06R BES2 ψ (2 | $S) \rightarrow \gamma \eta \pi^+ \pi^-$ | $\Gamma(\gamma 2(\pi^+\pi^-)K^+$ | $K^-)/\Gamma_{total}$ | | | Г ₁₄ |
| $(\gamma \eta(1405) \rightarrow \gamma K \overline{K})$ | $(\pi)/\Gamma_{total}$ | | Γ ₁₂₄ /Γ | VALUE (units 10^{-5}) | <u>CL%</u> | DOCUMENT ID | TECN | COMMENT |
| <u>'ALUE (units 10⁻⁴)</u> <u>CL%</u> | DO CUMENT ID | TECN COMMENT | 0 1 | <22 | 90 | ABLIKIM 07 | D BES2 | $e^+e^- \rightarrow \psi(2S)$ |
| <0.9 90 | ABLIKIM 06R e following data for avera | BES2 $\psi(2S) \rightarrow \gamma$ | | $\Gamma(\gamma 3(\pi^+\pi^-))/\Gamma$ | total | | | Г ₁₄ |
| <1.3 90 | | BES2 $\psi(2S) \rightarrow \gamma$ | | VALUE (units 10^{-5}) | <u>CL%</u> | DOCUMENT ID | | COMMENT |
| <1.2 90 | ¹³⁴ SCHARRE 80 | MRK1 e^+e^- | , | <17 | 90 | ABLIKIM 07 | D BES2 | $e^+e^- \rightarrow \psi(2S)$ |
| ³⁴ Includes unknown bra | anching fraction $\eta(1405)$ | $\rightarrow K\overline{K}\pi$. | | Γ(γK+K-K+K | $(-)/\Gamma_{total}$ | | | Γ ₁₄ |
| $(\gamma \eta(1405) \rightarrow \eta \pi^+ \pi$ | $\pi^-)/\Gamma_{\text{total}}$ | | Γ ₁₂₅ /Γ | VALUE (units 10^{-5}) | CL% | DO CUMENT ID | TECN | COMMENT |
| | | | ' 120 / ' | | | | | |
| | EVTS DOCUMENT I | ID TECN COM | · 125/· IMENT | <4 | 90 | ABLIKIM 07 | BES2 | $e^+e^- \rightarrow \psi(2S)$ |
| VALUE (units 10 ⁻⁴) | • | $\frac{D}{D}$ $\frac{TECN}{D}$ $\frac{COM}{V}$ | IMENT | <4 | 90 | | | |
| VALUE (units 10 ⁻⁴) 0.36±0.25±0.05 | DOCUMENT I 10 ABLIKIM | | IMENT | <4 ψ(2 | 90 (S) CROSS-F | PARTICLE BRANG | CHING R | ATIOS |
| • | DOCUMENT I 10 ABLIKIM | | $\frac{MMENT}{S) \rightarrow \gamma \eta \pi^+ \pi^-}$ | <4 ψ(2 For measur | 90 2S) CROSS-Fements involvin | | CHING R $(1P)) \times B(\chi)$ | ATIOS |
| VALUE (units 10^{-4}) 0.36±0.25±0.05 $\Gamma(\gamma \eta (1475) \to K \overline{K} \pi)$ VALUE (units 10^{-4}) <1.4 90 | T)/F _{total} DOCUMENT ID ABLIKIM DOCUMENT ID ABLIKIM OGR | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} \Gamma_{127}/\Gamma $ $ \frac{K^{+} K^{-} \pi^{0}}{K^{+} K^{-} \pi^{0}} $ | <4 ψ(2 For measur see the corr | 90 2.5) CROSS-Fements involving responding entr | PARTICLE BRANC and $\mathbf{B}(\psi(2S) \to \gamma \chi_{c,J})$ where $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is seen the $\chi_{c,J}(1P)$ is see | CHING R $(1P)) \times B(\chi)$ ections. | ATIOS $(cJ(1P) \rightarrow X)$ |
| VALUE (units 10^{-4}) $0.36\pm0.25\pm0.05$ $\Gamma\left(\gamma\eta(1475)\rightarrow K\overline{K}\pi\right)$ VALUE (units 10^{-4}) <1.4 <0.5 <0.5 <0.5 Vec 40 not use the | T)/Total DOCUMENT ID ABLIKIM BOOLUMENT ID ABLIKIM OGR Following data for avera | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ Iges, fits, limits, etc. | $ \frac{MENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} \\ \Gamma_{127}/\Gamma \\ K^{+} K^{-} \pi^{0} $ | ψ(2 For measur see the corr | 90 25) CROSS-Fements involving entroperations of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of t | PARTICLE BRANG as $\mathrm{B}(\psi(2S) 	o \gamma \chi_{c,J})$ ries in the $\chi_{c,J}(1P)$ so TUDE RATIOS IN | CHING R $(1P)) 	imes B(\chi)$ ections. | ATIOS |
| $\begin{array}{c} \text{VALUE (units } 10^{-4}) \\ \text{0.36} \pm \text{0.25} \pm \text{0.05} \\ \\ \hline \Gamma(\gamma \eta (1475) \rightarrow \overline{K} \overline{K} \pi \\ \text{VALUE (units } 10^{-4}) & \text{CL\%} \\ \text{<1.4} & 90 \\ \bullet \bullet \bullet \text{We do not use the} \\ \text{<1.5} & 90 \\ \end{array}$ | TO ABLIKIM T)/Ftotal ABLIKIM DOCUMENT ID ABLIKIM ABLIKIM OGR FOllowing data for avera ABLIKIM OGR | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} \\ \Gamma_{127}/\Gamma \\ K^{+} K^{-} \pi^{0} $ | ψ(2 For measur see the corr MULTIPO | 90 PS) CROSS-Fements involving responding entropoles \mathcal{O} LE AMPLIT $\mathcal{O}(2S) \rightarrow \gamma \chi$ | PARTICLE BRANC ag $B(\psi(2S) \to \gamma \chi_{CJ})$ ries in the $\chi_{CJ}(1P)$ so TUDE RATIOS IN $\chi_{CJ}(1P)$ and χ_{CJ} | CHING R $(1P)) \times B(\chi)$ ections. RADIATI $\rightarrow \gamma J/\psi$ | ATIOS $x_{cJ}(1P) \to X$ IVE DECAYS (15) |
| ALUE (units 10^{-4}) $0.36 \pm 0.25 \pm 0.05$ $(\gamma \eta (1475) \rightarrow K\overline{K}\pi)$ ALUE (units 10^{-4}) 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 | TO ABLIKIM ABLIKIM P)/Fotal DOCUMENT ID ABLIKIM 06R Following data for avera ABLIKIM ABLIKIM O6R | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ gges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MENT}{S} \rightarrow \gamma \eta \pi^{+} \pi^{-} $ $ \Gamma_{127}/\Gamma $ $ \frac{K^{+} K^{-} \pi^{0}}{K^{0} S^{+} \pi^{-} + \text{c.c.}} $ $ \Gamma_{128}/\Gamma $ | ψ(2 For measur see the corr MULTIPO | 90 PS) CROSS-Fements involving responding entropoles \mathcal{O} LE AMPLIT $\mathcal{O}(2S) \rightarrow \gamma \chi$ | PARTICLE BRANG as $\mathrm{B}(\psi(2S) 	o \gamma \chi_{c,J})$ ries in the $\chi_{c,J}(1P)$ so TUDE RATIOS IN | CHING R $(1P)) \times B(x)$ ections. RADIATI $\rightarrow \gamma J/\psi$ n amplitu | ATIOS $x_{cJ}(1P) \to X$ IVE DECAYS (15) |
| $ALUE$ (units 10^{-4}) $0.36\pm0.25\pm0.05$ $\Gamma\left(\gamma\eta(1475) \rightarrow K\overline{K}\pi\right)$ <1.4 <1.4 <1.4 <1.4 <1.4 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 <1.5 $<1.$ | TO ABLIKIM T)/Ftotal ABLIKIM DOCUMENT ID ABLIKIM ABLIKIM OGR FOllowing data for avera ABLIKIM OGR | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ gges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MENT}{S} \rightarrow \gamma \eta \pi^{+} \pi^{-} \\ \Gamma_{127}/\Gamma \\ K^{+} K^{-} \pi^{0} \\ K^{0} S K^{+} \pi^{-} + \text{c.c.} $ $ \Gamma_{128}/\Gamma \\ MENT $ | $\psi(2)$ For measure see the core MULTIPO $\psi(2)$ $\psi(2)$ $\psi(2)$ | 90 2.5) CROSS-Fements involving responding entropic sponding γ DLE AMPLIT γ γ Magnetic quinting γ γ γ γ γ γ γ | PARTICLE BRANCH $(2S) \rightarrow \gamma \chi_{cJ}$ ries in the $\chi_{cJ}(1P)$ so $\gamma_{cJ}(1P)$ so $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ and $\gamma_{cJ}(1P)$ | CHING R $(1P)) \times B(\chi)$ ections. RADIAT | ATIOS $(x_{cJ}(1P) \rightarrow X)$ IVE DECAYS (1S) $(1S)$ |
| $(ALUE (units 10^{-4}))$ $0.36\pm0.25\pm0.05$ $\Gamma(\gamma\eta(1475) \rightarrow K\overline{K}\pi)$ $(ALUE (units 10^{-4})$ 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 0.40 | TO ABLIKIM T)/Ftotal DOCUMENT ID ABLIKIM 06R To following data for avera ABLIKIM 06R TO FOLIA TO FOLIA ABLIKIM 06R ABLIKIM 06R ABLIKIM 06R TO FOLIA ABLIKIM 06R | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ gges, fits, limits, etc. 6 BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ $ \Gamma_{127}/\Gamma $ $ \frac{K^{+} K^{-} \pi^{0}}{K^{0} K^{+} \pi^{-} + \text{c.c.}} $ $ \Gamma_{128}/\Gamma $ $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ | For measure see the corresponding to $\psi(2)$ For measure see the corresponding to $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ 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| $(ALUE (units 10^{-4}))$ $0.36\pm0.25\pm0.05$ $\Gamma(\gamma\eta(1475) \rightarrow K\overline{K}\pi)$ $(ALUE (units 10^{-4}) \qquad CL\%$ $<1.4 \qquad 90$ $• • • We do not use the <1.5 \qquad 90$ $\Gamma(\gamma\eta(1475) \rightarrow \eta\pi^{+}\pi)$ <0.88 $\Gamma(\gamma2(\pi^{+}\pi^{-}))/\Gamma_{\text{total}}$ | TO ABLIKIM ABLIKIM ABLIKIM ABLIKIM ABLIKIM OGR FOR OGRAPI ABLIKIM OGR ABLIKIM OGR ABLIKIM ABLIKIM ABLIKIM ABLIKIM ABLIKIM ABLIKIM | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ ges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ 06R BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ $ \Gamma_{127}/\Gamma $ $ K^{+} K^{-} \pi^{0} $ $ K^{0} K^{+} K^{-} + c.c. $ $ \Gamma_{128}/\Gamma $ $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ $ \Gamma_{129}/\Gamma $ | For measure see the corresponding to $\psi(2)$ For measure see the corresponding to $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ 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| ALUE (units 10^{-4}) $0.36\pm0.25\pm0.05$ $(\gamma\eta(1475) \rightarrow K\overline{K}\pi)$ $(1.4 \qquad 90)$ $0.4 \qquad 0.4 \qquad 90$ $0.4 \qquad 0.4 \qquad 0.4 \qquad 90$ $0.4 \qquad 0.4 | TO ABLIKIM T)/Ftotal DOCUMENT ID ABLIKIM 06R To following data for avera ABLIKIM 06R TO FOLIA TO FOLIA ABLIKIM 06R ABLIKIM 06R ABLIKIM 06R TO FOLIA ABLIKIM 06R | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ ges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ 06R BES2 $\psi(2S) \rightarrow \gamma$ | $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ $ \Gamma_{127}/\Gamma $ $ \frac{K^{+} K^{-} \pi^{0}}{K^{0} K^{+} \pi^{-} + \text{c.c.}} $ $ \Gamma_{128}/\Gamma $ $ \frac{MMENT}{S) \rightarrow \gamma \eta \pi^{+} \pi^{-}} $ | For measure see the corresponding to $\psi(2)$ For measure see the corresponding to $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ $\psi(2)$ 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RADIATI $\rightarrow \gamma J/\psi$ n amplitu $\frac{TECN}{CLEO}$ | ATIOS $(x_{CJ}(1P) 	o X)$ IVE DECAYS (1S) Ide ratio $(x_{COMMENT} 	o y) 	o y) 	o y) 	o y)$ |
| ALUE (units 10^{-4}) .36±0.25±0.05 $(\gamma \eta (1475) \rightarrow K\overline{K}\pi)$ ALUE (units 10^{-4}) <1.4 90 • We do not use the <1.5 90 $(\gamma \eta (1475) \rightarrow \eta \pi^{+}\pi)$ ALUE (units 10^{-4}) <0.88 $(\gamma 2(\pi^{+}\pi^{-}))/\Gamma_{\text{total}}$ ALUE (units 10^{-5}) 96.6±2.8±5.0 $(\gamma K^{*0}K^{+}\pi^{-} + \text{c.c.})$ | TO ABLIKIM T)/Ftotal DOCUMENT ID ABLIKIM 06R FOR OBLIKIM 06R TO OBLIKIM 06R ABLIKIM 06R ABLIKIM 06R TO OBLIKIM 06R ABLIKIM 06R TO OBLIKIM 06R ABLIKIM 06R | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ ges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ 06R BES2 $\psi(2S) \rightarrow \gamma$ | $\begin{array}{c} (MENT) \\ S) \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline \Gamma_{127}/\Gamma \\ \hline K^+ K^- \pi^0 \\ \bullet \bullet \bullet \\ K_S^0 K^+ \pi^- + \text{c.c.} \\ \hline \Gamma_{128}/\Gamma \\ \hline MENT \\ \end{array}$ | For measure see the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the corresponding to the correspon | 90 2.5) CROSS-Fements involving esponding entropication γ_{x} Magnetic question γ_{x} EVTS 59k 13 Systematic γ_{x} Not independent γ_{y} Magnetic question γ_{x} Magnetic question γ_{x} | PARTICLE BRANG $\log B(\psi(2S) \rightarrow \gamma \chi_{cJ})$ ries in the $\chi_{cJ}(1P)$ so TUDE RATIOS IN $(c_J(1P)$ and χ_{cJ} - adrupole transitio $\frac{DOCUMENT\ ID}{2}$ $38\ ARTUSO$ 09 ors combined. Using $b_2(\chi_{c1})$, $b_2(\chi_{c2})$ and dent of values for a_2 usuadrupole transitio | CHING R $(1P)) \times B(\chi$ ections. RADIATI $\rightarrow \gamma J/\psi$ n amplitu $\frac{TECN}{CLEO}$ CLEO values from fixed E : $(\chi_{C1}(1P))$ n amplitu | ATIOS $(c_{cJ}(1P) \to X)$ IVE DECAYS (15) $(c_{cJ}(1P) \to X)$ IVE DECAYS (15) $(c_{cJ}(1P) \to X)$ IVE DECAYS (16) $(c_{cJ}(1P) \to X)$ IVE DECAYS (17) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ IVE DECAYS (18) $(c_{cJ}(1P) \to X)$ |
| $(ALUE (units 10^{-4}))$ 0.36±0.25±0.05 Γ (γη(1475) → $K\overline{K}π$ $(ALUE (units 10^{-4}))$ 0.40.4 90 0.0 • • We do not use the 0.1.5 90 Γ (γη(1475) → $ηπ^+π$ $(ALUE (units 10^{-4}))$ 0.88 Γ (γ2($π^+π^-$))/Γtotal $(ALUE (units 10^{-5}))$ 39.6±2.8±5.0 Γ (γ $K^{+0} K^+π^-$ + c.c. | TO ABLIKIM T)/Ftotal DOCUMENT ID ABLIKIM 06R FOR TOTAL ABLIKIM 06R TO DOCUMENT ID ABLIKIM 06R TO DOCUMENT ID ABLIKIM 06R TO DOCUMENT ID ABLIKIM 06R TO DOCUMENT ID ABLIKIM DOCUMENT ID ABLIKIM DOCUMENT ID ABLIKIM DOCUMENT ID BOCUMENT ID DOCUMENT I | 06R BES2 $\psi(2)$ TECN COMMENT BES2 $\psi(2S) \rightarrow \gamma$ ges, fits, limits, etc. BES2 $\psi(2S) \rightarrow \gamma$ 06R BES2 $\psi(2S) \rightarrow \gamma$ 07D TECN COM 07D BES2 e+ $\psi(2S)$ | $\begin{array}{c} \frac{MENT}{S) \rightarrow \gamma \eta \pi^+ \pi^-} \\ \hline \Gamma_{127}/\Gamma \\ \hline K^+ K^- \pi^0 \\ \hline K^0 K^+ K^- + \text{c.c.} \\ \hline \Gamma_{128}/\Gamma \\ \hline MENT \\ S) \rightarrow \gamma \eta \pi^+ \pi^- \\ \hline 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| $\frac{ALUE \text{ (units } 10^{-4})}{O.36 \pm 0.25 \pm 0.05}$ $\frac{C}{C} (\gamma \eta (1475) \rightarrow K\overline{K}\pi)$ $\frac{ALUE \text{ (units } 10^{-4})}{O.36 \pm 0.25}$ $\frac{CL\%}{O.36}$ $\frac{CL\%}{O.36}$ $\frac{CL\%}{O.36}$ $\frac{C}{C} (\gamma \eta (1475) \rightarrow \eta \pi^{+} \pi)$ $\frac{ALUE \text{ (units } 10^{-4})}{O.36}$ $\frac{C}{C} (\gamma 2(\pi^{+} \pi^{-})) / \Gamma_{\text{total}}$ $\frac{ALUE \text{ (units } 10^{-5})}{O.36}$ $\frac{C}{C} (\gamma K^{+3} K^{+} \pi^{-} + \text{C.C.})$ $\frac{C}{C} (ALUE \text{ (units } 10^{-5})}$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} (1475) + \frac{C}{C} (1475)$ $\frac{C}{C} 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RADIATI $\rightarrow \gamma J/\psi$ n amplitu $-\frac{TECN}{CLEO}$ values from d fixed £: $(x_{C1}(1P))$ n amplitu $-\frac{TECN}{CLEO}$ values from d fixed £: $(x_{C1}(1P))$ so amplitu $-\frac{TECN}{CLEO}$ values from d fixed £: $(x_{C1}(1P))$ ES | ATIOS $(c_{L}(1P) \rightarrow X)$ IVE DECAYS (1S) (1S) Ide ratio (c_{DMMENT}) $(c_{L}(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-})$ In fits with floating and $a_{2}(\chi_{C2}(1P))$ |

 $\psi(2S), \psi(3770)$

| ANDREOTTI | 07 | PL B654 74 | M. Andreotti et al. | (Femilab E835 Collab.) |
|-------------------------|--------------|-----------------------------------------------|-------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| AUBERT AUBERT | 07AK 07AU | PR D76 012008 PR D76 092005 | B. Aubert et al. B. Aubert et al. | (BABAR Collab.) (BABAR Collab.) |
| Also AUBERT | 07 BD | PR D76 092006 | rrat.) B. Aubert et al. B. Aubert et al | (BABAR Collab.) (BABAR Collab.) |
| PDG PEDLAR | 07 07 | Unofficial 2007 WWV PR D75 011102R | N/ edition | ` (PDG Collab.) (CLEO Collab.) |
| ABLIKIM | 06 G | PR D73 052004 | M. Ablikim et al. | `(BES Collab.) |
| ABLIKIM ABLIKIM | 061 061 | PR D74 012004 PRL 97 121801 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| ABLIKIM | 06R | PR D74 072001 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM ADAM | 06W 06 | PR D74 112003 PRL 96 082004 | M. Ablikim et al. N.E. Adam et al. | (BES Collab.) (CLEO Collab.) |
| AUBERT AUBERT | 06B 06D | PR D73 012005 PR D73 052003 | B. Aubert et al. B. Aubert et al. | (BÀBAR Collab.) (BABAR Collab.) |
| AUBERT,BE | 06 D | PR D74 091103R | B. Aubert et al. S. Dobbs et al. | (BABAR Collab.) |
| DOBBS ABLIKIM | 06A 05E | PR D74 011105R PR D71 072006 | S. Dobbs et al. M. Ablikim et al. | `(CLEO Collab.) (BES Collab.) |
| ABLIKIM | 05 H | PR D72 012002 | M. Ablikim et al. | (BES Collab.) |
| ABLIKIM ABLIKIM | 05 I 05 J | PL B614 37 PL B619 247 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| ABLIKIM ADAM | 05 O 05 | PL B630 21 PRL 94 012005 | M. Ablikim et al. N.E. Adam et al. | (BES Collab.) (CLEO Collab.) |
| ADAM | 05 A | PRL 94 232002 | N.E. Adam <i>et al</i> . | (CLEO Collab.) |
| ANDREOTTI AUBERT | 05 05 D | PR D71 032006 PR D71 052001 | M. Andreotti et al. B. Aubert et al. | (FNAL E835 Collab.) (BABAR Collab.) |
| BRIERE PEDLAR | 05 05 | PRL 95 062001 PR D72 051108R | R.A. Briere et al. T.K. Pedlar et al. J.L. Rosner et al. | (CLEO Collab.) |
| ROSNER | 05 | PRL 95 102003 | J.L. Rosner et al. | (CLEO Collab.) (CLEO Collab.) |
| ABLIKIM ABLIKIM | 04 B 04 K | PR D70 012003 PR D70 112003 | M. Ablikim et al. M. Ablikim et al. | (BES Collab.) (BES Collab.) |
| ABLIKIM | 04 L 04 | PR D70 112007 PR D70 112002 | M. Ablikim et al. | (BES Collab.) |
| ATHAR BAI | 04 04 B | PRL 92 052001 PR D69 072001 | S.B. Athar et al. J.Z. Bai et al. J.Z. Bai et al. | (ČLEO Collab.) (BES Collab.) |
| BAI BAI | 04 C 04 D | PR D69 072001 PL B589 7 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| BAI | 04 G | PR D70 012004 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) |
| BAI PDG | 041 04 | PR D70 012006 PL B592 1 | S. Eidelman <i>et al</i> . | (BES Collab.) (PDG Collab.) |
| SETH AULCHENKO | 04 03 | PR D69 097503 PL B573 63 | K.K. Seth V.M. Aulchenko <i>et al</i> . | (KEDR Collab.) |
| BAI | 03 B | PR D67 052002 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) |
| BAI AUBERT | 03 C 02 B | PR D67 032004 PR D65 031101R | J.Z. Baiet al. B. Aubert et al. | (BES Collab.) (BaBar Collab.) |
| BAI BAI | 02 02 B | PR D65 052004 PL B550 24 | J.Z. Baiet al. J.Z. Baiet al. | (BES Collab.) (BES Collab.) |
| BAI | 02 C | PRL 88 101802 | J.Z. Bai et al. | (BES Collab.) |
| PDG BAI | 02 01 | PR D66 010001 PR D63 032002 | K. Hagiwara et al. J.Z. Bai et al. | (BES Collab.) |
| AMBROGIANI ARTAMONOV | | PR D62 032004 PL B474 427 | M. Ambrogiani et al. A.S. Artamonov et al. | (FNAL È835 Collab.) |
| BAI BAI | 00 99 C | PRL 84 594 PRL 83 1918 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| BAI | 98 E | PR D57 3854 | J.Z. Bai et al. | (BES Collab.) |
| BAI BAI | 98 F 98 J | PR D58 097101 PRL 81 5080 | J.Z. Bai et al. J.Z. Bai et al. | (BES Collab.) (BES Collab.) |
| ARMSTRONG GRIBUSHIN | 97 96 | PR D55 1153 PR D53 4723 | T.A. Armstrong et al. | (È760 Collab.) |
| ARMSTRONG | 93 B | PR D47 772 | A. Gribushin et al. T.A. Armstrong et al. | (E672 Collab., E706 Collab.) (FNAL E760 Collab.) |
| ALEXANDER COHEN | 89 87 | NP B320 45 RMP 59 1121 | J.P. Alexander <i>et al.</i> E.R. Cohen, B.N. Taylor | (FNAL E760 COIIab.) (LBL, MICH, SLAC) (RISC, NBS) (Crystal Ball Collab.) |
| GAIS ER KURAEV | 86 85 | PR D3/L711 | I Gaiser et al | (Crystal Ball Collab.) (NOVO) |
| | | SJNP 41 466 Translated from YAF | 41 733. | . , |
| FRANKLIN EDWARDS | 83 82 C | PRL 51 963 PRL 48 70 | M.E.B. Franklin et al. C. Edwards et al. | (LBL, SLAC) (CIT, HARV, PRIN+) |
| LEM OIGNE HIM EL | 82 80 | PL 113B 509 PRL 44 920 | Y. Lemoigne et al. T. Himel et al. | (SACL, LOIC, SHMP+) (LBL, SLAC) |
| OREGLIA SCHARRE | 80 80 | PRI 45 959 | M.J. Oreglia et al. D.L. Scharre et al. | (SLAC, CIT, HARV+) (SLAC, LBL) |
| ZHOLENTZ | 80 | PL 97B 329 PL 96B 214 | A.A. Zholents <i>et al.</i> A.A. Zholents <i>et al.</i> A.A. Zholents <i>et al.</i> | (SEAC, LBE) (NOVO) (NOVO) |
| Also | | SJNP 34 814 Translated from YAF | A.A. Zholents et al. 34 1471. | (NOVO) |
| BRANDELIK BRANDELIK | 79B 79C | NP B160 426 ZPHY C1 233 | R. Brandelik et al. | (DASP Collab.) (DASP Collab.) |
| BARTEL | 78 B | PL 79B 492 | R. Brandelik <i>et al.</i> W. Bartel <i>et al.</i> | (ĎESY, HEIDP) |
| TANENBAUM BIDDICK | 78 77 | PR D17 1731 PRL 38 1324 | W.M. Tanenbaum <i>et al.</i> C.J. Biddick <i>et al.</i> | (SLAC, LBL) (UCSD, UMD, PAVI+) |
| BRAUNSCH BURMESTER | 77 77 | PL 67B 249 PL 66B 395 | W. Braunschweig et al. J. Burmester et al. | (UCSD, UMD, PAVI+) (DASP Collab.) (DESY, HAMB, SIEG+) |
| FELDMAN | 77 | PRPL 33 C 285 | C. I. Foldman, M. I. Borl | (LBL, SLAC) (DASP Collab.) |
| YAMADA BARTEL | 77 76 | Hamburg Conf. 69 PL 64B 483 | S. Yamada W. Bartel et al. W.M. Tanenhaum et al. | (DASP Collab.) (DESY, HEIDP) (SLAC, LBL)IG |
| TANENBAUM WHITAKER | 76 76 | PRL 36 402 PRL 37 1596 | IS Whitaker et al | |
| ABRAMS | 75 75 B | Stanford Symp. 25 PRL 34 1181 | G.S. Abrams | (LBL) (LBL, SLAC) |
| ABRAMS BOYARSKI | 75 C | PRL 34 1181 Palermo Conf. 54 PRL 35 625 | G.S. Abrams G.S. Abrams <i>et al.</i> A.M. Boyarski <i>et al.</i> | (LBL, SLAC) (SLAC, LBL) (STAN, PENN) |
| HILGER LIBERMAN | 75 75 | PRL 35 625 Stanford Symp. 55 | E. Hilger <i>et al.</i> A.D. Liberman | (SŤAN, PENN) (STAN) |
| LUTH WIIK | 75 75 | PRL 35 1124 Stanford Symp. 69 | V. Luth <i>et al.</i> B.H. Wiik | (STAN) (SLAC, LBL) JP (DESY) |
| TYTIES | 15 | Scannord Symp. 69 | D.II. WIIK | (DE3 Y) |

 ψ (3770)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

$\psi(3770)$ MASS (MeV)

OUR FIT includes measurements of $m_{\psi(2S)}, m_{\psi(3770)},$ and $m_{\psi(3770)} - m_{\psi(2S)}$

| VALUE (MeV) EVTS DOO | CUMENT ID | TECN | COMMENT |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|------------|---------------------------------------------|
| 3773.15 ± 0.33 OUR FIT | | | |
| 3778.1 ±1.2 OUR AVERAGE | | | |
| $3779.2 \ \stackrel{+}{-}1.8 \ \stackrel{+}{-}0.6 \ \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad $ | ASHIN 12A | KEDR | $e^+ e^- \rightarrow D \overline{D}$ |
| | | | $B \rightarrow D \overline{D} K$ |
| 3776 ±5 ±4 68 BR | ODZICKA 08 | BELL | $B^+ \rightarrow D^0 \overline{D}{}^0 K^+$ |
| 3778.8 ±1.9 ±0.9 AUI | BERT 07BE | BABR | $e^+ e^- \rightarrow D \overline{D} \gamma$ |
| • • • We do not use the following da | ta for averages, fi | ts, limits | , etc. • • • |
| 3772.0 ±1.9 2,3 ABI | | | $e^+e^- \rightarrow \text{hadrons}$ |

 $\frac{1}{2}$ Taking into account interference between the resonant and non-resonant $D\overline{D}$ production. Taking into account interference between the resonant and inter-resonant DD production. 2 Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta = 0^{\circ}$.

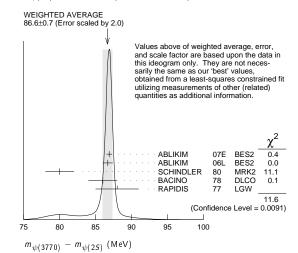
 3 Interference between the resonant and non-resonant $D\overline{D}$ production not taken into ac-

$m_{\psi(3770)} - m_{\psi(25)}$

OUR FIT includes measurements of $m_{\psi(2S)}$, $m_{\psi(3770)}$, and $m_{\psi(3770)} - m_{\psi(2S)}$

| VALUE | | DO CUMENT ID | | TECN | COMMENT |
|-------|---------------|---------------------|----|------|-------------------------|
| | ±0.33 OUR FIT | Form Santodes and | £ | -620 | Con the ideasure halou |
| | | | | | See the ideogram below. |
| 86.9 | | | | | $e^+e^-	o$ hadrons |
| 86.7 | ±0.7 | | | | $e^+e^-	o$ hadrons |
| 80 = | ±2 | SCHINDLER | | | e^+e^- |
| 86 = | ±2 | ⁵ BACINO | 78 | DLCO | e^+e^- |
| 88 = | ±3 | RAPIDIS | 77 | LGW | e^+e^- |
| 88 = | ±3 | RAPIDIS | 11 | LGVV | e i e |

 $^{^4}$ BES-II $\psi(2S)$ mass subtracted (see ABLIKIM 06L). 5 SPEAR $\psi(2S)$ mass subtracted (see SCHINDLER 80).



ψ (3770) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------|------|------------------------|-----|------|--------------------------------------------|
| 27.2± 1.0 OUR FIT 27.5± 0.9 OUR AVE | RAGE | | | | |
| $24.9 + 4.6 + 0.5 \\ - 4.0 - 1.1$ | | ⁶ ANASHIN | 12A | KEDR | $e^+e^- 	o D\overline{D}$ |
| 30.4 ± 8.5 | | ^{7,8} ABLIKIM | 08D | | $e^+e^- ightarrow hadrons$ |
| $27 \pm 10 \pm 5$ | 68 | BRODZICKA | 80 | BELL | $B^+ \rightarrow D^0 \overline{D}{}^0 K^+$ |
| $28.5 \pm 1.2 \pm 0.2$ | | ⁸ ABLIKIM | 07E | BES2 | $e^+e^- ightarrow hadrons$ |
| $23.5 \pm 3.7 \pm 0.9$ | | AUBERT | 07в | BABR | $e^+e^- \rightarrow D \overline{D} \gamma$ |
| $26.9 \pm 2.4 \pm 0.3$ | | ⁸ ABLIKIM | 06L | BES2 | $e^+e^- \rightarrow hadrons$ |
| 24 ± 5 | | ⁸ SCHINDLER | 80 | MRK2 | e^+e^- |
| 24 ± 5 | | ⁸ BACINO | 78 | DLCO | e^+e^- |
| 28 ± 5 | | ⁸ RAPIDIS | 77 | LGW | e^+e^- |

 $\frac{6}{2}$ Taking into account interference between the resonant and non-resonant $D\overline{D}$ production. 7 Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=0^\circ$.

8 Interference between the resonant and non-resonant $D\,\overline{D}$ production not taken into ac-

$\psi(3770)$ DECAY MODES

In addition to the dominant decay mode to $D\overline{D}$, $\psi(3770)$ was found to decay into the final states containing the J/ψ (BAI 05, ADAM 06). ADAMS 06 and HUANG 06A searched for various decay modes with light hadrons and found a statistically significant signal for the decay to $\phi\eta$ only (ADAMS 06).

| | Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|----------------|------------------------|----------------------------------|-----------------------------------|
| Γ ₁ | $D\overline{D}$ | (93 +8) % | S=2.0 |
| Γ_2 | $D^0 \overline{D}{}^0$ | (52 ±5) % | S=2.0 |
| Γ_3 | $D^+ D^-$ | $(41 \pm 4)\%$ | S=2.0 |
| Γ_4 | $J/\psi \pi^+ \pi^-$ | $(1.93 \pm 0.28) \times 10^{-6}$ | -3 |
| Γ_5 | $J/\psi \pi^0 \pi^0$ | $(8.0 \pm 3.0) \times 10^{-6}$ | -4 |
| Γ_6 | $J/\psi\eta$ | (9 ±4)×10 | -4 |
| Γ_7 | $J/\psi\pi^0$ | < 2.8 × 10 | ⁻⁴ CL=90% |
| Γ ₈ | $e^+ e^-$ | $(9.6 \pm 0.7) \times 10^{-6}$ | -6 S=1.3 |

 ψ (3770)

| | Decays to light | hadrons | | |
|------------------------------------|--------------------------------------------------------------------|------------------|----------------------------------------|------------------|
| Г9 | $b_1(1235)\pi$ | < 1.4 | $\times 10^{-5}$ | CL=90% |
| Γ_{10} | $\phi \eta'$ | < 7 | $\times 10^{-4}$ | CL=90% |
| Γ_{11} | $\omega \eta'$ | < 4 | $\times 10^{-4}$ | CL=90% |
| Γ_{12} | $\rho^0 \eta'$ | < 6 | $\times 10^{-4}$ | CL=90% |
| Γ_{13} | $\phi\eta$ | (3.1 ± 0.7) | $) \times 10^{-4}$ | |
| Γ_{14} | $\omega \eta$ | < 1.4 | $\times 10^{-5}$ | CL=90% |
| Γ_{15} | $\rho^{0}\eta$ | < 5 | $\times 10^{-4}$ | CL=90% |
| Γ ₁₆ | $\phi \pi^0$ | < 3 | $\times 10^{-5}$ | CL=90% |
| Γ ₁₇ | $\omega \pi^0$ | < 6 | $\times 10^{-4}$ | CL=90% |
| Γ ₁₈ | $\pi^{+}\pi^{-}\pi^{0}$ | < 5 | $\times 10^{-6}$ | CL=90% |
| Γ ₁₉ | $ ho\pi$ | < 5 | $\times 10^{-6}$ | CL=90% |
| Γ ₂₀ | $K^*(892)^+ K^- + \text{c.c.}$ | < 1.4 | $\times 10^{-5}$ | CL=90% |
| Γ ₂₁ | $K^*(892)^0 \overline{K}^0 + \text{c.c.}$ | < 1.2 | ×10 ⁻³ | CL=90% |
| Γ ₂₂ | $K_S^0 K_L^0$ | < 1.2 | ×10 ⁻⁵ | CL=90% |
| Γ ₂₃ | $2(\pi^{+}\pi^{-})$ | < 1.12 | ×10 ⁻³ | CL=90% |
| Γ ₂₄ | $2(\pi + \pi^{-})\pi^{0}$ | < 1.06 | ×10 ⁻³ | CL=90% |
| | $2(\pi + \pi - \pi^{0})$ | | % | CL=90% |
| Γ ₂₅ | $\omega \pi^+ \pi^-$ | | ×10 ⁻⁴ | CL=90% |
| Γ ₂₆ | $3(\pi^{+}\pi^{-})$ | | ×10 ⁻³ | CL=90% |
| Γ ₂₇ | $3(\pi^+\pi^-)\pi^0$ | < 9.1 | | |
| Γ ₂₈ | | < 1.37 | % | e |
| Γ ₂₉ | $3(\pi^{+}\pi^{-})2\pi^{0}$ | < 11.74 | % | CL=90% |
| Γ ₃₀ | $\eta \pi^+ \pi^-$ | < 1.24 | $\times 10^{-3}$ | CL=90% |
| Γ ₃₁ | $\pi^{+}\pi^{-}2\pi^{0}$ | < 8.9 | $\times 10^{-3}$ | CL=90% |
| Γ ₃₂ | $\rho^0\pi^+\pi^-$ | < 6.9 | $\times 10^{-3}$ | CL=90% |
| Γ ₃₃ | $\eta 3\pi$ | < 1.34 | $\times 10^{-3}$ | CL=90% |
| Γ ₃₄ | $\eta^{2}(\pi^{+}\pi^{-})$ | < 2.43 | % | |
| Γ ₃₅ | $\eta \rho^0 \pi^+ \pi^-$ | < 1.45 | % | CL=90% |
| Γ ₃₆ | η' 3 π | < 2.44 | $\times 10^{-3}$ | CL=90% |
| Γ ₃₇ | $K^{+} K^{-} \pi^{+} \pi^{-}$ | < 9.0 | $\times 10^{-4}$ | CL=90% |
| Γ ₃₈ | $\phi \pi^+ \pi^-$ | < 4.1 | $\times 10^{-4}$ | CL=90% |
| Γ ₃₉ | $K^{+}K^{-}2\pi^{0}$ | < 4.2 | $\times 10^{-3}$ | CL=90% |
| Γ ₄₀ | $4(\pi^{+}\pi^{-})$ | < 1.67 | % | CL=90% |
| Γ ₄₁ | $4(\pi^{+}\pi^{-})\pi^{0}$ | < 3.06 | % | CL=90% |
| Γ ₄₂ | $\phi f_0(980)$ | < 4.5 | $\times 10^{-4}$ | CL=90% |
| Γ ₄₃ | $K^{+}K^{-}\pi^{+}\pi^{-}\pi^{0}$ | < 2.36 | $\times 10^{-3}$ | CL=90% |
| Γ ₄₄ | $K^{+}K^{-}\rho^{0}\pi^{0}$ | < 8 | ×10 ⁻⁴ | CL=90% |
| Γ ₄₅ | $K^{+}K^{-}\rho^{+}\pi^{-}$ | < 1.46 | % | CL=90% |
| Γ ₄₆ | ω K ⁺ K ⁻ ϕ π^+ $\pi^ \pi^0$ | < 3.4 | $^{\times 10^{-4}}_{\times 10^{-3}}$ | CL=90% |
| Γ ₄₇ | $K^{*0}K^{-}\pi^{+}\pi^{0}$ + c.c. | < 3.8 | × 10 ° | CL=90% |
| Γ ₄₈ Γ ₄₉ | $K^{*+}K^{-}\pi^{+}\pi^{-} + \text{c.c.}$ | < 1.62 < 3.23 | % % | CL=90% |
| Γ ₅₀ | $K^{+}K^{-}\pi^{+}\pi^{-}2\pi^{0}$ | | % % | CL=90% CL=90% |
| Γ ₅₁ | $K^{+}K^{-}2(\pi^{+}\pi^{-})$ | < 2.67 < 1.03 | % | CL=90% |
| Γ ₅₂ | $K^{+}K^{-}2(\pi^{+}\pi^{-})\pi^{0}$ | < 3.60 | % | CL=90% |
| Γ ₅₃ | $\eta K^+ K^-$ | < 4.1 | ×10 ⁻⁴ | CL=90% |
| Γ ₅₄ | $\eta K^+ K^- \pi^+ \pi^-$ | < 1.24 | % | CL=90% |
| Γ ₅₅ | $\rho^0 K^+ K^-$ | < 5.0 | ×10 ⁻³ | CL=90% |
| Γ ₅₆ | $2(K^+K^-)$ | < 6.0 | ×10 ⁻⁴ | CL=90% |
| Γ ₅₇ | | < 7.5 | ×10 ⁻⁴ | CL=90% |
| Γ ₅₈ | $2(K^{+}K^{-})\pi^{0}$ | < 2.9 | ×10 ⁻⁴ | CL=90% |
| Γ ₅₉ | $2(K^{+}K^{-})\pi^{+}\pi^{-}$ | < 3.2 | $\times 10^{-3}$ | CL=90% |
| Γ ₆₀ | $K_{5}^{0} K^{-} \pi^{+}$ | < 3.2 | ×10 ⁻³ | CL=90% |
| Γ ₆₁ | $K_{5}^{0}K^{-}\pi^{+}\pi^{0}$ | < 1.33 | % | CL=90% |
| | $K_S^0 K^- \rho^+$ | | ×10 ⁻³ | CL=90% |
| Γ ₆₂ | K S K P - | | ×10 ×10 ⁻³ | CL=90% |
| Γ ₆₃ | $K_{S}^{0}K^{-}2\pi^{+}\pi^{-}$ | < 8.7 | | |
| Γ ₆₄ | $K_{S}^{0}K^{-}\pi^{+}\rho^{0}$ | < 1.6 | % | CL=90% |
| Γ ₆₅ | $K_S^0 K^- \pi^+ \eta$ | < 1.3 | % | CL=90% |
| Γ ₆₆ | $K_{S}^{0}K^{-}2\pi^{+}\pi^{-}\pi^{0}$ | < 4.18 | % | CL=90% |
| Γ ₆₇ | $K_S^{0}K^{-2}\pi^{+}\pi^{-}\eta$ | < 4.8 | % | CL=90% |
| Γ ₆₈ | $K_S^{0} K^{-} \pi^{+} 2(\pi^{+} \pi^{-})$ | < 1.22 | % | CL=90% |
| Γ ₆₉ | $K_{S}^{0}K^{-}\pi^{+}2\pi^{0}$ | < 2.65 | % | CL=90% |
| Γ ₇₀ | $K_{c}^{0}K^{-}K^{+}K^{-}\pi^{+}$ | < 4.9 | $\times 10^{-3}$ | CL=90% |
| Γ ₇₁ | $K_{S}^{0}K^{-}K^{+}K^{-}\pi^{+}\pi^{0}$ | < 3.0 | % | CL=90% |
| Γ ₇₂ | $K_{S}^{0}K^{-}K^{+}K^{-}\pi^{+}\eta$ | < 2.2 | % | CL=90% |
| Γ ₇₃ | $K^{*0}K^{-}\pi^{+} + \text{c.c.}$ | < 9.7 | ×10 ⁻³ | CL=90% |
| Γ ₇₄ | $p \overline{p} \pi^0$ | < 1.2 | ×10 ⁻³ | CL_30% |
| Γ ₇₅ | $p \overline{p} \pi$ $p \overline{p} \pi^+ \pi^-$ | < 5.8 | ×10 ×10 ⁻⁴ | CL=90% |
| Γ ₇₆ | $\Lambda \overline{\Lambda}$ | < 1.2 | ×10 ⁻⁴ | CL=90% |
| Γ ₇₇ | $p \overline{p} \pi^+ \pi^- \pi^0$ | < 1.2 | × 10 × 10 ⁻³ | CL=90% |
| Γ ₇₈ | $\omega p \overline{p}$ | < 2.9 | ×10 ⁻⁴ | CL=90% |
| Γ ₇₉ | $\Lambda \overline{\Lambda} \pi^0$ | < 1.2 | × 10 × 10 ⁻³ | CL=90% |
| Γ ₈₀ | $p\overline{p}2(\pi^+\pi^-)$ | < 2.6 | ×10 ⁻³ | CL=90% |
| Γ ₈₁ | $\eta p \overline{p}$ | < 5.4 | ×10 ⁻⁴ | CL=90% |
| . 91 | 111 | | ~ = 0 | SE-30/0 |

| Γ ₈₂ | $\eta \rho \overline{\rho} \pi^+ \pi^-$ | < 3.3 | $\times 10^{-3}$ | CL=90% |
|-----------------|------------------------------------------------------|-----------------|--------------------|--------|
| Γ_{83} | $ ho^0 p \overline{p}$ | < 1.7 | $\times 10^{-3}$ | CL=90% |
| Γ ₈₄ | p p K + K - | < 3.2 | $\times 10^{-4}$ | CL=90% |
| Γ ₈₅ | $\eta p \overline{p} K^+ K^-$ | < 6.9 | $\times 10^{-3}$ | CL=90% |
| Γ ₈₆ | $\pi^{0} p \overline{p} K^{+} K^{-}$ | < 1.2 | $\times 10^{-3}$ | CL=90% |
| Γ ₈₇ | $\phi p \overline{p}$ | < 1.3 | $\times 10^{-4}$ | CL=90% |
| Γ ₈₈ | $\Lambda \overline{\Lambda} \pi^+ \pi^-$ | < 2.5 | $\times 10^{-4}$ | CL=90% |
| Γ ₈₉ | Λ - - - | < 2.8 | $\times 10^{-4}$ | CL=90% |
| Γ_{90} | $\Lambda \overline{\rho} K^+ \pi^+ \pi^-$ | < 6.3 | $\times 10^{-4}$ | CL=90% |
| | Radia | tive decays | | |
| Γ_{91} | $\gamma \chi_{c2}$ | < 9 | $\times 10^{-4}$ | CL=90% |
| Γ_{92} | $\gamma \chi_{c1}$ | (2.9 ± 0.6) | $) \times 10^{-3}$ | |
| Γ_{93} | $\gamma \chi_{c0}$ | (7.3 ± 0.9) | $) \times 10^{-3}$ | |
| Γ_{94} | $\gamma \eta'$ | < 1.8 | $\times 10^{-4}$ | CL=90% |
| Γ_{95} | $\gamma\eta$ | < 1.5 | $\times 10^{-4}$ | CL=90% |
| Γ ₉₆ | $\gamma \pi^0$ | < 2 | $\times 10^{-4}$ | CL=90% |

CONSTRAINED FIT INFORMATION

An overall fit to the total width, a partial width, and 3 branching ratios uses 23 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2=$ 20.0 for 19 degrees of

The following off-diagonal array elements are the correlation coefficients $\langle \delta
ho_i \delta
ho_j \rangle / (\delta
ho_i \cdot \delta
ho_j)$, in percent, from the fit to parameters ho_i , including the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

$$\begin{array}{c|ccccc}
x_3 & 98 & & & \\
x_8 & 0 & 0 & & \\
\Gamma & 0 & 0 & -44 & & \\
\hline
x_2 & x_3 & x_8 & & & \\
\end{array}$$

| | Mode | Rate (MeV) | Scale factor |
|----------------|------------------------|------------------------------|--------------|
| Γ ₂ | $D^0 \overline{D}{}^0$ | 14.1 ±1.4 | 1.7 |
| Γ ₃ | $D^+ D^-$ | 11.2 ± 1.1 | 1.7 |
| Γ ₈ | $e^+ e^-$ | $(2.62\pm0.18)\times10^{-4}$ | 1.4 |

ψ (3770) PARTIAL WIDTHS

| Γ(e+e ⁻) | | | | | | | Гв |
|-------------------------------------------------------|----------|--------------------------|----------|-----------|----------------------|-----------------|----|
| VALUE (keV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| 0.262±0.018 OUR FIT | Error | includes scale factor | of 1.4 | l | | | |
| 0.256±0.016 OUR AVE | RAGE | Error includes scale | facto | r of 1.2. | | | |
| $0.154 {}^{+ 0.079}_{- 0.058} {}^{+ 0.021}_{- 0.027}$ | | | 12A | KEDR | $e^+e^- \rightarrow$ | $D\overline{D}$ | |
| 0.22 ± 0.05 | | ^{11,12} ABLIKIM | 08D | BES2 | $e^+e^- \rightarrow$ | hadrons | |
| $0.277 \pm 0.011 \pm 0.013$ | | ¹² ABLIKIM | 07E | BES2 | $e^+e^- \rightarrow$ | hadrons | |
| $0.203 \pm 0.003 ^{+ 0.041}_{- 0.027}$ | 1.4 M | 12,13 BESSON | 06 | CLEO | $e^+e^- \rightarrow$ | hadrons | |
| 0.276 ± 0.050 | | ¹² SCHINDLER | 80 | MRK2 | e^+e^- | | |
| 0.18 ± 0.06 | | ¹² BACINO | 78 | DLCO | e^+e^- | | |
| • • • We do not use th | e follov | ving data for average | s, fits, | limits, | etc. • • • | | |
| $0.414 {}^{+ 0.072 + 0.093}_{- 0.080 - 0.028}$ | | | 12A | KEDR | $e^+e^- \rightarrow$ | $D\overline{D}$ | |
| 0.37 ± 0.09 | | ¹⁵ RAPIDIS | 77 | LGW | e^+e^- | | |
| 9 Solution I of the two | solutio | ons. | | | | | |

- Taking into account interference between the resonant and non-resonant $D\overline{D}$ production. 11 Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7-5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=0^\circ$.
- 12 Interference between the resonant and non-resonant $^{D}\overline{D}$ production not taken into ac-
- count. 13 BESSON 06 (as corrected in BESSON 10) measure $\sigma(e^+e^- \to \psi(3770) \to \text{hadrons})$ = $6.36\pm0.08^{+}_{-}0.30$ nb at $\sqrt{s}=3773\pm1$ MeV, and obtain Γ_{ee} from the Born-level cross section calculated using $\psi(3770)$ mass and width from our 2004 edition, PDG 04.
- 14 Solution II of the two solutions. 15 See also $\Gamma\left(e^{+}\,e^{-}\right)/\Gamma_{\rm total}$ below.

ψ (3770) BRANCHING RATIOS

| Γ(D D)/Γ _{total} | EVTS | DOCUMENT ID | | TECN | $\Gamma_1/\Gamma = (\Gamma_2 + \Gamma_3)/\Gamma$ |
|----------------------------------------|----------|-----------------------|-----------|-----------|-----------------------------------------------------------------|
| VALUE | EVIS | DO COMENT ID | | TECN | COMMENT |
| 0.93 +0.08 OUR FIT | Error in | ncludes scale facto | or of 2.0 |). | |
| 0.93 +0.08 OUR AVE | RAGE | Error includes scal | le facto | r of 2.1. | |
| $0.849 \pm 0.056 \pm 0.018$ | | ¹⁶ ABLIKIM | 08в | BES2 | $e^+e^- ightarrow {\sf non}$ - ${\it D}$ ${\it \overline{D}}$ |
| $1.033 \pm 0.014 ^{+ 0.048}_{- 0.066}$ | 1.427 M | ¹⁷ BESSON | 06 | CLEO | $e^+e^- ightarrow { m hadrons}$ |

Meson Particle Listings ψ (3770)

| • • We do not use .866 ± 0.05 0 ± 0.036 | | ig data for averag ^{3,19} ABLIKIM | | $e^+e^- \rightarrow$ | non-D \overline{D} | $\Gamma(\omega\eta)/\Gamma_{	ext{total}}$ VALUE (units 10^{-5}) | CL% | DO CUMENT ID | TEC | N COMMENT | Γ ₁₄ /Ι |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-----------------------------------------------|-----------------------------|-----------------------------------------------------|-------------------------------------|--------------------------------------------------------------------------------------------------------|----------------------|---------------------------------------------------|---------|-----------------------------------------------------|--------------------|
| $836 \pm 0.073 \pm 0.042$ | | ¹⁹ ABLIKIM | 06L BES2 | $e^+e^- \to$ | $D\overline{D}$ | <1.4 | 90 | 22 ADAMS | | O e+e- → | $\psi(3770)$ |
| 355 ± 0.017 ± 0.058 | 1 | ^{9,20} ABLIKIM | U6N BES2 | e ⁺ e [−] → | _ | $\Gamma(ho^0\eta)/\Gamma_{ m total}$ | | | | | Γ ₁₅ / |
| $(D^0 \overline{D^0})/\Gamma_{\text{total}}$ | | DO CUMENT ID | TEC: | COMMENT | Γ_2/Γ | VALUE (units 10 ⁻⁴) | CL% | DOCUMENT ID | TEC | | • |
| 52 ±0.05 OUR FI | | cludes scale facto | or of 2.0. | COMMENT | | <5 | 90 | ²² ADAMS | 06 CLE | O e+e− → | $\psi(3770)$ |
| • • We do not use $167 \pm 0.047 \pm 0.023$ | the following | ng data for averag ABLIKIM | | etc. • • • $e^+e^- \rightarrow$ | $D_0 = 0$ | $\Gamma(\phi\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₁₆ /Ι |
| $467 \pm 0.047 \pm 0.023$ $499 \pm 0.013 \pm 0.038$ | | 20 ABLIKIM | | $e^+e^- \rightarrow e^+e^-$ | | <u>VALUE (units 10⁻⁵)</u> < 3 | <u>CL%</u> 90 | DO CUMENT ID 22 ADAMS | | $\frac{N}{EO}$ COMMENT $e^+e^- \rightarrow$ | -//(2770) |
| $(D^+D^-)/\Gamma_{\text{total}}$ | | | | | Γ ₃ /Γ | • • • We do not use | | | | | $\psi(3110)$ |
| LUE | T F :- | DO CUMENT ID | | COMMENT | | <50 | | ²³ ABLIKIM | | $62 	ext{ } e^+e^- \rightarrow$ | $\psi(3770)$ |
| 11 ±0.04 OUR FI | | cludes scale facto ng data for averag | | etc. • • • | | $\Gamma(\omega\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₁₇ / |
| $369 \pm 0.037 \pm 0.028$ | | ABLIKIM | | $e^+e^- \rightarrow$ | | VALUE (units 10^{-4}) | <u>CL%</u> | DO CUMENT ID | TEC | | |
| 357±0.011±0.034 | | ²⁰ ABLIKIM | 06N BES2 | $e^+ e^- \rightarrow$ | | <6 | 90 | ²² ADAMS | 06 CLE | EO e+e ⁻ → | $\psi(3770)$ |
| (D ⁰ \overline{D}^0)/\(\right) \right\(D + D \) | P -) EVTS | DO CUMENT ID |) TECN | COMMENT | Γ_2/Γ_3 | $\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$ | | | | | Γ ₁₈ / |
| 260±0.021 OUR FI | T | <u>DOCUMENT ID</u> | IECN | COMMENT | | <u>VALUE (units 10⁻⁶)</u> | <u>CL%</u> 90 | 22,24 ADAMS | 06 CLE | $\frac{N}{EO}$ $\frac{COMMENT}{e^+e^-} \rightarrow$ | |
| 260±0.021 OUR A\ 39 ±0.31 ±0.12 | /ERAGE | PAKHLOVA | 08 BELL | 10.6 e ⁺ e | $- \rightarrow D\overline{D}\gamma$ | - | 90 | ADAWS | 00 CLE | :0 e e → | |
| 78 ±0.33 ±0.24 | | AUBERT | 07BE BABF | $e^+e^- \rightarrow$ | $D\overline{D}\gamma$ | $\Gamma(ho\pi)/\Gamma_{	ext{total}}$ VALUE (units 10 ⁻⁶) | CL% | DO CUMENT ID | TEC | N COMMENT | Γ ₁₉ /Ι |
| 258±0.016±0.014 27 ±0.12 ±0.08 | | DOBBS ABLIKIM | | $e^+e^- \rightarrow e^+e^- \rightarrow$ | | <u>√ALUE (units 10 °)</u> <5 | | 22,24 ADAMS | | $e^+e^- \rightarrow$ | ψ(3770) |
| 43 ±1.50 ±0.43 | 34 | 21 CHISTOV | | $B^+ \rightarrow \psi$ | | Γ(K*(892)+K ⁻ + | | | | | Γ ₂₀ / |
| $(J/\psi\pi^+\pi^-)/\Gamma_{to}$ | tal | | | | Γ ₄ /Γ | VALUE (units 10 ⁻⁵) | CL% | DOCUMENT ID | TEC | N COMMENT | |
| LUE (units 10 ⁻³) | EVTS | <u>DO CUMENT</u> | ID TECN | COMMENT | · · | <1.4 | 90 | 22 ADAMS | | $e^+e^- \rightarrow$ | |
| 93±0.28 OUR AVE 89±0.20±0.20 | 231 ± 3 | 3 ADAM | 06 CLEO | $e^+e^- ightarrow$ | $\psi(3770)$ | $\Gamma(K^*(892)^0\overline{K}^0 + c$ | .c.)/Γ _{to} | tal | | | Γ ₂₁ / |
| ±1.4 ±0.9 | 17.8 ± 4 | | 05 BES2 | $e^+ e^- \rightarrow$ | $\psi(3770)$ | VALUE (units 10^{-3}) | CL% | DO CUMENT ID | TEC | | • |
| $(J/\psi\pi^0\pi^0)/\Gamma_{ m tot}$ | al | | | | Γ ₅ /Γ | <1.2 | 90 | 22 ADAMS | 06 CLE | O e+e ⁻ → | $\psi(3770)$ |
| LUE (units 10 ⁻²) | EVTS | DOCUMENT | | _ | | $\Gamma(K_S^0 K_L^0)/\Gamma_{	ext{total}}$ | | | | | Γ ₂₂ / |
| 080±0.025±0.016 | 39 ± 14 | ADAM | 06 CLE | O e ⁺ e ⁻ - | $\psi(3770)$ | VALUE (units 10 ⁻⁵) | CL% | DO CUMENT ID | TEC | | ((0.770) |
| $(J/\psi\eta)/\Gamma_{ m total}$ | | | | | Γ ₆ /Γ | < 1.2 • • • We do not use | 90 the follow | ²⁵ CRONIN-HEN ving data for average | | EO $e^+e^- \rightarrow$ ts, etc. • • • | $\psi(3770)$ |
| LUE (units 10 ⁻⁵) 7±33±22 | 22 ± 10 | <u>DOCUMENT</u> ADAM | | <u>COMMENT</u> 0 e ⁺ e ⁻ - | | <21 | 90 | ²⁶ ABLIKIM | 04F BES | | $\psi(3770)$ |
| | ± 10 | APAIN | JO CLE | – | , , | $\Gamma(2(\pi^+\pi^-))/\Gamma_{ m tota}$ | I | | | | Γ ₂₃ / |
| $(J/\psi\pi^0)/\Gamma_{ m total}$ LUE (units $10^{-5})$ CL: | % EVTS | DO CUMENT ID |) TECN | COMMENT | Γ ₇ /Γ | VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TEC | | |
| 28 90 | | ADAM | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <11.2 • • • We do not use | 90 the follow | ²⁷ HUANG ving data for average | | EO e^+e^- → ts, etc. • • • | $\psi(3770)$ |
| $(e^+e^-)/\Gamma_{\rm total}$ | | | | | Г ₈ /Г | <48 | | ²³ ABLIKIM | | $62 e^+e^- \rightarrow$ | $\psi(3770)$ |
| LUE (units 10 ⁻⁵) | | DO CUMENT ID | | COMMENT | . 0/ ' | $\Gamma(2(\pi^+\pi^-)\pi^0)/\Gamma_{\rm t}$ | ot al | | | | Γ ₂₄ / |
| 96±0.07 OUR FIT 3 ±0.2 | Error incl | ndes scale factor o | of 1.3. | e+ e- | | VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | TEC | N COMMENT | - 24/ |
| 3 ±0.2 .6 Neglecting interfer | rence. | KAPIDIS | II LGVV | e · e | | <10.6 | 90 | 27 HUANG | | O $e^+e^- \rightarrow$ | $\psi(3770)$ |
| Obtained by con | nparing a | measurement of | the total cr | oss section | (corrected in | • • • We do not use <62 | the follow | ving data for average ²³ ABLIKIM | | ts, etc. • • • \bullet 52 $e^+e^- \rightarrow$ | 2/1(3770) |
| BESSON 10) with 8 Using $\sigma^{obs} = 7.0$ | 7 ± 0.58 nl | and neglecting in | EO IN DOBBS nterference. | U7. | | | | ADLINIM | VID DES | 52 € € → | , , |
| ⁹ Not independent of Prom a measurem | of ABLIKIN | 108в. | | MeV using | the ali(3770) | $\Gamma(2(\pi^+\pi^-\pi^0))/\Gamma_t$ VALUE (units 10^{-3}) CL% | | DO CUMENT ID | TEC | N COMMENT | Γ ₂₅ / |
| resonance parame | ters measur | ed by ABLIKIM 0 |)6L. | i Mev, using | the $\psi(3770)$ | <58.5 90 | 305 | ABLIKIM | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| ¹ See ADLER 88c f | | | | | | $\Gamma(\omega\pi^+\pi^-)/\Gamma_{ m total}$ | | | | | |
| | | YS TO LIGHT | HADRONS | | | VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | TEC | N COMMENT | Γ ₂₆ / |
| $(b_1(1235)\pi)/\Gamma_{to}$ | | | | | ۲۰/۲ | < 6.0 | 90 | 27 HUANG | 06A CLE | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| LUE (units 10 ⁻⁵) 1.4 | <u>CL%</u> 90 | DOCUMENT ID 22 ADAMS | | $e^+e^- \rightarrow$ | ah(3770) | • • • We do not use <55 | the follow 90 | ving data for average ²³ ABLIKIM | | ts, etc. • • • 52 3.77 e ⁺ e | _ |
| | 20 | VDVINIS | OU CLEU | C · e → | | | | ADLINIM | VII DES | J2 J.11 E ' E | |
| $(\phi \eta')/\Gamma_{\text{total}}$ | CL% | DO CUMENT ID |) TECN | COMMENT | Γ ₁₀ /Γ | $\Gamma(3(\pi^+\pi^-))/\Gamma_{\text{tota}}$ | I | DO CUMENT ID | TEC | N COMMENT | Γ ₂₇ / |
| TUE (units 10 ') | 90 | 22 ADAMS | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <u>VALUE (units 10⁻⁴)</u> < 91 | | 23 ABLIKIM | | $\frac{N}{62} \frac{COMMENT}{e^+e^-} \rightarrow$ | $\psi(3770)$ |
| (| | | | | Г ₁₁ /Г | $\Gamma(3(\pi^+\pi^-)\pi^0)/\Gamma_{\rm t}$ | | | | | Γ ₂₈ /Ι |
| | CL% | DO CUMENT ID | TECN | COMMENT | '117' | 1 (3(π · π /)/1 t <u>VALUE</u> (units 10 ⁻⁴) | otal | DO CUMENT ID | TEC | N COMMENT | 1 28/ |
| . , | 90 | 22 ADAMS | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <137 | | 23 ABLIKIM | | 52 e ⁺ e [−] → | $\psi(3770)$ |
| LUE (units 10 ⁻⁴) | | | | | Γ ₁₂ /Γ | $\Gamma(3(\pi^+\pi^-)2\pi^0)/\Gamma$ | - total | | | | Γ ₂₉ /Ι |
| LUE (units 10 ⁻⁴) | | |) TECN | COMMENT | | <u>VALUE (units 10⁻³)</u> <u>CL</u> % | | DO CUMENT ID | TEC | N COMMENT | |
| ($ ho^0\eta')/\Gamma_{ m total}$ | CL% | DO CUMENT ID | | 1 - | . (0.770) | <117.4 90 | 59 | ABLIKIM | 08N BES | $e^+e^- \rightarrow$ | ψ(3770) |
| LUE (units 10^{-4}) (4 ($ ho^0 \eta'$)/ $\Gamma_{	ext{total}}$ LUE (units 10^{-4}) | <u>CL%</u> 90 | 22 ADAMS | 06 CLEO | $e^+e^ \rightarrow$ | $\psi(3770)$ | | | | | | , , |
| (ALUE (units 10^{-4}) (A $(\rho^0 \eta')/\Gamma_{\text{total}}$ (ALUE (units 10^{-4}) | | | 06 CLEO | e ⁺ e ⁻ → | ψ(3770) [Γ ₁₃ /Γ | $\Gamma(\eta\pi^+\pi^-)/\Gamma_{ m total}$ | | | | | Γ ₃₀ /Ι |
| $(\omega \eta')/\Gamma_{\text{total}}$ ALUE (units 10^{-4}) (4 $(\rho^0 \eta')/\Gamma_{\text{total}}$ ALUE (units 10^{-4}) (6 $(\phi \eta)/\Gamma_{\text{total}}$ ALUE (units 10^{-4}) 3.1±0.6±0.3 | | | <u>TECN</u> | $e^+e^- \rightarrow$ $\frac{COMMENT}{3.773 e^+}$ | Г ₁₃ /Г | $\frac{\Gamma(\eta \pi^+ \pi^-)/\Gamma_{\text{total}}}{\frac{VALUE \text{ (units } 10^{-3})}{< 1.24}}$ | <u>CL%</u> 90 | DOCUMENT ID | TEC | $\frac{N}{EO}$ COMMENT $e^+e^- \rightarrow$ | Γ ₃₀ / |

 ψ (3770)

| $\Gamma(\pi^+\pi^-2\pi^0)/\Gamma_{\text{tot}}$ | | | | | Г ₃₁ /Г | Γ(K*+ K-a | τ ⁺ π ⁻ + c.c.)/Γ ₁ | | | | | Γ ₄₉ /Γ |
|--------------------------------------------------------------------------|----------------------|----------------------------------------------|---------|-----------------------------------------|----------------------|-------------------------------------------------------------|------------------------------------------------------|----------------------------------------------|-------|-----------------|--------------------------------------|--------------------|
| VALUE (units 10 ⁻³) CL9 | | DO CUMENT ID | TECN | COMMENT | 131/1 | VALUE (units 10 | , . | i otal <u>DO CUMENT ID</u> | | TECN | COMMENT | 149/1 |
| <8.9 90 | 218 | ABLIKIM | 08N BES | $e^+e^- \rightarrow$ | $\psi(3770)$ | <323 | 90 | 23 ABLIKIM | 071 | BES2 | 3.77 e ⁺ e ⁻ | |
| $\Gamma(ho^0\pi^+\pi^-)/\Gamma_{ m total}$ | | | | | Γ ₃₂ /Γ | Γ(K+K-π | $^+\pi^-2\pi^0)/\Gamma_{ m tota}$ | I | | | | Γ ₅₀ /Ι |
| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | TECN | | | VALUE (units 10 | -3) <u>CL% EVTS</u> | DO CUMENT ID | | TECN | COMMENT | |
| <6.9 | 90 | ²³ ABLIKIM | 07F BES | 2 e ⁺ e [−] → | $\psi(3770)$ | <26.7 | 90 24 | ABLIKIM | 08N | BES2 | e^+e^- | $\psi(3770)$ |
| $\Gamma(\eta 3\pi)/\Gamma_{total}$ | | | | | Г ₃₃ /Г | • | $(\pi^+\pi^-))/\Gamma_{\text{total}}$ | | | | | Γ ₅₁ /Γ |
| VALUE (units 10 ⁻⁴) | <u>CL%</u> 90 | DOCUMENT ID | | $e^+e^- \rightarrow$ | -/-(2770) | VALUE (units 10 ⁻ | ⁻³) <u>CL%</u> 90 | 23 ABLIKIM | | TECN | $\frac{COMMENT}{e^+e^-} \rightarrow$ | -1.(2770) |
| • | | HUANG | UDA CLE | J e e → | ,, , | • | | | 075 | DE32 | e·e → | |
| $\Gamma(\eta 2(\pi^+\pi^-))/\Gamma_{to}$ VALUE (units 10 ⁻⁴) | tal | DO CUMENT ID | TECN | COMMENT | Г34/Г | VALUE (units 10 | $(\pi^+\pi^-)\pi^0)/\Gamma_{to}^{-3}$ | DOCUMENT ID | | TECN | COMMENT | Γ ₅₂ /Γ |
| <243 | | 23 ABLIKIM | | $e^+e^- \rightarrow$ | ψ(3770) | <36.0 | 90 | 23 ABLIKIM | | TECN BES2 | $e^+e^- \rightarrow$ | ψ(3770) |
| $\Gamma(\eta \rho^0 \pi^+ \pi^-)/\Gamma_{\rm tot}$ | | | | | Г ₃₅ /Г | Γ(ηK+K-) | ١/٢ | | | | | Г ₅₃ /І |
| VALUE (units 10 ⁻²) | CL%_ | DO CUMENT ID | TECN | COMMENT | . 35 / . | VALUE (units 10 | | DO CUMENT ID | | TECN | COMMENT | 153/1 |
| <1.45 | 90 | 23 ABLIKIM | 10D BES | $e^+e^- \rightarrow$ | ψ (3770) | < 4.1 | 90 | 27 HUANG | | | e^+e^- | $\psi(3770)$ |
| $\Gamma(\eta' 3\pi)/\Gamma_{\text{total}}$ | | | | | Γ ₃₆ /Γ | • • • VVe do <31 | not use the follows | ng data for average ²³ ABLIKIM | | | etc. • • • $e^+e^- \rightarrow$ | ah(3770) |
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TECN | | | | $\pi^+\pi^-)/\Gamma_{ m total}$ | ABEIRIN | 100 | DESE | | |
| <24.4 | 90 | ²⁷ HUANG | 06A CLE | o e ⁺ e [−] → | $\psi(3770)$ | VALUE (units 10 | • | DO CUMENT ID | | TECN | COMMENT | Γ ₅₄ /Γ |
| $\Gamma(K^+K^-\pi^+\pi^-)/$ | Γ _{total} | | | | Γ ₃₇ /Γ | <1.24 | 90 | 23 ABLIKIM | | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| <u>VALUE</u> (units 10 ^{−4}) < 9.0 | <u>CL%</u> 90 | DOCUMENT ID 27 HUANG | | $ \frac{COMMENT}{e^+e^-} \rightarrow $ | -l/(2770) | Γ(ρ ⁰ Κ+ Κ- | -)/[total | | | | | Γ ₅₅ /Γ |
| • • • We do not use | | | | | $\psi(3110)$ | VALUE (units 10 | 1 | DO CUMENT ID | | TECN | COMMENT | |
| <48 | | ²³ ABLIKIM | 07в BES | $e^+e^- \rightarrow$ | $\psi(3770)$ | <5.0 | 90 | ²³ ABLIKIM | 07F | BES2 | $e^+e^- \to$ | $\psi(3770)$ |
| $\Gamma(\phi\pi^+\pi^-)/\Gamma_{\rm total}$ | | | | | Γ ₃₈ /Γ | Γ(2(<i>K</i> + <i>K</i> - |))/Γ _{total} | | | | | Γ ₅₆ /Γ |
| VALUE (units 10 ⁻⁴) | <u>CL%</u> | DO CUMENT ID | | | | VALUE (units 10 | | DO CUMENT ID | | TECN | COMMENT | |
| < 4.1 • • • We do not use | 90 the follow | ²⁷ HUANG ving data for average | | O $e^+e^- \rightarrow$ s. etc. • • • | $\psi(3770)$ | < 6.0 • • • We do | 90 not use the followi | 27 HUANG ng data for average | | CLEO limits, | $e^+e^- \rightarrow$ etc. • • • | $\psi(3770)$ |
| <16 | | ²³ ABLIKIM | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <17 | | ²³ ABLIKIM | | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| $\Gamma(K^+K^-2\pi^0)/\Gamma_{to}$ | ntal . | | | | Г ₃₉ /Г | Γ (φ K ⁺ K ⁻) |)/Ftotal | | | | | Γ ₅₇ /Γ |
| VALUE (units 10 ⁻³) CL9 | | DO CUMENT ID | TECN | | | VALUE (units 10 | | DO CUMENT ID | | TECN | COMMENT | - 37,7 - |
| <4.2 90 | 14 | ABLIKIM | 08N BES | e ⁺ e [−] → | $\psi(3770)$ | < 7.5 | 90 | 27 HUANG ng data for average | | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| $\Gamma(4(\pi^+\pi^-))/\Gamma_{\text{tota}}$ | ıl | | | | Γ_{40}/Γ | <24 | not use the followi | 23 ABLIKIM | | | $e^+e^- \rightarrow$ | ψ(3770) |
| VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | | | | Γ(2(<i>K</i> + <i>K</i> - | 1-01/Γ | | | | | Γ ₅₈ /Γ |
| <16.7 | 90 | ²³ ABLIKIM | 07F BES | 2 e ⁺ e [−] → | $\psi(3770)$ | VALUE (units 10 | • | DO CUMENT ID | | TECN | COMMENT | '58/' |
| $\Gamma(4(\pi^+\pi^-)\pi^0)/\Gamma_t$ | | | | | Γ ₄₁ /Γ | < 2.9 | 90 | 27 HUANG | 06A | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| VALUE (units 10 ⁻³) | <u>CL%</u> 90 | 23 ABLIKIM | 07F BES | | a/s(3770) | • • • We do <46 | not use the followi | ng data for average ²³ ABLIKIM | | | etc. • • • $e^+e^- \rightarrow$ | -l.(2770) |
| _ | | //BEII(IIII | 011 023 | , | | | . I -> 4= | ABLIKIM | 078 | DE32 | e · e → | |
| $\Gamma(\phi f_0(980))/\Gamma_{total}$ VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TECN | COMMENT | Γ ₄₂ /Γ | VALUE (units 10 | $()\pi^+\pi^-)/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | COMMENT | Γ ₅₉ /Γ |
| <4.5 | 90 | 27 HUANG | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <3.2 | 90 | 23 ABLIKIM | 07F | BES2 | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| $\Gamma(K^+K^-\pi^+\pi^-\pi^0$ |))/[_{tota} | • | | | Γ ₄₃ /Γ | $\Gamma(K_S^0K^-\pi^-)$ | +)/[| | | | | Γ ₆₀ /Γ |
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | TECN | COMMENT | | , - | -3) CL% EVTS | DO CUMENT ID | | TECN | COMMENT | . 607. |
| < 23.6 | 90 | ²⁷ HUANG | | $e^+e^- \rightarrow$ | $\psi(3770)$ | <3.2 | 90 18 | ABLIKIM | 08м | BES2 | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| • • • We do not use <111 | the follow | ung data for average | | $e^+e^- \rightarrow$ | ψ(3770) | $\Gamma(K_S^0K^-\pi^-)$ | $^+\pi^0)/\Gamma_{ m total}$ | | | | | Γ ₆₁ /Γ |
| $\Gamma(K^+K^- ho^0\pi^0)/\Gamma$ | | | | | , | VALUE (units 10 | -3) <u>CL% EVTS</u> | DO CUMENT ID | | TECN | COMMENT | |
| VALUE (units 10^{-4}) | total CL% | DO CUMENT ID | TECN | COMMENT | Γ ₄₄ /Γ | <13.3 | 90 40 | ABLIKIM | М80 | BES2 | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| <8 | 90 | 23 ABLIKIM | | 3.77 e ⁺ e | _ | $\Gamma(K_S^0K^-\rho^+)$ | _ | | | | | Γ ₆₂ /Γ |
| $\Gamma(K^+K^-\rho^+\pi^-)/$ | Γ _{total} | | | | Γ ₄₅ /Γ | <u>VALUE (units 10</u> - | ⁻³) <u>CL%</u> 90 | DOCUMENT ID | | | COMMENT | ah(2770) |
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | | | | | ABLIKIM | 090 | DE 32 | $e^+e^- \rightarrow$ | |
| <146 | 90 | 23 ABLIKIM | 07ı BES | 3.77 e ⁺ e | _ | , - | $(\tau^+\pi^-)/\Gamma_{\text{total}}$ | | | | | Г ₆₃ /Г |
| $\Gamma(\omega K^+ K^-)/\Gamma_{\rm tota}$ | l | | | | Γ ₄₆ /Γ | VALUE (units 10 ⁻ | ⁻³) <u>CL% EVTS</u> 90 39 | <u>DOCUMENT ID</u> ABLIKIM | | | $e^+e^- \rightarrow$ | ψ(3770) |
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | | | Γ(K ⁰ _S K [−] π ⁻ | | | 20111 | | / | , , |
| < 3.4 • • • We do not use | 90 the follow | ²⁷ HUANG ving data for average | | $e^+e^- \rightarrow$ s, etc. • • • | $\psi(3770)$ | I (Λς Λ π <u>VALUE (units 10</u> | . ' | DO CUMENT ID | | TECN | COMMENT | Γ ₆₄ /Γ |
| <66 | 90 | ²³ ABLIKIM | | 2 3.77 e ⁺ e | _ | <1.6 | 90 | ABLIKIM | | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| $\Gamma(\phi\pi^+\pi^-\pi^0)/\Gamma_{\rm tot}$ | tal . | | | | Γ ₄₇ /Γ | $\Gamma(K_S^0K^-\pi^-)$ | + n)/[| | | | | Γ ₆₅ /Γ |
| <u>VALUE (units 10⁻⁴)</u> | <u>CL%</u> | DO CUMENT ID | TECN | COMMENT | | VALUE (units 10 | • | DO CUMENT ID | | TECN | COMMENT | . 65 / 1 |
| <38 | 90 | 23 ABLIKIM | | 3.77 e ⁺ e | | <1.3 | 90 | ABLIKIM | | | $e^+e^- \rightarrow$ | $\psi(3770)$ |
| $\Gamma(K^{*0}K^-\pi^+\pi^0+$ | с.с.)/Г ₊ | otal | | | Г ₄₈ /Г | Γ(K ⁰ ₅ K ⁻ 2π | $(\pi^+\pi^-\pi^0)/\Gamma_{ m tota}$ | İ | | | | Г ₆₆ /Г |
| VALUE (units 10 ⁻⁴) | <u>CL%</u> | DO CUMENT ID | TECN | COMMENT | | , - | -3) <u>CL% EVTS</u> | DO CUMENT ID | | TECN | | |
| <162 | 90 | ²³ ABLIKIM | 07ı BES | 2 3.77 e ⁺ e | _ | <41.8 | 90 23 | ABLIKIM | 08м | BES2 | $e^+e^- \to$ | $\psi(3770)$ |

 ψ (3770)

| $\Gamma(K_S^0K^-2\pi^+\pi^-\eta)$ VALUE (units 10 ⁻²) |)/ I total | DO CUMENT ID | TECN | COMMENT | Γ ₆₇ /Γ | $\Gamma(\rho \overline{\rho} K^+ K^-)/\Gamma_{to}$ VALUE (units 10^{-4}) | otal CL% | DOCUMENT ID | TEG | ON COMMENT | Г84/Г |
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| <4.8 | 90 | ABLIKIM | 09c BES2 | $e^+e^- \rightarrow$ | $\psi(3770)$ | < 3.2 | 90 | 27 HUANG | 06A CLI | O e+e | |
| $\Gamma(K_S^0 K^- \pi^+ 2(\pi^+))$ | π ⁻))/Γ _{tot} ; | al | | | Γ ₆₈ /Γ | • • • We do not use | the follow | ing data for averag ²³ ABLIKIM | | its, etc. • • • S2 e ⁺ e ⁻ - | ah(3770) |
| VALUE (units 10 ⁻³) CL9 | <u>EVTS</u> | DO CUMENT ID | TECN | COMMENT | | | | ABEIRIN | 0,0 02 | 52 0 0 | |
| <12.2 90 | 4 | ABLIKIM | 08м BES2 | $e^+e^- \rightarrow$ | $\psi(3770)$ | $\Gamma(\eta \rho \overline{\rho} K^+ K^-)/\Gamma$ VALUE (units 10^{-3}) | total CL% | DO CUMENT ID | TEG | N COMMENT | Γ ₈₅ / |
| $\Gamma(K_S^0K^-\pi^+2\pi^0)$ | | | | | Γ ₆₉ /Γ | <6.9 | 90 | 23 ABLIKIM | | S2 e ⁺ e ⁻ - | |
| VALUE (units 10 ⁻³) CL9 <26.5 90 | <u>EVTS</u> 17 | <u>DOCUMENT ID</u> ABLIKIM | 08M BES2 | $e^+e^- \rightarrow$ | ah(3770) | Γ(π ⁰ ρ | T _{total} | | | | Γ ₈₆ /Ι |
| Γ(K ⁰ _S K-K+K-π | | 7102111111 | 00 5202 | | | VALUE (units 10^{-3}) | CL% | DO CUMENT ID | | | - |
| VALUE (units 10 ⁻³) | CL% | DO CUMENT ID | TECN | COMMENT | Γ ₇₀ /Γ | <1.2 | 90 | ²³ ABLIKIM | 10D BE | S2 e ⁺ e ⁻ - | ψ(3770) |
| <4.9 | 90 | ABLIKIM | 09c BES2 | | $\psi(3770)$ | $\Gamma(\phi p \overline{p})/\Gamma_{\text{total}}$ | | | | | Γ ₈₇ /Ι |
| Γ(K ⁰ ₅ K-K+K-π | + π ⁰)/Γ _{to} | tal | | | Γ ₇₁ /Γ | <u>VALUE (units 10⁻⁴)</u> <1.3 | <u>CL%</u> 90 | DOCUMENT ID | | <u>COMMENT</u> EO e ⁺ e ⁻ - | |
| VALUE (units 10 ⁻²) | <u>CL%</u> | DO CUMENT ID | TECN | COMMENT | | • • • We do not use | | | | | → ψ(3110) |
| <3.0 | 90 | ABLIKIM | 09c BES2 | $e^+ e^- \rightarrow$ | $\psi(3770)$ | <9 | | ²³ ABLIKIM | 07B BE | S2 e ⁺ e ⁻ - | ψ(3770) |
| $\Gamma(K_S^0K^-K^+K^-\pi$ | $+\eta)/\Gamma_{tota}$ | l | | | Γ_{72}/Γ | $\Gamma(\Lambda \overline{\Lambda} \pi^+ \pi^-)/\Gamma_{\text{tot}}$ | tal | | | | Γ ₈₈ / |
| VALUE (units 10 ⁻²) | CL% | DO CUMENT ID | TECN DESCRI | COMMENT | . (0.770) | VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | _ | |
| <2.2 | 90 | ABLIKIM | 09c BES2 | e · e ⁻ → | , , | < 2.5 • • • We do not use | 90 the follow | ²⁷ HUANG ing data for averag | | EO e ⁺ e [−] − its, etc. • • • | ψ(3770) |
| $\Gamma(K^{*0}K^-\pi^+ + c.c)$ | - | | _ | | Γ ₇₃ /Γ | <39 | 90 | ²³ ABLIKIM | | S2 e ⁺ e ⁻ - | ψ(3770) |
| VALUE (units 10 ⁻³) <9.7 | <u>CL%</u> 90 | 23 ABLIKIM | 07F BES2 | $e^+e^- \rightarrow$ | ψ(3770) | Γ(Λ̄ρΚ+)/Γ _{total} | | | | | Γ ₈₉ /Ι |
| $\Gamma(p\overline{p}\pi^0)/\Gamma_{\rm total}$ | | | | | Г ₇₄ /Г | VALUE (units 10^{-4}) | CL% | DO CUMENT ID | TEC | N COMMENT | - |
| VALUE (units 10 ⁻⁴) | | DO CUMENT ID | TECN | COMMENT | 174/1 | <2.8 | 90 | ²⁷ HUANG | 06A CLI | EO e+e− − | $\psi(3770)$ |
| <12 | | 23 ABLIKIM | 07B BES2 | | $\psi(3770)$ | $\Gamma(\Lambda \overline{p} K^+ \pi^+ \pi^-)$ | Γ _{total} | | | | Γ ₉₀ /Ι |
| $\Gamma(p\overline{p}\pi^+\pi^-)/\Gamma_{\text{tota}}$ | i | | | | Γ ₇₅ /Γ | VALUE (units 10 ⁻⁴) | <u>CL%</u> | DO CUMENT ID | | | |
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | TECN | COMMENT | | <6.3 22 Comparing cross | 90 | ²⁷ HUANG | | EO e+e | |
| < 5.8 | | ²⁷ HUANG | 06A CLEO | | $\psi(3770)$ | ence, and using o | $r(\psi(3770)$ - | $\sqrt{s} = 3.773 \text{ GeV a}$ $\rightarrow D\overline{D}) = 6.39 \pm$ | 0.20 nb. | . 671 GeV, negi | ecting interier |
| <16 Γ (ΛӢ)/Γ_{total} | | ²³ ABLIKIM | 07в BES2 | | ψ(3770) Γ ₇₆ /Γ | 23 Assuming that in and using $\sigma^{obs}(e$ 24 Data suggest pos 25 Using $\sigma(e^+e^-$ | sible destru | ctive interference v | vith continu | ium. +0.41 -0.30) nb fro | m BESSON 0 |
| <16 \[\big(\lambda \overline{\big)} \big/\Gamma_{\text{total}} \\ \text{VALUE (units 10^{-4})} \\ <1.2 | <u>CL%</u> 90 the following | 23 ABLIKIM DOCUMENT ID THUANG | 06A CLEO | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \end{array}$ | Γ₇₆/Γ ψ(3770) | and using $\sigma^{obs}(e^{24}$ Data suggest pos 25 Using $\sigma(e^+e^1)$ and B($K_S^0 \to \pi^0$ 26 Using B($K_S^0 \to \pi^0$ 27 Using $\sigma_{tot}(e^+e^-1)$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0$ $\pi^{+}\pi^{-}) =$ $^{-}\rightarrow \psi(37)$ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 70)) = 7.9 \pm 0.6 n | with continuous \pm 0.08 b at the re | $^{+0.41}_{-0.30})$ nb fro | m BESSON 0 |
| <16 \[\begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} \begin{align*} align* | CL% 90 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average | 06A CLEO | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \end{array}$ | Γ₇₆/Γ ψ(3770) ψ(3770) | and using $\sigma^{obs}(e^{24}$ Data suggest pos 25 Using $\sigma(e^+e^$ and $B(K_S^0\to\pi^-)$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0$ $\pi^{+}\pi^{-}) =$ $^{-}\rightarrow \psi(37)$ $^{+}\pm 0.27 \pm$ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 70)) = 7.9 \pm 0.6 n = 0.27 nb and negle | with continuous \pm 0.08 \pm 0.08 \pm 0 at the resecting inter | $^{+0.41}_{-0.30})$ nb fro | m BESSON 0 |
| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <1.2 •• • We do not use <4 $\Gamma(\rho \overline{\rho} \pi^+ \pi^- \pi^0)/\Gamma_1$ | CL% 90 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average | 06A CLEO | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \end{array}$ | Γ₇₆/Γ ψ(3770) | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ e^-)$ and $B(K_S^0 \rightarrow e^-)$ 26 Using $B(K_S^0 \rightarrow e^-)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0$ $\pi^{+}\pi^{-}) =$ $^{-}\rightarrow \psi(37)$ $^{+}\pm 0.27 \pm$ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 70)) = 7.9 \pm 0.6 n | with continuous \pm 0.08 \pm 0.08 \pm 0 at the resecting inter | $^{+0.41}_{-0.30})$ nb fro | |
| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-4}\text{)}$ <1.2 • • • We do not use <4 $\Gamma(\rho \overline{\rho} \pi^+ \pi^- \pi^0)/\Gamma_1$ $VALUE \text{ (units } 10^{-4}\text{)}$ <18.5 | CL% 90 the following 90 otal CL% 90 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG | 06A CLEO 07F BES2 06A CLEO | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{\text{COMMENT}} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \\ \underline{\text{COMMENT}} \\ e^{+}e^{-} \rightarrow \end{array}$ | Γ ₇₆ /Γ ψ(3770) ψ(3770) Γ ₇₇ /Γ | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ e^-)$ and B($K_S^0 \rightarrow T_s^2$ 26 Using B($K_S^0 \rightarrow T_s^2$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = -$ $^{-}\rightarrow \psi(37)$ $^{+}5\pm 0.27 \pm 0.00$ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 70)) = 7.9 \pm 0.6 n \pm 0.27 nb and negle | with continuous 0.38 ± 0.08 b at the resecting inter | $^{+0.41}_{-0.30}$) nb fro sonance. ference. | |
| $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE \text{ (units } 10^{-4}\text{)}$ <1.2 • • • We do not use <4 $\Gamma(\rho \overline{p} \pi^+ \pi^- \pi^0)/\Gamma_0$ $VALUE \text{ (units } 10^{-4}\text{)}$ <18.5 • • • We do not use | CL% 90 the following 90 otal CL% 90 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average | 06A CLEO es, fits, limits, 07F BES2 TECN 06A CLEO es, fits, limits, 10TEON | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ \text{etc.} \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ \text{etc.} \bullet \bullet \end{array}$ | ψ(3770) ψ(3770) Γ77/Γ | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ e^-)$ and $B(K_S^0 \rightarrow e^-)$ 26 Using $B(K_S^0 \rightarrow e^-)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0$ $\pi^{+}\pi^{-}) =$ $^{-}\rightarrow \psi(37)$ $^{+}\pm 0.27 \pm$ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 70)) = 7.9 \pm 0.6 n = 0.27 nb and negle | vith continu | $+0.41 \atop -0.30$) nb fro sonance. ference. $\frac{v}{O} = \frac{COMMENT}{e^+e^- \rightarrow}$ | $\frac{Fg_1/Fg_1}{\psi(3770)} \to$ |
| <16 $\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<1.2}$ <1.2 <4 $\Gamma(\rho\overline{\rho}\pi^{+}\pi^{-}\pi^{0})/\Gamma_{1}$ $\frac{VALUE (units 10^{-4})}{<18.5}$ • • • We do not use <73 | CL% 90 the following 90 otal CL% 90 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG | 06A CLEO 07F BES2 06A CLEO | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ \text{etc.} \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \\ \text{etc.} \bullet \bullet \end{array}$ | $rac{\Gamma_{76}/\Gamma}{\psi(3770)}$ $\psi(3770)$ $rac{\Gamma_{77}/\Gamma}{\psi(3770)}$ $\psi(3770)$ | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ e^-)$ and $B(K_S^0 \rightarrow e^-)$ 26 Using $B(K_S^0 \rightarrow e^-)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi_{c2})/\Gamma_{total}$ WALUE (units 10^{-3}) | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $0.27 \pm 0.27 | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 70)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN | vith continu i.38 ± 0.08 b at the re- ecting inter ECAYS — TECA 06A CLE | $+0.41 \atop -0.30$) nb fro sonance. ference. $\frac{v}{O} = \frac{comment}{e^+e^-} \rightarrow \frac{v}{\gamma} J/\psi$ | $\frac{Fg_1/Fg_1}{\psi(3770)} \to$ |
| <16 $\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{\text{VALUE (units }10^{-4})}{\text{<}1.2}$ < • • • We do not use <4 $\Gamma(\rho\overline{\rho}\pi^{+}\pi^{-}\pi^{0})/\Gamma_{\text{total}}$ < 18.5 • • • We do not use <73 $\Gamma(\omega\rho\overline{\rho})/\Gamma_{\text{total}}$ | oct % 90 otal ct % 90 the following 00 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 4 data for average 23 ABLIKIM | 06A CLEO es, fits, limits, 07F BES2 TECN 06A CLEO 06A CLEO 25, fits, limits, 07B BES2 | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \\ etc. \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | ψ(3770) ψ(3770) Γ77/Γ | and using $\sigma^{obs}(e^{24}$ Data suggest pos 25 Using $\sigma(e^+e^e^-)$ and $B(\kappa_S^0 \to \pi^0)$ 26 Using $B(\kappa_S^0 \to \pi^0)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi_{c2})/\Gamma_{total} \frac{VALUE\ (units\ 10^{-3})}{< 0.9}$ | sible destru $\rightarrow \psi(3770)$ $^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $0.27 \pm 0.27 | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 70)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN | b at the recepting interesting interesting interesting interesting of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control | $+0.41 \\ -0.30$) nb fro sonance. ference. $\frac{v}{\sqrt{O}} = \frac{COMMENT}{\sqrt{e^+e^-}} \\ \frac{v}{\sqrt{\gamma}J/\psi} \\ \text{its, etc.} \bullet \bullet \bullet \bullet \bullet \bullet \bullet \bullet \bullet $ | $\frac{Fg_1/I}{\psi(3770)} \to \psi(3770) \to$ |
| <16 $\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<1.2}$ <1.2 <4 $\Gamma(\rho\overline{\rho}\pi^{+}\pi^{-}\pi^{0})/\Gamma_{1}$ $\frac{VALUE (units 10^{-4})}{<18.5}$ • • • We do not use <73 | otal cL% g0 the following g0 otal cL% g0 the following | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average | 06A CLEO es, fits, limits, 07F BES2 TECN 06A CLEO es, fits, limits, 10TEON | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ e^{+}e^{-} \rightarrow \\ \text{etc.} \bullet \bullet \bullet \\ e^{+}e^{-} \rightarrow \\ \\ \underline{comment} \\ \end{array}$ | Γ ₇₆ /Γ ψ(3770) ψ(3770) Γ ₇₇ /Γ ψ(3770) ψ(3770) Γ ₇₈ /Γ | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ e^-)$ and $B(K_S^0 \rightarrow \pi^-)$ 26 Using $B(K_S^0 \rightarrow e^-)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi c_2)/\Gamma_{total}$ $\frac{VALUE\ (units\ 10^{-3})}{< 0.9}$ • • • We do not use <2.0 | sible destru $\rightarrow \psi(3770)$ $+\pi^{-})=0.$ $\pi^{+}\pi^{-})=0.$ $\pi^{+}\pi^{-})=-\rightarrow \psi(37^{\circ})$ $\pm 0.27 \pm $ | ctive interference v \rightarrow hadrons) = (6 6895 \pm 0.0014. 0.6860 \pm 0.0027. 700)) = 7.9 \pm 0.6 nc = 0.27 nb and negle RADIATIVE DE $\frac{DOCUMENT\ ID}{29\ COAN}$ ing data for averag | b at the recepting interesting interesting interesting interesting of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control | $+0.41 \over 0.30$) nb fro sonance. ference. $\frac{v}{O} = \frac{COMMENT}{e^+e^-} - \frac{v}{\gamma \gamma J/\psi}$ its, etc. • • | $\begin{array}{c} \textbf{Fg1/I} \\ \psi(3770) \rightarrow \\ \psi(3770) \rightarrow \\ \text{adrons} \end{array}$ |
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| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <1.2 $< \bullet \bullet \text{We do not use}$ <4 $\Gamma(\rho \overline{\rho} \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <18.5 $\bullet \bullet \text{We do not use}$ <73 $\Gamma(\omega \rho \overline{\rho})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <2.9 $\bullet \bullet \text{We do not use}$ <30 $\Gamma(\Lambda \overline{\Lambda} \pi^0)/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <12 $\Gamma(\rho \overline{\rho} 2(\pi^+ \pi^-))/\Gamma_{\text{total}}$ $VALUE (units 10^{-3})$ <2.6 | CL 90 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 4 data for average 28 ABLIKIM DOCUMENT ID 23 ABLIKIM DOCUMENT ID 23 ABLIKIM | 06A CLEO es, fits, limits, 07F BES2 TECN 06A CLEO es, fits, limits, 07B BES2 TECN 06A CLEO es, fits, limits, 07B BES2 TECN 071 BES2 TECN 071 BES2 | $\begin{array}{c} e^+ e^- 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$3.9\pm1.4\pm0.6$ 5 $2.8\pm0.5\pm0.4$ 5 | sible destru $\rightarrow \psi(3770)$ $+\pi^-)=0$. $\pi^+\pi^-)=-\rightarrow \psi(37^-)$ $=-\rightarrow \psi(37^-)$ | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 700)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN ing data for averag 30 BRIERE DOCUMENT ID 31 BRIERE ing data for averag 32 BRIERE 29 COAN | with continu. 38 ± 0.08 b at the resecting inter ECAYS — TECN 06 CLE TECN 06 CLEO 66 CLEO 06A CLEO | $+0.41 \over 0.30$) nb fro sonance. ference. $\frac{V}{O} = \frac{COMMENT}{O} + \frac{e^+ e^- \rightarrow V}{\gamma + h}$ its, etc. $\bullet \bullet \bullet$ o $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- 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\Gamma_{91}/\\ \hline \psi(3770) \rightarrow \\ \psi(3770) \rightarrow \\ \hline \rho_{92}/\\ \hline \psi(3770) \rightarrow \\ rons, \ \gamma \gamma J/\psi \\ \psi(3770) \rightarrow \\ rons \\ \psi(3770) \rightarrow \\ \hline \Gamma_{92}/\Gamma_{92}/\Gamma_{92}/\Gamma_{92} \end{array}$ |
| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<1.2}$ <1.2 <. • • • We do not use <4 $\Gamma(\rho \overline{p} \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<18.5}$ • • • We do not use <73 $\Gamma(\omega \rho \overline{p})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<2.9}$ • • • We do not use <30 $\Gamma(\Lambda \overline{\Lambda} \pi^0)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<12}$ $\Gamma(\rho \overline{p} 2(\pi^+ \pi^-))/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<2.6}$ $\Gamma(\eta \rho \overline{p})/\Gamma_{\text{total}}$ | CL 90 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 4 data for average 28 ABLIKIM DOCUMENT ID 23 ABLIKIM DOCUMENT ID 23 ABLIKIM | 06A CLEO es, fits, limits, 07F BES2 TECN 06A CLEO es, fits, limits, 07B BES2 TECN 06A CLEO es, fits, limits, 07B BES2 TECN 071 BES2 TECN 071 BES2 | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ e^+ e^- \rightarrow \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ etc. \bullet \bullet \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ 3.77 e^+ e^- \\ \hline {comment} \\ \hline {comment} \\ \hline {comment} \\ \hline {comment} \\ \hline \\ \hline {comment} \\ \hline \\ \hline {comment} \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ \hline \\ $ | Γ ₇₆ /Γ ψ(3770) ψ(3770) ψ(3770) ψ(3770) Γ ₇₈ /Γ ψ(3770) Γ ₇₉ /Γ Γ ₈₀ /Γ | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^e^-)$ and $B(K_S^0 \rightarrow \pi^-)$ 26 Using $B(K_S^0 \rightarrow \pi^-)$ 27 Using $\sigma_{tot}(e^+e^-)$ 28 Using $\sigma^{obs} = 7.1$ $\frac{\Gamma(\gamma \chi_{c2})/\Gamma_{total}}{MLUE(units 10^{-3})}$ <0.9 •• • We do not use <2.0 $\frac{\Gamma(\gamma \chi_{c1})/\Gamma_{total}}{2.9\pm0.5\pm0.4}$ •• • We do not use $3.9\pm1.4\pm0.6$ $5.8\pm0.5\pm0.4$ 5 $\frac{\Gamma(\gamma \chi_{c1})/\Gamma(J/\psi \pi_{VALUE}}{2.8\pm0.5\pm0.4}$ | sible destru $\rightarrow \psi(3770)$ $+\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $\pi^{+}\pi^{-}) = 0.$ $5 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 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± 0.08 b at the resecting inter ECAYS — TECN 06 CLE 06 CLEO 06 CLEO 06 CLEO 06 CLEO | $+0.41 \over 0.30$) nb fro sonance. ference. $\frac{V}{O} = \frac{COMMENT}{O} + \frac{e^+ e^- \rightarrow V}{\gamma + h}$ its, etc. $\bullet \bullet \bullet$ o $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- \rightarrow V$ $e^+ e^- 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| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ <1.2 <1.2 $<.4$ $\Gamma(\rho \overline{p} \pi^{+} \pi^{-} \pi^{0})/\Gamma_{\text{total}}$ <18.5 $<.6$ • • We do not use <73 $\Gamma(\omega \rho \overline{p})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <2.9 • • We do not use <30 $\Gamma(\Lambda \overline{\Lambda} \pi^{0})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <12 $\Gamma(\rho \overline{p} 2(\pi^{+} \pi^{-}))/\Gamma_{\text{total}}$ $VALUE (units 10^{-3})$ <2.6 $\Gamma(\eta \rho \overline{p})/\Gamma_{\text{total}}$ $VALUE (units 10^{-4})$ <5.4 | CL 90 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 24 HUANG 4 data for average 25 ABLIKIM DOCUMENT ID 26 ABLIKIM DOCUMENT ID 27 HUANG 28 ABLIKIM DOCUMENT ID 29 ABLIKIM | 06A CLEO 07F BES2 07B BES2 07B BES2 07B BES2 07B BES2 07B BES2 07D BES2 07D BES2 07D BES2 07D BES2 07D BES2 07D BES2 | $\begin{array}{c} e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ {\it etc.} \bullet \bullet^- \\ e^+e^- \rightarrow \\ {\it etc.} \bullet \bullet^- \\ e^+e^- \rightarrow \\ {\it etc.} \bullet \bullet^- \\ e^+e^- \rightarrow \\ {\it etc.} \bullet \bullet^- \\ e^+e^- \rightarrow \\ {\it etc.} \bullet \bullet^- \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^+e^- \rightarrow \\ \hline {\it comment} \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^-e^- \rightarrow \\ e^$ | Γ ₇₆ /Γ ψ(3770) ψ(3770) ψ(3770) ψ(3770) (3770) - | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ a)$ and $B(K_S^0 \rightarrow \pi^-)$ 26 Using $B(K_S^0 \rightarrow \pi^-)$ 27 Using $\sigma_{tot}(e^+e^ a)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi_{c2})/\Gamma_{total}$ $\frac{MLUE}{2} \text{ (units } 10^{-3})$ < 0.9 • • • We do not use < 2.0 $\Gamma(\gamma \chi_{c1})/\Gamma_{total}$ $\frac{MLUE}{2} \text{ (units } 10^{-3})$ $2.9 \pm 0.5 \pm 0.4$ • • • We do not use $3.9 \pm 1.4 \pm 0.6$ $5.8 \pm 0.5 \pm 0.4$ $\Gamma(\gamma \chi_{c1})/\Gamma(J/\psi \pi_{MLUE})$ $1.49 \pm 0.31 \pm 0.26$ $\Gamma(\gamma \chi_{c0})/\Gamma_{total}$ | sible destru $\begin{array}{l} \text{sible destru} \\ \rightarrow \psi(3770) \\ +\pi^{-}) = 0. \\ \pi^{+}\pi^{-}) = - \\ -\rightarrow \psi(37^{\circ}) \\ 5 \pm 0.27 \\ \pm \\ \hline \\ 90 \\ \text{ethe follow} \\ 90 \\ \text{ethe follow} \\ 90 \\ \pm \text{vts} \\ \text{sthe follow} \\ 4 \pm 17 \\ 3 \pm 10 \\ \pm \\ \hline \\ \frac{EVTS}{53 \pm 10} \\ \end{array}$ | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 700)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN ing data for averag 30 BRIERE DOCUMENT ID 31 BRIERE ing data for averag 32 BRIERE 29 COAN | with continu. 38 ± 0.08 b at the resecting inter ECAYS — TECN 06 CLE 06 CLEO 06 CLEO 06 CLEO 06 CLEO | $+0.41 \over 0.30$) nb fro sonance. ference. $\frac{V}{O} = \frac{COMMENT}{O} = \frac{V}{\gamma} + \frac{V}{h} = \frac{COMMENT}{\gamma} + \frac{V}{h} = \frac{V}{\gamma} + \frac{V}{h} = \frac{V}{\gamma} + \frac{V}{h} = \frac{V}{O} = \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^+e^-} \rightarrow \frac{V}{e^-} \rightarrow V$ | $\begin{array}{c} & \Gamma_{91}/\\ \hline \psi(3770) \rightarrow \\ \psi(3770) \rightarrow \\ adrons & \Gamma_{92}/\\ \hline \psi(3770) \rightarrow \\ rons, \gamma\gamma J/\psi \\ \psi(3770) \rightarrow \\ rons & \psi(3770) \rightarrow \\ \hline \hline \psi(3770) \rightarrow \\ \hline \end{array}$ |
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BES2 | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} 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ψ(3770) ψ(3770) Γ ₇₈ /Γ ψ(3770) Γ ₈₀ /Γ ψ(3770) Γ ₈₁ /Γ ψ(3770) | and using $\sigma^{obs}(e)$ 24 Data suggest pos 25 Using $\sigma(e^+e^ a)$ and $B(K_S^0 \rightarrow \pi^-)$ 26 Using $B(K_S^0 \rightarrow \pi^-)$ 27 Using $\sigma_{tot}(e^+e^ a)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi c_2)/\Gamma_{total} \frac{MLUE}{(units 10^{-3})} < 0.9$ • • We do not use <2.0 $\Gamma(\gamma \chi c_1)/\Gamma_{total} \frac{MLUE}{(units 10^{-3})} = 0.9 + 0.5 \pm 0.4$ • • We do not use $3.9 \pm 1.4 \pm 0.6 = 0.5 \pm 0.4$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ $\Gamma(\gamma \chi c_1)/\Gamma(J/\psi \pi MLUE) = 0.00 + 0.00$ | sible destru $\rightarrow \psi(3770)$ $+ \pi^{-}) = 0$. $\pi^{+}\pi^{-}) = 0$. $\pi^{+}\pi^{-}) = 0$. $\pi^{+}\pi^{-}) = 0$. 0 . 0 0 0 0 0 0 0 0 0 0 0 0 | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 770)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN ing data for averag 30 BRIERE ing data for averag 32 BRIERE 29 COAN DOCUMENT ID 33 COAN | b at the recepting interest of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the continuous states of the 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BES2 07D BES2 | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline 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| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<1.2}$ < • • • We do not use <4 $\Gamma(\rho \overline{p} \pi^+ \pi^- \pi^0)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<18.5}$ • • • We do not use <73 $\Gamma(\omega \rho \overline{p})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<2.9}$ • • • We do not use <30 $\Gamma(\Lambda \overline{\Lambda} \pi^0)/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<12}$ <12 $\Gamma(\rho \overline{p} 2(\pi^+ \pi^-))/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<2.6}$ $\Gamma(\eta \rho \overline{p})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<2.6}$ < • • We do not use <11 $\Gamma(\eta \rho \overline{p} \pi^+ \pi^-)/\Gamma_{\text{total}}$ • • • We do not use | 20 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 24 HUANG 3 data for average 25 ABLIKIM DOCUMENT ID 26 ABLIKIM DOCUMENT ID 27 HUANG 3 ABLIKIM DOCUMENT ID 28 ABLIKIM DOCUMENT ID 29 ABLIKIM DOCUMENT ID 20 ABLIKIM | 06A CLEO 25, fits, limits, 07B BES2 06A CLEO 25, fits, limits, 07B BES2 07B BES2 07B BES2 07D BES2 07D BES2 07D BES2 07D BES2 07D BES2 07D BES2 | $\begin{array}{c} e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline {comment} \\ e^+ e^- \rightarrow \\ \hline 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\frac{\pi^{+}\pi^{-}}{\pi^{-}} = 0. $ $ \frac{\psi(377)}{-5} = 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 0.27 \pm 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06A CLEO | $\begin{array}{c} +0.41 \\ -0.30 \\ \end{array}) \text{ nb fro} \\ \\ \text{sonance.} \\ \\ \text{ference.} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c} & \Gamma_{91}/\\ \hline \psi(3770) \rightarrow \\ \psi(3770) \rightarrow \\ \hline \phi(3770) \rightarrow \\ rons, \ \gamma \gamma J/\psi \\ \psi(3770) \rightarrow \\ rons, \ \psi(3770) \rightarrow \\ \hline \Gamma_{92}/\Gamma \\ \hline \psi(3770) \rightarrow \\ \hline \psi(3770) \rightarrow \\ \hline \psi(3770) \rightarrow \\ \hline drons \\ \end{array}$ |
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\gamma \gamma J/\psi}$ | $\begin{array}{c} & \Gamma_{91}/\\ \hline \psi(3770) \rightarrow \\ \psi(3770) \rightarrow \\ \hline \phi(3770) \rightarrow \\ rons, \ \gamma \gamma J/\psi \\ \psi(3770) \rightarrow \\ rons, \ \psi(3770) \rightarrow \\ \hline \hline \psi(3770) \rightarrow \\ \hline \psi(3770) \rightarrow \\ \hline \psi(3770) \rightarrow \\ \hline \end{array}$ |
| <16 $\Gamma(\Lambda \overline{\Lambda})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<1.2}$ <1.2 • • We do not use <4 $\Gamma(\rho \overline{p} \pi^{+} \pi^{-} \pi^{0})/\Gamma_{\text{total}}$ <18.5 • • We do not use <73 $\Gamma(\omega \rho \overline{p})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<2.0}$ • • We do not use <30 $\Gamma(\Lambda \overline{\Lambda} \pi^{0})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-4})}{<12}$ <12 $\Gamma(\rho \overline{p} 2(\pi^{+} \pi^{-}))/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<2.6}$ $\Gamma(\eta \rho \overline{p})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<5.4}$ • • We do not use <11 $\Gamma(\eta \rho \overline{p} \pi^{+} \pi^{-})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<5.4}$ • • We do not use <11 $\Gamma(\eta \rho \overline{p} \pi^{+} \pi^{-})/\Gamma_{\text{total}}$ $\frac{VALUE (units 10^{-3})}{<5.4}$ • • We do not use | CL% 90 | 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 23 ABLIKIM DOCUMENT ID 23 ABLIKIM DOCUMENT ID 24 ABLIKIM DOCUMENT ID 25 ABLIKIM DOCUMENT ID 26 ABLIKIM DOCUMENT ID 27 HUANG 3 data for average 3 ABLIKIM | 06A CLEO 07F BES2 07B BES2 06A CLEO 08, fits, limits, 07B BES2 07B BES2 07B BES2 07B BES2 07B BES2 07F BES2 07F BES2 07F BES2 07F BES2 07F BES2 07F BES2 | $\begin{array}{c} e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ e^+ e^- \rightarrow \\ \text{etc.} \bullet \bullet \\ 3.77 e^+ e^- \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ \\ \underline{comment} \\ e^+ e^- \rightarrow \\ 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$\sigma_{tot}(e^+e^ a)$ 28 Using $\sigma^{obs} = 7.1$ $\Gamma(\gamma \chi_{c2})/\Gamma_{total} = \frac{MLUE}{2} (units 10^{-3})$ <0.9 •• • We do not use <2.0 $\Gamma(\gamma \chi_{c1})/\Gamma_{total} = \frac{MLUE}{2} (units 10^{-3})$ 2.9 ± 0.5 ± 0.4 •• • We do not use $3.9 \pm 1.4 \pm 0.6$ $2.8 \pm 0.5 \pm 0.4$ 5 $\Gamma(\gamma \chi_{c1})/\Gamma(J/\psi \pi_{MLUE})$ 1.49 ± 0.31 ± 0.26 $\Gamma(\gamma \chi_{c0})/\Gamma_{total} = \frac{MLUE}{2} (units 10^{-3}) = \frac{CL\%}{2}$ 7.3 ± 0.7 ± 0.6 •• • We do not use | sible destru | ctive interference v → hadrons) = (6 6895 ± 0.0014. 0.6860 ± 0.0027. 700)) = 7.9 ± 0.6 n = 0.27 nb and negle RADIATIVE DE DOCUMENT ID 29 COAN ing data for averag 30 BRIERE 31 BRIERE ing data for averag 32 BRIERE 29 COAN 33 COAN DOCUMENT ID 34 BRIERE ing data for averag | b at the resecting interest. CAYS — TECN 06 CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE 06A CLE | $+0.41 \over 0.30$) nb fro sonance. ference. $\frac{V}{O} = \frac{COMMENT}{O} = \frac{V}{V} + \frac{V}{V}$ its, etc. • • • $\frac{V}{V} = \frac{COMMENT}{V} = \frac{V}{V} + \frac{V}{V}$ or $\frac{V}{V} = \frac{V}{V} = \frac{V}{V} = \frac{V}{V} + \frac{V}{V}$ or $\frac{V}{V} = \frac{V}{V} = \frac{V}{V} = \frac{V}{V} + \frac{V}{V}$ its, etc. • • • $\frac{V}{V} = \frac{V}{V} = V$ | $\begin{array}{c} $ |

 $\psi(3770), X(3872)$

| VALUE • • • We do not | use the follow | <u>DOCUMENT ID</u> ring data for average |
|-----------------------------------------------|----------------------------------------------------------|-----------------------------------------------------------------------------------|
| 2.5 ± 0.6 | | 35 BRIERE |
| $\Gamma(\gamma \eta')/\Gamma_{\text{total}}$ | | |
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID |
| <1.8 | 90 | 36 PEDLAR |
| $\Gamma(\gamma\pi^0)/\Gamma_{ m total}$ | | 36 PEDLAR |
| VALUE (units 10 ⁻⁴) | | DO CUMENT ID |
| $D\overline{D}$) from HI | \equiv 05 for $\sigma(e^+)$ | PEDLAR $\pm 0.03 \pm 0.11$) keV $e^- \rightarrow \psi(3770)$). |
| 30 Uses B(ψ (2 S width from P | $) ightarrow \gamma \chi_{C2}) = DG 04, and \Gamma_{e}$ | $= 9.22 \pm 0.11 \pm 0.4$ $ee(\psi(2S)) = 2.54 \pm 0.4$ |
| 31 Averages the | two measurem | ents from COAN 06 = $9.07 \pm 0.11 \pm 0.9$ $ee(\psi(2S)) = 2.54 \pm 0.9$ |
| 33 Heiner D/a//27 | $(70) \rightarrow L/ab\pi$ | (1.89 ± 0) |
| Using D(\psi(3) | $IU_I \rightarrow J/\psi \pi$ | · // / = (1.05 ± 0 |

Γ93/Γ92 COMMENT

| ollowing data for average: | s, fits, | limits, | etc. • • • | |
|----------------------------|----------|---------|-----------------------|--------------|
| 35 | | | 1 | |
| ³⁵ BRIERE | 06 | CLEO | $e^+ e^- \rightarrow$ | $\psi(3770)$ |

TECN

| $\Gamma(\gamma \eta')/\Gamma_{total}$ | | | | | | Г94/Г |
|----------------------------------------|-----|----------------------|----|------|---------------------------------|-------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.8 | 90 | ³⁶ PEDLAR | 09 | CLE3 | $\psi(2S) \rightarrow \gamma X$ | |
| $\Gamma(\gamma\eta)/\Gamma_{ m total}$ | | | | | | Г95/Г |
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.5 | 90 | ³⁶ PEDLAR | 09 | CLE3 | $\psi(2S) \rightarrow \gamma X$ | |

| $\Gamma(\gamma\pi^0)/\Gamma_{ m total}$ | | | | | | | |
|-----------------------------------------|-----|--------------|----|------|---------------------------------|--|--|
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | | |
| <2 | 90 | PEDLAR | 09 | CLE3 | $\psi(2S) \rightarrow \gamma X$ | | |

^{0.11)} keV from ADAM 06 and taking $\sigma(e^+e^ightarrow$ (3770)).

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X(3872)

$$I^{G}(J^{PC}) = 0?(?^{?+})$$

Seen by CHOI 03 in $B \to K \pi^+ \pi^- J/\psi(1S)$ decays as a narrow peak in the invariant mass distribution of the $\pi^+\pi^-J/\psi(1S)$ final state, but not seen in the $\gamma\chi_{c1}$ final state of these decays. Possibly absent in the invariant mass spectrum of the final state $\pi^+\pi^-J/\psi(1S)$ in $e^+\,e^-$ collisions. Interpretation as a 1 $^-$ charmonium state not favored. Isovector hypothesis excluded by AUBERT 05B and CHOI 11. A helicity amplitude analysis of the $X(3872) \rightarrow J/\psi \pi^+ \pi^-$ decay gives two possible J^{PC} assignments: $J^{PC}=1^{++}$ and 2^{-+} (ABULENCIA 07E and CHOI 11). A study of the 3π invariant mass distribution in $J/\psi\omega$ decays slightly favors $J^P=2^-$ (DEL-AMO-SANCHEZ 10B).

See our note on "Developments in Heavy Quarkonium Spectroscopy".

X(3872) MASS FROM $J/\psi X$ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|------------|----------------------------|---------|-----------|----------------------------------------------------------------|
| 3871.68 ± 0.17 OUR | WERAGE | | | | |
| $3871.95 \pm 0.48 \pm 0.12$ | 0.6k | AAIJ | 12н | LHCB | $pp \rightarrow J/\psi \pi^+ \pi^- X$ |
| $3871.85 \pm 0.27 \pm 0.19$ | ~ 170 | $^{ m 1}$ CHOI | 11 | BELL | $B \rightarrow K \pi^+ \pi^- J/\psi$ |
| 3873 $^{+}_{-}$ $^{1.8}_{1.6}$ ± 1.3 | 27 ± 8 | ² DEL-AMO-SA | .10в | BABR | $B \to \omega J/\psi K$ |
| $3871.61 \pm\ 0.16 \pm 0.19$ | 6k | ^{2,3} AALT ONEN | | | $p \overline{p} \rightarrow J/\psi \pi^+ \pi^- X$ |
| 3871.4 \pm 0.6 \pm 0.1 | 93.4 | AUBERT | | | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| 3868.7 \pm 1.5 \pm 0.4 | 9.4 | AUBERT | 08Y | BABR | $B^0 \rightarrow K_S^0 J/\psi \pi^+ \pi^-$ |
| $3871.8 \pm 3.1 \pm 3.0$ | 522 | ^{2,4} ABAZOV | | | $p \overline{p} \rightarrow J/\psi \pi^+ \pi^- X$ |
| | he followi | ng data for average | s, fits | , limits, | etc. • • • |
| 3868.6 \pm 1.2 \pm 0.2 | 8 | ⁵ AUBERT | 06 | BABR | $B^0 \rightarrow K_S^0 J/\psi \pi^+ \pi^-$ |
| $3871.3 \ \pm \ 0.6 \ \pm 0.1$ | 61 | ⁵ AUBERT | 06 | | $B^- \rightarrow K^- J/\psi \pi^+ \pi^-$ |
| 3873.4 ± 1.4 | 25 | ⁶ AUBERT | 05R | BABR | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| $3871.3 \pm 0.7 \pm 0.4$ | 730 | ^{2,7} ACOSTA | 04 | CDF2 | $p \overline{p} \rightarrow J/\psi \pi^+ \pi^- X$ |
| $3872.0 \pm 0.6 \pm 0.5$ | 36 | | 03 | BELL | $B \rightarrow K \pi^+ \pi^- J/\psi$ |
| 3836 ± 13 | 58 | ^{2,9} ANTONIA ZZI | 94 | E705 | $300 \pi^{\pm} \text{Li} \rightarrow I/\psi \pi^{+} \pi^{-} X$ |

 $^{^1}$ The mass difference for the X(3872) produced in B^+ and B^0 decays is (- 0.71 \pm 0.96 \pm 0.19) MeV.

X(3872) MASS FROM $\overline{D}^{*0}D^{0}$ MODE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|----------------------|-----------------------|----------|------------|------------------------------------------|
| • • • We do not use | the following | data for averag | es, fits | s, limits, | etc. • • • |
| $3872.9 + 0.6 + 0.4 \\ -0.4 - 0.5$ | 50 10,1 | ^{l1} AUSHEV | 10 | BELL | $B \rightarrow \overline{D}^{*0} D^0 K$ |
| $3875.1 { + 0.7 \atop - 0.5} \pm 0.5$ | 33 ± 6 | ^{l1} AUBERT | 08B | BABR | $B \to \ \overline{D}{}^{*0} D^0 K$ |
| $3875.2 \pm 0.7 {}^{+\ 0.9}_{-\ 1.8}$ | 24 \pm 6 11,1 | ¹² GOKHROO | 06 | BELL | $B \to D^{0} \overline{D}{}^0 \pi^0 K$ |

 $^{^{10}}$ Calculated from the measured $m_{X(3872)} - m_{\overline{D}{}^{0}} - m_{\overline{\overline{D}{}^{0}}} = 1.1^{+0.6}_{-0.4} + 0.1_{-0.4}^{+0.0}$ MeV.

$m_{X(3872)} - m_{J/\psi}$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------|------|--------------|-----|------|---------------------------------------------------|
| 774.9±3.1±3.0 | 5 22 | ABAZOV | 04F | D0 | $p \overline{p} \rightarrow J/\psi \pi^+ \pi^- X$ |

$m_{X(3872)} - m_{\psi(25)}$

| VALUE (MeV) | EVTS | DOCUMENT IL | 00 | TECN | COMMENT |
|--------------------|-----------------|----------------------|-----------|-----------|------------------------------------------|
| • • • We do not us | se the followin | ng data for avera | ges, fits | , limits, | etc. • • • |
| 187.4 ± 1.4 | 25 | ¹³ AUBERT | 05 R | BABR | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| 13 Superseded by A | AUBERT 06. | | | | |

X (3872) WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT I |) | TECN | COMMENT |
|-----------------------------------|---------|----------|--------------------|-----------|-----------|------------------------------------------|
| <1.2 | 90 | | CHOI | 11 | BELL | $B \rightarrow K \pi^+ \pi^- J/\psi$ |
| ● ● We do not | use the | followin | g data for avera | ges, fits | , limits, | etc. • • • |
| <3.3 | 90 | | AUBERT | 08Y | BABR | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| <4.1 | 90 | 69 | AUBERT | 06 | BABR | $B \rightarrow K \pi^+ \pi^- J/\psi$ |
| <2.3 | 90 | 36 | ¹⁴ сноі | 03 | BELL | $B \rightarrow K \pi^+ \pi^- J/\psi$ |
| ¹⁴ Superseded b | у СНОІ | 11. | | | | |

X(3872) WIDTH FROM \overline{D}^{*0} D^{0} MODE

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-----------------|----------------------|-----------|-----------|--------------------------------------|
| • • • We do not us | e the following | data for averages | , fits, l | imits, et | c. • • • |
| $3.9 + 2.8 + 0.2 \\ -1.4 - 1.1$ | 50 | ¹⁵ AUSHEV | 10 | BELL | $B \to \overline{D}^{*0} D^0 K$ |
| $3.0^{+1.9}_{-1.4}\pm0.9$ | 33 ± 6 | AUBERT | 08в | BABR | $B \to \ \overline{D}{}^{*0} D^0 K$ |
| | | | | | |

¹⁵ With a measured value of B(B $\rightarrow X(3872) K) \times B(X(3872) \rightarrow D^{*0} \overline{D}^{0}) = (0.80 \pm 1.00)$ $0.20 \pm 0.10) \times 10^{-4}$, assumed to be equal for both charged and neutral modes.

 $^{0.11\,\}pm\,0.46\,\%$ from ATHAR 04, $\psi(2S)$ mass and = 2.54 \pm 0.03 \pm 0.11 keV from ADAM 06.

COAN 06A and BRIERE 06.

^{0.11} \pm 0.54 % from ATHAR 04, $\psi(2S)$ mass and $= 2.54 \pm 0.03 \pm 0.11$ keV from ADAM 06.

 $^{(1.89 \}pm 0.20 \pm 0.20) \times 10^{-3}$ from ADAM 06.

 $^{^{34}}$ Uses B(\(\psi(2S)\) \rightarrow \gamma_{\chi_0}() = 9.33 \pm 0.14 \pm 0.61 \% from ATHAR 04, \(\psi(2S)\) mass and width from PDG 04, and \(\Gamma_{\chi_0}(\psi(2S)) = 2.54 \pm 0.03 \pm 0.11 \text{ keV from ADAM 06.} \)

³⁵ Not independent of other results in BRIERE 06.

 $^{^{36}}$ Assuming maximal destructive interference between $\psi(3770)$ and continuum sources.

 $^{^2}$ Width consistent with detector resolution. 3 A possible equal mixture of two states with a mass difference greater than 3 6 MeV/c 2 is excluded at 9 5% CL.

⁴ Calculated from the corresponding $m_{X(3872)}-m_{J/\psi}$ using $m_{J/\psi}$ =3096.916 MeV.

 $^{^{5}}$ Calculated from the corresponding $m_{\chi(3872)}-m_{\psi(2S)}$ using $m_{\psi(2S)}=$ 3686.093 MeV. Superseded by AUBERT 08Y.

 $^{^6}$ Calculated from the corresponding $m_{X(3872)}-m_{\psi(2S)}$ using $m_{\psi(2S)}=$ 3685.96MeV. Superseded by AUBERT 06.

⁷ Superseded by AALTONEN 09AU.

⁸ Superseded by CHOI 11.

⁹ A lower mass value can be due to an incorrect momentum scale for soft pions.

¹¹ Experiments report $D^{*0} \overline{D^0}$ invariant mass above $D^{*0} \overline{D^0}$ threshold because D^{*0} decay products are kinematically constrained to the D^{*0} mass, even though the D^{*0} may decay

off-shell.

12 Superseded by AUSHEV 10.

 $/\Gamma_2$

I

Meson Particle Listings X(3872)

X(3872) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------|----------------------------|------------------------------|
| Γ ₁ | e+ e- | |
| Γ ₂ | $\pi^{+}\pi^{-}J/\psi(1S)$ | >2.6 % |
| Γ3 | $\rho^0 J/\psi(1S)$ | |
| Γ_4 | $\omega J/\psi(1S)$ | >1.9 % |
| Γ_5 | $D^0 \overline{D}^0 \pi^0$ | $> 3.2 \times 10^{-3}$ |
| Γ ₆ | $\overline{D}^{*0} D^0$ | $>5 \times 10^{-3}$ |
| Γ ₇ | γγ | |
| Γ8 | $D^0 \overline{D}{}^0$ | |
| Γ9 | $D^+ D^-$ | |
| Γ ₁₀ | $\gamma \chi_{c1}$ | |
| | $\eta J/\psi$ | 6 40-3 |
| | $\gamma J/\psi$ | >6 × 10 ⁻³ |
| ¹ 13 | $\gamma \psi(2S)$ | [a] >3.0 % |

[a] BHARDWAJ 11 does not observe this decay and presents a stronger 90% CL limit than this value. See measurements listings for details.

X(3872) PARTIAL WIDTHS

| Γ(e ⁺ e ⁻) | | | | | | Γ ₁ |
|---------------------------------------------------------------|---------------------|-------------------------------------------|-----------|------------|------------------------|--------------------|
| VALUE (keV) | CL% | DO CUMENT | 'D | TECN | COMMENT | |
| • • • We do not use t | he follow | ing data for avera | ges, fits | s, limits, | etc. • • • | |
| < 0.28 | 90 | ¹⁶ YUAN | 04 | RVUE | $e^+e^ \rightarrow$ | $\pi^+\pi^-J/\psi$ |
| ¹⁶ Using BAI 98E dat <i>X</i> (3872) is the sam | a on e ⁺ | $e^{-} \rightarrow \pi^{+} \pi^{-} e^{-}$ | eV) | Assumir | ng that $\Gamma(\pi^+$ | $\pi^-J/\psi)$ of |

$X(3872) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\pi^+\pi^-J/\psi$ | (15)) | $\times \Gamma(e^+e^-)/\Gamma_{to}$ | tal | | $\Gamma_2\Gamma_1/$ | Γ |
|---------------------------------|---------|-------------------------------------|------------------|-------------------------------|-------------------------------------------------------------------------------------------------------|---|
| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT | |
| < 6.2 | 90 1 | 7,18 AUBERT | 05D | BABR | $ \begin{array}{c} 10.6 \ e^{+} e^{-} \rightarrow \\ K^{+} K^{-} \pi^{+} \pi^{-} \gamma \end{array} $ | |
| ● ● We do n | | | | | , limits, etc. • • • | |
| < 8.3 | | | | | $e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$ | |
| <10 | 90 | ¹⁹ YUAN | 04 | RVUE | $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ | |
| 17 Using B(X (| 3872) — | $J/\psi \pi^+ \pi^-) \cdot B($ | J/ψ — | μ ⁺ μ ⁻ | $-$) $\cdot \Gamma(X(3872) \rightarrow e^{+}e^{-}) < 0.3$ | 7 |
| eV from AL | JBERT (| $05D$ and $B(J/\psi ightarrow$ | $\mu^{+}\mu^{-}$ | $^{-}) = 0.0$ | 0588 ± 0.0010 from the PDG 04. | |

18 Assuming X(3872) has $J^{PC}=1$ = 1 — 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 = 1 Using BAI 98E data on $e^+e^-\to\pi^+\pi^-\ell^+\ell^-$. From theoretical calculation of the production cross section and using B($J/\psi \rightarrow \mu^+ \mu^-$) = (5.88 \pm 0.10)%.

$X(3872) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\gamma\gamma) \times \Gamma(\pi)$ | $^{+}\pi^{-}J/\psi(1S)$ |)/F _{total} | | | | $\Gamma_7\Gamma_2/\Gamma$ |
|-------------------------------------------|-------------------------|----------------------|-----------|------------|-------------|-----------------------------|
| VALUE (eV) | CL% | DOCUMENT I | ID | TECN | COMMENT | |
| • • • We do not | t use the following | ng data for aver | ages, fit | s, limits, | etc. • • • | |
| <12.9 | 90 | ²⁰ DOBBS | 05 | CLE3 | $e^+e^-\to$ | $\pi^+ \pi^- J/\psi \gamma$ |
| 20 Assuming X(| 3872) has positi | ve C parity and | spin O. | | | |

X (3872) BRANCHING RATIOS

 Γ_2/Γ

 $\Gamma(\pi^+\pi^-J/\psi(1S))/\Gamma_{\text{total}}$

| VALUE | EVIS | DOCUMENT ID | | LECN | COMMENT |
|--------------------------------------|----------------------|---------------------------|-----------|---------------------|-------------------------------------------------|
| >0.026 | 93 ± 17 | ²¹ AUBERT | 08Y | BABR | $B \rightarrow X(3872) K$ |
| ● ● We do not us | e the followi | ng data for averag | ges, fits | , limits, | etc. • • • |
| >0.04 | | ²² AUBERT | | | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| >0.04 | 36 ± 7 | ²³ CHOI | 03 | BABR | $B^+ \rightarrow K^+ J/\psi \pi^+ \pi^-$ |
| ²¹ AUBERT 08Y | reports [Γ(| $X(3872) \rightarrow \pi$ | $+\pi^-$ | $1/\psi(15)$ | $)/\Gamma_{total}] \times [B(B^{+} \rightarrow$ |
| | | | ich we | divide b | y our best value B($B^+ ightarrow$ |
| $X(3872) K^+) <$ | 3.2×10^{-4} | | | | |
| ²² Superseded by A | UBERT 08Y | . AUBERT 05R re | eports [| $\Gamma(X(387))$ | 72) $\rightarrow \pi^+ \pi^- J/\psi(1S))/$ |
| | | | |) × 10 ⁻ | ⁵ which we divide by our |
| | | | 1 | | |

total $A = \frac{1}{2} \left(\frac{1}{100} + \frac{1}{100} \times \frac{1}{100} + \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} + \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{100} \times \frac{1}{10$ / [B($B^+\to \psi(2S)\,K^+$]) / [B($\psi(2S)\to J/\psi(1S)\,\pi^+\pi^-$]] = 0.063 ± 0.012 ± 0.070 which we multiply or divide by our best values B($B^+\to X(3872)\,K^+$) < 3.2 × 10⁻⁴, $B(B^+ \to \psi(2S)K^+) = (6.39 \pm 0.33) \times 10^{-4}, \ B(\psi(2S) \to J/\psi(1S)\pi^+\pi^-) = (33.6 \pm 0.4) \times 10^{-2}.$

| $\Gamma(\omega J/\psi(1S))/\Gamma_{\text{tota}}$ | ı | | | Γ ₄ | ι/Γ |
|--------------------------------------------------|---------------------|----------------------------------------------|--------------|-------------------------------------|---------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| >0.019 | 21 ± 7 | ²⁴ DEL-AMO-SA10B | BABR | $B^+ \rightarrow \omega J/\psi K^+$ | |
| ²⁴ DEL-A MO-SA NCH | EZ 10B re | ports $[\Gamma(X(3872) \rightarrow \omega)]$ | $J/\psi(1S)$ | $))/\Gamma_{total}] \times [B(B^+)$ | \rightarrow |
| $X(3872) K^{+})] = ($ | 6 ± 2 ± 1 | $(1) 	imes 10^{-6}$ which we div | ide by o | ur best value B(B+ | \rightarrow |
| $X(3872) K^{+}) < 3$ | $3.2 \times 10^{-}$ | 4. DEL-AMO-SANCH | EZ 10B | also reports B(B ⁰ | \rightarrow |

 $X(3872) K^{0} \times B(X(3872) \rightarrow J/\psi \omega) = (6 \pm 3 \pm 1) \times 10^{-6}$

| $\Gamma(\omega J/\psi(1S))/\Gamma(\pi^+\pi^-J/\psi(1S))$ | | | | | |
|--------------------------------------------------------------------------------------------|---------------------------------------------|------|---------------------------------|--|--|
| VALUE | DO CUMENT ID | | COMMENT | | |
| 0.8 ± 0.3 | ²⁵ DEL-AMO-SA10B | BABR | $B \rightarrow \omega J/\psi K$ | | |
| 25 Statistical and systematic $X(3872) \ K) \times B(X(3872)$ count the common system | $\rightarrow J/\psi \pi^+ \pi^-$) reported | | | | |

| $\Gamma(D^0 \overline{D}{}^0 \pi^0) / \Gamma_{\text{tot}}$ | ıl | | | | Γ ₅ /Γ |
|-----------------------------------------------------------------------------------------------------------------------|---------------------|-------------------------------------------------|--------------------|-----------|--------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $> 3.2 \times 10^{-3}$ | 17 ± 5 | ²⁶ GOKHROO | 06 | BELL | $B^+ \rightarrow D^0 \overline{D}{}^0 \pi^0 K^+$ |
| ²⁶ GOKHROO 06 re | ports $[\Gamma(X)]$ | $(3872) \rightarrow D^{0} \overline{D}^{0} \pi$ | $^{0})/\Gamma_{t}$ | otal] × [| $[B(B^+ \to X(3872) K^+)]$ |
| $= (1.02 \pm 0.31 + 0.21 \times 10^{-6}) \times 10^{-6}$ which we divide by our best value B($B^+ \to X(3872) K^+$) | | | | | |
| $< 3.2 \times 10^{-4}$ | | | | | |

| $\Gamma(\overline{D}^{*0}D^0)/\Gamma_{\text{total}}$ | | | | | Γ ₆ /Γ |
|------------------------------------------------------|------------|--------------------------------------------|-----------------------------------|--------------------------------------|-------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| >5 × 10 ⁻³ | 27 ± 6 | ²⁷ AUBERT | 08B BABR | $B^+ \rightarrow \overline{D}^{*0}D$ | 00 K+ |
| ²⁷ AUBERT 08B rep | orts [Γ(X(| $3872) \rightarrow \overline{D}^{*0}D^{0}$ | $/\Gamma_{\rm total}] \times [B]$ | $(B^+ \rightarrow X(3872))$ | $(K^{+})] =$ |
| | | urbich um divida bu | | | |

| $(1.67 \pm 0.36 \pm 0.47) \times 10^{-4}$ $< 3.2 \times 10^{-4}$. | ⁻⁶ which we divide by our | best value | $e B(B^+ \to X)$ | (3872) K+) |
|-----------------------------------------------------------------------|--------------------------------------|------------|------------------|---------------------|
| $\Gamma(D^0\overline{D}{}^0\pi^0)/\Gamma(\pi^+\pi^-J/\pi^0)$ | ψ(1 S)) | | | Γ_5/Γ_2 |
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| | 20 | | 0-0 | Λ |

| seen | 28 GOKHROO | 06 | BELL | $B \rightarrow D^{0}\overline{D}^{0}\pi^{0}K$ |
|------|----------------------------|---------|-----------|-----------------------------------------------|
| | following data for average | s, fits | , limits, | etc. • • • |
| seen | ALISHEV | 10 | BELL | $B \rightarrow D^0 \overline{D^0} = 0 K$ |

 $^{28}\,\mathrm{May}$ not necessarily be the same state as that observed in the $\mathrm{J/\psi\,\pi^+\,\pi^-}$ mode. Supersedes CHISTOV 04.

| $\Gamma(D^0\overline{D}^0)/\Gamma(\pi^+\pi^-J/\psi(1S))$ |)) | | | Γ_8/Γ_2 |
|----------------------------------------------------------|--------------------------|--------------|------------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use the following | ng data for averages, fi | its, limits, | etc. • • • | |

| $\Gamma(D^+D^-)/\Gamma(\pi^+\pi^-J/\psi(1S))$ |) | | | | Γ_9/Γ_2 |
|-----------------------------------------------|------------------|---------|------------|----------------------------------------|---------------------|
| not seen | CHISTOV | 04 | BELL | $B \rightarrow KD^{0}\overline{D}^{0}$ |) |
| • • • we do not use the following | data ioi average | 5, 1115 | , iiiiiis, | eic. • • • | |

| (| 7 4 (== 1) | | |
|-------------------------|------------------------------|----------------------------|---------|
| VALUE | DO CUMENT ID | TECN COMMENT | |
| • • • We do not use the | following data for averages, | fits, limits, etc. • • • | |
| not seen | CHISTOV (| 04 BELL $B \rightarrow KE$ | p + D - |

| $\Gamma(\gamma \chi_{c1})/\Gamma(\pi^+\pi^-J)$ | $/\psi(1S)$ | | | | Γ_{10}/Γ_{2} |
|------------------------------------------------|-------------|-------------|----|------|--------------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
| <0.89 | 90 | CHOI | 03 | BELL | $B \rightarrow K \pi^+ \pi^- J/\psi$ |

| $\Gamma(\eta J/\psi)/\Gamma(\pi^+\pi$ | $^-J/\psi(1S))$ |) | | | Γ ₁₁ |
|---------------------------------------|-----------------|------------------------|----------------|-----------|-----------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| • • • We do not use | the followin | g data for averages, f | its. limits. e | tc. • • • | |

AUBERT 04Y BABR $B \to K \eta J/\psi$ < 0.6

| $\Gamma(\gamma)$ | $J/\psi)/\Gamma_{tota}$ | I | | | | Г ₁₂ , |
|------------------|-------------------------|-------------------|------------------------|---------|-----------|---------------------------------------------|
| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
| >6 | ×10 ⁻³ | | ²⁹ BHARDWAJ | 11 | BELL | $B^{\pm} \rightarrow \gamma J/\psi K^{\pm}$ |
| • • • | We do not | use the following | g data for average | s, fits | , limits, | etc. • • • |

³⁰ AUBERT 09в ВАВК $B^+ o \gamma J/\psi \, K^+$ 19 31 AUBERT,BE 06M BABR $B^+ o \gamma J/\psi \, {\it K}^+$ >0.010

²⁹ BHARDWAJ 11 reports $\left[\Gamma\left(X(3872) \rightarrow \gamma J/\psi\right)/\Gamma_{\mathsf{total}}\right] \times \left[B(B^+ \rightarrow X(3872) K^+)\right] =$ $\frac{1.78 + 0.48 \pm 0.12) \times 10^{-6} \text{ which we divide by our best value B}(B^+ \to X(3872)K^+)] = (1.78 + 0.48 \pm 0.12) \times 10^{-6} \text{ which we divide by our best value B}(B^+ \to X(3872)K^+)$ $< 3.2 \times 10^{-4}$.

 30 AUBERT 09B reports $[\Gamma(X(3872)\rightarrow\gamma J/\psi)/\Gamma_{\text{total}}]\times[B(B^+\rightarrow X(3872)K^+)]=(2.8\pm0.8\pm0.1)\times10^{-6}$ which we divide by our best value B(B^+ $\rightarrow X(3872)K^+)$ $< 3.2 \times 10^{-4}$

31 Superseded by AUBERT 09B. AUBERT,BE 06M reports $[\Gamma(X(3872) \rightarrow \gamma J/\psi)/\Gamma_{\text{total}}]$ \times [B(B⁺ \to X(3872) K⁺)] = (3.3 ± 1.0 ± 0.3) \times 10⁻⁶ which we divide by our best value B(B⁺ \rightarrow X(3872) K⁺) $< 3.2 \times 10^{-4}$.

| $\Gamma(\gamma\psi(2S))/\Gamma_{total}$ | | | | | Γ ₁₃ /Γ |
|-----------------------------------------|------------|-------------------------|-----|------|---------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| not seen | | ³² BHARDWA J | 11 | BELL | $B^+ \rightarrow \gamma \psi(2S) K^+$ |
| >0.030 | 25 ± 7 | ³³ AUBERT | 09в | BABR | $B^+ \rightarrow \gamma \psi(2S) K^+$ |

 32 BHARDWAJ 11 reports B($B^+ o K^+ X(3872)) imes$ B($X o \gamma \psi(2S)$) $< 3.45 imes 10^{-6}$

at 90% CL. 33 AUBERT 09B reports $[\Gamma(X(3872) \to \gamma \psi(2S))/\Gamma_{\text{total}}] \times [B(B^+ \to X(3872)K^+)] =$ $(9.5 \pm 2.7 \pm 0.6) \times 10^{-6}$ which we divide by our best value B($B^+ \rightarrow X(3872) K^+$) $< 3.2 \times 10^{-4}$.

| $\Gamma(\gamma\psi(2S))/\Gamma(\gamma)$ | $\gamma J/\psi)$ | | | | Γ_{13}/Γ_{12} |
|-----------------------------------------|------------------|--------------|-----|------|--------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <2.1 | 90 | BHARDWAJ | 11 | BELL | $B^+ \rightarrow K^+ \psi(2S) \gamma$ |
| 3.4 ± 1.4 | | AUBERT | 09в | BABR | $B^+ \rightarrow \gamma c \overline{c} K'$ |

 $X(3872), X(3915), \chi_{c2}(2P)$

X (3872) REFERENCES

| AAIJ | 12 H | EPJ C72 1972 | R. Aaij et al. | (LHCb Collab.) |
|------------|--------|----------------|---------------------------|-----------------|
| BHARDWAJ | 11 | PRL 107 091803 | V. Bhardwaj et al. | (BELLE Collab.) |
| CHOI | 11 | PR D84 052004 | SK. Choi et al. | (BELLE Collab.) |
| AUSHEV | 10 | PR D81 031103R | T. Aushev et al. | (BELLE Collab.) |
| DEL-AMO-SA | . 10 B | PR D82 011101R | P. del Amo Sanchez et al. | (BABAR Collab.) |
| AALTONEN | 09AU | PRL 103 152001 | T. Aaltonen et al. | (CDF Collab.) |
| AUBERT | 09B | PRL 102 132001 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 08B | PR D77 011102R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 08Y | PR D77 111101R | B. Aubert et al. | (BABAR Collab.) |
| ABULENCIA | 07 E | PRL 98 132002 | A. Abulencia et al. | (CDF Collab.) |
| AUBERT | 06 | PR D73 011101R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT,BE | 06M | PR D74 071101R | B. Aubert et al. | (BABAR Collab.) |
| GOKHROO | 06 | PRL 97 162002 | G. Gokhroo et al. | (BELLE Collab.) |
| AUBERT | 05 B | PR D71 031501R | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 05 D | PR D71 052001 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 05 R | PR D71 071103R | B. Aubert et al. | (BABAR Collab.) |
| DOBBS | 05 | PRL 94 032004 | S. Dobbs et al. | (CLEO Collab.) |
| ABAZOV | 04 F | PRL 93 162002 | V.M. Abazov et al. | `(D0 Collab.) |
| ACOSTA | 04 | PRL 93 072001 | D. Acosta et al. | (CDF Collab.) |
| AUBERT | 04 Y | PRL 93 041801 | B. Aubert et al. | (BaBar Collab.) |
| CHISTOV | 04 | PRL 93 051803 | R. Chistov et al. | (BELLE Collab.) |
| PDG | 04 | PL B592 1 | S. Eidelman et al. | (PDG Collab.) |
| YUAN | 04 | PL B579 74 | C.Z. Yuan et al. | , , |
| CHOI | 03 | PRL 91 262001 | SK. Choi et al. | (BELLE Collab.) |
| BAI | 98 E | PR D57 3854 | J.Z. Bai et al. | ` (BES Collab.) |
| ANTONIAZZI | 94 | PR D50 4258 | L. Antoniazzi et al. | (È705 Collab.) |

X(3915)

$$I^{G}(J^{PC}) = 0^{+}(?^{?+})$$

Observed in $\omega J/\psi$, thus C=+. May be the same state as $\chi_{C2}(2P)$.

X(3915) MASS

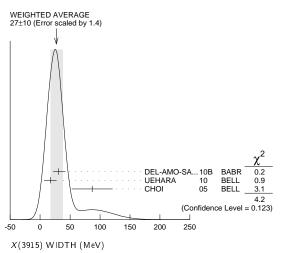
| VALUE (MeV.) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------|-------------|---------------------|-------|----------|----------------------------------------------------------------------------------------|
| 3917.5 ± 2.7 OUR A | VERAGE | | | | |
| 3919.1^{+}_{-} 3.8_{-} \pm 2.0 | | DEL-AMO-SA. | .10в | BABR | $B \to \omega J/\psi K$ |
| $3915~\pm~3~\pm~2$ | 49 ± 15 | ¹ UEHARA | 10 | BELL | $\begin{array}{c} 10.6 \ e^+ e^- \rightarrow \\ e^+ e^- \omega J/\psi \end{array}$ |
| 3943 ±11 ±13 • • • We do not use | 58 ± 11 | ² CHOI | 05 | BELL | $B \rightarrow \omega J/\psi K$ |
| $3914.6^{+}_{-}3.8^{\pm}_{-}2.0$ | | ² AUBERT | 08w | BABR | Superseded by DEL- AMO-SANCHEZ 10B |
| 1 May be $\chi_{C2}(2P)$ $^2\omegaJ/\psi$ threshold | enhancement | fitted as an S-wa | ve Br | eit-Wign | er resonance. |

X(3915) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT II | ס | TECN | COMMENT | | | | |
|----------------------------------|--------------------------|------------------------------------------|--------|---------|-----------------------------------------------------------------------------------|--|--|--|--|
| 27±10 OUR A | VERAGE Err | or includes scale | factor | of 1.4. | See the ideogram below. | | | | |
| $31^{+10}_{-8}\pm~5$ | | DEL-AMO-S | А10в | BABR | $B \to \omega J/\psi K$ | | | | |
| $17\pm10\pm 3$ $87\pm22\pm26$ | $49 \pm 15 \\ 58 \pm 11$ | ³ UEHARA ⁴ CHOI | | | 10.6 $e^+e^- \rightarrow e^+e^- \omega J/\psi$ $B \rightarrow \omega J/\psi K$ | | | | |
| • • • We do i | | | | | | | | | |
| 34 + 12 ± 5 | | ⁴ AUBERT | 08W | BABR | Superseded by DEL-AMO- SANCHEZ 10B | | | | |

 $^{^3}$ May be $\chi_{C2}(2P)$.

 $^{^4\,\}omega\,J/\psi$ threshold enhancement fitted as an S-wave Breit-Wigner resonance.



X(3915) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------------|------------------------------|
| Γ ₁ | $\frac{\omega}{D}$ *0 D 0 | seen |
| Γ ₃ | $\gamma\gamma$ | seen |

X (3915) Γ(i)Γ($\gamma\gamma$)/Γ(total)

| $\Gamma(\omega J/\psi) \times$ | $\Gamma(\gamma\gamma)/\Gamma$ | total | | | | $\Gamma_1\Gamma_3/\Gamma$ | | |
|--------------------------------|--------------------------------------------|-----------------------|--------|-------------|--------------------------|---------------------------|--|--|
| VALUE (eV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
| 18± 5±2 | 49 ± 15 | ^{5,6} UEHARA | 10 | BELL | 10.6 $e^+e^ \rightarrow$ | $e^+e^-\omegaJ/\psi$ | | |
| • • • We do | not use the | following data for a | verage | s, fits, li | mits, etc. • • • | | | |
| $61\pm17\pm8$ | 49 ± 15 | ^{5,7} UEHARA | 10 | BELL | 10.6 $e^+e^ \rightarrow$ | $e^+e^-\omegaJ/\psi$ | | |
| 5 May be χ_{c} | 2(2P). | | | | | | | |
| 6 For $J^{P} =$ | ⁶ For $J^P = 2^+$, helicity-2. | | | | | | | |
| 7 For $J^{P} =$ | 0+. | | | | | | | |

X(3915) BRANCHING RATIOS

| $\Gamma(\gamma\gamma)/\Gamma_{total}$ | | | | | Гз/Г |
|---------------------------------------|--------------|----|------|---------------------------|-----------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | 8 UEHARA | 10 | BELL | $10.6~e^+e^- \rightarrow$ | $e^+e^-\omega J/\psi$ |
| ⁸ May be $\chi_{a2}(2P)$. | | | | | |

| $\Gamma(\omega J/\psi)/\Gamma(\overline{D}^*)$ | $^{0}D^{0}$ | | | | | Γ_1/Γ_2 |
|------------------------------------------------|-------------|--------------|----|------|----------|---------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| > 0.71 | | 9 ALICUEV | 10 | DELL | D*0 D0 1 | |

 9 By combining the upper limit B(B \rightarrow X(3915) K) \times B(X(3915) \rightarrow $D^{*0}\overline{D}^0) < 0.67 \times 10^{-4}$ from AUSHEV 10 with the average of CHOI 05 and AUBERT 08w measurements B(B \rightarrow X(3915) K) \times B(X(3915) \rightarrow ω $J/\psi) = (0.51 \pm 0.11) \times 10^{-4}$.

| $\Gamma(\omega J/\psi)/\Gamma_{\text{total}}$ | DO CULIENT | 15 | T. C | 504445WT | Γ_1/Γ |
|-----------------------------------------------|--------------------|-------|-----------------------|---------------------------------|-------------------|
| VALUE | <u>DO CUMENT</u> | | TECN | COMMENT | |
| seen | | SA10B | BABR | $B \rightarrow \omega J/\psi K$ | |
| seen | ¹¹ сноі | 05 | BELL | $B \rightarrow \omega J/\psi K$ | |
| ¹⁰ DEL-A MO-SA NCHEZ | 10B reports B(B± → | X(391 | 5) K [±]) : | × B(X(3915) → | $J/\psi\omega$ |

11 CHOI 05 reports $B(B \to X(3915) \ K) \times B(X(3915) \to J/\psi \omega) = (7.1 \pm 1.3 \pm 3.1) \times 10^{-5}.$ X (3915) REFERENCES

| AUSHEV | 10 | PR D81 031103R | T. Aushev et al. | (BELLE Collab.) | |
|------------|------|----------------|-----------------------------|-----------------|--|
| DEL-AMO-SA | 10 B | PR D82 011101R | P. del Amo Sanchez et al. (| BABAR Collab.) | |
| UEHARA | 10 | PRL 104 092001 | S. Uehara et al. | (BELLE Collab.) | |
| AUBERT | W 80 | PRL 101 082001 | B. Aubert et al. (| BABAR Collab.) | |
| CHOI | 05 | PRL 94 182002 | SK. Choi et al. | (BELLE Collab.) | |



 $(2.1 \pm 0.9 \pm 0.3) \times 10^{-5}$.

$$I^{G}(J^{PC}) = 0^{+}(2^{+})$$

$\chi_{c2}(2P)$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|-----------|-------------|-----|------|-----------------------------------------------|
| 3927.2 ± 2.6 OUR | AVERAGE | · | | | |
| $3926.7 \pm 2.7 \pm 1.1$ | 76 ± 17 | AUBERT | 10G | BABR | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |
| $3929 \pm 5 \pm 2$ | 64 | UEHARA | 06 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |

$\chi_{c2}(2P)$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------|-----------|-------------|------|------|-----------------------------------------------|
| 24 ± 6 OUR | AVERAGE | | | | |
| $21.3 \pm 6.8 \pm 3.6$ | 76 ± 17 | AUBERT | 10 G | BABR | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |
| 29 ± 10 ± 2 | 64 | UEHARA | 06 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |

$\chi_{c2}(2P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------------------------------|------------------------------|
| Γ_1 | $\gamma\gamma$ | seen |
| Γ_2 | $K\overline{K}\pi$ | |
| Γ_3 | $K^{+} K^{-} \pi^{+} \pi^{-} \pi^{0}$ | |
| Γ_4 | $D\overline{D}$ | seen |
| Γ_5 | D^+D^- | seen |
| Γ ₆ | $D^0 \overline{D}{}^0$ | seen |

$\chi_{c2}(2P)$ PARTIAL WIDTHS $\chi_{c2}(2P)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(K\overline{K}\pi) \times \Gamma(\gamma\gamma)/$ | Γ _{total} | | | | $\Gamma_2\Gamma_1/\Gamma$ |
|---------------------------------------------------------|--------------------|---------------|------|-----------------------------------------|---------------------------|
| VALUE (eV) | CL% | DO CUMENT ID | TECN | COMMENT | |
| <2.1 | 90 | DEL-AMO-SA11M | BABR | $\gamma \gamma \rightarrow K_S^0 K_S^0$ | \pm_{π} \mp |

| Γ(K+K-π+ | $\pi^-\pi^0) \times \Gamma($ | $(\gamma\gamma)/\Gamma_{\rm total}$ | | | $\Gamma_3\Gamma_1/\Gamma$ |
|----------------------------------------|---------------------------------|-------------------------------------|------|-----------------------------------|---------------------------|
| VALUE (eV) | CL% | DOCUMENT ID | TECN | COMMENT | · |
| <3.4 | 90 | DEL-AMO-SA11M | BABR | $\gamma \gamma \rightarrow K^+ K$ | $-\pi^{+}\pi^{-}\pi^{0}$ |
| $\Gamma(D\overline{D}) \times \Gamma($ | $(\gamma\gamma)/\Gamma_{total}$ | | | | $\Gamma_4\Gamma_1/\Gamma$ |

| (00) ^ () | ' / / / total | | | | '4'1/' |
|-----------------------------------|----------------|------------------------------------|------|------|-----------------------------------------------|
| VALUE (keV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.21±0.04 OUR | AVERAGE | <u> </u> | | | |
| $0.24 \pm 0.05 \pm 0.04$ | 76 ± 17 | AUBERT | 10 G | BABR | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |
| $0.18 \pm 0.05 \pm 0.03$ | 64 | ¹ UEHARA | 06 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |
| ¹ Assuming B(<i>I</i> | $(D^+D^-) = 0$ | 0.89 B($D^{0}\overline{D}^{0}$). | | | |

$\chi_{c2}(2P)$ BRANCHING RATIOS

| $\Gamma(D^+D^-)/\Gamma(D^0$ | ⁰ D 0) | | | | Γ ₅ /Γ ₆ |
|-----------------------------|------------------------------|-------------|----|------|-----------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| $0.74 \pm 0.43 \pm 0.16$ | 64 | UEHARA | 06 | BELL | 10.6 $e^+e^- \rightarrow e^+e^-D\overline{D}$ |

$\chi_{c2}(2P)$ REFERENCES

| DEL-AMO-SA | 11M | PR D84 012004 | P. del Amo Sanchez et al. | (BABAR Collab.) |
|------------|------|---------------|---------------------------|-----------------|
| AUBERT | 10 G | PR D81 092003 | B. Aubert et al. | (BABAR Collab.) |
| UFHARA | 06 | PRI 96 082003 | S. Uehara et al | (BELLE Collab) |

X (3940)

$$I^{G}(J^{PC}) = ?^{?}(?^{??})$$

OMITTED FROM SUMMARY TABLE Reported by ABE 07, observed in $e^+\,e^- \to J/\psi X$.

X(3940) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|------|------------------|----|------|----------------------------------------------|--|--|--|
| 3942 + 7 ± 6 | 52 | PAKHLOV | 80 | BELL | $e^+e^- \to J/\psi X$ | | | |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. $ullet$ $ullet$ | | | | | | | | |
| 3943 ± 6 ± 6 | | ¹ ABE | 07 | BELL | $e^+ e^- \rightarrow J/\psi X$ | | | |
| $3936{\pm}14$ | 266 | ² ABE | 07 | BELL | $e^+ e^- \rightarrow J/\psi(c \overline{c})$ | | | |
| 1 From a fit to $D^{*+}D^-$ and $D^{*0}\overline{D}^0$ events. 2 From the inclusive fit. Not independent of the exclusive measurement by ABE 07. | | | | | | | | |

X(3940) WIDTH

| VALUE (MeV) | CL% | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|---------|-------------|------------------|----------|---------|---------------------------------|
| $37^{+26}_{-15}\pm 8$ | | 52 | PAKHLOV | 08 | BELL | $e^+ e^- \rightarrow J/\psi X$ |
| • • • We do not | use the | following | data for average | s, fits, | limits, | etc. • • • |
| < 52 | 90 | 25 | ABE | 07 | BELL | $e^+ e^- \rightarrow J/\psi X$ |

X(3940) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|----------------------------------------------------|------------------------------|
| Γ ₁ | $D\overline{D}^* + \text{c.c.}$ $D\overline{D}$ | seen not seen |
| Γ ₃ | $J/\psi\omega$ | not seen |

X (3940) BRANCHING RATIOS

| $\Gamma(D\overline{D}^* + c.c.)/\Gamma_{total}$ | | | | | | | | |
|-------------------------------------------------|-------------|----------|------------------|-------------|---------|--------------|------------|--|
| VALUE | CL% | EVTS | DO CUMENT | ID | TECN | COMMENT | | |
| • • • We do | not use the | followin | ig data for aver | ages, fits, | limits, | etc. • • • | | |
| >0.45 | 90 | 25 | 3,4 ABE | 07 | BELL | $e^+e^- \to$ | $J/\psi X$ | |
| 3 - 1/20 | 40) 4 | | | | | | | |

 3 For X(3940) decaying to final states with more than two tracks.

 $^{^4\,\}text{PA\,KHLOV}$ 08 finds that the inclusive peak near 3940 $\,\text{MeV}/\text{c}^2$ may consist of several states.

| $\Gamma(DD)/\Gamma_{\text{total}}$ | | | | | Γ2/Γ |
|------------------------------------|---------------------|--------------------|---------------|-------------------------|------------|
| VALUE | CL% | DO CUMENT ID | TEC | N COMMENT | |
| • • • We do no | t use the following | data for averages, | , fits, limit | ts, etc. • • • | |
| < 0.41 | 90 5 | ,6 ABE | 07 BEL | .L $e^+e^- \rightarrow$ | $J/\psi X$ |

 5 For X(3940) decaying to final states with more than two tracks.

| $\Gamma(J/\psi\omega)/\Gamma_{\rm tot}$ | ai | | | | | Гз/Г |
|-----------------------------------------------------------------------|--------------------------------------|--------------------------------------|---------------------------|------------------|---------------------------------|-----------------|
| VALUE | CL% | DO CUMEN | T ID | TECN | COMMENT | |
| • • • We do not | use the follow | ing data for av | erages, fits | , limits, | etc. • • • | |
| < 0.26 | 90 | 7,8 ABE | 07 | BELL | $e^+e^- \rightarrow$ | $J/\psi X$ |
| ⁷ For <i>X</i> (3940) ⁸ PAKHLOV 0 states. | decaying to fina 8 finds that the | al states with n e inclusive peal | nore than t k near 394 | wotrac 0 MeV/ | ks. 'c ² may con: | sist of several |

X(3940) REFERENCES

| | | • | • | |
|----------------|----------|---------------------------------|------------------------------------|------------------------------------|
| PAKHLOV ABE | 08 07 | PRL 100 202001 PRL 98 082001 | P. Pakhlov et al. K. Abe et al. | (BELLE Collab.) (BELLE Collab.) |
| | | | | |

 ψ (4040)

$$I^G(J^{PC}) = 0^-(1^{--})$$

ψ (4040) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------|----------------------------|----------|---------|----------------------|---------|
| 4039 ± 1 OUR ESTIM | MATE | | | | |
| 4039.6± 4.3 | ¹ ABLIKIM | 08D | BES2 | $e^+e^- \rightarrow$ | hadrons |
| \bullet \bullet \bullet We do not use the | following data for average | s, fits, | limits, | etc. • • • | |
| 4034 ± 6 | ² MO | 10 | RVUE | $e^+e^- \rightarrow$ | hadrons |
| 4037 ± 2 | ³ SETH | 05 A | RVUE | $e^+e^- \rightarrow$ | hadrons |
| 4040 ± 1 | ⁴ SETH | 05 A | RVUE | $e^+e^- \rightarrow$ | hadrons |
| 4040 ±10 | BRANDELIK | 78C | DA SP | e^+e^- | |
| | | | | | |

1 Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770),\,\psi(4040),\,\psi(4160),$ and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(130\,\pm\,46)^\circ.$

² Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ resonances and including interference effects.

³ From a fit to Crystal Ball (OSTERHELD 86) data.

⁴ From a fit to BES (BAI 02c) data

ψ (4040) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|----------------------------|-----------|---------|-----------------------------|
| 80 ±10 OUR ESTIMAT | ΓΕ | | | |
| 84.5 ± 12.3 | ⁵ ABLIKIM | 08D | BES2 | $e^+e^-	o$ hadrons |
| • • • We do not use the f | following data for average | es, fits, | limits, | etc. • • • |
| 87 ±11 | ⁶ MO | | | $e^+e^- ightarrow$ hadrons |
| 85 ±10 | ⁷ SETH | 05 A | RVUE | $e^+e^- ightarrow hadrons$ |
| 89 ± 6 | ⁸ SETH | 05 A | RVUE | $e^+e^-	o$ hadrons |
| 52 ±10 | BRANDELIK | 78C | DA SP | e^+e^- |

 5 Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770),\,\psi(4040),\,\psi(4160),$ and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(130\pm46)^\circ.$

 6 Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ resonances and including interference effects.

From a fit to Crystal Ball (OSTERHELD 86) data.

8 From a fit to BES (BAI 02c) data.

ψ (4040) DECAY MODES

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|----------------|------------------------------------------------------|------------------------------|------------------|
| Γ ₁ | $e^+ e^-$ | $(1.07 \pm 0.16) \times 10$ | ₀ –5 |
| Γ_2^- | $D\overline{D}$ | seen | |
| Γ_3 | $D^0 \overline{D}{}^0$ | seen | |
| Γ_4 | $D^+ D^-$ | seen | |
| Γ_5 | $D^*\overline{D}$ + c.c. | seen | |
| Γ_6 | $D^*(2007)^0 \overline{D}{}^0 + \text{ c.c.}$ | seen | |
| Γ_7 | $D^*(2010)^+ D^- + \text{c.c.}$ | seen | |
| Γ ₈ | $D^*\overline{D}^*$ | seen | |
| Γ9 | $D^*(2007)^0 \overline{D}^*(2007)^0$ | seen | |
| Γ_{10} | $D^*(2010)^+ D^*(2010)^-$ | seen | |
| Γ_{11} | $D\overline{D}\pi(\text{excl. }D^*\overline{D})$ | | |
| Γ_{12} | $D^0D^-\pi^++$ c.c. (excl. | not seen | |
| | $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.},$ | | |
| | $D^*(2010)^+ D^- + c.c.)$ | | |
| Γ_{13} | $D\overline{D}^*\pi(\text{excl. }D^*\overline{D}^*)$ | not seen | |
| Γ_{14} | $D^0 \overline{D}^{*-} \pi^+ + \text{c.c.}$ (excl. | seen | |
| | $D^*(2010)^+ D^*(2010)^-)$ | | |

 $^{^6\,\}text{PAKHLOV}$ 08 finds that the inclusive peak near 3940 MeV/c 2 may consist of several states.

 ψ (4040)

0.95 ± 0.09 ± 0.10

| $D_s^+ D_s^-$ | | seen | | | $\Gamma(D^*\overline{D}^*)/\Gamma(D^*\overline{D}+c.c.$ | |
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-----|
| $J/\psi(1S)$ hadrons $J/\psi\pi^+\pi^-$ | < | 4 | $\times 10^{-3}$ | 90% | <u>VALUE</u> 0.18±0.14±0.03 | |
| $J/\psi \pi^0 \pi^0$ | < | | × 10 × 10 ⁻³ | 90% | | |
| $J/\psi\eta$ | < | | × 10 ⁻³ | 90% | $\Gamma(D^*(2007)^0\overline{D}^*(2007)^0)$ | |
| $J/\psi \pi^{0}$ | < | 2 | $\times 10^{-3}$ | 90% | <u>VALUE</u> Seen | AUBERT 09M BABR $e^+e^- 	o D^{*0} \overline{D}^{*0}$ |
| $J/\psi \pi^{+} \pi^{-} \pi^{0}$ | < | | × 10 ⁻³ | 90% | seen | CRONIN-HEN09 CLEO $e^+e^- 	o D^{*0} \overline{D}^{*0}$ |
| $\chi_{c1} \gamma$ | | 1.1 1.7 | % | 90% 90% | $\Gamma(D^*(2007)^0\overline{D}^*(2007)^0$ | $)/\Gamma(D^*(2007)^0\overline{D}^0+\text{c.c.})$ |
| $\begin{array}{ccc} 3 & \chi_{c2} \gamma \\ 4 & \chi_{c1} \pi^+ \pi^- \pi^0 \end{array}$ | | 1.1 | % | 90% | VALUE | |
| $\chi_{c2} \pi^{+} \pi^{-} \pi^{0}$ | | 3.2 | % | 90% | 32.0±12.0 | 14 GOLDHABER 77 MRK1 $^{e^+e^-}$ |
| $h_c(1P)\pi^+\pi^-$ | < | | $\times 10^{-3}$ | 90% | 14 Phase-space factor (ho^3) ϵ | explicitly removed. |
| $\phi \pi^{+} \pi^{-}$ | < | 3 | $\times 10^{-3}$ | 90% | Γ(D*(2010)+ D*(2010)- | $^-$)/ $\Gamma_{ m total}$ $\Gamma_{ m 10}$ |
| $8 \mu^{+}\mu^{-}$ | | | | | VALUE | DOCUMENT ID TECN COMMENT |
| ψ(4 | 4040) PARTIAL WI | DTHS | | | seen seen | AUBERT 09M BABR $e^+e^- \rightarrow D^{*+}D^{*-}$ CRONIN-HEN09 CLEO $e^+e^- \rightarrow D^{*+}D^{*-}$ |
| - | , | | | - | seen | PAKHLOVA 07 BELL $e^+e^- \rightarrow D^{*+}D^{*-}$ |
| e+ e-) | DO CUMENT ID | TEGN | COMMENT | Г1 | Γ(D0D==+ ι c c (evel | $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.}, D^*(2010)^+ D^- + \text{c.c.}))/$ |
| LUE (keV) 6±0.07 OUR ESTIMATE | DO CUMENT ID | <u>TECN</u> | COMMENT | - | Γ_{total} | Γ ₁₂ |
| 33±0.20 | | | $e^+e^- \to$ | hadrons | <u>VALUE</u> | DOCUMENT ID TECN COMMENT |
| We do not use the follow | 1.0 | | | | not seen | PAKHLOVA 08A BELL $e^+e^- ightarrow D^0D^-\pi^-$ |
| to 1.4 8±0.11 | ¹⁰ MO 10 ¹¹ SETH 05 | | $e^+e^- \rightarrow e^+e^- \rightarrow$ | - | $\Gamma(D\overline{D}^*\pi(\text{excl. }D^*\overline{D}^*))$ | $/\Gamma_{ m total}$ $\Gamma_{ m 13}$ |
| 0.11 11±0.13 | 4.0 | | | | VALUE | DOCUMENT ID TECN COMMENT |
| 5 ± 0.15 | | BC DASP | | | not seen | CRONIN-HEN09 CLEO $e^+e^- 	o D\overline{D}{}^*\pi$ |
| Reanalysis of data presented region 3.7–5.0 GeV covering Phase angle fixed in the fit t | the $\psi(3770)$, $\psi(4040)$ | bal fit over , $\psi($ 4160 $)$, | the center-of and $\psi($ 4415 | f-mass energy i) resonances. | $\Gamma(D^0\overline{D}^{*-}\pi^+ + \text{c.c.})$ (exc | d. D*(2010)+ D*(2010)-))/Γ _{total} Γ ₁₄ |
| Reanalysis of data presented | in BAI 00 and BAI 02 | | | | seen | PAKHLOVA 09 BELL $e^+e^- ightarrow D^0 D^{*-}\pi^+$ |
| of-mass energy 3.8-4.8 GeV and including interference ef quality, mass and total widt | fects. Four sets of solu | tions are o | obtained with | the same fit | $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ | Γ ₁₅ |
| the range of values. | | | | ' ' I | seen | PAKHLOVA 11 BELL $e^+e^- \rightarrow D^+D^-$ |
| $^{ m I}$ From a fit to Crystal Ball (C | OSTERHELD 86) data. | | | | | |
| | \ data | | | | seen | DEL-AMO-SA10N BABR $e^+e^- \rightarrow D^+D^-\gamma$ |
| |) data. | | | | seen seen | DEL-AMO-SA10N BABR $e^+e^- \rightarrow D_s^+D_s^-$ CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+D_s^-$ |
| ² From a fit to BES (BAI 02c) |) data. D40) BRANCHING I | RATIOS | | | seen | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+D_s^-$ |
| ² From a fit to BES (BAI 02c) ψ (40 | , | RATIOS | | Γ. /Γ | seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{	ext{total}}$ | CRONIN-HEN09 CLEO $e^+e^- ightarrow {\cal D}_S^+{\cal D}_S^-$ |
| 2 From a fit to BES (BAI 02c) ψ (40 $(e^+e^-)/\Gamma_{	ext{total}}$ | 040) BRANCHING I | | COMMENT | Γ ₁ /Γ | seen | CRONIN-HEN09 CLEO $e^+e^- ightarrow {\cal D}_s^+{\cal D}_s^-$ F17 DOCUMENT ID TECN COMMENT |
| 2 From a fit to BES (BAI 02c) ψ (40 e^+e^-) $/\Gamma_{	ext{total}}$ LUE (units 10^{-5}) | DAO) BRANCHING I | TECN | | Γ ₁ /Γ | seen $ \frac{\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}}{\frac{VALUE \text{ (units }10^{-3})}{90}} \frac{CL\%}{90} $ | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+D_s^-$ COAN 06 CLEO $e^+e^- \rightarrow D_s^+D_s^-$ COMMENT CLEO 3.97-4.06 $e^+e^- \rightarrow$ hadro |
| ψ (40) $\psi(40)$ $e^+e^-)/\Gamma_{\text{total}}$ $UE \text{ (units } 10^{-5})$ • We do not use the follow | DAO) BRANCHING I | TECN | | Γ ₁ /Γ | seen | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+D_s^ D_s^ |
| From a fit to BES (BAI 02c) $\psi(40)$ $e^+e^-)/\Gamma_{\text{total}}$ $\frac{UE \text{ (units }10^{-5}\text{)}}{\text{ • We do not use the follow}}$ 1.0 | DOCUMENT ID DOCUMENT ID along data for averages, f | TECN | etc. • • • | | seen | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+ D_s^-$ COAN 06 CLEO $e^+e^- \rightarrow D_s^+ D_s^-$ COAN 06 CLEO COMMENT CLEO 3.97-4.06 $e^+e^- \rightarrow$ hadro COMMENT ID DOCUMENT ID TECN COMMENT |
| ψ (40) $e^+e^-)/\Gamma_{\text{total}}$ $UE (\text{units } 10^{-5})$ • We do not use the follow 1.0 $D^0 \overline{D}^0)/\Gamma_{\text{total}}$ | DOCUMENT ID ing data for averages, f | TECN its, limits, 7 MRK1 | etc. • • • e ⁺ e ⁻ | Γ ₁ /Γ | seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-3})}{<4} \frac{\text{CL\%}}{90}$ $\Gamma(J/\psi\pi^0\pi^0)/\Gamma_{\text{total}}$ $\frac{\text{MLUE (units }10^{-3})}{<2} \frac{\text{CL\%}}{90}$ | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+D_s^ D_s^ |
| ψ (40) $e^+e^-)/\Gamma_{\text{total}}$ $UE (\text{units } 10^{-5})$ • We do not use the follow 1.0 $D^0 \overline{D}^0)/\Gamma_{\text{total}}$ UE | DOCUMENT ID TELDMAN 77 | TECN its, limits, MRK1 | etc. • • • e^+e^- | Г ₃ /Г | seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-3})}{\sqrt{4}} \frac{CL\%}{90}$ $\Gamma(J/\psi\pi^0\pi^0)/\Gamma_{\text{total}}$ $\frac{VALUE \text{ (units }10^{-3})}{\sqrt{2}} \frac{CL\%}{90}$ $\Gamma(J/\psi\eta)/\Gamma_{\text{total}}$ | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+ D_s^-$ COAN 06 CLEO $e^+e^- \rightarrow D_s^+ D_s^-$ COAN 06 CLEO COMMENT CLEO 3.97-4.06 $e^+e^- \rightarrow$ hadro COMMENT ID DOCUMENT ID TECN COMMENT |
| ψ (40 e+ e-)/ Γ_{total} $UE \text{ (units } 10^{-5}\text{)}$ • We do not use the follow 1.0 $D^0 \overline{D^0}$)/ Γ_{total} $UE \text{ (units } 10^{-5}\text{)}$ | DOCUMENT ID TELDMAN 77 | TECN its, limits, 7 MRK1 TECN 9M BABR O CLEO | etc. \bullet \bullet \bullet e^+e^- COMMENT $e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^+e^-$ | Γ_3/Γ $D^0\overline{D}^0\gamma$ $D^0\overline{D}^0$ | seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\frac{MLUE \text{ (units }10^{-3})}{<4} \frac{CL\%}{90}$ $\Gamma(J/\psi\pi^0\pi^0)/\Gamma_{\text{total}}$ $\frac{MLUE \text{ (units }10^{-3})}{<2} \frac{CL\%}{90}$ $\Gamma(J/\psi\eta)/\Gamma_{\text{total}}$ $\frac{MLUE \text{ (units }10^{-3})}{} \frac{CL\%}{}$ | CRONIN-HEN09 CLEO $e^+e^- \rightarrow D_s^+ D_s^ D_s^- D_s^- D_s^-$ COAN 06 CLEO 2.97-4.06 $e^+e^- \rightarrow D_s^+ D_s^-$ Page 2.97-4.06 $e^+e^- \rightarrow D_s^+ D_s^-$ COAN 06 CLEO 3.97-4.06 $e^+e^- \rightarrow D_s^+ D_s^-$ DOCUMENT ID TECN COMMENT DOCUMENT ID TECN COMMENT Tage 2.97-4.06 $e^+e^- \rightarrow D_s^+ D_s^-$ |
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D^0\overline{D}^0\gamma \\ D^0\overline{D}^0\gamma \\ \hline D^0\overline{D}^0\gamma \end{array} $ $ \begin{array}{c c} \Gamma_4/\Gamma \\ \hline D^+D^-\gamma \\ D^+D^-\gamma \\ D^+D^-\gamma \end{array} $ $ \begin{array}{c c} \Gamma_2/\Gamma_5 \\ \hline \gamma D^{(*)}\overline{D} \end{array} $ | seen $\Gamma(J/\psi \pi^{+}\pi^{-})/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<4} \frac{CL\%}{90}$ $\Gamma(J/\psi \pi^{0}\pi^{0})/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<2} \frac{CL\%}{90}$ $\Gamma(J/\psi \eta)/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<7} \frac{CL\%}{90}$ $\Gamma(J/\psi \pi^{0})/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<2} \frac{CL\%}{90}$ $\Gamma(J/\psi \pi^{+}\pi^{-}\pi^{0})/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<2} \frac{CL\%}{90}$ $\Gamma(\chi_{c1}\gamma)/\Gamma_{\text{total}}$ $\frac{NALUE (\text{units }10^{-3})}{<11} \frac{CL\%}{90}$ 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09м BABR $e^+e^-
ightarrow \gamma D^* \overline{D}$

AUBERT

15 From several values of \sqrt{s} near the peak of the $\psi(4040)$, PEDLAR 11 measures $\sigma(e^+e^-\to h_C(1P)\,\pi^+\pi^-)=1.0\pm 8.0\pm 5.4\pm 0.2$ pb, where the errors are statistical, systematic, and due to uncertainty in $\mathrm{B}(\psi(2S)\to\pi^0\,h_C(1P))$, respectively.

| $\Gamma(\phi\pi^+\pi^-)/\Gamma_{ m to}$ | otal | | | | Γ ₂₇ /Γ |
|-----------------------------------------|------|-------------|----|------|--------------------------------------|
| VALUE (units 10^{-3}) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <3 | 90 | C OA N | 06 | CLEO | 3.97–4.06 $e^+e^- ightarrow$ hadrons |

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$$I(J^P) \ = \ ?(?^?)$$

OMITTED FROM SUMMARY TABLE

Observed by MIZUK 08 in the $\pi^+\chi_{c1}(1P)$ invariant mass distribution in $\overline B^0 \to K^-\pi^+\chi_{c1}(1P)$ decays. Not seen by LEES 12B in this same mode after accounting for $K\pi$ resonant mass and angular

$X(4050)^{\pm}$ MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------|--------------------|----|------|------------------------------------------------------|
| 4051±14+20 -41 | ¹ MIZUK | 08 | BELL | $\overline{B^0} \rightarrow K^- \pi^+ \chi_{c1}(1P)$ |

¹ From a Dalitz plot analysis with two Breit-Wigner amplitudes

X (4050) # WIDTH

| VALUE (MeV) | DOCUMENT I | פ | TECN | COMMENT |
|--------------------------------------|--------------------|----|------|------------------------------------------------------|
| $82 + \frac{21}{17} + \frac{47}{22}$ | ² MIZUK | 08 | BELL | $\overline{B}^0 \rightarrow K^- \pi^+ \chi_{c1}(1P)$ |

 $^2\,\mbox{From a Dalitz plot}$ analysis with two Breit-Wigner amplitudes.

$X(4050)^{\pm}$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----|-----------------------|------------------------------|
| Γ1 | $\pi^+ \chi_{c1}(1P)$ | seen |

X(4050) BRANCHING RATIOS

| $\Gamma(\pi^+\chi_{c1}(1P))/\Gamma$ | - total | | | Γ_1/Γ |
|-------------------------------------|---------------------------------------------|---------------------|------------------|------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| seen | ³ MIZUK | 08 | BELL | $\overline{B}^0 \rightarrow K^- \pi^+ \chi_{C1}(1P)$ |
| • • • We do not us | e the following data for ave | rages, | fits, limi | ts, etc. • • • |
| not seen | ⁴ LEES | 12B | BABR | $B \rightarrow K \pi \chi_{c1}(1P)$ |
| ³ With a product | branching fraction measu | ı re <u>m e</u> n | t of B(| $\overline{B}^0 \rightarrow K^- X(4050)^+) \times$ |
| $B(X(4050)^+ \rightarrow$ | $\pi^+ \chi_{c1}(1P)) = (3.0 + 1.5 \\ -0.8$ | $^{+3.7}_{-1.6}$ | $\times 10^{-5}$ | i. |
| ⁴ With a product 1 | oranching fraction limit of B | $(\overline{B^0} -$ | → X(405 | $(0)^+ K^-) \times B(X(4050)^+ \rightarrow$ |

X(4050) = REFERENCES

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| MIZUK | 00 | | | |
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X (4140

$$I^{G}(J^{PC}) = 0^{+}(?^{?+})$$

OMITTED FROM SUMMARY TABLE

 $\chi_{C1} \, \pi^+) < 1.8 \times 10^{-5} \, {\rm at} \, 90\% \, {\rm CL}.$

Needs confirmation.

Seen by AALTONEN 09AH in the $B^+ \to X K^+$, $X \to J/\psi \phi$. Not seen by SHEN 10 in $\gamma\gamma \to J/\psi\phi$.

X(4140) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|----------------|--------|--------------|----------|-----------------------------------|--|
| 4143.0±2.9±1.2 | 14 ± 5 | 1 AALT ONEN | 09AH CDF | $B^+ \rightarrow J/\psi \phi K^+$ | |

| X (4140) WIDTH |
|----------------|

 1 Statistical significance of 3.8 σ .

| | • | . () | • | |
|-----------------------------------|-------------------------|-----------------------|----------|-----------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| $11.7^{+8.3}_{-5.0}\pm3.7$ | 14 ± 5 | ² AALTONEN | 09AH CDF | $B^+ \rightarrow J/\psi \phi K^+$ |
| ² Statistical signific | cance of 3.8 σ . | | | |

X(4140) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------|------------------------------|
| $\overline{\Gamma_1}$ | $J/\psi \phi$ | seen |
| Γ_2 | $\gamma \gamma$ | not seen |

$X(4140) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\gamma\gamma) \times \Gamma(.$ | $J/\psi \phi)/\Gamma_{\rm to}$ | otal | | | | $\Gamma_2\Gamma_1/\Gamma$ |
|----------------------------------------|--------------------------------|-------------------|----------|------|---------------------------------------------------------------------------------|---------------------------|
| VALUE (eV) | CL% | DO CUMENT II | D | TECN | COMMENT | |
| <41 | 90 | ³ SHEN | 10 | BELL | $10.6 e^+e^- \rightarrow e^+e^- J/\psi \phi$ | |
| • • • We do n | ot use the fo | llowing data for | averages | | | |
| < 6 | 90 | ⁴ SHEN | 10 | BELL | $\begin{array}{c} 10.6 \ e^+e^- \rightarrow \\ e^+e^- J/\psi \phi \end{array}$ | |
| ${}^{3}_{4}$ For ${}^{JP}_{IP} = 0$ | ı+. .+ | | | | | |

X(4140) BRANCHING RATIOS

| $\Gamma(J/\psi\phi)/\Gamma_{ m total}$ | | | | Γ ₁ /Γ |
|----------------------------------------|---------------|-----------------------|----------|-----------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| seen | 14 ± 5 | ⁵ AALTONEN | 09AH CDF | $B^+ \rightarrow J/\psi \phi K^+$ |
| 5 Statistical significa | ance of 3.8 σ | | | |

| $\Gamma(\gamma\gamma)/\Gamma_{ m total}$ | | | | | Γ_2/Γ |
|------------------------------------------|--------------|----|------|---------------------------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| not seen | SHEN | 10 | BELL | $10.6 e^+e^- \rightarrow$ | |
| | SHEN | 10 | BELL | $10.6 e^{+}e^{-} \rightarrow e^{+}e^{-} \rightarrow 1/y/\phi$ | |

X(4140) REFERENCES

10 PRL 104 112004 09AH PRL 102 242002 SHEN AALT ON EN

 ψ (4160)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

$\psi(4160)$ MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|----------------------|---------|-----------|-----------------------------|
| 4153 ± 3 OUR ESTIMATE | | | | |
| 4191.7± 6.5 | ¹ ABLIKIM | 08D | BES2 | $e^+e^- ightarrow hadrons$ |
| | g data for average | s, fits | , limits, | etc. • • • |
| 4193 ± 7 | ² MO | 10 | RVUE | $e^+e^- ightarrow$ hadrons |
| 4151 ± 4 | ³ SETH | 05 A | RVUE | $e^+e^- ightarrow hadrons$ |
| 4155 ± 5 | ⁴ SETH | 05 A | RVUE | $e^+e^- ightarrow$ hadrons |
| 4159 ±20 | BRANDELIK | 78C | DA SP | e^+e^- |

¹ Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770),\,\psi(4040),\,\psi(4160),$ and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(293\pm57)^\circ.$

ψ (4160) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------------|------|-------|------------------------------|
| 103 ± 8 OUR ESTIMATE 71.8±12.3 | 5 ARLIKIM | 08D | RES2 | $e^+e^- \rightarrow hadrons$ |
| • • We do not use the following | g data for average | | | |
| 79 ±14 | ⁶ мо | 10 | RVUE | $e^+e^-	o$ hadrons |
| 107 ±10 | ⁷ SETH | 05 A | RVUE | $e^+e^- ightarrow$ hadrons |
| 107 ±16 | ⁸ SETH | 05 A | RVUE | $e^+e^-	o$ hadrons |
| 78 ±20 | BRANDELIK | 78C | DA SP | e^+e^- |

 $^{^{5}}$ Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(293\pm57)^\circ$.

Primage angle fixed in the interest to $\theta=(233\pm37)$. 2 Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ resonances and including interference effects. 3 From a fit to Crystal BaII (OSTERHELD 86) data.

⁴ From a fit to BES (BAI 02c) data.

Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040), \psi(4160)$ and $\psi(4415)$ resonances and including interference effects. From a fit to Crystal Ball (OSTERHELD 86) data. From a fit to BES (BAI 02c) data.

 ψ (4160)

$\psi(4160)$ DECAY MODES

Due to the complexity of the $c\overline{c}$ threshold region, in this listing, "seen" One of the company of the centimeshold region, in this histing, seen ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-------------------------------------------------------------------------|------------------------------|------------------|
| Γ_1 | $e^+ e^-$ | $(8.1 \pm 0.9) \times 10$ | -6 |
| Γ_2 | D D | seen | |
| Γ3 | $D^0 \overline{D}{}^0$ | seen | |
| Γ_4 | $\underline{D}^+ D^-$ | seen | |
| Γ_5 | $D^*\overline{D}$ + c.c. | seen | |
| Γ ₆ | $D^*(2007)^0 \overline{D}^0 + \text{c.c.}$ | seen | |
| Γ_7 | $D^*(2010)^+ D^- + \text{c.c.}$ | seen | |
| Γ ₈ | D* D * | seen | |
| Γ9 | $D^*(2007)^0 \overline{D}^*(2007)^0$ | seen | |
| Γ_{10} | $D^*(2010)^+ D^*(2010)^-$ | seen | |
| Γ_{11} | $D^{0}D^{-}\pi^{+} + \text{c.c.}$ (excl. | not seen | |
| | $D^*(2007)^0 \overline{D}^{0} + \text{c.c.},$ | | |
| _ | $D^*(2010)^+D^- + c.c.)$ | | |
| Γ ₁₂ | $D \overline{D}^* \pi + \text{c.c.} (\text{excl. } D^* \overline{D}^*)$ | seen | |
| Γ ₁₃ | $D^0 D^{*-} \pi^+ + \text{c.c.}$ (excl. | not seen | |
| _ | $D^*(2010)^+ D^*(2010)^-)$ | | |
| Γ ₁₄ | $D_s^+D_s^-$ | not seen | |
| Γ ₁₅ | $D_s^{*+}D_s^- + \text{c.c.}$ | seen | |
| Γ_{16} | $J/\psi \pi^+ \pi^-$ | < 3 × 10 | |
| Γ_{17} | $J/\psi \pi^0 \pi^0$ | < 3 × 10 | |
| Γ ₁₈ | $J/\psi K^+ K^-$ | < 2 × 10 | |
| Γ ₁₉ | $J/\psi \eta$ | < 8 × 10 | -3 90% |
| Γ ₂₀ | $J/\psi \pi^0$ | < 1 × 10 | |
| Γ ₂₁ | $J/\psi \eta'$ | < 5 × 10 | |
| Γ ₂₂ | $J/\psi \pi^{+} \pi^{-} \pi^{0}$ | < 1 × 10 | |
| | $\psi(2S)\pi^+\pi^-$ | < 4 × 10 | -3 90% |
| Γ ₂₄ | $\chi_{c1} \gamma$ | < 7 × 10 | |
| Γ ₂₅ | $\chi_{c2}\gamma_{\perp} = 0$ | < 1.3 % | 90% |
| Γ ₂₆ | $\chi_{c1} \pi^{+} \pi^{-} \pi^{0}$ | < 2 × 10 | -3 90% -3 |
| Γ ₂₇ | $\chi_{c2} \pi^{+} \pi^{-} \pi^{0}$ | < 8 × 10 | -3 90% |
| Γ ₂₈ | $h_c(1P)\pi^+\pi^-$ | < 5 × 10 | -3 90% -3 90% |
| Γ ₂₉ | $h_c(1P)\pi^0\pi^0$ | < 2 × 10 < 2 × 10 | |
| Γ ₃₀ | $h_c(1P)\eta$ | | |
| Γ ₃₁ | $h_c(1P)\pi^0$ $\phi\pi^+\pi^-$ | < 4 × 10 < 2 × 10 | |
| Γ ₃₂ | $\varphi\pi \cdot \pi$ | < 2 × 10 | -3 90% |

ψ (4160) PARTIAL WIDTHS

| ! (e ⁺ e ⁻) | | | | | | 11 |
|-----------------------------------------------|----------------------|----------|---------|-----------------------|---------|----|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | | |
| 0.83±0.07 OUR ESTIMATE | | | | | | |
| 0.48±0.22 | ⁹ ABLIKIM | 08D | BES2 | $e^+e^- \rightarrow$ | hadrons | |
| $\bullet~\bullet~$ We do not use the followin | g data for average | s, fits, | limits, | etc. • • • | | |
| | ¹⁰ MO | 10 | RVUE | e^+e^- | hadrons | |
| 0.00 ± 0.00 | | 05 A | RVUE | $e^+ e^- \rightarrow$ | hadrons | |
| 0.84 ± 0.13 | ¹² SETH | 05 A | RVUE | $e^+e^- \rightarrow$ | hadrons | |
| 0.77 ± 0.23 | BRA NDELIK | 78C | DASP | e^+e^- | | |

ψ (4160) BRANCHING RATIOS

| $\Gamma(D\overline{D})/\Gamma(D^*\overline{D}^*)$ | | | | | Γ_2/Γ_8 |
|---------------------------------------------------|------------------|---------|---------|--------------|-------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.02 \pm 0.03 \pm 0.02$ | AUBERT | 09м | BABR | $e^+e^- \to$ | $\gamma D^{(*)} \overline{D}^{(*)}$ |
| $\Gamma(D^0 \overline{D}{}^0)/\Gamma_{ m total}$ | | | | | Г3/Г |
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| seen | CRONIN-HEN. | 09 | CLEO | e^+e^- | $D^0 \overline{D}{}^0$ |
| seen | PAKHLOVA | 80 | BELL | e^+e^- | $D^0 \overline{D}{}^0 \gamma$ |
| • • • We do not use the following | data for average | s, fits | limits, | etc. • • • | |
| not seen | AUBERT | 09м | BABR | $e^+e^- \to$ | $D^0 \overline{D}{}^0 \gamma$ |

| $\Gamma(D^+D^-)/\Gamma_{\text{total}}$ | | DO 01:: | | | | Γ4/ |
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| <i>VA L U E</i> See n | | CRONIN-HE | | CLEO | $e^+e^- \rightarrow$ | D+ D- |
| seen | | PAKHLOVA | 08 | BELL | | $D^+D^-\gamma$ |
| • • • We do not use t | he following d | ata for averag | | | | |
| not seen | | AUBERT | 09м | BABR | $e^+e^ \rightarrow$ | $D^+D^-\gamma$ |
| $\Gamma(D^*(2007)^0 \overline{D}{}^0 + c$ | .c.)/Γ _{total} | | | | | Γ ₆ / |
| VALUE | | DO CUMENT IL |) | TECN | COMMENT | |
| seen | | AUBERT | | BABR | $e^+e^- \rightarrow e^+e^- \rightarrow$ | |
| seen | | CRONIN-HE | NU9 | CLEO | e · e → | D. • D• |
| $\Gamma(D^*(2010)^+D^-+$ | | | | | | Γ ₇ / |
| VALUE Seen | | DOCUMENT IL AUBERT | | TECN BABR | COMMENT | $D^{*+}D^{-}\gamma$ |
| seen | | CRONIN-HE | | CLEO | e+e- → | |
| seen | | PAKHLOVA | 07 | BELL | $e^+e^- \rightarrow$ | $D^{*+}D^{-}\gamma$ |
| $\Gamma(D^*\overline{D} + c.c.)/\Gamma(D$ | * D *) | | | | | Г ₅ /Г |
| VALUE | | DO CUMENT IL |) | TECN | COMMENT | |
| $0.34 \pm 0.14 \pm 0.05$ | | AUBERT | 09м | BABR | $e^+e^- \rightarrow$ | $\gamma D^{(*)} \overline{D}^{(*)}$ |
| Γ(<i>D</i> *(2007) ⁰ D *(20 | 07) ⁰)/Γ _{total} | | | | | Г9/ |
| VALUE | | DO CUMENT IL | | | COMMENT | |
| seen seen | | AUBERT CRONIN-HE | | BABR CLEO | $e^+e^- \rightarrow e^+e^- \rightarrow$ | $D^{*0} \overline{D}^{*0} \gamma$ $D^{*0} \overline{D}^{*0} \gamma$ |
| | | | IVU7 | CLEU | e · e → | |
| Γ(<i>D</i> *(2010)+ <i>D</i> *(20 | 10) ⁻)/Γ _{tot} | | | | | Γ ₁₀ / |
| VA <i>LUE</i> seen | | DOCUMENT IL AUBERT | | TECN BABR | | D*+ D*- |
| seen | | CRONIN-HE | | CLEO | | D*+ D*- |
| seen | | PAKHLOVA | 07 | BELL | $e^+e^- \rightarrow$ | D*+ D*- |
| $\Gamma(D^0D^-\pi^+ + \text{c.c.})$ | excl. <i>D</i> *(20 | 007) ⁰ \overline{D}^0 + | c.c., <i>D</i> | *(2010 |)+ <i>D</i> -+c | .c.))/ |
| T _{total} | | | | | | .с.,,, Г ₁₁ / |
| VALUE | | DOCUMENT IL | | | COMMENT_ | · |
| not seen | | PAKHLOVA | 08A | BELL | $e^+e^- \rightarrow$ | $D^{0}D^{-}\pi^{+}$ |
| | | TANTEOVA | OOA | | | |
| $\Gamma(D\overline{D}^*\pi+c.c.$ (exc | | | OOA | | | Γ ₁₂ / |
| VALUE | | /F _{total} <u>DOCUMENT IL</u> |) | | COMMENT | - |
| <u>VALUE</u> Seen | l. <i>D* D*</i>))/ | /F _{total} <u>DOCUMENT IL</u> CRONIN-HE | N09 | CLEO | $e^+e^- \rightarrow$ | - |
| NALUE Seen $\Gamma(D^0 D^{*-} \pi^+ + \text{c.c.})$ | (exd. <i>D</i> *))/ | /F _{total} <u>DOCUMENT II</u> CRONIN-HE 2010)+ <i>D</i> *(| N09 2010) | CLEO | $e^+e^- ightarrow$ otal | $D\overline{D}^*\pi$ |
| Seen $\Gamma(D^0D^{*-}\pi^+ + c.c.)$ VALUE | (exd. <i>D</i> *(2 | /T _{total} <u>DOCUMENT II</u> CRONIN-HE 2010) + D*(DOCUMENT II | 0 N09 2010) | CLEO -))/Γ _{tα} <u>TECN</u> | $e^{+}e^{-} \rightarrow$ otal $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | D D*π |
| NALUE Seen $\Gamma(D^0 D^{*-} \pi^+ + \text{c.c.})$ | (exd. <i>D</i> *(2 | /F _{total} <u>DOCUMENT II</u> CRONIN-HE 2010)+ <i>D</i> *(| N09 2010) | CLEO | $e^+e^- ightarrow$ otal | D D*π |
| Seen $\Gamma(D^0D^{*-}\pi^+ + \text{C.C.})$ NALUE not seen | (exd. <i>D</i> *(2 | /T _{total} <u>DOCUMENT II</u> CRONIN-HE 2010) + D*(DOCUMENT II | 0 N09 2010) | CLEO -))/Γ _{tα} <u>TECN</u> | $e^{+}e^{-} \rightarrow$ otal $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | ^D π π Γ ₁₃ / |
| Seen $\Gamma(D^0D^{*-}\pi^+ + c.c.)$ VALUE | (exd. <i>D</i> *(2 | /T _{total} <u>DOCUMENT II</u> CRONIN-HE 2010) + D*(DOCUMENT II | 0 N09 2010) 09 | CLEO))/F _{to} TECN BELL | $e^{+}e^{-} \rightarrow$ otal $\frac{COMMENT}{e^{+}e^{-}} \rightarrow$ | ^D π π Γ ₁₃ / |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ not seen $\Gamma(D_s^+D_s^-)/\Gamma_{	ext{total}}$ | (exd. <i>D</i> *(2 | /T _{total} DOCUMENT II CRONIN-HE 2010) + D*(DOCUMENT II PAKHLOVA | 0 N09 2010) 09 | CLEO))/F _{to} TECN BELL | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \text{At al} \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ D^{0}D^{*-} \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | $D\overline{D}^*\pi$ $\Gamma_{13}/\Gamma_{13}/\Gamma_{14}/\Gamma_{14}/\Gamma_{15}$ $\Gamma_{15}/\Gamma_{5}/\Gamma_{5}$ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ NALUE not seen $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ NALUE | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D*(DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S | 0 N09 2010) 09 09 | TECN BELL TECN BELL BELL BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \text{At al} \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ D^{0}D^{*-} \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | $D\overline{D}^*\pi$ $\Gamma_{13}/\Gamma_{13}/\Gamma_{14}/\Gamma_{14}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{$ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ $VALUE$ not seen $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ $VALUE$ not seen | (exd. <i>D</i> *(2 | /Ttotal DOCUMENT IL CRONIN-HE 2010)+ D*(DOCUMENT IL PAKHLOVA | 0 N09 2010) 09 09 | CLEO))/\(\Gamma_{tecn}\) BELL TECN BELL | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \text{At al} \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ D^{0}D^{*-} \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | $D\overline{D}^*\pi$ $\Gamma_{13}/\Gamma_{13}/\Gamma_{14}/\Gamma_{14}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{15}/\Gamma_{$ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ $\Gamma(D^sD^{*-})/\Gamma_{\text{total}}$ $VALUE$ not seen not seen not seen not seen not seen not seen | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D*(DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S | 0 N09 2010) 09 09 | TECN BELL TECN BELL BELL BABR | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ \text{At al} \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ D^{0}D^{*-} \\ \\ \underline{COMMENT} \\ e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \\ \end{array}$ | Γ ₁₃ / Γ ₁₄ / Γ ₁₄ / Γ ₁₅ Γ ₅ γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ ₅ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ Γ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.}$ $VALUE$ not seen $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ $VALUE$ not seen not seen not seen | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT II. CRONIN-HE 2010) + D*(DOCUMENT II. PAKHLOVA DOCUMENT II. PAKHLOVA DEL-AMO-S CRONIN-HE | N09 2010) 09 09 11 A10N N09 | TECN BELL BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \text{Atal} \\ \hline \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^- \\ \hline \\ \underline{comment}_{D^0D^{*-}} \\ \hline \end{array}$ | D D̄*π Γ13/ Γ14/ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ C ₁₅ / |
| Seen $\Gamma(D^0D^{*-}\pi^+ + \text{C.C.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{C.C.})$ $\Gamma(D^+_sD^s)/\Gamma_{\text{total}}$ $\Gamma(D^+_sD^s)/\Gamma_{\text{total}}$ $\Gamma(D^+_sD^s)/\Gamma_{\text{total}}$ not seen not seen $\Gamma(D^+_sD^s + \text{C.C.})/\Gamma_{\text{VALUE}}$ | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT II. CRONIN-HE 2010) + D*(DOCUMENT II. PAKHLOVA DOCUMENT II. PAKHLOVA DEL-AMO-S CRONIN-HE | N09 2010) 09 09 11 A10N N09 | TECN BELL BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \text{Atal} \\ \hline \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^- \\ \hline \\ \underline{comment}_{D^0D^{*-}} \\ \hline \end{array}$ | D D̄*π Γ13/ Γ14/ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ C ₁₅ / |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ not seen $\Gamma(D^*_sD^s)/\Gamma_{\text{total}}$ NALUE not seen not seen not seen $\Gamma(D^*_sD^s + \text{c.c.})/\Gamma_{\text{VALUE}}$ seen seen | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D*(DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S CRONIN-HE DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S | 0 N09 2010) 09 09 11 A10N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | D D̄*π Γ13/ Γ14/ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ not seen $\Gamma(D^*_sD^s)/\Gamma_{\text{total}}$ NALUE not seen not seen not seen $\Gamma(D^*_sD^s + \text{c.c.})/\Gamma_{\text{VALUE}}$ seen seen | (exd. <i>D</i> *(2 | / Ttotal DOCUMENT II. CRONIN-HE 2010) + D*(DOCUMENT II. PAKHLOVA DOCUMENT II. PAKHLOVA DEL-AMO-S CRONIN-HE | 0 N09 2010) 09 09 11 A10N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \hline \text{Atal} \\ \hline \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{D^0D^{*-}} \\ \hline \\ \underbrace{comment}_{e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^+e^- \rightarrow e^- \\ \hline \\ \underline{comment}_{D^0D^{*-}} \\ \hline \end{array}$ | D D̄*π Γ13/ Γ14/ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ D _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ C _S +D _S γ |
| Seen $\Gamma\left(D^0D^{*-}\pi^+ + \text{C.C.}\right)$ $\Gamma\left(D^0D^{*-}\pi^+ + \text{C.C.}\right)$ $\Gamma\left(D^s+D^s\right)/\Gamma_{\text{total}}$ $\Gamma\left(D^s+D^s\right)/\Gamma_{\text{total}}$ not seen $\Gamma\left(D^s+D^s+\text{C.C.}\right)/\Gamma_{\text{VALUE}}$ seen seen seen seen | (excl. <i>D</i> *(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D*(DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S CRONIN-HE DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S | 0 N09 2010) 09 09 11 A10N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \end{array}$ |
| seen $\Gamma(D^0D^{*-}\pi^+ + \text{C.C.}$ $\Gamma(D^sD^{*-}\pi^+ + \text{C.C.}$ $\Gamma(D^sD^-)/\Gamma_{\text{total}}$ $\Gamma(D^sD^-)/\Gamma_{\text{total}}$ $\Gamma(D^sD^-)/\Gamma_{\text{total}}$ not seen not seen $\Gamma(D^sD^-)/\Gamma_{\text{constant}}$ $\Gamma(D^sD^-)/\Gamma_{\text{constant}}$ | (excl. <i>D</i> *(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D*(DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S CRONIN-HE DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DEL-AMO-S | 09 09 11 11 A10N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{l} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0 D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \end{array}$ |
| Seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0S^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0S^{*-}\pi^+ + \text{c.c.})/\Gamma_{\text{total}}$ $\Gamma(D^0S^{*-}\pi^+ + \text{c.c.})/\Gamma_{\text{total}}$ $\Gamma(D^0S^{*-}\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ seen seen $\Gamma(D^0S^{*-}\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ $\Gamma(D^0S^{*-}\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ seen seen $\Gamma(D^0S^{*-}\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ | (excl. <i>D</i> *(2 | / Ttotal DOCUMENT II. CRONIN-HE 2010) + D*(DOCUMENT II. PAKHLOVA DOCUMENT II. PAKHLOVA DEL-AMO-S CRONIN-HE DOCUMENT II. CRONIN-HE | 11 1.1.0N N09 1.1.0N N09 1.1.0N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{l} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0 D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \\ \hline \Gamma_{16} / \\ \end{array}$ |
| Seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^+_sD^s)/\Gamma_{\text{total}}$ $VALUE$ Into seen not seen not seen not seen $\Gamma(D^*_sD^s + \text{c.c.})/\Gamma_{VALUE}$ $\Gamma(D^*_sD^s + \text{c.c.})/\Gamma_{VALUE}$ Seen seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ | (excl. <i>D*</i> (2 | / Ttotal DOCUMENT II. CRONIN-HE 2010) + D*(DOCUMENT II. PAKHLOVA DOCUMENT II. PAKHLOVA DEL-AMO-S CRONIN-HE DOCUMENT II. CRONIN-HE | 11 1.1.0N N09 1.1.0N N09 1.1.0N N09 | TECN BELL BABR CLEO TECN BELL BABR CLEO TECN BELL BABR CLEO | $\begin{array}{c} e^+e^- \rightarrow \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0 D^{*-} \\ \\ \hline \\ \frac{COMMENT}{e^+e^- \rightarrow } \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow $ $e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow $ | $\begin{array}{c c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ \hline \Gamma_{16} / \\ \hline \rightarrow \text{ hadrons} \end{array}$ |
| Seen $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^0D^{*-}\pi^+ + \text{c.c.})$ $\Gamma(D^+_SD^S)/\Gamma_{\text{total}}$ $VALUE$ not seen not seen not seen $\Gamma(D^{*+}_SD^S + \text{c.c.})/\Gamma_{VALUE}$ seen seen $\Gamma(J/\psi\pi^+\pi^-)/\Gamma_{\text{total}}$ $VALUE(units 10^{-3})$ $CL\%$ | (excl. D*(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D* (DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA CRONIN-HE DOCUMENT IL PAKHLOVA CRONIN-HE AL DOCUMENT IL DOCUMENT IL PAKHLOVA DEL-AMO-S CRONIN-HE | 11 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | CLEO))// FtcN BELL BABR CLEO ECOMM 4.12- | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ \hline \Gamma_{16} / \\ \hline \rightarrow \text{ hadrons} \end{array}$ |
| Seen $\Gamma\left(D^0D^{*-}\pi^+ + \text{C.C.}\right)$ $\Gamma\left(D^0D^{*-}\pi^+ + \text{C.C.}\right)$ $\Gamma\left(D^+_sD^s\right)/\Gamma_{\text{total}}$ $VALUE$ $VALUE$ $\Gamma\left(D^*_sD^s\right)/\Gamma_{\text{total}}$ $\Gamma\left(D^*_sD^s + \text{C.C.}\right)/\Gamma$ $VALUE$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ $SEEN$ S | (excl. D*(2 | / Ttotal DOCUMENT IL CRONIN-HE 2010) + D* (DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA DOCUMENT IL PAKHLOVA CRONIN-HE DOCUMENT IL PAKHLOVA DEL-AMO-S CRONIN-HE AMO-S CRONIN-HE | 09 09 11 1A10N N09 11 AA10N N09 TECN CLEO | CLEO))/Ftc TECN BELL BABR CLEO ELEO COMM 4.12- COMM | $\begin{array}{c} e^+e^- \rightarrow \\ \\ \text{comment} \\ e^+e^- \rightarrow \\ D^0D^{*-} \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | $\begin{array}{c} D \overline{D}^* \pi \\ \hline \Gamma_{13} / \\ \hline \Gamma_{14} / \\ \hline D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ D_s^+ D_s^- \gamma \\ \hline \Gamma_{15} / \\ \hline D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ D_s^{*+} D_s^- \gamma \\ \hline \Gamma_{16} / \\ \hline \rightarrow \text{ hadrons} \\ \hline \Gamma_{17} / \\ \end{array}$ |
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⁹ Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7-5.0 GeV covering the $\psi(3770)$, $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(293\pm57)^\circ$. ¹⁰ Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ resonances and including interference effects. Four sets of solutions are obtained with the same fit quality, mass and total width, but with different e^+e^- partial widths. We quote only the cange of values the range of values.

11 From a fit to Crystal Ball (OSTERHELD 86) data.

¹² From a fit to BES (BAI 02c) data.

Meson Particle Listings ψ (4160), X(4160), X(4250) $^{\pm}$

| $\Gamma(J/\psi\eta')/\Gamma_{\text{tot}}$ | al | | | | Γ ₂₁ /Γ |
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| VALUE (units 10 ⁻³) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <5 | 90 | C OA N | 06 | CLEO | 4.12–4.2 $e^+e^- \rightarrow \text{hadrons}$ |
| $\Gamma(J/\psi\pi^+\pi^-\pi$ | ⁰)/Γ _{total} | | | | Γ ₂₂ /Γ |
| /ALUE (units 10 ⁻³) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <1 | 90 | C OA N | 06 | CLEO | 4.12–4.2 $e^+e^- \rightarrow \text{hadrons}$ |
| $-(\psi(2S)\pi^{+}\pi^{-}$ |)/Ftotal | | | | Γ ₂₃ /Γ |
| ALUE (units 10 ⁻³) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <4 | 90 | C OA N | 06 | CLEO | 4.12 – $4.2 e^+ e^- \rightarrow \text{hadrons}$ |
| $(\chi_{c1} \gamma) / \Gamma_{\text{total}}$ | | | | | Γ ₂₄ /Γ |
| (XCL 1)/ ' total 'ALUE (units 10 ⁻³) | | DOCUMENT ID | | TECN | COMMENT |
| <7 | 90 | C OA N | 06 | | 4.12 – $4.2 e^+e^- \rightarrow \text{hadrons}$ |
| -/ \/= | | | | | F /F |
| $(\chi_{c2}\gamma)/\Gamma_{\text{total}}$ | | | | | Γ ₂₅ / Γ |
| /ALUE (units 10 ⁻³)_ <13 | 90 | DOCUMENT ID | 06 | CLEO | $\frac{COMMENT}{4.12-4.2 \ e^+ \ e^- \rightarrow \ hadrons}$ |
| | | COAN | 00 | CLLO | _ |
| $(\chi_{c1}\pi^+\pi^-\pi^0$ | ')/Γ _{total} | | | | Г ₂₆ /Г |
| 'ALUE (units 10 ⁻³) | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT |
| <2 | 90 | C OA N | 06 | CLEO | 4.12–4.2 $e^+e^- \rightarrow \text{hadrons}$ |
| $(\chi_{c2}\pi^+\pi^-\pi^0$ | (Γ_{total}) | | | | Γ ₂₇ /Γ |
| ALUE (units 10 ⁻³) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <8 | 90 | C OA N | 06 | CLEO | 4.12–4.2 $e^+e^- \rightarrow \text{hadrons}$ |
| $(h_c(1P)\pi^+\pi^-)$ | -)/Γ _{tota} | | | | Γ ₂₈ /Γ |
| ALUE (units 10 ⁻³) | | DO CUMEN | T ID | TE | CN COMMENT |
| <5 | 90 | 13 PEDLAR | - | 11 CL | EO $e^+e^- \rightarrow h_C(1P)\pi^+\pi^-$ |
| | 0 MeV, PE | DLAR 11 meas | ures a | $\sigma(e^+e^-$ | $\rightarrow h_C(1P)\pi^+\pi^-) = 15.6 \pm$ |
| ¹³ At $\sqrt{s} = 417$ | 0 nh | e the errors are | statis | tical, sys | stematic, and due to uncertainty |
| $2.3 \pm 1.9 \pm 3$ | | | | | , |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$ — | $\pi^0 h_C(1F)$ |)), respectively. | | | . 1 |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S) - \frac{1}{2}$ | → π ⁰ h _C (1F)/Γ _{total} | P)), respectively. | | | [Г ₂₉ /Г |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$ – $\Gamma(h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3}) | $h_c^{0} h_c^{0}$ |)), respectively. <u>DOCUMEN</u> : | | | Γ ₂₉ /Γ <u>CN</u> <u>COMMENT</u> |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$ – ($h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3}) | $\frac{\int_{0}^{\infty} h_{C}(1F)}{\int_{0}^{\infty} \frac{CL\%}{90}}$ |)), respectively. 14 <u>PEDLAR</u> | T ID | <u>TE</u> | F29/F COMMENT $EO e^+e^- \rightarrow h_c(1P)\pi^0\pi^0$ |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$) — ($h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3}) <2 14 At $\sqrt{s} = 4170$ | $ \frac{\int \Gamma_{\text{total}}}{\int 0} h_C (1F) $ | (1), respectively. 14 PEDLAR DLAR 11 measur | T ID | <u>TE</u> 11 CL e+e | Γ ₂₉ /Γ <u>CN</u> <u>COMMENT</u> |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$) — ($h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3}) <2 14 At $\sqrt{s} = 4170$ | $\pi^0 h_C(1F)$ //\(\Gamma_{\text{total}}\) $\frac{CL\%}{90}$ MeV, PEE where the | DOCUMENT 14 PEDLAR DLAR 11 measur | T ID | <u>TE</u> 11 CL e+e | F29/F COMMENT EO $e^+e^- \rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$ — ($h_c(1P)\pi^0\pi^0$ (ΔLUE (units 10^{-3}) (ΔLUE (units 10^{-3}) (ΔLUE (units ΔLUE) 14 At ΔLUE (units ΔLUE) B(ΔLUE) B(ΔLUE) B(ΔLUE) | $\begin{array}{c} \pi^0 h_C(1P) \\ \hline \end{pmatrix} / \Gamma_{\text{total}} \\ \hline \underline{CL\%} \\ 90 \\ \hline \text{MeV, PEE} \\ \text{where the} \\ \pi^0 h_C(1P)), \end{array}$ | DOCUMENT 14 PEDLAR DLAR 11 measur | T ID | <u>TE</u> 11 CL e+e | F29/F COMMENT EO $e^+e^- \rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ $\rightarrow h_c(1P)\pi^0\pi^0$ |
| $2.3 \pm 1.9 \pm 3$ in B($\psi(2S)$) = $(h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3})) <2 $1^4 \text{ At } \sqrt{s} = 417$ $1.1 \pm 0.6 \text{ pb}$, B($\psi(2S) \rightarrow 0$) = $(h_c(1P)\eta)/\Gamma_0$ | $\begin{array}{c} \pi^0 h_C(1P) \\ \hline \end{pmatrix} / \Gamma_{\text{total}} \\ \hline \underline{CL\%} \\ 90 \\ \hline \text{MeV, PEE} \\ \text{where the} \\ \pi^0 h_C(1P)), \end{array}$ | DOCUMENT 14 PEDLAR DLAR 11 measur errors are stat | r ID res σ(i | | $\begin{array}{c c} & \Gamma_{29}/\Gamma \\ \hline \text{COMMENT} \\ \hline \text{EO} & e^+e^- \rightarrow h_c(1P)\pi^0\pi^0 \\ \rightarrow & h_c(1P)\pi^0\pi^0) = 3.0 \pm 3.3 \pm \\ \text{atic, and due to uncertainty in} \\ \end{array}$ |
| 2.3 ± 1.9 ± 3 in B($\psi(2S)$ = $-(h_c(1P)\pi^0\pi^0$ (ALUE (units 10-3) 2.1 4 At \sqrt{s} = 417(1.1 ± 0.6 pb, B($\psi(2S)$) = $-(h_c(1P)\eta)/\Gamma_c$ (ALUE (units 10-3) | $\begin{array}{c} \pi^0 h_C(1P) \\ \hline \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | DOCUMEN: 14 PEDLAR DLAR 11 measure errors are state respectively. 6 DOCUMEN: 15 PEDLA | r ID res σ(r istical | $ \begin{array}{ccc} & TE \\ 11 & CL \\ e^+ e^ \\ , & \text{system} \end{array} $ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & \\ \hline CON & & & & & & & & & & & \\ EO & e^+e^- & \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & \text{atic, and due to uncertainty in} \\ \text{atic, and due to uncertainty in} \\ \hline \\ \hline F_{30}/\Gamma \\ \hline TECN & & & & & & \\ \hline CLEO & & & & & & \\ \hline \end{array} $ |
| 2.3 ± 1.9 ± 3 in B($\psi(2S)$ – $-$ ($h_c(1P) \pi^0 \pi^0$ (ALUE (units 10^{-3}) 22 14 At \sqrt{s} = 4170 1.1 ± 0.6 pb, B($\psi(2S)$) \rightarrow $-$ ($h_c(1P) \eta$)/ Γ_t (ALUE (units 10^{-3}) 22 15 At \sqrt{s} = 4170 | $ \begin{array}{c} $ | DOCUMEN: 14 PEDLAR DLAR 11 measure errors are stat, respectively. 5 DOCUMEN: 15 PEDLA LAR 11 measure | r ID res σ(r istical ENT ID R | $ \begin{array}{ccc} & \underline{TE} \\ 11 & \text{CL} \\ e^+ e^- & \underline{} \\ system \end{array} $ $ \begin{array}{c} & 11 \\ + e^- & \rightarrow \end{array} $ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & & &$ |
| 2.3 \pm 1.9 \pm 3 in B($\psi(2S)$ $ (h_c(1P)\pi^0\pi^0$ (ALUE (units 10^{-3}) <2 14 At $\sqrt{s} = 4170$ 1.1 \pm 0.6 pb, B($\psi(2S)$) \rightarrow $ -$ | $ \begin{array}{c} \rightarrow \pi^0 h_C(1F) \\ \hline)/\Gamma_{\text{total}} \\ \hline \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | DOCUMEN: 14 PEDLAR DLAR 11 measure errors are stat, respectively. 5 DOCUMEN: 15 PEDLA LAR 11 measure | r ID res σ(r istical ENT ID R | $ \begin{array}{ccc} & \underline{TE} \\ 11 & \text{CL} \\ e^+ e^- & \underline{} \\ system \end{array} $ $ \begin{array}{c} & 11 \\ + e^- & \rightarrow \end{array} $ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & \\ \hline CON & & & & & & & & & & & \\ EO & e^+e^- & \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & h_c(1P)\pi^0\pi^0 \\ \rightarrow & \text{atic, and due to uncertainty in} \\ \text{atic, and due to uncertainty in} \\ \hline \\ \hline F_{30}/\Gamma \\ \hline TECN & & & & & & \\ \hline CLEO & & & & & & \\ \hline \end{array} $ |
| 2.3 ± 1.9 ± 3 in B($\psi(2S)$ = $\Gamma(h_c(1P)\pi^0\pi^0$ (ALUE (units 10 ⁻³) 2 14 At \sqrt{s} = 4170 1.1 ± 0.6 pb, B($\psi(2S)$) = $\Gamma(h_c(1P)\eta)/\Gamma_c$ (ALUE (units 10 ⁻³) 2 15 At \sqrt{s} = 4170 pb, where the $\pi^0 h_c(1P)$), respectively. | $\pi^0 h_C(1F)$)/ $\Gamma_{\rm total}$ $CL\%$ 90 MeV, PEE where the $\pi^0 h_C(1P)$), total MeV, PEDI errors are espectively. | DOCUMEN: 14 PEDLAR DLAR 11 measure errors are stat, respectively. 5 DOCUMEN: 15 PEDLA LAR 11 measure | r ID res σ(r istical ENT ID R | $ \begin{array}{ccc} & \underline{TE} \\ 11 & \text{CL} \\ e^+ e^- & \underline{} \\ system \end{array} $ $ \begin{array}{c} & 11 \\ + e^- & \rightarrow \end{array} $ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & & &$ |
| 2.3 ± 1.9 ± 3 in B($\psi(2S)$ – $(h_c(1P)\pi^0\pi^0$ (ALUE (units 10 ⁻³) 2 14 At \sqrt{s} = 4170 1.1 ± 0.6 pb, B($\psi(2S)$) – $(h_c(1P)\eta)/\Gamma_c$ (ALUE (units 10 ⁻³) 2 15 At \sqrt{s} = 4170 pb, where the $\pi^0 h_c(1P)$), respectively. | $\pi^0 h_C(1F)$)/ $\Gamma_{\rm total}$ $CL\%$ 90 MeV, PEE where the $\pi^0 h_C(1P)$), total MeV, PEDI errors are espectively. | DOCUMEN: 14 PEDLAR DLAR 11 measure errors are stat, respectively. 5 DOCUMEN: 15 PEDLA LAR 11 measure | r ID res σ(r istical ENT ID R | $ \begin{array}{ccc} & \underline{TE} \\ 11 & \text{CL} \\ e^+ e^- & \underline{} \\ system \end{array} $ $ \begin{array}{c} & 11 \\ + e^- & \rightarrow \end{array} $ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & & &$ |
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| 2.3 ± 1.9 ± 3 in B($\psi(2S)$) = $(h_c(1P)\pi^0\pi^0)^{-1}$ (ALUE (units 10^{-3}) <2 14 At \sqrt{s} = 4170 1.1 ± 0.6 pb, B($\psi(2S)$) = $(h_c(1P)\eta)/\Gamma_t$ (ALUE (units 10^{-3}) <2 15 At \sqrt{s} = 4170 pb, where the $\pi^0h_c(1P)$), ref $(h_c(1P)\pi^0)/\Gamma_t$ (ALUE (units 10^{-3}) <0.4 16 At \sqrt{s} = 4170 0.7 ± 0.1 pb, B($\psi(2S)$) = $(\phi\pi^+\pi^-)/\Gamma_t$ (ALUE (units 10^{-3}) <2 2 CAKHLOVA 11 12 EDLAR 11 | $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ $n = n^0 h_c(1F)$ | DOCUMEN: 14 PEDLAR DLAR 11 measure state respectively. 6 DOCUMEN: 15 PEDLA LAR 11 measure statistical, system 16 PEDLA DLAR 11 measure statistical, system 16 PEDLA DLAR 10 measure statistical, system COAN ### (4160) RE | The set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of | $\begin{array}{c} TE\\ 11 & \text{CL}\\ e^+e^ \\ \text{, system} \end{array}$ $\begin{array}{c} 11\\ +e^- \rightarrow \\ \text{, and du} \end{array}$ $\begin{array}{c} 11\\ e^+e^ \\ \text{CLEO} \end{array}$ $\begin{array}{c} TECN\\ \text{CLEO} \end{array}$ | $ \begin{array}{c c} & & & & & & & & & & & & & & & & & \\ \hline CON & & & & & & & & & & & \\ EO & & & & & & & & & & \\ e^+e^- & & & & & & & & \\ h_c(1P)\pi^0\pi^0) & = & & & & & \\ h_c(1P)\pi^0\pi^0) & = & & & & \\ h_c(1P)\pi^0\pi^0\pi^0) & = & & & \\ \hline T30/\Gamma \\ \hline TECN & & & & & \\ CLEO & & & & & \\ e^+e^- & & & & & \\ h_c(1P)\eta & = & & & \\ h_c(1P)\eta & = & & & \\ h_c(1P)\eta & = & & & \\ h_c(1P)\pi^0 & = & & \\ h_c(1P)\pi^0 \\ \hline ECN & & & & \\ \hline T31/\Gamma \\ \hline TECN & & & & \\ \hline TECN & & & \\ \hline T20MMENT \\ \hline CLEO & & & & \\ e^+e^- & & & & \\ h_c(1P)\pi^0 & = & & \\ -0.7 & \pm 1.8 & \pm \\ atic, & & & \\ \hline A12/\Gamma \\ \hline COMMENT \\ \hline 4.12-4.2 & & & \\ \hline COMMENT \\ \hline 4.12-4.2 & & & \\ \hline \end{array} $ |
| 2.3 ± 1.9 ± 3 in B($\psi(2S)$) $ \Gamma$ ($h_c(1P)\pi^0\pi^0$ π^0 **ALUE (units 10^{-3})** 2.14 At $\sqrt{s} = 4170$ 1.1 ± 0.6 pb, B($\psi(2S)$) \rightarrow 7. ($h_c(1P)\eta$)/ Γ_t **ALUE (units 10^{-3}) 2.15 At $\sqrt{s} = 4170$ pb, where the $\pi^0h_c(1P)$), ref. 7. ($h_c(1P)\pi^0$)/ **ALUE (units 10^{-3}) 2.4. 16 At $\sqrt{s} = 4170$ 0.7 ± 0.1 pb, B($\psi(2S)$) \rightarrow 7. 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| 2.3 ± 1.9 ± 3 in B($\psi(2S)$) $ \Gamma$ ($h_c(1P)\pi^0\pi^0$ π^0 **ALUE (units 10^{-3})** **2 14 At $\sqrt{s} = 4170$ 1.1 ± 0.6 pb, B($\psi(2S)$) $ \times$ **T ($h_c(1P)\eta$)/ Γ_t **ALUE (units 10^{-3}) **2 15 At $\sqrt{s} = 4170$ pb, where the $\pi^0h_c(1P)$), ref Γ ($h_c(1P)\pi^0$)/ **ALUE (units 10^{-3}) **O.4 16 At $\sqrt{s} = 4170$ 0.7 ± 0.1 pb, B($\psi(2S)$) $ \times$ **C($\phi\pi^+\pi^-$)/ Γ_t **ALUE (units 10^{-3}) **2 **PAKHLOVA 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 **EDLAR 11 * | $\rightarrow \pi^0 h_C(1F)$)/ $\Gamma_{\rm total}$ CL% 90 MeV, PEE where the $\pi^0 h_C(1P)$), total CL% 90 MeV, PED errors are espectively. 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| 2.3 ± 1.9 ± 3 in B(ψ (2S) $ \Gamma$ (h_c (1P) $\pi^0\pi^0$ **ALUE (units 10 $^{-3}$)** **2 14 At \sqrt{s} = 4170 1.1 ± 0.6 pb, B(ψ (2S) \rightarrow ** **F(h_c (1P) η)/ Γ_t **ALUE (units 10 $^{-3}$)** **2 15 At \sqrt{s} = 4170 pb, where the π^0h_c (1P)), ref. **F(h_c (1P) π^0)/ **ALUE (units 10 $^{-3}$)** **O.4 16 At \sqrt{s} = 4170 0.7 ± 0.1 pb, B(ψ (2S) \rightarrow ** **EQLAR 11 25EL-AMO-SA 10N 010 UBERT 100 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 UBERT 010 | $\rightarrow \pi^0 h_C(1F)$)/ $\Gamma_{\rm total}$ $CL\%$ 90 MeV, PEE where the $\pi^0 h_C(1P)$), total $CL\%$ 90 MeV, PED errors are espectively. 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| 2.3 \pm 1.9 \pm 3 in B(ψ (2S) $-$ 7 (h_c (1P) $\pi^0\pi^0$ **ALUE (units 10^{-3})** **2 14 At $\sqrt{s} = 4170$ 1.1 \pm 0.6 pb, B(ψ (2S) \rightarrow ** **F(h_c (1P) η)/ f_s **ALUE (units 10^{-3})** **2 15 At $\sqrt{s} = 4170$ pb, where the π^0h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. (h_c (1P)), ref. 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| 7 (4100) |
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$$I^G(J^{PC}) = ??(???)$$

OMITTED FROM SUMMARY TABLE

Seen by PAKHLOV 08 in $e^+e^- o J/\psi X$, $X o D^* \overline{D}^*$

X(4160) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|------|--------------|----|------|-------------------------------|
| $4156 + \frac{25}{20} \pm 15$ | 24 | PAKHLOV | 08 | BELL | $e^+e^- \rightarrow J/\psi X$ |

X (4160) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|------|--------------|----|------|------------------------------|
| $139^{+111}_{-61} \pm 21$ | 24 | PAKHLOV | 08 | BELL | $e^+e^- ightarrow J/\psi X$ |

X(4160) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------------------------------|------------------------------|
| Γ_1 | $D\overline{D}$ | not seen |
| Γ_2 | $D^* \overline{D} + \text{c.c.}$ | not seen |
| Γ_3 | $D^* \overline{D}^*$ | seen |

X(4160) BRANCHING RATIOS

| $\Gamma(D\overline{D})/\Gamma(D^*\overline{D}^*)$ | *) | | | | | Γ_1/Γ_3 |
|---------------------------------------------------|-----------------------|--------------|----|------|----------------------|---------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.09 | 90 | PAKHLOV | 80 | BELL | $e^+e^- \rightarrow$ | $J/\psi X$ |
| $\Gamma(D^*\overline{D} + c.c.)/\Gamma$ | $(D^*\overline{D}^*)$ | | | | | Γ_2/Γ_3 |
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.22 | 90 | PAKHLOV | 80 | BELL | $e^+e^- \rightarrow$ | $J/\psi X$ |

X(4160) REFERENCES

PRL 100 202001 P. Pakhlov et al. PAKHLOV. 08 (BELLE Collab.)



$$I(J^P) = ?(??)$$

OMITTED FROM SUMMARY TABLE

Observed by MIZUK 08 in the $\pi^+\chi_{c1}(1P)$ invariant mass distribution in $\overline B^0 \to K^-\pi^+\chi_{c1}(1P)$ decays. Not seen by LEES 12B in this same mode after accounting for $K\pi$ resonant mass and angular structure.

$X(4250)^{\pm}$ MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|--------------|----|------|------------------------------------------------------|
| 4248 + 44 + 180 - 29 - 35 | 1 MIZUK | 08 | BELL | $\overline{B}^0 \rightarrow K^- \pi^+ \chi_{C1}(1P)$ |

 $^{
m 1}$ From a Dalitz plot analysis with two Breit-Wigner amplitudes.

X (4250) # WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|--------------------|----|------|----------------------------------------------|
| 177 + 54 + 316 177 - 39 - 61 | ² MIZUK | 08 | BELL | $\overline{B}^0 \to K^- \pi^+ \chi_{c1}(1P)$ |

² From a Dalitz plot analysis with two Breit-Wigner amplitudes.

X(4250)[±] DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\pi^+ \chi_{c1}(1P)$ | seen |

X(4250) BRANCHING RATIOS

| $\Gamma(\pi^+ \chi_{c1}(1P))/$ | Γ _{total} | | | | Γ_1/Γ_1 |
|--------------------------------|---------------------------------------|----------|-----------|---------------------------------------------|---------------------|
| VALUE | DO CUMENT IE |) | TECN | COMMENT | |
| seen | ³ MIZUK | 80 | BELL | $\overline{B}^0 \rightarrow \kappa^- \pi^+$ | $\chi_{c1}(1P)$ |
| • • • We do not u | se the following data for ave | erages, | fits, lim | its, etc. • • • | |
| not seen | ⁴ LEES | 12в | BABR | $B \rightarrow K \pi \chi_{c1}$ | 1P) |
| | t branching fraction meas | | | | 4250)+) > |
| $B(X(4250)^{+}$ | $\pi^{+} \chi_{c1}(1P) = (4.0 + 2.3)$ | 3 + 19.7 |) × 10 | -5 | |

 $B(X(4250)^+ \to \pi^+ \chi_{C1}(1P)) = (4.0 + 0.09 + 0.05) \times 10^{-3}$. ⁴ With a product branching fraction limit of $B(\overline{B}^0 \to X(4250)^+ K^-) \times B(X(4250)^+ \to 0.05)$ $\chi_{c1} \, \pi^+) < 4.0 \times 10^{-5} \, {\rm at } \, 90\% \, {\rm CL}.$

$X(4250)^{\pm}, X(4260)$

X(4250) + REFERENCES

LEES MIZUK 12B PR D85 052003 08 PR D78 072004 J.P. Lees et al. R. Mizuk et al. (BABAR Collab.)



$$I^G(J^{PC}) = ??(1--)$$

Seen in radiative return from $e^+\,e^-$ collisions at $\sqrt{s}=$ 9.54–10.58 GeV by AUBERT,B 051, HE 06B, and YUAN 07, and in $e^+e^$ collisions at $\sqrt{s}~\approx~$ 4.26 GeV by COAN 06. Possibly seen by AUBERT 06 in $B^- \rightarrow K^- \pi^+ \pi^- J/\psi$. See also the mini-review under the X(3872). (See the index for the page number.)

X(4260) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------|---------|----------------|-------|----------|-----------------------------------------------------|
| 4263 + 8 OUR | AVERAGE | Error includes | scale | factor o | of 1.1. |
| $4247 \pm 12 + 17 \\ -32$ | 1 | YUAN | 07 | BELL | 10.58 $e^+e^-\rightarrow\gamma\pi^+\pi^-J/\psi$ |
| $4284 {}^{+ 17}_{- 16} \!\pm 4$ | 13.6 | HE | 06в | CLEO | 9.4–10.6 $e^+e^-\rightarrow\gamma\pi^+\pi^-J/\psi$ |
| $4259 \pm 8 ^{+}_{-} ^{2}_{6}$ | 125 2 | AUBERT,B | 05ı | BABR | 10.58 $e^+e^- \rightarrow \gamma \pi^+\pi^- J/\psi$ |
| _ | | | | | |

From a two-resonance fit.

X(4260) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|--------|-----------------------|-----|------|-----------------------------------------------------|
| 95 ±14 OUR A | VERAGE | | | | |
| $108\!\pm\!19\!\pm\!10$ | | ³ YUAN | 07 | BELL | 10.58 $e^+e^- ightarrow \gamma \pi^+ \pi^- J/\psi$ |
| $73^{+39}_{-25}\pm\ 5$ | 13.6 | HE | 06в | CLEO | 9.4–10.6 $e^+e^-\rightarrow\gamma\pi^+\pi^-J/\psi$ |
| $88 \pm 23 + 6 \\ -4$ | 125 | ⁴ AUBERT,B | 05ı | BABR | 10.58 $e^+e^- ightarrow\gamma\pi^+\pi^-J/\psi$ |

³ From a two-resonance fit

X(4260) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------------------------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $e^{+} e^{-}$ | |
| Γ ₂ | $J/\psi \pi^+ \pi^-$ | seen |
| Γ_3 | $J/\psi \pi^0 \pi^0$ | seen |
| Γ ₄ | $J/\psi K^+ K^-$ | seen |
| Γ_5 | $J/\psi\eta$ | not seen |
| Γ_6 | $J/\psi \pi^0$ | not seen |
| Γ ₇ | $J/\psi \eta'$ | not seen |
| Γ ₈ | $J/\psi \pi^{+} \pi^{-} \pi^{0}$ | not seen |
| Г9 | $J/\psi \eta \eta$ | not seen |
| Γ_{10} | $\psi(2S)\pi^{+}\pi^{-}$ | not seen |
| Γ_{11} | $\psi(2S)\eta$ | not seen |
| Γ_{12} | $\chi_{c0} \omega$ | not seen |
| Γ_{13} | $\chi_{c1} \gamma$ | not seen |
| Γ_{14} | $\chi_{c2}\gamma$ | not seen |
| Γ_{15} | $\chi_{c1} \pi^{+} \pi^{-} \pi^{0}$ | not seen |
| Γ_{16} | $\chi_{c2} \pi^{+} \pi^{-} \pi^{0}$ | not seen |
| Γ_{17} | $h_c(1P)\pi^+\pi^-$ | not seen |
| Γ_{18} | $\phi \pi^+ \pi^-$ | not seen |
| Γ_{19} | $ \phi \pi^+ \pi^- \phi f_0(980) \rightarrow \phi \pi^+ \pi^- D \overline{D} $ | not seen |
| Γ_{20} | $D\overline{D}_{\underline{a}}$ | not seen |
| Γ_{21} | $D^0 \overline{D}{}^0$ | not seen |
| Γ_{22} | D^+D^- | not seen |
| Γ_{23} | $D^* \overline{D} + \text{c.c.}$ | not seen |
| Γ ₂₄ | $D^*(2007)^0 \overline{D}{}^0 + \text{c.c.}$ | not seen |
| Γ_{25} | $\underline{D}^*(2010)^+ D^- + \text{c.c.}$ | not seen |
| Γ ₂₆ | $D^*\overline{D}^*$ | not seen |
| Γ_{27} | $D^*(2007)^0 \overline{D}{}^*(2007)^0$ | not seen |
| Γ ₂₈ | $D^*(2010)^+ D^*(2010)^-$ | not seen |
| Γ_{29} | $D\overline{D}\pi$ +c.c. | |
| Γ_{30} | $D^0 D^- \pi^+ + \text{c.c.}$ (excl. $D^* (2007)^0 \overline{D}^{*0} + \text{c.c.}$, | not seen |
| | $D^*(2007)^0 D^{*0} + c.c.,$ | |
| | $D^*(2010)^+ D^- + \underline{c.c.}$ | |
| Γ ₃₁ | $D\overline{D}^*\pi + \text{c.c.}$ (excl. $D^*\overline{D}^*$) | not seen |
| Γ_{32} | $D^0 D^{*-} \pi^+ + \text{c.c.}$ (excl. | not seen |
| | $D^*(2010)^+ D^*(2010)^-)$ | |
| Γ ₃₃ | $D^0 D^* (2010)^- \pi^+ + \text{c.c.}$ | not seen |

| Γ ₃₆ Γ ₃₇ | $D^* \overline{D}^* \pi$ $D_s^+ D_s^-$ $D_s^{*+} D_s^- + c.c.$ $D_s^{*+} D_s^{*-}$ $P_s^{\overline{P}}$ $P_s^{\overline{P}}$ | not seen not seen not seen not seen not seen not seen not seen |
|------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Γ ₃₉ Γ ₄₀ | $ \begin{array}{l} \rho \overline{\rho} \\ K_S^0 K^{\pm} \pi^{\mp} \\ K^+ K^- \pi^0 \end{array} $ | not seen not seen |

$X(4260) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $I(J/\psi\pi'\pi$ |) × 1(| e'e)/Itotal | | | 2 1/ |
|-------------------------|--------|--------------|------|---------|-------|
| VALUE (eV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| 5.9 ^{+1.2} OUR | AVERAG | iE . | | | |

| $6.0\!\pm\!1.2\!+\!4.7\\-0.5$ | | ⁵ YUAN | 07 | BELL | 10.58 $e^+e^- ightarrow\gamma\pi^+\pi^-J/\psi$ |
|--------------------------------------------|--------|-----------------------|---------|-----------|----------------------------------------------------------|
| $8.9^{+3.9}_{-3.1}\pm1.8$ | 8.1 | HE | 06в | CLEO | 9.4-10.6 $e^+ e^- \rightarrow \gamma \pi^+ \pi^- J/\psi$ |
| $5.5 \pm 1.0 {}^{+ 0.8}_{- 0.7}$ | 125 | ⁶ AUBERT,B | 051 | BABR | 10.58 $e^+e^- ightarrow\gamma\pi^+\pi^-J/\psi$ |
| • • • We do not | use th | ne following data | for ave | rages, fi | ts, limits, etc. • • • |
| $20.6 \pm 2.3 \substack{+\ 9.1 \\ -1\ 7}$ | | ⁷ YUAN | 07 | BELL | 10.58 $e^+e^- ightarrow\gamma\pi^+\pi^-J/\psi$ |

⁵ Solution I of two equivalent solutions in a fit using two interfering resonances.

⁷ Solution II of two equivalent solutions in a fit using two interfering resonances.

| $\Gamma(J/\psi K^+ K^-)$ | × Γ(e+e | -)/Γ _{total} | | | | $\Gamma_4\Gamma_1/\Gamma$ |
|--------------------------|---------------|-----------------------|-----------|------------|-------------------------------|---------------------------|
| VALUE (eV) | CL% | DO CUMENT | ID | TECN | COMMENT | |
| • • • We do not | use the follo | wing data for av | erages, f | its, limit | s, etc. • • • | |
| <1.2 | 90 | ⁸ YUA N | 08 | BELL | $e^+e^- \rightarrow \gamma I$ | K^+K^-J/ψ |
| | | | | | | |

 8 From a fit of the broad $K^+\,K^-\,J/\psi$ enhancement including a coherent X(4260) amplitude with mass and width from YUAN 07.

| $\Gamma(\psi(2S)\pi^+$ | π^-) × Γ | $(e^+e^-)/\Gamma_{total}$ | | | $\Gamma_{10}\Gamma_1/\Gamma$ |
|------------------------|----------------------|---------------------------|--------------|--------------------|------------------------------|
| VALUE (eV) | CL% | DOCUMENT ID | TECN | COMMENT | |
| • • • We do | not use the | following data for av | erages, fits | . limits, etc. • • | • |

| • • • We do | not use the | e following | data for | avera | ges, fits, | limits, etc. • • • |
|--------------------------|-------------|-------------------|----------|-------|------------|-------------------------------------------------------------------------------------------------------|
| <4.3 | 90 | ⁹ LIU | | 08н | RVUE | $10.58 \ e^+ \ e^- \rightarrow \ \psi(2S) \ \pi^+ \ \pi^- \ \gamma$ |
| $7.4 {}^{+ 2.1}_{- 1.7}$ | | ¹⁰ LIU | | | | $ \psi(2S) \pi^{+} \pi^{-} \gamma $ $ 10.58 e^{+} e^{-} \rightarrow \psi(2S) \pi^{+} \pi^{-} \gamma $ |

 $^{^{9}}$ For constructive interference with the X(4360) in a combined fit of AUBERT 07s and

WANG 07D data with three resonances. 10 For destructive interference with the X(4360) in a combined fit of AUBERT 07s and WANG 07D data with three resonances.

| $\Gamma(\phi\pi^+\pi^-)$ | × Γ(e+ | e ⁻)/Γ _{total} | | | $\Gamma_{18}\Gamma_{1}/\Gamma$ |
|--------------------------|--------|-------------------------------------|------|---------|--------------------------------|
| VALUE (eV) | CL% | DOCUMENT ID | TECN | COMMENT | |

<0.4 90 AUBERT,BE 06D BABR 10.6
$$e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$$

 $e^+e^-)/\Gamma_{\text{total}}] \times [B(\phi(1020) \rightarrow K^+K^-)] < 0.14 \text{ eV}$ which we divide by our best value $B(\phi(1020) \rightarrow K^+K^-) = 48.9 \times 10^{-2}$.

| $\Gamma(K_S^0K^{\pm}\pi^{7}$ | -) × Γ(e ⁺ | · e ⁻)/Γ _{total} | | | $\Gamma_{39}\Gamma_1/\Gamma$ |
|------------------------------|-----------------------|---------------------------------------|------|---------|------------------------------|
| VALUE (aV.) | C1 % | DOCUMENT ID | TECN | COMMENT | |

ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet

AUBERT 08s BABR 10.6 $e^+e^- \rightarrow \kappa_S^0 \kappa^{\pm} \pi^{\mp} \gamma$

$\Gamma(K^+ K^- \pi^0) \, imes \, \Gamma(e^+ \, e^-) / \Gamma_{ m total}$ VALUE (eV) CL% DOCUMENT ID TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

AUBERT 08s BABR 10.6 $e^+\,e^ightarrow~K^+\,K^-\,\pi^0\,\gamma$ < 0.6 90

X(4260) BRANCHING RATIOS

 12 At $\sqrt{s}=$ 4260 MeV, PEDLAR 11 measures $\sigma(e^+e^-\to h_c(1P)\pi^+\pi^-)=32\pm17\pm6\pm6$ pb, where the errors are statistical, systematic, and due to uncertainty in B($\psi(2S)\to$ $\pi^0 h_C(1P)$), respectively.

$\Gamma(D\overline{D})/\Gamma(J/\psi\pi^+\pi^-)$ Γ_{20}/Γ_{2} DOCUMENT ID VALUE TECN COMMENT 13 AUBERT 07BE BABR $e^+e^- \rightarrow D\overline{D}\gamma$ 90 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet <4.0 90 CRONIN-HEN...09 CLEO e+e-

² From a single-resonance fit. Two interfering resonances are not excluded

⁴ From a single-resonance fit. Two interfering resonances are not excluded.

⁶/₂ From a single-resonance fit. Two interfering resonances are not excluded.

 $^{^{13}}$ Using 4259 \pm 10 MeV for the mass and 88 \pm 24 MeV for the width of X(4260).

¹⁴ Using 4263 $^{+8}_{-9}$ MeV for the mass of X(4260).

Meson Particle Listings X(4260)

| $\Gamma(D^0 \overline{D}{}^0) / \Gamma_{total}$ | | | | Γ_{21}/Γ | $\Gamma(D^*\overline{D}^*\pi)/\Gamma_{total}$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| /ALUE not seen | DO CUMENT ID CRONIN-HEN | | $e^+e^- \rightarrow$ | D ₀ D ₀ | NALUE not seen |
| • • We do not use the followin | | | | <i>D D</i> | |
| not seen | AUBERT | 09м BABR | $e^+e^- \rightarrow e^+e^- \rightarrow$ | $D_0^0 \overline{D}_0^0 \gamma$ | $\Gamma(D^*\overline{D}^*\pi)/\Gamma(J/\psi\pi^+\pi^-)$ |
| not seen | PAKHLOVA | 08 BELL | $e^+e^- \rightarrow$ | $D^0 \overline{D}{}^0 \gamma$ | <8.2 90 |
| $\Gamma(D^+D^-)/\Gamma_{ m total}$ | | | | Γ_{22}/Γ | r/n+ n=\/r |
| VALUE | DO CUMENT ID | | $e^+e^- \rightarrow$ | D+ D= | $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ |
| not seen • • • We do not use the followin | CRONIN-HEN g data for averages, | | | <i>D</i> · <i>D</i> | not seen |
| not seen | AUBERT | | $e^+e^- \rightarrow$ | | not seen |
| not seen | PAKHLOVA | 08 BELL | $e^+e^- \rightarrow$ | $D^+D^-\gamma$ | • • We do not use the follow |
| $(D^*\overline{D} + \text{c.c.})/\Gamma(J/\psi\pi^+\pi^-$ |) | | | Γ_{23}/Γ_2 | not seen |
| ALUE CL% | DOCUMENT ID | | COMMENT | | $\Gamma(D_s^+D_s^-)/\Gamma(J/\psi\pi^+\pi^-)$ |
| <34 90 • • • We do not use the followin | | | $e^+e^- \rightarrow$ etc. • • • | γυ* υ | VALUE CL% |
| <45 90 | CRONIN-HEN | | | | <0.7 95 • • • We do not use the follow |
| $D^*(D^*(2007)^0 \overline{D}{}^0 + \text{c.c.})/\Gamma_{\text{tot}}$ | | | | Γ /Γ | <1.3 90 |
| (D'(2007) D'+C.C.)/I tot: | DOCUMENT ID | TECN | COMMENT | Γ ₂₄ /Γ | • |
| ot seen | CRONIN-HEN | | $e^+e^- \rightarrow$ | $D^{*0}\overline{D}^{0}$ | $\Gamma(D_s^{*+}D_s^-+c.c.)/\Gamma_{total}$ |
| • We do not use the following | - | | | .0-0 | not seen |
| ot seen | AUBERT | 09м BABR | $e^+e^- \rightarrow$ | $D^{*0}D^{0}\gamma$ | not seen |
| $(D^*(2010)^+ D^- + c.c.)/\Gamma_{to}$ | tal | | | Γ ₂₅ /Γ | ● We do not use the follow |
| ALUE | DO CUMENT ID | | $\frac{COMMENT}{e^{+}e^{-} \rightarrow}$ | D*+ D- | not seen |
| ot seen ot seen | CRONIN-HEN PAKHLOVA | | $e^+e^- \rightarrow$ $e^+e^- \rightarrow$ | | $\Gamma(D_s^{*+}D_s^- + \text{c.c.})/\Gamma(J/\psi\pi)$ |
| • • We do not use the following | g data for averages, | | | , - | VALUE CL% |
| ot seen | AUBERT | 09м BABR | $e^+e^- \rightarrow$ | $D^{*+}D^{-}\gamma$ | < 0.8 90 |
| $(D^*\overline{D}^*)/\Gamma(J/\psi\pi^+\pi^-)$ | | | | Γ_{26}/Γ_{2} | • • We do not use the follow |
| ALUE CL% | DOCUMENT ID | TECN | COMMENT | | <44 95 |
| <11 90 | CRONIN-HEN | | | | $\Gamma(D_s^{*+}D_s^{*-})/\Gamma_{	ext{total}}$ |
| • • We do not use the followin <40 90 | = = | | $e^+e^- \rightarrow$ | ~ D* D * | VALUE |
| | | OM DADIO | | | not seen • • • We do not use the follow |
| Γ (D*(2007)⁰ | otal DOCUMENT ID | TECN | COMMENT | Γ ₂₇ /Γ | not seen |
| ot seen | CRONIN-HEN | | | $D^{*0}\overline{D}^{*0}$ | not seen |
| • We do not use the following | | | | | F(D*+ D*-)/F(/// + - |
| ot seen | AUBERT | 09м BABR | $e^+e^- \rightarrow$ | $D^{*0}\overline{D}^{*0}\gamma$ | $\Gamma(D_s^{*+}D_s^{*-})/\Gamma(J/\psi\pi^+\pi^-)$ VALUE CL% |
| $(D^*(2010)^+ D^*(2010)^-)/[$ | - total | | | Γ ₂₈ /Γ | < 9.5 90 |
| ALUE | DOCUMENT ID | | COMMENT | _+ | ◆ ◆ We do not use the follow |
| ot seen ot seen | CRONIN-HEN PAKHLOVA | .09 CLEO 07 BELL | $e^+e^- \rightarrow e^+e^- \rightarrow$ | $D^{*+}D^{*-}$ $D^{*+}D^{*-}\gamma$ | <30 95 |
| • • We do not use the following | | | | / • | $\Gamma(ho \overline{ ho})/\Gamma(J/\psi \pi^+ \pi^-)$ |
| ot seen | AUBERT | 09м BABR | $e^+e^- \rightarrow$ | $D^{*+}D^{*-}\gamma$ | VALUE CL% |
| $(D^0 D^- \pi^+ + \text{c.c.} \text{ (excl. } D^*)$ | (2007) ⁰ D *0 +c. | c <i>D</i> *(201 | 10)+ <i>D</i> -+ | c.c.))/ | <0.13 90 15 Using 4259 \pm 10 MeV for t |
| total | | • | • | ΄΄΄Γ ₃₀ /Γ | Osing 4259 ± 10 like v lor |
| ALUE ot seen | <u>DO CUMENT ID</u> PA KHLOVA | | COMMENT | <u> </u> | |
| or seen | TARRIEOVA | OOA DELL | $D^{0.6} e^{+}_{D} e^{-}$ | $\overrightarrow{\pi^+\gamma}$ | PAKHLOVA 11 PR D83 01110 |
| $(D\overline{D}^*\pi + c.c. (excl. D^*\overline{D}^*)$ | '))/F _{total} | | | Г ₃₁ /Г | PEDLAR 11 PRL 107 04180 DEL-AMO-SA 10N PR D82 05200 |
| ALUE | DOCUMENT ID | | COMMENT | | AUBERT 09M PR D79 09200 CRONIN-HEN09 PR D80 07200 |
| ot seen | CRONIN-HEN | .09 CLEO | $e^+ e^- \rightarrow$ | $D^*\overline{D}\pi$ | PAKHLOVA 09 PR D80 09110 AUBERT 08S PR D77 09200 |
| or seen | |) | | Γ_{31}/Γ_2 | LIU 08H PR D78 01403 PAKHLOVA 08 PR D77 01110 |
| | $^{\prime}))/\Gamma(J/\psi\pi^{+}\pi^{-}$ | | | | PAKHLOVA 08A PRL 100 06200 YUAN 08 PR D77 01110 |
| $\Gamma(D\overline{D}^*\pi+c.c.$ (excl. $D^*\overline{D}^*$ | DOCUMENT ID | TECN | COMMENT | | |
| $ \begin{array}{c c} C(D\overline{D}^*\pi + \text{c.c.} (\text{excl.} D^*\overline{D}^*) \\ ALUE & CL\% \\ 90 \end{array} $ | DOCUMENT ID CRONIN-HEN | .09 CLEO | e+ e- | | AUBERT 07AK PR D76 01200 AUBERT 07BE PR D76 11110 |
| $ \begin{array}{c c} C(D\overline{D}^*\pi + \text{c.c.} (\text{excl.} D^*\overline{D}^*) \\ ALUE & CL\% \\ 90 \end{array} $ | DOCUMENT ID CRONIN-HEN | <u>΄</u> <u>τεςν</u> 09 CLEO 10) -))/Γ t | e ⁺ e ⁻ | Г ₃₂ /Г | AUBERT 07AK PR D76 012000 AUBERT 07BE PR D76 111100 AUBERT 07S PRL 98 212001 PAKHLOVA 07 PRL 98 092001 |
| $\begin{array}{c} (D\overline{D}^*\pi + \text{c.c. (excl. }D^*\overline{D}^*\\ \frac{CLWE}{\sqrt{15}} & \frac{CLW}{\sqrt{90}} \\ (D^0D^{*-}\pi^+ + \text{c.c. (excl. }D^*\overline{D}^*\\ \frac{CLWE}{\sqrt{15}} & \frac{CLWE}{\sqrt{15}} \end{array}$ | DO CUMENT ID CRONIN-HEN 0*(2010)+ D*(20 DO CUMENT ID | <u>τεςν</u> 09 CLEO 10)-))/Γ _t <u>τεςν</u> | e ⁺ e ⁻ otal <u>COMMENT</u> | | AUBERT 07AK PR D76 012000 AUBERT 07BE PR D76 112000 AUBERT 075 PRL 98 212001 PAKHLOVA 07 PRL 98 092001 WANG 07D PRL 99 142002 YUAN 07 PRL 99 182004 |
| $\begin{array}{c} (D\overline{D}^*\pi + \text{c.c. (excl. }D^*\overline{D}^*\\ \frac{CLW}{D} & \frac{CLW}{90} \\ (D^0D^{*-}\pi^+ + \text{c.c. (excl. }D^*\overline{D}^*\\ \frac{CLW}{D} & \frac{CLW}{D} \end{array}$ | DOCUMENT ID CRONIN-HEN | <u>τεςν</u> 09 CLEO 10)-))/Γ _t <u>τεςν</u> | e ⁺ e ⁻ | | AUBERT 07AK PR D76 01200 AUBERT 07BE PR D76 1110 AUBERT 07S PRL 98 21200. PAKHLOVA 07 PRL 98 21200. WANG 07D PRL 99 12000. YUAN 07 PRL 99 18200. AUBERT 06 PR D73 01110 AUBERT 06B PR D73 01200 |
| $\begin{array}{c} C\left(D\overline{D}^*\pi + \text{c.c. (excl. }D^*\overline{D}^*\\ ALUE & \underline{CL\%}\\ <15 & 90 \end{array}\right)$ $C\left(D^0D^{*-}\pi^+ + \text{c.c. (excl. }D^*\overline{D}^*\\ D^*D^* = 0$ ot seen | DOCUMENT ID CRONIN-HEN. 0*(2010)+ D*(20 DOCUMENT ID PAKHLOVA | <u>τεςν</u> 09 CLEO 10)-))/Γ _t <u>τεςν</u> | e ⁺ e ⁻ otal <u>COMMENT</u> | -π ⁺ γ | AUBERT 07AK PR D76 01200 AUBERT 07BE PR D76 1110 AUBERT 075 PR 1 98 21200 PAKHLOVA 07 PR 1 98 02200 WANG 07D PR 1 99 14200 YUAN 07 PR 1 99 14200 YUAN 07 PR 1 99 14200 AUBERT 06B PR D73 01200 AUBERT 06B PR D73 01200 AUBERT,BE 06D PR D74 09110 COAN 06 PR 1 96 16200 |
| $\begin{array}{c} (D \overline{D}^* \pi + \text{c.c.} \ (\text{excl.} \ D^* \overline{D}^* \\ (215 $ | DOCUMENT ID CRONIN-HEN. 0*(2010)+ D*(20 DOCUMENT ID PAKHLOVA | 7 TECN 09 CLEO 10)-))/Γ _t 7 TECN 09 BELL | e^+e^- otal $COMMENT$ $e^+e^- ightharpoonup D^0$ D^{*-} | Γ ₃₃ /Γ ₂ | AUBERT 07AK PR D76 01200 AUBERT 07BE PR D76 11101 AUBERT 07BE PR D76 11101 AUBERT 07B PR L 98 212000 WANG 07D PRL 99 1242002 YUAN 07 PRL 99 1242002 YUAN 07 PRL 99 102000 AUBERT 06B PR D73 01110 AUBERT 06B PR D73 012010 COAN 06 PR L 96 1620010 HE 06B PR D74 020010 |
| $\begin{array}{c} (D\overline{D}^*\pi + \text{c.c.} \text{ (excl. } D^*\overline{D}^*\\ C15 & 90 \end{array})$ $\begin{array}{c} CL\% \\ OD^*D^*\pi + \text{c.c.} \text{ (excl. } D^*\overline{D}^*\\ OD^*D^*\pi + \text{c.c.} \text{ (excl. } D^*\overline{D}^*\\ OD^*D^*\pi + \text{c.c.} \text{ (excl. } D^*\overline{D}^*\\ OD^*D^*(2010)^{-1}\pi^+ + \text{c.c.})/\\ \end{array}$ | DOCUMENT ID CRONIN-HEN. 1*(2010) + D*(20 DOCUMENT ID PAKHLOVA Γ(J/ψπ+π-) DOCUMENT ID | 7 TECN 09 CLEO 10)-))/Γ _t 7 TECN 09 BELL | e^+e^- otal $COMMENT$ $e^+e^- ightharpoonup D^0$ D^{*-} | -π ⁺ γ | AUBERT 07AK PR D76 01200 AUBERT 07BE PR D76 11200 AUBERT 07BE PR D76 11200 PAKHLOVA 07 PRL 98 21200 WANG 07D PRL 99 142002 YUAN 07 PRL 99 142002 AUBERT 06 PR D73 01210 AUBERT 06B PR D73 012010 COAN 06 PR 196 162001 HE 06B PR D74 012011 |
| $\begin{array}{c} C(D\overline{D}^*\pi + \text{c.c.} (\text{excl. } D^*\overline{D}^*) \\ C(D^*D^*\pi + \text{c.c.} (\text{excl. } D^*\overline{D}^*) \\ C(D^*D^*\pi^+ + \text{c.c.} (\text{excl. } D^*) \\ C(D^*D^*\pi^+ + \text{c.c.} (\text{excl. } D^*)) \\ C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.}) \\ C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.}) \\ C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.}) \\ C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D^*D^*(2010)^+\pi^+ + \text{c.c.})/C(D$ | DOCUMENT ID CRONIN-HEN (2010) + D* (20 DOCUMENT ID PAKHLOVA Γ(J/ψπ+π-) DOCUMENT ID PAKHLOVA | 7 TECN 09 CLEO 10)-))/\(\Gamma_t\) 09 BELL 09 BELL | $\begin{array}{c} e^{+}e^{-} \\ \\ \text{Otal} \\ \\ -\frac{COMMENT}{e^{+}e^{-}} \xrightarrow[D^{0}D^{*}]{} \\ \\ \\ -\frac{COMMENT}{e^{+}e^{-}} \xrightarrow[e^{+}e^{-}]{} \end{array}$ | Γ ₃₃ /Γ ₂ | AUBERT 07AK PR D76 01200 AUBERT 07E PR D76 11200 AUBERT 07E PR D76 11200 PAKHLOVA 07 PRL 98 21200 WANG 07D PRL 99 14200 YUAN 07 PRL 99 14200 AUBERT 06 PR D73 01201 AUBERT 06B PR D74 01201 COAN 06 PR L9 16 16200 HE 06B PR D74 01201 |

| | | | | | (4260) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|-----------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(D^*\overline{D}^*\pi)/\Gamma_{\text{total}}$ | | DO CUMENT ID | TECN | COMMENT | Г ₃₄ /Г |
| not seen | | CRONIN-HEN09 | | $e^+e^- \rightarrow$ | $D^*\overline{D}^*\pi$ |
| $\Gamma(D^*\overline{D}^*\pi)/\Gamma(J/\psi)$ | π+π-) | | | | Γ ₃₄ /Γ ₂ |
| VALUE | | DO CUMENT ID | TECN | COMMENT | - 34/ - 2 |
| <8.2 | 90 | CRONIN-HEN09 | CLEO | e^+e^- | |
| $\Gamma(D_s^+D_s^-)/\Gamma_{\text{total}}$ | | | | | Г ₃₅ /Г |
| VALUE | | DO CUMENT ID | | | |
| not seen | | DEL-AMO-SA10N | BABR | e+e- → | $D_s^+ D_s^- \gamma$ |
| not seen • • • We do not use t | he following | CRONIN-HEN09 | | $e^+e^- \rightarrow$ | $D_{S}^{+}D_{S}^{-}$ |
| not seen | ne ronowing | PAKHLOVA 11 | | $e^+e^- \rightarrow$ | D+D-~ |
| | | TARRIES VA | DELL | | SSSI |
| $\Gamma(D_s^+D_s^-)/\Gamma(J/\psi \tau)$ | $(\pi^+\pi^-)$ | | | | Γ_{35}/Γ_2 |
| <u>VALUE</u> <0.7 | <u>CL%_</u> 95 | DEL-AMO-SA10N | | | _ |
| • • • We do not use t | | | | | |
| <1.3 | 90 | CRONIN-HEN09 | CLEO | e^+e^- | |
| $\Gamma(D_s^{*+}D_s^- + c.c.)/\Gamma$ | total | | | | Г ₃₆ /Г |
| VALUE | .J.ai | | _ | COMMENT | |
| not seen | | DEL-AMO-SA10N | | | |
| not seen | ha followin- | CRONIN-HEN09 | | | $D_s^{*+}D_s^-$ |
| • • We do not use t not seen | ne ronowing | PAKHLOVA 11 | | | $D_s^{*+}D_s^-\gamma$ |
| | | | DELL | e · e → | ν_s ν_s γ |
| $\Gamma(D_s^{*+}D_s^-+c.c.)/\Gamma$ | | | | | Γ_{36}/Γ_2 |
| <u>VALUE</u> < 0.8 | <u>CL%</u> 90 | DOCUMENT ID CRONIN-HEN09 | | | |
| • • • We do not use t | | | | | |
| <44 | 95 | DEL-AMO-SA10N | BABR | 10.6 e ⁺ e | - |
| $\Gamma(D_s^{*+}D_s^{*-})/\Gamma_{\text{total}}$ | | | | | Г ₃₇ /Г |
| VALUE YALUE | | DOCUMENT ID | | | |
| not seen | he fell | CRONIN-HEN09 | | | $D_{S}^{*+}D_{S}^{*-}$ |
| • • We do not use t not seen | ne ronowing | | | | D*+ D* |
| not seen | | PAKHLOVA 11 DEL-AMO-SA10N | BABR | e+e- → | $D_s \rightarrow D_s \gamma$ $D_s^{*+} D_s^{*-} \gamma$ |
| | \ | | .=., | | |
| $\Gamma(D_s^{*+}D_s^{*-})/\Gamma(J/t)$ VALUE | ψπ ⁺ π ⁻) <u>CL%</u> | DO CUMENT ID | TECN | COMMENT | Γ_{37}/Γ_2 |
| < 9.5 | 90 | CRONIN-HEN09 | | e^+e^- | |
| • • • We do not use t | | • | | | |
| <30 | 95 | DEL-AMO-SA10N | BABR | 10.6 e ⁺ e ⁻ | _ |
| $\Gamma(p\overline{p})/\Gamma(J/\psi\pi^+\pi^-)$ | -) | | | | Γ_{38}/Γ_{2} |
| VALUE | <u>CL%</u> an1 | | COMME | $\rightarrow p\overline{p}\gamma$ | |
| <0.13 15 Using 4259 ± 10 M | | mass and 88 \pm 24 MeV | | | (4260). |
| 5 <u></u> · · · | | 4260) REFERENCE | | / | · / |
| DAKIHOVA ** CC C | • | • | | /pc: | LE Collet \ |
| PEDLAR 11 PRL | 83 011101 107 041803 82 052004 | G. Pakhlova et al. T. Pedlar et al. P. del Amo Sanchez : | et al | `(CL | .LE Collab.) EO Collab.) AR Collab.) |
| DEL-AMO-NA HIM DD II | | | - v MI. | | AR Collab.) |
| AUBERT 09M PR D | 79 092001 80 072001 | B. Aubert <i>et al.</i> D. Cronin-Hennessy e | t al. | (C) | EO Collab 1 |
| AUBERT 09M PR D CRONIN-HEN09 PR D PAKHLOVA 09 PR D | | D. Cronin-Hennessy e G. Pakhlova <i>et al.</i> B. Aubert <i>et al.</i> | | (CL (BEL | EO Collab.) .LE Collab.) AR Collab.) |
| AUBERT 09M PR D CRONIN-HEN09 PR D PAKHLOVA 09 PR D AUBERT 08S PR D LIU 08H PR D | 80 072001 80 091101R | D. Cronin-Hennessy e | | (CL (BEL (BAB | AR Collab.) .LE Collab.) |
| AUBERT 09M PR D CRONIN-HEN 09 PR D PAKHLOVA 09 PR D AUBERT 08S PR D LIU 08H PR D PAKHLOVA 08 PR D PAKHLOVA 08 PR D YUAN 08 PR D | 80 072001 80 091101R 977 092002 978 014032 977 011103R 100 062001 977 011105R | D. Cronin-Hennessy e G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C G. Pakhlova et al. C.Z. Yuan et al. | | (CL (BEL (BAB (BEL (BEL (BEL | AR Collab.) .LE Collab.) .LE Collab.) .LE Collab.) |
| AUBERT 09M PR D CRONIN-HEN09 PR D PAKHLOVA 09 PR D UIU 08H PR D PAKHLOVA 08 PR D PAKHLOVA 08 PR D PAKHLOVA 08 PR D AUBERT 07AK PR D AUBERT 07AK PR D AUBERT 07BK PR D | 80 072001 80 091101R 77 092002 78 014032 77 011103R 100 062001 77 011105R 76 012008 76 111105R | D. Cronin-Hennessy ei G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C G. Pakhlova et al. G. Pakhlova et al. C.Z. Yuan et al. B. Aubert et al. B. Aubert et al. | | (CL (BEL (BAB (BEL (BEL (BAB (BAB | AR Collab.) LE Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) |
| AUBERT 99M PR C CRONIN-HEN09 PR C PAKHLOVA 08 PR C LIU 08H PR C PAKHLOVA 08 PR C PAKHLOVA 08 PR C PAKHLOVA 08 PR C AUBERT 07AK PR C AUBERT 075 PRL PAKHLOVA 07 PRL PAKHLOVA 07 PRL | 80 072001 80 091101R 177 092002 178 014032 177 011103R 100 062001 177 011105R 176 012008 177 011105R 178 012001 179 012001 | D. Cronin-Hennessy et G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C G. Pakhlova et al. C.Z. Yuan et al. B. Aubert et al. B. Aubert et al. G. Pakhlova et al. | | (CL (BEL (BAB (BEL (BEL (BAB (BAB (BAB | AR Collab.) LE Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) AR Collab.) |
| AUBERT 99M PR C CRONIN-HEN09 PR C PAKHLOVA 09 PR C AUBERT 085 PR C LIU 08H PR C PAKHLOVA 08 PR C PAKHLOVA 08 PR C AUBERT 074K PR C AUBERT 075K PR C AUBERT 075K PR C AUBERT 075 PR C PAKHLOVA 07 PR C WANG 070 PR C | 80 072001 80 091101R 77 092002 78 014032 77 011103R 100 062001 77 011105R 76 012008 76 111105R 98 212001 98 992001 99 142002 99 182004 | D. Cronin-Hennessy et G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C. G. Pakhlova et al. C.Z. Yuan et al. B. Aubert et al. B. Aubert et al. G. Pakhlova et al. X.L. Wang et al. C.Z. Yuan et al. | | (CL (BEL (BAB (BEL (BEL (BAB (BAB (BAB (BEL (BEL | AR Collab.) LE Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) AR Collab.) LE Collab.) LE Collab.) |
| AUBERT 99M PR C CRONIN-HEN9 PR C PAKHLOVA 09 PR C AUBERT 085 PR C LIU 08H PR C PAKHLOVA 08 PR C PAKHLOVA 08 PR C AUBERT 078E PR C AUBERT 078E PR C AUBERT 078E PR C AUBERT 078 PR C WANG 07D PR L YUAN 07 PR L WANG 07 PR C AUBERT 06 PR C AUBERT 06 PR C AUBERT 06 PR C AUBERT 06 PR C | 180 072001 180 091101R 177 092002 178 014032 177 011103R 100 062001 177 011105R 176 012008 176 11105R 176 12001 178 092001 179 142002 179 142002 173 011101R 173 012005 | D. Cronin-Hennessy et G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C. G. Pakhlova et al. G. Z. Xuan et al. B. Aubert et al. B. Aubert et al. G. Pakhlova et al. X.L. Wang et al. C.Z. Yuan et al. B. Aubert et al. B. Aubert et al. | | (CL (BEL (BAB (BEL (BAB (BAB (BEL (BEL (BAB (BAB (BAB | AR Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) AR Collab.) LE Collab.) LE Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) |
| AUBERT 09M PR C CRONIN-HEN09 PR C PAKHLOVA 09 PR C AUBERT 085 PR C LIU 08H PR C PAKHLOVA 08 PR C PAKHLOVA 08 PR C AUBERT 078 PR C AUBERT 074K PR C AUBERT 075K PR C AUBERT 075K PR C AUBERT 075K PR C AUBERT 075K PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 075 PR C AUBERT 066 PR C AUBERT,BE 065 PR C AUBERT,BE 066 PR C | 180 072001 180 091101R 177 092002 178 014032 177 011103R 177 011103R 176 012008 176 012008 177 111105R 198 092001 198 092001 199 142002 199 182004 173 011101R | D. Cronin-Hennessy et G. Pakhlova et al. B. Aubert et al. Z.Q. Liu, X.S. Qin, C G. Pakhlova et al. C.Z. Yuan et al. B. Aubert et al. B. Aubert et al. G. Pakhlova et al. X.L. Wang et al. C.Z. Yuan et al. B. Aubert et al. | | (CL (BEL (BAB (BEL (BEL (BAB (BAB (BEL (BEL (BAB (BAB (BAB (BAB | AR Collab.) LE Collab.) LE Collab.) AR Collab.) AR Collab.) AR Collab.) LE Collab.) LE Collab.) LE Collab.) AR Collab.) |

 $X(4350), X(4360), \psi(4415)$

X(4350)

$$I^G(J^{PC}) = 0^+(?^{?+})$$

OMITTED FROM SUMMARY TABLE

Seen by SHEN 10 in the $\gamma\gamma \to J/\psi\phi$. Needs confirmation.

X(4350) MASS

| VALUE (MeV) | EVTS | DOCUMENT | ID | TECN | COMMENT |
|------------------------------|-----------|----------|----|------|------------------------------------------------------------------------------------|
| $4350.6^{+4.6}_{-5.1}\pm0.7$ | 8.8 + 4.2 | 1 SHEN | 10 | BELL | $ \begin{array}{c} 10.6 \ e^+ e^- \rightarrow \\ e^+ e^- J/\psi \phi \end{array} $ |

 1 Statistical significance of 3.2 σ

X (4350) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT | r ID | TECN | COMMENT |
|-------------|---------------------|-------------------|------|------|------------------------------------------------------------------------------------|
| 13-18 ±4 | $8.8^{+4.2}_{-3.2}$ | ² SHEN | 10 | BELL | $ \begin{array}{c} 10.6 \ e^+ e^- \rightarrow \\ e^+ e^- J/\psi \phi \end{array} $ |

 2 Statistical significance of 3.2 σ .

X(4350) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------------|------------------------------|
| Γ_1 | $J/\psi \phi$ | seen |
| Γ_2 | $\gamma\gamma$ | seen |

$X(4350) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(\gamma\gamma) \times \Gamma(J)$ | $/\psi\phi)/\Gamma_{ m total}$ | | | | | $\Gamma_2\Gamma_1/\Gamma_2$ |
|---------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-------------------|------|------|----------------------------------------------|-----------------------------|
| VALUE (eV) | EVTS | DO CUMEN | T ID | TECN | COMMENT | |
| $6.7^{+3.2}_{-2.4}\pm1.1$ | $8.8^{+4.2}_{-3.2}$ | ³ SHEN | 10 | BELL | $10.6 e^+e^- \rightarrow e^+e^- J/\psi \phi$ | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $1.5{}^{+0.7}_{-0.6}{\pm}0.3$ | $8.8^{+4.2}_{-3.2}$ | ⁴ SHEN | 10 | BELL | $^{10.6}_{e^{+}e^{-}J/\psi\phi}^{e^{-}\to}$ | |
| 3 For $J^P=0^+$. Statistical significance of 3.2 σ . 4 For $J^P=2^+$. Statistical significance of 3.2 σ . | | | | | | |

X (4350) BRANCHING RATIOS

| $\Gamma(J/\psi\phi)/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|----------------------------------------|-------------------|----|------|--------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | ⁵ SHEN | 10 | BELL | $\frac{10.6 e^+ e^-}{e^+ e^- J/\psi \phi}$ | |
| 5 Statistical significant | re of 3.2 a | | | | |

 $\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_2/Γ DO CUMENT ID TECN COMMENT VALUE 10 BELL $10.6 e^+ e^- \rightarrow e^+ e^- J/\psi \phi$ ⁶ SHEN

 6 Statistical significance of 3.2 σ .

X(4350) REFERENCES

SHEN 10 PRI 104 112004 C.P. Shen et al. (BELLE Collab.)



$$I^{G}(J^{PC}) = ?^{?}(1^{-})$$

Seen in radiative return from $e^+\,e^-$ collisions at $\sqrt{s}=$ 9.54–10.58 GeV by AUBERT 07S and WANG 07D. See also the review under the X(3872) particle listings. (See the index for the page number.)

X(4360) MASS

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
|------------------------|----------------------|-----------------|---------------------------------------------------------------------------------------------|
| 4361 ± 9±9 | ¹ WANG | 07D BELL | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \gamma \pi^+ \pi^- \psi(2S) \end{array}$ |
| • • • We do not use th | e following data for | r averages, fit | |
| $4355 + 9 \pm 9$ | ² LIU | 08н RVUE | 10.58 $e^+ e^{\psi(2S)} \xrightarrow{\pi^+ \pi^-} \gamma$ |
| 4324 ± 24 | ³ AUBERT | | $\psi(2S) \pi^+ \pi^- \gamma$ $10.58 e^+ e^- \rightarrow$ $\gamma \pi^+ \pi^- \psi(2S)$ |

1 From a two-resonance fit. 2 From a combined fit of AUBERT 07s and WANG 07D data with two resonances.

³ From a single-resonance fit. Systematic errors not estimated.

X (4360) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------|---------------------|-------------|------------|-----------------------------------------------------------------------------------------------------|
| 74±15±10 | ⁴ WANG | 07 D | BELL | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \gamma \pi^+ \pi^- \psi(2S) \end{array}$ |
| • • • We do not use th | e following data fo | r avera | ages, fits | , limits, etc. • • • |
| $103 {}^{+ 1 7}_{- 15} {\pm} 11$ | ⁵ LIU | 08н | RVUE | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \psi(2S) \ \pi^+ \ \pi^- \ \gamma \end{array}$ |
| 172 ± 33 | ⁶ AUBERT | 07s | BABR | $ \begin{array}{ccc} 10.58 & e^+ & e^- \rightarrow \\ & & \gamma \pi^+ \pi^- \psi(2S) \end{array} $ |
| 4 = | | | | |

From a two-resonance fit.
 From a combined fit of AUBERT 07s and WANG 07D data with two resonances.

6 From a single-resonance fit. Systematic errors not estimated.

X(4360) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------|----------------------------------------------------------|------------------------------|
| Γ ₁ Γ ₂ Γ ₃ | $e^{+}e^{-}\ \psi(2S)\pi^{+}\pi^{-}\ D^{0}D^{*-}\pi^{+}$ | seen |

$X(4360) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\psi(2S)\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ | | | | | $\Gamma_2\Gamma_1/\Gamma$ |
|--------------------------------------------------------------------------|----------------------|-------------|-----------|--------------------------------------------------------------|---------------------------|
| VALUE (eV) | DOCUMENT I | D | TECN | COMMENT | |
| • • • We do not us | e the following data | for avera | ges, fits | , limits, etc. • • • | |
| $11.1^{+1.3}_{-1.2}$ | ⁷ LIU | 08н | RVUE | 10.58 $e^+e^- \rightarrow \psi(2S) \pi^+\pi^- \gamma$ | |
| $12.3\!\pm\!1.2$ | ⁸ LIU | 08н | RVUE | 10.58 $e^+e^- \to \psi(2S) \pi^+\pi^- \gamma$ | |
| $10.4\!\pm\!1.7\!\pm\!1.5$ | 9 WANG | 07 D | BELL | $10.58 e^+e^- \rightarrow \gamma \pi^+ \pi^- \psi(2S)$ | |
| $11.8 \pm 1.8 \pm 1.4$ | ¹⁰ WANG | 07 D | BELL | $10.58 e^{+}e^{-} \rightarrow \gamma \pi^{+}\pi^{-}\psi(2S)$ | |

⁷ Solution I in a combined fit of AUBERT 07s and WANG 07D data with two resonances.
⁸ Solution II in a combined fit of AUBERT 07s and WANG 07D data with two resonances.

Solution I of two equivalent solutions in a fit using two interfering resonances. $^{10}\,\mathrm{Solution}$ II of two equivalent solutions in a fit using two interfering resonances

X(4360) BRANCHING RATIOS

 11 Using 4355 $^{+}_{-10}$ 9 \pm 9 MeV for the mass of X (4360).

X(4360) REFERENCES

| PAKHLOVA | 09 | PR D80 091101R | G. Pakhlova et al. | (BELLE Collab.) |
|----------|------|----------------|-------------------------------|-----------------|
| LIU | 08 H | PR D78 014032 | Z.Q. Liu, X.S. Qin, C.Z. Yuan | |
| AUBERT | 07S | PRL 98 212001 | B. Aubert et al. | (BABAR Collab.) |
| WAN G | 07 D | PRL 99 142002 | X.L. Wang et al. | (BELLE Collab.) |

 ψ (4415)

$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

ψ (4415) MASS

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------------|-----------------------|-------------------|---------------------------------------------|
| 4421 ± 4 OUR ESTIMA | ATE . | | |
| 4415.1 ± 7.9 | ¹ ABLIKIM | 08D BES2 | $e^+e^-	o$ hadrons |
| • • • We do not use the fo | ollowing data for a | verages, fits, li | mits, etc. • • • |
| 4412 ±15 | | | $e^+e^-	o$ hadrons |
| 4411 ± 7 | ³ PAKHLOVA | 08A BELL | 10.6 $e^+e^- \rightarrow D^0D^-\pi^+\gamma$ |
| 4425 ± 6 | ⁴ SETH | 05A RVUE | $e^+ e^- ightarrow hadrons$ |
| 4429 ± 9 | ⁵ SETH | 05A RVUE | $e^+e^-	o$ hadrons |
| 4417 ±10 | BRANDELIK | 78C DASP | e^+e^- |
| 4414 ± 7 | SIEGRIST | 76 MRK1 | e^+e^- |

- 1 Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the ψ (3770), ψ (4040), ψ (4160), and ψ (4415) resonances. Phase angle fixed in the fit to $\delta=(234\pm88)^\circ$. 2 Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8–4.8 GeV covering the ψ (4040), ψ (4160) and ψ (4415) resonances and including interference effects
- including interference effects.
- ³ Systematic uncertainties not estimated.
- ⁴ From a fit to Crystal Ball (OSTERHELD 86) data.
- ⁵ From a fit to BES (BAI 02c) data.

ψ (4415) WIDTH

| | E (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----|-------------------------------------------|----------------------|--------|-------------|---------------------------------------------|
| 62 | ±20 OUR ESTIMAT | | | | |
| 71. | 5±19.0 | ⁶ ABLIKIM | 08D | BES2 | $e^+e^-	o$ hadrons |
| • • | We do not use the fol | lowing data for a | verage | s, fits, li | mits, etc. • • • |
| 118 | ± 32 | | | | $e^+e^-	o$ hadrons |
| 77 | ± 20 | | | | 10.6 $e^+e^- \rightarrow D^0D^-\pi^+\gamma$ |
| 119 | ± 16 | | | | $e^+e^-	o$ hadrons |
| 118 | ±35 | ¹⁰ SETH | 05A | RVUE | $e^+e^-	o$ hadrons |
| 66 | ± 15 | BRANDELIK | 78C | DASP | e^+e^- |
| 33 | +10 | SIEGRIST | 76 | MRK1 | e+ e- |

- 6 Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770),\,\psi(4040),\,\psi(4160),$ and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(234\pm88)^\circ.$
- 7 Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040),\psi(4160)$ and $\psi(4415)$ resonances and including interference effects.
- ⁸ Systematic uncertainties not estimated.
- ⁹ From a fit to Crystal Ball (OSTERHELD 86) data.
- 10 From a fit to BES (BAI 02c) data.

ψ (4415) DECAY MODES

Due to the complexity of the $c\,\overline{c}$ threshold region, in this listing, "seen" ("not seen") means that a cross section for the mode in question has been measured at effective \sqrt{s} near this particle's central mass value, more (less) than 2σ above zero, without regard to any peaking behavior in \sqrt{s} or absence thereof. See mode listing(s) for details and references.

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|------------------------------------------------------------------------------|--------------------------------|------------------|
| $\overline{\Gamma_1}$ | D D | not seen | |
| Γ_2 | $D^0\overline{D}{}^0$ | seen | |
| Γ_3 | D^+D^- | seen | |
| Γ_4 | $D^*\overline{D}$ + c.c. | not seen | |
| Γ_5 | $D^*(2007)^0 \overline{D}{}^0 + \text{ c.c.}$ | seen | |
| Γ ₆ | $D^*(2010)^+ D^- + \text{c.c.}$ | seen | |
| Γ_7 | $D^* \overline{D}^*$ | not seen | |
| Γ ₈ | $D^*(2007)^0 \overline{D}^*(2007)^0 + \text{ c.c.}$ | seen | |
| Γ9 | $D^*(2010)^+ D^*(2010)^- + c.c.$ | seen | |
| Γ_{10} | $D^{0}D^{-}\pi^{+}$ (excl. $D^{*}(2007)^{0}\overline{D}{}^{0}$ | < 2.3 % | 90% |
| | $+\text{c.c.}, D^*(2010)^+D^- +\text{c.c.}$ | | |
| Γ_{11} | $D \overline{D}_{2}^{*}(2460) \rightarrow D^{0} D^{-} \pi^{+} + \text{c.c.}$ | $(10 \pm 4)\%$ | |
| Γ_{12} | $D^{0}D^{*-}\pi^{+}+c.c.$ | < 11 % | 90% |
| Γ_{13} | $D_s^+ D_s^-$ | not seen | |
| Γ_{14} | $D_{s}^{*+}D_{s}^{-}+c.c.$ | seen | |
| Γ ₁₅ | $D_s^{*+}D_s^{-}$ + c.c. $D_s^{*+}D_s^{*-}$ | not seen | |
| Γ ₁₆ | $e^{+}e^{-}$ | $(9.4 \pm 3.2) \times 10^{-6}$ | 6 |
| | | | |

ψ (4415) PARTIAL WIDTHS

| Γ(e+e-) | | | | | Г ₁₆ |
|------------------------|-----------------------|----------|---------|----------------------|-----------------|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| 0.58±0.07 OUR ESTIMATE | | | | | |
| 0.35 ± 0.12 | ¹¹ ABLIKIM | 08D | BES2 | $e^+e^- \rightarrow$ | hadrons |
| | ving data for average | s, fits, | limits, | etc. • • • | |
| 0.4 to 0.8 | ¹² MO | | | $e^+e^- \to$ | |
| 0.72 ± 0.11 | ¹³ SETH | 05 A | RVUE | $e^+e^- \rightarrow$ | hadrons |
| 0.64 ± 0.23 | ¹⁴ SETH | 05 A | RVUE | $e^+e^- \rightarrow$ | hadrons |
| 0.49 ± 0.13 | BRA NDELIK | 78C | DASP | e^+e^- | |
| 0.44 ± 0.14 | SIEGRIST | 76 | MRK1 | e^+e^- | |

- 11 Reanalysis of data presented in BAI 02c. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the $\psi(3770),\,\psi(4040),\,\psi(4160),$ and $\psi(4415)$ resonances. Phase angle fixed in the fit to $\delta=(234\pm88)^\circ$.
- Phase angle fixed in the fit to $\delta=(234\pm 00)^{-}$. 12 Reanalysis of data presented in BAI 00 and BAI 02c. From a global fit over the center-of-mass energy 3.8-4.8 GeV covering the $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$ resonances and including interference effects. Four sets of solutions are obtained with the same fit quality, mass and total width, but with different e^+e^- partial widths. We quote only the range of values.
- 13 From a fit to Crystal Ball (OSTERHELD 86) data.
- 14 From a fit to BES (BAI 02c) data.

ALCANIS) REANCHING PATIOS

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| $\Gamma(D^0\overline{D}^0)/\Gamma_{\text{total}}$ | | | | | Γ2/Ι |
| VALUE | DO CUMENT ID | | TECN | | |
| seen | PAKHLOVA | | | $e^+e^- \rightarrow$ | $D^0 \overline{D}{}^0 \gamma$ |
| • • We do not use the following | ng data for average AUBERT | | | etc. • • • $e^+e^- \rightarrow$ | 50 5 0 |
| not seen | AUBERT | 09M | вавк | e · e → | $D^{\bullet}D^{\bullet}\gamma$ |
| $\Gamma(D^+D^-)/\Gamma_{\text{total}}$ | | | | | Γ ₃ /Ι |
| VALUE | DO CUMENT ID | | TECN | COMMENT | • |
| seen | PAKHLOVA | 80 | BELL | | $D^+D^-\gamma$ |
| | - | | | | |
| not seen | AUBERT | 09м | BABR | $e^+e^- \rightarrow$ | $D^+D^-\gamma$ |
| $\Gamma(D\overline{D})/\Gamma(D^*\overline{D}^*)$ | | | | | Γ_1/Γ_2 |
| VALUE | DO CUMENT ID | | TECN | COMMENT | -, |
| 0.14±0.12±0.03 | AUBERT | | | | $\gamma D^{(*)} \overline{D}^{(*)}$ |
| 5/D*/0003\(\) \\ | | | | | |
| $\Gamma(D^*(2007)^0\overline{D}^0 + \text{c.c.})/\Gamma_{\text{tot}}$ | | | | | Γ ₅ / |
| VALUE | DO CUMENT ID | | | | - ::0 =0 |
| seen | AUBERT | 09м | BABR | $e^+e^- \rightarrow$ | $D^{*0}D^{0}\gamma$ |
| $\Gamma(D^*(2010)^+D^- + c.c.)/\Gamma_{to}$ | otal | | | | Γ ₆ / |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| seen | AUBERT | 09м | BABR | | $D^{*+}D^{-}\gamma$ |
| seen | PAKHLOVA | 07 | BELL | $e^+e^- \rightarrow$ | $D^{*+}D^{-\gamma}$ |
| Γ(D* T) - c c \ /Γ(D* T)*) | | | | | г /г |
| $\Gamma(D^*\overline{D} + \text{c.c.})/\Gamma(D^*\overline{D}^*)$ | DO CULTENT ID | | TE 641 | 50.444ENT | Γ ₄ /Γ |
| VALUE | DO CUMENT ID | | | COMMENT_ | 5(*) 5 (*) |
| $0.17 \pm 0.25 \pm 0.03$ | AUBERT | 09M | BABR | e ' e → | $\gamma D^{(*)} \overline{D}^{(*)}$ |
| $\Gamma(D^*(2007)^0 \overline{D}^*(2007)^0 + c$ | .c.)/F _{total} | | | | Γ ₈ / |
| VALUE | DO CUMENT ID | | TECN | COMMENT | -, |
| seen | AUBERT | 09м | BABR | $e^+e^- \rightarrow$ | $D^{*0} \overline{D}^{*0} \gamma$ |
| 5/5t/2242) 5t/2242)- | \ | | | | |
| $\Gamma(D^*(2010)^+ D^*(2010)^- +$ | | | | | Г9/ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| | | | | | 5*1 5*- |
| | AUBERT | 09м | BABR | $e^+e^- \rightarrow$ | |
| seen | AUBERT PAKHLOVA | 09м | BABR | $e^+e^- \rightarrow$ | |
| | AUBERT PAKHLOVA | 09м | BABR | $e^+e^- \rightarrow$ | D*+ D*- |
| seen $\Gamma(D\overline{D}_2^*(2460) \rightarrow D^0D^-\pi^+$ | AUBERT PAKHLOVA | 09м 07 | BABR BELL | $ \begin{array}{c} e^+e^- \to \\ e^+e^- \to \end{array} $ | D*+ D*- |
| seen $\Gamma(D\overline{D}_2^*(2460) \to D^0D^-\pi^+$ <u>NALUE (units 10^{-2})</u> | AUBERT PAKHLOVA +c.c.)/F _{total} OCUMENT ID | 09м 07 <u>ТЕСМ</u> | BABR BELL . <u>com</u> | $ \begin{array}{c} e^+e^- \to \\ e^+e^- \to \end{array} $ MENT | D*+ D*- γ |
| seen $\Gamma(D\overline{D}_2^*(2460) \to D^0D^-\pi^+$ <u>NALUE (units 10^{-2})</u> | AUBERT PAKHLOVA +C.C.)/\(\Gamma_{\text{total}}\) OCUMENT ID AKHLOVA 08A | 09M 07 <u>TECN</u> BELL | BABR BELL COM | $ \begin{array}{c} e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \\ \end{array} $ $ \begin{array}{c} MENT \\ e^{+}e^{-} \rightarrow \\ \end{array} $ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
| seen $\Gamma(D \overline{D}_{2}^{*}(2460) \rightarrow D^{0} D^{-} π^{+} + \frac{VALUE \text{ (units } 10^{-2})}{10.5 \pm 2.4 \pm 3.8}$ 15 p, 15 Using 4421 ± 4 MeV for the | AUBERT PAKHLOVA +C.C.)/ Γ_{total} OCUMENT ID AKHLOVA 08A mass and 62 \pm 20 | 09M 07 TECN BELL MeV | BABR BELL COM 10.6 | $\begin{array}{c} e^+e^- \rightarrow \\ e^+e^- \rightarrow \end{array}$ width of $\psi(2)$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
| seen $ \Gamma(D \overline{D}_{2}^{*}(2460) \rightarrow D^{0} D^{-} \pi^{+} \\ \frac{VALUE \text{ (units } 10^{-2})}{10.5 \pm 2.4 \pm 3.8} $ | AUBERT PAKHLOVA + c.c.)/ Γ_{total} OCUMENT ID AKHLOVA 08A mass and 62 ± 20 $0^{0}\overline{D^{0}}$ + c.c., $D^{*}($ | 09M 07 TECN BELL MeV | BABR BELL COM 10.6 | $\begin{array}{c} e^+e^- \rightarrow \\ e^+e^- \rightarrow \end{array}$ width of $\psi(2)$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
| 10.5 ± 2.4 ± 3.8 15 Using 4421 ± 4 MeV for the $\Gamma(D^0D^-\pi^+ \text{ (excl. } D^*\text{ (2007)})$ $\Gamma(D^0D^-\pi^+\text{ (excl. } D^*\text{ (2007)})$ | AUBERT PAKHLOVA +C.C.)/[total OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID 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OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OCUMENT ID OC | 09M 07 **TECN BELL MeV (2010 | BABR BELL | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \end{array}$ width of $\psi(4)$ | $D^{*+}D^{*-}\gamma$ 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| seen | AUBERT PAKHLOVA +C.C.)/\Gamma_to_D OCUMENT ID AKHLOVA 0.82 Mass and 62 ± 20 0.00 -C.C., D*(+C.C.) OCUMENT ID | 09M 07 TECN BELL MeV (2010 | BABR BELL | $e^+e^- \rightarrow e^+e^- \rightarrow WENT$ $e^+e^- \rightarrow Width of \psi(4)$ $+C.C.)/$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}$ $D^{0}D^{-}\pi^{+}\gamma$ Γ_{10}/Γ_{11} |
| seen | AUBERT PAKHLOVA +C.C.)/[total OCUMENT ID O 8A M ass and 62 ± 20 100 700 +C.C., D*(+C.C.) OCUMENT ID O 8A | 09M 07 TECN BELL MeV (2010 TECN BELL | | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \end{array}$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \end{array}$ width of $\psi(4)$ $\begin{array}{c} +\text{C.C.} \end{pmatrix} / \\ \end{array}$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \end{array}$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
| seen | AUBERT PAKHLOVA +C.C.)/[total OCUMENT ID O 8A M ass and 62 ± 20 100 700 +C.C., D*(+C.C.) OCUMENT ID O 8A | 09M 07 TECN BELL MeV (2010 TECN BELL | | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \end{array}$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \end{array}$ width of $\psi(4)$ $\begin{array}{c} +\text{C.C.} \end{pmatrix} / \\ \end{array}$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \end{array}$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
| From Seen $\Gamma(D \overline{D}_2^*(2460) \rightarrow D^0 D^- \pi^+ \frac{1}{24LUE \text{ (units } 10^{-2})}$ $D D D^- \pi^+ \frac{1}{24LUE \text{ (units } 10^{-2})}$ $D D D^- \pi^+ \frac{1}{24LUE \text{ (units } 10^{-2})}$ $D D D^- \pi^+ \frac{1}{24LUE \text{ (2007)}}$ $D D D^- \pi^+ \frac{1}{24LUE \text{ (2017)}}$ $D D^- D D^- \pi^+ \frac{1}{24LUE \text{ (2017)}}$ $D D^- D D^- \pi^+ \frac{1}{24LUE \text{ (2017)}}$ $D D^- D D^- \pi^+ \frac{1}{24LUE \text{ (2017)}}$ $D D^- D D^- D^- \pi^+ \frac{1}{24LUE \text{ (2017)}}$ $D D^- D D^- D^- D^- D^- D^- D^- D^- D^- $ | AUBERT PAKHLOVA +C.C.)/\(\int \) \(\text{Total} \) O CUMENT ID A KHLOVA M ass and 62 \(\pm \) 20 +C.C., \(\nu \) O CUMENT ID A KHLOVA M ass and 62 \(\pm \) 20 A KHLOVA M ass and 62 \(\pm \) 20 | 09M 07 BELL MeV (2010 TECM BELL MeV | | $\begin{array}{c} e^{+}e^{-} \rightarrow \\ e^{+}e^{-} \rightarrow \end{array}$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \\ \text{width of } \psi(4) \\ \text{+C.C.} \end{pmatrix} /$ $\begin{array}{c} \text{MENT} \\ e^{+}e^{-} \rightarrow \\ \text{width of } \psi(4) \end{array}$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11}/\Gamma_{11$ |
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| From Section 17 Using 4421 \pm 4 MeV for the $\Gamma(D^0D^*_*(2460) \to D^0D^*_* \to D^0D^*_*$ $\to D^0D^*$ | AUBERT PAKHLOVA +C.C.)/\[\(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(\) \(| 09M 07 BELL MeV (2010 TECM BELL MeV | | $\begin{array}{c} e^+e^- \rightarrow \\ e^+e^- \rightarrow \end{array}$ width of $\psi(4$ +C.C.)/ $\begin{array}{c} \text{MENT} \\ +\text{C.C.} \end{pmatrix}$ width of $\psi(4$ | $D^{*+}D^{*-}$ $\Gamma_{11}/$ $D^{0}D^{-}\pi^{+}\gamma$ Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} Γ_{10}/Γ_{10} |
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\underline{e^+e^-} \rightarrow \\ \underline{e^+e^-} \rightarrow \\ \underline{e^+e^-} \rightarrow \\$ | $ \begin{array}{c} D^{*+}D^{*-}\gamma \\ \hline \Gamma_{11}/I \\ D^{0}D^{-}\pi^{+}\gamma \\ I^{415}). \end{array} $ $ \begin{array}{c} \Gamma_{10}/\Gamma_{11} \\ \hline D^{0}D^{-}\pi^{+}\gamma \\ I^{415}). $ $ \begin{array}{c} D^{0}D^{-}\pi^{+}\gamma \\ I^{415} \end{array} $ $ \begin{array}{c} D^{0}D^{*-}\pi^{+} \\ \hline \Gamma_{13}/I \\ D^{+}D^{-}S^{-}\gamma \\ D^{+}S^{-}S^{-}\gamma \end{array} $ |
| seen $ \Gamma\left(D\overline{D}_{2}^{*}(2460) \rightarrow D^{0}D^{-}\pi^{+} \right) $ $ \frac{D}{10.5 \pm 2.4 \pm 3.8} $ 15 p. 15 p. 15 p. 15 p. 15 p. 15 p. 15 p. 15 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 16 p. 17 Using 4421 ± 4 MeV for the $ \Gamma\left(D^{0}D^{*}\pi^{+} + \text{c.c.}\right)/\Gamma_{\text{total}} $ $ \frac{CL\%}{44.0E} $ | AUBERT PAKHLOVA +C.C.)/\(\text{Ftotal}\) \(\text{OCUMENT ID} \) AKHLOVA 0.8A mass and 62 \pm 20 0.0D^0 +C.C., \(D^*(\) +C.C.) \(\text{OCUMENT ID} \) AKHLOVA 0.8A mass and 62 \pm 20 \(\text{X} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) \(\text{C} \) 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| From Seen $ \Gamma(D \overline{D}_2^*(2460) \to D^0 D^- \pi^+ \\ \frac{VALUE \text{ (units } 10^{-2})}{10.5 \pm 2.4 \pm 3.8} $ 15 p., 15 p., 15 Using 4421 ± 4 MeV for the $ \Gamma(D^0 D^- \pi^+ \text{ (excl. } D^*(2007) \\ \Gamma(D \overline{D}_2^*(2460) \to D^0 D^- \pi^+ \\ \frac{VALUE}{\sqrt{0.22}} $ 90 16 p., 16 Using 4421 ± 4 MeV for the $ \Gamma(D^0 D^* - \pi^+ + \text{c.c.}) / \Gamma_{\text{total}} $ 17 Using 4421 ± 4 MeV for the $ \Gamma(D^0 D^* - \pi^+ + \text{c.c.}) / \Gamma_{\text{total}} $ 17 Using 4421 ± 4 MeV for the $ \Gamma(D_s^+ D_s^-) / \Gamma_{\text{total}} $ 18 Using 4421 ± 4 MeV for the $ \Gamma(D_s^+ D_s^-) / \Gamma_{\text{total}} $ 19 Using 4421 ± 4 MeV for the $ \Gamma(D_s^+ D_s^-) / \Gamma_{\text{total}} $ 10 MALUE not seen not seen $ \Gamma(D_s^+ D_s^-) + \text{c.c.} / \Gamma_{\text{total}} $ 10 MALUE Not seen $ \Gamma(D_s^+ D_s^-) + \text{c.c.} / \Gamma_{\text{total}} $ 10 MALUE Not seen Not seen $ \Gamma(D_s^+ D_s^-) + \text{c.c.} / \Gamma_{\text{total}} $ 10 MALUE Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not seen Not se | AUBERT PAKHLOVA +C.C.)/Γtotal OCUMENT ID AKHLOVA 08A mass and 62 ± 20)0 D0 +C.C., D*(+C.C.) OCUMENT ID AKHLOVA 08A mass and 62 ± 20 X Γ(e+e-)/Γtotal DOCUMENT ID 17 PAKHLOVA mass of ψ(4415). DOCUMENT ID PAKHLOVA DEL-AMO-SA | 09M 07 TECN BELL MeV (2010 TECN BELL MeV 09 | BABR BELL COM 10.6 for the COM 10.6 for the COM 10.6 for the COM TECN BELL BABR TECN TECN TECN TECN TECN TECN TECN TECN | $\begin{array}{c} e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \end{array}$ $\begin{array}{c} \underline{\text{MENT}} \\ e^+e^- \rightarrow \\ \text{width of } \psi(4) \\ +\text{C.C.} \end{pmatrix} / \\ \underline{\text{MENT}} \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ \end{array}$ | $D^{*+}D^{*-}\gamma$ $\Gamma_{11}/$ $D^{0}D^{-}\pi^{+}\gamma$ Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} Γ_{10}/Γ_{1} |
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| seen | AUBERT PAKHLOVA +C.C.)/Γtotal OCUMENT ID AKHLOVA 08A mass and 62 ± 20 ()0 D0 +C.C., D*(+C.C.) OCUMENT ID AKHLOVA 08A mass and 62 ± 20 X Γ(e+e-)/Γtot DOCUMENT ID 17 PAKHLOVA mass of ψ(4415). DOCUMENT ID PAKHLOVA DEL-AMO-SA DOCUMENT ID PAKHLOVA | 09M 07 BELL MeV (2010 MeV btal 09 | BABR BELL COM 10.6 for the COM 10.6 for the COM 10.6 for the COM TECN BELL BABR TECN TECN TECN TECN TECN TECN TECN TECN | $\begin{array}{c} e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \end{array}$ $\begin{array}{c} \underline{\text{MENT}} \\ e^+e^- \rightarrow \\ \text{width of } \psi(4) \\ +\text{C.C.} \end{pmatrix} / \\ \underline{\text{MENT}} \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ e^+e^- \rightarrow \\ \underline{\text{COMMENT}} \\ \end{array}$ | $ \begin{array}{c} D^{*+}D^{*-} - \gamma \\ \hline \Gamma_{11}/I \\ D^{0}D^{-} - \pi^{+} \gamma \\ I^{(15)}. \end{array} $ $ \begin{array}{c} \Gamma_{10}/\Gamma_{11} \\ \hline D^{0}D^{-} - \pi^{+} \gamma \\ I^{(15)}. \end{array} $ $ \begin{array}{c} D^{0}D^{-} - \pi^{+} \\ I^{(15)}. \end{array} $ $ \begin{array}{c} I^{0}D^{0}D^{-} - \pi^{+} \\ \hline \Gamma_{13}/I \\ D^{+}D^{-}S^{-} \gamma \\ D^{+}S^{-}S^{-} \gamma \\ \Gamma_{14}/I \\ D^{*+}D^{-}S^{-} \gamma \\ D^{*+}S^{-}S^{-} \gamma \\ D^{*+}S^{-}S^{-} \gamma \end{array} $ |
| seen | AUBERT PAKHLOVA +C.C.)/\(\int \text{Total}\) \(\text{OCUMENT ID} \) AKHLOVA 0.8A mass and 62 \pm 20 0.0D^0 +C.C., \(D^* \) +C.C.) \(\text{OCUMENT ID} \) AKHLOVA 0.8A mass and 62 \pm 20 X \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \((e^+ e^-) \) / \(\text{F} \((e^+ e^-) \) / \((e^+ e^-) \) / \((e^+ 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\rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- 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\rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^- \rightarrow \\ e^+e^-$ | Γ ₁₀ /Γ ₁₁ |

ψ(4415) REFERENCES

| PAKHLOVA | 11 | PR D83 011101 | G. Pakhlova et al. | (BELLE Collab.) |
|------------|------|----------------|-----------------------------|-----------------------------|
| DEL-AMO-SA | 10 N | PR D82 052004 | P. del Amo Sanchez et al. | (BABAR Collab.) |
| MO | 10 | PR D82 077501 | X.H. Mo, C.Z. Yuan, P. Wanj | g ` (BHEP) |
| AUBERT | 09 M | PR D79 092001 | B. Aubert et al. | (BABAR Collab.) |
| PAKHLOVA | 09 | PR D80 091101R | G. Pakhlova et al. | (BELLE Collab.) |
| ABLIKIM | 08 D | PL B660 315 | M. Ablikim et al. | (BES Collab.) |
| PAKHLOVA | 08 | PR D77 011103R | G. Pakhlova et al. | (BÈLLE Collab.) |
| PAKHLOVA | 08A | PRL 100 062001 | G. Pakhlova et al. | (BELLE Collab.) |
| PAKHLOVA | 07 | PRL 98 092001 | G. Pakhlova et al. | (BELLE Collab.) |
| SETH | 05A | PR D72 017501 | K.K. Seth | |
| BAI | 02 C | PRL 88 101802 | J.Z. Bai et al. | (BES Collab.) |
| BAI | 00 | PRL 84 594 | J.Z. Bai et al. | (BES Collab.) |
| OSTERHELD | 86 | SLAC-PUB-4160 | A. Osterheld et al. | (SLAC Crystal Ball Collab.) |
| BRANDELIK | 78 C | PL 76B 361 | R. Brandelik et al. | (DASP Collab.) |
| SIEGRIST | 76 | PRL 36 700 | J.L. Siegrist et al. | (LBL, SLAC) |

 $X(4430)^{\pm}, X(4660)$

 $X(4430)^\pm$

 $I(J^P) \ = \ ?(?^?)$

OMITTED FROM SUMMARY TABLE

Seen by CHOI 08 in $B \to K \pi^+ \psi(2S)$ decays and confirmed by reanalysis of the same data sample in MIZUK 09. Not seen by

$X(4430)^{\pm}$ MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------|--------------------|----------|-----------|----------------------------------|
| 4443+15+19 | ¹ MIZUK | 09 | BELL | $B \rightarrow K \pi^+ \psi(2S)$ |
| • • • We do not use the following | ng data for averag | es, fits | , limits, | etc. • • • |
| 4433± 4± 2 | ² сноі | 08 | BELL | $B \rightarrow K \pi^+ \psi(2S)$ |
| $^{ m 1}$ From a Dalitz plot analysis. $^{ m 2}$ Superseded by MIZUK 09. | | | | |

X (4430) ± WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------------------------------|--------------------|---------|-------------|----------------------------------|
| 107+86+74 -43-56 | ³ MIZUK | 09 | BELL | $B \rightarrow K \pi^+ \psi(2S)$ |
| • • • We do not use the following | g data for average | s, fits | , limits, e | etc. • • • |
| $\begin{array}{l} 45 + 18 + 30 \\ -13 - 13 \end{array}$ | ⁴ CHOI | 80 | BELL | $B \rightarrow K \pi^+ \psi(2S)$ |
| ³ From a Dalitz plot analysis. ⁴ Superseded by MIZUK 09. | | | | |

$X(4430)^{\pm}$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------|------------------------------|
| Γ ₁ | $\pi^+ \psi(2S)$ | seen |
| Γ_2 | $\pi^+ J/\psi$ | not seen |

X(4430) BRANCHING RATIOS

| $\Gamma(\pi^+\psi(2S))/\Gamma_{\text{tot}}$ | 1 | | | Г1 | /Γ |
|---------------------------------------------|---------------------------------------------|----------|-----------|----------------------------------|---------------|
| VALUE | DO CUMENT IE |) | TECN | COMMENT | |
| seen | ⁵ MIZUK | 09 | BELL | $B \rightarrow K \pi^+ \psi(2S)$ | |
| ● ● We do not use | the following data for averag | es, fits | , limits, | etc. • • • | |
| not seen | ⁶ AUBERT | 09A | BABR | $B \rightarrow K \pi^+ \psi(2S)$ | |
| ⁵ Measured a produc | ct of branching fractions B(\overline{B} | ·0 → K | -X(44 | $(30)^+) \times B(X(4430)^+)$ | \rightarrow |
| $\pi^+ \psi(2S)) = (3.2$ | $^{+1.8+5.3}_{-0.9-1.6})\times 10^{-5}$ | | | | |
| 6 ALIBERT DOAA a | 10tes B(B+ → K 0 Y(4430 | n+1 ~ | B/Y/A | 430) ± = #± 4/(25)) | |

| 4.7 \times 10 ⁻⁵ and B($B^0 \rightarrow$ at 95% CL. | $K^- X(4430)^+) \times I$ | $B(X(4430)^+ \rightarrow$ | $\pi^+ \psi(2S)) <$ | 3.1×10 ⁻⁵ |
|-------------------------------------------------------------------|---------------------------|---------------------------|---------------------|----------------------|
| $\Gamma(\pi^+ J/\psi)/\Gamma_{ m total}$ | | | | Γ_2/Γ |
| | | | | |

7 AUBERT 09AA BABR $B \rightarrow K \pi^+ J/\psi$ not seen 7 AUBERT 09AA quotes B($B^+
ightarrow \, \overline{K}{}^0 \, X(4430)^+) imes$ B($X(4430)^+
ightarrow \, \pi^+ \, J/\psi) < 1.5 imes$ $10^{-5} \text{ and } B(\overline{B}{}^0 \to \ \ K^- X(4430)^+) \ \times \ B(X(4430)^+ \to \ \pi^+ J/\psi) < \ 0.4 \times 10^{-5} \ \text{at}$

X(4430) ± REFERENCES

| AUBERT | 09 | PR D79 112001 | B. Aubert <i>et al.</i> | (BABAR Collab. |
|--------|----|----------------|-------------------------|-----------------|
| MIZUK | | PR D80 031104R | R. Mizuk <i>et al.</i> | (BELLE Collab. |
| CHOI | 80 | PRL 100 142001 | SK. Choi et al. | (BELLE Collab.) |

X (4660)

$$I^{G}(J^{PC}) = ?^{?}(1^{-})$$

Seen in radiative return from $e^+\,e^-$ collisions at $\sqrt{s}=$ 9.54–10.58 GeV by WANG 07D. Also obtained in a combined fit of WANG 07D and AUBERT 07s. See also the review under the X(3872) particle listings. (See the index for the page number.)

X(4660) MASS

| VALUE (MeV) | DO CUMENT II | 0 | TECN | COMMENT |
|------------------------------|--------------------|--------------|-----------|---------------------------------------------------------------------------------------------------|
| 4664±11±5 | WANG | 0 7 D | BELL | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \psi(2S) \ \pi^+ \ \pi^- \gamma \end{array}$ |
| • • • We do not use | the following data | for avera | ges, fits | , limits, etc. • • • |
| $4661 + 9 \pm 6$ | 1 _{LIU} | 08н | RVUE | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \psi(2S) \ \pi^+ \ \pi^- \ \gamma \end{array}$ |
| ¹ From a combined | fit of AUBERT 07s | and WA | NG 070 | data with two resonances. |

X (4660) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-------------------|--------------|-----------|---------------------------------------------------------------------------------------------------|
| 48±15±3 | WANG | 0 7 D | BELL | 10.58 $e^+ e^- \to \psi(2S) \pi^+ \pi^- \gamma$ |
| • • • We do not use the f | ollowing data for | avera | ges, fits | , limits, etc. • • • |
| $42^{+17}_{-12} \pm 6$ | ² LIU | 08н | RVUE | $\begin{array}{c} 10.58 \ e^+ \ e^- \rightarrow \\ \psi(2S) \ \pi^+ \ \pi^- \ \gamma \end{array}$ |

 2 From a combined fit of AUBERT 07s and WANG 07D data with two resonances.

X(4660) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------------------------------------|------------------------------|
| Γ_1 Γ_2 Γ_3 | $e^{+} e^{-} \ \psi(2S) \pi^{+} \pi^{-} \ D^{0} D^{*-} \pi^{+}$ | seen |

$X(4660) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\psi(2S)\pi^+\pi^-)$ | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | | T. C | | $\Gamma_2\Gamma_1/\Gamma$ |
|--------------------------------------|-----------------------------------------|-------------|------------|------------------------------------------------------------------------------------------------------------------------------|---------------------------|
| VALUE (eV) | <u>DO CUMENT</u> | ID | TECN | COMMENT | |
| ● ● We do not us | e the following data | for avera | iges, fits | , limits, etc. • • • | |
| $2.2^{+\ 0.7}_{-\ 0.6}$ | ³ LIU | 08н | RVUE | 10.58 $e^+e^- \rightarrow \psi(2S) \pi^+\pi^- \gamma$ | |
| $5.9 \!\pm\! 1.6$ | ⁴ LIU | 08н | RVUE | 10.58 $e^+e^- \rightarrow \psi(2S) \pi^+\pi^- \gamma$ | |
| $3.0 \pm 0.9 \pm 0.3$ | ⁵ WANG | 07 D | BELL | $10.58 e^+e^- \rightarrow$ | |
| $7.6\!\pm\!1.8\!\pm\!0.8$ | ⁶ WANG | 07 D | BELL | $ \begin{array}{c} \psi(2S) \pi^{+} \pi^{-} \gamma \\ 10.58 e^{+} e^{-} \to \\ \psi(2S) \pi^{+} \pi^{-} \gamma \end{array} $ | |
| | | | | | |

3 Solution I in a combined fit of AUBERT 07s and WANG 07D data with two resonances. 4 Solution II in a combined fit of AUBERT 07s and WANG 07D data with two resonances. 5 Solution I of two equivalent solutions in a fit using two interfering resonances.

⁶ Solution II of two equivalent solutions in a fit using two interfering resonances.

X (4660) BRANCHING RATIOS

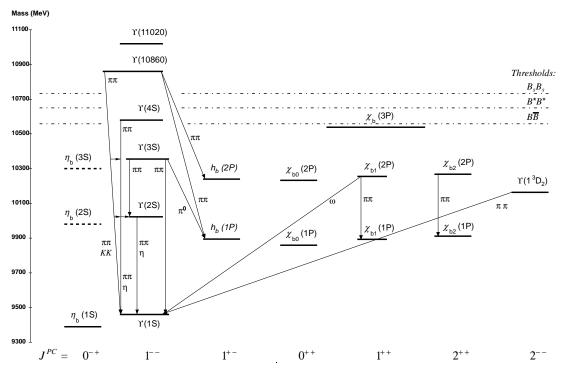
| $\Gamma(D^0D^{*-}\pi^+)/\Gamma(\pi^0)$ | $\psi(2S)\pi^+$ | π^{-}) | | | Γ_3/Γ_2 |
|----------------------------------------|-----------------|----------------------------------|----|------|------------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| <10 | 90 | PAKHLOVA | 09 | BELL | $e^+e^- \rightarrow X(4660) \rightarrow$ |
| | | | | | $D^{0}D^{*-}\pi^{+}$ |
| $\Gamma(D^0D^{*-}\pi^+)/\Gamma_{to}$ | tal × Γ(| $e^+ e^-)/\Gamma_{\text{total}}$ | | | $\Gamma_3/\Gamma \times \Gamma_1/\Gamma$ |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
| -0-0 | | 7 PAKHLOVA | 09 | BELL | $e^+e^- \rightarrow X(4660) \rightarrow$ |
| $< 0.37 \times 10^{-6}$ | 90 | PAKHLOVA | 09 | BELL | |
| <0.37 × 10 ° | 90 | PAKHLOVA | 09 | BELL | $D^{0}D^{*-}\pi^{+}$ |

X(4660) REFERENCES

| PAKHLOVA | 09 | PR D80 091101R | G. Pakhlova et al. | (BELLE Collab.) |
|----------|------|----------------|-------------------------------|-----------------|
| LIU | 08 H | PR D78 014032 | Z.Q. Liu, X.S. Qin, C.Z. Yuan | |
| AUBERT | 07S | PRL 98 212001 | B. Aubert et al. | (BABAR Collab.) |
| WAN G | 07 D | PRL 99 142002 | X.L. Wang et al. | (BELLE Collab.) |

$b\overline{b}$ MESONS

THE BOTTOMONIUM SYSTEM



The level scheme of the $b\bar{b}$ states showing experimentally established states with solid lines. Singlet states are called η_b and h_b , triplet states Υ and χ_{bJ} . In parentheses it is sufficient to give the radial quantum number and the orbital angular momentum to specify the states with all their quantum numbers. E.g., $h_b(2P)$ means 2^1P_1 with n=2, L=1, S=0, J=1, PC=+-. The figure shows observed hadronic transitions. The single photon transitions $\Upsilon(nS) \to \gamma \eta_b(mS)$, $\Upsilon(nS) \to \gamma \chi_{bJ}(mP)$, and $\chi_{bJ}(nP) \to \gamma \Upsilon(mS)$ are omitted for clarity.

WIDTH DETERMINATIONS OF THE Υ STATES

As is the case for the $J/\psi(1S)$ and $\psi(2S)$, the full widths of the $b\overline{b}$ states $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ are not directly measurable, since they are much narrower than the energy resolution of the e^+e^- storage rings where these states are produced. The common indirect method to determine Γ starts from

$$\Gamma = \Gamma_{\ell\ell}/B_{\ell\ell} \ , \tag{1}$$

where $\Gamma_{\ell\ell}$ is one leptonic partial width and $B_{\ell\ell}$ is the corresponding branching fraction ($\ell = e, \mu$, or τ). One then assumes $e^{-\mu-\tau}$ universality and uses

$$\Gamma_{\ell\ell} = \Gamma_{ee}$$

$$B_{\ell\ell} = \text{average of } B_{ee}, \ B_{\mu\mu}, \ \text{and } B_{\tau\tau} \ .$$
 (2)

The electronic partial width Γ_{ee} is also not directly measurable at e^+e^- storage rings, only in the combination $\Gamma_{ee}\Gamma_{\rm had}/\Gamma$, where $\Gamma_{\rm had}$ is the hadronic partial width and

$$\Gamma_{\text{had}} + 3\Gamma_{ee} = \Gamma \ . \tag{3}$$

This combination is obtained experimentally from the energy-integrated hadronic cross section

$$\int \sigma(e^+e^- \to \Upsilon \to \text{hadrons})dE$$

resonance

$$= \frac{6\pi^2}{M^2} \frac{\Gamma_{ee} \Gamma_{had}}{\Gamma} C_r = \frac{6\pi^2}{M^2} \frac{\Gamma_{ee}^{(0)} \Gamma_{had}}{\Gamma} C_r^{(0)} , \qquad (4)$$

where M is the Υ mass, and C_r and $C_r^{(0)}$ are radiative correction factors. C_r is used for obtaining Γ_{ee} as defined in Eq. (1), and contains corrections from all orders of QED for describing $(b\overline{b}) \to e^+e^-$. The lowest order QED value $\Gamma_{ee}^{(0)}$, relevant for comparison with potential-model calculations, is defined by the lowest order QED graph (Born term) alone, and is about 7% lower than Γ_{ee} .

The Listings give experimental results on B_{ee} , $B_{\mu\mu}$, $B_{\tau\tau}$, and $\Gamma_{ee}\Gamma_{\rm had}/\Gamma$. The entries of the last quantity have been re-evaluated consistently using the correction procedure of KU-RAEV 85. The partial width Γ_{ee} is obtained from the average values for $\Gamma_{ee}\Gamma_{\rm had}/\Gamma$ and $B_{\ell\ell}$ using

$$\Gamma_{ee} = \frac{\Gamma_{ee} \Gamma_{had}}{\Gamma(1 - 3B_{\ell\ell})} \ . \tag{5}$$

Bottomonium, $\eta_b(1S)$, $\Upsilon(1S)$

The total width Γ is then obtained from Eq. (1). We do not list Γ_{ee} and Γ values of individual experiments. The Γ_{ee} values in the Meson Summary Table are also those defined in Eq. (1).



 $I^{G}(J^{PC}) = 0^{+}(0^{-+})$

OMITTED FROM SUMMARY TABLE

Quantum numbers shown are quark-model predictions. Observed in radiative decay of the $\Upsilon(3S)$, therefore C=+.

$\eta_b(1S)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------|-----------------|---------------------|----------|-----------|-------------------------------------|
| 9391.0± 2.8 OUR AV | ERAGE | | | | |
| 9391.8 \pm 6.6 \pm 2.0 | $2.3\pm0.5k$ | $^{ m 1}$ bonvicini | 10 | CLEO | $\Upsilon(3S) \rightarrow \gamma X$ |
| $9394.2^{+}_{-}{}^{4.8}_{4.9}\!\pm2.0$ | $13\pm5k$ | ¹ AUBERT | 09A | BABR | $\Upsilon(2S) \rightarrow \gamma X$ |
| 9388.9 $^{+}_{-}$ $^{3.1}_{2.3}$ \pm 2.7 | $19\pm3k$ | $^{ m 1}$ AUBERT | 08∨ | BABR | $\Upsilon(3S) \rightarrow \gamma X$ |
| • • • We do not use | the following d | ata for averages, f | its, lim | its, etc. | • • • |
| 9300 ±20 ±20 | | HEISTER | 02D | | 181-209 e^+e^- |

 $^1{\rm Assuming}~\Gamma_{\eta_b(1S)}=10$ MeV. Not independent of the corresponding γ energy or mass difference measurements.

$m_{T(1S)} - m_{\eta_b}$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|---------------------|------------------------|-------|------|-------------------------------------|--|
| 69.3±2.8 OUR AVE | RAGE | | | | <u> </u> | |
| $68.5 \pm 6.6 \pm 2.0$ | $\rm 2.3 \pm 0.5 k$ | ² BONVICINI | 10 | CLEO | $\Upsilon(3S) \rightarrow \gamma X$ | |
| $66.1^{+4.8}_{-4.9}\pm2.0$ | $13\pm5k$ | ² AUBERT | 09a Q | BABR | $\Upsilon(2S) \rightarrow \gamma X$ | |
| $71.4^{+2.3}_{-3.1}\pm 2.7$ | $19\pm3k$ | ² AUBERT | 08∨ | BABR | $\Upsilon(3S) \rightarrow \gamma X$ | |

 2 Assuming $\Gamma_{\eta_b(1S)}=10$ MeV. Not independent of the corresponding γ energy or mass measurements.

γ ENERGY IN $\Upsilon(3S)$ DECAY

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|--------------|------------------------|-----|------|-------------------------------------|
| 920.6 ^{+2.8} OUR AVE | RAGE | _ | | | |
| $918.6 \pm 6.0 \pm 1.9$ | $2.3\pm0.5k$ | ³ BONVICINI | 10 | CLEO | $\Upsilon(3S) \rightarrow \gamma X$ |
| $921.2^{+2.1}_{-2.8}\pm 2.4$ | $19\pm3k$ | ³ AUBERT | 08∨ | BABR | $\Upsilon(35) \rightarrow \gamma X$ |

 3 Assuming $\Gamma_{\eta_b(15)}=10\,$ MeV. Not independent of the corresponding mass or mass difference measurements.

γ ENERGY IN $\Upsilon(2S)$ DECAY

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT | |
|-------------------|---------|---------------------|-----------|-------------------------------------|--|
| 609.3 + 4.6 + 1.9 | 13 + 5k | ⁴ AUBERT | 09A0 BABR | $\Upsilon(2S) \rightarrow \gamma X$ | |

 4 Assuming $\Gamma_{\eta_b(15)}=10\,$ MeV. Not independent of the corresponding mass or mass difference measurements.

$\eta_b(1S)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|----------------|-----------------------------------|------------------------------|------------------|
| Γ ₁ | 3h+3h- | not seen | |
| Γ_2^- | $2h^{+}2h^{-}$ | not seen | |
| Γ3 | 4 h ⁺ 4 h ⁻ | | |
| Γ_4 | $\gamma \gamma$ | not seen | |
| Γ_5 | $\mu^+\mu^-$ | $< 9 \times 10^{-3}$ | 90% |
| Γ_6 | $	au^+ 	au^-$ | <8 % | 90% |

$\eta_b(1S) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

| $\Gamma(3h^+3h^-) \times$ | $\Gamma(\gamma\gamma)/\Gamma_{\rm total}$ | | | | | $\Gamma_1\Gamma_4/\Gamma$ |
|---------------------------|-------------------------------------------|--------------------|----------|---------|---------------------------------------|----------------------------------|
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT | - |
| • • • We do not | use the followin | g data for average | s, fits, | limits, | etc. • • • | |
| <470 | 95 | ABDALLAH | 06 | DLPH | 161-209 e ⁺ e ⁻ | - |
| <132 | 95 | HEISTER | 02D | ALEP | 181-209 e ⁺ e ⁻ | - |
| $\Gamma(2h^+2h^-) \times$ | $\Gamma(\gamma\gamma)/\Gamma_{\rm total}$ | | | | | Γ ₂ Γ ₄ /Γ |
| VALUE (eV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not | use the followin | g data for average | s, fits, | limits, | etc. • • • | |
| <190 | 95 | ABDALLAH | 06 | DLPH | 161-209 e ⁺ e ⁻ | - |

HEISTER

02D ALEP 181-209 $e^+\,e^-$

< 48

| $\Gamma(4h^+4h^-) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ | | | | | | |
|----------------------------------------------------------------------|-----------|-------------------|---------|---------|--------------------------|---|
| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT | |
| • • • We do not use the | following | data for averages | , fits, | limits, | etc. • • • | |
| <660 | 95 | ABDALLAH | 06 | DLPH | 161-209 e ⁺ e | _ |

$\eta_b(1S)$ BRANCHING RATIOS

| $\Gamma(\mu^+\mu^-)/\Gamma_{\rm t}$ | otal | | | | Г₅/Г |
|-------------------------------------|--------------------|----------------------------------------|---------------------------|----------------------------------|------------------------------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| $< 9 \times 10^{-3}$ | 90 | ⁵ AUBERT | 09z BABR | $e^+e^- \rightarrow \gamma$ | 2S, 3S) $\rightarrow \gamma \eta_b$ |
| ⁵ Obtained us | ing B(γ (: | $(2S) \rightarrow \gamma \eta_b = (4)$ | $2^{+1.1}_{-1.0} \pm 0.9$ | $	imes 10^{-4}$ and B(| $\Upsilon(3S) \rightarrow \gamma \eta_b$ |
| | | 10 ⁻⁴ . This limit | is equivalent to | $B(\eta_b \rightarrow \mu^+ \mu$ | $\mu^{-}) = (-0.25 \pm$ |
| 0.51 ± 0.33 | 1% measu | rement | | | |

| <8 × 10 ⁻¹ | 2 | <u>CL%</u> 90 | DOCUMENT ID | 09P | TECN BABR | $\frac{\textit{COMMENT}}{e^+e^- \rightarrow \gamma \tau^+ \tau^-}$ | - |
|--------------------------------------------------------------------------|----------------------------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|------------------------------------|--------------|---------------------------------------------------------------------------------------------------------------------|----------------|
| | | η_b | (1 <i>S</i>) REFERE | NCE | s | | |
| BONVICINI AUBERT AUBERT AUBERT AUBERT ABDALLAH HEISTER | 10 09AQ 09P 09Z 08V 06 02D | PR D81 031104R PRL 103 161801 PRL 103 181801 PRL 103 081803 PRL 101 071801 PL B634 340 PL B530 56 | G. Bonvicini e B. Aubert et B. Aubert et B. Aubert et B. Aubert et J.M. Abdallah A. Heister et | al. al. al. al. et al. | | (CLEO Collab (BABAR Collab (BABAR Collab (BABAR Collab (BABAR Collab (DELPHI Collab (ALEPH Collab | .) .) .) |

$\Upsilon(1S)$

 $I^{G}(J^{PC}) = 0^{-}(1^{-})$

7(15) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|---------------------------|--------|-----------|------------------------------|
| 9460.30 ± 0.26 OUR AVERAGE | Error includes scale | fact | or of 3.3 | |
| $9460.51 \pm 0.09 \pm 0.05$ | ¹ ARTA MONOV | 00 | MD1 | $e^+e^- ightarrow hadrons$ |
| $9459.97 \pm 0.11 \pm 0.07$ | MACKAY | 84 | REDE | $e^+e^- ightarrow hadrons$ |
| • • • We do not use the follow | ing data for averages | , fits | , limits, | etc. • • • |
| $9460.60 \pm 0.09 \pm 0.05$ | | | | $e^+e^- ightarrow $ hadrons |
| 9460.59 ± 0.12 | | | | $e^+e^- ightarrow hadrons$ |
| 9460.6 ±0.4 | ^{3,4} ARTA MONOV | 84 | REDE | $e^+e^-	o$ hadrons |

- $^{
 m 1}$ Reanalysis of BARU 92B and ARTAMONOV 84 using new electron mass (COHEN 87).
- ² Superseding BARU 86.

Mode

- ³ Superseded by ARTAMONOV 00.
- ⁴ Value includes data of ARTAMONOV 82

r(1S) WIDTH

VALUE (keV) DOCUMENT ID

54.02\pm1.25 OUR EVALUATION See the Note on "Width Determinations of the γ " States"

Fraction (Γ_i/Γ)

Confidence level

T(1S) DECAY MODES

| Γ ₁ | $\tau^+ \tau^-$ | (2.60±0.10) % |
|----------------|----------------------------|--------------------------------|
| Γ_2^- | $e^+ e^-$ | (2.38±0.11) % |
| | $\mu^+ \mu^-$ | (2.48 ± 0.05) % |
| | | Hadronic decays |
| Γ_4 | ggg | (81.7 ±0.7) % |
| Γ_5 | γgg | (2.2 ±0.6) % |
| Γ_6 | $\eta'(958)$ anything | (2.94 ± 0.24) % |
| Γ_7 | $J/\psi(1S)$ anything | $(6.5 \pm 0.7) \times 10^{-4}$ |
| Γ ₈ | χ_{c0} anything | $< 5 	 \times 10^{-3} 	 90\%$ |
| Г9 | χ_{c1} anything | $(2.3 \pm 0.7) \times 10^{-4}$ |
| Γ_{10} | χ_{c2} anything | $(3.4 \pm 1.0) \times 10^{-4}$ |
| Γ_{11} | $\psi(2S)$ anything | $(2.7 \pm 0.9) \times 10^{-4}$ |
| Γ_{12} | $ ho\pi$ | $< 2 \times 10^{-4} 90\%$ |
| | $\pi^+\pi^-$ | $< 5 	 \times 10^{-4} 	 90\%$ |
| Γ_{14} | K^+K^- | $< 5 	 \times 10^{-4} 	 90\%$ |
| Γ_{15} | р <u> </u> | $< 5 	 \times 10^{-4} 	 90\%$ |
| Γ_{16} | $\pi^0\pi^+\pi^-$ | $< 1.84 \times 10^{-5}$ 90% |
| Γ_{17} | $D^*(2010)^{\pm}$ anything | (2.5 2 ± 0.20) % |
| Γ_{18} | ₫ anything | $(2.86\pm0.28)\times10^{-5}$ |

Meson Particle Listings $\Upsilon(1S)$

| г | Radiative $\gamma\pi^+\pi^-$ | - | | \ 10-5 | | | | | |
|------------------------------------|-------------------------------------------------------------------------|----------------------|----------------------|-----------------------------------------|------------|--|--|--|--|
| Γ ₁₉ Γ ₂₀ | $\gamma \pi^{0} \pi^{0}$ | | 6.3 ±1.8 1.7 ±0.7 | | | | | | |
| Γ ₂₁ | $\gamma \pi^0 \eta$ | < | | ×10 ⁻⁶ | 90% | | | | |
| Γ ₂₂ | $\gamma K^+ K^-$ | | 1.14 ± 0.1 | | 3070 | | | | |
| Γ ₂₃ | $\gamma p \overline{p}$ | [b] < | | ×10-6 | 90% | | | | |
| Γ ₂₄ | $\gamma 2h^+ 2h^-$ | (| 7.0 ±1.5 | $) \times 10^{-4}$ | | | | | |
| Γ ₂₅ | $\gamma 3h^+ 3h^-$ | (| 5.4 ±2.0 | $) \times 10^{-4}$ | | | | | |
| Γ ₂₆ | γ 4 h^+ 4 h^- | | $7.4\ \pm3.5$ | | | | | | |
| Γ ₂₇ | $\gamma \pi^+ \pi^- K^+ K^-$ | | 2.9 ± 0.9 | | | | | | |
| Γ ₂₈ | $\gamma 2\pi^+ 2\pi^-$ | | 2.5 ± 0.9 | | | | | | |
| Γ ₂₉ | $\gamma 3\pi^{+} 3\pi^{-}$ | | 2.5 ±1.2 | | | | | | |
| Γ ₃₀ | $\gamma 2\pi^{+} 2\pi^{-} K^{+} K^{-}$ | | 2.4 ±1.2 | | | | | | |
| Г31 | $\gamma \pi^+ \pi^- p \overline{p}$ | | 1.5 ±0.6 | | | | | | |
| Γ ₃₂ | $\gamma 2\pi^+ 2\pi^- p \overline{p}$ $\gamma 2K^+ 2K^-$ | | 4 ±6 2.0 ±2.0 | $) \times 10^{-5}$ | | | | | |
| Γ ₃₃ Γ ₃₄ | $\gamma 2 R \cdot 2 R$ $\gamma \eta'(958)$ | | 2.0 ±2.0 1.9 | × 10 -6 | 90% | | | | |
| Γ ₃₅ | $\gamma \eta$ (730) | | 1.0 | ×10 ⁻⁶ | 90% | | | | |
| Γ ₃₆ | $\gamma f_0(980)$ | < | | ×10 ⁻⁵ | 90% | | | | |
| Γ ₃₇ | $\gamma f_2'(1525)$ | | 3.8 ±0.9 | | 3070 | | | | |
| Γ ₃₈ | $\gamma f_2(1270)$ | | 1.01±0.0 | | | | | | |
| Γ ₃₉ | $\gamma \eta (1405)$ | < | | ×10 ⁻⁵ | 90% | | | | |
| Γ ₄₀ | $\gamma f_0(1500)$ | < | | $\times 10^{-5}$ | 90% | | | | |
| Γ ₄₁ | $\gamma f_0(1710)$ | < | | $\times 10^{-4}$ | 90% | | | | |
| Γ ₄₂ | $\gamma f_0(1710) \rightarrow \gamma K^+ K^-$ | < | 7 | $\times 10^{-6}$ | 90% | | | | |
| Γ_{43} | $\gamma f_0(1710) \rightarrow \gamma \pi^0 \pi^0$ | < | 1.4 | $\times 10^{-6}$ | 90% | | | | |
| Γ_{44} | $\gamma f_0(1710) \rightarrow \gamma \eta \eta$ | < | 1.8 | $\times 10^{-6}$ | 90% | | | | |
| Γ_{45} | $\gamma f_4(2050)$ | < | 5.3 | $\times 10^{-5}$ | 90% | | | | |
| Γ ₄₆ | $\gamma f_0(2200) \rightarrow \gamma K^+ K^-$ | < | 2 | ×10 ⁻⁴ | 90% | | | | |
| Γ ₄₇ | $\gamma f_J(2220) \rightarrow \gamma K^+ K^-$ | < | 8 | $\times 10^{-7}$ | 90% | | | | |
| Γ ₄₈ | $\gamma f_J(2220) \rightarrow \gamma \pi^+ \pi^-$ | < | | ×10 ⁻⁷ | 90% | | | | |
| Γ ₄₉ | $\gamma f_J(2220) \rightarrow \gamma p \overline{p}$ | < | 1.1 | ×10 ⁻⁶ | 90% | | | | |
| Γ ₅₀ | $\gamma \eta(2225) \rightarrow \gamma \phi \phi$ | < | 3 | $\times 10^{-3}$ | 90% | | | | |
| Γ ₅₁ | $\gamma \eta_c(1S)$ | < | 5.7 | $\times 10^{-5} \times 10^{-4}$ | 90% 90% | | | | |
| Γ ₅₂ Γ ₅₃ | $\gamma \chi_{c0}$ | < | | × 10 × 10 × 10 × 10 × 10 × 10 × 10 × 10 | 90% | | | | |
| Γ ₅₄ | $\gamma \chi_{c1}$ $\gamma \chi_{c2}$ | < | | ×10 ⁻⁶ | 90% | | | | |
| Γ ₅₅ | $\gamma X(3872) \rightarrow \pi^+ \pi^- J/\psi$ | < | 1.6 | ×10-6 | 90% | | | | |
| Γ ₅₆ | $\gamma X(3872) \rightarrow \pi^+ \pi^- \pi^0 J/\psi$ | < | 2.8 | ×10 ⁻⁶ | 90% | | | | |
| Γ ₅₇ | $\gamma X (3915) \rightarrow \omega J/\psi$ | < | 3.0 | $\times 10^{-6}$ | 90% | | | | |
| Γ ₅₈ | $\gamma X(4140) \rightarrow \phi J/\psi$ | < | 2.2 | $\times 10^{-6}$ | 90% | | | | |
| Γ ₅₉ | γX | [c] < | 4.5 | $\times 10^{-6}$ | 90% | | | | |
| Γ ₆₀ | $\gamma X \overline{X} (m_X < 3.1 \text{ GeV})$ | [d] < | 1 | $\times 10^{-3}$ | 90% | | | | |
| Γ ₆₁ | $\gamma X \overline{X} (m_X < 4.5 { m GeV})$ | [e] < | 2.4 | $\times 10^{-4}$ | 90% | | | | |
| Γ ₆₂ | $\gamma X \rightarrow \gamma + \geq 4 \text{ prongs}$ | [f] < | 1.78 | $\times 10^{-4}$ | 95% | | | | |
| Γ ₆₃ | $\gamma a_{1}^{0} \rightarrow \gamma \mu^{+} \mu^{-}$ | [g] < | 9 | $\times 10^{-6}$ | 90% | | | | |
| Γ ₆₄ | $\gamma a_1^0 \rightarrow \gamma \tau^+ \tau^-$ | [a] < | 5.0 | $\times 10^{-5}$ | 90% | | | | |
| | Lepton Family number | (LF) vi | olating m | odes | | | | | |
| Γ ₆₅ | I — | | 6.0 | , | 95% | | | | |
| 00 | | J | | | | | | | |
| Γ ₆₆ | Other of invisible | _ | 3.0 | ×10 ⁻⁴ | 90% | | | | |
| 1 66 | THVISIBLE | | 3.0 | X 10 | 30 /0 | | | | |
| a | $]~2m_{	au} < {\sf M}(au^+ 	au^-) < 7500~{\sf MeV}$ | | | | | | | | |
| | $] 2 < m_{K^+K^-} < 3 \text{ GeV}$ | | | | | | | | |
| | X = scalar with m < 8.0 GeV | | | | | | | | |
| | | , | | | | | | | |
| | $X\overline{X} = \underbrace{\text{vectors with } m < 3.1 \text{ GeV}}$ | | | | | | | | |
| |] X and $\overline{X}=$ zero spin with $m<2$ | 1.5 GeV | | | | | | | |
| [f] |] 1.5 GeV $< m_X <$ 5.0 GeV | | | | | | | | |
| |] 201 $<$ M $(\mu^+\mu^-)$ $<$ 3565 MeV | | | | | | | | |
| [0] | | | | | | | | | |
| | Υ(1S) Γ(i)Γ(e ⁻ | + e ⁻)/Γ | (total) | | | | | | |

| r | 15 | LΓ | 'nΓ | (e+ | e-' | ۱/۲ | (total) | |
|---|----|----|-----|-----|-----|-----|---------|--|
| | | | | | | | | |

 $\Gamma_2\Gamma_3/\Gamma$

 $\Gamma(e^+\,e^-)\, imes\,\Gamma(\mu^+\,\mu^-)/\Gamma_{
m total}$

| | ULAI | | | | 2.3/ |
|-------------------------------------------------------|---------------------|-------|------|-----------------------|---------------------------|
| VALUE (eV) | DO CUMENT ID | | TECN | COMMENT | |
| 31.2±1.6±1.7 | KOBEL | 92 | CBAL | $e^+e^- \to$ | $\mu^+\mu^-$ |
| $\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma$ | - total | | | | $\Gamma_0\Gamma_2/\Gamma$ |
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| 1.240 ± 0.016 OUR AVERAGE | · | | | | |
| $1.252 \pm 0.004 \pm 0.019$ | ⁵ ROSNER | 06 | CLEO | 9.5 $e^{+}e^{-}$ | → hadrons |
| $1.187 \pm 0.023 \pm 0.031$ | ⁵ BARU | 92B | MD1 | $e^+ e^- \rightarrow$ | hadrons |
| $1.23 \pm 0.02 \pm 0.05$ | 5 JAKUBOWSŁ | (1 88 | CBAL | $e^+ e^- \rightarrow$ | hadrons |
| $1.37 \pm 0.06 \pm 0.09$ | ⁶ GILES | 84B | CLEO | $e^+e^- \to$ | hadrons |
| | | | | | |

| 1.23 +0.08 +0.04 6 ALBRECHT 82 DASP $e^+e^- \rightarrow$ | |
|--------------------------------------------------------------------|---------|
| 1.13 $\pm 0.07 \pm 0.11$ 6 NICZYPORUK 82 LENA $e^+e^- \rightarrow$ | |
| , | |
| | |
| 1.35 ± 0.14 7 BERGER 79 PLUT $e^+e^- \rightarrow$ | hadrons |

⁵ Radiative corrections evaluated following KURAEV 85.

T(1S) PARTIAL WIDTHS

| Γ(e ⁺ e ⁻) | | Γ ₂ |
|-----------------------------------|-------------|----------------|
| VALUE (keV) | DOCUMENT ID | |
| 1.340±0.018 OUR EVALUATION | | |

T(1S) BRANCHING RATIOS

| $\Gamma(\tau^+\tau^-)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|----------------------------------------------|------|-----------------------|------|------|--------------------------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 2.60±0.10 OUR AV | | | | | |
| $2.53 \pm 0.13 \pm 0.05$ | 60k | ⁸ BESSON | 07 | CLEO | $e^+ e^- \rightarrow \Upsilon(1S) \rightarrow \tau^+ \tau^-$ |
| $2.61 \pm 0.12 + 0.09 \\ -0.13$ | 25 k | CINABRO | 94B | CLE2 | $e^+e^-\rightarrow\tau^+\tau^-$ |
| $2.7 \pm 0.4 \pm 0.2$ | | ⁹ ALBRECHT | 85 c | ARG | $\Upsilon(2S) \rightarrow \pi^+\pi^-\tau^+\tau^-$ |
| 34 + 04 + 04 | | GILES | 83 | CLEO | $e^+e^- \rightarrow \tau^+\tau^-$ |

⁸ BESSON 07 reports [$\Gamma(\Upsilon(1S) \rightarrow \ \tau^+ \ \tau^-)/\Gamma_{total}$] / [B($\Upsilon(1S) \rightarrow \ \mu^+ \ \mu^-$)] = 1.02 ± 0.02 ± 0.05 which we multiply by our best value B($\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.48\pm0.05) \times$ 10^{-2} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

9 Using B($\Upsilon(1S)
ightarrow e\,e) =$ B($\Upsilon(1S)
ightarrow \mu\mu) = 0.0256$; not used for width evaluations.

| $\Gamma(e^+e^-)/\Gamma_{\text{total}}$ | | | | | | Γ_2/Γ |
|----------------------------------------|------|--------------|------|------|----------------------------|----------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.38±0.11 OUR AVE | RAGE | · · | | | | |
| $2.29 \pm 0.08 \pm 0.11$ | | ALEXANDER | 98 | CLE2 | $\Upsilon(2S) \rightarrow$ | $\pi^{+}\pi^{-}e^{+}e^{-}$ |
| $2.42 \pm 0.14 \pm 0.14$ | 307 | ALBRECHT | 87 | ARG | $\Upsilon(2S) \rightarrow$ | $\pi^{+}\pi^{-}e^{+}e^{-}$ |
| $2.8 \pm 0.3 \pm 0.2$ | 826 | BESSON | 84 | CLEO | $\Upsilon(2S) \rightarrow$ | $\pi^{+}\pi^{-}e^{+}e^{-}$ |
| 5.1 +3.0 | | REDGER | 80 c | PLUT | a+a | a+a- |

| $\Gamma(\mu^+\mu^-)/\Gamma_{ m total}$ | | | | | Г ₃ /Г |
|-------------------------------------------------------|-------|---------------------|-----|------|---------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.0248 ± 0.0005 OUR AV | ERAGE | | | | |
| $0.0249 \pm 0.0002 \pm 0.0007$ | 345k | ADAMS | 05 | CLEO | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.0249 \pm 0.0008 \pm 0.0013$ | | ALEXANDER | 98 | CLE2 | $\Upsilon(2S) \rightarrow$ |
| | | | | | $\pi^{+}\pi^{-}\mu^{+}\mu^{-}$ |
| $0.0212 \pm 0.0020 \pm 0.0010$ | | ¹⁰ BARU | 92 | MD1 | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.0231 \pm 0.0012 \pm 0.0010$ | | ¹⁰ KOBEL | 92 | CBAL | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.0252 \pm 0.0007 \pm 0.0007$ | | CHEN | 89B | CLEO | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.0261 \pm 0.0009 \pm 0.0011$ | | KAARSBERG | 89 | CSB2 | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.0230 \pm 0.0025 \pm 0.0013$ | 86 | ALBRECHT | 87 | ARG | $\Upsilon(2S) \rightarrow$ |
| | | | | | $\pi^{+}\pi^{-}\mu^{+}\mu^{-}$ |
| $0.029 \pm 0.003 \pm 0.002$ | 864 | BESSON | 84 | CLEO | $\Upsilon(2S) \rightarrow$ |
| | | | | | $\pi^{+}\pi^{-}\mu^{+}\mu^{-}$ |
| $0.027 \pm 0.003 \pm 0.003$ | | ANDREWS | 83 | CLEO | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.032 \pm 0.013 \pm 0.003$ | | ALBRECHT | 82 | DASP | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.038 \pm 0.015 \pm 0.002$ | | NICZYPORUK | 82 | LENA | $e^+e^- \rightarrow \mu^+\mu^-$ |
| $0.014 \begin{array}{l} +0.034 \\ -0.014 \end{array}$ | | воск | 80 | CNTR | $e^+e^-\to\mu^+\mu^-$ |
| $0.022\ \pm0.020$ | | BERGER | 79 | PLUT | $e^+e^-\rightarrow\mu^+\mu^-$ |
| | | | | | |

 $^{\rm 10}\,{\rm Taking}$ into account interference between the resonance and continuum.

| $\Gamma(\tau^+\tau^-)/\Gamma(\mu^+\mu^-)$ | -) | | | Γ_1/Γ_3 |
|-------------------------------------------|----------------|-------------------------------|------|----------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| 1.008±0.023 OUR AV | /ERAGE | | | |
| $1.005 \pm 0.013 \pm 0.022$ | 0.7M | ¹¹ DEL-A MO-SA10 c | BABR | $\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$ |
| $1.02 \pm 0.02 \pm 0.05$ | 60k | BESSON 07 | CLEO | $e^+e^- \rightarrow \Upsilon(1S)$ |
| 4.4 | | | | |

 $^{^{11}}$ Allows any number of extra photons with total energy < 500 MeV.

| | | | | Γ_4/Γ |
|------|--------------|---------------|------|---------------------------------|
| EVTS | DO CUMENT ID | | TECN | COMMENT |
| 20M | 12 BESSON | 06A | CLEO | ${\mathcal T}(1S) 	o {hadrons}$ |
| | | _ | | |

 12 Calculated using the value $\Gamma(\gamma g g)/\Gamma(g g g)=(2.70\pm0.01\pm0.13\pm0.24)\%$ from BESSON 06A and PDG 08 values of B($\mu^+\mu^-$) = (2.48 \pm 0.05)% and Rhadrons = 3.51. The statistical error is negligible and the systematic error is partially correlated with that of $\Gamma(\gamma gg)/\Gamma_{\rm total}$ measurement of BESSON 06A.

| $\Gamma(\gamma g g)/\Gamma_{total}$ | | | | | Γ ₅ /Γ |
|-------------------------------------|------|--------------|-----|------|------------------------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 2.20±0.60 | 400k | 13 BESSON | 06A | CLEO | $\gamma(1S) ightarrow \gamma + hadrons$ |

 $^{^{13}}$ Calculated using BESSON 06A values of $\Gamma(\gamma g\,g)/\Gamma(g\,g\,g)=(2.70\pm0.01\pm0.13\pm0.24)\%$ and $\Gamma(g\,g\,g)/\Gamma_{total}$. The statistical error is negligible and the systematic error is partially correlated with that of $\Gamma(g\,g\,g)/\Gamma_{total}$ measurement of BESSON 06A.

⁶ Radiative corrections reevaluated by BUCHMUELLER 88 following KURAEV 85. 7 Radiative corrections reevaluated by ALEXANDER 89 using B $(\mu\mu)=0.026$.

 $\Upsilon(1S)$

| -/ \ \-/ \ | | -/ 1 >/- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\gamma gg)/\Gamma(ggg)$ | Γ_5/Γ_4 | $\Gamma(\gamma \pi^+ \pi^-)/\Gamma_{\text{total}}$ | DO CUMENT ID TECN | Г19/Г |
| VALUE (units 10 ⁻²) EVTS 2.70±0.01±0.27 20M | $\begin{array}{c ccccc} \underline{\textit{DOCUMENT ID}} & \underline{\textit{TECN}} & \underline{\textit{COMMENT}} \\ \text{BESSON} & 06\text{A} & \text{CLEO} & \mathcal{T}(1S) \rightarrow (\gamma +) \text{ hadrons} \end{array}$ | VALUE (units 10 ⁻⁵) 6.3±1.2±1.3 | 18 ANASTASSOV 99 CLE2 | |
| | () () .) | 18 For $m_{\pi\pi}>1$ GeV. | | |
| $\Gamma(\eta'(958) \text{ a nything})/\Gamma_{	ext{tot}}$ | al F6/F DOCUMENT ID TECN COMMENT | $\Gamma(\gamma\pi^0\pi^0)/\Gamma_{ m total}$ | | Γ ₂₀ /Ι |
| 0.0294 ± 0.0024 OUR AVERA | GE | VALUE (units 10 ⁻⁵) | DOCUMENT ID TECN | • |
| $0.030 \pm 0.002 \pm 0.002$ $0.028 \pm 0.004 \pm 0.002$ | AQUINES 06A CLE3 $\varUpsilon(1S) ightarrow \eta'$ anything ARTUSO 03 CLE2 $\varUpsilon(1S) ightarrow \eta'$ anything | 1.7±0.6±0.3 | 4.0 | $e^+e^- 	o hadrons$ |
| $\Gamma(J/\psi(1S)$ anything $)/\Gamma_{ m tc}$ | , , , | $^{19}\mathrm{For}~m_{\pi\pi}>$ 1 GeV. | | |
| | tal F7/F /TS DOCUMENT ID TECN COMMENT | $\Gamma(\gamma\pi^0\eta)/\Gamma_{ m total}$ | | Γ ₂₁ /Γ |
| 0.65 ± 0.07 OUR AVERAGE | | <u>VALUE (units 10⁻⁶)</u> <u>CL%</u> | DOCUMENT ID TECN | • |
| $0.64 \pm 0.04 \pm 0.06$ 730 \pm 1.1 ± 0.4 ± 0.2 | 40 BRIERE 04 CLEO $e^+e^- \rightarrow J/\psi X$ 14 FULTON 89 CLEO $e^+e^- \rightarrow \mu^+\mu^- X$ | <2.4 90 | | $e^+e^- \rightarrow \gamma(15)$ |
| | owing data for averages, fits, limits, etc. • • • | ²⁰ BESSON 07A obtained this | limit for 0.7 $<$ $m_{\pi^0\eta}$ $<$ 3 GeV. | |
| <0.68 90 | ALBRECHT 92J ARG $e^+e^- ightarrowe^+e^-{\sf X}, \ \mu^+\mu^-{\sf X}$ | $\Gamma(\gamma K^+ K^-)/\Gamma_{\text{total}}$ | | Γ ₂₂ /Γ |
| <1.7 90 | MASCHMANN 90 CBAL $e^+e^- \rightarrow \text{hadrons}$ | $(2 < m_{K^+K^-} < 3 \text{ GeV})$ | | |
| $<$ 20 90 14 Using B $((J/\psi) ightarrow \mu^+ \mu^-$ | NICZYPORUK 83 LENA | <u>VALUE (units 10^{−5})</u> <u>CL%</u> 1.14±0.08±0.10 90 | DOCUMENT ID TECN ATHAR 06 CLE3 | |
| | | | 71117111 00 0220 | |
| $\Gamma(\chi_{c0} \text{ anything})/\Gamma(J/\psi)$ | | Γ (γρ \overline{p})/ Γ total (2 < m_{p} \overline{p} < 3 GeV) | | Γ ₂₃ /Γ |
| < 7.4 90 | BRIERE 04 CLEO $e^+e^- 	o J/\psi X$ | VALUE (units 10 ⁻⁵) CL% | DO CUMENT ID TECN | |
| $\Gamma(\chi_{c1} \text{ anything})/\Gamma(J/\psi)$ | LS) anything) Γ ₉ /Γ ₇ | <0.6 90 | ATHAR 06 CLE3 | $\Upsilon(1S) \rightarrow \gamma \rho \overline{\rho}$ |
| VALUE EVTS | DOCUMENT ID TECN COMMENT | $\Gamma(\gamma 2h^+2h^-)/\Gamma_{ m total}$ | | Γ ₂₄ /Γ |
| 0.35±0.08±0.06 52 ± 12 | | VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN | COMMENT |
| $\Gamma(\chi_{c2} \text{ anything})/\Gamma(J/\psi(J))$ | | 7.0±1.1±1.0 80 ± 12 | FULTON 90B CLEO | $e^+ e^- ightarrow $ hadrons |
| <u>VALUE</u> <u>EVTS</u> 0.52±0.12±0.09 47 ± 11 | | $\Gamma(\gamma 3h^+3h^-)/\Gamma_{\text{total}}$ | | Γ ₂₅ /Γ |
| | | $\frac{VALUE \text{ (units } 10^{-4})}{5.4 \pm 1.5 \pm 1.3}$ $\frac{EVTS}{39 \pm 11}$ | DOCUMENT ID TECN FULTON 90B CLEO | $e^+e^- \rightarrow hadrons$ |
| $\Gamma(\psi(2S) \text{ anything})/\Gamma(J/\psi_{ALUE})$ | | | | |
| 0.41±0.11±0.08 42 ± 11 | BRIERE 04 CLEO $e^+e^- \rightarrow J/\psi \pi^+ \pi^- X$ | $\Gamma(\gamma 4h^+4h^-)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) EVTS | DOCUMENT ID TECN | Γ ₂₆ /Γ |
| F/ \/F | | 7.4 \pm 2.5 \pm 2.5 36 \pm 12 | | $e^+e^- \rightarrow hadrons$ |
| $\Gamma(\rho\pi)/\Gamma_{\text{total}}$ VALUE (units 10^{-4}) CL% | $	au_{12}$ /Γ DOCUMENT ID TECN COMMENT | $\Gamma(\gamma\pi^+\pi^-K^+K^-)/\Gamma_{ m total}$ | | Γ ₂₇ /Γ |
| < 2 90 | FULTON 90B $rac{comment}{r(1S) \rightarrow ho^0 \pi^0}$ | <u>VALUE (units 10⁻⁴) EVTS</u> | DOCUMENT ID TECN | COMMENT |
| • • • We do not use the follo | | 2.9±0.7±0.6 29 ± 8 | FULTON 90B CLEO | $e^+e^-	o$ hadrons |
| <10 90 <21 90 | BLINOV 90 MD1 $r(1S) ightarrow ho^0 \pi^0$ NICZYPORUK 83 LENA $r(1S) ightarrow ho^0 \pi^0$ | $\Gamma(\gamma 2\pi^+ 2\pi^-)/\Gamma_{ m total}$ | | Г ₂₈ /Г |
| $\Gamma(\pi^+\pi^-)/\Gamma_{\text{total}}$ | | $\frac{VALUE (units 10^{-4})}{EVTS}$ | DOCUMENT ID TECN | COMMENT |
| VALUE (units 10 ⁻⁴) CL% | Γ ₁₃ /Γ DOCUMENT ID TECN COMMENT | 2.5 ± 0.7 ± 0.5 26 ± 7 | FULTON 90B CLEO | $e^+e^-	o$ hadrons |
| <5 90 | BARU 92 MD1 $r(1S) \rightarrow \pi^+\pi^-$ | $\Gamma(\gamma 3\pi^+ 3\pi^-)/\Gamma_{\text{total}}$ | | Γ ₂₉ /Γ |
| $\Gamma(K^+K^-)/\Gamma_{\text{total}}$ | Γ ₁₄ /Γ | <u>VALUE (units 10⁻⁴) EVTS</u> 2.5 ± 0.9 ± 0.8 17 ± 5 | DOCUMENT ID TECN FULTON 90B CLEO | $e^+e^- \rightarrow hadrons$ |
| VALUE (units 10 ⁻⁴) CL% | | | | |
| <5 90 | BARU 92 MD1 $\Upsilon(1S) ightarrow K^+ K^-$ | $\Gamma(\gamma 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{\text{tot}}$ VALUE (units 10^{-4}) EVTS | | Γ ₃₀ /Γ |
| $\Gamma(p\overline{p})/\Gamma_{\text{total}}$ | Γ ₁₅ /Γ | 2.4±0.9±0.8 18 ± 7 | DOCUMENT ID TECN FULTON 90B CLEO | $e^+e^- \rightarrow hadrons$ |
| VALUE (units 10 ⁻⁴) CL% | 15 | $\Gamma(\gamma\pi^+\pi^-p\overline{p})/\Gamma_{\text{total}}$ | | Г ₃₁ /Г |
| <5 90 ¹⁵ Supersedes BARU 92 in the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second seco | 15 BARU 96 MD1 $r(1S) 	o p\overline{p}$ | VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN | COMMENT |
| | | 1.5 \pm 0.5 \pm 0.3 22 \pm 6 | | $e^+ e^- ightarrow hadrons$ |
| $\Gamma(\pi^0\pi^+\pi^-)/\Gamma_{\text{total}}$ VALUE (units 10^{-5}) CL% | Γ ₁₆ /Γ DOCUMENT ID TECN COMMENT | $\Gamma(\gamma 2\pi^+ 2\pi^- p \overline{p})/\Gamma_{ m total}$ | | Г ₃₂ /Г |
| <1.84 90 | A NASTASSOV 99 CLE2 $e^+e^- ightarrow$ hadrons | VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN | • |
| $\Gamma(D^*(2010)^{\pm} \text{ anything})/$ | Γ _{total} Γ ₁₇ /Γ | 0.4 ± 0.4 ± 0.4 7 ± 6 | FULTON 90B CLEC | $e^+e^- 	o hadrons$ |
| VALUE (units 10 ⁻³) CL% EVTS | | $\Gamma(\gamma 2K^+2K^-)/\Gamma_{\text{total}}$ | | Г ₃₃ /Г |
| 25.2±1.3±1.5 ≈ 2k | () | VALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN | |
| • • • We do not use the follows: | owing data for averages, fits, limits, etc. $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ $ullet$ u | 0.2±0.2 2 ± 2 | FULTON 90B CLEC | $e^+e^- 	o hadrons$ |
| 16 For $x_p > 0.1$. | ALDREGIT VE AND C C - D T A | $\Gamma(\gamma\eta'(958))/\Gamma_{\text{total}}$ | | Г ₃₄ /Г |
| 17 For $x_p > 0.2$. | | | THE STATE OF A CLEO $\Upsilon(1S)$ - | $\stackrel{\text{NT}}{\rightarrow} \gamma \eta' \rightarrow \gamma \pi^+ \pi^- \eta, \gamma \rho$ |
| Γ(d anything)/Γ _{total} | Г ₁₈ /Г | | ving data for averages, fits, limits | |
| <u>VALUE (units 10⁻⁵)</u> <u>EVT5</u> | • | <16 90 RIC | THICHI 01B CLE2 $	au(1S)$ | $\rightarrow \gamma \eta' \rightarrow \gamma \eta \pi^+ \pi^-$ |
| 2.86±0.19±0.21 455 | | $\Gamma(\gamma\eta)/\Gamma_{ m total}$ | | Г ₃₅ /Г |
| $\Gamma(ggg, \gamma gg ightarrow \overline{d}$ anyth | ning)/ $\Gamma(ggg, \gamma gg ightarrow$ anything) | VALUE (units 10^{-6}) CL% | | COMMENT |
| VALUE (units 10 ⁻⁵) EVTS | | < 1.0 90 | ATHAR 07A CLEO | $ \gamma(1S) \rightarrow \gamma \eta \rightarrow \gamma \gamma \gamma, \gamma \pi^{+} \pi^{-} \pi^{0}, \gamma 3 \pi^{0} $ |
| 3.36±0.23±0.25 455 | ASNER 07 CLEO $e^+e^- ightarrow \overline{d}X$ | | ving data for averages, fits, limits | , etc. • • • |
| | | <21 90 | MASEK 02 CLEO | $\Upsilon(1S) \rightarrow \gamma \eta$ |
| | | | | |

| | _ | | | Γ ₃₆ /Γ | $\Gamma(\gamma f_4(2050))/\Gamma_{to}$ | | | | _ | | Γ ₄₅ , |
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| ALUE (units 10 ⁻⁵) CL% (3 90 | 21 ATHAR | 06 CLE3 | $r(1S) \rightarrow r$ | νπ+ π= | VALUE (units 10 ⁻⁵) <5.3 | <u>CL%</u> 90 | 32 ATHAR | 06 | CLE3 | $r(1s) \rightarrow r$ | α _π + _π - |
| Assuming B $(f_0(980) ightarrow \pi)$ | | U0 CLE3 | I(15) → 1 | γπ · π | ³² Assuming B(f_4 (2 | | | 06 | CLE3 | 7(15) → · | $\gamma \pi \cdot \pi$ |
| $(\gamma f_2'(1525))/\Gamma_{\text{total}}$ | | | | Г ₃₇ /Г | $\Gamma(\gamma f_0(2200) \rightarrow \gamma$ | | | | | | Γ ₄₆ , |
| · - _ | TS DOCUMENT ID | TECN | COMMENT | 137/1 | VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | . 407 |
| 3.8±0.9 OUR AVERAGE | | | | | <0.0002 | 90 | BARU | 89 | MD1 | $r_{(1S)} \rightarrow r_{(1S)}$ | $\gamma K^+ K^-$ |
| | 5 ²² BESSON | 11 CLEO | $\Upsilon(1S) \rightarrow$ | $\kappa_S^0 \kappa_S^0$ | $\Gamma(\gamma f_J(2220) \rightarrow \gamma$ | K+K-)/[| total | | | | Γ ₄₇ , |
| $3.7 + 0.9 \pm 0.8$ | ATHAR | 06 CLE3 | $\Upsilon(1S) \rightarrow$ | $_{\gamma}$ K ⁺ K ⁻ | VALUE (units 10 ⁻⁷) | CL% | DO CUMENT ID | | TECN | COMMENT | . 477 |
| • We do not use the follow | | es, fits, limits, e | etc. • • • | | < 8 | 90 | ATHAR | 06 | CLE3 | $r(1s) \rightarrow r$ | γ K + K - |
| 14 90 | ²³ FULTON | | $\gamma(1s) \rightarrow$ | | ● ● We do not use | the following | g data for average | es, fits | , limits, | etc. • • • | , |
| 19.4 90 | ²³ ALBRECHT | | $\gamma(1s) \rightarrow$ | | < 160 | 90 | MASEK | 02 | CLEO | $\gamma(1s) \rightarrow \gamma$ | , |
| ² BESSON 11 reports (4.0 | | | | | < 150 < 290 | 90 90 | FULTON ALBRECHT | 90в 89 | CLEO ARG | $\Upsilon(1S) \rightarrow \Upsilon(1S) | |
| $\gamma f_2'(1525))/\Gamma_{\text{total}}] \times [B(3.1) \times 10^{-2}$, which we r | | | | | <2000 | 90 | BARU | 89 | MD1 | $r(1S) \rightarrow r(1S) | |
| $(2.2) \times 10^{-2}$. Our first $(3.1) \times 10^{-2}$ | | | | | F/ 6 (0000) | + -)/5 | | | | , | |
| systematic error from using | | | | | $\Gamma(\gamma f_J(2220) \rightarrow \gamma$ | | | | | | Γ ₄₈ |
| $=$ (69.20 \pm 0.05)% and B | | | | | <u>VALUE (units 10⁻⁷)</u> < 6 | <u>CL%</u> 90 | <u>DOCUMENT ID</u> ATHAR | 06 | CLE3 | $r(1s) \rightarrow r$ | + |
| ³ Assuming B($f'_2(1525) \rightarrow$ | $\overline{K}(K) = 0.71.$ | - | | - | • • • We do not use | | | | | | γπιπ |
| (a.f (1070))/F | | | | F /F | <120 | 90 | MASEK | | | $\gamma(1s) \rightarrow \gamma$ | $\gamma \pi^+ \pi^-$ |
| $(\gamma f_2(1270))/\Gamma_{\text{total}}$ | DO SUMENT ID | T504 | | Г ₃₈ /Г | E/ (/0000) | -\ /- | | | | , | |
| LUE (units 10 ⁻⁵) CL% 10.1 ± 0.9 OUR AVERAGE | DO CUMENT ID | <u>TECN</u> | COMMENT | - | $\Gamma(\gamma f_J(2220) \rightarrow \gamma$ | • | | | | | Γ ₄₉ |
| $10.5 \pm 1.6 ^{+}_{-} \overset{1.9}{1.8}$ | ²⁴ BESSON | 07A CLE3 | $\gamma(1s) \rightarrow \gamma$ | $_{\gamma\pi}^{0}\pi^{0}$ | <u>VALUE (units 10⁻⁷)</u> < 11 | <u>CL%</u> 90 | <u>DOCUMENT ID</u> ATHAR | 06 | CLE3 | $r(1s) \rightarrow r$ | ~ n c |
| $10.2 \pm 0.8 \pm 0.7$ | ATHAR | 06 CLE3 | $\gamma(1S) \rightarrow \gamma$ | | • • • We do not use | | | | | | 144 |
| $8.1 \pm 2.3 + 2.9$ | 25 ANASTASSON | | . , | • | <160 | 90 | MASEK | | | $\gamma(1s) \rightarrow \gamma$ | $\gamma p \overline{p}$ |
| We do not use the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the followi | | | | | $\Gamma(\gamma\eta(2225) \rightarrow \gamma\gamma$ | _{ሐሐ}) / г. | | | | | Γ ₅₀ |
| 21 90 | ²⁵ FULTON | 90B CLEO | | $_{\gamma\pi^{+}\pi^{-}}$ | | | CUMENT ID | TEC | ı com | MENT | 150 |
| 13 90 | ²⁵ ALBRECHT | 89 ARG | $\gamma(1s) \rightarrow \gamma$ | ' . | | | .RU 89 | MD1 | | $S) \rightarrow \gamma K^{+}$ | к- к+ к |
| 81 90 | SCHMITT | 88 CBAL | | | | | | | , | , , | |
| Using B($f_2(1270) \rightarrow \pi^0$ | π^0) = B(f_2 (1270) - | $\rightarrow \pi\pi)/3$ and | $B(f_2(1270)$ | \rightarrow $\pi\pi) =$ | $\Gamma(\gamma\eta_c(1S))/\Gamma_{\text{tota}}$ | | | | | | Г ₅₁ |
| $(0.845 + 0.025 \atop -0.012)\%$ | | | | | <u>VALUE (units 10⁻⁵)</u> <5.7 | <u>CL%</u> | DOCUMENT ID | 104 | TECN | COMMENT 20(1.6) | V |
| Using B($f_2(1270) \rightarrow \pi\pi$) | = 0.84. | | | | <5.7 | 90 | SHEN | 1 UA | BELL | $\Upsilon(1S) \rightarrow \Upsilon(1S)$ | |
| $(\gamma \eta(1405))/\Gamma_{ m total}$ | | | | Г39/Г | $\Gamma(\gamma\chi_{c0})/\Gamma_{ m total}$ | | | | | | Γ ₅₂ |
| LUE (units 10 ⁻⁵) CL% | DOCUMENT ID | TECN | COMMENT | • | VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| (8.2 90 | ²⁶ FULTON | 90B CLEO | $r(1S) \rightarrow \gamma$ | , K±π∓ K 0 S | <6.5 | 90 | SHEN | 10A | BELL | $r_{(1S)} \rightarrow r_{(1S)}$ | γX |
| ²⁶ Includes unknown branchir | g ratio of $\eta(1405) \rightarrow$ | κ±π∓κ0. | | J | $\Gamma(\gamma\chi_{c1})/\Gamma_{	ext{total}}$ | | | | | | Γ ₅₃ |
| | | 3 | | | | | DO CULTENT 10 | | | | |
| (((====)) /= | | | | - /- | VALUE (units 10^{-5}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $(\gamma f_0(1500))/\Gamma_{\text{total}}$ | | | | Γ_{40}/Γ | VALUE (units 10 ⁻⁵) <2.3 | 90 | SHEN | 10A | BELL | $rac{comment}{r(1s)} \rightarrow rac{comment}{r}$ | γX |
| LUE (units 10 ⁻⁵) CL% | | TECN COMM | | | <2.3 | | | 10A | | | , |
| LUE (units 10 ⁻⁵) CL% 1.5 90 27 | BESSON 07A | CLEO e^+e^- | → γ(1S) | | $\overline{<$ 2.3 $\Gamma(\gamma\chi_{c2})/\Gamma_{	ext{total}}$ | 90 | SHEN | 10A | BELL | $T(1S) \rightarrow T$ | , |
| LUE (units 10 ⁻⁵) CL% 1.5 90 27 • • We do not use the folio | BESSON 07A wing data for average | CLEO e^+e^- es, fits, limits, ϵ | au $	au$ $	au$ $	au$ $	au$ $	au$ etc. $ullet$ $ullet$ $ullet$ $	au$ | $\rightarrow \gamma \pi^0 \pi^0$ | <2.3 | | | | | | Г ₅₄ |
| $\frac{LUE \text{ (units } 10^{-5})}{1.5}$ $\frac{CL\%}{90}$ 27 • • We do not use the folloof.1 90 28 | BESSON 07A wing data for average BESSON 07A | CLEO e^+e^- es, fits, limits, e^- CLEO e^+e^- | au 	au 	au(1S) etc. $ullet 	au 	au$ | $ \rightarrow \gamma \pi^0 \pi^0 $ $ \rightarrow \gamma \eta \eta $ | <2.3 Γ(γχ _{c2})/Γ _{total} <u>VALUE (units 10⁻⁶)</u> <7.6 | 90 <u>CL%</u> 90 | SHEN DOCUMENT ID SHEN | | BELL TECN | $r(1s) \rightarrow r$ | Γ ₅₄ |
| 1.1 UE (units 10^{-5}) CL% 1.1.5 90 27 • • We do not use the folic 1.6.1 90 28 1.7 Using B(f_0 (1500) → π^0 1.0.349 ± 0.023)%. | BESSON 07A wing data for average BESSON 07A π^0) = B($f_0(1500)$ - | CLEO e^+e^- es, fits, limits, e^- CLEO $e^+e^ \rightarrow \pi\pi)/3$ and | au 	au 	au(1S) etc. $ullet 	au 	au$ | $ \rightarrow \gamma \pi^0 \pi^0 $ $ \rightarrow \gamma \eta \eta $ | $ \begin{array}{c} \hline <2.3 \\ $ | 90 | SHEN DOCUMENT ID SHEN (Ttotal | | BELL TECN BELL | $T(1S) \rightarrow C$ $\frac{COMMENT}{T(1S) \rightarrow C}$ | Γ ₅₄ |
| LUE (units 10^{-5}) CL% 1.5 90 27 • • We do not use the folic 6.1 90 28 7 Using B($f_0(1500)$ → π^0 (0.349 ± 0.023)%. | BESSON 07A wing data for average BESSON 07A π^0) = B($f_0(1500)$ - | CLEO e^+e^- es, fits, limits, e^- CLEO $e^+e^ \rightarrow \pi\pi)/3$ and | au 	au 	au(1S) etc. $ullet 	au 	au$ | $ \rightarrow \gamma \pi^0 \pi^0 $ $ \rightarrow \gamma \eta \eta $ | <2.3 $\Gamma(\gamma \chi_{c2})/\Gamma_{total}$ $\frac{VALUE \text{ (units } 10^{-6})}{<7.6}$ $\Gamma(\gamma X (3872) \rightarrow \pi$ $\frac{VALUE \text{ (units } 10^{-6})}{}$ | 90 | SHEN DOCUMENT ID SHEN Ttotal DOCUMENT ID | 10A | BELL TECN BELL | $T(1S) \rightarrow COMMENT$ $T(1S) \rightarrow COMMENT$ | Γ ₅₄ γ Χ |
| LUE (units 10 ⁻⁵) CL $\frac{8}{90}$ 27 • • We do not use the folic 6.1 90 28 7 Using B($f_0(1500)$ → π^0 (0.349 ± 0.023)%. 8 Calculated by us using B($\frac{1}{9}$ | BESSON 07A wing data for average BESSON 07A π^0) = B($f_0(1500)$ - | CLEO e^+e^- es, fits, limits, e^- CLEO $e^+e^ \rightarrow \pi\pi)/3$ and | au 	au 	au(1S) etc. $ullet 	au 	au$ | | $\begin{array}{c} <2.3 \\ \Gamma(\gamma \chi_{c2})/\Gamma_{total} \\ \frac{VALUE \text{ (units } 10^{-6})}{<7.6} \\ \hline \Gamma(\gamma X (3872) \rightarrow \pi \\ \frac{VALUE \text{ (units } 10^{-6})}{<1.6} \end{array}$ | 90 | SHEN DOCUMENT ID SHEN (Ttotal DOCUMENT ID SHEN | 10A | BELL TECN BELL | $T(1S) \rightarrow C$ $\frac{COMMENT}{T(1S) \rightarrow C}$ | Γ ₅₄ γ Χ |
| 1.5 $\frac{ct \%}{90}$ 27 • • We do not use the folic 6.1 90 28 7 Using B($f_0(1500) \rightarrow \pi^0$ (0.349 ± 0.023)%. 8 Calculated by us using B($\frac{1}{2}$)/ $\frac{1}{2}$ / $\frac{1}{2}$ (1710))/ $\frac{1}{2}$ / $\frac{1}{2}$ (1710)/ $\frac{1}{2}$ | BESSON 07A wing data for average BESSON 07A π^0) = B($f_0(1500)$ - | CLEO e^+e^- es, fits, limits, e^- CLEO $e^+e^ \rightarrow \pi\pi)/3$ and | au 	au 	au(1S) etc. $ullet 	au 	au$ | $ \rightarrow \gamma \pi^0 \pi^0 $ $ \rightarrow \gamma \eta \eta $ | <2.3 $\Gamma(\gamma \chi_{c2})/\Gamma_{total}$ $\frac{VALUE \text{ (units } 10^{-6})}{<7.6}$ $\Gamma(\gamma X (3872) \rightarrow \pi$ $\frac{VALUE \text{ (units } 10^{-6})}{}$ | 90 | SHEN DOCUMENT ID SHEN (Ttotal DOCUMENT ID SHEN | 10A | BELL TECN BELL | $T(1S) \rightarrow COMMENT$ $T(1S) \rightarrow COMMENT$ | Γ ₅₄ γ Χ Γ ₅₅ |
| $\frac{UE \text{ (units 10}^{-5})}{90}$ $\frac{Ct \%}{90}$ 27 1.5 • • We do not use the folice 6.1 90 28 $\frac{7}{4}$ Using B($\frac{7}{10}$ (1500) → $\frac{7}{10}$ (0.349 ± 0.023)%. $\frac{8}{4}$ Calculated by us using B($\frac{7}{10}$ (1710))/Γtotal $\frac{2UE \text{ (units 10}^{-4})}{2.6}$ 90 | BESSON 07A wing data for average BESSON 07A π^0) = B($f_0(1500)$ - $f_0(1500)$ $\rightarrow \eta\eta$) = (5 $\frac{DOCUMENT\ ID}{29}$ ALBRECHT | CLEO e^+e^- es, fits, limits, 6 CLEO $e^+e^ \pi\pi)/3$ and 5.1 \pm 0.9)%. | $\begin{array}{ccc} & & & & \\ & \rightarrow & & \\ \text{etc.} & \bullet & \bullet & \bullet \\ & \rightarrow & & \\ & \rightarrow & & \\ & & \rightarrow & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & & & \\ & 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10^{-6}) \\ <7.6 \\ \Gamma(\gamma X (3872) \rightarrow \pi \\ \times ALUE \text{ (units } 10^{-6}) \\ <1.6 \\ \Gamma(\gamma X (3872) \rightarrow \pi \\ \times ALUE \text{ (units } 10^{-6}) \end{array}$ | 90 | SHEN DOCUMENT ID SHEN Ttotal DOCUMENT ID SHEN DOCUMENT ID DOCUMENT ID | 10A | BELL TECN BELL TECN BELL | $T(1S) ightarrow COMMENT \ T(1S) ightarrow COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ 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\xrightarrow{\text{MLUE (units } 10^{-6})} <7.6 \\ \Gamma(\gamma X (3872) \rightarrow \pi \\ \xrightarrow{\text{MLUE (units } 10^{-6})} <1.6 \\ \Gamma(\gamma X (3872) \rightarrow \pi \\ \xrightarrow{\text{MLUE (units } 10^{-6})} <2.8 \end{array}$ | 90 | SHEN DOCUMENT ID SHEN Ttotal DOCUMENT ID SHEN DOCUMENT ID SHEN | 10A | BELL TECN BELL TECN BELL | $T(1S) ightarrow COMMENT \ T(1S) ightarrow COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ 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& \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & & \\ & &$ | $ \begin{array}{ccc} & & & & & \\ & & & & & \\ & & & & \\ & & & &$ | $ \frac{\langle 2.3 \rangle}{\Gamma(\gamma \chi_{c2})/\Gamma_{total}} $ $ \frac{VALUE (units 10^{-6})}{\langle 7.6 \rangle} $ $ \frac{VALUE (units 10^{-6})}{\langle 1.6 \rangle} $ $ \frac{VALUE (units 10^{-6})}{\langle 2.8 \rangle} $ $ \frac{VALUE (units 10^{-6})}{\langle 2.8 \rangle} $ $ \frac{VALUE (units 10^{-6})}{\langle 3.0 \rangle} $ | 90 | SHEN DOCUMENT ID SHEN Focument ID SHEN SHEN DOCUMENT ID SHEN I DOCUMENT ID SHEN SHEN | 10A 10A | TECN BELL TECN BELL TECN BELL TECN BELL | $T(1S) ightarrow COMMENT \ T(1S) ightarrow COMMENT \ T(1S) ightarrow COMMENT \ T(1S) ightarrow COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ COMMENT \ 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$\begin{array}{c} <2.3 \\ \Gamma(\gamma \chi_{c2})/\Gamma_{total} \\ \\ \xrightarrow{VALUE\ (units\ 10^{-6})} <7.6 \\ \Gamma(\gamma X(3872) \rightarrow \pi \\ \\ \xrightarrow{VALUE\ (units\ 10^{-6})} <1.6 \\ \Gamma(\gamma X(3872) \rightarrow \pi \\ \\ \xrightarrow{VALUE\ (units\ 10^{-6})} <2.8 \\ \Gamma(\gamma X(3915) \rightarrow \omega \\ \\ \xrightarrow{VALUE\ (units\ 10^{-6})} <3.0 \\ \Gamma(\gamma X(4140) \rightarrow \phi \\ \\ \xrightarrow{VALUE\ (units\ 10^{-6})} <2.2 \\ \Gamma(\gamma X)/\Gamma_{total} \end{array}$ | 90 $\frac{cL\%}{90}$ $+\pi^{-}J/\psi)/\frac{cL\%}{90}$ $+\pi^{-}\pi^{0}J/\psi$ $\frac{cL\%}{90}$ $\frac{cL\%}{90}$ $\frac{cL\%}{90}$ $\frac{J/\psi}{90}/\Gamma_{\text{tota}}$ $\frac{cL\%}{90}$ | SHEN DOCUMENT ID SHEN Formal DOCUMENT ID SHEN SHEN DOCUMENT ID SHEN DOCUMENT ID SHEN DOCUMENT ID SHEN DOCUMENT ID SHEN | 10A 10A 10A | TECN BELL TECN BELL TECN BELL TECN BELL TECN BELL | $T(1S) ightarrow COMMENT \ T(1S) ightarrow CO$ | γ Χ Γ ₅₅ γ Χ Γ ₅₆ γ Χ Γ ₅₇ γ Χ Γ ₅₇ γ Χ Γ 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\gamma K^{0} S K^{0} S \\ \gamma \pi^{+} \pi^{-} \\ \gamma X \\ \hline \Gamma_{42}/\Gamma \\ \rightarrow \gamma K^{+} K^{-} \\ \hline \Gamma_{43}/\Gamma \\ \rightarrow \gamma \pi^{0} \pi^{0} \end{array} $ | $ \frac{\langle 2.3 \rangle}{\Gamma(\gamma \chi_{c2})/\Gamma_{total}} $ $ \frac{NALUE (units 10^{-6})}{\langle 7.6 \rangle} $ $ \frac{(\gamma X (3872) \rightarrow \pi}{\langle 1.6 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 1.6 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 2.8 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 3.0 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 2.2 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 2.2 \rangle} $ $ \frac{(X = scalar wind MALUE (units 10^{-6})}{\langle 4.5 \rangle} $ $ \frac{NALUE (units 10^{-6})}{\langle 4.5 \rangle} $ | 90 | SHEN DOCUMENT ID SHEN For total DOCUMENT ID SHEN FOR TOTAL DOCUMENT ID SHEN I DOCUMENT ID SHEN I DOCUMENT ID SHEN GEV) DOCUMENT ID 33 DEL-AMO-SA 34 BALEST With mass m < 8 | 10A 10A 10A 10A 10A 10A 10A 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\\ & \rightarrow & & & \\ & \rightarrow & & & \\ & & \rightarrow & & & \\ & & \rightarrow & & & \\ & & & &$ | $ \begin{array}{c} $ | $\begin{array}{c} <2.3\\ \hline \Gamma(\gamma \chi_{C2})/\Gamma_{\text{total}}\\ \hline \times ALUE \text{ (units }10^{-6})\\ <7.6\\ \hline \Gamma(\gamma X (3872) \rightarrow \pi\\ \hline \times ALUE \text{ (units }10^{-6})\\ <1.6\\ \hline \Gamma(\gamma X (3872) \rightarrow \pi\\ \hline \times ALUE \text{ (units }10^{-6})\\ <2.8\\ \hline \Gamma(\gamma X (3915) \rightarrow \omega\\ \hline \times ALUE \text{ (units }10^{-6})\\ <3.0\\ \hline \Gamma(\gamma X (4140) \rightarrow \phi\\ \hline \times ALUE \text{ (units }10^{-6})\\ <2.2\\ \hline \Gamma(\gamma X)/\Gamma_{\text{total}}\\ (X = \text{scalar with}\\ \times ALUE \text{ (units }10^{-6})\\ <4.5\\ \bullet \bullet \bullet \text{ We do not use}\\ <30\\ \hline 33 \text{ For a noninteract}\\ 34 \text{ For a noninteract} \end{array}$ | 90 | SHEN DOCUMENT ID SHEN SHEN SHEN SHEN SHEN DOCUMENT ID SHEN I DOCUMENT 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Meson Particle Listings

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| ¹⁶ For a noninteractin | ıg scalar X wi | th mass $m < 4.5\mathrm{GeV}.$ | |
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| 9 90 | 37 LOV | E 08 CLEO | $\frac{\textit{comment}}{e^+ e^- \rightarrow \gamma \textit{a}_1^0 \rightarrow \gamma \mu^+ \mu^-}$ |
| ⁷ For a narrow scala | r or pseudosca | alar a_1^0 with 201 $<$ M $(\mu$ | $\mu^+\mu^-) <$ 3565 MeV, excluding |
| | | s a function of $M(\mu^+ \mu$ | $^{-}$) range from 1–9 \times 10 $^{-6}$. |
| $(\gamma a_1^0 	o \gamma 	au^+ 	au^-)$ | | | Γ ₆₄ / |
| $(2m_{\tau} < M(\tau^{+})$ | | | |
| . <i>DE</i> (units 10 °) CE | . <u>%</u> <u>000</u> 38 LOV | F 08 CLEO | $\frac{\textit{COMMENT}}{e^+ e^- \rightarrow \gamma a_1^0 \rightarrow \gamma \tau^+ \tau^-}$ |
| | | | $(\tau^+ \tau^-) < 7500$ MeV. Measure |
| | | $VI(au^+	au^-)$ range from 1 | |
| LEPTO | FAMILY N | IUMBER (<i>LF</i>) VIOL | ATING MODES —— |
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| $\mu^{\pm} 	au^{\mp})/\Gamma_{	ext{total}}$.UE (units 10 $^{-6}$) | CI % | DOCUMENT ID 1 | Γ ₆₅ / |
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| | ` | , men beenio | F / |
| invisible)/Γ _{total} . <i>UE</i> (units 10 ^{—4}) | CI% DO | CUMENT ID TECN | Γ ₆₆ / |
| | | | $\frac{\tau}{(3S)} \rightarrow \pi^{+}\pi^{-} \Upsilon(1S)$ |
| • • We do not use | | data for averages, fits, li | |
| | | | $ \begin{array}{ccc} $ |
| 25 | 90 TA | JIMA 07 BELL | $r(3S) \rightarrow \pi^+\pi^- r(1S)$ |
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| ARTAMONOV | 82 | PL 118B 225 | A.S. Artamonov et al. | (NOVO) |
| NICZYPORUK | 82 | ZPHY C15 299 | B. Niczyporuk et al. | (LENA Collab.) |
| BERGER | 80 C | PL 93B 497 | C. Berger et al. | (PLUTO Collab.) |
| BOCK | 80 | ZPHY C6 125 | P. Bock et al. | (HEIDP, MPIM, DESY, HAMB) |
| BERGER | 79 | ZPHY C1 343 | C. Berger et al. | ` (PLUTO Collab.) |
| | | | | <u> </u> |

$\chi_{b0}(\overline{1P})$

$$I^G(J^{PC}) = 0^+(0^{++})$$

J needs confirmation.

Observed in radiative decay of the $\Upsilon(2S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore

$\chi_{b0}(1P)$ MASS

VALUE (MeV)

DOCUMENT ID

9859.44 \pm 0.42 \pm 0.31 OUR EVALUATION From average γ energy below, using $\varUpsilon(2S)$ ${\sf mass} = 10023.26 \, \pm \, 0.31 \; {\sf MeV}$

γ ENERGY IN $\Upsilon(2S)$ DECAY

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-----------|--------------------------------------------------|
| 162.5 ±0.4 OUR AVERAGE | | | | |
| $162.56 \pm 0.19 \pm 0.42$ | ARTUSO | 05 | CLEO | $\Upsilon(2S) \rightarrow \gamma X$ |
| $162.0 \pm 0.8 \pm 1.2$ | EDWARDS | 99 | CLE2 | $\Upsilon(2S) \rightarrow \gamma \chi(1P)$ |
| $162.1 \pm 0.5 \pm 1.4$ | ALBRECHT | 85 E | ARG | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| 163.8 \pm 1.6 \pm 2.7 | NERNST | 85 | CBAL | $\Upsilon(2S) \rightarrow \gamma X$ |
| 158.0 ± 7 ± 1 | HAAS | 84 | CLEO | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| $149.4 \pm 0.7 \pm 5.0$ | KLOPFEN | 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma X$ |

$\chi_{b0}(1P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-----------------------------------------------------|------------------------------|-----------------------|
| Γ ₁ | $\gamma \Upsilon(1S)$ | (1.76±0.35) % | |
| Γ_2 | D^0X | < 10.4 | 6 90% |
| Γ_3 | $\pi^{+}\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | < 1.6 × | <10 ^{−4} 90% |
| Γ_4 | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}$ | < 5 × | (10 ⁻⁵ 90% |
| Γ_5 | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 5 × | 10-4 90% |
| Γ_6 | $2\pi^{+}2\pi^{-}2\pi^{0}$ | < 2.1 × | 10-4 90% |
| Γ_7 | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(1.1 \pm 0.6) \times$ | 10-4 |
| Γ ₈ | $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | < 2.7 × | (10 ⁻⁴ 90% |
| Г9 | $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | < 5 × | <10 ^{−4} 90% |
| Γ_{10} | $3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0}$ | < 1.6 × | <10 ^{−4} 90% |
| Γ_{11} | $3\pi^{+}3\pi^{-}$ | < 8 × | <10 ^{−5} 90% |
| Γ_{12} | $3\pi^{+}3\pi^{-}2\pi^{0}$ | < 6 × | <10 ^{−4} 90% |
| Γ_{13} | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | (2.4 ±1.2) × | : 10 ⁻⁴ |
| Γ_{14} | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | < 1.0 × | <10 ^{−3} 90% |
| Γ_{15} | $4\pi^+4\pi^-$ | < 8 × | 10 ⁻⁵ 90% |
| Γ ₁₆ | $4\pi^{+}4\pi^{-}2\pi^{0}$ | < 2.1 × | 10-3 90% |

$\chi_{b0}(1P)$ BRANCHING RATIOS

| $\Gamma(\gamma \Upsilon(1S))/$ | Γ _{total} | | | | Γ_1/Γ |
|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (%) | CL% EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.76±0.30 | ±0.18 87 | ^{1,2} KORNICER | 11 | CLEO | $e^+e^- \to \gamma\gamma\ell^+\ell^-$ |
| • • • We do n | ot use the following | data for averages, | fits, lir | nits, etc. | • • • |
| < 4.6 | 90 | ³ LEES | 11J | BABR | $\Upsilon(2S) \rightarrow X \gamma$ |
| < 6 | 90 | WALK | 86 | CBAL | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| <11 | 90 | PAUSS | 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| 2 KORNICER (6.59 ± 0.9) $= (3.8 \pm 0.9)$ the systema 3 LEES 111 q | $6\pm0.60)	imes10^{-4}$ wh $40)	imes10^{-2}$. Our firstic error from using | $P) \rightarrow \gamma \ \Upsilon(1S))/\Gamma$ ich we divide by out error is their expeour best value. e of $\Gamma(\chi_{b0}(1P)$ | total] r best eriment | value B('s error a | $egin{array}{ll} (2S) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (2S) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightarrow \gamma \chi_{b0}(1P) & ightarrow \gamma \chi_{b0}(1P) \end{array} = egin{array}{ll} (1P) & ightar$ |
| E(D() V) /E | | | | | - 1- |

| $\Gamma(D^0X)/\Gamma_{\text{total}}$ | | | | | Γ_2/Γ |
|--------------------------------------|-----|--------------|----|------|-----------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $<10.4 \times 10^{-2}$ | 90 | 4,5 BRIERE | 08 | CLEO | $ \gamma(2S) \rightarrow \gamma D^0 X $ |

⁴ For $p_{D^0} > 2.5 \text{ GeV/c.}$

⁵ The authors also present their result as $(5.6 \pm 3.6 \pm 0.5) \times 10^{-2}$.

 $\chi_{b0}(1P)$, $\chi_{b1}(1P)$

| $\Gamma(\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $^6 \text{ASNER}$ 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow \pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}] \times [\text{B}(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))] < 6 \times 10^{-6}$ which we divide by our best value B($\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$. |
| $\Gamma(2\pi^{+}\pi^{-}K^{-}S^{0})/\Gamma_{\text{total}}$ Γ_{4}/Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $^7 \text{ASNER}$ 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+\pi^- \text{K}^- \text{K}^0_S)/\Gamma_{\text{total}}] \times [\text{B}(\Upsilon(2S) \rightarrow \chi_{b0}(1P))] < 2 \times 10^{-6}$ which we divide by our best value $\text{B}(\Upsilon(2S) \rightarrow \chi_{b0}(1P)) = 3.8 \times 10^{-2}.$ |
| $\Gamma(2\pi^+\pi^-K^-K_S^02\pi^0)/\Gamma_{\text{total}}$ Γ_5/Γ |
| VALUE (units 10^{-4})CL%DOCUMENT IDTECNCOMMENT<5 |
| ⁸ ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+\pi^-K^-K_S^02\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \chi_{b0}(1P))] < 18 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \chi_{b0}(1P)) = 3.8 \times 10^{-2}$. |
| $\Gamma(2\pi^+2\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ |
| VALUE (units 10^{-4})CL%DOCUMENT IDTECNCOMMENT<2.1 |
| ⁹ ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))] < 8 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$. |
| $\Gamma(2\pi^+2\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_7/Γ |
| VALUE (units $10^{-4})$ EVTSDOCUMENT IDTECNCOMMENT1.1 ± 0.6 ± 0.17 10 ASNER08ACLEO $\Upsilon(2S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^-$ |
| 10 ASNER 08A reports $[\Gamma(\chi_{b0}(1P)\to 2\pi^+2\pi^-K^+K^-)/\Gamma_{\rm total}]\times [B(\varUpsilon(2S)\to \chi_{b0}(1P))]=(4\pm2\pm1)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(2S)\to \chi_{b0}(1P))=(3.8\pm0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| $\Gamma(2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_8/Γ |
| VALUE (units $10^{-4})$ CL%DOCUMENT IDTECNCOMMENT<2.7 |
| ¹¹ ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \chi_{b0}(1P))] < 10 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \chi_{b0}(1P)) = 3.8 \times 10^{-2}$. |
| $\Gamma(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})/\Gamma_{\text{total}}$ |
| VALUE (units 10^{-4})CL%DOCUMENT IDTECNCOMMENT<5 |
| $^{12}\text{ASNER}$ 08A reports [\Gamma $(\chi_{b0}(1P)\rightarrow 2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{total}] \times [\text{B(}\varUpsilon(2S)\rightarrow \gamma\chi_{b0}(1P))] < 20\times 10^{-6}$ which we divide by our best value B($\varUpsilon(2S)\rightarrow \gamma\chi_{b0}(1P))=3.8\times 10^{-2}.$ |
| $\Gamma(3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ |
| VALUE (units $10^{-4})$ CL%DOCUMENT IDTECNCOMMENT<1.6 |
| 13 ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^+ 2\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 3\pi^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S)$ |
| $\gamma\chi_{b0}(1P))]<6\times10^{-6}$ which we divide by our best value B($\Upsilon(2S)\to\gamma\chi_{b0}(1P)$) = 3.8 \times 10 ⁻² . |
| $\Gamma(3\pi^+3\pi^-)/\Gamma_{\text{total}}$ Γ_{11}/Γ |
| |
| ^ 14 ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+3\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))] < 3\times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8\times 10^{-2}$. |
| $\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{12}/Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $^{15} \text{ ASNER 08A reports } \left[\Gamma \left(\chi_{b0}(1P) \to 3\pi^{+} 3\pi^{-} 2\pi^{0} \right) / \Gamma_{\text{total}} \right] \times \left[\text{B(} \varUpsilon(2S) \to \gamma \chi_{b0}(1P)) \right] \\ < 22 \times 10^{-6} \text{ which we divide by our best value B(} \varUpsilon(2S) \to \gamma \chi_{b0}(1P)) \right] = 3.8 \times 10^{-2}.$ |
| $\Gamma(3\pi^+3\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{13}/Γ |
| VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT2.4 ± 1.2 ± 0.29 16 ASNER08ACLEO $\Upsilon(25) \rightarrow \gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-}$ |
| 16 ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \chi_{b0}(1P))] = (9 \pm 4 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. |
| Ÿ |

| $\begin{array}{c} 1P) \rightarrow \ \ 3\pi^{+} \ 3\pi^{-} \ K^{+} \ K^{-} \pi^{0}) / \Gamma_{\text{total}}] \ \times \ [\text{B}(\varUpsilon(2S) \rightarrow \text{hich we divide by our best value B}(\varUpsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) \\ \\ \hline \\ \frac{DOCUMENT\ ID}{18\ \text{ASNER}} \begin{array}{c} \underline{\tau_{ECN}} \\ 08a \end{array} \begin{array}{c} \underline{COMMENT} \\ \Gamma(2S) \rightarrow \gamma 4\pi^{+} 4\pi^{-} \end{array} \end{array}$ | 90 17 ASNE ASNER 08A reports $[\Gamma(\chi_{b0}(Y_{b0}(1P))] < 37 	imes 10^{-6}$ where |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ASNER 08A reports $[\Gamma(\chi_{b0}(\chi_{b0}(1P)))] < 37 \times 10^{-6}$ where |
| hich we divide by our best value B($\varUpsilon(2S) \to \gamma \chi_{b0}(1P)$) $ \frac{\Gamma_{15}/\Gamma}{\Gamma_{18} \Lambda_{SNER} \qquad 08a} \frac{\Gamma_{ECN}}{\Gamma_{CEO}} \frac{COMMENT}{\Gamma_{CEO}} + \gamma 4\pi^{+} 4\pi^{-} $ | $(\chi_{b0}(1P))] < 37 	imes 10^{-6} 	ext{ with }$ |
| $\frac{_{\rm DOCUMENTID}}{_{\rm 18ASNER}} \frac{_{\rm TECN}}{_{\rm ORB}} \frac{_{\rm COMMENT}}{_{\rm CLEO}} \frac{_{\rm COMMENT}}{_{\rm T}(2S) \rightarrow \ \gamma 4\pi^+ 4\pi^-}$ | $= 3.8 \times 10^{-2}$. |
| | $\pi^+4\pi^-)/\Gamma_{\text{total}}$ |
| | E (units 10 ') CL% |
| $(P) \rightarrow 4\pi^+ 4\pi^-)/\Gamma_{	ext{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$ by our best value B($\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$. | SNER 08A reports $[\Gamma(\chi_{b0})]$ |
| Γ ₁₆ /Γ | $\pi^+ 4\pi^- 2\pi^0)/\Gamma_{ m total}$ |
| ASNER 08A CLEO $\gamma(2S) \rightarrow \gamma 4\pi^+ 4\pi^- 2\pi^0$ | E (units 10 ⁻⁴) CL% |
| | |
| $P) 	o 4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{	ext{total}}] 	imes [B(\varUpsilon(2S) 	o \gamma\chi_{b0}(1P))]$ by our best value $B(\varUpsilon(2S) 	o \gamma\chi_{b0}(1P)) = 3.8 	imes 10^{-2}$. | ASNER 08A reports $[\Gamma(\chi_{b0})]$ $(1R \times 77 	imes 10^{-6})$ which we divide |
| S-PARTICLE BRANCHING RATIOS | $\chi_{b0}(1P)$ CROS |
| $_{\text{tal}} \times \Gamma(\Upsilon(2S) \to \gamma \chi_{b0}(1P)) / \Gamma_{\text{total}} $ $\Gamma_1 / \Gamma \times \Gamma_{15}^{\Upsilon(2S)} / \Gamma^{\Upsilon(2S)}$ | |
| DOCUMENT ID TECN COMMENT 20 LEES 11J BABR $\Upsilon(2S) 	o X \gamma$ | E CL%_ |
| ²⁰ LEES 11J BABR $\Upsilon(2S) \rightarrow X \gamma$ | 7 × 10 ⁻³ 90 |
| alue of $\Gamma(\chi_{b0}(1P) 	o \gamma \Upsilon(1S))/\Gamma_{total} 	imes \Gamma(\Upsilon(2S) 	o$ | EES 11) quotes a central va |
| $5.6^{+3.7}_{-2.6}) \times 10^{-4}$ and derives a 90% CL upper limit of | $(\chi_{b0}(1P))/\Gamma_{total} = (8.3 \pm$ |
| sing B($\Upsilon(4S) \to \gamma \chi_{b0}(1P)$) = (3.8 ± 0.4)%. | |
| $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) \times B(\Upsilon(1S) \rightarrow \ell^+\ell^-)$ | , , , , ,, |
| | E (units 10 ⁻⁵) EVTS |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | ±0.24 ± 0.15 87 |

| KORNICER | 11 | PR D83 054003 | M. Kornicer <i>et al.</i> | (CLEO Collab.) |
|----------|------|---------------|-------------------------------|--------------------------|
| LEES | 11J | PR D84 072002 | J.P. Lees <i>et al.</i> | (BABAR Collab.) |
| AS NER | 08 A | PR D78 091103 | D.M. Asner <i>et al.</i> | (CLEO Collab.) |
| BRIERE | 08 | PR D78 092007 | R.A. Briere <i>et al.</i> | (CLEO Collab.) |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso <i>et al.</i> | (CLEO Collab.) |
| EDWARDS | 99 | PR D59 032003 | K.W. Edwards <i>et al.</i> | (CLEO Collab.) |
| WALK | 86 | PR D34 2611 | W.S. Walk <i>et al.</i> | (Crystal Ball Collab.) |
| ALBRECHT | 85 E | PL 160B 331 | H. Albrecht <i>et al.</i> | (ARGUS Collab.) |
| NERNST | 85 | PRL 54 2195 | R. Nernst <i>et al.</i> | (Crystal Ball Collab.) |
| HAAS | 84 | PRL 52 799 | J. Haas <i>et al.</i> | (CLEO Collab.) |
| KLOPFEN | 83 | PRL 51 160 | C. Klopfenstein <i>et al.</i> | (CUSB Collab.) |
| PAUSS | 83 | PL 130B 439 | F. Pauss <i>et al.</i> | (MPIM, COLU, CORN, LSU+) |



 $\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$

$$I^G(J^{PC}) = 0^+(1^{++})$$

 J needs confirmation.

Observed in radiative decay of the $\Upsilon(2S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore P=+. J=1 from SKWARNICKI 87.

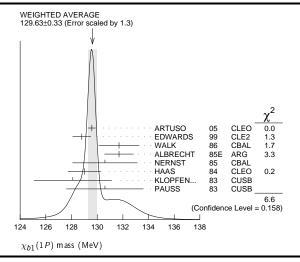
$\chi_{b1}(1P)$ MASS

 $\frac{\textit{VALUE}\,(\text{MeV})}{\textbf{9892.78} \pm 0.26 \pm 0.31~\text{OUR}~\text{EVALUATION}} \quad \text{From average} \ \gamma \ \text{energy below, using} \ \mathcal{T}(2S) \\ \text{mass} = 10023.26 \pm 0.31~\text{MeV}$

γ ENERGY IN \varUpsilon (2S) DECAY

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------------|-----------------------------|---------|------------------------------------------------------------|
| 129.63±0.33 OUR AVERAGE | Error includes scale factor | of 1.3. | See the ideogram below. |
| $129.58 \pm 0.09 \pm 0.29$ | ARTUSO 05 | CLEO | $\Upsilon(2S) \rightarrow \gamma X$ |
| $128.8 \pm 0.4 \pm 0.6$ | EDWARDS 99 | CLE2 | $\Upsilon(2S) \rightarrow \gamma \chi(1P)$ |
| $131.7 \pm 0.9 \pm 1.3$ | WALK 86 | CBAL | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $131.7 \pm 0.3 \pm 1.1$ | ALBRECHT 85E | ARG | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| $130.6 \pm 0.8 \pm 2.4$ | NER NST 85 | CBAL | $\Upsilon(2S) \rightarrow \gamma X$ |
| 129 $\pm 0.8 \pm 1$ | HAAS 84 | CLEO | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| $128.1 \pm 0.4 \pm 3.0$ | KLOPFEN 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma X$ |
| 130.6 ±3.0 | PAUSS 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |

 $\chi_{b1}(1P)$



$\chi_{b1}(1P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|-----------------------------------------------------|---------------------------------|------------------|
| $\overline{\Gamma_1}$ | $\gamma \Upsilon(1S)$ | (33.9 ± 2.2) % | |
| Γ_2 | D^0X | $(12.6 \pm 2.2) \%$ | |
| Γ_3 | $\pi^{+}\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | $(2.0 \pm 0.6) \times 10^{-4}$ | 4 |
| Γ_4 | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}$ | $(1.3\pm0.5)\times10^{-4}$ | 4 |
| Γ_5 | $2\pi^{+}\pi^{-}K^{-}K_{5}^{0}2\pi^{0}$ | < 6 × 10- | 4 90% |
| Γ_6 | $2\pi^{+} 2\pi^{-} 2\pi^{0}$ | $(8.0 \pm 2.5) \times 10^{-4}$ | 4 |
| Γ ₇ | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(1.5 \pm 0.5) \times 10^{-4}$ | 4 |
| Γ ₈ | $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | $(3.5 \pm 1.2) \times 10^{-4}$ | 4 |
| Γ9 | $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | (8.6 ± 3.2) × 10 ⁻⁴ | 4 |
| Γ_{10} | $3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0}$ | $(9.3 \pm 3.3) \times 10^{-4}$ | 4 |
| Γ_{11} | $3\pi^{+} 3\pi^{-}$ | $(1.9 \pm 0.6) \times 10^{-4}$ | 4 |
| Γ ₁₂ | $3\pi^{+}3\pi^{-}2\pi^{0}$ | $(1.7 \pm 0.5) \times 10^{-3}$ | 3 |
| Γ ₁₃ | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | $(2.6 \pm 0.8) \times 10^{-4}$ | 4 |
| Γ_{14} | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | $(7.5 \pm 2.6) \times 10^{-4}$ | 4 |
| Γ_{15} | $4\pi^{+}4\pi^{-}$ | $(2.6 \pm 0.9) \times 10^{-4}$ | 4 |
| Γ ₁₆ | $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.4 \pm 0.6) \times 10^{-3}$ | |

$\chi_{b1}(1P)$ BRANCHING RATIOS

| $\Gamma(\gamma \Upsilon(1S))/\Gamma_{total}$ | | | | | Γ ₁ /Γ |
|----------------------------------------------|-------|-------------------------|-----|------|------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.339±0.022 OUR AV | ERAGE | | | | |
| $0.331 \pm 0.018 \pm 0.017$ | 3222 | ^{1,2} KORNICER | 11 | CLEO | $e^+ e^- \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| $0.350 \pm 0.023 \pm 0.018$ | 13k | ³ LEES | 11J | BABR | $\Upsilon(2S) \rightarrow X \gamma$ |
| $0.32 \pm 0.06 \pm 0.07$ | | WALK | | | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| 0.47 ± 0.18 | | KLOPFEN | 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |

¹ Assuming B($\Upsilon(1S) \rightarrow \ell^+ \ell^-$) = (2.48 ± 0.05)%. ² KORNICER 11 reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (22.8 \pm 0.4 \pm 1.2) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))$ = $(6.9\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

³LEES 11J reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (24.1 \pm 0.6 \pm 1.5) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))$ $=(6.9\pm0.4) imes10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(D^{\circ}X)/\Gamma_{\text{total}}$ | | | | | Γ ₂ /Γ |
|--------------------------------------------|------|---------------------|----|------|---------------------------------------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| $12.6 \pm 1.9 \pm 1.1$ | 2310 | ⁴ BRIERE | 08 | CLEO | $\gamma(2S) \rightarrow \gamma D^0 X$ |
| ⁴ For $p_{D^0} > 2.5$ Ge | V/c. | | | | |

 $\Gamma(\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE (units 10^{-4}) EVTS DOCUMENT ID TECN COMMENT ⁵ ASNER 08A CLEO $\Upsilon(2S)
ightarrow \gamma \pi^+ \pi^- \, K^+ \, K^- \, \pi^0$

⁵ ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \rightarrow \pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\mathrm{total}}] \times [\mathrm{B}(\varUpsilon(2S) \rightarrow \pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\mathrm{total}}]$ $\gamma \chi_{b1}(1P)$] = $(14\pm 3\pm 3)\times 10^{-6}$ which we divide by our best value B($\Upsilon(2S)\to \gamma \chi_{b1}(1P)$) = $(6.9\pm 0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+\pi^-K^-K_S^0)/\Gamma_{\text{total}}$ Γ_4/Γ

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT ⁶ ASNER 08A CLEO $\gamma(2S) \rightarrow \gamma \overline{2\pi^+\pi^-\kappa^-\kappa^0_S}$ $1.3 \pm 0.5 \pm 0.1$ 11 ⁶ ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \rightarrow 2\pi^{+}\pi^{-}K^{-}K^{0}_{S})/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow 2\pi^{+}\pi^{-}K^{-}K^{0}_{S})/\Gamma_{total}]$

 $\gamma \chi_{b1}(1P))] = (9 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value B($\gamma(2S) \rightarrow$ $\gamma_{ND1}(1/I) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(2\pi^+\pi^-K^-K_S^02\pi^0)/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE (units 10⁻⁴) CL% DOCUMENT ID TECN COMMENT ⁷ ASNER 08A CLEO $\Upsilon(2S)
ightarrow \gamma \, 2\pi^+ \, \pi^- \, K^- \, 2\pi^0$ ⁷ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \rightarrow 2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0})/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \pi^{-}K_{S}^{0}2\pi^{0})/\Gamma_{total}] \times [B(\Upsilon(2S) \rightarrow \pi^{-}K_{S}^{0}2\pi^{0})/\Gamma_{total}]$ $\gamma \chi_{b1}(1P))] < 42 \times 10^{-6}$ which we divide by our best value B($\Upsilon(2S) \rightarrow \gamma \chi_{b1}(1P))$

 $\Gamma(2\pi^+2\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT

⁸ ASNER 08A CLEO $\Upsilon(2S)
ightarrow \gamma 2\pi^+ 2\pi^- 2\pi^0$ $8.0 \pm 2.4 \pm 0.4$ ⁸ ASNER 08A reports $[\Gamma(\chi_{b1}^{-}(1P) \to 2\pi^{+} 2\pi^{-} 2\pi^{0})/\Gamma_{\mathrm{total}}] \times [\mathrm{B}(\varUpsilon(2S) \to \gamma\chi_{b1}^{-}(1P))]$ which we divide by our best value B($\Upsilon(2S)
ightarrow \gamma \chi_{b1}(1P)$) $= (55 \pm 9 \pm 14) \times 10^{-3}$

= $(6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(2\pi^+2\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_7/Γ

 $\underline{\mathit{VALUE}}$ (units 10^{-4}) $\underline{\mathit{EVTS}}$ TECN COMMENT DO CUMENT ID 9 ASNER $1.5 \pm 0.5 \pm 0.1$ 08A CLEO $\Upsilon(2S)
ightarrow \gamma 2\pi^+ 2\pi^- K^+ K^-$ 18 $^{9}\,\mathrm{ASNER}$ 08A reports [$\Gamma(\chi_{b1}(1P)\ \rightarrow\ 2\pi^{+}\,2\pi^{-}\,\mathrm{K}^{+}\,\mathrm{K}^{-})/\Gamma_{\mathrm{total}}]\ \times\ [\mathrm{B}(\varUpsilon(2S)\ \rightarrow\ 2\pi^{+}\,2\pi^{-}\,\mathrm{K}^{+}\,\mathrm{K}^{-})/\Gamma_{\mathrm{total}}]$ $\gamma \chi_{b1}(1P))] = (10 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value B($\Upsilon(2S) \rightarrow$ $\gamma_{AD1}(\gamma) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\rm total}$

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT **3.5 \pm1.2\pm0.2** 22 ¹⁰ ASNER 08A CLEO $\Upsilon(2S) \rightarrow \gamma 2\pi^{+} 2\pi^{-} \kappa^{+} \kappa^{-} \pi^{0}$ $\gamma \chi_{b1}(1P))] = (24 \pm 6 \pm 6) \times 10^{-6}$ which we divide by our best value B($\Upsilon(2S) \rightarrow$ $\gamma\chi_{b1}(1P))=(6.9\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})/\Gamma_{\text{total}}$

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT 8.6±3.2±0.4 26 11 ASNER 08A CLEO $\Upsilon(2S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$ $^{11}\,\mathrm{ASNER}$ 08A reports $[\Gamma(\chi_{b1}(1P)\ \rightarrow\ 2\pi^{+}\,2\pi^{-}\,\mathrm{K}^{+}\,\mathrm{K}^{-}\,2\pi^{0})/\Gamma_{\mathrm{total}}]\,\times\,[\mathrm{B}(\,\varUpsilon(2S)\ \rightarrow\ 2\pi^{+}\,2\pi^{-}\,\mathrm{K}^{+}\,\mathrm{K}^{-}\,2\pi^{0})/\Gamma_{\mathrm{total}}]$ $\gamma \chi_{b1}(1P))] = (59 \pm 14 \pm 17) \times 10^{-6}$ which we divide by our best value B($\gamma (2S) \rightarrow 10^{-6}$ $\gamma_{AD1}(1/I) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT 9.3±3.3±0.5 21 12 ASNER 08A CLEO $\Upsilon(2S)
ightarrow ~\gamma \, 3\pi^+ \, 2\pi^- \, {\it K}^- \, {\it K}^{\,0}_{\,{\it S}} \, \pi^0$ $^{12}\,\mathrm{ASNER}$ 08A reports $[\Gamma\left(\chi_{b1}(1P)\right.\to\ 3\pi^{+}\,2\pi^{-}\,\mathit{K}^{-}\,\mathit{K}^{\,0}_{\,S}\,\pi^{0}\right)/\Gamma_{\mathrm{total}}]\,\times\,[\mathrm{B}(\,\varUpsilon(2S)\,\to\,3\pi^{+}\,2\pi^{-}\,\mathit{K}^{-}\,\mathit{K}^{\,0}_{\,S}\,\pi^{0})$

 $\gamma \chi_{b1}(1P)$] = $(64\pm 16\pm 16)\times 10^{-6}$ which we divide by our best value B($\Upsilon(2S)\to \gamma \chi_{b1}(1P)$) = $(6.9\pm 0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(3\pi^+3\pi^-)/\Gamma_{\text{total}}$ Γ_{11}/Γ

VALUE (units 10^{-4}) DO CUMENT ID EVTS TECN COMMENT 13 ASNER 25 08A CLEO $\Upsilon(2S)
ightarrow \gamma 3\pi^{+} 3\pi^{-}$

 13 ASNER 08A reports $[\Gamma(\chi_{b1}(1P)\to 3\pi^+3\pi^-)/\Gamma_{total}]\times [\mathrm{B}(\,\Upsilon(2S)\to\,\gamma\chi_{b1}(1P))]=(13\pm3\pm3)\times 10^{-6}$ which we divide by our best value B($\Upsilon(2S)\to\,\gamma\chi_{b1}(1P))=$ $(6.9\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{12}/Γ

VALUE (units 10^{-4}) EVTS TECN COMMENT ¹⁴ ASNER 08A CLEO $\Upsilon(2S)
ightarrow \gamma \, 3\pi^+ \, 3\pi^- \, 2\pi^0$ $17 \pm 5 \pm 1$ 56

 14 A SNER 08A reports [Γ $(\chi_{b1}(1P) \rightarrow 3\pi^+ 3\pi^- 2\pi^0)/\Gamma_{total}] \times$ [B($\varUpsilon(2S) \rightarrow \gamma \chi_{b1}(1P)$)] = $(119 \pm 18 \pm 32) \times 10^{-6}$ which we divide by our best value B($\varUpsilon(2S) \rightarrow \gamma \chi_{b1}(1P)$) $= (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(3\pi^+3\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{13}/Γ

VALUE (units 10^{-4}) EVTS DO CUMENT ID TECN COMMENT ¹⁵ ASNER 08A CLEO $\Upsilon(2S) \rightarrow \gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-}$ $2.6 \pm 0.8 \pm 0.1$

 15 ASNER 08A reports $[\Gamma(\chi_{b1}(1P)$ - \rightarrow 3 π^+ 3 π^- K⁺ K⁻)/ Γ_{total}] \times [B($\Upsilon(2S)$ \rightarrow $\gamma \chi_{b1}(1P))] = (18 \pm 4 \pm 4) \times 10^{-6}$ which we divide by our best value B($\Upsilon(2S) \rightarrow$ $7\lambda_{D1}(1/P) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ VALUE (units 10-4) EVTS DOCUMENT ID TECN COMMENT

7.5 ± 2.6 ± 0.4 28 16 ASNER 08A CLEO $r(2s) \rightarrow \gamma 3\pi^{+} 3\pi^{-} \kappa^{+} \kappa^{-} \pi^{0}$ $^{16}\,\text{ASNER}$ 08A reports [$\Gamma\left(\chi_{b1}(1P)\ \rightarrow\ 3\pi^{+}\ 3\pi^{-}\ \text{K}^{+}\ \text{K}^{-}\pi^{0}\right)/\Gamma_{total}$] \times [B($\Upsilon(2S)\ \rightarrow\$ $\gamma \chi_{b1}(1P)$] = $(52\pm11\pm14)\times 10^{-6}$ which we divide by our best value B($\gamma(2S)\to \gamma\chi_{b1}(1P)$] = $(6.9\pm0.4)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(4\pi^+4\pi^-)/\Gamma_{total}$ DOCUMENT ID VALUE (units 10^{-4}) EVTS TECN COMMENT 17 ASNER 24 08A CLEO $\Upsilon(2S) \rightarrow \gamma 4\pi^+ 4\pi^-$

 17 ASNER 08a reports $[\Gamma(\chi_{b1}(1P)\rightarrow 4\pi^+4\pi^-)/\Gamma_{total}]\times [B(\varUpsilon(2S)\rightarrow \Upsilon\chi_{b1}(1P))]=(18\pm 4\pm 5)\times 10^{-6}$ which we divide by our best value B($\varUpsilon(2S)\rightarrow \Upsilon\chi_{b1}(1P))=$ $(6.9\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(4\pi^+4\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{16}/Γ

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT 18 ASNER 08A CLEO $\Upsilon(2S)
ightarrow \gamma 4\pi^+ 4\pi^- 2\pi^0$ $14 \pm 5 \pm 1$ 26

 18 A SNER 08A reports $[\Gamma(\chi_{b1}(1P)\to 4\pi^+\,4\pi^-\,2\pi^0)/\Gamma_{\text{total}}]\times [B(\varUpsilon(2S)\to \gamma\chi_{b1}(1P))]=(96\pm24\pm29)\times 10^{-6}$ which we divide by our best value B($\varUpsilon(2S)\to \gamma\chi_{b1}(1P))$ $=(6.9\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\chi_{b1}(1P)$ Cross-Particle Branching Ratios

 $\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma \chi_{b1}(1P))/\Gamma_{total}$ $\Gamma_1/\Gamma \times \Gamma_{13}^{r(2s)}/\Gamma_{13}^{r(2s)}$ VALUE (units 10-3) DOCUMENT ID COMMENT

| THE OL (UIIIIS TO | | DOCOMENT | | 12010 | COMMENT |
|---------------------------------|--------------------------|----------------------------|------|-----------------|--------------------------------------------|
| 24.1±0.6±1.5 | 13k | LEES | 11) | BABR | $\Upsilon(2S) \rightarrow X \gamma$ |
| $B(\chi_{b1}(1P) \rightarrow C$ | $\gamma T(1S)) \times B$ | (<i>T</i> (2 <i>S</i>) → | γχы(| 1 <i>P</i>)) × | $B(\Upsilon(1S) \rightarrow \ell^+\ell^-)$ |
| VALUE (upits 10-4) | EVTC | DOCUMENT | ID | TECN | COMMENT |

 $\mathbb{B}(\chi_{b2}(1P) \to \ pX + \ \overline{p}X)/\mathbb{B}(\chi_{b1}(1P) \to \ pX + \ \overline{p}X)$ DOCUMENT ID TECN COMMENT 07 CLEO $\Upsilon(2S)
ightarrow \gamma \chi_{bJ}(1P)$ $1.068 \pm 0.010 \pm 0.040$ BRIERE

 $B(\chi_{b0}(1P) \rightarrow pX + \overline{p}X)/B(\chi_{b1}(1P) \rightarrow pX + \overline{p}X)$ TECN COMMENT 1.11±0.15±0.20 BRIERE 07 CLEO $\Upsilon(2S)
ightarrow \gamma \chi_{bJ}(1P)$

$\chi_{b1}(1P)$ REFERENCES

| KORNICER LEES ASNER BRIERE BRIERE ARTUSO EDWARDS SKWARNICKI | 11 11J 08A 08 07 05 99 87 | PR D83 054003 PR D84 072002 PR D78 091103 PR D78 092007 PR D76 012005 PRL 94 032001 PR D59 032003 PRL 58 972 | M. Kornicer et al. J.P. Lees et al. D.M. Asner et al. R.A. Briere et al. R.A. Briere et al. M. Artuso et al. K.W. Edwards et al. T. Skwarnicki et al. | (CLEO Collab.) (BABAR Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (COSTA Ball Collab.) (Crystal Ball (Clab.) |
|----------------------------------------------------------------------------------|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| SKWARNICKI | 87 | PRL 58 972 | T. Skwarnicki et al. | (Crystàl Ball Collab.) J |
| WALK | 86 | PR D34 2611 | W.S. Walk et al. | (Crystal Ball Collab.) |
| ALBRECHT | 85 E | PL 160B 331 | H. Albrecht et al. | (ARGUS COllab.) |
| NERNST | 85 | PRL 54 2195 | R. Nernst et al. | (Crystal Ball Collab.) |
| HAAS | 84 | PRL 52 799 | J. Haas et al. | (CLEO Collab.) |
| KLOPFEN | 83 | PRL 51 160 | C. Klopfenstein et al. | (CUSB Collab.) |
| PAUSS | 83 | PL 130B 439 | F. Pauss et al. | (MPIM, COLU, CORN, LSU+) |

 $h_b(1P)$

$$I^{G}(J^{PC}) = ?^{?}(1^{+})$$

Quantum numbers are quark model predictions, C=- established

$h_b(1P)$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID |) | TECN | COMMENT | _ |
|------------------------------------------------|--------|--------------|-----|------|----------------------------------------------------------------------|---|
| 9898.6±1.4 OUR AV | /ERAGE | <u> </u> | | | | |
| $9898.2 {}^{+ 1.1}_{- 1.0} {}^{+ 1.0}_{- 1.1}$ | 50.0k | ADACHI | | | $10.86 e^+e^- \rightarrow$ | |
| 9902 ±4 ±2 | 10.8k | LEES | 11ĸ | BABR | $\gamma^{+}\pi^{-}MM$ $\gamma(3S) \rightarrow \eta_{b}\gamma\pi^{0}$ | I |

hb(1P) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\eta_b(1S)\gamma$ | seen |

hb(1P) BRANCHING RATIOS

| $\Gamma(\eta_b(1S)\gamma)/\Gamma_{\text{total}}$ | | | | | | Γ_1/Γ |
|--------------------------------------------------|-------|--------------|-----|------|----------------------------|-----------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| seen | 10.8k | LEES | 11ĸ | BABR | $\Upsilon(3S) \rightarrow$ | $\eta_b \gamma \pi^0$ |

h_b(1P) REFERENCES

I. Adachi et al. J.P. Lees et al.

 $\chi_{b2}(1P)$

$$I^G(J^{PC}) = 0^+(2^{++})$$

J needs confirmation.

Observed in radiative decay of the $\Upsilon(2S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore P = +. J = 2 from SKWARNICKI 87.

$\chi_{b2}(1P)$ MASS

mass = 10023.26 ± 0.31 MeV

γ ENERGY IN $\Upsilon(2S)$ DECAY

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|----------------------|-------|---------|------------------------------------------------------------|
| 110.44 ± 0.29 OUR AVERAGE | Error includes scale | facto | of 1.1. | |
| $110.58 \pm 0.08 \pm 0.30$ | ARTUSO | 05 | CLEO | $\Upsilon(2S) \rightarrow \gamma X$ |
| $110.8 \pm 0.3 \pm 0.6$ | EDWARDS | 99 | CLE2 | $\Upsilon(2S) \rightarrow \gamma \chi(1P)$ |
| $107.0 \pm 1.1 \pm 1.3$ | WALK | 86 | CBAL | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| $110.6 \pm 0.3 \pm 0.9$ | ALBRECHT | 85 E | ARG | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| $110.4 \pm 0.8 \pm 2.2$ | NERNST | 85 | CBAL | $\Upsilon(2S) \rightarrow \gamma X$ |
| $109.5 \pm 0.7 \pm 1.0$ | HAAS | 84 | CLEO | $\Upsilon(2S) \rightarrow \text{conv.} \gamma X$ |
| $108.2 \pm 0.3 \pm 2.0$ | KLOPFEN | 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma X$ |
| 108.8 ±4.0 | PAUSS | 83 | CUSB | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |

$\chi_{b2}(1P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|----------------------------------------------------------------------------|--------------------------------|------------------|
| $\overline{\Gamma_1}$ | $\gamma \ \Upsilon(1S)$ | (19.1 ± 1.2) % | |
| Γ_2 | D^0X | < 7.9 % | 90% |
| Γ_3 | $\pi^{+}\pi^{-}{\cal K}^{+}{\cal K}^{-}\pi^{0}$ | $(8 \pm 5) \times 10^{-5}$ | 5 |
| Γ_4 | $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | < 1.0 × 10 ⁻⁴ | 90% |
| Γ_5 | $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}2\pi^{0}$ | $(5.3 \pm 2.4) \times 10^{-4}$ | 1 |
| Γ_6 | $2\pi^{+}2\pi^{-}2\pi^{0}$ | $(3.5 \pm 1.4) \times 10^{-4}$ | 1 |
| Γ_7 | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(1.1 \pm 0.4) \times 10^{-4}$ | |
| Γ ₈ | $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | $(2.1 \pm 0.9) \times 10^{-4}$ | 1 |
| Г9 | $2\pi^{+}2\pi^{-}\mathit{K}^{+}\mathit{K}^{-}2\pi^{0}$ | $(3.9 \pm 1.8) \times 10^{-4}$ | |
| Γ_{10} | $3\pi^+2\pi^-K^-K^0_S\pi^0$ | < 5 × 10 ⁻⁴ | 90% |
| Γ_{11} | $3\pi^{+} 3\pi^{-}$ | $(7.0 \pm 3.1) \times 10^{-5}$ | 5 |
| Γ_{12} | $3\pi^{+}3\pi^{-}2\pi^{0}$ | $(1.0 \pm 0.4) \times 10^{-3}$ | 3 |
| | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | < 8 × 10 ⁻⁵ | 90% |
| Γ_{14} | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | $(3.6 \pm 1.5) \times 10^{-4}$ | 1 |
| | $4\pi^{+}4\pi^{-}$ | $(8 \pm 4) \times 10^{-5}$ | 5 |
| Γ ₁₆ | $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.8 \pm 0.7) \times 10^{-3}$ | |

$\chi_{b2}(1P)$ BRANCHING RATIOS

| $\Gamma(\gamma T(1S))/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ_1 |
|-----------------------------------------------|-------|-------------------------|-----|------|------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.191 ± 0.012 OUR AVI | ERAGE | | | | |
| $0.186 \pm 0.011 \pm 0.009$ | 1770 | ^{1,2} KORNICER | 11 | CLEO | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| $0.194 {}^{+ 0.014}_{- 0.017} {}^{\pm 0.009}$ | 8k | ³ LEES | 11) | BABR | $\Upsilon(2S) \rightarrow X \gamma$ |
| $0.27 \pm 0.06 \pm 0.06$ | | WALK | 86 | CBAL | $\Upsilon(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |
| 0.20 ±0.05 | | KLOPFEN | 83 | CUSB | $\gamma(2S) \rightarrow \gamma \gamma \ell^{+} \ell^{-}$ |

¹ Assuming B($\Upsilon(1S) \rightarrow \ell^+ \ell^-$) = (2.48 ± 0.05)%.

2 KORNICER 11 reports $[\Gamma(\chi_{b2}(P) \to \gamma \Upsilon(15))/\Gamma_{\text{total}}] \times [\text{B}(\Upsilon(2S) \to \gamma \chi_{b2}(1P))] = (1.33 \pm 0.04 \pm 0.07) \times 10^{-2}$ which we divide by our best value $\text{B}(\Upsilon(2S) \to \gamma \chi_{b2}(1P))$ = $(7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error

a (.13 ± 0.35) \times 10 $^{-1}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. ³LEES 11J reports $[\Gamma(\chi_{b2}(1P) \to \gamma T(1S))/\Gamma_{total}] \times [B(T(2S) \to \gamma \chi_{b2}(1P))] = (13.9 \pm 0.5 + 0.9) \times 10^{-3}$ which we divide by our best value $B(T(2S) \to \gamma \chi_{b2}(1P))$ = $(7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D^0X)/\Gamma_{\rm total}$ VALUE DOCUMENT ID TECN COMMENT <7.9 × 10⁻² ^{4,5} BRIERE 90 08 CLEO $\Upsilon(2S) \rightarrow \gamma D^0 X$

 4 For $\rho_{D^0} > 2.5$ GeV/c.

⁵ The authors also present their result as $(5.4 \pm 1.9 \pm 0.5) \times 10^{-2}$.

| $(\pi^{+}\pi^{-}K^{+}K^{-}\pi^{0})/\Gamma$ | | Гз/Г |
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| ALUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN COMMENT | |
| .84±0.50±0.04 8 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | |
| $\gamma \chi_{h2}(1P))] = (6 \pm 3$ | $(Xb2^{(1P)}) \rightarrow \pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | $(\Upsilon(2S) \rightarrow (\Upsilon(2S) \rightarrow \Upsilon(2S)))$ |
| $\gamma \chi_{b2}(1P)) = (7.15 \pm $ second error is the syst | $(0.35) \times 10^{-2}$. Our first error is their experiment's er sematic error from using our best value. | ror and our |
| $(2\pi^+\pi^-K^-K_S^0)/\Gamma_{to}$ | | Γ4/Γ |
| LUE (units 10 ⁻⁴) CL% | DOCUMENT ID TECN COMMENT | 0 |
| 7.4.CNED 00: " | ⁷ ASNER 08A CLEO $r(2S) \rightarrow \gamma 2\pi^{+}\pi^{-}$ | ~ K ~ K § |
| $\gamma \chi_{b2}(1P))] < 7 \times 10$ = 7.15 × 10 ⁻² . | $ \begin{array}{ccc} [\Gamma(\chi_{b2}(1P) & \to & 2\pi^+\pi^- K^- K_S^0) / \Gamma_{\rm total}] \times [B(\pi^{-6}) W_{\rm to$ | $\gamma \chi_{b2}(1P)$ |
| $(2\pi^{+}\pi^{-}K^{-}K_{5}^{0}2\pi^{0})$ | | Γ ₅ /Γ |
| ### (units 10 ⁻⁴) | 8 ASNER 08A CLEO 7 COMMENT 7 7 7 2 7 7 | $-K^{-2\pi^{0}}$ |
| | $\Gamma(\chi_{b2}(1P) \rightarrow 2\pi^{+}\pi^{-}\kappa^{-}\kappa_{S}^{0}2\pi^{0})/\Gamma_{total}] \times [B]$ | |
| $\gamma \chi_{b2}(1P))] = (38 \pm 3)$ | $14\pm10)	imes10^{-6}$ which we divide by our best value B | $(\Upsilon(2S) \rightarrow$ |
| $\gamma \chi_{b2}(1P)) = (7.15 \pm $ second error is the syst | $0.35) 	imes 10^{-2}$. Our first error is their experiment's er ematic error from using our best value. | ror and our |
| $(2\pi^+2\pi^-2\pi^0)/\Gamma_{ m total}$ | | Γ ₆ /Γ |
| LUE (units 10 ⁻⁴) EVTS | | |
| 5±1.4±0.2 19 | | |
| ⁹ ASNER 08A reports [Γ (| $(\chi_{b2}(1P)	o 2\pi^+2\pi^-2\pi^0)/\Gamma_{	ext{total}}]	imes [B(\varUpsilon(2S)	o \gamma_{botal})]$ By the divide by our best value $B(\varUpsilon(2S)	o \gamma_{botal})$ | $\chi_{b2}(1P))]$ |
| $(7.15 \pm 0.35) \times 10^{-2}$ | Our first error is their experiment's error and our second | b2(1P)) = ond error is |
| the systematic error fro | om using our best value. | |
| 2π ⁺ 2π ⁻ K ⁺ K ⁻)/Γ | | Γ ₇ /Γ |
| LUE (units 10 ⁻⁴) EVTS | DOCUMENT ID TECN COMMENT | _ ,, |
| 1±0.4±0.1 14 | 10 ASNER 08A CLEO $\Upsilon(2S) ightarrow \gamma 2\pi^+ 2\pi$ | - K T K - |
| | $[\Gamma(\gamma_{++}/1P)] \rightarrow 2\pi + 2\pi - K + K - 1/\Gamma$ $1 \times [R/1P]$ | Y(25) - |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2$ | $[\Gamma(\chi_{b2}(1P) ightarrow 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}] 	imes [B(2\pm2) 	imes 10^{-6}$ which we divide by our best value B | $(\Upsilon(2S) \rightarrow (\Upsilon(2S) \rightarrow \Upsilon(2S) | $\gamma \chi_{b2}(1P))] = (8 \pm 2)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 2)$ | $(2\pm2)\times10^{-6}$ which we divide by our best value B $(0.35)\times10^{-2}$. Our first error is their experiment's er | $(\Upsilon(2S) \rightarrow$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 2)$ second error is the syst | $(2\pm2)\times10^{-6}$ which we divide by our best value B $(0.35)\times10^{-2}$. Our first error is their experiment's er ematic error from using our best value. | $(\varUpsilon(2S) ightarrow ror and our$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2 + 2 + 2 + 2 + 2 + 2 + 2 + 2 + 2 + 2$ | $(2\pm2)\times10^{-6}$ which we divide by our best value B $(0.35)\times10^{-2}$. Our first error is their experiment's erematic error from using our best value. | $(\Upsilon(2S) \rightarrow$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2 \gamma \chi_{b2}(1P)) = (7.15 \pm {\rm second \ error \ is \ the \ syst} \ (2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}) \ _{LUE \ (units \ 10^{-4})} \ _{EVTS}$ | $(2\pm2)\times10^{-6}$ which we divide by our best value B $(0.35)\times10^{-2}$. Our first error is their experiment's er dematic error from using our best value. | $(\varUpsilon(2S) ightarrow $ ror and our $oxedsymbol{\Gamma_8/\Gamma}$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2 \gamma \chi_{b2}(1P)) = (7.15 \pm 8 \pm 10) = (7.15 \pm 1 \pm 10) = (7.15 \pm 1 \pm 10) = (7.15 \pm 1 \pm 10) = (7.15 \pm 1 \pm 10) = (7.15 \pm 1 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 \pm 10) = (7.15 $ | $2\pm 2) 	imes 10^{-6}$ which we divide by our best value B 0.35) $	imes 10^{-2}$. Our first error is their experiment's erematic error from using our best value. // Ftotal $\frac{DOCUMENT\ ID}{ASNER} \qquad 08A \qquad CLEO \qquad \frac{COMMENT}{T(2S)} \rightarrow \gamma 2\pi^{+} 2\pi^{-} A = \frac{T(N)}{T(N)} \left[\frac{1}{N} \left[\frac{N}{N} \right] \left[\frac{N}{N} \right] \right] \times \left[\frac{N}{N} \right] $ | $(\Upsilon(2S) \rightarrow \text{ror and our}$ $\frac{\Gamma_8/\Gamma}{\kappa + \kappa - \pi^0}$ $(\Upsilon(2S) \rightarrow \text{ror and our})$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2 \\ \gamma \chi_{b2}(1P)) = (7.15 \pm \\ \text{second error is the syst} \\ (2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}) \\ \frac{LUE \text{ (units }10^{-4})}{13} \frac{EVTS}{13} \\ 1^{+}\text{ASNER 08A reports [} \\ \gamma \chi_{b2}(1P))] = (15 \pm \\ 15 \pm 15 \pm 15 \pm 15 \pm 15 \\ 15 \pm 15 \pm$ | $2\pm 2) 	imes 10^{-6}$ which we divide by our best value B 0.35) $	imes 10^{-2}$. Our first error is their experiment's erematic error from using our best value. // Ftotal $\frac{DOCUMENT\ ID}{ASNER} \qquad 08A \qquad CLEO \qquad \frac{COMMENT}{T(2S) 	op \gamma 2\pi^{+} 2\pi^{-}} T(\chi_{b2}(1P) 	op 2\pi^{+} 2\pi^{-} K^{+} K^{-} \pi^{0})/\Gamma_{total}] 	imes [B 5 \pm 4) 	imes 10^{-6}$ which we divide by our best value B | $(\Upsilon(2S) \rightarrow \Gamma R)$ ror and our Γ_8/Γ $K + K - \pi^0$ $(\Upsilon(2S) \rightarrow \Gamma R)$ $(\Upsilon(2S) \rightarrow \Gamma R)$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 5)$ second error is the syst $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $\frac{LUE \text{ (units }10^{-4})}{13}$ $\frac{EVTS}{1\pm 0.9\pm 0.1}$ $\frac{1}{3}$ ASNER 08A reports [$\gamma \chi_{b2}(1P))] = (15 \pm 5)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 5)$ second error is the syst | $(2\pm2)\times10^{-6}$ which we divide by our best value B $(0.35)\times10^{-2}$. Our first error is their experiment's er rematic error from using our best value. /\(\begin{align*} \begin{align*} \ldot \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \colon \co | $(\Upsilon(2S) \rightarrow \Gamma R)$ ror and our Γ_8/Γ $K + K - \pi^0$ $(\Upsilon(2S) \rightarrow \Gamma R)$ $(\Upsilon(2S) \rightarrow \Gamma R)$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 5)$ second error is the syst $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $\frac{LUE\ (units\ 10^{-4})}{13}$ $\frac{EVTS}{1}$ $\frac{1}{4}$ ASNER 08A reports [$\gamma \chi_{b2}(1P))] = (15 \pm 5)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 5)$ second error is the syst $(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})$ | $2\pm 2) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's er rematic error from using our best value. // Ftotal DOCUMENT ID ASNER $08A$ CLEO $T(2S) \rightarrow \gamma 2\pi^+ 2\pi^- \kappa^+ \kappa^- \pi^0)/\Gamma_{total}$ $5\pm 4) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's er rematic error from using our best value. | $(\varUpsilon(2S) \rightarrow ror and our$ |
| $\gamma \chi_{b2}(1P))] = (8 \pm 2)$ $\gamma \chi_{b2}(1P)) = (7.15 \pm 5)$ second error is the syst $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})$ $(2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0})$ | $2\pm 2) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's ergematic error from using our best value. // Ftotal DOCUMENT ID TECN COMMENT ASNER 08A CLEO $\Upsilon(2S) \rightarrow \gamma 2\pi^+ 2\pi^ \Gamma(\chi_b 2(1P) \rightarrow 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B$ $5\pm 4) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's ergematic error from using our best value. | $(\varUpsilon(2S) ightharpoonup \Gamma_8/\Gamma$ $(\varUpsilon(2S) ightharpoonup \Gamma_8/\Gamma$ $(\varUpsilon(2S) ightharpoonup \Gamma_9/\Gamma$ |
| $ \gamma \chi_{b2}(1P))] = (8 \pm 27 \chi_{b2}(1P)) = (7.15 \pm 52) \\ \gamma \chi_{b2}(1P)) = (7.15 \pm 52) \\ (2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}) \\ \frac{kUE \text{ (units }10^{-4})}{13} = \frac{EVTS}{11} $ 1.1 ASNER 08A reports [$ \gamma \chi_{b2}(1P))] = (15 \pm 7 \chi_{b2}(1P)) = (7.15 \pm 52) \\ \gamma \chi_{b2}(1P)) = (7.15 \pm 52) \\ \gamma \chi_{b2}(1P) = (7.15 \pm 7 \chi_{b2}(1P)) = (7.15 \pm 7 \chi_{b2}(1P)) $ (2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldo\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\text{\(\ldot\)}\(\ld | $2\pm 2) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's erematic error from using our best value. \begin{align*} \begin{align*} \begin{align*} \leftilde{V} \end{align*} \leftilde{V} \end{align*} \leftilde{V} \end{align*} \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \rightarrow \leftilde{V} \rightarrow \leftilde{V} \rightarrow \rightarrow \leftilde{V} \rightarrow \rightarrow \leftilde{V} \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \rightarrow \ri | $(\varUpsilon(2S) \rightarrow ror and our$ Γ_8/Γ $\kappa + \kappa - \pi^0$ $(\varUpsilon(2S) \rightarrow ror and our$ $(\varUpsilon(2S) \rightarrow ror and our$ Γ_9/Γ $\kappa + \kappa - 2\pi^0$ |
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| $ \gamma \chi_{b2}(1P))] = (8 \pm 2) \\ \gamma \chi_{b2}(1P)) = (7.15 \pm 5) \\ \text{second error is the syst} \\ (2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}) \\ \frac{14 \text{LUE} (\text{units }10^{-4})}{13} 11 $ ¹ ASNER 08A reports [$\gamma \chi_{b2}(1P))] = (15 \pm 7) \\ \gamma \chi_{b2}(1P)) = (7.15 \pm 5) \\ \text{second error is the syst} \\ (2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}) \\ \frac{1}{2} \text{LUE} (\text{units }10^{-4}) \text{EVTS} \\ 9\pm 1.8 \pm 0.2 11 12 $ ² ASNER 08A reports [$\gamma \chi_{b2}(1P)) = (28 \pm \gamma \chi_{b2}(1P)) = (7.15 \pm 5) \\ \text{second error is the syst} \\ (3\pi^{+}2\pi^{-}K^{-}K^{0}S_{\pi}^{0}) \\ \frac{1}{2} \text{LUE} (\text{units }10^{-4}) \text{CL}_{\pi}^{\infty} \\ \frac{1}{2} \text{ASNER 08A reports} $ ³ ASNER 08A reports [| $2\pm 2) \times 10^{-6}$ which we divide by our best value B $0.35) \times 10^{-2}$. Our first error is their experiment's erematic error from using our best value. //\textbf{Ftotal} \[\textit{DOCUMENT ID} \textit{TECN} \textit{COMMENT} \\ \textit{ASNER} \textit{08A} \text{CLEO} \text{T}(2S) \rightarrow \gamma 2\pi^+ 2\pi^- \rightarrow \\ \text{0.35} \times \gamma 10^{-6} \text{which we divide by our best value B} \\ \text{0.35} \times \gamma 10^{-2}. \text{Our first error is their experiment's erematic error from using our best value.} \[\text{Pocument ID} \frac{\text{TECN}}{\text{TECN}} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{T}(2S) \rightarrow \gamma 2\pi^+ 2\pi^- \rightarrow \\ \text{1.1} \div 7) \times 10^{-6} \text{which we divide by our best value B} \\ \text{0.35} \times 10^{-2}. \text{Our first error is their experiment's erematic error from using our best value.} \[\text{/Ftotal} \\ \text{DOCUMENT ID} \frac{\text{TECN}}{\text{TECN}} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{CAMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{CAMENT} \\ \text{ASNER} \text{09A} \text{08A} \text{08A} \text{08A} \\ 0 | $(\Upsilon(2S) \rightarrow \text{ror and our} \Gamma_8/\Gamma$ $K+K-\pi^0$ $(\Upsilon(2S) \rightarrow \text{ror and our} \Gamma_9/\Gamma$ $(\Upsilon(2S) \rightarrow \text{ror and our} \Gamma_10/\Gamma$ |
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Our first error is their experiment's erematic error from using our best value. //\textbf{Ftotal} \textit{DOCUMENT ID} \tag{TECN} \text{COMMENT} \text{ASNER} \text{08A} \text{CLEO} \text{T(2S)} \rightarrow \gamma \gamma \gamma \text{T} \text{E} \text{DOCUMENT ID} \text{IE} \text{COMMENT} \text{S} \frac{\pi}{2} \text{A} \times \text{10}^{-2} \text{ which we divide by our best value B} \text{0.35} \times \gamma \gamma \text{20} \text{Comment} \text{is error is their experiment's erematic error from using our best value.} \text{P(\text{DOCUMENT ID} \text{TECN} \text{COMMENT} \\ \text{ASNER} \text{08A} \text{CLEO} \text{T(2S)} \rightarrow \gamma \gamma \gamma \text{Total} \\ \text{DOCUMENT ID} \text{TECN} \text{COMMENT} \\ \text{11} \text{17} \text{10}^{-6} \text{ which we divide by our best value B} \text{0.35} \times \gamma \text{10}^{-2}. 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VALUE (units 10⁻⁴) EVTS 10.2±3.6±0.5

VALUE (MeV)

 $331.50 \pm 0.02 \pm 0.13$

| | -)/Γ _{total} | | | | Γ ₁₃ /Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------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| VALUE (units 10 ⁻⁴) CL9 | 1.0 | | ECN C | | |
| <0.8 90 | | | | | $\rightarrow \gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-}$ |
| $\gamma \chi_{b2}(1P))] < 0$ = 7.15 × 10 ⁻² . | forts [I (χ_{b2}) 6×10^{-6} which | ch we divide by o | π κ · · | value E | $[T_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow X_{b2}(1P))]$ |
| Γ(3π+3π-K+K VALUE (units 10-4) EN | • | ENT ID <u>TE</u> | CN CO | MMENT | Γ ₁₄ /Γ |
| 3.6±1.5±0.2 | | 08A CL | EO $r_{(}$ | 2 <i>S</i>) → | $\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}$ |
| $\gamma \chi_{b2}(1P))] = ($ | $26 \pm 8 \pm 7)$: $7.15 \pm 0.35) \times$ | $P) \rightarrow 3\pi^{+} 3\pi^{-} \times 10^{-6}$ which w 10^{-2} . Our first | - K + K e divide error is t | $-\pi^0)/$ by our their ex | $\Gamma_{total}] \times [B(\varUpsilon(2S) \to best \ value \ B(\varUpsilon(2S) \to cperiment's \ error \ and \ out)$ |
| $\Gamma(4\pi^+4\pi^-)/\Gamma_{\text{tot}}$ VALUE (units 10^{-4}) | | DOCUMENT ID | 7 | ECN | Γ ₁₅ /Γ |
| 0.84±0.40±0.04 | <u>EVTS</u> 7 | DOCUMENT ID ASNER | 08A C | LEO | $r(2S) \rightarrow \gamma 4\pi^{+} 4\pi^{-}$ |
| $= (6 \pm 2 \pm 2) \times$ | orts $[\Gamma(\chi_{b2}(1))] \times 10^{-6}$ which 10^{-2} . Our fire | $(P) \rightarrow 4\pi^{+}4\pi^{-}$ we divide by our st error is their ex |)/F _{total}] best val | × [B ue B(1 | $(\gamma(2S) ightarrow \gamma \chi_{b2}(1P))]$ $\gamma(2S) ightarrow \gamma \chi_{b2}(1P)) =$ or and our second error is |
| $\Gamma(4\pi^+4\pi^-2\pi^0)/$ | Γ _{total} | | | | Γ ₁₆ /Γ |
| VALUE (units 10 ⁻⁴) | | DOCUMENT ID | | | |
| 18±7±1 | | | | , | $2S) \rightarrow \gamma 4\pi^{+} 4\pi^{-} 2\pi^{0}$ |
| = (132 ± 31 ± 4 | is [F(χ_{b2} (1 P =0) $	imes$ 10 $^{-6}$ wh | $j \rightarrow 4\pi + 4\pi - 2\pi$ ich we divide by | ⁻//¹tot: our best | _{al} j×[l value l | $\beta(\Upsilon(2S) \to \gamma \chi_{b2}(1P))$ $\beta(\Upsilon(2S) \to \gamma \chi_{b2}(1P))$ |
| $= (7.15 \pm 0.35)$ | $\times 10^{-2}$. Our | | experim | | rror and our second error |
| | χ _{b2} (1P) C | ross-Particle B | ranchin | g Rat | ios |
| $\Gamma(\chi_{b2}(1P) \to \gamma 7$ | ົ (1S))/Γ _{tot} | $_{ m al}$ $	imes$ $\Gamma(T(2S)$ | $\rightarrow \gamma \chi_{l}$ | ₂ (1 <i>P</i> Γ1 |))/ $\Gamma_{	ext{total}}$ / $\Gamma 	imes \Gamma_{14}^{\mathcal{T}(2S)}$ / $\Gamma^{\mathcal{T}(2S)}$ |
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | <u></u> | | COMMENT |
| $13.9 \pm 0.5 ^{+ 0.9}_{- 1.1}$ | 8k | LEES | 11J B | ABR | $\Upsilon(2S) \rightarrow X \gamma$ |
| $B(\chi_{b2}(1P) \rightarrow \gamma$ <u>VALUE (units 10⁻⁴)</u> | | $B(\Upsilon(2S) \to \gamma$ DOCUMENT ID | | | $B(\mathcal{T}(1S) \to \ell^+\ell^-)$ |
| 3.29±0.09±0.16 | 1770 | KORNICER | | | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| $B(\chi_{b2}(1P) \rightarrow \gamma_{VALUE (units 10^{-5})}$ | | $B(\Upsilon(3S) \to \gamma)$ $\frac{DOCUMENT\ ID}{}$ | | | $B(\Upsilon(1S) \rightarrow \ell^+\ell^-)$ |
| 3.56±0.40±0.41 | 126 | KORNICER | | | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
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| LEES 11J PF ASNER 08A PF BRIERE 08 PF ARTUSO 05 PF EDWARDS 99 PF SKWARNICKI 87 PF WALK 86 ALBRECHT 85E PL NERNST 85 PF HAAS 84 PF KLOPFEN 83 PF AUSS 83 PL **T(25)** **VALUE (GeV)** **10.02326±0.00031 (10.0235 ±0.0005 10.0231 ±0.0004 • • • We do not us.** | R D78 032007 R D59 032003 R D59 032003 R D59 032003 R D54 2611 160B 331 R D54 2195 R D54 2195 R D54 2495 R D54 2495 R D54 2615 R D54 2615 | D.M. Asner et R.A. Briere et M. Arluso et K.W. Edwards T. Skwarnicki W.S. Walk et H. Albrecht et R. Nernst et J. Haas et al. C. Klopfenstei F. Pauss et al. DOCUMENT ID E | l. al. al. al. al. al. al. al. al. al. a | ECN MD1 EDE mits, e | (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (Cystal Ball Collab.) (Cystal Ball Collab.) (Cystal Ball Collab.) (Custal Ball Collab.) (CLEO Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) (CUSB Collab.) |
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TECN COMMENT

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ightarrow \pi^+\pi^- X$

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| VALUE (keV) | DOCUMENT ID |
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| 31.98±2.63 OUR EVALUATION States" | See the Note on "Width Determinations of the γ |

T(2S) DECAY MODES

| | T(2S) DECAY MODES | | | | | | | | |
|-----------------|-------------------------------------------------------|-----------|-----------------------------|----------------------|---------------------------------|--|--|--|--|
| | Mode | | Fraction (Γ _i /l | Г) Со | Scale factor/ nfidence level | | | | |
| Г | Υ (1S) π^+ π^- | | (17.92± 0. | 26) % | | | | | |
| Γ_2 | $\Upsilon(1S)\pi^0\pi^0$ | | (8.6 ± 0. | | | | | | |
| Γ ₃ | $\tau^+\tau^-$ | | (2.00± 0. | 21) % | | | | | |
| Γ_4 | $\mu^+\mu^-$ | | (1.93± 0. | 17) % | S=2.2 | | | | |
| Γ_5 | e+ e- | | (1.91± 0. | 16) % | | | | | |
| Γ ₆ | $\Upsilon(1S) \pi^0$ | | < 1.8 | $\times 10^{-4}$ | CL=90% | | | | |
| Γ ₇ | $\Upsilon(1S)\eta$ | | | $31) \times 10^{-4}$ | | | | | |
| Γ8 | $J/\psi(1S)$ anything | | < 6 | $\times 10^{-3}$ | CL=90% | | | | |
| Γ9 | \overline{d} anything | | | 6) $\times 10^{-5}$ | | | | | |
| Γ_{10} | hadrons | | |) % | | | | | |
| Γ ₁₁ | ggg | | (58.8 ± 1. | | | | | | |
| Γ_{12} | $\gamma g g$ | | (8.8 ± 1. | 1)% | | | | | |
| | Ra | diative o | lecays | | | | | | |
| Γ_{13} | $\gamma \chi_{b1}(1P)$ | | (6.9 ± 0. | 4) % | | | | | |
| Γ ₁₄ | $\gamma \chi_{b2}(1P)$ | | (7.15 ± 0.00) | .35) % | | | | | |
| Γ_{15} | $\gamma \chi_{b0}(1P)$ | | (3.8 ± 0.0) | 4) % | | | | | |
| Γ_{16} | $\gamma f_0(1710)$ | | < 5.9 | $\times 10^{-4}$ | CL=90% | | | | |
| Γ_{17} | $\gamma f_2'(1525)$ | | < 5.3 | $\times 10^{-4}$ | CL=90% | | | | |
| Γ_{18} | $\gamma f_2(1270)$ | | < 2.41 | $\times 10^{-4}$ | CL=90% | | | | |
| Γ_{19} | $\gamma f_J(2220)$ | | | | | | | | |
| Γ_{20} | $\gamma \eta_c(1S)$ | | < 2.7 | $\times 10^{-5}$ | CL=90% | | | | |
| Γ_{21} | $\gamma \chi_{c0}$ | | < 1.0 | $\times 10^{-4}$ | CL=90% | | | | |
| Γ_{22} | $\gamma \chi_{c1}$ | | < 3.6 | $\times 10^{-6}$ | CL=90% | | | | |
| Γ_{23} | $\gamma \chi_{c2}$ | | < 1.5 | $\times 10^{-5}$ | CL=90% | | | | |
| Γ_{24} | $\gamma X(3872) \rightarrow \pi^+ \pi^- J/\psi$ | | < 8 | $\times 10^{-7}$ | CL=90% | | | | |
| Γ ₂₅ | $\gamma X(3872) \to \pi^+ \pi^- \pi^0 J/$ | $'\psi$ | < 2.4 | ×10 ⁻⁶ | CL=90% | | | | |
| Γ_{26} | $\gamma X(3915) \rightarrow \omega J/\psi$ | | < 2.8 | $\times 10^{-6}$ | CL=90% | | | | |
| | γX (4140) $\rightarrow \phi J/\psi$ | | < 1.2 | × 10 ⁻⁶ | CL=90% | | | | |
| Γ ₂₈ | $\gamma X (4350) \rightarrow \phi J/\psi$ | | < 1.3 | × 10 ⁻⁶ | CL=90% | | | | |
| Γ ₂₉ | $\gamma \eta_b(1S)$ | | | $5) \times 10^{-4}$ | | | | | |
| Γ ₃₀ | $\gamma X \rightarrow \gamma + \geq 4 \text{ prongs}$ | | [a] < 1.95 | ×10 ⁻⁴ | CL=95% | | | | |
| Г ₃₁ | $\gamma A^0 \rightarrow \gamma$ hadrons | | < 8 | $\times 10^{-5}$ | CL=90% | | | | |
| | Lepton Family n | umber (| <i>LF</i>) violating m | odes | | | | | |
| Γ_{32} | $e^{\pm}	au^{\mp}$ | LF . | < 3.2 | $\times 10^{-6}$ | CL=90% | | | | |
| Γ ₃₃ | $\mu^{\pm}\tau^{\mp}$ | LF | < 3.3 | $\times 10^{-6}$ | CL=90% | | | | |
| _ | 1 1. | | | | | | | | |

[a] 1.5 GeV $< m_X <$ 5.0 GeV

$\Upsilon(2S) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\mu^+\mu^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$ | | | | $\Gamma_4\Gamma_5/\Gamma$ |
|------------------------------------------------------------------|-------------|----|------|-----------------------------------|
| VALUE (eV) | DOCUMENT ID | | TECN | COMMENT |
| 6.5 ± 1.5 ± 1.0 | KOBEL | 92 | CBAL | $e^+ e^- \rightarrow \mu^+ \mu^-$ |

| $\Gamma(\Upsilon(1S)\pi^+\pi^-$ | ·) × Γ(| $(e^+ e^-)/\Gamma_{\text{tota}}$ | l | | $\Gamma_1\Gamma_5/\Gamma$ |
|---------------------------------|---------|----------------------------------|----------|----------------------------|------------------------------------|
| VALUE (eV) | EVTS | DO CUMENT I | D TECN | COMMENT | |
| $105.4 \pm 1.0 \pm 4.2$ | 11.8K | ⁴ AUBERT | 08BPBABR | 10.58 $e^+e^- \rightarrow$ | $\gamma \pi^+ \pi^- \ell^+ \ell^-$ |

 4 Using B($\varUpsilon(1S) \rightarrow ~e^+e^-) = (2.38 \pm 0.11)\%$ and B($\varUpsilon(1S) \rightarrow ~\mu^+\mu^-) = (2.48 \pm 0.11)\%$ 0.05)%.

| $\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)/\Gamma_e$ | total | | | $\Gamma_{10}\Gamma_{5}/\Gamma$ |
|---------------------------------------------------------|--------------|------|---------|--------------------------------|
| VALUE (keV) | DO CUMENT ID | TECN | COMMENT | |
| A ! A AAA ALID AMEDAGE | | | | |

| VALUE (keV) | DO CUMENT ID | TECN | COMMENT |
|-------------------------------------|---------------------------|----------|---------------------------------|
| 0.577±0.009 OUR AVERAGE | · | | |
| $0.581 \pm 0.004 \pm 0.009$ | | | 10.0 $e^+e^- ightarrow$ hadrons |
| $0.552 \pm 0.031 \pm 0.017$ | ⁵ BARU | 96 MD1 | $e^+e^- ightarrow hadrons$ |
| $0.54 \pm 0.04 \pm 0.02$ | | | $e^+e^- ightarrow hadrons$ |
| $0.58 \pm 0.03 \pm 0.04$ | | | $e^+e^- ightarrow hadrons$ |
| $0.60 \pm 0.12 \pm 0.07$ | ⁶ ALBRECHT 8 | 82 DA SP | $e^+e^- ightarrow$ hadrons |
| $0.54 \pm 0.07 $ | ⁶ NICZYPORUK 8 | 81c LENA | $e^+e^- ightarrow $ hadrons |
| 0.41 ±0.18 | 6 BOCK | 80 CNTR | $e^+e^- \rightarrow hadrons$ |

 $^{^{5}\,\}mbox{Radiative}$ corrections evaluated following KURAEV 85.

T(2S) PARTIAL WIDTHS

| $\Gamma(e^+ e^-)$ | | Γ ₅ |
|----------------------------|--------------|----------------|
| VALUE (keV) | DO CUMENT ID | |
| 0.612±0.011 OUR EVALUATION | | |

$\Upsilon(2S)$ BRANCHING RATIOS

| $\Gamma(T(15)\pi^+\pi^-)/\Gamma_{\text{total}}$ | Γ_1/Γ |
|-------------------------------------------------|-------------------|
|-------------------------------------------------|-------------------|

| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-------|-------------------------|------|------|--------------------------------------------------------|
| 17.92±0.26 OUR AV | ERAGE | | | | |
| $16.8 \pm 1.1 \pm 1.3$ | 906k | ⁷ LEES | 11c | BABR | $e^+ e^- \rightarrow \pi^+ \pi^- X$ |
| $17.80 \pm 0.05 \pm 0.37$ | 170k | ⁸ LEES | 11L | BABR | $\Upsilon(2S) \rightarrow \pi^+ \pi^- \mu^+ \mu^-$ |
| $18.02 \pm 0.02 \pm 0.61$ | 851k | ⁹ BHARI | 09 | CLEO | $e^+e^- ightarrow~\pi^+\pi^-$ MM |
| $17.22 \pm 0.17 \pm 0.75$ | 11.8K | ¹⁰ AUBERT | | | $e^+ e^- \rightarrow \gamma \pi^+ \pi^- \ell^+ \ell^-$ |
| $19.2 \pm 0.2 \pm 1.0$ | 52.6k | ¹¹ ALEXANDER | 98 | CLE2 | $\pi^+\pi^-\ell^+\ell^-$, $\pi^+\pi^-$ MM |
| $18.1 \pm 0.5 \pm 1.0$ | 11.6k | ALBRECHT | 87 | ARG | $e^+ e^- ightarrow \pi^+ \pi^- {\sf MM}$ |
| 16.9 ±4.0 | | GELPHMAN | 85 | CBAL | $e^{+} e^{-} \rightarrow e^{+} e^{-} \pi^{+} \pi^{-}$ |
| $19.1 \pm 1.2 \pm 0.6$ | | BESSON | 84 | CLEO | $\pi^+\pi^-$ MM |
| 18.9 ± 2.6 | | FONSECA | 84 | CUSB | $e^+ e^- \rightarrow \ell^+ \ell^- \pi^+ \pi^-$ |
| 21 ±7 | 7 | NICZYPORUK | 81 B | LENA | $e^+ e^- ightarrow \ell^+ \ell^- \pi^+ \pi^-$ |

⁷LEES 11c reports $[\Gamma(\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \Upsilon(2S) \text{ any-}$ thing)] = $(1.78\pm0.02\pm0.11)\times10^{-2}$ which we divide by our best value B($\Upsilon(35)\to \Upsilon(2S)$ anything) = $(10.6\pm0.8)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

⁸ Using B($\Upsilon(1S) \to \mu^+ \mu^-) = (2.48 \pm 0.05)\%$

Sing B($\gamma(2S) \rightarrow \mu + \mu = 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25 \times 1.25$

11 Using B($\Upsilon(1S) \rightarrow e^+e^-) = (2.52 \pm 0.17)\%$ and B($\Upsilon(1S) \rightarrow \mu^+\mu^-) = (2.48 \pm 0.17)\%$

 $\Gamma(\Upsilon(1S)\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_2/Γ

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|-------------------------|----|------|---------------------------------------------------------|
| 8.6 ±0.4 OUR AVE | RAGE | | | | |
| $8.43 \pm 0.16 \pm 0.42$ | 38k | ¹² BHARI | 09 | CLEO | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\ell^{+}\ell^{-}$ |
| $9.2 \pm 0.6 \pm 0.8$ | 275 | ¹³ ALEXANDER | | | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\ell^{+}\ell^{-}$ |
| $9.5 \pm 1.9 \pm 1.9$ | 25 | ALBRECHT | | | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\ell^{+}\ell^{-}$ |
| 8.0 ±1.5 | | GELPH MA N | | | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\ell^{+}\ell^{-}$ |
| 10.3 ± 2.3 | | FONSECA | 84 | CUSB | $e^{+}e^{-} \rightarrow \pi^{0}\pi^{0}\ell^{+}\ell^{-}$ |
| | | | | | |

12 Authors assume B($\Upsilon(1S) \rightarrow e^+e^-)$ + B($\Upsilon(1S) \rightarrow \mu^+\mu^-)$ = 4.96%.

¹³ Using B($\Upsilon(1S) \rightarrow e^+e^-) = (2.52 \pm 0.17)\%$ and B($\Upsilon(1S) \rightarrow \mu^+\mu^-) = (2.48 \pm 0.17)\%$

$\Gamma(\Upsilon(1S)\pi^0\pi^0)/\Gamma(\Upsilon(1S)\pi^+\pi^-)$ Γ_2/Γ_1 DO CUMENT ID

• • • We do not use the following data for averages, fits, limits, etc. • • • 0.462 ± 0.037 ¹⁴ BHARI 09 CLEO $e^+e^- \rightarrow \Upsilon(2S)$

¹⁴ Not independent of other values reported by BHARI 09.

 $\Gamma(\tau^+\tau^-)/\Gamma_{\text{total}}$ Γ_3/Γ

| ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | | | | | | |
|-----------------------------------------|-------|----------------------|-----|------|-----------------------------------|------------------------------|
| VALUE (units 10^{-2}) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 2.00 ± 0.21 OUR AV | ERAGE | | | | | |
| $2.00 \pm 0.12 \pm 0.18$ | 22k | ¹⁵ BESSON | 07 | CLEO | $e^+e^- \rightarrow \Upsilon(2S)$ | \rightarrow $\tau^+\tau^-$ |
| $1.7 \pm 1.5 \pm 0.6$ | | HAAS | 84B | CLEO | $e^+e^- \rightarrow \tau^+\tau^-$ | |

 15 BESSON 07 reports $[\Gamma(\varUpsilon(2S)\to \tau^+\tau^-)/\Gamma_{\text{total}}]$ / $[B(\varUpsilon(2S)\to \mu^+\mu^-)]=1.04\pm0.04\pm0.05$ which we multiply by our best value B($\varUpsilon(2S)\to \mu^+\mu^-)=(1.93\pm0.17)\times$ 10^{-2} . Our first error is their experiment's error and our second error is the systematic error from using our best value.

 $\Gamma(\mu^+\mu^-)/\Gamma_{\text{total}}$ Γ_4/Γ DO CUMENT ID TECN COMMENT VALUE CL% EVTS

| 0.0193 ± 0.0017 OUR AVERAGE below. | iE Erro | or includes scale fac | tor of | f 2.2. S e | e the ideogram |
|------------------------------------|----------------|------------------------|---------|-------------------|---------------------------------------|
| $0.0203 \pm 0.0003 \pm 0.0008$ | 120k | | | | $e^+ e^- \rightarrow \mu^+ \mu^-$ |
| $0.0122 \pm 0.0028 \pm 0.0019$ | | | | | $e^+ e^- \rightarrow \ \mu^+ \mu^-$ |
| $0.0138 \pm 0.0025 \pm 0.0015$ | | | | | $e^+ e^- \rightarrow \mu^+ \mu^-$ |
| $0.009 \pm 0.006 \pm 0.006$ | | ¹⁷ ALBRECHT | 85 | ARG | $e^+ e^- \rightarrow \mu^+ \mu^-$ |
| $0.018 \pm 0.008 \pm 0.005$ | | HAAS | 84B | CLEO | $e^+ e^- \rightarrow \mu^+ \mu^-$ |
| • • • We do not use the follo | wing dat | a for averages, fits | , limit | s, etc. • | • • |

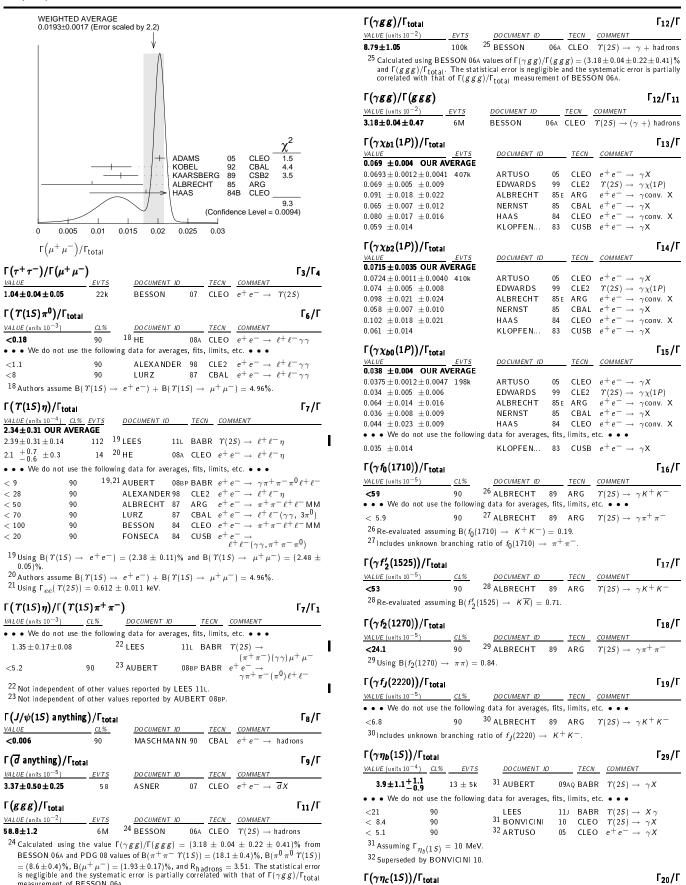
90 NICZYPORUK 81c LENA $e^+e^ightarrow \mu^+\mu^ ^{16}_{\rm -..}{\rm Taking}$ into account interference between the resonance and continuum.

 $^{17}\,\mathrm{Re}\text{-evaluated}$ using B($\varUpsilon(1\mathrm{S})\to~\mu^+\,\mu^-)=0.026.$

 $^{^6\,\}text{Radiative}$ corrections reevaluated by $\ensuremath{\text{BUCHMUELLER}}$ 88 following KURAEV 85.

measurement of BESSON 06A.

$\Upsilon(2S)$



 $< 2.7 \times 10^{-5}$

90

WANG

11B BELL $\Upsilon(2S) \rightarrow \gamma X$

Meson Particle Listings $\Upsilon(2S)$, $\Upsilon(1D)$, $\chi_{b0}(2P)$

| $\frac{(\mu^{\pm}\tau^{\mp})/\Gamma_{\text{total}}}{ALUE \text{ (units }10^{-6}\text{)}}$ < 3.3 • • We do not use | 95 T(2S) Cı | LOVE oss-Particle Br | 08A 08A anchi | , limits, CLEO ng Rati | etc. • • • $e^+e^- 	o \mu$ | |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------|-----------------------------------------------------|---------------------|-------------------------|-------------------------------------|---------------------|
| <3.2 $(\mu^{\pm}\tau^{\mp})/\Gamma_{\text{total}}$ $(ALUE (units 10^{-6})$ < 3.3 • • We do not use <14.4 | 90 the followin 95 | g data for averag LOVE | es, fits 08A | , limits, CLEO | etc. • • • $e^+e^- \rightarrow \mu$ | |
| $(\mu^{\pm}\tau^{\mp})/\Gamma_{\text{total}}$ ALUE (units 10^{-6}) < 3.3 • • We do not use | 90 the followin | g data for averag | es, fits | , limits, | etc. • • • | |
| $(\mu^{\pm} 	au^{\mp})/\Gamma_{	ext{total}}$ ALUE (units 10^{-6}) < 3.3 | 90 | | | | | . 7. |
| $(\mu^{\pm} 	au^{\mp})/\Gamma_{	ext{total}}$ | | | TOR | BABK | $e^+e^- \rightarrow \mu$ | |
| $(\mu^{\pm} 	au^{\mp})/\Gamma_{total}$ | | DO CUMENT ID | 100 | TECN | COMMENT 0+ 0- | .±∓ |
| <3.2 | | | | | | Г ₃₃ /І |
| | 90 | LEES | 10в | BABR | $e^+ e^- \rightarrow \epsilon$ | ± _τ ∓ |
| ALUE (units 10 ⁻⁶) | <u>CL%</u> | DO CUMENT ID | | | COMMENT | |
| $(e^{\pm} 	au^{\mp})/\Gamma_{ m total}$ | | | | | | Г ₃₂ /І |
| LEPTO | N FAMILY | NUMBER (LF |) VIC | LATIN | G MODES | |
| to 8 × 10 ⁻⁵ | ivicusured 5 | 070 CE 11111115 US 1 | Tunct | 1011 01 11 | A ⁰ Tunge not | |
| ³³ For a narrow scal range 0.3–7 GeV. | ar or pseudo Measured 9 | scalar A ^U , exclud 0% CL limits as a | ing kno | own reso | nances, with | mass in the |
| <8 × 10 ⁻⁵ | 90 | ³³ LEES | 11н | | $\gamma(2s) \rightarrow \gamma$ | |
| ALUE | 10 (. 50 V) <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT | |
| $(\gamma A^0 \rightarrow \gamma \text{ hadron})$ (0.3 GeV < m | ns)/Γ _{total} .ο ≤ 7 GeV) | | | | | Γ ₃₁ / Ι |
| | 95 | ROSNER | UZA | CLEO | e+ e ⁻ → ^ | |
| A <i>LUE</i> (units 10 ⁻⁴) <1.95 | <u>CL%</u> | DOCUMENT ID | 074 | | COMMENT | . v |
| (1.5 GeV < m) | | ') | | | | 50, |
| $(\gamma X \to \gamma + \geq 4)$ | prongs)/Γ _t | ntal | | | | Γ ₃₀ /Ι |
| (1.3 × 10 ⁻⁶ | 90 | WANG | 11в | BELL | $r(2s) \rightarrow \gamma$ | γ X |
| $(\gamma \times (4330) \rightarrow \varphi)$ | ~/ Ψ// ' tota <u>CL%</u> | II <u>DOCUMENT ID</u> | | TECN | COMMENT | 1 28/1 |
| $(\gamma X (4350) \rightarrow \phi$ | 1/2b) /F | •1 | | | | Γ ₂₈ /Ι |
| 1.2 × 10 ⁻⁶ | 90 | WA NG | 11в | | $\gamma(2s) \rightarrow \gamma$ | γX |
| (γΧ (4140) → φ LUE | ノ/ψ)/ tota | II <u>DOCUMENT ID</u> | | TECN | COMMENT | Γ ₂₇ /Ι |
| | | | 110 | | , (20) | |
| 2.8 × 10 ⁻⁶ | <u>CL%</u> 90 | <u>DO CUMENT ID</u> WANG | | TECN BELL | $\Upsilon(2S) \rightarrow \gamma$ | v X |
| $(\gamma X (3915) \rightarrow \omega$ | - | | | | | Γ ₂₆ /Ι |
| | 90 | WANG | 11в | BELL | $r(2s) \rightarrow r$ | |
| 4 <i>LUE</i> <2.4 × 10 ⁻⁶ | <u>CL%</u> | DOCUMENT ID | | TECN_ | COMMENT T(26) | . V |
| $(\gamma X(3872) \rightarrow \pi^{-1})$ | $+\pi^{-}\pi^{0}J/2$ | $\psi)/\Gamma_{total}$ | | | | Γ ₂₅ / Ι |
| <0.8 × 10 ⁻⁶ | 90 | WA NG | 11в | BELL | $\Upsilon(2S) \rightarrow \gamma$ | γX |
| ALUE | <u>CL%_</u> | DO CUMENT ID | | TECN | COMMENT | |
| $(\gamma X (3872) \rightarrow \pi^{-1})$ | $+\pi^-J/\psi$ | /Γ _{total} | | | | Γ24/Ι |
| <1.5 × 10 ⁻⁵ | 90 | WA NG | 11B | BELL | $\Upsilon(2S) \rightarrow \gamma$ | γX |
| ALUE | CL% | DO CUMENT ID | | TECN | COMMENT | . 237 |
| $(\gamma \chi_{c2})/\Gamma_{\rm total}$ | | | | | | Γ ₂₃ / |
| <3.6 × 10 ⁻⁶ | 90 | WANG | 11в | BELL | $r(2s) \rightarrow \gamma$ | γX |
| ALUE | CL% | DO CUMENT ID | | TECN | COMMENT | Γ ₂₂ /Ι |
| $(\gamma \chi_{c1})/ \text{total}$ | | | | | | |
| $(\gamma \chi_{c1})/\Gamma_{\text{total}}$ | 90 | WA NG | 11B | | $\Upsilon(2S) \rightarrow \gamma$ | γX |
| $\frac{4LUE}{\langle 1.0 \times 10^{-4} \rangle}$ | CL% | DO CUMENT ID | | TECN | COMMENT | Γ ₂₁ /Ι |

| LEES | IIC | PK D84 011104 | J.P. Lees et al. | (BABAR COIIAD.) | |
|-----------|-------|----------------|-----------------------|------------------------|--|
| LEES | 11H | PRL 107 221803 | J.P. Lees et al. | (BABAR Collab.) | |
| LEES | 11 J | PR D84 072002 | J.P. Lees et al. | (BABAR Collab.) | |
| LEES | 11L | PR D84 092003 | J.P. Lees et al. | (BABAR Collab.) | |
| WANG | 11B | PR D84 071107 | X.L. Wang et al. | (BELLE Collab.) | |
| BONVICINI | 10 | PR D81 031104R | G. Bonvicini et al. | (CLEO Collab.) | |
| LEES | 10 B | PRL 104 151802 | J.P. Lees et al. | (BABAR Collab.) | |
| AUBERT | 09AQ | PRL 103 161801 | B. Aubert et al. | (BABAR Collab.) | |
| BHARI | 09 | PR D79 011103 | S.R. Bhari et al. | (CLEO Collab.) | |
| AUBERT | 08 BP | PR D78 112002 | B. Aubert et al. | (BABAR Collab.) | |
| HE | 08A | PRL 101 192001 | Q. He et al. | (CLEO Collab.) | |
| LOVE | 08A | PRL 101 201601 | W. Love et al. | (CLEO Collab.) | |
| PDG | 08 | PL B667 1 | C. Amsler et al. | (PDG Collab.) | |
| ASNER | 07 | PR D75 012009 | D.M. Asner et al. | (CLEO Collab.) | |
| BESSON | 07 | PRL 98 052002 | D. Besson et al. | (CLEO Collab.) | |
| ROSNER | 07 A | PR D76 117102 | J.L. Rosner et al. | (CLEO Collab.) | |
| BESSON | 06A | PR D74 012003 | D. Besson et al. | (CLEO Collab.) | |
| ROSNER | 06 | PRL 96 092003 | J.L. Rosner et al. | (CLEO Collab.) | |
| ADAMS | 05 | PRL 94 012001 | G.S. Adams et al. | (CLEO Collab.) | |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso et al. | (CLEO Collab.) | |
| ARTAMONOV | 00 | PL B474 427 | A.S. Artamonov et al. | | |
| EDWARDS | 99 | PR D59 032003 | K.W. Edwards et al. | (CLEO Collab.) | |
| ALEXANDER | 98 | PR D58 052004 | J.P. Alexander et al. | (CLEO Collab.) | |
| BARU | 96 | PRPL 267 71 | S.E. Baru et al. | (NOVO) | |
| KOBEL | 92 | ZPHY C53 193 | M. Kobel et al. | (Crystal Ball Collab.) | |
| | | | | | |

| KAARS BERG BUCH MUEL | 90 89 89 88 Ali a | ZPHY C46 555 ZPHY C42 349 PRL 62 2077 HE e ⁺ e ⁻ Physics 412 nd P. Soeding, World Sci | | (Crystal Ball Collab.) (ARGUS Collab.) (CUSB Collab.) oper (HANN, DESY, MIT) |
|--------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ALBRECHT COHEN LURZ | 88 87 87 87 86 B | ZPHY C40 49 ZPHY C35 283 RMP 59 1121 ZPHY C36 383 ZPHY C32 622 (erratum | Z. Jakubowski et al. H. Albrecht et al. E.R. Cohen, B.N. Taylor B. Lurz et al. | (Crystal Ball Collab.) IGJPC (ARGUS Collab.) r (RISC, NBS) (Crystal Ball Collab.) (NOVO) |
| ALBRECHT ALBRECHT GELPHMAN | 85 85 E 85 85 | ZPHY C28 45 PL 160B 331 PR D32 2893 SJNP 41 466 Translated from YAF 41 | ´H. Albrecht et al. H. Albrecht et al. D. Gelphman et al. E.A. Kuraev, V.S. Fadin | (ARGUS Collab.) (ARGUS Collab.) (Crystal Ball Collab.) |
| BARBER BESS ON FONS ECA GILES HAAS KLOPFEN ALBRECHT NIC ZYPORUK | 85 84 84 84 84 84 84 84 83 82 81 81 81 80 | PRL 54 2195 PL 137B 272 PL 135B 498 PR D30 1433 NP B242 31 PR D29 1285 PRL 52 799 PR D30 1996 PRL 51 160 PRL 51 160 PL 116B 383 PL 100B 95 PL 99B 169 ZPHY C6 125 | R. Nernst et al. A.S. Artamonov et al. D.P. Barber et al. D. Besson et al. V. Fonseca et al. R. Giles et al. J. Haas et al. J. Haas et al. C. Klopfenstein et al. H. Albrecht et al. B. Niczyporuk et al. P. Bock et al. P. Bock et al. | (Crystal Ball Collab.) (NOVO) (DESY, ARGUS Collab.+) (CLEO Collab.) (CUSB Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CLEO Collab.) (CUSB Collab.) (DESY, DORT, HEIDH+) (LENA Collab.) (HEIDP, MPIM, DESY, HAMB) |

$\Upsilon(1D)$

$$I^{G}(J^{PC}) = 0^{-}(2^{-})$$

First observed by BONVICINI 04 in the decay to $\gamma\gamma$ $\Upsilon(1S)$ and confirmed by DEL-AMO-SANCHEZ 10R in the decay to $\pi^+\pi^ \Upsilon(1S)$. Data consistent with $J^P=2^-$. The states with J=1 and 3 also possibly seen, but need confirmation.

au(1D) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT | |
|---------------------------|---------|--------------------|--------------|------------------------------------|-------------------------------|
| 10163.7±1.4 OUR | AVERAGE | Error includes sca | le factor of | 1.7. | |
| $10164.5 \pm 0.8 \pm 0.5$ | | DEL-AMO-SA1 | | | |
| $10161.1\pm0.6\pm1.6$ | 38 | BONVICINI 0 | 4 CLE3 | $\Upsilon(3S) \rightarrow 4\gamma$ | ℓ ⁺ ℓ [−] |

T(1D) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|-----------------------------|------------------------------|
| Γ_1 | $\gamma\gamma \Upsilon(1S)$ | seen |
| Γ_2 | $\gamma \chi_{bJ}(1P)$ | seen |
| Γ_3 | $\eta \ \Upsilon(1S)$ | not seen |
| Γ_4 | $\pi^+\pi^-\varUpsilon(1S)$ | $(6.6\pm1.6)\times10^{-3}$ |

T(1D) BRANCHING RATIOS

| $\Gamma(\eta \Upsilon(1S))/\Gamma(\gamma \gamma)$ | T(15)) | | | | | Γ_3/Γ_1 |
|---------------------------------------------------|------------|------------------------------------------|-----------------------|-------|---------------------------------------|------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| < 0.25 | 90 | BONVICINI | 04 | CLE3 | $\Upsilon(3S) \rightarrow 4$ | $\gamma \ell^+ \ell^-$ |
| $\Gamma(\pi^+\pi^- \Upsilon(1S))/\Gamma$ | total | | | | | Γ4/Γ |
| VALUE (units 10^{-2}) | | DO CUMENT ID | TECN | CON | 1MENT | |
| $0.66^{+0.15}_{-0.14}\pm0.06$ | 1 | DEL-AMO-SA10R | BAB | R γ(3 | $3S) \rightarrow \gamma \gamma \pi^+$ | $\pi^-\ell^+\ell^-$ |
| ¹ Using theoretical p | redictions | for $B(\chi_{h,T}(2P) \rightarrow \cdot$ | $\gamma \Upsilon (1L$ | O)). | | |

| $^{ m 1}$ Using theoretica | predictions fo | or $B(\chi_{b,I}(2P) \rightarrow$ | · γ Υ(1D)). |
|----------------------------|----------------|-----------------------------------|-------------|
|----------------------------|----------------|-----------------------------------|-------------|

| $\Gamma(\pi^+\pi^-\Upsilon(1S))/\Gamma$ | $(\gamma\gamma T)$ | l <i>S</i>)) | | | | Γ_4/Γ_1 |
|-----------------------------------------|--------------------|------------------------|----|------|----------------------------|-----------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.2 | 90 | ² BONVICINI | 04 | CLE3 | $\Upsilon(3S) \rightarrow$ | $4\gamma\ell^+\ell^-$ |
| ² Assuming $J = 2$. | | | | | | |

au(1D) REFERENCES

| BONVICINI 04 FK D70 032001 G. BONVICINI EL AL. (CELO CONAD.) | DEL-AMO-SA 10 R | PR D82 111102 | P. del Amo Sanchez et al. | (BABAR Collab.) |
|--------------------------------------------------------------|-----------------|---------------|---------------------------|-----------------|
| | BONVICINI 04 | PR D70 032001 | G. Bonvicini et al. | (CLEO Collab.) |



$$I^G(J^{PC}) = 0^+(0^{++})$$

 J needs confirmation.

Observed in radiative decay of the $\Upsilon(3S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore

$\chi_{b0}(2P)$ MASS

| VALUE (GeV) | DO CUMENT | ID | | | |
|-----------------------------------|-----------|----------------------------|---------|----------------|------|
| 10.2325 ± 0.0004 ± 0.0005 OUR EVA | LUATION | From γ energy below | , using | $\Upsilon(3S)$ | mass |
| = 10355.2 + 0.5 MeV | | . 33 | | | |

 $\chi_{b0}(2P)$

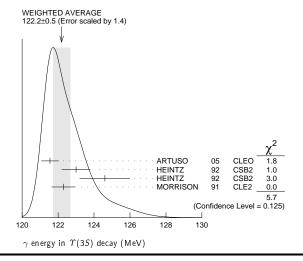
γ ENERGY IN $\Upsilon(3S)$ DECAY

| VALUE (MeV) | EVTS | DO CUMENT ID | 7 | TECN | COMMENT |
|----------------------------|----------|----------------------|------------|---------|---------------------------------------------------|
| 121.9 ±0.4 OUR EV | /ALUATIO | N Treating syster | natic erro | ors as | correlated |
| 122.2 ±0.5 OUR AV | /ERAGE | Error includes scale | e factor o | of 1.4. | See the ideogram below. |
| $121.55 \pm 0.16 \pm 0.46$ | | ARTUSO | 05 C | CLEO | $\Upsilon(3S) \rightarrow \gamma X$ |
| 123.0 ± 0.8 | 4959 | $^{ m 1}$ HEINTZ | 92 C | SB2 | $e^+ e^- \rightarrow \gamma X$ |
| 124.6 ± 1.4 | 17 | ² HEINTZ | 92 C | SB2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| $122.3 \pm 0.3 \pm 0.6$ | 9903 | MORRISON | 91 C | CLE2 | $e^+e^- \rightarrow \gamma X$ |

 $^{1}\,\mathrm{A}$ systematic uncertainty on the energy scale of 0.9% not included. Supersedes

NARAIN 91.

A systematic uncertainty on the energy scale of 0.9% not included. Supersedes



$\chi_{b0}(2P)$ DECAY MODES

| | Mode | Fraction (Γ | ·/F) | Confidence | level |
|----------------------------------|-------------------------------------------------------|----------------------|-------------------|------------|-------|
| Γ ₁ Γ ₂ | $\gamma \Upsilon(2S)$ $\gamma \Upsilon(1S)$ | (4.6 ± 2.1 (9 ± 6 | · _ | | |
| Γ_3 | $D^0 X$ | < 8.2 | % | | 90% |
| Γ_4 | $\pi^{+}\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | < 3.4 | $\times 10^{-5}$ | | 90% |
| Γ_5 | $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | < 5 | $\times 10^{-5}$ | | 90% |
| Γ_6 | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 2.2 | $\times 10^{-4}$ | | 90% |
| Γ_7 | $2\pi^{+}2\pi^{-}2\pi^{0}$ | < 2.4 | $\times 10^{-4}$ | | 90% |
| Γ ₈ | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | < 1.5 | $\times 10^{-4}$ | | 90% |
| Г9 | $2\pi^{+}2\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | < 2.2 | $\times 10^{-4}$ | | 90% |
| Γ_{10} | $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | < 1.1 | $\times 10^{-3}$ | | 90% |
| Γ_{11} | $3\pi^{+}2\pi^{-}K^{-}K^{0}_{S}\pi^{0}$ | < 7 | $\times 10^{-4}$ | | 90% |
| Γ_{12} | $3\pi^{+} 3\pi^{-}$ | < 7 | $\times 10^{-5}$ | | 90% |
| Γ_{13} | $3\pi^{+}3\pi^{-}2\pi^{0}$ | < 1.2 | $\times 10^{-3}$ | | 90% |
| Γ_{14} | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | < 1.5 | $\times 10^{-4}$ | | 90% |
| Γ_{15} | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | < 7 | $\times 10^{-4}$ | | 90% |
| Γ_{16} | $4\pi^{+}4\pi^{-}$ | < 1.7 | $\times 10^{-4}$ | | 90% |
| Γ ₁₇ | $4\pi^{+}4\pi^{-}2\pi^{0}$ | < 6 | ×10 ⁻⁴ | | 90% |

$\chi_{b0}(2P)$ BRANCHING RATIOS

| | /LDU (=- | , | | | | |
|--------------------------------------------------------------------|----------------------------|---------------------------------------------|-----------------|--------------------------|--------------------------------------------------------------------------|-------------------|
| $\Gamma(\gamma \Upsilon(2S))/\Gamma_{\text{total}}$ | CL W | DO CUMENT ID | | TECN | COMMENT | Γ_1/Γ |
| VALUE | <u>CL%</u> | DO CUMENT ID | | | | |
| $0.046 \pm 0.020 \pm 0.007$ | | 3 HEINTZ | 92 | CSB2 | $e^+ e^- \rightarrow \ell^+ \ell^-$ | $-\gamma\gamma$ |
| • • • We do not use the | following | data for average | s, fits | , limits, | etc. • • • | |
| < 0.028 | 90 | ⁴ LEES | | | | |
| < 0.089 | 90 | ⁵ CRAWFORD | 92B | CLE2 | $e^+ e^- \rightarrow \ell^+ \ell^-$ | $-\gamma\gamma$ |
| 3 Using B($\varUpsilon(2S) ightarrow 0.4 \pm 0.6)\%$ and assu | $\mu^+\mu^-)$ uming $e\mu$ | = $(1.44 \pm 0.10)\%$ universality. Supe | 6, B(ersede | Υ(35) - s HEINT | $\stackrel{ ightarrow}{	ilde{	au}} \gamma \chi_{b0}(2P)) = \Gamma Z 91.$ | (6.0 \pm |
| ⁴ LEES 111 quotes a c | entral val | ue of $\Gamma(\chi_{b0}(2P)$ | \rightarrow | $\gamma \Upsilon(2S)$ | $)/\Gamma_{total} \times \Gamma(\gamma)$ | (35) → |
| $\gamma \chi_{b0}(2P))/\Gamma_{total} =$ | (-0.3 ± | $0.2^{+0.5}_{-0.4})\%$ | | | , , , , , , , , , , , , , , , , , , , , | |
| 5 Using B($\Upsilon(2S) ightarrow \mu$ | $+\mu^{-}) =$ | $(1.37 \pm 0.26)\%$, E | $3(\Upsilon(3$ | $(S) \rightarrow \gamma$ | $(\gamma \Upsilon(2S)) \times 2 B(\Upsilon$ | `(2S) → |
| $\mu^+ \mu^-$) < 1.19 × 10 | | | | | | |
| | | | | | | |

| $\Gamma(\gamma \Upsilon(1S))/\Gamma_{total}$ | | | | | | Γ_2/Γ |
|-----------------------------------------------|-----------|-----------------------|---------|-----------|----------------------------|----------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $0.009 \pm 0.006 \pm 0.001$ | | 6 HEINTZ | 92 | CSB2 | e^+e^- | $\ell^+\ell^-\gamma\gamma$ |
| • • • We do not use the | following | data for average | s, fits | , limits, | etc. • • • | |
| < 0.012 | 90 | ⁷ LEES | | | $\Upsilon(3S) \rightarrow$ | |
| < 0.025 | 90 | ⁸ CRAWFORD | 92B | CLE2 | $e^+ e^- \rightarrow$ | $\ell^+\ell^-\gamma\gamma$ |

I

| ⁶ Using B($\Upsilon(1S) \rightarrow \mu^+\mu^-) = (2.57 \pm 0.07)\%$, B($\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (6.0 \pm 0.07)\%$ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $0.4 \pm 0.6)\%$ and assuming $e\mu$ universality. Supersedes HEINTZ 91. |
| ⁷ LEES 11J quotes a central value of $\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(3S) \rightarrow \Upsilon(1S))$ |
| $\gamma \chi_{b0}(2P))/\Gamma_{\text{total}} = (3.9 \pm 2.2 {+ 1.2 \atop -0.6}) \times 10^{-4}.$ |
| ⁸ Using B($\Upsilon(1S) \rightarrow \mu^+ \mu^-$) = (2.57 ± 0.07)%, B($\Upsilon(3S) \rightarrow \gamma \gamma \Upsilon(1S)$)×2 B($\Upsilon(1S) \rightarrow \gamma \gamma \Upsilon(1S)$) |
| $\mu^+ \mu^-) < 0.63 	imes 10^{-4}$, and B($\Upsilon(3S) 	o \chi_{b0}(2P) \gamma) = 0.049$. |

| $\Gamma(D^0X)/\Gamma_{\text{total}}$ | | | | | Г ₃ /Г |
|--------------------------------------|-----|--------------|----|------|-----------------------------------------|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
| $< 8.2 \times 10^{-2}$ | 90 | 9,10 BRIERE | 80 | CLEO | $ \gamma(3S) \rightarrow \gamma D^0 X $ |

 $^9\,{\rm For}\;\rho_{D^0}\;>$ 2.5 GeV/c.

¹⁰ The authors also present their result as $(4.1 \pm 3.0 \pm 0.4) \times 10^{-2}$.

 $\Gamma(\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_4/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT 11 ASNER 08A CLEO $T(3S) \rightarrow \gamma \pi^{+} \pi^{-} K^{+} K^{-} \pi^{0}$ < 0.34 90 ¹¹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow \pi^+\pi^-K^+K^-\pi^0)/\Gamma_{total}] \times [B(\Upsilon(3S) \rightarrow \chi_{b0}(2P))] < 2 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \chi_{b0}(2P))$

 $\Gamma(2\pi^+\pi^-K^-K_S^0)/\Gamma_{\text{total}}$ Γ_5/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT 12 ASNER 08A CLEO $\Upsilon(3S)
ightarrow \gamma 2\pi^+ \, \pi^- \, K^- \, K^0_{\, S}$ ¹²ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^{+}\pi^{-}K^{-}K_{S}^{0})/\Gamma_{total}] \times [B(\Upsilon(3S) \rightarrow 2\pi^{+}\pi^{-}K^{-}K_{S}^{0})/\Gamma_{total}]$ $\gamma \chi_{b0}(2P))] < 3 \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S)
ightarrow \gamma \chi_{b0}(2P))$ $= 5.9 \times 10^{\textstyle -2}$

 $\Gamma(2\pi^+\pi^-K^-K_S^02\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT 13 ASNER 08A CLEO $r(3S) \rightarrow \gamma 2\pi^{+} \pi^{-} \kappa^{-} 2\pi^{0}$ $^{13}\,\mathrm{ASNER}$ 08A reports [$\Gamma\left(\chi_{b0}(2P)\ \rightarrow\ 2\pi^{+}\,\pi^{-}\,\mathrm{K}^{-}\,\mathrm{K}^{\,0}_{\,S}\,2\pi^{0}\right)/\Gamma_{total}]\ \times\ [\mathrm{B}(\,\Upsilon(3S)\ \rightarrow\ T_{total})]$ $\gamma\chi_{b0}(2P))]<13\times10^{-6}$ which we divide by our best value B($\Upsilon(3S)\to\gamma\chi_{b0}(2P))=5.9\times10^{-2}$.

 $\Gamma(2\pi^+2\pi^-2\pi^0)/\Gamma_{\rm total}$ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT 14 ASNER 08A CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^{+} 2\pi^{-} 2\pi^{0}$ 90 14 ASNER 08A reports $[\Gamma(\chi_{b0}(2P)\to 2\pi^+\,2\pi^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \gamma\chi_{b0}(2P))] < 14\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \gamma\chi_{b0}(2P))=5.9\times 10^{-2}$.

 $\Gamma(2\pi^+2\pi^-K^+K^-)/\Gamma_{\rm total}$ Γ_8/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT ¹⁵ ASNER 90 08A CLEO $\Upsilon(3S)
ightarrow \gamma 2\pi^{+} 2\pi^{-} K^{+} K^{-}$ 15 ASNER 08A reports [\Gamma($\chi_{b0}(2P)\rightarrow 2\pi^{+}2\pi^{-}K^{+}K^{-})/\Gamma_{\rm total}]\times [{\rm B}(\varUpsilon(3S)\rightarrow \chi_{b0}(2P))]<9\times 10^{-6}$ which we divide by our best value B($\varUpsilon(3S)\rightarrow \chi_{b0}(2P))=5.9\times 10^{-2}$.

 $\Gamma(2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\rm total}$ Γ₉/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT 90 16 ASNER 08A CLEO $\Upsilon(3S)
ightarrow \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$ $^{16}\,\text{ASNER}$ 08A reports $[\Gamma\left(\chi_{\mbox{\footnotesize{b0}}}(2P)\ \rightarrow\ 2\pi^{+}\,2\pi^{-}\,\mbox{\footnotesize{K}}^{+}\,\mbox{\footnotesize{K}}^{-}\,\pi^{0}\right)/\Gamma_{\mbox{\footnotesize{total}}}]\ \times\ [\mbox{\footnotesize{B}}(\ \varUpsilon(3S)\ \rightarrow\ \Upsilon(3S)\ \rightarrow\ \Upsilon($ $\gamma \chi_{b0}(2P))] < 13 \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))$ $= 5.9 \times 10^{\textstyle -2}$

 $\Gamma(2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{10}/Γ VALUE (units 10^{-4}) CL% DOCUMENT ID TECN COMMENT $\overline{90}$ 17 ASNER 08A CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^{+} 2\pi^{-} \kappa^{+} \kappa^{-} 2\pi^{0}$ $^{17} {\rm ASNER}$ 08A reports $[\Gamma(\chi_{b0}(2P) \to 2\pi^+ \, 2\pi^- \, K^+ \, K^- \, 2\pi^0)/\Gamma_{\rm total}] \times [{\rm B}(\, \Upsilon(3S) \to \chi_{b0}(2P))] < 63 \times 10^{-6}$ which we divide by our best value ${\rm B}(\, \Upsilon(3S) \to \chi_{b0}(2P))$

 $\Gamma(3\pi^+2\pi^-K^-K^0_S\pi^0)/\Gamma_{\text{total}}$ Γ_{11}/Γ 18 ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^{+}\,2\pi^{-}\,K^{-}\,K_{\,\,S}^{\,0}\,\pi^{0})/\Gamma_{\rm total}]\,\times\,[B(\,\varUpsilon(3S)\,\rightarrow\,3\pi^{+}\,2\pi^{-}\,K^{-}\,K_{\,\,S}^{\,0}\,\pi^{0})/\Gamma_{\rm total}]\,\times\,[B(\,\varUpsilon(3S)\,\rightarrow\,3\pi^{+}\,2\pi^{-}\,K^{-}\,K_{\,\,S}^{\,0}\,\pi^{0})/\Gamma_{\rm total}]\,\times\,[B(\,\varUpsilon(3S)\,\rightarrow\,3\pi^{+}\,2\pi^{-}\,K^{-}\,K_{\,\,S}^{\,0}\,\pi^{0})/\Gamma_{\rm total}]$ $\gamma \chi_{b0}(2P))] < 39 \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S) \to \gamma \chi_{b0}(2P)$) $= 5.9 \times 10^{-2}$

 $\Gamma(3\pi^+3\pi^-)/\Gamma_{\text{total}}$ Γ_{12}/Γ VALUE (units 10^{-4}) DOCUMENT ID TECN COMMENT ¹⁹ ASNER 08A CLEO $\Upsilon(3S) \rightarrow \gamma 3\pi^{+} 3\pi^{-}$ $^{19}\,\mathrm{ASNER}$ OBA reports $[\Gamma\big(\chi_{b0}(2P)\ \rightarrow\ 3\pi^+\ 3\pi^-\big)/\Gamma_{\mathrm{total}}]\times[\mathrm{B}(\ \varUpsilon(3S)\ \rightarrow\ \gamma\chi_{b0}(2P))]$ $<4\times10^{-6}$ which we divide by our best value B($\Upsilon(3S)\to\gamma\chi_{b0}(2P)$) = 5.9×10⁻².

 $\chi_{b0}(2P)$, $\chi_{b1}(2P)$

| $\Gamma(3\pi^{+}3\pi^{-}2\pi^{0})$ | $/\Gamma_{total}$ | | | | Γ ₁₃ /Γ |
|------------------------------------|-------------------|---------------------|-----|------|----------------------------------------------------------------------------------------------------------------------|
| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT |
| <12 | 90 | ²⁰ ASNER | 08A | CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^{+} 3\pi^{-} 2\pi^{0}$ |
| | | | | | $\times \left[B(\Upsilon(3S) \to \gamma \chi_{b0}(2P)) \right] \\ \to \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}.$ |

| I(3π ⁺ 3π ⁻ K ⁻ | -K-)/ | l to | tal | | | | | 114/ |
|--------------------------------------------------|-------|------|-------------|-----|------|--------------------------|-----------------|--------------------|
| VALUE (units 10^{-4}) | CL% | | DOCUMENT ID | | TECN | COMMENT | | |
| <1.5 | 90 | 21 | ASNER | 08A | CLEO | <i>Υ</i> (3 <i>S</i>) → | $\gamma 3\pi^+$ | $3\pi^- K^+ K^-$ |
| 21 A CNED 00. | | - | ((OD) | | | - 14-1/5 | | [D (20 (2.6) |

 21 ASNER 08A reports $[\Gamma(\chi_{b0}(2P)\to 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}]\times [\mathrm{B}(\Upsilon(3S)\to \gamma\chi_{b0}(2P))]<9\times10^{-6}$ which we divide by our best value $\mathrm{B}(\Upsilon(3S)\to \gamma\chi_{b0}(2P))=5.9\times10^{-2}.$

$$\Gamma(3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0})/\Gamma_{\text{total}}$$
 Γ_{15}/Γ

<u>VALUE (units 10⁻⁴)</u> <u>CL%</u> <u>DOCUMENT</u> **<7** 90 22 ASNER DO CUMENT ID TECN COMMENT 08A CLEO $\Upsilon(3S)
ightarrow \gamma 3\pi^{+} 3\pi^{-} \kappa^{+} \kappa^{-} \pi^{0}$

²²ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 3\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 43 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

| $\Gamma(4\pi^+4\pi^-)/\Gamma_{\text{total}}$ | | | | | | Γ ₁₆ /Γ |
|----------------------------------------------|-----|---------------------|------|------|--------------------------|-----------------------------|
| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <1.7 | 90 | ²³ ASNER | 08A | CLEO | $\gamma(3S) \rightarrow$ | γ 4 π +4 π - |
| 23 A CNED 004 | rr/ | (20) 4 ± 4 = |) /E | 1 [6 | (m(2c) | (20))1 |

²³ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 4\pi^+ 4\pi^-)/\Gamma_{total}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ $<10\times10^{-6}$ which we divide by our best value B($\Upsilon(3S) \to \gamma\chi_{b0}(2P)$) = 5.9×10^{-2} .

$$\begin{split} \Gamma\big(\chi_{b0}(2P) &\to \gamma \ T(1S)\big) / \Gamma_{\text{total}} \ \times \ \Gamma\big(\ T(3S) \to \gamma \chi_{b0}(2P)\big) / \Gamma_{\text{total}} \\ & \Gamma_2 / \Gamma \times \Gamma_{21}^{T(3S)} / \Gamma^{\Upsilon(3S)} \end{split}$$

| VALUE (units 10 ⁻⁴) | CL% | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------------|--------|---------------------------------|-----|----------------------|------------------------------|-------------------------------------------------|
| <8.2 | 90 | 25 LEES | 11J | BABR | <i>Υ</i> (35) → | Χγ |
| ²⁵ LEES 11J quotes a c | entral | value of $\Gamma(\chi_{b0}(2P)$ | → · | $\gamma \gamma (15)$ | $/\Gamma_{ m total}$ $	imes$ | $\Gamma \left(\varUpsilon (3S) \rightarrow $ |
| (0.5)\/= | (0.0 | + 1 2 4 | | | 000/ 61 | |

 $\gamma\chi_{b0}(2P))/\Gamma_{total}=(3.9\pm2.2^{+}_{-0.6})\times10^{-4}$ and derives a 90% CL upper limit of $B(\chi_{b0}(2P)\to\gamma \Upsilon(1S))<1.2\%$ using $B(\Upsilon(3S)\to\gamma\chi_{b0}(2P))=(5.9\pm0.6)\%$.

$\Gamma(\chi_{b0}(2P) \to \gamma T(2S))/\Gamma_{total} \times \Gamma(T(3S) \to \gamma \chi_{b0}(2P))/\Gamma_{total}$ $\Gamma_1/\Gamma \times \Gamma_{21}^{\Upsilon(3S)}/\Gamma^{\Upsilon(3S)}$

| VALUE (units 10 ⁻³) | CL% | DO CUMENT | ID | TECN | COMMENT |
|-----------------------------------------------|---------|-----------------------------------|---------|-----------------------|---------------------------------------------------------------|
| <1.6 | 90 | ²⁶ LEES | 111 | BABR | $\Upsilon(3S) \rightarrow X \gamma$ |
| ²⁶ LEES 11J quotes a | central | value of $\Gamma(\chi_{b0})$ | (P) → · | $\gamma \Upsilon(2S)$ | $)/\Gamma_{\rm total} \times \Gamma(\Upsilon(3S) \rightarrow$ |
| $\gamma \chi_{b0}(2P))/\Gamma_{total}$ | = (-0 | $0.3 \pm 0.2 + 0.5 \atop -0.4)\%$ | and de | rives a | 90% CL upper limit of |
| $B(\chi_{h0}(2P) \rightarrow \gamma \Upsilon$ | (25)) < | 2.8% using B(γ | (35) → | 2x60(2 | $(P)) = (5.9 \pm 0.6)\%.$ |

$\chi_{b0}(2P)$ REFERENCES

| LEES | 11 J | PR D84 072002 | J.P. Lees et al. | (BABAR Collab.) |
|----------|------|---------------|------------------------|-------------------|
| ASNER | 08A | PR D78 091103 | D.M. Asner et al. | `(CLEO Collab.) |
| BRIERE | 08 | PR D78 092007 | R.A. Briere et al. | (CLEO Collab.) |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso et al. | (CLEO Collab.) |
| CRAWFORD | 92 B | PL B294 139 | G. Crawford, R. Fulton | (CLEO Collab.) |
| HEINTZ | 92 | PR D46 1928 | U. Heintz et al. | (CÙSB II Collab.) |
| HEINTZ | 91 | PRL 66 1563 | U. Heintz et al. | `(CUSB Collab.) |
| MORRISON | 91 | PRL 67 1696 | R.J. Morrison et al. | (CLEO Collab.) |
| NARAIN | 91 | PRL 66 3113 | M. Narain et al. | (CUSB Collab.) |



$$I^G(J^{PC}) = 0^+(1^{++})$$

J needs confirmation.

Observed in radiative decay of the $\Upsilon(3S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore

$\chi_{b1}(2P)$ MASS

10.25546 \pm 0.00022 \pm 0.00050 OUR EVALUATION From γ energy below, using $\varUpsilon(3S)$ mass $= 10355.2 \pm 0.5 \; \text{MeV}$

$m_{\chi_{b1}(2P)} - m_{\chi_{b0}(2P)}$

| VALUE (MeV) DOCUMENT ID TECN COMMENT | - _{γγ} |
|--------------------------------------|-----------------|
| | |

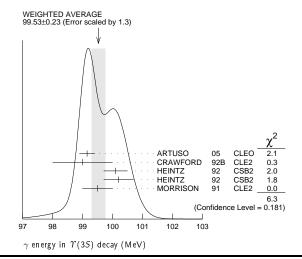
¹ From the average photon energy for inclusive and exclusive events. Supersedes

γ ENERGY IN Υ (3S) DECAY

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|----------|----------------------|---------|-----------|---------------------------------------------------|
| 99.26 ± 0.22 OUR E | VALUATIO | ON Treating system | matic | errors as | correlated |
| 99.53±0.23 OUR A | VERAGE | Error includes scale | e facto | or of 1.3 | . See the ideogram below. |
| $99.15 \pm 0.07 \pm 0.25$ | | ARTUSO | 05 | CLEO | $\Upsilon(3S) \rightarrow \gamma X$ |
| 99 ±1 | 169 | CRAWFORD | 92B | CLE2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| 100.1 ± 0.4 | 11147 | ² HEINT Z | 92 | CSB2 | $e^+e^- \rightarrow \gamma X$ |
| 100.2 ± 0.5 | 223 | ³ HEINT Z | 92 | CSB2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| 99.5 $\pm 0.1 \pm 0.5$ | 25759 | MORRISON | 91 | CLE2 | $e^+ e^- \rightarrow \gamma X$ |

- $^2\mathrm{A}$ systematic uncertainty on the energy scale of 0.9% not included. Supersedes
- NARAIN 91.

 A systematic uncertainty on the energy scale of 0.9% not included. Supersedes



$\chi_{b1}(2P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor |
|----------------|-----------------------------------------------------|--------------------------------|--------------|
| Γ_1 | $\omega \ \varUpsilon(1S)$ | $(1.63 + 0.40 \atop -0.34)\%$ | |
| Γ_2 | $\gamma \ \Upsilon(2S)$ | $(19.9 \pm 1.9)\%$ | |
| | $\gamma \Upsilon(1S)$ | $(9.2 \pm 0.8)\%$ | 1.1 |
| Γ_4 | $\pi\pi\chi_{b1}(1P)$ | $(9.1 \pm 1.3) \times 10^{-3}$ | |
| Γ_5 | D^0X | (8.8 ± 1.7) % | |
| | $\pi^{+}\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | $(3.1 \pm 1.0) \times 10^{-4}$ | |
| Γ_7 | $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | $(1.1 \pm 0.5) \times 10^{-4}$ | |
| Γ ₈ | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | $(7.7 \pm 3.2) \times 10^{-4}$ | |
| Г9 | $2\pi^{+}2\pi^{-}2\pi^{0}$ | $(5.9 \pm 2.0) \times 10^{-4}$ | |
| | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | $(10 \pm 4) \times 10^{-5}$ | |
| | $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | $(5.5 \pm 1.8) \times 10^{-4}$ | |
| | $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | $(10 \pm 4) \times 10^{-4}$ | |
| Γ_{13} | $3\pi^+2\pi^-K^-K^0_S\pi^0$ | $(6.7 \pm 2.6) \times 10^{-4}$ | |
| | $3\pi^{+}3\pi^{-}$ | $(1.2 \pm 0.4) \times 10^{-4}$ | |
| | $3\pi^{+}3\pi^{-}2\pi^{0}$ | $(1.2 \pm 0.4) \times 10^{-3}$ | |
| | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | $(2.0 \pm 0.8) \times 10^{-4}$ | |
| | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | $(6.1 \pm 2.2) \times 10^{-4}$ | |
| | $4\pi^{+}4\pi^{-}$ | $(1.7 \pm 0.6) \times 10^{-4}$ | |
| Γ_{19} | $4\pi^{+}4\pi^{-}2\pi^{0}$ | $(1.9 \pm 0.7) \times 10^{-3}$ | |

$\chi_{b1}(2P)$ BRANCHING RATIOS

| $\Gamma(\omega \Upsilon(1S))/\Gamma_{ m total}$ | | | | | Γ_1/Γ |
|---------------------------------------------------------|---------------------------|---------------------------|--------|----------------------------|------------------------------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | TECN | COMMENT | - |
| $\substack{1.63 + 0.35 + 0.16 \\ - 0.31 - 0.15}$ | $32.6 {}^{+ 6.9}_{- 6.1}$ | ⁴ CRONIN-HEN04 | CLE3 | $\Upsilon(3S) \rightarrow$ | $\gamma \omega \Upsilon(1S)$ |
| 4 Using B($\Upsilon(3S) \rightarrow$ | $\gamma \chi_{b1}(2$ | $P)) = (11.3 \pm 0.6)\%$ | and B(| $\Upsilon(1S) \rightarrow$ | $\ell^+\ell^-) = 2$ |
| $B(\Upsilon(1S) \rightarrow \mu^{+}\mu^{-}$ | -) = 2 (2.4 | 48 ± 0.06)%. | | | |

| $\Gamma(\gamma T(2S))/\Gamma_{total}$ | | | | | | Γ_2/Γ |
|---------------------------------------|------|-----------------------|-----|-------|----------------------------|----------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.199 ± 0.019 OUR AVE | RAGE | | | | | |
| $0.190 \pm 0.018 \pm 0.017$ | 4.3k | ⁵ LEES | 11J | BABR | $\Upsilon(3S) \rightarrow$ | $X \gamma$ |
| $0.356 \pm 0.042 \pm 0.092$ | | ⁶ CRAWFORD | 92B | CLE2 | $e^+e^- \rightarrow$ | $\ell^+\ell^-\gamma\gamma$ |
| $0.199 \pm 0.020 \pm 0.022$ | | 7 HEINTZ | 92 | CSB 2 | $e^+e^- \rightarrow$ | $\ell^+\ell^-\gamma\gamma$ |

 $\chi_{b1}(2P)$

| ⁵ LEES 11J reports $[\Gamma(\chi_{b1}(2P) \rightarrow \gamma \Upsilon(2S))/\Gamma_{total}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b1}(2P))] =$ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $(2.4 \pm 0.1 \pm 0.2) 	imes 10^{-2}$ which we divide by our best value B($\Upsilon(3S) ightarrow \gamma \chi_{b1}(2P)$) |
| $=(12.6\pm1.2)	imes10^{-2}$. Our first error is their experiment's error and our second error |
| is the systematic error from using our best value. |
| $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = 0$ $\theta = $ |

⁶ Using B($\Upsilon(2S) \rightarrow \mu^+ \mu^-$) = (1.37 ± 0.26)%, B($\Upsilon(3S) \rightarrow \gamma \gamma \Upsilon(2S)$)×2 B($\Upsilon(2S) \rightarrow \mu^+ \mu^-$) = (10.23±1.20±1.26)×10^{−4}, and B($\Upsilon(3S) \rightarrow \gamma \chi_{b1}(2P)$) = 0.105 $^+$ 0.003 ± 0.013.

7 Using B($\varUpsilon(2S) \to \mu^+\mu^-$) = (1.44 \pm 0.10)%, B($\varUpsilon(3S) \to \gamma\chi_{b1}(2P)$) = (11.5 \pm 0.5 \pm 0.5)% and assuming $e\mu$ universality. Supersedes HEINTZ 91.

$\Gamma(\gamma \Upsilon(1S))/\Gamma_{\text{total}}$

al

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | |
|-----------------------------|------|-----------------------|--------|---------|----------------------------|-------------------------------|
| 0.092±0.008 OUR AVE | RAGE | Error includes scale | factor | of 1.1. | | |
| $0.098 \pm 0.005 \pm 0.009$ | 15 k | | 11J | BABR | $\Upsilon(3S) \rightarrow$ | $X \gamma$ |
| $0.120 \pm 0.021 \pm 0.021$ | | ⁹ CRAWFORD | 92B | CLE2 | $e^+ e^- \rightarrow$ | $\ell^+\ell^-\gamma\gamma$ |
| $0.080 \pm 0.009 \pm 0.007$ | | ¹⁰ HEINTZ | 92 | CSB2 | $e^+e^- \to$ | $\ell^+ \ell^- \gamma \gamma$ |

<code>8 LEES 11J</code> reports $[\Gamma(\chi_{b1}(2P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(3S) \to \gamma \chi_{b1}(2P))] = (12.4 \pm 0.3 \pm 0.6) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(3S) \to \gamma \chi_{b1}(2P)) = (12.6 \pm 1.2) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

9 Using B(Υ (15) → $\mu^+\mu^-$) = (2.57 ± 0.07)%, B(Υ (35) → $\gamma\gamma$ Υ (15))×2 B(Υ (15) → $\mu^+\mu^-$) = (6.47 ± 1.12 ± 0.82)×10⁻⁴ and B(Υ (35) → $\gamma\chi_{b1}$ (2P)) = 0.105 ± 0.003 ± 0.013

10 0.013. 015. 015. \oplus $\mu^+\mu^-$)=(2.57 \pm 0.07)%, B(Υ (3S) $\to \gamma \chi_{b1}(2P)$) = (11.5 \pm 0.5 \pm 0.5)% and assuming $e \mu$ universality. Supersedes HEINTZ 91.

$\Gamma(\pi\pi\chi_{b1}(1P))/\Gamma_{total}$

 Γ_4/Γ

 Γ_3/Γ

| ,. | | | | | |
|---------------------------------|------|-------------------------|----|------|-----------------------------------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 9.1 ± 1.3 OUR AVERA | \GE | | | | |
| $9.2 \pm 1.1 \pm 0.8$ | 31 k | ¹¹ LEES | | | $e^+ e^- \rightarrow \pi^+ \pi^- X$ |
| $8.6 \pm 2.3 \pm 2.1$ | | ¹² CAWLFIELD | 06 | CLE3 | $\Upsilon(3S) \rightarrow 2(\gamma \pi \ell)$ |

 $\begin{array}{l} 11 \text{ LEES 11c measures B}(\mathcal{T}(3S) \to \chi_{b1}(2P)X) \times \mathrm{B}(\chi_{b1}(2P) \to \chi_{b1}(1P)\,\pi^+\,\pi^-) = \\ (1.16 \pm 0.07 \pm 0.12) \times 10^{-3}. \text{ We derive the value assuming B}(\mathcal{T}(3S) \to \chi_{b1}(2P)X) \\ = \mathrm{B}(\mathcal{T}(3S) \to \chi_{b1}(2P)\gamma) = (12.6 \pm 1.2) \times 10^{-2}. \end{array}$

12 CAWLFIELD 06 quote $\Gamma(\chi_b(2P) \to \pi\pi\chi_b(1P))=0.83\pm0.22\pm0.08\pm0.19$ keV assuming I-spin conservation, no D-wave contribution, $\Gamma(\chi_{b1}(2P))=96\pm16$ keV, and $\Gamma(\chi_{b2}(2P))=138\pm19$ keV.

$\Gamma(D^0X)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-2})EVTSDOCUMENT IDTECNCOMMENT8.8 \pm 1.5 \pm 0.8224313 BRIERE08CLEO $\Upsilon(3S) \rightarrow \gamma D^0 X$

 13 For $p_{D^0} > 2.5 \; {\rm GeV/c.}$

$\Gamma(\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ

VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT

3.1±1.0±0.3 30 14 ASNER 08A CLEO $\Upsilon(3S)$ → $\gamma \pi^+ \pi^- K^+ K^- \pi^0$

 14 ASNER 08a reports $[\Gamma(\chi_{b1}(2P)\to\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{total}]\times[B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(39\pm8\pm9)\times10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^{+}\pi^{-}K^{-}K^{0}_{S})/\Gamma_{total}$ Γ_{7}/Γ

 15 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 2\pi^+\pi^-K^-K^0_S)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(14\pm5\pm3)\times 10^{-6}$ which we divide by our best value B($\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0})/\Gamma_{\text{total}}$

 $\frac{VALUE (units 10^{-4})}{15}$ $\frac{EVTS}{16}$ $\frac{DOCUMENT ID}{16}$ $\frac{TECN}{16}$ $\frac{COMMENT}{15}$ $\frac{COMMENT}{15}$ $\frac{16}{16}$ ASNER 08A CLEO $\frac{1}{16}$ CLEO $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}{16}$ $\frac{1}$

 16 ASNER 08a reports $[\Gamma(\chi_{b1}(2P)\to 2\pi^+\pi^-\kappa^-\kappa^0_S\,2\pi^0)/\Gamma_{total}]\times [\mathrm{B}(\,\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(97\pm30\pm26)\times10^{-6}$ which we divide by our best value B($\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+2\pi^-2\pi^0)/\Gamma_{\text{total}}$

 17 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 2\pi^+\,2\pi^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))]$ = $(74\pm16\pm19)\times10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))$ = $(12.6\pm1.2)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^{+}2\pi^{-}K^{+}K^{-})/\Gamma_{\text{total}}$ Γ_{10}/Γ

 $\frac{VALUE \text{ (units } 10^{-4})}{\textbf{1.0±0.4±0.1}}$ $\frac{EVTS}{12}$ $\frac{DOCUMENT \ ID}{18}$ ASNER 08A CLEO $\frac{COMMENT}{12}$ $\frac{COMMENT}{12}$ $\frac{1}{18}$ ASNER 08A CLEO $\frac{COMMENT}{12}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ ASNER 08A CLEO $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{1}{18}$ $\frac{$

 $^{18} \text{ASNER}$ 08a reports $[\Gamma(\chi_{b1}(2P) \to 2\pi^+ 2\pi^- \, \text{K}^+ \, \text{K}^-)/\Gamma_{\text{total}}] \times [\text{B}(\Upsilon(3S) \to \gamma\chi_{b1}(2P))] = (12 \pm 4 \pm 3) \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S) \to \gamma\chi_{b1}(2P)) = (12.6 \pm 1.2) \times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$

 Γ_{11}/Γ

 $^{19} \text{ASNER 08a reports} \ [\Gamma(\chi_{b1}(2P) \to 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [\text{B(}\Upsilon(3S) \to \gamma\chi_{b1}(2P))] = (69 \pm 13 \pm 17) \times 10^{-6} \ \text{which we divide by our best value B(}\Upsilon(3S) \to \gamma\chi_{b1}(2P)) = (12.6 \pm 1.2) \times 10^{-2}. \ \text{Our first error is their experiment's error and our second error is the systematic error from using our best value.}$

$\Gamma(2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{12}/Γ

<u>VALUE (units 10⁻⁴) EVTS DOCUMENT ID TECN COMMENT</u> **9.6±3.5±0.9** 27 20 ASNER 08A CLEO $T(3S) \rightarrow \gamma 2\pi^{+} 2\pi^{-} K^{+} K^{-} 2\pi^{0}$ 20 ASNER 08A CLEO $T(3S) \rightarrow \gamma 2\pi^{+} 2\pi^{-} K^{+} K^{-} 2\pi^{0}$

 20 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 2\pi^+\,2\pi^-\,\kappa^+\,\kappa^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(121\pm29\pm33)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0})/\Gamma_{\text{total}}$ Γ_{13}/Γ

²¹ ASNER 08A reports $[\Gamma(\chi_{b1}(2P) \to 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{total}] \times [B(\Upsilon(3S) \to \gamma\chi_{b1}(2P))] = (85 \pm 23 \pm 22) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \to \gamma\chi_{b1}(2P)) = (12.6 \pm 1.2) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^{+}3\pi^{-})/\Gamma_{\text{total}}$ Γ_{14}/Γ

VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT $1.2 \pm 0.4 \pm 0.1$ 18 22 ASNER08ACLEO $^{7}(3S) \rightarrow \gamma 3\pi^{+} 3\pi^{-}$

 22 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 3\pi^+3\pi^-)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))]=(15\pm 4\pm 3)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))=(12.6\pm 1.2)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$

 $\Gamma_{15}/$

 23 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 3\pi^+\,3\pi^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))]=(150\pm30\pm40)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \gamma\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{16}/Γ

VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT2.0 ± 0.7 ± 0.216 2^4 A SNER08ACLEO $r(3s) \rightarrow \gamma 3\pi^+ 3\pi^- K^+ K^-$

 24 ASNER 08a reports $[\Gamma(\chi_{b1}(2P)\to 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(25\pm7\pm6)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_{17}/Γ

 25 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))]=(77\pm17\pm21)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(4\pi^+4\pi^-)/\Gamma_{\text{total}}$ Γ_{18}/Γ

VALUE (units 10^{-4})EVTSDOCUMENT IDTECNCOMMENT $1.7 \pm 0.6 \pm 0.2$ 1626 ASNER08ACLEO $\gamma(35) \rightarrow \gamma 4\pi^+ 4\pi^-$

 26 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 4\pi^+\,4\pi^-)/\Gamma_{\rm total}]\times [B(\,\varUpsilon(3S)\to\,\gamma\chi_{b1}(2P))]=(22\pm6\pm5)\times10^{-6}$ which we divide by our best value $B(\,\varUpsilon(3S)\to\,\gamma\chi_{b1}(2P))=(12.6\pm1.2)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(4\pi^+4\pi^-2\pi^0)/\Gamma_{total}$ Γ_{19}/Γ

 27 ASNER 08A reports $[\Gamma(\chi_{b1}(2P)\to 4\pi^+\,4\pi^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \varUpsilon\chi_{b1}(2P))]=(241\pm47\pm72)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \Upsilon\chi_{b1}(2P))=(12.6\pm1.2)\times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\chi_{b1}(2P)$ Cross-Particle Branching Ratios

 $\Gamma\big(\chi_{b1}(2P) \to \gamma \, T(1S)\big) / \Gamma_{\mathsf{total}} \, \times \, \Gamma\big(\, T(3S) \to \gamma \chi_{b1}(2P)\big) / \Gamma_{\mathsf{total}} \\ \Gamma_3 / \Gamma \times \Gamma_{20}^{T(3S)} / \Gamma^{T(3S)}$

VALUE (units 10^{-3})EVTSDOCUMENT IDTECNCOMMENT12.4 \pm 0.3 \pm 0.615kLEES11JBABR $\Upsilon(3S) \rightarrow X \gamma$

| $\Gamma(\chi_{b1}(2P) \to \gamma T($ | 2 <i>S</i>))/Γ _{tot} | $_{\rm al}$ \times $\Gamma(T(3S)$ | $\rightarrow \gamma$ | | $(r))/\Gamma_{\text{total}}$ $(r)^{2}/\Gamma \times \Gamma_{20}^{T(3S)}/\Gamma^{T(3S)}$ | |
|-----------------------------------------|--------------------------------|-------------------------------------|----------------------|----------------|-----------------------------------------------------------------------------------------|---|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 2.4 ± 0.1 ± 0.2 | 4.3k | LEES | 11J | BABR | $\Upsilon(3S) \rightarrow X \gamma$ | |
| $B(\chi_{b1}(2P) \rightarrow \chi_{b1}$ | | | | $\chi_{b1}(2I$ | P)X) | |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $1.16 \pm 0.07 \pm 0.12$ | 31 k | LEES | 110 | BABR | $e^+e^- \rightarrow \pi^+\pi^- X$ | ı |
| $B(\chi_{b2}(2P) \rightarrow pX$ | + <u>¬</u> X)/ | | | | | |
| VALUE | | <u>DO CUMENT ID</u> | | TECN | COMMENT | - |
| $1.109 \pm 0.007 \pm 0.040$ | | BRIERE | 07 | CLEO | $\Upsilon(3S) \rightarrow \gamma \chi_{bJ}(2P)$ | |

$\chi_{b1}(2P)$ REFERENCES

 $B(\chi_{b0}(2P) \rightarrow pX + \overline{p}X)/B(\chi_{b1}(2P) \rightarrow pX + \overline{p}X)$

| LEES | 11 C | PR D84 011104 | IP Lees et al | (BABAR Collab.) |
|------------|------|---------------|---------------------------|-------------------|
| LEES | 11J | PR D84 072002 | IP Lees et al. | (BABAR Collab.) |
| | | | | |
| ASNER | 08A | PR D78 091103 | D.M. Asner et al. | (CLEO Collab.) |
| BRIERE | 08 | PR D78 092007 | R.A. Briere et al. | (CLEO Collab.) |
| BRIERE | 07 | PR D76 012005 | R.A. Briere et al. | (CLEO Collab.) |
| CAWLFIELD | 06 | PR D73 012003 | C. Cawlfield et al. | (CLEO Collab.) |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso et al. | (CLEO Collab.) |
| CRONIN-HEN | . 04 | PRL 92 222002 | D. Cronin-Hennessy et al. | (CLEO Collab.) |
| CRAWFORD | 92 B | PL B294 139 | G. Crawford, R. Fulton | (CLEO Collab.) |
| HEINTZ | 92 | PR D46 1928 | U. Heintz et al. | (CÙSB II Collab.) |
| HEINTZ | 91 | PRL 66 1563 | U. Heintz et al. | (CUSB Collab.) |
| MORRISON | 91 | PRL 67 1696 | R.J. Morrison et al. | (CLEO Collab.) |
| NARAIN | 91 | PRL 66 3113 | M. Narain et al. | (CUSB Collab.) |

$h_b(2P)$

1.082±0.025±0.060

$$I^{G}(J^{PC}) = ??(1 + -)$$

TECN COMMENT

CLEO $\Upsilon(3S)
ightarrow \gamma \chi_{bJ}(2P)$

OMITTED FROM SUMMARY TABLE

Quantum numbers are quark model predictions.

$h_b(2P)$ MASS

| VALUE (GeV) | EVTS | DO CUMENT IL | פ | TECN | COMMENT |
|--------------------------------------------------|-------|--------------|----|------|-------------------------------------------------------------------------------------------|
| $10.2598 \pm 0.0006 {}^{+\ 0.0014}_{-\ 0.0010}$ | 83.9k | ADA CHI | 12 | BELL | $\begin{array}{ccc} 10.86 \ e^+ \ e^- \rightarrow \ \pi^+ \pi^- \\ \text{MM} \end{array}$ |

hb(2P) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----|---------|------------------------------|
| Γı | hadrons | not seen |

hb(2P) BRANCHING RATIOS

| Γ(hadrons |)/Γ _{total} | | | | Γ ₁ /Γ |
|------------|----------------------|-------------|----|------|--------------------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| not seen | 83.9k | ADACHI | 12 | BELL | 10.86 $e^+ e^- \rightarrow \pi^+ \pi^-$ MM |

hb(2P) REFERENCES

| ADACHI | 12 | DDI 109 032001 | I Adachi et al | (DELLE Collab |
|--------|----|----------------|----------------|---------------|



$$I^G(J^{PC}) = 0^+(2^{++})$$

J needs confirmation.

Observed in radiative decay of the $\Upsilon(3S)$, therefore C=+. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore

$\chi_{b2}(2P)$ MASS

VALUE (GeV) DOCUMENT ID

10.26865 \pm 0.00022 \pm 0.00050 OUR EVALUATION From γ energy below, using $\Upsilon(3S)$ $\mathsf{mass} = \overline{10355.2} \pm \overline{0.5} \; \mathsf{MeV}$

 $m_{\chi_{b2}(2P)} - m_{\chi_{b1}(2P)}$

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------------------|-------------|----|------|-----------------------------------------------------------|
| 13.5 ± 0.4 ± 0.5 | 1 HEINTZ | 92 | CSB2 | $e^+e^- \rightarrow \gamma X, \ell^+\ell^- \gamma \gamma$ |

¹ From the average photon energy for inclusive and exclusive events. Supersedes

γ ENERGY IN Υ (3S) DECAY

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|---------------|---------------------|--------|----------|-------------------------------------|
| 86.19±0.22 OUR EVAI | UATION T | reating systematic | errors | as corre | elated |
| 86.40±0.18 OUR AVE | RAGE | | | | |
| $86.04 \pm 0.06 \pm 0.27$ | | ARTUSO | | | $\Upsilon(3S) \rightarrow \gamma X$ |
| 86 ±1 | 101 | CRAWFORD | 92B | CLE2 | $e^+e^{\ell^+\ell^-\gamma\gamma}$ |
| 86.7 ±0.4 | 10319 | ² HEINTZ | 92 | CSB2 | $e^+e^- \rightarrow \gamma X$ |
| 86.9 ±0.4 | 157 | ³ HEINTZ | 92 | CSB2 | $e^+e^{\ell^+\ell^-\gamma\gamma}$ |
| 86.4 ± 0.1 ± 0.4 | 30741 | MORRISON | | | $e^+e^- \rightarrow \gamma X$ |
| ² A systematic unce | rtainty on th | e energy scale of | 0.9% | not i | ncluded. Supersedes |

NARAIN 91.
3 A systematic uncertainty on the energy scale of 0.9% not included. Supersedes HEINTZ 91.

$\chi_{b2}(2P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-----------------------------------------------------|------------------------------|--------------------------|
| Γ ₁ | $\omega \ \Upsilon(1S)$ | $(1.10^{+0.34}_{-0.30})$ | % |
| Γ_2 | $\gamma \Upsilon(2S)$ | (10.6 ±2.6) | % S=2.0 |
| | $\gamma \Upsilon(1S)$ | (7.0 ±0.7) 9 | 6 |
| Γ_4 | $\pi\pi\chi_{b2}(1P)$ | (5.1 ±0.9) > | < 10-3 |
| Γ_5 | D^0X | < 2.4 | 6 CL=90% |
| Γ_6 | $\pi^{+}\pi^{-}\mathit{K}^{+}\mathit{K}^{-}\pi^{0}$ | < 1.1 | <10 ⁻⁴ CL=90% |
| Γ_7 | $2\pi^{+}\pi^{-}K^{-}K^{0}_{S}$ | < 9 | <10 ⁻⁵ CL=90% |
| Γ ₈ | $2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0}$ | < 7 | <10 ⁻⁴ CL=90% |
| Г9 | $2\pi^{+}2\pi^{-}2\pi^{0}$ | (3.9 ±1.6) > | < 10-4 |
| Γ ₁₀ | $2\pi^{+}2\pi^{-}K^{+}K^{-}$ | (9 ±4)> | |
| Γ_{11} | $2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0}$ | (2.4 ±1.1) > | < 10−4 |
| Γ_{12} | $2\pi^{+}2\pi^{-}K^{+}K^{-}2\pi^{0}$ | (4.7 ±2.3) > | < 10 ⁻⁴ |
| Γ_{13} | $3\pi^{+}2\pi^{-}K^{-}K^{0}_{S}\pi^{0}$ | < 4 | <10 ⁻⁴ CL=90% |
| Γ_{14} | $3\pi^{+}3\pi^{-}$ | (9 ±4) > | < 10 ⁻⁵ |
| Γ_{15} | $3\pi^{+} 3\pi^{-} 2\pi^{0}$ | (1.2 ±0.4) > | < 10-3 |
| | $3\pi^{+}3\pi^{-}K^{+}K^{-}$ | (1.4 ±0.7) > | < 10−4 |
| Γ_{17} | $3\pi^{+}3\pi^{-}K^{+}K^{-}\pi^{0}$ | (4.2 ±1.7) > | < 10 ⁻⁴ |
| Γ_{18} | $4\pi^{+}4\pi^{-}$ | (9 ±5) > | < 10 ⁻⁵ |
| Γ_{19} | $4\pi^{+}4\pi^{-}2\pi^{0}$ | (1.3 ± 0.5) | < 10 ⁻³ |

$\chi_{b2}(2P)$ BRANCHING RATIOS

| $\Gamma(\omega \Upsilon(1S))/\Gamma_{total}$ | | | | | Γ_1/Γ |
|----------------------------------------------|------------------------------------|---------------------|--------|----------------------------|------------------------------|
| VALUE (units 10 ⁻²) | EVTS | DO CUMENT ID | TECN | COMMENT | |
| $1.10 {}^{+ 0.32 + 0.11}_{- 0.28 - 0.10}$ | $20.1 {}^{+ 5.8}_{- 5.1}$ | 4 CRONIN-HEN04 | CLE3 | $\Upsilon(3S) \rightarrow$ | $\gamma \omega \Upsilon(1S)$ |
| 4 Using B($\Upsilon(3S)$ $-$ | $\rightarrow \gamma \chi_{b2}(2F)$ | P)) = (11.4 ± 0.8)% | and B(| $\Upsilon(1S) \rightarrow$ | $\ell^+\ell^-) = 2$ |
| $B(\Upsilon(1S) \rightarrow \mu^{+}\mu$ | $\iota^{-}) = 2(2.4)$ | 8 ± 0.06)%. | | | |

$\Gamma(\gamma \Upsilon(2S))/\Gamma_{\text{total}}$ Γ_2/Γ

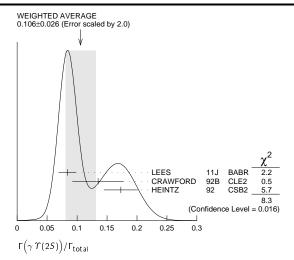
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ightarrow X \gamma$ 6 CRAWFORD 92B CLE2 $e^{+}e^{-}
ightarrow \ell^{+}\ell^{-}$ $0.135 \pm 0.025 \pm 0.035$ ⁷ HEINTZ 92 CSB2 $e^+e^- \rightarrow \ell^+\ell^-\gamma\gamma$ $0.173 \pm 0.021 \pm 0.019$

 5 LEES 11J reports $[\Gamma(\chi_{b2}(2P)\to~\gamma~T(2S))/\Gamma_{total}]\times [B(~T(3S)\to~\gamma\chi_{b2}(2P))]=(1.1\pm0.1\pm0.1)\times 10^{-2}$ which we divide by our best value B($T(3S)\to~\gamma\chi_{b2}(2P))=(13.1\pm1.6)\times 10^{-2}$. Our first error is their experiment's error and our second error

= (13.1 \pm 1.6) × 10 - . Our lists terror is their experiment's error and our second error is the experiment's error from using our best value. 6 Using B($\tau(2S) \rightarrow \mu^+\mu^-$) = (1.37 \pm 0.26)%, B($\tau(3S) \rightarrow \gamma\gamma\tau(2S)$)×2 B($\tau(2S) \rightarrow \mu^+\mu^-$) = (4.98 \pm 0.94 \pm 0.62)×10⁻⁴, and B($\tau(3S) \rightarrow \gamma\chi_{b2}(2P)$) = 0.135 \pm 0.003 \pm 0.017.

0.017. 7 Using B($\Upsilon(2S) oup \mu^\pm \mu^-$) = (1.44 \pm 0.10)%, B($\Upsilon(3S) oup \gamma \chi_{b2}(2P)$) = (11.1 \pm 0.5 \pm 0.4)% and assuming $e\mu$ universality. Supersedes HEINTZ 91.

 $\chi_{b2}(2P)$



| $\Gamma(\gamma \Upsilon(1S))/\Gamma_{total}$ | | | | | Г ₃ /Г |
|----------------------------------------------|-----------------|----------------------------------------------|--------|----------|----------------------------------------------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.070±0.007 OUR AVE | RAGE | | | | |
| $0.070 \pm 0.004 \pm 0.008$ | 11 k | ⁸ LEES | | | $\Upsilon(3S) \rightarrow X \gamma$ |
| $0.072 \pm 0.014 \pm 0.013$ | | | 92B | CLE2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| $0.070 \pm 0.010 \pm 0.006$ | | ¹⁰ HE⊦NTZ | 92 | CSB2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| ⁸ LEES 11J reports [I | $(\chi_{b2}(2)$ | $P) \rightarrow \gamma \Upsilon(1S))/\Gamma$ | total] | × [Β(γ | $\Gamma(3S) \rightarrow \gamma \chi_{b2}(2P))] = B(\Upsilon(3S) \rightarrow \gamma \chi_{b2}(2P))$ |
| $(9.2 \pm 0.3 \pm 0.4) \times$ | 10^{-3} w | hich we divide by o | ur be | st value | $B(\Upsilon(3S) \rightarrow \gamma \chi_{b2}(2P))$ |

= $(13.1\pm1.6)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 9 Using B($r(1S) \rightarrow \mu^+\mu^-$) = $(2.57\pm0.07)\%$, B($r(3S) \rightarrow \gamma\gamma r(2S))\times2$ B($r(1S) \rightarrow \mu^+\mu^-$) = $(5.03\pm0.94\pm0.63)\times10^{-4}$, and B($r(3S) \rightarrow \gamma\chi_{b2}(2P)$) = $0.135\pm0.003\pm0.017$.

10 Using B($\Upsilon(1S) \to \mu^+\mu^-$) = (2.57 ± 0.07)%, B($\Upsilon(3S) \to \gamma \chi_{b2}(2P)$) = (11.1 ± 0.5 ± 0.4)% and assuming $e\mu$ universality. Supersedes HEINTZ 91.

$\Gamma(\pi\pi\chi_{b2}(1P))/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-3}) EVTS DOCUMENT ID TECN COMMENT 5.1±0.9 OUR AVERAGE 4.9±0.7±0.6 17k 11 LEES 11c BABR e^+e^- →

12 CAWLFIELD 06 quote $\Gamma(\chi_b(2P) \to \pi\pi\chi_b(1P))=0.83\pm0.22\pm0.08\pm0.19$ keV assuming I-spin conservation, no *D*-wave contribution, $\Gamma(\chi_{b1}(2P))=96\pm16$ keV, and $\Gamma(\chi_{b2}(2P))=138\pm19$ keV.

 $\Gamma(D^0X)/\Gamma_{total}$ YALUE CL% DOCUMENT ID TECN COMMENT

 $^{13}\,\mathrm{For}~p_{D^{\,0}}~>2.5~\mathrm{GeV/c}.$

¹⁴ The authors also present their result as $(0.2 \pm 1.4 \pm 0.1) \times 10^{-2}$.

$\Gamma(\pi^+\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$

 Γ_6/Γ

 15 ASNER 08A reports $[\Gamma(\chi_{b2}(2P)\to \pi^+\pi^-\kappa^+\kappa^-\pi^0)/\Gamma_{total}]\times [\mathrm{B}(\varUpsilon(3S)\to \Upsilon\chi_{b2}(2P))]<14\times10^{-6}$ which we divide by our best value B($\varUpsilon(3S)\to \Upsilon\chi_{b2}(2P))=13.1\times10^{-2}.$

 $\Gamma(2\pi^{+}\pi^{-}K^{-}K^{0}_{S})/\Gamma_{\text{total}}$ Γ_{7}/Γ

 16 ASNER 08A reports $[\Gamma(\chi_{b2}(2P)\to 2\pi^+\pi^-K^-K^0_5)/\Gamma_{\rm total}]\times [{\rm B}(\Upsilon(3S)\to \gamma\chi_{b2}(2P))]<12\times 10^{-6}$ which we divide by our best value ${\rm B}(\Upsilon(3S)\to \gamma\chi_{b2}(2P))=13.1\times 10^{-2}.$

$\Gamma(2\pi^{+}\pi^{-}K^{-}K_{S}^{0}2\pi^{0})/\Gamma_{\text{total}}$ Γ_{8}/Γ

 $^{17} \text{ASNER}$ 08A reports $[\Gamma(\chi_{b2}(2P) \to 2\pi^+\pi^- K^- K_5^0 \, 2\pi^0)/\Gamma_{\text{total}}] \times [\text{B}(\, \Upsilon(3S) \to \gamma \chi_{b2}(2P))] < 87 \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S) \to \gamma \chi_{b2}(2P)) = 13.1 \times 10^{-2}$.

$\Gamma(2\pi^+2\pi^-2\pi^0)/\Gamma_{\text{total}}$

Γ9/Γ

 18 ASNER 08A reports $[\Gamma\left(\chi_{b2}(2P)\to 2\pi^+\,2\pi^-\,2\pi^0\right)/\Gamma_{total}]\times [B(\Upsilon(3S)\to \gamma\chi_{b2}(2P))]=(51\pm16\pm13)\times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S)\to \gamma\chi_{b2}(2P))=(13.1\pm1.6)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+2\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{10}/Γ

$\Gamma(2\pi^{+}2\pi^{-}K^{+}K^{-}\pi^{0})/\Gamma_{total}$ Γ_{11}/Γ

$\Gamma(2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{12}/Γ

 $\Gamma(3\pi^{+}2\pi^{-}K^{-}K_{S}^{0}\pi^{0})/\Gamma_{\text{total}}$ Γ_{13}/Γ

 22 ASNER 08A reports $[\Gamma(\chi_{b2}(2P)\to 3\pi^+2\pi^-K^-K^0_S\pi^0)/\Gamma_{\rm total}]\times [{\rm B}(\varUpsilon(3S)\to \gamma\chi_{b2}(2P))]<5.8\times10^{-6}$ which we divide by our best value ${\rm B}(\varUpsilon(3S)\to \gamma\chi_{b2}(2P))=13.1\times10^{-2}.$

$\Gamma(3\pi^{+}3\pi^{-})/\Gamma_{\text{total}}$ Γ_{14}/Γ

 23 ASNER 08A reports $[\Gamma(\chi_{b2}(2P)\to 3\pi^+3\pi^-)/\Gamma_{total}]\times [B(\varUpsilon(35)\to \gamma\chi_{b2}(2P))]=(12\pm 4\pm 3)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(35)\to \gamma\chi_{b2}(2P))=(13.1\pm 1.6)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$ Γ_{15}/Γ

 VALUE (units $10^{-4})$ EVTS
 DOCUMENT ID
 TECN
 COMMENT

 12±4±1
 45
 24 ASNER
 08A
 CLEO
 $^{7}(35) \rightarrow ^{7}3\pi^{+}3\pi^{-}2\pi^{0}$

 24 ASNER 08A reports $[\Gamma(\chi_{b2}(2P)\to 3\pi^+\,3\pi^-\,2\pi^0)/\Gamma_{total}]\times [B(\varUpsilon(3S)\to \gamma\chi_{b2}(2P))]=(159\pm33\pm43)\times 10^{-6}$ which we divide by our best value $B(\varUpsilon(3S)\to \gamma\chi_{b2}(2P))=(13.1\pm1.6)\times 10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-)/\Gamma_{\text{total}}$ Γ_{16}/Γ

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ Γ_{17}/Γ

 $\frac{\text{VALUE (units 10^{-4})}}{\textbf{4.2\pm 1.7\pm 0.5}} \underbrace{\text{EVTS}}_{16} \underbrace{\text{DOCUMENT ID}}_{26} \underbrace{\text{ASNER}}_{\text{ASNER}} \underbrace{\text{08A}}_{\text{CLEO}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3\pi^{+} 3\pi^{-} K^{+} K^{-} \pi^{0}} \underbrace{\text{CLEO}}_{\text{T}(3S)} \xrightarrow{\gamma 3$

 $\gamma \chi_{b2}(2P)$] = $(55 \pm 16 \pm 15) \times 10^{-6}$ which we divide by our best value B($\Upsilon(3S) \rightarrow \gamma \chi_{b2}(2P)$) = $(13.1 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(4\pi^+4\pi^-)/\Gamma_{ ext{total}}$ Γ_{18}/Γ

 $27\,\mathrm{ASNER}$ 08A reports $[\Gamma\left(\chi_{b2}(2P)\to 4\pi^+4\pi^-\right)/\Gamma_{\mathrm{total}}]\times[\mathrm{B}(\,\Upsilon(3S)\to\,\gamma\chi_{b2}(2P))]=(12\pm5\pm3)\times10^{-6}$ which we divide by our best value $\mathrm{B}(\,\Upsilon(3S)\to\,\gamma\chi_{b2}(2P))=(13.1\pm1.6)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

Meson Particle Listings $\chi_{b2}(2P)$, $\Upsilon(3S)$

| $(4\pi^+4\pi^-2\pi^0$ |)/r _{total} | | | | | Γ19/Γ |
|-----------------------------------------------|--------------------------------|--------------------------------------------|----------------------|----------------|-----------------------------------------|------------------------------|
| ALUE (units 10 ⁻⁴) 3±5±2 | <u>EVTS</u> 27 | DOCUMENT ID ASNER | 084 C | ECN C | $\Gamma(3S) \rightarrow \gamma 4$ | $_{\pi^{+}4\pi^{-}2\pi^{0}}$ |
| 28 ASNER 08A re | ports [Γ(χ _b ρ(| $2P) \rightarrow 4\pi^{+} 4\pi^{-} 2$ | $\pi^0)/\Gamma_1$ | ·otail× | $[B(\Upsilon(3S) \rightarrow$ | 2Xb2(2P))] |
| $= (165 \pm 46)$ | $\pm 50) \times 10^{-6}$ | which we divide by | our be | st value | $B(\Upsilon(3S) \rightarrow$ | $\gamma \chi_{h2}(2P)$ |
| $= (13.1 \pm 1.6)$ | $(5) \times 10^{-2}$ Ou | ır first error is their | exper | iment's | error and our | second error |
| is the systema | itic error from | using our best valu | ie. | | | |
| | $\chi_{b2}(2P)$ | Cross-Particle E | Branch | ning Ra | itios | |
| $(\chi_{h2}(2P) \rightarrow \cdot$ | γ Υ (1 S))/Γ | $_{\rm total} \times \Gamma(\Upsilon(3S))$ | $\rightarrow \gamma$ | X 62 (2) | P))/Γ _{total} | |
| (ADZ () | , , ,,, | COLAI (C | ' | Т | $_3/\Gamma \times \Gamma_{19}^{\gamma}$ | 35) _{/F} 7(35) |
| ALUE (units 10 ⁻³) | FVTS | DOCUMENT IE | | | COMMENT | ,. |
| .2±0.3±0.4 | 11k | LEES | 111 | BABR | $r(3s) \rightarrow$ | Χγ |
| $(\gamma_{+\alpha}(2P) \rightarrow i$ | ~ T(25))/F | $_{\rm total} \times \Gamma(\Upsilon(3S))$ | ۰ | V+2(2) | P1)/[| |
| (XB2(21)) | , , (2 3)), , | iotal × 1 (7 (55 | , , , | <i>XD2</i> (2. | $r_2/\Gamma \times \Gamma_{19}^{(3)}$ | 35) /r T(35) |
| ALUE (units 10 ⁻²) | EVE | DOCUMENT IS | | | | / ' ' |
| .1±0.1±0.1 | | <u>DO CUMENT ID</u> LEES | 11J | | $r(3S) \rightarrow$ | Χγ |
| $3(\chi_{h2}(2P) \rightarrow$ | $\chi_{b2}(1P)\pi^{\dagger}$ | π^-) × B(Υ (35 | 5) → | Y 62 (2 | P)X) | |
| ALUE (units 10^{-3}) | | DO CUMENT IE | | | | |
| $.64 \pm 0.05 \pm 0.08$ | 17k | LEES | 11€ | BABR | $e^+ e^- \rightarrow$ | $\pi^+\pi^-X$ |
| | | χ _{b2} (2 <i>P</i>) REFEF | RENCE | ES | | |
| EES 11C | PR D84 011104 | | | | (RAR/ | AR Collab.) |
| EES 11J | PR D84 072002 | J.P. Lees et | | | (BABA | AR Collab.) |
| SNER 08A RIERE 08 | PR D78 091103 PR D78 092007 | R.A. Briere e | t al. | | (CLE | O Collab.) O Collab.) |
| AWLFIELD 06 RTUSO 05 | PR D73 012003 PRL 94 032001 | | | | (CLE | O Collab.) O Collab.) |
| RONIN-HEN 04 RAW FORD 92B | PRL 92 222002 PL B294 139 | D. Cronin-He G. Crawford, | | | | EO Collab.) EO Collab.) |
| EINTZ 92 EINTZ 91 | PR D46 1928 PRL 66 1563 | U. Heintz et U. Heintz et | al. | | | II Collab.) SB Collab.) |
| ORRISON 91 ARAIN 91 | PRL 67 1696 PRL 66 3113 | R.J. Morrisor M. Narain et | et al. | | (CLE | EO Collab.) SB Collab.) |
| | T N.C. 00 0220 | | U1. | | (000 | , comut., |
| $\Upsilon(2C)$ | | ıG | ıPC. | \ _ 0: | - ₍₁ ₎ | |
| $\Upsilon(3S)$ | | r | (, |) — 0 | (1) | |
| | | | | | | |
| | | γ (3 S) MA | SS | | | |
| ALUE (GeV) | | DO CUMENT IE | 1 | TECN | COMMENT | |
| 0.3552±0.0005 | 45 - 6-11 | ¹ ARTAMONC | | MD1 | | hadrons |
| | use the follow | ing data for averag 2,3 BARU | | | $e^+e^- \rightarrow$ | |
| 0.3553 ± 0.0005 | DADII 06n ua | ng new electron m | | | | naurons |
| 2 Reanalysis of | | | ass (CC | JHEN 8 | 7). | |
| ³ Superseded by | | | | | | |
| | | $m_{\Upsilon(3S)}-m$ | r(25) | | | |
| ALUE (MaV) | | ` ' | ` ' | TECN | COMMENT | |
| <i>ALUE</i> (MeV) 3 31.50±0.02±0. 3 | 13 | DOCUMENT IE LEES | | | $e^+e^- \rightarrow$ | $\pi^+\pi^-\chi$ |
| | | | | | ' | |
| | | r(3 s) WID | TH | | | |
| | | | | | | |

| Mode | Fraction (Γ_i/Γ) | Scale factor/ Confidence level |
|-------------------------------------------|------------------------------|-----------------------------------|
| \varUpsilon (2 S) anything | (10.6 ±0.8) | % |
| $\Upsilon(2S)\pi^+\pi^-$ | (2.82 ± 0.18) | % S=1.6 |
| $\Upsilon(2S)\pi^0\pi^0$ | (1.85 ± 0.14) | % |
| $\Upsilon(2S)\gamma\gamma$ | (5.0 ± 0.7) | % |
| $\Upsilon(2S)\pi^0$ | < 5.1 | ×10 ⁻⁴ CL=90% |
| $\Upsilon(1S)\pi^+\pi^-$ | (4.37±0.08) | % |
| $\Upsilon(1S) \pi^0 \pi^0$ | $(2.20\pm0.13)^{\circ}$ | % |
| $\Upsilon(1S)\eta$ | < 1 | ×10 ⁻⁴ CL=90% |
| $\Upsilon(1S) \pi^0$ | < 7 | ×10 ⁻⁵ CL=90% |
| $h_b(1P) \pi^0$ | < 1.2 | $\times 10^{-3}$ CL=90% |
| $h_b(1P)\pi^0 \to \gamma \eta_b(1S)\pi^0$ | (4.3 ± 1.4): | × 10 ⁻⁴ |

 τ (3s) DECAY MODES

Γ₁ Γ₂ Γ₃ Γ₄ Γ₅ Γ₆ Γ₇ Γ₈ Γ₁₀ Γ₁₁

| | $h_b(1P) \pi^+ \pi^-$ | | < 1.2 | $\times 10^{-4}$ | CL=90% |
|-----------------|-------------------------------------------------------|-----------|-------------------------|----------------------|---------|
| Γ_{13} | $\tau^+\tau^-$ | | (2.29±0. | .30) % | |
| Γ ₁₄ | $\mu^{+} \mu^{-}$ | | (2.18±0 | .21) % | S=2.1 |
| Γ ₁₅ | e^+e^- | | seen | | |
| | hadrons | | | | |
| 10 | ggg | | (35.7 ±2 | .6) % | |
| _ | γgg | | | $(8) \times 10^{-3}$ | |
| 10 | | | , | , | |
| | | Radiative | decays | | |
| Γ_{19} | $\gamma \chi_{b2}(2P)$ | | (13.1 ±1 | .6) % | S=3.4 |
| Γ_{20} | $\gamma \chi_{b1}(2P)$ | | (12.6 ± 1) | .2) % | S = 2.4 |
| Γ_{21} | $\gamma \chi_{b0}(2P)$ | | (5.9 ± 0.0) | .6) % | S=1.4 |
| | $\gamma \chi_{b2}(1P)$ | | (9.9 ±1 | $3) \times 10^{-3}$ | S=2.0 |
| Γ_{23} | $\gamma A^0 \rightarrow \gamma$ hadrons | | < 8 | $\times 10^{-5}$ | CL=90% |
| | $\gamma \chi_{b1}(1P)$ | | (9 ±5 | $) \times 10^{-4}$ | S=1.9 |
| Γ ₂₅ | $\gamma \chi_{b0}(1P)$ | | | $4) \times 10^{-3}$ | |
| | $\gamma \eta_b(2S)$ | | | ×10 ⁻⁴ | CL=90% |
| | $\gamma \eta_b(1S)$ | | (5.1 ±0 | $(7) \times 10^{-4}$ | |
| | $\gamma X \rightarrow \gamma + \geq 4 \text{ prongs}$ | | [a] < 2.2 | | CL=95% |
| | $\gamma a_1^0 \rightarrow \gamma \tau^+ \tau^-$ | | [b] < 1.6 | | CL=90% |
| 2, | 1 | | | | |
| | | number | (<i>LF</i>) violating | | |
| Γ_{30} | $e^{\pm}	au^{\mp}$ | LF | < 4.2 | $\times 10^{-6}$ | CL=90% |
| Γ_{31} | $\mu^{\pm}\tau^{\mp}$ | LF | < 3.1 | $\times 10^{-6}$ | CL=90% |
| | | | | | |
| [a | $[1.5 \; { m GeV} < m_X < 5.0 \; { m GeV}]$ | eV | | | |
| [h | For $m_{	au^+	au^-}$ in the ranges | 5 4 03-9 | 52 and 9 61-10 | 10 GeV | |
| [D | $_{1}$ $_{	au^{+}\tau^{-}}$ the range. | | 52 GHG 5.01 10 | | |

$\Upsilon(3S) \Gamma(i)\Gamma(e^+e^-)/\Gamma(total)$

| $\Gamma(\text{hadrons}) \times \Gamma(e^+e^-)$ | -)/Γ _{total} | | | Γ ₁₆ Γ ₁₅ /Γ |
|------------------------------------------------|-----------------------|-------|----------|------------------------------------|
| VALUE (keV) | DO CUMENT IL |) | TECN | COMMENT |
| 0.414±0.007 OUR AVERA | GE | | | |
| $0.413 \pm 0.004 \pm 0.006$ | ROSNER | 06 | CLEO | 10.4 $e^+e^- ightarrow hadrons$ |
| $0.45 \pm 0.03 \pm 0.03$ | ⁴ GILES | 84B | CLEO | $e^+e^- ightarrow $ hadrons |
| ⁴ Radiative corrections re | evaluated by BUCHI | MUELL | ER 88 fo | ollowing KURAEV 85. |

| $\Gamma(\Upsilon(1S)\pi^+\pi^-)$ | × Γ(e ⁺ | [⊢] e−)/Γ _{total} | | Γ ₆ Γ ₁₅ /Γ |
|----------------------------------------------|---------------------------------|-------------------------------------|---------------------|-----------------------------------------------------|
| VALUE (eV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 18.46±0.27±0.77 | 6.4K | ⁵ AUBERT | 08BP BABR | $e^+e^- \rightarrow \ \gamma\pi^+\pi^-\ell^+\ell^-$ |
| ⁵ Using B(Υ(1 <i>S</i>) 0.05)%. | → e ⁺ e ⁻ | _) = (2.38 ± 0.11) | % and B(γ (| $1S) \rightarrow \mu^{+}\mu^{-}) = (2.48 \pm$ |

τ (35) PARTIAL WIDTHS

| $\Gamma(e^+ e^-)$ | | Γ ₁₅ |
|----------------------------|--------------|-----------------|
| VALUE (keV) | DO CUMENT ID | |
| 0.443±0.008 OUR EVALUATION | | |

au(3s) Branching ratios

| $\Gamma(\Upsilon(2S))$ a nyt | $hing)/\Gamma_{total}$ | | | | Γ_1/Γ | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|-----------------------------------|----------|-----------------|---------------------------------------------------|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.106 ±0.008 | OUR AVERAG | GE . | | | | |
| 0.1023 ± 0.0105 | 4625 | ^{6,7,8} BUTLER | 94B | CLE2 | $e^+e^- \rightarrow \ell^+\ell^- X$ | |
| 0.111 ± 0.012 | 4891 | ^{7,8,9} BROCK | 91 | CLEO | $e^+e^- \rightarrow \pi^+\pi^-X$, | |
| | | | | | $\pi^{+} \pi^{-} \ell^{+} \ell^{-}$ | |
| 6 Using B(Υ (2 | $2S) \rightarrow \Upsilon(1S)$ | $\gamma\gamma) = (0.038 \pm 0.09$ | 07)%, a | and B(γ | $\gamma(2S) \rightarrow \gamma(1S) \pi^0 \pi^0 =$ | |
| (1/2)B(\(\gamma(2) | $S) \rightarrow \Upsilon(1S)$ | $\pi^{+}\pi^{-}$). | | | | |
| | | | | | mption of $e\mu$ universality. | |
| 8 Using B($\Upsilon(2S) \to \Upsilon(1S) \pi^+ \pi^-$) = (18.5 ± 0.8)%. | | | | | | |
| ⁹ Using B($\Upsilon(2S) \rightarrow \mu^+ \mu^-$) = (1.31 ± 0.21)%, B($\Upsilon(2S) \rightarrow \Upsilon(1S) \gamma \gamma$)×2B($\Upsilon(1S) \rightarrow$ | | | | | | |
| $\mu^{+} \mu^{-}) = (0.188 \pm 0.035)\%$, and B($\Upsilon(2S) \rightarrow \Upsilon(1S) \pi^{0} \pi^{0}) \times 2B(\Upsilon(1S) \rightarrow \mu^{+} \mu^{-})$ | | | | | | |
| = (0.436 + | 0.056)%. Wit | h the assumption of | e u univ | versality. | | |

| $I(I(25)\pi'\pi)/$ | total | | | | 12/1 |
|----------------------------------|------------|-------------------------|---------|------------|------------------------------------------------------|
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT I | D | TECN | COMMENT |
| 2.82±0.18 OUR AVE | RAGE E | rror includes scale | e facto | or of 1.6 | . See the ideogram below. |
| $3.00 \pm 0.02 \pm 0.14$ | 543k | LEES | 11 € | BABR | $e^+ e^- \rightarrow \pi^+ \pi^- X$ |
| $2.40 \pm 0.10 \pm 0.26$ | 800 | ¹⁰ AUBERT | | | $e^+e^- \rightarrow \gamma \pi^+\pi^-e^+e^-$ |
| 3.12 ± 0.49 | 980 | ^{11,12} BUTLER | 94B | CLE2 | $e^+ e^- \rightarrow \pi^+ \pi^- \ell^+ \ell^-$ |
| 2.13 ± 0.38 | 974 | ¹³ BROCK | 91 | CLEO | $e^+ e^- \rightarrow \pi^+ \pi^- X$, |
| | | | | | $\pi^{+} \pi^{-} \ell^{+} \ell^{-}$ |
| • • • We do not use | the follow | ving data for aver | ages, | fits, limi | ts, etc. • • • |
| $4.82 \!\pm\! 0.65 \!\pm\! 0.53$ | 138 | ¹³ WU | | | $\Upsilon(3S) \rightarrow \pi^+ \pi^- \ell^+ \ell^-$ |
| 3.1 + 2.0 | 5 | MAGERAS | 82 | CUSB | $\Upsilon(3S) \rightarrow \pi^+ \pi^- \ell^+ \ell^-$ |

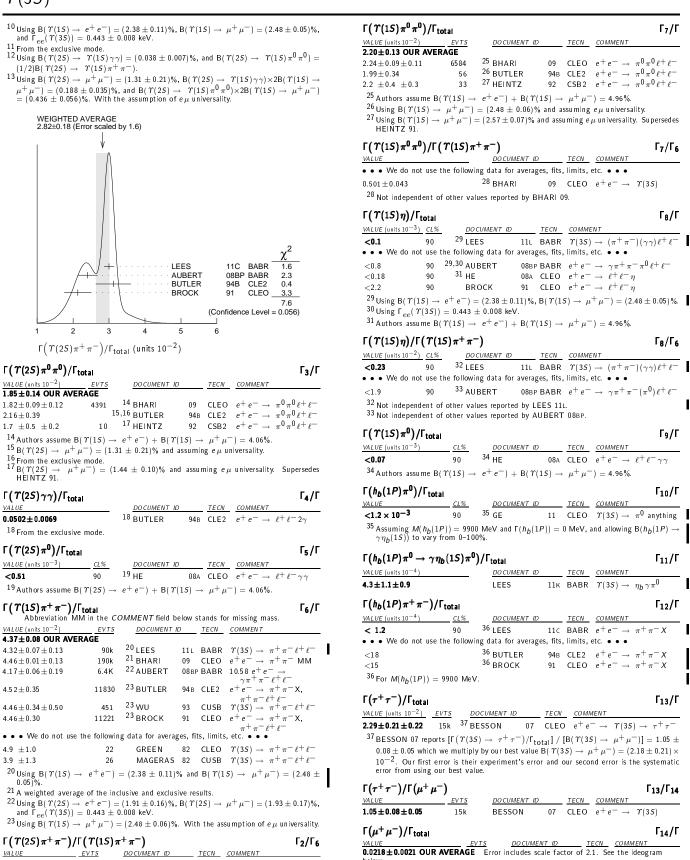
• • • We do not use the following data for averages, fits, limits, etc. • • •

0.577 \pm 0.026 \pm 0.060 800 ²⁴ AUBERT 08BP BABR $e^+e^- \to \gamma \pi^+ \pi^- \ell^+ \ell^-$

24 Using B($\Upsilon(1S) \rightarrow e^+ e^-) = (2.38 \pm 0.11)\%$, B($\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.48 \pm 0.05)\%$,

 $B(T(25) \to e^+e^-) = (1.91 \pm 0.16)\%$, and $B(T(25) \to \mu^+\mu^-) = (1.93 \pm 0.17)\%$. Not independent of other values reported by AUBERT 08BP.

$\Upsilon(3S)$



 $0.0239 \pm 0.0007 \pm 0.0010$

 $0.0202 \pm 0.0019 \pm 0.0033$

 $0.0173 \pm 0.0015 \pm 0.0011$

 $0.033 \pm 0.013 \pm 0.007$

 Γ_7/Γ

 Γ_7/Γ_6

 Γ_8/Γ

 Γ_8/Γ_6

 Γ_9/Γ

 Γ_{11}/Γ

 Γ_{12}/Γ

 Γ_{13}/Γ

 Γ_{13}/Γ_{14}

CLEO $e^+e^- \rightarrow \mu^+\mu^-$

89B CLEO $e^+e^- \rightarrow \mu^+\mu^-$

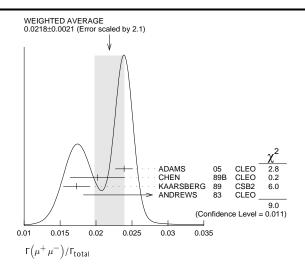
KAARSBERG 89 CSB2 $e^+e^- \rightarrow \mu^+\mu^-$

ANDREWS 83 CLEO $e^+e^- \rightarrow \mu^+\mu^-$

ADAMS

CHEN

1096



| $\Gamma(ggg)/\Gamma_{\text{total}}$ | | | | | Γ ₁₇ /Γ |
|-------------------------------------|------|--------------|-----|------|---------------------------|
| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 35.7±2.6 | 3 M | 38 BESSON | 06A | CLEO | $\Upsilon(3S) 	o hadrons$ |

 38 Calculated using BESSON 06A value of $\Gamma(\gamma g g)/\Gamma(g g g)=(2.72\pm0.06\pm0.32\pm0.37)\%$ and the PDG 08 values of B($\Upsilon(25)$ + anything) = (10.6 \pm 0.8)%, B($\pi^+\pi^ \Upsilon(15)$) = (4.40 \pm 0.10)%, B($\pi^0\pi^0$ $\Upsilon(15)$) = (2.20 \pm 0.13)%, B($\gamma\chi_{b2}(2P)$) = (13.1 \pm 1.6)%, B($\gamma\chi_{b1}(2P)$) = (12.6 \pm 1.2)%, B($\gamma\chi_{b0}(2P)$) = (5.9 \pm 0.6)%, B($\gamma\chi_{b0}(1P)$) = (0.30 \pm 0.11)% ,B($\mu^+\mu^-$) = (2.18 \pm 0.21)%, and R_{hadrons} = 3.51. The statistical error is negligible and the systematic error is partially correlated with $\Gamma(\gamma g\,g)/\Gamma_{\rm total}$ BESSON 06A value.

 $\Gamma(\gamma g g)/\Gamma_{\text{total}}$ Γ_{18}/Γ

| VALUE (units 10^{-2}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|----------------------|-----|------|------------------------------------------------|
| 0.97±0.18 | 60k | ³⁹ BESSON | 06A | CLEO | $\gamma(3S) ightarrow \gamma + {\sf hadrons}$ |

 39 Calculated using BESSON 06A values of $\Gamma(\gamma g\,g)/\Gamma(g\,g\,g)=(2.72\pm0.06\pm0.32\pm0.37)\%$ and $\Gamma(g\,g\,g)/\Gamma_{total}$. The statistical error is negligible and the systematic error is partially correlated with $\Gamma(g\,g\,g)/\Gamma_{total}$ BESSON 06A value.

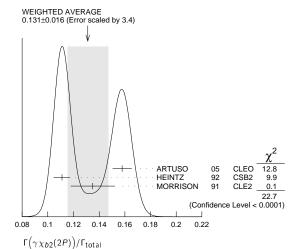
$\Gamma(\gamma g g)/\Gamma(g g g)$

 Γ_{18}/Γ_{17} VALUE (units 10^{-2}) DOCUMENT ID TECN COMMENT $2.72 \pm 0.06 \pm 0.49$ 06A CLEO $\Upsilon(3S)
ightarrow (\gamma +)$ hadrons

 $\Gamma(\gamma \chi_{b2}(2P))/\Gamma_{total}$ Γ_{19}/Γ

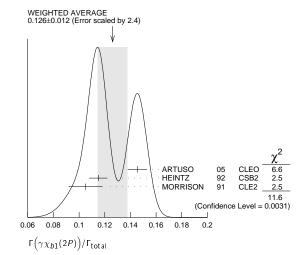
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-------|----------------------|---------|----------|--------------------------------|
| 0.131 ±0.016 OUR AVERAGE | Error | includes scale fact | or of 3 | 3.4. See | the ideogram |
| below. | | | | | · · |
| $0.1579 \pm 0.0017 \pm 0.0073$ | 568k | ARTUSO | 05 | CLEO | $e^+e^- \rightarrow \gamma X$ |
| $0.111 \pm 0.005 \pm 0.004$ | 10319 | ⁴⁰ HEINTZ | 92 | CSB2 | $e^+ e^- \rightarrow \gamma X$ |
| $0.135 \pm 0.003 \pm 0.017$ | 30741 | MORRISON | 91 | CLE2 | $e^+e^- \rightarrow \gamma X$ |

⁴⁰ Supersedes NARAIN 91.



| $\Gamma(\gamma \chi_{b1}(2P))/\Gamma_{total}$ | | | | | Γ_{20}/Γ |
|-----------------------------------------------|-----------------|----------------------|-------|----------|----------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.126 ±0.012 OUR AVERAGE below. | GE Error | includes scale fact | or of | 2.4. See | the ideogram |
| $0.1454 \pm 0.0018 \pm 0.0073$ | 537k | ARTUSO | 05 | CLEO | $e^+e^- \rightarrow \gamma X$ |
| $0.115\ \pm0.005\ \pm0.005$ | 11147 | ⁴¹ HEINTZ | 92 | CSB 2 | $e^+ e^- ightarrow \gamma {\sf X}$ |
| $0.105 \ ^{+}_{-}0.003 \ \pm 0.013$ | 25 75 9 | MORRISON | 91 | CLE2 | $e^+e^- \to \ \gamma {\rm X}$ |
| 44 | | | | | |

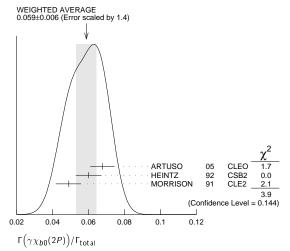
⁴¹ Supersedes NARAIN 91.



| $\Gamma(\gamma \chi_{b0}(2P))$ | $/\Gamma_{total}$ | | | | | Γ ₂₁ /Γ |
|--------------------------------|-------------------|-----------|----------------------|-------|----------|--------------------------------|
| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.059 ± 0.006 | OUR AVERA | AGE Error | includes scale fact | or of | 1.4. See | the ideogram |
| below. | | | | | | ŭ |
| 0.0677 ± 0.0020 | ± 0.0065 | 225 k | ARTUSO | 05 | CLEO | $e^+e^- \rightarrow \gamma X$ |
| 0.060 ± 0.004 | ±0.006 | 4959 | ⁴² HEINTZ | 92 | CSB 2 | $e^+ e^- \rightarrow \gamma X$ |
| 0.049 + 0.003 | ± 0.006 | 9903 | MORRISON | 91 | CLE2 | $e^+ e^- \rightarrow \gamma X$ |

⁴² Supersedes NARAIN 91.

 7.15×10^{-2}



| $\Gamma(\gamma \chi_{b2}(1P))/$ | Γ _{total} | | | | Γ ₂₂ /Γ |
|--------------------------------------------------------------------------------------------------------------|---------------------------------------|----------------------------------------|--------------------|-----------------------------|-------------------------------------------------------|
| VALUE (units 10^{-3}) | CL% EVTS | DO CUMENT ID | | TECN | COMMENT |
| 9.9±1.3 OUR | AVERAGE E | rror includes scale | factor | of 2.0. | |
| $7.5\pm 1.2\pm 0.5$ | 126 ⁴³ | ^{3,44} KORNICER | 11 | CLEO | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| $10.5 \pm 0.3 ^{+0.7}_{-0.6}$ | 9.7k | LEES | 11J | BABR | $\Upsilon(3S) \rightarrow X \gamma$ |
| | use the following | ng data for average | es, fits | , limits, | etc. • • • |
| <19 | 90 | ⁴⁵ ASNER | | | $\Upsilon(3S) \rightarrow \gamma + \text{hadrons}$ |
| seen | | ⁴⁶ HEINTZ | 92 | CSB2 | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| 43 Assuming B(7 | $r(1S) \rightarrow \ell^{+} \ell^{-}$ | $^{-}) = (2.48 \pm 0.05)$ |)%. | | |
| 44 KORNICER 1 | 1 reports [$\Gamma(\Upsilon)$ | $3S) \rightarrow \gamma \chi_{h2}(1P)$ |))/Γ _{to} | $ \times _{\text{let}}$ | $B(\chi_{h2}(1P) \to \gamma \Upsilon(1S))]$ |
| | | | | | best value $B(\chi_{h2}(1P) \rightarrow$ |
| $\gamma \Upsilon(1S)) = (19.1 \pm 1.2) 	imes 10^{-2}$. Our first error is their experiment's error and our | | | | | |
| second error is the systematic error from using our best value. | | | | | |
| 45 ASNER 08A r | eports [$\Gamma(\Upsilon(3))$ | $(5) \rightarrow \gamma \chi_{b2}(1P)$ |)/r _{tot} | _{al}] / [B | $\{(\Upsilon(2S) \rightarrow \gamma \chi_{b2}(1P))\}$ |
| | $^{-2}$ which we | multiply by our b | est va | lue B(7 | $\gamma(2S) \rightarrow \gamma \chi_{b2}(1P) =$ |
| 7 15 10-2 | | | | | |

VALUE (units 10^{-6})

Meson Particle Listings

 $\Upsilon(3S)$, $\chi_b(3P)$, $\Upsilon(4S)$

| 46 HEINTZ 92, while unable to distinguish between different J states, measures $\sum_J \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \!$ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $r(1S) \rightarrow \ell^+\ell^-$ |
| $\Gamma(\gamma\chi_{b1}(1P))/\Gamma_{total}$ VALUE (units 10 ⁻³) CL% EVTS DOCUMENT ID TECN COMMENT |
| 0.9 \pm 0.5 OUR AVERAGE Error includes scale factor of 1.9. 1.6 \pm 0.5 \pm 0.1 50 47,48 KORNICER 11 CLEO $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| $0.5\pm0.3^{+}0.2 \atop -0.1$ LEES 11J BABR $\Upsilon(3S) \to X\gamma$ • • • We do not use the following data for averages, fits, limits, etc. • • • |
| (1.7 90 $\stackrel{49}{\sim}$ ASNER 08A CLEO $\gamma(35) \rightarrow \gamma+$ hadrons seen 50 HEINTZ 92 CSB2 $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$ |
| 47 Assuming B($\Upsilon(1S) \rightarrow \ell^+\ell^-) = (2.48 \pm 0.05)\%.$ 48 KORNICER 11 reports [$\Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b1}(1P))/\Gamma_{total}] \times [B(\chi_{b1}(1P) \rightarrow \gamma \Upsilon(1S))] = (5.38 \pm 1.20 \pm 0.95) \times 10^{-4}$ which we divide by our best value B($\chi_{b1}(1P) \rightarrow \gamma \Upsilon(1S)) = (33.9 \pm 2.2) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. 49 ASNER 08a reports [$\Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b1}(1P))/\Gamma_{total}] / [B(\Upsilon(2S) \rightarrow \gamma \chi_{b1}(1P))] < 0.0000000000000000000000000000000000$ |
| 2.5×10^{-2} which we multiply by our best value B($\Upsilon(25)\to \gamma\chi_{B1}(1P))=6.9\times 10^{-2}.$ 50 HEINTZ 92, while unable to distinguish between different J states, measures $\sum_J \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \! \!$ |
| $\Gamma(\gamma\chi_{b0}(1P))/\Gamma_{total}$ Γ_{25}/Γ VALUE (units 10^{-2}) CL% EVTS DOCUMENT ID TECN COMMENT |
| 0.27 ± 0.04 OUR AVERAGE 0.27 ± 0.04 ± 0.02 |
| 51 ASNER 08A reports $[\Gamma(\Upsilon(3S)\to \gamma\chi_{b0}(1P))/\Gamma_{\rm total}]$ / $[{\rm B}(\Upsilon(2S)\to \gamma\chi_{b0}(1P))]$ $<21.9\times 10^{-2}$ which we multiply by our best value ${\rm B}(\Upsilon(2S)\to \gamma\chi_{b0}(1P))=3.8\times 10^{-2}.$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| < 6.2 90 ARTUSO 05 CLEO $e^+e^- \rightarrow \gamma X$ • • • We do not use the following data for averages, fits, limits, etc. • • • <19 90 LEES 11J BABR $\Upsilon(3S) \rightarrow X \gamma$ |
| $\Gamma(\gamma\eta_b(1S))/\Gamma_{	ext{total}}$ $\Gamma_{27}/\Gamma_{	ext{VALUE (units }10^{-4})}$ CL% EVTS DOCUMENT ID TECN COMMENT |
| 5.1±0.7 OUR AVERÂGE 7.1±1.8±1.3 2.3±0.5k $ \begin{array}{cccccccccccccccccccccccccccccccccc$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $<8.5 \qquad 90 \qquad \text{LEES} \qquad 111 \text{BABR} \varUpsilon(3S) \to X\gamma \\ 4.8 \pm 0.5 \pm 1.2 \qquad 19 \pm 3k ^{52,53} \text{AUBERT} \qquad 08v \text{BABR} \varUpsilon(3S) \to \gamma X \\ <4.3 \qquad 90 \qquad ^{54} \text{ARTUSO} \qquad 05 \text{CLEO} e^+e^- \to \gamma X$ |
| $^{52} \rm Assuming~\Gamma_{\eta_b(1S)}=10~MeV.$ $^{53} \rm Systematic~error~re-evaluated~by~AUBERT~09AQ.$ $^{54} \rm Superseded~by~BONVICINI~10.$ |
| $ \begin{array}{c} \Gamma \left(\gamma X \rightarrow \gamma + \geq \text{4 prongs} \right) / \Gamma_{\text{total}} \\ \text{(1.5 GeV} < m_X < \text{5.0 GeV}) \end{array} $ |
| VALUE (units 10^{-4})CL%DOCUMENT IDTECNCOMMENT<2.2 |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 55 For a narrow scalar or pseudoscalar $a_1^{\rm U}$ with ${\rm M}(\tau^+\tau^-)$ in the ranges 4.03–9.52 and 9.61–10.10 GeV. Measured 90% CL limits as a function of ${\rm M}(\tau^+\tau^-)$ range from 1.5 –16 \times 10 $^{-5}$. |
| $ \begin{array}{c cccc} \Gamma(\gamma A^0 \to \gamma \text{hadrons})/\Gamma_{\text{total}} & \Gamma_{23}/\Gamma \\ \text{(0.3 GeV} < m_{A^0} < 7 \text{ GeV}) & \\ \hline \text{VALUE} & \text{CL}\% & DOCUMENT ID} & \text{TECN} & COMMENT \\ \end{array} $ |
| <8 × 10⁻⁵ 90 ⁵⁶ LEES 11H BABR $\Upsilon(3S) \rightarrow \gamma$ hadrons |
| 56 For a narrow scalar or pseudoscalar A^0 , excluding known resonances, with mass in the range 0.3–7 GeV. Measured 90% CL limits as a function of m_{A^0} range from 1×10^{-6} to 8×10^{-5} . |
| LEPTON FAMILY NUMBER (LF) VIOLATING MODES |
| $\Gamma(e^{\pm}\tau^{\mp})/\Gamma_{	ext{total}}$ VALUE (with 10 ⁻⁶) CL% DOCUMENT ID TECH COMMENT |

DOCUMENT ID

LEES

TECN COMMENT 10B BABR $e^+\,e^ightarrow\,e^\pm \overline{ au^\mp}$

| $\Gamma(\mu^{\pm}\tau^{\mp})$ VALUE (units | | al | DO CUMENT ID | | TECN | Г 31 | /г |
|--------------------------------------------|------------|--------------------------------|----------------------------------|----------|---------|------------------------------------------|----|
| < 3.1 | | 90 | LEES | | | $e^+e^- ightarrow \mu^{\pm} 	au^{\mp}$ | |
| • • • vve | do not | use the following | data for average | s, fits, | ilmits, | etc. • • • | |
| <20.3 | | 95 | LOVE | 08A | CLEO | $e^+e^- \rightarrow \mu^{\pm}\tau^{\mp}$ | |
| | | r | (3S) REFERE | NCE | 5 | | |
| GE | 11 | PR D84 032008 | J.Y. Ge et al. | | | (CLEO Collab.) | |
| KORNICER LEES | 11 11 C | PR D83 054003 PR D84 011104 | M. Kornicer et J.P. Lees et a | | | (CLEO Collab.) (BABAR Collab.) | |
| LEES | 11H | PRI 107 221803 | J.P. Lees et al | | | (BABAR Collab.) | |
| LEES | 11J | PR D84 072002 | J.P. Lees et al | | | (BABAR Collab.) | |
| LEES | 11K | PR D84 091101 | J.P. Lees et a | | | (BABAR Collab.) | |
| LEES | 11 L | PR D84 092003 | J.P. Lees et a | | | (BABAR Collab.) | |
| BONVICINI | 10 | PR D81 031104R | G. Bonvicini e | | | (CLEO Collab.) | |
| LEES | 10 B | PRL 104 151802 | J.P. Lees et a | | | (BABAR Collab.) | |
| AUBERT | | PRL 103 161801 | B. Aubert et . | | | (BABAR Collab.) | |
| AUBERT | 09P | PRL 103 181801 | B. Aubert et . | al. | | (BABAR Collab.) | |

| KORNICER | 11 | PR D83 054003 | M. Kornicer et al. | (CLEO Collab.) |
|-------------|------|---------------------------|---------------------------------------------------------------------------|--------------------|
| LEES | 11 C | PR D84 011104 | J.P. Lees et al. | (BABAR Collab.) |
| LEES | 11H | PRL 107 221803 | J.P. Lees et al. | (BABAR Collab.) |
| LEES | 11 J | PR D84 072002 | J.P. Lees et al. | (BABAR Collab.) |
| LEES | 11K | PR D84 091101 | J.P. Lees et al. | (BABAR Collab.) |
| LEES | 11L | PR D84 092003 | J.P. Lees et al. | (BABAR Collab.) |
| BONVICINI | 10 | PR D81 031104R | G. Bonvicini et al. | `(CLEO Collab.) |
| LEES | 10 B | PRL 104 151802 | J.P. Lees et al. | (BABAR Collab.) |
| AUBERT | 09AQ | PRL 103 161801 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 09P | PRL 103 181801 | B. Aubert et al. | (BABAR Collab.) |
| BHARI | 09 | PR D79 011103 | S.R. Bhari et al. | (CLEO Collab.) |
| ASNER | 08A | | D.M. Asner et al. | (CLEO Collab.) |
| AUBERT | 08BP | PR D78 112002 | B. Aubert et al. | (BABAR Collab.) |
| AUBERT | 08V | | B. Aubert et al. | (BABAR Collab.) |
| HE | 08A | PRL 101 192001 | Q. He et al. | `(CLEO Collab.) |
| LOVE | 08A | PRL 101 201601 | W. Love et al. | (CLEO Collab.) |
| PDG | 80 | PL B667 1 | C. Amsler et al. | `(PDG Collab.) |
| BESSON | 07 | PRL 98 052002 | D. Besson et al. | (ČLEO Collab.) |
| ROSNER | 07 A | PR D76 117102 | J.L. Rosner et al. | (CLEO Collab.) |
| BESSON | 06A | PR D74 012003 | D. Besson et al. | (CLEO Collab.) |
| ROSNER | 06 | PRL 96 092003 | J.L. Rosner et al. | (CLEO Collab.) |
| ADAMS | 05 | PRL 94 012001 | G.S. Adams et al. | (CLEO Collab.) |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso et al. | (CLEO Collab.) |
| ARTAM ON OV | | PL B474 427 | A.S. Artamonov et al. | * |
| BUTLER | 94 B | PR D49 40 | F. Butler et al. | (CLEO Collab.) |
| WU | 93 | PL B301 307 | Q.W. Wu et al. | (CUSB Collab.) |
| HEINTZ | 92 | PR D46 1928 | U. Heintz et al. I.C. Brock et al. U. Heintz et al. R. I. Morrison et al. | (CÙSB II Collab.) |
| BROCK | 91 | PR D43 1448 | I.C. Brock et al. | (CLEO Collab.) |
| HEINTZ | 91 | PRL 66 1563 | U. Heintz <i>et al.</i> | (CUSB Collab.) |
| MORRISON | 91 | 1 ICE 01 1070 | | (CLEO Collab.) |
| NARAIN | 91 | PRL 66 3113 | | (CUSB Collab.) |
| CHEN | 89B | PR D39 3528 | W.Y. Chen et al. | (CLEO Collab.) |
| KAARS BER G | 89 | | T.M. Kaarsberg et al. | (CUSB Collab.) |
| BUCHMUEL | | | W. Buchmueller, S. Cooper | (HANN, DESY, MIT) |
| | | nd P. Soeding, World Scie | | |
| COHEN | 87 | RMP 59 1121 | E.R. Cohen, B.N. Taylor | (RISC, NBS) |
| BARU | 86B | ZPHY C32 622 (erratum | | (NOVO) |
| KURAEV | 85 | SJNP 41 466 | E.A. Kuraev, V.S. Fadin | (NOVO) |
| ADTAMONOU | 0.4 | Translated from YAF 41 7 | | (NOVS) |
| ARTAMONOV | | PL 137B 272 | A.S. Artamonov et al. | (NOVO) |
| GILES | 84 B | PR D29 1285 PRL 50 807 | R. Giles et al. | (CLEO Collab.) |
| ANDREWS | | | D.E. Andrews et al. | (CLEO Collab.) |
| GREEN | 82 | PRL 49 617 | J. Green et al. | (CLEO Collab.) |
| MAGERAS | 82 | PL 118B 453 | G. Mageras et al. | (COLU, CORN, LSU+) |
| | | | | |

 $\chi_b(3\overline{P})$

I

$$I^G(J^{PC}) = ??(?^{?+})$$

OMITTED FROM SUMMARY TABLE A mixture of $J=0,\ 1,\ {\rm and}\ 2$ spin components observed in the radiative decay to $\Upsilon(1S)$ and $\Upsilon(2S)$, therefore C=+.

$\chi_b(3P)$ MASS

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|---------------------|---------|----------------|-----------------------------------------|
| 10.530 ± 0.005 ± 0.009 | 1 AAD | 12A | ATLS | $pp \rightarrow \gamma \mu^+ \mu^- + X$ |
| ¹ The mass barycenter of th | e merged lineshapes | from th | e <i>J</i> = 1 | and 2 states. |

$\chi_b(3P)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|----------------------|------------------------------|
| <u>Γ</u> 1 | $r(1S)\gamma$ | seen |
| 12 | $\Upsilon(2S)\gamma$ | seen |

$\chi_b(3P)$ BRANCHING RATIOS

| $\Gamma(\Upsilon(1S)\gamma)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|----------------------------------------------------|--------------|-----|------|-----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| seen | AAD | 12A | ATLS | $pp \rightarrow \gamma \mu^+ \mu^- + X$ |
| $\Gamma(\Upsilon(2S)\gamma)/\Gamma_{total}$ | | | | Γ_2/Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| seen | AAD | 12A | ATLS | $pp \rightarrow \gamma \mu^+ \mu^- + X$ |

$\chi_b(3P)$ REFERENCES

AAD 12A PRL 108 152001 G. Aad et al. (ATLAS Collab.)



$$I^{G}(J^{PC}) = 0^{-}(1^{-})$$

$\Upsilon(4S)$ MASS

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------------------|----------|-----------|----------------------------|
| 10.5794 ± 0.0012 OUR AVERA | GE | | | |
| $10.5793 \pm 0.0004 \pm 0.0012$ | AUBERT | 05 Q | BABR | $e^+e^- ightarrow$ hadrons |
| 10.5800 ± 0.0035 | ¹ вевек | 87 | CLEO | $e^+e^- ightarrow$ hadrons |
| • • • We do not use the follow | wing data for average | es, fits | , limits, | etc. • • • |
| 10.5774 ± 0.0010 | ² LOVELOCK | 85 | CUSB | $e^+e^- ightarrow$ hadrons |
| ¹ Reanalysis of BESSON 85. | | | | |

² No systematic error given.

au(4s) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------|----------------------|----------|---------|----------------------------|
| 20.5 ± 2.5 OUR AVERAGE | | | | |
| $20.7 \pm 1.6 \pm 2.5$ | AUBERT | 05 Q | BABR | $e^+e^-	o$ hadrons |
| 20 ±2 ±4 | BESSON | 85 | CLEO | $e^+e^- ightarrow$ hadrons |
| | ing data for average | s, fits, | limits, | etc. • • • |
| 25 ± 2.5 | LOVELOCK | 85 | CUSB | $e^+e^- ightarrow$ hadrons |

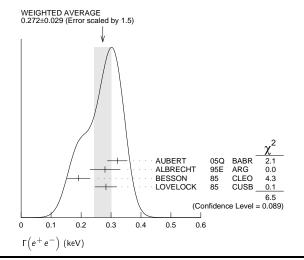
$\Upsilon(4S)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|----------------------------------------------------------|------------------------------|----------------------|
| Γ_1 | В <u>.</u> В | > 96 | % 95% |
| Γ_2^- | $B^+ B^-$ | (51.3 ± 0.6) | % |
| Γ_3 | $\frac{D_s^+}{B^0}$ anything + c.c. $B^0 \overline{B^0}$ | (17.8 ± 2.6) | % |
| Γ_4 | | (48.7 ± 0.6) | % |
| Γ_5 | $J/\psi K_S^0 (J/\psi, \eta_c) K_S^0$ | < 4 | $\times 10^{-7}$ 90% |
| Γ_6 | non- $B\overline{B}$ | < 4 | % 95% |
| Γ_7 | $e^+ e^-$ | (1.57 ± 0.08) | $\times 10^{-5}$ |
| Γ ₈ | $ ho^+ ho^-$ | < 5.7 | $\times 10^{-6}$ 90% |
| Г9 | $J/\psi(1S)$ anything | < 1.9 | $\times 10^{-4}$ 95% |
| Γ_{10} | D^{st+} anything $+$ c.c. | < 7.4 | % 90% |
| Γ_{11} | ϕ anything | (7.1 ± 0.6) | |
| Γ_{12} | $\phi\eta$ | < 1.8 | $\times 10^{-6}$ 90% |
| Γ_{13} | $\phi \eta'$ | < 4.3 | $\times 10^{-6}$ 90% |
| Γ_{14} | $ ho\eta$ | < 1.3 | $\times 10^{-6}$ 90% |
| Γ_{15} | $ ho\eta'$ | < 2.5 | $\times 10^{-6}$ 90% |
| Γ_{16} | $\varUpsilon(1S)$ anything | | $\times 10^{-3}$ 90% |
| Γ_{17} | $\Upsilon(1S)\pi^+\pi^-$ | (8.1 ± 0.6) | $\times 10^{-5}$ |
| Γ_{18} | $\Upsilon(1S)\eta$ | (1.96 ± 0.11) | |
| Γ_{19} | $\gamma(2S)\pi^{+}\pi^{-}$ | (8.6 ± 1.3) | $\times 10^{-5}$ |
| Γ_{20} | $\underline{h}_b(1P)\pi^+\pi^-$ | not seen | _ |
| Γ ₂₁ | \overline{d} anything | < 1.3 | $\times 10^{-5}$ 90% |

au(4S) PARTIAL WIDTHS

| Γ(e+e-) | | | | Γ ₇ |
|-----------------------------|-----------------------|--------|---------|------------------------------|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT |
| 0.272±0.029 OUR AVERAGE | Error includes scale | factor | of 1.5. | See the ideogram below. |
| $0.321 \pm 0.017 \pm 0.029$ | AUBERT | | | $e^+e^- ightarrow $ hadrons |
| $0.28 \pm 0.05 \pm 0.01$ | ³ ALBRECHT | 95 E | ARG | $e^+e^- ightarrow $ hadrons |
| $0.192 \pm 0.007 \pm 0.038$ | BESSON | 85 | CLEO | $e^+e^- ightarrow hadrons$ |
| 0.283 ± 0.037 | LOVELOCK | 85 | CUSB | $e^+e^- \rightarrow hadrons$ |

³Using LEYAOUANC 77 parametrization of $\Gamma(s)$.



au(4s) branching ratios

— *ВВ* DECAYS —

The ratio of branching fraction to charged and neutral B mesons is often derived assuming isospin invariance in the decays, and relies on the knowledge of the B^+/B^0 lifetime ratio. "OUR EVALUATION" is obtained based on averages of rescaled data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account the common dependence of the measurement on the value of the lifetime ratio.

| $\Gamma(B^+B^-)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| 0.513±0.006 OUR EVALUA | <u>DOCUMEN</u> ATION Assuming | $B(\Upsilon(4S) \rightarrow$ | $B\overline{B})=1$ | |
| $\Gamma(D_s^+ \text{ anything } + \text{ c.c.})$ | /F _{total} | T ID T | ECN COMME | Г₃/Г |
| 0.178±0.021±0.016 | 4 ARTUSO | 05в С | <u>CECN COMME</u> CLE3 e ⁺ e ⁻ | $\rightarrow D_X X$ |
| 4 ARTUSO 05B reports [Γ = $(8.0 \pm 0.2 \pm 0.9) \times$ $(4.5 \pm 0.4) \times 10^{-2}$. O the systematic error from | $(\Upsilon(4S) 	o D_S^+)$ and 10^{-3} which we distort first error is their | ything + c.c vide by our t r experiment | .)/ $\Gamma_{	ext{total}}$] $	imes$ [Expression Expression | $B(D_s^+ \to \phi \pi^+)]$ $D_s^+ \to \phi \pi^+) =$ |
| $\Gamma(B^0\overline{B}^0)/\Gamma_{\text{total}}$ | | | | Γ_4/Γ |
| VALUE 0.487±0.006 OUR EVALUA | DOCUMENT ID | | | |
| • • • We do not use the fo | | | | |
| 0.487±0.010±0.008 | - | - | | $\overline{B}B \rightarrow D^*\ell\nu_{\ell}$ |
| ⁵ Direct measurement. TI | | with the valu | e extracted fro | m the $\Gamma(B^+B^-)$ |
| $/\Gamma(B^0\overline{B}{}^0)$ measureme | nts. | | | |
| $/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ | | | | Γ_2/Γ_4 |
| $/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ NALUE | DO CUMENT ID | TECN | <u>COMMENT</u> | Γ ₂ /Γ ₄ |
| $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ NALUE 1.005 ±0.025 OUR EVALUE 1.006 ±0.031 1.01 ±0.03 ±0.09 1.058 ±0.084 ±0.136 1.10 ±0.06 ±0.05 | DOCUMENT ID ATION 6 AUBERT 6 HASTINGS 7 ATHAR 8 AUBERT | 04F BABR 03 BELL 02 CLEO 02 BABR | $\Upsilon(4S) \rightarrow E$ $\Upsilon(4S) \rightarrow E$ $\Upsilon(4S) \rightarrow E$ $\Upsilon(4S) \rightarrow E$ $\Upsilon(4S) \rightarrow E$ | $3\overline{B} \rightarrow J/\psi K$ $3\overline{B} \rightarrow \text{dileptons}$ $3\overline{B} \rightarrow D^*\ell \nu$ $3\overline{B} \rightarrow (c\overline{c})K^*$ |
| $/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ $\frac{VALUE}{1.055\pm0.025}$ OUR EVALUU $1.006\pm0.036\pm0.031$ $1.01\pm0.03\pm0.09$ $1.058\pm0.084\pm0.136$ | ATION 6 AUBERT 6 HASTINGS 7 ATHAR 8 AUBERT 9 ALEXANDER BERT 04F assume τ 3^{+}) / τ (B^{0}) = 1.0 (B^{+}) / τ (B^{0}) = 1. | $04F$ BABR 03 BELL 02 CLEO 02 BABR 01 CLEO $-f(B^+)$ / $\tau(B^-)$ 74 \pm 0.028. $-602 \pm$ 0.029 | $\Upsilon(4S) ightarrow E \ \Upsilon(4S) ightarrow E \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersedes BA \ Supersede$ | $B \overline{B} \rightarrow J/\psi K$ $B \overline{B} \rightarrow dileptons$ $B \overline{B} \rightarrow D^* \ell \nu$ $B \overline{B} \rightarrow (c \overline{c}) K^*$ $B \overline{B} \rightarrow J/\psi K^*$ 0.017. |
| $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement 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| $B \overline{B} \rightarrow J/\psi \ K$ $B \overline{B} \rightarrow dileptons$ $B \overline{B} \rightarrow D^* \ell \nu$ $B \overline{B} \rightarrow (c \overline{c}) K^*$ $B \overline{B} \rightarrow J/\psi K^*$ 0.017. RISH 95. |
| $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^$ | ATION 6 AUBERT 6 HASTINGS 7 ATHAR 8 AUBERT 9 ALEXANDER BERT 04F assume τ β^+) $\tau(\beta^0) = 1$. $(\beta^+) / \tau(\beta^0)$ 1)// total vriance. | 04F BABR 03 BELL 02 CLEO 02 BABR 01 CLEO $r(B^+) / r(B^+) / $ | $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ Supersedes BA .024. | $B \overline{B} \rightarrow J/\psi \ K$ $B \overline{B} \rightarrow dileptons$ $B \overline{B} \rightarrow D^* \ell \nu$ $B \overline{B} \rightarrow (c \overline{c}) K^*$ $B \overline{B} \rightarrow J/\psi K^*$ 0.017. RISH 95. |
| $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^+B^-)/\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measureme $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0\overline{B}^0)$ measurement $\Gamma(B^0B$ | ATION 6 AUBERT 6 HASTINGS 7 ATHAR 8 AUBERT 9 ALEXANDER BERT 04F assume τ β^+ / $\tau(\beta^0) = 1$. (β^+) / $\tau(\beta^0)$ = 1. (β^+) / $\tau(\beta^0)$ = 1. (β^+) / (β^0) = 1. | 04F BABR 03 BELL 02 CLEO 02 BABR 01 CLEO $7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{+}) / 7 (B^{$ | $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ $\Upsilon(4S) ightarrow E$ Supersedes BA .024. | $B \overline{B} \rightarrow J/\psi \ K$ $B \overline{B} \rightarrow dileptons$ $B \overline{B} \rightarrow D^* \ell \nu$ $B \overline{B} \rightarrow (c \overline{c}) K^*$ $B \overline{B} \rightarrow J/\psi K^*$ 0.017. RISH 95. |

| $\Gamma(\text{non-}BB)/\Gamma_{\text{total}}$ | | | | | | | Γ ₆ /Γ |
|-----------------------------------------------|------------|------|--------------------------|------|------|----------------------|-------------------|
| VALUE | CL% | | DO CUMENT ID | | TECN | COMMENT | |
| <0.04 | 95 | | BARISH | 96в | CLEO | e^+e^- | |
| $\Gamma(e^+e^-)/\Gamma_{\rm total}$ | | | | | | | Γ ₇ /Γ |
| VALUE (units 10^{-5}) | | | DO CUMENT ID | | TECN | COMMENT | |
| 1.57±0.08 OUR AVE | RAGE | | | | | | |
| $1.55 \pm 0.04 \pm 0.07$ | | | AUBERT | | | e^+e^- | |
| $2.77 \pm 0.50 \pm 0.49$ | | 11 | ALBRECHT | 95 E | ARG | $e^+e^- \rightarrow$ | hadrons |
| ¹¹ Using LEYAOUAN | C 77 parar | netr | ization of $\Gamma(s)$. | | | | |

| $\Gamma(\rho^+ \rho^-)/\Gamma_{\rm total}$ | | | | | Г ₈ /Г |
|--------------------------------------------|-----|--------------|-----------|----------|----------------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT | |
| $< 5.7 \times 10^{-6}$ | 90 | AUBERT | 08во BABR | e^+e^- | $\pi^{+} \pi^{-} 2\pi^{0}$ |

$\Gamma(J/\psi(1S) \text{ anything})/\Gamma_{\text{total}}$ Γ_9/Γ

| VALUE (units 10^{-4}) | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|---------|----------------------|--------|------------|----------------------------------------------------------|
| <1.9 | 95 | 12 ABE | 02D | BELL | $e^+e^- \rightarrow J/\psi X \rightarrow \ell^+\ell^- X$ |
| • • • We do not | use the | following data for | averag | ges, fits, | limits, etc. • • • |
| <4.7 | 90 | ¹² AUBERT | 01∈ | BABR | $e^+ e^- \to \ J/\psi X \to \ \ell^+ \ell^- X$ |
| 12 Uses B(1/2/2 - | → e+e | -) - 0.0593 + 0.00 | 010 an | d B(I/a/ | $a \rightarrow u^{+}u^{-} = 0.0588 \pm 0.0010$ |

| $\Gamma(D^{*+} \text{ anything } + \text{ c.c.})/\Gamma_{\text{total}}$ | | | | | | |
|-------------------------------------------------------------------------|-----|-------------------------|-----|------|----------|--|
| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT | |
| <0.074 | 90 | ¹³ ALEXANDER | 90c | CLEO | e^+e^- | |
| 13 | | | | | | |

Meson Particle Listings $\Upsilon(4S), X(10610)^{\pm}$

| | Γ ₁₁ /Γ | $\Gamma(T(2S)\pi^{+})$ | π^-)/ $\Gamma(\Upsilon(1S))$ | π⁺ π⁻) DOCUMENT I | n | TECN | COMMENT | Γ ₁₉ /Γ |
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| ## ALUE (units 10^{-2}) | | $1.16 \pm 0.16 \pm 0$ | not use the follow | ing data for avers | nges, fits 08BP | , limits, BABR | etc. \bullet \bullet \bullet \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow \uparrow | |
| 14 For x > 0.52. | | | $\rightarrow e^+e^-) = (1.9)$ endent of other va | | | | $+\mu^{-})=(1.$ | .93 ± 0.17) |
| | Γ_{12}/Γ | $\Gamma(h_b(1P)\pi^+$ | | ides reported by | NOBER | · OODI. | | Γ ₂₀ |
| (1.8 90 $\frac{DOCUMENT\ ID}{15}$ BELOUS 09 BELL $e^+e^- 	o \phi \eta$ | - | VALUE | <u>EVTS</u> | DO CUMENT | | TECN | | |
| ◆ We do not use the following data for averages, fits, limits, etc. | | not seen | 35 ± 21k | ²⁹ ADACHI | | | 10.58 $e^+ \epsilon h_b(1P)$ | $\pi^+\pi^-$ |
| 2.5 90 AUBERT,BE 06F BABR ${ m e^+e^-} ightarrow\phi\eta$ 5 Using all intermedite branching fraction values from PDG 08. | | 29 From the $_{10}$ | upper limit on the (S) of 0.27. | ratio of $\sigma(e^+e^-$ | $\rightarrow h_b($ | $(1P) \pi^{+}$ | π^-) at the $^\prime$ | γ(4 <i>S</i>) to ti |
| | Γ ₁₃ /Γ | $\Gamma(\overline{d} \text{ anythin})$ | * | | | | | Г ₂₁ |
| LUE (units 10^{-6}) CL% DOCUMENT ID TECN COMMENT 4.3 90 16 BELOUS 09 BELL $e^+e^- \rightarrow \phi \eta'$ | | VALUE (units 10 | , . | <u>DO CUMENT</u> | | TECN | | |
| 6 Using all intermedite branching fraction values from PDG 08. | | <1.3 | 90 | ASNER | 07 | CLEO | $e^+e^- \rightarrow$ | ₫X |
| $(ho\eta)/\Gamma_{ m total}$ | Γ ₁₄ /Γ | | | au(4 s) REFEI | RENCE | S | | |
| 1.3 $\frac{CL\%}{17}$ $\frac{DOCUMENT\ ID}{18}$ $\frac{TECN}{e^+e^- \rightarrow \rho\eta}$ | | ADACHI 1: BELOUS 0 | | l. Adachi e K. Belous | | | (BEL | .LE Collab.) .LE Collab.) |
| 7 Using all intermedite branching fraction values from PDG 08. $e^+e^- \rightarrow \rho \eta$ | | SOKOLOV 0 AUBERT 0 | 9 PR D79 051103 BBO PR D78 071103 | R A. Sokolov B. Aubert | et al. et al. | | (BEL (BAB. | .LE Collab.) AR Collab.) |
| | Γ ₁₅ /Γ | | BBP PR D78 112002 B PL B667 1 | B. Aubert C. Amsler D.M. Asne | et al. et al. | | (BAB. (PI | AR Collab.) DG Collab.) EO Collab.) |
| LUE (units 10 ⁻⁶) CL% DOCUMENT ID TECN COMMENT | | HUANG 0 SOKOLOV 0 | 7 PR D75 012002 7 PR D75 071103 | G.S. Huang R A. Sokolov | et al. et al. | | (CL (BEL | EO Collab.) .LE Collab.) |
| 2.5 90 18 BELOUS 09 BELL $e^+e^- 	o ho \eta'$ 8 Using all intermedite branching fraction values from PDG 08. | | AUBERT 0 | 7A PRL 99 211601 6R PRL 96 232001 6F PR D74 111103 | O. Tajima B. Aubert R. B. Aubert | et al. | | (BAB. | .LE Collab.) AR Collab.) AR Collab.) |
| | Г ₁₆ /Г | ARTUSO 0: AUBERT 0: | 5B PRL 95 261801 5Q PR D72 032005 | M. Artuso B. Aubert | et al. et al. | | `(CL (BAB | EO Collab.) AR Collab.) |
| LUE CL% DOCUMENT ID TECN COMMENT 0.004 90 ALEXANDER 90c CLEO e ⁺ e ⁻ | . | | 5H PRL 95 042001 4F PR D69 071101 3 PR D67 052004 | B. Aubert B.Aubert ø N.C. Hastii | t al. | | , | AR Collab.) .LE Collab.) |
| | F /F | ABE 0: ATHAR 0: | 2D PRL 88 052001 2 PR D66 052003 | K. Abe <i>et</i> S.B. Athar | al. et al. | | (BEL (CL | .LE Collab.) EO Collab.) |
| $T(1S)\pi^+\pi^-)/\Gamma_{	ext{total}}$.UE (units 10^{-5}) CL% EVTS DOCUMENT ID TECN COMMENT | Γ ₁₇ /Γ | AUBERT 0: ALEXANDER 0 AUBERT 0 | | B. Aubert J.P. Alexar B. Aubert | der et al. | | (CL | Bar Collab.) EO Collab.) Bar Collab.) |
| 1 ±0.6 OUR AVERAGE 5 ±1.3 ±0.2 113 ±16 19 SOKOLOV 09 BELL $e^+e^- \to \pi^+\pi^-$ | += | GLENN 9 | | S. Glenn e B.C. Barist | t al. | | , | EO Collab.) |
| $0.00\pm0.64\pm0.27$ 430 20 AUBERT 0.000 BABR 100 100 100 100 100 100 | $_{\ell^+\ell^-}^{\mu^+\mu^-}$ | BARISH 9 | | H. Albrech B.C. Barist | et al. et al. | | `(CL | US Collab.) EO Collab.) |
| • • We do not use the following data for averages, fits, limits, etc. • • • $.8 \pm 4.0 \pm 0.3$ $21,22 \text{ SOKOLOV 07} \text{BELL} e^+e^- \rightarrow \pi^+\pi^-$ | + - | ALEXANDER 9 BEBEK 8 BESSON 8 | | J. Alexando C. Bebek e | t al. | | (CL | EO Collab.) EO Collab.) EO Collab.) |
| .0 $\pm 1.5 \pm 0.2$ 167 ± 19 23 AUBERT 06R BABR $e^+e^- \rightarrow \pi^+\pi^-$ | μ· μ μ+ μ- | LOVELOCK 8 | 5 PRL 54 377 | D. Besson D.M.J. Lov | elock et a | | | SB Collab.) (ORSAY) |
| | $\mu \cdot \mu$ | LEYAOUAN C 7 | 7 PL B71 397 | A. Le Yaoi | ianic et ai. | | | (OKSAT) |
| 12 90 GLENN 99 CLE2 e ⁺ e ⁻ | | | 7 PL B71 397 | | | | | (OKSAT) |
| 12 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \rightarrow \mu]$ $= (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value B($\Upsilon(1S) \rightarrow \mu$) | $(+\mu^{-})$] 15) \rightarrow | | | | | = ?+ | (1 ⁺) | (OKSAT) |
| 9 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- = (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value B($\Upsilon(1S) \to \mu^- = (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$. Our first error is their experiment's error a second error is the systematic error from using our best value. | $^+\mu^-)]$ 15) $ ightarrow$ and our | X(106) | $(10)^{\pm}$ | 10 | | | (1 ⁺) | (oldar) |
| 90 GLENN 99 CLE2 $e^+e^ (0.211\pm0.030\pm0.014)\times 10^{-5}$ which we divide by our best value B($T(1S)\to \mu^+\mu^-$) = $(0.211\pm0.030\pm0.014)\times 10^{-5}$ which we divide by our best value B($T(1S)\to \mu^+\mu^-$) = $(0.248\pm0.05)\times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. 0 Using B($T(1S)\to e^+e^-$) = $(0.38\pm0.11)\%$ and B($T(1S)\to \mu^+\mu^-$) = $(0.051\%$. | $(2.48 \pm \mu^{-})$ | X(106 OMITTED Obse | $(10)^\pm$ | Γ ⁽ ARY TABLE R 12 in <i>Υ</i> (5 <i>S</i>) | $\widehat{S}(J^P)$ decays | $=$? $^+$ to γ (n | ıS)π ⁺ π ⁻ (| n = |
| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma\left(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-\right)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. 10 Using B($\Upsilon(1S) \to e^+e^-$) = (2.38 ± 0.11)% and B($\Upsilon(1S) \to \mu^+\pi^-$) = (0.05)%. 15 SOKOLOV 07 reports $[\Gamma\left(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-\right)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-)/\Gamma_{\text{total}}] | $(2.48 \pm \mu^{-})$] | X(106 OMITTED Obse 1, 2, | FROM SUMM strved by BONDA 3) and $h_b(mP)$: | Γ ⁽ ARY TABLE R 12 in <i>Υ</i> (5 <i>S</i>) | $\widehat{S}(J^P)$ decays | $=$? $^+$ to γ (n | ıS)π ⁺ π ⁻ (| n = |
| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- = (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^- + \mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. $0 = 0.05$ (0.05)%. $0 = 0.05$ (0.05)%. $0 = 0.05$ (0.05)%. $0 = 0.05$ (0.05)%. $0 = 0.05$ (0.05)%. $0 = 0.05$ (1.000 V 07 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- + (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^- + (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^- + (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ our first error is their experiment's error and our secon is the systematic error from using our best value. | $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(4.48 \pm \mu^{-})$] | X(106 OMITTED Obse 1, 2, | $(10)^\pm$ | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, | decays 2). J^P | $=$? $^+$ to γ (n | ıS)π ⁺ π ⁻ (| n = |
| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-)] \times [0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^-) \times [0.248 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. 0 Using $B(\Upsilon(1S) \to e^+e^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)\%$. $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-)] \times [A(42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^-) \times [2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our secon is the systematic error from using our best value. | $(+\mu^{-})$] 15) \rightarrow and our 2.48 \pm $(+\mu^{-})$] $(+\mu^{-})$ $(+\mu^{-})$ $(+\mu^{-})$ $(+\mu^{-})$ $(+\mu^{-})$ | X(106 OMITTED Obse 1, 2, | FROM SUMM strved by BONDA 3) and $h_b(mP)$: | Γ ⁽ ARY TABLE R 12 in <i>Υ</i> (5 <i>S</i>) | decays 2). J^P | $=$? $^+$ to γ (n | ıS)π ⁺ π ⁻ (| n = |
| 90 GLENN 99 CLE2 $e^+e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^ e^$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $(+ \mu^-)$] $(+ \mu^-)$ $(+ \mu^-)$ And error | X (106 OMITTED Obse 1, 2, angu | FROM SUMM strved by BONDA 3) and $h_b(mP)$: | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, X(10610) $^{\pm}$ DOCUMENT ID | decays 2). J^P | $=?^{+}$ to $\Upsilon(n)^{2}=1^{+}$ | $(S)\pi^+\pi^-$ (is favored f | n = from |
| 9 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- = (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^- \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. 0 Using $B(\Upsilon(1S) \to e^+e^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)\%$. 1 SOKOLOV 07 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- = (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^- = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our secon is the systematic error from using our best value. 2 According to the authors, systematic errors were underestimated. 3 Superseded by AUBERT 08BP, AUBERT 06R reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+ \pi^-)]$ | $(2.48 \pm \mu^{-})$] 15) \rightarrow and our $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] | X (106 OMITTED Obse 1, 2, angu VALUE (MeV) 10607.2±2.0 | FROM SUMM strved by BONDA 3) and $h_b(mP)$: | ARY TABLE R 12 in $\Upsilon(55)$ $\pi^+\pi^-$ (m = 1, $X(10610)^{\pm}$ $\frac{DOCUMENT ID}{1 BONDAR}$ ing data for avers | decays 2). J^P MASS 12 Eages, fits | to Υ (n) $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = 1^+$ $T = $ | $(S)\pi^+\pi^-$ (is favored for S) is favored for S . | n = from |
| OSOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)] \times [B(\Upsilon(1S) \to \mu^- \pi^+ \pi^-)] \times [B(\Upsilon(1S) \to \mu^- \pi^- \pi^- \pi^-)] \times [B(\Upsilon(1S) \to \mu^- \pi^- \pi^- \pi^- \pi^- \pi^- \pi^- \pi^- \pi^- \pi^- \pi$ | $(2.48 \pm \mu^{-})$] 15) \rightarrow and our $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] $(2.48 \pm \mu^{-})$] | X (106 OMITTED Obse 1, 2, angu VALUE (MeV) 10607.2±2.0 • • We do 10611 ±4 ± | FROM SUMM rived by BONDA 3) and $h_b(mP)$: lar analyses. | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, $X(10610)^{\pm}$ $\frac{DOCUMENT ID}{1 \text{ BONDAR}}$ ing data for aver: $\frac{2}{1 \text{ BONDAR}}$ | decays 2). J^P MASS 12 Eages, fits 12 E | $=?^{+}$ to Υ (n $=1^{+}$ $\frac{TECN}{BELL} = 6$ s, limits, $BELL = 6$ | $(S)\pi^+\pi^-$ (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^+\pi^-$) (is favored for $(S)\pi^-\pi^-$) (is favored for $(S)\pi^-\pi^-$) (is favored for $(S)\pi^-\pi^-$) (is favored for $(S)\pi^-\pi^-\pi^-$ i^-$) (is favored for $(S)\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi$ | n= from |
| 30 GLENN 99 CLE2 e^+e^- CSOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] \times [B(\Upsilon(1S) \to \mu^-)] 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And error $(+ \mu^-)$ | X (106 OMITTED Obse 1, 2, angu MALUE (MeV) 10607.2±2.0 • • • We do 10611 ±4 ± 10609 ±2 ± 10609 ±2 ± 10608 ±2 ± | FROM SUMM arved by BONDA 3) and $h_b(mP)$: lar analyses. | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, $X(10610)^{\pm}$ $\frac{DOCUMENT\ ID}{1}$ BONDAR $\frac{2}{5}$ BONDAR $\frac{2}{5}$ BONDAR $\frac{2}{5}$ BONDAR | decays 2). 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| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.38 \pm 0.11)$ % and $B(\Upsilon(1S) \to \mu^+\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^+\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ %. $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)$ % and $B(\Upsilon(1S) \to \mu^-\mu^-)]$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $(+ \mu^-)$] $(+ \mu^-)$ And error $(+ \pi^-)$ And erro | X (106 OMITTED Obse 1, 2, angu MALUE (MeV) 10607.2±2.0 ● ● We do 10611 ±4 ± 10609 ±2 ± 10608 ±2 ± 10608 ±2 ± | FROM SUMM rived by BONDA 3) and $h_b(mP)$: and use the follow $= 3$ $= 3$ $= 3$ $= 3$ $= 3$ | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, $X(10610)^{\pm}$ $\frac{DOCUMENT ID}{1 \text{ BONDAR}}$ $\frac{2 \text{ BONDAR}}{2 \text{ BONDAR}}$ $\frac{2 \text{ BONDAR}}{2 \text{ BONDAR}}$ | decays 2). 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| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-) + (2.34 \pm 0.05) \times 10^{-2}]$. Our first error is their experiment's error a second error is the systematic error from using our best value. B($\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. Outsing B($\Upsilon(1S) \to e^+e^-) = (2.38 \pm 0.11)\%$ and B($\Upsilon(1S) \to \mu^+\mu^-) = (0.05)\%$. SOKOLOV 07 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\mu^-)] = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second is the systematic error from using our best value. According to the authors, systematic errors were underestimated. Superseded by AUBERT 08BP. AUBERT 06R reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.23 \pm 0.25 \pm 0.27) \times 10^{-6}$ which we divour best value B($\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best value B($\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $(\Upsilon(1S) \eta)/\Gamma_{\text{total}}$. BUE (units $10^{-4}) \to \frac{EVTS}{56} \to \frac{DOCUMENT\ ID}{24} \to \frac{TECN}{4} \to \frac{COMMENT}{7(4S) \to \pi^+\pi^-\pi^0}$. 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AUBERT 06R reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)] \times [\Gamma(T(4S) \to \Upsilon(1S) \pi^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.23 \pm 0.25 \pm 0.27) \times 10^{-6}$ which we diviour best value $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $A(T(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $A(T(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $A(T(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $A(T(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. 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| 3 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\pi^-)] \times [B(\Psi(1S) \to \mu^+\pi^-)] \times [$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $+ \mu^-)$] $(\mu^+ \mu^-)$ and error $(+ \mu^-)$ ivide by is their t value. 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The sound $h_b(mP)$: are analyses. The sound $h_b(mP)$: are analyses. The sound $h_b(mP)$: are analyses. The sound $h_b(mP)$: are analyses. | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, $X(10610)^\pm$ $\frac{DOCUMENT ID}{1}$ BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR $\frac{2}{3}$ BONDAR $\frac{1}{3}$ BONDAR BONDAR | decays 2). 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| GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-)]$ $= (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error as second error is the systematic error from using our best value. Ousing $B(\Upsilon(1S) \to e^+e^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)\%$. SOKOLOV 07 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\mu^-)] = (0.05)\%$. $= (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^-\mu^-) = (0.05)\%$. $= (4.42 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^-\mu^-\mu^-) = (0.05)\%$. $= (4.42 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second is the systematic error from using our best value. According to the authors, systematic errors were underestimated. Superseded by AUBERT 08BP. AUBERT 06R reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)] \times [B(\Upsilon(1S) \to \mu^+\mu^-)] = (2.23 \pm 0.25 \pm 0.27) \times 10^{-6}$ which we divour best value $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error experiment's error and our second error is the systematic error from using our best $[\Gamma(T(1S) \eta)/\Gamma(T(1S) \pi^+\pi^-)] \times [B(\Psi(1S) \to \mu^+\mu^-)] = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.38 \pm 0.11)\%$ and $B(\Upsilon(1S$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $+ \mu^-)$] $\downarrow^+ \mu^-)$ and error $\downarrow^+ \pi^-)$ / vide by is their t value. Γ_{18}/Γ $\ell^+ \ell^-$ 2.48 \pm $18/\Gamma_{17}$ $\ell^+ \ell^-$ | X (106 OMITTED Obse 1, 2, angu 10607.2±2.0 • • • We do 10611 ±4 ±1 10609 ±2 ±1 10608 ±2 ±1 10599 ±6 3 ±1 Average of 2 Superseder VALUE (MeV) 18.4±2.4 • • • We do 22.3± 7.7±3 | FROM SUMM rvved by BONDA 3) and $h_b(mP)$: lar analyses. not use the follow $ \begin{array}{ccccccccccccccccccccccccccccccccccc$ | ARY TABLE R 12 in $\Upsilon(5S)$ $\pi^+\pi^-$ (m = 1, $X(10610)^\pm$ $\frac{DOCUMENT ID}{1}$ BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR BONDAR $\frac{2}{3}$ BONDAR $\frac{1}{3}$ BONDAR BONDAR | decays 2). 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| GLENN 99 CLE2 e^+e^- SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\mu^-) = (0.211 \pm 0.030 \pm 0.014) \times 10^{-5}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^+\mu^-) = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error a second error is the systematic error from using our best value. Our properties $B(\Upsilon(1S) \to e^+e^-) = (2.38 \pm 0.11)$ % and $B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)$ %. SOKOLOV 07 reports $B(\Upsilon(1S) \to \Upsilon(1S) \to \Upsilon(1S) \to \pi^+\pi^-)/\Gamma_{\text{total}} \times B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)$ %. SOKOLOV 07 reports $B(\Upsilon(1S) \to \Upsilon(1S) \to \Upsilon(1S) \to \pi^+\pi^-)/\Gamma_{\text{total}} \times B(\Upsilon(1S) \to \mu^+\mu^-) = (0.05)$ %. SOKOLOV 07 reports $B(\Upsilon(1S) \to \Upsilon(1S) \to \Upsilon(1S) \to \pi^+\pi^-)/\Gamma_{\text{total}} \times B(\Upsilon(1S) \to \mu^-\mu^-) = (0.442 \pm 0.81 \pm 0.56) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(1S) \to \mu^-\mu^-) = (0.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error and our second is the systematic error from using our best value. According to the authors, systematic errors were underestimated. Superseded by AUBERT 08BP. AUBERT 06R reports $B(\Upsilon(1S) \to \Upsilon(1S) \to \pi^+\pi^-) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi(1S) \times \Phi$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $+ \mu^-)$] $(+ \mu^-)$ and error $(+ \mu^-)$ odd error $(+ \mu^-)$ fivide by is their to value. 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| 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+ \pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+ \mu^-)] = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error as second error is the systematic error from using our best value. $B(\Upsilon(1S) \to \mu^+ \mu^-)] = (2.48 \pm 0.05) \times 10^{-2}$. Our first error is their experiment's error as second error is the systematic error from using our best value. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. $(0.05)\%$. | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $(+ \mu^-)$] $(+ \mu^-)$ and error $(+ \pi^-)$ / ivide by its their t value. 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| 90 GLENN 99 CLE2 e^+e^- 9 SOKOLOV 09 reports $[\Gamma(\Upsilon(4S) \to \Upsilon(1S) \pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\pi^+\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\pi^-\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\pi^-\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\pi^-\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(1S) \to \mu^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^-\pi^$ | $(+ \mu^-)$] 15) \rightarrow and our 2.48 \pm $(+ \mu^-)$] $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ $(+ \mu^-)$ | X (106 OMITTED Obse 1, 2, angu 10607.2±2.0 • • • We do 10611 ±4 ± 10609 ±2 ± 10608 ±2 ± 10609 ±2 ± 10599 +6 −3 −3 −3 −3 −3 −3 −3 −3 −3 −3 −3 −3 −3 | FROM SUMM rived by BONDA 3) and $h_b(mP)$: ar analyses. not use the follow $ \begin{array}{c} $ | ARY TABLE R12 in $\Upsilon(55)$ $\pi^+\pi^-$ (m = 1, $X(10610)^{\pm}$ DOCUMENT ID 1 BONDAR ing data for avera 2 BONDAR 2 BONDAR 2 BONDAR 3 BONDAR Measurement of E $X(10610)^{\pm}V$ DOCUMENT ID 3 BONDAR ing data for avera 4 BONDAR 4 BONDAR 4 BONDAR 4 BONDAR 4 BONDAR 4 BONDAR | decays 2). JP MASS 12 E 12 E 12 E 12 E 12 E 12 E 12 E 12 | to \(\gamma(n) \) to \(\gamma(n) \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) BELL \(\text{c} \) | $(COMMENT)$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ $e^{+}e^{-} \rightarrow ha$ | In a series of the form |
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 $^{^3\,\}text{Average}$ of the BONDAR 12 measurements in separate channels. $^4\,\text{Superseded}$ by the average measurement of BONDAR 12.

X(10610)+ DECAY MODES

 $X(10610)^{-}$ decay modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Upsilon(1S)\pi^+$ | seen |
| Γ_2 | $\Upsilon(2S)\pi^+$ | seen |
| Γ_3 | $\Upsilon(3S)\pi^+$ | seen |
| Γ_4 | $h_b(1P)\pi^+$ | seen |
| Γ_5 | $h_b(2P)\pi^+$ | seen |

X(10610) BRANCHING RATIOS

| $\Gamma(\varUpsilon(1S)\pi^+)/\Gamma_{total}$ | | | | | Γ_1/Γ |
|---------------------------------------------------|-------------|----|-------------|-----------------------|----------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| seen | BONDAR | 12 | BELL | e^+e^- | γ (15) $\pi^+\pi^-$ |
| $\Gamma(\Upsilon(2S)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | COMMENT | Γ2/Γ |
| seen | BONDAR | 12 | BELL | $e^+e^- \to$ | $\gamma(2S) \pi^+ \pi^-$ |
| $\Gamma(\Upsilon(3S)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | <u>TECN</u> | <u>COMMENT</u> | Г3/Г |
| seen | BONDAR | 12 | BELL | $e^+ e^- \rightarrow$ | γ (35) $\pi^+\pi^-$ |
| $\Gamma(h_b(1P)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | COMMENT | Γ4/Γ |
| seen | BONDAR | 12 | BELL | $e^+e^- \to$ | $h_b(1P) \pi^+ \pi^-$ |
| $\Gamma(h_b(2P)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | COMMENT | Γ ₅ /Γ |
| seen | BONDAR | 12 | | | $h_b(2P) \pi^+ \pi^-$ |

X(10610) + REFERENCES

12 PRL 108 122001 A. Bondar et al. (BELLE Collab.)

 $(10650)^{\pm}$

 $I^G(J^P) = ?^+(1^+)$

OMITTED FROM SUMMARY TABLE

Observed by BONDAR 12 in $\Upsilon(5S)$ decays to $\Upsilon(\mathsf{nS})\pi^+\pi^-$ (n = 1, 2, 3) and $h_b(\text{mP})\pi^+\pi^-$ (m = 1, 2). $J^P=1^+$ is favored from angular analyses.

$X(10650)^{\pm}$ MASS

| VALUE (MeV) | DO CUMENT ID |) | TECN | COMMENT |
|-----------------------------------------------------------|----------------------|-----------|------------|------------------------------------------------|
| 10652.2±1.5 | ¹ BONDAR | 12 | BELL | $e^+e^- ightarrow$ hadrons |
| • • • We do not use the fol | lowing data for aver | rages, fi | its, limit | s, etc. • • • |
| 10657 ± 6 ± 3 | ² BONDAR | 12 | BELL | $e^+e^- \rightarrow \gamma(1S) \pi^+\pi^-$ |
| 10651 ± 2 ± 3 | | 12 | BELL | $e^+ e^- \rightarrow \gamma(2S) \pi^+ \pi^-$ |
| 10652 ± 1 ± 2 | ² BONDAR | 12 | BELL | $e^+ e^- ightarrow $ |
| 10654 $\pm 3 \begin{array}{c} +1 \\ -2 \end{array}$ | ² BONDAR | 12 | BELL | $e^+ e^- \rightarrow \ h_b(1P) \pi^+ \pi^-$ |
| 10651 $\begin{array}{ccc} +2 & +3 \\ -3 & -2 \end{array}$ | ² BONDAR | 12 | BELL | $e^+e^-\to~h_b(2P)\pi^+\pi^-$ |

Average of the BONDAR 12 measurements in separate channels.

X (10650) # WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------------|-------------------------|---------|------------|-------------------------------------------------|
| 11.5 ± 2.2 | ³ BONDAR | 12 | BELL | $e^+e^-	o$ hadrons |
| • • • We do not use the | following data for aver | ages, f | its, limit | s, etc. • • • |
| $16.3 \pm 9.8 ^{+}_{-} \begin{array}{c} 6.0 \\ 2.0 \end{array}$ | ⁴ BONDAR | 12 | BELL | $e^+e^- ightarrow \gamma(1S)\pi^+\pi^-$ |
| $13.3 \pm 3.3 + 4.0 \\ -3.0$ | ⁴ BONDAR | 12 | BELL | $e^+e^- ightarrow \varUpsilon(2S)\pi^+\pi^-$ |
| $8.4 \pm 2.0 \pm 2.0$ | ⁴ BONDAR | 12 | BELL | $e^+ e^- \rightarrow \gamma(3S) \pi^+ \pi^-$ |
| $20.9^{+5.4+$ | ⁴ BONDAR | 12 | BELL | $e^+e^-\to~h_b(1P)\pi^+\pi^-$ |
| 19 $\pm 7 \begin{array}{c} +11 \\ -7 \end{array}$ | ⁴ BONDAR | 12 | BELL | $e^+e^- ightarrow h_b(2P)\pi^+\pi^-$ |

³ Average of the BONDAR 12 measurements in separate channels.

X(10650)+ DECAY MODES

 $X(10650)^{-}$ decay modes are charge conjugates of the modes below.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Upsilon(1S)\pi^+$ | seen |
| Γ_2 | $\Upsilon(2S) \pi^+$ | seen |
| Γ_3 | $\Upsilon(3S) \pi^+$ | seen |
| Γ_4 | $h_b(1P)\pi^+$ | seen |
| Γ_5 | $h_b(2P)\pi^+$ | seen |

X(10650) BRANCHING RATIOS

| $\Gamma(\Upsilon(1S)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | <u>TECN</u> | Γ ₁ /Γ | - |
|---------------------------------------------------|--------------|----|-------------|----------------------------------------------|---|
| seen | BONDAR | 12 | BELL | $e^+e^- \rightarrow \Upsilon(1S) \pi^+\pi^-$ | |
| $\Gamma(\Upsilon(2S)\pi^+)/\Gamma_{total}$ | DOCUMENT ID | | TECN | Γ ₂ /Γ | |
| seen | BONDAR | 12 | BELL | $e^+e^- \rightarrow \Upsilon(2S) \pi^+\pi^-$ | |
| $\Gamma(\Upsilon(3S)\pi^+)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | Г ₃ /Г | |
| seen | BONDAR | 12 | BELL | $e^+e^- \rightarrow \Upsilon(3S) \pi^+\pi^-$ | |
| $\Gamma(h_b(1P)\pi^+)/\Gamma_{\text{total}}$ | DO CUMENT ID | | <u>TECN</u> | Γ ₄ /Γ | _ |
| seen | BONDAR | 12 | BELL | $e^+e^- \rightarrow h_b(1P) \pi^+\pi^-$ | |
| $\Gamma(h_b(2P)\pi^+)/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | Γ ₅ /Γ | |
| seen | BONDAR | 12 | BELL | $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$ | |

X(10650) * REFERENCES

PRL 108 122001 A. Bondar et al. (BELLE Collab.)

 $\Upsilon(10860)$

 $I^{G}(J^{PC}) = 0^{-}(1^{-})$

T(10860) MASS

VALUE (MeV)

DOCUMENT ID

TECN
COMMENT

10876 ±11 OUR EVALUATION Weighted-average of Belle and BaBar results, but tripling the scaling S-factors applied to the uncertainties to account for model-dependence, handling of radiative corrections, and interference effects.

 \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$

| 10879 | ± 3 | 1 | ^{L,2} CHEN | 10 | BELL | $e^+ e^- \rightarrow$ | hadrons |
|---------|-----------|-----|-----------------------|-----|------|-----------------------|------------------------------------|
| 10888.4 | 1 + 2.7 ± | 1.2 | ³ CHEN | 10 | BELL | $e^+e^- \to$ | γ (1S, 2S, 3S) $\pi^+\pi^-$ |
| 10876 | ± 2 | | ¹ AUBERT | 09E | BABR | $e^+e^- \to$ | hadrons |
| 10869 | ± 2 | | ⁴ AUBERT | 09E | BABR | $e^+e^- \rightarrow$ | hadrons |
| 10868 | ± 6 ±! | 5 | ⁵ BESSON | | | $e^+e^- \to$ | |
| 10845 | ± 20 | | ⁶ LOVELOCK | 85 | CUSB | $e^+e^- \rightarrow$ | hadrons |
| 4 | | | | | | | |

 1 In a model where a flat non-resonant $b\overline{b}$ -continuum is incoherently added to a second flat component interfering with two Breit-Wigner resonances. Systematic uncertainties not estimated. 2 The parameters of the $\gamma(11020)$ are fixed to those in AUBERT 09E.

 3 In a model where a flat nonresonant $~\Upsilon({\rm 1S,2S,3S})\,\pi^+\,\pi^-$ continuum interferes with a single Breit-Wigner resonance.

 4 In a model where a non-resonant $^{b}\overline{b}$ -continuum represented by a threshold function at $\sqrt{s}{=}2m_B$ is incoherently added to a flat component interfering with two Breit-Wigner resonances. Not independent of other AUBERT 09E results. Systematic uncertainties not estimated

 $\frac{5}{4}$ Assuming four Gaussians with radiative tails and a single step in R.

⁶ In a coupled-channel model with three resonances and a smooth step in R.

r(10860) WIDTH

DOCUMENT ID VALUE (MeV) TECN COMMENT 55 ±28 OUR EVALUATION Weighted-average of Belle and BaBar results, but tripling the scaling 5-factors applied to the uncertainties to account for model-dependence, handling of radiative corrections, and interference effects.

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 46 + 9 - 7 | ^{7,8} CHEN | 10 | BELL | $e^+e^-\to$ | hadrons |
|-----------------------------------------------------------------------|------------------------|-----|------|-----------------------|------------------------------------------------------------|
| 30.7^{+}_{-} $\begin{array}{c} 8.3 \\ 7.0 \\ \end{array} \pm \ 3.1$ | 9 CHEN | 10 | BELL | $e^+e^- \to$ | $\gamma_{(1\mathrm{S},2\mathrm{S},3\mathrm{S})\pi^+\pi^-}$ |
| 43 ± 4 | ⁷ AUBERT | 09E | BABR | $e^+e^- \to$ | hadrons |
| 74 ± 4 | ¹⁰ AUBERT | 09E | BABR | $e^+e^- \rightarrow$ | hadrons |
| $112 \pm 17 \pm 23$ | ¹¹ BESSON | 85 | CLEO | $e^+ e^- \rightarrow$ | hadrons |
| 110 ±15 | ¹² LOVELOCK | 85 | CUSB | $e^+ e^- \rightarrow$ | hadrons |

² Superseded by the average measurement of BONDAR 12.

⁴ Superseded by the average measurement of BONDAR 12.

$\Upsilon(10860)$

| ⁷ In a model where a flat non-resonant $b\overline{b}$ -continuum is incoherently added to a second |
|----------------------------------------------------------------------------------------------------------------|
| flat component interfering with two Breit-Wigner resonances. Systematic uncertainties |
| not estimated. |

 8 The parameters of the $\varUpsilon(11020)$ are fixed to those in AUBERT 09E.

T(10860) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------|-----------------------------------------------------------|----------------------------------------------------------|------------------|
| Γ ₁ | $B\overline{B}X$ | (75.9 ^{+2.7} _{-4.0}) % | |
| Γ_2 | В <u>.</u> В | (5.5 ±1.0) % | |
| Γ_3 | $B\overline{B^*}$ + c.c. | $(13.7 \pm 1.6)\%$ | |
| Γ_4 | B <u>*</u> B* | $(38.1 \pm 3.4)\%$ | |
| Γ_5 | $B\overline{B}^{(*)}\pi$ | < 19.7 % | 90% |
| Γ ₆ | $B\overline{B}\pi$ | (0.0 ± 1.2) % | |
| Γ_7 | $B^*B\pi + BB^*\pi$ | (7.3 ± 2.3) % | |
| | <u>Β</u> * Β * π | (1.0 ± 1.4) % | |
| Γ9 | $B\overline{B}\pi\pi$ | < 8.9 % | 90% |
| Γ_{10} | $B_s^{(*)} \overline{B}_s^{(*)} B_s \overline{B}_s^{(*)}$ | $(19.9 \pm 3.0)\%$ | |
| Γ_{11} | $B_s \overline{B}_s$ | (5 ±5)× | 10-3 |
| Γ_{12} | $B_s \overline{B}_s^* + \text{c.c.}$ | $(1.5 \pm 0.7)\%$ | |
| | $B_s^*\overline{B_s^*}$ | (17.9 \pm 2.8) % | |
| Γ_{14} | no open-bottom | $(4.2^{+5.0}_{-0.6})\%$ | |
| Γ ₁₅ | $e^+ e^-$ | (5.6 ±3.1)× | 10-6 |
| Γ ₁₆ | $\Upsilon(1S)\pi^+\pi^-$ | (5.3 ±0.6)× | 10-3 |
| Γ_{17} | $\gamma(2S)\pi^+\pi^-$ | $(7.8 \pm 1.3) \times$ | 10-3 |
| Γ ₁₈ | γ (3S) $_{\pi^+\pi^-}$ | $(4.8 \begin{array}{c} +1.9 \\ -1.7 \end{array}) \times$ | 10-3 |
| Γ_{19} | $\Upsilon(1S)K^+K^-$ | (6.1 ±1.8)× | 10-4 |
| Γ_{20} | $h_b(1P)\pi^+\pi^-$ | $(3.5^{+1.0}_{-1.3})\times$ | 10-3 |
| Γ_{21} | $h_b(2P)\pi^+\pi^-$ | $(6.0^{+2.1}_{-1.8})\times$ | 10-3 |

Inclusive Decays.

These decay modes are submodes of one or more of the decay modes above.

| Γ ₂₂ | ϕ anything | (13.8 +2.4) % |
|-----------------|-------------------------|-------------------|
| Γ ₂₃ | D^0 anything + c.c. | (108 ±8)% |
| Γ ₂₄ | D_s anything $+$ c.c. | $(46 \pm 6)\%$ |
| Γ ₂₅ | J/ψ anything | $(2.06\pm0.21)\%$ |
| Γ_{26} | B^0 anything $+$ c.c. | (77 ±8)% |
| Γ ₂₇ | B^+ anything $+$ c.c. | $(72 \pm 6)\%$ |

Υ (10860) PARTIAL WIDTHS

| $\Gamma(e^+e^-)$ | | | Γ ₁₅ |
|--------------------------|---------------------------|------------|------------------------------|
| VALUE (keV) | DO CUMENT ID | TECN | COMMENT |
| 0.31 ±0.07 OUR AVERAGE | Error includes scale fact | or of 1.3. | |
| $0.22 \pm 0.05 \pm 0.07$ | BESSON 85 | CLEO | $e^+e^- ightarrow$ hadrons |
| 0.365 ± 0.070 | LOVELOCK 85 | CUSB | $e^+e^- ightarrow $ hadrons |

au(10860) BRANCHING RATIOS

"OUR EVALUATION" is obtained based on averages of rescaled data listed below. The averages and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/.

| $\Gamma(B\overline{B}X)/\Gamma_{\text{total}}$ | | | | | | Γ_1/Γ | |
|------------------------------------------------|------------|-----------------------------------------------|----------|-------------|----------------------------|-------------------|---|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
| 0.759+0.027 OUR EV | /ALUATI | ON | | | | | |
| 0.71 ±0.06 OUR AV | /ERAGE | | | | | | |
| $0.737 \pm 0.032 \pm 0.051$ | 1063 | ¹³ DRUTSKOY | 10 | BELL | $\gamma(5S) \rightarrow$ | B^+X , B^0X | 1 |
| $0.589 \pm 0.100 \pm 0.092$ | | ¹³ DRUTSKOY ¹⁴ HUANG | 07 | CLEO | $r(5S) \rightarrow$ | hadrons | - |
| $\Gamma(B\overline{B})/\Gamma_{\text{total}}$ | | | | | | Γ_2/Γ | |
| VALUE (units 10 ⁻²) | CL% | DOCUMENT ID | | TECN | COMMENT | | |
| $5.5 + 1.0 \pm 0.4$ | | ¹⁵ DRUTSKOY | 10 | BELL | $\gamma(5S) \rightarrow$ | $B^+ X$, $B^0 X$ | ı |
| • • • We do not use | the follov | ving data for averag | ges, fit | ts, limits, | etc. • • • | | |
| <13.8 | 90 | ¹⁴ HUANG | 07 | CLEO | $\Upsilon(5S) \rightarrow$ | hadrons | |

| $\Gamma(B\overline{B})/\Gamma(B\overline{B}X)$ | | | | | Γ_2/Γ |
|---------------------------------------------------------------------------------------------------|------------------|-----------------------------------------------|----------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <u>√ALUE</u> <0.22 | <u>CL%</u> 90 | <u>DOCUMENT ID</u> AQUINES | 06 | TECN CLE3 | $rac{	extit{COMMENT}}{	au(5S) ightarrow 	ext{hadrons}}$ |
| $\Gamma(B\overline{B}^* + \text{c.c.})/\Gamma_{\text{tot}}$ | al | | | | Γ ₃ / |
| VALUE 0.137±0.016 OUR AVE | RAGE | DOCUMENT ID | | TECN | COMMENT |
| $0.137 \pm 0.013 \pm 0.011$ $0.143 \pm 0.053 \pm 0.027$ | | ¹⁵ DRUTSKOY ¹⁴ HUANG | 10 07 | BELL CLEO | $\Upsilon(5S) \rightarrow B^+ X$, $B^0 X$ $\Upsilon(5S) \rightarrow \text{hadrons}$ |
| Γ(Β<u>Β</u>* + c.c.)/Γ (Β | BX) | DOCUMENT ID | | TECN | Γ ₃ /Γ |
| 0.24±0.09±0.03 | 10 | AQUINES | 06 | CLE3 | $rac{\sigma(5S)}{\rightarrow}$ hadrons |
| Γ(B* B*)/Γ _{total} | | DOCUMENT ID | | <u>TECN</u> | Γ ₄ / |
| 0.381 ± 0.034 OUR AVE | RAGE | 15 ppuzavov | | 55 | m/- a) |
| $0.375 + 0.021 \pm 0.030$ $0.436 \pm 0.083 \pm 0.072$ | | ¹⁵ DRUTSKOY ¹⁴ HUANG | 10 07 | CLEO | $\Upsilon(5S) \rightarrow B^+ X, B^0 X$ $\Upsilon(5S) \rightarrow \text{hadrons}$ |
| Γ(Β* <u>B</u> *)/Γ(Β <u>B</u> X) | _EVTS | DO CUMENT ID | | TECN | Γ ₄ /Γ |
| 0.74±0.15±0.08 | 31 | AQUINES | 06 | CLE3 | $\Upsilon(5S) 	o 	ext{hadrons}$ |
| $\Gamma(B\overline{B}^{(*)}\pi)/\Gamma_{\text{total}}$ | | | | _ | Γ ₅ / |
| <u>√ALUE</u> <0.197 | <u>CL%</u> 90 | DOCUMENT ID 14 HUANG | 07 | <u>TECN</u> CLEO | |
| · Γ(Β Β (*)π)/Γ(ΒΒλ | () | | | | Г ₅ /Г |
| VALUE | <u>CL%</u> 90 | DOCUMENT ID | | TECN CLE2 | |
| < 0.32 $\Gamma(B\overline{B}\pi)/\Gamma_{\text{total}}$ | 90 | AQUINES | 06 | CLE3 | $\varUpsilon(5S) ightarrow hadrons$ $oldsymbol{\Gamma_6}$ |
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.0±1.2±0.3 | 0 | ¹⁵ DRUTSKOY | 10 | BELL | $\Upsilon(5S) \rightarrow B^{+,0} \pi^- X$ |
| $\left[\Gamma(B^*\overline{B}\pi) + \Gamma(B\overline{B})\right]$ WALUE (units 10 ⁻²) | *π)]/ EVTS | T _{total} | | TECN | Γ ₇ / |
| $7.3^{+2.3}_{-2.1}\pm0.8$ | 38 | 15 DRUTSKOY | 10 | BELL | $rac{T(5S) \rightarrow B^{+,0}\pi^{-}X}$ |
| $\Gamma(B^*\overline{B}^*\pi)/\Gamma_{total}$ | | | | | Γ ₈ / |
| VALUE (units 10 ⁻²) | EVTS | DOCUMENT ID | | TECN | |
| $1.0^{+1.4}_{-1.3} \pm 0.4$ | 5 | ¹⁵ DRUTSKOY | 10 | BELL | $\Upsilon(5S) \rightarrow B^{+,0} \pi^- X$ |
| Γ(Β <mark>Β</mark> ππ)/Γ _{total} | CL% | DO CUMENT ID | | TECN | Г 9/ |
| <0.089 | 90 | 14 HUANG | 07 | CLEO | $\gamma(5S) \rightarrow hadrons$ |
| $\Gamma(B\overline{B}\pi\pi)/\Gamma(B\overline{B}X)$ |) | | | | Г9/Г |
| <u>VALUE</u> <0.14 | <u>CL%</u> 90 | <u>DO CUMENT ID</u> AQUINES | 06 | TECN CLE3 | $\gamma(5S) 	o 	ext{hadrons}$ |
| $\Gamma(B_s^{(*)}\overline{B}_s^{(*)})/\Gamma_{\text{total}}$ | | | | | $\Gamma = (\Gamma_{11} + \Gamma_{12} + \Gamma_{13})/$ |
| 0.199±0.030 OUR EVA | LUATI | <u>DOCUMENT ID</u> ON | | <u> TECN</u> | COMMENT |
| 0.195 + 0.030 OUR AVE | RAGE | | | | |
| 0.180±0.013±0.032 | | | | | $\Upsilon(5S) \rightarrow D^0 X, D_S X$ |
| $0.21 \begin{array}{c} +0.06 \\ -0.03 \end{array}$ | _ | ¹⁷ HUANG | | | $\Upsilon(5S) \rightarrow D_S X$ |
| • • • We do not use th $0.160 \pm 0.026 \pm 0.058$ | ie tollov | ving data for averag ¹⁸ ARTUSO | | | etc. • • • $e^+e^- \rightarrow D_Y X$ |
| $\Gamma(B_s^{(*)}\overline{B}_s^{(*)})/\Gamma(B\overline{B})$ | X) | ANTUSU | UDE | CLEU | $e^+e^- \rightarrow D_X X$ Γ_{10}/Γ |
| VALUE 0.262 + 0.051 0.262 + 0.043 OUR EVA | | <u>DOCUMENT ID</u> | | - | _3, |
| $\Gamma(B_s^*\overline{B}_s^*)/\Gamma(B_s^{(*)}\overline{B}_s^{(*)})$ | | | Γ1 | ₁₃ /Γ ₁₀ = | = \Gamma_{13} / (\Gamma_{11} + \Gamma_{12} + \Gamma_{13} |
| VALUE (units 10 ⁻²) | | DOCUMENT ID | _ | ECN CC | NAME OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OF THE OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER OWNER O |

• • • We do not use the following data for averages, fits, limits, etc. • • •

DOCUMENT ID

LOUVOT

 $^{19}\,\mathrm{DRUTSKOY}$ 07A BELL Superseded by LOUVOT 09

TECN COMMENT 09 BELL 10.86 $e^+e^- \rightarrow B_s^{(*)} \overline{B_s^{(*)}}$

 $\Gamma_{11}/\Gamma_{10} = \Gamma_{11}/(\Gamma_{11}+\Gamma_{12}+\Gamma_{13})$

93 $^{+7}_{-9}$ ± 1

 $\Gamma(B_s \overline{B}_s)/\Gamma(B_s^{(*)} \overline{B}_s^{(*)})$

⁸ The parameters of the $\Upsilon(11020)$ are fixed to those in AUBERT 09E.

⁹ In a model where a flat nonresonant $\Upsilon(1S,2S,3S)\pi^+\pi^-$ continuum interferes with a single Breit-Wigner resonance.

¹⁰ In a model where a non-resonant $b\overline{b}$ -continuum represented by a threshold function at $\sqrt{s}{=}2m_B$ is incoherently added to a flat component interfering with two Breit-Wigner resonances. Not independent of other AUBERT 09E results. Systematic uncertainties not estimated.

¹¹ Assuming four Gaussians with radiative tails and a single step in R.

¹² In a coupled-channel model with three resonances and a smooth step in R.

Meson Particle Listings $\Upsilon(10860)$

| | \overline{B}_s^*) | | | | | Γ_{11}/Γ_{13} |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| 4 <i>LUE</i> <0.16 | <u>CL%</u> 90 | DO CUMENT BONVICIN | | TECN CLE3 | <u>COMMENT</u> e ⁺ e [−] | |
| (D. 15*) | رد (م(*) م (*) ر | | | /- | F //F | |
| $(B_s \overline{B}_s^* + \text{c.c.})$ | | OCUMENT ID | | | [:] | +Γ ₁₂ +Γ ₁₃) |
| $3^{+3.3}_{-3.0}\pm0.1$ | L | TOVUC | 09 BE | LL 10. | 86 e ⁺ e ⁻ - | $\rightarrow B_S^{(*)} \overline{B}_S^{(*)}$ |
| $(B_s \overline{B}_s^* + c.c.)$ | /Γ(<i>B</i> _s * B _s) | DOCUMENT | ID. | TECN | COMMENT | Γ_{12}/Γ_{13} |
| <0.16 | 90 | BONVICIN | | CLE3 | e ⁺ e ⁻ | |
| (no open-botto | m)/Γ _{total} | <u>DO CUMENT</u> | ID | | | Γ ₁₄ /Γ |
| 042+0.046 OUR | EVALUATION | | | • | | |
| $(\tau(1S)\pi^{+}\pi^{-})$ | | | | | | Γ ₁₆ /Γ |
| 1LUE (units 10 ⁻³) 3±0.3±0.5 | 325 20 CHE | N 08 | BELL | 10.87 a | | r(1S) π ⁺ π ⁻ |
| | | N 00 | DLLL | 10.07 | • e → 1 | |
| $(T(2S)\pi^+\pi^-)$ | , | UMENT ID | TECN | сомме | V.T | Γ ₁₇ /Γ |
| 8±0.6±1.1 | 186 ²⁰ CHE | | BELL | | | r(2S) π ⁺ π ⁻ |
| $(T(3S)\pi^{+}\pi^{-})$ | | | | | | Γ ₁₈ /Γ |
| (| | UMENT ID | TECN | COMME | VT | 118/1 |
| $8^{+1.8}_{-1.5}\pm 0.7$ | 10 ²⁰ CHE | | BELL | 10.87 e | + e ⁻ → 1 | $r(3S) \pi^{+} \pi^{-}$ |
| (T(1S) K+ K- | • | UMENT ID | TECN | COMME | N <i>T</i> | Γ ₁₉ /Ι |
| 1+1.6 ±1.0 | 20 ²⁰ CHE | | BELL | | | r(15) K+K- |
| $(h_b(1P)\pi^+\pi^-$ | | | | | | Γ_{20}/Γ_{17} |
| ALUE + 0.07 | | DOCUMENT ID | | | OMMENT - | |
| $45 \pm 0.08 + 0.07 \\ -0.12$ | | ADACHI | 12 E | BELL 1 | 0.86 6 6 | → hadrons |
| $(h_b(2P)\pi^+\pi^-$ | | | | | | Γ_{21}/Γ_{17} |
| 77±0.08+0.22 0.17 | | <i>DO CUMENT ID</i> ADACHI | | | 0 <i>MMENT</i> 0.86 e+e- | → hadrons |
| | | , , , , , , , , , , , , , , , , , , , , | | , | | |
| (φ anything)/Γ Α <i>LUE</i> | total | <u>DO CUMENT</u> | ID | TECN | COMMENT | Γ ₂₂ /Γ |
| .138±0.007 ⁺ 0.02 | 23 | HUANG | 07 | CLEO | $r_{(5S)} \rightarrow$ | ϕX |
| | | | | | | |
| | + cc \/ | | | | | - /- |
| | · c.c.)/ · total | DOCUMENT | ID | TECN | COMMENT | Γ ₂₃ /Γ |
| ALUE | | <u>DOCUMENT</u> DRUTSKO | | TECN BELL | $\frac{\textit{COMMENT}}{\varUpsilon(5S)} ightarrow$ | |
| 076±0.040±0.06 | 58 | | | | | D ⁰ X |
| ALUE 076±0.040±0.06 (<i>D_s</i> anything ⊢ | 68 + c.c.)/Γ _{total} | | Y 07 | BELL | | D ⁰ X |
| NLUE 076±0.040±0.06 (D _S anything + NLUE 46 ±0.06 OUR | F c.c.)/Γ _{total} | DRUTSKO DO CUMENT | Y 07 | BELL | $r_{(5S)} ightarrow comment$ | D ⁰ X Γ ₂₄ /Γ |
| NLUE 076±0.040±0.06 (D _S anything → NLUE 46 ±0.06 OUR 472±0.024±0.07 | 68 - c.c.)/Γ _{total} AVERAGE 72 | DRUTSKO | Y 07 | BELL TECN | $r_{(5S)} \rightarrow$ | $D^0 X$ Γ_{24}/Γ $D_S X$ |
| (<i>D_s</i> anything + 4.0.06 OUR 472±0.024±0.07 44 ±0.09 ±0.04 | 68 + c.c.)/Γ _{total} AVERAGE 72 1 2 | DRUTSKO <u>DOCUMENT</u> 6 DRUTSKO | <i>ID</i> Y 07 | BELL TECN BELL | $r(5S) ightarrow $ $\frac{COMMENT}{r(5S)} ightarrow$ | D ⁰ X F ₂₄ / |
| $\frac{NLUE}{NCO}$ 076 \pm 0.040 \pm 0.06 (D_S anything + $\frac{NLUE}{46}$ 46 \pm 0.06 OUR 472 \pm 0.024 \pm 0.07 44 \pm 0.09 \pm 0.04 (J/ψ anything | 68 + c.c.)/Γ _{total} AVERAGE 72 1 2 | DRUTSKO <u>DOCUMENT</u> 6 DRUTSKO | ID 07 07 05 B | BELL TECN BELL | $r(5S) ightarrow $ $\frac{COMMENT}{r(5S)} ightarrow$ | D ⁰ X F ₂₄ / |
| NLUE (units 10^{-2}) | 568 + c.c.)/\(\Gamma_{\text{total}}\) AVERAGE 72 1 1 2 | DRUTSKO DOCUMENT 16 DRUTSKO 21 ARTUSO | ID 07 07 05 B | BELL TECN BELL CLE3 | $\begin{array}{c} \varUpsilon(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ \varUpsilon(5S) \rightarrow \\ e^+ e^- \rightarrow \end{array}$ | D ⁰ X F ₂₄ / F F ₂₅ / F F ₂₅ / F |
| $\frac{\hat{L}UE}{0.040\pm0.06}$ (D_S anything + $\frac{\hat{L}UE}{46\pm0.06}$ OUR 472±0.024±0.07 44 ±0.09 ±0.04 (J/ψ anything $\frac{\hat{L}UE}{0.040\pm0.06}$ ($\frac{U}{0.040\pm0.06}$ = $\frac{\hat{L}UE}{0.040\pm0.06}$ = $\frac{\hat{L}UE}{0.040\pm0.060\pm0.160\pm0.13}$ | AVERAGE (1)/\(\Gamma_{\text{total}}\) (2) (3) (4) (4) (5) (6) (7) (7) (7) (7) (8) (8) (9) (9) (1) (1) (1) (1) (1) (1 | DRUTSKO DOCUMENT OF DRUTSKO ARTUSO DOCUMENT | ID 07 07 05 B | BELL TECN BELL CLE3 | $T(5S) \rightarrow \frac{COMMENT}{T(5S)} \rightarrow e^+e^- \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow 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| $\frac{NLUE}{NCE}$ 076±0.040±0.06 (D_S anything + $\frac{NLUE}{NCE}$ 46±0.06 OUR 472±0.024±0.07 44±0.09 ±0.04 (J/ψ anything $\frac{NLUE}{NCE}$ 060±0.160±0.13 (B^0 anything - $\frac{NLUE}{NCE}$ | 58 H C.C.)/\(\Gamma_{\text{total}}\) AVERAGE \[\begin{align*} 72 & 1 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & | DRUTSKO DOCUMENT 16 DRUTSKO 11 ARTUSO DOCUMENT DRUTSKO | NY 07 NY 07 O5B NO 07 | BELL TECN BELL CLE3 TECN BELL | $T(5S) \rightarrow \frac{COMMENT}{T(5S)} \rightarrow e^+e^- \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow COMME$ | $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ $D_{S}^{0}X$ |
| NLUE 0.040 ± 0.06 (D_{S} anything $+0.040\pm0.06$ OUR $472\pm0.024\pm0.07$ $44\pm0.09\pm0.04$ $\pm0.09\pm0.04$ (J/ψ anything $0.040\pm0.160\pm0.13$ (B^{0} anything -0.040 ± 0.09 ±0.04 (J/ψ -0.056 ± 0.00 | 568 H C.C.)/\(\Gamma_{\text{total}}\) AVERAGE 72 1 1 1 2)/\(\Gamma_{\text{total}}\) 4 + C.C.)/\(\Gamma_{\text{total}}\) EVTS 61 352 | DRUTSKO DOCUMENT 16 DRUTSKO 17 DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO | NY 07 NY 07 O5B NO 07 | BELL TECN BELL CLE3 | $T(5S) \rightarrow \frac{COMMENT}{T(5S)} \rightarrow e^+e^- \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} \rightarrow \frac{COMMENT}{T(5S)} 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| (D ⁰ anything - 0.076±0.040±0.06 (D _S anything + 46±0.06 OUR 472±0.024±0.07 44 ±0.09 ±0.04 (J/\psi anything ALUE (units 10 ⁻²) 0.060±0.160±0.13 (B ⁰ anything - 0.056±0.06 (B ⁺ a nything - 0.056±0.06 | 58 H C.C.)/\(\Gamma_{\text{total}}\) AVERAGE 72 1 1 1 1 2)/\(\Gamma_{\text{total}}\) 4 + C.C.)/\(\Gamma_{\text{total}}\) 51 352 + C.C.)/\(\Gamma_{\text{total}}\) | DRUTSKO DOCUMENT A B DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO | Y 07 D | BELL TECN BELL CLE3 TECN BELL TECN BELL | $\begin{array}{c} r(5S) \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ e^+e^- \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ \hline \end{array}$ | $D^0 X$ $\Gamma_{24}/\Gamma_{25}/\Gamma_{25}/\Gamma_{25}/\Gamma_{25}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}/\Gamma_{26}$ |
| ALUE $\Delta LUE = 0.040 \pm 0.06$ (D_S anything ± 0.06 OUR ± 0.06 OUR $\pm 0.02 \pm 0.04$ ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.09 ± 0.0 | 568 AVERAGE 72 1 1 1 2 1)/\(\tau_{\text{total}}\) AVERAGE 72 1 1 2 1 4 2 2 1 4 4 4 4 4 4 4 6 6 6 7 7 7 7 7 7 7 7 7 7 | DRUTSKO DOCUMENT AG DRUTSKO POCUMENT DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO | Y 07 D | BELL TECN BELL TECN BELL TECN BELL | $\begin{array}{c} r(5S) \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ e^+ e^- \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ \hline comment \\ r(5S) \rightarrow \\ \hline \\ comment \\ comment \\ \end{array}$ | $\Gamma_{24}/\Gamma_{0s}X$ $\Gamma_{25}/\Gamma_{0s}X$ $\Gamma_{25}/\Gamma_{0s}X$ $\Gamma_{26}/\Gamma_{0s}X$ $\Gamma_{26}/\Gamma_{0s}X$ |
| ALUE ALUE ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION ACCION A | 58 H C.C.)/\(\Gamma_{\text{total}}\) AVERAGE \[\begin{align*} 72 & 1 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & 2 & | DRUTSKO DOCUMENT ARTUSO DOCUMENT DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO | Y 07 ID Y 07 05B ID Y 07 ID Y 10 ID Y 10 | BELL TECN BELL CLE3 TECN BELL TECN BELL TECN BELL | $\begin{array}{c} r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \end{array}$ | $D_{S}^{0}X$ $\Gamma_{24}/\Gamma_{S}^{0}X$ $\Gamma_{25}/\Gamma_{S}^{0}X$ $\Gamma_{26}/\Gamma_{S}^{0}X$ $\Gamma_{27}/\Gamma_{S}^{0}X$ |
| ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE ALUE | AVERAGE 74 2)/\(\tau_{\text{total}}\) 4 + C.C.\(\text{C.C.}\)/\(\text{Total}\) 61 352 + C.C.\(\text{C.C.}\)/\(\text{Total}\) EVTS 50 711 at of DRUTSKO ments or limits for | DRUTSKO DOCUMENT ARTUSO DOCUMENT DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO Y 10 values for | Y 07 D | BELL TECN BELL CLE3 TECN BELL TECN BELL TECN BELL | $\begin{array}{c} r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \end{array}$ | $D_{S}^{0}X$ $\Gamma_{24}/\Gamma_{S}^{0}X$ $\Gamma_{25}/\Gamma_{S}^{0}X$ $\Gamma_{26}/\Gamma_{S}^{0}X$ $\Gamma_{27}/\Gamma_{S}^{0}X$ |
| ALUE 0.076 \pm 0.040 \pm 0.06 (D_S anything + 46 \pm 0.06 OUR 472 \pm 0.024 \pm 0.07 44 \pm 0.09 \pm 0.04 (J/ψ anything ALUE (units 10^{-2}) 0.060 \pm 0.160 \pm 0.13 (B^0 anything - ALUE (B^+ 0.056 \pm 0.00 (B^+ 0.056 \pm 0.00 (B^+ 0.039 \pm 0.00 | AVERAGE AVERAGE 14 2)/\Gamma_t 34 + C.C.)/\Gamma_t EVTS 50 711 at of DRUTSKO ments or limits fi in conservation. | DRUTSKO DOCUMENT 1.6 DRUTSKO 1.1 ARTUSO DOCUMENT DRUTSKO DOCUMENT DRUTSKO DOCUMENT DRUTSKO Y 10 values form AQUINE: | Y 07 D | BELL TECN BELL CLE3 TECN BELL TECN BELL TECN BELL $A = A = A = A$ | $\begin{array}{c} r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ e^+e^- \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \\ \underline{COMMENT} \\ r(5S) \rightarrow \\ \hline \end{array}$ | $D_{S}^{0}X$ $\Gamma_{24}/\Gamma_{S}^{0}X$ $\Gamma_{25}/\Gamma_{S}^{0}X$ $\Gamma_{26}/\Gamma_{S}^{0}X$ $\Gamma_{27}/\Gamma_{S}^{0}X$ |

18 Uses a model-dependent estimate B($B_S \rightarrow D_S X$) = (92 \pm 11)%.

GeV. $\frac{5}{20}$ Assuming that the observed events are solely due to the $\Upsilon(5S)$ resonance.

¹⁹ From a measurement of $\sigma(e^+e^- \to B_S^*\overline{B}_S^*)$ / $\sigma(e^+e^- \to B_S^{(*)}\overline{B}_S^{(*)})$ at $\sqrt{s}=10.86$

 21 ARTUSO 05B reports $[\Gamma(\Upsilon(10860)\to D_S \text{ anything } + \text{c.c.})/\Gamma_{\text{total}}]\times[B(D_S^+\to \phi\pi^+)]=0.0198\pm0.0019\pm0.0038$ which we divide by our best value $B(D_S^+\to \phi\pi^+)=(4.5\pm0.4)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

au(10860) REFERENCES

| ADACHI CHEN DRUTS KOY AUBERT LOUVOT CHEN DRUTS KOY HUAN G AQUINES BONVICINI PDG ARTUSO BESS ON | 12 10 10 09 E 09 08 07 07 A 07 06 06 06 05 B | PRL 108 032001 PR D82 091106R PR D81 112003 PRL 102 012001 PRL 100 112001 PRL 100 112001 PRL 190 052001 PR D76 012002 PR D75 012002 PRL 96 152001 PRL 96 022002 JPG 33 1801 PRL 95 261801 PRL 94 381 | I. Adachi et al. KF. Chen et al. A. Drutskoy et al. B. Aubert et al. R. Louvot et al. KF. Chen et al. A. Drutskoy et al. A. Drutskoy et al. G. S. Huang et al. O. Aquines et al. G. Bonvicini et al. WM. Yao et al. M. Artuso et al. D. Besson et al. D. Besson et al. | BELLE (BELLE (BABAR (BELLE (BELLE (BELLE (CLEO (CLEO (PDG (CLEO | Collab.) Collab.) Collab.) Collab.) Collab.) |
|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------|
| BESS ON LOVELOCK | 85 85 | PRL 54 381 PRL 54 377 | D. Besson et al. D.M.J. Lovelock et al. | | Collab.) Collab.) |
| | | | | | |

$\Upsilon(11020)$

$$I^G(J^{PC}) = 0^-(1^{--})$$

7(11020) MASS

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|---------------------|---------|-----------|----------------------------|
| 11.019±0.008 OUR AVERAGE | ·- | | | |
| $11.019 \pm 0.005 \pm 0.007$ | BESSON | 85 | CLEO | $e^+e^- ightarrow$ hadrons |
| 11.020 ± 0.030 | LOVELOCK | 85 | CUSB | $e^+e^- ightarrow$ hadrons |
| ● ● We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 10.996 ± 0.002 | ¹ AUBERT | 09E | BABR | $e^+e^- ightarrow$ hadrons |

 $^{\rm 1}$ In a model where a flat non-resonant $b\overline{b}\text{-}{\rm continuum}$ is incoherently added to a second flat component interfering with two Breit-Wigner resonances. Systematic uncertainties not estimated.

au(11020) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------------------------------------------------|---------------------|-----|------|------------------------------|--|
| 79±16 OUR AVERAGE | · | | | | |
| $61 \pm 13 \pm 22$ | BESSON | 85 | CLEO | $e^+e^- ightarrow hadrons$ | |
| 90 ± 20 | LOVELOCK | 85 | CUSB | $e^+e^- ightarrow$ hadrons | |
| • • We do not use the following data for averages, fits, limits, etc. | | | | | |
| 37± 3 | ² AUBERT | 09E | BABR | $e^+e^- ightarrow $ hadrons | |

 $^2\,\text{ln}$ a model where a flat non-resonant $\it b\overline{b}$ -continuum is incoherently added to a second flat component interfering with two Breit-Wigner resonances. Systematic uncertainties not estimated.

au(11020) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|------------|------------------------------|
| Γ_1 | $e^+ e^-$ | $(1.6\pm0.5)\times10^{-6}$ |

au(11020) PARTIAL WIDTHS

| Γ(e ⁺ e ⁻) | | | | | Γ1 |
|-----------------------------------|--------------|----|------|-----------------------------|----|
| VALUE (keV) | DO CUMENT ID | | TECN | COMMENT | |
| 0.130 ± 0.030 OUR AVERAGE | | | | | |
| $0.095 \pm 0.03 \pm 0.035$ | BESSON | 85 | CLEO | $e^+e^- ightarrow hadrons$ | |
| 0.156 ± 0.040 | LOVELOCK | 85 | CUSB | $e^+e^- ightarrow$ hadrons | |

r(11020) REFERENCES

| AUBERT | 09E | PRL 102 012001 | B. Aubert et al. | (BABAR Collab.) |
|----------|-----|----------------|------------------------|-----------------|
| BESSON | 85 | PRL 54 381 | D. Besson et al. | (CLEO Collab.) |
| LOVELOCK | 85 | PRL 54 377 | D.M.J. Lovelock et al. | (CUSB Collab.) |

| $N~{ m BARYONS}~(S=0,I=1/2)$ | DOUBLY-CHARMED BARYONS ($C=+2$) |
|------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|
| $p \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots$ | \mathcal{Z}_{cc}^+ |
| n | BOTTOM (BEAUTY) BARYONS ($B = -1$) |
| A DADVONG (G. O. I. O.O.) | Λ_b^0 |
| Δ BARYONS ($S=0, I=3/2$) | Σ_b |
| Δ resonances | Σ_b^* |
| $\Lambda 	ext{ BARYONS } (S=-1,I=0)$ | $\mathcal{Z}_b^0, \mathcal{Z}_b^-$ |
| Λ | b -baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$ 1409 |
| Λ resonances | N |
| Σ BARYONS $(S=-1,I=1)$ | Notes in the Baryon Listings |
| Σ^+ | Baryon Decay Parameters |
| Σ^0 | Baryon Magnetic Moments |
| Σ^- | Λ and Σ Resonances |
| Σ resonances | The $\Sigma(1670)$ Region |
| Ξ BARYONS ($S=-2,I=1/2$) | Radiative Hyperon Decays |
| $\Xi^0 \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots$ | Ξ Resonances |
| \mathcal{Z}^- | Charmed Baryons (rev.) |
| Ξ resonances | Λ_c^+ Branching Fractions |
| O DADWONG (C | |
| Ω BARYONS $(S=-3,I=0)$ | |
| Ω^- | |
| 12 Tesonances | |
| CHARMED BARYONS ($C=+1$) | |
| Λ_c^+ | |
| $\Lambda_c(2595)^+$ | |
| $\Lambda_c(2625)^+$ | |
| $\Lambda_c(2765)^+$ | |
| $A_c(2880)^+$ | |
| $\Lambda_c(2940)^+$ | |
| $\Sigma_c(2433)$ | |
| $\Sigma_c(2800)$ | |
| \mathcal{Z}_c^+ | |
| Ξ_c^0 | |
| $\Xi_c^{\prime+}$ | |
| $\Xi_c^{\prime 0}$ | |
| $\Xi_c^c(2645)$ | |
| $\Xi_c(2790)$ | |
| $\Xi_c(2815)$ | |
| $\Xi_c(2930)$ | |
| $\Xi_c(2980)$ | |
| $\Xi_c(3055)$ | |
| $\Xi_c(3000)$ | |
| Ω_c^0 | |
| $\Omega_c(2770)^0$ | |



N BARYONS (S=0, I=1/2)

 $p, N^+ = uud; \quad n, N^0 = udd$



| $I(J^P) = \frac{1}{2}$ | $\frac{1}{2}(\frac{1}{2}^+)$ Status: | **** |
|------------------------|--------------------------------------|------|
|------------------------|--------------------------------------|------|

p MASS (atomic mass units u)

The mass is known much more precisely in u (atomic mass units) than in MeV. See the next data block.

| VALUE (u) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------------|----------|-----------|-------------------|
| $1.007276466812 \pm 0.000000000090$ | MOHR | 12 | RVUE | 2010 CODATA value |
| | data for averag | es, fits | , limits, | etc. • • • |
| $1.00727646677 \pm 0.000000000010$ | MOHR | 08 | RVUE | 2006 CODATA value |
| $1.00727646688 \pm 0.00000000013$ | MOHR | 05 | RVUE | 2002 CODATA value |
| $1.00727646688 \pm 0.00000000013$ | MOHR | 99 | RVUE | 1998 CODATA value |
| $1.007276470 \qquad \pm 0.000000012$ | COHEN | 87 | RVUE | 1986 CODATA value |

p MASS (MeV)

The mass is known much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u = 931.494 061(21) MeV/ c^2 (MOHR 12, the 2010 CODATA value), involves the relatively poorly known electronic charge.

| VALUE (MeV) | DO CUMENT ID | 1 | TECN | COMMENT |
|-----------------------------------|-----------------|----------|-----------|-------------------|
| 938.272046±0.000021 | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • We do not use the following | data for averag | es, fits | , limits, | etc. • • • |
| 938.272013 ± 0.000023 | MOHR | 08 | RVUE | 2006 CODATA value |
| 938.272029 ± 0.000080 | MOHR | 05 | RVUE | 2002 CODATA value |
| 938.271998 ± 0.000038 | MOHR | 99 | RVUE | 1998 CODATA value |
| 938.27231 ±0.00028 | COHEN | 87 | RVUE | 1986 CODATA value |
| 938.2796 ±0.0027 | COHEN | 73 | RVUE | 1973 CODATA value |

$|m_p - m_{\overline{p}}|/m_p$

A test of *CPT* invariance. Note that the comparison of the \overline{p} and p chargeto-mass ratio, given in the next data block, is much better determined

| VALUE | CL% | <u>DO CUMENT</u> | ID | TECN | COMMENT |
|-----------------------|---------------|--------------------|------------|-----------|--------------------------------------------------|
| <2 ×10 ⁻⁹ | 90 | ¹ HORI | 06 | SPEC | <u>p</u> e−He atom |
| | se the follow | ing data for ave | rages, fit | s, limits | , etc. • • • |
| $<1.0 \times 10^{-8}$ | 90 | ¹ HORI | 03 | SPEC | $\overline{p}e^{-4}$ He, $\overline{p}e^{-3}$ He |
| $< 6 \times 10^{-8}$ | 90 | 1 HORI | 01 | SPEC | <u></u> $ \overline{\rho} $ e He atom |
| $< 5 \times 10^{-7}$ | | ² TORII | 99 | SPEC | <u></u> $ \overline{\rho} $ e He atom |

 $^{^1}$ HORI 01, HORI 03, and HORI 06 use the more-precisely-known constraint on the $\overline{\rho}$ charge-to-mass ratio of GABRIELSE 99 (see below) to get their results. Their results are not independent of the HORI 01, HORI 03, and HORI 06 values for $|q_p+q_{\overline{p}}|/e$, below.

\overline{p}/p CHARGE-TO-MASS RATIO, $\left|\frac{q_{\overline{p}}}{m_{\overline{p}}}\right|/\left(\frac{q_{\overline{p}}}{m_{\overline{p}}}\right)$

A test of CPT invariance. Listed here are measurements involving the inertial masses. For a discussion of what may be inferred about the ratio of \overline{p} and p gravitational masses, see ERICSÓN 90; they obtain an upper bound of 10^{-6} – 10^{-7} for violation of the equivalence principle for \overline{p} 's.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------------|----------|-----------|--------------|
| $0.99999999991 \pm 0.00000000009$ | GABRIELSE | 99 | TRAP | Penning trap |
| | data for average | es, fits | , limits, | etc. • • • |
| $1.0000000015 \pm 0.0000000011$ | ³ GABRIELSE | 95 | TRAP | Penning trap |
| $1.000000023 \pm 0.000000042$ | ⁴ GABRIELSE | 90 | TRAP | Penning trap |

$(\left|\frac{q_{\overline{p}}}{m_{\overline{p}}}\right| - \frac{q_{\overline{p}}}{m_{\overline{p}}}) / \frac{q_{\overline{p}}}{m_{\overline{p}}}$

A test of *CPT* invariance. Taken from the \overline{p}/p charge-to-mass ratio, above

| VALUE | DO CUMENT ID |
|------------------------------------|--------------|
| $(-9\pm9)\times10^{-11}$ OUR EVALU | JATION |

$|q_p + q_{\overline{p}}|/e$

A test of CPT invariance. Note that the comparison of the \overline{p} and p chargeto-mass ratios given above is much better determined. See also a similar test involving the electron.

| VALUE | CL% | <u>DO CUMENT</u> | ID | TECN | COMMENT |
|-------------------------|-----------|--------------------|-------------|---------|--------------------------------------------------|
| <2 × 10 ⁻⁹ | 90 | ⁵ HORI | 06 | SPEC | <u></u> $ \overline{p} $ e He atom |
| • • • We do not use the | he follow | ing data for aver | ages, fits, | limits, | etc. • • • |
| $<1.0 \times 10^{-8}$ | 90 | ⁵ HORI | 03 | SPEC | $\overline{p}e^{-4}$ He, $\overline{p}e^{-3}$ He |
| $<6 \times 10^{-8}$ | 90 | ⁵ HORI | 01 | SPEC | <u>p</u> e−He atom |
| $< 5 \times 10^{-7}$ | | ⁶ TORII | 99 | SPEC | <u></u> <i>p</i> e−He atom |
| <2 × 10 ⁻⁵ | | 7 HUGHES | 92 | RVUE | |

 5 HORI 01, HORI 03, and HORI 06 use the more-precisely-known constraint on the \overline{p} charge-to-mass ratio of GABRIELSE 99 (see above) to get their results. Their results are not independent of the HORI 01, HORI 03, and HORI 06 values for $|m_p - m_{\overline{p}}|/m_p$,

TORII 99 uses the more-precisely-known constraint on the \overline{p} charge-to-mass ratio of GABRIELSE 95 (see above) to get this result. This is not independent of the TORII 99 value for $|m_p - m_{\overline{p}}|/m_p$, above.

⁷HUGHES 92 uses recent measurements of Rydberg-energy and cyclotron-frequency ra-

$|q_p + q_e|/e$

See BRESSI 11 for a summary of experiments on the neutrality of matter. See also "n CHARGE" in the neutron Listings

| VALUE | DO CUMENT ID | | COMMENT |
|----------------------------------------|-----------------------|-----------|-------------------------------|
| <1 × 10 ⁻²¹ | ⁸ BRESSI | 11 | Neutrality of SF ₆ |
| ullet $ullet$ We do not use the follow | ing data for average | es, fits, | , limits, etc. • • • |
| $< 3.2 \times 10^{-20}$ | ⁹ SENGUPTA | 00 | binary pulsar |
| $< 0.8 \times 10^{-21}$ | MARINELLI | 84 | Magnetic levitation |
| $<1.0 \times 10^{-21}$ | ⁸ DYLLA | 73 | Neutrality of SF ₆ |
| _ | | | |

 $^{8}\,\mathrm{BRESSI}$ 11 uses the method of DYLLA 73 but finds serious errors in that experiment that greatly reduce its accuracy. The BRESSI 11 limit assumes that $n \to p \, e^- \, \nu_e$ conserves charge. Thus the limit applies equally to the charge of the neutron.

SENGUPTA 00 uses the difference between the observed rate of of rotational energy loss by the binary pulsar PSR B1913+16 and the rate predicted by general relativity to set this limit. See the paper for assumptions.

p MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the A Listings.

| VALUE (µN) | DO CUMENT | ID | TECN | COMMENT |
|--------------------------------|---------------|-------------|---------|-------------------|
| $2.792847356 \pm 0.000000023$ | MOHR | 12 | RVUE | 2010 CODATA value |
| | data for aver | ages, fits, | limits, | etc. • • • |
| $2.792847356 \pm 0.000000023$ | MOHR | 08 | RVUE | 2006 CODATA value |
| $2.792847351 \pm 0.000000028$ | MOHR | 05 | RVUE | 2002 CODATA value |
| $2.792847337 \pm 0.0000000029$ | MOHR | 99 | RVUE | 1998 CODATA value |
| $2.792847386 \pm 0.000000063$ | COHEN | 87 | RVUE | 1986 CODATA value |
| 2.7928456 ± 0.0000011 | COHEN | 73 | RVUE | 1973 CODATA value |

P MAGNETIC MOMENT

A few early results have been omitted.

| VALUE (µN) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|-------------|----|------|------------------------------------------------------------|
| -2.793 ±0.006 OUR AVERAGE | • | | | |
| -2.7862 ± 0.0083 | PASK | 09 | CNTR | \overline{p} He $^+$ hyperfine structure |
| -2.8005 ± 0.0090 | KREISSL | 88 | CNTR | \overline{p} ²⁰⁸ Pb 11 \rightarrow 10 X-ray |
| -2.817 ± 0.048 | ROBERTS | 78 | CNTR | |
| -2.791 ± 0.021 | HU | 75 | CNTR | Exotic atoms |

$(\mu_p + \mu_{\overline{p}}) / \mu_p$

A test of CPT invariance. Calculated from the p and \overline{p} magnetic moments,

DOCUMENT ID $(-0.1\pm2.1)\times10^{-3}$ OUR EVALUATION

p ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance.

| VALUE (10 ⁻²³ ecm) | VTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------|-----------|-------------------|---------|---------|---------------------------------|
| < 0.54 | 10 | DMITRIEV | 03 | | Uses ¹⁹⁹ Hg atom EDM |
| ullet $ullet$ $ullet$ We do not use the | following | data for averages | , fits, | limits, | etc. • • • |
| $-$ 3.7 \pm 6.3 | | CHO | 89 | NMR | TI F molecules |
| < 400 | | DZUBA | 85 | THEO | Uses ¹²⁹ Xe moment |
| 130 ± 200 | | WILKENING | 84 | | |
| 900 ±1400 | 12 | WILKENING | 84 | | |
| 700 ± 900 | 1G | HARRISON | 69 | MBR | Molecular beam |

 $^{^2}$ TORII 99 uses the more-precisely-known constraint on the \overline{p} charge-to-mass ratio of GABRIELSE 95 (see below) to get this result. This is not independent of the TORII 99 value for $\left|q_{\overline{p}}\!+\!q_{\overline{\overline{p}}}\right|/e$, below.

⁽G. Gabrielse, private communication). ⁴ GABRIELSE 90 also measures $m_{\overline{p}}/m_{e^-}=1836.152660\pm0.000083$ and $m_p/m_{e^-}=1836.152680\pm0.000088$. Both are completely consistent with the 1986 CODATA (COHEN 87) value for m_p/m_{e^-} of 1836.152701 \pm 0.000037.

Baryon Particle Listings

- $^{10}\,\mathrm{DMITRIEV}$ 03 calculates this limit from the limit on the electric dipole moment of the $^{199} {
 m Hg\ atom}$
- $^{11}_{-1}$ This WILKENING 84 value includes a finite-size effect and a magnetic effect.
- $^{12}\mathrm{This}$ WILKENING 84 value is more cautious than the other and excludes the finite-size effect, which relies on uncertain nuclear integrals.

p ELECTRIC POLARIZABILITY α_p

For a very complete review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05. His recommended values for the proton are $\alpha_p=(12.0\pm0.6)\times10^{-4}~{\rm fm}^3$ and $\beta_p=(1.9\mp0.6)\times10^{-4}$ $\,$ fm 3 , almost exactly our averages.

| VALUE (10 ⁻⁴ fm ³) | DOCUMENT ID | | E (10 ⁻⁴ fm ³) <u>DOCUMENT ID</u> <u>TECN</u> | | TECN | COMMENT |
|-------------------------------------------|--------------------------|--------|----------------------------------------------------------------------|------------------------------------------------------------------------|------|---------|
| 12.0 ±0.6 OUR AVER | AGE | | | | | |
| $12.1 \ \pm 1.1 \ \pm 0.5$ | ¹³ BEANE | 03 | | $EFT + \gamma p$ | | |
| $11.82 \pm 0.98 + 0.52 \\ -0.98$ | | | | $p(\vec{\gamma},\gamma), p(\vec{\gamma},\pi^0), p(\vec{\gamma},\pi^+)$ | | |
| $11.9 \pm 0.5 \pm 1.3$ | ¹⁵ OLMOSDEL | 01 | CNTR | γp Compton scattering | | |
| $12.1 \ \pm 0.8 \ \pm 0.5$ | ¹⁶ MACGIBBON | 95 | RVUE | global average | | |
| • • • We do not use th | e following data fo | r aver | ages, fit | s, limits, etc. • • • | | |
| $11.7 \pm 0.8 \pm 0.7$ | ¹⁷ BARANOV | 01 | RVUE | Global average | | |
| $12.5 \pm 0.6 \pm 0.9$ | MACGIBBON | 95 | CNTR | γp Compton scattering | | |
| $9.8 \pm 0.4 \pm 1.1$ | HALLIN | 93 | CNTR | γp Compton scattering | | |
| $10.62 {+1.25 + 1.07 \atop -1.19 - 1.03}$ | ZIEGER | 92 | CNTR | γp Compton scattering | | |
| $10.9 \ \pm 2.2 \ \pm 1.3$ | ¹⁸ FEDERSPIEL | 91 | CNTR | γp Compton scattering | | |
| | | | | | | |

- 13 BEANE 03 uses effective field theory and low-energy $\gamma \rho$ and γd Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_{N} = (13.0 \pm 0.00)$ $1.9^{+3.9}_{-1.5})\times 10^{-4}~{\rm fm^3~and}~\beta_{\it N} = (-1.8\pm 1.9^{+2.1}_{-0.9})\times 10^{-4}~{\rm fm^3}.$
- 14 BLANPIED 01 gives $\alpha_p+\beta_p$ and $\alpha_p-\beta_p$. The separate α_p and β_p are provided to us by A. Sandorfi. The first error above is statistics plus systematics; the second is from
- 15 This OLMOSDELEON 01 result uses the TAPS data alone, and does not use the (reevaluated) sum-rule constraint that $lpha+eta=(13.8\pm0.4) imes10^{-4}~{
 m fm}^3$. See the paper for
- 16 MACGIBBON 95 combine the results of ZIEGER 92, FEDERSPIEL 91, and their own experiment to get a "global average" in which model errors and systematic errors are treated in a consistent way. See MACGIBBON 95 for a discussion.
- 17 BARANOV 01 combines the results of 10 experiments from 1958 through 1995 to get a global average that takes into account both systematic and model errors and does not use the theoretical constraint on the sum $\alpha_p+\beta_p$.
- 18 FEDERSPIEL 91 obtains for the (static) electric polarizability $\alpha_{_D}$, defined in terms of the induced electric dipole moment by ${\bf D}=4\pi\epsilon_0\alpha_p{\bf E}$, the value $(7.0\pm2.2\pm1.3)\times10^{-4}~{\rm fm^3}$.

p MAGNETIC POLARIZABILITY β_{D}

The electric and magnetic polarizabilities are subject to a dispersion sumrule constraint $\overline{\alpha}+\overline{\beta}=(14.2\pm0.5)\times10^{-4}~{\rm fm^3}.$ Errors here are anticorrelated with those on $\overline{\alpha}_p$ due to this constraint.

| VALUE (10 ⁻⁴ fm ³) | DOCUMENT ID | TECN COMMENT | |
|-------------------------------------------|----------------------------|-----------------------------------------------------------------------------------|--|
| 1.9 ±0.5 OUR AVER | RAGE | | |
| $3.4 \pm 1.1 \pm 0.1$ | ¹⁹ BEANE 03 | $EFT + \gamma p$ | |
| $1.43 \pm 0.98 + 0.52 \\ -0.98$ | | LEGS $p(\vec{\gamma},\gamma)$, $p(\vec{\gamma},\pi^0)$, $p(\vec{\gamma},\pi^+)$ | |
| $1.2 \pm 0.7 \pm 0.5$ | 21 OLMOSDEL 01 | CNTR γp Compton scattering | |
| $2.1 \pm 0.8 \pm 0.5$ | ²² MACGIBBON 95 | RVUE global average | |
| ● ● We do not use t | the following data for av | verages, fits, limits, etc. • • • | |
| $2.3 \pm 0.9 \pm 0.7$ | 23 BARANOV 01 | . RVUE Global average | |
| $1.7 \pm 0.6 \pm 0.9$ | MACGIBBON 95 | CNTR γp Compton scattering | |
| $4.4 \pm 0.4 \pm 1.1$ | HALLIN 93 | CNTR γp Compton scattering | |
| $3.58 + 1.19 + 1.03 \\ -1.25 - 1.07$ | ZIEGER 92 | ? CNTR γp Compton scattering | |
| $3.3 \pm 2.2 \pm 1.3$ | FEDERSPIEL 91 | CNTR γp Compton scattering | |

- 19 BEANE 03 uses effective field theory and low-energy $\gamma \, \rho$ and $\gamma \, d$ Compton-scattering data. It also gets for the isoscalar polarizabilities (see the erratum) $\alpha_{N} = (13.0 \pm 1.9 ^{+3.9}_{-1.5}) \times 10^{-4} \; \mathrm{fm^3}$ and $\beta_{N} = (-1.8 \pm 1.9 ^{+2.1}_{-0.9}) \times 10^{-4} \; \mathrm{fm^3}.$
- 20 BLANPIED 01 gives $\alpha_p+\beta_p$ and $\alpha_p-\beta_p$. The separate α_p and β_p are provided to us by A. Sandorfi. The first error above is statistics plus systematics; the second is from
- 21 This OLMOSDELEON 01 result uses the TAPS data alone, and does not use the (reevaluated) sum-rule constraint that $\alpha+\beta=(13.8\pm0.4)\times10^{-4}~\text{fm}^3$. See the paper for
- 2a discussion.
 2b MACGIBBON 95 combine the results of ZIEGER 92, FEDERSPIEL 91, and their own experiment to get a "global average" in which model errors and systematic errors are treated in a consistent way. See MACGIBBON 95 for a discussion.
- 23 BARANOV 01 combines the results of 10 experiments from 1958 through 1995 to get a global average that takes into account both systematic and model errors and does not use the theoretical constraint on the sum $\alpha_p + \beta_p$.

p CHARGE RADIUS

This is the rms electric charge radius, $\sqrt{\langle r_E^2 \rangle}$

Most measurements of the radius of the proton involve electron-proton interactions, and most of the more recent values agree with one another. The most precise of these is $r_p = 0.879(8)$ fm (BERNAUER 10). The CODATA 10 value (MOHR 12), obtained from the electronic results, is 0.8775(51). However, a measurement using muonic hydrogen finds $r_p=0.84184(67)$ fm (POHL 10), which is eight times more precise and seven standard deviations (using the CODATA 10 error) from the electronic

Since POHL 10, there has been a lot of discussion about the disagreement, especially concerning the modeling of muonic hydrogen. Here is an incomplete list of papers: DERUJULA 10, CLOET 11, DISTLER 11, DERUJULA 11, ARRINGTON 11, BERNAUER 11, and HILL 11.

Until the difference between the $e\,p$ and μp values is understood, it does not make much sense to average all the values together. For the present, we stick with the less precise (and provisionally suspect) CODATA 2010 value (MOHR 12). It is up to workers in this field to solve this puzzle.

| VALUE (| fm) | | DO CUMENT ID | | TECN | COMMENT |
|-------------------|----------------------|------------------|-----------------------------------|--------|--------------|-----------------------------------|
| 0.8775 | ±0.0051 | | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • ' | We do not | use the follow | ing data for avera | ges, f | fits, limits | s, etc. • • • |
| 0.879 | ±0.005 | ± 0.006 | BERNAUER | 10 | SPEC | e p ightarrow e p form factor |
| 0.912 | ± 0.009 | ± 0.007 | BORISYUK | 10 | | reanalyzes old <i>ep</i> data |
| 0.871 | ± 0.009 | ± 0.003 | HILL | 10 | | z-expansion reanalysis |
| 0.84184 | 1 ± 0.00036 | ± 0.00056 | POHL | 10 | | μp-atom Lamb shift |
| 0.8768 | ±0.0069 | | MOHR | 08 | RVUE | 2006 CODATA value |
| 0.844 | $^{+0.008}_{-0.004}$ | | BELUSHKIN | 07 | | Dispersion analysis |
| 0.897 | ± 0.018 | | BLUNDEN | 05 | | SICK 03 $+$ 2 γ correction |
| 0.8750 | ±0.0068 | | MOHR | 05 | RVUE | 2002 CODATA value |
| 0.895 | ± 0.010 | ±0.013 | SICK | 03 | | $ep \rightarrow ep$ reanalysis |
| 0.830 | ± 0.040 | ± 0.040 | ²⁴ ESCHRICH | 01 | | $ep \rightarrow ep$ |
| 0.883 | ± 0.014 | | MELNIKOV | 00 | | 1S Lamb Shift in H |
| 0.880 | ± 0.015 | | ROSENFELDF | R00 | | ep + Coul. corrections |
| 0.847 | ± 0.008 | | MERGELL | 96 | | ep + disp. relations |
| 0.877 | ± 0.024 | | WONG | 94 | | reanalysis of Mainz ep |
| | | | | | | data |
| 0.865 | ± 0.020 | | MCCORD | 91 | | $e p \rightarrow e p$ |
| 0.862 | ± 0.012 | | SIMON | 80 | | $e p \rightarrow e p$ |
| 0.880 | ± 0.030 | | BORKOWSKI | 74 | | $ep \rightarrow ep$ |
| 0.810 | ± 0.020 | | AKIMOV | 72 | | $e p \rightarrow e p$ |
| 0.800 | ± 0.025 | | FREREJACQ | . 66 | | $ep \rightarrow ep (CH_2 tgt.)$ |
| 0.805 | ±0.011 | | HA ND | 63 | | e p → e p |
| ²⁴ ES0 | CHRICH 0 | 1 actually gives | $\langle r^2 \rangle = (0.69 \pm$ | 0.06 | ± 0.06) f | m ² . |

p MAGNETIC RADIUS

| This is the rms magnetic radius, $\sqrt{\langle r_M^{} angle}$. | | | | | | | | | |
|-------------------------------------------------------------------|--------------------|---------------|----------------------------------------|--|--|--|--|--|--|
| VALUE (fm) | DO CUMENT ID | TECN | COMMENT | | | | | | |
| $0.777 \pm 0.013 \pm 0.010$ | BERNAUER | 10 SPEC | $ep \rightarrow ep$ form factor | | | | | | |
| ● We do not use the fol | lowing data for av | erages, fits, | limits, etc. • • • | | | | | | |
| $0.876 \pm 0.010 \pm 0.016$ | BORISYUK | 10 | reanalyzes old $ep ightarrow ep$ data | | | | | | |
| 0.854 ± 0.005 | BELUSHKIN | 07 | Dispersion analysis | | | | | | |

p MEAN LIFE

A test of baryon conservation. See the "p Partial Mean Lives" section below for limits for identified final states. The limits here are to "anything" or are for "disappearance" modes of a bound proton (ρ) or (n). See also the 3ν modes in the "Partial Mean Lives" section. Table 1 of BACK 03 is a nice summary.

| LIMI I (ye ars) | PARTICLE | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------|-----------|------------------------|---------|----------|----------------------------------|
| >5.8 × 10 ²⁹ | n | 90 | ²⁵ ARAKI | 06 | KLND | n ightarrow invisible |
| >2.1 × 10 ²⁹ | P | 90 | ²⁶ AHMED | 04 | SNO | $ ho ightarrow {\sf invisible}$ |
| • • • We do not us | se the followin | g data fo | r averages, fits, lim | its, et | c. • • • | • |
| $>$ 1.9 \times 10 ²⁹ | n | 90 | ²⁶ AHMED | 04 | SNO | n 	o invisible |
| $>1.8 \times 10^{25}$ | n | 90 | ²⁷ BACK | 03 | BORX | |
| $>1.1 \times 10^{26}$ | p | 90 | ²⁷ BACK | 03 | BORX | |
| $>$ 3.5 \times 10 ²⁸ | p | 90 | ²⁸ ZDESENKO | 03 | | $p \rightarrow invisible$ |
| $>1 \times 10^{28}$ | p | 90 | ²⁹ AHMAD | 02 | SNO | $ ho ightarrow {\sf invisible}$ |
| >4 × 10 ²³ | p | 95 | TRETYAK | 01 | | $d \rightarrow n + ?$ |
| $>$ 1.9 \times 10 ²⁴ | p | 90 | ³⁰ BERNABEI | 00B | DAMA | |
| $>1.6 \times 10^{25}$ | p, n | 31 | .,32 EVANS | 77 | | |
| $>3 \times 10^{23}$ | p | | ³² DIX | 70 | CNTR | |
| $>$ 3 \times 10 ²³ | p, n | 32 | ^{2,33} FLEROV | 58 | | |

- ²⁵ ARAKI 06 looks for signs of de-excitation of the residual nucleus after disappearance of a neutron from the $s\,{ ext{shell}}\,$ of $^{12}{ ext{C}}.$
- ²⁶AHMED 04 looks for γ rays from the de-excitation of a residual ¹⁵ O* or ¹⁵ N* following the disappearance of a neutron or proton in $^{16}\mathrm{O}.$
- 27 BACK 03 looks for decays of unstable nuclides left after N decays of parent 12 C, 13 C,
- 16O nuclei. These are "invisible channel" limits.
 28 ZDESENKO 03 gets this limit on proton disappearance in deuterium by analyzing SNO
- 29 AHMAD 02 (see its footnote 7) looks for neutrons left behind after the disappearance of the proton in deuterons.
- 30 BERNABEI 00B looks for the decay of a $^{128}_{53}$ I nucleus following the disappearance of a proton in the otherwise-stable $^{129}_{54}$ Xe nucleus.
- 31 EVANS 77 looks for the daughter nuclide 129 Xe from possible 130 Te decays in ancient Te ore samples.

| 32 This mean-life limit has been | obtained from | n a half-life limit | by dividing the | latter by In(2) |
|----------------------------------|---------------|---------------------|-----------------|-----------------|
| = 0.693. | | | | |

 $^{^{33}}$ = 0.003. TLEROV 58 looks for the spontaneous fission of a 232 Th nucleus after the disappearance of one of its nucleons.

アMEAN LIFE

Of the two astrophysical limits here, that of GEER 00D involves considerably more refinements in its modeling. The other limits come from direct observations of stored antiprotons. See also " \overline{p} Partial Mean Lives," after "p Partial Mean Lives," below, for exclusive-mode limits. The best (lifetime/branching fraction) limit there is 7×10^5 years, for $\overline{p} \rightarrow e^- \gamma$. We advance only the exclusive-mode limits to our Summary Tables.

| (years) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------|----------|---------------------|-------------|----------|-------------------------------------|
| • • • We do no | t use the | followin | g data for averages | , fits, lii | mits, et | .c. • • • |
| $>$ 8 \times 10 ⁵ | 90 | | ³⁴ GEER | 00D | | \overline{p}/p ratio, cosmic rays |
| >0.28 | | | GABRIELSE | 90 - | TRAP | Penning trap |
| >0.08 | 90 | 1 | BELL | 79 (| CNTR | Storage ring |
| $>1 \times 10^{7}$ | | | GOLDEN | 79 9 | SPEC | \overline{p}/p ratio, cosmic rays |
| $> 3.7 \times 10^{-3}$ | | | BREGMAN | 78 (| CNTR | Storage ring |

 $^{^{34}}$ GEER 00D uses agreement between a model of galactic \overline{p} production and propagation and the observed \overline{p}/p cosmic-ray spectrum to set this limit.

p DECAY MODES

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1173) for a short review.

The "partial mean life" limits tabulated here are the limits on τ/B_j , where τ is the total mean life and B_j is the branching fraction for the mode in question. For N decays, p and n indicate proton and neutron partial lifetimes

| | Mode | Partial mean life (10 ³⁰ years) | Confidence level |
|-------------|------------------------------------------|-----------------------------------------------|------------------|
| | | Antilepton + meson | |
| τ_1 | $N \rightarrow e^+ \pi$ | > 158 (n), > 8200 (p |) 90% |
| τ_2 | $N \rightarrow \mu^+ \pi$ | > 100 (n), > 6600 (p) | 90% |
| τ_3 | $N \rightarrow \nu \pi$ | > 112 (n), > 25 (p) | 90% |
| τ_4 | $p \rightarrow e^+ \eta$ | > 313 | 90% |
| τ_5 | $ ho ightarrow \mu^+ \eta$ | > 126 | 90% |
| τ_6 | $n ightarrow u \eta$ | > 158 | 90% |
| τ_7 | $N ightarrow e^+ ho$ | > 217 (n), > 75 (p) | 90% |
| $	au_8$ | $N \rightarrow \mu^+ \rho$ | $> 228 \ (n), > 110 \ (p)$ | 90% |
| $	au_9$ | $N \rightarrow \nu \rho$ | > 19 (n), > 162 (p) | 90% |
| $	au_{10}$ | $p ightarrow e^+ \omega$ | > 107 | 90% |
| τ_{11} | $p \rightarrow \mu^+ \omega$ | > 117 | 90% |
| τ_{12} | $n \rightarrow \nu \omega$ | > 108 | 90% |
| $	au_{13}$ | $N \rightarrow e^+ K$ | > 17 (n), > 150 (p) | 90% |
| τ_{14} | $ ho ightarrow \ e^+ K^0_S$ | > 120 | 90% |
| $	au_{15}$ | $ ho ightarrow \ e^+ K_L^{ m V}$ | > 51 | 90% |
| τ_{16} | $N \rightarrow \mu^+ K$ | > 26 (n), > 120 (p) | 90% |
| $	au_{17}$ | $p \rightarrow \mu^+ K_S^0$ | > 150 | 90% |
| τ_{18} | $p ightarrow~\mu^+ {\cal K}_L^{reve{0}}$ | > 83 | 90% |
| τ_{19} | $N \rightarrow \nu K$ | > 86 (n), > 670 (p) | 90% |
| τ_{20} | $n \rightarrow \nu K_S^0$ | > 51 | 90% |
| τ_{21} | $p \rightarrow e^+ K^*(892)^0$ | > 84 | 90% |
| τ_{22} | $N \rightarrow \nu K^*(892)$ | > 78 (n), > 51 (p) | 90% |
| | | Antilepton + mesons | |
| τ_{23} | $p \rightarrow e^+ \pi^+ \pi^-$ | > 82 | 90% |
| τ_{24} | $p \rightarrow e^+ \pi^0 \pi^0$ | > 147 | 90% |
| τ_{25} | $n \rightarrow e^+\pi^-\pi^0$ | > 52 | 90% |
| τ_{26} | $ ho ightarrow \ \mu^+ \pi^+ \pi^-$ | > 133 | 90% |
| τ_{27} | $p \rightarrow \mu^+ \pi^0 \pi^0$ | > 101 | 90% |
| τ_{28} | $n \rightarrow \mu^{+} \pi^{-} \pi^{0}$ | > 74 | 90% |
| $	au_{29}$ | $n ightarrow e^+ K^0 \pi^-$ | > 18 | 90% |
| | | Lepton + meson | |
| τ_{30} | $n \rightarrow e^- \pi^+$ | · > 65 | 90% |
| τ_{31} | $n \rightarrow \mu^- \pi^+$ | > 49 | 90% |
| τ_{32} | $n \rightarrow e^- \rho^+$ | > 62 | 90% |
| τ_{33} | $n \rightarrow \mu^- \rho^+$ | > 7 | 90% |
| $	au_{34}$ | $n ightarrow e^- K^+$ | > 32 | 90% |
| τ_{35} | $n \rightarrow \mu^- K^+$ | > 57 | 90% |

| <i>T</i> | $p ightarrow e^- \pi^+ \pi^+$ | 1 + mesons | 0.00/ |
|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| τ_{36} | $\begin{array}{ccc} p \to & e^-\pi + \pi^- \\ n \to & e^-\pi + \pi^0 \end{array}$ | > 30 > 29 | 90% 90% |
| τ_{37} | $p \rightarrow \mu^- \pi^+ \pi^+$ | > 17 | 90% |
| $	au_{38}$ $	au_{39}$ | $n \rightarrow \mu^- \pi^+ \pi^0$ | > 34 | 90% |
| τ_{40} | $p \rightarrow e^- \pi^+ K^+$ | > 75 | 90% |
| τ_{41} | $p \rightarrow \mu^- \pi^+ K^+$ | > 245 | 90% |
| . 41 | | | ,* |
| | - | n + photon(s) | |
| τ_{42} | $p \rightarrow e^+_{\perp} \gamma$ | > 670 | 90% |
| $	au_{43}$ | $p \rightarrow \mu^+ \gamma$ | > 478 | 90% |
| τ_{44} | $n \rightarrow \nu \gamma$ | > 28 | 90% |
| τ_{45} | $p \rightarrow e^+ \gamma \gamma$ | > 100 | 90% |
| τ_{46} | $n \rightarrow \nu \gamma \gamma$ | > 219 | 90% |
| | | more) leptons | |
| $	au_{47}$ | $p \rightarrow e^+e^+e^-$ | > 793 | 90% |
| $	au_{48}$ | $p \rightarrow e^+ \mu^+ \mu^-$ | > 359 | 90% |
| τ_{49} | $p \rightarrow e^+ \nu \nu$ | > 17 | 90% |
| τ_{50} | $n \rightarrow e^+ e^- \nu$ | > 257 | 90% |
| τ_{51} | $n \rightarrow \mu^+ e^- \nu$ | > 83 | 90% |
| τ_{52} | $n \rightarrow \mu^+ \mu^- \nu$ | > 79 | 90% |
| τ_{53} | $p \rightarrow \mu^+ e^+ e^-$ | > 529 | 90% |
| τ_{54} | $p \rightarrow \mu_{\perp}^{+} \mu^{+} \mu^{-}$ | > 675 | 90% |
| τ_{55} | $p \rightarrow \mu^+ \nu \nu$ | > 21 | 90% |
| τ_{56} | $p \rightarrow e^- \mu^+ \mu^+$ | > 6 | 90% |
| τ_{57} | $n \rightarrow 3\nu$ $n \rightarrow 5\nu$ | > 0.0005 | 90% |
| τ_{58} | $H \rightarrow 3\nu$ | | |
| | | ive modes | |
| τ_{59} | $N \rightarrow e^+$ anything | > 0.6 (n, p) | 90% |
| $	au_{60}$ | $N \rightarrow \mu^+$ anything | > 12 (n, p) | 90% |
| $	au_{61}$ | $N \rightarrow \nu$ anything | 2.5 () | |
| τ_{62} | $N \rightarrow e^+ \pi^0$ anything | > 0.6 (n, p) | 90% |
| $	au_{63}$ | N ightarrow 2 bodies, $ u$ -free | | |
| | $\Delta B = 2 d$ | inucleon modes | |
| | The following are lifetime limits p | er iron nucleus. | |
| $	au_{64}$ | $pp \rightarrow \pi^+\pi^+$ | > 0.7 | 90% |
| τ_{65} | $pn \rightarrow \pi^+\pi^0$ | > 2 | 90% |
| τ_{66} | $n n \rightarrow \pi^+ \pi^-$ | > 0.7 | 90% |
| τ_{67} | $n n \rightarrow \pi^0 \pi^0$ | > 3.4 | 90% |
| τ_{68} | $p p \rightarrow e^+ e^+$ | > 5.8 | 90% |
| τ_{69} | $p p \rightarrow e^+ \mu^+$ | > 3.6 | 90% |
| | | | |
| τ_{70} | $p p \rightarrow \mu^+ \mu^+$ | > 1.7 | 90% |
| | $p n \rightarrow e^+ \overline{\nu}$ | | 90% 90% |
| $	au_{70}$ | | > 1.7 | |
| $	au_{70} \ 	au_{71}$ | $p n \rightarrow e^+ \overline{\nu}$ | > 1.7 > 2.8 | 90% |
| $	au_{70} \ 	au_{71} \ 	au_{72}$ | $p n \rightarrow e^+ \overline{\nu}$ $p n \rightarrow \mu^+ \overline{\nu}$ | > 1.7 > 2.8 > 1.6 > 0.000049 | 90% 90% |
| $\tau_{70} \\ \tau_{71} \\ \tau_{72} \\ \tau_{73}$ | $\begin{array}{ll} p n \to e^+ \overline{\nu} \\ p n \to \mu^+ \overline{\nu} \\ n n \to \nu_e \overline{\nu}_e \\ n n \to \nu_\mu \overline{\nu}_\mu \\ p n \to \text{invisible} \end{array}$ | > 1.7 > 2.8 > 1.6 | 90% 90% |
| $	au_{70} \ 	au_{71} \ 	au_{72} \ 	au_{73} \ 	au_{74}$ | $\begin{array}{lll} p n \to & e^+ \overline{\nu} \\ p n \to & \mu^+ \overline{\nu} \\ n n \to & \nu_e \overline{\nu}_e \\ n n \to & \nu_\mu \overline{\nu}_\mu \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 | 90% 90% 90% |
| $	au_{70} \ 	au_{71} \ 	au_{72} \ 	au_{73} \ 	au_{74} \ 	au_{75}$ | $\begin{array}{ll} p n \to e^+ \overline{\nu} \\ p n \to \mu^+ \overline{\nu} \\ n n \to \nu_e \overline{\nu}_e \\ n n \to \nu_\mu \overline{\nu}_\mu \\ p n \to \text{invisible} \\ p p \to \text{invisible} \end{array}$ | $ > 1.7 $ $ > 2.8 $ $ > 1.6 $ $ > 0.000049 $ $ > 2.10 \times 10^{25} $ | 90% 90% 90% |
| $	au_{70} \ 	au_{71} \ 	au_{72} \ 	au_{73} \ 	au_{74} \ 	au_{75}$ | $\begin{array}{ll} p n \to e^+ \overline{\nu} \\ p n \to \mu^+ \overline{\nu} \\ n n \to \nu_e \overline{\nu}_e \\ n n \to \nu_\mu \overline{\nu}_\mu \\ p n \to \text{invisible} \\ p p \to \text{invisible} \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 | 90% 90% 90% |
| $	au_{70} \ 	au_{71} \ 	au_{72} \ 	au_{73} \ 	au_{74} \ 	au_{75}$ | $\begin{array}{ll} p n \to e^+ \overline{\nu} \\ p n \to \mu^+ \overline{\nu} \\ n n \to \nu_e \overline{\nu}_e \\ n n \to \nu_\mu \overline{\nu}_\mu \\ p n \to \text{invisible} \\ p p \to \text{invisible} \end{array}$ | $ > 1.7 $ $ > 2.8 $ $ > 1.6 $ $ > 0.000049 $ $ > 2.10 \times 10^{25} $ $ > 0.00005 $ | 90% 90% 90% |
| ττο ττ1 ττ2 ττ3 ττ4 ττ5 ττ6 | $\begin{array}{ll} p n \to & \mathrm{e}^+ \overline{\nu} \\ p n \to & \mu^+ \overline{\nu} \\ n n \to & \nu_e \overline{\nu}_e \\ n n \to & \nu_\mu \overline{\nu}_\mu \\ p n \to & \mathrm{invisible} \\ p p \to & \mathrm{invisible} \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) | 90% 90% 90% 90% 90% Confidence level |
| $	au_{70}$ $	au_{71}$ $	au_{72}$ $	au_{73}$ $	au_{74}$ $	au_{75}$ $	au_{76}$ | $\begin{array}{cccc} p n \to & \mathrm{e}^+ \overline{\nu} \\ p n \to & \mu^+ \overline{\nu} \\ n n \to & \nu_e \overline{\nu}_e \\ n n \to & \nu_\mu \overline{\nu}_\mu \\ p n \to & \mathrm{invisible} \\ p p \to & \mathrm{invisible} \\ \hline p p \to & \mathrm{invisible} \\ \\ \hline \overline{p} \to & \mathrm{e}^- \gamma \\ \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) | 90% 90% 90% 90% 90% Confidence level |
| 770 771 772 773 774 775 776 | $\begin{array}{cccc} p n & \rightarrow & e^+ \overline{\nu} \\ p n & \rightarrow & \mu^+ \overline{\nu} \\ n n & \rightarrow & \nu_e \overline{\nu}_e \\ n n & \rightarrow & \nu_\mu \overline{\nu}_\mu \\ p n & \rightarrow & \text{invisible} \\ p p & \rightarrow & \text{invisible} \\ \hline p p & \rightarrow & \text{invisible} \\ \\ \hline \hline \hline \rho DEC. \\ \hline \\ \hline \text{Mode} \\ \hline \hline \hline \rho & e^- \gamma \\ \hline \overline{\rho} & \mu^- \gamma \\ \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) $> 7 \times 10^{5}$ $> 5 \times 10^{4}$ | 90% 90% 90% 90% 90% Confidence level 90% 90% |
| 770 771 772 773 774 775 776 | $\begin{array}{cccc} p n & \rightarrow & e^+ \overline{\nu} \\ p n & \rightarrow & \mu^+ \overline{\nu} \\ n n & \rightarrow & \nu_e \overline{\nu}_e \\ n n & \rightarrow & \nu_\mu \overline{\nu}_\mu \\ p n & \rightarrow & \text{invisible} \\ p p & \rightarrow & \text{invisible} \\ \hline p p & \rightarrow & \text{invisible} \\ \\ \hline \hline \hline \rho b & e^- \gamma \\ \hline \hline \rho & \rightarrow & \mu^- \gamma \\ \hline \rho & \rightarrow & e^- \pi^0 \\ \end{array}$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) $> 7 \times 10^{5}$ $> 5 \times 10^{4}$ $> 4 \times 10^{5}$ | 90% 90% 90% 90% 90% Confidence level 90% 90% |
| 770 771 772 773 774 775 776 @ 777 778 779 780 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) $> 7 \times 10^{5}$ $> 5 \times 10^{4}$ $> 4 \times 10^{5}$ $> 5 \times 10^{4}$ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% |
| 770 771 772 773 774 775 776 @ 777 778 779 780 781 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 $ $ > 2.8 $ $ > 1.6 $ $ > 0.000049 $ $ > 2.10 \times 10^{25} $ $ > 0.00005 $ AY MODES | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 788 779 780 781 782 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 $ $ > 2.8 $ $ > 1.6 $ $ > 0.000049 $ $ > 2.10 \times 10^{25} $ $ > 0.00005 $ AY MODES Partial mean life (years) $ > 7 \times 10^{5} $ $ > 5 \times 10^{4} $ $ > 4 \times 10^{5} $ $ > 5 \times 10^{4} $ $ > 2 \times 10^{4} $ $ > 8 \times 10^{3} $ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 788 779 780 781 782 783 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 2 \times 10^4 \\ > 8 \times 10^3 \\ > 900 $ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 788 780 781 782 783 784 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | > 1.7 > 2.8 > 1.6 > 0.000049 $> 2.10 \times 10^{25}$ > 0.00005 AY MODES Partial mean life (years) $> 7 \times 10^{5}$ $> 5 \times 10^{4}$ $> 4 \times 10^{5}$ $> 5 \times 10^{4}$ $> 2 \times 10^{4}$ $> 8 \times 10^{3}$ > 900 $> 4 \times 10^{3}$ | 90% 90% 90% 90% 00% Confidence level 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 778 779 780 781 782 783 784 785 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $\begin{array}{c} > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 \\ \\ > 2.10 \times 10^{25} \\ > 0.00005 \\ \hline \textbf{AY MODES} \\ \\ \begin{array}{c} \text{Partial mean life} \\ \text{(years)} \\ \\ \hline \\ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 2 \times 10^4 \\ > 8 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 9 \times 10^3 \\ \\ \end{array}$ | 90% 90% 90% 90% 00% Confidence level 90% 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 78 779 780 781 782 783 784 785 786 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10$ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 788 779 780 781 782 783 784 785 786 787 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 2 \times 10^4 \\ > 8 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 9 \times 10^3 \\ > 7 \times 10^3 \\ > 2 \times 10^4 $ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 778 779 780 781 782 783 784 785 786 787 788 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10^5 \\ > 7 \times 10$ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 2 \times 10^4 \\ > 8 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 9 \times 10^3 \\ > 7 \times 10^3 \\ > 2 \times 10^4 \\ > 2 \times 10^4 \\ > 2 \times 10^4 $ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% 90% 90% 90% 90% |
| 770 771 772 773 774 775 776 © 777 778 779 780 781 782 783 784 785 786 787 788 | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | $ > 1.7 \\ > 2.8 \\ > 1.6 \\ > 0.000049 $ $ > 2.10 \times 10^{25} \\ > 0.00005 $ $ AY MODES $ Partial mean life (years) $ > 7 \times 10^5 \\ > 5 \times 10^4 \\ > 4 \times 10^5 \\ > 5 \times 10^4 \\ > 2 \times 10^4 \\ > 8 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 900 \\ > 4 \times 10^3 \\ > 9 \times 10^3 \\ > 7 \times 10^3 \\ > 2 \times 10^4 $ | 90% 90% 90% 90% 90% Confidence level 90% 90% 90% 90% 90% 90% 90% 90% |

p PARTIAL MEAN LIVES

The "partial mean life" limits tabulated here are the limits on τ/B_i , where au is the total mean life for the proton and B_i is the branching fraction for the mode in question.

Decaying particle: p= proton, n= bound neutron. The same event may appear under more than one partial decay mode. Background estimates may be accurate to a factor of two.

| Antilepton | | macan | |
|----------------|---|----------|--|
| Alluquo | - | IIICOUII | |

| $\tau(N \to e^{-1})$ | ⁺ π) | | | | | | | $	au_1$ |
|--------------------------|-----------------|-----------|-----|-----------------------|-------|------------------|-----|---------|
| (10 ³⁰ years) | PARTICLE | CL% EV | TS | BKGD EST | | DOCUMENT ID | | TECN |
| >8200 | P | 90 | 0 | 0.3 | | NISHINO | 09 | SKAM |
| > 158 | n | 90 | 3 | 5 | | MCGREW | 99 | IMB3 |
| • • • We d | lo not use the | following | dat | a for averages, fits, | , lir | nits, etc. • • • | | |
| > 540 | p | 90 | 0 | 0.2 | | MCGREW | 99 | IMB3 |
| >1600 | p | 90 | 0 | 0.1 | | SHIOZAWA | 98 | SKAM |
| > 70 | p | 90 | 0 | 0.5 | | BERGER | 91 | FREJ |
| > 70 | n | 90 | 0 | ≤ 0.1 | | BERGER | 91 | FREJ |
| > 550 | p | 90 | 0 | 0.7 | 35 | BECKER-SZ | 90 | IMB3 |
| > 260 | p | 90 | 0 | < 0.04 | | HIRATA | 89c | KAMI |
| > 130 | n | 90 | 0 | < 0.2 | | HIRATA | 89c | KAMI |
| > 310 | p | 90 | 0 | 0.6 | | SEIDEL | 88 | IMB |
| > 100 | n | 90 | 0 | 1.6 | | SEIDEL | 88 | IMB |
| > 1.3 | n | 90 | 0 | | | BARTELT | 87 | SOUD |
| > 1.3 | p | 90 | 0 | | | BARTELT | 87 | SOUD |
| > 250 | p | 90 | 0 | 0.3 | | HAINES | 86 | IMB |
| > 31 | n | 90 | 8 | 9 | | HAINES | 86 | IMB |
| > 64 | p | 90 | 0 | < 0.4 | | ARISAKA | 85 | KAMI |
| > 26 | n | 90 | 0 | < 0.7 | | ARISAKA | 85 | KAMI |
| > 82 | p (free) | 90 | 0 | 0.2 | | BLEWITT | 85 | IMB |
| > 250 | p | 90 | 0 | 0.2 | | BLEWITT | 85 | IMB |
| > 25 | n | 90 | 4 | 4 | | PARK | 85 | IMB |
| > 15 | p, n | 90 | 0 | | | BATTISTON | 84 | NUSX |
| > 0.5 | p | 90 | 1 | 0.3 | 36 | BARTELT | 83 | SOUD |
| > 0.5 | n | 90 | 1 | 0.3 | 36 | DANTELL | 83 | SOUD |
| > 5.8 | p | 90 | 2 | | 37 | MINISHINA | 82 | KOLR |
| > 5.8 | n | 90 | 2 | | 37 | | 82 | KOLR |
| > 0.1 | n | 90 | | | 38 | GURR | 67 | CNTR |

³⁵ This BECKER-SZENDY 90 result includes data from SEIDEL 88. 36 Limit based on zero events. 37 We have calculated 90% CL limit from 1 confined event. 38 We have converted half-life to 90% CL mean life.

| $\tau(N \to \mu)$ | ⁺ π) | | | | | | $	au_2$ |
|-----------------------------------|-----------------|-------------|------|---------------------------|------------------|-----|---------|
| (10 ³⁰ years) | PARTICLE | CL% EV | T S | BKGD EST | DOCUMENT ID | | TECN |
| >6600 | P | 90 | 0 | 0.3 | NISHINO | 09 | SKAM |
| > 100 | 'n | 90 | 0 | <0.2 | HIRATA | 89c | KAMI |
| • • • We d | lo not use the | following o | lata | a for averages, fits, lir | nits, etc. • • • | | |
| > 473 | p | 90 | 0 | 0.6 | MCGREW | 99 | IMB3 |
| > 90 | n | 90 | 1 | 1.9 | MCGREW | 99 | IMB3 |
| > 81 | p | 90 | 0 | 0.2 | BERGER | 91 | FREJ |
| > 35 | n | 90 | 1 | 1.0 | BERGER | 91 | FREJ |
| > 230 | p | 90 | 0 | < 0.07 | HIRATA | 89c | KAMI |
| > 270 | p | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 63 | n | 90 | 0 | 0.5 | SEIDEL | 88 | IMB |
| > 76 | p | 90 | 2 | 1 | HAINES | 86 | IMB |
| > 23 | n | 90 | 8 | 7 | HAINES | 86 | IMB |
| > 46 | p | 90 | 0 | < 0.7 | ARISAKA | 85 | KAMI |
| > 20 | n | 90 | 0 | < 0.4 | ARISAKA | 85 | KAMI |
| > 59 | p (free) | 90 | 0 | 0.2 | BLEWITT | 85 | IMB |
| > 100 | p | 90 | 1 | 0.4 | BLEWITT | 85 | IMB |
| > 38 | n | 90 | 1 | 4 | PARK | 85 | IMB |
| > 10 | p, n | 90 | 0 | | BATTISTON | 84 | NUSX |
| > 1.3 | p, n | 90 | 0 | | ALEKSEEV | 81 | BAKS |
| $\tau(N \to \nu)$ | π) | | | | | | $	au_3$ |
| LIMIT (10 ³⁰ years) | PARTICLE | CL% EV | TS | BKGD EST | DOCUMENT ID | | TECN |
| > 16 | P | 90 | 6 | 6.7 | WALL | 00B | SOU2 |
| >112 | n | 90 | 6 | 6.6 | MCGREW | 99 | IMB3 |
| • • • We d | lo not use the | following o | lata | a for averages, fits, lir | nits, etc. • • • | | |
| > 39 | n | 90 | 4 | 3.8 | WALL | 00в | SOU2 |
| > 10 | p | 90 1 | 5 | 20.3 | MCGREW | 99 | IMB3 |
| > 13 | n | 90 | 1 | 1.2 | BERGER | 89 | FREJ |
| > 10 | p | 90 1 | 1 | 14 | BERGER | 89 | FREJ |
| > 25 | p | 90 3 | 32 | 32.8 | HIRATA | 89c | KAMI |
| >100 | n | 90 | 1 | 3 | HIRATA | 89c | KAMI |
| > 6 | n | 90 | 73 | 60 | HAINES | 86 | IMB |
| > 2 | p | 90 1 | 6 | 13 | KAJITA | 86 | KAMI |

| > 40 | п | 90 | 0 | 1 | KAJITA 86 KAMI |
|------|-----|----|-----|----|-------------------------------|
| > 7 | n | 90 | 28 | 19 | PARK 85 IMB |
| > 7 | n | 90 | 0 | | BATTISTONI 84 NUSX |
| > 2 | p | 90 | ≤ 3 | | BATTISTONI 84 NUSX |
| > 5. | 8 p | 90 | 1 | | ⁴⁰ KRISHNA 82 KOLR |
| > 0. | 3 p | 90 | 2 | | ⁴¹ CHERRY 81 HOME |
| > 0. | 1 p | 90 | | | ⁴² GURR 67 CNTR |

 $^{^{39}}$ In estimating the background, this HIRATA 89c limit (as opposed to the later limits of WALL 00B and MCGREW 99) does not take into account present understanding that the flux of ν_{μ} originating in the upper atmosphere is depleted. Doing so would reduce the background and thus also would reduce the limit here. 40 We have calculated 90% CL limit from 1 confined event. 41 We have converted 2 possible events to 90% CL limit. 42 We have converted 40 No. (CL maps) life

| 42 We have converted | | |
|----------------------|--|--|

| p → e ⁻ | $\lceil \eta angle$ | | | | | | τ_4 |
|--------------------|------------------------------|-----------------------------------------------------------------------------------------------------|------|-------------------------|---------------------|------------------------------------------------|------------------------------------------------|
| IT O years) | PARTICLE | CL% EV | TS | BKGD EST | DO CUMENT ID | | TECN |
| 13 | P | 90 | 0 | 0.2 | MCGREW | 99 | IMB3 |
| • We o | do not use the | following | data | a for averages, fits, l | imits, etc. • • • | | |
| 81 | p | 90 | 1 | 1.7 | WALL | 00в | SOU 2 |
| 44 | p | 90 | 0 | 0.1 | BERGER | 91 | FREJ |
| 40 | p | 90 | 0 | < 0.04 | HIRATA | 89c | KAMI |
| 00 | p | 90 | 0 | 0.6 | SEIDEL | 88 | IMB |
| :00 | p | 90 | 5 | 3.3 | HAINES | 86 | IMB |
| 64 | p | 90 | 0 | < 0.8 | ARISAKA | 85 | KAMI |
| 64 | p (free) | 90 | 5 | 6.5 | BLEWITT | 85 | IMB |
| :00 | p | 90 | 5 | 4.7 | BLEWITT | 85 | IMB |
| 1.2 | p | 90 | 2 | 4 | ³ CHERRY | 81 | HOME |
| | 81 44 44 40 000 64 64 64 000 | 10 years) PARTICLE 113 p • • We do not use the 81 p 44 p 40 p 00 p 00 p 00 p 64 p 64 p (free) 00 p | | | | PARTICLE CL% EVTS BKGD EST DOCUMENT ID | PARTICLE CL% EVTS BKGD EST DOCUMENT ID |

 $^{^{43}\,\}text{We}$ have converted 2 possible events to 90% CL limit.

| $\tau(p \rightarrow I)$ | $\mu^+ \eta)$ | | | | | τ |
|-------------------------|-----------------|-----------|---------|----------------|----------------------------|------|
| (10 ³⁰ year | rs) PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | TECN |
| >126 | P | 90 | 3 | 2.8 | MCGREW 99 | IMB3 |
| • • • V | Ve do not use t | he follow | ing dat | a for averages | , fits, limits, etc. • • • | |
| > 89 | p | 90 | 0 | 1.6 | WALL 00B | SOU2 |
| > 26 | p | 90 | 1 | 0.8 | BERGER 91 | FREJ |
| > 69 | p | 90 | 1 | < 0.08 | HIRATA 89c | KAMI |
| > 1.3 | p | 90 | 0 | 0.7 | PHILLIPS 89 | HPW |
| > 34 | p | 90 | 1 | 1.5 | SEIDEL 88 | IMB |
| > 46 | p | 90 | 7 | 6 | HAINES 86 | IMB |
| > 26 | p | 90 | 1 | < 0.8 | ARISAKA 85 | KAMI |
| > 17 | p (free) | 90 | 6 | 6 | BLEWITT 85 | IMB |
| > 46 | p | 90 | 7 | 8 | BLEWITT 85 | IMB |

| $\tau(n 	o u \tau)$ | ₁) | | | | | $	au_6$ |
|-----------------------------------|----------------|-----|------|----------|-------------|---------|
| LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | TECN |

| (10 | years) PARTICE | E CL76 | EVIS | DNUD EST | DOCUMENTID | | TECN |
|-------|----------------|----------------|--------|---------------|-----------------------------|-----|------|
| >158 | 3 п | 90 | 0 | 1.2 | MCGREW | 99 | IMB3 |
| • • • | • We do not us | e the followin | g dat: | a for average | s, fits, limits, etc. • • • | | |
| > 71 | n | 90 | 2 | 3.7 | WALL | 00в | SOU2 |
| > 29 |) n | 90 | 0 | 0.9 | BERGER | 89 | FREJ |
| > 54 | l n | 90 | 2 | 0.9 | HIRATA | 89c | KAMI |
| > 16 | o n | 90 | 3 | 2.1 | SEIDEL | 88 | IMB |
| > 25 | i n | 90 | 7 | 6 | HAINES | 86 | IMB |
| > 30 |) n | 90 | 0 | 0.4 | KAJITA | 86 | KAMI |
| > 18 | 3 n | 90 | 4 | 3 | PARK | 85 | IMB |
| > (|).6 n | 90 | 2 | | ⁴⁴ CHERRY | 81 | HOME |

| -(N → 0 IMIT | ν) | | | | | | | |
|----------------------------------------|--------------|------------|--------|-------------------|----------|-----------------|-----|------|
| <i>IMIT</i> 10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | | DOCUMENT ID | | TECN |
| >217 | n | 90 | 4 | 4.8 | | MCGREW | 99 | IMB3 |
| > 75 | P | 90 | 2 | 2.7 | | HIRATA | 89c | KAN |
| • • We | do not use t | he followi | ng dat | a for averages, f | its, lim | its, etc. • • • | • | |
| > 29 | p | 90 | 0 | 2.2 | | BERGER | 91 | FRE |
| > 41 | n | 90 | 0 | 1.4 | | BERGER | 91 | FRE. |
| > 58 | n | 90 | 0 | 1.9 | | HIRATA | 89c | KAN |
| > 38 | n | 90 | 2 | 4.1 | | SEIDEL | 88 | IMB |
| > 1.2 | р | 90 | 0 | | | BARTELT | 87 | SOU |
| > 1.5 | n | 90 | 0 | | | BARTELT | 87 | SOU |
| > 17 | р | 90 | 7 | 7 | | HAINES | 86 | IMB |
| > 14 | n | 90 | 9 | 4 | | HAINES | 86 | IMB |
| > 12 | р | 90 | 0 | <1.2 | | ARISAKA | 85 | ΚΑN |
| > 6 | n | 90 | 2 | <1 | | ARISAKA | 85 | ΚΑN |
| > 6.7 | p (free) | 90 | 6 | 6 | | BLEWITT | 85 | IMB |
| > 17 | р | 90 | 7 | 7 | | BLEWITT | 85 | IMB |
| > 12 | n | 90 | 4 | 2 | | PARK | 85 | IMB |
| > 0.6 | n | 90 | 1 | 0.3 | | BARTELT | 83 | SOU |
| > 0.5 | p | 90 | 1 | 0.3 | | BARTELT | 83 | SOU |
| > 9.8 | p | 90 | 1 | | 46 | KRISHNA | 82 | KOL |
| > 0.8 | р | 90 | 2 | | 47 | CHERRY | 81 | HO1 |

⁴⁵ Limit based on zero events.
46 We have calculated 90% CL limit from 0 confined events.

⁴⁷ We have converted 2 possible events to 90% CL limit.

| $(N \rightarrow \mu$ | + a) | | | | | | <i>τ</i> 8 | $\tau(N \rightarrow e^{-}$ | + K) | | | | | | | $	au_1$ |
|-------------------------------|----------------------------|------------------|--------------------|----------------------------------|------------------------------------------------|----------------|---------------------|------------------------------------------|--------------------------------|-------------------|-------------|---------------------|-------------|--------------------------------|-----------|--------------|
| MIT | • | | | | | | 78 | LIMIT | • | | | | | | | 71 |
| 0 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST 9.5 | DO CUMENT ID | 00 | TECN_ | (10 ³⁰ years) | PARTICLE | | | BKGD EST 29.4 | - | DOCUMENT ID | | TECN |
| >228 >110 | n P | 90 90 | | 1.7 | MCGREW HIRATA | 99 89c | IMB3 KAMI | > 17 >150 | n P | 90 90 | 35 0 | < 0.27 | | MCGREW HIRATA | 99 89c | IMB3 KAMI |
| | | | | | fits, limits, etc. • • • | | | | | | ng data | | , fits, li | mits, etc. • • | | |
| - 12 | p | 90 | | 0.5 | BERGER | 91 | FREJ | > 85 | p | 90 | | 4.9 | | WALL | 00 | SOU 2 |
| 22 23 | n n | 90 90 | | 1.1 1.8 | BERGER HIRATA | 91 89c | FREJ KAMI | > 31 > 60 | p | 90 90 | 23 0 | 25.2 | | MCGREW BERGER | 99 91 | IMB3 FREJ |
| 4.3 | p | 90 | | 0.7 | PHILLIPS | 89 | HPW | > 70 | p p | 90 | | 1.8 | | SEIDEL | 88 | IMB |
| 30 | p | 90 | | 0.5 | SEIDEL | 88 | IMB | > 77 | p | 90 | 5 | 4.5 | | HAINES | 86 | IMB |
| 11 16 | n p | 90 90 | | 1.1 4.5 | SEIDEL HAINES | 88 86 | IMB IMB | > 38 | p (6) | 90 | | < 0.8 | | ARISAKA | 85 | KAMI |
| . 7 | n | 90 | | 5 | HAINES | 86 | IMB | > 24 > 77 | p (free) p | 90 90 | 5 | 8.5 4 | | BLEWITT BLEWITT | 85 85 | IMB IMB |
| 12 | p | 90 | | < 0.7 | ARISAKA | 85 | KAMI | > 1.3 | p p | 90 | 0 | | | ALEKSEEV | 81 | BAKS |
| · 5 · 5.5 | n p (free) | 90 90 | 4 | <1.2 5 | ARISAKA BLEWITT | 85 85 | KAMI IMB | > 1.3 | n | 90 | 0 | | | ALEKSEEV | 81 | BAKS |
| 16 | p | 90 | 4 | | BLEWITT | 85 | IMB | $\tau(p \rightarrow e^+$ | K_5^0 | | | | | | | τ |
| . 9 | n | 90 | 1 | 2 | PARK | 85 | IMB | LIMIT | ٠, | GLD/ | FVTC | DV.CD FCT | | DO CUMENT ID | | |
| $(N \rightarrow \nu)$ | ρ) | | | | | | <i>T</i> 9 | (10 ³⁰ years) >2000 | PARTICLE D | <u>CL%</u> 90 | EVTS 6 | BKGD EST 4.7 | - 5: | DOCUMENT ID KOBAYASHI | 05 | TECN SKAN |
| MIT 0 ³⁰ years) | • | GLD/ | FVTC | DV.CD FCT | DO CUMENT ID | | TECN | | | | | | | mits, etc. • • | | 510711 |
| >162 | PARTICLE P | <u>CL%</u> 90 | EVTS 18 | | <u>DOCUMENT ID</u> MCGREW | 99 | IMB3 | > 120 | р | 90 | 1 | 1.3 | | WALL | 00 | SOU2 |
| 19 | n | 90 | | 0.5 | SEIDEL | 88 | IMB | > 76 | p | 90 | | 0.5 | | BERGER | 91 | FREJ |
| • • We d | lo not use the | followi | ng dat | a for averages, | fits, limits, etc. • • • | | | ⁵³ We hav | e doubled th | $p \rightarrow$ | $e^+ K^0$ | limit given in | KOB/ | AYASHI 05 to 0 | obtain | this p - |
| 9 | n | 90 | | 2.4 | BERGER | 89 | FREJ | e^+ κ^0_S | limit. | | | | | | | |
| 24 27 | p p | 90 90 | | 0.9 1.5 | BERGER HIRATA | 89 89c | FREJ KAMI | $\tau(p \rightarrow e^+$ | - K ⁰) | | | | | | | τ_1 |
| 13 | n | 90 | 4 | 3.6 | HIRATA | 89c | KAMI | LIMĮŢ | | | | | | | | |
| 13 8 | p | 90 | | 1.1 | SEIDEL | 88 | IMB | | PARTICLE | | | BKGD EST | - | DO CUMENT ID | | TECN |
| | р п | 90 90 | 6 15 | | HAINES HAINES | 86 86 | IMB IMB | >51 | p To not use th | 90 ne followii | | 3.5 for averages | fits li | WALL mits, etc. • • ∙ | 00 | SOU 2 |
| 2 11 | p | 90 | 2 | | KAJITA | 86 | KAMI | >44 | D | 90 | - | ≤ 0.1 | , | BERGER | 91 | FREJ |
| 4 4.1 | n (c.) | 90 | | 2 | KA JITA | 86 | KAMI | | • | 30 | • | - *** | | DENGEN | | |
| 4.1 8.4 | p (free) p | 90 90 | | 7 5 | BLEWITT BLEWITT | 85 85 | IMB IMB | $	au(N	o\mu$ | + <i>K</i>) | | | | | | | τ |
| 2 | n | 90 | 7 | | PARK | 85 | IMB | LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | | DO CUMENT ID | | TECN |
| 0.9 | p | 90 | 2 | | 48 CHERRY | 81 | HOME | >120 | p | 90 | 0 | <1.2 | - | WALL | 00 | SOU2 |
| 0.6 3 xav- h | n | 90 | 2 | s to 90% CL li | ⁴⁸ CHERRY | 81 | HOME | >120 | P | 90 | | 7.2 | | MCGREW | 99 | IMB3 |
| | | possible | e eveni | .S 10 90% CL II | mit. | | | > 26 >120 | n P | 90 90 | | 28.4 0.4 | | MCGREW HIRATA | 99 89c | IMB3 KAMI |
| $p \rightarrow e^+$ | ω) | | | | | | $	au_{10}$ | | | | | | , fits, li | mits, etc. • • | | |
| <i>IIT</i> 30 years) | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TECN | > 54 | p | 90 | 0 | | | BERGER | 91 | FREJ |
| 107 | P | 90 | | 10.8 | MCGREW | 99 | IMB3 | > 3.0 | p | 90 | | 0.7 | | PHILLIPS | 89 | HPW |
| | | | | | fits, limits, etc. • • • | | | > 19 > 1.5 | p p | 90 90 | 3 0 | 2.5 | 5, | SEIDEL ¹ BARTELT | 88 87 | IMB SOUD |
| 17 45 | p p | 90 90 | | 1.1 1.45 | BERGER HIRATA | 91 89c | FREJ KAMI | > 1.1 | n | 90 | 0 | | | BARTELT | 87 | SOUD |
| 26 | p | 90 | | 1.0 | SEIDEL | 88 | IMB | > 40 | p | 90 | | 6 | | HAINES | 86 | IMB |
| 1.5 | p | 90 | 0 | | BARTELT | 87 | SOUD | > 19 > 6.7 | p p (free) | 90 90 | 1 11 | <1.1 | | ARISAKA BLEWITT | 85 85 | KAMI IMB |
| 37 25 | p p | 90 90 | 6 1 | 5.3 <1.4 | HAINES ARISAKA | 86 85 | IMB KAMI | > 40 | p () | 90 | | 8 | | BLEWITT | 85 | IMB |
| 12 | p (free) | 90 | | 7.5 | BLEWITT | 85 | IMB | > 6 | p | 90 | 1 | | 51 | BATTISTON | | NUSX |
| 37 | p | 90 | | 5.7 | BLEWITT | 85 | IMB | > 0.6 > 0.4 | p n | 90 90 | 0 | | 5! | BARTELT | 83 83 | SOUD SOUD |
| 0.6 9.8 | p | 90 90 | 1 | 0.3 | ⁴⁹ BARTELT ⁵⁰ KRISHNA | 83 82 | SOUD KOLR | > 5.8 | p | 90 | 2 | | 5/ | KRISHNA | 82 | KOLR |
| 2.8 | p p | 90 | 2 | | 51 CHERRY | 81 | HOME | > 2.0 | p | 90 | 0 | | 5 | CHERRY GURR | 81 | HOME |
| 9 Limit b | sed on zero | vents. | | | | | | > 0.2 | n | 90 | | 1.440 | 3 | GURR | 67 | CNTR |
| °vve nav | e calcillated s | 111% (1 | limit f e event | rom 0 confined s to 90% CL li | events. mit. | | | | LT 87 limit | | | | | | | |
| $p \rightarrow \mu^+$ | | | | | | | | 56 We hav | e calculated | 90% CL | limit fr | om 1 confined | l event | | | |
| | ω) | | | | | | $	au_1$ | 57 We hav | e converted | half-life to | 90% | CL mean life. | | | | |
| | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TECN | $\tau(ho 	o \mu^{+}$ | [⊦] K _S 0) | | | | | | | $	au_1$ |
| 117 • • \/\^ c | p lo not use the | 90 followi | | 12.1 | MCGREW fits, limits, etc. • • • | 99 | IMB3 | <i>LIMIT</i> (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | | DOCUMENT ID | | TECN |
| 11 | p | 90 | - | 1.0 | BERGER | 91 | FREJ | >2600 | D | 90 | | 3.9 | - 5: | KOBAYASHI | 05 | SKAM |
| 57 | p | 90 | | 1.9 | HIRATA | | KAMI | | • | | | | | mits, etc. • • | | 510,000 |
| 4.4 | p | 90 | | 0.7 | PHILLIPS | 89 | HPW | > 150 | р | 90 | - 0 | < 0.8 | | WALL | 00 | SOU2 |
| 10 23 | p p | 90 90 | | 1.3 1 | SEIDEL HAINES | 88 86 | IMB IMB | > 64 | p | 90 | | 1.2 | | BERGER | 91 | FREJ |
| 6.5 | p (free) | 90 | | 8.7 | BLEWITT | 85 | IMB | | | $p \rightarrow p$ | $\mu^+ K^0$ | limit given in | ı KOB/ | AYASHI 05 to 0 | obtain | this p |
| 23 | p | 90 | 8 | 7 | BLEWITT | 85 | IMB | $\mu^+ \kappa^0_S$ | limit. | | | | | | | |
| $n \rightarrow \nu a$ | <i>)</i>) | | | | | | <i>τ</i> 12 | $	au(ho 	o \mu^{+}$ | + K ⁰) | | | | | | | η |
| UT. | , | | | | | | | LIMIT | | | | | | | | |
| 108 | PARTICLE | <u>CL%</u> 90 | | BKGD EST 22.5 | DOCUMENT ID | 99 | IMB3 | (10 ³⁰ years) >83 | PARTICLE | | | BKGD EST | - | DOCUMENT ID | 00 | SOU 2 |
| | n lo not use the | | | | MCGREW fits, limits, etc. • • • | 99 | I IVID 3 | | p do not use ti | | | | , fits, li | | | 3002 |
| 17 | n | 90 | - | 0.7 | BERGER | 89 | FREJ | >44 | p | 90 | - | ≤ 0.1 | , | BERGER | 91 | FREJ |
| 43 | n | 90 | 3 | 2.7 | HIRATA | 89c | KAMI | | • | - | · | | | | | |
| 6 | n n | 90 90 | | 1.3 6 | SEIDEL HAINES | 88 86 | IMB IMB | | | | | | | | | |
| 12 | | J U | 0 | J | HAINES | 86 | IND | | | | | | | | | |
| 12 18 | n | 90 | | 2 | KAJITA | 86 | KAMI | | | | | | | | | |
| | | | | | | 86 85 81 | KAMI IMB HOME | | | | | | | | | |

Baryon Particle Listings

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| r(N → ν . _{IMIT} | · n) | | | | | | $	au_{19}$ | $\tau(p \rightarrow e^+)$ | <i>π π</i> -) | | | | | | τ |
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| .0 ³⁰ years) | PARTICLE | CL% | | BKGD EST | DO CUMENT ID | | TECN | (10 ³⁰ years) | PARTICLE | | | BKGD EST | DO CUMENT ID | | TEC |
| >2300 | P | 90 | | 1.3 | KOBAYA SHI | 05 | SKAM | >147 | P | 90 | | 0.8 | | 99 | IMB |
| > 86 | n | 90 | | 2.4 | HIRATA | | KAMI | | lo not use the | | - | _ | fits, limits, etc. • • • | | |
| | | | | | fits, limits, etc. • • • | | | > 38 | p | 90 | 1 | 0.5 | BERGER | 91 | FRE |
| - 26 - 670 | n | 90 90 | 16 | 9.1 | WALL | 00 | SOU2 | $\tau(n \rightarrow e^+$ | ~~~0) | | | | | | |
| > 670 > 151 | p p | 90 | 15 | 21.4 | HAYATO MCGREW | 99 99 | SKAM IMB3 | | | | | | | | |
| > 30 | n | 90 | | 34.1 | MCGREW | | IMB3 | LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TECI |
| > 43 | p | 90 | | 1.54 | ⁵⁹ ALLISON | 98 | SOU2 | >52 | n | 90 | 38 | 34.2 | MCGREW | 99 | IMB |
| > 15 | n | 90 | 1 | 1.8 | BERGER | 89 | FREJ | • • • We d | lo not use the | followi | ng dat | a for averages, | fits, limits, etc. • • • | | |
| > 15 | p | 90 | | 1.8 | BERGER | 89 | FREJ | >32 | n | 90 | 1 | 0.8 | BERGER | 91 | FRE |
| > 100 | p | 90 | | 7.3 | HIRATA | | KAMI | • | | | | | | | |
| > 0.28 | p | 90 | | 0.7 | PHILLIPS | 89 | HPW | $\tau(ho 	o \mu^+$ | $^{+}\pi^{+}\pi^{-})$ | | | | | | |
| > 0.3 | p | 90 90 | 0 | | BARTELT ⁶⁰ BARTELT | 87 | SOUD | LIMIT (10 ³⁰ years) | • | | | | | | |
| > 0.75 > 10 | n | 90 | 6 | E | HAINES | 87 86 | SOUD IMB | | PARTICLE | CL% | | BKGD EST | DO CUMENT ID | | TEC |
| > 15 | p n | 90 | 3 | | HAINES | | IMB | >133 | P | 90 | 25 | 38.0 | | 99 | IMB |
| > 28 | D D | 90 | 3 | | KAJITA | 86 | KAMI | • • • We d | lo not use the | followi | ng dat | a for averages, | fits, limits, etc. • • • | | |
| > 32 | n | 90 | | 1.4 | KAJITA | 86 | KAMI | > 17 | p | 90 | 1 | 2.6 | BERGER | | FRE |
| > 1.8 | p (free) | 90 | 6 | 11 | BLEWITT | 85 | IMB | > 3.3 | p | 90 | 0 | 0.7 | PHILLIPS | 89 | HPV |
| > 9.6 | p | 90 | 6 | 5 | BLEWITT | 85 | IMB | / | - 0 0 | | | | | | |
| > 10 | n | 90 | 2 | 2 | PARK | 85 | IMB | $\tau(p \to \mu^+$ | | | | | | | |
| > 5 | n | 90 | 0 | | BATTISTONI | 84 | NUSX | <i>LIMIT</i> (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TECN |
| > 2 | p | 90 | 0 | | BATTISTONI | 84 | NUSX | >101 | PARTICLE D | 90 | | 1.6 | | | IMB: |
| > 0.3 | n | 90 | 0 | | 61 BARTELT | 83 | SOUD | | | | | | fits, limits, etc. • • • | ,, | IVID |
| > 0.1 | p | 90 | 0 | | 62 KRICHNA | 83 | SOUD | | | | - | _ | | | |
| > 5.8 > 0.3 | p n | 90 90 | 1 2 | | ⁶² KRISHNA ⁶³ CHERRY | 82 81 | KOLR HOME | > 33 | p | 90 | 1 | 0.9 | BERGER | 91 | FRE |
| | | | | | | | | $	au(extsf{n}	o \mu^+$ | + _π - _π 0) | | | | | | |
| Ihis A | LLISON 98 li | mit is w 0 | ith no | packground su | btraction; with subtra | iction | ine iimit | I (II → μ LIMIT | , | | | | | | |
| Decom | es $>$ 46 $	imes$ 10^3 ELT 87 limit a | years. | | , , 0 | | | | (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TEC |
| BAKTI | ELI 07 IIMILA | ppnes to | $n \rightarrow$ | $\nu \kappa_{\tilde{S}}$ | | | | >74 | n | 90 | 17 | 20.8 | MCGREW | 99 | IMB |
| 62 Mo hay | pased on zero | events. | limit fi | om 1 confined | ovent | | | • • • We d | lo not use the | followi | ng dat | a for averages, | fits, limits, etc. • • • | | |
| 63 We hav | ve converted 2 | possible | e event | s to 90% CL lir | nit. | | | >33 | n | 90 | 0 | 1.1 | BERGER | 91 | FRE |
| | | | | | | | | | | | | | | | |
| $(n \rightarrow \nu$ | Ks) | | | | | | $	au_{20}$ | $\tau(n \rightarrow e^{+}$ | $K^{0}\pi^{-}$ | | | | | | |
| IMIT | | | | | | | | LIMIT | , | | | | | | |
| | | CL% | EVTS | BKGD EST | DO CUMENT ID | | | (10 ³⁰ years) | DADTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TEC |
| | - | | | | 6.4 | | TECN | (10 years) | PARTICLE | | | | | _ | |
| > 260 • • We > 51 ⁶⁴ We hav | n do not use the | 90 e followi 90 | 34 ng dat 16 | 30 a for averages, t 9.1 | 64 KOBAYA SHI fits, limits, etc. • • • WALL AYASHI 05 to obtain t | 00 | SKAM SOU2 | $7 (n \rightarrow e^{-10})$ | n - | 90 | 1 | 0.2 pton + meso | BERGER | | |
| > 260 • • We > 51 64 We have limit. | n do not use the n ve doubled the | 90 e followi 90 n → v | 34 ng dat 16 | 30 a for averages, t 9.1 | fits, limits, etc. • • • WALL | 00 | SKAM SOU2 | >18 | n - | | 1 | | BERGER | 91 | |
| > 260 • • We > 51 64 We have limit. | n do not use the | 90 e followi 90 n → v | 34 ng dat 16 | 30 a for averages, t 9.1 | fits, limits, etc. • • • WALL | 00 | SKAM SOU2 | 718 $\tau(n \rightarrow e^{-1})$ LIMIT | π - π ⁺) | 90 | 1 — Lep | pton + meso | BERGER DOCUMENT ID | 91 | <u>TECI</u> |
| >260 • • We > 51 64 We have limit. | n do not use the n ve doubled the + K*(892)0) | 90 e followi 90 $n \rightarrow \nu$ | 34 ng dat 16 K ⁰ lim | 30 a for averages, 1 9.1 it given in KOB | fits, limits, etc. • • • • WALL AYASHI 05 to obtain 1 | 00 | SKAM $SOU2$ $\rightarrow \nu K_S^0$ 721 | >18 $\tau(n \rightarrow e^{-1})$ $\frac{LIMIT}{(10^{30} \text{ years})}$ >65 | π+) PARTICLE n | 90 <u>CL%</u> 90 | 1 — Lep <u>EVTS</u> 0 | <u>BKGD EST</u> 1.6 | BERGER DOCUMENT ID | 91 | |
| >260 • • • We > 51 64 We have limit. • (p → e 10 ³⁰ years) | n do not use the n ve doubled the + K*(892)0 | 90 e followi 90 $n \rightarrow \nu$ | 34 ng dat 16 K ⁰ lim | 30 a for averages, 1 9.1 it given in KOB | fits, limits, etc. • • • WALL AYASHI 05 to obtain i | 00 this <i>n</i> | SKAM SOU 2 $\rightarrow \nu K_S^0$ 721 | >18 $\tau(n \rightarrow e^{-1})$ $\frac{LIMIT}{(10^{30} \text{ years})}$ >65 | π+) PARTICLE n | 90 <u>CL%</u> 90 | 1 — Lep EVTS 0 ng dat | <u>BKGD EST</u> 1.6 | BERGER DOCUMENT ID SEIDEL fits, limits, etc. • • • | 91 | <u>TECN</u> |
| >260 > • • We > 51 64 We have limit. - (p → e MMT 1030 years) >84 | n do not use the n re doubled the + K*(892)0 p | 90 e followi 90 $n \rightarrow \nu$ CL% 90 | 34 ng dat 16 K ⁰ lim <u>EVTS</u> 38 | 30 a for averages, 1 9.1 it given in KOB BKGD EST 52.0 | fits, limits, etc. • • • WALL AYASHI 05 to obtain to the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company of the company | 00 this <i>n</i> | SKAM $SOU2$ $\rightarrow \nu K_S^0$ 721 | >18 $\tau(n \rightarrow e^{-})$ $(10^{30})_{\text{years}}$ >65 ••• We co | n π^+) PARTICLE n Io not use the | 90 <u>CL%</u> 90 followi | 1 — Lep EVTS 0 ng dat | BKGD EST 1.6 a for averages, 1.09 | BERGER DOCUMENT ID SEIDEL fits, limits, etc. • • • BERGER | 91 88 91 _B | <u>TECI</u> I MB |
| >260 • • We > 51 64 We have limit. • (p → e) 1030 years) >84 • • We | n do not use the n ve doubled the + K*(892)0 PARTICLE p do not use the | 90 e followi 90 $n \rightarrow \nu$ CL% 90 e followi | 34 ng dat 16 K ⁰ lim EVTS 38 ng dat | 30 a for averages, 1 9.1 it given in KOB BKGD EST 52.0 a for averages, 1 | fits, limits, etc. • • • WALL AYASHI 05 to obtain to the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the companie of the comp | 00 this <i>n</i> | SKAM SOU2 $\rightarrow \nu K_S^0$ 721 TECN IMB3 | >18 \(\tau(n \to e^{-\text{LIMIT}} \) \(\text{(10^{30} years)} \) >65 \(\text{• • • We co} \) >55 | n $\pi^+)$ PARTICLE n lo not use the | 90 CL% 90 followi | Lep EVTS O ng dat 0 | BKGD EST 1.6 a for averages, 1.09 7 | BERGER DOCUMENT ID SEIDEL fits, limits, etc. • • • • BERGER HAINES | 91 88 91 _B 86 | <u>TECI</u> IMB FRE |
| >260 • • We > 51 64 We have limit. • (p → e MIT 1030 years) >84 • • We >10 | n do not use the n re doubled the + K*(892)0 PARTICLE P do not use the p | 90 e followi 90 $n \rightarrow \nu$ CL% 90 e followi 90 | 34 ng dat 16 K ⁰ lim EVTS 38 ng dat 0 | 30 a for averages, 1 9.1 it given in KOB BKGD EST 52.0 a for averages, 1 0.8 | fits, limits, etc. • • • WALL AYASHI 05 to obtain to to obtain to to obtain to to obtain to to obtain to to obtain to to obtain to to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain to obtain the obtain to obtain the obtain to obtain the obtain to obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain the obtain | 99 | SKAM SOU2 $\rightarrow \nu K_S^0$ 721 $\frac{TECN}{1MB3}$ FREJ | >18 \(\tau(n \rightarrow e^{-1}) \) \(\tau(10^{30} \text{ years}) \) >65 • • • We of (10) >55 >16 >25 | π+) PARTICLE n lo not use the n n | 90 <u>CL%</u> 90 following 90 90 | 1 - Lep EVTS 0 ng dat 0 9 | BKGD EST 1.6 a for averages, 1.09 7 | BERGER DOCUMENT ID SEIDEL fits, limits, etc. • • • • BERGER HAINES | 91 88 91 _B 86 | TECN IMB FRE IMB IMB |
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| >260 • • We > 51 64 We have limit(p → e MM/T 10300 years) >84 • • We >10 >51 -(N → v MM/T 1030 years) >51 >78 • • We >22 >17 >20 >10 >5 >8 >6 >5 8 >9 6 >5 8 >9 6 >5 8 >10 -(p → e MM/T 10300 years) >6 -(p → e MM/T 10300 years) >82 | n do not use the n re doubled the + K*(892)0 PARTICLE P do not use the p p p r K*(892)) PARTICLE P n do not use the n p p n p r f f f f f f f f f f f f f f f f f f | 90 e followi 90 90 90 90 90 90 90 90 90 90 90 90 90 | ### 34 Antile ### 20 Antile ### 20 Antile ### 20 Antile ### 20 Antile ### 20 Antile ### 20 Antile ### 20 Antile #### 20 Antile #### 20 Antile #### 20 Antile #### 20 Antile ################################### | 30 a for averages, 1 9.1 It given in KOB BKGD EST 52.0 a for averages, 1 0.8 1.55 <1 BKGD EST 9.1 2.4 2.1 2.4 6 6 7 2 1.6 16 6 4 to 90% CL lim epton + meso | DOCUMENT ID MCGREW fits, limits, etc. • • • MALL AYASHI 05 to obtain to the state of the state of the state of the state of the state of the state of the state of the state of 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| (Π → μ IMIT LO ³⁰ years) | ν, | | | | | | $	au_{35}$ | $\tau(p \to e^{-})$ | | | | | | | 1 |
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| | | | | BKGD EST | DO CUMENT ID | | TECN | LIMIT (10 ³⁰ years) | | | | BKGD EST | DO CUMENT ID | | TECN |
| • • We | n do not use th | 90 e followir | 0 2 ng data | | BERGER ts, limits, etc. • • • | 91B | FREJ | >100 | P | 90 | 1 | 0.8 | BERGER | 91 | FRE. |
| 4.7 | n | 90 | 0 (| = | PHILLIPS | 89 | HPW | $\tau(n \to \nu)$ | γγ) | | | | | | 1 |
| | | ,,, | | | | • • • | | LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DOCUMENT ID | | TECN |
| | • | | - Lept | on + mesons | | | | >219 | n | 90 | | 7.5 | MCGREW | 99 | IMB |
| $(p \rightarrow e^{-})$ | $^{-}\pi^{+}\pi^{+})$ | | | | | | <i>T</i> 36 | | - | | | | | | |
| MIT (³⁰ years) | | G1.0/ | EV.T.C. | | 00.004545 40 | | T5.00 | | | | nree | (or more) lep | tons ——— | | |
| .30 years) -30 | PARTICLE P | <u>CL%</u> . | | BKGD EST | <u>DOCUMENT ID</u> BERGER | 01 p | TECN FREJ | $\tau(p \rightarrow e^{-}$ | + e+ e−) | | | | | | |
| | • | | | | ts, limits, etc. • • • | 210 | TICES | LIMIT (10 ³⁰ years) | | G1.0/ | | DV 00 50T | 0.0 (1145) 7 (0.1 | | T. C. |
| 2.0 | D | 90 | 0 (| _ | PHILLIPS | 89 | HPW | (10 ³⁰ years) > 793 | PARTICLE | | <u>EV 1 S</u> | BKGD EST 0.5 | <u>DO CUMENT ID</u> MCGREW | 99 | TECN IMB: |
| | • | | - | | | | | | p do not use th | | _ | | fits, limits, etc. • • • | | IIVID |
| $(n \rightarrow e)$ | $^{-}\pi^{+}\pi^{0})$ | | | | | | <i>T</i> 37 | >147 | p | 90 | - | 0.1 | BERGER | 91 | FRE |
| MIT) ³⁰ years) | PARTICLE | CL% | EVTS I | BKGD EST | DO CUMENT ID | | TECN | >510 | p | 90 | | 0.3 | HAINES | 86 | IMB |
| 29 | 7 | 90 | 1 | | BERGER | 91в | FREJ | > 89 | p (free) | 90 | | 0.5 | BLEWITT | 85 | IMB |
| , | | | | | | | | >510 | p | 90 | U | 0.7 | BLEWITT | 85 | IMB |
| | $(-\pi^{+}\pi^{+})$ | | | | | | <i>T</i> 38 | $\tau(p \rightarrow e^{-}$ | $^{+}\mu^{+}\mu^{-})$ | | | | | | |
| MIT) ³⁰ years) | PARTICLE | CL% | EVTS I | BKGD EST | DO CUMENT ID | | TECN | LIMIT (10 ³⁰ years) | | CL0/ | FVTC | DVCD FCT | DO CUMENT ID | | TECA |
| 17 | p | 90 | 1 | 1.72 | BERGER | 91B | FREJ | >35 9 | PARTICLE P | | <u>EV 13</u> | BKGD EST | <u>DOCUMENT ID</u> MCGREW | 99 | TECN IMB |
| • • We | do not use th | e followir | ng data | for averages, fi | ts, limits, etc. 🔸 🔸 🔸 | | | - | • | | _ | | fits, limits, etc. • • • | | TIVID |
| 7.8 | p | 90 | 0 (|).7 | PHILLIPS | 89 | HPW | > 81 | р | 90 | - | 0.16 | BERGER | 91 | FRE |
| | $-\pi^{+}\pi^{0}$ | | | | | | <i>T</i> 39 | > 5.0 | p | 90 | 0 | 0.7 | PHILLIPS | 89 | HPV |
| IIT | , | | | | | | ,33 | $\tau(\rho \to e^-$ | + νν) | | | | | | |
| 30 years) | | | | BKGD EST | DO CUMENT ID | | TECN | LIMIT (10 ³⁰ years) | | | | | | | |
| 34 | п | 90 | 0 (|).78 | BERGER | 91B | FREJ | | | | | BKGD EST | DO CUMENT ID | | TEC |
| $p \rightarrow e^{i}$ | $^{-}\pi^{+}K^{+})$ | | | | | | $	au_{40}$ | >17 | p do not uso th | 90 o followin | 152 | | MCGREW fits, limits, etc. \bullet \bullet | 99 | IMB |
| UT | • | | | | | | | >11 | D | 90 | - | 6.08 | BERGER | | FRE |
| | | <u>CL%</u> | | BKGD EST 127.2 | DOCUMENT ID | | TECN | | • | 90 | 11 | 0.00 | BENGEN | 31 D | IIVL |
| ′5 • We | p do not use th | 90 e followir | | | MCGREW ts, limits, etc. • • • | 99 | IMB3 | $\tau(n \rightarrow e^{-}$ | ⊦e−ν) | | | | | | |
| :0 | p | 90 | 3 2 | = | BERGER | 91 B | FREJ | LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVTS | BKGD EST | DO CUMENT ID | | TEC |
| | • | 30 | | | BERGER | 710 | 11(23 | >257 | n | 90 | | 7.5 | MCGREW | 99 | IME |
| $p \rightarrow \mu$ | $-\pi^{+}K^{+}$ | | | | | | $	au_{41}$ | | do not use th | ne followin | ng dat | a for averages, | fits, limits, etc. • • • | | |
| <i>IIT</i> 30 _{years)} | PARTICLE | CL% | FVTS I | BKGD EST | DO CUMENT ID | | TECN | > 74 | n | 90 | 0 | < 0.1 | BERGER | 91B | FRE |
| 245 | P | 90 | | 1.0 | MCGREW | 99 | IMB3 | > 45 | n | 90 | | 5 | HAINES | 86 | IMB |
| • • We | - | e followir | ng data | for averages, fi | ts, limits, etc. • • • | | | > 26 | n | 90 | 4 | 3 | PARK | 85 | IMB |
| 5 | p | 90 | 2 (| 0.78 | BERGER | 91в | FREJ | $\tau(n \to \mu$ | + e ⁻ ν) | | | | | | |
| | | a | ntilent | on + photon | (s) ——— | | | LIMIT (10 ³⁰ years) | PARTICLE | CL% | EVT S | BKGD EST | DOCUMENT ID | | TEC |
| | | • | с ор | on , photon | .(-) | | | >83 | n | 90 | 25 | 29.4 | MCGREW | 99 | IME |
| $p \rightarrow e^{-}$ | $^{+}\gamma)$ | | | | | | $	au_{42}$ | • • • We | do not use th | ne followin | ng dat | a for averages, | fits, limits, etc. • • • | | |
| 11 <i>T</i> 30 _{ye ars)} | PARTICLE | CL% | EVTS I | BKGD EST | DO CUMENT ID | | TECN | >47 | n | 90 | 0 | < 0.1 | BERGER | 91B | FRE |
| 670 | P | 90 | | 0.1 | MCGREW | 99 | IMB3 | $\tau(n \to \mu$ | + u- v) | | | | | | |
| • We | do not use th | e followir | ng data | for averages, fi | ts, limits, etc. 🔸 🔸 🔸 | | | | μ ν) | | | | | | |
| 133 | p | 90 | 0 (| | BERGER | 91 | FREJ | <i>LIMIT</i> (10 ³⁰ years) | PARTICLE | | EVTS | BKGD EST | DO CUMENT ID | | TEC |
| 460 | p | 90 | 0 (| | SEIDEL | 88 | IMB | >79 | n | 90 | 100 | | MCGREW | 99 | IMB |
| 360 87 | p p (free) | 90 90 | 0 (| | HAINES BLEWITT | 86 85 | IMB IMB | | | | - | = | fits, limits, etc. • • • | | EDE |
| 360 | p (1100) | 90 | 0 (| | BLEWITT | 85 | IMB | >42 > 5.1 | n n | 90 90 | | 1.4 0.7 | BERGER PHILLIPS | 91B 89 | FRE HP\ |
| JUU | p | 90 | | | ⁶⁶ GURR | 67 | CNTR | >16 | n | 90 | 14 | | HAINES | 86 | IMB |
| 0.1 | | alf-life to | 90% (| CL mean life. | | | | >19 | n | 90 | 4 | 7 | PARK | 85 | IMB |
| 0.1 | ve converted h | | | | | | $	au_{43}$ | $\tau(\rho \to \mu$ | + e+ e-) | | | | | | |
| 0.1 We hav | | | | | | | -43 | | | | | | | | |
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BKGD EST | MCGREW ts, limits, etc. • • • BERGER SEIDEL HAINES BLEWITT BLEWITT 67 GURR | 91 88 86 85 85 | FREJ IMB IMB IMB IMB CNTR | >529 • • • We > 91 T(p → µ LIMIT (10 ³⁰ years) >675 • • • We >119 > 10.5 >190 > 44 >190 > 2.1 | p do not use the p + \(\mu^+ \mu^- \) \(\begin{align*} \text{PARTICLE} & \\ \mu \\ \nu & \end{align*} do not use the p p p (free) p p p (free) p p p (free) p p p p (free) p p p (free) p p (free) p p (free) p p (free) p p (free) p p (free) p p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (free) p (| 90 ne followin 90 | 0 ng dat 0 | a for averages, ≤ 0.1 $\frac{\mathit{BKGD EST}}{\textbf{0.3}}$ 0.3 a for averages, 0.2 0.7 0.1 0.7 0.9 | DOCUMENT ID MCGREW fits, limits, etc. • • • BERGER BERGER PHILLIPS HAINES BLEWITT BLEWITT 68 BATTISTONI | 91 99 91 89 86 85 | FRE HPV IME IME |
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| 0.1 b We hav p → µ /// /// /// /// /// /// /// /// /// | PARTICLE P p p p p p p p p p p p p | 90 e followin 90 90 90 90 90 90 90 alf-life to | 0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 | 0.1 for averages, fi 0.1 0.5 2 0.2 0.6 CL mean life. BKGD EST 144.7 for averages, fi 5.86 50 | MCGREW ts, limits, etc. • • • BERGER SEIDEL HAINES BLEWITT BLEWITT 67 GURR DOCUMENT ID MCGREW ts, limits, etc. • • • | 91 88 86 85 85 67 99 | FREJ IMB3 FREJ IMB IMB IMB CNTR T44 TECN IMB3 FREJ | >529 ••• We solve to produce the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the produce of the pr | p do not use the p + \(\mu^+ \mu^- \) PARTICLE P do not use the p p p p p p p p p p re- converted | 90 ne followin 90 | 0 ng dat 0 | a for averages, ≤ 0.1 $\frac{\mathit{BKGD EST}}{\textbf{0.3}}$ 0.3 a for averages, 0.2 0.7 0.1 0.7 0.9 | DOCUMENT ID MCGREW fits, limits, etc. • • • BERGER BERGER PHILLIPS HAINES BLEWITT BLEWITT 68 BATTISTONI | 91 99 91 89 86 85 85 | FRE HP\ IME IME |
| 0.1 We hav $\mathbf{p} = \mathbf{p} = p$ | PARTICLE P do not use th P P P P P P P P P P P P P | 200 e following 90 90 90 90 90 90 90 90 90 90 90 90 90 | 0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 (0 | 0.1 for averages, fi 0.1 0.5 2 0.2 0.6 CL mean life. BKGD EST 144.7 for averages, fi 5.86 50 | MCGREW ts, limits, etc. • • • BERGER SEIDEL HAINES BLEWITT BLEWITT 67 GURR DOCUMENT ID MCGREW ts, limits, etc. • • • | 91 88 86 85 85 67 99 | FREJ IMB IMB IMB IMB CNTR FECN IMB3 | >529 ••• We so 91 T(p → µ LMMT (10 ³⁰ years) >675 ••• We so 119 > 10.5 >190 > 44 >190 > 2.1 68 We have | p do not use the p + \(\mu^+ \mu^- \) PARTICLE P do not use the p p p p p p p p p p re- converted | 90 90 20% 90 90 90 90 90 90 90 90 90 90 1 possible | 0 g dat 0 0 eV/S 0 1 1 1 1 1 event | a for averages, ≤ 0.1 $\frac{\mathit{BKGD EST}}{\textbf{0.3}}$ 0.3 a for averages, 0.2 0.7 0.1 0.7 0.9 | DOCUMENT ID MCGREW fits, limits, etc. • • • BERGER BERGER PHILLIPS HAINES BLEWITT BLEWITT 68 BATTISTONI | 91 99 91 89 86 85 85 82 | FRE HP' IME IME |

Baryon Particle Listings

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| | $\tau(nn\to\pi^0\pi^0)$ |
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| | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT >3.4 90 0 0.78 BERGER 91B FREJ $	au$ per iron nucleus |
| $(n \rightarrow 3\nu)$ τ_{57} | $	au(pp 	o e^+e^+)$ |
| See also the "to anything" and "disappearance" limits for bound nucleons in the "p Mean Life" data block just in front of the list of possible p decay modes. Such modes | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT |
| could of course be to three (or five) neutrinos, and the limits are stronger, but we do not repeat them here. | >5.8 90 0 <0.1 BERGER 91B FREJ $	au$ per iron nucleus |
| <u>II</u> T | $	au(pp 	o e^+\mu^+)$ |
| 30 years) PARTICLE CL% EVTS BKGD EST DOCUMENT ID TECN 0.00049 n 90 2 2 69 SUZUKI 93B KAMI | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT |
| • We do not use the following data for averages, fits, limits, etc. • • | >3.6 90 0 <0.1 BERGER 91B FREJ $	au$ per iron nucleus |
| 0.0023 | $	au(pp	o\mu^+\mu^+)$ |
| 0.00012 n 90 7 11.2 ⁷¹ BERGER 91B FREJ | LIMIT |
| 0.0005 n 90 0 LEARNED 79 RVUE The SUZUKI 93B limit applies to any of $\nu_e \nu_e \overline{\nu}_e$, $\nu_\mu \nu_\mu \overline{\nu}_\mu$, or $\nu_\tau \nu_\tau \overline{\nu}_\tau$. | (10 30 years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT >1.7 90 0 0.62 BERGER 91B FREJ τ per iron nucleus |
| GLICENSTEIN 97 uses Kamioka data and the idea that the disappearance of the neu- | $	au(pn	o e^+\overline{ u})$ |
| tron's magnetic moment should produce radiation. 1 The first BERGER 91B limit is for $n \to \nu_e \nu_e \overline{\nu}_e$, the second is for $n \to \nu_\mu \nu_\mu \overline{\nu}_\mu$. | LIMIT |
| | (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT >2.8 90 5 9.67 BERGER 918 FREJ τ per iron nucleus |
| $(n \to 5\nu)$ 758 See the note on $\tau(n \to 3\nu)$ on the previous data block. | (+-) |
| ŲŢ | LIMIT |
| 30 years) PARTICLE CL% EVTS BKGD EST DOCUMENT ID TECN • • We do not use the following data for averages, fits, limits, etc. • • • | 10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT >1.6 90 4 4.37 BERGER 91B FREJ τ per iron nucleus |
| 0.0017 n 90 ⁷² GLICENSTEIN 97 KAMI | (-) |
| ² GLICENSTEIN 97 uses Kamioka data and the idea that the disappearance of the neutron's magnetic moment should produce radiation. | $	au(extbf{n} 	au 	au_{	extbf{e}} 	au_{	extbf{e}})$ We include "invisible" modes here. |
| | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT |
| Inclusive modes —— | >1.4 90 76 ARAKI 06 KLND nn → invisible ••• We do not use the following data for averages, fits, limits, etc. ••• |
| $N 	o e^+$ anything) $	au_{59}$ | >0.000042 90 77 TRETYAK 04 CNTR |
| 36 years) PARTICLE CL% EVTS BKGD EST DOCUMENT ID TECN | >0.000049 90 |
| .6 p, n 90 73 LEARNED 79 RVUE The electron may be primary or secondary. | >0.000012 90 5 9.7 BERRIAGE 008 DAIMA >0.000012 90 5 9.7 BERGER 91B FREJ τ per iron nucleu: |
| • | ⁷⁶ ARAKI 06 looks for signs of de-excitation of the residual nucleus after disappearance |
| $N ightarrow \mu^+$ anything) $	au_0$ | two neutrons from the s shell of 12 C. 77 TRETYAK 04 uses data from an old Homestake-mine radiochemical experiment on lim |
| 30 years) PARTICLE CL% EVTS BKGD EST DOCUMENT ID TECN 12 p, n 90 2 74,75 CHERRY 81 HOME | for invisible decays of 39 K to 37 Ar. 78 BACK 03 looks for decays of unstable nuclides left after NN decays of parent 12 C, 13 |
| 12 p, n 90 2 (4,75 CHERRY 81 HOME •• We do not use the following data for averages, fits, limits, etc. ••• | ¹⁶ O nuclei. These are "invisible channel" limits |
| 1.8 p, n 90 75 COWSIK 80 CNTR | 79 BERNABEI 00B looks for the decay of a $_{54}^{127}$ Xe nucleus following the disappearance an nn pair in the otherwise-stable $_{54}^{129}$ Xe nucleus. The limit here applies as well to nn |
| 6 p, n 90 ⁷⁵ LEARNED 79 RVUE 4 We have converted 2 possible events to 90% CL limit. | $ u_{\mu}\overline{ u}_{\mu}$, $nn	o \ v_{	au}\overline{v}_{	au}$, or any "disappearance" mode. |
| The muon may be primary or secondary. | $	au(ar{n}ar{n} ightarrow u_{\mu} \overline{ u}_{\mu})$ |
| The muon may be primary or secondary. | $\gamma(\mu\mu \to \nu_{\mu}\nu_{\mu})$ |
| $(N 	o u {\sf anything})$ $	au_{61}$ | · · · · · · · · · · · · · · · · · · · |
| $N \rightarrow \nu$ anything) Anything = π , ρ , K , etc. | 1 (ΠΠ → VμVμ) LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $N 	o u$ anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anything π Anythin | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ any high $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow \nu$ anything $N \rightarrow $ | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • >0.000006 90 4 4.4 BERGER 91B FREJ τ per iron nucleus |
| $N \rightarrow \nu$ anything) Anything = π , ρ , K , etc. IT $\frac{100}{100} \frac{1}{100} | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| $N \rightarrow \nu$ anything) Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Overall PARTICLE CL% EVTS BKGDEST DOCUMENT ID TECN One We do not use the following data for averages, fits, limits, etc. One of ν anything ν RVUE $N \rightarrow e^+ \pi^0$ anything To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To anything ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν The any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν To any ν T | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
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| Anything $= \pi$, ρ , K , etc. Anything $= \pi$, ρ , K , etc. Anything $= \pi$, ρ , K , etc. Anything $= \pi$, ρ , K , etc. Anything $= \pi$, ρ , K , etc. Anything $= \pi$, ρ , K , etc. • We do not use the following data for averages, fits, limits, etc. • • • 0. 0.0002 p , n 90 0 LEARNED 79 RVUE (N \rightarrow e+ π^0 anything) T62 (N \rightarrow e+ π^0 anything) T62 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T64 (N \rightarrow 2 bodies, ν -free) T65 (N \rightarrow 2 bodies, ν -free) T67 (N \rightarrow 2 bodies, ν -free) T68 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T61 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T64 (N \rightarrow 2 bodies, ν -free) N \rightarrow 4 bodies, ν -free) T65 (N \rightarrow 2 bodies, ν -free) T66 (N \rightarrow 2 bodies, ν -free) T67 (N \rightarrow 2 bodies, ν -free) T68 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T61 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T64 (N \rightarrow 2 bodies, ν -free) T65 (N \rightarrow 2 bodies, ν -free) T67 (N \rightarrow 2 bodies, ν -free) T68 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T61 (N \rightarrow 2 bodies, ν -free) T62 (N \rightarrow 2 bodies, ν -free) T63 (N \rightarrow 2 bodies, ν -free) T64 (N \rightarrow 2 bodies, ν -free) T65 (N \rightarrow 2 bodies, ν -free) T67 (N \rightarrow 2 bodies, ν -free) T68 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T69 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T60 (N \rightarrow 2 bodies, ν -free) T61 | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • |
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| Anything = π , ρ , K , etc. IT | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • >0.000006 90 4 4.4 BERGER 91B FREJ \(\tau\) per iron nucleus \(\tau(pn \rightarrow\) invisible) \(\tau(10^{30} years)\) CL% DOCUMENT ID TECN \(\tau(10^{30} years)\) 90 80 TRETYAK 04 CNTR \(\text{80}\) TRETYAK 04 uses data from an old Homestake-mine radiochemical experiment on lim for invisible decays of \(^{30}\) K to \(^{37}\)Ar. \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible) \(\tau(pp \rightarrow\) invisible channel invisible channel invisible enuclies left after NN decays of parent \(^{12}C\), \(^{13}\) 160 nuclei. These are "invisible channel" limits. \(\text{82}\) BERNABEI 00B looks for the decay of a \(\text{52}\) Te nucleus following the disappearance of \(\tau(pp) p) \tau(pp) \text{pair in the otherwise-stable} \(\text{129}\) 28 xe nucleus. |
| Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. Anything = π , ρ , K , etc. • We do not use the following data for averages, fits, limits, etc. • • • 0.0002 ρ , n 90 0 LEARNED 79 RVUE $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything $N \rightarrow e^{+}\pi^{0}$ anything N | LIMIT (10 ³⁰ years) CL% EVTS BKGD EST DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • >0.000006 90 4 4.4 BERGER 91B FREJ τ per iron nucleus: τ(pn→ invisible) This violates charge conservation as well as baryon number conservation. VALUE (10 ³⁰ years) CL% DOCUMENT ID TECN >0.000021 90 80 TRETYAK 04 CNTR 80 TRETYAK 04 uses data from an old Homestake-mine radiochemical experiment on lim for invisible decays of 39 K to 37 Ar. τ(pp→ invisible) This violates charge conservation as well as baryon number conservation. LIMIT (10 ³⁰ years) CL% EVTS BKGD EST CL% DOCUMENT ID TECN >0.00005 >0.000005 90 81 BACK 03 BORX • • • We do not use the following data for averages, fits, limits, etc. • • • >0.00000055 90 82 BERNABEI 00B DAMA 81 BACK 03 looks for decays of unstable nuclides left after NN decays of parent 12C, 13 16O nuclei. These are "invisible channel" limits. 82 BERNABEI 00B looks for the decay of a 12 ² / ₂ Te nucleus following the disappearance of pp pair in the otherwise-stable 12 ⁹ / ₂ Se nucleus. □ PARTIAL MEAN LIVES The "partial mean life" limits tabulated here are the limits on ₹/B _j , where ₹ is the total mean life for the antiproton and B _j is the branching fraction |

>1848

94 CALO 8.9 GeV/c \overline{p} beam

> 7 x 10⁵ 90 GEER 00 APEX 8.9 GeV/c \overline{p} beam
• • • We do not use the following data for averages, fits, limits, etc. • • •

GEER

95

| $r(\overline{p} \to \mu^- \gamma)$ | CL W | DOCUMENT ID | | TECN | COMMENT | 77 |
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| /ALUE (years) >5 × 10 ⁴ | 90 | DOCUMENT ID | 00 | | 8.9 GeV/c p beam | |
| • • We do not use the | | | | | | |
| $>5.0 \times 10^4$ | 90 | HU | 98B | APEX | 8.9 ${ m GeV}/c~\overline{p}$ beam | |
| $e^{-(\overline{p} \rightarrow e^{-}\pi^{0})}$ | | | | | | 77 |
| ALUE (years) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| > 4×10 ⁵ | 90 | GEER | 00 | | 8.9 GeV/c \overline{p} beam | |
| • We do not use the >554 | 95 | GEER | 94 | | 8.9 GeV/c \overline{p} beam | |
| | 55 | GEER | 74 | CALO | 0.5 GeV/e p beam | |
| $\pi(\overline{p} \to \mu^- \pi^0)$ | CL N | DO CUMENT ID | | TECN | COMMENT | 78 |
| A <i>LUE</i> (years) >5 × 10 ⁴ | 90 | DOCUMENT ID | 00 | | 8.9 GeV/c p beam | |
| • We do not use the | | | | | | |
| $>4.8 \times 10^4$ | 90 | HU | 98B | APEX | 8.9 GeV/ $c~\overline{p}$ beam | |
| $r(\overline{p} \rightarrow e^- \eta)$ | | | | | | <i>T</i> 8 |
| ALUE (years) | CL% | DOCUMENT ID | | TECN | COMMENT | .0 |
| > 2 × 10 ⁴ | 90 | GEER | 00 | | 8.9 GeV/ $c~\overline{p}$ beam | |
| We do not use the | _ | · - | | | | |
| >171 | 95 | GEER | 94 | CALO | 8.9 GeV/c $\overline{ ho}$ beam | |
| $(\overline{p} \to \mu^- \eta)$ | | | | | | 78 |
| ALUE (years) | <u>CL%</u> | DOCUMENT ID | | | COMMENT | |
| >8 × 10 ³ • • We do not use the | 90 e following | GEER data for average | 00 s, fits, | | 8.9 GeV/ $c \overline{p}$ beam etc. • • • | |
| >7.9 × 10 ³ | 90 | HU | | | 8.9 GeV/c \overline{p} beam | |
| $e^{-(\overline{p} \rightarrow e^{-}K_{S}^{0})}$ | | | | | | _ |
| $(P \rightarrow e \land s)$ $(ALUE (years))$ | CL% | DO CUMENT ID | | TECN | COMMENT | 78 |
| >900 | 90 | GEER | 00 | | 8.9 GeV/c \overline{p} beam | |
| • We do not use the | _ | · - | | | | |
| > 29 | 95 | GEER | 94 | CALO | 8.9 GeV/ $c \overline{p}$ beam | |
| $(\overline{p} \rightarrow \mu^- K_S^0)$ | | | | | | 78. |
| ALUE (years) | CL% | DOCUMENT ID | | | | |
| >4 × 10 ³ • • We do not use the | 90 following | GEER | | | 8.9 GeV/ $c \overline{p}$ beam | |
| $>4.3 \times 10^3$ | 90 | HU | | | 8.9 GeV/c p beam | |
| | | | | | | |
| / - - (40) | | | | | / - / | |
| | CI % | DOCUMENT ID | | TECN | , . | <i>τ</i> 8: |
| ALUE (years) | <u>CL%</u> 90 | DOCUMENT ID | | | COMMENT | 78 |
| ALUE (years) >9 × 10 ³ | 90 | GEER | 00 | APEX | <u>COMMENT</u> 8.9 GeV/c p beam | 78 |
| ALUE (years) >9 × 10 ³ • • We do not use the | 90 | GEER | 00 | APEX limits, | <u>COMMENT</u> 8.9 GeV/c p beam | 78 |
| ALUE (years) >9 × 10 ³ • • We do not use the >9 | 90 e following | GEER data for average | 00 s, fits, | APEX limits, | $\frac{COMMENT}{8.9 \text{ GeV}/c \ \overline{p} \text{ beam}}$ etc. • • • | |
| ALUE (years) $>9 \times 10^{3}$ • • We do not use the years >9 $-(\overline{p} \rightarrow \mu^{-} K_{L}^{0})$ | 90 e following | GEER data for average | 00 s, fits, | APEX limits, CALO | $\frac{COMMENT}{8.9 \text{ GeV}/c \ \overline{p} \text{ beam}}$ etc. • • • | |
| ALUE (years) $>9 \times 10^{3}$ • • We do not use the >9 $(\overline{p} \rightarrow \mu^{-} K_{L}^{0})$ $>10^{3}$ ALUE (years) $>7 \times 10^{3}$ | 90 e following 95 <u>CL%</u> 90 | GEER data for average GEER <u>DOCUMENT ID</u> GEER | 00 s, fits, 94 | APEX limits, CALO | COMMENT 8.9 GeV/ $c \ \overline{p}$ beam etc. 8.9 GeV/ $c \ \overline{p}$ beam $\frac{COMMENT}{8.9 \text{ GeV}/c \ \overline{p}} \text{ beam}$ | |
| ALUE (years) $>9 \times 10^{3}$ • • We do not use the system $(\overline{p} \rightarrow \mu^{-} K_{L}^{0})$ $>7 \times 10^{3}$ • • We do not use the system $= 10^{3} \times 10^{3}$ | 90 e following 95 <u>CL%</u> 90 e following | GEER data for average GEER <u>DOCUMENT ID</u> GEER data for average | 00 ss, fits, 94 00 ss, fits, | APEX, limits, CALO TECN APEX, limits, | COMMENT 8.9 GeV/ $c \ \overline{p}$ beam etc. 8.9 GeV/ $c \ \overline{p}$ beam $\underline{comment}$ 8.9 GeV/ $c \ \overline{p}$ beam etc. • • • | |
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| ALUE (years) $>9 \times 10^{3}$ • • We do not use the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set o | 90 e following 95 <u>CL%</u> 90 e following | GEER data for average GEER <u>DOCUMENT ID</u> GEER data for average HU | 00 s, fits, 94 00 s, fits, | APEX, limits, CALO TECN APEX, limits, APEX | | 78 |
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KRISHNA... ALEKSEEV

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| FLEROV | 58 | DOKL 3 79 | G.N. Flerov et al. | |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

We have omitted some results that have been superseded by later experiments. See our earlier editions.

Anyone interested in the neutron should look at these two new review articles: D. Dubbers and M.G. Schmidt, "The neutron and its role in cosmology and particle physics," Reviews of Modern Physics 83 1111 (2011); and F.E. Wietfeldt and G.L. Greene, "The neutron lifetime," Reviews of Modern Physics 83 1173 (2011).

n MASS (atomic mass units u)

The mass is known much more precisely in u (atomic mass units) than in MeV. See the next data block.

| VALUE (u) | DO CUMENT IE |) | TECN | COMMENT |
|------------------------------------|------------------|-----------|-----------|-------------------|
| 1.00866491600±0.00000000043 | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • We do not use the following | g data for avera | ges, fits | , limits, | etc. • • • |
| $1.00866491597 \pm 0.000000000043$ | MOHR | 08 | RVUE | 2006 CODATA value |
| $1.00866491560 \pm 0.000000000055$ | MOHR | 05 | RVUE | 2002 CODATA value |
| $1.00866491578 \pm 0.000000000055$ | MOHR | 99 | RVUE | 1998 CODATA value |
| $1.008665904 \pm 0.000000014$ | COHEN | 87 | RVUE | 1986 CODATA value |

n MASS (MeV)

The mass is known much more precisely in u (atomic mass units) than in MeV. The conversion from u to MeV, 1 u $= 931.494061(21)~{
m MeV}/c^2$ (MOHR 12, the 2010 CODATA value), involves the relatively poorly known electronic charge.

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------|--------------------------|----------|-----------|--------------------------|
| 939.565379±0.000021 | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • We do not use the fo | lowing data for average | es, fits | , limits, | etc. • • • |
| 939.565346 ± 0.000023 | MOHR | 08 | RVUE | 2006 CODATA value |
| 939.565360 ± 0.000081 | MOHR | 05 | RVUE | 2002 CODATA value |
| 939.565331 ± 0.000037 | ¹ KESSLER | 99 | SPEC | $np \rightarrow d\gamma$ |
| 939.565330 ± 0.000038 | MOHR | 99 | RVUE | 1998 CODATA value |
| 939.56565 ±0.00028 | ^{2,3} DIFILIPPO | 94 | TRAP | Penning trap |
| 939.56563 ±0.00028 | COHEN | 87 | RVUE | 1986 CODATA value |
| 939.56564 ±0.00028 | 3,4 GREENE | 86 | SPEC | $np \rightarrow d\gamma$ |
| 939 5731 + 0 0027 | 3 COHEN | 73 | RVHE | 1973 CODATA value |

 $^{^{}m 1}$ We use the 1998 CODATA u-to-MeV conversion factor (see the heading above) to get this mass in MeV from the much more precisely measured KESSLER 99 value of

7 MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------|------|-------------|----|------|-------------------------------------------|
| 939.485 ± 0.051 | 5 9 | 5 CRESTI | 86 | нвс | $\overline{p}p \rightarrow \overline{n}n$ |

 $^{^5\,\}mbox{This}$ is a corrected result (see the erratum). The error is statistical. The maximum systematic error is 0.029 MeV.

$(m_n - m_{\overline{n}})/m_n$

A test of CPT invariance. Calculated from the n and \overline{n} masses, above.

| (9±6) × 10 ⁻⁵ OUR EVALUATION | |
|-----------------------------------------|--|
| VALUE DO CUMENT ID | |

$m_n - m_p$

| VALUE (MeV) | | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----|-------------------|---------|-----------|--------------------------|
| 1.29333217±0.00000042 | 6 | MOHR | 12 | RVUE | 2010 CODATA value |
| • • • We do not use the following | g d | lata for averages | , fits, | limits, e | etc. • • • |
| $1.29333214 \pm 0.00000043$ | | MOHR | 80 | RVUE | 2006 CODATA value |
| 1.2933317 ± 0.0000005 | | MOHR | 05 | RVUE | 2002 CODATA value |
| 1.2933318 ± 0.0000005 | | MOHR | 99 | RVUE | 1998 CODATA value |
| 1.293318 ±0.000009 | 10 | COHEN | 87 | RVUE | 1986 CODATA value |
| 1.2933328 ± 0.0000072 | | GREENE | 86 | SPEC | $np \rightarrow d\gamma$ |
| 1 293429 + 0 000036 | | COHEN | 73 | RVHE | 1973 CODATA value |

 6 The 2010 CODATA mass difference in u is $m_n-m_p=1.388\,449\,19(45)\times 10^{-3}u$.

⁷ Calculated by us from the MOHR 08 ratio $m_n/m_p = 1.00137841918(46)$. In u, $m_n = 1.00137841918(46)$. $m_D = 1.38844920(46) \times 10^{-3} \text{ u.}$

⁸ Calculated by us from the MOHR 05 ratio $m_{n}/m_{p}=1.00137841870\pm0.00000000058.$ In u, $m_n - m_p = (1.3884487 \pm 0.0000006) \times 10^{-3}$ u.

 9 Calculated by us from the MOHR 99 ratio $m_n/m_p=1.00137841887\pm0.00000000058.$ In u, $m_n-m_p=(1.3884489\pm0.0000006)\times10^{-3}$ u.

 10 Calculated by us from the COHEN 87 ratio $m_{\it n}/m_{\it p}=$ 1.001378404 \pm 0.000000009. In u, $m_n - m_p = 0.001388434 \pm 0.0000000099$ u.

n MEAN LIFE

Limits on lifetimes for bound neutrons are given in the section "p PARTIAL MEAN LIVES "

The mean life of the neutron, 878.5 \pm 0.8 s, obtained by SEREBROV 05 (for a more detailed account, see SEREBROV 08A) was so far from our average of seven other measurements, 885.7 \pm 0.8 s, that it made no sense to include it in our average. Thus our 2006, 2008, and 2010 Reviews stayed with 885.7 \pm 0.8 s; but we noted that in light of SEREBROV 05 our value should be regarded as suspect until further experiments clarified matters.

However, after our 2010 Review, PICHLMAIER 10 obtained a mean life of 880.7 ± 1.8 s, and we averaged the best seven results to get 881.5 ± 1.5 s for our 2011 off-year web update. And since then, ARZUMANOV 12, responding to comments of SEREBROV 10B, recalculated the systematic corrections to its 2000 measurement (ARZUMANOV 00) and lowered its value from 885.4 \pm 0.9 \pm 0.4 s to 881.6 \pm 0.8 \pm 1.9 s. Thus the trend is definitely toward a shorter lifetime.

There seems little better to do than to again average the best seven measurements. The result, 880.1 \pm 1.1 s (including a scale factor of 1.8), is $5.6\,s$ lower than the value we gave in 2010-a drop of 7.0 old and 5.1 new standard deviations.

For a full review of all matters concerning the neutron lifetime, see F.E. Wietfeldt and G.L. Greene, "The neutron lifetime," Reviews of Modern Physics 83 1173 (2011). In particular, there is a full discussion of the experimental methods and results; and an average lifetime is obtained making several different selections of those results. (The revised ARZU-MANOV 12 mean life was not yet available.)

| VALUE (s) | | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------|------|-------------------|-------|-----------|-------------------------------------|
| 880.1 ± 1.1 OUR AVERAGE | | | | ctor of 1 | .8. See the ideogram below. |
| 881.6± 0.8± 1.9 | 11 | ARZUMANOV | 12 | CNTR | UCN double bottle |
| 880.7± 1.3± 1.2 | | PICHLMAIER | 10 | CNTR | UCN material bottle |
| 886.3± 1.2± 3.2 | | NICO | 05 | CNTR | In-beam <i>n</i> , trapped <i>p</i> |
| 878.5 ± 0.7 ± 0.3 | | SEREBROV | 05 | CNTR | UCN gravitational trap |
| 889.2± 3.0± 3.8 | | BYRNE | 96 | CNTR | Penning trap |
| 882.6± 2.7 | 12 | MAMPE | 93 | CNTR | UCN material bottle |
| 887.6± 3.0 | | MAMPE | 89 | CNTR | UCN material bottle |
| ullet $ullet$ $ullet$ We do not use the fo | llow | ing data for aver | ages, | fits, lim | its, etc. • • • |
| 886.8± 1.2± 3.2 | | DEWEY | 03 | CNTR | See NICO 05 |
| 885.4 ± 0.9 ± 0.4 | | ARZUMANOV | 00 | CNTR | See ARZUMANOV 12 |
| 888.4± 3.1± 1.1 | 13 | NESVIZHEV | 92 | CNTR | UCN material bottle |
| 888.4± 2.9 | | ALFIMENKOV | 90 | CNTR | See NESVIZHEVSKII 92 |
| 893.6± 3.8± 3.7 | | BYRNE | 90 | CNTR | See BYRNE 96 |
| 878 ±27 ±14 | | KOSSAKOW | 89 | TPC | Pulsed beam |
| 877 ±10 | | PAUL | 89 | CNTR | Magnetic storage ring |
| 876 ±10 ±19 | | LAST | 88 | SPEC | Pulsed beam |
| 891 ± 9 | | SPIVAK | 88 | CNTR | Beam |
| 903 ±13 | | KOSVINTSEV | 86 | CNTR | UCN material bottle |
| 937 ±18 | 14 | BYRNE | 80 | CNTR | |
| 875 ±95 | | KOSVINTSEV | 80 | CNTR | |
| 881 ± 8 | | BONDAREN | 78 | CNTR | See SPIVAK 88 |
| 918 ±14 | | CHRISTENSE | J72 | CNTR | |

 $^{11}\,\mathrm{ARZUMA\,NOV}$ 12 reanalyzes its systematic corrections in ARZUMANOV 00 and obtains

this corrected value. $^{12}\mbox{IGNATOVICH}$ 95 calls into question some of the corrections and averaging procedures used by MAMPE 93. The response, BONDARENKO 96, denies the validity of the

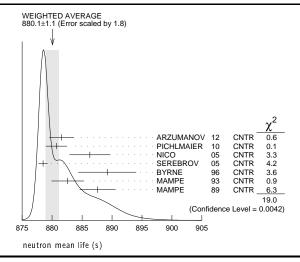
13 The NESVIZHEVSKII 92 measurement has been withdrawn by A. Serebrov.

¹⁴The BYRNE 80 measurement has been withdrawn (J. Byrne, private communication, 1990).

 $[\]frac{1.00866491637\pm0.00000000082\,\text{u}.}{2\,\text{The mass is known much more precisely in u:}\ m=1.0086649235\,\pm\,0.0000000023\,\text{u}.$ We use the 1986 CODATA conversion factor to get the mass in MeV.

 $^{^3}$ These determinations are not independent of the $m_{\it n}-m_{\it p}$ measurements below.

 $^{^4}$ The mass is known much more precisely in u: $m=1.008664919\pm0.000000014$ u.



n MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings.

| VALUE (µN) | DO CUMENT IL |) | TECN | COMMENT |
|--------------------------------------------------|----------------------|------------|---------|-------------------|
| -1.91304272±0.00000045 | MOHR | 12 | | 2010 CODATA value |
| ● ● We do not use the follow | ving data for avera | ges, fits, | limits, | etc. • • • |
| $-1.91304273 \pm 0.00000045$ | MOHR | 80 | RVUE | 2006 CODATA value |
| $-1.91304273 \pm 0.00000045$ | MOHR | 05 | RVUE | 2002 CODATA value |
| $-1.91304272 \pm 0.00000045$ | MOHR | 99 | RVUE | 1998 CODATA value |
| $-1.91304275 \pm 0.00000045$ | COHEN | 87 | RVUE | 1986 CODATA value |
| $-1.91304277 \pm 0.00000048$ | ¹⁵ GREENE | 82 | MRS | |

 $^{^{15}}$ GREENE 82 measures the moment to be (1.04187564 \pm 0.00000026) \times 10 $^{-3}$ Bohr magnetons. The value above is obtained by multiplying this by $m_p/m_e=$ 1836.152701 \pm 0.000037 (the 1986 CODATA value from COHEN 87).

n ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance. A number of early results have been omitted. See RAMSEY 90, GOLUB 94, and LAMOREAUX 09 for reviews.

| $VALUE (10^{-25} ecm)$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------|-----------------------|-------|--------------|---------------------------------------|
| < 0.29 | 90 | ¹⁶ BAKER | 06 | MRS | UCN's, $h\nu = 2\mu_n B \pm 2d_n E$ |
| ● ● We do not | use the | following data for av | erage | es, fits, li | mits, etc. • • • |
| < 0.63 | 90 | ¹⁷ HARRIS | 99 | MRS | $d = (-0.1 \pm 0.36) \times 10^{-25}$ |
| < 0.97 | 90 | ALTAREV | 96 | MRS | $(+0.26\pm0.40\pm0.16)\times10^{-25}$ |
| < 1.1 | 95 | ALTAREV | 92 | MRS | See ALTAREV 96 |
| < 1.2 | 95 | SMITH | 90 | MRS | See HARRIS 99 |
| < 2.6 | 95 | ALTAREV | 86 | MRS | $d = (-1.4 \pm 0.6) \times 10^{-25}$ |
| 0.3 ± 4.8 | | PENDLEBURY | 84 | MRS | Ultracold neutrons |
| < 6 | 90 | ALTAREV | 81 | MRS | $d = (2.1 \pm 2.4) \times 10^{-25}$ |
| <16 | 90 | ALTAREV | 79 | MRS | $d = (4.0 \pm 7.5) \times 10^{-25}$ |

¹⁶ LAMOREAUX 07 faults BAKER 06 for not including in the estimate of systematic error an effect due to the Earth's rotation. BAKER 07 replies (1) that the effect was included to the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the part of the p implicitly in the analysis and (2) that further analysis confirms that the BAKER 06 limit is correct as is. See also SILENKO 07.

This HARRIS 99 result includes the result of SMITH 90. However, the averaging of the

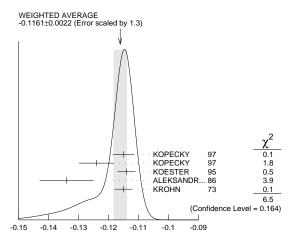
n MEAN-SQUARE CHARGE RADIUS

The mean-square charge radius of the neutron, $\langle r_n^2 \rangle$, is related to the neutron-electron scattering length $b_{n\,e}$ by $\langle r_n^2 \rangle = 3(m_e a_0/m_n) b_{n\,e}$, where m_e and m_n are the masses of the electron and neutron, and a_0 is the Bohr radius. Numerically, $\langle r_n^2 \rangle = 86.34~b_{n\,e}$, if we use a_0 for a nucleus with infinite mass with infinite mass.

| VALUE (fm ²) | DO CUMENT ID | | COMMENT |
|--------------------------------------------------------|--------------------|----------|---------------------------------|
| -0.1161±0.0022 OUR AVERAGE | Error includes | scale : | factor of 1.3. See the ideogram |
| below. | | | |
| $-0.115 \pm 0.002 \pm 0.003$ | KOPECKY | 97 | ne scattering (Pb) |
| $-0.124 \pm 0.003 \pm 0.005$ | KOPECKY | 97 | <i>ne</i> scattering (Bi) |
| -0.114 ± 0.003 | KOESTER | 95 | ne scattering (Pb, Bi) |
| -0.134 ± 0.009 | ALEKSANDR. | 86 | ne scattering (Bi) |
| -0.115 ± 0.003 | ⁸ KROHN | 73 | ne scattering (Ne, Ar, Kr, Xe) |
| ullet $ullet$ We do not use the following | data for average | es, fits | , limits, etc. ● ● ● |
| $-0.117 \begin{array}{c} +0.007 \\ -0.011 \end{array}$ | BELUSHKIN | 07 | Dispersion analysis |
| $-0.113 \pm 0.003 \pm 0.004$ | KOPECKY | 95 | ne scattering (Pb) |
| -0.114 ± 0.003 | KOESTER | 86 | ne scattering (Pb, Bi) |
| -0.118 ± 0.002 | KOESTER | 76 | ne scattering (Pb) |
| -0.120 ± 0.002 | KOESTER | 76 | ne scattering (Bi) |
| -0.116 ± 0.003 | KROHN | 66 | ne scattering (Ne, Ar, Kr, Xe) |
| | | | |

I

 $^{18}\,\mathrm{This}$ value is as corrected by KOESTER 76.



n mean-square charge radius

n MAGNETIC RADIUS

| This is the rms magnetic | radius, $\sqrt{\langle r_M^2 angle}$. | | |
|--------------------------|-----------------------------------------|----|---------------------|
| VALUE (fm) | DO CUMENT ID | | COMMENT |
| 0.862 + 0.009 | BELUSHKIN | 07 | Dispersion analysis |

n ELECTRIC POLARIZABILITY α_n

Following is the electric polarizability α_n defined in terms of the induced electric dipole moment by ${\bf D}=4\pi\epsilon_0\alpha_n{\bf E}$. For a review, see SCHMIED-

For a very complete review of the "polarizability of the nucleon and Compton scattering," see SCHUMACHER 05. His recommended values for the neutron are $\alpha_n=(12.5\pm1.7)\times10^{-4}~{\rm fm^3}$ and $\beta_n=(2.7\mp1.8)\times10^{-4}$ $\,\mathrm{fm}^{\,3}$, which agree with our averages within errors.

| VALUE (10 ⁻⁴ fm ³) | | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------------------------------|--------------|---------------------|----------------------------------------------------|
| 11.6± 1.5 OUR AVERAGE | | | | | |
| $12.5 \pm 1.8^{+1.6}_{-1.3}$ | 19 | KOSSERT | 03 | CNTR | $\gamma d \rightarrow \gamma p n$ |
| 8.8± 2.4±3.0 | 20 | LUNDIN | 03 | CNTR | $\gamma d \rightarrow \gamma d$ |
| $12.0 \pm\ 1.5 \pm 2.0$ | | SCH MIED M | 91 | CNTR | n Pb transmission |
| $10.7 + 3.3 \\ -10.7$ | | ROSE | 90B | CNTR | $\gamma d \rightarrow \gamma np$ |
| • • • We do not use the following | g d | ata for averages | , fits, | limits, e | etc. • • • |
| 13.6 | 21 | KOLB | 00 | CNTR | $\gamma d \rightarrow \gamma np$ |
| 0.0 ± 5.0 | 22 | KOESTER | 95 | CNTR | n Pb, n Bi transmission |
| $11.7^{+\ 4.3}_{-11.7}$ | | ROSE | 90 | CNTR | See ROSE 90B |
| 8 ±10 | | | | | $n \; Pb, \; n \; Bi \; transmission$ |
| 12 ±10 | | | | | n Pb, n C transmission |
| 19 KOSSERT 03 gets $\alpha_{\it n} - \beta_{\it n} =$ | (9 | $0.8 \pm 3.6^{+2.1}_{-1.1} =$ | ± 2.2) | $\times 10^{-4}$ | 4 fm 3 , and uses $lpha_{\it n}+eta_{\it n}$ |
| $= (15.2 \pm 0.5) \times 10^{-4} \text{ fm}^3 \text{ f}$ anti-correlated. | roi | m LEVCHUK 0 | 0. Th | us the | errors on $lpha_{m{n}}$ and $eta_{m{n}}$ are |
| 20 LUNDIN 03 measures $\alpha_N - \beta$ | 3 N | $= (6.4 \pm 2.4)$ | × 10 | -4 fm ³ | and uses accurate values |
| ²⁰ LUNDIN 03 measures $\alpha_N - \beta$ for α_p and α_p and a precise s uncertainty, and errors on α_p a | un and | n-rule result for | α_n + | β _n . Th | e second error is a model |
| 21 KOLB 00 obtains this value wit | | | | | 3 but no upper limit from |

²² KOESTER 95 uses natural Pb and the isotopes 208, 207, and 206. See this paper for a discussion of methods used by various groups to extract α_n from data.

n MAGNETIC POLARIZABILITY β_n

| <u>VALUE (10⁻⁴ fm³)</u> 3.7 ± 2.0 OUR AVERAGE | DO CUMENT IE |) | TECN | COMMENT |
|------------------------------------------------------------------------|-----------------------|----------|-----------|-----------------------------------|
| $2.7 \pm 1.8 + 1.3 \\ -1.6$ | ²³ KOSSERT | 03 | CNTR | $\gamma d \rightarrow \gamma p n$ |
| $6.5 \pm 2.4 \pm 3.0$ | ²⁴ LUNDIN | 03 | CNTR | $\gamma d \rightarrow \gamma d$ |
| | wing data for averag | es, fits | , limits, | etc. • • • |
| 1.6 | ²⁵ KOLB | 00 | CNTR | $\gamma d \rightarrow \gamma np$ |

results of these two experiments has been criticized by LAMOREAUX 00.

n

- ²³ KOSSERT 03 gets $\alpha_n-\beta_n=(9.8\pm3.6^{+2.1}_{-1.1}\pm2.2)\times10^{-4}$ fm 3 , and uses $\alpha_n+\beta_n=(15.2\pm0.5)\times10^{-4}$ fm 3 from LEVCHUK 00. Thus the errors on α_n and β_n are anti-correlated
- anti-correlated. 24 LUNDIN 03 measures $\alpha_N-\beta_N=(6.4\pm2.4)\times10^{-4}~{\rm fm}^3$ and uses accurate values for α_p and α_p and a precise sum-rule result for $\alpha_n+\beta_n$. The second error is a model uncertainty, and errors on α_n and β_n are anticorrelated.
- 25 KOLB 00 obtains this value with an upper limit of 7.6×10^{-4} fm³ but no lower limit from this experiment alone. Combined with results of ROSE 90, the $1-\sigma$ range is $(1.2-7.6) \times 10^{-4}$ fm³.

n CHARGE

See also " $|q_D^{}+q_e^{}|/e$ " in the proton Listings.

| VALUE (10 ⁻²¹ e) | DO CUMENT ID | | NCOMMENT | | | |
|--------------------------------------------|------------------------------|--------------|--------------------------------|--|--|--|
| − 0.2± 0.8 OUR AVERAGE | | | | | | |
| -0.1 ± 1.1 | | 11 | Neutrality of SF ₆ | | | |
| -0.4 ± 1.1 | ²⁷ BAUMANN | 88 | Cold <i>n</i> deflection | | | |
| | | | | | | |
| -15 ± 22 | ²⁸ GAEHLER | 82 CN7 | Γ R Cold n deflection | | | |
| ²⁶ As a limit, this BRESSI 11 v | value is $< 1 	imes 10^{-2}$ | 1 e. | | | | |
| 27 The BAU MANN 88 error \pm | 1.1 gives the 68% (| CL limits ab | out the the value -0.4 . | | | |
| 28 The GAEHLER 82 error ± 2 | 2 gives the 90% CL | limits abou | it the the value -15 . | | | |

LIMIT ON AT OSCILLATIONS

Mean Time for $n\overline{n}$ Transition in Vacuum

A test of $\Delta B = 2$ baryon number nonconservation. MOHAPATRA 80 and MOHAPATRA 80 discuss the theoretical motivations for looking for $n\overline{n}$ oscillations. DOVER 83 and DOVER 85 give phenomenological analyses. The best limits come from looking for the decay of neutrons bound in nuclei. However, these analyses require model-dependent corrections for nuclear effects. See KABIR 83, DOVER 89, ALBERICO 91, and GAL 00 for discussions. Direct searches for $n \rightarrow \overline{n}$ transitions using reactor neutrons are cleaner but give somewhat poorer limits. We include limits for both free and bound neutrons in the Summary Table. See MOHAPATRA 09 for a recent review.

| VALUE (s) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-------------|------------------|---------|-----------|-------------------------|
| >1.3 × 10 ⁸ | 90 | CHUNG | 02в | SOU2 | n bound in iron |
| $> 8.6 \times 10^{7}$ | 90 | BALDO | 94 | CNTR | Reactor (free) neutrons |
| • • • We do not use the | e following | data for average | s, fits | , limits, | etc. • • • |
| >1 × 10 ⁷ | 90 | BALDO | 90 | CNTR | See BALDO- CEOLIN 94 |
| $>1.2 \times 10^{8}$ | 90 | BERGER | 90 | FREJ | n bound in iron |
| $>4.9 \times 10^{5}$ | 90 | BRESSI | 90 | CNTR | Reactor neutrons |
| $>4.7 \times 10^{5}$ | 90 | BRESSI | 89 | CNTR | See BRESSI 90 |
| $>1.2 \times 10^{8}$ | 90 | TAKITA | 86 | CNTR | n bound in oxygen |
| $>1 \times 10^{6}$ | 90 | FIDECARO | 85 | CNTR | Reactor neutrons |
| $> 8.8 \times 10^{7}$ | 90 | PARK | 85B | CNTR | |
| $>3 \times 10^{7}$ | | BATTISTONI | 84 | NUSX | |
| $> 2.7 \times 10^7 - 1.1 \times 10^8$ | | JONES | 84 | CNTR | |
| $>2 \times 10^{7}$ | | CHERRY | 83 | CNTR | |

LIMIT ON nn' OSCILLATIONS

Lee and Yang (LEE 56) proposed the existence of mirror world in an attempt to restore global parity symmetry. See BEREZHIANI 06 for a recent discussion.

| VALUE (s) | CL% | DO CUMENT ID | | TECN | COMMENT | | |
|-------------------------------|-----|-----------------------|-----|------|--------------------------------------|--|--|
| >414 | 90 | SEREBROV | 08 | CNTR | UCN, B field on & off | | |
| ● ● We do | | | | | | | |
| > 12 | 95 | ²⁹ ALTAREV | 09A | CNTR | UCN, scan $0 \leq B \leq 12.5~\mu T$ | | |
| >103 | 95 | BAN | 07 | CNTR | UCN, B field on & off | | |

 $^{^{29}}$ Losses of neutrons due to oscillations to mirror neutrons would be maximal when the magnetic fields B and B' in the two worlds were equal. Hence the scan over B by ALTAREV 09A: the limit applies for any B' over the given range. At B'=0, the limit is 141 s (95% CL).

n DECAY MODES

| Mode Fraction (Γ_i/Γ) | Confidence level |
|------------------------------------------------------|------------------------|
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | % ×10 ⁻³ |

Charge conservation (Q) violating mode

| Γ_4 | $p \nu_e \overline{\nu}_e$ | Q | < 8 | $\times 10^{-27}$ | 68% |
|------------|----------------------------|---|-----|-------------------|-----|
| | | | | | |

[a] This limit is for γ energies between 15 and 340 keV.

n BRANCHING RATIOS

| $\Gamma(pe^-\overline{ u}_e\gamma)/\Gamma_{ m total}$ | | | | | Γ_2/Γ | |
|--------------------------------------------------------------------------------|----------|----------------------|----------|-----------|------------------------------------|--|
| VALUE (units 10^{-3}) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| $3.09 \pm 0.11 \pm 0.30$ | | ³⁰ COOPER | 10 | CNTR | γ , p , e^- coincidence | |
| • • • We do not use th | e follow | ing data for averag | es, fits | , limits, | etc. • • • | |
| $3.13 \pm 0.11 \pm 0.33$ | | NICO | 06 | CNTR | See COOPER 10 | |
| < 6.9 | 90 | ³¹ BECK | 02 | CNTR | γ , p , e^- coincidence | |
| 30 This COOPER 10 result is for γ energies between 15 and 340 keV. | | | | | | |
| 31 This BECK 02 limit is for γ energies between 35 and 100 keV. | | | | | | |

| $\Gamma(ext{hydrogen-atom } \overline{ u}_e)/\Gamma_{	ext{total}}$ | | | | | | | |
|---------------------------------------------------------------------|-----------|--------------------|---------|--------------------|--|--|--|
| VALUE | CL% | DOCUMENT ID | | TECN | | | |
| ullet $ullet$ We do not use the | following | data for averages | , fits, | limits, etc. • • • | | | |
| $< 3 \times 10^{-2}$ | 95 32 | ² GREEN | 90 | RVUE | | | |

 32 GREEN 90 infers that $\tau(\text{hydrogen-atom} \overline{v}_e) > 3 \times 10^4 \, \text{s}$ by comparing neutron lifetime measurements made in storage experiments with those made in β -decay experiments. However, the result depends sensitively on the lifetime measurements, and does not of course take into account more recent measurements of same.

 Γ_3/Γ

 $\Gamma(p\nu_{e}\overline{\nu}_{e})/\Gamma_{total}$ Γ_{4}/Γ_{e}

| Forbladen by | cnarge conser | vation. | | | |
|-------------------------|------------------|----------------------|---------|------------|-----------------------------------------------------|
| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
| $< 8 \times 10^{-27}$ | 68 | ³³ NORMAN | 96 | RVUE | $^{71}\text{Ga} ightarrow ^{71}\text{Ge neutrals}$ |
| | se the following | ng data for averag | es, fit | s, limits, | , etc. • • • |
| $< 9.7 \times 10^{-18}$ | 90 | ROY | | | $^{113}\text{Cd} ightarrow ^{113}m$ In neut. |
| $< 7.9 \times 10^{-21}$ | | VAIDYA | 83 | CNTR | $^{87}\text{Rb} \rightarrow ^{87m}\text{Srneut}.$ |
| $< 9 \times 10^{-24}$ | 90 | | | | 71 Ga \rightarrow 71 Ge X |
| $< 3 \times 10^{-19}$ | | NOR MA N | 79 | CNTR | $^{87}\text{Rb} \rightarrow ^{87}m \text{Srneut}.$ |

 33 NORMAN 96 gets this limit by attributing SAGE and GALLEX counting rates to the charge-nonconserving transition $^{71}\mbox{Ga} \rightarrow ~^{71}\mbox{Ge+neutrals}$ rather than to solar-neutrino reactions.

BARYON DECAY PARAMETERS

Written 1996 by E.D. Commins (University of California, Berkeley).

$Baryon\ semileptonic\ decays$

I

The typical spin-1/2 baryon semileptonic decay is described by a matrix element, the hadronic part of which may be written

$$\overline{B}_f \left[f_1(q^2) \gamma_\lambda + i \ f_2(q^2) \sigma_{\lambda\mu} q^\mu + g_1(q^2) \gamma_\lambda \gamma_5 + g_3(q^2) \gamma_5 q_\lambda \right] B_i . \tag{1}$$

Here B_i and \overline{B}_f are spinors describing the initial and final baryons, and $q=p_i-p_f$, while the terms in f_1 , f_2 , g_1 , and g_3 account for vector, induced tensor ("weak magnetism"), axial vector, and induced pseudoscalar contributions [1]. Second-class current contributions are ignored here. In the limit of zero momentum transfer, f_1 reduces to the vector coupling constant g_V , and g_1 reduces to the axial-vector coupling constant g_A . The latter coefficients are related by Cabibbo's theory [2], generalized to six quarks (and three mixing angles) by Kobayashi and Maskawa [3]. The g_3 term is negligible for transitions in which an e^\pm is emitted, and gives a very small correction, which can be estimated by PCAC [4], for μ^\pm modes. Recoil effects include weak magnetism, and are taken into account adequately by considering terms of first order in

$$\delta = \frac{m_i - m_f}{m_i + m_f} \,, \tag{2}$$

where m_i and m_f are the masses of the initial and final baryons.

The experimental quantities of interest are the total decay rate, the lepton-neutrino angular correlation, the asymmetry coefficients in the decay of a polarized initial baryon, and the polarization of the decay baryon in its own rest frame for an unpolarized initial baryon. Formulae for these quantities are derived by standard means [5] and are analogous to formulae for nuclear beta decay [6]. We use the notation of Ref. 6 in the Listings for neutron beta decay. For comparison with experiments at higher q^2 , it is necessary to modify the form factors at $q^2 = 0$ by a "dipole" q^2 dependence, and for high-precision comparisons to apply appropriate radiative corrections [7].

The ratio q_A/q_V may be written as

$$g_A/g_V = |g_A/g_V| e^{i\phi_{AV}}. (3)$$

The presence of a "triple correlation" term in the transition probability, proportional to $\text{Im}(g_A/g_V)$ and of the form

$$\sigma_i \cdot (\mathbf{p}_\ell \times \mathbf{p}_\nu)$$
 (4)

for initial baryon polarization or

$$\sigma_f \cdot (\mathbf{p}_\ell \times \mathbf{p}_\nu)$$
 (5)

for final baryon polarization, would indicate failure of timereversal invariance. The phase angle ϕ has been measured precisely only in neutron decay (and in ¹⁹Ne nuclear beta decay), and the results are consistent with T invariance.

Hyperon nonleptonic decays

The amplitude for a spin-1/2 hyperon decaying into a spin-1/2 baryon and a spin-0 meson may be written in the form

$$M = G_F m_\pi^2 \cdot \overline{B}_f (A - B\gamma_5) B_i , \qquad (6)$$

where A and B are constants [1]. The transition rate is proportional to

$$R = 1 + \gamma \widehat{\boldsymbol{\omega}}_{f} \cdot \widehat{\boldsymbol{\omega}}_{i} + (1 - \gamma)(\widehat{\boldsymbol{\omega}}_{f} \cdot \widehat{\mathbf{n}})(\widehat{\boldsymbol{\omega}}_{i} \cdot \widehat{\mathbf{n}}) + \alpha(\widehat{\boldsymbol{\omega}}_{f} \cdot \widehat{\mathbf{n}} + \widehat{\boldsymbol{\omega}}_{i} \cdot \widehat{\mathbf{n}}) + \beta \widehat{\mathbf{n}} \cdot (\widehat{\boldsymbol{\omega}}_{f} \times \widehat{\boldsymbol{\omega}}_{i}) ,$$
 (7)

where $\hat{\mathbf{n}}$ is a unit vector in the direction of the final baryon momentum, and $\hat{\boldsymbol{\omega}}_i$ and $\hat{\boldsymbol{\omega}}_f$ are unit vectors in the directions of the initial and final baryon spins. (The sign of the last term in the above equation was incorrect in our 1988 and 1990 editions.) The parameters α , β , and γ are defined as

$$\alpha = 2 \operatorname{Re}(s^* p) / (|s|^2 + |p|^2) ,$$

$$\beta = 2 \operatorname{Im}(s^* p) / (|s|^2 + |p|^2) ,$$

$$\gamma = (|s|^2 - |p|^2) / (|s|^2 + |p|^2) ,$$
(8)

where s = A and $p = |\mathbf{p}_f| B/(E_f + m_f)$; here E_f and \mathbf{p}_f are the energy and momentum of the final baryon. The parameters α , β , and γ satisfy

$$\alpha^2 + \beta^2 + \gamma^2 = 1. \tag{9}$$

If the hyperon polarization is \mathbf{P}_Y , the polarization \mathbf{P}_B of the decay baryons is

$$\mathbf{P}_{B} = \frac{(\alpha + \mathbf{P}_{Y} \cdot \widehat{\mathbf{n}})\widehat{\mathbf{n}} + \beta(\mathbf{P}_{Y} \times \widehat{\mathbf{n}}) + \gamma\widehat{\mathbf{n}} \times (\mathbf{P}_{Y} \times \widehat{\mathbf{n}})}{1 + \alpha\mathbf{P}_{Y} \cdot \widehat{\mathbf{n}}} . \quad (10)$$

Here \mathbf{P}_B is defined in the rest system of the baryon, obtained by a Lorentz transformation along $\hat{\mathbf{n}}$ from the hyperon rest frame, in which $\hat{\mathbf{n}}$ and \mathbf{P}_Y are defined.

An additional useful parameter ϕ is defined by

$$\beta = (1 - \alpha^2)^{1/2} \sin \phi \ . \tag{11}$$

In the Listings, we compile α and ϕ for each decay, since these quantities are most closely related to experiment and are essentially uncorrelated. When necessary, we have changed the signs of reported values to agree with our sign conventions. In the Baryon Summary Table, we give α , ϕ , and Δ (defined below) with errors, and also give the value of γ without error.

Time-reversal invariance requires, in the absence of final-state interactions, that s and p be relatively real, and therefore that $\beta=0$. However, for the decays discussed here, the final-state interaction is strong. Thus

$$s = |s| e^{i\delta_s}$$
 and $p = |p| e^{i\delta_p}$, (12)

where δ_s and δ_p are the pion-baryon s- and p-wave strong interaction phase shifts. We then have

$$\beta = \frac{-2|s||p|}{|s|^2 + |p|^2} \sin(\delta_s - \delta_p) . \tag{13}$$

One also defines $\Delta = -\tan^{-1}(\beta/\alpha)$. If T invariance holds, $\Delta = \delta_s - \delta_p$. For $\Lambda \to p\pi^-$ decay, the value of Δ may be compared with the s- and p-wave phase shifts in low-energy $\pi^- p$ scattering, and the results are consistent with T invariance.

See also the note on "Radiative Hyperon Decays" in the Ξ^0 Listings in this *Review*.

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$n ightarrow p \, e^- \overline{ u}_e$ DECAY PARAMETERS

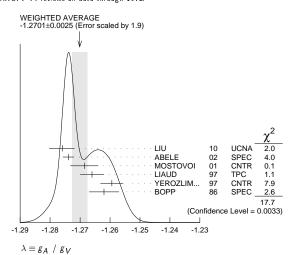
See the above "Note on Baryon Decay Parameters." For discussions of recent results, see the references cited at the beginning of the section on the neutron mean life. For discussions of the values of the weak coupling constants g_A and g_V obtained using the neutron lifetime and asymmetry parameter A, comparisons with other methods of obtaining these constants, and implications for particle physics and for astrophysics, see DUBBERS 91 and WOOLCOCK 91. For tests of the $V\!-\!A$ theory of

neutron decay, see EROZOLIMSKII 91B, MOSTOVOI 96, NICO 05, SEV-ERIJNS 06, and ABELE 08.

$\lambda \equiv g_A / g_V$

| ^ — BA / BV | | | |
|----------------------------------------|------------------------|-----------------|---------------------------------------|
| VALUE | DO CUMENT ID | TECN | |
| -1.2701 ±0.0025 OUR AVER below. | AGE Error include | s scale facto | or of 1.9. See the ideogram |
| $-1.27590 ^{+0.00409}_{-0.00445}$ | LIU | 10 UCN | A Ultracold <i>n</i> , polarized |
| -1.2739 ± 0.0019 | ³⁴ ABELE | 02 SPEC | Cold <i>n</i> , polarized, A |
| $-1.2686\ \pm0.0046\ \pm0.0007$ | 35 MOSTOVOI | 01 CNT | R A and B × polariza- |
| -1.266 ± 0.004 | LIAUD | 97 TPC | |
| -1.2594 ± 0.0038 | ³⁶ YEROZLIM | 97 CNT | R Cold <i>n</i> , polarized, <i>A</i> |
| -1.262 ± 0.005 | BOPP | 86 SPEC | Cold <i>n</i> , polarized, <i>A</i> |
| ullet $ullet$ We do not use the follow | ing data for average | s, fits, limits | s, etc. • • • |
| -1.275 ± 0.006 ± 0.015 | SCHUMANN | 08 CNT | R Cold <i>n</i> , polarized |
| -1.274 ± 0.003 | ABELE | 97D SPEC | Cold <i>n</i> , polarized, <i>A</i> |
| -1.266 ± 0.004 | SCHRECK | 95 TPC | See LIAUD 97 |
| -1.2544 ± 0.0036 | EROZOLIM | 91 CNT | R See YEROZOLIM- SKY 97 |
| -1.226 ± 0.042 | MOSTOVOY | 83 RVU | E |
| -1.261 ± 0.012 | EROZOLIM | 79 CNT | R Cold <i>n</i> , polarized, <i>A</i> |
| -1.259 ± 0.017 | ³⁷ STRATOWA | 78 CNT | R p recoil spectrum, a |
| -1.263 ± 0.015 | EROZOLIM | 77 CNT | R See EROZOLIMSKII 79 |
| -1.250 ± 0.036 | 37 DOBROZE | 75 CNT | R See STRATOWA 78 |
| -1.258 ± 0.015 | 38 KROHN | 75 CNT | R Cold <i>n</i> , polarized, <i>A</i> |
| -1.263 ± 0.016 | ³⁹ KROPF | 74 RVU | E <i>n</i> decay alone |
| -1.250 ± 0.009 | ³⁹ KROPF | 74 RVU | E n decay $+$ nuclear ft |
| 34 This is the combined result. | of ADELE 00 and A | DELE 075 | |

This is the combined result of ABELE 02 and ABELE 97D.



e- ASYMMETRY PARAMETER A

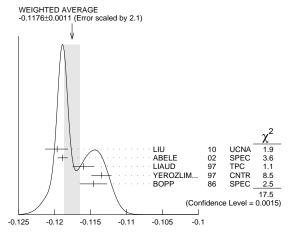
This is the neutron-spin electron-momentum correlation coefficient. Unless otherwise noted, the values are corrected for radiative effects and weak magnetism. In the Standard Model, A is related to $\lambda\equiv g_A/g_V$ by $A=-2(\lambda^2-|\lambda|)~/~(1+3\lambda^2);$ this assumes that ${\it g}_A$ and ${\it g}_V$ are real.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|-------|-----------|--------------------------------|
| -0.1176 ±0.0011 OUR AVERAGE | Error includes | scale | factor o | of 2.1. See the ideogram |
| below. | | | | |
| $-0.11966 \pm 0.00089 + 0.00123 \\ -0.00140$ | LIU | 10 | UCNA | Ultracold <i>n</i> , polarized |
| -0.1189 ± 0.0007 40 | ABELE | 02 | SPEC | Cold n, polarized |
| $-0.1160 \pm 0.0009 \pm 0.0012$ | LIAUD | 97 | TPC | Cold n, polarized |
| -0.1135 ± 0.0014 41 | YEROZLIM | 97 | CNTR | Cold n, polarized |
| -0.1146 ± 0.0019 | BOPP | 86 | SPEC | Cold n, polarized |
| ullet $ullet$ We do not use the following d | ata for averages, | fits, | limits, e | tc. • • • |
| $-0.1138 \pm 0.0046 \pm 0.0021$ | PATTIE | 09 | SPEC | Ultracold <i>n</i> , polarized |
| -0.1168 ± 0.0017 42 | MOSTOVOI | 01 | CNTR | Inferred |
| -0.1189 ± 0.0012 | ABELE | 97D | SPEC | Cold n, polarized |
| $-0.1160 \pm 0.0009 \pm 0.0011$ | SCHRECK | 95 | TPC | See LIAUD 97 |
| -0.1116 ± 0.0014 | EROZOLI M | 91 | CNTR | See YEROZOLIM- |
| 0.114 0.005 43 | ED0.701.114 | | CNTD | SKY 97 |
| | | 79 | | Cold <i>n</i> , polarized |
| -0.113 ± 0.006 | KROHN | 75 | CNTR | Cold <i>n</i> , polarized |

 40 This is the combined result of ABELE 02 and ABELE 97D.

41 YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value. 42 MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

43 These results are not corrected for radiative effects and weak magnetism, but the corrections are small compared to the errors.



e- asymmetry parameter A

v_e ASYMMETRY PARAMETER B

This is the neutron-spin antineutrino-momentum correlation coefficient. In the Standard Model, B is related to $\lambda \equiv g_A/g_V$ by $B=2\lambda(\lambda-1)/(1+3\lambda^2)$; this assumes that ${\it g}_A$ and ${\it g}_V$ are real.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------------|---------|-----------|-------------------|
| 0.9807±0.0030 OUR AVERAGE | | | | |
| $0.9802 \pm 0.0034 \pm 0.0036$ | SCHUMANN | 07 | CNTR | Cold n, polarized |
| $0.967 \pm 0.006 \pm 0.010$ | KREUZ | 05 | CNTR | Cold n, polarized |
| 0.9801 ± 0.0046 | SEREBROV | 98 | CNTR | Cold n, polarized |
| 0.9894 ± 0.0083 | KUZNETSOV | 95 | CNTR | Cold n, polarized |
| 1.00 ± 0.05 | CHRISTENSEN | 170 | CNTR | Cold n, polarized |
| 0.995 ± 0.034 | EROZOLIM | 70C | CNTR | Cold n, polarized |
| | lata for averages | , fits, | limits, e | etc. • • • |
| 0.9876 ± 0.0004 | MOSTOVOI | 01 | CNTR | Inferred |

⁴⁴ MOSTOVOI 01 calculates this from its measurement of $\lambda = g_A/g_V$ above.

PROTON ASYMMETRY PARAMETER C

Describes the correlation between the neutron spin and the proton momentum. In the Standard Model, C is related to $\lambda \equiv g_A/g_V$ by $C=-x_c~(A~+~B)=x_c~4\lambda/(1~+~B)$ 3 λ^2), where $x_c=$ 0.27484 is a kinematic factor; this assumes that g_A and g_V are real.

DO CUMENT ID TECN COMMENT $-0.2377 \pm 0.0010 \pm 0.0024$ SCHUMANN 08 CNTR Cold n, polarized

$e extstyle{-}\overline{ u}_e$ ANGULAR CORRELATION COEFFICIENT a

For a review of past experiments and plans for future measurements of the a parameter, see WIETFELDT 05. In the Standard Model, a is related to $\lambda \equiv g_A/g_V$ by a=(1 $(1 + 3\lambda^2)$ / $(1 + 3\lambda^2)$; this assumes that g_A and g_V are real.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|----------------------|---------|-----------|------------------------|
| -0.103 ±0.004 OUR AVERA | GE | | | |
| -0.1054 ± 0.0055 | BYRNE | 02 | SPEC | Proton recoil spectrum |
| -0.1017 ± 0.0051 | STRATOWA | 78 | CNTR | Proton recoil spectrum |
| -0.091 ± 0.039 | GRIGOREV | 68 | SPEC | Proton recoil spectrum |
| | ing data for average | s, fits | , limits, | etc. • • • |
| -0.1045 ± 0.0014 | 45 MOSTOVOI | 01 | CNTR | Inferred |

 $^{^{45}}$ MOSTOVOI 01 calculates this from its measurement of $\lambda{=}g_A/g_V$ above.

 ϕ_{AV} , PHASE OF g_A RELATIVE TO g_V Time reversal invariance requires this to be 0 or 180°. This is related to D given in the next data block and $\lambda \equiv g_A/g_V$ by $\sin(\phi_{AV}) \equiv D(1+3\lambda^2)/2|\lambda|$; this assumes that ${\it g}_A$ and ${\it g}_V$ are real.

| VALUE (°) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|---------------------------|---------|------------|-------------------------------|
| 180.018 ± 0.026 OUR AVE | RAGE | | | |
| 180.013 ± 0.028 | MUMM | 11 | CNTR | Cold n , polarized $> 91\%$ |
| 180.04 ±0.09 | SOLDNER | 04 | CNTR | Cold n, polarized |
| 180.08 ±0.13 | LISING | 00 | CNTR | Polarized > 93% |
| \bullet \bullet \bullet We do not use the | following data for averag | ges, fi | ts, limits | , etc. • • • |
| 179.71 ± 0.39 | EROZOLIM | 78 | CNTR | Cold n, polarized |
| 180.35 ±0.43 | | 74 | CNTR | Cold <i>n</i> , polarized |
| 181.1 ±1.3 | ⁴⁶ KROPF | 74 | RVUE | n decay |
| 180.14 ±0.22 | STEINBERG | 74 | CNTR | Cold n, polarized |

⁴⁶ KROPF 74 reviews all data through 1972.

³⁵ MOSTOVOI 01 measures the two P-odd correlations A and B, or rather SA and SB, where S is the n polarization, in free neutron decay.
36 YEROZOLIMSKY 97 makes a correction to the EROZOLIMSKII 91 value.

These experiments measure the absolute value of g_A/g_V only.

³⁸ KROHN 75 includes events of CHRISTENSEN 70. 39 KROPF 74 reviews all data through 1972.

TRIPLE CORRELATION COEFFICIENT ${\it D}$

These are measurements of the component of n spin perpendicular to the decay plane in β decay. Should be zero if T invariance is not violated.

| VALUE (units 10 ⁻⁴) | DOCUMENT ID | | TECN | COMMENT | |
|-----------------------------------|-----------------|---------|------------|------------------------------|---|
| - 1.2 ± 2.0 OUR AVERAGE | | | | | |
| $-$ 0.96 \pm 1.89 \pm 1.01 | MUMM | 11 | CNTR | Cold n , polarized $>$ 91% | ı |
| $-$ 2.8 \pm 6.4 \pm 3.0 | | | | Cold n, polarized | - |
| $-6 \pm 12 \pm 5$ | LISING | 00 | CNTR | Polarized > 93% | |
| • • • We do not use the following | data for averag | es, fit | s, limits, | etc. • • • | |
| +22 ±30 | EROZOLIM | 78 | CNTR | Cold n, polarized | |
| -27 ± 50 47 | EROZOLIM | 74 | CNTR | Cold n, polarized | |
| -11 ± 17 | STEINBERG | 74 | CNTR | Cold n, polarized | |
| 47 = 0 = 20111401111 = - | | | | | |

 $^{^{47}\}textsc{EroZoLiMSKII}$ 78 says asymmetric proton losses and nonuniform beam polarization may give a systematic error up to 30×10^{-4} , thus increasing the <code>EROZOLIMSKII</code> 74 error to 50×10^{-4} . <code>STEINBERG</code> 74 and <code>STEINBERG</code> 76 estimate these systematic errors to be insignificant in their experiment.

TRIPLE CORRELATION COEFFICIENT R

Another test of time-reversal invariance. R measures the polarization of the electron in the direction perpendicular to the plane defined by the neutron spin and the electron momentum. R=0 for T invariance.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|----|------|------------------|
| $+0.008\pm0.015\pm0.005$ | 48 KOZELA | 09 | CNTR | Mott polarimeter |

 $^{^{48}}$ KOZELA 09 also measures the polarization of the electron along the direction of the neutron spin. This is nonzero in the Standard Model; the correlation coefficient is $\textit{N} = +0.056 \pm 0.011 \pm 0.005$.

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| CHUNG MOSTOVOI AR ZUMANOV GAL KOLB LAMOREAUX LEV CHUK LISING HARRIS KESSLER MOHR Also SEREBROV | 02 B 01 00 00 00 00 00 00 00 99 99 99 | JPG 28 1325 PR D66 033004 PAN 64 1955 Translated from YAF 64 21 PL 8483 15 PR C61 028201 PRL 85 1388 PR D61 051301R NP A674 449 PR C62 055501 PRL 82 904 PL A255 221 JPCRD 28 1713 RMP 72 351 JETP 86 1074 Translated from ZETF 113 | J. Byme et al. J. Chung et al. Vu.A. Mostovoi et al. 040. S. Arzumanov et al. A. Gal N.R. Kolb et al. S. K. Lamoreaux, R. Golub MI. Levchuk, A.I. L'vov L.J. Lising et al. P.G. Harris et al. E.G. Kessler Jr et al. P.J. Mohr, B.N. Taylor A.P. Serebrov et al. 1963. | (SOUDAN-2 Collab.) (BELA, LEBD) (NIST emiT Collab.) (NIST) |
| CHUNG MOSTOVOI ARZUMANOV GAL KOLB LAMOREAUX LEVCHUK LISING HARRIS KESSLER MOHR Also SEREBROV ABELE | 02 B 01 00 00 00 00 00 00 00 99 99 99 98 | JPG 28 1325 PR D66 032004 PAN 64 1955 Translated from YAF 64 21 PL 8483 15 PR C61 028201 PRL 85 1388 PR D61 051301R NP A674 449 PRL 62 055501 PRL 82 904 PL A255 221 JPCRD 28 1713 RMP 72 351 JETP 86 1074 Translated from ZETF 113 PL 8407 212 | J. Byme et al. J. Chung et al. Yu.A. Mostovoi et al. 040. S. Arzumanov et al. A. Gal N.R. Kolb et al. S. K. Lamore aux, R. Golub M.I. Levchuk, A.I. L'vov L.J. Lising et al. E.G. Kessler Jr et al. P.J. Mohr, B.N. Taylor P.J. Mohr, B.N. Taylor P.J. Mohr, B.N. Taylor A.P. Serebrov et al. 1963. | (SOUDAN-2 Collab.) (BELA, LEBD) (NIST emiT Collab.) |
| CHUNG MOSTOVOI ARZUMANOV GAL KOLB LAMOREAUX LEVCHUK LISING HARRIS KESSLER MOHR Also SEREBROV ABELE | 02 B 01 00 00 00 00 00 00 00 99 99 99 99 98 97 D 97 | JPG 28 1325 PR D66 033004 PAN 64 1955 Translated from YAF 64 27 PL 8483 15 PR C61 028201 PRL 85 1388 PR D61 051301R NP A674 449 PR C62 055501 PRL 82 904 PL A255 221 JPCRD 28 1713 RMP 72 351 JETP 86 1074 Translated from ZETF 115 PL 8407 212 PR C56 2229 | J. Byme et al. J. Chung et al. Yu.A. Mostovoi et al. 040. S. Arzumanov et al. A. Gal N.R. Kolb et al. S. K. Lamoreaux, R. Golub M.I. Everhuk, A.I. L'vov L.J. Lising et al. P.G. Harris et al. E.G. Kessler Jr et al. P.J. Mohr, B.N. Taylor P.J. Mohr, B.N. Taylor A.P. Serebrov et al. 11963. H. Abele et al. S. Kopecky et al. | (SOUDAN-2 Collab.) (BELA, LEBD) (NIST emit Collab.) (NIST) (HEIDP, ILLG) |
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| CHUNG MOSTOVOI ARZUMANOV GAL KOLB LAMOREAUX LEVCHUK LISING HARRIS AISO SEREBROV ABELE KOPECKY LIAUD YERO ZLIM ALTAREV BONDAREN | 02 B 01 00 00 00 00 00 00 00 99 99 99 98 97 D 97 97 96 | JPG 28 1325 PR D66 032004 PAN 66 1955 Translated from YAF 64 27 PL 8483 15 PR C61 028201 PRL 85 1388 PR D61 051301R NP A674 449 PR C62 055501 PRL 82 904 PL A255 221 JPCRD 28 1713 RMP 72 351 JETP 86 1074 Translated from ZETF 113 PL 8407 212 PR C56 2229 NP A612 53 PN E612 54 PAN 59 1152 Translated from YAF 59 11 JETPL 64 416 Translated from ZETFP 64 PAN 59 1152 Translated from TETFP 64 PAT 154 PT A154 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 155 PT 15 | J. Byme et al. J. Chung et al. Yu.A. Mostovoi et al. 040. S. Arzumanov et al. A. Gal N.R. Kolb et al. S. K. Lamoreaux, R. Golub M.I. Levchuk, A.J. L'vov L.J. Lising et al. P.G. Harris et al. E.G. Kessler Jr et al. P.J. Mohr, B.N. Taylor A.P. Serebrov et al. 1163. H. Abole et al. S. Kopecky et al. P. Liaud et al. S. Kropecky et al. 15. Altarev et al. 204. L.N. Bondarenko et al. 4.382. | (SOUDAN-2 Collab.) (BELA, LEBD) (NIST emiT collab.) (NIST) (HEIDP, ILLG) (ILLG, LAPP) (HARV, PNPI, KIAE) (KIAE) |
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| SCHRECK | 95 | PRL 75 794 PL B349 427 | I.A. Kuznetsov et al. K. Schreckenbach et al. | (PNPI, KIAE, HARV+) (MUNT, ILLG, LAPP) |
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| Also | | PRL 71 1998 | V. Natarajan et al. | (MIT) |
| GOLUB MAMPE | 94 93 | PRPL 237C 1 JETPL 57 82 | R. Golub, K. Lamoreaux B. Mampe <i>et al.</i> | (HAHN, WASH) (KIAE) |
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| DUBBERS Also | 91 | NP A527 239c EPL 11 195 | D. Dubbers D. Dubbers, W. Mampe, J. Dohner | (ILLG) (ILLG, HEID) |
| ER OZOLIM | 91 | PL B263 33 SJNP 52 999 | B.G. Erozolimsky et al. B.G. Erozolimsky et al. | (PNPI, KIAE) (PNPI, KIAE) |
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| SCHMIEDM WOOLCOCK | 91 91 | PRL 66 1015 MPL A6 2579 | J. Schmied mayer et al. W.S. Woolcock | (TUW, ORNL) (CANB) |
| ALFIMENKOV | 90 | JETPL 52 373 Translated from ZETFP 52 | V.P. Alfimenkov et al. | (PNPÌ, JINR) |
| BALDO | 90 | PL B236 95 | M. Baldo-Ceolin et al. | (PADO, PAVI, HEIDP+) |
| BERGER BRESSI | 90 90 | PL B240 237 NC 103A 731 | C. Berger et al. G. Bressi et al. | (FREJUS Collab.) (PAVI, ROMA, MILA) |
| BYRNE GREEN | 90 90 | PRL 65 289 JPG 16 L75 | J. Byrne et al. (SUS K. Green, D. Thompson | S, NBS, SCOT, CBNM) (RAL) |
| RAMSEY | 90 90 | ARNPS 40 1 | N.F. Ramsey | (HÀRV) |
| ROSE ROSE | 90 B | PL B234 460 NP A514 621 | K.W. Rose et al. | (GOET, MPCM, MANZ) (GOET, MPCM) (SUSS, RAL, HARV+) |
| SMITH BRESSI | 90 89 | PL B234 191 ZPHY C43 175 | K.F. Smith et al. G. Bressi et al. (INF | (SUSS, RAL, HARV+) N, MILA, PAVI, ROMA) |
| DOVER | 89 | NIM A284 13 | C.B. Dover, A. Gal, J.M. Richard | (BNL, HEBR+) |
| KOSSAKOW MAMPE | 89 89 | NP A503 473 PRL 63 593 | | (LAPP, SAVO, ISNG+) ILLG, RISL, SUSS, URI) |
| MOHAPATRA PAUL | 89 89 | NIM A284 1 ZPHY C45 25 | R.N. Mohapatra W. Paul et al. (BON | (UMD) N, WUPP, MPIH, ILLG) |
| S CHM IE DM | 89 | NIM A284 137 | J. Schmiedmayer, H. Rauch, P. Rie | hs (WIEN) |
| BAUMANN KOESTER | 88 88 | PR D37 3107 ZPHY A329 229 | J. Baumann et al. L. Koester, W. Waschkowski, J. Me | (BAYR, MUNI, ILLG) ier (MUNI, MUNT) |
| LAST SCHMIEDM | 88 88 | PRL 60 995 PRL 61 1065 | I. Last et al. J. Schmiedmayer, H. Rauch, P. Rie | (HEIDP, ILLG, ANL) |
| Also | | PRL 61 2509 (erratum) | J. Schmiedmayer, H. Rauch, P. Rie | hs (TUW) |
| SPIVAK | 88 | JETP 67 1735 Translated from ZETF 94 | P.E. Spivak L. | (KIAE) |
| COHEN ALEKSANDR | 87 86 | RMP 59 1121 SJNP 44 900 | E.R. Cohen, B.N. Taylor Yu.A. Aleksandrov et al. | (RISC, NBS) |
| ALTAREV | 86 | Translated from YAF 44 13 JETPL 44 460 | 84. I.S. Altarev et al. | (PNPI) |
| ВОРР | 86 | Translated from ZETFP 44 PRL 56 919 | 360. | |
| Also | | ZPHY C37 179 | P. Bopp et al. E. Klempt et al. | (HEIDP, ANL, ILLG) (HEIDP, ANL, ILLG) |
| CRESTI Also | 86 | PL B177 206 PL B200 587 (erratum) | M. Cresti et al. M. Cresti et al. | (PADO) (PADO) |
| GREENE KOESTER | 86 86 | PRL 56 819 Physica B137 282 | G.L. Greene et al. L. Koester et al. | (NBŠ, ILLG) |
| KOSVINTSEV | 86 | JETPL 44 571 | Y.Y. Kosvintsev, V.I. Morozov, G.I. | Terekhov (KIAE) |
| TAKITA | 86 | Translated from ZETFP 44 PR D34 902 | M. Takita et al. | (KEK, TOKY+) |
| DOVER FIDECARO | 85 85 | PR C31 1423 PL 156B 122 | C.B. Dover, A. Gal, J.M. Richard G. Fidecaro et al. | (BNL) (CERN, ILLG, PADO+) |
| PARK | 85 B 84 | NP B252 261 | H.S. Park et al. | (IMB Collab.) |
| BATTISTONI JONES | 84 | PL 133B 454 PRL 52 720 | G. Battistoni et al. T.W. Jones et al. | (NUSEX Collab.) (IMB Collab.) |
| PENDLEBURY CHERRY | 84 83 | PL 136B 327 PRL 50 1354 | J.M. Pendlebury et al. M.L. Cherry et al. | (SUSS, HARV, RAL+) (PENN, BNL) |
| DOVER | 83 | PR D27 1090 | C.B. Dover, A. Gal, J.M. Richard | (BNL) (HARV) |
| KABIR MOSTOVOY | 83 83 | PRL 51 231 JETPL 37 196 | P.K. Kabir Y.A. Mostovoy | (KIAE) |
| ROY | 83 | Translated from ZETFP 37 PR D28 1770 | 162. A. Roy et al. | (TATA) |
| VAIDYA GAEHLER | 83 82 | PR D27 486 PR D25 2887 | S.C. Vaidya et al. R. Gahler, J. Kalus, W. Mampe | (TATA) (BAYR, ILLG) |
| GREENE | 82 | Metrologia 18 93 | G.L. Greene et al. | (YALE, HÀRV, ILLG+) |
| ALTAREV BARABANOV | 81 80 | PL 102B 13 JETPL 32 359 | I.S. Altarev et al. I.R. Barabanov et al. | (PNPI) (PNPI) |
| BYRNE | 80 | Translated from ZETFP 32 PL 92B 274 | 384. J. Byrne et al. | (SUSS, RL) |
| KOSVINTSEV | 80 | JETPL 31 236 Translated from ZETFP 31 | Y.Y. Kosvintsev et al. | (JINR) |
| MOHAPATRA | 80 | PRL 44 1316 | R.N. Mohapatra, R.E. Marshak | (CUNY, VPI) |
| ALTAREV | 79 | JETPL 29 730 Translated from ZETFP 29 | | (PNPI) |
| EROZOLIM | 79 | SJNP 30 356 Translated from YAF 30 69 | B.G. Erozolimsky et al. 2. | (KIAE) |
| NORMAN BONDAREN | 79 78 | PRL 43 1226 JETPL 28 303 | E.B. Norman, A.G. Seamster L.N. Bondarenko <i>et al.</i> | (WASH) (KIAE) |
| Also | | Translated from ZETFP 28 Smolenice Conf. | 328. P.G. Bond aren ko | (KIAE) |
| EROZOLIM | 78 | SJNP 28 48 | B.G. Erozolimsky et al. | (KIAE) |
| STRATOWA | 78 | Translated from YAF 28 98 PR D18 3970 | C. Stratowa, R. Dobrozemsky, P. W. | einzierI (SEIB) |
| EROZOLIM | 77 | JETPL 23 663 Translated from ZETFP 23 | B.G. Erozolimsky et al. 720. | (KIAE) |
| KOESTER STEINBERG | 76 76 | PRL 36 1021 PR D13 2469 | L. Koester et al. R.I. Steinberg et al. | (YALE, ISNG) |
| DOBROZE | 75 | PR D11 510 | R. Dobrozemsky et al. | (SEIB) |
| KROHN EROZOLIM | 75 74 | PL 55B 175 JETPL 20 345 | V.E. Krohn, G.R. Ringo B.G. Erozolimsky et al. | (ANL) |
| KROPF | 74 | Translated from ZETFP 20 ZPHY 267 129 | 745. H. Kropf, E. Paul | (LINZ) |
| Also | 74 | NP A154 160 PRL 33 41 | H. Paul | (VIEN) |
| STEINBERG | 74 73 | JPCRD 2 664 | R.I. Steinberg <i>et al.</i> E.R. Cohen, B.N. Taylor | (YALE, ISNG) (RISC, NBS) |
| COHEN | | | V L Krohn C D Dingo | |
| KROHN | 73 | PR D8 1305 PR D5 1628 | V.E. Krohn, G.R. Ringo C.J. Christensen et al. | (RISO) |
| KROHN CHRISTENSEN CHRISTENSEN | 73 72 70 | PR D5 1628 PR C1 1693 | C.J. Christensen et al. C.J. Christensen, V.E. Krohn, G.R. | |
| KROHN CHRISTENSEN | 73 72 | PR D5 1628 PR C1 1693 PL 33B 351 SJNP 6 239 | C.J. Christensen et al. C.J. Christensen, V.E. Krohn, G.R. B.G. Erozolimsky et al. V.K. Grigoriev et al. | (RISO) Ringo (ANL) (KIAE) (ITEP) |
| KROHN CHRISTENSEN CHRISTENSEN EROZOLIM | 73 72 70 70 C | PR D5 1628 PR C1 1693 PL 33B 351 | C.J. Christensen et al. C.J. Christensen, V.E. Krohn, G.R. B.G. Erozolimsky et al. V.K. Grigoriev et al. | Ringo (ANL) (KIAE) |

N's and Δ 's

N AND Δ RESONANCES

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I. Introduction

The excited states of the nucleon have been studied in a large number of formation and production experiments. The Breit-Wigner masses and widths, the pole positions, and the elasticities of the N and Δ resonances in the Baryon Summary Table come largely from partial-wave analyses of πN total, elastic, and charge-exchange scattering data. The most comprehensive analyses were carried out by the Karlsruhe-Helsinki (KH80) [1], Carnegie Mellon-Berkeley (CMB80) [2], and George Washington U (GWU) [3] groups. Partial-wave analyses have also been performed on much smaller πN reaction data sets to get $N\eta$, ΛK , and ΣK branching fractions. Other branching fractions come from analyses of $\pi N \to N\pi\pi$ data. A number of groups have undertaken multichannel analyses of these and associated photo-induced reactions (see Sec. VI).

Table 1. The status of the N resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

| | | Status as seen in — | | | | | | | | |
|-------------------|--------|---------------------|------------|---------|-----------|-----------|-------------|------------|---------|--------------|
| D | | Status | | | | | | | | |
| Particle J^P | overal | $11 \pi N$ | γN | $N\eta$ | $N\sigma$ | $N\omega$ | ΛK | ΣK | $N\rho$ | $\Delta \pi$ |
| $N = 1/2^{+}$ | **** | | | | | | | | | |
| $N(1440) 1/2^+$ | **** | **** | **** | | *** | | | | * | *** |
| $N(1520)3/2^-$ | **** | **** | **** | *** | | | | | *** | *** |
| $N(1535)1/2^-$ | **** | **** | **** | **** | | | | | ** | * |
| $N(1650)1/2^-$ | **** | **** | *** | *** | | | *** | ** | ** | *** |
| $N(1675)5/2^-$ | **** | **** | *** | * | | | * | | * | *** |
| $N(1680)5/2^+$ | **** | **** | **** | * | ** | | | | *** | *** |
| N(1685) ? | * | | | | | | | | | |
| $N(1700) 3/2^-$ | *** | *** | ** | * | | | * | * | * | *** |
| $N(1710) 1/2^+$ | *** | *** | *** | *** | | ** | *** | ** | * | ** |
| $N(1720) 3/2^+$ | **** | **** | *** | *** | | | ** | ** | ** | * |
| $N(1860)5/2^+$ | ** | ** | | | | | | | * | * |
| $N(1875) 3/2^-$ | *** | * | *** | | | ** | *** | ** | | *** |
| $N(1880) 1/2^+$ | ** | * | * | | ** | | * | | | |
| $N(1895)1/2^-$ | ** | * | ** | ** | | | ** | * | | |
| $N(1900) 3/2^+$ | *** | ** | *** | ** | | ** | *** | ** | * | ** |
| $N(1990) 7/2^+$ | ** | ** | ** | | | | | * | | |
| $N(2000)5/2^+$ | ** | * | ** | ** | | | ** | * | ** | |
| $N(2040) 3/2^+$ | * | | | | | | | | | |
| $N(2060)5/2^-$ | ** | ** | ** | * | | | | ** | | |
| $N(2100) 1/2^+$ | * | | | | | | | | | |
| $N(2150)3/2^-$ | ** | ** | ** | | | | ** | | | ** |
| $N(2190) 7/2^-$ | **** | **** | *** | | | * | ** | | * | |
| $N(2220) 9/2^+$ | **** | **** | | | | | | | | |
| $N(2250) 9/2^-$ | **** | **** | | | | | | | | |
| $N(2600)11/2^-$ | *** | *** | | | | | | | | |
| $N(2700) 13/2^+$ | ** | ** | | | | | | | | |

*** Existence is certain, and properties are at least fairly well explored.

** Existence is very likely but further confirmation of quantum numbers and branching fractions is required.

- ** Evidence of existence is only fair.
- Evidence of existence is poor.

In recent years, a large amount of data on photoproduction of many final states has been accumulated, and these data are beginning to make a significant impact on the properties of baryon resonances. A survey of data on photoproduction can be found in the proceedings of recent conferences [4] and workshops [5], and in a recent review [6].

II. Naming scheme for baryon resonances

In the past, when nearly all resonance information came from elastic πN scattering, it was common to label resonances with the incoming partial wave $L_{2I,2J}$, as in $\Delta(1232)P_{33}$ and $N(1680)F_{15}$. However, most recent information has come from γN experiments. Therefore, we have replaced $L_{2I,2J}$ with the spin-parity J^P of the state, as in $\Delta(1232)$ 3/2⁺ and N(1680) 5/2⁺. This applies to all baryons, including those such as the Ξ resonances and charm baryons that are not produced in formation experiments. Names of the stable baryons $(N, \Lambda, \Sigma, \Xi, \Omega, \Lambda_c, \cdots)$ have no spin, parity, or mass attached.

Table 2. The status of the Δ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

| | | | | | S | tatus | as se | en in | _ | |
|---------------------------|-------|-------------------|------------|---------|-----------|------------|-------------|------------|---------|-----------------|
| Particle J^P | overa | Status II πN | γN | $N\eta$ | $N\sigma$ | $N\omega$ | ΛK | ΣK | $N\rho$ | $\Delta \pi$ |
| $\Delta(1232) \ 3/2^{+}$ | **** | **** | **** | F | | | | | | |
| $\Delta(1600) \ 3/2^{+}$ | *** | *** | *** | О | | | | | * | *** |
| $\Delta(1620) 1/2^{-}$ | **** | **** | *** | | r | | | | *** | *** |
| $\Delta(1700) \ 3/2^-$ | **** | **** | **** | | b | | | | ** | *** |
| $\Delta(1750) 1/2^{+}$ | * | * | | | i | | | | | |
| $\Delta(1900) 1/2^{-}$ | ** | ** | ** | | | d | | ** | ** | ** |
| $\Delta(1905) 5/2^+$ | **** | **** | **** | | | d | | *** | ** | ** |
| $\Delta(1910) 1/2^{+}$ | **** | **** | ** | | | ϵ | | * | * | ** |
| $\Delta(1920) \ 3/2^{+}$ | *** | *** | ** | | | | n | *** | | ** |
| $\Delta(1930) \ 5/2^-$ | *** | *** | | | | | | | | |
| $\Delta(1940) \ 3/2^{-}$ | ** | * | ** | F | | | | (see | n in | $\Delta \eta$) |
| $\Delta(1950) 7/2^{+}$ | **** | **** | **** | О | | | | *** | * | *** |
| $\Delta(2000) 5/2^{+}$ | ** | | | | r | | | | | ** |
| $\Delta(2150) 1/2^{-}$ | * | * | | | b | | | | | |
| $\Delta(2200) 7/2^{-}$ | * | * | | | i | | | | | |
| $\Delta(2300) 9/2^{+}$ | ** | ** | | | | d | | | | |
| $\Delta(2350) \ 5/2^-$ | * | * | | | | d | | | | |
| $\Delta(2390) 7/2^{+}$ | * | * | | | | 6 | 9 | | | |
| $\Delta(2400) 9/2^{-}$ | ** | ** | | | | | n | | | |
| $\Delta(2420) \ 11/2^{+}$ | **** | **** | * | | | | | | | |
| $\Delta(2750) \ 13/2^{-}$ | ** | ** | | | | | | | | |
| $\Delta(2950) 15/2^{+}$ | ** | ** | | | | | | | | |

- **** Existence is certain, and properties are at least fairly well explored.

 *** Existence is very likely but further confirmation of quantum numbers and branching fractions is required.
- ** Evidence of existence is only fair.
- * Evidence of existence is poor.

III. Using the N and Δ listings

Tables 1 and 2 list all the N and Δ entries in the Baryon Listings and give our evaluation of the overall status, the status from $\pi N \to N\pi$ scattering data and from photoproduction experiments, and the status channel by channel. Only the established resonances (overall status 3 or 4 stars) are promoted to the Baryon Summary Table. We have omitted from the Listings information from old analyses, prior to KH80 and CMB80 which can be found in earlier editions. A rather complete survey of older results was given in our 1982 edition [7].

Baryon Particle Listings N's and Δ 's

The star rating assigned to a resonance depends on the data base and the analysis. As a rule, we award an overall status *** or **** only to those resonances which are confirmed by independent analyses and which are derived from analyses based on complete information, *i.e.*, for analyses based on three observables in πN scattering or eight properly chosen observables in photoproduction. Use of dispersion relations (as in the KH80, CMB80, and GWU analyses) may lift these requirements. Three and four-star resonances should be observed in one of their strongest decay modes. Weak signals or signals emerging in analyses with incomplete experimental information are given ** or * status. We do not consider new results without proper error evaluation.

In the Data Listings, we give first the Breit-Wigner mass and width but warn the reader that Breit-Wigner parameters depend on the formalism used, such as for angular momentum barrier factors or cut-off parameters, and the assumed or modeled background. Then we give pole-related quantities, such as the position of the pole and its elastic residue. For the first time, we give residues and phases of hadronic transition amplitudes and helicity amplitudes. Branching ratios and photoproduction amplitudes follow.

IV. Properties of resonances

Resonances are defined by poles of the scattering amplitude in the complex energy $w=\sqrt{s}$ plane [8]. In contrast to other quantities related to resonance phenomena, such as the Breit-Wigner mass or the K-matrix pole, a pole of the scattering amplitude does not depend on the chosen field parameterization, and production and decay properties factorize. It is the pole position which should be compared to eigenvalues of the Hamiltonian of full QCD.

Examining the Listings, one finds a much larger spread in Breit-Wigner parameters compared to pole parameters. In his pole-emic against Breit-Wigner parameters, Höhler [9] concluded: "In contrast to the conventional (Breit-Wigner) parameters, the pole positions and speed plots have a well-defined relation to S-matrix theory. They also give more information on the resonances and thresholds and can be used for the prediction on other reactions that couple to the excited states [italics in original]."

In scattering theory, the amplitude for the scattering process leading from the initial state a to the final state b is given by the S matrix, which can be decomposed as follows:

$$S_{ab} = I_{ab} + 2i\sqrt{\rho_a}T_{ab}\sqrt{\rho_b}.$$
 (1)

Here I_{ab} is the identity operator, and T_{ab} describes the transition from the initial state to the final state (e.g. πN to ΣK). T_{ab} contains coupling constants, the decay momenta k to the power L to yield the correct threshold behavior when angular momenta are involved, and a correction $F(L, r^2, k^2)$, e.g. in Blatt-Weisskopf form, with a range parameter r. The two-body phase-space ρ is given (see Eq. 39.17 in Sec. 39) by

$$\rho(s) = \frac{1}{16\pi} \frac{2|\vec{k}|}{\sqrt{s}} \,. \tag{2}$$

The transition amplitude T contains poles due to resonances and background terms. Above the threshold for inelastic reactions, a resonance is associated with a cluster of poles in different Riemann sheets. The pole closest to the real axis has the strongest impact on the data. It is situated on the second Riemann sheet, starting at the highest threshold below the pole position. If the threshold is close to the pole position, poles in other sheets may have an important impact as well.

Other complications may occur: Broad resonances are difficult to disentangle from background amplitudes, e.g., due to left-hand cuts originating from meson and baryon exchange forces. A two-particle subsystem generates a square-root singularity at its threshold; poles in a two-body subsystem, e.g., the ρ meson in the $\pi\pi$ system, lead to branch points in the complex energy plane. Neglecting some of these aspects leads to a model dependence of the pole position. These uncertainties increase with the particle width.

Several particle properties are related to poles. First, poles exist on multiple Riemann sheets. In the Listings, we give for each resonance the position of the most relevant pole. The poles of the scattering amplitude can be found by analytic continuation of the amplitude. The real part of the pole position in the complex energy plane defines the particle mass, the imaginary part its half width: $w_{\text{pole}} = m_{\text{pole}} - i\Gamma_{\text{pole}}/2$. Residues of transition amplitudes are the first term in a Laurent expansion and can be calculated through a contour integral of the amplitude T_{ab} around the pole position in the energy plane:

$$Res(a \to b) = \oint \frac{d\sqrt{s}}{2\pi i} \sqrt{\rho_a} T_{ab}(s) \sqrt{\rho_b}$$

$$= \frac{1}{2w_{\text{pole}}} \sqrt{\rho_a(s_{\text{pole}})} g_a g_b \sqrt{\rho_b(s_{\text{pole}})}, \qquad (4)$$

where g_a and g_b are coupling constants. In the Listings, we give normalized residues, $2 \operatorname{Res}(a \to b)/\Gamma_{\text{pole}}$. For elastic scattering, e.g., for $\pi N \to N\pi$, this gives the elastic residue:

$$Res(a \to a) = \frac{1}{2w_{\text{pole}}} \rho_a(s_{\text{pole}}) g_a^2. \tag{5}$$

Branching ratios of a pole can be defined by

$$BR_{\text{pole}}(\text{channel } b) = \frac{|Res(\pi N \to b)|^2}{|Res(\pi N \to N\pi)| \cdot (\Gamma_{\text{pole}}/2)}.$$
 (6)

This information is, however, not given in the literature.

Within models, background amplitudes can be parameterized using an effective Lagrangian approach (as in dynamical coupled-channel approaches), or by low-order polynomial functions. In the latter case, resonances are then added, sometimes in the form of Breit-Wigner amplitudes. In the Listings, particle properties related to fits to data using Breit-Wigner amplitudes are given as well. These are the Breit-Wigner mass and width, the partial decay widths, and the branching ratios. It should be noted that Breit-Wigner parameters depend on the background parameterization.

N's and Δ 's

The multichannel relativistic Breit-Wigner amplitude is given by

$$A_{ab} = \sqrt{\rho_a} T_{ab} \sqrt{\rho_b} = \frac{-g_a g_b \sqrt{\rho_a \rho_b}}{s - m_{\text{BW}}^2 + i \sum_a g_a^2 \rho_a} , \qquad (7)$$

where $m_{\rm BW}$ is called the Breit-Wigner mass. In the case of two channels, Eq. (7) is known as the Flatté formula. The inclusion of angular momenta leads to additional factors. The energy-dependent partial decay widths, defined by $\sqrt{s}\,\Gamma_a(s)=g_a^2\rho_a(s)$, can be used to bring Eq. (7) into the form of Eq. (39.57). Evaluated at the Breit-Wigner mass, it gives the partial decay width Γ_a at the resonance position

$$m_{\rm BW}\Gamma_a = g_a^2 \rho_a(m_{BW}^2). \tag{8}$$

The branching ratio for the decay of a resonance into channel a,

$$BR_a = \Gamma_a/\Gamma_{\rm BW}$$
, (9)

vanishes by definition for decay modes with thresholds above the Breit-Wigner mass. That the sum $\sum_a BR_a$ equals one follows from the definition. Unobserved decay modes lead to the inequality $\sum_a BR_a \leq 1$. In the case of broad resonances, definitions (8) and (9) may be counter-intuitive. Branching ratios can also be defined as

$$BR' = \int_{\text{threshold}}^{\infty} \frac{ds}{\pi} \frac{g_a^2 \rho(s)}{(m_{\text{BW}}^2 - s)^2 + (\sum_a g_a^2 \rho_a(s))^2}.$$
 (10)

Here $\rho(s)$ should not be continued below threshold. These branching ratios include decays of resonances into channels with thresholds above their nominal masses. The relation $\sum_a BR'_a = 1$ is needed for normalization.

V. Electromagnetic interactions

A new approach to the nucleon excitation spectrum is provided by dedicated facilities at the Universities of Bonn and Mainz, and at the national laboratories Jefferson Lab in the US and SPring-8 in Japan. High-precision cross sections and polarization observables in photoproduction of pseudoscalar mesons provide a data set that is nearly a "complete experiment," one that fully constrains the four complex amplitudes describing the spin-structure of the reaction. A large number of photoproduction reactions has been studied.

In photoproduction, the spins of the photon and nucleon can be parallel or anti-parallel, and there are spin-flip and non-flip transitions. Four independent amplitudes can be defined using the photon polarization and the hadronic current [10]. The amplitudes can be expanded in a series of electric and magnetic multipoles. In general, two amplitudes, one electric and one magnetic, contribute to one J^P combination. For a given resonance, these two amplitudes are related to the helicity amplitudes $A_{1/2}$ and $A_{3/2}$. The final state may have isospin I=1/2 or I=3/2.

If a Breit-Wigner parametrization is used, the $N\gamma$ partial width, Γ_{γ} , is given in terms of the helicity amplitudes $A_{1/2}$ and $A_{3/2}$ by

$$\Gamma_{\gamma} = \frac{k_{\text{BW}}^2}{\pi} \frac{2m_N}{(2J+1)m_{\text{BW}}} \left(|A_{1/2}|^2 + |A_{3/2}|^2 \right) . \tag{11}$$

Here m_N and $m_{\rm BW}$ are the nucleon and resonance masses, J is the resonance spin, and $k_{\rm BW}$ is the photon c.m. decay momentum. Most earlier analyses have quoted the real quantities $A_{1/2}$ and $A_{3/2}$.

Other more recent studies have quoted related complex quantities, evaluated at the T-matrix pole. The complex helicity amplitudes for photoproduction of the final state b, $\tilde{A}_{1/2}$ and $\tilde{A}_{3/2}$, are given by

$$Res\Big((\gamma N)_h \to b\Big) = \frac{\tilde{A}^h g_b}{2w_{\text{pole}}} |k_{\text{pole}}| \sqrt{\frac{2m_N}{(2J+1)\pi} \cdot \rho_b(w_{\text{pole}}^2)}.$$
(12)

 $\tilde{A}_{1/2}$ and $\tilde{A}_{3/2}$ are defined at the pole position, and are normalized to reproduce Eq. (11) when the pole position is replaced by the Breit-Wigner mass.

The amplitudes $\tilde{A}_{1/2}$ and $\tilde{A}_{3/2}$, the elastic residues, and the residues of the transition amplitudes are complex numbers. Eq. (8) defines $g_{N\pi}$ up to a sign. (Here, $g_{N\pi}$ is the $N\pi$ decay constant of a resonance, not the πN coupling constant!) Due to Eq. (12), the phase of the helicity amplitude depends on this definition. We define the phase of $g_{N\pi}$ clockwise.

The determination of eight real numbers from four complex amplitudes (with one overall phase undetermined) requires at least seven independent data points. At least one further measurement is required to resolve discrete ambiguities that result from the fact that data are proportional to squared amplitudes. Photon beams and nucleon targets can be polarized (with linear or circular polarization P_{\perp} , P_{\odot} , and \vec{T} , respectively); and the recoil polarization of the outgoing nucleon \vec{R} can be measured. Experiments can be divided into three classes: those with polarized photons and a polarized target (BT); and those measuring the baryon recoil polarization and using either a polarized photon (BR) or a polarized target (TR). Different sign conventions are used in the literature, as summarized in Ref. 12.

A large number of polarization observables has been determined that constrain energy-dependent partial-wave solutions. One of the best studied reactions is $\gamma p \to \Lambda K^+$. Published data include differential cross sections, the beam asymmetry Σ , the target asymmetry T, the recoil polarization P, and the BR double-polarization variables C_x, C_z, O_x , and O_z . For $\gamma p \to p \pi^0$, $\gamma p \to n \pi^+$, and $\gamma p \to p \eta$, differential cross sections and beam asymmetries have been published; BT data for E, F, G, and H have been presented at conferences [13].

Electroproduction of mesons provides information on the internal structure of resonances. The helicity amplitudes become functions of the momentum transfer, and a third amplitude, $S_{1/2}$, contributes to the process. Recent experimental results and their interpretation are reviewed by I.G. Aznauryan and

V.D. Burkert [14] and by L. Tiator, D. Drechsel, S.S. Kamalov, and M. Vanderhaeghen [15].

VI. Partial wave analyses

Several PWA groups are now actively involved in the analysis of the new data. Of the three "classical" analysis groups at KH, CMB, and GWU, only the GWU group is still active. This group maintains a nearly complete database, covering reactions from πN and KN elastic scattering to $\gamma N \to N\pi$, $N\eta$, and $N\eta'$. It is presently the only group determining energy-independent πN elastic amplitudes from scattering data. Given the high-precision of photoproduction data already collected and to be taken in the near future, we estimate that an improved spectrum of N and Δ resonances should become available in the forthcoming years.

Energy-dependent fits are performed by various groups with the aim to understand the reaction dynamics and to identify Nand Δ resonances. Ideally, the Bethe-Salpeter equation should be solved to describe the data. For practical reasons, approximations have to be made. We mention here: (1) The Mainz unitary isobar model [16] focusses on the correct treatment of the low-energy domain; resonances are added to the unitary amplitude as a sum of Breit-Wigner amplitudes. (2) Multichannel analyses using K-matrix parameterizations derive background terms from a chiral Lagrangian—providing a microscopical description of the background—(Giessen [17,18]), or from phenomenology (Bonn-Gatchina [19]). (3) Several groups (Argonne-Osaka [20], Bonn-Jülich [22,23], Dubna-Mainz-Taipeh [21], EBAC-Jlab [24], Valencia [25]) use dynamical reaction models, driven by chiral Lagrangians, which take dispersive parts of intermediate states into account. The Giessen group pioneered multichannel analyses of large data sets on pion- and photoinduced reactions [17,18]. The Bonn-Gatchina group included recent high-statistics data and reported systematic searches for new baryon resonances in all relevant partial waves. A summary of their results can be found in Ref. 19.

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 $N(1440) 1/2^{+}$

 $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

N(1440) BREIT-WIGNER MASS

| ALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 420 to 1470 (≈ 1440) OUR | ESTIMATE | | | |
| 430 ± 8 | ANISOVICH | 12A | DPWA | Multichannel |
| .485.0 ± 1.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| .462 ±10 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 440 ±30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 410 ±12 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • We do not use the follow | ing data for average | s, fits | , limits, e | etc. • • • |
| 440 ±12 | ANISOVICH | 10 | DPWA | Multichannel |
| .439 ±19 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| 436 ±15 | SARANTSEV | 08 | DPWA | Multichannel |
| 468.0 ± 4.5 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 518 ± 5 | PENNER | 02c | DPWA | Multichannel |
| 479 ±80 | VRANA | 00 | DPWA | Multichannel |
| .463 ± 7 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 467 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 465 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 471 | CUTKOSKY | 90 | IPWA | $\pi N \rightarrow \pi N$ |
| .380 | $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 390 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1440) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------|-----|------|----------------------------------------|
| 200 to 450 (≈ 300) OUR ESTIMAT | E | | | |
| 365 ± 35 | ANISOVICH | 12A | DPWA | Multichannel |
| 284 ± 18 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 391 ± 34 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 340± 70 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| $135\pm~10$ | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

Baryon Particle Listings N(1440)

| • • • We do not use the following | g data for average | s, fits | , limits, etc. • • • |
|-----------------------------------|-----------------------|---------|-------------------------------------------|
| 335 ± 50 | ANISOVICH | 10 | DPWA Multichannel |
| 437±141 | BATINIC | 10 | DPWA $\pi N \to N \pi$, $N \eta$ |
| 335 ± 40 | SARANTSEV | 80 | DPWA Multichannel |
| 360 ± 26 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 668± 41 | PENNER | 02c | DPWA Multichannel |
| 490±120 | VRA NA | 00 | DPWA Multichannel |
| 360 ± 20 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 440 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 315 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ |
| 545 ± 170 | CUTKOSKY | 90 | IPWA $\pi N \rightarrow \pi N$ |
| 200 | ¹ LONGACRE | 77 | IPWA $\pi N \rightarrow N \pi \pi$ |
| 200 | ² LONGACRE | 75 | IPWA $\pi N \rightarrow N \pi \pi$ |

N(1440) POLE POSITION

REAL PART

| DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IMATE | | | |
| ANISOVICH | 12A | DPWA | Multichannel |
| ³ ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| g data for average | s, fits | , limits, e | etc. • • • |
| ANISOVICH | 10 | DPWA | Multichannel |
| BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| SARANTSEV | 08 | DPWA | Multichannel |
| ⁵ ARNDT | 04 | DPWA | π N \rightarrow π N, η N |
| VRA NA | 00 | DPWA | Multichannel |
| ⁶ ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| ⁷ ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| CUTKOSKY | 90 | IPWA | $\pi N \rightarrow \pi N$ |
| ⁸ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| | MATE A NISOVICH A NISOVICH HOEHLER CUT KOSKY ANISOVICH BATINIC SARANTSEV ARNOT VRA NA ARNOT ARNOT UTKOSKY LONGACRE | ANISOVICH 12A 3 ARNDT 06 4 HOEHLER 93 CUTKOSKY 80 g data for averages, fits ANISOVICH 10 BATINIC 10 BATINIC 10 SARANTSEV 08 5 ARNDT 04 VRANA 00 6 ARNDT 95 7 ARNDT 91 CUTKOSKY 90 8 LONGACRE 78 | A NISOVICH 2A DPWA A HODELER 93 SPED CUTKOSKY 80 IPWA CUTKOSKY 80 IPWA CUTKOSKY 80 IPWA CONTROL 10 DPWA BATINIC 10 DPWA BATINIC 10 DPWA SARANTSEV 80 DPWA VRA NA 00 DPWA VRA NA 00 DPWA ARNDT 95 DPWA ARNDT 95 DPWA CUTKOSKY 90 IPWA CUTKOSKY 91 IPWA CUTKOSKY 91 IPWA |

2×IMAGINARY PART

| MALUE (MeV) DOCUMENT ID TECN COMMENT 160 to 220 (≈ 190) OUR ESTIMATE ANISOVICH 12A DPWA Multichannel 162 3 ARNDT 06 DPWA $\pi N \rightarrow \pi N$, ηN 164 4 HOEHLER 93 SPED $\pi N \rightarrow \pi N$ 180 ± 40 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ • • We do not use the following data for averages, fits, limits, etc. • • • • π π π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N π N | -2×IMAGINARY PART | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|-----------------------|---------|-----------|---------------------------------------------|
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 160 to 220 (≈ 190) OUR ESTIM | ATE | | | |
| 164 4 HOEHLER 93 SPED $\pi N \rightarrow \pi N$, $\eta N \rightarrow \pi N$ 180±40 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ 0 • • • We do not use the following data for averages, fits, limits, etc. • • • 193±7 ANISOVICH 10 DPWA $\pi N \rightarrow \pi N \rightarrow \pi N$ 151±13 BATINIC 10 DPWA $\pi N \rightarrow \pi N $ | 190± 7 | | 12A | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 162 | AKNDI | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • 193 ± 7 | 164 | ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 180 ± 40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | ullet $ullet$ We do not use the following | ng data for average | s, fits | , limits, | etc. • • • |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 193± 7 | ANISOVICH | 10 | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 151 ± 13 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 192 ± 20 | | 80 | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 160 | ⁵ ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 316 | | 00 | DPWA | Multichannel |
| 228 CUTKOSKY 90 IPWA π N \rightarrow π N 209 or 210 8 LONGACRE 78 IPWA π N \rightarrow N π | 176 | | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 209 or 210 8 LONGACRE 78 IPWA π N \rightarrow N π π | 252 | ⁷ ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | 228 | | 90 | IPWA | $\pi N \rightarrow \pi N$ |
| 167 or 234 1 LONGACRE 77 IPWA π N \rightarrow N π π | 209 or 210 | | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| | 167 or 234 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1440) ELASTIC POLE RESIDUE

MODULUS |r|

| 0 2 0 2 0 0 1 | | | |
|---------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
| 40 to 52 (≈ 46) OUR E | STIMATE | | |
| 48±3 | ANISOVICH | 12a DPWA | Multichannel |
| 38 | ³ ARNDT | 06 DPWA | $\Lambda \pi N \rightarrow \pi N, \eta N$ |
| 40 | HOEHLER | 93 SPED | $\pi N \rightarrow \pi N$ |
| 52±5 | CUTKOSKY | 80 IPWA | $\pi N \rightarrow \pi N$ |
| • • We do not use the | e following data for averages, | fits, limits, | etc. • • • |
| 44 | | 10 DPWA | $\Lambda \pi N \rightarrow N\pi, N\eta$ |
| 36 | ⁵ ARNDT | 04 DPWA | $\lambda \pi N \rightarrow \pi N, \eta N$ |
| 42 | ⁶ ARNDT | 95 DPWA | $\lambda \pi N \rightarrow N \pi$ |
| 109 | ⁷ ARNDT | 91 DPW | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | CHTROCKY | 90 IPWA | $\pi N \rightarrow \pi N$ |
| 74 | CUTKOSKY | 90 IPVVA | $\kappa \mapsto \kappa \mapsto$ |
| | CUTKOSKY | 90 IPVVA | K IV → K IV |
| PHASE θ | | | |
| | DO CUMENT ID | TECN | COMMENT |
| PHASE <i>θ</i> <u>/ALUE (°)</u> 75 to 100 (≈ 85) OU | DO CUMENT ID | TECN | COMMENT |
| PHASE 0 VALUE (°) | DOCUMENT ID R ESTIMATE A NISOVICH | TECN 12A DPW | COMMENT |
| PHASE <i>θ</i> WALUE (°) 75 to 100 (≈ 85) OU - 78 ± 4 | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT | <u>TECN</u> 12A DPWA 06 DPWA | COMMENT Multichannel |
| PHASE <i>θ</i> VALUE (°) 75 to 100 (≈ 85) OU - 78 ± 4 - 98 - 100 ± 35 | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT | 12A DPWA 06 DPWA 80 IPWA | COMMENT Multichannel $A N \rightarrow \pi N, \eta N$ $\pi N \rightarrow \pi N$ |
| PHASE <i>θ</i> VALUE (°) 75 to 100 (≈ 85) OU - 78 ± 4 - 98 - 100 ± 35 | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT CUTKOSKY e following data for averages, | TECN 12A DPWA 06 DPWA 80 IPWA fits, limits, | COMMENT Multichannel $A N \rightarrow \pi N, \eta N$ $\pi N \rightarrow \pi N$ |
| PHASE <i>θ</i> MLUE (°) 75 to 100 (≈ 85) OU 78 ± 4 98 100±35 • • • We do not use the | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT CUTKOSKY e following data for averages, BATINIC | TECN 12A DPWA 06 DPWA 80 IPWA fits, limits, 10 DPWA | $\begin{array}{c} \underline{COMMENT} \\ \text{A Multichannel} \\ \Lambda & N \to \pi N, \eta N \\ \pi & N \to \pi N \\ \text{etc.} \bullet \bullet \end{array}$ |
| PHASE <i>θ</i> (ALUE (°) 75 to 100 (≈ 85) OU 78 ± 4 98 100 ± 35 • • • We do not use the 88 | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT CUT KOSKY e following data for averages, BATINIC 5 ARNDT | TECN 12A DPWA 06 DPWA 80 IPWA fits, limits, 10 DPWA 04 DPWA | $\begin{array}{c} \underline{COMMENT} \\ \Lambda Multich annel \\ \Lambda \pi N \rightarrow \pi N, \ \eta N \\ \pi N \rightarrow \pi N \\ \text{etc.} \bullet \bullet \\ \Lambda \pi N \rightarrow N \pi, \ N \eta \end{array}$ |
| PHASE <i>θ</i> (ALUE (°) 75 to 100 (≈ 85) OU 78 ± 4 98 -100 ± 35 • • • We do not use the 88 -102 | DOCUMENT ID R ESTIMATE A NISOVICH 3 ARNDT CUTKOSKY e following data for averages, BATINIC 5 ARNDT 6 ARNDT | 12A DPWA 06 DPWA 80 IPWA fits, limits, 10 DPWA 04 DPWA 95 DPWA | COMMENT Multichannel $ \begin{array}{lll} \Lambda & \mathcal{N} & \to & \mathcal{N}, & \eta & \mathcal{N} \\ \pi & \mathcal{N} & \to & \pi & \mathcal{N}, & \eta & \mathcal{N} \\ \text{etc.} & \bullet & \bullet & \bullet \\ \Lambda & \pi & \mathcal{N} & \to & \mathcal{N} & \pi, & \eta & \eta & \mathcal{N} \\ \Lambda & \pi & \mathcal{N} & \to & \pi & \mathcal{N}, & \eta & \eta & \mathcal{N} \end{array} $ |

N(1440) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \to N(1440) \to \Delta \pi$, P-wave DOCUMENT ID TECN COMMENT ANISOVICH 12A DPWA Multichannel MODULUS (%) PHASE (°) 27±2 40 ± 5 Normalized residue in $N\pi \to N(1440) \to N(\pi\pi)_{S-wave}^{I=0}$ MODULUS (%) PHASE (°) DOCUMENT ID TECN COMMENT 21±5 -135 ± 7 ANISOVICH 12A DPWA Multichannel

N(1440) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) | |
|-----------------------|------------------------------------------|------------------------------|--|
| $\overline{\Gamma_1}$ | $N\pi$ | 55-75 % | |
| Γ_2 | N η | (0.0 ± 1.0) % | |
| Γ_3 | $N\pi\pi$ | 30-40 % | |
| Γ_4 | $\Delta\pi$ | 20-30 % | |
| Γ_5 | Δ (1232) π , \emph{P} -wave | 15-30 % | |
| Γ_6 | $N \rho$ | <8 % | |
| Γ ₇ | $N\rho$, $S=1/2$, P -wave | (0.0 ± 1.0) % | |
| Γ ₈ | $N\rho$, $S=3/2$, P -wave | | |
| Г9 | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | 10-20 % | |
| Γ_{10} | $p\gamma$ | 0.035-0.048 % | |
| Γ_{11} | $p\gamma$, helicity=1/2 | 0.035-0.048 % | |
| Γ ₁₂ | n γ | 0.02-0.04 % | |
| Γ ₁₃ | $n\gamma$, helicity=1/2 | 0.02-0.04 % | |

N(1440) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|----------------------------------------|----------------------|---------|-----------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 55 to 75 OUR ESTIMATE | | | | |
| 62 ±3 | ANISOVICH | 12A | DPWA | Multichannel |
| 78.7 ± 1.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 69 ±3 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 68 ±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 51 ±5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the follow | ing data for average | s, fits | , limits, | etc. • • • |
| 60 ±6 | ANISOVICH | 10 | DPWA | Multichannel |
| 62 ±4 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 75.0 ± 2.4 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 57 ±1 | PENNER | 02c | DPWA | Multichannel |
| 72 ±5 | VRANA | 00 | DPWA | Multichannel |
| 68 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| $\Gamma(N\eta)/\Gamma_{\rm total}$ | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 0±1 | VRANA | 00 | DPWA | Multichannel |

Note: Signs of couplings from $\pi\,N \to N\,\pi\,\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)$ π .

| | $V\pi \to N(1440) \to \Delta(1232)\pi$, P | |
|--------------------------------------------------------------------|--------------------------------------------------------------|------------------------------------------------------------------------|
| +0.37 to +0.41 OUR | | TECN COMMENT |
| $+0.37 \pm 0.02$ | MANLEY 92 I | PWA $\pi N \rightarrow \pi N \& N \pi \pi$ |
| +0.41 | ^{1,9} LONGACRE 77 | PWA $\pi N \rightarrow N \pi \pi$ |
| +0.37 | ² LONGACRE 75 I | PWA $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi$, <i>P</i> -wa | ave)/Γ _{total} | Γ ₅ /Γ |
| VALUE (%) | | TECN COMMENT |
| 15 to 30 (≈ 20) OUR | ESTIMATE | |
| 21 ± 8 | ANISOVICH 12A E | DPWA Multichannel |
| 16±1 | VRANA 00 E | DPWA Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}}$ in I | $N\pi \rightarrow N(1440) \rightarrow N\rho$, $S=1/2$, I | |
| VALUE | DOCUMENT ID 1 | <u>COMMENT</u> |
| ±0.07 to ±0.2 | 5 OUR ESTIMATE | |
| | | |
| -0.11 | 2 | PWA $\pi N \rightarrow N \pi \pi$ PWA $\pi N \rightarrow N \pi \pi$ |

DOCUMENT ID

VRANA

TECN COMMENT

00 DPWA Multichannel

 Γ_7/Γ

 $\Gamma(N\rho, S=1/2, P-wave)/\Gamma_{total}$

VALUE (%)

0±1

| VALUE | 1,9 LONGACRE | | TECN | COMMENT |
|--------------------------------------------------------------------|--------------------------------|---------------|------|----------------------------------------|
| +0.18 | ^{1,9} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}}$ in N | $\pi \to N(1440) \to N(\pi\pi$ |) =0 S-wa | ve | (۲₁۲ ₉) ^½ /۲ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| ±0.17 to ±0.25 OUR I | STIMATE | | | |
| $+0.24 \pm 0.03$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| -0.18 | ^{1,9} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| - 0.23 | | 75 | | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{t}$ | otal | | | ٦/و٦ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 10 to 20 (≈ 15) OUR E | STIMATE | | | |
| 17±7 | ANISOVICH | 12A | DPWA | Multichannel |
| 12±1 | VRA NA | 00 | DPWA | Multichannel |

N(1440) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$N(1440) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|-----------------------|---------|-----------|------------------------------|
| -0.060 ± 0.004 OUR ESTIMAT | ГЕ | | | |
| -0.061 ± 0.008 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.051 ± 0.002 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.063 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.069 ± 0.018 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.063 ± 0.008 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • We do not use the follow | ving data for average | s, fits | , limits, | etc. • • • |
| -0.052 ± 0.010 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.061 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.087 | PENNER | 02D | DPWA | Multichannel |
| -0.085 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.129 | ¹⁰ WADA | 84 | DPWA | Compton scattering |
| | | | | |

$N(1440) \rightarrow n\gamma$, helicity-1/2 amplitude A_{1/2}

| "(1440) → "/, "alcity-1/ | Z amplicade Al | /2 | | | |
|---------------------------------|---------------------|-----------|-------------|------------------------------|---|
| $VALUE$ (GeV $^{-1/2}$) | DOCUMENT ID | | TECN | COMMENT | |
| +0.040 ± 0.010 OUR ESTIMATE | | | | | • |
| 0.045 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.037 ± 0.010 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.030 ± 0.003 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| • • • We do not use the followi | ng data for average | es, fits, | , limits, e | etc. • • • | |
| 0.054 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.121 | PENNER | | | Multichannel | |
| 0.085 ± 0.006 | LL | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| | | | | | |

N(1440) FOOTNOTES

- ¹ LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ² From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix
- amplitudes.
 3 ARNDT 06 also finds a second-sheet pole with real part = 1388 MeV, $-2 \times \text{imaginary}$ part = 165 MeV, and residue with modulus 86 MeV and phase = -46 degrees.
 4 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
 5 ARNDT 04 also finds a second-sheet pole with real part = 1385 MeV, $-2 \times \text{imaginary}$ part = 166 MeV, and residue with modulus 82 MeV and phase = -51° .
 6 ARNDT 95 also finds a second-sheet pole with real part = 1383 MeV, $-2 \times \text{imaginary}$ part = 210 MeV, and residue with modulus 92 MeV and phase = -54° .
 7 ARNDT 91 (Soln SM90) also finds a second-sheet pole with real part = 1413 MeV.

- 7 ARNDT 91 (Soln SM90) also finds a second-sheet pole with real part = 1413 MeV, $-2 \times$ imaginary part = 256 MeV, and residue = (78–153f) MeV.
- 8 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 9 LONGACRE 77 considers this coupling to be well determined.
- 10 WADA 84 is inconsistent with other analyses; see the Note on N and Δ Resonances.

N(1440) REFERENCES

For early references, see Physics Letters $\mathbf{111B}\ 1\ (1982)$

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|------|--------------------|-------------------------------------------|-----------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| SARANTSEV | 08 | PL B659 94 | A.V. Sarantsev et al. (CB-ELSA/A2 | ?-TAPS Čollab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jefferson Lai | CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workman | `(VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |

| LI | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
|----------|----|------------------|----------------------------|-------------------|
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| CUTKOSKY | 90 | PR D42 235 | R.E. Cutkosky, S. Wang | ` (CMU) |
| WADA | 84 | NP B247 313 | Y. Wada et al. | (INUS) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | ` (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| FUJII | 81 | NP B187 53 | K. Fujii et al. | (NAGO, OSAK) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Čutkosky et al. | ` (CMU, LBL)IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | `(KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBĽ, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | ` (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | | - | |

N(1520) 3/2

 $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

N(1520) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|-------------------------|---------|-------------|----------------------------------------|
| 1515 to 1525 (≈ 1520) OU | R ESTIMATE | | | |
| 1517 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 1514.5 ± 0.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1524 ± 4 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1525 ±10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| l519 ± 4 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the foll | lowing data for average | s, fits | , limits, e | etc. • • • |
| 1524 ± 4 | ANISOVICH | 10 | DPWA | Multichannel |
| 1522 ± 8 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1520 ±10 | THOMA | 80 | DPWA | Multichannel |
| 1516.3 ± 0.8 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1509 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 1518 ± 3 | VRANA | 00 | DPWA | Multichannel |
| 1516 ±10 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1515 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1510 | | 93 | | $\gamma N \rightarrow \pi N$ |
| 1510 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1520 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1520) BREIT-WIGNER WIDTH

| MALUZE (MeV) DO CUMENT ID TECN COMMENT 100 to 125 (≈ 115) OUR ESTIMATE TECN COMMENT 114 ± 5 ANISOVICH 12a DPWA Multichannel 103.6± 0.4 ARNDT 06 DPWA $\pi N \rightarrow \pi N$, ηN 124 ± 8 MANLEY 92 IPWA $\pi N \rightarrow \pi N$ & $N \pi$ 120 ±15 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ πN 114 ± 7 HOEHLER 79 IPWA $\pi N \rightarrow \pi N$ πN 117 ± 6 ANISOVICH 10 DPWA $\pi N \rightarrow \pi N$ πN < | | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------|---------|-----------|----------------------------------------|
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | VALUE (MeV) | | | TECN | COMMENT |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 100 to 125 (≈ 115) OUR ESTIM | MATE | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 114 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 103.6± 0.4 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | 124 ± 8 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| | 120 ±15 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 114 ± 7 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | ● ● We do not use the following | g data for average | s, fits | , limits, | etc. • • • |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 117 ± 6 | ANISOVICH | 10 | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 132 ±11 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 125 ±15 | THOMA | 80 | DPWA | Multichannel |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 98.6± 2.6 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | 100 ± 2 | PENNER | 02c | DPWA | Multichannel |
| 106 ARNDT 95 DPWA $\pi N \rightarrow N\pi$ 120 LI 93 IPWA $\gamma N \rightarrow \pi N$ 110 $\frac{1}{2}$ LONGACRE 77 IPWA $\pi N \rightarrow N\pi\pi$ | 124 ± 4 | VRANA | 00 | DPWA | Multichannel |
| 120 LI 93 IPWA $\gamma N \rightarrow \pi N$ 110 1 LONGACRE 77 IPWA $\pi N \rightarrow N \pi \pi$ | 106 ± 4 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 110 $\frac{1}{2}$ LONGACRE 77 IPWA $\pi N \rightarrow N \pi \pi$ | 106 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| | 120 | | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 150 2 LONGACRE 75 IPWA $\pi N \rightarrow N \pi \pi$ | 110 | 1 LONGACRE | | | $\pi N \rightarrow N \pi \pi$ |
| | 150 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1520) POLE POSITION

REAL PART

| NEAL FAIL | | | | |
|-----------------------------------------|----------------------------|----------|-----------|-----------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 1505 to 1515 (≈ 1510) C | OUR ESTIMATE | | | |
| 1507 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 1515 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1510 | ³ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 1510 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ $ullet$ We do not use the | following data for average | s, fits, | , limits, | etc. • • • |
| 1512 ± 3 | ANISOVICH | 10 | DPWA | Multichannel |
| 1506 ± 9 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 1509 ± 7 | THOMA | 80 | DPWA | Multichannel |
| 1514 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1504 | VRANA | 00 | DPWA | Multichannel |
| 1515 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1511 | ARNDT | 91 | DPWA | $\pi{\it N} \rightarrow \pi{\it N}$ Soln SM90 |
| 1514 or 1511 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1508 or 1505 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1520)

| -2×IMAGINARY PART | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------|-------------------------|---------|-------------|---------------------------------------------|
| 105 to 120 (≈ 110) OUR ES | | | 72.00 | COMMENT |
| 111± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 113 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 120 | ³ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 114 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the fol | lowing data for average | s, fits | , limits, e | etc. • • • |
| 110± 6 | ANISOVICH | 10 | DPWA | Multichannel |
| 122± 9 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 113±12 | THOMA | 80 | DPWA | Multichannel |
| 102 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 112 | VRA NA | 00 | DPWA | Multichannel |
| 110 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 108 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 146 or 137 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 109 or 107 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1520) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-------------|--------------------------------------------------------------------|
| 35±3 OUR ESTIMATE | | | | |
| 36±3 | ANISOVICH | 12A | DPWA | Multichannel |
| 38 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 32 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 35 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 35 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 35 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 34 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 33 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |
| | | | | |

| PHASE 6 | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-------------|-------------------------------------------------------------------------------|
| -10±5 OUR ESTIMATE | | | | |
| -14 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| - 5 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| - 8 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| -12 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| - 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| - 6 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 7 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| -10 | ARNDT | 91 | DPWA | $\pi \: {\it N} \: \rightarrow \: \pi \: {\it N} \: {\it Soln} \: {\it SM90}$ |

N(1520) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

Normalized residue in $N\pi \to N(1520) \to \Delta\pi$, S-wave

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|---------------|----------------------|----------------------------------------|--------|--------------|
| 33±5 | 150 ± 20 | ANISOVICH 12 | A DPWA | Multichannel |
| Normalized re | sidue in $N\pi 	o N$ | $V(1520) \rightarrow \Delta \pi$, L | -wave | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 25 ± 3 | 100 ± 20 | ANISOVICH 12 | A DPWA | Multichannel |

N(1520) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ | 55-65 % |
| Γ_2 | N η | $(2.3\pm0.4)\times10^{-3}$ |
| Γ_3 | $N\pi\pi$ | 20-30 % |
| Γ_4 | $\Delta\pi$ | 15-25 % |
| Γ_5 | ${\it \Delta}(1232)\pi$, $\it S-wave$ | 10-20 % |
| Γ_6 | ${\it \Delta}(1232)\pi$, ${\it D}	ext{-}$ wave | 10-15 % |
| Γ ₇ | $N \rho$ | 15-25 % |
| Γ ₈ | $N\rho$, $S=3/2$, S -wave | (9.0 ± 1.0) % |
| Γ9 | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | <8 % |
| Γ_{10} | $p\gamma$ | 0.31-0.52 % |
| Γ_{11} | $p\gamma$, helicity=1/2 | 0.01-0.02 % |
| Γ_{12} | $p\gamma$, helicity=3/2 | 0.30-0.50 % |
| Γ_{13} | n γ | 0.30-0.53 % |
| Γ_{14} | $n\gamma$, helicity=1/2 | 0.04-0.10 % |
| Γ ₁₅ | $n\gamma$, helicity=3/2 | 0.25-0.45 % |

N(1520) BRANCHING RATIOS

| | | | | Г ₁ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------|-------------------------------------------------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 55 to 65 OUR ESTIM | | | | |
| 62 ±3 | ANISOVICH | | | Multichannel |
| 63.2 ± 0.1 | ARNDT | 06 | | $\pi N \rightarrow \pi N$, ηN |
| 59 ±3 | MANLEY | 92 | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 58 ±3 | CUTKOSKY | 80 | | $\pi N \rightarrow \pi N$ |
| 54 ±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use t | he following data for averag | es, fits | , limits, e | etc. • • • |
| 57 ±5 | ANISOVICH | 10 | DPWA | Multichannel |
| 55 ±5 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 58 ±8 | THOMA | 80 | DPWA | Multichannel |
| 64.0 ± 0.5 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| | DEMMED | 020 | DΡWΔ | Multichannel |
| 56 ±1 | PENNER | 020 | | |
| 56 ±1 63 ±2 | VRANA | 00 | | Multichannel |
| | | | DPWA | |
| 63 ±2 61 | VRANA | 00 | DPWA | Multichannel $\pi N \rightarrow N \pi$ |
| 63 ±2 61 Γ (Νη)/Γ_{total} | VRA NA AR NDT | 00 | DPWA DPWA | Multichannel $\pi \ {\it N} \ ightarrow \ {\it N} \ \pi$ |
| 63 ±2 61 | VRANA ARNDT <u>DOCUMENT ID</u> | 00 | DPWA | Multichannel $\pi N \rightarrow N \pi$ |
| 63 ±2 61 Γ(<i>N η</i>)/Γ_{total} <i>VALUE</i> (%) | VRANA ARNDT <u>DOCUMENT ID</u> | 00 95 | DPWA DPWA | Multichannel $\pi \ {\it N} \ ightarrow \ {\it N} \ \pi$ |
| 63 ±2 61 Γ(Νη)/Γ _{total} να LUE (%) 0.23±0.04 OUR AVER | VRANA ARNDT DOCUMENT ID | 00 95 | DPWA DPWA TECN DPWA | Multichannel $\pi \ N \to N \pi$ Γ_2 |
| 63 ±2 61 Γ(Nη)/Γ _{total} νΔLUE (%) 0.23±0.04 OUR AVER 0.23±0.04 0 ±1 | VRANA ARNDT DOCUMENT ID AGE PENNER | 00 95 02c 00 | DPWA DPWA <u>TECN</u> DPWA DPWA | Multichannel $\pi N \to N \pi$ |
| 63 ±2 61 Γ(Nη)/Γ _{total} VALUE (%) 0.23±0.04 OUR AVER 0.23±0.04 0 ±1 • • • • We do not use t | VRANA ARNDT DOCUMENT ID AGE PENNER VRANA | 00 95 02c 00 | DPWA DPWA TECN DPWA DPWA DPWA , limits, o | Multichannel $\pi N \to N \pi$ COMMENT Multichannel Multichannel etc. • • • |
| 63 ± 2 61 $\Gamma(N\eta)/\Gamma_{\text{total}}$ $VALUE(\%)$ 0.23 ± 0.04 OUR AVER 0.23 ± 0.04 0 ± 1 • • • We do not use t 0.1 ± 0.1 | VRANA ARNDT DOCUMENT ID AGE PENNER VRANA he following data for averag BATINIC | 00 95 02c 00 es, fits | DPWA DPWA TECN DPWA DPWA Ilmits, 6 | Multichannel $\pi N \to N \pi$ |
| 63 ±2 61 Γ(Nη)/Γ _{total} νΔLUE (%) 0.23±0.04 OUR AVER 0.23±0.04 0 ±1 | VRANA ARNDT DOCUMENT ID AGE PENNER VRANA he following data for averag | 00 95 02c 00 es, fits | DPWA DPWA DPWA DPWA DPWA DPWA DPWA DPWA | $\begin{array}{ccc} \text{Multichannel} \\ \pi N \rightarrow N \pi \end{array}$ |

Note: Signs of couplings from $\pi\,N \to N\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)\,\,S_{31}$ coupling to $\Delta(1232)\,\pi$.

| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $N\pi \to$ | $N(1520) \rightarrow \Delta(123)$ | 2)π. | S-wave | e (Γ ₁ Γ ₅) ^{1/2} /Γ |
|------------------------------------------------------------------------|-----------------------------------|------|--------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | | COMMENT |
| -0.26 to -0.20 OUR ESTIM | IATE | | | |
| -0.18 ± 0.05 | | | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| -0.26 | ^{1,5} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -0.24 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

| $\Gamma(\Delta(1232)\pi, S$ -wave)/ Γ_{tot} | al | | | | Γ ₅ |
|-----------------------------------------------------------|---------------------|----------|-------------|--------------|----------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 10 to 20 OUR ESTIMATE | | | | | |
| 19±4 | ANISOVICH | 12A | DPWA | Multichannel | |
| 15 ± 2 | VRANA | 00 | DPWA | Multichannel | |
| • • • We do not use the follow | ing data for averag | es, fits | , limits, e | etc. • • • | |
| 12±4 | THOMA | 08 | DPWA | Multichannel | |

| $(\Gamma_1\Gamma_6)^{7/2}/\Gamma$ |
|-----------------------------------|
| |
| |
| V & Nππ |
| ππ |
| $\pi\pi$ |
| |

| $\Gamma(\Delta(1232)\pi, D$ -wa | ve)/Γ _{total} | | | | Γ_6/Γ |
|---------------------------------|------------------------------|----------|-------------|--------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 10 to 15 OUR ESTIMA | ATE | | | | |
| 9 ± 2 | ANISOVICH | 12A | DPWA | Multichannel | |
| 11 ± 2 | VRANA | 00 | DPWA | Multichannel | |
| | he following data for averag | es, fits | , limits, e | etc. • • • | |
| 14±5 | THOMA | 08 | DPWA | Multichannel | |

| 9±1 | VRANA | 00 | DPWA | Multichannel |
|---------------------------------|-------------------------|----|------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| $\Gamma(N\rho, S=3/2, S-wave)/$ | Γ _{total} | | | Γ ₈ /Ι |
| -0.24 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -0.35 | ^{1,5} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -0.35 ± 0.03 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| -0.35 to -0.31 OUR ESTII | MATE | | | |
| VALUE | DO CUMENT ID | | TECN | COMMENT |

| (' <i>i</i> ' <i>f</i>) ' / ' tota ''' / ' | (119) | | | |
|----------------------------------------------|-------------------------|--------|---------------------------------|--|
| VALUE | DO CUMENT ID | TECN | <u>COMMENT</u> | |
| -0.22 to -0.06 OUR | ESTIMATE | | | |
| -0.13 | ^{1,5} LONGACRE | | | |
| -0.17 | ² LONGACRE | 75 IPW | $A \pi N \rightarrow N \pi \pi$ | |

| $\Gamma(N(\pi\pi)_{S-wave}^{I=0})/\Gamma_{total}$ | | | | | Γ9/Γ |
|---------------------------------------------------|-----------------|----------|-------------|--------------|------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 1±1 | VRA NA | 00 | DPWA | Multichannel | |
| • • • We do not use the following | data for averag | es, fits | , limits, e | etc. • • • | |
| <4 | THOMA | 80 | DPWA | Multichannel | |

N(1520) PHOTON DECAY AMPLITUDES

Papers on $\gamma\,N$ amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$N(1520) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

| | -, | | | |
|-----------------------------------|-----------------------|---------|-----------------------------------|--|
| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN_COMMENT | |
| -0.024 ± 0.009 OUR ESTIMATE | | | | |
| -0.022 ± 0.004 | ANISOVICH | 12A | DPWA Multichannel | |
| -0.028 ± 0.002 | DUGGER | 07 | DPWA $\gamma N \rightarrow \pi N$ | |
| -0.038 ± 0.003 | AHRENS | 02 | DPWA $\gamma N \rightarrow \pi N$ | |
| -0.020 ± 0.007 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ | |
| -0.028 ± 0.014 | CRAWFORD | 83 | IPWA $\gamma N \rightarrow \pi N$ | |
| -0.007 ± 0.004 | AWA JI | 81 | DPWA $\gamma N \rightarrow \pi N$ | |
| • • • We do not use the following | data for average | s, fits | , limits, etc. ● ● ● | |
| -0.032 ± 0.006 | ANISOVICH | 10 | DPWA Multichannel | |
| -0.027 | DRECHSEL | 07 | DPWA $\gamma N \rightarrow \pi N$ | |
| -0.003 | PENNER | 02D | DPWA Multichannel | |
| $-0.052\pm0.010\pm0.007$ | ⁶ MUKHOPAD | . 98 | $\gamma p \rightarrow \eta p$ | |
| -0.020 ± 0.002 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ | |
| -0.012 | WADA | 84 | DPWA Compton scattering | |

$N(1520) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| | -/- | | | |
|-------------------------------------------|-----------------------|---------|-----------|-------------------------------|
| $VALUE$ (GeV $^{-1/2}$) | DO CUMENT ID | | TECN | COMMENT |
| 0.150±0.015 OUR ESTIMATE | | | | |
| 0.131 ± 0.010 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.143 ± 0.002 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.147 ± 0.010 | AHRENS | 02 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.167 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.156 ± 0.022 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.168 ± 0.013 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 0.138 ± 0.008 | ANISOVICH | 10 | DPWA | Multichannel |
| 0.161 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.151 | | 02D | DPWA | Multichannel |
| $0.130 \pm 0.020 \pm 0.015$ | ⁶ MUKHOPAD | . 98 | | $\gamma p \rightarrow \eta p$ |
| 0.167 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.168 | WADA | 84 | DPWA | Compton scattering |

$N(1520) \rightarrow n\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT | | | |
|-------------------------------------------------------------------------------|-------------|-----|------|------------------------------|--|--|--|
| -0.059±0.009 OUR ESTIMATE | | | | | | | |
| -0.048 ± 0.008 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | | | |
| -0.066 ± 0.013 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | | | |
| -0.067 ± 0.004 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| -0.077 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | | | |
| - 0.084 | PENNER | 02D | DPWA | Multichannel | | | |
| -0.058 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | | | |

$N(1520) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

| • | • | • | | | -/- | | |
|---------|-----------------------|--------------|----------|---------------|-------------|-----------|------------------------------|
| VALUE (| GeV ^{-1/2}) | | | DO CUMENT | ID | TECN | COMMENT |
| -0.139 | ±0.011 | OUR ESTI | MATE | | | | |
| -0.140 | ± 0.010 | | | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.124 | ± 0.009 | | | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.158 | ± 0.003 | | | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • \ | Ne do no | t use the fo | ollowing | lata for aver | ages, fits, | limits, e | etc. • • • |
| -0.154 | | | | DRECHSEL | . 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.159 | | | | PENNER | 02D | DPWA | Multichannel |
| -0.131 | ± 0.003 | | | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | | | | |

N(1520) FOOTNOTES

- 1 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi\,N\to\,M\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- $^2\,\text{From}$ method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- 3 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 4 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- ⁵ LONGACRE 77 considers this coupling to be well determined.
- ⁶ MUKHOPADHYAY 98 uses an effective Lagrangian approach to analyze η photoproduction data. The *ratio* of the $A_{3/2}$ and $A_{1/2}$ amplitudes is determined, with less model dependence than the amplitudes themselves, to be $A_{3/2}/A_{1/2}=-2.5\pm0.5\pm0.4$.

N(1520) REFERENCES

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| | | | | |

$N(1535) 1/2^{-1}$

ı

 $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(1535) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|---------|-------------|------------------------------------------|
| 1525 to 1545 (≈ 1535) OUR EST | IMATE | | | |
| 1519 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 1547.0 ± 0.7 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1534 ± 7 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1550 ±40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1526 ± 7 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for averages | , fits, | , limits, e | etc. • • • |
| 1535 ±20 | ANISOVICH | 10 | DPWA | Multichannel |
| 1553 ± 8 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 1548 ±15 | THOMA | 80 | DPWA | Multichannel |
| 1546.7± 2.2 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1526 ± 2 | PENNER | 02c | DPWA | Multichannel |
| 1530 ±10 | BAI | 01B | BES | $J/\psi \rightarrow p \overline{p} \eta$ |
| 1522 ±11 | THOMPSON | 01 | CLAS | $\gamma^* p \rightarrow p \eta$ |
| 1542 ± 3 | VRANA | 00 | DPWA | Multichannel |
| 1532 ± 5 | ARMSTRONG | 99B | DPWA | $\gamma^* p \rightarrow p \eta$ |
| 1549.0 ± 2.1 | ABAEV | 96 | DPWA | $\pi^- p \rightarrow \eta n$ |
| 1525 ±10 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1535 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1544 ±13 | KRUSCHE | 95 | DPWA | $\gamma p \rightarrow p \eta$ |
| 1518 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1520 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1510 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1535) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------------------|----------|-------------|------------------------------------------|
| 125 to 175 (≈ 150) Ol | JR ESTIMATE | | | |
| 128 ±14 | ANISOVICH | 12A | DPWA | Multichannel |
| 188.4 ± 3.8 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 148.2± 8.1 | GREEN | 97 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 151 ±27 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 240 ±80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 120 ±20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the | e following data for average | s, fits, | , limits, e | etc. • • • |
| 170 ±35 | ANISOVICH | 10 | DPWA | Multichannel |
| 182 ±25 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 170 ±20 | THOMA | 80 | DPWA | Multichannel |
| 178.0 ± 11.6 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 129 ± 8 | PENNER | 02c | DPWA | Multichannel |
| 95 ±25 | BAI | 01B | BES | $J/\psi \rightarrow p \overline{p} \eta$ |

THOMPSON 01 CLAS $\gamma^* p \rightarrow p \eta$

Baryon Particle Listings N(1535)

| 112 \pm 19 154 \pm 20 212 \pm 20 168.8 \pm 11.6 103 \pm 5 66 200 \pm 40 84 | ARMSTRONG 3 KRUSCHE ABAEV ARNDT ARNDT KRUSCHE LI | 97 96 96 95 95 93 | DPWA DPWA DPWA IPWA DPWA DPWA IPWA | Multichannel $ \gamma^* p \rightarrow p \eta $ $ \gamma N \rightarrow \eta N $ $ \pi^- p \rightarrow \eta n $ $ \gamma N \rightarrow \pi N $ $ \pi N \rightarrow N \pi $ $ \gamma P \rightarrow p \eta $ $ \gamma N \rightarrow \pi N $ $ \pi N \rightarrow N \pi $ |
|-------------------------------------------------------------------------------------------------------------|---------------------------------------------------|----------------------------------|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 135 100 | ¹ LONGACRE ² LONGACRE | | | |

N(1535) POLE POSITION

REAL PART

| IVEVE I VIVI | | | | |
|-------------------------------------------|-----------------------|----------|-----------|---------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 1490 to 1530 (≈ 1510) OUR EST | MATE | | | |
| 1501 ± 4 | ANISOVICH | 12A | DPWA | Multichannel |
| 1502 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1487 | ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1510±50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | s, fits, | limits, e | etc. • • • |
| 1510 ± 25 | ANISOVICH | 10 | DPWA | Multichannel |
| 1521 ± 14 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| $1508 + 10 \\ -30$ | THOMA | 80 | DPWA | Multichannel |
| 1526 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1525 | VRA NA | 00 | DPWA | Multichannel |
| 1510 ± 10 | ⁵ ARNDT | 98 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1501 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1499 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1496 or 1499 | ⁶ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1525 or 1527 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

| -2×IMAGINARY PART | | | | |
|---------------------------------------------------|-----------------------|--------|-------------|---------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 90 to 250 (≈ 170) OUR ESTIMA | TE | | | |
| 134 ± 11 | ANISOVICH | 12A | DPWA | Multichannel |
| 95 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 260±80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● We do not use the following | data for averages | , fits | , limits, e | etc. • • • |
| 140±30 | ANISOVICH | 10 | DPWA | Multichannel |
| 190±28 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 165 ± 15 | THOMA | 80 | DPWA | Multichannel |
| 130 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 102 | VRA NA | 00 | DPWA | Multichannel |
| 170±30 | ⁵ ARNDT | 98 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 124 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 110 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 103 or 105 | ⁶ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 135 or 123 | $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| | | | | |

N(1535) ELASTIC POLE RESIDUE

MODULUS |r|

| MODULOS II I | | | | |
|----------------------------|---------------------------|---------|-------------|-------------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 50±20 OUR ESTIMATE | | | | |
| 31 ± 4 | ANISOVICH | 12A | DPWA | Multichannel |
| 16 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 120±40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the fo | ollowing data for average | s, fits | , limits, e | etc. • • • |
| 68 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 33 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 31 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 23 | ARNDT | 91 | DPWA | $\pi \: {\it N} \: \rightarrow \: \pi \: {\it N} \: {\it Soln} \: {\it SM90}$ |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -15±15 OUR ESTIMATE | | | | |
| -29 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| -16 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| $+15\pm45$ | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the fo | ollowing data for average | s, fits | , limits, e | etc. • • • |
| 12 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 14 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| -12 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| -13 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | | | | |

N(1535) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

Normalized residue in $N\pi \to N(1535) \to N\eta$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|-------------|-----------|---------------|------|--------------|
| 43±3 | -76 ± 5 | ANISOVICH 12A | DPWA | Multichannel |

| Normalized re | sidue in $N\pi ightarrow$ | $N(1535) \rightarrow \Delta \pi$, D- | wave | |
|---------------|----------------------------|---------------------------------------|------|--------------|
| MODULUS (%) | PHASE (°) | DOCUMENT ID | TECN | COMMENT |
| 12±3 | 145 ± 17 | ANISOVICH 12A | DPWA | Multichannel |

N(1535) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ | 35-55 % |
| Γ_2 | N η | (42 ±10)% |
| Γ_3 | $N \pi \pi$ | 1-10 % |
| Γ_4 | $\Delta\pi$ | <1 % |
| Γ_5 | Δ (1232) π , D -wave | 0-4 % |
| Γ_6 | $N \rho$ | <4 % |
| Γ_7 | $N\rho$, $S=1/2$, S -wave | (2.0 ± 1.0) % |
| Γ ₈ | $N\rho$, $S=3/2$, D -wave | (0.0 ± 1.0) % |
| Γ9 | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | (2 ± 1) % |
| Γ_{10} | $N(1440)\pi$ | (8 ± 3)% |
| Γ_{11} | $p\gamma$ | 0.15-0.30 % |
| Γ_{12} | $p\gamma$, helicity=1/2 | 0.15-0.30 % |
| Γ_{13} | n γ | 0.01-0.25 % |
| Γ_{14} | $n\gamma$, helicity=1/2 | 0.01-0.25 % |

N(1535) BRANCHING RATIOS

| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|----------------------------|----------|-------------|----------------------------------------|
| 35 to 55 OUR ESTIMA | ΓE | | | |
| 54 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 35.5 ± 0.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 39.4± 0.9 | GREEN | 97 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 51 ± 5 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 50 ±10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 38 ± 4 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits, | , limits, e | etc. • • • |
| 35 ±15 | ANISOVICH | 10 | DPWA | Multichannel |
| 46 ± 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 37 ± 9 | THOMA | 80 | DPWA | Multichannel |
| 36.0± 0.9 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 36 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 35 ± 8 | VRANA | 00 | DPWA | Multichannel |
| 33.0± 1.1 | ABAEV | 96 | DPWA | $\pi^- p \rightarrow \eta n$ |
| 31 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

| $\Gamma(N\eta)/\Gamma_{\rm total}$ | | | | | | Γ_2/Γ |
|------------------------------------|---------------|--------------------------|--------|-------------|-----------------------------------|---------------------|
| VALUE (%) | CL% | DO CUMENT ID | | TECN | COMMENT | |
| 42 ±10 OUR E | STIMATE | | | | | |
| 33 ± 5 | | ANISOVICH | 12A | DPWA | Multichannel | |
| 53 ± 1 | | PENNER | 02c | DPWA | Multichannel | |
| 51 ± 5 | | VRANA | 00 | DPWA | Multichannel | |
| • • • We do not use | the following | data for averages | , fits | , limits, e | etc. • • • | |
| 50 ± 7 | | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ | |
| 40 ±10 | | THOMA | 80 | | Multichannel | |
| >45 | 95 | $^{7}\mathrm{ARMSTRONG}$ | 99B | DPWA | $p(e,e'p)\eta$ | |
| 56.8 ± 1.1 | | GREEN | | | $\pi N \rightarrow \pi N, \eta N$ | |
| $59.1\pm~1.7$ | | ABAEV | 96 | DPWA | $\pi^- p \rightarrow \eta n$ | |
| $\Gamma(N\eta)/\Gamma(N\pi)$ | | | | | | Γ_2/Γ_1 |
| VALUE | | DOCUMENT ID | | TECN | COMMENT | |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $\boldsymbol{0.95 \pm 0.03}$ AZNAURYAN 09 CLAS π , η electroproduction

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1535) \to N\eta$ $(\Gamma_1 \Gamma_2)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1535) \to N\eta$ | | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|----|------|----------------------------------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| +0.44 to +0.50 OUR EST MATE | | | - | | |
| $+0.47\pm0.02$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ | |

Note: Signs of couplings from $\pi\,{\it N}\,\to\,{\it N}\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\varDelta(1620)$ S_{31} coupling to $\varDelta(1232)\,\pi.$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | $535) \rightarrow \Delta(123)$ | $(2)\pi$ | D-wave | e (Γ ₁ Γ ₅) ^{1/2} /Γ |
|---------------------------------------------------------------------------------------|--------------------------------|----------|--------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.04 to +0.06 OUR EST MATE | | | | |
| $+0.00\pm0.04$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.00 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| . 0.00 | 210000000 | | 101444 | |

| $(\Delta(1232)\pi$, D -wave $)/\Gamma_{total}$ | | | | Γ ₅ /Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4LUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 0 to 4 OUR ESTIMATE | | | | |
| 2.5 ± 1.5 | ANISOVICH | | | Multichannel |
| 1 ±1 | VRA NA | 00 | | Multichannel |
| • • We do not use the following | g data for average | es, fits | , limits, | etc. • • • |
| 3 ±8 | THOMA | 80 | DPWA | Multichannel |
| $\Gamma_i \Gamma_f)^{1/2} / \Gamma_{	ext{total}}$ in $N \pi 	o N(1)$ | $535) \rightarrow N\rho, S$ DOCUMENT ID | =1/2 | , S-wav | e (Γ ₁ Γ ₇) ^{1/2} /Γ |
| 0.14 to -0.06 OUR ESTIMATE | | | | - |
| 0.10 ± 0.03 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.10 | MANLEY 1 LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 0.09 | ² LONGACRE | 75 | IPWA | |
| $(N\rho, S=1/2, S-wave)/\Gamma_{total}$ | Ì | | | Γ ₇ /Γ |
| ALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| ±1 | VRA NA | 00 | DPWA | Multichannel |
| | | | | Γ ₈ /Γ |
| $(N\rho, S=3/2, D-wave)/\Gamma_{tota}$ | d . | | | . 0/ . |
| | DOCUMENT ID | | TECN | COMMENT |
| ±1 | DOCUMENT ID | 00 | DPWA | COMMENT Multichannel |
| ± 1 $\Gamma_i \Gamma_f)^{1/2} / \Gamma_{	ext{total}} 	ext{ in } N\pi 	o N(1)$ ALUE | $ \frac{DOCUMENT\ ID}{VRA\ NA} $ 535) $\rightarrow N(\pi\pi)$ $ \frac{DOCUMENT\ ID}{DOCUMENT\ ID} $ | 00)/=0 S-wa | DPWA | COMMENT |
| $\frac{\lambda L \cup E (\%)}{\pm 1}$ $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{	ext{total}} 	ext{ in } N \pi 	o N (1 AL \cup E)$ -0.03 to +0.13 OUR ESTIMATE | $ \frac{DOCUMENT\ ID}{VRA\ NA} $ 535) $\rightarrow N(\pi\pi)$ $ \frac{DOCUMENT\ ID}{DOCUMENT\ ID} $ | 00)/=0 S-wa | DPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{12}}/\Gamma_0$ COMMENT |
| ± 1 $\Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1$ ALUE 0.03 to +0.13 OUR ESTIMATE 0.07 \pm 0.04 | $\frac{DOCUMENT\ ID}{VRA\ NA}$ 535) $\rightarrow N(\pi\pi)$ $\frac{DOCUMENT\ ID}{MA\ NLEY}$ | 00)/=0 S-wa | DPWA TECN IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{2}}/\Gamma$ COMMENT $\pi N \to \pi N \& N \pi \pi$ |
| ± 1 $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \rightarrow N(1$ $\frac{4 L UE}{0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE}}$ 0.07 ± 0.04 0.08 | $\frac{DOCUMENT\ ID}{VRA\ NA}$ 535) $\rightarrow N(\pi\pi)$ $\frac{DOCUMENT\ ID}{MA\ NLEY}$ 1 LONGACRE | 00)I=0 S-wa 92 77 | DPWA TECN IPWA IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{12}}/\Gamma_0$ COMMENT $\pi N \to \pi N \& N \pi \pi$ $\pi N \to N \pi \pi$ |
| ± 1 $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \rightarrow N(1$ $\frac{4 L UE}{0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE}}$ 0.07 ± 0.04 0.08 | $\frac{DOCUMENT\ ID}{VRA\ NA}$ 535) $\rightarrow N(\pi\pi)$ $\frac{DOCUMENT\ ID}{MA\ NLEY}$ | 00)/=0 S-wa | DPWA TECN IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{2}}/\Gamma$ COMMENT $\pi N \to \pi N \& N \pi \pi$ |
| ± 1 $\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1$ $0.03 \text{ to } +0.13 \text{ OUR ESTIMATE}$ 0.07 ± 0.04 0.08 0.09 | $\frac{DOCUMENT\ ID}{VRA\ NA}$ 535) $\rightarrow N(\pi\pi)$ $\frac{DOCUMENT\ ID}{MA\ NLEY}$ 1 LONGACRE | 00)I=0 S-wa 92 77 | DPWA TECN IPWA IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{12}}/\Gamma_0$ COMMENT $\pi N \to \pi N \& N \pi \pi$ $\pi N \to N \pi \pi$ |
| $\begin{array}{l} \frac{1}{\pm 1} \\ \pm 1 \\ \Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \rightarrow N(1) \\ \frac{1}{4 \times 10^{-2}} \\ 0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE} \\ 0.07 \pm 0.04 \\ 0.08 \\ 0.09 \\ (N(\pi \pi)^{I=0}_{S-\text{wave}}) / \Gamma_{\text{total}} \end{array}$ | $\frac{DOCUMENT\ ID}{VRA\ NA}$ 535) $\rightarrow N(\pi\pi)$ $\frac{DOCUMENT\ ID}{MA\ NLEY}$ 1 LONGACRE | 00)I=0 S-wa 92 77 | DPWA TECN IPWA IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{2}}/\Gamma$ COMMENT $\pi N \to \pi N \& N \pi \pi$ $\pi N \to N \pi \pi$ $\pi N \to N \pi \pi$ |
| $\begin{array}{l} \frac{1}{\pm 1} \\ \pm 1 \\ \Gamma_{I} \Gamma_{f} \right)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \rightarrow N(1) \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \\ \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4} \frac{1}{4$ | DOCUMENT ID VRA NA 535) → N (ππ DOCUMENT ID MANLEY 1 LONGACRE 2 LONGACRE | 00)I=0 S-wa 92 77 | DPWA TECN IPWA IPWA IPWA IPWA | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{2}}/\Gamma$ COMMENT $\pi N \to \pi N \& N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ |
| $\begin{array}{l} \frac{\lambda L U E \ (\%)}{\pm 1} \\ \frac{1}{4 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\ \frac{1}{1 L U E} \\$ | DOCUMENT ID VRA NA 535) → N (ππ DOCUMENT ID NANLEY 1 LONGACRE 2 LONGACRE DOCUMENT ID VRA NA 535) → N(144 | 00)I=0 S-wa 92 77 75 00 | DPWA TECN IPWA IPWA IPWA DPWA | $\frac{COMMENT}{\left(\Gamma_{1}\Gamma_{9}\right)^{\frac{1}{2}}/\Gamma}$ $\frac{N \to \pi N \& N\pi\pi}{\pi N \to N\pi\pi}$ $\pi N \to N\pi\pi$ $\frac{\Gamma_{9}/\Gamma}{COMMENT}$ Multichannel |
| $\begin{array}{l} \frac{1}{2} \frac{1}{2} \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N \pi \rightarrow N(1) \\ \frac{1}{2} \int_{\Gamma_{total}} \ln N$ | DOCUMENT ID VRA NA 535) → N (ππ DOCUMENT ID NANLEY LONGACRE LONGACRE DOCUMENT ID VRA NA | 00)I=0 S-wa 92 77 75 00 | DPWA TECN IPWA IPWA IPWA TECN DPWA | $\frac{COMMENT}{\left(\Gamma_{1}\Gamma_{9}\right)^{\frac{1}{2}}/\Gamma}$ $\frac{N \to \pi N \& N\pi\pi}{\pi N \to N\pi\pi}$ $\pi N \to N\pi\pi$ $\frac{\Gamma_{9}/\Gamma}{COMMENT}$ Multichannel |
| $\begin{array}{l} \frac{NLUE}{\pm 1} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow N(1) \\ \frac{NLUE}{0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE}} \\ 0.07 \pm 0.04 \\ 0.08 \\ 0.09 \\ \left(N(\pi\pi)^{I=0}_{S-\text{wave}}\right)/\Gamma_{total} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow N(1) \\ \frac{NLUE}{0.10 \pm 0.05} \\ \left(N(1440)\pi\right)/\Gamma_{total} \end{array}$ | DOCUMENT ID VRA NA 535) → N(ππ DOCUMENT ID NANLEY LONGACRE 2 LONGACRE DOCUMENT ID VRA NA 535) → N(144 DOCUMENT ID MANLEY | 00)I=0 S-wa 92 77 75 00 0)π | IPWA IPWA IPWA IPWA IPWA TECN DPWA | COMMENT Multichannel $(\Gamma_1\Gamma_9)^{\frac{1}{2}}/\Gamma$ $\pi N \to \pi N \& N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ Multichannel $(\Gamma_1\Gamma_{10})^{\frac{1}{2}}/\Gamma$ $\frac{COMMENT}{\pi N \to \pi N \& N\pi\pi}$ Γ_{10}/Γ |
| $\begin{array}{l} \pm 1 \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{4LUE}{0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE}} \\ 0.07 \pm 0.04 \\ 0.08 \\ 0.09 \\ (N(\pi\pi)^{I=0}_{5-\text{wave}})/\Gamma_{\text{total}} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{4LUE}{0.10 \pm 0.05} \\ (N(1440)\pi)/\Gamma_{\text{total}} \\ \frac{4LUE}{4LUE(\%)} \\ \pm 1 \\ \frac{4LUE}{0.10 \pm 0.05} \\ (N(1440)\pi)/\Gamma_{\text{total}} \\ \frac{4LUE}{4LUE(\%)} \\ \frac{4LUE}{0.10 \pm 0.05} \\ \end{array}$ | DOCUMENT ID VRA NA 535) → N (ππ DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRA NA 535) → N(144 DOCUMENT ID | 00)I=0 S-wa 92 77 75 00 0)π | DPWA TECN IPWA IPWA IPWA TECN TECN | COMMENT Multichannel $(\Gamma_1 \Gamma_9)^{\frac{1}{12}}/\Gamma$ $\pi N \to \pi N \& N \pi \pi$ $\pi N \to N \pi \pi$ $\pi N \to N \pi \pi$ $\pi N \to N \pi \pi$ $\pi N \to N \pi \pi$ Multichannel $(\Gamma_1 \Gamma_{10})^{\frac{1}{12}}/\Gamma$ $COMMENT$ $\pi N \to \pi N \& N \pi \pi$ |
| $\begin{array}{l} \pm 1 \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{4LUE}{0.03 \text{ to } + 0.13 \text{ OUR ESTIMATE}} \\ 0.07 \pm 0.04 \\ 0.08 \\ 0.09 \\ (N(\pi\pi)^{I=0}_{5-\text{wave}})/\Gamma_{\text{total}} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{4LUE}{0.10 \pm 0.05} \\ (N(1440)\pi)/\Gamma_{\text{total}} \\ \frac{4LUE(\%)}{8 \pm 3 \text{ OUR ESTIMATE}} \end{array}$ | DOCUMENT ID VRA NA 535) → N(ππ DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRA NA 535) → N(144 DOCUMENT ID MANLEY DOCUMENT ID MANLEY | 00)/s=0 92 77 75 00 00 92 | IPWA IPWA IPWA IPWA IPWA TECN DPWA | COMMENT Multichannel $(\Gamma_1\Gamma_9)^{\frac{1}{2}}/\Gamma$ $\pi N \to \pi N \& N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ Multichannel $(\Gamma_1\Gamma_{10})^{\frac{1}{2}}/\Gamma$ COMMENT $\pi N \to \pi N \& N\pi\pi$ Γ_{10}/Γ COMMENT |
| $\begin{array}{l} (N\rho,S=3/2,D\text{-wave})/\Gamma_{\text{total}} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{ALUE}{2} \\ -0.03 \text{ to } +0.13 \text{ OUR ESTIMATE} \\ -0.08 \\ -0.09 \\ -0.09 \\ \Gamma(N(\pi\pi)^{I=0}_{S\text{-wave}})/\Gamma_{\text{total}} \\ \pm 1 \\ \Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N(1) \\ \frac{ALUE}{2} \\ -0.10 \pm 0.05 \\ \Gamma(N(1440)\pi)/\Gamma_{\text{total}} \\ \frac{ALUE}{2} \\ \frac{ALUE}{2} \\ \frac{8 \pm 3}{2} \text{ OUR ESTIMATE} \\ \frac{8 \pm 2}{2} \\ 0 \pm 9 \end{array}$ | DOCUMENT ID VRA NA 535) → N(ππ DOCUMENT ID NANLEY LONGACRE 2 LONGACRE DOCUMENT ID VRA NA 535) → N(144 DOCUMENT ID MANLEY | 00)I=0 S-wa 92 77 75 00 0)π | IPWA IPWA IPWA IPWA IPWA TECN IPWA | COMMENT Multichannel $(\Gamma_1\Gamma_9)^{\frac{1}{2}}/\Gamma$ $\pi N \to \pi N \& N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ $\pi N \to N\pi\pi$ Multichannel $(\Gamma_1\Gamma_{10})^{\frac{1}{2}}/\Gamma$ $\frac{COMMENT}{\pi N \to \pi N \& N\pi\pi}$ Γ_{10}/Γ |

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006)

$N(1535) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV-1/2) | | DOCUMENT ID | | TECN | COMMENT | |
|-----------------------------------------------|----|-------------------|---------|-----------|----------------------------------|---|
| $+0.090\pm0.030$ OUR ESTIMATE | | | | | | |
| 0.105 ± 0.010 | | ANISOVICH | 12A | DPWA | Multichannel | |
| 0.091 ± 0.002 | | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| $0.120 \pm 0.011 \pm 0.015$ | 3 | KRUSCHE | 97 | DPWA | $\gamma N \rightarrow \eta N$ | |
| 0.060 ± 0.015 | | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.097 ± 0.006 | | BENMERROU. | .95 | DPWA | $\gamma N \rightarrow N \eta$ | |
| 0.095 ± 0.011 | 9 | BENMERROU. | .91 | | $\gamma p \rightarrow p \eta$ | |
| 0.053 ± 0.015 | | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.077 ± 0.021 | | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| $\bullet~\bullet~$ We do not use the followin | gc | lata for averages | , fits, | limits, e | etc. • • • | |
| 0.090 ± 0.015 | | ANISOVICH | 10 | DPWA | Multichannel | 1 |
| 0.090 ± 0.025 | 10 | ANISOVICH | 09A | DPWA | $\gamma d \rightarrow \eta N(N)$ | |
| 0.066 | | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.090 | | PENNER | 02D | DPWA | Multichannel | |
| 0.110 to 0.140 | | KRUSCHE | 95 | DPWA | $\gamma p \rightarrow p \eta$ | |
| 0.125 ± 0.025 | | KRUSCHE | 95 c | IPWA | $\gamma d \rightarrow \eta N(N)$ | |
| 0.061 ± 0.003 | | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.055 | | WADA | 84 | DPWA | Compton scattering | |
| | | | | | | |

$N(1535) \rightarrow n\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV-1/2) | DOCUMENT ID | | TECN COMMENT |
|-------------------------------------------------|-------------------------|---------|---------------------------------------|
| -0.046±0.027 OUR ESTIMATE | | | |
| -0.080 ± 0.020 | ^{l1} ANISOVICH | 09A | DPWA $\gamma d \rightarrow \eta N(N)$ |
| -0.020 ± 0.035 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 0.035 ± 0.014 | AWA JI | 81 | DPWA $\gamma N \rightarrow \pi N$ |
| -0.062 ± 0.003 | FUJII | 81 | DPWA $\gamma N \rightarrow \pi N$ |
| \bullet \bullet We do not use the following | data for average | s, fits | , limits, etc. ● ● ● |
| -0.051 | DRECHSEL | 07 | DPWA $\gamma N \rightarrow \pi N$ |
| -0.024 | PENNER | 02D | DPWA Multichannel |
| -0.100 ± 0.030 | KRUSCHE | 95 c | IPWA $\gamma d \rightarrow \eta N(N)$ |
| -0.046 ± 0.005 | Ll | 93 | IPWA $\gamma N \rightarrow \pi N$ |

$N(1535) \rightarrow N\gamma$, ratio $A_{1/2}^n/A_{1/2}^p$

VALUE (GeV -1/2) DOCUMENT ID TECN • • • We do not use the following data for averages, fits, limits, etc. • • • -0.84 ± 0.15 MUKHOPAD... 95B IPWA

N(1535) FOOTNOTES

- $^{1}\, {\sf LONGACRE}$ 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes. From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix

- amplitudes. 3 KRUSCHE 97 fits with the mass fixed at 1544 MeV. 4 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 5 ARNDT 98 also lists pole residues, which display more model dependence than do the associated pole positions.
- described positions. 6 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 7 The best value ARMSTRONG 99B obtains is \simeq 0.55; this assumes S_{11} dominance in the reaction $p(e, e'p) \eta$ at $Q^2 = 4 (GeV/c)^2$
- ⁸ This STAROSTIN 03 value is an estimate made using simplest assumptions.
- $^9\,{\sf BENMERROUCHE}$ 91 uses an effective Lagrangian approach to analyze η photoproduc-
- tion data. 10 This ANISOVICH 09A amplitude is evaluated at the pole position; the phase is $(20\pm15)^{\circ}$.
- $^{11}\,\text{This}$ A NISOVICH 09A amplitude is evaluated at the pole position; the phase is ($20\pm20)^{\circ}$.

N(1535) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. (BC | ONN, PNPI) |
|-------------------|------------|-----------------------------|---------------------------------------------|-----------------|
| ANISOVICH | 10 | EPJ A44 203 | | ONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| ANISOVICH | 09A | EPJ A41 13 | | NPI, BASL) |
| AZNAURYAN | 09 | PR C80 055203 | | AS Collab.) |
| THOMA | 08 | PL B659 87 | | SA Collab.) |
| DRECHSEL | 07 | EPJ A34 69 | | NNZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jefferson Lab CL | |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | | DG Collab. |
| ARNDT | 04 | PR C69 035213 | | WU, TRIU) |
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| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
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| BAI | 02 D | PL B510 75 | J.Z. Bai et al. (E | BES Collab.) |
| | 01 | | R. Thompson et al. (Jefferson CL | |
| THOMPSON VRANA | 00 | PRL 86 1702 PRPL 328 181 | | (PITT+) |
| ARMSTRONG | 99 B | PR D60 052004 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | (PH I+) |
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| ARNDT | 97 | PR C55 R2167 | R.A. Arndt et al. | TIC MUNICO) |
| GREEN | | | | ELS, WINR) |
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| ABAEV | 96 96 | | V.V. Abaev, B.M.K. Nefkens | (UCLA) |
| ARNDT | 95 | PR C53 430 PR C52 2120 | R.A. Arndt, I.I. Strakovsky, R.L. Workman | (VPI) |
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| BENMERROU | . 95 95 | PR D51 3237 PRL 74 3736 | M. Benmerrouche, N.C. Mukhopadhyay, J.F. Zh | |
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| KRUSCHE | 95 C | PL B358 40 | | IZ, GLAS+) |
| MUKHOPAD | | PL B364 1 | N.C. Mukhopadhyay, J.F. Zhang, M. Benmerrou | |
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| LI | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
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| ARNDT | 91 | PR D43 2131 | | VPI, TELE) IJP |
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| WADA | 84 | NP B247 313 | Y. Wada et al. | (INUS) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
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| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
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| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
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| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| Also | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. (| LBL, S LAC) IJP |
| | | | | |

Baryon Particle Listings N(1650)

N(1650) 1/2

 $I(J^P) = \frac{1}{2}(\frac{1}{2})$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete Table edition, mysis Editers 1118 111902). Some little obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(1650) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|-----------------------|---------|-------------|------------------------------------------|
| 1645 to 1670 (≈ 1655) OUR EST | IMATE | | | |
| 1651 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1634.7± 1.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1659 ± 9 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1650 ±30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1670 ± 8 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| \bullet \bullet We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 1680 ±40 | ANISOVICH | 10 | DPWA | Multichannel |
| 1652 ± 9 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1655 ± 15 | THOMA | 80 | DPWA | Multichannel |
| 1651.2± 4.7 | ARNDT | 04 | DPWA | π N \rightarrow π N, η N |
| 1665 ± 2 | PENNER | 02c | DPWA | Multichannel |
| 1647 ±20 | BAI | 01B | BES | $J/\psi \rightarrow p \overline{p} \eta$ |
| 1689 ±12 | VRA NA | 00 | DPWA | Multichannel |
| 1677 ± 8 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1667 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1712 | ¹ ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1674 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1672 | MUSETTE | 80 | IPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1680 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1700 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1660 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1650) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------------|-----------------------|---------|-------------|------------------------------------------|
| 120 to 180 (≈ 150) OUR ESTIM | | | | |
| 104 ±10 | ANISOVICH | 12A | DPWA | Multichannel |
| 115.4 ± 2.8 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 167.9± 9.4 | GREEN | 97 | DPWA | π N \rightarrow π N, η N |
| 173 ±12 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 150 ±40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 180 ±20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | s, fits | , limits, e | etc. • • • |
| 170 ±45 | ANISOVICH | 10 | DPWA | Multichannel |
| 202 ±16 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 180 ±20 | THOMA | 80 | DPWA | Multichannel |
| 130.6 ± 7.0 | ARNDT | 04 | DPWA | π N \rightarrow π N, η N |
| 138 ± 7 | PENNER | 02c | DPWA | Multichannel |
| $ \begin{array}{ccc} +80 \\ -45 \end{array} $ | BAI | 01в | BES | $J/\psi \rightarrow p \overline{p} \eta$ |
| 202 ±40 | VRA NA | 00 | DPWA | Multichannel |
| 160 ±12 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 90 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 184 | ¹ ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 225 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 179 | MUSETTE | 80 | IPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 120 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 170 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 130 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1650) POLE POSITION

REAL PART

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|------------------------------|---------|-----------|---------------------------------------------|
| 1640 to 1670 (≈ 1655) | OUR ESTIMATE | | | |
| 1647 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1648 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1670 | ⁴ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 1640 ± 20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the | e following data for average | s, fits | , limits, | etc. • • • |
| 1670 ± 35 | ANISOVICH | 10 | DPWA | Multichannel |
| 1646 ± 8 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1645 ± 15 | THOMA | 80 | DPWA | Multichannel |
| 1653 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1663 | VRA NA | 00 | DPWA | Multichannel |
| 1660 ± 10 | ⁵ ARNDT | 98 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1673 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1689 | ¹ ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1657 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1648 or 1651 | ⁶ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1699 or 1698 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

| VALUE (MeV) | DO CUMENT ID | | TECN COMMENT |
|-------------------------------------------|----------------------|---------|-------------------------------------------|
| 100 to 170 (≈ 135) OUR ESTIMA | TE | | |
| 103± 8 | ANISOVICH | 12A | DPWA Multichannel |
| 80 | ARNDT | | DPWA $\pi N \rightarrow \pi N$, ηN |
| 163 | ⁴ HOEHLER | 93 | ARGD $\pi N \rightarrow \pi N$ |
| 150 ± 30 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | s, fits | , limits, etc. • • • |
| 170±40 | ANISOVICH | 10 | DPWA Multichannel |
| 204 + 17 | BATINIC | 10 | DPWA $\pi N \rightarrow N \pi N n$ |

| 150 ± 30 | CUTKOSKY | 80 | IPVVA $\pi N \rightarrow \pi N$ |
|-------------------------------------------|-----------------------|---------|-------------------------------------------|
| ullet $ullet$ We do not use the following | data for averages | s, fits | , limits, etc. • • • |
| 170±40 | ANISOVICH | 10 | DPWA Multichannel |
| 204 ± 17 | BATINIC | 10 | DPWA $\pi N \rightarrow N \pi$, $N \eta$ |
| 187 ± 20 | THOMA | 80 | DPWA Multichannel |
| 182 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 240 | VRANA | 00 | DPWA Multichannel |
| 140 ± 20 | ⁵ ARNDT | 98 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 82 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 192 | $^{ m 1}$ ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 160 | ARNDT | 91 | DPWA $\pi N \rightarrow \pi N$ Soln SM90 |
| 117 or 119 | ⁶ LONGACRE | 78 | IPWA $\pi N \rightarrow N \pi \pi$ |
| 174 or 173 | ² LONGACRE | 77 | IPWA $\pi N \rightarrow N \pi \pi$ |
| | | | |

N(1650) ELASTIC POLE RESIDUE

MODULUS Id

-2×IMAGINARY PART

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------------------------|----------|---------------------------------------|------------------------------------------------------------------------|
| 20 to 50 (≈ 35) OUI | RESTIMATE | | · · · · · · · · · · · · · · · · · · · | |
| 24 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 14 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 39 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 60 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • We do not use | the following data for average | s, fits | , limits, e | etc. • • • |
| | | | | |
| | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 100 69 | BATINIC ARNDT | 10 04 | | $\pi N \rightarrow N \pi, N \eta$ $\pi N \rightarrow \pi N, \eta N$ |
| 100 | = | | DPWA | . , |
| 100 69 | ARNDT | 04 | DPWA DPWA | $\pi N \rightarrow \pi N, \eta N$ |

PHASE **0**

23±4

 -30 ± 20

| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------|-------------------|---------|-------------|--------------------------------------------------------------------|
| 50 to 80 (≈ 70) OUR ESTIMATE | | | | |
| -75 ± 12 | ANISOVICH | 12A | DPWA | Multichannel |
| -69 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| -37 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| -75 ± 25 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following of | data for averages | s, fits | , limits, e | etc. • • • |
| -65 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| -55 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 29 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| - 85 ¹ | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| -38 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |

N(1650) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|-------------------|--------------------|----------------|--------|--------------|
| 29±3 | 134 ± 10 | ANISOVICH 12 | A DPWA | Multichannel |
| Normalized r | esidue in $N\pi$ – | → N(1650) → ΛK | | |
| 110 0111 110 (0() | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| MODULUS (%) | FRASE) | DO COMENT ID | | |
| 23±9 | 85 ± 9 | ANISOVICH 12 | | |
| 23±9 | 85 ± 9 | | A DPWA | |

N(1650) DECAY MODES

ANISOVICH 12A DPWA Multichannel

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) | |
|----------------|-------------------------------------------|------------------------------|--|
| Γ ₁ | Nπ | 50-90 % | |
| Γ_2 | N η | 5-15 % | |
| Γ_3 | ΛK | 3-11 % | |
| Γ_4 | ΣΚ | | |
| Γ_5 | $N\pi\pi$ | 10-20 % | |
| Γ_6 | $\Delta\pi$ | 0-25 % | |
| Γ_7 | ${\it \Delta}(1232)\pi$, ${\it D}$ -wave | 0-25 % | |
| Γ ₈ | $N \rho$ | 4-12 % | |
| | | | |

 $(\Gamma_1\Gamma_9)^{\frac{1}{2}}/\Gamma$

 Γ_9/Γ

 Γ_{10}/Γ

 Γ_{11}/Γ

 Γ_{12}/Γ

_(Γ₁Γ₁₂)^{1/2}/Γ

 $_{_{-}}^{}(\Gamma_{1}\Gamma_{10})^{\frac{1}{2}}/\Gamma$

 $(\Gamma_1\Gamma_{11})^{\frac{1}{2}}/\Gamma$

COMMENT $\pi N \rightarrow \pi N \& N \pi \pi$

Multichannel $\begin{array}{ccc} \gamma \, d \, \to \, & \eta \, N \, (N) \\ \gamma \, N \, \to \, & \pi \, N \end{array}$ Multichannel $\gamma N \rightarrow \pi N$ Compton scattering

 $\pi \: \mathsf{N} \: \to \: \pi \: \mathsf{N} \: \And \: \mathsf{N} \: \pi \: \pi$ $\begin{array}{ccc}
\pi \, \mathsf{N} \to & \mathsf{N} \pi \pi \\
\pi \, \mathsf{N} \to & \mathsf{N} \pi \pi
\end{array}$

 $19\!\pm\!9$

 2 ± 1

10±5

ANISOVICH 12A DPWA Multichannel

00 DPWA Multichannel

08 DPWA Multichannel

VRA NA

THOMA

 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| | | | | | | | | N(1 |
|-------------------------------------------------------------------------------------|--------------------------------|------------------------------|----------------------------------------------------------------------------------------|---|------------------------------------------------------------------------------------|------------------------------------------------------|------------------|--------------------------------------------------------------|
| Γ_9 $N \rho$, $S=1/2$, S -w Γ_{10} $N \rho$, $S=3/2$, D -w | | (1.0±1.0) % (13.0±3.0) % | | | $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{	ext{total}}$ in $N\pi	o N$ | $I(1650) \rightarrow N\rho, S=1$ | /2, S-wav | e (Γ ₁ |
| $\Gamma_{11} \qquad N(\pi\pi)_{S-\text{wave}}^{I=0}$ | | <4 % | | | ±0.03 to ±0.19 OUR E | | | <u>comment</u> |
| $N(1440)\pi$ | | <5 % | | | -0.01 ± 0.09 | | 2 IPWA | $\pi N \rightarrow \pi N \&$ |
| $_{13}$ $p\gamma$ | | 0.04-0.20 % | | | + 0.17 | ^{2,7} LONGACRE 7 ³ LONGACRE 7 | | $\pi N \rightarrow N \pi \pi$ |
| $p\gamma$, helicity=1/2 | | 0.04-0.20 % | | | -0.16 | ³ LONGACRE 7 | 5 IPWA | $\pi N \rightarrow N \pi \pi$ |
| $_{15}$ $n\gamma$ | | 0.003-0.17 % | | | $\Gamma(N\rho, S=1/2, S-wave)/\Gamma_{to}$ | otal | | |
| $n\gamma$, helicity=1/2 | | 0.003-0.17 % | | | VALUE (%) | DO CUMENT ID | TECN | COMMENT |
| *** | > | | | - | 1±1 | VRANA 0 | 0 DPWA | Multichannel |
| ` | 50) BRANCHIN | G RATIOS | | | $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\mathrm{total}}$ in $N\pi 	o N$ | $I(1650) \rightarrow N\rho, S=3$ | | /e (Γ ₁ Γ |
| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | Γ ₁ /Ι | Γ | VALUE +0.17 to +0.29 OUR ESTIMA | <u>DO CUMENT ID</u> | TECN | COMMENT |
| 4LUE (%) | DO CUMENT ID | TECN | COMMENT | _ | +0.16 ± 0.06 | | 2 IPWA | $\pi N \rightarrow \pi N \&$ |
| 50 to 90 (≈ 70) OUR ESTIM | | | | | +0.29 | ^{2,7} LONGACRE 7 | | $\pi N \rightarrow N \pi \pi$ |
| 51 ± 4 | ANISOVICH | | Multichannel | | -/ | | | |
| 00 73.5 ± 1.1 | ARNDT GREEN | | $\Lambda \pi N \rightarrow \pi N, \eta N$ $\Lambda \pi N \rightarrow \pi N, \eta N$ | | $\Gamma(N\rho, S=3/2, D-wave)/\Gamma_t$ | | | |
| 39 ± 7 | MANLEY | | $\pi N \rightarrow \pi N \& N \pi \pi$ | | VALUE (%) | DO CUMENT ID | TECN | COMMENT |
| 55 ±10 | CUTKOSKY | 80 IPWA | $\pi N \rightarrow \pi N$ | | 13±3 | VRANA 0 | 0 DPWA | Multichannel |
| 51 ± 4 | HOEHLER | 79 IPWA | $\pi N \rightarrow \pi N$ | | 14 | | | |
| • We do not use the following | ng data for average | | | | $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{total}$ in $N\pi \to N$ | | -wave | (Γ ₁ Γ |
| 60 ±25 | ANISOVICH | 10 DPW | Multichannel | | VALUE | DO CUMENT ID | TECN | COMMENT |
| 9 ± 6 | BATINIC | | $\pi N \rightarrow N\pi, N\eta$ | | +0.04 to +0.18 OUR EST MA | | | |
| '0 ±15 | THOMA | | Multichannel | | $+0.12 \pm 0.08$ | ^ - | 2 IPWA 7 IPWA | $\pi N \rightarrow \pi N \&$ |
| 0.0 | ARNDT | | $\pi N \rightarrow \pi N, \eta N$ | | 0.00 + 0.25 | ^{2,7} LONGACRE 7 | | $\pi N \rightarrow N \pi \pi$ $\pi N \rightarrow N \pi \pi$ |
| 5 ± 4 | PENNER | | Multichannel | | +0.23 | LONGACKE 1 | 3 IFVVA | $\pi N \rightarrow N \pi \pi$ |
| 74 ± 2 | VRA NA | | Multichannel | | $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{\text{total}}$ | | | |
| 99 27 | ARNDT ¹ ARNDT | | $\Lambda \pi N \rightarrow N \pi$ $\Lambda \pi N \rightarrow N \pi$ | | VALUE (%) | DOCUMENT ID | TECN | COMMENT |
| | AKNDI | 93 DF WA | | _ | 1±1 | | | Multichannel |
| (Nη)/Γ _{total} | DO CUMENT ID | TECN | Γ ₂ /Ι <i>COMMENT</i> | l | $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N$ | /(1650) → N(1440) | _ | (F. F |
| to 15 OUR ESTIMATE | DO COMENT ID | 7207 | COMMENT | _ | (| DOCUMENT ID | N TECN | (F ₁ F ₁ |
| ±4 | ANISOVICH | 12A DPWA | Multichannel | | +0.11±0.06 | | 2 IPWA | $\pi N \rightarrow \pi N \&$ |
| $.0 \pm 0.6$ | PENNER | 02c DPW | Multichannel | | 1 0.11 1 0.00 | WWW.WEET 5 | **** | *** |
| ±1 | VRA NA | | Multichannel | | $\Gamma(N(1440)\pi)/\Gamma_{ m total}$ | | | |
| We do not use the following | ng data for average | es, fits, limits, | etc. • • • | | VALUE (%) | DOCUMENT ID | TECN | COMMENT |
| ±5 | BATINIC | | $\pi N \rightarrow N\pi$, $N\eta$ | | 3±1 | | | Multichannel |
| ± 6 | THOMA | 08 DPW | Multichannel | | | | | |
| $(\Lambda K)/\Gamma_{\text{total}}$ | | | Г3/1 | Γ | N(1650) | PHOTON DECAY A | MPLITU | DES |
| ALUE (%) | DOCUMENT ID | TECN | COMMENT | _ | | des predating 1981 may | be found in | our 2006 edition, |
| 2.9±0.4 OUR AVERAGE Erro D ±5 | or includes scale fac | | Multichannel | | Journal of Physics, G | 33 1 (2006). | | |
| 0 ±5 4 ±1 | A NI SOVI CH SH KLYAR | | Multichannel | | M(1650) . no holiottu 1 | /O amalituda A | | |
| 2.7±0.4 | PENNER | | Multichannel | | $N(1650) \rightarrow p\gamma$, helicity-1 | ./2 amplicade A _{1/2} | | |
| | | | | | VALUE (GeV $^{-1/2}$) | DO CUMENT ID | TECN | COMMENT |
| $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N($ | 1650) → AK | | (Γ ₁ Γ ₃) ^{1/2} /Ι | Г | +0.053±0.016 OUR ESTIMAT | | | |
| ALUE | DO CUMENT ID | TECN | COMMENT | | 0.033 ± 0.007 | A NISOVICH 1 DUGGER 0 | | Multichannel $\gamma N \rightarrow \pi N$ |
| 0.27 to -0.17 OUR ESTIMAT | E | | | _ | 0.022 ± 0.007 0.069 ± 0.005 | ARNDT 9 | | $\gamma N \rightarrow \pi N$ $\gamma N \rightarrow \pi N$ |
| - 0.22 | BELL | | $\pi^- p \rightarrow \Lambda K^0$ | | 0.033±0.015 | CRAWFORD 8 | | $\gamma N \rightarrow \pi N$ |
| - 0.22 | SAXON | 80 DPW | $\pi^- \rho \rightarrow \Lambda K^0$ | | 0.050 ± 0.010 | | | $\gamma N \rightarrow \pi N$ |
| 1/ | | | 1/ | | ● ● We do not use the follow | | | |
| $\Gamma_i \Gamma_f$) $^{1/2} / \Gamma_{\text{total}}$ in $N \pi \rightarrow N($ | $1650) \rightarrow \Sigma K$ | | (Γ ₁ Γ ₄) ^{1/2} /Ι | Γ | 0.060 ± 0.020 | ANISOVICH 1 | 0 DPWA | Multichannel |
| ALUE | DO CUMENT ID | TECN | COMMENT | _ | 0.100±0.035 | 0 | | $\gamma d \rightarrow \eta N(N)$ |
| • We do not use the following | ng data for average | s, fits, limits, | etc. • • • | | 0.033 | | 7 DPWA | $\gamma N \rightarrow \pi N$ |
| 0.254 | LIVANOS | 80 DPW | $\pi p \rightarrow \Sigma K$ | | 0.049 | PENNER 0 | | Multichannel |
| | | | | | 0.068 ± 0.003 | LI 9 | | $\gamma N \rightarrow \pi N$ |
| Note: Signs of couplings | from $\pi N \rightarrow N \pi$ | π analyses we | re changed in the | | 0.091 | WADA 8 | 4 DPWA | Compton scatte |
| 1986 edition to agree w | | | | | $N(1650) \rightarrow n\gamma$, helicity-1 | /2 amplitude A _{1/2} | | |
| ambiguity is resolved by | y choosing a negat | ive sign for t | he $\Delta(1620)$ S_{31} | | | · -/- | | |
| coupling to $\Delta(1232)\pi$. | | | | | <u>VALUE (GeV^{-1/2})</u> -0.015±0.021 OUR ESTIMAT | DO CUMENT ID | <u>TECN</u> | COMMENT |
| 16 | | | 14 | _ | -0.055±0.020 | ^ | 9a DPWA | $\gamma d \rightarrow \eta N(N)$ |
| $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N($ | | | | Γ | -0.035 ± 0.020 -0.015 ± 0.005 | | | $\gamma N \rightarrow \pi N$ |
| ALUE | DOCUMENT ID | TECN | COMMENT | _ | -0.008 ± 0.004 | AWA JI 8 | | $\gamma N \rightarrow \pi N$ |
| 0.15 to 0.23 OUR ESTIMATE | NAA NU = 37 | 00 101411 | A1 | | 0.004 ± 0.004 | FUJII 8 | | $\gamma N \rightarrow \pi N$ |
| + 0.12 ± 0.04 | MANLEY 2,7 LONGACRE | | $\pi N \rightarrow \pi N \& N \pi \pi$ | | | | | , |
| - 0.29 - 0.15 | 3 LONGACRE | | $\pi N \rightarrow N \pi \pi$ $\pi N \rightarrow N \pi \pi$ | | 0.009 | DRECHSEL 0 | 7 DPWA | $\gamma N \rightarrow \pi N$ |
| • • We do not use the following | | | | | -0.011 | | | Multichannel |
| | = = | | | | -0.002 ± 0.002 | | | $\gamma N \rightarrow \pi N$ |
| -0.26 ± 0.14 | THOMA | 08 DPW | Multichannel | | | | | |
| $(\Delta(1232)\pi, D$ -wave $)/\Gamma_{tota}$ | al | | Γ ₇ /Ι | Г | N(1650) | $\gamma p \rightarrow \Lambda K^+ A$ | MPLITU | DES |
| (\(\alpha\)(1232)\(\beta\); \(\text{tota}\) | DO CUMENT ID | TECN | • | | | | | |
| 0 to 25 OUR ESTIMATE | DO COMENT ID | 1201 | | _ | $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{total}$ in $p \gamma \to i$ | | | (Fo. ami |

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow N(1650) \rightarrow \Lambda K^+$ $(E_{0+}$ amplitude) VALUE (units 10^{-3}) DOCUMENT ID TECN \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet WORKMAN 90 DPWA $7.8\ \pm0.3$ 8.13 TANABE 89

N(1650), N(1675)

| $p\gamma \rightarrow N(1650) \rightarrow \Lambda K^{+}$ | phase angle $	heta$ | | $(E_{0+} \text{ amplitude})$ |
|---------------------------------------------------------|-------------------------|-------------------|------------------------------|
| VALUE (degrees) | DO CUMENT ID | TECN | |
| ullet $ullet$ We do not use the follows: | wing data for averages, | fits, limits, etc | . • • • |
| -107 ± 3 | WORKMAN 9 | 90 DPWA | |
| -107.8 | TA NABE 8 | 89 DPWA | |
| | | | |

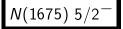
N(1650) FOOTNOTES

- 1 ARNDT 95 finds two distinct states. 2 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi\,N\to\,N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ³ From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix
- Asset HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial—wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- ARNDT 98 also lists pole residues, which display more model dependence than do the associated pole positions.
- described positions. 6 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \rightarrow N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 7 LONGACRE 77 considers this coupling to be well determined.
- 8 This A NISOVICH 09A amplitude is evaluated at the pole position; the phase is ($25\pm20)^\circ$.
- 9 This ANISOVICH 09A amplitude is evaluated at the pole position; the phase is ($30\pm25)^\circ$

N(1650) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

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|---------------------|----------|--------------------------|---------------------------------------|----------------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| ANISOVICH | 09A | EPJ A41 13 | A.V. Anisovich et al. | (BONN, PNPI, BASL) |
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| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiato | |
| DUGGER | 07 | PR C76 025211 | | rson Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| SHKLYAR | 05 | PR C72 015210 | V. Shkiyar, H. Lenske, U. Mosel | (GIES) |
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| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | ÌGIESÍ |
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| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. I | _ee ` (PITT+) |
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| GREEN | 97 | PR C55 R2167 | A.M. Green, S. Wycech | (HELS, WINR) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Wo | rkman (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | ` (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | `(VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KĖNT) IJP |
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| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
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| A Iso | | NC 102A 193 | M. Kohno, H. Tanabe, C. Bennhold | (MANZ) |
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| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CRAWFORD | 83 | NP B2111 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| FUJII | 81 | NP B187 53 | K. Fujii et al. | (NAGO, OSAK) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | 00 | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| LIVANOS | 80 | Toronto Conf. 35 | P. Livanos et al. | (SACL) IJP |
| MUSETTE | 80 80 | NC 57A 37 | M. Musette | (BRUX) IJP |
| S AX ON H OEHLER | 79 | NP B162 522 PDAT 12-1 | D.H. Saxon et al. G. Hohler et al. | (RHEL, BRIS) IJP |
| Also | 19 | Toronto Conf. 3 | R. Koch | (KARLT) IJP (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| Also | ., | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| LONGACILE | , 3 | 1 2 33 2 413 | N.S. Long dere et al. | (EDE, SEAC) DE |



$$I(J^P) = \frac{1}{2}(\frac{5}{2})$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(1675) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|-----|------|----------------------------------------|
| 1670 to 1680 (≈ 1675) OU | R ESTIMATE | | | |
| 1664 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 1674.1 ± 0.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1676 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1675 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1679 ± 8 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

| | ng data for average | es, fits | , limits, etc. • • • |
|-------------|-----------------------|----------|-------------------------------------------|
| 1678 ± 5 | ANISOVICH | 10 | DPWA Multichannel |
| 1679 ± 9 | BATINIC | 10 | DPWA $\pi N \rightarrow N \pi$, $N \eta$ |
| 1678 ±15 | THOMA | 80 | DPWA Multichannel |
| 1676.2± 0.6 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 1685 ± 4 | VRANA | 00 | DPWA Multichannel |
| 1673 ± 5 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 1673 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 1666 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ |
| 1670 | SAXON | | DPWA $\pi^- p \rightarrow \Lambda K^0$ |
| 1650 | | 77 | IPWA $\pi N \rightarrow N \pi \pi$ |
| 1660 | ² LONGACRE | 75 | IPWA $\pi N \rightarrow N \pi \pi$ |

N(1675) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 130 to 165 (≈ 150) OUR ESTIM | IATE | | | |
| 152 ± 7 | ANISOVICH | 12A | DPWA | Multichannel |
| 146.5 ± 1.0 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 159 ± 7 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 160 ±20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 120 ±15 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 177 ±15 | ANISOVICH | 10 | DPWA | Multichannel |
| 152 ± 8 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 220 ±25 | THOMA | 80 | DPWA | Multichannel |
| 151.8± 3.0 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 131 ±10 | VRANA | 00 | DPWA | Multichannel |
| 154 ± 7 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 154 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 136 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 40 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 130 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 150 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1675) POLE POSITION

REAL PART

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------|------------------------------|----------|-------------|-----------------------------------------------|
| 1655 to 1665 (≈ 1660) C | OUR ESTIMATE | | · | |
| 1654 ± 4 | ANISOVICH | 12A | DPWA | Multichannel |
| 1657 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1656 | ³ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 1660 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | e following data for average | s, fits, | , limits, e | etc. • • • |
| 1650 ± 5 | ANISOVICH | 10 | DPWA | Multichannel |
| 1658± 9 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 1639 ± 10 | THOMA | 80 | DPWA | Multichannel |
| 1659 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1674 | VRANA | 00 | DPWA | Multichannel |
| 1663 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1655 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1663 or 1668 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1649 or 1650 | $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -2×IMAGINARY PA | RT | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 125 to 150 (≈ 135) OUR | ESTIMATE | | | |
| 151 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 139 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 126 | ³ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 140 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | e following data for average | s, fits, | , limits, e | etc. • • • |
| 143± 7 | ANISOVICH | 10 | DPWA | Multichannel |
| 137± 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 180 ± 20 | THOMA | 08 | DPWA | Multichannel |
| 146 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 120 | VRANA | 00 | DPWA | Multichannel |
| 152 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 124 | ARNDT | 91 | DPWA | $\pi{\it N} \rightarrow \pi{\it N}$ Soln SM90 |
| 146 or 171 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 127 or 127 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1675) ELASTIC POLE RESIDUE

MODULUS Irl

ı

| MIODOFO2 II | | | | |
|-------------------------------------------|------------------|---------|-------------|--------------------------------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 27±5 OUR ESTIMATE | | | | |
| 28 ± 1 | ANISOVICH | 12A | DPWA | Multichannel |
| 27 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 23 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 31 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 25 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| 29 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 29 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 28 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |

| PHASE <i>0</i> | | | | | |
|---------------------------------|--------------------|-----------|-----------|--------------------------------------------------------------------|---|
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
| -25 ± 6 OUR ESTIMATE | · | | | | |
| -26 ± 4 | ANISOVICH | 12A | DPWA | Multichannel | |
| -21 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | _ |
| -22 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ | |
| -30 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the followi | ng data for averag | es, fits, | , limits, | etc. • • • | |
| -16 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ | I |
| -22 | ARNDT | 04 | | $\pi N \rightarrow \pi N, \eta N$ | - |
| - 6 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| -17 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ | |
| | | | | | |

N(1675) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

Normalized residue in $N\pi \rightarrow N(1675) \rightarrow \Delta\pi$, D-wave MODULUS (%) PHASE (°) DOCUMENT ID TECN

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|---------------|---------------------|-------------------------------|----------|--------------|
| 33±5 | 82 ± 10 | ANISOVICH | 12A DPWA | Multichannel |
| Normalized re | sidue in $N\pi	o N$ | $I(1675) \rightarrow N\sigma$ | | |
| MODULUS (%) | PHASE (°) | DOCUMENT ID | TECN | COMMENT |
| 15 ± 4 | 132 ± 18 | ANISOVICH | | Multichannel |

N(1675) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------|-------------------------------------------------------|------------------------------|
| Γ ₁ | $N\pi$ | 35-45 % |
| Γ_2 | N η | (0.0 ± 1.0) % |
| Γ_3 | ΛK | <1 % |
| Γ_4 | ΣΚ | |
| Γ_5 | $N\pi\pi$ | 50-60 % |
| Γ_6 | $\Delta\pi$ | 50-60 % |
| Γ_7 | $\mathit{\Delta}(1232)\pi$, $\mathit{D}	ext{-}$ wave | (50 ±15) % |
| Γ ₈ | ${\it \Delta}(1232)\pi$, ${\it G}$ -wave | |
| Г9 | $N \rho$ | < 1-3 % |
| Γ_{10} | $N\rho$, $S=1/2$, D -wave | (0.0 ± 1.0) % |
| Γ_{11} | $N\rho$, $S=3/2$, D -wave | (1.0 ± 1.0) % |
| Γ_{12} | $N\rho$, $S=3/2$, G -wave | |
| Γ_{13} | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | (7.0 ± 3.0) % |
| Γ_{14} | $p\gamma$ | 0-0.02 % |
| Γ_{15} | $p\gamma$, helicity=1/2 | 0-0.01 % |
| Γ_{16} | $p\gamma$, helicity=3/2 | 0-0.01 % |
| Γ_{17} | n γ | 0-0.15 % |
| Γ_{18} | $n\gamma$, helicity=1/2 | 0-0.05 % |
| Γ ₁₉ | $n\gamma$, helicity=3/2 | 0-0.10 % |

N(1675) BRANCHING RATIOS

| DO CUMENT ID | | | |
|--------------------|--------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DOCOMENTIO | | TECN | COMMENT |
| | | | |
| ANISOVICH | 12A | DPWA | Multichannel |
| ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ng data for averag | es, fits | , limits, e | etc. • • • |
| ANISOVICH | 10 | DPWA | Multichannel |
| BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| THOMA | 80 | DPWA | Multichannel |
| ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| VRA NA | 00 | DPWA | Multichannel |
| ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| | | | Γ ₂ /Γ |
| DO CUMENT ID | | TECN | COMMENT |
| VRA NA | 00 | DPWA | Multichannel |
| ng data for averag | es, fits | , limits, e | etc. • • • |
| BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| THOMA | 08 | DPWA | Multichannel |
| | A NISOVICH ARNDT MANLEY CUT KOSKY HOEHLER ng data for averag A NISOVICH BATINIC THOMA ARNDT VRA NA ARNDT VRA NA ng data for averag BATINIC | A NISOVICH 12A ARNDT 06 MANLEY 92 CUTKOSKY 80 HOEHLER 79 ng data for averages, fits A NISOVICH 10 BATINIC 10 THOMA 08 ARNDT 04 VRA NA 00 ARNDT 95 DOCUMENT ID VRA NA 00 ng data for averages, fits BATINIC 10 | ANISOVICH 12A DPWA ARNDT 06 DPWA MANLEY 92 IPWA CUTKOSKY 80 IPWA HOEHLER 79 IPWA ang data for averages, fits, limits, of ANISOVICH 10 DPWA BATINIC 10 DPWA THOMA 08 DPWA ARNDT 04 DPWA VRA NA 00 DPWA ARNDT 95 DPWA DOCUMENT ID TECN VRA NA 00 DPWA ang data for averages, fits, limits, of BATINIC 10 DPWA |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | V(1675) → <i>ΛK</i> | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
|------------------------------------------------------------------------------------|---------------------|----|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| ±0.04 to ±0.08 OUR EST M | ATE | | | |
| -0.01 | BELL | | | $\pi^- p \rightarrow \Lambda K^0$ |
| +0.036 | ⁵ SAXON | 80 | DPWA | $\pi^- ho ightarrow \Lambda K^0$ |

Note: Signs of couplings from $\pi\,{\it N}\to~{\it N}\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)~5_{31}$ coupling to $\Delta(1232) \pi$.

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \rightarrow$ | DO CUMENT ID | -,, | TECN | e (Γ ₁ Γ ₇) ^{1/2} / |
|------------------------------------------------------------------------------------------|---------------------------------|---------|-----------------|-------------------------------------------------------|
| +0.46 to +0.50 OUR EST | MATE | | | - |
| $+0.496\pm0.003$ | MANLEY 1,6 LONGACRE | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| +0.46 | ^{1,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.50 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, D$ -wave)/[| total | | | Γ ₇ / |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 50±15 OUR ESTIMATE | | | | |
| 33± 8 | ANISOVICH | 12A | DPWA | Multichannel |
| 63± 2 | VRANA | 00 | DPWA | Multichannel |
| ● ● We do not use the fol | lowing data for average | s, fits | , limits, | etc. • • • |
| 24± 8 | THOMA | 80 | DPWA | Multichannel |
| $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\rm total}$ in $N\pi \to$ | $N(1675) \rightarrow N\rho$, S | =1/2 | , <i>D</i> -wav | re (Γ ₁ Γ ₁₀) ^{1/2} / |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.04\pm0.02$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| | г | | | Γ ₁₀ / |
| $\Gamma(N \rho, S=1/2, D-wave)/VALUE(%)$ | 'total DOCUMENT ID | | TECN | COMMENT |

| $1(N\rho, S=1/2, D-wave)/1$ | total | | | | 10/1 |
|------------------------------------------------------------------------------------|--------------------------------|---------------|----------------|----------------------|-------------------------------------|
| VALUE (%) | DO CUMENT I | D | TECN | COMMENT | |
| 0±1 | VRANA | 00 | DPWA | Multichannel | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | $V(1675) \rightarrow N \rho$, | <i>5</i> =3/2 | , D-wav | re (Γ ₁ Γ | 1 ₁ 1) ^{1/2} /Γ |
| -0.12 to -0.06 OUR ESTIM | ATE | | | | |

| -0.12 to -0.00 OUR ESTIMA | 16 | | | | |
|-----------------------------------------|-------------------------|----|------|-------------------------------------------------|--------------------|
| -0.03 ± 0.02 | MANLEY | | | $\pi N \rightarrow \pi N \&$ | $N\pi\pi$ |
| -0.15 | ^{1,6} LONGACRE | 77 | IPWA | $\pi {\it N} \rightarrow {\it N} \pi \pi$ | |
| $\Gamma(N\rho, S=3/2, D-wave)/\Gamma_t$ | otal | | | | Γ ₁₁ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 1±1 | VRANA | 00 | DPWA | Multichannel | |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1675) \to N(\pi\pi)_{S-\text{wave}}^{I=0}$ | | | (Γ ₁ Γ ₁₃) ^{1/2} /Γ | | |
|----------------------------------------------------------------------------------------------------------------------|-------------------------|----|-----------------------------------------------------|-------------------------------|----------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| +0.03 | ^{1,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | COMMENT | Γ_{13}/Γ |

ANISOVICH N(1675) PHOTON DECAY AMPLITUDES

12A DPWA Multichannel

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$\textit{N}(1675) \rightarrow \textit{p}\,\gamma$, helicity-1/2 amplitude $\textit{A}_{1/2}$

7±3

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| VALUE (GeV -1/2) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|-------------------|---------|-----------|------------------------------|
| +0.019±0.008 OUR EST/MATE | | | | |
| 0.024 ± 0.003 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.018 ± 0.002 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.015 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.021 ± 0.011 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.034 ± 0.005 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| | data for averages | , fits, | limits, e | etc. • • • |
| 0.021 ± 0.004 | ANISOVICH | 10 | DPWA | Multichannel |
| 0.015 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.012 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

$N(1675) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| 11(2010) · p // Holloldy 0/2 | apcaac./.3/ | 2 | | |
|-------------------------------------------|------------------|---------|-----------|------------------------------|
| VALUE (GeV -1/2) | DO CUMENT ID | | TECN | COMMENT |
| $+0.015\pm0.009$ OUR ESTIMATE | | | | |
| 0.025 ± 0.007 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.021 ± 0.001 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.010 ± 0.007 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.015 ± 0.009 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.024 ± 0.008 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 0.024 ± 0.008 | ANISOVICH | 10 | DPWA | Multichannel |
| 0.022 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.021 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

Baryon Particle Listings N(1675), N(1680)

$N(1675) \rightarrow n\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV-1/2) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------|-------------------|---------|-----------|------------------------------|
| -0.043±0.012 OUR ESTIMATE | | | | |
| -0.049 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.057 ± 0.024 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.033 ± 0.004 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| $\bullet~\bullet~$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| -0.062 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.060 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

$N(1675) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|---------|-------------|------------------------------|
| -0.058±0.013 OUR ESTIMATE | | | | |
| -0.051 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.077 ± 0.018 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.069 ± 0.004 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| -0.084 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.074 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

N(1675) FOOTNOTES

- $^{
 m 1}$ LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi\,N\to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ² From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix
- amplitudes. ³ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 4 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 5 SAXON 80 finds the coupling phase is near 90°.
- ⁶LONGACRE 77 considers this coupling to be well determined.

N(1675) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

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|-----------|-----|--------------------|--------------------------------|------------------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | ` (ZAGR) |
| THOMA | 08 | PL B65987 | U. Thoma et al. | (CB-ELSA Collab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L | Tiator `(MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. | (Jefferson Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, T | S.H. Lee (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, F | R.L. Workman (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | `(VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KĖNT) IJP |
| A Iso | | PR D30 904 | D.M. Manley et al. | (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| FUJII | 81 | NP B187 53 | K. Fujii et al. | (NAGO, OSAK) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | | | |



 $I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(1680) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|--------------|-----|------|----------------------------------------|
| 1680 to 1690 (≈ 1685) OUR EST | MATE | | | |
| 1689 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1680.1 ± 0.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1684 ± 4 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1680 ±10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1684 ± 3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

| ● We do not use the following | g data for average | s, fits | , limits, etc. • • • |
|---------------------------------------------------|-----------------------|---------|-------------------------------------------|
| 1685 ± 5 | ANISOVICH | 10 | DPWA Multichannel |
| 1680 ± 7 | BATINIC | 10 | DPWA $\pi N \rightarrow N \pi$, $N \eta$ |
| 1684 ± 8 | THOMA | 08 | DPWA Multichannel |
| 1683.2± 0.7 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 1679 ± 3 | VRANA | 00 | DPWA Multichannel |
| 1679 ± 5 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 1678 | | | DPWA $\pi N \rightarrow N \pi$ |
| 1660 | | | IPWA $\pi N \rightarrow N \pi \pi$ |
| 1670 | ² LONGACRE | 75 | IPWA $\pi N \rightarrow N \pi \pi$ |
| | | | |

N(1680) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 120 to 140 (≈ 130) OUR ESTIM | ATE | | | |
| 118 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 128.0 ± 1.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 139 ± 8 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 120 ±10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 128 ± 8 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 117 ±12 | ANISOVICH | 10 | DPWA | Multichannel |
| 142 ± 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 105 ± 8 | THOMA | 80 | DPWA | Multichannel |
| 134.4 ± 3.8 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 128 ± 9 | VRANA | 00 | DPWA | Multichannel |
| 124 ± 4 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 126 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 150 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 130 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1680) POLE POSITION

RFAI PART

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------|------------------------------|---------|-------------|--------------------------------------------------------------------|
| 1665 to 1680 (≈ 1675) | OUR ESTIMATE | | | |
| 1676 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1674 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1673 | ³ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 1667 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use th | e following data for average | s, fits | , limits, e | etc. • • • |
| 1672±4 | ANISOVICH | 10 | DPWA | Multichannel |
| 1666±8 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 1674 ± 5 | THOMA | 80 | DPWA | Multichannel |
| 1678 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1667 | VRANA | 00 | DPWA | Multichannel |
| 1670 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1670 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |
| 1668 or 1674 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1656 or 1653 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 2 MACINARY D | ADT | | | |

−2×IMAGINARY PART

110 to 135 (\approx 120) OUR ESTIMATE

| 113 主 4 | ANISOVICH | 1ZA | DP VVA MULLICITATITIES |
|-------------------------------------------------|-----------------------|---------|-------------------------------------------|
| 115 | ARNDT | 06 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 135 | ³ HOEHLER | 93 | ARGD $\pi N \rightarrow \pi N$ |
| 110 ± 10 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ |
| \bullet \bullet We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 114 ± 12 | ANISOVICH | 10 | DPWA Multichannel |
| 135 ± 6 | BATINIC | 10 | DPWA $\pi N \rightarrow N\pi$, $N\eta$ |
| 95 ± 1 0 | THOMA | 08 | DPWA Multichannel |
| 120 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 122 | VRANA | 00 | DPWA Multichannel |
| 120 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 116 | ARNDT | 91 | DPWA $\pi N \rightarrow \pi N$ Soln SM90 |
| 132 or 137 | ⁴ LONGACRE | 78 | IPWA $\pi N \rightarrow N \pi \pi$ |
| 145 or 143 | ¹ LONGACRE | 77 | IPWA $\pi N \rightarrow N \pi \pi$ |
| | | | |

DOCUMENT ID

TECN COMMENT

A NICOVICH 124 DDWA Multichannel

N(1680) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|---------|-----------|---------------------------------------------|
| 40±5 OUR ESTIMATE | | | | |
| 43±4 | ANISOVICH | 12A | DPWA | Multichannel |
| 42 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 44 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 34 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 44 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| 43 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 40 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 37 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

| PHASE 0 VALUE (°) | DOCUMENT ID | | TECN | COMMENT |
|----------------------|--------------------------------|----------|-----------|---------------------------------------------|
| -10±10 OUR ESTIM | ATE | | | |
| -2 ± 10 | ANISOVICH | 12A | DPWA | Multichannel |
| - 4 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| -17 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| -25 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use | the following data for average | es, fits | , limits, | etc. • • • |
| -19 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 1 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| + 1 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| -14 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

N(1680) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

| Normalized r | esidue in $N\pi ightharpoonup$ | $N(1680) \rightarrow \Delta \pi, P$ | -wave | | |
|--------------|---------------------------------|-------------------------------------|--------------|--------------|--|
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 15 ± 3 | -70 ± 45 | ANISOVICH 12 | DPWA | Multichannel | |
| Normalized r | esidue in $N\pi ightarrow$ | $N(1680) \rightarrow \Delta \pi, F$ | -wave | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 23±4 | 85 ± 15 | ANISOVICH 12 | DPWA | Multichannel | |
| Normalized r | esidue in $N\pi ightarrow$ | $N(1680) \rightarrow N(\pi\pi)$ | =0 5-wave | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 26±4 | -56 ± 15 | ANISOVICH 12A | DPWA | Multichannel | |

N(1680) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ | 65-70 % |
| Γ_2 | N η | (0.0±1.0) % |
| Γ_3 | ΛK | |
| Γ_4 | ΣΚ | |
| Γ_5 | $N\pi\pi$ | 30-40 % |
| Γ_6 | $\Delta\pi$ | 5-15 % |
| Γ_7 | ${\it \Delta}(1232)\pi$, $\it P$ -wave | (10 ±5) % |
| Γ ₈ | ${\it \Delta}(1232)\pi$, $\it F-wave$ | 0-12 % |
| Г9 | $N \rho$ | 3-15 % |
| Γ_{10} | $N\rho$, $S=1/2$, F -wave | |
| Γ_{11} | $N\rho$, $S=3/2$, P -wave | <12;% |
| Γ_{12} | $N\rho$, $S=3/2$, F -wave | 1-5 % |
| Γ_{13} | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | (11 ±5) % |
| Γ_{14} | $p\gamma$ | 0.21-0.32 % |
| Γ_{15} | $p\gamma$, helicity=1/2 | 0.001-0.011 % |
| Γ_{16} | $p\gamma$, helicity=3/2 | 0.20-0.32 % |
| Γ_{17} | n γ | 0.021-0.046 % |
| Γ_{18} | $n\gamma$, helicity=1/2 | 0.004-0.029 % |
| Γ_{19} | $n\gamma$, helicity=3/2 | 0.01-0.024 % |

N(1680) BRANCHING RATIOS

 Γ_1/Γ

 11 ± 5

 $\Gamma(N\pi)/\Gamma_{\rm total}$

| · (····)/ · total | | | | |
|------------------------------------------------------------------------------------------|-------------------------|---------|-------------|-------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 65 to 70 OUR ESTIMATE | | | | _ |
| 64 ± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 70.1 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 70 ± 3 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 62 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 65 ± 2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following of | data for averages | , fits, | , limits, e | etc. • • • |
| 66 ± 8 | ANISOVICH | 10 | DPWA | Multichannel |
| 67 ± 3 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 72 ±15 | THOMA | 80 | DPWA | Multichannel |
| 67.0± 0.4 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 69 ± 2 | VRA NA | 00 | DPWA | Multichannel |
| 68 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(168)$ | $80) \rightarrow N\eta$ | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| ullet $ullet$ We do not use the following of | data for averages | , fits | , limits, e | etc. • • • |
| not seen | BAKER | 79 | DPWA | $\pi^- p \rightarrow n \eta$ |

| 4LUE (%) | DO CUMENT II | פ | TECN | COMMENT |
|-------------------------------------------------------------------------------------------------------------------------------------------|----------------------|-----------|-----------|-------------------------------------------------|
| 0 ±1 | VRANA | 00 | DPWA | Multichannel |
| • We do not use the following | owing data for avera | ges, fits | , limits, | etc. • • • |
| 0.4 ± 0.2 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1 | THOMA | 80 | DPWA | Multichannel |
| $0.15 {}^{+ 0.35}_{- 0.10}$ | TIATOR | 99 | DPWA | $\gamma p \to p \eta$ |
| [a] ^{1/2} /[in N = → | N(1680) → AK | | | (Γ ₁ Γ ₃) ^{1/2} |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \rightarrow Coupling to } \Lambda K \text{ not respectively}$ | N(1680) → AK | of CA | V () N () | |

Note: Signs of couplings from $\pi\,N\to\,N\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$.

| $(\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\pi 	o N(168)$.31 to -0.21 OUR ESTIMATE | DOCUMENT ID | | TECN | COMMENT | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|
| 26 ± 0.04 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \&$ | Νππ |
| .27 1,5 | LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| 25 | ² LONGACRE | 75 | IPWA | $\pi {\it N} \rightarrow {\it N} \pi \pi$ | |
| $(1232)\pi$, <i>P</i> -wave $)/\Gamma_{total}$ | | | | | Γ ₇ /Ι |
| 6 OUR ESTIMATE | DO CUMENT ID | | TECN | COMMENT | |
| | ANISOVICH | 12A | | Multichannel | |
| | VRANA | 00 | | Multichannel | |
| We do not use the following | _ | | | | |
| | THOMA | 80 | DPWA | Multichannel | |
| $^{1\!\!\!\!/2}/\Gamma_{total}$ in $N\pi	o N(168)$ | 80) → Δ (123: | 2)π, | <i>F</i> -wave | (Г1 | Γ ₈) ^{1/2} /Ι |
| | DOCUMENT ID | , | TECN | COMMENT | •, , |
| +0.11 OUR EST MATE | MANLEY | 92 | IDVA/A | A1 A1 0 | Δ. |
| 1.5 | LONGACRE | 92 77 | | $\pi N \rightarrow \pi N \& \pi N \rightarrow N \pi \pi$ | ıvππ |
| 2 | LONGACRE LONGACRE | 75 | | $\pi N \rightarrow N \pi \pi$ $\pi N \rightarrow N \pi \pi$ | |
| | | | | 14 // // | |
| 232) π , <i>F</i> -wave)/Γ _{total}) | | | | | Γ ₈ /Ι |
| (≈5) OUR ESTIMATE | DO CUMENT ID | | TECN | COMMENT | |
| SO OUR ESTIMATE | A NISOVICH | 124 | DBMA | Multichannel | |
| | | 00 | | Multichannel | |
| not use the following (| | | | | |
| st ase the following (| THOMA | 08 | | Multichannel | |
| | | | | | |
| C !- A! A!/464 | | | | | 1/ |
| $\tau/$ i total in $N\pi 	o N$ (16) | 80) $\rightarrow N \rho$, S= | =3/2 | , <i>P</i> -wav | e (Γ ₁ Γ | 11) ^{1/2} /I |
| | 80) → Nρ, S= <u>DOCUMENT ID</u> | =3/2 | , <i>P</i> -wav TECN | е (Г ₁ Г <u>соммент</u> | 11)1/2/1 |
| o -0.10 OUR ESTIMATE | DO CUMENT ID | | TECN | COMMENT | |
| -0.10 OUR ESTIMATE | MANLEY | 92 | TECN IPWA | $\frac{COMMENT}{\pi N \rightarrow \pi N \&}$ | |
| to -0.10 OUR ESTIMATE = 0.05 | DO CUMENT ID | 92 77 | TECN IPWA | $\begin{array}{ccc} \hline \pi \ N \rightarrow & \pi \ N \ \& \\ \pi \ N \rightarrow & N \ \pi \ \pi \end{array}$ | |
| to -0.10 OUR ESTIMATE ± 0.05 | MANLEY LONGACRE | 92 77 | IPWA IPWA | $\begin{array}{ccc} \hline \pi \ N \rightarrow & \pi \ N \ \& \\ \pi \ N \rightarrow & N \ \pi \ \pi \end{array}$ | Νππ |
| -0.10 OUR ESTIMATE 1,0 5-3/2, <i>P</i> -wave)/Γ _{total} | MANLEY LONGACRE LONGACRE | 92 77 | IPWA IPWA IPWA | $\begin{array}{cccc} & COMMENT & \\ \pi & N & \rightarrow & \pi & N & \& \\ \pi & N & \rightarrow & N & \pi & \\ \pi & N & \rightarrow & N & \pi & \\ \end{array}$ | Νππ |
| to -0.10 OUR ESTIMATE ± 0.05 1,5 | MANLEY LONGACRE LONGACRE | 92 77 75 | IPWA IPWA IPWA | $\begin{array}{cccc} \hline {\it COMMENT} \\ \hline \pi \ {\it N} \to & \pi \ {\it N} \ \& \\ \hline \pi \ {\it N} \to & {\it N} \pi \pi \\ \hline \pi \ {\it N} \to & {\it N} \pi \pi \\ \hline \end{array}$ | Νππ |
| to -0.10 OUR ESTIMATE ± 0.05 1,5 | MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA | 92 77 75 | IPWA IPWA IPWA DPWA | $\begin{array}{ccc} \hline {\it COMMENT} \\ \hline \pi \ {\it N} \ \rightarrow \ \pi \ {\it N} \ \& \\ \hline \pi \ {\it N} \ \rightarrow \ {\it N} \pi \pi \\ \hline \pi \ {\it N} \ \rightarrow \ {\it N} \pi \pi \\ \hline \pi \ {\it N} \ \rightarrow \ {\it N} \pi \pi \\ \hline \hline {\it COMMENT} \\ \hline {\it Multichannel} \end{array}$ | Nππ Γ 11/Ι |
| 5 – 0.10 OUR ESTIMATE 0.05 1,5 S=3/2, <i>P</i> -wave)/Γ _{total} | MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA $N \rho$, S= | 92 77 75 00 | IPWA IPWA IPWA DPWA | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Nππ Γ 11/Ι |
| $0-0.10$ OUR ESTIMATE 0.05 1.5 2 $S=3/2$, P -wave)/ $\Gamma_{	ext{total}}$ | MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA | 92 77 75 00 | IPWA IPWA IPWA DPWA | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | Nππ Γ 11/Ι |
| =3/2, P -wave)/ $\Gamma_{	ext{total}}$ in $N\pi 	o N(168)$ | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA No. Se DOCUMENT ID MANLEY | 92 77 75 00 | IPWA IPWA IPWA DPWA | $\begin{array}{l} N \to \pi N & \\ \pi N \to \pi N & \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ COMMENT \\ \end{array}$ | Nππ Γ ₁₁ /Ι |
| =3/2, P -wave)/ Γ_{total} Γ_{total} Γ_{total} Γ_{total} Γ_{total} Γ_{total} Γ_{total} | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA 80) N \(\rho_1 \) S= DOCUMENT ID | 92 77 75 00 = 3/2 | IPWA IPWA IPWA IPWA TECN DPWA | $\begin{array}{l} N \to \pi N & \\ \pi N \to \pi N & \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ COMMENT \\ \end{array}$ | Nππ Γ ₁₁ /Ι |
| 1.0 OUR ESTIMATE 1.5 3/2, P -wave)/ Γ_{total} 1.5 1.6 1.7 1.7 1.7 1.7 1.7 1.7 1.7 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA No. Se DOCUMENT ID MANLEY | 92 77 75 00 = 3/2 | IPWA IPWA IPWA IPWA TECN DPWA F-wav TECN IPWA | $\begin{array}{l} N \to \pi N \& \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \\ \hline Multichannel \\ \mathbf{e} \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad$ | Nππ Γ ₁₁ /Ι Γ ₁₂) ^{1/2} /Ι Νππ |
| 0.10 OUR ESTIMATE 1,5 3/2, P -wave)/ Γ total total in $N\pi \rightarrow N(16i)$ 0.10 OUR ESTIMATE | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID WANNA MANLEY LONGACRE | 92 77 75 00 = 3/2 92 77 | IPWA IPWA IPWA DPWA F-wav TECN IPWA | $\begin{array}{l} N \to \pi N \& \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \mathbf{e} \\ COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \end{array}$ | Nππ Γ ₁₁ /Ι |
| 1.5 (2, P -wave)/ $\Gamma_{	ext{total}}$ 1.6 (2, P -wave)/ $\Gamma_{	ext{total}}$ 1.6 (1.6 (1.6 (1.6 (1.6 (1.6 (1.6 (1.6 (| DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID MANLEY LONGACRE MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE | 92 77 75 00 = 3/2 92 77 | IPWA IPWA IPWA DPWA F-wav IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \\ \hline \pi N \to N \pi \pi \\ \hline \\ COMMENT \\ \hline \\ COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \hline \\ COMMENT \\ \hline \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \hline \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ COMMENT \\ \\ \\ \\ COMMENT \\ \\ \\ \\ COMMENT \\ \\ \\ \\ \\ COMMENT \\ \\ \\ \\ \\ COMMENT \\ \\ \\ \\ \\ COMMENT \\ \\ \\ \\ \\ \\ \\ COMMENT \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\$ | Nππ Γ ₁₁ /Ι Γ ₁₂) ^{1/2} /Ι Νππ |
| 1.10 OUR ESTIMATE 1.5 2.7/2, P -wave)/ Γ_{total} 1.5 1.6 1.7 1.7 1.7 1.7 1.7 1.7 1.7 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA | 92 77 75 00 = 3/2 92 77 | IPWA IPWA IPWA DPWA F-wav IPWA IPWA IPWA | $\begin{array}{l} N \to \pi N \& \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \mathbf{e} \\ COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \end{array}$ | Nππ Γ ₁₁ / I Γ ₁₂ / I Nππ Γ ₁₂ / I |
| 1.10 OUR ESTIMATE 1.5 3/2, P -wave)/ Γ_{total} 1.10 1.10 OUR ESTIMATE 1.2 1.3 1.4 1.5 1.7 1.7 1.7 1.7 1.7 1.7 1.7 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA | 92 77 75 00 = 3/2 92 77 | IPWA IPWA IPWA DPWA F-wav IPWA IPWA IPWA | $\begin{array}{l} N \to \pi N \& \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \mathbf{e} \\ COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \end{array}$ | Nππ Γ ₁₁ /Ι Γ ₁₂) ^{1/2} /Ι Νππ |
| 0.10 OUR ESTIMATE 1,5 3/2, P -wave)/ Γ_{total} 1,5 1,6 1,7 1,7 1,7 1,1 1,1 1,1 1,1 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA | 92 77 75 00 =3/2 92 77 00 J=0 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} N \to \pi N \& \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \mathbf{e} \\ COMMENT \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \end{array}$ $\begin{array}{l} COMMENT \\ \text{Multichannel} \\ \end{array}$ | Nππ Γ ₁₁ / I Γ ₁₂ / I Nππ Γ ₁₂ / I |
| 0.10 OUR ESTIMATE 1,5 3/2, P -wave)/ Γ_{total} 1,5 1,6 1,7 1,7 1,7 1,7 1,7 1,7 1,7 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID WANNA MANLEY LONGACRE DOCUMENT ID VRANA DOCUMENT ID VRANA V V V V V V V V | 92 77 75 00 =3/2 92 77 00 01=0 5-wa | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \hline \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \\ \hline \pi N \to N \pi \pi \\ \hline \\ Multichannel \\ \hline \mathbf{e} \\ \hline \begin{array}{l} COMMENT \\ \pi N \to N \pi \pi \\ \hline \\ Multichannel \\ \hline \end{array} \\ \hline \begin{array}{l} COMMENT \\ \hline \\ Multichannel \\ \hline \end{array} \\ \hline \\ \hline \begin{array}{l} COMMENT \\ \hline \\ \hline \end{array} \\ \hline \end{array}$ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Γ ₁₃) ^{1/2} / |
| 10 OUR ESTIMATE 1,5 2/2, P -wave)/ $\Gamma_{	ext{total}}$ 10 OUR ESTIMATE 1,5 1,7 10 OUR ESTIMATE 1,5 1,7 1,7 1,7 1,7 1,7 1,7 1,7 | DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA 80) $\rightarrow N \rho$, S- DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA 80) $\rightarrow N (\pi\pi)$ DOCUMENT ID MANLEY MANLEY MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY | 92 77 75 00 =3/2 92 77 00 1=0 92 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \ \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline e \\ COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline \\ COMMENT \\ \hline \\ Multichannel \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow $ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Γ ₁₃) ^{1/2} / |
| 0.10 OUR ESTIMATE 1.5 2.3/2, P -wave)/ Γ_{total} 1.5 1.5 0.10 OUR ESTIMATE 3 1.5 3/2, F -wave)/ Γ_{total} 1.5 1.5 1.5 1.5 1.7 1.7 1.7 1.7 | DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE MANLEY LONGACRE | 92 77 75 00 =3/2 92 77 00 1=0 5-wa | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \mathbf{e} \\ COMMENT \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline \\ (\Gamma_1 \ I \ I \ I \ I \ I \ I \ I \ I \ I \ $ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Γ ₁₃) ^{1/2} / |
| =3/2, P -wave)/ Γ_{total} =3/2, P -wave)/ Γ_{total} / Γ_{total} in $N\pi \rightarrow N(16i)$ =3/2, F -wave)/ Γ_{total} =3/2, F -wave)/ Γ_{total} / Γ_{total} in $N\pi \rightarrow N(16i)$ +0.35 OUR ESTIMATE 04 | DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA 80) $\rightarrow N \rho$, S- DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA 80) $\rightarrow N (\pi\pi)$ DOCUMENT ID MANLEY MANLEY MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY | 92 77 75 00 =3/2 92 77 00 1=0 92 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \ \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline e \\ COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline \\ COMMENT \\ \hline \\ Multichannel \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ \hline \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow \pi \ N \ \& \\ T \ N \rightarrow $ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Γ ₁₃) ^{1/2} / |
| =3/2, P -wave)/ Γ_{total} =3/2, P -wave)/ Γ_{total} =7 \(\text{Total} \text{ in } \N\pi \rightarrow N(16) \) =3/2, F -wave)/ Γ_{total} =3/2, F -wave)/ Γ_{total} =7 \(\text{Total} \text{ in } \N\pi \rightarrow N(16) \) =0.35 \(\text{OUR ESTIMATE}\) | DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE MANLEY LONGACRE | 92 77 75 00 =3/2 92 77 00 1=0 5-wa | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \mathbf{e} \\ COMMENT \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ COMMENT \\ Multichannel \\ \hline \\ (\Gamma_1 \ I \ I \ I \ I \ I \ I \ I \ I \ I \ $ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Νππ Γ ₁₂ / Νππ |
| 1.10 OUR ESTIMATE 1.5 1.7 1.7 1.7 1.7 1.7 1.7 1.7 | DOCUMENT ID MANLEY LONGACRE LONGACRE LONGACRE VRANA MANLEY LONGACRE MANLEY LONGACRE DOCUMENT ID VRANA MANLEY LONGACRE MANLEY LONGACRE MANLEY LONGACRE LONGACRE LONGACRE LONGACRE | 92 77 75 00 = 3/2 92 77 00 S-wa | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} N \to \pi N & \& \\ \pi N \to \pi N & \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \\ \hline \pi N \to N \pi \pi \\ \hline \text{Multichannel} \\ \\ \textbf{e} & \textbf{(\Gamma_1 I_{\text{model}})} \\ \hline \text{COMMENT} \\ \pi N \to \pi N & \& \\ \pi N \to N \pi \pi \\ \hline \\ \text{Multichannel} \\ \hline \\ \hline \text{COMMENT} \\ \hline \text{Multichannel} \\ \hline \\ \hline \text{COMMENT} \\ \hline \\ \pi N \to \pi N & \& \\ \pi N \to N \pi \pi \\ \hline \\ \pi N \to N \pi \pi \\ \hline \\ \pi N \to N \pi \pi \\ \hline \\ \pi N \to N \pi \pi \\ \hline \end{array}$ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Νππ Γ ₁₂ / Νππ |
| 10 OUR ESTIMATE 1.5 2.7 2.7 2.7 2.7 2.7 2.7 2.7 2 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID WANNA MANLEY LONGACRE DOCUMENT ID WANNA MANLEY LONGACRE MANLEY LONGACRE LONGACRE DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID MANLEY LONGACRE LONGACRE | 92 77 75 00 = 3/2 92 77 00 J=0 92 77 75 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline Multichannel \\ \textbf{e} \\ \hline COMMENT \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \hline Multichannel \\ \hline (\Gamma_1 \ I \ COMMENT \\ \hline Multichannel \\ \hline (COMMENT \ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline COMMENT \\ \hline \end{array}$ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Γ ₁₃) ^{1/2} / |
| 0.05 1.5 $S=3/2$, P -wave)/ Γ_{total} in $N\pi \rightarrow N(16i)$ 2.5 0.03 1.5 $S=3/2$, F -wave)/ Γ_{total} in $N\pi \rightarrow N(16i)$ 2.5 0.03 1.5 0.03 1.5 | DOCUMENT ID MANLEY LONGACRE LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID ANISOVICH | 92 77 75 00 =3/2 92 77 00 05-wa 92 77 75 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{l} COMMENT \\ \hline \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \pi N \to N \pi \pi \\ \hline \pi N \to N \pi \pi \\ \hline \\ Multichannel \\ \hline \mathbf{e} \\ \hline \begin{array}{l} COMMENT \\ \hline \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \hline \\ Multichannel \\ \hline \end{array} \\ \hline \begin{array}{l} COMMENT \\ \hline \\ Multichannel \\ \hline \end{array} \\ \hline \begin{array}{l} T_1 \\ \hline \\ COMMENT \\ \hline \\ \pi N \to \pi N \& \\ \pi N \to N \pi \pi \\ \hline \\ \pi N \to N \pi \pi \\ \hline \\ \pi N \to N \pi \pi \\ \hline \\ \hline \end{array} \\ \hline \begin{array}{l} COMMENT \\ \hline \\ Multichannel \\ \hline \end{array}$ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Νππ Γ ₁₂ / Νππ |
| I_{P} , $S=3/2$, P -wave)/ Γ_{total} I_{E} (%) I_{E} (%) 18 to -0.10 OUR ESTIMATE 13 ± 0.03 1,5 I_{P} , $S=3/2$, F -wave)/ Γ_{total} I_{E} (%) 19 I_{E} (%) 10 11 12 15 17 18 19 19 19 10 10 11 11 11 12 13 14 15 15 16 17 18 18 18 18 18 18 18 18 18 | DOCUMENT ID MANLEY LONGACRE DOCUMENT ID VRANA 80) → N ρ, S= DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID MANLEY LONGACRE DOCUMENT ID ANISOVICH VRANA | 92 77 75 00 =3/2 92 77 00 1=0 92 77 75 | IPWA IPWA IPWA IPWA IPWA IPWA IPWA IPWA | $\begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \pi \ N \rightarrow N \pi \pi \\ \hline \pi \ N \rightarrow N \pi \pi \\ \hline \\ \underline{COMMENT} \\ \hline Multichannel \\ \underline{COMMENT} \\ \underline{COMMENT} \\ \underline{COMMENT} \\ \underline{Multichannel} \\ \underline{COMMENT} \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ \pi \ N \rightarrow N N \ \& \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ \pi \ N \rightarrow N \pi \pi \\ \hline \\ \underline{COMMENT} \\ \hline \\ \underline{COMMENT} \\ \hline \\ \underline{Multichannel} \\ \underline{COMMENT} \\ \hline \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ \underline{Multichannel} \\ Multichanne$ | Nππ Γ ₁₁ / Γ ₁₂) ^{1/2} / Νππ Γ ₁₂ / Νππ Γ ₁₂ / Νππ |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet ТНОМА

08 DPWA Multichannel

Baryon Particle Listings N(1680), N(1685), N(1700)

N(1680) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 1 (2006).

$N(1680) ightarrow ho \gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV - 1/2) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|------------------|----------|-------------|------------------------------|
| -0.015 ± 0.006 OUR ESTIMATE | | | | |
| -0.013 ± 0.003 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.017 ± 0.001 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.010 ± 0.004 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.017 ± 0.018 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.009 ± 0.006 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| | data for average | es, fits | , limits, e | etc. • • • |
| -0.012 ± 0.006 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.025 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.006 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

$N(1680) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN COMMENT |
|-------------------------------------------|------------------|---------|-----------------------------------|
| +0.133±0.012 OUR ESTIMATE | | | |
| 0.135 ± 0.006 | ANISOVICH | 12A | DPWA Multichannel |
| 0.134 ± 0.002 | DUGGER | 07 | DPWA $\gamma N \rightarrow \pi N$ |
| 0.145 ± 0.005 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 0.132 ± 0.010 | CRAWFORD | 83 | IPWA $\gamma N \rightarrow \pi N$ |
| 0.115 ± 0.008 | AWA JI | 81 | DPWA $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 0.136 ± 0.012 | ANISOVICH | 10 | DPWA Multichannel |
| 0.134 | DRECHSEL | 07 | DPWA $\gamma N \rightarrow \pi N$ |
| 0.154 ± 0.002 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ |

$N(1680) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV -1/2) | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------|-------------------------|----------|-----------|------------------------------|--|
| +0.029±0.010 OUR ESTIN | MATE | | | | |
| 0.030 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.017 ± 0.014 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.032 ± 0.003 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| • • • We do not use the fo | llowing data for averag | es, fits | , limits, | etc. • • • | |
| 0.028 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.022 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |

$N(1680) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------------|----------|-----------|------------------------------|
| -0.033±0.009 OUR ESTIMATI | • | | | |
| -0.040 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.033 ± 0.013 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.023 ± 0.005 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | ng data for averag | es, fits | , limits, | etc. • • • |
| -0.038 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.048 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

N(1680) FOOTNOTES

- 1 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ² From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- 3 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 4 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- ⁵ LONGACRE 77 considers this coupling to be well determined.

ANISOVICH 12A EPI A48 15

N(1680) REFERENCES

For early references, see Physics Letters **111B** 1 (1982). For very early references, see Reviews of Modern Physics **37** 633 (1965).

A.V. Anisovich et al.

(RONN PNPI)

| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|----|--------------------|-------------------------------------------|-----------------|
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| THOMA | 80 | PL B65987 | U. Thoma et al. (CE | 3-ELSA Čollab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jefferson Lai | CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | ` (PITT+) |
| TIATOR | 99 | PR C60 035210 | L. Tiator et al. | . , |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workman | (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | `(VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KĖNT) IJI |
| Also | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| | | | | |

| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
|----------|----|------------------|----------------------------|-------------------|
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| FUJII | 81 | NP B187 53 | K. Fujii et al. | (NAGO, OSAK) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| BAKER | 79 | NP B156 93 | R.D. Baker et al. | (RHEL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | | | |

N(1685) ?[?]

 $I(J^P) = \frac{1}{2}(??)$ Status: *

OMITTED FROM SUMMARY TABLE

There is a small literature (which we do not try to cover) on this possible narrow state. See KUZNETSOV 11A, MART 11, and the other papers for further references. This state does not gain status by being a sought-after member of a baryon anti-decuplet.

N(1685) MASS

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------|--------------|------|--------------------------------------|
| ~ 1670 | JA EGLE 11 | CBTP | $\gamma d \rightarrow \eta n (\rho)$ |
| ~ 1685 | KUZNETSOV 11 | GRAL | $\gamma d \rightarrow \gamma n(p)$ |
| ~ 1680 | KUZNETSOV 07 | GRAL | $\gamma d \rightarrow \eta n (\rho)$ |

N(1685) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------|-------------------------------|------------|------------------------------------|
| ~ 25 | JA EGLE 11 | CBTP | $\gamma d \rightarrow \eta n (p)$ |
| | owing data for averages, fits | s, limits, | etc. • • • |
| < 30 | KUZNETSOV 11 | GRAL | $\gamma d \rightarrow \gamma n(p)$ |
| < 30 | KUZNETSOV 07 | GRAI | $\alpha d \rightarrow nn(n)$ |

N(1685) REFERENCES

| | 11 | EPJ A47 89 | I. Jaegle et al. | (CBELSA/TAPS Collab.) |
|-----------|-----|----------------|------------------------------|-----------------------|
| A Iso | | PRL 100 252002 | I. Jaegle et al. | (CBELSA/TAPS Collab.) |
| KUZNETSOV | 11 | PR C83 022201 | V. Kuznetsov et al. | (GRAAL Collab.) |
| KUZNETSOV | 11A | JETPL 94 503 | V. Kuznetsov, M.V. Polyakov, | |
| MART | 11 | PR D83 094015 | T. Mart | (U. Indonesia) |
| KUZNETSOV | 07 | PL B647 23 | V. Kuznetsov et al. | (GRAAL Collab.) |

$N(1700) 3/2^{-}$

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$
 Status: ***

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The various partial-wave analyses do not agree very well.

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1700) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-------------------------------|---------|-------------|----------------------------------------|
| 1650 to 1750 (≈ 1700) | OUR ESTIMATE | | | |
| 1790 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 1737 ± 44 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1675 ± 25 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1731 ± 15 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use t | he following data for average | s, fits | , limits, e | etc. • • • |
| 1817 ± 22 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1740 ± 20 | THOMA | 80 | DPWA | Multichannel |
| 1736 ± 33 | VRANA | 00 | DPWA | Multichannel |
| 1650 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1690 to 1710 | BAKER | 78 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1719 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |
| 1670 ± 10 | ¹ BAKER | 77 | IPWA | $\pi^- \rho \rightarrow \Lambda K^0$ |
| 1690 | ¹ BAKER | 77 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1660 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1710 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

/F F 1/2 /F

See key on page 457 N(1700) BREIT-WIGNER WIDTH DOCUMENT ID TECN COMMENT 100 to 250 (≈ 150) OUR ESTIMATE 390 ± 140 ANISOVICH 12A DPWA Multichannel 250 ± 220 MANLEY 92 IPWA $\pi N \rightarrow \pi N \& N \pi \pi$ 90 ± 40 CUTKOSKY IPWA $\pi N \rightarrow \pi N$ $110\pm\ 30$ HOEHLER IPWA $\pi N \rightarrow \pi N$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet DPWA $\pi N \rightarrow N \pi$, $N \eta$ 134 ± 37 BATINIC 10 180 + 30THOMA 08 DPWA Multichannel DPWA Multichannel 175 ± 133 VRA NA 00 70 SAXON 80 DPWA $\pi^- p \rightarrow \Lambda K^0$ BAKER DPWA $\pi^- p \rightarrow \Lambda K^0$ 70 to 100 78 126 BARBOUR DPWA $\gamma N \rightarrow \pi N$ 78 $^{\mathrm{1}}$ baker IPWA $\pi^- p \rightarrow \Lambda K^0$ 90± 25 77 ¹ BAKER DPWA $\pi^- p \rightarrow \Lambda K^0$ 100 77 ²LONGACRE 600 77 IPWA $\pi N \rightarrow N \pi \pi$ 300 ³ LONGACRE 75 IPWA $\pi N \rightarrow N \pi \pi$ N(1700) POLE POSITION **REAL PART** DOCUMENT ID TECN COMMENT 1650 to 1750 (≈ 1700) OUR ESTIMATE 1770 ± 40 A NISOVICH 4 HOEHLER DPWA Multichannel 1700 93 SPED $\pi N \rightarrow \pi N$ CUTKOSKY IPWA $\pi N \rightarrow \pi N$ 1660 ± 30 80 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet 1806 ± 23 BATINIC DPWA $\pi N \rightarrow N\pi$, $N\eta$ ı 10 THOMA DPWA Multichannel 1710 ± 15 1704 VRANA 00 DPWA Multichannel ARNDT 91 DPWA $\pi N \rightarrow \pi N \; \mathrm{Soln} \; \mathrm{SM90}$ 1710 or 1678 ⁵ LONGACRE 78 IPWA $\pi N \rightarrow N \pi \pi$ ²LONGACRE 1616 or 1613 77 IPWA $\pi N \rightarrow N \pi \pi$ -2×IMAGINARY PART DOCUMENT ID TECN COMMENT 100 to 300 OUR ESTIMATE DPWA Multichannel ANISOVICH 420 ± 180 ⁴ HOEHLER 93 $\mathsf{SPED} \quad \pi \: \mathsf{N} \: \to \: \pi \: \mathsf{N}$ CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 129± 33 BATINIC 10 DPWA $\pi N \rightarrow N \pi$, $N \eta$ 155 ± 25 THOMA 08 DPWA Multichannel VRANA DPWA Multichannel not seen ARNDT 91 DPWA $\pi N \rightarrow \pi N \text{ Soln SM90}$ 607 or 567 5 LONGACRE $\mathsf{IPWA} \quad \pi \, \mathsf{N} \to \; \mathsf{N} \pi \pi$ ² LONGACRE 577 or 575 77 IPWA $\pi N \rightarrow N \pi \pi$ N(1700) ELASTIC POLE RESIDUE MODULUS |r| VALUE (MeV) DOCUMENT ID TECN COMMENT 5 to 50 OUR ESTIMATE 50 ± 40 ANISOVICH 12A DPWA Multichannel HOEHLER 93 $\mathsf{SPED} \quad \pi \, \mathit{N} \, \to \, \pi \, \mathit{N}$ CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ 6 ± 3 \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

| 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
|--------------------------------------|-------------------|---------|-------------|------------------------------------|
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DOCUMENT ID | | TECN | COMMENT |
| -120 to 20 OUR ESTIMATE | | | | |
| -100 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 0±50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following of | lata for averages | s, fits | , limits, e | etc. • • • |
| - 34 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |

N(1700) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

| Normalized r | esidue in $N\pi \rightarrow$ | $N(1700) \rightarrow \Delta \pi, S$ | wave | | |
|--------------|------------------------------|-------------------------------------|-------|--------------|--|
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 34±21 | -60 ± 40 | ANISOVICH 12A | DPWA | Multichannel | |
| Normalized r | esidue in $N\pi ightarrow$ | $N(1700) \rightarrow \Delta \pi, D$ | -wave | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 8±6 | 90 ± 35 | ANISOVICH 12A | DPWA | Multichannel | |

N(1700) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-------------------------------------------|------------------------------|
| Γ_1 | $N\pi$ | (12 ±5) % |
| Γ_2 | N η | (0.0 ± 1.0) % |
| Γ_3 | ΛK | < 3 % |
| Γ_4 | ΣK | |
| | $N\pi\pi$ | 85-95 % |
| Γ_6 | $\Delta\pi$ | |
| Γ_7 | ${\it \Delta}(1232)\pi$, $\it S$ -wave | 10-90 % |
| Γ ₈ | ${\it \Delta}(1232)\pi$, ${\it D}$ -wave | < 20 % |
| Г9 | $N \rho$ | < 35 % |
| Γ_{10} | $N\rho$, $S=1/2$, D -wave | |
| Γ_{11} | $N\rho$, $S=3/2$, S -wave | (7.0 ± 1.0) % |
| Γ_{12} | $N\rho$, $S=3/2$, D -wave | |
| Γ_{13} | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | |
| Γ_{14} | $p\gamma$ | 0.01-0.05 % |
| Γ_{15} | $p\gamma$, helicity=1/2 | 0.0-0.024 % |
| Γ_{16} | $p\gamma$, helicity=3/2 | 0.002-0.026 % |
| Γ_{17} | $n\gamma$ | 0.01-0.13 % |
| Γ_{18} | $n\gamma$, helicity=1/2 | 0.0-0.09 % |
| Γ_{19} | $n\gamma$, helicity=3/2 | 0.01-0.05 % |

N(1700) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|---------------------------------------------|----------------------------|-----------|-----------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 12±5 OUR ESTIMATE | | | | |
| 12±5 | ANISOVICH | 12A | DPWA | Multichannel |
| 1 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 11±5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 8±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the f | following data for average | es, fits, | limits, e | etc. • • • |
| 9±6 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 8+8-4 | THOMA | 80 | DPWA | Multichannel |
| 4 ± 2 | VRANA | 00 | DPWA | Multichannel |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | Γ ₂ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 0±1 | VRANA | 00 | DPWA | Multichannel |
| • • • We do not use the f | following data for average | es, fits, | limits, | etc. • • • |
| 14±5 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 10±5 | THOMA | 80 | DPWA | Multichannel |
| | | | | |

| $(i f)^2/ total II N\pi$ | $\rightarrow N(1700) \rightarrow \Lambda K$ | | | (1 3)"/ |
|-------------------------------------------|---------------------------------------------|----------|-----------|-----------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.06 to +0.04 OUR E | STIMATE | | | |
| -0.012 | BELL | 83 | | $\pi^- p \rightarrow \Lambda K^0$ |
| -0.012 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| ● ● We do not use the | following data for averag | es, fits | , limits, | etc. • • • |
| -0.04 | ⁶ BAKER | 78 | DPWA | See SAXON 80 |
| -0.03 ± 0.004 | ¹ BAKER | 77 | IPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| -0.03 | ¹ BAKER | 77 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| $+0.026\pm0.019$ | DEVENISH | 74B | | Fixed-t dispersion rel. |
| | | | | - 4 |

/F F 1/2/F

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N$: | (Γ ₁ Γ ₄) ^{1/2} /Γ | | | |
|-----------------------------------------------------------------------------|----------------------------------------------------|-------|-----------|------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use th | ne following data for averages, | fits, | , limits, | etc. • • • |
| not seen | | 30 | DPWA | $\pi p \rightarrow \Sigma K$ |
| < 0.017 | ⁷ DEANS | 75 | DPWA | $\pi N \rightarrow \Sigma K$ |

Note: Signs of couplings from $\pi N \to N\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)~s_{31}$ coupling to $\Delta(1232)~\pi$.

| $(\Gamma_i \Gamma_f)^2 / \Gamma_{\text{total}} \text{ in } N\pi \to \Lambda$ | $I(1700) \rightarrow \Delta(123)$ | 2)π, | S-wave | (Γ ₁ Γ ₇) ^{/2} /Γ |
|------------------------------------------------------------------------------|-----------------------------------|---------|-------------|---------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.02\pm0.03$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.00 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -0.16 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, S$ -wave)/ Γ_{to} | tai | | | Γ ₇ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 10 to 90 OUR ESTIMATE | | | | |
| 72 ± 23 | ANISOVICH | 12A | DPWA | Multichannel |
| 11 ± 1 | VRANA | 00 | DPWA | Multichannel |
| • • • We do not use the follow | ving data for average | s, fits | , limits, e | etc. • • • |

THOMA

08 DPWA Multichannel

Baryon Particle Listings N(1700) N(1710)

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to N$ | $(1700) \rightarrow \Delta(123)$ $DOCUMENT ID$ | 32)π, | D-wave | e (Γ : | ıΓ8) ¹ ⁄⁄⁄/[|
|-------------------------------------------------------------------------------------------------------------|------------------------------------------------|---------------|---------------------|-------------------------------|-----------------------------------|
| $+0.10 \pm 0.09$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N &$ | Νππ |
| -0.12 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| +0.14 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $\Gamma(\Delta(1232)\pi, D$ -wave $)/\Gamma_{ m to}$ | tal | | | | Г8/Г |
| ALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| <20 OUR ESTIMATE | | | D D | | |
| <10 | ANISOVICH | | | Multichannel | |
| 79±56 • • We do not use the follow | VRANA | 00 es fits | | Multichannel | |
| 20±11 | THOMA | 08 | | Multichannel | |
| $\left(\Gamma_i \Gamma_f\right)^{1/2} / \Gamma_{	ext{total}} \ 	ext{in} \ \mathcal{N} \pi 	o \mathcal{N}$ | (1700) . N . G | -2/2 | C | . /г | Г ₁₁) ^½ /Г |
| ALUE | DO CUMENT ID |)=3/2 | , J-W av | COMMENT | '11)'-/' |
| ±0.01 to ±0.13 OUR E | | | | | |
| -0.04 ± 0.06 | MANLEY | 92 | IPWA | | . Νππ |
| - 0.07 | ² LONGACRE ³ LONGACRE | | | | |
| +0.07 | OLONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $(N\rho, S=3/2, S-wave)/\Gamma_{to}$ | | | | | Γ ₁₁ /Γ |
| /ALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| '±1 | VRA NA | 00 | DPWA | Multichannel | |
| $\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to N$ | (1700) → N(ππ | r)/=0 | | (Γ ₁ | Г ₁₃) ^½ /Г |
| ALUE | DO CUMENT ID | | TECN | COMMENT | |
| ±0.02 to ±0.28 OUR E | | | | | |
| $+0.02\pm0.02$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N &$ | $V N \pi \pi$ |
| 0.00 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| - 0.2 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{\text{total}}$ | | | | | Γ_{13}/Γ_{13} |
| /ALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 0± 1 | VRA NA | 00 | | Multichannel | |
| • • We do not use the follow | ing data for averag | es, fits | , limits, | etc. • • • | |
| .8±12 | THOMA | 80 | DPWA | Multichannel | |
| N(1700) | PHOTON DECA | YAM | PLITU | DES | |
| Papers on γ N amplitudes γ Journal of Physics, G | les predating 1981 n | | | | ١, |
| $V(1700) ightarrow ho\gamma$, helicity-1 | , , | - | | | |
| | , | /2 | | | |
| | | - | | | |
| ALUE (GeV ^{-1/2}) -0.018±0.013 OUR ESTIMAT | <u>DO CUMENT ID</u> | | TECN | COMMENT | |

| VALUE (GeV-1/2) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|---------|-----------|------------------------------|
| -0.018 ± 0.013 OUR ESTIMATE | | | | |
| 0.041 ± 0.017 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.016 ± 0.014 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.002 ± 0.013 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| -0.033 ± 0.021 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |

$N(1700) \rightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|------------------------------|
| -0.002±0.024 OUR ESTIMATE | | | | |
| -0.034 ± 0.013 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.009 ± 0.012 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.029 ± 0.014 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, e | etc. • • • |
| -0.014 ± 0.025 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |

$\mathit{N}(1700) ightarrow \mathit{n}\gamma$, helicity-1/2 amplitude $\mathrm{A}_{1/2}$

| VALUE (GeV 1/2) | DO CUMENT ID | | I E CN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|------------------------------|
| 0.000 ± 0.050 OUR ESTIMATE | | | | |
| 0.006 ± 0.024 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.002 ± 0.013 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, e | etc. • • • |
| $+0.050\pm0.042$ | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |

$N(1700) \rightarrow n\gamma$, helicity-3/2 amplitude A_{3/2}

| | -, | _ | | |
|-----------------------------------|------------------|---------|-------------|------------------------------|
| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
| -0.003±0.044 OUR ESTIMATE | | | | |
| -0.033 ± 0.017 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.018 ± 0.018 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| $+0.035\pm0.030$ | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

$\gamma p \rightarrow \Lambda K^+ \text{ AMPLITUDES}$ N(1700)

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow$ | (E ₂ _ amplitude) | |
|--------------------------------------------------------------------------------------|--------------------------------|----------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TECN |
| • • • We do not use the foll | lowing data for averages, fits | , limits, etc. • • • |
| 4.09 | TANABE 89 | DPWA |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow N($ | (M ₂ _ amplitude) | | | | | |
|-------------------------------------------------------------------------------------------------|------------------------------|--------------------------------------|--|--|--|--|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TECN | | | | |
| ullet $ullet$ We do not use the following | g data for averages, fits | s, limits, etc. • • • | | | | |
| -7.09 | TANABE 89 | DPWA | | | | |
| $p\gamma \to N(1700) \to \Lambda K^+$ phase angle θ (E_{2-} amplitude) | | | | | | |
| $p\gamma \rightarrow N(1700) \rightarrow \Lambda K^+ ph$ | hase angle $	heta$ | $(E_{2-} \text{ amplitude})$ | | | | |
| $p\gamma \rightarrow N(1700) \rightarrow \Lambda K^+ \text{ ph}$ VALUE (degrees) | nase angle 0 | (<i>E</i> ₂ _ amplitude) | | | | |
| | DO CUMENT ID | <u>TECN</u> | | | | |
| VALUE (degrees) | DO CUMENT ID | <u>TECN</u> | | | | |

N(1700) FOOTNOTES

- $^{
 m 1}\,{
 m The}$ two BAKER 77 entries are from an IPWA using the Barrelet-zero method and from
- The two BACLAY reinters are from an IFVM using the Barrietz-zero method and from a conventional energy-dependent analysis. **2LONGACRE 77** pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes. **3** From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- amplitudes.

 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters. of N and \(\Delta\) resonances as determined from Argand diagrams of \(\tilde{N}\) N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. \(\frac{5}{2}\) LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first
- (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- ⁶ The overall phase of BAKER 78 couplings has been changed to agree with previous
- $^{7}\,\mathrm{Conventions.}$ $^{7}\,\mathrm{The\ range\ given\ is\ from\ the\ four\ best\ solutions.}$

N(1700) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

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|-----------|------|--------------------|-----------------------------------------|-------------------|-----|
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) | |
| THOMA | 08 | PL B659 87 | U. Thoma et al. | (CB-ELSA Collab.) | |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) | |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) | |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | ` (PITT+) | |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | `(KARL) | |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) | IJР |
| Also | | PR D30 904 | D.M. Manley et al. | ` (VPI) | |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) | IJР |
| TANABE | 89 | PR C39 741 | H. Tanabe, M. Kohno, C. Bennhold | (MANZ) | |
| Also | | NC 102A 193 | M. Kohno, H. Tanabe, C. Bennhold | (MANZ) | |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | ` (RL) | IJР |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) | |
| PDG | 82 | PL 111B 1 | | (HELS, CIT, CERN) | |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) | |
| Also | | NP B197 365 | K. Fujii et al. | ÌNAGOÌ | |
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| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | ` (KARLT) | |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) | |
| BAKER | 78 | NP B141 29 | R.D. Baker et al. | (RL, CAVE) | IJР |
| BARBOUR | 78 | NP B141 253 | I.M. Barbour, R.L. Crawford, N.H. Parso | | |
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| DEANS | 75 | NP B96 90 | S.R. Deans et al. | (SFLA, ALAH) | |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) | |
| DEVENISH | 74 B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt, B.R. M | | |
| | | | | | |

N(1710) 1/2

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1710) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | |
|-----------------------|-------------------------------|---------|-----------|----------------------------------------|--|--|
| 1680 to 1740 (≈ 1710) | OUR ESTIMATE | | | | | |
| 1710 ± 20 | ANISOVICH | 12A | DPWA | Multichannel | | |
| 1717 ± 28 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ | | |
| 1700 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | | |
| 1723 ± 9 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | | |
| • • • We do not use t | he following data for average | s, fits | limits, e | etc. • • • | | |
| 1725 ± 25 | ANISOVICH | 10 | DPWA | Multichannel | | |
| 1729 ± 16 | ¹ BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ | | |
| 1752± 3 | PENNER | 02c | DPWA | Multichannel | | |
| 1699 ± 65 | VRANA | 00 | DPWA | Multichannel | | |
| 1720 ± 10 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | | |
| 1706 | CUTKOSKY | 90 | IPWA | $\pi N \rightarrow \pi N$ | | |
| 1730 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ | | |
| 1720 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | | |
| 710 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ | | |

 Γ_1/Γ

 Γ_2/Γ

Гз/Г

 Γ_4/Γ

 Γ_5/Γ

DOCUMENT ID TECN COMMENT

ANISOVICH 12A DPWA Multichannel

| N(17 | '10) BREIT-WIGI | NER WIE | TH | | | | $N(1710) \rightarrow I$ | | | |
|--------------------------------|------------------------------------------------|---------------|-----------------------------------------------------------------------------|------------------------------------|-----------------------------------|---------------------------------|--------------------------------|-----------|--------------------------|----------------------------------------------------------|
| /ALUE (MeV) | DO CUMENT ID | TE | CN COMMENT | <u>модица</u> 17±6 | | <u>SE (°)</u> 10 ± 20 | <u>DO CUMENT</u> A NISOVICE | | | N <u>COMMENT</u> WA Multichannel |
| 50 to 250 (≈ 100) OUR EST | | 40 00 | | . — | | | | | | |
| 200± 18 | ANISOVICH | | WA Multichannel | | | N(17 | 10) DECAY N | MOD | ES | |
| 180±230 93± 30 | MA NLEY CUT KOSKY | | $NA \pi N \rightarrow \pi N \& N \pi \pi$ $NA \pi N \rightarrow \pi N$ | | The fellowin | | | | | £ |
| 90± 30 | CUTKOSKY | | $NA \pi N \rightarrow \pi N$ $NA \pi N \rightarrow \pi N$ | | The followin | ig branching fra | ctions are our e | sumau | es, not | nts or averages. |
| .20 ± 15 | HOEHLER | | $NA \pi N \rightarrow \pi N$ | | Mada | | | Eract: | on /F /F | ۲) |
| • • We do not use the follow | | | | | Mode | | | Fractio | on (Γ_i/Γ_i) | 1 |
| 200± 35 | ANISOVICH | | WA Multichannel | Γ_1 | $N\pi$ | | | 5-20 9 | % | |
| 180± 17 | $^{ m 1}$ BATINIC | 10 DF | WA $\pi N \rightarrow N\pi$, $N\eta$ | Γ_2 | $N \eta$ | | | 10-30 | % | |
| 386± 59 | PENNER | 02c DF | WA Multichannel | - Г3 | $N \omega$ | | | (13.0: | ±2.0) % | |
| 43±100 | VRA NA | | WA Multichannel | Γ_4 | ΛK | | | 5-25 | % | |
| 105 ± 10 | ARNDT | | $NA \gamma N \rightarrow \pi N$ | Γ_5 | ΣΚ | | | | | |
| 540 | BELL | | WA $\pi^- p \rightarrow \Lambda K^0$ WA $\pi^- p \rightarrow \Lambda K^0$ | Γ ₆ | $N \pi \pi$ | | | 40-90 | % | |
| 550 120 | SAXON ² LONGACRE | | | Γ ₇ | $\Delta \pi$ | | | 15-40 | % | |
| 75 | 3 LONGACRE | | $NA \pi N \rightarrow N \pi \pi$ $NA \pi N \rightarrow N \pi \pi$ | Γ ₈ | Δ (123) | 2) π , P -wave | | | | |
| 7.5 | LONGMENE | 75 11 | 1471 X 14 7 14 X X | Γ ₉ | $N \rho$ | , | | 5-25 | % | |
| 1 | /(1710) POLE P | OSITION | | Γ ₁₀ | | =1/2, <i>P</i> -wave | | | | |
| REAL PART | | | | Γ ₁₁ Γ ₁₂ | $N \rho, S = N (\pi \pi)_{S}^{I}$ | =3/2, <i>P</i> -wav∈ :0 | | 10-40 | % | |
| ALUE (MeV) | DO CUMENT ID | TE | CN COMMENT | _ | $p\gamma$ | wave | | | -0.08 % | |
| .670 to 1770 (≈ 1720) OUR E | | | | Γ ₁₄ | $p\gamma$ $p\gamma$, helici | itv=1/2 | | | -0.08 % | |
| 1687 ± 17 | ANISOVICH | | WA Multichannel | _ | | 1.5 — 1/2 | | 0.002- | | |
| 1690 | 4 HOEHLER | | ED $\pi N \rightarrow \pi N$ | _** | $n\gamma$ $n\gamma$, helici | ity-1/2 | | 0.0-0. | | |
| .698 .690 ± 20 | CUT KOSKY CUT KOSKY | | $NA \pi N \rightarrow \pi N$ $NA \pi N \rightarrow \pi N$ | Γ ₁₆ | π·γ, nenci | ity = 1 / 2 | | 0.0-0. | .0276 | |
| • • • We do not use the follow | | | | | | N/1710) | DDANCHIN | C DA | TIOS | |
| 1708±18 | | | WA Multichannel | | | W(1710) | BRANCHIN | G KA | 1103 | |
| 1708 ± 18 1711 ± 15 | A NISOVICH 1 BATINIC | | WA $\pi N \rightarrow N\pi$, $N\eta$ | | | | | | | |
| 1679 | VRA NA | | WA Multichannel | • Γ(Nπ |)/F _{total} | | | | | |
| 1770 | ARNDT | | WA $\pi N \rightarrow N \pi$ | VALUE (| | | DOCUMENT ID | | TECN | COMMENT |
| 636 | ARNDT | 91 DF | WA $\pi N \rightarrow \pi N$ Soln SM90 | | O OUR ESTIN | MATE | | | | |
| 708 or 1712 | ⁵ LONGACRE | 78 IP | $NA \pi N \rightarrow N \pi \pi$ | 5 ± 4 | | | ANISOVICH | 12A 92 | | Multichannel |
| .720 or 1711 | ² LONGACRE | 77 IP | $NA \pi N \rightarrow N \pi \pi$ | 9± 4 20± 4 | | | MANLEY CUTKOSKY | 92 80 | | $\pi N \rightarrow \pi N \& N$ $\pi N \rightarrow \pi N$ |
| -2×IMAGINARY PART | | | | 12± 4 | | | HOEHLER | 79 | | $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ |
| ALUE (MeV) | DOCUMENT ID | TF | CN COMMENT | | We do not use | the following o | lata for average | | | |
| 80 to 380 (≈ 230) OUR EST | | | COMMENT | 12± 6 | | | ANISOVICH | 10 | | Multichannel |
| 200±25 | ANISOVICH | 124 DE | WA Multichannel | 22±24 | | 1 | BATINIC | 10 | | $\pi N \rightarrow N\pi, N\eta$ |
| 200 | 4 HOEHLER | | ED $\pi N \rightarrow \pi N$ | 14 ± 8 | | | PENNER | | | Multichannel |
| 88 | CUTKOSKY | | $NA \pi N \rightarrow \pi N$ | 27±13 | | | VRANA | 00 | | Multichannel |
| 80 ± 20 | CUTKOSKY | 80 IP | $NA \pi N \rightarrow \pi N$ | | | | | | | |
| • • We do not use the follow | ving data for averag | es, fits, lim | its, etc. • • • | $\Gamma(N\eta)$ |)/Γ _{total} | | | | | |
| 200±20 | ANISOVICH | 10 DF | WA Multichannel | VALUE (| | | DOCUMENT ID | | TECN | COMMENT |
| 174 ± 16 | $^{ m 1}$ BATINIC | | WA π N \rightarrow N π , N η | | O OUR ESTIN | MATE | | | | |
| 132 | VRA NA | | WA Multichannel | 17±10 | | | ANISOVICH | 12A | | Multichannel |
| 378 | ARNDT | | WA $\pi N \rightarrow N \pi$ | 36±11 6± 1 | | | PENNER VRANA | 020 | | Multichannel Multichannel |
| 17 00 | ARNDT | | WA $\pi N \rightarrow \pi N$ Soln SM90 | | We do not use | the following o | lata for average: | | | |
| 17 or 22 23 or 115 | ⁵ LONGACRE ² LONGACRE | | $NA \pi N \rightarrow N \pi \pi$ $NA \pi N \rightarrow N \pi \pi$ | | | | BATINIC | | | |
| 123 OF 115 | - LONGACRE | // IP | $NA \pi N \rightarrow N \pi \pi$ | 6± 8 | | - | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| N/17 | IN ELASTIC DO | I E DECI | DITE | $\Gamma(N\omega)$ |)/F _{total} | | | | | |
| 14(17 | 10) ELASTIC PO | LE RESI | DUE | VALUE (| | | DOCUMENT ID | | TECN | COMMENT |
| MODULUS r | | | | 13±2 | , | , | PENNER | 02c | | Multichannel |
| /ALUE (MeV) | DO CUMENT ID | TE | CN COMMENT | _ | | | | | | |
| 6±4 | ANISOVICH | | WA Multichannel | (F.F.A) | ½/Г in | $N\pi \rightarrow N(17)$ | $(0) \rightarrow AK$ | | | (Γ ₁ Γ ₄ |
| 15 | HOEHLER | | ED $\pi N \rightarrow \pi N$ | VALUE | , , , total | (21. | DOCUMENT ID | | TECN | COMMENT |
| 9 | CUTKOSKY | 90 IP | $NA \pi N \rightarrow \pi N$ | | to +0.18 OUI | R ESTIMATE | | | | |
| 8 ± 2 | CUTKOSKY | 80 IP | $NA \pi N \rightarrow \pi N$ | +0.16 | | | BELL | 83 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| • • We do not use the follow | ving data for averag | es, fits, lim | its, etc. • • • | +0.14 | | | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 24 | $^{ m 1}$ BATINIC | 10 DF | WA $\pi N \rightarrow N\pi$, $N\eta$ | | · | | | | | |
| 37 | ARNDT | 95 DF | WA $\pi N \rightarrow N \pi$ | - Γ(Λ <i>K</i> |)/F _{total} | | | | | |
| 49 | ARNDT | 91 DF | WA $\pi N \rightarrow \pi N$ Soln SM90 | VALUE (| | | DOCUMENT ID | | TECN | COMMENT |
| DUACE A | | | | | 5 OUR ESTIN | MATE | A NUC 03 // =:: | | D.D | NA DECEMBER |
| PHASE 0 /ALUE (°) | DO CUMENT ID | TE | CN COMMENT | 23± 7 | | | ANISOVICH | 12A | | Multichannel |
| 120±70 | A NISOVICH | | 'WA Multichannel | 5 ± 3 5 ± 2 | | | SHKLYAR PENNER | 05 02c | | Multichannel Multichannel |
| -120±70 -167 | CUTKOSKY | | $NA \pi N \rightarrow \pi N$ | 10±10 | | | VRANA | 020 | | Multichannel |
| 175 ± 35 | CUTKOSKY | | $NA \pi N \rightarrow \pi N$ $NA \pi N \rightarrow \pi N$ | 10 ± 10 | | | *11/11/04 | 50 | DI WA | .viaiticii aiiii Ci |
| • • We do not use the follow | | | | Γ(ΣΚ | ()/Γ _{total} | | | | | |
| 20 | ¹ BATINIC | | WA $\pi N \rightarrow N\pi$, $N\eta$ | VALUE (| | | DOCUMENT ID | | TECN | COMMENT |
| -167 | ARNDT | | WA $\pi N \rightarrow N \pi$, $N \eta$ | | | the following o | lata for average | s, fits | | |
| | ARNDT | | WA $\pi N \rightarrow \pi N$ Soln SM90 | 7±7 | 1101 450 | | PENNER | | | Multichannel |
| 149 | | | | | | | | | | |

Baryon Particle Listings N(1710), N(1720)

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to \infty$ | (Γ ₁ Γ ₅) ^½ /Γ | |
|---------------------------------------------------------------------------------|--------------------------------------------------|----------------------------------|
| VALUE | DO CUMENT ID | TECN COMMENT |
| • • • We do not use the follo | wing data for averages, fit | s, limits, etc. • • • |
| -0.034 | LIVANOS 80 | DPWA $\pi p ightarrow \Sigma K$ |

Note: Signs of couplings from $\pi\,{\it N} \to {\it N}\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$.

| coupling to $\Delta(1232)\pi$ | | | | |
|----------------------------------------------------------------------------------------------|------------------------------------------------|----------|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(1)$ | 710) → △(123 | | | · (Γ ₁ Γ ₈) ^{1/2} /Γ |
| ±0.16 to ±0.22 OUR EST | MATE | | 7 2 0.1 | COMMENT |
| -0.21 ± 0.04 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| -0.17 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.20 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, P$ -wave $)/\Gamma_{total}$ | | | | Г ₈ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 39±8 | VRA NA | 00 | DPWA | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(1)$ | 710) → Nρ, S | =1/2 | , <i>P</i> -wav | $(\Gamma_1\Gamma_{10})^{\frac{1}{2}}/\Gamma$ |
| ±0.09 to ±0.19 OUR EST | MATE | | IECN | COMMENT |
| + 0.05 ± 0.06 | | 92 | ΙΡΙΛΙΔ | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| +0.19 | MANLEY ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -0.20 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(N\rho, S=1/2, P-wave)/\Gamma_{tota}$ | I DOCUMENT ID | | TECN | Γ ₁₀ /Γ |
| 17±1 | VRA NA | 00 | | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | 710) → Nρ, S: DOCUMENT ID LONGACRE | =3/2 | , P -wav | e (Г ₁ Г ₁₁) ¹ //_/Г |
| +0.31 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(1)$ VALUE | DO CUMENT ID | | | $(\Gamma_1\Gamma_{12})^{\frac{1}{2}}/\Gamma$ |
| ±0.14 to ±0.22 OUR EST | MATE | | | |
| $+0.04\pm0.05$ | MANIEV | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.04 ± 0.00 | IVIAINEEI | 92 | | |
| -0.26 | MANLEY 2 LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| . – | ² LONGACRE ³ LONGACRE | 77 75 | | $\begin{array}{ccc} \pi \ {\cal N} \ \longrightarrow & {\cal N} \pi \pi \\ \pi \ {\cal N} \ \longrightarrow & {\cal N} \pi \pi \end{array}$ |
| -0.26 -0.28 $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{\text{total}}$ | ³ LONGACRE | | IPWA IPWA | $\pi N \rightarrow N \pi \pi$ Γ_{12}/Γ |
| - 0.26 - 0.28 | | | IPWA IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1710) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006).

$N(1710) ightarrow ho \gamma$, helicity-1/2 amplitude ${ m A}_{1/2}$

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|-------------------|----------|-------------|------------------------------|
| 0.024 ± 0.010 OUR ESTIMATE | | | | |
| 0.052 ± 0.015 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.007 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.006 ± 0.018 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.028 ± 0.009 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| \bullet \bullet We do not use the following | data for averages | s, fits, | , limits, e | etc. • • • |
| 0.025 ± 0.010 | ANISOVICH | 10 | DPWA | Multichannel |
| 0.044 | PENNER | 02D | DPWA | Multichannel |
| -0.037 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| N/(1710) . no belicity 1/2 : | molitude A | | | |

$N(1710) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|------------------------------|
| -0.002±0.014 OUR ESTIMATE | | | | |
| -0.002 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.000 ± 0.018 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.001 ± 0.003 | FUJII | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | lata for averages | , fits, | limits, e | etc. • • • |
| -0.024 | PENNER | 02D | DPWA | Multichannel |
| 0.052 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

N(1710) $\gamma p \rightarrow \Lambda K^+ \text{ AMPLITUDES}$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow$ | (M_{1-} amplitude) | | |
|----------------------------------------------------------------------------------------------|---------------------------|-------------------|-------|
| VALUE (units 10^{-3}) | DO CUMENT ID | TECN | |
| • • • We do not use the follo | wing data for averages, f | its, limits, etc. | • • • |
| -10.6 ± 0.4 | WORKMAN 9 | DPWA | |
| - 7.21 | TA NABE 8 | DPWA | |

| $p\gamma \rightarrow N(1710) \rightarrow \Lambda K^{+}$ | phase angle $	heta$ | | | $(M_{1-}$ amplitude) |
|---------------------------------------------------------|-----------------------|---------|---------------|----------------------|
| VALUE (degrees) | DO CUMENT ID | | TECN | |
| • • • We do not use the follow | wing data for average | s, fits | , limits, etc | • • • |
| 215 ±3 | WORKMAN | 90 | DPWA | |
| 176.3 | TANABE | 89 | DPWA | |

N(1710) FOOTNOTES

 1 BATINIC 10 finds evidence for a second P_{11} state with all parameters except for the phase of the pole residue very similar to the parameters we give here. 2 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N - N\pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

³From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix

4 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. 5 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first

(second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

N(1710) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|------------|------|-------------------|-----------------------------------------|-------------------|
| ANIS OVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| SHKLYAR | 05 | PR C72 015210 | V. Shklyar, H. Lenske, U. Mosel | (GIES) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workr | |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÉNT) IJP |
| A Iso | | PR D30 904 | D.M. Manley et al. | (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt <i>et al</i> . | (VPI, TELE) IJP |
| CUTKOSKY | 90 | PR D42 235 | R.E. Cutkosky, S. Wang | ` (CMU) |
| WORKMAN | 90 | PR C42 781 | R.L. Workman | `(VPI) |
| TANABE | 89 | PR C39 741 | H. Tanabe, M. Kohno, C. Bennhold | (MÀNZ) |
| A Iso | | NC 102A 193 | M. Kohno, H. Tanabe, C. Bennhold | (MANZ) |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | ` (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| FUJII | 81 | NP B187 53 | K. Fujii et al. | (NAGO, OSAK) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Čutkosky et al. | ` (CMU, LBL)IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| LIVANOS | 80 | Toronto Conf. 35 | P. Livanos et al. | (SACL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | ` (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT)IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |

N(1720) 3/2

 $I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

N(1720) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 1700 to 1750 (≈ 1720) OUR ES | TIMATE | | | |
| 1690 + 70 - 35 | ANISOVICH | 12A | DPWA | Multichannel |
| 1763.8± 4.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1717 ± 31 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1700 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1710 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | g data for average | s, fits | , limits, e | etc. • • • |
| 1770 ±100 | ANISOVICH | 10 | DPWA | Multichannel |
| 1720 ± 18 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| 1790 ±100 | THOMA | 80 | DPWA | Multichannel |
| 1749.6± 4.5 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1705 ± 10 | PENNER | 02c | DPWA | Multichannel |
| 1716 ±112 | VRANA | 00 | DPWA | Multichannel |
| 1713 ± 10 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1820 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1720 | LI | 93 | IPWA | |
| 1690 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 1750 | $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1720 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

TECN COMMENT

TECN COMMENT

TECN COMMENT

ANISOVICH 12A DPWA Multichannel

ANISOVICH 12A DPWA Multichannel

ANISOVICH 12A DPWA Multichannel

ANISOVICH 12A DPWA Multichannel

15±8 OUR ESTIMATE

 22 ± 8

 8 ± 2

25

15

20

20

39

11

PHASE θ

 -115 ± 30

 -160 ± 30

- 94

-109

- 88

- 70

-130

-130±30 OUR ESTIMATE

| | N(1720) BREIT-WIGN | IER V | VIDTH | |
|--------------------------|--------------------------------|---------------|----------------|--------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 150 to 400 (≈ 250) OUR | ESTIMATE | | | |
| 420 ± 100 | ANISOVICH | | | Multichannel |
| 210± 22 | ARNDT | 06 | | $\pi N \rightarrow \pi N$, ηN |
| 380 ± 180 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 125 ± 70 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 190± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | e following data for average | | | |
| 650±120 | ANISOVICH | 10 | | Multichannel |
| 244 ± 28 | BATINIC | 10 | | $\pi N \rightarrow N\pi, N\eta$ |
| 690±100 | THOMA | 08 | | Multichannel |
| 256± 22 | ARNDT | 04 | | $\pi N \rightarrow \pi N, \eta N$ |
| 237± 73 | PENNER VRA NA | 020 | | Multichannel Multichannel |
| 121 ± 39 153 ± 15 | ARNDT | 96 | IPWA | |
| 354 | ARNDT | 95 | | $ \gamma N \rightarrow \pi N $ $ \pi N \rightarrow N \pi $ |
| 200 | LI LI | 93 | IPWA | $\gamma N \rightarrow N \pi$ $\gamma N \rightarrow \pi N$ |
| 120 | SAXON | 80 | | $\pi^- p \rightarrow \Lambda K^0$ |
| 130 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 150 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| | N/1700) DOLE DO | CITI | ON . | |
| DEAL DADT | N(1720) POLE PO | יוווכע | ON | |
| REAL PART VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 1660 to 1690 (≈ 1675) C | | | | |
| 1660 ± 30 | ANISOVICH | | | Multichannel |
| 1666 | ARNDT | 06 | | $\pi N \rightarrow \pi N, \eta N$ |
| 1686 | 3 HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1680 ± 30 | CUT KOSKY | 80 | IPWA limits | $\pi N \rightarrow \pi N$ |
| | e following data for average | | | |
| 1660 ± 35 | ANISOVICH | 10 | | Multichannel |
| 1691 ± 23 | BATINIC | 10 | | $\pi N \rightarrow N\pi, N\eta$ |
| 1630 ± 90 | THOMA | 08 | | Multichannel |
| 1655 | ARNDT | 04 00 | | $\pi N \rightarrow \pi N$, ηN Multichannel |
| 1692 | VRA NA | 95 | | $\pi N \rightarrow N \pi$ |
| 1717 1675 | ARNDT ARNDT | 91 | | $\pi N \rightarrow N \pi$ $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1716 or 1716 | 4 LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1745 or 1748 | 1 LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ $\pi N \rightarrow N \pi \pi$ |
| -2×IMAGINARY PA | | | | 7 14 7 14 A A |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 150 to 400 (≈ 250) OUR | | 10 | DDM | NA 112 h |
| 450±100 | ANISOVICH | 12A | | Multichannel |
| 355 | ARNDT 3 HOEHLER | 06 | | $\pi N \rightarrow \pi N, \eta N$ |
| 187 | 3 HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 120 ± 40 | CUTKOSKY | 80 se fite | IPWA limits | $\pi N \rightarrow \pi N$ |
| | e following data for average | | | |
| 360± 80 | ANISOVICH | 10 | | Multichannel |
| 233 ± 23 | BATINIC | 10 | | $\pi N \rightarrow N\pi, N\eta$ |
| 460± 80 278 | THOMA | 08 | | Multichannel |
| | ARNDT | 04 | | $\pi N \rightarrow \pi N, \eta N$ Multichannel |
| 94 | VRANA A P N D T | 00 05 | | Multichannel |
| 388 | ARNDT | 95 91 | | $\pi N \rightarrow N \pi$ $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 114 124 or 126 | ARNDT ⁴ LONGACRE | 91 78 | IPWA | $\pi N \rightarrow \pi N$ Soin SM90 $\pi N \rightarrow N \pi \pi$ |
| 135 or 123 | ¹ LONGACRE | 78 77 | IPWA | $\pi N \rightarrow N \pi \pi$ $\pi N \rightarrow N \pi \pi$ |
| 199 OI 129 | LONGACKE | 11 | IF VVA | π iv \rightarrow iv π |
| | N(1720) ELASTIC PO | LE RI | ESIDUE | Ē |
| MODULUS r VALUE (MeV) | DOCUMENT ID | | | |
| | | | TECN | COMMENT |

ANISOVICH

ARNDT

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

HOEHLER

BATINIC

ARNDT

ARNDT

ARNDT

DOCUMENT ID

ANISOVICH

CUTKOSKY

ARNDT

ARNDT

ARNDT

ARNDT

• • • We do not use the following data for averages, fits, limits, etc. • • • BATINIC

CUTKOSKY

93

80

95

06

80

04

95

12A DPWA Multichannel

DPWA $\pi N \rightarrow \pi N$, ηN

DPWA $\pi N \rightarrow N \pi$, $N \eta$

DPWA $\pi N \rightarrow \pi N$, ηN DPWA $\pi N \rightarrow N \pi$

DPWA $\pi\,{\it N} \, \rightarrow \, \pi\,{\it N},\, \eta\,{\it N}$

DPWA π N \rightarrow π N, η N

DPWA $\pi N \rightarrow \pi N$ Soln SM90

VALUE (%)

75 ± 15

IPWA $\pi N \rightarrow \pi N$

10 DPWA $\pi\,{\it N}
ightarrow \,{\it N}\,\pi$, ${\it N}\,\eta$

DPWA $\pi N \rightarrow N \pi$

DPWA $\pi N \rightarrow \pi N \text{ Soln SM90}$

 $\mathsf{SPED} \quad \pi \, \mathit{N} \, \to \, \pi \, \mathit{N}$

IPWA $\pi N \rightarrow \pi N$

TECN COMMENT

12A DPWA Multichannel

Normalized residue in $N\pi \rightarrow N(1720) \rightarrow \Delta\pi$, P-wave

Normalized residue in N $\pi \to N(1720) \to \Delta \pi$, F-wave

N(1720) DECAY MODES The following branching fractions are our estimates, not fits or averages.

DOCUMENT ID

N(1720) INELASTIC POLE RESIDUE

DOCUMENT ID

DOCUMENT ID

DOCUMENT ID

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \rightarrow N(1720) \rightarrow N\eta$

Normalized residue in $N\pi \rightarrow N(1720) \rightarrow \Lambda K$

 -150 ± 45

PHASE (°)

 80 ± 40

3±2

29±8

MODULUS (%) PHASE (°)

| | Mode | Fraction (Γ_i/Γ) |
|-----------------|-----------------------------------|------------------------------|
| Γ_1 | $N\pi$ | (11± 3) % |
| Γ_2 | N η | (4 ± 1) % |
| Γ_3 | ΛK | 1-15 % |
| Γ_4 | ΣΚ | |
| Γ_5 | $N\pi\pi$ | >70 % |
| Γ ₆ | $\Delta\pi$ | |
| Γ_7 | Δ (1232) π , P -wave | (75 ±15) % |
| Γ ₈ | $N \rho$ | 70-85 % |
| Г9 | $N\rho$, $S=1/2$, P -wave | large |
| Γ_{10} | $N\rho$, $S=3/2$, P -wave | |
| Γ_{11} | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | |
| Γ_{12} | $p\gamma$ | 0.05-0.25 % |
| Γ_{13} | $p\gamma$, helicity=1/2 | 0.05-0.15 % |
| Γ_{14} | $p\gamma$, helicity=3/2 | 0.002-0.16 % |
| Γ_{15} | n γ | 0.0-0.016 % |
| Γ_{16} | $n\gamma$, helicity=1/2 | 0.0-0.01 % |
| Γ ₁₇ | $n\gamma$, helicity=3/2 | 0.0-0.015 % |

N(1720) BRANCHING RATIOS

| Γ(Nπ)/Γ _{total} VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
|---------------------------------------------------|------------------------|----------|-----------|--------------------------------------|-------------------|
| 11 ±3 OUR ESTIMATE | ************* | | | | |
| 10 ±5 | ANISOVICH | 12A | | Multichannel | |
| 9.4±0.5 | ARNDT | 06 | | $\pi N \rightarrow \pi N, \eta N$ | |
| 13 ±5 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& \Lambda$ | $\pi\pi$ |
| 10 ±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 14 ±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| • • We do not use the fol | | | | | |
| 14 ±5 | ANISOVICH | 10 | | Multichannel | |
| 18 ±3 | BATINIC | 10 | | $\pi N \rightarrow N \pi$, $N \eta$ | |
| 9 ±6 | THOMA | 08 | | Multichannel | |
| 19.0 ± 0.4 | ARNDT | 04 | | $\pi N \rightarrow \pi N, \eta N$ | |
| 17 ±2 | PENNER | 02c | | Multichannel | |
| 5 ±5 | VRANA | 00 | | Multichannel | |
| 16 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 3.8±0.9 OUR AVERAGE | | | | | |
| 3 ±2 | ANISOVICH | 12A | DPWA | Multichannel | |
| 4 ±1 | VRANA | 00 | DPWA | Multichannel | |
| • • • We do not use the fol | lowing data for averag | es, fits | , limits, | etc. • • • | |
| 0 ±1 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ | |
| 10 ±7 | THOMA | 08 | | Multichannel | |
| 0.2±0.2 | PENNER | 02c | | Multichannel | |
| $\Gamma(\Lambda K)/\Gamma_{\text{total}}$ | | | | | Гз/Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | ٠, |
| 4.4±0.4 OUR AVERAGE | | | | - | |
| 4.3 ± 0.4 | SHKLYAR | 05 | DPWA | Multichannel | |
| 9 ±3 | PENNER | 02c | | Multichannel | |
| • • We do not use the fol | | | | | |
| 12 ±9 | THOMA | 08 | | Multichannel | |
| $\Gamma(\Delta(1232)\pi, P$ -wave)/ Γ | | | | | Γ_7/Γ |
| . (_(1232) // 1 ********************************* | totai | | | | . //' |

TECN COMMENT

ANISOVICH 12A DPWA Multichannel

N(1720)

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to N(17)$ | 20) → Λ <i>K</i> | | | (Γ₁Γ₃) ¹ /2/Γ |
|---------------------------------------------------------------------------------|------------------|----|------|--------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.14 to -0.06 OUR ESTIMATE | | | | |
| -0.09 | BELL | | | $\pi^- \rho \rightarrow \Lambda K^0$ |
| -0.11 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |

Note: Signs of couplings from $\pi N \to N \pi \pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232)\pi$.

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to I$ | V(1720) → △(123 | 2)π, | P-wave | : | $(\Gamma_1\Gamma_7)^{\frac{1}{2}}/\Gamma$ |
|-----------------------------------------------------------------------------|-----------------|------|--------|-----------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| -0.17 | 1 LONGACRE | 77 | IPWA | $\pi N \rightarrow N$ | ππ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | 720) $\rightarrow N\rho$, S | =1/2 | ., <i>P</i> -wav | re (۲ ₁ ۲ ₉) ^{1/} 2/۱ |
|---------------------------------------------------------------------------------------|------------------------------|------|------------------|-------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.30 to +0.40 OUR ESTIMATE | | | | |
| $+0.34 \pm 0.05$ | | | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| -0.26 | ¹ LONGACRE | | | |
| +0.40 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

$$\frac{\left(\Gamma_{1}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{\text{total in }N\pi\to N}(1720)\to N\rho, S=3/2, P\text{-wave}}{\frac{VALUE}{+0.15}} \frac{\left(\Gamma_{1}\Gamma_{10}\right)^{\frac{1}{2}}/\Gamma_{\text{total in }N\pi\to N\pi\pi}}{\frac{DOCUMENT\ ID}{1\ \text{LONGACRE}}} \frac{TECN}{1\ \text{PWA}} \frac{COMMENT\ }{\pi\ N\to\ N\pi\pi}$$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | $N(1720) \rightarrow N(\pi\pi)$ |)/=0 5-wa | ive | (Г₁Г₁₁) ^½ /Г |
|------------------------------------------------------------------------------------|---------------------------------|--------------|------|-------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.19 | $^{ m 1}$ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1720) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$N(1720) ightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-------------|------------------------------|
| -0.01 to $+0.11$ OUR ESTIMATE | | | | |
| 0.110 ± 0.045 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.097 ± 0.003 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.015 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.044 ± 0.066 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.004 ± 0.007 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 0.130 ± 0.050 | ANISOVICH | 10 | DPWA | Multichannel |
| 0.073 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.053 | PENNER | 02D | DPWA | Multichannel |
| 0.012 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

$N(1720) ightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-----------|------------------------------|
| -0.019±0.020 OUR ESTIMATE | | | | |
| 0.150 ± 0.030 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.039 ± 0.003 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.007 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.024 ± 0.006 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.040 ± 0.016 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 0.100 ± 0.050 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.011 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.027 | PENNER | 02D | DPWA | Multichannel |
| -0.022 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

$N(1720) \rightarrow n\gamma$, helicity-1/2 amplitude A_{1/2}

| ` ' | , . | • , | | 1/2 | | | |
|-------------------------------|------------|-------------|---------------|-------------|-----------|------------------------------|--|
| $VALUE (GeV^{-1/2})$ |) | | DO CUMENT | ID | TECN | COMMENT | |
| $+0.004 \pm 0.015$ | OUR EST | MATE | | | | | |
| 0.007 ± 0.015 | | | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.002 ± 0.005 | | | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| ullet $ullet$ $ullet$ We do n | ot use the | following o | lata for aver | ages, fits, | limits, e | etc. • • • | |
| -0.003 | | | DRECHSE | L 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| -0.004 | | | PENNER | 02D | DPWA | Multichannel | |
| 0.050 ± 0.004 | | | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |

$N(1720) \rightarrow n\gamma$, helicity-3/2 amplitude A_{3/2}

| $VALUE$ (GeV $^{-1/2}$) | DO CUMENT ID | | TECN COMMENT |
|--------------------------------------------------------------------|--------------------------|---------|---------------------------------------------------------------------------------------|
| -0.010 to +0.020 OUR ESTIMATI | <u> </u> | | |
| -0.005 ± 0.025 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| -0.015 ± 0.019 | AWA JI | 81 | DPWA $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, etc. • • • |
| $\begin{array}{c} -0.031 \\ 0.003 \\ -0.017 \pm 0.004 \end{array}$ | DRECHSEL PENNER LI | 02D | DPWA $\gamma N \rightarrow \pi N$ DPWA Multichannel IPWA $\gamma N \rightarrow \pi N$ |

N(1720) $\gamma p \rightarrow \Lambda K^+ AMPLITUDES$

| | $\rightarrow N(1720) \rightarrow \Lambda K^{+}$ | | | $(E_{1+}$ amplitude) |
|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------|---------|---------------|-------------------------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | |
| • • • We do not use the | e following data for averages | , fits, | , limits, etc | i. • • • |
| 10.2 ± 0.2 | WORKMAN | 90 | DPWA | |
| 9.52 | TANABE | 89 | DPWA | |
| $p\gamma \rightarrow N(1720) \rightarrow$ | ΛK^+ phase angle $	heta$ | | | $(E_{1+} \text{ amplitude})$ |
| VALUE (degrees) | DO CUMENT ID | | TECN | |
| • • • We do not use the | e following data for averages | , fits, | , limits, etc | . • • • |
| -124 ± 2 | WORKMAN | 90 | DPWA | |
| -103.4 | TANABE | 89 | DPWA | |
| | | | | (44 |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p_{\gamma}$ | $\rightarrow N(1720) \rightarrow \Lambda K^{+}$ | | | (<i>M</i> 1+ amplitude) |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p\gamma$ MALUE (units 10 ⁻³) | $N(1720) \rightarrow NK^+$ DOCUMENT ID | | <u>TECN</u> | (M ₁₊ amplitude) |
| VALUE (units 10^{-3}) | | | | , |
| VALUE (units 10^{-3}) | DO CUMENT ID | | | (<i>M</i> ₁₊ amplitude) |

N(1720) FOOTNOTES

- 1 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ² From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ³ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- ⁴ LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CFRN) partial-wave analysis

N(1720) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

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| ANISOVICH | 12A | EPJ A48 15 | A V Anisovich et al | (BONN, PNPI) |
|-----------|------|-------------------|----------------------------------------|-----------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| THOMA | 08 | PL B65987 | U. Thoma et al. | (CB-ELSA Collab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | | son Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| SHKLYAR | 05 | PR C72 015210 | V. Shklyar, H. Lenske, U. Mosel | (GIES) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Le | |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Work | |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BRCO) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP |
| Also | 72 | PR D30 904 | D.M. Manley et al. | (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| WORKMAN | 90 | PR C42 781 | R.L. Workman | (VPI) |
| TANABE | 89 | PR C39 741 | H. Tanabe, M. Kohno, C. Bennhold | (MANZ) |
| Also | 0, | NC 102A 193 | M. Kohno, H. Tanabe, C. Bennhold | (MANZ) |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA.II | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMÙ, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| Also | | NP B108 365 | J. Dolbeau et al. | SACL IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | | | (===, ==, ==, ==, |

 $N(1860) 5/2^{+}$

 $I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

Before the 2012 *Review*, all the evidence for a $J^P=5/2^+$ state with a mass above 1800 MeV was filed under a two-star N(2000). There is now some evidence from ANISOVICH 12A for two $5/2^+$ states in this region, so we have split the older data (according to mass) between two two-star $5/2^+$ states, an N(1860) and an N(2000).

N(1860) BREIT-WIGNER MASS

| <u>VALUE (MeV)</u> 1820 to 1960 (≈ 1860) OUR EST | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------------|----------------------------|-----|------|---------------------------------------------------------------------------|
| $1860 \begin{array}{c} +120 \\ -60 \end{array}$ | ANISOVICH | 12A | DPWA | Multichannel |
| 1817.7 1903 ± 87 1882 + 10 | ARNDT MANLEY HOEHLER | | IPWA | $ \pi N \to \pi N, \eta N \pi N \to \pi N & N \pi \pi \pi N \to \pi N $ |
| | | | | |
| 1814 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

N(1860) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------|------------------|---------|-----------|----------------------------------------|
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | ANISOVICH | 12A | DPWA | Multichannel |
| 117.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 490 ±310 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 95 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 176 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

N(1860) POLE POSITION

DOCUMENT ID

REAL PART

| $1830 + 120 \\ -60$ | ANISOVICH | 12A | DPWA | Multichannel | |
|---------------------|--------------|-----|------|----------------------------------------------------------------|--|
| 1807 | ARNDT | 06 | DPWA | $\pi \ {\it N} \ ightarrow \ \pi \ {\it N}, \ \eta \ {\it N}$ | |
| -2×IMAGINARY PART | | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
| 250 + 150 | ANISOVICH | 12A | DPWA | Multichannel | |

TECN COMMENT

06 DPWA $\pi N \rightarrow \pi N$, ηN

N(1860) ELASTIC POLE RESIDUE

MODULUS |r|

109

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------|--------------------|-----|------|------------------------------------------------|
| 50 ± 20 60 | ANISOVICH ARNDT | | | Multichannel $\pi N \rightarrow \pi N, \eta N$ |
| PHASE θ | DOCUMENT ID | | TECN | COMMENT |
| -80±40 | ANISOVICH | 124 | | |
| - 80 ± 40 - 67 | ARNDT | | | $\pi N \rightarrow \pi N, \eta N$ |

N(1860) DECAY MODES

| | Mode |
|-----------------------|------------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ |
| Γ_2 | $N\pi\pi$ |
| Γ_3 | Δ (1232) π , P -wave |
| Γ_4 | $N\rho$, $S=3/2$, <i>P</i> -wave |
| Γ_5 | $N\rho$, $S=3/2$, F -wave |

N(1860) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|--------------------------|---------|-------------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 20 ±6 | ANISOVICH | 12A | DPWA | Multichannel |
| 12.7 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 8 ±5 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 4 ±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the fo | llowing data for average | s, fits | , limits, e | etc. • • • |
| 10 | ARNDT | 95 | DΡWΔ | $\pi N \rightarrow N \pi$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to I$ | V(1860) → △(123 | 2)π, <i>P</i> -w | rave (Γ ₁ Γ ₃) ^{1/2} /Γ |
|-------------------------------------------------------------------------------------|-----------------|------------------|---------------------------------------------------------|
| VALUE | DO CUMENT ID | TEC | CN COMMENT |
| $+0.10\pm0.06$ | MANLEY | 92 IPV | VA $\pi N \rightarrow \pi N \& N \pi \pi$ |

| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | $V(1860) \rightarrow N \rho, S=$ | 3/2, <i>P</i> -wav | /e (Γ ₁ Γ ₄) ^{1/2} /Γ |
|------------------------------------------------------------------------------------|----------------------------------|--------------------|-------------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| -0.22 ± 0.08 | MANLEY | 92 IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |

| $(\Gamma_i \Gamma_f)^{72} / \Gamma_{\text{total}} \text{ in } N\pi \to N($ | $1860) \rightarrow N\rho$, S | `=3/2, <i>F</i> | wave | $(\Gamma_1\Gamma_5)^{72}/\Gamma_1$ |
|----------------------------------------------------------------------------|-------------------------------|-----------------|------|----------------------------------------|
| VALUE | DO CUMENT ID | TE | CN | COMMENT |
| $+0.11\pm0.06$ | MANLEY | 92 IP | WA | $\pi N \rightarrow \pi N \& N \pi \pi$ |

N(1860) PHOTON DECAY AMPLITUDES

$N(1860) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV-1/2) | | DOCUMENT ID | | TECN | COMMENT | |
|-------------------|---|-------------|-----|------|----------------------------|--|
| 0.020 ± 0.012 | 1 | ANISOVICH | 12A | DPWA | $Phase=(120\pm50)^{\circ}$ | |
| | | | | | | |

$N(1860) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-------------------|--------------|-----|------|--------------------------------|
| 0.050 ± 0.020 | 1 ANISOVICH | 12A | DPWA | $Phase = (-80 \pm 60)^{\circ}$ |

N(1860) FOOTNOTES

N(1860) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|---------------|---------------------------|--------------|
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BRCO) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) |

$N(1875) \ 3/2^-$

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$$I(J^P) = \frac{1}{2}(\frac{3}{2})$$
 Status: ***

Before the 2012 *Review*, all the evidence for a $J^P=3/2^-$ state with a mass above 1800 MeV was filed under a two-star N(2080). There is now evidence from ANISOVICH 12A for two $3/2^-$ states in this region, so we have split the older data (according to mass) between a three-star N(1875) and a two-star N(2120).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1875) BREIT-WIGNER MASS

| VALUE (MeV.) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 1820 to 1920 (≈ 1875) OUR ESTI | | | TECN | COMMENT |
| 1880 ± 20 | ANISOVICH | 12A | DΡWΔ | Multichannel |
| 1804 ± 55 | MANLEY | 92 | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1920 | BELL | 83 | | $\pi^- p \rightarrow \Lambda K^0$ |
| 1880±100 | ¹ CUTKOSKY | | | $\pi N \rightarrow \pi N$ |
| 1900 | SAXON | 80 | DPWA | $\pi^- \rho \rightarrow \Lambda K^0$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | tc. • • • |
| 2048± 65 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 1946± 1 | PENNER | 02c | DPWA | Multichannel |
| 1895 | MART | 00 | DPWA | $\gamma p \rightarrow \Lambda K^+$ |
| 2003± 18 | VRANA | 00 | DPWA | Multichannel |
| 1880 | BAKER | 79 | DPWA | $\pi^- \rho \rightarrow n \eta$ |

N(1875) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|----------|-----------|----------------------------------------------|
| 160 to 320 (≈ 220) OUR ESTIM | ATE | | | |
| 200 ± 25 | ANISOVICH | 12A | DPWA | Multichannel |
| 450 ± 185 | MANLEY | 92 | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 320 | BELL | 83 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 180± 60 | ¹ CUTKOSKY | 80 | | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| 240 | SAXON | 80 | DPWA | $\pi^- ho ightarrow \Lambda K^0$ |
| • • • We do not use the following | g data for average | s, fits, | limits, e | etc. • • • |
| 529 ± 128 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 859± 7 | PENNER | 02c | DPWA | Multichannel |
| 372 | MART | 00 | DPWA | $\gamma p \rightarrow \Lambda K^+$ |
| 1070 ± 858 | VRANA | 00 | DPWA | Multichannel |
| 87 | BAKER | 79 | DPWA | $\pi^- \rho \rightarrow n \eta$ |

N(1875) POLE POSITION

REAL PART

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|----------|-----------|----------------------------------------------|
| 1800 to 1950 OUR ESTIMATE | | | | |
| 1860 ± 25 | ANISOVICH | | | |
| 1880 ± 100 | ¹ CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| • • • We do not use the following | g data for average | s, fits, | limits, e | etc. • • • |
| 1957± 49 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1824 | VRANA | 00 | DPWA | Multichannel |
| not seen | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

 $^{^{\}rm 1}\,{\rm This}$ ANISOVICH 12A value is the complex helicity amplitude at the pole position.

| MODULUS r ALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|------------------------|----------|-----------|----------------------------------------------|
| N(187 | 75) ELASTIC PO | LE R | ESIDUE | Ē |
| not seen | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 514 | VRA NA | 00 | | Multichannel |
| 167±106 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| • • • We do not use the follow | ving data for average | es, fits | , limits, | etc. • • • |
| 160± 80 | ¹ CUT KOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| 200± 20 | ANISOVICH | | | |
| 50 to 250 OUR ESTIMATE | <u></u> | | | |
| ALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |

| MODULUS IT | | | | |
|--------------------------------|-----------------------|----------|-------------|----------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 2 to 10 OUR ESTIMATE | | | | |
| 2.5 ± 1.0 | ANISOVICH | | | |
| 10 ±5 | ¹ CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| • • • We do not use the follow | ing data for average | s, fits, | , limits, e | etc. • • • |
| 53 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| $100\!\pm\!80$ | $^{ m 1}$ CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| • • • We do not use the follow | ing data for average | s, fits, | , limits, e | etc. • • • |
| - 65 | BATINIC | 10 | DPWA | π N \rightarrow N π , N η |

N(1875) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

| Normalized residue in $N\pi \rightarrow MODULUS(\%)$ | N(1875) → AK | TECN | COMMENT | |
|------------------------------------------------------|--------------------------------|--------|-------------------------|----|
| 1.5 ± 0.5 | ANISOVICH 12A | | | Ī |
| Normalized residue in $N\pi ightarrow$ | $N(1875) \rightarrow \Sigma K$ | | | |
| MODULUS (%) 4±2 | DOCUMENT ID A NISOVICH 12A | | COMMENT Multichannel | ٠, |
| Normalized residue in $N\pi \rightarrow$ | | DIWA | Muttellannel | • |
| MODULUS (%) PHASE (°) | DO CUMENT ID | TEC | V COMMENT | |
| 8 ± 3 -170 ± 65 | ANISOVICH 1 | 2A DPV | VA Multichannel | |

N(1875) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor |
|-----------------------|---------------------------------------------|------------------------------|--------------|
| $\overline{\Gamma_1}$ | $N\pi$ | (12 ±10)% | |
| Γ_2 | N η | $(3.5\pm3.5)\%$ | 2.5 |
| Γ_3 | N ω | (21 ± 7) % | |
| Γ_4 | ΛK | | |
| Γ_5 | ΣΚ | $(7 \pm 4) \times 10^{-3}$ | |
| Γ_6 | $N\pi\pi$ | | |
| Γ_7 | $\Delta(1232)\pi$, S -wave | (40 ±10) % | |
| Γ ₈ | $\Delta(1232)\pi$, $	extit{D}	ext{-}$ wave | (17 ±10) % | |
| Γ9 | $N\rho$, $S=3/2$, S -wave | (6 ± 6)% | |
| Γ_{10} | $N(\pi\pi)^{1=0}_{S-\text{wave}}$ | (24 ±24) % | |
| Γ_{11} | $n\gamma$, helicity=1/2 | | |
| Γ_{12} | $n\gamma$, helicity=3/2 | | |
| Γ_{13} | $p\gamma$ | 0.008-0.016 % | |
| Γ_{14} | $p\gamma$, helicity=1/2 | 0.006-0.010 % | |
| Γ_{15} | $p\gamma$, helicity=3/2 | 0.002-0.006 % | |

N(1875) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|----------------------------------------|-----------------------|----------|-----------|----------------------------------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 12±10 OUR ESTIMATE | | | | |
| 3± 2 | ANISOVICH | 12A | DPWA | Multichannel |
| 23± 3 | | | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 10± 4 | ¹ CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (lower } m)$ |
| • • • We do not use the following | ng data for average | es, fits | , limits, | etc. • • • |
| 17± 7 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 12± 2 | PENNER | 02c | DPWA | Multichannel |
| 13± 3 | VRA NA | 00 | DPWA | Multichannel |
| $\lceil (N\eta)/\lceil_{total} \rceil$ | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 3.5 ± 3.5 OUR AVERAGE Error | includes scale fact | or of 2 | 2.5. | |
| 7 ±2 | PENNER | 02c | DPWA | Multichannel |
| | | | | |

00 DPWA Multichannel

10 DPWA $\pi N \rightarrow N \pi$, $N \eta$

VRA NA

BATINIC

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

 8 ± 3

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | $875) \rightarrow N\eta$ DOCUMENT ID | | TECN | (Γ ₁ Γ ₂) ^{1/2} / |
|--------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------|--------|-----------------------------------------------------------------|
| VALUE (%) 6 ±4 OUR ESTIMATE | DOCUMENT ID | | | |
| 5 ±2 6.5 | A NISOVICH BAKER | 12A 79 | | Multichannel $\pi^- p \rightarrow n \eta$ |
| | | | | |
| $\Gamma(N\omega)/\Gamma_{\text{total}}$ VALUE (%) | DO CUMENT ID | | TECN | Γ ₃ / |
| 21±7 | PENNER | | | Multichannel |
| $\Gamma(\Lambda K)/\Gamma_{\text{total}}$ | | | | Γ ₄ / |
| VALUE (%) | DO CUMENT ID | | TECN | |
| • • • We do not use the following | | | | |
| 0.2 ± 0.2 | PENNER | 02c | DPWA | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | 975) <i>→ A K</i> | | | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}$ |
| $(i \mid i \mid f)$ / i total $iii \land v \land i \rightarrow \land v \land i$ | DOCUMENT ID | | TECN | ('1'4) / COMMENT |
| 4±2 OUR ESTIMATE | | | | |
| 4±2 4 | A NISOVICH BELL | 12A 83 | | Multichannel $\pi^- p \rightarrow \Lambda K^0$ |
| 3 | SAXON | 80 | | $\pi^- \rho \rightarrow \Lambda K^0$ |
| $\Gamma(\Sigma K)/\Gamma_{\text{total}}$ | | | | Γ ₅ / |
| VALUE (%) | DO CUMENT ID | | TECN | • |
| 0.7±0.4 | PENNER | | | Multichannel |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\pi	o N(1$ | 07E) , T & | | | (Γ ₁ Γ ₅) ^{1/2} / |
| VALUE (%) | 875) → ∠ K DOCUMENT ID | | TECN | (1 5)'-/ COMMENT |
| 1 to 10 OUR ESTIMATE | | | | |
| 15 ±8 1.4 to 3.7 | ANISOVICH ² DEANS | 12A 75 | | Multichannel $\pi N \rightarrow \Sigma K$ |
| | | | | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | 875) → △(123 | $32)\pi$, | S-wave | (Γ ₁ Γ ₇) ^{1/2} / |
| <u>VALUE</u> − 0.09 ± 0.09 | DOCUMENT ID MANLEY | 92 | | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| | | | | |
| $\Gamma(\Delta(1232)\pi$, S-wave)/ Γ_{total} | DO CUMENT ID | | TECN | Γ ₇ / |
| 40±10 | VRANA | 00 | | Multichannel |
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | 875) → ⊿ (123 | 32)π, | D-wave | e (Γ ₁ Γ ₈) ^{1/2} / |
| <u>VALUE</u> + 0.22 ± 0.07 | DO CUMENT ID | 92 | | |
| . – | MANLEY | 92 | IP VVA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, D$ -wave)/ Γ_{total} | | | | Гв/ |
| VALUE (%) 17±10 | DO CUMENT ID | 00 | | COMMENT Multichannel |
| | | | | , |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | | | | |
| <u>VALUE</u> − 0.24 ± 0.06 | <u>DO CUMENT ID</u> MANLEY | 92 | | $ \frac{COMMENT}{\pi N \rightarrow \pi N \& N \pi \pi} $ |
| | | 92 | IF VVA | |
| $\Gamma(N\rho, S=3/2, S-wave)/\Gamma_{tota}$ | | | | Гер |
| VALUE (%) 6±6 | DO CUMENT ID VRANA | 00 | | COMMENT Multichannel |
| | | | | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(1)$ | $875) \rightarrow N(\pi\pi$ |)/=0 S-wa | ive | (Γ ₁ Γ ₁₀) ¹ ⁄ ₂ / |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.25 \pm 0.06$ | MANLEY | 92 | IPVVA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $\Gamma(N(\pi\pi)_{S-wave}^{I=0})/\Gamma_{total}$ | | | | Γ ₁₀ / |
| VALUE (%) 24 ± 24 | DO CUMENT ID | 00 | DPWA | COMMENT Multichannel |
| | | υU | DF WA | |
| | 275) → Mm | | | (Γ ₁₃ Γ ₂) ^{1/2} / |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow N(18)$ VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| | DOCUMENT ID ANISOVICH HICKS | | DPWA | |

N(1875) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$N(1875) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| | -, | _ | | | |
|----------------------------------------------|----------------------|----------|-----------|------------------------------|--|
| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT | |
| 0.018 ± 0.010 | ANISOVICH | 12A | DPWA | Multichannel | |
| -0.020 ± 0.008 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| \bullet \bullet We do not use the follow | ing data for average | s, fits, | limits, e | etc. • • • | |
| 0.012 | PENNER | 02D | DPWA | Multichannel | |
| 0.026 ± 0.052 | DEVENISH | 74 | DPWA | $\gamma N \rightarrow \pi N$ | |

ı

ı

92 IPWA $\pi N \rightarrow \pi N \& N \pi \pi$

 Γ_3/Γ

ANISOVICH 12A DPWA Multichannel

DOCUMENT ID TECN COMMENT
A NISOVICH 12A DPWA Multichannel

MANLEY

| | | | N(1875), N(1880) |
|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------|
| $N(1875) \rightarrow p\gamma$, helicity-3/ | 2 amplitude A _{3/2} | 1/(1000) 1 (0± | $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ** |
| VALUE (GeV -1/2) | DOCUMENT ID TECN COMMENT | $N(1880) 1/2^+$ | $I(J) = \frac{1}{2}(\frac{1}{2})$ Status. 1949 |
| -0.009 ± 0.005 0.017 ± 0.011 | A NISOVICH 12A DPWA Multichannel AWA JI 81 DPWA $\gamma N \to \pi N$ ng data for averages, fits, limits, etc. $\bullet \bullet \bullet$ | OMITTED FROM SUMMA | RY TABLE |
| -0.010 0.128±0.057 | PENNER 02D DPWA Multichannel DEVENISH 74 DPWA $\gamma N ightarrow \pi N$ | N(1880 |) BREIT-WIGNER MASS |
| $N(1875) \rightarrow n\gamma$, helicity-1/3 | , | VALUE (MeV) 1870 ± 35 | DOCUMENT ID TECN COMMENT ANISOVICH 12A DPWA Multichannel |
| VALUE (GeV ^{-1/2}) | DOCUMENT ID TECN COMMENT | 1885 ± 30 | MANLEY 92 IPWA $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.007±0.013 • • • We do not use the following | AWA JI 81 DPWA γ N \rightarrow π N and a for averages, fits, limits, etc. \bullet \bullet | N(1880 | D) BREIT-WIGNER WIDTH |
| 0.023 0.053±0.083 | PENNER 02D DPWA Multichannel DEVENISH 74 DPWA $\gamma N ightarrow \pi N$ | VALUE (MeV) | DOCUMENT ID TECN COMMENT |
| $N(1875) \rightarrow n\gamma$, helicity-3/2 | , | 235 ± 65 113 ± 44 | ANISOVICH 12A DPWA Multichannel MANLEY 92 IPWA $\pi N ightarrow \pi N \& N \pi \pi$ |
| VALUE (GeV ^{-1/2}) | DOCUMENT ID TECN COMMENT | | |
| -0.053 ± 0.034 | AWA JI 81 DPWA $\gamma N \rightarrow \pi N$ | N(1 | 1880) POLE POSITION |
| - 0.009 | ng data for averages, fits, limits, etc. • • • PENNER 02D DPWA Multichannel | REAL PART VALUE (MeV) | DOCUMENT ID TECN COMMENT |
| 0.100 ± 0.141 | DEVENISH 74 DPWA $\gamma N \rightarrow \pi N$ | 1860 ± 35 | ANISOVICH 12A DPWA Multichannel |
| N(1875) | $\gamma p \rightarrow \Lambda K^+ \text{ AMPLITUDES}$ | -2×IMAGINARY PART | |
| ., | •• | <u>VALUE (MeV)</u> 250±70 | ANISOVICH 12A DPWA Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow N$ VALUE (units 10 ⁻³) | | | |
| | DOCUMENT ID TECN COMMENT ng data for averages, fits, limits, etc. • • • | N(1880) |) ELASTIC POLE RESIDUE |
| $2.29^{+0.7}_{-0.2}$ | MART 00 DPWA $\gamma p \rightarrow \Lambda K^+$ | MODULUS r | 20000000 |
| 5.5 ± 0.3 | WORKMAN 90 DPWA | <u>VALUE (MeV)</u> 6±4 | ANISOVICH 12A DPWA Multichannel |
| 4.09 | TANABE 89 DPWA | PHASE θ | |
| $p\gamma \rightarrow N(1875) \rightarrow \Lambda K^+ p$ | · · · · · | VALUE (°) | DOCUMENT ID TECN COMMENT |
| VALUE (degrees) • • • We do not use the following | DOCUMENT ID TECN ng data for averages, fits, limits, etc. • • • | 80±65 | ANISOVICH 12A DPWA Multichannel |
| -48 ± 5 | WORKMAN 90 DPWA | N(1880) | INELASTIC POLE RESIDUE |
| - 35.9 | TA NABE 89 DPWA | The "normalized residue" | " is the residue divided by Γ_{pole} |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \to N$ | | Normalized residue in $N\pi ightarrow$ | $N(1880) \rightarrow N\eta$ |
| VALUE (units 10 ⁻³) • • • We do not use the following | DOCUMENT ID TECN ng data for averages, fits, limits, etc. • • • | <u>MODULUS (%)</u> PHASE (°) 11±7 −75 ± 55 | DOCUMENT ID TECN COMMENT A NISOVICH 12A DPWA Multichannel |
| -6.7 ± 0.2 | WORKMAN 90 DPWA | | |
| -4.09 | TA NABE 89 DPWA | Normalized residue in $N\pi \rightarrow MODULUS$ (%) PHASE (°) | → N(1880) → NK DOCUMENT ID TECN COMMENT |
| ^ | /(1875) FOOTNOTES | 3±2 40 ± 40 | ANISOVICH 12A DPWA Multichannel |
| $^{ m 1}$ CUTKOSKY 80 finds a lower | mass D_{13} resonance, as well as one in this region. Both | Normalized residue in $N\pi ightarrow$ | $N(1880) \rightarrow \Sigma K$ |
| | 75 is from the four best solutions. Disagrees with $\pi^+ p 	o$ | MODULUS (%) PHASE (°) 11±6 95 ± 40 | ANISOVICH 12A DPWA Multichannel |
| $\Sigma^+ K^+$ data of WINNIK 77 | around 1920 MeV. | | |
| ٨ | /(1875) REFERENCES | Normalized residue in $N\pi \rightarrow MODULUS$ (%) PHASE (°) | DOCUMENT ID TECN COMMENT |
| For early references, see | Physics Letters 111B 1 (1982). | 20 ± 8 -150 ± 50 | ANISOVICH 12A DPWA Multichannel |
| ANISOVICH 12A EPJ A48 15 BATINIC 10 PR C82 038203 | A.V. Anisovich et al. (BONN, PNPI) M. Batinic et al. (ZAGR) | | 1880) DECAY MODES |
| ARNDT 06 PR C74 045205 PDG 06 JPG 33 1 | R.A. Arndt et al. (GWU) WM. Yao et al. (PDG Collab.) | • | , |
| PENNER 02C PR C66 055211 PENNER 02D PR C66 055212 | G. Penner, U. Mosel (GIES) | Mode | |
| MART 00 PR C61 012201 VRANA 00 PRPL 328 181 | G. Penner, U. Mosel (GIES) T. Mart, C. Bennhold T.P. Vrana, S.A. Dytman., TS.H. Lee (PITT+) | Γ_1 $N π$ Γ_2 $N η$ | |
| MANLEY 92 PR D45 4002 Also PR D30 904 ARNDT 91 PR D43 2131 | D.M. Manley, E.M. Šaleski (KENT) IJP D.M. Manley <i>et al.</i> (VPI) R.A. Arndt <i>et al.</i> (VPI, TELE) IJP | Γ ₃ ΛΚ | |
| WORKMAN 90 PR C42 781 TANABE 89 PR C39 741 | R.L. Workman (VPI) H. Tanabe, M. Kohno, C. Bennhold (MANZ) | Γ_4 Σ K Γ_5 $\Delta(1232)\pi$ | |
| Also NC 102A 193 BELL 83 NP B222 389 | M. Kohno, H. Tanabe, C. Bennhold (MANZ) K.W. Bell <i>et al.</i> (RL) IJP | | |
| AWAJI 81 Bonn Conf. 352 Also NP B197 365 CULTION 80 Towns Conf. 19 | N. Awaji, R. Kajikawa (NAGO) K. Fujiji et al. (NAGO) P. E. Guthorius at al. (AMILLE) U.B. | N(188 | 80) BRANCHING RATIOS |
| CUTKOSKY 80 Toronto Conf. 19 Also PR D20 2839 SAXON 80 NP B162 522 | R.E. Čutkosky et al. (CMU, LBL) IJP R.E. Cutkosky et al. (CMU, LBL) IJP D.H. Saxon et al. (RHEL, BRIS) IJP | $\Gamma(N\pi)/\Gamma_{ m total}$ | Γ ₁ /Γ |
| BAKER 79 NP B156 93 WINNIK 77 NP B128 66 | R.D. Baker et al. (RHEL) IJP M. Winnik et al. (HAIF) I | VALUE (%) 5 ± 3 | A NISOVICH 12A DPWA Multichannel |
| DEANS 75 NP B96 90 DEVENISH 74 PL 52B 227 | S.R. Deans <i>et al.</i> (SFLA, ÀLAH) IJP R.C.E. Devenish, D.H. Lyth, W.A. Rankin (DESY+) IJP | 15 ± 6 | MANLEY 92 IPWA $\pi N \rightarrow \pi N \& N \pi \pi$ |
| HICKS 73 PR D7 2614 | H.R. Hicks et al. (CMU, ORNĚ, SFLA) IJP | $\Gamma(N\eta)/\Gamma_{ m total}$ | Γ_2/Γ |
| | | VALUE (%) | DOCUMENT ID TECN COMMENT |
| | | ne + 30 | ANICOVICH 124 DRAW Multichannel |

 $25 + 30 \\
-20 \\
-19 \pm 8$

VALUE (%) $2\!\pm\!1$

 $\Gamma(\Lambda K)/\Gamma_{\text{total}}$

Baryon Particle Listings N(1880), N(1895)

| Γ (ΣΚ)/Γ_{total} VALUE (%) | DOCUMENT ID | | TECN | COMMENT | Γ ₄ /Γ |
|----------------------------------------------|--------------|-----|------|--------------|-------------------|
| 17±7 | ANISOVICH | 12A | DPWA | Multichannel | |
| $\Gamma(\Delta(1232)\pi)/\Gamma_{ m total}$ | | | | | Г ₅ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| $29\!\pm\!12$ | ANISOVICH | 12A | DPWA | Multichannel | |

N(1880) PHOTON DECAY AMPLITUDES

| $N(1880) \rightarrow$ | $p\gamma$. | helicity-1/2 | amplitude | A ₁ | /2 |
|-----------------------|-------------|--------------|-----------|----------------|----|
|-----------------------|-------------|--------------|-----------|----------------|----|

| | , | |
|-------------|-----------------------------|--------------------------------------|
| VALUE | DO CUMENT ID | TECN COMMENT |
| 0.014±0.003 | ¹ A NISOVICH 12A | DPWA Phase = $(-130 \pm 60)^{\circ}$ |

N(1880) FOOTNOTES

 $^{
m 1}$ This A NISOVICH 12A value is the complex helicity amplitude at the pole position.

N(1880) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|-------------|---------------------------|-----------------|
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) (VPI) |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) |

N(1895) 1/2

$$I(J^P) = \frac{1}{2}(\frac{1}{2})$$
 Status: **

OMITTED FROM SUMMARY TABLE

Before our 2012 Review, this state appeared in our Listings as the $\mathit{N}(\text{2090}).$ Any structure in the S_{11} wave above 1800 MeV is listed here. A few early results that are now obsolete have been omitted.

The latest GWU analysis (ARNDT 06) finds no evidence for this

N(1895) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|----------------------|----------|-------------|-------------------------------------------|
| ≈ 2090 OUR ESTIMATE | | | | |
| 1895 ± 15 | ANISOVICH | 12A | DPWA | Multichannel |
| 1928±59 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 2180 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1880 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the follow | ing data for average | es, fits | , limits, e | etc. • • • |
| 1812 ± 25 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1822±43 | VRA NA | 00 | DPWA | Multichannel |
| $1897 \pm 50 + \frac{30}{2}$ | PLOETZKE | 98 | SPEC | $\gamma \rho \rightarrow \rho \eta'(958)$ |

N(1895) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------------|----------|-------------|----------------------------------------|
| $90 {+} \atop {-} \atop {15} $ | ANISOVICH | 12A | DPWA | Multichannel |
| 414 ± 157 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 350 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 95 ± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | g data for average | es, fits | , limits, e | etc. • • • |
| 405 ± 40 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 248 ± 185 | VRA NA | 00 | DPWA | Multichannel |
| $396 \pm 155 + \frac{35}{45}$ | PLOETZKE | 98 | SPEC | $\gamma p \rightarrow p \eta'(958)$ |

N(1895) POLE POSITION

REAL PART

| VALUE (WEV) | DOCUMENT ID | | TECH COMMENT | _ |
|----------------------------------------|-----------------------|----------|-------------------------------------------|---|
| 1900 ± 15 | ANISOVICH | 12A | DPWA Multichannel | ı |
| 2150 ± 70 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ | |
| 1937 or 1949 | ¹ LONGACRE | 78 | IPWA $\pi N \rightarrow N \pi \pi$ | |
| ullet $ullet$ We do not use the follow | ving data for average | s, fits, | , limits, etc. • • • | |
| 1797 ± 26 | BATINIC | 10 | DPWA $\pi N \rightarrow N \pi$, $N \eta$ | |
| 1795 | VRA NA | 00 | DPWA Multichannel | |
| -2×IMAGINARY PART | DOCUMENT ID | | TECN COMMENT | _ |
| 90 + 30 - 15 | ANISOVICH | 12A | DPWA Multichannel | I |
| 350 ± 100 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ | |
| 139 or 131 | ¹ LONGACRE | 78 | IPWA $\pi N \rightarrow N \pi \pi$ | |
| ullet $ullet$ We do not use the follow | ving data for average | s, fits, | , limits, etc. • • • | |
| 420± 45 | BATINIC | 10 | DPWA $\pi N \to N \pi$, $N \eta$ | 1 |
| 220 | VRA NA | 0.0 | DPWA Multichannel | _ |

N(1895) ELASTIC POLE RESIDUE

MODULUS |r|

-164

MODULUS (%)

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------|------------------------|---------|-------------|---------------------------------------------------------------------|
| 1 ± 1 | ANISOVICH | 12A | DPWA | Multichannel |
| 40±20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the follow | owing data for average | s, fits | , limits, e | etc. • • • |
| 60 | BATINIC | 10 | DPWA | $\pi {\it N} \rightarrow {\it N} \pi \text{, } {\it N} \eta$ |
| PHASE <i>0</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| 0 ± 90 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | owing data for average | s, fits | , limits, e | etc. • • • |

N(1895) INELASTIC POLE RESIDUE

10 DPWA $\pi N \to N \pi$, $N \eta$

TECN COMMENT

BATINIC

The "normalized residue" is the residue divided by Γ_{pole}

PHASE (°)

| 6±2 | 40 ± 20 | ANISOVICH 12A | DPWA | Multichannel |
|-------------|------------------------------|---------------------------------|------|--------------|
| Normalized | residue in $N\pi ightarrow$ | $N(1895) \rightarrow \Lambda K$ | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 5 ± 2 | -90 ± 30 | ANISOVICH 12A | DPWA | Multichannel |

DOCUMENT ID

Normalized residue in $N\pi \to N(1895) \to \Sigma K$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|-------------|-----------|---------------|------|--------------|
| 6 ± 2 | 40 ± 30 | ANISOVICH 12A | DPWA | Multichannel |

N(1895) DECAY MODES

| Mode |
|---------------------------------------|
| $N\pi$ |
| $N\eta$ |
| ΛK |
| ΣΚ |
| $N\pi\pi$ |
| $\Delta\pi$ |
| $\Delta(1232)\pi$, $	extit{D}$ -wave |
| N ho |
| $N\rho$, $S=1/2$, S-wave |
| $N\rho$, $S=3/2$, D-wave |
| $N(\pi\pi)_{S-\text{wave}}^{I=0}$ |
| $N(1440)\pi$ |
| |

N(1895) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|-------------------------------------------------------------------------|----------------------------|---------|-----------|------------------------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 2± 1 | ANISOVICH | 12A | DPWA | Multichannel |
| 10±10 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 18± 8 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 9± 5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • |
| 32± 6 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 17± 3 | VRANA | 00 | DPWA | Multichannel |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 21 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 41 ± 4 | VRANA | 00 | DPWA | Multichannel |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • |
| 22±10 | BATINIC | 10 | DPWA | $\pi {\sf N} ightarrow {\sf N} \pi$, ${\sf N} \eta$ |
| $\Gamma(\Lambda K)/\Gamma_{\text{total}}$ | | | | Г ₃ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 18±5 | ANISOVICH | 12A | DPWA | Multichannel |
| $\Gamma(\Sigma K)/\Gamma_{\text{total}}$ | | | | Γ ₄ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 13±7 | ANISOVICH | 12A | DPWA | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}}$ in $N\pi$ - | → N(1805) → A¥ | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
| ('i'f) /'total III N'π- | → W(1022) → VV | | | (1113)/1 |

SAXON

VRANA

DOCUMENT ID

 $\Gamma(\Delta(1232)\pi, D\text{-wave})/\Gamma_{\text{total}}$

VALUE (%)

 1 ± 1

DPWA $\pi^- p \rightarrow \Lambda K^0$

TECN COMMENT

00 DPWA Multichannel

 Γ_7/Γ

 Γ_1/Γ

Baryon Particle Listings N(1895), N(1900)

| $\Gamma(N\rho, S=1/2, S-wave)/\Gamma_{total}$ | | | | | ٦/و٦ |
|-----------------------------------------------------------------------|--------------------------------------------------------------|-------------------|--------------|-------------------------|----------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 36±1 | VRA NA | 00 | DPWA | Multichannel | |
| $\Gamma(N\rho, S=3/2, D-wave)/\Gamma_{total}$ | | | | | Γ_{10}/Γ |
| /ALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 1 ± 1 | VRA NA | 00 | DPWA | Multichannel | |
| $\Gamma(N(\pi\pi)_{S	ext{-wave}}^{I=0})/\Gamma_{	ext{total}}$ | | | | | Γ ₁₁ /Γ |
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | . 11/. |
| 2±1 | VRA NA | 00 | DPWA | Multichannel | |
| $\Gamma(N(1440)\pi)/\Gamma_{\text{total}}$ | | | | | Γ ₁₂ /Γ |
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | - 12, |
| 2±1 | VRA NA | 00 | DPWA | Multichannel | |
| | | | | | |
| $N(1895) \rightarrow p\gamma$, helicity-1/2 avalue 0.012 ± 0.006 | mplitude A _{1,} | /2 | | COMMENT Phase = (120 : | ± 50)° |
| $N(1895) \rightarrow p\gamma$, helicity-1/2 avalue 0.012 ± 0.006 | amplitude A _{1,} DOCUMENT ID ANISOVICH 1895) FOOTI | /2 12A NOTE | TECN DPWA | COMMENT Phase = (120 : | |

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) | |
|-----------|-----|------------------|---------------------------------|----------------------|---|
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | ` (ZAGR) | |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) | |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. | Lee (PITT+) | |
| PLOETZKE | 98 | PL B444 555 | R. Ploetzke et al. (1 | Bonn SAPHIR Collab.) | |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJI | Ρ |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) | |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL)IJI | Ρ |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) | |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS)IJI | Ρ |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJI | Ρ |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJI | Ρ |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) | |
| | | | | | |

 $N(1900) 3/2^{+}$

 $I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$ Status: ***

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1900) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|------------------|---------|-----------|----------------------------------------|
| ≈ 1900 OUR ESTIMATE | | | | |
| 1905 ± 30 | ANISOVICH | 12A | DPWA | Multichannel |
| 1915 ± 60 | NIKONOV | 08 | DPWA | Multichannel |
| 1879 ± 17 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| | data for average | s, fits | , limits, | etc. • • • |
| 1951 ± 53 | PENNER | 02c | DPWA | Multichannel |

N(1900) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-------------|----------------------------------------|
| ~ 250 OUR ESTIMATE | | | | |
| $250 + 120 \\ -50$ | ANISOVICH | 12A | DPWA | Multichannel |
| 180± 40 | NIKONOV | 80 | DPWA | Multichannel |
| 498± 78 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 622± 42 | PENNER | 02c | DPWA | Multichannel |

N(1900) POLE POSITION

| REAL PART | DO CUMENT ID | | TECN | COMMENT | |
|-------------------|--------------|-----|------|--------------|---|
| 1900±30 | ANISOVICH | 12A | DPWA | Multichannel | |
| -2×IMAGINARY PART | DOCUMENT ID | | TECN | COMMENT | |
| 200 + 100 60 | A NISOVICH | 12A | DPWA | Multichannel | I |

N(1900) ELASTIC POLE RESIDUE

| MODULUS | 7 | |
|---------|---|--|
|---------|---|--|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------|--------------|-----|------|--------------|
| 3±2 | ANISOVICH | 12A | DPWA | Multichannel |

| PHASE θ | | | | |
|-------------|--------------|-----|------|--------------|
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| 10 ± 35 | ANISOVICH | 12A | DPWA | Multichannel |

N(1900) INELASTIC POLE RESIDUE

| The | "normalized residue" | is the residue divided by I | pole | |
|-------------|------------------------------|---------------------------------|------|--------------|
| Normalized | residue in $N\pi ightarrow$ | $N(1900) \rightarrow N\eta$ | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 5 ± 2 | 70 ± 60 | ANISOVICH 12A | DPWA | Multichannel |
| Normalized | residue in $N\pi ightarrow$ | $N(1900) \rightarrow \Lambda K$ | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 7 ± 3 | 135 ± 25 | ANISOVICH 12A | DPWA | Multichannel |
| Normalized | residue in $N\pi ightarrow$ | $N(1900) \rightarrow \Sigma K$ | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 4 ± 2 | 110 ± 30 | ANISOVICH 12A | DPWA | Multichannel |

N(1900) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | | | | | |
|-----------------------|--------------------------------|------------------------------|--|--|--|--|--|
| $\overline{\Gamma_1}$ | $N\pi$ | ~ 10 % | | | | | |
| Γ_2 | $N\pi\pi$ | | | | | | |
| Г3 | $N \rho$, $S=1/2$, P -wave | | | | | | |
| Γ_4 | $N\eta$ | ~ 12 % | | | | | |
| Γ_5 | N ω | (39 ±9)% | | | | | |
| Γ_6 | ΛK | 0-10 % | | | | | |
| Γ_7 | ΣΚ | (5.0 ± 2.0) % | | | | | |

N(1900) BRANCHING RATIOS

 $\Gamma(N\pi)/\Gamma_{\text{total}}$

| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| ~ 10 OUR ESTIMATE 3±2 | ANISOVICH | 124 | DDWA | Multichannel | |
| 26±6 | MANLEY | 92 | | $\pi N \rightarrow \pi N \&$ | Nππ |
| • • We do not use the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the following the fol | | | | | W A A |
| 2 to 9 | NIKONOV | 08 | | Multichannel | |
| $16\!\pm\!2$ | PENNER | 02c | DPWA | Multichannel | |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | | Γ_4/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| ~ 12 OUR ESTIMATE | | | | | |
| 10±4 | ANISOVICH | | | Multichannel | |
| 14±5 | PENNER | 02c | DPWA | Multichannel | |
| $\Gamma(N\omega)/\Gamma_{ m total}$ | | | | | Γ_5/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 171202 (70) | | 02c | DPWA | Multichannel | |
| 39±9 | PENNER $N(1900) ightarrow N ho$, S | | | е (Г ₁ | Гз) ¹ ⁄2/Г |
| 39±9 $ (\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \infty $ NALUE | N(1900) → Nρ, S <u>DOCUMENT ID</u> | =1/2 | , <i>P</i> -wav | COMMENT | Γ ₃) ^{1/2} /Γ |
| $\overline{39\pm9}$ $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to 0$ | $N(1900) \rightarrow N \rho$, S | ≔1/2 | , <i>P</i> -wav | COMMENT | |
| 39±9 $ (\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \infty $ NALUE | N(1900) → Nρ, S <u>DOCUMENT ID</u> | =1/2 | , <i>P</i> -wav | COMMENT | |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{\frac{1}{2}}}{\Gamma_i \Gamma_f} \frac{\Gamma_i \Gamma_f}{\Gamma_f} \frac{\Gamma_i \Gamma_f}{\Gamma_f} \frac{1}{\Gamma_i \Gamma_f} $ | N(1900) → Nρ, S <u>DOCUMENT ID</u> | =1/2 | , <i>P</i> -wav | COMMENT | Νππ |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N\pi + N\pi + N\pi + N\pi + N\pi + N\pi + N\pi +$ | N(1900) → Nρ, S DOCUMENT ID DOCUMENT ID | ⊆1/2 92 | , P-wav <u>TECN</u> IPWA | $\frac{\textit{COMMENT}}{\pi \; \textit{N} \to \; \pi \; \textit{N} \; \&}$ $\frac{\textit{COMMENT}}{}$ | Νππ |
| 39 \pm 9 ($\Gamma_1\Gamma_f$) $^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N\pi = 0.034 \pm 0.03$ $\Gamma(\Lambda K)/\Gamma_{total}$ $N\pi \rightarrow N\pi = 0.03$ $N\pi = 0.03$ | N(1900) → N ρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH | =1/2 92 12A | , P-wav <u>TECN</u> IPWA <u>TECN</u> DPWA | $COMMENT$ $\pi N 	o \pi N \&$ $COMMENT$ Multichannel | Νππ |
| 39±9 $ \frac{(\Gamma_I \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi$ | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR | 92 12A 05 | P-wav TECN IPWA TECN DPWA DPWA | $\frac{\textit{COMMENT}}{\pi \; \textit{N} \to \; \pi \; \textit{N} \; \; \&}$ $\frac{\textit{COMMENT}}{\textit{Multichannel}}$ $\textit{Multichannel}$ | Νππ |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{1/2}}{\Gamma_i \Gamma_i \Gamma_i} \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i$ | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR owing data for average | =1/2 92 12A 05 es, fits, | , P-wav TECN IPWA TECN DPWA DPWA Limits, 6 | $\begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \\ \underline{COMMENT} \\ \\ \text{Multichannel} \\ \text{Multichannel} \\ \text{etc.} \bullet \bullet \end{array}$ | Νππ |
| 39±9 $(\Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow N\pi$ $\frac{NALUE}{-0.34 \pm 0.03}$ $\Gamma(\Lambda K)/\Gamma_{\text{total}}$ $\frac{NALUE}{0}$ 0 to 10 OUR ESTIMATE 16 ±5 2.4 ± 0.3 • • • We do not use the following to 15 | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR Owing data for average NIKONOV | =1/2 92 12A 05 es, fits, | P-wav TECN IPWA DPWA DPWA Imits, 6 | $ \begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \\ \underline{COMMENT} \\ \\ \text{Multichannel} \\ \text{Multichannel} \\ \text{etc.} \bullet \bullet \\ \\ \text{Multichannel} \\ \end{array} $ | Νππ |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{1/2}}{\Gamma_i \Gamma_i \Gamma_i} \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i$ | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR owing data for average | =1/2 92 12A 05 es, fits, | P-wav TECN IPWA DPWA DPWA Imits, 6 | $\begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \\ \underline{COMMENT} \\ \\ \text{Multichannel} \\ \text{Multichannel} \\ \text{etc.} \bullet \bullet \end{array}$ | Νππ |
| 39±9 $ \frac{\left(\Gamma_{i}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \frac{1}{2} \\ \frac{VMLUE}{-0.34 \pm 0.03} $ $ \frac{\Gamma(\Lambda K)/\Gamma_{total}}{0 \text{ to 10 OUR ESTIMATE}} $ 16 ±5 2.4±0.3 • • • We do not use the folice 5 to 15 0.1±0.1 $ \Gamma(\Sigma K)/\Gamma_{total} $ | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR Owing data for average NIKONOV | =1/2 92 12A 05 es, fits, | P-wav TECN IPWA DPWA DPWA , limits, 6 DPWA | $ \begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \\ \underline{COMMENT} \\ \\ \text{Multichannel} \\ \text{Multichannel} \\ \text{etc.} \bullet \bullet \\ \\ \text{Multichannel} \\ \end{array} $ | Νππ |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{1/2}}{\Gamma_i \Gamma_i \Gamma_f} \frac{\Gamma_i \Gamma_f}{\Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i \Gamma_i $ | N(1900) → Nρ, S DOCUMENT ID MANLEY DOCUMENT ID ANISOVICH SHKLYAR Owing data for average NIKONOV | 92 12A 05 es, fits, 08 02c | P-wav TECN IPWA DPWA DPWA , limits, 6 DPWA | $ \begin{array}{c} \underline{COMMENT} \\ \pi \ N \rightarrow \pi \ N \ \& \\ \\ \underline{COMMENT} \\ \\ \text{Multichannel} \\ \text{Multichannel} \\ \text{etc.} \bullet \bullet \\ \\ \text{Multichannel} \\ \end{array} $ | <i>Νππ</i> Γ6/Γ |
| 39±9 $ \frac{(\Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi$ | N(1900) → Nρ, S DOCUMENT ID MANLEY ANISOVICH SHKLYAR Owing data for average, NIKONOV PENNER DOCUMENT ID ANISOVICH ANISOVICH | 92 12A 05 es, fits, 08 02c | P-wav TECN IPWA DPWA DPWA DPWA DPWA DPWA DPWA | $\frac{COMMENT}{\piN\rightarrow\piN\&}$ $\frac{COMMENT}{Multichannel}$ Multichannel etc. • • • Multichannel Multichannel $\frac{COMMENT}{Multichannel}$ Multichannel | <i>Νππ</i> Γ6/Γ |
| 39±9 $ \frac{(\Gamma_i \Gamma_f)^{1/2}}{\Gamma_i \Gamma_f} \Gamma_{\text{total}}^{1/2} \text{ in } N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi \rightarrow N\pi$ | N(1900) → Nρ, S DOCUMENT ID MANLEY ANISOVICH SHKLYAR Owing data for average, NIKONOV PENNER DOCUMENT ID ANISOVICH ANISOVICH | 92 12A 05 es, fits, 08 02c | P-wav TECN IPWA DPWA DPWA DPWA DPWA DPWA DPWA | $\frac{COMMENT}{\piN\rightarrow\piN\&}$ $\frac{COMMENT}{Multichannel}$ Multichannel etc. • • • Multichannel Multichannel $\frac{COMMENT}{Multichannel}$ Multichannel | <i>Νππ</i> Γ6/Γ |

N(1900) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$N(1900) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT | |
|--------------------------------|------------------------|---------|-----------|--------------|--|
| 0.026 ± 0.015 | ANISOVICH | 12A | DPWA | Multichannel | |
| • • • We do not use the follow | ving data for averages | , fits, | limits, e | tc. • • • | |
| -0.017 | PENNER | 02D | DPWA | Multichannel | |

| VALUE (GeV | -1/2 ₎ | | DO CUMENT ID | , | TECN | COMMENT |
|----------------|-------------------|----------------------------|--------------------------|----------|-------------|--------------|
| -0.065 ± 0 | | | ANISOVICH | | | |
| • • • We | do not | use the following | g data for averag | es, fits | , limits, e | etc. • • • |
| 0.031 | | | PENNER | 02D | DPWA | Multichannel |
| N(1900) | → n | γ , helicity- $1/2$ | amplitude A ₁ | /2 | | |
| VALUE (GeV | -1/2 ₎ | | DO CUMENT ID | | TECN | COMMENT |
| | | use the following | | | | |
| -0.016 | | | PENNER | 02D | DPWA | Multichannel |
| VALUE (GeV | -1/2 ₎ | γ, helicity-3/2 | DO CUMENT ID | | | |
| \// | do not | use the following | g data for averag | | | |
| | 40 | ` | | | | |
| - 0.002 | 40 | | PENNER | 02D | DPWA | Multichannel |
| | | N(| PENNER (1900) REFER | | | Muttichanner |

$N(1990) 7/2^{+}$

 $I(J^P) = \frac{1}{2}(\frac{7}{2}^+)$ Status: **

ı

OMITTED FROM SUMMARY TABLE

Most of the results published before 1975 are now obsolete and have $\,$ been omitted. They may be found in our 1982 edition, Physics Letters $\mathbf{111B}\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The various analyses do not agree very well with one another.

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(1990) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|--------------------|----------|-----------|----------------------------------------|
| ≈ 1990 OUR ESTIMATE | | | | |
| 2060± 65 | ANISOVICH | 12A | DPWA | Multichannel |
| 2086± 28 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1970± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2005 ± 150 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 1999 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | es, fits | , limits, | etc. • • • |
| 2311± 16 | VRA NA | 00 | DPWA | Multichannel |

N(1990) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-----------------------|---------|-------------|----------------------------------------|
| 240 ± 50 | ANISOVICH | 12A | DPWA | Multichannel |
| 535 ± 120 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 350 ± 120 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 350 ± 100 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 216 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the follow | ring data for average | s, fits | , limits, e | etc. • • • |
| 205 + 72 | VRA NA | 0.0 | DPWA | Multichannel |

N(1990) POLE POSITION

| REAL | PART |
|------|------|
| | |

not seen

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
|-----------------------------------------------------|------------------|---------|-----------|---------------------------------------------------------------------|---|
| 2030 ± 65 | ANISOVICH | 12A | DPWA | Multichannel | ı |
| 1900 ± 30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • | |
| 2301 | VRA NA | 00 | DPWA | Multichannel | |
| not seen | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} \text{Soln SM90}$ | |
| -2×IMAGINARY PART | DOCUMENT ID | | TECN | COMMENT | |
| VALUE (MeV) | ANISOVICH | 10. | | Multichannel | |
| 240 ± 60 | | | | | |
| 260±60 | CUTKOSKY | | | $\pi N \rightarrow \pi N$ | |
| ● ● We do not use the following | data for average | s, fits | , limits, | etc. • • • | |
| 202 | VRA NA | 0.0 | DΡWΔ | Multichannel | |

91

DPWA $\pi N \rightarrow \pi N$ Soln SM90

ARNDT

N(1990) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----------------|-----|------|---------------------------|
| 2±1 | ANISOVICH 12A E | | DPWA | Multichannel |
| 9±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| PHASE θ | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| 125 ± 65 | ANISOVICH | 12A | DPWA | Multichannel |
| -60 ± 30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

N(1990) DECAY MODES

| | Mode |
|----------------|--------------------------|
| Γ_1 | $N\pi$ |
| Γ_2 | $N\eta$ |
| Г3 | ΛK |
| Γ_4 | ΣΚ |
| Γ ₅ | $N\pi\pi$ |
| Γ_6 | $p\gamma$, helicity=1/2 |
| Γ_7 | $p\gamma$, helicity=3/2 |
| Γ ₈ | $n\gamma$, helicity=1/2 |
| Γ ₉ | $n\gamma$, helicity=3/2 |

N(1990) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|----------------------------|---------|-------------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 2± 1 | ANISOVICH | 12A | DPWA | Multichannel |
| 6 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 6 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 4 ± 2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits | , limits, e | etc. • • • |
| 22±11 | VRANA | 00 | DPWA | Multichannel |

| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{total}$ in $N\pi \to N(1990) \to N\eta$ | | | | (Γ ₁ Γ ₂) ^{1/2} /Γ | | |
|-----------------------------------------------------------------------------------|--------------|----|------|----------------------------------------------------|-------------------|--|
| VALUE | DO CUMENT IL |) | TECN | COMMENT | | |
| -0.043 | BAKER | 79 | DPWA | $\pi^- p \rightarrow n \eta$ | | |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | | Γ_2/Γ | |
| VALUE (%) | DO CUMENT IL |) | TECN | COMMENT | | |
| 0 ± 1 | VRANA | 00 | DPWA | Multichannel | | |

| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to N(1990) \to \Lambda K$ | | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
|-----------------------------------------------------------------------------------------------------|--------------|------|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.01 | BELL | 83 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| not seen | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| -0.021 ± 0.033 | DEVENISH | 7/ID | | Fixed thispersion rel |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \rightarrow$ | N(1990) → ΣK | | | | (Γ ₁ Γ ₄) ^{1/2} /Γ |
|----------------------------------------------------------------------------------|--------------------|----|--------|---------------------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMME | VT |
| 0.010 to 0.023 | ¹ DEANS | 75 | DPWA | $\pi N \rightarrow$ | ΣΚ |
| 0.06 | LANGREIN | 73 | ID\A/A | $\pi M \rightarrow$ | $\sum K (\text{sol} 1)$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | $V(1990) \rightarrow N\pi\pi$ | | (Γ ₁ Γ ₅) ^{1/2} /Γ |
|------------------------------------------------------------------------------------|-------------------------------|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| not seen | LONGACRE 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

N(1990) PHOTON DECAY AMPLITUDES

Papers on $\gamma\,N$ amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1\,$ (2006).

$N(1990) \rightarrow \rho \gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN COMMENT |
|---------------------------------|-------------------------|-----------|-------------------------------------|
| 0.042 ± 0.014 | ² A NISOVICH | 12A | DPWA Phase = $(-30 \pm 20)^{\circ}$ |
| 0.030 ± 0.029 | AWA JI | 81 | DPWA $\gamma N \rightarrow \pi N$ |
| • • • We do not use the followi | ng data for average | es, fits, | , limits, etc. ● ● ● |
| 0.040 | BARBOUR | 78 | DPWA $\gamma N \rightarrow \pi N$ |

$N(1990) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------|-------------------------|-----------|---------|--------------------------------|--|
| 0.058 ± 0.012 | ² A NISOVICH | 12A | DPWA | Phase = $(-35 \pm 25)^{\circ}$ | |
| 0.086 ± 0.060 | AVVA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| | ng data for average | es, fits, | limits, | etc. • • • | |
| +0.004 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ | |

I

| $N(1990) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$ | N(2000) ELASTIC POLE RESIDUE |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (GeV ^{-1/2}) DOCUMENT ID TECN COMMENT | MODULUS r |
| -0.001 AWAJI 81 DPWA γ N $ ightarrow$ π N | VALUE (MeV) DOCUMENT ID TECN COMMENT |
| • • • We do not use the following data for averages, fits, limits, etc. • • • $-0.069 \qquad \qquad \text{BARBOUR} \qquad 78 \qquad \text{DPWA} \gamma \text{N} \rightarrow \pi \text{N}$ | $35 {+80 \atop -15}$ ANISOVICH 12A DPWA Multichannel |
| ' | • • • We do not use the following data for averages, fits, limits, etc. • • • |
| $N(1990) \rightarrow n\gamma$, helicity-3/2 amplitude $A_{3/2}$ | 47 ARNDT 04 DPWA $\pi N \rightarrow \pi N$, ηN |
| VALUE (GeV - 1/2) DOCUMENT ID TECN COMMENT | PHASE θ |
| -0.178 AWA JI 81 DPWA $\gamma N \rightarrow \pi N$ • • • We do not use the following data for averages, fits, limits, etc. • • | VALUE (°) DO CUMENT ID TECN COMMENT |
| -0.072 BARBOUR 78 DPWA $\gamma N \rightarrow \pi N$ | -100±40 ANISOVICH 12A DPWA Multichannel |
| | • • • We do not use the following data for averages, fits, limits, etc. • • • $- 61 \hspace{1cm} ARNDT \hspace{0.5cm} 04 \hspace{0.5cm} DPWA \hspace{0.5cm} \pi \hspace{0.5cm} N \to \pi \hspace{0.5cm} N, \eta \hspace{0.5cm} N$ |
| N(1990) FOOTNOTES | $= 01 \qquad \qquad \text{ANND1} \qquad 04 \qquad \text{DI VWA} N \rightarrow NN, \eta N$ |
| ¹ The range given for DEANS 75 is from the four best solutions. ² This ANISOVICH 12A value is the complex helicity amplitude at the pole position. | N(2000) DECAY MODES |
| N(1990) REFERENCES | Mode |
| For early references, see Physics Letters 111B 1 (1982). | $\Gamma_1 N \pi$ |
| For early references, see Finysics Letters 111B 1 (1702). | $egin{array}{cccccccccccccccccccccccccccccccccccc$ |
| ANISOVICH 12A EPJ A48 15 A.V. Anisovich et al. (BONN, PNPI) ARNDT 06 PR C74 045205 R.A. Arndt et al. (GWU) | Γ_4 ΣK |
| PDG 06 JPG 33 1 W-M. Yao <i>et al.</i> (PDG Collab.) VRANA 00 PRPL 328 181 T.P. Vrana, S.A. Dytman., TS.H. Lee (PITT+) | Γ_5 $p\gamma$ |
| MANLEY 92 PR D45 4002 D.M. Manley, E.M. Saleski (KENT) UP Also PR D30 904 D.M. Manley et al. (VPI) | |
| ARNDT 91 PR D43 2131 R.A. Arnot et al. (VPI, TELE JUP BELL 83 NP B222 389 K.W. Bell et al. (RL JUP | N(2000) BRANCHING RATIOS |
| PDG 82 PL 111B 1 M. Roos <i>et al.</i> (HELS, CIT, CERN) AWAJI 81 Bonn Conf. 352 N. Awaji, R. Kajikawa (NAGO) | $\Gamma(N\pi)/\Gamma_{\text{total}}$ Γ_1/Γ |
| Also NP B197 365 K. Fujiji et al. (NAGO) CUTKOSKY 80 Toronto Conf. 19 R.E. Cutkosky et al. (CMU, LBL) IJP | VALUE (%) DO CUMENT ID TECN COMMENT |
| Also PR D20 2839 R.E. Cutkosky et al. (CMU, LBL) UP SAXON 80 NP B162 522 D.H. Saxon et al. (RHEL, BRIS) UP | 9 ± 4 ANISOVICH 12A DPWA Multichannel 8 AYED 76 IPWA π N \to π N |
| BAKER 79 NP B156 93 R.D. Baker et al. (RHEL) IJP | 25 ALMEHED 72 IPWA $\pi N \rightarrow \pi N$ |
| HOEHLER | 14 |
| BARBOUR 78 NP B141 253 LM. Barbour, R.L. Crawford, N.H. Parsons (GLAS) DEANS 75 NP B96 90 S.R. Deans et al. (SELA, ALAH) UP | $(\Gamma_1\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to N(2000) \to N\eta$ $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| LONGACRE 75 PL 55B 415 R.S. Longacre et al. (LBL, SLAC) IJP DEVENISH 74B NP B81 330 R.C.E. Devenish, C.D. Froggatt, B.R. Martin (DESY+) | VALUEDOCUMENT IDTECNCOMMENT $+0.03$ BAKER79DPWA $\pi^-p \rightarrow n\eta$ |
| LANGBEIN 73 NP B53 251 W. Langbein, F. Wagner (MUNI) IJP | |
| | $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(2000) \to \Lambda K $ $(\Gamma_1 \Gamma_3)^{\frac{1}{2}} / \Gamma$ |
| $N(2000) 5/2^+$ $I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$ Status: ** | VALUE DOCUMENT ID TECN COMMENT not seen SAXON 80 DPWA $\pi^- p \rightarrow \Lambda K^0$ |
| () - 1 | |
| OMITTED FROM SUMMARY TABLE Before the 2012 <i>Review</i> , all the evidence for a $J^P = 5/2^+$ state with | $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(2000) \to \Sigma K$ $(\Gamma_1 \Gamma_4)^{\frac{1}{2}} / \Gamma$ |
| Before the 2012 <i>Review</i> , all the evidence for a $J^+ = 5/2^+$ state with a mass above 1800 MeV was filed under a two-star $N(2000)$. There | VALUE <u>DO CUMENT ID</u> <u>TECN</u> <u>COMMENT</u> |
| is now some evidence from ANISOVICH 12A for two $5/2^+$ states | 0.022 2 DEANS 75 DPWA $\pi N \rightarrow \Sigma K$ 0.05 1 LANGBEIN 73 IPWA $\pi N \rightarrow \Sigma K$ (sol. 2) |
| in this region, so we have split the older data (according to mass) | |
| between two two-star $5/2^+$ states, an $N(1860)$ and an $N(2000)$. | $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \to N(2000) \to \Lambda K $ $(\Gamma_5 \Gamma_3)^{\frac{1}{2}} / \Gamma$ |
| N(2000) BREIT-WIGNER MASS | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| VALUE (MeV) DOCUMENT ID TECN COMMENT | N(2000) PHOTON DECAY AMPLITUDES |
| 1950 to 2150 (≈ 2050) OUR ESTIMATE | Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, |
| 2090 \pm 120 ANISOVICH 12A DPWA Multichannel 2025 AYED 76 IPWA π $N \rightarrow \pi$ N | Journal of Physics, G 33 1 (2006). |
| 1970 | |
| 2175 ALMEHED 72 IPWA $\pi N \rightarrow \pi N$ 1930 DEANS 72 MPWA $\gamma p \rightarrow \Lambda K$ (sol. D) | $N(2000) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$ |
| DEA INS 12 IMP VVA $\gamma p \rightarrow \pi \pi$ (SOI. D) | |
| N(2000) BREIT-WIGNER WIDTH | _ , |
| | $N(2000) ightarrow p\gamma$, helicity-3/2 amplitude $A_{3/2}$ |
| VALUE (MeV) DOCUMENT ID TECN COMMENT 460±100 ANISOVICH 12a DPWA Multichannel | VALUE (GEV ^{-1/2}) DOCUMENT ID TECN COMMENT |
| 157 AYED 76 IPWA $\pi N \rightarrow \pi N$ | 0.050 ± 0.014 3 ANISOVICH 12A DPWA Phase = $(-130\pm40)^{\circ}$ |
| 170 1 LANGBEIN 73 IPWA π $N 	o \Sigma$ K (sol. 2) | N(2000) FOOTNOTES |
| 150 ALMEHED 72 IPWA $\pi N \rightarrow \pi N$ 112 DEANS 72 MPWA $\gamma p \rightarrow \Lambda K$ (sol. D) | 1 Not seen in solution 1 of LANGBEIN 73. |
| $\frac{112}{DEA NS} = \frac{12}{12} \text{ INIT VAR } \gamma p \rightarrow N N \text{ (SOI. D)}$ | Not seen in solution 1 of LANGBEIN 73. Value given is from solution 1 of DEANS 75; not present in solutions 2, 3, or 4. |

1 Not seen in solution 1 of LANGBEIN 73. 2 Value given is from solution 1 of DEANS 75; not present in solutions 2, 3, or 4. 3 This ANISOVICH 12A value is the complex helicity amplitude at the pole position. **N(2000) REFERENCES**

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|-------------------|-------------------------|------------------|
| PDG | 06 | JPG 33 1 | WM. Yao et al. | `(PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| BAKER | 79 | NP B156 93 | R.D. Baker et al. | (RHEL) IJP |
| AYED | 76 | Thesis CEA-N-1921 | R. Ayed | (SACL) IJP |
| DEANS | 75 | NP B96 90 | S.R. Deans et al. | (SFLA, ÄLAH) IJP |
| LAN GBEIN | 73 | NP B53 251 | W. Langbein, F. Wagner | (MUNI) IJP |
| ALMEHED | 72 | NP B40 157 | S. Almehed, C. Lovelace | (LUND, RUTG)IJP |
| DEANS | 72 | PR D6 1906 | S.R. Deans et al. | ` (SFLA) IJP |
| | | | | |

RFAI PART

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-------------|-----------------------------------------|
| 2030±110 | ANISOVICH | 12A | DPWA | Multichannel |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 1779 | ARNDT | 04 | DPWA | π N \rightarrow π N, η N |
| -2×IMAGINARY PART | | | | |

N(2000) POLE POSITION

| - ZAIMAUMANI TANI | | | |
|-------------------------------|------------------------|----------|--------------|
| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
| 480±100 | ANISOVICH 12A | DPWA | Multichannel |
| We do not use the following d | lata for averages fits | limits e | tc |

248 ARNDT 04 DPWA $\pi N \rightarrow \pi N$, ηN

Baryon Particle Listings *N*(2040), *N*(2060)

 $N(2040) 3/2^{+}$

 $J^P = \frac{3}{2}^+$ Status: *

OMITTED FROM SUMMARY TABLE

| N | (2040) | MASS |
|---|--------|------------|
| | 2070 | , ,,,,,,,, |

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------|--------------|-----|------|-----------------------------------------------------------------|
| 2052 ⁺¹³ ₋₂₁ OUR AVERAGE | | | | |
| $2040 + \frac{3}{4} \pm 25$ | ABLIKIM | 09в | BES2 | $J/\psi \rightarrow p \overline{p} \pi^0$ |
| $2068 \pm 3^{+15}_{-40}$ | ABLIKIM | 06K | BES2 | $J/\psi \rightarrow p \overline{n} \pi^-, n \overline{p} \pi^+$ |

N(2040) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-------------|-----|------|-----------------------------------------------------------------|
| 191±33 OUR AVERAGE | | | | |
| 230± 8±52 | ABLIKIM | 09в | BES2 | $J/\psi \rightarrow \rho \overline{\rho} \pi^0$ |
| $165 \pm 14 \pm 40$ | ABLIKIM | 06K | BES2 | $J/\psi \rightarrow p \overline{n} \pi^-, n \overline{p} \pi^+$ |

N(2040) REFERENCES

 ABLIKIM
 09B
 PR D80 052004
 M. Ablikim et al.
 (BES2 Collab.)

 ABLIKIM
 06K
 PRL 97 062001
 M. Ablikim et al.
 (BES2 Collab.)

 $N(2060) 5/2^-$

$$I(J^P) = \frac{1}{2}(\frac{5}{2})$$
 Status: **

OMITTED FROM SUMMARY TABLE

Before our 2012 $\it Review$, this state appeared in our Listings as the $\it N(2200)$.

The latest $\ensuremath{\mathsf{GWU}}$ analysis (ARNDT 06) finds no evidence for this resonance.

N(2060) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|----------------------|----------|-----------|------------------------------------|
| ≈ 2060 OUR ESTIMATE | | | | |
| 2060 ± 15 | ANISOVICH | 12A | DPWA | Multichannel |
| 1900 | BELL | 83 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 2180 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1920 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| 2228 ± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | ing data for average | es, fits | , limits, | etc. • • • |
| 2217 ± 27 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |

N(2060) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN COMMENT |
|-----------------------------------|------------------|---------|-----------------------------------------------|
| 375 ± 25 | ANISOVICH | 12A | DPWA Multichannel |
| 130 | BELL | 83 | DPWA $\pi^- p \rightarrow \Lambda K^0$ |
| 400 ± 100 | CUTKOSKY | | IPWA $\pi N \rightarrow \pi N$ |
| 220 | SAXON | 80 | DPWA $\pi^- p \rightarrow \Lambda K^0$ |
| 310± 50 | HOEHLER | 79 | IPWA $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 481 ± 17 | BATINIC | 10 | DPWA π N \rightarrow N π , N η |

N(2060) POLE POSITION

REAL PART

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------------------|----------|---------------|-----------------------------------------|
| 2040 ± 15 | ANISOVICH | 12A | DPWA | Multichannel |
| 2100 ± 60 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the follow | wing data for average | s, fits, | , limits, e | etc. • • • |
| 2144 ± 31 | BATINIC | 10 | DPWA | $\pi \ N \rightarrow \ N \pi, \ N \eta$ |
| -2×IMAGINARY PART | | | | |
| -ZXIMAGINANI FANI | | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| | DOCUMENT ID ANISOVICH | 12A | $\overline{}$ | COMMENT Multichannel |
| VALUE (MeV) | | | DPWA | |
| <u>VALUE (MeV)</u> 390±25 | A NISOVICH CUT KOSKY | 80 | DPWA IPWA | Multichannel $\pi N \to \pi N$ |

N(2060) ELASTIC POLE RESIDUE

MODULUS Irl

| mobocos p | | | | |
|-------------------------|-----------------------------|---------|-----------|---------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 19± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 20 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for averages | , fits, | limits, e | etc. • • • |
| 26 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |

| PHASE <i>θ</i> | | | | |
|-------------------------|-------------------------------|---------|-------------|---------------------------------|
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -125 ± 20 | ANISOVICH | 12A | DPWA | Multichannel |
| -90 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | he following data for average | s, fits | , limits, e | etc. • • • |
| - 71 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |

N(2060) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

| Normalized | residue | in | $N\pi \rightarrow$ | N(2060) → | Nη |
|------------|---------|----|--------------------|-----------|----|
| | | | | | |

| MODULUS (%) | PHASE (°) | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----------|--------------|-----|------|--------------|
| 5 ± 3 | 40 ± 25 | ANISOVICH | 12A | DPWA | Multichannel |

Normalized residue in $N\pi \to N(2060) \to \Lambda K$

| MODULUS (%) | DOCUMENT ID | | TECN | COMMENT |
|-------------|-------------|-----|------|--------------|
| 1 ± 0.5 | ANISOVICH | 12A | DPWA | Multichannel |

Normalized residue in $N\pi \to N(2060) \to \Sigma K$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|-------------|--------------|----------------|------|--------------|
| 4 ± 2 | -70 ± 30 | A NISOVICH 12A | DPWA | Multichannel |

N(2060) DECAY MODES

| | Mode |
|-----------------------|------------------------------------------------------|
| Γ ₁ | $egin{array}{c} N\pi \ N\eta \ \LambdaK \end{array}$ |
| Γ_2 Γ_3 | N η |
| Γ_3 | ΛK |
| Γ_4 | ΣΚ |

N(2060) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|---------------------------------------|----------------------------|---------|-----------|------------------------------------------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 8±2 | ANISOVICH | 12A | DPWA | Multichannel | |
| 10±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 7 ± 2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • | |
| 13±4 | BATINIC | 10 | DPWA | $\pi {\it N} ightarrow {\it N} \pi$, ${\it N} \eta$ | |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 4 ±2 | ANISOVICH | 12A | DPWA | Multichannel | |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • | |
| 0.2 ± 1.0 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ | |
| | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | V(2060) → Nη | | | (Γ ₁ Γ ₂) ¹ ⁄⁄₂/Γ |
|------------------------------------------------------------------------------------|--------------|----|------|-----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.066 | BAKER | 79 | DPWA | $\pi^- p \rightarrow n \eta$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to N(2)$ | 060) → <i>∧K</i> | | | (Γ ₁ Γ ₃) ¹ ⁄ ₂ /Γ |
|---------------------------------------------------------------------------------------|------------------|----|------|-----------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.03 | BELL | | | $\pi^- p \rightarrow \Lambda K^0$ |
| -0.05 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| | | | | |

| Γ(ΣΚ)/Γ _{total} | | | | | Γ4/Γ |
|--------------------------|--------------|-----|------|--------------|------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 3±2 | ANISOVICH | 12A | DPWA | Multichannel | |

N(2060) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$N(2060) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| | , | |
|-------------------|----------------------------|-----------------------------------|
| VALUE (GeV-1/2) | DO CUMENT ID | TECN COMMENT |
| 0.065 ± 0.012 | ¹ ANISOVICH 12A | DPWA Phase = $(15 \pm 8)^{\circ}$ |

$N(2060) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| $VALUE$ (GeV $^{-1/2}$) | DO CUMENT ID | TECN | COMMENT |
|--------------------------|----------------------------|------|-----------------------------|
| $0.055 + 15 \\ -35$ | ¹ ANISOVICH 12/ | DPWA | Phase = $(15 \pm 10)^\circ$ |

N(2060) FOOTNOTES

 $^{^{}m 1}{
m This}$ ANISOVICH 12A value is the complex helicity amplitude at the pole position.

 Γ_1/Γ

N(2060) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|------------------|-----------------------|-----------------|
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | ` (ZAGR) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL)IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL)IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS)IJP |
| BAKER | 79 | NP B156 93 | R.D. Baker et al. | ` (RHEL)IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |

$N(2100) 1/2^{+}$

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: *

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(2100) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN COMMENT |
|----------------------------------|--------------------|---------|------------------------------------------------|
| ≈ 2100 OUR ESTIMATE | | | · —— |
| 2125 ± 75 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ |
| 2050 ± 20 | HOEHLER | 79 | IPWA $\pi N \rightarrow \pi N$ |
| • • • We do not use the followin | g data for average | s, fits | , limits, etc. • • • |
| 2157 ± 42 | BATINIC | 10 | DPWA π N \rightarrow N π , N η |
| $2068 \pm 3^{+15}_{-40}$ | ABLIKIM | 06K | BES2 $J/\psi ightarrow (p\pi^-)\overline{n}$ |
| 2084 ± 93 | VRA NA | 00 | DPWA Multichannel |
| $1986 \pm 26 {}^{+ 10}_{- 30}$ | PLOETZKE | 98 | SPEC $\gamma \rho \rightarrow \rho \eta'(958)$ |

N(2100) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|---------|--------------|--------------------------------------------------|
| 260±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 200± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | , limits, et | tc. • • • |
| 355 ± 88 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi, N \eta$ |
| $165 \pm 14 \pm 40$ | ABLIKIM | 06K | BES2 | $J/\psi \rightarrow (\rho \pi^{-}) \overline{n}$ |
| 1077 ± 643 | VRA NA | 00 | DPWA | Multichannel |
| $296 \pm 100 + 60 \\ -10$ | PLOETZKE | 98 | SPEC | $\gamma p \rightarrow p \eta'(958)$ |

N(2100) POLE POSITION

REAL PART

| INEME I MINI | | | | |
|-------------------------------------------|------------------|----------|-------------|---------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 2120 ± 40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | es, fits | , limits, e | tc. • • • |
| 2120 ± 47 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 1810 | VRA NA | 00 | DPWA | Multichannel |
| not seen | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | | | | |

-2×IMAGINARY PART

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------------|-----------|-----------|---------------------------------------------|
| 240 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | ng data for averag | es, fits, | , limits, | etc. • • • |
| 346 ± 80 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 622 | VRA NA | 00 | DPWA | Multichannel |
| not seen | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

N(2100) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN COMMENT |
|---------------------------------|------------------|---------|--------------------------------------------------|
| 14±7 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ |
| ● ● We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 33 | BATINIC | 10 | DPWA π N $ ightarrow$ N π , N η |
| PHASE 0 VALUE (°) | DO CUMENT ID | | TECN COMMENT |
| 35 ± 25 | CUTKOSKY | | $\overline{IPWA} \overline{\pi N \to \pi N}$ |
| | data for average | s, fits | , limits, etc. • • • |
| -59 | BATINIC | 10 | DPWA π N \rightarrow N π , N η |

N(2100) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ | _ |
| Γ_2 | $N\eta$ | (61±60) % |
| Γ_3 | ΛK | |
| Γ_4 | $N\pi\pi$ | |
| Γ_5 | $\Delta(1232)\pi$, $	extit{P}	ext{-wave}$ | |
| Γ_6 | $N\rho$, $S=1/2$, P -wave | |
| Γ ₇ | $N(\pi\pi)_{S-\text{wave}}^{I=0}$ | |

N(2100) BRANCHING RATIOS

| 21 ± 20 | VRANA | 00 | DPWA | Multichannel | |
|-------------------------------------------|------------------------------|---------|-----------|---------------------------------------------------------------------|--------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | . 3/ . |
| $\Gamma(\Lambda K)/\Gamma_{\text{total}}$ | | | | | $\Gamma_3/1$ |
| 83± 5 | BATINIC | 10 | DPWA | $\pi {\it N} \rightarrow {\it N} \pi \text{, } {\it N} \eta$ | |
| • • • We do not use the | e following data for average | s, fits | , limits, | etc. • • • | |
| 61±61 | VRANA | 00 | DPWA | Multichannel | |
| Γ(Nη)/Γ _{total} VALUE (%) | DOCUMENT ID | | TECN | COMMENT | Γ2/ |
| 2±5 | VRANA | 00 | DPWA | Multichannel | |
| 16±5 | BATINIC | 10 | | $\pi \: N \: \to \: \: N \: \pi \text{, } \: N \: \eta$ | |
| • • • We do not use the | e following data for average | s, fits | , limits, | etc. • • • | |
| 10±4 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 12±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |

| $\Gamma(\Delta(1232)\pi, P$ -wave $)/\Gamma_{total}$ | | | | | Γ_5/Γ |
|-----------------------------------------------------------------|--------------|----|------|--------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 2 ± 1 | VRANA | 00 | DPWA | Multichannel | |
| $\Gamma(N\rho, S=1/2, P-wave)/\Gamma_{total}$ | | | | | Γ ₆ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 4±1 | VRANA | 00 | DPWA | Multichannel | |
| $\Gamma(N(\pi\pi)_{S-\text{wave}}^{I=0})/\Gamma_{\text{total}}$ | | | | | Γ ₇ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 10±1 | VRANA | 00 | DPWA | Multichannel | |

N(2100) REFERENCES

| BATINIC ABLIKIM ARNDT VRANA PLOETZKE | 10 06 K 06 00 98 | PR C82 038203 PRL 97 062001 PR C74 045205 PRPL 328 181 PL B444 555 | M. Batinic et al. M. Ablikim et al. R.A. Arndt et al. T.P. Vrana, S.A. Dytman,, TS.H. Lee R. Ploetzke et al. (Bonr | SAPHIR Collab.) |
|--------------------------------------------------|------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| CUTKOSKY Also | 80 | Toronto Conf. 19 PR D20 2839 | R.E. Cutkosky <i>et al.</i> R.E. Cutkosky <i>et al.</i> | (CMU, LBL)IJP (CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |

N(2120) 3/2

 $\Gamma(N\pi)/\Gamma_{\text{total}}$

$$I(J^P) = \frac{1}{2}(\frac{3}{2})$$
 Status: **

OMITTED FROM SUMMARY TABLE

Before the 2012 $\it Review, \ {\rm all} \ {\rm the \ evidence \ for \ a} \ \it J^P = 3/2^- \ {\rm state}$ with a mass above 1800 MeV was filed under a two-star N(2080). There is now evidence from ANISOVICH 12A for two $3/2^-$ states in this region, so we have split the older data (according to mass) between a three-star N(1875) and a two-star N(2120).

N(2120) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------|-----------------------|-----|------|---------------------------|
| 2120 OUR ESTIMATE | | | | |
| 2150 ± 60 | ANISOVICH | 12A | DPWA | Multichannel |
| 2060 ± 80 | ¹ cutkosky | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2081 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

N(2120) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------|-------------|-----|------|-----------------------------------------------|
| 330 ± 45 | ANISOVICH | 12A | DPWA | Multichannel |
| 300 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (higher } m)$ |
| 265 ± 40 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

Baryon Particle Listings *N*(2120), *N*(2190)

N(2120) POLE POSITION

| REAL PART VALUE (MeV) 2110 ±50 2050 ± 70 | DOCUMENT ID ANISOVICH CUTKOSKY | 12A 80 | | $\frac{\textit{COMMENT}}{\textit{Multichannel}}$ $\pi \ \textit{N} \rightarrow \ \pi \ \textit{N} \ (\textit{higher} \ \textit{m})$ | I |
|---------------------------------------------|--------------------------------|-----------|------|-------------------------------------------------------------------------------------------------------------------------------------|---|
| -2×IMAGINARY PART VALUE (MeV) 340±45 | DOCUMENT ID | 12A | | COMMENT Multichannel | |
| 200 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (higher } m)$ | |

N(2120) ELASTIC POLE RESIDUE

MODULUS |r|

 $2\!\pm\!1.5$

E/M \/E

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------|-------------|-----|------|-----------------------------------------------|
| 13± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 30 ± 20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (higher } m)$ |
| PHASE θ | | | | |
| VALUE (°) | DOCUMENT ID | | TECN | COMMENT |
| -20 ± 10 | ANISOVICH | 12A | DPWA | Multichannel |
| 0 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (higher } m)$ |

N(2120) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \rightarrow N(2120) \rightarrow \Lambda K$

| MODULUS (%) | PHASE (*) | DOCUMENT ID | IECN | COMMENT | |
|---------------|----------------------------|--------------------------------|----------|--------------|--|
| $3\!\pm\!1$ | 100 ± 30 | ANISOVICH | 12A DPWA | Multichannel | |
| Normalized re | sidue in $N\pi ightarrow$ | $N(2120) \rightarrow \Sigma K$ | | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |

ANISOVICH 12A DPWA Multichannel

N(2120) DECAY MODES

| | Mode |
|----------------|--------|
| Γ ₁ | $N\pi$ |

N(2120) BRANCHING RATIOS

| I(Nπ)/I _{total} | | | | 11/1 |
|--------------------------|--------------|-----|------|-----------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 6±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 14±7 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N \text{ (higher } m)$ |
| 6±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | | | | |

N(2120) PHOTON DECAY AMPLITUDES

| $N(2120) \rightarrow$ | $p\gamma$, helicity-1/2 | amplitude A _{1/2} |
|-----------------------|--------------------------|----------------------------|
|-----------------------|--------------------------|----------------------------|

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|---------------|-------------------------|-----|------|--------------------------------|
| 0.125 ± 0.045 | ² A NISOVICH | 12A | DPWA | Phase = $(-55 \pm 20)^{\circ}$ |

$N(2120) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-------------------|----------------------------|------|--------------------------------|
| 0.150 ± 0.060 | ² ANISOVICH 12A | DPWA | Phase $= (-35 \pm 15)^{\circ}$ |

N(2120) FOOTNOTES

N(2120) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|------------------|-----------------------|--------------|
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | `(CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) |

N(2190) 7/2

$$I(J^P) = \frac{1}{2}(\frac{7}{2})$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters $111B\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G $33\ 1\ (2006)$.

N(2190) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|----------------------------------------|
| 2100 to 2200 (≈ 2190) OUR EST | MATE | | | |
| 2180 ± 20 | ANISOVICH | 12A | DPWA | Multichannel |
| 2152.4 ± 1.4 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2127 ± 9 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 2200 ±70 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2140 ±12 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2140 ±40 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, e | tc. • • • |
| 2125 ± 61 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 2192.1 ± 8.7 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2168 ±18 | VRANA | 00 | DPWA | Multichannel |
| 2131 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 2180 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |

N(2190) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|----------|-------------|----------------------------------------|
| 300 to 700 (≈ 500) OUR ESTIMAT | Έ | | | |
| 335 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 484 ± 13 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 550± 50 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 500 ± 150 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 390± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 270 ± 50 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | s, fits, | , limits, e | etc. • • • |
| 381 ± 160 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ |
| 726± 62 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 453±101 | VRANA | 00 | DPWA | Multichannel |
| 476 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 80 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |

N(2190) POLE POSITION

REAL PART

| REAL PART | | | | |
|----------------------------|--------------------------|---------|-------------|---------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 2050 to 2100 (≈ 2075) OUI | R ESTIMATE | | | |
| 2150 ± 25 | ANISOVICH | 12A | DPWA | Multichannel |
| 2070 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 2042 | ¹ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 2100 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the fo | llowing data for average | s, fits | , limits, e | etc. • • • |
| 2063 ± 32 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 2076 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 2107 | VRANA | 00 | DPWA | Multichannel |
| 2030 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 2060 | ARNDT | 91 | DPWA | $\pi{\it N} \rightarrow \pi{\it N} {\rm Soln} {\rm SM90}$ |
| -2×IMAGINARY PAR | т | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 400 to 520 (≈ 450) OUR E | _ | | | |
| 330± 30 | ANISOVICH | 12A | DPWA | Multichannel |
| 520 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 482 | $^{ m 1}$ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 400±160 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the fo | llowing data for average | s, fits | , limits, e | etc. • • • |
| 330±101 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| 502 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 380 | VRANA | 00 | DPWA | Multichannel |
| 460 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 464 | ARNDT | 91 | DEWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

N(2190) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|------------------|----------|-------------|--------------------------------------------------------------------|
| 30± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| 72 | ARNDT | 06 | DPWA | π N \rightarrow π N, η N |
| 45 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 25 ± 10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following of | data for average | s, fits, | , limits, e | etc. • • • |
| 34 | BATINIC | 10 | DPWA | $\pi N \rightarrow N \pi$, $N \eta$ |
| 68 | ARNDT | 04 | DPWA | π N \rightarrow π N, η N |
| 46 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 54 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |

 $^{^1}$ CUTKOSKY 80 finds a lower mass D_{13} resonance, as well as one in this region. Both are listed here. 2 This ANISOVICH 12A value is the complex helicity amplitude at the pole position.

| VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------|------------------------|----------|-------------|---------------------------------------------|--|
| 30 ± 10 | ANISOVICH | 12A | DPWA | Multichannel | |
| -32 | ARNDT | 06 | DPWA | π N \rightarrow π N, η N | |
| -30 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| ullet $ullet$ We do not use the fol | lowing data for averag | es, fits | , limits, e | etc. • • • | |
| -19 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi$, $N\eta$ | |
| -32 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| -23 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| -44 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ | |

N(2190) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \to N(2190) \to \Lambda K$

| MODULUS (%) | PHASE (°) | DOCUMENT ID | TECN | COMMENT |
|-------------|-----------|--------------|------|--------------|
| 3±1 | 20 ± 15 | ANISOVICH 12 | | Multichannel |

N(2190) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) | |
|-----------------------|--------------------------|------------------------------|--|
| $\overline{\Gamma_1}$ | Νπ | 10-20 % | |
| Γ_2 | $N\eta$ | (0.0 ± 1.0) % | |
| Γ_3 | $N \omega$ | seen | |
| Γ_4 | ΛK | seen | |
| Γ_5 | ΣΚ | | |
| Γ ₆ | $N\pi\pi$ | seen | |
| Γ_7 | $N \rho$ | seen | |
| Γ ₈ | $p\gamma$ | 0.02-0.06 % | |
| Γ9 | $p\gamma$, helicity=1/2 | 0.02-0.04 % | |
| Γ_{10} | $p\gamma$, helicity=3/2 | 0.002-0.02 % | |

N(2190) BRANCHING RATIOS

| N(219 | U) BRANCHIN | IG KA | 11103 | |
|----------------------------------------------------------------------------------------|-----------------------------|----------------|--------------|-----------------------------------------------------------------------------------------------------------------------------|
| Γ(Nπ)/Γ _{total} _{VALUE} (%) | DO CUMENT ID | | TECN | Γ_1/Γ |
| 10 to 20 OUR ESTIMATE 16 ± 2 | ANISOVICH | 12A | DPWA | Multichannel |
| 23.8 ± 0.1 22 ± 1 12 ± 6 | ARNDT MANLEY CUTKOSKY | 06 92 80 | IPWA IPWA | $ \pi N \to \pi N, \eta N \pi N \to \pi N & N \pi \pi \pi N \to \pi N $ |
| 14 ± 2 16 ± 4 | HOEHLER HENDRY | 79 78 | MP WA | $\begin{array}{ccc} \pi \ {\it N} \ \rightarrow & \pi \ {\it N} \\ \pi \ {\it N} \ \rightarrow & \pi \ {\it N} \end{array}$ |
| • • We do not use the followin | | | | |
| 18 ±12 | BATINIC | 10 | | $\pi N \rightarrow N\pi, N\eta$ |
| 23.0± 0.2 | ARNDT | 04 | | $\pi N \rightarrow \pi N, \eta N$ |
| 20 ± 4 23 | VRA NA AR NDT | 00 95 | | Multichannel $\pi N \rightarrow N \pi$ |
| $\Gamma(N\eta)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 0 ±1 | VRA NA | 00 | DPWA | Multichannel |
| \bullet \bullet We do not use the followin | g data for averag | es, fits | , limits, | etc. • • • |
| 0.1 ± 0.3 | BATINIC | 10 | DPWA | $\pi N \rightarrow N\pi, N\eta$ |
| $\Gamma(N\omega)/\Gamma_{ m total}$ | | | | Г ₃ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| seen | WILLIAMS | 09 | IPWA | $\gamma p \rightarrow p \omega$ |
| Γ(ΛΚ)/Γ _{total} | DOCUMENT ID | | TECN | Γ ₄ /Γ |
| 0.5 ± 0.3 | ANISOVICH | | | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(2)$ | 190) → <i>ΛK</i> | | | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
| VALUE | DO CUMENT ID | | | |
| -0.02 | BELL | 83 | | $\pi^- p \rightarrow \Lambda K^0$ |
| -0.02 | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(2)$ | | | | |
| VALUE | DO CUMENT ID | | | |
| -0.25 ± 0.03 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| | | | | |

VRA NA

 $\Gamma(N\rho, S=3/2, D-wave)/\Gamma_{total}$

VALUE (%)

 29 ± 28

N(2190) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$N(2190) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| <u>VALUE</u> (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------|-------------|-----|------|--------------|
| -0.065 ± 0.008 | ANISOVICH | 12A | DPWA | Multichannel |
| M(0100) - L-U-in- 2/0 - | | | | |

$N(2190) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| <u>VALUE (GeV - 1/2)</u> | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|-----|------|--------------|
| 0.035 ± 0.017 | ANISOVICH | 12A | DPWA | Multichannel |

$\mathit{N}(2190) ightarrow \mathit{p}\,\gamma$, ratio of helicity amplitudes $A_{3/2}/A_{1/2}$

N(2190) $\gamma p \rightarrow \Lambda K^+ AMPLITUDES$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \rightarrow N(2)$ | | (E ₄ _ amplitude) | | |
|---------------------------------------------------------------------------------------------------|------------------------|------------------------------|----------------|------------------------------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | | TECN | |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, etc. | • • • |
| 2.5 ±1.0 | WORKMAN | 90 | DPWA | |
| 2.04 | TANABE | 89 | DPWA | |
| $p\gamma \rightarrow N(2190) \rightarrow \Lambda K^+ pha$ | _ | | | (E ₄ _ amplitude) |
| VALUE (degrees) | DO CUMENT ID | | TECN | |
| ● We do not use the following | data for average | s, fits | , limits, etc. | • • • |
| - 4 ±9 | WORKMAN | 90 | DPWA | |
| -27.5 | TANABE | 89 | DPWA | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } p \gamma \to N(2)$ | 190) → ΛK ⁺ | - | | (Ma_ amplitude) |

| $(i \ i' \ f)$ '/ total iii $p \gamma \rightarrow r$ | (2190) → //K· | (W4_ allip | ,III LI |
|------------------------------------------------------|-----------------------------|----------------------|---------|
| VALUE (units 10 ⁻³) | DO CUMENT ID | TECN | |
| • • • We do not use the follow | ing data for averages, fits | , limits, etc. • • • | |
| -7.0 ± 0.7 | WORKMAN 90 | DPWA | |
| _ 5. 70 | TANABE 89 | DPW/A | |

N(2190) FOOTNOTES

N(2190) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|-------------------|------------------------------------|--------------------|
| BATINIC | 10 | PR C82 038203 | M. Batinic et al. | (ZAGR) |
| WILLIAMS | 09 | PR C80 065209 | | CEBAF CLAS Collab. |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lo | |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI) BRCO) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt ét al. | (VPI, TELE) IJP |
| WORKMAN | 90 | PR C42 781 | R.L. Workman | ` (VPI) |
| TANABE | 89 | PR C39 741 | H. Tanabe, M. Kohno, C. Bennhold | (MÀNZ) |
| Also | | NC 102A 193 | M. Kohno, H. Tanabe, C. Bennhold | (MANZ) |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | ` (RL)IJP |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | ` (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IND) |
| | | | | |

$N(2220) 9/2^{+}$

 Γ_0/Γ

TECN COMMENT

00 DPWA Multichannel

 $I(J^P) = \frac{1}{2}(\frac{9}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters $\mathbf{111B}$ 1 (1982). Some further obsolete results published before 1980 were last included in our 2006 edition, Journal of Physics, G $\mathbf{33}$ 1 (2006).

N(2220) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------------|----------------------------|---------|-------------|--------------------------------------|
| 2200 to 2300 (≈ 2250) (| OUR ESTIMATE | | | |
| 2316.3± 2.9 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2230 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2205 ± 10 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2300 ±100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the f | following data for average | s. fits | . limits. e | etc. • • • |

 $^{^1}$ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

| N(2220), | N(2250) |
|----------|---------|
|----------|---------|

| 2270 ± 11 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
|-----------|-------|----|-------------------------------------------|
| 2258 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |

N(2220) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|-------------------|---------|-------------|--------------------------------------|
| 350 to 500 (≈ 400) OUR ESTIMAT | Έ | | | |
| 633± 17 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 500 ± 150 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 365 ± 30 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 450±150 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ |
| ● • We do not use the following | data for average: | s, fits | , limits, e | etc. • • • |
| 366± 42 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 334 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

N(2220) POLE POSITION

REAL PART

| INDIVE I MINI | | | | |
|---------------------------------|----------------------|---------|-------------|---------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 2130 to 2200 (≈ 2170) OUR EST | MATE | | | |
| 2150 ± 35 | ANISOVICH | 12A | DPWA | Multichannel |
| 2199 | ARNDT | | | $\pi N \rightarrow \pi N$, ηN |
| 2135 | ¹ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 2160 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • We do not use the following | g data for average | s, fits | , limits, e | etc. • • • |
| 2209 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2203 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 2253 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

| -2×IMAGINARY PART | | | | |
|-------------------------------|----------------------|---------|-------------|--------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 400 to 560 (≈ 480) OUR ESTIMA | TE | | | |
| 440 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 372 | ARNDT | | | $\pi N \rightarrow \pi N$, ηN |
| 400 | ² HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 480 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | s, fits | , limits, e | etc. • • • |
| 564 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 5 3 6 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 640 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |

N(2220) ELASTIC POLE RESIDUE

MODULUS |r|

| 1.1 | | | | |
|--------------------------------------|-------------------|---------|-----------|--------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 60±12 | ANISOVICH | 12A | DPWA | Multichannel |
| 33 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 40 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 45 ± 20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following of | lata for averages | , fits, | limits, e | etc. • • • |
| 96 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 68 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 85 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |
| PHASE 0 | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -58 ± 12 | ANISOVICH | 12A | DPWA | Multichannel |
| -33 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| -50 | HOFHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |

| - 45 ± 25 | CUINUSKY | 80 | IP VVA $\pi N \rightarrow$ | π IV |
|------------------------------------------------|-------------------|---------|----------------------------|---------------------------|
| $\bullet~\bullet~$ We do not use the following | data for averages | , fits, | limits, etc. ● ● | • |
| -71 | ARNDT | 04 | DPWA $\pi N \rightarrow$ | π N, η N |
| -43 | ARNDT | 95 | DPWA $\pi N \rightarrow$ | $N\pi$ |
| -62 | ARNDT | 91 | DPWA $\pi N \rightarrow$ | $\pi\mathrm{N}$ Soln SM90 |
| | | | | |

N(2220) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------|------------|------------------------------|
| Γ ₁ | Nπ | 15-25 % |
| Γ ₁ Γ ₂ Γ ₃ | N η Λ Κ | |

N(2220) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ1/Γ |
|--------------------------------------|-------------------|---------|-------------|--------------------------------------|------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | |
| 15 to 25 OUR ESTIMATE | | | | | |
| 24 ±5 | ANISOVICH | 12A | DPWA | Multichannel | |
| 24.6 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| 15 ±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 18.0 ± 1.5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 12 ±4 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the following | data for averages | , fits, | , limits, e | etc. • • • | |
| 20.0 ± 0.6 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ | |
| 26 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to I$ | | (Γ ₁ Γ ₃) ^{1/2} /Γ | | |
|------------------------------------------------------------------------------------|--------------|----------------------------------------------------|------|--------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| not required | BELL | | | $\pi^- \rho \rightarrow \Lambda K^0$ |
| not seen | SAXON | 80 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |

N(2220) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$N(2220) \rightarrow p\gamma$, helicity-1/2 amplitude A_{1/2}

| | - | -, | _ | | |
|------------------|---|--------------|-----|------|--------------|
| VALUE (GeV -1/2) | _ | DO CUMENT ID | | TECN | COMMENT |
| < 0.01 | 3 | ANISOVICH | 12A | DPWA | Multichannel |

$N(2220) ightarrow ho \gamma$, helicity-3/2 amplitude $A_{3/2}$

| VALUE (GeV - 1/2) | DO CUMENT ID | | TECN | COMMENT |
|-------------------|-------------------------|-----|------|--------------|
| < 0.01 | ³ A NISOVICH | 12A | DPWA | Multichannel |

N(2220) FOOTNOTES

 1 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. 2 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. 3 This ANISOVICH 12A value is the complex helicity amplitude at the pole position.

N(2220) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH ARNDT PDG ARNDT ARNDT HOEHLER ARNDT BELL PDG CUTKOSKY Also SAXON HOEHLER Also | 12A 06 06 04 95 93 91 83 82 80 80 | EPJ A48 15 PR C74 045205 JPG 33 1 PR C69 035213 PR C59 035213 PR C52 2120 # N Newsletter 9 1 PR D43 2213 PB 222 389 PL 111B 1 Toronto Conf. 19 PR D20 2839 NP B162 522 PDAT 12-1 Toronto Conf. 3 | A.V. Anisovich et al. R.A. Arndt et al. WM. Yao et al. R.A. Arndt et al. R.A. Arndt et al. G. Hohler R.A. Arndt et al. K.W. Bell et al. M. Roos et al. R.E. Cutkosky et al. R.E. Cutkosky et al. D.H. Saxon et al. G. Hohler et al. R. K.W. | (BONN, PNPI) (GWU) (PDG Collab.) (GWU, TRIU) (VPI, BRCO) (KARL) (VPI, TELE) IJP (RL) IJP (HELS, CIT, CERN) (CMU, LBL) IJP (CMU, LBL) IJP (RHEL, BRIS) IJP (KARLT) IJP (KARLT) IJP |
|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Also | 78 | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| Also | | ANP 136 1 | A.W. Hendry | (IND) |

N(2250) 9/2⁻

 $I(J^P) = \frac{1}{2}(\frac{9}{2})$ Status: ***

Some obsolete results published before 1980 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

N(2250) BREIT-WIGNER MASS

| VALUE (MeV) | | | TECN | COMMENT |
|-------------------------------------------------|------------------|---------|-------------|--------------------------------------|
| 2200 to 2350 (≈ 2275) OUR ESTIM | <i>I</i> ATE | | | |
| 2280 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 2302± 6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 2250± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2268± 15 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2200 ± 100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| \bullet \bullet We do not use the following | data for average | s, fits | , limits, e | tc. • • • |
| 2376 ± 43 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2291 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

N(2250) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|--------------------------------------|
| 230 to 800 (≈ 500) OUR ESTIMAT | E | | | |
| 520± 50 | ANISOVICH | 12A | DPWA | Multichannel |
| 628± 28 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 480 ± 120 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 300 ± 40 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 350 ± 100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, e | tc. • • • |
| 924 ± 178 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 772 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| | | | | |

N(2250) POLE POSITION DOCUMENT ID

COMMENT

| REA | L | PAR | T |
|-----|---|-----|---|
| | | | |

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|-----------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2150 to 2250 (≈ 2200) OUR EST | MATE | | | |
| 2195 ± 45 | ANISOVICH | 12A | DPWA | Multichannel |
| 2217 | | | | $\pi N \rightarrow \pi N$, ηN |
| 2187 | ¹ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 2150 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | s, fits, | limits, e | etc. • • • |
| 2238 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 2087 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 2243 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | | | | |
| -2×IMAGINARY PART | DO CUMENT ID | | TECN | COMMENT |
| -2×IMAGINARY PART VALUE (MeV) 350 to 550 (≈ 450) OUR ESTIMA | DOCUMENT ID | | TECN | COMMENT |
| VALUE (MeV) | | | | <u>COMMENT</u> Multichannel |
| <u>VALUE (MeV)</u> 350 to 550 (≈ 450) OUR ESTIMA | TE A NISOVICH | 12A | DPWA | |
| <u>VALUE (MeV)</u> 350 to 550 (≈ 450) OUR ESTIMA 470± 50 | TE A NISOVICH | 12A 06 | DPWA DPWA | Multichannel $\pi N \rightarrow \pi N, \eta N$ |
| <u>VALUE (MeV)</u> 350 to 550 (≈ 450) OUR ESTIMA 470± 50 431 | ANISOVICH ARNDT | 12A 06 93 | DPWA DPWA SPED | Multichannel $\pi N \rightarrow \pi N, \eta N$ |
| $rac{\textit{VALUE}(\text{MeV})}{350}$ to 550 (≈ 450) OUR ESTIMA $470\pm\ 50$ 431 388 | A NISOVICH AR NDT 1 HOEHLER CUT KOSKY | 12A 06 93 80 | DPWA DPWA SPED IPWA | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ |
| <u>WALUE (MeV)</u> 350 to 550 (≈ 450) OUR ESTI MA 470 ± 50 431 388 360 ± 100 | A NISOVICH AR NDT 1 HOEHLER CUT KOSKY | 12A 06 93 80 s, fits, | DPWA DPWA SPED IPWA limits, 6 | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ |
| VALUE (MeV) 350 to 550 (\approx 450) OUR ESTI MA 470 \pm 50 431 388 360 \pm 100 • • • We do not use the following | TE ANISOVICH ARNDT HOEHLER CUTKOSKY data for average | 12A 06 93 80 s, fits, | DPWA DPWA SPED IPWA limits, 6 | Multichannel $ \pi \ N \to \pi \ N, \ \eta \ N \\ \pi \ N \to \pi \ N \\ \pi \ N \to \pi \ N \\ \pi \ N \to \pi \ N \\ \text{tt.} \bullet \bullet \bullet $ |

N(2250) ELASTIC POLE RESIDUE

MODULUS |r| VALUE (MeV)

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|---------------------|---------------------------------------------|
| 26±5 | ANISOVICH | 12A | DPWA | Multichannel |
| 21 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 21 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 20±6 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 33 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 24 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 47 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| PHASE θ | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| - 38 ± 25 | ANISOVICH | 12A | | Multichannel |
| - 30 ± 25 - 20 | ARNDT | 06 | | $\pi N \rightarrow \pi N, \eta N$ |
| -50±20 | | | | |
| | | | | |
| | CUTKOSKY | 80 | | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | | | | |
| | | | , limits, e | |
| • • • We do not use the following | data for average | s, fits | , limits, e DPWA | etc. • • • |

N(2250) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|----------------------------------|------------|--------------------------------------|
| Γ ₁ Γ ₂ | N π N η | 5-15 % |
| Γ3 | ΛΚ | |

N(2250) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|---------------------|----------|-----------|--------------------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 5 to 15 OUR ESTIMATE | · | | | | |
| 12 ±4 | ANISOVICH | 12A | DPWA | Multichannel | |
| 8.9 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| 10 ±2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 10 ±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 9 ±2 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the follow | ng data for average | es, fits | , limits, | etc. • • • | |
| 11.0 ± 0.4 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| 10 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to N(2250) \to \Lambda K$ | | | | (Γ ₁ Γ ₃) ^½ /Γ |
|---------------------------------------------------------------------------------------------------------|--------------|----|---------|--------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.02 | BELL | 83 | DPWA | $\pi^- p \rightarrow \Lambda K^0$ |
| not seen | SAYON | 80 | D D W/A | $\pi^- n \rightarrow \Lambda \kappa^0$ |

N(2250) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006)

$N(2250) ightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV-1/2) | DO CUMENT ID | TECN | COMMENT |
|-----------------|---------------------------|------|--------------|
| < 0.01 | ² ANISOVICH 12 | DPWA | Multichannel |

$N(2250) \rightarrow p\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | TECN | COMMENT |
|------------------------------|----------------------------|------|--------------|
| <0.01 | ² ANISOVICH 12A | DPWA | Multichannel |

N(2250) FOOTNOTES

 1 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. $^2\,\text{This}$ ANISOVICH 12A value is the complex helicity amplitude at the pole position.

N(2250) REFERENCES

| ANISOVICH | 12 A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|------|------------------|-----------------------|------------------|
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU. TRIU) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BRCO) |
| HOEHLER | 93 | πN Newsletter 9 | 1 G. Hohler | (KARL) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| BELL | 83 | NP B222 389 | K.W. Bell et al. | (RL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL)IJP |
| Also | | PR D20 2839 | R.E. Cutkoský et al. | (CMU, LBL) IJP |
| SAXON | 80 | NP B162 522 | D.H. Saxon et al. | (RHEL, BRIS) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| Also | | ANP 136 1 | A.W. Hendry | (IND) |
| | | | • | |

N(2600) 11/2

 $I(J^P) = \frac{1}{2}(\frac{11}{2})$ Status: ***

N(2600) BREIT-WIGNER MASS

| VALUE (MeV) 2550 to 2750 (≈ 2600) OUR ESTI | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------|------------------|----------|------|-------------------------------------------------------------|
| 2623±197 2577+ 50 | ARNDT HOEHLER | 06 79 | | $\pi N \rightarrow \pi N, \eta N$ $\pi N \rightarrow \pi N$ |
| 2700±100 | HENDRY | 78 | | $\pi N \rightarrow \pi N$ |

N(2600) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------|--------------|----|------|--------------------------------------|
| 500 to 800 (≈ 650) OUR | ESTIMATE | | | |
| 1311 ± 996 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 400 ± 100 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 900 ± 100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |

N(2600) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|--------|------------------------------|
| Γ_1 | $N\pi$ | 5-10 % |

N(2600) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|--------------|----|------|-----------------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 5 to 10 OUR ESTIMATE | | | | | |
| 5.0 ± 1.8 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ | |
| 5 ±1 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 8 ±2 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ | |

N(2600) REFERENCES

| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
|---------|----|-----------------|-------------------|----------------|
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| Also | | ANP 136 1 | A.W. Hendry | ` (IND) |

 $N(2700) 13/2^{+}$

 $I(J^P) = \frac{1}{2}(\frac{13}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

N(2700) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|----|------|---------------------------|
| ≈ 2700 OUR ESTIMATE | | | | |
| 2612± 45 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 3000 ± 100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |

N(2700) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------|--------------|----|------|---------------------------|
| 350± 50 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 900 ± 150 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |

N(2700), $N(\sim 3000)$

N(2700) DECAY MODES

| | Mode |
|----------------|------|
| Γ ₁ | Νπ |

N(2700) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|--------------|----|-------|---------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 4±1 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 7 ± 2 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ | |
| | | | | | |

N(2700) REFERENCES

| M(ZIOO) NEI ENEMOES | | | | |
|--------------------------------------------|----------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------|
| ARNDT HOEHLER Also HENDRY Also | 06 79 78 | PR C74 045205 PDAT 12-1 Toronto Conf. 3 PRL 41 222 ANP 136 1 | R.A. Arndt et al. G. Hohler et al. R. Koch A.W. Hendry A.W. Hendry | (GWU) (KARLT) IJP (KARLT) IJP (IND, LBL) IJP (IND) |
| | | | | |

$N(\sim 3000 \text{ Region})$ Partial-Wave Analyses

OMITTED FROM SUMMARY TABLE

We list here miscellaneous high-mass candidates for isospin-1/2 resonances found in partial-wave analyses.

Our 1982 edition had an N(3245), an N(3690), and an N(3755), each a narrow peak seen in a production experiment. Since nothing has been heard from them since the 1960's, we declare them to be dead. There was also an N(3030), deduced from total cross-section and 180° elastic cross-section measurements; it is the KOCH 80 $L_{1,15}$ state below.

N(∼ 3000) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT IL |) | TECN | COMMENT |
|---------------------|--------------|----|------|------------------------------------------------------------------------------------|
| ≈ 3000 OUR ESTIMATE | · | | | |
| 2600 | KOCH | 80 | IPWA | $\pi N \rightarrow \pi N D_{13}$ |
| 3100 | KOCH | 80 | IPWA | $\pi	extsf{N} ightarrow \pi	extsf{N}L_{1.15}$ wave |
| 3500 | KOCH | 80 | IPWA | $\pi N \rightarrow \pi N M_{1.17}$ |
| 3500 to 4000 | косн | 80 | IPWA | wave $\pi N \rightarrow \pi N N_{1,19}$ wave |
| 3500 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N L_{1.15}$ wave |
| 3800 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N M_{1,17}$ |
| 4100 ± 200 | HENDRY | 78 | MPWA | $\pi \stackrel{Wave}{N} \rightarrow \pi \stackrel{N}{N} \stackrel{N_{1,19}}{wave}$ |

$N(\sim 3000)$ BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------|-------------|----|------|------------------------------------------------------------------------------------------------------|
| 1300 ± 200 | HENDRY | 78 | MPWA | $\pi{\sf N} ightarrow \pi{\sf N} {\sf L}_{1.15}$ wave |
| 1600 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N M_{1,17}$ |
| 1900 ± 300 | HENDRY | 78 | MPWA | $\pi \stackrel{\text{wave}}{N} \rightarrow \pi \stackrel{\text{N}}{N} \stackrel{\text{N}}{N}_{1,19}$ |
| | | | | wave |

N(∼ 3000) DECAY MODES

| Mode | |
|------|--|
|------|--|

| | Μ. |
|---|---------|
| 1 | $N \pi$ |

N(∼ 3000) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|--------------|----|------|----------------------------------------------------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 6 ±2 | HENDRY | 78 | MPWA | $\pi\text{N} 	o \pi\text{N} \text{L}_{1,15}$ wave |
| 4.0 ± 1.5 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N M_{1,17}$ |
| 3.0 ± 1.5 | HENDRY | 78 | MPWA | wave $\pi \stackrel{N}{N} \rightarrow \pi \stackrel{N}{N} \stackrel{N}{N}_{1,19}$ wave |

N(∼ 3000) REFERENCES

| KOCH HENDRY Also | 80 78 | Toronto Conf. 3 PRL 41 222 ANP 136 1 | A.W | Koch V. Hendry V. Hendry | (KARLT) IJP (IND, LBL) IJP (IND) IJP |
|------------------------|----------|--------------------------------------------|-----|--------------------------------|--------------------------------------------|
| | | | | | |

Baryon Particle Listings $\Delta(1232)$

\triangle BARYONS (S = 0, I = 3/2)

 $\Delta^{++} = u \, u \, u \, , \quad \Delta^{+} = u \, u \, d , \quad \Delta^{0} = u \, d \, d , \quad \Delta^{-} = d \, d \, d$

 $\Delta(1232) \ 3/2^{+}$

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters $111B\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G $33\ 1\ (2006)$.

△(1232) BREIT-WIGNER MASSES

MIXED CHARGES

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|---------------------|-----------|-----------|----------------------------------------|
| 1230 to 1234 (≈ 1232) OUR E | STIMATE | | | |
| 1228 ±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 1233.4 ± 0.4 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1231 ±1 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1232 ±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1233 ±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | ng data for average | es, fits, | , limits, | etc. • • • |
| 1230 ±2 | ANISOVICH | 10 | DPWA | Multichannel |
| 1232.9 ± 1.2 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1228 ±1 | PENNER | 02c | DPWA | Multichannel |
| 1234 ±5 | VRA NA | 00 | DPWA | Multichannel |
| 1233 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

△(1232)++ MASS

| _() | | | | |
|-----------------------------------|-------------------|---------|-------------|----------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| • • • We do not use the following | ng data for avera | iges, i | fits, limit | s, etc. • • • |
| 1230.55 ± 0.20 | GRIDNEV | 06 | DPWA | $\pi N \rightarrow \pi N$ |
| 1231.88 ± 0.29 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 1230.5 ± 0.2 | ABAEV | 95 | IP WA | $\pi N \rightarrow \pi N$ |
| 1230.9 ± 0.3 | KOCH | 80B | IP WA | $\pi N \rightarrow \pi N$ |
| 1231.1 ±0.2 | PEDRONI | 78 | | $\pi N \rightarrow \pi N 70-370 \text{ MeV}$ |

Δ (1232)+ MASS

| VALUE (MeV) | DO CUMENT ID | COMMENT |
|---------------------------------|-----------------------------|---------------------|
| • • • We do not use the followi | ng data for averages, fits, | limits, etc. • • • |
| 1234.9 ± 1.4 | MIROSHNIC 79 | Fit photoproduction |

$\Delta(1232)^0$ MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|--------|-------------|----------------------------------------------|
| ullet $ullet$ We do not use the following | ng data for avera | ges, 1 | fits, limit | s, etc. • • • |
| 1231.3 ± 0.6 | BREITSCHOP. | .06 | CNTR | Using new CHEX data |
| 1233.40 ± 0.22 | GRIDNEV | 06 | DPWA | $\pi N \rightarrow \pi N$ |
| 1234.35 ± 0.75 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 1233.1 ±0.3 | ABAEV | 95 | IP WA | $\pi N \rightarrow \pi N$ |
| 1233.6 ±0.5 | KOCH | 80B | IP WA | $\pi N \rightarrow \pi N$ |
| 1233.8 ±0.2 | PEDRONI | 78 | | $\pi N \rightarrow \pi N 70-370 \text{ MeV}$ |

$m_{\Delta^0} - m_{\Delta^{++}}$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------|-----------------------|-----------------|-------------------|-------------------------------|
| • • • We do not use the follo | wing data for average | es, fits | , limits, | etc. • • • |
| 2.86 ± 0.30 | GRIDNEV | 06 | DPWA | $\pi N \rightarrow \pi N$ |
| 2.25 ± 0.68 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 2.6 ±0.4 | | | | $\pi N \rightarrow \pi N$ |
| 2.7 ± 0.3 | ¹ PEDRONI | 78 | | See the masses |
| 1 Using $\pi^{\pm} d$ as well, PEC 4.6 \pm 0.2 MeV. | RONI 78 determine | (M ⁻ | - M ⁺⁺ | $^{+}) + (M^{0} - M^{+})/3 =$ |

△(1232) BREIT-WIGNER WIDTHS

MIXED CHARGES

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|------------------|----------|-------------|----------------------------------------|
| 114 to 120 (≈ 117) OUR ESTIM | ATE | | | |
| 110 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 118.7 ± 0.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 118 ± 4 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 120 ± 5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 116 ± 5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | es, fits | , limits, e | etc. • • • |
| 112 ± 4 | ANISOVICH | 10 | DPWA | Multichannel |
| 118.0 ± 2.2 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 106 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 112 ±18 | VRA NA | 00 | DPWA | Multichannel |
| 114 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

| Δ | (1232) | ++ | W | ID' | ТН |
|---|--------|----|---|-----|----|
|---|--------|----|---|-----|----|

| VALUE (MeV) | DO CUMENT ID | T | ECN | COMMENT |
|--------------------------------|--------------------|------------|---------|----------------------------------------------|
| • • • We do not use the follow | owing data for ave | ages, fits | , limit | s, etc. • • • |
| 112.2 ± 0.7 | GRIDNEV | 06 D | PWA | $\pi N \rightarrow \pi N$ |
| 109.07 ± 0.48 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 111.0 ±1.0 | KOCH | 80B IP | WA | $\pi N \rightarrow \pi N$ |
| 111.3 ±0.5 | PEDRONI | 78 | | $\pi N \rightarrow \pi N 70-370 \text{ MeV}$ |

△(1232)⁺ WIDTH

| VALUE (MeV) | DO CUMENT ID | COMMENT |
|---------------------------------|--------------------------|---------------------|
| • • We do not use the following | data for averages, fits, | limits, etc. • • • |
| 131.1 + 2.4 | MIR OSH NIC 79 | Fit photoproduction |

△(1232)⁰ WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|--------|------------|----------------------------------------------------|
| ullet $ullet$ We do not use the following | ig data for avera | ges, f | its, limit | s, etc. • • • |
| 112.5 ±1.9 | BREITSCHOP. | .06 | CNTR | Using new CHEX data |
| 116.9 ±0.7 | GRIDNEV | 06 | DPWA | $\pi N \rightarrow \pi N$ |
| 117.58 ± 1.16 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 113.0 ±1.5 | KOCH | 80B | IP WA | $\pi N \rightarrow \pi N$ |
| 117.9 ±0.9 | PEDRONI | 78 | | $\pi\mathrm{N}\rightarrow\pi\mathrm{N}$ 70–370 MeV |

Δ⁰-Δ⁺⁺ WIDTH DIFFERENCE

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|---------|---------|---------------------------|
| • • • We do not use the following | data for average | s, fits | limits, | etc. • • • |
| 4.66 ± 1.0 | GRIDNEV | 06 | DPWA | $\pi N \rightarrow \pi N$ |
| 8.45 ± 1.11 | BERNICHA | 96 | | Fit to PEDRONI 78 |
| 5.1 ±1.0 | ABAEV | 95 | IPWA | $\pi N \rightarrow \pi N$ |
| 6.6 ±1.0 | PEDRONI | 78 | | See the widths |

△(1232) POLE POSITIONS

REAL PART, MIXED CHARGES

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|----------------------|---------|-------------|---------------------------------------------|
| 1209 to 1211 (≈ 1210) OUR ES | TIMATE | | | |
| 1210.5 ± 1.0 | ANISOVICH | 12A | DPWA | Multichannel |
| 1211 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1209 | ² HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 1210 ±1 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | g data for average | s, fits | , limits, e | etc. • • • |
| 1211 ±1 | ANISOVICH | 10 | DPWA | Multichannel |
| 1210 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1217 | VRANA | 00 | DPWA | Multichannel |
| 1211 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1210 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

-2×IMAGINARY PART, MIXED CHARGES

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|----------------------|----------|-----------|--------------------------------------------------------------------|
| 98 to 102 (≈ 100) OUR ESTIMA | ATE | | | |
| 99±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 99 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 100 | ² HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 100±2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the followin | g data for average | es, fits | , limits, | etc. • • • |
| 100 ± 2 | ANISOVICH | 10 | DPWA | Multichannel |
| 100 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 96 | VRANA | 00 | DPWA | Multichannel |
| 100 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 100 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |

REAL PART, Δ(1232)++

| VALUE (IVIEV) | DOCUMENTID | | COMMENT |
|-----------------------------------|--------------------|-------|-------------------|
| • • • We do not use the following | data for averages, | fits, | limits, etc. • • |
| 1212.50 ± 0.24 | BERNICHA | 96 | Fit to PEDRONI 78 |

COMMENT

-2×IMAGINARY PART, \(\Delta(1232)^{++}\) VALUE (MeV) DO CUMENT ID

| • • • We do not | use the following | data for | averages, | fits, | limits, | etc. | • • • | • |
|------------------|-------------------|----------|-----------|-------|---------|------|-------|----|
| 97.37 ± 0.42 | | BERNI | СНА | 96 | Fit to | PEDF | RONI | 78 |

REAL PART, △(1232)+

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|---------------------|---------|-----------|------------------------------|
| • • • We do not use the following | g data for averages | , fits, | limits, e | etc. • • • |
| 1211 ± 1 to 1212 ± 1 | HANSTEIN | 96 | DPWA | $\gamma N \rightarrow \pi N$ |
| 1206.9 ± 0.9 to 1210.5 ± 1.8 | MIROSH NIC | 79 | | Fit photoproduction |

$-2 \times IMAGINARY PART, \Delta(1232)^+$

| VALUE (MEV) | DO COMENT ID | TECN COMMENT |
|-----------------------------------|---------------------------|-----------------------------------|
| • • • We do not use the following | data for averages, fits, | limits, etc. • • • |
| 102 ±2 to 99 ± 2 | ³ HA NSTEIN 96 | DPWA $\gamma N \rightarrow \pi N$ |
| 111.2 ± 2.0 to 116.6 ± 2.2 | MIROSHNIC 79 | Fit photoproduction |

$\Delta(1232)$

| KEAL PAKI, △(1232 | DOCUMENT ID COMMENT | |
|-------------------------|--------------------------------------------------------------|--------|
| • • • We do not use the | following data for averages, fits, limits, etc. ● ● | |
| 1213.20 ± 0.66 | BERNICHA 96 Fit to PEDRONI 78 | |
| -2×IMAGINARY PA | RT, Δ(1232) ⁰ | |
| VALUE (MeV) | DO CUMENT ID COMMENT | |
| • • • We do not use the | following data for averages, fits, limits, etc. ● ● | |
| 104.10 ± 1.01 | BERNICHA 96 Fit to PEDRONI 78 | |
| 2 See HOEHLER 93 for | a detailed discussion of the evidence for and the note narar | neters |

 $^{^2}$ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial—wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. 3 The second (lower) value of HANSTEIN 96 here goes with the second (higher) value of the real part in the preceding data block.

△(1232) ELASTIC POLE RESIDUES

ABSOLUTE VALUE, MIXED CHARGES

| VALUE (MeV) | DO CUMENT ID | | TECN CO | OMMENT |
|-----------------------------------|--------------------|---------|-------------|-----------------------------------------|
| 51.6 ± 0.6 | ANISOVICH | 12A | DPWA M | l ultich annel |
| 52 | ARNDT | 06 | DPWA π | $N \rightarrow \pi N, \eta N$ |
| 50 | HOEHLER | 93 | ARGD π | $N \rightarrow \pi N$ |
| 53 ±2 | CUTKOSKY | 80 | IPWA π | $N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | limits, etc | . • • • |
| 53 | ARNDT | 04 | DPWA π | $N \rightarrow \pi N, \eta N$ |
| 38 | ⁴ ARNDT | 95 | DPWA π | $N \rightarrow N\pi$ |
| 52 | ARNDT | 91 | DPWA π | $N \rightarrow \pi N \text{ Soln SM90}$ |

PHASE, MIXED CHARGES

| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|----------------------|----------|-------------|---------------------------------------------|
| -46 ± 1 | ANISOVICH | 12A | DPWA | Multichannel |
| -47 | ARNDT | 06 | DPWA | π N \rightarrow π N, η N |
| -48 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| -47 ± 1 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the follow | wing data for averag | es, fits | , limits, e | etc. • • • |
| -47 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| -22 | ⁴ ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| -31 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |

 $^{^4\,\}text{This}$ ARNDT 95 value is in error, as pointed out by HOHLER 01. The corrected value is in line with the ARNDT 91 value (R.A. Arndt, private communication).

△(1232) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------------|------------------------------|
| Γ ₁ | $N\pi$ | 100 % |
| Γ ₂ | $N\gamma$ | 0.55-0.65 % |
| Γ_3 | $N\gamma$, helicity=1/2 | 0.11-0.13 % |
| Γ_4 | $N\gamma$, helicity $=3/2$ | 0.44-0.52 % |

△(1232) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|--------------------------------------|-----------------------|----------|-----------|----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 1.0 OUR ESTIMATE | | | | |
| 1.00 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1.0 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1.0 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1.0 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the follow | wing data for average | es, fits | , limits, | etc. • • • |
| 1.0 | ANISOVICH | 10 | DPWA | Multichannel |
| 1.000 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1.00 | PENNER | 02c | DPWA | Multichannel |
| 1.00 ±0.01 | VRA NA | 00 | DPWA | Multichannel |
| 1.0 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |

△(1232) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$\Delta(1232) ightarrow \ \emph{N} \, \gamma$, helicity-1/2 amplitude $\emph{A}_{1/2}$

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|-----|------|---------------------------------------------------|
| -0.135 ±0.006 OUR ESTIMATE | | | | |
| -0.131 ± 0.004 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.139 ± 0.004 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.137 ± 0.005 | AHRENS | 04A | DPWA | $\vec{\gamma}\vec{p} \rightarrow N\pi$ |
| -0.129 ± 0.001 | ARNDT | | | $\gamma p \rightarrow N \pi$ |
| $-0.1357 \pm 0.0013 \pm 0.0037$ | | | | $\gamma p \rightarrow p \gamma, p \pi^0, n \pi^+$ |
| -0.131 ± 0.001 | BECK | 00 | IPWA | $\vec{\gamma} p \rightarrow p \pi^0$, $n \pi^+$ |
| -0.140 ± 0.005 | KAMALOV | 99 | DPWA | $\gamma N \rightarrow \pi N$ |

| -0.1294 ± 0.0013 | HANSTEIN | 98 | IPWA | $\gamma N \rightarrow \pi N$ |
|----------------------------------------------|-------------------|---------|------------|------------------------------|
| -0.135 ± 0.005 | ARNDT | 97 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.1278 ± 0.0012 | DAVIDSON | 97 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.141 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.135 ± 0.016 | DAVIDSON | 91B | FIT | $\gamma N \rightarrow \pi N$ |
| -0.145 ± 0.015 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.138 ± 0.004 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, et | tc. • • • |
| -0.136 ± 0.005 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.140 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.128 | PENNER | 02D | DPWA | Multichannel |
| -0.1312 | HA NSTEIN | 98 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.143 ± 0.004 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.140 ± 0.007 | | 90 | | |

$\Delta(1232) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV -1/2) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-----------|-----------------------------------------------------|
| -0.250 ±0.008 OUR ESTIMATE | | | | |
| -0.254 ± 0.005 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.258 ± 0.005 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.256 ± 0.003 | AHRENS | 04A | DPWA | $\vec{\gamma}\vec{p} \rightarrow N\pi$ |
| -0.243 ± 0.001 | ARNDT | 02 | | $\gamma p \rightarrow N \pi$ |
| $-0.2669 \pm 0.0016 \pm 0.0078$ | BLANPIED | 01 | | $\gamma p \rightarrow p \gamma, p \pi^0, n \pi^+$ |
| -0.251 ± 0.001 | BECK | 00 | IPWA | $\vec{\gamma} \rho \rightarrow \rho \pi^0, n \pi^+$ |
| -0.258 ± 0.006 | KAMALOV | 99 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.2466 ± 0.0013 | HANSTEIN | 98 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.250 ± 0.008 | ARNDT | 97 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.2524 ± 0.0013 | DAVIDSON | 97 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.261 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.251 ± 0.033 | DAVIDSON | 91B | FIT | $\gamma N \rightarrow \pi N$ |
| -0.263 ± 0.026 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.259 ± 0.006 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| -0.267 ± 0.008 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.265 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.247 | PENNER | 02D | DPWA | Multichannel |
| -0.2522 | HA NSTEIN | 98 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.262 ± 0.004 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.254 ± 0.011 | DAVIDSON | 90 | FIT | See DAVIDSON 91B |

$\Delta(1232) \rightarrow N\gamma$, E_2/M_1 ratio

| DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|---------------------------------------------------|
| E | | | |
| AHRENS | 04A | DPWA | $\vec{\gamma}\vec{\rho} \rightarrow N\pi$ |
| ARNDT | 02 | | $\gamma p \rightarrow N \pi$ |
| BLANPIED | 01 | LEGS | $\gamma p \rightarrow p \gamma, p \pi^0, n \pi^+$ |
| GALLER | 01 | DPWA | $\gamma p \rightarrow \gamma p$ |
| BECK | 00 | IPWA | $\vec{\gamma} p \rightarrow p \pi^0, n \pi^+$ |
| HANSTEIN | 98 | IPWA | $\gamma N \rightarrow \pi N$ |
| ⁵ ARNDT | 97 | IPWA | $\gamma N \rightarrow \pi N$ |
| DAVIDSON | 97 | DPWA | $\gamma N \rightarrow \pi N$ |
| g data for averages | , fits, | limits, e | tc. • • • |
| DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| PENNER | 02D | DPWA | Multichannel |
| HANSTEIN | 98 | DPWA | $\gamma N \rightarrow \pi N$ |
| BECK | 97 | IPWA | $\gamma N \rightarrow \pi N$ |
| BLANPIED | 97 | DPWA | $\gamma N \rightarrow \pi N, \gamma N$ |
| KHANDAKER | 95 | DPWA | $\gamma N \rightarrow \pi N$ |
| WORKMAN | 92 | | $\gamma N \rightarrow \pi N$ |
| DAVIDSON | 91B | FIT | $\gamma N \rightarrow \pi N$ |
| DAVIDSON | 90 | FIT | $\gamma N \rightarrow \pi N$ |
| DAVIDSON | 86 | | |
| TANABE | 85 | FIT | $\gamma N \rightarrow \pi N$ |
| | AHRENS ARNDT BLANPIED GALLER BECK HANSTEIN ANOTDAVIDSON G data for averages DRECHSEL PENNER HANSTEIN BECK BLANPIED KHANDAKER WORKMAN DAVIDSON DAVIDSON DAVIDSON DAVIDSON | DOCUMENT ID | DOCUMENT ID TECN |

$\Delta(1232) \rightarrow N\gamma$, absolute value of E_2/M_1 ratio at pole

| VALUE | DO CUMENT ID | | TECN COMMENT |
|-------------------------------|-----------------------|---------|-----------------------------------|
| • • • We do not use the follo | wing data for average | s, fits | , limits, etc. • • • |
| 0.065 ± 0.007 | ARNDT | 97 | DPWA $\gamma N \rightarrow \pi N$ |
| 0.058 | HA NSTEIN | 96 | DPWA $\gamma N \rightarrow \pi N$ |

$\Delta(1232) \rightarrow N\gamma$, phase of E_2/M_1 ratio at pole

| VALUE | DO CUMENT ID | | TECN COMMENT | |
|-----------------------------------|--------------------|----------|-----------------------------------|---|
| • • • We do not use the following | ng data for averag | es, fits | , limits, etc. • • • | |
| -122 ± 5 | ARNDT | 97 | DPWA $\gamma N \rightarrow \pi N$ | V |
| _127.2 | HANSTEIN | 96 | $DPMA \sim M \rightarrow \pi A$ | V |

 $^{^5}$ This ARNDT 97 value is very sensitive to the database being fitted. The result is from a fit to the full pion photoproduction database, apart from the BLANPIED 97 cross-section measurements.

△(1232) MAGNETIC MOMENTS

Δ (1232)++ MAGNETIC MOMENT

The values are extracted from UCLA and SIN data on π^+p bremsstrahlung using a variety of different theoretical approximations and methods. Our estimate is only a

| VALUE (μ _N) 3.7 to 7.5 OUR EST | DOCUMENT ID | TECN | COMMENT |
|--------------------------------------------|--------------------|----------------|------------------------------------------------------------------|
| | | a for averages | , fits, limits, etc. • • • |
| 6.14 ± 0.51 | LOPEZCAST. | 01 DPWA | $\pi^+ p \rightarrow \pi^+ p \gamma$ |
| $4.52\pm0.50\pm0.45$ | BOSSHARD | 91 | $\pi^+ p \rightarrow \pi^+ p \gamma$ (SIN data) |
| 3.7 to 4.2 | LIN | 91B | $\pi^+ p \rightarrow \pi^+ p \gamma$ (from UCLA data) |
| 4.6 to 4.9 | LIN | 91B | $\pi^+ p \rightarrow \pi^+ p \gamma$ (from SIN data) |
| 5.6 to 7.5 | WITTMAN | 88 | $\pi^+ p \rightarrow \pi^+ p \gamma$ (from UCLA data) |
| 6.9 to 9.8 | HELLER | 87 | $\pi^+ p \rightarrow \pi^+ p \gamma$ (from UCLA data) |
| 4.7 to 6.7 | NEFKENS | 78 | $\pi^+ ho ightarrow \pi^+ ho \gamma (extsf{UCLA data})$ |
| △(1232)+ MAGN | ETIC MOMEN | Т | |
| VALUE (µN) | DO | CUMENT ID | COMMENT |
| | the following data | a for averages | , fits, limits, etc. • • • |

 $^{2.7^{\,+\,1.0}}_{\,-\,1.3}\pm1.5\,\pm\,3$ 6 KOTULLA 02 $\gamma p
ightarrow p \, \pi^{0} \, \gamma'$ ⁶The second error is systematic, the third is an estimate of theoretical uncertainties.

△(1232) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-------------|------|----------------------------|-------------------------------------|--------------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiat | or (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jefl | ferson Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| BREITSCHOP. | 06 | PL B639 424 | J. Breitschopf et al. | (TUBIN, HEBR, CSUS) |
| GRIDNEV | 06 | PAN 69 1542 | A.B. Grid nev et al. | (PNPI, BONN, GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| AHRENS | 04 A | EPJ A21 323 | J. Ahrens et al. | (Mainz GDH, A2 Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | ` (GWU, TRIU) |
| ARNDT | 02 | PR C66 055213 | R. A. Arndt et al. | ` (GWU) |
| KOTULLA | 02 | PRL 89 272001 | M. Kotulla et al. | (MAMI TAPS Collab.) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| BLANPIED | 01 | PR C64 025203 | G. Blanpied et al. | (BNL LEGS Collab.) |
| GALLER | 01 | PL B503 245 | G. Galler et al. | (Mainz LARA Collab.) |
| HOHLER | 01 | NSTAR 2001 185 | G. Hohler | (KARL) |
| LOPEZCAST | 01 | PL B517 339 | G. Lopez Castro, A. Mariano | ` / |
| Also | | NP A697 440 | G. Lopez Castro, A. Mariano | |
| BECK | 00 | PR C61 035204 | | Microtron DAPHNE Col.) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman, TS.H. | |
| KAMALOV | 99 | PRL 83 4494 | S.S. Kam alov, S.N. Yang | (Taiwan U.) |
| HANSTEIN | 98 | NP A632 561 | O. Hanstein, D. Drechsel, L. Tiato | |
| ARNDT | 97 | PR C56 577 | R.A. Arndt, I.I. Strakovsky, R.L. W | |
| BECK | 97 | PRL 78 606 | | NZ, SACL, PAVI, GLASÍ |
| Also | | PRL 79 4510 | R.L. Beck, H.P. Krahn | (MANZ) |
| Also | | PRL 79 4512 | R.L. Beck, H.P. Krahn | (MANZ) |
| Also | | PRL 79 4515 (erratum) | | NZ, SACL, PAVI, GLAS) |
| BLANPIED | 97 | PRL 79 4337 | G.S. Blanpied et al. | (LEGS Collab.) |
| DAVIDS ON | 97 | PRL 79 4509 | R.M. Davidson, N.C.A. Mukhopad | |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. W | |
| BERNICHA | 96 | NP A597 623 | A. Bernicha, G. Lopez Castro, J. P | |
| HANSTEIN | 96 | PL B385 45 | O. Hanstein, D. Drechsel, L. Tiato | r `(MANZ) |
| ABAEV | 95 | ZPHY A352 85 | V.V. Abaev, S.P. Kruglov | `(PNPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BRCO) |
| KHANDAKER | 95 | PR D51 3966 | M. Khandaker, A.M. Sandorfi | `(BNL, VPI) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | ` (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | ` (VPI) |
| WORKMAN | 92 | PR C46 1546 | R.L. Workman, R.A. Arndt, Z.J. L | i (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| BOSSHARD | 91 | PR D44 1962 | A. Bosshard et al. | (ZURI, LBL, VILL+) |
| Also | | PRL 64 2619 | A. Bosshard et al. | (CATH, LAUS, LBL+) |
| DAVIDS ON | 91B | PR D43 71 | R.M. Davidson, N.C. Mukhopadhy | ay, R.S. Wittman |
| LIN | 91B | PR C44 1819 | D.H. Lin, M.K. Liou, Z.M. Ding | (CUNY, CSOK) |
| A Iso | | PR C43 R930 | D. Lin, M.K. Liou | (CUNY) |
| DAVIDS ON | 90 | PR D42 20 | R.M. Davidson, N.C. Mukhopadhy | ay (RPI) |
| WITTMAN | 88 | PR C37 2075 | R. Wittman | (TRIU) |
| HELLER | 87 | PR C35 718 | L. Heller et al. | (LANL, MIŤ, ILL) |
| DAVIDS ON | 86 | PRL 56 804 | R.M. Davidson, N.C. Mukhopadhy | ay, R. Wittman (RPI) |
| TANABE | 85 | PR C31 1876 | H. Tanabe, K. Ohta | (KOMAB) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| KOCH | 80 B | NP A336 331 | R. Koch, E. Pietarinen | (KARLT) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| MIR OS HNIC | 79 | SJNP 29 94 | I.I. Miroshnichenko et al. | (KFTI) IJP |
| NEEKENG | 70 | Translated from YAF 29 1 | | AUGUA CATURES |
| NEFKENS | 78 | PR D18 3911 NP A300 321 | B.M.K. Nefkens et al. | (UCLA, CATH) IJP |
| PEDRONI | 78 | NF M300 321 | E. Pedroni et al. | (SIN, ISNG, KARLE+) IJP |

$\Delta(1600) \ 3/2^{+}$

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$
 Status: ***

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters $\mathbf{111B}\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The various analyses are not in good agreement.

△(1600) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------------------------------|----------|-----------|----------------------------------------|
| 1500 to 1700 (≈ 1600) | OUR ESTIMATE | | | |
| 1510 ± 20 | ANISOVICH | 12A | DPWA | Multichannel |
| 1706 ± 10 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1600±50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1522 ± 13 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use t | he following data for averages | s, fits, | limits, e | etc. • • • |
| 1650±40 | HORN | 08A | DPWA | Multichannel |
| 1667 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 1687 ± 44 | VRANA | 00 | DPWA | Multichannel |
| 1672 ± 15 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1706 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1690 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1560 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1640 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1600) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------------|---------|-----------|----------------------------------------|
| 220 to 420 (≈ 320) OUR ESTIMA | TE | | | |
| 220 ± 45 | ANISOVICH | 12A | DPWA | Multichannel |
| 430 ± 73 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 300 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 220± 40 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | limits, e | etc. • • • |
| 530± 60 | HORN | 08A | DPWA | Multichannel |
| 397± 10 | PENNER | 02c | DPWA | Multichannel |
| 493± 75 | VRANA | 00 | DPWA | Multichannel |
| 315 ± 20 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 215 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 250 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 180 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 300 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1600) POLE POSITION

REAL PART

230

323 or 325

178 or 178

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|----------------------------|---------|-----------|---------------------------------------------|
| 1460 to 1560 (≈ 1510) C | OUR ESTIMATE | | | |
| 1498 ± 25 | ANISOVICH | 12A | DPWA | Multichannel |
| 1457 | | | | $\pi N \rightarrow \pi N, \eta N$ |
| 1550 | ³ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1550 ± 40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | , fits, | limits, | etc. • • • |
| $1510 + 20 \\ -50$ | HORN | 08A | DPWA | Multichannel |
| 1599 | VRANA | 00 | DPWA | Multichannel |
| 1675 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1612 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1609 or 1610 | ⁴ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1541 or 1542 | ¹ LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -2×IMAGINARY PA | .RT | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 200 to 350 (≈ 275) OUR | ESTIMATE | | | |
| 230 ± 50 | ANISOVICH | 12A | DPWA | Multichannel |
| 400 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 200 ± 60 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the | following data for average | , fits | limits, e | etc. • • • |
| 230±40 | HORN | 08A | DPWA | Multichannel |
| 312 | VRANA | 00 | DPWA | Multichannel |
| 386 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| | | | | |

ARNDT

⁴ LONGACRE

¹LONGACRE

91

78

77

DPWA $\pi N \rightarrow \pi N$ Soln SM90 IPWA $\pi N \rightarrow N \pi \pi$

IPWA $\pi N \rightarrow N \pi \pi$

Baryon Particle Listings $\Delta(1600)$

△(1600) ELASTIC POLE RESIDUE

| MODULUS |
|---------|
|---------|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------------------------------------------|----------------------------------------------------------|-----------------------|-----------------------------------|---------------------------------------------------------------------------|
| 11 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 44 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 17±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | owing data for average | es, fits, | , limits, e | etc. • • • |
| 52 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 16 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| | <u>DO CUMENT ID</u> A NI SOVI CH | 12A | | COMMENT Multichannel |
| VALUE (°) | - | 12A 06 | DPWA | |
| <u>VALUE</u> (°) −160 ± 33 | ANISOVICH | | DPWA DPWA | Multichannel |
| VALUE (°) -160 ± 33 +147 | ANISOVICH ARNDT CUTKOSKY | 06 80 | DPWA DPWA IPWA | Multichannel $\pi N \rightarrow \pi N, \eta N \\ \pi N \rightarrow \pi N$ |
| MALUE (°) -160 ± 33 +147 -150 ± 30 | ANISOVICH ARNDT CUTKOSKY | 06 80 | DPWA DPWA IPWA limits, e | Multichannel $\pi N \rightarrow \pi N, \eta N \\ \pi N \rightarrow \pi N$ |
| $ \frac{VALUE}{-160 \pm 33} \\ +147 \\ -150 \pm 30$ • • • We do not use the follows: | ANISOVICH ARNDT CUTKOSKY owing data for average | 06 80 es, fits, | DPWA DPWA IPWA limits, o | Multichannel $\pi N \to \pi N, \eta N \to \pi N \to \pi N$ etc. • • |

△(1600) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \to \Delta(1600) \to \Delta\pi$, P-wave

| MODULUS (%) | PHASE (°) | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------------------------------------------------|-----------|--------------|------|-------|--------------|---|
| 14±10 | 154 ± 40 | ANISOVICH | 12A | DPWA | Multichannel | |
| Normalized residue in $N\pi \to \Delta(1600) \to \Delta\pi$, F-wave | | | | | | |
| MODULUS (%) | | DO CUMENT ID | TE | CN CO | MMENT | |
| 1.0 ± 0.5 | | ANISOVICH 12 | A DP | WA M | ultichannel | 1 |

△(1600) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) | |
|----------------|-----------------------------------------------|------------------------------|--|
| Γ ₁ | Νπ | 10-25 % | |
| Γ_2^- | ΣΚ | | |
| Γ_3 | $N\pi\pi$ | 75-90 % | |
| Γ_4 | $\Delta\pi$ | 40-70 % | |
| Γ_5 | ${\it \Delta}$ (1232) π , ${\it P}$ -wave | | |
| Γ ₆ | ${\it \Delta}$ (1232) π , ${\it F}$ -wave | | |
| Γ_7 | $N \rho$ | <25 % | |
| Γ ₈ | $N\rho$, $S=1/2$, P -wave | | |
| Γ9 | $N\rho$, $S=3/2$, P -wave | | |
| Γ_{10} | $N\rho$, $S=3/2$, F -wave | | |
| Γ_{11} | $N(1440)\pi$ | 10-35 % | |
| Γ_{12} | $N(1440)\pi$, $\it P$ -wave | | |
| Γ_{13} | $N\gamma$ | 0.001-0.035 % | |
| Γ_{14} | $N\gamma$, helicity=1/2 | 0.0-0.02 % | |
| Γ_{15} | $N\gamma$, helicity=3/2 | 0.001-0.015 % | |

△(1600) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\rm total}$ |
|-----------------------------------|
| VALUE (9/.) |

| $(\pi)/\Gamma_{total}$ | | | | Γ_1/Γ |
|------------------------|-------------|------|---------|-------------------|
| 'E (%) | DOCUMENT ID | TECN | COMMENT | |
| 25 OHD ESTIMATE | | | | |

| VALUE (76) | DOCUMENTID | | IECIV | COMMENT |
|-------------------------------------------|-------------------|---------|-------------|----------------------------------------|
| 10 to 25 OUR ESTIMATE | · | | | |
| 12±5 | ANISOVICH | 12A | DPWA | Multichannel |
| 12±2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 18±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 21 ± 6 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | s, fits | , limits, e | etc. • • • |
| 10 ± 3 | HORN | 08A | DPWA | Multichannel |
| 13±1 | PENNER | 02c | DPWA | Multichannel |
| 28±5 | VRA NA | 00 | DPWA | Multichannel |
| | | | | |

$(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1600) \to \Sigma K$ VALUE — DO CUMENT ID -0.36 to -0.28 OUR ESTIMATE

• • • We do not use the following data for averages, fits, limits, etc. • • • ⁵ DEA NS 0.006 to 0.042 75 DPWA $\pi N \rightarrow \Sigma K$

> Note: Signs of couplings from $\pi N \rightarrow N \pi \pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232) \pi$.

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi$ | · → △(1600) → △(123 | 2)π, | <i>P</i> -wave | e (Γ ₁ Γ ₅) ^½ /Γ |
|------------------------------------------------------------------------------|-----------------------|------|----------------|----------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| +0.27 to +0.33 OUR E | STIMATE | | | |
| $+0.29 \pm 0.02$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $+0.24\pm0.05$ | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.34 | LONGACILE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.30 | ² LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

| $\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{\text{total}}$ | | DOCUMENT ID | | TECN | Γ ₅ /Γ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-----------------------------|-----------|-----------------|------------------------------------------------------|
| <u>VALUE (%)</u> | _ | ANISOVICH | | | Multichannel |
| 78 ± 6 59 ± 10 | | √RANA | 12A 00 | DPWA | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to \Delta(\Xi_{NALUE})^{\frac{1}{2}}$ $-0.15 \text{ to } -0.03 \text{ OUR ESTIMATION}$ | 1600 <u>/</u> | D) → Δ(123: | 2)π, | F-wave | (Γ ₁ Γ ₆) ^{1/2} /Γ |
| −0.15 to −0.03 OUR ESTIMATI −0.07 | E 1,6 L | ONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to \Delta$ | 1600 | $(0) \rightarrow N\rho, S=$ | =1/2 | , <i>P</i> -wav | e $(\Gamma_1\Gamma_8)^{\frac{1}{2}}/\Gamma$ |
| <u>VALUE</u> + 0.10 | 1,6 | ONGACRE | 77 | ΙΡΙΛ/Δ | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to \Delta$ $+ 0.10$ | 1600 | DOCUMENT ID | =3/2 | , <i>P</i> -wav | e (Γ ₁ Γ ₉) ^{1/2} /Γ |
| +0.10 | 1,6 L | ONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1)$ | |)) → N(1440 |))π. | P-wave | (F. F)½ /F |
| VALUE | | DOCUMENT ID | | | |
| +0.15 to +0.23 OUR EST MAT | E | DOCUMENT ID | _ | TECN | COMMENT |
| +0.15 to +0.23 OUR EST MAT +0.16 ±0.02 +0.23 ±0.04 | E I | | _ | TECN IPWA | |
| $+0.15$ to $+0.23$ OUR EST MAT I $+0.16\pm0.02$ | E I | MANLEY | 92 80 | IPWA IPWA | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |

△(1600) PHOTON DECAY AMPLITUDES

Papers on $\gamma\,\mathrm{M}$ amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006).

$\Delta(1600) \rightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

| $VALUE$ (GeV $^{-1/2}$) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|--------------------|---------|-------------|------------------------------|
| -0.023±0.020 OUR ESTIMATE | | | | |
| -0.050 ± 0.009 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.018 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.039 ± 0.030 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.046 ± 0.013 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| | g data for average | s, fits | , limits, e | etc. • • • |
| 0.0 | PENNER | 02D | DPWA | Multichannel |
| -0.026 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.200 | ⁷ WADA | 84 | DPWA | Compton scattering |
| 0.000 ± 0.030 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |

$\Delta(1600) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| <u>VALUE</u> (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|-----------|------------------------------|
| -0.009 ± 0.021 OUR ESTIMATE | | | | |
| -0.040 ± 0.012 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.025 ± 0.015 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.013 ± 0.014 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.025 ± 0.031 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| -0.024 | PENNER | 02D | DPWA | Multichannel |
| -0.016 ± 0.002 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.023 | WADA | 84 | DPWA | Compton scattering |
| 0.000 ± 0.045 | BARBOUR | 78 | DPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

△(1600) FOOTNOTES

- $^1\, {\rm LONGACRE}$ 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi\, N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

 2 From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- amplitudes. 3 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 4LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 5 The range given is from the four best solutions. DEANS 75 disagrees with $\pi^{+}\,
 ho$ ightarrow
- Σ^+ K^+ data of WINNIK 77 around 1920 MeV. 6 LONGACRE 77 considers this coupling to be well determined.
- 7 WADA 84 is inconsistent with other analyses see the Note on N and Δ Resonances.

△(1600) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|------|--------------------|-----------------------------------|-------------------|
| HORN | 08A | EPJ A38 173 | I. Horn et al. | (CB-ELSA Collab.) |
| Also | | PRL 101 202002 | I. Horn et al. | (CB-ELSA Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | ` (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS. | .H. Lee (PÌTT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. | Workman (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | ` (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | ` (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt ét al. | (VPI, TELE) IJP |
| WADA | 84 | NP B247 313 | Y. Wada et al. | ` (INUS) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | ` (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| BARNHAM | 80 | NP B168 243 | K.W.J. Barnham et al. | (LOIC) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | `(KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| BARBOUR | 78 | NP B141 253 | I.M. Barbour, R.L. Crawford, N. | H. Parsons (GLAS) |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| WINNIK | 77 | NP B128 66 | M. Winnik et al. | (HAIF) I |
| DEANS | 75 | NP B96 90 | S.R. Deans et al. | (SFLA, ÀLAH) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |

$\Delta(1620) \; 1/2^-$

$$I(J^P) = \frac{3}{2}(\frac{1}{2})$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

△(1620) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|-----------------------|----------|-------------|----------------------------------------|
| 1600 to 1660 (≈ 1630) OUR ES | | | 1201 | COMMENT |
| 1600 ± 8 | ANISOVICH | 12A | DPWA | Multichannel |
| 1615.2± 0.4 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1672 ± 7 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1620 ±20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1610 ± 7 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | s, fits, | , limits, e | etc. • • • |
| 1625 ±10 | ANISOVICH | 10 | DPWA | Multichannel |
| 1650 ±25 | THOMA | 80 | DPWA | Multichannel |
| 1614.1 ± 1.1 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1612 ± 2 | PENNER | 02c | DPWA | Multichannel |
| 1617 ± 15 | VRA NA | 00 | DPWA | Multichannel |
| 1672 ± 5 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1617 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1669 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1620 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1712.8± 6.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 1786.7± 2.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 1580 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1600 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

$\Delta(1620)$ BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------------------|--------|-------------|---------------------------------------------|
| 130 to 150 (≈ 140) OU | R ESTIMATE | | | |
| 130 ±11 | ANISOVICH | 12A | DPWA | Multichannel |
| 146.9± 1.9 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 154 ±37 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 140 ±20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 139 ±18 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for av | erages | , fits, lin | nits, etc. • • • |
| 148 ±15 | ANISOVICH | 10 | DPWA | Multichannel |
| 250 ±60 | THOMA | 80 | DPWA | Multichannel |
| 141.0 ± 6.0 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 202 ± 7 | PENNER | 02c | DPWA | Multichannel |
| 143 ±42 | VRA NA | 00 | DPWA | Multichannel |
| 147 ± 8 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 108 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 184 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 120 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 228.3±18.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ (lower mass) |
| 30.0± 6.4 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ (higher mass) |
| 120 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 150 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1620) POLE POSITION

| REAL | PART |
|------|------|
|------|------|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | | | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|--|--|--|
| 1590 to 1610 (≈ 1600) OUR EST | MATE | | | | | | | |
| 1597± 4 | ANISOVICH | 12A | DPWA | Multichannel | ı | | | |
| 1595 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | | | | |
| 1608 | ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ | | | | |
| 1600 ± 15 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | | | | |
| | | | | | | | | |
| 1596± 7 | ANISOVICH | 10 | DPWA | Multichannel | ı | | | |
| 1615 ± 25 | THOMA | 80 | DPWA | Multichannel | | | | |
| 1594 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | | | | |
| 1607 | VRANA | 00 | DPWA | Multichannel | | | | |
| 1585 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | | | | |
| 1587 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ | | | | |
| 1583 or 1583 | ⁵ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| 1575 or 1572 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| a IMACINARY PART | | | | | | | | |
| | | | | | | | | |
| -2×IMAGINARY PART | DO CUMENT ID | | TECN | COMMENT | | | | |
| - 2XIMAGINARY PART <u>VALUE (MeV)</u> 120 to 140 (≈ 130) OUR ESTIMA | <u>DOCUMENT ID</u> | | TECN | COMMENT | | | | |
| VALUE (MeV) | | 12A | | <u>COMMENT</u> Multichannel | Ī | | | |
| <u>VALUE (MeV)</u> 120 to 140 (≈ 130) OUR ESTIMA | ATE. | 12A 06 | DPWA | | I | | | |
| <u>VALUE (MeV)</u> 120 to 140 (≈ 130) OUR ESTIMA 130± 9 | ATE ANISOVICH | | DPWA | Multichannel π $N \to \pi$ N , η N | I | | | |
| <u>VALUE (MeV)</u> 120 to 140 (≈ 130) OUR ESTIMA 130 ± 9 135 | ATE ANISOVICH ARNDT | 06 | DPWA DPWA SPED | Multichannel π $N \to \pi$ N , η N | I | | | |
| $\frac{\textit{VALUE} (\text{MeV})}{120 \text{to} 140} (≈ 130) \text{OUR ESTIMA}}{130 \pm 9}$ 135 116 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY | 06 93 80 | DPWA DPWA SPED IPWA | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ | 1 | | | |
| <u>VALUE (MeV)</u> 120 to 140 (≈ 130) OUR ESTIMA 130± 9 135 116 120±20 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY | 06 93 80 | DPWA DPWA SPED IPWA , limits, e | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ | 1 | | | |
| VALUE (MeV) 120 to 140 (≈ 130) OUR ESTIMA 130 \pm 9 135 116 120 \pm 20 • • • • We do not use the following | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average | 06 93 80 s, fits | DPWA DPWA SPED IPWA , limits, o | $\begin{array}{lll} & \text{Multichannel} \\ \pi \ N \rightarrow & \pi \ N, \ \eta \ N \\ \pi \ N \rightarrow & \pi \ N \\ \pi \ N \rightarrow & \pi \ N \\ \end{array}$ | 1 | | | |
| VALUE (MeV) 120 to 140 (\approx 130) OUR ESTIMA 130 \pm 9 135 116 120 \pm 20 • • • We do not use the following 130 \pm 10 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH | 06 93 80 s, fits | DPWA DPWA SPED IPWA , limits, of DPWA DPWA | $\begin{array}{ll} Multichannel \\ \pi \ N \rightarrow \ \pi \ N, \ \eta \ N \\ \pi \ N \rightarrow \ \pi \ N \\ \pi \ N \rightarrow \ \pi \ N \\ etc. \bullet \bullet \\ Multichannel \end{array}$ | 1 | | | |
| VALUE (MeV) 120 to 140 (≈ 130) OUR ESTIMA 130 \pm 9 135 116 120 \pm 20 • • • • We do not use the following 130 \pm 10 180 \pm 35 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH THOMA | 06 93 80 s, fits 10 08 | DPWA DPWA SPED IPWA , limits, o DPWA DPWA DPWA | $\begin{array}{lll} & \text{Multichannel} \\ \pi \ N \ \rightarrow \ \pi \ N, \ \eta \ N \\ \pi \ N \ \rightarrow \ \pi \ N \\ \pi \ N \ \rightarrow \ \pi \ N \\ \text{etc.} & \bullet \ \bullet \\ & \text{Multichannel} \\ & \text{Multichannel} \end{array}$ | 1 | | | |
| VALUE (MeV) 120 to 140 (\approx 130) OUR ESTIMA 130 \pm 9 135 116 120 \pm 20 \bullet \bullet \bullet We do not use the following 130 \pm 10 180 \pm 35 118 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH THOMA ARNDT | 06 93 80 s, fits 10 08 04 | DPWA DPWA SPED IPWA , limits, o DPWA DPWA DPWA DPWA | Multichannel $\pi N \to \pi N$, ηN $\pi N \to \pi N$ ηN $\pi N \to \pi N$ etc. $\bullet \bullet$ Multichannel Multichannel $\pi N \to \pi N$, ηN | I | | | |
| VALUE (MeV) 120 to 140 (\approx 130) OUR ESTIMA 130 \pm 9 135 116 120 \pm 20 • • • We do not use the following 130 \pm 10 180 \pm 35 118 148 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH THOMA ARNDT VRANA ARNDT ARNDT ARNDT | 06 93 80 s, fits 10 08 04 | DPWA SPED IPWA , limits, o DPWA DPWA DPWA DPWA DPWA | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ etc. $\bullet \bullet \bullet$ Multichannel $\pi N \to \pi N, \eta N$ Multichannel | 1 | | | |
| VALUE (MeV) 120 to 140 (≈ 130) OUR ESTIMA 130± 9 135 116 120±20 • • • We do not use the following 130±10 180±35 118 148 104 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH THOMA ARNDT VRANA ARNDT ARNDT 5 LONGACRE | 06 93 80 ss, fits 10 08 04 00 95 | DPWA DPWA SPED IPWA , limits, o DPWA DPWA DPWA DPWA DPWA DPWA DPWA | $\begin{array}{lll} & \text{Multichannel} \\ \pi N & \rightarrow & \pi N, \eta N \\ \pi N & \rightarrow & \pi N \\ \pi N & \rightarrow & \pi N \\ \text{etc.} & \bullet & \bullet \\ & \text{Multichannel} \\ & \text{Multichannel} \\ & \pi N & \rightarrow & \pi N, \eta N \\ & \text{Multichannel} \\ & \pi N & \rightarrow & \pi N, \eta N \\ & \text{Multichannel} \\ & \pi N & \rightarrow & \pi N, \eta N \\ & \text{Multichannel} \\ & \pi N & \rightarrow & N \pi \\ \end{array}$ | 1 | | | |
| VALUE (MeV) 120 to 140 (≈ 130) OUR ESTIMA 130± 9 135 116 120±20 • • • We do not use the followin 130±10 180±35 118 148 104 120 | ATE ANISOVICH ARNDT HOEHLER CUTKOSKY g data for average ANISOVICH THOMA ARNDT VRANA ARNDT ARNDT ARNDT | 06 93 80 s, fits 10 08 04 00 95 91 | DPWA DPWA SPED IPWA , limits, o DPWA DPWA DPWA DPWA DPWA DPWA DPWA | Multichannel $\pi N \to \pi N$, ηN $\pi N \to \pi N$ πN $\pi N \to \pi N$ etc. • • • Multichannel Multichannel $\pi N \to \pi N$, ηN Multichannel $\pi N \to \pi N$, ηN $\pi N \to \pi N$ Soln SM90 | 1 | | | |

△(1620) ELASTIC POLE RESIDUE

MODULUS Irl

| MODOLOS II | | | | |
|---------------------------------|---------------------|----------|-------------|--------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 18±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 15 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 19 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 15 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the followi | ng data for average | es, fits | , limits, e | etc. • • • |
| 17 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 14 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 15 | ARNDT | 91 | DPWA | $\pi {\it N} ightarrow \pi {\it N} {\rm Soln} {\rm SM90}$ |
| PHASE θ | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -100± 5 | ANISOVICH | 12A | DPWA | Multichannel |
| - 92 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| - 95 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| -110 ± 20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the followi | ng data for average | es, fits | , limits, e | etc. • • • |
| -104 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| -121 | ARNDT | 95 | | $\pi N \rightarrow N \pi$ |
| -125 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | | | | |

△(1620) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \rightarrow \Delta(1620) \rightarrow \Delta\pi$, D-wave MODULUS (%) PHASE (°) DOCUMENT ID TECN COMMENT 38±9 -85 ± 30 ANISOVICH 12A DPWA Multichannel

△(1620) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) | |
|-----------------------|------------------------------------------|------------------------------|--|
| $\overline{\Gamma_1}$ | $N\pi$ | 20-30 % | |
| Γ_2 | $N \pi \pi$ | 70-80 % | |
| Γ_3 | $\Delta\pi$ | 30-60 % | |
| Γ_4 | Δ (1232) π , \emph{D} -wave | | |
| Γ_5 | $N \rho$ | 7-25 % | |
| Γ_6 | $N\rho$, $S=1/2$, S -wave | | |
| Γ_7 | $N\rho$, $S=3/2$, D -wave | | |
| Γ ₈ | $N(1440)\pi$ | | |
| Γ9 | $N\gamma$ | 0.03-0.10 % | |
| Γ_{10} | $N\gamma$, helicity=1/2 | 0.03-0.10 % | |

 $\Delta(1620), \Delta(1700)$

△(1620) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ | |
|--------------------------------------|-------------------|--------|-------------|-------------------------------------------------------------------------------|-------------------|---|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | | |
| 20 to 30 OUR ESTIMATE | | | | | | |
| 28 ± 3 | ANISOVICH | 12A | DPWA | Multichannel | | |
| 31.5 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | | |
| 9 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ | | |
| 25 ± 3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | | |
| 35 ± 6 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | | |
| • • • We do not use the follow | ving data for ave | erages | , fits, lin | nits, etc. • • • | | |
| 23 ± 5 | ANISOVICH | 10 | DPWA | Multichannel | | I |
| 22 ±12 | THOMA | 80 | DPWA | Multichannel | | Ī |
| 31.0± 0.4 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | | |
| 34 ± 1 | PENNER | 02c | DPWA | Multichannel | | |
| 45 ± 5 | VRA NA | 00 | DPWA | Multichannel | | |
| 29 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | | |
| 60 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ (lower i | mass) | |
| 36 | CHEW | 80 | BPWA | $\pi^+ \stackrel{p}{ ightarrow} \stackrel{\pi^+}{ ightarrow} p$ (higher mass) | , | |

Note: Signs of couplings from $\pi\,{\it N} \to {\it N}\,\pi\,\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)~S_{31}$ counting to A(1232) =

| $ \frac{(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \to \Delta(1620) \to \Delta(1232)\pi, D\text{-wave}}{-0.36 \text{ to } -0.28 \text{ OUR ESTIMATE}} \\ -0.24 \pm 0.03 & \text{MANLEY} & 92 \text{ IPWA} & \pi N \to \pi N \& N\pi\pi \\ -0.33 \pm 0.06 & \text{BARNHAM} & 80 \text{ IPWA} & \pi N \to \pi N \& N\pi\pi \\ -0.39 & 2.6 \text{ LONGACRE} & 75 \text{ IPWA} & \pi N \to N\pi\pi \\ -0.40 & 3 \text{ LONGACRE} & 75 \text{ IPWA} & \pi N \to N\pi\pi \\ \hline (\Delta(1232)\pi, D\text{-wave})/\Gamma_{total} & \frac{\Gamma_4/\Gamma}{N^2} \\ \frac{VALUE}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} \\ \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}{N^2} & \frac{N}$ | coupling to $\Delta(1232) \pi$. | | | | | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------------------|----------|-------------|-------------------------------------------------------------|-------------------------------------|--|--|--|
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | 2)π, | | | Γ ₄)½/Γ | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | -0.36 to -0.28 OUR ESTIMATE | | | | | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | -0.24 ± 0.03 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \&$ | Νππ | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | -0.33 ± 0.06 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | -0.39 | ^{2,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | ³ LONGACRE | 75 | IPWA | $\pi \: {\it N} \: \rightarrow \: \: {\it N} \: \pi \: \pi$ | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\Gamma(\Delta(1232)\pi, D$ -wave $)/\Gamma_{ m total}$ | l | | | | Γ_4/Γ | | | |
| 39 \pm 2 | | | | TECN | COMMENT | | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | 60±17 | ANISOVICH | 12A | DPWA | Multichannel | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 39± 2 | VRA NA | 00 | DPWA | Multichannel | - | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | • • • We do not use the followin | g data for average | s, fits, | , limits, e | etc. • • • | | | | |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 48 ± 25 | THOMA | 80 | DPWA | Multichannel | | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | VALUE | · · · · · · · · · · · · · · · · · · · | | | | | | | |
| $^{+0.40\pm0.10}$ $^{+0.8}$ $^{+0.8}$ $^{+0.28}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.8}$ $^{-0.$ | +0.12 to +0.22 OUR ESTIMATE | | | | | <u> </u> | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $+$ 0.15 \pm 0.02 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \&$ | Νππ | | | |
| +0.28 $\frac{3}{\text{LONGACRE}}$ 75 IPWA $\pi N \rightarrow N\pi\pi$ $\Gamma(N\rho, S=1/2, S-\text{wave})/\Gamma_{\text{total}}$ $\frac{DOCUMENT\ ID}{VRA\ NA}$ $\frac{DOCUMENT\ ID}{VRA\ NA}$ $\frac{TECN}{DPWA}$ $\frac{COMMENT}{Multichannel}$ $(\Gamma_1\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \rightarrow \Delta(1620) \rightarrow N\rho, S=3/2, D-\text{wave}$ $\frac{VALUE}{-0.15\ \text{to} -0.03\ \text{OUR ESTIMATE}}$ -0.06 ± 0.02 -0.13 $\frac{MANLEY}{2.6\ \text{LONGACRE}}$ $\frac{DOCUMENT\ ID}{7}$ $\frac{TECN}{TECN}$ $\frac{COMMENT}{TECN}$ $\frac{COMMENT}{TECN}$ $\frac{TECN}{TECN}$ $\frac{COMMENT}{TECN}$ $\frac{TECN}{TECN}$ $\frac{COMMENT}{TECN}$ $\frac{TECN}{TECN}$ | | | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | +0.08 | ^{2,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | | | | |
| $ \frac{VALUE (\%)}{14\pm 3} \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ $ \frac{\left(\Gamma_{1}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1620) \rightarrow N\rho, S=3/2, D-wave}{-0.15 \text{ to } -0.03 \text{ OUR ESTIMATE}} \frac{DOCUMENT ID}{DOCUMENT ID} \frac{TECN}{TECN} \frac{COMMENT}{TECN} \frac{COMMENT}{TECN} \frac{N\pi N \rightarrow \pi N \& N\pi \pi}{\pi N \rightarrow N\pi \pi} $ $ \frac{1}{2.6} \frac{N\rho, S=3/2, D-wave}{TECN} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}{1000} \frac{1}$ | +0.28 | ³ LONGACRE | 75 | IPWA | $\pi \: {\it N} \: \rightarrow \: \: {\it N} \: \pi \: \pi$ | | | | |
| 14 ± 3 VRA NA 00 DPWA Multichannel $ (\Gamma_{\rm I}\Gamma_{\rm f})^{1/2}/\Gamma_{\rm total} \ {\rm in} \ N\pi \to \Delta (1620) \to N\rho, S=3/2, \ D-{\rm wave} \qquad (\Gamma_{\rm I}\Gamma_{\rm f})^{1/2}/\Gamma $ $ 0.15 \ {\rm to} -0.03 \ {\rm OUR} \ {\rm ESTIMATE} \qquad \qquad DOCUMENT \ ID \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad COMMENT \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN \qquad TECN $ | $\Gamma(N\rho, S=1/2, S-wave)/\Gamma_{tota}$ | ıl | | | | Γ_6/Γ | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | VALUE (%) | DO CUMENT ID | | TECN | COMMENT | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 14 ± 3 | VRA NA | 00 | DPWA | Multichannel | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | | | ι _{Γ7}) ¹ ⁄2/Γ | | | |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | | DO COMENT ID | | TECH | COMMENT | | | | |
| -0.13 2,6 LONGACRE 77 IPWA π N \rightarrow N π π Γ (N ρ , S=3/2, D-wave)/ Γ total Γ_7/Γ | | | 92 | IPWA | $\pi N \rightarrow \pi N &$ | Νππ | | | |
| $\Gamma(N\rho, S=3/2, D$ -wave)/ Γ_{total} Γ_7/Γ | -0.13 | ^{2,6} LONGACRE | | | | | | | |
| VALUE (%) DO CUMENT ID TECN COMMENT | | | | | | Γ ₇ /Γ | | | |
| | VALUE (%) | DO CUMENT ID | | TECN | COMMENT | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta$ | $(\Gamma_1 \Gamma_8)^{\frac{1}{2}}/1$ | | | | |
|------------------------------------------------------------------------------------------|---------------------------------------|----------|-------------|-----------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.11 ± 0.05 | BARNHAM | 80 | IPWA | $\pi \: N \: \to \: \: N \: \pi \: \pi$ | |
| $\Gamma(N(1440)\pi)/\Gamma_{\text{total}}$ | | | | | Г ₈ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 0± 1 | VRA NA | 00 | | Multichannel | |
| • • We do not use the follow | ing data for average | s, fits, | , limits, e | etc. • • • | |
| 19±12 | THOMA | 08 | DPWA | Multichannel | |

00

DPWA Multichannel

ı

VRA NA

△(1620) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006)

$\Delta(1620) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

 2 ± 1

| VALUE (GeV -1/2) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|--------------|-----|------|------------------------------|
| +0.027±0.011 OUR EST MATE | · | | | |
| 0.052 ± 0.005 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.050 ± 0.002 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.035 ± 0.020 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.035 ± 0.010 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.010 ± 0.015 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |

| • | • We do not use the following of | data for averages | , fits, | limits, e | etc. • • • |
|---|----------------------------------|-------------------|---------|-----------|------------------------------|
| | 0.063 ± 0.012 | ANISOVICH | 10 | DPWA | Multichannel |
| | 0.066 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| _ | 0.050 | PENNER | 02D | DPWA | Multichannel |
| | 0.042 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | 0.066 | WADA | 84 | DPWA | Compton scattering |

△(1620) FOOTNOTES

 1 CHEW 80 reports two S_{31} resonances at somewhat higher masses than other analyses. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83.

Problems with this analysis are discussed in section 2.1.11 or HOEHLER 03. 2 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \rightarrow N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes. 3 From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix 3 From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix

From method in General Total System ...

4 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

 5 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

⁶LONGACRE 77 considers this coupling to be well determined.

△(1620) REFERENCES

For early references, see Physics Letters $\mathbf{111B}\ 1\ (1982)$

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|------|--------------------------|-----------------------------------------|---------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| THOMA | 08 | PL B659 87 | U. Thom a et al. | (CB-ELSA Collab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | | n Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | W -M Yao et al | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Worki | |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BRCO) |
| HOEHLER | 93 | πN Newsletter 9.1 | G. Hohler | (KARL) |
| II | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| WADA | 84 | NP B247 313 | Y. Wada et al. | ` (INUS) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| HOEHLER | 83 | Landolt-Boernstein 1/9B2 | | (KARLT) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| BARNHAM | 80 | NP B168 243 | K.W.J. Barnham et al. | `(LOIC) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | `(LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBĽ, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| A Iso | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |

 $\Delta(1700) \ 3/2$

 $I(J^P) = \frac{3}{2}(\frac{3}{2})$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

△(1700) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------|-----------------------|---------|-------------|------------------------------------------------|
| 1670 to 1750 (≈ 1700) OUR ES | TI MATE | | | |
| $1715 \begin{array}{c} +30 \\ -15 \end{array}$ | ANISOVICH | 12A | DPWA | Multichannel |
| 1695.0 ± 1.3 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1762 ±44 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1710 ±30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1680 ±70 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 1780 ±40 | ANISOVICH | 10 | DPWA | Multichannel |
| 1790 ±30 | HORN | 08A | DPWA | Multichannel |
| 1770 ±40 | THOMA | 80 | DPWA | Multichannel |
| 1687.9± 2.5 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1678 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 1732 ± 23 | VRANA | 00 | DPWA | Multichannel |
| 1690 ±15 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1680 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1655 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1650 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $1718.4 + 13.1 \\ -13.0$ | $^{\mathrm{1}}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 1600 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 1680 | ³ LONGACRE | 75 | IPWA | $\pi {\it N} \rightarrow {\it N} \pi \pi$ |

△(1700) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------|-----------------------|---------|-----------|----------------------------------------|
| 200 to 400 (≈ 300) OUR ESTIN | MATE | | | |
| $310 \begin{array}{ccc} + & 40 \\ - & 15 \end{array}$ | ANISOVICH | 12A | DPWA | Multichannel |
| 375.5 ± 7.0 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 600 ±250 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 280 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 230 ± 80 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | g data for average | s, fits | , limits, | etc. • • • |
| 580 ±120 | ANISOVICH | 10 | DPWA | Multichannel |
| 580 ± 60 | HORN | 08A | DPWA | Multichannel |
| 630 ±150 | THOMA | 80 | DPWA | Multichannel |
| 364.8± 16.6 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 606 ± 15 | PENNER | 02c | DPWA | Multichannel |
| 119 ± 70 | VRA NA | 00 | DPWA | Multichannel |
| 285 ± 20 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 272 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 348 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 160 | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 193.3± 26.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 200 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 240 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1700) POLE POSITION

REAL PART

| DO CUMENT ID | | TECN | COMMENT |
|-----------------------|------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MATE | | | |
| ANISOVICH | 12A | DPWA | Multichannel |
| ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| g data for averages | , fits, | , limits, e | etc. • • • |
| ANISOVICH | 10 | DPWA | Multichannel |
| HORN | 08A | DPWA | Multichannel |
| THOMA | 80 | DPWA | Multichannel |
| ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| VRA NA | 00 | DPWA | Multichannel |
| ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| ⁵ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| | MATE ANISOVICH ARNDT 4 HOEHLER CUTKOSKY G data for averages ANISOVICH HORN THOMA ARNDT VRA NA ARNDT 5 LONGACRE | ANISOVICH 12A ARNDT 06 4 HOEHLER 93 CUTKOSKY 80 g data for averages, fits, ANISOVICH 10 HORN 08A THOMA 08 ARNDT 04 VRANA 00 ARNDT 95 ARNDT 91 LONGACRE 78 | MATE A NISOVICH 12A DPWA AR NDT 06 DPWA 4 HOEHLER 93 SPED CUT KOSKY 80 IPWA 5 data for averages, fits, limits, of A NISOVICH 10 DPWA HORN 08A DPWA ATHOMA 08 DPWA AR NDT 04 DPWA VRA NA 00 DPWA AR NDT 95 DPWA AR NDT 95 DPWA 5 LONGACRE 78 IPWA |

| -2×IMAGINARY PART | | | | |
|---------------------------------------------------|-----------------------|----------|-------------|---------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 160 to 300 (≈ 230) OUR EST MA | TE | | | |
| 305 ± 15 | ANISOVICH | 12A | DPWA | Multichannel |
| 253 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 159 | ⁴ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 220±40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● We do not use the following | g data for average | s, fits, | , limits, e | etc. • • • |
| 275 ± 35 | ANISOVICH | 10 | DPWA | Multichannel |
| 325 ± 35 | HORN | 08A | DPWA | Multichannel |
| 320±60 | THOMA | 80 | DPWA | Multichannel |
| 226 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 118 | VRA NA | 00 | DPWA | Multichannel |
| 242 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 208 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 245 or 241 | ⁵ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| 208 or 201 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1700) ELASTIC POLE RESIDUE

MODULUS |r|

| DOCUMENT ID | | TECN | COMMENT | |
|-------------------|-----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ANISOVICH | 12A | DPWA | Multichannel | I |
| ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | _ |
| HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ | |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| data for averages | s, fits, | , limits, e | etc. • • • | |
| ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ | |
| | | | | |
| DO CUMENT ID | | TECN | COMMENT | |
| ANISOVICH | 12A | DPWA | Multichannel | I |
| ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | _ |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| data for averages | s, fits, | , limits, e | etc. • • • | |
| ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| ARNDT | 91 | DEWA | π N → π N Soln S M90 | |
| | ANISOVICH ARNDT HOEHLER CUTKOSKY Jata for averages ARNDT ARNDT ARNDT ANISOVICH ARNDT CUTKOSKY Jata for averages | ANISOVICH 12A ARNDT 06 HOEHLER 93 CUTKOSKY 80 data for averages, fits, ARNDT 95 ARNDT 91 DOCUMENT ID ANISOVICH 12A ARNDT 06 CUTKOSKY 80 data for averages, fits, ARNDT 04 ARNDT 05 ARNDT 06 ARNDT 06 ARNDT 07 ARNDT 07 ARNDT 07 ARNDT 07 ARNDT 07 ARNDT 07 | ANISOVICH 12A DPWA ARNDT 06 DPWA HOEHLER 93 SPEC CUTKOSKY 80 IPWA data for averages, fits, limits, of ARNDT 95 DPWA ARNDT 91 DPWA DOCUMENT ID TECN ANISOVICH 12A DPWA ARNDT 06 DPWA CUTKOSKY 80 IPWA ARNDT 06 DPWA CUTKOSKY 80 IPWA ARNDT 06 DPWA CUTKOSKY 80 IPWA ARNDT 06 DPWA ARNDT 06 DPWA ARNDT 07 DPWA ARNDT 08 DPWA ARNDT 09 DPWA ARNDT 09 DPWA | ANISOVICH 12A DPWA $Multichannel$ ARNDT 06 DPWA $\pi N \rightarrow \pi N, \eta N$ HOEHLER 93 SPED $\pi N \rightarrow \pi N$ data for averages, fits, limits, etc. • • • ARNDT 04 DPWA $\pi N \rightarrow \pi N, \eta N$ ARNDT 95 DPWA $\pi N \rightarrow \pi N, \eta N$ ARNDT 91 DPWA $\pi N \rightarrow \pi N \rightarrow \pi N$ DPWA $\pi N \rightarrow \pi N \rightarrow \pi N$ ANISOVICH 12A DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N$ ANISOVICH 12A DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N$ ANISOVICH 12A DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N, \eta N \rightarrow \pi N, \eta N$ CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N, \eta N \rightarrow \pi N$ ARNDT 04 DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N$ ARNDT 05 DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N \rightarrow \pi N$ ARNDT 05 DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N \rightarrow \pi N$ DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N \rightarrow \pi N$ ARNDT 05 DPWA $\pi N \rightarrow \pi N, \eta N \rightarrow \pi N \rightarrow \pi N$ |

△(1700) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \to \Delta(1700) \to \Delta\eta$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | DO CUMENT ID | | DO CUMENT ID | | COMMENT |
|-------------|-----------|--------------|--------------|------|--------------|--|---------|
| 12±3 | -60 ± 15 | ANISOVICH | 12A | DPWA | Multichannel | | |

△(1700) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | Nπ | 10-20 % |
| Γ_2 | ΣΚ | |
| Γ_3 | $N\pi\pi$ | 80-90 % |
| Γ_4 | $\Delta\pi$ | 30-60 % |
| Γ_5 | Δ (1232) π , S -wave | 25-50 % |
| Γ_6 | ${\it \Delta}$ (1232) π , ${\it D}$ -wave | 5-15 % |
| Γ_7 | $N \rho$ | 30-55 % |
| Γ ₈ | $N\rho$, $S=1/2$, D -wave | |
| Γ9 | $N\rho$, $S=3/2$, S -wave | 5-20 % |
| Γ_{10} | $N\rho$, $S=3/2$, D -wave | |
| Γ_{11} | $N(1535)\pi$ | |
| Γ_{12} | Δ (1232) η | (5.0±2.0) % |
| Γ_{13} | N γ | 0.22-0.60 % |
| Γ_{14} | $N\gamma$, helicity $=1/2$ | 0.12-0.30 % |
| Γ_{15} | $N\gamma$, helicity=3/2 | 0.10-0.30 % |

△(1700) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|-------------------|---------|-------------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 10 to 20 OUR ESTIMATE | | | | - |
| 22 ±4 | ANISOVICH | 12A | DPWA | Multichannel |
| 15.6 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 14 ±6 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 12 ±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 20 ±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | s, fits | , limits, e | etc. • • • |
| 16 ±7 | ANISOVICH | 10 | DPWA | Multichannel |
| 20 ±7 | HORN | 08A | DPWA | Multichannel |
| 15 ±8 | THOMA | 08 | DPWA | Multichannel |
| 15.0 ± 0.1 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 14 ±1 | PENNER | 02c | DPWA | Multichannel |
| 5 ±1 | VRANA | 00 | DPWA | Multichannel |
| 16 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 16 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

Note: Signs of couplings from $\pi\,N\to N\,\pi\,\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)$ S_{31} coupling to $\Delta(1232) \pi$.

/F F 1/2 /F

/F F 1/2 /F

| $(i f)''/ total in N\pi \rightarrow .$ | $\Delta(1700) \rightarrow \Delta(123)$ | $2)\pi$, | 5-wave | (1 5) /2/ |
|------------------------------------------------------------------------------------|----------------------------------------|-----------|----------------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.21 to +0.29 OUR EST M | ATE | | | |
| $+0.32 \pm 0.06$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $+0.18 \pm 0.04$ | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.30 | ^{2,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| +0.24 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, S$ -wave)/ $\Gamma_{\rm t}$ | otal | | | Г ₅ /Г |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 20^{+25}_{-13} | ANISOVICH | 12A | DPWA | Multichannel |
| 90± 2 | VRANA | 00 | DPWA | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to 1$ | ∆ (1700) → ∆ (123 | 2)π, | <i>D</i> -wave | e (Γ ₁ Γ ₆) ^{1/2} /Γ |

| (<i>j</i> <i>f</i>) ' - / total / ν π · | $\rightarrow \Delta(1700) \rightarrow \Delta(123)$ | zjπ, | D-Wav | e (1116) /1 |
|------------------------------------------------------|----------------------------------------------------|------|-------|----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.05 to +0.11 OUR ES | TIMATE | | | |
| $+0.08 \pm 0.03$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 0.14 ± 0.04 | BARNHAM | | | $\pi N \rightarrow N \pi \pi$ |
| +0.05 | ^{2,6} LONGACRE | | | |
| +0.10 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| =(| | | | |

| 0.10 | LONGACIAL | 15 | | A 14 / 14 A A | |
|------------------------------------------------------------|--------------|-----|------|---------------|-------------------|
| $\Gamma(\Delta(1232)\pi, D$ -wave $)/\Gamma_{	ext{total}}$ | | | | | Γ_6/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 5 to 15 OUR ESTIMATE | | | | | |
| $12 + \frac{14}{7}$ | ANISOVICH | 12A | DPWA | Multichannel | |
| 4± 1 | VRANA | 00 | DPWA | Multichannel | |
| | | | | | |

 $\Delta(1700), \Delta(1750)$

| VALUE | $\Delta(1700) \rightarrow N \rho, S$ DOCUMENT ID | | TECN | re (F | |
|-------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|------------------|-----------|-------------------------------|----------------------------------|
| $+0.17 \pm 0.05$ | BARNHAM | 80 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $(\Gamma_i\Gamma_f)^{1\!\!\!/2}/\Gamma_{	ext{total}}$ in $N\pi$ $ ightarrow$ | DO CUMENT ID | | | | 1√و) أ⁄2/ر |
| ±0.11 to ±0.19 OUR | ESTIMATE | | | | |
| $+0.10 \pm 0.03$ | MANLEY | | IPWA | | |
| + 0.04 | ^{2,6} LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| - 0.30 | ³ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| $\Gamma(N\rho, S=3/2, S-wave)/$ | Γ _{total} | | | | ٦/و٦ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 1 ± 1 | VRA NA | 00 | DPWA | Multichannel | |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\pi ightarrow$ | $\Delta(1700) \rightarrow N \rho, S$ | | | | Г ₁₀)½/Г |
| 0.18±0.07 | BARNHAM | 80 | IPWA | | |
| $\Gamma(N(1535)\pi)/\Gamma_{\text{total}}$ | | | | | Γ ₁₁ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| • • We do not use the fol | lowing data for average | es, fits, | limits, e | etc. • • • | |
| 4±2 | HORN | 08A | DPWA | Multichannel | |
| $\Gamma(\Delta(1232)\eta)/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | COMMENT | Γ ₁₂ /Γ |
| | A NISOVICH | | | Multichannel | |
| | | 1ZA | DPVVA | | |
| 5±2 | | | limits, e | etc. • • • | |
| 5±2 • • • We do not use the fol | | | | etc. • • • Multich annel | |
| 5 ± 2 • • • We do not use the fol 2 ± 1 | lowing data for average HORN | es, fits, | | | Γ11/Γ12 |
| Friction (18) 5 ± 2 ••• We do not use the fol 2 ± 1 $\Gamma(N(1535)\pi)/\Gamma(\Delta(1232))$ WALUE | lowing data for average HORN | es, fits, | DPWA | | Γ ₁₁ /Γ ₁₂ |
| 5 ± 2 ••• We do not use the fol 2 ± 1 $\Gamma(N(1535)\pi)/\Gamma(\Delta(1232))$ | lowing data for average HORN 2)η) <u>DOCUMENT ID</u> | es, fits, 08A | DPWA | Multich annel | Γ ₁₁ /Γ ₁₂ |

△(1700) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$\Delta(1700) \rightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV-1/2) | DO CUMENT ID | | TECN | COMMENT | |
|-----------------------------|-------------------|---------|-----------|------------------------------|--|
| +0.104 ± 0.015 OUR ESTIMATE | | | | | |
| 0.160 ± 0.020 | ANISOVICH | 12A | DPWA | Multichannel | |
| 0.125 ± 0.003 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.090 ± 0.025 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.111 ± 0.017 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.089 ± 0.033 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| | data for averages | s, fits | , limits, | etc. • • • | |
| 0.160 ± 0.045 | ANISOVICH | 10 | DPWA | Multichannel | |
| 0.160 ± 0.040 | HORN | 08A | DPWA | Multichannel | |
| 0.226 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.096 | PENNER | 02D | DPWA | Multichannel | |
| 0.121 ± 0.004 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| | | | | | |

$\Delta(1700) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT | |
|-----------------------------------|-------------------|---------|-------------|------------------------------|---|
| +0.085 ±0.022 OUR ESTIMATE | | | | | |
| 0.165 ± 0.025 | ANISOVICH | 12A | DPWA | Multichannel | |
| 0.105 ± 0.003 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.097 ± 0.020 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.107 ± 0.015 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ | |
| 0.060 ± 0.015 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| • • • We do not use the following | data for averages | , fits, | , limits, e | etc. • • • | |
| 0.160 ± 0.040 | ANISOVICH | 10 | DPWA | Multichannel | |
| 0.150 ± 0.030 | HORN | 08A | DPWA | Multichannel | • |
| 0.210 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | |
| 0.154 | PENNER | 02D | DPWA | Multichannel | |
| 0.115 ± 0.004 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| | | | | | |

△(1700) FOOTNOTES

 1 Problems with CHEW 80 are discussed in section 2.1.11 of HOEHLER 83. 2 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi \, N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

fits with Breit-Wigner circles to the 1-matrix amplitudes.

From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams of the speeds with which the amplitudes traverse the diagrams.

FLONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

 $^{
m 6}$ LONGACRE 77 considers this coupling to be well determined.

△(1700) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|------------|------|--------------------------|----------------------------------------|-----------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| KASHEVAROV | 09 | EPJ A42 141 | V.L. Kashevarov et al. (MAI | Al Crystal Ball/TAPS) |
| HORN | 08A | EPJ A38 173 | I. Horn et al. | (ĆB-ELSA Collab.) |
| Also | | PRL 101 202002 | I. Horn et al. | (CB-ELSA Collab.) |
| THOMA | 08 | PL B65987 | U. Thoma et al. | (CB-ELSA Collab.) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jeffers | on Lab CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Le | e (PÌTT+Í |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Worl | |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | ` (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | ` (VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| HOEHLER | 83 | Landolt-Boernstein 1/9B2 | | (KARLT) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA II | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| BARNHAM | 80 | NP B168 243 | K.W.J. Barnham et al. | `(LOIC) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | `(LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkoský et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| Also | | Toronto Conf. 3 | R Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBL, SLAC) |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | (SACL) IJP |
| Also | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | . = | | (===, 0 = 10) 131 |

 Δ (1750) $1/2^{+}$

 $I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$ Status: *

OMITTED FROM SUMMARY TABLE

Neither ARNDT 06 nor ANISOVICH 12A finds any evidence for this

△(1750) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|---------|---------|----------------------------------------|
| ≈ 1750 OUR ESTIMATE | | | | |
| 1744 ±36 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, | etc. • • • |
| 1712 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 1721 ±61 | VRANA | 00 | DPWA | Multichannel |
| 1715.2 ± 21.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 1778.4 ± 9.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

△(1750) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|---------------------|-----------|---------|----------------------------------------|
| 300 ±120 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| • • • We do not use the follow | ing data for averag | es, fits, | limits, | etc. • • • |
| 643 ± 17 | PENNER | 02c | DPWA | Multichannel |
| 70 ± 50 | VRANA | 00 | DPWA | Multichannel |
| 93.3± 55.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 23.0 ± 29.0 | 1 CHEW | 80 | ΒΡΙΛΙΔ | $\pi^+ p \rightarrow \pi^+ p$ |

△(1750) POLE POSITION

REAL PART

| VALUE (MeV) | DO CUMENT IL |) | TECN | COMMENT |
|-------------------------|---------------------------|-----------|-------------|--------------------------------------|
| 1748 | ² ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| • • • We do not use the | following data for averag | ges, fits | , limits, e | etc. • • • |
| 1714 | VRANA | 00 | DPWA | Multichannel |
| -2×IMAGINARY PA | RT | | | |
| VALUE (MeV) | DO CUMENT IL |) | TECN | COMMENT |
| 524 | ² ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| • • • We do not use the | following data for averag | ges, fits | , limits, e | etc. • • • |
| 68 | VRANA | 00 | DPWA | Multichannel |

△(1750) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------|--------------------|----|------|--------------------------------------|
| 48 | ² ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| PHASE θ | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| 158 | ² ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N. nN$ |

ı

△(1750) DECAY MODES

| | Mode |
|----------------|----------------------------------------------------------|
| Γ ₁ | $N\pi$ |
| Γ_2^- | $egin{array}{l} N\pi \ N\pi\pi \ N(1440)\pi \end{array}$ |
| Γ_3 | $N(1440)\pi$ |
| Γ_4 | ΣΚ |

△(1750) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | $\Gamma_1/$ |
|--------------------------------------------|------------------------------|----------|-------------|------------------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 8 ± 3 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| • • • We do not use the | following data for average | es, fits | , limits, e | etc. • • • |
| 1 ± 1 | PENNER | 02c | DPWA | Multichannel |
| 6 ± 9 | VRA NA | 00 | DPWA | Multichannel |
| 18 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 20 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| $\frac{VALUE}{+0.15\pm0.03}$ | <u>DOCUMENT ID</u> MANLEY | 92 | IPWA | $\frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ |
| | | 92 | | |
| $\Gamma(N(1440)\pi)/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | Γ ₃ / |
| 83±1 | VRA NA | 00 | | Multichannel |
| $\Gamma(\Sigma K)/\Gamma_{total}$ | | | | Γ ₄ / |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| • • • We do not use the | following data for average | es, fits | , limits, e | etc. • • • |
| 0.1 ± 0.1 | PENNER | | D D | Multichannel |

△(1750) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$\Delta(1750) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | TECN COMMENT |
|----------------------------------|---------------------------|----------------------|
| • • • We do not use the followin | g data for averages, fits | , limits, etc. • • • |
| 0.053 | PENNER 02D | DPWA Multichannel |

△(1750) FOOTNOTES

 1 CHEW 80 reports four resonances in the P_{31} wave — see also the $\varDelta(1910).$ Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83.

2 ARNDT 04 gives no corresponding Breit-Wigner parameters for this state, because the mass so obtained is about 500 MeV higher than that suggested by the position of the pole.

△(1750) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|------|--------------------------|-------------------------------------|---------------|
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | (GIES) |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | (PÌTT+) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | `(KENT) |
| A Iso | | PR D30 904 | D.M. Manley et al. | (VPI) |
| HOEHLER | 83 | Landolt-Boernstein 1/9B: | 2 G. Hohler | (KARLT) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | `(LBL) |
| | | | | |

△(1900) 1/2⁻

 $I(J^P) = \frac{3}{2}(\frac{1}{2})$ Status: **

OMITTED FROM SUMMARY TABLE

Some obsolete results published before 1980 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(1900) BREIT-WIGNER MASS

| DO CUMENT ID | | TECN | COMMENT |
|--------------|---------------------|----------------------------------------------|----------------------------------------|
| JR ESTIMATE | | | |
| ANISOVICH | 12A | DPWA | Multichannel |
| MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| | MANLEY CUT KOSKY | A NISOVICH 12A MA NLEY 92 CUT KOSKY 80 | A NISOVICH 12A DPWA |

| 1802 ±87 | VRANA | 00 | DPWA Multichannel |
|-------------------|-------|----|------------------------------------|
| 1918.5 ± 23.0 | CHEW | 80 | BPWA $\pi^+ p \rightarrow \pi^+ p$ |

△(1900) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------------|----------|-----------|----------------------------------------|
| 300 ±45 | ANISOVICH | 12A | DPWA | Multichannel |
| 263 ±39 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 170 ±50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 140 ±40 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | g data for average | s, fits, | limits, e | etc. • • • |
| 48 ±45 | VRANA | 00 | DPWA | Multichannel |
| 93.5 ± 54.0 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

△(1900) POLE POSITION

REAL PART

| REAL PART | | | | |
|-------------------------------------------|-----------------------|----------|-------------|-----------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 1845 ± 25 | ANISOVICH | 12A | DPWA | Multichannel |
| 1780 | $^{ m 1}$ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1870 ± 40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | s, fits, | , limits, e | etc. • • • |
| 1795 | VRANA | 00 | DPWA | Multichannel |
| not seen | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 2029 or 2025 | ² LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -2×IMAGINARY PART | | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 300±45 | ANISOVICH | 12A | DPWA | Multichannel |
| 180 ± 5 0 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | g data for average | s, fits, | , limits, e | etc. • • • |
| 58 | VRANA | 00 | DPWA | Multichannel |
| not seen | ARNDT | 91 | DPWA | $\pi{\it N} \rightarrow \pi{\it N}$ Soln SM90 |
| 164 or 163 | ² LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1900) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|----------------|--------------|-----|------|---------------------------|--|
| 10±3 | ANISOVICH | 12A | DPWA | Multichannel | |
| 10 ± 3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| PHASE θ | | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
| -125 ± 20 | ANISOVICH | 12A | DPWA | Multichannel | |
| + 20+40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |

△(1900) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi o au(1900) o au K$

| MODULUS (% | <u>6) PHASE (°)</u> | DO CUMENT ID | TECN | COMMENT |
|----------------|---------------------------------|-----------------------------------------|--------|--------------|
| 7 ± 2 | -50 ± 30 | ANISOVICH 12 | a DPWA | Multichannel |
| Normalize | ed residue in $N\pi ightarrow$ | $\Delta(1900) \rightarrow \Delta \pi$, | D-wave | |
| MODULUS (% | 6) PHASE (°) | DO CUMENT ID | TECN | COMMENT |
| 12^{+8}_{-5} | 110 ± 20 | ANISOVICH 12 | A DPWA | Multichannel |

△(1900) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|----------------|------------------------------------------|--------------------------------------|
| Γ ₁ | $N\pi$ | 10-30 % |
| Γ_2 | ΣΚ | |
| Γ_3 | $N \pi \pi$ | |
| Γ_4 | $\Delta\pi$ | |
| Γ_5 | Δ (1232) π , \emph{D} -wave | |
| Γ_6 | $N \rho$ | |
| Γ_7 | $N\rho$, $S=1/2$, S -wave | |
| Γ ₈ | $N\rho$, $S=3/2$, D -wave | |
| Γ9 | $N(1440)\pi$, S -wave | |
| Γ_{10} | N γ , helicity=1/2 | |

Baryon Particle Listings $\Delta(1900)$, $\Delta(1905)$

| Λ | 1900 | BRA | NCE | HNG | RAT | IOS |
|---|------|--------|-----|------|------|-----|
| _ | 1,00 | יייי ו | | 1111 | 1001 | |

| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |) BRANCHIN | G KA | 11105 | |
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| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | Г1/Г |
| $\begin{array}{cccccccccccccccccccccccccccccccccccc$ | DOCUMENT ID | | TECN | COMMENT |
| 10± 3 8± 4 HOEHLER 79 IPWA $\pi N \to \pi N$ HOEHLER 79 IPWA $\pi N \to \pi N$ 3±10 VRA NA 00 DPWA Multichannel 28 ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Sigma K$ VALUE OCCUMENT ID TECN OMMENT ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Delta (1232) \pi$, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Delta (1232) \pi$, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Delta (1232) \pi$, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Delta (1232) \pi$, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to \Delta (1232) \pi$, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=1/2, S-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=1/2, S-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=1/2, S-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900) \to N \rho$, S=3/2, D-wave ($\Gamma_1 \Gamma_f \gamma_1^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (1900)$ | ANISOVICH | 12A | DPWA | Multichannel |
| 88 ± 4 | MANLEY | 92 | IPWA | $\pi \: N \: \to \: \pi \: N \: \& \: N \: \pi \: \pi$ |
| We do not use the following data for averages, fits, limits, etc. • • • • • • • • • • • • • • • • • • • | | | | |
| VRANA 00 DPWA Multichannel BPWA $\pi^+ p \rightarrow \pi^+ p$ ($\Gamma_1 \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f \Gamma_f$ | | | | |
| CHEW 80 BPWA $\pi^+ p \rightarrow \pi^+ p$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Sigma K$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Sigma K$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=1/2, S\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=1/2, S\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=1/2, S\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=1/2, S\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho, S=3/2, D\text{-wave}$ $(\Gamma_1 \Gamma_f)^{\frac{1}{2}}/\Gamma_{total$ | data for average | s, fits, | , limits, e | etc. • • • |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| CANDLIN 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ $(\Gamma_1 \Gamma_p)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi$, D-wave $(\Gamma_1 \Gamma_5)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi$, D-wave $(\Gamma_1 \Gamma_5)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow \Delta(1232) \pi$, D-wave $(\Gamma_1 \Gamma_5)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=1/2, S-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=1/2, S-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=1/2, S-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N \pi \rightarrow \Delta(1900) \rightarrow N \rho$, S=3/2, D-wave $(\Gamma_1 \Gamma_1)^{\frac{1}{2}}/\Gamma_{\text{total}} i$ | | | TECN | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | 84 | DPW/A | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | CANDEIN | 04 | DIVVA | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | | | F /F |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | DO CUMENT ID | | TECN | |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | ANISOVICH | 12A | DPWA | Multichannel |
| $ \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N\rho, S=1/2, S-\text{wave}}{\text{MANLEY}} \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{DOCUMENT ID}{1PWA} \frac{TECN}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(N\rho, S=1/2, S-\text{wave})/\Gamma_{total}}{30\pm 2} \frac{DOCUMENT ID}{\text{VRA NA}} \frac{TECN}{000} \frac{COMMENT}{\text{Multichannel}} $ $ \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N\rho, S=3/2, D-\text{wave}}{\text{MANLEY}} \frac{(\Gamma_{1}\Gamma_{8})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\text{IPWA}} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(N\rho, S=3/2, D-\text{wave})/\Gamma_{total}}{\text{MANLEY}} \frac{DOCUMENT ID}{92} \frac{TECN}{\text{IPWA}} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S-\text{wave}}{\text{MANLEY}} \frac{(\Gamma_{1}\Gamma_{9})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\text{Multichannel}} $ $ \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S-\text{wave}}{\text{MANLEY}} \frac{(\Gamma_{1}\Gamma_{9})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S-\text{wave}}{\text{MANLEY}} \frac{(\Gamma_{1}\Gamma_{9})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{4})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{DOCUMENT ID}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{9})^{\frac{1}{2}}/\Gamma_{total}}{\text{MANLEY}} \frac{TECN}{92} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ | VRA NA | 00 | DPWA | Multichannel |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | DOCUMENT ID | =1/2 | TECN_ | COMMENT |
| $ \frac{VALUE (\%)}{30\pm 2} \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}}{V^{2}/\Gamma_{total}} \frac{In N\pi \rightarrow \Delta(1900) \rightarrow N\rho, S=3/2, D\text{-wave}}{MANLEY} \frac{(\Gamma_{1}\Gamma_{8})^{1/2}/\Gamma_{1}}{IPWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{N\rho, S=3/2, D\text{-wave}}{IPWA} \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(N\rho, S=3/2, D\text{-wave})/\Gamma_{total}}{VRA NA} \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}/\Gamma_{total}}{IPWA} \frac{IN N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S\text{-wave}}{IPWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}/\Gamma_{total}}{IPWA} \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $ \frac{VALUE (\%)}{30\pm 2} \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}}{V^{2}/\Gamma_{total}} \frac{In N\pi \rightarrow \Delta(1900) \rightarrow N\rho, S=3/2, D\text{-wave}}{MANLEY} \frac{(\Gamma_{1}\Gamma_{8})^{1/2}/\Gamma_{1}}{IPWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{N\rho, S=3/2, D\text{-wave}}{IPWA} \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(N\rho, S=3/2, D\text{-wave})/\Gamma_{total}}{VRA NA} \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}/\Gamma_{total}}{IPWA} \frac{IN N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S\text{-wave}}{IPWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{(\Gamma_{1}\Gamma_{7})^{1/2}/\Gamma_{total}}{IPWA} \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ $ \frac{IPWA}{\pi N \rightarrow \pi N \& N\pi\pi} $ | | | | Γ ₇ /Γ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | DOCUMENT ID | | TECN | COMMENT |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | VRA NA | 00 | DPWA | Multichannel |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | 00) → Na S | -3/2 | D-way | re (F. Fa)½/F |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | DOCUMENT ID | | TECN | |
| $\frac{VALUE (\%)}{5\pm 1} \qquad \frac{DOCUMENT ID}{VRA NA} \qquad 00 \qquad \frac{TECN}{DPWA} \qquad \frac{COMMENT}{Multichannel}$ $\frac{(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S\text{-wave}}{VALUE} \qquad \frac{DOCUMENT ID}{MANLEY} \qquad \frac{TECN}{92} \qquad \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ $\frac{\Gamma(N(1440)\pi, S\text{-wave})/\Gamma_{total}}{VALUE (\%)} \qquad \frac{DOCUMENT ID}{DOCUMENT ID} \qquad \frac{TECN}{TECN} \qquad \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $ \frac{DOCUMENT ID}{VRA NA} 00 \frac{TECN}{DPWA} \frac{COMMENT}{Multichannel} $ | | | | Га/Г |
| VRA NA 00 DPWA Multichannel $(\Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\pi \rightarrow \Delta(1900) \rightarrow N(1440)\pi, S-\text{wave}$ $\frac{DOCUMENT ID}{MANLEY} 92 \text{ IPWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ $\Gamma(N(1440)\pi, S-\text{wave})/\Gamma_{total}$ $\frac{DOCUMENT ID}{NAULE(\%)} \frac{TECN}{TECN} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ | DOCUMENT ID | | TECN | COMMENT |
| $\frac{pocument\ iD}{MANLEY} = \frac{pocument\ iD}{MANLEY} = \frac{TECN}{1PWA} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ $\frac{\Gamma(N(1440)\pi, S\text{-wave})/\Gamma_{total}}{NALUE(\%)} = \frac{DOCUMENT\ iD}{DOCUMENT\ iD} = \frac{TECN}{1ECN} \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ | | | | |
| $\frac{DOCUMENT\ D}{MANLEY} 92 PWA \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ $\Gamma(N(1440)\pi, S\text{-wave})/\Gamma_{total}$ $\frac{DOCUMENT\ D}{MANLEY} 92 PWA \frac{COMMENT}{\pi N \rightarrow \pi N \& N\pi\pi}$ | | | | ./ |
| -0.16 ± 0.11 MANLEY 92 IPWA π N \rightarrow π N & N π π Fg/T (N(1440) π , S-wave)/ Γ_{total} DOCUMENT ID TECN COMMENT | $00) \rightarrow N(144)$ | $0)\pi$, | S-wave | |
| VALUE (%) DO CUMENT ID TECN COMMENT | | | | |
| VALUE (%) DO CUMENT ID TECN COMMENT | | | | Г. /Г |
| | | | | 19/1 |
| | DOCUMENT ID | | TECN | COMMENT |
| 4±1 | | DOCUMENT ID ANISOVICH MANLEY CUTKOSKY HOPELER data for average VRA NA CHEW 00) → ∑ K DOCUMENT ID CANDLIN MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY DOCUMENT ID MANLEY DOCUMENT ID VRA NA 00) → N ρ, S: DOCUMENT ID MANLEY DOCUMENT ID VRA NA 00) → N ρ, S: DOCUMENT ID VRA NA 00) → N 144 DOCUMENT ID VRA NA | DOCUMENT ID ANISOVICH 12A MANLEY 92 CUTKOSKY 80 HOEHLER 79 data for averages, fits VRA NA 00 CHEW 80 00) → Σ Κ DOCUMENT ID CANDLIN 84 00) → Δ(1232)π, DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID VRA NA 00 00) → N ρ, S=1/2 DOCUMENT ID MANLEY 92 DOCUMENT ID VRA NA 00 00) → N ρ, S=3/2 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 DOCUMENT ID MANLEY 92 | ANISOVICH 12A DPWA MANLEY 92 IPWA CUTKOSKY 80 IPWA HOEHLER 79 IPWA data for averages, fits, limits, of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the composition of the |

Δ (1900) PHOTON DECAY AMPLITUDES

Papers on $\gamma\,N$ amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,$ 1 (2006).

$\Delta(1900) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------------|----|------|-------------------------------|
| 0.059 ± 0.016 | ³ A NISOVICH 1 | 2A | DPWA | Phase $= (60 \pm 25)^{\circ}$ |
| -0.004 ± 0.016 | CRAWFORD 8 | | | |
| 0.029 ± 0.008 | AWA JI | 31 | DPWA | $\gamma N \rightarrow \pi N$ |

△(1900) FOOTNOTES

- 1 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams. 2 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first
- ²LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- 3 This A NISOVICH 12A value is the complex helicity amplitude at the pole position.

△(1900) REFERENCES

For early references, see Physics Letters $\mathbf{111B}\ 1\ (1982).$

| ANISOVICH 12A EPJ A48 15 A.V. Anisovich et al. (BONN, PN | |
|----------------------------------------------------------------|---------|
| ARNDT 06 PR C74 045205 R.A. Arndt et al. (GV | /U) |
| PDG 06 JPG 33 1 WM. Yao et al. (PDG Coll | 1b.) |
| VRANA 00 PRPL 328 181 T.P. Vrana, S.A. Dytman,, TS.H. Lee (PIT | +) |
| HOEHLER 93 πN Newsletter 9 1 G. Hohler (KA | RL) |
| MANLEY 92 PR D45 4002 D.M. Manley, E.M. Saleski (KE | IT) IJP |
| Also PR D30 904 D.M. Manley et al. (\ | PI) |
| ARNDT 91 PR D43 2131 R.A. Arndt ét al. (VPI, TÈ | LE) IJP |

| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
|----------|----|-------------------|----------------------------|-------------------|
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | ` (KARLT)IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBĽ, SLAC) |

Δ (1905) 5/2 $^{+}$

 $I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status: ****

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

△(1905) BREIT-WIGNER MASS

| VALUE (MoV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|-----------------------|----------|-------------|---------------------------------------------|
| VALUE (MeV) 1855 to 1910 (≈ 1880) OUR ES | | | TECN | COMMENT |
| 1033 10 1910 (≈ 1000) OOK E3 | IIMAIE | | | |
| 1861 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1857.8 ± 1.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1881 ±18 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1910 ±30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1905 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits, | , limits, e | etc. • • • |
| 1890 ± 25 | $^{ m 1}$ A NISOVICH | 10 | DPWA | Multichannel |
| 1855.7 ± 4.2 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1873 ±77 | VRANA | 00 | DPWA | Multichannel |
| 1895 ± 8 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1850 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1960 ±40 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| $1787.0 + 6.0 \\ -5.7$ | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 1830 | ² LONGACRE | 75 | IPWA | $\pi \; N \; \rightarrow \; \; N \pi \pi$ |

△(1905) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------------|-----------------------|---------|-------------|-------------------------------------------------|
| 270 to 400 (≈ 330) OUR ES | TIMATE | | | |
| 335 ± 18 | ANISOVICH | 12A | DPWA | Multichannel |
| 320.6± 8.6 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 327 ± 51 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 400 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 260 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the follow | ving data for average | s, fits | , limits, e | etc. • • • |
| 335 ± 30 | ANISOVICH | 10 | DPWA | Multichannel |
| 334 ± 22 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 461 ±111 | VRANA | 00 | DPWA | Multichannel |
| 354 ± 10 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 294 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 270 ± 40 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| $66.0 + 24.0 \\ - 16.0$ | CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 220 | ² LONGACRE | 75 | IPWA | $\pi {\it N} \rightarrow {\it N} \pi \pi$ |

△(1905) POLE POSITION

| REA | 1 0 | 'ΑΙ | эт |
|-----|-----|-----|----|
| | | | |

| VALUE (MeV) | DO CUMENT ID | | TECN CC | DMMENT |
|-------------------------------|-----------------------|----------|--------------|-----------------------------------------|
| 1805 to 1835 (≈ 1820) OUR EST | MATE | | | |
| 1805 ± 10 | ANISOVICH | 12A | DPWA M | ultichannel |
| 1819 | ARNDT | 06 | DPWA π | $N \rightarrow \pi N, \eta N$ |
| 1829 | ³ HOEHLER | 93 | SPED π | $N \rightarrow \pi N$ |
| 1830 ± 40 | CUTKOSKY | 80 | IPWA π | $N \rightarrow \pi N$ |
| | g data for average | s, fits, | limits, etc. | • • • |
| 1800 ± 15 | ANISOVICH | 10 | DPWA M | ultichannel |
| 1825 | ARNDT | 04 | DPWA π | $N \rightarrow \pi N, \eta N$ |
| 1793 | VRANA | 00 | DPWA M | ultichannel |
| 1832 | ARNDT | 95 | DPWA π | $N \rightarrow N \pi$ |
| 1794 | ARNDT | 91 | DPWA π | $N \rightarrow \pi N \text{ Soln SM90}$ |
| 1813 or 1808 | ⁴ LONGACRE | 78 | IPWA π | $N \rightarrow N \pi \pi$ |

-2×IMAGINARY PART

VALUE (MeV)

| 265 to 300 (≈ 280) OUR ESTIM | NATE | | |
|------------------------------------------------|-----------------------|---------|-------------------------------------------|
| 300 ± 15 | ANISOVICH | 12A | DPWA Multichannel |
| 247 | ARNDT | | DPWA $\pi N \rightarrow \pi N$, ηN |
| 303 | ³ HOEHLER | 93 | SPED $\pi N \rightarrow \pi N$ |
| 280 ± 60 | CUTKOSKY | 80 | IPWA $\pi N \rightarrow \pi N$ |
| ● We do not use the follow | ing data for average | s, fits | , limits, etc. ● ● ● |
| 300 ± 20 | ANISOVICH | 10 | DPWA Multichannel |
| 270 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 302 | VRANA | 00 | DPWA Multichannel |
| 254 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 230 | ARNDT | 91 | DPWA $\pi N \rightarrow \pi N$ Soln SM90 |
| 193 or 187 | ⁴ LONGACRE | 78 | IPWA $\pi N \rightarrow N \pi \pi$ |

DOCUMENT ID TECN COMMENT

△(1905) ELASTIC POLE RESIDUE

| ` , | | | | | |
|----------------------------------------------------|------------------|----------|-------------|-------------------------------------------------------------------------------|---|
| MODULUS r | | | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
| 20 ± 2 | ANISOVICH | 12A | DPWA | Multichannel | 1 |
| 15 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ | _ |
| 25 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ | |
| 25±8 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| \bullet \bullet We do not use the following | data for average | s, fits, | , limits, e | etc. • • • | |
| 16 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ | |
| 12 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| 14 | ARNDT | 91 | DPWA | $\pi \: {\it N} \: \rightarrow \: \pi \: {\it N} \: {\it Soln} \: {\it SM90}$ | |
| PHASE θ | | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT | |
| -44 ± 5 | ANISOVICH | 12A | DPWA | Multichannel | |
| -30 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| -50 ± 20 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| \bullet \bullet $$ We do not use the following | data for average | s, fits, | , limits, e | etc. • • • | |
| - 25 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| - 4 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ | |
| -40 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soin SM90}$ | |

△(1905) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi \to \Delta(1905) \to \Delta\pi$, P-wave

| MODULUS (%) | PHASE (°) | DOCUMENT ID | TECN | COMMENT |
|-------------|-----------|---------------|------|--------------|
| 25 ± 6 | 0 ± 15 | ANISOVICH 12A | DPWA | Multichannel |

△(1905) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-------------------------------------------|------------------------------|
| Γ1 | Nπ | 9–15 % |
| Γ_2 | ΣΚ | |
| Γ_3^- | $N\pi\pi$ | 85-95 % |
| Γ_4 | $\Delta\pi$ | <25 % |
| Γ_5 | $\Delta(1232)\pi$, <i>P</i> -wave | |
| Γ_6 | ${\it \Delta}(1232)\pi$, ${\it F}$ -wave | |
| Γ_7 | $N \rho$ | >60 % |
| Γ ₈ | $N\rho$, $S=3/2$, P -wave | |
| Г9 | $N\rho$, $S=3/2$, F -wave | |
| Γ_{10} | $N\rho$, $S=1/2$, F -wave | |
| Γ_{11} | $N\gamma$ | 0.012-0.036 % |
| Γ_{12} | $N\gamma$, helicity $=$ 1 $/2$ | 0.002-0.006 % |
| Γ_{13} | $N\gamma$, helicity=3/2 | 0.01-0.03 % |

△(1905) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | Г1/Г |
|---------------------------------------------------------------------------------|----------------------------------|
| | IMENT |
| 9 to 15 OUR ESTIMATE | |
| 13 ± 2 ANISOVICH 12A DPWA Mul | tichannel |
| 12.2 ± 0.1 ARNDT 06 DPWA π N | $\rightarrow \pi N$, ηN |
| 12 \pm 3 MANLEY 92 IPWA π N | $\rightarrow \pi N \& N \pi \pi$ |
| 8 \pm 3 CUTKOSKY 80 IPWA π N | $\rightarrow \pi N$ |
| 15 ± 2 HOEHLER 79 IPWA π N | $\rightarrow \pi N$ |
| ullet $ullet$ We do not use the following data for averages, fits, limits, etc. | • • |
| 12 ± 3 ANISOVICH 10 DPWA Mul | tichannel |
| 12.0 ± 0.2 ARNDT 04 DPWA π N | $\rightarrow \pi N$, ηN |
| 9 ± 1 VRANA 00 DPWA Mul | tichannel |
| 12 ARNDT 95 DPWA πN | $\rightarrow N\pi$ |
| 11 CHEW 80 BPWA π^+ | $\rho \rightarrow \pi^+ \rho$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to A$ | $\Delta(1905) \rightarrow \Sigma K$ | | (Γ ₁ Γ ₂) ^{1/2} /Γ |
|-------------------------------------------------------------------------------------|-------------------------------------|---------|----------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 0.015 ± 0.003 | CANDLIN 9 | 4 DDW/A | -+ n . \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ |

Note: Signs of couplings from $\pi\,{\it N}\to~{\it N}\,\pi\,\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)~S_{31}$ coupling to $\Delta(1232)~\pi$.

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta$ | ∆(1905) → ∆(123 | 2)π, | P-wave | e (Γ ₁ Γ ₅) ^½ /Γ |
|------------------------------------------------------------------------------------------|-----------------|------|--------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.04 ± 0.05 | MANIEY | 92 | IPWA | $\pi N \rightarrow \pi N & N \pi \pi$ |

| $\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | Γ ₅ /Γ |
|--------------------------------------------------------------------------------------------|-------------------------------------------|-----------|--------------|------------------------------------------------------|
| 45 ±14 23 ± 1 | A NISOVICH VRA NA | 12A 00 | | Multichannel Multichannel |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\pi	o \Delta(1)$ | 905) → △(123 | 32)π, | F-wave | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ |
| + 0.02 ± 0.03 + 0.20 | | 92 | IPWA | $\pi N \rightarrow \pi N & N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, F\text{-wave})/\Gamma_{\text{total}}$ | DO CUMENT ID | | TECN | Γ ₆ /Γ |
| 44±1 | VRANA | 00 | | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1)$ | 905) → Νρ, <i>S</i> <u>DOCUMENT ID</u> | | | |
| $+$ 0.30 to $+$ 0.36 OUR EST MATE $+$ 0.33 \pm 0.03 $+$ 0.33 | | 92 75 | IPWA IPWA | $\begin{array}{cccccccccccccccccccccccccccccccccccc$ |
| Γ(Nρ, S=3/2, P-wave)/Γ _{tota} | I DOCUMENT ID | | TECN | Γ ₈ /Γ |
| 24±1 | VRANA | 00 | DPWA | Multichannel |

△(1905) PHOTON DECAY AMPLITUDES

Papers on $\gamma\,N$ amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1\,$ (2006).

$\Delta(1905) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| | | ,- | | |
|---------------------------------|---------------------|----------|-------------|------------------------------|
| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
| +0.026±0.011 OUR ESTIMATE | | | | |
| 0.025 ± 0.004 | ANISOVICH | 12A | DPWA | Multichannel |
| 0.021 ± 0.004 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.022 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.021 ± 0.010 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.043 ± 0.020 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the followi | ng data for average | s, fits, | , limits, e | etc. • • • |
| 0.028 ± 0.012 | $^{ m 1}$ ANISOVICH | 10 | DPWA | Multichannel |
| 0.018 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.055 ± 0.004 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

$\Delta(1905) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| | _ | ,- | | |
|-------------------------------------------|-------------------------|---------|-------------|------------------------------|
| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
| -0.045 ± 0.020 OUR ESTIMATE | | | | |
| -0.049 ± 0.004 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.046 ± 0.005 | DUGGER | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.045 ± 0.005 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.056 ± 0.028 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.025 ± 0.023 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| -0.042 ± 0.015 | ¹ A NISOVICH | 10 | DPWA | Multichannel |
| -0.028 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| 0.002 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| | | | | |

△(1905) FOOTNOTES

- $1\,\text{ANISOVICH}$ 10 finds an alternate solution for this resonance. The only statistically significant differences are in the Breit-Wigner mass and γp couplings. $2\,\text{From}$ method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix
- amplitudes. 3 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- 4 LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

△(1905) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|-------------------|-------------------------------------------|---------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. Tiator | (MAINZ, JINR) |
| DUGGER | 07 | PR C76 025211 | M. Dugger et al. (Jefferson Lab | CLAS Collab.) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workman | (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | (VPI) |
| | | | | |

Baryon Particle Listings $\Delta(1905)$, $\Delta(1910)$

| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
|----------|----|-------------------|----------------------------|-------------------|
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| CRAWFORD | 83 | NP B2111 | R.L. Crawford, W.T. Morton | ` (GLAS) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBĽ, SLAC) |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |

$\Delta(1910) \ 1/2^{+}$

$$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters $111B\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G $33\ 1\ (2006)$.

△(1910) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|-----------------------|---------|-------------|-----------------------------------------|
| 1860 to 1910 (≈ 1890) OUR ES | TIMATE | | | |
| 1860 ±40 | ANISOVICH | 12A | DPWA | Multichannel |
| 2067.9± 1.7 | ARNDT | 06 | DPWA | π N \rightarrow π N, η N |
| 1882 ±10 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1910 ±40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1888 ± 20 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the followin | g data for average | s, fits | , limits, e | etc. • • • |
| 1995 ±12 | VRA NA | 00 | DPWA | Multichannel |
| 2152 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1960.1 ± 21.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| $2121.4 + 13.0 \\ -14.3$ | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 1790 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1910) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|-----------------------|---------|-------------|-----------------------------------------|
| 220 to 340 (≈ 280) OUR ESTII | MATE | | | |
| 350 ± 55 | ANISOVICH | 12A | DPWA | Multichannel |
| 543 ± 10 | ARNDT | 06 | DPWA | π N \rightarrow π N, η N |
| 239 ± 25 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 225 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 280 ± 50 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the followin | g data for average | s, fits | , limits, e | etc. • • • |
| 713 ±465 | VRA NA | 00 | DPWA | Multichannel |
| 760 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 152.9± 60.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 172.2± 37.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 170 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1910) POLE POSITION

DOCUMENT ID

TECN COMMENT

REAL PART

| 1830 to 1880 (≈ 1855) O | UR ESTIMATE | | | |
|----------------------------------------------------------|------------------------------------------------|---------------------|-------------------------------------|-------------------------------------------------------------------------------------------------|
| 1850 ± 40 | ANISOVICH | 12A | DPWA | Multichannel |
| 1771 | ARNDT | | | $\pi N \rightarrow \pi N, \eta N$ |
| 1874 | ³ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1880 ± 30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the | following data for average | s, fits | , limits, e | etc. • • • |
| 1880 | VRA NA | 00 | DPWA | Multichannel |
| 1810 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1950 | ARNDT | 91 | | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| 1792 or 1801 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| -2×IMAGINARY PA VALUE (MeV) 200 to 500 (≈ 350) OUR | DO CUMENT ID | | TECN | COMMENT |
| 350±45 | ANISOVICH | 124 | DDMA | Multichannel |
| 479 | ARNDT | | | $\pi N \rightarrow \pi N, \eta N$ |
| 283 | 3 HOEHLER | | | |
| | CUTKOSKY | | | $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ |
| | | | | |
| 200±40 | | | | |
| | following data for average | s, fits | , limits, e | etc. • • • |
| | following data for average VRA NA | s, fits 00 | , limits, e DPWA | etc. • • • Multichannel |
| • • • We do not use the | following data for average VRA NA AR NDT | s, fits 00 95 | , limits, e DPWA DPWA | etc. \bullet \bullet \bullet Multichannel $\pi \ \mathcal{N} \rightarrow \mathcal{N} \pi$ |
| • • • We do not use the | following data for average VRA NA | s, fits 00 95 | , limits, e DPWA DPWA DPWA | etc. • • • Multichannel |

△(1910) ELASTIC POLE RESIDUE

MODULUS |r|

I

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|---------------------|-----------------------------------|---------------------------------------------------------------------------|
| 24 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 45 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 38 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 20±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for averages | s, fits, | , limits, e | etc. • • • |
| 53 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 37 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |
| | | | | |
| PHASE 0 | DOCUMENT ID | | TECN | COMMENT |
| VALUE (°) | DOCUMENT ID | 124 | TECN | COMMENT Multichannel |
| <u>VALUE</u> (°) −145 ± 30 | ANISOVICH | 12A 06 | DPWA | Multichannel |
| <u>VALUE</u> (°) −145±30 +172 | A NISOVICH ARNDT | 06 | DPWA DPWA | Multichannel $\pi \: {\sf N} \to \: \pi \: {\sf N}, \: \eta \: {\sf N}$ |
| <u>VALUE</u> (°) −145 ± 30 | ANISOVICH ARNDT CUTKOSKY | 06 80 | DPWA DPWA IPWA | Multichannel $\pi N \rightarrow \pi N, \eta N \\ \pi N \rightarrow \pi N$ |
| <u>WALUE</u> (°) -145±30 +172 - 90±30 | ANISOVICH ARNDT CUTKOSKY | 06 80 | DPWA DPWA IPWA Iimits, e | Multichannel $\pi N \rightarrow \pi N, \eta N \\ \pi N \rightarrow \pi N$ |
| $\begin{array}{l} \underline{\textit{VALUE}(^\circ)} \\ -145 \pm 30 \\ +172 \\ -90 \pm 30 \\ \bullet \bullet \bullet \text{We do not use the following.} \end{array}$ | ANISOVICH ARNDT CUTKOSKY data for averages | 06 80 s, fits | DPWA DPWA IPWA limits, e | Multichannel $\pi N \to \pi N, \eta N \\ \pi N \to \pi N$ etc. • • |

△(1910) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

Normalized residue in $N\pi o again (1910) o again K$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | | |
|-------------------------------------------------------------------------|---------------|---------------|------|--------------|--|--|
| 7±2 | -110 ± 30 | ANISOVICH 12A | DPWA | Multichannel | | |
| Normalized residue in $N\pi \to \Delta(1910) \to \Delta\pi$, P -wave | | | | | | |
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | | |
| 16±9 | 95 ± 40 | ANISOVICH 12A | DPWA | Multichannel | | |

△(1910) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | Nπ | 15-30 % |
| Γ_2 | ΣK | (9± 5)% |
| Γ_3 | $N\pi\pi$ | |
| Γ_4 | $\Delta\pi$ | (60±28) % |
| Γ_5 | ${\it \Delta}(1232)\pi$, ${\it P}$ -wave | |
| Γ_6 | $N \rho$ | |
| Γ_7 | $N\rho$, $S=3/2$, P -wave | |
| Γ8 | $N(1440)\pi$ | |
| Г9 | $N(1440)\pi$, $\it P$ -wave | |
| Γ_{10} | N γ | 0.0-0.02 % |
| Γ ₁₁ | $N\gamma$, helicity=1/2 | 0.0-0.02 % |

△(1910) BRANCHING RATIOS

, ,

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|-------------------|---------|-----------|----------------------------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 15 to 30 OUR ESTIMATE | | | | |
| 12 ± 3 | ANISOVICH | 12A | DPWA | Multichannel |
| 23.9± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 23 ± 8 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 19 ± 3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 24 ± 6 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 29 ±21 | VRANA | 00 | DPWA | Multichannel |
| 26 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 17 | ¹ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 40 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

| (| $\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\mathrm{total}}$ in $N\pi 	o \Delta(19)$ | $(10) \rightarrow \Sigma K$ | | | (Γ ₁ Γ ₂) ^{1/2} /Γ |
|---|--------------------------------------------------------------------------------------|-----------------------------|----------|---------|----------------------------------------------------|
| V | ALUE | DO CUMENT ID | | TECN | COMMENT |
| | < 0.03 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| • | • • We do not use the following | data for average | s, fits, | limits, | etc. • • • |
| | -0.019 | LIVANOS | 80 | DPWA | $\pi p \rightarrow \Sigma K$ |
| | | | | | |

Note: Signs of couplings from $\pi N \to N \pi \pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)~S_{31}$ coupling to $\Delta(1232)~\pi$.

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to A$ | $\Delta(1910) \rightarrow \Delta(123)$ | 2)π | , <i>P</i> -wave | e (Γ ₁ Γ ₅) ^{1/2} /Γ |
|----------------------------------------------------------------------------|----------------------------------------|-----|------------------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.06 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |

Baryon Particle Listings $\Delta(1910)$, $\Delta(1920)$

| Γ(Δπ)/Γ _{total} | DOCUMENT ID | | TECN | Γ ₄ /Γ |
|------------------------------------------------------------------------------------------|-----------------------|-----|------|----------------------------------------|
| 60±28 | ANISOVICH | 12A | DPWA | Multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta$ | DO CUMENT ID | | TECN | COMMENT |
| +0.29 | ² LONGACRE | 77 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to \Delta($ | 1910) → N(144 | | | |
| -0.39 ± 0.04 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| Γ(N(1440)π)/Γ _{total} | DO CUMENT ID | | TECN | Г ₈ /Г |
| 56±7 | VRA NA | 00 | DPWA | Multichannel |

△(1910) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$\Delta(1910) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| $VALUE$ (GeV $^{-1/2}$) | DOCUMENT ID | • | TECN | COMMENT |
|-----------------------------------|------------------|---------|-------------|------------------------------|
| +0.003±0.014 OUR ESTIMATE | | | | |
| 0.022 ± 0.009 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.002 ± 0.008 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.014 ± 0.030 | CRAWFORD | 83 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.025 ± 0.011 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 0.032 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

△(1910) FOOTNOTES

 1 CHEW 80 reports four resonances in the P_{31} wave — see also the $\Delta(1750)$. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83. 2 LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the

²LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N \pi \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

³ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

△(1910) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|--------------------------|-----------------------------------------|-------------------|
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | `(PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Workn | nan `(VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | ` (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | `(VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| CRAWFORD | 83 | NP B211 1 | R.L. Crawford, W.T. Morton | (GLAS) |
| HOEHLER | 83 | Landolt-Boernstein 1/9B2 | G. Hohler | (KARLT) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| A Iso | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| LIVANOS | 80 | Toronto Conf. 35 | P. Livanos et al. | (SACL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 77 | NP B122 493 | R.S. Longacre, J. Dolbeau | `(SACL)IJP |
| Also | | NP B108 365 | J. Dolbeau et al. | (SACL) IJP |
| | | | | |

$\Delta(1920) \ 3/2^{+}$

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+)$$
 Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters $111B\ 1\ (1982)$. Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G $33\ 1\ (2006)$.

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(1920) BREIT-WIGNER MASS

| VALUE | (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------|---------------------|-------------|-----|------|----------------------------------------|
| 1900 | to 1970 (≈1920) OUR | ESTIMATE | | | |
| 1900 | ± 30 | ANISOVICH | 12A | DPWA | Multichannel |
| 2014 | \pm 16 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1920 | ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1868 | + 10 | HOFHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

| • • • We do not use the following | g data for average | s, fits | , limits, etc. • • • |
|-----------------------------------|--------------------|---------|-----------------------------------------|
| 1990 ± 35 | HORN | 08A | DPWA Multichannel |
| 2057 ± 1 | PENNER | 02c | DPWA Multichannel |
| 1889 ±100 | VRANA | 00 | DPWA Multichannel |
| 1840 ± 40 | CANDLIN | | DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| 1955.0 ± 13.0 | ¹ CHEW | 80 | BPWA $\pi^+ p \rightarrow \pi^+ p$ |
| $2065.0 + 13.6 \\ - 12.9$ | $^{ m 1}$ CHEW | 80 | BPWA $\pi^+ p \rightarrow \pi^+ p$ |

△(1920) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------|---------|-------------|----------------------------------------|
| 180 to 300 (≈ 260) OUR ESTIM | ATE | | | |
| 310 ± 60 | ANISOVICH | 12A | DPWA | Multichannel |
| 152 ± 55 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 300 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 220 ± 80 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | s, fits | , limits, e | etc. • • • |
| 330 ± 60 | HORN | 08A | DPWA | Multichannel |
| 525 ± 32 | PENNER | 02c | DPWA | Multichannel |
| 123 ± 53 | VRANA | 00 | DPWA | Multichannel |
| 200 ± 40 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| 88.3± 35.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 62.0± 44.0 | ¹ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

△(1920) POLE POSITION

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------------------------------------------------|----------------------|----------|-------------|-----------------------------------------------|--|
| 1850 to 1950 (≈ 1900) OUR ESTIM | MATE | | | | |
| 1890 ± 30 | ANISOVICH | 12A | DPWA | Multichannel | |
| 1900 | ² HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ | |
| 1900 ± 80 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| \bullet \bullet We do not use the following | data for averages | s, fits, | , limits, e | etc. • • • | |
| $1980 + 25 \\ -45$ | HORN | 08A | DPWA | Multichannel | |
| 1880 | VRANA | 00 | DPWA | Multichannel | |
| not seen | ARNDT | 91 | DPWA | $\pi{\it N} \rightarrow \pi{\it N}$ Soln SM90 | |
| -2×IMAGINARY PART | | | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
| 200 to 400 (≈ 300) OUR ESTIMAT | Έ | | | | |
| 300± 60 | ANISOVICH | 12A | DPWA | Multichannel | |
| 300 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| • • We do not use the following data for averages, fits, limits, etc. | | | | | |
| 310 ⁺ 40 - 60 | HORN | 08A | DPWA | Multichannel | |
| 120 | | | | | |
| 120 | VRANA | 00 | DPVVA | Multichannel | |

△(1920) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------|---------------|--------|---------------------------|
| 17 ± 8 | A NISOVICH 12 | A DPWA | Multichannel |
| 24 ± 4 | CUTKOSKY 80 | IPWA | $\pi N \rightarrow \pi N$ |
| PHASE <i>θ</i> | | | |
| VALUE (°) | DO CUMENT ID | TECN | COMMENT |
| -40 ± 20 | A NISOVICH 12 | A DPWA | Multichannel |
| -150 ± 30 | CUTKOSKY 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(1920) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by $\Gamma_{pole}.$

| Normalized | residue in | $N\pi \rightarrow$ | A(1920) → | Λ_n |
|------------|------------|--------------------|-----------|-------------|

| MODULUS (%) | PHASE (°) | DO CUMENT ID | | TECN | COMMENT |
|---------------|-------------------|--------------|-----|------|--------------|
| 17±8 | 70 ± 20 | ANISOVICH | 12A | DPWA | Multichannel |
| Maumalinad va | aldus is N = . A/ | 1000\ | , | | |

Normalized residue in $N\pi \to \Delta(1920) \to \Sigma K$

| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT |
|---------------|---------------|--------------|---------|--------------|
| 9±3 | 80 ± 40 | ANISOVICH 12 | 2A DPWA | Multichannel |
| Normalized re | sidue in Na - | A(1920) → A= | D wave | |

Normalized residue in $N\pi \to \Delta(1920) \to \Delta\pi$, P-wave

| MODULUS (%) | PHASE (°) | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----------|--------------|-----|------|--------------|
| 20±12 | -120 ± 30 | ANISOVICH | 12A | DPWA | Multichannel |

Normalized residue in $N\pi \to \Delta(1920) \to \Delta\pi$, F-wave

| MODULUS (%) | PHASE (°) | DO CUMENT ID | | TECN | COMMENT | |
|-------------|-----------|--------------|-----|------|--------------|--|
| 28±7 | - 95 ± 35 | ANISOVICH | 12A | DPWA | Multichannel | |

 $\Delta(1920), \Delta(1930)$

 $\Gamma(N(1535)\pi)/\Gamma_{\text{total}}$

 $\Gamma(Na_0(980))/\Gamma_{total}$

 $\Gamma(\Delta(1232)\eta)/\Gamma_{\mathrm{total}}$

VALUE (%)

VALUE (%)

 10 ± 5

△(1920) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------------------|------------------------------|
| Г | $N\pi$ | 5-20 % |
| Γ_2 | ΣΚ | (2.14 ± 0.30) % |
| Γ_3 | $N\pi\pi$ | |
| Γ_4 | Δ (1232) π , P -wave | |
| Γ_5 | $\Delta(1232)\pi$, $\it F-wave$ | |
| Γ_6 | $N(1440)\pi$, P -wave | |
| Γ_7 | $N(1535)\pi$ | |
| Γ ₈ | N a ₀ (980) | |
| Г9 | Δ (1232) η | (15 ±8) % |
| Γ_{10} | $N\gamma$ | 0.0-0.4 % |
| Γ_{11} | $N\gamma$, helicity=1/2 | 0.0-0.2 % |
| Γ_{12} | $N\gamma$, helicity=3/2 | 0.0-0.2 % |

| Γ_{11} $N\gamma$, helicity=1/2 Γ_{12} $N\gamma$, helicity=3/2 | | 0.0-0 0.0-0 | | |
|-----------------------------------------------------------------------------------------------|--------------------------------|----------------|----------------|-----------------------------------------------------------------|
| ∆ (1920 |) BRANCHIN | G R/ | TIOS | |
| $\Gamma(N\pi)/\Gamma_{\text{total}}$ VALUE (%) | DOCUMENT ID | | TECN | Γ ₁ /Γ |
| 5 to 20 OUR ESTIMATE | DO COMENT ID | | 1200 | COMMENT |
| 8±4 | ANISOVICH | 12A | DPWA | Multichannel |
| 2 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 20±5 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 14±4 • • • We do not use the following | HOEHLER | 79 | IPWA limits | $\pi N \rightarrow \pi N$ |
| | HORN | | | Multichannel |
| 15 ± 8 15 ± 1 | PENNER | | | Multichannel |
| 5±4 | VRA NA | 00 | | Multichannel |
| 24 | ¹ CHEW | 80 | | $\pi^+ p \rightarrow \pi^+ p$ |
| 18 | ¹ CHEW | 80 | | $\pi^+ \stackrel{r}{\rho} \rightarrow \pi^+ \stackrel{r}{\rho}$ |
| 1/. | | | | 1/ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta(19)$ | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.052 ± 0.015 | CANDLIN | 84 | | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| ◆ ◆ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| - 0.049 | LIVANOS | 80 | DPWA | $\pi p \rightarrow \Sigma K$ |
| $\Gamma(\Sigma K)/\Gamma_{\text{total}}$ | | | | Γ ₂ /Γ |
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 2.14±0.30 OUR AVERAGE | DO COMENT ID | | TECH | COMMENT |
| 4 ±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 2.1 ±0.3 | PENNER | 02c | DPWA | Multichannel |
| 1/. | | | | 14 |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta (19)$ | $(20) \rightarrow \Delta(123)$ | $(2)\pi$, | P-wave | e (Γ ₁ Γ ₄) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | | | |
| -0.13 ± 0.04 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi, P$ -wave $)/\Gamma_{total}$ | | | | Γ ₄ /Γ |
| VALUE (%) | DOCUMENT ID | | TECN | |
| 22±12 | ANISOVICH | 12A | | Multichannel |
| 41± 3 | VRA NA | 00 | | Multichannel |
| E(4(4000) | | | | |
| $\Gamma(\Delta(1232)\pi$, <i>F</i> -wave $)/\Gamma_{	ext{total}}$ | | | | Г ₅ /Г |
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 45 ± 20 | ANISOVICH | 12A | DPWA | Multichannel |
| (== 1/4,== 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, | | - \ | _ | ·- · 1/4 ·- |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(19)$ | | | | |
| VALUE | DOCUMENT ID | | | |
| $+0.06\pm0.07$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $\Gamma(N(1440)\pi, P\text{-wave})/\Gamma_{\text{total}}$ | | | | Γ ₆ /Γ |
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 53±8 | VRA NA | 00 | | Multichannel |
| | | | 2 | |

DOCUMENT ID

DOCUMENT ID

DOCUMENT ID

ANISOVICH

• • • We do not use the following data for averages, fits, limits, etc. • •

• • • We do not use the following data for averages, fits, limits, etc. • • HORN

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet HORN

HORN

△(1920) PHOTON DECAY AMPLITUDES Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G 33 1 (2006).

$\Delta(1920) \rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV - 1/2) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|---------|-----------|------------------------------|
| $0.130^{+\ 0.030}_{-\ 0.060}$ | ANISOVICH | 12A | DPWA | Multichannel |
| 0.040 ± 0.014 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| • • • We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 0.022 ± 0.008 | HORN | 08A | DPWA | Multichannel |
| 0.007 | DENINED | 020 | D D M/A | Multichannel |

I

I

$\Delta(1920) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------------|------------------|----------|-------------|------------------------------|
| $-0.115 ^{+ 0.025}_{- 0.050}$ | ANISOVICH | 12A | DPWA | Multichannel |
| 0.023 ± 0.017 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits, | , limits, e | etc. • • • |
| $\begin{array}{c} 0.042 \pm 0.012 \\ -0.001 \end{array}$ | HORN PENNER | | | Multichannel Multichannel |

△(1920) FOOTNOTES

- ¹ CHEW 80 reports two P_{33} resonances in this mass region. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83.

 ² See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave N and N are the following the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the propert amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

△(1920) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) | |
|-----------|------|--------------------------|--------------------------------|-------------------|--|
| HORN | 08A | EPJ A38 173 | I. Horn et al. | (CB-ELSA Collab.) | |
| Also | | PRL 101 202002 | I. Horn et al. | (CB-ELSA Collab.) | |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | ` (GWU) | |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Čollab.) | |
| PENNER | 02 C | PR C66 055211 | G. Penner, U. Mosel | ` (GIES) | |
| PENNER | 02 D | PR C66 055212 | G. Penner, U. Mosel | (GIES) | |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.F | | |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | (KARL) | |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP | |
| Also | | PR D30 904 | D.M. Manley et al. | `(VPI) | |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP | |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) | |
| HOEHLER | 83 | Landolt-Boernstein 1/9B2 | G. Hohler | (KARLT) | |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) | |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) | |
| Also | | NP B197 365 | K. Fujii et al. | ÌNAGΟΊ | |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP | |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP | |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | CMU, LBL\IJP | |
| LIVAN OS | 80 | Toronto Conf. 35 | P. Livanos et al. | ` (SACL) IJP | |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP | |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP | |
| | | | | (| |

$\Delta(1930) 5/2$

 Γ_7/Γ

 Γ_8/Γ

Г9/Г

TECN COMMENT

08A DPWA Multichannel

TECN COMMENT

08A DPWA Multichannel

TECN COMMENT

12A DPWA Multichannel

08A DPWA Multichannel

 $I(J^P) = \frac{3}{2}(\frac{5}{2})$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

△(1930) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|----------|-----------|----------------------------------------|
| 1900 to 2000 (≈ 1950) OUR ES | ΓIMATE | | | |
| 2233 ± 53 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1956 ± 22 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1940 ± 30 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1901 ± 15 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | es, fits | , limits, | etc. • • • |
| 2046 ± 45 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1932 ±100 | VRANA | 00 | DPWA | Multichannel |
| 1955 ± 15 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 2056 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1963 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| $1910.0^{+}_{-}{}^{15.0}_{17.2}$ | CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |

△(1930) BREIT-WIGNER WIDTH

| VALU | E (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------|---------------------------|-------------|----|------|----------------------------------------|
| 220 | to 500 (≈ 360) OUR ESTIMA | TE | | | |
| 773 | ± 187 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 530 | ± 140 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 320 | ± 60 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 195 | ± 60 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

| • • • We do not use the following | data for average | s, fits | , limits, etc. • • • |
|-----------------------------------|------------------|---------|-------------------------------------------|
| 402 ±198 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 316 ±237 | VRA NA | 00 | DPWA Multichannel |
| 350 ± 20 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 590 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 260 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ |
| $74.8 + 17.0 \\ - 16.0$ | CHEW | 80 | BPWA $\pi^+ p \rightarrow \pi^+ p$ |

△(1930) POLE POSITION

REAL PART

| REAL PAKI | | | | |
|-------------------------------------------|----------------------------|----------|---------|-------------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 1840 to 1960 (≈ 1900) C | OUR ESTIMATE | | | |
| 2001 | | | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1850 | ¹ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 1890 ± 50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● ● We do not use the | following data for average | s, fits, | limits, | etc. • • • |
| 1966 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 1883 | VRA NA | 00 | DPWA | Multichannel |
| 1913 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 2018 | ARNDT | 91 | DPWA | $\pi \: {\it N} \: \rightarrow \: \pi \: {\it N} \: {\it Soln} \: {\it SM90}$ |
| -2×IMAGINARY PA | RT | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 175 to 360 (≈ 270) OUR | ESTIMATE | | | |
| 387 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 180 | ¹ HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 260±60 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits, | limits, | etc. • • • |
| 364 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 250 | VRA NA | 00 | DPWA | Multichannel |
| 246 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 398 | ARNDT | 91 | DPWA | $\pi N \rightarrow \pi N \text{ Soln SM90}$ |
| | | | | |

△(1930) ELASTIC POLE RESIDUE

MODULUS |r|

 $\Gamma(N-)/\Gamma$

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|---------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------|
| 7 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 20 | HOEHLER | 93 | SPED | $\pi N \rightarrow \pi N$ |
| 18±6 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 16 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 8 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 15 | ARNDT | 91 | DPWA | $\pi \textit{N} \rightarrow \pi \textit{N} $ |
| | | | | |
| PHASE θ | | | | |
| PHASE 0 VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| | <u>DOCUMENT ID</u> ARNDT | | | $\frac{\textit{COMMENT}}{\pi \ \textit{N} \to \ \pi \ \textit{N}, \ \eta \ \textit{N}}$ |
| VALUE (°) | | 06 | DPWA | |
| <u>VALUE</u> (°) −12 | ARNDT CUTKOSKY | 06 80 | DPWA IPWA | $ \begin{array}{cccc} \pi \ N \to & \pi \ N, \ \eta \ N \\ \pi \ N \to & \pi \ N \end{array} $ |
| <u>VALUE</u> (°) -12 -20±40 | ARNDT CUTKOSKY | 06 80 | DPWA IPWA , limits, | $ \begin{array}{cccc} \pi \ N \to & \pi \ N, \ \eta \ N \\ \pi \ N \to & \pi \ N \end{array} $ |
| $\begin{array}{l} \underline{\mathit{VALUE}}(^{\circ}) \\ -12 \\ -20 \pm 40 \\ \bullet \bullet \bullet \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | ARNDT CUTKOSKY data for average | 06 80 s, fits | DPWA IPWA , limits, DPWA | $\begin{array}{ccc} \pi \ N \rightarrow & \pi \ N, \ \eta \ N \\ \pi \ N \rightarrow & \pi \ N \end{array}$ etc. • • |

△(1930) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|--------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ | 5-15 % |
| Γ_2 | ΣK | |
| Γ_3 | $N \pi \pi$ | |
| Γ ₄ Γ ₅ | $N\gamma$ | 0.0-0.02 % |
| Γ_5 | $N\gamma$, helicity=1/2 | 0.0-0.01 % |
| Γ ₆ | $N\gamma$, helicity=3/2 | 0.0-0.01 % |

△(1930) BRANCHING RATIOS

| I (/Vπ)/I total | | | | 11/1 |
|-----------------------------------|------------------|----------|-----------|----------------------------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 5 to 15 OUR ESTIMATE | | | | |
| 8.1 ± 1.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 18 ±2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 14 ±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 4 ±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | es, fits | , limits, | etc. • • • |
| 4.0 ± 1.4 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 9 ±8 | VRA NA | 00 | DPWA | Multichannel |
| 11 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 11 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(19)$ | 30) → ΣK | | | (Γ₁Γ₂) ¹ /2/Γ |
|---------------------------------------------------------------------------------------------|----------------------------|---------|-------------|----------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| < 0.015 | CANDLIN | 84 | DPWA | $\pi^+ \rho \rightarrow \Sigma^+ K^+$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | tc. • • • |
| - 0.031 | LIVANOS | 80 | DPWA | $\pi p \rightarrow \Sigma K$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(19)$ | $(30) \rightarrow N\pi\pi$ | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| not seen | LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1930) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

Δ (1930) $\rightarrow N\gamma$, helicity-1/2 amplitude A_{1/2}

| VALUE (GeV ^{-1/2}) | DO CUMENT | ID | TECN | COMMENT |
|------------------------------|-------------------|-------------|-----------|------------------------------|
| -0.009 ± 0.028 OUR ESTIMATE | | | | |
| -0.007 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 0.009 ± 0.009 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| | ng data for avera | ages, fits, | limits, e | etc. • • • |
| -0.019 ± 0.001 | 1.1 | 93 | IPWA | $\sim N \rightarrow \pi N$ |

$\Delta(1930) \rightarrow N\gamma$, helicity-3/2 amplitude $A_{3/2}$

| <u>VALUE (GeV = 1/2)</u> | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------|------------------|---------|-----------|------------------------------|
| -0.018±0.028 OUR ESTIMATE | | | | |
| 0.005 ± 0.010 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.025 ± 0.011 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| ● ● We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 0.009 ± 0.001 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

Δ (1930) FOOTNOTES

△(1930) REFERENCES

For early references, see Physics Letters 111B 1 (1982).

| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
|----------|----|--------------------|---------------------------------------|-------------------|
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. L | .ee (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. Wor | kman (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | π N Newsletter 9 1 | G. Hohler | (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | ` (VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt ét al. | (VPI, TELE) IJP |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| AWA JI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | ` (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkoský et al. | (CMU, LBL) IJP |
| LIVAN OS | 80 | Toronto Conf. 35 | P. Livanos et al. | (SACL) IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT Î IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBĽ, SLAC) IJP |

 $\Delta(1940) 3/2$

г. /г

 $I(J^P) = \frac{3}{2}(\frac{3}{2})$ Status: **

OMITTED FROM SUMMARY TABLE
The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(1940) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------|------------------|----------|-----------|----------------------------------------|
| 1940 to 2060 (≈ 2000) OUR EST | TIMATE | | | |
| 1995 $ \begin{array}{c} +105 \\ -60 \end{array} $ | ANISOVICH | 12A | DPWA | Multichannel |
| 2057 ±110 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 2058.1 ± 34.5 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 1940 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| | data for average | s, fits, | limits, e | etc. • • • |
| $1990 \ \pm \ 40$ | HORN | 08A | DPWA | Multichannel |

△(1940) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------------------|------------------|---------|-------------|----------------------------------------|
| 450 ±100 | ANISOVICH | 12A | DPWA | Multichannel |
| 460 ±320 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 198.4 ± 45.5 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 200 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ● We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 410 ± 70 | HORN | 08A | DPWA | Multichannel |

 $^{^1}$ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of π N elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

 $\Delta(1940), \Delta(1950)$

| ∆ (1940) | POLE | POS | TION |
|-----------------|------|-----|------|
| | | | |

| KEAL | PAR |
|-------|-------|
| VALUE | (MeV) |

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------------|--------------------|----------|-------------|-------------------------------|--|
| 1990 + 100 | ANISOVICH | 12A | DPWA | Multichannel | |
| 1900±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 1915 or 1926 | $^{ m 1}$ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ | |
| • • • We do not use the followin | g data for average | s, fits, | , limits, e | etc. • • • | |

HORN

1985 ± 30 -2×IMAGINARY PART

| - ZAIMAUMANI IANI | | | | |
|-----------------------------------|-----------------------|----------|-------------|-------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 450±90 | ANISOVICH | 12A | DPWA | Multichannel |
| 200 ± 60 | CUTKOSKY | | | |
| 190 or 186 | ¹ LONGACRE | 78 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| • • • We do not use the following | ig data for average | s, fits, | , limits, e | etc. • • • |
| 390±50 | HORN | 08A | DPWA | Multichannel |

08A DPWA Multichannel

80 IPWA $\pi N \rightarrow \pi N$

△(1940) ELASTIC POLE RESIDUE

MODULUS |r|

135 ±45

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------|--------------|----|------|---------------------------|
| 4 ± 4 | | | | Multichannel |
| 8±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |

CUTKOSKY △(1940) DECAY MODES

| | Mode |
|-----------------------|---------------------------------------|
| $\overline{\Gamma_1}$ | $N\pi$ |
| Γ_2 | ΣΚ |
| Гз | $N\pi\pi$ |
| Γ_4 | $\Delta(1232)\pi$, S -wave |
| Γ_5 | $\Delta(1232)\pi$, $	extit{D}$ -wave |
| Γ_6 | $N\rho$, $S=3/2$, S-wave |
| Γ_7 | $N(1535)\pi$ |
| Γ ₈ | $Na_0(980)$ |
| Г9 | $\Delta(1232)\eta$ |
| Γ_{10} | $N\gamma$, helicity=1/2 |
| Γ_{11} | $N\gamma$, helicity=3/2 |

△(1940) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|--------------------------------------|----------------------------|---------|-----------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 18 ± 12 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 18 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 5 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • |
| 9+ 4 | HORN | 08A | DPWA | Multichannel |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi$ | $\rightarrow \Delta(1940) \rightarrow \Sigma K$ | | (Γ ₁ Γ ₂) ^{1/2} /Γ |
|------------------------------------------------------------------------------|-------------------------------------------------|--------|----------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| < 0.015 | CANDLIN 8 | 4 DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta$ | $\Delta(1940) \rightarrow \Delta(123)$ | 2)π | , <i>S</i> -wave | : | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
|------------------------------------------------------------------------------------------|----------------------------------------|-----|------------------|-------------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $+0.11 \pm 0.10$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi$ | Ν & Νππ |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to A$ | ∆(1940) → △(123 | 2)π, | , <i>D</i> -wav | e (Γ ₁ Γ ₅) ^{1/2} /Γ |
|-----------------------------------------------------------------------------|-----------------|------|-----------------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.27 \pm 0.16$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to Z$ | $\Delta(1940) \rightarrow N \rho, S=$ | =3/2 | 2, <i>S</i> -wav | re | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ |
|------------------------------------------------------------------------------------|---------------------------------------|------|------------------|-------------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $+0.25 \pm 0.10$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi$ | Ν & Νππ |

| $\Gamma(N(1535)\pi)/\Gamma_{\text{total}}$ | | | | Γ ₇ /Ι |
|--------------------------------------------|--------------------------|----------|-----------|-------------------|
| VALUE (%) | DO CUMENT ID | TECN | COMMENT | |
| • • We do not use the following | nσ data for averages fit | s limits | etc • • • | |

| 2 ± 1 | HORN | 08A | DPWA | Multichannel | |
|------------------------------------------------------------|--------------|-----|------|--------------|-------------------|
| Γ (Na₀(980))/Γ_{total} VALUE (%) | DO CUMENT ID | | TECN | COMMENT | Γ ₈ /Γ |

• • • We do not use the following data for averages, fits, limits, etc. • • • HORN 08A DPWA Multichannel 2 ± 1

| $\Gamma(\Delta(1232)\eta)/\Gamma_{\text{total}}$ | | | | | |
|--------------------------------------------------|------------------------|-----------------|--------------|--|--|
| VALUE (%) | DO CUMENT ID | TECN | COMMENT | | |
| • • • We do not use the follow | ving data for averages | , fits, limits, | etc. • • • | | |
| 4±2 | HORN | 08A DPWA | Multichannel | | |

△(1940) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1\,$ (2006).

$\Delta(1940) \rightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV ^{-1/2}) | DO CUMENT | ID | TECN | COMMENT | |
|--------------------------------|--------------------|------------|-----------|------------------------------|--|
| -0.036 ± 0.058 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| • • • We do not use the follow | ing data for avera | ges, fits, | limits, e | etc. • • • | |
| 0.160 ± 0.040 | HORN | 08A | DPWA | Multichannel | |

$\Delta(1940) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| | =(15.15) 7 10 // Harristy 5/2 ampricado 713/2 | | | | | | | |
|---|-----------------------------------------------|--------------------|------------|-----------|------------------------------|--|--|--|
| | VALUE (GeV ^{-1/2}) | DO CUMENT I | D | TECN | COMMENT | | | |
| | -0.031 ± 0.012 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | | | |
| • | • • • We do not use the follow | ing data for avera | ges, fits, | limits, e | etc. • • • | | | |
| | 0.110 ± 0.030 | HORN | 08A | DPWA | Multichannel | | | |

△(1940) FOOTNOTES

△(1940) REFERENCES

| ANISOVICH HORN Also ARNDT PDG | 12A 08A 06 06 | EPJ A48 15 EPJ A38 173 PRL 101 202002 PR C74 045205 IPG 33 1 | A.V. Anisovich et al. I. Horn et al. I. Horn et al. R.A. Arndt et al. WM. Yao et al. | (BONN, PNPI) (CB-ELSA Collab.) (CB-ELSA Collab.) (GWU) (PDG Collab.) |
|-------------------------------------------|------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| MANLEY Also | 92 | PR D45 4002 PR D30 904 | D.M. Manley, E.M. Saleski D.M. Manley <i>et al</i> . | ` (KENT) IJP (VPI) |
| CANDLIN AWAJI Also | 84 81 | NP B238 477 Bonn Conf. 352 NP B197 365 | D.J. Candlin et al. N. Awaji, R. Kajikawa K. Fujii et al. | (EDIN, RAL, LOWC) (NAGO) (NAGO) |
| CHEW CUTKOSKY Also LONGACRE | 80 80 78 | Toronto Conf. 123 Toronto Conf. 19 PR D20 2839 PR D17 1795 | D.M. Chew R.E. Cutkosky et al. R.E. Cutkosky et al. R.S. Longacre et al. | `(LBL)IJP (CMU, LBL)IJP (CMU, LBL) (LBL, SLAC) |

 $\Delta(1950) 7/2^{-1}$

 $I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$ Status: ***

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters 111B 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G 33 1 (2006).

△(1950) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|--------------------|----------|-------------|----------------------------------------|
| 1915 to 1950 (≈ 1930) OUR ES | TIMATE | | | |
| 1915 ± 6 | ANISOVICH | 12A | DPWA | Multichannel |
| 1921.3 ± 0.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1945 ± 2 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 1950 ±15 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 1913 ± 8 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits, | , limits, e | etc. • • • |
| 1928 ± 8 | ANISOVICH | 10 | DPWA | Multichannel |
| 1923.3 ± 0.5 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 1936 ± 5 | VRANA | 00 | DPWA | Multichannel |
| 1947 ± 9 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1921 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 1940 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |
| 1925 ± 20 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| $1855.0 + 11.0 \\ -10.0$ | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 1925 | $^{ m 1}$ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |

△(1950) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|--------------|-----|------|----------------------------------------|
| 235 to 335 (≈ 285) OUR ESTII | MATE | | | |
| 246 ±10 | ANISOVICH | 12A | DPWA | Multichannel |
| 271.1 ± 1.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 300 ± 7 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 340 ±50 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 224 ±10 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

 $^{^1}$ LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi \, {\it N} \, \to \, N \, \pi \, \pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

I

| • • • We do not use the follo | wing data for average | es, fits | , limits, etc. • • • |
|-------------------------------|-----------------------|----------|-------------------------------------------|
| 290 ±14 | ANISOVICH | 10 | DPWA Multichannel |
| 278.2± 3.0 | ARNDT | 04 | DPWA $\pi N \rightarrow \pi N$, ηN |
| 245 ±12 | VRA NA | 00 | DPWA Multichannel |
| 302 ± 9 | ARNDT | 96 | IPWA $\gamma N \rightarrow \pi N$ |
| 232 | ARNDT | 95 | DPWA $\pi N \rightarrow N \pi$ |
| 306 | LI | 93 | IPWA $\gamma N \rightarrow \pi N$ |
| 330 ±40 | CANDLIN | 84 | DPWA $\pi^+ ho ightarrow \Sigma^+ K^+$ |
| 157.2 + 22.0 | CHEW | 80 | BPWA $\pi^+ p \rightarrow \pi^+ p$ |
| 240 | $^{ m 1}$ LONGACRE | 75 | IPWA $\pi N \rightarrow N \pi \pi$ |

△(1950) POLE POSITION

| VALUE (MeV) | DOCUMENT ID TECN COMMENT | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|
| 1870 to 1890 (≈ 1880) | OUR ESTIMATE | |
| 1890± 4 | ANISOVICH 12A DPWA Multichannel | |
| 1876 | ARNDT 06 DPWA $\pi N \rightarrow \pi N$, ηN | |
| 1878 | ² HOEHLER 93 ARGD $\pi N \rightarrow \pi N$ | |
| 1890 ± 15 | CUTKOSKY 80 IPWA $\pi N ightarrow \pi N$ | |
| • • • We do not use th | he following data for averages, fits, limits, etc. • • • | |
| 1882± 8 | ANISOVICH 10 DPWA Multichannel | |
| 1874 | ARNDT 04 DPWA $\pi N \rightarrow \pi N$, ηN | |
| 1910 | VRANA 00 DPWA Multichannel | |
| 1880 | ARNDT 95 DPWA $\pi N \rightarrow N \pi$ | |
| 1884 | ARNDT 91 DPWA $\pi N \rightarrow \pi N$ Soln SN | 1 90 |
| 1924 or 1924 | ³ LONGACRE 78 IPWA $\pi N \rightarrow N \pi \pi$ | |
| –2×IMAG∣NARY P | | |
| - ZXIMAGINAKT F VALUE (MeV) | DO CUMENT ID TECN COMMENT | |
| | | _ |
| | | |
| · · · | | |
| 243± 8 | ANISOVICH 12A DPWA Multichannel | |
| 220 to 260 (≈ 240) OU 243± 8 227 230 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \rightarrow \pi N, \eta N$ | |
| 243± 8 227 230 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ | |
| 243± 8 227 230 260±40 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ | |
| 243± 8 227 230 260±40 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ | |
| 243± 8 227 230 260±40 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ | |
| 243± 8 227 230 260±40 • • • We do not use the | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ ne following data for averages, fits, limits, etc. • • • | |
| 243± 8 227 230 260±40 • • • We do not use the 262±12 | ANISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ PHOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ ne following data for averages, fits, limits, etc. • • • ANISOVICH 10 DPWA Multichannel | |
| 243± 8 227 230 260±40 • • We do not use the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second sec | A NISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ ne following data for averages, fits, limits, etc. • • • ANISOVICH 10 DPWA Multichannel ARNDT 04 DPWA $\pi N \to \pi N, \eta N$ | |
| 243 ± 8 227 230 260 ± 40 • • We do not use ti 262 ± 12 236 230 | A NISOVICH 12A DPWA Multichannel ARNDT 06 DPWA $\pi N \to \pi N, \eta N$ 2 HOEHLER 93 ARGD $\pi N \to \pi N$ CUTKOSKY 80 IPWA $\pi N \to \pi N$ ne following data for averages, fits, limits, etc. • • ANISOVICH 10 DPWA Multichannel ARNDT 04 DPWA $\pi N \to \pi N, \eta N$ VRA NA 00 DPWA Multichannel | <i>1</i> 190 |

△(1950) ELASTIC POLE RESIDUE

DOCUMENT ID

TECN COMMENT

MODULUS |r|VALUE (MeV)

| VALUE (MEV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------------------------------------|-------------------------------------------------------------------|----------------------------------|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 58±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 53 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 47 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 50±7 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | ing data for average | s, fits | , limits, e | etc. • • • |
| 57 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 54 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 61 | ARNDT | 91 | DPWA | $\pi \ \textit{N} \ ightarrow \ \pi \ \textit{N} \ \ \text{Soln} \ \ \text{SM90}$ |
| PHASE θ | | | | |
| | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| | DO CUMENT ID | 12A | | <u>COMMENT</u> Multichannel |
| VALUE (°) | | 12A 06 | DPWA | |
| <u>VALUE</u> (°) − 24 ± 3 | ANISOVICH | | DPWA DPWA | Multichannel |
| <u>VALUE</u> (°) - 24 ± 3 - 31 | ANISOVICH ARNDT | 06 | DPWA DPWA ARGD | Multichannel $\pi \: N \to \: \pi \: N, \: \eta \: N$ |
| <u>VALUE (°)</u> - 24 ± 3 - 31 - 32 | A NISOVICH ARNDT HOEHLER CUT KOSKY | 06 93 80 | DPWA DPWA ARGD IPWA | Multichannel $\pi N \rightarrow \pi N, \eta N$ $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ |
| VALUE (°) - 24 ± 3 - 31 - 32 - 33 ± 8 | A NISOVICH ARNDT HOEHLER CUT KOSKY | 06 93 80 | DPWA DPWA ARGD IPWA , limits, e | Multichannel $\pi N \rightarrow \pi N, \eta N$ $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ |
| VALUE (°) -24±3 -31 -32 -32 - 33±8 • • • • We do not use the following | ANISOVICH ARNDT HOEHLER CUTKOSKY ing data for average | 06 93 80 es, fits | DPWA DPWA ARGD IPWA , limits, e | Multichannel $\pi N \to \pi N, \eta N$ $\pi N \to \pi N, \eta N$ $\pi N \to \pi N$ $\pi N \to \pi N$ etc. |
| <u>VALUE (°)</u> -24±3 -31 -32 -32±8 • • • • We do not use the following -34 | ANISOVICH ARNDT HOEHLER CUTKOSKY ing data for average ARNDT | 06 93 80 es, fits 04 | DPWA DPWA ARGD IPWA , limits, e DPWA DPWA | Multichannel $ \pi \ N \to \pi \ N, \ \eta \ N $ $ \pi \ N \to \pi \ N $ $ \pi \ N \to \pi \ N $ $ \pi \ N \to \pi \ N $ $ \pi \ N \to \pi \ N $ $ \text{etc.} \bullet \bullet \bullet $ $ \pi \ N \to \pi \ N, \ \eta \ N $ |

△(1950) INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole}

| Normalized i | residue in $N\pi \rightarrow$ | $\Delta(1950) \rightarrow \Sigma K$ | | | |
|--------------|-------------------------------|----------------------------------------------|----------------|--------------|--|
| MODULUS (%) | PHASE (°) | DO CUMENT ID | TECN | COMMENT | |
| 5 ± 1 | -65 ± 25 | ANISOVICH 12 | A DPWA | Multichannel | |
| | | | | | |
| Normalized i | residue in $N\pi ightarrow$ | $\Delta(1950) \rightarrow \Delta \pi$, I | F-wave | | |
| Normalized I | residue in Nπ → PHASE (°) | Δ (1950) $\rightarrow \Delta \pi$, I | F-wave TECN | COMMENT | |

△(1950) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|-----------------|-----------------------------------------------|------------------------------|
| Γ_1 | $N\pi$ | 35-45 % |
| Γ_2 | ΣK | |
| Γ_3 | $N\pi\pi$ | |
| Γ_4 | $\Delta\pi$ | 20-30 % |
| Γ_5 | ${\it \Delta}(1232)\pi$, ${\it F}$ -wave | |
| Γ ₆ | ${\it \Delta}$ (1232) π , ${\it H}$ -wave | |
| Γ_7 | $N \rho$ | <10 % |
| Γ ₈ | $N\rho$, $S=1/2$, F -wave | |
| Г9 | $N\rho$, $S=3/2$, F -wave | |
| Γ_{10} | $N\gamma$ | 0.08-0.13 % |
| Γ_{11} | $N\gamma$, helicity=1/2 | 0.03-0.055 % |
| Γ ₁₂ | $N\gamma$, helicity=3/2 | 0.05-0.075 % |

△(1950) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|------------------------------------------------------------------------------|----------------------------|---------|-----------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 35 to 45 OUR ESTIMAT | ΓΕ | | | |
| 45 ±2 | ANISOVICH | 12A | DPWA | Multichannel |
| 47.1 ± 0.1 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 38 ±1 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 39 ±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 38 ±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the | following data for average | s, fits | , limits, | etc. • • • |
| 44 ±8 | ANISOVICH | 10 | DPWA | Multichannel |
| 48.0±0.2 | ARNDT | 04 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 44 ±1 | VRANA | 00 | DPWA | Multichannel |
| 49 | ARNDT | 95 | DPWA | $\pi N \rightarrow N \pi$ |
| 44 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi$ | | | | $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$ |
| VALUE | <u>DO CUMENT ID</u> | | TECN | COMMENT |
| -0.053 ± 0.005 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| $\Gamma(\Sigma K)/\Gamma_{\text{total}}$ | | | | Γ_2/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 0.4±0.1 | ANISOVICH | 12A | DPWA | Multichannel |

Note: Signs of couplings from $\pi\,N\to N\,\pi\pi$ analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the $\Delta(1620)\,\,S_{31}$ coupling to $\Delta(1232)\,\pi$.

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1)$ | 950) → △ (123 | 2)π, | <i>F</i> -wave | (Γ ₁ Γ ₅) ¹ ⁄2/Γ |
|------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|------|----------------|----------------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.28 to +0.32 OUR EST MATE | | | | |
| $+0.27 \pm 0.02$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ $\pi N \rightarrow N \pi \pi$ |
| +0.32 | $^{ m 1}$ LONGACRE | 75 | IPWA | $\pi N \rightarrow N \pi \pi$ |
| $\Gamma(\Delta(1232)\pi$, <i>F</i> -wave $)/\Gamma_{ m total}$ | | | | Γ ₅ /Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 2.8 ± 1.4 | ANISOVICH | 12A | DPWA | Multichannel |
| 36 ±1 | VRANA | 00 | DPWA | Multichannel |
| | | | | |
| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1)$ | | | | |
| $\frac{\left(\Gamma_{i}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to \Delta(1)}{\frac{VALUE}{+0.24}}$ | 950) → Nρ.Sa DOCUMENT ID 1 LONGACRE | - | TECN | COMMENT |

△(1950) PHOTON DECAY AMPLITUDES

Papers on γ N amplitudes predating 1981 may be found in our 2006 edition, Journal of Physics, G $\,$ 33 $\,1$ (2006).

$\Delta(1950) ightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

| VALUE (GeV ^{-1/2}) | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------|------------------|---------|-------------|------------------------------|
| -0.076 ± 0.012 OUR ESTIMATE | | | | |
| 0.071 ± 0.004 | ANISOVICH | 12A | DPWA | Multichannel |
| -0.079 ± 0.006 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ |
| -0.068 ± 0.007 | AWA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ |
| | data for average | s, fits | , limits, e | etc. • • • |
| -0.083 ± 0.008 | ANISOVICH | 10 | DPWA | Multichannel |
| -0.094 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ |
| -0.102 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ |

Baryon Particle Listings Δ (1950), Δ (2000), Δ (2150)

$\Delta(1950) \rightarrow N\gamma$, helicity-3/2 amplitude A_{3/2}

| | | -,- | | | |
|---------------------|-------------------------------|------------|-------------|------------------------------|---|
| VALUE (GeV-1/2) | | | TECN | COMMENT | |
| -0.097±0.010 OUR E | ESTIMATE | | | | |
| -0.094 ± 0.005 | ANISOVICH | 12A | DPWA | Multichannel | |
| -0.103 ± 0.006 | ARNDT | 96 | IPWA | $\gamma N \rightarrow \pi N$ | _ |
| -0.094 ± 0.016 | AVVA JI | 81 | DPWA | $\gamma N \rightarrow \pi N$ | |
| • • • We do not use | the following data for averag | ges, fits, | , limits, e | etc. • • • | |
| -0.092 ± 0.008 | ANISOVICH | 10 | DPWA | Multichannel | 1 |
| -0.121 | DRECHSEL | 07 | DPWA | $\gamma N \rightarrow \pi N$ | - |
| -0.115 ± 0.003 | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| | | | | | |

△(1950) FOOTNOTES

- $^{
 m 1}$ From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes
- ² See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- ³LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

△(1950) REFERENCES

| ANISOVICH | 12A | EPJ A48 15 | A.V. Anisovich et al. | (BONN, PNPI) |
|-----------|-----|-------------------|-----------------------------------|----------------------|
| ANISOVICH | 10 | EPJ A44 203 | A.V. Anisovich et al. | (BONN, PNPI) |
| DRECHSEL | 07 | EPJ A34 69 | D. Drechsel, S.S. Kamalov, L. | Tiator (MAINZ, JINR) |
| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
| PDG | 06 | JPG 33 1 | WM. Yao et al. | (PDG Collab.) |
| ARNDT | 04 | PR C69 035213 | R.A. Arndt et al. | (GWU, TRIU) |
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS | .H. Lee (PITT+) |
| ARNDT | 96 | PR C53 430 | R.A. Arndt, I.I. Strakovsky, R.L. | . Workman (VPI) |
| ARNDT | 95 | PR C52 2120 | R.A. Arndt et al. | (VPI, BŘCO) |
| HOEHLER | 93 | πN Newsletter 9 1 | G. Hohler | ` (KARL) |
| LI | 93 | PR C47 2759 | Z.J. Li et al. | `(VPI) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KÈNT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| ARNDT | 91 | PR D43 2131 | R.A. Arndt et al. | (VPI, TELE) IJP |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | `(HELS, CIT, CERN) |
| AWAJI | 81 | Bonn Conf. 352 | N. Awaji, R. Kajikawa | (NAGO) |
| Also | | NP B197 365 | K. Fujii et al. | (NAGO) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | `(LBL)IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL)IJP |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT) IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| LONGACRE | 78 | PR D17 1795 | R.S. Longacre et al. | (LBĽ, SLAC) |
| LONGACRE | 75 | PL 55B 415 | R.S. Longacre et al. | (LBL, SLAC) IJP |
| | | | - | |

 $\Delta(2000) 5/2$

 $I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this

△(2000) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-------------|----|------|----------------------------------------|
| ≈ 2000 OUR ESTIMATE | · | | | |
| 1724± 61 | VRA NA | 00 | DPWA | Multichannel |
| 1752± 32 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 2200 ± 125 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2000) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------|--------------|----|--------|----------------------------------------|
| 138± 68 | VRA NA | 00 | DPWA | Multichannel |
| 251 ± 93 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 400 ± 1.25 | CHTKOSKV | 80 | ID\A/A | $\pi N \rightarrow \pi N$ |

△(2000) POLE POSITION

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------|--------------------|----------|--------------|----------------------------------------|
| 1697 2150±100 | VRA NA CUTKOSKY | 00 80 | | Multichannel $\pi N \rightarrow \pi N$ |
| -2×IMAGINARY PART | DOCUMENT ID | | TECN | COMMENT |
| 112 350±100 | VRA NA CUTKOSKY | 00 80 | DPWA IPWA | Multichannel $\pi N \rightarrow \pi N$ |

△(2000) ELASTIC POLE RESIDUE

MODULUS |r|

| 1.1 | | | | |
|-------------|-------------|--------|---------------------------|--|
| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT | |
| 16+5 | CUTKOSKV 80 | ID\A/A | $\pi N \rightarrow \pi N$ | |

| P | н | A | S | F | A |
|---|---|---|---|---|---|
| | | | | | |

| VALUE (°) | DO CUMENT ID | TECN | COMMENT |
|-----------|--------------|------|---------------------------|
| 150±90 | CUTKOSKY 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2000) DECAY MODES

Mode

| 1 | Nπ |
|---|----------------------------------------|
| 2 | $N\pi\pi$ |
| 3 | Δ (1232) π , P -wave |
| 4 | ${\it \Delta}(1232)\pi$, $\it F-wave$ |
| | No S-3/2 Pways |

△(2000) BRANCHING RATIOS

| I (Nπ)/I total | | | | 11/1 |
|----------------|-------------|----|------|----------------------------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT |
| 0±1 | VRANA | 00 | DPWA | Multichannel |
| 2 ± 1 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 7±4 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(20)$ | 000) → △ (123 | 2)π, | P-wave | e (Γ ₁ Γ ₃) ^{1/2} /Γ |
|-------------------------------------------------------------------------------------|----------------------|------|--------|------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.07\pm0.03$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| $\Gamma(\Lambda(1232)\pi P\text{-wave})/\Gamma_{\text{total}}$ | | | | Га/Г |

| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
|----------------------------------------------------------------------------------|-----------------------------------------------------|------|--------|------------|-------------------------------------------------|
| 0±1 | VRANA | 00 | DPWA | Multichann | iel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\pi \to Z$ | $\Delta(2000) \rightarrow \Delta(1232)$ DOCUMENT ID | 2)π, | F-wave | COMMENT | (Γ ₁ Γ ₄) ^{1/2} |

| () // / LOLA! | , , | , . | | | -, , |
|-----------------------------------------------------|--------------|-----|------|------------------------------|-----------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $+0.09\pm0.04$ | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \&$ | $N\pi\pi$ |
| $\Gamma(\Delta(1232)\pi, F$ -wave $)/\Gamma_{tota}$ | l | | | | Γ4/Γ |
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 40±1 | VRANA | 0.0 | DPWA | Multichannel | |

| | ******** | 00 5 | THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OT THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL CONTROL OF THE TOTAL |
|-------------------------------------------------------------------|--------------------------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{ m total}$ in $N\pi ightarrow$ | $\Delta(2000) \rightarrow N\rho, S=$ | =3/2, <i>P</i> -wave | e (Γ ₁ Γ ₅) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | TECN | COMMENT |

| ('/''') /'total''''''' | <u> </u> | ,, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | · ('1'5) /' |
|------------------------|--------------|-----------------------------------------|----------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| -0.06 ± 0.01 | MANLEY 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |

| $\Gamma(N\rho, S=3/2, P-wave)/\Gamma_{total}$ | | | | | Г ₅ /Г |
|-----------------------------------------------|--------------|----|------|---------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| (0 (0 | A A D A NIA | 00 | DDWA | Marketalanana | |

△(2000) REFERENCES

| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
|----------|----|------------------|-------------------------------------|------------|
| VRANA | 00 | PRPL 328 181 | T.P. Vrana, S.A. Dytman,, TS.H. Lee | (PITT+) |
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | (KENT) IJP |
| Also | | PR D30 904 | D.M. Manley et al. | (VPI) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) |
| A Iso | | PR D20 2839 | R.F. Cutkosky et al. | (CMU_LBL) |

 $\Delta(2150) 1/2$

 $I(J^P) = \frac{3}{2}(\frac{1}{2})$ Status: *

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(2150) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|----------------|----|------|-------------------------------------|
| ≈ 2150 OUR ESTIMATE | | | | |
| 2047.4 ± 27.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ |
| 2203.2± 8.4 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 2150 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2150) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------|----------------|----|------|-------------------------------|
| 121.6± 62.0 | 1 CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 120.5 ± 45.0 | $^{ m 1}$ CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |
| 200 ±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2150) POLE POSITION

| REAL | PART |
|------|------|
| | |

| VALUE (MeV) | DOCUMENT ID | TECN | COMMENT |
|-------------|-------------|------|---------------------------|
| 2140 ± 80 | CUTKOSKY 80 | IPWA | $\pi N \rightarrow \pi N$ |

 Γ_1/Γ

 $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$

(IND)

 2100 ± 50

VALUE (MeV

 340 ± 80

-2×IMAGINARY PART

△(2200) ELASTIC POLE RESIDUE -2×IMAGINARY PART DOCUMENT ID TECN COMMENT MODULUS |r| 200 ± 80 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ VALUE (MeV TECN COMMENT 8 ± 3 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ △(2150) ELASTIC POLE RESIDUE PHASE 0 MODULUS |r| DOCUMENT ID TECN COMMENT VALUE (VALUE (MeV) DOCUMENT ID TECN CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ -70 ± 40 7 ± 2 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ △(2200) DECAY MODES PHASE 0 TECN COMMENT DOCUMENT ID -60 ± 90 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ Mode Γ_1 $N\pi$ △(2150) DECAY MODES Γ_2 ΣK Mode △(2200) BRANCHING RATIOS $N\pi$ $\Gamma(N\pi)/\Gamma_{\text{total}}$ Γ_2 ΣK VALUE (%) DOCUMENT ID TECN COMMENT △(2150) BRANCHING RATIOS 6 ± 2 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ HOEHLER IPWA 5 ± 2 79 $\pi N \rightarrow \pi N$ $\Gamma(N\pi)/\Gamma_{\text{total}}$ Γ_1/Γ HENDRY MPWA $\pi N \rightarrow \pi N$ DOCUMENT ID VALUE (%) TECN COMMENT $(\Gamma_I \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to \Delta(2200) \to \Sigma K$ 41 ¹ CHEW 80 BPWA $\pi^+ \rho \rightarrow \pi^+ \rho$ DOCUMENT ID 80 BPWA $\pi^+ p \rightarrow \pi^+$ TECN COMMENT CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ -0.014 ± 0.005 CANDLIN 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \pi \to \Delta(2150) \to \Sigma K$ △(2200) REFERENCES DO CUMENT ID TECN COMMENT PR C74 045205 NP B238 477 Toronto Conf. 19 PR D20 2839 PDAT 12-1 (GWU) (EDIN, RAL, LOWC) (CMU, LBL) IJP (CMU, LBL) IJP (KARLT) IJP (KARLT) IJP (IND, LBL) IJP ARNDT CANDLIN CUTKOSKY R.A. Arndt et al. D.J. Candlin et al. R.E. Cutkosky et al. R.E. Cutkosky et al. 06 84 80 < 0.03 CANDLIN 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ Also HOEHLER △(2150) FOOTNOTES 79 G. Hohler et al $^1\,\rm CHEW$ 80 reports two S_{31} resonances in this mass region. Problems with this analysis are discussed in section 2.1.11 of HOEHLER 83. Toronto Conf. 3 PRL 41 222 R. Koch Also HENDRY ANP 136 1 A.W. Hendry △(2150) REFERENCES $I(J^P) = \frac{3}{2}(\frac{9}{2}+)$ Status: ** Δ (2300) 9/2⁺ ARNDT PR C74 045205 R.A. Arndt et a (EDIN, RAL, LOWC) (KARLT) (LBL) IJP (CMU, LBL) IJP NR B238 47 AFRIEL et al. D.J. Candlin et al. Landolt-Boernstein 1/9B2 G. Hohler Toronto Conf. 123 D.M. Chew Toronto Conf. 19 R.E. Cutkosky et al. PR D20 2839 R.E. Cutkosky et al. CANDLIN HOEHLER OMITTED FROM SUMMARY TABLE CHEW CUTKOSKY Also The latest GWU analysis (ARNDT 06) finds no evidence for this resonance $I(J^P) = \frac{3}{2}(\frac{7}{2})$ Status: * △(2300) BREIT-WIGNER MASS $\Delta(2200) 7/2$ VALUE (MeV) DOCUMENT ID TECN COMMENT ≈ 2300 OUR ESTIMATE OMITTED FROM SUMMARY TABLE 2204.5 ± 3.4 CHEW BPWA $\pi^+ p \rightarrow \pi^+ p$ The various analyses are not in good agreement. 2400 ± 125 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ The latest GWU analysis (ARNDT 06) finds no evidence for this $2217\ \pm\ 80$ HOEHLER 79 IPWA $\pi N \rightarrow \pi N$ MPWA $\pi N \rightarrow \pi N$ 2450 ± 100 HENDRY 78 • • • We do not use the following data for averages, fits, limits, etc. • • • △(2200) BREIT-WIGNER MASS 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ 2400 CANDLIN DOCUMENT ID VALUE (MeV) TECN COMMENT △(2300) BREIT-WIGNER WIDTH ≈ 2200 OUR ESTIMATE CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ 2200 ± 80 VALUE (MeV) DOCUMENT ID TECN COMMENT IPWA $\pi N \rightarrow \pi N$ **HOEHLER** 2215 ± 60 79 32.3 ± 1.0 CHEW 80 BPWA $\pi^+ p \rightarrow \pi^+ p$ HENDRY 78 MPWA $\pi N \rightarrow \pi N$ CUTKOSKY $\mathsf{IPWA} \quad \pi \, \mathsf{N} \, \to \, \pi \, \mathsf{N}$ 425 ± 150 80 • • • We do not use the following data for averages, fits, limits, etc. • • • HOEHLER IPWA $\pi N \rightarrow \pi N$ 300 ±100 79 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ HENDRY 78 MPWA $\pi N \rightarrow \pi N$ 500 ± 200 ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet△(2200) BREIT-WIGNER WIDTH 200 CANDLIN 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ TECN COMMENT VALUE (MeV DOCUMENT ID △(2300) POLE POSITION 450 ± 100 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ 400±100 HOFHLER IPWA 79 REAL PART MPWA $\pi N \rightarrow \pi N$ 400 ± 150 HENDRY 78 TECN COMMENT \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet $\overline{\text{CUT}}$ KOSKY 80 IPWA $\pi N \rightarrow \pi N$ 2370 ± 80 84 DPWA $\pi^+ p \rightarrow \Sigma^+ K^+$ 400 ± 50 CANDLIN -2×IMAGINARY PART TECN COMMENT △(2200) POLE POSITION 420±160 CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$ **REAL PART** DOCUMENT ID TECN COMMENT VALUE (MeV △(2300) ELASTIC POLE RESIDUE

80 IPWA $\pi N \rightarrow \pi N$

80 IPWA $\pi N \rightarrow \pi N$

TECN COMMENT

MODULUS |r|

DOCUMENT ID

TECN COMMENT

CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$

VALUE (MeV)

 10 ± 4

CUTKOSKY

DOCUMENT ID

CUTKOSKY

 $\Delta(2300), \Delta(2350), \Delta(2390)$

| PHASE <i>θ</i> | | | |
|----------------|-------------|------|---------------------------|
| VALUE (°) | DOCUMENT ID | TECN | COMMENT |
| -20 ± 30 | CUTKOSKY 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2300) DECAY MODES

| | Mode | |
|----------------------------------|------------|--|
| Γ ₁ Γ ₂ | N π Σ K | |

△(2300) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|--------------|----|--------|-------------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 5 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ | |
| 6 ± 2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 3 ± 2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 8 + 2 | HENDRY | 78 | MP W/A | $\pi N \rightarrow \pi N$ | |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\pi \to A$ | $\Delta(2300) \rightarrow \Sigma K$ | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------|-------------------------------------|----|------|-----------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| -0.017 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow$ | Σ+ K+ |

△(2300) REFERENCES

| ARNDT CANDLIN | 06 84 | PR C74 045205 NP B238 477 | R.A. Arndt et al. D.J. Candlin et al. | (GWU) (EDIN, RAL, LOWC) |
|------------------|----------|------------------------------|------------------------------------------|----------------------------|
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL) IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | ` (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IND) |

 $\Delta(2350) 5/2$

$$I(J^P) = \frac{3}{2}(\frac{5}{2})$$
 Status: *

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(2350) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------------|----------|---------|----------------------------------------|
| ≈ 2350 OUR ESTIMATE | | | | |
| 2171 ± 18 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 2400±125 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2305 ± 26 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | ng data for average | s, fits, | limits, | etc. • • • |
| 2459 ± 100 | VRA NA | 00 | DPWA | Multichannel |

△(2350) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|---------|-----------|----------------------------------------|
| 264 ± 51 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 400 ± 150 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 300± 70 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 480 ± 360 | VRA NA | 00 | DPWA | Multichannel |

△(2350) POLE POSITION

| REAL PART | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|-------------|----|------|--------------|
| 2400 ± 125 | CUTKOSKY | | | |
| • • We do not use the following 2427 | VRA NA | 00 | | Multichannel |

2 VIMAGINARY PART

| -ZAIMAGINAINI TAINT | | | | |
|-------------------------------------------|-------------------|---------|-------------|---------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 400±150 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for averages | , fits, | , limits, e | etc. • • • |
| 458 | VRA NA | 00 | DPWA | Multichannel |

△(2350) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------|--------------|----|------|---------------------------|
| 15 ± 8 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| PHASE θ | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -70 ± 70 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2350) DECAY MODES

| | Mode | |
|----------------------------------|------------|--|
| Γ ₁ Γ ₂ | N π Σ K | |

△(2350) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|----------------------|---------|-----------|----------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT |
| 2.0± 0.3 | MANLEY | 92 | IPWA | $\pi N \rightarrow \pi N \& N \pi \pi$ |
| 20 ±10 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 4 ± 2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| • • • We do not use the follow | ing data for average | s, fits | , limits, | etc. • • • |
| 7 ±14 | VRANA | 00 | DPWA | Multichannel |

| $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \to 4$ | $\Delta(2350) \rightarrow \Sigma K$ | | | (Γ ₁ Γ ₂) ^{1/2} /Γ |
|------------------------------------------------------------------|-------------------------------------|----|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| < 0.015 | CANDLIN | 84 | DPWA | $\pi^+ \rho \rightarrow \Sigma^+ K^+$ |

△(2350) REFERENCES

| ARNDT VRANA | 06 00 | PR C74 045205 PRPL 328 181 | R.A. Arndt <i>et al.</i> T.P. Vrana, S.A. Dytman,, TS.H. | (GWU) Lee (PITT+) |
|----------------|----------|-------------------------------|-------------------------------------------------------------|----------------------|
| MANLEY | 92 | PR D45 4002 | D.M. Manley, E.M. Saleski | `(KENT)IJP |
| A Iso | | PR D30 904 | D.M. Manley et al. | `(VPI) |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LÔWC) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | CMU, LBL)IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler <i>et al</i> . | ` (KARLT)IJP |
| Also | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |

 Δ (2390) 7/2⁺

$$I(J^P) = \frac{3}{2}(\frac{7}{2}^+)$$
 Status: *

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

△(2390) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|----|------|---------------------------|
| ≈ 2390 OUR ESTIMATE | · | | | |
| 2350 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2425 ± 60 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

△(2390) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|-------------|-------------|----|------|---------------------------|
| 300±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 300± 80 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |

△(2390) POLE POSITION

| REAL PART VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------------|----|------|---------------------------|
| 2350 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| -2×IMAGINARY PART | | | | |
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| 260±100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2390) ELASTIC POLE RESIDUE

| MODULUS r | | | | |
|----------------|--------------|---------|---------------------------|--|
| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT | |
| $12\!\pm\!6$ | CUTKOSKY | 80 IPWA | $\pi N \rightarrow \pi N$ | |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | TECN | COMMENT | |
| -90 ± 60 | CHTKOSKY | an IPWA | $\pi N \rightarrow \pi N$ | |

△(2390) DECAY MODES

| | Mode | | |
|-----------------------|------|--|--|
| $\overline{\Gamma_1}$ | Nπ | | |
| Γ̈́2 | ΣΚ | | |

△(2390) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | • | , | | | | Γ_1/Γ |
|--------------------------------------|---|--------------|----|------|---------------------------|-------------------|
| VALUE (%) | | DO CUMENT ID | | TECN | COMMENT | |
| 8±4 | | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 7±4 | | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |

| (Γ _i Γ _f) ^{1/2} / | Γ _{tota} | in $N\pi	o \Delta(23)$ | $390) \rightarrow \Sigma K$ $DO CUMENT ID$ |) | TECN | (Γ ₁ | Γ ₂) ^{1/2} / |
|---------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|--------------------------------|----------------------------|------------------------------------------|-----------------------------------|
| < 0.015 | | | CANDLIN | 84 | | $\pi^+ \rho \rightarrow \Sigma^+ \kappa$ | + |
| | | Δ(| 2390) REFEF | RENCI | ES | | |
| ARNDT CANDLIN CUTKOSKY Also HOEHLER Also | 06 84 80 79 | PR C74 045205 NP B238 477 Toronto Conf. 19 PR D20 2839 PDAT 12-1 Toronto Conf. 3 | R.A. Arndt e D.J. Candlin R.E. Cutkosk R.E. Cutkosk G. Hohler et R. Koch | et al. y et al. y et al. | | (EDIN, RAL, È (CMU, (CMU, (KA | LBL) IJP |
| $\Lambda(2)$ | 400 |)) 9/2 [—] | I(J | <i>P</i>) = | $\frac{3}{2}(\frac{9}{2})$ |) Status: * | * |

| A(2400) | BREIT-WIGNER | MASS |
|----------|-----------------|-------|
| 24(2400) | DIVELL-MAIGIMEN | MUUDO |

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|----|-------|--------------------------------------|
| ≈ 2400 OUR ESTIMATE | | | | |
| 2643 ± 141 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2300 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2468± 50 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2200 ± 100 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ |

△(2400) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------|-------------|----|-------|-----------------------------------|
| 895 ±432 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 330 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 480±100 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 450 ± 200 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ |

△(2400) POLE POSITION

| REAL PART VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|--------------|----|------|--------------------------------------|
| 1983 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N, \eta N$ |
| 2260 ± 60 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| -2×IMAGINARY PART | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 878 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 320±160 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2400) ELASTIC POLE RESIDUE

| MODULUS r | | | | |
|--------------------------|-------------------|----------|------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 24 8±4 | ARNDT CUTKOSKY | 06 80 | | $\begin{array}{ccc} \pi \ {\it N} \ \rightarrow & \pi \ {\it N}, \ \eta \ {\it N} \\ \pi \ {\it N} \ \rightarrow & \pi \ {\it N} \end{array}$ |
| PHASE 0 VALUE (°) | DOCUMENT ID | | TECN | COMMENT |
| -139 -25 ± 15 | ARNDT CUTKOSKY | 06 80 | | $ \begin{array}{ccc} \pi \ N \to & \pi \ N, \ \eta \ N \\ \pi \ N \to & \pi \ N \end{array} $ |

△(2400) DECAY MODES

| | Mode | |
|-----------------------|------------|--|
| Γ_1 Γ_2 | N π Σ K | |

△(2400) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ_1 |
|--------------------------------------|--------------|----|-------|--------------------------------------|---------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 6.4 ± 2.2 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| 5 ±2 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 6 ±3 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 10 ±3 | HENDRY | 78 | MP WA | $\pi N \rightarrow \pi N$ | |
| | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \pi \to A$ | $\Delta(2400) \rightarrow \Sigma K$ | | | (Γ₁Γ₂) ^{1/2} /Γ |
|-------------------------------------------------------------------------------------|-------------------------------------|----|------|------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| < 0.015 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |

△(2400) REFERENCES

| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
|----------|----|------------------|----------------------|-------------------|
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | ` (CMU, LBL)IJP |
| A Iso | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | ` (IND) |
| | | | | |

Δ (2420) 11/2⁺

 $I(J^P) = \frac{3}{2}(\frac{11}{2}^+)$ Status: ***

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** 1 (1982).

△(2420) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|------------------|---------|---------------------------------------|--------------------------------------|
| 2300 to 2500 (≈ 2420) OUR EST | IMATE | | · · · · · · · · · · · · · · · · · · · | |
| 2633 ± 29 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2400 ±125 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| 2416 ± 17 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2400 ± 60 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, et | tc. • • • |
| 2400 | CANDLIN | 84 | DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |
| 2358.0 ± 9.0 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

△(2420) BREIT-WIGNER WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------------|-------------------|----------|------------|---------------------------------------|
| 300 to 500 (≈ 400) OUR ESTIM | ATE | | | |
| 692 ± 47 | ARNDT | 06 | DPWA - | $\pi N \rightarrow \pi N, \eta N$ |
| 450 ±150 | CUTKOSKY | 80 | IPWA - | $\pi N \rightarrow \pi N$ |
| 340 ± 28 | HOEHLER | 79 | IPWA - | $\pi N \rightarrow \pi N$ |
| 460 ±100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |
| $\bullet~\bullet~$ We do not use the following | data for averages | s, fits, | limits, et | .c. • • • |
| 400 | CANDLIN | 84 | DPWA | $\pi^+ \rho \rightarrow \Sigma^+ K^+$ |
| 202.2± 45.0 | CHEW | 80 | BPWA | $\pi^+ p \rightarrow \pi^+ p$ |

△(2420) POLE POSITION

| REAL | PA | R | 1 |
|------|----|---|---|
|------|----|---|---|

| VALUE (MeV) | DO CUMENT ID | DO CUMENT ID | | COMMENT |
|--------------------------|----------------------|--------------|------|--------------------------------------|
| 2260 to 2400 (≈ 2330) Ol | JR ESTIMATE | | | |
| 2529 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 2300 | ¹ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 2360 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| -2×IMAGINARY PAR | RT | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 350 to 750 (≈ 550) OUR I | ESTIMATE | | | |
| 621 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 620 | ¹ HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| 420 ± 100 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2420) ELASTIC POLE RESIDUE

MODULUS |r|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------|--------------|----|------|--------------------------------------|
| 33 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| 39 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| $18\!\pm\!6$ | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |
| PHASE <i>θ</i> | | | | |
| VALUE (°) | DO CUMENT ID | | TECN | COMMENT |
| -45 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN |
| -60 | HOEHLER | 93 | ARGD | $\pi N \rightarrow \pi N$ |
| -30 ± 40 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ |

△(2420) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|------------|------------------------------|
| Γ ₁ Γ ₂ | N π Σ K | 5-15 % |

△(2420) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|-----------------------|---------|-----------|--------------------------------------|-------------------|
| VALUE (%) | DO CUMENT ID | | TECN | COMMENT | |
| 5 to 15 OUR ESTIMATE | | | | | |
| 8.5 ± 0.8 | ARNDT | 06 | DPWA | $\pi N \rightarrow \pi N$, ηN | |
| 8 ±3 | CUTKOSKY | 80 | IPWA | $\pi N \rightarrow \pi N$ | |
| 8.0 ± 1.5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 11 ±2 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ | |
| • • • We do not use the follo | wing data for average | s, fits | , limits, | etc. • • • | |
| 22 | CHEW | 80 | BPWA | $\pi^+ \rho \rightarrow \pi^+ \rho$ | |

 $\Delta(2420), \Delta(2750), \Delta(2950), \Delta(\sim 3000)$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\pi 	o \Delta$ | Δ(2420) → Σ K | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------------------|---------------|--------|-------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| -0.016 | CANDLIN 8 | 4 DPWA | $\pi^+ p \rightarrow \Sigma^+ K^+$ |

△(2420) FOOTNOTES

1 See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

△(2420) REFERENCES

| ARNDT | 06 | PR C74 045205 | R.A. Arndt et al. | (GWU) |
|----------|----|--------------------|----------------------|-------------------|
| | | | | |
| HOEHLER | 93 | π N Newsletter 9 1 | . G. Hohler | (KARL) |
| CANDLIN | 84 | NP B238 477 | D.J. Candlin et al. | (EDIN, RAL, LOWC) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| CHEW | 80 | Toronto Conf. 123 | D.M. Chew | (LBL) IJP |
| CUTKOSKY | 80 | Toronto Conf. 19 | R.E. Cutkosky et al. | (CMU, LBL)IJP |
| Also | | PR D20 2839 | R.E. Cutkosky et al. | (CMU, LBL) |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IN D) |
| | | | | |

 $\Delta(2750) \ 13/2$

 $I(J^P) = \frac{3}{2}(\frac{13}{2})$ Status: **

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance

△(2750) BREIT-WIGNER MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-------------|----|------|---------------------------|
| ≈ 2750 OUR ESTIMATE | | | | |
| 2794± 80 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ |
| 2650 ± 100 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ |

△(2750) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN COMMENT |
|--------------------|-------------------------|---------------------------------------------------------------|
| 350±100 500±100 | HOEHLER 79 HENDRY 78 | IPWA $\pi N \rightarrow \pi N$ MPWA $\pi N \rightarrow \pi N$ |

△(2750) DECAY MODES

Mode Γ_1 $N\pi$

△(2750) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|-------------|----|------|---------------------------|-------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | |
| 4.0 ± 1.5 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 5 ±1 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ | |

△(2750) REFERENCES

| ARNDT | 06 | PR C74 045205 | R A Arndt et al | (GWU) |
|---------|-----|-----------------|-------------------|-----------------|
| AKNDI | 0.0 | PR C/4 045205 | N.A. ATHUL EL al. | |
| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (INÌD, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IND) |



 $I(J^P) = \frac{3}{2}(\frac{15}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

| BREIT-WIGNE | R MASS | |
|-------------|-----------------------|---------------------------|
| DOCUMENT ID | TECN | COMMENT |
| | | |
| HOEHLER 7 | 9 IPWA | $\pi N \rightarrow \pi N$ |
| HENDRY 7 | 8 MPWA | $\pi N \rightarrow \pi N$ |
| | DOCUMENT ID HOEHLER 7 | HOEHLER 79 IPWA |

△(2950) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|--------------------|--------------|------|-----------------------------------------------------|
| 330±100 700+200 | HOEHLER 79 | | $\pi N \rightarrow \pi N$ $\pi N \rightarrow \pi N$ |

△(2950) DECAY MODES

| | Mode | | |
|----------------|--------|--|--|
| Γ ₁ | $N\pi$ | | |

△(2950) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------|-------------|----|------|---------------------------|-------------------|
| VALUE (%) | DOCUMENT ID | | TECN | COMMENT | |
| 4±2 | HOEHLER | 79 | IPWA | $\pi N \rightarrow \pi N$ | |
| 3 ± 1 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N$ | |

△(2950) REFERENCES

| HOEHLER | 79 | PDAT 12-1 | G. Hohler et al. | (KARLT)IJP |
|---------|----|-----------------|------------------|----------------|
| A Iso | | Toronto Conf. 3 | R. Koch | (KARLT) IJP |
| HENDRY | 78 | PRL 41 222 | A.W. Hendry | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IND) |

$\Delta (\sim 3000 \; { m Region})$ Partial-Wave Analyses

OMITTED FROM SUMMARY TABLE

We list here miscellaneous high-mass candidates for isospin-3/2 resonances found in partial-wave analyses.

Our 1982 edition also had a $\Delta(2850)$ and a $\Delta(3230)$. The evidence for them was deduced from total cross-section and 180° elastic crosssection measurements. The $\Delta(2850)$ has been resolved into the Δ (2750) $I_{3,13}$ and Δ (2950) $K_{3,15}$. The Δ (3230) is perhaps related to the $K_{3,13}$ of HENDRY 78 and to the $L_{3,17}$ of KOCH 80.

△(~ 3000) BREIT-WIGNER MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|----------------|----|------|-------------------------------------------------------------|
| ≈ 3000 OUR ESTIMATE | · | | | |
| 3300 | $^{ m 1}$ KOCH | 80 | IPWA | $\pi N \rightarrow \pi N L_{3.17}$ wave |
| 3500 | $^{ m 1}$ KOCH | 80 | IPWA | $\pi N \rightarrow \pi N M_{3,19}$ |
| 2850 ± 150 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N I_{3.11}$ wave |
| 3200 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N K_{3,13}$ |
| 3300 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N L_{3.17}$ wave |
| 3700 ± 200 | HENDRY | 78 | MPWA | $\pi N \rightarrow \pi N M_{3,19}$ |
| 4100±300 | HENDRY | 78 | MPWA | $\pi \stackrel{Wave}{\sim} \pi \stackrel{N}{\sim} N_{3,21}$ |

△(~ 3000) BREIT-WIGNER WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------|--------------|-------|--------------------------------------------------------------------------------------------------------|
| 700 ± 200 | HENDRY 7 | B MPW | A $\pi N \rightarrow \pi N I_{3.11}$ wave |
| 1000 ± 300 | HENDRY 7 | MPW. | $A \pi N \rightarrow \pi N K_{3,13}$ |
| 1100 ± 300 | HENDRY 7 | MPW. | A $\pi N \rightarrow \pi N L_{3.17}$ wave |
| 1300 ± 400 | HENDRY 7 | MPW. | $A \pi N \rightarrow \pi N M_{3,19}$ |
| 1600 ± 500 | HENDRY 7 | B MPW | A $\pi \stackrel{\text{wave}}{N} \rightarrow \pi \stackrel{\text{N}}{N} \stackrel{\text{N}}{N_{3,21}}$ |

△(~3000) DECAY MODES

Mode $N\pi$ Γ_1

△(~ 3000) BRANCHING RATIOS

| $\Gamma(N\pi)/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|--------------------------------------|--------------|----|----------|------------------------------------------------------------------------------|
| VALUE (%) | DO CUMENT ID | | TECN COI | MENT |
| 6 ± 2 | HENDRY | 78 | MPWA πΛ | \rightarrow π N I $_{3,11}$ wave |
| 5 ± 2 | HENDRY | 78 | | $_{ m wave}^{ m l} ightarrow \pi$ N $_{ m N}$ $_{ m N}$ $_{ m N}$ $_{ m N}$ |
| 3±1 | HENDRY | 78 | MPWA πΛ | $\rightarrow \pi N L_{3,17}$ wave |
| 3±1 | HENDRY | 78 | | $_{\mathrm{wave}}^{\prime} \rightarrow \pi N M_{3,19}$ |
| 2±1 | HENDRY | 78 | | $_{ m wave}^{\prime} ightarrow \pi$ N N $_{3,21}$ |

Δ (\sim 3000) FOOTNOTES

 $^{1}\,\mathrm{ln}$ addition, KOCH 80 reports some evidence for an $\mathit{S}_{31}\,\Delta(2700)$ and a $\mathit{P}_{33}\,\Delta(2800).$

△(~ 3000) REFERENCES

| KOCH | 80 | Toronto Conf. 3 | A.W. Hendry | (KARLT) IJP |
|--------|----|-----------------|-------------|----------------|
| HENDRY | 78 | PRL 41 222 | | (IND, LBL) IJP |
| A Iso | | ANP 136 1 | A.W. Hendry | (IND) |

Λ BARYONS (S = -1, I = 0)

 $\Lambda^0 = u ds$



$$I(J^P) = O(\frac{1}{2}^+)$$
 Status: ***

We have omitted some results that have been superseded by later experiments. See our earlier editions.

A MASS

The fit uses Λ , Σ^+ , Σ^0 , Σ^- mass and mass-difference measurements

| /ALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------|----------|-----------------------|----------|-----------|---------------|
| 115.683 ± 0.006 OUR FI | T | | | | |
| 115.683 ± 0.006 OUR AV | /ERAGE | | | | |
| $115.678 \pm 0.006 \pm 0.006$ | 20k | HARTOUNI | 94 | SPEC | pp 27.5 GeV/c |
| $115.690 \pm 0.008 \pm 0.006$ | 18k | ¹ HARTOUNI | 94 | SPEC | pp 27.5 GeV/c |
| • • We do not use the | followin | g data for averages | s, fits, | limits, e | tc. • • • |
| 115.59 ±0.08 | 935 | HYMAN | 72 | HEBC | |
| 115.39 ±0.12 | 195 | MAYEUR | 67 | EMUL | |
| 115.6 ± 0.4 | | LONDON | 66 | HBC | |
| 115.65 ±0.07 | 488 | ² SCHMIDT | 65 | HBC | |
| 1115.44 ±0.12 | | 3 BHOWMIK | 63 | RVUE | |

 $^{^1}$ We assume $\it CPT$ invariance: this is the $\overline{\it A}$ mass as measured by HARTOUNI 94. See below for the fractional mass difference, testing $\it CPT$.

$$(m_{\Lambda}-m_{\overline{\Lambda}})/m_{\Lambda}$$

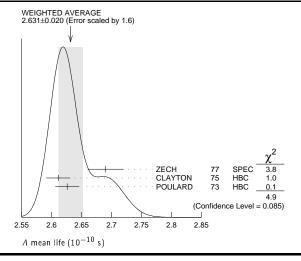
A test of CPT invariance.

| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------------------------|-----------|----------------------|---------|-----------|--------------------------|--|
| - 0.1 ± 1.1 OUR AV | ERAGE E | rror includes scal | e fact | or of 1. | 6. | |
| $+$ 1.3 \pm 1.2 | 31 k | ⁴ RYBICKI | 96 | NA 32 | π^- Cu, 230 GeV | |
| -1.08 ± 0.90 | | HARTOUNI | 94 | SPEC | pp 27.5 GeV/c | |
| 4.5 ± 5.4 | | CHIEN | 66 | HBC | 6.9 GeV/c p p | |
| • • • We do not use the | following | data for averages | , fits, | limits, e | etc. • • • | |
| -26 ± 13 | | BADIER | 67 | HBC | 2.4 GeV/c p p | |
| ⁴ RYBICKI 96 is an analysis of old ACCMOR (NA32) data. | | | | | | |

ℳMEAN LIFE

Measurements with an error $\geq 0.1\times 10^{-10}$ s have been omitted altogether, and only the latest high-statistics measurements are used for the average.

| VALUE (10 ⁻¹⁰ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|---------------|----------------------|----------|-----------|-------------------------------------|
| 2.632±0.020 OUR A | VERAGE | Error includes scale | factor | of 1.6. | See the ideogram below. |
| 2.69 ± 0.03 | 53k | ZECH | 77 | SPEC | Neutral hyperon beam |
| 2.611 ± 0.020 | 34 k | CLAYTON | 75 | HBC | 0.96-1.4 GeV/c K ⁻ p |
| 2.626 ± 0.020 | 36k | POULARD | 73 | HBC | 0.4-2.3 GeV/c K-p |
| • • • We do not use | the following | ng data for averages | s, fits, | limits, e | etc. • • • |
| 2.69 ± 0.05 | 6582 | ALTHOFF | 73B | OSP K | $\pi^+ n \rightarrow \Lambda K^+$ |
| 2.54 ± 0.04 | 4572 | BALTAY | 71B | HBC | K^-p at rest |
| 2.535 ± 0.035 | 8342 | GRIMM | 68 | HBC | |
| 2.47 ± 0.08 | 2600 | HEPP | 68 | HBC | |
| 2.35 ± 0.09 | 916 | BURAN | 66 | HLBC | |
| $2.452 + 0.056 \\ -0.054$ | 2213 | ENGELMANN | 66 | нвс | |
| 2.59 ±0.09 | 794 | HUBBARD | 64 | HBC | |
| 2.59 ±0.07 | 1378 | SCHWARTZ | 64 | HBC | |
| 2.36 ± 0.06 | 2239 | BLOCK | 63 | HEBC | |
| | | | | | |



$$(\tau_{\Lambda} - \tau_{\overline{\Lambda}}) / \tau_{\Lambda}$$

A test of CPT invariance

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|--------------|----|------|------------------------------------------------------------|
| -0.001 ±0.009 OUR AVERAGE | | | | |
| $-0.0018 \pm 0.0066 \pm 0.0056$ | BARNES | 96 | CNTR | LEAR $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ |
| 0.044 ± 0.085 | BADIER | 67 | нвс | 2.4 GeV/ <i>c</i> p p |

BARYON MAGNETIC MOMENTS

Written 1994 by C.G. Wohl (LBNL).

The figure below shows the measured magnetic moments of the stable baryons. It also shows the predictions of the simplest quark model, using the measured $p,\,n,$ and Λ moments as input. In this model, the moments are [1]

$$\begin{array}{ll} \mu_p = (4\mu_u - \mu_d)/3 & \mu_n = (4\mu_d - \mu_u)/3 \\ \mu_{\Sigma^+} = (4\mu_u - \mu_s)/3 & \mu_{\Sigma^-} = (4\mu_d - \mu_s)/3 \\ \mu_{\Xi^0} = (4\mu_s - \mu_u)/3 & \mu_{\Xi^-} = (4\mu_s - \mu_d)/3 \\ \mu_{\Lambda} = \mu_s & \mu_{\Sigma^0} = (2\mu_u + 2\mu_d - \mu_s)/3 \\ \mu_{\Omega^-} = 3\mu_s \end{array}$$

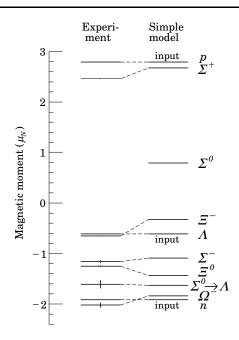
and the $\Sigma^0 \to \Lambda$ transition moment is

$$\mu_{\Sigma^0\Lambda} = (\mu_d - \mu_u)/\sqrt{3} \ .$$

The quark moments that result from this model are $\mu_u=+1.852\,\mu_N,\ \mu_d=-0.972\,\mu_N,\$ and $\mu_s=-0.613\,\mu_N.$ The corresponding effective quark masses, taking the quarks to be Dirac point particles, where $\mu=q\hbar/2m,$ are 338, 322, and 510 MeV. As the figure shows, the model gives a good first approximation to the experimental moments. For efforts to make a better model, we refer to the literature [2].

² The SCHMIDT 65 masses have been reevaluated using our April 1973 proton and K^{\pm} and π^{\pm} masses. P. Schmidt, private communication (1974).

 $^{^3}$ The mass has been raised 35 keV to take into account a 46 keV increase in the proton mass and an 11 keV decrease in the π^\pm mass (note added Reviews of Modern Physics $39\,1~(1967)).$



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 - cited therein Also, see references cited in discussions of results in the experimental papers..

A MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" above. Measurements with an error $\,\geq 0.15~\mu_{\,\hbox{\scriptsize N}}$ have been omitted.

| VALUE (μ_N) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------|-------------|--------------|------|------|--------------|
| -0.613 ± 0.004 | OUR AVERAGE | | | | |
| -0.606 ± 0.015 | 200k | COX | 81 | SPEC | |
| -0.6138 ± 0.0047 | 3M | SCHACHIN | 78 | SPEC | |
| -0.59 ± 0.07 | 350k | HELLER | 77 | SPEC | |
| -0.57 ± 0.05 | 1.2M | BUNCE | 76 | SPEC | |
| -0.66 ± 0.07 | 1300 | DAHL-JENSEI | N 71 | EMUL | 200 kG field |

A ELECTRIC DIPOLE MOMENT

A nonzero value is forbidden by both T invariance and P invariance.

| VALUE (10 ⁻¹⁶ ecm) | CL% | DO CUMENT ID | | TECN | | | |
|------------------------------------------------------------------------------------------------------------------------|-----------|----------------------|---------|----------------------|--|--|--|
| < 1.5 | 95 | ⁵ PONDROM | 81 | SPEC | | | |
| • • • We do not use the | following | data for averages | , fits, | , limits, etc. • • • | | | |
| <100 | 95 | ⁶ BARONI | 71 | EMUL | | | |
| < 500 | 95 | GIBSON | 66 | EMUL | | | |
| 5 PONDROM 81 measures $(-3.0\pm7.4)\times10^{-17}$ e-cm. 6 BARONI 71 measures $(-5.9\pm2.9)\times10^{-15}$ e-cm. | | | | | | | |

1 DECAY MODES

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-----------------------|-----------------------------------|----------------------------------------|
| $\overline{\Gamma_1}$ | pπ ⁻ | (63.9 ±0.5)% |
| Γ_2 | $n \pi^0$ | $(35.8 \pm 0.5)\%$ |
| Γ_3 | n γ | $(1.75 \pm 0.15) \times 10^{-3}$ |
| Γ_4 | $p\pi^-\gamma$ | [a] (8.4 ± 1.4) $\times 10^{-4}$ |
| Γ_5 | $pe^{-}\overline{ u}_{e}$ | $(8.32 \pm 0.14) \times 10^{-4}$ |
| Γ ₆ | $\rho \mu^- \overline{\nu}_{\mu}$ | $(1.57 \pm 0.35) \times 10^{-4}$ |

[a] See the Listings below for the pion momentum range used in this mea-

CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 20 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2 =$ 10.5 for 16 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left<\delta x_i\delta x_j\right>/(\delta x_i\cdot\delta x_j)$, in percent, from the fit to the branching fractions, $x_i\equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

| x_2 | -100 | | | |
|-----------------------|----------------|-----------------------|-----------------------|-----------------------|
| <i>x</i> ₃ | -2 | -1 | | |
| <i>X</i> ₅ | 46 | -46 | -1 | |
| <i>x</i> ₆ | 0 | 0 | 0 | 0 |
| | x ₁ | <i>X</i> ₂ | <i>X</i> ₃ | <i>X</i> ₅ |

A BRANCHING RATIOS

| $\Gamma(p\pi^-)/\Gamma(N\pi)$ | | | | | $\Gamma_{1}/(\Gamma_{1}+\Gamma_{2}$ |) |
|------------------------------------------|---------------|--------------------|----------|-----------|-------------------------------------|---|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | Ĺ |
| 0.641 ± 0.005 OUR FI | =' | | | | | |
| 0.640 ± 0.005 OUR AV | ERAGE | | | | | |
| 0.646 ± 0.008 | 4572 | BALTAY | 71B | HBC | K−p at rest | |
| 0.635 ± 0.007 | 6736 | DOYLE | 69 | HB C | $\pi^- p \rightarrow \Lambda K^0$ | |
| 0.643 ± 0.016 | 903 | HUMPHREY | 62 | HBC | | |
| 0.624 ± 0.030 | | CRAWFORD | 59B | нвс | $\pi^- p \rightarrow \Lambda K^0$ | |
| $\Gamma(n\pi^0)/\Gamma(N\pi)$ | | | | | $\Gamma_2/(\Gamma_1+\Gamma_2)$ |) |
| | EVTS | DO CUMENT ID | | TECN | , , | • |
| 0.359±0.005 OUR FI | Г | | | | | |
| 0.310 ± 0.028 OUR AV | | | | | | |
| 0.35 ±0.05 | | BROWN | 63 | HLBC | | |
| 0.291 ± 0.034 | 75 | CHRETIEN | 63 | HLBC | | |
| $\Gamma(n\gamma)/\Gamma_{\text{total}}$ | | | | | Г3/ | Γ |
| VALUE (units 10-3) | EVTS | DO CUMENT IE |) | TECN | COMMENT | |
| 1.75 ± 0.15 OUR FIT | | | | | | _ |
| 1.75±0.15 | 1816 | LARSON | 93 | SPEC | K−p at rest | |
| ullet $ullet$ $ullet$ We do not use | the following | g data for average | es, fits | , limits, | etc. • • • | |
| $1.78 \pm 0.24 {}^{+\; 0.14}_{-\; 0.16}$ | 287 | NOBLE | 92 | SPEC | See LARSON 93 | |
| $\Gamma(n\gamma)/\Gamma(n\pi^0)$ | | | | | Г ₃ /Г | 2 |

VALUE (units 10⁻³) EVTS DOCUMENT ID TECN COMMENT \bullet \bullet $\,\bullet$ We do not use the following data for averages, fits, limits, etc. $\,\bullet$ $\,\bullet$ 86 SPEC SPS hyperon beam $2.86 \pm 0.74 \pm 0.57$ 24 BIAGI

| $\Gamma(p\pi^-\gamma)/\Gamma(p\pi^-)$ | | | | | Γ_4/Γ_1 |
|---------------------------------------|------|--------------|-----|------|-------------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.32 ± 0.22 | 72 | BAGGETT | 72C | нвс | $\pi^-~<95~{\rm MeV}/c$ |

| | | | | | , |
|-------------------------------------------------------|-----------------|----------------------|---------|--------|----------------------------------------|
| $\Gamma(\rho e^- \overline{\nu}_e) / \Gamma(\rho \pi$ | -) | | | | Γ_5/Γ_1 |
| VALUE (units 10^{-3}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.301 ± 0.019 OUR | FIT | | | | |
| 1.301 ± 0.019 OUR | AVERAGE | | | | |
| 1.335 ± 0.056 | 7111 | BOURQUIN | 83 | SPEC | SPS hyperon beam |
| 1.313 ± 0.024 | 10k | WISE | 80 | SPEC | |
| 1.23 ± 0.11 | 544 | LINDQUIST | 77 | SPEC | $\pi^- p \rightarrow \kappa^0 \Lambda$ |
| 1.27 ± 0.07 | 1089 | KATZ | 73 | HBC | |
| 1.31 ± 0.06 | 1078 | ALTHOFF | 71 | OSPK | |
| 1.17 ± 0.13 | 86 | ⁷ CANTER | 71 | HBC | K - p at rest |
| 1.20 ± 0.12 | 143 | ⁸ MALONEY | 69 | HBC | |
| 1.17 ± 0.18 | 120 | ⁸ BAGLIN | 64 | FBC | K^- freon 1.45 GeV/ c |
| 1.23 ±0.20 | 150 | ⁸ ELY | 63 | FBC | , |
| Mo do not us | a the following | or data for average | oc fite | limite | otc |

- ullet ullet We do not use the following data for averages, fits, limits, etc. ullet ullet⁷ LINDQUIST 71 OSPK See LINDQUIST 77
 - 7 Changed by us from $\Gamma(p\,e^-\overline{
 u}_e)/\Gamma(N\,\pi)$ assuming the authors used $\Gamma(p\,\pi^-)/\Gamma_{ ext{total}}=$
 - ⁸ Changed by us from $\Gamma(pe^-\overline{\nu}_e)/\Gamma(N\pi)$ because $\Gamma(pe^-\nu)/\Gamma(p\pi^-)$ is the directly mea-

| $\Gamma(\rho\mu^-\overline{\nu}_\mu)/\Gamma(N\tau)$ | π) | | | | $\Gamma_6/(\Gamma_1+\Gamma_2)$ |
|-----------------------------------------------------|-------|--------------|-----|------|--------------------------------|
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.57±0.35 OUR FIT | | | | | |
| 1.57±0.35 OUR AV | ERAGE | | | | |
| 1.4 ± 0.5 | 14 | BAGGETT | 72B | HBC | K−p at rest |
| 2.4 ± 0.8 | 9 | CANTER | 71B | HBC | K−p at rest |
| 1.3 ± 0.7 | 3 | LIND | 64 | RVUE | |
| 1.5 ± 1.2 | 2 | RONNE | 64 | FBC | |
| | | | | | |

1 DECAY PARAMETERS

See the "Note on Baryon Decay Parameters" in the neutron Listings. Some early results have been omitted.

| α <u>-</u> . σ | <i>-</i> | | | | |
|-------------------|----------|-------------|----|-------|-----------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.642±0.013 OUR | AVERAGE | | | | |
| 0.584 ± 0.046 | 8500 | ASTBURY | 75 | SPEC | |
| 0.649 ± 0.023 | 10325 | CLELAND | 72 | OSP K | |
| 0.67 ± 0.06 | 3520 | DAUBER | 69 | HBC | From <i>E</i> decay |
| 0.645 ± 0.017 | 10130 | OVERSETH | 67 | OSP K | Λ from $π$ ⁻ p |
| 0.62 ± 0.07 | 1156 | CRONIN | 63 | CNTR | Λ from $π$ ⁻ p |

α_{\perp} FOR $\overline{\Lambda} \rightarrow \overline{D}\pi^{+}$

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|------------------------------|----------------|--------------|----|------|-------------------------------------------------|--|
| -0.71 ±0.08 OUR AV | ERAGE | · | | | | |
| $-0.755 \pm 0.083 \pm 0.063$ | \approx 8.7k | ABLIKIM | 10 | BES | $J/\psi \rightarrow \Lambda \overline{\Lambda}$ | |
| -0.63 ± 0.13 | 770 | TIXIER | 88 | DM2 | $J/\psi \rightarrow \Lambda \overline{\Lambda}$ | |

ϕ ANGLE FOR $\Lambda \rightarrow p\pi^-$

| $(tan \phi = \beta / r)$ | γ |
|--------------------------|---|
|--------------------------|---|

TECN COMMENT

| φ ANGLE I OK | $n \rightarrow p_{R}$ | | | | $(\text{call} \varphi - \rho / \gamma)$ |
|-------------------|-----------------------|-------------|----|-------|-----------------------------------------|
| VALUE (°) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| - 6.5 ± 3.5 OUR | AVERAGE | | | | |
| -7.0 ± 4.5 | 10325 | CLELAND | 72 | OSP K | Λ from $π$ ⁻ p |
| $-$ 8.0 \pm 6.0 | 10130 | OVERSETH | 67 | OSP K | Λ from $π$ ⁻ p |
| 13.0 ± 17.0 | 1156 | CRONIN | 63 | OSP K | $Λ$ from $π^-p$ |

$\alpha_0 \ / \ \alpha_- = \alpha (\varLambda \to \ n\pi^0) \ / \ \alpha (\varLambda \to \ p\pi^-)$

| 1.01 ±0.07 | OUR AVERAGE | | | | |
|-------------------|-------------|--------------------|----|-------|-----------------------------------|
| 1.000 ± 0.068 | 4760 | ⁹ OLSEN | 70 | OSP K | $\pi^+ n \rightarrow \Lambda K^+$ |
| 1.10 ± 0.27 | | CORK | 60 | CNTR | |

 $^{^9\,\}text{OLSEN}$ 70 compares proton and neutron distributions from \varLambda decay.

$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda \to p\pi^-, \overline{\Lambda} \to \overline{p}\pi^+$

Zero if CP is conserved; α_- and α_+ are the asymmetry parameters for $\varLambda \to p \pi^$ and $\overline{\Lambda} \to \, \overline{p} \pi^+$ decay. See also the Ξ^- for a similar test involving the decay chain $\Xi^- o \Lambda \pi^-$, $\Lambda o p \pi^-$ and the corresponding antiparticle chain.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|----------------|-----------------------|----------|-----------|------------------------------------------------------------|
| 0.006 ± 0.021 OUR A | /ERAGE | | | | |
| $-0.081\pm0.055\pm0.059$ | \approx 8.7k | ABLIKIM | 10 | BES | $J/\psi \rightarrow \Lambda \overline{\Lambda}$ |
| $+0.013\pm0.022$ | 96k | BARNES | 96 | CNTR | LEAR $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ |
| $+0.01 \pm 0.10$ | 770 | TIXIER | 88 | DM2 | $J/\psi \rightarrow \Lambda \overline{\Lambda}$ |
| -0.02 ± 0.14 | 10k | ¹⁰ CHAUVAT | 85 | CNTR | pp, p p ISR |
| • • • We do not use th | e following | data for averages, | fits, li | mits, etc | . • • • |
| -0.07 ± 0.09 | 4063 | BARNES | 87 | CNTR | See BARNES 96 |

 $^{^{10}}$ CHAUVAT 85 actually gives $\alpha_+(\overline{\Lambda})/\alpha_-(\Lambda)=-1.04\pm0.29$. Assumes polarization is same in $\overline{\rho}p\to \overline{\Lambda}X$ and $pp\to \Lambda X$. Tests of this assumption, based on C-invariance and fragmentation, are satisfied by the data.

g_A / g_V FOR $\Lambda \to pe^- \overline{\nu}_e$ Measurements with fewer than 500 events have been omitted. Where necessary, signs have been changed to agree with our conventions, which are given in the "Note on Baryon Decay Parameters" in the neutron Listings. The measurements all assume that the form factor $g_2=0$. See also the footnote on DWORKIN 90.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|-----------|-----------------------|----------|-----------|---------------------------------------------------------------------------------|
| -0.718±0.015 OUR A | /ERAGE | | | | |
| $-0.719\pm0.016\pm0.012$ | 37k | ¹¹ DWORKIN | 90 | SPEC | e u angular corr. |
| -0.70 ± 0.03 | 7111 | BOURQUIN | 83 | SPEC | $\Xi \rightarrow \Lambda \pi^-$ |
| -0.734 ± 0.031 | 10k | ¹² WISE | 81 | SPEC | e u angular correl. |
| • • • We do not use th | e followi | ng data for average | es, fits | , limits, | etc. • • • |
| -0.63 ± 0.06 | 817 | ALTHOFF | 73 | OSP K | Polarized / |
| 0.97, as given by the | CVC hy | pothesis and as ass | umed | by the o | $w\equiv g_W(0)/g_V(0)$ to be ther listed measurements. Hen $g_A/g_V=-0.731\pm$ |

^{10.016. 12} This experiment measures only the absolute value of g_A/g_V .

1 REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

| ABLIKIM | 10 | PR D81 012003 | M. Ablikim et al. | (BES Collab.) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------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| BARNES | 96 | PR C54 1877 | P.D. Barnes et al. | (CERN PS-185 Collab.) |
| RYBICKI | 96 | APP B27 2155 | K. Rybicki | |
| HARTOUNI | 94 | PRL 72 1322 | E.P. Hartouni et al. | (BNL E766 Collab.) |
| Also | 93 | PRL 72 2821 (erratum) | E.P. Hartouni et al. | (BNL E766 Collab.) |
| LARSON | 93 92 | PR D47 799 | K.D. Larson et al. A.J. Noble et al. | (BNL-811 Collab.) (BIRM, BOST, BRCO+) |
| NOBLE DWORKIN | 90 | PRL 69 414 PR D41 780 | J. Dworkin et al. | (MICH, WISC, RUTG+) |
| TIXIER | 88 | PL B212 523 | M.H. Tixier et al. | (DM2 Collab.) |
| BARNES | 87 | PL B199 147 | P.D. Barnes et al. | (CMU, SACL, LANL+) |
| BIAGI | 86 | ZPHY C30 201 | S.F. Biagi et al. | (BRIS, CERN, GEVA+) |
| CHAUVAT | 85 | PL 163B 273 | P. Chauvat et al. | (CERN, CLER, UCLA+) |
| BOURQUIN | 83 | ZPHY C21 1 | M.H. Bourquin et al. | (BRIS, GEVA, HEIDP+) |
| COX | 81 | PRL 46 877 | P.T. Cox et al. | (MICH, WISC, RUTG, MINN+) |
| PONDROM | 81 | PR D23 814 | L. Pondrom et al. | (WISC, MICH, RUTG+) |
| WIS E WIS E | 81 80 | PL 98B 123 PL 91B 165 | J.E. Wise et al. J.E. Wise et al. | (MASA, BNL) (MASA, BNL) |
| S CHA CHIN | 78 | PRL 41 1348 | L. Schachinger et al. | (MICH, RUTG, WISC) |
| HELLER | 77 | PL 68B 480 | K. Heller et al. | (MICH, WISC, HEIDH) |
| LINDQUIST | 77 | PR D16 2104 | J. Lindguist et al. | (EFI, OSU, ANL) |
| AÌso | | JPG 2 L211 | J. Lindquist et al. | (EFI, WUSL, OSU+) |
| ZECH | 77 | NP B124 413 | G. Zech et al. | (SIEG, CERN, DORT, HEIDH) |
| BUNCE | 76 | PRL 36 1113 | G.R.M. Bunce et al. | (WISC, MICH, RUTG) |
| ASTBURY | 75 | NP B99 30 | P. Astbury et al. | (LOIC, CERN, ETH+) |
| CLAYTON | 75 73 | NP B 95 130 PL 43B 237 | E.F. Clayton et al. | (LOIC, RHEL) |
| ALTHOFF ALTHOFF | 73 B | NP B66 29 | K.H. Althoff et al. K.H. Althoff et al. | (CERN, HEID) (CERN, HEID) |
| KATZ | 73 | Thesis MDDP-TR-74-044 | | (CERN, HEID) (UMD) |
| POULARD | 73 | PL 46B 135 | G. Poulard, A. Givernaud, | |
| BAGGETT | 72B | ZPHY 252 362 | M.J. Baggett et al. | (HEID) |
| BAGGETT | 72 C | PL 42B 379 | M.J. Baggett et al. | (HEID) |
| CLELAND | 72 | NP B40 221 | W.E. Cleland et al. | (CERN, GEVA, LUND) |
| HYMAN | 72 | PR D5 1063 | L.G. Hyman et al. | (ANL, CMU) |
| ALTHOFF | 71 71B | PL 37B 531 | K.H. Althoff et al. | (CERN, HEID) |
| BALTAY | | PR D4 670 | C. Baltay et al. | (COLU, BING) |
| BARONI | 71 | LNC 2 1256 | G Baroni S Petrera G R | omano (ROMA) |
| BARONI CANTER | 71 71 | LNC 2 1256 PRI 26 868 | G. Baroni, S. Petrera, G. R. J. Canter et al. | omano (ROMA) (STON COLU) |
| CANTER | 71 71 71B | LNC 2 1256 PRL 26 868 PRL 27 59 | G. Baroni, S. Petrera, G. R J. Canter et al. J. Canter et al. | (STON, COLU) |
| | 71 71B 71 | PRL 26 868 PRL 27 59 NC 3A 1 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) |
| CANTER CANTER DAHL-JENSEN LIND QUIST | 71 71B 71 71 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) |
| CANTER CANTER DAHL-JENSEN LIND QUIST OLSEN | 71 71B 71 71 71 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) |
| CANTER CANTER DAHL-JENSEN LIND QUIST OLSEN DAUBER | 71 71B 71 71 71 70 69 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. P.M. Dauber et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRL) |
| CANTER CANTER DAHL-JENSEN LIND QUIST OLS EN DAUBER DOYLE | 71 71B 71 71 70 69 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. P.M. Dauber et al. J.C. Doyle | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRL) (LRL) |
| CANTER CANTER DAHL-JENSEN LINDQUIST OLSEN DAUBER DOYLE MALONEY | 71 71B 71 71 70 69 69 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. P.M. Dauber et al. J.C. Doyle J.E. Maloney, B. Sechi-Zor | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRL) (LRL) (UMD) |
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| CANTER CANTER DAHL-JENSEN LINDQUIST OLSEN DAUBER DOYLE MALONEY | 71 71B 71 71 70 69 69 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. P.M. Dauber et al. J.C. Doyle J.E. Maloney, B. Sechi-Zor | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRL) (LRL) (UMD) |
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| CANTER CANTER DAHL-JENSEN LIND QUIST OLSEN DAUBER MALONEY GRIMM HEPP BADIER MAYEUR OVERSETH PDG BURAN | 71 71B 71 71 70 69 69 69 68 68 67 67 67 67 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 NC 54A 167 ZPHY 214 71 PL 25B 152 U.Libr.Brux.Bul. 32 PRL 19 391 RMP 39 1 PL 20 318 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. J. Lindquist et al. S.L. Olsen et al. P.M. Dauber et al. J.C. Doyle J.E. Maloney, B. Sechi-Zor H.J. Grimm V. Hepp, H. Schleich J. Badier et al. C. Mayeur, E. Tompa, J.H. O.E. Overseth, R.F. Roth A.H. Rosenfeld et al. T. Buran et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSL+) (WISC, MICH) (LRL) (LRL) (LRL) (HEID) (HEID) (HEID) (WICKENS (BELG, LOUC) (MICH, PRINC) (LRL, CERN, YALE) |
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| CANTER CANTER DAHL-JENSEN LINDQUIST OLSEN DAUBER DOYLE MALONEY MALONEY BADIER MAYEUR OVERSETH PDG BURAN CHIEN EN GELMANN | 71 71B 71 71 70 69 69 69 68 68 67 67 67 66 66 66 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 NC 54A 187 ZPHY 214 71 PL 25B 152 U.Libr.Brux.Bul. 32 PRL 19 391 RMP 39 1 PL 20 318 PR 152 1171 NC 45A 1038 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. E. Dahl-Jensen et al. S.L. Olsen et al. PM. Dauber et al. J.C. Doyle J.E. Maloney, B. Sechi-Zor H.J. Grimm V. Hepp, H. Schleich J. Badier et al. C. Mayeur, E. Tompa, J.H. O.E. Överseth, R.F. Roth A.H. Rosenfeld et al. C.Y. Chien et al. C.Y. Chien et al. R. Engelmann et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRC) (LRC) (LRC) (LMD) (HEID) (HEID) (HEID) (WICKENS (BELG, LOUC) (MICH, PRIN) (LRL, CERN, VALE) (YALE, BNL) (HEID, EHO) |
| CANTER CANTER DAHL-JENSEN LINDQUIST OLSEN DAUBER DOYLE MALONEY GRIMM HEPP BADIER MAYEUR OVERSETH PDG BURAN CHIEN EN GELMANN GIBSON | 71 71B 71 71 70 69 69 68 68 67 67 67 66 66 66 66 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 NC 54A 187 ZPHY 214 71 PL 25B 152 UL libr.Brux.Bul. 32 PRL 19 391 PRL 93 18 PR P 39 1 PL 20 318 PR P 39 1 PC 45A 1038 NC 45A 882 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. S.L. Olsen et al. S.L. Olsen et al. S.L. Olsen et al. J.C. Doyle J.E. M. Janney, B. Sechi-Zor H.J. Grimm V. Hepp, H. Schleich J. Badier et al. C. Mayeur, E. Tompa, J. H. O.E. Overseth, R.F. Roth A.H. Rosenfeld et al. T. Buran et al. V. Chen et al. R. Engelmann et al. R. Engelmann et al. W.M. Gibson, K. Green | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU) (WISC, MICH) (LRL) (LRL) (HEID) (HEID) (HEID) (WICKENS (BELG, LOUC, WICK, PRIN) (LRL, CERN, YALE) (OSLO) (YALE, BNL) (HEID, REHO) (BRIS) |
| CANTER CANTER DAHL-JENSEN LINDQUIST OLSEN DAUBER DOYLE MALONEY MALONEY BADIER MAYEUR OVERSETH PDG BURAN CHIEN EN GELMANN | 71 71B 71 71 70 69 69 69 68 68 67 67 67 66 66 66 | PRL 26 868 PRL 27 59 NC 3A 1 PRL 27 612 PRL 24 843 PR 179 1262 Thesis UCRL 18139 PRL 23 425 NC 54A 187 ZPHY 214 71 PL 25B 152 U.Libr.Brux.Bul. 32 PRL 19 391 RMP 39 1 PL 20 318 PR 152 1171 NC 45A 1038 | J. Canter et al. J. Canter et al. E. Dahl-Jensen et al. E. Dahl-Jensen et al. S.L. Olsen et al. PM. Dauber et al. J.C. Doyle J.E. Maloney, B. Sechi-Zor H.J. Grimm V. Hepp, H. Schleich J. Badier et al. C. Mayeur, E. Tompa, J.H. O.E. Överseth, R.F. Roth A.H. Rosenfeld et al. C.Y. Chien et al. C.Y. Chien et al. R. Engelmann et al. | (STON, COLU) (STON, COLU) (CERN, ANKA, LAUS+) (EFI, WUSL, OSU+) (WISC, MICH) (LRC) (LRC) (LRC) (LMD) (HEID) (HEID) (HEID) (WICKENS (BELG, LOUC) (MICH, PRIN) (LRL, CERN, VALE) (YALE, BNL) (HEID, EHO) |
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Λ , Λ 's and Σ 's

Λ AND Σ RESONANCES

Introduction: Since our last edition, there have been a few measurements of properties of the lowest Λ and Σ resonances—mostly of masses and widths. But the field remains at a stand-still. What follows is a much abbreviated version of the note on Λ and Σ Resonances from our 1990 edition [1]. In particular, see that edition for some representative Argand plots from partial-wave analyses.

Table 1 is an attempt to evaluate the status, both overall and channel by channel, of each Λ and Σ resonance in the Particle Listings. The evaluations are of course partly subjective. A blank indicates there is no evidence at all: either the relevant couplings are small or the resonance does not really exist. The main Baryon Summary Table includes only the established resonances (overall status 3 or 4 stars). A number of the 1- and 2-star entries may eventually disappear, but there are certainly many resonances yet to be discovered underlying the established ones.

Sign conventions for resonance couplings: In terms of the isospin-0 and -1 elastic scattering amplitudes A_0 and A_1 , the amplitude for $K^-p \to \overline{K}^0n$ scattering is $\pm (A_1 - A_0)/2$, where the sign depends on conventions used in conjunction with the Clebsch-Gordan coefficients (such as, is the baryon or the meson the "first" particle). If this reaction is partial-wave analyzed and if the overall phase is chosen so that, say, the $\Sigma(1775)D_{15}$ amplitude at resonance points along the positive imaginary axis (points "up"), then any Σ at resonance will point "up" and any Λ at resonance will point "down" (along the negative imaginary axis). Thus the phase at resonance determines the isospin. The above ignores background amplitudes in the resonating partial waves.

That is the basic idea. In a similar but somewhat more complicated way, the phases of the $\overline{K}N \to \Lambda\pi$ and $\overline{K}N \to \Sigma\pi$ amplitudes for a resonating wave help determine the SU(3) multiplet to which the resonance belongs. Again, a convention has to be adopted for some overall arbitrary phases: which way is "up"? Our convention is that of Levi-Setti [2] and is shown in Fig. 1, which also compares experimental results with theoretical predictions for the signs of several resonances. In the Listings, a + or – sign in front of a measurement of an inelastic resonance coupling indicates the sign (the *absence* of a sign means that the sign is not determined, *not* that it is positive). For more details, see Appendix II of our 1982 edition [3].

Errors on masses and widths: The errors quoted on resonance parameters from partial-wave analyses are often only statistical, and the parameters can change by more than these errors when a different parametrization of the waves is used.

Furthermore, the different analyses use more or less the same data, so it is not really appropriate to treat the different determinations of the resonance parameters as independent or to average them together. In any case, the spread of the masses, widths, and branching fractions from the different analyses is certainly a better indication of the uncertainties than are the quoted errors. In the Baryon Summary Table, we usually give a range reflecting the spread of the values rather than a particular value with error.

For three states, the $\Lambda(1520)$, the $\Lambda(1820)$, and the $\Sigma(1775)$, there is enough information to make an overall fit to the various branching fractions. It is then necessary to use the quoted errors, but the errors obtained from the fit should not be taken seriously.

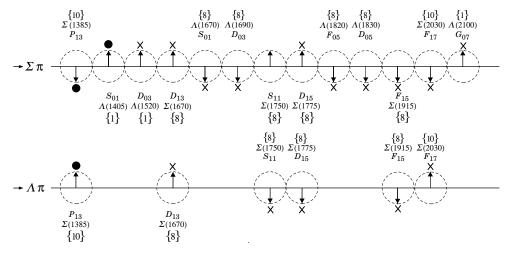


Figure 1. The signs of the imaginary parts of resonating amplitudes in the $\overline{K}N \to \Lambda\pi$ and $\Sigma\pi$ channels. The signs of the $\Sigma(1385)$ and $\Lambda(1405)$, marked with a \bullet , are set by convention, and then the others are determined relative to them. The signs required by the SU(3) assignments of the resonances are shown with an arrow, and the experimentally determined signs are shown with an \times .

Table 1. The status of the Λ and Σ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

| | | | | Status | s as seen | in — |
|-----------------|-------|-------------------|-----------------|--------------|--------------|----------------------------------------|
| Particle | J^P | Overall status | $N\overline{K}$ | $\Lambda\pi$ | $\Sigma \pi$ | Other channels |
| $\Lambda(1116)$ | 1/2+ | **** | | F | | $N\pi$ (weakly) |
| $\Lambda(1405)$ | 1/2- | **** | **** | O | **** | |
| $\Lambda(1520)$ | 3/2- | **** | **** | r | **** | $\Lambda\pi\pi, \Lambda\gamma$ |
| $\Lambda(1600)$ | 1/2 + | *** | *** | b | ** | |
| $\Lambda(1670)$ | 1/2- | **** | **** | i | **** | $\Lambda \eta$ |
| $\Lambda(1690)$ | 3/2- | **** | **** | d | **** | $\Lambda \pi \pi, \Sigma \pi \pi$ |
| $\Lambda(1800)$ | 1/2- | *** | *** | d | ** | $N\overline{K}^*, \Sigma(1385)\pi$ |
| $\Lambda(1810)$ | 1/2 + | *** | *** | e | ** | $N\overline{K}^*$ |
| $\Lambda(1820)$ | 5/2+ | **** | **** | n | **** | $\Sigma(1385)\pi$ |
| $\Lambda(1830)$ | 5/2- | **** | *** | F | **** | $\Sigma(1385)\pi$ |
| $\Lambda(1890)$ | 3/2+ | **** | **** | 0 | ** | $N\overline{K}^*, \Sigma(1385)\pi$ |
| $\Lambda(2000)$ | , . | * | | r | * | $\Lambda \omega, N \overline{K}^*$ |
| $\Lambda(2020)$ | 7/2 + | * | * | b | * | , |
| $\Lambda(2100)$ | 7/2- | **** | **** | i | *** | $\Lambda \omega, N \overline{K}^*$ |
| $\Lambda(2110)$ | 5/2+ | *** | ** | d | * | $\Lambda \omega, N\overline{K}^*$ |
| $\Lambda(2325)$ | 3/2- | * | * | d | | $\Lambda \omega$ |
| $\Lambda(2350)$ | , | *** | *** | e | * | |
| $\Lambda(2585)$ | | ** | ** | n | | |
| $\Sigma(1193)$ | 1/2+ | **** | | | | $N\pi$ (weakly) |
| $\Sigma(1385)$ | 3/2+ | **** | | **** | **** | 3) |
| $\Sigma(1480)$ | , . | * | * | * | * | |
| $\Sigma(1560)$ | | ** | | ** | ** | |
| $\Sigma(1580)$ | 3/2 - | * | * | * | | |
| $\Sigma(1620)$ | 1/2- | ** | ** | * | * | |
| $\Sigma(1660)$ | 1/2 + | *** | *** | * | ** | |
| $\Sigma(1670)$ | 3/2- | **** | **** | **** | **** | several others |
| $\Sigma(1690)$ | | ** | * | ** | * | $\Lambda \pi \pi$ |
| $\Sigma(1750)$ | 1/2- | *** | *** | ** | * | $\Sigma \eta$ |
| $\Sigma(1770)$ | 1/2 + | * | | | | |
| $\Sigma(1775)$ | 5/2- | **** | **** | **** | *** | several others |
| $\Sigma(1840)$ | 3/2 + | * | * | ** | * | |
| $\Sigma(1880)$ | 1/2 + | ** | ** | ** | | $N\overline{K}^*$ |
| $\Sigma(1915)$ | 5/2 + | **** | *** | **** | *** | $\Sigma(1385)\pi$ |
| $\Sigma(1940)$ | 3/2- | *** | * | *** | ** | quasi-2-body |
| $\Sigma(2000)$ | 1/2- | * | | * | | $N\overline{K}^*$, $\Lambda(1520)\pi$ |
| $\Sigma(2030)$ | 7/2 + | **** | **** | **** | ** | several others |
| $\Sigma(2070)$ | 5/2 + | * | * | | * | |
| $\Sigma(2080)$ | 3/2 + | ** | | ** | | |
| $\Sigma(2100)$ | 7/2- | * | | * | * | |
| $\Sigma(2250)$ | | *** | *** | * | * | |
| $\Sigma(2455)$ | | ** | * | | | |
| $\Sigma(2620)$ | | ** | * | | | |
| $\Sigma(3000)$ | | * | * | * | | |
| $\Sigma(3170)$ | | * | | | | multi-body |

**** Existence is certain, and properties are at least fairly well explored.

Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined.

Production experiments: Partial-wave analyses of course separate partial waves, whereas a peak in a cross section or an invariant mass distribution usually cannot be disentangled from background and analyzed for its quantum numbers; and more than one resonance may be contributing to the peak. Results from partial-wave analyses and from production experiments are generally kept separate in the Listings, and in the Baryon Summary Table results from production experiments are used only for the low-mass states. The $\Sigma(1385)$ and $\Lambda(1405)$ of course lie below the $\overline{K}N$ threshold and nearly everything about them is learned from production experiments; and production and formation experiments agree quite well in the case

of $\Lambda(1520)$ and results have been combined. There is some disagreement between production and formation experiments in the 1600–1700 MeV region: see the note on the $\Sigma(1670)$.

References

- 1. Particle Data Group, Phys. Lett. **B239**, VIII.64 (1990).
- 2. R. Levi-Setti, in *Proceedings of the Lund International Conference on Elementary Particles* (Lund, 1969), p. 339.
- Particle Data Group, Phys. Lett. 111B (1982).

 $\Lambda(1405)~1/2^-$

$$I(J^P) = O(\frac{1}{2})$$
 Status: ***

The nature of the $\Lambda(1405)$ has been a puzzle for decades: three-quark state or hybrid; two poles or one. We cannot here survey the rather extensive literature. See, for example, CIEPLY 10, KISSLINGER 11, and SEKIHARA 11, for discussions and earlier references

It seems to be the universal opinion of the chiral-unitary community that there are two poles in the 1400-MeV region. ZYCHOR 08 presents experimental evidence against the two-pole model, but this is disputed by GENG 07A. See also REVAI 09, which finds little basis for choosing between one- and two-pole models.

A single, ordinary three-quark $\Lambda(1405)$ fits nicely into a $J^P=1/2^-$ SU(4) $\overline{4}$ multiplet, whose other members are the $\Lambda_C(2595)^+$, $\Xi_C(2790)^+$, and $\Xi_C(2790)^0$; see Fig. 1 of our note on "Charmed Baryons."

Λ(1405) MASS

TECN COMMENT

| PRODUCTIO | N EXPE | KIMEN IS |
|-------------|--------|-------------|
| VALUE (MeV) | EVTS | DOCUMENT ID |
| | | |

| VALUE | iev j | LVIJ | DOCUMENT ID | | I L CIV | COMINENT |
|-------------|-----------------------|------------|------------------------|-------|-------------|-----------------------------------------------------------------------------------|
| 1405. | 1 + 1.3 OU | JR AVER | AGE | | | |
| 1405 | $^{+}$ 1.4 $^{-}$ 1.0 | | ESMAILI | 10 | RVUE | 4 He $ {\it K}^- ightarrow {\it \Sigma}^{\pm} \pi^{\mp} {\it X} $ at rest |
| 1406. | 5 ± 4.0 | | ¹ DALITZ | 91 | | M-matrix fit |
| • • • V | Ve do not ι | ise the fo | llowing data for a | verag | es, fits, l | imits, etc. • • • |
| 1391 | ± 1 | 700 | ¹ HEMINGWAY | 85 | нвс | K [−] p 4.2 GeV/c |
| ~ 1405 | | 400 | ² THOMAS | 73 | HBC | $\pi^- p \ 1.69 \ \text{GeV}/c$ |
| 1405 | | 120 | BARBARO | 68B | DBC | K-d 2.1-2.7 GeV/c |
| 1400 | ± 5 | 67 | BIRMINGHAM | 66 | HBC | K^-p 3.5 GeV/ c |
| 1382 | ± 8 | | ENGLER | 65 | HDBC | $\pi^- p$, $\pi^+ d$ 1.68 GeV/c |
| 1400 | ± 24 | | MUSGRAVE | 65 | HBC | <u>p</u> p 3−4 GeV/c |
| 1410 | | | ALEXANDER | 62 | HBC | $\pi^- p$ 2.1 GeV/ c |
| 1405 | | | ALSTON | 62 | HBC | K [−] p 1.2-0.5 GeV/c |
| 1405 | | | ALSTON | 61 B | HBC | K [−] p 1.15 GeV/c |

EXTRAPOLATIONS BELOW $N\overline{K}$ THRESHOLD

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|---------------------|-----------|-----------|-----------------------|
| • • • We do not use the followin | g data for averag | es, fits, | limits, e | etc. • • • |
| 1407.56 or 1407.50 | ³ KIMURA | 00 | | potential model |
| 1411 | 4 MARTIN | 81 | | K-matrix fit |
| 1406 | ⁵ CHAO | 73 | DPWA | 0-range fit (sol. B) |
| 1421 | MARTIN | 70 | RVUE | Constant K-matrix |
| 1416 ±4 | MARTIN | 69 | HBC | Constant K-matrix |
| 1403 ±3 | KIM | 67 | HBC | K-matrix fit |
| 1407.5 ± 1.2 | 6 KITTEL | 66 | HBC | 0-effective-range fit |
| 1410.7 ± 1.0 | KIM | 65 | HBC | 0-effective-range fit |
| 1409.6 ± 1.7 | ⁶ SAKITT | 65 | HBC | 0-effective-range fit |

Λ(1405) WIDTH

PRODUCTION EXPERIMENTS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------|------------|------------------------|-------|-----------|----------------------------------------------------------------------------|
| 50± 2 | | ¹ DALITZ | 91 | | M-matrix fit |
| • • • We do n | ot use the | following data for a | verag | es, fits, | limits, etc. • • • |
| 24 + 4 | | ESMAILI | 10 | RVUE | 4 He $ {\it K}^- ightarrow \Sigma^{\pm} \pi^{\mp} {\it X} $ at rest |
| $32\pm~1$ | 700 | ¹ HEMINGWAY | 85 | нвс | K-p 4.2 GeV/c |
| 45 to 55 | 400 | ² THOMAS | 73 | HBC | $\pi^- p \ 1.69 \ \text{GeV}/c$ |
| 35 | 120 | BARBARO | 68B | DBC | K - d 2.1-2.7 GeV/c |
| 50 ± 10 | 67 | BIRMINGHAM | 66 | HBC | K = p 3.5 GeV/ c |
| 89 ± 20 | | ENGLER | 65 | HDBC | |
| 60 ± 20 | | MUSGRAVE | 65 | HBC | |
| 35 ± 5 | | ALEXANDER | 62 | HBC | |
| 50 | | ALSTON | 62 | HBC | |
| 20 | | ALSTON | 61B | HBC | |

^{**} Evidence of existence is only fair.

^{*} Evidence of existence is poor.

Λ(1405), Λ(1520)

| VALUE (MeV) | DOCUMENT IE | oc fito | limite . | + | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|--------------------------|-----------------------------|-------------------------------------------------|----------------------------------|
| | e following data for averag | | , iimits, e | | |
| 50.24 or 50.26 | 3 KIMURA | 00 | | potential model | |
| 30 | ⁴ MARTIN ^{5,7} CHAO | 81 | D.D.M.M | K-matrix fit | , |
| 55 20 | | 73 | | 0-range fit (sol. B | |
| 20 29 ±6 | MARTIN MARTIN | 70 69 | RVUE HBC | Constant K-matrix | |
| 29 ±0 50 ±5 | KIM | 67 | НВС | K-matrix fit | |
| 34.1±4.1 | 6 KITTEL | 66 | HBC | IX-III attix iit | |
| 37.0±3.2 | KIM | 65 | НВС | | |
| 28.2±4.1 | 6 SAKITT | 65 | нвс | | |
| | Λ(1405) DECAY | MOD | ES | | |
| Mode | | Fract | ion (Γ_j/Γ_j) | -) | |
| $\Gamma_1 = \Sigma \pi$ | | 100 % | 6 | | |
| | | | | | |
| $\Gamma_3 \Sigma_{\underline{0}} \gamma$ | Λ(1405) PARTIAL | W D | THS | | |
| $\Gamma_3^{\overline{3}} \qquad \Sigma^{\dot{0}} \gamma \ \Gamma_4 \qquad N \overline{K}$ | Λ(1405) PARTIAL | W ID | THS | | Г, |
| $\Gamma_3 \qquad \Sigma^0 \gamma \ \Gamma_4 \qquad N K$ | ` ' | | | N/T | Γ |
| $\Gamma_3^{}$ $\Sigma^0 \gamma$ $\Gamma_4^{}$ $N\overline{K}^{}$ $\Gamma(A\gamma)_{VALUE(keV)}$ | <u>DOCUMENT IE</u> |) | COMME | | Γ |
| $ \begin{array}{cccc} \Gamma_3 & \Sigma^0 \gamma \\ \Gamma_4 & N \overline{K} \end{array} $ $ \Gamma(\Lambda \gamma)$ VALUE (keV) • • • We do not use th | <u>DOCUMENT IC</u> e following data for averag | es, fits | <u>COMME</u> , limits, e | etc. • • • | Γ |
| $ \begin{array}{cccc} \Gamma_3 & \Sigma^0 \gamma \\ \Gamma_4 & N \overline{K} \end{array} $ $ \Gamma(\Lambda \gamma)$ VALUE (keV) • • • We do not use th | <u>DOCUMENT IE</u> | es, fits | <u>COMME</u> , limits, e | | Γ2 |
| $ \begin{array}{ccc} \Gamma_3 & \Sigma^0 \gamma \\ \Gamma_4 & N K \end{array} $ $ \Gamma(\Lambda \gamma)$ $ \stackrel{\text{VALUE (keV)}}{\bullet \bullet \bullet} \text{ We do not use th} $ $ 27 \pm 8 $ | <u>DOCUMENT IC</u> e following data for averag | es, fits | <u>COMME</u> , limits, e | etc. • • • | |
| Γ_3 $\Sigma^0 \gamma$ Γ_4 NK $\Gamma(A\gamma)$ $VALUE (keV)$ • • • We do not use th 27 ± 8 $\Gamma(\Sigma^0 \gamma)$ | <u>DOCUMENT IE</u> e following data for averag BURKHARD | es, fits T 91 | COMME, limits, e | etc. • • • nodel fit | |
| $ \begin{array}{ccc} \Gamma_{3} & \Sigma^{0} \gamma \\ \Gamma_{4} & N \overline{K} \end{array} $ $ \Gamma(\Lambda \gamma)$ $ \stackrel{VALUE (keV)}{\bullet} \bullet \bullet We do not use th 27 \pm 8 $ $ \Gamma(\Sigma^{0} \gamma)$ $VALUE (keV)$ | <u>DOCUMENT IE</u> e following data for averag BURKHARD <u>DOCUMENT IE</u> | es, fits T 91 | COMME, limits, e | etc. • • • nodel fit | |
| $ \Gamma_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \gamma \Gamma_{\mathbf{A}} \qquad \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{$ | DOCUMENT IE e following data for average BURKHARD DOCUMENT IE | ges, fits T 91 | COMME. Isobar r COMME. | etc. • • • model fit VT etc. • • • | |
| $ \Gamma_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \gamma \Gamma_{\mathbf{A}} \qquad \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{$ | <u>DOCUMENT IE</u> e following data for averag BURKHARD <u>DOCUMENT IE</u> | ges, fits T 91 | COMME. Isobar r COMME. | etc. • • • nodel fit | |
| $ \Gamma_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \gamma \Gamma_{\mathbf{A}} \qquad \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{\mathbf{A}} \sum_{$ | DOCUMENT IE e following data for average BURKHARD DOCUMENT IE | ges, fits T 91 ges, fits | COMME, limits, of lsobar r | etc. • • • model fit VT etc. • • • | |
| $ \Gamma_{3} \sum_{\Gamma} \stackrel{\circ}{D}_{\gamma} \\ \Gamma_{4} N K $ $ \Gamma(A\gamma) $ • • • We do not use th $ 27 \pm 8 $ $ \Gamma(\Sigma^{0}\gamma) $ VALUE (keV) | DOCUMENT IC e following data for average BURKHARD DOCUMENT IC e following data for average BURKHARD | ges, fits T 91 ges, fits | COMME, limits, of lsobar r | etc. • • • model fit VT etc. • • • model fit | Γ ₂ Γ ₃ |

Λ(1405) FOOTNOTES

HEMINGWAY 85 HBC K^-p 4.2 GeV/c

95

<3

- 1 DALITZ 91 fits the HEMINGWAY 85 data. 2 THOMAS 73 data is fit by CHAO 73 (see next section). 3 The KIMURA $\underline{00}$ values are from fits A and B from a coupled-channel potential model using low-energy \overline{K} N and $\Sigma\pi$ data, kaonic-hydrogen x-ray measurements, and our $\Lambda(1405)$ mass and width. The results bear mainly on the *nature* of the $\Lambda(1405)$: three-quark state 4 The MARTIN 81 fit includes the $K^{\pm}p$ forward scattering amplitudes and the dispersion
- relations they must satisfy.
- ⁵ See also the accompanying paper of THOMAS 73.
- 6 Data of SAKITT 65 are used in the fit by KITTEL 66.
- $^7\,\text{An}$ asymmetric shape, with $\Gamma/2=41\,$ MeV below resonance, 14 MeV above.

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| MARTIN | 70 | NP B16 479 | A.D. Martin, G.G. Ross | (ĎURH) |
| MARTIN | 69 | PR 183 1352 | B.R. Martin, M. Sakitt | (LOUČ, BNL) |
| A Iso | | PR 183 1345 | B.R. Martin, M. Sakitt | (LOUC, BNL) |
| BARBARO | 68 B | PRL 21 573 | A. Barbaro-Galtieri et al. | `(LRL, SLAC) |
| KIM | 67 | PRL 19 1074 | J.K. Kim | ` (YALE) |
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| ENGLER | 65 | PRL 15 224 | A. Engler et al. | (CMU, BNL)IJ |
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| | | | | |

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| BARRETT | 89 | NC 102A 179 | R.C. Barrett | (SURR) |
| BATTY | 89 | NC 102A 255 | C.J. Batty, A. Gal | (RAL, HEBR) |
| CAPSTICK | 89 | Excited Baryons 88, p.32 | S. Capstick | (GUEL) |
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| WORKMAN | 88 | PR D37 3117 | R.L. Workman, H.W. Fearing | (TRIU) |
| SCHNICK | 87 | PRL 58 1719 | J. Schnick, R.H. Landau | (ORST) |
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| KIANG | 84 | PR C30 1638 | D. Kiang et al. | (DALH, MCMS) |
| MILLER | 84 | Conference paper | D. Klang et ar. D.J. Miller | (LOUC) |
| | | ns between Particle and Ni | | (1000) |
| VANDIJK | 84 | PR D30 937 | W. van Dijk | (MCMS) |
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| Heidelberg | | | K.H. Dalitz et al. | (OXFIF) |
| DALITZ | 81 | Kaon Conf. | R.H. Dalitz, J.G. McGinley | (OXFTP) |
| | | diate Energy Kaon-Nucleon | | (OXFIF) |
| MARTIN | 81B | Kaon Conf. | A.D. Martin | (DURH) |
| | | diate Energy Kaon-Nucelon | | (DOKH) |
| OADES | 77 | NC 42A 462 | G.C. Oades, G. Rasche | (AARH, ZURI) |
| SHAW | 73 | Purdue Conf. 417 | G.L. Shaw | (MAKH, ZUKI) (UCI) |
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| ABRAMS | 65 | PR 139 B454 | G.S. Abrams, B. Sechi-Zorn | (UMD) |
| | | | | |

 $\Lambda(1520) \ 3/2$

$$I(J^P) = O(\frac{3}{2})$$
 Status: ***

Discovered by FERRO-LUZZI 62; the elaboration in WATSON 63 is the classic paper on the Breit-Wigner analysis of a multichannel

The measurements of the mass, width, and elasticity published before 1975 are now obsolete and have been omitted. They were last listed in our 1982 edition Physics Letters 111B 1 (1982).

Production and formation experiments agree quite well, so they are $% \left(1\right) =\left(1\right) \left(1\right)$ listed together here.

Λ(1520) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
|------------------------|--------------|-------------|-----|------|-------------------------------------------|-----|
| 1519.5 ±1.0 | OUR ESTIMATE | | | | | |
| 1519.53±0.19 | OUR AVERAGE | | | | | |
| 1520.4 \pm 0.6 \pm | ±1.5 1 | QIANG | 10 | SPEC | $ep \rightarrow e'K^+X$ (fit to X) | |
| 1517.3 ± 1.5 | 300 | BARBER | 80D | SPEC | $\gamma p \rightarrow \Lambda(1520) K^+$ | |
| 1517.8 ± 1.2 | 5k | BARLAG | 79 | | K−p 4.2 GeV/c | |
| 1520.0 ± 0.5 | | ALSTON | 78 | DPWA | $\overline{K}N \rightarrow \overline{K}N$ | |
| 1519.7 ± 0.3 | 4k | CAMERON | 77 | HBC | K [−] p 0.96–1.36 GeV/c | |
| 1519 ± 1 | | GOPAL | 77 | DPWA | K N multichannel | |
| 1519.4 ± 0.3 | 2000 | CORDEN | 75 | DBC | K [−] d 1.4–1.8 GeV/c | |
| 4 | | | | | | - 1 |

 $^{1}\,\mathrm{QIANG}$ 10 gets 1518.8 MeV for the pole mass (no errors given).

Λ(1520) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
|------------------------|----------|---------------------|--------|-----------|---------------------------------------------|---|
| 15.6 ±1.0 OUR E | ESTIMATE | | | | | |
| 15.64 ± 0.29 OUR A | AVERAGE | | e fact | or of 1.1 | • | |
| $18.6 \pm 1.9 \pm 1.0$ | | ² QIANG | 10 | SPEC | $ep \rightarrow e'K^+X$ (fit to X) | I |
| 16.3 ± 3.3 | 300 | BARBER | 80D | SPEC | $\gamma p \rightarrow \Lambda(1520) K^+$ | |
| 16 ± 1 | | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 14 ±3 | 677 | ³ BARLAG | 79 | | K [−] p 4.2 GeV/c | |
| 15.4 ± 0.5 | | ALSTON | 78 | DPWA | $\overline{K}N \rightarrow \overline{K}N$ | |
| 16.3 ± 0.5 | 4k | CAMERON | 77 | HBC | K−p 0.96–1.36 GeV/c | |
| 15.0 ± 0.5 | | GOPAL | 77 | DPWA | K N multichannel | |
| 15.5 ± 1.6 | 2000 | CORDEN | 75 | DBC | $K^- d 1.4-1.8 \text{ GeV}/c$ | |
| | | | | | | |

 $^2_{\mbox{\scriptsize QIANG}}$ 10 gets 17.2 MeV for the pole width (no errors given).

 $^3\,\mathrm{From}$ the best-resolution sample of $\varLambda\,\pi\,\pi$ events only

A(1520) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 45 ± 1% |
| Γ_2 | $\Sigma \pi$ | 42 ± 1% |
| Γ_3 | $\Lambda \pi \pi$ | $10 \pm 1\%$ |
| Γ_4 | Σ (1385) π | |
| Γ_5 | $\Sigma(1385)\pi(\rightarrow \Lambda\pi\pi)$ | |
| Γ_6 | $\Lambda(\pi\pi)_{S-\text{wave}}$ | |
| Γ_7 | $\Sigma \pi \pi$ | $0.9\pm0.1\%$ |
| Γ ₈ | $\Lambda\gamma$ | $0.85\pm0.15\%$ |
| Γ9 | $\Sigma^0 \gamma$ | |

CONSTRAINED FIT INFORMATION

An overall fit to 9 branching ratios uses 26 measurements and one constraint to determine 6 parameters. The overall fit has a $\chi^2=17.6$ for 21 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.

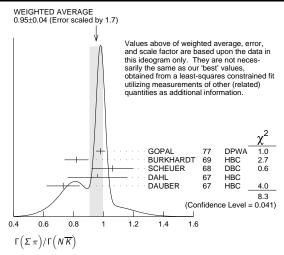
A(1520) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ | | | | |
|-------------------------------------------------------------------------------------------|-------------------|---------|-----------|-------------------------------------------|--|--|--|--|
| VALUE | DOCUMENT ID | | TECN | COMMENT | | | | |
| 0.45 ±0.01 OUR ESTIMATE | | | | | | | | |
| 0.447±0.007 OUR FIT Error inclu | des scale factor | of 1.2 | 2. | | | | | |
| 0.455 ± 0.011 OUR AVERAGE | | | | | | | | |
| 0.47 ±0.02 | GOPAL | 80 | | $\overline{K}N \rightarrow \overline{K}N$ | | | | |
| 0.45 ±0.03 | ALSTON | | | $\overline{K}N \to \overline{K}N$ | | | | |
| 0.448±0.014 | CORDEN | | | K-d 1.4-1.8 GeV/c | | | | |
| • • We do not use the following data for averages, fits, limits, etc. | | | | | | | | |
| 0.47 ± 0.01 | GOPAL | 77 | | See GOPAL 80 | | | | |
| 0.42 | MAST | 76 | нвс | $K^- \rho \rightarrow \overline{K}^0 n$ | | | | |
| $\Gamma(\Sigma\pi)/\Gamma_{total}$ | | | | Γ ₂ /Γ | | | | |
| VALUE | DO CUMENT ID | | TECN | | | | | |
| 0.42 ±0.01 OUR ESTIMATE | DO COMENT ID | | TECH | COMMENT | | | | |
| 0.420 ± 0.007 OUR FIT Error inclu | des scale factor | of 1.2 | 2. | | | | | |
| 0.423±0.011 OUR AVERAGE | | | | | | | | |
| 0.426 ± 0.014 | CORDEN | 75 | DBC | K-d 1.4-1.8 GeV/c | | | | |
| 0.418 ± 0.017 | BARBARO | 69B | нвс | K-p 0.28-0.45 GeV/c | | | | |
| ullet $ullet$ We do not use the following of | data for averages | s, fits | , limits, | etc. • • • | | | | |
| 0.46 | KIM | 71 | DPWA | K-matrix analysis | | | | |
| $\Gamma(\Sigma\pi)/\Gamma(N\overline{K})$ | | | | Γ_2/Γ_1 | | | | |
| VALUE | DO CUMENT ID | | TECN | -, - | | | | |
| 0.940±0.026 OUR FIT Error inclu | | | | COMMENT | | | | |
| 0.95 ±0.04 OUR AVERAGE Erro | or includes scale | facto | r of 1.7. | See the ideogram below. | | | | |
| 0.98 ±0.03 | GOPAL | 77 | DPWA | K N multichannel | | | | |
| 0.82 ±0.08 | BURKHARDT | 69 | нвс | K^-p 0.8-1.2 GeV/c | | | | |
| 1.06 ± 0.14 | SCHEUER | 68 | DBC | K [−] N 3 GeV/c | | | | |
| 0.96 ± 0.20 | DAHL | 67 | | $\pi^- p \ 1.6-4 \ \text{GeV}/c$ | | | | |
| 0.73 ± 0.11 | DAUBER | 67 | нвс | K-p 2 GeV/c | | | | |
| ullet $ullet$ We do not use the following of | data for averages | s, fits | , limits, | etc. • • • | | | | |
| 1.06 ±0.12 | BERTHON | 74 | нвс | Quasi-2-body σ | | | | |
| | | | | . , . | | | | |

MUSGRAVE 65 HBC

 $^4\,\text{The}~\overline{\textit{K}}\,\textit{N}\rightarrow~\Sigma\,\pi$ amplitude at resonance is $+\,0.46\,\pm\,0.01.$



| $\Gamma(\Lambda\pi\pi)/\Gamma_{\rm total}$ | | | | Γ ₃ /Γ |
|---------------------------------------------------------------|----------------------|----------|-----------|------------------------------------|
| VALUE | DO CUMENT ID | I | TECN | COMMENT |
| 0.10 ±0.01 OUR ESTIMATE | | | | |
| 0.095 ± 0.005 OUR FIT Error | includes scale facto | r of 1.2 | 2. | |
| 0.096±0.008 OUR AVERAGE | Error includes scal | e facto | r of 1.6. | |
| 0.091 ± 0.006 | CORDEN | 75 | DBC | K-d 1.4-1.8 GeV/c |
| 0.11 ±0.01 | ⁵ MAST | 73B | IPWA | $K^-p \rightarrow \Lambda \pi \pi$ |
| 5 Assumes $\Gamma(N\overline{K})/\Gamma_{	ext{total}} =$ | 0.46 ± 0.02 . | | | |
| $\Gamma(\Lambda\pi\pi)/\Gamma(N\overline{K})$ | | | | Γ_3/Γ_1 |

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|---------|-----------|----------------------------------|
| 0.213±0.012 OUR FIT Error incl | udes scale factor | of 1.2 | | |
| 0.202±0.021 OUR AVERAGE | | | | |
| 0.22 ± 0.03 | BURKHARDT | 69 | HBC | K - p 0.8-1.2 GeV/c |
| 0.19 ±0.04 | SCHEUER | 68 | DBC | $K^- N 3 \text{ GeV}/c$ |
| 0.17 ±0.05 | DAHL | 67 | HBC | $\pi^- p \ 1.6-4 \ \text{GeV}/c$ |
| 0.21 ±0.18 | DAUBER | 67 | HBC | K [−] p 2 GeV/c |
| • • • We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 0.27 ±0.13 | BERTHON | 74 | нвс | Quasi-2-body σ |
| 0.2 | KIM | 71 | DPWA | K-matrix analysis |

| $\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi\pi)$ | | | | | Γ_2/Γ_3 |
|----------------------------------------------|---------------------|---------|------|--------------------------|---------------------|
| VALUE | DO CUMENT I | D | TECN | COMMENT | · |
| 4.42±0.25 OUR FIT Error in | cludes scale factor | of 1.2. | | · | |
| 3.9 ±0.6 OUR AVERAGE | | | | | |
| 3.9 ±1.0 | UHLIG | 67 | HBC | K = p 0.9-1.0 | GeV/c |
| 3.3 ±1.1 | BIR MI NGH A | M 66 | HBC | K [−] p 3.5 Ge\ | //c |
| 4.5 ±1.0 | ARMENTER | OS65 c | нвс | | |
| $\Gamma(\Sigma(1385)\pi)/\Gamma_{\rm total}$ | | | | | Γ4/Γ |
| VALUE | DO CUMENT I | D | TECN | COMMENT | |
| 0.041 0.005 | CHAN | | LIDG | | |

| 0.041 ± 0.005 | CHAN | 72 | нвс | $K^-p \rightarrow \Lambda$ | $\pi\pi$ |
|--------------------------------------------------------------|---------------------------|---------|-----------|----------------------------|-----------------------|
| $\Gamma(\Sigma(1385)\pi(\rightarrow \Lambda\pi\pi))/\Gamma($ | [/1ππ] | | | | Γ_5/Γ_3 |
| The $\Lambda \pi \pi$ mode is largely d | ue to $\Sigma(1385)\pi$. | Only t | the value | s of $(\Sigma(1385)$ | $)\pi)/(\Lambda 2\pi$ |
| given by MAST 72B and Co | ODDEN 75 are be | acod on | roal 3 h | ody partial w | avo analycoc |

given by MAST 73B and CORDEN 75 are based on real 3-body partial-wave analyses. The discrepancy between the two results is essentially due to the different hypotheses made concerning the shape of the $(\pi\pi)_{S-\text{Wave}}$ state.

| VALUE | <u>CL%</u> | <u>DO CUMENT ID</u> | | TECN | COMMENT |
|--------------------------------------|-----------------|------------------------|----------|---------|--------------------------------------------|
| 0.58 ± 0.22 | | CORDEN | 75 | DBC | $K^- d 1.4-1.8 \text{ GeV}/c$ |
| 0.82 ± 0.10 | | ⁶ MAST | 73B | IP WA | $K^- p \rightarrow \Lambda \pi \pi$ |
| ● ● We do not us | e the following | g data for average | es, fits | limits, | etc. • • • |
| < 0.44 | 90 | WIELAND | 11 | SPHR | $\gamma p \rightarrow K^{+} \Lambda(1520)$ |
| $\boldsymbol{0.39 \pm 0.10}$ | | ⁷ BURKHARDT | 71 | HB C | $K^- p \rightarrow (\Lambda \pi \pi) \pi$ |
| 65 =(+005) | | | | | |

 6 Both $\Sigma(1385)\,\pi$ DS_{03} and $\Sigma\,(\pi\pi)$ DP_{03} contribute. 7 The central bin (1514–1524 MeV) gives 0.74 \pm 0.10; other bins are lower by 2-to-5 standard deviations.

| $\Gamma(\Lambda(\pi\pi)_{S-wave})/\Gamma(\Lambda\pi\pi)$ | | | | Γ_6/Γ_3 |
|----------------------------------------------------------|---------------------|-----|------|------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.20±0.08 | CORDEN | 75 | DBC | $K^- d 1.4-1.8 \text{ GeV}/c$ |
| $\Gamma(\Sigma\pi\pi)/\Gamma_{\rm total}$ | | | | Γ ₇ /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.009 ±0.001 OUR ESTIMATE | | | | |
| 0.0086 ± 0.0005 OUR FIT | | | | |
| 0.0086 ± 0.0005 OUR AVERAGE | | | | |
| 0.007 ± 0.002 | ⁸ CORDEN | 75 | DBC | $K^- d 1.4-1.8 \text{ GeV}/c$ |
| 0.0085 ± 0.0006 | ⁹ MAST | 73 | MPWA | $K^- p \rightarrow \Sigma \pi \pi$ |
| 0.010 ± 0.0015 | BARBARO | 69B | нвс | $K^- p$ 0.28-0.45 ${ m GeV}/c$ |

 $^{^{8}}$ Much of the $\Sigma\pi\pi$ decay proceeds via $\Sigma(1385)\,\pi.$ 9 Assumes $\Gamma(N\,\overline{K})/\Gamma_{\rm total}=0.46.$

Baryon Particle Listings $\Lambda(1520)$, $\Lambda(1600)$, $\Lambda(1670)$

| $\Gamma(\Lambda\gamma)/\Gamma_{\rm total}$ | | | | | Г ₈ /Г |
|--------------------------------------------|--------|-------------|-----|------|------------------------------------------------------------|
| VALUE (units 10^{-3}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 8.5 ± 1.5 OUR ES | TIMATE | | | | |
| 8.8±1.1 OUR FI | Γ | | | | |
| 8.8±1.1 OUR AV | ERAGE | | | | |
| $10.7 \pm 2.9 {}^{+ 1.5}_{- 0.4}$ | 32 | TAYLOR | 05 | CLAS | $\gamma p \rightarrow K^+ \Lambda \gamma$ |
| $10.2\!\pm\!2.1\!\pm\!1.5$ | 290 | ANTIPOV | 04A | SPNX | $p N(C) \rightarrow \Lambda(1520) K^+ N(C)$ |
| 8.0 ± 1.4 | 238 | MAST | 68B | нвс | Using $\Gamma(N\overline{K})/\Gamma_{\text{total}} = 0.45$ |
| Γ(Σ ⁰ ~)/Γ | | | | | Γο./Γ |

 10 Calculated from $\Gamma(\Lambda\gamma)/\Gamma_{total}$, assuming SU(3). Needed to constrain the sum of all the branching ratios to be unity.

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 $\Lambda(1600) \ 1/2^{+}$

 $I(J^P) = O(\frac{1}{2}^+)$ Status: ***

See also the $\Lambda(1810)^-P_{01}.$ There are quite possibly two P_{01} states in this region.

Λ(1600) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN_COMMENT | | | | | |
|-------------------------|------------------------------------|----------|------------------------------------------------|--|--|--|--|--|
| 1560 to 1700 (≈ 1600) O | 1560 to 1700 (≈ 1600) OUR ESTIMATE | | | | | | | |
| 1568 ± 20 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | | | | | |
| 1703 ± 100 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | | | | | |
| 1573 ± 25 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel | | | | | |
| 1596± 6 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ | | | | | |
| 1620 ± 10 | LANGBEIN | 72 | IPWA KN multichannel | | | | | |
| • • • We do not use the | following data for average | es, fits | , limits, etc. • • • | | | | | |
| 1572 or 1617 | ¹ MARTIN | 77 | DPWA $\overline{K}N$ multichannel | | | | | |
| 1646± 7 | ² CARROLL | 76 | DPWA Isospin-0 total σ | | | | | |
| 1570 | KIM | 71 | DPWA K-matrix analysis | | | | | |

Λ(1600) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | | | |
|-----------------------------------|----------------------|---------|-------------|---------------------------------------------|--|--|--|
| 50 to 250 (≈ 150) OUR ESTIMATE | | | | | | | |
| 116± 20 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | | | |
| 593 ± 200 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | | | |
| 147± 50 | GOPAL | 77 | DPWA | K N multichannel | | | |
| 175 ± 20 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ | | | |
| 60± 10 | LANGBEIN | 72 | IPWA | K N multichannel | | | |
| • • • We do not use the following | g data for average | s, fits | , limits, e | etc. • • • | | | |
| 247 or 271 | | 77 | DPWA | K N multichannel | | | |
| 20 | ² CARROLL | 76 | DPWA | lsospin-O total σ | | | |
| 50 | KIM | 71 | DPWA | K-matrix analysis | | | |
| | | | | | | | |

A(1600) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------------------------------|------------------------------|
| Γ ₁ | N K Σ π | 15-30 % 10-60 % |
| '2 | The above branching fractions are our | |

Λ(1600) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|---------------------|----------|-----------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.15 to 0.30 OUR ESTIMATE | <u> </u> | | | | |
| 0.23 ± 0.04 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.14 ± 0.05 | ALSTON | 78 | DPWA | $\overline{K}N \rightarrow \overline{K}N$ | |
| 0.25 ± 0.15 | LANGBEIN | 72 | IPWA | K N multichannel | |
| $\bullet~\bullet~$ We do not use the follow | ing data for averag | es, fits | , limits, | etc. • • • | |
| 0.24 ± 0.04 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.30 or 0.29 | $^{ m 1}$ MARTIN | 77 | DPWA | K N multichannel | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Lambda(16)$ | | (Γ ₁ Γ ₂) ^{1/2} /Γ | | |
|-------------------------------------------------------------------------------------------------------|-----------------------------|----------------------------------------------------|-------------|----------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| -0.16 ± 0.04 | GOPAL | 77 | DPWA | K N multichannel |
| -0.33 ± 0.11 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| 0.28 ± 0.09 | LANGBEIN | 72 | IPWA | K N multichannel |
| ullet $ullet$ We do not use the following | data for average | s, fits, | , limits, e | etc. • • • |
| -0.39 or -0.39 not seen | ¹ MARTIN HEPP | | | \overline{K} N multichannel $K^ N$ $	o$ $\Sigma \pi$ |

A(1600) FOOTNOTES

1 The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.

 $^2\,\text{A}$ total cross-section bump with (J+1/2) $\Gamma_{\mbox{el}}$ / $\Gamma_{\mbox{total}}$ = 0.04.

Λ(1600) REFERENCES

| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
|----------|-----|-------------------|------------------------------|--------------------------|
| ALS T ON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+) IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+)IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R | .G. Moorhouse (LOUC+)IJP |
| Also | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| Also | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | `(BNL)I |
| HEPP | 76B | PL 65B 487 | V. Hepp et al. | (CERN, HEIDH, MPIM)IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| LANGBEIN | 72 | NP B47 477 | W. Langbein, F. Wagner | (MPIM) IJP |
| KIM | 71 | PRL 27 356 | J.K. Kim | (HARV) IJP |

Λ(1670) 1/2

 $I(J^P) = O(\frac{1}{2})$ Status: ***

The measurements of the mass, width, and elasticity published before 1974 are now obsolete and have been omitted. They were last listed in our 1982 edition Physics Letters **111B** 1 (1982).

Λ(1670) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------------------|----------|-------------|---------------------------------------------|
| 1660 to 1680 (≈ 1670) OUR | ESTIMATE | | | |
| 1677.5 ± 0.8 | ¹ GARCIA-REC | 03 | DPWA | K N multichannel |
| 1673 ±2 | MANLEY | 02 | DPWA | K N multichannel |
| 1670.8 ± 1.7 | KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 1667 ±5 | GOPAL | 80 | | $\overline{K} N \rightarrow \overline{K} N$ |
| 1671 ±3 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1670 ±5 | GOPAL | 77 | DPWA | K N multichannel |
| 1675 ± 2 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 1679 ±1 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 1665 ±5 | PREVOST | 74 | DPWA | $K^- N \rightarrow \Sigma(1385) \pi$ |
| • • • We do not use the follow | ing data for average | es, fits | , limits, e | etc. • • • |
| 1668.9 ± 2.0 | ABAEV | 96 | DPWA | $K^- p \rightarrow \Lambda \eta$ |
| 1664 | ² MARTIN | 77 | DPWA | KN multichannel |

Λ(1670) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|--------------------------|----|------|---------------------------------------------|
| 25 to 50 (≈ 35) OUR ESTIMATE | · | | | |
| 29.2± 1.4 | ¹ GARCIA-REC. | 03 | DPWA | K N multichannel |
| 23 ± 6 | MANLEY | 02 | DPWA | KN multichannel |
| 34.1 ± 3.7 | KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 29 ± 5 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 29 ± 5 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |

| 45 | ± 10 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel |
|------|-----------------------------|---------------------|---------|-------------------------------------------|
| 46 | ± 5 | HEPP | 76B | DPWA $K^- N 	o \Sigma \pi$ |
| 40 | ± 3 | KANE | 74 | DPWA $K^- p \rightarrow \Sigma \pi$ |
| 19 | ± 5 | PREVOST | 74 | DPWA $K^- N \rightarrow \Sigma(1385) \pi$ |
| • • | We do not use the following | data for averages | , fits, | , limits, etc. • • • |
| 21.: | L± 3.6 | ABAEV | 96 | DPWA $K^-p \rightarrow \Lambda \eta$ |
| 12 | | ² MARTIN | 77 | DPWA KN multichannel |

A(1670) DECAY MODES

| | Mode | Fraction $(\Gamma_{\dot{I}}/\Gamma)$ |
|----------------------------------------------------|-------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | NK | 20-30 % |
| Γ ₂ Γ ₃ Γ ₄ | $\Sigma \pi$ | 25-55 % |
| Γ_3 | $\Lambda\eta$ | 10-25 % |
| Γ_4 | $\Sigma(1385)\pi$ | |

The above branching fractions are our estimates, not fits or averages.

A(1670) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(NK)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ_1 |
|----------------------------------------------------------------------------------|----------------------------------------------------------------|-----------|-------------|---------------------------------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.20 to 0.30 OUR ESTIMA | | | | | |
| 0.37 ± 0.07 | MANLEY | 02 | | K N multichannel | |
| 0.18 ± 0.03 | GOPAL | 80 | | $\overline{K}N \rightarrow \overline{K}N$ | |
| 0.17 ± 0.03 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| ● ● We do not use the formula | ollowing data for average | es, fits, | , limits, | etc. • • • | |
| 0.20 ± 0.03 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.15 | ² MARTIN | 77 | DPWA | K N multichannel | |
| $\Gamma(\Lambda\eta)/\Gamma_{\rm total}$ | | | | | Гз/Г |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use the fo | ollowing data for average | es, fits, | , limits, | etc. • • • | |
| 0.30 ± 0.08 | ABAEV | 96 | DPWA | $K^- p \rightarrow \Lambda \eta$ | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $N\overline{K}$ - | $\rightarrow \Lambda(1670) \rightarrow \Sigma \pi$ DOCUMENT ID | | <u>TECN</u> | (Γ ₁ Γ ₂ |) ^½ /Γ |
| -0.38 ± 0.03 | MANLEY | 02 | DPWA | K N multichannel | |
| -0.26 ± 0.02 | KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ | |
| -0.31 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel | |
| -0.29 ± 0.03 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ | |
| -0.23 ± 0.03 | LONDON | 75 | HLBC | $K^- p \rightarrow \Sigma^0 \pi^0$ | |
| -0.27 ± 0.02 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ | |
| • • • We do not use the fo | ollowing data for average | es, fits, | , limits, | etc. • • • | |
| -0.13 | ² MARTIN | 77 | DPWA | $\overline{K} N$ multichannel | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}}$ in $N\overline{K}$ – | | | | (Γ ₁ Γ ₃ |) ¹ ⁄⁄[|
| VALUE | DO CUMENT ID | | | COMMENT | |
| $+0.24 \pm 0.04$ | MANLEY | | | K N multichannel | |
| $+0.20 \pm 0.05$ | | | D D I A I A | $K^-p \rightarrow \text{neutrals}$ | |
| | BAXTER | | | | |
| • • • VVe do not use the form | BAXIER ollowing data for average | | | | |
| • • • We do not use the for 0.24 | | | , limits, | | |

Λ(1670) FOOTNOTES

MANLEY

PREVOST

 $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Lambda(1670) \to \Sigma(1385) \pi$

0.26

 -0.17 ± 0.06

 -0.18 ± 0.05

 1 GARCIA-RECIO 03 gives pole, not Breit-Wigner, parameters, but the narrow width of the $\Lambda(1670)$ means there will be little difference.

ARMENTEROS69C HBC

74

DPWA $\overline{K}N$ multichannel

DPWA $K^- N \rightarrow \Sigma(1385) \pi$

 2 MARTIN 77 obtains identical resonance parameters from a T-matrix pole and from a Breit-Wigner fit.

Λ(1670) REFERENCES

| GARCIA-REC | 03 | PR D67 076009 | C. Garcia-Recio et al. | (GRAN, VALE) |
|------------|----|-------------------|-------------------------------|----------------------------|
| MANLEY | 02 | PRL 88 012002 | D.M. Manley et al. | (BNL Crystal Ball Collab.) |
| ABAEV | 96 | PR C53 385 | V.V. Abaev, B.M.K. Nefkens | ` (UCLA) |
| KOISO | 85 | NP A433 619 | H. Koiso et al. | (TOKY, MASA) |
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALSTON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MTHO+)IJP |
| Also | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R. | G. Moorhouse (LOUC+)IJP |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) HP |

| HEPP | 76B | PL 65B 487 | V. Hepp et al. | (CERN, HEIDH, MPIM) IJP |
|-----------|-------|---------------------|----------------------|-------------------------|
| LONDON | 75 | NP B85 289 | G.W. London et al. | `(BNL, CERN, EPOL+) |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| PREVOST | 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, ĤEID) |
| BAXTER | 73 | NP B 67 125 | D.F. Baxter et al. | (OXF) IJP |
| KIM | 71 | PRL 27 356 | J.K. Kim | (HÀRV) IJP |
| Also | | Duke Conf. 161 | J.K. Kim | (HARV) IJP |
| | | ices, 1970 | | |
| ARMENTERO | S 69C | Lund Paper 229 | R. Armenteros et al. | (CERN, HEID, SACL)IJP |
| | | d in LEVI-SETTI 69. | | |
| BERLEY | 65 | PRL 15 641 | D. Berley et al. | (BNL) IJP |
| | | | | |

Л(1690) 3/2[—]

 $I(J^P) = O(\frac{3}{2})$ Status: ***

The measurements of the mass, width, and elasticity published before 1974 are now obsolete and have been omitted. They were last listed in our 1982 edition Physics Letters **111B** 1 (1982).

Λ(1690) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|---------|-----------|---------------------------------------------|
| 1685 to 1695 (≈ 1690) OUR EST | MATE | | | |
| 1695.7 ± 2.6 | KOISO | 85 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| 1690 ±5 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1692 ±5 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1690 ±5 | GOPAL | 77 | DPWA | K N multichannel |
| 1690 ±3 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 1689 ±1 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| • • • We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 1687 or 1689 | MARTIN | 77 | DPWA | K N multichannel |
| 1692 ±4 | CARROLL | 76 | DPWA | lsospin-O total σ |
| | | | | |

Λ(1690) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------------|---------|-------------|---------------------------------------------|
| 50 to 70 (≈ 60) OUR ESTIMATE | | | | |
| 67.2± 5.6 | KOISO | 85 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| 61 ± 5 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 64 ±10 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 60 ± 5 | GOPAL | 77 | DPWA | K N multichannel |
| 82 ± 8 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 60 ± 4 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| • • • We do not use the following | data for average | s, fits | , limits, e | etc. • • • |
| 62 or 62 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 38 | CARROLL | 76 | DPWA | lsospin=0 total σ |
| | | | | |

Λ(1690) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | |
|-----------------------|-------------------------------|------------------------------|--|
| $\overline{\Gamma_1}$ | NK | 20-30 % | |
| Γ_2 | $\Sigma \pi$ | 20-40 % | |
| Γ_3 | $\Lambda \pi \pi$ | \sim 25 $\%$ | |
| Γ_4 | $\Sigma \pi \pi$ | \sim 20 % | |
| Γ_5 | $\Lambda\eta$ | | |
| Γ ₆ | $\Sigma(1385)\pi$, S -wave | | |

The above branching fractions are our estimates, not fits or averages.

Λ(1690) BRANCHING RATIOS

The sum of all the quoted branching ratios is more than 1.0. The two-body ratios are from partial-wave analyses, and thus probably are more reliable than the three-body ratios, which are determined from bumps in cross sections. Of the latter, the $\Sigma\pi\pi$ bump looks more significant. (The error given for the $\Lambda\pi\pi$ ratio looks unreasonably small.) Hardly any of the $\Sigma\pi\pi$ decay can be via $\Sigma(1385)$, for then seven times as much $\Lambda\pi\pi$ decay would be required. See "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|----------------------------------------------|---------|-------------|---------------------------------------------|-------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| 0.2 to 0.3 OUR ESTIMATE | <u>- </u> | | | | |
| 0.23 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.22 ± 0.03 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| ullet $ullet$ We do not use the following of | data for averages | s, fits | , limits, e | etc. • • • | |
| 0.24 ± 0.03 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.28 or 0.26 | L MARTIN | 77 | DPWA | K N multichanne | |
| | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Lambda(1690) \to \Sigma \pi$ | | | | (Γ ₁ Γ ₂) ^{1/2} /Γ |
|------------------------------------------------------------------------------------------------------------------------|----------------------------|-----------|-------------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.34 ± 0.02 | KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| -0.25 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| -0.29 ± 0.03 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| -0.28 ± 0.03 | LONDON | 75 | HLBC | $K^- p \rightarrow \Sigma^0 \pi^0$ |
| -0.28 ± 0.02 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| • • • We do not use the | following data for average | es, fits, | , limits, e | etc. • • • |
| -0.30 or -0.28 | 1 MARTIN | 77 | DPWA | K N multichannel |

 $\Lambda(1690), \Lambda(1800)$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K}$ | (Γ₁Γ₅) ¹ /2/Γ | | |
|----------------------------------------------------------------------------------------|---------------------------------------------------------------------|-----------|-------------------------------------------|
| VALUE | DO CUMENT ID | TECN | |
| 0.00 ± 0.03 | BAXTER 73 | DPWA | $K^-p \rightarrow \text{neutrals}$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K}$ | $\rightarrow \Lambda(1690) \rightarrow \Lambda \pi \pi$ DOCUMENT ID | TECN | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/\Gamma$ |
| • • • We do not use the | following data for averages, fits | , limits, | etc. • • • |
| 0.25 ± 0.02 | ² BARTLEY 68 | HDBC | $K^- p \rightarrow \Lambda \pi \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K}$ | $\rightarrow \Lambda(1690) \rightarrow \Sigma \pi \pi$ | TECN | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
| | | | COMMENT |
| 0.21 | ARMENTEROS68c | HDBC | $K - N \rightarrow \Sigma \pi \pi$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to A$ | Λ(1690) → Σ(1385 | δ)π, | S-wave | | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------------------------|------------------|------|--------|---------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | | COMMENT | |
| $+0.27 \pm 0.04$ | PREVOST | 74 | DPWA | $K^- N \rightarrow$ | Σ(1385) π |

∧(1690) FOOTNOTES

Λ(1690) REFERENCES

| KOISO 85 | NP A433 619 | H. Koiso et al. | (TOKY, MASA) |
|----------------|-------------------|---------------------------------|-------------------------|
| PDG 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| GOPAL 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALSTON 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+ĴIJP |
| Also | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| GOPAL 77 | NP B119 362 | G.P. Gopal et al. | `(LOIC, RHEL)IJP |
| MARTIN 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.O. | G. Moorhouse (LOUC+)IJP |
| Also | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| Also | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| CARROLL 76 | PRL 37 806 | A.S. Carroll et al. | `(BNL)I |
| HEPP 76B | PL 65B 487 | V. Hepp et al. | (CERN, HEIDH, MPIM)IJP |
| LONDON 75 | NP B85 289 | G.W. London et al. | (BNL, CERN, EPOL+) |
| KANE 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| PREVOST 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, ĤEID) |
| BAXTER 73 | NP B67 125 | D.F. Baxter et al. | (OXF)IJP |
| PREVOST 71 | Amsterdam Conf. | J. Prevost | (CERN, HEID, ŠACL) |
| ARMENTEROS 68C | NP B8 216 | R. Armenteros et al. | (CERN, HEID, SACL)I |
| BARTLEY 68 | PRL 21 1111 | J.H. Bartley et al. | (TUFTS, FSU, BRAN)I |
| | | | |

 $\Lambda(1800) 1/2$

$$I(J^P) = O(\frac{1}{2})$$
 Status: ***

This is the second resonance in the S_{01} wave, the first being the $\varLambda(1670).$

Λ(1800) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN COMMENT |
|-------------------------------------------|---------------------|---------|------------------------------------------------|
| 1720 to 1850 (≈ 1800) OUR ESTI | MATE | | |
| 1845 ± 10 | MANLEY | 02 | DPWA $\overline{K}N$ multichannel |
| 1841 ± 10 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1725 ± 20 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1825 ± 20 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel |
| 1830 ± 20 | LANGBEIN | 72 | IPWA $\overline{K}N$ multichannel |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 1767 or 1842 | ¹ MARTIN | 77 | DPWA $\overline{K}N$ multichannel |
| 1780 | KIM | 71 | DPWA K-matrix analysis |
| 1872 ± 10 | BRICMAN | 70B | DPWA $\overline{K}N \rightarrow \overline{K}N$ |

Λ(1800) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN COMMENT |
|-------------------------------------------|---------------------|---------|------------------------------------------------|
| 200 to 400 (≈ 300) OUR ESTIMAT | ΓE | | |
| 518±84 | MANLEY | 02 | DPWA $\overline{K}N$ multichannel |
| 228 ± 20 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 185 ± 20 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 230 ± 20 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel |
| 70 ± 15 | LANGBEIN | 72 | IPWA KN multichannel |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, etc. • • • |
| 435 or 473 | ¹ MARTIN | 77 | DPWA $\overline{K}N$ multichannel |
| 40 | KIM | 71 | DPWA K-matrix analysis |
| $100\!\pm\!20$ | BRICMAN | 70B | DPWA $\overline{K}N \rightarrow \overline{K}N$ |

Λ(1800) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 25-40 % |
| Γ_2 | $\Sigma \pi$ | seen |
| Γ_3 | $\Sigma(1385)\pi$ | seen |
| Γ_4 | N \overline{K}^* (892) | seen |
| Γ_5 | $N\overline{K}^*$ (892), $S=1/2$, S -wave | |
| Γ_6 | $N\overline{K}^*(892)$, $S=3/2$, D -wave | |

The above branching fractions are our estimates, not fits or averages.

Λ(1800) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------------------------------|----------------------------|---------|-------------|---------------------------------------------|
| 0.25 to 0.40 OUR ESTIM | | | | |
| 0.24 ± 0.10 | MANLEY | 02 | DPWA | K N multichannel |
| 0.36 ± 0.04 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.28 ± 0.05 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.35 ± 0.15 | LANGBEIN | 72 | IPWA | K N multichannel |
| • • • We do not use the | following data for average | s, fits | , limits, e | etc. • • • |
| 0.37 ± 0.05 | GOPAL | 77 | DPWA | See GOPAL 80 |
| 1.21 or 0.70 | 1 MARTIN | 77 | DPWA | K N multichannel |
| 0.80 | KIM | 71 | DPWA | K-matrix analysis |
| 0.18 ± 0.02 | BRICMAN | 70B | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\overline{K}$ | → Λ(1800) → Σπ | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}$ |
| VALUE | DOCUMENT ID | | TECN | COMMENT ('1'2) / |
| -0.08 ± 0.05 | GOPAL | 77 | DPWA | K N multichannel |
| • • • We do not use the | following data for average | s, fits | , limits, e | etc. • • • |
| -0.74 or -0.43 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| | KIM | 71 | D D 1444 | K-matrix analysis |

| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to 1$ | $\Lambda(1800) \rightarrow \Sigma(1385)$ |)π | | | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/\Gamma$ |
|---------------------------------------------------------------------------------------------|------------------------------------------|----|------|--------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| + 0.056 ± 0.028 | ² CAMERON | 78 | DPWA | K ⁻ p → | Σ (1385) π |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow$ | Λ(1800) → N\(\overline{K}^*\)(8 | 92), | S=1/2 | , S-wave | $(\Gamma_1\Gamma_5)^{\frac{1}{2}}/\Gamma$ |
|---------------------------------------------------------------------------------------------------|---------------------------------|------|-------|----------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| -0.17+0.03 | 2 CAMERON | 78B | DPWA | K-n → | N K * |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow$ | $\Lambda(1800) \rightarrow N\overline{K}^*(892)$ | 2), <i>5</i> =3/2 | , <i>D</i> -wave | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ |
|---------------------------------------------------------------------------------------------------|--------------------------------------------------|-------------------|------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| -0.13 ± 0.04 | CAMERON 7 | BB DPWA | K- p → | N K* |

∧(1800) FOOTNOTES

∧(1800) REFERENCES

| MANLEY | 02 | PRL 88 012002 | D.M. Manley et al. | (BNL Crystal Ball Collab.) |
|----------|---------|-------------------|-----------------------------|----------------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS T ON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+)IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC)IJP |
| CAMERON | 78 B | NP B146 327 | W. Cameron et al. | (RHEL, LOIC) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, | R.G. Moorhouse (LOUC+)IJP |
| Also | | NP B126 266 | B.R. Martin, M.K. Pidcock | (LOUC) |
| Also | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| LANGBEIN | 72 | NP B47 477 | W. Langbein, F. Wagner | (MPIM) IJP |
| KIM | 71 | PRL 27 356 | J.K. Kim | (HARV) IJP |
| Also | | Duke Conf. 161 | J.K. Kim | (HARV) IJP |
| Hyperon | Resonar | ices, 1970 | | ` ′ |
| BRICMAN | 70 B | PL 33B 511 | C. Bricman, M. Ferro-Luzzi, | J.P. Lagnaux (CERN) IJP |

 $^{^1}$ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. Another \mathcal{D}_{03} A at 1966 MeV is also suggested by MARTIN 77, but is very uncertain.

²BARTLEY 68 uses only cross-section data. The enhancement is not seen by PRE-VOST 71.

¹ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.

 $^{^2\,\}mathrm{The}$ published sign has been changed to be in accord with the baryon-first convention.

 $\Lambda(1810)\ 1/2^{+}$

$$I(J^P) = O(\frac{1}{2}^+)$$
 Status: ***

Almost all the recent analyses contain a P_{01} state, and sometimes two of them, but the masses, widths, and branching ratios vary greatly. See also the $\Lambda(1600)$ P_{01} .

Λ(1810) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------------|---------------|-----------|---------------------------------------------|
| 1750 to 1850 (≈ 1810) OUR EST | MATE | | | |
| 1841 ± 20 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1853 ± 20 | GOPAL | 77 | DPWA | K N multichannel |
| 1735 ± 5 | CARROLL | 76 | DPWA | lsospin=0 total σ |
| 1746 ± 10 | PREVOST | 74 | DPWA | $K^- N \rightarrow \Sigma(1385) \pi$ |
| 1780 ± 20 | LANGBEIN | 72 | IPWA | K N multichannel |
| • • • We do not use the following | g data for averag | es, fits | , limits, | etc. • • • |
| 1861 or 1953 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 1755 | KIM | 71 | DPWA | K-matrix analysis |
| 1800 | ARMENTER | OS70 | HBC | $\overline{K} N \rightarrow \overline{K} N$ |
| 1750 | ARMENTER | OS70 | HBC | $\overline{K} N \rightarrow \Sigma \pi$ |
| 1690 ± 10 | BARBARO | . 70 | HBC | $\overline{K} N \rightarrow \Sigma \pi$ |
| 1740 | BAILEY | 69 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1745 | ARMENTER | ЭS68 в | HBC | $\overline{K} N \rightarrow \overline{K} N$ |

Λ(1810) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|--------|-------------|---------------------------------------------|
| 50 to 250 (≈ 150) OUR ESTIMAT | Έ | | | |
| 164 ± 20 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 90±20 | CAMERON | 78B | DPWA | $K^- p \rightarrow N \overline{K}^*$ |
| 166±20 | GOPAL | 77 | DPWA | K N multichannel |
| 46±20 | PREVOST | 74 | DPWA | $K^- N \rightarrow \Sigma(1385) \pi$ |
| 120 ± 10 | LANGBEIN | 72 | IPWA | K N multichannel |
| • • • We do not use the following | data for averages | , fits | , limits, e | etc. • • • |
| 535 or 585 | L MARTIN | 77 | DPWA | K N multichannel |
| 28 | CARROLL | 76 | DPWA | lsospin-0 total σ |
| 35 | KIM | 71 | DPWA | K-matrix analysis |
| 30 | ARMENTERO | S70 | | $\overline{K} N \rightarrow \overline{K} N$ |
| 70 | ARMENTERO | S70 | | $\overline{K} N \rightarrow \Sigma \pi$ |
| 22 | BARBARO | 70 | | $\overline{K} N \rightarrow \Sigma \pi$ |
| 300 | BAILEY | 69 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 147 | ARMENTERO | S68B | нвс | |

Λ(1810) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 20-50 % |
| Γ_2 | $\Sigma \pi$ | 10-40 % |
| Γ_3 | $\Sigma(1385)\pi$ | seen |
| Γ_4 | N K*(892) | 30-60 % |
| Γ_5 | $N\overline{K}^*$ (892), $S=1/2$, P -wave | |
| Γ ₆ | $N\overline{K}^*(892)$, $S=3/2$, <i>P</i> -wave | |

The above branching fractions are our estimates, not fits or averages.

A(1810) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

DOCUMENT ID TECN COMMENT

 Γ_1/Γ

 $\Gamma(N\overline{K})/\Gamma_{\text{total}}$

| 0.2 to 0.5 OUR ESTIMATE | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|-------------------------------------------|----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.24 ± 0.04 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.36 ± 0.05 | LANGBEIN | 72 | IPWA | K N multichannel |
| ● We do not use the fol | lowing data for averag | es, fits | , limits, e | etc. • • • |
| 0.21 ± 0.04 | GOPAL | 77 | DPWA | See GOPAL 80 |
| 0.52 or 0.49 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 0.30 | KIM | 71 | DPWA | K-matrix analysis |
| 0.15 | ARMENTER | OS70 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.55 | BAILEY | 69 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| | | | | |
| 0.4 | ARMENTER | OS68B | DPWA | $\overline{K}N \to \overline{K}N$ |
| 0.4 (Γ_IΓ_f)^{1/2}/Γ_{total} in N<i>T</i>K → VALUE | | | DPWA <u>TECN</u> | $KN \rightarrow KN$ $ (\Gamma_1 \Gamma_2)^{\frac{1}{2}} / \Gamma_2 $ $ COMMENT$ |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $N\overline{\mathcal{K}}$ \rightarrow | <i>Λ</i> (1810) → Σπ | | <u>TECN</u> | (Γ ₁ Γ ₂) ^{1/2} /Ι |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\overline{K}$ $ ightharpoons$ | $ \Lambda(1810) \rightarrow \Sigma \pi $ DOCUMENT IS GOPAL | 77 | <i>TECN</i> DPWA | $\frac{(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma_2}{\overline{K}N \text{ multichannel}}$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK \rightarrow \frac{VALUE}{-0.24 \pm 0.04}$ | $ \Lambda(1810) \rightarrow \Sigma \pi $ DOCUMENT IS GOPAL | 77 (es, fits | | $\frac{(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma_2}{\overline{K}N \text{ multichannel}}$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK \rightarrow \frac{1}{2}$ $VALUE$ -0.24 ± 0.04 • • • We do not use the following the following the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second sec | $ \begin{array}{c} $ | 77 (es, fits | TECN DPWA , limits, o | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/I$ \overline{K} N multichannel etc. ••• |
| $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $NK \rightarrow 0$ $VALUE$ -0.24 ± 0.04 • • • We do not use the fol $+0.25 \text{ or } +0.23$ | DOCUMENT IL GOPAL Iowing data for average 1 MARTIN LANGBEIN KIM | 77 ges, fits 77 72 71 | TECN DPWA , limits, of DPWA IPWA | $\frac{(\Gamma_1\Gamma_2)^{\frac{1}{2}}/I}{\overline{K}N \text{ multichannel}}$ etc. • • • |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK \rightarrow \frac{VALUE}{2}$ -0.24 ± 0.04 • • • We do not use the foleman and the second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second second secon | DOCUMENT IL GOPAL lowing data for average 1 MARTIN LANGBEIN | 77 ges, fits 77 72 71 | DPWA, limits, of DPWA | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/I$ $\overline{K}N$ multichannel etc. • • • $\overline{K}N$ multichannel $\overline{K}N$ multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK \rightarrow \frac{VALUE}{-0.24 \pm 0.04}$ • • • We do not use the fol $+0.25 \text{ or } +0.23$ < 0.01 0.17 | DOCUMENT IL GOPAL lowing data for average 1 MARTIN LANGBEIN KIM 2 ARMENTER | 77 ges, fits 77 72 71 OS70 | DPWA, limits, of IPWA DPWA DPWA | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/I$ $\overline{K}N$ multichannel etc. \bullet \bullet \bullet \bullet \bullet \bullet \bullet K N multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multichannel $\overline{K}N$ multich |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Lambda(1810) \to \Sigma(1385)\pi$ | | | | | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/\Gamma$ |
|-----------------------------------------------------------------------------------------------------------------------------|-------------|----|------|-------------------|-------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT | |
| $+0.18\pm0.10$ | PREVOST | 74 | DPWA | $K-N \rightarrow$ | Σ (1385) π |

$$\frac{\left(\Gamma_{l}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\overline{K} \rightarrow \Lambda(1810) \rightarrow N\overline{K}^{*}(892), S=1/2, P\text{-wave} }{\frac{DOCUMENT\ ID}{-0.14\pm0.03}} \frac{TECN}{DPWA} \frac{COMMENT}{K^{-}\rho \rightarrow N\overline{K}^{*}}$$

$$\begin{array}{c|c} (\Gamma_1\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \Lambda(1810) \rightarrow N\overline{K}^*(892), S=3/2, P\text{-wave} \\ \frac{NLUE}{+0.35\pm0.06} & \frac{DOCUMENT\ ID}{CAMERON} & \frac{78B}{} & \frac{DPWA}{K} & \frac{COMMENT}{K} \end{array}$$

A(1810) FOOTNOTES

Λ(1810) REFERENCES

| GOPAL 80 CAMERON 78 B GOPAL 77 MARTIN 77 Also | Toronto Conf. 159 NP B146 327 NP B119 362 NP B127 349 NP B126 266 | G.P. Gopal W. Cameron <i>et al.</i> G.P. Gopal <i>et al.</i> B.R. Martin, M.K. Pidcock, R.G. B.R. Martin, M.K. Pidcock | (RHEL) IJP (RHEL, LOIC) IJP (LOIC, RHEL) IJP Moorhouse (LOUC+) IJP (LOUC) |
|-----------------------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Also | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| CARROLL 76 | PRL 37 806 | A.S. Carroll et al. | `(BNL)I |
| PREVOST 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, HEID) |
| LANGBEIN 72 | NP B47 477 | W. Langbein, F. Wagner | (MPIM) UP |
| KIM 71 | PRL 27 356 | J.K. Kim | (HARV) IJP |
| A Iso | Duke Conf. 161 | J.K. Kim | (HARV) IJP |
| Hyperon Resona | nces, 1970 | | |
| ARMENTEROS 70 | Duke Conf. 123 | R. Armenteros et al. | (CERN, HEID, SACL)IJP |
| Hyperon Resona | nces, 1970 | | |
| BARBARO 70 | | A. Barbaro-Galtieri | (LRL) IJP |
| Hyperon Resona | | | |
| BAILEY 69 | Thesis UCRL 50617 | J.M. Bailey | (LLL) IJP |
| ARMENTEROS 68B | NP B8 195 | R. Armenteros et al. | (CERN, HEID, SACL)IJP |
| | | | |

Л(1820) 5/2⁺

$$I(J^P) = O(\frac{5}{2}^+)$$
 Status: ***

This resonance is the cornerstone for all partial-wave analyses in this region. Most of the results published before 1973 are now obsolete and have been omitted. They may be found in our 1982 edition Physics Letters **111B** 1 (1982).

Most of the quoted errors are statistical only; the systematic errors due to the particular parametrizations used in the partial-wave analyses are not included. For this reason we do not calculate weighted averages for the mass and width.

Λ(1820) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN COMMENT |
|----------------------------------------------------|--------------------------|----------|------------------------------------------------|
| 1815 to 1825 (≈ 1820) OUR | ESTIMATE | | |
| 1823 ± 3 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1819 ± 2 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1822 ± 2 | GOPAL | 77 | DPWA KN multichannel |
| 1821 ± 2 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| \bullet \bullet \bullet We do not use the fo | llowing data for average | es, fits | , limits, etc. ● ● ● |
| 1830 | DECLAIS | 77 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1817 or 1819 | 1 MARTIN | 77 | DPWA $\overline{K}N$ multichannel |

Λ(1820) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------|----------|-------------|---------------------------------------------|
| 70 to 90 (≈ 80) OUR ESTIMATE | | | · · | |
| 77±5 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 72±5 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 81 ±5 | GOPAL | 77 | DPWA | KN multichannel |
| 87±3 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| | data for average | es, fits | , limits, e | tc. • • • |
| 82 | DECLAIS | | | |
| 76 or 76 | ¹ MARTIN | 77 | DPWA | K N multichannel |

A(1820) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------------|-------------------------------------|
| $\overline{\Gamma_1}$ | NK | 55-65 % |
| Γ_2 | $\Sigma \pi$ | 8-14 % |
| Γ_3 | $\Sigma(1385)\pi$ | 5-10 % |
| Γ_4 | $\Sigma(1385)\pi$, P -wave | |
| Γ_5 | $\Sigma(1385)\pi$, <i>F</i> -wave | |
| Γ_6 | $\Lambda\eta$ | |
| Γ_7 | $\Sigma \pi \pi$ | |
| | The above branching fractions are o | ur estimates, not fits or averages. |

 $^{^1\,\}mathrm{The}$ two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. $^2\,\mathrm{The}$ published sign has been changed to be in accord with the baryon-first convention.

 $\Lambda(1820), \Lambda(1830)$

A(1820) BRANCHING RATIOS

Errors quoted do not include uncertainties in the parametrizations used in the partial-wave analyses and are thus too small. See also "Sign conventions for resonance couplings" in the Note on Λ and Σ Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|----------------------------------------------------------------------------|--------------------------------------------------------------------|----------|-----------|---------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.55 to 0.65 OUR EST | MATE | | | |
| 0.58 ± 0.02 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.60 ± 0.03 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| | e following data for averag | es, fits | , limits, | etc. • • • |
| 0.51 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.57 ± 0.02 | GOPAL | 77 | DPWA | See GOPAL 80 |
| 0.59 or 0.58 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N7$ | $ \overline{\zeta} \to \Lambda(1820) \to \Sigma \pi $ DO CUMENT ID | | TECN | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| -0.28 ± 0.03 | GOPAL | | | K N multichannel |
| -0.28 ± 0.01 | KANE | 74 | | $K^-p \rightarrow \Sigma \pi$ |
| | e following data for averag | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Lambda$ | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ | | | |
|----------------------------------------------------------------------------------------------------|-------------------------------------------|----|-------|--|
| VALUE | DO CUMENT ID | | TECN | |
| -0.096 + 0.040 | RADER | 73 | MP WA | |

 $^{
m 1}$ MARTIN

| $\Gamma(\Sigma\pi\pi)/\Gamma_{ m total}$ | | | | Γ ₇ /Γ |
|------------------------------------------|----------------------------|------|------------------------------------|-------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| no clear signal | ² ARMENTEROS68c | HDBC | $K^- N \rightarrow \Sigma \pi \pi$ | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow$ | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ | | | | |
|----------------------------------------------------------------------------------------------------|-------------------------------------------|----|------|--------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| -0.167 ± 0.054 | ³ CAMERON | 78 | DPWA | $K^-p \rightarrow$ | $\Sigma(1385)\pi$ |
| $+0.27\ \pm0.03$ | PREVOST | 74 | DPWA | $\kappa^-N\to$ | $\Sigma(1385)\pi$ |
| | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to A$ | $(\Gamma_1\Gamma_5)^{\frac{1}{2}}/\Gamma$ | | | | |
|----------------------------------------------------------------------------------------------|-------------------------------------------|----|------|--------------------|-----------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $+0.065 \pm 0.029$ | 3 CAMERON | 78 | DPWA | K ⁻ p → | Σ(1385) π |

Λ(1820) FOOTNOTES

 1 The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. 2 There is a suggestion of a bump, enough to be consistent with what is expected from $_\Sigma(1385) \to _\Sigma\pi$ decay.

The published sign has been changed to be in accord with the baryon-first convention.

Λ(1820) REFERENCES

| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
|------------|------|-------------------|---------------------------------|----------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALSTON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+) IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC) IJP |
| DECLAIS | 77 | CERN 77-16 | Y. Declais et al. | (ČAEN, CERN) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | `(LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G. | Moorhouse (LOUC+)IJP |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | `(LBL) IJP |
| PREVOST | 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, ĤEID) |
| RADER | 73 | NC 16A 178 | R.K. Rader et al. | (SACL, HEID, CERN+) |
| ARMENTEROS | 68 C | NP B8 216 | R. Armenteros et al. | (CERN, HEID, SACL)I |

 $\Lambda(1830) \; 5/2^-$

$$I(J^P) = O(\frac{5}{2})$$
 Status: ***

77 DPWA $\overline{K}N$ multichannel

For results published before 1973 (they are now obsolete), see our 1982 edition Physics Letters ${\bf 111B}~1~(1982).$

The best evidence for this resonance is in the $\Sigma\pi$ channel.

Λ(1830) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------------|----------|-----------|---------------------------------------------|
| 1810 to 1830 (≈ 1830) OUR EST | MATE | | | |
| 1831 ± 10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1825 ± 10 | GOPAL | 77 | DPWA | K N multichannel |
| 1825 ± 1 | KANE | 74 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |
| • • • We do not use the following | g data for average | es, fits | , limits, | etc. • • • |
| 1817 or 1818 | ¹ MARTIN | 77 | DPWA | K N multichannel |

Λ(1830) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|---------------------|---------|-------------|---------------------------------------------|
| 60 to 110 (≈ 95) OUR ESTIMAT | E | | · · | |
| 100 ± 10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 94 ± 10 | GOPAL | 77 | DPWA | K N multichannel |
| 119± 3 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| | data for average | s, fits | , limits, e | etc. • • • |
| 56 or 56 | ¹ MARTIN | 77 | DPWA | \overline{K} N multichannel |

A(1830) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------------------------|------------------------------|
| Γ ₁ | NK | 3-10 % |
| Γ_2 | $\Sigma \pi$ | 35-75 % |
| | $\Sigma(1385)\pi$ | >15 % |
| Γ_4 | $\Sigma(1385)\pi$, \emph{D} -wave | |
| Γ ₅ | $\Lambda\eta$ | |

The above branching fractions are our estimates, not fits or averages.

A(1830) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(NK)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-------------------------------------------|---------------------------|----------|-------------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.03 to 0.10 OUR ESTIM | ATE | | | | |
| 0.08 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.02 ± 0.02 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| ● ● We do not use the | following data for averag | es, fits | , limits, e | etc. • • • | |
| 0.04 ± 0.03 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.04 or 0.04 | 1 MARTIN | 77 | DPWA | K N multichanne | |
| | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K}$ | | (Γ ₁ Γ ₂) ^{1/2} /Γ | | |
|---------------------------------------------------------------------------------------|---------------------------|----------------------------------------------------|-------------|-------------------------------|
| VALUE | DOCUMENT ID | | TECN | COMMENT |
| -0.17 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| -0.15 ± 0.01 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| • • • We do not use the fe | ollowing data for average | s, fits | , limits, e | etc. • • • |
| -0.17 or -0.17 | 1 MARTIN | 77 | DPWA | K N multichannel |

$$\begin{array}{c|c} \left(\Gamma_{1}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\overline{K} \rightarrow \Lambda(1830) \rightarrow \Lambda \eta \\ \frac{NALUE}{-0.044 \pm 0.020} & \frac{DOCUMENT\ ID}{RADER} & \frac{TECN}{73} & MPWA \end{array}$$

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Lambda(1830) \to \Sigma(1385) \pi$ | | | | (Γ ₁ Γ ₃) ^{1/2} /Ι |
|----------------------------------------------------------------------------------------------------------------------|------------------|-------------------------|------|----------------------------------------------------|
| | VALUE | DO CUMENT ID | TECN | COMMENT |
| | $+0.141\pm0.014$ | ² CAMERON 78 | DPWA | $K^- \rho \rightarrow \Sigma(1385) \pi$ |
| | $+0.13 \pm 0.03$ | PREVOST 74 | DPWA | $K^- N \rightarrow \Sigma(1385) \pi$ |
| | | | | |

Λ(1830) FOOTNOTES

 $\frac{1}{2}$ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.

The CAMBERON 78 upper limit on G-wave decay is 0.03. The published sign has been changed to be in accord with the baryon-first convention.

Λ(1830) REFERENCES

| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
|----------|----|-------------------|--------------------------------|------------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS T ON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MTHO+)IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+)IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G | . Moorhouse (LOUC+)IJP |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| PREVOST | 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, ĤEID) |
| RADER | 73 | NC 16A 178 | R.K. Rader et al. | (SACL, HEID, CERN+) |

ለ(1890) 3/2⁺

$$I(J^P) = O(\frac{3}{2}^+)$$
 Status: ***

For results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982).

The ${\it J}^{\it P}={\it 3/2}^{\it +}$ assignment is consistent with all available data (including polarization) and recent partial-wave analyses. The dominant inelastic modes remain unknown.

Λ(1890) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN COMMENT | |
|-------------------------------------------|------------------------|--------|------------------------------------------------|--|
| 1850 to 1910 (≈ 1890) OUR ESTI | MATE | | | |
| 1897 ± 5 | | | DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| 1908 ± 10 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| 1900± 5 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel | |
| 1894 ± 10 | HEMINGWAY | 75 | DPWA $K^-p \rightarrow \overline{K}N$ | |
| ullet $ullet$ We do not use the following | data for averages | , fits | limits, etc. • • • | |
| 1856 or 1868 | | | DPWA $\overline{K}N$ multichannel | |
| 1900 | ² NAKKASYAN | 75 | DPWA $K^-p \rightarrow \Lambda \omega$ | |

Λ(1890) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN_COMMENT |
|------------------------------|------------------------|---------|------------------------------------------------|
| 60 to 200 (≈ 100) OUR ESTIMA | TE | | |
| 74 ± 10 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 119±20 | | | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 72±10 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel |
| 107 ± 10 | HEMINGWAY | 75 | DPWA $K^-p \rightarrow \overline{K}N$ |
| | data for average | s, fits | , limits, etc. • • • |
| 191 or 193 | | | DPWA $\overline{K}N$ multichannel |
| 100 | ² NAKKASYAN | 75 | DPWA $K^- p \rightarrow \Lambda \omega$ |

A(1890) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|--------------------------------|
| $\overline{\Gamma_1}$ | $N\overline{K}$ | 20-35 % |
| Γ_2 | $\Sigma \pi$ | 3-10 % |
| Γ_3 | $\Sigma(1385)\pi$ | seen |
| Γ_4 | $\Sigma(1385)\pi$, P -wave | |
| Γ_5 | $\Sigma(1385)\pi$, $\emph{F}	ext{-}$ wave | |
| Γ_6 | $N\overline{K}^*(892)$ | seen |
| Γ_7 | $N\overline{K}^*$ (892), $S=1/2$, P -wave | |
| Γ8 | $\Lambda \omega$ | |
| | The above branching fractions are our | estimates not fits or averages |

A(1890) BRANCHING RATIOS

ALSTON-...

• • • We do not use the following data for averages, fits, limits, etc. • • •

 $\Gamma(N\overline{K})/\Gamma_{\text{total}}$

 0.20 ± 0.02 0.34 ± 0.05

 0.24 ± 0.04

0.20 to 0.35 OUR EST MATE

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

80 DPWA $\overline{K}N \rightarrow \overline{K}N$ 78 DPWA $\overline{K}N \rightarrow \overline{K}N$

HEMINGWAY 75 DPWA $K^-p \rightarrow \overline{K}N$

 Γ_1/Γ

| | 0 0 | | | |
|----------------------------------------------------------------------------------------------|--------------------------------------------------------|---------|-------------|--------------------------------------------|
| 0.18 ± 0.02 | GOPAL | 77 | DPWA | See GOPAL 80 |
| 0.36 or 0.34 | ¹ MARTIN | 77 | DPWA | See GOPAL 80 \overline{K} N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to K$ | $\Lambda(1890) \rightarrow \Sigma \pi$ DOCUMENT ID | | <u>TECN</u> | $(\Gamma_1\Gamma_2)^{\frac{1}{12}}/\Gamma$ |
| -0.09 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| • • • We do not use the follow | wing data for average | s, fits | , limits, e | etc. • • • |
| +0.15 or + 0.14 | ¹ MARTIN | 77 | DPWA | \overline{K} N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to K$ | $\Lambda(1890) \rightarrow \Lambda \omega$ DOCUMENT ID | | <u>TECN</u> | $(\Gamma_1\Gamma_8)^{\frac{1}{12}}/\Gamma$ |
| seen | BACCARI | 77 | IPWA | $K^- p \rightarrow \Lambda \omega$ |
| 0.032 | ² NAKKASYAN | 75 | DPWA | $K^-p \rightarrow \Lambda \omega$ |
| | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow K$ | $\Lambda(1890) \rightarrow \Sigma(1385)$ | 5)π, | P-wave | | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ | |
|------------------------------------------------------------------------------------------------------|------------------------------------------|------|--------|--------------------|-------------------------------------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| <0.03 | CAMERON | 78 | DPWA | $K^-p \rightarrow$ | Σ (1385) π | |
| | | | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to 1$ | Λ(1890) → Σ(138 | 5)π, | <i>F</i> -wave | | $(\Gamma_1\Gamma_5)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------------------------|-----------------|------|----------------|--------------------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| -0.126 ± 0.055 | 3 CAMERON | 78 | DPWA | K ⁻ p → | Σ(1385) π |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{tot}}$ | in $N\overline{K} \to A$ | $N(1890) \rightarrow N\overline{K}^*(8)$ | 392) | | | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ |
|-----------------------------------------------------------|--------------------------|------------------------------------------|------|------|---------|-------------------------------------------|
| VALUE | | DO CUMENT ID | | TECN | COMMENT | |
| -0.07 ± 0.03 | | 3,4 CAMERON | 78B | DPWA | K - p → | N K * |

A(1890) FOOTNOTES

 $\frac{1}{2}$ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.

 2 Found in one of two best solutions. 3 The published sign has been changed to be in accord with the baryon-first convention. 4 Upper limits on the P_3 and F_3 waves are each 0.03.

∧(1890) REFERENCES

| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
|-----------|------|-------------------|----------------------------|---------------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS T ON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+) IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | `(RHEL, LOIC)IJP |
| CAMERON | 78 B | NP B146 327 | W. Cameron et al. | (RHEL, LOIC) IJP |
| BACCARI | 77 | NC 41A 96 | B. Baccari et al. | (ŠACL, CDEF) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, | R.G. Moorhouse (LOUC+)IJP |
| Also | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| Also | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| HEMINGWAY | 75 | NP B91 12 | R.J. Hemingway et al. | (CERN, HEIDH, MPIM)IJP |
| NAKKASYAN | 75 | NP B93 85 | A. Nakkasyan | (CERN) IJP |

$\Lambda(2000)$

 $+\,0.09\pm0.03$

$$I(J^P) = 0(??)$$
 Status: *

OMITTED FROM SUMMARY TABLE

We list here all the ambiguous resonance possibilities with a mass around 2 GeV. The proposed quantum numbers are $\it D_{\rm 3}$ (BARBARO-GALTIERI 70 in $\Sigma\pi$), D_3+F_5 , P_3+D_5 , or P_1+D_3 (BRANDSTET-TER 72 in $\Lambda\omega$), and S_1 (CAMERON 78B in $N\overline{K}^*$). The first two of the above analyses should now be considered obsolete. See also NAKKASYAN 75.

Λ(2000) MASS

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|----------------------|---------------------------------------|--------------|--------------------------------------|
| ≈ 2000 OUR ESTIMATE | | | |
| 2030 ± 30 | CAMERON 78B | DPWA | $K^- p \rightarrow N \overline{K}^*$ |
| 1935 to 1971 | ¹ BRANDSTET72 | DPWA | $K^- p \rightarrow \Lambda \omega$ |
| 1951 to 2034 | ¹ BRANDSTET72 | DPWA | $K^- p \rightarrow \Lambda \omega$ |
| 2010 ± 30 | BARBARO 70 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| | | | |
| | ∕ 1(2000) WIDTH | | |
| VALUE (MeV) | A(2000) WIDTH | TECN | COMMENT |
| VALUE (MeV) 125 ± 25 | DOCUMENT ID CAMERON 78B | | |
| | DOCUMENT ID CAMERON 78B BRANDSTET72 | DPWA | |
| 125 ± 25 | DOCUMENT ID CAMERON 78B | DPWA DPWA | $K^-p \rightarrow N\overline{K}^*$ |

A(2000) DECAY MODES

| | Mode |
|-----------------------|----------------------------------------------|
| $\overline{\Gamma_1}$ | NK |
| Γ_2 | $\Sigma \pi$ |
| Γ_3 | $\Lambda \omega$ |
| Γ_4 | $N\overline{K}^*(892)$, $S=1/2$, S-wave |
| Γ_5 | $N\overline{K}^*$ (892), $S=3/2$, D -wave |

A(2000) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| VALUE | DO CUMENT ID | TECN | (Γ ₁ Γ ₂) ^{1/2} /Ι |
|-------------------------------------------------------------------|-------------------------------------------------------------------------|------|----------------------------------------------------|
| -0.20 ± 0.04 | BARBARO 70 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |
| | | | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}}$ in N7 | $\overline{\zeta} \rightarrow \Lambda(2000) \rightarrow \Lambda \omega$ | | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/1$ |
| $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{ m total}$ in N7 | $7 \rightarrow \Lambda(2000) \rightarrow \Lambda \omega$ DOCUMENT ID | TECN | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/\Gamma_3$ |
| | | DPWA | (lower mass) |

| $(i f)'^-/ total n / n \rightarrow$ | $V(5000) \rightarrow W V(885)$ | , 3=1/2 | ,5-wave (1114)'-/1 |
|-----------------------------------------------------------------------------------------------|--------------------------------|---------|-----------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| -0.12 ± 0.03 | ² CAMERON 78B | DPWA | $K^- \rho \rightarrow N \overline{K}^*$ |
| $(\Gamma, \Gamma, \Lambda)^{\frac{1}{2}}/\Gamma, \dots$ in $\Lambda \overline{K} \rightarrow$ | A(2000) → N K*(892) | S-3/2 | D-wave (F.F.) 1/2 /F |

CAMERON

TECN COMMENT

78B DPWA $K^-p \rightarrow N\overline{K}^*$

Baryon Particle Listings $\Lambda(2000)$, $\Lambda(2020)$, $\Lambda(2100)$

A(2000) FOOTNOTES

- 1 The parameters quoted here are ranges from the three best fits; the lower state probably has $J \leq 3/2$, and the higher one probably has $J \leq 5/2$.
- 2 The published sign has been changed to be in accord with the baryon-first convention.

Λ(2000) REFERENCES

| CAMERON | 78 B | NΡ | В | 141 | 5 32 | !7 |
|------------|------------|-------|----|-----|------|-----|
| NAKKASYAN | 75 | NΡ | В | 93 | 85 | |
| BRANDSTET | 72 | NP | В | 39 | 13 | |
| BARBARO | 70 | Duk | e | Co | nf. | 173 |
| Hyperon Re | eso n an o | es, : | 19 | 70 | | |

W. Cameron *et al.* A. Nakkasyan A.A. Brandstetter *et al.* A. Barbaro-Galtieri (RHEL, LOIC) IJP (CERN) IJP (RHEL, CDEF+) (LRL) IJP

$\Lambda(2020) \ 7/2^{+}$

$$I(J^P) = O(\frac{7}{2}^+)$$
 Status: *

OMITTED FROM SUMMARY TABLE

In LITCHFIELD 71, need for the state rests solely on a possibly inconsistent polarization measurement at 1.784 GeV/c. HEMINGWAY 75 does not require this state. GOPAL 77 does not need it in either $N\overline{K}$ or $\Sigma\pi$. With new K^-n angular distributions included, DECLAIS 77 sees it. However, this and other new data are included in GOPAL 80 and the state is not required. BACCARI 77 weakly supports it.

Λ(2020) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|----|------|---------------------------------------------|
| ≈ 2020 OUR ESTIMATE | · | | | |
| 2140 | | | | $K^-p \rightarrow \Lambda \omega$ |
| 2117 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2100 ± 30 | LITCHFIELD | 71 | DPWA | $K^- p \rightarrow \overline{K} N$ |
| 2020 ± 20 | BARBARO | 70 | DPWA | $K^- p \rightarrow \Sigma \pi$ |

Λ(2020) WIDTH

| VALUE (MeV) | DO CUMENT ID | TEC | N COMMENT |
|--------------|---------------|--------|-----------------------------------------------------|
| 128 | BACCARI | 77 DPV | $NA \xrightarrow{K^- p \rightarrow \Lambda \omega}$ |
| 167 | DECLAIS 7 | 77 DP\ | $NA \overline{K} N \rightarrow \overline{K} N$ |
| 120 ± 30 | LIT CHFIELD 7 | 71 DP\ | $NA K^- p \rightarrow \overline{K} N$ |
| 160 ± 30 | BARBARO | 70 DPV | NA $K^- p \rightarrow \Sigma \pi$ |

A(2020) DECAY MODES

| | Mode |
|-----------------------|--------------------------------|
| $\overline{\Gamma_1}$ | NK |
| Γ_2 | $N\overline{K} \ \Sigma \ \pi$ |
| Γ_3 | $\Lambda \omega$ |

Λ(2020) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|--------------|----|------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.05 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| $\boldsymbol{0.05 \pm 0.02}$ | LITCHFIELD | 71 | DPWA | $K^- p \rightarrow \overline{K} N$ | |

| $(\Gamma_I \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N \overline{K} \to \Lambda(2020) \to \Sigma \pi$ | | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------------------------------------|------------------|--------------|----|------|-------------------------------------------|
| | VALUE | DO CUMENT ID | | TECN | COMMENT |
| | -0.15 ± 0.02 | BARBARO 7 | 70 | DPWA | $K^-p \rightarrow \Sigma \pi$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow .$ | (Γ₁Γ₃) ^½ /Γ | | |
|------------------------------------------------------------------------------------------------------|------------------------|------|-----------------------------------|
| VALUE | DOCUMENT ID | TECN | COMMENT |
| < 0.05 | BACCARI 77 | DPWA | $K^-p \rightarrow \Lambda \omega$ |

Λ(2020) REFERENCES

| | 80 77 77 77 75 71 | Toronto Conf. 159 NC 41A 96 CERN 77-16 NP B119 362 NP B91 12 NP B30 125 Duke Conf. 173 | G.P. Gopal B. Baccari et al. Y. Declais et al. G.P. Gopal et al. R.J. Hemingway et al. P.J. Litchfield et al. A. Barbaro-Galiferi | (RHEL) (SACL, CDEF) IJP (CAEN, CERN) IJP (LOIC, RHEL) (CERN, HEIDH, MPIM) IJP (RHEL, CDEF, SACL) IJP |
|-----------|----------------------------------|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| BARBARO | | Duke Conf. 173 | A. Barbaro-Galtieri | (LRL)IJP |
| Hyperon F | teso n ai | nces, 1970 | | |

$\Lambda(2100) \ 7/2^-$

$$I(J^P) = O(\frac{7}{2})$$
 Status: ***

Discovered by COOL 66 and by WOHL 66. Most of the results published before 1973 are now obsolete and have been omitted. They may be found in our 1982 edition Physics Letters **111B** 1 (1982).

This entry only includes results from partial-wave analyses. Parameters of peaks seen in cross sections and in invariant-mass distributions around 2100 MeV used to be listed in a separate entry immediately following. It may be found in our 1986 edition Physics Letters 170B 1 (1986).

Λ(2100) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------------------------|--------|-------------|---------------------------------------------|
| 2090 to 2110 (≈ 2100) O | UR ESTIMATE | | | |
| 2104 ± 10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2106 ± 30 | DEBELLEFON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2110 ± 10 | GOPAL | 77 | DPWA | K N multichannel |
| 2105 ± 10 | HEMINGWAY | 75 | DPWA | $K^- p \rightarrow \overline{K} N$ |
| 2115 ± 10 | KANE | 74 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |
| • • • We do not use the | following data for averages | , fits | , limits, e | etc. • • • |
| 2094 | BACCARI | 77 | DPWA | $K^-p \rightarrow \Lambda \omega$ |
| 2094 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2110 or 2089 | ¹ NA KKA SYA N | 75 | DPWA | $K^- p \rightarrow \Lambda \omega$ |

Λ(2100) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|-----------------------------|--------|-------------|---------------------------------------------|
| 100 to 250 (≈ 200) OUR | ESTIMATE | | | |
| 157 ± 40 | DEBELLEFON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 250 ± 30 | GOPAL | 77 | DPWA | K N multichannel |
| 241 ± 30 | HEMINGWAY | 75 | DPWA | $K^- p \rightarrow \overline{K} N$ |
| $152 \!\pm\! 15$ | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| \bullet \bullet \bullet We do not use the | following data for averages | , fits | , limits, e | etc. • • • |
| 98 | BACCARI | 77 | DPWA | $K^-p \rightarrow \Lambda \omega$ |
| 250 | DECLAIS | | | |
| 244 or 302 | ¹ NA KKA SYA N | 75 | DPWA | $K^- p \rightarrow \Lambda \omega$ |

A(2100) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 25-35 % |
| Γ_2 | $\Sigma \pi$ | \sim 5 % |
| Γ_3 | $\Lambda\eta$ | <3 % |
| Γ_4 | ΞK | <3 % |
| Γ_5 | $\Lambda \omega$ | <8 % |
| Γ ₆ | N K *(892) | 10-20 % |
| Γ_7 | $N\overline{K}^*$ (892), $S=1/2$, G -wave | |
| Γ ₈ | $N\overline{K}^*$ (892), S =3/2, D -wave | |

The above branching fractions are our estimates, not fits or averages.

A(2100) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| Resonances. | , 0 | |
|-------------|-----|--|
| F/N77\/F | | |

| $\Gamma(N\overline{K})/\Gamma_{total}$ | | | Γ_1/Γ |
|----------------------------------------|-------------------------------------|--------------|---------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| 0.25 to 0.35 OUR ESTI | MATE | | |
| 0.34 ± 0.03 | GOPAL 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.24 ± 0.06 | DEBELLEFON 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.31 ± 0.03 | HEMINGWAY 75 | DPWA | $K^- p \rightarrow \overline{K} N$ |
| • • • We do not use th | e following data for averages, fits | s, limits, e | etc. • • • |
| 0.29 | DECLAIS 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.30 ± 0.03 | GOPAL 77 | DPWA | See GOPAL 80 |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to A$ | $\Lambda(2100) \rightarrow \Sigma \pi$ | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma_2$ |
|---------------------------------------------------------------------------------------------|----------------------------------------|----|------|---------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.12\pm0.04$ | GOPAL | 77 | DPWA | K N multichannel |
| $\pm 0.11 \pm 0.01$ | KANE | 7/ | DEWA | $K = D \rightarrow \nabla \pi$ |

| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $N\overline{\mathcal{K}} \to \Lambda$ | (2100) → Λη | | (Γ ₁ Γ ₃ | _з) ^{1/2} /Г |
|---------------------------------------------------------------------------------------------------|-------------|------|------------------------------------|----------------------------------|
| VALUE | DOCUMENT ID | TEC | N COMMENT | |
| -0.050 ± 0.020 | RADER 7 | 3 MP | WA $K^-p \rightarrow \Lambda \eta$ | |

| VALUE | | | TECN | COMMENT |
|------------------------------------------|-----------------------------------------------------------------------|----------------|----------------------|----------------------------------|
| 0.035 ± 0.018 | | | | $K^- p \rightarrow \Xi K$ |
| ● ● We do not use th | e following data for average | s, fits | , limits, e | etc. • • • |
| 0.003 | MULLER | 69B | DPWA | $K^-p \rightarrow \Xi K$ |
| 0.05 | TRIPP | 67 | RVUE | $K^- p \rightarrow \Xi K$ |
| VALUE | $ \overline{K} \rightarrow \Lambda(2100) \rightarrow \Lambda \omega $ | | TECN | COMMENT |
| VALUE | | | TECN | COMMENT |
| | <u>DOCUMENT ID</u> 2 BACCARI | 77 | DPWA | COMMENT GD ₃₇ wave |
| VALUE | <u>DOCUMENT ID</u> 2 BACCARI | 77 | DPWA | GD27 wave |
| - 0.070 | DOCUMENT ID | 77 77 77 | DPWA DPWA DPWA | GD27 wave |

3 CAMERON Λ(2100) FOOTNOTES

 $^{
m 1}\,{
m The}\,$ NAKKASYAN 75 values are from the two best solutions found. Each has the $\Lambda(2100)$ and one additional resonance (P_3 or F_5).

 $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \Lambda(2100) \rightarrow N\overline{K}^*(892), S=1/2, G-\text{wave } (\Gamma_1 \Gamma_7)^{\frac{1}{2}}/\Gamma$

- 2 Note that the three for BACCARI 77 entries are for three different waves. 3 The published sign has been changed to be in accord with the baryon-first convention. The upper limit on the $\it G_3$ wave is 0.03.

Λ(2100) REFERENCES

| PDG | 86 | PL 170B 1 | M. Aguilar-Benitez et al. | (CERN, CIT+) |
|------------|------|-------------------|---------------------------|--------------------------|
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| CAMERON | 78 B | NP B146 327 | W. Cameron et al. | (RHEL, LOIC) IJP |
| DEBELLEFON | 78 | NC 42A 403 | A. de Bellefon et al. | (CDEF, SACL) IJP |
| BACCARI | 77 | NC 41A 96 | B. Baccari et al. | (SACL, CDEF)IJP |
| DECLAIS | 77 | CERN 77-16 | Y. Declais et al. | (ČAEN, CERN)IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| HEMINGWAY | 75 | NP B91 12 | R.J. Hemingway et al. | (CERN, HÈIDH, MPIM)IJP |
| NAKKASYAN | 75 | NP B93 85 | A. Nakkasyan | (CERN) IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| RADER | 73 | NC 16A 178 | R.K. Rader et al. | (SACL, HEID, CERN+) |
| LITCHFIELD | 71 | NP B30 125 | P.J. Litchfield et al. | (RHEL, CDEF, SACL)IJP |
| MULLER | 69B | Thesis UCRL 19372 | R.A. Muller | ` (LRL) |
| TRIPP | 67 | NP B3 10 | R.D. Tripp et al. | (LRL, SLAC, CERN+) |
| COOL | 66 | PRL 16 1228 | R.L. Cool et al. | (BNL) |
| WOHL | 66 | PRL 17 107 | C.G. Wohl, F.T. Solmitz, | M.L. Stevenson (LRL) IJP |

ላ(2110) 5/2⁺

 -0.04 ± 0.03

$$I(J^P) = O(\frac{5}{2}^+)$$
 Status: ***

TECN COMMENT 78B DPWA $K^-p \rightarrow N\overline{K}^*$

For results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982). All the references have been retained.

This resonance is in the Baryon Summary Table, but the evidence for it could be better.

Λ(2110) MASS

| VALUE (MeV) | DO CUMENT ID | TEC | N COMMENT |
|-------------------------------------------|--------------------------|-----------|----------------------------------------------|
| 2090 to 2140 (≈ 2110) OUR EST/I | MATE | | |
| 2092 ± 25 | GOPAL 8 | 30 DP | WA $\overline{K}N \rightarrow \overline{K}N$ |
| 2125 ± 25 | | | WA $K^-p \rightarrow N\overline{K}^*$ |
| 2106 ± 50 | DEBELLEFON 7 | 78 DP | WA $\overline{K}N \rightarrow \overline{K}N$ |
| 2140 ± 20 | | | WA $K^-p 	o \Sigma \pi$ |
| 2100 ± 50 | GOPAL 7 | 77 DP | WA KN multichannel |
| 2112 ± 7 | KANE 7 | 74 DP | WA $K^-p \rightarrow \Sigma \pi$ |
| ullet $ullet$ We do not use the following | data for averages, | fits, lim | ts, etc. • • • |
| 2137 | BACCARI 7 | 77 DP | WA $K^-p \rightarrow \Lambda \omega$ |
| 2103 | ¹ NAKKASYAN 7 | 75 DP | WA $K^-p \rightarrow \Lambda \omega$ |

Λ(2110) WIDTH

| VALUE (MeV) | DOCUMENT ID TECN COMMENT | |
|-------------------------|--------------------------------------------------------------|------|
| 150 to 250 (≈ 200) OU | IR ESTIMATE | |
| 245 ± 25 | GOPAL 80 DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| 160 ± 30 | CAMERON 78B DPWA $K^-p \rightarrow N\overline{K}$ | * |
| 251 ± 50 | DEBELLEFON 78 DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| 140 ± 20 | DEBELLEFON 77 DPWA $K^- p \rightarrow \Sigma \pi$ | |
| 200 ± 50 | GOPAL 77 DPWA \overline{K} N multicha | nnel |
| 190 ± 30 | KANE 74 DPWA $K^-p \rightarrow \Sigma \pi$ | |
| • • • We do not use the | he following data for averages, fits, limits, etc. • • • | |
| 132 | BACCARI 77 DPWA $K^-p \rightarrow \Lambda \omega$ | |
| 391 | 1 NAKKASYAN 75 DPWA $K^{-}p \rightarrow \Lambda \omega$ | |

A(2110) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 5-25 % |
| Γ_2 | $\Sigma \pi$ | 10-40 % |
| Γ_3 | $\Lambda \omega$ | seen |
| Γ_4 | $\Sigma(1385)\pi$ | seen |
| Γ_5 | $\Sigma(1385)\pi$, $	extit{P}$ -wave | |
| Γ_6 | N K* (892) | 10-60 % |
| Γ_7 | $N\overline{K}^*$ (892), S =1/2, F -wave | |
| | T1 1 1 11 6 21 | |

The above branching fractions are our estimates, not fits or averages.

Λ(2110) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|-------------------------|--------|-------------|-------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.05 to 0.25 OUR ESTIMATE | | | | | |
| 0.07 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K}$ | N |
| 0.27 ± 0.06 | ² DEBELLEFON | 78 | DPWA | $\overline{K} N \to \overline{K}$ | N |
| • • • We do not use the following | data for averages | , fits | , limits, e | etc. • • • | |
| 0.07 ± 0.03 | GOPAL | 77 | DPWA | See GOPAI | _ 80 |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to 1$ | $\Lambda(2110) \rightarrow \Sigma \pi$ | | | (Γ ₁ Γ ₂) ^{1/2} / | ′Г |
|---------------------------------------------------------------------------------------------|----------------------------------------|-------------|-------------|---------------------------------------------------|----|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $+0.14\pm0.01$ | DEBELLEFON | J 77 | DPWA | $K^- p \rightarrow \Sigma \pi$ | |
| $+0.20 \pm 0.03$ | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ | |
| • • • We do not use the follo | wing data for average | es, fits | , limits, e | etc. • • • | |
| $+0.10\pm0.03$ | GOPAL | 77 | DPWA | K N multichannel | |

$$\frac{\left(\Gamma_{I}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{\text{total in }N\overline{K}} \rightarrow \Lambda(2110) \rightarrow \Sigma(1385)\pi}{\frac{DOCUMENT D}{3} \frac{DOCUMENT D}{CAMERON 78}} \underbrace{\frac{TECN}{DPWA} \frac{COMMENT}{K^{-}p \rightarrow \Sigma(1385)\pi}}_{C = 1385)\pi}$$

$$\frac{\left(\Gamma_{i}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{\text{total in }}N\overline{K} \rightarrow \Lambda(2110) \rightarrow N\overline{K}^{*}(892)}{\frac{DOCUMENT \ IO}{17 \ IOM}} \underbrace{\frac{TECN}{K} \quad \frac{COMMENT}{K}}_{CAMEDON A 700}$$

⁴ CAMERON 78B DPWA $K^-p \rightarrow N\overline{K}^*$

Λ(2110) FOOTNOTES

³ The CAMERON 78 upper limit on F-wave decay is 0.03. The sign here has been changed to be in accord with the baryon-first convention.

Λ(2110) REFERENCES

| PDG GOPAL CAMERON CAMERON DEBELLEFON BACCARI DEBELLEFON | 82 80 78 78 B 78 77 | PL 111B 1 Toronto Conf. 159 NP B143 189 NP B146 327 NC 42A 403 NC 41A 96 NC 37A 175 | M. Roos et al. G.P. Gopal W. Cameron et al. W. Cameron et al. A. de Bellefon et al. B. Baccari et al. A de Bellefon et al. | (HELS, CIT, CERN) (RHEL) IJP (RHEL, LOIC) IJP (RHEL, LOIC) IJP (CDEF, SACL) IJP (SACL, CDEF) IJP (CDEF, SACL) IJP |
|---------------------------------------------------------------------------|------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| DEBELLEFON | | NC 37A 175 | A. de Bellefon <i>et al.</i> | (CDEF, SACL) IJP |
| GOPAL | | NP B119 362 | G.P. Gopal <i>et al.</i> | (LOIC, RHEL) IJP |
| NAKKASYAN | | NP B93 85 | A. Nakkasyan | (CERN) IJP |
| KANE | | LBL-2452 | D.F. Kane | (LBL) IJP |

 $\Lambda(2325) 3/2$

$$I(J^P) = O(\frac{3}{2})$$
 Status: *

OMITTED FROM SUMMARY TABLE

BACCARI 77 finds this state with either $J^P=3/2^-$ or $3/2^+$ in a energy-dependent partial-wave analyses of $\mathit{K}^-\,\mathit{p}\,\rightarrow\,\mathit{\Lambda}\,\omega$ from 2070 to 2436 MeV. A subsequent semi-energy-independent analysis from threshold to 2436 MeV selects $3/2^-$. DEBELLEFON 78 (same group) also sees this state in an energy-dependent partial-wave analysis of $K^- p \rightarrow \overline{K} N$ data, and finds $J^{P} = 3/2^-$ or $3/2^+$. They again prefer $J^P=3/2^-$, but only on the basis of model-dependent considerations.

 $[\]frac{1}{2}$ Found in one of two best solutions. $\frac{2}{3}$ The published error of 0.6 was a misprint.

 $^{^4}$ The published sign has been changed to be in accord with the baryon-first convention. The CAMERON 78B upper limits on the P_3 and F_3 waves are each 0.03.

$\Lambda(2325), \Lambda(2350), \Lambda(2585)$ Bumps

| | Л(2325) MASS | |
|--------------------------------------------------|-----------------------------|-------------------------------------------------------------------------------------------------|
| VALUE (MeV) | DOCUMENT ID | TECN COMMENT |
| ≈ 2325 OUR ESTIMATE 2342±30 2327±20 | DEBELLEFON 78 BACCARI 77 | |
| | Л(2325) WIDTH | |
| | | |
| VALUE (MeV) | DOCUMENT ID | TECN COMMENT |
| VALUE (MeV) 177±40 | | $\frac{\textit{TECN}}{DPWA} \; \frac{\textit{COMMENT}}{\overline{K} N \to \; \overline{K} N}$ |

| | Mode |
|-----------------------|------------------|
| $\overline{\Gamma_1}$ | ΝK |
| Γ_2 | $\Lambda \omega$ |

A(2325) BRANCHING RATIOS

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | Γ_1/Γ |
|-----------------------------------------------|---------------|------------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | TECN COMMENT | |
| 0.19 ± 0.06 | DEBELLEFON 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | |

| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Lambda(2325) \to \Lambda \omega$ | | | | (Γ₁Γ₂) ^½ /Γ |
|-----------------------------------------------------------------------------------------------------------------------------|----------------------|----|------|------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.06 ± 0.02 | | 77 | IPWA | DS ₃₃ wave |
| 0.05 ± 0.02 | ¹ BACCARI | 77 | DPWA | DD ₁₃ wave |
| 0.08 ± 0.03 | ¹ BACCARI | 77 | DPWA | DD ₃₃ wave |

Λ(2325) FOOTNOTES

 $^{1} \; \text{Note that the three BACCARI 77 entries are for three different waves.}$

A(2325) REFERENCES

DEBELLEFON 78 BACCARI 77

A. de Bellefon et al. B. Baccari et al.

(CDEF, SACL) IJP (SACL, CDEF) IJP

ለ(2350) 9/2⁺

$$I(J^P) = O(\frac{9}{2}^+)$$
 Status: ***

DAUM 68 favors $J^P = 7/2^- \text{ or } 9/2^+$. BRICMAN 70 favors $9/2^+$. LASINSKI 71 suggests three states in this region using a Pomeron + resonances model. There are now also three formation experiments from the College de France-Saclay group, DEBELLEFON 77, BACCARI 77, and DEBELLEFON 78, which find 9/2+ in energydependent partial-wave analyses of $\overline{K}N \to \Sigma \pi$, $\Lambda \omega$, and $N \overline{K}$.

Λ(2350) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|---------------------------------------------|
| 2340 to 2370 (≈ 2350) OUR ESTIM | IATE | | | |
| 2370 ± 50 | DEBELLEFON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2365 ± 20 | DEBELLEFON | 77 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 2358± 6 | BRICMAN | 70 | CNTR | Total, charge exchange |
| ullet $ullet$ We do not use the following of | data for averages | , fits, | limits, e | etc. • • • |
| 2372 | BACCARI | 77 | DPWA | $K^- p \rightarrow \Lambda \omega$ |
| 2344 ± 15 | COOL | 70 | CNTR | K^-p , K^-d total |
| 2360 ± 20 | LU | 70 | CNTR | $\gamma p \rightarrow K^+ Y^*$ |
| 2340 ± 7 | BUGG | 68 | CNTR | K^-p , K^-d total |
| | | | | |

Λ(2350) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN C | COMMENT |
|-------------------------------------------------------------------------------|--------------|----|--------|-------------------------------------------|
| 100 to 250 (≈ 150) OUR ESTIMA | TE | | | |
| 204 ± 50 | DEBELLEFON | 78 | DPWA 7 | $\overline{K}N \rightarrow \overline{K}N$ |
| 110 ± 20 | DEBELLEFON | 77 | DPWA P | $(-p \rightarrow \Sigma \pi)$ |
| 324 ± 30 | BRICMAN | 70 | CNTR T | otal, charge exchange |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 257 | BACCARI | 77 | DPWA P | $(-p \rightarrow \Lambda \omega)$ |
| 190 | COOL | 70 | CNTR P | $K^- p$, $K^- d$ total |
| 55 | LU | 70 | CNTR γ | $p \rightarrow K^+ Y^*$ |
| 140 ± 20 | BUGG | 68 | CNTR P | (-p, K-d total) |

A(2350) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------------------------|------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | ~ 12 % |
| Γ ₁ Γ ₂ Γ ₃ | $\Sigma \pi$ | $\sim 10~\%$ |
| Γ ₃ | $\Lambda \omega$ | |

The above branching fractions are our estimates, not fits or averages.

A(2350) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------------------------------------------------------------------------------|----------------------------------------|------|---------------------------------------------|
| ~ 0.12 OUR ESTIMATE 0.12 ± 0.04 | DEBELLEFON 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \to VALUE}$ | $\Lambda(2350) \rightarrow \Sigma \pi$ | TECN | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| _0.11 ± 0.02 | DEBELLEFON 77 | | |

| 0.11 ± 0.02 | DEBLEEL ON 11 | D1 11/1 | N P / Z N |
|-------------------------------------------------------------------------------------|--------------------------------------------|---------|----------------------------------------------------|
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to A$ | $\Lambda(2350) \rightarrow \Lambda \omega$ | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | TECN | COMMENT |
| < 0.05 | BACCARI 77 | DPWA | $K^-p \rightarrow \Lambda \omega$ |

Λ(2350) REFERENCES

| DEBELLEFON BACCARI | 77 | NC 42A 403 NC 41A 96 | A. de Bellefon <i>et al.</i> B. Baccari <i>et al.</i> | (CDEF, SACL) IJP (SACL, CDEF) IJP |
|-----------------------|----|-------------------------|----------------------------------------------------------|--------------------------------------|
| DEBELLEFON | 77 | NC 37A 175 | A. de Bellefon <i>et al</i> . | (CDEF, SACL)IJP |
| LAS INS KI | 71 | NP B29 125 | T.A. Lasinski | (EFI) IJP |
| BRICMAN | 70 | PL 31B 152 | C. Bricman et al. | (CERN, CAEN, SÀCL) |
| COOL | 70 | PR D1 1887 | R.L. Cool et al. | (BNL)I |
| A Iso | | PRL 16 1228 | R.L. Cool et al. | (BNL) I |
| LU | 70 | PR D2 1846 | D.C. Lu et al. | (ŶALE) |
| BUGG | 68 | PR 168 1466 | D.V. Bugg et al. | (RHEL, BIRM, CAVE) I |
| DAUM | 68 | NP B7 19 | C. Daum et al. | (CERN) JP |

1(2585) Bumps

 $\Gamma(N\overline{K})/\Gamma_{\text{total}}$

 $I(J^P) = O(?^?)$ Status: **

 Γ_1/Γ

OMITTED FROM SUMMARY TABLE

Λ(2585) MASS (BUMPS)

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|----|------|--------------------------------|
| ≈ 2585 OUR ESTIMATE | <u> </u> | | | |
| 2585 ± 45 | ABRAMS | 70 | CNTR | $K^- p$, $K^- d$ total |
| 2530 ± 25 | LU | 70 | CNTR | $\gamma p \rightarrow K^+ Y^*$ |

Λ(2585) WIDTH (BUMPS)

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------|--------------|----|------|--------------------------------|
| 300 | ABRAMS | 70 | CNTR | K^-p , K^-d total |
| 150 | LU | 70 | CNTR | $\gamma p \rightarrow K^+ Y^*$ |

Λ(2585) DECAY MODES (BUMPS)

Mode ΝK

A(2585) BRANCHING RATIOS (BUMPS)

| $(J+\frac{1}{2})\times\Gamma(NK)/\Gamma_{total}$ J is not known, so only $(J+\frac{1}{2})\times\Gamma(N\overline{K})/\Gamma_{total}$ can be given. | | | | | | | | | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----|------|------------------------|--|--|--|--|--|--|
| VALUE | DOCUMENT ID | | TECN | COMMENT | | | | | | |
| 1 | ABRAMS | 70 | CNTR | K^-p , K^-d total | | | | | | |
| 0.12 ± 0.12 | ¹ BRICMAN | 70 | CNTR | Total, charge exchange | | | | | | |

A(2585) FOOTNOTES (BUMPS)

 $^{
m 1}\,{
m The}$ resonance is at the end of the region analyzed — no clear signal.

Λ(2585) REFERENCES (BUMPS)

| ABRAMS 70 PR D1 1917 R.J. Abrams et al. | (BNL) I |
|-----------------------------------------|--------------------|
| Also PR L 16 1228 R.L. Cool et al. | (BNL) I |
| BRICMAN 70 PL 31B 152 C. Bricman et al. | (CERN, CAEN, SACL) |
| LU 70 PR D2 1846 D.C. Lu et al. | (YALE) |

Σ BARYONS (S = -1, I = 1)

 $\Sigma^+=uus$, $\Sigma^0=uds$, $\Sigma^-=dds$

$$I(J^P) = 1(\frac{1}{2}^+)$$
 Status: ***

We have omitted some results that have been superseded by later experiments. See our earlier editions.

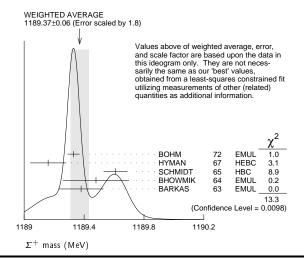
Σ+ MASS

The fit uses Σ^+ , Σ^0 , Σ^- , and Λ mass and mass-difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|---------------|----------------------|---------|-----------|------------------------------|
| 1189.37 ± 0.07 OU | R FIT Error i | ncludes scale fact | or of 2 | 2.2. | |
| 1189.37 ± 0.06 OUI | RAVERAGE | Error includes sca | le fact | or of 1.8 | . See the ideogram |
| below. | | | | | · · |
| 1189.33 ± 0.04 | 607 | ¹ вонм | 72 | EMUL | |
| 1189.16 ± 0.12 | | HYMAN | 67 | HEBC | |
| 1189.61 ± 0.08 | 4205 | SCHMIDT | 65 | HBC | See note with Λ mass |
| 1189.48 ± 0.22 | 58 | ² BHOWMIK | 64 | EMUL | |
| 1189.38 ± 0.15 | 144 | ² BARKAS | 63 | EMUL | |

 $^{^1\,\}mathrm{BOHM}$ 72 is updated with our 1973 K^- , π^- , and π^0 masses (Reviews of Modern Physics 45 S1 (1973)).

 $^{^2}$ These masses have been raised 30 keV to take into account a 46 keV increase in the proton mass and a 21 keV decrease in the π^0 mass (note added 1967 edition, Reviews of Modern Physics $\bf 39$ 1 (1967)).



Σ+ MEAN LIFE

Measurements with fewer than 1000 events have been omitted

| VALUE (10-10 s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------|--------|----------------------|------|------|------------------------------------|
| 0.8018±0.0026 OUR A | VERAGE | <u> </u> | | | |
| $0.8038 \pm 0.0040 \pm 0.001$ | 4 | BARBOSA | 00 | E761 | hyperons, 375 GeV |
| $0.8043 \pm 0.0080 \pm 0.001$ | 4 | ³ BARBOSA | 00 | E761 | hyperons, 375 GeV |
| 0.798 ±0.005 | 30k | MARRAFFIN | 08 C | НВС | K ⁻ p 0.42-0.5 GeV/c |
| 0.807 ± 0.013 | 5719 | CONFORTO | 76 | HBC | K^-p 1-1.4 GeV/c |
| 0.795 ± 0.010 | 20k | EISELE | 70 | HBC | K^-p at rest |
| 0.803 ± 0.008 | 10664 | BARLOUTAU | D 69 | НВС | K [−] p 0.4–1.2 GeV/c |
| 0.83 ± 0.032 | 1300 | ⁴ CHANG | 66 | HBC | • |

 $^{^3}$ This is a measurement of the $\overline{\Sigma}^-$ lifetime. Here we assume CPT invariance; see below for the fractional Σ^+ - $\overline{\Sigma}^-$ lifetime difference obtained by BARBOSA 00.

$$(au_{\Sigma^+} - au_{\overline{\Sigma}^-}) / au_{\Sigma^+}$$

A test of CPT invariance.

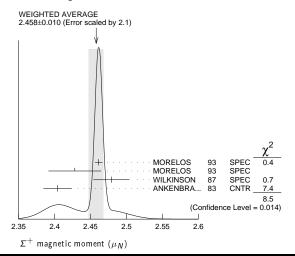
| VALUE | DO CUMENT ID T | | | COMMENT |
|--------------------------|----------------|----|------|-------------------|
| $(-6\pm12)\times10^{-4}$ | BARBOSA | 00 | E761 | hyperons, 375 GeV |

Σ+ MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings. Measurements with an error \geq 0.1 μ_N have been omitted.

| VALUE (μ_N) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|-------------|-----------------------|----------|-------|---------------------|
| 2.458 ±0.010 OUR AVER | AGE Error i | ncludes scale facto | r of 2.1 | . See | the ideogram |
| below. | | | | | |
| $2.4613 \pm 0.0034 \pm 0.0040$ | 250k | | 93 9 | SPEC | <i>p</i> Cu 800 GeV |
| 2.428 ±0.036 ±0.007 | 12k | ⁵ MORELOS | 93 9 | SPEC | p Cu 800 GeV |
| $2.479 \pm 0.012 \pm 0.022$ | 137k | WILKINSON | 87 5 | SPEC | p Be 400 GeV |
| 2.4040 ± 0.0198 | 44k | ⁶ ANKENBRA | 83 (| CNTR | p Cu 400 GeV |
| | | | | | |

 5 We assume $\it CPT$ invariance: this is (minus) the $\overline{\Sigma}^-$ magnetic moment as measured by MORELOS 93. See below for the moment difference testing $\it CPT$. 6 ANKENBRANDT 83 gives the value 2.38 \pm 0.02 μ_N . MORELOS 93 uses the same hyperon magnet and channel and claims to determine the field integral better, leading to the revised value given here.



$$\left(\mu_{\Sigma^+} \,+\, \mu_{\overline{\Sigma}^-}\right) \,\big/\, \mu_{\Sigma^+}$$

A test of CPT invariance

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-------------|--------------|------|---------------------|
| 0.014±0.015 | 7 MORELOS 93 | SPEC | <i>p</i> Cu 800 GeV |

 $^{^7}$ This is our calculation from the MORELOS 93 measurements of the Σ^+ and $\overline{\Sigma}^-$ magnetic moments given above. The statistical error on $\mu_{\overline{\Sigma}^-}$ dominates the error here.

Σ+ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) Confidence level |
|----------------|------------------|-----------------------------------------------|
| Γ ₁ | $p\pi^0$ | (51.57±0.30) % |
| Γ_2 | n π^+ | (48.31±0.30) % |
| Γ_3 | $p\gamma$ | $(1.23\pm0.05)\times10^{-3}$ |
| Γ_4 | n $\pi^+ \gamma$ | [a] (4.5 ± 0.5) $\times 10^{-4}$ |
| Γ_5 | Λ $e^+ \nu_e$ | $(2.0 \pm 0.5) \times 10^{-5}$ |

$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 1$ weak neutral current (S1) modes

| | | | | | |
|------------|---------------------------------|------------|-------|--------------------|-----|
| Γ_6 | n e $^+ u_e$ | SQ | < 5 | $\times 10^{-6}$ | 90% |
| Γ_7 | n $\mu^+ u_\mu$ | SQ | < 3.0 | $\times 10^{-5}$ | 90% |
| Γ8 | p e ⁺ e ⁻ | S1 | < 7 | $\times 10^{-6}$ | |
| Го | $p \mu^{+} \mu^{-}$ | <i>S</i> 1 | (9 +9 | $) \times 10^{-8}$ | |

[a] See the Listings below for the pion momentum range used in this mea-

CONSTRAINED FIT INFORMATION

An overall fit to 2 branching ratios uses 14 measurements and one constraint to determine 3 parameters. The overall fit has a $\chi^2 =$ 7.7 for 12 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j \rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{\mathrm{total}}$. The fit constrains the x_i whose labels appear in this array to sum to

$$\begin{array}{c|cccc} x_2 & -100 & \\ x_3 & 12 & -14 \\ \hline & x_1 & x_2 \end{array}$$

⁴ We have increased the CHANG 66 error of 0.018; see our 1970 edition, Reviews of Modern Physics 42 87 (1970).

| | Σ+ | BRANCHING | RATIOS | | | | $^+ u_e)/\Gamma(\Sigma^-$ - | | | | | $\Gamma_6/\Gamma_3^{\Sigma^2}$ |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|-----------------------------------------------------|---------------------------|------------------------------------------------------------|-------------------------|-----------------------------------------------------|-------------------------------------------|-----------------------------------------------|---------------------------|------------------------------|-----------------------------------------------------|--------------------------------|
| $\Gamma(n\pi^+)/\Gamma(N\pi)$ | | | | | $(\Gamma_1 + \Gamma_2)$ | <u>∨ALUE</u> <0.009 OUR I | <u>CL% EVTS</u> L IMIT Our 90% | <u>DOCUMENT ID</u> CL limit, using Γ(| | $\frac{ECN}{\Gamma(n\pi^+)}$ | | |
| ALUE 0.4836±0.0030 OUR | <u>EVTS</u> | DOCUMENT ID | TE | CN COMMENT | | | | ring data for averag | | . , | | |
| .4836±0.0030 OUR | | | | | | < 0.019 | 90 0 | EBENHOH | | | − _{p at rest} | |
| $.4828 \pm 0.0036$ | 10k | ⁸ MARRAFFING | | | ${\sf GeV}/c$ | < 0.018 | 90 0 | SECHI-ZOR N | | | p at rest | |
| .488 ±0.008 .484 ±0.015 | 1861 537 | NOWAK TOVEE | 78 HE 71 EN | | | < 0.12 | 95 0 | COLE | | | p at rest | |
| 0.488 ± 0.010 | 1331 | BARLOUTAU | | | GeV / c | < 0.03 | 90 0 | EISELE | 69B HI | 3C See | e EBENHO | H 74 |
| .46 ±0.02 | 534 | CHANG | 66 HE | | , | $\Gamma(\Sigma^+ \to n\mu$ | $(+ \nu_{\mu})/\Gamma(\Sigma^{-}$ | $\rightarrow n \mu^- \overline{\nu}_{\mu}$ | | | | $\Gamma_7/\Gamma_4^{\Sigma}$ |
| .490 ±0.024 | 308 | HUMPHREY | | | | VALUE | EVTS | DO CUMENT ID | | | DMMENT | '' 4 |
| ⁸ MARRAFFINO 80 | actually giv | $/es \Gamma(p\pi^0)/\Gamma(tot)$ | al) = 0.51 | 72 ± 0.0036. | | <0.12 OUR LI | MIT Our 90% | CL limit, using $\Gamma(n)$ | $\mu^+ \nu_{\mu})/\Gamma$ | $(n\pi^+)$ a | above. | |
| $\Gamma(\rho\gamma)/\Gamma(\rho\pi^0)$ | | | | | Γ_3/Γ_1 | • • • We do n | not use the follow | ring data for averag | es, fits, lir | nits, etc. | • • • | |
| ALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TE | CN COMMENT | | $0.06 + 0.045 \\ -0.03$ | 2 | EISELE | 69B H | вс <i>к</i> - | – p at rest | |
| .38±0.10 OUR FIT | DACE | | | | | -0.03 | | | | | • | |
| .38±0.10 OUR AVE .32±0.11±0.10 | RAGE 32k | TIMM | 95 E7 | 61 Σ ⁺ 375 GeV | | | $^+\nu)/\Gamma(\Sigma^- \rightarrow$ | nℓ ⁻ v) | | (Γ ₆ - | +Γ ₇)/(Γ ₃ Σ | -+Γ <u>Σ</u> - |
| $.81 \pm 0.39 + 0.21 \\ -0.43$ | 408 | HESSEY | | ITR $K^-p \rightarrow \Sigma^+$ | π^- at | Test of Z | $\Delta S = \Delta \dot{Q}$ rule. EVTS | DO CUMENT ID | Tí | ECN_ | | |
| | | 9 KOBAYASHI | 07 61 | ITR $\pi^+ \stackrel{\text{rest}}{p} \rightarrow \Sigma^+$ | , u. | | | <u>υσουμέντης</u> CL limit, using Γ | | | ±ν.)]/[(n | 2π±) |
| 2.5 2 ± 0.28 | 190 | | | | | | | ring data for averag | | | | ,,,, |
| $2.46 + 0.30 \\ -0.35$ | 155 | BIAGI | | ITR CERN hyperon | | <0.08 | iot use the follow | NORTON | 69 HI | | ••• | |
| 2.11±0.38 2.1 ±0.3 | 46 45 | MA NZ A NG | 80 НЕ 69в НЕ | | π | < 0.08 | 0 | BAGGETT | 67 HI | | | |
| 1.76±0.51 | 31 | GERSHWIN | 69B HE | | π^- | | | | | | | |
| 3.7 ±0.8 | 24 | BAZIN | 65 HE | SC K ⁻ p at rest | | | Σ | + DECAY PARA | METER | :S | | |
| ⁹ KOBAYASHI 87 a | ctually gives | $\Gamma(p\gamma)/\Gamma(\text{total})$: | $=(1.30 \pm$ | $0.15) \times 10^{-3}$. | | See th | ne "Note on Barr | yon Decay Paramet | ers" in the | e neutror | n Listinas | Δ |
| $(n\pi^+\gamma)/\Gamma(n\pi^+)$ | | | | | Γ_4/Γ_2 | | arly results have I | | 213 111 1110 | . ilcutron | i Listings. 7 | |
| | | iffer so we do no | t average | the results but simp | | α_0 FOR Σ^+ | 0 | | | | | |
| latest value in ti | | | | ine results but simp | , ase the | VALUE | $\rightarrow p\pi^{\circ}$ | DO CUMENT ID | TI | FCN CO | OMMENT | |
| /ALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | TE | | | -0.980+0.017 | | | | | | |
| 0.93±0.10 | 180 | EBENHOH | 73 HE | | V/c | | | | | | | |
| • We do not use | | | | | V / | -0.980 + 0.017 | OUR AVERAGI | E | | | | |
| 0.27 ± 0.05 1.8 | 29 | A NG BA ZI N | 69в НЕ 65в НЕ | | | $-0.945 + 0.055 \\ -0.042$ | 1259 | ¹⁵ LIPMAN | 73 O | SPK π† | $p \rightarrow \Sigma^+$ | |
| | | DILLIN | 000 112 | , C % < 110 WK | . • / • | -0.940 ± 0.042 | | BELLA MY | | | $+ p \rightarrow \Sigma^{+}$ | |
| $(\Lambda e^+ \nu_e) / \Gamma_{\text{total}}$ | | | | | Г ₅ /Г | $-0.98 \begin{array}{l} +0.05 \\ -0.02 \end{array}$ | 1335 | ¹⁶ HARRIS | | | $p \rightarrow \Sigma^+$ | |
| ALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | <u>TE</u> | CN COMMENT | | | | | | | • | |
| 2.0 ± 0.5 OUR AVERA 6 ± 0.7 | 1 GE 5 | BALTAY | 69 HE | SC K-pat rest | | -0.999 ± 0.022 | | BANGERTER | . 69 Н | BC K⁻ | [—] р 0.4 GeV | 1/c |
| 2.9 ± 1.0 | 10 | EISELE | 69 HE | | | | ons scattered off ons scattered off | | | | | |
| 2.0 ± 0.8 | 6 | BARASH | 67 HE | $K^-\rho$ at rest | | · · | | • | | | | 0.1 |
| $\Gamma(ne^+\nu_e)/\Gamma(n\pi^+$ |) | | | | Γ_6/Γ_2 | φ ₀ ANGLE F | FOR $\Sigma^+ \to p$ | DO CUMENT ID | т. | ECN CO | (ταπ φ₀ Эммент | $_0 = eta/\gamma$ |
| Test of $\Delta S = \Delta S$ | ΔQ rule. Exp | periments with an | effective (| lenominator less tha | | 36 ±34 OU | | DO COMENT ID | | <u>.cw</u> <u>co</u> | MINIENT | |
| have been omitt EFFECTIVE DENOM. EV | | OCUMENT ID | TECN | COMMENT | | $38.1 + 35.7 \\ -37.1$ | 1259 | ¹⁷ LIP MAN | 73 O | SPK π^+ | $p \rightarrow \Sigma^+$ | κ^+ |
| < 1.1 × 10 ⁻⁵ OUR L | | | | | ator | - 37.1 22 ± 90 | | ¹⁸ HARRIS | 70 O | SPK π^+ | $p \rightarrow \Sigma^{+}$ | ĸ+ |
| um). [Number of eve | ents increase | d to 2.3 for a 90% | % confiden | ce level.] | | | on scattered off | | | | , | |
| .11000 .05000 | | BENHOH 74 ECHI-ZORN 73 | | K [−] p at rest K [−] p at rest | | | ons scattered off | | | | | |
| ¹⁰ Effective denomina | | | пьс | r parresi | | α_{+} / α_{0} | | | | | | |
| | | ed by us. | | | | Older res | sults have been o | | | | | |
| $(n\mu^+\nu_\mu)/\Gamma(n\pi^+$ |) | | | | Γ_7/Γ_2 | $\frac{VALUE}{-0.069 \pm 0.013}$ | EVTS LOUR FIT | DO CUMENT ID | <u>TE</u> | ECN CO | DMMENT | |
| Test of $\Delta S = \Delta S$ | AQ rule. <u>/TS D</u> / | OCUMENT ID | TECN | | | -0.073±0.021 | | MARRAFFIN | O 80 H | вс <i>к</i> - | - _p 0.42-0.5 | 5 GeV/ <i>c</i> |
| $< 6.2 \times 10^{-5}$ OUR L | I MIT Our | 90% CL limit = (| 6.7 events |)/(effective denomin | ator | 50D E4 | | | | | | |
| ium). [Number of eve 33800 | ents increase | d to 6.7 for a 90% | % confiden 3 HBC | ce level.] | | α_+ FOR Σ^+ | · → Ππ ⁺ EVTS | DO CUMENT ID | 7. | ECN CO | OMMENT | |
| 52000 52000 | | SELE 69B | | | | 0.068±0.013 C | | DO COMENT ID | | (1) | MINIETN I | |
| 0150 | 0 12 C | OURANT 64 | НВС | | | | OUR AVERAGE | | | | | |
| 1710 | | AUENBERG 64 | HBC | | | 0.037 ± 0.049 | 4101 | BERLEY | 70B HI | | = - 0.4 C-V | |
| 120 11 Effective denomina | | ALTIERI 62 | EMUL | | | 0.069 ± 0.017 | 35k | BANGERTER | υυ HI | BC K- | — р 0.4 GeV | ,/, |
| 12 Effective denomina | | | | | | ϕ_+ ANGLE I | FOR $\Sigma^+ ightarrow \iota$ | π^+ | | | | $_{\perp} = \beta / \gamma$ |
| | | " | | | F /F | VALUE (°) | EVTS | DO CUMENT ID | | | MMENT | |
| Γ(p e ⁺ e ⁻)/Γ _{total} | | | | | Г ₈ /Г | 167±20 OUR . 184±24 | AVERAGE Erro 1054 | r includes scale fact ¹⁹ BERLEY | tor of 1.1. 70B HI | | | |
| 'ALUE (units 10 ⁻⁶) | | 13 ANG | | CN COMMENT | | 143±29 | 560 | BANGERTER | | | - _{р 0.4} GeV | I/c |
| < 7 | 1 - | | 69B HE | • | | | | to agree with our si | | | • | , |
| | | | | $\gamma \rightarrow e^+e^-$ conver | sion from | | | J 2. | J | | | |
| | giveii i | .c.c is for incutial | cum cirtă. | | | $α_γ$ FOR Σ ⁺ | | DOCUMENT IS | Ŧ. | ECN CO | OMMENT | |
| $\Sigma^+ 	o ho \gamma$. The | _ 11- | outral current by | also all- | od by higher " | Γg/Γ | | OUR AVERAGE | <u>DO CUMENT ID</u> | | .c/v <u>CO</u> | WIVENI | |
| $\Sigma^+ 	o ho \gamma$. The $\Gamma(ho \mu^+ \mu^-)/\Gamma_{ m total}$ | = I weak ne | oural current, but | aiso allow | eu by nigher-order el | crioweak | -0.720 ± 0.086 | 6 ± 0.045 35 k | ²⁰ FOUCHER | | | + 375 GeV | |
| $\Sigma^+ 	o p \gamma$. The | | DO CUMENT ID | TE | CN COMMENT | | -0.86 ± 0.13 | $\pm0.04\qquad 190$ | KOBAYASHI | | | $p \rightarrow \Sigma^+$ | |
| $\Sigma^+ \to p \gamma$. The $\Gamma(p \mu^+ \mu^-)/\Gamma_{total}$ A test for a ΔS interactions. (ALUE (units 10^{-8}) | EVTS | DO COMENT ID | | | | $-0.53 \begin{array}{l} +0.38 \\ -0.36 \end{array}$ | 4.6 | MANZ | 80 HI | BC K | | · _{\pi} - |
| $\Sigma^+ \to p \gamma$. The $\Gamma \left(p \mu^+ \mu^- \right) / \Gamma_{\text{total}}$ A test for a ΔS interactions. (ALUE (units 10^{-8}) | | 14 PARK | 05 HY | ′CP <i>p</i> Cu,800 GeV | | -0.55 -0.36 | 46 | IVIAINZ | 00 H | DC N | $-p \rightarrow \Sigma^+$ | |
| $\Sigma^+ \rightarrow \rho \gamma$. The $\Gamma(\rho \mu^+ \mu^-)/\Gamma_{\text{total}}$ A test for a ΔS interactions. ALUE (units 10^{-8}) $1.6 + 6.6 \pm 5.5$ | 3 | 14 PARK | | • | | | 61 | GERSHWIN | | | $-p \rightarrow \Sigma^+$ $-p \rightarrow \Sigma^+$ | |
| $\Sigma^+ \to p \gamma$. The $\Gamma(p \mu^+ \mu^-)/\Gamma_{\rm total}$ A test for a $\Delta S_{\rm interactions.}$ ALUE (units 10^{-8}) $1.6 + 6.6 \pm 5.5$ 14 The masses of the | 3 three dimud | 14 PARK | re within 1 | MeV of one anothe | , perhaps | $-1.03 \begin{array}{l} +0.52 \\ -0.42 \end{array}$ | 61 | GERSHWIN | 69в НI | | | |
| $\Sigma^+ \to p \gamma$. The $\left(p \mu^+ \mu^- \right) / \Gamma_{\text{total}}$ A test for a ΔS interactions. ALUE (units 10^{-8}) $6 + \frac{6}{5} \cdot 4 \pm 5 \cdot 5$ 14 The masses of the indicating the exist | 3 three dimud | 14 PARK ons of PARK 05 are we state P^0 with | re within 1 mass 214.3 | • | , perhaps case, the | $-1.03 \begin{array}{l} +0.52 \\ -0.42 \end{array}$ | 61 | | 69в НI | | | |

Σ⁺ REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

| PARK 05 | | | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|------|------------------|---------------------|------------------------|
| TIMM | PARK (| 05 | PRL 94 021801 | H.K. Park et al. | (FNAL HyperCP Collab.) |
| MORELOS 93 PRI. 71 3417 A Morelos et al FMAL E751 Collab FOUCHER 92 PRI. 68 3004 M. Foucher et al (FMAL E751 Collab) HESSEY 92 PPHY C42 175 M. P. Hessey et al (FMAL E751 Collab) HESSEY 93 PRI. 98 68 M. Kobayashi et al (KYOT) (KYOT) WILKINSON 87 PRI. 58 658 M. Kobayashi et al (CERN WA62 Collab) PRI. 58 658 M. Kobayashi et al (CERN WA62 Collab) PRI. 58 658 M. Kobayashi et al (CERN WA62 Collab) PRI. 58 658 M. Kobayashi et al (CERN WA62 Collab) PRI. 58 659 PRI. 58 639 BARBOSA (| 00 | PR D61 031101R | R.F. Barbosa et al. | (FNAL E761 Collab.) |
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| HARRIS 70 | | | | | |
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$$I(J^P) = 1(\frac{1}{2}^+)$$
 Status: ***

COURANT 63 and ALFF 65, using $\Sigma^0
ightarrow \varLambda \, e^+ \, e^-$ decays (Dalitz decays), determined the Σ^0 parity to be positive, given that J=1/2and that certain very reasonable assumptions about form factors are true. The results of experiments involving the Primakoff effect, from which the Σ^0 mean life and $\Sigma^0 \to \Lambda$ transition magnetic moment come (see below), strongly support J=1/2.

Σ^0 MASS

The fit uses Σ^+ , Σ^0 , Σ^- , and Λ mass and mass-difference measurements.

| VALUE (MeV) | | EVTS | DO CUMENT I | 'D | TECN | COMMENT |
|-------------|-------------------|-----------|-------------------|-------------|-----------|---------------------------------|
| 1192.642±0 | 0.024 OUR FIT | | | | | |
| • • • We d | o not use the t | following | data for average | s, fits, li | mits, etc | . • • • |
| 1192.65 ±0 | 0.020 ± 0.014 | 3327 | ¹ WANG | 97 | SPEC | $\Sigma^0 	o \Lambda \gamma 	o$ |
| | | | | | | $(p\pi^{-})(e^{+}e^{-})$ |

 $^1\,\text{This}$ WANG 97 result is redundant with the $\varSigma^0\text{--}\!\varLambda$ mass-difference measurement below.

$m_{\Sigma^-} - m_{\Sigma^0}$

| VALUE (| MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------|---------|--------------|-----------------------|--------|---------|------------------------------|
| 4.807± | 0.035 C | UR FIT Error | includes scale factor | of 1.1 | | |
| 4.86 ± | :0.08 C | UR AVERAGE | Error includes scale | factor | of 1.2. | |
| $4.87 \pm$ | 0.12 | 37 | DOSCH | 65 | HBC | |
| 5.01 ± | 0.12 | 12 | SCHMIDT | 65 | HBC | See note with Λ mass |
| 4.75 ± | 0.1 | 18 | BURNSTEIN | 64 | HBC | |

$m_{\Sigma^0} - m_{\Lambda}$

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|------|-------------|----|------|---------------------------------------------------|
| 76.959±0.023 OUR FIT | • | | | | |
| $76.966 \pm 0.020 \pm 0.013$ | 3327 | WANG | 97 | SPEC | $\Sigma^0 \rightarrow \Lambda \gamma \rightarrow$ |
| | | | | | (p ==) (a ± a =) |

 $(p\,\pi^-)\stackrel{\cdot}{(}e^+\,e^-)$ • • • We do not use the following data for averages, fits, limits, etc. • • •

| 76.23 ± 0.55 | 109 | COLAS | 75 | HLBC | $\Sigma^0 \rightarrow \Lambda \gamma$ |
|--------------|-----|---------|----|------|---------------------------------------|
| 76.63 ±0.28 | 208 | SCHMIDT | 65 | HBC | See note with Λ mass |

Σ^0 MEAN LIFE

These lifetimes are deduced from measurements of the cross sections for the Primakoff process $\Lambda \to \Sigma^0$ in nuclear Coulomb fields. An alternative expression of the same information is the Σ^0 - Λ transition magnetic moment given in the following section. The relation is $(\mu_{\Sigma}_{\Lambda}/\mu_{N})^2$ $\tau=$ 1.92951×10^{-19} s (see DEVLIN 86).

| VALUE (10 ⁻²⁰ s) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|------------------------------------|----------|-----------|---------------------------|
| 7.4±0.7 OUR EVALUATION | Using $\mu_{\sum \Lambda}$ (see th | e abov | re note). | |
| $6.5 + 1.7 \\ -1.1$ | ² DEVLIN | 86 | SPEC | Primakoff effect |
| $7.6 \pm 0.5 \pm 0.7$ | ³ PETERSEN | 86 | SPEC | Primakoff effect |
| | owing data for averag | es, fits | , limits, | etc. • • • |
| $5.8 \!\pm\! 1.3$ | ² DYDAK | 77 | SPEC | See DEVLIN 86 |
| ² DEVLIN 86 is a recalculat | ion of the results of C | YDAk | 77 rem | oving a numerical approx- |

imation made in that work. 3 An additional uncertainty of the Primakoff formalism is estimated to be < 5%.

$|\mu(\Sigma^0 \to \Lambda)|$ Transition magnetic moment

See the note in the $\boldsymbol{\Sigma}^0$ mean-life section above. Also, see the "Note on Baryon Magnetic Moments" in the A Listings.

| VALUE (μ_N) | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|------------------------|----------|-----------|------------------|
| 1.61±0.08 OUR AVERAGE | | | | |
| $1.72 + 0.17 \\ -0.19$ | ⁴ DEVLIN | 86 | SPEC | Primakoff effect |
| $1.59 \pm 0.05 \pm 0.07$ | ⁵ PETERSEN | 86 | SPEC | Primakoff effect |
| • • • We do not use the foll | owing data for average | es, fits | , limits, | etc. • • • |
| $1.82 + 0.25 \\ -0.18$ | ⁴ DYDAK | 77 | SPEC | See DEVLIN 86 |

⁴ DEVLIN 86 is a recalculation of the results of DYDAK 77 removing a numerical approximation made in that work. 5 An additional uncertainty of the Primakoff formalism is estimated to be < 2.5%.

Σ^0 DECAY MODES

| | Mode | Fraction (I _i /I) | Confidence level |
|------------|-------------------------|------------------------------|------------------|
| Γ_1 | $\Lambda\gamma$ | 100 % | _ |
| Γ_2 | $\Lambda \gamma \gamma$ | < 3 % | 90% |
| Γ_3 | $\Lambda e^+ e^-$ | [a] 5×10^{-3} | |

[a] A theoretical value using QED.

Σ⁰ BRANCHING RATIOS

| $\Gamma(\Lambda\gamma\gamma)/\Gamma_{ m total}$ | | | | Γ_2/Γ |
|-------------------------------------------------|-----|--------------|------|-------------------|
| VALUE | CL% | DO CUMENT ID | TECN | |
| -0.02 | 0.0 | COLAC | | |

 $\Gamma(\Lambda e^+e^-)/\Gamma_{total}$ See COURANT 63 and ALFF 65 for measurements of the invariant-mass spectrum of the Dalitz nairs

| 0.00545 | FEINBERG | 58 | Theoretical QED calculation | |
|---------|--------------|----|-----------------------------|--|
| VALUE | DO CUMENT ID | | COMMENT | |

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| PETERSEN | 86 | PRL 57 949 | P.C. Petersen et al. | (RUTG, WISC, MICH+) |
| DYDAK | 77 | NP B118 1 | F. Dydak et al. | (CERN, DORT, HEIDH) |
| COLAS | 75 | NP B91 253 | J. Colas et al. | (ORSAY) |
| ALFF | 65 | PR 137 B1105 | C. Alff et al. | (COLU, RUTG, BNL)P |
| DOSCH | 65 | PL 14 239 | H.C. Dosch et al. | (HEID) |
| SCHMIDT | 65 | PR 140B 1328 | P. Schmidt | (ČOLU) |
| BURNSTEIN | 64 | PRL 13 66 | R.A. Burnstein et al. | (UMD) |
| COURANT | 63 | PRL 10 409 | H. Courant et al. | (CERN, UMD) P |
| FEINBERG | 58 | PR 109 1019 | G. Feinberg | ` (BNL) |

 Σ^{-}



 $I(J^P) = 1(\frac{1}{2}^+)$ Status: ***

We have omitted some results that have been superseded by later experiments. See our earlier editions.

Σ^- MASS

The fit uses Σ^+ , Σ^0 , Σ^- , and Λ mass and mass-difference measurements.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------------------------|-----------|--------------------|----------|-----------|---------------------------------------|
| 1197.449±0.030 OUF | FIT Error | includes scale fa | actor of | 1.2. | |
| 1197.45 ±0.04 OUF | R AVERAGE | Error includes | scale fa | ctor of 1 | 1.2. |
| 1197.417 ± 0.040 | | GUREV | 93 | SPEC | Σ^- C atom, crystal |
| 1197.532 ± 0.057 | | GALL | 88 | CNTR | Σ^{-} Pb, Σ^{-} W atoms |
| 1197.43 ± 0.08 | 3000 | SCHMIDT | 65 | HBC | See note with Λ mass |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| 1197.24 ±0.15 | | ¹ DUGAN | 75 | CNTR | Exotic atoms |

 $^{1\,\}mathrm{GALL}$ 88 concludes that the DUGAN 75 mass needs to be reevaluated.

$m_{\Sigma^-} - m_{\Sigma^+}$

| VALUE (MeV) | EVTS | DO CUMENT II | ס | TECN | | |
|-------------------------------------------------------|------|--------------|----|------|--|--|
| 8.08±0.08 OUR FIT Error includes scale factor of 1.9. | | | | | | |
| 8.09±0.16 OUR AVERAGE | | | | | | |
| 7.91 ± 0.23 | 86 | BOHM | 72 | EMUL | | |
| $8.25 \pm 0.25 $ | 2500 | DOSCH | 65 | HBC | | |
| 8.25 ± 0.40 | 87 | BARKAS | 63 | EMUL | | |

$m_{\Sigma^-} - m_{\Lambda}$

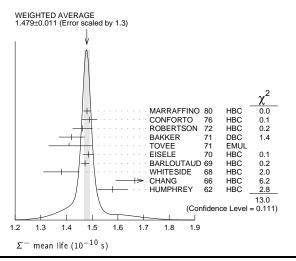
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-------------|--------------------|--------|------|------------------------------|
| 81.766±0.030 OUR FI | F Error inc | cludes scale facto | r of 1 | .2. | |
| 81.69 ±0.07 OUR AV | ERAGE | | | | |
| 81.64 ± 0.09 | 2279 | HEPP | 68 | HBC | |
| 81.80 ± 0.13 | 85 | SCHMIDT | 65 | HBC | See note with Λ mass |
| 81.70 ± 0.19 | | BURNSTEIN | 64 | HBC | |

Σ- MEAN LIFE

Measurements with an error $~\geq~0.2 \times 10^{-10}~\text{s}$ have been omitted.

| 10 | | | | | |
|-------------------------------|--------|----------------------|--------|---------|--------------------------------------|
| VALUE (10 ⁻¹⁰ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.479±0.011 OUR A | VERAGE | Error includes scale | factor | of 1.3. | See the ideogram below. |
| 1.480 ± 0.014 | 16k | MARRAFFINO | 80 | HBC | K^-p 0.42-0.5 GeV/ c |
| 1.49 ± 0.03 | 8437 | CONFORTO | 76 | HBC | K^-p 1–1.4 GeV/ c |
| 1.463 ± 0.039 | 2400 | ROBERTSON | 72 | HBC | K^-p 0.25 GeV/c |
| 1.42 ± 0.05 | 1383 | BAKKER | 71 | DBC | $K^- N \rightarrow \Sigma^- \pi \pi$ |
| $1.41 \ ^{+ 0.09}_{- 0.08}$ | | TOVEE | 71 | EMUL | |
| 1.485 ± 0.022 | 100k | EISELE | 70 | HBC | K^-p at rest |
| 1.472 ± 0.016 | 10k | BARLOUTAUD | 69 | HBC | K - p 0.4-1.2 GeV/c |
| 1.38 ± 0.07 | 506 | WHITESIDE | 68 | HBC | K^-p at rest |
| 1.666 ± 0.075 | 3267 | ² CHANG | 66 | HBC | K^-p at rest |
| 1.58 ± 0.06 | 1208 | HUMPHREY | 62 | HBC | K^-p at rest |
| | | | | | |

 $^{^2\,\}text{We}$ have increased the CHANG 66 error of 0.026; see our 1970 edition, Reviews of Modern Physics 42 87 (1970).

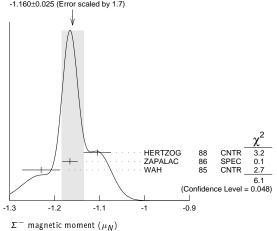


Σ^- MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the \varLambda Listings. Measurements with an error $\,\geq 0.3~\mu_{\, N}$ have been omitted.

| VALUE (μ_N) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------|--------------|----------------------------|-------------|---------|--------------------------------|
| -1.160 ± 0.025 OUR AVERAGE | E Error inc | ludes scale facto | r of 1 | .7. See | the ideogram |
| below. $-1.105 \pm 0.029 \pm 0.010$ | | HERTZOG | 88 | CNTR | Σ^- Pb, Σ^- W |
| $-1.166\pm0.014\pm0.010$ | 671k | ZAPALAC | 86 | SPEC | $ne^-\nu$, $n\pi^-$ decays |
| $-1.23 \pm 0.03 \pm 0.03$ • • • We do not use the follow | ving data fo | WAH r averages, fits, l | 85 imits | | $p Cu \rightarrow \Sigma^- X$ |
| -0.89 ± 0.14 | 516k | DECK | 83 | | $p Be 	o \Sigma^- X$ |





Σ- CHARGE RADIUS

| VALUE (fm) | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|----------------------------|------|----------|-------------------------------------|
| 0.780±0.080±0.060 | 3 ESCHRICH | 01 | SELX | $\Sigma^- e \rightarrow \Sigma^- e$ |
| 3 ESCHRICH 01 actually gives | $(r^2) = (0.61 \pm 0.000)$ | 12 + | 0 09) fm | 2 |

Σ^- DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------------------|----------------------------------------|
| Γ ₁ | $n\pi^-$ | (99.848 ± 0.005) % |
| Γ_2 | n $\pi^-\gamma$ | [a] (4.6 ± 0.6) $\times 10^{-4}$ |
| Γ_3 | n e $^-\overline{ u}_e$ | $(1.017 \pm 0.034) \times 10^{-3}$ |
| Γ_4 | n $\mu^-\overline{ u}_\mu$ | $(4.5 \pm 0.4) \times 10^{-4}$ |
| Γ_5 | $\Lambda e^{-} \overline{\nu}_{e}$ | $(5.73 \pm 0.27) \times 10^{-5}$ |

[a] See the Listings below for the pion momentum range used in this measurement.

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 16 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2=8.7$ for 13 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one

Σ- BRANCHING RATIOS

 $\Gamma(n\pi^-\gamma)/\Gamma(n\pi^-)$

 Γ_2/Γ_1

The π^+ momentum cuts differ, so we do not average the results but simply use the latest value for the Summary Table.

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|-------------------|---------|-----------|-------------------------|
| 0.46 ± 0.06 | 292 | EBENHOH | 73 | нвс | π^+ < 150 MeV/c |
| • • • We do not use the | following d | lata for averages | , fits, | limits, e | etc. • • • |
| 0.10 ± 0.02 | 23 | ANG | 69B | нвс | $\pi^ < 110~{ m MeV}/c$ |
| ~ 1.1 | | BAZIN | 65B | HB C | $\pi^ < 166~{ m MeV}/c$ |
| | | | | | |

| $\Gamma(ne^-\overline{\nu}_e)/\Gamma(n\pi^-)$ | Γ_3/Γ_1 |
|------------------------------------------------------------------------|---------------------|
| Measurements with an error $\geq 0.2 	imes 10^{-3}$ have been omitted. | |

| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|--------|-------------------------|-----|------|------------------|
| 1.019±0.035 OUR F | Т | | | | |
| 1.019+0.031 OUR A | VERAGE | | | | |
| 0.96 ± 0.05 | 2847 | BOURQUIN | 83c | SPEC | SPS hyperon beam |
| $1.09 \begin{array}{l} +0.06 \\ -0.08 \end{array}$ | 601 | ⁴ EBENHOH | 74 | нвс | K^-p at rest |
| $1.05 \begin{array}{c} +0.07 \\ -0.13 \end{array}$ | 455 | ⁴ SECHI-ZORN | 73 | нвс | K^-p at rest |
| 0.97 ± 0.15 | 57 | COLE | 71 | HBC | K−p at rest |
| 1.11 ± 0.09 | 180 | BIERMAN | 68 | HBC | |

 $^{^4\,\}mbox{An}$ additional negative systematic error is included for internal radiative corrections and latest form factors; see BOURQUIN 83C.

| $\Gamma(n\mu^-\overline{\nu}_\mu)/\Gamma(n\pi^-$ | -) | | | | | Γ_4/Γ_1 |
|------------------------------------------------------|------|--------------|-----|------|----------------|---------------------|
| VALUE (units 10 ⁻³) | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| 0.45 ± 0.04 OUR FIT | | <u> </u> | | | | |
| 0.45 ± 0.04 OUR AVE | RAGE | | | | | |
| 0.38 ± 0.11 | 13 | COLE | 71 | HBC | K^-p at rest | |
| 0.43 ± 0.06 | 72 | A NG | 69 | HBC | K^-p at rest | |
| 0.43 ± 0.09 | 56 | BAGGETT | 69 | HBC | K^-p at rest | |
| 0.56 ± 0.20 | 11 | BAZIN | 65B | HBC | K^-p at rest | |
| 0.66 ± 0.15 | 22 | COURANT | 64 | HBC | | |
| $\Gamma(\Lambda e^- \overline{\nu}_e)/\Gamma(n\pi^-$ | -) | | | | | Γ_5/Γ_1 |
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.574±0.027 OUR FI | T | · | | | | |

| . (/ic Pe)/! (// | · <i>)</i> | | | | .2/.1 |
|--------------------------|------------|-----------------------|----|------|--------------------------|
| VALUE (units 10^{-4}) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.574±0.027 OUR | FIT | · | | | |
| 0.574±0.027 OUR | AVERAGE | | | | |
| 0.561 ± 0.031 | 1620 | ⁵ BOURQUIN | 82 | SPEC | SPS hyperon beam |
| 0.63 ± 0.11 | 114 | THOMPSON | 80 | ASPK | Hyperon beam |
| 0.52 ± 0.09 | 31 | BALTAY | 69 | HBC | K−p at rest |
| 0.69 ± 0.12 | 31 | EISELE | 69 | HBC | K−p at rest |
| 0.64 ± 0.12 | 35 | BARASH | 67 | HBC | K^-p at rest |
| 0.75 ± 0.28 | 11 | COURANT | 64 | HBC | K [−] p at rest |
| _ | | | | | |

⁵ The value is from BOURQUIN 83B, and includes radiation corrections and new acceptance.

Σ- DECAY PARAMETERS

See the "Note on Baryon Decay Parameters" in the neutron Listings. Older, outdated results have been omitted.

α_- FOR $\Sigma^- \to n\pi^-$

| -0.068 ± 0.008 OUR AV | ERAGE | | | | |
|-----------------------------|-------------------------|---------------------|------------|----------|------------------------------------|
| -0.062 ± 0.024 | 28k | HANSL | 78 | HBC | $K^- p \rightarrow \Sigma^- \pi^+$ |
| -0.067 ± 0.011 | 60k | BOGERT | 70 | HBC | K^-p 0.4 GeV/c |
| -0.071 ± 0.012 | 51k | BANGERTER | 69 | HBC | K-p 0.4 GeV/ c |
| | | | | | |
| ϕ ANGLE FOR Σ^- | \rightarrow $n\pi^-$ | | | | $(an \phi = eta / \gamma)$ |
| φ ANGLE FOR Σ ⁻ | | DOCUMENT ID | | TECN | $(\tan \phi = \beta / \gamma)$ |
| • | EVTS | DOCUMENT ID | | TECN | |
| VALUE (°) | <u>EVTS</u> E | DOCUMENT ID BERLEY | 70B | TECN HBC | |
| VALUE (°) 10±15 OUR AVERAG | <u>EVTS</u> E | | 70в 69в | | COMMENT |

⁶BERLEY 70B changed from -5 to $+5^{\circ}$ to agree with our sign convention.

 g_A/g_V FOR $\Sigma^- o ne^- \overline{
u}_e$ Measurements with fewer than 500 events have been omitted. Where necessary, signs have been changed to agree with our conventions, which are given in the "Note on Baryon Decay Parameters" in the neutron Listings. What is actually listed is $|g_1/f_1-f_2| \leq |g_1/f_1-f_2|$ $0.237g_2/f_1$ |. This reduces to $g_A/g_V\equiv g_1(0)/f_1(0)$ on making the usual assumption that $g_2=0$. See also the note on HSUEH 88.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------------------|-------------|------------------------|---------|-----------|--------------------|
| 0.340 ± 0.017 OUR AV | ERAGE | | | | |
| $+0.327\pm0.007\pm0.019$ | | ⁷ HSUEH | | | Σ^- 250 GeV |
| $+ 0.34 \pm 0.05$ | | | | SPEC | SPS hyperon beam |
| 0.385 ± 0.037 | 3507 | ⁹ TANENBAUM | 74 | ASPK | |
| • • • We do not use the | e following | data for averages | , fits, | limits, e | etc. • • • |
| 0.29 ± 0.07 | 25 k | HSUEH | 85 | SPEC | See HSUEH 88 |
| $0.17 \begin{array}{l} + 0.07 \\ - 0.09 \end{array}$ | 519 | DECAMP | 77 | ELEC | Hyperon beam |
| | | | | | |

⁷ The sign is, with our conventions, unambiguously positive. The value assumes, as usual, that $g_2=0$. If g_2 is included in the fit, than (with our sign convention) $g_2=-0.56\pm0.37$, with a corresponding reduction of g_A/g_V to $+0.20\pm0.08$.

$f_2(0)/f_1(0)$ FOR $\Sigma^- ightarrow ne^- \overline{ u}_e$

The signs have been changed to be in accord with our conventions, given in the "Note on Baryon Decay Parameters" in the neutron Listings.

| on Dailyon Decay | i di dilicters | in the neutron | Listing | 50. | |
|------------------------|----------------|----------------|---------|------|--------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.97 ± 0.14 OUR AVE | RAGE | | | | |
| $+~0.96\pm0.07\pm0.13$ | 50k | HSUEH | 88 | SPEC | Σ^- 250 GeV |
| $+1.02\pm0.34$ | 4456 | BOURQUIN | 83c | SPEC | SPS hyperon beam |

TRIPLE CORRELATION COEFFICIENT D for $\Sigma^- ightarrow \, n \, e^- \, \overline{ u}_e$

The coefficient D of the term D $\mathbf{P} \cdot (\boldsymbol{\beta}_{e} \times \boldsymbol{\delta}_{\nu})$ in the $\Sigma^{-} \to ne^{-}\overline{\nu}$ decay angular distribution. A nonzero value would indicate a violation of time-reversal invariance. EVTS DOCUMENT ID TECN COMMENT TECN COMMENT

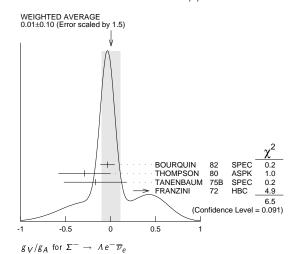
88 SPEC Σ^- 250 GeV 0.11 ± 0.10 5 0k **HSUEH**

 g_V/g_A FOR $\Sigma^- o \Lambda e^- \overline{
u}_e$ For the sign convention, see the "Note on Baryon Decay Parameters" in the neutron Listings. The value is predicted to be zero by conserved vector current theory. The values averaged assume CVC-SU(3) weak magnetism term.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------|--------------------|---------------------------|-------|-----------|---------------------|
| 0.01 ± 0.10 | OUR AVERAGE | Error includes scal | e fac | tor of 1. | 5. See the ideogram |
| below. | | | | | |
| -0.034 ± 0.080 | 1620 | ¹⁰ BOURQUIN | 82 | SPEC | SPS hyperon beam |
| -0.29 ± 0.29 | 114 | THOMPSON | 80 | ASPK | BNL hyperon beam |
| -0.17 ± 0.35 | 55 | | 75B | SPEC | BNL hyperon beam |
| $+0.45 \pm 0.20$ | 186 | ^{10,11} Franzini | 72 | HBC | |

 $^{^{10}\,\}mathrm{The}$ sign has been changed to agree with our convention.

¹¹ The FRANZINI 72 value includes the events of earlier papers.



gwm/g_A FOR $\Sigma^- \to \Lambda e^- \overline{\nu}_e$ The values quoted assume the CVC prediction $g_V = 0$

| i ne varaes quotea | assume the | C V C prediction | 8 V . | _ 0. | |
|---------------------|------------|------------------|-------|------|------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 2.4 ±1.7 OUR AVERAG | iΕ | | | | |
| 1.75 ± 3.5 | 114 | THOMPSON | 80 | ASPK | BNL hyperon beam |
| 3.5 ±4.5 | 55 | TANENBAUM | 75B | SPEC | BNL hyperon beam |
| 2.4 ± 2.1 | 186 | FRANZINI | 72 | нвс | |
| | | | | | |

Σ- REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

| ES CHRICH | 01 | PL B522 233 | I. Eschrich et al. | (FNAL SELEX Collab.) |
|------------|------|--------------------------|----------------------------|---------------------------|
| GUREV | 93 | JETPL 57 400 | M.P. Gurev et al. | (PNPI) |
| | | Translated from ZETFP 57 | | * * * |
| GALL | 88 | PRL 60 186 | K.P. Gall et al. | (BOST, MIT, WILL, CIT+) |
| HERTZOG | 88 | PR D37 1142 | D.W. Hertzog et al. | ` (WILL, BOST, MIT+) |
| HSUEH | 88 | PR D38 2056 | S.Y. Hsueh et al. | (CHIC, ELMT, FNAL+) |
| ZAPALAC | 86 | PRL 57 1526 | G. Zapalac et al. | (EFI, ELMT, FNAL+) |
| HSUEH | 85 | PRL 54 2399 | S.Y. Hsueh et al. | (CHIC, ELMT, FNAL+) |
| WAH | 85 | PRL 55 2551 | Y.W. Wah et al. | ` (FNAL, IOWA, ISU) |
| BOURQUIN | 83 B | ZPHY C21 27 | M.H. Bourquin et al. | (BRIS, GEVA, HEIDP+) |
| BOURQUIN | 83 C | ZPHY C21 17 | M.H. Bourguin et al. | (BRIS, GEVA, HEIDP+) |
| DECK | 83 | PR D28 1 | L. Deck et al. | (RUTĞ, WISC, MICH, MINN) |
| BOURQUIN | 82 | ZPHY C12 307 | M.H. Bourguin et al. | (BRIS, GEVA, HEIDP+) |
| MARRAFFINO | 80 | PR D21 2501 | J. Marraffino et al. | (VAND, MPIM) |
| THOMPSON | 80 | PR D21 25 | J.A. Thompson et al. | (PITT, BNL) |
| HANSL | 78 | NP B132 45 | T. Hansl et al. | (MPIM, VAND) |
| DECAMP | 77 | PL 66B 295 | D. Decamp et al. | (LALO, EPOL) |
| CONFORTO | 76 | NP B105 189 | B. Conforto et al. | (RHEL, LOIC) |
| DUGAN | 75 | NP A254 396 | G. Dugan et al. | (COLU, YALE) |
| TANENBAUM | 75 B | PR D12 1871 | W. Tanenbaum et al. | (YALÈ, FNAL, BNL) |
| EBENHOH | 74 | ZPHY 266 367 | H. Ebenhoh et al. | (HEIDT) |
| TANENBAUM | 74 | PRL 33 175 | W. Tanenbaum et al. | (YALE, FNAL, BNL) |
| EBENHOH | 73 | ZPHY 264 413 | W. Ebenhoh et al. | (HEIDT) |
| SECHI-ZORN | 73 | PR D8 12 | B. Sechi-Zorn, G.A. Snow | `(UMD) |
| BOHM | 72 | NP B48 1 | G. Bohm et al. | (BERL, KIDR, BRUX, IÀSD+) |
| FRANZINI | 72 | PR D6 2417 | P. Franzini et al. | (COLU, HEID, UMD+) |
| ROBERTSON | 72 | Thesis UMI 78-00877 | R.M. Robertson | (IIT) |
| BAKKER | 71 | LNC 1 37 | A.M. Bakker et al. | (SABRE Collab.) |
| COLE | 71 | PR D4 631 | J. Cole et al. | `(STON, COLU) |
| Also | | Thesis Nevis 175 | H. Norton | ` (COLU) |
| TOVEE | 71 | NP B33 493 | D.N. Tovee et al. | (LOUC, KIDR, BERL+) |
| BERLEY | 70 B | PR D1 2015 | D. Berley et al. | (BNL, MASA, YALE) |
| BOGERT | 70 | PR D2 6 | D.V. Bogert et al. | (BNL, MASA, YALE) |
| EISELE | 70 | ZPHY 238 372 | F. Eisele et al. | (HEID) |
| PDG | 70 | RMP 42 87 | A. Barbaro-Galtieri et al. | (LRL, BŘAN+) |
| ANG | 69 | ZPHY 223 103 | G. Ang et al. | (HEID) |
| ANG | 69B | ZPHY 228 151 | G. Ang et al. | (HEID) |
| | | | - | * / |

⁸BOURQUIN 83C favors the positive sign by at least 2.6 standard deviations.

 $^{^9}$ TANENBAUM 74 gives 0.435 \pm 0.035, assuming no g^2 dependence in g_A and g_{V} . The listed result allows q^2 dependence, and is taken from HSUEH 88.

Σ^- , $\Sigma(1385)$

| BAGGETT | 69 | PRL 23 249 | N.V. Baggett, B. Kehoe, G.A. Snov | (UMD) |
|------------|------|-------------------|-----------------------------------|--------------------|
| BALTAY | 69 | PRL 22 615 | C. Baltay et al. | (COLU, ŠTON) |
| BANGERTER | 69 | Thesis UCRL 19244 | R.O. Bangerter | ` (LRL) |
| BANGERTER | 69B | PR 187 1821 | R.O. Bangerter et al. | (LRL) |
| BARLOUTAUD | 69 | NP B14 153 | R. Barloutaud et al. | (SACL, CERN, HEID) |
| EISELE | 69 | ZPHY 221 1 | F. Eisele et al. | (HEID) |
| BIERMAN | 68 | PRL 20 1459 | E. Bierman et al. | (PRIN) |
| HEPP | 68 | ZPHY 214 71 | V. Hepp, H. Schleich | (HEID) |
| WHITESIDE | 68 | NC 54A 537 | H. Whiteside, J. Gollub | (ÒBER) |
| BARASH | 67 | PRL 19 181 | N. Barash et al. | (UMD) |
| CHANG | 66 | PR 151 1081 | C.Y. Chang | (COLU) |
| BAZIN | 65 B | PR 140B 1358 | M. Bazin et al. | (PRIN, RUTG, COLU) |
| DOSCH | 65 | PL 14 239 | H.C. Dosch et al. | ` (HEID) |
| Also | | PR 151 1081 | C.Y. Chang | (COLU) |
| S CHMIDT | 65 | PR 140B 1328 | P. Schmidt | (COLU) |
| BURNSTEIN | 64 | PRL 13 66 | R.A. Burnstein et al. | (UMD) |
| COURANT | 64 | PR 136 B1791 | H. Courant et al. | (CERN, HEID, UMD+) |
| BARKAS | 63 | PRL 11 26 | W.H. Barkas, J.N. Dyer, H.H. Heck | mian (LRL) |
| HUMPHREY | 62 | PR 127 1305 | W.E. Humphrey, R.R. Ross | (LRL) |

$\Sigma(1385) \ 3/2^+$

$$I(J^P) = 1(\frac{3}{2}^+)$$
 Status: ***

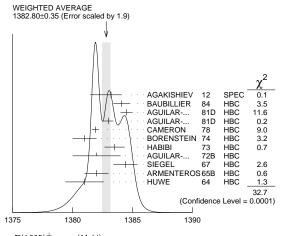
Discovered by ALSTON 60. Early measurements of the mass and width for combined charge states have been omitted. They may be found in our 1984 edition Reviews of Modern Physics **56** S1 (1984).

We average only the most significant determinations. We do not average results from inclusive experiments with large backgrounds or results which are not accompanied by some discussion of experimental resolution. Nevertheless systematic differences between experiments remain. (See the ideograms in the Listings below.) These differences could arise from interference effects that change with production mechanism and/or beam momentum. They can also be accounted for in part by differences in the parametrizations employed. (See BORENSTEIN 74 for a discussion on this point.) Thus BORENSTEIN 74 uses a Breit-Wigner with energyindependent width, since a P-wave was found to give unsatisfactory fits. CAMERON 78 uses the same form. On the other hand HOLM-GREN 77 obtains a good fit to their $\Lambda\pi$ spectrum with a P-wave Breit-Wigner, but includes the partial width for the $\Sigma\pi$ decay mode in the parametrization. AGUILAR-BENITEZ 81D gives masses and widths for five different Breit-Wigner shapes. The results vary considerably. Only the best-fit S-wave results are given here.

Σ(1385) MASSES

Σ(1385)+ MASS

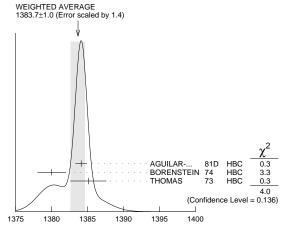
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------|-------------------|-------------------------|--------|------------|------------------------------------------------------|
| 1382.80 ± 0.35 (| OUR AVERAGE | Error includes so | ale fa | ctor of | 1.9. See the ideogram |
| below. | 0.1 | | | | |
| 1383.2 ±0.9 + | - 0.1 - 1.5 | AGAKISHIEV | 12 | SPEC | $pp \rightarrow \Sigma(1385)^+ K^+ n$, 3.5 GeV |
| 1384.1 ± 0.7 | 1897 | BAUBILLIER | 84 | HBC | K [−] p 8.25 GeV/c |
| 1384.5 ± 0.5 | 5256 | AGUILAR | 81D | HBC | $K^-p \rightarrow \Lambda \pi \pi 4.2 \text{ GeV}/c$ |
| 1383.0 ± 0.4 | 9361 | AGUILAR | 81D | HBC | $K^- p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| 1381.9 ± 0.3 | 6900 | CAMERON | 78 | HBC | K^-p 0.96-1.36 GeV/ c |
| 1381 ± 1 | 6846 | BORENSTEIN | 74 | HBC | K [−] p 2.18 GeV/c |
| 1383.5 ± 0.85 | 2300 | HABIBI | 73 | HBC | $K^-p \rightarrow \Lambda \pi \pi$ |
| 1382 ± 2 | 400 | AGUILAR | 72B | HBC | $K^- p \rightarrow \Lambda \pi$'s |
| 1384.4 ± 1.0 | 1260 | SIEGEL | 67 | HBC | K^-p 2.1 GeV/ c |
| 1382 ± 1 | 75 0 | ARMENTEROS | 65B | HBC | K [−] p 0.9–1.2 GeV/c |
| 1381.0 ± 1.6 | 85 9 | HUWE | 64 | HBC | $K^- p \ 1.22 \ \text{GeV}/c$ |
| • • • We do no | ot use the follow | ing data for avera | ges, f | its, limit | s, etc. • • • |
| 1385.1 ± 1.2 | 600 | BAKER | 80 | HYBR | π^+ p 7 GeV/ c |
| 1383.2 ± 1.0 | 75 0 | BAKER | 80 | HYBR | K [−] p 7 GeV/c |
| 1381 ± 2 | 7k | ¹ BAUBILLIER | 79B | HBC | K−p 8.25 GeV/c |
| 1391 ± 2 | 2k | CAUTIS | 79 | HYBR | $\pi^{+} p / K^{-} p 11.5 \text{GeV}$ |
| 1390 ± 2 | 100 | ¹ SUGAHARA | 79B | HBC | $\pi^- p$ 6 GeV/ c |
| 1385 ± 3 | 22k []] | ^{1,2} barreiro | 77B | HBC | K-p 4.2 GeV/c |
| 1385 ± 1 | 25 94 | HOLMGREN | 77 | HBC | See AGUILAR- |
| 1380 ±2 | | 1 BARDADIN | 75 | нвс | BENITEZ 81D K^-p 14.3 GeV/ c |
| 1382 ±1 | 3740 | ³ BERTHON | 74 | нвс | K-p 1263-1843 MeV/c |
| 1390 ±6 | 46 | AGUILAR | 70B | НВС | $K^- p \rightarrow \Sigma \pi$'s 4 GeV/c |
| 1383 ±8 | 62 | ⁴ BIRMINGHAM | | нвс | K-p 3.5 GeV/c |
| 1378 ±5 | 135 | LONDON | 66 | нвс | K-p 2.24 GeV/c |
| 1384.3 ±1.9 | 25 0 | ⁴ SMITH | 65 | нвс | $K = p \cdot 1.8 \text{ GeV}/c$ |
| 1382.6 ±2.1 | 25 0 | ⁴ SMITH | 65 | нвс | K-p 1.95 GeV/c |
| 1375.0 ±3.9 | 170 | COOPER | 64 | нвс | K-p 1.45 GeV/c |
| 1376.0 ±3.9 | 154 | ⁴ ELY | 61 | HLBC | K - p 1.11 GeV/c |
| | | | | | |



 $\Sigma(1385)^+$ mass (MeV)

Σ (1385)0 MASS

| VALUE | (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------|--------------|--------------|-------------------------|---------|-------------|---------------------------------------------------|
| 1383. | 7±1.0 OUR A | /ERAGE | Error includes scale | e fact | or of 1.4 | See the ideogram below. |
| 1384. | 1 ± 0.8 | 5722 | AGUILAR | 81D | HBC | $K^-p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| 1380 | ± 2 | 3100 | ⁵ BORENSTEIN | 74 | HBC | $K^-p \rightarrow \Lambda 3\pi 2.18$ |
| | | | | | | GeV/c |
| 1385. | 1 ± 2.5 | 240 | ⁴ THOMAS | 73 | HBC | $\pi^- p \rightarrow \Lambda \pi^0 K^0$ |
| • • • | We do not us | e the follov | ving data for avera | ges, fi | its, limits | s, etc. • • • |
| 1389 | ± 3 | 500 | ⁶ BAUBILLIER | 79B | нвс | K [−] p 8.25 GeV/c |

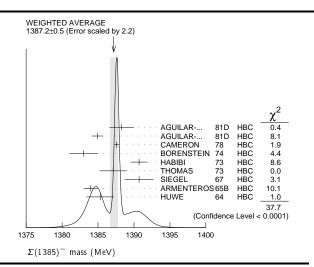


 $\Sigma(1385)^0$ mass (MeV)

Σ (1385)- MASS

| _(1000) | • | | | | |
|--------------------|--------------|-------------------------|---------|-----------|------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1387.2±0.5 OUR A | VERAGE | Error includes scale | e fact | or of 2.2 | 2. See the ideogram below. |
| 1388.3 ± 1.7 | 620 | AGUILAR | 81D | HBC | $K^-p \rightarrow \Lambda \pi \pi 4.2 \text{ GeV}/c$ |
| 1384.9 ± 0.8 | 3346 | AGUILAR | 81D | HBC | $K^-p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| 1387.6 ± 0.3 | 9720 | CAMERON | 78 | HBC | K [−] p 0.96-1.36 GeV/c |
| 1383 ± 2 | 2303 | BORENSTEIN | 74 | HBC | K−p 2.18 GeV/c |
| 1390.7 ± 1.2 | 1900 | HABIBI | 73 | HBC | $K^-p \rightarrow \Lambda \pi \pi$ |
| 1387.1 ± 1.9 | 630 | ⁴ THOMAS | 73 | HBC | $\pi^- p \rightarrow \Lambda \pi^- K^+$ |
| 1390.7 ± 2.0 | 370 | SIEGEL | 67 | HBC | K^-p 2.1 GeV/ c |
| 1384 ± 1 | 1380 | ARMENTEROS | 565B | HBC | K^-p 0.9–1.2 GeV/ c |
| 1385.3 ± 1.9 | 1086 | ⁴ HUWE | 64 | HBC | K [−] p 1.15-1.30 GeV/c |
| • • • We do not us | se the follo | owing data for avera | ges, fi | ts, limit | s, etc. • • • |
| 1383 ± 1 | 4.5k | ¹ BAUBILLIER | 79B | нвс | K [−] p 8.25 GeV/c |
| 1380 ± 6 | 150 | ¹ SUGAHARA | 79B | HBC | $\pi^- p$ 6 GeV/ c |
| 1387 ± 3 | 12k | ^{1,2} barreiro | 77B | HBC | K−p 4.2 GeV/c |
| 1391 ± 3 | 193 | HOLMGREN | 77 | HBC | See AGUILAR- |
| 1383 ±2 | | ¹ BARDADIN | 75 | нвс | BENITEZ 81D K ⁻ p 14.3 GeV/c |
| 1389 ±1 | 3060 | ³ BERTHON | 74 | HBC | K - p 1263-1843 MeV/c |
| 1389 ±9 | 15 | LONDON | 66 | HBC | $K = p \ 2.24 \ \text{GeV}/c$ |
| 1391.5 ± 2.6 | 120 | ⁴ SMITH | 65 | HBC | K - p 1.8 GeV/c |
| 1399.8 ± 2.2 | 58 | ⁴ SMITH | 65 | HBC | $K = p \ 1.0 \ \text{GeV}/c$ |
| 1392.0 ± 6.2 | 200 | COOPER | 64 | НВС | $K = p \ 1.45 \ \text{GeV}/c$ |
| 1382 ±3 | 93 | DAHL | 61 | DBC | $K = d \ 0.45 \ \text{GeV}/c$ |
| | | ⁴ ELY | | | , |
| 1376.0 ± 4.4 | 224 | ELY | 61 | HLBC | K [−] p 1.11 GeV/c |

Baryon Particle Listings Σ (1385)



| VALUE (MeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------------|-------------------|-------------------------|---------|---------|-------------------------------------|
| • • • We do not u | ise the following | data for averages | , fits, | limits, | etc. • • • |
| - 2 to +6 | 95 | ⁷ BORENSTEIN | 74 | HBC | K [−] p 2.18 GeV/c |
| 7.2 ± 1.4 | | ⁷ HABIBI | 73 | HBC | $K^- p \rightarrow \Lambda \pi \pi$ |
| 6.3 ± 2.0 | | ⁷ SIEGEL | 67 | HBC | K^-p 2.1 GeV/c |
| 11 ± 9 | | ⁷ LONDON | 66 | HBC | K^-p 2.24 GeV/ c |
| 9 ±6 | | LONDON | 66 | HBC | $\Lambda 3\pi$ events |
| 2.0 ± 1.5 | | 7 ARMENTEROS | S65B | HBC | K^-p 0.9-1.2 GeV/c |
| 7.2 ± 2.1 | | ⁷ SMITH | 65 | HBC | $K^- p 1.8 \text{ GeV}/c$ |
| 17.2 ± 2.0 | | ⁷ SMITH | 65 | HBC | K−p 1.95 GeV/c |
| 17 ±7 | | ⁷ COOPER | 64 | HBC | $K^- p 1.45 \text{ GeV}/c$ |
| 4.3 ± 2.2 | | ⁷ HUWE | 64 | HBC | K-p 1.22 GeV/c |
| 0.0 ± 4.2 | | ⁷ ELY | 61 | HLBC | K−p 1.11 GeV/c |
| | | | | | |

$m_{\Sigma(1385)^0} - m_{\Sigma(1385)^+}$

| VALUE (MeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|-------------------------|-----------|----------------------------|---------|-------------------------------|
| • • • We do not use the | following | data for averages, fits, | limits, | etc. • • • |
| -4 to +4 | 95 | ⁷ BORENSTEIN 74 | нвс | $K = p \ 2.18 \ \text{GeV}/c$ |

$m_{\Sigma(1385)^-} - m_{\Sigma(1385)^0}$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|----------------------|-------|---------|-----------------------------------------|
| • • • We do not use the followin | g data for averages, | fits, | limits, | etc. • • • |
| 2.0 ± 2.4 | ⁷ THOMAS | 73 | нвс | $\pi^- p \rightarrow \Lambda \pi^- K^+$ |

Σ (1385) WIDTHS

DOCUMENT ID TECN COMMENT

Σ(1385)+ WIDTH VALUE (MeV) EVTS 36.0+ 0.7 OUR AVERAGE

| 30.UI | U./ OUR AVE | KAGE | | | | | |
|------------|---------------------|------------------|-----|-------------------|---------|------------|-------------------------------------------------------|
| $40.2 \pm$ | $2.1 + 1.2 \\ -2.8$ | | | AGAKISHIEV | 12 | SPEC | $pp \rightarrow \Sigma(1385)^+ K^+ n$, 3.5 GeV |
| $37.2 \pm$ | 2.0 | 1897 | | BAUBILLIER | 84 | нвс | K-p 8.25 GeV/c |
| $35.1\pm$ | 1.7 | 5256 | | AGUILAR | 81D | нвс | $K^- p \rightarrow \Lambda \pi \pi 4.2 \text{ GeV}/c$ |
| $37.5\pm$ | 2.0 | 9361 | | AGUILAR | 81D | нвс | $K^-p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| $35.5\pm$ | 1.9 | 6900 | | CAMERON | 78 | нвс | K-p 0.96-1.36 GeV/c |
| $34.0\pm$ | 1.6 | 6846 | | | 74 | HBC | K [−] p 2.18 GeV/c |
| $38.3\pm$ | 3.2 | 2300 | 9 | HABIBI | 73 | HBC | $K^- p \rightarrow \Lambda \pi \pi$ |
| $32.5\pm$ | 6.0 | 400 | | | 72B | HBC | $K^-p \rightarrow \Lambda \pi$'s |
| $36 \pm$ | 4 | 1260 | 9 | SIEGEL | 67 | HBC | K^-p 2.1 GeV/c |
| $32.0\pm$ | 4.7 | 75 0 | 9 | ARMENTEROS | 65B | HBC | K [−] p 0.95-1.20 GeV/c |
| $46.5\pm$ | 6.4 | 85 9 | 9 | HUWE | 64 | HBC | K−p 1.15-1.30 GeV/c |
| • • • | We do not use | the follow | ing | g data for averag | ges, fi | ts, limits | , etc. • • • |
| 40 \pm | 3 | 600 | | BAKER | 80 | HYBR | $\pi^+ p$ 7 GeV/ c |
| $37\ \pm$ | 2 | 75 0 | | BAKER | 80 | HYBR | K [−] p 7 GeV/c |
| $37 \pm$ | 2 | 7k | 1 | BAUBILLIER | 79B | HBC | K−p 8.25 GeV/c |
| $30 \pm$ | 4 | 2k | | CAUTIS | 79 | HYBR | $\pi^{+} p/K^{-} p$ 11.5 GeV |
| $30 \pm$ | 6 | 100 | | SUGAHARA | 79B | HBC | $\pi^- p$ 6 GeV/ c |
| 43 \pm | 5 | 22k ¹ | ,2 | BARREIRO | 77B | HBC | K [−] p 4.2 GeV/c |
| 34 ± | 2 | 2594 | | HOLMGREN | 77 | HBC | See AGUILAR- |
| 40.0± | 3.2 | | 1 | BARDADIN | 75 | нвс | BENITEZ 81D K^-p 14.3 GeV/ c |
| 48 ± | | 3740 | | BERTHON | 74 | HBC | K-p 1263-1843 MeV/c |
| 33 ± | | 46 | | AGUILAR | | НВС | $K^- p \rightarrow \Sigma \pi$'s 4 GeV/c |
| 25 ± | | 62 | | BIRMINGHAM | | нвс | K^-p 3.5 GeV/c |
| 30.3± | | 25 0 | 9 | SMITH | 65 | НВС | K-p 1.8 GeV/c |
| 33.1± | | 25 0 | | SMITH | | нвс | K-p 1.95 GeV/c |
| 51 ± | | 170 | | COOPER | 64 | нвс | K-p 1.45 GeV/c |
| 48 ± | | 154 | | ELY | 61 | HLBC | K-p 1.11 GeV/c |
| | | | | | | | |

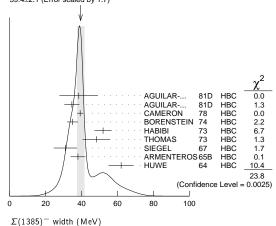
Σ(1385)0 WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------|-------------|--------------------------|---------|------------|----------------------------------------------------|
| 36 ± 5 OUR AVE | RAGE | | | | |
| 34.8± 5.6 | 5722 | AGUILAR | 81D | HBC | $K^- p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| 39.3 ± 10.2 | 240 | ⁹ THOMAS | 73 | HBC | $\pi^- p \rightarrow \Lambda \pi^0 K^0$ |
| ● We do not use | the followi | ing data for avera | ges, fi | its, limit | s, etc. • • • |
| 53 ± 8 | 3100 1 | ¹⁰ BORENSTEIN | 74 | нвс | $K^-p \rightarrow \Lambda 3\pi 2.18$ GeV/c |
| 30 ± 9 | 106 | CURTIS | 63 | OSP K | $\pi^- p \ 1.5 \ { m GeV}/c$ |

Σ (1385) - WIDTH

| 2(1303) ** | D 1 11 | | | | |
|-----------------|----------------|-------------------------|--------|------------|-------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 39.4± 2.1 OUR | AVERAGE | Error includes scale | facto | r of 1.7. | See the ideogram below. |
| 38.4 ± 10.7 | 620 | AGUILAR | 81D | HBC | $K^- p \rightarrow \Lambda \pi \pi 4.2 \text{ GeV}/c$ |
| 34.6 ± 4.2 | 3346 | AGUILAR | 81D | HBC | $K^- p \rightarrow \Lambda 3\pi 4.2 \text{ GeV}/c$ |
| 39.2 ± 1.7 | 9720 | CAMERON | 78 | HBC | K [−] p 0.96-1.36 GeV/c |
| 35 ± 3 | 2303 | ⁸ BORENSTEIN | 74 | HBC | K^-p 2.18 GeV/c |
| 51.9± 4.8 | 1900 | 9 HABIBI | 73 | HBC | $K^- p \rightarrow \Lambda \pi \pi$ |
| 48.2± 7.7 | 630 | ⁹ THOMAS | 73 | HBC | $\pi^- p \rightarrow \Lambda \pi^- K^0$ |
| 31.0 ± 6.5 | 370 | ⁹ SIEGEL | 67 | HBC | K^-p 2.1 GeV/ c |
| 38.0 ± 4.1 | 1382 | 9 ARMENTEROS | S65B | HBC | K^-p 0.95-1.20 GeV/ c |
| 62 ± 7 | 1086 | HUWE | 64 | HBC | K^-p 1.15-1.30 GeV/ c |
| • • • We do no | t use the foll | owing data for avera | ges, f | its, limit | s, etc. • • • |
| 44 ± 4 | 4.5k | ¹ BAUBILLIER | 79B | нвс | K−p 8.25 GeV/c |
| 58 ± 4 | 150 | ¹ SUGAHARA | 79B | HBC | $\pi^- p$ 6 GeV/ c |
| 45 ± 5 | 12k | ^{1,2} barreiro | 77B | HBC | K-p 4.2 GeV/c |
| 35 ±10 | 193 | HOLMGREN | 77 | нвс | See AGUILAR- BENITEZ 81D |
| 47 ± 6 | | ¹ BARDADIN | 75 | HBC | K^-p 14.3 GeV/c |
| 40 ± 3 | 3060 | ³ BERTHON | 74 | HBC | K^-p 1263–1843 ${ m MeV}/c$ |
| 29.2 ± 10.6 | 120 | ⁹ SMITH | 65 | HBC | K^-p 1.80 GeV/c |
| 17.1 ± 8.9 | 58 | ⁹ SMITH | 65 | HBC | K^-p 1.95 GeV/c |
| 88 ± 24 | 200 | ⁹ COOPER | 64 | HBC | K^-p 1.45 GeV/c |
| 40 | | DAHL | 61 | DBC | K-d 0.45 GeV/ c |
| 66 ±18 | 224 | ⁹ ELY | 61 | HLBC | K^-p 1.11 GeV/ c |
| | | | | | |





Σ (1385) POLE POSITIONS

Σ (1385)+ REAL PART

| VALUE | DO CUMENT ID | COMMENT |
|--------|---------------|------------------------|
| 1379±1 | LICHTENBERG74 | Extrapolates HABIBI 73 |

Σ (1385)⁺ –IMAGINARY PART

| VALUE | DO CUMENT ID | COMMENT |
|----------------|---------------|------------------------|
| 17.5 ± 1.5 | LICHTENBERG74 | Extrapolates HABIBI 73 |

Σ (1385) - REAL PART

| VALUE | DO CUMENT ID | COMMENT |
|--------|---------------|------------------------|
| 1383±1 | LICHTENBERG74 | Extrapolates HABIBI 73 |

Σ(1385) - -IMAGINARY PART

| Z (1303) | -IMAGINAKI | FARI | | |
|------------|------------|---------------|------------------------|--|
| VALUE | | DO CUMENT ID | COMMENT | |
| 22.5 ± 1.5 | | LICHTENBERG74 | Extrapolates HABIBI 73 | |

Baryon Particle Listings $\Sigma(1385)$, $\Sigma(1480)$ Bumps

Σ(1385) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|----------------|----------------------------|------------------------------|---------------------|
| Γ ₁ | $\Lambda\pi$ | (87.0 ±1.5) % | |
| Γ_2 | $\Sigma \pi$ | (11.7 ± 1.5) % | |
| Γ_3 | $\Lambda\gamma$ | $(1.25^{+0.13}_{-0.12})$ % | |
| Γ_4 | $\Sigma^-\gamma$ | < 2.4 × 10 |) ⁻⁴ 90% |
| Γ ₅ | $\frac{\Sigma^-\gamma}{K}$ | | |

The above branching fractions are our estimates, not fits or averages.

Σ(1385) BRANCHING RATIOS

| $\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ | | | | | Γ_2/Γ_1 |
|--------------------------------------------|-------------------------------------|------|-------------------------|------------|------------------------------------------------------------------------------------------------------------------------|
| VALUE | DOCUMENT ID | | TECN | CH G | COMMENT |
| 0.135 ± 0.011 O | UR AVERAGE | | | | |
| 0.20 ± 0.06 | DIONISI | 78B | HBC | \pm | $K^- p \rightarrow Y^* K \overline{K}$ |
| 0.16 ± 0.03 | BERTHON | 74 | HBC | + | K [−] p 1.26–1.84 GeV/c |
| 0.11 ± 0.02 | BERTHON | 74 | HBC | _ | K [−] p 1.26–1.84 GeV/c |
| 0.21 ± 0.05 | BORENSTEIN | 74 | нвс | + | $K^- p \rightarrow \Lambda \pi^+ \pi^-,$ $\Sigma^0 \pi^+ \pi^-$ |
| $0.18\ \pm0.04$ | MAST | 73 | MPWA | ± | $K^{-}\stackrel{\circ}{p} \xrightarrow{\Lambda} \stackrel{\circ}{\pi^{+}} \pi^{-},$ $\Sigma^{0} _{\pi^{+}} \pi^{-}$ |
| 0.10 ± 0.05 | THOMAS | 73 | нвс | _ | $\pi^- p \rightarrow \Lambda K \pi, \Sigma K \pi$ |
| 0.16 ± 0.07 | AGUILAR | 72B | HBC | + | K-p 3.9, 4.6 GeV/c |
| 0.13 ± 0.04 | COLLEY | 71B | DBC | -0 | K [−] N 1.5 GeV/c |
| 0.13 ± 0.04 | PAN | 69 | HBC | + | $\pi^+ p \rightarrow \Lambda K \pi, \Sigma K \pi$ |
| 0.08 ± 0.06 | LONDON | 66 | HBC | + | K-p 2.24 GeV/c |
| 0.163 ± 0.041 | ARMENTEROS | 65B | нвс | ± | K-p 0.95-1.20 GeV/c |
| 0.09 ± 0.04 | HUWE | 64 | нвс | \pm | K ⁻ p 1.2-1.7 GeV |
| • • • We do not | use the following data for | aver | rages, fit | s, limit | s, etc. • • • |
| < 0.04 | ALSTON | 62 | нвс | ± 0 | $K^- p \ 1.15 \ \text{GeV}/c$ |
| $0.04\ \pm0.04$ | BASTIEN | 61 | нвс | \pm | . , |
| $\Gamma(\Lambda\gamma)/\Gamma(\Lambda\pi)$ | 0 | | | | Γ_3/Γ_1 |
| | s of course for $arSigma(1385)^0$. | → Λ | γ and $arLambda$ | π^0 . | |
| VALUE (units 10^{-2}) | EVTS DOCUMEN | T ID | TECN | COM | IMENT |
| 1.43 ^{+0.15} _{-0.13} OUR | AVERAGE | | | | |
| $1.42 \!\pm\! 0.12 \!+\! 0.11 \\ -0.07$ | 624 ± 25 KELLER | 11 | CLAS | γp | $\rightarrow K^+ \Lambda \gamma$, E_{γ} 1.6–3.8 GeV |
| $1.53 \pm 0.39 {}^{+ 0.15}_{- 0.24}$ | 61 TAYLOR | 05 | CLAS | γp | $\rightarrow K^+ \Lambda \gamma$ |
| $\Gamma(\Sigma^-\gamma)/\Gamma_{total}$ | | | | | Γ ₄ /Γ |
| | CL% DOCUMENT ID | | | CHG | COMMENT |
| | 90 ¹¹ MOLCHANOV | | SELX | - | Σ^- Pb $ ightarrow$ $\Sigma(1385)^-$ Pb, 600 GeV |
| | use the following data for | | - | s, IIIIIII | |
| $<6.1 \times 10^{-4}$ | 90 ¹² A RIK | 77 | SPEC | _ | Σ^- Pb $ ightarrow$ $\Sigma(1385)^-$ Pb, 23 GeV |
| | | | | | |

Σ (1385) FOOTNOTES

13 DEVENISH

CHG COMMENT

Fixed-t dispersion rel.

74B 0

 $+0.586 \pm 0.319$

- 1 From fit to inclusive $\Lambda\pi$ spectrum.

 2 Includes data of HOLMGREN 77.

 3 The errors are statistical only. The resolution is not unfolded.

 4 The error is enlarged to Γ/\sqrt{N} . See the note on the $K^*(892)$ mass in the 1984 edition.

 5 From a fit to $\Lambda\pi^0$ with the width fixed at 34 MeV.

 6 From fit to inclusive $\Lambda\pi^0$ spectrum with the width fixed at 40 MeV.
- ⁷ Redundant with data in the mass Listings.

 $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma(1385) \to \Lambda \pi$

- ⁸ Results from $\Lambda \pi^+ \pi^-$ and $\Lambda \pi^+ \pi^- \pi^0$ combined by us.
- $\frac{9}{2}$ The error is enlarged to $4\Gamma/\sqrt{N}$. See the note on the $K^*(892)$ mass in the 1984 edition.
- 10 Consistent with +, 0, and widths equal.
- 11 We calculate this from the MOLCHANOV 04 upper limit of 9.5 keV on the $\Sigma^-\gamma$ width.
- 12 We calculate this from the ARIK 77 upper limit of 24 keV on the $\Sigma^-\,\gamma$ width. 13 An extrapolation of the parametrized amplitude below threshold.

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| Also | | PR C72 039902 (errat.) | S. Taylor et al. | (JLab CLAS Collab.) |
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| | | | | |

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|-------------|------|-------------------|-----------------------------------------------------|---|
| BERTHON | 74 | NC 21A 146 | A. Berthon et al. (CDEF, RHEL, SACL+) | |
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| HABIBI | 73 | Thesis Nevis 199 | M. Habibi (COLU) | |
| A Iso | | Purdue Conf. 387 | C. Baltay et al. (COLU, BING) | |
| MAST | 73 | PR D7 3212 | T.S. Mast et al. (LBL) IJP |) |
| A Iso | | PR D7 5 | T.S. Mast et al. (LBL) IJP | |
| THOMAS | 73 | NP B56 15 | D.W. Thomas et al. (ČMU) JP | |
| AGUILAR | 72 B | PR D6 29 | M. Aguilar-Benitez et al. (BNL) | |
| COLLEY | 71B | NP B31 61 | D.C. Colley et al. (BIRM, EDIN, GLAS+) | |
| AGUILAR | 70 B | PRL 25 58 | M. Aguilar-Benitez et al. (BNL, SYRA) | |
| PAN | 69 | PRL 23 808 | Y.L. Pan, F.L. Forman (PENN) I | |
| SIEGEL | 67 | Thesis UCRL 18041 | D.M. Siegel (LRL) | |
| BIRMINGHAM | 66 | PR 152 1148 | M. Haque et al. (BIRM, GLAS, LOIC, OXF+) | |
| LONDON | 66 | PR 143 1034 | G.W. London et al. (BNL, SYRA) J | |
| ARMENTEROS | 65 B | PL 19 75 | R. Armenteros et al. (CERN, HEID, SACL) | |
| SMITH | 65 | Thesis UCLA | L.T. Smith (UCLA) | |
| COOPER | 64 | PL 8 365 | W.A. Cooper et al. (CERN, AMST) | |
| HUWE | 64 | Thesis UCRL 11291 | D.O. Huwe (LRL) JP | |
| A Iso | | PR 181 1824 | D.O. Huwe (LRL) | |
| CURTIS | 63 | PR 132 1771 | L.J. Curtis et al. (MICH) J | |
| ALSTON | 62 | CERN Conf. 311 | M.H. Alston et al. (LRL) | |
| BASTIEN | 61 | PRL 6 702 | P.L. Bastien, M. Ferro-Luzzi, A.H. Rosenfeld (LRL) | |
| DAHL | 61 | PRL 6 142 | O.I. Dahl et al. (LRL) | |
| ELY | 61 | PRL 7 461 | R.P. Ely et al. (LRL) J | |
| ALSTON | 60 | PRL 5 520 | M.H. Alston et al. (LRL) I | |
| | | | | |

$\Sigma(1480)$ Bumps

 $I(J^P) = 1(??)$ Status: *

OMITTED FROM SUMMARY TABLE

These are peaks seen in $\Lambda\pi$ and $\Sigma\pi$ spectra in the reaction $\pi^+p \to$ $(Y\pi)K^+$ at 1.7 GeV/c. Also, the Y polarization oscillates in the

MILLER 70 suggests a possible alternate explanation in terms of a reflection of $N(1675) \rightarrow \Lambda K$ decay. However, such an explanation for the $(\Sigma^+ \pi^0) K^+$ channel in terms of $\Delta(1650) \rightarrow \Sigma K$ decay seems unlikely (see PAN 70). In addition such reflections would also have to account for the oscillation of the Y polarization in the 1480 MeV region.

HANSON 71, with less data than PAN 70, can neither confirm nor deny the existence of this state. MAST 75 sees no structure in this region in $K^- p \rightarrow \Lambda \pi^0$.

ENGELEN 80 performs a multichannel analysis of $K^- p \to p \overline{K}^0 \pi^$ at 4.2 ${\rm GeV}/c$. They observe a 3.5 standard-deviation signal at 1480 MeV in $\rho \, \overline{\mathcal{K}}^0$ which cannot be explained as a reflection of any competing channel.

PRAKHOV 04 sees no evidence for this or other light Σ resonances, aside from the Σ (1385), in $K^-p\to \Lambda\pi^0\pi^0$.

ZYCHOR 06 finds peaks in $pp \rightarrow pK^+(\pi^{\pm}X^{\mp})$ at $p_{\text{beam}} =$

Σ(1480) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------|------------|-------------|----|------|----------------------------------------------------|
| ≈ 1480 OUR EST | MATE | · | | | |
| 1480 ± 15 | 365 ± 60 | ZYCHOR | 06 | SPEC | $pp \rightarrow pK^{+}(\pi^{\pm}X^{\mp})$ |
| 1480 | 120 | ENGELEN | 80 | HBC | $K^- \rho \rightarrow (\rho \overline{K}^0) \pi^-$ |
| 1485 ± 10 | | CLINE | 73 | MPWA | $K^- d \rightarrow (\Lambda \pi^-) p$ |
| 1479 ± 10 | | PAN | 70 | HBC | $\pi^+ p \rightarrow (\Lambda \pi^+) K^+$ |
| 1465 ± 15 | | PAN | 70 | нвс | $\pi^+ p \rightarrow (\Sigma \pi) K^+$ |

Σ(1480) WIDTH (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------|------------|-------------|----|------|----------------------------------------------|
| $60\!\pm\!15$ | 365 ± 60 | ZYCHOR | | | $pp \rightarrow pK^{+}(\pi^{\pm}X^{\mp})$ |
| 80 ± 20 | 120 | ENGELEN | 80 | HBC | $K^- p \rightarrow (p \overline{K}^0) \pi^-$ |
| 40 ± 20 | | CLINE | 73 | MPWA | $K^- d \rightarrow (\Lambda \pi^-) p$ |
| 31 ± 15 | | PAN | 70 | HBC | $\pi^+ p \rightarrow (\Lambda \pi^+) K^+$ |
| 30 ± 20 | | PAN | 70 | нвс | $\pi^+ p \rightarrow (\Sigma \pi) K^+$ |

Σ(1480) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode |
|-----------------------|--------------|
| $\overline{\Gamma_1}$ | NK |
| Γ_2 | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |

Baryon Particle Listings $\Sigma(1480)$ Bumps, $\Sigma(1560)$ Bumps, $\Sigma(1580)$

| (PRODUCTION EXPERIMENTS) | | | | | |
|--------------------------------------------------|-----------------------------|----|-------|---------------------------------------|--|
| $\frac{\Gamma(\Sigma\pi)}{\Gamma(\Lambda\pi)}$ | DOCUMENT ID | | TECN | Γ ₃ /Γ ₂ | |
| $0.82\!\pm\!0.51$ | PA N | 70 | нвс | + | |
| $\Gamma(N\overline{K})/\Gamma(\Lambda\pi)$ NALUE | DOCUMENT ID | | TECN | Γ ₁ /Γ ₂ | |
| 0.72 ± 0.50 | PA N | 70 | нвс | + | |
| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | DOCUMENT ID | | TECN | Γ_1/Γ | |
| <i>VALUE</i> small | <u>DOCUMENT ID</u> CLINE | 73 | MP WA | $K^- d \rightarrow (\Lambda \pi^-) p$ | |
| | | | | | |

T/1400) DDANCHING DATIOS

Σ (1480) REFERENCES (PRODUCTION EXPERIMENTS)

| ZYCHOR | 06 | PRL 96 012002 | l. Zychor et al. | (ANE | (E Collab.) |
|---------|--------|----------------|---------------------------|----------------|-------------|
| PRAKHOV | 04 | PR C69 042202 | S. Érakhov et al. | (BNL Crystal B | |
| ENGELEN | 80 | NP B167 61 | J.J. Engelen et al. | (NIJM, AMST | , CERN+) |
| MAST | 75 | PR D11 3078 | T.S. Mast et al. | , | (LBL) |
| CLINE | 73 | LNC 6 205 | D. Cline, R. Laumann, J. | Марр | (ŴIS C) IJP |
| HANSON | 71 | PR D4 1296 | P. Hanson, G.E. Kalmus, J | Louie | `(LBL)I |
| MILLER | 70 | Duke Conf. 229 | D.H. Miller | | (PÙRD) |
| Hyperon | Resona | nces, 1970 | | | |
| PAN | 70 | PR D2 449 | Y.L. Pan et al. | | (PENN) |
| A Iso | | PRL 23 808 | Y.L. Pan, F.L. Forman | | (PENN)I |
| Also | | PRL 23 806 | Y.L. Pan. F.L. Forman | | (PENN)I |

$\Sigma(1560)$ Bumps

 $I(J^P) = 1(??)$ Status: **

OMITTED FROM SUMMARY TABLE

This entry lists peaks reported in mass spectra around 1560 MeV without implying that they are necessarily related.

DIONISI 78B observes a 6 standard-deviation enhancement at 1553 MeV in the charged $\Lambda/\Sigma\pi$ mass spectra from $K^-p\to (\Lambda/\Sigma)\pi K\overline{K}$ at 4.2 GeV/c. In a CERN ISR experiment, LOCKMAN 78 reports a narrow 6 standard-deviation enhancement at 1572 MeV in $\Lambda\pi^\pm$ from the reaction $pp\to\Lambda\pi^+\pi^-X$. These enhancements are unlikely to be associated with the $\Sigma(1580)$ (which has not been confirmed by several recent experiments – see the next entry in the Listings).

CARROLL 76 observes a bump at 1550 MeV (as well as one at 1580 MeV) in the isospin-1 $\overline{K}\,N$ total cross section, but uncertainties in cross section measurements outside the mass range of the experiment preclude estimating its significance.

See also MEADOWS 80 for a review of this state.

Σ (1560) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|-----------------|------|-------------|-----|------|-------|--------------------------|
| ≈ 1560 OUR ESTI | MATE | · | | | | |
| 1553 ± 7 | 121 | DIONISI | 78B | HBC | \pm | $K^-p \rightarrow$ |
| | | | | | | $(Y \pi) K \overline{K}$ |
| 1572 ± 4 | 40 | LOCKMAN | 78 | SPEC | ± | $pp \rightarrow$ |
| | | | | | | $\Lambda \pi^+ \pi^- X$ |

Σ (1560) WIDTH (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
|-------------|------|----------------------|-----|------|-------|---------------------------------------------------------------|
| 79±30 | 121 | DIONISI | 78B | нвс | \pm | $K^-p \rightarrow$ |
| 15± 6 | 40 | ¹ LOCKMAN | 78 | SPEC | ± | $(Y\pi) K \overline{K}$ $pp \to \\ \Lambda \pi^{+} \pi^{-} Y$ |

Σ (1560) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|--------------------------|------------------------------|
| Γ_1 Γ_2 | $\Lambda\pi \ \Sigma\pi$ | seen |

Σ (1560) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

| $\Gamma(\Sigma\pi)/[\Gamma(\Lambda\pi)+\Gamma(\Sigma\pi)]$ | | | | | $\Gamma_2/(\Gamma_1+\Gamma_2)$ |
|------------------------------------------------------------|--------------|-----|------|-------|----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.35 ± 0.12 | DIONISI | 78B | нвс | \pm | $K^-p \rightarrow (Y\pi)K\overline{K}$ |

| $\Gamma(\Lambda\pi)/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------------|-------------|----|------|-----|-----------------------------------------|
| VALUE | DOCUMENT ID | | TECN | CHG | COMMENT |
| seen | LOCKMAN | 78 | SPEC | ± | $p p \rightarrow \Lambda \pi^+ \pi^- X$ |

Σ (1560) FOOTNOTES (PRODUCTION EXPERIMENTS)

 $^{
m 1}$ The width observed by LOCKMAN 78 is consistent with experimental resolution.

Σ (1560) REFERENCES (PRODUCTION EXPERIMENTS)

| MEADOWS | 80 | Toronto Conf. 283 | B.T. Meadows | (CINC) |
|---------|------|--------------------|------------------------------------|----------------|
| DIONISI | 78 B | PL 78B 154 | C. Dionisi, R. Armenteros, J. Diaz | (CERN, AMST+)I |
| LOCKMAN | 78 | Saclay DPHPE 78-01 | W. Lockman <i>et al</i> . | (UCLA, SACL) |
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | (BNL)I |

$\Sigma(1580) \ 3/2^{-}$

 $I(J^P) = 1(\frac{3}{2}^-)$ Status: *

OMITTED FROM SUMMARY TABLE

Seen in the isospin-1 \overline{K} N cross section at BNL (LI 73, CARROLL 76) and in a partial-wave analysis of $K^-p \to \Lambda\pi^0$ for c.m. energies 1560–1600 MeV by LITCHFIELD 74. LITCHFIELD 74 finds $J^P=3/2^-$. Not seen by ENGLER 78 or by CAMERON 78C (with larger statistics in $K^0_L p \to \Lambda\pi^+$ and $\Sigma^0\pi^+$).

Neither OLMSTED 04 (in $K^-p\to \Lambda\pi^0$) nor PRAKHOV 04 (in $K^-p\to \Lambda\pi^0\pi^0$) see any evidence for this state.

| | Σ(1580) MAS | S | | | |
|------------------------------------------------|----------------------------------|----------|--------------|---------------------------------------------------|---|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | _ |
| ≈ 1580 OUR ESTIMATE 1583±4 1582±4 | 1 CARROLL 2 LITCHFIELD | 76 74 | DPWA DPWA | Isospin-1 total σ $K^-p \to \Lambda \pi^0$ | |
| | | | | | |
| | Σ(1580) WID | ГН | | | _ |
| VALUE (MeV) | | ГН | TECN | COMMENT | _ |

Σ(1580) DECAY MODES

| | Mode |
|----------------|---------------|
| Γ ₁ | NK |
| Γ_2 | $\Lambda\pi$ |
| Γ ₃ | $\Sigma \pi$ |

Σ(1580) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|---------------------------------------------------------------------------------------|-----------------------------------------------|-------------|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| $+0.03\pm0.01$ | ² LIT CHFIELD | 74 | DPWA | K N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K}$ | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| not seen | CAMERON ENGLER ² LIT CHFIELD | 7 8C | нвс | $K_I^0 p \rightarrow \Lambda \pi^+$ |
| not seen | ENGLER | 78 | нвс | $K_I^{0} p \rightarrow \Lambda \pi^{+}$ |
| $+0.10\pm0.02$ | ² LIT CHFIELD | 74 | DPWA | $\kappa^{-} \rho \rightarrow \Lambda \pi^{0}$ |
| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K}$ | | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |

| $(i j i f)^{-}/i total ill N $ | | | | ('1'3) ~/' | |
|---------------------------------------------------------------|----------------|-------------------------|----|------------|----------------------------------------------|
| | VALUE | DO CUMENT ID | | TECN | COMMENT |
| | not seen | | | | $K_I^0 \rho \rightarrow \Sigma^0 \pi^+$ |
| | not seen | ENGLER | 78 | HBC | $\kappa_I^0 \rho \rightarrow \Sigma^0 \pi^+$ |
| | $+0.03\pm0.04$ | ² LITCHFIELD | 74 | DPWA | $\overline{K}^{L}N$ multichannel |
| | | | | | |

Σ (1580) FOOTNOTES

 $^{^{1}}$ CARROLL 76 sees a total-cross-section bump with (J+1/2) Γ_{el} / $\Gamma_{ ext{total}}=0.0\underline{6}.$

The main effect observed by LITCHFIELD 74 is in the $\Lambda\pi$ final state; the $\overline{K}N$ and $\Sigma\pi$ couplings are estimated from a multichannel fit including total-cross-section data of LI 73.

$\Sigma(1580)$, $\Sigma(1620)$, $\Sigma(1620)$ Production Experiments

Σ(1580) REFERENCES

| OLMS TED PRAKHOV | 04 04 | PL B588 29 PR C69 042202 | J. Olmsted <i>et al.</i> S. Prakhov <i>et al.</i> | (BNL Crystal Ball Collab.) (BNL Crystal Ball Collab.) |
|---------------------|----------|-----------------------------|------------------------------------------------------|----------------------------------------------------------|
| CAMERON | 78 C | NP B132 189 | W. Cameron et al. | (BGNA, EDIN, GLAS+)I |
| ENGLER | 78 | PR D18 3061 | A. Engler et al. | ` (CMU, ANL) |
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | ` (BNL)I |
| LITCHFIELD | 74 | PL 51B 509 | P.J. Litchfield | (ČERNÍ JJP |
| LI | 73 | Purdue Conf. 283 | K.K. Li | `(BNL)I |

$\Sigma(1620) \ 1/2^-$

$$I(J^P) = 1(\frac{1}{2})$$
 Status: **

OMITTED FROM SUMMARY TABLE

The S_{11} state at 1697 MeV reported by VANHORN 75 is tentatively listed under the $\Sigma(1750)$. CARROLL 76 sees two bumps in the isospin-1 total cross section near this mass.

Production experiments are listed separately in the next entry.

| | Σ(1620) MA | SS | | |
|---------------------|----------------------|----|------|-----------------------------------|
| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
| ≈ 1620 OUR ESTIMATE | <u> </u> | | | |
| 1600± 6 | ¹ MORRIS | 78 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 1608± 5 | ² CARROLL | 76 | DPWA | lsospin-1 total σ |
| 1633±10 | ³ CARROLL | 76 | DPWA | lsospin-1 total σ |
| 1630 ± 10 | LANGBEIN | 72 | IPWA | K N multichannel |
| 1620 | KIM | 71 | DPWA | K-matrix analysis |

Σ(1620) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-------------|-------------------------|------|-----------------------------------|
| 87±19 | 1 MORRIS 78 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 15 | | DPWA | lsospin-1 total σ |
| 10 | ³ CARROLL 76 | DPWA | lsospin-1 total σ |
| 65 ± 20 | LANGBEIN 72 | IPWA | K N multichannel |
| 40 | KIM 71 | DPWA | K-matrix analysis |

Σ(1620) DECAY MODES

| | Mode | |
|-----------------------|--------------|--|
| $\overline{\Gamma_1}$ | NK | |
| Γ_2^- | $\Lambda\pi$ | |
| Γ_3 | $\Sigma \pi$ | |

Σ(1620) BRANCHING RATIOS

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ_1 |
|-----------------------------------------------|--------------|----|------|-------------------|---------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.22±0.02 | LANGBEIN | 72 | IPWA | K N multichannel | |
| 0.05 | KIM | 71 | DPWA | K-matrix analysis | |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{total} \text{ in } N \overline{K} \to \Sigma(1620) \to \Lambda \pi$ | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}$ | | |
|----------------------------------------------------------------------------------------------------------|---------------------|----|------|-----------------------------------------|--|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| 0.12 ± 0.02 | ¹ MORRIS | 78 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ | | |
| not seen | BAILLON | 75 | IPWA | $\overline{K}N \rightarrow \Lambda \pi$ | | |
| 0.15 | KIM | 71 | DPWA | K-matrix analysis | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma (16)$ | (Γ₁Γ₃) ¹ ⁄2/Γ | | | |
|--------------------------------------------------------------------------------------------------------|--------------------------|-----|------|--------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| not seen | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 0.40 ± 0.06 | LANGBEIN | 72 | IPWA | K N multichannel |
| 0.08 | KIM | 71 | DPWA | K-matrix analysis |
| | | | | |

Σ(1620) FOOTNOTES

- 1 MORRIS 78 obtains an equally good fit without including this resonance.
- ² Total cross-section bump with (J+1/2) $\Gamma_{\rm el}$ / $\Gamma_{\rm total}$ is 0.06 seen by CARROLL 76.
- 3 Total cross-section bump with (J+1/2) Γ_{el} / Γ_{total} is 0.04 seen by CARROLL 76.

Σ (1620) REFERENCES

| MORRIS CARROLL HEPP BAILL ON VANHORN AISO LANGBEIN KIM AISO | 78 76 76 B 75 75 72 71 | PR D17 55 PRL 37 806 PL 65B 487 NP B94 39 NP B87 145 NP B87 157 NP B47 477 PRL 27 356 Duke Conf. 161 | W.A. Morris et al. A.S. Carroll et al. V. Hepp et al. P.H. Baillon, P.J. Litchfield A.J. van Horn A.J. van Horn W. Langbein, F. Wagner J.K. Kim J.K. Kim | (FSU) IJP (BNL) I (CERN, HEIDH, MPIM) IJP (CERN, RHEL) IJP (LBL) IJP (MPIM) IJP (HARV) IJP (HARV) IJP |
|-------------------------------------------------------------------------------------|------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| | Resonan | ices, 1970 | J.K. KIIII | (HAKV) IJP |

$\Sigma(1620)$ Production Experiments

 $I(J^P) = 1(??)$

OMITTED FROM SUMMARY TABLE

Formation experiments are listed separately in the previous entry.

The results of CRENNELL 69B at 3.9 GeV/c are not confirmed by SABRE 70 at 3.0 GeV/c. However, at 4.5 GeV/c, AMMANN 70 sees a peak at 1642 MeV which on the basis of branching ratios they do not associate with the $\Sigma(1670)$. See MILLER 70 for a review of these conflicts.

Σ (1620) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------|----------------------|-------------------|---------|---------|--------|-----------------------------------------|
| ≈ 1620 OUR ES | STIMATE | | | | | |
| 1642 ± 12 | | AMMANN | 70 | DBC | | K-N 4.5 GeV/ c |
| $1618\pm~3$ | 20 | BLUMENFELD | 69 | нвс | + | $\kappa_L^0 p$ |
| $1619\pm~8$ | | CRENNELL | 69в | DBC | \pm | $K = N \rightarrow \Lambda \pi \pi \pi$ |
| • • • We do no | ot use the following | data for averages | , fits, | limits, | etc. • | • • |
| 1616± 8 | | CRENNELL | 68 | DBC | ± | See CREN- NELL 69B |

Σ (1620) WIDTH (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------|-----------------|-------------------|--------|-----------|--------|-----------------------|
| 55 ± 24 | | AMMANN | 70 | DBC | | K-N 4.5 GeV/ c |
| $30\!\pm\!10$ | 20 | BLUMENFELD | 69 | нвс | + | |
| $72 + 22 \\ -15$ | | CRENNELL | 69в | DBC | \pm | |
| | e the following | data for averages | , fits | , limits, | etc. • | • • |
| $66\!\pm\!16$ | | CRENNELL | 68 | DBC | ± | See CREN- NELL 698 |

Σ(1620) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode |
|-----------------------|----------------------------------------------------|
| $\overline{\Gamma_1}$ | $N\overline{K}$ |
| Γ_2 | $\Lambda\pi$ |
| Гз | $\Sigma \pi$ |
| Γ_4 | $\Lambda\pi\pi$ |
| Γ_5 | $\Sigma \pi$ $\Lambda \pi \pi$ $\Sigma (1385) \pi$ |
| Γ ₆ | $\Lambda(1405)\pi$ |

Σ (1620) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

| $\Gamma(\Lambda\pi\pi)/\Gamma(\Lambda\pi)$ | | | | | | Γ_4/Γ_2 |
|-----------------------------------------------|------|-------------|----|------|--------|-----------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | CHG | |
| ~ 2.5 | 14 | BLUMENFELD | 69 | HBC | + | |
| $\Gamma(N\overline{K})/\Gamma(\Lambda\pi)$ | | | | | | Γ_1/Γ_2 |
| VALUE | | DOCUMENT ID | | TECN | CHG | COMMENT |
| 0.4 ± 0.4 | | AMMANN | 70 | DBC | | $K^{-}p$ 4.5 GeV/c |
| 0.0 ± 0.1 | | CRENNELL | 68 | DBC | + | See CREN- NELL 69B |
| $\Gamma(\Lambda\pi)/\Gamma_{\rm total}$ | | | | | | Γ_2/Γ |
| VALUE | | DOCUMENT ID | | TECN | CHG | |
| large | | CRENNELL | 68 | DBC | \pm | |
| $\Gamma(\Sigma(1385)\pi)/\Gamma(\Lambda\pi)$ |) | | | | | Γ_5/Γ_2 |
| VALUE | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
| < 0.3 | 95 | AMMANN | 70 | DBC | | K^-p 4.5 GeV/c |
| 0.2 ± 0.1 | | CRENNELL | 68 | DBC | \pm | |
| $\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ | | | | | | Γ_3/Γ_2 |
| VALUE | CL% | DOCUMENT ID | | TECN | COMI | 1ENT |
| <1.1 | 95 | AMMANN | 70 | DBC | κ- I | V 4.5 GeV/c |
| $\Gamma(\Lambda(1405)\pi)/\Gamma(\Lambda\pi)$ | | | | | | Γ_6/Γ_2 |
| VALUE | | DOCUMENT ID | | TECN | COMI | MENT |
| 0.7 ± 0.4 | | AMMANN | 70 | DBC | K^-p | 4.5 GeV/ <i>c</i> |

Σ (1620) REFERENCES (PRODUCTION EXPERIMENTS)

| AMMANN 70 PRL 24 327 A.C. Ammann et al. Also PR D7 1345 A.C. Ammann et al. | (PURD, IND) (PURD, IUPU) |
|----------------------------------------------------------------------------|-----------------------------|
| MILLER 70 Duke Conf. 229 D.H. Miller | (PURD) |
| Hyperon Resonances, 1970 | , , |
| SABRE 70 NP B16 201 R. Barloutaud et al. (S | ABRE Collab.) |
| BLUMENFELD 69 PL 29B 58 B.J. Blumenfeld, G.R. Kalbfleisch | (BNL)I |
| CRENNELL 69B Lund Paper 183 D.J. Crennell et al. | (BNL, CUNY)I |
| Results are quoted in LEVÍ-SETTI 69C. | |
| Also Lund Conf. R. Levi-Setti | (EFI) |
| CRENNELL 68 PRL 21 648 D.J. Crennell et al. | (BNL, CÛNY)I |

$\Sigma(1660)\ 1/2^+$

 $I(J^P) = 1(\frac{1}{2}^+)$ Status: ***

For results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters **111B** 1 (1982).

Σ(1660) MASS

| VALUE (MeV) 1630 to 1690 (≈ 1660) OUR ES | <u>DO CUMENT ID</u> | | TECN COMMENT |
|------------------------------------------|---------------------|----------|------------------------------------------------|
| $1634.8 + 2.7 \\ -4.5$ | GAO | 11 | DPWA $K^- ho ightarrow \Lambda \pi^0$ |
| 1665.1 ± 11.2 | ¹ KOISO | 85 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| 1670 ±10 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1679 ±10 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1676 ±15 | GOPAL | 77 | DPWA $\overline{K}N$ multichannel |
| 1668 ±25 | VANHORN | 75 | DPWA $K^- p \rightarrow \Lambda \pi^0$ |
| 1670 ±20 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| • • • We do not use the followin | g data for average | es, fits | , limits, etc. • • • |
| 1565 or 1597 | ² MARTIN | 77 | DPWA KN multichannel |
| 1660 ±30 | | | IPWA $\overline{K}N \rightarrow \Lambda \pi$ |
| 1671 ± 2 | ⁴ PONTE | 75 | DPWA $K^- p ightarrow \Lambda \pi^0$ |

Σ(1660) WIDTH

| VALUE (M | eV) | DOCUMENT ID | | TECN | COMMENT |
|------------------------|----------------------------|-------------------------------------------------------------------|---------|-----------|------------------------------------------------------------------------------------------|
| 40 to | 200 (≈ 100) OUR ESTIM | ATE | | | |
| $120 \pm$ | 12 | GAO | 11 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| $81.5\pm$ | 22.2 | ¹ KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| $152 \pm$ | 20 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 38 ± | 10 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| $120 \pm$ | 20 | GOPAL | 77 | DPWA | K N multichannel |
| 230 +1 | 65 60 | VANHORN | 75 | DPWA | ${\it K}^- \rho \to \Lambda \pi^0$ |
| 250 ± 1 | 10 | KANE | 74 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| • • • W | e do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| 202 or 80 ± 81 ± | | ² MARTIN ³ BAILLON ⁴ PONTE | 75 | IPWA | $\overline{K} N$ multichannel $\overline{K} N \to \Lambda \pi$ $K^- p \to \Lambda \pi^0$ |

Σ(1660) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------|------------------------------|
| $\overline{\Gamma_1}$ | $N\overline{K}$ | 10-30 % |
| Γ_2 | $\Lambda\pi$ | seen |
| Γ ₃ | $\Sigma \pi$ | seen |

Σ(1660) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|------------------------|----------|-----------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.1 to 0.3 OUR ESTIMAT | E | | | | |
| 0.12 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.10 ± 0.05 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| • • • We do not use the follo | owing data for average | es, fits | , limits, | etc. • • • | |
| < 0.04 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.27 or 0.29 | ² MARTIN | 77 | DPWA | KN multichanne | el |

| <0.04 | GOPAL | | | See GOPAL 80 | |
|-----------------------------------------------------------------------------------------|---------------------------------------------------|----------|-------------|-----------------------------------------------|---|
| 0.27 or 0.29 | ² MARTIN | 77 | DPWA | K N multichannel | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} -$ | $\rightarrow \Sigma(1660) \rightarrow \Lambda\pi$ | | | $(\Gamma_{1}\Gamma_{2})^{\frac{1}{2}}/\Gamma$ | |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $- 0.065 {}^{+ 0.015}_{- 0.017}$ | GAO | 11 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ | I |
| < 0.04 | GOPAL | 77 | DPWA | K N multichannel | |
| $0.12 \begin{array}{l} +0.12 \\ -0.04 \end{array}$ | VANHORN | 75 | DPWA | $K^- \rho \to \Lambda \pi^0$ | |
| • • • We do not use the fo | llowing data for average | es, fits | , limits, e | etc. • • • | |
| -0.10 or -0.11 | | | | K N multichannel | |
| -0.04 ± 0.02 | ³ BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ | |
| $+0.16 \pm 0.01$ | ⁴ PONTE | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K}$ | $\rightarrow \Sigma(1660) \rightarrow \Sigma \pi$ | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
|---------------------------------------------------------------------------------------|---------------------------------------------------|----------|-------------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.13 ± 0.04 | ¹ KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| -0.16 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| -0.11 ± 0.01 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| ullet $ullet$ We do not use the | following data for averag | es, fits | , limits, e | etc. • • • |
| -0.34 or -0.37 | ² MARTIN | 77 | DPWA | K N multichannel |
| not seen | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| | | | | |

Σ (1660) FOOTNOTES

- ¹ The evidence of KOISO 85 is weak.
- ²The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
- ³ From solution 1 of BAILLON 75; not present in solution 2.

⁴ From solution 2 of PONTE 75; not present in solution 1.

Σ(1660) REFERENCES

| GA O KOIS O | 11 85 | NP A867 41 NP A433 619 | P. Gao, B.S. Zou, A. Sibirtsev H. Koiso <i>et al.</i> | (BHEP, BEIJT+) (TOKY, MASA) |
|----------------|----------|---------------------------|----------------------------------------------------------|--------------------------------|
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS T ON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+)IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+)IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | `(LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G | Moorhouse (LOUC+)IJP |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| HEPP | 76B | PL 65B 487 | V. Hepp <i>et al</i> . | (CERN, HEIDH, MPIM)IJP |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL)IJP |
| PONTE | 75 | PR D12 2597 | R.A. Ponte et al. | (MASA, TENN, UCR) IJP |
| VANHORN | 75 | NP B87 145 | A.J. van Horn | ` (LBL) IJP |
| A Iso | | NP B87 157 | A.J. van Horn | (LBL) IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| | | | | |

THE $\Sigma(1670)$ REGION

Production experiments: The measured $\Sigma \pi / \Sigma \pi \pi$ branching ratio for the $\Sigma(1670)$ produced in the reaction $K^-p \to \pi^-\Sigma(1670)^+$ is strongly dependent on momentum transfer. This was first discovered by EBERHARD 69, who suggested that there exist two Σ resonances with the same mass and quantum numbers: one with a large $\Sigma \pi \pi$ (mainly $\Lambda(1405)\pi$) branching fraction produced peripherally, and the other with a large $\Sigma \pi$ branching fraction produced at larger angles. The experimental results have been confirmed by AGUILAR-BENITEZ 70, ASPELL 74, ESTES 74, and TIMMERMANS 76. If, in fact, there are two resonances, the most likely quantum numbers for both the $\Sigma\pi$ and the $\Lambda(1405)\pi$ states are D_{13} . There is also possibly a third Σ in this region, the $\Sigma(1690)$ in the Listings, the main evidence for which is a large $\Lambda \pi / \Sigma \pi$ branching ratio. These topics have been reviewed by EBERHARD 73 and by MILLER 70.

Formation experiments: Two states are also observed near this mass in formation experiments. One of these, the $\Sigma(1670)D_{13}$, has the same quantum numbers as those observed in production and has a large $\Sigma\pi/\Sigma\pi\pi$ branching ratio; it may well be the $\Sigma(1670)$ produced at larger angles (see TIMMERMANS 76). The other state, the $\Sigma(1660)P_{11}$, has different quantum numbers, its $\Sigma\pi/\Sigma\pi\pi$ branching ratio is unknown, and its relation to the produced $\Sigma(1670)$ states is obscure.

 $\Sigma(1670)$

 $\Sigma(1670) \ 3/2$

 $I(J^P) = 1(\frac{3}{2})$ Status: ***

For most results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters ${\bf 111B}~1~(1982).$

Results from production experiments are listed separately in the next

Σ(1670) MASS

| VALUE (MeV) 1665 to 1685 (≈ 1670) OUR ESTI | DO CUMENT ID | | TECN COMMENT |
|-----------------------------------------------|-------------------|---------|------------------------------------------------|
| | WAIE | | |
| $1673.1 + 1.4 \\ - 1.6$ | GAO | 11 | DPWA $K^- \rho \rightarrow \Lambda \pi^0$ |
| 1665.1 ± 4.1 | KOISO | 85 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| 1682 ± 5 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1679 ±10 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ |
| 1670 ± 5 | GOPAL | 77 | DPWA KN multichannel |
| 1670 ± 6 | HEPP | 76B | DPWA $K^-N \rightarrow \Sigma \pi$ |
| 1685 ± 20 | BAILLON | 75 | IPWA $\overline{K}N \rightarrow \Lambda\pi$ |
| $1659 \begin{array}{c} +12 \\ -5 \end{array}$ | VANHORN | 75 | DPWA $K^- \rho \rightarrow \Lambda \pi^0$ |
| 1670 ± 2 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| | data for averages | s, fits | , limits, etc. ● ● |
| 1667 or 1668 | MARTIN | 77 | DPWA $\overline{K}N$ multichannel |
| 1650 | DEBELLEFON | 76 | IPWA $K^-p \rightarrow \Lambda \pi^0$ |
| 1671 ± 3 | PONTE | 75 | DPWA $K^-p \rightarrow \Lambda \pi^0$ (sol. 1) |
| 1655 ± 2 | PONTE | 75 | |

Σ(1670) WIDTH

| <u>VA L</u> | UE (MeV) to 80 (≈ 60) OUR ESTIMATE | DOCUMENT ID | | TECN | COMMENT |
|-------------|------------------------------------|-------------------|---------|-----------|---------------------------------------------|
| 53 | + 7 - 5.5 | GAO | 11 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 65. | 0± 7.3 | KOISO | 85 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 79 | ± 10 | GOPAL | 80 | DPWA | $\overline{K}N \rightarrow \overline{K}N$ |
| 56 | ± 20 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 50 | ± 5 | GOPAL | 77 | DPWA | K N multichannel |
| 56 | ± 3 | HEPP | 76B | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 85 | ± 25 | BAILLON | 75 | | $\overline{K}N \rightarrow \Lambda \pi$ |
| 32 | ± 11 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 79 | ± 6 | KANE | 74 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |
| • • | • We do not use the following d | lata for averages | , fits, | limits, e | etc. • • • |
| 46 | or 46 | MARTIN | 77 | DPWA | K N multichannel |
| 80 | | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 44 | ± 11 | PONTE | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ (sol. 1) |
| 76 | ± 5 | PONTE | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ (sol. 2) |

Σ (1670) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | N K | 7-13 % |
| Γ_2 | $\Lambda\pi$ | 5-15 % |
| Γ_3 | $\Sigma \pi$ | 30-60 % |
| Γ_4 | $\Lambda \pi \pi$ | |
| Γ_5 | $\Sigma \pi \pi$ | |
| Γ_6 | $\Sigma(1385)\pi$ | |
| Γ_7 | $\Sigma(1385)\pi$, S -wave | |
| Γ ₈ | Λ (1405) π | |
| Γ9 | $\Lambda(1520)\pi$ | |

The above branching fractions are our estimates, not fits or averages. Σ(1670) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|-------------------------|----------|-----------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.07 to 0.13 OUR EST MAT | E | | | | |
| 0.10 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.11 ± 0.03 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| • • • We do not use the fol | lowing data for average | es, fits | , limits, | etc. • • • | |
| 0.08 ± 0.03 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.07 or 0.07 | 1 MARTIN | 77 | DPWA | K N multichann | el . |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $N\overline{K} \to Z$ | $\Sigma(1670) \rightarrow \Lambda\pi$ | | TECN | (Γ ₁ Γ ₂) ^{1/2} / |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $+0.08 \begin{array}{l} +0.022 \\ -0.018 \end{array}$ | GAO | 11 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| 0.17 ±0.03 | ² MORRIS | 78 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 0.13 ±0.02 | ² MORRIS | 78 | | $K^- n \rightarrow \Lambda \pi^-$ |
| $+0.10 \pm 0.02$ | GOPAL | 77 | | $\overline{K}N$ multichannel |
| $+0.06 \pm 0.02$ | BAILLON | 75 | IPWA | |
| $+0.09 \pm 0.02$ | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| +0.018±0.060 | DEVENISH | 74B | Disable a | Fixed-t dispersion rel. |
| • • We do not use the follow | | | | |
| +0.08 or +0.08 | 1 MARTIN | 77 N. 76 | | K N multichannel |
| +0.05 0.08 ±0.01 | DEBELLEFO PONTE | | DDWA | $K^- p \rightarrow \Lambda \pi^0$ $K^- p \rightarrow \Lambda \pi^0 \text{ (sol. 1)}$ |
| 0.17 ±0.01 | PONTE | 75 75 | | $K^- p \rightarrow \Lambda \pi^0 \text{ (sol. 2)}$ $K^- p \rightarrow \Lambda \pi^0 \text{ (sol. 2)}$ |
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \mathbb{R}$ | $\Sigma(1670) \rightarrow \Sigma \pi$ | | | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}$ |
| VALUE | DO CUMENT IE | | | COMMENT |
| $+0.20 \pm 0.02$ | KOISO | 85 | | $K^- p \rightarrow \Sigma \pi$ |
| $+0.21 \pm 0.02$ | GOPAL | 77 | | K N multichannel |
| $+0.20\pm0.01$ | HEPP | 76B | | $K^- N \rightarrow \Sigma \pi$ |
| $+0.21\pm0.03$ • • • We do not use the follow | KANE | 74 | | $K^-p \rightarrow \Sigma \pi$ |
| +0.18 or +0.17 | MARTIN | 77 | | <i>KN</i> multichannel |
| $\Gamma(\Lambda\pi\pi)/\Gamma_{ m total}$ | | | | Γ ₄ / |
| VALUE | DO CUMENT IE | | TECN | |
| • • We do not use the follow | wing data for averag | es, fits | , limits, | etc. • • • |
| | | | | |
| <0.11 | ARMENTER | | | $K^- \rho \ (\Gamma_1 = 0.09)$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $+0.11 \pm 0.03$ | $\Sigma(1670) \rightarrow \Sigma(13)$ $\frac{DOCUMENT ID}{PREVOST}$ | 8 85) π | , S-wav o <u>TECN</u> DPWA | $ \begin{array}{ccc} e & (\Gamma_1 \Gamma_7)^{\frac{1}{2}} / \\ \frac{COMMENT}{K^- N \rightarrow \Sigma(1385) \pi} \end{array} $ |
| $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $ALUE$ $+0.11\pm0.03$ $\bullet \bullet \bullet \text{ We do not use the follows}$ | $\Sigma(1670) ightarrow \Sigma(13)$ $DOCUMENT ID$ PREVOST wing data for average | 74 es, fits | , S-wav e TECN DPWA , limits, | $\begin{array}{ccc} \mathbf{e} & & & & & & & & & \\ \mathbf{COMMENT} & & & & & & & \\ \frac{COMMENT}{K-N} & \rightarrow & & & & & & \\ \mathbf{etc.} & \bullet & \bullet & \bullet & & & & \\ \end{array}$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $ALUE$ $+0.11 \pm 0.03$ $\bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 | $\Sigma(1670) \rightarrow \Sigma(13)$ $\frac{DOCUMENT ID}{PREVOST}$ | 8 85) π | , S-wav o <u>TECN</u> DPWA | e $\frac{(\Gamma_1 \Gamma_7)^{1/2}}{K^- N \rightarrow \Sigma(1385) \pi}$ etc. $\bullet \bullet \bullet$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \overline{L}_{NALUE}$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ | Σ (1670) $ ightarrow \Sigma$ (13) DOCUMENT IL PREVOST wing data for average 3 SIMS | 74 es, fits 68 | DPWA, limits, DBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K-N \to \Sigma(1385)\pi}$ etc. $\bullet \bullet \bullet$ $K-N \to \Lambda\pi\pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \overline{L}$ $(ALUE)^{\frac{1}{2}}+0.11\pm0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}}$ $(ALUE)^{\frac{1}{2}}$ | Σ (1670) $\rightarrow \Sigma$ (13) $\frac{DOCUMENT IC}{PREVOST}$ Wing data for average 3 SIMS | 74 es, fits 68 | DPWA, limits, DBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K-N \to \Sigma(1385)\pi}$ etc. $\bullet \bullet \bullet$ $K-N \to \Lambda\pi\pi$ $\Gamma_5/COMMENT$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $(\Lambda L U E)$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $AL U E$ $\bullet \bullet \bullet \text{ We do not use the follow}$ | Σ (1670) $ ightarrow \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (13) $ ightharpoonup \Sigma$ (14) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15) $ ightharpoonup \Sigma$ (15 | 74 es, fits 68 | DPWA, limits, DBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K-N \to \Sigma(1385)\pi}$ etc. $\bullet \bullet \bullet$ $K-N \to \Lambda\pi\pi$ COMMENT etc. $\bullet \bullet \bullet$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $ALUE$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $ALUE$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.14 | Σ (1670) $\rightarrow \Sigma$ (13) $\frac{DOCUMENT IC}{PREVOST}$ Wing data for average 3 SIMS | 74 es, fits 68 | DPWA, limits, DBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $\frac{K^-N \to \Lambda\pi\pi}{K^-N \to K\pi}$ etc. • • • $\frac{\Gamma_5}{K^-\rho}$, K^-d ($\Gamma_1=0.09$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $ALUE$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $ALUE$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.14 | Σ (1670) $\rightarrow \Sigma$ (13) DOCUMENT IL PREVOST wing data for average 3 SIMS DOCUMENT IL wing data for average 4 ARMENTER | 74 es, fits 68 es, fits | DPWA, limits, DBC TECN DECN TECN HBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to \Lambda\pi\pi$ comment etc. • • • $K^-\rho$, K^-d (Γ_1 =0.09 |
| $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\overline{K} \rightarrow \overline{L}$ $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\overline{K} \rightarrow \overline{L}$ $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ $(\Gamma_1\Gamma_f)^{1/2}$ $(\Gamma_2\Gamma_f)^{1/2}$ | E(1670) → E(13) DOCUMENT IC PREVOST wing data for averag 3 SIMS DOCUMENT IC 4 ARMENTER | 74 es, fits 68 es, fits OS68E | , S-wave TECN DPWA, limits, on DBC TECN HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385) \pi}$ etc. • • • $K^-N \to \Lambda \pi \pi$ etc. • • • $K^-N \to \Lambda \pi \pi$ $\frac{COMMENT}{K^-p, K^-d}$ ($\Gamma_1 = 0.0^\circ$ |
| $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total in }N\overline{K}} \rightarrow \frac{1}{2}$ $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total in }N\overline{K}} \rightarrow \frac{1}{2}$ $(\Gamma_1\Gamma_f)^{1/2}/\Gamma_{\text{total in }N\overline{K}} \rightarrow \frac{1}{2}$ $(\Gamma_1\Gamma_f)^{1/2}$ $(\Gamma_1\Gamma_f)^{$ | E(1670) → E(13) DOCUMENT IC PREVOST wing data for averag 3 SIMS DOCUMENT IC 4 ARMENTER | 74 es, fits 68 es, fits OS68E | DPWA, limits, DBC TECN , limits, HBC TECN , limits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385) \pi}$ etc. • • • $K^-N \to \Lambda \pi \pi$ Etc. • • • $K^-N \to \Lambda \pi \pi$ Etc. • • • $K^-P, K^-d \ (\Gamma_1 = 0.0^\circ)$ Etc. • • • • $K^-P, K^-D \ (\Gamma_1 = 0.0^\circ)$ Etc. • • • • • • • • • • • • • • • • • • • |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $ALUE$ $+0.11 \pm 0.03$ $\bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $ALUE$ $\bullet \bullet \text{ We do not use the follow}$ <0.14 $\Gamma(\Lambda(1405)\pi)/\Gamma_{\text{total}}$ $ALUE$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.06 | E(1670) → E(13 DOCUMENT IE PREVOST wing data for averag 3 SIMS DOCUMENT IE wing data for averag 4 ARMENTER DOCUMENT IE ARMENTER | 74 es, fits 68 es, fits OS68E | DPWA, limits, DBC TECN , limits, HBC TECN , limits, HBC | e $(\Gamma_1\Gamma_7)^{\frac{1}{2}}$ / $K^-N \rightarrow \Sigma(1385)\pi$ etc. • • • $K^-N \rightarrow \Lambda\pi\pi$ f ₅ / comment etc. • • • $K^-\rho$, K^-d ($\Gamma_1=0.09$ etc. • • • $K^-\rho$, K^-d ($\Gamma_1=0.09$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ 0.000 0.17 ± 0.00 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 | DOCUMENT IE DOCUMENT IE PREVOST Wing data for average SIMS DOCUMENT IE Wing data for average 4 ARMENTER DOCUMENT IE ARMENTER ARMENTER ARMENTER ARMENTER 670) → Λ(1405): | 74 es, fits 68 es, fits OS68E | DPWA, limits, DBC TECN , limits, HBC TECN , limits, HBC | e $\frac{(\Gamma_1 \Gamma_7)^{\frac{1}{2}}}{K^- N \to \Sigma(1385) \pi}$ etc. • • • $K^- N \to \Lambda \pi \pi$ $\frac{\Gamma_5}{\text{etc.}}$ etc. • • • $K^- \rho, K^- d (\Gamma_1 = 0.09)$ etc. • • • $K^- \rho, K^- d (\Gamma_1 = 0.09)$ |
| ($\Gamma_i \Gamma_f$) $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $+0.11\pm0.03$ •• • We do not use the follow 0.17 ± 0.02 ($\Gamma(\Sigma\pi\pi)/\Gamma_{total}$ <0.14 •• • We do not use the follow <0.14 (<0.14 (<0.14 (<0.14 (<0.14 •• • We do not use the follow <0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 (<0.06 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| ($\Gamma_i \Gamma_f$) $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ | DOCUMENT IE DOCUMENT IE PREVOST Wing data for average SIMS DOCUMENT IE Wing data for average 4 ARMENTER DOCUMENT IE MY ARMENTER ARMENTER ARMENTER ARMENTER 670) → Λ(1405): DOCUMENT IE BRUCKER | 74 es, fits 68 es, fits OS68E r 70 | S-wave TECN DP WA , limits, DBC TECN , limits, HBC TECN , limits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to K(1385)\pi$ etc. • • • $K^-N \to \Lambda\pi\pi$ $\frac{\Gamma_5}{COMMENT}$ etc. • • • $K^-p, K^-d \ (\Gamma_1=0.09)$ $\frac{COMMENT}{K^-p, K^-d} \ (\Gamma_1=1.09)$ $\frac{COMMENT}{K^-p, K^-d} \ (\Gamma_1=1.09)$ |
| $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\overline{K} \rightarrow Z$ $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\overline{K} \rightarrow Z$ $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}$ $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $(\Gamma$ | DOCUMENT IE DOCUMENT IE PREVOST Wing data for average SIMS DOCUMENT IE Wing data for average 4 ARMENTER DOCUMENT IE MY ARMENTER ARMENTER ARMENTER ARMENTER 670) → Λ(1405): DOCUMENT IE BRUCKER | 74 es, fits 68 es, fits OS68E r 70 | S-wave TECN DP WA , limits, DBC TECN , limits, HBC TECN , limits, HBC | e $\frac{(\Gamma_1\Gamma_7)^{\frac{1}{2}}}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to \Lambda\pi\pi$ F5/ etc. • • • $K^-N \to \Lambda\pi\pi$ COMMENT etc. • • • $K^-P, K^-d \ (\Gamma_1=0.09)$ etc. • • • $K^-P, K^-d \ (\Gamma_1=0.09)$ $\frac{(\Gamma_1\Gamma_8)\Gamma}{K^-P, K^-d \ (\Gamma_1=0.09)}$ etc. • • • $K^-P, K^-R \ (\Gamma_1=0.09)$ $\frac{(\Gamma_1\Gamma_8)\Gamma}{K^-N \to \Sigma\pi\pi}$ etc. • • • |
| ($\Gamma_i \Gamma_f$) $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{t$ | E(1670) → E(13 DOCUMENT IL PREVOST wing data for average 3 SIMS DOCUMENT IL wing data for average 4 ARMENTER DOCUMENT IL wing data for average ARMENTER ARMENTER 5 BRUCKER wing data for average BERLEY ### ARMENT IL ### ARMENT IL BRUCKER BERLEY ### BRUCKER ### BRUCKER ### BERLEY | 74 es, fits 68 es, fits OS68E 70 es, fits 69 | S-wave TECN DPWA Ilmits, DBC TECN HBC TECN Ilmits, HBC TECN DBC Ilmits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to \Lambda \pi \pi$ $\frac{\Gamma_5}{COMMENT}$ etc. • • • $K^-p, K^-d (\Gamma_1 = 0.09)$ $\frac{\Gamma_0MMENT}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1\Gamma_8/\Gamma}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1\Gamma_8/\Gamma}{K^-N \to \Sigma \pi \pi}$ etc. • • • $K^-p \ 0.6 - 0.82 \ \text{GeV}/c$ Γ_8/Γ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z_{\text{VALUE}}$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $VALUE$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.14 $\Gamma(\Lambda(1405)\pi)/\Gamma_{\text{total}}$ $VALUE$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.06 $\Gamma_i \Gamma_f/\Gamma_{\text{total}}^2 \text{ in } N\overline{K} \rightarrow \Sigma(11)$ $VALUE$ 0.007 ± 0.002 $\bullet \bullet \text{ We do not use the follow}$ <0.03 $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ $VALUE$ | DOCUMENT IE DOCUMENT IE PREVOST Wing data for average 3 SIMS DOCUMENT IE Wing data for average 4 ARMENTER DOCUMENT IE DOCUMENT IE 5 BRUCKER Wing data for average ARMENTER 670) → Λ(1405): 5 BRUCKER Wing data for average BERLEY DOCUMENT IE DOCUMENT IE DOCUMENT IE DOCUMENT IE DOCUMENT IE | 74 74 es, fits 68 es, fits OS68E 70 es, fits 69 | S-wave TECN DPWA Ilimits, Ilimits, HBC TECN DBC TECN DBC Ilimits, HBC TECN DBC Ilimits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385) \pi}$ etc. • • • $K^-N \to \Lambda \pi \pi$ $\frac{\Gamma_5}{COMMENT}$ etc. • • • $K^-p, K^-d (\Gamma_1 = 0.09)$ $\frac{\Gamma_8}{COMMENT}$ etc. • • • $K^-p, K^-d (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1 \Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ |
| ($\Gamma_i \Gamma_f$) $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ in $N\overline{K} \rightarrow Z$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{total}$ $^{1/2}/\Gamma_{t$ | E(1670) → E(13 DOCUMENT IL PREVOST wing data for average 3 SIMS DOCUMENT IL wing data for average 4 ARMENTER DOCUMENT IL wing data for average ARMENTER ARMENTER 5 BRUCKER wing data for average BERLEY ### ARMENT IL ### ARMENT IL BRUCKER BERLEY ### BRUCKER | 74 es, fits 68 es, fits OS68E 70 es, fits 69 | S-wave TECN DPWA Ilmits, DBC TECN HBC TECN Ilmits, HBC TECN DBC Ilmits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to \Lambda \pi \pi$ $\frac{\Gamma_5}{COMMENT}$ etc. • • • $K^-p, K^-d (\Gamma_1 = 0.09)$ $\frac{\Gamma_0MMENT}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1\Gamma_8/\Gamma}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1\Gamma_8/\Gamma}{K^-N \to \Sigma \pi \pi}$ etc. • • • $K^-p \ 0.6 - 0.82 \ \text{GeV}/c$ Γ_8/Γ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow Z_{\text{NALUE}}$ $+0.11 \pm 0.03$ $\bullet \bullet \bullet \text{ We do not use the follow}$ 0.17 ± 0.02 $\Gamma(\Sigma \pi \pi)/\Gamma_{\text{total}}$ $(ALUE)$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.14 $\Gamma(\Lambda(1405)\pi)/\Gamma_{\text{total}}$ $(ALUE)$ $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.06 $\Gamma_i \Gamma_f/\Gamma_{\text{total}}^2 \text{ in } N\overline{K} \rightarrow \Sigma(11)$ $(ALUE)$ 0.007 ± 0.002 $\bullet \bullet \bullet \text{ We do not use the follow}$ <0.03 $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1385)\pi)$ $(ALUE)$ | DOCUMENT IE DOCUMENT IE PREVOST wing data for average 3 SIMS DOCUMENT IE Wing data for average 4 ARMENTER DOCUMENT IE WING data for average ARMENTER 670) → Λ(1405): DOCUMENT IE BRUCKER WING data for average BERLEY π) DOCUMENT IE BRUCKER | 74 74 es, fits 68 es, fits OS68E 70 70 220) π | S-wave TECN DPWA Ilimits, Ilimits, HBC TECN DBC TECN DBC Ilimits, HBC TECN DBC Ilimits, HBC | e $\frac{COMMENT}{K^-N \to \Sigma(1385)\pi}$ etc. • • • $K^-N \to \Lambda\pi\pi$ $\frac{\Gamma_5}{COMMENT}$ etc. • • • $K^-p, K^-d (\Gamma_1 = 0.09)$ $\frac{COMMENT}{K^-p, K^-d} (\Gamma_1 = 0.09)$ $\frac{\Gamma_1\Gamma_8}{K^-p, K^-d} (\Gamma_1 = 0.09)$ |

Σ (1670) FOOTNOTES

- 1 The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. 2 Results are with and without an S_{11} $\Sigma(1620)$ in the fit. 3 SIMS 68 uses only cross-section data. Result used as upper limit only. 4 Ratio only for Σ 2π system in I=1, which cannot be $\Sigma(1385)$.
- 5 Assuming the $\Lambda(1405)\,\pi$ cross-section bump is due only to $3/2^-$ resonance.
- ⁶The CAMERON 77 upper limit on *F*-wave decay is 0.03.

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| | | | | |

$\Sigma(1670)$ Bumps

 $I(J^P) = 1(??)$

OMITTED FROM SUMMARY TABLE

Formation experiments are listed separately in the preceding entry.

Probably there are two states at the same mass with the same quantum numbers, one decaying to $\Sigma\pi$ and $\Lambda\pi$, the other to $\Lambda(1405)\pi$. See the note in front of the preceding entry.

Σ (1670) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) EVT | S DOCUMENT ID | | TECN | CH G | COMMENT |
|-----------------------------|-----------------------|--------|-------------|--------|--------------------------------------------------|
| ≈ 1670 OUR ESTIMATE | | | | | |
| 1670 ± 4 | ¹ CARROLL | 76 | DPWA | | lsospin-1 total σ |
| 1675 ± 10 | ² HEPP | 76 | DBC | _ | $K^- N$ 1.6-1.75 GeV/ c |
| 1665 ± 1 | APSELL | 74 | HBC | | K [−] p 2.87 GeV/c |
| 1688 ± 2 or 1683 ± 51.2 | k BERTHON | 74 | HBC | 0 | Quasi-2-body σ |
| 1670± 6 | AGUILAR | 70B | HBC | | $K^- p \rightarrow \Sigma \pi \pi \text{ 4 GeV}$ |
| 1668 ± 10 | AGUILAR | 70B | HBC | | $K^- p \rightarrow \Sigma 3\pi 4 \text{ GeV}$ |
| 1660 ± 10 | ALVAREZ | 63 | HBC | + | K^-p 1.51 GeV/c |
| • • • We do not use the fo | ollowing data for ave | rages, | , fits, lim | its, e | tc. • • • |
| 1668±10 15 | 3 FERRERSORIA | 81 | OMEG | _ | $\pi^- p$ 9,12 GeV/ c |
| 1655 to 1677 | TIMMERMAN | S76 | HBC | + | K^-p 4.2 GeV/c |
| 1665 ± 5 | BUGG | 68 | CNTR | | K^-p , d total σ |
| 1661 ± 9 7 | D PRIMER | 68 | HBC | + | See BARNES 69E |
| 1685 | ALEXANDER | 62c | нвс | -0 | $\pi^- p$ 2-2.2 GeV/ c |

$\Sigma(1670)$ WIDTH (PRODUCTION EXPERIMENTS)

| VALUE | E (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------|--------------------------------------|-------------|----------------------------------|---------|---------|--------|-----------------------------------------|
| 67.0 | ± 2.4 | | APSELL | 74 | НВС | | K−p 2.87 GeV/c |
| 110 | | | AGUILAR | 70B | НВС | | $K^-p \rightarrow \Sigma \pi \pi 4$ GeV |
| 135 | $^{+40}_{-30}$ | | AGUILAR | 70B | НВС | | $K^-p \rightarrow \Sigma 3\pi 4$ GeV |
| 40 | ± 10 | | ALVAREZ | 63 | HBC | + | |
| • • • | We do not use th | e following | data for averages | , fits, | limits, | etc. • | • • |
| 90 | ± 20 | | ³ FERRERSORI <i>A</i> | 81 | OMEG | _ | $\pi^- p$ 9,12 GeV/ c |
| 52 | | | ^l CARROLL | 76 | DPWA | | lsospin- 1 total σ |
| 48 | to 63 | | TIMMERMAN | S76 | HBC | + | K^-p 4.2 GeV/c |
| 30 | ± 15 | | BUGG | 68 | CNTR | | |
| 60 | ± 20 | 70 | PRIMER | 68 | HBC | + | See BARNES 69E |
| 45 | | | ALEXANDER | 62c | HBC | -0 | |

Σ (1670) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode |
|-----------------------|--------------------|
| $\overline{\Gamma_1}$ | NK |
| Γ_2^- | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |
| Γ_4 | $\Lambda\pi\pi$ |
| Γ_5 | $\Sigma \pi \pi$ |
| Γ ₆ | $\Sigma(1385)\pi$ |
| Γ ₇ | $\Lambda(1405)\pi$ |

Σ (1670) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

| $\Gamma(N\overline{K})/\Gamma(\Sigma\pi)$ | | | | | | Γ_1/Γ_3 |
|-------------------------------------------|------|--------------|------|------|-----|----------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| < 0.03 | | TIMMERMAI | NS76 | нвс | + | K-p 4.2 GeV/c |
| < 0.10 | | BERTHON | 74 | HBC | 0 | Quasi-2-body σ |
| < 0.2 | | AGUILAR | 70B | HBC | | |
| < 0.26 | | BARNES | 69E | НВС | + | K−ρ 3.9–5 GeV/c |
| 0.025 | | BUGG | 68 | CNTR | 0 | Assuming $J = \frac{3}{2}$ |

| | | $\Sigma(167)$ | 70) | , Σ(| 167 | 0) Bumps |
|----------------------------------------------------|--------------------|------------------------------------|----------------|-------------------|-----------------|-----------------------------------------------------|
| <0.24 | 0 | PRIMER | 68 | нвс | + | K ⁻ p 4.6-5 |
| < 0.6 | | LONDON | 66 | нвс | + | GeV/ <i>c</i> K - p 2.25 |
| < 0.19 | 0 | ALVAREZ | 63 | нвс | + | GeV/c K-p 1.15 |
| $\geq 0.5~\pm 0.25$ | | SMITH | 63 | НВС | -0 | GeV/ <i>c</i> |
| $\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi)$ | | | | | | Γ_2/Γ_3 |
| 0.76 ± 0.09 | EVTS | <u>DOCUMENT ID</u> ESTES | 74 | TECN HBC | <u>снс</u> 0 | K-p 2.1,2.6 |
| $\textbf{0.45} \pm \textbf{0.15}$ | | BARNES | 69E | нвс | + | GeV/ <i>c</i> K-p 3.9-5 |
| 0.15 ± 0.07 | | HUWE | 69 | нвс | + | GeV/c |
| 0.11 ± 0.06 • • • We do not use the | 33 ne following | BUTTON g data for average | 68 es, fits | HBC s, limits, | + etc. • | K−p 1.7 GeV/c • • |
| $\leq 0.45 \pm 0.07$ 0.55 ± 0.11 | | TIMMERMAI BERTHON | NS76 74 | HBC HBC | + | K^-p 4.2 GeV/ c Quasi-2-body σ |
| 0 | 0 | PRIMER | 68 | нвс | + | See BARNES 69E |
| <0.6 | | LONDON | 66 | HBC | + | K - p 2.25 GeV / c |
| 1.2 | 130 | ALVAREZ | 63 | HBC | + | К ⁻ р 1.15 GeV/c |
| 1.2 | | SMITH | 63 | НВС | -0 | |
| $\frac{\Gamma(\Lambda\pi\pi)}{\Gamma(\Sigma\pi)}$ | EVTS | DO CUMENT ID | | TECN | <u>CHG</u> | Γ ₄ /Γ ₃ |
| <0.6 | · | LONDON | 66 | НВС | + | K ⁻ p 2.25 GeV/c |
| 0.56 | 90 | ALVAREZ | 63 | нвс | + | K ⁻ p 1.15 GeV/c |
| 0.17 | | SMITH | 63 | нвс | -0 | 301/0 |
| $\Gamma(\Sigma\pi\pi)/\Gamma(\Sigma\pi)$ | | | | | | Γ_5/Γ_3 |
| VALUE largest at small angles | EVTS | DOCUMENT ID ESTES | 74 | HB C | <u>СНБ</u> 0 | COMMENT K-p 2.1,2.6 |
| • • • We do not use th | ne followin | g data for average | es, fits | s, limits, | etc. • | GeV/ <i>c</i> • • |
| < 0.2 | | ² HEPP | 76 | DBC | - | K ⁻ N 1.6-1.75 GeV/c |
| 0.56 | 180 | ALVAREZ | 63 | нвс | + | K-p 1.15 GeV/c |
| $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma\pi)$ | -) | | | | | Γ ₇ /Γ ₃ |
| VALUE | <u>EVTS</u> | DOCUMENT ID | | TECN | <u>CHG</u> | COMMENT |
| 1.8 ±0.3 to 0.02 ± 0.07 | | 3,4 TIMMERMAI | | HBC | + | K = p 4.2 GeV/c |
| largest at small angles 3.0 ± 1.6 | EO | ESTES | 74 66 | нвс нвс | ± | K - p 2.1,2.6 GeV/c |
| | 50 | LONDON | | | + | K - p 2.25 GeV/c |
| 0.58±0.20 | 17 | PRIMER | 68 | HB C | + | See BARNES 69E |
| $\Gamma(\Sigma\pi)/\Gamma(\Sigma\pi\pi)$ | | | | | | Γ_3/Γ_5 |
| VALUE | | 5 APSELL | 74 | TECN HBC | <u>CHG</u> | <u>COMMENT</u> K - p 2.87 |
| varies with prod. angle 1.39 ± 0.16 | | BERTHON | 74 | нвс | + | GeV/c |
| 2.5 to 0.24 | | ⁴ EBERHARD | 69 | НВС | U | Quasi-2-body σ K^-p 2.6 GeV/ c |
| < 0.4 0.30 ± 0.15 | | BIRMINGHAN LONDON | √1 66 66 | HBC HBC | ++ | K ⁻ p 3.5 GeV/c K ⁻ p 2.25 |
| | | | | | | ĠeV/ <i>c</i> |
| $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma\pi)$ | π) | DO CUMENT ID | | TECN | CHG | Γ ₇ /Γ ₅ |
| 0.97±0.08 | | TIMMERMAN | | нвс | | K−p 4.2 GeV/c |
| 1.00±0.02 | | APSELL | 74 | нвс | | K ⁻ ρ 2.87 GeV/c |
| $0.90 + 0.10 \\ -0.16$ | | EBERHARD | 65 | НВС | + | K−p 2.45 GeV/c |
| $\Gamma(\Lambda(1405)\pi)/\Gamma(\Sigma(1100)\pi)$ | $1385)\pi)$ | | | | | Γ ₇ /Γ ₆ |
| VALUE | | DOCUMENT ID | 65 | TECN | <u>CHG</u> | COMMENT K = p 2 4E |
| <0.8 | | EBERHARD | 65 | НВС | + | K [−] p 2.45 GeV/c |
| $\Gamma(\Lambda\pi\pi)/\Gamma(\Sigma\pi\pi)$ | | | | | | Γ_4/Γ_5 |
| <u>VALUE</u> 0.35 ± 0.2 | | <u>DOCUMENT ID</u> BIRMINGHAN | VI 66 | TECN HBC | <u>CHG</u> + | $K^- p$ 3.5 GeV/ c |
| $\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi\pi)$ | | | | | | Γ ₂ /Γ ₅ |
| VALUE <0.2 | | <u>DO CUMENT ID</u> BIR MINGHAI | 1.00 | TECN HBC | <u>CHG</u> | COMMENT |
| | | | | HRC | + | $K^{-}p$ 3.5 GeV/c |

DOCUMENT ID TECN
AGUILAR-... 70B HBC

 $\Gamma(\Lambda\pi)/[\Gamma(\Lambda\pi)+\Gamma(\Sigma\pi)]$

$\Sigma(1670)$ Bumps, $\Sigma(1690)$ Bumps, $\Sigma(1750)$

| $\Gamma(\Sigma(1385)\pi)/\Gamma(\Sigma\pi)$ | | | Γ_6/Γ_3 |
|---------------------------------------------|--------------|------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| $\leq 0.21 \pm 0.05$ | TIMMERMANS76 | НВС | K^-p 4.2 GeV/ c |

Σ(1670) QUANTUM NUMBERS (PRODUCTION EXPERIMENTS)

| VALUE | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT | |
|---------------|------|-------------|----|------|-----|------------------------|--|
| $J^P = 3/2^-$ | 400 | BUTTON | 68 | НВС | ± | $\Sigma^0 \pi$ | |
| $J^P = 3/2^-$ | | EBERHARD | 67 | HBC | + | Λ (1405) π | |
| $J^P = 3/2^+$ | | LEVEQUE | 65 | HBC | | Λ (1405) π | |

Σ (1670) FOOTNOTES

- ¹ Total cross-section bump with (J+1/2) Γ_{el} / Γ_{total} = 0.23.
- 2 Enhancements in $\Sigma\pi$ and $\Sigma\pi\pi$ cross sections. 3 Backward production in the $\Lambda\pi^ K^+$ final state.
- Depending on production angle.

 APSELL 74, ESTES 74, and TIMMERMANS 76 find strong branching ratio dependence on production angle, as in earlier production experiments.

Σ(1670) REFERENCES (PRODUCTION EXPERIMENTS)

| FERRERSORIA | | NP B178 373 | A. Ferrer Soria et al. | (CERN, CDEF, EPOL+) |
|-------------|------|-----------------|---------------------------|--------------------------|
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | (BNL)I |
| HEPP | 76 | NP B115 82 | V. Hepp et al. | (CERN, HEID, MPIM)I |
| TIMMERMANS | 76 | NP B112 77 | J.J.M. Timmermans et al. | (NIJM, CERN+) JP |
| APSELL | 74 | PR D10 1419 | S.P. Apsell et al. | (BRAN, UMD, SYRA+)I |
| BERTHON | 74 | NC 21A 146 | A. Berthon et al. | (CDEF, RHEL, SACL+) |
| ESTES | 74 | Thesis LBL-3827 | R.D. Estes | (LBL) |
| AGUILAR | 70 B | PRL 25 58 | M. Aguilar-Benitez et al. | (BNL, SÝRA) |
| BARNES | 69E | BNL 13823 | V.E. Barnes et al. | (BNL, SYRA) |
| EBERHARD | 69 | PRL 22 200 | P.H. Eberhard et al. | ` (LRL) |
| HUWE | 69 | PR 181 1824 | D.O. Huwe | (LRL) |
| BUGG | 68 | PR 168 1466 | D.V. Bugg et al. | (RHEL, BIRM, ČAVE)I |
| BUTTON | 68 | PRL 21 1123 | J. Button-Shafer | (MASA, LRL)JP |
| PRIMER | 68 | PRL 20 610 | M. Primer et al. | (SYRA, BNL) |
| EBERHARD | 67 | PR 163 1446 | P. Eberhard et al. | ` (LRL, ILL) IJP |
| BIRMINGHAM | 66 | PR 152 1148 | M. Hague et al. | (BIRM, GLAS, LOIC, OXF+) |
| LONDON | 66 | PR 143 1034 | G.W. London et al. | (BNL, SYRA) IJ |
| EBERHARD | 65 | PRL 14 466 | P.H. Eberhard et al. | `(LRL, ILL)I |
| LEVEQUE | 65 | PL 18 69 | A. Levegue et al. | (SACL, EPOL, GLAS+)JP |
| ALVAREZ | 63 | PRL 10 184 | L.W. Alvarez et al. | (LRL)I |
| SMITH | 63 | Athens Conf. 67 | G.A. Smith | (LRL) |
| ALEXANDER | 62 C | CERN Conf. 320 | G. Alexander et al. | (LRL)I |
| | | | | |

$\Sigma(1690)$ Bumps

 $I(J^P) = 1(??)$ Status: **

OMITTED FROM SUMMARY TABLE

See the note preceding the $\Sigma(1670)$ Listings. Seen in production experiments only, mainly in $\Lambda \pi$.

Σ(1690) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------|------|----------------------|----|------|-----|-------------------------------------|
| ≈ 1690 OUR ESTI | MATE | | | | | |
| 1698 ± 20 | 70 | ¹ GODDARD | 79 | HBC | + | $\pi^{+} p \ 10.3 \ \text{GeV}/c$ |
| 1707 ± 20 | 40 | ² GODDARD | 79 | HBC | + | $\pi^{+} p \ 10.3 \ \text{GeV}/c$ |
| 1698 ± 20 | 15 | ADERHOLZ | 69 | HBC | + | $\pi^+ p$ 8 GeV/ c |
| $1682\pm\ 2$ | 46 | BLUMENFELD | 69 | HBC | + | K_{IP}^{0} |
| 1700 ± 20 | | MOTT | 69 | нвс | + | K - p 5.5 GeV/c |
| 1694 ± 24 | 60 | ³ PRIMER | 68 | НВС | + | K - p 4.6-5 GeV /c |
| 1700± 6 | | ⁴ SIMS | 68 | нвс | _ | $K^- N \rightarrow \Lambda \pi \pi$ |
| 1715 ± 12 | 30 | COLLEY | 67 | HBC | + | K^-p 6 GeV/ c |
| | | | | | | |

Σ(1690) WIDTH (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | CHG | COMMENT |
|---------------------------|------|-------------------------|------|-----|-------------------------------------|
| 240± 60 | 70 | ¹ GODDARD 79 | нвс | + | $\pi^+ p$ 10.3 GeV/ c |
| $130 {}^{+ 1 00}_{- 60}$ | 40 | ² GODDARD 79 | НВС | + | $\pi^+ p$ 10.3 GeV/ c |
| 142± 40 | 15 | ADERHOLZ 69 | HBC | + | $\pi^+ p$ 8 GeV/ c |
| $25\pm~10$ | 46 | BLUMENFELD 69 | HBC | + | $K_I^0 p$ |
| 130± 25 | | MOTT 69 | HBC | + | κ – p 5.5 GeV/c |
| 105 ± 35 | 60 | ³ PRIMER 68 | НВС | + | K [−] p 4.6–5 GeV /c |
| 62± 14 | | ⁴ SIMS 68 | HBC | _ | $K^- N \rightarrow \Lambda \pi \pi$ |
| 100 ± 35 | 30 | COLLEY 67 | HBC | + | K^-p 6 GeV/ c |

Σ(1690) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode |
|----------------|----------------------------------------------------|
| Γ ₁ | NK |
| Γ ₂ | $\Lambda\pi$ |
| Г | $\Sigma \pi$ |
| Γ_4 | $\Sigma(1385)\pi$ |
| Γ_5 | $\Lambda\pi\pi$ (including Σ (1385) π) |
| | |

Σ (1690) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

| $\Gamma(N\overline{K})/\Gamma(\Lambda\pi)$ | | | | | | Γ_1/Γ_2 |
|--------------------------------------------|----------------|------------------------|------|------|-----|-------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| small | | GODDARD | 79 | HB C | + | $\pi^{+}p$ 10.2 GeV/c |
| < 0.2 | | MOTT | 69 | HB C | + | K^-p 5.5 GeV/c |
| $\textbf{0.4} \pm \textbf{0.25}$ | 18 | COLLEY | 67 | HBC | + | 6/30 events |
| $\Gamma(\Sigma\pi)/\Gamma(\Lambda\pi)$ | | | | | | Γ_3/Γ_2 |
| VALUE | CL% | DO CUMENT ID | | TECN | CHG | COMMENT |
| small | | GODDARD | 79 | HB C | + | $\pi^{+}p$ 10.2 GeV/c |
| < 0.4 | 90 | MOTT | 69 | HB C | + | $K^- p$ 5.5 GeV/c |
| 0.3 ± 0.3 | | COLLEY | 67 | HBC | + | 4/30 events |
| $\Gamma(\Sigma(1385)\pi)/\Gamma($ | $\Lambda\pi$) | | | | | Γ_4/Γ_2 |
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| < 0.5 | | MOTT | 69 | нвс | + | $K^- p$ 5.5 GeV/ c |
| $\Gamma(\Lambda\pi\pi(including))$ | Σ(1385)π |))/Γ(<i>Λ</i> π) | | | | Γ_5/Γ_2 |
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| 2.0 ± 0.6 | | BLUMENFEL | D 69 | HBC | + | 31/15 events |
| 0.5 ± 0.25 | | COLLEY | 67 | нвс | + | 15/30 events |
| $\Gamma(\Sigma(1385)\pi)/\Gamma($ | Λππ(includ | ding $\Sigma(1385)\pi$ |)) | | | Γ_4/Γ_5 |
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| large | | SIMS | 68 | нвс | _ | $K^- N \rightarrow \Lambda \pi \pi$ |
| small | | COLLEY | 67 | нвс | + | K^-p 6 GeV/c |
| | | | | | | , |

Σ (1690) FOOTNOTES (PRODUCTIÓN EXPERIMENTS)

- ¹ From $\pi^+ p \rightarrow (\Lambda \pi^+) K^+$. J > 1/2 is not required by the data.
- $^2\,{\rm From}\,\,\pi^+\,p\,\to\,(\Lambda\,\pi^+)\,(\,K\,\pi)^+$. $J^{'}\,{>}1/2$ is indicated, but large background precludes a
- definite conclusion. 3 See the $\Sigma(1670)$ Listings. AGUILAR-BENITEZ 70B with three times the data of PRIMER 68 find no evidence for the $\Sigma(1690)$.
- 4 This analysis, which is difficult and requires several assumptions and shows no unambiguous $\Sigma(1690)$ signal, suggests $J^P=5/2^+$. Such a state would lead all previously known Y* trajectories.

Σ(1690) REFERENCES (PRODUCTION EXPERIMENTS)

| GODDARD AGUILAR ADERHOLZ BLUMENFELD MOTT Also | 69 69 69 | PR D19 1350 PRL 25 58 NP B11 259 PL 29B 58 PR 177 1966 PRL 18 266 PRL 18 266 | B.J. Blumenfeld, G.R. Kalbfleisch J. Mott <i>et al.</i> M. Derrick <i>et al.</i> | (TNTO, BNL) IJ (BNL, SYRA) 3, BERL, CERN+) I (BNL) I (NWES, ANL) I (ANL, NWES) I |
|--------------------------------------------------------------|----------------|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| PRIMER SIMS COLLEY | 68 68 67 | PRL 20 610 PRL 21 1413 PL 24B 489 | M. Primer et al. W.H. Sims et al. (FS | (SYRA, BNL)I U, TUFTS, BRAN)I DIC, MUNI, OXF+)I |

$\Sigma(1750) \ 1/2$

 $I(J^P) = 1(\frac{1}{2}^-)$ Status: ***

For most results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982).

There is evidence for this state in many partial-wave analyses, but with wide variations in the mass, width, and couplings. The latest analyses indicated significant couplings to $N\overline{K}$ and $\Lambda\pi$, as well as to $\Sigma\eta$ whose threshold is at 1746 MeV (JONES 74).

Σ(1750) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|-------------|----|------|---------------------------------------------|
| 1730 to 1800 (≈ 1750) OUR ESTIM | IATE | | | |
| 1756 ± 10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1770 ± 10 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1770 ± 15 | GOPAL | 77 | DPWA | K N multichannel |

| • • • We do not use the follo | owing data for averages | , fits, | , limits, e | etc. • • • |
|-------------------------------|-------------------------|---------|-------------|-----------------------------------------------------------|
| 1800 or 1813 | | | | K N multichannel |
| 1715 ± 10 | | | | lsospin-1 total σ |
| 1730 | DEBELLEFON | | | $K^- p \rightarrow \Lambda \pi^0$ |
| 1780 ± 30 | BAILLON | | | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 1)}$ |
| 1700 ± 30 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 2)}$ |
| $1697 + 20 \\ -10$ | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 1785 ± 12 | CHU | 74 | DBC | Fits $\sigma(K^- n \rightarrow \Sigma^- \eta)$ |
| 1760 ± 5 | ³ JONES | 74 | HBC | Fits $\sigma(K^- \rho \rightarrow \Sigma^0 \eta)$ |
| 1739 ± 10 | PREVOST | 74 | | $K^- N \rightarrow \Sigma(1385) \pi$ |

Σ (1750) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|----------------------|---------|-----------|-----------------------------------------------------------|
| 60 to 160 (≈ 90) OUR ESTIMA | TE | | | |
| 64±10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 161 ± 20 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 60±10 | GOPAL | 77 | DPWA | K N multichannel |
| • • • We do not use the followin | g data for average | s, fits | , limits, | etc. • • • |
| 117 or 119 | | 77 | DPWA | K N multichannel |
| 10 | ² CARROLL | 76 | | lsospin- 1 total σ |
| 110 | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 140±30 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 1)}$ |
| 160±50 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 2)}$ |
| 66^{+14}_{-12} | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 89±33 | CHU | 74 | DBC | Fits $\sigma(K^- n \rightarrow \Sigma^- \eta)$ |
| 92± 7 | ³ JONES | 74 | HBC | Fits $\sigma(K^- p \rightarrow \Sigma^0 \eta)$ |
| 108 ± 20 | PREVOST | 74 | DPWA | $K^- N \rightarrow \Sigma(1385) \pi$ |

Σ (1750) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|-----------------------|--------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 10-40 % |
| Γ_2 | $\Lambda\pi$ | seen |
| Γ_3 | $\Sigma \pi$ | <8 % |
| Γ_4 | $\Sigma \eta$ | 15-55 % |
| Γ_5 | $\Sigma(1385)\pi$ | |
| Γ ₆ | $\Lambda(1520)\pi$ | |

The above branching fractions are our estimates, not fits or averages.

Σ(1750) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
|-----------------------------------------------|---------------------------|----------|------------------------------------------------|-------------------|
| VALUE | | | TECN_COMMENT | |
| 0.1 to 0.4 OUR ESTIMA | ATE | | | |
| 0.14 ± 0.03 | GOPAL | 80 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| 0.33 ± 0.05 | ALSTON | 78 | DPWA $\overline{K}N \rightarrow \overline{K}N$ | |
| • • • We do not use the | following data for averag | es, fits | , limits, etc. • • • | |
| 0.15 ± 0.03 | GOPAL | 77 | DPWA See GOPAL 80 | |
| 0.06 or 0.05 | ¹ MARTIN | 77 | DPWA $\overline{K}N$ multichann | nel |
| /F F > 1/2 . N = 1 | . E(1750) 4 | | /= | - 1/6/- |

| $(\Gamma_i \Gamma_f)^{72} / \Gamma_{\text{total}} \text{ in } N K \to \Sigma(1)$ | | $(\Gamma_1\Gamma_2)^{72}/\Gamma$ | | |
|----------------------------------------------------------------------------------|---------------------|----------------------------------|-----------|-----------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.04 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| $\bullet~\bullet~$ We do not use the following | data for averages | , fits, | limits, e | etc. • • • |
| -0.10 or -0.09 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| -0.12 | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.12 ± 0.02 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 1)}$ |
| -0.13 ± 0.03 | | | | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 2)}$ |
| -0.13 ± 0.04 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.120 ± 0.077 | DEVENISH | 74B | | Fixed-t dispersion rel. |
| | | | | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to 1$ | (Γ₁Γ₃) ¹ /2/Γ | | | |
|----------------------------------------------------------------------------------------------|--------------------------|---------|-------------|------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.09 ± 0.05 | GOPAL | 77 | DPWA | K N multichannel |
| • • • We do not use the follo | wing data for average | s, fits | , limits, e | etc. • • • |
| +0.06 or +0.06 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 0.13 ± 0.02 | LANGBEIN | 72 | IPWA | K N multichannel |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow$ | (Γ₁Γ₄) ¹ ⁄2/Γ | | | |
|----------------------------------------------------------------------------------------------------|--------------------------|---------|-----------|------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.23 ± 0.01 | ³ JONES | 74 | нвс | Fits $\sigma(K^- p \rightarrow \Sigma^0 \eta)$ |
| • • • We do not use the follo | wing data for average | s, fits | , limits, | etc. • • • |
| seen | CLINE | 69 | DBC | Threshold bump |

| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma(1750) \to \Sigma(1385) \pi$ | | | | | | |
|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|----------|-------------|----------------------------------------|-------------------------------------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| $+0.18\pm0.15$ | PREVOST | 74 | DPWA | $\textit{K}^{-}\textit{N} \rightarrow$ | $\Sigma(1385)\pi$ | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \frac{\sqrt{ALUE}}{2}$ | $\Sigma(1750) \rightarrow \Lambda(152)$ | | <u>TECN</u> | COMMENT | $(\Gamma_1\Gamma_6)^{\frac{1}{2}}/\Gamma$ | |
| • • • We do not use the follow | owing data for averag | es, fits | , limits, e | etc. • • • | | |
| 0.032±0.021 | CAMERON | 77 | DPWA | P-wave de | ec ay | |
| | | | | | | |

Σ (1750) FOOTNOTES

- 1 The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. 2 A total cross-section bump with (J+1/2) Γ_{el} / $\Gamma_{total}=0.30.$ 3 An S-wave Breit-Wigner fit to the threshold cross section with no background and errors statistical only.

Σ(1750) REFERENCES

| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
|------------|------|-------------------|---------------------------------|------------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS TON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+) IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| CAMERON | 77 | NP B131 399 | W. Cameron et al. | `(RHEL, LOIC)IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G. | . Moorhouse (LOUC+)IJP |
| Also | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| Also | | NP B126 285 | B.R. Martin, M.K. Pidcock | ÌLOUCΊIJΡ |
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | `(BNL)I |
| DEBELLEFON | 76 | NP B109 129 | A. de Bellefon, A. Berthon | (ČDEF) IJP |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| VANHORN | 75 | NP B87 145 | A.I. van Horn | ` (LBL) IJP |
| Also | | NP B87 157 | A.J. van Horn | |
| CHU | 74 | NC 20A 35 | R.Y.L. Chu et al. | |
| DEVENISH | 74 B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt, | |
| JONES | 74 | NP B73 141 | M.D. Jones | (CHIC) IJP |
| PREVOST | 74 | NP B69 246 | J. Prevost et al. | |
| LANGBEIN | | | | |
| | 72 | NP B47 477 | W. Langbein, F. Wagner | |
| CLINE | 69 | LNC 2 407 | D. Cline, R. Laumann, J. Mapp | (WISC) |
| | | | | |

 $\Sigma(1770) \ 1/2$

 $I(J^P) = 1(\frac{1}{2}^+)$ Status: *

OMITTED FROM SUMMARY TABLE

Evidence for this state now rests solely on solution 1 of BAILLON 75, (see the footnotes) but the $\varLambda\,\pi$ partial-wave amplitudes of this solution are in disagreement with amplitudes from most other $\varLambda\,\pi$ anal-

Σ(1770) MASS

| VALUE (MeV) | DO CUMENT ID |) | TECN | COMMENT |
|-------------------------------------------------|--------------------------------|----------------|------|---------------------------------------------------------------------------------------|
| ≈ 1770 OUR ESTIMATE 1738±10 1770±20 1772 | 1 GOPAL 2 BAILLON 3 KANE | 77 75 72 | IPWA | $\overline{K} N$ multichannel $\overline{K} N \to \Lambda \pi$ $K^- p \to \Sigma \pi$ |

Σ(1770) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------|----------------------|----|------|------------------------------------------|
| 72±10 | ¹ GOPAL | 77 | DPWA | K N multichannel |
| 80 ± 30 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 80 | ³ KANE | 72 | DPWA | $K^-p \rightarrow \Sigma \pi$ |

Σ (1770) DECAY MODES

| | Word |
|------------|--------------|
| Γ_1 | ΝK |
| Γ_2 | $\Lambda\pi$ |
| Г | $\sum \pi$ |

Σ(1770) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ ₁ /Γ |
|-----------------------------------------------|--------------------|----|------|-------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.14 ± 0.04 | ¹ GOPAL | 77 | DPWA | K N multichannel |
| 16 | | | | 1/2 |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K}$ | (Γ ₁ Γ ₂) ^{1/2} / | | | |
|----------------------------------------------------------------------------------------|---------------------------------------------------|----|------|------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| < 0.04 | GOPAL | 77 | DPWA | K N multichannel |
| -0.08 ± 0.02 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |

| $(\Gamma_i\Gamma_f)^{1\!\!/2}/\Gamma_{total}$ in $N\overline{K}	o \varSigma(1770)	o \varSigma\pi$ | | | | (Γ ₁ Γ ₃) ^{1/2} /Ι |
|---------------------------------------------------------------------------------------------------|-------------------|----|------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| < 0.04 | GOPAL | 77 | DPWA | K N multichannel |
| - 0.108 | ³ KANE | 72 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |

Baryon Particle Listings $\Sigma(1770), \Sigma(1775)$

Σ(1770) FOOTNOTES

- 1 Required to fit the isospin-1 total cross section of CARROLL 76 in the $\overline{\it K}$ N channel. The addition of new K^-p polarization and K^-n differential cross-section data in GOPAL 80 find it to be more consistent with the $\Sigma(1660)$ P_{11} .
- 2 From solution 1 of BAILLON 75; not present in solution 2.
- 3 Not required in KANE 74, which supersedes KANE 72.

Σ (1770) REFERENCES

| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) |
|---------|----|-------------------|-------------------------------|-----------------|
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| CARROLL | 76 | PRL 37 806 | A.S. Carroll et al. | ` (BNL)I |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL)IJP |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| KANE | 72 | PR D5 1583 | D.F.J. Kane | (LBL) |

$\Sigma(1775)~5/2$

$$I(J^P) = 1(\frac{5}{2})$$
 Status: ***

Discovered by GALTIERI 63, this resonance plays the same role as cornerstone for isospin-1 analyses in this region as the $\Lambda(1820)\,F_{05}$ does in the isospin-0 channel.

For most results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982).

Σ(1775) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|-------------------|--------|-----------|---------------------------------------------------------|
| 1770 to 1780 (≈ 1775) OUR ESTIN | ATE | | | |
| 1778 ± 5 | GOPAL | | | $\overline{K} N \rightarrow \overline{K} N$ |
| 1777 ± 5 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1774 ± 5 | GOPAL | 77 | DPWA | K N multichannel |
| 1775 ± 10 | BAILLON | | | $\overline{K} N \rightarrow \Lambda \pi$ |
| 1774 ± 10 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 1772± 6 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| • • • We do not use the following | data for averages | , fits | limits, e | etc. • • • |
| 1772 or 1777 1765 | | | | \overline{K} N multichannel $K^- p \to \Lambda \pi^0$ |

Σ(1775) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------------|--------|--------------|---------------------------------------------|
| 105 to 135 (≈ 120) OUR ESTIMAT | E | | | |
| 137 ± 10 | GOPAL | 80 | DPWA 7 | $\overline{K} N \rightarrow \overline{K} N$ |
| 116 ± 10 | ALSTON | 78 | DPWA 7 | $\overline{K} N \rightarrow \overline{K} N$ |
| 130 ± 10 | GOPAL | 77 | DPWA | K N multichannel |
| 125 ± 15 | BAILLON | | | |
| 146±18 | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| 154 ± 10 | KANE | 74 | DPWA | $K^- \rho \rightarrow \Sigma \pi$ |
| • • • We do not use the following | data for averages | , fits | , limits, et | C. • • • |
| 102 or 103 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 120 | DEBELLEFON | 76 | IPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |

Σ(1775) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 37-43% |
| Γ_2 | $\Lambda\pi$ | 14-20% |
| Г3 | $\Sigma \pi$ | 2-5% |
| Γ_4 | $\Sigma(1385)\pi$ | 8-12% |
| Γ_5 | $\Sigma(1385)\pi$, $	extit{D}$ -wave | |
| Γ ₆ | $\Lambda(1520)\pi$ | 17-23% |
| Γ_7 | $\Sigma \pi \pi$ | |

The above branching fractions are our estimates, not fits or averages.

CONSTRAINED FIT INFORMATION

An overall fit to 8 branching ratios uses 16 measurements and one constraint to determine 5 parameters. The overall fit has a χ^2 = 63.9 for 12 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\langle \delta x_i \delta x_j
angle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to one.

Σ(1775) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances. Also, the errors quoted do not include uncertainties due to the parametrization used in the partial-wave analyses and are thus too

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-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| Γ(NK)/Γ _{total} | DOCUMENT ID | | TECN | COMMENT | Γ_1/Γ |
| 0.37 to 0.43 OUR ESTIMATE | | | | | |
| 0.45 ±0.04 OUR FIT Error inclu 0.391±0.017 OUR AVERAGE | des scale factor | OT 3.1 | • | | |
| 0.40 ± 0.02 | GOPAL | 80 | | $\overline{K}N \rightarrow \overline{K}N$ | |
| 0.37 ± 0.03 • • We do not use the following | ALSTON | | | $\overline{K}N \to \overline{K}N$ | |
| 0.41 ±0.03 | _ | 77 | | See GOPAL 80 | |
| 0.37 or 0.36 | MARTIN | 77 | DPWA | K N multichann | el |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma (17)^{\frac{1}{2}}$ | 775) → Λπ DO CUMENT ID | | TECN | (Γ ₁ Γ | 2) ^{1/2} /Γ |
| | ludes scale facto | | | COMMENT | |
| -0.262±0.015 OUR AVERAGE -0.28 ±0.03 | GOPAL | 77 | DΡWΔ | KN multichann | al |
| -0.25 ± 0.02 | | 75 | | $\overline{K}N \to \Lambda\pi$ | |
| $-0.28 \begin{array}{l} +0.04 \\ -0.05 \end{array}$ | VANHORN | 75 | DPWA | $K^- \rho \to \Lambda \pi^0$ | |
| $-0.259{\pm}0.048$ | | 74B | | Fixed-t dispersion | n rel. |
| • • We do not use the following | | | | | |
| -0.29 or -0.28 -0.30 | ^L MARTIN DEBELLEFON | | | $\overline{K}N$ multichanne $K^-p \rightarrow \Lambda \pi^0$ | BI |
| | | | **/ | • | 1/ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma(17)$ | | | | | з) ^{1/2} /Г |
| 0.105 ± 0.025 OUR FIT Error inc | DOCUMENT ID | r of 3 | TECN 1 | COMMENT | |
| 0.098±0.016 OUR AVERAGE E | rror includes scal | le fact | or of 1.8 | | |
| $+0.13 \pm 0.02$ 0.09 ± 0.01 | GOPAL KANE | 77 74 | | $\overline{K} N$ multichanne $K^- p \rightarrow \Sigma \pi$ | el |
| • • • We do not use the following • | | | | | |
| +0.08 or +0.08 | ^L MARTIN | 77 | DPWA | K N multichann | el |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{\mathcal{K}} \to \Sigma (17)$ | 75) → Λ(1520 | 0)π | | | 6) ^{1/2} /Γ |
| 0.315 ± 0.010 OUR FIT Error inc | <u>DOCUMENT ID</u> cludes scale facto | r of 1 | | COMMENT | |
| | igns on measurer | | | | . 0 |
| -0.305 ± 0.010 0.31 ± 0.02 | ² CAMERON BARLETTA | 77 72 | | $K^- p \rightarrow \Lambda(152)$ $K^- p \rightarrow \Lambda(152)$ | |
| 0.27 ±0.03 | ARMENTEROS | | | $K^-p \rightarrow \Lambda(152)$ $K^-p \rightarrow \Lambda(152)$ | |
| (= =) ¹ / ₂ (= - 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 + 1 | | | | <i>,</i> | . 1/4 |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma (17)$ | $75) \rightarrow \Sigma (138)$ | 5)π | TECN | (11 | |
| <u>VALUE</u> 0.211±0.022 OUR FIT Error inc | ludes scale facto | | 1 L CIV | | 4) ^{1/2} /Γ |
| | | | | | 4)'-/ |
| | igns on measurer | ments | were ig | nored. | |
| -0.184 ± 0.011 | igns on measurer 3 CAMERON | ments 78 | were igi DPWA | nored. $K^- p ightarrow \Sigma (138)$ | B5) π |
| | igns on measurer ³ CAMERON PREVOST | ments 78 74 | were ig DPWA DPWA | nored. $K^- p \rightarrow \Sigma (138)$ $K^- N \rightarrow \Sigma (13)$ | B5) π |
| $\begin{array}{c} -0.184\pm0.011\\ +0.20\ \pm0.02\\ \bullet\bullet\bullet\ \mbox{We do not use the following}\\ 0.32\ \pm0.06 \end{array}$ | igns on measurer CAMERON PREVOST data for averages SIMS | ments 78 74 s, fits, 68 | were ign DPWA DPWA limits, e | mored. $\begin{array}{ccc} K^{-}p \to & \Sigma(138) \\ K^{-}N \to & \Sigma(13) \\ etc. & \bullet & \bullet \\ K^{-}N \to & \Lambda\pi\pi \end{array}$ | B5) π |
| $\begin{array}{l} -0.184 \pm 0.011 \\ +0.20 \ \pm 0.02 \\ \bullet \ \bullet \ \ \text{We do not use the following} \\ 0.32 \ \pm 0.06 \\ 0.24 \ \pm 0.03 \end{array}$ | igns on measurer ³ CAMERON PREVOST data for averages | ments 78 74 s, fits, 68 | were ign DPWA DPWA limits, e | nored. $\begin{array}{ccc} K^-p \to & \Sigma(138) \\ K^-N \to & \Sigma(138) \\ etc. & \bullet & \bullet \end{array}$ | B5) π |
| $\begin{array}{c} -0.184\pm0.011\\ +0.20\ \pm0.02\\ \bullet\bullet\bullet\ \mbox{We do not use the following}\\ 0.32\ \pm0.06 \end{array}$ | igns on measurer CAMERON PREVOST data for averages SIMS | ments 78 74 s, fits, 68 | were ign DPWA DPWA limits, e | mored. $\begin{array}{ccc} K^{-}p \to & \Sigma(138) \\ K^{-}N \to & \Sigma(13) \\ etc. & \bullet & \bullet \\ K^{-}N \to & \Lambda\pi\pi \end{array}$ | B5) π |
| -0.184 ± 0.011 +0.20 ±0.02 • • • We do not use the following 0.32 ±0.06 0.24 ±0.03 $\Gamma(\Lambda\pi)/\Gamma(N\overline{K})$ | igns on measurer CAMERON PREVOST data for averages SIMS ARMENTEROS | ments 78 74 3, fits, 68 S67c | were ign DPWA DPWA limits, e | mored. $\begin{array}{ccc} K^{-}p \to & \Sigma(138) \\ K^{-}N \to & \Sigma(13) \\ etc. & \bullet & \bullet \\ K^{-}N \to & \Lambda\pi\pi \end{array}$ | 85) π 85) π |
| $\begin{array}{l} -0.184 \pm 0.011 \\ +0.20 \ \pm 0.02 \\ \bullet \ \bullet \ \ \text{We do not use the following} \\ 0.32 \ \pm 0.06 \\ 0.24 \ \pm 0.03 \end{array}$ | igns on measurer CAMERON PREVOST data for averages SIMS ARMENTEROS | ments 78 74 3, fits, 68 S67c | were ign DPWA DPWA limits, 6 DBC HBC | mored. $ \begin{array}{ll} K^-p \to & \Sigma(138) \\ K^-N \to & \Sigma(138) \\ \text{etc.} & \bullet & \bullet \\ K^-N \to & \Lambda\pi\pi \\ K^-p \to & \Lambda\pi\pi \end{array} $ | 85) π 85) π Γ₂/Γ₁ |
| -0.184 ± 0.011 $+0.20 \pm 0.02$ •• We do not use the following 0.32 ± 0.06 0.24 ± 0.03 $\Gamma(\Lambda\pi)/\Gamma(NK)$ MALUE 0.46 ± 0.09 OUR FIT Error include 0.33 ± 0.05 | igns on measurer CAMERON PREVOST data for averages SIMS ARMENTEROS DOCUMENT ID s scale factor of | 78 74 5, fits, 68 S67c | were ign DPWA DPWA limits, 6 DBC HBC | mored. $ K^-p \to \Sigma(138 \\ K^-N \to \Sigma(138 \\ K^-N \to \Lambda \pi \pi $ setc. • • • • • • • • • • • • • • • • • • • | 35) π 85) π Γ ₂ /Γ ₁ |
| $\begin{array}{lll} -0.184\pm0.011 \\ +0.20 & \pm0.02 \\ \bullet & \bullet & \text{We do not use the following of 0.32} \\ 0.32 & \pm0.06 \\ 0.24 & \pm0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ & & & \\ \hline 0.46\pm0.09 & \text{OUR FIT} & \text{Error include 0.33} \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \end{array}$ | igns on measurer ACMERON PREVOST data for averages SIMS ARMENTEROS POCUMENT ID S scale factor of UHLIG | 78 74 5, fits, 68 S67C | were ign DPWA DPWA limits, e DBC HBC TECN HBC | mored. $K^-p \rightarrow \Sigma(13i \ K^-N \rightarrow \Sigma(13i \ K^-N \rightarrow \Lambda \pi \pi \ K^-p \rightarrow \Lambda \pi \pi$ $K^-p \rightarrow \Lambda \pi \pi$ $COMMENT$ $K^-p = 0.9 \text{ GeV}/c$ | 85) π 85) π Γ₂/Γ₁ |
| $\begin{array}{lll} -0.184\pm0.011 \\ +0.20 & \pm0.02 \\ \bullet & \bullet & \text{We do not use the following of 0.32} \\ 0.32 & \pm0.06 \\ 0.24 & \pm0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ & & & \\ \hline 0.46\pm0.09 & \text{OUR FIT} & \text{Error include 0.33} \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \end{array}$ | igns on measurer ACMERON PREVOST data for averages SIMS ARMENTEROS POCUMENT ID S scale factor of UHLIG | 78 74 5, fits, 68 S67c | were ign DPWA DPWA limits, 6 DBC HBC TECN TECN TECN | nored. $K^-p \rightarrow \Sigma(13i \ K^-N \rightarrow \Sigma(13i \ K^-N \rightarrow \Lambda \pi \pi \ K^-p \rightarrow \Lambda \pi \pi$ $K^-p \rightarrow \Lambda \pi \pi$ $COMMENT$ $K^-p 0.9 \text{ GeV/} COMMENT$ | 35) π 85) π Γ ₂ /Γ ₁ |
| $\begin{array}{cccc} -0.184 \pm 0.011 \\ +0.20 & \pm 0.02 \\ \bullet & \bullet & \text{We do not use the following of } \\ 0.32 & \pm 0.06 \\ 0.24 & \pm 0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ \underline{WALUE} \\ 0.33 \pm 0.05 \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \\ \underline{WALUE} \\ \bullet & \bullet & \text{We do not use the following of } \\ \end{array}$ | igns on measurer ACMERON PREVOST data for averages SIMS ARMENTEROS DOCUMENT ID S scale factor of UHLIG DOCUMENT ID data for averages | 78 74 5, fits, 68 567c 2.9. 67 | were ign DPWA DPWA limits, 6 DBC HBC TECN limits, 6 | nored. $K^-p \rightarrow \Sigma(13i \ K^-N \rightarrow \Sigma(13i \ K^-N \rightarrow \Lambda \pi \pi \ K^-p \rightarrow \Lambda \pi \pi$ $K^-p \rightarrow \Lambda \pi \pi$ $COMMENT$ $K^-p 0.9 \text{ GeV/} COMMENT$ | 35) π 85) π Γ ₂ /Γ ₁ |
| $\begin{array}{cccc} -0.184 \pm 0.011 \\ +0.20 & \pm 0.02 \\ \bullet & \bullet & \text{We do not use the following of } \\ 0.32 & \pm 0.06 \\ 0.24 & \pm 0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ \underline{WALUE} \\ 0.33 \pm 0.05 \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \\ \underline{WALUE} \\ \bullet & \bullet & \text{We do not use the following of } \\ \end{array}$ | igns on measurer ACMERON PREVOST data for averages SIMS ARMENTEROS DOCUMENT ID S scale factor of UHLIG DOCUMENT ID data for averages | 78 74 5, fits, 68 567c 2.9. 67 | were ign DPWA DPWA limits, 6 DBC HBC TECN limits, 6 | mored. $K^-p \rightarrow \Sigma(13i \\ K^-p \rightarrow \Sigma(13i \\ K^-N \rightarrow \Sigma(13i \\ \text{etc.} \bullet \bullet \bullet$ $K^-N \rightarrow \Lambda \pi \pi \\ K^-p \rightarrow \Lambda \pi \pi$ $\frac{COMMENT}{K^-p \cdot 0.9 \text{ GeV/o}}$ $\frac{COMMENT}{\text{etc.} \bullet \bullet \bullet}$ | 35) π 85) π Γ ₂ /Γ ₁ |
| $-0.184 \pm 0.011 \\ +0.20 \pm 0.02 \\ \bullet \bullet \bullet \text{ We do not use the following } \\ 0.32 \pm 0.06 \\ 0.24 \pm 0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ \hline NALUE \\ 0.33 \pm 0.05 \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \\ \hline NAUUE \\ \bullet \bullet \text{ We do not use the following } \\ 0.12 \\ \hline \Gamma(\Sigma(1385)\pi)/\Gamma(N\overline{K}) \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE \\ \hline NAUUE$ | igns on measurer ACMERON PREVOST data for averages SIMS ARMENTEROS DOCUMENT ID DOCUMENT ID data for averages ARMENTEROS ARMENTEROS | ments 78 74 68 68 667 2.9. 67 | were ign DPWA DPWA limits, 6 DBC HBC TECN limits, 6 | mored. $K^-p \rightarrow \Sigma(13i \\ K^-p \rightarrow \Sigma(13i \\ K^-N \rightarrow \Sigma(13i \\ \text{etc.} \bullet \bullet \bullet$ $K^-N \rightarrow \Lambda \pi \pi \\ K^-p \rightarrow \Lambda \pi \pi$ $\frac{COMMENT}{K^-p \cdot 0.9 \text{ GeV/o}}$ $\frac{COMMENT}{\text{etc.} \bullet \bullet \bullet}$ | 35) π 85) π Γ ₂ /Γ ₁ Γ ₇ /Γ |
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| $-0.184 \pm 0.011 \\ +0.20 \pm 0.02 \\ \bullet \bullet \bullet \text{ We do not use the following of } \\ 0.32 \pm 0.06 \\ 0.24 \pm 0.03 \\ \hline \Gamma(\Lambda\pi)/\Gamma(N\overline{K}) \\ \frac{VALUE}{0.03 \pm 0.05} \\ \hline \Gamma(\Sigma\pi\pi)/\Gamma_{\text{total}} \\ \frac{VALUE}{0.02 \pm 0.05} \\ \hline \Gamma(\Sigma(1385)\pi)/\Gamma(N\overline{K}) \\ \frac{VALUE}{0.22 \pm 0.07 \text{ OUR FIT}} \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline O.20 \pm 0.07 \text{ OUR FIT} \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25 \pm 0.09 \\ \hline Error include 0.25$ | igns on measurer ACAMERON PREVOST data for averages SIMS ARMENTERO: DOCUMENT ID S scale factor of UHLIG DOCUMENT ID data for averages ARMENTERO: DOCUMENT ID s scale factor of UHLIG | ments 78 74 74 75, fits, 68 8567c 2.9. 67 3.6. | were ign DPWA DPWA limits, e DBC HBC TECN HBC TECN Imits, e TECN TECN TECN TECN TECN TECN | mored. $K^-p \rightarrow \Sigma(13i \ K^-N \rightarrow \Sigma(13i \ K^-N \rightarrow \Lambda \pi \pi \ K^-p \rightarrow \Lambda \pi \pi$ $\frac{COMMENT}{K^-p} 0.9 \text{ GeV/o}$ etc. • • • $K^-N \rightarrow K^-N Γ_{2}/Γ_{1} Γ_{7}/Γ Γ_{4}/Γ_{1} |
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Σ (1775) FOOTNOTES

 $\Sigma(1385)\pi$ rate, as seen in $\Lambda\pi\pi$.

¹ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
2 This rate combines P-wave and F-wave decays. The CAMERON 77 results for the separate P-wave- and F-wave decays are -0.303 ± 0.010 and -0.037 ± 0.014 . The published signs have been changed here to be in accord with the baryon-first convention.
3 The CAMERON 78 upper limit on G-wave decay is 0.03.
4 For about 3/4 of this, the $\Sigma\pi$ system has I=0 and is almost entirely $\Lambda(1520)$. For the rest, the $\Sigma\pi$ has I=1, which is about what is expected from the known $\Sigma(1775) \to \Sigma(1385)$ rate as seen in $\Lambda = \pi$.

 $\Sigma(1775), \Sigma(1840), \Sigma(1880)$

Σ (1775) REFERENCES

| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
|------------|------|-------------------|-----------------------------------|-----------------------|
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| ALS TON | 78 | PR D18 182 | M. Alston-Garnjost et al. | (LBL, MŤHO+) IJP |
| A Iso | | PRL 38 1007 | M. Alston-Garnjost et al. | (LBL, MTHO+) IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CAMERON | 77 | NP B131 399 | W. Cameron et al. | (RHEL, LOIC) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G. | |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | (LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| DEBELLEFON | 76 | NP B109 129 | A. de Bellefon, A. Berthon | (CDEF) IJP |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| VANHORN | 75 | NP B87 145 | A.J. van Horn | (LBL) IJP |
| A Iso | | NP B87 157 | A.J. van Horn | (LBL) IJP |
| DEVENISH | 74 B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt, | B.R. Martin (DESY+) |
| KANE | 74 | LBL-2452 | D.F. Kane | (LBL) IJP |
| PREVOST | 74 | NP B69 246 | J. Prevost et al. | (SACL, CERN, HEID) |
| BARLETTA | 72 | NP B40 45 | W.A. Barletta | (EFI) IJP |
| A Iso | | PRL 17 841 | S. Fenster et al. | (CHIC, ANL, CERN)IJP |
| ARMENTEROS | | NP B8 216 | R. Armenteros et al. | (ČERN, HEID, SACL) I |
| SIMS | 68 | PRL 21 1413 | W.H. Sims et al. | (FSU, TUFTS, BRAN) |
| ARMENTEROS | | ZPHY 202 486 | R. Armenteros et al. | (CERN, HEID, SACL) |
| UHLIG | 67 | PR 155 1448 | R.P. Uhlig et al. | (UMD, NRL) |
| ARMENTEROS | | PL 19 338 | R. Armenteros et al. | (CERN, HEID, SACL)IJP |
| GALTIERI | 63 | PL 6 296 | A. Galtieri, A. Hussain, R. Tripp | (LRL) IJ |
| | | | | |

Σ (1840) 3/2⁺

Γ

 $I(J^P) = 1(\frac{3}{2}^+)$ Status: *

OMITTED FROM SUMMARY TABLE

For the time being, we list together here all resonance claims in the P_{13} wave between 1700 and 1900 MeV.

Σ(1840) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|----------------------|----|------|------------------------------------------|
| ≈ 1840 OUR ESTIMATE | | | | |
| 1798 or 1802 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 1720± 30 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 1925 ± 200 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 1840± 10 | LANGBEIN | 72 | IPWA | K N multichannel |

Σ(1840) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|------------------|----------------------|----|------|------------------------------------------|
| 93 or 93 | 1 MARTIN | 77 | | K N multichannel |
| 120 ± 30 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| $65 + 50 \\ -20$ | VANHORN | 75 | DPWA | $K^- \rho \to \Lambda \pi^0$ |
| 120 ± 10 | LANGBEIN | 72 | IPWA | K N multichannel |

Σ(1840) DECAY MODES

| | Mode |
|----------------|--------------|
| Γ ₁ | NK |
| Γ_2^- | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |

Σ (1840) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $(N\overline{K})/\Gamma_{\text{total}}$ | Γ ₁ |
|-----------------------------------------|----------------|
| | |

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|-----------------|--------------|----|------|------------------|
| 0 or 0 | 1 MARTIN | 77 | DPWA | K N multichannel |
| 0.37 ± 0.13 | LANGBEIN | 72 | IPWA | K N multichannel |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} -$ | $\rightarrow \Sigma(1840) \rightarrow \Lambda\pi$ | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|------------------------------------------------------------------------------------------|---------------------------------------------------|-----|------|-------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.03 or $+0.03$ | ¹ MARTIN | 77 | DPWA | K N multichannel |
| $+0.11 \pm 0.02$ | ² BAILLON | 75 | IPWA | $\overline{K}N \rightarrow \Lambda \pi$ |
| $+0.06 \pm 0.04$ | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| $+0.122\pm0.078$ | DEVENISH | 74B | | Fixed-t dispersion rel. |
| 0.20 ± 0.04 | LANGBEIN | 72 | IPWA | K N multichannel |

| $(\Gamma_i\Gamma$ | $_f)^{\frac{1}{2}}/\Gamma_{\mathrm{total}}$ in $N\overline{K} \to \Gamma_{\mathrm{total}}$ | $\Sigma(1840) \rightarrow \Sigma \pi$ | | | (Γ₁Γ₃) ^½ /Γ |
|-------------------|--------------------------------------------------------------------------------------------|---------------------------------------|----|------|------------------------|
| VALUE | | DO CUMENT ID | | TECN | COMMENT |
| -0.0 | 4 or −0.04 | 1 MARTIN | 77 | DPWA | K N multichannel |
| 0.1 | 5 + 0.04 | LANGBEIN | 72 | IPWA | K N multichannel |

Σ(1840) FOOTNOTES

Σ(1840) REFERENCES

| M | IARTIN | 77 | NP B127 | 349 | B.R. Martin, | M.K. Pi | idcock, I | R.G. M | oorhouse | (LOUC+) | IJР |
|---|----------|------|----------|-----|---------------|-----------|------------|----------|-----------|-----------|-----|
| | Also | | NP B126 | 266 | B.R. Martin, | M.K. Pi | idcock | | | (LOUC) | |
| | A Iso | | NP B126 | 285 | B.R. Martin, | M.K. Pi | idcock | | | (LOUC) | IJР |
| В | AILLON | 75 | NP B94 3 | 39 | P.H. Baillon, | P.J. Lito | c h fie ld | | (CE | RN, RHEL) | IJР |
| V | ANHORN | 75 | NP B87 | 145 | A.J. van Hoi | 'n | | | | (LBL) | IJР |
| | A Iso | | NP B87 | 157 | A.J. van Hoi | 'n | | | | (LBL) | IJР |
| D | EVENISH | 74 B | NP B81 3 | 330 | R.C.E. Devei | nish, C.D | . Frogga | itt, B.F | R. Martin | (DESY+) | |
| L | AN GBEIN | 72 | NP B47 4 | 177 | W. Langbein | , F. Wag | gner | | | (MPIM) | IJР |
| | | | | | | | | | | | |

$\Sigma(1880) \ 1/2^{+}$

 $I(J^P) = 1(\frac{1}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

A P_{11} resonance is suggested by several partial-wave analyses, but with wide variations in the mass and other parameters. We list here all claims which lie well above the P_{11} $\Sigma(1770)$.

Σ(1880) MASS

| VALUE (MeV) | DOCUMENT ID | DO CUMENT ID | | COMMENT |
|---------------------|----------------------|--------------|------|---------------------------------------------|
| ≈ 1880 OUR ESTIMATE | | | | |
| 1826 ± 20 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1870 ± 10 | CAMERON | 78B | DPWA | $K^- p \rightarrow N \overline{K}^*$ |
| 1847 or 1863 | $^{ m 1}$ MARTIN | 77 | DPWA | K N multichannel |
| 1960 ± 30 | ² BAILLON | 75 | | $\overline{K} N \rightarrow \Lambda \pi$ |
| 1985 ± 50 | VA NH OR N | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 1898 | ³ LEA | 73 | DPWA | Multichannel K-matrix |
| ~ 1850 | ARMENTERO | S70 | IPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1950±50 | BARBARO | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| 1920 ± 30 | LITCHFIELD | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| 1850 | BAILEY | 69 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1882 ± 40 | SMART | 68 | DPWA | $K^- N \rightarrow \Lambda \pi$ |

Σ (1880) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|---------------|----------------------|-----|------|---------------------------------------------|
| 86± 15 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 80± 10 | CAMERON | 78B | DPWA | $K^- p \rightarrow N \overline{K}^*$ |
| 216 or 220 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 260± 40 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 220 ± 140 | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| 222 | ³ LEA | 73 | DPWA | Multichannel K-matrix |
| ~ 30 | ARMENTERO | S70 | IPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 200± 50 | BARBARO | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| 170± 40 | LITCHFIELD | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| 200 | BAILEY | 69 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 222 ± 150 | SMART | 68 | DPWA | $K^- N \rightarrow \Lambda \pi$ |

Σ (1880) DECAY MODES

| | Mode |
|--------------|----------------------------------------------------------|
| Γ_1 | NK |
| Γ_2^- | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |
| Γ_4 | $N\overline{\underline{K}}^*$ (892), $S=1/2$, P -wave |
| Γ_5 | $N\overline{K}^*(892)$, $S=3/2$, P -wave |

Σ(1880) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ ₁ /Γ |
|-----------------------------------------------|---------------------|----|------|---------------------------------------------|-------------------|
| VALUE | | | TECN | COMMENT | |
| 0.06 ± 0.02 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.27 or 0.27 | ¹ MARTIN | 77 | DPWA | K N multichannel | |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma (1)$ | 880) → Λπ | | | ([₁[₂) ^{1/2} /[|
|-------------------------------------------------------------------------------------------------------|------------------|----|------|-------------------------------------------|
| 0.22 | BAILEY | 69 | DPWA | $\overline{K}N \rightarrow \overline{K}N$ |
| 0.20 | ARMENTERO | | | |
| 0.31 | ³ LEA | 73 | DPWA | Multichannel K-matrix |
| 0.27 or 0.27 | | 77 | DPWA | K N multichannel |
| 0.00 ± 0.02 | GOFAL | | | $N N \rightarrow N N$ |

| ('1'f) /'tota ''' ''' | Z(1000) - /// | | | ('1'2) /' |
|----------------------------|----------------------|-----|------|------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.24 or -0.24 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| -0.12 ± 0.02 | ² BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| $+0.05 {}^{+0.07}_{-0.02}$ | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.169 ± 0.119 | DEVENISH | 74B | | Fixed-t dispersion rel. |
| -0.30 | ³ LEA | 73 | DPWA | Multichannel K-matrix |
| -0.09 ± 0.04 | BARBARO | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| -0.14 ± 0.03 | LITCHFIELD | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| -0.11 ± 0.03 | SMART | 68 | DPWA | $K^- N \rightarrow \Lambda \pi$ |

The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.

² From solution 1 of BAILLON 75; not present in solution 2.

 $\Sigma(1880), \Sigma(1915)$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{R}$ | $\overline{\zeta} \to \Sigma(1880) \to \Sigma \pi$ | | | (Γ₁Γ₃) ^½ /Γ |
|---------------------------------------------------------------------------------------|-----------------------------------------------------|-------|-----------------|----------------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| +0.30 or +0.29 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| not seen | ³ LEA | 73 | DPWA | Multichannel K-matrix |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{R}$ | $\overline{C} \to \Sigma(1880) \to N\overline{K}^*$ | (892) | , <i>S</i> =1/: | 2, <i>P</i> -wave (Γ ₁ Γ ₄) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| _ 0.05 ± 0.03 | 4 CAMERON | 70n | DDMA | $K = D \rightarrow N\overline{K}^*$ |

 $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow \Sigma(1880) \rightarrow N\overline{K}^*(892), S=3/2, P-\text{wave } (\Gamma_1 \Gamma_5)^{\frac{1}{2}}/\Gamma_5$ DOCUMENT ID TECN COMMENT CAMERON 78B DPWA $K^-p \rightarrow N\overline{K}^*$

Σ(1880) FOOTNOTES

- ¹ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
- ² From solution 1 of BAILLON 75; not present in solution 2.
- $^3\,\mbox{Only}$ unconstrained states from table 1 of LEA 73 are listed.
- ⁴ The published sign has been changed to be in accord with the baryon-first convention.

Σ(1880) REFERENCES

| GOPAL 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
|-----------------|-------------------|--------------------------------------------|-----------------|
| CAMERON 78B | NP B146 327 | W. Cameron et al. (| RHEL, LOIC) IJP |
| MARTIN 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R.G. Moorhous | (LOUC+)IJP |
| A Iso | NP B126 266 | B.R. Martin, M.K. Pidcock | (LOUC) |
| A Iso | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| BAILLON 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield (C | ERN, RHEL) IJP |
| VANHORN 75 | NP B87 145 | A.J. van Horn | (LBL) IJP |
| A Iso | NP B87 157 | A.J. van Horn | (LBL) IJP |
| DEVENISH 74B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt, B.R. Marti | n (DESY+) |
| LEA 73 | NP B56 77 | A.T. Lea et al. (RHEL, LOUC, C | |
| ARMENTEROS 70 | Duke Conf. 123 | R. Armenteros et al. (CERN, | HEID, SACL) IJP |
| Hyperon Resonan | ices, 1970 | | |
| BARBARO 70 | Duke Conf. 173 | A. Barbaro-Galtieri | (LRL)IJP |
| Hyperon Resonan | ices, 1970 | | |
| LIT CHFIELD 70 | NP B22 269 | P.J. Litchfield | (RHEL) IJP |
| BAILEY 69 | | J.M. Bailey | (LLL) IJP |
| SMART 68 | PR 169 1330 | W.M. Smart | (LRL) IJP |

 Σ (1915) 5/2 $^+$

$$I(J^P) = 1(\frac{5}{2}^+)$$
 Status: ***

Discovered by COOL 66. For results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982).

This entry only includes results from partial-wave analyses. Parameters of peaks seen in cross sections and invariant-mass distributions in this region used to be listed in in a separate entry immediately following. They may be found in our 1986 edition Physics Letters 170B 1 (1986).

Σ(1915) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN CC | DMMENT |
|-----------------------------------|---------------------|--------|---------------------|------------------------------------|
| 1900 to 1935 (≈ 1915) OUR ESTI | | | | |
| 1937 ± 20 | ALSTON | 78 | DPWA \overline{K} | $N \rightarrow \overline{K}N$ |
| 1894 ± 5 | ¹ CORDEN | 77C | K | $-n \rightarrow \Sigma \pi$ |
| 1909 ± 5 | ¹ CORDEN | 77c | K | $-n \rightarrow \Sigma \pi$ |
| 1920 ± 10 | GOPAL | 77 | DPWA \overline{K} | N multichannel |
| 1900 ± 4 | ² CORDEN | 76 | DPWA K | $-n \rightarrow \Lambda \pi^-$ |
| 1920 ± 30 | BAILLON | 75 | IPWA K | $N \rightarrow \Lambda \pi$ |
| 1914 ± 10 | HEMINGWAY | 75 | DPWA K | $-p \rightarrow \overline{K}N$ |
| $1920 + 15 \\ -20$ | VANHORN | 75 | DPWA K | $- \rho \rightarrow \Lambda \pi^0$ |
| 1920 ± 5 | KANE | 74 | DPWA K | $-p \rightarrow \Sigma \pi$ |
| • • • We do not use the following | data for averages | , fits | limits, etc. | • • • |
| not seen | DECLAIS | 77 | DPWA K | $N \rightarrow \overline{K} N$ |
| 1925 or 1933 | ³ MARTIN | 77 | DPWA \overline{K} | N multichannel |
| 1915 | DEBELLEFON | 76 | IPWA K | $-p \rightarrow \Lambda \pi^0$ |

Σ(1915) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-----------------------------|-------------------------|--------------|---------------------------------------------|
| 80 to 160 (≈ 120) OUR ESTIN | MATE | | |
| 161 ± 20 | ALSTON 78 | B DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 107 ± 14 | ¹ CORDEN 7 | 7C | $K^- n \rightarrow \Sigma \pi$ |
| 85 ± 13 | ¹ CORDEN 7 | 7C | $K^- n \rightarrow \Sigma \pi$ |
| 130 ± 10 | GOPAL 7 | 7 DPWA | K N multichannel |
| 75 ± 14 | ² CORDEN 70 | 5 DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 70±20 | BAILLON 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 85 ± 15 | HEMINGWAY 75 | | $K^- p \rightarrow \overline{K} N$ |
| 102±18 | VANHORN 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 162±25 | KANE 74 | 1 DPWA | $K^- p \rightarrow \Sigma \pi$ |
| | ng data for averages, f | its, limits, | etc. • • • |
| 171 or 173 | 3 MARTIN 7 | 7 DPWA | K N multichannel |
| 60 | DEBELLEFON 70 | 5 IPWA | $K^- p \rightarrow \Lambda \pi^0$ |

Σ(1915) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 5-15 % |
| Γ ₂ Γ ₃ | $\Lambda\pi$ | seen |
| Γ_3 | $\Sigma \pi$ | seen |
| Γ_4 | $\Sigma(1385)\pi$ | <5 % |
| Γ_5 | $\Sigma(1385)\pi$, P -wave | |
| Γ ₆ | $\Sigma(1385)\pi$, <i>F</i> -wave | |

The above branching fractions are our estimates, not fits or averages.

Σ(1915) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|-----------------------------------------------|---------------------------------------------------|---------|-------------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.05 to 0.15 OUR ESTIM | ATE | | | | |
| 0.03 ± 0.02 | ⁴ GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.14 ± 0.05 | ALSTON | 78 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |
| 0.11 ± 0.04 | HEMINGWAY | 75 | DPWA | $K^- p \rightarrow \overline{K} N$ | |
| • • • We do not use the | following data for average | s, fits | , limits, e | etc. • • • | |
| 0.05 ± 0.03 | GOPAL | 77 | DPWA | See GOPAL 80 | |
| 0.08 or 0.08 | ³ MARTIN | 77 | DPWA | K N multichanne | l |
| ., | | | | | ., |
| ([:[e] 1/2/[tests in NT | $\rightarrow \Sigma(1915) \rightarrow \Lambda\pi$ | | | (F ₁ F ₂ | ა¹½ /Γ |

| $(i \ j \mid f)$ / $i \ total \ iii \ N \ A \rightarrow Z$ | .(1913) → //W | | | ('1'2) /' |
|------------------------------------------------------------|-----------------------|---------|-----------|------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.09 ± 0.03 | | 77 | DPWA | K N multichannel |
| -0.10 ± 0.01 | ² CORDEN | 76 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| -0.06 ± 0.02 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| -0.09 ± 0.02 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.087 ± 0.056 | DEVENISH | 74B | | Fixed-t dispersion rel. |
| ullet $ullet$ We do not use the follow | ing data for averages | , fits, | limits, e | etc. • • • |
| -0.09 or -0.09 | | | | K N multichannel |
| -0.10 | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow$ | (Γ ₁ Γ ₃) ^{1/2} /Γ | | | |
|----------------------------------------------------------------------------------------------------|----------------------------------------------------|------|----------|--------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.17 ± 0.01 | $^{ m 1}$ corden | 77c | | $K^- n \rightarrow \Sigma \pi$ |
| -0.15 ± 0.02 | ¹ CORDEN | 77c | | $K^- n \rightarrow \Sigma \pi$ |
| -0.19 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| -0.16 ± 0.03 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| We do not use the fell | owing data for average | fite | limite a | otc |

• • • We do not use the following data for averages, fits, limits, etc. • • • 3 MARTIN 77 DPWA \overline{K} N multichannel

 $\frac{\left(\Gamma_{I}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total}\text{ in }N\overline{K}\rightarrow}{<0.01}\frac{\Sigma(1915)\rightarrow\Sigma(1385)\pi}{\text{CAMERON}}, P\text{-wave} \\ \frac{DOCUMENT\ ID}{\text{CAMERON}} \xrightarrow{\text{TECN}} \frac{COMMENT}{K^{-}p\rightarrow\Sigma(1385)\pi}$

 $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma(1915) \to \Sigma(1385)\pi$, F-wave $+0.039\pm0.009$

Σ (1915) FOOTNOTES

- $^{
 m 1}$ The two entries for CORDEN 77C are from two different acceptable solutions.
- 2 Preferred solution 3; see CORDEN 76 for other possibilities.
- ³ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit.
- 4 The mass and width are fixed to the GOPAL 77 values due to the low elasticity. $^{5}\,\mathrm{The}$ published sign has been changed to be in accord with the baryon-first convention.

Σ(1915) REFERENCES

| PDG 86 PDG 80 PDG 80 ALST ON 78 Also 77 COPECIAN 77 COPECIAN 77 COPECIAN 77 COPECIAN 77 COPECIAN 77 COPECIAN 77 Also Also 76 BAILLON 75 BAILLON 75 VANHORN 75 VANHORN 75 Also Also 75 EVENISH 74B | PL 170B 1 PL 111B 1 Toronto Conf. 159 PR D18 182 PRL 38 1007 NP B143 189 NP B125 61 CERN 77-16 NP B119 362 NP B127 349 NP B126 266 NP B104 382 NP B104 382 NP B104 382 NP B109 129 NP B94 39 NP B94 39 NP B97 145 NP B87 145 NP B87 157 NP B87 157 NP B81 330 | M. Aguilar-Benitez et al. M. Roos et al. G.P. Gopal M. Alston-Garnjost et al. M. Alston-Garnjost et al. W. Cameron et al. W. Cameron et al. Y. Declais et al. G.P. Gopal et al. B.R. Martin, M.K. Pidcock, R.C. B.R. Martin, M.K. Pidcock M.J. Corden et al. A. de Bellefon, A. Berthon P.H. Baillon, P.J. Litchfield R.J. Hemingway et al. A.J. van Horn A.J. van Horn A.J. van Horn A.J. van Horn A.J. Evenish, C.D. Froggatt, | (LOUC) (LOUC) UP (BIRM) UP (CDEF) UP (CERN, HELDH, MPM) UP (CERN, HEIDH, MPM) UP (LBL) UP (LBL) UP B.R. Martin (DESY+) |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| DEVENISH 74B KANE 74 COOL 66 | NP B81 330 LBL-2452 PRL 16 1228 | R.C.E. Devenish, C.D. Froggatt, D.F. Kane R.L. Cool <i>et al.</i> | B.R. Martin (DESY+) (LBL)IJP (BNL) |
| | | | |

 $\Sigma(1940) \ 3/2$

$$I(J^P) = 1(\frac{3}{2})$$
 Status: ***

For results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters **111B** 1 (1982).

Not all analyses require this state. It is not required by the GOYA L 77 $\,$ analysis of $K^- n \to (\Sigma \pi)^-$ nor by the GOPAL 80 analysis of $K^- n \rightarrow K^- n$. See also HEMINGWAY 75.

Σ(1940) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN COMMENT | | |
|------------------------------------|-------------------|-------------|-------------------------------------------------------|--|--|
| 1900 to 1950 (≈ 1940) OUR ESTIMATE | | | | | |
| 1920±50 | GOPAL | | DPWA $\overline{K}N$ multichannel | | |
| 1950 ± 30 | BAILLON | 75 | IPWA $\overline{K}N \rightarrow \Lambda\pi$ | | |
| $1949 + 40 \\ -60$ | VANHORN | 75 | DPWA $K^- p ightarrow \Lambda \pi^0$ | | |
| 1935 ± 80 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ | | |
| 1940 ± 20 | LITCHFIELD | 74B | DPWA $K^-p \rightarrow \Lambda(1520)\pi^0$ | | |
| 1950 ± 20 | LITCHFIELD | 74 C | DPWA $K^-p \rightarrow \Delta(1232)\overline{K}$ | | |
| | data for averages | , fits | , limits, etc. ● ● ● | | |
| 1886 or 1893 | MARTIN | 77 | DPWA $\overline{K}N$ multichannel | | |
| 1940 | DEBELLEFON | 76 | IPWA $K^-p \rightarrow \Lambda \pi^0$, F_{17} wave | | |

Σ(1940) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|---------------------|-------------|-----------|--------------------------------------------------|
| 150 to 300 (≈ 220) OUR ESTIMA | TE | | | |
| 170 ± 25 | CAMERON | 78B | DPWA | $K^- p \rightarrow N \overline{K}^*$ |
| 300 ± 80 | GOPAL | 77 | DPWA | K N multichannel |
| 150 ± 75 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 160^{+70}_{-40} | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 330 ± 80 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 60 ± 20 | LITCHFIELD | 74B | DPWA | $K^-p \rightarrow \Lambda(1520)\pi^0$ |
| $70 + 30 \\ -20$ | LITCHFIELD | 74 C | DPWA | $K^- \rho \rightarrow \Delta(1232) \overline{K}$ |
| ullet $ullet$ We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 157 or 159 | ¹ MARTIN | 77 | DPWA | K N multichannel |

Σ (1940) DECAY MODES

| | Mode | Fraction (Γ_{i}/Γ) |
|-----------------------|----------------------------------------------|--------------------------------|
| $\overline{\Gamma_1}$ | NK | <20 % |
| Γ_2 | $\Lambda\pi$ | seen |
| Γ_3 | $\Sigma \pi$ | seen |
| Γ_4 | $\Sigma(1385)\pi$ | seen |
| Γ_5 | $\Sigma(1385)\pi$, $\mathit{S}	ext{-}wave$ | |
| Γ_6 | $\Lambda(1520)\pi$ | seen |
| Γ_7 | $\Lambda(1520)\pi$, P -wave | |
| Γ8 | $\Lambda(1520)\pi$, \emph{F} -wave | |
| Гэ | Δ (1232) \overline{K} | seen |
| Γ_{10} | Δ (1232) \overline{K} , S-wave | |
| Γ_{11} | $\Delta(1232)\overline{K}$, D-wave | |
| Γ ₁₂ | N K * (892) | seen |
| Γ ₁₃ | $N\overline{K}^*$ (892), $S=3/2$, S -wave | |

Σ(1940) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

 $\Gamma(N\overline{K})/\Gamma_{total}$

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------------------------------------------------------|---------------------------------------|----------|-----------|-------------------------------------------|
| < 0.2 OUR ESTIMATE | _ | | | |
| < 0.04 | GOPAL | 77 | DPWA | K N multichannel |
| 0.14 or 0.13 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow$ | $\Sigma(1940) \rightarrow \Lambda\pi$ | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.06 ± 0.03 | GOPAL | 77 | DPWA | K N multichannel |
| -0.04 ± 0.02 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| $-0.05 \begin{array}{c} +0.03 \\ -0.02 \end{array}$ | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.153 ± 0.070 | DEVENISH | 74B | | Fixed-t dispersion rel. |
| | owing data for average | es, fits | , limits, | etc. • • • |
| _0.15 or _0.14 | 1 MARTIN | 77 | D D W/A | K N multichannel |

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to .$ | $\Sigma(1940) \rightarrow \Sigma \pi$ | | | (Γ ₁ Γ ₃) ^{1/2} /Γ |
|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|-------------|-------------|----------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| -0.08 ± 0.04 | GOPAL | 77 | DPWA | K N multichannel |
| -0.14 ± 0.04 | KANE | | | $K^-p \rightarrow \Sigma \pi$ |
| ullet $ullet$ We do not use the following | wing data for average | s, fits | , limits, e | etc. • • • |
| +0.16or+0.16 | ¹ MARTIN | 77 | DPWA | \overline{K} N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to C$ | Σ(1940) → Λ(152 DOCUMENT ID | | | |
| < 0.03 | | | | $K^- p \rightarrow \Lambda(1520) \pi^0$ |
| -0.11 ± 0.04 | LITCHFIELD | 74B | DPWA | $K^-p \rightarrow \Lambda(1520)\pi^0$ |
| $(\Gamma_I \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to C$ | | | | |
| VALUE | DOCUMENT ID | | | |
| | | | | $K^- p \rightarrow \Lambda(1520) \pi^0$ |
| -0.08 ± 0.04 | LITCHFIELD | 74B | DPWA | $K^- p \rightarrow \Lambda(1520) \pi^0$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to C$ | $\Sigma(1940) \rightarrow \Delta(123)$ DOCUMENT ID | | | |
| -0.16 ± 0.05 | LITCHFIELD | 74 C | DPWA | $K^- p \rightarrow \Delta(1232) \overline{K}$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to C$ | DO CUMENT ID | | TECN | COMMENT |
| -0.14 ± 0.05 | LITCHFIELD | 74 C | DPWA | $K^- p \rightarrow \Delta(1232) \overline{K}$ |
| $\frac{(\Gamma_I \Gamma_f)^{\frac{1}{2}}}{\Gamma_{\text{total}} \text{ in } N \overline{K} \to \frac{N}{K}}$ $+ 0.066 \pm 0.025$ | $\Sigma(1940) \rightarrow \Sigma(136)$ | B5)π | TECN | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
| + 0.066 ± 0.025 | ² CAMERON | 78 | DPWA | $K^- p \rightarrow \Sigma(1385) \pi$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to X_{NALUE}$ | Σ(1940) → N\(\overline{K}\)*(| 892) | | ([1[12] ¹ /2] |
| -0.09 ± 0.02 | 3 CAMERON | 78B | DPWA | $\frac{COMMENT}{K^- p \to N \overline{K}^*}$ |
| ¹ The two MARTIN 77 value | Σ(1940) FOOTN es are from a T-matri | | | m a Breit-Wigner fit. |

 2 The published sign has been changed to be in accord with the baryon-first convention. 3 Upper limits on the D_1 and D_3 waves are each 0.03.

Σ(1940) REFERENCES

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| GOPAL 80 | Toronto Conf. 159 | G.P. Gopal | ` (RHEL) |
| CAMERON 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CAMERON 78B | NP B146 327 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CAMERON 77 | NP B131 399 | W. Cameron et al. | (RHEL, LOIC) IJP |
| GOPAL 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| GOYAL 77 | PR D16 2746 | D.P. Goyal, A.V. Sodhi | ` (DELH) |
| MARTIN 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, R. | G. Moorhouse (LÒUC+)IJP |
| A Iso | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| Also | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| DEBELLEFON 76 | NP B109 129 | A. de Bellefon, A. Berthon | (CDEF) IJP |
| BAILLON 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| HEMINGWAY 75 | NP B91 12 | R.J. Hemingway et al. | (CERN, HEIDH, MPIM) IJP |
| VANHORN 75 | NP B87 145 | A.J. van Horn | (LBL) IJP |
| A Iso | NP B87 157 | A.J. van Horn | (LBL) IJP |
| DEVENISH 74B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt | , B.R. Martin (DESY+) |
| KANE 74 | LBL-2452 | D.F. Kane | ` (LBL) IJP |
| LIT CHFIELD 74B | NP B74 19 | P.J. Litchfield et al. | (CERN, HÉIDH) IJP |
| LIT CHFIELD 74 C | NP B74 39 | P.J. Litchfield <i>et al</i> . | (CERN, HEIDH) IJP |
| | | | |

$\Sigma(2000) 1/2$

 Γ_1/Γ

 $I(J^P) = 1(\frac{1}{2}^-)$ Status: *

OMITTED FROM SUMMARY TABLE

We list here all reported S_{11} states lying above the $\Sigma(1750)$ S_{11} .

| | Σ(2000) MA | ASS | | |
|-------------------------|-----------------------------|-----|--------------|------------------------------------------------------------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| ≈ 2000 OUR ESTIMATE | | | | |
| 1944 ± 15 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 1955 ± 15 | GOPAL | 77 | DPWA | K N multichannel |
| 1755 or 1834 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| 2004 ± 40 | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| | | | | |
| | Σ(2000) WII | ЭТН | | |
| <i>VALUE</i> (MeV) | Σ(2000) WII | | TECN | <u>COMMENT</u> |
| VALUE (MeV) 215 ± 25 | , , | | | $\frac{\textit{COMMENT}}{\overline{\textit{K}}\textit{N}\rightarrow\overline{\textit{K}}\textit{N}}$ |
| 1 | DOCUMENT ID | 1 | DPWA | |
| 215 ± 25 | <u>DOCUMENT ID</u> GOPAL | 80 | DPWA DPWA | $\overline{K} N \rightarrow \overline{K} N$ |

 $\Sigma(2000), \Sigma(2030)$

Σ(2000) DECAY MODES

| | Mode |
|-----------------------|-----------------------------------------------|
| $\overline{\Gamma_1}$ | NK |
| Γ_2 | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |
| Γ_4 | $\Lambda(1520)\pi$ |
| Γ_5 | $N\overline{K}^*(892)$, $S=1/2$, S -wave |
| Γ ₆ | $N \overline{K}^*(892)$, $S=3/2$, D -wave |

Σ(2000) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| resonances. | | | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|----------|-----------------|-----------------------------------------------------------------------------------------------------------|
| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Γ_1/Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.51 ± 0.05 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.44 ± 0.05 | GOPAL | 77 | DPWA | See GOPAL 80 |
| 0.62 or 0.57 | ¹ MARTIN | 77 | DPWA | K N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ | DO CUMENT ID | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| 0.08 ± 0.03 | GOPAL | 77 | | K N multichannel |
| -0.19 or -0.18 | ¹ MARTIN | 77 | | $\overline{K}N$ multichannel |
| not seen | BAILLON | 75 | IPWA | $\overline{K}N \rightarrow \Lambda \pi$ |
| $+0.07^{+0.02}_{-0.01}$ | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| $\frac{\left(\Gamma_{i}\Gamma_{f}\right)^{\frac{1}{2}}/\Gamma_{total} \text{ in } N\mathcal{K} \rightarrow \Sigma}{\frac{VALUE}{+0.20 \pm 0.04}}$ +0.26 or +0.24 | $ \begin{array}{c} (2000) \to \Sigma \pi \\ & \underline{DOCUMENT\ ID} \\ & GOPAL \\ 1 MARTIN \end{array} $ | 77 | DPWA | $(\Gamma_1\Gamma_3)^{\frac{1}{2}}/\Gamma$ \overline{K} N multichannel \overline{K} N multichannel |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ VALUE | Γ (2000) $\rightarrow \Lambda$ (152) $\frac{DOCUMENT\ ID}{2}$ CAMERON | $(0)\pi$ | <u>TECN</u> | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
| $+0.081\pm0.021$ | ² CAMERON | 77 | DPWA | P-wave decay |
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ | $(2000) \rightarrow N\overline{K}^*$ $\frac{DOCUMENT\ ID}{2}$ | (892) | , S=1/2 | 2, S-wave $(\Gamma_1\Gamma_5)^{\frac{1}{2}}/\Gamma$ $\frac{COMMENT}{K^-p \rightarrow N\overline{K}^*}$ |
| $+0.10\pm0.02$ | ² CAMERON | 78B | DPWA | $K - p \rightarrow N K^*$ |
| $(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ | (2000) → N\(\overline{K}^*\) | (892) | , <i>S</i> =3/2 | 2, <i>D</i> -wave (Γ ₁ Γ ₆) ^{1/2} /Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| | | | | $K^-p \rightarrow N\overline{K}^*$ |
| -0.07 ± 0.03 | CAMERON | /8B | DPWA | $\kappa p \rightarrow N \kappa^{\perp}$ |

Σ (2000) FOOTNOTES

¹ The two MARTIN 77 values are from a T-matrix pole and from a Breit-Wigner fit. ²The published sign has been changed to be in accord with the baryon-first convention.

Σ(2000) REFERENCES

| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
|---------|------|-------------------|-------------------------------|---------------------------|
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| CAMERON | 77 | NP B131 399 | W. Cameron et al. | (RHEL, LOIC) IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL) IJP |
| MARTIN | 77 | NP B127 349 | B.R. Martin, M.K. Pidcock, | R.G. Moorhouse (LOUC+)IJP |
| A Iso | | NP B126 266 | B.R. Martin, M.K. Pidcock | `(LOUC) |
| A Iso | | NP B126 285 | B.R. Martin, M.K. Pidcock | (LOUC) IJP |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| VANHORN | 75 | NP B87 145 | A.J. van Horn | ` (LBL) IJP |
| A Iso | | NP B87 157 | A.J. van Horn | (LBL) IJP |

$\Sigma(2030) 7/2^{+}$

 $I(J^P) = 1(\frac{7}{2}^+)$ Status: ***

Discovered by COOL 66 and by WOHL 66. For most results published before 1974 (they are now obsolete), see our 1982 edition Physics Letters 111B 1 (1982).

This entry only includes results from partial-wave analyses. Parameters of peaks seen in cross sections and invariant-mass distributions around 2030 MeV may be found in our 1984 edition, Reviews of Modern Physics 56 S1 (1984).

Σ(2030) MASS

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|------------------|-----|------|---------------------------------------------|
| 2025 to 2040 (≈ 2030) | OUR ESTIMATE | | | |
| 2036± 5 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2038 ± 10 | CORDEN | 77B | | $K^- N \rightarrow N \overline{K}^*$ |
| 2040 ± 5 | GOPAL | 77 | DPWA | K N multichannel |
| $2030\pm~3$ | $^{ m 1}$ corden | 76 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 2035 ± 15 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |

| 2038 ± 10 | HEMINGWAY | 75 | DPWA $K^-p \rightarrow \overline{K}N$ |
|-----------------------------------|-------------------|---------|--------------------------------------------------|
| 2042 ± 11 | | | DPWA $K^-p \rightarrow \Lambda \pi^0$ |
| 2020± 6 | KANE | 74 | DPWA $K^-p \rightarrow \Sigma \pi$ |
| 2035 ± 10 | LITCHFIELD | 74B | DPWA $K^-p \rightarrow \Lambda(1520)\pi^0$ |
| 2020 ± 30 | LITCHFIELD | 74 C | DPWA $K^-p \rightarrow \Delta(1232)\overline{K}$ |
| 2025 ± 10 | LITCHFIELD | 74D | DPWA $K^-p \rightarrow \Lambda(1820)\pi^0$ |
| • • • We do not use the following | data for averages | s, fits | , limits, etc. • • • |
| 2027 to 2057 | GOYAL | 77 | DPWA $K^- N 	o \Sigma \pi$ |
| 2030 | DEBELLEFON | 76 | IPWA $K^-p \rightarrow \Lambda \pi^0$ |
| | | | |

Σ(2030) WIDTH

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------|-------------------|--------|-------------|--------------------------------------------------|
| 150 to 200 (≈ 180) OUR ESTIMAT | E | | | |
| 172 ± 10 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 137 ± 40 | CORDEN | 77B | | $K^- N \rightarrow N \overline{K}^*$ |
| 190±10 | GOPAL | 77 | DPWA | K N multichannel |
| 201 ± 9 | CORDEN | 76 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 180 ± 20 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi$ |
| 172±15 | HEMINGWAY | 75 | | $K^- p \rightarrow \overline{K} N$ |
| 178 ± 13 | VANHORN | 75 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| 111 ± 5 | KANE | 74 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 160 ± 20 | LITCHFIELD | 74B | DPWA | $K^- p \rightarrow \Lambda(1520) \pi^0$ |
| 200 ± 30 | LITCHFIELD | 74 C | DPWA | $K^- \rho \rightarrow \Delta(1232) \overline{K}$ |
| • • • We do not use the following of | lata for averages | , fits | , limits, e | etc. • • • |
| 260 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 126 to 195 | GOYAL | 77 | DPWA | $K^- N \rightarrow \Sigma \pi$ |
| 160 | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 70 to 125 | LITCHFIELD | 74D | DPWA | $K^- p \rightarrow \Lambda(1820) \pi^0$ |

Σ (2030) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | NK | 17-23 % |
| Γ_2 | $\Lambda\pi$ | 17-23 % |
| Г | $\Sigma \pi$ | 5-10 % |
| Γ_4 | ΞK | <2 % |
| Γ_5 | $\Sigma(1385)\pi$ | 5-15 % |
| Γ ₆ | $\Sigma(1385)\pi$, F-wave | |
| Γ_7 | $\Lambda(1520)\pi$ | 10-20 % |
| Γ ₈ | $\Lambda(1520)\pi$, <i>D</i> -wave | |
| Г9 | $\Lambda(1520)\pi$, G-wave | |
| Γ_{10} | $\Delta(1232)\overline{K}$ | 10-20 % |
| Γ ₁₁ | $\Delta(1232)\overline{K}$, F-wave | |
| Γ ₁₂ | $\Delta(1232)\overline{K}$, H-wave | |
| Γ ₁₃ | N K *(892) | <5 % |
| Γ ₁₄ | $N\overline{K}^*(892)$, $S=1/2$, F -wave | |
| Γ_{15} | $N\overline{K}^*$ (892), $S=3/2$, F -wave | |
| Γ ₁₆ | $\Lambda(1820)\pi$, P -wave | |

The above branching fractions are our estimates, not fits or averages.

Σ(2030) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{	ext{total}}$ | | | | Γ ₁ /Γ |
|---------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|-----------------------|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0.17 to 0.23 OUR ESTIMATE | DOCUMENT ID | | TECN | COMMENT |
| 0.19 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \to \overline{K} N$ |
| 0.18 ± 0.03 | HEMINGWAY | 75 | DPWA | $K^-p \rightarrow \overline{K}N$ |
| • • • We do not use the following | data for average | s, fits | , limits, | etc. • • • |
| 0.15 | DECLAIS | 77 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 0.24 ± 0.02 | GOPAL | 77 | DPWA | See GOPAL 80 |
| | | | | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma(20)$ | 030) → Λπ <u>DOCUMENT ID</u> | | TECN | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
| | | 77 | | |
| <u>VALUE</u> +0.18 ±0.02 | DO CUMENT ID | 77 76 | DPWA | COMMENT |
| <u>VALUE</u> +0.18 ±0.02 | DOCUMENT ID | | DPWA DPWA IPWA | $\frac{COMMENT}{K \text{ N multichannel}}$ $\frac{K^- n \to \Lambda \pi^-}{K \text{ N } \to \Lambda \pi}$ |
| $ \begin{array}{r} & \underline{\text{VALUE}} \\ & +0.18 \pm 0.02 \\ & +0.20 \pm 0.01 \end{array} $ | DOCUMENT ID GOPAL CORDEN | 76 | DPWA DPWA IPWA | \overline{K} N multichannel $K^ n \to \Lambda \pi^-$ |
| $ \begin{array}{l} \underline{VALUE} \\ +0.18 \pm 0.02 \\ +0.20 \pm 0.01 \\ +0.18 \pm 0.02 \end{array} $ | DOCUMENT ID GOPAL CORDEN BAILLON | 76 75 | DPWA DPWA IPWA | $\frac{COMMENT}{K \text{ N multichannel}}$ $\frac{K^- n \to \Lambda \pi^-}{K \text{ N } \to \Lambda \pi}$ |
| <u>VALUE</u> +0.18 ±0.02 +0.20 ±0.01 +0.18 ±0.02 +0.20 ±0.01 | DOCUMENT ID GOPAL CORDEN BAILLON VANHORN DEVENISH | 76 75 75 74B | DPWA DPWA IPWA DPWA | $\begin{array}{c} \underline{COMMENT} \\ \overline{K} N \text{multichannel} \\ K^- n \to \Lambda \pi^- \\ \overline{K} N \to \Lambda \pi \\ K^- p \to \Lambda \pi^0 \\ \text{Fixed-} t \text{dispersion rel.} \end{array}$ |

Baryon Particle Listings $\Sigma(2030), \Sigma(2070), \Sigma(2080)$

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} -$ | $\rightarrow \Sigma(2030) \rightarrow \Sigma \pi$ DO CUMENT ID | | TECN | COMMENT | (Γ ₁ Γ ₃) ^{1/2} /Γ |
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| -0.09 ±0.01 | ² CORDEN | 77C | | K-n → | |
| -0.06 ± 0.01 | ² CORDEN | 77C | | $K^- n \rightarrow$ | $\Sigma \pi$ |
| -0.15 ± 0.03 | GOPAL | 77 | DPWA | $\overline{K}N$ mult | ichannel |
| -0.10 ± 0.01 | KANE | 74 | DPWA | $K^-p \rightarrow$ | $\Sigma \pi$ |
| • • • We do not use the fo | ollowing data for average | s, fits, | limits, e | etc. • • • | |
| -0.085 ± 0.02 | ³ GOYAL | 77 | | $K^- N \rightarrow$ | $\Sigma \pi$ |
| (Γ _I Γ _f) ^{1/2} /Γ _{total} in N K – | $\rightarrow \Sigma(2030) \rightarrow \Xi K$ DO CUMENT ID | | TECN | <u>COMMENT</u> | $(\Gamma_1\Gamma_4)^{\frac{1}{2}}/\Gamma$ |
| 0.023 | MULLER | 69B | | $K^-p \rightarrow$ | |
| < 0.05 | BURGUN | 68 | | $K^-p \rightarrow$ | |
| < 0.05 | TRIPP | 67 | | $\kappa^- p \rightarrow$ | |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\overline{K}$ – | $\rightarrow \Sigma(2030) \rightarrow \Lambda(182)$ DO CUMENT ID | 0)π, | P-wave | : COMMENT | (Γ ₁ Γ ₁₆) ^½ /Γ |
| 0.14±0.02 | CORDEN | | | | $N\overline{K}\pi^-$ |
| 0.18 ± 0.04 | LITCHFIELD | 74D | DPWA | $K^-p \rightarrow$ | $\Lambda(1820)\pi^{0}$ |
| $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{	ext{total}}$ in $N\overline{K}$ – | → Σ(2030) → Λ(152 | 0)π, | D-wave | C OMMENT | $(\Gamma_1\Gamma_8)^{\frac{1}{2}}/\Gamma$ |
| $+0.114 \pm 0.010$ | 4 CAMERON | 77 | DPWA | K ⁻ p → | $\Lambda(1520)\pi^{0}$ |
| 0.14 ± 0.03 | LITCHFIELD | | | | |
| • • We do not use the form | | | | | (, |
| $0.10\ \pm0.03$ | ⁵ CORDEN | | | | $N\overline{K}\pi^-$ |
| 1/ | _, , ., | | _ | | (۲ ₁ ۲ ₉) ^½ /۲ |
| (Γ¡Γƒ) ^½ /Γ _{total} in N K − VALUE | DO CUMENT ID | | TECN | COMMENT | |
| VALUE | DOCUMENT ID 4 CAMERON | 77 | TECN DPWA | $K^- p \rightarrow$ | $\Lambda(1520)\pi^{0}$ |
| VALUE | → Σ (2030) → Λ (152 DOCUMENT ID 4 CAMERON LITCHFIELD | 77 | TECN DPWA | $K^- p \rightarrow$ | $\Lambda(1520) \pi^{0}$ |
| value +0.146±0.010 0.02±0.02 (Γ _I Γ _Γ) ^{1/2} /Γ _{total} in N K – | $ \begin{array}{c} $ | 77 74B 32) K | TECN DPWA DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^- p \rightarrow \\ K^- p \rightarrow \end{array}$ | $\frac{\Lambda(1520)\pi^0}{\Lambda(1520)\pi^0}$ $\frac{(\Gamma_1\Gamma_{11})^{\frac{1}{2}}}{\Gamma_1}$ |
| $\begin{array}{l} \frac{VALUE}{+0.146\pm0.010} \\ 0.02\pm0.02 \end{array}$ $(\Gamma_{I}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} - \frac{1}{2}$ VALUE | $ \begin{array}{c} \frac{DOCUMENT ID}{4} \\ 4 \text{ CAMERON} \\ \text{LITCHFIELD} \end{array} $ $ \rightarrow \Sigma(2030) \rightarrow \Delta(1230) \\ \frac{DOCUMENT ID}{2000} $ | 77 74B 32) K | TECN DPWA DPWA , F-wav | $\begin{array}{c} \underline{COMMENT} \\ K^- p \rightarrow \\ K^- p \rightarrow \end{array}$ $\begin{array}{c} \bullet \\ \underline{COMMENT} \end{array}$ | $\Lambda(1520)\pi^{0}$ $\Lambda(1520)\pi^{0}$ $\Gamma(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ |
| (F ₁ (F ₁)) | DOCUMENT ID 4 CAMERON LITCHFIELD → Σ(2030) → Δ(12: DOCUMENT ID LITCHFIELD | 77 74B 32) <i>K</i> | DPWA DPWA , F-wav TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ K^-p \to \end{array}$ $\begin{array}{c} \mathbf{e} \\ \underline{COMMENT} \\ K^-p \to \end{array}$ | $\Lambda(1520)\pi^{0}$ $\Lambda(1520)\pi^{0}$ $\Gamma(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ |
| VALUE $+0.146\pm0.010$ 0.02 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ VALUE 0.16 ± 0.03 • • • We do not use the fo | DOCUMENT ID 4 CAMERON LITCHFIELD → Σ(2030) → Δ(12: DOCUMENT ID LITCHFIELD | 77 74B 32) K 74C es, fits, | DPWA DPWA , F-wav TECN DPWA limits, 6 | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \end{array}$ $\begin{array}{c} \mathbf{e} \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \mathbf{etc.} \bullet \bullet \bullet \end{array}$ | $ \begin{array}{c} \Lambda(1520) \pi^{0} \\ \Lambda(1520) \pi^{0} \\ \Gamma_{1} \Gamma_{11} \Gamma_{11} \Gamma_{11} \Gamma_{11} \end{array} $ $ \Delta(1232) \overline{K} $ |
| VALUE $+0.146 \pm 0.010$ 0.02 ± 0.02 $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - VALUE}$ 0.16 ± 0.03 • • We do not use the for 0.17 ± 0.03 | DOCUMENT ID 4 CAMERON LITCHFIELD → Σ(2030) → Δ(12: DOCUMENT ID LITCHFIELD Sollowing data for average 5 CORDEN | 77 74B 32) K 74C es, fits, | DPWA DPWA F-wav TECN DPWA DPWA limits, 6 | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \end{array}$ $\begin{array}{c} \mathbf{e} \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \mathbf{etc.} \bullet \bullet \bullet \\ K^-n \rightarrow \end{array}$ | $\Lambda(1520) \pi^{0} \\ \Lambda(1520) \pi^{0}$ $\Gamma(\Gamma_{11})^{1/2}/\Gamma$ $\Gamma(\Gamma_{12})^{1/2}/\Gamma$ $\Gamma(\Gamma_{13})^{1/2}/\Gamma$ $\Gamma(\Gamma_{13})^{1/2}/\Gamma$ |
| VALUE $+0.146 \pm 0.010$ 0.02 ± 0.02 $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - VALUE}$ 0.16 ± 0.03 • • We do not use the for 0.17 ± 0.03 | DOCUMENT ID 4 CAMERON LITCHFIELD → Σ(2030) → Δ(12: DOCUMENT ID LITCHFIELD Sollowing data for average 5 CORDEN | 77 74B 32) K 74C es, fits, | DPWA DPWA F-wav TECN DPWA DPWA limits, 6 | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \end{array}$ $\begin{array}{c} \mathbf{e} \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \mathbf{etc.} \bullet \bullet \bullet \\ K^-n \rightarrow \end{array}$ | $\Lambda(1520) \pi^{0} \\ \Lambda(1520) \pi^{0}$ $\Gamma(\Gamma_{11})^{1/2}/\Gamma$ $\Gamma(\Gamma_{12})^{1/2}/\Gamma$ $\Gamma(\Gamma_{13})^{1/2}/\Gamma$ $\Gamma(\Gamma_{13})^{1/2}/\Gamma$ |
| WALUE $+0.146\pm0.010$ 0.02 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - VALUE}$ 0.16 ± 0.03 \bullet \bullet \bullet We do not use the for 0.17 ± 0.03 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - VALUE}$ 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - VALUE}$ | $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ LITCHFIELD $\rightarrow \Sigma(2030) \rightarrow \Delta(12:$ $\frac{DOCUMENT ID}{1000000000000000000000000000000000000$ | 77 74B 32) K 74C 25, fits, 75B 32) K 74C | TECN DPWA DPWA F-wav TECN DPWA limits, o DBC H-wav TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | $\frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}}$ $(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $N\overline{K}\pi^{-}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ |
| VALUE $+0.146\pm0.010$ 0.02 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ VALUE 0.16 ± 0.03 •• • We do not use the for 0.17 ± 0.03 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ VALUE 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ VALUE $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ VALUE | $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ LITCHFIELD | 77 74B 32) K 74C 25, fits, 75B 32) K 74C | TECN DPWA DPWA F-wav TECN DPWA limits, o DBC H-wav TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \\ \underline{COMMENT} \\ K^-p \rightarrow \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $ | $\frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}}$ $(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $N\overline{K}\pi^{-}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $(\Gamma_{1}\Gamma_{15})^{\frac{1}{2}}/\Gamma$ |
| VALUE $+0.146 \pm 0.010$ 0.02 ± 0.02 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - \frac{1}{2}$ 0.16 ± 0.03 $\bullet \bullet \bullet \text{ We do not use the foliation}$ $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - \frac{1}{2}$ 0.00 ± 0.02 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - \frac{1}{2}$ 0.0153 ± 0.026 | $\begin{array}{c} \frac{DOCUMENT ID}{4} \\ CAMERON \\ LITCHFIELD \\ \end{array}$ $\rightarrow \mathcal{F}(2030) \rightarrow \Delta(12: \\ \frac{DOCUMENT ID}{2} \\ LITCHFIELD \\ SIDDE \\ \end{array}$ $\rightarrow \mathcal{F}(2030) \rightarrow \Delta(12: \\ \frac{DOCUMENT ID}{2} \\ LITCHFIELD \\ \longrightarrow \mathcal{F}(2030) \rightarrow \mathcal{F}(13: \\ \frac{DOCUMENT ID}{4} \\ CAMERON \\ \end{array}$ | 77 748 32) K 74c 74c 78 78 | TECN DPWA DPWA Imits, o DBC H-wav TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ K^-p \to \\ \end{array}$ $\begin{array}{c} COMMENT \\ K^-p \to \\ \end{array}$ $\begin{array}{c} COMMENT \\ K^-p \to \\ \end{array}$ $\begin{array}{c} COMMENT \\ K^-p \to \\ \end{array}$ | $ \frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}} $ $ (\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma $ $ \Delta(1232)\overline{K} $ $ N\overline{K}\pi^{-} $ $ (\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma $ $ \Delta(1232)\overline{K} $ $ (\Gamma_{1}\Gamma_{5})^{\frac{1}{2}}/\Gamma $ $ \Sigma(1385)\pi $ |
| WALUE $+0.146 \pm 0.010$ 0.02 ± 0.02 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - 0.02$ $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - 0.03$ • • • We do not use the form 0.17 ± 0.03 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - 0.00 \pm 0.02$ $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } NK - 0.0153 \pm 0.026$ | DOCUMENT ID 4 CAMERON LITCHFIELD $\rightarrow \mathcal{L}(2030) \rightarrow \Delta(12:$ DOCUMENT ID LITCHFIELD billowing data for average 5 CORDEN $\rightarrow \mathcal{L}(2030) \rightarrow \Delta(12:$ DOCUMENT ID LITCHFIELD $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ $\rightarrow \mathcal{L}(2030) \rightarrow \mathcal{L}(13:$ | 77 74B 74C 74C 75B 74C 74C 75B 74C 78 74C 78 74C | TECN DPWA DPWA F-wav TECN DPWA limits, o DBC H-wav TECN DPWA TECN DPWA TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ K^-p \rightarrow \\ \end{array}$ e $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ \end{array}$ e $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ \end{array}$ v $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \rightarrow \\ \end{array}$ | $\frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}}$ $(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $N\overline{K}\pi^{-}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $(\Gamma_{1}\Gamma_{5})^{\frac{1}{2}}/\Gamma$ $\Sigma(1385)\pi$ |
| WALUE $+0.146\pm0.010$ 0.02 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ WALUE 0.16 ± 0.03 •• • We do not use the for 0.17 ± 0.03 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ WALUE 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ WALUE 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ WALUE 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ WALUE 0.00 ± 0.02 $(\Gamma_i\Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}}$ in $NK-$ | DOCUMENT ID 4 CAMERON LITCHFIELD → \(\Sigma(2030) \rightarrow \Delta(12) DOCUMENT ID LITCHFIELD SIDDING ACT OF THE PROPERTY ID LITCHFIELD \(\sigma(2030) \rightarrow \Delta(12) DOCUMENT ID 4 CAMERON → \(\Sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\sigma(2030) \rightarrow \NT**(DOCUMENT ID \(\ | 77 748 74c ss, fits, 758 74c 74c 758 758 74c 786 (892) | TECN DPWA DPWA F-wav TECN DPWA Limits, o DBC H-wav TECN DPWA TECN DPWA TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \mathbf{e} \\ \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \mathbf{e} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ | $\frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}}$ $(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $N\overline{K}\pi^{-}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $(\Gamma_{1}\Gamma_{15})^{\frac{1}{2}}/\Gamma$ $\Sigma(1385)\pi$ $(\Gamma_{1}\Gamma_{14})^{\frac{1}{2}}/\Gamma$ |
| WALUE $+0.146\pm0.010$ 0.02 ± 0.02 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}$ in $NK VALUE$ 0.16 ± 0.03 • • • We do not use the for 0.17 ± 0.03 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}$ in $NK VALUE$ 0.00 ± 0.02 $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}$ in $NK VALUE$ $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}$ in $NK VALUE$ $+0.153\pm0.026$ $(\Gamma_{i}\Gamma_{f})^{\frac{1}{2}}/\Gamma_{total}$ in $NK VALUE$ $+0.06\pm0.03$ | $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ $+ \mathcal{F}(2030) \rightarrow \Delta(12)$ $\frac{DOCUMENT ID}{4 \text{ CORDEN}}$ $+ \mathcal{F}(2030) \rightarrow \Delta(12)$ $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ $+ \mathcal{F}(2030) \rightarrow \mathcal{F}(13)$ $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ $+ \mathcal{F}(2030) \rightarrow N\mathcal{F}^*(4)$ $\frac{DOCUMENT ID}{4 \text{ CAMERON}}$ | 77 74B 32) K 74C 74C 78B 78B 78B | TECN DPWA DPWA F-wav TECN DPWA Ilimits, o DBC H-wav TECN DPWA TECN DPWA TECN DPWA TECN DPWA | $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ K^-p \to \\ \end{array}$ e $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ etc. $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ $\begin{array}{c} \underline{COMMENT} \\ K^-p \to \\ \end{array}$ | $\frac{\Lambda(1520)\pi^{0}}{\Lambda(1520)\pi^{0}}$ $(\Gamma_{1}\Gamma_{11})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $N\overline{K}\pi^{-}$ $(\Gamma_{1}\Gamma_{12})^{\frac{1}{2}}/\Gamma$ $\Delta(1232)\overline{K}$ $(\Gamma_{1}\Gamma_{5})^{\frac{1}{2}}/\Gamma$ $\Sigma(1385)\pi$ $(\Gamma_{1}\Gamma_{14})^{\frac{1}{2}}/\Gamma$ $N\overline{K}^{*}$ |
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| WALUE +0.146 ± 0.010 0.02 ± 0.02 ($\Gamma_{i}\Gamma_{f}$) ^{1/2} / Γ_{total} in NK — WALUE 0.16 ± 0.03 ••• We do not use the for 0.17 ± 0.03 ($\Gamma_{i}\Gamma_{f}$) ^{1/2} / Γ_{total} in NK — WALUE 0.00 ± 0.02 ($\Gamma_{i}\Gamma_{f}$) ^{1/2} / Γ_{total} in NK — WALUE +0.153 ± 0.026 ($\Gamma_{i}\Gamma_{f}$) ^{1/2} / Γ_{total} in NK — WALUE +0.06 ± 0.03 -0.02 ± 0.01 ($\Gamma_{i}\Gamma_{f}$) ^{1/2} / Γ_{total} in NK — | DOCUMENT ID 4 CAMERON LITCHFIELD $\rightarrow \mathcal{L}(2030) \rightarrow \Delta(12:1)$ DOCUMENT ID LITCHFIELD Solvent of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the property of the 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\frac{(\Gamma_{1}\Gamma_{15})^{\frac{1}{2}}/\Gamma}{N\overline{K}^{*}} \end{array}$ |

Σ (2030) FOOTNOTES

- Preferred solution 3; see CORDEN 76 for other possibilities.
- The two entries for CORDEN 77c are from two different acceptable solutions.
- ³ This coupling is extracted from unnormalized data.
- 4 The published sign has been changed to be in accord with the baryon-first convention.
- ⁵ An upper limit.
- 6 The upper limit on the G_3 wave is 0.03.

Σ(2030) REFERENCES

| PDG | 84 | RMP 56 S1 | C.G. Wohl et al. | (LBL, CIT, CERN) |
|------------|------|-------------------|-------------------------------|-------------------|
| PDG | 82 | PL 111B 1 | M. Roos et al. | (HELS, CIT, CERN) |
| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
| CAMERON | 78 | NP B143 189 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CAMERON | 78 B | NP B146 327 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CAMERON | 77 | NP B131 399 | W. Cameron et al. | (RHEL, LOIC) IJP |
| CORDEN | 77 B | NP B121 365 | M.J. Corden et al. | ` (BIRM)IJP |
| CORDEN | 77 C | NP B125 61 | M.J. Corden et al. | (BIRM) IJP |
| DECLAIS | 77 | CERN 77-16 | Y. Declais et al. | (CAEN, CERN)IJP |
| GOPAL | 77 | NP B119 362 | G.P. Gopal et al. | (LOIC, RHEL)IJP |
| GOYAL | 77 | PR D16 2746 | D.P. Goyal, A.V. Sodhi | (DELH) IJP |
| CORDEN | 76 | NP B104 382 | M.J. Corden et al. | (BIRM) IJP |
| DEBELLEFON | 76 | NP B109 129 | A. de Bellefon, A. Berthon | (CDEF) IJP |
| BAILLON | 75 | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| | | | | |

| CORDEN HEMINGWAY VANHORN | 75 B 75 75 | NP B92 365 NP B91 12 NP B87 145 | M.J. Corden et al. R.J. Hemingway et al. A.J. van Horn | (BIRM) IJP (CERN, HEIDH, MPIM) IJP (LBL) IJP |
|--------------------------------|------------------|---------------------------------------|--------------------------------------------------------------|----------------------------------------------------|
| Also | 15 | NP B87 157 | A.J. van Horn | (LBL) IJP |
| DEVENISH | 74 B | NP B81 330 | R.C.E. Devenish, C.D. Froggatt | , B.R. Martin (DESY+) |
| KANE | 74 | LBL-2452 | D.F. Kane | ` (LBL) IJP |
| LITCHFIELD | 74 B | NP B74 19 | P.J. Litchfield et al. | (CERN, HÈIDH) IJP |
| LIT CHFIELD | 74 C | NP B74 39 | P.J. Litchfield et al. | (CERN, HEIDH) IJP |
| LIT CHFIELD | 74 D | NP B74 12 | P.J. Litchfield et al. | (CERN, HEIDH) IJP |
| MULLER | 69B | Thesis UCRL 19372 | R.A. Muller | ` (LRL) |
| BURGUN | 68 | NP B8 447 | G. Burgun et al. | (SACL, CDEF, RHEL) |
| TRIPP | 67 | NP B3 10 | R.D. Tripp et al. | (LRL, SLAC, CERN+) |
| COOL | 66 | PRL 16 1228 | R.L. Cool et al. | ` (BNL) |
| WOHL | 66 | PRL 17 107 | C.G. Wohl, F.T. Solmitz, M.L. | Stevenson (LRL) IJP |

$\Sigma(2070) 5/2^{-1}$

 $I(J^P) = 1(\frac{5}{2}^+)$ Status: *

OMITTED FROM SUMMARY TABLE

This state suggested by BERTHON 70B finds support in GOPAL 80 $\,$ with new K^-p polarization and K^-n angular distributions. The very broad state seen in KANE 72 is not required in the later (KANE 74) analysis of $\overline{K}N \to \Sigma\pi$.

| Σ(2 | 070) | MASS |
|-----|------|------|
|-----|------|------|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|--------------|-----|------|---------------------------------------------|
| ≈ 2070 OUR ESTIMATE | | | | |
| 2051 ± 25 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 2057 | KANE | 72 | DPWA | $K^-p \rightarrow \Sigma \pi$ |
| 2070 ± 10 | BERTHON | 70B | DPWA | $K^-p \rightarrow \Sigma \pi$ |

Σ (2070) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|--------------|-------------|-----|------|---------------------------------------------|
| 300±30 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ |
| 906 | KANE | 72 | DPWA | $K^- p \rightarrow \Sigma \pi$ |
| 140 ± 20 | BERTHON | 70B | DPWA | $K^- p \rightarrow \Sigma \pi$ |

Σ (2070) DECAY MODES

| | Mode |
|------------|--------------|
| Γ_1 | NK |
| Гэ | $\Sigma \pi$ |

Σ(2070) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma

| $\Gamma(N\overline{K})/\Gamma_{total}$ | | | | | Γ_1/Γ |
|----------------------------------------|--------------|----|------|---------------------------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.08 ± 0.03 | GOPAL | 80 | DPWA | $\overline{K} N \rightarrow \overline{K} N$ | |

| $(\Gamma_I\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\overline{\mathcal{K}} 	o \Sigma(2070) 	o \Sigma\pi$ | | | | | | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|-----------------------------------------------------------------------------------------------------|---------------|--------------|-----|------|------------------------|-------------------------------------------|
| | VALUE | DO CUMENT ID | | TECN | COMMENT | |
| | +0.104 | KANE | 72 | DPWA | $K^- \rho \rightarrow$ | $\Sigma \pi$ |
| | ⊥ 0 12 + 0 02 | BERTHON | 70B | DΡWΔ | $K^- n \rightarrow$ | Σπ |

Σ(2070) REFERENCES

| GOPAL | 80 | Toronto Conf. 159 | G.P. Gopal | (RHEL) IJP |
|---------|------|-------------------|-----------------|---------------------|
| KANE | 74 | LBL-2452 | D.F. Kane | `(LBL) |
| KANE | 72 | PR D5 1583 | D.F.J. Kane | (LBL) |
| BERTHON | 70 B | NP B24 417 | A Berthon et al | (CDEE RHEL SACL)LIP |



 $I(J^P) = 1(\frac{3}{2}^+)$ Status: **

OMITTED FROM SUMMARY TABLE

Suggested by some but not all partial-wave analyses across this re-

| 7 | (2080) | MASS |
|---|--------|------|

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------|---------------------|----|------|-----------------------------------------------------------|
| ≈ 2080 OUR ESTIMATE | | | | |
| 2091 ± 7 | ¹ CORDEN | 76 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 2070 to 2120 | DEBELLEFON | 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 2120±40 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 1)}$ |
| 2140±40 | BAILLON | 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 2)}$ |
| 2082± 4 | COX | 70 | DPWA | See CORDEN 76 |
| 2070 ± 30 | LITCHFIELD | 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |
| | | | | |

Baryon Particle Listings $\Sigma(2080)$, $\Sigma(2100)$, $\Sigma(2250)$

Σ(2080) WIDTH

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|--------------|---------------|------|-----------------------------------------------------------|
| 186±48 | 1 CORDEN 76 | DPWA | $K^- n \rightarrow \Lambda \pi^-$ |
| 100 | DEBELLEFON 76 | IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| 240±50 | BAILLON 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 1)}$ |
| 200 ± 5 0 | BAILLON 75 | IPWA | $\overline{K} N \rightarrow \Lambda \pi \text{ (sol. 2)}$ |
| 87±20 | COX 70 | DPWA | See CORDEN 76 |
| 250 ± 40 | LITCHFIELD 70 | DPWA | $K^- N \rightarrow \Lambda \pi$ |

Σ(2080) DECAY MODES

| | Mode |
|----------------------------------|------------------------------|
| Γ ₁ Γ ₂ | $N\overline{K}$ $\Lambda\pi$ |

Σ(2080) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N\overline{K} \rightarrow VALUE}$ | $\Sigma(2080) \rightarrow \Lambda \pi$ | TECN | $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$ |
|----------------------------------------------------------------------------------------------------------|----------------------------------------|---------|---------------------------------------------------------------------|
| -0.10 ± 0.03 | | | $K^- n \rightarrow \Lambda \pi^-$ |
| -0.10 | DEBELLEFON | 76 IPWA | $K^- p \rightarrow \Lambda \pi^0$ |
| -0.13 ± 0.04 | BAILLON | 75 IPWA | $\overline{K} {\it N} ightarrow {\it \Lambda} \pi$ (sol. 1 and |
| -0.16 ± 0.03 | COX | 70 DPWA | 2) See CORDEN 76 |
| -0.10 ± 0.03 -0.09 ± 0.03 | | | $K^- N \rightarrow \Lambda \pi$ |

Σ(2080) FOOTNOTES

Σ(2080) REFERENCES

| CORDEN | 76 | NP B104 382 | M.J. Corden <i>et al.</i> | (BIRM) IJP |
|-------------|----|-------------|-------------------------------|------------------------------|
| DEBELLEFON | 76 | NP B109 129 | A. de Bellefon, A. Berthon | (CDEF) IJP |
| Also | 75 | NP B90 1 | A. de Bellefon <i>et al.</i> | (CDEF, SACL) IJP |
| BAILLON | | NP B94 39 | P.H. Baillon, P.J. Litchfield | (CERN, RHEL) IJP |
| COX | 70 | NP B19 61 | G.F. Cox <i>et al.</i> | (BIRM, EDIN, GLAS, LOIC) IJP |
| LIT CHFIELD | 70 | NP B22 269 | P.J. Litchfield | (RHEL) IJP |

 $\Sigma(2100) \ 7/2^-$

$$I(J^P) = 1(\frac{7}{2})$$
 Status: *

 $(\Gamma_1\Gamma_2)^{\frac{1}{2}}/\Gamma$

OMITTED FROM SUMMARY TABLE

 $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma(2100) \to \Lambda \pi$

| $\Sigma(2100)$ | MASS |
|----------------|------|
|----------------|------|

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|---------------------|--------------|------|--------------------------------------|
| ≈ 2100 OUR ESTIMATE | | | ^ |
| 2060 ± 20 | BARBARO 70 | DPWA | $K^- \rho \rightarrow \Lambda \pi^0$ |
| 2120±30 | BARBARO 70 | DPWA | $K^- p \rightarrow \Sigma \pi$ |

Σ(2100) WIDTH

| VALUE (MeV) DOCUMENT ID TECN COMMENT | |
|-------------------------------------------------------------------------------------------|--|
| 70 \pm 30 BARBARO 70 DPWA $K^-p\to\Lambda$ 135 \pm 30 BARBARO 70 DPWA $K^-p\to\Sigma$ | |

Σ (2100) DECAY MODES

| | Mode |
|------------|--------------|
| Г | NK |
| Γ_2 | $\Lambda\pi$ |
| Γ_3 | $\Sigma \pi$ |

Σ (2100) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| VALUE | DO CUMENT ID | TECN COMMENT |
|----------------------------------------------------------------------------------------------------|---------------------------------------|--------------------------------------------------|
| -0.07 ± 0.02 | BARBARO 70 | DPWA $K^- ho ightarrow \Lambda \pi^0$ |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \rightarrow$ | $\Sigma(2100) \rightarrow \Sigma \pi$ | (Γ ₁ Γ ₃) ^½ /Γ |
| VALUE | DO CUMENT ID | TECN COMMENT |
| $+0.13\pm0.02$ | BARBARO 70 | DPWA $K^-p \rightarrow \Sigma \pi$ |

Σ(2100) REFERENCES

BARBARO-... 70 Duke Conf. 173 A. Barbaro-Galtieri (LRL) JJP Hyperon Resonances, 1970

Σ (2250)

$$I(J^P) = 1(??)$$
 Status: ***

Results from partial-wave analyses are too weak to warrant separating them from the production and cross-section experiments. LASINSKI 71 in $\overline{K}N$ using a Pomeron + resonances model, and DEBELLEFON 76, DEBELLEFON 77, and DEBELLEFON 78 in energy-dependent partial-wave analyses of $\overline{K}N \to \Lambda\pi$, $\Sigma\pi$, and $N\overline{K}$, respectively, suggest two resonances around this mass.

Σ(2250) MASS

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
|------------------------------------|-------------------|---------|-----------|----------------------------------------|--|
| 2210 to 2280 (≈ 2250) OUR ESTIMATE | | | | | |
| 2270 ± 50 | DEBELLEFON | 78 | DPWA | D ₅ wave | |
| 2210 ± 30 | DEBELLEFON | 78 | DPWA | G ₉ wave | |
| 2275 ± 20 | DEBELLEFON | 77 | DPWA | D ₅ wave | |
| 2215 ± 20 | DEBELLEFON | | | Gg wave | |
| 2300 ± 30 | DEBELLEFON | 75B | HBC | $K^- \rho \rightarrow \Xi^{*0} K^0$ | |
| $2251 + 30 \\ -20$ | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0, F_5$ | |
| 2280 ± 14 | AGUILAR | 70B | HBC | K-p 3.9, 4.6 GeV/c | |
| 2237 ± 11 | BRICMAN | 70 | CNTR | Total, charge exchange | |
| 2255 ± 10 | COOL | 70 | CNTR | K^-p , K^-d total | |
| 2250 ± 7 | BUGG | 68 | CNTR | K^-p , K^-d total | |
| | lata for averages | , fits, | limits, e | etc. • • • | |
| 2260 | DEBELLEFON | 76 | IPWA | D ₅ wave | |
| 2215 | DEBELLEFON | 76 | IPWA | G _q wave | |
| 2250 ± 20 | LU | 70 | CNTR | $\gamma p \rightarrow K^+ Y^*$ | |
| 2245 | BLANPIED | 65 | CNTR | $\gamma p \rightarrow K^+ Y^*$ | |
| 2299± 6 | ВОСК | 65 | HBC | <u>p</u> p 5.7 GeV/c | |

Σ(2250) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------------|---------|-----------|-----------------------------------------------|
| 60 to 150 (≈ 100) OUR ESTIMAT | E | | | |
| 120±40 | DEBELLEFON | 78 | DPWA | D ₅ wave |
| 80±20 | DEBELLEFON | 78 | DPWA | G ₉ wave |
| 70 ± 20 | DEBELLEFON | 77 | DPWA | D ₅ wave |
| 60±20 | DEBELLEFON | 77 | DPWA | G ₉ wave |
| 130±20 | DEBELLEFON | 75B | | $\kappa^- \rho \rightarrow \Xi^{*0} \kappa^0$ |
| 192 ± 30 | VANHORN | 75 | DPWA | $K^- p \rightarrow \Lambda \pi^0$, F_5 |
| 100 ± 20 | AGUILAR | 70B | HBC | K [−] p 3.9, 4.6 GeV/c |
| 164±50 | BRICMAN | 70 | CNTR | Total, charge exchange |
| 230 ± 20 | BUGG | 68 | CNTR | K^-p , K^-d total |
| ullet $ullet$ We do not use the following of | lata for averages | , fits, | limits, e | etc. • • • |
| 100 | DEBELLEFON | 76 | IPWA | D ₅ wave |
| 140 | DEBELLEFON | 76 | IPWA | G ₉ wave |
| 170 | COOL | 70 | CNTR | K^-p , K^-d total |
| 125 | LU | 70 | CNTR | $\gamma p \rightarrow K^+ Y^*$ |
| 150 | BLANPIED | 65 | CNTR | $\gamma p \rightarrow K^+ Y^*$ |
| $21 + 17 \\ -21$ | воск | 65 | нвс | $\overline{p}p$ 5.7 GeV/ c |

Σ(2250) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|--------------------------|------------------------------|
| Γ_1 | NK | <10 % |
| Γ_2 | $\Lambda\pi$ | seen |
| Γ_3 | $\Sigma \pi$ | seen |
| Γ_4 | $N\overline{K}\pi$ | |
| Γ ₄ Γ ₅ | <i>Ξ</i> (1530) <i>K</i> | |

The above branching fractions are our estimates, not fits or averages.

Σ(2250) BRANCHING RATIOS

See "Sign conventions for resonance couplings" in the Note on \varLambda and \varSigma Resonances.

| $\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
|--------------------------------------------------------------------|--------------------|----------|-----------|---------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| <0.1 OUR ESTIMATE | | | | | |
| 0.08 ± 0.02 | DEBELLEFO | N 78 | DPWA | D ₅ wave | |
| 0.02 ± 0.01 | DEBELLEFO | N 78 | DPWA | G ₉ wave | |
| $(J+\frac{1}{2})\times\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | | Γ_1/Γ |
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| ullet $ullet$ We do not use the following | ng data for averag | es, fits | , limits, | etc. • • • | |
| 0.16 ± 0.12 | BRICMAN | 70 | CNTR | Total, charge e | xchange |
| 0.42 | COOL | 70 | CNTR | K^-p , K^-d to | tal |
| 0.47 | BUGG | 68 | CNTR | | |
| | | | | | |

 $^{^{1}\,\}mathrm{Preferred}$ solution 3; see CORDEN 76 for other possibilities, including a D_{15} at this mass.

Σ (2250), Σ (2455) Bumps, Σ (2620) Bumps, Σ (3000) Bumps

 Σ (3000) DECAY MODES

Σ(3000) REFERENCES

R. Ehrlich, W. Selove, H. Yuta

(PENN)I

Mode

ΝK

 $\Lambda\pi$

66 PR 152 1194

 Γ_1

 Γ_2

EHRLICH

| $(\Gamma_i \Gamma_f)^{\frac{1}{2}}/\Gamma_{\text{total}} \text{ in } N\overline{K} \to \Sigma$ | $2250) \rightarrow \Lambda \pi \qquad \qquad (\Gamma_1 \Gamma_2)^{\frac{1}{2}} / \Gamma$ DOCUMENT ID TECN COMMENT | $oldsymbol{arSigma}$ (2455) FOOTNOTES 1 Fit of total cross section given by BRICMAN 70 is poor in this region. | |
|---------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------------------|
| -0.16 ± 0.03 | VANHORN 75 DPWA $K^- p ightarrow \varLambda \pi^0$, F_5 wave | Σ (2455) REFERENCES | |
| | g data for averages, fits, limits, etc. ● ● | Z (2433) KEI EKENCES | |
| + 0.11 - 0.10 | DEBELLEFON 76 IPWA D_5 wave DEBELLEFON 76 IPWA G_9 wave | | BNL)I BNL) |
| -0.10 -0.18 | DEBELLEFON 76 IPWA G_9 wave BARBARO 70 DPWA $K^- \rho \to \Lambda \pi^0$, G_9 wave | BRICMAN 70 PL 31B 152 C. Bricman <i>et al.</i> (CERN, CAEN, ŠA BUGG 68 PR 168 1466 D.V. Bugg <i>et al.</i> (RHEL, BIRM, CA | ACL) |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ | 2250) $\rightarrow \Sigma \pi$ DOCUMENT ID TECN COMMENT ($\Gamma_1 \Gamma_3$) $\frac{1}{2} / \Gamma$ | Σ (2620) Bumps $I(J^P) = 1(??)$ Status: *> | * |
| $+0.06\pm0.02$ | DEBELLEFON 77 DPWA D ₅ wave | Z(2020) Bumps | • |
| -0.03 ± 0.02 + 0.07 | DEBELLEFON 77 DPWA G ₉ wave | OMITTED FROM SUMMARY TABLE | |
| + 0.07 | BARBARO 70 DPWA $K^-p \rightarrow \Sigma \pi$, G_9 wave | OMITTED THOM SOMMATIC INDEE | |
| $\Gamma(N\overline{K})/\Gamma(\Sigma\pi)$ | Γ_1/Γ_3 | Σ(2620) MASS | |
| VALUE | DOCUMENT ID TECN COMMENT | VALUE (MeV) DOCUMENT ID TECN COMMENT | |
| <0.18 | g data for averages, fits, limits, etc. • • • BARNES 69 HBC 1 standard dev. limit | ≈ 2620 OUR ESTIMATE | |
| V.10 | BARNES 69 ABC 1 Stalldard GeV. Hillit | 2542 \pm 22 DIBIANCA 75 DBC $K^-N \rightarrow \Xi K \pi$ | |
| $\Gamma(\Lambda\pi)/\Gamma(\Sigma\pi)$ | Γ_2/Γ_3 | 2620 ± 15 ABRAMS 70 CNTR K^-p , K^-d total | al |
| • • • We do not use the followin | DOCUMENT ID TECN COMMENT g data for averages, fits, limits, etc. • • • | Σ(2620) WIDTH | |
| < 0.18 | BARNES 69 HBC 1 standard dev. limit | | |
| 1/ | 1/. | VALUE (MeV) DOCUMENT ID TECN COMMENT | |
| $(\Gamma_i \Gamma_f)^{\frac{1}{2}} / \Gamma_{\text{total}} \text{ in } N \overline{K} \to \Sigma$ | | 221 \pm 81 DIBIANCA 75 DBC $K^-N \rightarrow \Xi K \pi$ 175 ABRAMS 70 CNTR K^-p , K^-d total | |
| 0.18±0.04 | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | | |
| | | Σ (2620) DECAY MODES | |
| | (2250) FOOTNOTES | Mode | |
| * Seen in the (initial and final s | tate) $D_{f 5}$ wave. Isospin not determined. | $\overline{\Gamma_1 N \overline{K}}$ | |
| Σ | (2250) REFERENCES | Σ(2620) BRANCHING RATIOS | |
| DEBELLEFON 78 NC 42A 403 DEBELLEFON 77 NC 37A 175 | A. de Bellefon et al. (CDEF, SACL) IJP A. de Bellefon et al. (CDEF, SACL) IJP | | |
| DEBELLEFON 76 NP B109 129 | A. de Bellefon, A. Berthon (CDEF) IJP | $(J+\frac{1}{2})\times\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | Γ_1/Γ |
| Also NP B 90 1 DEBELLEFON 75B NC 28A 289 | A. de Bellefon <i>et al.</i> (CDEF, SACL) IJP A. de Bellefon <i>et al.</i> (CDEF, SACL) | VALUE <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> | |
| VANHORN 75 NP B87 145 Also NP B87 157 | A.J. van Horn (LBL) IJP A.J. van Horn (LBL) IJP | 0.32 ABRAMS 70 CNTR K^-p , K^-d tota 0.36 \pm 0.12 BRICMAN 70 CNTR Total, charge exc | |
| LASINSKI 71 NP B29 125 AGUILAR 70B PRL 25 58 | T.A. Lasinski (EFI) IJP M. Aguilar-Benitez <i>et al.</i> (BNL, SYRA) | 0.30±0.12 BINCIMAIN 70 CIVITY TOTAL, CHANGE EXC | change |
| BARBARO 70 Duke Conf. 173 Hyperon Resonances, 1970 | A. Barbaro-Galtieri (LRL) IJP | Σ (2620) REFERENCES | |
| BRICMAN 70 PL 31B 152 COOL 70 PR D1 1887 | C. Bricman et al. (CERN, CAEN, SACL) R.L. Cool et al. (BNL) I | DIBIANCA 75 NP B98 137 F.A. Dibianca, R.J. Endorf (CI | MU) |
| Also PRL 16 1228 LU 70 PR D2 1846 | R.L. Cool et al. (BNL) I D.C. Lu et al. (YALE) | ABRAMS 70 PR D1 1917 R.J. Abrams et al. (B | BNL)I BNL) |
| BARNES 69 PRL 22 479 BUGG 68 PR 168 1466 | V.E. Barnes et al. (BNL, SYRA) D.V. Bugg et al. (RHEL, BIRM, CAVE) I | BRICMAN 70 PL 31B 152 C. Bricman et al. (CERN, CAEN, SA | |
| BLANPIED 65 PRL 14 741 BOCK 65 PL 17 166 | W.A. Blanpied et al. (YALE, CEA) | | |
| DOCK 00 PE 1/ 100 | R.K. Bock et al. (ČERN, SACL) | Σ (3000) Bumps $I(J^P) = 1(??)$ Status: * | |
| E(0.455) D | $I(J^P) = 1(??)$ Status: ** | 2 (3000) Dullips | |
| Σ (2455) Bump | $I(J^P) = 1(?^\ell) \text{Status: } **$ | OMITTED FROM SUMMARY TABLE | |
| OMITTED EDOM CURANA | DV TABLE | Seen as an enhancement in $\Lambda\pi$ and \overline{K} N invariant mass spectra and | |
| OMITTED FROM SUMMA | .RY TABLE ht evidence for Y^st states in this mass region | in the missing mass of neutrals recoiling against a κ^0 . | |
| | $\rightarrow K^+ X$ — see GREENBERG 68. | Σ(3000) MASS | |
| | Σ(2455) MASS | , , | |
| | = (= 150) 111/150 | VALUE (MeV) <u>DOCUMENT ID</u> <u>TECN CHG COMMENT</u> ≈ 3000 OUR ESTIMATE | |
| VALUE (MeV) ≈ 2455 OUR ESTIMATE | DOCUMENT ID TECN COMMENT | 3000 COR ESTIMATE 3000 EHRLICH 66 HBC 0 $\pi^- p$ 7.91 | GeV/c |
| ≈ 2400 UUK ESIIMAIE | ADDAMS 70 CNTD K- p K- d total | | |

| Σ(2455) | DECAY | MODES |
|---------|-------|-------|
| | | |

ABRAMS

Σ(2455) WIDTH

DOCUMENT ID

ABRAMS

BUGG

BUGG

70 CNTR K^-p , K^-d total

TECN COMMENT

70 CNTR 68 CNTR

CNTR K^-p , K^-d total

CNTR K^-p , K^-d total

 $2455 \pm \! 10$

 2455 ± 7

VALUE (MeV)

Mode $N\overline{K}$

140 100±20

Σ (2455) BRANCHING RATIOS

| $(J+\frac{1}{2})\times\Gamma(N\overline{K})/\Gamma_{\text{total}}$ | | | | Г ₁ /Г |
|--------------------------------------------------------------------|----------------------|----|------|------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.39 | ABRAMS | 70 | CNTR | K^-p , K^-d total |
| 0.05 ± 0.05 | ¹ BRICMAN | 70 | CNTR | Total, charge exchange |
| 0.3 | BUGG | 68 | CNTR | |
| | | | | |

Baryon Particle Listings Σ (3170) Bumps

$\Sigma(3170)$ Bumps

 $I(J^P) = 1(??)$ Status: *

OMITTED FROM SUMMARY TABLE

Seen by AMIRZADEH 79 as a narrow 6.5-standard-deviation enhancement in the reaction $K^-p \to Y^{*+}\pi^-$ using data from independent high statistics bubble chamber experiments at 8.25 and 6.5 GeV/c. The dominant decay modes are multibody, multistrange final states and the production is via isospin-3/2 baryon exchange. Isospin 1 is favored.

Not seen in a K^-p experiment in LASS at 11 GeV/c (ASTON 85B).

Σ (3170) MASS (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-----------------|------|--------------|------|----------------------------------|
| ≈ 3170 OUR ESTI | MATE | | | |
| $3170{\pm}5$ | 35 | AMIRZADEH 79 | HBC | $K^- p \rightarrow Y^{*+} \pi^-$ |

Σ (3170) WIDTH (PRODUCTION EXPERIMENTS)

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------|------|---------------------------|------|--------------------------------|
| <20 | 35 | ¹ AMIRZADEH 79 | нвс | $K^-p \rightarrow Y^{*+}\pi^-$ |

Σ (3170) DECAY MODES (PRODUCTION EXPERIMENTS)

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|---------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda K \overline{K} \pi$'s | seen |
| Γ_2 | $\Sigma K\overline{K}\pi$'s | seen |
| Γ ₃ | Ξ K π 's | seen |

Σ(3170) BRANCHING RATIOS (PRODUCTION EXPERIMENTS)

| $\Gamma(\Lambda K \overline{K} \pi 's)/\Gamma_{total}$ | | | Γ_1/Γ |
|---------------------------------------------------------|--------------|--------|----------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| seen | AMIRZADEH 7 | 79 HBC | $K^- p \rightarrow Y^{*+} \pi^-$ |
| $\Gamma(\Sigma K \overline{K} \pi 's) / \Gamma_{total}$ | | | Γ_2/Γ |
| VALUE | DO CUMENT ID | TECN | COMMENT |
| seen | AMIRZADEH 7 | 79 HBC | $K^- p \rightarrow Y^{*+} \pi^-$ |
| $\Gamma(\Xi K \pi 's)/\Gamma_{total}$ | | | Г ₃ /Г |
| VALUE | DO CUMENT ID | TECN | COMMENT |
| seen | AMIRZADEH 7 | 79 HBC | $K^- p \rightarrow Y^{*+} \pi^-$ |

Σ (3170) FOOTNOTES (PRODUCTION EXPERIMENTS)

Σ (3170) REFERENCES (PRODUCTION EXPERIMENTS)

| ASTON | 85 B | PR D32 2270 | D. Aston et al. | (SLAC, CARL, CNRC, CINC) |
|-------------|------|-------------------|---------------------|--------------------------|
| AM IR ZADEH | 79 | PL 89B 125 | J. Amirzadeh et al. | (BIRM, CERN, GLAS+)I |
| A Iso | | Toronto Conf. 263 | J.B. Kinson et al. | (BIRM, CERN, GLAS+)I |
| | | | | |

¹ Observed width consistent with experimental resolution.

E BARYONS (S=-2, I=1/2)

 $\Xi^0 = uss$, $\Xi^- = dss$



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

The parity has not actually been measured, but + is of course ex-

■ MASS

The fit uses the Ξ^0 , Ξ^- , and $\overline{\Xi}^+$ masses and the $\Xi^--\Xi^0$ mass difference. It assumes that the Ξ^- and $\overline{\Xi}^+$ masses are the same.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN COMMENT | |
|-----------------------------|------------|-------------------|----------|--------------------|-----|
| 1314.86 ± 0.20 OUR FIT | Ī | | | · · | |
| $1314.82 \pm 0.06 \pm 0.20$ | 3120 | FA NT I | 00 | NA48 p Be, 450 | GeV |
| • • • We do not use th | e followin | g data for averag | es, fits | limits, etc. • • • | |
| 1315.2 ± 0.92 | 49 | WILQUET | 72 | HLBC | |
| 1313.4 ±1.8 | 1 | PALMER | 68 | HBC | |

$m_{\Xi^-} - m_{\Xi^0}$

The fit uses the Ξ^0 , Ξ^- , and $\overline{\Xi}^+$ masses and the Ξ^- — Ξ^0 mass difference. It assumes that the Ξ^- and $\overline{\Xi}^+$ masses are the same.

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-------------------|-------------------|----------|-----------|-----------------|
| 6.85 ± 0.21 OUR F | iT. | | | | |
| 6.3 ±0.7 OUR A | VERAGE | | | | |
| 6.9 ± 2.2 | 29 | LONDON | 66 | HBC | |
| 6.1 ±0.9 | 88 | PJERROU | 65B | HBC | |
| 6.8 ± 1.6 | 23 | JAUNEAU | 63 | FBC | |
| ullet $ullet$ We do not | use the following | g data for averag | es, fits | , limits, | etc. • • • |
| 6.1 ± 1.6 | 45 | CARMONY | 64B | нвс | See PJERROU 65B |

≡⁰ MEAN LIFE

| VALUE (10 ⁻¹⁰ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|--------------|---------------------|---------|-----------|---------------------------|
| 2.90±0.09 OUR AVE | RAGE | | | | |
| $2.83 \!\pm\! 0.16$ | 6300 | $^{ m 1}$ ZECH | 77 | SPEC | Neutral hyperon beam |
| $2.88 + 0.21 \\ -0.19$ | 65 2 | BALTAY | 74 | нвс | 1.75 GeV/ $c\ K^-p$ |
| $2.90^{+0.32}_{-0.27}$ | 157 | ² MAYEUR | 72 | HLBC | $2.1~{ m GeV}/c~{ m K}^-$ |
| $3.07 + 0.22 \\ -0.20$ | 340 | DAUBER | 69 | нвс | |
| $3.0\ \pm0.5$ | 80 | PJERROU | 65B | нвс | |
| $2.5 \begin{array}{c} +0.4 \\ -0.3 \end{array}$ | 101 | HUBBARD | 64 | нвс | |
| $3.9 \begin{array}{c} +1.4 \\ -0.8 \end{array}$ | 24 | JAUNEAU | 63 | FBC | |
| • • • We do not use | the followin | g data for average | s, fits | , limits, | etc. • • • |
| $\begin{array}{cc} 3.5 & +1.0 \\ -0.8 \end{array}$ | 45 | CARMONY | 64B | нвс | See PJERROU 65B |

 $^{^1\,{\}rm The}$ ZECH 77 result is $\tau_{\,\Xi^0}\,=\,[2.77-(\tau_{\,\Lambda}-2.69)]\,\times 10^{-10}$ s, in which we use $\tau_{\,\Lambda}\,=\,$ 2.63×10^{-10} s. 2 The MAYEUR 72 value is modified by the erratum.

≡⁰ MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the A Listings.

| VALUE (µN) | EVTS | DO CUMENT I | D | TECN |
|--------------------|---------|-------------|----|------|
| -1.250 ± 0.014 OUR | AVERAGE | | | |
| -1.253 ± 0.014 | 270k | COX | 81 | SPEC |
| -1.20 ± 0.06 | 42k | BUNCE | 79 | SPEC |

=⁰ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|------------|------------------------------------|---------------------------------------------------|--------------------|
| Γ_1 | $\Lambda \pi^0$ | (99.525±0.012) | % |
| | $\Lambda\gamma$ | (1.17 ± 0.07) | × 10 ⁻³ |
| Γ_3 | $\Lambda e^+ e^-$ | (7.6 ±0.6) | < 10 ^{−6} |
| Γ_4 | $\Sigma^0\gamma$ | (3.33 ± 0.10) | × 10 ⁻³ |
| Γ_5 | $\Sigma^+ e^- \overline{ u}_e$ | (2.53 ± 0.08) | < 10 ⁻⁴ |
| Γ_6 | $\Sigma^+\mu^-\overline{ u}_{\mu}$ | $(4.6 \begin{array}{c} +1.8 \\ -1.4 \end{array})$ | × 10 ⁻⁶ |

$\Delta S = \Delta Q$ (SQ) violating modes or $\Delta S = 2$ forbidden (S2) modes

| Γ ₇ | $\Sigma^-e^+ u_e$ | SQ | < 9 | $\times 10^{-4}$ | 90% |
|----------------|-----------------------------|----|-------|------------------|-----|
| Γ ₈ | $\Sigma^-\mu^+ u_\mu$ | SQ | < 9 | $\times 10^{-4}$ | 90% |
| Г9 | $p\pi^-$ | 52 | < 8 | $\times 10^{-6}$ | 90% |
| Γ_{10} | $pe^{-}\overline{\nu}_{e}$ | 52 | < 1.3 | $\times 10^{-3}$ | |
| Γ_{11} | $p\mu^-\overline{ u}_{\mu}$ | 52 | < 1.3 | $\times 10^{-3}$ | |
| | | | | | |

CONSTRAINED FIT INFORMATION

An overall fit to 3 branching ratios uses 9 measurements and one constraint to determine 4 parameters. The overall fit has a χ^2 = 4.6 for 6 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle \! / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv$ $\Gamma_i/\Gamma_{
m total}$. The fit constrains the x_i whose labels appear in this array to sum to

$$\begin{array}{c|cccc}
x_2 & -57 & & \\
x_4 & -82 & 0 & \\
x_5 & -7 & 0 & 0 \\
\hline
& x_1 & x_2 & x_4
\end{array}$$

=0 BRANCHING RATIOS

| $\Gamma(\Lambda\gamma)/\Gamma(\Lambda\pi^0)$ | | | | | | Γ_2/Γ_1 |
|----------------------------------------------|------------|--------------------|------|-------|--------------------|---------------------|
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 1.17±0.07 OUR FIT | | | | | | |
| 1.17±0.07 OUR AVE | RAGE | | | | | |
| $1.17 \pm 0.05 \pm 0.06$ | 672 | ³ LAI | 04A | NA 48 | p Be, 450 GeV | |
| $1.91 \pm 0.34 \pm 0.19$ | 31 | ⁴ FANTI | 00 | NA 48 | p Be, 450 GeV | |
| $1.06 \pm 0.12 \pm 0.11$ | 116 | JAMES | 90 | SPEC | FNAL hyperons | |
| 3 LAT 044 used our | 2002 value | of 99.5% for the | =0 _ | λ 1π0 | branching fraction | n to get |

 $\Gamma(\Xi^0 \to \Lambda \pi)/\Gamma_{\rm total} = (1.16 \pm 0.05 \pm 0.06) \times 10^{-3}$. We adjust slightly to go back to what was directly measured. 4 FANTI 00 used our 1998 value of 99.5% for the $\Xi^0 \to \Lambda \pi^0$ branching fraction to get

 $\Gamma(=0-\Lambda\gamma)/\Gamma_{\rm total}=(1.90\pm0.34\pm0.19)\times 10^{-3}$. We adjust slightly to go back to what was directly measured.

$\Gamma(\Lambda e^+ e^-)/\Gamma_{\text{total}}$ Γ_3/Γ

| VALUE (units 10 ⁻⁶) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|------------|-------------|-----|------|---------------|
| 7.6±0.4±0.5 | 397 ± 21 | 5 BATLEY | 07c | NA48 | p Be, 400 GeV |

⁵ This BATLEY 07c result is consistent with internal bremsstrahlung.

$\Gamma(\Sigma^0 \gamma)/\Gamma(\Lambda \pi^0)$ Γ_4/Γ_1 VALUE (units 10⁻³) EVTS DOCUMENT ID TECN COMMENT

| 3.35 ± 0.10 OUR FIT 3.35 ± 0.10 OUR AVE | | | | | |
|--------------------------------------------|---------|---------------------|----------|------|--------------------|
| $3.34 \pm 0.05 \pm 0.09$ | 4 0 4 5 | ALAVI-HAF | RATI 01c | KTEV | p nucleus, 800 GeV |
| $3.16 \pm 0.76 \pm 0.32$ | 17 | ⁶ FA NTI | 00 | NA48 | p Be, 450 GeV |
| $3.56 \pm 0.42 \pm 0.10$ | 85 | TEIGE | 89 | SPEC | FNAL hyperons |

 6 FANTI 00 used our 1998 value of 99.5% for the $\it \Xi^0 \rightarrow \Lambda \pi^0$ branching fraction to get $\Gamma(\Xi^0\to\Sigma^0\gamma)/\Gamma_{\rm total}=(3.14\pm0.76\pm0.32)\times10^{-3}$. We adjust slightly to go back to what was directly measured.

$\Gamma(\Sigma^+ e^- \overline{\nu}_e) / \Gamma_{\text{total}}$ Γ_5/Γ

| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------|---------------|------------------------------------------------------------------|------|-------|--------------------|
| 2.53±0.08 OUR FIT | | | | | |
| 2.53±0.08 OUR AVE | RAGE | | | | |
| $2.51 \pm 0.03 \pm 0.09$ | 6101 | BATLEY | 07 | NA48 | p Be, 400 GeV |
| $2.55 \pm 0.14 \pm 0.10$ | 419 | ⁷ BATLEY | 07 | NA 48 | p Be, 400 GeV |
| $2.71 \pm 0.22 \pm 0.31$ | 176 | AFFOLDER | 99 | KTEV | p nucleus, 800 GeV |
| ⁷ This BATLEY 07 | result is for | $\overline{\Xi}{}^0 \rightarrow \overline{\Sigma}{}^- e^+ \nu_e$ | even | ts. | |

| $\Gamma(\Sigma^+\mu^-\overline{\nu}_\mu)/\Gamma(\Sigma^+$ | $e^-\overline{\nu}_e)$ | | | | | Γ_6/Γ_5 |
|-------------------------------------------------------------|------------------------|--------------|----|------|---------------|---------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| $0.018 ^{+ 0.007}_{- 0.005} \pm 0.002$ | 9 | ABOUZAID | 05 | KTEV | p nucleus 800 | GeV |
| $\Gamma(\Sigma^+\mu^-\overline{\nu}_\mu)/\Gamma(\Lambda\pi$ | .0) | | | | | Γ_6/Γ_1 |

| , , | μ), (~ , | , | | | | | ٠, . |
|-----------------|-----------------------|----------|-------------------|------------|---------|-----------------|-------|
| VALUE (units 10 | 1 ⁻³) CL% | EVTS | DO CUMENT IL |) | TECN | COMMENT | |
| • • • We do | not use the | followin | g data for averag | ges, fits, | limits, | etc. • • • | |
| <1.1 | 90 | 0 | YEH | 74 | нвс | Effective denom | =2100 |
| ∠1 E | | | DALIDED | 60 | HD C | | |

| <1.5 <7 | DAUBER HUBBARD | HB C HB C | | |
|---------------------------------------------------------------------------------------------|-------------------|------------------|---------|---------------------|
| $\Gamma(\Sigma^- e^+ \nu_e) / \Gamma(\Lambda \pi^0)$ Test of $\Delta S = \Delta Q$ rule. | | | | Γ_7/Γ_1 |
| VALUE (units 10 ⁻³) CL% EVTS | DO CUMENT ID | TECN | COMMENT | |

74 HBC Effective denom.=2500 < 0.9 90 YEH • • • We do not use the following data for averages, fits, limits, etc. • • • < 1.5DAUBER 69 HBC <6 HUBBARD 66 HBC

 \equiv°

| $\Gamma(\Sigma^-\mu^+\nu_\mu)$ Test of Δ | /Γ(Λπ ^υ |) rula | | | | Γ_8/Γ_1 |
|-------------------------------------------------------------|-------------------------------------|-------------|--------------------|----------|-----------|---------------------------------|
| VALUE (units 10 ⁻³ | | | DO CUMENT ID | | TECN | COMMENT |
| <0.9 | 90 | 0 | YEH | 74 | нвс | Effective denom. = 2500 |
| • • • We do n | ot use the | followin | g data for average | es, fits | , limits, | etc. • • • |
| <1.5 | | | DAUBER | 69 | нвс | |
| <6 | | | HUBBARD | 66 | нвс | |
| $\Gamma(p\pi^-)/\Gamma(\Lambda$ | π^0) | | | | | Γ_9/Γ_1 |
| | | | der weak interact | ion. | TE 644 | COMMENT |
| VALUE (units 10-6 | | EVIS | DO CUMENT ID | | TECN | |
| < 8.2 | 90 | | WHITE | 05 | | ρ Cu, 800 GeV |
| • • • VVe do n | ot use the | followin | g data for average | es, fits | , limits, | etc. • • • |
| < 36 | 90 | | GEWENIGER | | SPEC | |
| <1800 | 90 | 0 | YEH | 74 | нвс | Effective denom.=1300 |
| < 900 | | | DAUBER | 69 | нвс | |
| < 5000 | | | HUBBARD | 66 | нвс | |
| $\Gamma(pe^{-}\overline{\nu}_{e})/\Gamma$ | $(\Lambda \pi^0)$ | in first o | der weak interact | ion | | Γ_{10}/Γ_{1} |
| $\Delta 3=2$. F VALUE (units 10^{-3} | | | DO CUMENT ID | | TECN | COMMENT |
| <1.3 | <u> </u> | <u> </u> | DAUBER | 69 | HBC | COMMENT |
| - | ot use the | followin | g data for average | | | etc. • • • |
| <3.4 | 90 | 0 | YEH | 74 | нвс | Effective denom.=670 |
| <6 | ,,, | · | HUBBARD | 66 | HBC | Eliccitive delionit.=070 |
| _0 | | | HODDARD | 00 | пьс | |
| $\Gamma(p\mu^-\overline{\nu}_{\mu})/\Gamma$ $\Delta S=2. F$ | (Λπ⁰) orbidden | in first-oi | der weak interact | ion. | | Γ ₁₁ /Γ ₁ |
| VALUE (units 10^{-3} | | | DO CUMENT ID | | TECN | COMMENT |
| <1.3 | | | DAUBER | 69 | нвс | · · |
| • • • We do no | ot use the | followin | g data for average | es, fits | , limits, | etc. • • • |
| < 3.5 | 90 | 0 | YEH | 74 | нвс | Effective denom. = 664 |
| <6 | = | - | HUBBARD | 66 | HBC | |

=0 DECAY PARAMETERS

See the "Note on Baryon Decay Parameters" in the neutron Listings.

$\alpha(\Xi^0) \alpha_-(\Lambda)$

| This is a product of the $\Xi^0 	o \Lambda \pi^0$ and $\Lambda 	o p \pi^-$ asymmetries. | | | | | | | |
|-----------------------------------------------------------------------------------------|------|--------------|-----|------|-------------------------|--|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| -0.261 ± 0.006 OUR AVERAGE | | | | | | | |
| $-0.276 \pm 0.001 \pm 0.035$ | 4 M | BATLEY | 10B | NA48 | p Be, 400 GeV | | |
| $-0.260 \pm 0.004 \pm 0.005$ | 300k | HANDLER | 82 | SPEC | FNAL hyperons | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | | |
| -0.317 ± 0.027 | 6075 | BUNCE | 78 | SPEC | FNAL hyperons | | |
| -0.35 ± 0.06 | 505 | BALTAY | 74 | HBC | K−p 1.75 GeV/c | | |
| -0.28 ± 0.06 | 739 | DAUBER | 69 | нвс | K^-p 1.7–2.6 GeV/ c | | |

α FOR $= 0 \rightarrow \Lambda \pi^0$

The above average, $\alpha(\Xi^0)\alpha_-(A)=-0.261\pm0.006$, divided by our current average $\alpha_-(A)=0.642\pm0.013$, gives the following value for $\alpha(\Xi^0)$.

<u>VALUE</u> −0.406 ± 0.013 OUR EVALUATION

| ϕ ANGLE FOR | $\Xi^0 \rightarrow \Lambda \pi^0$ | | | | (ta n $\phi=eta/\gamma$) |
|-----------------------------|-----------------------------------|---------------------|---------|-----------|----------------------------------|
| VALUE (°) | EVTS | DO CUMENT IL |) | TECN | COMMENT |
| 21 ± 12 OUR AV | /ERAGE | | | | |
| 16 ± 17 | 65 2 | BALTAY | 74 | HBC | 1.75 GeV/c K ⁻ p |
| 38 ± 19 | 739 | ⁸ DAUBER | 69 | HBC | |
| -8 ± 30 | 146 | ⁹ BERGE | 66 | HBC | |
| ⁸ DAUBER 69 u | ises $\alpha_{\Lambda} = 0.647$ | ± 0.020. | | | |
| ⁹ The errors hav | | d by 1.2 due to a | pproxin | nations u | sed for the $arXi$ polarization; |

RADIATIVE HYPERON DECAYS

Revised July 2011 by J.D. Jackson (LBNL).

The weak radiative decays of spin-1/2 hyperons, $B_i \to B_f \gamma$, yield information about matrix elements (form factors) similar to that gained from weak hadronic decays. For a polarized spin-1/2 hyperon decaying radiatively via a $\Delta Q = 0$, $\Delta S = 1$ transition, the angular distribution of the direction $\hat{\mathbf{p}}$ of the final spin-1/2 baryon in the hyperon rest frame is

$$\frac{dN}{d\Omega} = \frac{N}{4\pi} \left(1 + \alpha_{\gamma} \mathbf{P}_{i} \cdot \hat{\mathbf{p}} \right) . \tag{1}$$

Here \mathbf{P}_i is the polarization of the decaying hyperon, and α_{γ} is the asymmetry parameter. In terms of the form factors $F_1(q^2)$,

 $F_2(q^2)$, and $G(q^2)$ of the effective hadronic weak electromagnetic vertex,

$$F_1(q^2)\gamma_\lambda + iF_2(q^2)\sigma_{\lambda\mu}q^\mu + G(q^2)\gamma_\lambda\gamma_5$$
,

 α_{γ} is

$$\alpha_{\gamma} = \frac{2 \operatorname{Re}[G(0) F_M^*(0)]}{|G(0)|^2 + |F_M(0)|^2} , \qquad (2)$$

where $F_M = (m_i - m_f)[F_2 - F_1/(m_i + m_f)]$. If the decaying hyperon is unpolarized, the decay baryon has a longitudinal polarization given by $P_f = -\alpha_{\gamma}$ [1].

The angular distribution for the weak hadronic decay, $B_i \to B_f \pi$, has the same form as Eq. (1), but of course with a different asymmetry parameter, α_{π} . Now, however, if the decaying hyperon is unpolarized, the decay baryon has a longitudinal polarization given by $P_f = +\alpha_{\pi}$ [2,3]. The difference of sign is because the spins of the pion and photon are different.

 $\Xi^0 \to \Lambda \gamma \ decay$ —The radiative decay $\Xi^0 \to \Lambda \gamma$ of an unpolarized Ξ^0 uses the hadronic decay $\Lambda \to p\pi^-$ as the analyzer. As noted above, the longitudinal polarization of the Λ will be $P_{\Lambda} = -\alpha_{\Xi\Lambda\gamma}$. Let α_- be the $\Lambda \to p\pi^-$ asymmetry parameter and $\theta_{\Lambda p}$ be the angle, as seen in the Λ rest frame, between the Λ line of flight and the proton momentum. Then the hadronic version of Eq. (1) applied to the $\Lambda \to p\pi^-$ decay gives

$$\frac{dN}{d\cos\theta_{\Lambda p}} = \frac{N}{2} \left(1 - \alpha_{\Xi\Lambda\gamma} \alpha_{-} \cos\theta_{\Lambda p} \right) \tag{3}$$

for the angular distribution of the proton in the Λ frame. Our current value, from the CERN NA48/1 experiment [4], is $\alpha_{\Xi\Lambda\gamma} = -0.704 \pm 0.019 \pm 0.064$.

 $\Xi^0 \to \Sigma^0 \gamma$ decay—The asymmetry parameter here, $\alpha_{\Xi\Sigma\gamma}$, is measured by following the decay chain $\Xi^0 \to \Sigma^0 \gamma$, $\Sigma^0 \to$ $\Lambda \gamma$, $\Lambda \to p\pi^-$. Again, for an unpolarized Ξ^0 , the longitudinal polarization of the Σ^0 will be $P_{\Sigma} = -\alpha_{\Xi\Sigma\gamma}$. In the $\Sigma^0 \to$ $\Lambda \gamma$ decay, a parity-conserving magnetic-dipole transition, the polarization of the Σ^0 is transferred to the Λ , as may be seen as follows. Let $\theta_{\Sigma\Lambda}$ be the angle seen in the Σ^0 rest frame between the Σ^0 line of flight and the Λ momentum. For Σ^0 helicity +1/2, the probability amplitudes for positive and negative spin states of the Σ^0 along the Λ momentum are $\cos(\theta_{\Sigma\Lambda}/2)$ and $\sin(\theta_{\Sigma\Lambda}/2)$. Then the amplitude for a negative helicity photon and a negative helicity Λ is $\cos(\theta_{\Sigma\Lambda}/2)$, while the amplitude for positive helicities for the photon and Λ is $\sin(\theta_{\Sigma\Lambda}/2)$. For Σ^0 helicity -1/2, the amplitudes are interchanged. If the Σ^0 has longitudinal polarization P_{Σ} , the probabilities for Λ helicities $\pm 1/2$ are therefore

$$p(\pm 1/2) = \frac{1}{2}(1 \mp P_{\Sigma})\cos^{2}(\theta_{\Sigma\Lambda}/2) + \frac{1}{2}(1 \pm P_{\Sigma})\sin^{2}(\theta_{\Sigma\Lambda}/2), (4)$$

and the longitudinal polarization of the Λ is

$$P_{\Lambda} = -P_{\Sigma} \cos \theta_{\Sigma \Lambda} = +\alpha_{\Xi \Sigma \gamma} \cos \theta_{\Sigma \Lambda} . \tag{5}$$

Using Eq. (1) for the $\Lambda \to p\pi^-$ decay again, we get for the joint angular distribution of the $\Sigma^0 \to \Lambda \gamma$, $\Lambda \to p\pi^-$ chain,

$$\frac{d^2N}{d\cos\theta_{\Sigma\Lambda}\,d\cos\theta_{\Lambda p}} = \frac{N}{4}\left(1 + \alpha_{\Xi\Sigma\gamma}\cos\theta_{\Sigma\Lambda}\,\alpha_{-}\cos\theta_{\Lambda p}\right)\,. \eqno(6)$$

Our current average for $\alpha_{\Xi\Sigma\gamma}$ is -0.69 ± 0.06 [4,5].

References

- 1. R.E. Behrends, Phys. Rev. 111, 1691 (1958); see Eq. (7) or
- In ancient times, the signs of the asymmetry term in the angular distributions of radiative and hadronic decays of polarized hyperons were sometimes opposite. For roughly 50 years, however, the overwhelming convention has been to make them the same. The aim, not always achieved, is to remove ambiguities.
- For the definition of α_{π} , see the note on "Baryon Decay Parameters" in the Neutron Listings.
- J.R. Batley et al., Phys. Lett. **B693**, 241 (2010).
- A. Alavi-Harati et al., Phys. Rev. Lett. 86, 3239 (2001).

α FOR $\Xi^0 \rightarrow \Lambda \gamma$

See the note above on "Radiative Hyperon Decays."

| VALUE | EVTS | DO CUMENT I | D | TECN | COMMENT |
|------------------------------|----------|----------------------|------------|---------|----------------|
| $-0.704 \pm 0.019 \pm 0.064$ | 52k | ¹⁰ BATLEY | 10в | NA48 | p Be, 400 GeV |
| • • • We do not use th | e follow | ng data for avera | ges, fits, | limits, | etc. • • • |
| $-0.78 \pm 0.18 \pm 0.06$ | 672 | LAI | 04A | NA48 | See BATLEY 10B |
| -0.43 ± 0.44 | 87 | ¹¹ JAMES | 90 | SPEC | FNAL hyperons |
| 1.0 | | | | | |

 $^{10}\,\mathrm{BATLEY}$ 10B also measured the $\overline{\Xi}{}^0$ ightarrow $\overline{\Lambda}\gamma$ asymmetry to be -0.798 ± 0.064 (no systematic error given) with 4769 events.

 $^{11}\,\mathrm{The}$ sign has been changed; see the erratum, JAMES 02.

| α FOR $\Xi^0 \rightarrow \Lambda e^+$ | e ⁻ | | | | | |
|----------------------------------------------|----------------|-------------|-----|------|---------------|--|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT | |
| -0.8±0.2 | 397 ± 21 | 12 BATLEY | 07c | NA48 | p Be, 400 GeV | |

¹²This BATLEY 07c result is consistent with the asymmetry α for $\Xi^0 \to \Lambda \gamma$, as expected if the mechanism is internal bremsstrahlung.

$\alpha \text{ FOR } \Xi^0 \to \Sigma^0 \gamma$

See the note above on "Radiative Hyperon Decays."

| VALUE | EVTS | DO CUMENT I | D | TECN | COMMENT | |
|---------------------------|-----------|----------------------|------------|---------|--------------------|--|
| -0.69 ±0.06 OUR AV | ERAGE | | | | | |
| $-0.729\pm0.030\pm0.076$ | 15 k | ¹³ BATLEY | 10B | NA48 | p Be, 400 GeV | |
| $-0.63\ \pm0.08\ \pm0.05$ | 4045 | ALAVI-HAR | ATI01c | KTEV | p nucleus, 800 GeV | |
| • • • We do not use th | e followi | ng data for avera | ges, fits, | limits, | etc. • • • | |
| $+0.20 \pm 0.32 \pm 0.05$ | 85 | ¹⁴ TEIGE | 89 | SPEC | FNAL hyperons | |

 13 BATLEY 10B also measured the $\Xi^0 \to \overline{\Sigma}{}^0 \, \gamma$ asymmetry to be -0.786 ± 0.104 (no systematic error given) with 1404 events. 14 This result has been withdrawn, due to an error. See the erratum, TEIGE 02.

$g_1(0)/f_1(0)$ FOR $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$

| VALUE | EVTS | <u>DO CUMENT II</u> | כ | TECN | COMMENT | |
|--------------------------------|-------|-------------------------|---------|-------|--------------------|--|
| 1.21 ± 0.05 OUR AV | ERAGE | | | | | |
| $+1.20\pm0.04\pm0.03$ | 6520 | ¹⁵ BATLEY | 07 | NA 48 | p Be, 400 GeV | |
| $+1.32^{+0.21}_{-0.17}\pm0.05$ | 487 | ¹⁶ ALAVI-HAR | AT 01 | KTEV | p nucleus, 800 GeV | |

 $^{15}\,\mathrm{This}$ BATLEY 07 result uses our 2006 value of Vus from semileptonic kaon decays as

 10 ALAVI-HARATI 011 assumes here that the second-class current is zero and that the weak-magnetism term takes its exact SU(3) value.

$g_2(0)/f_1(0)$) FOR $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$

| ,, ,, | | • | | |
|----------------------------|------|---------------------|------|--------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| $-1.7^{+2.1}_{-2.0}\pm0.5$ | 487 | 17 ALAVI-HARATI 01ı | KTEV | p nucleus, 800 GeV |

 17 ALAVI-HARATI 01: thus assumes that $g_2=0$ in calculating g_1/f_1 , above.

$f_2(0)/f_1(0)$ FOR $\Xi^0 \rightarrow \Sigma^+ e^- \overline{\nu}_e$

| - \ // - \ / | | • | | |
|-----------------|------|------------------|------|--------------------|
| VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
| 2.0 ± 1.2 ± 0.5 | 487 | ALAVI-HARATI 01ı | KTEV | p nucleus, 800 GeV |

=0 REFERENCES

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| WHITE | 05 | PRL 94 101804 | C.G. White et al. | (FNAL HyperCP Collab.) |
| LAI | 04 A | PL B584 251 | A. Lai et al. | (CERN NA48 Collab.) |
| JAM ES | 02 | PRL 89 169901 (erratum |)C. James et al. | (MINN, MICH, WISC, RUTG) |
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| TEIGE | 89 | PRL 63 2717 | S. Teige et al. | (RUTG, MICH, MINN) |
| HANDLER | 82 | PR D25 639 | R. Handler et al. | (WISC, MICH, MINN+) |
| COX | 81 | PRL 46 877 | P.T. Cox et al. | (MICH, WISC, RUTG, MINN+) |
| BUNCE | 79 | PL 86B 386 | G.R.M. Bunce et al. | (BNL, MICH, RUTG+) |
| BUNCE | 78 | PR D18 633 | G.R.M. Bunce et al. | (WISC, MICH, RUTG) |
| ZECH | 77 | NP B124 413 | G. Zech et al. | (SIEG, CERN, DORT, HEIDH) |
| GEWENIGER | 75 | PL 57B 193 | C. Geweniger et al. | (CERN, HEIDH) |
| BALTAY | 74 | PR D9 49 | C. Baltay et al. | `(COLU, BING)J |
| YEH | 74 | PR D10 3545 | N. Yeh et al. | (BING, COLU) |
| MAYEUR | 72 | NP B47 333 | C. Mayeur et al. | (BRUX, CERN, TUFTS, LOUC) |
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| WILQUET | 72 | PL 42B 372 | G. Wilquet et al. | (BRUX, CERN, TUFTS+) |
| DAUBER | 69 | PR 179 1262 | P.M. Dauber et al. | (LRL) |
| PALMER | 68 | PL 26B 323 | R.B. Palmer et al. | (BNL, SÝRA) |
| BERGE | 66 | PR 147 945 | J.P. Berge et al. | (LRL) |
| HUBBARD | 66 | Thesis UCRL 11510 | J.R. Hubbard | (LRL) |
| LONDON | 66 | PR 143 1034 | G.W. London et al. | (BNL, SÝRA) |
| PJERROU | 65 B | PRL 14 275 | G.M. Pjerrou et al. | (UCLA) |
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| HUBBARD | 64 | PR 135 B183 | J.R. Hubbard et al. | (LRL) |
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| A Iso | | Siena Conf. 11 | L. Jauneau et al. | (EPOL, CERN, LOUC+) |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

The parity has not actually been measured, but + is of course ex-

We have omitted some results that have been superseded by later experiments. See our earlier editions.

≡ − MASS

The fit uses the $\Xi^-, \ \overline{\Xi}^+$, and Ξ^0 masses and the $\Xi^-\overline{\Xi}^+$ mass difference. It assumes that the Ξ^- and $\overline{\Xi}^+$ masses are the same.

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----------------|-------------------------|--------|----------|--------------------------|
| 1321.71 ± 0.07 OUR F | IT | | | | |
| $1321.70 \pm 0.08 \pm 0.05$ | 2478 ± 68 | ABDALLAH | 06E | DLPH | from Z decays |
| \bullet \bullet We do not use | the following d | ata for averages, fits | , limi | ts, etc. | • • • |
| 1321.46 ± 0.34 | 632 | DIBIANCA | 75 | DBC | 4.9 GeV/c K-d |
| 1321.12 ± 0.41 | 268 | WILQUET | 72 | HLBC | |
| 1321.87 ± 0.51 | 195 | ¹ GOLDWASSER | 70 | HBC | 5.5 GeV/c K-p |
| 1321.67 ± 0.52 | 6 | CHIEN | 66 | HBC | 6.9 GeV/c p p |
| 1321.4 ±1.1 | 299 | LONDON | 66 | HBC | |
| 1321.3 ± 0.4 | 149 | | 65в | HBC | |
| 1321.1 ± 0.3 | 241 | | 64 | HBC | |
| 1321.4 ± 0.4 | 517 | | 63D | FBC | |
| 1321.1 ± 0.65 | 62 | ² SCH NEIDER | 63 | HBC | |
| | | | | | |

 $^{^{1}}$ GOLDWASSER 70 uses $m_{\Lambda}=1115.58$ MeV.

王+ MASS

The fit uses the Ξ^- , $\overline{\Xi}^+$, and Ξ^0 masses and the Ξ^- — $\overline{\Xi}^+$ mass difference. It assumes that the Ξ^- and $\overline{\Xi}^+$ masses are the same.

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|--------------|---------------------|--------|-----------|--------------------------|
| 1321.71 ± 0.07 OUR FIT | | | | | |
| 1321.73±0.08±0.05 22 | 56 ± 63 | ABDALLAH | 06E | DLPH | from Z decays |
| • • • We do not use the f | ollowing dat | a for averages, fit | s, lim | its, etc. | • • • |
| 1321.6 ±0.8 | 35 | VOTRUBA | 72 | нвс | 10 GeV/c K+p |
| 1321.2 ± 0.4 | 34 | STONE | 70 | HBC | |
| 1320.69 ± 0.93 | 5 | CHIEN | 66 | HBC | 6.9 GeV/c p p |

$$(m_{\Xi^{-}} - m_{\Xi^{+}}) / m_{\Xi^{-}}$$

A test of CPT invariance

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------|-------------|-----|------|---------------|
| $(-2.5\pm8.7)\times10^{-5}$ | ABDALLAH | 06E | DLPH | from Z decays |

²These masses have been increased 0.09 MeV because the Λ mass increased.

 \equiv

= MEAN LIFE

Measurements with an error $>0.2\times10^{-10}$ s or with systematic errors not included have been omitted.

| VALUE (10 ⁻¹⁰ s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|---------------|-------------|------|------|------------------------------------------------|
| 1.639±0.015 OUR AV | ERAGE | | | | |
| $1.65 \pm 0.07 \pm 0.12$ | 2478 ± 68 | ABDALLAH | 06E | DLPH | from Z decays |
| 1.652 ± 0.051 | 32k | BOURQUIN | 84 | SPEC | Hyperon beam |
| 1.665 ± 0.065 | 41k | BOURQUIN | 79 | SPEC | Hyperon beam |
| 1.609 ± 0.028 | 4286 | HEMINGWAY | 78 | HBC | 4.2 GeV/c K-p |
| 1.67 ± 0.08 | | DIBIANCA | 75 | DBC | 4.9 GeV/c K-d |
| 1.63 ± 0.03 | 4303 | BALTAY | 74 | нвс | $1.75 \; \text{GeV}/c \; \text{K}^- \text{p}$ |
| $1.73 \begin{array}{l} +0.08 \\ -0.07 \end{array}$ | 680 | MAYEUR | 72 | HLBC | $2.1~{ m GeV}/c~K^-$ |
| 1.61 ± 0.04 | 2610 | DAUBER | 69 | HBC | |
| 1.80 ± 0.16 | 299 | LONDON | 66 | HBC | |
| 1.70 ± 0.12 | 246 | PJERROU | 65 B | HBC | |
| 1.69 ± 0.07 | 794 | HUBBARD | 64 | нвс | |
| $1.86 \begin{array}{l} +0.15 \\ -0.14 \end{array}$ | 517 | JAUNEAU | 63D | FBC | |

王+ MEAN LIFE

| VALUE (10 ⁻¹⁰ s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------------------|-------------------|----------------------|---------|-----------|--------------------------|
| 1.70±0.08±0.12 | 2256 ± 63 | ABDALLAH | 06E | DLPH | from Z decays |
| ● ● We do not use | the following dat | ta for averages, fi | ts, lim | its, etc. | • • • |
| $1.55 + 0.35 \\ -0.20$ | 35 | ³ VOTRUBA | 72 | нвс | 10 GeV/c K^+p |
| 1.6 ± 0.3 | 34 | STONE | 70 | нвс | |
| $1.9 \begin{array}{c} +0.7 \\ -0.5 \end{array}$ | 12 | ³ SHEN | 67 | нвс | |
| 1.51 ± 0.55 | 5 | ³ CHIEN | 66 | нвс | 6.9 GeV/c p p |
| ³ The error is statis | tical only. | | | | |

 $(\tau_{\equiv -} - \tau_{\overline{\equiv} +}) / \tau_{\equiv -}$

A test of *CPT* invariance.

| VALUE | DO CUMENT ID | | TECN | COMMENT | |
|------------------|--------------|-----|------|---------------|--|
| -0.01 ± 0.07 | ABDALLAH | 06E | DLPH | from Z decays | |

= MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings.

| VALUE (µN) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|---------------|--------------------|---------|--------|---------------------------|
| -0.6507±0.0025 OUR AVE | RAGE | | | | |
| -0.6505 ± 0.0025 | 4.36M | DURYEA | 92 | SPEC | 800 GeV p Be |
| $-0.661 \pm 0.036 \pm 0.036$ | 44k | TROST | 89 | SPEC | ${\it \Xi}^ \sim$ 250 GeV |
| -0.69 ± 0.04 | 218k | RAMEIKA | 84 | SPEC | 400 GeV <i>p</i> Be |
| | lowing data f | or averages, fits, | limits, | etc. ● | • • |
| $-0.674\ \pm0.021\ \pm0.020$ | 122k | НО | 90 | SPEC | See DURYEA 92 |
| -2.1 ± 0.8 | 2436 | COOL | 74 | OSP K | 1.8 GeV/c K p |
| -0.1 ± 2.1 | 2724 | BINGHAM | 70B | OSP K | 1.8 GeV/c K-p |

T+ MAGNETIC MOMENT

See the "Note on Baryon Magnetic Moments" in the Λ Listings.

| VALUE (μ_N) | EVTS | DO CUMENT ID | | DO CUMENT ID | | TECN | COMMENT |
|--------------------------|------|--------------|----|--------------|---------------------|------|---------|
| $+0.657\pm0.028\pm0.020$ | 70k | НО | 90 | SPEC | 800 GeV <i>p</i> Be | | |

$\left(\mu_{\Xi^-} + \mu_{\overline{\Xi}^+}\right) / \left|\mu_{\Xi^-}\right|$

A test of CPT invariance. We calculate this from the Ξ^- and $\overline{\Xi}^+$ magnetic moments above.

| VALUE | | |
|------------------|-----|------------|
| $+0.01 \pm 0.05$ | OUR | EVALUATION |

DO CUMENT ID

= DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|---------------------------------------|---------------------------------------------------|----------------------|
| $\overline{\Gamma_1}$ | $\Lambda\pi^-$ | (99.887±0.035) | % |
| Γ_2 | $\Sigma^-\gamma$ | (1.27 ± 0.23) : | $\times 10^{-4}$ |
| Γ_3 | $\Lambda e^- \overline{ u}_e$ | (5.63 \pm 0.31): | $\times 10^{-4}$ |
| | $\Lambda \mu^- \overline{ u}_{\mu}$ | $(3.5 \begin{array}{c} +3.5 \\ -2.2 \end{array})$ | × 10 ⁻⁴ |
| Γ_5 | $\Sigma^0 e^- \overline{\nu}_e$ | (8.7 ±1.7): | $\times 10^{-5}$ |
| Γ ₆ | $\Sigma^0 \mu^- \overline{\nu}_{\mu}$ | < 8 | $\times 10^{-4}$ 90% |
| Γ_7 | $\equiv^0 e^{-\frac{r}{\nu_e}}$ | < 2.3 | $\times 10^{-3}$ 90% |

| | | $\Delta S = 2$ forbidden | (52) | modes | | |
|----------------|-----------------------------------|--------------------------|------|-------|---------------------------|-----|
| Γ ₈ | $n\pi^-$ | 52 | < | 1.9 | $\times 10^{-5}$ | 90% |
| Г9 | n e $^-\overline{ u}_e$ | 52 | < | 3.2 | $\times 10^{-3}$ | 90% |
| Γ_{10} | n $\mu^-\overline{ u}_\mu$ | 52 | < | 1.5 | % | 90% |
| Γ_{11} | $p\pi^-\pi^-$ | 52 | < | 4 | \times 10 ⁻⁴ | 90% |
| Γ_{12} | $p\pi^-e^-\overline{\nu}_e$ | 52 | < | 4 | $\times 10^{-4}$ | 90% |
| Γ_{13} | $p\pi^-\mu^-\overline{\nu}_{\mu}$ | 52 | < | 4 | \times 10 ⁻⁴ | 90% |
| Γ_{14} | $p\mu^-\mu^-$ | L | < | 4 | $\times 10^{-8}$ | 90% |

CONSTRAINED FIT INFORMATION

An overall fit to 4 branching ratios uses 5 measurements and one constraint to determine 5 parameters. The overall fit has a $\chi^2=1.0$ for 1 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle / (\delta x_i \cdot \delta x_j)$, in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i / \Gamma_{\text{total}}$. The fit constrains the x_i whose labels appear in this array to sum to one

| -6 | | | |
|-----|-----------|-----------------------|-------------------------------------------------------|
| -8 | 0 | | |
| _99 | 0 | -1 | |
| -5 | 0 | 0 | 0 |
| X1 | Χa | Xa | <i>x</i> ₄ |
| | -8 -99 | -8 0 -99 0 -5 0 | $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ |

<12

= BRANCHING RATIOS

A number of early results have been omitted.

| $\Gamma(\Sigma^-\gamma)/\Gamma(\Lambda\pi^-)$ | | | | | Γ_2/Γ_1 |
|-----------------------------------------------|------|--------------------|-----|------|---------------------|
| VALUE (units 10^{-4}) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1.27±0.24 OUR FIT | | · | | | |
| 1.27±0.23 OUR AVEF | AGE | | | | |
| $1.22 \pm 0.23 \pm 0.06$ | 211 | ⁴ DUBBS | 94 | E761 | Ξ− 375 GeV |
| 2.27 ± 1.02 | 9 | BIAGI | 87в | SPEC | SPS hyperon beam |

 4 DUBBS 94 also finds weak evidence that the asymmetry parameter α_γ is positive $(\alpha_\gamma=1.0\pm1.3).$

| = 1.0 ± 1.5). | | | | | |
|----------------------------------------------------------|-----------------|--------------------|---------|---------|---------------------|
| $\Gamma(\Lambda e^- \overline{\nu}_e)/\Gamma(\Lambda n)$ | τ-) | | | | Γ_3/Γ_1 |
| VALUE (units 10 ⁻³) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.564 ± 0.031 OUR | FIT | | | | |
| 0.564 ± 0.031 | 2857 | BOURQUIN | 83 | SPEC | SPS hyperon beam |
| • • • We do not us | se the followin | g data for average | s, fits | limits, | etc. • • • |
| $0.30\ \pm0.13$ | 11 | THOMPSON | 80 | ASPK | Hyperon beam |
| $\Gamma(\Lambda\mu^-\overline{\nu}_\mu)/\Gamma(\Lambda$ | π^-) | | | | Γ_4/Γ_1 |
| VALUE (units 10^{-3}) | CL% EVTS | DO CUMENT ID | | TECN | COMMENT |

 $\frac{\Gamma(\Sigma^0\,e^-\nu_e)/\Gamma(\Lambda\pi^-)}{\frac{\text{VALUE (units }10^{-3})}{\text{0.087 \pm 0.017 OUR FIT}}} \underbrace{\text{EVTS}}_{\text{EVTS}} \qquad \underbrace{\text{DOCUMENT ID}}_{\text{TECN}} \underbrace{\text{TECN}}_{\text{COMMENT}}$

66 HBC

 0.087±0.017 OUR FIT
 DOCUMENT ID
 TECN
 COMMENT

 0.087±0.017
 154
 BOURQUIN
 83
 SPEC
 SPS hyperon beam

BERGE

 5 See the separate BOURQUIN 83 values for $\Gamma(\Lambda e^-\overline{\nu}_e)/\Gamma(\Lambda\pi^-)$ and $\Gamma(\Sigma^0\,e^-\overline{\nu}_e)/\Gamma(\Lambda\pi^-)$ above.

 6 DUCLOS 71 cannot distinguish Σ^0 's from \varLambda 's. The Cabibbo theory predicts the Σ^0 rate is about a factor 6 smaller than the \varLambda rate.

| $\Gamma(\Sigma^0 \mu^- \overline{ u}_\mu) / \Gamma(\Lambda \pi^-)$ | | | | | | | | |
|--------------------------------------------------------------------|-----------------------------------------------------------------------------|------|-------------|----|------|-----------------------|--|--|
| VALUE (units 10^{-3}) | CL% | EVTS | DO CUMENT I | D | TECN | COMMENT | | |
| < 0.76 | 90 | 0 | YEH | 74 | нвс | Effective denom.=3026 | | |
| ● ● We do not | • • • We do not use the following data for averages, fits, limits, etc. • • | | | | | | | |
| <5 | | | BERGE | 66 | нвс | | | |

| $\frac{\Gamma(n\pi^{-})/\Gamma(\Lambda\pi^{-})}{\Delta S=2. \text{ For } I}$ | | in first-orde | r weak interactio | on. | | Γ ₈ /Γ ₁ |
|--------------------------------------------------------------------------------------------------------------------------------------|--------------|---------------------|-----------------------------------------|-----------------|-------------------|----------------------------------------------------------|
| $VALUE$ (units 10^{-3}) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| <0.019 • • • We do not | 90 use th | e following o | BIAGI data for averages | 82B s, fits, | SPEC limits, | SPS hyperon beam etc. • • • |
| <3.0 <1.1 <5.0 | 90 | 0 | YEH DAUBER FERRO-LUZZI | 74 69 63 | HBC HBC HBC | Effective denom.=760 |
| $\Gamma(ne^-\overline{\nu}_e)/\Gamma(/2)$ | | in first ands | r weak interactio | | | Γ_9/Γ_1 |
| $\Delta 3=2$. For $VALUE$ (units 10^{-3}) | | | DOCUMENT ID | on. | TECN | COMMENT |
| < 3.2 | 90 | 0 | YEH | 74 | HBC | Effective denom = 715 |
| • • • We do not | use th | e following o | | | | |
| <10 | 90 | J | BINGHAM | 65 | RVUE | |
| | bidden | | r weak interactio | on. | | Γ_{10}/Γ_{1} |
| VALUE (units 10 ⁻³) | | | DO CUMENT ID | | TECN | COMMENT |
| <15.3 | 90 | 0 | YEH | 74 | HBC | Effective denom.=150 |
| | bidden | in first-orde | r weak interactio | on. | | Γ_{11}/Γ_1 |
| | CL% | | DO CUMENT ID | | TECN | COMMENT |
| <3.7 | 90 | 0 | YEH | 74 | HBC | Effective denom. = 6200 |
| $\Gamma(p\pi^-e^-\overline{\nu}_e)/\Delta S=2$. For MALUE (units 10^{-4}) | bidden | in first-orde | r weak interactio <u>DOCUMENT ID</u> | on. | TECN | Γ ₁₂ /Γ ₁ |
| <3.7 | 90 | 0 | YEH | 74 | HBC | Effective denom. = 6200 |
| $\Gamma(\rho\pi^-\mu^-\overline{ u}_\mu)/$ $\Delta S=2$. For | | | r weak interactio | on. | | Γ_{13}/Γ_1 |
| VALUE (units 10^{-4}) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| <3.7 | 90 | 0 | YEH | 74 | HBC | Effective denom. $=$ 6200 |
| $ \Gamma(p\mu^-\mu^-)/\Gamma(\Lambda\pi^-) \\ \text{A } \Delta L = 2 \text{ decay, forbidden by total lepton number conservation.} $ | | | | | | |
| VALUE (units 10 ⁻⁸) | | CL%_ | DO CUMENT ID | | | COMMENT |
| <4.0 • • • We do not | uco th | 90 o following o | RAJARAM | 05 fite | | p Cu, 800 GeV |
| | use in | ٠. | | | | |
| $< 3.7 \times 10^4$ | | | LITTENBERG | | HBC | Uses YEH 74 data |
| modes all resu | lt fror | n nonobserv | | rong | | is for the preceding three if the Ξ^- . One could as |

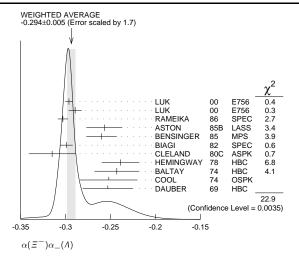
=- DECAY PARAMETERS

See the "Note on Baryon Decay Parameters" in the neutron Listings.

$\alpha(\Xi^-)\alpha_-(\Lambda)$

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------------------|-------------------|--------------------|--------|---------|---------------------|
| -0.294 ±0.005 OUR AVERA | . GE Error | includes scale fac | tor of | 1.7. Se | e the ideogram |
| below. | | | | | |
| -0.2963 ± 0.0042 | 189k | LUK | 00 | E756 | p Be, 800 GeV |
| -0.2894 ± 0.0073 | 63k | ⁸ LUK | 00 | E756 | p Be, 800 GeV |
| $-0.303 \pm 0.004 \pm 0.004$ | 192k | RAMEIKA | 86 | SPEC | 400 GeV <i>p</i> Be |
| -0.257 ± 0.020 | 11k | ASTON | 85B | LASS | 11 GeV/c K-p |
| -0.260 ± 0.017 | 21k | BENSINGER | 85 | MPS | 5 GeV/c K-p |
| -0.299 ± 0.007 | 150k | BIAGI | 82 | SPEC | SPS hyperon beam |
| -0.315 ± 0.026 | 9046 | CLELAND | 80c | ASPK | BNL hyperon beam |
| -0.239 ± 0.021 | 6599 | HEMINGWAY | 78 | HBC | 4.2 GeV/c K-p |
| -0.243 ± 0.025 | 4303 | BALTAY | 74 | нвс | 1.75 GeV/c K-p |
| -0.252 ± 0.032 | 2436 | COOL | 74 | OSPK | 1.8 GeV/c K- p |
| -0.253 ± 0.028 | 2781 | DAUBER | 69 | нвс | 221, 0 N p |

 8 This LUK 00 value is for $lpha(\overline{\Xi}^+)$ $lpha_+(\overline{\Lambda}).$ We assume *CP* conservation here by including it in the average for $\alpha(\Xi^-)$ $\alpha_-(A)$. But see the second data block below for the *CP*



α FOR $\varXi^- o \Lambda \pi^-$

The above average, $\alpha(\Xi^-)$ $\alpha_-(\Lambda)=-0.294\pm0.005$, where the error includes a scale factor of 1.7, divided by our current average $lpha_{-}(\varLambda)=0.642\pm0.013$, gives the following value for $\alpha(\Xi^-)$.

<u>VALUE</u> <u>DO CUMENT ID</u> <u>−0.458±0.012 OUR EVALUATION</u> Error includes scale factor of 1.8.

 $\begin{array}{l} [\pmb{\alpha}(\pmb{\Xi}^-)\pmb{\alpha}_-(\pmb{\Lambda}) - \pmb{\alpha}(\pmb{\Xi}^+)\pmb{\alpha}_+(\overline{\pmb{\Lambda}})] \\ [\pmb{\alpha}(\pmb{\Xi}^-)\pmb{\alpha}_-(\pmb{\Lambda}) + \pmb{\alpha}(\pmb{\Xi}^+)\pmb{\alpha}_+(\overline{\pmb{\Lambda}})] \\ \text{This is zero if } CP \text{ is conserved.} \quad \text{The } \alpha\text{'s are the decay-asymmetry parameters for } \overline{\Xi}^- \to \Lambda\pi^- \text{ and } \Lambda \to p\pi^- \text{ and for } \overline{\Xi}^+ \to \overline{\Lambda}\pi^+ \text{ and } \overline{\Lambda} \to \overline{p}\pi^+. \\ \end{array}$

| VALUE (units 10^{-4}) | EVTS | DO CUMEN | T ID | TECN | COMMENT | |
|-----------------------------------------------------------------------------|-------|----------|--------|------|---------------|--|
| 0.0± 5.1±4.4 | 158M | HOLMST | ROM 04 | HYCP | p Cu, 800 GeV | |
| • • • We do not use the following data for averages, fits, limits, etc. • • | | | | | | |
| $+120 \pm 140$ | 25 2k | LUK | 00 | E756 | p Be, 800 GeV | |

| ϕ ANGLE FOR $arXilon^-	o \Lambda\pi^-$ | ($	an\phi=eta/\gamma$) |
|---------------------------------------------|--------------------------|
| • | |

| VALUE (°) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------|-------------|-------------------------|------|----------|-------------------------------------|
| - 2.1 ± 0.8 OUR A | VERAGE | | | | |
| $-~2.39\!\pm~0.64\!\pm\!0.64$ | 144 M | | | HYCP | |
| $-\ 1.61 \pm\ 2.66 \pm 0.37$ | 1.35 M | ¹⁰ CHAKRAVO | 03 | E756 | p Be, 800 GeV |
| 5 ± 10 | 11k | ASTON | 85B | LASS | K-p |
| 14.7 ± 16.0 | 21k | ¹¹ BENSINGER | 85 | MPS | 5 GeV/c K-p |
| 11 ± 9 | 4303 | BALTAY | 74 | HB C | 1.75 GeV/c K ⁻ p |
| 5 ± 16 | 2436 | COOL | 74 | OSP K | 1.8 GeV/c K-p |
| -14 ± 11 | 2781 | DAUBER | 69 | HBC | Uses $\alpha_{\Lambda} = 0.647 \pm$ |
| 0 ±12 | 1004 | ¹² BERGE | 66 | нвс | 0.020 |
| • • • We do not use t | he followii | ng data for averages | fits | limits (| etc • • • |

• • We do not use the following data for averages, fits, limits, etc.

| -26 | ± 30 | | BINGHAM | | | |
|-----|------------|-----|-----------------------|-----|------|-------------------------------|
| 0 | ± 20.4 | 364 | ¹² LONDON | 66 | HB C | Using $\alpha_{\Lambda}=0.62$ |
| 54 | ± 30 | 356 | ¹² CARMONY | 64B | HB C | |

 $^9\,{\rm From}$ this result and α_{Ξ} , HUANG 04 gets $\beta_{\Xi}\,=\,-\,0.037\,\pm\,0.011\,\pm\,0.010$ and $\gamma_{\Xi}\,=\,$ $0.888\pm0.0004\pm0.006$. And the strong p-s phase difference for $\Lambda\pi^-$ scattering is $(4.6\pm1.4\pm1.2)^\circ$.

 10 From this result and α_{Ξ} , CHAKRAVORTY 03 obtains $\beta_{\Xi}=-0.025\pm0.042\pm0.006$ and $\gamma_{\Xi}=0.889\pm0.001\pm0.007$. And the strong p-s phase difference for $\Lambda\pi^-$ scattering is $(3.17\pm5.28\pm0.73)^\circ$.

11 BENSINGER 85 used $\alpha_{\Lambda}=0.642\pm0.013$. 12 The errors have been multiplied by 1.2 due to approximations used for the Ξ polarization; see DAUBER 69 for a discussion.

$g_A / g_V \text{ FOR } \Xi^- \rightarrow \Lambda e^- \overline{\nu}_e$

| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
|------------------|------|----------------|------|------------------|
| -0.25 ± 0.05 | 1992 | 13 BOURQUIN 83 | SPEC | SPS hyperon beam |

 13 BOURQUIN 83 assumes that $g_2=0$. Also, the sign has been changed to agree with our conventions, given in the "Note on Baryon Decay Parameters" in the neutron Listings.

=- REFERENCES

We have omitted some papers that have been superseded by later experiments. See our earlier editions.

| ABDALLAH | 06E | PL B639 179 | J. Abdallah et al. | (DELPHI Collab.) |
|------------|------|---------------|------------------------------|--------------------------|
| RAJARAM | 05 | PRL 94 181801 | D. Rajaram et al. | (FNAL HyperCP Collab.) |
| HOLMSTROM | 04 | PRL 93 262001 | T. Holmstrom et al. | (FNAL HyperCP Collab.) |
| HUANG | 04 | PRL 93 011802 | M. Huang et al. | (FNAL HyperCP Collab.) |
| CHAKRAV O | 03 | PRL 91 031601 | A. Chakravorty et al. | (FNAL E756 Collab.) |
| LUK | 00 | PRL 85 4860 | K.B. Luk et al. | (FNAL E756 Collab.) |
| DUBBS | 94 | PRL 72 808 | T. Dubbs et al. | (FNAL E761 Collab.) |
| DURYEA | 92 | PRL 68 768 | J. Duryea et al. | (MINN, FNAL, MICH, RUTG) |
| LITTENBERG | 92 B | PR D46 R892 | L.S. Littenberg, R.E. Shrock | (BNL, STON) |
| но | 90 | PRL 65 1713 | P.M. Ho et al. | (MICH, FNAL, MINN, RUTG) |
| Also | | PR D44 3402 | P.M. Ho et al. | (MICH, FNAL, MINN, RUTG) |
| TROST | 89 | PR D40 1703 | L.H. Trost et al. | (FNAL-715 Collab.) |
| BIAGI | 87 B | ZPHY C35 143 | S.F. Biagi et al. | (BRÌS, CERN, GEVA+) |
| RAMEIKA | 86 | PR D33 3172 | R. Rameika et al. | (RUTG. MICH. WISC+) |

Ξ^- , Ξ 's, $\Xi(1530)$

| ASTON BENSINGER BOURQUIN RAMEIKA BOURQUIN BIAGI BIAGI CLELAND THOM PSON BOURQUIN HEMINGWAY | 85 B 85 84 84 83 82 82 B 80 C 80 79 78 | PR D32 2270 NP B252 561 NP B241 1 PRL 52 581 ZPHY C21 1 PL 112B 265 PL 112B 277 PR D21 12 PR D21 25 PL 87B 297 NP B142 205 | D. Aston et al. J.R. Bensinger et al. M.H. Boum uin et al. R. Rameika et al. M.H. Boum uin et al. S.F. Biggl et al. S.F. Biggl et al. V.E. Cletand et al. M.H. Boum uin et al. M.H. Boum uin et al. R.J. Hemingway et al. | (SLAC, CARL, CARC, CINC) (CHIC, EMMT, FNAL+) (BRIS, GEVA, HEIDP+) (RUTG, MICH, WISC-) (BRIS, GEVA, HEIDP+) (BRIS, CAVE, GEVA+) (LOQM, GEVA, RL+) (PITT, BNL) (BRIS, GEVA, HEIDP+) (CERN, ZEEM, NIJM+) |
|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DIBIAN CA | 75 | NP B98 137 | F.A. Dibianca, R.J. Endorf | (CMU) |
| BALTAY | 74 | PR D9 49 | C. Baltay et al. | (COLU, BING) J |
| COOL | 74 | PR D10 792 PRL 29 1630 | R.L. Cool et al. R.L. Cool et al. | (BNL) |
| Also YEH | 74 | PR D10 3545 | N. Yeh et al. | (BNL) (BING, COLU) |
| MAYEUR | 72 | NP B47 333 | | BRUX, CERN, TUFTS, LOUC) |
| VOTRUBA | 72 | NP B45 77 | M.F. Votruba, A. Safder, T.N | |
| WILQUET | 72 | PL 42B 372 | G. Wild uet et al. | (BRUX, CERN, TUFTS+) |
| DUCLOS | 71 | NP B32 493 | J. Duclos et al. | (CERN) |
| BINGHAM | 70 B | PR D1 3010 | G.M. Bingham et al. | (UCSD, WASH) |
| GOLDWASSER | | PR D1 1960 | E.L. Goldwasser, P.F. Schultz | |
| STONE | 70 | PL 32B 515 | S.L. Stone et al. | (RÒCH) |
| DAUBER | 69 | PR 179 1262 | P.M. Dauber et al. | `(LRL)J |
| SHEN | 67 | PL 25B 443 | B.C. Shen, A. Firestone, G. G. | ioldhaber (UCB+) |
| BERGE | 66 | PR 147 945 | J.P. Berge et al. | `(LRL) |
| CHIEN | 66 | PR 152 1171 | C.Y. Chien et al. | (YALE, BNL) |
| LONDON | 66 | PR 143 1034 | G.W. London et al. | (BNL, SYRA) |
| BINGHAM | 65 | PRSL 285 202 | H.H. Bingham | (CERN) |
| PJERROU | 65 B | PRL 14 275 | G.M. Pjerrou et al. | (UCLA) |
| A Iso | | Thesis | G.M. Pjerrou | (UCLA) |
| BADIER | 64 | Dubna Conf. 1 593 | J. Badier et al. | (EPOL, SACL, ZEEM) |
| CARMONY | 64 B | PRL 12 482 | D.D. Carmony et al. | (UCLA) J |
| HUBBARD FERRO-LUZZI | 64 63 | PR 135 B183 PR 130 1568 | J.R. Hubbard et al. M. Ferro-Luzzi et al. | (LRL) (LRL) |
| JAUNEAU | 63 D | Siena Conf. 4 | I Jauneau et al | (EPOL, CERN, LOUC+) |
| Also | 03 D | PL 5 261 | L. Jauneau et al. | (EPOL, CERN, LOUC+) |
| SCHNEIDER | 63 | PL 4 360 | J. Schneider | (CERN) |
| o ceibeit | | | 5. 5011101001 | (CERN) |

Ξ RESONANCES

The accompanying table gives our evaluation of the present status of the Ξ resonances. Not much is known about Ξ resonances. This is because (1) they can only be produced as a part of a final state, and so the analysis is more complicated than if direct formation were possible, (2) the production cross sections are small (typically a few μ b), and (3) the final states are topologically complicated and difficult to study with electronic techniques. Thus early information about Ξ resonances came entirely from bubble chamber experiments, where the numbers of events are small, and only in the 1980's did electronic experiments make any significant contributions. However, nothing of significance on Ξ resonances has been added since our 1988

For a detailed earlier review, see Meadows [1].

Table 1. The status of the Ξ resonances. Only those with an overall status of *** or **** are included in the Baryon Summary Table.

| | | | | | Status | as seen in | _ |
|-------------|-------|-------------------|----------|-------------|------------|----------------|----------------|
| Particle | J^P | Overall status | $\Xi\pi$ | ΛK | ΣK | $\Xi(1530)\pi$ | Other channels |
| Ξ(1318) | 1/2+ | **** | | | | | Decays weakly |
| $\Xi(1530)$ | 3/2 + | **** | **** | | | | |
| $\Xi(1620)$ | | * | * | | | | |
| $\Xi(1690)$ | | *** | | *** | ** | | |
| $\Xi(1820)$ | 3/2- | *** | ** | *** | ** | ** | |
| $\Xi(1950)$ | | *** | ** | ** | | * | |
| $\Xi(2030)$ | | *** | | ** | *** | | |
| $\Xi(2120)$ | | * | | * | | | |
| $\Xi(2250)$ | | ** | | | | | 3-body decays |
| $\Xi(2370)$ | | ** | | | | | 3-body decays |
| $\Xi(2500)$ | | * | | * | * | | 3-body decays |

Existence is certain, and properties are at least fairly well explored. Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, etc. are not well determined

- Evidence of existence is only fair.
- Evidence of existence is poor.

Reference

1. B.T. Meadows, in *Proceedings of the IVth Interna*tional Conference on Baryon Resonances (Toronto, 1980), ed. N. Isgur, p. 283.

E(1530) 3/2⁺

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$
 Status: ***

This is the only Ξ resonance whose properties are all reasonably well known. Assuming that the Λ_c^+ has $J^P=1/2^+$, AUBERT 08AK, in a study of $\Lambda_c^+ \to \Xi^- \pi^+ K^+$, finds conclusively that the spin of the $\Xi(1530)^0$ is 3/2. In conjunction with SCHLEIN 63B and BUTTON-SHAFER 66, this proves also that the parity is +.

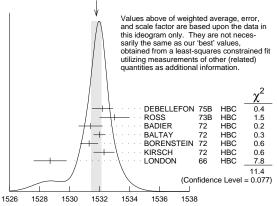
We use only those determinations of the mass and width that are accompanied by some discussion of systematics and resolution.

Ξ(1530) MASSES

-/1520\0 MACC

| =(1930), MY22 | | | | | |
|-------------------------------------------|------------------|-------------------------|---------|-----------|-----------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1531.80 ± 0.32 OUR | FIT Error in | cludes scale factor | of 1. | 3. | |
| 1531.78±0.34 OUR below. | AVERAGE E | Error includes scale | facto | or of 1.4 | . See the ideogram |
| 1532.2 ± 0.7 | | DEBELLEFON | 75B | HB C | $K^- p \rightarrow \Xi^- \overline{K} \pi$ |
| 1533 ± 1 | | ROSS | 73B | HBC | $K^- p \rightarrow \Xi \overline{K} \pi(\pi)$ |
| 1531.4 ± 0.8 | 59 | BADIER | 72 | HBC | K^-p 3.95 GeV/ c |
| 1532.0 ± 0.4 | 1262 | BALTAY | 72 | HBC | $K^- p$ 1.75 GeV/ c |
| 1531.3 ± 0.6 | 324 | BORENSTEIN | 72 | HBC | $K^- p$ 2.2 GeV/c |
| 1532.3 ± 0.7 | 286 | KIRSCH | 72 | HBC | K^-p 2.87 GeV/c |
| 1528.7 ± 1.1 | 76 | LONDON | 66 | HBC | K^-p 2.24 GeV/ c |
| ● ● We do not us | se the following | g data for averages | , fits, | limits, | etc. • • • |
| 1532.1 ± 0.4 | 1244 | ASTON | 85B | LASS | K^-p 11 GeV/c |
| 1532.1 ± 0.6 | 2700 | ¹ BAUBILLIER | 81B | HBC | K^-p 8.25 GeV/c |
| 1530 ± 1 | 450 | BIAGI | 81 | SPEC | SPS hyperon beam |
| 1527.000000000000000000000000000000000000 | 80 | SIXEL | 79 | HBC | K^-p 10 GeV/ c |
| 1535 ±4 | 100 | SIXEL | 79 | HBC | K^-p 16 GeV/ c |
| 1533.6 ± 1.4 | 97 | BERTHON | 74 | HBC | Quasi-2-body σ |
| | | | | | |





 $\Xi(1530)^0$ mass (MeV)

| Ξ (1530) [−] MASS | | | | | |
|-----------------------------------|---------------|-------------------|---------|-------------|----------------------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 1535.0±0.6 OUR FIT | | | | | |
| 1535.2±0.8 OUR AVER | AGE | | | | |
| 1534.5 ± 1.2 | | DEBELLEFON | 75B | HB C | $K^-p \rightarrow \Xi^-\overline{K}\pi$ |
| 1535.3 ± 2.0 | | ROSS | 73B | HBC | $K^-p \rightarrow \Xi \overline{K} \pi(\pi)$ |
| 1536.2 ± 1.6 | 185 | KIRSCH | 72 | HBC | K−p 2.87 GeV/c |
| 1535.7 ± 3.2 | 38 | LONDON | 66 | HBC | K^-p 2.24 GeV/c |
| | e following o | data for averages | , fits, | , limits, e | etc. • • • |
| 1540 ±3 | 48 | BERTHON | 74 | нвс | Quasi-2-body σ |
| 1534.7 ± 1.1 | 334 | BALTAY | 72 | HBC | K^-p 1.75 GeV/ c |

| m ₌₍₁₅₃₀₎ - | - m _{≡(1530)} |
|------------------------|------------------------|
| *** =/15301- | ····=(1530) |

| /ALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------------|--------------|-----|------|---------------------------------|
| 3.2±0.6 OUR FIT 2.9±0.9 OUR AVERAGE | | | | |
| 2.7±1.0 | BALTAY | 72 | HBC | K−p 1.75 GeV/c |
| 2.0 ± 3.2 | MERRILL | 66 | HBC | K-p 1.7-2.7 GeV/c |
| 5.7±3.0 | PJERROU | 65B | HBC | K [−] p 1.8-1.95 GeV/c |
| | | | | |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| 3.9 ± 1.8 | | ² KIRSCH | 72 | нвс | K [−] p 2.87 GeV/c |
|-------------------------------------------|-------------|----------------------|-------|-----------|--------------------------------------------------|
| 7 ±4 | | ² LONDON | 66 | НВС | K^-p 2.24 GeV/c |
| | | Ξ(1530) WID7 | ГНЅ | | |
| <i>Ξ</i> (1530) ⁰ WID | тн | | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 9.1±0.5 OUR A | VERAGE | | | | |
| 9.5 ± 1.2 | | DEBELLEFON | 75 B | нвс | $K^- p \rightarrow \Xi^- \overline{K} \pi$ |
| 9.1 ± 2.4 | | ROSS | 73B | HBC | $K^- \rho \rightarrow \Xi \overline{K} \pi(\pi)$ |
| 11 ±2 | | BADIER | 72 | нвс | K^-p 3.95 GeV/c |
| 9.0 ± 0.7 | | BALTAY | 72 | нвс | K−p 1.75 GeV/c |
| 8.4 ± 1.4 | | BORENSTEIN | 72 | HBC | $\Xi^-\pi^+$ |
| 11.0 ± 1.8 | | KIRSCH | 72 | нвс | $\Xi^-\pi^+$ |
| 7 ±7 | | BERGE | 66 | HBC | $K^- p 1.5 - 1.7 \text{ GeV}/c$ |
| 8.5 ± 3.5 | | LONDON | 66 | HBC | K^-p 2.24 GeV/c |
| 7 ±2 | | SCHLEIN | 63B | | K ⁻ ρ 1.8, 1.95 GeV/d |
| • • • VVe do not | | ng data for average: | | , limits, | etc. • • • |
| 12.8 ± 1.0 | 2700 | 1 BAUBILLIER | 81B | HBC | K [−] p 8.25 GeV/c |
| 19 ±6 | 80 | 3 SIXEL | 79 | HBC | K^-p 10 GeV/ c |
| 14 ±5 | 100 | ³ SIXEL | 79 | HBC | K [−] p 16 GeV/c |
| Ξ (1530) [−] WIE | OTH | | | | |
| VALUE (MeV) | | DO CUMENT ID | | TECN | COMMENT |
| 9.9 ^{+1.7} _{-1.9} OUR A | VERAGE | | | | |
| 9.6 ± 2.8 | | DEBELLEFON | 75 B | нвс | $K^- p \rightarrow \Xi^- \overline{K} \pi$ |
| 8.3 ± 3.6 | | ROSS | 73B | нвс | $K^- p \rightarrow \Xi \overline{K} \pi(\pi)$ |
| $7.8 + 3.5 \\ -7.8$ | | BALTAY | 72 | нвс | K [−] p 1.75 GeV/c |
| | | | | | $\Xi^-\pi^0$, $\Xi^0\pi^-$ |
| 16.2±4.6 | | KIRSCH | 72 | нвс | Ξ π°, Ξ°π |
| | <i>≣</i> (: | 1530) POLE PO | SITIC | ONS | |
| Ξ(1530) ⁰ REA | L PART | | | | |
| VALUE | | DO CUMENT ID | | COMME | ENT |
| 1531.6 ± 0.4 | | LICHTENBER | G74 | Using | HABIBI 73 |
| Ξ(1530) ⁰ IMA | GINARY PAI | | | COMM | EN.E |
| VALUE | | DOCUMENT ID | C74 | COMME | |
| 4.45 ± 0.35 | | LICHTENBER | G / 4 | using | HABIBI 73 |
| Ξ(1530) [—] REA | AL PART | | | | |
| VALUE | | DO CUMENT ID | | COMME | ENT |

≡(1530) DECAY MODES

LICHTENBERG74 Using HABIBI 73

LICHTENBERG74 Using HABIBI 73

COMMENT

| | Mode | Fraction (Γ_i/Γ) | Confidence le | evel |
|-----------------------|----------------------|------------------------------|---------------|------|
| Γ_1 Γ_2 | $\Xi \pi \Xi \gamma$ | 100 % <4 % | 9 | 90% |

Ξ(1530) BRANCHING RATIOS

| $\Gamma(\Xi\gamma)/\Gamma_{total}$ | | | | Γ_2/Γ |
|------------------------------------|-----|----------------|------|-------------------|
| VALUE | CL% | DO CUMENT ID | TECN | COMMENT |
| <0.04 | 90 | KALBFLEISCH 75 | HBC | K^-p 2.18 GeV/c |

Ξ (1530) FOOTNOTES

- $^{
 m 1}$ BAUBILLIER 81B is a fit to the inclusive spectrum. The resolution (5 MeV) is not 2 Infolded. 2 Redundant with data in the mass Listings. 3 SIXEL 79 doesn't unfold the experimental resolution of 15 MeV.

Ξ(1530)- IMAGINARY PART

3.9 + 1.75

≡(1530) REFERENCES

| AUBERT | 08AK | PR D78 034008 | B. Aubert et al. | (BABAR Collab.) |
|-------------|------|-------------------|-------------------------|-----------------------------|
| ASTON | 85 B | PR D32 2270 | D. Aston et al. | (SLAC, CARL, CNRC, CINC) |
| BAUBILLIER | 81B | NP B192 1 | M. Baubillier et al. | ` (BIRM, CERN, GLAS+) |
| BIAGI | 81 | ZPHY C9 305 | S.F. Biagi et al. | (BRIS, CAVE, GEVA+) |
| SIXEL | 79 | NP B159 125 | P. Sixel et al. | (AACH3, BERL, CERN, LOIC+) |
| DEBELLEFON | 75 B | NC 28A 289 | A. de Bellefon et al. | (CDEF, SACL) |
| KALBFLEISCH | 75 | PR D11 987 | G.R. Kalbfleisch, R.C. | Strand, J.W. Chapman (BNL+) |
| BERTHON | 74 | NC 21A 146 | A. Berthon et al. | (CDEF, RHEL, SACL+) |
| LICHTENBERG | 74 | PR D10 3865 | D.B. Lichtenberg | (IND) |
| Also | | Private Comm. | D.B. Lichtenberg | (ÌN D) |
| HABIBI | 73 | Thesis Nevis 199 | M. Habibi | (CÒLU) |
| ROSS | 73 B | Purdue Conf. 355 | R.T. Ross, J.L. Lloyd, | D. Radojicic (OXF) |
| BADIER | 72 | NP B37 429 | J. Badier et al. | (ÈPOL) |
| BALTAY | 72 | PL 42B 129 | C. Baltay et al. | (COLU, BING) |
| BORENSTEIN | 72 | PR D5 1559 | S.R. Borenstein et al. | (BNL, MICH) I |
| KIRS CH | 72 | NP B40 349 | L.E. Kirsch et al. | (BRAN, UMD, SYRA+)I |
| BERGE | 66 | PR 147 945 | J.P. Berge et al. | ` (LRL)I |
| BUTTON | 66 | PR 142 883 | J. Button-Shafer et al. | (LRL) JP |
| LONDON | 66 | PR 143 1034 | G.W. London et al. | (BNL, SYRA)IJ |
| MERRILL | 66 | Thesis UCRL 16455 | D.W. Merrill | (LRL)JP |
| PJERROU | 65 B | PRL 14 275 | G.M. Pjerrou et al. | (ÚCLA) |
| SCHLEIN | 63 B | PRI 11 167 | PF Schlein et al | ÌUCLAÌ LIP |

OTHER RELATED PAPERS -

| MA ZZUCAT O | 81 | NP B178 1 | M. Mazzucato et al. | (AMST, CERN, NIJM+) |
|-------------|----|-------------|-------------------------|---------------------|
| BRIEFEL | 77 | PR D16 2706 | E. Briefel et al. | (BRAN, UMD, SYRA+) |
| BRIEFEL | 75 | PR D12 1859 | E. Briefel et al. | (BRAN, UMD, SYRA+) |
| HUNGERBU | 74 | PR D10 2051 | V. Hungerbuhler et al. | `(YALE, FNAL, BNL+) |
| BUTTON | 66 | PR 142 883 | J. Button-Shafer et al. | ` (LRL) JP |

$\Xi(1620)$

$$I(J^P) = \frac{1}{2}(?^?)$$
 Status: *
J, P need confirmation.

OMITTED FROM SUMMARY TABLE

What little evidence there is consists of weak signals in the $\Xi\pi$ channel. A number of other experiments (e.g., BORENSTEIN 72 and HASSALL 81) have looked for but not seen any effect.

Ξ(1620) MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------|------|-------------|-----|------|-----------------------------------------------|
| ≈ 1620 OUR ESTIMAT | E | | | | |
| 1624 ± 3 | 31 | BRIEFEL | 77 | HB C | K^-p 2.87 GeV/c |
| 1633 ± 12 | 34 | DEBELLEFON | 75B | HB C | $K^- \rho \rightarrow \Xi^- \overline{K} \pi$ |
| 1606 ± 6 | 29 | ROSS | 72 | HB C | K^-p 3.1-3.7 GeV/c |
| | | | | | |

Ξ(1620) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|------|----------------------|-----|------|--------------------------------------------|
| 22.5 | 31 | ¹ BRIEFEL | 77 | нвс | K-p 2.87 GeV/c |
| 40 ±15 | 34 | DEBELLEFON | 75B | HBC | $K^- p \rightarrow \Xi^- \overline{K} \pi$ |
| 21 ± 7 | 29 | ROSS | 72 | HBC | |
| | | | | | $\Xi^{-}\pi^{+}K^{*0}$ (892) |

Ξ(1620) DECAY MODES

 $\Xi \pi$

Ξ(1620) FOOTNOTES

¹ The fit is insensitive to values between 15 and 30 MeV

Ξ(1620) REFERENCES

| HASSALL BRIEFEL | 81 77 | NP B189 397 PR D16 2706 | J.K. Hassall et al. E. Briefel et al. | (CAVE, MSU) (BRAN, UMD, SYRA+) |
|--------------------|----------|----------------------------|------------------------------------------|-----------------------------------|
| A Iso | | Duke Conf. 317 | E. Briefel et al. | (BRAN, UMD, SYRA+) |
| Hyperon R | eso n an | ces, 1970 | | |
| A Iso | | PR D12 1859 | E. Briefel et al. | (BRAN, UMD, SYRA+) |
| DEBELLEFON | 75 B | NC 28A 289 | A. de Bellefon et al. | (CDEF, SACL) |
| BORENSTEIN | 72 | PR D5 1559 | S.R. Borenstein et al. | `(BNL, MICH)I |
| ROSS | 72 | PL 38B 177 | R.T. Ross et al. | ` (OXF)I |

OTHER RELATED PAPERS -

| HUNGERBU | 74 | PR D10 2051 | V. Hungerbuhler et al. | (YALE, FNAL, BNL+) |
|-------------|---------|------------------|---------------------------|---------------------|
| SCHMIDT | 73 | Purdue Conf. 363 | P.E. Schmidt | (BRAN) |
| KALBFLEISCH | | Duke Conf. 331 | G.R. Kalbfleisch | (BNL) |
| Hyperon F | Resonai | nces 1970 | | |
| APSELL | 69 | PRL 23 884 | S.P. Apsell et al. | (BRAN, UMD, SYRA+) |
| BARTS CH | 69 | PL 28B 439 | J. Bartsch <i>et al</i> . | (AACH, BERL, CERN+) |
| | | | | |

$\Xi(1690)$

$$I(J^P) = \frac{1}{2}(?^?)$$
 Status: ***

AUBERT 08AK, in a study of $\Lambda_c^+
ightarrow \, \Xi^- \pi^+ \, K^+$, finds some evidence that the $\Xi(1690)$ has $J^P = 1/2^-$.

DIONISI 78 sees a threshold enhancement in both the neutral and negatively charged $\Sigma \overline{K}$ mass spectra in $K^-p \to (\Sigma \overline{K}) K \pi$ at 4.2 GeV/c. The data from the $\Sigma \overline{K}$ channels alone cannot distinguish between a resonance and a large scattering length. Weaker evidence at the same mass is seen in the corresponding $\varLambda\,\overline{K}$ channels, and a coupled-channel analysis yields results consistent with a new \varXi .

BIAGI 81 sees an enhancement at 1700 MeV in the diffractively produced $\varLambda\, K^-$ system. A peak is also observed in the $\varLambda\, \overline{K}{}^0$ mass spectrum at 1660 MeV that is consistent with a 1720 MeV resonance decaying to $\varSigma^0\,\overline{K}^0$, with the γ from the \varSigma^0 decay not detected.

BIAGI 87 provides further confirmation of this state in diffractive dissociation of \varXi^- into $\varLambda\, K^-$. The significance claimed is 6.7 standard deviations.

ADAMOVICH 98 sees a peak of 1400 \pm 300 events in the $\Xi^-\pi^+$ spectrum produced by 345 GeV/c Σ^- -nucleus interactions.

 $\Xi(1690), \Xi(1820)$

| Ξ (1690) | MASSES |
|-----------------|--------|
|-----------------|--------|

| М | IX | ED | CHA | RG | ES |
|---|----|----|-----|----|----|
|---|----|----|-----|----|----|

DOCUMENT ID

1690±10 OUR ESTIMATE This is only an educated guess; the error given is larger than the error on the average of the published values.

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------|------|----------------------------------------------|----|-------|----------------------------------------------------------|
| 1686±4 | 1400 | ADAMOVICH | 98 | WA 89 | Σ^- nucleus, 345 GeV/c |
| $\begin{array}{c} 1699{\pm}5 \\ 1684{\pm}5 \end{array}$ | | ¹ DIONISI ² DIONISI | | | K ⁻ p 4.2 GeV/c K ⁻ p 4.2 GeV/c |
| | | | | | |

Ξ(1690)[−] MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------|------|----------------------|----|------|------------------|
| 1691.1± 1.9±2.0 | 104 | BIAGI | 87 | SPEC | Ξ−Be 116 GeV |
| 1700 ±10 | 150 | ³ BIAGI | 81 | SPEC | Ξ−H 100, 135 GeV |
| 1694 ± 6 | 45 | ⁴ DIONISI | 78 | HBC | K^-p 4.2 GeV/c |

Ξ(1690) WIDTHS

MIXED CHARGES

<30 OUR ESTIMATE

DOCUMENT ID

Ξ(1690)⁰ WIDTH

| VALUE (MeV) | EVIS | DO CUMENT ID | | IECN | COMMENT |
|-------------|------|----------------------|----|-------|----------------------------------|
| 10± 6 | 1400 | ADAMOVICH | 98 | WA 89 | Σ^- nucleus, 345 GeV/ c |
| 44 ± 23 | | ¹ DIONISI | 78 | нвс | K-p 4.2 GeV/c |
| 20± 4 | 183 | ² DIONISI | 78 | HBC | K^-p 4.2 GeV/c |

Ξ(1690)[−] WIDTH

| VALUE (MeV) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|------|----------------------|----|------|------------------|
| < 8 | 90 | 104 | BIAGI | 87 | SPEC | Ξ−Be 116 GeV |
| 47 ± 14 | | 150 | ³ BIAGI | 81 | SPEC | Ξ-H 100, 135 GeV |
| 26 ± 6 | | 45 | ⁴ DIONISI | 78 | HBC | K - p 4.2 GeV/c |

≡(1690) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-------------------------|------------------------------|
| Γ ₁ | $\Lambda \overline{K}$ | seen |
| Γ_2 | $\Sigma \overline{K}$ | seen |
| Гз | $\equiv \pi$ | seen |
| Γ_4 | $\Xi^{-}\pi^{+}\pi^{0}$ | |
| Γ_5 | $\Xi^-\pi^+\pi^-$ | possibly seen |
| Γ_6 | $\Xi(1530)\pi$ | |

| | <i>Ξ</i> (169 | 0) BRANCHIN | G RA | TIOS | | |
|-------------------------------------------------------------------------------------------------|---------------|-------------------------------|-----------------|--------------------|-----------------|-----------------------------------------------------------------------|
| $\Gamma(\Lambda\overline{K})/\Gamma_{\text{total}}$ | EVTS | DOCUMENT ID | | TECN | CHG | Γ ₁ /Γ |
| seen | 104 | BIAGI | 87 | SPEC | _ | Ξ−Be 116 GeV |
| Γ (ΣҠ)/Γ(ΛҠ) VALUE | EVTS | DOCUMENT ID | | TECN | снс | Γ ₂ /Γ ₁ |
| 0.75 ± 0.39 2.7 ± 0.9 3.1 ± 1.4 | 75 | ABE DIONISI DIONISI | 02c 78 78 | BELL HBC HBC | 0 | $e^+e^- \approx \Upsilon(4S)$ K^-p 4.2 GeV/c K^-p 4.2 GeV/c |
| $\Gamma(\Xi\pi)/\Gamma(\Sigma\overline{K})$ VALUE | | DOCUMENT ID | | TECN | <u>CHG</u> | Γ ₃ /Γ ₂ |
| < 0.09 | | DIONISI | 78 | нвс | 0 | K^-p 4.2 GeV/ c |
| $\Gamma(\Xi\pi)/\Gamma_{\text{total}}$ | | DOCUMENT ID | | TECN | <u>COMI</u> | Γ ₃ /Γ |
| seen | | ADAMOVICH | 98 | WA 89 | | nucleus, 345 eV/ <i>c</i> |
| $\Gamma(\Xi^-\pi^+\pi^0)/\Gamma(\Sigma_{NALUE})$ | (K) | DOCUMENT ID | | <u>TECN</u> | <u>CHG</u> | Γ ₄ /Γ ₂ |
| < 0.04 | | DIONISI | 78 | нвс | 0 | K [−] p 4.2 GeV/c |
| $\frac{\Gamma(\Xi^-\pi^+\pi^-)/\Gamma_{\text{tot}}}{\frac{\text{VALUE}}{\text{possibly seen}}}$ | <u>EVTS</u> 4 | <u>DOCUMENT ID</u> BIAGI | 87 | TECN_ | <u>CHG</u> | Γ ₅ /Γ <u>COMMENT</u> Ξ ⁻ Be 116 GeV |
| $\Gamma(\Xi^-\pi^+\pi^-)/\Gamma(\Sigma^-\pi^+\pi^-)$ | • | | 01 | | cuc | Γ_5/Γ_2 |
| <u>VALUE</u> <0.03 | | <u>DOCUMENT ID</u> DIONISI | 78 | HBC | <u>CHG</u> — | K-p 4.2 GeV/c |

| $\Gamma(\Xi(1530)\pi)/\Gamma(\Sigma\overline{K})$ | | | | | Γ_6/Γ_2 |
|---------------------------------------------------|--------------|----|------|-----|---------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| < 0.06 | DIONISI | 78 | нвс | - | K^-p 4.2 GeV/ c |

≡(1690) FOOTNOTES

≡(1690) REFERENCES

| AUBERT ABE ADAMOVICH BIAGI BIAGI | 02 C 98 87 81 | PR D78 034008 PL B524 33 EPJ C5 621 ZPHY C34 15 ZPHY C9 305 | B. Aubert et al. K. Abe et al. M.I. Adamovich et al. S.F. Biagi et al. S.F. Biagi et al. | (BABAR Collab.) (KEK BELLE Collab.) (CERN WA89 Collab.) (BRIS, CERN, GEVA+)I (BRIS, CAVE, GEVA+) |
|----------------------------------------------|------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| DIONISI | 78 | | C. Dionisi et al. | (CERN, AMST, NIJM+)I |

$\Xi(1820) \ 3/2$

 $I(J^P) = \frac{1}{2}(\frac{3}{2})$ Status: ***

The clearest evidence is an 8-standard-deviation peak in $\it \Lambda \, K^-$ seen by GAY 76C. TEODORO 78 favors J=3/2, but cannot make a parity discrimination. BIAGI 87C is consistent with J=3/2 and favors negative parity for this J value.

Ξ(1820) MASS

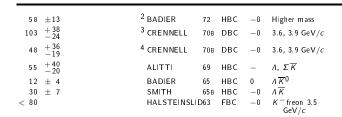
We only average the measurements that appear to us to be most significant and best determined.

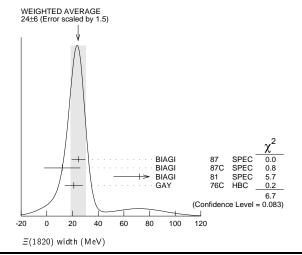
| VALUE | (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------|-----------|-------------------------|---------------------|--------|-----------|--------|---------------------------------------------------|
| 1823 | ± 5 (| OUR ESTIMATE | | | | | |
| 1823. | 4± 1.4 (| OUR AVERAGE | | | | | |
| 1819. | 4 ± 3.1 ± | :2.0 280 ¹ | BIAGI | 87 | SPEC | 0 | $\Xi^- \text{Be} (\Lambda K^-) X$ |
| 1826 | ± 3 ± | :1 54 | BIAGI | 87c | SPEC | 0 | $\Xi^{-} \xrightarrow{Be} \xrightarrow{\sigma} X$ |
| 1822 | ± 6 | | JENKINS | 83 | MPS | - | $K^-p \rightarrow K^+$ |
| 1830 | ± 6 | 300 | BIAGI | 81 | SPEC | - | SPS hyperon beam |
| 1823 | ± 2 | 130 | GAY | 76C | HB C | - | K^-p 4.2 GeV/c |
| • • • | We do i | not use the following (| data for averages | , fits | , limits, | etc. • | • • |
| 1817 | \pm 3 | | ADAMOVICH | 99в | WA 89 | | Σ [—] nucleus, 345 GeV |
| 1797 | ± 19 | 74 | BRIEFEL | 77 | нвс | 0 | K−p 2.87 GeV/c |
| 1829 | ± 9 | 68 | BRIEFEL | 77 | HB C | -0 | $\Xi(1530)\pi$ |
| 1860 | ± 14 | 39 | BRIEFEL | 77 | HB C | _ | $\Sigma^{-}\overline{K}^{0}$ |
| 1870 | ± 9 | 44 | BRIEFEL | 77 | HB C | 0 | $\Lambda \overline{K}^0$ |
| 1813 | ± 4 | 57 | BRIEFEL | 77 | HB C | _ | ΛK ⁻ |
| 1807 | ± 27 | | DIBIANCA | 75 | DBC | -0 | $\Xi \pi \pi$, $\Xi^* \pi$ |
| 1762 | ± 8 | 28 | BADIER | 72 | HB C | -0 | $\Xi \pi$, $\Xi \pi \pi$, Y K |
| 1838 | ± 5 | 38 | ² BADIER | 72 | HB C | -0 | $\Xi \pi$, $\Xi \pi \pi$, $Y K$ |
| 1830 | ± 10 | 25 | 3 CRENNELL | 70B | DBC | -0 | 3.6, 3.9 GeV/c |
| 1826 | ± 12 | 4 | CRENNELL | 70B | DBC | -0 | 3.6, 3.9 GeV/c |
| 1830 | ± 10 | 40 | ALITTI | 69 | HB C | - | Λ , $\Sigma \overline{K}$ |
| 1814 | ± 4 | 30 | BADIER | 65 | HB C | 0 | л К 0 |
| 1817 | ± 7 | 29 | SMITH | 65 C | HB C | -0 | л к 0, лк— |
| 1770 | | | HALSTEINSLII | D63 | FBC | -0 | K freon 3.5 GeV/ c |

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------|-----------------|----------------------|--------------|-----------|--------|-----------------------------------------------------------------------------------------------------------|
| 24 + 15 O | UR ESTIMATE | | | | | |
| 24 ± 6 O | UR AVERAGE | Error includes scale | fact | or of 1.5 | . See | the ideogram |
| 24.6± 5.3 | 280 | ¹ BIAGI | 87 | SPEC | 0 | $\Xi^- \text{Be} \rightarrow (\Lambda K^-) X$ |
| 12 ±14 ±1 | 7 54 | BIAGI | 8 7 c | SPEC | 0 | $\Xi \stackrel{\cap}{=} \stackrel{\text{Be}}{\to} \stackrel{\rightarrow}{\to} (\Lambda \overline{K^0}) X$ |
| 72 ± 20 | 300 | BIAGI | 81 | SPEC | - | SPS hyperon beam |
| 21 ± 7 | 130 | GAY | 76C | НВС | - | K−p 4.2 GeV/c |
| • • • vve do not | use the followi | ng data for averages | , rits, | , iimits, | etc. • | • • |
| 23 ± 13 | | ADAMOVICH | 99в | WA 89 | | Σ^- nucleus, 345 GeV |
| 99 ±57 | 74 | BRIEFEL | 77 | НВС | 0 | K [−] p 2.87 GeV/c |
| 52 ±34 | 68 | BRIEFEL | 77 | HBC | -0 | $\Xi(1530) \pi$ |
| 72 ± 17 | 39 | BRIEFEL | 77 | нвс | _ | $\Sigma - \overline{K}^0$ |
| 44 ±11 | 44 | BRIEFEL | 77 | нвс | 0 | $\Lambda \overline{K}^0$ |
| 26 ± 11 | 57 | BRIEFEL | 77 | нвс | _ | Λ K- |
| 85 ±58 | | DIBIANCA | 75 | DBC | -0 | $\Xi \pi \pi$, $\Xi^* \pi$ |
| 51 ± 13 | | ² BADIER | 72 | HBC | -0 | Lower mass |

 $^{^1\,\}mathrm{From}$ a fit to the $\varSigma^+\,\mathrm{\it K}^-$ spectrum.

 $^{^2}$ From a coupled-channel analysis of the Σ^+K^- and $\Lambda\overline{K}^0$ spectra. 3 A fit to the inclusive spectrum from $\Xi^-N\to\Lambda K^-X$. 4 From a coupled-channel analysis of the Σ^0K^- and ΛK^- spectra.





Ξ(1820) DECAY MODES

| Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
| $ \begin{array}{l} \Lambda \overline{K} \\ \Sigma \overline{K} \\ \Xi \pi \\ \Xi (1530) \pi \\ \Xi \pi \pi (\text{not } \Xi (1530) \pi) \end{array} $ | large small small small |

Ξ(1820) BRANCHING RATIOS

The dominant modes seem to be $\Lambda \overline{K}$ and (perhaps) $\Xi(1530) \pi$, but the branching fractions are very poorly determined.

| $\Gamma(\Lambda \overline{K})/\Gamma_{\text{total}}$ | | | | | | Γ_1/Γ |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|----------------------------------------------------|---------------|------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.25 ± 0.05 OUR AVER | AGE | | | | | |
| 0.24 ± 0.05 | | ANISOVICH | 12A | DPWA | | Multichannel |
| 0.30 ± 0.15 | | ALITTI | 69 | НВС | _ | K ⁻ ρ 3.9–5 GeV/c |
| $\Gamma(\Xi\pi)/\Gamma_{total}$ | | | | | | Γ_3/Γ |
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.10±0.10 | | ALITTI | 69 | НВС | - | K [−] p 3.9–5 GeV/c |
| $\Gamma(\Xi\pi)/\Gamma(\Lambda\overline{K})$ | | | | | | Γ_3/Γ_1 |
| VALUE | CL% | DO CUMENT ID | | TECN | CHG | COMMENT |
| <0.36 | 95 | GAY | 76C | HBC | - | K^-p 4.2 GeV/ c |
| 0.20 ± 0.20 | | BADIER | 65 | HBC | 0 | K^-p 3 GeV/ c |
| | | | | | | |
| $\Gamma(\Xi\pi)/\Gamma(\Xi(1530))$ | π) | | | | | Γ_3/Γ_4 |
| $\Gamma(\Xi\pi)/\Gamma(\Xi(1530))$ | π) | DOCUMENT ID | | TECN | <u>CHG</u> | Γ ₃ /Γ ₄ |
| , , , | π) | <u>DOCUMENT ID</u> APSELL | 70 | TECN HBC | <u>снс</u> 0 | |
| $1.5 + 0.6 \Gamma(\Sigma \overline{K})/\Gamma_{\text{total}}$ | π) | APSELL | 70 | НВС | 0 | COMMENT K ⁻ ρ 2.87 GeV/c Γ ₂ /Γ |
| $ \begin{array}{c} 1.5 + 0.6 \\ 1.5 - 0.4 \end{array} $ $ \Gamma(\Sigma \overline{K})/\Gamma_{\text{total}} $ VALUE | π) | APSELL DO CUMENT ID | | HBC TECN | | COMMENT K ⁻ ρ 2.87 GeV/c Γ ₂ /Γ |
| $ \frac{VALUE}{1.5 + 0.6} $ $ \frac{\Gamma(\Sigma \overline{K})}{\Gamma_{\text{total}}} $ $ \frac{VALUE}{0.30 \pm 0.15} $ | | APSELL DOCUMENT ID ALITTI | 69 | HBC TECN HBC | 0 <u>CHG</u> — | COMMENT K - p 2.87 GeV/c F2/F COMMENT K - p 3.9-5 GeV/c |
| $ \begin{array}{c} 1.5 + 0.6 \\ 1.5 - 0.4 \end{array} $ $ \Gamma(\Sigma \overline{K})/\Gamma_{\text{total}} $ VALUE | | APSELL DOCUMENT ID ALITTI | 69 | HBC TECN HBC | 0 <u>CHG</u> — | COMMENT K - p 2.87 GeV/c F2/F COMMENT K - p 3.9-5 GeV/c |
| $ \frac{VALUE}{1.5 + 0.6} $ $ \frac{\Gamma(\Sigma \overline{K})}{\Gamma_{\text{total}}} $ $ \frac{VALUE}{0.30 \pm 0.15} $ | | APSELL DOCUMENT ID ALITTI | 69 | HBC TECN HBC | 0 <u>CHG</u> — | COMMENT K - p 2.87 GeV/c F2/F COMMENT K - p 3.9-5 GeV/c |
| $ \frac{VALUE}{1.5 + 0.6} $ $ \Gamma(\Sigma \overline{K})/\Gamma_{\text{total}} $ $ \frac{VALUE}{0.30 \pm 0.15} $ • • • We do not use the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condition of the condit | | APSELL DOCUMENT ID ALITTI data for average TRIPP | 69 s, fits | HBC TECN HBC , limits, RVUE | 0 <u>CHG</u> — etc. • | $\frac{COMMENT}{K^-p \ 2.87} \frac{COMMENT}{GeV/c}$ $\frac{COMMENT}{K^-p \ 3.9-5} \frac{GeV/c}{GeV/c}$ • • Use SMITH 65c |
| $VALUE$ 1.5 + 0.6 1.5 - 0.4 Γ(Σ \overline{K})/Γtotal $VALUE$ 0.30 ± 0.15 • • • We do not use to <0.02 | | APSELL DOCUMENT ID ALITTI data for average | 69 s, fits | HBC TECN HBC , limits, RVUE | 0 <u>CHG</u> — | $\begin{array}{c} \underline{COMMENT} \\ K-p \ 2.87 \\ \text{GeV}/c \\ \hline \\ \hline \hline \hline \\ \underline{COMMENT} \\ K-p \ 3.9-5 \\ \text{GeV}/c \\ \hline \\ \hline \\ \text{Use SMITH 65c} \\ \end{array}$ |

| $\Gamma(\Xi(1530)\pi)/\Gamma_{total}$ | | | | | Γ4/Γ |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|------------------------------|------------------------------|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.30 ± 0.15 | ALITTI | 69 | нвс | - | K−p 3.9–5 GeV/c |
| ● ● We do not use the f | following data for average | es, fits | , limits, | etc. • | • • |
| seen | ASTON | 85B | LASS | | K^-p 11 GeV/c |
| not seen | ⁵ HA SSALL | 81 | HBC | | K-p 6.5 GeV/c |
| < 0.25 | ⁶ DAUBER | 69 | нвс | | K [−] p 2.7 GeV/c |
| $\Gamma(\Xi(1530)\pi)/\Gamma(\Lambda\overline{K})$ | | | | | Γ_4/Γ_1 |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.38±0.27 OUR AVERAGE | E Error includes scale f | actor c | of 2.3. | | |
| | | | HBC | | $K^{-}p$ 4.2 GeV/c |
| 1.0 ±0.3 | GAY | 76C | пьс | _ | |
| $\begin{array}{c} - \\ 1.0 \pm 0.3 \\ 0.26 \pm 0.13 \end{array}$ | GAY SMITH | | НВС | _ _0 | K-p 2.45-2.7 GeV/c |
| | SMITH | | | -0 | K ⁻ p 2.45-2.7 GeV/c |
| 0.26 ± 0.13 $\Gamma(\Xi \pi \pi \text{ (not } \Xi(1530) \pi))$ | SMITH | | | _0 0 | κ-p 2.45-2.7 |
| 0.26 ± 0.13 $\Gamma(\Xi \pi \pi \text{ (not } \Xi(1530) \pi))$ | smith r))/Γ(Λ <i>K</i>) | | НВС | | $K^{-}_{p} \stackrel{2.45-2.7}{\text{GeV}/c}$ |
| 0.26 ± 0.13 $\Gamma(\Xi \pi \pi \text{ (not } \Xi(1530) \pi)$ 0.30 ± 0.20 | SMITH r))/Г(ЛК) | 65 c | HBC TECN SPEC | <u>снв</u> – | K^-p 2.45-2.7 GeV/c F_5/F_1 $\frac{COMMENT}{\Xi^- Be 116 GeV}$ |
| 0.26 ± 0.13 $\Gamma(\Xi \pi \pi \text{ (not } \Xi(1530) \pi)$ 0.30 ± 0.20 | SMITH r))/Г(ЛК) | 65 c | HBC TECN SPEC | <u>снв</u> – | K^-p 2.45-2.7 GeV/c F_5/F_1 $\frac{COMMENT}{\Xi^- Be 116 GeV}$ |
| Γ ($\Xi \pi \pi$ (not Ξ (1530) π $VALUE$ 0.30 \pm 0.20 • • • We do not use the f | SMITH r))/Γ(ΛΚ) DOCUMENT ID BIAGI following data for average | 87 es, fits 65 | HBC TECN SPEC , limits, | <u>CHG</u> — etc. • | $K = p 2.45 - 2.7$ GeV/c F_5/F_1 $\underline{COMMENT}$ Ξ Be 116 GeV |
| 0.26 \pm 0.13 $\Gamma\left(\Xi\pi\pi\left(\text{not }\Xi(1530\right)\pi\right)$ $VALUE$ 0.30 \pm 0.20 • • • We do not use the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solutio | SMITH r))/Γ(ΛΚ) DOCUMENT ID BIAGI following data for average 7 BADIER SMITH | 87 es, fits 65 | HBC TECN SPEC , limits, HBC | <u>CHG</u> — etc. • | $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_1 $E - Be \ 116 \ GeV$ • • 1 st. dev. limit $K - p \ 2.45 - 2.7$ GeV/c |
| Γ ($\Xi \pi \pi$ (not Ξ (1530) π $VALUE$ 0.30 \pm 0.20 • • • We do not use the π <0.14 | SMITH r))/Γ(ΛΚ) DOCUMENT ID BIAGI following data for average 7 BADIER SMITH | 87 es, fits 65 | HBC TECN SPEC , limits, HBC | <u>CHG</u> — etc. • | $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_1 $\Xi - Be \ 116 \ GeV$ • • 1 st. dev. limit $K - p \ 2.45 - 2.7$ |
| 0.26 \pm 0.13 Γ ($\Xi \pi \pi$ (not Ξ (1530) π VALUE 0.30 \pm 0.20 • • • We do not use the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of | SMITH (r))/ $\Gamma(\Lambda \overline{K})$ BIAGI following data for average 7 BADIER SMITH (r))/ $\Gamma(\Xi(1530)\pi)$ | 87 es, fits 65 65 c | TECN SPEC, limits, HBC | <u>CHG</u> _ etc. • 0 _ 0 | $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_1 $E - Be \ 116 \ GeV$ • • 1 st. dev. limit $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_4 |
| 0.26 \pm 0.13 $\Gamma(\Xi \pi \pi (\text{not } \Xi(1530) \pi))$ VALUE 0.30 \pm 0.20 • • • We do not use the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the solution of the s | SMITH r))/ $\Gamma(\Lambda K)$ BIAGI following data for average 7 BADIER SMITH r))/ $\Gamma(\Xi(1530)\pi)$ DOCUMENT ID GAY | 87 es, fits 65 65 c | TECN SPEC, limits, HBC HBC | <u>CHG</u> — etc. • 0 —0 | $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_5 $COMMENT$ Ξ - Be 116 GeV • 1 st. dev. limit $K - p \ 2.45 - 2.7$ GeV/c Γ_5/Γ_A $COMMENT$ $K - p \ 4.2 \ GeV/c$ |

Ξ(1820) FOOTNOTES

- 1 BIAGI 87 also sees weak signals in the in the $\Xi^-\pi^+\pi^-$ channel at 1782.6 \pm 1.4 MeV ($\Gamma=6.0\pm1.5$ MeV) and 1831.9 \pm 2.8 MeV ($\Gamma=9.6\pm9.9$ MeV). 2 BADIER 72 adds all channels and divides the peak into lower and higher mass regions. The data can also be fitted with a single Breit-Wigner of mass 1800 MeV and width 150 MeV. 3 From a fit to inclusive $\Xi\pi$, $\Xi\pi\pi$, and ΛK^- spectra. 4 From a fit to inclusive $\Xi\pi$ and $\Xi\pi\pi$ spectra only. 5 Including $\Xi\pi\pi$

I

- From a fit to inclusive $\equiv \pi$ and $\equiv \pi$ and $\equiv \pi$ and $\equiv \pi$. Specially, $\equiv \pi$ including $\equiv \pi\pi$. 6 DAUBER 69 uses in part the same data as SMITH 65c. 7 For the decay mode $\equiv \pi + \pi^0$ only. This limit includes $\equiv (1530)\pi$. 8 Or less. Upper limit for the 3-body decay.

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 $\Xi(1950), \Xi(2030)$

$\Xi(1950)$

$$I(J^P) = \frac{1}{2}(?^?)$$
 Status: ***

We list here everything reported between 1875 and 2000 MeV. The accumulated evidence for a Ξ near 1950 MeV seems strong enough to include a Ξ (1950) in the main Baryon Table, but not much can be said about its properties. In fact, there may be more than one Ξ near this mass.

| | | <i>Ξ</i> (1950) MAS | S | | |
|--------------------|-------|---------------------|-----|-------|-----------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1950±15 OUR EST | IMATE | | | | |
| 1955 ± 6 | | ADAMOVICH | 99B | WA 89 | Σ^- nucleus, 345 GeV |
| 1944 ± 9 | 129 | BIAGI | 87 | | $\Xi^- \text{Be} (\Xi^- \pi^+) \pi^- X$ |
| $1963 \pm 5 \pm 2$ | 63 | BIAGI | 87c | SPEC | Ξ^- Be $\rightarrow (\Lambda \overline{K}^0) X$ |
| 1937 ± 7 | 150 | BIAGI | 81 | SPEC | SPS hyperon beam |
| 1961 ± 18 | 139 | BRIEFEL | 77 | НВС | $2.87 K^- p \rightarrow \Xi^- \pi^+ X$ |
| 1936 ± 22 | 44 | BRIEFEL | 77 | нвс | |
| 1964 ± 10 | 56 | BRIEFEL | 77 | HBC | $\Xi(1530)\pi$ |
| 1900 ± 12 | | DIBIANCA | 75 | DBC | $\Xi \pi$ |
| 1952 ± 11 | 25 | ROSS | 73C | | $(\Xi\pi)^-$ |
| 1956 ± 6 | 29 | BADIER | 72 | HBC | $\Xi\pi$, $\Xi\pi\pi$, YK |
| 1955 ± 14 | 21 | GOLDWASSER | 70 | HBC | $\Xi \pi$ |
| 1894 ± 18 | 66 | DAUBER | 69 | HBC | $\Xi \pi$ |
| 1930 ± 20 | 27 | ALITTI | 68 | HBC | $\Xi^{-}\pi^{+}$ |
| 1933 ± 16 | 35 | BADIER | 65 | нвс | $\Xi^-\pi^+$ |

Ξ(1950) WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-------|-------------|-----|-------|-----------------------------------------------------------|
| 60±20 OUR EST | IMATE | | | | |
| $68\!\pm\!22$ | | ADA MOVICH | 99B | WA 89 | Σ^- nucleus, 345 GeV |
| 100 ± 31 | 129 | BIAGI | 87 | | Ξ^{-} Be \rightarrow $(\Xi^{-}\pi^{+})\pi^{-}$ X |
| $25 \pm 15 \pm 1.2$ | 63 | BIAGI | 87c | SPEC | Ξ^{-} Be $\rightarrow (\Lambda \overline{K}^{0}) X$ |
| 60± 8 | 150 | BIAGI | 81 | SPEC | SPS hyperon beam |
| 159 ± 57 | 139 | BRIEFEL | 77 | HBC | $2.87 K^-p \rightarrow$ |
| | | | | | $\Xi^-\pi^+X$ |
| 87 ± 26 | 44 | BRIEFEL | 77 | HBC | 2.87 $K^- p \to \Xi^0 \pi^- X$ |
| 60 ± 39 | 56 | BRIEFEL | 77 | HBC | $\Xi(1530)\pi$ |
| 63±78 | | DIBIANCA | 75 | DBC | $\Xi \pi$ |
| 38 ± 10 | | ROSS | 73C | | (Ξπ) ⁻ |
| 35 ± 11 | 29 | BADIER | 72 | HBC | $\Xi \pi$, $\Xi \pi \pi$, Y K |
| 56 ± 26 | 21 | GOLDWASSEF | 70 | HBC | $\equiv \pi$ |
| 98 ± 23 | 66 | DAUBER | 69 | HBC | $\Xi \pi$ |
| 80±40 | 27 | ALITTI | 68 | HBC | $\Xi^-\pi^+$ |
| 140 ± 35 | 35 | BADIER | 65 | нвс | $\Xi^-\pi^+$ |

≡(1950) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|-----------------------------------------------------------------------|------------------------------|
| Γ ₁ Γ ₂ | Λ <u>Κ</u> Σ <u>Κ</u> | seen possibly seen |
| | $\Xi \pi$ $\Xi (1530) \pi$ $\Xi \pi \pi (\text{not } \Xi (1530) \pi)$ | seen |

Ξ(1950) BRANCHING RATIOS

| $\Gamma(\Sigma \overline{K})/\Gamma(\Lambda \overline{X})$ | K) | | | | | Γ_2/Γ_1 |
|------------------------------------------------------------|----------------|----------|-----------------|-------------|------|--------------------------------|
| VALUE | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| <2.3 | 90 | 0 | BIAGI | 87 c | SPEC | Ξ−Be 116 GeV |
| $\Gamma(\Sigma \overline{K})/\Gamma_{\text{tota}}$ | ıl | | | | | Г2/Г |
| VALUE | | EVTS | DO CUMENT ID | | TECN | COMMENT |
| possibly seen | | 17 | HASSALL | 81 | HBC | K^-p 6.5 GeV/ c |
| $\Gamma(\Xi\pi)/\Gamma(\Xi($ | 1530)π | r) | | | | Γ_3/Γ_4 |
| VALUE | | <u> </u> | DO CUMENT ID | | TECN | |
| $2.8 {}^{+ 0.7}_{- 0.6}$ | | | APSELL | 70 | нвс | |
| Γ(Ξππ(not 3 | = (1530 |) π))/Γ(| $\Xi(1530)\pi)$ | | | Γ ₅ /Γ ₄ |
| VALUE | | | DOCUMENT ID | | TECN | |
| 0.0 ± 0.3 | | | APSELL | 70 | HBC | |

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| A Iso | | Duke Conf. 317 | E. Briefel et al. | (BRAN, UMD, SYRA+) |
| Hyperon R | eso n an | ces, 1970 | | |
| DIBIAN CA | 75 | NP B98 137 | F.A. Dibianca, R.J. Endorf | (CMU) |
| ROSS | 73 C | Purdue Conf. 345 | R.T. Ross, J.L. Lloyd, D. Rado | jicic (OXF) |
| BADIER | 72 | NP B37 429 | J. Badier et al. | (ÈPOL) |
| APSELL | 70 | PRL 24 777 | S.P. Apsell et al. | (BRAN, UMD, SYRA+)I |
| GOLDWASSER | 70 | PR D1 1960 | E.L. Goldwasser, P.F. Schultz | (ILL) |
| DAUBER | 69 | PR 179 1262 | P.M. Dauber et al. | (ÌRLÍ I |
| ALITTI | 68 | PRL 21 1119 | J. Alitti et al. | (BNL, SÝRA)I |
| BADIER | 65 | PL 16 171 | J. Badier et al. | (EPOL, SACL, AMST) I |

$\Xi(2030)$

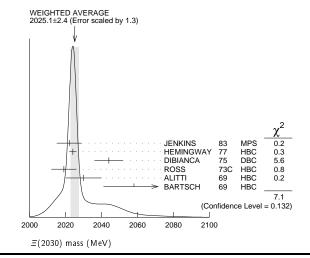
$$I(J^P) = \frac{1}{2} (\geq \frac{5}{2}?$$
\$tatus: ***

The evidence for this state has been much improved by HEMING-WAY 77, who see an eight standard deviation enhancement in $\Sigma\overline{K}$ and a weaker coupling to $\Lambda\overline{K}$. ALITTI 68 and HEMINGWAY 77 observe no signals in the $\Xi\pi\pi$ (or $\Xi(1530)\pi$) channel, in contrast to DIBIANCA 75. The decay $(\Lambda/\Sigma)\overline{K}\pi$ reported by BARTSCH 69 is also not confirmed by HEMINGWAY 77.

A moments analysis of the HEMINGWAY 77 data indicates at a level of three standard deviations that $J \geq 5/2$.

≡(2030) MASS

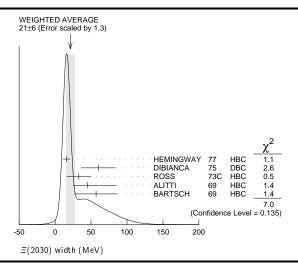
| VALUE | (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-------|----------|--------------|----------------------|-------|-----------|--------|-----------------------------|
| 2025 | ± 5 | OUR ESTIMATE | | | | | |
| 2025. | 1 ± 2.4 | OUR AVERAGE | Error includes scale | facto | r of 1.3. | See th | ne ideogram below. |
| 2022 | ± 7 | | JENKINS | 83 | MPS | _ | $K^-p \rightarrow K^+$ |
| | | | | | | | MM |
| 2024 | \pm 2 | 200 | HEMINGWAY | 77 | HBC | _ | $K^- p$ 4.2 GeV/c |
| 2044 | ± 8 | | DIBIANCA | 75 | DBC | -0 | $\Xi \pi \pi$, $\Xi^* \pi$ |
| 2019 | ± 7 | 15 | ROSS | 73C | HB C | -0 | $\Sigma \overline{K}$ |
| 2030 | ± 10 | 42 | ALITTI | 69 | HB C | _ | K - p 3.9-5 |
| | | | | | | | GeV / c |
| 2058 | ± 17 | 40 | BARTSCH | 69 | HBC | -0 | K [−] p 10 GeV/c |



Ξ(2030) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|-----------------------------------------------|-------------------|---------------------|-------|----------|--------|-----------------------------|
| 20 ^{+ 15} / ₅ OUR ESTIMAT | ΓΕ | | | | | |
| 21 ± 6 OUR AVERAG | E Error in | cludes scale factor | of 1. | 3. See t | he ide | ogram below. |
| $16\pm$ 5 | 200 | HEMINGWAY | 77 | нвс | _ | K^-p 4.2 GeV/ c |
| 60 ± 24 | | DIBIANCA | 75 | DBC | -0 | $\Xi \pi \pi$, $\Xi^* \pi$ |
| 33 ± 17 | 15 | ROSS | 73C | нвс | -0 | $\Sigma \overline{K}$ |
| $45 + 40 \\ -20$ | | ALITTI | 69 | нвс | - | K−p 3.9–5 GeV/c |
| 57±30 | | BARTSCH | 69 | HB C | -0 | K^-p 10 GeV/c |

Baryon Particle Listings $\Xi(2030), \Xi(2120)$



Ξ(2030) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda \overline{K}$ | ~ 20 % |
| Γ_2 | $\Sigma \overline{K}$ | \sim 80 % |
| Г3 | $\equiv \pi$ | small |
| Γ_4 | $\Xi(1530)\pi$ | small |
| Γ_5 | $\Xi \pi \pi $ (not Ξ (1530) π) | small |
| Γ ₆ | $\Lambda \overline{K} \pi$ | small |
| Γ_7 | $\Sigma \overline{K} \pi$ | small |

Ξ(2030) BRANCHING RATIOS $\Gamma(\Xi\pi)/\big[\Gamma(\Lambda\overline{K})+\Gamma(\Sigma\overline{K})+\Gamma(\Xi\pi)+\Gamma(\Xi(1530)\pi)\big] \quad \Gamma_3/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4)$

| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------------------------------------------------------|---------------------------------|-------------------------------------------|-------------|-----------------|--------|-----------------------------------------------------|
| • • • We do not use | the followir | ng data for average | es, fits | s, limits, | etc. • | • • |
| < 0.30 | | ALITTI | 69 | НВС | - | 1 standard dev. limit |
| $\Gamma(\Xi\pi)/\Gamma(\Sigma\overline{K})$ | | | | | | Γ3/Γ2 |
| VALUE | CL% | DOCUMENT ID | | TECN | CHG | COMMENT |
| < 0.19 | 95 | HEMINGWAY | 77 | нвс | - | K−p 4.2 GeV/c |
| $\Gamma(\Lambda \overline{K})/[\Gamma(\Lambda \overline{K}) +$ | $\Gamma(\Sigma \overline{K})$ - | | | | | |
| 0.25 ± 0.15 | | <u>DO CUMENT ID</u> ALITTI | 69 | HBC | | COMMENT K - p 3.9-5 GeV/c |
| $\Gamma(\Lambda \overline{K})/\Gamma(\Sigma \overline{K})$ | | | | | | Γ ₁ /Γ ₂ |
| VALUE | | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.22±0.09 | | HEMINGWAY | 77 | нвс | - | K-p 4.2 GeV/c |
| $\Gamma(\Sigma \overline{K})/[\Gamma(\Lambda \overline{K}) +$ | · Γ(Σ K) | + Γ(<i>Ξ</i> π) + Γ(<i>Ξ</i> | E(153 | 30)π)] | Γ2/(| $\Gamma_{1} + \Gamma_{2} + \Gamma_{3} + \Gamma_{4}$ |
| VALUE | | DO CUMENT ID | | | | |
| 0.75 ± 0.20 | | ALITTI | 69 | НВС | - | K [−] p 3.9–5 GeV/c |
| Γ(Ξ(1530)π)/[Γ(| л ₹) + г(| $(\Sigma \overline{K}) + \Gamma(\Xi \pi)$ | + Γ(| Ξ(153 | | |
| | | | | | | $\Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_4$ |
| VALUE | | | | | | COMMENT |
| • • • We do not use | the following | | | | | |
| < 0.15 | | ALITTI | 69 | нвс | _ | 1 standard dev. limit |
| [Γ(Ξ(1530)π) + Γ | (Ξππ(no | ot Ξ(1530) π))] | /Γ(Σ | (K) | | $(\Gamma_4 + \Gamma_5)/\Gamma_2$ |
| VALUE | | DO CUMENT ID | | | CHG | // - |
| < 0.11 | 95 | 1 HEMINGWAY | | | _ | K-p 4.2 GeV/c |
| $\Gamma(\Lambda \overline{K}\pi)/\Gamma_{\text{total}}$ | | | | | | Γ ₆ /Ι |
| VALUE | | DO CUMENT ID | | TECN | COMI | -, |
| • • • We do not use | the followin | | | | | |
| seen | | BARTSCH | 69 | | | 10 GeV |
| $\Gamma(\Lambda \overline{K}\pi)/\Gamma(\Sigma \overline{K})$ | | | | | | Γ ₆ /Γ ₂ |
| VALUE | C1 % | DOCUMENT ID | | TECN | CHG | COMMENT |

< 0.32

95

HEMINGWAY 77 HBC - K^-p 4.2 GeV/c

| $\Gamma(\Sigma \overline{K}\pi)/\Gamma_{\text{total}}$ | | | | | | | Γ_7/Γ |
|--------------------------------------------------------------|---------------|------------------------|---------|-----------|--------|------------|---------------------|
| VALUE | | DO CUMENT ID | | TECN | COMN | 1ENT | • |
| | the following | g data for average | s, fits | , limits, | etc. • | • • | |
| seen | | BARTSCH | 69 | нвс | K^-p | 10 GeV | |
| $\Gamma(\Sigma \overline{K}\pi)/\Gamma(\Sigma \overline{K})$ |) | | | | | | Γ_7/Γ_2 |
| VALUE | CL% | DO CUMENT ID | | TECN | CHG | COMMENT | |
| < 0.04 | 95 | ² HEMINGWAY | 77 | нвс | - | K^-p 4.2 | GeV/c |
| | Ē | (2030) FOOTN | ОТЕ | S | | | |

 $^{^{1}}$ For the decay mode $\Xi^{-}\pi^{+}\pi^{-}$ only.

Ξ(2030) REFERENCES

| JEN KINS | 83 | PRL 51 951 | C.M. Jenkins et al. | (FSU, BRAN, LBL+) |
|-----------|------|------------------|--------------------------------|-----------------------|
| HEMINGWAY | 77 | PL 68B 197 | R.J. Hemingway et al. | (AMST, CERN, NIJM+)IJ |
| A Iso | | PL 62B 477 | J.B. Gay et al. | `(AMST, CERN, NIJM) |
| DIBIAN CA | 75 | NP B98 137 | F.A. Dibianca, R.J. Endorf | (CMU) |
| ROSS | 73 C | Purdue Conf. 345 | R.T. Ross, J.L. Lloyd, D. Rado | jicic (OXF) |
| ALITTI | 69 | PRL 22 79 | J. Alitti et al. | (BNL, SYRA) I |
| BARTS CH | 69 | PL 28B 439 | J. Bartsch et al. | (AACH, BERL, CERN+) |
| ALITTI | 68 | PRL 21 1119 | J. Alitti et al. | ` (BNL, SYRA) |

$\Xi(2120)$

F/AV)/F

 $I(J^P) = \frac{1}{2}(?^?)$ Status: * J, P need confirmation.

OMITTED FROM SUMMARY TABLE

| Ξ(2120) MASS |
|--------------|
|--------------|

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------|------|------------------------|-----|------|---------------------------|
| ≈ 2120 OUR ESTIMATI | E | | | | |
| 2137 ± 4 | 18 | ¹ CHLIAPNIK | 79 | HBC | K ⁺ ρ 32 GeV/c |
| 2123 ± 7 | | ² GAY | 76C | HB C | K^-p 4.2 GeV/ c |

Ξ(2120) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|------|------------------|-----|------|-----------------|
| <20 | 18 | 1 CHLIAPNIK | 79 | нвс | K+ p 32 GeV/c |
| 25 + 12 | | ² GAY | 76C | HBC | K - n 4 2 GeV/c |

Ξ(2120) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------------|------------------------------|
| Γ ₁ | $\Lambda \overline{K}$ | seen |

Ξ(2120) BRANCHING RATIOS

| '(/\^)/'total | | | 11/1 |
|---------------|------------------|---------|------------------------------------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT |
| seen | | 79 HBC | $K^+ p \rightarrow (\overline{\Lambda} K^+) X$ |
| seen | ² GAY | 76c HBC | K^-p 4.2 GeV/c |
| | | | |

Ξ (2120) FOOTNOTES

Ξ(2120) REFERENCES

| CHLIAPNIK 7 HEMINGWAY 7 GAY 7 | 77 PI | L 68B 197 | P.V. Chliapnikov et al. R.J. Hemingway et al. J.B. Gay et al. | (CERN, BELG, MONS) (AMST, CERN, NIJM+) (AMST, CERN, NIJM) |
|-------------------------------------|-------|-----------|---------------------------------------------------------------------|-----------------------------------------------------------------|
|-------------------------------------|-------|-----------|---------------------------------------------------------------------|-----------------------------------------------------------------|

² For the decay mode $\Sigma^{\pm} K^{-} \pi^{\mp}$ only.

 $^{^1}$ CHLIAPNIKOV 79 does not uniquely identify the K^+ in the $(\overline{\Lambda}\,K^+)$ X final state. It also reports bumps with fewer events at 2240, 2540, and 2830 MeV. 2 GAY 76c sees a 4-standard deviation signal. However, HEMINGWAY 77, with more events from the same experiment points out that the signal is greatly reduced if a cut is made on the 4-momentum u. This suggests an anomalous production mechanism if the $\Xi(2120)$ is real.

 $\Xi(2250), \Xi(2370), \Xi(2500)$

(2250)

 $I(J^P) = \frac{1}{2}(?^?)$ Status: **

J, P need confirmation.

OMITTED FROM SUMMARY TABLE

The evidence for this state is mixed. BARTSCH 69 sees a bump of not much statistical significance in $\Lambda \overline{K} \pi$, $\Sigma \overline{K} \pi$, and $\Xi \pi \pi$ mass spectra. GOLDWASSER 70 sees a narrower bump in $\Xi\,\pi\,\pi$ at a higher mass. Not seen by HASSALL 81 with 45 events/ μ b at 6.5 ${\rm GeV}/c$. Seen by JENKINS 83. Perhaps seen by BIAGI 87.

| | | <i>Ξ</i> (2250) MA | SS | | | |
|-------------------|------|---------------------|------|------|-----|-----------------------------------------------|
| ALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| ≈ 2250 OUR EST | MATE | | | | | |
| 2189± 7 | 66 | BIAGI | 87 | SPEC | - | Ξ^{-} Be $$ $(\Xi^{-}\pi^{+}\pi^{-})$ |
| $2214 \pm \ 5$ | | JENKINS | 83 | MPS | - | $K \stackrel{\wedge}{=} p \rightarrow K^+$ MM |
| 2295 ± 15 | 18 | GOLDWASSE | R 70 | HBC | _ | K-p 5.5 GeV/ |
| $2244 \!\pm\! 52$ | 35 | BARTSCH | 69 | нвс | | K ⁻ ρ 10 GeV/c |
| | | <i>Ξ</i> (2250) WID | ТН | | | |
| ALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| 46±27 | 66 | BIAGI | 87 | SPEC | - | Ξ^- Be \rightarrow $(\Xi^-\pi^+\pi^-)$ |
| < 30 | | GOLDWASSE | R 70 | нвс | _ | $K \stackrel{\frown}{=} p 5.5 \text{ GeV}/$ |
| 130±80 | | BARTSCH | 69 | нвс | | . , |

Ξ(2250) DECAY MODES

| | Mode |
|----------------|----------------------------|
| Γ ₁ | $\Xi \pi \pi$ |
| Γ_2 | $\Lambda \overline{K} \pi$ |
| Γ_3 | $\Sigma \overline{K} \pi$ |

Ξ(2250) REFERENCES

| BIAGI | 87 | ZPHY C34 15 | S.F. Biagi et al. | (BRIS, CERN, GEVA+) |
|------------|----|-------------|-------------------------------|---------------------|
| JENKINS | 83 | PRL 51 951 | C.M. Jenkins et al. | (FSU, BRAN, LBL+) |
| HASSALL | 81 | NP B189 397 | J.K. Hassall et al. | (CAVE, MSU) |
| GOLDWASSER | 70 | PR D1 1960 | E.L. Goldwasser, P.F. Schultz | (ILL) |
| BARTS CH | 69 | PL 28B 439 | J. Bartsch <i>et al</i> . | (AACH, BERL, CERN+) |



 $I(J^P) = \frac{1}{2}(?^?)$ Status: ** J, P need confirmation.

OMITTED FROM SUMMARY TABLE

| | | <i>Ξ</i> (2370) MA | cc | | | |
|-------------------|------|---------------------|-----|------|-----|--------------------------------|
| | | =(2370) MA | 33 | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| ≈ 2370 OUR EST | MATE | | | | | |
| $2356 \!\pm\! 10$ | | JENKINS | 83 | MPS | - | $K^-p \rightarrow K^+$ MM |
| 2370 | 50 | HASSALL | 81 | HBC | -0 | K^-p 6.5 GeV/ c |
| 2373± 8 | 94 | AMIRZADEH | 80 | НВС | -0 | K−p 8.25 GeV/c |
| 2392±27 | | DIBIANCA | 75 | DBC | | $\Xi 2\pi$ |
| | | <i>≣</i> (2370) WID | TH | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | CHG | COMMENT |
| 80 | 50 | HASSALL | 81 | HBC | -0 | K^-p 6.5 GeV/c |
| 80 ± 25 | 94 | AMIRZADEH | 80 | НВС | -0 | K ⁻ p 8.25 GeV/c |
| 75 ± 69 | | DIBIANCA | 75 | DBC | | Ξ 2π |
| | -/ | 2270) DECAV I | 400 | VEC. | | |

Ξ(2370) DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|---------------------------------------------------------------|------------------------------|
| Γ ₁ | $\Lambda \overline{K} \pi$ Includes $\Gamma_4 + \Gamma_6$. | seen |
| Γ_2 | $\Sigma \overline{K} \pi$ Includes $\Gamma_5 + \Gamma_6$. | seen |
| Γ_3 | Ω^-K | |
| Γ ₃ Γ ₄ | Λ K *(892) | |
| Γ_5 | $\Sigma \overline{K}^*(892)$ | |
| Γ ₆ | $\Sigma(1385)\overline{K}$ | |

Ξ(2370) BRANCHING RATIOS

| $\Gamma(\Lambda \overline{K}\pi)/\Gamma_{total}$ | | | | | Γ_1/Γ |
|-----------------------------------------------------------------------------------------------------------------------|---------------------|----|------|------------|--------------------------------|
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| seen | AMIRZADEH | 80 | нвс | -0 | K−p 8.25 GeV/c |
| $\Gamma(\Sigma \overline{K}\pi)/\Gamma_{total}$ | | | | | Γ_2/Γ |
| VALUE | DO CUMENT ID | | TECN | <u>CHG</u> | COMMENT |
| seen | AMIRZADEH | 80 | НВС | -0 | K [−] p 8.25 GeV/c |
| $\left[\Gamma\left(\Lambda\overline{K}\pi\right)+\Gamma\left(\Sigma\overline{K}\pi\right)\right]/\Gamma_{\text{tot}}$ | al | | | | $(\Gamma_1 + \Gamma_2)/\Gamma$ |
| VALUE EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
| seen 50 | HASSALL | 81 | HBC | -0 | K^-p 6.5 GeV/ c |
| $\Gamma(\Omega^-K)/\Gamma_{\text{total}}$ | | | | | Γ_3/Γ |
| VALUE | DO CUMENT ID | | TECN | <u>CHG</u> | COMMENT |
| 0.09 ± 0.04 | ¹ KINSON | 80 | НВС | - | K [−] p 8.25 GeV/c |
| $[\Gamma(\Lambda \overline{K}^*(892)) + \Gamma(\Sigma \overline{K}^*(892))]$ | , - | | | | $(\Gamma_4 + \Gamma_5)/\Gamma$ |
| VALUE | DO CUMENT ID | | TECN | CHG | COMMENT |
| 0.22 ± 0.13 | ¹ KINSON | 80 | НВС | - | K−p 8.25 GeV/c |
| $\Gamma(\Sigma(1385)\overline{K})/\Gamma_{total}$ | | | | | Γ_6/Γ |
| VALUE | DO CUMENT ID | | TECN | <u>CHG</u> | COMMENT |
| 0.12 ± 0.08 | ¹ KINSON | 80 | НВС | - | K [−] p 8.25 GeV/c |

Ξ(2370) FOOTNOTES

 $^{1}\, \text{KINSON}$ 80 is a reanalysis of AMIRZADEH 80 with 50% more events.

Ξ(2370) REFERENCES

| JEN KINS HAS SALL AM IR ZADEH KINS ON DIBIAN CA | 83 81 80 80 75 | PRL 51 951 NP B189 397 PL 90B 324 Toronto Conf. 2 NP B98 137 | J.K. J. A 263 J.B. | . Jenkins et al. Hassall et al. mirzadeh et al. Kinson et al. Dibianca, R.J. Endorf | (FSU, BRA (CA (BIRM, CERN (BIRM, CERN | .VĖ, MSU) I, GLAS+)I |
|-------------------------------------------------------------|----------------------------|--------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------|-------------------------|
|-------------------------------------------------------------|----------------------------|--------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------|-------------------------|



 0.5 ± 0.2

 $I(J^P) = \frac{1}{2}(?^?)$ Status: * J, P need confirmation.

OMITTED FROM SUMMARY TABLE

The ALITTI 69 peak might be instead the $\Xi(2370)$ or might be neither the $\Xi(2370)$ nor the $\Xi(2500)$.

≡(2500) MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|------------------|------|--------------|----|-------|-----|----------------------------------|
| ≈ 2500 OUR ESTIM | MATE | | | | | |
| 2505 ± 10 | | JENKINS | 83 | MPS | - | $K^-p \rightarrow K^+$ |
| 0400 00 | 20 | ALITT | | LID C | | MM |
| 2430 ± 20 | 30 | ALITTI | 69 | нвс | - | K [—] p 4.6−5 GeV /c |
| 2500±10 | 45 | BARTSCH | 69 | нвс | -0 | $K^- p$ 10 GeV/c |
| 2300±10 | 45 | DAICTSCIT | 0, | пьс | -0 | K p 10 dcv/c |

Ξ(2500) WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | CHG |
|-------------------|-------------|----|------|-----|
| $150 + 60 \\ -40$ | ALITTI | 69 | нвс | _ |
| 59±27 | BARTSCH | 69 | нвс | -0 |

Ξ(2500) DECAY MODES

| | Mode | Fraction (Γ _i /Γ) |
|-----------------------|-------------------------------------------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Xi \pi$ | |
| Γ_2^- | $\overline{\Xi} \frac{\pi}{K}$ | |
| Γ_3 | $\Sigma \overline{K}$ | |
| Γ_4 | $\Xi \pi \pi$ | seen |
| Γ_5 | $\Xi(1530)\pi$ | |
| Γ ₆ | $ \Xi \pi \pi \Xi (1530) \pi \Lambda \overline{K} \pi + \Sigma \overline{K} \pi $ | seen |

Ξ(2500) BRANCHING RATIOS

| $\Gamma(\Xi\pi)/[\Gamma(\Xi\pi) +$ | $\Gamma(\Lambda \overline{K}) + \Gamma(\Sigma \overline{K}) + \Gamma(\Xi \overline{K})$ | E(153 | 0)π)] | $\Gamma_1/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$ |
|---------------------------------------------------|-----------------------------------------------------------------------------------------|-------|-------|--------------------------------------------------|
| VALUE | <u>DO CÚMENT ÎE</u> | | | COMMENT |
| < 0.5 | ALITTI | 69 | нвс | 1 standard dev. limit |
| $\Gamma(\Lambda \overline{K})/[\Gamma(\Xi \pi) +$ | $\Gamma(\Lambda \overline{K}) + \Gamma(\Sigma \overline{K}) + \Gamma(\Xi \overline{K})$ | E(153 | 0)π)] | $\Gamma_2/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_5)$ |

69 HBC

ALITTI

Baryon Particle Listings Ξ (2500)

| <u>VALUE</u> 0.5 ± 0.2 | $ \begin{array}{c c} + \Gamma(\Sigma\overline{K}) + \Gamma(\Xi(1530)\pi) & \Gamma_3/(\Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_5) \\ \hline \frac{DOCUMENT \ ID}{ALITTI} & 69 & \frac{TECN}{HBC} & \frac{CHG}{-} \end{array} $ | $ \frac{\left[\Gamma\left(\Lambda \overline{K}\pi\right) + \Gamma\left(\Sigma \overline{K}\pi\right)\right]/\Gamma_{total}}{\text{seen}} \qquad \frac{DOCUMENT\ ID}{\text{BARTSCH}} \qquad \frac{TECN}{69} \qquad \frac{CHG}{HBC} $ |
|-------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\Gamma(\Xi(1530)\pi)/[\Gamma(\Xi\pi)+\Gamma$ | $\Gamma(\Lambda \overline{K}) + \Gamma(\Sigma \overline{K}) + \Gamma(\Xi(1530)\pi) \Big] \Gamma_5/(\Gamma_1 + \Gamma_2 + \Gamma_3 + \Gamma_5)$ | Ξ(2500) REFERENCES |
| <u>VALUE</u> <0.2 | DOCUMENT ID TECN COMMENT ALITTI 69 HBC 1 standard dev. limit | JENKINS 83 PRL 51 951 C.M. Jenkins et al. (FSU, BRAN, LBL+) ALITTI 69 PRL 22 79 J. Alitti et al. (BNL, SYRA) I BARTS CH 69 PL 28B 439 J. Bartsch et al. (AACH, BERL, CERN+) |
| $\Gamma(\Xi\pi\pi)/\Gamma_{\text{total}}$ VALUE seen | Γ ₄ /Γ <u>DOCUMENT ID</u> <u>TECN</u> <u>CHG</u> BARTSCH 69 HBC -0 | |

Ω BARYONS (S = -3, I = 0)



$$I(J^P) = O(\frac{3}{2}^+)$$
 Status: ***

The unambiguous discovery in both production and decay was by BARNES 64. The quantum numbers follow from the assignment of the particle to the baryon decuplet. DEUTSCHMANN 78 and BAUBILLIER 78 rule out J=1/2 and find consistency with J=3/2. AUBERT,BE 06 finds from the decay angular distributions of $\Xi_c^0 \to \Omega^- K^+$ and $\Omega_c^0 \to \Omega^- K^+$ that J=3/2; this depends on the spins of the Ξ_C^0 and Ω_C^0 being J=1/2, their supposed values.

We have omitted some results that have been superseded by later experiments. See our earlier editions.

Ω^- MASS

The fit assumes the Ω^- and $\overline{\Omega}^+$ masses are the same, and averages them

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------|----------------|------------------------|--------|------------|------------------------------------------|
| 1672.45 ± 0.29 OU | | | | | |
| 1672.43 ± 0.32 OU | R AVERAGE | | | | |
| 1673 ± 1 | 100 | HARTOUNI | 85 | SPEC | 80-280 GeV K ⁰ _L C |
| 1673.0 ± 0.8 | 41 | BAUBILLIER | 78 | нвс | 8.25 GeV/c K = p |
| 1671.7 ± 0.6 | 27 | HEMINGWAY | 78 | HBC | 4.2 GeV/c K-p |
| 1673.4 ± 1.7 | 4 | ¹ DIBIANCA | 75 | DBC | 4.9 GeV/c K-d |
| 1673.3 ± 1.0 | 3 | PALMER | 68 | нвс | K [−] p 4.6, 5 GeV/c |
| 1671.8 ± 0.8 | 3 | SCHULTZ | 68 | HBC | $K^{-}p$ 5.5 GeV/c |
| 1674.2 ± 1.6 | 5 | SCOTTER | 68 | HBC | K^-p 6 GeV/ c |
| 1672.1 ± 1.0 | 1 | ² FRY | 55 | EMUL | |
| • • • We do not u | ise the follow | ing data for averag | es, fi | ts, limits | , etc. • • • |
| 1671.43 ± 0.78 | 13 | ³ DEUTSCH | 73 | нвс | K-p 10 GeV/ c |
| 1671.9 ± 1.2 | 6 | ³ SPETH | 69 | HBC | See DEUTSCHMANN 73 |
| 1673.0 ± 8.0 | 1 | ABRAMS | 64 | нвс | $\rightarrow \Xi^-\pi^0$ |
| 1670.6 ± 1.0 | 1 | ² FRY | 55B | EMUL | |
| 1615 | 1 | ⁴ EISENBERG | 54 | EMUL | |

 $\frac{1}{2}$ DIBIANCA 75 gives a mass for each event. We quote the average.

 2 The FRY 55 and FRY 55B events were identified as Ω^- by ALVAREZ 73. The masses assume decay to ΛK^- at rest. For FRY 55B, decay from an atomic orbit could Doppler assume use M of M and the resulting Ω^- mass by several MeV. This shift is negligible for FRY 55 because the Ω decay is approximately perpendicular to its orbital velocity, as is known because the Λ strikes the nucleus (L. Alvarez, private communication 1973). We have calculated the error assuming that the orbital N is 4 or larger. N is a summary N is a summary N is a summary N in the summary N is a summary N in the summary N is N in the summary N is N in the summary N in the summary N is N in the summary N in the summary N in the summary N is N in the summary N in the summary N in the summary N is N in the sum N in the summary N in the sum N in the sum N is N in the sum N in the sum N in the sum N is N in the sum N in the sum N in the sum N in the sum N is N in the sum N in the sum N in the sum N in the sum N is N in the sum N in the sum N in the sum N in the sum N is N in the sum N in the sum N in the sum N is N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N is sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the sum N in the

icantly from other measurements.

⁴ The EISENBERG 54 mass was calculated for decay in flight. ALVAREZ 73 has shown that the Ω interacted with an Ag nucleus to give $K = \Xi Ag$.

Ω+ MASS

The fit assumes the Ω^- and $\overline{\Omega}^+$ masses are the same, and averages them

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------|-------------|-------------|-----|------|----------------|
| 1672.45 ± 0.29 (| | | | | |
| 1672.5 ± 0.7 | OUR AVERAGE | | | | _ |
| 1672 ± 1 | 72 | HARTOUNI | 85 | SPEC | 80-280 GeV K C |
| 1673.1 ± 1.0 | 1 | FIRESTONE | 71B | HBC | 12 GeV/c K+d |

$(m_{\Omega^-} - m_{\overline{\Omega}^+}) / m_{\Omega^-}$

A test of CPT invariance.

| VALUE | DO CUMENT ID | TE | CN COMMENT | |
|-----------------------------------|--------------|-------|------------------|--|
| $(-1.44 \pm 7.98) \times 10^{-5}$ | CHAN | 98 E7 | 56 p Be, 800 GeV | |

Ω- MEAN LIFE

Measurements with an error $>0.1\times 10^{-10}$ s have been omitted. The fit assumes the Ω^- and $\overline{\Omega}^+$ mean lives are the same, and averages them together.

| VALUE (10 ⁻¹⁰ s) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------|-------------|--------------------|----------|-----------|------------------|
| 0.821±0.011 OUR FIT | Ī | | | | |
| 0.821 ± 0.011 OUR AV | ERAGE | | | | |
| $0.817 \pm 0.013 \pm 0.018$ | 6934 | CHAN | 98 | E756 | p Be, 800 GeV |
| 0.811 ± 0.037 | 1096 | LUK | 88 | SPEC | pBe 400 GeV |
| 0.823 ± 0.013 | 12k | BOURQUIN | 84 | SPEC | SPS hyperon beam |
| ● ● We do not use t | he followin | g data for average | es, fits | , limits, | etc. • • • |

 0.822 ± 0.028 BOURQUIN 79B SPEC See BOURQUIN 84

$\overline{\Omega}$ ⁺ MEAN LIFE

The fit assumes the Ω^- and $\overline{\Omega}^+$ mean lives are the same, and averages

| VALUE (10 ⁻¹⁰ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------|--------------|----|------|---------------|
| 0.821 ± 0.011 OUR FIT | | | | | |
| $0.823 \pm 0.031 \pm 0.022$ | 1801 | CHAN | 98 | E756 | p Be, 800 GeV |

$$(\tau_{\Omega^-} - \tau_{\overline{\Omega}^+}) / \tau_{\Omega^-}$$

A test of $\operatorname{\textit{CPT}}$ invariance. Our calculation, from the averages in the preceding two data blocks.

0.00±0.05 OUR ESTIMATE

 $\Gamma(\Lambda K^{-})/\Gamma_{total}$

DOCUMENT ID

Ω^- MAGNETIC MOMENT

| VALUE (µN) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|--------|-------------|----|------|--------------------------|
| -2.02 ±0.05 OUR AV | /ERAGE | | | | |
| -2.024 ± 0.056 | 235 k | WALLACE | 95 | SPEC | Ω^- 300–550 GeV |
| $-1.94 \pm 0.17 \pm 0.14$ | 25 k | DIEHL | 91 | SPEC | Spin-transfer production |

Ω^- DECAY MODES

| | Mode | Fraction (Γ_i/Γ) Confidence le | evel |
|-----------------------|------------------------------|--------------------------------------------|------|
| $\overline{\Gamma_1}$ | ΛK ⁻ | (67.8±0.7) % | |
| Γ_2 | $\equiv^0\pi^-$ | (23.6 ± 0.7) % | |
| Γ_3 | $\Xi^-\pi^0$ | $(8.6 \pm 0.4)\%$ | |
| Γ_4 | $\Xi^-\pi^+\pi^-$ | $(3.7^{+0.7}_{-0.6}) \times 10^{-4}$ | |
| Γ_5 | $\Xi(1530)^{0}\pi^{-}$ | $< 7 \times 10^{-5}$ | 0% |
| Γ ₆ | $\Xi^0 e^- \overline{\nu}_e$ | $(5.6\pm2.8)\times10^{-3}$ | |
| Γ ₇ | $\equiv -\gamma$ | $< 4.6 \times 10^{-4}$ 9 | 0% |
| | | $\Delta S = 2$ forbidden (S2) modes | |
| Γ8 | $\Lambda\pi^-$ | $52 < 2.9 \times 10^{-6}$ | 0% |

Ω^- BRANCHING RATIOS

The BOURQUIN 84 values (which include results of BOURQUIN 79B, a separate experiment) are much more accurate than any other results, and so the other results have been omitted.

 Γ_1/Γ

| · (/·/· //·total | | | | | .1/. |
|-------------------------------------------------------|--------------|----------------------|----------|---------|-------------------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.678 ± 0.007 | 14k | BOURQUIN | 84 | SPEC | SPS hyperon beam |
| • • • We do not use | he following | ng data for averages | s, fits, | limits, | etc. • • • |
| 0.686 ± 0.013 | 1920 | BOURQUIN | 79B | SPEC | See BOURQUIN 84 |
| $\Gamma(\Xi^0\pi^-)/\Gamma_{ m total}$ | | | | | Γ_2/Γ |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 0.236 ± 0.007 | 1947 | BOURQUIN | 84 | SPEC | SPS hyperon beam |
| • • • We do not use | he followin | ng data for averages | s, fits, | limits, | etc. • • • |
| 0.234 ± 0.013 | 317 | BOURQUIN | 79B | SPEC | See BOURQUIN 84 |
| $\Gamma(\Xi^-\pi^0)/\Gamma_{ m total}$ | | | | | Г ₃ /Г |
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.086 ± 0.004 | 759 | BOURQUIN | 84 | SPEC | SPS hyperon beam |
| • • • We do not use | he following | ng data for averages | s, fits, | limits, | etc. • • • |
| 0.080 ± 0.008 | 145 | BOURQUIN | 79B | SPEC | See BOURQUIN 84 |
| $\Gamma(\Xi^-\pi^+\pi^-)/\Gamma_{\rm tot}$ | ıl | | | | Γ ₄ /Γ |
| VALUE (units 10 ⁻⁴) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $3.74 + 0.67 \\ -0.56$ | 100 | ⁵ KAMAEV | 10 | HYCP | p Cu, 800 GeV |
| • • • We do not use | he following | ng data for averages | s, fits, | limits, | etc. • • • |
| $\begin{array}{ccc} 4.3 & +3.4 \\ & -1.3 \end{array}$ | 4 | BOURQUIN | 84 | SPEC | SPS hyperon beam |

 5 This KAMAEV 10 value uses 76 $\varOmega^-\to \Xi^-\pi^+\pi^-$ and 24 $\overline{\varOmega}^+\to \overline{\Xi}^+\pi^-\pi^+$ decays. The \varOmega^- and $\overline{\varOmega}^+$ branching fractions measurements are statistically equal. The errors given combine statistical and systematic contributions. The CP branching-fraction asymmetry, $(\Omega^- - \overline{\Omega}^+)/\text{sum}$, is $+ 0.12 \pm 0.20$.

We have omitted some papers that have been superseded by later experi-

O. Kamaev et al.
B. Aubert et al.
L.C. Lu et al.
Y.C. Chen et al.
L.C. Lu et al.
Y.C. Chen et al.
L.C. Lu et al.
A.W. Chan et al.
A.W. Chan et al.
A.W. B. Wallace et al.
I.F. Albuquerque et al.
H.T. Diehl et al.
K.B. Luk et al.
E.P. Hartouni et al.
M.H. Bourquin et al.
M.H. Bourquin et al.
M.H. Bourquin et al.
M.H. Bourquin et al.
M. Baubillier et al.

(FNAL HyperCP Collab.)
(BABAR Collab.)
(FNAL HyperCP Collab.)
(FNAL HyperCP Collab.)
(FNAL HyperCP Collab.)
(FNAL HyperCP Collab.)
(FNAL HyperCP Collab.)
(FNAL HYPERCP Collab.)
(FNAL E765 Collab.)
(FNAL E761 Collab.)
(RUTG, FNAL, MICH +)
(RUTG, WISC, MICH, MINN)
(BUTS, GEVA, HEIDP +)
(BRIS, GEVA, HEIDP +)
(BRIS, GEVA, HEIDP +)
(BRIS, GEVA, HEIDP +)
(BRIS, GEVA, HEIDP +)

ments. See our earlier editions.

PL 8693 236 PRL 97 112001 PRL 96 242001 PR D71 051102R PL B617 11 PRL 94 101804 PR D58 072002 PRL 74 3732 PR D50 R18 PRL 67 804 PR D38 19 PRL 54 628 NP B241 1 PL 37B 297 PL 58B 392 PL 58B 392 PL 78B 342

KAMAEV 10
AUBERT, BE 06
LU 06
CHEN 05
LU 05A
WHITE 05
CHAN 98
WALLACE 95
ALBUQUERQ... 91
LUK 88
HARTOUNI 85
BOURQUIN 79
BOURQUIN 79
BOURQUIN 79
BAUBILLIER 78

| $\Gamma(\Xi(1530)^0\pi^-)/\Gamma_{\text{total}}$ | | Γ ₅ /Γ DEUTSCH | 78 PL 73B 96 | M. Deutschmann <i>et al</i> . | (AACH3, BERL, CERN+)J |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| , , ,, ,, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | OCUMENT ID TECN COMMENT | HEMINGWA DIBIANCA | 7 78 NP B142 205 75 NP B98 137 | R.J. Hemingway <i>et al.</i> F.A. Dibianca, R.J. End | |
| <0.7 90 K • • • We do not use the following dat | AMAEV 10 HYCP p Cu, 800 GeV a for averages, fits, limits, etc. • • • | ALVAREZ DEUTSCH FIRESTONE | 73 PR D8 702 73 NP B61 102 71B PRL 26 410 | L.W. Alvarez M. Deutschmann <i>et al.</i> I. Firestone <i>et al.</i> | `(LBL) (ABCLV Collab.) (LRL) |
| 6.4 + 5.1 4 6 B | OURQUIN 84 SPEC SPS hyperon bea | SPETH PALMER SCHULTZ | 69 PL 29B 252 68 PL 26B 323 68 PR 168 1509 | R. Speth <i>et al.</i> R.B. Palmer <i>et al.</i> P.F. Schultz <i>et al.</i> | (AACH, BERL, CERN, LÒIC+) (BNL, SYRA) (ILL, ANL, NWES+) |
| 6 The same 4 events as in the previou $\Xi(1530)^0 \to \Xi^0 \pi^0$ decays include that $\Xi(1530)^0 \pi^-$ would dominate | us mode, with the isospin factor to take into a ed. BOURQUIN 84 adopted a theoretical assu $\Xi^-\pi^+\pi^-$ decay. | SCOTTER ABRAMS mption BARNES FRY FRY | 68 PL 26B 474 64 PRL 13 670 64 PRL 12 204 55 PR 97 1189 55B NC 2 346 | D. Scotter <i>et al.</i> G.S. Abrams <i>et al.</i> V.E. Barnes <i>et al.</i> W.F. Fry, J. Schneps, M W.F. Fry, J. Schneps, M | (BÌRM, GLAS, LOIC+) (UMD, NRL) (BNL) I.S. Swami (WISC) I.S. Swami (WISC) |
| $\Gamma(\Xi^0 e^- \overline{ u}_e) / \Gamma_{ m total}$ | | Γ ₆ /Γ | 54 PR 96 541 | Y. Eisenberg | (CORN) |
| | OCUMENT ID TECN COMMENT OURQUIN 84 SPEC SPS hyperon bea | | OEO)= | 1(1P) = | 0(? [?]) Status: *** |
| • • • We do not use the following dat | 31 | ` | 250)- | 7(3) = | o(.) Status. I I I |
| $\Gamma(\Xi^-\gamma)/\Gamma_{\text{total}}$ | | Γ ₇ /Γ | | $\Omega(2250)^-$ MASS | |
| · · · · · · · · · · · · · · · · · · · | OCUMENT ID TECN COMMENT | VALUE (Me\ | | DO CUMENT ID | TECN COMMENT |
| 4.6 90 0 A • • • We do not use the following dat | LBUQUERQ94 E761 Ω ⁻ 375 GeV | 2252± 9 2253±13 | OUR AVERAGE 44 | ASTON 87B | LASS K-p 11 GeV/c |
| <22 90 9 B | OURQUIN 84 SPEC SPS hyperon bea | m 2251 ± 9: | | | SPEC SPS = beam |
| <31 90 0 B $ \Gamma(\Lambda \pi^-)/\Gamma_{\text{total}} $ | OURQUIN 79B SPEC See BOURQUIN | 84 | | $\Omega(2250)^-$ WIDTH | |
| ΔS =2. Forbidden in first-order w | veak interaction. OCUMENT ID TECN COMMENT | VALUE (Me\ | | DO CUMENT ID | TECN COMMENT |
| < 2.9 90 W | VHITE 05 HYCP p Cu, 800 GeV | 81 ± 38 | J R AVERAGE 44 | | LASS $K^- \rho$ 11 GeV/ c |
| ullet $ullet$ We do not use the following dat < 190 90 B | OURQUIN 84 SPEC SPS hyperon bea | m 48±20 | 78 | BIAGI 86B | SPEC SPS = beam |
| <1300 90 B | OURQUIN 79B SPEC See BOURQUIN | 84 | Ω(2 | 250) [—] DECAY MOD | ES |
| Ω− DEC | CAY PARAMETERS | Mc | | Fractio | n (Γ_i/Γ) |
| α FOR $\Omega^- \to \Lambda K^-$ Some early results have been om | | | - π ⁺ K ⁻ Ξ (1530) ⁰ K ⁻ | seen seen | |
| <u>VALUE</u> <u>EVTS</u> 0.0180±0.0024 OUR AVERAGE | 7 CHEN OF LINCE COMMENT | | 0(2250 |) BRANCHING RA | TIOS |
| $+ 0.0207 \pm 0.0051 \pm 0.0081$ 960k $+ 0.0178 \pm 0.0019 \pm 0.0016$ 4.5 M | 7 CHEN 05 HYCP p Cu, 800 Gr 7 LU 05A HYCP p Cu, 800 Gr | ٥V | 0) ⁰ K ⁻)/Γ(Ξ ⁻ π ⁺ K | - | Γ ₂ /Γ _: |
| • • • We do not use the following dat -0.028 ± 0.047 6953 | a for averages, fits, limits, etc. • • • CHAN 98 E756 p Be, 800 Ge | WILLE | 0) K)/1 (= % K | | TECN COMMENT |
| -0.026 ±0.047 0933 -0.034 ±0.079 1743 -0.025 ±0.028 12k | LUK 88 SPEC p Be 400 Ge BOURQUIN 84 SPEC SPS hyperon | V ∼1.0 | .20 44 .20 49 | | LASS K^-p 11 GeV/ c SPEC Ξ^- Be 116 GeV/ c |
| _ | 5A are from different experimental runs. | | | \- DEEEBENGE | <u> </u> |
| $\overline{\alpha} \text{ FOR } \overline{\Omega}^+ \rightarrow \overline{\Lambda} K^+$ VALUE _EVTS | DOCUMENT ID TECN COMMENT | | • | 2250) REFERENCE | |
| | | | | | |
| -0.0181±0.0028±0.0026 1.89M | LU 06 HYCP p Cu, 800 G | ASTON eV BIAGI | 87B PL B194 579 86B ZPHY C31 33 | D. Aston et al. S.F. Biagi et al. | (SLAC, NAGO, CINC, INUS) (LOQM, GEVA, RAL+) |
| -0.0181±0.0028±0.0026 1.89M ••• We do not use the following dat | LU 06 HYCP p Cu, 800 Go a for averages, fits, limits, etc. | eV BIAGI | | | (SLAC, NAGO, CINC, INUS) (LOQM, GEVA, RAL+) |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 | LU 06 HYCP p Cu, 800 G a for averages, fits, limits, etc. • • • • CHAN 98 E756 p Be, 800 G | eV BIAGI | | | (SLAC, NAGO, CINC, INUS) (LOQM, GEVA, RAL+) Status: ** |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Omega^- \to \Lambda K^-$ Zero if CP is conserved. | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • CHAN 98 E756 p Be, 800 Gr $\overline{\Omega}^+ \rightarrow \overline{\Lambda} K^+$ | eV BIAGI Ω(2 | 380) ⁻ | S.F. Biagi et al. | (LOQM, GEVA, RAL+) |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Omega^- \to \Lambda K$ Zero if <i>CP</i> is conserved. | LU 06 HYCP p Cu, 800 Gr a for averages, fits, limits, etc. • • • CHAN 98 E756 p Be, 800 Gr ¬, Ω+ → ΛK+ OCUMENT ID TECN COMMENT | eV BIAGI Ω(2 | 86B ZPHY C31 33 | S.F. Biagi et al. | ` (LOQM, GEVA, RAL+) |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Omega^- \to \Lambda K$ Zero if <i>CP</i> is conserved. | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • • CHAN 98 E756 p Be, 800 Gr $\overline{\Omega}^+ \rightarrow \overline{\Lambda} K^+$ OCUMENT ID TECN COMMENT U 06 HYCP p Cu, 800 GeV | eV BIAGI Ω(2 | 380) ⁻ | S.F. Biagi et al. | ` (LOQM, GEVA, RAL+) |
| -0.0181 ± 0.0028 ± 0.0026 1.89 M • • • We do not use the following dat $+0.017 \pm 0.077$ 1823 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) \text{ in } \Omega^- \rightarrow \Lambda K'$ Zero if CP is conserved. VALUE -0.016 ± 0.092 ± 0.089 8 Li This value uses the results of CHEI α FOR $\Omega^- \rightarrow \Xi^0 \pi^-$ | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • • CHAN 98 E756 p Be, 800 Gr $\overline{\Omega}^+ \rightarrow \overline{\Lambda} K^+$ COUMENT ID TECN COMMENT U 06 HYCP p Cu, 800 GeV N 05, LU 05A, and LU 06. | eV BIAGI Ω(2 OMITTE | 380) - D FROM SUMMA | S.F. Biagi et al. RY TABLE Ω(2380) MASS | (LOQM, GEVA, RAL+) |
| $-0.0181\pm0.0028\pm0.0026$ 1.89 M • • • We do not use the following dat $+0.017\pm0.077$ 1823 (α + $\overline{\alpha}$)/(α - $\overline{\alpha}$) in Ω^- → ΛΚ΄ Zero if CP is conserved. VALUE $-0.016\pm0.092\pm0.089$ 8 Li **This value uses the results of CHEI α FOR Ω^- → $\Xi^0\pi^-$ VALUE $EVTS$ D. | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • • CHAN 98 E756 p Be, 800 Gr $\overline{\Omega}^+ \rightarrow \overline{\Lambda} K^+$ OCUMENT ID TECN COMMENT U 06 HYCP p Cu, 800 GeV | eV BIAGI | 380) SUMMA D FROM SUMMA EVTS R ESTIMATE | S.F. Biagi et al. RY TABLE Ω(2380) — MASS DOCUMENT ID | Status: ** |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha}) \text{ in } \Omega^- \rightarrow \Lambda K$ Zero if CP is conserved. VALUE -0.016±0.092±0.089 8 Li **This value uses the results of CHEI **\alpha FOR \Omega^- \rightarrow \frac{\pi}{2} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{1630} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \frac{\pi}{\pi} \f | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • CHAN 98 E756 p Be, 800 Gr - , | eV BIAGI | 380) - D FROM SUMMA D FROM SUMMA EVTS ### ESTIMATE ### 45 | RY TABLE RY TABLE DOCUMENT ID BIAGI 86B | Status: ** TECN COMMENT |
| -0.0181±0.0028±0.0026 1.89M • • • We do not use the following dat +0.017 ±0.077 1823 $(α + \overline{α})/(α - \overline{α}) \text{ in } Ω^- → ΛK^-$ Zero if CP is conserved. -0.016±0.092±0.089 8 LI 8 This value uses the results of CHEI α FOR $Ω^- → Ξ^0 π^-$ | LU 06 HYCP p Cu, 800 Gr as for averages, fits, limits, etc. • • • CHAN 98 E756 p Be, 800 Gr ¬, ¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬¬ | eV BIAGI Ω(2 OMITTE | 380) - D FROM SUMMA D FROM SUMMA D EVTS JR ESTIMATE ±8 45 | RY TABLE RY TABLE DOCUMENT ID BIAGI 86B Q(2380)— WIDTH | Status: ** TECN COMMENT |

Ω(2380) BRANCHING RATIOS

 $\Omega(2380)^-$ DECAY MODES

 $\Xi^-\pi^+K^ \Xi(1530)^0K^-$

 $\Xi \stackrel{\cdot}{-} \overline{K}^* (892)^0$

 Γ_1 Γ_2

 Γ_3

Fraction (Γ_i/Γ)

seen

| $\Gamma(\Xi(1530)^{\circ}K^{-}$ | ·)/۲(| $\Xi^-\pi^+F$ | (-) | | | | Γ_2/Γ_1 |
|---------------------------------|-------|---------------|-----------------|-------|------|--------------|---------------------|
| VALUE | CL% | EVTS | <u>DO CUMEI</u> | VT ID | TECN | COMMENT | |
| < 0.44 | 90 | 9 | BIAGI | 86в | SPEC | Ξ−Be 116 GeV | /c |

 $\Omega(2380)^-$, $\Omega(2470)^-$

| Γ(Ξ ⁻ Κ̄*(892) | $^{0})/\Gamma(\varXi^{-}\pi^{+}F)$ | (-) | | | Γ | 3/Г1 |
|---------------------------|------------------------------------|--------------|-----|------|---------------|------|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.5 ± 0.3 | 21 | BIAGI | 86в | SPEC | Ξ−Be 116 GeV/ | s |

$\Omega(2380)^-$ REFERENCES

86B ZPHY C31 33 BIAGI S.F. Biagi et al. (LOQM, GEVA, RAL+)



Status: **

OMITTED FROM SUMMARY TABLE A peak in the $\Omega^-\pi^+\pi^-$ mass spectrum with a signal significance claimed to be at least 5.5 standard deviations. There is no reason to seriously doubt the existence of this state, but unless the evidence $% \left(1\right) =\left(1\right) \left(1\right$ is overwhelming we usually wait for confirmation from a second experiment before elevating peaks to the Summary Table.

$\Omega(2470)^-$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|------|--------------|-----|------|--------------|
| 2474±12 | 5 9 | ASTON | 88G | LASS | K−p 11 GeV/c |

$\Omega(2470)^-$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-------------|------|-------------|----------|----------------|
| 72±33 | 59 | ASTON | 88G LASS | K = p 11 GeV/c |

$\Omega(2470)^-$ DECAY MODES

 $\Omega^-\pi^+\pi^-$

$\Omega(2470)^-$ REFERENCES

ASTON 88 G PL B215 799 D. Aston et al. (SLAC, NAGO, CINC, INUS)

CHARMED BARYONS (C = +1)

 $\begin{array}{lll} \varLambda_c^+ = u\, d\, c, & \varSigma_c^{++} = u\, u\, c, & \varSigma_c^+ = u\, d\, c, & \varSigma_c^0 = d\, d\, c, \\ & \varXi_c^+ = u\, s\, c, & \varXi_c^0 = d\, s\, c, & \varOmega_c^0 = s\, s\, c \end{array}$

CHARMED BARYONS

Revised March 2012 by C.G. Wohl (LBNL).

There are 17 known charmed baryons, and four other candidates not well enough established to be promoted to the Summary Tables.* Fig. 1(a) shows the mass spectrum, and for comparison Fig. 1(b) shows the spectrum of the lightest strange baryons. The Λ_c and Σ_c spectra ought to look much like the Λ and Σ spectra, since a Λ_c or a Σ_c differs from a Λ or a Σ only by the replacement of the s quark with a c quark. However, a Ξ or an Ω has more than one s quark, only one of which is changed to a c quark to make a Ξ_c or an Ω_c . Thus the Ξ_c and Ω_c spectra ought to be richer than the Ξ and Ω spectra.**

Before discussing the observed spectra, we review the theory of SU(4) multiplets, which tells what charmed baryons to expect; this is essential, because few of the spin-parity values given in Fig. 1(a) have been measured. Rather, they have been assigned in accord with expectations of the theory. However, they are all very likely as shown (see below).

SU(4) multiplets—Baryons made from u, d, s, and c quarks belong to SU(4) multiplets. The multiplet numerology, analogous to $3\times3\times3=10+8_1+8_2+1$ for the subset of baryons made from just u, d, and s quarks, is $4\times4\times4=20+20'_1+20'_2+\bar{4}$. Figure 2(a) shows the 20-plet whose bottom level is an SU(3) decuplet, such as the decuplet that includes the $\Delta(1232)$. Figure 2(b) shows the 20'-plet whose bottom level is an SU(3) octet, such as the octet that includes the nucleon. Figure 2(c) shows the $\bar{4}$ multiplet, an inverted tetrahedron. One level up from the bottom level of each multiplet are the baryons with one c quark. All the baryons in a given multiplet have the same spin and parity. Each N or Δ or SU(3)-singlet- Λ resonance calls for another 20'- or 20- or $\bar{4}$ -plet, respectively.

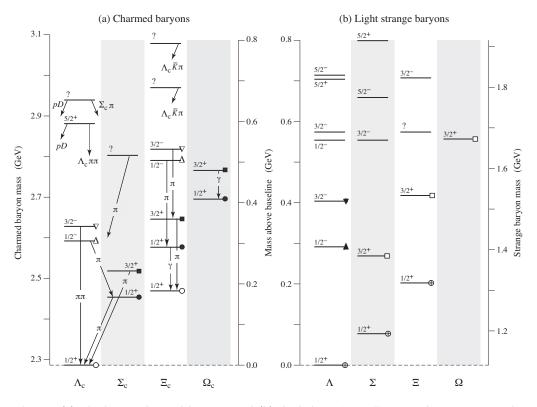


Fig. 1. (a) The known charmed baryons, and (b) the lightest "4-star" strange baryons. Note that there are two $J^P=1/2^+$ Ξ_c states, and that the lightest Ω_c does not have J=3/2. The $J^P=1/2^+$ states, all tabbed with a circle, belong to the SU(4) multiplet that includes the nucleon; states with a circle with the same fill belong to the same SU(3) multiplet within that SU(4) multiplet. Similar remarks apply to the other states: same shape of tab, same SU(4) multiplet; same fill of that shape, same SU(3) multiplet. The $J^P=1/2^-$ and $3/2^-$ states tabbed with triangles complete two SU(4) $\overline{4}$ multiplets.

Charmed Baryons

The flavor symmetries shown in Fig. 2 are of course badly broken, but the figure is the simplest way to see what charmed baryons should exist. For example, from Fig. 2(b), we expect to find, in the same $J^P=1/2^+$ 20'-plet as the nucleon, a Λ_c , a Σ_c , two Ξ_c 's, and an Ω_c . Note that this Ω_c has $J^P=1/2^+$ and is not in the same SU(4) multiplet as the famous $J^P=3/2^+$ Ω^-

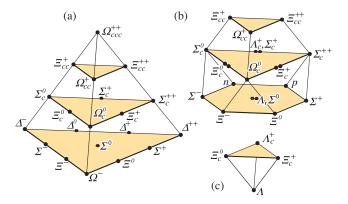


Figure 2: SU(4) multiplets of baryons made of u, d, s, and c quarks. (a) The 20-plet with an SU(3) decuplet on the lowest level. (b) The 20'-plet with an SU(3) octet on the lowest level. (c) The $\overline{4}$ -plet. Note that here and in Fig. 3, but not in Fig. 1, each charge state is shown separately.

Figure 3 shows in more detail the middle level of the 20'-plet of Fig. 2(b); it splits apart into two SU(3) multiplets, a $\bar{3}$ and a 6. The states of the $\bar{3}$ are antisymmetric under the interchange of the two light quarks (the u, d, and s quarks), whereas the states of the 6 are symmetric under this interchange. We use a prime to distinguish the Ξ_c in the 6 from the one in the $\bar{3}$.

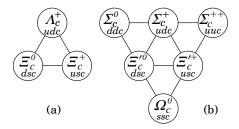


Figure 3: The SU(3) multiplets on the second level of the SU(4) multiplet of Fig. 2(b). The Λ_c and Ξ_c tabbed with open circles in Fig. 1(a) complete a $J^P = 1/2^+$ SU(3) $\overline{3}$ -plet, as in (a) here. The Σ_c , Ξ_c , and Ω_c tabbed with closed circles in Fig. 1(a) complete a $J^P = 1/2^+$ SU(3) 6-plet, as in (b) here. Together the nine particles complete the charm = +1 level of a $J^P = 1/2^+$ SU(4) 20'-plet, as in Fig. 2(b).

The observed spectra—(1) The parity of the lightest Λ_c is defined to be positive (as are the parities of the p, n, and Λ); the limited evidence about its spin is consistent with J=1/2. However, few of the J^P quantum numbers given in Fig. 1(a) have been measured. Models using spin-spin and spin-orbit interactions between the quarks, with parameters determined using a few of the masses as input, lead to the J^P assignments shown.[†] There are no surprises: the $J^P=1/2^+$ states come first, then the $J^P=3/2^+$ states . . .

- (2) There is, however, evidence that many of the J^P assignments in Fig. 1(a) must be correct. As is well known, the successive mass differences between the $J^P=3/2^+$ particles, the $\Delta(1232)^-$, $\Sigma(1385)^-$, $\Xi(1535)^-$, and Ω^- , which lie along the lower left edge of the 20-plet in Fig. 2(a), should according to SU(3) be about equal; and indeed experimentally they nearly are. In the same way, the mass differences between the $J^P=1/2^+$ $\Sigma_c(2455)^0$, Ξ_c^0 , and Ω_c^0 , the particles along the left edge of Fig. 3(b), should be about equal—assuming, of course, that they do all have the same J^P . The measured differences are 125.0 ± 2.9 MeV and 117.3 ± 3.4 MeV—not perfect, but close. Similarly, the mass differences between the presumed $J^P=3/2^+$ $\Sigma_c(2520)^0$, $\Xi_c(2645)^0$, and $\Omega_c(2770)^0$ are 127.1 ± 0.8 MeV and 120.0 ± 2.1 MeV. In Fig. 1(a), these two sets of charm particles are tabbed with solid circles and solid squares.
- (3) Other evidence comes from the decay of the $\Lambda_c(2593)$. The only allowed strong decay is $\Lambda_c(2593)^+ \to \Lambda_c^+ \pi \pi$, and this appears to be dominated by the submode $\Sigma_c(2455)\pi$, despite little available phase space for the latter (the "Q" is about 2 MeV, the c.m. decay momentum about 20 MeV/c). Thus the decay is almost certainly s-wave, which, assuming that the $\Sigma_c(2455)$ does indeed have $J^P=1/2^+$, makes $J^P=1/2^-$ for the $\Lambda_c(2593)$.

Footnotes:

- * The unpromoted states are a $\Lambda_c(2765)^+$, a $\Xi_c(2930)$, a $\Xi_c(3055)$, and a $\Xi_c(3123)$. There is also very weak evidence for a baryon with *two c* quarks, a Ξ_{cc}^+ at 3519 MeV. See the Particle Listings.
- ** For example, there are three Ω_c^0 states (properly symmetrized states of ssc, scs, and css) corresponding to each Ω^- (sss) state.
- [†] This is not the place to discuss the details of the models, nor to attempt a guide to the literature. See the discovery papers of the various charmed baryons for references to the models that lead to the quantum-number assignments.
- [‡] A reminder about the Particle Data Group naming scheme: A particle has its mass as part of its name if and only if it decays strongly. Thus $\Sigma(1385)$ and $\Sigma_c(2455)$ but Ω^- and Ξ_c' .



$$I(J^P) = O(\frac{1}{2}^+)$$
 Status: ***

The parity of the Λ_c^+ is defined to be positive (as are the parities of the proton, neutron, and Λ). The quark content is udc. Results of an analysis of $pK^-\pi^+$ decays (JEZABEK 92) are consistent with J=1/2. Nobody doubts that the spin is indeed 1/2.

The only new measurements since our 2010 Review are of limits on rare or forbidden $\Lambda_c^+ \to \rho \ell^+ \ell^-$ and $\overline{\rho} \ell^+ \ell^+$ modes.

We have omitted some results that have been superseded by later experiments. The omitted results may be found in earlier editions.

1 MASS

Our value in 2004, 2284.9 \pm 0.6 MeV, was the average of the measurements now filed below as "not used." The BABAR measurement is so much better that we use it alone. Note that it is about 2.6 (old) standard deviations above the 2004 value.

The fit also includes Σ_c – Λ_c^+ and Λ_c^{*+} – Λ_c^+ mass-difference measurements, but this doesn't affect the Λ_c^+ mass. The new (in 2006) Λ_c^+ mass simply pushes all those other masses higher.

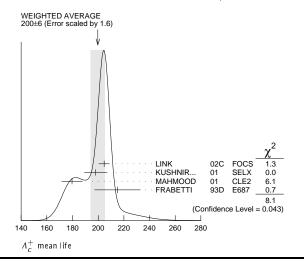
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|-----------|----------------------|--------|------------|-----------------------------------------------------|
| 2286.46 ± 0.14 OUR | | 1 | | 5.455 | |
| 2286.46 ± 0.14 | 4891 | | | | $\Lambda K_S^0 K^+$ and $\Sigma^0 K_S^0 K^+$ |
| ● ● We do not use | the follo | owing data for avera | ges, f | its, limit | s, etc. • • • |
| $2284.7 \ \pm 0.6 \ \pm 0.7$ | 1134 | AVERY | 91 | CLEO | Six modes |
| 2281.7 ± 2.7 ± 2.6 | 29 | ALVAREZ | 90B | NA14 | $\rho K^- \pi^+$ |
| $2285.8 \ \pm 0.6 \ \pm 1.2$ | 101 | BARLAG | 89 | NA 32 | $p K^- \pi^+$ |
| $2284.7 \ \pm 2.3 \ \pm 0.5$ | 5 | AGUILAR | | | p K ⁻ π ⁺ |
| 2283.1 ± 1.7 ± 2.0 | 628 | ALBRECHT | 88c | ARG | $p K^- \pi^+$, $p \overline{K}^0$, $\Lambda 3\pi$ |
| 2286.2 ± 1.7 ± 0.7 | 97 | ANJOS | 88B | E691 | $\rho K^- \pi^+$ |
| 2281 ±3 | 2 | JONES | 87 | HBC | $p K^- \pi^+$ |
| 2283 ±3 | 3 | BOSETTI | 82 | HBC | $p K^- \pi^+$ |
| 2290 ±3 | 1 | CALICCHIO | 80 | HYBR | $\rho K^- \pi^+$ |

 1 AUBERT,B 05s uses low-Q $\Lambda\,K_S^0\,K^+$ and $\Sigma^0\,K_S^0\,K^+$ decays to minimize systematic errors. The error above includes systematic as well as statistical errors. Many cross checks and adjustments to properties of the BABAR detector, as well as the large number of clean events, make this by far the best measurement of the Λ_C^+ mass.

14 MEAN LIFE

Measurements with an error $\ge 100\times 10^{-15}$ s or with fewer than 20 events have been omitted from the Listings.

| VALUE (10-15 s) | | DO CUMENT ID | | | |
|-----------------------------------------------|---------------------|-----------------|----------|-----------|----------------------------------------------------------|
| 200 ± 6 OUR A | VERAGE Error | includes scale | factor | of 1.6. | See the ideogram below. |
| $204.6 \pm \ 3.4 \pm \ 2.5$ | 8034 | LINK | 02c | FOCS | $p K^- \pi^+$ |
| $198.1 \pm \ 7.0 \pm \ 5.6$ | 1630 | KUSHNIR | 01 | SELX | $\Lambda_c^+ \rightarrow p K^- \pi^+$ |
| $179.6 \pm \ 6.9 \pm \ 4.4$ | 4749 | MAHMOOD | | | $e^{+}e^{-}pprox \gamma(4S)$ |
| $215\pm 16\pm8$ | 1340 | FRABETTI | 93D | E687 | $\gamma \text{Be, } \Lambda_c^+ \rightarrow p K^- \pi^+$ |
| ullet $ullet$ We do not u | ise the following d | lata for averag | es, fits | , limits, | etc. • • • |
| $180\ \pm 30\ \pm 30$ | 29 | ALVAREZ | 90 | NA14 | γ , $\Lambda_c^+ \rightarrow p K^- \pi^+$ |
| $200 \pm 30 \pm 30$ | 90 | FRABETTI | 90 | E687 | $\gamma \text{Be}, \Lambda_c^+ \rightarrow p K^- \pi^+$ |
| $196 \begin{array}{c} +23 \\ -20 \end{array}$ | 101 | BARLAG | 89 | NA 32 | $p K^{-} \pi^{+} + c.c.$ |
| 220 ±30 ±20 | 97 | ANJOS | 88B | E691 | $p K^- \pi^+ + c.c.$ |



1+ DECAY MODES

Nearly all branching fractions of the Λ_c^+ are measured relative to the $\rho\,K^-\pi^+$ mode, but there are no model-independent measurements of this branching fraction. We explain how we arrive at our value of $\mathrm{B}(\Lambda_c^+\to\rho\,K^-\pi^+)$ in a Note at the beginning of the branching-ratio measurements, below. When this branching fraction is eventually well determined, all the other branching fractions will slide up or down proportionally as the true value differs from the value we use here.

Mode Fraction (Γ_j/Γ) Confidence level

Hadronic modes with a p: S = -1 final states $p\overline{K}^0$ Γ_1 (2.3 ± 0.6) % $pK^-\pi^+$ Γ_2 $(5.0 \pm 1.3)\%$ $p\overline{K}^*(892)^0$ Γ_3 $(1.6 \pm 0.5)\%$ $\Delta(1232)^{++}K^{-}$ $(8.6 \pm 3.0) \times 10^{-3}$ Γ_4 $\Lambda(1520)\pi^{+}$ Γ_5 $(1.8 \pm 0.6)\%$ $pK^-\pi^+$ nonresonant $(2.8 \pm 0.8)\%$ Γ_7 $(3.3 \pm 1.0)\%$ $p\overline{K}^0\eta$ Γ8 $(1.2 \pm 0.4)\%$ $p \overline{K}^0 \pi^+ \pi$ Г9 $(2.6 \pm 0.7)\%$ $p\,K^-\,\pi^+\,\pi^0$ Γ_{10} $(3.4 \pm 1.0)\%$ $pK^*(892)^-\pi^+$ Γ_{11} [b] (1.1 \pm 0.5) % $p(K^{-}\pi^{+})_{\text{nonresonant}} \pi^{0}$ $\Delta(1232)\overline{K}^{*}(892)$ Γ_{12} $(3.6 \pm 1.2)\%$ Γ_{13} seen $pK^{-}\pi^{+}\pi^{+}\pi^{-}$ $pK^{-}\pi^{+}\pi^{0}\pi^{0}$ $(1.1 \pm 0.8) \times 10^{-3}$ $(8 \pm 4) \times 10^{-3}$ Γ_{15} $p K^- \pi^+ 3\pi^0$ Γ_{16}

Hadronic modes with a p: S = 0 final states

| Γ_{17} | $p\pi^+\pi^-$ | | $(3.5 \pm 2.0) \times 10^{-3}$ |
|---------------|---------------------------------|-----|--------------------------------|
| Γ_{18} | $p f_0(980)$ | [b] | $(2.8 \pm 1.9) \times 10^{-3}$ |
| | $p\pi^{+}\pi^{+}\pi^{-}\pi^{-}$ | | $(1.8 \pm 1.2) \times 10^{-3}$ |
| Γ_{20} | p K ⁺ K ⁻ | | $(7.7 \pm 3.5) \times 10^{-4}$ |
| Γ_{21} | $p\phi$ | [b] | $(8.2 \pm 2.7) \times 10^{-4}$ |
| Γ_{22} | pK^+K^- n on- ϕ | | $(3.5 \pm 1.7) \times 10^{-4}$ |

Hadronic modes with a hyperon: S = -1 final states

| Γ ₂₃ | $\Lambda\pi^+$ | (1.07± 0.28) % | |
|-----------------|----------------------------------------------------------------------|-------------------------------------------------|--------|
| Γ ₂₄ | $\Lambda \pi^+ \pi^0$ | $(3.6 \pm 1.3)\%$ | |
| Γ ₂₅ | Λho^+ | < 5 % | CL=95% |
| Γ ₂₆ | $\Lambda \pi^+ \pi^+ \pi^-$ | $(2.6 \pm 0.7)\%$ | |
| Γ ₂₇ | Σ (1385) $^+\pi^+\pi^-$, $\Sigma^{*+} ightarrow$ | $(7 \pm 4) \times 10^{-3}$ | |
| Γ ₂₈ | Σ (1385) $^-\pi^+\pi^+$, $\Sigma^{*-}	o$ | $(5.5 \pm 1.7) \times 10^{-3}$ | |
| Γ29 | $\Lambda \pi^- \Lambda \pi^+ ho^0$ | $(1.1 \pm 0.5)\%$ | |
| Γ ₃₀ | $\Sigma(1385)^+ ho^0$, $\varSigma^{*+} ightarrow$ $\varLambda\pi^+$ | $(3.7 \pm 3.1) \times 10^{-3}$ | |
| Γ ₃₁ | $\Lambda\pi^+\pi^+\pi^-$ nonresonant | $< 8 \times 10^{-3}$ | CL=90% |
| Γ ₃₂ | $\Lambda\pi^+\pi^+\pi^-\pi^0$ total | $(1.8 \pm 0.8)\%$ | |
| Γ ₃₃ | $\Lambda \pi^+ \eta$ | [b] (1.8 ± 0.6) % | |
| Γ ₃₄ | Σ (1385) $^+\eta$ | [b] (8.5 \pm 3.3) \times 10 ⁻³ | |
| Γ ₃₅ | $\Lambda\pi^+\omega$ | [b] (1.2 ± 0.5) % | |
| Γ ₃₆ | $\varLambda\pi^{+}\pi^{+}\pi^{-}\pi^{0}$, no η or ω | < 7 × 10 ⁻³ | CL=90% |
| Γ ₃₇ | $\Lambda K^+ \overline{K}^0$ | $(4.7 \pm 1.5) \times 10^{-3}$ | S=1.2 |
| Γ ₃₈ | $\Xi(1690)^0K^+$, $\Xi^{*0} ightarrow \Lambda \overline{K}{}^0$ | $(1.3 \pm 0.5) \times 10^{-3}$ | |
| Г ₃₉ | $\Sigma^0 \pi^+$ | (1.05 ± 0.28) % | |
| Γ ₄₀ | $\Sigma^+\pi^0$ | (1.00± 0.34) % | |
| Γ_{41} | $\Sigma^+\eta$ | $(5.5 \pm 2.3) \times 10^{-3}$ | |
| Γ ₄₂ | $\Sigma^+\pi^+\pi^-$ | $(3.6 \pm 1.0)\%$ | |
| Γ ₄₃ | $\Sigma^+ ho^0$ | < 1.4 % | CL=95% |
| Γ_{44} | $\Sigma^-\pi^+\pi^+$ | $(1.7 \pm 0.5)\%$ | |
| Γ ₄₅ | $\sum_{0}^{0} \pi^{+} \pi^{0}$ | $(1.8 \pm 0.8)\%$ | |
| Γ ₄₆ | $\Sigma^{0} \pi^{+} \pi^{+} \pi^{-}$ | $(8.3 \pm 3.1) \times 10^{-3}$ | |
| Γ ₄₇ | $\Sigma^+\pi^+\pi^-\pi^0$ | | |
| Γ ₄₈ | $\Sigma^+\omega$ | [b] (2.7 ± 1.0) % | |
| Γ ₄₉ | $\Sigma^+ K^+ K^-$ | $(2.8 \pm 0.8) \times 10^{-3}$ | |
| Γ_{50} | $\Sigma^+\phi$ | [b] $(3.1 \pm 0.9) \times 10^{-3}$ | |
| Γ_{51} | ${\it \Xi}$ (1690) 0 K $^{+}$, ${\it \Xi}^{*0}$ $ ightarrow$ | $(8.1 \pm 3.0) \times 10^{-4}$ | |
| | $\Sigma^{+}K^{-}$ | 4 | |
| Γ ₅₂ | $\Sigma^+ K^+ K^-$ nonresonant | $< 6 \times 10^{-4}$ | CL=90% |
| Γ ₅₃ | $\Xi^0 K^+$ | $(3.9 \pm 1.4) \times 10^{-3}$ | |
| Γ_{54} | $\Xi^- K^+ \pi^+$ | $(5.1 \pm 1.4) \times 10^{-3}$ | |

[b] $(2.6 \pm 1.0) \times 10^{-3}$

 $\Xi(1530)^0 K^+$



Hadronic modes with a hyperon: S = 0 final states ΛK^+ Γ_{56} $(5.0 \pm 1.6) \times 10^{-4}$ Γ_{57} $\times\,10^{-4}$ $\Lambda K^{+} \pi^{+} \pi$ CL=90% $\Sigma^0 K^+$ ($4.2~\pm~1.3$) $\times\,10^{-4}$ $\Sigma^0 K^+ \pi^+ \pi$ Γ_{59} $\times\,10^{-4}$ CL=90% < 2.1 $\Sigma^+ K^+ \pi^ (1.7 \pm 0.7) \times 10^{-3}$ Γ_{60} $\Sigma^+ K^*$ (892) 0 [b] (2.8 \pm 1.1) \times 10⁻³ $\times 10^{-3}$ $\Sigma^- K^+ \pi^+$ < 1.0 CL=90% Doubly Cabibbo-suppressed modes $pK^+\pi^ \times\,10^{-4}$ < 2.3 CL=90% Semileptonic modes $\varLambda\ell^+\,\nu_\ell$ [c] (2.0 \pm 0.6) % Γ₆₄ Γ_{65} $\Lambda e^+ \nu_e$ $(2.1 \pm 0.6)\%$ Γ_{66} $\Lambda \mu^+ \nu_{\mu}$ $(2.0 \pm 0.7)\%$ Inclusive modes e^+ anything $(4.5 \pm 1.7)\%$ Γ₆₇ pe+ anything (1.8 \pm 0.9) % Γ_{68} Γ_{69} Λe^+ anything p anything (50 ± 16) % p anything (no Λ) (12 ± 19) % Γ_{72} p hadrons Γ_{73} n anything (50) % ± 16 Γ₇₄ n anything (no Λ) (29 ± 17) % Γ_{75} Λ anything ±11)% S=1.4 Γ_{76} Σ^{\pm} anything [d] (10 ± 5)% 3prongs (24 ± 8

$\Delta C = 1$ weak neutral current (C1) modes, or Lepton Family number (LF), or Lepton number (L), or Baryon number (B) violating modes

| Г ₇₈ Г ₇₉ | $p e^+ e^- \\ p \mu^+ \mu^-$ | C1 C1 | < 5.5 < 4.4 | $\times 10^{-6} \times 10^{-5}$ | CL=90% CL=90% |
|------------------------------------|-----------------------------------------------------|-----------|----------------|---------------------------------|------------------|
| Γ ₈₀ | $pe^+\mu^-$ | LF | < 9.9 | $\times10^{-6}$ | CL=90% |
| Г ₈₁ Г ₈₂ | $\frac{p e^- \mu^+}{\overline{p} 2 e^+}$ | LF L.B | < 1.9 < 2.7 | $\times 10^{-5} \times 10^{-6}$ | CL=90% CL=90% |
| Γ ₈₃ | $\overline{p}2\mu^+$ | L,B | < 9.4 | ×10 ⁻⁶ | CL=90% |
| ٠. | $\overline{p} e^+ \mu^+ $ $\Sigma^- \mu^+ \mu^+$ | L,B L | < 1.6 < 7.0 | $\times 10^{-5} \times 10^{-4}$ | CL=90% CL=90% |

- [a] See the note on " \varLambda_c^+ Branching Fractions" below.
- [b] This branching fraction includes all the decay modes of the final-state resonance.
- [c] An ℓ indicates an e or a μ mode, not a sum over these modes.
- [d] The value is for the sum of the charge states or particle/antiparticle states indicated.

CONSTRAINED FIT INFORMATION

An overall fit to 18 branching ratios uses 33 measurements and one constraint to determine 12 parameters. The overall fit has a $\chi^2=$ 15.5 for 22 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle/(\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.

| • | x ₂ | <i>x</i> ₂₃ | <i>x</i> ₂₆ | <i>X</i> 37 | X39 | x ₄₂ | X ₄₄ | <i>X</i> 46 | <i>X</i> ₄₉ | <i>X</i> 50 |
|------------------------|----------------|------------------------|------------------------|-------------|-----|-----------------|-----------------|-------------|------------------------|-------------|
| X ₅₄ | 93 | 96 | 90 | 80 | 94 | 87 | 77 | 64 | 82 | 79 |
| <i>X</i> ₅₀ | 85 | 82 | 83 | 70 | 81 | 90 | 72 | 59 | 84 | |
| X49 | 88 | 85 | 86 | 72 | 84 | 93 | 75 | 61 | | |
| <i>x</i> ₄₆ | 69 | 66 | 70 | 57 | 66 | 65 | 57 | | | |
| <i>x</i> ₄₄ | 82 | 79 | 80 | 68 | 78 | 80 | | | | |
| x ₄₂ | 93 | 90 | 91 | 77 | 88 | | | | | |
| X39 | 95 | 98 | 92 | 82 | | | | | | |
| X37 | 82 | 83 | 80 | | | | | | | |
| <i>x</i> ₂₆ | 97 | 93 | | | | | | | | |
| X23 | 96 | | | | | | | | | |

Λ_a^+ BRANCHING FRACTIONS

Revised 2002 by P.R. Burchat (Stanford University).

Most Λ_c^+ branching fractions are measured relative to the decay mode $\Lambda_c^+ \to p K^- \pi^+$. However, there are no completely model-independent measurements of the absolute branching fraction for $\Lambda_c^+ \to p K^- \pi^+$. Here we describe the measurements that have been used to extract $\mathrm{B}(\Lambda_c^+ \to p K^- \pi^+)$, the model-dependence of the results, and the method we have used to average the results.

ARGUS (ALBRECHT 88C) and CLEO (CRAWFORD 92) measure $B(\overline{B} \to \Lambda_c^+ X) \cdot B(\Lambda_c^+ \to pK^-\pi^+)$ to be $(0.30 \pm 0.12 \pm 0.06)\%$ and $(0.273 \pm 0.051 \pm 0.039)\%$. Under the assumptions that decays of \overline{B} mesons to baryons are dominated by $\overline{B} \to \Lambda_c^+ X$ and that $\Lambda_c^+ X$ final states other than $\Lambda_c^+ \overline{N} X$ can be neglected, they also measure $B(\overline{B} \to \Lambda_c^+ X)$ to be $(6.8 \pm 0.5 \pm 0.3)\%$ (ALBRECHT 92O) and $(6.4 \pm 0.8 \pm 0.8)\%$ (CRAWFORD 92). Combining these results, we get $B(\Lambda_c^+ \to pK^-\pi^+) = (4.14 \pm 0.91)\%$. However, the assumption that \overline{B} decay modes to baryons other than $\Lambda_c^+ \overline{N} X$ are negligible is not on solid ground experimentally or theoretically [2]. Therefore, the branching fraction for $\Lambda_c^+ \to pK^-\pi^+$ given above may be low by some undetermined amount.

A second type of model-dependent determination of B($\Lambda_c^+ \to pK^-\pi^+$) is based on measurements by ARGUS (ALBRECHT 91G) and CLEO (BERGFELD 94) of $\sigma(e^+e^- \to \Lambda_c^+ {\rm X}) \cdot {\rm B}(\Lambda_c^+ \to \Lambda_c^+ \nu_\ell) = (4.15 \pm 1.03 \pm 1.18)$ pb and $(4.77 \pm 0.25 \pm 0.66)$ pb. ARGUS (ALBRECHT 96E) and CLEO (AVERY 91) have also measured $\sigma(e^+e^- \to \Lambda_c^+ {\rm X}) \cdot {\rm B}(\Lambda_c^+ \to pK^-\pi^+)$. The weighted average is (11.2 ± 1.3) pb.

From these measurements, we extract $R \equiv \mathrm{B}(\Lambda_c^+ \to p K^- \pi^+)/\mathrm{B}(\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell) = 2.40 \pm 0.43$. We estimate the $\Lambda_c^+ \to p K^- \pi^+$ branching fraction from the equation

$$B(\Lambda_c^+ \to pK^-\pi^+) = R f F \frac{\Gamma(D \to X\ell^+\nu_\ell)}{1 + |V_{cd}/V_{cs}|^2} \cdot \tau(\Lambda_c^+) , \quad (1)$$

where $f = \mathrm{B}(\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell)/\mathrm{B}(\Lambda_c^+ \to X_s \ell^+ \nu_\ell)$ and $F = \Gamma(\Lambda_c^+ \to X_s \ell^+ \nu_\ell)/\Gamma(D^0 \to X_s \ell^+ \nu_\ell)$. When we use $1 + |V_{cd}/V_{cs}|^2 = 1.05$ and the world averages $\Gamma(D \to \mathrm{X} \ell^+ \nu_\ell) = (0.166 \pm 0.006) \times 10^{12} \, \mathrm{s}^{-1}$ and $\tau(\Lambda_c^+) = (0.192 \pm 0.005) \times 10^{-12} \, \mathrm{s}$, we calculate $\mathrm{B}(\Lambda_c^+ \to p K^- \pi^+) = (7.3 \pm 1.4)\% \cdot f F$. Theoretical estimates for f and F are near 1.0 with significant uncertainties.

So, we have two results with significant model-dependence: $\mathrm{B}(\Lambda_c^+ \to pK^-\pi^+) = (4.14\pm0.91)\%$ from \overline{B} decays, and $\mathrm{B}(\Lambda_c^+ \to pK^-\pi^+) = (7.3\pm1.4)\% \cdot f\, F$ from semileptonic Λ_c^+ decays. If we set $f\, F = 1.0$ in the second result, and assign an uncertainty of 30% to each result to account for the unknown model-dependence, we get the consistent results $\mathrm{B}(\Lambda_c^+ \to pK^-\pi^+) = (4.14\pm0.91\pm1.24)\%$ and $\mathrm{B}(\Lambda_c^+ \to pK^-\pi^+) = (7.3\pm1.4\pm2.2)\%$. The weighted average of these two results is $\mathrm{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0\pm1.3)\%$, where the uncertainty contains both the experimental uncertainty and the 30% estimate of model dependence in each result. We assigned the value $(5.0\pm1.3)\%$ to the $\Lambda_c^+ \to pK^-\pi^+$ branching fraction in our 2000 Review [1].

A third type of measurement of $B(\Lambda_c^+ \to pK^-\pi^+)$ has been published by CLEO (JAFFE 00). Under the assumption that a \overline{D} meson and an antiproton in opposite hemispheres is evidence for a Λ_c^+ in the hemisphere of the \overline{p} , the fraction of such $\overline{D} \overline{p}$ events with a $\Lambda_c^+ \to pK^-\pi^+$ decay can be used to determine the $\Lambda_c^+ \to p K^- \pi^+$ branching fraction. CLEO measures $B(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$, which is coincidentally exactly the same value as our PDG 00 average given above. The quoted uncertainty includes significant contributions from model-dependent effects (e.g., differences between the \overline{p} momentum spectrum in events with a Λ_c^+ and \overline{p} in the same hemisphere, and with a \overline{D} and \overline{p} in opposite hemispheres; extrapolation of the Λ_c^+ and \overline{D} momentum spectrum below the minimum value used for rejecting B decay products; and our limited understanding of backgrounds such as $D\overline{D}N\overline{p}$ events).

We have chosen to continue to assign the value $(5.0 \pm 1.3)\%$ to the $\Lambda_c^+ \to p K^- \pi^+$ branching fraction (given as PDG 02 below). As was noted earlier, most of the other Λ_c^+ decay modes are measured relative to this mode.

New methods for measuring the Λ_c^+ absolute branching fractions have been proposed [2,3].

References

- 1. D.E. Groom et al. (Particle Data Group), Review of Particle Physics, Eur. Phys. J. C15, 1 (2000).
- I. Dunietz, Phys. Rev. **D58**, 094010 (1998).
- P. Migliozzi et al., Phys. Lett. **B462**, 217 (1999).

1 BRANCHING RATIOS

- Hadronic modes with a p: S = -1 final states -

| $\Gamma(p\overline{K}^0)/\Gamma(pK^{-1})$ | τ ⁺) | | | | Γ_1/Γ_2 |
|-------------------------------------------|------------------|-------------|-----|------|--------------------------------|
| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 0.47±0.04 OUR AVE | RAGE | | | | |
| $0.46 \pm 0.02 \pm 0.04$ | 1 0 2 5 | ALAM | 98 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |
| $0.44 \pm 0.07 \pm 0.05$ | 133 | AVERY | 91 | CLEO | e^+e^- 10.5 GeV |
| $0.55 \pm 0.17 \pm 0.14$ | 45 | ANJOS | 90 | E691 | γ Be 70–260 GeV |
| $0.62 \pm 0.15 \pm 0.03$ | 73 | ALBRECHT | 88c | ARG | e^+e^- 10 GeV |
| | | | | | |

 $\Gamma(pK^-\pi^+)/\Gamma_{\text{total}}$ Γ_2/Γ See the note on " Λ_c^+ Branching Fractions" above.

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------|------------|-------------------------|----------|------------|------------------------------|
| 0.050±0.013 OUR FIT | Γ | | | | |
| 0.050 ± 0.013 | | PDG | 02 | | See note at top of ratios |
| • • • We do not use | the follov | ving data for averag | es, fits | s, limits, | etc. • • • |
| $0.050 \pm 0.005 \pm 0.012$ | 1 2 0 5 | ² JAFFE | | | e^+e^- 10.52–10.58 GeV |
| 0.041 ± 0.010 | | | | | $e^+ e^- \approx \gamma(4S)$ |
| 0.044 ± 0.012 | | ^{3,5} CRAWFORD | 92 | CLEO | e^+e^- 10.5 GeV |

 2 JAFFE 00 assumes that a $\overline{\it D}$ meson and an antiproton in opposite hemispheres tags for a Λ_C^+ in the hemisphere of the \overline{p} . The fraction of such $\overline{D}\,\overline{p}$ events with a $\Lambda_C^+ \to$ $\rho\,{\it K}^-\,\pi^+$ decay then gives the $\rho\,{\it K}^-\,\pi^+$ branching fraction. See the paper for assumptions, caveats, etc.

³ To extract $\Gamma(p \, K^- \, \pi^+)/\Gamma_{\text{total}}$, we use $B(\overline{B} \to \Lambda_C^+ \, X) \cdot B(\Lambda_C^+ \to p \, K^- \, \pi^+) = (0.28 \pm 0.28 \pm$ 0.06)%, which is the average of measurements from ARGUS (ALBRECHT 88c) and CLEO (CRAWFORD 92).

⁴ ALBRECHT 920 measures B($\overline{B} \rightarrow \Lambda_c^+ X$) = (6.8 ± 0.5 ± 0.3)%.

⁵ CRAWFORD 92 measures B($\overline{B} \rightarrow \Lambda_C^+ X$) = (6.4 ± 0.8 ± 0.8)%.

 $\Gamma(\rho \overline{K}^*(892)^0)/\Gamma(\rho K^-\pi^+)$ Γ_3/Γ_2

| | V | | _ | | | | ٠, |
|---|-------------------------------------------|-------------|---------------------|----------|---------|------------------------------------|----|
| | Unseen decay mo | des of the | K*(892)0 are in | cluded. | | | |
| | /ALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| (| 0.31±0.04 OUR AVER | AGE | | | | | |
| (| $0.29 \pm 0.04 \pm 0.03$ | | ⁶ AITALA | 00 | E791 | π^- N, 500 GeV | |
| (| $0.35 {}^{+ 0.06}_{- 0.07} {}^{\pm 0.03}$ | 39 | BOZEK | 93 | NA 32 | $\pi^-\mathrm{Cu}$ 230 GeV | |
| (| 0.42±0.24 | 12 | BASILE | 81B | CNTR | $pp \rightarrow \Lambda_c^+ e^- X$ | |
| • | • • We do not use t | he followin | g data for averag | es, fits | limits, | etc. • • • | |
| (| 0.35 ± 0.11 | | BARLAG | 90D | NA32 | See BOZEK 93 | |

 6 AITALA 00 makes a coherent 5-dimensional amplitude analysis of 946 \pm 38 Λ_c^+ \to $p K^- \pi^+$ decays.

| $\Gamma(\Delta(1232)^{++}K^{-})/\Gamma(pK^{-}\pi^{+})$ | | | | | | |
|--------------------------------------------------------|---------|----------------------|--------|--------|-----------------------------------------|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 0.17±0.04 OUR AVER | AGE Err | or includes scale fa | ctor o | f 1.1. | | |
| $0.18 \pm 0.03 \pm 0.03$ | | ⁷ AITALA | 00 | E791 | π^- N, 500 GeV | |
| $0.12^{+0.04}_{-0.05}\pm 0.05$ | 14 | BOZEK | 93 | NA 32 | π^- Cu 230 GeV | |
| 0.40 ± 0.17 | 17 | BASILE | 81B | CNTR | $pp \rightarrow \Lambda_C^+ e^- \times$ | |

 7 AlTALA 00 makes a coherent 5-dimensional amplitude analysis of 946 \pm 38 Λ_c^+ \to

 $\Gamma(\Lambda(1520)\pi^+)/\Gamma(pK^-\pi^+)$ Γ_5/Γ_2 Unseen decay modes of the $\Lambda(1520)$ are included.

DO CUMENT ID TECN COMMENT 0.35 ± 0.08 OUR AVERAGE ⁸ AITALA $0.34 \pm 0.08 \pm 0.05$ 00 F791 π⁻ N 500 GeV $0.40^{\,+\,0.18}_{\,-\,0.13}\,\pm\,0.09$ BOZEK 93 NA 32 π^- Cu 230 GeV

 8 AITALA 00 makes a coherent 5-dimensional amplitude analysis of 946 \pm 38 Λ_c^+ \to $p K^- \pi^+$ decays.

| $\Gamma(\rho K^-\pi^+ \text{ nonresonant})/\Gamma(\rho K^-\pi^+)$ | | | | | | | |
|-------------------------------------------------------------------|------|---------------------|----|-------|--------------------|--|--|
| VALUE | EVTS | DO CUMENT II |) | TECN | COMMENT | | |
| 0.55 ± 0.06 OUR AVE | RAGE | | | | | | |
| $0.55 \pm 0.06 \pm 0.04$ | | ⁹ AITALA | 00 | E791 | π^- N, 500 GeV | | |
| $0.56^{+0.07}_{-0.09}\pm0.05$ | 71 | BOZEK | 93 | NA 32 | π^- Cu 230 GeV | | |

 9 AITALA 00 makes a coherent 5-dimensional amplitude analysis of 946 \pm 38 Λ_c^+ \to $p K^- \pi^+$ decays.

 $\Gamma(\rho \overline{K}{}^0\pi^0)/\Gamma(\rho K^-\pi^+)$ Γ_7/Γ_2 DOCUMENT ID TECN COMMENT 0.66±0.05±0.07 ALAM CLE2 $e^+e^- \approx \Upsilon(4S)$

 $\Gamma(p\overline{K}^0\eta)/\Gamma(pK^-\pi^+)$ Γ_8/Γ_2 Unseen decay modes of the η are included. VALUE EVTS DO CUMENT ID TECN COMMENT CLE2 $e^+e^- \approx \Upsilon(4S)$

 $\Gamma(\rho \overline{K}^0 \pi^+ \pi^-)/\Gamma(\rho K^- \pi^+)$ Γ_9/Γ_2 DOCUMENT IE TECN COMMENT 0.51±0.06 OUR AVERAGE $0.52 \pm 0.04 \pm 0.05$ ALAM 98 CLE2 $e^+e^- \approx \Upsilon(4S)$ CLEO $e^+\,e^-$ 10.5 GeV $0.43 \pm 0.12 \pm 0.04$ 83 AVERY 91

 $0.98 \pm 0.36 \pm 0.08$ BARLAG NA32 π^- 230 GeV 12 90D $\Gamma(\rho K^-\pi^+\pi^0)/\Gamma(\rho K^-\pi^+)$ Γ_{10}/Γ_{2} EVTS DOCUMENT ID TECN COMMENT

 $0.67 \pm 0.04 \pm 0.11$ ALAM 98 CLE2 $e^+e^- \approx \Upsilon(4S)$

 $\Gamma(pK^*(892)^-\pi^+)/\Gamma(p\overline{K}^0\pi^+\pi^-)$ Γ_{11}/Γ_{9} Unseen decay modes of the $K^*(892)^-$ are included. DO CUMENT ID TECN COMMENT 94 BIS2 nN 20-70 GeV

 $\Gamma(p(K^-\pi^+)_{\text{nonresonant}}\pi^0)/\Gamma(pK^-\pi^+)$ Γ_{12}/Γ_{2} DOCUMENT ID TECN COMMENT $0.73 \pm 0.12 \pm 0.05$ BOZEK 93 NA 32 π^- Cu 230 GeV

 $\Gamma(\Delta(1232)\overline{K}^*(892))/\Gamma_{\text{total}}$ Γ_{13}/Γ DOCUMENT ID TECN COMMEN AMENDOLIA 87

 $\Gamma(\rho K^-\pi^+\pi^+\pi^-)/\Gamma(\rho K^-\pi^+)$ Γ_{14}/Γ_{2} DOCUMENT ID TECN_COMMENT 0.022 ± 0.015 BARLAG 90D NA32 π⁻ 230 GeV

 $\Gamma(pK^-\pi^+\pi^0\pi^0)/\Gamma(pK^-\pi^+)$ Γ_{15}/Γ_{2} EVTS DOCUMENT ID TECN COMMENT 0.16±0.07±0.03 BOZEK 93 NA 32 π C μ 230 GeV

 $\Gamma(\rho K^-\pi^+3\pi^0)/\Gamma(\rho K^-\pi^+)$ Γ_{16}/Γ_{2} EVTS DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • BOZEK

 $0.10 \pm 0.06 \pm 0.02$

— Hadronic modes with a p: S = 0 final states -

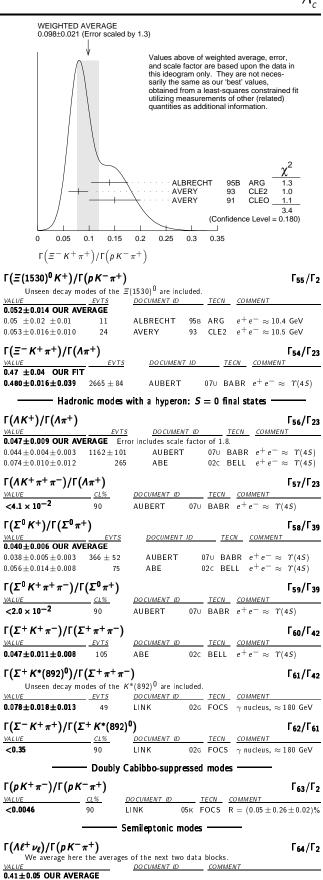
93 NA32 π^{-} Cu 230 GeV

 $\Gamma(p\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ Γ_{17}/Γ_{2} DOCUMENT ID TECN COMMENT 0.069 ± 0.036 BARLAG 90D NA32 π^- 230 GeV

 Λ_c^+

| $\Gamma(pf_0(980))/\Gamma(pK^-\pi^+)$ Unseen decay modes of the f_0 | | | Γ_{18}/Γ_{2} | Γ(ρ Κ ⁰ π+π-)/Γ(<u>VALUE</u> | (Λπ ⁺ π ⁺ π ⁻ <u>EVTS</u> | DOCUMENT ID | TECN | Γ9/Γ ; <u>COMMENT</u> |
|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------|--------------------------------------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------|--------------|-----------------------------------------------------------------------------------------|
| <u>VALUE</u> 0.055±0.036 | DOCUMENT ID BARLAG 90D | $\frac{TECN}{NA32} = \frac{COMMENT}{\pi}$ | ieV | • • • We do not use | the following | | | |
| $\Gamma(\rho\pi^+\pi^+\pi^-\pi^-)/\Gamma(\rho K^-\pi^+$ |) | | Γ_{19}/Γ_{2} | 2.6±1.2 4.3±1.2 | 130 | ALEEV ALEEV | | C n nucleus, 50 GeV/c nC 40-70 GeV |
| <u>VALUE</u> 0.036±0.023 | DOCUMENT ID BARLAG 90D | TECN COMMENT NA32 π^- 230 G | ieV | $\Gamma(\Lambda\pi^+\pi^+\pi^-\pi^0 t)$ | otal)/Γ(<i>p K</i> | (-π+) DOCUMENT ID | | Г ₃₂ /I — соммент |
| | BARREAG 300 | 147.52 / 250 0 | _ | 0.36±0.09±0.09 | | | | $e^+e^- \approx \gamma(4S)$ |
| Γ(ρΚ ⁺ Κ ⁻)/Γ(ρΚ ⁻ π ⁺) VALUE <u>EVTS</u> | DOCUMENT ID | TECN COMMENT | Γ ₂₀ /Γ ₂ | ¹⁰ CRONIN-HENNE below. | SSY 03 finds | this channel to | be dominan | tly $arLambda\eta\pi^+$ and $arLambda\omega\pi^+$; s |
| 0.015±0.006 OUR AVERAGE Erro 0.014±0.002±0.002 676 | or includes scale factor ABE 02c | or of 2.1. : BELL $e^+e^-\approx$ | $\Upsilon(4S)$ | $\Gamma(\Lambda\pi^+\eta)/\Gamma(\rho K^-)$ | -+1 | | | Г ₃₃ /I |
| $0.039 \pm 0.009 \pm 0.007$ 214 | ALEXANDER 960 | CLE2 e^+e^-pprox | · / | Unséen decay r | nodes of the | | | , |
| • • • We do not use the following $0.096\pm0.029\pm0.010$ 30 | = | i E687 γ Be, \overline{E}_{γ} | 220 GeV | <u>VALUE</u> 0.36±0.07 OUR AVE | RAGE | DO CUMENT ID | TECN | COMMENT |
| 0.048 ± 0.027 | | NA32 π^- 230 G | | $0.41 \pm 0.17 \pm 0.10$ $0.35 \pm 0.05 \pm 0.06$ | 11 116 | CRONIN-HEN AMMAR | | $e^+e^-pprox \Upsilon(4S)$ $e^+e^-pprox \Upsilon(4S)$ |
| $\Gamma(ho\phi)/\Gamma(hoK^-\pi^+)$ | | | Γ_{21}/Γ_2 | $\Gamma(\Sigma(1385)^+\eta)/\Gamma$ | | | | Г ₃₄ /І |
| Unseen decay modes of the ϕ <u>VALUE</u> <u>EVTS</u> | are included. <u>DOCUMENT ID</u> | TECN COMMENT | | | | $\Sigma(1385)^+$ and η | are included | |
| 0.0164 ± 0.0032 OUR AVERAGE E $0.015 \pm 0.002 \pm 0.002$ 345 | | ctor of 1.2. BELL $e^+e^-\approx$ | $\Upsilon(AS)$ | <u>VALUE</u> 0.17±0.04±0.03 | <u>EVTS</u> 54 | <u>DO CUMENT ID</u> A MMAR | 95 CLE3 | $\frac{COMMENT}{e^+e^-} \approx \Upsilon(4S)$ |
| $0.024 \pm 0.006 \pm 0.003$ 54 | ALEXANDER 960 | CLE2 e^+e^-pprox | | | | AWWAN | 93 CEL2 | |
| $ullet$ • • We do not use the following 0.040 ± 0.027 | = | s, limits, etc. \bullet \bullet \bullet NA32 π^- 230 G | -1/ | $\Gamma(\Lambda\pi^+\omega)/\Gamma(\rho K^-)$ Unseen decay r | | ω are included. | | Γ ₃₅ / Ι |
| | | NA32 π 230 G | | <u>VALUE</u> 0.24±0.06±0.06 | | DO CUMENT ID CRONIN-HEN | | |
| Γ(pK+K-non-φ)/Γ(pK-π+ <u>VALUE</u> EVTS |) <u>DO CUMENT ID</u> | | Γ_{22}/Γ_2 | $\Gamma(\Lambda\pi^+\pi^+\pi^-\pi^0$, | | | | . , |
| 0.007±0.002±0.002 344 | • | BELL $e^+e^-\approx$ | Y(4S) | VALUE | 110 η 01 ω) / <u>CL%</u> | DOCUMENT ID | TECN | Г ₃₆ /I |
| Hadronic modes w | ith a hyperon: S | =-1 final states | | <0.13 | 90 | CRONIN-HEN | 03 CLE3 | $e^+e^- \approx \gamma(4S)$ |
| $\Gamma(\Lambda\pi^+)/\Gamma(pK^-\pi^+)$ | | | Γ_{23}/Γ_2 | $\Gamma(\Lambda K^+ \overline{K}{}^0)/\Gamma(\rho I$ | | | | Г37/І |
| <u>VALUE</u> <u>CL%</u> <u>EV</u> TS 0.214±0.016 OUR FIT Error in | | TECN COMMENT 1.1. | | 0.093±0.018 OUR F | | DOCUMENT ID ludes scale factor | of 1.7. | COMMENT |
| 0.204±0.019 OUR AVERAGE | | _ | = 0.190 CoV | 0.131±0.020 OUR A 0.142±0.018±0.022 | | LINK | 05F FOCS | γ nucleus, $\overline{E}_{\gamma} pprox 180$ Ge |
| | ALBRECHT 92 | FOCS γ nucleus, I ARG $e^+e^- \approx 10$ | 1 | $0.12 \pm 0.02 \pm 0.02$ | 59 | | | $e^+e^- \approx \Upsilon(4S)$ |
| $0.18 \pm 0.03 \pm 0.03$ 87 • • • We do not use the following | | CLEO e^+e^- 10.5 s, limits, etc. • • • | GeV | Γ(Ξ(1690) ⁰ K ⁺ ,Ξ | | | | Γ ₃₈ /Γ |
| <0.33 90 | | E691 γBe 70-260 | | <u>VALUE</u> 0.28±0.07 OUR AVE | EVTS RAGE | DO CUMENT ID | | COMMENT |
| | ALBRECHT 88c | ARG e ⁺ e ⁻ 10 C | _ | $0.32 \pm 0.10 \pm 0.04$ $0.26 \pm 0.08 \pm 0.03$ | 93 ± 24 | | | γ nucleus, $\overline{E}_{\gamma} \approx 180$ Ge' $e^+e^- \approx \Upsilon(45)$ |
| Γ (Λπ⁺π⁰)/Γ(ρΚ⁻π⁺) VALUE EVTS | DOCUMENT ID | TECN COMMENT | Γ_{24}/Γ_2 | $\Gamma(\Lambda K^+ \overline{K}^0)/\Gamma(\Lambda n)$ | | | 020 0222 | |
| 0.73±0.09±0.16 464 | AVERY 94 | CLE2 $e^+e^- \approx$ | $\Upsilon(3S),\Upsilon(4S)$ | VALUE | EVTS | | | Γ ₃₇ /Γ <u>;</u> <u>τεςν <u>comment</u></u> |
| $\Gamma(\Lambda ho^+)/\Gamma(ho K^-\pi^+)$ | | | Γ_{25}/Γ_2 | 0.43 ±0.08 OUR F 0.395±0.026±0.036 | From Error inc. 460 ± 30 | | | BABR $e^+e^-pprox \Upsilon(4S)$ |
| | | TECN COMMENT CLE2 $e^+e^-\approx 1$ | 2(35) 2(45) | $\Gamma(\Sigma^0\pi^+)/\Gamma(pK^-)$ | | | | Г39/І |
| | WEI(1)4 | CLE2 C C ~ 7 | ,, ,, | VALUE | EVTS | DOCUMENT ID | TECN | COMMENT |
| $\Gamma(\Lambda\pi^+\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ VALUE EVTS | DOCUMENT ID | TECN COMMENT | Γ ₂₆ /Γ ₂ | 0.210±0.018 OUR F 0.20 ±0.04 OUR A | | | | |
| 0.525±0.032 OUR FIT 0.522±0.032 OUR AVERAGE | | | | $\begin{array}{cccc} 0.21 & \pm 0.02 & \pm 0.04 \\ 0.17 & \pm 0.06 & \pm 0.04 \end{array}$ | 196 | AVERY 9 ALBRECHT 9 | 4 CLE2 | $e^+ e^- \approx \Upsilon(3S), \Upsilon(4S)$ $e^+ e^- \approx 10.4 \text{ GeV}$ |
| 0.5 08 ± 0.024 ± 0.024 135 6 | | FOCS γ nucleus, \overline{I} | , | _ | ` | ALBRECHT 9 | 2 ANG | |
| | | CLEO e^+e^- 10.5 E691 γ Be 70-260 | | Γ(Σ ⁰ π ⁺)/Γ(Λπ ⁺ <u>VALUE</u> |) | DOCUMENT ID | TECN | Γ ₃₉ /Γ |
| 0.94 ±0.41 ±0.13 10 | BARLAG 90D | NA32 π^- 230 Ge | V | 0.98 ±0.05 OUR F 0.98 ±0.05 OUR A | | | | |
| | ALBRECHT 88c | | | $0.977 \pm 0.015 \pm 0.051$ | 33k | | | $e^+ e^- \approx \underline{\Upsilon}(4S)$ |
| $\Gamma(\Sigma(1385)^+\pi^+\pi^-,\Sigma^{*+}\to N)$ NALUE | , , | r [—]) <u>ECN COMMENT</u> | Γ_{27}/Γ_{26} | $1.09 \pm 0.11 \pm 0.19$ | 750 | LINK 0 | 5F FOCS | γ nucleus, $E_{\gamma} \approx 180$ Ge' |
| | | OCS γ nucleus, \overline{E} | $\gamma \approx 180 \text{ GeV}$ | $\Gamma(\Sigma^+\pi^0)/\Gamma(\rho K^-)$ | - π +) EVTS | DO CUMENT ID | TECA | Γ ₄₀ /Ι |
| $\Gamma(\Sigma(1385)^-\pi^+\pi^+,\Sigma^{*-}	o A)$ | $(\pi^-)/\Gamma(\Lambda\pi^+\pi^+\pi^+\pi^-)$ | r ⁻) | Γ_{28}/Γ_{26} | 0.20±0.03±0.03 | 93 | KUBOTA | 93 CLE2 | $\frac{COMMENT}{e^+e^-} \approx \Upsilon(4S)$ |
| VALUE D | OCUMENT ID | ECN COMMENT | - 100 C-1/ | $\Gamma(\Sigma^+\eta)/\Gamma(pK^-\eta)$ | π+) | | | Γ ₄₁ /Ι |
| 0.21±0.03±0.02 LI $\Gamma(\Lambda\pi^{+}\rho^{0})/\Gamma(\Lambda\pi^{+}\pi^{+}\pi^{-})$ | NK 05F F | FOCS γ nucleus, \overline{E} | γ ≈ 180 GeV Γ ₂₉ /Γ ₂₆ | Unseen decay r <u>VALUE</u> | | η are included. <u>DOCUMENT ID</u> | <u>TECN</u> | |
| VALUE D | | ECN COMMENT | | $0.11 \pm 0.03 \pm 0.02$ | 26 | AMMAR | 95 CLE2 | $e^+e^- \approx \Upsilon(4S)$ |
| 0.40±0.12±0.12 LI | NK 05F F | OCS γ nucleus, \overline{E} | $_{\gamma} pprox 180 \; { m GeV}$ | $\Gamma(\Sigma^+\pi^+\pi^-)/\Gamma(\mu^-)$ | , | Document : | D === | Γ ₄₂ /I |
| $\Gamma(\Sigma(1385)^+ ho^0$, $\Sigma^{*+} 	o \Lambda \pi^+)$ | | ECN COMMENT | Γ ₃₀ /Γ ₂₆ | 0.72±0.07 OUR FIT 0.69±0.08 OUR AVE | RAGE | <u>DOCUMENT II</u> |) rec | CN_COMMENT |
| VALUE | | OCS γ nucleus, \overline{E} | $_{\gamma} \approx 180 \text{ GeV}$ | 0.72 ± 0.14 | 47 ± 9 | VAZQUEZ-J | | LX Σ^- nucleus, 600 Ge |
| | | | | $0.74 \pm 0.07 \pm 0.09$ | 487 | KUBOTA | 93 CLI | E2 $e^+e^-\approx \Upsilon(4S)$ |
| 0.14±0.09±0.07 | $(\Lambda\pi^+\pi^+\pi^-)$ | | Γ_{31}/Γ_{26} | 0.54 + 0.18 | 11 | BARLAG | 92 NA | 32 π ⁻ Cu 230 GeV |
| 0.14 \pm 0.09 \pm 0.07 LI $\Gamma(\Lambda \pi^{+} \pi^{+} \pi^{-} \text{ nonresonant})/\Gamma(\frac{VALUE}{2})$ | OCUMENT ID | ECN <u>COMMENT</u> | | 0.54 + 0.18 | 11 | BARLAG | 92 NA | 32 π ⁻ Cu 230 GeV |
| 0.14 \pm 0.09 \pm 0.07 LI $\Gamma(\Lambda \pi^{+} \pi^{+} \pi^{-} \text{nonresonant})/\Gamma(\frac{MLUE}{2})$ | OCUMENT ID | $\frac{COMMENT}{COCS}$ $\frac{COMMENT}{\gamma}$ nucleus, \overline{E}_{γ} | | $0.54^{+0.18}_{-0.15}$ $\Gamma(\Sigma^{+}\rho^{0})/\Gamma(\rho K^{-})$ | | BARLAG DOCUMENT ID | 92 NA | Γ ₄₃ /Ι |

| $\Gamma(\Sigma^-\pi^+\pi^+)/\Gamma(\rho K^-\pi^+$ |) | Γ ₄₄ /Γ ₂ |
|----------------------------------------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| <u>VALUE</u> <u>EVT</u> 0.33 ±0.06 OUR FIT | S DOCUMENT ID | TECN COMMENT |
| 0.314±0.067 30 ± | 6 VAZQUEZ-JA08 | SELX Σ^- nucleus, 600 GeV |
| $\Gamma(\Sigma^-\pi^+\pi^+)/\Gamma(\Sigma^+\pi^+\pi^+)$ VALUE EVTS | DOCUMENT ID | Γ₄₄/Γ₄₂ <i>τεςν comment</i> |
| 0.46±0.09 OUR FIT 0.53±0.15±0.07 56 | | E687 γ Be, \overline{E}_{γ} 220 GeV |
| | TRABLITI 946 | , |
| $\Gamma(\Sigma^0\pi^+\pi^0)/\Gamma(\rho K^-\pi^+)$ VALUE EVTS | DO CUMENT ID T | Γ ₄₅ /Γ ₂ ECN COMMENT |
| 0.36±0.09±0.10 117 | | CLE2 $e^+e^- \approx \Upsilon(3S), \Upsilon(4S)$ |
| $\Gamma(\Sigma^0\pi^+\pi^+\pi^-)/\Gamma(\rho K^-)$ | π ⁺) DOCUMENT ID | Γ ₄₆ /Γ ₂ <u>τεςν</u> <u>comment</u> |
| 0.17±0.04 OUR FIT 0.21±0.05±0.05 90 | AVERY 94 | CLE2 $e^+e^-\approx$ |
| | | r(3s), r(4s) |
| $\Gamma(\Sigma^0\pi^+\pi^+\pi^-)/\Gamma(\Lambda\pi^+\pi^-)$ | | Γ ₄₆ /Γ ₂₆ |
| 0.31±0.08 OUR FIT 0.26±0.06±0.09 480 | · · · · · · · · · · · · · · · · · · · | CS γ nucleus, $\overline{E}_{\gamma} \approx 180~{ m GeV}$ |
| $\Gamma(\Sigma^+\omega)/\Gamma(pK^-\pi^+)$ | 211410 | Γ_{48}/Γ_{2} |
| Unseen decay modes of t | | |
| <u>VALUE</u> <u>EVTS</u> 0.54±0.13±0.06 107 | DO CUMENT ID KUBOTA 93 | $\frac{\textit{TECN}}{CLE2} \frac{\textit{COMMENT}}{e^+ e^- \approx \ \varUpsilon(4S)}$ |
| $\Gamma(\Sigma^+ K^+ K^-)/\Gamma(\rho K^- \pi^+)$ | +) | Γ_{49}/Γ_{2} |
| <u>VALUE</u> <u>EVTS</u> 0.056±0.008 OUR FIT | <u>DOCUMENT ID</u> | TECN COMMENT |
| 0.070±0.011±0.011 59 | AVERY 93 | CLE2 $e^+e^-pprox 10.5 \text{ GeV}$ |
| $\Gamma(\Sigma^+ K^+ K^-)/\Gamma(\Sigma^+ \pi^+)$ VALUE EVTS | π ⁻) DO CUMENT ID | Γ ₄₉ /Γ ₄₂ <u>τεςν</u> <u>comment</u> |
| 0.078±0.009 OUR FIT 0.074±0.009 OUR AVERAGE | | |
| $0.076 \pm 0.007 \pm 0.009$ 246 $0.071 \pm 0.011 \pm 0.011$ 103 | | BELL $e^+e^-pprox \varUpsilon(4S)$ FOCS γ nucleus, $pprox 180$ GeV |
| $\Gamma(\Sigma^+\phi)/\Gamma(\rho K^-\pi^+)$ | LINK 026 | Γ_{50}/Γ_{2} |
| Unseen decay modes of t | he φ are included. <u>DO CUMENT ID</u> | TECN COMMENT |
| 0.062±0.010 OUR FIT 0.069±0.023±0.016 26 | AVERY 93 | CLE2 $e^+e^- \approx 10.5 \text{ GeV}$ |
| $\Gamma(\Sigma^{+}\phi)/\Gamma(\Sigma^{+}\pi^{+}\pi^{-})$ | AVERT 93 | Γ ₅₀ /Γ ₄₂ |
| Unseen decay modes of t | he φ are included. DOCUMENT ID | TECN COMMENT |
| 0.087±0.012 OUR FIT 0.086±0.012 OUR AVERAGE | DOCUMENTID | TECH COMMENT |
| $0.085 \pm 0.012 \pm 0.012 \qquad 129$ | | BELL $e^+e^-\approx \Upsilon(4S)$ |
| 0.087±0.016±0.006 57 | | FOCS γ nucleus, $\approx 180~{ m GeV}$ |
| $\Gamma(\Xi(1690)^0 K^+, \Xi^{*0} \rightarrow \Sigma_{VALUE} \xrightarrow{EVTS}$ | | Γ ₅₁ /Γ ₄₂ |
| 0.023±0.005 OUR AVERAGE 0.023±0.005±0.005 75 | ABE 02c | BELL $e^+e^-pprox \Upsilon(4S)$ |
| 0.022±0.006±0.006 34 | | FOCS γ nucleus, $\approx 180~{ m GeV}$ |
| $\Gamma(\Sigma^+ K^+ K^- \text{ nonresonant})$ | | Γ ₅₂ /Γ ₄₂ TECN COMMENT |
| <0.018 90 | ABE 02c | BELL $e^+e^-pprox \Upsilon(4S)$ |
| • • • We do not use the follow <0.028 90 | = = | FOCS γ nucleus, \approx 180 GeV |
| $\Gamma(\Xi^0 K^+)/\Gamma(pK^-\pi^+)$ | | Γ_{53}/Γ_{2} |
| <u>VALUE</u> <u>EVTS</u> 0.078±0.013±0.013 56 | DOCUMENT ID AVERY 93 | $\begin{array}{ccc} \underline{\textit{TECN}} & \underline{\textit{COMMENT}} \\ \text{CLE2} & e^+ e^- \approx 10.5 \text{GeV} \end{array}$ |
| $\Gamma(\Xi^-K^+\pi^+)/\Gamma(pK^-\pi^+$ | | Γ ₅₄ /Γ ₂ |
| VALUE EVTS 0.102±0.010 OUR FIT Error | DO CUMENT ID | TECN COMMENT |
| 0.098±0.021 OUR AVERAGE | Error includes scale factor | of 1.3. See the ideogram below. |
| $0.14 \pm 0.03 \pm 0.02$ 34 $0.079 \pm 0.013 \pm 0.014$ 60 | ALBRECHT 95B AVERY 93 | ARG $e^+e^-\approx 10.4~{\rm GeV}$ CLE2 $e^+e^-\approx 10.5~{\rm GeV}$ |
| 0.15 ±0.04 ±0.03 | AVERY 91 | CLEO $e^{+}e^{-}$ 10.5 GeV |



 $\begin{array}{ll} \text{O2} & \text{Our } \Gamma(\varLambda\,e^+\,\nu_e)/\Gamma(\rho\,K^-\,\pi^+) \\ \text{O2} & \text{Our } \Gamma(\varLambda\,\mu^+\,\nu_\mu)/\Gamma(\rho\,K^-\,\pi^+) \end{array}$

PDG

 0.42 ± 0.07

 0.39 ± 0.08

 Λ_c^+

| $\Gamma(\Lambda e^+ u_e)/\Gamma(ho K^- \pi^+)$ | Γ ₆₅ /Γ ₂ | 21 ABE 86 includes ${\it \Lambda}$'s from ${\it \Sigma}^{0}$ decay. |
|-------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| 0.42±0.07 OUR AVERAGE | JMENT ID TECN COMMENT | WEIGHTED AVERAGE |
| 0.43±0.08 11,12 BERG 0.38±0.14 12,13 ALBF | | 0.35±0.11 (Error scaled by 1.4) |
| 11 BERGFELD 94 measures $\sigma(e^+e^- ightarrow 0.69)$ pb. | $\Lambda_{C}^{+} X) \cdot B(\Lambda_{C}^{+} \rightarrow \Lambda e^{+} \nu_{e}) = (4.87 \pm 0.28 \pm$ | \ \frac{1}{1} |
| | \rightarrow p $K^-\pi^+$), we use $\sigma(e^+e^- \rightarrow \Lambda_c^+ {\rm X}) \cdot {\rm B}(\Lambda_C \rightarrow$ | |
| $p K^- \pi^+) = (11.2 \pm 1.3) \text{pb, which}$ | is the weighted average of measurements from | |
| | (AVERY 91). | |
| $\Gamma(\Lambda \mu^+ u_{\mu})/\Gamma(ho K^- \pi^+)$ | Γ ₆₆ /Γ ₂ | |
| <u>VALUE</u> <u>DOCU</u> | JMENT ID TECN COMMENT | 2 |
| 0.39 ± 0.08 OUR AVERAGE 0.40 ± 0.09 $14,15$ BERO 0.35 ± 0.20 $15,16$ ALBF | | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 14 BERGFELD 94 measures $\sigma(e^+e^- ightarrow$ | $\Lambda_c^+ X) \cdot B(\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu) = (4.43 \pm 0.51 \pm$ | ADAMOVICH 87 EMUL 0.3 |
| 0.64) pb. 15 To extract $\Gamma(\Lambda_{-}^{+} \rightarrow \Lambda \mu^{+} \nu_{\mu})/\Gamma(\Lambda_{-}^{+} -$ | $\rightarrow p K^- \pi^+$), we use $\sigma(e^+ e^- \rightarrow \Lambda_C^+ {\rm X}) \cdot {\rm B}(\Lambda_C \rightarrow$ | (Confidence Level = 0.126) |
| | is the weighted average of measurements from | -0.5 0 0.5 1 1.5 2 |
| 16 ALBRECHT 91G measures $\sigma(e^+e^0.90)$ pb. | $\rightarrow \Lambda_c^+ X) \cdot B(\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu) = (3.91 \pm 2.02 \pm$ | $\Gamma(\Lambda \text{ anything})/\Gamma_{\text{total}}$ $\Gamma(\Sigma^{\pm} \text{anything})/\Gamma_{\text{total}}$ Γ_{76}/Γ |
| Inclus | sive modes ——— | VALUE EVTS DOCUMENT ID TECN COMMENT |
| $\Gamma(e^+ \text{ anything})/\Gamma_{\text{total}}$ | Γ ₆₇ /Γ | $\textbf{0.1\pm0.05}$ 5 ABE 86 HYBR 20 GeV γp |
| <u>VALUE</u> <u>DO CU</u> | MENT ID TECN COMMENT | $\Gamma(3\text{prongs})/\Gamma_{\text{total}}$ Γ_{77}/Γ |
| 0.045 ± 0.017 VELL | | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| Γ(pe ⁺ anything)/Γ _{total} VALUE DOCU | F68/F JMENT ID TECN COMMENT | Rare or forbidden modes |
| 0.018\pm0.009 17 VELL 17 VELLA 82 includes protons from Λ dec | | $\Gamma(pe^+e^-)/\Gamma_{	ext{total}}$ A test for the $\Delta C = 1$ weak neutral current. Allowed by higher-order electroweak inter- |
| $\Gamma(\Lambda e^+ \text{ anything})/\Gamma_{\text{total}}$ | Г ₆₉ /Г | actions. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| | MENT ID TECN COMMENT | <5.5 × 10^{−6} 90 4.0 ± 7.1 LEES 11G BABR $e^+e^- \approx \Upsilon(4S)$ |
| • • We do not use the following data for | - | $\Gamma(p\mu^+\mu^-)/\Gamma_{	ext{total}}$ Γ_{79}/Γ |
| 18 VELLA 82 includes $\it \Lambda$'s from $\it \Sigma^0$ decay | | A test for the ΔC =1 weak neutral current. Allowed by higher-order electroweak interactions. |
| Γ(p anything)/Γ _{total} | Γ ₇₀ /Γ | $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 0.5 0 ± 0.08 ± 0.14 19 CRAV | WFORD 92 CLEO e^+e^- 10.5 GeV | $< 3.4 \times 10^{-4}$ 90 0 KODAMA 95 E653 π^- emulsion 600 GeV |
| ¹⁹ This CRAWFORD 92 value includes pro- but account is taken of this in the system | otons from $\it \Lambda$ decay. The value is model dependent, ematic error. | $\Gamma(pe^+\mu^-)/\Gamma_{ m total}$ $\Gamma_{ m 80}/\Gamma$ |
| Γ(p anything (no Λ))/Γ _{total} | Γ ₇₁ /Γ | A test of lepton family-number conservation. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| · · · · · · · · · · · · · · · · · · · | WFORD 92 CLEO e ⁺ e ⁻ 10.5 GeV | <9.9 × 10⁻⁶ 90 -0.7 ± 3.0 LEES 116 BABR $e^+e^-\approx \Upsilon(4S)$ |
| Γ(n anything)/Γ _{total} | Γ ₇₃ /Γ | $\Gamma(\rhoe^-\mu^+)/\Gamma_{	ext{total}}$ A test of lepton family-number conservation. |
| | $\frac{\textit{JMENT ID}}{\textit{WFORD}} = \frac{\textit{TECN}}{\textit{CLEO}} = \frac{\textit{COMMENT}}{e^+ e^- 10.5 \text{ GeV}}$ | |
| ²⁰ This CRAWFORD 92 value includes ne | eutrons from Λ decay. The value is model depen- | ` ' |
| dent, but account is taken of this in th | | $\Gamma(\overline{p}2e^+)/\Gamma_{total}$ Γ_{82}/Γ A test of lepton- and baryon-number conservation. |
| Γ(n anything (no Λ))/Γ _{total} <u>VALUE</u> <u>DOCU</u> | Γ ₇₄ /Γ JMENT ID <u>TECN</u> <u>COMMENT</u> | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | WFORD 92 CLEO e^+e^- 10.5 GeV | $\Gamma(\overline{p}2\mu^+)/\Gamma_{	ext{total}}$ Γ_{83}/Γ |
| Γ(ρ hadrons)/Γ _{total} VALUE DOCU | Γ ₇₂ /Γ UMENT ID TECN COMMENT | A test of lepton- and baryon-number conservation and of lepton family-number con- servation. |
| • • We do not use the following data for | | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| 0.41 ± 0.24 ADAI $\Gamma(\Lambda \text{ anything})/\Gamma_{\text{total}}$ | MOVICH 87 EMUL γ A 20–70 GeV/ c | $\Gamma(\overline{p}e^+\mu^+)/\Gamma_{	ext{total}}$ |
| <u>VALUE</u> <u>EVTS</u> <u>DOCU</u> | JMENT ID <u>TECN</u> COMMENT | A test of lepton- and baryon-number conservation and of lepton family-number conservation. |
| | es scale factor of 1.4 . See the ideogram below. WFORD 92 CLEO $e^+e^-10.5$ GeV | $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ |
| | MOVICH 87 EMUL γ A 20–70 GeV/ c | $\Gamma(\Sigma^-\mu^+\mu^+)/\Gamma_{\text{total}}$ |
| | | A test of lepton-number conservation. VALUE CL% EVTS DOCUMENT ID TECN COMMENT |
| | | <7.0 x 10 ⁻⁴ 90 0 KODAMA 95 E653 π [−] emulsion 600 GeV |

Baryon Particle Listings Λ_c^+ , $\Lambda_c(2595)^+$

1 DECAY PARAMETERS

See the note on "Baryon Decay Parameters" in the neutron Listings

α FOR $\Lambda_c^+ \rightarrow \Lambda \pi^+$

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------|-------|----------------------|-----|------|-------------------------------------------------------------|
| -0.91 ± 0.15 OUR AV | ERAGE | | | | |
| $-0.78\pm0.16\pm0.19$ | | LINK | 06A | FOCS | γ A, $\overline{E}_{\gamma} \approx 180 \; { m GeV}$ |
| $-0.94\pm0.21\pm0.12$ | 414 | ²² BISHAI | 95 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |
| -0.96 ± 0.42 | | ALBRECHT | 92 | ARG | $e^+e^-pprox 10.4{ m GeV}$ |
| -1.1 ± 0.4 | 86 | AVERY | 90B | CLEO | $e^+e^-pprox 10.6$ GeV |

 22 BISHAI 95 actually gives $\alpha{=}-0.94^{+}0.21^{+}0.12^{-}$, chopping the errors at the physical limit -1.0. However, for $\alpha{\approx}-1.0$, some experiments should get unphysical values $(\alpha<-1.0)$, and for averaging with other measurements such values (or errors that extend below -1.0) should not be chopped.

α FOR $\Lambda_c^+ \rightarrow \Sigma^+ \pi^0$

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|------|--------------|----|------|--------------------------------|
| $-0.45 \pm 0.31 \pm 0.06$ | 89 | BISHAI | 95 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

α FOR $\Lambda_c^+ \rightarrow \Lambda \ell^+ \nu_{\ell}$

The experiments don't cover the complete (or same incomplete) $M(\Lambda \ell^+)$ range, but we average them together anyway.

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------------------|-------------|------------------------|---------|-----------|--------------------------------------|
| -0.86 ± 0.04 OUR AV | ERAGE | | | | |
| $-0.86\pm0.03\pm0.02$ | 3201 | ²³ HINSON | 05 | CLEO | $e^+ e^- \approx \Upsilon(4S)$ |
| $-0.91\pm0.42\pm0.25$ | | ²⁴ ALBRECHT | 94B | ARG | $e^+ e^- \approx 10 \; \mathrm{GeV}$ |
| • • • We do not use | the followi | ng data for average | s, fits | , limits, | etc. • • • |
| $-0.82^{+0.09+0.06}_{-0.06-0.03}$ | 700 | ²⁵ CRAWFORD | 95 | CLE2 | See HINSON 05 |
| $-0.89 {}^{+ 0.17 + 0.09}_{- 0.11 - 0.05}$ | 35 0 | ²⁶ BERGFELD | 94 | CLE2 | See CRAWFORD 95 |

²³ HINSON 05 measures the form-factor ratio $R \equiv f_2/f_1$ for $\Lambda_C^+ \to \Lambda \, e^+ \, \nu_e$ events to be $-0.31\pm0.05\pm0.04$ and the pole mass to be 2.21 $\pm0.08\pm0.14~{\rm GeV/c^2}$, and from these calculates $\alpha_{\rm s}$ averaged over q^2 , where $\langle q^2\rangle=0.67~({\rm GeV/c})^2$. 24 ALBRECHT 94B uses Λe^+ and $\Lambda \mu^+$ events in the mass range 1.85 $<\!M(\Lambda\ell^+)<2.20$

²⁵ CRAWFORD 95 measures the form-factor ratio $R \equiv f_2/f_1$ for $\Lambda_c^+ \to \Lambda e^+ \nu_e$ events to be $-0.25\pm0.14\pm0.08$ and from this calculates lpha, averaged over q^2 , to be the above. 26 BERGFELD 94 uses Λe^+ events.

Λ_c^+ , $\overline{\Lambda}_c^-$ CP-VIOLATING DECAY ASYMMETRIES

 $(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda \pi^+$, $\overline{\Lambda}_c^- \to \overline{\Lambda} \pi^-$ This is zero if CP is conserved.

| VALUE | DO CUMENT ID | | TECN | COMMENT |
|---------------------------------------|--------------|------|------|---------------------------------------------------|
| $-0.07 \pm 0.19 \pm 0.24$ | LINK | 06A | FOCS | γ A, $\overline{E}_{\gamma} pprox$ 180 GeV |
| (a, 1 =)/(a, =) in A ⁺ , | 1a+ | 7.0- | | |

 $-\overline{\alpha})/(\alpha-\overline{\alpha})$ in $\Lambda_c^+\to\Lambda e$ This is zero if *CP* is conserved.

VALUE. DO CUMENT ID TECN COMMENT $0.00 \pm 0.03 \pm 0.02$ 05 CLEO $e^+e^-\approx \Upsilon(4S)$

Λ_c^+ REFERENCES

We have omitted some papers that have been superseded by later experiments. The omitted papers may be found in our 1992 edition (Physical Review D45, 1 June, Part II) or in earlier editions.

| LEES | 11 G | PR D84 072006 | J.P. Lees et al. | (BABAR | Collab.) |
|---------------|------|---------------------------|----------------------------|--------------------|----------|
| VAZQUEZ-JA | 08 | PL B666 299 | E. Vazquez-Jauregui et al. | (SELEX | Collab.) |
| AUBERT | 07 U | PR D75 052002 | B. Aubert et al. | (BABAR | Collab.) |
| LINK | 06A | PL B634 165 | J.M. Link et al. | (FNAL FOCUS | Collab.) |
| AUBERT,B | 05S | PR D72 052006 | B. Aubert et al. | ` (BABAR | Collab.) |
| HINS ON | 05 | PRL 94 191801 | J.W. Hinson et al. | (CLEO | Collab.) |
| LINK | 05 F | PL B624 22 | J.M. Link et al. | (FNAL FOCUS | Collab.) |
| LINK | 05 K | PL B624 166 | J.M. Link et al. | (FNAL FOCUS | Collab.) |
| CRONIN-HEN | 03 | PR D67 012001 | D. Cronin-Hennessy et al. | ` (CLEO | Collab.) |
| KAYIS-T OPAK. | .03 | PL B555 156 | A. Kayis-Topaksu ét al. | (CERN CHORUS | Collab.) |
| ABE | 02 C | PL B524 33 | K. Abe et al. | ` (KEK BELLE | Collab.) |
| LINK | 02 C | PRL 88 161801 | J.M. Link et al. | (FNAL FOCUS | Collab.) |
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| MAHMOOD | 01 | PRL 86 2232 | A.H. Mahmood et al. | ` (CLEO | Collab.) |
| AITALA | 00 | PL B471 449 | E.M. Aitala et al. | (FNAL E791 | Collab.) |
| JAFFE | 00 | PR D62 072005 | D.E. Jaffe et al. | ` (CLEO | Collab.) |
| ALAM | 98 | PR D57 4467 | M.S. Alam et al. | (CLEO | Collab.) |
| ALBRECHT | 96 E | PRPL 276 223 | H. Albrecht et al. | (ARGUS | Collab.) |
| ALEEV | 96 | JINRRC 3-77 31 | A.N. Aleev et al. | (Serpukhov EXCHARM | Collab.) |
| ALEXANDER | 96 C | PR D53 R1013 | J.P. Alexander et al. | (CLEO | Collab.) |
| ALBRECHT | 95 B | PL B342 397 | H. Albrecht et al. | (ARGUS | Collab.) |
| AMMAR | 95 | PRL 74 3534 | R. Ammar et al. | `(CLEO | Collab.) |
| BISHAI | 95 | PL B350 256 | M. Bishai et al. | | Collab.) |
| CRAWFORD | 95 | PRL 75 624 | G. Crawford et al. | (CLEO | Collab.) |
| KODAMA | 95 | PL B345 85 | K. Kodama et al. | (FNAL E653 | Collab.) |
| ALBRECHT | 94 B | PL B326 320 | H. Albrecht et al. | ` (ARGUS | Collab.) |
| ALEEV | 94 | PAN 57 1370 | A.N. Aleev et al. | (Serpukhov BIS-2 | Collab.) |
| | | Translated from YF 57 144 | | | |
| AVERY | 94 | PL B325 257 | P. Avery et al. | | Collab.) |
| BERGFELD | 94 | PL B323 219 | T. Bergfeld et al. | | Collab.) |
| FRABETTI | 94 E | PL B328 193 | P.L. Frabetti et al. | (FNAL E687 | |
| AVERY | 93 | PRL 71 2391 | P. Avery et al. | | Collab.) |
| BOZEK | 93 | PL B312 247 | A. Bozek et al. | (CERN NA32 | Collab.) |
| | | | | | |

| FRABETTI | 93 D | PRL 70 1755 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
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| ALBRECHT | 92 | PL B274 239 | H. Albrecht et al. | (ARGUS Collab.) |
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| JEZABEK | 92 | PL B286 175 | M. Jezabek, K. Rybicki, R. Ry | |
| ALBRECHT | 91 G | PL B269 234 | H. Albrecht et al. | (ARGUS Collab.) |
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| ALVAREZ | 90 | ZPHY C47 539 | M.P. Alvarez et al. | (CERN NA14/2 Collab.) |
| ALVARE7 | 90 B | PL B246 256 | M.P. Alvarez et al | (CERN NA14/2 Collab.) |
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| AVERY | 90 B | PRL 65 2842 | P. Avery et al. | (CLEO Collab.) |
| BARLAG | 90 D | 7PHY C48 29 | S. Barlag et al. | (ACCMOR Collab.) |
| FRABETTI | 90 | PL B251 639 | PI Frahetti et al | (FNAL E687 Collab.) |
| BARLAG | 89 | PL B218 374 | S. Barlag et al. | (ACCMOR Collab.) |
| AGUILAR | 88 B | ZPHY C40 321 | M. Aguilar-Benitez et al. | (LEBC-EHS Collab.) |
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| ALBRECHT | 88 C | PL B207 109 | H. Albrecht et al. | (ARGUS Collab.) |
| ANJOS | 88 B | PRL 60 1379 | J.C. Anjos et al. | (FNÀL E691 Collab.) |
| ADAMOVICH | 87 | EPL 4 887 | M.I. Adamovich et al. | (Photòn Emulsion Collab.) |
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| | | Translated from YAF 46 7 | 99. | , |
| AM EN DOLIA | 87 | ZPHY C36 513 | S.R. Amendolia et al. | (CERN NA1 Collab.) |
| JONES | 87 | ZPHY C36 593 | G.T. Jones et al. | (ČERN WA21 Collab.) |
| ABE | 86 | PR D33 1 | K. Abe et al. | |
| ALEEV | 84 | ZPHY C23 333 | A.N. Aleev et al. | (BIS-2 Collab.) |
| BOSETTI | 82 | PL 109B 234 | P.C. Bosetti et al. | (AACH3, BÒNN, CERN+) |
| VELLA | 82 | PRL 48 1515 | E. Vella et al. | (SLAC, LBL, UCB) |
| BASILE | 81B | NC 62A 14 | M. Basile et al. | (CERN, BĠNA, PGIA, FRAS) |
| CALICCHIO | 80 | PL 93B 521 | M. Calicchio et al. | (BARI, BIRM, BRUX+) |
| | | | | |

OTHER RELATED PAPERS -

PL B462 217 PR D58 094010 P. Migliozzi *et al* I. Dunietz MIGLIOZZI

$\Lambda_c(2595)^+$

$$I(J^P) = 0(\frac{1}{2})$$
 Status: ***

The $\Lambda_c^+\pi^+\pi^-$ mode is largely, and perhaps entirely, $\Sigma_c\pi$, which is just at threshold; since the Σ_c has $J^P = 1/2^+$, the J^P here is almost certainly $1/2^-$. This result is in accord with the theoretical expectation that this is the charm counterpart of the strange $\Lambda(1405).$

$\Lambda_c(2595)^{+}$ MASS

The mass is obtained from the $\Lambda_c(2595)^+ - \Lambda_c^+$ mass-difference measure-

VALUE (MeV) 2592.25 ± 0.28 OUR FIT DOCUMENT ID

$\Lambda_c(2595)^+ - \Lambda_c^+$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|---------------|----------------------------|---------|---------|--------------------------------------------------------------|
| 305.79 ± 0.24 OUR FI | Т | · | | - | |
| $305.79 \pm 0.14 \pm 0.20$ | 3.5 k | AALTONEN | 11 H | CDF | $p\overline{p}$ at 1.96 TeV |
| ullet $ullet$ We do not use | the following | g data for averages | , fits, | limits, | etc. • • • |
| 305.6 ± 0.3 | | $^{ m 1}$ $^{ m BLECHMAN}$ | 03 | | Threshold shift |
| $309.7 \pm 0.9 \pm 0.4$ | 19 | ALBRECHT | 97 | | e^+e^-pprox 10 GeV |
| $309.2 \ \pm 0.7 \ \pm 0.3$ | 14 ± 4.5 | FRABETTI | 96 | E687 | γ Be, $\overline{E}_{\gamma} \approx 220 \text{ GeV}$ |
| $307.5 \ \pm 0.4 \ \pm 1.0$ | 112 ± 17 | EDWARDS | 95 | CLE2 | e^+e^-pprox 10.5 GeV |

¹ BLECHMAN 03 finds that a more sophisticated treatment than a simple Breit-Wigner for the proximity of the threshold of the dominant decay, $\Sigma_{\mathcal{C}}(2455)\,\pi$, lowers the $\Lambda_{\it C}(25\,95)^+ - \Lambda_{\it C}^+$ mass difference by 2 or 3 MeV. The analysis of AALTONEN 11H bears this out.

$\Lambda_c(2595)^{+}$ WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------------------------------------------|---------------------|-----------------------|-----------------|--------------------|------------------------------------------------|
| $2.59 \pm 0.30 \pm 0.47$ | 3.5k | ² AALTONEN | 11н | CDF | ρ p at 1.96 TeV |
| • • • We do not use | the following d | lata for averages, fi | its, lir | nits, etc | . • • • |
| $2.9 \begin{array}{c} +2.9 \\ -2.1 \end{array} \begin{array}{c} +1.8 \\ -1.4 \end{array}$ | 19 | ALBRECHT | 97 | ARG | e^+e^-pprox 10 GeV |
| $3.9 \begin{array}{l} +1.4 & +2.0 \\ -1.2 & -1.0 \end{array}$ | 112 ± 17 | EDWA RDS | 95 | CLE2 | $e^+e^-\approx~10.5~\text{GeV}$ |
| ² AALTONEN 11H | treats the thre | ee charged modes | $\Lambda_{C}(2$ | 2595) ⁺ | \rightarrow $\Sigma_{C}(2455)^{++}\pi^{-}$, |
| | | | | | coupling constant h ₂ |
| and obtains $h_2^2 =$ | 0.36 ± 0.08 . F | rom this the width | . is d€ | etermine | d. |

 $\Lambda_c(2595)^+$, $\Lambda_c(2625)^+$

$\Lambda_c(2595)^+$ DECAY MODES

 $\Lambda_C^+\pi\pi$ and its submode $\Sigma_C(2455)\pi$ — the latter just barely — are the only strong decays allowed to an excited Λ_C^+ having this mass; and the submode seems to dominate.

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ | |
|-----------------------|-----------------------------------|--------------------------------------|--|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ \pi^+ \pi^-$ | [a] ≈ 67 % | |
| Γ_2 | $\Sigma_c(2455)^{++}\pi^-$ | 24 ± 7 % | |
| Γ_3 | $\Sigma_c(2455)^0 \pi^+$ | 24 ± 7 % | |
| Γ_4 | $\Lambda_c^+ \pi^+ \pi^-$ 3-b ody | 18 \pm 10 % | |
| Γ_5 | $\Lambda_c^+ \pi^0$ | [b] not seen | |
| Γ ₆ | $\Lambda_c^+ \gamma$ | not seen | |

- [a] Assuming isospin conservation, so that the other third is $\Lambda_c^+ \pi^0 \pi^0$.
- [b] A test that the isospin is indeed 0, so that the particle is indeed a Λ_c^+ .

$\Lambda_c(2595)^+$ BRANCHING RATIOS

| $\frac{\Gamma(\Sigma_c(2455)^{++}\pi^-)}{\frac{VALUE}{0.36\pm0.10}}$ | | +π-) DOCUMENT ID | | TECN | Γ ₂ / | Γ1 | |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|---------------------------------|----------|------|------------------------------------------------------------------------|----|--|
| 0.37±0.12±0.13 0.36±0.09±0.09 | AGE | ALBRECHT EDWARDS | 97 95 | | $e^+ e^- \approx 10 \text{ GeV}$ $e^+ e^- \approx 10.5 \text{ GeV}$ | | |
| $\Gamma(\Sigma_c(2455)^0\pi^+)/\Gamma$ | $(\Lambda_c^+ \pi^+)$ | π ⁻) DOCUMENT ID | | TECN | Г ₃ / | Γ1 | |
| 0.37±0.10 OUR AVER 0.29±0.10±0.11 0.42±0.09±0.09 | AGE | ALBRECHT EDWARDS | 97 95 | | $e^+ e^- \approx 10 \text{ GeV}$ $e^+ e^- \approx 10.5 \text{ GeV}$ | | |
| $\left[\Gamma\left(\Sigma_c(2455)^{++}\pi^{-}\right)\right]$ |) + Γ(Σ _ι | | | | • | Γ1 | |
| • • • We do not use the | | | | | | | |
| $0.66 + 0.13 \pm 0.07$ | | ALBRECHT | 97 | ARG | e^+e^-pprox 10 GeV | | |
| >0.10 | 90 | ³ FRABETTI | 96 | E687 | γ Be, $\overline{E}_{\gamma} \approx $ 220 GeV | , | |
| ³ The results of FRAI | BETTI 96 | | | | , | | |
| $\Gamma(\Lambda_c^+\pi^0)/\Gamma(\Lambda_c^+\pi^+\pi^-)$ $\Lambda_c^+\pi^0$ decay is forbidden by isospin conservation if this state is in fact a Λ_c . | | | | | | | |
| να LUE | <u>CL%_</u> | DO CUMENT ID | LIOII II | TECN | | | |
| <3.53 | 90 | EDWARDS | 95 | | $e^+ e^- \approx 10.5 \text{ GeV}$ | | |
| $\Gamma(\Lambda_c^+ \gamma)/\Gamma(\Lambda_c^+ \pi^+ \pi^-)$ | ·-) | DO CUMENT ID | | TECN | Γ ₆ / | Г1 | |
| <0.98 | 90 | EDWARDS | 95 | CLE2 | $e^+e^-\approx 10.5 \text{ GeV}$ | _ | |

$\Lambda_c(2595)^+$ REFERENCES

| AALTONEN | 11 H | PR D84 012003 | T. Aaltonen <i>et al</i> . | (CDF Collab.) |
|----------|------|---------------|----------------------------|---------------------|
| BLECHMAN | 03 | PR D67 074033 | A.E. Blechman et al. | (JHU, FLOR) |
| ALBRECHT | 97 | PL B402 207 | H. Albrecht et al. | (ARGUS Collab.) |
| FRABETTI | 96 | PL B365 461 | P.L. Frabetti et al. | (FNÅL E687 Collab.) |
| EDWARDS | 95 | PRL 74 3331 | K.W. Edwards et al. | (CLEO Collab.) |
| | | | | |



$$I(J^P) = O(\frac{3}{2})$$
 Status: ***

The spin-parity has not been measured but is expected to be 3/2 $^-$: this is presumably the charm counterpart of the strange $\Lambda(1520).$

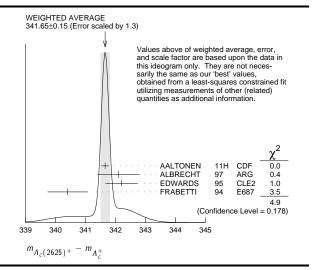
$\Lambda_c(2625)^+$ MASS

The mass is obtained from the $\Lambda_{C}(2625)^{+}\!-\!\Lambda_{C}^{+}$ mass-difference measurements below.

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT | | | |
|----------------------------------------------------------|---------------|-----------------------|---------------|-----------------|--|--|--|
| 2628.11±0.19 OUR FIT Error includes scale factor of 1.1. | | | | | | | |
| ullet $ullet$ $ullet$ We do not use | the following | data for averages, fi | ts, limits, e | etc. • • • | | | |
| $2626.6 \pm 0.5 \pm 1.5$ | 42 ± 9 | ALBRECHT 9: | 3F ARG | See ALBRECHT 97 | | | |

$\Lambda_c(2625)^+ - \Lambda_c^+$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------------------|---------------|---------------------|---------------|-----------------------------------------------|
| 341.65 ± 0.13 OUR FI | Γ Error inclu | des scale factor of | f 1.1. | |
| 341.65 ± 0.15 OUR AV | ERAGE Err | or includes scale f | actor of 1.3. | See the ideogram below. |
| $341.65 \pm 0.04 \pm 0.12$ | 6.2k | AALTONEN | 11H CDF | $p\overline{p}$ at 1.96 TeV |
| $342.1 \pm 0.5 \pm 0.5$ | 51 | ALBRECHT | 97 ARG | e^+e^-pprox 10 GeV |
| $342.2 \pm 0.2 \pm 0.5$ | 245 ± 19 | EDWARDS | | e^+e^-pprox 10.5 GeV |
| $340.4 \ \pm 0.6 \ \pm 0.3$ | 40 ± 9 | FRABETTI | 94 E687 | γ Be, $\overline{E}_{\gamma}=$ 220 GeV |



$\Lambda_c(2625)^+$ WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|-----------|--------------|--------------------|---------|-----------|-----------------------------|
| < 0.97 | 90 | 6.2k | AALTONEN | 11н | CDF | $p\overline{p}$ at 1.96 TeV |
| • • • We do | not use t | he following | data for averages, | fits, I | imits, et | C. • • • |
| <1.9 | 90 2 | 245 ± 19 | EDWARDS | 95 | CLE2 | e^+e^-pprox 10.5 GeV |
| < 3.2 | 90 | | ALBRECHT | 93F | ARG | $e^+e^-pprox \Upsilon$ (45) |

$\Lambda_c(2625)^+$ DECAY MODES

 $\Lambda_c^+\pi\pi$ and its submode $\Sigma(2455)\pi$ are the only strong decays allowed to an excited Λ_c^+ having this mass.

| | Mode | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|--------------------------------------------------------------|------------------------------|------------------|
| $\overline{\Gamma_1}$ | $\Lambda_{c}^{+} \pi^{+} \pi^{-}$ | [a] ≈ 67% | |
| Γ_2 | $\Sigma_{c}(2455)^{++}\pi^{-} \ \Sigma_{c}(2455)^{0}\pi^{+}$ | <5 | 90% |
| Гз | $\Sigma_c(2455)^0 \pi^+$ | <5 | 90% |
| Γ_4 | $\Lambda_c^+ \pi^+ \pi^-$ 3-body | large | |
| Γ_5 | $\Lambda_c^+ \pi^0$ | [b] not seen | |
| Γ_6 | $\Lambda_c^+ \gamma$ | not seen | |

- [a] Assuming isospin conservation, so that the other third is $\Lambda_c^+ \pi^0 \pi^0$.
- [b] A test that the isospin is indeed 0, so that the particle is indeed a Λ_c^+ .

$\Lambda_c(2625)^+$ BRANCHING RATIOS

| VALUE | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------------------|-------------------------------------|---------------------|----------------------|--------------|----------------------------------------------------|
| <0.08 | 90 | EDWARDS | 95 | CLE2 | e^+e^-pprox 10.5 GeV |
| $\Gamma(\Sigma_c(2455)^0)$ | $\pi^+)/\Gamma(\Lambda_c^+\pi^+)$ | π^-) | | | Γ_3/Γ_1 |
| VALUE | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
| <0.07 | 90 | EDWA RDS | 95 | CLE2 | e^+e^-pprox 10.5 GeV |
| $[\Gamma(\Sigma_c(2455)^{+})]$ | $^{++}\pi^{-}) + \Gamma(\Sigma_{c}$ | $[(2455)^0\pi^+)]/$ | $\Gamma(\Lambda_c^+$ | $\pi^+\pi^-$ |) (Γ ₂ +Γ ₃)/Γ ₁ |
| ALUE | CL% EVTS | DO CUMENT ID | | TECN | COMMENT |
| • • We do no | ot use the following | ng data for averag | es, fits | , limits, | etc. • • • |
| < 0.36 | 90 | FRABETTI | 94 | E687 | γ Be, $\overline{E}_{\gamma}=$ 220 GeV |
| 0.46 ± 0.14 | 21 | | | | $e^+e^-\stackrel{\prime}{pprox} \Upsilon(4S)$ |
| $\Gamma(\Lambda_c^+\pi^+\pi^-3$ | -b od y)/Γ(Λ+ 1 | $(\tau^{+}\pi^{-})$ | | | Γ_4/Γ_1 |
| ` • | , , | DO CUMENT ID | | TECN | COMMENT |
| • • We do no | nt use the following | ng data for averag | es, fits | , limits, | etc. • • • |
| 0.54±0.14 | 16 | ALBRECHT | 93F | ARG | $e^+e^-pprox \Upsilon(4S)$ |
| $\Gamma(\Lambda_c^+ \pi^0)/\Gamma(\Lambda_c^+ \pi^0)$ | $A_c^+ \pi^+ \pi^-)$ | | | | Γ_5/Γ_1 |
| $\Lambda_c^+ \pi^0$ dec | cay is forbidden b | y isospin conserva | tion if | this sta | te is in fact a Λ _C . |
| C | | DO CUMENT ID | | | = |
| | | | | | $e^+e^-\approx 10.5 \text{ GeV}$ |

EDWARDS

CLE2 e^+e^-pprox 10.5 GeV

<0.52

 $\Lambda_c(2625)^+$, $\Lambda_c(2765)^+$, $\Lambda_c(2880)^+$, $\Lambda_c(2940)^+$

$\Lambda_c(2625)^+$ REFERENCES

| AALTONEN | 11H | PR D84 012003 | T. Aaltonen et al. | (CDF Collab.) |
|----------|------|---------------|----------------------|---------------------|
| ALBRECHT | 97 | PL B402 207 | H. Albrecht et al. | (ARGUS Collab.) |
| EDWARDS | 95 | PRL 74 3331 | K.W. Edwards et al. | (CLEO Collab.) |
| FRABETTI | 94 | PRL 72 961 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| ALBRECHT | 93 F | PL B317 227 | H Albrecht et al | (ARGUS Collab.) |

 $\Lambda_c(2765)^+$ or $\Sigma_c(2765)$

$$I(J^P) = ?(?^?)$$
 Status: *

OMITTED FROM SUMMARY TABLE

A broad, statistically significant peak (997 $^{+141}_{-129}$ events) seen in $\Lambda_c^+\pi^+\pi^-$. However, nothing at all is known about its quantum numbers, including whether it is a Λ_c^+ or a Σ_c , or whether the width might be due to overlapping states.

$\Lambda_c(2765)^{+}$ MASS

The mass is obtained from the $\Lambda_{\it C}(2765)^{+}-\Lambda_{\it C}^{+}$ mass-difference measurement below.

VALUE (MeV)
2766.6±2.4 OUR FIT

DO CUMENT ID

$\Lambda_c(2765)^+ - \Lambda_c^+$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------|-----------|-------------|----|------|--------------------------------|
| 480.1 ± 2.4 OUR FIT | | · | | | |
| 480.1 ± 2.4 | 997 + 141 | ARTUSO | 01 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

$\Lambda_c(2765)^+$ WIDTH

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT | |
|-------------|-------------|----|------|-----------------------------|--|
| 50 | ARTUSO | 01 | CLE2 | $e^+e^- \approx \gamma(45)$ | |

$\Lambda_c(2765)^+$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------------------|------------------------------|
| Γ ₁ | $\Lambda_{c}^{+} \pi^{+} \pi^{-}$ | seen |

$\Lambda_c(2765)^+$ REFERENCES

ARTUSO 01 PRL 86 4479 M. Artuso et al. (CLEO Collab.)

 $\Lambda_c(2880)^+$

$$I(J^P) = O(\frac{5}{2}^+)$$
 Status: ***

A narrow peak seen in $\Lambda_c^+\pi^+\pi^-$ and in $\rho\,D^0$. It is not seen in $\rho\,D^+$, and therefore it is probably a Λ_c^+ and not a \varSigma_c . The evidence for spin 5/2 comes from the $\varSigma_c(2455)\pi$ decay angular distribution, and the evidence for parity + comes from agreement of the $\varSigma_c(250)/\varSigma_c(2455)$ branching ratio with a prediction of heavy quark symmetry (see MIZUK 07).

$\Lambda_c(2880)^{+}$ MASS

| VALUE (MeV) | EVIS | DOCUMENT ID | | I E CN | COMMENT |
|------------------------------|----------------|-------------|----|--------|-------------------------------------------------|
| 2881.53 ± 0.35 OUR | FIT | · | | | |
| 2881.50 ± 0.35 OUR | AVERAGE | | | | |
| $2881.9 \ \pm 0.1 \ \pm 0.5$ | $2.8k \pm 190$ | | | | in ρD^0 |
| $2881.2\ \pm0.2\ \pm0.4$ | 690 ± 50 | MIZUK | 07 | BELL | in $\Sigma_{\mathcal{C}}(2455)^{0,++}\pi^{\pm}$ |
| | | | | | |

$\Lambda_c(2880)^+ - \Lambda_c^+$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------|-------------------|--------------|----|------|------------------------------|
| 595.1±0.4 OUR FIT | | · · | | | |
| 596 ±1 ±2 | $350 + 57 \\ -55$ | ARTUSO | 01 | CLE2 | in $\Lambda_c^+ \pi^+ \pi^-$ |

$\Lambda_c(2880)^+$ WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------|------------------|-------------|------------------|-------|-----------|--------------------------------------|
| 5.8±1.1 OL | IR AVERAGE | | | | | |
| $5.8 \pm 1.5 \pm 1$ | .1 2.8k | ± 190 | AUBERT | | | in ρD^0 |
| $5.8 \pm 0.7 \pm 1$ | .1 690 | \pm 50 | MIZUK | 07 | BELL | in $\Sigma_c(2455)^{0,++} \pi^{\pm}$ |
| • • • We d | o not use the fo | ollowing da | ta for averages, | fits, | limits, e | tc. • • • |
| <8 | 90 | | ARTUSO | 01 | CLEO | in $\Lambda_a^+ \pi^+ \pi^-$ |

$\Lambda_c(2880)^+$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ \pi^+ \pi^-$ | seen |
| Γ_2 | $\Sigma_c (2455)^{0,++} \pi^{\pm} \Sigma_c (2520)^{0,++} \pi^{\pm}$ | seen |
| Γ_3 | $\Sigma_{c}(2520)^{0}, ++\pi^{\pm}$ | seen |
| Γ_4 | p D ⁰ | seen |

$\Lambda_c(2880)^+$ BRANCHING RATIOS

| I(∆ _C (245 | 5) ^{0,++} π | ^೬)/Γ(Λ _c + | $\pi^+\pi^-)$ | | | | Γ_2/Γ_1 |
|-----------------------|----------------------|-----------------------------------|---------------------------------------|----------|------------|-------------------------------|---------------------|
| VALUE | | <u>EVTS</u> | DO CUMENT ID | | TECN | COMMENT | |
| 0.392 ± 0.03 | 1 OUR AV | ERAGE I | Error includes scale | facto | | _ | |
| 0.404 ± 0.02 | 21 ± 0.014 | | MIZUK | 07 | BELL | in $\Sigma_c(2455)^{0,+}$ | + π [±] |
| 0.31 ± 0.06 | ± 0.03 | 96 | ARTUSO | 01 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ | |
| $\Gamma(\Sigma_c(252$ | 0) ^{0,++} π | ^೬)/Γ(Λ _c + | $\pi^{+} \pi^{-})$ | | | | Γ_3/Γ_1 |
| VALUE | | CL% | DO CUMENT ID | | TECN | COMMENT | |
| 0.091 ± 0 | $.025 \pm 0.010$ |) | MIZUK | 07 | BELL | in $\Sigma_c(2455)^{0,+}$ | + π [±] |
| • • We d | do not use t | he followin | ng data for average | | | | |
| < 0.11 | | 90 | ARTUSO | 01 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ | |
| $\Gamma(\Sigma_c(252$ | $0)^{0,++}\pi^{-}$ | $^{\rm L})/\Gamma(\Sigma_c$ | (2455) ⁰ ,++π [±] |) | | | Γ3/Γ2 |
| VALUE | | | DO CUMENT ID | , | TECN | COMMENT | |
| • • • We d | do not use t | he followin | ng data for average | es, fits | , limits, | etc. • • • | |
| 0.225 ± 0.06 | 52 ± 0.025 | | ¹ MIZUK | 07 | BELL | in $\Sigma_c(2455)^{0,+}$ | $+\pi^{\pm}$ |
| ¹ This MI | ZUK 07 rat | io is redun | dant with MIZUK | 07 ra | itios give | en above. | |
| | | | | | | | |
| | | Λ _c | (2880) ⁺ REFEI | RENC | ES | | |
| | | | | | | | |
| AUBERT MIZUK | | 98 012001 98 262001 | B. Aubert et R. Mizuk et a | | | (BABAR Co | |

$\Lambda_c(2940)^+$

$$I(J^P) = 0(??)$$
 Status: ***

A fairly narrow peak of good statistical significance first seen in the $p\,D^0$ mass spectrum. It is not seen in $p\,D^+$, and thus it is probably a Λ_c^+ and not a Σ_c . It is also seen in $\Sigma_c(2455)^{0,++}\,\pi^\pm$.

$\Lambda_{c}(2940)^{+}$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------------------------------|-----------------------|-------------|----|------|--------------------------------------------------------|
| 2939.3 + 1.4 OUR | AVERAGE | | | | |
| $2939.8 \pm 1.3 \pm 1.0$ | 2280 ± 310 | AUBERT | 07 | BABR | in <i>p D</i> ⁰ |
| $2938.0 \pm 1.3 ^{+\ 2.0}_{-\ 4.0}$ | $220^{+\ 80}_{-\ 60}$ | MIZUK | 07 | BELL | in $\Sigma_{\mathcal{C}}$ (2455) $^{0,++}$ π^{\pm} |

$\Lambda_{c}(2940)^{+}$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------------------------------|-------------------|-------------|----|------|----------------------------------------------------|
| 17 +8 OUR AV | ERAGE | | | | |
| $17.5\!\pm\!5.2\!\pm\ 5.9$ | 2280 ± 310 | AUBERT | 07 | BABR | in ρD^0 |
| $13 \begin{array}{ccc} +8 & +27 \\ -5 & -7 \end{array}$ | $220 + 80 \\ -60$ | MIZUK | 07 | BELL | in $\Sigma_{\mathcal{C}}(2455)^{0,++}$ π^{\pm} |

$\Lambda_c(2940)^+$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|----------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | p D ⁰ | seen |
| Γ_2 | $\Sigma_c(2455)^{0,++}\pi^{\pm}$ | seen |

$\Lambda_c(2940)^+$ REFERENCES

| (BEEEE COME.) | AUBERT | 07 | PRL 98 012001 | B. Aubert <i>et al.</i> | (BABAR Collab.) |
|---------------|--------|----|---------------|-------------------------|-----------------|
| | MIZUK | 07 | PRL 98 262001 | R. Mizuk <i>et al.</i> | (BELLE Collab.) |

 $\Sigma_c(2455)$

 $\Sigma_c(2455)$

 $I(J^P) = 1(\frac{1}{2}^+)$ Status: ***

The angular distribution of $B^-
ightarrow \ \Sigma_{\mathcal{C}} (2455)^0 \, \overline{p}$ favors J=1/2 (as the quark model predicts). J=3/2 is excluded by more than four σ see AUBERT 08BN.

Σ_c (2455) MASSES

The masses are obtained from the mass-difference measurements that fol-

$\Sigma_c(2455)^{++}$ MASS

DO CUMENT ID 2453.98±0.16 OUR FIT

 $\Sigma_c(2455)^+$ MASS

VALUE (MeV)
2452.9±0.4 OUR FIT

DOCUMENT ID

 $\Sigma_c(2455)^0$ MASS

 $166.6 \ \pm 0.5 \ \pm 0.6$

 $167.1 \ \pm 0.3 \ \pm 0.2$

 $168.4 \pm 1.0 \pm 0.3$

 $167.9 \ \pm 0.5 \ \pm 0.3$

 $167.0 \ \pm 0.5 \ \pm 1.6$

 $178.2 \ \pm 0.4 \ \pm 2.0$

2453.74 ± 0.16 OUR FIT

DOCUMENT ID

$\Sigma_c(2455) - \Lambda_c^+$ MASS DIFFERENCES

| | -, , | · | | | |
|---------------------------------------|---------------|---------------------|----------|-----------|-------------------------------------------------------|
| $m_{\Sigma_c^{++}} - m_{\Lambda_c^+}$ | | | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 167.52± 0.08 OUR F | T | | | | - |
| 167.51± 0.09 OUR A | VERAGE I | Error includes scal | e fact | or of 1.1 | |
| $167.44 \pm 0.04 \pm 0.12$ | 13.8k | AALTONEN | 11H | CDF | $p\overline{p}$ at 1.96 TeV |
| $167.4 \pm 0.1 \pm 0.2$ | 2k | ARTUSO | 02 | CLE2 | $e^+e^-\approx \gamma(4S)$ |
| $167.35 \pm 0.19 \pm 0.12$ | 461 | LINK | 00c | FOCS | γ nucleus, \overline{E}_{γ} 180 GeV |
| $167.76 \pm\ 0.29 \pm 0.15$ | 122 | AITALA | 96B | E791 | π ⁻ N, 500 GeV |
| $167.6 \ \pm \ 0.6 \ \pm 0.6$ | 56 | FRABETTI | 96 | E687 | γ Be, $\overline{E}_{\gamma} \approx $ 220 GeV |
| $168.2 \pm 0.3 \pm 0.2$ | 126 | CRAWFORD | 93 | CLE2 | $e^+e^-\stackrel{'}{pprox} \gamma(45)$ |
| $167.8 \pm 0.4 \pm 0.3$ | 54 | BOWCOCK | 89 | CLEO | e^+e^- 10 GeV |
| $168.2 \pm 0.5 \pm 1.6$ | 92 | ALBRECHT | 88D | ARG | e^+e^- 10 GeV |
| $167.4 \ \pm \ 0.5 \ \pm 2.0$ | 46 | DIESBURG | 87 | SPEC | $nA\sim 600~GeV$ |
| ullet $ullet$ We do not use | the following | g data for average | s, fits, | limits, | etc. • • • |
| 167 ± 1 | 2 | JO NE S | 87 | HBC | u p in BEBC |
| 166 ± 1 | 1 | BOSETTI | 82 | HBC | See JONES 87 |
| 168 ± 3 | 6 | BALTAY | 79 | HLBC | u Ne-H in 15-ft |
| 166 ± 15 | 1 | CAZZOLI | 75 | HBC | νp in BNL 7-ft |
| m _ m | | | | | |
| $m_{\Sigma_c^+} - m_{\Lambda_c^+}$ | | | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 166.4±0.4 OUR FIT | | | | | |
| $166.4 \pm 0.2 \pm 0.3$ | 661 | AMMAR | 01 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |
| • • • We do not use | the following | g data for average | s, fits, | limits, | etc. • • • |
| $168.5 \pm 0.4 \pm 0.2$ | 111 | CRAWFORD | 93 | CLE2 | See AMMAR 01 |
| 168 ±3 | 1 | CALICCHIO | 80 | HBC | u p in BEBC-TST |
| $m_{\Sigma_c^0} - m_{\Lambda_c^+}$ | | | | | |
| | EVTS | DOCUMENT ID | | TECN | COMMENT |
| VALUE (MeV) 167.27±0.08 OUR FI | | DO CUMENT ID | | TECN | COMMENT |
| 167.29 ± 0.09 OUR AV | | | | | |
| 167.28 ± 0.03 ± 0.12 | 15.9k | AALTONEN | 11н | CDF | $p\overline{p}$ at 1.96 TeV |
| $167.2 \pm 0.1 \pm 0.2$ | 2k | ARTUSO | 02 | CLE2 | $e^+e^-\approx \Upsilon(4S)$ |
| $167.38 \pm 0.21 \pm 0.13$ | 362 | LINK | 00c | FOCS | γ nucleus, \overline{E}_{γ} 180 GeV |
| 167.38 ± 0.29 ± 0.15 | 143 | AITALA | 96в | E791 | π ⁻ N, 500 GeV |
| $167.8 \pm 0.6 \pm 0.2$ | | ALEEV | 96 | SPEC | n nucleus, 50 GeV/c |
| 1666 105 106 | | ED A DETT! | 0.0 | EC 07 | D- E - 220 C-V |

96 E687 γ Be, $\overline{E}_{\gamma} \approx$ 220 GeV 93 CLE2 $e^+e^- \approx \Upsilon(4S)$

89D E691 γBe 90-260 GeV

89 CLEO e^+e^- 10 GeV 88D ARG e^+e^- 10 GeV

87 SPEC $nA \sim 600 \text{ GeV}$

69

124

14

85

FRABETTI

¹ BOWCOCK

¹ ALBRECHT ² DIESBURG

ANJOS

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

CRAWFORD

Σ_c (2455) MASS DIFFERENCES

$m_{\Sigma^{++}} - m_{\Sigma^0}$

| -c -c | | | | |
|--------------------------------|-----------------------|---------|-----------|---------------------------------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 0.24 ± 0.09 OUR FIT Error | includes scale facto | r of 1. | 1. | |
| 0.26±0.14 OUR AVERAGE | Error includes scal | e facto | or of 1.2 | |
| $+$ 0.2 \pm 0.1 \pm 0.1 | ARTUSO | 02 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |
| $-0.03\pm0.28\pm0.11$ | LINK | 00c | FOCS | γ nucleus, \overline{E}_{γ} 180 GeV |
| $+ \ \ 0.38 \pm 0.40 \pm 0.15$ | AITALA | 96B | E791 | π^- N, 500 GeV |
| $+\ 1.1\ \pm0.4\ \pm0.1$ | CRAWFORD | 93 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |
| $-$ 0.1 \pm 0.6 \pm 0.1 | BOWCOCK | 89 | CLEO | e^+e^- 10 GeV |
| $+$ 1.2 ± 0.7 ± 0.3 | ALBRECHT | 88D | ARG | $e^+e^-\sim$ 10 GeV |
| • • • We do not use the follow | ring data for average | s, fits | , limits, | etc. • • • |
| -10.8 ± 2.9 | ³ DIESBURG | 87 | SPEC | $n \text{A} \sim 600 \text{GeV}$ |

 $^3\, \text{DIESBURG}$ 87 is completely incompatible with the other experiments, which is surprising since it agrees with them about $m_{\sum_{c}(2455)^{++}}-m_{\Lambda_{c}^{+}}$. We go with the majority here.

 $m_{\Sigma_c^+} - m_{\Sigma_c^0}$

VALUE (MeV) -0.9±0.4 OUR FIT

DOCUMENT ID TECN COMMENT

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet CRAWFORD 93 CLE2 See AMMAR 01 $1.4 \pm 0.5 \pm 0.3$

Σ_c (2455) WIDTHS

Σ_c(2455)++ WIDTH

| -c(- +55) | **** | | | | |
|-------------------------------------|------------------------------------------------------------|-------------------------------------------------------|--------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| ALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| .26±0.25 OUR | AVERAGE | | | | |
| $.34 \pm 0.13 \pm 0.4$ | 5 13.8k | AALTONEN | 11 H | CDF | $p\overline{p}$ at 1.96 TeV |
| $.3 \pm 0.2 \pm 0.3$ | 2k | ARTUSO | 02 | CLE2 | $e^+e^-pprox \Upsilon(45)$ |
| $.05 {}^{+ 0.41}_{- 0.38} \pm 0.3$ | 8 1110 | LINK | 02 | FOCS | γ nucleus, $\overline{E}_{\gamma}\approx 180~{\rm GeV}$ |
| 9 | MLUE (MeV) .26±0.25 OUR .34±0.13±0.4 .3 ±0.2 ±0.3 | 26±0.25 OUR AVERAGE .34±0.13±0.45 13.8k .3±0.2±0.3 2k | ALUE (MeV) EVTS DO CUMENT ID .26±0.25 OUR AVERAGE .34±0.13±0.45 13.8k AALTONEN .3±0.2±0.3 2k ARTUSO | ALUE (MeV) EVTS DOCUMENT ID .26±0.25 OUR AVERAGE .34±0.13±0.45 13.8k AALTONEN 11H .3 ±0.2 ±0.3 2k ARTUSO 02 | ALUE (MeV) EVTS DOCUMENT ID TECN .26±0.25 OUR AVERAGE .34±0.13±0.45 13.8k AALTONEN 11H CDF .3 ±0.2 ±0.3 2k ARTUSO 02 CLE2 |

$\Sigma_c(2455)^+$ WIDTH

| VALUE (MeV) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-------------|-----|------|-------------|----|------|-------------------------------|
| <4.6 | 90 | 661 | AMMAR | 01 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ |

Σ_c (2455)0 WIDTH

| · · · / | | | | |
|---------------------------------------|-------|------------------------|---------------|---------------------------------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 2.16±0.26 OUR AVE | RAGE | Error includes scale t | factor of 1.1 | |
| $1.65 \pm 0.11 \pm 0.49$ | 15.9k | AALTONEN | 11H CDF | $p\overline{p}$ at 1.96 TeV |
| $2.6 \ \pm 0.5 \ \pm 0.3$ | | AUBERT | 08BN BABF | $B^- \rightarrow \overline{p} \Lambda_c^+ \pi^-$ |
| $2.5\ \pm0.2\ \pm0.3$ | 2k | ARTUSO | 02 CLE2 | $e^+e^-pprox\ \Upsilon(4S)$ |
| $1.55 {}^{+ 0.41}_{- 0.37} \pm 0.38$ | 913 | LINK | 02 FOCS | γ nucleus, $\overline{E}_{\gamma} pprox 180$ GeV |

Σ_c (2455) DECAY MODES

 $\Lambda_C^+\pi$ is the only strong decay allowed to a Σ_C having this mass.

| | Mode | Fraction (Γ_i/Γ) | | |
|-----------------------|-------------------|------------------------------|--|--|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ \pi$ | ≈ 100 % | | |

Σ_c (2455) REFERENCES

| AALTONEN | 11H | PR D84 012003 | T. Aaltonen et al. | (CDF Collab.) |
|-----------|--------|-------------------------|-----------------------|-----------------------------|
| AUBERT | 08 B N | PR D78 112003 | B. Aubert et al. | (BABAR Collab.) |
| ARTUSO | 02 | PR D65 071101R | M. Artuso et al. | `(CLEO Collab.) |
| LINK | 02 | PL B525 205 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| AMMAR | 01 | PRL 86 1167 | R. Ammar et al. | ` (CLEO Collab.) |
| LINK | 00 C | PL B488 218 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| AITALA | 96B | PL B379 292 | E.M. Aitala et al. | ` (FNAL E791 Collab.) |
| ALEEV | 96 | JINRRC 3-77 31 | A.N. Aleev et al. | (Serpukhov EXCHARM Collab.) |
| FRABETTI | 96 | PL B365 461 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| CRAWFORD | 93 | PRL 71 3259 | G. Crawford et al. | ` (CLEO Collab.) |
| ANJOS | 89D | PRL 62 1721 | J.C. Anjos et al. | (FNAL E691 Collab.) |
| BOWCOCK | 89 | PRL 62 1240 | T.J.V. Bowcock et al. | ` (CLEO Collab.) |
| ALBRECHT | 88 D | PL B211 489 | H. Albrecht et al. | (ARGUS Collab.) |
| DIESBURG | 87 | PRL 59 2711 | M. Diesburg et al. | (FNÅL E400 Collab.) |
| JONES | 87 | ZPHY C36 593 | G.T. Jones et al. | (ČERN WA21 Collab.) |
| AMMAR | 86 | JETPL 43 515 | R. Ammar et al. | (ITEP) |
| | | Translated from ZETFP 4 | | |
| BOSETTI | 82 | PL 109B 234 | P.C. Bosetti et al. | (AACH3, BONN, CERN+) |
| CALICCHIO | 80 | PL 93B 521 | M. Calicchio et al. | (BARI, BIRM, BRUX+) |
| BALTAY | 79 | PRL 42 1721 | C. Baltay et al. | ` (COLU, BNL)I |
| CAZZOLI | 75 | PRL 34 1125 | E.G. Cazzoli et al. | ` (BNL) |
| | | | | |

¹ AMMAR 86 EMUL ν A 1 This result enters the fit through $m_{\Sigma_c^{++}}-m_{\Sigma_c^0}$ given below.

 $^{^2}$ See the note on DIESBURG 87 in the $m_{\Sigma_c^{++}}-m_{\Sigma_c^0}$ section below.

Baryon Particle Listings $\Sigma_c(2520)$

 $\Sigma_c(2520)$

$$I(J^P) = 1(\frac{3}{2}^+)$$
 Status: ***

Seen in the $\Lambda_c^+\pi^\pm$ mass spectrum. The natural assignment is that this is the $J^P = 3/2^+$ excitation of the $\Sigma_c(2455)$, the charm counterpart of the $\Sigma(1385)$, but neither J nor \widetilde{P} has been measured.

Σ_c (2520) MASSES

The masses are obtained from the mass-difference measurements that fol-

$\Sigma_c(2520)^{++}$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------------|-------------|---------------------|---------|-----------|-----------------------------|
| 2517.9±0.6 OUR FIT | Error incl | udes scale factor o | of 1.6. | | |
| ● ● We do not use t | he followin | g data for average | s, fits | , limits, | etc. • • • |
| 2530 ± 5 ± 5 | 6 | $^{ m 1}$ AMMOSOV | 93 | HLBC | |
| | | | | | $\mu^- \Sigma_C^{(2530)++}$ |

 $^{
m 1}$ AMMOSOV 93 sees a cluster of 6 events and estimates the background to be 1 event.

$\Sigma_c(2520)^+$ MASS

VALUE (MeV) 2517.5 ± 2.3 OUR FIT

DOCUMENT ID

$\Sigma_c(2520)^0$ MASS

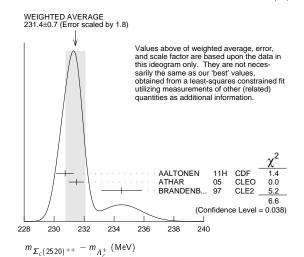
DOCUMENT ID

2518.8±0.6 OUR FIT Error includes scale factor of 1.5.

Σ_c (2520) MASS DIFFERENCES

$m_{\Sigma_c(25\,20)^{++}} - m_{\Lambda_c^+}$

EVTS DOCUMENT ID TECN COMMENT 231.4 ±0.6 OUR FIT Error includes scale factor of 1.6. 231.4 ±0.7 OUR AVERAGE Error includes scale factor of 1.8. See the ideogram below $230.73 \pm 0.56 \pm 0.16$ 8.8k AALTONEN 11H CDF $p\overline{p}$ at 1.96 TeV ATHAR 05 CLEO e^+e^- , 9.4–11.5 GeV BRANDENB... 97 CLE2 $e^+e^- \approx \varUpsilon(4S)$ $231.5 \ \pm 0.4 \ \pm 0.3 \ 1330 \pm 110$ $234.5 \pm 1.1 \pm 0.8$

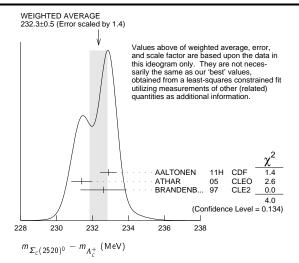


$m_{\Sigma_c(2520)^+} - m_{\Lambda_c^+}$

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|------|--------------|----|------|--------------------------------|
| 231.0±2.3 OUR FIT | | | | | |
| $231.0 \pm 1.1 \pm 2.0$ | 327 | AMMAR | 01 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

$m_{\Sigma_c(25\,20)^0} - m_{\Lambda_c^+}$

| VALUE (MeV) | EVIS | DO CUMENT ID | TECN | COMMENT |
|-----------------------------|-------------------|--------------------|----------------|-----------------------------|
| 232.3 ±0.5 OUR | FIT Error include | es scale factor of | 1.6. | |
| 232.3 ±0.5 OUR | AVERAGE Error | includes scale fa | ctor of 1.4. S | See the ideogram below. |
| $232.88 \pm 0.43 \pm 0.16$ | 9.0k | AALTONEN | 11H CDF | $p\overline{p}$ at 1.96 TeV |
| $231.4 \ \pm 0.5 \ \pm 0.3$ | 1350 ± 120 | ATHAR | 05 CLEO | e^+e^- , 9.4–11.5 GeV |
| 2326 +10 +08 | 5.04 | BRA NDENB | 97 CLE2 | $e^+e^- \approx r(45)$ |



$m_{\Sigma_c(2520)^{++}} - m_{\Sigma_c(2520)^0}$

| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
|---------------------------|---------------------------|---------|-----------|-----------------------------|
| • • • We do not use the f | ollowing data for average | s, fits | , limits, | etc. • • • |
| $+0.1\pm0.8\pm0.3$ | | | | $e^{+}e^{-}$, 9.4–11.5 GeV |
| $1.9 \pm 1.4 \pm 1.0$ | ³ BRANDENB | 97 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |

 $^2\,\text{This}$ ATHAR 05 result is redundant with measurements in earlier entries. $^3\,\text{This}$ BRANDENBURG 97 result is redundant with measurements in earlier entries.

Σ_c (2520) WIDTHS

Σ_c (2520)++ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|--------------|-------------|-----|------|-------------------------------|
| 14.9 ±1.5 OUR | VERAGE | | | | |
| $15.03\!\pm\!2.12\!\pm\!1.36$ | | AALTONEN | 11н | CDF | $p\overline{p}$ at 1.96 TeV |
| $14.4 \ ^{+1.6}_{-1.5} \ \pm 1.4$ | 1330 ± 110 | ATHAR | 05 | CLEO | $e^{+}e^{-}$, 9.4–11.5 GeV |
| $17.9 \ ^{+3.8}_{-3.2} \ \pm 4.0$ | 677 | BRANDENB | 97 | CLE2 | $e^+e^- \approx \Upsilon(45)$ |
| | | | | | |

$\Sigma_c(2520)^+$ WIDTH

| VALUE (MeV) | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|------|--------------|----|------|------------------------|
| <17 | 90 | 327 | AMMAR | 01 | CLE2 | $e^+e^- \approx r(4S)$ |

Σ_c(2520)⁰ WIDTH

| ZC(2320) **1D | | | | | |
|-----------------------------------------|--------------|-------------|-----|------|-----------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 14.5 ±1.5 OUR | VERAGE | | | | |
| $12.51 \pm 1.82 \pm 1.37$ | 9.0k | AALTONEN | 11H | CDF | $p\overline{p}$ at 1.96 TeV |
| $16.6 \ ^{+1.9}_{-1.7} \ \pm 1.4$ | 1350 ± 120 | ATHAR | 05 | CLEO | $e^{+}e^{-}$, 9.4–11.5 GeV |
| $13.0 \ ^{+ 3.7}_{- 3.0} \ \pm 4.0$ | 504 | BRANDENB | 97 | CLE2 | $e^+e^-pprox \Upsilon(45)$ |
| | | | | | |

$\Sigma_c(2520)$ DECAY MODES

 $\Lambda_c^+\pi$ is the only strong decay allowed to a Σ_c having this mass.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|------------------|------------------------------|
| Γ ₁ | $\Lambda_c^+\pi$ | ≈ 100 % |

Σ_c (2520) REFERENCES

| AALTONEN | 11H | PR D84 012003 | T. Aaltonen et al. | (CDF Collab.) |
|------------|-----|-----------------------|-----------------------|----------------|
| ATHAR | 05 | PR D71 051101R | S.B. Athar et al. | (ČLEO Collab.) |
| AMMAR | 01 | PRL 86 1167 | R. Ammar et al. | (CLEO Collab.) |
| BRANDENB | 97 | PRL 78 2304 | G. Brandenburg et al. | (CLEO Collab.) |
| AM M OS OV | 93 | JETPL 58 247 | V.V. Ammosov et al. | ` (SERP) |
| | | Translated from ZETFP | 58 241. | ` ′ |

 $\Sigma_c(2800), \Xi_c^+$

 $\Sigma_c(2800)$

$$I(J^P) = 1(?^?)$$
 Status: ***

Seen in the $\Lambda_c^+\pi^+$, $\Lambda_c^+\pi^0$, and $\Lambda_c^+\pi^-$ mass spectra.

$\Sigma_c(2800)$ MASSES

The charged ++ and + masses are obtained from the mass-difference measurements that follow. The neutral mass is dominated by the mass-difference measurement, but is pulled up somewhat by the less well-determined but considerably higher direct-mass measurement. It is possible, in fact, that AUBERT 08BN is seeing a different $\Sigma_{\mathcal{C}}.$

| Σ_c | (2800 |)++ | MASS |
|------------|-------|-----|------|
|------------|-------|-----|------|

VALUE (MeV)

DOCUMENT ID

2801 + 4 OUR FIT

 $\Sigma_c(2800)^+$ MASS

VALUE (MeV)

DO CUMENT ID

2792 + 14 OUR FIT

 $\Sigma_c(2800)^0$ MASS

DOCUMENT ID TECN COMMENT

2806 $\pm \frac{5}{7}$ **OUR FIT** Error includes scale factor of 1.3.

2846±8±10

VALUE (MeV)

AUBERT 0

08BN BABR $B^- \rightarrow \overline{p} \Lambda_c^+ \pi^-$

Σ_c (2800) MASS DIFFERENCES

| $m_{\Sigma_c(2800)^{++}}-n$ | ^η Λ _c + | | | | |
|----------------------------------------------------------------------------|--------------------------------|-------------|----|------|------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | I | TECN | COMMENT |
| 514 +4 OUR FIT | | | | | |
| $514.5 + 3.4 + 2.8 \\ -3.1 - 4.9$ | $2810 {}^{+ 1090}_{- 775}$ | MIZUK | 05 | BELL | $e^+e^-pprox \Upsilon(45)$ |
| $m_{\Sigma_c(2800)^+}-m_{\rho}$ | 1 , | | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | 1 | TECN | COMMENT |
| 505 +14 OUR FI | т | | | | |
| $505.4 + 5.8 + 12.4 \\ -4.6 - 2.0$ | $1540 {}^{+ 175 0}_{- 105 0}$ | MIZUK | 05 | BELL | $e^+e^-pprox \Upsilon(4S)$ |
| $m_{\Sigma_c(2800)^0}-m_{\Lambda}$ | + c | | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | 1 | TECN | COMMENT |
| 519 $^{+5}_{-7}$ OUR FIT Error includes scale factor of 1.3. | | | | | |
| $515.4 + 3.2 + 2.1 \\ -3.1 - 6.0$ | $2240 + 1300 \\ - 740$ | MIZUK | 05 | BELL | $e^+e^-pprox ~ \Upsilon(4S)$ |

Σ_c (2800) WIDTHS

| $\Sigma_c(2800)^{++}$ WII | ОТН | | | | |
|----------------------------------------------|--------------------------------|--------------|------|------|------------------------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 75 + 18 + 12 75 - 13 - 11 | $2810 + 1090 \\ - 775$ | MIZUK | 05 | BELL | $e^+e^- \approx \Upsilon(4S)$ |
| $\Sigma_c(2800)^+$ WID | ТН | | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| $62 + 37 + 52 \\ -23 - 38$ | $1540 {}^{+ 175 0}_{- 105 0}$ | MIZUK | 05 | BELL | $e^+e^-pprox \Upsilon(45)$ |
| Σ_c (2800) 0 WIDT | 'Н | | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 72 ⁺²² ₋₁₅ OUR AVERAGE | | | | | |
| $86 {}^{+ 33}_{- 22} {\pm} 12$ | | AUBERT | 1880 | BABR | $B^- \to \overline{p} \Lambda_c^+ \pi^-$ |
| $61 + 18 + 22 \\ -13 - 13$ | $2240 {}^{+ 130 0}_{- 740}$ | MIZUK | 05 | BELL | $e^+e^- \approx \ \Upsilon(45)$ |

$\Sigma_c(2800)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------|------------------------------|
| Γ ₁ | $\Lambda_{c}^{+} \pi$ | seen |

Σ_c (2800) REFERENCES

JBERT 08BN PR D78 112003 B. Aubert et al. IZUK 05 PRL 94 122002 R. Mizuk et al. (BABAR Collab.) (BELLE Collab.) Ξ_c^+

 $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ***

DOCUMENT ID ____ TECN COMMENT

According to the quark model, the Ξ_c^+ (quark content usc) and Ξ_c^0 form an isospin doublet, and the spin-parity ought to be $J^P=1/2^+$. None of I, J, or P has actually been measured.

Ξ_c^+ MASS

The fit uses the Ξ_c^+ and Ξ_c^0 mass and mass-difference measurements.

| 2467.8+ 0.4 OUR FIT | | | | | | | |
|--------------------------------|--------------------|--------------------|-------|----------|------------------------------------------------|--|--|
| 2467.6 + 0.4 OUR AV | /ERAGE | | | | | | |
| $2468.1 \pm 0.4 + 0.2 \\ -1.4$ | 4950 ± 286 1 | LESIAK | 05 | BELL | e^+e^- , $\Upsilon(4S)$ | | |
| $2465.8 \pm 1.9 \pm 2.5$ | 90 | FRABETTI | 98 | E687 | γ Be, $\overline{E}_{\gamma} =$ 220 GeV | | |
| $2467.0 \pm 1.6 \pm 2.0$ | 147 | EDWARDS | 96 | CLE2 | $e^+e^-\approx \gamma(45)$ | | |
| $2465.1 \pm \ 3.6 \pm \ 1.9$ | 30 | ALBRECHT | 90F | ARG | e^+e^- at $\Upsilon(4S)$ | | |
| $2467 \pm 3 \pm 4$ | 23 | ALAM | 89 | CLEO | e^+e^- 10.6 GeV | | |
| $2466.5 \pm 2.7 \pm 1.2$ | 5 | BARLAG | 89c | ACCM | π^- Cu 230 GeV | | |
| • • • We do not use | the following data | for averages, fits | , lim | its, etc | . • • • | | |
| $2464.4 \pm \ 2.0 \pm \ 1.4$ | 30 | FRABETTI | 93B | E687 | See FRABETTI 98 | | |
| $2459 \pm 5 \pm 30$ | 56 2 | COTEUS | 87 | SPEC | nA ≃ 600 GeV | | |
| 2460 ± 25 | 82 | BIAGI | 83 | SPEC | Σ^- Be 135 GeV | | |

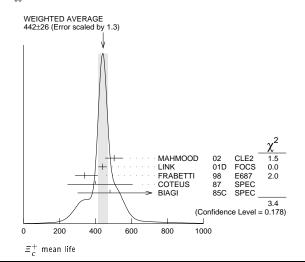
 $^{1}\,\mathrm{The}$ systematic error was (wrongly) given the other way round in LESIAK 05; see the erratum

erratum. Although COTEUS 87 claims to agree well with BIAGI 83 on the mass and width, there appears to be a discrepancy between the two experiments. BIAGI 83 sees a single peak (stated significance about 6 standard deviations) in the $\Lambda K^-\pi^+\pi^+$ mass spectrum. COTEUS 87 sees two peaks in the same spectrum, one at the Ξ_c^+ mass, the other 75

MeV lower. The latter is attributed to $\Xi_{+}^{+} \to \Sigma^{0} K^{-} \pi^{+} \pi^{+} \to (\Lambda \gamma) K^{-} \pi^{+} \pi^{+}$, with the γ unseen. The *combined* significance of the double peak is stated to be 5.5 standard deviations. But the absence of any trace of a lower peak in BIAGI 83 seems to us to throw into guestion the interpretation of the lower peak of COTEUS 87.

≡+ MEAN LIFE

| $VALUE (10^{-15} s)$ | EVTS | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------|----------------|-------------------|--------|------------|----------------------------------------------------------------|
| 442± 26 OUR AV | ERAGE Err | or includes scale | factor | of 1.3. | See the ideogram below. |
| $503 \pm 47 \pm 18$ | 250 | MAHMOOD | | | $e^+ e^- \approx \Upsilon(4S)$ |
| 439± 22± 9 | 532 | LINK | 01D | FOCS | γ nucleus, $\overline{E}_{\gamma}~\approx~180~{ m GeV}$ |
| $340 + 70 \pm 20$ | 56 | FRABETTI | 98 | E687 | γ Be, $\overline{\it E}_{\gamma} =$ 220 GeV |
| $400 {}^{+ 1 80}_{- 1 20} {\pm} 100$ | 102 | COTEUS | 87 | SPEC | $nA \simeq 600 \; \mathrm{GeV}$ |
| $^{480}_{-150}{}^{+210}_{-100}$ | 53 | BIAGI | 85 C | SPEC | Σ^- Be 135 GeV |
| • • • We do not ι | ise the follow | ing data for aver | ages, | fits, limi | ts, etc. • • • |
| $410^{+110}_{-80}\pm20$ | 30 | FRABETTI | 93в | E687 | See FRABETTI 98 |
| $200 {}^{+ 1 1 0}_{- 60}$ | 6 | BARLAG | 89c | ACCM | $\pi^-~(\ensuremath{\ensuremath{\mathcal{K}}^-})$ Cu 230 GeV |



Ξ_c^+ DECAY MODES

Mode Fraction (Γ_i/Γ) Confidence level

| | ranching fractions have been measured | | $\Gamma(oldsymbol{\Sigma}^0 K^- 2\pi^+)/\Gamma$ | $(\Lambda K^- 2\pi^+)$ |) | | Г | 9/Γ4 |
|---------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|-------------------------------------------------|---------------------------------------------------|--------------------------------|---------------------------------------|---------------------|-----------------------------------------------------|------------------------------|
| i ne tollowing | are branching <i>ratios</i> relative to $\Xi^-2\pi^+$ | • | <u>VALUE</u> 0.84±0.36 | <u>EVTS</u> 47 | 4 COTEUS | 97 SDEC | nA ≃ 600 GeV | |
| | bbo-favored ($S = -2$) decays | | 4 See, however, the | | | | | |
| $\Gamma_1 p \stackrel{2}{\stackrel{\sim}{\stackrel{\sim}{\stackrel{\sim}{\stackrel{\sim}{\stackrel{\sim}{\stackrel{\sim}{\stackrel{\sim}{$ | [a] 0.087 ± 0.022 | | | | 00.200 tr = c | | | |
| $\Gamma_2 = \Lambda \overline{K}^0 \pi^+$ | _ | | $\Gamma(\Xi^0\pi^+)/\Gamma(\Xi^{-2})$ | , | | | | /Γ ₁₁ |
| $\Gamma_3 \qquad \Sigma(1385)^+ \overline{K}^0$ $\Gamma_4 \qquad \Lambda K^- 2\pi^+$ | [a,b] 1.0 ± 0.5 [a] 0.323 ± 0.033 | | VALUE 0.55 ± 0.13 ± 0.09 | | DO CUMENT ID EDWARDS | 96 CLE2 | $e^+e^- \approx \Upsilon(45)$ | |
| $\frac{1}{5} \frac{1}{\Lambda K^*} (892)^0 \pi^+$ | [a,b] < 0.2 | 90% | | | EDWARDS | JO CLEZ | , | |
| $\Sigma_{6} = \Sigma(1385)^{+} K^{-} \pi^{+}$ | [a,b] < 0.3 | 90% | $\Gamma(\Xi^-2\pi^+)/\Gamma_{total}$ | | | | | 11/Г |
| $\Sigma^{+}K^{-}\pi^{+}$ | [a] 0.94 ± 0.11 | | <u>VALUE</u> • • • We do not use | <u>EVTS</u> e the following | DOCUMENT ID data for average | | | |
| $\Sigma^{+} \overline{K}^{*} (892)^{0}$ $\Sigma^{0} K^{-} 2\pi^{+}$ | $[a,b]$ 0.81 \pm 0.15 | | seen | 131 | BERGFELD | | $e^+e^-\approx \Upsilon(4S)$ | |
| $\frac{1}{10} = \frac{\sum_{0}^{0} K^{-} 2\pi^{+}}{\sum_{0}^{0} \pi^{+}}$ | [a] 0.29 ± 0.16 [a] 0.55 ± 0.16 | | seen | 160 | AVERY | | e+e−≈ \(\gamma(45)\) | |
| $\Xi^{-}2\pi^{+}$ | [a] DEFINED AS 1 | | seen | 30 30 | FRABETTI ALBRECHT | 93B E687 90F ARG | γ Be, $\overline{E}_{\gamma} = 220$ Ge | V |
| $\Xi(1530)^0\pi^+$ | [a,b] < 0.1 | 90% | see n see n | 23 | ALAM | | e^+e^- at $\varUpsilon(4S)$ e^+e^- 10.6 GeV | |
| $\Xi^{0}\pi^{+}\pi^{0}$ $\Xi^{0}\pi^{-}2\pi^{+}$ | [a] 2.34 ± 0.68 | | E/=(1500)0 ±)/ | r(=- 0 ±) | | | - | /- |
| 0 | [a] 1.74 ± 0.50 | | $\Gamma(\Xi(1530)^0\pi^+)/$ | ` , | $\Xi(1530)^0$ are incl | udod | l 12 | /Γ11 |
| | [a] $2.3 + 0.7 \\ -0.9$ | | VALUE VALUE | | OCUMENT ID | TECN CO | OMMENT | |
| $\Omega^{-} K^{+} \pi^{+}$ | [a] 0.07 ± 0.04 | | <0.1 | | | | nucleus, $\overline{\it E}_{\gamma} \approx$ 180 C | ieV |
| (| Cabibbo-suppressed decays | | • • • We do not use | | | | | |
| $pK^{-}\pi^{+}$ | [a] 0.21 ± 0.03 | | < 0.2 | 90 B | SERGFELD 96 | CLE2 e | $^+e^-\approx \ \Upsilon(4S)$ | |
| $p\overline{K}^*(892)^0$ $\Sigma^+\pi^+\pi^-$ | [a,b] 0.12 ± 0.02 [a] 0.48 ± 0.20 | | $\Gamma(\Xi^0\pi^+\pi^0)/\Gamma(\Xi^0\pi^+\pi^0)$ | $-2\pi^{+}$) | | | Г ₁₃ | /Γ11 |
| $\Sigma^{-19} \Sigma^{-1} 2\pi^{+}$ | [a] 0.48 ± 0.20 [a] 0.18 ± 0.09 | | VALUE | EVTS | DO CUMENT ID | TECN | COMMENT | |
| $\Sigma^{+}K^{+}K^{-}$ | [a] 0.15 ± 0.07 | | $2.34 \pm 0.57 \pm 0.37$ | 81 | EDWARDS | 96 CLE2 | $e^+e^-\approx \Upsilon(4S)$ | |
| $\Sigma^+ \phi$ | [a,b] < 0.11 | 90% | $\Gamma(\Xi(1530)^0\pi^+)/$ | $\Gamma(\Xi^0\pi^+\pi^0$ |) | | Γ ₁₂ | /Γ ₁₃ |
| Ξ_{23} $\Xi(1690)^0K^+$, $\Xi(\Sigma^+K^-)$ | $(1690)^0 \rightarrow [a] < 0.05$ | 90% | VALUE | <u>CL%</u> | DO CUMENT ID | | COMMENT | |
| Z · K | | | • • • We do not use | - | _ | | etc. • • • $e^+e^-pprox \ \gamma(4S)$ | |
| • • | ng fractions have been measured. The | value here is | <0.3 | 90 | EDWARDS | 96 CLE2 | e · e ≈ 1(45) | |
| the branching <i>ratio</i> i | | | $\Gamma(\Xi^0\pi^-2\pi^+)/\Gamma($ | • , | | | | /Γ ₁₁ |
| • • | ion includes all the decay modes of t | he final-state | <u>VALUE</u> 1.74±0.42±0.27 | <u>EVTS</u> 57 | <u>DO CUMENT ID</u> EDWA RDS | 96 CLE2 | $e^+e^- \approx \Upsilon(4S)$ | |
| resonance. | | | | | EDWARDS | JO CLEZ | | |
| 3 | E BRANCHING RATIOS | | $\Gamma(\Xi^0 e^+ \nu_e)/\Gamma(\Xi^0 e^+ \nu_e)$ | | DO 611145117 40 | T-041 | | /Γ ₁₁ |
| | bbo-favored ($S = -2$) decays $$ | _ | VALUE | <u>EVTS</u> | DOCUMENT ID | TECN | | |
| | 2) decays | | $2.3 \pm 0.6 + 0.3 \\ -0.6$ | 41 | ALEXANDER | 95B CLE2 | $e^+e^-\approx \Upsilon(4S)$ | |
| $\Gamma(p2K_S^0)/\Gamma(\Xi^-2\pi^+)$ | DOCUMENT ID TEST COMME | Γ ₁ /Γ ₁₁ | $\Gamma(\Omega^-K^+\pi^+)/\Gamma($ | $(\Xi^{-}2\pi^{+})$ | | | Γ ₁₆ | /Γ11 |
| #ALUE <u>EVTS</u> 1.087±0.016±0.014 168 ± | | | VALUE | <u>EVTS</u> | DOCUMENT ID | | COMMENT | |
| | | ` ' | $0.07 \pm 0.03 \pm 0.03$ | 14 | LINK 0 | BE FOCS - | < 0.12, 90% CL | |
| $(\Sigma(1385)^+\overline{K}^0)/\Gamma(\Xi^-2i)$ | | Γ_3/Γ_{11} | _ | Cab | ibb o-s uppressed | decays — | | |
| ALUE EVTS | the $\Sigma(1385)^+$ are included. <u>DOCUMENT ID TECN COMMENT</u> | | $\Gamma(\rho K^-\pi^+)/\Gamma(\Xi^-)$ | $^{-}2\pi^{+})$ | | | Γ ₁₇ | /Γ11 |
| .00±0.49±0.24 20 | LINK 03E FOCS < 1.72, 90% | 6 CL | VALUE | <u>EVTS</u> | DOCUMENT IL | <u>TEC</u> | N COMMENT | |
| $\Gamma(\Lambda K^- 2\pi^+)/\Gamma(\Xi^- 2\pi^+)$ | | Γ_4/Γ_{11} | 0.21 ±0.04 OUR A 0.194±0.054 | 47 ± 11 | VAZQUEZ-J | A08 SEL | X Σ^- nucleus, 600 |) GeV |
| ALUE EVTS | DOCUMENT ID TECN COMMENT | | $0.234 \pm 0.047 \pm 0.022$ | 202 | LINK | 01B FOC | CS γ nucleus | |
| .323 ± 0.033 OUR AVERAGE | 5 LESIAK 05 BELL e^+e^- , $\Upsilon(e^-)$ | 4.5) | • • • We do not use | - | = | | | |
| .32 ±0.03 ±0.02 1177 ±5 .28 ±0.06 ±0.06 58 | 5 LESIAK 05 BELL e^+e^- , $\Upsilon(q)$ | | $0.20 \pm 0.04 \pm 0.02$ | 76 | JUN | 00 SEL | X See VAZQUEZ- JAUREGUI 08 | 3 |
| .58 ±0.16 ±0.07 61 | BERGFELD 96 CLE2 e^+e^-pprox 7 | | Γ(<i>p\</i> *(892) ⁰)/Γ(| (ρK-π+) | | | Г19 | /Γ17 |
| $(\Lambda \overline{K}^*(892)^0 \pi^+)/\Gamma(\Lambda K^-)$ | -2π ⁺) | Γ_5/Γ_4 | | | <u>K</u> *(892) ⁰ are incl | uded. | - 10 | , - 1. |
| Unseen decay modes of t | the $\overline{K}^*(892)^0$ are included. | 15/14 | VALUE | | DO CUMENT ID | | COMMENT | |
| ALUE CL% | DOCUMENT ID TECN COMMENT | | $0.54 \pm 0.09 \pm 0.05$ | | LINK | 01B FOCS | γ nucleus | |
| <0.5 90 | BERGFELD 96 CLE2 $e^+e^ \approx$ | Y(45) | $\Gamma(\Sigma^+\pi^+\pi^-)/\Gamma($ | $\Xi^-2\pi^+)$ | | | Г ₁₉ | /Γ ₁₁ |
| $\Gamma(\Sigma(1385)^+K^-\pi^+)/\Gamma(\Lambda$ | $K^{-}2\pi^{+}$) | Γ_6/Γ_4 | VALUE | <u>EVTS</u> | DOCUMENT ID | | COMMENT | |
| , , , | the $\Sigma(1385)^+$ are included. | ٠, . | 0.48±0.20 | 21 ± 8 | VAZQUEZ-JA. | 08 SELX | Σ^- nucleus, 600 (| ∍eV |
| ALUE CL% | DOCUMENT ID TECN COMMENT | | $\Gamma(\Sigma^-2\pi^+)/\Gamma(\Xi^-$ | -2π ⁺) | | | | /Γ ₁₁ |
| <0.7 90 | BERGFELD 96 CLE2 $e^+e^-\approx$ | 1 (45) | VALUE 0.19±0.00 | EVTS | DOCUMENT ID | TECN | | |
| $(\Sigma^+ K^- \pi^+)/\Gamma(\Xi^- 2\pi^+$ | | Γ_7/Γ_{11} | 0.18±0.09 | 10 ± 4 | | vo SELX | Σ^- nucleus, 600 (| j∈ V |
| .94±0.10 OUR AVERAGE | DOCUMENT ID TECN COMMENT | | $\Gamma(\Sigma^+ K^+ K^-)/\Gamma$ | ` | , | | | 1/F7 |
| .91±0.11±0.04 251 | LINK 03E FOCS γ nucleus, $\overline{\it E}$ | $\overline{E}_{\gamma} \approx 180 \text{ GeV}$ | <u>VALUE</u> 0.16±0.06±0.01 | · | DOCUMENT ID LINK 0: | | COMMENT = 180 | GeV |
| $.92 \pm 0.20 \pm 0.07$ | 3 JUN 00 SELX Σ^- nucleus | s, [′] 600 GeV | 0.10±0.00±0.01 | 11 | LINK U | , I UC3 1 | γ nucleus, $\overline{E}_{\gamma} pprox 180$ | GC V |
| $.18 \pm 0.26 \pm 0.17$ 119 | BERGFELD 96 CLE2 $e^+ e^- \approx r$ | (45) | $\Gamma(\Sigma^+\phi)/\Gamma(\Sigma^+\kappa)$ | | | | Γ ₂ | ₂ /Γ ₇ |
| | dant with other results given below. | | Unseen decay r | | φ are included. OCUMENT ID | TECN CO | OMMENT | |
| $(\Sigma^+ \overline{K}^*(892)^0)/\Gamma(\Xi^- 21)$ | τ ⁺) | Γ_8/Γ_{11} | <0.12 | | | | nucleus, $\overline{E}_{\gamma} pprox 180$ (| ieV |
| | - | | | | | | , | |
| Unseen decay modes of t | ne K'(892)° are included. <u>DOCUMENT ID TECN COMMENT</u> | | Γ(Ξ(1690) ⁰ K+× | D(=(1600)(|) , r+v-11 | バスキャー | _+1 - | 3/F ₇ |

BERGFELD 96 CLE2 $e^+e^- \approx r(4s)$

03E FOCS γ nucleus, $\overline{\it E}_{\gamma} \approx 180~{
m GeV}$

0.81±0.15 OUR AVERAGE $0.78 \pm 0.16 \pm 0.06 \qquad 119$

61

 $0.92 \!\pm\! 0.27 \!\pm\! 0.14$

 Ξ_{c}^{+}, Ξ_{c}^{0}

=⁺ REFERENCES

| VAZQUEZ-JA. | . 08 | PL B666 299 | E. Vazquez-Jauregui et al. | (SELEX Collab.) |
|-------------|------|-----------------------|----------------------------|----------------------|
| LESIAK | 05 | PL B605 237 | T. Lesiak et al. | (BELLE Collab.) |
| A Iso | | PL B617 198 (erratum) | T. Lesiak et al. | (BELLE Collab.) |
| LINK | 03 E | PL B571 139 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| MAHMOOD | 02 | PR D65 031102 | A.H. Mahmood et al. | (CLEO Collab.) |
| LINK | 01B | PL B512 277 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| LINK | 01 D | PL B523 53 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| JUN | 00 | PRL 84 1857 | S.Y. Jun et al. | (FNAL SELEX Collab.) |
| FRABETTI | 98 | PL B427 211 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| BERGFELD | 96 | PL B365 431 | T. Bergfeld et al. | (CLEO Collab.) |
| EDWARDS | 96 | PL B373 261 | K.W. Edwards et al. | (CLEO Collab.) |
| ALEXANDER | 95 B | PRL 74 3113 | J. Alexander et al. | (CLEO Collab.) |
| A Iso | | PRL 75 4155 (erratum) | J. Alexander et al. | (CLEO Collab.) |
| AVERY | 95 | PRL 75 4364 | P. Avery et al. | (CLEO Collab.) |
| FRABETTI | 93 B | PRL 70 1381 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| ALBRECHT | 90 F | PL B247 121 | H. Albrecht et al. | (ARGUS Collab.) |
| ALAM | 89 | PL B226 401 | M.S. Alam et al. | (CLEO Collab.) |
| BARLAG | 89 C | PL B233 522 | S. Barlag et al. | (ACCM OR Collab.) |
| COTEUS | 87 | PRL 59 1530 | P. Coteus et al. | (FÑAL E400 Collab.) |
| BIAGI | 85 C | PL 150B 230 | S.F. Biagi et al. | (CERN WA62 Collab.) |
| BIAGI | 83 | PL 122B 455 | S.F. Biagi et al. | (CERN WA62 Collab.) |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

According to the quark model, the Ξ_c^0 (quark content dsc) and Ξ_c^+ form an isospin doublet, and the spin-parity ought to be $J^P=1/2^+$. None of I,J, or P has actually been measured.

Ξ_c MASS

The fit uses the Ξ_C^0 and Ξ_C^+ mass and mass-difference measurements.

| VALUE (MeV) EV | /TS | DO CUMENT ID | TECN | COMMENT |
|------------------------|-------------|------------------------|------|---------|
| 2470.88 + 0.34 OUR FIT | Error inclu | udes scale factor of 1 | .1. | |

2471.09 + 0.35 OUR AVERAGE

| 2471.0 | ±0.3 | $+0.2 \\ -1.4$ | 8620 ± 355 | ¹ LESIAK | 05 | BELL | e^+e^- , $\Upsilon(4S)$ |
|---------|-----------|----------------|---------------|-----------------------|--------|-----------|---------------------------------------------------|
| 2470.0 | ±2.8 | ±2.6 | 85 | FRABETTI | 98B | E687 | γ Be, $\overline{\it E}_{\gamma}=$ 220 GeV |
| 2469 | ± 2 | ± 3 | 9 | HENDERSON | 92B | CLEO | Ω- K+ |
| 2472.1 | ±2.7 | ± 1.6 | 54 | ALBRECHT | 90F | ARG | e^+e^- at $\varUpsilon(4S)$ |
| 2473.3 | ± 1.9 | ± 1.2 | 4 | | | | $\pi^-~(\mathrm{\it K}^-)~\mathrm{Cu}$ 230 GeV |
| 2472 | ± 3 | ± 4 | 19 | ALAM | 89 | CLEO | e^+e^- 10.6 GeV |
| • • • ' | We do | not use | the following | data for averages, | , fits | , limits, | etc. • • • |
| 2462.1 | ±3.1 | ± 1.4 | 42 | ² FRABETTI | 93c | E687 | See FRABETTI 98B |
| 2471 | ± 3 | ± 4 | 14 | AVERY | 89 | CLEO | See ALAM 89 |
| | | | | | | | |

 1 The systematic error was (wrongly) given the other way round in LESIAK 05.

\varXi_c^0 — \varXi_c^+ MASS DIFFERENCE

| VALUE (MeV) | DOCUMENT ID | | TECN | COMMENT |
|----------------------|-------------|-----|------|-----------------------------------------------------------|
| 3.1 + 0.4 OUR FIT | | | | |
| 3.1±0.5 OUR AVERAGE | | | | |
| $+2.9\pm0.5$ | LESIAK | 05 | BELL | e^+e^- , $\Upsilon(4S)$ |
| $+7.0\pm4.5\pm2.2$ | ALBRECHT | 90F | ARG | e^+e^- at $\Upsilon(4S)$ |
| $+6.8\pm3.3\pm0.5$ | BARLAG | 90 | ACCM | π^- (K^-) Cu 230 GeV |
| $+5$ ± 4 ± 1 | ALAM | 89 | CLEO | $arpi_c^0 ightarrow arpi^-\pi^+$, $arpi_c^+ ightarrow$ |
| | | | | $\Xi^-\pi^+\pi^+$ |

≡0 MEAN LIFE

| VALUE (10 ⁻¹⁵ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|------|--------------|-----|------|-----------------------------------------------------------------|
| 112+13 OUR AVERAG | iE | | | | |
| $118^{+14}_{-12} \pm 5$ | 110 | LINK | 02н | FOCS | γ nucleus, $pprox$ 180 GeV |
| $101^{+25}_{-17}\pm 5$ | 42 | FRABETTI | 93c | E687 | $\gamma\mathrm{Be}$, $\overline{E}_{\gamma} = 220\mathrm{GeV}$ |
| $82 + 59 \\ -30$ | 4 | BARLAG | 90 | ACCM | $\pi^-\;(\mathrm{\it K}^-)$ Cu 230 GeV |

Ξ_c^0 DECAY MODES

No absolute branching fractions have been measured. Several measurements of ratios of fractions may be found in the Listings that follow.

| | Mode | Fraction (Γ_i/Γ) |
|------------|-----------------------------------------------------|------------------------------|
| Γ_1 | $ hoK^-K^-\pi^+$ | seen |
| Γ_2 | | seen |
| Γ_3 | $pK^{-}K^{-}\pi^{+}$ no $\overline{K}^{*}(892)^{0}$ | seen |
| Γ_4 | ΛK_S^0 | seen |
| Γ_5 | $\Lambda K^- \pi^+$ | |

| _ | 4 TZD + - | | |
|----------------|----------------------------------------|------|--|
| Γ ₆ | $\Lambda \overline{K}{}^0 \pi^+ \pi^-$ | seen | |
| | $\Lambda K^-\pi^+\pi^+\pi^-$ | seen | |
| | $\Xi^-\pi^+$ | seen | |
| | $\Xi^{-}\pi^{+}\pi^{+}\pi^{-}$ | seen | |
| | $\Omega^- K^+$ | seen | |
| | $\Xi^- e^+ u_e$ | seen | |
| Γ_{12} | $\Xi^-\ell^+$ anything | seen | |

≡⁰ BRANCHING RATIOS

| $\Gamma(pK^-K^-\pi^+)/\Gamma(\Xi^-\pi^+)$ | | | | | | | | |
|-------------------------------------------|-------------|--------------|----|------|-------------------------------|--|--|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
| 0.34±0.04 OUR AVE | RAGE | | | | | | | |
| $0.33 \pm 0.03 \pm 0.03$ | 1908 ± 62 | LESIAK | 05 | BELL | $e^{+}e^{-}$, $\Upsilon(4S)$ | | | |
| $0.35 \pm 0.06 \pm 0.03$ | 148 ± 18 | DANKO | 04 | CLEO | e^+e^- | | | |

| $\Gamma(\rho K^- \overline{K}^*(892)^0)/\Gamma(\Xi^- \pi^+)$ | Γ_2/Γ_8 |
|--------------------------------------------------------------|---------------------|
| | |

Unseen decay modes of the $\overline{K}^*(892)^0$ are included.

WALUE

DOCUMENT ID

DANKO

0.210 \pm 0.045 \pm 0.015

DANKO

O.210 \pm 0 CLEO e^+e^- Seen

BARLAG

90

ACCM $\pi^-(K^-)$ Cu 230 GeV

 $\frac{\Gamma(pK^-K^-\pi^+ \text{ no } \overline{K}^*(892)^0)/\Gamma(\Xi^-\pi^+)}{0.21\pm 0.04\pm 0.02} \xrightarrow{DOCUMENT\ ID} \frac{\text{TECN}}{\text{DANKO}} \xrightarrow{CDEO} \frac{COMMENT}{e^+e^-}$

seen 7 ALBRECHT 95B ARG $e^+e^- \approx 10.4~{\rm GeV}$

0.50 \pm 0.21 \pm 0.05 9 HENDERSON 92B CLEO $e^+e^-\approx 10.6$ GeV $\Gamma(\Xi^-e^+\nu_e)/\Gamma(\Xi^-\pi^+) = \frac{\Gamma_{11}/\Gamma_8}{VALUE} = \frac{EVTS}{DOCUMENT\ ID} = \frac{TECN}{TECN} = \frac{COMMENT}{TECN}$

3.1±1.0+0.3 54 ALEXANDER 95B CLE2 $e^+e^-\approx r(4S)$

 $\Gamma(\Xi^-\ell^+ \text{a nything})/\Gamma(\Xi^-\pi^+) \qquad \qquad \Gamma_{12}/\Gamma_8$ The ratio is for the average (not the sum) of the Ξ^-e^+ anything and $\Xi^-\mu^+$ anything

 $\Gamma(\Xi^-\ell^+ \text{ a nything})/\Gamma(\Xi^-\pi^+\pi^+\pi^-)$ Γ_{12}/Γ_{22}

The ratio is for the average (not the sum) of the Ξ^-e^+ anything and $\Xi^-\mu^+$ anything modes. <u>MALUE</u> <u>EVTS</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u> **0.29 ± 0.12 ± 0.04**18 ALBRECHT 93B ARG $e^+e^- \approx 10.4 \text{ GeV}$

=⁰ DECAY PARAMETERS

See the note on "Baryon Decay Parameters" in the neutron Listings.

 α FOR $\Xi_c^0 \to~\Xi^-\pi^+$

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|------|-------------|----|------|-------------------------------|
| $-0.56\pm0.39^{+0.10}_{-0.09}$ | 138 | CHAN | 01 | CLE2 | $e^+e^- \approx \Upsilon(4S)$ |

²The FRABETTI 93c mass is well below the other measurements.

 Ξ_c^0 , $\Xi_c'^+$, $\Xi_c'^0$, $\Xi_c(2645)$

E REFERENCES

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|-----------|------|-----------------------|----------------------|----------------------|
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| LINK | 02 H | PL B541 211 | J.M. Link et al. | (FNAL FOCUS Collab.) |
| CHAN | 01 | PR D63 111102R | S. Chan et al. | (CLEO Collab.) |
| FRABETTI | 98 B | PL B426 403 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| ALBRECHT | 95 B | PL B342 397 | H. Albrecht et al. | ` (ARGUS Collab.) |
| ALEXANDER | 95 B | PRL 74 3113 | J. Alexander et al. | `(CLEO Collab.) |
| Also | | PRL 75 4155 (erratum) | J. Alexander et al. | (CLEO Collab.) |
| ALBRECHT | 93 B | PL B303 368 | H. Albrecht et al. | (ARGUS Collab.) |
| FRABETTI | 93 C | PRL 70 2058 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| HENDERSON | 92 B | PL B283 161 | S. Henderson et al. | ` (CLEO Collab.) |
| ALBRECHT | 90 F | PL B247 121 | H. Albrecht et al. | (ARGUS Collab.) |
| BARLAG | 90 | PL B236 495 | S. Barlag et al. | (ACCM OR Collab.) |
| ALAM | 89 | PL B226 401 | M.S. Alam et al. | ` (CLEO Collab.) |
| AVERY | 89 | PRL 62 863 | P. Avery et al. | (CLEO Collab.) |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

The $\equiv_c^{\prime+}$ and $\equiv_c^{\prime0}$ presumably complete the SU(3) sextet whose other members are the Σ_c^{++} , Σ_c^+ , Σ_c^0 , and Ω_c^0 : see Fig. 3 in the Note on Charmed Baryons just before the Λ_c^+ Listings. The quantum numbers given above come from this presumption but have not been measured.

$\Xi_c^{\prime+}$ MASS

The mass is obtained from the mass-difference measurement that follows.

| VALUE | (MeV) | | |
|--------|-------|-----|-----|
| 2575.6 | ±3.1 | OUR | FIT |

DO CUMENT ID

$\Xi_{c}^{\prime+} - \Xi_{c}^{+}$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|------|--------------|----|------|--------------------------------|
| 107.8±3.0 OUR FIT | | | | | |
| $107.8 \pm 1.7 \pm 2.5$ | 25 | JESSOP | 99 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

$\Xi_c^{\prime+}$ DECAY MODES

The $\Xi_C^{\prime+}$ – Ξ_C^+ mass difference is too small for any strong decay to occur.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------------|------------------------------|
| Γ ₁ | $\equiv_c^+ \gamma$ | seen |

$\Xi_c^{\prime+}$ REFERENCES

JESSOP 99 PRL 82 492 C.P. Jessop et al. (CLEO Collab.)



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: ***

See the note in the Listing for the $\Xi_c^{\prime+}$, above.

Ξ'0 MASS

The mass is obtained from the mass-difference measurement that follows.

| VALUE (MeV) | | | |
|-------------|-----|-----|--|
| 2577 9+2 9 | OHR | FIT | |

DO CUMENT ID

Ξ_c⁰ – Ξ_c MASS DIFFERENCE

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-----------------------------------------|--------------|----|------|--------------------------------|
| 107.0±2.9 OUR FIT | - · · · · · · · · · · · · · · · · · · · | | | | |
| $107.0 \pm 1.4 \pm 2.5$ | 28 | JESSOP | 99 | CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

Ξ'0 DECAY MODES

The $\Xi_C^{\prime 0} = \Xi_C^0$ mass difference is too small for any strong decay to occur.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|-----------------------------|------------------------------|
| Γ ₁ | $\equiv {0 \atop c} \gamma$ | seen |

Ξ'0 REFERENCES

JESSOP 99 PRL 82 492 C.P. Jessop et al. (CLEO Collab.)

$\overline{\Xi_c}$ (2645)

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$
 Status: ***

A narrow peak seen in the $\Xi_{C}\pi$ mass spectrum. The natural assignment is that this is the $J^{P}=3/2^{+}$ excitation of the Ξ_{C} in the same SU(4) multiplet as the $\Delta(1232)$, but the quantum numbers have not been measured.

$\Xi_{c}(2645)$ MASSES

The masses are obtained from the mass-difference measurements that fol-

| Ξ_c (2645) $^+$ MASS | | | | | |
|-----------------------------------------|----------------|---------------------|----|------|----------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 2645.9 + 0.5 OUR FIT | Error includes | scale factor of 1.1 | 1. | | |
| $2645.6 \pm 0.2 ^{+\ 0.6}_{-\ 0.8}$ | 578 ± 32 | LESIAK | 80 | BELL | $e^+e^-pprox \Upsilon(45)$ |
| Ξ _c (2645) ⁰ MASS | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 2645.9 ± 0.5 OUR FIT | | | | | |
| $2645.7 \pm 0.2 + 0.6 \\ -0.7$ | 611 ± 32 | LESIAK | 80 | BELL | $e^+e^-pprox \Upsilon(4S)$ |

$\Xi_c(2645) - \Xi_c$ MASS DIFFERENCES

| $m_{\Xi_c(2645)^+} - m_{\Xi_c^0}$ | | | | | | | |
|-----------------------------------|--------------|---------------------|--------|------|---------------------------------------------------|--|--|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT | | |
| 175.0 $^{+0.8}_{-0.6}$ OUR FIT | Error includ | des scale factor o | f 1.2. | | | | |
| 175.6±1.4 OUR AVE | RAGE Erro | r includes scale fa | | | | | |
| $177.1 \pm 0.5 \pm 1.1$ | 47 | FRABETTI | 98B | E687 | γ Be, $\overline{\it E}_{\gamma}=$ 220 GeV | | |
| $174.3 \pm 0.5 \pm 1.0$ | 34 | GIBBONS | | | $e^+e^-\stackrel{'}{pprox} \varUpsilon(4S)$ | | |
| $m_{\Xi_c(2645)^0} - m_{\Xi_c^+}$ | | | | | | | |
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| 178.1 ± 0.6 OUR FIT | | | | | | | |
| $178.2 \pm 0.5 \pm 1.0$ | 55 | AVERY | 95 | CLE2 | $e^+e^-pprox \Upsilon(4S)$ | | |

$\Xi_c(2645)^+ - \Xi_c(2645)^0$ MASS DIFFERENCE

| $m_{\Xi_c(2645)^+} - m_{\Xi_c(2645)^0}$ | | | | |
|-----------------------------------------|--------------|----|------|---------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 0.0±0.5 OUR FIT | | | | |
| $-0.1\pm0.3\pm0.6$ | LESIAK | 80 | BELL | pprox 600 evts each |
| | | | | |

$\Xi_c(2645)$ WIDTHS

| Ξ _C (2645)+ V | VIDTH | CL% | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|---------------|------|-------------|----|------|-----------------------------|
| <3.1 | | 90 | GIBBONS | 96 | CLE2 | $e^+e^- \approx \gamma(4S)$ |
| Ξ _C (2645) ⁰ W | 'I DTH | EVTS | DOCUMENT ID | | TECN | COMMENT |
| <5.5 | 90 | 55 | AVERY | 95 | CLE2 | $e^+e^-\approx \gamma(45)$ |

$\Xi_c(2645)$ DECAY MODES

 $\Xi_{\mathcal{C}} \pi$ is the only strong decay allowed to a $\Xi_{\mathcal{C}}$ resonance having this mass.

| | Mode | Fraction (Γ_i/Γ) |
|----------------------------------|----------------------------------|------------------------------|
| Γ ₁ Γ ₂ | $ \Xi_c^0 \pi^+ \Xi_c^+ \pi^- $ | seen seen |

$\Xi_c(2645)$ REFERENCES

| LESIAK | 08 | PL B665 9 | T. Lesiak et al. | (BELLE Collab.) |
|----------|------|-------------|----------------------|---------------------|
| FRABETTI | 98 B | PL B426 403 | P.L. Frabetti et al. | (FNAL E687 Collab.) |
| GIBBONS | 96 | PRL 77 810 | L.K. Gibbons et al. | ` (CLEO Collab.) |
| AVERY | 95 | PRL 75 4364 | P. Avery et al. | (CLEO Collab.) |

 $\Xi_c(2790), \Xi_c(2815), \Xi_c(2930), \Xi_c(2980)$

 $\Xi_c(2790)$

$$I(J^P) = \frac{1}{2}(\frac{1}{2})$$
 Status: ***

A peak seen in the $\Xi_{c}^{\prime}\pi$ mass spectrum. The simplest assignment, based on the mass, width, and decay mode, is that this belongs in the same SU(4) multiplet as the $\Lambda(1405)$ and the $\Lambda_{C}(2595)^{+}$, but the spin and parity have not been measured.

$\Xi_{C}(2790)$ MASSES

The masses are obtained from the mass-difference measurements that fol-

 $\Xi_c(2790)^+$ MASS

VALUE (MeV)
2789.1 ± 3.2 OUR FIT

DOCUMENT ID

 $\Xi_c(2790)^0$ MASS

DO CUMENT ID

2791.8±3.3 OUR FIT

| $\Xi_{c}(2790)$ | _ = | MASS | DIFFERENCES |
|-----------------|-----|------|-------------|

| $m_{\Xi_c(2790)^+} - m_{\Xi_c^0}$ | | | | | |
|------------------------------------|------|--------------|----|------|--------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 318.2±3.2 OUR FIT 318.2±1.3±2.9 | 18 | CSORNA | 01 | CLEO | $e^+ e^- \approx \gamma(4S)$ |
| $m_{\Xi_c(2790)^0} - m_{\Xi_c^+}$ | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 324.0±3.3 OUR FIT | LVIJ | DOCUMENT ID | | TECH | COMMENT |
| 324.0±1.3±3.0 | 14 | CSORNA | 01 | CLEO | $e^+ e^- \approx \Upsilon(45)$ |

$\Xi_c(2790)$ WIDTHS

| $\Xi_c(2790)^+$ WIDTH VALUE (MeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------|-----|-------------|----|------|--------------------------------------|
| <15 | 90 | CSORNA | 01 | CLEO | $e^+ e^- \approx \ \varUpsilon(4S)$ |
| $\Xi_c(2790)^0$ WIDTH | | | | | |
| VALUE (MeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
| <12 | 90 | CSORNA | 01 | CLEO | $e^+ e^- \approx \gamma(4S)$ |

$\Xi_c(2790)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|------------|-----------------------|------------------------------|
| Γ_1 | $\Xi_{c}^{\prime}\pi$ | seen |

$\Xi_c(2790)$ REFERENCES

CSORNA PRL 86 4243 S.E. Csorna et al. (CLEO Collab.)

 $\Xi_c(2815)$

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$
 Status: ***

A narrow peak seen in the $\Xi_{\mathcal{C}} \pi \pi$ mass spectrum. The simplest assignment is that this belongs to the same SU(4) multiplet as the $\Lambda(1520)$ and the $\Lambda_{\mathcal{C}}(2625)$, but the spin and parity have not been measured.

$\Xi_c(2815)$ MASSES

The masses are obtained from the mass-difference measurements that fol-

| = (201E)+ MA | cc |
|--------------------|----|
| $\Xi_c(2815)^+$ MA | 33 |

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------------------------------------------------|---------|-------------|----|------|------------------------------|
| 2816.6±0.9 OUR FIT 2817.0±1.2 ⁺ 0.7 -0.8 | 73 ± 10 | LESIAK | 08 | DELL | $e^+e^-\approx \Upsilon(4S)$ |
| | 75 ± 10 | LESIAN | 00 | BELL | e e ≈ 7 (43) |
| $arxiii_c(2815)^0$ MASS | | | | | |
| VALUE (MeV) 2819.6±1.2 OUR FIT | EVTS | DOCUMENT ID | | TECN | COMMENT |
| _ | | | | | |
| $2820.4 \pm 1.4 ^{+0.9}_{-1.0}$ | 48 ± 8 | LESIAK | 80 | BELL | $e^+e^-pprox \Upsilon(4S)$ |

$\Xi_c(2815) - \Xi_c$ MASS DIFFERENCES

| $m_{\Xi_c(2815)^+} - m_{\Xi_c^+}$ | | | | |
|-----------------------------------|---------------------------------------|--------------|---------|--------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 348.8±0.9 OUR FIT | · · · · · · · · · · · · · · · · · · · | · | | · |
| $348.6 \pm 0.6 \pm 1.0$ | 20 | ALEXANDER 9 | 9B CLE2 | $e^+ e^- \approx \Upsilon(4S)$ |

| $m_{\Xi_c(2815)^0} - m_{\Xi_c^0}$ | | | | | |
|-----------------------------------|------|-------------|-----|------|----------------------------|
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 348.7±1.2 OUR FIT | | · | | | |
| $347.2 \pm 0.7 \pm 2.0$ | 9 | ALEXANDER | 99B | CLE2 | $e^+e^-pprox \Upsilon(4S)$ |
| | | | | | |

$\Xi_c(2815)^+ - \Xi_c(2815)^0$ MASS DIFFERENCE

| $m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0}$ | | | | |
|-----------------------------------------|--------------|----|------|----------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| -3.1±1.3 OUR FIT | | | | |
| $-3.4\pm1.9\pm0.9$ | LESIAK | 80 | BELL | 73 & 48 events |

$\Xi_c(2815)$ WIDTHS

| Ξ _c (2815)+ WIDTH | <u>CL%</u> | DOCUMENT ID | | TECN | COMMENT |
|------------------------------------------|------------|--------------|-----|------|------------------------------|
| <3.5 | 90 | ALEXANDER | 99B | CLE2 | $e^+e^-pprox \Upsilon(45)$ |
| Ξ _c (2815) ⁰ WIDTH | CL% | DO CUMENT ID | | TECN | COMMENT |
| <6.5 | 90 | | 99B | | $e^+e^-\approx \Upsilon(4S)$ |

$\Xi_c(2815)$ DECAY MODES

The $\Xi_C \pi \pi$ modes are consistent with being entirely via $\Xi_C(2645) \pi$.

| | Mode | Fraction $(\Gamma_{\hat{I}}/\Gamma)$ |
|-----------------------|--------------------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | $\Xi_{c}^{+}\pi^{+}\pi^{-}$ | seen |
| Γ_2 | $\equiv_{c}^{0}\pi^{+}\pi^{-}$ | seen |

$\Xi_c(2815)$ REFERENCES

T. Lesiak et al. J.P. Alexander et al. LESIAK 08 PL B665 9 ALEXANDER 99B PRL 83 3390



$$I(J^P) = ?(?^?)$$
 Status: *

OMITTED FROM SUMMARY TABLE

A peak seen in the $\varLambda_c^+ K^-$ mass projection of $B^- \to \varLambda_c^+ \overline{\varLambda}_c^- K^-$

| VALUE (MeV) | EVIS | DO CUMENT ID | | TECN | COMMENT | |
|-------------|------|--------------|-----|------|------------------------------------------|--|
| 2931 ± 3±5 | ≈ 34 | AUBERT | 08н | BABR | $\Upsilon(4S) \rightarrow B\overline{B}$ | |
| | | | | | | |

Ξ_c (2930) WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | T | TECN | COMMENT |
|-------------|------|--------------|---|------|------------------------------------------|
| 36±7±11 | ≈ 34 | AUBERT | | BABR | $\Upsilon(4S) \rightarrow B\overline{B}$ |

Ξ_c (2930) REFERENCES

08H PR D77 031101R B. Aubert et al. AUBERT (BABAR Collab.)

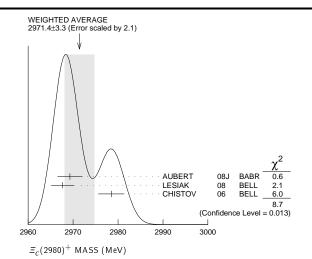
 Ξ_c (2980)

$$I(J^P) = \frac{1}{2}(??)$$
 Status: ***

Ξ_c (2980) MASSES

$\Xi_c(2980)^+$ MASS

| -, , | | | | | |
|-----------------------------------|---------------|-------------------|----------|----------|--------------------------------|
| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 2971.4 ± 3.3 OUR | AVERAGE Error | includes scale fa | ctor of | 2.1. See | the ideogram below. |
| $2969.3 \pm 2.2 \pm 1.7$ | 756 ± 206 | AUBERT | 180 L | BABR | $e^+e^-pprox~10.58~{ m GeV}$ |
| $2967.7 \pm 2.3 ^{+ 1.1}_{- 1.2}$ | 78 ± 13 | LESIAK | 08 | BELL | $e^+ e^- \approx \Upsilon(4S)$ |
| $2978.5 \pm 2.1 \pm 2.0$ | 405 ± 51 | CHISTOV | 06 | BELL | $e^+e^-\approx \gamma(4S)$ |



$\Xi_c(2980)^0$ MASS

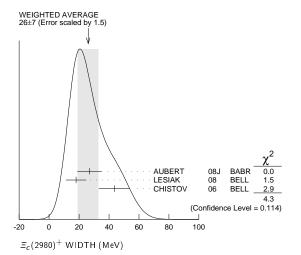
The evidence is statistically weaker for this charge state.

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN_ | COMMENT |
|--------------------------------|--------------|--------------------|--------------|----------------------------|
| 2968.0±2.6 OUR A | VERAGE Error | includes scale fac | ctor of 1.2. | |
| $2972.9 \pm 4.4 \pm 1.6$ | 67 ± 44 | AUBERT | 08J BABR | e^+e^-pprox 10.58 GeV |
| $2965.7 \pm 2.4 + 1.1 \\ -1.2$ | 57 ± 13 | LESIAK | 08 BELL | $e^+e^-pprox \Upsilon(4S)$ |
| $2977.1 \pm 8.8 \pm 3.5$ | 42 ± 24 | CHISTOV | 06 BELL | $e^+e^-pprox \Upsilon(4S)$ |

Ξ_c (2980) WIDTHS

$\Xi_c(2980)^+$ WIDTH

| VAL | UE (M | eV) | EVTS | DO CUMENT | ID | TECN | COMMENT | |
|-----|---------|---------|--------------|----------------------|------------|--------|-------------------|-----------------|
| 26 | ±7 | OUR | AVERAGE Erro | r includes scale fac | ctor of 1. | 5. See | the ideogran | n below. |
| 27 | ± 8 | ± 2 | 756 ± 206 | AUBERT | 081 | BABR | $e^+ e^- \approx$ | 10.58 GeV |
| 18 | ± 6 | ± 3 | 78 ± 13 | LESIAK | 08 | BELL | $e^+ e^- \approx$ | $\Upsilon(4S)$ |
| 43 | 5 + 7 ! | 5 + 7 0 | 405 ± 51 | CHISTOV | 06 | BELL | e+e- ≈ | $\Upsilon(4.5)$ |



$\Xi_c(2980)^0$ WIDTH

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|------------------|---------------|-------------------|------|------|------------------------------|
| 20±7 OUR AVERAGE | Error include | s scale factor of | 1.3. | | |
| $31\pm7\pm8$ | 67 ± 44 | AUBERT | 08J | BABR | $e^+e^-pprox~10.58~{ m GeV}$ |
| $15\pm 6\pm 3$ | 57 ± 13 | LESIAK | 80 | BELL | $e^+e^-pprox \Upsilon(4S)$ |

Ξ_{c} (2980) DECAY MODES

| | Mode | Fraction (Γ_j/Γ) |
|-----------------------|----------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ \overline{K} \pi$ | seen |
| Γ_2 | Σ_c (2455) \overline{K} | seen |
| Γ ₃ | $\Lambda_c^+\overline{K}$ | not seen |
| Γ_4 | $\Xi_c 2\pi$ | seen |
| Γ_5 | $\Xi_c(2645)\pi$ | seen |

Ξ_c (2980) BRANCHING RATIOS

| $\Gamma(\Lambda_c^+ \overline{K}\pi)/\Gamma_{\text{total}}$ | 0.0 500 450 7 10 | | TE 611 | 50.445NT | | Γ_1/Γ |
|-------------------------------------------------------------------------|------------------|-----|--------|-----------------|----------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | | |
| seen | AUBERT | 08J | | $e^+e^-\approx$ | | |
| seen | CHISTOV | 06 | BELL | $e^+e^-\approx$ | $\Upsilon(4S)$ | |
| $\Gamma(\Sigma_c(2455)\overline{K})/\Gamma(\Lambda_c^+\overline{K}\pi)$ | | | | | ſ | 2/Γ1 |
| VALUE | DOCUMENT ID | | TECN | <u>COMMENT</u> | | |
| $0.55 \pm 0.07 \pm 0.13$ | AUBERT | 180 | BABR | $e^+e^-\approx$ | $\Upsilon(45)$ | |
| $\Gamma(\Xi_c(2645)\pi)/\Gamma_{\text{total}}$ | | | | | | Γ ₅ /Γ |
| VALUE | DOCUMENT ID | | TECN | COMMENT | | |
| seen | LESIAK | 80 | BELL | $e^+e^-\approx$ | $\Upsilon(4S)$ | |

Ξ_c (2980) REFERENCES

| AUBERT | 08 J | PR D77 012002 | B. Aubert et al. | (BABAR Collab.) |
|----------|------|---------------|-------------------|-----------------|
| LES IA K | 08 | PL B665 9 | T. Lesiak et al. | (BELLE Collab.) |
| CHISTOV | 06 | PRL 97 162001 | R. Chistov et al. | (BELLE Collab.) |



 $I(J^P) = ?(??)$ Status: **

08J PR D77 012002

OMITTED FROM SUMMARY TABLE A peak in the $\Sigma_c(2455)^{++}$ $K^- \to \Lambda_c^+$ $K^-\pi^+$ mass spectrum with a claimed significance of 6.4 standard deviations.

Ξ_c (3055) MASSES

 $\Xi_c(3055)^+$ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|----------|--------------|-----|------|------------------------------------|
| 3054.2±1.2±0.5 | 218 ± 95 | AUBERT | 08J | BABR | $e^+e^- \approx 10.58 \text{ GeV}$ |

Ξ_c (3055) WIDTHS

 $\Xi_c(3055)$ + WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|-------------|----------|--------------|----------|------------------------------------|
| 17±6±11 | 218 ± 95 | AUBERT (| 08J BABR | $e^+e^- \approx 10.58 \text{ GeV}$ |

B. Aubert et al.

 Ξ_c (3055) REFERENCES

 $\Xi_c(3080)$

AUBERT

$$I(J^P) = \frac{1}{2}(?^?)$$
 Status: ***

06 BELL $e^+e^- \approx \Upsilon(4S)$

(BABAR Collab.)

A narrow peak seen in the Λ_c^+ $K^-\pi^+$ and Λ_c^+ $K_S^0\pi^-$ mass spectra.

Ξ_c (3080) MASSES

 $\Xi_c(3080)^+$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|--------------|-------------------|---------|------|-------------------------------|
| 3077.0 ± 0.4 OUR A | ∨ERAGE | | | | |
| $3077.0 \pm 0.4 \pm 0.2$ | 403 ± 60 | AUBERT | 08J E | BABR | e^+e^-pprox 10.58 GeV |
| $3076.7 \pm 0.9 \pm 0.5$ | 326 ± 40 | CHISTOV | 06 E | BELL | $e^+e^-pprox \Upsilon(4S)$ |
| $\Xi_c(3080)^0$ MASS | i | | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 3079.9±1.4 OUR A | VERAGE Error | includes scale fa | ctor of | 1.3. | |
| $3079.3 \pm 1.1 \pm 0.2$ | 90 ± 27 | AUBERT | 08J E | BABR | e^+e^-pprox 10.58 GeV |
| $3082.8\pm1.8\pm1.5$ | 67 ± 20 | CHISTOV | 06 E | BELL | $e^+e^- \approx \Upsilon(4S)$ |

$\Xi_c(3080)$ WIDTHS

| $\Xi_c(3080)^+$ | WIDTH |
|-----------------|-------|
| VALUE (MeV.) | |

 $5.2 \pm 3.1 \pm 1.8$

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------------------------|--------------|-------------|-----|------|----------------------------------------|
| 5.8 ± 1.0 OUR AVE | RAGE | | | | |
| $5.5 \pm 1.3 \pm 0.6$ | 403 ± 60 | AUBERT | 081 | BABR | e^+e^-pprox 10.58 GeV |
| $6.2\!\pm\!1.2\!\pm\!0.8$ | 326 ± 40 | CHISTOV | 06 | BELL | $e^+e^-pprox \Upsilon(4S)$ |
| $\Xi_c(3080)^0$ WID | TH | | | | |
| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
| 5.6 ± 2.2 OUR AVE | RAGE | | | | |
| 59+23+15 | 90 + 27 | AUBERT | 081 | RARR | $e^{+}e^{-} \approx 10.58 \text{ GeV}$ |

CHISTOV

 $67\,\pm\,20$

 $\Xi_c(3080), \Xi_c(3123), \Omega_c^0$

$\Xi_c(3080)$ DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-----------------------------------------------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ \overline{K} \pi$ | seen |
| Γ_2 | Σ_c (2455) \overline{K} | seen |
| | $\Sigma_c(2455)\overline{K} + \Sigma_c(2520)\overline{K}$ | seen |
| Γ_4 | $\Lambda_c^+ \overline{K}$ | not seen |
| Γ_5 | $\Lambda_c^+ \overline{K} \pi^+ \pi^-$ | not seen |

Ξ_c (3080) BRANCHING RATIOS

| $\Gamma(\Sigma_c(2455)\overline{K})/\Gamma(\Lambda_c^+\overline{K}\pi)$ | DO CUMENT ID | | TECN | COMMENT | |
|-------------------------------------------------------------------------------------------------|-----------------------------------------------------------------|---------|------|---------------------------------------------------------------------------|------|
| 0.45 ± 0.06 OUR AVERAGE | | | | | |
| $0.45 \pm 0.05 \pm 0.05$ | AUBERT | 180 | BABR | in $\Lambda_c^+ K^- \pi^+$ | |
| $0.44\pm0.12\pm0.07$ | AUBERT | U80 | BABR | in $\Lambda_c^+ K_S^0 \pi^-$ | |
| | | | | | |
| $\left[\Gamma\left(\Sigma_c(2455)\overline{K}\right) + \Gamma\left(\Sigma_c(250)\right)\right]$ | $[520)\overline{K}]/\Gamma(\Lambda_c^+\overline{K})$ | π) | | | Γ3/Γ |
| VALUE | 520) Κ)]/Γ(Λ <mark>+</mark> Κ <u>DOCUMENT ID</u> | π) | TECN | COMMENT | Г3/Г |
| • ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' ' | , , , , , | | | | Г3/Г |
| VALUE | , , , , , | | | $\frac{COMMENT}{\ln \Lambda_c^+ K^- \pi^+}$ $\ln \Lambda_c^+ K_S^0 \pi^-$ | Г3/Г |

Ξ_c (3080) REFERENCES

| AUBERT | 08 J | PR D77 012002 | B. Aubert et al. | (BABAR Collab.) |
|---------|------|---------------|-------------------|------------------|
| CHISTOV | 06 | PRL 97 162001 | R. Chistov et al. | `(BELLE Collab.) |

 $\Xi_c(3123)$

$$I(J^P) = ?(?^?)$$
 Status: *

OMITTED FROM SUMMARY TABLE A peak in the $\Sigma_c(2520)^{++}$ $K^- \to \Lambda_c^+ K^- \pi^+$ mass spectrum with a significance of 3.6 standard deviations.

Ξ_c (3123) MASSES

 $\Xi_c(3123)^+$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|------------|-------------|-----|------|-------------------------------|
| $3122.9 \pm 1.3 \pm 0.3$ | 101 ± 35 | AUBERT | 08J | BABR | $e^+e^-pprox~10.58~{\rm GeV}$ |

Ξ_c (3123) WIDTHS

 $\Xi_c(3123)$ + WIDTH

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-------------|----------|--------------|-----|------|-----------------------------------|
| 4.4±3.4±1.7 | 101 ± 35 | AUBERT | 08J | BABR | $e^+e^-\approx 10.58 \text{ GeV}$ |

Ξ_c (3123) REFERENCES

B. Aubert et al. AUBERT 08J PR D77 012002 (BABAR Collab.)



$$I(J^P) = O(\frac{1}{2}^+)$$
 Status: ***

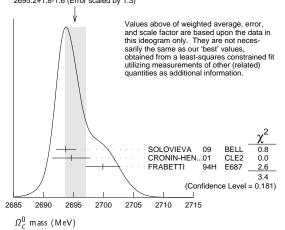
The quantum numbers have not been measured, but are simply assigned in accord with the quark model, in which the $\Omega_{\scriptscriptstyle C}^0$ is the ssc ground state.

Ω_c^0 MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|---------------------------------------------------------------------------------------|------------|-------------------------------------------------------|----------------|------------------------------------------------------------------------------------------------|
| 2695.2± 1.7 OUR | FIT Error | includes scale factor of | of 1.3. | |
| 2695.2 + 1.8 OUR below. | AVERAGE | Error includes scale | factor of | f 1.3. See the ideogram |
| $2693.6 \pm 0.3^{+1.8}_{-1.5}$ | 725 ± 45 | SOLOVIEVA 09 | BELL | $\Omega^-\pi^+$ in $e^+e^- ightarrow \gamma$ (45) |
| $\begin{array}{ccc} 2694.6 \pm & 2.6 \pm 1.9 \\ 2699.9 \pm & 1.5 \pm 2.5 \end{array}$ | 40 42 | ¹ CRONIN-HEN01 ² FRABETTI 94 | CLE2 + E687 | $e^+e^-pprox~10.6~{ m GeV}$ γ Be, $\overline{E}_{\gamma}=$ 221 ${ m GeV}$ |
| | | ving data for averages | | |
| $2705.9\!\pm\ 3.3\!\pm\!2.0$ | 10 | ³ FRABETTI 93 | E687 | γ Be, $\overline{E}_{\gamma} =$ 221 GeV |
| $2719.0 \pm 7.0 \pm 2.5$ | 11 | ⁴ ALBRECHT 92 | ARG | $e^+ e^- \stackrel{\sim}{\approx} 10.6 \text{ GeV}$ $\Sigma^- \text{Be } 135 \text{ GeV}/c$ |

- 1 CRONIN-HENNESSY 01 sees 40.4 \pm 9.0 events in a sum over five channels. 2 FRABETTI 94H claims a signal of 42.5 \pm 8.8 Σ^+ $K^ K^ \pi^+$ events. The background
- is about 24 events. 3 FRABETTI 93 claims a signal of 10.3 \pm 3.9 $\varOmega^-\pi^+$ events above a background of 5.8
- events. 4 ALBRECHT 92H claims a signal of 11.5 \pm 4.3 $\Xi^ K^ \pi^+$ π^+ events. The background is about 5 events.

WEIGHTED AVERAGE 2695.2+1.8-1.6 (Error scaled by 1.3)



Ω_c^0 MEAN LIFE

| VALUE (10 ⁻¹⁵ s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------|-------|--------------|-------------|-------|------------------------------------------------------------|
| 69±12 OUR AV | ERAGE | | | | |
| $72 \pm 11 \pm 11$ | 64 | LINK | 03 c | FOCS | $\Omega^-\pi^+$, $\Xi^-K^-\pi^+\pi^+$ |
| $55 + 13 + 18 \\ -11 - 23$ | 86 | ADAMOVICH | 95B | WA 89 | $\varOmega^-\pi^-\pi^+\pi^+$, \varXi^- K $^-\pi^+\pi^+$ |
| $86^{+27}_{-20}\pm28$ | 25 | FRABETTI | 95 D | E687 | Σ^+ K $^-$ K $^ \pi^+$ |

Ω_c^0 DECAY MODES

No absolute branching fractions have been measured.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------------------------------------|------------------------------|
| | Σ^+ K ⁻ K ⁻ π^+ | seen |
| | $\Xi^0 K^- \pi^+$ | seen |
| Γ_3 | $\Xi^- K^- \pi^+ \pi^+$ | seen |
| Γ_4 | $\Omega^- e^+ u_e$ | seen |
| Γ_5 | $\Omega^-\pi^+$ | seen |
| Γ_6 | $\Omega^-\pi^+ \ \Omega^-\pi^+\pi^0$ | seen |
| Γ ₇ | $\Omega^-\pi^-\pi^+\pi^+$ | seen |

Ω_c^0 BRANCHING RATIOS

| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $\Gamma(\Sigma^+ K^- K^- \pi^+)$ | /Γ _{total} |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------|
| $\Gamma(\Sigma^{+}K^{-}K^{-}\pi^{+})/\Gamma(\Omega^{-}\pi^{+})$ $VALUE$ ••• We do not use the following data for averages, fits, limits, etc. ••• <4.8 90 CRONIN-HEN01 CLE2 $e^{+}e^{-}\approx 10.6$ GeV $\Gamma(\Xi^{0}K^{-}\pi^{+})/\Gamma(\Omega^{-}\pi^{+})$ $VALUE$ $EVTS$ $A.0 \pm 2.5 \pm 0.4$ 9 CRONIN-HEN01 CLE2 $e^{+}e^{-}\approx 10.6$ GeV $\Gamma(\Xi^{-}K^{-}\pi^{+}\pi^{+})/\Gamma_{\text{total}}$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ $VALUE$ VAL | VALUE | EVTS |
| WALUE CL% DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • <4.8 | seen | 42 |
| • • • We do not use the following data for averages, fits, limits, etc. • • • • < 4.8 90 CRONIN-HEN01 CLE2 $e^+e^-\approx 10.6$ GeV $ \Gamma(\Xi^0K^-\pi^+)/\Gamma(\Omega^-\pi^+) = \frac{DOCUMENT\ ID}{CRONIN-HEN01} = \frac{TECN}{CLE2} \frac{COMMENT}{e^+e^-\approx 10.6} = \frac{T_3}{CLE2} = \frac{T_3}{e^+e^-\approx 10.6} = \frac{T_3}{CLE2} = \frac{T_3}{e^+e^-\approx 10.6} = \frac{T_3}{CLE2} = \frac{T_3}{e^+e^-\approx 10.6} = \frac{T_3}{CLE2} = \frac{T_3}{E^-E^-\approx 10.6} = \frac{T_3}{E^-E^-E^-\approx 10.6} = \frac{T_3}{E^-E^-E^-E^-\approx 10.6} = \frac{T_3}{E^-E^-E^-E^-E^-E^-E^-E^-E^-E^-E^-E^-E^-E$ | $\Gamma(\Sigma^+ K^- K^- \pi^+)$ | $/\Gamma(\Omega^-\pi^+)$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | VALUE | CL% |
| $\begin{array}{c ccccccccccccccccccccccccccccccccccc$ | ullet $ullet$ We do not us | the following |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | <4.8 | 90 |
| 4.0±2.5±0.4 9 CRONIN-HEN01 CLE2 $e^+e^- \approx 10.6 \text{ GeV}$ $ Γ(Ξ-K^-π^+π^+)/Γ_{total} $ | $\Gamma(\Xi^0 K^-\pi^+)/\Gamma($ | $(2^-\pi^+)$ |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | VALUE | EVTS |
| $ \begin{array}{c ccccccccccccccccccccccccccccccccccc$ | $4.0 \pm 2.5 \pm 0.4$ | 9 |
| seen11ALBRECHT92HARG $e^+e^-\approx 10.6$ GeVseen3BIAGI85BSPEC $Σ^-$ Be 135 GeV/c | $\Gamma(\Xi^-K^-\pi^+\pi^+)$ | Γ _{total} |
| Seen 3 BIAGI 85B SPEC Σ^- Be 135 GeV/ c | VALUE | EVTS |
| ' | seen | 11 |
| | seen | 3 |
| $\Gamma(\Xi^-K^-\pi^+\pi^+)/\Gamma(\Omega^-\pi^+)$ Γ_3/Γ_3 | $\Gamma(\Xi^-K^-\pi^+\pi^+)$ | $\Gamma(\Omega^-\pi^+)$ |
| VALUE CL% EVTS DOCUMENT ID TECN COMMENT | VALUE | CL% EVTS |
| 0.46 \pm 0.13 \pm 0.03 45 \pm 12 AUBERT 07AH BABR $e^{+}e^{-}\approx \varUpsilon(4S)$ | $0.46 \pm 0.13 \pm 0.03$ | 45 ± 12 |
| | ● ● We do not us | the following |
| 1.6 \pm 1.1 \pm 0.4 7 CRONIN-HEN01 CLE2 $e^+e^- \approx 10.6$ GeV | $1.6 \pm 1.1 \pm 0.4$ | 7 |

< 2.8

FRABETTI 93 E687 γ Be, \overline{E}_{γ} = 221 GeV

Baryon Particle Listings Ω_c^0 , $\Omega_c(2770)^0$

| $\Gamma(\Omega^-\pi^+)/\Gamma($ | | | | | | Γ ₅ /Γ ₄ |
|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|--------------|-----------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| 0.41±0.19±0.04 | <u>EVTS</u> 11 | <u>DO CUMENT ID</u> A MMAR | | TECN CLE2 | | Υ(4S) |
| $\Gamma(\Omega^-\pi^+\pi^0)/V$ | $\Gamma(\Omega^-\pi^+)$ | DOCUMENT ID | | TECN | <u>COMMENT</u> | Γ_6/Γ_5 |
| 1.27±0.31±0.11 | 64 ± 15 | | 07ан | BABR | $e^+ e^- \approx$ | Υ(4S) |
| $4.2 \ \pm 2.2 \ \pm 0.9$ | 12 | CRONIN-HEN | 01 | CLE2 | $e^+e^-\approx$ | 10.6 GeV |
| $\Gamma(\Omega^-\pi^-\pi^+\pi^-)$ | ·+)/Γ(Ω ⁻ π+) | | ID | TEC | N COMME | Γ ₇ /Γ ₅ |
| 0.28±0.09±0 • • • We do no | | | 07/ | н ВАЕ | 3R e ⁺ e ⁻ | |
| <0.56 seen <1.6 | 90 90 | CRONIN-H ADAMOVIO FRABETTI | | | 89 Σ ⁻ 34 | pprox 10.6 GeV 0 GeV $\gamma=$ 221 GeV |
| | | Ω_c^0 REFEREN | CES | | | |
| SOLOVIEVA 09 AUBERT 07AI LINK 03C AMMAR 02 CRONIN-HEN 01 ADAMOVICH 95B FRABETTI 95D FRABETTI 94H FRABETTI 92H BIAGI 85B | PL B672 1 H PRL 99 062001 PL B561 41 PRL 89 171803 PRL 86 3730 PL B358 151 PL B357 678 PL B338 106 PL B300 190 PL B288 367 ZPHY C28 175 | E. Solovieva e B. Aubert et J.M. Link et R. Ammar et D. Cronin-Hen M.I. Adamovic P.L. Frabetti e P.L. Frabetti e P.L. Frabetti e H. Albrecht et S.F. Biagi et | al. al. nessy et th et al. et al. et al. et al. | al. | (BAE (FNAL FOO (CI (CERN W. (FNAL E (FNAL E (FNAL E | LLE Collab.) SAR Collab.) CUS Collab.) EO Collab.) A89 Collab.) 687 Collab.) 687 Collab.) GUS Collab.) GUS Collab.) GUS Collab.) |

|--|

$$I(J^P) = O(\frac{3}{2}^+)$$
 Status: ***

The natural assignment is that this goes with the $\Sigma_c(2520)$ and $\Xi_c(2645)$ to complete the lowest mass $J^P=\frac{3}{2}^+$ SU(3) sextet, part of the SU(4) 20-plet that includes the $\Delta(1232)$. But J and P have not been measured.

$\Omega_c(2770)^0$ MASS

The mass is obtained from the mass-difference measurement that follows.

VALUE (MeV)DO CUMENT ID2765.9±2.0 OUR FITError includes scale factor of 1.2.

$\Omega_c(2770)^0 - \Omega_c^0$ MASS DIFFERENCE

| VALUE (MeV) | EVTS | DO CUMENT ID | TECN | COMMENT |
|------------------------------|------------|--------------|----------|-----------------------------------------------------------|
| 70.7+0.8 OUR F | ŧТ | | | |
| 70.7 ^{+0.8} OUR A | WERAGE | | | |
| $70.7 \pm 0.9 + 0.1 \\ -0.9$ | 54 ± 9 | SOLOVIEVA | 09 BELL | $\Omega_c^0 \gamma$ in $e^+ e^- \rightarrow \Upsilon(45)$ |
| $70.8\!\pm\!1.0\!\pm\!1.1$ | 105 ± 22 | AUBERT,BE | 061 BABR | $e^+e^-pprox \Upsilon(4S)$ |

$\Omega_c(2770)^0$ DECAY MODES

The $\varOmega_{\mathcal{C}}(2770)^0 - \varOmega_{\mathcal{C}}^0$ mass difference is too small for any strong decay to occur.

| | Mode | Fraction (Γ_i/Γ) |
|----------------|---------------------|------------------------------|
| Γ ₁ | $\Omega_c^0 \gamma$ | presumably 100% |

$\Omega_c(2770)^0$ REFERENCES

| AUBERT.BE | 07 | PRI 97 232001 | E. SUIOVIEVA et al. | (BABAR Collab.) |
|-----------|-----|---------------|---------------------|-----------------|
| AUBERT,BE | 061 | PRL 97 232001 | B. Aubert et al. | (BABAR COHAD.) |
| | | | | |

DOUBLY CHARMED BARYONS (C = +2)

 $\Xi_{cc}^{++} = \mathit{ucc}, \, \Xi_{cc}^{+} = \mathit{dcc}, \, \Omega_{cc}^{+} = \mathit{scc}$



$$I(J^P) = ?(?^?)$$
 Status: *

OMITTED FROM SUMMARY TABLE

This would presumably be an isospin-1/2 particle, a ccu Ξ_{cc}^{++} and a $\operatorname{\mathit{ccd}} \ \Xi_{\operatorname{\mathit{cc}}}^+.$ However, opposed to the evidence cited below, the BABAR experiment has found no evidence for a Ξ_{cc}^+ in a search in $\Lambda_c^+ K^- \pi^+$ and $\Xi_c^0 \pi^+$ modes, and no evidence of a Ξ_{cc}^{++} in $\Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^0 \pi^+ \pi^+$ modes (AUBERT, B 06D). Nor has the BELLE experiment found any evidence for a Ξ_{cc}^+ in the \varLambda_c^+ $K^ \pi^+$ mode (CHISTOV 06).

\varXi_{cc}^+ MASS

| VALUE (MeV) | EVTS | DO CUMENT ID | | TECN | COMMENT |
|----------------|---------|------------------------|------|------|----------------------------------------|
| 3518.9±0.9 OUR | AVERAGE | | | | |
| 3518 ± 3 | 6 | ¹ OCHERASHV | ′I05 | SELX | Σ^- nucleus \approx 600 |
| 3519 ± 1 | 16 | ² MATTSON | 02 | SELX | Σ^{-} nucleus \approx 600 GeV |

Ξ_{cc}^{+} MEAN LIFE

| VALUE (10-15 s) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------------|-----|-------------|----|------|-----------------------------------|
| <33 | 90 | MATTSON | 02 | SELX | Σ^- nucleus, ≈ 600 |

Ξ_{cc}^{+} DECAY MODES

| | Mode |
|-----------------------|-------------------------|
| $\overline{\Gamma_1}$ | $\Lambda_c^+ K^- \pi^+$ |
| Γ_2 | pD^+K^- |

| $\Gamma(\rho D^+ K^-)/\Gamma$ | $(\Lambda_c^+ K^- \pi^+)$ | | | Γ_2/Γ_1 |
|-------------------------------|---------------------------|--------------|------|-------------------------|
| VALUE | EVTS | DO CUMENT ID | TECN | COMMENT |
| 0.36±0.21 | 6 | OCHERASHVI05 | SELX | $\Sigma^ pprox$ 600 GeV |

Ξ⁺_{cc} REFERENCES

| CHISTOV 06 PRL 97 162001 R. Chistov et al. (BELLE Collab.) OCHERASHVI05 PL BEZ8 18 A. Ocherashvill et al. (FNAL SELEX Collab.) MATTSON 02 PRL 89 112001 M. Mattson et al. (FNAL SELEX Collab.) | CHIST OV OCHERASHVI | 06 .05 | PL B628 18 | A. Ocherashvili et al. | (FNAL SELEX Collab.) |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-----------|------------|------------------------|----------------------|
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|-----------|------------|------------------------|----------------------|

 $^{^1}$ OCHERASHVILI 05 claims "an excess of 5.62 events over ... 1.38 ± 0.13 events" for a significance of 4.8 σ in $p\,D^+\,K^-$ events. 2 MATT SON 02 claims "an excess of 15.9 events over an expected background of 6.1 ±0.5 events, a statistical significance of 6.3 $\sigma^{\prime\prime}$ in the $\Lambda_c^+\,K^-\pi^+$ invariant-mass spectrum. The probability that the peak is a fluctuation increases from 1.0×10^{-6} to 1.1×10^{-4} when the number of bins searched is considered.

Scale factor/

BOTTOM BARYONS (B = -1)

$$\Lambda_b^0 = u db$$
, $\Xi_b^0 = u sb$, $\Xi_b^- = d sb$, $\Omega_b^- = s sb$

$$I(J^P) = O(\frac{1}{2}^+)$$
 Status: ***

In the quark model, a \varLambda_b^0 is an isospin-0 udb state. The lowest \varLambda_b^0 ought to have $J^P = 1/2^+$. None of I, J, or P have actually been

AB MASS

$m_{\Lambda_{\nu}^0}$

| VALUE | (MeV) | | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---------|------------------|---------------|----------|-----------------------|---------|-----------|-------------------------------------------------|
| 5619.4 | ± 0.7 | OUR AVE | RAGE | | | | |
| 5619.1 | 9± 0.7 | 0± 0.30 | | ¹ AAIJ | 12E | LHCB | pp at 7 TeV |
| 5619.7 | ± 1.2 | \pm 1.2 | | ² ACOSTA | 06 | CDF | $p\overline{p}$ at 1.96 TeV |
| 5621 | ± 4 | ± 3 | | ³ ABE | 97B | CDF | $p\overline{p}$ at 1.8 TeV |
| 5 6 6 8 | \pm 16 | ± 8 | 4 | ⁴ ABREU | 96 N | DLPH | $e^+ e^- \rightarrow Z$ |
| 5614 | \pm 21 | ± 4 | 4 | ⁴ BUSKULIC | 96L | ALEP | $e^+e^- \rightarrow Z$ |
| • • • | We do n | ot use the fo | ollowing | data for averages, | fits, I | imits, et | C. • • • |
| not se | en | | | ⁵ ABE | 93B | CDF | Sup. by ABE 97B |
| 5 640 | \pm 50 | ± 30 | 16 | ⁶ ALBAJAR | 91 E | UA1 | ρ ρ 630 GeV |
| 5 640 | $^{+100}_{-210}$ | | 52 | BARI | 91 | SFM | $\Lambda_b^0 ightarrow ho D^0 \pi^-$ |
| 5650 | $^{+150}_{-200}$ | | 90 | BARI | 91 | SFM | $\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-$ |
| 1 | ٥ | | | | | | |

 $^{^1\, {\}rm Uses} \,\, \varLambda^0_h \, \to \,\, J/\psi \varLambda \,\, {\rm fully} \,\, {\rm reconstructed} \,\, {\rm decays}.$

$m_{A_{1}^{0}} - m_{B^{0}}$

| VALUE (MeV) DOCUMENT ID TECN COMMENT | |
|-------------------------------------------------------------|--|
| 339.2±1.4±0.1 7 ACOSTA 06 CDF $p\bar{p}$ at 1.96 TeV | |

⁷Uses exclusively reconstructed final states containing $J/\psi \to \mu^+\mu^-$ decays.

$m_{A0} - m_{B+}$

| A _b B+ | | | | | |
|--------------------------------------------|--------------------|------------|---------------------|----------------------|--|
| VALUE (MeV) | DO CUMENT | ID | TECN | COMMENT | |
| 339.71±0.71±0.09 | 8 AAIJ | 12E | LHCB | pp at 7 TeV | |
| ⁸ Uses exclusively reconstructe | ed final states co | ntaining J | $/\psi \rightarrow$ | $\mu^+\mu^-$ decays. | |

1 MEAN LIFE

See b-baryon Admixture section for data on b-baryon mean life average over species of $\emph{b}\text{-}\text{baryon}$ particles.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors.

| VALUE (10 ⁻¹² s) | VTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------------------------|------|--------------------------|-----|------|-----------------------------------|
| 1.425 ± 0.032 OUR EVAI | UATI | ON | | | |
| $1.537\pm0.045\pm0.014$ | | ⁹ AALTONEN | 11 | CDF | p p at 1.96 TeV |
| $1.401\pm0.046\pm0.035$ | 1 | ^{LO} AALTONEN | 10B | CDF | $p\overline{p}$ at 1.96 TeV |
| $1.218 {}^{+ 0.130}_{- 0.115} \pm 0.042$ | | ⁹ ABAZOV | 07s | D0 | $ ho \overline{ ho}$ at 1.96 TeV |
| $1.290 {}^{+ 0.11 9}_{- 0.11 0 - 0.091}$ | 1 | ^{l1} ABAZOV | 07∪ | D0 | $p\overline{p}$ at 1.96 TeV |
| $1.11 \ ^{+ 0.19}_{- 0.18} \ \pm 0.05$ | 1 | ¹² ABREU | 99W | DLPH | $e^+ e^- ightarrow Z$ |
| $1.29 \ ^{+ 0.24}_{- 0.22} \ \pm 0.06$ | 1 | ¹² ACKERSTAFF | 98G | OPAL | $e^+ e^- ightarrow Z$ |
| 1.21 ± 0.11 | 1 | ^{L2} BARATE | 98D | ALEP | $e^+e^- \rightarrow Z$ |
| $1.32 \pm 0.15 \pm 0.07$ | 1 | ^{l3} abe | 96м | CDF | $p\overline{p}$ at 1.8 TeV |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| $1.593 ^{+ 0.083}_{- 0.078} \pm 0.033$ | | ⁹ ABULENCIA | 07A | CDF | Repl. by AALTONEN 11 |
|--------------------------------------------------|----|------------------------|------|------|-------------------------|
| $1.22 \ ^{+ 0.22}_{- 0.18} \ \pm 0.04$ | | ⁹ ABAZOV | 05 € | D0 | Repl. by ABAZOV 07s |
| $1.19 \ ^{+ 0.21}_{- 0.18} \ ^{+ 0.07}_{- 0.08}$ | | ABREU | 96D | DLPH | Repl. by ABREU 99W |
| $1.14 \ ^{+ 0.22}_{- 0.19} \ \pm 0.07$ | 69 | AKERS | 95 K | OPAL | Repl. by ACKERSTAFF 98G |
| $1.02 \ ^{+ 0.23}_{- 0.18} \ \pm 0.06$ | 44 | BUSKULIC | 95 L | ALEP | Repl. by BARATE 98D |

$au_{A_b^0}/ au_{B^0}$ MEAN LIFE RATIO

$au_{A_{\bullet}^0}/ au_{B^0}$ (direct measurements)

ı

I

 Γ_{17} Γ_{18} $p h^-$

 Γ_{19}

 Γ_{20}

 $p\pi$

 Γ_{21} $\Lambda \mu^+ \mu^-$

pK-

| · · | | | |
|------------------------------------------------------|-------------------------------------------------|-----------------|-----------------------------|
| VALUE | DO CUMENT ID | | |
| 1.00 ±0.06 OUR AVERA | | | |
| $1.020 \pm 0.030 \pm 0.008$ | | | $p\overline{p}$ at 1.96 TeV |
| $0.811^{+0.096}_{-0.087}\pm0.034$ | ^{14,15} ABAZOV | 07s D0 | ρ p at 1.96 TeV |
| • • • We do not use the t | following data for aver | ages, fits, lir | mits, etc. • • • |
| 1.041 ± 0.057 | ¹⁶ ABULENCIA | 07A CDF | Repl. by AALTONEN 11 |
| $0.87 \ ^{+ 0.17}_{- 0.14} \ \pm 0.03$ | ¹⁶ ABAZOV | 05c D0 | Repl. by ABAZOV 07s |
| ¹⁴ Uses fully reconstructed | $d \Lambda_b \rightarrow J/\psi \Lambda decays$ | s. | |
| ¹⁵ Uses $B^0 \rightarrow J/\psi K_S^0$ of | lecays for denominator | r. | |
| ¹⁶ Measured mean life rat | io using fully reconstr | ucted decays | 5. |

1 DECAY MODES

The branching fractions B(b-baryon $\rightarrow \Lambda \ell^- \overline{\nu}_\ell$ anything) and B($\Lambda_b^0 \rightarrow$ $\Lambda_{c}^{+}\ell^{-}\overline{
u}_{\ell}$ anything) are not pure measurements because the underlying measured products of these with B($b \rightarrow b$ -baryon) were used to determine $\mathsf{B}(b o b ext{-baryon})$, as described in the note "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, e.g., $\Lambda_b \to \overline{\Lambda}_c$ anything, the values usually are multiplicities, not branching fractions. They can be greater

| | Mode | - 1 | Fraction (Γ_i/Γ) | Confidence level |
|-----------------------|---------------------------------------------------------------------------------------------------------------------|-----|------------------------------------------------------------|------------------|
| $\overline{\Gamma_1}$ | $J/\psi(1S)\Lambda \times B(b \rightarrow \Lambda_b^0)$ | | $(5.8 \pm 0.8) \times 10^{-5}$ | |
| Γ_2 | $pD^0\pi^-$ | | | |
| Γ_3 | $\Lambda_c^+ \pi^-$ | | $(5.7^{+4.0}_{-2.6}) \times 10^{-3}$ | S=1.6 |
| Γ_4 | $\Lambda_c^+ a_1 (1260)^-$ | | seen | |
| Γ_5 | $\Lambda_c^+ \pi^+ \pi^- \pi^-$ | | $(8 \ ^{+5}_{-4} \) \times 10^{-3}$ | S=1.6 |
| Γ ₆ | $\Lambda_{c}(2595)^{+}\pi^{-}$, $\Lambda_{c}(2595)^{+} ightarrow \Lambda_{c}^{+}\pi^{+}\pi^{-}$ | | $(3.7^{+2.8}_{-2.3}) \times 10^{-4}$ | |
| Γ ₇ | $\Lambda_{\mathcal{C}}(2625)^+\pi^-$, $\Lambda_{\mathcal{C}}(2625)^+ ightarrow \Lambda_{\mathcal{C}}^+\pi^+\pi^-$ | | $(3.6^{+2.7}_{-2.1}) \times 10^{-4}$ | |
| Γ ₈ | Σ_c (2455) 0 π^+ π^- , Σ_c^0 $ ightarrow$ Λ_c^+ π^- | | $(6 \begin{array}{c} +5 \\ -4 \end{array}) \times 10^{-4}$ | |
| Γ9 | Σ_c (2455) $^{++}$ $\pi^ \pi^-$, Σ_c^{++} $ ightarrow$ Λ_c^+ π^+ | | $(3.5 + 2.8 \atop -2.3) \times 10^{-4}$ | |
| Γ_{10} | $\Lambda K^{0} 2\pi^{+} 2\pi^{-}$ | | | |
| Γ_{11} | $A_c^+ \ell^- \overline{ u}_\ell$ anything | [a] | (9.8 ± 2.3) % | |
| Γ_{12} | $\Lambda_c^+ \ell^- \overline{ u}_\ell$ | | $(6.5 + \frac{3.2}{-2.5})$ % | S=1.8 |
| Γ_{13} | $\Lambda_c^+ \pi^+ \pi^- \ell^- \overline{ u}_\ell$ | | $(5.6 \pm 3.1) \ \%$ | |
| Γ_{14} | $\Lambda_c(2595)^+ \ell^- \overline{ u}_\ell$ | | $(8 \pm 5) \times 10^{-3}$ | |
| Γ_{15} | $\Lambda_c(2625)^+ \ell^- \overline{ u}_\ell$ | | $(1.4^{+0.9}_{-0.7})$ % | |

[a] Not a pure measurement. See note at head of Λ_h^0 Decay Modes.

[b] < 2.3

 $\times\,10^{-5}$

 $(3.5\pm1.0)\times10^{-6}$

 $(5.5\pm1.4)\times10^{-6}$

 $(1.7 \pm 0.7) \times 10^{-6}$

CL=90%

CL=90%

[b] Here h^- means π^- or K^- .

 $\Sigma_c (2455)^0 \pi^+ \ell^- \overline{\nu}_{\ell}$ $\Sigma_{c}(2455)^{++}\pi^{-}\ell^{-}\overline{\nu}_{\ell}$

²Uses exclusively reconstructed final states containing a $J/\psi
ightarrow \mu^+\mu^-$ decays.

 $^{^3}$ ABE 97B observed 38 events with a background of 18 \pm 1.6 events in the mass range 5.60–5.65 GeV/ c^2 , a significance of > 3.4 standard deviations.

 $^{^4}$ Uses 4 fully reconstructed Λ_b events.

⁵ ABE 93B states that, based on the signal claimed by ALBAJAR 91E, CDF should have found 30 \pm 23 $\Lambda_{~b}^{~0}$ \rightarrow $~J/\psi(1S)\Lambda$ events. Instead, CDF found not more than 2 events.

 $^{^6}$ ALBAJAR 91E claims 16 \pm 5 events above a background of 9 \pm 1 events, a significance of about 5 standard deviations.

 $^{^9}$ Measured mean life using fully reconstructed $\Lambda_b^0\to J/\psi\Lambda$ decays. 10 Measured mean life using fully reconstructed $\Lambda_b^0\to\Lambda_c^+\pi^-$ decays.

 $^{^{11}}$ Measured using semileptonic decays $\Lambda^0_b \to \Lambda^+_c \mu \nu X$ and $\Lambda^+_c \to K^0_S p$.

 $^{^{12}}$ Measured using $\Lambda_{\it C}\,\ell^-$ and $\Lambda\,\ell^+\,\ell^-$

 $^{^{13}}$ Excess $\Lambda_{\it C}\ell^{-}$, decay lengths.

Baryon Particle Listings



CONSTRAINED FIT INFORMATION

An overall fit to 5 branching ratios uses 5 measurements and one constraint to determine 4 parameters. The overall fit has a $\chi^2=3.9$ for 2 degrees of freedom.

The following off-diagonal array elements are the correlation coefficients $\left\langle \delta x_i \delta x_j \right\rangle/(\delta x_i \cdot \delta x_j),$ in percent, from the fit to the branching fractions, $x_i \equiv \Gamma_i/\Gamma_{\rm total}.$ The fit constrains the x_i whose labels appear in this array to sum to one.



| | ∕10 BRAN | ICHING RATI | os | |
|--------------------------------------------------------|-----------------------|---------------------------------------|------------------------|---------------------------------------|
| $\Gamma(J/\psi(1S)\Lambda \times B(b \to \Lambda_b^0)$ |))/Γ _{total} | | | Γ ₁ /Γ |
| VALUE (units 10 ⁻⁵) | EVTS | DO CUMENT ID | TECN | COMMENT |
| 5.8 ± 0.8 OUR AVERAG | | | | |
| $6.01 \pm 0.60 \pm 0.58 \pm 0.28$ | | ¹⁷ ABAZOV | 110 D0 | ρ p at 1.96 TeV |
| $4.7 \pm 2.3 \pm 0.2$ | | ¹⁸ ABE | 97B CDF | ρ p at 1.8 TeV |
| | wing data | for averages, fits | , limits, etc. • | • • |
| $180\pm 60\pm 90$ | 16 | ALBAJAR | 91E UA1 | ρ p at 630 GeV |
| 17 ABAZOV 110 uses B(0 | | | | |
| obtain the result. The (\pm | $0.08) \times 10$ | $^{-4}$ uncertainty o | of this product | is listed as the last |
| uncertainty of the measure | | | | |
| 18 ABE 97B reports [B(Λ_h^0 – | J/ψΛ): | $\times B(b \rightarrow \Lambda_b^0)$ | $/ [B(B^0 \rightarrow$ | $J/\psi K_s^0 \times B(b \rightarrow$ |
| B^0)] = 0.27 ± 0.12 ± 0.05 | | | | |

| • | | 0 | | | | |
|----------------------------------------------|---------------|--------------------|----------|-----------|----------------------------------|-------------------|
| $\Gamma(p D^0 \pi^-)/\Gamma_{\rm total}$ | | | | | | Γ_2/Γ |
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| • • • We do not use | the following | g data for average | es, fits | , limits, | etc. • • • | |
| seen | 52 | BARI | 91 | | $D^0 \rightarrow \kappa^- \pi^+$ | |
| seen | | BASILE | 81 | SFM | $D^0 \rightarrow K^-\pi^+$ | |
| $\Gamma(\Lambda_c^+\pi^-)/\Gamma_{ m total}$ | | | | | | Гз/Г |
| VALUE (units 10 ⁻³) | EVTS | DO CUMENT ID | | TECN | COMMENT | |
| 4 0 | | | _ | | | |

 $B^{0})=(1.74\pm0.08) imes10^{-4}$. Our first error is their experiment error and our second

is the systematic error from using our best value

 19 The result is obtained from $(f_{\rm baryon}/f_{\rm d})~({\rm B}(\Lambda_b^0\to\Lambda_c^+\pi^-)/{\rm B}(\overline{B}^0\to D^+\pi^-))=0.82\pm0.08\pm0.11\pm0.22,$ assuming $f_{\rm baryon}/f_{\rm d}=0.25\pm0.04$ and ${\rm B}(\overline{B}^0\to D^+\pi^-)=(2.68\pm0.13)\times10^{-3}.$

| $\Gamma(\Lambda_c^+ a_1(1260)^-$ | -)/Γ _{total} | | | | Γ ₄ /Γ |
|----------------------------------|-----------------------|--------------|-----|-------|---------------------------------------------------------------------------------------------------|
| VALUE | EVTS | DO CUMENT ID | | TE CN | COMMENT |
| seen | 1 | ABREU | 96N | DLPH | $\Lambda_c^+ \rightarrow p K^- \pi^+, a_1^- \rightarrow 0 \pi^- \rightarrow \pi^+ \pi^- \pi^-$ |

8⁺⁵₋₄ **OUR FIT** Error includes scale factor of 1.6.

 $4.4 \pm 1.7 + 0.6$

17±4 $^{+11}_{-8}$ 20 AALTONEN 12A CDF $p\overline{p}$ at 1.96 TeV

•• We do not use the following data for averages, fits, limits, etc. •• • seen 90 BARI 91 SFM $\Lambda_c^+ \to p \, K^- \pi^+$

 20 AALTONEN 12A reports $[\Gamma(\Lambda_b^0\to\Lambda_c^+\pi^+\pi^-\pi^-)/\Gamma_{\rm total}]$ / $[B(\Lambda_b^0\to\Lambda_c^+\pi^-)]=3.04\pm0.33^{+0.70}_{-0.55}$ which we multiply by our best value $B(\Lambda_b^0\to\Lambda_c^+\pi^-)=(5.7^{+4.0}_{-2.6})\times10^{-3}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\Lambda_c^+\pi^+\pi^-\pi^-)/\Gamma(\Lambda_c^+\pi^-)$ | ·) | | | Γ_5/Γ_3 |
|---------------------------------------------------------------|---------------------------------------------------|------------------------|--------------------------|---------------------|
| VALUE | DO CUMENT ID | TECN | COMMENT | |
| 1.46±0.22 OUR FIT Error in | cludes scale factor of 1. | 1. | | |
| $1.43 \pm 0.16 \pm 0.13$ | AAIJ 1 | 1E LHCB | pp at 7 TeV | |
| $\Gamma(\Lambda_c(2595)^+\pi^-, \Lambda_c(2595)^+$ | $)^+ \rightarrow \Lambda_c^+ \pi^+ \pi^-)/\Gamma$ | (Λ <mark>+</mark> π+ π | - π -) COMMENT | Γ_6/Γ_5 |

11E LHCB pp at 7 TeV

AAIJ

| VALUE (units 10^{-2}) | DO CUMENT | ID | TECN | COMMENT | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|----------------------------|--------------|---------------------|--------------------|
| 4.3±1.5±0.4 | AAIJ | 11E | LHCB | pp at 7 TeV | |
| $\Gamma(Σ_c(2455)^0\pi^+\pi^-,Σ_c^0$ | $\rightarrow \Lambda_c^+ \pi^-)/\Gamma(\Lambda_c^+$ | + π+π- | π^-) | | Г8/Г |
| VALUE (units 10^{-2}) | DO CUMENT | ID | TECN | COMMENT | |
| $7.4 \pm 2.4 \pm 1.2$ | AAIJ | 11E | LHCB | pp at 7 TeV | |
| $\Gamma(\Sigma_c(2455)^{++}\pi^-\pi^-$, Σ | $C_c^{++} \rightarrow \Lambda_c^+ \pi^+)/1$ | $\Gamma(\Lambda_c^+\pi^-)$ | + π- π | -) | ب۲) و۲ |
| | | | | | |
| VALUE (units 10^{-2}) | <u>DO CUMENT</u> | ID | TECN | COMMENT | |
| • | <u>DOCUMENT</u> AAIJ | | | COMMENT pp at 7 TeV | |
| VALUE (units 10 ⁻²) 4.2±1.8±0.7 | | | | | Γ ₁₀ /Ι |
| VALUE (units 10 ⁻²) | AAIJ | 11E | LHCB | pp at 7 TeV | Γ ₁₀ /Ι |
| $\begin{array}{l} \frac{\text{MALUE (units }10^{-2})}{4.2\pm1.8\pm0.7} \\ \Gamma \left(\Lambda \text{K}^{0} 2\pi^{+} 2\pi^{-} \right) / \Gamma_{\text{total}} \end{array}$ | AAIJ <u>DOCUMENT</u> | 11E | LHCB TECN | pp at 7 TeV | Γ ₁₀ /Ι |

21 See the footnote to the ARENTON 86 mass value

 $\Gamma(\Lambda_c^+\ell^-\overline{
u}_\ell$ anything)/ Γ_{total} Γ_{11}/Γ The values and averages in this section serve only to show what values result if one

The values and averages in this section serve only to show what values result if one assumes our $B(b \to b ext{-baryon})$. They cannot be thought of as measurements since the underlying product branching fractions were also used to determine $B(b \to b ext{-b-baryon})$ as described in the note on "Production and Decay of $b ext{-Flavored Hadrons."}$ WE DOCUMENT ID TECN COMMENT

| 0.098±0.023 OUR AVER | AGE | | | | |
|-----------------------------|--------|------------------------|-------------|---------|---------------------------------------|
| $0.092 \pm 0.017 \pm 0.016$ | | ²² BARATE | 98D | ALEP | $e^+e^- \rightarrow Z$ |
| $0.13 \pm 0.04 \pm 0.02$ | 29 | ²³ ABREU | 95 s | DLPH | $e^+e^- \rightarrow Z$ |
| • • • We do not use the | follow | ing data for averag | es, fits, | limits, | etc. • • • |
| $0.081 \pm 0.020 \pm 0.014$ | 55 | ²⁴ BUSKULIC | 95 L | ALEP | Repl. by BARATE 98D |
| $0.16 \pm 0.06 \pm 0.03$ | 21 | ²⁵ BUSKULIC | 92E | ALEP | $\Lambda_c^+ \rightarrow p K^- \pi^+$ |

 22 BARATE 98D reports $[\Gamma(\Lambda_D^0 \to \Lambda_C^+ \ell^- \overline{\nu}_\ell \, {\rm anything}) / \Gamma_{\rm total}] \times [B(\overline{b} \to b{\rm -baryon})] = 0.0086 \pm 0.0007 \pm 0.0014$ which we divide by our best value $B(\overline{b} \to b{\rm -baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Measured using $\Lambda_C \ell^-$ and $\Lambda \ell^+ \ell^-$.

²³ABREU 95s reports $[\Gamma(\Lambda^0_b \to \Lambda^+_c \ell^- \overline{\nu}_\ell \text{anything})/\Gamma_{\text{total}}] \times [B(\overline{b} \to b\text{-baryon})] = 0.0118 \pm 0.0026^{+0.0031}_{-0.0021}$ which we divide by our best value $B(\overline{b} \to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 24 BUSKULIC 95L reports $\left[\Gamma(\Lambda_b^0\to\Lambda_c^+\ell^-\overline{\nu}_\ell\text{anything})/\Gamma_{\text{total}}\right]\times\left[B(\overline{b}\to b\text{-baryon})\right] = 0.00755\pm0.0014\pm0.0012$ which we divide by our best value $B(\overline{b}\to b\text{-baryon})=(9.3\pm1.6)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

²⁵ BUSKULIC 92E reports $[\Gamma(\Lambda_{\overline{b}}^0 \to \Lambda_{\overline{c}}^+ \ell^- \overline{\nu}_\ell anything)/\Gamma_{total}] \times [B(\overline{b} \to b\text{-baryon})] = 0.015 \pm 0.0035 \pm 0.0045$ which we divide by our best value $B(\overline{b} \to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Superseded by BUSKULIC 95L.

 $\Gamma(\Lambda_c^+\ell^-\overline{\nu}_\ell)/\Gamma_{\text{total}}$ VALUEDOCUMENT ID

TECH

COMMENT

DOCUMENT ID

TECH

COMMENT

 $0.065 \stackrel{+}{-} \stackrel{0.032}{0.025}$ OUR FIT Error includes scale factor of 1.8.

0.050 $^{+0.011}_{-0.008} ^{+0.016}_{-0.002}$ 26 ABDALLAH 04A DLPH $e^+e^-
ightarrow z^0$

 26 Derived from a combined likelihood and event rate fit to the distribution of the Isgur-Wise variable and using HQET. The slope of the form factor is measured to be $\rho^2=2.03\pm0.46^{+0.72}_{-1.00}$.

 $\Gamma(\Lambda_c^+\ell^-\overline{\nu}_\ell)/\Gamma(\Lambda_c^+\pi^-)$ NALUE

DOCUMENT ID

TECN
COMMENT

11 $\frac{+4}{5}$ OUR FIT Error includes scale factor of 1.2.

16.6±3.0+2.8 AALTONEN 09E CDF $p\overline{p}$ at 1.96 TeV

 $\frac{\Gamma(\Lambda_c^+\pi^+\pi^-\ell^-\overline{\nu}_\ell)/\Gamma_{total}}{\frac{VALUE}{0.056} + 0.031} \qquad \frac{DOCUMENT ID}{27} \qquad \frac{TECN}{ABDALLAH} \qquad \frac{COMMENT}{24} \qquad \frac{COMMENT}{27} \qquad \frac{1}{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}/\Gamma_{13}$

²⁷ Derived from the fraction of $\Gamma(\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell)$ / ($\Gamma(\Lambda_b^0 \to \Lambda_c^+ \ell^- \overline{\nu}_\ell)$ + $\Gamma(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \ell^- \overline{\nu}_\ell)$) = 0.47 $^+$ 0.10 $^+$ 0.08 $^-$ 0.08.

 $\frac{\Gamma(\Lambda_c^+\ell^-\nu_\ell)/\left[\Gamma(\Lambda_c^+\ell^-\nu_\ell) + \Gamma(\Lambda_c^+\pi^+\pi^-\ell^-\nu_\ell)\right]}{\frac{DOCUMENT\ ID}{0.47 + 0.19 + 0.06}} \underbrace{\frac{\Gamma_{12}/(\Gamma_{12} + \Gamma_{13})}{ECN}}_{ABDALLAH} \underbrace{\frac{COMMENT}{0.19}}_{OLPH} \underbrace{\frac{COMMENT}{0.19}}_{e^+e^- \rightarrow Z^0}$

1.3±2.1±0.4

Baryon Particle Listings

| $\Gamma(\Lambda_c(2625)^+\ell^-\overline{\nu}_\ell)/\Gamma(N_c)$ | $\Lambda_c^+ \ell^- \overline{\nu}_\ell$) DOCUMENT ID TECN | Γ ₁₅ /Γ ₁₂ <i>COMMENT</i> | $B(\Lambda_b \to \Lambda \mu^+ \mu^-) (0.0 < \text{VALUE (units } 10^{-7})$ | q ² < 4.3 G досиме |
|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| $0.210 \pm 0.042 ^{+\ 0.071}_{-\ 0.050}$ | AALTONEN 09E CDF | ρ <u>ρ</u> at 1.96 TeV | 2.7±2.5±0.9 | AALTO |
| $\left[\frac{1}{2}\Gamma(\Sigma_c(2455)^0\pi^+\ell^-\overline{\nu}\right]$ | Γ_{ℓ}) + $\frac{1}{2}\Gamma\left(\Sigma_{c}(2455)^{++}\pi^{-}\ell^{-}\overline{\nu}_{\ell}\right)$ | $\frac{1}{2} \left[\frac{\Lambda_c^+ \ell^- \overline{\nu}_\ell}{\Gamma_{16} + \frac{1}{2} \Gamma_{17}} \right]$ | A_{CP} is defined as | CP VIO |
| VALUE | DOCUMENT ID TECN | | | $B(\Lambda_{h}^{0})$ |
| $0.054 \pm 0.022 + 0.021 \\ -0.018$ | AALTONEN 09E CDF | $p\overline{p}$ at 1.96 TeV | A | $\Lambda_{CP} = \frac{B(\Lambda_b^0)}{B(\Lambda_b^0)}$ |
| $\Gamma(ph^-)/\Gamma_{\text{total}}$ | | Γ ₁₈ /Γ | the <i>CP-</i> violation asym | nmetry of exclu |
| VALUE CL <2.3 × 10 ⁻⁵ 90 | | <u>COMMENT</u> p σ at 1.96 TeV | $A_{CP}(\Lambda_b 	o p\pi^-)$ | DO CUM |
| ²⁸ Assumes $f_A / f_d = 0.25$ | , and equal momentum distribution t | for Λ _b and B mesons. | 0.03±0.17±0.05 | . <u>DOCUME</u> AALTO |
| $\Gamma(p\pi^-)/\Gamma_{\rm total}$ | | Γ ₁₉ /Γ | $A_{CP}(\Lambda_b \rightarrow pK^-)$ | |
| VALUE (units 10 ⁻⁶) CL 3.5 ± 0.8 ± 0.6 | | <u>COMMENT</u> ρ p at 1.96 TeV | <u>VALUE</u> 0.37±0.17±0.03 | . <u>DOCUME</u> AALTO |
| | ollowing data for averages, fits, limits, | , etc. • • • | | 40 DEEL |
| <50 90 | | $e^+e^- \rightarrow Z$ | | Ab REF |
| b-baryon)] / $[B(\overline{b} \rightarrow by \text{ our best values } B(B = (9.3 \pm 1.6) \times 10^{-2},$ experiment's error and o | is $[\Gamma(\Lambda_0^0 \to p\pi^-)/\Gamma_{\rm total}] / [B(B^0 B^0)] = 0.042 \pm 0.007 \pm 0.006$ where $(B^0 \to K^+\pi^-) = (1.94 \pm 0.06) \times B(\overline{D} \to B^0) = (40.1 \pm 0.8) \times 10^{-1}$ ur second error is the systematic error is PDG 96 production fractions for B^0 | hich we multiply or divide 10^{-5} , $B(\overline{b} \rightarrow b\text{-baryon})$ $^{-2}$. Our first error is their from using our best values. | AAIJ 12E PL B708 241 AALTONEN 12A PR D85 09200 AAIJ 11E PR D84 09200 AALTONEN 11A PRL 107 2018 AALTONEN 11A PRL 107 2018 AALTONEN 11A PRL 106 1818 ABAZOV 11O PR D84 03110 AALTONEN 10B PR L 104 10318 AALTONEN 09C PRL 103 10318 AALTONEN 09C PRL 103 703 ABAZOV 75 PRL 99 11200 ABAZOV 75 PRL 99 11200 | 01 R. Aa 04 T. Aa 02 T. Aa 02 T. Aa 02 T. Aa 02 V.M. 02 T. Aa 01 T. Aa 01 T. Aa |
| • • • | | COMMENT | ABAZOV 07U PRL 99 18200 ABULENCIA 07A PRL 98 12200 | V.M. |
| 5.5±1.0±1.0 | 31 AALTONEN 09C CDF ollowing data for averages, fits, limits, | $p\overline{p}$ at 1.96 TeV | ABULENCIA 07B PRL 98 12200 ACOSTA 06 PRL 96 20200 | 1 D. Ac |
| <360 90 | | $e^+e^- \rightarrow Z$ | ABAZOV 05C PRL 94 10200 ACOSTA 05O PR D72 05110 | 04R D. Ac |
| < 50 90 | 2.2 | $e^+ e^- \rightarrow Z$ | ABDALLAH 04A PL B585 63 ACOSTA 02G PR D66 11200 ABREU 99W EPJ C10 185 | J. Abi D. Ac P. Ab |
| by our best values B(B = $(9.3 \pm 1.6) \times 10^{-2}$, experiment's error and o 32 ADAM 96D assumes f_B 6 | $\begin{array}{lll} B^0)] = 0.066 \pm 0.009 \pm 0.008 \text{ wi} \\ 0 \to K^+\pi^-) = (1.94 \pm 0.06) \times \\ B(\bar{b} \to B^0) = (40.1 \pm 0.8) \times 10^- \\ \text{ur second error is the systematic error} \\ 0 = f_{B^-} = 0.39 \text{ and } f_{B_S} = 0.12. \\ \text{s PDG 96 production fractions for } B^0 \end{array}$ | 10^{-5} , B($\overline{b} \rightarrow b$ -baryon) $^{-2}$. Our first error is their from using our best values. | ABE 97B PR D55 1142 ABE 96M PRL 77 1439 ABREU 96D ZPHY C71 19 ABREU 96D ZPHY C71 29 ABREU 96D ZPHY C72 20 BUSKULIC 96L PL 8380 442 BUSKULIC 96V PL B364 471 PDG 96 PR D54 1 ABREU 95S ZPHY C68 37: | P. Abi 7 W. Ad D. Bu D. Bu R. M. 5 P. Abi |
| $\Gamma(\Lambda\mu^+\mu^-)/\Gamma_{ m total}$ | | Γ ₂₁ /Γ | AKERS 95K PL B353 402 BUSKULIC 95L PL B357 685 ABE 93B PR D47 R2639 | R. Akı D. Bu 9 F. Abı |
| VALUE (units 10 ⁻⁷) 17.3±4.2±5.5 | DOCUMENT ID TECN AALTONEN 11AI CDF | COMMENT pp at 1.96 TeV | ABE 93B PR D47 R2639 BUSKULIC 92E PL B294 145 ALBAJAR 91E PL B273 540 | D. Bu C. Alt |
| | AALTONEN TIAT COT | | BARI 91 NC 104A 1787 ARENTON 86 NP B274 707 | 7 G. Ba M.W. |
| $\Gamma(\Lambda\gamma)/\Gamma_{	ext{total}}$ VALUE CL | L% DOCUMENT ID TECN | Γ ₂₂ /Γ | BASILE 81 LNC 31 97 | M. Ba |
| <1.3 × 10 ⁻³ 90 | ACOSTA 02G CDF | $p\overline{p}$ at 1.8 TeV | \sum_{i} | |
| PARTIAL BR $B(\Lambda_b \rightarrow \Lambda \mu^+ \mu^-) (q^2)$ $VALUE (units 10^{-7})$ $0.15 \pm 2.01 \pm 0.05$ | ANCHING FRACTIONS IN Λ_b < 2.0 GeV ² /c ²) DOCUMENT ID AALTONEN 11AI CDF | | In the quark model state. The lowest Σ P have actually been | _b ought to h |
| $B(\Lambda_b \to \Lambda \mu^+ \mu^-) \ (2.0$ | | | | Σ_b l |
| VALUE (units 10 ⁻⁷) 1.8±1.7±0.6 | | <u>СОММЕНТ</u> р р at 1.96 TeV | Σ ⁺ _b MASS VALUE (MeV) | DO CUMENT |
| $B(\Lambda_b \to \Lambda \mu^+ \mu^-) (4.3$ | $3 < q^2 < 8.68 \text{ GeV}^2/c^2$ | | $5811.3 + 0.9 \pm 1.7$ | 1 AALTONE |
| VALUE (units 10 ⁻⁷) | DOCUMENT ID TECN | | • • • We do not use the follow | wing data for |
| -0.2±1.6±0.1 | AALTONEN 11AI CDF | ρ ρ at 1.96 TeV | $5807.8 + 2.0 \pm 1.7$ | ² AALTONE! |
| $B(\Lambda_b 	o \Lambda \mu^+ \mu^-) \ (10.$ VALUE (units 10^{-7}) | .09 < q ² < 12.86 GeV ² /c ²) | COMMENT | Σ_b^- MASS | |
| 3.0±1.5±1.0 | AALTONEN 11AI CDF | $p\overline{p}$ at 1.96 TeV | VALUE (MeV) | <u>DO CUMENT</u> |
| $B(\Lambda_b\to\Lambda\mu^+\mu^-)\ (14.$ | $1.18 < q^2 < 16.0 \text{ GeV}^2/c^2$ | | $5815.5 + 0.6 \pm 1.7$ • • • We do not use the follow | AALTONE! Wing data for: |
| VALUE (units 10 ⁻⁷) 1.0±0.7±0.3 | DOCUMENT ID TECN AALTONEN 11AI CDF | <u>COMMENT</u> ρ p at 1.96 TeV | 5815.2±1.0±1.7 | ² AALTONE! |
| $B(\Lambda_b \to \Lambda \mu^+ \mu^-) (16.$ | | | $m_{\Sigma_b^+} - m_{\Sigma_b^-}$ | |
| $\frac{D(N_0 \rightarrow N\mu^+\mu^-)}{VALUE \text{ (units } 10^{-7}\text{)}}$ | | COMMENT | VALUE (MeV) | <u>DO CUME</u> |
| 7.0±1.9±2.2 | AALTONEN 11AI CDF | p p̄ at 1.96 TeV | $-4.2^{+1.1}_{-1.0}\pm0.1$ | ¹ AALTO |
| $B(\Lambda_b \to \Lambda \mu^+ \mu^-) (1.0$ | • • | | 1 Measured using the fully re | |
| VALUE (units 10 ⁻⁷) | DO CUMENT ID TECN | COMMENT | 2 Observed four $^0_b\pi^\pm$ reson | rances in the f |

AALTONEN 11AI $\overline{\text{CDF}}$ \overline{p} at 1.96 TeV

 ${\rm GeV^2/c^2})$ MENT ID MENT ID TECN COMMENT
ONEN 11AI CDF $p\overline{p}$ at 1.96 TeV

OLATION

$$A_{CP} = \frac{B(\Lambda_b^0 \to f) - B(\overline{\Lambda}_b^0 \to \overline{f})}{B(\Lambda_b^0 \to f) + B(\overline{\Lambda}_b^0 \to \overline{f})},$$

clusive ${\it \Lambda}_{b}^{\,0}$ and $\overline{\it \Lambda}_{b}^{\,0}$ decay.

| $A_{CP}(\Lambda_b \rightarrow p\pi^-)$ VALUE | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------|-------------|-----|------|-----------------------------------|
| 0.03±0.17±0.05 | AALTONEN | 11N | CDF | <i>p</i> p at 1.96 TeV |
| $A_{CP}(\Lambda_b \to pK^-)$ VALUE | DOCUMENT ID | | TECN | COMMENT |
| 0.37±0.17±0.03 | AALTONEN | 11N | CDF | p p at 1.96 TeV |

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| AALI | 11E | PR D84 092001 | R. Aaij et al. | (LHCb Collab.) |
| AALTONEN | 11 | PRL 106 121804 | T. Aaltonen et al. | (CDF Collab.) |
| AALTONEN | 11AI | PRL 107 201802 | T. Aaltonen et al. | (CDF Collab.) |
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| ABREU | 96 D 96 N | ZPHY C71 199 PL B374 351 | P. Abreu et al. | (DELPHI Collab.) |
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| PDG | 96 | PR D54 1 | R. M. Barnett et al. | (DELDIII C-II-L) |
| ABREU | 95S | ZPHY C68 375 | P. Abreu et al. | (DELPHI Collab.) |
| AKERS | 95 K | PL B353 402 | R. Akers et al. | (OPAL Collab.) |
| BUS KULIC | 95 L | PL B357 685 | D. Buskulic et al. | (ALEPH Collab.) |
| ABE | 93 B | PR D47 R2639 | F. Abe et al. | (CDF Collab.) |
| BUS KULIC | 92 E | PL B294 145 | D. Buskulic et al. | (ALEPH Collab.) |
| ALBAJAR | 91E | PL B273 540 | C. Albajar et al. | (UA1 Collab.) |
| BARI | 91 | NC 104A 1787 | G. Bari et al. | (CERN R422 Collab.) |
| ARENTON | 86 | NP B274 707 | M.W. Arenton et al. | (ARIZ, NDAM, VAND) |
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 $I(J^P)=1(\frac{1}{2}^+)$ Status: *** $I,\ J,\ P$ need confirmation. Σ_b^- are an isotriplet (*uub*, *udb*, *ddb*) have $J^P=1/2^+$. None of $I,\ J,\$ or

MACC

| | Σ_b MA | .SS | | |
|-----------------------------------|--------------------------------------|------------------|------------|------------------------------------------------------|
| Σ_b^+ MASS | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $5811.3 + 0.9 \pm 1.7$ | $^{ m 1}$ aaltonen | 12F | CDF | ρ p at 1.96 TeV |
| • • • We do not use th | e following data for ave | rages, | fits, lim | nits, etc. • • • |
| $5807.8 + 2.0 \pm 1.7$ | ² AALTONEN | 07κ | CDF | Repl. by AALTONEN 12F |
| Σ_b^- MASS | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| 5815.5 ^{+ 0.6} ± 1.7 | $^{ m 1}$ AALTONEN | 12F | CDF | $p\overline{p}$ at 1.96 TeV |
| • • • We do not use th | e following data for aver | rages, | fits, lim | nits, etc. • • • |
| $5815.2 \pm 1.0 \pm 1.7$ | ² AALTONEN | 07K | CDF | Repl. by AALTONEN 12F |
| $m_{\Sigma_h^+} - m_{\Sigma_h^-}$ | | | | |
| VALUE (MeV.) | <u>DO CUMENT</u> | ID | TE | CN COMMENT |
| $-4.2^{+1.1}_{-1.0}\pm0.1$ | $^{ m 1}$ aaltone | N 1 | L2F CE | DF $p\overline{p}$ at 1.96 TeV |
| ¹ Measured using the | fully reconstructed Λ ⁰ - | → Λ ⁺ | π^- an | d $\Lambda_{-}^{+} \rightarrow K^{-}\pi^{+}$ decays. |

- fully reconstructed decay mode $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, where $\Lambda_c^+ \rightarrow p K^- \pi^+$.

Baryon Particle Listings

 $\Sigma_b, \Sigma_b^*, \Xi_b^0, \Xi_b^-$

| | Σ_b WIDTH | | | | | |
|-------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|--|--|--|--|--|
| Σ ⁺ _b WIDTH VALUE (MeV) | DOCUMENT ID TECN COMMENT | | | | | |
| $9.7 + 3.8 + 1.2 \\ -2.8 - 1.1$ | ³ AALTONEN 12F CDF $p\overline{p}$ at 1.96 TeV | | | | | |
| Σ _b WIDTH VALUE (MeV) | DOCUMENT ID TECN COMMENT | | | | | |
| $4.9^{+3.1}_{-2.1}\pm1.1$ | 3 AALTONEN 12F CDF ρρat 1.96 TeV | | | | | |
| 3 Measured using the fully reconstructed $\Lambda^0_b \to \Lambda^+_c \pi^-$ and $\Lambda^+_c \to K^- \pi^+$ decays. | | | | | | |
| | Σ. DECAY MODES | | | | | |

| Σ_h | DE | CAY | MO | DES |
|------------|----|-----|----|-----|

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------|------------------------------|
| $\overline{\Gamma_1}$ | $arLambda_b^0\pi$ | dominant |

Σ_b BRANCHING RATIOS

| $\Gamma(\Lambda_b^0\pi)/\Gamma_{\text{total}}$ VALUE dominant | <u>DOCUMENT ID</u> AALTONEN | 07ĸ | TECN CDF | <u>СОММЕНТ</u> р р at 1.96 TeV | Γ ₁ /Γ | | |
|----------------------------------------------------------------|--------------------------------|-----|-------------|----------------------------------------------|-------------------|--|--|
| Σ _k REFERENCES | | | | | | | |

| | |
|--|------|
| | |
| | |

| PR D85 092011 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |
|-----------------|---------------------------|---------------|
| K PRL 99 202001 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |
| | | |



$$I(J^P) = 1(\frac{3}{2}^+)$$
 Status: ***

I. J. P need confirmation.

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Σ_b^* MASS

| Σ_b^{*+} MASS | | | | |
|-----------------------------------------|----------------------------------------|------|-------------------|-----------------------------|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $5832.1 \pm 0.7 + 1.7 \\ -1.8$ | $^{ m 1}$ aaltonen | 12F | CDF | $p\overline{p}$ at 1.96 TeV |
| Σ_b^{*-} MASS | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $5835.1 \pm 0.6 ^{+1.7}_{-1.8}$ | $^{ m 1}$ aaltonen | 12F | CDF | $p\overline{p}$ at 1.96 TeV |
| $m_{\Sigma_b^{*+}}-m_{\Sigma_b^{*-}}$ | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT |
| $-3.0^{+1.0}_{-0.9}\pm0.1$ | $^{ m 1}$ aaltonen | 12F | CDF | $p\overline{p}$ at 1.96 TeV |
| $^{ m 1}$ Measured using the fully reco | nstructed $\Lambda_b^0 	o \Lambda_c^+$ | + π- | and Λ_c^+ | $K^-\pi^+$ decays. |

Σ* WIDTH

| Σ _b ' WIDTH | | | | | |
|----------------------------------|-----------------------|-----|------|-----------------------------------|-----|
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
| $11.5 + 2.7 + 1.0 \\ -2.2 - 1.5$ | ² AALTONEN | L2F | CDF | $p\overline{p}$ at 1.96 TeV | |
| Σ_b^{*-} WIDTH | | | | | |
| VALUE (MeV) | DO CUMENT ID | | TECN | COMMENT | |
| $7.5 + 2.2 + 0.9 \\ -1.8 - 1.4$ | ² AALTONEN | L2F | CDF | $\rho \overline{ ho}$ at 1.96 TeV | |
| 2 | 0 1 | | | | - 1 |

| ² Measured using the full | v reconstructed AO | $\rightarrow \Lambda^{+}\pi^{-}$ | and $\Lambda^+ \rightarrow$ | $\kappa - \pi^+$ | decav |
|--------------------------------------|--------------------|----------------------------------|-----------------------------|------------------|-------|
| | | | | | |

| $m_{\Sigma_b^*}-m_{\Sigma_b}$ | | | | |
|------------------------------------|---------------------------|------|-----------------------------|--|
| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT | |
| $21.2^{+2.0}_{-1.9}^{+0.4}_{-0.3}$ | ³ AALTONEN 07ĸ | CDF | $p\overline{p}$ at 1.96 TeV | |

 $^{^3}$ Observed four $\varLambda_b^0\,\pi^\pm$ resonances in the fully reconstructed decay mode $\varLambda_b^0\,\to\,\varLambda_c^+\pi^-$, where $\Lambda_c^+ \to p K^- \pi^+$. Assumes $m_{\Sigma_b^{*+}} - m_{\Sigma_b^+} = m_{\Sigma_b^{*-}} - m_{\Sigma_b^-}$

Σ_b^* DECAY MODES

| | Mode | Fraction (Γ_i/Γ) |
|-----------------------|-------------------|------------------------------|
| $\overline{\Gamma_1}$ | $\Lambda_b^0 \pi$ | dominant |

Σ* BRANCHING RATIOS

| $\Gamma(\Lambda_b^0\pi)/\Gamma_{ m total}$ | | | | | Γ ₁ /Ι |
|--------------------------------------------|--------------|-----|------|-----------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| dominant | AALTONEN | 07ĸ | CDF | $p\overline{p}$ at 1.96 TeV | |

Σ* REFERENCES

| AALTONEN | 12 F | PR D85 092011 | T. Aaltonen et al. | (CDF Collab.) |
|----------|------|---------------|---------------------------|---------------|
| AALTONEN | 07 K | PRL 99 202001 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |



$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$$
 Status: *** I, J, P need confirmation.

In the quark model, Ξ_b^0 and Ξ_b^- are an isodoublet (*usb*, *dsb*) state; the lowest Ξ_b^0 and Ξ_b^- ought to have $J^P=1/2^+$. None of I, J, or P have actually been measured.

Ξ_b MASSES

Ξ_b^- MASS

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|-----------------------------------------------------------|-------------------------------|---------------------------|---------------------------------|
| 5791.1 ± 2.2 OUR AVERAGE | Includes data fror | m the datab | lock that follows this one. |
| | ¹ AALTONEN 1: | | |
| | ² AALTONEN 0 | | |
| 5774 ±11 ±15 | ³ ABAZOV 0' | 7ĸ D0 | $p\overline{p}$ at 1.96 TeV |
| • • • We do not use the follow | wing data for avera | ges, fits, lim | its, etc. • • • |
| $5792.9 \pm\ 2.5 \pm\ 1.7$ | ⁴ AALTONEN 0 | 7A CDF | Repl. by AALTONEN 09AP |
| ¹ Measured in $\Xi_b^- \to \Xi_c^0 \pi$ | - with 25.8 + 5.5 c | andidates. | |
| ² Measured in $\Xi_b^- \to J/\psi$ | ≡ [−] decays with 66 | $^{+14}_{-9}$ candida | ates. |
| ³ Observed in $\Xi_b^2 \rightarrow J/\psi \Xi$ | e decays with 15. | $2 \pm 4.4 + 1.5 \\ -0.4$ | g candidates, a significance of |
| 5.5 sigma. | | | • |

Ξ_b MASS

<u>VALUE (MeV)</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>
The data in this block is included in the average printed for a previous datablock.

 4 Observed in $\Xi_b^ \to$ $J/\psi\,\Xi^-$ decays with 17.5 \pm 4.3 candidates, a significance of 7.7

⁵ AALTONEN 11x CDF $p\overline{p}$ at 1.96 TeV 5 Measured in $\Xi_b^0 \rightarrow ~\Xi_c^+ \, \pi^-$ with $25.3 {+5.6 \atop -5.4}$ candidates.

$m_{\Xi_{h}^{-}} - m_{\Xi_{h}^{0}}$

| VALUE (MeV) | DO CUMENT ID | TECN | COMMENT |
|---------------|----------------|------|----------------------------|
| 3.1 ±5.6 ±1.3 | 6 AALTONEN 113 | CDF | p p at 1.96 TeV |

 $^{^6}$ Derived from measurements in $\Xi_b^0\to\Xi_c^+\pi^-$ and $\Xi_b^-\to J/\psi\,\Xi^-$ from AALTONEN 09AP taking correlated systematic uncertainties into account.

Ξ- MEAN LIFE

| VALUE (10 ⁻¹² s) | DOCUMENT ID | TECN | COMMENT |
|---------------------------------|-----------------------|----------|-----------------------------|
| $1.56^{+0.27}_{-0.25}{\pm}0.02$ | ⁷ AALTONEN | 09AP CDF | $p\overline{p}$ at 1.96 TeV |

 $^{^7}$ Measured in $\Xi_b^- \to ~J/\psi\,\Xi^-$ decays with 66 $_-^{+\,14}$ candidates.

Ξ_b MEAN LIFE

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and

asymmetric lifetime errors. <u>VALUE (10⁻¹² s)</u> <u>EVTS</u> DOCUMENT ID TECN COMMENT

$1.49^{+0.19}_{-0.18}$ OUR EVALUATION

| $1.56^{+0.27}_{-0.25}\pm0.02$ | ⁸ AALTONEN | 09AP CDF | $p\overline{p}$ at 1.96 TeV |
|--------------------------------------------------|------------------------|------------------|-----------------------------|
| $1.48^{+0.40}_{-0.31}{\pm}0.12$ | ⁹ ABDALLAH | 05c DLPH | $e^+e^- \to ~Z^0$ |
| $1.35 {}^{+ 0.37}_{- 0.28} {}^{+ 0.15}_{- 0.17}$ | ¹⁰ BUSKULIC | 96T ALEP | $e^+e^- ightarrow Z$ |
| | lowing data for averag | es, fits, limits | . etc. • • • |

8 ¹¹ ABREU 95 V DLPH Repl. by ABDALLAH 05 c

- 8 Measured in $\Xi_b^- \to ~J/\psi\,\Xi^-$ decays with 66 $^{+\,14}_{-\,9}$ candidates. $^9_{-}$ Used the decay length of Ξ^- accompanied by a lepton of the same sign.
- 10 Excess $\Xi^-\ell^-$, impact parameters. 11 Excess $\Xi^-\ell^-$, decay lengths.

Eb DECAY MODES

| | Mode | Fraction (Γ_i/Γ) | Scale factor |
|-----------------------|------------------------------------------------------------------------------------------------------------------|-----------------------------------------|--------------|
| $\overline{\Gamma_1}$ | $\overline{\Xi}_b \to \overline{\Xi}^- \ell^- \overline{\nu}_\ell X \times B(\overline{b} \to \overline{\Xi}_b)$ | $(3.9 \pm 1.2) \times 10^{-4}$ | 1.4 |
| Γ_2 | $\overline{\Xi}_b^- \to J/\psi \overline{\Xi}^- \times B(b \to \overline{\Xi}_b^-)$ | $(1.02^{+0.26}_{-0.21}) \times 10^{-5}$ | |

Ξ_b BRANCHING RATIOS

$\Gamma(\overline{\Xi}^-\ell^-\overline{\nu}_{\ell}X \times B(\overline{b} \to \overline{\Xi}_b))/\Gamma_{total}$ Γ_1/Γ DOCUMENT ID TECN 3.9±1.2 OUR AVERAGE Error includes scale factor of 1.4. ABDALLAH 05c DLPH $e^+e^- \rightarrow Z^0$ BUSKULIC 96T ALEP Excess $\Xi^-\ell^-$ over $\Xi^-\ell^+$ 3.0 + 1.0 + 0.3 $5.4 \pm 1.1 \pm 0.8$ \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet 95 ∨ DLPH Repl. by ABDALLAH 05 c $\Gamma(J/\psi \equiv - \times B(b \rightarrow \Xi_b^-))/\Gamma_{\text{total}}$ Γ_2/Γ DOCUMENT ID TECN COMMENT

0.102+0.026 OUR AVERAGE

 $0.098 \,{}^{+\, 0.023}_{-\, 0.016} \,{\pm}\, 0.014$ 12 AALTONEN 09AP CDF $p\overline{p}$ at 1.96 TeV ¹³ ABAZOV 07к D0 *р* \overline{p} at 1.96 TeV $0.16\ \pm0.07\ \pm0.02$

 12 AALTONEN 09AP reports $[\Gamma(\Xi_b^- \to ~J/\psi\,\Xi^- \times \,{\rm B}(b \to ~\Xi_b^-)~)/\Gamma_{\rm total}]~/~[{\rm B}(\Lambda_b^0 \to ~J/\psi\,\Xi^- \times \,{\rm B}(b \to ~\Xi_b^-)~)/\Gamma_{\rm total}]$ $J/\psi(1S)$ $\Lambda \times$ B($b \to \Lambda_b^0$)]] = 0.167 $^+$ 0.037 $^+$ 0.012 which we multiply by our best value B($\Lambda_b^0 \to J/\psi(1S)$ $\Lambda \times$ B($b \to \Lambda_b^0$)) = (5.8 \pm 0.8) \times 10⁻⁵. Our first error is their experiment's error and our second error is the systematic error from using our best

Value. 13 ABAZOV 07K reports $\left[\Gamma\left(\Xi_{b}^{-}\to J/\psi\Xi^{-}\times B(b\to\Xi_{b}^{-})\right)/\Gamma_{\mathrm{total}}\right]/\left[B(\Lambda_{b}^{0}\to J/\psi(1S)\Lambda\times B(b\to\Lambda_{b}^{0})\right]=0.28\pm0.09^{+0.09}_{-0.08}$ which we multiply by our best value $B(\Lambda_b^0 \to J/\psi(1s)\Lambda \times B(b \to \Lambda_b^0)) = (5.8 \pm 0.8) \times 10^{-5}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

E_b REFERENCES

| AALTONEN | 11X PRL 107 102001 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |
|----------|--------------------|---------------------------|------------------|
| AALTONEN | 09AP PR D80 072003 | T. Aaltonen <i>et al.</i> | (CDF Collab.) |
| AALTONEN | 07A PRL 99 052002 | T. Aaltonen <i>et al.</i> | (CDF Colab.) |
| ABAZOV | 07K PRL 99 052001 | V.M. Abazov <i>et al.</i> | (D0 Collab.) |
| ABDALLAH | 05C EPJ C44 299 | J. Abdallah <i>et al.</i> | (DELPHI Collab.) |
| BUSKULIC | 96T PL B384 449 | D. Buskulic <i>et al.</i> | `(ALEPH Collab.) |
| ABREU | 95V ZPHY C68 541 | P. Abreu <i>et al.</i> | (DELPHI Collab.) |



 $I(J^P) = O(\frac{1}{2}^+)$ Status: *** I, J, P need confirmation.

In the quark model Ω_{D}^{-} is ssb ground state. None of its quantum numbers has been measured.

Ω_b^- MASS

| VALUE (MeV) | DO CUMENT ID | | COMMENT |
|---------------------------------------------------------|---------------------------------|----------------|-----------------------------|
| 6071 ±40 OUR AVERAGE | | | |
| 6054.4± 6.8± 0.9 | $^{ m 1}$ aaltonen | | |
| 6165 ± 10 ± 13 | ² ABAZOV | 08AL D0 | $p\overline{p}$ at 1.96 TeV |
| 1 Observed in $\Omega_b^- 	o J/\psi \Omega$ | $^-$ decays with 16^{+6}_{-4} | candidates, a | significance of 5.5 sigma |
| from a combined mass-lifet | | | |
| ² Observed in $\Omega_h^- \to J/\psi \Omega$ | — decays with 17.8 ± | ± 4.9 ± 0.8 ca | ndidates, a significance of |
| 5.4 sigma. | | | |

Ω_b MEAN LIFE

| VALUE (10 ⁻¹² s) | DO CUMENT ID | TECN | COMMENT |
|------------------------------------|-----------------------|----------|-----------------------------------|
| $1.13^{+\ 0.53}_{-\ 0.40}\pm 0.02$ | ³ AALTONEN | 09AP CDF | $\rho \overline{ ho}$ at 1.96 TeV |

 3 Observed in $\Omega_b^-\to J/\psi\,\Omega^-$ decays with $16{+6\over4}$ candidates, a significance of 5.5 sigma from a combined mass-lifetime fit.

Ω_b^- DECAY MODES

| | Mode | Fraction (Γ _i /Γ) |
|-----------------------|--------------------------------------------|--------------------------------------|
| $\overline{\Gamma_1}$ | $J/\psi \Omega^- \times B(b \to \Omega_b)$ | $(2.9^{+1.1}_{-0.8}) \times 10^{-6}$ |

Ω- BRANCHING RATIOS

| VALUE (units 10 ⁻⁴) | DO CUMENT ID | TECN | COMMENT | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------|----------------------|
| 0.029 + 0.011 OUR AVERAGE | Ē | | | |
| $0.026 {}^{+ 0.010}_{- 0.007} {}^{\pm 0.004}$ | ⁴ AALTONEN | 09AP CDF | p p at 1.96 TeV | |
| 0.08 ±0.04 ±0.02 | ⁵ ABAZOV | 08AL D0 | $p\overline{p}$ at 1.96 TeV | |
| ⁴ AALTONEN 09AP report $J/\psi(1S) \Lambda \times B(b \to \Lambda^0_b)$ value $B(\Lambda^0_b \to J/\psi(1S))$ their experiment's error at value. | [b] = 0.045 + 0.017 = 0.012 = 0.045 + 0.012 = 0.012 = 0.045 + 0.012 = 0.045 + 0.017 = 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 = 0.045 + 0.017 | \pm 0.004 which (5.8 \pm 0.8) \Rightarrow | we multiply by o 10^{-5} . Our first | ur best error is |
| ⁵ ABAZOV 08AL reports [$J/\psi \Xi^- \times B(b \to \Xi_b^-)$ $B(\Xi_b^- \to J/\psi \Xi^- \times B(b)$ experiment's error and our |)] = $0.80 \pm 0.32^{+0}_{-0}$; b $\rightarrow \Xi_{b}^{-}$) = (1.02) | $^{14}_{22}$ which we r $^{+0.26}_{-0.21}) 	imes 10^{-1}$ | multiply by our bes 5. Our first error | st value is their |

Ω_h^- REFERENCES

AALT ON EN ABAZOV 09AP PR D80 072003 08AL PRL 101 232002 T. Aaltonen et al. V.M. Abazov et al (CDF Collab.) (D0 Collab.)

b-baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$

b-baryon ADMIXTURE MEAN LIFE

Each measurement of the $\emph{b}\text{-}\text{baryon}$ mean life is an average over an admixture of various b baryons which decay weakly. Different techniques emphasize different admixtures of produced particles, which could result in a different b-baryon mean life. More b-baryon flavor specific channels are not included in the measurement.

"OUR EVALUATION" is an average using rescaled values of the data listed below. The average and rescaling were performed by the Heavy Flavor Averaging Group (HFAG) and are described at http://www.slac.stanford.edu/xorg/hfag/. The averaging/rescaling procedure takes into account correlations between the measurements and asymmetric lifetime errors.

| , | | | | | |
|------------------------------------------------------------------------------------------------|------------|----------------------------------------------------------------|----------------|---------------------|-----------------------------------------------------------------------------------|
| VALUE (10 ⁻¹² s) | EVTS | DO CUMENT ID | | TECN | COMMENT |
| 1.382±0.029 OUR EVAL 1.401±0.046±0.035 | .UATION | I ¹ AALTONEN | 10в | CDF | p p at 1.96 TeV |
| $1.218 {}^{+ 0.1 30}_{- 0.1 15} {\pm} 0.042$ | | ² ABAZOV | 07s | D0 | ρ p at 1.96 TeV |
| $1.290 + 0.119 + 0.087 \\ -0.110 - 0.091$ | | ³ ABAZOV | 07∪ | D0 | $p\overline{p}$ at 1.96 TeV |
| $1.593 ^{+0.083}_{-0.078} \pm 0.033$ | | ² ABULENCIA | 07A | CDF | p p at 1.96 TeV |
| $1.16 \pm 0.20 \pm 0.08$ $1.19 \pm 0.14 \pm 0.07$ | | ⁴ ABREU ⁵ ABREU | | DLPH DLPH | $\begin{array}{ccc} e^+e^- & ightarrow & Z \\ e^+e^- & ightarrow & Z \end{array}$ |
| $1.11 ^{+ 0.1 9}_{- 0.1 8} \pm 0.05$ | | ⁶ ABREU | 99W | DLPH | $e^+e^- ightarrow Z$ |
| $1.29 {}^{+ 0.24}_{- 0.22} \pm 0.06$ | | ⁶ ACKERSTAFF | 98G | OPAL | $e^+e^- ightarrow Z$ |
| 1.20 ±0.08 ±0.06 1.21 ±0.11 1.32 ±0.15 ±0.07 | | ⁷ BARATE ⁶ BARATE ⁸ ABE | | ALEP ALEP CDF | $e^+e^- \rightarrow Z$ $e^+e^- \rightarrow Z$ $p\overline{p}$ at 1.8 TeV |
| $1.10 \begin{array}{c} +0.19 \\ -0.17 \end{array} \pm 0.09$ | | ⁶ ABREU | 96D | DLPH | $e^+e^- \rightarrow Z$ |
| 1.16 ±0.11 ±0.06 • • • We do not use the | e followin | ⁶ AKERS g data for averages | 96 s, fits, | OPAL limits, e | $e^+e^- \rightarrow Z$ |
| $1.22 ^{+ 0.22}_{- 0.18} \pm 0.04$ | | ² ABAZOV | 05 c | D0 | Repl. by ABAZOV 07s |
| 1.14 ±0.08 ±0.04 | | ⁹ ABREU | 99w | DLPH | $e^+e^- \rightarrow Z$ |
| $1.46 \begin{array}{c} +0.22 \\ -0.21 \end{array} \begin{array}{c} +0.07 \\ -0.09 \end{array}$ | | ABREU | 96D | DLPH | Repl. by ABREU 99w |
| $1.27 \ ^{+ 0.35}_{- 0.29} \ \pm 0.09$ | | ABREU | 95s | DLPH | Repl. by ABREU 99w |
| $1.05 \begin{array}{c} +0.12 \\ -0.11 \end{array} \pm 0.09$ | 290 | BUSKULIC | 95 L | ALEP | Repl. by BARATE 98D |
| $1.04 ^{+ 0.48}_{- 0.38} \pm 0.10$ | 11 | ¹⁰ ABREU | 93F | DLPH | Excess $\Lambda \mu^-$, decay lengths |
| $1.05 \ ^{+ 0.23}_{- 0.20} \ \pm 0.08$ | 157 | ¹¹ AKERS | 93 | OPAL | Excess Λℓ [−] , decay lengths |
| $1.12 \ ^{+ 0.32}_{- 0.29} \ \pm 0.16$ | 101 | ¹² BUSKULIC | 921 | ALEP | Excess $\Lambda \ell^-$, impact |

 $^{^1}$ Measured mean life using fully reconstructed $\varLambda_{\slashed b}^{0} \to \varLambda_{\slashed c}^{+} \pi^-$ decays.

² Measured mean life using fully reconstructed $\Lambda_b^0 \to J/\psi \Lambda$ decays.

³ Measured using semileptonic decays $\Lambda_b(0) \to \Lambda_c^+ \mu \nu X$, $\Lambda_c^+ \to K_S^0 p$.

⁴ Measured using $\Lambda \ell^-$ decay length. ⁵ Measured using $p\ell^-$ decay length.

 $^{^6}$ Measured using $\Lambda_{\mathcal{C}} \ell^-$ and $\Lambda \ell^+ \ell^-$

 $^{^7}$ Measured using the excess of $\Lambda\,\ell^-$, lepton impact parameter.

Baryon Particle Listings b-baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$

⁸ Measured using $\Lambda_c \ell^-$.

 $^{
m 10}$ ABREU 93F superseded by ABREU 96D

b-baryon ADMIXTURE DECAY MODES $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$

These branching fractions are actually an average over weakly decaying b-baryons weighted by their production rates at the LHC, LEP, and Tevatron, branching ratios, and detection efficiencies. They scale with the b-baryon production fraction $\mathrm{B}(b \to b$ -baryon).

The branching fractions $\mathsf{B}(b ext{-baryon}\to \Lambda\ell^-\overline{
u}_\ell$ anything) are not pure measurements because the underlying measured products of these with $\mathsf{B}(b\to b ext{-baryon})$ were used to determine $\mathsf{B}(b\to b ext{-baryon})$, as described in the note "Production and Decay of $b ext{-Flavored Hadrons."}$ "

For inclusive branching fractions, e.g., $B\to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one

| | Mode | Fraction (Γ_i/Γ) |
|----------------|--------------------------------------------------|--------------------------------|
| Γ ₁ | $p\mu^-\overline{ u}$ anything | (5.3 + 2.2) % |
| Γ_2 | $ ho\ell\overline{ u}_\ell$ anything | (5.1 ± 1.2) % |
| Γ_3 | <i>p</i> a nything | (63 ±21)% |
| Γ_4 | $\Lambda \ell^- \overline{ u}_\ell$ anything | (3.4 ± 0.6) % |
| Γ_5 | $arLambda \ell^+ u_\ell$ a nything | |
| Γ_6 | Λ anything | |
| Γ_7 | $\Lambda_c^+ \ell^- \overline{ u}_\ell$ anything | |
| Γ ₈ | $\Lambda / \overline{\Lambda}$ anything | (35 ± 8)% |
| Γ_9 | $\Xi^-\ell^-\overline{ u}_\ell$ a nything | $(5.9 \pm 1.6) \times 10^{-3}$ |

b-baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$ BRANCHING RATIOS

 Γ_1/Γ

| $\Gamma(\rho\mu^-\overline{\nu}_a \text{ nything})/\Gamma_{\text{total}}$ | | | | | | | |
|---------------------------------------------------------------------------|------|---------------------|-----|------|------------------------|--|--|
| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | |
| $0.053^{+0.020}_{-0.017} \pm 0.009$ | 125 | ¹³ ABREU | 95s | DLPH | $e^+e^- ightarrow ~Z$ | | |

 13 ABREU 95s reports $[\Gamma(b\text{-baryon}\to p\,\mu^-\overline{\nu}\text{anything})/\Gamma_{\text{total}}]\times[B(\overline{b}\to b\text{-baryon})] = 0.0049 \pm 0.0011 ^{+}_{-0.0011}$ which we divide by our best value $B(\overline{b}\to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\lceil (ho \ell \overline{ u}_\ell bigan bigar 	ag{thing} / \lceil_{	ext{total}}$ | | | | | Γ_2/Γ |
|---------------------------------------------------------------------------------------|--------------|-----|------|-------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.051 \pm 0.009 \pm 0.009$ | 14 BARATE | 98∨ | ALEP | $e^+ e^- \rightarrow Z$ | |

 14 BARATE 98v reports $[\Gamma(b\text{-baryon}\to p\ell\overline{\nu}_\ell\text{ anything})/\Gamma_{\text{total}}]\times[B(\overline{b}\to b\text{-baryon})]=(4.72\pm0.66\pm0.44)\times10^{-3}$ which we divide by our best value $B(\overline{b}\to b\text{-baryon})=(9.3\pm1.6)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(ho\ell\overline{ u}_\ell$ anything $)/\Gamma(ho$ anything $)$ | | | | | |
|-------------------------------------------------------------------------|--------------|-----|------|-------------------------|--|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.080 \pm 0.012 \pm 0.014$ | BARATE | 98v | ALEP | $e^+ e^- \rightarrow Z$ | |

 $\Gamma(\Lambda\ell^-\overline{
u}_\ell$ anything)/ Γ_{total} The values and averages in this section serve only to show what values result if one assumes our $B(b \to b$ -baryon). They cannot be thought of as measurements since the underlying product branching fractions were also used to determine $B(b \to b$ -baryon) as described in the note on "Production and Decay of b-Flavored Hadrons."

| VALUE | EVTS | DO CUMENT ID | | TECN | COMMENT | | | |
|-----------------------------------------------------------------------------|------|------------------------|-------------|------|--------------------------------------------------|--|--|--|
| 0.034±0.006 OUR AVERAGE | | | | | | | | |
| $0.035 \pm 0.005 \pm 0.006$ | | ¹⁵ BARATE | 98D | ALEP | $e^+ e^- \rightarrow Z$ | | | |
| $0.031 \pm 0.004 \pm 0.005$ | | ¹⁶ AKERS | 96 | OPAL | Excess of $\Lambda \ell^-$ over $\Lambda \ell^+$ | | | |
| $0.032\!\pm\!0.008\!\pm\!0.006$ | 262 | ¹⁷ ABREU | 95 s | DLPH | Excess of $\Lambda \ell^-$ over | | | |
| $0.066 \pm 0.013 \pm 0.011$ | 290 | ¹⁸ BUSKULIC | 95 L | ALEP | Excess of $\Lambda \ell^-$ over $\Lambda \ell^+$ | | | |
| • • • We do not use the following data for averages, fits, limits, etc. • • | | | | | | | | |
| seen | 157 | ¹⁹ AKERS | 93 | OPAL | Excess of $\Lambda \ell^-$ over $\Lambda \ell^+$ | | | |
| $0.075\pm0.022\pm0.013$ | 101 | ²⁰ BUSKULIC | 921 | ALEP | Excess of $\Lambda \ell^-$ over $\Lambda \ell^+$ | | | |

 15 BARATE 98D reports [\Gamma(b-baryon $\rightarrow \Lambda \ell^-\overline{\nu}_\ell$ anything)/ $\Gamma_{total}] \times [B(\overline{b} \rightarrow b\text{-baryon})] = 0.00326 \pm 0.00016 \pm 0.00039$ which we divide by our best value $B(\overline{b} \rightarrow b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Measured using the excess of $\Lambda \ell^-$, lepton impact parameter.

 16 AKERS 96 reports $[\Gamma(b\text{-baryon}\to \Lambda\ell^{-}\overline{\nu}_{\ell}\text{anything})/\Gamma_{total}]\times[B(\overline{b}\to b\text{-baryon})]=0.00291\pm0.00023\pm0.00025$ which we divide by our best value B($\overline{b}\to b\text{-baryon})=(9.3\pm1.6)\times10^{-2}.$ Our first error is their experiment's error and our second error is the systematic error from using our best value.

17 ABREU 95s reports $[\Gamma(b\text{-baryon}) \to \Lambda\ell^-\overline{\nu}_\ell \text{ anything})/\Gamma_{\text{total}}] \times [B(\overline{b} \to b\text{-baryon})] = 0.0030 \pm 0.0006 \pm 0.0004$ which we divide by our best value $B(\overline{b} \to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

¹⁸ BUSKULIC 95L reports [Γ (*b*-baryon → $\Lambda \ell^- \overline{\nu}_\ell$ anything)/ Γ_{total}] × [B(\overline{b} → b-baryon)] = 0.0061 ± 0.0006 ± 0.0010 which we divide by our best value B(\overline{b} → b-baryon) = (9.3 ± 1.6) × 10⁻². Our first error is their experiment's error and our second error is the systematic error from using our best value.

¹⁹ AKERS 93 superseded by AKERS 96.

 20 BUSKULIC 92I reports [\Gamma(b-baryon $\rightarrow \Lambda \ell^- \overline{\nu}_\ell$ anything)/ $\Gamma_{total}] \times [B(\overline{b} \rightarrow b\text{-baryon})] = 0.0070 \pm 0.0010 \pm 0.0018$ which we divide by our best value $B(\overline{b} \rightarrow b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value. Superseded by BUSKULIC 95L.

| $\Gamma(\Lambda \ell^+ \nu_\ell \text{a nything})/\Gamma(\Lambda \text{a nything})$ | | | | | |
|-------------------------------------------------------------------------------------|--------------------|----------|-----------|----------------------------|---|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| $0.080 \pm 0.012 \pm 0.008$ | ABBIENDI | 99L | OPAL | $e^+e^- ightarrow Z$ | |
| • • • We do not use the following | ng data for averag | es, fits | , limits, | etc. • • • | |
| $0.070 \pm 0.012 \pm 0.007$ | ACKERSTAF | F 97N | OPAL | Repl. by ABBI- ENDI 99L | - |

| $\Gamma(\Lambda/\overline{\Lambda}anything)/\Gamma_{tot}$ | al | | | | Γ_8/Γ |
|-----------------------------------------------------------|---------------------------|----------|-----------|----------------------------|-------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT | |
| 0.35 ± 0.08 OUR AVERAGE | iE | | | • | |
| $0.38 \pm 0.05 \pm 0.06$ | ²¹ ABBIENDI | 99L | OPAL | $e^+e^- \rightarrow Z$ | |
| $0.24 {}^{+ 0.13}_{- 0.08} \pm 0.04$ | ²² ABREU | 95 ⊂ | DLPH | $e^+e^- ightarrow Z$ | |
| • • • We do not use the | following data for averag | es, fits | , limits, | etc. • • • | |
| $0.42 \pm 0.06 \pm 0.07$ | ²³ ACKERSTAF | F 97N | OPAL | Repl. by ABBI- ENDI 99L | |

²² ABREU 95c reports $0.28^{+0.12}_{-0.12}$ from a measurement of $[\Gamma(b\text{-baryon} \rightarrow A/A \text{ anything})/\Gamma_{\text{total}}] \times [B(\overline{b} \rightarrow b\text{-baryon})]$ assuming $B(\overline{b} \rightarrow b\text{-baryon}) = 0.08 \pm 0.02$, which we rescale to our best value $B(\overline{b} \rightarrow b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

23 ACKERSTAFF 97N reports $[\Gamma(b\text{-baryon} \to A/\overline{A} \text{anything})/\Gamma_{\text{total}}] \times [B(\overline{b} \to b\text{-baryon})] = 0.0393 \pm 0.0046 \pm 0.0037$ which we divide by our best value $B(\overline{b} \to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

| $\Gamma(\Xi^-\ell^-\overline{\nu}_\ell \text{ anything})/\Gamma_{\text{total}}$ | | | | Г9/Г |
|---------------------------------------------------------------------------------|------------------------|-----|------|-----------------------------------------|
| VALUE | DO CUMENT ID | | TECN | COMMENT |
| 0.0059±0.0016 OUR AVERAGE | | | | |
| $0.0058 \pm 0.0015 \pm 0.0010$ | ²⁴ BUSKULIC | 96т | ALEP | Excess $\Xi^-\ell^-$ over $\Xi^-\ell^+$ |
| $0.0063 \pm 0.0025 \pm 0.0011$ | ²⁵ ABREU | 95∨ | DLPH | Excess $\Xi^-\ell^-$ over $\Xi^-\ell^+$ |

 24 BUSKULIC 96T reports $[\Gamma(b\text{-baryon}\to \overline{\Xi}^-\ell^-\overline{\nu}_\ell\,\text{anything})/\Gamma_{\text{total}}]\times [B(\overline{b}\to b\text{-baryon})]=0.00054\pm0.00011\pm0.00008$ which we divide by our best value $B(\overline{b}\to b\text{-baryon})=(9.3\pm1.6)\times10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

 25 ABREU 95v reports [\Gamma(b-baryon $\to \Xi^-\ell^-\overline{\nu}_\ell$ anything)/ $\Gamma_{\rm total}] \times [\underline{B}(\overline{b} \to b\text{-baryon})] = 0.00059 \pm 0.00021 \pm 0.0001$ which we divide by our best value $B(\overline{b} \to b\text{-baryon}) = (9.3 \pm 1.6) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

b-baryon ADMIXTURE $(\Lambda_b, \Xi_b, \Sigma_b, \Omega_b)$ REFERENCES

 $^{^9}$ This ABREU 99W result is the combined result of the $\Lambda\ell^-,~\rho\ell^-,$ and excess $\Lambda\mu^-$ impact parameter measurements.

 $^{^{11}\,\}mathrm{A\,KERS}$ 93 superseded by AKERS 96.

 $^{^{12}\,\}mathrm{BUSKULIC}$ 921 superseded by BUSKULIC 95L.

| MISCELLANEOUS SEARCHES Magnetic Monopole Searches |
|----------------------------------------------------|
| Notes in the Search Listings |
| Magnetic Monopoles (rev.) |
| SEARCHES IN OTHER SECTIONS |
| Higgs Bosons — H^0 and H^\pm |



SEARCHES FOR MONOPOLES, SUPERSYMMETRY, TECHNICOLOR, COMPOSITENESS, EXTRA DIMENSIONS, etc.

Magnetic Monopole Searches

MAGNETIC MONOPOLES

Updated August 2011 by D. Milstead (Stockholm Univ.) and E.J. Weinberg (Columbia Univ.).

The symmetry between electric and magnetic fields in the sourcefree Maxwell's equations naturally suggests that electric charges might have magnetic counterparts, known as magnetic monopoles. Although the greatest interest has been in the supermassive monopoles that are a firm prediction of all grand unified theories, one cannot exclude the possibility of lighter monopoles, even though there is at present no strong theoretical motivation for these.

In either case, the magnetic charge is constrained by a quantization condition first found by Dirac [1]. Consider a monopole with magnetic charge Q_M and a Coulomb magnetic field

$$\mathbf{B} = \frac{Q_M}{4\pi} \frac{\hat{\mathbf{r}}}{r^2} \,. \tag{1}$$

Any vector potential ${\bf A}$ whose curl is equal to ${\bf B}$ must be singular along some line running from the origin to spatial infinity. This Dirac string singularity could potentially be detected through the extra phase that the wavefunction of a particle with electric charge Q_E would acquire if it moved along a loop encircling the string. For the string to be unobservable, this phase must be a multiple of 2π . Requiring that this be the case for any pair of electric and magnetic charges gives the condition that all charges be integer multiples of minimum charges Q_E^{\min} and Q_M^{\min} obeying

$$Q_E^{\min} Q_M^{\min} = 2\pi. \tag{2}$$

(For monopoles which also carry an electric charge, called dyons, the quantization conditions on their electric charges can be modified. However, the constraints on magnetic charges, as well as those on all purely electric particles, will be unchanged.)

Another way to understand this result is to note that the conserved orbital angular momentum of a point electric charge moving in the field of a magnetic monopole has an additional component, with

$$\mathbf{L} = m\mathbf{r} \times \mathbf{v} - 4\pi Q_E Q_M \hat{\mathbf{r}} \tag{3}$$

Requiring the radial component of \mathbf{L} to be quantized in half-integer units yields Eq. (2).

If there are unbroken gauge symmetries in addition to the U(1) of electromagnetism, the above analysis must be modified [2,3]. For example, a monopole could have both a

U(1) magnetic charge and a color magnetic charge. The latter could combine with the color charge of a quark to give an additional contribution to the phase factor associated with a loop around the Dirac string, so that the U(1) charge could be the Dirac charge $Q_M^D \equiv 2\pi/e$, the result that would be obtained by substituting the electron charge into Eq. (2). On the other hand, for monopoles without color-magnetic charge, one would simply insert the quark electric charges into Eq. (2) and conclude that Q_M must be a multiple of $6\pi/e$.

The prediction of GUT monopoles arises from the work of 't Hooft [4] and Polyakov [5], who showed that certain spontaneously broken gauge theories have nonsingular classical solutions that lead to magnetic monopoles in the quantum theory. The simplest example occurs in a theory where the vacuum expectation value of a triplet Higgs field ϕ breaks an SU(2) gauge symmetry down to the U(1) of electromagnetism and gives a mass M_V to two of the gauge bosons. In order to have finite energy, ϕ must approach a vacuum value at infinity. However, there is a continuous family of possible vacua, since the scalar field potential determines only the magnitude v of $\langle \phi \rangle$, but not its orientation in the internal SU(2) space. In the monopole solution, the direction of ϕ in internal space is correlated with the position in physical space; i.e., $\phi^a \sim v \hat{r}^a$. The stability of the solution follows from the fact that this twisting Higgs field cannot be smoothly deformed to a spatially uniform vacuum configuration. Reducing the energetic cost of the spatial variation of ϕ requires a nonzero gauge potential, which turns out to yield the magnetic field corresponding to a charge $Q_M = 4\pi/e$. Numerical solution of the classical field equations shows that the mass of this monopole is

$$M_{\rm mon} \sim \frac{4\pi M_V}{e^2} \,. \tag{4}$$

The essential ingredient here was the fact that the Higgs fields at spatial infinity could be arranged in a topologically nontrivial configuration. A discussion of the general conditions under which this is possible is beyond the scope of this review, so we restrict ourselves to the two phenomenologically most important cases.

The first is the electroweak theory, with $SU(2) \times U(1)$ broken to U(1). There are no topologically nontrivial configurations of the Higgs field, and hence no topologically stable monopole solutions.

The second is when any simple Lie group is broken to a subgroup with a U(1) factor, a case that includes all grand unified theories. The monopole mass is determined by the mass scale of the symmetry breaking that allows nontrivial topology. For example, an SU(5) model with

$$\mathrm{SU}(5) \xrightarrow{M_X} \mathrm{SU}(3) \times \mathrm{SU}(2) \times \mathrm{U}(1) \xrightarrow{M_W} \mathrm{SU}(3) \times \mathrm{U}(1) \quad (5)$$

has a monopole [6] with $Q_M=2\pi/e$ and mass

$$M_{\rm mon} \sim \frac{4\pi M_{\rm X}}{g^2} \,, \tag{6}$$

Searches Particle Listings Magnetic Monopole Searches

where g is the SU(5) gauge coupling. For a unification scale of 10^{16} GeV, these monopoles would have a mass $M_{\rm mon} \sim 10^{17}$ – 10^{18} GeV.

In theories with several stages of symmetry breaking, monopoles of different mass scales can arise. In an SO(10) theory with

$$SO(10) \xrightarrow{M_1} SU(4) \times SU(2) \times SU(2) \xrightarrow{M_2} SU(3) \times SU(2) \times U(1)$$
(7)

there is monopole with $Q_M = 2\pi/e$ and mass $\sim 4\pi M_1/g^2$ and a much lighter monopole with $Q_M = 4\pi/e$ and mass $\sim 4\pi M_2/g^2$ [7].

The central core of a GUT monopole contains the fields of the superheavy gauge bosons that mediate baryon number violation, so one might expect that baryon number conservation could be violated in baryon–monopole scattering. The surprising feature, pointed out by Callan [8] and Rubakov [9], is that these processes are not suppressed by powers of the gauge boson mass. Instead, the cross-sections for catalysis processes such as $p + \text{monopole} \rightarrow e^+ + \pi^0 + \text{monopole}$ are essentially geometric; i.e., $\sigma_{\Delta B}\beta \sim 10^{-27} \text{ cm}^2$, where $\beta = v/c$. Note, however, that intermediate mass monopoles arising at later stages of symmetry breakings, such as the doubly charged monopoles of the SO(10) theory, do not catalyze baryon number violation.

Production and Annihilation: GUT monopoles are far too massive to be produced in any foreseeable accelerator. However, they could have been produced in the early universe as topological defects arising via the Kibble mechanism [10] in a symmetry-breaking phase transition. Estimates of the initial monopole abundance, and of the degree to which it can be reduced by monopole-antimonopole annihilation, predict a present-day monopole abundance that exceeds by many orders of magnitude the astrophysical and experimental bounds described below [11]. Cosmological inflation and other proposed solutions to this primordial monopole problem generically lead to present-day abundances exponentially smaller than could be plausibly detected, although potentially observable abundances can be obtained in scenarios with carefully tuned parameters.

If monopoles light enough to be produced at colliders exist, one would expect that these could be produced by analogs of the electromagnetic processes that produce pairs of electrically charged particles. Because of the large size of the magnetic charge, this is a strong coupling problem for which perturbation theory cannot be trusted. Indeed, the problem of obtaining reliable quantitative estimates of the production cross-sections remains an open one, on which there is no clear consensus.

Astrophysical and Cosmological Bounds: If there were no galactic magnetic field, one would expect monopoles in the galaxy to have typical velocities of the order of $10^{-3}c$, comparable to the virial velocity in the galaxy (relevant if the monopoles cluster with the galaxy) and the peculiar velocity of the galaxy with respect to the CMB rest frame (relevant if the monopoles are not bound to the galaxy). This situation is modified by the existence of a galactic magnetic field $B \sim 3\mu G$.

A monopole with the Dirac charge and mass M would be accelerated by this field to a velocity

$$v_{\text{mag}} \sim \begin{cases} c, & M \lesssim 10^{11} \text{GeV} , \\ 10^{-3} c \left(\frac{10^{17} \text{ GeV}}{M}\right)^{1/2}, & M \gtrsim 10^{11} \text{GeV} . \end{cases}$$
 (8)

Accelerating these monopoles drains energy from the magnetic field. Parker [12] obtained an upper bound on the flux of monopoles in the galaxy by requiring that the rate of this energy loss be small compared to the time scale on which the galactic field can be regenerated. With reasonable choices for the astrophysical parameters (see Ref. 13 for details), this Parker bound is

$$F < \begin{cases} 10^{-15} \,\mathrm{cm}^{-2} \,\mathrm{sr}^{-1} \,\mathrm{sec}^{-1}, & M \lesssim 10^{17} \,\mathrm{GeV}, \\ 10^{-15} \left(\frac{M}{10^{17} \,\mathrm{GeV}}\right) \,\mathrm{cm}^{-2} \,\mathrm{sr}^{-1} \,\mathrm{sec}^{-1}, & M \gtrsim 10^{17} \,\mathrm{GeV}. \end{cases}$$
(9)

Applying similar arguments to an earlier seed field that was the progenitor of the current galactic field leads to a tighter bound [14],

$$F < \left[\frac{M}{10^{17} \text{GeV}} + (3 \times 10^{-6}) \right] 10^{-16} \,\text{cm}^{-2} \text{sr}^{-1} \text{sec}^{-1}.$$
 (10)

Considering magnetic fields in galactic clusters gives a bound [15] which, although less secure, is about three orders of magnitude lower than the Parker bound.

A flux bound can also be inferred from the total mass of monopoles in the universe. If the monopole mass density is a fraction Ω_M of the critical density, and the monopoles were uniformly distributed throughout the universe, there would be a monopole flux

$$F_{\text{uniform}} = 1.3 \times 10^{-16} \Omega_M \left(\frac{10^{17} \text{ GeV}}{M} \right) \left(\frac{v}{10^{-3} c} \right) \text{cm}^{-2} \text{sr}^{-1} \text{sec}^{-1}.$$
(11)

If we assume that $\Omega_M \sim 0.1$, this gives a stronger constraint than the Parker bound for $M \sim 10^{15}$ GeV. However, monopoles with masses $\sim 10^{17}$ GeV are not ejected by the galactic field and can be gravitationally bound to the galaxy. In this case their flux within the galaxy is increased by about five orders of magnitude for a given value of Ω_M , and the mass density bound only becomes stronger than the Parker bound for $M \sim 10^{18}$ GeV.

A much more stringent flux bound applies to GUT monopoles that catalyze baryon number violation. The essential idea is that compact astrophysical objects would capture monopoles at a rate proportional to the galactic flux. These monopoles would then catalyze proton decay, with the energy released in the decay leading to an observable increase in the luminosity of the object. A variety of bounds, based on neutron stars [16–20], white dwarfs [21], and Jovian planets [22] have been obtained. These depend in the obvious manner on the catalysis cross section, but also on the details of the astrophysical scenarios; e.g., on how much the accumulated density is reduced by monopole-antimonopole annihilation, and

on whether monopoles accumulated in the progenitor star survive its collapse to a white dwarf or neutron star. The bounds obtained in this manner lie in the range

$$F\left(\frac{\sigma_{\Delta B}\beta}{10^{-27}\text{cm}^2}\right) \sim (10^{-18} - 10^{-29})\text{cm}^{-2}\text{sr}^{-1}\text{sec}^{-1}.$$
 (12)

It is important to remember that not all GUT monopoles catalyze baryon number nonconservation. In particular, the intermediate mass monopoles that arise in some GUTs at later stages of symmetry-breaking are examples of theoretically motivated monopoles that are exempt from the bound of Eq. (12).

Searches for Magnetic Monopoles: To date there have been no confirmed observations of exotic particles possessing magnetic charge. Precision measurements of the properties of known particles have led to tight limits on the values of magnetic charge they may possess. Using the induction method (see below), the electron's magnetic charge has been found to be $Q_e^m < 10^{-24} Q_M^D$ [23](where Q_M^D is the Dirac charge). Furthermore, measurements of the anomalous magnetic moment of the muon have been used to place a model dependent lower limit of 120 GeV on the monopole mass ¹ [24]. less, guided mainly by Dirac's argument and the predicted existence of monopoles from spontaneous symmetry breaking mechanisms, searches have been routinely made for monopoles produced at accelerators, in cosmic rays, and bound in mat-Although the resultant limits from such searches are usually made under the assumption of a particle possessing only magnetic charge, most of the searches are also sensitive to dyons.

Search Techniques: Search strategies are determined by the expected interactions of monopoles as they pass through matter. These would give rise to a number of striking characteristic signatures. Since a complete description of monopole search techniques falls outside of the scope of this minireview, only the most common methods are described below. More comprehensive descriptions of search techniques can be found in Refs. [26,27].

The induction method exploits the long-ranged electromagnetic interaction of the monopole with the quantum state of a superconducting ring which would lead to a monopole which passes through such a ring inducing a permanent current. The induction technique typically uses Superconducting Quantum Interference Devices (SQUID) technology for detection and is employed for searches for monopoles in cosmic rays and matter. Another approach is to exploit the electromagnetic energy loss of monopoles. Monopoles with Dirac charge would typically lose energy at a rate which is several thousand times larger than that expected from particles possessing the elementary electric charge. Consequently, scintillators, gas chambers and nuclear track detectors (NTDs) have been used in cosmic ray and collider experiments. A further approach, which has

been used at colliders, is to search for particles describing a non-helical path in a uniform magnetic field.

Searches for Monopoles Bound in Matter: Monopoles have been sought in a range of bulk materials which it is assumed would have absorbed incident cosmic ray monopoles over a long exposure time of order million years. Materials which have been studied include moon rock, meteorites, manganese modules, and sea water [28]. A stringent upper limit on the monopoles per nucleon ratio of $\sim 10^{-29}$ has been obtained [28].

Searches in Cosmic Rays: Direct searches for monopoles in cosmic rays refer to those experiments in which the passage of the monopole is measured by an active detector. Catalysis processes in which GUT monopoles could induce nucleon decay are discussed in the next section. To interpret the results of the non-catalysis searches, the cross section for the catalysis process is typically either set to zero [29] or assigned a modest value (1mb) [30]. Searches which explicitly exploit the expected catalysed decays are discussed in the next section.

Although early cosmic ray searches using the induction technique [31] and NTDs [32] observed monopole candidates, none of these apparent observations have been confirmed. Recent experiments have typically employed large scale detectors. The MACRO experiment at the Gran Sasso underground laboratory comprised three different types of detector: liquid scintillator, limited stream tubes, and NTDs, which provided a total acceptance of $\sim 10000 \mathrm{m}^2$ for an isotropic flux. As shown in Fig. 1, this experiment has so far provided the most extensive β -dependent flux limits for GUT monopoles with Dirac charge [30]. Also shown are limits from an experiment at the OHYA mine in Japan [29], which used a $2000 \mathrm{m}^2$ array of NTDs.

In Fig. 1, upper flux limits are also shown as a function of mass for monopole speed $\beta > 0.05$. In addition to MACRO and OYHA flux limits, results from the SLIM [33] high-altitude experiment are shown. The SLIM experiment provided a good sensitivity to intermediate mass monopoles $(10^5 \lesssim M \lesssim 10^{12}$ GeV). In addition to the results shown in Fig. 1, a limit of $\sim 9\times 10^{-16}~\rm cm^{-2}s^{-1}sr^{-1}$ was obtained for monopoles with $\beta=$ 0.76 by The AMANDA-II experiment [34]. This limit extends to $\sim 4 \times 10^{-17} \ \mathrm{cm^{-2} s^{-1} sr^{-1}}$ for $\beta \sim 1$. The most stringent constraints on the flux of ultra-relativistic monopoles have been obtained by the RICE [35] and ANITA-II experiments [36] at the South Pole which were sensitive to monopoles with γ values of $10^7 \lesssim \gamma \lesssim 10^{12}$ and $10^9 \lesssim \gamma \lesssim 10^{13}$, respectively, and which produced flux limits as low as 10^{-19} cm⁻²s⁻¹sr⁻¹. In addition to the aforementioned flux limits for monopoles with the Dirac charge, the OHYA experiment also presented limits for monopoles with charges up to $3Q_M^D$, as did the the SLIM experiment.

¹ Where no ambiguity is likely to arise, a reference to a monopole implies a particle possessing Dirac charge.

Searches Particle Listings

Magnetic Monopole Searches

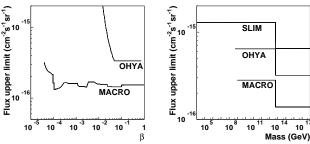


Figure 1: Upper flux limits for (a) GUT monopoles as a function of β (b) Monopoles as a function of mass for $\beta > 0.05$.

Searches via the Catalysis of Nucleon-Decay: Searches have also been performed for evidence of the catalysed decay of a nucleon, as predicted by the Callan-Rubakov mechanism. Searches have been made at a range of experiments which are sensitive to the induced nucleon decay of a passing monopole. For example, searches have been made with the Soudan [37] and Macro [38] experiments, using tracking detectors. Searches at Kamiokande [39], IMB [40] and the underwater Lake Baikal experiment [41] which exploit the Cerenkov effect have also been made. The resulting β -dependent flux limits from these experiments, which typically vary between $6 \times 10^{-17} - 9 \times 10^{-17}$ $10^{-14} \mathrm{cm}^{-2} \mathrm{sr}^{-1} \mathrm{s}^{-1}$ [25], are sensitive to the assumed values of the catalysis cross sections.

Searches at Colliders: Searches have been performed at hadron-hadron, electron-positron and lepton-hadron experiments. Collider searches can be broadly classed as being direct or indirect. In a direct search, evidence of the passage of a monopole through material, such as a charged particle track, is sought. In indirect searches, virtual monopole processes are assumed to influence the production rates of certain final states.

Direct Searches at Colliders: Collider experiments typically express their results in terms of upper limits on a production cross section and/or monopole mass. To calculate these limits, ansatzes are used to model the kinematics of monopoleantimonopole pair production processes since perturbative field theory cannot be used to calculate the rate and kinematic properties of produced monopoles. Limits therefore suffer from a degree of model-dependence, implying that a comparison between the results of different experiments can be problematic, in particular when this concerns excluded mass regions. A conservative approach with as little model-dependence as possible is thus to present the upper cross-section limits as a function of one half the centre-of-mass energy of the collisions, as shown in Fig. 2 for recent results from high energy colliders.

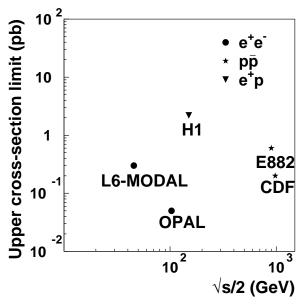


Figure 2: Upper limits on the production cross sections of monopoles from various collider-based experiments.

Searches for monopoles produced at the highest available energies in hadron-hadron collisions were made at the Tevatron by the CDF [42] and E882 [43] experiments. Complementary approaches were used; the CDF experiment used a dedicated time-of-flight system whereas the E882 experiment employed the induction technique to search for stopped monopoles in discarded detector material which had been part of the CDF and D0 detectors using periods of luminosity. Considered together, the searches provide a sensitivity to monopoles with charges between Q_M^D and $6Q_M^D$ and masses up to around 900 GeV. Earlier searches at the Tevatron, such as Ref. 44, used NTDs and were based on comparatively modest amounts of integrated luminosity. Lower energy hadron-hadron experiments have employed a variety of search techniques including plastic track detectors [45] and searches for trapped monopoles [46].

The only LEP-2 search was made by OPAL [47] which quoted cross section limits for the production of monopoles possessing masses up to around 103 GeV. At LEP-1, searches were made with NTDs deployed around an interaction region. This allowed a range of charges to be sought for masses up to ~ 45 GeV. The L6-MODAL experiment [48] gave limits for monopoles with charges in the range $0.9Q_M^D$ and $3.6Q_M^D$, whilst an earlier search by the MODAL experiment was sensitive to monopoles with charges as low as $0.1Q_M^D$ [49]. The deployment of NTDs around the beam interaction point was also used at earlier e^+e^- colliders such as KEK [50] and PETRA [51]. Searches at e^+e^- facilities have also been made for particles following non-helical trajectories [52.53].

There has so far been one search for monopole production in lepton-hadron scattering. Using the induction method,

Searches Particle Listings Magnetic Monopole Searches

monopoles were sought which could have stopped in the aluminium beampipe which had been used by the H1 experiment at HERA [54]. Cross section limits were set for monopoles with charges in the range $Q_M^D - 6Q_M^D$ for masses up to around 140 GeV.

Indirect Searches at Colliders: It has been proposed that virtual monopoles can mediate processes which give rise to multi-photon final-states [55,56]. Photon-based searches were made by the D0 [57] and L3 [58] experiments. The D0 work led to spin-dependent lower mass limits of between 610 and 1580 GeV, while L3 reported a lower mass limit of 510 GeV. However, it should be stressed that uncertainties on the theoretical calculations which were used to derive these limits are difficult to estimate.

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Monopole Production Cross Section — Accelerator Searches CHG ENERGY (GeV) DO CUMENT TECN < 5E - 3845-102 206 1 ABBIENDI OPAL < 0.2E - 36 200-700 ² ABULENCIA 06K CNTR 1960 pπ $^{3,4}\,\mathrm{AKTAS}$ < 2.E-36 300 05 A INDU < 0.2 E-36 300 e^+p 3,4 AKTAS INDU e^+p $^{3,4}\,\mathrm{AKTAS}$ $\,<\,0.09E\,{-}\,36$ 05A INDU < 0.05E-36 e^+p 3,4 AKTAS 300 05A INDU 3,5 AKTAS < 2.E - 36300 e^+p 05A INDU e^+p 3,5 AKTAS < 0.2E - 36300 05 A INDU e^+p 3,5 AKTAS < 0.07E - 36 05 A INDU e^+p 3,5 AKTAS < 0.06E - 36≥ 6 300 05 A INDU ⁶ KALBFLEISCH 04 < 0.6E - 361800 ⁶ KALBFLEISCH 04 < 0.2E - 36>355 1800 ⁶ KALBFLEISCH 04 < 0.07E - 36>410 INDU

| | | | | _ | 6 KALBELEISCH M. INDII |
|------------------------------|----------------|----------|--------------|--------------------------|--------------------------------------------------------------------------|
| < 0.2E – 36 | >375 | 6 | 1800 | p <u>p</u> | - NALDI LLISCII V4 INDO |
| < 0.7E – 36 | >295 | 1 2 | 1800 | р <u></u> | ^{7,8} KALBFLEISCH 00 INDU ^{7,8} KALBFLEISCH 00 INDU |
| < 7.8E-36 < 2.3E-36 | >260 >325 | 3 | 1800 1800 | р <u>Б</u> | 7,9 KALBFLEISCH 00 INDU |
| < 2.3E – 36 < 0.11E – 36 | >325 | 5 6 | 1800 | р <u>Р</u> р <u>Р</u> | 7,9 KALBFLEISCH 00 INDU |
| < 0.11E - 36 < 0.65E - 33 | <3.3 | ≥ 2 | 11A | ρρ 197 _{Δ11} | 10 HE 97 |
| | < 3.3 < 8.1 | | | 208 _{Pb} | 10 HE 97 |
| <1.90E – 33 | | ≥ 2 | 160A | e+e- | 116 77 |
| <3.E – 37 | <45.0 | 1.0 | 88-94 | e · e e+e- | PINFOLD 93 PLAS |
| <3.E – 37 | <41.6 | 2.0 | 88-94 | | PINFOLD 93 PLAS |
| <7.E – 35 | <44.9 | 0.2-1.0 | 89-93 | e+e- | KINOSHITA 92 PLAS |
| <2.E – 34 | < 850 | ≥ 0.5 | 1800 | p p | BERTANI 90 PLAS |
| <1.2E-33 | <800 | ≥ 1 | 1800 | ρ p | PRICE 90 PLAS |
| <1.E – 37 | <29 | 1 | 50-61 | e+ e- | KINOSHITA 89 PLAS |
| < 1.E - 37 | <18 | 2 | 50-61 | e+ e- | KINOSHITA 89 PLAS |
| < 1.E - 38 | <17 | <1 | 35 | e^+e^- | BRAUNSCH 88B CNTR |
| < 8.E - 37 | <24 | 1 | 50-52 | e^+e^- | KINOSHITA 88 PLAS |
| < 1.3E - 35 | <22 | 2 | 50-52 | e^+e^- | KINOSHITA 88 PLAS |
| < 9.E - 37 | <4 | < 0.15 | 10.6 | e^+e^- | GENTILE 87 CLEO |
| < 3.E - 32 | <800 | ≥ 1 | 1800 | $p\overline{p}$ | PRICE 87 PLAS |
| < 3.E - 38 | | <3 | 29 | e^+e^- | FRYBERGER 84 PLAS |
| < 1.E - 31 | | 1,3 | 540 | $p\overline{p}$ | AUBERT 83B PLAS |
| < 4.E - 38 | <10 | <6 | 34 | e^+e^- | MUSSET 83 PLAS |
| < 8.E - 36 | <20 | | 52 | pр | ¹¹ DELL 82 CNTR |
| < 9.E - 37 | < 30 | <3 | 29 | e^+e^- | KINOSHITA 82 PLAS |
| < 1.E - 37 | <20 | < 24 | 63 | pр | CARRIGAN 78 CNTR |
| < 1.E - 37 | < 30 | <3 | 56 | pр | HOFFMANN 78 PLAS |
| | | | 62 | pр | ¹¹ DELL 76 SPRK |
| < 4.E - 33 | | | 300 | р | 11 STEVENS 76B SPRK |
| < 1.E - 40 | < 5 | <2 | 70 | р | 12 ZRELOV 76 CNTR |
| < 2.E - 30 | | | 300 | n | ¹¹ BURKE 75 OSPK |
| < 1.E - 38 | | | 8 | ν | ¹³ CARRIGAN 75 HLBC |
| <5.E-43 | <12 | <10 | 400 | р | EBERHARD 75B INDU |
| < 2.E - 36 | < 30 | <3 | 60 | pр | GIACOMELLI 75 PLAS |
| <5.E-42 | <13 | < 24 | 400 | р | CARRIGAN 74 CNTR |
| < 6.E - 42 | <12 | < 24 | 300 | р | CARRIGAN 73 CNTR |
| < 2.E - 36 | | 1 | 0.001 | γ | ¹² BARTLETT 72 CNTR |
| < 1.E - 41 | <5 | | 70 | р | GUREVICH 72 EMUL |
| < 1.E - 40 | < 3 | <2 | 28 | p | AMALDI 63 EMUL |
| <2.E-40 | < 3 | <2 | 30 | p | PURCELL 63 CNTR |
| < 1.E - 35 | <3 | <4 | 28 | р | FIDECARO 61 CNTR |
| <2.E – 35 | <1 | 1 | 6 | p | BRADNER 59 EMUL |
| | | | | | |

 $^{^1}$ ABBIENDI 08 assume production of spin 1/2 monopoles with effective charge $g\beta$ (n=1), via $e^+e^- \to \gamma^* \to M\overline{M}$, so that the cross section is proportional to $(1+\cos^2\theta)$. There is no z information for such highly saturated tracks, so a parabolic track in the jet chamber is projected onto the xy plane. Charge per hit in the chamber produces a clean separation of signal and background.

Monopole Production — Other Accelerator Searches

| MASS (GeV) | CHG (g) | SPIN | ENERGY (GeV) | BEAM | DOCUMENT ID | | TECN |
|---------------|------------|------|-----------------|-----------------|------------------------|------|------|
| > 610 | ≥ 1 | 0 | 1800 | $p\overline{p}$ | ¹⁴ ABBOTT | 98ĸ | D0 |
| > 870 | ≥ 1 | 1/2 | 1800 | $p\overline{p}$ | ¹⁴ ABBOTT | 98ĸ | D0 |
| >1580 | ≥ 1 | 1 | 1800 | $p\overline{p}$ | ¹⁴ ABBOTT | 98K | D0 |
| > 510 | | | 88-94 | e^+e^- | ¹⁵ ACCIARRI | 95 c | L3 |

 $^{^{14}}$ ABBOTT 98K search for heavy pointlike Dirac monopoles via central production of a

Monopole Flux — Cosmic Ray Searches

^{&#}x27;Caty" in the charge column indicates a search for monopole-catalyzed nucleon decay.

| FLUX | MA SS | CH G | COMMENTS | | | | | |
|------------|-----------|------|------------------|------|--------------|----|------|--|
| (cm-2sr-1s | -1 ((GeV) | (g) | $(\beta = v/c)$ | EVTS | DO CUMENT ID | | TECN | |
| <1E-19 | | 1 | $\gamma > 1$ E10 | 0 | 16 DETRIXHE | 11 | ANIT | |

| <3.8E-17 | | 1 | 0 > 0.76 | 0 | 17 | ABBASI | 10A | AMND |
|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|-------------------------------------------------|-----|-------|------------------|----------|----------------|
| < 1.3E – 15 | 1E4 <m<5e< td=""><td>1 12 1</td><td>$\beta > 0.76$ $\beta > 0.05$</td><td>0</td><td>18</td><td>BALESTRA</td><td>08</td><td>PLAS</td></m<5e<> | 1 12 1 | $\beta > 0.76$ $\beta > 0.05$ | 0 | 18 | BALESTRA | 08 | PLAS |
| <0.65E-15 | >5E13 | 13 1 | $\beta > 0.05$ $\beta > 0.05$ | 0 | | BALESTRA | 08 | PLAS |
| <1E-18 | /JL13 | 1 | $\gamma > 1$ E8 | 0 | | HOGAN | 08 | RICE |
| <1.4E-16 | | 1 | $1.1E - 4 < \beta < 1$ | 0 | 19 | AMBROSIO | 02B | MCRO |
| <3E-16 | | | $1.1E-4 < \beta < 1$ $1.1E-4 < \beta < 5E-3$ | 0 | 20 | AMBROSIO | 02c | MCRO |
| <1.5E-15 | | 1 | $5E-3 < \beta < 0.99$ | 0 | | AMBROSIO | 02D | MCRO |
| <1E-15 | | 1 | $1.1 \times 10^{-4} - 0.1$ | 0 | | AMBROSIO | 97 | MCRO |
| | | 1 | (0.18-3.0)E-3 | 0 | 23 | AHLEN | 94 | MCRO |
| <5.6E-15 | | | $\beta \sim 1 \times 10^{-3}$ | 0 | | BECKER-SZ | 94 | IMB |
| <2.7E-15 | | _ | >2.E-3 | 0 | | THRON | 92 | SOUD |
| <8.7E-15 <4.4E-12 | | 1 | all β | 0 | | GARDNER | 91 | INDU |
| | | | | 0 | | | 91 | |
| <7.2E-13 | > E10 | 1 | all β | 0 | 25 | HUBER ORITO | | INDU |
| <3.7E-15 <3.2E-16 | >E12 | 1 | $\beta = 1.E - 4$ | 0 | 25 | ORITO | 91 91 | PLAS |
| <3.2E-16 | >E10 | 1 | $\beta > 0.05$ | 0 | 25 | ORITO | | PLA S PLA S |
| <3.8E-13 | >E10-E12 | 2, 3 1 | all $oldsymbol{eta}$ | 0 | | BERMON | 91 90 | INDU |
| <5.E-16 | | | $\beta < 1.E - 3$ | 0 | 24 | BEZRUKOV | 90 | CHER |
| | | Caty 1 | | 0 | 26 | BUCKLAND | 90 | |
| <1.8E-14 | | 1 | $\beta > 1.1E-4$ | | 27 | GHOSH | 90 | HEPT MICA |
| <1E-18 | | 1 | $3.E-4 < \beta < 1.5E-3$ | 0 | | | 90 | INDU |
| <7.2E-13 <5.E-12 | >E7 | 1 | all β 3.E-4 < β <5.E-3 | 0 | | HUBER BARISH | 90 87 | CNTR |
| | /L1 | | | 0 | 24 | BARTELT | 87 | SOUD |
| <1.E-13 | | | $1.E-5 < \beta < 1$ | 0 | | EBISU | 87 | |
| <1.E-10 | | 1 | all β | 0 | | | 87 | INDU |
| <2.E-13 | | | $1.E-4 < \beta < 6.E-4$ | | | MASEK | | HEPT |
| <2.E – 14 | | | $4.E-5 < \beta < 2.E-4$ | 0 | | NAKAMURA | 87 | PLAS |
| <2.E – 14 | | | $1.E-3 < \beta < 1$ | 0 | | NAKAMURA | 87 | PLAS |
| <5.E-14 | | | $9 E - 4 < \beta < 1 E - 2$ | 0 | | SHEPKO | 87 | CNTR |
| <2.E-13 | | - 1 | $4.E-4 < \beta < 1$ | 0 | 28 | TSUKAMOTO | | CNTR |
| <5.E-14 | | 1 | all $oldsymbol{eta}$ | 1 | | CAPLIN | 86 | INDU |
| <5.E-12 | | 1 | 75 4 . 0 | 0 | | CROMAR | 86 | INDU |
| <1.E-13 | | 1 | $7.E-4 < \beta$ | 0 | | HARA | 86 | CNTR |
| <7.E-11 | | 1 | all β | 0 | 27 | INCANDELA | 86 | INDU |
| <1.E-18 | | | $4.E-4 < \beta < 1.E-3$ | 0 | | PRICE | 86 | MICA |
| <5.E-12 | | 1 | | 0 | | BERMON | 85 | INDU |
| <6.E-12 | | 1 | | 0 | | CAPLIN | 85 | INDU |
| <6.E-10 | | 1 | | 0 | 24 | EBISU | 85 | INDU |
| < 3.E – 15 | | Caty | $5.E-5 \le \beta \le 1.E-3$ | 0 | 24 29 | KAJITA | 85 | KA MI |
| < 2.E - 21 | | Caty | $\beta < 1.E - 3$ | | 24,23 | KAJITA | 85 | KAMI |
| <3.E-15 | | Caty | $1.E-3 < \beta < 1.E-1$ | 0 | 2-1 | PARK | 85B | CNTR |
| <5.E-12 | | 1 | $1.E-4 < \beta < 1$ | 0 | | BATTISTONI | 84 | NUSX |
| <7.E-12 | | 1 | | 0 | 26 | INCANDELA | 84 | INDU |
| <7.E-13 | | 1 | $3E-4 < \beta$ | 0 | 20 | KAJINO | 84 | CNTR |
| <2.E-12 | | 1 | $3.E-4 < \beta < 1.E-1$ | 0 | | KAJINO | 84B | CNTR |
| <6.E-13 | | 1 | $5.E-4 < \beta < 1$ | 0 | 24 | KAWAGOE | 84 | CNTR |
| <2.E-14 | | | $1.E - 3 < \beta$ | 0 | | KRISH NA | 84 | CNTR |
| <4.E-13 | | 1 | | 0 | 27 | LISS | 84 | CNTR |
| <1.E-16 | | | $3 E - 4 < \beta < 1 E - 3$ | 0 | | PRICE | 84 | MICA |
| <1.E-13 | | 1 | $1.E-4 < \beta$ | 0 | | PRICE | 84B | PLAS |
| < 4.E - 13 | | 1 | $6.E-4 < \beta < 2.E-3$ | 0 | 30 | TARLE | 84 | CNTR |
| 10 | | | 15 0 . 0 . 15 0 | 7 | • | ANDERSON | 83 | EMUL |
| <4.E-13 | | 1 | $1.E-2 < \beta < 1.E-3$ | 0 | | BARTELT | 83B | CNTR |
| <1.E-12 | | 1 | $7.E - 3 < \beta < 1$ | 0 | | BARWICK | 83 | PLAS |
| <3.E-13 | | 1 | $1.E-3 < \beta < 4.E-1$ | 0 | 24 | BONARELLI | 83 | CNTR |
| <3.E-12 | | | $5 E-4 < \beta < 5 E-2$ | 0 | | BOSETTI | 83 | CNTR |
| <4.E-11 | | 1 | 15 0 . 0 .1 | 0 | | CABRERA | 83 | INDU |
| <5.E-15 | | 1 | $1.E-2 < \beta < 1$ | 0 | 24 | DOKE ERREDE | 83 | PLAS |
| < 8.E - 15 | | | $1.E-4 < \beta < 1.E-1$ | 0 | | | 83 | IMB |
| <5.E-12 | | 1 | $1.E-4 < \beta < 3.E-2$ | 0 | | GROOM | 83 | CNTR |
| <2.E-12 | | - 1 | $6.E-4 < \beta < 1$ | 0 | | MASHIMO | 83 | CNTR |
| <1.E-13 | | 1 | $\beta = 3.E - 3$ | 0 | | ALEXEYEV | 82 | CNTR |
| <2.E-12 | | 1 | $7.E - 3 < \beta < 6.E - 1$ | 0 | 31 | BONARELLI | 82 | CNTR |
| 6.E-10 | | 1 | all β | 1 | 51 | CABRERA | 82 | INDU |
| <2.E-11 | | | $1.E-2 < \beta < 1.E-1$ | 0 | | MASHIMO | 82 | CNTR |
| <2.E – 15 | s 1 | | concentrator | 0 | | BARTLETT | 81 | PLAS |
| <1.E-13 | >1 | | $1.E - 3 < \beta$ | 0 | | KINOSHITA | 81B | PLAS |
| <5.E-11 | <e17< td=""><td></td><td>$3 E - 4 < \beta < 1 E - 3$</td><td>0</td><td></td><td>ULLMAN</td><td>81</td><td>CNTR</td></e17<> | | $3 E - 4 < \beta < 1 E - 3$ | 0 | | ULLMAN | 81 | CNTR |
| <2.E-11 | . 200 | ^ | concentrator | 0 | 32 | BARTLETT | 78 | PLAS |
| 1.E-1 | >200 | 2 | | 1 | 52 | PRICE | 75 | PLAS |
| <2.E-13 | | >2 | h 141 | 0 | | FLEISCHER | 71 | PLAS |
| <1.E-19 | .15 | >2 | obsidian, mica | 0 | | FLEISCHER | 69c | PLAS |
| <5.E-15 | <15 | <3 | concentrator | 0 | | CARITHERS | 66 | ELEC |
| <2.E-11 | | | concentrator | 0 | | MALKUS | 51 | EMUL - |
| 16 HOGAN | 08 and DETI | RIXHE | 11 limits on relativisti | c m | nonop | oles are based o | n nor | iobser- |

vation of radio Cherenkov signals at the South Pole. Limits are speed-dependent.

² ABULENCIA 06k searches for high-ionizing signals in CDF central outer tracker and time-of-flight detector. For Drell-Yan $M\overline{M}$ production, the cross section limit implies M>360 GeV at 95% CL.

³ MY > 500 GeV at 195% CL.

3 AKTAS OSA model-dependent limits as a function of monopole mass shown for arbitrary mass of 60 GeV. Based on search for stopped monopoles in the H1 Al beam pipe.

 $^{^{4}\,\}mathrm{AKTAS}$ 05A limits with assumed elastic spin 0 monopole pair production.

⁵ AKTAS 05A limits with assumed inelastic spin 1/2 monopole pair production.

 $^{^{6}\,\}mathrm{KALBFLEISCH}$ 04 reports searches for stopped magnetic monopoles in Be, Al, and Pb samples obtained from discarded material from the upgrading of DØ and CDF. A large-aperture warm-bore cryogenic detector was used. The approach was an extension of the methods of KALBFLEISCH 00. Cross section results moderately model dependent; interpretation as a mass lower limit depends on possibly invalid perturbation expansion.

 $^{^7}$ KALBFLEISCH 00 used an induction method to search for stopped monopoles in pieces of the DØ $\,$ (FNAL) beryllium beam pipe and in extensions to the drift chamber aluminum support cylinder. Results are model dependent.

⁸ KALBFLEISCH 00 result is for aluminum. 9 KALBFLEISCH 00 result is for beryllium.

 $^{^{}m 10\,HE}$ 97 used a lead target and barium phosphate glass detectors. Cross-section limits are well below those predicted via the Drell-Yan mechanism.

¹¹ Multiphoton events.

¹² Cherenkov radiation polarization.

¹³ Re-examines CERN neutrino experiments.

pair of photons with high transverse energies. 15 ACCIARRI 95c finds a limit B($\!Z \to \gamma \gamma \gamma) < 0.8 \times 10^{-5} \!$ (which is possible via a monopole loop) at 95% CL and sets the mass limit via a cross section model.

¹⁷ ABBASI 10A was based on a Cherenkov signature in an array of optical modules which were sunk in the Antarctic ice cap. Limits are speed-dependent.

 $^{^{18}}$ BALESTRA 08 exposed of nuclear track detector modules totaling 400 m 2 for 4 years at BALESTRA to expose of induced track detector induced strains 40 kg stars in 10.4 years at the Chacaltaya Laboratory (5230 m) in search for intermediate-mass monopoles with $\beta > 0.05$. The analysis is mainly based on three CR39 modules. For $M > 5 \times 10^{13}$ GeV there can be upward-going monopoles as well, hence the flux limit is half that obtained for less massive monopoles. Previous experiments (e.g. MACRO and OHYA (ORITO 91)) had set limits only for M $> 1 \times 10^9$ GeV.

Set limits only for $M > 1 \times 10^{-5}$ GeV. 19 AMBROSIO 028 direct search final result for $m \ge 10^{17}$ GeV, based upon 4.2 to 9.5 years of running, depending upon the subsystem. Limit with CR39 track-etch detector extends the limit from $\beta = 4 \times 10^{-5}$ (3.1 $\times 10^{-16}$ cm $^{-2}$ sr $^{-1}$ s $^{-1}$) to $\beta = 1 \times 10^{-4}$ $(2.1 \times 10^{-16} \, \text{cm}^{-2} \, \text{sr}^{-1} \, \text{s}^{-1})$. Limit curve in paper is piecewise continuous due to different detection techniques for different β ranges.

- $^{\rm 20}\,\mathrm{A\,MBR\,OSIO}$ 02c limit for catalysis of nucleon decay with catalysis cross section of ≈ 1 mb. The flux limit increases by ~ 3 at the higher β limit, and increases to $1\times 10^{-14}~\rm cm^{-2}\,sr^{-1}\,s^{-1}$ if the catalysis cross section is 0.01 mb. Based upon 71193 hr of data with the streamer detector, with an acceptance of 4250 m 2 sr. 21 A MBROSIO 02D result for "more than two years of data." Ionization search using several
- 24 AMBROSIO 020 result for "more than two years of data." Ionization search using several subsystems. Limit curve as a function of β not given. Included in AMBROSIO 028. 22 AMBROSIO 97 global MACRO 90%CL is 0.78 $\times 10^{-15}$ at $\beta = 1.1 \times 10^{-4}$, goes through a minimum at 0.61×10^{-15} near $\beta = (1.1-2.7) \times 10^{-3}$, then rises to 0.84×10^{-15} at $\beta = 0.1$. The global limit in this region is below the Parker bound at 10^{-15} . Less stringent limits are established for $4 \times 10^{-5} < \beta < 1 \times 10^{-4}$. Limits set by various triggers and different subdetectors are given in the paper. All limits assume a catalysis cross section smaller than a few mb.
- triggers and different subdetectors are given in the paper. All limits assume a catalysis cross section smaller than a few mb. $^{23} \text{AHLEN 94 limit for dyons extends down to } \beta = 0.9E 4 \text{ and a limit of } 1.3E 14 \text{ extends to } \beta = 0.8E 4. \text{ Also see comment by PRICE 94 and reply of BARISH 94. One loophole in the AHLEN 94 result is that in the case of monopoles catalyzing nucleon decay, relativistic particles could veto the events. See AMBROSIO 97 for additional results.$
- 24 Catalysis of nucleon decay; sensitive to assumed catalysis cross section.
- ²⁵ ORITO 91 limits are functions of velocity. Lowest limits are given here.
- ²⁶Used DKMPR mechanism and Penning effect.
- 27 Assumes monopole attaches fermion nucleus.
- ²⁸ Limit from combining data of CAPLIN 86, BERMON 85, INCANDELA 84, and CABR-ERA 83. For a discussion of controversy about CAPLIN 86 observed event, see GUY 87. Also see SCHOUTEN 87. 29 Based on lack of high- energy solar neutrinos from catalysis in the sun. 30 Anomalous long-range α (4 He) tracks.

- $^{31}\,\text{CABRERA}$ 82 candidate event has single Dirac charge within $\pm 5\%.$
- 32 ALVAREZ 75, FLEISCHER 75, and FRIEDLANDER 75 explain as fragmenting nucleus. EBERHARD 75 and ROSS 76 discuss conflict with other experiments. HAGSTROM 77 reinterprets as antinucleus. PRICE 78 reassesses.

Monopole Flux — Astrophysics

| FLUA | IVIASS | CHU | CUMINIENTS | | | | |
|---------------|----------------------------------------------------------------------------------------------------------------------------|-----|---------------------|------|------------------------|------|------|
| (cm-2sr-1s-1) | (Ge V) | (g) | $(\beta = v/c)$ | EVTS | DO CUMENT ID | | TECN |
| < 1.3E - 20 | | | faint white dwarf | | 33 FREESE | 99 | ASTR |
| < 1.E - 16 | E17 | 1 | galactic field | 0 | ³⁴ ADAMS | 93 | COSM |
| <1.E-23 | | | Jovian planets | | ³³ ARAFUNE | 85 | ASTR |
| < 1.E - 16 | E15 | | solar trapping | 0 | BRACCI | 85 B | ASTR |
| < 1.E - 18 | | 1 | | 0 | ³³ HARVEY | 84 | COSM |
| < 3.E - 23 | | | neutron stars | | KOLB | 84 | ASTR |
| < 7.E - 22 | | | pulsars | 0 | ³³ FREESE | 83B | ASTR |
| < 1.E - 18 | <e18< td=""><td>1</td><td>intergalactic field</td><td>0</td><td>³³ REPHAELI</td><td>83</td><td>COSM</td></e18<> | 1 | intergalactic field | 0 | ³³ REPHAELI | 83 | COSM |
| < 1.E - 23 | | | neutron stars | 0 | ³³ DIMOPOUL | 82 | COSM |
| < 5.E - 22 | | | neutron stars | 0 | ³³ KOLB | 82 | COSM |
| <5.E -15 | >E21 | | galactic halo | | SALPETER | 82 | COSM |
| < 1.E - 12 | E19 | 1 | $\beta = 3.E - 3$ | 0 | ³⁵ TURNER | 82 | COSM |
| < 1.E - 16 | | 1 | galactic field | 0 | PARKER | 70 | COSM |
| | | | | | | | |

- ³³ Catalysis of nucleon decay.
- 34 ADAMS 93 limit based on "survival and growth of a small galactic seed field" is $10^{-16}~(m/10^{17}~{\rm GeV})~{\rm cm}^{-2}~{\rm s}^{-1}~{\rm sr}^{-1}.$ Above $10^{17}~{\rm GeV},$ limit $10^{-16}~(10^{17}~{\rm GeV}/m)$ $cm^{-2}s^{-1}sr^{-1}$ (from requirement that monopole density does not overclose the universe) is more stringent.

 35 Re-evaluates PARKER 70 limit for GUT monopoles.

Monopole Density — Matter Searches

| DENSITY | (g) | MATERIAL | EVTS | DOCUMENT ID | | TECN |
|-----------------|-------|----------------------|------|-----------------------|-----|------|
| <6.9E-6/gram | >1/3 | Meteorites and other | 0 | JEON | 95 | INDU |
| <2.E - 7/gram | >0.6 | Fe ore | 0 | ³⁶ EBISU | 87 | INDU |
| <4.6E-6/gram | > 0.5 | deep schist | 0 | KOVALIK | 86 | INDU |
| < 1.6E - 6/gram | > 0.5 | manganese nodules | 0 | ³⁷ KOVALIK | 86 | INDU |
| <1.3E-6/gram | > 0.5 | seawater | 0 | KOVALIK | 86 | INDU |
| > 1.E + 14/gram | >1/3 | iron aerosols | >1 | MIKHAILOV | 83 | SPEC |
| <6.E-4/gram | | air, seawater | 0 | CARRIGAN | 76 | CNTR |
| <5.E $-1/gram$ | >0.04 | 11 materials | 0 | CABRERA | 75 | INDU |
| <2.E-4/gram | >0.05 | moon rock | 0 | ROSS | 73 | INDU |
| <6.E – 7/gram | <140 | seawater | 0 | KOLM | 71 | CNTR |
| <1.E $-$ 2/gram | <120 | manganese nodules | 0 | FLEISCHER | 69 | PLAS |
| <1.E-4/gram | >0 | manganese | 0 | FLEISCHER | 69B | PLAS |
| <2.E – 3/gram | <1-3 | magnetite, meteor | 0 | GOTO | 63 | EMUL |
| <2.E $-$ 2/gram | | meteorite | 0 | PETUKHOV | 63 | CNTR |
| | | _ | | | | |

 36 Mass 1 \times 10^{14} –1 \times 10^{17} GeV. 37 KOVALIK 86 examined 498 kg of schist from two sites which exhibited clear mineralogical evidence of having been buried at least 20 km deep and held below the Curie temperature.

Monopole Density — Astrophysics

| DENSITY | (g) | MATERIAL | EVTS | DOCUMENT ID | | TECN |
|--------------------|----------|-----------------|------|-----------------------|----|------|
| <1.E-9/gram | 1 | sun, catalysis | 0 | ³⁸ ARAFUNE | 83 | COSM |
| <6.E - 33/nucl | 1 | moon wake | 0 | SCHATTEN | 83 | ELEC |
| < 2.E - 28/nucl | | earth heat | 0 | CARRIGAN | 80 | COSM |
| < 2.E - 4/prot | | 42cm absorption | 0 | BRODERICK | 79 | COSM |
| $< 2.E - 13/m^3$ | | moon wake | 0 | SCHATTEN | 70 | ELEC |
| 38 Catalysis of nu | cleon de | -av | | | | |

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| KRISHNA | 84 | PL 142B 99 | M.R. Krishnaswamy et al. (TATA, OSKC+) | |
| LISS PRICE | 84 84 | PR D30 884 PRL 52 1265 | T.M. Liss, S.P. Ahlen, G. Tarle (UCB, IND+) P.B. Price et al. (ROMA, UCB, IND+) | |
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| BOSETTI | 83 | PL 133B 265 | P.C. Bosetti et al. (AACH3, HAWA, TOKY) | |
| CABRERA DOKE | 83 83 | PRL 51 1933 PL 129B 370 | B. Cabrera et al. (STAN) T. Doke et al. (WASU, RIKK, TTAM, RIKEN) | |
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| BARTLETT | 78 | PR D18 2253 | D.F. Bartlett, D. Soo, M.G. White (COLO, PRIN) | |
| CARRIGAN HOFFMANN | 78 78 | PR D17 1754 LNC 23 357 | R.A. Carrigan, B.P. Strauss, G. Giacomelli (FNAL+) H. Hoffmann <i>et al.</i> (CERN, ROMA) | |
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Searches Particle Listings

Magnetic Monopole Searches, Supersymmetric Particle Searches

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| CARRIGAN 76 | PR D13 1823 | R.A. Carrigan, F.A. Nezrick, B.P. Strauss | (FNAL) |
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| | Thesis | B. Cabrera | (STAN) |
| | NP B91 279 | R.A. Carrigan, F.A. Nezrick | (FNAL) |
| | PR D3 56 | R.A. Carrigan, F.A. Nezrick | (FNAL) |
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| | LBL-4289 | P.H. Eberhard | (LBL) |
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| | PRL 35 1167 | M.W. Friedlander | (WUSL) |
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| | PR D8 5717 PR D8 698 | R.A. Carrigan, F.A. Nezrick, B.P. Strauss R.R. Ross et al. (LBI | (FNAL) ., SLAC) |
| | PR D4 3260 | | ., SLAC) |
| | SCI 167 701 | | , SLAC) |
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| | PL 38B 549 | I.I. Gurevich et al. (KIAE, NOVO | |
| | JETP 34 917 | | (KIAE+) |
| | Translated from ZETF 61 | | (|
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| FLEIS CHER 71 | PR D4 24 | R.L. Fleischer et al. | (GESC) |
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| | APJ 160 383 | E.N. Parker | (CHIC) |
| | PR D1 2245 | K.H. Schatten | (NASA) |
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| | PR 184 1393 | R.L. Fleischer et al. (GESC, UNCS | |
| | PR 184 1398 | R.L. Fleischer, P.B. Price, R.T. Woods | (GESC) |
| | JAP 41 958 | R.L. Fleischer et al. | (GESC) |
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| | NC 28 773 | E. Amaldi et al. (ROMA, UCSD | |
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Supersymmetric Particle Searches

SUPERSYMMETRY, PART I (THEORY)

Revised December 2011 by Howard E. Haber (UC Santa Cruz).

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- I.1. Introduction: Supersymmetry (SUSY) is a generalization of the space-time symmetries of quantum field theory that transforms fermions into bosons and vice versa. The existence of such a non-trivial extension of the Poincaré symmetry of ordinary quantum field theory was initially surprising, and its form is highly constrained by theoretical principles [1]. persymmetry also provides a framework for the unification of particle physics and gravity [2-5], which is governed by the Planck energy scale, $M_P \approx 10^{19}$ GeV (where the gravitational interactions become comparable in magnitude to the gauge interactions). In particular, it is possible that supersymmetry will ultimately explain the origin of the large hierarchy of energy scales from the W and Z masses to the Planck scale [6–10]. This is the so-called *gauge hierarchy*. The stability of the gauge hierarchy in the presence of radiative quantum corrections is not possible to maintain in the Standard Model, but can be maintained in supersymmetric theories.

If supersymmetry were an exact symmetry of nature, then particles and their superpartners (which differ in spin by half a unit) would be degenerate in mass. Since superpartners have not (yet) been observed, supersymmetry must be a broken symmetry. Nevertheless, the stability of the gauge hierarchy can still be maintained if the supersymmetry breaking is soft [11,12], and the corresponding supersymmetry-breaking mass parameters are no larger than a few TeV. In particular, soft-supersymmetry-breaking terms of the Lagrangian are either linear, quadratic, or cubic in the fields, with some restrictions elucidated in Ref. 11. The impact of such terms becomes negligible at energy scales much larger than the size of the supersymmetry-breaking masses. The most interesting theories of this type are theories of "low-energy" (or "weak-scale") supersymmetry, where the effective scale of supersymmetry breaking is tied to the scale of electroweak symmetry break-The latter is characterized by the Standard Model Higgs vacuum expectation value, $v \simeq 246$ GeV.

Although there are no unambiguous experimental results (at present) that require the existence of new physics at the TeV-scale, expectations of the latter are primarily based on three theoretical arguments. First, a natural explanation (i.e., one that is stable with respect to quantum corrections) of the gauge hierarchy demands new physics at the TeV-scale [10]. Second, the unification of the three Standard Model gauge couplings at a very high energy close to the Planck scale is possible if new physics beyond the Standard Model (which modifies the running of the gauge couplings above the electroweak scale) is present. The minimal supersymmetric extension of the Standard Model, where supersymmetric masses lie below a few TeV, provides simple example of successful gauge coupling unification [13]. Third, the existence of dark matter, which

makes up approximately one quarter of the energy density of the universe, cannot be explained within the Standard Model of particle physics [14]. Remarkably, a stable weakly-interacting massive particle (WIMP) whose mass and interaction rate are governed by new physics associated with the TeV-scale can be consistent with the observed density of dark matter (this is the so-called WIMP miracle, which is reviewed in Ref. 15). The lightest supersymmetric particle is a promising (although not the unique) candidate for the dark matter [16,17]. Further aspects of dark matter can be found in Ref. 18.

I.2. Structure of the MSSM: The minimal supersymmetric extension of the Standard Model (MSSM) consists of taking the fields of the two-Higgs-doublet extension of the Standard Model and adding the corresponding supersymmetric partners [19,20]. The corresponding field content of the MSSM and their gauge quantum numbers are shown in Table 1. The electric charge $Q = T_3 + \frac{1}{2}Y$ is determined in terms of the third component of the weak isospin (T_3) and the U(1) hypercharge (Y).

Table 1: The fields of the MSSM and their $SU(3)\times SU(2)\times U(1)$ quantum numbers are listed. Only one generation of quarks and leptons is exhibited. For each lepton, quark, and Higgs super-multiplet, there is a corresponding anti-particle multiplet of charge-conjugated fermions and their associated scalar partners.

| Field Content of the MSSM | | | | | | | |
|---------------------------|----------------------------------------|---------------------------------------------|-------|-------|------|--|--|
| Super- | Boson | Fermionic | | | | | |
| Multiplets | Fields | Partners | SU(3) | SU(2) | U(1) | | |
| gluon/gluino | g | \widetilde{g} | 8 | 1 | 0 | | |
| gauge/ | W^{\pm} , W^0 | \widetilde{W}^{\pm} , \widetilde{W}^{0} | 1 | 3 | 0 | | |
| gaugino | B | \widetilde{B} | 1 | 1 | 0 | | |
| slepton/ | $(\widetilde{\nu}, \widetilde{e}^-)_L$ | $(\nu, e^-)_L$ | 1 | 2 | -1 | | |
| lepton | \tilde{e}_R^- | e_R^- | 1 | 1 | -2 | | |
| squark/ | $(\widetilde{u}_L,\widetilde{d}_L)$ | $(u,d)_L$ | 3 | 2 | 1/3 | | |
| quark | \widetilde{u}_R | u_R | 3 | 1 | 4/3 | | |
| | \widetilde{d}_R | d_R | 3 | 1 | -2/3 | | |
| Higgs/ | (H_d^0,H_d^-) | $(\widetilde{H}_d^0,\widetilde{H}_d^-)$ | 1 | 2 | -1 | | |
| higgsino | (H_u^+,H_u^0) | $(\widetilde{H}_u^+,\widetilde{H}_u^0)$ | 1 | 2 | 1 | | |

The gauge super-multiplets consist of the gluons and their gluino fermionic superpartners, and the $SU(2)\times U(1)$ gauge bosons and their gaugino fermionic superpartners. The Higgs multiplets consist of two complex doublets of Higgs fields, their higgsino fermionic superpartners, and the corresponding antiparticle fields. The matter super-multiplets consist of three generations of left-handed and right-handed quarks and lepton fields, their scalar superpartners (squark and slepton fields), and the corresponding antiparticle fields. The enlarged Higgs sector of the MSSM constitutes the minimal structure needed to guarantee the cancellation of anomalies from the introduction of the higgsino superpartners. Moreover, without a second Higgs doublet, one cannot generate mass for both "up"-type and

"down"-type quarks (and charged leptons) in a way consistent with the supersymmetry [21–23].

A general supersymmetric Lagrangian is determined by three functions of the superfields (composed of the fields of the super-multiplets): the superpotential, the Kähler potential, and the gauge kinetic-energy function [5]. malizable globally supersymmetric theories, minimal forms for the latter two functions are required in order to generate canonical kinetic energy terms for all the fields. A renormalizable superpotential, which is at most cubic in the superfields, yields supersymmetric Yukawa couplings and mass terms. A combination of gauge invariance and supersymmetry produces couplings of gaugino fields to matter (or Higgs) fields and their corresponding superpartners. The (renormalizable) MSSM Lagrangian is then constructed by including all possible supersymmetric interaction terms (of dimension four or less) that satisfy $SU(3)\times SU(2)\times U(1)$ gauge invariance and B-L conservation (where B = baryon number and L = lepton number). Finally, the most general soft-supersymmetry-breaking terms are added [11,12,24]. To generate nonzero neutrino masses, extra structure is needed as discussed in Section I.8.

I.2.1. R-parity and the lightest supersymmetric particle: As a consequence of B-L invariance, the MSSM possesses a multiplicative R-parity invariance, where $R = (-1)^{3(B-L)+2S}$ for a particle of spin S [25]. Note that this implies that all the ordinary Standard Model particles have even R parity, whereas the corresponding supersymmetric partners have odd R parity. The conservation of R parity in scattering and decay processes has a crucial impact on supersymmetric phenomenology. For example, starting from an initial state involving ordinary (Reven) particles, it follows that supersymmetric particles must be produced in pairs. In general, these particles are highly unstable and decay into lighter states. However, R-parity invariance also implies that the lightest supersymmetric particle (LSP) is absolutely stable, and must eventually be produced at the end of a decay chain initiated by the decay of a heavy unstable supersymmetric particle.

In order to be consistent with cosmological constraints, a stable LSP is almost certainly electrically and color neutral [26]. (There are some model circumstances in which a colored gluino LSP is allowed [27], but we do not consider this possibility further here.) Consequently, the LSP in an R-parity-conserving theory is weakly interacting with ordinary matter, *i.e.*, it behaves like a stable heavy neutrino and will escape collider detectors without being directly observed. Thus, the canonical signature for conventional R-parity-conserving supersymmetric theories is missing (transverse) energy, due to the escape of the LSP. Moreover, as noted at the end of Section I, the LSP is a promising candidate for dark matter [16,17].

I.2.2. The goldstino and gravitino: In the MSSM, supersymmetry breaking is accomplished by including the most general renormalizable soft-supersymmetry-breaking terms consistent with the $SU(3)\times SU(2)\times U(1)$ gauge symmetry and R-parity invariance. These terms parameterize our ignorance of

the fundamental mechanism of supersymmetry breaking. If supersymmetry breaking occurs spontaneously, then a massless Goldstone fermion called the goldstino ($\widetilde{G}_{1/2}$) must exist. The goldstino would then be the LSP, and could play an important role in supersymmetric phenomenology [28].

However, the goldstino degrees of freedom are physical only in models of spontaneously-broken global supersymmetry. If supersymmetry is a local symmetry, then the theory must incorporate gravity; the resulting theory is called supergrav-In models of spontaneously-broken supergravity, the goldstino is "absorbed" by the gravitino (G) [sometimes called $\widetilde{g}_{3/2}$ in the older literature], the spin-3/2 superpartner of the graviton [30]. By this super-Higgs mechanism, the goldstino is removed from the physical spectrum and the gravitino acquires a mass $(m_{3/2})$. In processes with center-of-mass energy $E \gg m_{3/2}$, the goldstino-gravitino equivalence theorem [31] states that the interactions of the helicity $\pm \frac{1}{2}$ gravitino (whose properties approximate those of the goldstino) dominate those of the helicity $\pm \frac{3}{2}$ gravitino. The interactions of gravitinos with with other light fields can be described by a low-energy effective Lagrangian that is determined by fundamental principles (see, e.g., Ref. 32).

I.2.3. Hidden sectors and the structure of supersymmetry breaking [24]: It is very difficult (perhaps impossible) to construct a realistic model of spontaneously-broken low-energy supersymmetry where the supersymmetry breaking arises solely as a consequence of the interactions of the particles of the MSSM. An alternative scheme posits a theory consisting of at least two distinct sectors: a hidden sector consisting of particles that are completely neutral with respect to the Standard Model gauge group, and a visible sector consisting of the particles of the MSSM. There are no renormalizable tree-level interactions between particles of the visible and hidden sectors. Supersymmetry breaking is assumed to originate in the hidden sector, and its effects are transmitted to the MSSM by some mechanism (often involving the mediation by particles that comprise an additional messenger sector). Two theoretical scenarios have been examined in detail: gravity-mediated and gauge-mediated supersymmetry breaking.

Supergravity models provide a natural mechanism for transmitting the supersymmetry breaking of the hidden sector to the particle spectrum of the MSSM. In models of gravity-mediated supersymmetry breaking, gravity is the messenger of supersymmetry breaking [33–35]. More precisely, supersymmetry breaking is mediated by effects of gravitational strength (suppressed by inverse powers of the Planck mass). In this scenario, the gravitino mass is of order the electroweak-symmetry-breaking scale, while its couplings are roughly gravitational in strength [2,36]. Such a gravitino typically plays no role in supersymmetric phenomenology at colliders (except perhaps indirectly in the case where the gravitino is the LSP [37]).

In gauge-mediated supersymmetry breaking, gauge forces transmit the supersymmetry breaking to the MSSM. A typical structure of such models involves a hidden sector where supersymmetry is broken, a messenger sector consisting of particles (messengers) with $SU(3)\times SU(2)\times U(1)$ quantum numbers, and the visible sector consisting of the fields of the MSSM [38–40]. The direct coupling of the messengers to the hidden sector generates a supersymmetry-breaking spectrum in the messenger sector. Finally, supersymmetry breaking is transmitted to the MSSM via the virtual exchange of the messengers. In models of direct gauge mediation, the supersymmetry-breaking sector includes fields that carry Standard Model quantum numbers, in which case no separate messenger sector is required [41].

The gravitino mass in models of gauge-mediated supersymmetry breaking is typically in the eV range (although in some cases it can be as large as a GeV), which implies that \widetilde{G} is the LSP. In particular, the gravitino is a potential dark matter candidate (for a recent review and guide to the literature, see Ref. 17). The couplings of the helicity $\pm \frac{1}{2}$ components of \widetilde{G} to the particles of the MSSM (which approximate those of the goldstino, cf. Section I.2.3) are significantly stronger than gravitational strength and amenable to experimental collider analyses.

The concept of a hidden sector is more general than supersymmetry. *Hidden valley* models [42] posit the existence of a hidden sector of new particles and interactions that are very weakly coupled to particles of the Standard Model. The impact of a hidden valley on supersymmetric phenomenology at colliders can be significant if the LSP lies in the valley sector [43].

I.2.4. Supersymmetry and extra dimensions:

Approaches to supersymmetry breaking have also been developed in the context of theories in which the number of space dimensions is greater than three. In particular, a number of supersymmetry-breaking mechanisms have been proposed that are inherently extra-dimensional [44]. The size of the extra dimensions can be significantly larger than $M_{\rm P}^{-1}$; in some cases on the order of (TeV)⁻¹ or even larger [45,46].

For example, in one approach, the fields of the MSSM live on some brane (a lower-dimensional manifold embedded in a higher-dimensional spacetime), while the sector of the theory that breaks supersymmetry lives on a second-separated brane. Two examples of this approach are anomaly-mediated supersymmetry breaking of Ref. 47, and gaugino-mediated supersymmetry breaking of Ref. 48; in both cases supersymmetry breaking is transmitted through fields that live in the bulk (the higher-dimensional space between the two branes). This setup has some features in common with both gravity-mediated and gauge-mediated supersymmetry breaking (e.g., a hidden and visible sector and messengers).

Alternatively, one can consider a higher-dimensional theory that is compactified to four spacetime dimensions. In this approach, supersymmetry is broken by boundary conditions on the compactified space that distinguish between fermions and bosons. This is the so-called Scherk-Schwarz mechanism [49]. The phenomenology of such models can be strikingly different

from that of the usual MSSM [50]. All these extra-dimensional ideas clearly deserve further investigation, although they will not be discussed further here.

I.2.5. Split-supersymmetry: If supersymmetry is not connected with the origin of the electroweak scale, string theory suggests that supersymmetry still plays a significant role in Planck-scale physics. However, it may still be possible that some remnant of the superparticle spectrum survives down to the TeV-scale or below. This is the idea of split-supersymmetry [51], in which supersymmetric scalar partners of the quarks and leptons are significantly heavier (perhaps by many orders of magnitude) than 1 TeV, whereas the fermionic partners of the gauge and Higgs bosons have masses on the order of 1 TeV or below (presumably protected by some chiral symmetry). With the exception of a single light neutral scalar whose properties are indistinguishable from those of the Standard Model Higgs boson, all other Higgs bosons are also taken to be very heavy.

The supersymmetry breaking required to produce such a scenario would destabilize the gauge hierarchy. In particular, split-supersymmetry cannot provide a natural explanation for the existence of the light Standard-Model-like Higgs boson, whose mass lies orders below the mass scale of the heavy scalars. Nevertheless, models of split-supersymmetry can account for the dark matter (which is assumed to be the LSP) and gauge coupling unification. Thus, there is some motivation for pursuing the phenomenology of such approaches [52]. One notable difference from the usual MSSM phenomenology is the existence of a long-lived gluino [53].

I.3. Parameters of the MSSM: The parameters of the MSSM are conveniently described by considering separately the supersymmetry-conserving sector and the supersymmetry-breaking sector. A careful discussion of the conventions used in defining the tree-level MSSM parameters can be found in Ref. 54. For simplicity, consider first the case of one generation of quarks, leptons, and their scalar superpartners.

I.3.1. The supersymmetric-conserving parameters:

The parameters of the supersymmetry-conserving sector consist of: (i) gauge couplings: g_s , g, and g', corresponding to the Standard Model gauge group $SU(3)\times SU(2)\times U(1)$ respectively; (ii) a supersymmetry-conserving higgsino mass parameter μ ; and (iii) Higgs-fermion Yukawa coupling constants: λ_u , λ_d , and λ_e (corresponding to the coupling of one generation of left-and right-handed quarks and leptons, and their superpartners to the Higgs bosons and higgsinos). Because there is no right-handed neutrino (and its superpartner) in the MSSM as defined here, one cannot introduce a Yukawa coupling λ_{ν} .

I.3.2. The supersymmetric-breaking parameters:

The supersymmetry-breaking sector contains the following set of parameters: (i) gaugino Majorana masses M_3 , M_2 , and M_1 associated with the SU(3), SU(2), and U(1) subgroups of the Standard Model; (ii) five scalar squared-mass parameters for the squarks and sleptons, $M_{\widetilde{O}}^2$, $M_{\widetilde{U}}^2$, $M_{\widetilde{D}}^2$, $M_{\widetilde{L}}^2$, and $M_{\widetilde{E}}^2$

[corresponding to the five electroweak gauge multiplets, i.e., superpartners of $(u,d)_L$, u_L^c , d_L^c , $(\nu, e^-)_L$, and e_L^c , where the superscript c indicates a charge-conjugated fermion and flavor indices are suppressed]; and (iii) Higgs-squark-squark and Higgs-slepton-slepton trilinear interaction terms, with coefficients $\lambda_u A_U$, $\lambda_d A_D$, and $\lambda_e A_E$ (which define the so-called "A-parameters"). It is traditional to factor out the Yukawa couplings in the definition of the A-parameters (originally motivated by a simple class of gravity-mediated supersymmetrybreaking models [2,4]). If the A-parameters defined in this way are parametrically of the same order (or smaller) as compared to other supersymmetry-breaking mass parameters, then only the A-parameters of the third generation will be phenomenologically relevant. Finally, we add: (iv) three scalar squared-mass parameters—two of which $(m_1^2 \text{ and } m_2^2)$ contribute to the diagonal Higgs squared-masses, given by $m_1^2 + |\mu|^2$ and $m_2^2 + |\mu|^2$, and a third which contributes to the off-diagonal Higgs squared-mass term, $m_{12}^2 \equiv B\mu$ (which defines the "B-parameter").

The breaking of the electroweak symmetry $SU(2)\times U(1)$ to $U(1)_{EM}$ is only possible after introducing the supersymmetry-breaking Higgs squared-mass parameters. Minimizing the resulting tree-level Higgs scalar potential, these three squared-mass parameters can be re-expressed in terms of the two Higgs vacuum expectation values, v_d and v_u (also called v_1 and v_2 , respectively, in the literature), and the CP-odd Higgs mass A^0 (cf. Section I.5). Here, v_d [v_u] is the vacuum expectation value of the neutral component of the Higgs field H_d [H_u] that couples exclusively to down-type (up-type) quarks and leptons. Note that $v_d^2 + v_u^2 = 4m_W^2/g^2 \simeq (246 \text{ GeV})^2$ is fixed by the W mass and the gauge coupling, whereas the ratio

$$\tan \beta = v_u/v_d \tag{1}$$

is a free parameter of the model. By convention, the phases of the Higgs field are chosen such that $0 \le \beta \le \pi/2$. Equivalently, the tree-level conditions for the scalar potential minimum relate the diagonal and off-diagonal Higgs squared-masses in terms of $m_Z^2 = \frac{1}{4}(g^2 + g'^2)(v_d^2 + v_u^2)$, the angle β and the CP-odd Higgs mass m_A :

$$\sin 2\beta = \frac{2m_{12}^2}{m_1^2 + m_2^2 + 2|\mu|^2} = \frac{2m_{12}^2}{m_A^2},\tag{2}$$

$$\frac{1}{2}m_Z^2 = -|\mu|^2 + \frac{m_1^2 - m_2^2 \tan^2 \beta}{\tan^2 \beta - 1}.$$
 (3)

Note that supersymmetry-breaking mass terms for the fermionic superpartners of scalar fields and non-holomorphic trilinear scalar interactions (*i.e.*, interactions that mix scalar fields and their complex conjugates) have not been included above in the soft-supersymmetry-breaking sector. These terms can potentially destabilize the gauge hierarchy [11] in models with a gauge-singlet superfield. The latter is not present in the MSSM; hence as noted in Ref. 12, these so-called non-standard soft-supersymmetry-breaking terms are benign. However, the coefficients of these terms (which have dimensions of mass)

are expected to be significantly suppressed compared to the TeV-scale in a fundamental theory of supersymmetry-breaking. Consequently, we follow the usual approach and omit these terms from further consideration.

I.3.3. MSSM-124: The total number of independent physical parameters that define the MSSM (in its most general form) is quite large, primarily due to the soft-supersymmetry-breaking sector. In particular, in the case of three generations of quarks, leptons, and their superpartners, $M_{\widetilde{Q}}^2$, $M_{\widetilde{U}}^2$, $M_{\widetilde{D}}^2$, $M_{\widetilde{D}}^2$, $M_{\widetilde{L}}^2$, and $M_{\widetilde{E}}^2$ are hermitian 3×3 matrices, and A_U , A_D , and A_E are complex 3×3 matrices. In addition, M_1 , M_2 , M_3 , M_4 , M_5 , and M_6 are, in general, complex. Finally, as in the Standard Model, the Higgs-fermion Yukawa couplings, λ_f (f=u, d, and e), are complex 3×3 matrices that are related to the quark and lepton mass matrices via: $M_f = \lambda_f v_f/\sqrt{2}$, where $v_e \equiv v_d$ [with v_u and v_d as defined above Eq. (1)].

However, not all these parameters are physical. Some of the MSSM parameters can be eliminated by expressing interaction eigenstates in terms of the mass eigenstates, with an appropriate redefinition of the MSSM fields to remove unphysical degrees of freedom. The analysis of Ref. 55 shows that the MSSM possesses 124 independent parameters. Of these, 18 parameters correspond to Standard Model parameters (including the QCD vacuum angle $\theta_{\rm QCD}$), one corresponds to a Higgs sector parameter (the analogue of the Standard Model Higgs mass), and 105 are genuinely new parameters of the model. The latter include: five real parameters and three CPviolating phases in the gaugino/higgsino sector, 21 squark and slepton masses, 36 real mixing angles to define the squark and slepton mass eigenstates, and 40 CP-violating phases that can appear in squark and slepton interactions. The most general R-parity-conserving minimal supersymmetric extension of the Standard Model (without additional theoretical assumptions) will be denoted henceforth as MSSM-124 [56].

I.4. The supersymmetric-particle spectrum: The supersymmetric particles (sparticles) differ in spin by half a unit from their Standard Model partners. The supersymmetric partners of the gauge and Higgs bosons are fermions, whose names are obtained by appending "ino" at the end of the corresponding Standard Model particle name. The gluino is the color-octet Majorana fermion partner of the gluon with mass $M_{\tilde{q}} = |M_3|$. The supersymmetric partners of the electroweak gauge and Higgs bosons (the gauginos and higgsinos) can mix. As a result, the physical states of definite mass are model-dependent linear combinations of the charged and neutral gauginos and higgsinos, called charginos and neutralinos, respectively. Like the gluino, the neutralinos are also Majorana fermions, which provide for some distinctive phenomenological signatures [57,58]. The supersymmetric partners of the quarks and leptons are spin-zero bosons: the squarks, charged sleptons, and sneutrinos, respectively. A complete set of Feynman rules for the sparticles of the MSSM can be found in Ref. 59. The MSSM Feynman rules also are implicitly contained in a number of Feynman diagram and amplitude generation software packages (see e.g., Refs. 60–62).

I.4.1. The charginos and neutralinos: The mixing of the charged gauginos (\widetilde{W}^{\pm}) and charged higgsinos (H_u^+) and H_d^- is described (at tree-level) by a 2×2 complex mass matrix [63–65]:

$$M_C \equiv \begin{pmatrix} M_2 & \frac{1}{\sqrt{2}}gv_u \\ \frac{1}{\sqrt{2}}gv_d & \mu \end{pmatrix} . \tag{4}$$

To determine the physical chargino states and their masses, one must perform a singular value decomposition [66,67] of the complex matrix M_C :

$$U^* M_C V^{-1} = \text{diag}(M_{\widetilde{\chi}_1^+}, M_{\widetilde{\chi}_2^+}),$$
 (5)

where U and V are unitary matrices, and the right-hand side of Eq. (5) is the diagonal matrix of (non-negative) chargino masses. The physical chargino states are denoted by $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^{\pm}$. These are linear combinations of the charged gaugino and higgsino states determined by the matrix elements of U and V [63–65]. The chargino masses correspond to the singular values [66] of M_C , i.e., the positive square roots of the eigenvalues of $M_C^{\dagger}M_C$:

$$M_{\widetilde{\chi}_{1}^{+},\widetilde{\chi}_{2}^{+}}^{2} = \frac{1}{2} \left\{ |\mu|^{2} + |M_{2}|^{2} + 2m_{W}^{2} \mp \left[(|\mu|^{2} + |M_{2}|^{2} + 2m_{W}^{2})^{2} \right] \right\}$$

$$-4|\mu|^2|M_2|^2 - 4m_W^4 \sin^2 2\beta + 8m_W^2 \sin 2\beta \operatorname{Re}(\mu M_2) \bigg]^{1/2} \bigg\}, (6)$$

where the states are ordered such that $M_{\widetilde{\chi}_1^+} \leq M_{\widetilde{\chi}_2^+}$.

It is convenient to choose a convention where $\tan \beta$ and M_2 are real and positive. Note that the relative phase of M_2 and μ is meaningful. (If CP-violating effects are neglected, then μ can be chosen real but may be either positive or negative.) The sign of μ is convention-dependent; the reader is warned that both sign conventions appear in the literature. The sign convention for μ in Eq. (4) is used by the LEP collaborations [68] in their plots of exclusion contours in the M_2 vs. μ plane derived from the non-observation of $e^+e^- \to \widetilde{\chi}_1^+\widetilde{\chi}_1^-$.

The mixing of the neutral gauginos $(\widetilde{B} \text{ and } \widetilde{W}^0)$ and neutral higgsinos $(\widetilde{H}_d^0 \text{ and } \widetilde{H}_u^0)$ is described (at tree-level) by a 4×4 complex symmetric mass matrix [63,64,69,70]:

$$M_{N} \equiv \begin{pmatrix} M_{1} & 0 & -\frac{1}{2}g'v_{d} & \frac{1}{2}g'v_{u} \\ 0 & M_{2} & \frac{1}{2}gv_{d} & -\frac{1}{2}gv_{u} \\ -\frac{1}{2}g'v_{d} & \frac{1}{2}gv_{d} & 0 & -\mu \\ \frac{1}{2}g'v_{u} & -\frac{1}{2}gv_{u} & -\mu & 0 \end{pmatrix} . \quad (7)$$

To determine the physical neutralino states and their masses, one must perform a Takagi-diagonalization [66,67,71,72] of the complex symmetric matrix M_N :

$$W^T M_N W = \operatorname{diag}(M_{\widetilde{\chi}_1^0}, M_{\widetilde{\chi}_2^0}, M_{\widetilde{\chi}_3^0}, M_{\widetilde{\chi}_4^0}), \tag{8}$$

where W is a unitary matrix and the right-hand side of Eq. (8) is the diagonal matrix of (non-negative) neutralino masses. The physical neutralino states are denoted by $\tilde{\chi}_{i}^{0}$ (i = 1, ...4), where

the states are ordered such that $M_{\widetilde{\chi}_1^0} \leq M_{\widetilde{\chi}_2^0} \leq M_{\widetilde{\chi}_3^0} \leq M_{\widetilde{\chi}_4^0}$. The $\widetilde{\chi}_i^0$ are the linear combinations of the neutral gaugino and higgsino states determined by the matrix elements of W (in Ref. 63, $W=N^{-1}$). The neutralino masses correspond to the singular values of M_N (i.e., the positive square roots of the eigenvalues of $M_N^{\dagger}M_N$). Exact formulae for these masses can be found in Refs. [69] and [73]. A numerical algorithm for determining the mixing matrix W has been given by Ref. 74.

If a chargino or neutralino state approximates a particular gaugino or higgsino state, it is convenient to employ the corresponding nomenclature. Specifically, if M_1 and M_2 are small compared to m_Z and $|\mu|$, then the lightest neutralino $\tilde{\chi}_1^0$ would be nearly a pure photino, $\tilde{\gamma}$, the supersymmetric partner of the photon. If M_1 and m_Z are small compared to M_2 and $|\mu|$, then the lightest neutralino would be nearly a pure bino, \overline{B} , the supersymmetric partner of the weak hypercharge gauge boson. If M_2 and m_Z are small compared to M_1 and $|\mu|$, then the lightest chargino pair and neutralino would constitute a triplet of roughly mass-degenerate pure winos, \widetilde{W}^{\pm} , and \widetilde{W}_{3}^{0} , the supersymmetric partners of the weak SU(2) gauge bosons. Finally, if $|\mu|$ and m_Z are small compared to M_1 and M_2 , then the lightest neutralino would be nearly a pure higgsino. Each of the above cases leads to a strikingly different phenomenology. I.4.2. The squarks, sleptons and sneutrinos: For a given fermion f, there are two supersymmetric partners, f_L and f_R , which are scalar partners of the corresponding leftand right-handed fermion. (There is no $\tilde{\nu}_R$ in the MSSM.) However, in general, f_L and f_R are not mass eigenstates, since there is \widetilde{f}_L - \widetilde{f}_R mixing. For three generations of squarks, one must in general diagonalize 6×6 matrices corresponding to the basis $(\tilde{q}_{iL}, \tilde{q}_{iR})$, where i = 1, 2, 3 are the generation labels. For simplicity, only the one-generation case is illustrated in detail below. (The effects of second and third generation squark mixing can be significant and is treated in Ref. 75.)

Using the notation of the third family, the one-generation tree-level squark squared-mass matrix is given by [76]

$$M_F^2 = \begin{pmatrix} M_{\widetilde{Q}}^2 + m_q^2 + L_q & m_q X_q^* \\ m_q X_q & M_{\widetilde{R}}^2 + m_q^2 + R_q \end{pmatrix}, \qquad (9)$$

where

$$X_q \equiv A_q - \mu^*(\cot \beta)^{2T_{3q}}, \qquad (10)$$

and $T_{3q} = \frac{1}{2} [-\frac{1}{2}]$ for q = t [b]. The diagonal squared masses are governed by soft-supersymmetry-breaking squared masses $M_{\widetilde{Q}}^2$ and $M_{\widetilde{R}}^2 \equiv M_{\widetilde{U}}^2 [M_{\widetilde{D}}^2]$ for q = t [b], the corresponding quark masses m_t [m_b], and electroweak correction terms:

$$L_q \equiv (T_{3q} - e_q \sin^2 \theta_W) m_Z^2 \cos 2\beta , \quad R_q \equiv e_q \sin^2 \theta_W m_Z^2 \cos 2\beta ,$$

$$\tag{11}$$

where $e_q = \frac{2}{3}$ $[-\frac{1}{3}]$ for q = t [b]. The off-diagonal squared squark masses are proportional to the corresponding quark masses and depend on $\tan \beta$ [Eq. (1)], the soft-supersymmetry-breaking A-parameters and the higgsino mass parameter μ . The signs of the A and μ parameters are convention-dependent;

other choices appear frequently in the literature. Due to the appearance of the *quark* mass in the off-diagonal element of the squark squared-mass matrix, one expects the \tilde{q}_L – \tilde{q}_R mixing to be small, with the possible exception of the third generation, where mixing can be enhanced by factors of m_t and $m_b \tan \beta$.

In the case of third generation $\tilde{q}_L - \tilde{q}_R$ mixing, the mass eigenstates (usually denoted by \tilde{q}_1 and \tilde{q}_2 , with $m_{\tilde{q}_1} < m_{\tilde{q}_2}$) are determined by diagonalizing the 2×2 matrix M_F^2 given by Eq. (9). The corresponding squared masses and mixing angle are given by [76]:

$$\begin{split} m_{\tilde{q}_{1,2}}^2 &= \frac{1}{2} \left[\text{Tr} \, M_F^2 \mp \sqrt{(\text{Tr} M_F^2)^2 - 4 \det M_F^2} \right] \,, \\ \sin 2\theta_{\tilde{q}} &= \frac{2m_q |X_q|}{m_{\tilde{q}_2}^2 - m_{\tilde{q}_1}^2} \,. \end{split} \tag{12}$$

The one-generation results above also apply to the charged sleptons, with the obvious substitutions: $q \to \tau$ with $T_{3\tau} = -\frac{1}{2}$ and $e_{\tau} = -1$, and the replacement of the supersymmetry-breaking parameters: $M_{\widetilde{Q}}^2 \to M_{\widetilde{L}}^2$, $M_{\widetilde{D}}^2 \to M_{\widetilde{E}}^2$, and $A_q \to A_{\tau}$. For the neutral sleptons, $\widetilde{\nu}_R$ does not exist in the MSSM, so $\widetilde{\nu}_L$ is a mass eigenstate.

In the case of three generations, the supersymmetry-breaking scalar-squared masses $[M_{\widetilde{Q}}^2, M_{\widetilde{U}}^2, M_{\widetilde{D}}^2, M_{\widetilde{L}}^2]$, and $M_{\widetilde{E}}^2$ and the A-parameters that parameterize the Higgs couplings to up- and down-type squarks and charged sleptons (henceforth denoted by A_U , A_D , and A_E , respectively) are now 3×3 matrices as noted in Section I.3. The diagonalization of the 6×6 squark mass matrices yields $\tilde{f}_{iL} - \tilde{f}_{jR}$ mixing (for $i \neq j$). In practice, since the $\tilde{f}_L - \tilde{f}_R$ mixing is appreciable only for the third generation, this additional complication can often be neglected (although see Ref. 75 for examples in which the mixing between the second and third generations is relevant).

Radiative loop corrections will modify all tree-level results for masses quoted in this section. These corrections must be included in any precision study of supersymmetric phenomenol-Beyond tree level, the definition of the supersymmetric parameters becomes convention-dependent. For example, one can define physical couplings or running couplings, which differ beyond the tree level. This provides a challenge to any effort that attempts to extract supersymmetric parameters from data. The Supersymmetry Les Houches Accord (SLHA) [78] has been adopted, which establishes a set of conventions for specifying generic file structures for supersymmetric model specifications and input parameters, supersymmetric mass and coupling spectra, and decay tables. These provide a universal interface between spectrum calculation programs, decay packages, and high energy physics event generators. Ultimately, these efforts will facilitate the reconstruction of the fundamental supersymmetric theory (and its breaking mechanism) from high-precision studies of supersymmetric phenomena at future colliders.

I.5. The Higgs sector of the MSSM: Next, consider the MSSM Higgs sector [22,23,79]. Despite the large number

of potential CP-violating phases among the MSSM-124 parameters, the tree-level MSSM Higgs sector is automatically CP-conserving. That is, unphysical phases can be absorbed into the definition of the Higgs fields such that $\tan \beta$ is a real parameter (conventionally chosen to be positive). Consequently, the physical neutral Higgs scalars are CP eigenstates. The MSSM Higgs sector contains five physical spin-zero particles: a charged Higgs boson pair (H^{\pm}) , two CP-even neutral Higgs bosons (denoted by h^0 and H^0 where $m_h < m_H$), and one CP-odd neutral Higgs boson (A^0) .

I.5.1 The Tree-level MSSM Higgs sector: The properties of the Higgs sector are determined by the Higgs potential, which is made up of quadratic terms [whose squared-mass coefficients were specified above Eq. (1)] and quartic interaction terms governed by dimensionless couplings. The quartic interaction terms are manifestly supersymmetric at tree level (although these are modified by supersymmetry-breaking effects at the loop level). In general, the quartic couplings arise from two sources: (i) the supersymmetric generalization of the scalar potential (the so-called "F-terms"), and (ii) interaction terms related by supersymmetry to the coupling of the scalar fields and the gauge fields, whose coefficients are proportional to the corresponding gauge couplings (the so-called "D-terms").

In the MSSM, F-term contributions to the quartic couplings are absent (although such terms may be present in extensions of the MSSM, e.g., models with Higgs singlets). As a result, the strengths of the MSSM quartic Higgs interactions are fixed in terms of the gauge couplings. Due to the resulting constraint on the form of the two-Higgs-doublet scalar potential, all the tree-level MSSM Higgs-sector parameters depend only on two quantities: $\tan \beta$ [defined in Eq. (1)] and one Higgs mass usually taken to be m_A . From these two quantities, one can predict the values of the remaining Higgs boson masses, an angle α (which measures the component of the original $Y = \pm 1$ Higgs doublet states in the physical CP-even neutral scalars), and the Higgs boson self-couplings.

I.5.2 The radiatively-corrected MSSM Higgs sector: When radiative corrections are incorporated, additional parameters of the supersymmetric model enter via virtual loops. The impact of these corrections can be significant [80]. example, the tree-level MSSM-124 prediction for the upper bound of the lightest CP-even Higgs mass, $m_h \leq m_Z |\cos 2\beta| \leq$ m_Z [22,23], can be substantially modified when radiative corrections are included. The qualitative behavior of these radiative corrections can be most easily seen in the large topsquark mass limit, where in addition, both the splitting of the two diagonal entries and the two off-diagonal entries of the top-squark squared-mass matrix [Eq. (9)] are small in comparison to the average of the two top-squark squared masses, $M_{\rm S}^2 \equiv \frac{1}{2}(M_{\widetilde{t}_1}^2 + M_{\widetilde{t}_2}^2)$. In this case (assuming $m_A > m_Z$), the predicted upper bound for m_h (which reaches its maximum at large $\tan \beta$) is approximately given by

$$m_h^2 \lesssim m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2} \left[\ln \left(M_{\rm S}^2/m_t^2 \right) + \frac{X_t^2}{M_{\rm S}^2} \left(1 - \frac{X_t^2}{12 M_{\rm S}^2} \right) \right], \ (13)$$

where $X_t \equiv A_t - \mu \cot \beta$ is the top-squark mixing factor [see Eq. (9)].

A more complete treatment of the radiative corrections [81] shows that Eq. (13) somewhat overestimates the true upper bound of m_h . These more refined computations, which incorporate renormalization group improvement and the leading two-loop contributions, yield $m_h \lesssim 135$ GeV (with an accuracy of a few GeV) for $m_t = 175$ GeV and $M_S \lesssim 2$ TeV [81]. This Higgs-mass upper bound can be relaxed somewhat in non-minimal extensions of the MSSM, as noted in Section I.9.

In addition, one-loop radiative corrections can introduce CP-violating effects in the Higgs sector, which depend on some of the CP-violating phases among the MSSM-124 parameters [82]. Although these effects are more model-dependent, they can have a non-trivial impact on the Higgs searches at future colliders. A summary of the current MSSM Higgs mass limits can be found in Ref. 83.

I.6. Restricting the MSSM parameter freedom: In Sections I.4 and I.5, we surveyed the parameters that comprise the MSSM-124. However, in its most general form, the MSSM-124 is not a phenomenologically-viable theory over most of its parameter space. This conclusion follows from the observation that a generic point in the MSSM-124 parameter space exhibits: (i) no conservation of the separate lepton numbers L_e , L_μ , and L_τ ; (ii) unsuppressed flavor-changing neutral currents (FCNC's); and (iii) new sources of CP violation that are inconsistent with the experimental bounds.

For example, the MSSM contains many new sources of CPIn particular, some combinations of the comviolation [84]. plex phases of the gaugino-mass parameters, the A-parameters, and μ must be less than on the order of 10^{-2} – 10^{-3} (for a supersymmetry-breaking scale of 100 GeV) to avoid generating electric dipole moments for the neutron, electron, and atoms in conflict with observed data [85–87]. The non-observation of FCNC's [88-90] places additional strong constraints on the off-diagonal matrix elements of the squark and slepton softsupersymmetry-breaking squared masses and A-parameters (see Section I.3.3). As a result of the phenomenological deficiencies listed above, almost the entire MSSM-124 parameter space is ruled out! This theory is viable only at very special "exceptional" regions of the full parameter space.

The MSSM-124 is also theoretically incomplete as it provides no explanation for the origin of the supersymmetry-breaking parameters (and in particular, why these parameters should conform to the exceptional points of the parameter space mentioned above). Moreover, there is no understanding of the choice of parameters that leads to the breaking of the electroweak symmetry. What is needed ultimately is a fundamental theory of supersymmetry breaking, which would provide a rationale for a set of soft-supersymmetry-breaking terms that is consistent with all phenomenological constraints.

The successful unification of the $SU(3)\times SU(2)\times U(1)$ gauge couplings in supersymmetric grand unified theories [8,51,91,92]

suggests the possibility that the high-energy structure of the theory may be considerable simpler than its low-energy realization. The desired phenomenological constraints of the low-energy theory can often be implemented by the dynamics which govern the more fundamental theory that resides at the high energy scale.

In this Section, we examine a number of theoretical frameworks that yield phenomenologically viable regions of the the general MSSM parameter space. The resulting supersymmetric particle spectrum is then a function of a relatively small number of input parameters. This is accomplished by imposing a simple structure on the soft-supersymmetry-breaking terms at a common high-energy scale M_X (typically chosen to be the Planck scale, $M_{\rm P}$, the grand unification scale, $M_{\rm GUT}$, or the messenger scale, $M_{\rm mess}$). Using the renormalization group equations, one can then derive the low-energy MSSM parameters relevant for collider physics. The initial conditions (at the appropriate high-energy scale) for the renormalization group equations depend on the mechanism by which supersymmetry breaking is communicated to the effective low energy theory.

Examples of this scenario are provided by models of gravity-mediated and gauge-mediated supersymmetry breaking, to be discussed in more detail below. In some of these approaches, one of the diagonal Higgs squared-mass parameters is driven negative by renormalization group evolution [93]. In such models, electroweak symmetry breaking is generated radiatively, and the resulting electroweak symmetry-breaking scale is intimately tied to the scale of low-energy supersymmetry breaking.

$I. 6.1. \ \ Gaugino\ mass\ unification:$

One prediction that arises in many grand unified supergravity models and gauge-mediated supersymmetry-breaking models is the unification of the (tree-level) gaugino mass parameters at some high-energy scale M_X :

$$M_1(M_X) = M_2(M_X) = M_3(M_X) = m_{1/2}.$$
 (14)

Consequently, the effective low-energy gaugino mass parameters (at the electroweak scale) are related:

$$M_3 = (g_s^2/g^2)M_2 \simeq 3.5M_2$$
, $M_1 = (5g'^2/3g^2)M_2 \simeq 0.5M_2$. (15)

In this case, the chargino and neutralino masses and mixing angles depend only on three unknown parameters: the gluino mass, μ , and $\tan \beta$. If in addition $|\mu| \gg M_1 \gtrsim m_Z$, then the lightest neutralino is nearly a pure bino, an assumption often made in supersymmetric particle searches at colliders.

Although Eqs. (14) and (15) are often assumed in many phenomenological studies, a truly model-independent approach would take the gaugino mass parameters, M_i , to be independent parameters to be determined by experiment. For example, although LEP data yields a lower bound of 46 GeV on the mass of the lightest neutralino [94], an exactly massless neutralino cannot be ruled out today in a model-independent analysis [95].

It is possible that the tree-level masses for the gauginos are absent. In this case, the gaugino mass parameters arise at one-loop and do not satisfy Eq. (15). In supergravity, there exists a model-independent contribution to the gaugino mass whose origin can be traced to the super-conformal (super-Weyl) anomaly, which is common to all supergravity models [47]. Eq. (15) is then replaced (in the one-loop approximation) by:

$$M_i \simeq \frac{b_i g_i^2}{16\pi^2} m_{3/2} \,,$$
 (16)

where $m_{3/2}$ is the gravitino mass (assumed to be on the order of 1 TeV), and b_i are the coefficients of the MSSM gauge beta-functions corresponding to the corresponding U(1), SU(2), and SU(3) gauge groups: $(b_1,b_2,b_3)=(\frac{33}{5},1,-3)$. Eq. (16) yields $M_1\simeq 2.8M_2$ and $M_3\simeq -8.3M_2$, which implies that the lightest chargino pair and neutralino comprise a nearly mass-degenerate triplet of winos, \widetilde{W}^\pm , \widetilde{W}^0 (c.f. Table 1), over most of the MSSM parameter space. (For example, if $|\mu|\gg m_Z$, then Eq. (16) implies that $M_{\widetilde{\chi}_1^\pm}\simeq M_{\widetilde{\chi}_1^0}\simeq M_2$ [96].)

The corresponding supersymmetric phenomenology differs significantly from the standard phenomenology based on Eq. (15), and is explored in detail in Ref. 97. Under certain theoretical assumptions on the structure of the Kähler potential (the so-called sequestered form introduced in Ref. 47), anomaly-mediated supersymmetry breaking also generates (approximate) flavor-diagonal squark and slepton mass matrices. This approach is called anomaly-mediated supersymmetry breaking (AMSB). However in its simplest formulation, AMSB yields negative squared-mass contributions for the sleptons in the MSSM. It may be possible to cure this fatal flaw in approaches beyond the minimal supersymmetric model [98]. Alternatively, one can assume that anomaly-mediation is not the sole source of supersymmetry-breaking in the slepton sector.

Finally, it should be noted that the unification of gaugino masses (and scalar masses) can be accidental. In particular, the energy scale where unification takes place may not be directly related to any physical scale. This phenomenon has been called *mirage unification* and can occur in certain theories of fundamental supersymmetry-breaking [99].

I.6.2. The constrained MSSM: mSUGRA, CMSSM, ... In the minimal supergravity (mSUGRA) framework [2–4], a form of the Kähler potential is employed that yields minimal kinetic energy terms for the MSSM fields [100]. As a result, the soft-supersymmetry-breaking parameters at the high-energy scale M_X take a particularly simple form in which the scalar squared masses and the A-parameters are flavor-diagonal and universal [34]:

$$\begin{split} M_{\widetilde{Q}}^2(M_X) &= M_{\widetilde{U}}^2(M_X) = M_{\widetilde{D}}^2(M_X) = m_0^2 \mathbf{1} \,, \\ M_{\widetilde{L}}^2(M_X) &= M_{\widetilde{E}}^2(M_X) = m_0^2 \mathbf{1} \,, \\ m_1^2(M_X) &= m_2^2(M_X) = m_0^2 \,, \\ A_U(M_X) &= A_D(M_X) = A_E(M_X) = A_0 \mathbf{1} \,, \end{split} \tag{17}$$

where $\mathbf{1}$ is a 3×3 identity matrix in generation space. As in the Standard Model, this approach exhibits minimal flavor violation, whose unique source is the nontrivial flavor structure of the Higgs-fermion Yukawa couplings. The gaugino masses are also unified according to Eq. (14).

Renormalization group evolution is then used to derive the values of the supersymmetric parameters at the low-energy (electroweak) scale. For example, to compute squark masses, one must use the low-energy values for $M_{\widetilde{Q}}^2$, $M_{\widetilde{U}}^2$, and $M_{\widetilde{D}}^2$ in Eq. (9). Through the renormalization group running with boundary conditions specified in Eqs. (15) and (17), one can show that the low-energy values of $M_{\widetilde{Q}}^2$, $M_{\widetilde{U}}^2$, and $M_{\widetilde{D}}^2$ depend primarily on m_0^2 and $m_{1/2}^2$. A number of useful approximate analytic expressions for superpartner masses in terms of the mSUGRA parameters can be found in Ref. 101.

In the mSUGRA approach, one typically finds that four flavors of squarks (with two squark eigenstates per flavor) and \widetilde{b}_R are nearly mass-degenerate. The \widetilde{b}_L mass and the diagonal \widetilde{t}_L and \widetilde{t}_R masses are reduced compared to the common squark mass of the first two generations. In addition, there are six flavors of nearly mass-degenerate sleptons (with two slepton eigenstates per flavor for the charged sleptons and one per flavor for the sneutrinos); the sleptons are expected to be somewhat lighter than the mass-degenerate squarks. Finally, third-generation squark masses and tau-slepton masses are sensitive to the strength of the respective f_L - f_R mixing, as discussed below Eq. (9). The LSP is typically the lightest neutralino, $\tilde{\chi}_1^0$, which is dominated by its bino component. In particular, mSUGRA parameter regimes in which the LSP is a chargino or the $\tilde{\tau}_1$ (the lightest scalar superpartner of the τ -lepton) are not phenomenologically viable.

One can count the number of independent parameters in the mSUGRA framework. In addition to 18 Standard Model parameters (excluding the Higgs mass), one must specify m_0 , $m_{1/2}$, A_0 , the Planck-scale values for μ and B-parameters (denoted by μ_0 and B_0), and the gravitino mass $m_{3/2}$. Without additional model assumptions, $m_{3/2}$ is independent of the parameters that govern the mass spectrum of the superpartners of the Standard Model [34]. In principle, A_0 , B_0 , μ_0 , and $m_{3/2}$ can be complex, although in the mSUGRA approach, these parameters are taken (arbitrarily) to be real.

As previously noted, renormalization group evolution is used to compute the low-energy values of the mSUGRA parameters, which then fixes all the parameters of the low-energy MSSM. In particular, the two Higgs vacuum expectation values (or equivalently, m_Z and $\tan\beta$) can be expressed as a function of the Planck-scale supergravity parameters. The simplest procedure is to remove μ_0 and B_0 in favor of m_Z and $\tan\beta$ [the sign of μ_0 , denoted $\mathrm{sgn}(\mu_0)$ below, is not fixed in this process]. In this case, the MSSM spectrum and its interaction strengths are determined by five parameters:

$$m_0$$
, A_0 , $m_{1/2}$, $\tan \beta$, and $sgn(\mu_0)$, (18)

in addition to the 18 parameters of the Standard Model and an independent gravitino mass $m_{3/2}$. This framework is conventionally called the *constrained minimal sypersymmetric extension of the Standard Model* (CMSSM).

In the early literature, additional conditions were obtained by assuming a simplifying form for the hidden sector that provides the fundamental source of supersymmetry breaking. Two additional relations emerged among the mSUGRA parameters [100]: $B_0 = A_0 - m_0$ and $m_{3/2} = m_0$. These relations characterize a theory that was called minimal supergravity when first proposed. In the more recent literature, it has been more common to omit these extra conditions in defining the mSUGRA model (in which case the mSUGRA model and the CMSSM are synonymous). The authors of Ref. 102 advocate restoring the original nomenclature in which the mSUGRA model is defined with the extra conditions as originally proposed. Additional mSUGRA variations can be considered where different relations among the CMSSM parameters are imposed.

One can also relax the universality of scalar masses by decoupling the squared-masses of the Higgs bosons and the squarks/sleptons. This leads to the non-universal Higgs mass models (NUHM), thereby adding one or two new parameters to the CMSSM depending on whether the diagonal Higgs scalar squared-mass parameters $(m_1^2 \text{ and } m_2^2)$ are set equal (NUHM1) or taken to be independent (NUHM2) at the high energy scale M_X^2 . Clearly, this modification preserves the minimal flavor violation of the mSUGRA approach. Nevertheless, the mSUGRA approach and its NUHM generalizations are probably too simplistic. Theoretical considerations suggest that the universality of Planck-scale soft-supersymmetry-breaking parameters is not generic [103]. In particular, effective operators at the Planck scale exist that do not respect flavor universality, and it is difficult to find a theoretical principle that would forbid them.

I.6.3. Gauge-mediated supersymmetry breaking: In contrast to models of gravity-mediated supersymmetry breaking, the universality of the fundamental soft-supersymmetrybreaking squark and slepton squared-mass parameters is guaranteed in gauge-mediated supersymmetry breaking because the supersymmetry breaking is communicated to the sector of MSSM fields via gauge interactions [39,40]. minimal gauge-mediated supersymmetry-breaking (GMSB) approach, there is one effective mass scale, Λ , that determines all low-energy scalar and gaugino mass parameters through loop effects (while the resulting A-parameters are suppressed). In order that the resulting superpartner masses be on the order of 1 TeV or less, one must have $\Lambda \sim 100$ TeV. The origin of the μ and B-parameters is quite model-dependent, and lies somewhat outside the ansatz of gauge-mediated supersymmetry breaking. The simplest models of this type are even more restrictive than the CMSSM, with two fewer degrees of freedom. Benchmark reference points for GMSB models have been proposed in Ref. 104 to facilitate collider studies.

The minimal GMSB is not a fully realized model. The sector of supersymmetry-breaking dynamics can be very complex,

and no complete model of gauge-mediated supersymmetry yet exists that is both simple and compelling. However, advances in the theory of dynamical supersymmetry breaking (which exploit the existence of metastable supersymmetry-breaking vacua in broad classes of models [105]) have generated new ideas and opportunities for model building. As a result, simpler models of successful gauge mediation of supersymmetry breaking have been achieved with the potential for overcoming a number of long-standing theoretical challenges [106]. In addition, model-independent techniques that encompass all known gauge mediation models have been recently formulated [107]. These methods are well-suited for a comprehensive analysis [108] of the phenomenological profile of gauge-mediated supersymmetry breaking.

It was noted in Section I.2 that the gravitino is the LSP in GMSB models. As a result, the next-to-lightest supersymmetric particle (NLSP) now plays a crucial role in the phenomenology of supersymmetric particle production and decays. Note that unlike the LSP, the NLSP can be charged. In GMSB models, the most likely candidates for the NLSP are $\widetilde{\chi}_1^0$ and $\widetilde{\tau}_R^\pm$. The NLSP will decay into its superpartner plus a gravitino (e.g., $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$, $\widetilde{\chi}_1^0 \to Z \widetilde{G}$, or $\widetilde{\tau}_R^\pm \to \tau^\pm \widetilde{G}$), with lifetimes and branching ratios that depend on the model parameters.

Different choices for the identity of the NLSP and its decay rate lead to a variety of distinctive supersymmetric phenomenologies [40,109]. For example, a long-lived $\widetilde{\chi}_1^0$ -NLSP that decays outside collider detectors leads to supersymmetric decay chains with missing energy in association with leptons and/or hadronic jets (this case is indistinguishable from the standard phenomenology of the $\widetilde{\chi}_1^0$ -LSP). On the other hand, if $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$ is the dominant decay mode, and the decay occurs inside the detector, then nearly all supersymmetric particle decay chains would contain a photon. In contrast, in the case of a $\widetilde{\tau}_R^\pm$ -NLSP, the $\widetilde{\tau}_R^\pm$ would either be long-lived or would decay inside the detector into a τ -lepton plus missing energy.

I.6.4. The phenomenological MSSM: Of course, any of the theoretical assumptions described in this Section could be wrong and must eventually be tested experimentally. To facilitate the exploration of MSSM phenomena in a more model-independent way while respecting the constraints noted at the beginning of this Section, the phenomenological MSSM (pMSSM) has been introduced [110].

The pMSSM is governed by 19 independent real parameters beyond the Standard Model, which include the three gaugino masses M_1 , M_2 and M_3 , the Higgs sector parameters m_A and $\tan \beta$, the Higgsino mass parameter μ , five squark and slepton squared-mass parameters for the degenerate first and second generations $(M_{\widetilde{Q}}^2, M_{\widetilde{U}}^2, M_{\widetilde{D}}^2, (M_{\widetilde{L}}^2 \text{ and } M_{\widetilde{L}}^2)$, the five corresponding squark and slepton squared-mass parameters for the third generation, and three third-generation A-parameters $(A_t, A_b \text{ and } A_{\tau})$. Note that the first and second generation A-parameters can be neglected as their phenomenological consequences are negligible. Search strategies at the LHC for the more general pMSSM have been examined in Ref. 111.

If supersymmetric phenomena are discovered, the measurements of (low-energy) supersymmetric parameters may eventually provide sufficient information to determine the organizing principle governing supersymmetry breaking and yield significant constraints on the values of the fundamental (high-energy) supersymmetric parameters. In particular, a number of sophisticated techniques have been recently developed for analyzing experimental data to test the viability of the particular supersymmetric framework and for measuring the fundamental model parameters and their uncertainties [112].

I.7. Experimental data confronts the MSSM:

Suppose some version of the MSSM satisfies the phenomenological constraints addressed in Section I.6. What are the expectations for the magnitude of the parameters that define such a model, and are these expectations consistent with present experimental data? For details on the constraints on supersymmetric particle masses from previous collider studies at LEP and the Tevatron and the most recent constraints from LHC data, see Ref. 94. Additional constraints arise from limits on the contributions of virtual supersymmetric particle exchange to a variety of Standard Model processes [88–90].

Recent LHC data has been especially effective in ruling out the existence of colored supersymmetric particles (primarily the gluino and the first two generations of squarks) with masses below about 1 TeV in the CMSSM [113]. However, such constraints are relaxed, in some cases by as much as a factor of two, in more generic frameworks of the MSSM [114].

I.7.1 Naturalness constraints and the little hierarchy:

In Section I, weak-scale supersymmetry was motivated as a natural solution to the hierarchy problem, which could provide an understanding of the origin of the electroweak symmetry-breaking scale without a significant fine-tuning of the fundamental MSSM parameters. In this framework, the soft-supersymmetry-breaking masses must be generally of the order of 1 TeV or below [115]. This requirement is most easily seen in the determination of m_Z by the scalar potential minimum condition. In light of Eq. (3), to avoid the fine-tuning of MSSM parameters, the soft-supersymmetry breaking squared-masses m_1^2 and m_2^2 and the higgsino squared-mass $|\mu|^2$ should all be roughly of $\mathcal{O}(m_Z^2)$. Many authors have proposed quantitative measures of fine-tuning [115,116]. One of the simplest measures is the one given by Barbieri and Giudice [115],

$$\Delta_i \equiv \left| \frac{\partial \ln m_Z^2}{\partial \ln p_i} \right|, \qquad \Delta \equiv \max \ \Delta_i,$$
(19)

where the p_i are the MSSM parameters at the high-energy scale M_X , which are set by the fundamental supersymmetry-breaking dynamics. The theory is more fine-tuned as Δ becomes larger.

One can apply the fine-tuning measure to any explicit model of supersymmetry-breaking. For example, in the approaches discussed in Section I.6, the p_i are parameters of the model at the energy scale M_X where the soft-supersymmetry breaking operators are generated by the dynamics of supersymmetry breaking. Renormalization group evolution then determines the

values of the parameters appearing in Eq. (3) at the electroweak scale. In this way, Δ is sensitive to all the supersymmetry-breaking parameters of the model (see e.g. Ref. 117).

Consequently, there is a tension between the present experimental lower limits on the masses of colored supersymmetric particles [118] and the expectation that supersymmetrybreaking is associated with the electroweak symmetry-breaking scale. Moreover, this tension is exacerbated [119,120] by the experimental lower Higgs mass bound ($m_h \gtrsim 115 \text{ GeV}$) [83], which is not far from the the MSSM upper bound $(m_h \lesssim 135 \text{ GeV})$ [the dependence of the latter on the top-squark mass and mixing was noted in Section I.5.2]. If M_{SUSY} characterizes the scale of supersymmetric particle masses, then one would expect $\Delta \sim M_{\rm SUSY}^2/m_Z^2$. For example, if $M_{\rm SUSY} \sim 1$ TeV then there must be at least a $\Delta^{-1} \sim 1\%$ fine-tuning of the MSSM parameters to achieve the observed value of the Z mass. This separation of the electroweak symmetry breaking and supersymmetry breaking scales is an example of the little hierarchy problem [119,121].

However, one must be very cautious when drawing conclusions about the viability of weak-scale supersymmetry to explain the origin of electroweak symmetry breaking. First, one must decide the largest tolerable value of Δ within the framework of weak-scale supersymmetry (should it be $\Delta \sim 10$? 100? 1000?). Second, the fine-tuning parameter Δ depends quite sensitively on the assumptions of the supersymmetry-breaking dynamics (e.g. the value of M_X and relations among supersymmetry-breaking parameters in the fundamental high energy theory).

For example, in so-called focus point supersymmetry models [122], all squark masses can be as heavy as 5 TeV without significant fine-tuning. This can be attributed to a focusing behavior of the renormalization group evolution when certain relations hold among the high-energy values of the scalar squared-mass supersymmetry-breaking parameters. In this approach, the mass of the light CP-even Higgs boson can naturally be near its maximally allowed MSSM upper bound [123]. A recent reanalysis of focus-point and related models with modest fine-tuning in the context of CMSSM can be found in Ref. 124.

Among the colored superpartners, the third generation squarks generically have the most significant impact on the naturalness constraints [125], whereas their masses are the least constrained by LHC data. Hence, in the absence of any relation between third generation squarks and those of the first two generations, the naturalness constraints due to present LHC data can be considerably weaker than those obtained in the CMSSM. Indeed, models with first and second generation squark masses in the multi-TeV range do not generically require significant fine tuning. Such models have the added benefit that undesirable FCNCs mediated by squark exchange are naturally suppressed [126]. Other MSSM mass spectra that are compatible with moderate fine tuning have been investigated in Ref. 127. Moreover, one can also consider extensions of the MSSM in which the degree of fine-tuning is relaxed [128].

Finally, experimentally reported upper limits for supersymmetric particle masses are rarely model-independent. For example, mass limits for the gluino and the first and second generation squarks obtained under the assumption of the CMSSM can often be evaded in alternative or extended MSSM models, e.g., compressed supersymmetry [129] and stealth supersymmetry [130]. Moreover, experimental limits on the masses for the third generation squarks and color-neutral supersymmetric particles are less constrained than the masses of other colored supersymmetric states. The simplified models approach [131] is sometimes advertised as being more model-independent by focusing narrowly on a specific generic production process and decay chain. However this approach also depends on assumptions of the relative masses of the produced particle and decay products and the lack of interference from competing processes.

Thus, it is certainly premature in the first few years of the LHC era to conclude that weak scale supersymmetry is on the verge of exclusion.

I.7.2 Constraints from virtual exchange of supersymmetric particles

There are a number of low-energy measurements that are sensitive to the effects of new physics through supersymmetric loop effects. For example, the virtual exchange of supersymmetric particles can contribute to the muon anomalous magnetic moment, $a_{\mu} \equiv \frac{1}{2}(g-2)_{\mu}$ [132], The Standard Model prediction for a_{μ} exhibits a 3.3 σ deviation from the experimentally observed value [133], although a very recent theoretical re-analysis claims that the deviation exceeds 4σ [134].

The rare inclusive decay $b \to s\gamma$ also provides a sensitive probe to the virtual effects of new physics beyond the Standard Model. Experimental measurements of $B \to X_s + \gamma$ by the BELLE collaboration [135] are in very good agreement with the theoretical predictions of Ref. 136. In both cases, supersymmetric corrections can contribute an observable shift from the Standard Model prediction in some regions of the MSSM parameter space [137,138].

The rare decay $B_s \to \mu^+\mu^-$ is especially sensitive to supersymmetric loop effects, with some loop contributions that scale as $\tan^6 \beta$ when $\tan \beta \gg 1$ [139]. Current experimental limits [140] are within about a factor of five of the predicted Standard Model rate. The absence of a *significant* deviation in these and other *B*-physics observables from their Standard Model predictions places interesting constraints on the low-energy supersymmetry parameters [141].

I.8. Massive neutrinos in low-energy supersymmetry: In the minimal Standard Model and its supersymmetric extension, there are no right-handed neutrinos, and Majorana mass terms for the left-handed neutrinos are absent. However, given the overwhelming evidence for neutrino masses and mixing [142,143], any viable model of fundamental particles must provide a mechanism for generating neutrino masses [144]. In extended supersymmetric models, various mechanisms exist for producing massive neutrinos [145]. Although one can devise models for generating massive Dirac neutrinos [146], the

most common approaches for incorporating neutrino masses are based on *L*-violating supersymmetric extensions of the MSSM, which generate massive Majorana neutrinos. Two classes of *L*-violating supersymmetric models will now be considered.

I.8.1. The supersymmetric seesaw: Neutrino masses can be incorporated into the Standard Model by introducing $SU(3)\times SU(2)\times U(1)$ singlet right-handed neutrinos (ν_R) and super-heavy Majorana masses (typically on the order of a grand unified mass) for the ν_R . In addition, one must also include a standard Yukawa couplings between the lepton doublets, the Higgs doublet, and the ν_R . The Higgs vacuum expectation value then induces an off-diagonal ν_L - ν_R masses on the order of the electroweak scale. Diagonalizing the neutrino mass matrix (in the three-generation model) yields three superheavy neutrino states, and three very light neutrino states that are identified as the light neutrino states observed in nature. This is the seesaw mechanism [147].

The supersymmetric generalization of the seesaw model of neutrino masses is now easily constructed [148,149]. In the seesaw-extended Standard Model, lepton number is broken due to the presence of $\Delta L=2$ terms in the Lagrangian (which include the Majorana mass terms for the light and superheavy neutrinos). Consequently, the seesaw-extended MSSM conserves R-parity. The supersymmetric analogue of the Majorana neutrino mass term in the sneutrino sector leads to sneutrino-antisneutrino mixing phenomena [149,150].

I.8.2. R-parity-violating supersymmetry: A second approach to incorporating massive neutrinos in supersymmetric models is to retain the minimal particle content of the MSSM, while removing the assumption of R-parity invariance [152]. The most general R-parity-violating (RPV) model involving the MSSM spectrum introduces many new parameters to both the supersymmetry-conserving and the supersymmetry-breaking sectors. Each new interaction term violates either B or L conservation. For example, consider new scalar-fermion Yukawa couplings derived from the following interactions:

$$(\lambda_L)_{pmn}\widehat{L}_p\widehat{L}_m\widehat{E}_n^c + (\lambda_L')_{pmn}\widehat{L}_p\widehat{Q}_m\widehat{D}_n^c + (\lambda_B)_{pmn}\widehat{U}_n^c\widehat{D}_m^c\widehat{D}_n^c, (20)$$

where $p,\ m$, and n are generation indices, and gauge group indices are suppressed. In the notation above, $\hat{Q},\ \hat{U}^c,\ \hat{D}^c,\ \hat{L}$, and \hat{E}^c respectively represent $(u,d)_L,\ u^c_L,\ d^c_L,\ (\nu,\ e^-)_L$, and e^c_L and the corresponding superpartners.

The Yukawa interactions are obtained from Eq. (20) by taking all possible combinations involving two fermions and one scalar superpartner. Note that the term in Eq. (20) proportional to λ_B violates B, while the other two terms violate L. Even if all the terms of Eq. (20) are absent, there is one more possible supersymmetric source of R-parity violation. In the notation of Eq. (20), one can add a term of the form $(\mu_L)_p \hat{H}_u \hat{L}_p$, where \hat{H}_u represents the Y=1 Higgs doublet and its higgsino superpartner. This term is the RPV generalization of the supersymmetry-conserving Higgs mass parameter μ of the MSSM, in which the Y=-1 Higgs/higgsino super-multiplet

 \widehat{H}_d is replaced by the slepton/lepton super-multiplet \widehat{L}_p . The RPV-parameters $(\mu_L)_p$ also violate L.

Phenomenological constraints derived from data on various low-energy B- and L-violating processes can be used to establish limits on each of the coefficients $(\lambda_L)_{pmn}$, $(\lambda_L')_{pmn}$, and $(\lambda_B)_{pmn}$ taken one at a time [152,153]. If more than one coefficient is simultaneously non-zero, then the limits are, in general, more complicated [154]. All possible RPV terms cannot be simultaneously present and unsuppressed; otherwise the proton decay rate would be many orders of magnitude larger than the present experimental bound. One way to avoid proton decay is to impose B or L invariance (either one alone would suffice). Otherwise, one must accept the requirement that certain RPV coefficients must be extremely suppressed.

One particularly interesting class of RPV models is one in which B is conserved, but L is violated. It is possible to enforce baryon number conservation, while allowing for lepton-number-violating interactions by imposing a discrete ${\bf Z}_3$ baryon triality symmetry on the low-energy theory [155], in place of the standard ${\bf Z}_2$ R-parity. Since the distinction between the Higgs and matter super-multiplets is lost in RPV models, R-parity violation permits the mixing of sleptons and Higgs bosons, the mixing of neutrinos and neutralinos, and the mixing of charged leptons and charginos, leading to more complicated mass matrices and mass eigenstates than in the MSSM. Recent attempts to fit neutrino masses and mixing in this framework can be found in Ref. 151.

The supersymmetric phenomenology of the RPV models exhibits features that are quite distinct from that of the MSSM [152]. The LSP is no longer stable, which implies that not all supersymmetric decay chains must yield missing-energy events at colliders. Nevertheless, the loss of the missing-energy signature is often compensated by other striking signals (which depend on which R-parity-violating parameters are dominant). For example, supersymmetric particles in RPV models can be singly produced (in contrast to R-parity-conserving models where supersymmetric particles must be produced in pairs). The phenomenology of pair-produced supersymmetric particles is also modified in RPV models due to new decay chains not present in R-parity-conserving supersymmetry [152].

In RPV models with lepton number violation (these include low-energy supersymmetry models with baryon triality mentioned above), both $\Delta L = 1$ and $\Delta L = 2$ phenomena are allowed, leading to neutrino masses and mixing [156], neutrinoless double-beta decay [157], sneutrino-antisneutrino mixing [158], s-channel resonant production of sneutrinos in e^+e^- collisions [159] and charged sleptons in $p\bar{p}$ and pp collisions [160].

I.9. Extensions beyond the MSSM: Extensions of the MSSM have been proposed to solve a variety of theoretical problems. One such problem involves the μ parameter of the MSSM. Although μ is a supersymmetric-preserving parameter, it must be of order the supersymmetry-breaking scale to yield a consistent supersymmetric phenomenology. In the MSSM, one must devise a theoretical mechanism to guarantee that the

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magnitude of μ is not larger than the TeV-scale (e.g., in gravity-mediated supersymmetry, the Giudice-Masiero mechanism of Ref. 161 is the most cited explanation).

In extensions of the MSSM, new compelling solutions to the so-called μ -problem are possible. For example, one can replace μ by the vacuum expectation value of a new SU(3)×SU(2)×U(1) singlet scalar field. In such a model, the Higgs sector of the MSSM is enlarged and the corresponding fermionic higgsino superpartner is added. This is the so-called NMSSM (here, NM stands for non-minimal) [162]. There are some advantages to extending the model further by adding an additional U(1) broken gauge symmetry [163] (which yields the USSM [72]) .

Non-minimal extensions of the MSSM involving additional matter and/or Higgs super-multiplets can also yield a less restrictive bound on the mass of the lightest Higgs boson (as compared to the bound quoted in Section I.5.2). For example, MSSM-extended models consistent with gauge coupling unification can be constructed in which the upper limit on the lightest Higgs boson mass can be as high as 200—300 GeV [164] (a similar relaxation of the Higgs mass bound occurs in split supersymmetry [165] and extra-dimensional scenarios [166]).

Other MSSM extensions considered in the literature include an enlarged electroweak gauge group beyond $SU(2)\times U(1)$ [167]; and/or the addition of new, possibly exotic, matter supermultiplets (e.g., new U(1) gauge groups and a vector-like color triplet with electric charge $\frac{1}{3}e$ that appear as low-energy remnants in E₆ grand unification models [168]). A possible theoretical motivation for such new structures arises from the study of phenomenologically viable string theory ground states [169].

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SUPERSYMMETRY, PART II (EXPERIMENT)

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II.1. Introduction

Supersymmetry (SUSY) [1–9] is one of the most compelling possible extensions of the Standard Model of particle physics (SM), and a leading contender for a new principle about nature

that could be discovered at high-energy colliders such as the Large Hadron Collider (LHC).

On theoretical grounds SUSY is motivated as a generalization of space-time symmetries. A low-energy realization of SUSY, *i.e.*, SUSY at the TeV scale, is, however, not a necessary consequence. Instead, low-energy SUSY is motivated by the possible cancellation of quadratic divergences in radiative corrections to the Higgs boson mass [10–15]. Furthermore, it is intriguing that a weakly interacting, (meta)stable supersymmetric particle might make up some or all of the dark matter in the universe [16–18]. In addition, SUSY predicts that gauge couplings, as measured experimentally at the electroweak scale, unify at an energy scale $\mathcal{O}(10^{16}) \text{GeV}$ ("GUT scale") near the Planck scale [19–25].

In the minimal supersymmetric extension to the Standard Model, the so called MSSM [26,27,11], a supersymmetry transformation pairs bosons with fermions and therefore relates every particle in the SM to a supersymmetric partner with half a unit of spin difference, but otherwise with the same properties and quantum numbers. These are the "sfermions": squarks and sleptons, the "gauginos," and the partners of the Higgs doublets, the "higgsinos." The charged weak gauginos and higgsinos mix to "charginos," and the neutral ones mix to "neutralinos." The fact that such particles are not yet observed leads to the conclusion that, if supersymmetry is realized, it is a broken symmetry. A description of SUSY in the form of an effective Lagrangian with only "soft" SUSY-breaking terms and SUSY masses at the TeV scale maintains cancellation of quadratic divergences in particle physics models.

The phenomenology of SUSY is to a large extent determined by the SUSY-breaking mechanism and the SUSYbreaking scale. This determines the SUSY particle masses, the mass hierarchy, the field contents of physical particles, and their decay modes. In addition, phenomenology crucially depends on whether the multiplicative quantum number of R-parity [27], $R = (-1)^{3(B-L)+2S}$, where B and L are baryon and lepton numbers and S is the spin, is conserved or violated. If R-parity is conserved, SUSY particles, which have odd R-parity, are produced in pairs and the decays of each SUSY particle must involve an odd number of lighter SUSY particles. The lightest SUSY particle (LSP) is then stable and often assumed to be a weakly interacting massive particle (WIMP). If R-parity is violated, new terms λ_{ijk} , λ'_{ijk} and λ''_{ijk} appear in the superpotential, where ijk are generation indices; λ -type couplings appear between lepton superfields only, λ'' -type are between quark superfields only, and λ' -type couplings connect the two. R-parity violation implies lepton and/or baryon number violation. More details of the theoretical framework of SUSY are discussed elsewhere in this volume [28].

Today low-energy data from flavor physics experiments, high-precision electroweak observables as well as astrophysical data impose strong constraints on the allowed SUSY parameter space. Examples of such data include measurements of precision electroweak observables, of the anomalous magnetic

moment of the muon and of the cosmological dark matter relic density, as well as limits on rare B-meson and K-meson decays, on electric dipole moments, on proton decay, and on WIMP-nucleon scattering cross sections. These indirect constraints are often more sensitive to higher SUSY mass scales than experiments searching for direct SUSY particle (sparticle) production at colliders, but the interpretation of these results are often strongly model dependent. In contrast, direct searches for sparticle production at collider experiments are much less subject to interpretation ambiguities and therefore they play a crucial role in the discovery strategy for SUSY.

In the rest of this review we limit ourselves to direct searches, covering data analyses at LEP, HERA, the Tevatron and the LHC. With the advent of the LHC, the experimental situation is changing rapidly. Compared to earlier PDG reviews, more emphasis is given to LHC results; for more details on LEP and Tevatron constraints, see earlier PDG reviews [29]. The SUSY Higgs sector is covered elsewhere in this volume [30].

II.2. Experimental search program

The electron-positron collider LEP was operational at CERN between 1989 and 2000. In the initial phase, center-of-mass energies around the Z-peak were probed, but after 1995 the LEP experiments collected a significant amount of luminosity at higher center-of-mass energies, some 235 pb⁻¹ per experiment at $\sqrt{s} \ge 204$ GeV, with a maximum \sqrt{s} of 209 GeV.

Searches for new physics at e^+e^- colliders benefit from the clean experimental environment and the fact that momentum balance can be measured not only in the plane transverse to the beam, but also in the direction along the beam (up to the beam pipe holes), the longitudinal direction. Searches at LEP are dominated by the data samples taken at the highest center-of-mass energies. The LEP limits for electroweak gauginos and sleptons are still competitive.

Significant constraints on SUSY have been set by the CDF and D0 experiments at the Tevatron, a proton-antiproton collider at a center-of-mass energy of up to 1.96 TeV. CDF and D0 have collected integrated luminosities between 10 and 11 ${\rm fb}^{-1}$ each up to the end of collider operations in 2011.

The electron-proton collider HERA provided collisions to the H1 and ZEUS experiments between 1992 and 2007, at a center-of-mass energy up to 318 GeV. A total integrated luminosity of approximately $0.5~{\rm fb^{-1}}$ has been collected by each experiment. Since in ep collisions no annihilation process takes place, SUSY searches at HERA typically look for R-parity violating production of single SUSY particles.

The landscape of SUSY searches, however, has significantly changed since the Large Hadron Collider (LHC) at CERN has started proton-proton operation at a center-of-mass energy of 7 TeV in 2010. By the end of 2011 the experiments CMS and ATLAS had collected about 5 fb⁻¹ of integrated luminosity each, and the LHCb experiment had collected approximately 1 fb⁻¹.

Proton-(anti)proton colliders produce interactions at higher center-of-mass energies than those available at LEP, and cross sections of QCD-mediated processes are larger, which is reflected in the higher sensitivity for SUSY particles carrying color charge: squarks and gluinos. Large backgrounds, however, pose challenges to trigger and analysis. Such backgrounds are dominated by multijet production processes, including, particularly at the LHC, those of top quark production, as well as jet production in association with vector bosons. The proton momentum is shared between its parton constituents, and in each collision only a fraction of the total center-of-mass energy is available in the hard parton-parton scattering. Since the parton momenta in the longitudinal direction are not known on an event-by-event basis, momentum conservation is restricted to the transverse plane, leading to the use in the experimental analyses of transverse variables, such as the missing transverse momentum, and the transverse mass. Proton-proton collisions at the LHC differ from proton-antiproton collisions at the Tevatron in the sense that there are no valence anti-quarks in the proton, and that gluon-initiated processes play a more dominant role. The increased center-of-mass energy of the LHC compared to the Tevatron significantly extends the kinematic reach for SUSY searches. This is reflected foremost in the sensitivity for squarks and gluinos, but also for other SUSY particles.

The main production mechanisms of massive colored sparticles at hadron colliders are squark-squark, squark-gluino and gluino-gluino production; when "squark" is used "antisquark" is also implied. The typical SUSY search signature at hadron colliders contains high- $p_{\rm T}$ jets, which are produced in the decay chains of heavy squarks and gluinos, and significant missing momentum originating from the two lightest supersymmetric particles (LSP) produced at the end of the decay chain. Assuming R-parity conservation, the LSPs are neutral and weakly interacting massive particles which escape detection. Backgrounds to such searches arise from multijet events with real missing momentum, dominated by heavy flavor decays, but also from instrumental effects in multijet events such as nonuniform calorimeter response or jet mismeasurement. Selection variables designed to separate the SUSY signal from the backgrounds include $H_{\rm T},~E_{\rm T}^{\rm miss}$ and $m_{\rm eff}.$ The quantities $H_{\rm T}$ and $E_{\rm T}^{\rm miss}$ refer to the measured energy and missing transverse momentum in the event, respectively. They are usually defined as the scalar $(H_{\rm T})$ and negative vector sum $E_{\rm T}^{\rm miss}$ of the transverse jet energies or transverse calorimeter clusters energies measured in the event. The quantity m_{eff} is referred to as the effective mass of the event and is defined as $m_{\text{eff}} = H_{\text{T}} + |E_{\text{T}}^{\text{miss}}|$. The peak of the $m_{\rm eff}$ distribution for SUSY signal events correlates with the SUSY mass scale [31]. Additional reduction of multijet backgrounds can be achieved by demanding isolated leptons, multileptons or photons in the final states.

In the past few years alternative approaches have been developed to increase the sensitivity to pair production of heavy sparticles with masses around 1 TeV focusing on the kinematics of their decays, and to further suppress the background from multijet production. Prominent examples of these

new approaches are searches using the $\alpha_{\rm T}$ [32–34], razor [35], stransverse mass $(m_{\rm T2})$ [36], and contransverse mass $(m_{\rm CT})$ [37] variables.

II.3. Interpretation of results

Since the mechanism by which SUSY is broken is unknown, a general approach to SUSY via the most general soft SUSY breaking Lagrangian adds a significant number of new free parameters. For the minimal supersymmetric standard model, MSSM, *i.e.*, the model with the minimal particle content, these comprise 105 new parameters. A phenomenological analysis of SUSY searches leaving all these parameters free is not feasible. For the practical interpretation of SUSY searches at colliders several approaches are taken to reduce the number of free parameters.

One approach is to assume a SUSY breaking mechanism and lower the number of free parameters through the assumption of additional constraints. In particular, interpretations of experimental results are often done in constrained models of gravity mediated [38,39], gauge mediated [40,41], and anomaly mediated [42,43] SUSY breaking. The most popular model for interpretation of collider based SUSY searches is the constrained MSSM (CMSSM) [38,44,45], which in the literature is also referred to as minimal supergravity, or MSUGRA. The CMSSM is described by five parameters: the common sfermion mass m_0 , the common gaugino mass $m_{1/2}$, and the common trilinear coupling parameter A_0 , all expressed at the GUT scale, the ratio of the vacuum expectation values of the Higgs fields for up-type and down-type fermions $\tan \beta$, and the sign of the Higgsino mass parameter μ . In gauge mediation models, the paradigm of general gauge mediation (GGM) [46] is slowly replacing minimal gauge mediation, denoted traditionally as GMSB (gauge mediated SUSY breaking)

These constrained SUSY models are theoretically well motivated and provide a rich spectrum of experimental signatures. Therefore, they represent a useful framework to benchmark performance, compare limits or reaches and assess the expected sensitivity of different search strategies. However, with universality relations imposed on the soft SUSY-breaking parameters, they do not cover all possible kinematic signatures and mass relations of SUSY. For this reason, an effort has been made in the past years to complement the traditional constrained models with more flexible interpretation approaches.

One answer to study a broader and more comprehensive subset of the MSSM is via the phenomenological-MSSM, or pMSSM [47–49]. It is derived from the MSSM, using experimental data to eliminate parameters that are free in principle but have already been highly constrained by measurements of e.g., flavor mixing and CP-violation. This effective approach reduces the number of free parameters in the MSSM to 19, making it a practical compromise between the full MSSM and highly constrained universality models such as the CMSSM.

Even less dependent on fundamental assumptions are interpretations in terms of so-called simplified models [50–53]. Such models assume a limited set of SUSY particle production and decay modes and leave open the possibility to vary masses and other parameters freely. Therefore, simplified models enable comprehensive studies of individual SUSY topologies without limitations on fundamental kinematic properties such as masses, production cross sections, and decay modes.

The landscape of SUSY searches and corresponding interpretations continues to change rapidly and this review covers results up to March 2012. Since none of the searches performed so far have shown significant excess above the SM background prediction, the interpretation of the presented results are exclusion limits on SUSY parameter space. This review will mainly focus on limits expressed in the context of CMSSM, gauge mediation, pMSSM and various simplified models.

II.4. Exclusion limits on gluino and squark masses

Gluinos and squarks are the SUSY partners of gluons and quarks, and thus carry color charge. Although limits on squark masses of the order 100 GeV have been set by the LEP experiments, hadron collider experiments are able to set much higher mass limits. The results of the LHC experiments now dominate the search for direct squark and gluino production. Pair production of these massive colored sparticles at hadron colliders generally involve both s-channel and t-channel parton-parton interactions. Since there is a negligible amount of bottom and top quark content in the proton, top- and bottom squark production proceeds through s-channel diagrams only with small cross sections. Experimental analyses of squark and/or gluino production typically assume the first and second generation squarks to be approximately degenerate in mass.

Assuming R-parity conservation, squarks will predominantly decay to a quark and a neutralino or chargino, if kinematically allowed. Other decay modes depend on the masses of the weak gauginos and may involve heavier neutralinos or charginos. For first and second generation squarks, the simplest decay modes involve two jets and missing momentum, with potential extra jets stemming from initial state radiation (ISR) or from decay modes with longer cascades. Similarly, gluino pair production leads to four jets and missing momentum, and possibly additional jets from ISR or cascades. Associated production of a gluino and a (anti)squark is also possible, in particular if squarks and gluinos have similar masses, typically leading to three or more jets in the final state. In cascades, isolated photons or leptons may appear from the decays of sparticles such as neutralinos or charginos. Final states are thus characterized by significant missing transverse momentum, and at least two, and possibly many more high $p_{\rm T}$ jets, which can be accompanied by one or more isolated objects like photons or leptons, including τ leptons, in the final state. Table 1 shows a schematic overview of characteristic final state signatures of gluino and squark production for different mass hierarchy assumptions.

Table 1: Typical search signatures at hadron colliders for direct gluino and first- and second-generation squark production assuming different mass hierarchies.

| Mass | Main | Dominant | Typical | |
|---------------------------------------|-----------------------------------------|--------------------------------------------|--------------------------------------------------------|--|
| Hierarchy | Production | Decay | Signature | |
| $m_{\tilde{q}} << m_{\tilde{g}}$ | $	ilde{q}	ilde{q},	ilde{q}ar{	ilde{q}}$ | $\tilde{q} \to q \tilde{\chi}_1^0$ | $\geq 2 \text{ jets} + E_{\text{T}}^{\text{miss}} + X$ | |
| $m_{\tilde{q}} \approx m_{\tilde{g}}$ | $	ilde{q}	ilde{g},ar{	ilde{q}}	ilde{g}$ | $\tilde{q} \to q \tilde{\chi}_1^0$ | $\geq 3 \text{ jets} + E_{\text{T}}^{\text{miss}} + X$ | |
| | | $\tilde{g} \to q \bar{q} \tilde{\chi}_1^0$ | | |
| $m_{\tilde{q}} >> m_{\tilde{g}}$ | $	ilde{g}	ilde{g}$ | $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ | $\geq 4 \text{ jets} + E_{\text{T}}^{\text{miss}} + X$ | |

II.4.1 Exclusion limits on the gluino mass

Limits set by the Tevatron experiments on the gluino mass assume the framework of the CMSSM, with $\tan \beta = 5$ (CDF) or $\tan \beta = 3$ (D0), $A_0 = 0$ and $\mu < 0$, and amount to lower limits of about 310 GeV for all squark masses, or 390 GeV for the case $m_{\tilde{q}} = m_{\tilde{q}}$ [54,55].

At the LHC, limits on the gluino mass have been set using up to approximately 5 fb⁻¹ of data. As shown in Fig. 1, in the framework of the CMSSM, gluino masses below 800 GeV are excluded by the ATLAS collaboration for all squark masses. For equal squark and gluino masses, the limit is about 1400 GeV [56]. Similar results are reported by the CMS collaboration [57]. These limits are dominated by hadronic searches, which veto any contribution from isolated leptons and, for CMS, isolated photons. Although these results are derived for $\tan \beta = 10$, $A_0 = 0$, and $\mu > 0$, they are only mildly dependent on the choice of these CMSSM parameters.

In a simplified model, assuming only gluino pair production and a single decay chain of $\tilde{g} \to q\bar{q} \tilde{\chi}^0_1,$ upper limits on gluino pair production are derived as a function of the gluino and neutralino (LSP) mass. As shown in Fig. 2, using the next to leading order cross section for gluino pair production as reference, the CMS collaboration excludes in this simplified model gluino masses below 900 GeV, for a massless neutralino. In scenarios where neutralinos are not very light, the efficiency of analyses is reduced by the fact that jets are less energetic, and there is less missing transverse momentum in the event. Therefore, limits on gluino masses are strongly affected by the assumption of the neutralino mass. For example, for a gluino mass of around 1 TeV the upper limit on the gluino pair production cross section in this simplified model ranges from a few 10^{-2} pb for a massless neutralino to about 1 pb for a neutralino of ≈ 800 GeV. Furthermore, for neutralino masses above 300 - 400 GeV no general limit on the gluino mass can be set. Similar results have been obtained by ATLAS [60].

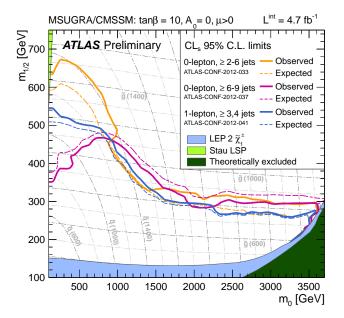
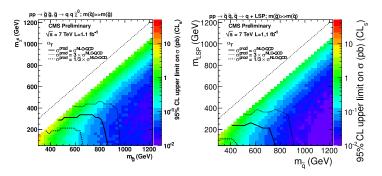


Figure 1: Limits, at 95% C.L., on the CMSSM parameters m_0 and $m_{1/2}$ derived from multi-jet analysis [56,58] and an analysis of jets and one isolated lepton [59] by the ATLAS experiment, for tan $\beta = 10$, $A_0 = 0$ and $\mu > 0$.



Upper limits, at 95% C.L., on the Figure 2: cross section of gluino pair production (left) or first- or second generation squark pair production (right) set by the CMS collaboration defined in the framework of simplified models assuming a single decay chain of $\tilde{g} \to q\bar{q}\tilde{\chi}_1^0$ (left) or $\tilde{q} \to q \tilde{\chi}_1^0$ (right). The contours illustrate where the reference cross section, calculated at next to leading order, and the upper limit on the cross section intersect. The reference cross section is scaled by a factor 3 or 1/3 to illustrate the effect of cross section or branching ratio variations. The diagonal part of $m_{\tilde{q}/\tilde{q}} - m_{\tilde{\chi}^0_1} < 200 \text{ GeV}$ is not kinematically accessible for the analysis and therefore no limit is provided.

If the gluino decay is suppressed, for example if squark masses are high, gluinos may live longer than typical hadronization times. It is expected that such gluinos will hadronize to semi-stable strongly interacting particles known as R-hadrons. Searches for R-hadrons exploit the typical signature of stable charged massive particles in the detector. As shown in Fig. 3, the CMS experiment excludes semi-stable gluino R-hadrons with masses below approximately 1 TeV [61]. The limits depend on the probability for gluinos to form bound states known as gluinoballs, as these are neutral and not observed in the tracking detectors. Similar limits are obtained by the ATLAS experiment [62].

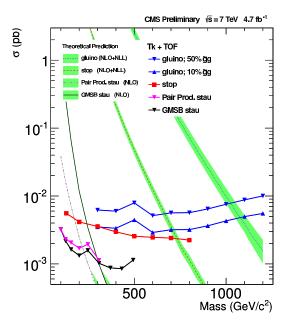


Figure 3: Observed 95% C.L. upper limits on the cross section for different combinations of models and scenarios considered: pair production of semi-stable tau sleptons, top squarks or gluinos. For gluinos, different fractions of gluinoball states produced after hadronization scenarios are indicated. The observed limits are compared with the predicted theoretical cross sections where the bands represent the theoretical uncertainties on the cross section values.

Alternatively, since such R-hadrons are strongly interacting, they may be stopped in the calorimeter or in other material, and decay later into energetic jets. These decays are searched for by identifying the jets outside the time window associated with bunch-bunch collisions [63–65]. The CMS analysis sets limits at 95% C.L. on gluino production over 13 orders of magnitude of gluino lifetime. For a mass difference $m_{\tilde{g}} - m_{\tilde{\chi}_1^0} > 100$ GeV, assuming a 100% branching fraction for gluino decay to gluon + neutralino, gluinos with lifetimes from 10 μ s to 1000 s and $m_{\tilde{g}} < 600$ GeV are excluded.

II.4.2. Exclusion limits on first and second generation squark masses

Limits on first and second generation squark masses set by the Tevatron experiments assume the CMSSM model, and amount to lower limits of about 380 GeV for all gluino masses, or 390 GeV for the case $m_{\tilde{q}} = m_{\tilde{q}}$ [54,55].

At the LHC, limits on squark masses have been set using up to approximately 5 fb⁻¹ of data. As for limits on the gluino mass, the highest sensitivity on squark production is obtained from fully-hadronic searches. As shown in Fig. 1, the ATLAS collaboration [56] excludes in the framework of the CMSSM squark masses below 1300 GeV for all gluino masses; for equal squark and gluino masses, the limit is about 1400 GeV. The limits obtained by CMS [57] are again very similar.

An interpretation of the CMS analysis using a simplified model characterizing squark pair production with only one decay chain of $\tilde{q} \to q \tilde{\chi}^0_1$ yields an exclusion of squark masses below 750 GeV for a massless neutralino (see Fig. 2). The effects of heavy neutralinos on squark limits are similar to those discussed in the gluino case (see section "Exclusion limits on the gluino mass") and only for neutralino masses below 200-300 GeV squark masses can be excluded.

The ATLAS analysis [56] is also interpreted in the framework of a simplified model with only squark and gluino production, for a massless neutralino, and assuming that all other sparticles are very massive. Results are shown in Fig. 4. In this interpretation, squark masses below 1500 GeV are excluded for $m_{\tilde{g}} \approx m_{\tilde{q}}$, while for large gluino masses the limit is reduced to about 1400 GeV in squark mass. Increasing the neutralino mass to values above ~ 200 GeV again leads to a degradation of these limits.

An overview of exclusion limits on first and second generation squark and gluino masses from CMS for different simplified models [66] is shown in Fig. 5. Like for the other simplified model limits, the reference cross sections for the different processes are calculated at next to leading order precision. To illustrate the impact of the neutralino mass on the limits, two mass scenarios for $m_{\tilde{\chi}_1^0} = 0$ GeV (dark blue) and $m_{\text{mother}} - m_{\tilde{\chi}_1^0}$ = 200 GeV (light blue) are presented. As expected, the simplified model exclusion limits vary strongly with the assumption on the mass splitting $(m_{\text{mother}} - m_{\tilde{\chi}_{1}^{0}})$ between the mother sparticle and LSP. The exclusion limits are strongest for maximal mass splitting and significantly weaken for more compressed spectra. Depending on the simplified model, the least stringent limits for compressed spectra are in the range of 400 GeV to 550 GeV, while the most stringent ones for maximal splitting are in the range of 650 GeV to 900 GeV. The corresponding results of ATLAS are very similar [67].

A summary of the most important first generation squark and gluino mass limits for different interpretations assuming R-parity conservation is shown in Table 2.

Supersymmetric Particle Searches

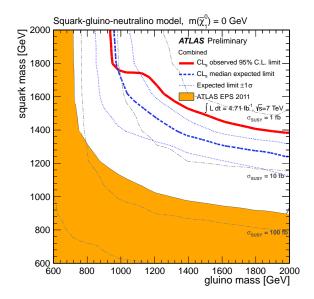


Figure 4: Limits on the masses of gluinos and first and second generation squarks, at 95% C.L., derived by ATLAS using simplified models with a massless neutralino, and assuming that the masses of all other SUSY particles are very large.

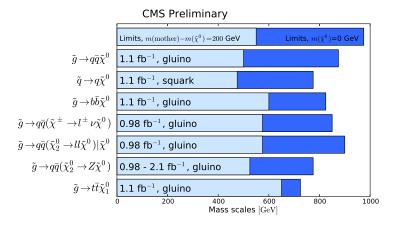


Figure 5: Exclusion limits, at 95% C.L., on first- or second generation squark and gluino masses from CMS for different simplified models. The reference cross sections for gluino and squark pair production are calculated at next to leading order precision and the branching fraction of their decays to daughter particles is assumed to be 100%. To show the impact of the neutralino mass on the limits, two mass scenarios are displayed: $m_{\tilde{\chi}_1^0} = 0$ GeV (dark blue) and $m_{\rm mother} - m_{\tilde{\chi}_1^0} = 200$ GeV (light blue).

R-parity violating production of single squarks via a λ' -type coupling has been studied at HERA. In such models, a lower limit on the squark mass of the order of 275 GeV has been set for electromagnetic-strength-like couplings $\lambda' = 0.3$ [68].

Table 2: Summary of first- or second generation squark mass and gluino mass limits using different interpretation approaches assuming R-parity conservation. Masses in this table are provided in GeV.

| Model | Assumption | $m_{	ilde{q}}$ | $m_{	ilde{g}}$ |
|-----------------------------------------|-----------------------------------------------------------------|----------------|----------------|
| | $m_{\tilde{q}} \approx m_{\tilde{g}}$ | 1400 | 1400 |
| CMSSM | all $m_{\tilde{q}}$ | - | 800 |
| | all $m_{\tilde{g}}$ | 1300 | - |
| Simplified model $\tilde{g}\tilde{g}$ | $m_{\tilde{\chi}_{1}^{0}} = 0$ | - | 900 |
| | $m_{\tilde{\chi}_1^0} > 300$ | - | no limit |
| Simplified model $\tilde{q}\tilde{q}$ | $m_{\tilde{\chi}_{1}^{0}} = 0$ | 750 | - |
| | $m_{\tilde{\chi}_1^0} > 250$ | no limit | - |
| Simplified model | $m_{\tilde{\chi}_1^0} = 0, m_{\tilde{q}} \approx m_{\tilde{g}}$ | 1500 | 1500 |
| $	ilde{g}	ilde{q},	ilde{g}ar{	ilde{q}}$ | $m_{\tilde{\chi}_1^0} = 0$, all $m_{\tilde{g}}$ | 1400 | - |
| | $m_{\tilde{\chi}_1^0} = 0$, all $m_{\tilde{q}}$ | - | 900 |

II.4.3. Exclusion limits on third generation squark masses

TeV-scale SUSY is often motivated by naturalness arguments, most notably as a solution to stabilize quadratic divergences in radiative corrections to the Higgs boson mass. In this context, the most relevant terms for SUSY phenomenology arise from the interplay between the masses of the third generation squarks and the (large) Yukawa coupling of the top quark to the Higgs boson. This motivates a potential constraint on the masses of the top squarks and the left-handed bottom squark. Due to the large top quark mass, significant mixing between $\tilde{t}_{\rm L}$ and $\tilde{t}_{\rm R}$ is expected, leading to a lighter mass state $\tilde{t}_{\rm 1}$ and a heavier mass state $\tilde{t}_{\rm 2}$. In much of MSSM parameter space, the lightest top squark ($\tilde{t}_{\rm 1}$) is also the lightest squark. Top squark masses below the top quark mass are not excluded.

In the absence of a SUSY discovery so far, searches for third generation squark production have become a major focus. Direct- and gluino mediated top and/or bottom squark production processes, leading to experimental signatures that are rich in jets originating from bottom quarks (b-jets), are either subject of re-interpretation of inclusive analyses or targets for dedicated third generation squark searches. This review contains results up to March 2012, but more results from the LHC experiments on the 2011 data sample are expected.

The top squark decay modes depend on the SUSY mass spectrum. If kinematically allowed, $\tilde{t} \to t \tilde{\chi}^0$ and $\tilde{t} \to b \tilde{\chi}^\pm$ are expected to dominate. If not, $\tilde{t} \to b f \bar{f}' \tilde{\chi}^0$ (where f and \bar{f}' denote a fermion-antifermion pair with appropriate quantum numbers) or the two-body decay $\tilde{t} \to c \tilde{\chi}^0$ is open. For light sneutrinos, $\tilde{t} \to b \ell \tilde{\nu}$ needs to be taken into account.

Limits from LEP on the \tilde{t}_1 mass are > 96 GeV in the charm plus neutralino final state, and > 93 GeV in the lepton, b-quark and sneutrino final state [69].

Direct production of top squark pairs at hadron colliders is suppressed with respect to first generation squarks, due to the absence of t-quarks in the proton. At the LHC, for example, this suppression is typically a factor 100 at $m_{\tilde{t}}=600$ GeV. Moreover, at the LHC, there is a very large background of top quark pair production, making experimental analysis of top squark pair production a challenge.

The Tevatron experiments have performed a number of searches for top squarks, often assuming direct pair production. In the $b\ell\tilde{\nu}$ decay channel, and assuming a 100% branching fraction, limits are set as $m_{\tilde{t}} > 210 \text{ GeV}$ for $m_{\tilde{\nu}} < 110 \text{ GeV}$ and $m_{\tilde{t}} - m_{\tilde{\nu}} > 30 \text{ GeV}, \text{ or } m_{\tilde{t}} > 235 \text{ GeV for } m_{\tilde{\nu}} < 50 \text{ GeV } [70,71].$ In the $\tilde{t} \to c\tilde{\chi}^0$ decay mode, a top squark with a mass below 180 GeV is excluded for a neutralino lighter than 95 GeV [72,73]. In both analyses, no limits on the top squark can be set for heavy sneutrinos or neutralinos. In the $\tilde{t} \to b\tilde{\chi}_1^{\pm}$ decay channel, searches for a relatively light top squark have been performed in the dilepton final state [74,75]. CDF sets limits in the $\tilde{t} - \tilde{\chi}_1^0$ mass plane for various branching fractions of the chargino decay to leptons and for two values of $m_{\tilde{\chi}_1^{\pm}}$. For $m_{\tilde{\chi}_1^{\pm}} = 105.8 \text{ GeV}$ and $m_{\tilde{\chi}^0_+} = 47.6$ GeV, top squarks between 128 and 135 GeV are excluded for W-like leptonic branching fractions of the chargino.

Top squarks may also be the product of gluino decays, if kinematically allowed: $\tilde{g} \to \tilde{t}t$. This leads to the characteristic "four tops" final state $tttt\tilde{\chi}_1^0\tilde{\chi}_1^0$, *i.e.*, a signature with as many as four isolated leptons, four b-jets, several light quark jets, and significant missing momentum from the neutrinos in the W decay and the two neutralinos. At the LHC, such final states are searched for in analyses demanding b-tagged jets and a lepton, or two leptons of the same charge (same-sign leptons), or many jets plus large missing momentum [76–78].

The interpretation of the results is performed in simplified models assuming specific decay modes, and MSSM production cross sections. Assuming the top squark is light enough, a simplified model with the decay chain $\tilde{g} \to \tilde{t}t$ and $\tilde{t} \to t\tilde{\chi}_1^0$ is used to characterize the reach of the searches, with gluino mass, stop mass and neutralino mass as free parameters. As shown in Fig. 6, a CMS search for same-sign lepton production accompanied with b-jets excludes gluino masses below some 850 GeV for top squark masses up to 650 GeV [78].

Taking into account top squark decay via $\tilde{t} \to t \tilde{\chi}_1^0$, and thus assuming $\tilde{g} \to t \bar{t} \tilde{\chi}_1^0$, as shown in Fig. 7, an ATLAS analysis searching for multijet plus $E_{\rm T}^{\rm miss}$ final states excludes gluino masses below 880(830) GeV for $m_{\tilde{\chi}_1^0} < 100(200)$ GeV [58]. For neutralino masses above 250 GeV, no limit can be placed on the top squark mass for this scenario.

R-parity violating production of single top squarks has been searched for at HERA [79]. Top squarks are assumed to be produced via a λ' coupling and decay either to $b\tilde{\chi}_1^{\pm}$ or R-parity-violating to a lepton and a jet. Limits are set on λ'_{131} as a function of the top squark mass in an MSSM framework with gaugino mass unification at the GUT scale. Within a variant of the CMSSM with R-parity violation, and assuming $\tan \beta = 6$, $A_0 = 0$, $\mu < 0$, a top squark with mass below 260 GeV is excluded for $\lambda' = 0.3$.

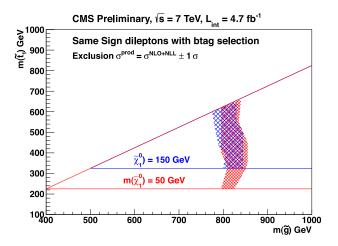


Figure 6: 95% C.L. exclusion in the stop-gluino mass plane for different choices of the neutralino mass. The used simplified model assumes the decay chain $\tilde{g} \to \tilde{t}t$, $\tilde{t} \to t\tilde{\chi}^0_1$. The bands represent the theoretical uncertainty on the gluino pair production cross-section.

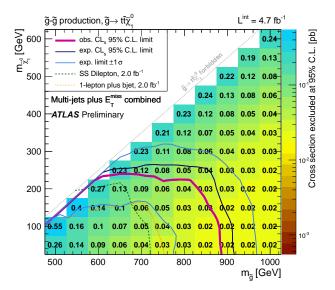


Figure 7: 95% C.L. upper limits on the cross section for gluino pair production as a function of gluino and neutralino mass. The used simplified model assumes the decay $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$. The contours illustrate where the reference cross section and the upper limit on the cross section intersect. Apart from the limit of the multijet analysis, also limits arising from a same-sign dilepton analysis, and a lepton plus b-jet analysis are shown.

Top squarks can also be long-lived and hadronize to a R-hadron, for example in the scenario where the top squark is the next-to-lightest SUSY particle (NLSP), with a small mass difference to the LSP. Searches for massive stable charged particles are sensitive to such top squarks. As shown in Fig. 3

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for the CMS analysis [61], the LHC experiments have set limits $m_{\tilde{t}} > 720$ GeV in such scenarios, surpassing the earlier Tevatron limits of about 300 GeV [80,81].

Bottom squarks are expected to decay predominantly to $b\tilde{\chi}^0$. Direct production of bottom squark pairs has been studied at the Tevatron and at the LHC. Limits from the Tevatron are $m_{\tilde{b}} > 247$ GeV for a massless neutralino [82,83]. The LHC experiments now surpass these limits; as shown in Fig. 8, ATLAS has set a limit of $m_{\tilde{b}} > 392$ GeV for the same scenario, and $m_{\tilde{b}} > 375$ GeV for $m_{\tilde{\chi}^0_1} < 100$ GeV [84].

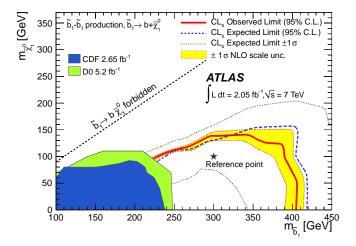


Figure 8: 95% C.L. exclusion contours in the sbottom-neutralino mass plane, for direct bottom squark pair production followed by the decay $\tilde{b} \to b \tilde{\chi}_1^0$.

Gluino pair production followed by $\tilde{g} \to b\tilde{b}$ has been searched for [85–86], and results exclude a gluino with a mass below 920 GeV for sbottom masses below 750 GeV and a light neutralino. Interpreting this search in a simplified model for gluino pair production and $\tilde{g} \to b\bar{b}\chi_1^0$ excludes a gluino with a mass below 900 GeV for neutralino masses below 300 GeV.

II.5. Exclusion limits on slepton masses

In models with slepton and gaugino mass unification at the GUT scale, the right-handed slepton, $\tilde{\ell}_{\rm R}$, is expected to be lighter than the left-handed slepton, $\tilde{\ell}_{\rm L}$. For tau sleptons there may be considerable mixing between the L and R states, leading to a significant mass difference between the lighter $\tilde{\tau}_1$ and the heavier $\tilde{\tau}_2$.

II.5.1. Exclusion limits on the masses of charged sleptons

The cleanest searches for selectrons, smuons and staus originate from the LEP experiments [87]. Smuon production only takes place via s-channel γ^*/Z exchange. Search results are often quoted for $\tilde{\mu}_{\rm R}$, since it is typically lighter than $\tilde{\mu}_{\rm L}$ and has a weaker coupling to the Z boson; limits are therefore conservative. Decays are expected to be dominated by

 $\tilde{\mu}_{\rm R} \to \mu \tilde{\chi}_1^0$, leading to two non-back-to-back muons and missing momentum. Limits are calculated in the MSSM under the assumption of gaugino mass unification at the GUT scale, and depend on the mass difference between the smuon and $\tilde{\chi}_1^0$. A $\tilde{\mu}_{\rm R}$ with a mass below 94 GeV is excluded for $m_{\tilde{\mu}_{\rm R}} - m_{\tilde{\chi}_1^0} > 10$ GeV. The selectron case is similar to the smuon case, except that an additional production mechanism is provided by t-channel neutralino exchange. The $\tilde{e}_{\rm R}$ lower mass limit is 100 GeV for $m_{\tilde{\chi}_1^0} < 85$ GeV. Due to the t-channel neutralino exchange, $\tilde{e}_{\rm R}\tilde{e}_{\rm L}$ pair production was possible at LEP, and a lower limit of 73 GeV was set on the selectron mass regardless of the neutralino mass. The potentially large mixing between $\tilde{\tau}_{\rm L}$ and $\tilde{\tau}_{\rm R}$ not only makes the $\tilde{\tau}_1$ light, but also decreases its coupling to the Z boson. LEP limits range between 87 and 93 GeV depending on the $\tilde{\chi}_1^0$ mass, for $m_{\tilde{\tau}} - m_{\tilde{\chi}_1^0} > 7$ GeV [87].

In gauge-mediated SUSY breaking models, sleptons can be (co-)NLSPs, i.e., the next-to-lightest SUSY particles and almost degenerate in mass, decaying to a lepton and a gravitino. This decay can either be prompt, or the slepton can have a non-zero lifetime. Combining several analyses, lower mass limits on $\tilde{\mu}_{\rm R}$ of 96.3 GeV and on \tilde{e}_{R} of 66 GeV are set for all slepton lifetimes at LEP [88]. In a considerable part of parameter space in these models, the $\tilde{\tau}$ is the NLSP. The LEP experiments have set lower limits on the mass of such a $\tilde{\tau}$ between 87 and 97 GeV, depending on the $\tilde{\tau}$ lifetime. ATLAS has searched for final states with τ s, jets and missing transverse momentum, and has interpreted the results in GMSB models setting limits on the model parameters [89,90]. CMS has interpreted a multilepton analysis in terms of limits on gauge mediation models with slepton (co-)NLSP [91].

Limits also exist on sleptons in R-parity violating models, both from LEP and the Tevatron experiments. From LEP, lower limits on $\tilde{\mu}_R$ and \tilde{e}_R masses in such models are 97 GeV, and the limits on the stau mass are very close: 96 GeV [92].

Charged slepton decays may be kinematically suppressed, for example in the scenario of a NLSP slepton with a very small mass difference to the LSP. Such a slepton may appear to be a stable charged massive particle. Interpretation of searches at LEP for such signatures within GMSB models with stau NLSP or slepton co-NLSP exclude masses up to 99 GeV [93]. Searches of stable charged particles at the Tevatron [80,81] and at the LHC [94,61] are also interpreted in terms of limits on stable charged sleptons. As shown in Fig. 3, CMS excludes stable staus with masses below approximately 300 GeV [61].

II.5.2. Exclusion limits on sneutrino masses

The invisible width of the Z boson puts a lower limit on the sneutrino mass of about 45 GeV. Tighter limits are derived from other searches, notably for gauginos and sleptons, under the assumption of gaugino and sfermion mass universality at the GUT scale, and amount to approximately 94 GeV in the MSSM. It is possible that the lightest sneutrino is the LSP; however, a lefthanded sneutrino LSP is ruled out as a cold dark matter candidate [95,96].

Production of pairs of sneutrinos in R-parity violating models has been searched for at LEP [92]. Assuming fully leptonic decays via λ -type couplings, lower mass limits between 85 and 100 GeV are set. At the Tevatron [97,98] and at the LHC [99], searches have focused on scenarios with resonant production of a sneutrino, decaying to $e\mu$ final states (as well as to $\mu\tau$, and $e\tau$ for CDF). No signal has been seen, and limits have been set on sneutrino masses as a function of the value of relevant RPV couplings. As an example, the ATLAS analysis excludes a resonant tau sneutrino with a mass below 600 GeV for $\lambda_{312} > 0.01$ and $\lambda'_{311} > 0.01$ [99].

II.6. Exclusion limits on the masses of charginos and neutralinos

Charginos and neutralinos result from mixing of the charged wino and higgsino states, and the neutral bino, wino and higgsino states, respectively. The mixing is determined by a limited number of parameters. For charginos these are the wino mass parameter M_2 , the Higgsino mass parameter μ , and $\tan \beta$, and for neutralinos these are the same parameters plus the bino mass parameter M_1 . The mass states are four charginos $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_{2}^{\pm}$, and four neutralinos $\tilde{\chi}_{1}^{0}$, $\tilde{\chi}_{2}^{0}$, $\tilde{\chi}_{3}^{0}$ and $\tilde{\chi}_{4}^{0}$, ordered in increasing mass. Depending on the mixing, the chargino and neutralino composition is dominated by specific states, which are referred to as bino-like $(M_1 \ll M_2, \mu)$, wino-like $(M_2 \ll M_1, \mu)$, or Higgsino-like ($\mu \ll M_1, M_2$). If gaugino mass unification at the GUT scale is assumed, a relation between M_1 and M_2 at the electroweak scale follows: $M_1 = 5/3 \tan^2 \theta_W M_2 \approx 0.5 M_2$ (with θ_W the weak mixing angle), with consequences for the chargino-neutralino mass relation after mixing. Charginos and neutralinos carry no color charge, and only have electroweak couplings (neglecting gravity).

II.6.1. Exclusion limits on chargino masses

If kinematically allowed, two body decay modes such as $\tilde{\chi}^{\pm} \to \ell^{\pm} \tilde{\nu}$ are dominant. If not, three body decay $\tilde{\chi}^{\pm} \to f f' \tilde{\chi}^{0}$ are mediated through virtual W bosons or sfermions. If sfermions are heavy, the W mediation dominates, and f f' are distributed with branching fractions similar to W decay products. If, on the other hand, sleptons are light enough to play a significant role in the decay mediation, leptonic final states will be enhanced.

At LEP, charginos have been searched for in fully-hadronic, semi-leptonic and fully leptonic decay modes [100,101]. A general lower limit on the lightest chargino mass of 103.5 GeV is derived, except in corners of phase space with low electron sneutrino mass, where destructive interference in chargino production, or two-body decay modes, play a role. The limit is also affected if the mass difference between $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ is small; dedicated searches for such scenarios set a lower limit of 92 GeV.

At the Tevatron, charginos are searched for via production of a pair of charginos, or associated production of $\tilde{\chi}_1^{\pm} + \tilde{\chi}_2^0$. Decay modes involving multilepton final states provide the best discrimination against the large multijet background. Analyses

look for at least three charged isolated leptons, or for two leptons with the same charge. Depending on the $\tilde{\chi}_1^\pm - \tilde{\chi}_1^0$ and/or $\tilde{\chi}_2^0 - \tilde{\chi}_1^0$ mass differences, leptons may be soft. In a recent CDF analysis, results are interpreted in CMSSM-inspired scenarios, with $\tan \beta = 3$, $A_0 = 0$ and $\mu > 0$, and assuming $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_2^0} = 2m_{\tilde{\chi}_1^0}$ [102]. Slepton masses are either assumed to be just above $m_{\tilde{\chi}^\pm}$, maximizing leptonic branching ratios in three-body chargino decays, or to be very large. In the first scenario, charginos with a mass below 168 GeV are excluded. D0 excludes a chargino below 130 GeV for the maximized leptonic branching fraction case for all $\tan \beta < 10$, and sets limits in the CMSSM $m_0 - m_{1/2}$ plane for $\tan \beta = 3$, $A_0 = 0$, and $\mu > 0$ [103].

At the LHC, the search strategy is similar to that at the Tevatron. In an ATLAS analysis of the three lepton final state [104], interpretation of the results is performed in the MSSM as well as using simplified models. In the MSSM, a scan over M_2 and μ is made for $M_1=100$ GeV and $\tan\beta=6$, and M_2 values below 350 GeV are excluded for $|\mu|<190$ GeV. The simplified models assume $\tilde{\chi}_1^{\pm}+\tilde{\chi}_2^0$ production, and $m_{\tilde{\chi}^{\pm}}=m_{\tilde{\chi}_2^0},$ leaving $m_{\tilde{\chi}^{\pm}}$ and $m_{\tilde{\chi}_1^0}$ free. In a scenario that favors leptonic decays of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$, charginos with masses up to 300 GeV are excluded for massless neutralinos, and charginos up to 250 GeV are excluded for $m_{\tilde{\chi}_1^0}<150$ GeV. More LHC results in these channels based on the 2011 data sample are expected.

In both the wino region (a characteristic of anomaly-mediated SUSY-breaking models) and the higgsino region of the MSSM, the mass splitting between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ is small. In such scenarios, charginos may be long-lived. Charginos decaying in the detectors away from the primary vertex could lead to signatures such as kinked-tracks, or apparently disappearing tracks, since, for example, the pion in $\tilde{\chi}_1^\pm \to \pi^\pm \tilde{\chi}_1^0$ might be too soft to be reconstructed. At the LHC, a search has been performed for such disappearing tracks, and interpreted with anomaly-mediated SUSY breaking models. For specific AMSB parameters, charginos with lifetimes between 0.2 and 90 ns are excluded for chargino masses up to 90 GeV, and limits reach up to 118 GeV for lifetimes around 1 ns [105].

Charginos with a lifetime longer than the time needed to pass through the detector appear as charged stable massive particles. Limits have been derived by the LEP experiments [93] and by D0 at the Tevatron [81]. D0 results exclude higgsinolike stable charginos below 217 GeV, and gaugino-like stable charginos below 267 GeV.

II.6.2. Exclusion limits on neutralino masses

In a considerable part of the MSSM parameter space, and in particular when demanding that the LSP carries no electric or color charge, the lightest neutralino $\tilde{\chi}^0_1$ is the LSP. If R-parity is conserved, such a $\tilde{\chi}^0_1$ is stable. Since it is weakly interacting, it will typically escape detectors unseen. Limits on the invisible width of the Z boson apply to neutralinos with a mass below 45.5 GeV, but depend on the Z-neutralino coupling. Such a coupling could be small or even absent; in such a scenario

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there is no general lower limit on the mass of the lightest neutralino [106]. In models with gaugino mass unification at high energy scales, a neutralino mass limit is derived from the chargino mass limit, and amounts to 47 GeV. Assuming a constraining model like the CMSSM, this limit increases to 50 GeV at LEP; however the strong constraints now set by the LHC increase such CMSSM-derived $\tilde{\chi}_1^0$ mass limits to well above 100 GeV.

Even though a LSP neutralino is only weakly interacting, collider experiments are not blind to neutralino pair production. Pair production of neutralinos accompanied by initial state radiation could lead to an observable final state. At LEP, final states with only a single isolated photon were studied, but backgrounds from neutrino pair production were too large. At hadron colliders, monojet final states have been used to set limits on the pair production cross section [107,108].

The lightest neutralino can decay in models with R-parity violation, or in cases where it is not the LSP, as in gauge mediation models. In the latter case, a NLSP neutralino will decay to a gravitino and a SM particle whose nature is determined by the neutralino composition. Final states with two high $p_{\rm T}$ photons and missing momentum are searched for, and interpreted in gauge mediation models with bino-like neutralinos [109–113]. Assuming only gluino pair production and a bino-like neutralino produced in gluino decay, limits on gluino masses of about 1 TeV are set for all neutralino masses, as shown in Fig. 9 for the CMS diphoton analysis.

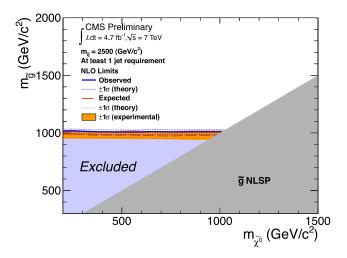


Figure 9: Observed 95% C.L. limits on the gluino mass as a function of the neutralino mass, in general gauge mediation models assuming only gluino pair production, with a bino-like neutralino produced in gluino decay, and a neutralino decay to photon plus gravitino.

Assuming the production of at least two neutralinos per event, neutralinos with large non-bino components can also be searched for in ZZ and γZ final states. Searches for final states with Z ($\rightarrow \ell^+\ell^-$) bosons and missing transverse momentum have been performed at the Tevatron [114] and at the LHC [115], and are interpreted in such models.

In gauge mediation models, NLSP neutralino decay need not be prompt, and experiments have searched for late decays. CDF have searched for delayed $\tilde{\chi}_1^0 \to \gamma Z$ decays using the timing of photon signals in the calorimeter [116], and exclude a neutralino with mass below 101 GeV with a lifetime of 5 ns. CMS has used converted photons to search for photon production away from the primary vertex [117]. Results are given as upper limits on the neutralino production cross section of order 0.12 – 0.24 pb for $c\tau$ between 5 and 25 cm. D0 has looked at the direction of showers in the electromagnetic calorimeter with a similar goal [118].

Heavier neutralinos, in particular $\tilde{\chi}_2^0$, have been searched for in their decays to the lightest neutralino plus a Z boson. Analyses include searches for Z production plus missing energy, Z plus jets plus missing energy, two Z bosons plus missing energy, and Z plus W production plus missing energy [118,119–122]. In $\tilde{\chi}_2^0$ decays to $\tilde{\chi}_1^0$ and a lepton pair, the lepton pair invariant mass distribution may show a structure that can be used to measure the $\tilde{\chi}_2^0 - \tilde{\chi}_1^0$ mass difference in case of a signal [123], but it can also be used in the search itself, in order to suppress background [124].

II.7. Global interpretations

Apart from the interpretation of the direct searches for sparticle production at colliders in terms of limits on masses of individual SUSY particles, model-dependent interpretations of allowed SUSY parameter space are derived from global SUSY fits. Typically these fits combine the results from collider experiments with indirect constraints on SUSY as obtained from low-energy experiments, flavor physics, high-precision electroweak results, and astrophysical data.

In the pre-LHC era these fits were mainly dominated by indirect constraints. Even for very constrained models like the CMSSM, the allowed parameter space, in terms of squark and gluino masses, ranged from several hundreds of GeV to a few TeV. For the theoretically well motivated class of constrained supergravity models like the CMSSM, global fits indicated that squarks and gluino masses in the range of 500 to 1000 GeV were the preferred region of parameter space, although values as high as few TeV were allowed with lower probabilities [125].

With ATLAS and CMS now probing mass scales around 1 TeV and even beyond, the importance of the direct searches for global analyses of allowed SUSY parameter space has significantly increased. For example, imposing the new experimental limits on constrained supergravity models pushes the most likely values of first generation squark and gluino masses beyond 1 TeV, typically resulting in overall values of fit quality

significantly worse than those in the pre-LHC era [126]. Although these constrained models are not yet ruled out, the extended experimental limits impose tight constraints on the allowed parameter space.

For this reason, the emphasis of global SUSY fits has shifted more towards less-constrained SUSY models. Especially interpretations in the pMSSM [48,127,128] and in simplified models have been useful to generalize SUSY searches, for example in order to increase their sensitivity for compressed spectra where the mass of the LSP is much closer to squark and gluino masses than predicted by for example the CMSSM. As shown in Table 2, for neutralino masses above a few hundred GeV the current set of ATLAS and CMS searches cannot exclude the existence of light squarks and gluinos.

II.8. Summary and Outlook

Although the search for SUSY at the LHC has just begun, results of the ATLAS and CMS experiments are already probing direct production of colored SUSY particles at the 1 TeV mass scale. So far no evidence of new particle production has been observed in the data and therefore limits on allowed parameter space in various models have been set. While typically squark and gluino masses around 1 TeV and below are excluded in constrained models, weaker bounds on SUSY particle masses are obtained in less constrained scenarios demonstrating that SUSY below the 1 TeV scale is certainly not ruled out in general. For non-colored sparticles the impact of the LHC is to a large extent yet to come, and limits from LEP and the Tevatron are still competitive. An overview of the current landscape of SUSY searches and corresponding exclusion limits at the LHC is shown in Fig. 10 from the ATLAS experiment [67]. corresponding results of the CMS experiment are similar [66].

Furthermore, the LHC experiments have reported significant constraints on the allowed mass range of a SM-like Higgs boson based on an analysis of 5 fb⁻¹ of data [129,130]. A SM-like Higgs boson is excluded over a large mass range, except in a narrow window around 125 GeV or at a large mass above some 600 GeV. These results impose further tight bounds on the allowed SUSY parameter space, and the first studies of global analyses indicate (see e.g., [131–133]) that the limits on the Higgs boson mass worsen the overall compatibility of the available data with constrained models like the CMSSM. Scenarios of rather light third generation squarks, however, perhaps accompanied with heavy neutralinos as realized in compressed spectra, or first generation squarks and gluinos with masses significantly above 1 TeV are still compatible with the present set of direct and indirect constraints.

Additional searches at the LHC in 2012, at a higher centerof-mass energy of 8 TeV, are expected to make further important steps in the experimental search for SUSY. Once the LHC reaches its full energy after 2013, even higher mass scales will be in reach.

Like the experimental landscape of SUSY searches, the field of global interpretations of allowed SUSY parameters is still rapidly changing. Yet, it seems reasonable to expect that

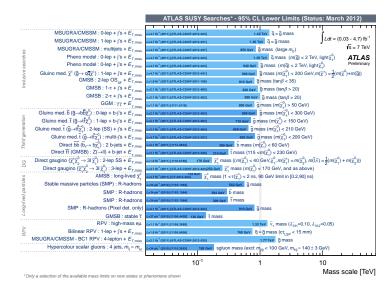


Figure 10: Overview of the current landscape of SUSY searches at the LHC. The plot shows exclusion mass limits of ATLAS for different searches and interpretation assumptions. The corresponding results of CMS are comparable

the emphasis on interpretations in constrained SUSY models is now shifting towards more flexible models, which in turn motivates an even stronger experimental emphasis on searches for direct production of third generation squarks, of electroweak gauginos, or involving compressed $m_{\rm mother}-m_{\tilde{\chi}_1^0}$ mass spectra. An increased emphasis on R-parity violating models and on models with long-lived particles can also be expected.

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SUPERSYMMETRIC MODEL ASSUMPTIONS

The exclusion of particle masses within a mass range (m_1, m_2) will be denoted with the notation "none $m_1 - m_2$ " in the VALUE column of the following Listings. The latest unpublished results are described in the "Supersymmetry: Experiment" review.

Most of the results shown below, unless stated otherwise, are based on the Minimal Supersymmetric Standard Model (MSSM), as described in the Note on Supersymmetry. Unless otherwise indicated, this includes the assumption of common gaugino and scalar masses at the scale of Grand Unification (GUT), and use of the resulting relations in the spectrum and decay branching ratios. It is also assumed that R-parity (R) is conserved. Unless otherwise indicated, the results also assume

- 1) The $\tilde{\chi}_1^0$ is the lighest supersymmetric particle (LSP)
- 2) $m_{\widetilde{f}_L} = m_{\widetilde{f}_R}$, where $\widetilde{f}_{L,R}$ refer to the scalar partners of leftand right-handed fermions.

Limits involving different assumptions are identified in the Comments or in the Footnotes. We summarize here the notations used in this Chapter to characterize some of the most common deviations from the MSSM (for further details, see the Note on Supersymmetry).

Theories with R-parity violation (R) are characterized by a superpotential of the form: $\lambda_{ijk}L_iL_je_k^c + \lambda'_{ijk}L_iQ_jd_k^c +$ $\lambda''_{ijk}u_i^c d_i^c d_k^c$, where i,j,k are generation indices. The presence of any of these couplings is often identified in the following by the symbols $LL\overline{E}$, $LQ\overline{D}$, and \overline{UDD} . Mass limits in the presence of R will often refer to "direct" and "indirect" decays. Direct refers to R decays of the particle in consideration. Indirect refers to cases where R appears in the decays of the

In several models, most notably in theories with so-called Gauge Mediated Supersymmetry Breaking (GMSB), the gravitino (G) is the LSP. It is usually much lighter than any other massive particle in the spectrum, and $m_{\widetilde{C}}$ is then neglected in all decay processes involving gravitinos. In these scenarios, particles other than the neutralino are sometimes considered as the next-to-lighest supersymmetric particle (NLSP), and are assumed to decay to their even-R partner plus G. If the lifetime is short enough for the decay to take place within the detector, \widetilde{G} is assumed to be undetected and to give rise to missing energy (E) or missing transverse energy (E_T) signatures.

When needed, specific assumptions on the eigenstate content of $\tilde{\chi}^0$ and $\tilde{\chi}^{\pm}$ states are indicated, using the notation $\tilde{\gamma}$ (photino), \widetilde{H} (higgsino), \widetilde{W} (wino), and \widetilde{Z} (zino) to signal that the limit of pure states was used. The terms gaugino is also used, to generically indicate wino-like charginos and zino-like neutralinos.

CONTENTS:

 $\widetilde{\chi}_1^0$ (Lightest Neutralino) Mass Limit

- Accelerator limits for stable $\widetilde{\chi}_1^0$
- Bounds on $\widetilde{\chi}_1^0$ from dark matter searches
- $-\stackrel{ extstyle 1}{\widetilde{\chi}}_1^0$ -p elastic cross section Spin-dependent interactions
- Spin-independent interactions Other bounds on $\widetilde{\chi}^0_1$ from astrophysics and cosmology
- Unstable $\widetilde{\chi}_1^0$ (Lightest Neutralino) Mass Limit

 $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$ (Neutralinos) Mass Limits

 $\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_2^{\pm}$ (Charginos) Mass Limits

Long-lived $\tilde{\chi}^{\pm}$ (Chargino) Mass Limits

 $\widetilde{\nu}$ (Sneutrino) Mass Limit Charged Sleptons

- $-\widetilde{e}$ (Selectron) Mass Limit $-\widetilde{\mu}$ (Smuon) Mass Limit $-\widetilde{\tau}$ (Stau) Mass Limit

- Degenerate Charged Sleptons
- Long-lived $\widetilde{\ell}$ (Slepton) Mass Limit

a (Squark) Mass Limit

Long-lived \widetilde{q} (Squark) Mass Limit \widetilde{b} (Sbottom) Mass Limit

 \widetilde{t} (Stop) Mass Limit

Heavy \widetilde{g} (Gluino) Mass Limit

Long-lived/light \widetilde{g} (Gluino) Mass Limit Light \widetilde{G} (Gravitino) Mass Limits from Collider Experiments

Supersymmetry Miscellaneous Results

$\widetilde{\chi}_1^0$ (Lightest Neutralino) MASS LIMIT

 $\widetilde{\chi_1^0}$ is often assumed to be the lightest supersymmetric particle (LSP). See also the $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$ section below.

We have divided the $\widetilde{\chi}_1^0$ listings below into five sections:

- 1) Accelerator limits for stable $\widetilde{\chi}_1^0$,
- 2) Bounds on $\widetilde{\chi}_1^0$ from dark matter searches,
- 3) $\tilde{\chi}_1^0 p$ elastic cross section (spin-dependent, spin-independent interactions),
- 4) Other bounds on $\widetilde{\chi}_1^0$ from astrophysics and cosmology, and
- 5) Unstable $\widetilde{\chi}_1^0$ (Lightest Neutralino) mass limit.

8 ARE

– Accelerator limits for stable $\widetilde{\chi}^0_1$ -

Unless otherwise stated, results in this section assume spectra, production rates, decay modes, and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers $\,$ generally study production of $\widetilde{\chi}_i^0\,\widetilde{\chi}_i^0$ ($i\ge 1$, $j\ge 2$), $\widetilde{\chi}_1^+\,\widetilde{\chi}_1^-$, and (in the

case of hadronic collisions) $\tilde{\chi}_1^+ \tilde{\chi}_2^0$ pairs. The mass limits on $\tilde{\chi}_1^0$ are either direct, or follow indirectly from the constraints set by the non-observation of $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters M_2 and μ . In some cases, information is used from the nonobservation of slepton decays.

Obsolete limits obtained from e^+e^- collisions up to \sqrt{s} =184 GeV have been removed from this compilation and can be found in the 2000 Edition (The European Physical Journal C15 1 (2000)) of this Review. $\Delta m = m_{\widetilde{\chi}^0_2} - m_{\widetilde{\chi}^0_1}$

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|------------|-----------------------|---------|------------|----------------------------------------------------|
| >40 | 95 | ¹ abbiendi | 04н | OPAL | all tan eta , $\Delta m > 5$ GeV, |
| | | | | | $m_0 > 500 \text{ GeV}, A_0 = 0$ |
| >42.4 | 95 | ² HEISTER | 04 | ALEP | all $tan \beta$, all Δm , all m_0 |
| >39.2 | 95 | ³ ABDALLAH | 03м | DLPH | all $\tan \beta$, $m_{\widetilde{\nu}} >$ 500 GeV |
| >46 | 95 | ⁴ ABDALLAH | 03м | DLPH | all $\tan \beta$, all Δm , all m_0 |
| >32.5 | 95 | 5 ACCIARRI | 00D | L3 | $tan \beta > 0.7$, $\Delta m > 3$ GeV, all m_0 |
| • • • We | do not use | the following data | for ave | erages, fi | its, limits, etc. • • • |
| | | 6 DREINER | 09 | THEO | |
| | | 7 | | | ± 0 |

Searches Particle Listings Supersymmetric Particle Searches

- $^{
 m 1}$ ABBIENDI 04H search for charginos and neutralinos in events with acoplanar leptons+jets and multi-jet final states in the 192–209 GeV data, combined with the results on leptons final states from ABBIENDI 04. The results hold for a scan over the parameter space covering the region $0 < M_2 < 5000$ GeV, $-1000 < \mu < 1000$ GeV and $\tan \beta$ from 1 to 40. This limit supersedes ABBIENDI 00H.
- ²HEISTER 04 data collected up to 209 GeV. Updates earlier analysis of selectrons from HEISTER 02c, includes a new analysis of charginos and neutralinos decaying into stau and uses results on charginos with initial state radiation from HEISTER 02. The limit is based on the direct search for charginos and neutralinos, the constraints from the slepton search and the Higgs mass limits from HEISTER 02 using a top mass of 175 GeV, interpreted in a framework with universal gaugino and sfermion masses. Assuming the mixing in the stau sector to be negligible, the limit improves to 43.1 GeV. Under the assumption of MSUGRA with unification of the Higgs and sfermion masses, the limit improves to 50 GeV, and reaches 53 GeV for $A_0=0$. These limits include and update the results of BARATE 01.
- 3 ABDALLAH 03M uses data from $\sqrt{s}=$ 192–208 GeV. A limit on the mass of $\widetilde{\chi}_1^0$ is derived from direct searches for neutralinos combined with the chargino search. Neutralinos are searched in the production of $\widetilde{\chi}_1^0 \widetilde{\chi}_2^0$, $\widetilde{\chi}_1^0 \widetilde{\chi}_3^0$, as well as $\widetilde{\chi}_2^0 \widetilde{\chi}_3^0$ and $\widetilde{\chi}_2^0 \widetilde{\chi}_4^0$ giving rise to cascade decays, and $\widetilde{\chi}_1^0 \widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^0 \widetilde{\chi}_2^0$, followed by the decay $\widetilde{\chi}_2^0 \to \widetilde{\tau}\tau$. The results hold for the parameter space defined by values of $\mathit{M}_2 < 1$ TeV, $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP. The limit is obtained for $\tan\beta=1$ and large m_0 , where $\widetilde{\chi}_2^0\widetilde{\chi}_4^0$ and chargino pair production are important. If the constraint from Higgs searches is also imposed, the limit improves to 49.0 GeV in the M $_h^{max}$ scenario with $m_t{=}174.3$ GeV. These limits update the results of ABREU 00J.
- 4 ABDALLAH 03M uses data from $\sqrt{s}=1$ 92–208 GeV. An indirect limit on the mass of $\widetilde{\chi}_1^0$ is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays and $\tilde{\tau}\tau$ final states), for charginos (for all Δm_+) and for sleptons, stop and sbottom. The results hold for the full parameter space defined by values of $M_2 < 1$ TeV, $|\mu| \leq$ 2 TeV with the $\widetilde{\chi}_1^0$ as LSP. Constraints from the Higgs search in the M_h^{max} scenario assuming m_t =174.3 GeV are included. The limit is obtained for $\tan \beta \geq 5$ when stau mixing leads to mass degeneracy between $\widetilde{\tau}_1$ and $\widetilde{\chi}_1^0$ and the limit is based on $\widetilde{\chi}_2^0$ production followed by its decay to $\widetilde{\tau}_1 \tau$. In the pathological scenario where m_0 and $|\mu|$ are large, so that the $\widetilde{\chi}^0_2$ production cross section is negligible, and where there is mixing in the stau sector but not in stop nor sbottom, the limit is based on charginos with soft decay products and an ISR photon. The limit then degrades to 39 GeV. See Figs 40–42 for the dependence of the limit on $\tan \beta$ and $m_{\widetilde{\nu}}$. These limits update the results of ABREU 00w.
- 5 ACCIARRI 00D data collected at $\sqrt{s}{=}189$ GeV. The results hold over the full parameter space defined by $0.7 \le \tan\beta \le 60,~0 \le M_2 \le 2$ TeV, $m_0 \le 500$ GeV, $|\mu| \le 2$ TeV. The minimum mass limit is reached for $\tan\beta{=}1$ and large m_0 . The results of slepton searches from ACCIARRI 99w are used to help set constraints in the region of small m_0 . The limit improves to 48 GeV for $m_0 \gtrsim 200$ GeV and $\tan\beta \gtrsim 10$. See their Figs. 6–8 for the $\tan\beta$ and m_0 dependence of the limits. Updates ACCIARRI 98F.
- ⁶ DREINER 09 show that in the general MSSM with non-universal gaugino masses there exists no model-independent laboratory bound on the mass of the lightest neutralino. An essentially massless χ^0_1 is allowed by the experimental and observational data, imposing some constraints on other MSSM parameters, including M_{2} , μ and the slepton and
- squark masses. 7 ABBOTT 98c searches for trilepton final states $(\ell = e, \mu)$. See footnote to ABBOTT 98c in the Chargino Section for details on the assumptions. Assuming a negligible decay rate of $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ to quarks, they obtain $m_{\tilde{\chi}_2^0} \gtrsim 51$ GeV.
- 8 ABE 98J searches for trilepton final states $(\ell\!=\!e,\!\mu).$ See footnote to ABE 98J in the Chargino Section for details on the assumptions. The quoted result corresponds to the best limit within the selected range of parameters, obtained for $m_{\widetilde{q}} > m_{\widetilde{g}}, \tan\beta = 2,$ and $\mu = -600 \text{ GeV}.$

– Bounds on $\widetilde{\chi}^0_1$ from dark matter searches -

These papers generally exclude regions in the M_2 – μ parameter plane assuming that $\tilde{\chi}_1^0$ is the dominant form of dark matter in the galactic halo. These limits are based on the lack of detection in laboratory experiments, telescopes, or by the absence of a signal in underground neutrino detectors. The latter signal is expected if $\widetilde{\chi}_1^0$ accumulates in the Sun or the Earth and annihilates into high-energy ν 's.

| VALUE | DO CUMENT ID | <u>TECN</u> | |
|-------------------------------------------|------------------------|-------------|----------------------------------|
| ullet $ullet$ We do not use the following | data for averages | , fits, | limits, etc. \bullet \bullet |
| | ¹ ABRAMOWSK | 111 | HESS |
| | ² abdo | 10 | |
| | ³ ACKERMANN | 10 | FRMI |
| | ⁴ ABBASI | | ICCB |
| | 5 ACHTERBERG | 06 | AMND |
| | ⁶ ACKERMANN | 06 | AMND |
| | ⁷ DEB OER | 06 | RVUE |
| | ⁸ DESAI | 04 | SKAM |
| | ⁸ AMBROSIO | 99 | MCRO |
| | ⁹ LOSECCO | 95 | RVUE |
| | ⁰ MORI | 93 | KAMI |
| 1 | 1 BOTTINO | 92 | COSM |
| 1 | ² bottino | 91 | RVUE |
| 1 | ³ GELMINI | 91 | COSM |
| 1 | 4 KAMIONKOW. | .91 | RVUE |
| 1 | ⁵ MORI | 91B | KAMI |
| | ⁶ OLIVE | 88 | COSM |

- 1 ABRAMOWSKI 11 place upper limits on the annihilation cross section with $\gamma\gamma$ final
- states. 2 ABDO 10 place upper limits on the annihilation cross section with $\gamma\gamma$ or $\mu^+\mu^-$ final
- 3 ACKERMANN 10 place upper limits on the annihilation cross section with $b\overline{b}$ or $\mu^+\,\mu^-$
- main states. 4 ABBASI 09 is based on data collected during 104.3 effective days with the IceCube 22-string detector. They looked for interactions of ν_{μ} 's from neutralino annihilations in the Sun over a background of atmospheric neutrinos and set 90% CL limits on the muon flux. They also obtain limits on the spin dependent neutralino-proton cross section for neutralino masses in the range 250-5000 GeV.
- ⁵ ACHTERBERG 06 is based on data collected during 421.9 effective days with the AMANDA detector. They looked for interactions of ν_{μ} s from the centre of the Earth over a background of atmospheric neutrinos and set 90 % CL limits on the muon flux. Their limit is compared with the muon flux expected from neutralino annihilations into W^+ W^- and $b\,\overline{b}$ at the centre of the Earth for MSSM parameters compatible with the relic dark matter density, see their Fig. 7.
- 6 ACKERMANN 06 is based on data collected during 143.7 days with the AMANDA-II detector. They looked for interactions of $\nu_{\mu} {\rm s}$ from the Sun over a background of atmospheric neutrinos and set 90 % CL limits on the muon flux. Their limit is compared with the muon flux expected from neutralino annihilations into W^{+} W^{-} in the Sun for SUSY model parameters compatible with the relic dark matter density, see their Fig. 3.
- ⁷ DEBOER 06 interpret an excess of diffuse Galactic gamma rays observed with the EGRET Satellite as originating from π^0 decays from the annihilation of neutralinos into quartiets. They analyze the corresponding parameter space in a supergravity inspired MSSM model with radiative electroweak symmetry breaking, see their Fig. 3 for the preferred region in the $(m_0,\,m_{1/2})$ plane of a scenario with large $\tan\beta$.
- 8 AMBROSIO 99 and DESAI 04 set new neutrino flux limits which can be used to limit the parameter space in supersymmetric models based on neutralino annihilation in the
- Sun and the Earth. Sun and the Earth. Sun and the Earth. The Date of the LSP is a photino and 10 GeV if the LSP is a higgsino based on LSP annihilation in the sun producing high-energy neutrinos and the limits on neutrino fluxes from the IMB detector. MORI 93 excludes some region in M_2 - μ parameter space depending on $\tan\beta$ and lightest scalar Higgs mass for neutrinos from neutrino annihilation in the Sun and the Earth. The Date in the IMO 92 excludes some region M_2 - μ parameter space assuming that the lightest contribution of the IMO 92 excludes some region M_2 - μ parameter space assuming that the lightest in the IMO 92 excludes some region M_2 - μ parameter space assuming that the lightest contribution is the IMO 92 excludes some region M_2 - μ parameter space assuming that the lightest contribution is the IMO 92 excludes some region M_2 - μ parameter space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space assuming that the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightest space as the lightes
- produced by energetic neutrinos from neutralino annihilation in the sun and the Earth. 18 DOTTINO 92 excludes some region M_{2} - μ parameter space assuming that the lightest neutralino is the dark matter, using upgoing muons at Kamiokande, direct searches by Ge detectors, and by LEP experiments. The analysis includes top radiative corrections on Higgs parameters and employs two different hypotheses for nucleon-Higgs coupling. Effects of rescaling in the local neutralino density according to the neutralino relic abundance are taken into account. 18 BOTTINO 91 excluded a region in M_2 - μ plane using upgoing muon data from Kamioka experiment, assuming that the dark matter surrounding us is composed of neutralinos and that the Higgs boson is not too heavy. 13 GET MIMI 91 exclude a region in M_2 - μ plane using dark matter searches.
- 13 GELMINI 91 exclude a region in $\mathit{M}_2 \mu$ plane using dark matter searches.
- 14 KAMIONKOWSKI 91 excludes a region in the $M_2{\rm -}\mu$ plane using IMB limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the sun, assuming that the dark matter is composed of neutralinos and that $m_{H_1^0}\lesssim$ 50 GeV. See Fig. 8
- 15 MORI 91B exclude a part of the region in the M_2 - μ plane with $m_{\widetilde{\chi}_1^0}\lesssim 80$ GeV using a limit on upgoing muons originated by energetic neutrinos from neutralino annihilation in the earth, assuming that the dark matter surrounding us is composed of neutralinos and that $m_{H_1^0}\lesssim 80$ GeV.
- 16 OLIVE 88 result assumes that photinos make up the dark matter in the galactic halo. Limit is based on annihilations in the sun and is due to an absence of high energy neutrinos detected in underground experiments. The limit is model dependent.

$\widetilde{\chi}_1^0$ -p elastic cross section

Experimental results on the $\widetilde{\chi}_1^0$ -p elastic cross section are evaluated at $m_{\widetilde{\chi}_1^0}$ =100 GeV. The experimental results on the cross section are often mass dependent. Therefore, the mass and cross section results are also mass dependent. Therefore, the mass and cross section results are also given where the limit is strongest, when appropriate. Results are quoted separately for spin-dependent interactions (based on an effective 4-Fermi Lagrangian of the form $\overline{\chi}\gamma^{\mu}\gamma^{5}\chi\overline{q}\gamma_{\mu}\gamma^{5}q$) and spin-independent interactions ($\overline{\chi}\chi\overline{q}q$). For calculational details see GRIEST 88B, ELLIS 88D, BAR-BIERI 89C, DREES 93B, ARNOWITT 96, BERGSTROM 96, and BAER 97 in addition to the theory papers listed in the Tables. For a description of the theoretical assumptions and experimental techniques underlying most of the listed papers, see the review on "Dark matter" in this "Review of Particle Physics," and references therein. Most of the following papers use galactic halo and nuclear interaction assumptions from (LEWIN 96).

Spin-dependent interactions

| VALUE (pb) | CL% | DO CUMENT ID | | TECN | COMMENT |
|----------------------------------|-----------|--------------------------|-------|---------|-------------------|
| • • • We do not use t | he follow | ing data for averages, | fits, | limits, | etc. • • • |
| < 0.07 | 90 | ¹ BEHNKE : | 11 | COUP | CF ₃ I |
| 5×10^{-10} to 10^{-5} | 95 | ² BUCHMUEL : | | | • |
| < 0.3 | 90 | 3 ARCHAMBAU(|)9 | PICA | F |
| < 0.8 | 90 | ⁴ LEBEDENKO (|)9A | ZEP3 | Xe |
| < 1 | 90 | ⁵ ANGLE (| A80 | XE10 | Xe |
| < 0.055 | | ⁶ BEDNYAKOV (| 8 | HDMS | Ge |
| < 0.33 | 90 | ⁷ BUHNKE (| 8 | COUP | CF ₃ I |
| < 15 | 90 | ⁸ ALNER (|)7 | ZEP2 | Xe |
| < 0.17 | 90 | |)7A | KIMS | Csl |
| < 5 | | | 06 | CDMS | Ge |
| < 2 | | ¹¹ SHIMIZU (|)6A | CNTR | CaEo |

Supersymmetric Particle Searches

| < 0.4 | ¹² ALNER | 05 | NALA | Mal Cain Don |
|-------------------------------------------|------------------------|-----|------|------------------|
| | 13 | | NAIA | Nal Spin Dep. |
| < 2 | 13 BARNABE-HE. | | | C |
| < 1.4 | ¹⁴ GIRARD | 05 | SMPL | F, Cl |
| 2×10^{-11} to 1×10^{-4} | 15 ELLIS | 04 | THEO | $\mu > 0$ |
| < 16 | 16 GIULIANI | 04 | SIMP | F |
| < 0.8 | | 03 | NAIA | Nal Spin Dep. |
| < 40 | | 03 | BOLO | NaF Spin Dep. |
| < 10 | ¹⁹ ANGLOHER | 02 | CRES | Saphire |
| 8×10^{-7} to 2×10^{-5} | | 01c | THEO | $	aneta \leq 10$ |
| < 3.8 | ²¹ BERNABEI | 00D | DAMA | Xe |
| < 15 | ²² COLLAR | 00 | SMPL | F |
| < 0.8 | SPOONER | 00 | UKDM | Nal |
| < 4.8 | ²³ BELLI | 99c | DAMA | F |
| <100 | ²⁴ ootani | 99 | BOLO | LiF |
| < 0.6 | BERNABEI | 98c | DAMA | Xe |
| < 5 | ²³ BERNABEI | 97 | DAMA | F |

- 1 The strongest limit is 0.05 pb and occurs at $m_\chi=$ 55 GeV.
- 2 Predictions for the spin-dependent elastic cross section based on a frequentist approach to electroweak observables in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- 3 The strongest limit is 0.16 pb and occurs at $m_\chi=24$ GeV. The strongest limit for the scattering on neutrons is 2.6 pb, also at $m_\chi=24$ GeV.
- $^4\,\mathrm{The}$ strongest upper limit is 0.76 pb and occurs at $m_\chi\simeq$ 55 GeV. The strongest limit on the neutron spin-dependent cross section is 0.01 pb, also at $m_\chi \simeq$ 55 GeV (the same limit is achieved for $m_\chi=100~{\rm GeV}).$
- 5 The strongest limit is 0.6 pb and occurs at $m_\chi =$ 30 GeV. The limit for scattering on neutrons is 0.01 pb at $m_\chi =$ 100 GeV, and the strongest limit is 0.0045 pb at $m_\chi =$ 30 GeV.
 6 Limit applies to neutron elastic cross section.
- $^7\,\mathrm{The}$ strongest upper limit is 0.25 pb and occurs at $m_\chi \simeq$ 40 GeV.
- 8 The strongest upper limit is 14 pb and occurs at $m_\chi^2 \simeq 65$ GeV. The limit on the neutron spin-dependent cross section is 0.08 pb at $m_\chi = 100$ GeV and the strongest limit for scattering on neutrons is 0.07 pb at $m_\chi = 65$ GeV.
- $^9\,\mathrm{The}$ limit on the neutron spin-dependent cross section is 6 pb at $m_\chi=100$ GeV.
- 10 The strongest upper limit is 4 pb and occurs at $m_{\widetilde{\chi}} \simeq 60$ GeV. The limit on the neutron spin-dependent elastic cross section is 0.07 pb. This latter limit is improved in AHMED 09, where a limit of 0.02 pb is obtained at $m_\chi=100$ GeV. The strongest limit in AHMED 09 is 0.018 pb and occurs at $m_\chi=60$ GeV.
- 11 The strongest upper limit is 1.2 pb and occurs at $m_\chi~\simeq~$ 40 GeV. The limit on the neutron spin-dependent cross section is 35 pb.
- $^{12}\,\mathrm{The}$ strongest upper limit is 0.35 pb and occurs at $m_\chi~\simeq~60$ GeV.
- 13 The strongest upper limit is 1.2 pb and occurs $m_\chi \, \simeq \,$ 30 GeV.
- $^{14}\,\mathrm{The}$ strongest upper limit is 1.2 pb and occurs $m_\chi^{-}\simeq~$ 40 GeV.
- 15 ELLIS 04 calculates the χp elastic scattering cross section in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry, but without universal scalar masses. In the case of universal squark and slepton masses, but non-universal Higgs masses, the limit becomes 2×10^{-4} , see ELLIS 03E.
- 16 The strongest upper limit is 10 pb and occurs at $m_\chi \simeq$ 30 GeV.
- $^{17}\,\mathrm{The}$ strongest upper limit is 0.75 pb and occurs at $m_\chi\approx$ 70 GeV.
- $^{18}\,\mathrm{The}$ strongest upper limit is 30 pb and occurs at $m_\chi^{}\approx~20$ GeV.
- $^{19}\,\mathrm{The}$ strongest upper limit is 8 pb and occurs at $m_\chi \simeq$ 30 GeV.
- 20 ELLIS 01c calculates the $\chi\text{-}p$ elastic scattering cross section in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. In models with nonuniversal Higgs masses, the upper limit to the cross section is 6×10^{-4} .
- 21 The strongest upper limit is 3 pb and occurs at $m_\chi \simeq$ 60 GeV. The limits are for inelastic
- scattering $X^0 + {}^{129}Xe \rightarrow X^0 + {}^{129}Xe^* (39.58 \text{ keV}).$ $^{22}{\rm The\ strongest\ upper\ limit\ is\ 9\ pb\ and\ occurs\ at\ } m_\chi \simeq 30\ {\rm GeV}.$
- $^{23}\,\mathrm{The}$ strongest upper limit is 4.4 pb and occurs at $m_\chi\simeq$ 60 GeV.
- 24 The strongest upper limit is about 35 pb and occurs at $m_{_Y} \simeq 15$ GeV.

Spin-independent interactions

| VALUE (pb) | CL% | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------------------------|----------|-------------------------|--------|-----------|-------------------|
| • • • We do not use the foll | owing da | ata for averages, fits | s, lim | its, etc. | • • • |
| $< 3.3 \times 10^{-8}$ | 90 | ¹ AHMED | 11A | | Ge |
| $< 3.1 \times 10^{-8}$ | 90 | ² APRILE | 11 | X100 | Xe |
| $< 1.0 \times 10^{-8}$ | 90 | ³ APRILE | 11в | X100 | Xe |
| $< 4.4 \times 10^{-8}$ | 90 | ⁴ ARMENGAUD | 11 | EDE2 | Ge |
| $3.5 \times 10^{-11} \text{ to } 8 \times 10^{-8}$ | 95 | ⁵ BUCHMUEL | 11B | THEO | |
| 3.5×10^{-11} to 1.4×10^{-8} | 95 | ⁶ FARINA | 11 | THEO | |
| $< 4 \times 10^{-8}$ | 90 | ⁷ AHMED | 10 | CDMS | Ge |
| $< 4 \times 10^{-8}$ | 90 | ⁸ APRILE | 10 | X100 | Xe |
| $< 1 \times 10^{-7}$ | 90 | ⁹ ARMENGAUD | 10 | EDE2 | Ge |
| 1×10^{-10} to 1×10^{-7} | | ¹⁰ CAO | 10 | THEO | |
| $< 5 \times 10^{-8}$ | 90 | ¹¹ AHMED | 09 | CDM2 | Ge |
| $< 7 \times 10^{-7}$ | 90 | ¹² ANGLOHER | | CRES | CaWO ₄ |
| 3×10^{-10} to 3×10^{-8} | 95 | ¹³ BUCHMUEL | | THEO | |
| $< 1 \times 10^{-7}$ | 90 | ¹⁴ LEBEDENKO | 09 | ZEP3 | Xe |
| $< 1 \times 10^{-7}$ | 90 | ¹⁵ ANGLE | 80 | XE10 | Xe |
| $< 1 \times 10^{-6}$ | 90 | BENETTI | 80 | WARP | Ar |
| $< 7.5 \times 10^{-7}$ | 90 | ¹⁶ ALNER | 07A | ZEP2 | Xe |
| $< 22 \times 10^{-7}$ | 90 | ¹⁷ LEE | 07A | KIMS | Csl |
| $< 2 \times 10^{-7}$ | | ¹⁸ AKERIB | 06A | CDMS | Ge |

| 4×10^{-11} to 2×10^{-7} | 95 | | DE-AUSTRI | 06 | THEO | |
|----------------------------------------------|----|-------|-----------|-----|---------|-------------------|
| $< 90 \times 10^{-7}$ | | 20 | LEE | 06 | KIMS | Csl |
| $< 5 \times 10^{-7}$ | | 21 | AKERIB | 05 | CDMS | Ge |
| <90 ×10 ⁻⁷ | | | ALNER | 05 | NAIA | Nal Spin Indep. |
| <12 × 10 ⁻⁷ | | 22 | ALNER | 05A | ZEPL | |
| $<20 \times 10^{-7}$ | | 23 | | 05 | CRES | CaWO ₄ |
| <14 × 10 ⁻⁷ | | | SANGLARD | 05 | EDEL | Ge |
| $< 4 \times 10^{-7}$ | | 24 | AKERIB | 04 | CDMS | Ge |
| 2×10^{-11} to 1.5×10^{-7} | 95 | 25 | BALTZ | 04 | THEO | |
| 2×10^{-11} to 8×10^{-6} | | 26,27 | ELLIS | 04 | THEO | $\mu > 0$ |
| $< 5 \times 10^{-8}$ | | 28 | PIERCE | 04A | THEO | • |
| $< 2 \times 10^{-5}$ | | 29 | | 03 | NAIA | Nal Spin Indep. |
| $< 3 \times 10^{-6}$ | | 30 | AKERIB | 03 | CDMS | Ge |
| 2×10^{-13} to 2×10^{-7} | | 31 | BAER | | THEO | |
| $< 1.4 \times 10^{-5}$ | | 32 | KLAPDOR-K | 03 | HDMS | Ge |
| $< 6 \times 10^{-6}$ | | 33 | | | CDMS | |
| $< 1.4 \times 10^{-6}$ | | | BENOIT | 02 | EDEL | Ge |
| 1×10^{-12} to 7×10^{-6} | | | | 02в | THEO | |
| $< 3 \times 10^{-5}$ | | 35 | | 02в | CSME | Ge |
| $< 1 \times 10^{-5}$ | | 36 | MORALES | 02c | IGEX | Ge |
| $< 1 \times 10^{-6}$ | | | BALTZ | 01 | THEO | |
| $< 3 \times 10^{-5}$ | | 37 | BAUDIS | 01 | HDMS | Ge |
| $< 4.5 \times 10^{-6}$ | | | BENOIT | 01 | EDEL | Ge |
| $< 7 \times 10^{-6}$ | | 38 | | | THEO | |
| < 1 × 10 ⁻⁸ | | | | | | $	aneta \leq 25$ |
| 5×10^{-10} to 1.5×10^{-8} | | | | 01c | THEO | $	aneta \leq 10$ |
| $< 4 \times 10^{-6}$ | | | GOMEZ | | THEO | |
| 2×10^{-10} to 1×10^{-7} | | | LAHANAS | | THEO | |
| $< 3 \times 10^{-6}$ | | | ABUSAIDI | | CDMS | Ge, Si |
| $< 6 \times 10^{-7}$ | | 41 | ACCOMANDO | | THEO | |
| 0 | | | BERNABEI | 00 | DAMA | |
| 2.5×10^{-9} to 3.5×10^{-8} | | | FENG | 00 | | $\tan \beta = 10$ |
| $< 1.5 \times 10^{-5}$ | | | MORALES | | IGEX | |
| $< 4 \times 10^{-5}$ | | | SPOONER | 00 | UKDM | |
| $< 7 \times 10^{-6}$ | | | BAUDIS | | HDMO | |
| | | | BERNABEI | | DAMA | |
| 6 | | | | 98 | DAMA | |
| $< 7 \times 10^{-6}$ | | | | | DAMA | |
| LAUMED 114 Street Combi | | 6 | CDMC | EDE | LVVELCC | The second of the |

- 1 AHMED 11A gives combined results from CDMS and EDELWEISS. The strongest limit is at $m_\chi=90$ GeV.
- 2 APRILE 11 updates the result of APRILE 10. The strongest upper limit is 2.4 \times 10 $^{-8}$ pb and occurs at $m_\chi~\simeq~50$ GeV. Superseded by APRILE 11B.
- 3 APRILE 11B updates the result of APRILE 10 and APRILE 11. The strongest upper limit is 7 imes 10 $\dot{-}$ 9 pb and occurs at $m_\chi~\simeq~$ 50 GeV.
- $^4\,\mathrm{ARMENGAUD}\,11$ updates result of ARMENGAUD 10. Strongest limit at $m_\chi=$ 85 GeV.
- ⁵ Predictions for the spin-independent elastic cross section based on a frequentist approach to electroweak observables in the framework of $\mathit{N}=1$ supergravity models with radiative
- breaking of the electroweak gauge symmetry.

 6 Predictions for the spin-independent elastic cross section based on a frequentist approach to electroweak observables in the framework of ${\it N}=1$ supergravity models with radiative breaking of the electroweak gauge symmetry.
- ⁷ The strongest upper limit is $< 3.8 \times 10^{-8}$ pb and occurs at $m_{\chi} \simeq 70$ GeV. AHMED 10 updates the results of AHMED 09.
- 8 The strongest upper limit is $< 3.4 \times 10^{-8}$ pb and occurs at $m_V \simeq 55$ GeV. Superseded
- $^9\,\mathrm{The\ strongest\ limit\ is\ at\ }m_\chi=$ 80 GeV. Superseded ARMENGAUD 11.
- $^{10}\,\text{Uses}$ relic density and various collider experiments to set limits on neutralino-nucleon cross section in MSSM models with gaugino mass unification.
- 11 AHMED 09 updates the results of AKERIB 06A. The strongest limit is 4.6 \times 10 $^{-8}$ pb and occurs at $m_\chi=$ 60 GeV. Superseded by AHMED 10.
- 12 The strongest upper limit is 4.8×10^{-7} pb and occurs at $m_\chi = 50$ GeV.
- $^{13}\,\mathrm{BUCHMUELLER}$ 09 makes predictions for the spin-independent elastic cross section based on a frequentist approach to electroweak observables in the framework of N=1supergravity models with radiative breaking of the electroweak gauge symmetry. 14 The strongest upper limit is 8.1×10^{-8} pb and occurs at $m_\chi=60$ GeV.
- ¹⁵ The strongest upper limit is 5.1×10^{-8} pb and occurs at m_{χ} quoted here are based on the analysis performed in ANGLE $\overset{X}{08}$ with the update from SORENSEN 09.
- 16 The strongest upper limit is 6.6×10^{-7} pb and occurs at $m_\chi \simeq 65$ GeV
- $^{17}{\rm The~strongest}$ upper limit is $19\times 10^{-7}~{\rm pb}$ and occurs at $\overset{\cdot \cdot \cdot }{m_\chi} \simeq$ 65 GeV. Supersedes
- LEE 06. $$^{18}\rm{AKERIB}$ 06. Updates the results of AKERIB 05. The strongest upper limit is 1.6 \times $10^{-7}~{\rm pb}$ and occurs at $m_{\chi}~\approx~60~{\rm GeV}$
- $^{
 m 19}$ Predictions for the spin-independent elastic cross section based on a Bayesian approach to electroweak observables in the framework of $\mathit{N}=1$ supergravity models with radiative breaking of the electroweak gauge symmetry. We also show that the strongest upper limit is 8×10^{-6} pb and occurs at $m_\chi\simeq 70$ GeV.
- $^{21}\,\mathrm{A\,KERIB}$ 05 is incompatible with the DAMA most likely value. The strongest upper limit is 4 \times 10 ⁻⁷ pb and occurs at $m_\chi \simeq$ 60 GeV.
- ²²The strongest upper limit is also close to 1.0×10^{-6} pb and occurs at $m_V \simeq 70$ GeV. BENOIT 06 claim that the discrimination power of ZEPLIN-I measurement (ALNER 05A) is not reliable enough to obtain a limit better than $1\times10^{-3}~\text{pb.}$ However, SMITH 06 do not agree with the criticisms of BENOIT 06.
- ²³ The strongest upper limit is also close to 1.4 imes 10⁻⁶ pb and occurs at $m_{\chi} \simeq$ 70 GeV.

- 24 AKERIB 04 is incompatible with BERNABEI 00 most likely value, under the assumption of standard WIMP-halo interactions. The strongest upper limit is 4×10^{-7} pb and occurs at $m_\chi \simeq 60~{\rm GeV}$
- 25 Predictions for the spin-independent elastic cross section in the framework of $N\,=\,1$ supergravity models with radiative breaking of the electroweak gauge symmetry.
- 26 KIM 02 and ELLIS 04 calculate the χp elastic scattering cross section in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry,
- of N=1 Supergravity modes with radiative breaking of the electroscal gasgo symmetry, but without universal scalar masses. 27 in the case of universal squark and slepton masses, but non-universal Higgs masses, the limit becomes 2×10^{-6} (2×10^{-11} when constraint from the BNL g-2 experiment are included), see ELLIS 03z. ELLIS 05 display the sensitivity of the elastic scattering cross ction to the $\pi ext{-Nucleon } \Sigma$ term.
- 28 PIERCE 04A calculates the χp elastic scattering cross section in the framework of models with very heavy scalar masses. See Fig. 2 of the paper. 29 The strongest upper limit is 1.8×10^{-5} pb and occurs at $m_\chi \approx 80$ GeV.
- 30 Under the assumption of standard WIMP-halo interactions, Akerib 03 is incompatible with BERNABEI 00 most likely value at the 99.98% CL. See Fig. 4.
- 31 BAER 03A calculates the χp elastic scattering cross section in several models including the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. 32 The strongest upper limit is 7 \times 10 $^{-6}$ pb and occurs at $m_\chi \simeq$ 30 GeV.
- 33 ABRAMS 02 is incompatible with the DAMA most likely value at the 99.9% CL. The strongest upper limit is 3×10^{-6} pb and occurs at $m_\chi\simeq 30$ GeV.
- 34 BENOIT 02 excludes the central result of DAMA at the 99.8%CL. 35 The strongest upper limit is 2×10^{-5} pb and occurs at $m_\chi\simeq40$ GeV.
- 36 The strongest upper limit is 7 \times 10 $^{-6}$ pb and occurs at $m_\chi^{\chi} \simeq$ 46 GeV.
- $^{37}\,\mathrm{The}$ strongest upper limit is 1.8×10^{-5} pb and occurs at $\overset{\frown}{m}_{\chi}\simeq32~\mathrm{GeV}$
- 38 BOTTINO 01 calculates the χ-p elastic scattering cross section in the framework of the following supersymmetric models: N=1 supergravity with the radiative breaking of the electroweak gauge symmetry, N=1 supergravity with nonuniversal scalar masses and an effective MSSM model at the electroweak scale.
- 39 Calculates the x-p elastic scattering cross section in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- 40 ELLIS 01c calculates the χ -p elastic scattering cross section in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. ELLIS 02B find a range 2×10^{-8} – 1.5×10^{-7} at $\tan \beta$ =50. In models with nonuniversal Higgs masses, the upper limit to the cross section is $4\times 10^{-7}\,$
- 41 ACCOMANDO 00 calculate the x-p elastic scattering cross section in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. The limit is relaxed by at least an order of magnitude when models nonuniversal scalar masses are considered. A subset of the authors in ARNOWITT 02 updated the limit to $<9\times10^{-8}~(\tan\beta~<55)$.
- 42 BERNABEI 00 search for annual modulation of the WIMP signal. The data favor the hypothesis of annual modulation at 4σ and are consistent, for a particular model framework quoted there, with $m_{\chi 0} = 44 \frac{-12}{19}$ GeV and a spin-independent X^0 -proton cross section of $(5.4 \pm 1.0) \times 10^{-6}$ pb. See also BERNABEI 01 and BERNABEI 00c.
- 43 FENG 00 calculate the χ -p elastic scattering cross section in the framework of $N\!=\!1$ supergravity models with radiative breaking of the electroweak gauge symmetry with a particular emphasis on focus point models. At $\tan\beta$ =50, the range is 8×10^{-8} – 4×10^{-7} .
- 44 BERNABEI 99 search for annual modulation of the WIMP signal. The data favor the hypothesis of annual modulation at 99.6%CL and are consistent, for the particular model framework considered there, with $m_{\chi^0} = 59 ^{+17}_{-14}$ GeV and spin-independent χ^0 -proton cross section of $(7.0^{+0.4}_{-1.2}) \times 10^{-6}$ pb $(1~\sigma$ errors).
- 45 BERNABEI 98 search for annual modulation of the WIMP signal. The data are consistent, for the particular model framework considered there, with m_{χ^0} =59 $^{+36}_{-19}$ GeV and spin-independent X^0 -proton cross section of $(1.0^{+0.1}_{-0.4}) \times 10^{-5}$ pb $(1 \sigma \text{ errors})$.

– Other bounds on $\widetilde{\chi}^0_1$ from astrophysics and cosmology –

Most of these papers generally exclude regions in the \textit{M}_2 – μ parameter plane by requiring that the $\widetilde{\chi}_1^0$ contribution to the overall cosmological density is less than some maximal value to avoid overclosure of the Universe. Those not based on the cosmological density are indicated. Many of these papers also include LEP and/or other bounds.

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------|-----------------------|-------|-------------|-------------------|
| >46 GeV | ^l ELLIS | 00 | RVUE | |
| ullet $ullet$ We do not use the foll | owing data for a | verag | es, fits, l | imits, etc. • • • |
| : | ² AKULA | 11 A | COSM | |
| | ³ ALLANACH | 11 A | COSM | |
| 4 | [‡] BUCHMUEL | 11 | COSM | |
| | BUCHMUEL | | COSM | |
| | BUCHMUEL | 11B | COSM | |
| | FARINA | 11 | COSM | |
| | PROFUMO | 11 | COSM | |
| | ROSZKOWSKI | | COSM | |
| | BECHTLE | 10 | COSM | |
| | ELLIS | 10 | COSM | |
| | BUCHMUEL | 09 | COSM | |
| | DREINER | 09 | THEO | |
| | BUCHMUEL | 80 | COSM | |
| 15 | ELLIS | 08 | COSM | |
| | CALIBBI | 07 | COSM | |
| | ELLIS | 07 | COSM | |
| | ALLANACH | 06 | COSM | |
| 10 | DE-AUSTRI | 06 | COSM | |
| | BAER | 05 | COSM | |

| | 10 |
|----------------------|-----------------------------------------------------------------------------|
| | 19 BALTZ 04 COSM |
| > 6 GeV | 20,21 BELANGER 04 THEO |
| | ²² ELLIS 04B COSM |
| | 23 PIERCE 04A COSM |
| | ²⁴ BAER 03 COSM |
| > 6 GeV | ²⁰ BOTTINO 03 COSM |
| | ²⁴ CHATTOPAD03 COSM |
| | ²⁵ ELLIS 03 COSM |
| | ⁹ ELLIS 03B COSM |
| | ²⁴ ELLIS 03c COSM |
| > 18 GeV | 20 HOOPER 03 COSM $\Omega_{\chi}=$ 0.05-0.3 |
| | ²⁴ LAHANAS 03 COSM |
| | ²⁶ BAER 02 COSM |
| | ²⁷ ELLIS 02 COSM |
| | ²⁸ LAHANAS 02 COSM |
| | ²⁹ BARGER 01c COSM |
| | ²⁶ DJOUADI 01 COSM |
| | ³⁰ ELLIS 01B COSM |
| | ²⁶ ROSZKOWSKI 01 COSM |
| | ²⁵ BOEHM 00B COSM |
| | ³¹ FENG 00 COSM |
| | 32 LAHANAS 00 COSM |
| < 600 GeV | 33 ELLIS 98B COSM |
| | 34 EDSJO 97 COSM Co-annihilation |
| | 35 BAER 96 COSM |
| | 9 BEREZINSKY 95 COSM |
| | 36 FALK 95 COSM CP-violating phases |
| | 37 DREES 93 COSM Minimal supergravity |
| | 38 FALK 93 COSM Sfermion mixing |
| | 37 KELLEY 93 COSM Minimal supergravity |
| | 39 MIZUTA 93 COSM Co-annihilation |
| | 40 LOPEZ 92 COSM Minimal supergravity, |
| | $m_0=A=0$ |
| | ⁴¹ MCDONALD 92 COSM |
| | ⁴² GRIEST 91 COSM |
| | 43 NOJIRI 91 COSM Minimal supergravity |
| | 44 OLIVE 91 COSM |
| | ⁴⁵ ROSZKOWSKI 91 COSM |
| | ⁴⁶ GRIEST 90 COSM |
| | 44 OLIVE 89 COSM |
| none 100 eV - 15 GeV | SREDNICKI 88 COSM $\widetilde{\gamma}; m_{\widetilde{f}} = 100 \; { m GeV}$ |
| none 100 eV-5 GeV | ELLIS 84 COSM $\widetilde{\gamma}$; for $m_{\widetilde{f}} = 100$ GeV |
| · | GOLDBERG 83 COSM $\widetilde{\gamma}$ |
| | 47 KRAUSS 83 COSM $\widetilde{\gamma}$ |
| | |
| _ | VYSOTSKII 83 COSM $\widetilde{\gamma}$ |

 1 ELLIS 00 updates ELLIS 98. Uses LEP $e^+\,e^-$ data at $\sqrt{s}{=}202$ and 204 GeV to improve bound on neutralino mass to 51 GeV when scalar mass universality is assumed and 46 GeV when Higgs mass universality is relaxed. Limits on $\tan \beta$ improve to > 2.7 $(\mu > 0), >$ 2.2 $(\mu < 0)$ when scalar mass universality is assumed and > 1.9 (both signs of μ) when Higgs mass universality is relaxed.

 2 AKULA 11a places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry using results from 35 pb $^{-1}$ of LHC data.

 3 ALLANACH 11A updates the results of ALLANACH 11 and places constraints on the SUSY parameter space in the framework of ${\it N}=1$ supergravity models with radiative breaking of the electroweak gauge symmetry using results from 35 ${\rm pb}^{-1}$ of LHC data.

⁴ BUCH MUELLER 11 places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches and including supersymmetry breaking relations between A and B parameters.

 5 BUCH MUELLER 11a places constraints on the SUSY parameter space in the framework of ${\it N}=1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches and results from 35 ${
m pb}^{-1}$ of LHC data. Superseded by BUCHMUELLER 11B.

⁶ BUCHMUELLER 11B places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry using results from 35 pb $^{-1}$ of LHC data and from XENON100 data as well as indirect experimental searches. See also BUCHMUELLER 11A.

 7 FARINA 11 places constraints on the SUSY parameter space in the framework of N = 1 supergravity models with radiative breaking of the electroweak gauge symmetry using results from 1.1 fb $^{-1}$ of LHC data and from XENON100 data as well as indirect experimental searches.

 $^8\,{\sf PROFUMO}\,\,11$ places constraints on the SUSY parameter space in the framework of N $=\!1$ supergravity models with radiative breaking of the electroweak gauge symmetry using results from 35 pb $^{-1}$ of LHC data and from XENON100.

Places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry but non-Universal

- 18 BECHTLE 10 places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- 11 ELLIS 10 places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry with universality above the GUT scale.
- 12 BUCHMUELLER 09 places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches.

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- $^{13}\,\text{DREINER}$ 09 show that in the general MSSM with non-universal gaugino masses there exists no model-independent laboratory bound on the mass of the lightest neutralino. An essentially massless χ_1^0 is allowed by the experimental and observational data, imposing some constraints on other MSSM parameters, including M_{2} , μ and the slepton and
- 14 BUCHMUELLER 08 places constraints on the SUSY parameter space in the framework of $\mathit{N}=1$ supergravity models with radiative breaking of the electroweak gauge symmetry using indirect experimental searches.
- 15 CALIBBI 07 places constraints on the SUSY parameter space in the framework of $\emph{N}=$ 1 supergravity models with radiative breaking of the electroweak gauge symmetry with universality above the GUT scale including the effects of right-handed neutrinos.
- 16 ELLIS 07 places constraints on the SUSY parameter space in the framework of N = $1\ {\rm supergravity}\ {\rm models}\ {\rm with}\ {\rm radiative}\ {\rm breaking}\ {\rm of}\ {\rm the}\ {\rm electroweak}\ {\rm gauge}\ {\rm symmetry}\ {\rm with}\ {\rm universality}\ {\rm below}\ {\rm the}\ {\rm GUT}\ {\rm scale}.$
- $^{17}\mathrm{ALLA\,NA\,CH}$ 06 places constraints on the SUSY parameter space in the framework of N =1 supergravity models with radiative breaking of the electroweak gauge symmetry. 18 DE-AUSTRI 06 places constraints on the SUSY parameter space in the framework of N
- : 1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- $\frac{19}{8} \text{ALTZ O4 places constraints on the SUSY parameter space in the framework of } N=1$ supergravity models with radiative breaking of the electroweak gauge symmetry.
- 20 HOOPER 03, BOTTINO 03 (see also BOTTINO 03A and BOTTINO 04) , and BE-LANGER 04 do not assume gaugino or scalar mass unification.
- 21 Limit assumes a pseudo scalar mass < 200 GeV. For larger pseudo scalar masses, m_χ >18(29) GeV for an eta = 50(10). Bounds from WMAP, $(g-2)_{\mu}$, $b
 ightarrow s \gamma$, LEP.
- ²² ELLIS 04B places constraints on the SUSY parameter space in the framework of N=1 supergravity models with radiative breaking of the electroweak gauge symmetry including supersymmetry breaking relations between A and B parameters. See also ELLIS 03D.
- 23 PIERCE 04A places constraints on the SUSY parameter space in the framework of models with very heavy scalar masses
- 24 BAER 03, CHATTOPADHYAY 03, ELLIS 03c and LAHANAS 03 place constraints on the SUSY parameter space in the framework of $N\!=\!1$ supergravity models with radiative breaking of the electroweak gauge symmetry based on WMAP results for the cold dark
- $^{25}\, {\sf BOEHM}$ 00B and ELLIS 03 place constraints on the SUSY parameter space in the Framework of minimal M=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Includes the effect of χ - $\bar{\chi}$ co-annihilations. ²⁶ DJOUADI 01, ROSZKOWSKI 01, and BAER 02 place constraints on the SUSY parame-
- ter space in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- ²⁷ELLIS 02 places constraints on the soft supersymmetry breaking masses in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry.
- ²⁸LAHA NAS 02 places constraints on the SUSY parameter space in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Focuses on the role of pseudo-scalar Higgs exchange.
- ²⁹BARGER 01c use the cosmic relic density inferred from recent CMB measurements to constrain the parameter space in the framework of minimal $N\!=\!1$ supergravity models with radiative breaking of the electroweak gauge symmetry.
- 30 ELLIS OIB places constraints on the SUSY parameter space in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge symmetry. Focuses on models with large $tan \beta$.
- $^{31}\,\mathsf{FENG}$ 00 explores cosmologically allowed regions of MSSM parameter space with multi-
- $^{
 m 32}$ LAHANAS 00 use the new cosmological data which favor a cosmological constant and its implications on the relic density to constrain the parameter space in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge
- 33 ELLIS 98B assumes a universal scalar mass and radiative supersymmetry breaking with universal gaugino masses. The upper limit to the LSP mass is increased due to the inclusion of $\chi \bar{\tau}_R$ coannihilations.
- ³⁴EDSJO 97 included all coannihilation processes between neutralinos and charginos for any neutralino mass and composition.
- 35 Notes the location of the neutralino Z resonance and h resonance annihilation corridors in minimal supergravity models with radiative electroweak breaking. 36 Mass of the bino (=LSP) is limited to $m_{\widetilde{B}} \lesssim 350$ GeV for $m_t = 174$ GeV.
- $^{
 m 37}$ DREES 93, KELLEY 93 compute the cosmic relic density of the LSP in the framework of minimal N=1 supergravity models with radiative breaking of the electroweak gauge
- 38 FALK 93 relax the upper limit to the LSP mass by considering sfermion mixing in the
- ³⁹ MIZUTA 93 include coannihilations to compute the relic density of Higgsino dark matter.
- 40 LOPEZ 92 calculate the relic LSP density in a minimal SUSY GUT model.
- 41 MCDONALD 92 calculate the relic LSP density in the MSSM including exact tree-level annihilation cross sections for all two-body final states.
- $^{
 m 42}$ GRIEST 91 improve relic density calculations to account for coannihilations, pole effects, and threshold effects.

 43 NOJIRI 91 uses minimal supergravity mass relations between squarks and sleptons to
- 44 Mass of the bino (=LSP) is limited to $m_{\widetilde{H}} \lesssim 350$ GeV for $m_t \leq 200$ GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim 1$ TeV for $m_t \leq 200$ GeV.
- 45 ROSZKOWSKI 91 calculates LSP relic density in mixed gaugino/higgsino region. 46 Mass of the bino (=LSP) is limited to $m_{\widetilde{B}}\lesssim 550$ GeV. Mass of the higgsino (=LSP) is limited to $m_{\widetilde{H}} \lesssim$ 3.2 TeV.
- 47 KRAUSS 83 finds $m_{\widetilde{\gamma}}$ not 30 eV to 2.5 GeV. KRAUSS 83 takes into account the gravitino decay. Find that $\lim_{N\to\infty}^{N}$ its depend strongly on reheated temperature. For example a new allowed region $m_{\widetilde{\gamma}}=$ 4–20 MeV exists if $m_{\rm gravitino}$ <40 TeV. See figure 2.

Unstable $\widetilde{\chi}_1^0$ (Lightest Neutralino) MASS LIMIT -

Unless otherwise stated, results in this section assume spectra and production rates as evaluated in the MSSM. Unless otherwise stated, the goldstino or gravitino mass $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses. In the following, \widetilde{G} is assumed to be undetected and to give rise to a missing energy (₺) signature.

| VAL | UE (GeV) | CL% | | DO CUMENT ID | | TECN | COMMENT |
|-----|----------|-------|--------|-------------------|-------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | • We d | o not | use th | he following data | a for | averages | , fits, limits, etc. • • • |
| | | | 1 | CHATRCHYAN | 111в | CMS | $\widetilde{W}^0 \rightarrow \gamma \widetilde{G}, \widetilde{W}^{\pm} \rightarrow \ell^{\pm} \widetilde{G}, \text{GMSB}$ |
| >1 | 49 | 95 | | AALTONEN | 10 | CDF | $\rho\overline{\rho}\rightarrow\ \widetilde{\chi}\widetilde{\chi},\widetilde{\chi}{=}\widetilde{\chi}_{2}^{0},\widetilde{\chi}_{1}^{\pm},\widetilde{\chi}_{1}^{0}\rightarrow\ \gamma\widetilde{G},$ |
| >1 | 75 | 95 | 3 | ABAZOV | 10p | D0 | $\widetilde{\chi}_1^0 \stackrel{GMSB}{	o} \gamma \widetilde{G}, GMSB$ |
| | | | 4 | AALTONEN | 08 U | CDF | $\widetilde{\chi}_1^{0} \rightarrow \gamma \widetilde{G}$, GMSB |
| >1 | 25 | 95 | 5 | ABAZOV | 08F | D0 | $p\overline{p} \rightarrow \widetilde{\chi}\widetilde{\chi}, \widetilde{\chi} = \widetilde{\chi}_{2}^{0}, \widetilde{\chi}_{1}^{\pm}, \widetilde{\chi}_{1}^{0} \rightarrow \gamma \widetilde{G},$ |
| | | | | ABAZOV | 08x | D0 | $\widetilde{\chi}_1^0 \to Z^0 \widetilde{G}$, GMSB |
| | | | 7 | ABULENCIA | 07н | CDF | <u>Ŗ</u> , LL <u>E</u> |
| | | | 8 | ABAZOV | 06D | D0 | Ŗ, LL Ē |
| | | | 9 | ABAZOV | 06P | D0 | R , λ_{122} |
| > | 96.8 | 95 | 10 | ABBIENDI | 06в | OPAL | $e^+ e^- \rightarrow \widetilde{B} \widetilde{B}, (\widetilde{B} \rightarrow \widetilde{G} \gamma)$ |
| | | | 11 | ABDALLAH | 05B | DLPH | $e^+e^- \rightarrow \widetilde{G}\widetilde{\chi}_1^0, (\widetilde{\chi}_1^0 \rightarrow \widetilde{G}\gamma)$ |
| > | 96 | 95 | 12 | ABDALLAH | 05в | DLPH | $e^+ e^- \rightarrow \widetilde{B} \widetilde{B}, (\widetilde{B} \rightarrow \widetilde{G} \gamma)$ |
| > | 93 | 95 | 13 | ACOSTA | 05 E | CDF | $ \rho \overline{\rho} \to \widetilde{\chi} \widetilde{\chi}, \widetilde{\chi} = \widetilde{\chi}_2^0, \widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^0 \to \gamma \widetilde{G}, $ |
| | | | 14 | AKTAS | 05 | H1 | $e^{\pm} \stackrel{GMSB}{p} \rightarrow q \widetilde{\chi}_{1}^{0}, \widetilde{\chi}_{1}^{0} \rightarrow \gamma \widetilde{G},$ |
| | | | | | | | GMSB+ <i>I</i> ₹ <i>LQD</i> |
| | | | 15 | ABBIENDI | 04N | OPAL | $e^+ e^- \rightarrow \gamma \gamma E$ |
| > | 66 | 95 | 16,17 | ABDALLAH | 04н | DLPH | AMSB, $\mu > 0$ |
| > | 38.0 | 95 | 18,19 | ABDALLAH | 04м | DLPH | $R(\overline{U}\overline{D}\overline{D})$ |
| | | | | ACHARD | 04E | L3 | $e^+ e^- ightarrow \ \widetilde{G} \widetilde{\chi}_1^0, \widetilde{\chi}_1^0 ightarrow \ \widetilde{G} \gamma$ |
| > | 99.5 | 95 | | ACHARD | 04E | L3 | $e^+ e^- \rightarrow \widetilde{B} \widetilde{B}^1, (\widetilde{B}^1 \rightarrow \widetilde{G} \gamma)$ |
| > | 89 | | 22 | ABDALLAH | 03D | DLPH | $e^+ e^- ightarrow \widetilde{\chi}^0_1 \widetilde{\chi}^0_1$, GMSB, |
| | | | 23 | | | | $m(\widetilde{G}) < 1eV$ |
| | | | 23 | HEISTER | 03c | ALEP | $\begin{array}{ccc} e^{+} \stackrel{\longleftarrow}{e^{-}} \stackrel{\nearrow}{\rightarrow} & \widetilde{B} \widetilde{B}, (\widetilde{B} \rightarrow \gamma \widetilde{G}) \\ e^{+} \stackrel{\longleftarrow}{e^{-}} \rightarrow & \widetilde{G} \widetilde{\chi}_{1}^{0}, (\widetilde{\chi}_{1}^{0} \rightarrow \widetilde{G} \gamma) \end{array}$ |
| | | | 24 | HEISTER | 03c | ALEP | |
| | 39.9 | 95 | 25 | ACHARD | 02 | L3 | R, MSUGRA |
| | 92 | 95 | | HEISTER | 02R | ALEP | short lifetime |
| | 54 | 95 | 20 | HEISTER | 02R | ALEP | any lifetime |
| > | | 95 | 27 | ABBIENDI | 01 | OPAL | $e^+e^- \rightarrow \widetilde{\chi}_{1}^{0}\widetilde{\chi}_{1}^{0}$, GMSB, $\tan\beta=2$ |
| - | 76 | 95 | 21 | ABBIENDI | 01 | OPAL | $e^+e^- ightarrow~\widetilde{\chi}_1^{0}\widetilde{\chi}_1^{0}$, GMSB, tan eta =20 |
| > | 32.5 | 95 | 28 | ACCIARRI | 01 | L3 | R , all m_0 , $0.7 \le \tan \beta \le 40$ |
| | | | 29 | ADAMS | 01 | NTEV | $\tilde{\chi}^0 \rightarrow \mu \mu \nu, R, LL\overline{E}$ |
| > | 29 | 95 | 30 | ABBIENDI | 99T | OPAL | $e^+e^- \rightarrow \widetilde{\chi}_1^0\widetilde{\chi}_1^0$, R , $m_0=$ 500 GeV, $\tan\beta>1.2$ |
| > | 29 | 95 | 31 | BARATE | 99E | ALEP | R , $LQ\overline{D}$, $\tan \beta = 1.41$, $m_0 = 500$ GeV |
| | | | 32 | ABREU | 98 | DLPH | $e^+e^- \rightarrow \widetilde{\chi}^0_1\widetilde{\chi}^0_1(\widetilde{\chi}^0_1 \rightarrow \gamma\widetilde{G})$ |
| > | 23 | 95 | 33 | BARATE | 98s | ALEP | R , $LL\overline{E}$ |
| - | | | 34 | ELLIS | 97 | THEO | $e^+e^- \rightarrow \widetilde{\chi}_1^0\widetilde{\chi}_1^0, \widetilde{\chi}_1^0 \rightarrow \gamma\widetilde{G}$ |
| | | | | CABIBBO | 81 | COSM | A1 A1 A1 |
| | | | | | | | |

 1 CHATRCHYAN 11B looked in 35 pb $^{-1}$ of pp collisions at \sqrt{s} =7 TeV for events with an isolated lepton (e or μ), a photon and \mathcal{E}_T which may arise in a generalized gauge mediated model from the decay of Wino-like NLSPs. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark/gluino mass versus Wino mass (see Fig. 4). Mass degeneracy of the produced squarks and gluinos is

 2 AALTONEN 10 searched in 2.6 fb $^{-1}$ of $p \overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for diphoton events with large $ot\!\!E_T$. They may originate from the production of $\widetilde{\chi}^\pm$ in pairs or as-is derived on the $\tilde{\chi}_1^0$ mass of 149 GeV for $\tau_{\tilde{\chi}_1^0}\ll 1$ ns, which improves the results of

 3 ABAZOV 10P looked in 6.3 fb $^{-1}$ of $p\,\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with $ilde{\chi}^0_1$ mass range is obtained.

 4 AALTONEN 08u searched in 570 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events that contain a time-delayed photon, at least one jet, and large \rlap/E_T . The time-of-arrival is measured for each electromagnetic tower with a resolution of 0.50 ns. The number of observed events in the signal region is consistent with the background estimation. An upper limit on the cross section is derived as a function of the $\widetilde{\chi}^0_1$ mass and lifetime, shown in their Fig. 24. The comparison with the NLO cross section for GMSB yields an exclusion of the $\widetilde{\chi}_1^0$ mass as a function of its lifetime, see Fig. 25. See ABULENCIA 07P

for a previous analysis of the same data set. 5 ABAZOV 08F looked in 1.1 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for diphoton events with large \wp_T . They may originate from the production of χ^+ in pairs or associated to a $\tilde{\chi}^0_2$, decaying to a $\tilde{\chi}^0_1$ which itself decays promptly in GMSB to $\tilde{\chi}^0_1 \to \gamma \tilde{G}$. No significant excess was found compared to the background expectation. A limit is derived on the masses of SUSY particles in the GMSB framework for $M=2\Lambda$, N=1, $\tan\beta=15$ and $\mu>0$, see Figure 2. It also excludes $\Lambda<91.5$ TeV. Supersedes the results of ABAZOV 05A. Superseded by ABAZOV 10P.

6 ABAZOV 08X searched in 1.1 fb⁻¹ of $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV for an excess of events with electron pairs. Their vertex, reconstructed from the directions measured in the segmented electromagnetic calorimeter, is required to be away from the primary interaction point. Such delayed decays might be expected for a Higgsign like $\tilde{\chi}^0$ in

interaction point. Such delayed decays might be expected for a Higgsino-like $\widetilde{\chi}^0_1$ in

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GMSB. No significant excess was found compared to the background expectation. Upper limits on the cross-section times branching ratio are extracted as a function of the lifetime for several ranges of dielectron invariant masses, see their Fig. 3.

 7 ABULENCIA 07H searched in 346 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least three leptons (e or μ) from the decay of $\overline{\chi}_1^0$ via $LL\overline{E}$ couplings. The results are consistent with the hypothesis of no signal. Upper limits on the cross-section are extracted and a limit is derived in the framework of mSUGRA on the masses of $\widetilde{\chi}^0_1$ and

 $\widetilde{\chi}_1^\pm$, see e.g. their Fig. 3 and Tab. II.

 χ_1 , see e.g. their rig. 5 and 1ab. II.

8 ABAZOV 06D looked in 360 pb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with three leptons originating from the pair production of charginos and neutralinos, followed by R decays mediated by $LL\overline{E}$ couplings. One coupling is assumed to be dominant at a time. No significant excess was found compared to the background expectation in the $ee\ell$, $\mu\mu\ell$ nor $ee\tau$ ($\ell=e$, μ) final states. Upper limits on the cross-section are extracted in a specific MSUGRA model and a MSSM model without unification of M_1 and M_2 at the GUT scale. A limit is derived on the masses of charginos and neutralinos for both scenarios assuming λ_{ijk} couplings such that the decay length is less than 1 cm, see their

PABAZOV 06P looked in 380 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 opposite sign isolated muons which might arise from the decays of neutralinos into $\mu\mu\nu$ via R couplings $LL\overline{E}$. No events are observed in the decay region defined by a radius between 5 and 20 cm, in agreement with the SM expectation. Limits are set on the cross-section times branching ratio as a function of lifetime, shown in their Fig. 2. This limit availables the SLISV interpretation of the NuTeV excess of dimuon events 3. This limit excludes the SUSY interpretation of the NuTeV excess of dimuon events

reported in ADAMS 01.

 10 ABBIENDI 06B use 600 pb $^{-1}$ of data from \sqrt{s} = 189–209 GeV. They look for events with diphotons + E final states originating from prompt decays of pair-produced neutralinos in a GMSB scenario with $\tilde{\chi}_1^0$ NLSP. Limits on the cross-section are computed as a function of m($\widetilde{\chi}^0_1$), see their Fig. 14. The limit on the $\widetilde{\chi}^0_1$ mass is for a pure Bino state assuming

a prompt decay, with lifetimes up to 10^{-9} s. Supersedes the results of ABBIENDI 04N. ¹¹ ABDALLAH 05B use data from $\sqrt{s} = 180-209$ GeV. They look for events with single photons + E final states. Limits are computed in the plane $(m(\widetilde{G})$, $m(\widetilde{\chi}_1^0))$, shown in their Fig. 9b for a pure Bino state in the GMSB framework and in Fig. 9c for a no-scale

supergravity model. Supersedes the results of ABREU 00z.

12 ABDALLAH 05B use data from $\sqrt{s}=130-209$ GeV. They look for events with diphotons + \$\mathbb{E}\$ final states and single photons not pointing to the vertex, expected in GMSB when the $\widetilde{\chi}^0_1$ is the NLSP. Limits are computed in the plane (m(\widetilde{G}), m($\widetilde{\chi}^0_1$)), see their Fig. 10. The lower limit is derived on the $\widetilde{\chi}_1^0$ mass for a pure Bino state assuming a prompt decay and $m_{\widetilde{e}_R} = m_{\widetilde{e}_L} = 2 \ m_{\widetilde{\chi}_1^0}$. It improves to 100 GeV for $m_{\widetilde{e}_R} = m_{\widetilde{e}_L} = 1.1 \ m_{\widetilde{\chi}_1^0}$. and

- the limit in the plane $(m(\widetilde{\chi}^0_1), m(\overline{e}_R))$ is shown in Fig. 10b. For long-lived neutralinos, cross-section limits are displayed in their Fig 11. Supersedes the results of ABREU 00z. ¹³ ACOSTA 05E looked in 202 pb⁻¹ of $\rho\overline{p}$ collisions at \sqrt{s} =1.96 TeV for diphoton events with large $ot\!\!\!E_T$. They may originate from the production of $\widetilde{\chi}^\pm$ in pairs or associated to a $\widetilde{\chi}_2^0$, decaying to a $\widetilde{\chi}_1^0$ which itself decays promptly in GMSB to $\gamma\,\widetilde{G}$. No events are as A_2 , according to a A_1 minor local according promptly in GMSB to γ 0. No events after the selected at large E_T compared to the background expectation. A limit is derived on the masses of SUSY particles in the GMSB framework for M=2 Λ , N=1, $\tan\beta=15$ and $\mu>0$, see Figure 2. It also excludes $\Lambda<69$ TeV. Supersedes the results of ABE 99. They look for E0 results of E1 and E2 of E3. They look for E3 resonant E3 production via E3 channel exchange of a E4, followed by
- prompt GMSB decay of the $\widetilde{\chi}_1^0$ to $\gamma \widetilde{G}$. Upper limits at 95% on the cross section are derived, see their Figure 4, and compared to two example scenarios. In Figure 5, they display 95% exclusion limits in the plane of $M(\widetilde{\chi}^0_1)$ versus $M(\widetilde{e}_L) - M(\widetilde{\chi}^0_1)$ for the two

scenarios and several values of the λ' Yukawa coupling. ¹⁵ ABBIENDI 04N use data from $\sqrt{s}=189$ –209 GeV, setting limits on $\sigma(e^+e^-\to 189$

 $XX) \times B^2(X \to Y \gamma)$, with Y invisible (see their Fig. 4). Limits on $\widetilde{\chi}_1^0$ masses for a specific model are given. Supersedes the results of ABBIENDI, G 00D. 16 ABDALLAH 04H use data from LEP 1 and $\sqrt{s} = 192-208$ GeV. They re-use results or re-analyze the data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region $1 < m_3/2$ <50 TeV, $0 < m_0 < 1000$ GeV, $1.5 < \tan \beta < 35$, both signs of μ . The constraints are obtained from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the coupled from the cou are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM Z width of 3.2 MeV. The limit is for $m_t=174.3$ GeV (see Table 2 for other m_t values).

17 The limit improves to 73 GeV for $m_{\tilde{t}}=174.5$ GeV (see Table 2101 other $m_{\tilde{t}}$ values).
18 ABDALLAH 04M use data from $\sqrt{s}=192-208$ GeV to derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or \overline{UDD} couplings. The results are valid in the ranges $90 < m_0 < 500$ GeV, $0.7 < \tan \beta < 30$, $-200 < \mu < 200$ GeV, $0 < M_2 < 400$ GeV. Supersedes the result of ABREU 01D and ABREU 00U.

¹⁹ The limit improves to 39.5 GeV for $LL\overline{E}$ couplings.

- 20 ACHARD 04E use data from $\sqrt{s}=189$ – 209 GeV. They look for events with single their Fig. 8c for a no-scale supergravity model, excluding, e.g., Gravitino masses below
- 10^{-5} eV for neutralino masses below 172 GeV. Supersedes the results of ACCIARRI 99R. 21 ACHARD 04E use data from $\sqrt{s}=189$ –209 GeV. They look for events with diphotons The limit on the $\widetilde{\chi}^0_1$ mass is for a pure Bino state assuming a prompt decay, with $m_{\widetilde{e}_l}$ = 1.1 $m_{\widetilde{\chi}_1^0}$ and $m_{\widetilde{e}_R}^{-}=$ 2.5 $m_{\widetilde{\chi}_1^0}.$ Supersedes the results of ACCIARRI 99R.
- ²²ABDALIAH 03D use data from $\sqrt{s}=161$ –208 GeV. They look for 4-tau + \cancel{E} final states, expected in GMSB when the $\widehat{\tau}_1$ is the NLSP, and 4-lepton + \cancel{E} final states, expected in the co-NLSP scenario, and assuming a short-lived $\tilde{\chi}_1^0$ (m(\tilde{G})<1 eV). Limits are computed in the plane $(m(\widetilde{\tau}_1), m(\widetilde{\chi}_1^0))$ from a scan of the GMSB parameters space, after combining these results with the search for slepton production from the same paper to cover prompt decays and for the case of $\widetilde{\chi}_1^0$ NLSP from ABREU 00z. The limit Stronger limits are obtained when more messenger generations are assumed or when the $\widetilde{\tau}_1$ is the NLSP. Stronger limits are obtained when more messenger generations are assumed or when the other sleptons are co-NLSP, see their Fig. 10. Supersedes the results of ABREU 01G.
 23 HEISTER 03C use the data from $\sqrt{s}=189$ -209 GeV to search for $\gamma\not\!\!E_T$ final states with non-pointing photons and $\gamma\gamma\not\!\!E_T$ events. Interpreted in the framework of Minimal

GMSB, a lower bound on the $\widetilde{\chi}^0_1$ mass is obtained as function of its lifetime. For a laboratory lifetime of less than 3 ns, the limit at 95% CL is 98.8 GeV. For other lifetimes, see their Fig. 5. These results are interpreted in a more general GMSB framework in HEISTER 02R.

24 HEISTER 03C use the data from $\sqrt{s}=$ 189–209 GeV to search for $\gamma \not\!\! E_T$ final states. They obtained an upper bound on the cross section for the process $e^+ \, e^-
ightarrow \, \widetilde{G} \, \widetilde{\chi}^0_1$, followed by the prompt decay $\widetilde{\chi}^0_1 \to \gamma \, \widetilde{\mathcal{G}}$, shown in their Fig. 4. These results supersede

BARATE 98H.

- BARATE 98H.
 25 ACHARD 02 searches for the production of sparticles in the case of R prompt decays with $LL\bar{E}$ or $UD\bar{D}$ couplings at \sqrt{s} =189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit holds for $UD\bar{D}$ couplings and increases to 40.2 GeV for $LL\bar{E}$ couplings. For L3 limits from $LQ\bar{D}$ couplings, see ACCLARRI 01. ACCIARRI 01.
- 26 HEISTER 02R search for signals of GMSB in the 189–209 GeV data. For the $\widetilde{\chi}_1^0$ NLSP interaction vertex. For the $\widetilde{\ell}$ NLSP case, the topologies consist of $\ell\ell E\!\!\!\!/$ or $4\ell E\!\!\!\!/$ (from $\widetilde{\chi}_1^0\widetilde{\chi}_1^0)$ production), including leptons with large impact parameters, kinks, or stable particles. Limits are derived from a scan over the GMSB parameters (see their Table 5 for the ranges). The limits are valid whichever is the NLSP. The absolute mass bound on the $\tilde{\chi}_1^0$ for any lifetime includes indirect limits from the chargino search, and from the slepton search HEISTER 02E preformed within the MSUGRA framework. A bound for any NLSP and any lifetime of 77 GeV has also been derived by using the constraints from the neutral Higgs search in HEISTER 02. Limits on the universal SUSY mass scale

in the plane $(m_{\widetilde{\chi}_1^0}, m_{\widetilde{\tau}_1})$, see Fig. 6, allowing either the $\widetilde{\chi}_1^0$ or a $\widetilde{\ell}_1$ to be the NLSP. Two scenarios are considered: $\tan\beta = 2$ with the 3 sleptons degenerate in mass and $\tan\beta = 20$ where the $\widetilde{ au}_1$ is lighter than the other sleptons. Data taken at $\sqrt{s}{=}189$ GeV.

28 ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from R prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or \overline{UDD} couplings at \sqrt{s} =189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}_1^0$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z0 width measurements from ACCIARRI 00C in a scan of the parameter space assuming MSUGRA with gaugino and scalar mass universality. Updates and supersedes

the results from ACCIARRI 99.

29 ADAMS 01 looked for neutral particles with mass > 2.2 GeV, produced by 900 GeV ADAMS of lowest of neutral particles with mass 2.2 dev, produced by 900 dev protons incident on a Beryllium oxide target and decaying through weak interactions into $\mu\mu$, μe , or $\mu\pi$ final states in the decay channel of the NuTeV detector (E815) at Fermilab. The number of observed events is $3 \mu\mu$, $0 \mu e$, and $0 \mu\pi$ with an expected background of 0.069 ± 0.010 , 0.13 ± 0.02 , and 0.14 ± 0.02 , respectively. The $\mu\mu$ events are consistent with the R decay of a neutralino with mass around 5 GeV. However, they share several aspects with ν -interaction backgrounds. An upper limit on the differential production for the control of the decay hearth production cross section of neutralinos in pp interactions as function of the decay length

s given in Fig. 3.

30 ABBIENDI 99T searches for the production of neutralinos in the case of R-parity violation with $LL\overline{F}$, $LQ\overline{D}$, or \overline{UDD} couplings using data from \sqrt{s} =183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. Mixed decays (where one particle has a direct, the other an indirect decay) are also considered for the \overline{UDD} couplings. Upper limits on the cross section are derived which, combined with the constraint from the Z^0 width, allow to exclude regions in the M_2 versus μ plane for

any coupling. Limits on the neutralino mass are obtained for non-zero $LL\overline{E}$ couplings $>10^{-5}$. The limit disappears for $\tan\beta<1.2$ and it improves to 50 GeV for $\tan\beta>20$. ³¹ BARATE 99E looked for the decay of gauginos via R-violating couplings $LQ\overline{D}$. The bound is significantly reduced for smaller values of m_0 . Data collected at \sqrt{s} =130-172

32 ABREU 98 uses data at \sqrt{s} =161 and 172 GeV. Upper bounds on $\gamma\gamma E$ cross section are obtained. Similar limits on γE are also given, relevant for $e^+ \, e^- \to \, \widetilde{\chi}_1^0 \, \widetilde{G}$ production.

33 BARATE 98s looked for the decay of gauginos via R-violating coupling LLE. The bound improves to 25 GeV if the chargino decays into neutralino which further decays into lepton pairs. Data collected at \sqrt{s} =130-172 GeV. 34 ELLIS 97 reanalyzed the LEP2 (\sqrt{s} =161 GeV) limits of $\sigma(\gamma\gamma + E_{miss}) < 0.2$ pb to exclude

 $m_{\widetilde{\chi}_1^0} <$ 63 GeV if $m_{\widetilde{e}_L} = m_{\widetilde{e}_R} <$ 150 GeV and $\widetilde{\chi}_1^0$ decays to $\gamma \widetilde{G}$ inside detector

 $\stackrel{\sim}{}_{35}$ CABIBBO 81 consider $\stackrel{\sim}{\gamma} \rightarrow \gamma +$ goldstino. Photino must be either light enough (<30 eV) to satisfy cosmology bound, or heavy enough (>0.3 MeV) to have disappeared at early universe.

 $\widetilde{\chi}_2^0$, $\widetilde{\chi}_3^0$, $\widetilde{\chi}_4^0$ (Neutralinos) MASS LIMITS Neutralinos are unknown mixtures of photinos, z-inos, and neutral higgsinos (the supersymmetric partners of photons and of Z and Higgs bosons). The limits here apply persymmetric partners of photons and of Z and rings bosons). The limits here apply only to $\tilde{\chi}_2^0$, $\tilde{\chi}_0^0$, and $\tilde{\chi}_4^0$, $\tilde{\chi}_1^0$ is the lightest supersymmetric particle (LSP); see $\tilde{\chi}_1^0$ Mass Limits. It is not possible to quote rigorous mass limits because they are extremely model dependent; i.e. they depend on branching ratios of various $\tilde{\chi}^0$ decay modes, on the masses of decay products ($\tilde{\epsilon}_1$, $\tilde{\gamma}_1$, $\tilde{\epsilon}_2$), and on the $\tilde{\epsilon}_1$ mass exchanged in $e^+e^- o ilde{\chi}^0_i ilde{\chi}^0_i$. Limits arise either from direct searches, or from the MSSM constraints set on the gaugino and higgsino mass parameters M_2 and μ through searches for lighter charginos and neutralinos. Often limits are given as contour plots in the $m_{\widetilde{\chi}^0}-m_{\widetilde{e}}$ plane vs other parameters. When specific assumptions are made, e.g, the neutralino is a pure photino $(\widetilde{\gamma})$, pure z-ino (\widetilde{Z}) , or pure neutral higgsino (\widetilde{H}^0) , the neutralinos will be labelled as such.

Limits obtained from e^+e^- collisions at energies up to 136 GeV, as well as other limits from different techniques, are now superseded and have not been included in

Supersymmetric Particle Searches

this compilation. They can be found in the 1998 Edition (The European Physical Journal **C3** 1 (1998)) of this Review. $\Delta m = m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT | | |
|-------------|-----|-------------------------|-----|------|-------------------------------------------------------------------------------------------------------------|--|--|
| > 78 | 95 | ¹ ABBIENDI | 04н | OPAL | $\widetilde{\chi}_2^0$, all tan eta , $\Delta m{>}$ 5 GeV, | | |
| > 62.4 | 95 | ² ABREU | 00w | DLPH | $m_0 >$ 500 GeV, $A_0 = 0$ $\widetilde{\chi}_2^0, 1 \leq \tan\beta \leq 40$, all Δm , all m_0 | | |
| > 99.9 | 95 | ² A BREU | 00w | DLPH | $\widetilde{\chi}_3^0$, $1 \leq 	aneta \leq 40$, all Δm , | | |
| >116.0 | 95 | ² A BREU | | | all m_0 $\widetilde{\chi}_4^0, 1 \leq 	aneta \leq 40$, all Δm , all m_0 | | |
| | | | | | | | |
| | | ³ A BULENCIA | 07n | CDF | $p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ | | |

| | | ³ A BULENCIA | | CDF | $p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
|--------|----|----------------------------|-----|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | | ⁴ ABDALLAH | 05в | DLPH | $\begin{array}{ccc} e^{+} e^{-} & \rightarrow & \widetilde{\chi}_{2}^{0} \widetilde{\chi}_{2}^{0}, (\widetilde{\chi}_{2}^{0} \rightarrow & \widetilde{\chi}_{1}^{0} \gamma) \\ e^{+} e^{-} & \rightarrow & \widetilde{\chi}_{2}^{0} \widetilde{\chi}_{2}^{0}, (\widetilde{\chi}_{2}^{0} \rightarrow & \widetilde{\chi}_{1}^{0} \gamma) \end{array}$ |
| | | ⁵ ACHARD | 04E | L3 | $e^+e^- \rightarrow \widetilde{\chi}_2^0\widetilde{\chi}_2^0$, $(\widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0\gamma)$ |
| > 80.0 | 95 | ⁶ ACHARD | 02 | | $\widetilde{\chi}_{2}^{0}$, R , MSUGRA |
| >107.2 | 95 | ⁶ ACHARD | 02 | L3 | $\widetilde{\chi}_3^{0}$, R , MSUGRA |
| | | ⁷ A BREU | 01в | DLPH | $e^{+}e^{-} \rightarrow \tilde{\chi}_{i}^{0}\tilde{\chi}_{i}^{0}$ |
| > 68.0 | 95 | ⁸ ACCIARRI | 01 | L3 | $\widetilde{\chi}_2^0$, R , all m_0 , $0.7 \le \tan \beta \le 40$ |
| > 99.0 | 95 | ⁸ ACCIARRI | 01 | L3 | $\widetilde{\chi}_3^0$, R , all m_0 , $0.7 \le \tan \beta \le 40$ |
| > 50 | 95 | ⁹ A BREU | 00υ | DLPH | $\widetilde{\chi}_{2}^{0}$, $\not R$ (LL \overline{E}), all Δm , |
| | | 10 ABBIENDI 11 ABBIENDI | 99F | OPAL OPAL | $\begin{array}{l} 1 \leq \tan\beta \leq 30 \\ e^{+} e^{-} \rightarrow \widetilde{\chi}_{2}^{0} \widetilde{\chi}_{1}^{0} (\widetilde{\chi}_{2}^{0} \rightarrow \gamma \widetilde{\chi}_{1}^{0}) \\ e^{+} e^{-} \rightarrow \widetilde{\chi}_{2}^{0} \widetilde{\chi}_{2}^{0} (\widetilde{\chi}_{2}^{0} \rightarrow \gamma \widetilde{\chi}_{1}^{0}) \end{array}$ |
| | | ¹² ABBOTT | 98c | D0 | $p\overline{p} \rightarrow \widetilde{\chi}_{1}^{\pm} \widetilde{\chi}_{2}^{0}$ |
| > 82.2 | 95 | ¹³ ABE | 981 | CDF | ~1 ~2 |
| > 92 | 95 | ¹⁴ ACCIARRI | 98F | L3 | \widetilde{H}_2^0 , tan β =1.41, M_2 $<$ 500 GeV |
| | | ¹⁵ ACCIARRI | 98v | L3 | $e^{+}e^{-} \rightarrow \tilde{\chi}_{2}^{0}\tilde{\chi}_{1,2}^{0}$ |
| | | | | | $(\widetilde{\chi}_2^0 \to \gamma \widetilde{\chi}_1^0)$ |
| > 53 | 95 | 16 BARATE | 98н | ALEP | $\begin{array}{ccc} e^{+} e^{-} & \rightarrow & \widetilde{\gamma} \widetilde{\gamma} \ (\widetilde{\gamma} \rightarrow & \gamma \widetilde{H}^{0}) \\ e^{+} e^{-} & \rightarrow & \widetilde{\gamma} \widetilde{\gamma} \ (\widetilde{\gamma} \rightarrow & \gamma \widetilde{H}^{0}) \end{array}$ |
| > 74 | 95 | ¹⁷ BARATE | 981 | ALEP | |
| | | ¹⁸ АВАСНІ | 96 | D0 | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
| | | ¹⁹ ABE | 96K | CDF | $p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |

- ¹ ABBIENDI 04H search for charginos and neutralinos in events with acoplanar leptons+jets and multi-jet final states in the 192-209 GeV data, combined with the results on leptonic final states from ABBIENDI 04. The results hold for a scan over the parameter space covering the region 0 < M_2 <5000 GeV, -1000 < μ <1000 GeV and tan β from 1 to 40. This limit supersedes ABBIENDI 00H.
- 20. This limit supersects ABBLEUO over the Supersection of Section 1989 and Section 1989. The mass limit is obtained by constraining the MSSM parameter space with gaugino and sfermion mass universality at the GUT scale, using the results of negative direct searches for neutralinos (including cascade decays and \vec{r}_T final states) from ABREU 01, for charginos from ABREU 00J and ABREU 00T (for all Δm_+), and for charged sleptons from ABREU 01B. The results hold for the full parameter space defined by all values of $|M_2|$ and $|\mu| \leq 2$ TeV with the $\widetilde{\chi}_1^0$ as LSP.
- 3 ABULENCIA 07N searched in 1 fb $^{-1}$ of $ho\overline{
 ho}$ collisions at $\sqrt{s}=1.96$ TeV for events with two same sign leptons (e or μ) from the decay of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 X$ and large E_T . A slight excess of 13 events is observed over a SM background expectation of 7.8 \pm 1.1. However, the kinematic distributions do not show any anomalous deviation from expectations in any
- ABDALLAH 05B use data from $\sqrt{s}=130-209$ GeV, looking for events with diphotons + $\not\!\! E$. Limits on the cross-section are computed in the plane $(\mathsf{m}(\widetilde{\chi}_2^0),\,\mathsf{m}(\widetilde{\chi}_1^0))$, see Fig. 12. Supersedes the results of ABREU 00z.
- 5 ACHARD 04E use data from $\sqrt{s}=$ 189–209 GeV, looking for events with diphotons + $ot\!\!\!E$. Limits are computed in the plane $(\mathsf{m}(\widetilde{\chi}_2^0),\,\mathsf{m}(\widetilde{e}_R))$, for $\Delta m > 10$ GeV, see Fig. 7. Supersedes the results of ACCIARRI 99R.
- ACHARD 02 searches for the production of sparticles in the case of R prompt decays with LLE or \overline{UDD} couplings at \sqrt{s} =189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit of $\widetilde{\chi}_2^0$ holds for \overline{UDD} couplings and increases to 84.0 GeV for LLE couplings. The same $\widetilde{\chi}^0_3$ limit holds for both $LL\overline{E}$ and \overline{UDD} couplings. For L3 limits from $LQ\overline{D}$ couplings, see ACCIARRI 01. 7 ABREU 01B used data from \sqrt{s} =189 GeV to search for the production of $\widetilde{\chi}_i^0 \, \widetilde{\chi}_i^0$. They
- looked for di-jet and di-lepton pairs with E for events from $\widetilde{\chi}_i^0 \, \widetilde{\chi}_i^0$ with the decay $\widetilde{\chi}_i^0 \to$ $f\overline{f}\widetilde{\chi}_1^0$; multi-jet and multi-lepton pairs with or without additional photons to cover the cascade decays $\widetilde{\chi}_j^0 \to f \overline{f} \widetilde{\chi}_2^0$, followed by $\widetilde{\chi}_j^0 \to f \overline{f} \widetilde{\chi}_1^0$ or $\widetilde{\chi}_j^0 \to \gamma \widetilde{\chi}_1^0$; multi-tau final states from $\tilde{\chi}^0_2 \to \tilde{\tau} \tau$ with $\tilde{\tau} \to \tau \tilde{\chi}^0_1$. See Figs. 9 and 10 for limits on the (μ, M_2) plane for $\tan \beta = 1.0$ and different values of m_0 .
- 8 ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from R prompt decays with $LL\overline{E}$, $LQ\overline{D}$, or \overline{UDD} couplings at \sqrt{s} =189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00c in a scan of the parameter space assuming MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 991.
- 9 ABREU 000 searches for the production of charginos and neutralinos in the case of R-parity violation with $LL\overline{E}$ couplings, using data from \sqrt{s} =189 GeV. They investigate topologies with multiple leptons or jets plus leptons, assuming one coupling to be nonzero

- at the time and giving rise to direct or indirect decays. Limits are obtained in the M_2 versus μ plane and a limit on the neutralino mass is derived from a scan over the parameters m_0 and $\tan\beta$.
- ABBIENDI 99F looked for γE final states at \sqrt{s} =183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \to \tilde{\chi}_2^0 \tilde{\chi}_1^0$ followed by the prompt decay $\tilde{\chi}^0_2\to\gamma\tilde{\chi}^0_1$ of 0.075–0.80 pb in the region $m_{\tilde{\chi}^0_2}+m_{\tilde{\chi}^0_1}>m_Z$, $m_{\tilde{\chi}^0_2}=$ 91–183 GeV, and $\Delta m>$ 5 GeV. See Fig. 7 for explicit limits in the $(m_{\tilde{\chi}^0_2},m_{\tilde{\chi}^0_1})$ plane.
- 11 ABBIENDI 99F looked for $\gamma\gamma E$ final states at \sqrt{s} =183 GeV. They obtained an upper bound on the cross section for the production $e^+\,e^-
 ightarrow \, \widetilde{\chi}^0_2 \, \widetilde{\chi}^0_2$ followed by the prompt decay $\widetilde{\chi}_2^0 \to \gamma \widetilde{\chi}_1^0$ of 0.08–0.37 pb for $m_{\widetilde{\chi}_2^0}$ =45–81.5 GeV, and $\Delta m > 5$ GeV. See Fig. 11 for explicit limits in the $(m_{\widetilde{\chi}^0_2}, m_{\widetilde{\chi}^0_1})$ plane.
- 12 ABBOTT 98c searches for trilepton final states (ℓ =e, μ). See footnote to ABBOTT 98c in the Chargino Section for details on the assumptions. Assuming a negligible decay rate of $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ to quarks, they obtain $m_{\widetilde{\chi}_2^0} \gtrsim$ 103 GeV.
- 13 ABE 98J searches for trilepton final states $(\ell{=}e{,}\mu)$. See footnote to ABE 98J in the Chargino Section for details on the assumptions. The quoted result for $m_{\widetilde{\chi}^0_2}$ corresponds to the best limit within the selected range of parameters, obtained for $m_{\widetilde{q}} > m_{\widetilde{g}}$, $\tan \beta = 2$, and $\mu{=}{-}\,600$ GeV.
- $^{14}\text{ACCIARRI 98F}$ is obtained from direct searches in the $e^+\,e^-\,\to\,\,\widetilde{\chi}^0_{1,2}\,\widetilde{\chi}^0_2$ production channels, and indirectly from $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_1^0$ searches within the MSSM. See footnote to ACCIARRI 98F in the chargino Section for further details on the assumptions. Data taken at $\sqrt{s}=130$ –172 GeV.
- 15 ACCIARRI 98V looked for $\gamma(\gamma) E$ final states at \sqrt{s} =183 GeV. They obtained an upper bound on the cross section for the production $e^+e^- \to \widetilde{\chi}_2^0 \widetilde{\chi}_{1,2}^0$ followed by the prompt decay $\widetilde{\chi}^0_2 \to \gamma \widetilde{\chi}^0_1$. See Figs. 4a and 6a for explicit limits in the $(m_{\widetilde{\chi}^0_2}, m_{\widetilde{\chi}^0_1})$ plane.
- 16 BARATE 98H looked for $\gamma\gamma\not\!\! E$ final states at $\sqrt{s}=161,\!172$ GeV. They obtained an upper bound on the cross section for the production $e^+e^- \to \widetilde{\chi}^0_2\widetilde{\chi}^0_2$ followed by the prompt decay $\widetilde{\chi}^0_2 \to \gamma \widetilde{\chi}^0_1$ of 0.4–0.8 pb for $m_{\widetilde{\chi}^0_2}=$ 10–80 GeV. The bound above is for the specific case of $\widetilde{\chi}_1^0=\widetilde{H}^0$ and $\widetilde{\chi}_2^0=\widetilde{\gamma}$ and $m_{\widetilde{e}_R}=100$ GeV. See Fig. 6 and 7 for explicit limits in the $(\widetilde{\chi}^0_2,\widetilde{\chi}^0_1)$ plane and in the $(\widetilde{\chi}^0_2,\widetilde{e}_R)$ plane.
- 17 BARATE 98J looked for $\gamma\gamma\not\!\! E$ final states at $\sqrt{s}=161$ –183 GeV. They obtained an upper bound on the cross section for the production $e^+e^-\to \widetilde{\chi}_2^0\widetilde{\chi}_2^0$ followed by the prompt decay $\tilde{\chi}^0_2 \to \gamma \tilde{\chi}^0_1$ of 0.08–0.24 pb for $m_{\tilde{\chi}^0_2} <$ 91 GeV. The bound above is for the specific case of $\widetilde{\chi}^0_1=\widetilde{H}^0$ and $\widetilde{\chi}^0_2=\widetilde{\gamma}$ and $m_{\widetilde{e}_R}^{\ \ \ }=$ 100 GeV.
- 18 ABACHI 96 searches for 3-lepton final states. Efficiencies are calculated using mass relations and branching ratios in the Minimal Supergravity scenario. Results are presented as lower bounds on $\sigma(\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0) \times \mathsf{B}(\widetilde{\chi}_1^{\pm} \to \ell\nu_{\ell}\widetilde{\chi}_1^0) \times \mathsf{B}(\widetilde{\chi}_2^0 \to \ell^+\ell^-\widetilde{\chi}_1^0)$ as a function of $m_{\widetilde{\chi}_1^0}$. Limits range from 3.1 pb ($m_{\widetilde{\chi}_1^0} =$ 45 GeV) to 0.6 pb ($m_{\widetilde{\chi}_1^0} =$ 100 GeV).
- 19 ABE 96K looked for trilepton events from chargino-neutralino production. They obtained lower bounds on $m_{\widetilde{\chi}^0_2}$ as a function of μ . The lower bounds are in the 45–50 GeV range

for gaugino-dominant $ilde{\chi}_2^0$ with negative μ , if $an\!eta <\!10$. See paper for more details of the assumptions

 $\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_2^{\pm}$ (Charginos) MASS LIMITS

Charginos are unknown mixtures of w-inos and charged higgsinos (the supersymmetric partners of W and Higgs bosons). A lower mass limit for the lightest chargino $(\widetilde{\chi}_1^{\pm})$ of approximately 45 GeV, independent of the field composition and of the decay mode, has been obtained by the LEP experiments from the analysis of the Z width and decays. These results, as well as other now superseded limits from e^+e^- collisions energies below 136 GeV, and from hadronic collisions, can be found in the 1998 Edition (The European Physical Journal C3 1 (1998)) of this Review

Unless otherwise stated, results in this section assume spectra, production rates, decay modes and branching ratios as evaluated in the MSSM, with gaugino and sfermion mass unification at the GUT scale. These papers generally study production of $\widetilde{\chi}_1^0\widetilde{\chi}_2^0$, $\widetilde{\chi}_1^+\widetilde{\chi}_1^-$ and (in the case of hadronic collisions) $\widetilde{\chi}_1^+\widetilde{\chi}_2^0$ pairs, including the effects of cascade decays. The mass limits on $\widetilde{\chi}_1^\pm$ are either direct, or follow indirectly from the constraints set by the non-observation of $\overline{\chi}_2^0$ states on the gaugino and higgsino MSSM parameters M_2 and μ . For generic values of the MSSM parameters, limits from high-energy e^+e^- collisions coincide with the highest value of the mass allowed by phase-space, namely $m_{\widetilde{\chi}_1^\pm}\lesssim \sqrt{s}/2$. The still unpublished combination of the results of the four LEP collaborations from the 2000 run of LEP2 at \sqrt{s} up to \simeq 209 GeV yields a lower mass limit of 103.5 GeV valid for general MSSM models. The limits become however weaker in certain regions of the MSSM parameter space where the detection efficiencies or production cross sections are suppressed. For example, this may happen when: (i) the mass differences $\Delta m_+ = m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\chi}_1^0}$ or $\Delta m_\nu = m_{\widetilde{\chi}_1^\pm} - m_{\widetilde{\nu}}$ are very small, and the detection efficiency is reduced; (ii) the electron sneutrino mass is small, and the $\widetilde{\chi}_1^\pm$ production rate is suppressed due to a destructive interference between s and t channel exchange diagrams. The regions of MSSM parameter space where the

following limits are valid are indicated in the comment lines or in the footnotes.

DO CUMENT ID

 1 ABBIENDI

TECN COMMENT

04н OPAL all $an\!eta$, $\Delta m_+^{}$ >5 GeV,

VALUE (GeV) CL%

95

>101

Searches Particle Listings Supersymmetric Particle Searches

| 7 | | | | | | $m_0 > 500 \text{ GeV}, A_0 = 0$ |
|-------------------|----------|---------|--------------------------|------------|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| > 89 | | 2 | ABBIENDI | 03н | OPAL | $0.5 \leq \Delta m_{+} \leq 5$ GeV, higgsinolike, $\tan \beta = 1.5$ |
| > 97.1 | 95 | 3 | ABDALLAH | 03м | DLPH | $\widetilde{\chi}_{1}^{\pm}$, $\Delta m_{+} \geq 3$ GeV, $m_{\widetilde{\nu}} > m_{\widetilde{\chi}^{\pm}}$ |
| > 75 | 95 | 3 | ABDALLAH | 03м | DLPH | $\widetilde{\chi}_{1}^{\pm}$, higgsino, all Δm_{+} , $m_{\widetilde{f}} > m_{\widetilde{\chi}^{\pm}}$ |
| > 70 | 95 | 3 | ABDALLAH | 03м | DLPH | $\widetilde{\chi}_1^{\pm}$, all Δm_+ , $m_{\widetilde{\nu}} > 500$ GeV, $M_2 \leq 2M_1 \leq 10M_2$ |
| > 94 | 95 | 4 | ABDALLAH | 03м | DLPH | $\widetilde{\chi}_{1}^{\pm}$, $\tan \beta \leq 40$, $\Delta m_{+} > 3$ GeV, all |
| > 88 | 95 | 5 | HEISTER | 02J | ALEP | $\tilde{\chi}_1^{\pm}$, all Δm_+ , large m_0 |
| > 67.7 | 95 | 6 | ACCIARRI | 00D | L3 | $	aneta>0.7$, all Δm_{+} , all m_{0} |
| > 69.4 | 95 | 7 | ACCIARRI | 00ĸ | L3 | $e^+e^- ightarrow\widetilde{\chi}^\pm\widetilde{\chi}^\mp$, all Δm_+ , |
| \\\\\ a do \ | at use | . + 1 | fallowing data fo | | ramon fi | heavy scalars |
| • • • vve do i | iot use | | - | | _ | ts, limits, etc. • • • |
| >163 | 95 | | CHATRCHYAN CHATRCHYAN | | CMS CMS | $\widetilde{W}^0 \to \gamma \widetilde{G}, \widetilde{W}^{\pm} \to \ell^{\pm} \widetilde{G}, \text{GMSB}$ |
| >103 | 95 | • | CHAIRCHYAN | 1110 | CIVIS | $tan\beta=3$, $m_0=60$ GeV, $A_0=0$, $\mu>0$ |
| >129 | 95 | 10 | AALTONEN | 09G | CDF | $p\overline{p} \rightarrow \tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$ |
| >138 | 95 | 11 | ABAZOV | 09т | D0 | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_{1}^{\pm} \widetilde{\chi}_{2}^{\overline{0}}$ |
| | | 12 | AALTONEN | 08AF | CDF | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_{1}^{\pm} \widetilde{\chi}_{2}^{0}$ |
| | | | AALTONEN | 08L | CDF | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^{0}$ |
| >229 | 95 | | ABAZOV | 08F | D0 | $p\overline{p} \rightarrow \widetilde{\chi}_1 \chi_2$ $p\overline{p} \rightarrow \widetilde{\chi}\widetilde{\chi}, \widetilde{\chi} = \widetilde{\chi}_2^0, \widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^0 \rightarrow$ |
| 7229 | 93 | | ABAZOV | UUF | DU | $\gamma \widetilde{G}$, GMSB |
| | | 15 | AALTONEN | 07J | CDF | $p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
| | | | ABULENCIA | 075 07H | CDF | R , $LL\overline{E}$ |
| | | | ABULENCIA | 07N | CDF | $p\overline{p} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
| | | 18 | ABAZOV | 06D | D0 | R, LLE |
| >195 | 95 | | ABAZOV | 05A | D0 | $p\overline{p} \rightarrow \widetilde{\chi}\widetilde{\chi}, \widetilde{\chi} = \widetilde{\chi}_{2}^{0}, \widetilde{\chi}_{1}^{\pm}, \widetilde{\chi}_{1}^{0} \rightarrow$ |
| | | | | | | $\gamma \tilde{G}$, GMSB |
| >167 | 95 | 20 | ACOSTA | 05 E | CDF | $\rho \overline{\rho} \rightarrow \widetilde{\chi} \widetilde{\chi}, \ \widetilde{\chi} = \widetilde{\chi}_2^0, \ \widetilde{\chi}_1^{\pm}, \widetilde{\chi}_1^0 \rightarrow$ |
| > 66 | 95 | 21.22 | ABDALLAH | 04н | DLPH | $\gamma \widetilde{G}$, GMSB AMSB, $\mu > 0$ |
| >102.5 | 95 | 23,24 | ABDALLAH | 04H | DLPH | $R(\overline{U}\overline{D}\overline{D})$ |
| >100 | | | ABDALLAH | 03D | DLPH | $e^+e^- \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} (\tilde{\chi}_1^{\pm} \rightarrow \tilde{\tau}_1 \nu_{\tau},$ |
| | | | | | | $\widetilde{\tau}_1 \rightarrow \tau \widetilde{G})$ |
| >103 | | 26 | HEISTER | 03G | ALEP | $R 	ext{ decays, } m_0 > 500 	ext{ GeV}$ |
| >102.7 | 95 | 27 | ACHARD | 02 | L3 | Ŗ, MSUGRA |
| | | 20 | GHODBANE | 02 | THEO | + |
| > 94.3 | 95 95 | | ABREU ACCIARRI | 01c | DLPH | $\tilde{\chi}^{\pm} \rightarrow \tau J$ |
| > 93.8 >100 | 95 95 | | BARATE | 01 01в | L3 ALEP | R , all m_0 , $0.7 \le \tan \beta \le 40$ |
| > 91.8 | 95 | | ABREU | 00V | DLPH | $\begin{array}{l} R \text{ decays, } m_0 > \text{500 GeV} \\ e^+ e^- \rightarrow \widetilde{\chi}_1^\pm \widetilde{\chi}_1^\pm (\widetilde{\chi}_1^\pm \rightarrow \widetilde{\tau}_1 \nu_\tau, \end{array}$ |
| <i>></i> 71.0 | ,, | | | 000 | DEITI | $\widetilde{\tau}_1 \rightarrow \tau \widetilde{G}$) |
| | | 33 | CHO | 00в | THEO | EW analysis |
| > 76 | 95 | 35 | ABBIENDI | 99T | OPAL | $R, m_0 = 500 \text{ GeV}$ |
| > 51 | 95 | | MALTONI | 99B | THEO | EW analysis, $\Delta m_+ \sim 1 \text{ GeV}$ |
| > 81.5 | 95 | 37 | ABE | 98J | CDF | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
| . (5.7 | 0.5 | 38 | ACKERSTAFF | 98K | OPAL | $\tilde{\chi}^+ \rightarrow \ell^+ \not\!\!E$ |
| > 65.7 | 95 | 39 | ACKERSTAFF ACKERSTAFF | 98∟ 98∨ | OPAL OPAL | $\Delta m_+ > 3$ GeV, $\Delta m_ u > 2$ GeV |
| | | | CARENA | 98V 97 | THEO | light gluino $g_{\mu}-2$ |
| | | | KALINOWSKI | | THEO | $y_{\mu} - z$ $W \rightarrow \tilde{\chi}_{1}^{\pm} \tilde{\chi}_{1}^{0}$ |
| | | 42 | ABE | | | |
| 1 | | | | 96K | | $\rho \overline{\rho} \rightarrow \widetilde{\chi}_1^{\pm} \widetilde{\chi}_2^0$ |
| 1 A D D I E M D I | 0411.04 | aarch : | for chargings and | 4 | | n avanta with acontanay lantons Lists |

- 1 ABBIENDI 04H search for charginos and neutralinos in events with acoplanar leptons+jets and multi-jet final states in the 192–209 GeV data, combined with the results on leptonic final states from ABBIENDI 04. The results hold for a scan over the parameter space covering the region $0 < M_2 < 5000$ GeV, $-1000 < \mu < 1000$ GeV and $\tan\beta$ from 1 to 40. This limit supersedes ABBIENDI 00H.
- ²ABBIENDI 03H used e^+e^- data at $\sqrt{s}=188$ –209 GeV to search for chargino pair production in the case of small Δm_+ They select events with an energetic photon, large $\not\!\!E$ and little hadronic or leptonic activity. The bound applies to higgsino-like charginos with zero lifetime and a 100% branching ratio $\bar{\chi}_1^+ \to \bar{\chi}_1^0 W^*$. The mass limit for gaugino-like charginos, in case of non-universal gaugino masses, is of 92 GeV for $m_{\widetilde{\nu}}=$ 1000 GeV and is lowered to 74 GeV for $m_{\widetilde{\nu}} \geq 100$ GeV. Limits in the plane $(m_{\widetilde{\chi}_1^+})$

 Δm_+) are shown in Fig. 7. Exclusion regions are also derived for the AMSB scenario in the $(m_{3/2}, \tan \beta)$ plane, see their Fig. 9.

 3 ABDALLAH 03M searches for the production of charginos using data from $\sqrt{s}=192$ to 208 GeV to investigate topologies with multiple leptons, jets plus leptons, multi-jets, or isolated photons. The first limit holds for tan $\beta\geq 1$ and is obtained at $\Delta m_+=3$ GeV in the higgsino region. For $\Delta m_+\geq 10$ (5) GeV and large m_0 , the limit improves to 102.7 (101.7) GeV. For the region of small Δm_+ , all data from $\sqrt{s}=$ 130 to 208 GeV are used to investigate final states with heavy stable charged particles, decay vertices inside the detector and soft topologies with a photon from initial state radiation. The second limit is obtained in the higgsino region, assuming gaugino mass universality at the GUT scale and $1{<}{}$ tan $\beta<$ 50. For the case of non-universality of gaugino masses, the parameter space is scanned in the domain $1{<}{}$ tan $\beta<$ 50 and, for $\Delta m_+<3$ GeV, for values of M_1 , M_2 and μ such that $M_2 \leq 2M_1 \leq 10\,M_2$ and $|\mu| \geq M_2$. The third limit is obtained in the gaugino region. See Fig. 36 for the dependence of the low Δm_+ limits on Δm_+ . These limits include and update the results of ABREU 00J and ABREU 00T.

- 4 ABDALLAH 03M uses data from $\sqrt{s}=1$ 92–208 GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass of charginos is derived by constraining the MSSM parameter space by and for sleptons. These limits are valid for values of $M_2 < 1$ TeV, $|\mu| \le 2$ TeV with the $\tilde{\chi}_1^0$ as LSP. Constraints from the Higgs search in the M_h^{max} scenario assuming $m_t = 174.3$ GeV are included. The quoted limit applies if there is no mixing in the third family or when $m_{\widetilde{\chi}_1} - m_{\widetilde{\chi}_2^0} > 6$ GeV. If mixing is included the limit degrades to 90 GeV. See the results from direct searches for neutralinos (including cascade decays), for charginos
- Fig. 43 for the mass limits as a function of $tan \beta$. These limits update the results of ABREU 00w.
- ABRED 00W. SHEISTER 02J search for chargino production with small Δm_+ in final states with a hard isolated initial state radiation photon and few low-momentum particles, using 189–208 GeV data. This search is sensitive in the intermediate Δm_+ region. Combined with searches for $\not\!\!E$ topologies and for stable charged particles, the above bound is obtained for m_0 larger than few hundred GeV, $1 < \tan \beta < 300$ and holds for any chargino field contents. For light scalars, the general limit reduces to the one from the Z^0 , but under the assumption of gaugino and sfermion mass unification the above bound is recovered. See Figs. 4–6 for the more general dependence of the limits on Δm_+ . Updates BARATE 98x.
- 6 ACCIARRI 00D data collected at $\sqrt{s}{=}189$ GeV. The results hold over the full parameter space defined by $0.7 \leq \tan \beta \leq 60,~0 \leq M_2 \leq 2$ TeV, $|\mu| \leq 2$ TeV $m_0 \leq 500$ GeV. The results of slepton searches from ACCIARRI 99w are used to help set constraints in the region of small m_0 . See their Figs. 5 for the $\tan \beta$ and M_2 dependence on the limits. See the text for the impact of a large B($\tilde{\chi}^{\pm} \to \tau \tilde{\nu}_{\tau}$) on the result. The region of small Δm_{+} is excluded by the analysis of ACCIARRI 00K. Updates ACCIARRI 98F.
- 7 ACCIARRI 00K searches for the production of charginos with small Δm_{\perp} using data from \sqrt{s} =189 GeV. They investigate soft final states with a photon from initial state radiation. The results are combined with the limits on prompt decays from ACCIARRI 00D and from heavy stable charged particles from ACCIARRI 99L (see Heavy Charged Lepton Searches). The production and decay branching ratios are evaluated within the MSSM, assuming heavy sfermions. The parameter space is scanned in the domain $1 < \tan \beta < 50$, $0.3 < M_1/M_2 < 50$, and $0 < |\mu| < 2$ TeV. The limit is obtained in the higgsino region and improves to 78.6 GeV for gaugino-like charginos. The limit is unchanged for light scalar quarks. For light $\bar{\tau}$ or $\bar{\nu}_{\tau}$, the limit is unchanged in the gaugino-like region and is lowered by 0.8 GeV in the higgsino-like case. For light $\bar{\mu}$ or $\bar{\nu}_{\mu}$, the limit is unchanged in the higgsino-like region and is the higgsino-like region and is lowered by 0.9 GeV in the gaugino-like region. No direct
- The higgsino-like region and is lowered by 0.9 GeV in the gaugino-like region. No direct mass limits are obtained for light δ or $\bar{\nu}_{e}$. 8 CHATRCHYAN 11B looked in 35 pb $^{-1}$ of pp collisions at \sqrt{s} =7 TeV for events with an isolated lepton (e or μ), a photon and E_T which may arise in a generalized gauge mediated model from the decay of Wino-like NLSPs. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark/gluino mass versus Wino mass (see Fig. 4). Mass degeneracy of the produced squarks and gluinos is assumed.
- assumed. 9 CHATRCHYAN 11v looked in $35~{\rm pb}^{-1}$ of pp collisions at $\sqrt{s}=7~{\rm TeV}$ for events with ≥ 3 isolated leptons $(e,~\mu~{\rm or}~\tau)$, with or without jets and $\not\!\!\!E_T$. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,~m_{1/2})$ plane for $\tan \beta = 3$ (see Fig. 5).
- 10 AALTONEN 09G searched in 976 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with trileptons $(\mu\mu\mu$ or $\mu\mu e)$ with a low, 5 GeV, p_T threshold, and large $\not\!\!E_T$ from the decay of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 X$. The selected number of events is consistent with the SM background expectation. The results are combined with the analysis of AALTONEN 07J to set a limit on the $\tilde{\chi}_1^{\pm}$ mass for a mSUGRA scenario with no slepton mixing.
- 11 ABAZOV 09T searched in 2.3 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV for events with trileptons (e,μ or hadronically decaying τ) from the decay of $\widetilde{\chi^{+}}\widetilde{\chi}_{2}^{0}X$ and large E_{T} . No evidence for a signal is observed. The data are used to constrain the cross section times branching ratio as a function of the $\widetilde{\chi}_1^\pm$ mass under the assumption that $m_{\widetilde{\chi}_1^\pm}=m_{\widetilde{\chi}_2^0}$

= $2\ m_{\widetilde{\chi}_1^0}$, $\tan\beta=3$, $\mu>0$ and that the sleptons are heavier than the $\widetilde{\chi}_1^{\pm}$, see their Fig. 8. A chargino lighter than 138 GeV is excluded in the "3l-max" scenario. Exclusion regions in the $(m_0,m_{1/2})$ plane are shown in their Fig. 9 for a mSUGRA scenario with $\tan\beta=3$, $A_0=0$ and $\mu>0$. The $\tan\beta$ dependence of this exclusion is illustrated in Fig. 10. Supersedes the results of ABAZOV 050.

 12 AALT ONEN 08AE searched in 2.0 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with trileptons (e, μ or a charged isolated track from au) from the decay of $p\overline{p} \to ~\widetilde{\chi}_1^{\pm} \, \widetilde{\chi}_2^0 X$ and large E_T . The selected number of events is consistent with the SM background expectation. The data are used to constrain the cross section times branching ratio as a function of the $\widetilde{\chi}_1^\pm$ mass. Exclusion regions in the $(m_0, m_{1/2})$ plane are shown in their

Fig. 2 for a mSUGRA scenario. When the $\widetilde{\chi}_1^\pm$ is nearly mass degenerate with the $\widetilde{\tau}_1$ the leptons are too soft and no limit is obtained. For the case $m_0=60$ GeV a lower limit of 145 GeV on the chargino mass is obtained in this mSUGRA scenario. $^{13}\text{AALTONEN 08L searched in 0.7 to 1.0 fb}^{-1} \text{ of } p\overline{p} \text{ collisions at } \sqrt{s}=1.96 \text{ TeV for events with one high}-p_T \text{ electron or muon and two additional leptons } (e \text{ or } \mu) \text{ from the model}$

events with one nigh- p_T electron or muon and two additional leptons (e or μ) from the decay of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 X$. The selected number of events is consistent with the SM background expectation. The data are used to constrain the cross section times branching ratio as a function of the $\tilde{\chi}_1^\pm$ mass. The results are compared to three MSSM scenarios. An exclusion on chargino and neutralino production is only obtained in a scenario of on mixing between sleptons, yielding nearly equal branching ratios to all three lepton flavors. It amounts to $m_{\tilde{\chi}_2^\pm} > 151$ GeV, while the analysis is not sensitive to chargino masses below about 110 GeV. The analyses have been combined with the analyses of AALTONEN 071 and ABULENCIA 07N. The observed limits for the combination are less stripgent than the one obtained for the high- p_{CT} analysis due to slight excesses in the

other channels. 14 ABAZOV 08F looked in 1.1 fb $^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV for diphoton events with large \mathcal{L}_T . They may originate from the production of $\tilde{\chi}^{\pm}$ in pairs or associated to a $\tilde{\chi}^0_2$, decaying to a $\tilde{\chi}^0_1$ which itself decays promptly in GMSB to $\tilde{\chi}^0_1 \to \gamma \tilde{G}$. No significant excess was found compared to the background expectation. A limit is derived on the masses of SUSY particles in the GMSB framework for $M=2\Lambda$, N=1, $\tan\beta=15$ and x>0. See Figure 2.1 tags explicitly $\Delta = 0.15$. TeV. Supercodes the scale of $M=2\Lambda$, N=1, $\tan\beta=15$ and x>0. 15 and $\mu>0$, see Figure 2. It also excludes N < 91.5 TeV. Supersedes the results of ABAZOV 05A.

Supersymmetric Particle Searches

- 15 AALTONEN 07J searched in 0.7 to 1.1 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV for events with either two same sign leptons $(e \text{ or } \mu)$ or trileptons from the decay of $\widetilde{\chi}_1^\pm \widetilde{\chi}_2^0 X$ and large E_T . The selected number of events is consistent with the SM background expectation. The data are used to constrain the cross section times branching ratio as a function of the χ_1^\pm mass. The results, shown in their Fig. 2, are compared to several MSSM scenarios. The strongest exclusion is in the case of no mixing between sleptons, yielding nearly equal branching ratios to all three lepton flavors, and amounting to $m_{\tilde{\chi}_1^\pm} > 129$
- GeV. This analysis includes the same sign dilepton analysis of ABULENCIA 07N. 16 ABULENCIA 07H searched in 346 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least three leptons (e or μ) from the decay of $\overline{\chi}_1^0$ via $LL\overline{E}$ couplings. The results are consistent with the hypothesis of no signal. Upper limits on the cross-section are extracted and a limit is derived in the framework of mSUGRA on the masses of $\widetilde{\chi}^0_1$ and $\widetilde{\chi}_1^\pm$, see e.g. their Fig. 3 and Tab. II.
- 17 ABULENCIA 07N searched in 1 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with two same sign leptons (e or μ) from the decay of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 X$ and large E_T . A slight excess of 13 events is observed over a SM background expectation of 7.8 \pm 1.1. However, the kinematic distributions do not show any anomalous deviation from expectations in any particular region of parameter space.
- 18 ABAZOV 06 D looked in 360 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with three leptons originating from the pair production of charginos and neutralinos, followed by R decays mediated by LLE couplings. One coupling is assumed to be dominant at a by μ decays interesting to securing is assumed to be dominant at a time. No significant excess was found compared to the background expectation in the $ee\ell$, $\mu\mu\ell$ nor eer ($\ell=e,\mu$) final states. Upper limits on the cross-section are extracted in a specific MSUGRA model and a MSSM model without unification of M_1 and M_2 at the GUT scale. A limit is derived on the masses of charginos and neutralinos for both scenarios assuming λ_{ijk} couplings such that the decay length is less than 1 cm, see their Table III and Fig. 4.
- 19 ABAZOV 05 A looked in 263 pb $^{-1}$ of $^{}$ $^{}$ $^{}$ collisions at $^{}$ $^{}$ $^{}$ $^{}$ TeV for diphoton events with large $ot\!\!E_T$. They may originate from the production of $\widetilde{\chi}^\pm$ in pairs or associated
- $_{20}$ results of ABBOTT 98. $_{20}$ ACOSTA 05E looked in 202 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}{=}1.96$ TeV for diphoton events with large $ot\!\!\!E_T$. They may originate from the production of $\widetilde{\chi}^\pm$ in pairs or associated to a $\widetilde{\chi}_2^0$, decaying to a $\widetilde{\chi}_1^0$ which itself decays promptly in GMSB to $\gamma\,\widetilde{G}$. No events are
- a χ_2^* , decaying to a χ_1^* winch itself decays promptly in GMSB to γ 6. No events are selected at large E_T compared to the background expectation. A limit is derived on the masses of SUSY particles in the GMSB framework for M=2 A, N=1, $\tan\beta=15$ and $\mu>0$, see Figure 2. It also excludes A<69 TeV. Supersedes the results of ABE 991. 21 ABDALLAH 04H use data from LEP 1 and $\sqrt{s}=192-208$ GeV. They re-use results or re-analyze the data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region $1 < m_{3/2} <$ 50 TeV, $0 < m_0 <$ 1000 GeV, 1.5 < tan $\beta <$ 35, both signs of μ . The constraints are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM Z width of 3.2 MeV. The limit is for $m_t=174.3~{\rm GeV}$ (see Table 2 for other m_t values).
- Width of 3.2 MeV. The limit is for $m_L = 177.5$ GeV (see Tebe 1.3 standard) 22 The limit improves to 73 GeV for $\mu < 0$. 23 ABDALLAH 04M use data from $\sqrt{s} = 192-208$ GeV to derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or \overline{UDD} couplings. The results are valid in the ranges $90 < m_0 < 500$ GeV, $0.7 < \tan \beta < 30$, $-200 < \mu < 200$ GeV, $0 < M_2 < 400$ GeV. Supersedes the result of ABREU 01D and ABREU 00U.
- 24 The limit improves to 103 GeV for LLE couplings. 25 ABDALLAH 03D use data from $\sqrt{s}=183-208$ GeV. They look for final states with two acoplanar leptons, expected in GMSB when the $\tilde{\tau}_1$ is the NLSP and assuming a shortlived $\widetilde{\chi}_1^{\pm}$. Limits are obtained in the plane $(m(\widetilde{\tau}), m(\widetilde{\chi}_1^{\pm}))$ for different domains of $m(\widetilde{G})$, after combining these results with the search for slepton pair production from the same paper. The limit above is valid if the $\widetilde{ au}_1$ is the NLSP for all values of $\mathrm{m}(\widetilde{G})$ provided $\mathsf{m}(\widetilde{\chi}_1^\pm) - \mathsf{m}(\widetilde{\tau}_1) \, \geq \, 0.3$ GeV. For larger $\mathsf{m}(\widetilde{G}) > 100$ eV the limit improves to 102 GeV, see their Fig. 11. In the co-NLSP scenario, the limits are 96 and 102 GeV for all m(\widetilde{G}) and m(\widetilde{G}) > 100 eV, respectively. Supersedes the results of ABREU 01G.
- and m(6) > 100eV, respectively. Superseues the results of ADREO VIS. 26 HEISTER 03G searches for the production of charginos prompt decays. in the case of R prompt decays with $LL\bar{E}$, LQD or UDD couplings at \sqrt{s} =189-209 GeV. The search is performed for indirect decays, assuming one coupling at a time to be non-zero. The limit holds for $\tan \beta$ =1.41. Excluded regions in the (μ,M_2) plane are shown in their Fig. 3.
- noids for tail p=1.41. Excluded regions in the (μ, m_Z) plane are shown in the 1.52 ACHARD 02 searches for the production of sparticles in the case of R prompt decays with LLE or UDD couplings at $\sqrt{s}=189-208$ GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit of $\widetilde{\chi}_1^\pm$ holds for \overline{UDD} couplings and increases to 103.0 GeV for $LL\overline{E}$ couplings. For L3 limits from $LQ\overline{D}$ couplings, see ACCIARRI 01.
- 28 GHODBANE 02 reanalyzes DELPHI data at \sqrt{s} =189 GeV in the presence of complex phases for the MSSM parameters.
- ²⁹ ABREU 01c looked for au pairs with ot E at \sqrt{s} =183–189 GeV to search for the associated production of charginos, followed by the decay $\bar{\chi}^{\pm} \rightarrow \tau J$, J being an invisible massless particle. See Fig. 6 for the regions excluded in the (μ, M_2) plane. ³⁰ ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from R prompt decays with $LL\bar{E}$, $LQ\bar{D}$, or \overline{UDD} couplings at \sqrt{s} =189 GeV. The search is performed for
- direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\widetilde{\chi}^0_1$ or a $\widetilde{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00c in a scan of the parameter space assuming MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 991.
- If the results from ACCIANN 271.

 BARATE 01B searches for the production of charginos in the case of R prompt decays with LLE, LQD, or \overline{UDD} couplings at \sqrt{s} =189-202 GeV. The search is performed for indirect decays, assuming one coupling at a time to be nonzero. Updates BARATE 00H.

- 32 ABREU 00v use data from $\sqrt{s}=$ 183–189 GeV. They look for final states with two acoplanar leptons, expected in GMSB when the $\tilde{\tau}_1$ is the NLSP and assuming a shortlived $\widetilde{\chi}_1^\pm$. Limits are obtained in the plane $(m_{\widetilde{\tau}}, m_{\widetilde{\chi}_1^\pm})$ for different domains of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00q. The limit above is valid for all values of $m_{\widetilde{G}}$.
- $^{
 m 33}\,\text{CHO}$ 00B studied constraints on the MSSM spectrum from precision EW observables. Global fits favour charginos with masses at the lower bounds allowed by direct searches. Allowing for variations of the squark and slepton masses does not improve the fits.
- Allowing for variations of the squark and stepton masses uses not improve the riss. 34 ABBIENDI 99T searches for the production of neutralinos in the case of R-pairty violation with LLE, LQD, or \overline{UDD} couplings using data from \sqrt{s} =183 GeV. They investigate topologies with multiple leptons, jets plus leptons, or multiple jets, assuming one coupling at the time to be non-zero and giving rise to direct or indirect decays. Mixed decays (where one particle has a direct, the other an indirect decay) are also considered for the \overline{UDD} couplings. Upper limits on the cross section are derived which, combined with the constraint from the Z^0 width, allow to exclude regions in the M_2 versus μ plane for any coupling. Limits on the chargino mass are obtained for non-zero $LL\overline{E}$ couplings $>10^{-5}$ and assuming decays via a W^*
- 35 MALTONI 99B studied the effect of light chargino-neutralino to the electroweak precision data with a particular focus on the case where they are nearly degenerate ($\Delta m_+ \sim 1$ GeV) which is difficult to exclude from direct collider searches. The quoted limit is for higgsino-like case while the bound improves to 56 GeV for wino-like case. The values of the limits presented here are obtained in an update to MALTONI 99B, as described in
- the limits presented here are obtained in an update to main specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific specific speci
- 0.23 pb $(m_{\widetilde{\chi}_1^\pm}=$ 100 GeV) at 95%CL. The gaugino mass unification hypothesis and the assumed mass relation between squarks and gluinos define the value of the leptonic described miss relation between squarks and graines define the value of the leptonic branching ratios. The quoted result corresponds to the best limit within the selected range of parameters, obtained for $m_{\overline{q}} > m_{\overline{g}}$, $\tan \beta = 2$, and $\mu = -600$ GeV. Mass limits for different values of $\tan \beta$ and μ are given in Fig. 2. 37 ACKERSTAFF 98k looked for dilepton+ $\not\!\!E_T$ final states at $\sqrt{s} = 130 - 172$ GeV. Limits on
- $\sigma(e^+e^-\to \widetilde\chi_1^+\widetilde\chi_1^-)\times \mathsf{B}^2(\ell),$ with $\mathsf{B}(\ell)\!=\!\mathsf{B}(\chi^+\to\ell^+\nu_\ell\chi_1^0)$ $(\mathsf{B}(\ell)\!=\!\mathsf{B}(\chi^+\to\ell^+\bar\nu_\ell)),$ are given in Fig. 16 (Fig. 17).
- are given in Fig. 10 (Fig. 17). 38 ACKERSTAFF 98L limit is obtained for $0 < M_2 < 1500$, $|\mu| < 500$ and $\tan\beta > 1$, but remains valid outside this domain. The dependence on the trilinear-coupling parameter A is studied, and found negligible. The limit holds for the smallest value of m_0 consistent with scalar lepton constraints (ACKERSTAFF 97H) and for all values of m_0 where the condition $\Delta m_{\widetilde{\nu}} > 2.0\,\mathrm{GeV}$ is satisfied. $\Delta m_{\nu} > 10\,\mathrm{GeV}$ if $\widetilde{\chi}^{\pm} \to \ell \widetilde{\nu}_{\ell}$. The limit improves to 84.5 GeV for $m_0 = 1\,\mathrm{TeV}$. Data taken at $\sqrt{s} = 130 - 172\,\mathrm{GeV}$.
- ³⁹ ACKERSTAFF 98v excludes the light gluino with universal gaugino mass where charginos, neutralinos decay as $\widetilde{\chi}_1^\pm,\widetilde{\chi}_2^0 \to q \, \overline{q} \, \widetilde{g}$ from total hadronic cross sections at \sqrt{s} =130–172 GeV. See paper for the case of nonuniversal gaugino mass.
- 40 CARENA 97 studied the constraints on chargino and sneutrino masses from muon g-2. The bound can be important for large $\tan\beta$.
- 41 KALINOWSKI 97 studies the constraints on the chargino-neutralino parameter space from limits on $\Gamma(W \to \widetilde{\chi}_1^\pm \widetilde{\chi}_1^0)$ achievable at LEP2. This is relevant when $\widetilde{\chi}_1^\pm$ is "invisible," i.e., if $\widetilde{\chi}_1^\pm$ dominantly decays into $\overline{\nu}_\ell\ell^\pm$ with little energy for the lepton. Small otherwise allowed regions could be excluded.
- 42 ABE 96K looked for trilepton events from chargino-neutralino production. The bound on $m_{\widetilde{\chi}^{\pm}_1}$ can reach up to 47 GeV for specific choices of parameters. The limits on the combined production cross section times 3-lepton branching ratios range between 1.4 and 0.4 pb, for 45</ri> $m_{\widetilde{\chi}_1^+}({\rm GeV}){<}100.$ See the paper for more details on the parameter dependence of the results

Long-lived $\widetilde{\chi}^{\pm}$ (Chargino) MASS LIMITS

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|-----|-----------------------|-----|------|--------------------------------------------------------------------------------|
| >171 | 95 | 1 ABAZOV | 09м | D0 | \widetilde{H} |
| >102 | 95 | ² ABBIENDI | 03L | OPAL | $m_{\widetilde{\nu}} > 500 \text{ GeV}$ |
| none 2-93.0 | 95 | ³ ABREU | 00т | DLPH | $\widetilde{H}^{\stackrel{F}{=}}$ or $m_{\widetilde{u}} > m_{\widetilde{z},+}$ |

 \bullet \bullet \bullet We do not use the following data for averages, fits, limits, etc. \bullet \bullet

⁴ BARATE 97ĸ ALEP 95 ADA CHI 90c TOPZ > 28.2

- 1 ABAZOV 09M searched in $1.1~{\rm fb^{-1}}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96~{\rm TeV}$ for events with direct production of a pair of charged massive stable particles identified by their TOF. The number of the observed events is consistent with the predicted background. The $^{-1}$ data are used to constrain the production cross section as a function of the $\widetilde{\chi}_1^\pm$ mass, see their Fig. 2. The quoted limit improves to 206 GeV for gaugino-like charginos
- ABBIENDI 03L used e^+e^- data at $\sqrt{s}=130$ –209 GeV to select events with two high momentum tracks with anomalous dE/dx. The excluded cross section is compared to the theoretical expectation as a function of the heavy particle mass in their Fig. 3. The bounds are valid for colorless fermions with lifetime longer than 10^{-6} s. Supersedes the results from ACKERSTAFF 98P.
- results from ACKERSTAFF 98P. 3 ABREU 00T searches for the production of heavy stable charged particles, identified by their ionization or Cherenkov radiation, using data from \sqrt{s} = 130 to 189 GeV. These limits include and update the results of ABREU 98P. 4 BARATE 97K uses e^+e^- data collected at \sqrt{s} = 130–172 GeV. Limit valid for $\tan\beta = \sqrt{2}$ and $m_{\widetilde{\nu}} > 100$ GeV. The limit improves to 86 GeV for $m_{\widetilde{\nu}} > 250$ GeV.

$\widetilde{\boldsymbol{\nu}}$ (Sneutrino) MASS LIMIT

The limits may depend on the number, $extit{ extit{M}}(\widetilde{
u})$, of sneutrinos assumed to be degenerate in mass. Only $\widetilde{
u}_L$ (not $\widetilde{
u}_R$) is assumed to exist. It is possible that $\widetilde{
u}$ could be the lightest supersymmetric particle (LSP).

We report here, but do not include in the Listings, the limits obtained from the fit of the ... Joseph By the LET Collaborations on the invisible width of the Z boson ($\Delta\Gamma_{\rm inv.} < 2.0$ MeV, LEP-SLC 06): $m_{\widetilde{\nu}} > 43.7$ GeV ($N(\widetilde{\nu}){=}1)$ and $m_{\widetilde{\nu}} > 44.7$ GeV ($N(\widetilde{\nu}){=}3)$.

| VALUE (GeV) | CL% | | DO CUMENT ID | | TECN | COMMENT |
|------------------|--------|----------|-----------------------------------------|-------------|-------------|---------------------------------------------------------------------------------------|
| > 94 | 95 | 1 | ABDALLAH | 03м | DLPH | $\frac{1 \leq \tan\beta \leq 40,}{}$ |
| | | | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | | | $m_{\widetilde{e}_R} - m_{\widetilde{\chi}_1^0} \stackrel{>}{>} 10 \text{ GeV}$ |
| > 84 | 95 | 2 | HEISTER | 02N | ALEP | $\widetilde{\nu}_{e}$, any Δm |
| > 37.1 | 95 | | ADRIANI | 93M | L3 | $\Gamma(Z \rightarrow \text{invisible}); N(\widetilde{\nu})=1$ |
| > 41 | 95 | | DECAMP | 92 | ALEP | $\Gamma(Z \to \text{invisible}); N(\widetilde{\nu}) = 3$ |
| > 36 | 95 | | ABREU | 91F | DLPH | $\Gamma(Z \rightarrow \text{invisible}); N(\widetilde{\nu})=1$ |
| > 31.2 | 95 | 5 | ALEXANDER | 91F | OPAL | $\Gamma(Z \rightarrow \text{invisible}); N(\widetilde{\nu})=1$ |
| • • • We do i | ot use | | | or ave | rages, fi | ts, limits, etc. • • • |
| | | | AAD | 11н | ATLS | $\widetilde{ u}_{_{\mathcal{T}}}$, R , s-channel |
| | | | AAD | 11z | ATLS | $\widetilde{ u}_{_{\mathcal{T}}}$, R , s-channel |
| | | ď | AALTONEN | 10z | CDF | $\widetilde{ u}_{\tau}$, R |
| | | 10 | ABAZOV | 10M | D0 | $\widetilde{\nu}_{	au}$, R |
| | | 11 | AALTONEN | 09∨ | CDF | $p\overline{p} \rightarrow \widetilde{\nu} \rightarrow \mu\mu$, $R LQ\overline{D}$ |
| | | 12 | ABAZOV | 08Q | D0 | $\tilde{\nu}_{\tau}$, R |
| | | | SCHAEL | 07A | ALEP | $\tilde{\nu}_{\mu,\tau}$, R , (s+t)-channel |
| | | | ABAZOV ABDALLAH | 06ı 06c | DI DU | \mathbb{R} , λ'_{211} |
| | | 15 | ABULENCIA | 06С | DLPH CDF | $\widetilde{ u}_{\ell}$, R , (s+t)-channel $\widetilde{ u}_{	au}$, R |
| | | | ABULENCIA | 05A | CDF | $p\overline{p} \rightarrow \widetilde{\nu} \rightarrow e e, \mu\mu, R LQ\overline{D}$ |
| | | 17 | ACOSTA | 05R | CDF | $p\overline{p} \rightarrow \widetilde{\nu} \rightarrow \tau \tau, R, LQ\overline{D}$ |
| | | 18 | ABBIENDI | 04F | OPAL | $R, \widetilde{\nu}_{e,\mu,	au}$ |
| > 95 | 95 1 | | ABDALLAH | 04н | DLPH | AMSB, $\mu > 0$ |
| > 98 | 95 | 21 | ABDALLAH | 04м | DLPH | $R(LL\overline{E}), \widetilde{\nu}_e, \text{indirect}, \Delta m > 5 \text{ GeV}$ |
| > 85 | 95 | 21 | ABDALLAH | 04м | DLPH | $R(LL\overline{E}), \widetilde{\nu}_{\mu}$, indirect, $\Delta m > 5$ GeV |
| > 85 | 95 | 21 | ABDALLAH | 04м | DLPH | $R(LL\overline{E}), \widetilde{\nu}_{\tau}$, indirect, $\Delta m > 5$ GeV |
| | | 22 | ABDALLAH | 03F | DLPH | $\tilde{\nu}_{\mu,\tau}$, R $LL\overline{E}$ decays |
| | | 23 | ACOSTA | 03E | CDF | $\widetilde{\nu}$, R , $LQ\overline{D}$ production and $LL\overline{E}$ decays |
| > 88 | 95 | 24 | HEISTER | 03 G | ALEP | $\widetilde{\nu}_e$, R decays, $\mu=-200$ GeV, $\tan\beta=2$ |
| > 65 | 95 | 24 | HEISTER | 03G | ALEP | $\widetilde{\nu}_{\mu,\tau}$, \mathcal{R} decays |
| | | 25 | ABAZOV | 02н | D0 | $\mathbb{R}, \lambda'_{211}$ |
| > 95 | 95 | | ACHARD | 02 | L3 | $\widetilde{\nu}_e$, R decays, μ = -200 GeV, |
| | | | | | | $\tan \beta = \sqrt{2}$ |
| > 65 | 95 | | ACHA RD | 02 | L3 | $\widetilde{ u}_{ u,	au}$, $ ot\!\!R$ decays |
| >149 | 95 | | ACHARD | 02 | L3 | ν̄, R̄ decays, MSUGRA |
| | | | HEISTER | 02F | ALEP | $e \gamma ightarrow \widetilde{ u}_{\mu, \tau} \ell_{k}$, R LL \overline{E} |
| none 100-264 | 95 | 20 | ABBIENDI | 00R | OPAL | $\widetilde{ u}_{\mu,	au}$, R, $(s+t)$ -channel |
| none 100-200 | 95 | 2∩ 20 | ABBIENDI | 00R | OPAL | $\widetilde{ u}_{\mathcal{T}}$, R , s-channel |
| 50 010 | 0.5 | | ABREU | 00s | DLPH | $\tilde{\nu}_{\ell}$, R , $(s+t)$ -channel |
| none 50-210 | 95 | | ACCIARRI | 00P | L3 | $\widetilde{\nu}_{\mu,	au}$, R , s-channel |
| none 50-210 | 95 | | BARATE | 001 | ALEP | $\widetilde{ u}_{\mu,	au}$, R , $(s+t)$ -channel |
| none 90-210 | 95 | | BARATE | 001 | ALEP | ũ _{μ,τ} , Æ, s-channel |
| none 100-160 | 95 | 34 35 | ABBIENDI | 99 | OPAL | $\widetilde{\nu}_e$, R , t -channel |
| ≠ ^m Z | 95 | 35 | ACCIARRI | 97u | L3 | $\widetilde{\nu}_{\tau}$, R , s-channel |
| none 125-180 | 95 | | ACCIARRI CARENA | 97∪ 97 | L3 THEO | $\widetilde{ u}_{	au}$, R , s-channel $g_{\mu}-2$ |
| > 46.0 | 95 | 37 | BUSKULIC | 95 E | ALEP | $N(\widetilde{\nu})=1, \widetilde{\nu} \rightarrow \nu \nu \ell \overline{\ell}'$ |
| none 20-25000 |) | 38 | BECK | 94 | COSM | Stable $\widetilde{ u}$, dark matter |
| <600 | | 39 | FALK | 94 | COSM | $\widetilde{ u}$ LSP, cosmic abundance |
| none 3-90 | 90 | 40 | SATO | 91 | KAMI | Stable $\widetilde{ u}_e$ or $\widetilde{ u}_\mu$, |
| none 4-90 | 90 | 40 | SATO | 91 | KAMI | dark matter Stable $\widetilde{ u}_{\mathcal{T}}$, dark matter |
| 1 | | | – | | | |

- 1 ABDALLAH 03M uses data from $\sqrt{s}=192-208$ GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of $\rm M_2 < 1~TeV$, $|\mu| \leq 1~TeV$ with the $\tilde{\chi}_1^0$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass imits as a function of aneta. These limits update the results of ABREU 00w.
- 2 HEISTER 02N derives a bound on $m_{\widetilde{
 u}_o}$ by exploiting the mass relation between the $\widetilde{
 u}_e$ and \widetilde{e} , based on the assumption of universal GUT scale gaugino and scalar masses $m_{1/2}$ and m_0 and the search described in the \tilde{e} section. In the MSUGRA framework with at rillnear coupling A_0 =0 at the GUT scale. See Figs. 5 and 7 for the dependence of the
- 3 ADRIANI 93M limit from $\Delta\Gamma(Z)$ (invisible)< 16.2 MeV.
- $^4\,\mathrm{DECA\,MP}$ 92 limit is from $\Gamma(\mathrm{invisible})/\Gamma(\ell\ell)=5.91\pm0.15$ ($\mathit{N}_{\nu}=2.97\pm0.07$).
- 5 ALEXANDER 91F limit is for one species of $\widetilde{
 u}$ and is derived from $\Gamma(\text{invisible, new})/\Gamma(\ell\ell)$
- 6 AAD 11H looked in 35 pb $^{-1}$ of $p\,p$ collisions at $\sqrt{s}=$ 7 TeV for events with one electron and one muon of opposite charge from the production of $\widetilde{
 u}_{ au}$ via an R λ'_{311} coupling and followed by a decay via λ_{312} into $e+\mu$. No evidence for an excess over the SM expectation is observed, and a limit is derived in the plane of λ'_{311} versus $m_{\widetilde{
 u}}$ for several values of $\lambda_{312}\text{, see their Fig. 2. Superseded by AAD 11z.}$

- 7 AAD 11z looked in 1.07 fb $^{-1}$ of $p\,p$ collisions at $\sqrt{s}=$ 7 TeV for events with one electron and one muon of opposite charge from the production of $\widetilde{
 u}_{ au}$ via an R λ'_{311} coupling and followed by a decay via λ_{312} into $e+\mu$. No evidence for an (e,μ) resonance over the SM expectation is observed, and a limit is derived in the plane of λ'_{311} versus $m_{\widetilde{\nu}}$ for three values of λ_{312} , see their Fig. 2. Masses $m_{\widetilde{\nu}} < 1.32$ (1.45) TeV are excluded for
- $\lambda'_{311}=0.10$ and $\lambda_{312}=0.05$ ($\lambda'_{311}=0.11$ and $\lambda_{312}=0.07$). 8 AALTONEN 10z searched in 1 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events from the production $d\,\overline{d} \to \widetilde{\nu}_{\mathcal{T}}$ with the subsequent decays $\widetilde{\nu}_{\mathcal{T}} \to e\,\mu,\;\mu\,\tau,\;e\,\tau$ in the MSSM framework with R. Two isolated leptons of different flavor and opposite charges are required, with au s identified by their hadronic decay. No statistically significant excesses are observed over the SM background. Upper limits on χ^2_{311} times the branching ratio are listed in their Table III for various $\widetilde{\nu}_{\tau}$ masses. Limits on the cross section times branching ratio for $\lambda'_{311}=$ 0.10 and $\lambda_{i3k}^{'}=$ 0.05, displayed in Fig. 2, are used to set limits on the $\tilde{\nu}_{\tau}$ mass of 558 GeV for the $e\mu$, 441 GeV for the $\mu\tau$ and 442 GeV for the τ channels
- 9 ABAZOV 10M looked in 5.3 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with exactly one pair of high p_T isolated $e\mu$ and a veto against hard jets. No evidence for an excess over the SM expectation is observed, and a limit at 95% C.L. on the cross section times branching ratio is derived, see their Fig. 3. These limits are translated into limits on couplings as a function of $m_{\widetilde{\nu}_{\tau}}$ as shown on their Fig. 4. As an example, for $m_{\widetilde{\nu}_{\tau}}$
- 100 GeV and $\lambda_{312} \leq$ 0.07, couplings $\lambda_{311}' >$ 7.7 \times 10 $^{-4}$ are excluded.
- 100 GeV and $\lambda_{312} \leq 0.07$, couprings $\lambda_{311} > 1.7$ A $\lambda_{31} > 1.9$ The Section 10 AALTONEN 09V searched in 2.3 fb⁻¹ of $\rho \overline{\rho}$ collisions at $\sqrt{s} = 1.96$ TeV for events with an oppositely charged pair originating from the R production of a sneutrino decaying to dimuons. A limit is derived on the cross section times branching ratio, B, of $\overline{\nu} \rightarrow \mu \mu$ for several values of the coupling λ' , see their Fig. 3. For $\lambda'^2 B = 0.01$, the range 100 GeV $\leq m_{\widetilde{\nu}} \leq$ 810 GeV is excluded.
- 11 ABAZOV 08Q searched in 1.04 fb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for an excess of events with oppositely charged $e\mu$ pairs. They might be expected in a SUSY model with R where a sneutrino is produced by $LQ\overline{D}$ couplings and decays via $LL\overline{E}$ couplings, focusing on $\bar{\nu}_{\mathcal{T}}$, hence on the λ'_{311} and λ_{312} constants. No significant excess was found compared to the background expectation. Upper limits on the cross-section times branching ratio are extracted and displayed in their Fig. 2. Exclusion regions are determined for the $\bar{\nu}_{\mathcal{T}}$ mass as a function of both couplings, see their Fig. 3. As an indication, for $\widetilde{\nu}_{\tau}$ masses of 100 GeV and $\lambda_{312}=0.01$, values of $\lambda'_{311}\geq 1.6\times 10^{-3}$ are excluded at the 95% C.L. Superseded by ABAZOV 10M.
- 12 SCHAEL 07A searches for the s- or t-channel exchange of sneutrinos in the case of R with LLE couplings by studying di-lepton production at $\sqrt{s}=189-209$ GeV. Limits are obtained on the couplings as a function of the $\widetilde{
 u}$ mass, see their Figs. 22-24. The results of this analysis are combined with BARATE 001.
- 13 ABAZOV 061 looked in 380 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 muons and 2 jets for s-channel production of $\widetilde{\mu}$ or $\widetilde{\nu}$ and subsequent decay via R couplings $LQ\overline{D}$. The data are in agreement with the SM expectation. They set limits on resonant slepton production and derive exclusion contours on λ'_{211} in the mass plane of $\widetilde{\ell}$ versus $\widetilde{\chi}_1^0$ assuming a MSUGRA model with $\tan\beta=$ 5, $\mu<0$ and $A_0=0$, see their Fig. 3. For $\lambda'_{211} \geq 0.09$ slepton masses up to 358 GeV are excluded. Supersedes the results of ABAZOV 02H.
- 14 ABDALLAH 06c searches for anomalies in the production cross sections and forward-ABDALEATH of searches of the $\ell^+\ell^-(\gamma)$ final states $(\ell=e,\mu,\tau)$ from 675 pb $^-1$ of e^+e^- data at $\sqrt{s}{=}130{-}207$ GeV. Limits are set on the s- and t-channel exchange of sneutrinos in the presence of R with $\lambda LL\overline{E}$ couplings. For points between the energies at which data were taken, information is obtained from events in which a photon was radiated. Exclusion limits in the $(\lambda, m_{\widetilde{\nu}})$ plane are given in Fig. 16. These limits include and update the results of ABREU 00s.
- the results of ABRED GUS. The results of ABRED GUS. The results of ABRED GUS. The searched in 344 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for an excess of events with oppositely charged $e\mu$ pairs. They might be expected in a SUSY model with R where a sneutrino is produced by LQD couplings and decays via $LL\overline{E}$ couplings, focusing on $\widetilde{\nu}_{ au}$, hence on the λ'_{311} and λ_{132} constants. No significant excess was found compared to the background expectation. Upper limits on the cross-section times branching ratio are extracted and exclusion regions determined for the $\widetilde{\nu}_T$ mass as a function of both couplings, see their Fig. 3. As an indication, $\widetilde{\nu}_T$ masses are excluded up to 300 GeV for $\lambda'_{311} \geq~0.01$ and $\lambda_{132} \geq~0.02$. Superseded by AALTONEN 10z.
- 16 ABULENCIA 05A looked in \sim 200 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for dimuon and dielectron events. They may originate from the R production of a sneutrino decaying to dileptons. No significant excess rate was found compared to the background expectation. A limit is derived on the cross section times branching ratio, B, of $\stackrel{\circ}{\nu} \rightarrow e \, e$, $\mu\mu$ of 25 fb at high mass, see their Figure 2. Sneutrino masses are excluded at 95% CL below 680, 620, 460 GeV (ee channel) and 665, 590, 450 GeV ($\mu\mu$ channel) for a λ' coupling
- and branching ratio such that $\lambda^{\prime 2}B=0.01,0.05,0.001$, respectively. 17 ACOSTA 05R looked in 195 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for ditau events with one identified hadronic tau decay and one other tau decay. They may originate from the R production of a sneutrino decaying to au au. No significant excess rate was found compared to the background expectation, dominated by Drell-Yan. A limit is derived on the cross section times branching ratio, B, of $\tilde{\nu} \to au au$, see their Figure 3. Sneutrino masses below 377 GeV are excluded at 95% CL for a λ' coupling to $d\overline{d}$ and branching ratio such that $\lambda'^2 B = 0.01$.
- 16 ABBIENDI 04F use data from $\sqrt{s}=189-209$ GeV. They derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or $LQ\overline{D}$ couplings. The results are valid for $\tan\beta=1.5$, $\mu=-200$ GeV, and a BR for the decay given by CMSSM, assuming no sensitivity. to other decays. Limits are quoted for $m_{\widetilde{\chi}^0}=$ 60 GeV and degrade for low-mass $\widetilde{\chi}^0_1$. For $\widetilde{\nu}_e$ the direct (indirect) limits with $LL\overline{E}$ couplings are 89 (95) GeV and with $LQ\overline{D}$ they are 89 (88) GeV. For $\widetilde{
 u}_{\mu, au}$ the direct (indirect) limits with $LL\overline{E}$ couplings are 79 (81) GeV and with $LQ\overline{D}$ they are 74 (no limit) GeV. Supersedes the results of ABBIENDI 00.
- 19 ABDALLAH 04H use data from LEP 1 and $\sqrt{s}=$ 192–208 GeV. They re-use results or re-analyze the data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region $1< m_{3/2} <$ 50 TeV, $0 < m_0 <$ 1000 GeV, 1.5 < tan $\beta <$ 35, both signs of μ . The constraints are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM Z width of 3.2 MeV. The limit is for $m_{\tilde{t}}=174.3$ GeV (see Table 2 for other $m_{\tilde{t}}$ values).

 $^{20}\,\text{The limit improves to 114 GeV for }\mu~<0.$

Supersymmetric Particle Searches

- 21 ABDALLAH 04M use data from $\sqrt{s}=189-208$ GeV. The results are valid for $\mu=-200$ GeV, $\tan\beta=1.5$, $\Delta m>5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect decays using the neutralino constraint of 39.5 GeV, also derived in ABDALLAH 04M. For indirect decays the limit on $\vec{\nu}_e$ decreases to 96 GeV if the constraint from the neutralino is not used and for direct decays the remains 96 GeV. For indirect decays the limit on $\vec{\nu}_e$ decreases to 8.6 GeV if the constraint from the if the constraint from the neutralino is not used and for direct decays it remains 96 GeV. For indirect decays the limit on $\widetilde{\nu}_{\mu}$ decreases to 82 GeV if the constraint from the neutralino is not used and to 83 GeV for direct decays. For indirect decays the limit on $\widetilde{\nu}_{\tau}$ decreases to 82 GeV if the constraint from the neutralino is not used and improves to 91 GeV for direct decays. Supersedes the results of ABREU 000. 2^2 ABDALLAH 03F looked for events of the type $e^+e^- \rightarrow \widetilde{\nu} \rightarrow \widetilde{\chi}^0 \nu$, $\widetilde{\chi}^\pm \ell^\mp$ followed by Barana of the $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi}^0$ via $\widetilde{\chi$
- by R decays of the $\bar{\chi}^0$ via $\lambda_{1|1}$ (j = 2,3) couplings in the data at \sqrt{s} = 183–208 GeV. From a scan over the SUGRA parameters, they derive upper limits on the $\lambda_{1|1}$ couplings
- as a function of the sneutrino mass, see their Figs. 5–8. production cross-section and decay branching ratio for a $\widetilde{
 u}$ in RPV models (see Fig. 3).
- made of the bound $\mathit{m}(\widetilde{\chi}^0_1) >$ 23 GeV from BARATE 98s. Supersedes the results from
- BARATE 01B. 25 ABAZOV 02H looked in 94 pb $^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with at least 2 muons and 2 jets for s-channel production of $\overline{\mu}$ or $\overline{\nu}$ and subsequent decay via \overline{R} couplings $LQ\overline{D}$. A scan over the MSUGRA parameters is performed to exclude regions of the $(m_0, m_{1/2})$ plane, examples being shown in Fig. 2.
- 26 ACHARD 02 searches for the associated production of sneutrinos in the case of R prompt decays with $LL\overline{E}$ or \overline{UDD} couplings at \sqrt{s} =189–208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit holds for direct decays via $LL\overline{E}$ couplings. Stronger limits are reached for $(\overline{\nu}_e, \overline{\nu}_{\mu, \tau})$ for LLE indirect (99,78) GeV and for \(\bar{UDD}\) direct or indirect (99,70) GeV decays. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit holds for \(\bar{UDD}\) couplings and increases to 152.7 GeV for \(LE\) couplings.
- 27 HEISTER 02F searched for single sneutrino production via $e\gamma
 ightarrow ~ \widetilde{
 u}_j \ell_k$ mediated by $\not \! R$ LL \overline{E} couplings, decaying directly or indirectly via a $\widetilde{\chi}_1^0$ and assuming a single coupling to be nonzero at a time. Final states with three leptons and possible $\not\!\!E_T$ due to neutrinos were selected in the 189–209 GeV data. Limits on the couplings λ_{1jk} as function of the sneutrino mass are shown in Figs. 10–14. The couplings λ_{232} and λ_{233} are not accessible and λ_{121} and λ_{131} are measured with better accuracy in sneutrino resonant production. For all tested couplings, except λ_{133} , the limits are significantly improved compared to the law according to compared to the low-energy limits.
- 28 ABBIENDI 00R studied the effect of s- and *t*-channel au or μ sneutrino exchange in $e^+e^- o e^+e^-$ at \sqrt{s} =130–189 GeV, via the R-parity violating coupling $\lambda_{111}L_1L_2$ (i=2 or 3). The limits quoted here hold for λ_{1i1} >0.13, and supersede the results of ABBIENDI 99. See Fig. 11 for limits on $m_{\widetilde{\nu}}$ versus coupling.
- ²⁹ABBIENDI 90. Studied the effect of s-channel τ sneutrino exchange in $e^+e^- \rightarrow \mu^+\mu^-$ at \sqrt{s} =130-189 GeV, in presence of the R-parity violating couplings $\lambda_{i3i}L_iL_3e_i$ (i=1 and 2), with $\lambda_{131}=\lambda_{232}$. The limits quoted here hold for $\lambda_{131}>0.09$, and supersede the results of ABBIENDI 99. See Fig. 12 for limits on $m_{\widetilde{\nu}}$ versus coupling.
- 30 ABREU 00s searches for anomalies in the production cross sections and forwardbackward asymmetries of the $\ell^+\ell^-(\gamma)$ final states $(\ell=e,\mu, au)$ from e^+e^- collisions vacuation asymmetries of the $\ell^+\ell^-(\gamma)$ final states ($\ell=e,\mu,\tau$) from e^+e^- collisions at $\sqrt{s}=130-189$ GeV. Limits are set on the s- and t-channel exchange of sneutrinos in the presence of R with $\lambda L L E$ couplings. For points between the energies at which data were taken, information is obtained from events in which a photon was radiated. Exclusion limits in the $(\lambda,m_{\widetilde{\nu}})$ plane are given in Fig. 5. These limits include and update the results of ABREU 99A.
- 31 ACCIARRI 00P use the dilepton total cross sections and asymmetries at $\sqrt{s} = m_Z$ and \sqrt{s} =130-189 GeV data to set limits on the effect of $RLL\overline{E}$ couplings giving rise to μ or au sneutrino exchange. See their Fig. 5 for limits on the sneutrino mass versus couplings.
- 32 BARATE 001 studied the effect of s-channel and $\it t$ -channel $\it au$ or $\it \mu$ sneutrino exchange in ightarrow $e^+\,e^-$ at \sqrt{s} = 130–183 GeV, via the *R*-parity violating coupling $\lambda_{1j1} L_1 L_j e_1^C$ (i=2 or 3). The limits quoted here hold for $\lambda_{1/1}>0.1$. See their Fig. 15 for limits as a function of the coupling. Superseded by SCHAEL 07A.
- 33 BARATE 001 studied the effect of s-channel au sneutrino exchange in $e^+e^ightarrow \,\mu^+\mu^$ at \sqrt{s} = 130–183 GeV, in presence of the *R*-parity violating coupling $\lambda_{j3j}L_jL_3e_j^C$ (i=1 and 2). The limits quoted here hold for $\sqrt{|\lambda_{131}\lambda_{232}|}>0.2$. See their Fig. 16 for limits as a function of the coupling. Superseded by SCHAEL 07A. ³⁴ ABBIENDI 99 studied the effect of t-channel electron sneutrino exchange in $e^+e^- \rightarrow$
- $au^+\, au^-$ at \sqrt{s} = 130 183 GeV, in presence of the R -parity violating couplings $\lambda_{131} L_1 L_3 e_1^C$. The limits quoted here hold for $\lambda_{131} > 0.6$.
- 35 ACCIARRI 970 studied the effect of the s-channel tau-sneutrino exchange in $e^+e^-\to e^+e^-$ at $\sqrt{s}=m_Z$ and $\sqrt{s}=130$ –172 GeV, via the R-parity violating coupling $\lambda_{131}L_1L_i^ee_1^e$. The limits quoted here hold for $\lambda_{131}>0.05$. Similar limits were studied in $e^+\,e^-\,\rightarrow\,\,\mu^+\,\mu^-$ together with $\lambda_{232} {\it L}_2 \,{\it L}_3 \,e_2^c$ coupling.
- 36 CARENA 97 studied the constraints on chargino and sneutrino masses from muon g-2. The bound can be important for large $\tan\beta$. The bound can be important for large $\tan\beta$. The bound can be important for large $\tan\beta$. Where $\overline{\nu} \to \nu \chi_1^0$ and χ_1^0 decays via R-parity
- violating interactions into two leptons and a neutrino.
- ³⁸ BECK 94 limit can be inferred from limit on Dirac neutrino using $\sigma(\tilde{\nu})=4\sigma(\nu)$. Also private communication with H.V. Klapdor-Kleingrothaus.
- 39 FALK 94 puts an upper bound on $m_{\widetilde{
 u}}$ when $\widetilde{
 u}$ is LSP by requiring its relic density does not overclose the Universe
- 40 SATO 91 search for high-energy neutrinos from the sun produced by annihilation of sneutrinos in the sun. Sneutrinos are assumed to be stable and to constitute dark matter in our galaxy. SATO 91 follow the analysis of NG 87, OLIVE 88, and GAISSER 86.

CHARGED SLEPTONS

This section contains limits on charged scalar leptons $(\bar{\ell},$ with $\ell = e, \mu, \tau)$. Studies of width and decays of the Z boson (use is made here of $\Delta \Gamma_{\rm inV} < 2.0$ MeV, LEP 00) conclusively rule out $m_{\overline{\ell}_R} < 40$ GeV (41

GeV for $\widetilde{\ell}_L$) , independently of decay modes, for each individual slepton. The limits improve to 43 GeV (43.5 GeV for $\widetilde{\ell}_L$) assuming all 3 flavors to be degenerate. Limits on higher mass sleptons depend on model assumptions and on the mass splitting $\Delta \emph{m}=\emph{m}_{\widetilde{\ell}}-\emph{m}_{\widetilde{\chi}_{1}^{0}}$. The mass and composition

of $\tilde{\chi}_1^0$ may affect the selectron production rate in e^+e^- collisions through t-channel exchange diagrams. Production rates are also affected by the potentially large mixing angle of the lightest mass eigenstate $\widetilde{\ell}_1 = \widetilde{\ell}_R \sin \theta_\ell$ + $\widetilde{\ell}_L$ $\cos\! heta_\ell$. It is generally assumed that only $\widetilde{ au}$ may have significant mixing. The coupling to the Z vanishes for $\theta_\ell{=}0.82$. In the high-energy limit of $e^+\,e^-$ collisions the interference between γ and Z exchange leads to a minimal cross section for $\theta_\ell{=}0.91$, a value which is sometimes used in the following entries relative to data taken at LEP2. When limits on $m_{\widetilde{\ell}_{R}}$ are quoted, it is understood that limits on $m_{\widetilde{\ell}_L}$ are usually at least as strong.

Possibly open decays involving gauginos other than $\widetilde{\chi}_1^0$ will affect the detection efficiencies. Unless otherwise stated, the limits presented here result from the study of $\widetilde{\ell}^+\widetilde{\ell}^-$ production, with production rates and decay properties derived from the MSSM. Limits made obsolete by the recent analyses of $e^+\,e^-$ collisions at high energies can be found in previous Editions of this Review.

For decays with final state gravitinos (\widetilde{G}), $m_{\widetilde{G}}$ is assumed to be negligible relative to all other masses.

€ (Selectron) MASS LIMIT

| e (Selectro | N) MAS | S LIMI I | | | |
|-------------------------------|---------|------------------------|-------------|-----------|----------------------------------------------------------------------------------------------------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| > 97.5 | | ¹ ABBIENDI | 04 | OPAL | \widetilde{e}_R , $\Delta m > 11$ GeV, $\left \mu \right > 100$ GeV, $	aneta = 1.5$ |
| > 94.4 | | ² ACHARD | 04 | L3 | \widetilde{e}_R , $\Delta m > 10$ GeV, $\left \mu\right > 200$ GeV, $\tan \beta > 2$ |
| > 71.3 | | ² ACHARD | 04 | L3 | \widetilde{e}_R , all $\overline{\Delta m}$ |
| none 30-94 | 95 | ³ ABDALLAH | 03м | DLPH | $\Delta m > 15$ GeV, $\tilde{e}_R^+ \tilde{e}_R^-$ |
| > 94 | 95 | ⁴ ABDALLAH | 03м | DLPH | \widetilde{e}_R , $1 \leq \tan \beta \leq 40$, $\Delta m > 10$ GeV |
| > 95 | 95 | ⁵ HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $\tilde{e}_{R}^{+} \tilde{e}_{R}^{-}$ |
| > 73 | 95 | ⁶ HEISTER | 02N | ALEP | \widetilde{e}_R , any Δm |
| >107 | 95 | ⁶ HEISTER | 02N | ALEP | ẽ _L , any ∆ <i>m</i> |
| ● ● We do | not use | the following data t | for ave | erages, f | its, limits, etc. • • • |
| > 89 | 95 | ⁷ ABBIENDI | 04F | OPAL | R , \tilde{e}_L |
| > 92 | 95 | ⁸ ABDALLAH | 04M | DLPH | \mathbb{R} , \widetilde{e}_R , indirect, $\Delta m > 5$ GeV |
| > 93 | 95 | 9 HEISTER | 03 G | ALEP | \widetilde{e}_R , \widetilde{R} decays, $\mu = -200$ GeV, $\tan \beta = 2$ |
| > 69 | 95 | ¹⁰ ACHARD | 02 | L3 | \widetilde{e}_R , R decays, $\mu=-200$ GeV, $\tan \beta = \sqrt{2}$ |
| > 92 | 95 | ¹¹ BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $\tilde{e}_R^+ \tilde{e}_R^-$ |
| > 77 | 95 | ¹² ABBIENDI | 00J | OPAL | $\Delta m > 5$ GeV, $\tilde{e}_{R}^{+} \tilde{e}_{R}^{-}$ |
| > 83 | 95 | ¹³ ABREU | 00υ | DLPH | \widetilde{e}_R , $\Re (LL\overline{E})$ |
| > 67 | 95 | ¹⁴ ABREU | 00∨ | DLPH | $\widetilde{e}_R \ \widetilde{e}_R \ (\widetilde{e}_R \rightarrow e \ \widetilde{G}), \ m_{\widetilde{G}} > 10 \text{ eV}$ |
| > 85 | 95 | ¹⁵ BARATE | 00g | ALEP | $\widetilde{\ell}_R ightarrow \ell \widetilde{G}$, any $	au(\widetilde{\ell}_R)$ |
| > 29.5 | 95 | ¹⁶ ACCIARRI | 991 | L3 | \widetilde{e}_R , R , $\tan \beta \geq 2$ |
| > 56 | 95 | ¹⁷ ACCIARRI | 98F | L3 | $\Delta m > 5$ GeV, $\widetilde{e}_R^+ \widetilde{e}_R^-$, $\tan \beta \ge 1.41$ |
| > 77 | 95 | ¹⁸ BARATE | 98ĸ | ALEP | Any Δm , $\tilde{e}_{P}^{+}\tilde{e}_{P}^{-}$, $\tilde{e}_{R}^{-} \rightarrow e \gamma \tilde{G}$ |
| > 77 | 95 | ¹⁹ BREITWEG | 98 | ZEUS | $m_{\widetilde{q}} = m_{\widetilde{e}}, \ m(\widetilde{\chi}_1^0) = 40 \text{ GeV}$ |
| > 63 | 95 | ²⁰ AID | 96 C | H1 | $m_{\widetilde{q}} = m_{\widetilde{e}}, m_{\widetilde{\chi}_1^0} = 35 \text{ GeV}$ |
| | | | | | |

 1 ABBIENDI 04 search for $\widetilde{e}_R\,\widetilde{e}_R^{}$ production in acoplanar di-electron final states in the 183–208 GeV data. See Fig. 13 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$ and for the limit at $\tan\beta$ =35 This limit supersedes ABBIENDI 00G.

ACHARD 04 search for $\widetilde{e}_R\widetilde{e}_L$ and $\widetilde{e}_R\widetilde{e}_R$ production in single- and acoplanar di-electron final states in the 192–209 GeV data. Absolute limits on $m_{\widetilde{e}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and m_0 , $1 \leq \tan\beta \leq 60$ and $-2 \leq \mu \leq 2$ TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$. This limit supersedes ACCIARRI 99w.

 3 ABDALLAH 03M looked for acoplanar dielectron $+
ot \!\!\!E$ final states at $\sqrt{s}=1$ 89–208 GeV. The limit assumes $\mu=-200$ GeV and $\tan\beta=1.5$ in the calculation of the production cross section and $B(\widetilde{e}\to e\chi_1^0)$. See Fig. 15 for limits in the $(m_{\widetilde{e}_R},m_{\chi_1^0})$ plane. These limits include and update the results of ABREU 01

 4 ABDALLAH 03M uses data from $\sqrt{s}=192$ –208 GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect of the MSSM with gaugino and stermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of $M_2 < 1 \text{ TeV}$, $|\mu| \leq 1 \text{ TeV}$ with the $\tilde{\chi}_1^0$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass limits as a function of tan β . These limits update the results of ABREU 00w. 5 HEISTER 02E looked for acoplanar dielectron $+ \not\!\! E_T$ final states from e^+e^- interactions between 183 and 209 GeV. The mass limit assumes $\mu < -200$ GeV and $\tan \beta = 2$ for the

production cross section and B($\tilde{e} \rightarrow e \tilde{\chi}_1^0$)=1. See their Fig. 4 for the dependence of the limit on Δm . These limits include and update the results of BARATE 01.

⁶ HEISTER 02N search for \widetilde{e}_R \widetilde{e}_L and \widetilde{e}_R \widetilde{e}_R production in single- and acoplanar di-electron final states in the 183–208 GeV data. Absolute limits on $m_{\widetilde{e}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and m_0 , $1 \leq \tan\beta \leq 50$ and $-10 \leq \mu \leq 10$ TeV. The region of small $|\mu|$, where cascade decays are important, is covered by a search for $\widetilde{\chi}_1^0\widetilde{\chi}_3^0$ in final states with leptons and possibly photons. Limits on $m_{\widetilde{e}_L}$ are derived by exploiting the mass relation between the \widetilde{e}_L and \widetilde{e}_R , based on universal m_0 and $m_{1/2}$. When the constraint from the mass limit of the lightest Higgs from HEISTER 02 is included, the bounds improve

the mass limit of the lightest Higgs from HEISTER 02 is included, the bounds improve to $m_{\widetilde{e}_R} > 77(75)$ GeV and $m_{\widetilde{e}_L} > 115(115)$ GeV for a top mass of 175(180) GeV. In the MSUGRA framework with radiative electroweak symmetry breaking, the limits improve further to $m_{\widetilde{e}_R} > 95$ GeV and $m_{\widetilde{e}_L} > 152$ GeV, assuming a trilinear coupling $A_0 = 0$ at the GUT scale. See Figs. 4, 5, 7 for the dependence of the limits on tan β . 7 ABBIENDI 04F use data from $\sqrt{s} = 189-209$ GeV. They derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or $LQ\overline{D}$ couplings. The results are valid for $tan\beta = 1.5$, $\mu = -200$ GeV, with, in addition, $\Delta m > 5$ GeV for indirect decays via $LQ\overline{D}$. The limit quoted applies to direct decays via $LL\overline{E}$ or $LQ\overline{D}$ couplings. For indirect decays, the limits on the \overline{e}_R mass are respectively 99 and 92 GeV for $LL\overline{E}$ and $LQ\overline{D}$ couplings and $m_{\pi^+} = 10$ GeV and degrade slightly for larger \overline{s}^0 mass. Supersedes the results of and $m_{\widetilde{\chi}0}=10$ GeV and degrade slightly for larger $\widetilde{\chi}_1^0$ mass. Supersedes the results of

and $m_{\gamma 0}=10$ GeV and degrade signify for larger χ_1^2 mass. Supersedes the results of ABBIENDI 00. ABDALLAH 04M use data from $\sqrt{s}=192-208$ GeV to derive limits on sparticle masses under the assumption of R with LLE or \overline{UDD} couplings. The results are valid for $\mu=-200$ GeV, $\tan\beta=1.5$, $\Delta m>5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect \overline{UDD} decays using the neutralino constraint of 39.5 GeV for LLE and of 38.0 GeV for \overline{UDD} couplings, also derived in ABDALLAH 04M. For indirect decays via LLE the limit improves to 95 GeV if the constraint from the neutralino is used and to 94 GeV if it is not used. For indirect decays via \overline{UDD} couplings it remains unchanged when the neutralino constraint is not used. Supersedes the result of ABRELI 0001.

ABREU 00U. HEISTER 03G searches for the production of selectrons in the case of \Re prompt decays with $LL\overline{E}$, $LQ\overline{D}$ or \overline{UDD} couplings at $\sqrt{s}=189$ –209 GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be non-zero. The limit holds for indirect decays mediated by $LQ\overline{D}$ couplings with $\Delta m>10$ GeV. Limits are also given for $LL\overline{E}$ direct ($m_{\widetilde{e},R}>96$ GeV) and indirect decays ($m_{\widetilde{e},R}>96$ GeV for

 $m(\widetilde{\chi}_1^0) >$ 23 GeV from BARATE 98s) and for $\overline{\mathit{UDD}}$ indirect decays ($m_{\widetilde{e},R} >$ 94 GeV

with $\Delta m~>10$ GeV). Supersedes the results from BARATE 01B.

with $\Delta m > 10$ GeV). Supersedes the results from BARALE ULB. 10 ACHARD 02 searches for the production of selectrons in the case of R prompt decays with $LL\overline{E}$ or \overline{UDD} couplings at \sqrt{s} =189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit holds for direct decays via $LL\overline{E}$ couplings. Stronger limits are reached for $LL\overline{E}$ indirect (79 GeV) and for \overline{UDD} direct or indirect (96 GeV) decays.

GeV) and for UDD direct of indirect (90 GeV) decays. If BARATE 01 looked for acoplanar dielectron $+ E_T$ final states at 189 to 202 GeV. The limit assumes $\mu = -200$ GeV and $\tan \beta = 2$ for the production cross section and 100% branching ratio for $\tilde{e} \to e \tilde{\chi}_1^0$. See their Fig. 1 for the dependence of the limit on Δm . These limits include and update the results of BARATE 990.

These limits include and update the results of BAKALE 370. 12 ABBIENDI 00J looked for acoplanar dielectron + E_T final states at \sqrt{s} = 161–183 GeV. The limit assumes $\mu < -100$ GeV and $\tan \beta$ =1.5 for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\widetilde{e} \rightarrow e \, \widetilde{\chi}_1^0$. See their Fig. 12 for the dependence of the limit on Δm and $\tan \beta$.

13 ABREU 00u studies decays induced by *R*-parity violating *LLE* couplings, using data from √s=189 GeV. They investigate topologies with multiple leptons, assuming one coupling at the time to be nonzero and giving rise to indirect decays. The limits assume a neutralino mass limit of 30 GeV, also derived in ABREU 00u. Updates ABREU 00u.

Superseded by ABDALLAH 04M. $^{14} ABREU$ 00V use data from $\sqrt{s} = 130 \text{-}189$ GeV to search for tracks with large impact ABREU OW use data from $\sqrt{s}=130$ –189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as a function of $m_{\widetilde{G}}$, from a scan of the GMSB parameters space, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

15 BARATE 00G combines the search for acoplanar dileptons, leptons with large impact parameters, kinks, and stable heavy-charged tracks, assuming 3 flavors of degenerate sleptons, produced in the schannel. Data collected at \sqrt{s} =189 GeV. 16 ACCIARRI 991 establish indirect limits on $m_{\widetilde{e}_R}$ from the regions excluded in the M_2

versus m_0 plane by their chargino and neutralino searches at \sqrt{s} =130–183 GeV. The situations where the $\widetilde{\chi}^0_1$ is the LSP (indirect decays) and where a $\widetilde{\ell}$ is the LSP (direct decays) were both considered. The weakest limit, quoted above, comes from direct

decays with \overline{UDD} couplings; $LL\overline{E}$ couplings or indirect decays lead to a stronger limit. ACCIARRI 98F looked for acoplanar dielectron+ $\not\!\!E_T$ final states at \sqrt{s} =130–172 GeV. The limit assumes $\mu=-$ 200 GeV, and zero efficiency for decays other than $\widetilde{e}_{R}
ightarrow e\,\widetilde{\chi}_{1}^{0}$

See their Fig. 6 for the dependence of the limit on Δm . 18 BARATE 98k looked for $e^+e^-\gamma\gamma+E$ final states at $\sqrt{s}=$ 161–184 GeV. The limit assumes $\mu=-200$ GeV and $\tan\beta=2$ for the evaluation of the production cross section. See Fig. 4 for limits on the $(m_{\widetilde{e}_R},m_{\widetilde{\chi}_1^0})$ plane and for the effect of cascade decays.

19 BREITWEG 98 used positron+jet events with missing energy and momentum to look for $e^+ q \to \widetilde{e} \widetilde{q}$ via gaugino-like neutralino exchange with decays into $(e \widetilde{\chi}_1^0)(q \widetilde{\chi}_1^0)$. See paper for dependences in $m(\widetilde{q})$, $m(\widetilde{\chi}_1^0)$.

 20 AID 96C used positron+jet events with missing energy and momentum to look for $e^+ q
ightarrow$ $\widetilde{e}\,\widetilde{q}$ via neutralino exchange with decays into $(e\,\widetilde{\chi}^0_1)(q\,\widetilde{\chi}^0_1)$. See the paper for dependences on $m_{\widetilde{q}}$, $m_{\widetilde{\chi}_1^0}$

$\widetilde{\mu}$ (Smuon) MASS LIMIT

| r (| | | | | |
|-------------|-----|-----------------------|-----|------|----------------------------------------------------------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| >91.0 | | 1 ABBIENDI | 04 | OPAL | $\Delta m > 3 \text{ GeV}, \ \widetilde{\mu}_R^+ \widetilde{\mu}_R^-,$ |
| | | | | | $ \mu >$ 100 GeV, $	aneta=$ 1.5 |
| >86.7 | | ² ACHARD | 04 | L3 | Δm >10 GeV, $\widetilde{\mu}_R^+ \widetilde{\mu}_R^-$, |
| | | | | | $ \mu >$ 200 GeV, $	aneta\geq 2$ |
| none 30-88 | 95 | ³ ABDALLAH | 03м | DLPH | $\Delta m >$ 5 GeV, $\widetilde{\mu}_R^+ \widetilde{\mu}_R^-$ |
| >94 | 95 | ⁴ ABDALLAH | 03м | DLPH | $\widetilde{\mu}_{R,1} \leq 	aneta \leq 	aneta \leq 	a0, \ \Delta m > 10 \; GeV$ |
| | | E | | | |
| >88 | 95 | ⁵ HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $\widetilde{\mu}_R^+ \widetilde{\mu}_R^-$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

| | | OABAZOV | 061 | D0 | R, λ'_{211} |
|-----|----|------------------------|-------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| >74 | 95 | ⁷ ABBIENDI | 04 F | OPAL | $\mathbb{R}, \widetilde{\mu}_{l}$ |
| >87 | 95 | ⁸ ABDALLAH | 04 м | DLPH | \mathbb{R} , $\widetilde{\mu}_R$, indirect, $\Delta m > 5$ GeV |
| >81 | 95 | ⁹ HEISTER | 03 G | ALEP | $\widetilde{\mu}_L$, \mathcal{R} decays |
| | | ¹⁰ ABAZOV | 02H | D0 | R, λ'_{211} |
| >61 | 95 | ¹¹ ACHARD | 02 | L3 | $\widetilde{\mu}_R$, R decays |
| >85 | 95 | ¹² BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $\widetilde{\mu}_R^+ \widetilde{\mu}_R^-$ |
| >65 | 95 | ¹³ ABBIENDI | ١00 | OPAL | $\Delta m > 2$ GeV, $\widetilde{\mu}_R^+ \widetilde{\widetilde{\mu}}_R^-$ |
| >80 | 95 | ¹⁴ ABREU | 00v | DLPH | $\widetilde{\mu}_R \widetilde{\mu}_R (\widetilde{\mu}_R \to \mu \widetilde{\widetilde{G}}), m_{\widetilde{\widetilde{G}}} > 8 \text{ eV}$ |
| >77 | 95 | ¹⁵ BARATE | 98K | ALEP | Any Δm , $\widetilde{\mu}_{R}^{+}\widetilde{\mu}_{R}^{-}$, $\widetilde{\mu}_{R}^{-} \rightarrow \mu \gamma \widetilde{G}$ |

 1 ABBIENDI 04 search for $\widetilde{\mu}_R\,\widetilde{\mu}_R$ production in acoplanar di-muon final states in the 183–208 GeV data. See Fig. 14 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$ and for the

limit at $\tan\beta$ =35. Under the assumption of 100% branching ratio for $\overline{\mu}_R \to \mu \overline{\chi}_1^0$, the limit improves to 94.0 GeV for $\Delta m > 4$ GeV. See Fig. 11 for the dependence of the limits on m $\overline{\chi}_1^0$ at several values of the branching ratio. This limit supersedes ABBIENDI 006.

² ACHARD 04 search for $\widetilde{\mu}_R\widetilde{\mu}_R$ production in acoplanar di-muon final states in the 192–209 GeV data. Limits on $m_{\widetilde{\mu}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and m_0 , $1 \leq m_0$ $aneta \leq$ 60 and $-2 \leq \mu \leq$ 2 TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}^0_+}$. This limit supersedes ACCIARRI 99w.

The limit assumes B($\widetilde{\mu} \to ~\mu \widetilde{\chi}_1^0$) = 100%. See Fig. 16 for limits on the $(m_{\widetilde{\mu}_R}, ~m_{\widetilde{\chi}_1^0})$

plane. These limits include and update the results of ABREU 01. ⁴ ABDALLAH 03M uses data from $\sqrt{s} = 192$ –208 GeV to obtain limits in the framework of the MSSM with gaugino and sfermion mass universality at the GUT scale. An indirect limit on the mass is derived by constraining the MSSM parameter space by the results from direct searches for neutralinos (including cascade decays) and for sleptons. These limits are valid for values of M $_2<1$ TeV, $|\mu|\leq 1$ TeV with the $\tilde{\chi}_1^0$ as LSP. The quoted limit is obtained when there is no mixing in the third family. See Fig. 43 for the mass limits as a function of tan β . These limits update the results of ABREU 00w.

 5 HEISTER 02E looked for acoplanar dimuon $+
ot \!\!\!\!E_T$ final states from $e^+ \, e^-$ interactions between 183 and 209 GeV. The mass limit assumes B($\widetilde{\mu} \to \mu \widetilde{\chi}_1^0$)=1. See their Fig. 4 for the dependence of the limit on Δm . These limits include and update the results of

for the dependence of the limit on Δm . These minits include and appared to example BARATE 01. 6 ABAZOV 06i looked in 380 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 muons and 2 jets for s-channel production of $\tilde{\mu}$ or $\tilde{\nu}$ and subsequent decay via R couplings $LQ\overline{D}$. The data are in agreement with the SM expectation. They set limit to the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set of the set o on resonant slepton production and derive exclusion contours on λ'_{211} in the mass plane of $\widetilde{\ell}$ versus $\widetilde{\chi}_1^0$ assuming a MSUGRA model with $\tan\beta=$ 5, $\mu<0$ and $A_0=0$, see their Fig. 3. For $\lambda'_{211} \geq 0.09$ slepton masses up to 358 GeV are excluded. Supersedes the results of ABAZOV 02H.

ABBIENDI 04F use data from $\sqrt{s} = \underline{1}89 - 209$ GeV. They derive limits on sparticle masses ABBLENDI 04F use data from $\sqrt{s} = 169 - 209$ GeV. They derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or $LQ\overline{D}$ couplings. The results are valid for $\tan\beta$ = 1.5, μ = -200 GeV, with, in addition, $\Delta m > 5$ GeV for indirect decays via $LQ\overline{D}$. The limit quoted applies to direct decays with $LL\overline{E}$ couplings and improves to 75 GeV for $LQ\overline{D}$ couplings. The limits on the $\overline{\mu}_R$ mass for indirect decays are respectively 94 and 87 GeV for $LL\overline{E}$ and $LQ\overline{D}$ couplings and $m_{\widetilde{\chi}^0} = 10$ GeV. Supersedes the results

of ABBIENDI 00. of ABBIENDI 00. 8 ABDALLAH 04M use data from $\sqrt{s}=192-208$ GeV to derive limits on sparticle masses under the assumption of R with LLE or \overline{UDD} couplings. The results are valid for $\mu=-200$ GeV, $\tan\beta=1.5$, $\Delta m > 5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect \overline{UDD} decays using the neutralino constraint of 39.5 GeV for \overline{UDD} couplings, also derived in ABDALLAH 04M. For indirect decays via LLE the limit improves to 90 GeV if the constraint from the neutralino is used and remains at 87 GeV if it is not used. For indirect decays via \overline{UDD} couplings it decayed to 25 GeV when the neutralino constraint is not used. degrades to 85 GeV when the neutralino constraint is not used. Supersedes the result of ABREU 00u.

ABREU 000.

HEISTER 03G searches for the production of smuons in the case of R prompt decays with LLE, $LQ\overline{D}$ or \overline{UDD} couplings at $\sqrt{s}=189-209$ GeV. The search is performed for direct and indirect decays, assuming one coupling at a time to be non-zero. The limit holds for direct decays mediated by R $LQ\overline{D}$ couplings and improves to 90 GeV for indirect decays (for $\Delta m > 10$ GeV). Limits are also given for $LL\overline{E}$ direct ($m_{\overline{L}R} > 87$ GeV) and indirect Rdecays ($m_{\widetilde{u}R} >$ 96 GeV for $m(\widetilde{\chi}^0_1) >$ 23 GeV from BARATE 98s) and for \overline{UDD} indirect

decays ($m_{\widetilde{\mu}R}^{-}$ > 85 GeV for Δm > 10 GeV). Supersedes the results from BARATE 01B. 10 ABAZOV 02H looked in 94 pb $^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s}{=}1.8$ TeV for events with at least 2 muons and 2 jets for $s{=}$ -channel production of $\bar{\mu}$ or $\bar{\nu}$ and subsequent decay via R couplings $LQ\bar{D}$. A scan over the MSUGRA parameters is performed to exclude regions of the $(m_0,m_{1/2})$ plane, examples being shown in Fig. 2.

11 ACHARD 02 searches for the production of smuons in the case of

R prompt decays with

LLE or UDD couplings at √s=189-208 GeV. The search is performed for direct and
indirect decays, assuming one coupling at the time to be nonzero. The limit holds for
direct decays via LLE couplings. Stronger limits are reached for LLE indirect (87 GeV)
and for UDD direct or indirect (86 GeV) decays.

The limit assumes $B(\widetilde{\mu} \to \mu \widetilde{\chi}_1^0) = 1$. Using decay branching ratios derived from the MSSM, a lower limit of 65 GeV is obtained for $\mu < -100$ GeV and $\tan \beta = 1.5$. See their Figs. 10 and 13 for the dependence of the limit on the branching ratio and on Δm .

14 ABREU 00v use data from \sqrt{s} = 130-189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{C}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 000. For limits at different $m_{\widetilde{\mathbb{Q}}}$, see their Fig. 12.

Supersymmetric Particle Searches

 15 BARATE 98K looked for $\mu^+\mu^-\gamma\gamma+\not\!\!E$ final states at $\sqrt{s}=$ 161–184 GeV. See Fig. 4 for limits on the $(m_{\widetilde{\mu}_R},m_{\widetilde{\chi}_1^0})$ plane and for the effect of cascade decays.

$\tilde{\tau}$ (Stau) MASS LIMIT

| . (| | | | | |
|---------------------------------|---------|-------------------------|-------|-------------|-------------------------------------------------------------------------------------------------------------------------------|
| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
| >85.2 | | ¹ abbiendi | 04 | OPAL | $\Delta m >$ 6 GeV, $	heta_{	au} {=} \pi/2$, $ \mu >$ |
| | | 2 | | | 100 GeV, $tan \beta = 1.5$ |
| >78.3 | | ² ACHARD | 04 | L3 | $\Delta m > 15$ GeV, $	heta_{	au} = \pi/2$, |
| | | | | | $ \mu >$ 200 GeV, $	aneta\geq 2$ |
| >81.9 | 95 | ³ ABDALLAH | 03м | DLPH | $\Delta m >$ 15 GeV, all $	heta_{	au}$ |
| none m_{τ} – 26.3 | 95 | ³ ABDALLAH | 03м | DLPH | $\Delta m > m_{_{T}}$, all $\theta_{_{T}}$ |
| >79 | 95 | ⁴ HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $	heta_{	au} = \pi/2$ |
| >76 | 95 | ⁴ HEISTER | 02E | ALEP | $\Delta m > 15$ GeV, $	heta_{	au} = 0.91$ |
| ullet $ullet$ $ullet$ We do not | use the | following data for a | verag | es, fits, l | imits, etc. • • • |
| >87.4 | 95 | ⁵ ABBIENDI | 06в | OPAL | $\widetilde{	au}_R ightarrow 	au \widetilde{	ilde{G}}$, all $	au (\widetilde{	au}_R)$ |
| >74 | 95 | ⁶ ABBIENDI | 04 F | OPAL | $R, \widetilde{\tau}_{l}$ |
| >68 | 95 | ^{7,8} ABDALLAH | 04н | DLPH | AMSB, $\mu > 0$ |
| >90 | 95 | ⁹ ABDALLAH | 04 M | DLPH | R , $\widetilde{\tau}_R$, indirect, $\Delta m >$ 5 GeV |
| >82.5 | | ¹⁰ ABDALLAH | 03D | DLPH | $\widetilde{\tau}_R \rightarrow \tau \widetilde{G}$, all $\tau(\widetilde{\tau}_R)$ |
| >70 | 95 | ¹¹ HEISTER | 03 G | ALEP | $\widetilde{	au}_R$, R decay |
| >61 | 95 | ¹² ACHARD | 02 | L3 | $\widetilde{\tau}_R$, R decays |
| >77 | 95 | ¹³ HEISTER | 02R | ALEP | τ_1 , any lifetime |
| >70 | 95 | ¹⁴ BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $\theta_{	au} = \pi/2$ |
| >68 | 95 | ¹⁴ BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $	heta_{	au} = 0.91$ |
| >64 | 95 | ¹⁵ ABBIENDI | 001 | OPAL | $\Delta m > 10$ GeV, $\widetilde{\tau}_R^{\dot{+}} \widetilde{\tau}_R^-$ |
| >84 | 95 | ¹⁶ ABREU | 00v | DLPH | |
| . 70 | 0.5 | ¹⁷ ABREU | 00 | | eV |
| >73 | 95 | 18 BARATE | | DLPH | $\widetilde{\tau}_1 \widetilde{\tau}_1 (\widetilde{\tau}_1 \to \tau \widetilde{G}), \text{ all } \tau(\widetilde{\tau}_1)$ |
| >52 | | RAKAIF | 98K | ALEP | Any $\Delta m, \theta_{\tau} = \pi/2, \widetilde{\tau}_{R} \rightarrow \tau \gamma \widetilde{G}$ |
| | | | | | |

 1 ABBIENDI 04 search for $\widetilde{ au}\widetilde{ au}$ production in acoplanar di-tau final states in the 183–208 GeV data. See Fig. 15 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$ and for the limit

at $\tan\beta$ =35. Under the assumption of 100% branching ratio for $\tilde{\tau}_R \to \tau \tilde{\chi}_1^0$, the limit improves to 89.8 GeV for $\Delta m >$ 8 GeV. See Fig. 12 for the dependence of the limits on $\tilde{\chi}_1^0$ at level values of the branching ratio and for their dependence on θ_{τ} . This limit supersedes ABBIENDI 00G.

 2 ACHARD 04 search for $\widetilde{\tau\tau}$ production in acoplanar di-tau final states in the 192–209 GeV data. Limits on $m_{\widetilde{\tau}_R}$ are derived from a scan over the MSSM parameter space with universal GUT scale gaugino and scalar masses $m_{1/2}$ and m_0 , $1 \le an\!eta \le 60$ and $-2 \le \mu \le 2$ TeV. See Fig. 4 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$

 3 ABDALLAH 03M looked for acoplanar ditaus + E final states at $\sqrt{s} = 130$ –208 GeV. A dedicated search was made for low mass $\tilde{\tau}s$ decoupling from the Z^0 . The limit assumes B($\tilde{\tau} \rightarrow ~\tau \tilde{\chi}_1^0) = 100\%$. See Fig. 20 for limits on the $(m_{\widetilde{\tau}}, m_{\widetilde{\chi}_1^0})$ plane and as function

of the $\widetilde{\chi}_1^0$ mass and of the branching ratio. The limit in the loranss region improves to 29.6 and 31.1 GeV for $\widetilde{\tau}_R$ and $\widetilde{\tau}_L$, respectively, at $\Delta m > m_\tau$. The limit in the high-mass region improves to 84.7 GeV for $\widetilde{\tau}_R$ and $\Delta m > 15$ GeV. These limits include and update the results of ABREU 01.

4 HEISTER 02E looked for acoplanar ditau $+ \not\!\!E_T$ final states from e^+e^- interactions between 183 and 209 GeV. The mass limit assumes B($ilde{ au} o au ilde{\chi}_1^0$)=1. See their Fig. 4 for the dependence of the limit on Δm . These limits include and update the results of BARATE 01.

BARATE 01. ABBIENDI 06B use 600 pb $^{-1}$ of data from $\sqrt{s}=189-209$ GeV. They look for events from pair-produced staus in a GMSB scenario with $\tilde{\tau}$ NLSP including prompt $\tilde{\tau}$ decays to ditaus $+\not\!\!E$ final states, large impact parameters, kinked tracks and heavy stable charged particles. Limits on the cross-section are computed as a function of m($\tilde{\tau}$) and the lifetime, see their Fig. 7. The limit is compared to the $\sigma \cdot BR^2$ from a scan over the GMSB parameter space.

GMBB parameter space.

6 ABBIENDI 04F use data from $\sqrt{s} = 189-209$ GeV. They derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ or $LQ\overline{D}$ couplings. The results are valid for $\tan \beta = 1.5$, $\mu = -200$ GeV, with, in addition, $\Delta m > 5$ GeV for indirect decays via $LQ\overline{D}$. The limit quoted applies to direct decays with $LL\overline{E}$ couplings and improves to 75 GeV for $LQ\overline{D}$ couplings. The limit on the T_R mass for indirect decays is 92 GeV for $LL\overline{E}$ couplings at $m_{\sim 0}=10~{
m GeV}$ and no exclusion is obtained for $L\,Q\,\overline{D}$ couplings. Supersedes

the results of ABBIENDI 00. 7 ABDALLAH 04H use data from ABDALLAH 03M to put limits on the parameter space of anomaly-mediated supersymmetry breaking (AMSB), which is scanned in the region $1 < m_{3/2} < 50 \, {\rm TeV}$, $0 < m_0 < 1000 \, {\rm GeV}$, $1.5 < {\tan\beta} < 35$, both signs of μ . The constraints are obtained from the searches for mass degenerate chargino and neutralino, for SM-like and invisible Higgs, for leptonically decaying charginos and from the limit on non-SM Z width of 3.2 MeV. The limit is for $m_t=174.3~{\rm GeV}$ (see Table 2 for other m_t values).

width of 3.2 MeV. The limit is for $m_t=174.3$ GeV (see Table 2 for other m_t values). 8 The limit improves to 75 GeV for $\mu<0$. 9 ABDALLAH 04M use data from $\sqrt{s}=192-208$ GeV to derive limits on sparticle masses under the assumption of R with $LL\overline{E}$ couplings. The results are valid for $\mu=-200$ GeV, $\tan \beta=1.5$, $\Delta m>5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect decays using the neutralino constraint of 39.5 GeV, also derived in ABDALLAH 04M. For indirect decays via $LL\overline{E}$ the limit decreases to 86 GeV if the constraint from the neutralino is not used. Supersedes the result of ABREU 00u.
10 ABDALLAH 03D use data from $\sqrt{s}=130-208$ GeV to search for tracks with large impact parameter or visible decay vertices and for heavy charged stable particles. Limits are obtained as function of m(\overline{G}), after combining these results with the search for slepton pair production in the SUGRA framework from ABDALLAH 03M to cover prompt decays.
The above limit is reached for the stau decaying promptly, m(\overline{G}) < 6 eV, and is computed

for $LL\overline{E}$ direct $(m_{\widetilde{\tau}_R}~>87~{\rm GeV})$ and indirect decays $(m_{\widetilde{\tau}_R}~>95~{\rm GeV}$ for $m(\widetilde{\chi}^0_1)>23$ GeV from BARATE 985) and for $LQ\overline{D}$ indirect decays $(m_{\widetilde{\tau}_R}~>76~{\rm GeV})$. Supersedes

the results from BARATE 01B. $^{12}\text{ACHARD 02} \text{ searches for the production of staus in the case of } R \text{ prompt decays with } LLE \text{ or } UDD \text{ couplings at } \sqrt{s=189-208} \text{ GeV}. \text{ The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit holds for direct decays via LLE couplings. Stronger limits are reached for LLE indirect (86 GeV) and for UDD direct or indirect (75 GeV) decays.$

 13 HEISTER 02R search for signals of GMSB in the 189–209 GeV data. For the $ilde{\chi}^0_1$ NLSP 3 HEISTER 02n search for signals of GMSB in the 189–209 GeV data. For the $\overline{\chi}_1^{\rm M}$ NLSP scenario, they looked for topologies consisting of $\gamma\gamma E$ or a single γ not pointing to the interaction vertex. For the $\bar{\ell}$ NLSP case, the topologies consist of $\ell L E$, including leptons with large impact parameters, kinks, or stable particles. Limits are derived from a scan over the GMSB parameters (see their Table 5 for the ranges). The limit remains valid whichever is the NLSP. The absolute mass bound on the $\bar{\chi}_1^0$ for any lifetime includes indirect limits from the slepton search HEISTER 02E preformed within the MSUGRA framework. A bound for any NLSP and any lifetime of 77 GeV has also been derived by using the constraints from the neutral Higgs search in HEISTER 02. In the co-NLSP scenario, limits $m_{\widetilde{\ell}_R} >$ 83 GeV (neglecting t-channel exchange) and $m_{\widetilde{\mu}_R} >$ 88 GeV are obtained independent of the lifetime. Supersedes the results from BARATE 00G. A slight ABRATE 01 looked for accolance disaute. For final states at 189 to 202 GeV. A slight

 14 BARATE 01 looked for acoplanar ditau + E_T final states at 189 to 202 GeV. A slight excess (with 1.2% probability) of events is observed relative to the expected SM background. The limit assumes 100% branching ratio for $\tilde{\tau} \to \tau \tilde{\chi}_1^0$. See their Fig. 1 for the dependence of the limit on Δm . These limits include and update the results of

15 ABBIENDI 00J looked for acoplanar ditau $+
ot \!\!\!E_T$ final states at \sqrt{s} = 161–183 GeV. The limit assumes B($ilde{ au} o au \widetilde{\chi}_1^0$)=1. Using decay branching ratios derived from the MSSM, a lower limit of 60 GeV at $\Delta m >$ 9 GeV is obtained for $\mu < -100$ GeV and $an \beta$ =1.5. See their Figs. 11 and 14 for the dependence of the limit on the branching ratio and on

 $16\,\Delta m$.

16 ABREU 00v use data from $\sqrt{s}=130-189$ GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00q. The above limit assumes the degeneracy of stau and smuon. For limits at different $m_{\widetilde{G}}$,

17 ABREU 000 used data from \sqrt{s} = 130–189 GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{e}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 000. The above limit is reached for the stau mixing yielding the minimal cross section and decaying promptly. Stronger limits are obtained for longer lifetimes or for $\widetilde{\tau}_R$; see their Fig. 11. For $10 \le m_{\widetilde{G}} \le 310\,\mathrm{eV}$, the whole range $2 \le m_{\widetilde{\tau}_1} \le 80\,\mathrm{GeV}$ is excluded. Supersedes the results of ABREU 99c and ABREU 99F.

 18 BARATE 98K looked for $au^+ au^-\gamma\gamma+
ot\!\!E$ final states at $\sqrt{s}=$ 161–184 GeV. See Fig. 4 for limits on the $(m_{\widetilde{\tau}_R}, m_{\widetilde{\chi}_1^0})$ plane and for the effect of cascade decays

Degenerate Charged Sleptons

Unless stated otherwise in the comment lines or in the footnotes, the following limits assume 3 families of degenerate charged sleptons.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------|-------------|-----------------------|----------|-----------|-------------------------------------------------------------------------------------------------------------------------|
| >93 | 95 | ¹ BARATE | 01 | ALEP | $\Delta m > 10$ GeV, $\tilde{\ell}_R^+ \tilde{\ell}_R^-$ |
| >70 | 95 | ¹ BARATE | 01 | ALEP | all Δm , $\tilde{\ell}_R^+ \tilde{\ell}_R^-$ |
| • • • We do not use | the followi | ng data for average | s, fits, | , limits, | etc. • • • |
| >91.9 | 95 | ² ABBIENDI | 06в | | $\widetilde{\ell}_R \to \ell \widetilde{G}$, all $\ell(\widetilde{\ell}_R)$ |
| >88 | | ³ ABDALLAH | 03D | DLPH | $\widetilde{\ell}_R \to \ell \widetilde{G}$, all $\ell(\widetilde{\ell}_R)$ |
| >82.7 | 95 | ⁴ ACHARD | 02 | L3 | $\widetilde{\ell}_R$, R decays, MSUGRA |
| >83 | 95 | ⁵ ABBIENDI | 01 | OPAL | $e^+e^- \rightarrow \ell_1 \tilde{\ell}_1,$ GMSB, $tan \beta = 2$ |
| | | ⁶ ABREU | 01 | DLPH | $\ell \to \ell \tilde{\chi}_2^0, \tilde{\chi}_2^0 \to \gamma \tilde{\chi}_1^0,$ |
| >68.8 | 95 | ⁷ ACCIARRI | 01 | L3 | $\begin{array}{c} \ell = e, \mu \\ \widetilde{\ell}_{R}, R, 0.7 \leq \tan\beta \leq 40 \end{array}$ |
| >84 | 95 | ^{8,9} ABREU | 00∨ | DLPH | $\widetilde{\ell}_R \widetilde{\ell}_R (\widetilde{\ell}_R \to \ell \widetilde{G}),$ $m_{\widetilde{G}} > 9 \text{ eV}$ |
| | | | | | |

¹ BARATE 01 looked for acoplanar dilepton $+ \not\!\! E_T$ and single electron (for $\widetilde{e}_R \widetilde{e}_L$) final states at 189 to 202 GeV. The limit assumes $\mu = -200$ GeV and $\tan \beta = 2$ for the production states at 189 to 202 GeV. The limit assumes $\mu=-200$ GeV and $\tan\beta=2$ for the production cross section and decay branching ratios, evaluated within the MSSM, and zero efficiency for decays other than $\ell\to\ell\chi_1^0$. The slepton masses are determined from the GUT relations without stau mixing. See their Fig. 1 for the dependence of the limit on Δm . ² ABBIENDI 06B use 600 pb⁻¹ of data from $\sqrt{s}=189-209$ GeV. They look for events from pair-produced staus in a GMSB scenario with ℓ co-NLSP including prompt ℓ decays to dileptons +E final states, large impact parameters, kinked tracks and heavy stable

charged particles. Limits on the cross-section are computed as a function of $m(\widetilde{\ell})$ and the lifetime, see their Fig. 7. The limit is compared to the $\sigma \cdot BR^2$ from a scan over the GMSB parameter space. The highest mass limit is reached for $\widetilde{\mu}_R$, from which the quoted mass limit is derived by subtracting $m_{\mathcal{T}}$.

quoted mass limit is derived by subtracting $m_{\mathcal{T}}$. 3 ABDALLAH 03D use data from $\sqrt{s}=130$ –208 GeV to search for tracks with large impact parameter or visible decay vertices and for heavy charged stable particles. Limits are obtained as function of m(\widetilde{G}), after combining these results with the search for slepton pair production in the SUGRA framework from ABDALLAH 03M to cover prompt decays The above limit is reached for prompt decays and assumes the degeneracy of the sleptons. For limits at different m(\widetilde{G}), see their Fig. 9. Supersedes the results of ABREU 01G. 4 ACHARD 02 searches for the production of sparticles in the case of R prompt decays with $LL\widetilde{E}$ or \overline{UDD} couplings at \sqrt{s} =189–208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The MSUGRA limit results from a scan over the MSSM parameter space with the assumption of gaugino and scalar mass unification at the GUT scale and no mixing in the slepton sector, imposing simultaneously the exclusions from neutralino, chargino, sleptons, and squarks analyses. The limit holds for $LL\widetilde{E}$ couplings, see ACCIARRI 01. L3 limits from $LQ\overline{D}$ couplings, see ACCIARRI 01.

⁵ ABBIENDI 01 looked for final states with $\gamma\gamma E$, $\ell\ell E$, with possibly additional activity and four leptons + E to search for prompt decays of $\widetilde{\chi}_1^0$ or $\overline{\ell}_1$ in GMSB. They derive limits in the plane $(m_{\widetilde{\chi}_1^0}, m_{\widetilde{\tau}_1})$, see Fig. 6, allowing either the $\widetilde{\chi}_1^0$ or a $\overline{\ell}_1$ to be the NLSP.

Two scenarios are considered: $\tan\beta=2$ with the 3 sleptons degenerate in mass and $\tan\beta=20$ where the $\tilde{\tau}_1$ is lighter than the other sleptons. Data taken at $\sqrt{s}=189$ GeV. For $\tan\beta=20$, the obtained limits are $m_{\tilde{\tau}_1}>69$ GeV and $m_{\tilde{e}_1,\tilde{\mu}_1}>88$ GeV.

⁶ ABREU 01 looked for acoplanar dilepton + diphoton + E final states from $\tilde{\ell}$ cascade decays at \sqrt{s} =130–189 GeV. See Fig. 9 for limits on the (μ, M_2) plane for $m_{\tilde{\ell}}$ =80 GeV, _tan β =1.0, and assuming degeneracy of $\tilde{\mu}$ and $\tilde{\epsilon}$.

ACCIARRI 01 searches for multi-lepton and/or multi-jet final states from R prompt decays with LLE, $LQ\overline{D}$, or \overline{UDD} couplings at \sqrt{s} =189 GeV. The search is performed for direct and indirect decays of neutralinos, charginos, and scalar leptons, with the $\overline{\chi}_1^0$ or a $\overline{\ell}$ as LSP and assuming one coupling to be nonzero at a time. Mass limits are derived using simultaneously the constraints from the neutralino, chargino, and slepton analyses; and the Z^0 width measurements from ACCIARRI 00c in a scan of the parameter space assuming MSUGRA with gaugino and scalar mass universality. Updates and supersedes the results from ACCIARRI 90.

the results from ACCIARRI 99. 8 ABREU 000 use data from $\sqrt{s} = 130-189$ GeV to search for tracks with large impact parameter or visible decay vertices. Limits are obtained as function of $m_{\widetilde{G}}$, after combining these results with the search for slepton pair production in the SUGRA framework from ABREU 01 to cover prompt decays and on stable particle searches from ABREU 00Q. For limits at different $m_{\widetilde{G}}$, see their Fig. 12.

⁹The above limit assumes the degeneracy of stau and smuon.

Long-lived $\widetilde{\boldsymbol{\ell}}$ (Slepton) MASS LIMIT

Limits on scalar leptons which leave detector before decaying. Limits from Z decays are independent of lepton flavor. Limits from continuum e^+e^- annihilation are also independent of flavor for smuons and staus. Selectron limits from e^+e^- collisions in the continuum depend on MSSM parameters because of the additional neutralino exchange contribution.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------|------------------|-----------------------|-----------|---------|-----------------------------------------------------------|
| > 98 | 95 | ¹ abbiendi | 03L | OPAL | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| none 2-87.5 | 95 | ² ABREU | 00Q | DLPH | $\widetilde{\mu}_R$, $\widetilde{\tau}_R$ |
| > 81.2 | 95 | ³ ACCIARRI | 99н | L3 | $\tilde{\mu}_R$, $\tilde{\tau}_R$ |
| > 81 | 95 | ⁴ BARATE | 98K | ALEP | $\tilde{\mu}_R$, $\tilde{\tau}_R$ |
| • • • We do not u | ise the followir | ng data for averag | es, fits, | limits, | etc. • • • |
| >136 | 95 | ⁵ AAD | 11P | ATLS | stable $\widetilde{	au}$, GMSB sce- nario, $	aneta=5$ |

 1 ABBIENDI 03L used e^+e^- data at $\sqrt{s}=130\text{--}209$ GeV to select events with two high momentum tracks with anomalous dE/dx. The excluded cross section is compared to the theoretical expectation as a function of the heavy particle mass in their Fig. 3. The limit improves to 98.5 GeV for $\bar{\mu}_L$ and $\bar{\tau}_L$. The bounds are valid for colorless spin 0 particles with lifetimes longer than 10^{-6} s. Supersedes the results from ACKERSTAFF 98P.

 2 ABREU 00Q searches for the production of pairs of heavy, charged stable particles in $e^+\,e^-$ annihilation at $\sqrt{s}{=}\,130{-}189$ GeV. The upper bound improves to 88 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$. These limits include and update the results of ABREU 98P.

 3 ACCIARRI 99H searched for production of pairs of back-to-back heavy charged particles at \sqrt{s} =130–183 GeV. The upper bound improves to 82.2 GeV for $\widetilde{\mu}_L$, $\widetilde{\tau}_L$

 4 The BARATE 98K mass limit improves to 82 GeV for $\widetilde{\mu}_L,\widetilde{\tau}_L$. Data collected at $\sqrt{s}{=}161{-}184$ GeV.

 \sqrt{s} =161-184 GeV. 5 AAD 11P looked in 37 pb $^{-1}$ of pp collisions at \sqrt{s} = 7 TeV for events with two heavy stable particles, reconstructed in the Inner tracker and the Muon System and identified by their time of flight in the Muon System. No evidence for an excess over the SM expectation is observed. Limits on the mass are derived, see Fig. 3, for \tilde{r} in a GMSB scenario and for sleptons produced by electroweak processes only, in which case the limit degrades to 110 GeV.

q̃ (Squark) MASS LIMIT

For $m_{\widetilde{q}} > 60\text{--}70$ GeV, it is expected that squarks would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included.

Limits from $e^+\,e^-$ collisions depend on the mixing angle of the lightest mass eigenstate $\bar{q}_1\!=\!\bar{q}_R\!\sin\!q_q\!+\!\bar{q}_L\!\cos\!q_q$. It is usually assumed that only the sbottom and stop squarks have non-trivial mixing angles (see the stop and sbottom sections). Here, unless otherwise noted, squarks are always taken to be either left/right degenerate, or purely of left or right type. Data from Z decays have set squark mass limits above 40 GeV, in the case of $\bar{q} \to q \bar{\chi}_1$ decays if $\Delta m\!=\!m_{\widetilde{q}}-m_{\widetilde{\chi}_1^0}\!\gtrsim\! 5$ GeV. For smaller values of

 $\Delta m_{\rm r}$ current constraints on the invisible width of the Z ($\Delta \Gamma_{\rm inv} <$ 2.0 MeV, LEP 00) exclude $m_{\widetilde{u}_L,R} <$ 44 GeV, $m_{\widetilde{d}_R} <$ 33 GeV, $m_{\widetilde{d}_L} <$ 44 GeV and, assuming all squarks degenerate, $m_{\widetilde{q}} <$ 45 GeV.

Limits made obsolete by the most recent analyses of e^+e^- , $p\overline{p}$, and ep collisions can be found in previous Editions of this *Review*.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------|-----|------------------|-----|------|---------------------------------------------------------------|
| > 690 | 95 | ¹ AAD | 11B | ATLS | $\ell^{\pm}\ell^{\pm}+\cancel{E}_{T}$, |
| | | | | | $m_{\widetilde{g}} = m_{\widetilde{q}} + 10 \text{GeV},$ |
| | | | | | $m_{\widetilde{\chi}_{0}^{0}}^{\circ}=100$ GeV, $\tan\beta=4$ |
| > 550 | 95 | 1 aad | 11B | ATLS | $\ell^+\ell^-+\cancel{E}_T$, |
| | | | | | $m_{\widetilde{g}} = m_{\widetilde{a}} + 10 \text{GeV},$ |
| | | | | | $m_{\mathfrak{T}^0}=100\mathrm{GeV}$, tan $eta=4$ |

| > | 558 | 95 | ² AAD | 11 c | ATLS | $\ell^+ \ell^- + \text{jets} + \cancel{E}_T,$ $m_{\widetilde{g}} = m_{\widetilde{q}} + 10 \text{GeV},$ |
|----|------|-----|-------------------------|------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | | | | | | $m_{\widetilde{\chi}_1^0}^{\sigma} = 100 \text{GeV}$, $\tan \beta = 4$ |
| > | 700 | 95 | ³ AAD | 11 G | ATLS | $ \begin{array}{c} \lambda_1 \\ \ell + \mathrm{jets} + E_T, \ \tan\beta = 3, \ A_0 = 0, \\ \mu > 0, \ m_{\widetilde{\varrho}} = m_{\widetilde{q}} \end{array} $ |
| > | 870 | 95 | ⁴ AAD | 11 N | ATLS | jets $+ \not\!\!E_T$, degenerate $m_{\widetilde{a}}$ |
| | | | | | | of first two generations, $m_{\widetilde{\chi}_1^0} = 0$, all other supersymmetric particles heavy, $m_{\widetilde{d}} = m_{\widetilde{d}}$ |
| > | 775 | 95 | ⁴ AAD | 11 N | ATLS | jets+ $\not\!\!E_T$, CMSSM, $m_{\widetilde{a}} = m_{\widetilde{p}}$ |
| >1 | 100 | 95 | ⁵ CHATRCHYAN | 11w | CMS | jets + ₺T, CMSSM |
| > | 392 | 95 | ⁶ AALTONEN | 09s | CDF | $jets+\cancel{E}_{T}$, $m_{\widetilde{q}}=m_{\widetilde{g}}$ |
| > | 379 | 95 | ⁷ ABAZOV | 08G | D0 | jets+ $\not\!\!E_T$, $\tan\beta=3$, $\mu<0$, $A_0=0$, any $m_{\widetilde{\varrho}}$ |
| > | 99.5 | | ⁸ ACHARD | 04 | L3 | $\Delta m > 10 \text{ GeV}, \ \stackrel{\circ}{e^+} e^- ightarrow \widetilde{q}_{L,R} \ \stackrel{\circ}{\overline{q}}_{L,R}$ |
| > | 97 | | ⁸ ACHARD | 04 | L3 | $\Delta m > 10 \text{ GeV}, e^+e^- \rightarrow \widetilde{q}_R \widetilde{q}_R$ |
| > | 138 | 95 | ⁹ ABBOTT | 01 D | D0 | $\ell\ell$ +jets+ $\not\!\!E_T$, $	aneta < 10$, $m_0 < 300$ GeV, $\mu < 0$, $A_0 = 0$ |
| > | 255 | 95 | ⁹ ABBOTT | 01 D | D0 | $\tan \beta = 2$, $m_{\widetilde{g}} = m_{\widetilde{q}}$, $\mu < 0$, $A_0 = 0$, $\ell \ell + \text{jets} + \cancel{E}_T$ |
| > | 97 | 95 | ¹⁰ BARATE | 01 | ALEP | $e^+e^- \rightarrow \widetilde{q}\overline{\widetilde{q}}, \Delta m > 6 \text{ GeV}$ |
| - | 224 | | ¹¹ ABE | | CDF | $m_{\widetilde{g}} \leq m_{\widetilde{q}}$; with cascade |
| | | ,,, | NDL . | JUD | CDI | $g \leq mq$, with caseade decays, $\ell\ell$ +jets+ $\not\!\!E_T$ |

| | | | | | decays, $\ell\ell+$ jets $+ ot\!\!\!E_T$ |
|----------------|-----------|--------------------------|--------------|-----------|-----------------------------------------------------------------------------------------------------------------|
| • • • We do no | ot use th | e following data for a | | es, fits, | limits, etc. • • • |
| | | 12 CHATRCHYAN | N12 | CMS | e,μ , jets, razor, CMSSM |
| | | ¹³ AAD | | ATLS | $\ell^{\pm}\ell^{\pm}$ |
| | | 14 AAD | 11 AF | ATLS | \geq 6 jets $+ ot \!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| > 290 | 95 | ¹⁵ AARON | 11 | H1 | $e^- p \rightarrow \widetilde{d}_R$, R , $LQ\overline{D}$, $\lambda' = 0.3$ |
| > 275 | 95 | ¹⁵ AARON | 11 | H1 | $e^+ p \rightarrow \widetilde{u}_L$, R , $L Q \overline{D}$, $\lambda' = 0.3$ |
| > 330 | 95 | ¹⁶ AARON | 11€ | | \widetilde{u} , R , $LQ\overline{\overline{D}}$, $\lambda'=0.3$ |
| | | ¹⁷ CHATRCHYAN | V 11A | CMS | jets $+ ot \!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| | | ¹⁸ CHATRCHYAN | V 11C | CMS | $\widetilde{q} \rightarrow X \widetilde{\widetilde{\chi}}_2^0 \rightarrow X \ell^+ \ell^- \widetilde{\chi}_1^0$ |
| | | ¹⁹ CHATRCHYAN | V 116 | CMS | $\tilde{\chi}_1^0 \rightarrow \gamma \tilde{\tilde{G}}$ |
| | | 20 CHATRCHYAN | V11Q | CMS | ℓ + jets + $\not\!\!E_T$ |
| > 830 | 95 | 21 CHATRCHYAN | V11 V | CMS | GMSB scenario, $\overline{\ell}$ co-NLSP |
| | | 22 CHATRCHYAN | V11 V | CMS | Ŗ |
| | | ²³ KHACHATRY. | 111 | CMS | jets $+ ot\!\!\!E_T$ |
| | | ²⁴ ABAZOV | 09s | D0 | jets $+\tau+\cancel{E}_T$, tan $\beta=15$, $\mu<0$, $A_0=-2m_0$ |
| | | 25 | | | |
| > 490 | 95 | 25 SCHAEL | 07A | ALEP | d_R , R , $\lambda = 0.3$ |
| > 544 | 95 | 25 SCHAEL | 07A | ALEP | \tilde{s}_R , R , $\lambda = 0.3$ |
| > 273 | 95 | 26 CHEKANOV | 05 A | ZEUS | $\widetilde{q} \rightarrow \mu q, R, LQ\overline{D}, \lambda=0.3$ |
| > 270 | 95 | 26 CHEKANOV | 05 A | ZEUS | $\widetilde{q} \rightarrow \tau q$, R , $LQ\overline{D}$, $\lambda = 0.3$ |
| > 275 | | ²⁷ AKTAS | 04 D | H1 | $e^{\pm} p \rightarrow \widetilde{U}_{L}, R, LQ\overline{D}$ |
| > 280 | | ²⁷ AKTAS | 04 D | H1 | $e^{\pm} p \rightarrow \overline{D}_R, R, LQ\overline{D}$ |
| 276 | | 28 ADLOFF | 03 | H1 | $e^{\pm} p \rightarrow \widetilde{q}, R, LQ\overline{D}$ |
| > 276 | 95 | 29 CHEKANOV | 03в | ZEUS | $\widetilde{d} \rightarrow e^- u, \nu d, R, LQ\overline{D}, \lambda > 0.1$ |
| > 260 | 95 | 29 CHEKANOV | 03B | ZEUS | $\widetilde{u} \to e^+ d, R, LQ\overline{D}, \lambda > 0.1$ |
| > 82.5 | 95 95 | 30 HEISTER | 03 G | ALEP | \widetilde{u}_R , \mathcal{R} decay |
| > 77 | | 30 HEISTER | 03 G | ALEP | d_R , R decay |
| > 240 | 95 | ³¹ ABAZOV | 02F | D0 | \widetilde{q} , $\Re \lambda^{'}_{2jk}$ indirect decays, |
| | | | | | $\tan \bar{\beta} = 2$, any $m_{\widetilde{g}}$ |
| > 265 | 95 | ³¹ ABAZOV | 02F | D0 | \widetilde{q} , $\Re \lambda'_{2jk}$ indirect decays, |
| | | | | | $\tan \beta = 2$, $m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| | | 32 ABAZOV | 02 G | D0 | $p\overline{p} ightarrow $ |
| none 80-121 | 95 | 33 ABBIENDI | 02 | OPAL | $e \gamma \rightarrow \widetilde{u}_{L}, R L Q \overline{D}, \lambda = 0.3$ |
| none 80-158 | 95 | 33 ABBIENDI | 02 | OPAL | $e \gamma \rightarrow \widetilde{d}_R$, $R LQ\overline{D}$, $\lambda=0.3$ |
| none 80-185 | 95 | ³⁴ ABBIENDI | 02B | OPAL | $e \gamma \rightarrow \widetilde{u}_L$, $R L Q \overline{D}$, $\lambda = 0.3$ |
| none 80-196 | 95 | ³⁴ ABBIENDI | 02в | OPAL | $e \gamma \rightarrow \widetilde{d}_{R}^{L}$, $R LQ\overline{D}$, $\lambda=0.3$ |
| > 79 | 95 | ³⁵ ACHARD | 02 | L3 | \widetilde{u}_R , R decays |
| > 55 | 95 | ³⁵ ACHARD | 02 | L3 | \widetilde{d}_R , R decays |
| > 263 | 95 | 36 CHEKANOV | 02 | ZEUS | $\widetilde{u}_{I} \rightarrow \mu q, R, LQ\overline{D}, \lambda=0.3$ |
| > 258 | 95 | ³⁶ CHEKANOV | 02 | ZEUS | $\widetilde{u}_L \rightarrow \tau q$, R , $LQ\overline{D}$, $\lambda = 0.3$ |
| > 82 | 95 | 37 BARATE | 01B | ALEP | \widetilde{u}_R , R decays |
| > 68 | 95 | ³⁷ barate | 01B | ALEP | \widetilde{d}_R , R decays |
| none 150-204 | 95 | ³⁸ BREITWEG | 01 | ZEUS | $e^+ p \rightarrow \widetilde{d}_R$, $R LQ\overline{D}$, $\lambda = 0.3$ |
| > 200 | 95 | ³⁹ abbott | 00 c | D0 | \widetilde{u}_L , \mathcal{R} , λ'_{2jk} decays |
| > 180 | 95 | ³⁹ АВВОТТ | 00 c | D0 | \widetilde{d}_R , \mathcal{R} , λ'_{2jk} decays |
| | 95 | ⁴⁰ ACCIARRI | 00P | | |
| > 390 | 95 95 | 41 AFFOLDER | 00P | L3 CDF | $e^+e^- \rightarrow q \overline{q}, R, \lambda=0.3$ |
| > 148 | | | | | d_L , $\Re \lambda'_{ij3}$ decays |
| > 200 | 95 | ⁴² BARATE | 001 | ALEP | $e^+e^- \rightarrow q \overline{q}, R, \lambda = 0.3$ |
| none 150-269 | 95 | 43 BREITWEG | 00E | ZEUS | $e^+ p \rightarrow \widetilde{u}_L$, R , $LQ\overline{D}$, $\lambda = 0.3$ |
| > 240 | 95 | ⁴⁴ ABBOTT | 99 | D0 | $\widetilde{q} \rightarrow \widetilde{\chi}_2^0 X \rightarrow \widetilde{\chi}_1^0 \gamma X$ |
| | | | | | $m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}} \stackrel{>}{>} 20 \text{ GeV}$ |
| > 320 | 95 | ⁴⁴ ABBOTT | 99 | D0 | $\widetilde{q} \to \widetilde{\widetilde{\chi}}_1^0 X \to \widetilde{G} \gamma X$ |
| > 243 | OE. | 45 ADDOTT | 001/ | D0 | any m. B tang 2 < 0 |

⁴⁵ ABBOTT

99K D0

any $m_{\widetilde{\varrho}}$, R, aneta=2, $\mu<0$

> 243

Supersymmetric Particle Searches

| > 250 | 95 | ⁴⁶ ABBOTT | 99L | D0 | tan 8 2 < 0 4 0 into 1 77 |
|--------------|----------|--------------------------|------|------|------------------------------------------------------------------------------------------------------------|
| | 95 95 | 47 ABE | | | $\tan \beta = 2$, $\mu < 0$, $A = 0$, jets $+ \cancel{E}_T$ |
| > 200 | | | 99м | | $p\overline{p} \rightarrow \widetilde{q}\widetilde{q},R$ |
| none 80-134 | 95 | 48 ABREU | 99 G | DLPH | $e \gamma \rightarrow \widetilde{u}_L$, $\Re LQ\overline{D}$, $\lambda=0.3$ |
| none 80-161 | 95 | ⁴⁸ ABREU | 99 G | DLPH | $e \gamma \rightarrow \widetilde{d}_{R}^{-}$, $R LQ\overline{D}$, $\lambda = 0.3$ |
| > 225 | 95 | ⁴⁹ ABBOTT | 98E | D0 | \tilde{u}_L , \mathcal{R} , λ_{1jk}^{j} decays |
| > 204 | 95 | ⁴⁹ ABBOTT | 98E | D0 | \tilde{d}_R , R , λ'_{1jk} decays |
| > 79 | 95 | ⁴⁹ ABBOTT | 98E | D0 | \tilde{d}_L , \mathcal{R} , λ'_{ijk} decays |
| > 202 | 95 | ⁵⁰ ABE | 98s | CDF | ũ _L , Γλ λ' _{2 j k} decays |
| > 160 | 95 | ⁵⁰ ABE | 98s | CDF | \tilde{d}_R , $\Re \lambda_{2jk}'$ decays |
| > 140 | 95 | ⁵¹ ACKERSTAFF | 98v | OPAL | $e^+e^- \rightarrow q \overline{q}, R, \lambda=0.3$ |
| > 77 | 95 | ⁵² BREITWEG | 98 | ZEUS | $m_{\widetilde{q}} = m_{\widetilde{e}}, \ m(\widetilde{\chi}_1^0) = 40 \text{ GeV}$ |
| | | ⁵³ DATTA | 97 | THEO | $\widetilde{\nu}$'s lighter than $\widetilde{\chi}_1^{\pm}$, $\widetilde{\chi}_2^0$ |
| > 016 | 95 | 54 DERRICK | 97 | ZEUS | |
| > 216 | | | | | $e p \rightarrow \widetilde{q}, \widetilde{q} \rightarrow \mu j \text{ or } \tau j, R$ |
| none 130-573 | 95 | ⁵⁵ HEWETT | 97 | THEO | $q\widetilde{g} \rightarrow \widetilde{q}, \widetilde{q} \rightarrow q\widetilde{g}$, with a light gluino |
| none 190-650 | 95 | ⁵⁶ TEREKHOV | 97 | THEO | $qg \rightarrow \widetilde{q}\widetilde{g}, \widetilde{q} \rightarrow q\widetilde{g}, \text{ with a}$ |
| | | | | | light gluino |
| > 63 | 95 | ⁵⁷ AID | 96 C | H1 | $m_{\widetilde{q}} = m_{\widetilde{e}}, m_{\widetilde{\chi}_1^0} = 35 \text{ GeV}$ |
| none 330-400 | 95 | ⁵⁸ TEREKHOV | 96 | THEO | $ug \rightarrow \widetilde{u}\widetilde{g}, \widetilde{u} \rightarrow u\widetilde{g} \text{ with a}$ |
| | | | | | light gluino |
| > 176 | 95 | ⁵⁹ ABACHI | 95 C | D0 | Any $m_{\widetilde{g}}$ <300 GeV; with cas- |
| | | | | | cade decays |
| | | ⁶⁰ ABE | 95 T | CDF | $\tilde{q} \rightarrow \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \gamma$ |
| > 90 | 90 | ⁶¹ ABE | 92L | CDF | Any $m_{\widetilde{g}}^2$ <410 GeV; with |
| | | | | | cascade decay |
| > 100 | | 62 ROY | 92 | RVUE | $p \overline{p} \rightarrow \widetilde{q} \widetilde{q}; R$ |
| | | ⁶³ NOJIRI | 91 | COSM | |
| _ | | | | | |

- 1 AAD 11B looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=$ 7 TeV for events with same or opposite charge dileptons (e or μ) and $\not\!\!E_T$ from the production of squarks and gluinos with leptonic decays from $\tilde{\chi}_1^\pm$ or $\tilde{\chi}_2^0$. No evidence for an excess over the SM expectation is observed, and limits are derived in the CMSSM $(m_0, m_{1/2})$ plane (see Fig. 2) and in the $(m_{\widetilde{g}}, m_{\widetilde{q}})$ plane under the assumptions $\tan\beta=4$, $\mu=1.5$ M, $m_{\widetilde{\chi}_2^0}=M$ -100 GeV, $m_{\widetilde{\ell}_L}=\mathrm{M/2}$, $m_{\widetilde{\chi}_1^0}=100$ GeV, where $M=\min(m_{\widetilde{g}}, m_{\widetilde{q}})$ (see Fig. 3). The exclusion limit for a compressed spectrum is 590 GeV for the same charge and 450 GeV for the opposite charge events.
- opposite charge events. 2 AAD 11c looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with jets, same flavor opposite charge dileptons (e or μ) and E_T from the production of squarks and gluinos with decays $\widetilde{q} \to q \widetilde{\chi}_2^0$ and $\widetilde{\chi}_2^0 \to \ell^+\ell^-\widetilde{\chi}_1^0$. No evidence for an excess over the SM expectation is observed, and a limit is derived in the $(m_{\widetilde{q}}, m_{\widetilde{q}})$ plane under the assumptions $\tan\beta = 4$, $\mu = 1.5$ M, $m_{\widetilde{\chi}_2^0} = M 100$ GeV, $m_{\widetilde{\ell}_L^0} = M/2$, $m_{\widetilde{\chi}_1^0} = 100$ GeV, where $M=\min(m_{\widetilde{g}}, m_{\widetilde{q}})$. The excluded mass region is shown in a plane of $(m_{\widetilde{g}}, m_{\widetilde{q}})$, see their Fig. 3. The exclusion limit for a compressed spectrum is 503 GeV.
- 3 AAD 11G looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=$ 7 TeV for events with a single lepton (e or μ), jets and $\not\!\! E_T$ from the production of squarks and gluinos. No evidence for an excess over the SM expectation is observed, and a limit is derived in the CMSSM $(m_0, m_{1/2})$ plane for an eta = 3, see Fig. 2.
- 4 AAD 11N looked in 35 pb $^{-1}$ of ρp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 jets and $\not\!\!E_T$. Four signal regions were defined, and the background model was found to be in good agreement with the data. Limits are derived in the $(m_{\widetilde{q}}, m_{\widetilde{q}})$ plane (see Fig. 2) for a simplified model where degenerate masses of the squarks of the first two generations are assumed, $m_{\widetilde{\chi}_1^0} = 0$, and all other masses including third generation squarks are set to 5 TeV. Limits are also derived in the CMSSM ($m_0,\,m_{1/2}$) plane (see Fig. 3) for $an\!eta$
- 5 CHATRCHYAN 11w looked in 1.14 fb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 jets, large total jet energy, and E_T . After combining multi-jet events into two pseudo-jets signal events are selected by a cut on $\alpha_T=E_T^{j_2}/M_T$, the transverse energy of the less energetic jet over the transverse mass. Given the lack of an excess over the SM backgrounds, limits are derived in the CMSSM $(m_0, m_{1/2})$ plane (see Fig. 4) for $\tan \beta = 10$. The limits are only weakly dependent on $\tan \beta$ and A_0 .
- tan $\beta=10$. The limits are only weakly dependent on tan β and A_0 . 6 AALTONEN 09s searched in 2 fb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 jets and E_T . No evidence for a signal is observed. A limit is derived for a mSUGRA scenario in the $m_{\overline{Q}}$ evenus $m_{\overline{Q}}$ plane, see their Fig. 2. For $m_{\overline{Q}}<340$ GeV the bound increases to 400 GeV. 7 ABAZOV 08G looked in 2.1 fb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with acoplanar jets or multijets with large E_T . No significant excess was found compared to the background expectation. A limit is derived on the masses of squarks and gluinos for specific MSUGRA parameter values, see Figure 3. Similar results would be obtained for a large class of parameter sets. Supersedes the results of ABAZOV 06c. 8 ACHARD 04 search for the production of $\overline{\alpha}$ of the first two generations in acoplanar
- 8 ACHARD 04 search for the production of $q\bar{q}$ of the first two generations in acoplanar di-jet final states in the 192–209 GeV data. Degeneracy of the squark masses is assumed either for both left and right squarks or for right squarks only, as well as $\mathsf{B}(\widetilde{q} o q \, \widetilde{\chi}_1^0) = 1$ See Fig. 7 for the dependence of the limits on $m_{\widetilde{\chi}_1^0}$. This limit supersedes ACCIARRI 99v.
- 9 ABBOTT 01D looked in \sim 108 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}{=}1.8$ TeV for events with e e, $\mu\mu$, or $e\,\mu$ accompanied by at least 2 jets and E_{T^-} Excluded regions are obtained in the MSUGRA framework from a scan over the parameters 0< m_0 <300 GeV, 10< $m_{1/2}$ <110 GeV, and $1.2 < \tan \beta < 10$.
- 10 BARATE 01 looked for acoplanar dijets $+
 ot\!\!\!E_T$ final states at 189 to 202 GeV. The limit assumes B($\widetilde{q} \to q \widetilde{\chi}_1^0$)=1, with $\Delta m = m_{\widetilde{q}} - m_{\widetilde{\chi}_1^0}$. It applies to tan β =4, μ = -400 GeV. See their Fig. 2 for the exclusion in the $(m_{\widetilde{q}}, m_{\widetilde{g}})^{-1}$ plane. These limits include and update
- the results of BARATE 990. The results of BARATE 990. The results of BARATE 990. The results of searched for production of gluinos and five degenerate squarks in final states containing a pair of leptons, two jets, and missing $E_{\mathcal{T}}$. The two leptons arise from the semileptonic decays of charginos produced in the cascade decays. The limit is derived for

- fixed $\tan\beta=4.0$, $\mu=-400$ GeV, and $m_{H^+}=500$ GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity
- Scenario. 12 CHATRCHYAN 12 looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with e and/or μ and/or jets, a large total transverse energy, and \rlap/E_T . The event selection is based on the dimensionless razor variable R, related to the \rlap/E_T and M_R , an indicator of the heavy particle mass scale. No evidence for an excess over the expected background is observed. Units are derived in the CMSSM $(m_0, m_1/2)$ plane for $\tan\beta=3$, 10 and
- 50 (see Fig. 7 and 8). Limits are also obtained for Simplified Model Spectra. $^{13}\text{AAD }11\text{AE looked in }34\text{ pb}^{-1}\text{ of }pp\text{ collisions at }\sqrt{s}=7\text{ TeV for events with }\geq2$ same charge isolated leptons (e,μ) and ≥1 jet. They are assumed to come from $\widetilde{q}\widetilde{q}$ production, where the \widetilde{q} decays to $\widetilde{\chi}_1^\pm$ or $\widetilde{\chi}_2^0$ with equal branching ratios, followed by the decays $\tilde{\chi}_1^{\pm} \to W^{\pm} \tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to Z^0 \tilde{\chi}_1^0$. No evidence for an excess over the expected background is observed. Limits are derived on the cross sections as a function of the
- masses of the \widetilde{q} , $\widetilde{\chi}_1^{\pm}/\widetilde{\chi}_0^2$ and $\widetilde{\chi}_1^0$ (see Fig. 9 and 10). ¹⁴ AAD 11AF looked in 1.34 fb⁻¹ of pp collisions at $\sqrt{s}=7$ TeV for events with 6 up to 8 jets and \cancel{E}_T . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_{1/2})$ plane for $\tan\beta=10$ (see Fig. 5). The limit improves to $m_{\widetilde{q}}=80$ GeV for $m_{\widetilde{q}}=2$ $m_{\widetilde{g}}=2$.
- 15 AARON 11 looked in 255 pb $^{-1}$ of $e^+ p$ and 183 pb $^{-1}$ of $e^- p$ collisions at $\sqrt{s}=$ 319 GeV for events with at least 1 lepton and jets from R_p violation with $L\,Q\,\overline{D}$ couplings, assuming dominance of a single λ'_{ijk} coupling. No evidence for an excess over the SM expectation is observed, and limits are derived in the $(\lambda', m_{\overline{q}})$ plane for the MSSM with $\tan\beta=6$, see their Figs. 7 and 8. Limits are also derived in a CMSSM-type scenario. ¹⁶ AARON 11c looked in 281 pb $^{-1}$ of e^+p and 165 pb $^{-1}$ of e^-p collisions at $\sqrt{s}=319$
- GeV and \sqrt{s} =301 GeV for contact interactions measured from deviations of the d σ /d Q^2 of neutral current events. They are interpreted in the framework of R-parity violation with $L\,Q\,\overline{D}$ couplings. No evidence for an excess over the SM expectation is observed, and limits are derived for $m_{\widetilde{q}}/\lambda'$, see Table 4.
- 17 CHATRCHYAN 11 AC looked in 36 pb $^{-1}$ of p p collisions at $\sqrt{s}=$ 7 TeV for events with \geq 3 jets, a large total transverse energy, and E_T . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_{1/2})$ plane and the $(m_{\widetilde{g}},m_{\widetilde{q}})$ plane for $\tan\beta=10$ (see Fig. 10). Limits are also obtained for Simplified Model Spectra.
- 18 CHATRCHYAN 11C looked in 34 pb $^{-1}$ of pp collisions at \sqrt{s} =7 TeV for events with opposite charge isolated dileptons (e or μ), jets and E_T from pair production of \tilde{g} and \tilde{q} . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,\,m_{1/2})$ plane for aneta=3 (see Fig. 4).
- 19 CHATRCHYAN 11G looked in 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=$ 7 TeV for events with \geq 2 isolated photons, 2 1 jet and E_{TP} , which may arise in a generalized gauge mediated model from the decay of a $\widetilde{\chi}_1^0$ NLSP. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark versus gluino mass (see Fig. 4) for several values of $m_{\widetilde{\chi}_1^0}$.
- 20 CHATRCHYAN 11Q looked in 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with a single isolated lepton (e or μ), \geq 4 jets and \cancel{E}_T . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,\,m_{1/2})$ plane for $tan \beta = 10$ (see Fig. 7).
- Scenario, 22 CHATRCHYAN 11v looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 3 isolated leptons $(e,\mu$ or $\tau)$, with or without jets and E_T . No evidence for an excess over the expected background is observed. Limits are derived in the R framework (see Fig. 4) in the $(m_{\widetilde{g}},m_{\widetilde{q}})$ plane assuming the dominance of a λ_{122} or λ_{123} coupling, $m_{\widetilde{\chi}_1^0}=300$ GeV, $m_{\widetilde{\ell}}=1000$ GeV, and decoupled wino and Higgsino.
- 23 KHACHATRYAN 111 looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=$ 7 TeV for events with \geq 2 jets and $ot\!\!E_T$. After combining multi-jet events into two pseudo-jets signal events are selected by a cut on $\alpha_T=E_T^{j_2}/M_T$, the transverse energy of the less energetic jet over the transverse mass. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,m_{1/2})$ plane (see Fig. 5) for $\tan\beta=\frac{1}{2}$
- 3. Superseded by CHATRCHYAN 11W. at least 2 jets, a tau decaying hadronically and $\not E_T$ from the production $\vec q_L \vec q_R$, with the taus originating from the decay of a $\vec \chi_2^0$ or $\vec \chi_1^\pm$. The results were combined with ABAZOV 08G which searched for events with jets and $\not E_T$ without requiring taus. No evidence for an excess over the SM expectation is observed. The excluded region is shown for an mSUGRA model in a plane of $m_{1/2}$ versus m_0 in the "tau corridor," see their Figs. 5 and 6. The largest excluded squark mass in the corridor is 340 GeV for the tau analysis only and 410 GeV for the combined analysis.
- 25 SCHAEL 07A studied the effect on hadronic cross sections and charge asymmetries of t-channel down-type squark exchange via R-parity violating couplings $LQ\overline{D}$ at $\sqrt{s}=$ 189–209 GeV. The limit here refers to the case j= 1, 2 and holds for $\lambda^{'}_{1jk}$ of electromagnetic strength. The results of this analysis are combined with BARATE 001.
- 26 CHEKANOV 05A search for lepton flavor violating processes $e^\pm p \to \ell X$, where $\ell=\mu$ or τ with high p_T , in 130 pb $^{-1}$ at 300 and 318 GeV. Such final states may originate from LQD couplings with simultaneously non-zero λ'_{1jk} and λ'_{ijk} (i=2 or 3). The quoted mass bounds hold for a u-type squark, assume a λ' of electromagnetic strength and contributions from only direct squark decays. For d-type squarks the bounds are strengthened to 278 and 275 GeV for the μ and τ final states, respectively. Supersedes
- the results of CHEKANOV 02. 27 AKTAS 04D looked in 77.8 pb $^{-1}$ of $e^\pm p$ collisions at $\sqrt{s}=$ 319 GeV for resonant production of \widetilde{q} by R-parity violating $LQ\overline{D}$ couplings assuming that one of the λ' couplings

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dominates over all others. They consider final states with or without leptons and/or jets and/or p_T' resulting from direct and indirect decays. They combine the channels to derive limits on $\lambda_{1j1}^{'}$ and $\lambda_{11k}^{'}$ as a function of the squark mass, see their Figs. 8 and 9, from a scan over the parameters 70 < M_2 < 350 GeV, -300 < μ < 300 GeV, $\tan\beta=$ 6, for a fixed mass of 90 GeV for degenerate sleptons and an LSP mass > 30 GeV. The quoted limits refer to $\lambda'=$ 0.3, with U=u,c,t and D=d,s,b. Supersedes the results of ADLOFF 01B. Superseded by AARON 11.

 28 ADLOFF 03 looked for the s-channel production of squarks via R $LQ\overline{D}$ couplings in The comparison of the s-channel production or squarks via k LQD couplings in 117.2 pb $^{-1}$ of e ^+p data at $\sqrt{s}=301$ and 319 GeV and of e ^-p data at $\sqrt{s}=319$ GeV. The comparison of the data with the SM differential cross section allows limits to be set on couplings for processes mediated through contact interactions. They obtain lower bounds on the value of $m_{\overline{q}}/\lambda'$ of 710 GeV for the process $e^+\overline{u}\to \widetilde{a}^k$ (and charge conjugate), mediated by λ'_{11k} , and of 430 GeV for the process $\mathrm{e}^+\,d
ightarrow \, \tilde{u}^j$ (and charge conjugate), mediated by $\lambda_{1j1}^{\prime 110}$. Superseded by AARON 11c.

²⁹ CHEKA NOV 03B used 131.5 pb⁻¹ of e^+p and e^-p data taken at 300 and 318 GeV to look for narrow resonances in the eq or νq final states. Such final states may originate from $LQ\overline{D}$ couplings with non-zero χ'_{1j1} (leading to \overline{u}_j) or χ'_{11k} (leading to \overline{d}_k). See their Fig. 8 and explanations in the text for limits. The quoted mass bound assumes that only direct squark decays contribute. $^{30}\, \rm HEISTER$ 03G searches for the production of squarks in the case of R prompt decays

with \overline{DD} direct couplings at at $\sqrt{s}=189$ –209 GeV. ³¹ ABAZOV 02F looked in 77.5 pb⁻¹ of $p\overline{p}$ collisions at 1.8 TeV for events with $\geq 2\mu + \geq 4$ jets, originating from associated production of squarks followed by an indirect R decay (of the $\tilde{\chi}_1^0$) via $LQ\overline{D}$ couplings of the type λ_{2jk}^{\prime} where j=1,2 and k=1,2,3. Bounds are obtained in the MSUGRA scenario by a scan in the range $0 \leq M_0 \leq 400$ GeV, $60 \leq M_{1/2} \leq 120$ GeV for fixed values $A_0=0$, $\mu<0$, and $\tan\beta=2$ or 6. The bounds are weaker for tan $\beta=6$. See Figs. 2,3 for the exclusion contours in $m_{1/2}$ versus m_0 for tan $\beta=2$ and

³² ABAZOV 02G search for associated production of gluinos and squarks in 92.7 pb $^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV, using events with one electron, \geq 4 jets, and large E_T . The results are compared to a MSUGRA scenario with μ <0, A_0 =0, and $\tan \beta$ =3 and allow to exclude a region of the $(m_0,m_{1/2})$ shown in Fig. 11.

 33 ABBIENDI 02 looked for events with an electron or neutrino and a jet in $e^+\,e^-$ at 189 GeV. Squarks (or leptoquarks) could originate from a $LQ\overline{D}$ coupling of an electron with a quark from the fluctuation of a virtual photon. Limits on the couplings $\lambda'_{1j\,k}$ as a function of the squark mass are shown in Figs. 8-9, assuming that only direct squark decays contribute.

 34 ABBIENDI 02B looked for events with an electron or neutrino and a jet in e^+e^- at 189–209 GeV. Squarks (or leptoquarks) could originate from a LQD coupling of an electron with a quark from the fluctuation of a virtual photon. Limits on the couplings λ_{1ik}' as a function of the squark mass are shown in Fig. 4, assuming that only direct squark decays contribute. The quoted limits are read off from Fig. 4. Supersedes the results of ABBIENDI 02.

35 SACHARD 02 searches for the production of squarks in the case of R prompt decays with \overline{UDD} couplings at \sqrt{s} =189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit holds for indirect decays. Stronger limits are reached for $(\widetilde{u}_R,\widetilde{d}_R)$ direct (80,56) GeV and $(\widetilde{u}_L,\widetilde{d}_L)$ direct or indirect (87,86) GeV decays.

36 CHEKA NOV 02 search for lepton flavor violating processes $e^+p \to \ell X$, where $\ell=\mu$ or τ with high p_T , in 47.7 pb $^{-1}$ of e^+p collisions at 300 GeV. Such final states may originate from $LQ\overline{D}$ couplings with simultaneously nonzero λ'_{1jk} and λ'_{ijk} (i=2 or 3). The quoted mass bound assumes that only direct squark decays contribute.

The quoted mass bound assumes that only direct squark decays continuous. $378\,\mathrm{BARATE}$ 01B searches for the production of squarks in the case of R prompt decays with LLE indirect or \overline{UDD} direct couplings at \sqrt{s} =189-202 GeV. The limit holds for direct decays mediated by R \overline{UDD} couplings. Limits are also given for LLE indirect decays $(m_{\widetilde{U}_R} > 90\,\mathrm{GeV}$ and $m_{\widetilde{d}_R} > 89\,\mathrm{GeV})$. Supersedes the results from BARATE 00H.

 38 BREITWEG 01 searches for squark production in 47.7 pb $^{-1}$ of $e^+\,p$ collisions, mediated by R couplings $LQ\overline{D}$ and leading to final states with $\widetilde{
u}$ and ≥ 1 jet, complementing the $e^+ X$ final states of BREITWEG 00E. Limits are derived on $\lambda' \sqrt{\beta}$, where β is the

branching fraction of the squarks into $e^+q+\overline{\nu}q$, as function of the squark mass, see their Fig. 15. The quoted mass limit assumes that only direct squark decays contribute. 39 ABBOTT 00c searched in \sim 94 pb $^{-1}$ of $p\overline{p}$ collisions for events with $\mu\mu$ +jets, originating from associated production of leptoquarks. The results can be interpreted as limits on production of squarks followed by direct R decay via $\lambda'_{2jk}L_2Q_jd_k^C$ couplings. Bounds are obtained on the cross section for branching ratios of 1 and of 1/2, see their Fig. 4. The former yields the limit on the \widetilde{u}_L . The latter is combined with the bound of ABBOTT 99J from the $\mu\nu$ +jets channel and of ABBOTT 98E and ABBOTT 98J from the $\nu \nu + {
m jets}$ channel to yield the limit on $\widetilde{\it d}_R$.

 40 ACCIARRI 00P studied the effect on hadronic cross sections of t-channel down-type squark exchange via R-parity violating coupling $\lambda'_{1jk}L_1Q_jd_k^c$. The limit here refers to the

case j=1,2, and holds for $\chi_{1jk}'=0.3$. Data collected at $\sqrt{s}=130-189$ GeV, superseding the results of ACCIARRI 98J.

41 AFFOLDER 00k searched in $\sim 88\,\mathrm{pb}^{-1}$ of $p\overline{p}$ collisions for events with 2–3 jets, at least one being b-tagged, large E_T and no high p_T leptons. Such $\nu\nu+b$ -jets events would originate from associated production of squarks followed by direct E decay via $V_{ij} = V_{ij} $\lambda_{i\,i\,3}^{\prime}L_{i\,Q_{i}}d_{3}^{c}$ couplings. Bounds are obtained on the production cross section assuming zero branching ratio to charged leptons.

42 BARATE 001 studied the effect on hadronic cross sections and charge asymmetries of t-channel down-type squark exchange via R-parity violating coupling $\lambda_{1jk}' L_1 Q_j d_k^{\mathcal{C}}$. The limit here refers to the case j=1,2, and holds for $\chi_{1jk}'=0.3$. A 50 GeV limit is found for up-type squarks with k=3. Data collected at $\sqrt{s}=130-183$ GeV. Superseded by SCHAEL 07A.

43 BREITWEG 00E searches for squark exchange in e^+p collisions, mediated by R couplings $LQ\overline{D}$ and leading to final states with an identified e^+ and ≥ 1 jet. The limit applies to up-type squarks of all generations, and assumes $B(\widetilde{q} \to qe) = 1$. ⁴⁴ ABBOTT 99 searched for $\gamma \not\!\! E_T + \geq 2$ jet final states, and set limits on $\sigma(\rho \, \overline{\rho} \to 0)$ \widetilde{q} +X)·B($\widetilde{q} \to \gamma \not\!\! E_T$ X). The quoted limits correspond to $m_{\widetilde{g}} \geq m_{\widetilde{q}}$, with B($\widetilde{\chi}_2^0 \to$ $\widetilde{\chi}_1^0\gamma)$ = 1 and B ($\widetilde{\chi}_1^0 o\widetilde{G}\gamma$) = 1, respectively. They improve to 310 GeV (360 GeV in the case of $\gamma \widetilde{G}$ decay) for $m_{\widetilde{g}} = m_{\widetilde{q}}$.

 $^{
m 45}\,{\sf ABBOTT}$ 99K uses events with an electron pair and four jets to search for the decay of the $\widetilde{\chi}_1^0$ LSP via R $LQ\overline{D}$ couplings. The particle spectrum and decay branching ratios are taken in the framework of minimal supergravity. An excluded region at 95% CL is obtained in the $(m_0,m_{1/2})$ plane under the assumption that A_0 =0, μ <0, $\tan\beta$ =2 and

any one of the couplings $\lambda_{1jk}^{-}>10^{-3}~(j=1,2~{\rm and}~k=1,2,3)$ and from which the above limit is computed. For equal mass squarks and gluinos, the corresponding limit is 277 GeV. The results are essentially independent of A_0 , but the limit deteriorates rapidly with increasing aneta or $\mu>$ 0.

46 ABBOTT 99L consider events with three or more jets and large E_T . Spectra and decay rates are evaluated in the framework of minimal Supergravity, assuming five flavors of degenerate squarks, and scanning the space of the universal gaugino $(m_{1/2})$ and scalar (m_0) masses. See their Figs. 2–3 for the dependence of the limit on the relative value of $m_{\widetilde{q}}$ and $m_{\widetilde{g}}$.

47 ABE 99M looked in 107 pb $^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with like sign dielectrons and two or more jets from the sequential decays $\widetilde{q} \to q \widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^0 \to e q \overline{q}'$, assuming R coupling $L_1 Q_j D_k^c$, with j=2,3 and k=1,2,3. They assume five degenerate squark flavors, B($\widetilde{q} \to q\widetilde{\chi}_1^0$)=1, B($\widetilde{\chi}_1^0 \to e \, q\overline{q}'$)=0.25 for both e^+ and e^- , and $m_{\widetilde{g}} \geq$ 200 GeV. The limit is obtained for $m_{\widetilde{\chi}_1^0} \ge m_{\widetilde{q}}/2$ and improves for heavier gluinos or

⁴⁸ ABREU 96 looked for events with an electron or neutrino and a jet in e^+e^- at 183 GeV. Squarks (or leptoquarks) could originate from a $LQ\overline{D}$ coupling of an electron with a quark from the fluctuation of a virtual photon. Limits on the couplings λ'_{1jk} as a function of the squark mass are shown in Fig. 4, assuming that only direct squark decays

contribute. 49 ABBOTT 98E searched in $\sim 115 \text{ pb}^{-1}$ of $p\bar{p}$ collisions for events with $e\nu$ +jets, origination. ing from associated production of squarks followed by direct R decay via $\lambda'_{1jk}L_1Q_jd^c_k$ couplings. Bounds are obtained by combining these results with the previous bound of ABBOTT 97B from the ee+jets channel and with a reinterpretation of ABACHI 96B

50 ABE 988 looked in $\sim 110\,\mathrm{pb}^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with $\mu\mu$ +jets originating from associated production of squarks followed by direct R decay via λ'_{2ik} L $_2$ Q $_id_k^c$ couplings. Bounds are obtained on the production cross section times the square of the branching ratio, see Fig. 2. Mass limits result from the comparison with theoretical cross sections and branching ratio equal to 1 for \widetilde{u}_L and 1/2 for \widetilde{d}_R

 51 ACKERSTAFF 98v and ACCIARRI 98J studied the interference of *t*-channel squark (\widetilde{d}_R) exchange via R-parity violating $\lambda_{1jk}' L_1 \, Q_j \, d_k^c$ coupling in $e^+ \, e^- \, o \, q \, \overline{q}$. The limit is for $\lambda'_{1jk}\!=\!0.3.$ See paper for related limits on \tilde{u}_L exchange. Data collected at $\sqrt{s}\!=\!130\text{-}172$ GeV.

52 BREITWEG 98 used positron+jet events with missing energy and momentum to look for $e^+ \, q \to \widetilde{e} \, \widetilde{q}$ via gaugino-like neutralino exchange with decays into $(e \, \widetilde{\chi}_1^0)(q \, \widetilde{\chi}_1^0)$. See paper for dependences in $m_{\widetilde{e}}, m_{\widetilde{\chi}_1^0}$.

⁵³DATTA 97 argues that the squark mass bound by ABACHI 95c can be weakened by 10-20 GeV if one relaxes the assumption of the universal scalar mass at the GUT-scale so that the $\widetilde{\chi}_1^\pm,\widetilde{\chi}_2^0$ in the squark cascade decays have dominant and invisible decays to

DERRICK 97 looked for lepton-number violating final states via R-parity violating couplings $\lambda'_{ijk} L_i \ Q_j d_k$. When $\lambda'_{11k} \lambda'_{ijk} \neq 0$, the process $e \ u \to \overline{d}_k^* \to \ell_i \ u_j$ is possible. When $\lambda'_{1j1} \lambda'_{ijk} \neq 0$, the process $e \ \overline{d} \to \overline{u}_j^* \to \ell_i \ \overline{d}_k$ is possible. 100% branching fraction $\overline{q} \to \ell_j$ is assumed. The limit quoted here corresponds to $\overline{t} \to \tau q$ decay, with $t \to t = 0$.

 λ' =0.3. For different channels, limits are slightly better. See Table 6 in their paper. ⁵⁵ HEWETT 97 reanalyzed the limits on possible resonances in di-jet mode $(\tilde{q} \to q\tilde{g})$ from ALITTI 93 quoted in "Limits for Excited q (q^*) from Single Production," ABE 96 in "SCALE LIMITS for Contact Interactions: $\Lambda(q\,q\,q\,q)$," and unpublished CDF, DØ bounds. The bound applies to the gluino mass of 5 GeV, and improves for lighter gluino. The analysis has gluinos in parton distribution function.

56 TEREKHOV 97 improved the analysis of TEREKHOV 96 by including di-jet angular distributions in the analysis.

⁵⁷ AID 96c used positron+jet events with missing energy and momentum to look for $e^+q \to \widetilde{e}\,\widetilde{q}$ via neutralino exchange with decays into $(e\,\widetilde{\chi}^0_1)(q\,\widetilde{\chi}^0_1)$. See the paper for dependences

 58 TEREKHOV 96 reanalyzed the limits on possible resonances in di-jet mode $(\widetilde{u}\to u\widetilde{g})$ from ABE 95N quoted in "MASS LIMITS for g_A (axigluon)." The bound applies only

to the case with a light gluino. 59 ABACHI 95c assume five degenerate squark flavors with $m_{\widetilde{q}_L} = m_{\widetilde{q}_R}$. Sleptons are assumed to be heavier than squarks. The limits are derived for fixed $\tan\beta = 2.0~\mu = -250$ GeV, and $m_{H^+} = 500$ GeV, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario. The bounds are weakly sensitive to the three fixed parameters for a large fraction of parameter space. No limit is given for $m_{
m gluino}$ >547 GeV.

 60 ABE 95T looked for a cascade decay of five degenerate squarks into $\widetilde{\chi}^0_2$ which further decays into $\widetilde{\chi}_1^0$ and a photon. No signal is observed. Limits vary widely depending on the choice of parameters. For $\mu=-40$ GeV, $\tan\beta=1.5$, and heavy gluinos, the range $50{<}m_{\widetilde{q}}$ (GeV) ${<}110$ is excluded at 90% CL. See the paper for details.

 61 ABE 92L assume five degenerate squark flavors and $m_{\widetilde{q}_L}=m_{\widetilde{q}_R}$. ABE 92L includes the effect of cascade decay, for a particular choice of parameters, $\mu=-250$ GeV, $\tan\beta=2$. Results are weakly sensitive to these parameters over much of parameter space. No limit for $m_{\widetilde{q}} \leq 50$ GeV (but other experiments rule out that region). Limits are 10-20GeV higher if $\mathsf{B}(\widetilde{q} \to q \widetilde{\gamma}) = 1$. Limit assumes GUT relations between gaugino masses

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and the gauge coupling; in particular that for $|\mu|$ not small, $m_{\widetilde{\chi}_1^0} \approx m_{\widetilde{g}}/6$. This last relation implies that as $m_{\widetilde{g}}$ increases, the mass of $\widetilde{\chi}^0_1$ will eventually exceed $m_{\widetilde{q}}$ so that no decay is possible. Even before that occurs, the signal will disappear; in particular no bounds can be obtained for $m_{\widetilde{g}} >$ 410 GeV. $m_{H^+} =$ 500 GeV.

 62 ROY 92 reanalyzed CDF limits on di-lepton events to obtain limits on squark production in R-parity violating models. The 100% decay $\widetilde{q} \to q \widetilde{\chi}$ where $\widetilde{\chi}$ is the LSP, and the LSP decays either into $\ell q \overline{d}$ or $\ell \ell \overline{\epsilon}$ is assumed.

63 NOJIRI 91 argues that a heavy squark should be nearly degenerate with the gluino in minimal supergravity not to overclose the universe.

Long-lived \tilde{q} (Squark) MASS LIMIT

The following are bounds on long-lived scalar quarks, assumed to hadronise into hadrons with lifetime long enough to escape the detector prior to a possible decay. Limits may depend on the mixing angle of mass eigenstates: $\tilde{q}_1 = \tilde{q}_L \cos\theta_a + \tilde{q}_R \sin\theta_a$. The coupling to the ${\it Z}^0$ boson vanishes for up-type squarks when $\theta_u = 0.98$, and for down type squarks when $\theta_d = 1.17$.

| VALUE (GeV) | <u>CL%</u> | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|------------|----------------------|----------|---------|----------------------------------------|
| • • • We do not use the | following | data for average | s, fits, | limits, | etc. • • • |
| >249 | 95 | $^{ m 1}$ aaltonen | 09z | CDF | \tilde{t} |
| > 95 | 95 | ² HEISTER | 03н | ALEP | ũ |
| > 92 | 95 | ² HEISTER | 03н | ALEP | ď |
| none 2-85 | 95 | ³ ABREU | 98P | DLPH | \widetilde{u}_I |
| none 2-81 | 95 | ³ ABREU | 98P | DLPH | \tilde{u}_R |
| none 2-80 | 95 | ³ ABREU | 98P | DLPH | \widetilde{u} , $\theta_{II} = 0.98$ |
| none 2-83 | 95 | ³ ABREU | 98P | DLPH | \tilde{d}_{l} |
| none 5-40 | 95 | ³ ABREU | 98P | DLPH | \tilde{d}_R^{-} |
| none 5-38 | 95 | ³ ABREU | 98P | DLPH | $\tilde{d}, \theta_d = 1.17$ |

 1 AALTONEN 09z searched in 1 fb $^{-1}$ of $^{}p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with direct production of a pair of charged massive stable particles identified by their TOF. No excess of events is observed over the expected background. The data are used to

set a bound on the production cross section, and the result is compared with the pair production cross section of stable stops as a function of the t mass, see their Fig. 2. 2 HEISTER 03H use e^+e^- data at and around the Z^0 peak to look for hadronizing stable squarks. Combining their results on searches for charged and neutral R-hadrons with JANOT 03, a lower limit of 15.7 GeV on the mass is obtained. Combining this further with the centre of the processor of the production of the form of the processor of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the production of the product with the results of searches for tracks with anomalous ionization in data from 183 to 208 GeV yields the quoted bounds.

 3 ABREU 98P assumes that 40% of the squarks will hadronise into a charged hadron, and 60% into a neutral hadron which deposits most of its energy in hadron calorimeter. Data collected at \sqrt{s} =130–183 GeV.

b (Sbottom) MASS LIMIT

Limits in e^+e^- depend on the mixing angle of the mass eigenstate $\tilde{b}_1=\tilde{b}_L\cos\theta_D+$ $\widetilde{b}_R {
m sin} heta_b$. Coupling to the Z vanishes for $heta_b \sim 1.17$. As a consequence, no absolute constraint in the mass region \lesssim 40 GeV is available in the literature at this time from $e^+\,e^-$ collisions. In the Listings below, we use $\Delta m=m_{\widetilde b_1}-m_{\widetilde \chi_1^0}$

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------|---------|------------------------|-------|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| >230 | 95 | $^{ m 1}$ aaltonen | 10R | CDF | $\widetilde{b}_1 ightarrow b \widetilde{\chi}^0_1$, $m_{\widetilde{\chi}^0_1} <$ 70 GeV |
| >247 | 95 | ² ABAZOV | 10L | D0 | $\widetilde{b}_1 ightarrow b \widetilde{\chi}^0_1, m_{\widetilde{\chi}^0_1} = 0 { m GeV}$ |
| >220 | 95 | ³ ABULENCIA | 061 | CDF | $\widetilde{g} \rightarrow \widetilde{b} b$, $\Delta m >$ 6 GeV, $\widetilde{b}_1 \rightarrow$ |
| | | | | | $b\widetilde{\chi}_1^0,m_{\widetilde{arphi}}<$ 270 GeV |
| > 95 | | ⁴ ACHARD | 04 | L3 | $\tilde{b} \rightarrow b \tilde{\chi}_1^0, \theta_b = 0, \Delta m > 15-25 \text{ GeV}$ |
| > 81 | | ⁴ ACHARD | 04 | L3 | $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0$, all θ_b , $\Delta m > 15-25$ GeV |
| > 7.5 | 95 | ⁵ JANOT | 04 | THEO | unstable $\hat{ar{b}}_1$, $e^+e^- ightarrow$ hadrons |
| > 93 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\widetilde{b} \rightarrow b\widetilde{\chi}^{0}$, $\theta_{b}=0$, $\Delta m > 7$ GeV |
| > 76 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\widetilde{b} \rightarrow b\widetilde{\chi}^0$, all θ_b , $\Delta m > 7$ GeV |
| > 85.1 | 95 | ⁷ ABBIENDI | 02н | OPA L | $\widetilde{b} ightarrow b\widetilde{\chi}^0_1$, all θ_b , $\Delta m > 10$ GeV, |
| > 89 | 95 | 8 HEISTER | 02к | ALEP | $\widetilde{b} \to b \widetilde{\chi}_1^0, \text{ all } \theta_b, \ \Delta m > 8 \text{ GeV},$ |
| none 3.5-4.5 | 95 | 9 SAVINOV | 01 | CLEO | CDF B meson |
| none 80-145 | | ¹⁰ AFFOLDER | 00D | CDF | $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0}$ <50 GeV |
| • • • We do | not use | e the following data | for a | verages, | fits, limits, etc. • • • |
| >294 | 95 | ¹¹ AAD | 11ĸ | ATLS | stable $\widetilde{\it b}$ |
| | | ¹² AAD | 110 | ATLS | $\widetilde{g} \rightarrow \widetilde{b}_1 b$, $\widetilde{b}_1 \rightarrow b \widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0} = 60$ |
| | | 13 CHATRCHYAN | V11D | CMS | $\begin{array}{c} \operatorname{GeV} \\ \widetilde{b}, \widetilde{t} \to b \\ \widetilde{g} \to b \widetilde{b}, \widetilde{b} \to b \widetilde{\chi}_1^0 \end{array}$ |
| | | ¹⁴ AALTONEN | 09R | CDF | $\widetilde{g} \rightarrow b\widetilde{b}, \widetilde{b} \rightarrow b\widetilde{\chi}_1^0$ |
| >193 | 95 | ¹⁵ AALTONEN | 07E | CDF | $\widetilde{b}_1 \rightarrow b \widetilde{\chi}_1^0, m_{\widetilde{\chi}_1^0} = 40 \text{ GeV}$ |
| none 35-222 | 95 | ¹⁶ ABAZOV | 06R | D0 | $\widetilde{b} \rightarrow b\widetilde{\chi}_1^0, m_{\widetilde{\chi}_1^0} = 50 \text{ GeV}$ |
| > 78 | 95 | ¹⁷ ABDALLAH | 04м | DLPH | R, \tilde{b}_L , indirect, $\Delta m > 5$ GeV |
| none 50-82 | 95 | ¹⁸ ABDALLAH | 03c | DLPH | $\widetilde{b} \rightarrow b\widetilde{g}$, stable \widetilde{g} , all θ_b , |
| | | ¹⁹ BERGER | 03 | THEO | $\Delta m > 10 \text{ GeV}^{-}$ |
| > 71.5 | 95 | 20 HEISTER | 03G | ALEP | \widetilde{b}_I , \mathbb{R} decay |
| > 27.4 | 95 | ²¹ HEISTER | 03н | ALEP | $\widetilde{b} \to b\widetilde{g}$, stable \widetilde{g} or \widetilde{b} |

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<sup>22</sup> ACHARD
                                                                                                                \dot{\it b}_1 , R decays
                                            ^{23}\,\mathrm{BAEK}
                                                                                              THEO
                                            <sup>24</sup> BECHER
                                                                                                THEO
                                             <sup>25</sup> CHEUNG
                                                                                    02B THEO
                                             <sup>26</sup> CHO
                                                                                    02
                                                                                              THEO
                                            <sup>27</sup> BERGER
                                                                                              \begin{array}{ccc} {\sf THEO} & p\overline{p} \, \to \, {\sf X} + b\text{-quark} \\ {\sf D0} & \widetilde{b} \, \to \, b \, \widetilde{\chi}_1^0, \, m_{\widetilde{\chi}_1^0} < \!\! 20 \; {\sf GeV} \end{array}
                                                                                    01
                                             <sup>28</sup> ABBOTT
none 52-115 95
                                                                                    99F D0
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 1 AALTONEN 10R searched in 2.65 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with \cancel{E}_T and exactly two jets, at least one of which is b-tagged. The results are in agreement with the SM prediction, and a limit on the cross section of 0.1 pb is obtained for the range of masses 80 $< m_{\widetilde{b}_1} <$ 280 GeV assuming that the sbottom decays exclusively to

 $b\widetilde{\chi}^0_1$. The excluded mass region in the framework of conserved R_p is shown in a plane of $(m_{\widetilde{b}_1}, m_{\widetilde{\chi}_1^0})$, see their Fig. 2.

 2 ABAZOV 10L looked in 5.2 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with ABACOV lot looked in \mathcal{D}_T from the production of $\widetilde{\mathcal{D}_1}$ $\widetilde{\mathcal{D}}_1$. No evidence for an excess over the SM expectation is observed, and a limit on the cross section is derived under the assumption of 100% branching ratio. The excluded mass region in the framework of conserved R_p is shown in a plane of $(m_{\widetilde{\mathcal{D}}_1}, m_{\widetilde{\chi}_1^0})$, see their Fig. 3b. The exclusion also extends to $m_{\widetilde{\chi}_1^0} = 110$ GeV for $160 < m_{\widetilde{\mathcal{D}}_1} < 200$ GeV.

 3 ABULENCIA 06i searched in 156 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for multijet events with large $\not\!\!E_T$. They request at least 2 b-tagged jets and no isolated leptons. They investigate the production of gluinos decaying into \tilde{b}_1 b followed by $\tilde{b}_1 \to b \tilde{\chi}_1^0$ Both branching fractions are assumed to be 100% and the LSP mass to be 60 GeV. No significant excess was found compared to the background expectation. Upper limits on the cross-section are extracted and a limit is derived on the masses of sbottom and

gluinos, see their Fig.3. 4 ACHARD 04 search for the production of $\widetilde{b}\widetilde{b}$ in acoplanar b-tagged di-jet final states in the 192–209 GeV data. See Fig. 6 for the dependence of the limits on $m_{\widetilde{\chi}0}$. This limit

supersedes ACCIARRI 99v.

 5 JA NOT 04 reanalyzes $e^{+}\,e^{-} \rightarrow \,$ hadrons total cross section data with $\sqrt{s}=$ 20–209 GeV from PEP, PETRA, TRISTAN, SLC, and LEP and constrains the mass of \widetilde{b}_1 assuming it decays quickly to hadrons.

⁶ ABDALLAH 03M looked for \tilde{b} pair production in events with acoplanar jets and E at \sqrt{s} = 189–208 GeV. The limit improves to 87 (98) GeV for all θ_b (θ_b = 0) for $\Delta m > 10$ GeV. See Fig. 24 and Table 11 for other choices of Δm . These limits include and update the results of ABREU, P 000.

The results of ABREU, P volu. TABREU, P volu. TABREUN, P volu. TABREUN, P volu. TABREUN 02H search for events with two acoplanar jets and ψ_T in the 161–209 GeV data. The limit assumes 100% branching ratio and uses the exclusion at large Δm from CDF (AFFOLDER 00D). For $\theta_D = 0$, the bound improves to > 96.9 GeV. See Fig. 4 and Table 6 for the more general dependence on the limits on Δm . These results supersede ABBIENDI 99M.

HEISTER 02k search for bottom squarks in final states with acoplanar jets with b tagging, using 183–209 GeV data. The mass bound uses the CDF results from AFFOLDER 00D. See Fig. 5 for the more general dependence of the limits on Δm . Updates BARATE 01.

9 SAVINOV 01 use data taken at \sqrt{s} =10.52 GeV, below the $B\overline{B}$ threshold. They look for events with a pair of leptons with opposite charge and a fully reconstructed hadronic Dor D^* decay. These could originate from production of a light-sbottom hadron followed by $\widetilde{B} \to D^{(*)} \ell^- \widetilde{\nu}$, in case the $\widetilde{\nu}$ is the LSP, or $\widetilde{B} \to D^{(*)} \pi \ell^-$, in case of R. The mass range $3.5 \le M(\bar{B}) \le 4.5$ GeV was explored, assuming 100% branching ratio reither of the decays. In the $\bar{\nu}$ LSP scenario, the limit holds only for $M(\bar{\nu})$ less than about $1~{\rm GeV}$ and for the D^* decays it is reduced to the range 3.9–4.5 GeV. For the $R\!\!\!/$ decay, the whole range is excluded.

 10 AFFOLDER 00 D search for final states with 2 or 3 jets and $ot\!\!E_T$, one jet with a b tag. See their Fig. 3 for the mass exclusion in the $m_{\widetilde{t}}, \, m_{\widetilde{\chi}_1^0}^+$ plane.

 11 AAD 11K looked in 34 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the tile calorimeter, from pair production of \widetilde{b} . No evidence for an excess over the SM expectation is observed and limits on the mass are derived for pair production of sbottom,

see Fig. 4. $^{12}\text{AAD 110 looked in 35 pb}^{-1} \text{ of } pp \text{ collisions at } \sqrt{s} = 7 \text{ TeV for events with jets, of which at least one is a } b\text{-jet, and } \cancel{E_T}. \text{ No excess above the Standard Model was found. Limits are derived in the } (m_{\widetilde{g}}, m_{\widetilde{b}_1}) \text{ plane (see Fig. 2) under the assumption of 100% }$

branching ratios and \widetilde{b}_1 being the lightest squark. The quoted limit is valid for $m_{\widetilde{b}_1}$

500 GeV. A similar approach for \widetilde{t}_1 as the lightest squark with $\widetilde{g} \to \widetilde{t}_1 t$ and $\widetilde{t}_1 \to b \widetilde{\chi}_1^\pm$ with 100% branching ratios leads to a gluino mass limit of 520 GeV for 130 $< m_{\widetilde{t}_1} < 1$ 300 GeV. Limits are also derived in the CMSSM (m_0 , $m_{1/2}$) plane for an eta = 40, see

Fig. 4, and in scenarios based on the gauge group SO(1). ^{17/2} CHATRCHYAN 11D looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with \geq 2 jets, at least one of which is b-tagged, and $ot\!\!E_T$, where the b-jets are decay products of \tilde{t} or \tilde{b} . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_{1/2})$ plane for $\tan\beta=50$ (see Fig. 2).

¹⁴ AALTONEN 09R searched in 2.5 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 b-tagged jets and $ot\!\!E_T$, originating from the decay $\widetilde{g} \to b\widetilde{b}$ followed by $\widetilde{b} \to b\widetilde{b}$ $b\,\widetilde{\chi}_1^0$. Both decays are assumed to have 100% branching ratio. No significant deviation from the SM prediction is observed. An upper limit on the gluino pair production cross section is calculated as a function of the gluino mass, see their Fig. 2. A limit is derived in the $m_{\widetilde{b}}$ versus $m_{\widetilde{g}}$ plane which improves the results of previous searches, see their

15 15 AALTONEN 07E searched in 295 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for multijet events with large \cancel{E}_T . They request at least one heavy flavor-tagged jet and no identified leptons. The branching ratio $\vec{b}_1 \to b \, \widetilde{\chi}_1^0$ is assumed to be 100%. No significant excess was found compared to the background expectation. Upper limits on the cross-section are extracted and a limit is derived on the masses of sbottom versus $\tilde{\chi}^0_1$, see their Fig. 5. Superseded by AALTONEN 10R.

- 16 ABAZOV 06R looked in $310~{\rm pb}^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with 2 or 3 jets and large E_T with at least 1 b-tagged jet and a veto against isolated leptons. No excess is observed relative to the SM background expectations. Limits are set on the sbottom pair production cross-section under the assumption that the only decay mode is into $b\,\widetilde{\chi}_1^0$. Exclusion contours are derived in the plane of sbottom versus neutralino masses, shown in their Fig. 2. The observed limit is more constraining than the expected one due to a lack of events corresponding to large sbottom masses. Superseded by _ABAZOV 10L.
- ABAZOV 101. 17 ABDALLAH 04M use data from $\sqrt{s}=192-208$ GeV to derive limits on sparticle masses under the assumption of R with \overline{UDD} couplings. The results are valid for $\mu=-200$ GeV, $\tan\beta=1.5$, $\Delta m > 5$ GeV and assuming a BR of 1 for the given decay. The limit quoted is for indirect \overline{UDD} decays using the neutralino constraint of 38.0 GeV, also derived in ABDALLAH 04M, and assumes no mixing. For indirect decays it remains at 78 GeV when the neutralino constraint is not used. Supersedes the result of ABREU 01D. 18 ABDALLAH 03C looked for events of the type $q \overline{q} R^2 + R^2$, $q \overline{q} R^2 R^0$ or e^+e^- interactions at $\sqrt{s}=189-208$ GeV. The R^\pm bound states are identified by anomalous dF/dx in the tracking chambers and the R^0 by missing energy due to their
- 18 ABDALLAH 03c looked for events of the type $q\overline{q}\,R^{\pm}\,R^{\pm}$, $q\overline{q}\,R^{\pm}\,R^{0}$, or $q\overline{q}\,R^{0}\,R^{0}$ in $e^{+}\,e^{-}$ interactions at $\sqrt{s}=189-208$ GeV. The R^{\pm} bound states are identified by anomalous dE/dx in the tracking chambers and the R^{0} by missing energy due to their reduced energy loss in the calorimeters. Excluded mass regions in the $(m(\bar{b}),\,m(\bar{g}))$ plane for $m(\bar{g})>2$ GeV are obtained for several values of the probability for the gluino to fragment into R^{\pm} or R^{0} , as shown in their Fig. 19. The limit improves to 94 GeV for $\theta_{h=0}$.
- 19 BERGER 03 studies the constraints on a \widetilde{b}_1 with mass in the 2.2–5.5 GeV region coming from radiative decays of $\Upsilon({\rm nS})$ into sbottomonium. The constraints apply only if \widetilde{b}_1 lives long enough to permit formation of the sbottomonium bound state. A small region of mass in the $m_{\widetilde{b}_1}-m_{\widetilde{g}}$ plane survives current experimental constraints from CLEO.
- 20 HEISTER 03G searches for the production of \widetilde{b} pairs in the case of R prompt decays with $LL\overline{E}, LQ\overline{D}$ or \overline{UDD} couplings at $\sqrt{s}=189$ –209 GeV. The limit holds for indirect decays mediated by R \overline{UDD} couplings. It improves to 90 GeV for indirect decays mediated by R $LL\overline{E}$ couplings and to 80 GeV for indirect decays mediated by R $LL\overline{E}$ couplings and to 80 GeV for indirect decays mediated by R $LQ\overline{D}$ couplings. Supersedes the results from BARATE 01B.
- 21 HEISTER 03H use their results on bounds on stable squarks, on stable gluinos and on squarks decaying to a stable gluino from the same paper to derive a mass limit on $\overline{b},$ see their Fig. 13. The limit for a long-lived \overline{b}_1 is 92 GeV.
- The limit of a long-model of 1992 across of \$\mathbb{R}\$ prompt decays with \$\frac{UDD}{UDD}\$ couplings at \$\sqrt{\$}\$=189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit is computed for the minimal cross section and holds for indirect decays and reaches 55 GeV for direct decays.
- 23 BAEK 02 studies the constraints on a \tilde{b}_1 with mass in the 2.2–5.5 GeV region coming from precision measurements of Z^0 decays. It is noted that CP-violating couplings in the MSSM parameters relax the strong constraints otherwised derived from CP conservation.
- ²⁴ BECHER 02 studies the constraints on a \widetilde{b}_1 with mass in the 2.2–5.5 GeV region coming from radiative B meson decays, and sets limits on the off-diagonal flavor-changing couplings $q\widetilde{b}\widetilde{g}$ (q=d,s).
- 25 CHEUNG 02B studies the constraints on a \tilde{b}_1 with mass in the 2.2–5.5 GeV region and a gluino in the mass range 12–16 GeV, using precision measurements of Z^0 decays and $e^+\,e^-$ annihilations at LEP2. Few detectable events are predicted in the LEP2 data for the model proposed by BERGER 01.
- 26 CHO 02 studies the constraints on a \widetilde{b}_1 with mass in the 2.2–5.5 GeV region coming from precision measurements of Z^0 decays. Strong constraints are obtained for $\it CP$ -conserving MSSM couplings.
- 27 BERGER of reanalyzed interpretation of Tevatron data on bottom-quark production. Argues that pair production of light gluinos ($m\sim 12\text{--}16$ GeV) with subsequent 2-body decay into a light sbottom ($m\sim 2\text{--}5.5$ GeV) and bottom can reconcile Tevatron data with predictions of perturbative QCD for the bottom production rate. The sbottom must either decay hadronically via a R--pairly-- and B--violating interaction, or be long-lived. Constraints on the mass spectrum are derived from the measurements of time-averaged $B^0\text{--}\overline{B}^0$ mixing.
- 28 ABBOTT 99F looked for events with two jets, with or without an associated muon from b decay, and $\cancel{E}_{\mathcal{T}^-}$ See Fig. 2 for the dependence of the limit on $m_{\widetilde{\chi}_1^0}$. No limit for $m_{\widetilde{\chi}_1^0} >$ 47 GeV. Superseded by ABAZOV 06R.

\widetilde{t} (Stop) MASS LIMIT

Limits depend on the decay mode. In e^+e^- collisions they also depend on the mixing angle of the mass eigenstate $\tilde{t}_1=\tilde{t}_L\cos\theta_t+\tilde{t}_R\sin\theta_t$. The coupling to the Z vanishes when $\theta_t=$ 0.98. In the Listings below, we use $\Delta m\equiv m_{\tilde{t}_1}-m_{\widetilde{\chi}_1^0}$ or $\Delta m\equiv m_{\widetilde{t}_1}-m_{\widetilde{\nu}}$, depending on relevant decay mode. See also bounds in " \tilde{q} (Squark)

MASS LIMIT." Limits made obsolete by the most recent analyses of e^+e^- and $p\overline{p}$ collisions can be found in previous Editions of this *Review*.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT | |
|-------------|-----|-----------------------|------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|---|
| >210 | 95 | ¹ ABAZOV | 11 N | D0 | $\widetilde{t}_1 \rightarrow b\ell \widetilde{\nu}, m_{\widetilde{\nu}} < 110 \mathrm{GeV}, \ m_{\widetilde{t}_1} - m_{\widetilde{\nu}} > 30 \mathrm{GeV}$ | l |
| none 60-180 | 95 | ² AALTONEN | | CDF | $\widetilde{t}_1 \rightarrow b\ell\widetilde{\nu}, m_{\widetilde{\nu}} = 45 \text{ GeV}$ | I |
| none 95-150 | 95 | ³ ABAZOV | 08 Z | D0 | $\widetilde{t} \rightarrow c \widetilde{\chi}_{1}^{0},$ $m_{C} < \Delta m < m_{W} + m_{h}$ | |
| none 80-120 | 95 | ⁴ ABAZOV | 04 | D0 | $\tilde{t} \rightarrow b\ell\nu\tilde{\chi}^0, m_{\tilde{\chi}^0} = 50 \text{ GeV}$ | |
| > 90 | | ⁵ ACHARD | 04 | L3 | $\widetilde{t} ightarrow c \widetilde{\chi}_1^0$, all θ_t , $\Delta m >$ | |
| > 93 | | ⁵ ACHARD | 04 | L3 | $15-25 \text{ GeV}$ $\widetilde{b} \rightarrow b\ell \widetilde{\nu}, \text{ all } \theta_t,$ $\Delta m > 15 \text{ GeV}$ | |
| > 88 | | ⁵ ACHARD | 04 | L3 | $\widetilde{b} \rightarrow b\tau \widetilde{\nu}$, all $\theta_{+}, \Delta m > 15 \text{ GeV}$ | |
| > 75 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\tilde{t} \to c \tilde{\chi}^0, \theta_t = 0,$ | |
| > 71 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\Delta m > 2$ GeV $\widetilde{t} \rightarrow c \widetilde{\chi}^0$, all $\theta_{\widetilde{t}}$, $\Delta m > 2$ GeV | |
| | | | | | | |

| > 96 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\tilde{t} \rightarrow c \tilde{\chi}_{0}^{0}, \theta_{t} = 0, \Delta m > 10 \text{ GeV}$ |
|---------------------|-----------|--------------------------|-------|------------|------------------------------------------------------------------------------------------------------------------------------------|
| > 92 | 95 | ⁶ ABDALLAH | 03м | DLPH | $\tilde{t} \rightarrow c \tilde{\chi}^0$, all θ_t , $\Delta m > 10 \text{ GeV}$ |
| > 95.7 | 95 | ⁷ ABBIENDI | 02н | OPAL | $c \widetilde{\chi}_1^0$, all θ_t , $\Delta m > 10 \text{ GeV}$ |
| > 92.6 | 95 | ⁷ ABBIENDI | 02н | OPAL | $b\ell\widetilde{\nu}$, all θ_t , $\Delta m > 10 \text{ GeV}$ |
| > 91.5 | 95 | ⁷ ABBIENDI | 02н | OPAL | $b \tau \widetilde{\nu}$, all θ_t , $\Delta m > 10 \text{ GeV}$ |
| > 63 | 95 | ⁸ HEISTER | 02K | | any decay, any lifetime, all θ_t |
| > 92 | 95 | 8 HEISTER | | ALEP | $\widetilde{t} \rightarrow c \widetilde{\chi}_1^0$, all θ_t , $\Delta m > 8$ |
| • | | | | | GeV, CDF |
| > 97 | 95 | ⁸ HEISTER | 02K | ALEP | $\widetilde{t} ightarrow b \ell \widetilde{ u}$, all $	heta_{\widetilde{t}}$, $\Delta m >$ 8 |
| | | 8 | | | GeV, DØ |
| > 78 | 95 | ⁸ HEISTER | 02K | ALEP | $\widetilde{t} \rightarrow b\widetilde{\chi}_1^0 W^*$, all θ_t , $\Delta m > 8$ |
| • • • We do no | t use the | e following data for a | verag | es. fits. | |
| >309 | 95 | 9 AAD | _ | ATLS | stable \widetilde{t} |
| >202 | 95 | ¹⁰ KHACHATRY. | | CMS | ~ |
| | 95 | 11 AALTONEN | | | stable t_1 |
| none 128-135 | 95 | AALTONEN | 100 | CDF | $\widetilde{t}_1 \rightarrow b\widetilde{\chi}_1^{\pm} \rightarrow b\ell\widetilde{\chi}_1^0 \nu$, $m_{\widetilde{\chi}_1^{\pm}}$ |
| | | | | | $=106$ GeV, $m_{\widetilde{\chi}_1^0}=48$ GeV |
| | | ¹² ABAZOV | 09 N | D0 | $\tilde{t} \rightarrow b \tilde{\chi}_1^{\pm}$ |
| | | 13 ABAZOV | 090 | D0 | $\widetilde{t} \rightarrow b\chi_{1}$ $\widetilde{t} \rightarrow b\ell\widetilde{\nu}$ |
| >153 | 95 | 14 AALTONEN | 08Z | CDF | |
| >185 | 95 | 15 ABAZOV | 082 | D0 | \vec{t} , $t_1 \rightarrow b\tau$ $\vec{t} \rightarrow b\ell \widetilde{\nu}$, $m_{\widetilde{\nu}} = 70 \text{ GeV}$ |
| >132 | ,,, | 16 AALTONEN | 07E | CDF | $\tilde{t} \rightarrow b \epsilon \nu, m_{\tilde{\nu}} = r \sigma G \epsilon \nu$ |
| >132 | | | 076 | CDF | $\widetilde{t}_1 \rightarrow c \widetilde{\chi}_1^0, m_{\widetilde{\chi}_1^0} = 48 \text{ GeV}$ |
| none 80-134 | 95 | ¹⁷ ABAZOV | 07в | D0 | $\widetilde{t} ightarrow c \widetilde{\chi}_1^0, m_{\widetilde{\chi}_1^0} < 48 \mathrm{GeV}$ |
| | | 18 CHEKANOV | 07 | ZEUS | $e^+ p \rightarrow \widetilde{t}_1, R, LQ\overline{D}$ |
| > 77 | 95 | ¹⁹ ABBIENDI | 04 F | OPAL | R , direct, all θ_t |
| > 77 | 95 | ²⁰ ABDALLAH | 04 M | DLPH | R , indirect, all θ_t , $\Delta m > 5$ GeV |
| | | ²¹ AKTAS | 04B | 111 | $\Delta m > 5 \text{ GeV}$ |
| > 74.5 | | ²² DAS | 04B | H1 THEO | R, t_1 |
| > 74.5 | | DAS | 04 | THEO | $\widetilde{t}\widetilde{t} \rightarrow b\ell\nu_{\ell}\chi^{0}\overline{b}q\overline{q}'\chi^{0}, m_{\chi_{1}^{0}}$ |
| | | 22 | | | $_{\sim}$ = 15 GeV, no $\overline{t} ightarrow c \chi^0$ |
| none 50-87 | 95 | ²³ ABDALLAH | 03c | DLPH | $\widetilde{t} ightarrow c\widetilde{g}$, stable \widetilde{g} , all $	heta_t$, $\Delta M > 10 \; { m GeV}$ |
| none 80-131 | 95 | ²⁴ ACOSTA | 03 c | CDF | $\widetilde{t} \to b\ell\widetilde{\nu}, m_{\widetilde{\nu}} \le 63 \text{ GeV}$ |
| | | 25 CHAKRAB | 03 | THEO | $p\overline{p} \rightarrow \widetilde{t}\widetilde{t}^*, RPV$ |
| > 71.5 | 95 | ²⁶ HEISTER | 03 G | ALEP | \widetilde{t}_L , \mathcal{R} decay |
| > 80 | 95 | ²⁷ HEISTER | 03н | ALEP | $\widetilde{t} \rightarrow c\widetilde{g}$, stable \widetilde{g} or \widetilde{t} , all θ_t , |
| | | | | | _∼ all ΔM |
| >144 | 95 | 28 ABAZOV | 02c | D0 | $t \to b\ell \widetilde{\nu}, m_{\widetilde{\nu}} = 45 \text{ GeV}$ |
| > 77 | 95 | ²⁹ ACHARD | 02 | L3 | \widetilde{t}_1 , \mathcal{R} decays |
| | | ³⁰ AFFOLDER | 01 B | CDF | $t \to \tilde{t} \chi_1^0$ |
| > 61 | 95 | ³¹ ABREU | 001 | DLPH | $R(LL\overline{E}), \theta_t=0.98, \Delta m>4$ |
| none 68-119 | 95 | ³² AFFOLDER | 00D | CDF | $\widetilde{t} \to c \widetilde{\chi}_1^0$, $m_{\widetilde{\chi}_1^0}$ <40 GeV |
| none 84-120 | 95 | 33 AFFOLDER | 00 G | CDF | τ χ ₁ τ σε σεν |
| | 95 | 34 ABE | 99M | | $t_1 \rightarrow b\ell \widetilde{\nu}, m_{\widetilde{\nu}} < 45 \text{ GeV}$ |
| >120 none 9-24.4 | 95 95 | 35 AID | 96 | H1 | $p\overline{p} \to t_1 t_1, R$ |
| >138 | 95 95 | 36 AID | 96 | H1 | $e p \rightarrow \widetilde{t} t$, R decays $e p \rightarrow \widetilde{t}$, R , $\lambda \cos \theta_t > 0.03$ |
| > 45 | 90 | 37 CHO | 96 | RVUE | $B^0 - \overline{B}^0$ and ϵ , $\theta_t = 0.98$, |
| / 10 | | | ,,, | N. V.O.L. | $\tan \beta < 2$ |
| none 11-41 | 95 | ³⁸ BUSKULIC | 95 E | ALEP | $\Re (LL\overline{E}), \theta_t = 0.98$ |
| none 6.0-41.2 | 95 | AKERS | 94 K | OPAL | $\tilde{t} \rightarrow c \tilde{\chi}_1^0, \theta_t = 0, \Delta m > 2$ |
| | OΓ | AKEDO | 0.41: | ODA | GeV * |
| none 5.0-46.0 | 95 | AKERS | 94 K | OPAL | $\widetilde{t} \to c \widetilde{\chi}_1^0, \ \theta_t = 0, \ \Delta m > 5$ |

 1 ABAZOV 11N looked in 5.4 fb $^{-1}$ of $p\overline{\rho}$ collisions at $\sqrt{s}=1.96$ TeV for events with exactly one e and μ and $\not\!\!E_T$ from the production of $\overline{t}_1\,\overline{t}_1$. No evidence for an excess over the SM expectation is observed, and a limit is derived in a plane of $(m_{\widetilde{t}_1}$, $m_{\widetilde{\nu}})$, see

94

94 κ OPAL \tilde{t}

VNS

GeV

 GeV

GeV

GeV

none 11.2-25.5

none 7.9-41.2

none 7.6-28.0

none 10-20

95

AKERS

AKERS

39 SHIRAI

39 SHIRAL

 $c \widetilde{\chi}_{1}^{0}$, $\theta_{t} = 0.98$, $\Delta m > 2$

 $c \, \widetilde{\chi}_1^0$, $\theta_t = 0.98$, $\Delta m > 5$

 \rightarrow $c\,\widetilde{\chi}_1^0$, any $heta_t$, $\Delta m > 10$

 $\widetilde{t} \rightarrow c \widetilde{\chi}_1^0$, any θ_t , $\Delta m > 2.5$

- their Fig. 4, under the assumption of 100% branching ratio for $\tilde{t}_1 \to b\ell\bar{\nu}$. 2 AALTONEN 107 searched in 1 fb $^-1$ of $\rho\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with an oppositely charged lepton pair (e or μ), E_T and at least one jet. A limit is derived on the cross section assuming 100% branching ratio of $\tilde{t}_1 \to b\ell\bar{\nu}$ and an invisible $\bar{\nu}$, see their Fig. 10. In Fig. 11, the exclusion contour is shown in the plane of $(m_{\tilde{t}_1}, m_{\tilde{\nu}})$.
- 3 ABAZOV 082 looked in 995 pb $^{-1}$ of $\rho\overline{\rho}$ collisions at $\sqrt{s}=1.96$ TeV for events with exactly 2 jets, at least one being tagged as heavy quark, and \cancel{E}_T , originating from stop pair production. Branching ratios are assumed to be 100% for $\overline{t}_1 \rightarrow c\, \overline{\chi}_1^0$. No evidence for an excess over the SM expectation is observed. The excluded region is shown in a plane of $m_{\overline{t}}$ versus $m_{\overline{\chi}_1^0}$, see their Fig. 5. No limit can be obtained for $m_{\overline{\chi}_1^0} > 70$ GeV. Superseds the results of ABAZOV 078
- Supersedes the results of ABAZOV 07B. ${}^4\text{ABAZOV 04 looked at } 108.3pb^{-1} \text{ of } p\overline{p} \text{ collisions at } \sqrt{s} = 1.8 \text{ TeV for events with } e + \mu + E_T \text{ as signature for the } 3- \text{ and } 4\text{-body decays of stop into } b\ell\nu\overline{\chi}^0 \text{ final states.}$ For the $b\ell\overline{\nu}$ channel they use the results from ABAZOV 02c. No significant excess is observed compared to the Standard Model expectation and limits are derived on the mass of \overline{t}_1 for the 3- and 4-body decays in the $(m_{\widetilde{t}}, m_{\overline{\chi}^0})$ plane, see their Figure 4.
- 5 ACHARD 04 search in the 192–209 GeV data for the production of $\widetilde{t}t$ in acoplanar di-jet final states and, in case of $b\ell\widetilde{\nu}$ ($b\tau\widetilde{\nu}$) final states, two leptons (taus). The limits for $\theta_t=$ 0 improve to 95, 96 and 93 GeV, respectively. All limits assume 100% branching ratio

Supersymmetric Particle Searches

for the respective decay modes. See Fig. 6 for the dependence of the limits on $m_{\widetilde{\chi}^0_+}$ These limits supersede ACCIARRI 99v.

⁶ ABDALLAH 03M looked for t pair production in events with acoplanar jets and E at \sqrt{s} = 189–208 GeV. See Fig. 23 and Table 11 for other choices of Δm . These limits include and update the results of ABREU,P 00D.

 7 ABBIENDI 02H looked for events with two acoplanar jets, p_T , and, in the case of $b\ell ilde{
u}$ final states, two leptons, in the 161–209 GeV data. The bound for $c\widetilde{\chi}^0_1$ applies to the region where $\Delta m < m_W + m_b$, else the decay $\tilde{t}_1 \to b \tilde{\chi}_1^0 W^+$ becomes dominant. The limit for $b \ell \tilde{\nu}$ assumes equal branching ratios for the three lepton flavors and for $b \tau \tilde{\nu}$ 100% for this channel. For θ_t =0, the bounds improve to > 97.6 GeV ($c\,\widetilde{\chi}_1^0$), > 96.0 GeV $(b\ell \overline{\nu})$, and > 95.5 $(b\tau \overline{\nu})$. See Figs. 5–6 and Table 5 for the more general dependence of the limits on Δm . These results supersede ABBIENDI 99M.

⁸ HEISTER 02K search for top squarks in final states with jets (with/without b tagging or leptons) or long-lived hadrons, using 183–209 GeV data. The absolute mass bound is obtained by varying the branching ratio of $\tilde{t} \to c \, \widetilde{\chi}_1^0$ and the lepton fraction in $\tilde{t} \to b \, \widetilde{\chi}_1^0 \, f \, \overline{f}'$ decays. The mass bound for $\widetilde{t} o c \widetilde{\chi}_1^0$ uses the CDF results from AFFOLDER 00D and

for $\widetilde{t} \rightarrow b\ell\widetilde{\nu}$ the DØ results from ABAZOV 02c. See Figs. 2–5 for the more general dependence of the limits on Δm . Updates BARATE 01 and BARATE 00P 9AAD 11k looked in 34 pb⁻¹ of pp collisions at $\sqrt{s}=7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the tile calorimeter, from pair production of \widetilde{t} . No evidence for an excess over the SM expectation is observed and limits on the mass are derived for pair production of stop, see Fig. 4.

 10 KHACHATRYAN 11c looked in 3.1 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the muon chambers, from pair production of \tilde{t}_1 . No evidence for an excess over the expected background is observed. Limits are derived for pair production of stop as a function of mass, see Fig. 3, and compared to the production cross section in a benchmark scenario.

to the $\widetilde{t}_1\,\widetilde{t}_1$ hypothesis. Assuming a 100% branching ratio of $\widetilde{t}_1 o b\widetilde{\chi}_1^\pm$, the exclusion

is independent of the value of the $\widetilde{\chi}_1^\pm \to \ \ell \widetilde{\chi}_1^0 \, \nu$ branching ratio.

- 12 ABAZOV 09N looked in 0.9 fb $^{-1}$ of $\rho \overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with ≥ 3 jets, at least one being b-tagged, one electron or muon and $\not\!\!E_T$ originating from associated production $\widetilde{t}\widetilde{t}$, with one \widetilde{t} decaying leptonically, the other hadronically. The branching ratios for $\bar{t}_1 \to b\bar{\chi}_1^\pm$ and $\bar{\chi}_1^\pm \to \bar{\chi}_1^0$ W^\pm are assumed to be 100%. The separation from the dominant $t\bar{t}$ background is based on a multivariate likelihood discriminant analysis. The tested mass range is 130 GeV $\leq m_{\bar{t}} \leq 190$ GeV, 90 GeV $\leq m_{\bar{\chi}_1^\pm} \leq 150$ GeV and $m_{\bar{\chi}_1^0} = 50$ GeV fixed. The excluded cross section is a factor 2-13 larger than the theoretical expectation in the considered MSSM scenarios, see their
- 13 ABAZOV 090 looked in 1 fb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with two electrons or one electron and one muon and $\not\!\!\!E_T$ originating from associated production $t\overline{t}$, followed by the three-body decays $\overline{t}\to b\ell\overline{\nu}$. No evidence for an excess over the SM expectation is observed. The excluded region is shown in a plane of $m_{\widetilde{\nu}}$ versus $m_{\widetilde{\tau}}$, see
- expectation is observed. The excluded \widetilde{t} mass is 175 GeV for a $\widetilde{\nu}$ mass of 45 GeV, and the largest excluded $\widetilde{\nu}$ mass is 96 GeV for a \widetilde{t} mass of 140 GeV. Superseded by ABAZOV 11N. 1^4 AALTONEN 08z searched in 322 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for dijet events with a lepton (e or μ) and a hadronic τ decay produced via R-parity violating couplings $LQ\overline{D}$. No heavy flavour-tagged jets are requested. No significant excess was found compared to the background expectation. Upper limits on the cross-section times the square of the branching ratio $B(\widetilde{t}_1 \to b\tau)$ are extracted, and a limit is derived on the stop mass assuming $B(\widetilde{t}_1 \to b\tau)=1$, see their Fig. 2. Supersedes the results of ACOSTA 04B. ACOSTA 04B.
- 15 ABAZOV 08 looked at approximately 400 pb $^{-1}$ of $p\,\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with $b\,\overline{b}\,\ell\ell'\not\!\!E_T$ with $\ell\ell'=e^{\pm}\mu^{\mp}$ or $\ell\ell'=\mu^+\mu^-$, originating from associated production $\widetilde{t}\widetilde{t}$. Branching ratios are assumed to be 100% for both $\widetilde{\chi}_1^\pm \to \ell \widetilde{\nu}$ and $\widetilde{\nu} \to$ $\nu \tilde{\chi}_1^0$. No evidence for an excess over the SM expectation is observed. The excluded region
- $m_{\widetilde{t}}$ so their Fig.3. Superseded by ABAZOV 090. ¹⁶ AALTONEN 07E searched in 295 pb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for multijet events with large E_T . They request at least one heavy flavor-tagged jet and no identified leptons. The branching ratio $\tilde{t}_1 \to c \tilde{\chi}_1^0$ is assumed to be 100%. No significant excess was found compared to the background expectation. Upper limits on the cross-section are extracted and a limit is derived on the masses of stop versus $\widetilde{\chi}_1^0$, see their Fig. 4.
- 17 ABAZOV 07B looked in 360 pb $^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with a pair of acoplanar heavy-flavor jets with $ot\!\!E_T$. No excess is observed relative to the SM background expectations. Limits are set on the production of \widetilde{t}_1 under the assumption that the only decay mode is into $c\widetilde{\chi}_1^0$, see their Fig. 4 for the limit in the $(m_{\widetilde{t}}, m_{\widetilde{\chi}_1^0})$ plane. No limit can be obtained for $m_{\widetilde{\chi}_1^0} >$ 54 GeV. Supersedes the results of

 18 CHEKA NOV 07 search for the $^{LQ\overline{D}}$ R-parity violating process $e^+p o \widetilde{t_1}$ in 65 pb $^{-1}$ at 318 GeV. Final states may originate from $LQ\overline{D}$ couplings $\widetilde{t} \rightarrow e^+ d$ and from the R-parity conserving decay $\widetilde{t} \to \widetilde{\chi}^+ b$, giving rise to e+ jet, e+ multi-jet, and $\nu+$ multi-jet. The excluded region in an MSSM scenario is presented for λ_{131} as a function of the stop mass in Fig. 6. Other excluded regions in a more restricted mSUGRA model are shown in Fig. 7 and 8.

19 ABBIENDI 04F use data from $\sqrt{s}=189$ –209 GeV. They derive limits on the stop mass under the assumption of R with $LQ\overline{D}$ or \overline{UDD} couplings. The limit quoted applies to direct decays with $\overline{U}\overline{D}\overline{D}$ couplings when the stop decouples from the Z^0 and improves to 88 GeV for $\theta_{t}=$ 0. For L Q \overline{D} couplings, the limit improves to 98 (100) GeV for $\lambda_{13k}^{'}$ or λ'_{23k} couplings and all θ_t ($\theta_t=0$). For λ'_{33k} couplings it is 96 (98) GeV for all θ_t ($\theta_t=0$). Supersedes the results of ABBIENDI 00. $^{20} \text{ABDALLAH 04M use data from } \sqrt{s}=192-208 \text{ GeV to derive limits on sparticle masses under the assumption of } \mathcal{R} \text{ with } LL\overline{E} \text{ or } \overline{UDD} \text{ couplings. The results are valid for } \mu=$

 $-200~{\rm GeV}$, $\tan \beta = 1.5$, $\Delta m > 5~{\rm GeV}$ and assuming a BR of 1 for the given decay. The limit quoted is for decoupling of the stop from the Z^0 and indirect \overline{UDD} decays using the neutralino constraint of 39.5 GeV for $LL\overline{E}$ and of 38.0 GeV for \overline{UDD} couplings, also derived in ABDALLAH 04M. For no mixing (decoupling) and indirect decays via $LL\overline{E}$ the limit improves to 92 (87) GeV if the constraint from the neutralino is used and to 88 (81) GeV if it is not used. For indirect decays via \overline{UDD} couplings it improves to 87 GeV for no mixing and using the constraint from the neutralino, whereas it becomes 81 GeV (67) GeV for no mixing (decoupling) if the neutralino constraint is not used. Supersedes the result of ABREU 01b.

AKTAS 04B looked in 106 pb $^{-1}$ of $e^{\pm}p$ collisions at $\sqrt{s}=310~{\rm GeV}$ and $320~{\rm GeV}$

21 AKTAS 04B looked in 106 pb^{-1} of $e^{\pm}p$ collisions at $\sqrt{s}=$ 319 GeV and 301 GeV for resonant production of \widetilde{t}_1 by R-parity violating $LQ\overline{D}$ couplings couplings with λ'_{131} , others being zero. They consider the decays $\widetilde{t}_1 \to e^+ d$ and $\widetilde{t}_1 \to W\widetilde{b}$ followed by $b
ightarrow \overline{
u}_e \, d$ and assume gauginos too heavy to participate in the decays. They combine the channels jep_T' , $j\mu p_T'$, $jjjp_T'$ to derive limits in the plane $(m_{\widetilde{t}}$, $\lambda_{131}')$, see their

22 DAS 04 reanalyzes AFFOLDER 00G data and obtains constraints on $m_{\widetilde{t}_1}$ as a function of $\mathsf{B}(\widetilde{t}\to b\ell\nu\chi^0)\times\mathsf{B}(\widetilde{t}\to b\overline{q}\,q'\chi^0)$, $\mathsf{B}(\widetilde{t}\to c\chi^0)$ and m_{χ^0} . Bound weakens for larger B($\widetilde{t} \to c \, \chi^0$) and m_{χ^0} .

- ²³ABDALLAH 03c looked for events of the type $q \, \overline{q} \, R^{\pm} R^{\pm}$, $q \, \overline{q} \, R^{\pm} R^{0}$ or $q \, \overline{q} \, R^{0} \, R^{0}$ in $e^{+} \, e^{-}$ interactions at $\sqrt{s} = 189$ –208 GeV. The R^{\pm} bound states are identified by anomalous dE/dx in the tracking chambers and the $\it R^{0}$ by missing energy, due to their reduced energy loss in the calorimeters. Excluded mass regions in the $(m(\tilde{t}), m(\tilde{g}))$ plane for $m(\tilde{g}) > 2$ GeV are obtained for several values of the probability for the gluino to fragment into R^\pm or R^0 , as shown in their Fig. 18. The limit improves to 90 GeV for
- ²⁴ ACOSTA 03c searched in 107 pb^{-1} of $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV for pair production The country of \overline{v} is a searched in 10 $p\bar{p}$ of \bar{p} consists at $\sqrt{s}=1.8$ feV for pair production of \bar{t} followed by the decay $\bar{t} \to b\ell\bar{\nu}$. They looked for events with two isolated leptons (e or μ), at least one jet and E_T . The excluded mass range is reduced for larger $m_{\widetilde{\nu}}$, and no limit is set for $m_{\widetilde{\nu}} > 88.4$ GeV (see Fig. 2). Superseded by AALTONEN 10v. 25 Theoretical analysis of e^+e^-+2 jet final states from the RPV decay of $\bar{t}\,\bar{t}^*$ pairs produced in $p\bar{p}$ collisions at $\sqrt{s}=1.8$ TeV. 95%CL limits of 220 (165) GeV are derived for
- $B(\widetilde{t} \rightarrow eq)=1 (0.5)$
- B($t \to eq f = 1$ (0.3). 26 HEISTER 03G searches for the production of \tilde{t} pairs in the case of R prompt decays with $LL\bar{E}$, $LQ\bar{D}$ or $U\bar{D}\bar{D}$ couplings at $\sqrt{s}=189-209$ GeV. The limit holds for indirect decays mediated by R $U\bar{D}\bar{D}$ couplings. It improves to 91 GeV for indirect decays mediated by R $LL\bar{E}$ couplings, to 97 GeV for direct (assuming $B(\tilde{t}_L \to q\tau)=100\%$) and to 85 GeV for indirect decays mediated by R $LQ\overline{D}$ couplings. Supersedes the results from BARATE 01B. $^{27}\,\mathrm{HEISTER}$ 03H use $e^+\,e^-$ data from 183–208 GeV to look for the production of stop

decaying into a c quark and a stable gluino hadronizing into charged or neutral R-hadrons. Combining these results with bounds on stable squarks and on a stable gluino LSP from the same paper yields the quoted limit. See their Fig. 13 for the dependence

of the mass limit on the gluino mass and on $heta_t$

²⁸ABAZOV 02c looked in 108.3pb $^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with $e\mu E_T$, originating from associated production \widetilde{tt} . Branching ratios are assumed to be 100%. The bound for the $b\ell \widetilde{\nu}$ decay weakens for large $\widetilde{\nu}$ mass (see Fig. 3), and no limit is set when $m_{\widetilde{
u}}>$ 85 GeV. See Fig. 4 for the limits in case of decays to a real $\widetilde{\chi}_1^\pm$, followed by $\widetilde{\chi}_1^\pm
ightarrow \ell \widetilde{
u}$, as a function of $m_{\widetilde{\chi}_1^\pm}$

 29 ACHARD 02 searches for the production of squarks in the case of R prompt decays with \overline{UDD} couplings at \sqrt{s} =189-208 GeV. The search is performed for direct and indirect decays, assuming one coupling at the time to be nonzero. The limit is computed for the minimal cross section and holds for both direct and indirect decays

30 AFFOLDER 01B searches for decays of the top quark into stop and LSP, in tT events. Limits on the stop mass as a function of the LSP mass and of the decay branching ratio are shown in Fig. 3. They exclude branching ratios in excess of 45% for SLP masses up

to 40 GeV.

31 ABREU 001 searches for the production of stop in the case of R-parity violation with LLE couplings, for which only indirect decays are allowed. They investigate topologies with jets plus leptons in data from \sqrt{s} =183 GeV. The lower bound on the stop mass assumes a neutralino mass limit of 27 GeV, also derived in ABREU 001.

32 AFFOLDER 00D search for final states with 2 or 3 jets and $\not\!\!E_T$, one jet with a c tag. See their Fig. 2 for the mass exclusion in the $(m_{\widetilde t}, m_{\widetilde \chi_1^0})$ plane. The maximum excluded $\emph{m}_{\widetilde{t}}$ value is 119 GeV, for $\emph{m}_{\widetilde{\chi}_{1}^{0}}{=}$ 40 GeV.

33AFFOLDER 00g searches for $\widetilde{t_1}$ $\widetilde{t_1}^*$ production, with $\widetilde{t_1} \to b\ell\widetilde{\nu}$, leading to topologies with ≥ 1 isolated lepton (e or μ), $\not\!\!\!E_T$, and ≥ 2 jets with ≥ 1 tagged as b quark by a secondary vertex. See Fig. 4 for the excluded mass range as a function of $m_{\widetilde{\nu}}$. Cross-section limits for \tilde{t}_1 \tilde{t}_1^* , with $\tilde{t}_1 \to b \chi_1^\pm (\chi_1^\pm \to \ell^\pm \nu \tilde{\chi}_1^0)$, are given in Fig. 2. Superseded by AALTONEN 10Y.

 34 ABE 99M looked in 107 pb $^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with like sign dielectrons and two or more jets from the sequential decays $\widetilde{q} \to ~q \, \widetilde{\chi}^0_1$ and $\widetilde{\chi}^0_1 \to ~e \, q \, \overline{q}'$, assuming R coupling $L_1Q_jD_k^c$, with j=2,3 and k=1,2,3. They assume $\mathrm{B}(\widetilde{t}_1\to c\widetilde{\chi}_1^0)$ =1, ${\sf B}(\widetilde{\chi}_1^0 \to e \, q \, \overline{q}') = 0.25$ for both e^+ and e^- , and $m_{\widetilde{\chi}_1^0} \ge m_{\widetilde{t}_1}/2$. The limit improves for

heavier $\widetilde{\chi}_1^0$. 35 AID 96 considers photoproduction of $\widetilde{t}\,\widetilde{t}$ pairs, with 100% *R*-parity violating decays of \widetilde{t}

to eq, with q=d, s, or b quarks. ³⁶AID 96 considers production and decay of \tilde{t} via the R-parity violating coupling

 37 CHO 96 studied the consistency among the B^0 – $\overline B^0$ mixing, ϵ in K^0 – $\overline K^0$ mixing, and the measurements of $V_{cb},~V_{ub}/V_{cb}.~$ For the range 25.5 GeV<m $_{\widetilde t_1}$ <m $_Z/2$ left by AKERS 94K for $\theta_t=0.98$, and within the allowed range in M_2 - μ parameter space from chargino, neutralino searches by ACCIARRI 95E, they found the scalar top contribution to B^0 - \overline{B}^0 mixing and ϵ to be too large if $\tan\beta < 2$. For more on their assumptions, see the paper and their reference 10.

 38 BUSKULIC 95E looked for $Z o \ \widetilde{t}\, \overline{\widetilde{t}}$, where $\widetilde{t} o c\,\chi_1^0$ and χ_1^0 decays via R-parity violating interactions into two leptons and a neutrino.

 39 SHIRAI 94 bound assumes the cross section without the s-channel Z-exchange and the QCD correction, underestimating the cross section up to 20% and 30%, respectively. They assume $m_{C}\!=\!1.5$ GeV.

Heavy g (Gluino) MASS LIMIT

95

VALUE (GeV)

> 520

For $m_{\widetilde{g}} > 60$ –70 GeV, it is expected that gluinos would undergo a cascade decay via a number of neutralinos and/or charginos rather than undergo a direct decay to photinos as assumed by some papers. Limits obtained when direct decay is assumed are usually higher than limits when cascade decays are included. Limits made obsolete by the most recent analyses of $p\overline{p}$ collisions can be found in previous Editions of this Review.

11AF ATLS

TECN COMMENT

DOCUMENT ID

1 AAD

| > 7 | 00 | 95 | ² AAD | 11 G | ATLS | $ \begin{array}{c} -1 & +1 & +1 \\ \ell + \mathrm{jets} + E_T, \ \tan\beta = 3, \ A_0 = 0, \\ \mu > 0, \ m_{\widetilde{g}} = m_{\widetilde{q}} \end{array} $ |
|-----|---------------|----|------------------------------------------------------|--------------|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| > 5 | 00 | 95 | ³ AAD | 11 N | ATLS | p > 0, $mg = mqpercent = mqof first two genera-$ |
| | | | | | | tions, $m_{\widetilde{\chi}_1^0} = 0$, all other |
| | | | | | | supersymmetric particles heavy, any $m_{\widetilde{q}}$ |
| > 8 | 370 | 95 | ³ AAD | 11 N | ATLS | jets $+\cancel{E}_T$, degenerate $m_{\widetilde{q}}$ |
| | | | | | | of first two genera- |
| | | | | | | tions, $m_{\widetilde{\chi}_1^0} = 0$, all other |
| | | | | | | supersymmetric particles heavy, $m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| > 7 | 75 | 95 | ³ AAD | | ATLS | jets $+ ot\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| > 5 | 90 | 95 | ⁴ AAD | 110 | ATLS | $\widetilde{g} ightarrow \widetilde{b}_1 b, \widetilde{b}_1 ightarrow b \widetilde{\chi}_1^0, \ m_{\widetilde{\chi}_1^0} = 60 \mathrm{GeV}$ |
| > 5 | 00 | 95 | ⁵ CHATRCHYAN | 11AC | CMS | jets $+ \not\!\!E_T$, CMSSM, |
| | | | 6 | | | $m_{\widetilde{q}} < 1000$ GeV |
| > 2 | 180 | 95 | ⁶ AALTONEN | 09s | CDF | jets+ $\not\!\!E_T$, tan β =5, μ <0, A_0 =0, any $m_{\widetilde{q}}$ |
| > 3 | 192 | 95 | ⁶ AALTONEN | 09s | CDF | jets+ $\not\!\!E_T$, tan β =5, μ <0, A_0 =0, $m_{\widetilde{q}}$ = $m_{\widetilde{g}}$ |
| > 3 | 808 | 95 | ⁷ ABAZOV | 08G | D0 | jets+ $\not\!\!E_T$, $\tan\beta=3$, $\mu<0$, $A_0=0$, any $m_{\widetilde{a}}$ |
| > 3 | 90 | 95 | ⁷ ABAZOV | 08G | D0 | |
| > 2 | 270 | 95 | ⁸ ABULENCIA | 061 | CDF | $\widetilde{g} \rightarrow \widetilde{b}b$, $\Delta m > 6$ GeV, $\widetilde{b}_1 \rightarrow$ |
| | | | | | | $b\widetilde{\chi}_1^0$, $m_{\widetilde{b}_1}^{}<$ 220 GeV |
| > 1 | | 95 | 9 AFFOLDER | 02 | CDF | Jets $+ \not\!\!E_T$, any $m_{\widetilde{a}}$ |
| > 3 | | 95 | 9 AFFOLDER | 02 | CDF | $Jets + \not\!\! E_T, \ m_{\widetilde{q}} = m_{\widetilde{g}}$ |
| > 1 | .29 | 95 | ¹⁰ ABBOTT | 01 D | D0 | $\ell\ell+{ m jets}+ ot\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!\!$ |
| > 1 | .75 | 95 | ¹⁰ ABBOTT | 01 D | D0 | $A_0=0$ $\ell\ell+\mathrm{jets}+\cancel{E}_T$, $\tan\beta=2$, large m_0 , $\mu<0$, $A_0=0$ |
| > 2 | 255 | 95 | ¹⁰ ABBOTT | 01 D | D0 | $\begin{array}{l} m_0, \ \mu < 6, \ m_0 = 0 \\ \ell\ell + \mathrm{jets} + E_T, \ \tan\beta = 2, \\ m_{\widetilde{g}} = m_{\widetilde{q}}, \ \mu < 0, \ A_0 = 0 \end{array}$ |
| > 1 | .68 | 95 | ¹¹ AFFOLDER | 01 J | CDF | $\begin{array}{c} g & q^{\gamma}, \\ \ell\ell + \mathrm{Jets} + \not\!\!\!E_T, \ \tan\beta = 2, \\ \mu = -800 \ \mathrm{GeV}, \ m_{\widetilde{q}} \gg m_{\widetilde{g}} \end{array}$ |
| > 2 | 221 | 95 | ¹¹ AFFOLDER | 01 J | CDF | $\ell\ell+\mathrm{Jets}+\cancel{E}_T$, $\tan\beta=2$, $\mu=-800~\mathrm{GeV}$, $m_{\widetilde{q}}=m_{\widetilde{g}}$ |
| > 1 | .90 | 95 | ¹² ABBOTT | 99L | D0 | Jets $+\cancel{E}_T$, tan β =2, μ <0, |
| > 2 | 260 | 95 | ¹² ABBOTT | 99L | D0 | $A=0^{-}$ $Jets+\cancel{E}_{T}, \ m_{\widetilde{g}}=m_{\widetilde{q}}$ |
| • • | • We do not u | | ollowing data for a | verage | s, fits, l | |
| | | | 13 CHATRCHYAN | 12 | CMS | e , μ , jets, razor, CMSSM |
| > 5 | 60 | | ¹⁴ AAD | 11× | ATLS | $\widetilde{g} \rightarrow \widetilde{\chi}_1^0 X \rightarrow \gamma \widetilde{G} X$ |
| > 1 | .55 | | 15 AALTONEN | 11 Q | | R , $\overline{U}\overline{D}\overline{D}$, $m_{\widetilde{q}}=m_{\widetilde{g}}+10$ GeV |
| | | | 16 CHATRCHYAN | 11 AB | CMS | $\ell^{\pm}\ell^{\pm}$ |
| | | | ¹⁷ CHATRCHYAN ¹⁸ CHATRCHYAN | 11G | CMS | $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$ |
| >10 | 040 | 95 | ¹⁹ CHATRCHYAN | 11 Q 11 V | CMS | $\ell+jets+\not\!\!E_T$ GMSB scenario, $\overline{\ell}$ co-NLSP |
| /10 | | | 20 CHATRCHYAN | 11w | | jets $+ \not\!\!E_T$, CMSSM |
| | | | ²¹ KHACHATRY | .11) | CMS | jets $+ \not\!\!E_T$ |
| > 2 | 224 | 95 | ²² ABAZOV | 02F | D0 | R_{2jk} indirect decays, $\tan \beta = 2$, any $m_{\widetilde{q}}$ |
| > 2 | 265 | 95 | ²² ABAZOV | 02F | D0 | $\mathbb{R} \lambda'_{2ik}$ indirect decays, |
| | . 00 | | | | | tan $\beta=2$, $m_{\widetilde{q}}=m_{\widetilde{g}}$ |
| | | | ²³ ABAZOV ²⁴ CHEUNG | 02G | D0 | $p\overline{p} \rightarrow \widetilde{g}\widetilde{g},\widetilde{g}\widetilde{q}$ |
| | | | ²⁵ BERGER | 02в 01 | THEO | $p\overline{p} \rightarrow X + b$ -quark |
| > 2 | 240 | 95 | ²⁶ ABBOTT | 99 | D0 | $\widetilde{g} \rightarrow \widetilde{\chi}_{0}^{0} X \rightarrow \widetilde{\chi}_{1}^{0} \gamma X$. |
| | | | | | | $\widetilde{g} \rightarrow \widetilde{\chi}_{2}^{0} X \rightarrow \widetilde{\chi}_{1}^{0} \gamma X,$ $m_{\widetilde{\chi}_{2}^{0}} - m_{\widetilde{\chi}_{1}^{0}} > 20 \text{ GeV}$ |
| > 3 | | | ²⁶ ABBOTT | 99 | D0 | $g \rightarrow \widetilde{\chi}_1^0 X \rightarrow G \gamma X$ |
| > 2 | 227 | | ²⁷ ABBOTT | 99K | D0 | any $m_{\widetilde{\alpha}}$, R , $	aneta=2$, $\mu<0$ |
| > 2 | 212 | 95 | ²⁸ ABACHI | 95 C | D0 | $m_{\widetilde{g}} \geq m_{\widetilde{q}}$; with cascade de- |
| | | | | | | cays ' |

| > 144 | 95 | ²⁸ АВАСНІ | 95 € D0 | y y |
|------------|----|------------------------|----------|--------------------------------------------------------------------------------------------|
| | | ²⁹ ABE | 95 T CDI | F $\widetilde{g} \rightarrow \widetilde{\chi}_2^0 \rightarrow \widetilde{\chi}_1^0 \gamma$ |
| | | ³⁰ HEBBEKER | | JE e+e- jet analyses |
| > 218 | 90 | ³¹ ABE | 92L CDI | F $m_{\widetilde{a}} \leq m_{\widetilde{a}}$; with cascade |
| | | 22 | | decay |
| > 100 | | 32 ROY | 92 RVI | JE $p\overline{p} \rightarrow \widetilde{g}\widetilde{g}; R$ |
| | | ³³ nojiri | 91 CO: | SM |
| none 4-53 | 90 | ³⁴ ALBAJAR | 87D UA | 1 Any $m_{\widetilde{a}} > m_{\widetilde{g}}$ |
| none 4-75 | 90 | ³⁴ ALBAJAR | 87D UA | |
| none 16-58 | 90 | ³⁵ ANSARI | 87D UA: | |

- 1 AAD 11AF looked in 1.34 fb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with 6 up to 8 jets and $\not\!\!\!E_T$. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,\,m_{1/2})$ plane for $\tan\beta=10$ (see Fig. 5). The limit improves to $m_{\widetilde{g}}>60$ GeV for $m_{\widetilde{q}}=2$ $m_{\widetilde{g}}$.
- 2 AAD 11G looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with a single lepton (e or μ), jets and E_T from the production of squarks and gluinos. No evidence for an excess over the SM expectation is observed, and a limit is derived in the CMSSM $(m_0,\,m_{1/2})$ plane for $\tan\beta=3$, see Fig. 2.
- 3 AAD 11N looked in 35 pb⁻¹ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 jets and E_T . Four signal regions were defined, and the background model was found to be in good agreement with the data. Limits are derived in the $(m_{\widetilde{g}}, m_{\widetilde{q}})$ plane (see Fig. 2) for a simplified model where degenerate masses of the squarks of the first two generations are assumed, $m_{\widetilde{\chi}_1^0} = 0$, and all other masses including third generation squarks are set to 5 TeV. Limits are also derived in the CMSSM $(m_0, m_{\star}, n_{\star})$ plane (see Fig. 3) for $\tan \beta$
- to 5 TeV. Limits are also derived in the CMSSM (m_0 , $m_{1/2}$) plane (see Fig. 3) for $\tan\beta$ = 3.
- 4 3 3 3 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
- branching ratios and \widetilde{b}_1 being the lightest squark. The quoted limit is valid for $m_{\widetilde{b}_1} <$
- 500 GeV. A similar approach for \widetilde{t}_1 as the lightest squark with $\widetilde{g} \to \widetilde{t}_1$ t and $\widetilde{t}_1 \to \hat{b} \widetilde{\chi}_1^{\pm}$ with 100% branching ratios leads to a gluino mass limit of 520 GeV for 130 $< m_{\widetilde{t}_1} < 300$ GeV. Limits are also derived in the CMSSM $(m_0, m_{1/2})$ plane for $\tan\beta = 40$, see Fig. 4, and in scenarios based on the gauge group SO(10).
- ⁵ CHATRCHYAN 11Ac looked in 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 3 jets, a large total transverse energy, and E_T . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_{1/2})$ plane and the $(m_{\widetilde{g}}, m_{\widetilde{q}})$ plane for $\tan\beta=10$ (see Fig. 10). Limits are also obtained for Simplified Model Spectra.
- Simplified Model Spectra. 6 AALTONEN 09s searched in 2 fb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events with at least 2 jets and \cancel{E}_T . No evidence for a signal is observed. A limit is derived for a mSUGRA scenario in the $m_{\widetilde{q}}$ versus $m_{\widetilde{g}}$ plane, see their Fig. 2.
- ⁷ ABAZOV 08G looked in 2.1 fb⁻¹ of $p\bar{p}$ collisions at \sqrt{s} =1.96 TeV for events with acoplanar jets or multijets with large E_T . No significant excess was found compared to the background expectation. A limit is derived on the masses of squarks and gluinos for specific MSUGRA parameter values, see Figure 3. Similar results would be obtained for allowed to the contract of parameters and squares and parameters are supported to the possible of PAZOV.
- a large class of parameter sets. Supersedes the results of ABAZOV 06c.
 8 ABULENCIA 06I searched in 156 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for multijet events with large E_T . They request at least 2 b-tagged jets and no isolated leptons. They investigate the production of gluinos decaying into \overline{b}_1 b followed by $\overline{b}_1 \rightarrow b \overline{\chi}_1^0$. Both branching fractions are assumed to be 100% and the LSP mass to be 60 GeV. No significant excess was found compared to the background expectation. Upper limits on the cross-section are extracted and a limit is derived on the masses of sbottom and gluinos con their E_1 0.
- affolder of searched in $\sim 84~{\rm pb}^{-1}$ of $p\overline{p}$ collisions for events with ≥ 3 jets and E_{T} , arising from the production of gluinos and/or squarks. Limits are derived by scanning the parameter space, for $m_{\widetilde{q}} \geq m_{\widetilde{g}}$ in the framework of minimal Supergravity, assuming five flavors of degenerate squarks, and for $m_{\widetilde{q}} < m_{\widetilde{g}}$ in the framework of constrained MSSM, assuming conservatively four flavors of degenerate squarks. See Fig. 3 for the variation
- assuming conservatively out havous of degenerate squarks. Supersedes the results of ABE 97K. 10 ABBOTT 01D looked in $\sim 108\,\mathrm{pb}^{-1}$ of $p\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with $e\,e$, $\mu\mu$, or $e\,\mu$ accompanied by at least 2 jets and E_T . Excluded regions are obtained in the MSUGRA framework from a scan over the parameters $0 < m_0 < 300$ GeV, $10 < m_1/2 < 110$ GeV, and $1.2 < \tan\beta < 10$.
- 11 AFFOLDER 011 searched in $\sim 106~{\rm pb}^{-1}$ of $p\overline{p}$ collisions for events with 2 like-sign leptons (e or μ), ≥ 2 jets and E_T , expected to arise from the production of gluinos and/or squarks with cascade decays into $\overline{\chi}^{\pm}$ or $\overline{\chi}_2^0$. Spectra and decay rates are evaluated in the framework of minimal Supergravity, assuming five flavors of degenerate squarks and a pseudoscalar Higgs mass m_A =500 GeV. The limits are derived for $\tan\beta=2$, $\mu=-800$ GeV, and scanning over $m_{\widetilde{g}}$ and $m_{\widetilde{q}}$. See Fig. 2 for the variation of the limit as function of the squark mass. These limits supersede the results of ABE 96D.
- 12 ABBOTT 99L consider events with three or more jets and large E_T . Spectra and decay rates are evaluated in the framework of minimal Supergravity, assuming five flavors of degenerate squarks, and scanning the space of the universal gaugino $(m_{1/2})$ and scalar (m_0) masses See their Figs. 2–3 for the dependence of the limit on the relative value of m_{π} and m_{π} .
- The following and the second of the following and the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the second of the sec

Supersymmetric Particle Searches

- 14 AAD 11x looked in 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 photons and E_T from the pair production of gluinos with cascade decays to $\widetilde{\chi}_1^0$ followed by $\widetilde{\chi}_1^0 \to \gamma \widetilde{G}$ prompt decay. No evidence for an excess over the SM expectation is observed, and a limit on the number of new physics events is set. Limits are derived in a Generalized Gauge Mediated model in the $(m_{\widetilde{g}}^{},m_{\widetilde{\chi}_1^0}^0)$ plane (see Fig. 5) under the assumptions $\tan\beta$
 - = 2 and all sparticle masses at 1.5 TeV, except the \widetilde{g} , $\widetilde{\chi}_{1}^{0}$, and $\widetilde{\mathit{G}}$.
- 15 AALTONEN 11Q searched in 3.2 fb⁻¹ of $\rho \overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events with at least 6 jets from the pair production of gluinos and squarks with the subsequent decays $\overline{g} \rightarrow 3$ jets in the MSSM framework with \overline{g} . No statistically significant bumps in the 3-jet systems are observed over the SM background. Limits on the cross section times branching ratio are derived as a function of the gluino mass, displayed in Fig. 3. For decoupled squarks in the range $0.5 < m_{\overline{q}} < 0.7$ TeV gluinos are excluded below 144 GeV. The guided limit is for near degeneracy of squark and gluino masses.
- The quoted limit is for near degeneracy of squark and gluino masses. 16 CHATRCHYAN 11AB looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 same charge isolated leptons $(e, \mu \text{ or } \tau)$, jets and E_T . Such events might be produced from $\widetilde{g}\widetilde{g}$ or $\widetilde{g}\widetilde{q}$ decaying via charginos into leptons. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_1/2)$ plane for $\tan \beta = 3$ (see Fig. 10).
- 17 CHATRCHYAN 11G looked in 36 pb $^{-1}$ of ρp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 isolated photons, ≥ 1 jet and E_T , which may arise in a generalized gauge mediated model from the decay of a $\widetilde{\chi}_1^0$ NLSP. No evidence for an excess over the expected background is observed. Limits are derived in the plane of squark versus gluino mass (see Fig. 4) for several values of $m_{\widetilde{\chi}_1^0}$
- 13 CHATRCHYAN 11Q looked in 36 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with a single isolated lepton (e or μ), \geq 4 jets and \cancel{E}_T . No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0,\,m_{1/2})$ plane for $\tan\beta=10$ (see Fig. 7).
- for tan $\beta=10$ (see Fig. 7). 19 CHATRCHYAN 11v looked in 35 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 3 isolated leptons $(e, \mu \text{ or } \tau)$, with or without jets and E_T . Multi-lepton final states originate from $\tilde{q} \to \tilde{\chi}^0 + X$, followed by $\tilde{\chi}^0 \to \tilde{\ell}^\pm \ell^\mp$ and $\tilde{\ell} \to \ell \tilde{G}$. No evidence for an excess over the expected background is observed. Limits are derived (see Fig. 4) for a GMSB-type scenario with mass-degenerate right-handed sleptons (slepton co-NLSP scenario).
- 20 CHATRCHYAN 11w looked in 1.14 fb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 jets, large total jet energy, and \rlap/E_T . After combining multi-jet events into two pseudo-jets signal events are selected by a cut on $\alpha_T=E_T^{j2}/M_T$, the transverse energy of the less energetic jet over the transverse mass. Given the lack of an excess over the SM backgrounds, limits are derived in the CMSSM $(m_0,\,m_1/2)$ plane (see Fig. 4) for $\tan\beta=10$. The limits are only weakly dependent on $\tan\beta$ and A_0 .
- 21 KHACHATRYAN 111 looked in 35 pb⁻¹ of pp collisions at $\sqrt{s}=7$ TeV for events with ≥ 2 Jets and pq. After combining multi-jet events into two pseudo-jets signal events are selected by a cut on $\alpha_T = E_T^{j_2}/M_T$, the transverse energy of the less energetic jet over the transverse mass. No evidence for an excess over the expected background is observed. Limits are derived in the CMSSM $(m_0, m_{1/2})$ plane (see Fig. 5) for $\tan \beta = 3$. Superseded by CHATRCHYAN 11w.
- 3. Superseded by CHATRCHYAN 11w. $^{22}\text{ABAZOV }02\text{F looked in }77.5\text{ pb}^{-1}\text{ of }\rho\overline{\rho}\text{ collisions at }1.8\text{ TeV for events with }\geq 2\mu+\geq 4\text{jets, originating from associated production of squarks followed by an indirect }R\text{ decay (of the }\overline{\chi}_1^0)\text{ via }LQ\overline{\rho}\text{ couplings of the type }\lambda_{2jk}^2\text{ where }j=1,2\text{ and }k=1,2,3\text{. Bounds are obtained in the MSUGRA scenario by a scan in the range }0\leq M_0\leq 400\text{ GeV, }60\leq m_{1/2}\leq 120\text{ GeV for fixed values }A_0=0,\mu<0,\text{ and }\tan\beta=2\text{ or }6\text{. The bounds are weaker for }\tan\beta=6\text{. See Figs. }2,3\text{ for the exclusion contours in }m_{1/2}\text{ versus }m_0\text{ for }\tan\beta=2\text{ and }k=1,2,3\text{ or }k=1,2,3\text{ for the exclusion contours in }m_{1/2}\text{ versus }m_0\text{ for }\tan\beta=2\text{ and }k=1,2,3\text{ for the exclusion contours in }m_{1/2}\text{ versus }m_0\text{ for }\tan\beta=2\text{ and }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{ for }k=1,2,3\text{$
- 23, Respectively. 23 ABAZOV 02G search for associated production of gluinos and squarks in 92.7 pb $^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}{=}1.8$ TeV, using events with one electron, \geq 4 jets, and large E_T . The results are compared to a MSUGRA scenario with μ <0, $A_0{=}0$, and $\tan\beta{=}3$ and allow to exclude a region of the $(m_0,m_{1/2})$ shown in Fig. 11.
- 24 CHEUNG 02B studies the constraints on a \tilde{b}_1 with mass in the 2.2–5.5 GeV region and a gluino in the mass range 12–16 GeV, using precision measurements of Z^0 decays and e^+e^- annihilations at LEP2. Few detectable events are predicted in the LEP2 data for the model proposed by BERGER 01.
- 25 BERGER 01 reanalyzed interpretation of Tevatron data on bottom-quark production. Argues that pair production of light gluinos ($m \sim 12$ –16 GeV) with subsequent 2-body decay into a light sbottom ($m \sim 2$ –5.5 GeV) and bottom can reconcile Tevatron data with predictions of perturbative QCD for the bottom production rate. The sbottom must either decay hadronishly via a Parity and P. Widshiring interaction or belong lived.
- either decay hadronically via a R-parity- and B-violating interaction, or be long-lived. 26 ABBOTT 99 searched for $\gamma \not\!\! E_T + \geq 2$ jet final states, and set limits on $\sigma(\rho \overline{\rho} \to \overline{g} + X) \cdot B(\overline{g} \to \gamma \not\!\! E_T X)$. The quoted limits correspond to $m_{\widetilde{q}} \geq m_{\widetilde{g}}$, with $B(\widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0 \gamma) = 1$ and $B(\widetilde{\chi}_1^0 \to \overline{G} \gamma) = 1$, respectively. They improve to 310 GeV (360 GeV in the case of γG decay) for $m_{\widetilde{g}} = m_{\widetilde{q}}$.
- 27 ABBOTT 99K uses events with an electron pair and four jets to search for the decay of the $\tilde{\chi}_1^0$ LSP via R $LQ\overline{D}$ couplings. The particle spectrum and decay branching ratios are taken in the framework of minimal supergravity. An excluded region at 95% CL is obtained in the $(m_0,m_{1/2})$ plane under the assumption that A_0 =0, μ <0, $\tan \beta$ =2 and
- any one of the couplings $\lambda'_{1jk} > 10^{-3}$ (j=1,2 and k=1,2,3) and from which the above limit is computed. For equal mass squarks and gluinos, the corresponding limit is 277 GeV. The results are essentially independent of A_0 , but the limit deteriorates rapidly with increasing $\tan\beta$ or μ >0.
- 28 ABACHI 95c assume five degenerate squark flavors with with $m_{\widetilde{q}_1}=m_{\widetilde{q}_{\widetilde{B}}}$. Sleptons are assumed to be heavier than squarks. The limits are derived for fixed $\tan\beta=2.0~\mu=-250~{\rm GeV}$, and $m_{H^+}=500~{\rm GeV}$, and with the cascade decays of the squarks and gluinos calculated within the framework of the Minimal Supergravity scenario. The bounds are weakly sensitive to the three fixed parameters for a large fraction of parameter space.
- 29 ABE 95T looked for a cascade decay of gluino into $\widetilde{\chi}_2^0$ which further decays into $\widetilde{\chi}_1^0$ and a photon. No signal is observed. Limits vary widely depending on the choice of parameters. For $\mu=-40$ GeV, $\tan\beta=1.5$, and heavy squarks, the range $50 < m_{\widetilde{g}}$ (GeV)<140 is excluded at 90% CL. See the paper for details.

- 30 HEBBEKER 93 combined jet analyses at various $e^+\,e^-$ colliders. The 4-jet analyses at TRISTAN/LEP and the measured $\alpha_{\rm S}$ at PEP/PETRA/TRISTAN/LEP are used. A constraint on effective number of quarks ${\it N}{=}6.3\pm1.1$ is obtained, which is compared to that with a light gluino, ${\it N}{=}8$.
- 31 ABE 92L bounds are based on similar assumptions as ABACHI 95C. Not sensitive to $m_{\rm gluino}$ <40 GeV (but other experiments rule out that region).
- 32 ROY 92 reanalyzed CDF limits on di-lepton events to obtain limits on gluino production in R-parity violating models. The 100% decay $\tilde{g} \to q \overline{q} \, \tilde{\chi}$ where $\tilde{\chi}$ is the LSP, and the LSP decays either into $\ell q \, \overline{d}$ or $\ell \ell \overline{e}$ is assumed.
- 33 NOJIRI 91 argues that a heavy gluino should be nearly degenerate with squarks in minimal supergravity not to overclose the universe.
- ³⁴ The limits of ALBAJAR 87D are from $p\overline{p}\to \widetilde{g}\widetilde{g}$ X $(\widetilde{g}\to q\overline{q}\widetilde{\gamma})$ and assume $m_{\widetilde{q}}>m_{\widetilde{g}}$. These limits apply for $m_{\widetilde{\gamma}}\lesssim$ 20 GeV and $\tau(\widetilde{g})<10^{-10}$ s.
- 35 The limit of ANSARI 87D assumes $m_{\widetilde{q}} > m_{\widetilde{g}}$ and $m_{\widetilde{\gamma}} \approx 0$.

Long-lived/light \widetilde{g} (Gluino) MASS LIMIT

Limits on light gluinos ($m_{\widetilde{g}}~<5$ GeV), or gluinos which leave the detector before decaying.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-----------------------|---------------------------------------------------------------|---------------------------------------------|------------|--------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| • • • We do not | use the following data for averages, fits, limits, etc. • • • | | | | |
| >586 | 95 | ¹ AAD | 11 K | ATLS | stable \widetilde{g} |
| >544 | 95 | ² AAD | 11 P | ATLS | stable $\widetilde{\widetilde{g}}$, GMSB scenario, $\tan \beta = 5$ |
| >370 | 95 | ³ KHACHATRY. | .11 | CMS | long lived \widetilde{g} |
| >398 | 95 | ⁴ KHACHATRY. | 11 € | CMS | stable \widetilde{g} |
| > 15 | 90 | ⁵ BERGER | 10 | THEO | hadron scattering data, $lpha_{\it S}$ |
| > 51 | 95 | ⁶ KAPLAN | 80 | THEO | event shapes at LEP |
| | | ⁷ ABAZOV | 07L | D0 | long-lived \widetilde{g} |
| > 12 | | ⁸ BERGER | 05 | THEO | hadron scattering data |
| none 2-18 | 95 | 9 ABDALLAH | 03€ | DLPH | $e^+e^- ightarrowq\overline{q}\widetilde{g}\widetilde{g}$, stable \widetilde{g} |
| > 5 | | ¹⁰ ABDALLAH | 03 G | DLPH | QCD beta function |
| | | 11 HEISTER | 03 | ALEP | Color factors |
| > 26.9 | 95 | 12 HEISTER | 03н | | $e^+e^- \rightarrow q \overline{q} \widetilde{g} \widetilde{g}$ |
| > 6.3 | | 13 JANOT | 03 | RVUE | $\Delta\Gamma_{had}$ <3.9 MeV |
| | | 14 MAFI | 00 | THEO | $pp \rightarrow \text{jets} + p_T$ |
| | | ¹⁵ ALAVI-HARAT | 199E | KTEV | $pN \rightarrow R^0$, with $R^0 \rightarrow \rho^0 \widetilde{\gamma}$ and $R^0 \rightarrow \pi^0 \widetilde{\gamma}$ |
| | | ¹⁶ BAER | 99 | RVUE | Stable \widetilde{g} hadrons |
| | | ¹⁷ FANTI | 99 | NA48 | $p \operatorname{Be} \to R^0 \to \eta \widetilde{\gamma}$ |
| | | 18 ACKERSTAFF | | OPAL | $e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$ |
| | | 19 ADAMS | 97B | KTEV | $\rho N \to R^0 \xrightarrow{1} \rho^0 \widetilde{\gamma}$ |
| | | ²⁰ ALBUQUERQ. | | E761 | $R^+(uud\widetilde{g}) \rightarrow S^0(uds\widetilde{g})\pi^+,$ $X^-(ssd\widetilde{g}) \rightarrow S^0\pi^-$ |
| > 6.3 | 95 | 21 BARATE | 97L | ALEP | Color factors |
| > 5 | 99 | 22 CSIKOR | 97 | RVUE | β function, $Z \rightarrow$ jets |
| > 1.5 | 90 | 23 DEGOUVEA | 97 | THEO | $Z \rightarrow jjjj$ |
| none 1.9-13.6 | 95 | ²⁴ FARRAR ²⁵ AKERS | 96 95 R | RVUE OPAL | $R^0 ightarrow \pi^0 \widetilde{\gamma}$ Z decay into a long-lived |
| < 0.7 | | ²⁶ CLAVELLI | 95 | RVUE | $(\widetilde{g} q \overline{q})^{\pm}$ |
| < 0.7 none 1.5-3.5 | | 27 CAKIR | 95 94 | RVUE | quarkonia $\Upsilon(1S) ightarrow \gamma + { m gluinonium}$ |
| not 3-5 | | 28 LOPEZ | 93 c | RVUE | LEP γ+ gramomam |
| ≈ 4 | | 29 CLAVELLI | 92 | RVUE | α_S running |
| | | ³⁰ ANTONIADIS | 91 | RVUE | $\alpha_{\rm S}$ running |
| > 1 | | 31 ANTONIADIS | 91 | RVUE | $p N \rightarrow \text{missing energy}$ |
| - | | ³² NAKAMURA | 89 | SPEC | R-Δ ⁺⁺ |
| > 3.8 | 90 | 33 ARNOLD | 87 | EMUL | π^- (350 GeV). $\sigma \simeq A^1$ |
| > 3.2 | 90 | ³³ ARNOLD | 87 | EMUL | π^- (350 GeV). $\sigma \simeq A^{0.72}$ |
| none 0.6-2.2 | 90 | ³⁴ TUTS | 87 | CUSB | $\Upsilon(1S) \rightarrow \gamma + \text{gluinonium}$ |
| none 1 -4.5 | 90 | ³⁵ ALBRECHT | 86 c | ARG | $\begin{array}{l} \gamma(1S) \rightarrow \gamma + \text{gluinonium} \\ 1\times10^{-11} \lesssim \tau \lesssim 1\times10^{-9}\text{s} \\ 1\times10^{-10} < \tau < 1\times10^{-7}\text{s} \end{array}$ |
| none 1-4 | 90 | ³⁶ BADIER | 86 | BDMP | $1 \times 10^{-10} < \tau < 1 \times 10^{-7} s$ |
| none 3-5 | | ³⁷ BARNETT | 86 | RVUE | $p\overline{p} \rightarrow \text{gluino gluino gluon}$ |
| none | | ³⁸ VOLOSHIN | 86 | RVUE | lf (quasi) stable; $\widetilde{g}uud$ |
| none 0.5-2 | | ³⁹ COOPER | 85 B | BDMP | For $m_{\widetilde{q}} = 300 \text{ GeV}$ |
| none 0.5-4 | | ³⁹ COOPER | 85 B | BDMP | For $m_{\widetilde{q}}$ <65 GeV |
| none 0.5-3 | | ³⁹ COOPER | 85 B | BDMP | For $m_{\widetilde{q}} = 150 \text{ GeV}$ |
| none 2-4 | | ⁴⁰ DAWSON | 85 | RVUE | $\tau > 10^{-7} \text{ s}$ |
| none 1-2.5 | | ⁴⁰ DAWSON | 85 | RVUE | For $m_{\widetilde{q}} = 100$ GeV |
| none 0.5-4.1 | 90 | ⁴¹ FARRAR | 85 | RVUE | FNAL beam dump |
| > 1 | | 42 GOLDMAN | 85 | RVUE | Gluinonium |
| >1-2 | | 43 HABER | 85 | RVUE | |
| | | 44 BALL | 84 | CALO | |
| | | 45 BRICK | 84 | RVUE | |
| | | 46 FARRAR | 84 | RVUE | F <100 C-V |
| > 2 | | ⁴⁷ BERGSMA | 83 c | RVUE | For $m_{\widetilde{q}} < 100 \text{ GeV}$ |
| | | 48 CHANOWITZ | 83 | RVUE | $\widetilde{g}u\overline{d}$, $\widetilde{g}uud$ |
| >2-3 | | ⁴⁹ KANE | 82 | RVUE | Beam dump |
| >1.5-2 | | FARRAR | 78 | RVUE | R-hadron |
| | | | | | |

Searches Particle Listings Supersymmetric Particle Searches

- 1 AAD 1 K looked in 34 pb $^{-1}$ of p p collisions at $\sqrt{s}=7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or time of flight in the tile calorimeter, from pair production of \tilde{g} . No evidence for an excess over the SM expectation is observed. Limits are derived for pair production of gluinos as a function of mass (see Fig. 4), for a fraction, f=10%, of formation of $\tilde{g}-g$ (R-gluonball) if instead of a phase space driven approach for the hadronic scattering of the R-hadrons, a triple-Regge model or a bag-model is used, the limit degrades to 566 and 562 GeV, respectively.
- 2 AAD 11P looked in 37 pb $^{-1}$ of pp collisions at $\sqrt{s}=$ 7 TeV for events with heavy stable particles, reconstructed and identified by their time of flight in the Muon System. There is no requirement on their observation in the tracker to increase the sensitivity to cases where gluinos have a large fraction, f, of formation of neutral $\widetilde{g}-g$ (R-gluonball). No evidence for an excess over the SM expectation is observed. Limits are derived as a function of mass (see Fig. 4), for f=0.1. For fractions f = 0.5 and 1.0 the limit degrades to 537 and 530 GeV, respectively.
- 3 KHACHATRYAN 11 looked in 10 pb $^{-1}$ of pp collisions at $\sqrt{s}=7$ TeV for events with pair production of long-lived gluinos. The hadronization of the gluinos leads to R-hadrons pan production long-invasions and intermediate in the games test of the which may stop inside the detector and later decay via $\tilde{g} \to g \tilde{\chi}_1^0$ during gaps between the proton bunches. No significant excess over the expected background is observed. From a counting experiment, a limit at 95% C.L. on the cross section times branching ratio is derived for $m_{\widetilde{g}}-m_{\widetilde{\chi}_1^0}>100$ GeV, see their Fig. 2. Assuming 100% branching

ratio, lifetimes between 75 ns and 3×10^5 s are excluded for $m_{\widetilde{g}}=300$ GeV. The \widetilde{g} mass exclusion is obtained with the same assumptions for lifetimes between $10~\mu s$ and mass exclusion is obtained with the same assumptions for interactions with matter, illustrated in Fig. 3. From a time-profile analysis, the mass exclusion is 382 GeV for a lifetime of $10~\mu s$ under the same assumptions as above. ⁴ KHACHATRYAN 11c looked in 3.1 pb⁻¹ of pp collisions at $\sqrt{s}=7$ TeV for events with heavy stable particles, identified by their anomalous dE/dx in the tracker or additionally

- requiring that it be identified as muon in the muon chambers, from pair production of \widetilde{g} . No evidence for an excess over the expected background is observed. Limits are derived for pair production of gluinos as a function of mass (see Fig. 3), depending on the fraction, f, of formation of g-g (R-gluonball). The quoted limit is for f=0.1, while for f=0.5 it degrades to 357 GeV. In the conservative scenario where every hadronic interaction causes it to become neutral, the limit decreases to 311 GeV for f=0.1.
- BERGER 10 updated the results of BERGER 05. They fit parton distribution functions including the effects of a light gluino as an extra parton. Different data on α_S is also included. A fit for $\alpha_S(M_Z)$ is performed as a function of the gluino mass. The bound is determined by comparing the quality of the fit to the CT10 fit, and the CT10 tolerance criterion is used to define the significance. The lower bound is 25 GeV for fixed $\alpha_S(M_Z)$
- 6 KAPLAN 08 reanalysed jet event shape data from LEP 1 and LEP 2 using soft collinear effective theory methods. These data are sensitive to the effects of new degrees of freedoms, including a relatively light gluino, at different energy scales, roughly between 5 and 50 GeV. The analysis relies on theoretical modeling of and approximations for non-perturbative effects and matching between different scales.

 7 ABAZOV 07L looked in approximately 410 pb $^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV for events with a long-lived gluino from split supersymmetry, decaying after stopping in the detector into $g\,\tilde{\chi}^0_1$ with lifetimes from 30 μ s to 100 h. The signal signature is a largely empty event with a single large transverse energy deposit in the calorimeter. The main background is due to cosmic muons interacting in the calorimeter. The data agree with the estimated background and allow the authors to estimate a limit on the rate of an out-of-time monoiet signal of a given energy. Assuming the branching ratios $\tilde{\sigma} = \sigma\,\tilde{\sigma}^0$ out-of-time monojet signal of a given energy. Assuming the branching ratios $\tilde{g} \to g \tilde{\chi}_1^0$ to be 100% the results can be translated to limits on the gluino cross section versus the gluino mass for fixed $\tilde{\chi}^0_1$ mass. After comparing to the expected gluino cross sections, the excluded region of gluino masses can be obtained, see examples in their Fig. 3.
- ⁸ BERGER 05 include the light gluino in proton PDF and perform global analysis of hadronic data. Effects on the running of α_S also included. Strong dependency on $\alpha_S(m_Z)$. Bound quoted for $\alpha_S(m_Z)=0.118$. Superseded by BERGER 10.
- ASDALLAH 03c looked for events of the type $q \overline{q} R^{\pm} R^{\pm}$, $q \overline{q} R^{\pm} R^{0}$ or $q \overline{q} R^{0} R^{0}$ in $e^{+}e^{-}$ interactions at 91.2 GeV collected in 1994. The R^{\pm} bound states are identified by anomalous dE/dx in the tracking chambers and the R^{0} by missing energy, due to their reduced energy loss in the calorimeters. The upper value of the excluded range depends on the probability for the gluino to fragment into R^{\pm} or R^{0} , see their Fig. 17. It improves to 23 GeV for 100% fragmentation to R^{\pm} .
- 10 ABDALLAH 03G used e^+e^- data at and around the Z^0 peak, above the Z^0 up to $\sqrt{s}=202$ GeV and events from radiative return to cover the low energy region. They perform a direct measurement of the QCD beta-function from the means of fully inclusive event observables. Compared to the energy range, gluinos below 5 GeV can be considered massless and are firmly excluded by the measurement.
- 11 HEISTER 03 use e^+e^- data from 1994 and 1995 at and around the Z^0 peak to measure the 4-jet rate and angular correlations. The comparison with QCD NLO calculations allow $\alpha_S(M_Z)$ and the color factor ratios to be extracted and the results are in a greement with the expectations from QCD. The inclusion of a massless gluino in the beta functions yields $T_R / C_F = 0.15 \pm 0.06 \pm 0.06$ (expectation is $T_R / C_F = 3.8$), excluding a massless gluino at more than 95% C.L. As no NLO calculations are available for massive gluinos, the earlier LO results from BARATE 97L for massive gluinos remain valid.
- guinos, the earlier LO Tesuis from BARATE 97L for massive guinos remain valid.

 12 HEISTER 03H use e^+e^- data at and around the Z^0 peak to look for stable gluinos hadronizing into charged or neutral R-hadrons with arbitrary branching ratios. Combining these results with bounds on the Z^0 hadronic width from electroweak measurements (JANOT 03) to cover the low mass region the quoted lower limit on the mass of a lengthing blaine is obtained. long-lived gluino is obtained.
- $^{13}\,\mathsf{JANOT}\,\,^{\circ}\!\!^{\circ}\!\!^{\circ}$ excludes a light gluino from the upper limit on an additional contribution to the Z hadronic width. At higher confidence levels, $m_{\widetilde{g}} > 5.3(4.2)$ GeV at $3\sigma(5\sigma)$ level.
- 14 MAFI 00 reanalyzed CDF data assuming a stable heavy gluino as the LSP, with model for R-hadron-nucleon scattering. Gluino masses between 35 GeV and 115 GeV are excluded based on the CDF Run I data. Combined with the analysis of BAER 99, this allows a LSP gluino mass between 25 and 35 GeV if the probability of fragmentation into charged *R*-hadron P>1/2. The cosmological exclusion of such a gluino LSP are assumed to be avoided as in BAER 99. Gluino could be NLSP with $au_{\widetilde{g}} \sim 100$ yrs, and decay to gluon
- 15 ALAVI-HARATI 99E looked for R0 bound states, yielding $\pi^+\pi^-$ or π^0 in the final state. The experiment is sensitive to values of $\Delta m = m_{R^0} - m_{\widetilde{\gamma}}$ larger than 280 MeV and 140 MeV for the two decay modes, respectively, and to R^0 mass and lifetime in the ranges 0.8–5 GeV and 10^{-10} – 10^{-3} s. The limits obtained depend on $B(R^0 \to 0.00)$

- $\pi^+\pi^-$ photino) and B($R^0 o\pi^0$ photino) on the value of $m_{R^0}/m_{\widetilde{\gamma}}$, and on the ratio of production rates $\sigma(R^0)/\sigma(K_I^0)$. See Figures in the paper for the excluded R^0 production rates as a function of $\Delta D_A M_c^0$ mass and lifetime. Using the production rates expected from perturbative QCD, and assuming dominance of the above decay channels over the suitable phase space, R^0 masses in the range 0.8–5 GeV are excluded at 90%CL for a large fraction of the sensitive lifetime region. ALAVI-HARATI 99E updates and supersedes
- 16 BAER 99 set constraints on the existence of stable \widetilde{g} hadrons, in the mass range $m_{\widetilde{g}} > 3$ GeV. They argue that strong-interaction effects in the low-energy annihilation rates could leave small enough relic densities to evade cosmological constraints up to $m_{\widetilde{g}} < 10$ TeV. They consider jet+ $\not\!\!E_T$ as well as heavy-ionizing charged-particle signatures from production of stable \widetilde{g} hadrons at LEP and Tevatron, developing modes for the energy loss production of stable \widetilde{g} nations at LEP and revarion, developing modes for the energy loss of \widetilde{g} hadrons inside the detectors. Results are obtained as a function of the fragmentation probability P of the \widetilde{g} into a charged hadron. For P<1/2, and for various energy-loss models, OPAL and CDF data exclude gluinos in the $3 < m_{\widetilde{g}}(\text{GeV}) < 130$ mass range. For P>1/2, gluinos are excluded in the mass ranges $3 < m_{\widetilde{g}}(\text{GeV}) < 23$ and $50 < m_{\widetilde{g}}({
 m GeV}) < 200.$
- 17 FANTI 99 looked for 0 bound states yielding high 0 0 0 decays. The experiment is sensitive to a region of R^0 mass and lifetime in the ranges of 1–5 GeV and 10^{-10} – 10^{-3} s. The limits obtained depend on $B(R^0\to\eta\tilde{\gamma})$, on the value of $m_{R^0}/m_{\widetilde{\gamma}}$, and on the ratio of production rates $\sigma(R^0)/\sigma(K_I^0)$. See Fig. 6–7 for the excluded production rates as a function of R^0 mass and lifetime.
- 18 ACKERSTAFF 98v excludes the light gluino with universal gaugino mass where charginos, neutralinos decay as $\widetilde{\chi}_1^{\pm},\widetilde{\chi}_2^0 \to q \overline{q} \widetilde{g}$ from total hadronic cross sections at \sqrt{s} =130–172
- GeV. See paper for the case of nonuniversal gaugino mass. ¹⁹ ADAMS 97B looked for $\rho^0 \to \pi^+\pi^-$ as a signature of $R^0 = (\tilde{g} \, g)$ bound states. The experiment is sensitive to an R^0 mass range of 1.2-4.5 GeV and to a lifetime range of 10^{-10} - 10^{-3} sec. Precise limits depend on the assumed value of $m_{R^0}/m_{\widetilde{\gamma}^*}$. See Fig. 7 for the excluded mass and lifetime region.
- for the excluded mass and interime region.

 20 ALBUQUERQUE 97 looked for weakly decaying baryon-like states which contain a light gluino, following the suggestions in FARRAR 96. See their Table 1 for limits on the production fraction. These limits exclude gluino masses in the range 100-600 MeV for the predicted lifetimes (FARRAR 96) and production rates, which are assumed to be comparable to those of strange or charmed baryons.
- $^{21}\,\mathrm{BARATE}$ 97L studied the QCD color factors from four-jet angular correlations and the differential two-jet rate in Z decay. Limit obtained from the determination of $n_f=4.24\pm0.29\pm1.15$, assuming $T_F/C_F=3/8$ and $C_A/C_F=9/4$.
- 22 CSIKOR 97 combined the α_S from $\sigma(e^+e^-\to hadron),~\tau$ decay, and jet analysis in Z decay. They exclude a light gluino below 5 GeV at more than 99.7%CL.
- Z decay. They exclude a light guillo below 5 dev at more than 27.74c.

 32 DEGOUVEA 97 reanalyzed AKERS 95A data on Z decay into four jets to place constraints on a light stable gluino. The mass limit corresponds to the pole mass of 2.8 GeV. The analysis, however, is limited to the leading-order QCD calculation.
 24 FARRAR 96 studied the possible $R^0 = (\tilde{g} \, g)$ component in Fermilab E799 experiment and used its bound $B(K_L^0 \to \pi^0 \nu \overline{\nu}) \le 5.8 \times 10^{-5}$ to place constraints on the combination of \mathbb{R}^0 production cross section and its lifetime.
- 25 AKERS 95R looked for Z decay into $q\overline{q}\,\widetilde{g}\,\widetilde{g}$, by searching for charged particles with dE/dx consistent with \widetilde{g} fragmentation into a state ($\widetilde{g}\,q\overline{q})^{\pm}$ with lifetime $\tau>10^{-7}$ sec. The fragmentation probability into a charged state is assumed to be 25%.
- 26 CLAVELLI 95 updates the analysis of CLAVELLI 93, based on a comparison of the hadronic widths of charmonium and bottomonium S-wave states. The analysis includes a parametrization of relativistic corrections. Claims that the presence of a light gluino with the data by claving days the unning of control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the control of the contr improves agreement with the data by slowing down the running of $lpha_{S}$.
- improves agreement with the data by slowing down the running or α_S . 27 CAKIR 94 reanalyzed TUTS 87 and later unpublished data from CUSB to exclude pseudo-scalar gluinonium $\eta_{\widetilde{g}}(\widetilde{g})$ of mass below 7 GeV. It was argued, however, that the perturbative QCD calculation of the branching fraction $T \to \eta_{\widetilde{g}} \gamma$ is unreliable for $m_{\eta_{\widetilde{g}}} < 3$ GeV. The gluino mass is defined by $m_{\widetilde{g}} = (m_{\eta_{\widetilde{q}}})/2$. The limit holds for any gluino lifetime. 28 LOPEZ 93c uses combined restraint from the radiative symmetry breaking scenario within the minimal supergrayity model, and the LEP bounds on the $(M_{\Omega,U})$ plane. Claims that
- the minimal supergravity model, and the LEP bounds on the (M_2,μ) plane. Claims that the light gluino window is strongly disfavored.
- 29 CLAVELLI 92 claims that a light gluino mass around 4 GeV should exist to explain the discrepancy between $\alpha_{\rm S}$ at LEP and at quarkonia (\varUpsilon) , since a light gluino slows the running of the QCD coupling.
- 30 ANTONIADIS 91 argue that possible light gluinos (< 5 GeV) contradict the observed running of $\alpha_{\rm S}$ between 5 GeV and m_Z . The significance is less than 2 s.d. 31 ANTONIADIS 91 interpret the search for missing energy events in 450 GeV/c pN colli-
- sions, AKESSON 91, in terms of light gluinos. 32 NAKAMURA 89 searched for a long-lived ($au\gtrsim 10^{-7}$ s) charge-(± 2) particle with mass
- $\lesssim 1.6$ GeV in proton-Pt interactions at 12 GeV and found that the yield is less than \sim 10^{-8} times that of the pion. This excludes R- Δ^{++} (a $\widetilde{g}\,u\,u\,u$ state) lighter than 1.6
- GeV. 33 The limits assume $m_{\widetilde{q}}=100$ GeV. See their figure 3 for limits vs. $m_{\widetilde{q}}$.
- 34 The gluino mass is defined by half the bound $\widetilde{g}\widetilde{g}$ mass. If zero gluino mass gives a $\widetilde{g}\widetilde{g}$ of mass about 1 GeV as suggested by various glueball mass estimates, then the low-mass bound can be replaced by zero. The high-mass bound is obtained by comparing the data with nonrelativistic potential-model estimates.
- 35 ALBRECHT 86c search for secondary decay vertices from $\chi_{b1}(1P) \to \widetilde{g}\,\widetilde{g}\,g$ where \widetilde{g} 's make long-lived hadrons. See their figure 4 for excluded region in the $m_{\widetilde{g}}-m_{\widetilde{g}}$ and $m_{\widetilde{g}} - m_{\widetilde{q}}$ plane. The lower $m_{\widetilde{g}}$ region below \sim 2 GeV may be sensitive to fragmentation effects. Remark that the \widetilde{g} -hadron mass is expected to be ~ 1 GeV (glueball mass) in the zero \widetilde{g} mass limit.
- 36 BADIER 86 looked for secondary decay vertices from long-lived \widetilde{g} -hadrons produced at 300 GeV π^- beam dump. The quoted bound assumes \widetilde{g} -hadron nucleon total cross section of $10\mu b$. See their figure 7 for excluded region in the $m_{\widetilde{g}}-m_{\widetilde{q}}$ plane for several assumed total cross-section values.
- 37 BARNETT 86 rule out light gluinos (m=3–5 GeV) by calculating the monojet rate from gluino gluino gluon events (and from gluino gluino events) and by using UA1 data from $p\overline{p}$ collisions at CERN.

Supersymmetric Particle Searches

- 38 VOLOSHIN 86 rules out stable gluino based on the cosmological argument that predicts too much hydrogen consisting of the charged stable hadron \tilde{g} uud. Quasi-stable $(\tau>1.\times 10^{-7}\text{s})$ light gluino of $m_{\widetilde{g}}<3$ GeV is also ruled out by nonobservation of the stable charged particles, \tilde{g} uud, in high energy hadron collisions.
- 39 COOPER-SARKAR 85B is BEBC beam-dump. Gluinos decaying in dump would yield $\tilde{\gamma}$'s in the detector giving neutral-current-like interactions. For $m_{\widetilde{q}} > 330$ GeV, no limit
- 40 DAWSON 85 first limit from neutral particle search. Second limit based on FNAL beam
- 41 FARRAR 85 points out that BALL 84 analysis applies only if the \widetilde{g} 's decay before interacting, i.e. $m_{\widetilde{q}} < 80 m_{\widetilde{g}}^{-1.5}$. FARRAR 85 finds $m_{\widetilde{g}} < 0.5$ not excluded for $m_{\widetilde{q}} = 30$ –1000 GeV and $m_{\widetilde{g}} < 1.0$ not excluded for $m_{\widetilde{q}} = 100$ –500 GeV by BALL 84 experiment.
- 42 GOLDMAN $^{"}$ 85 use nonobservation of a pseudoscalar \widetilde{g} - \widetilde{g} bound state in radiative ψ
- $^{43}\,\text{HABER}$ 85 is based on survey of all previous searches sensitive to low mass $\widetilde{\textit{g}}$'s. Limit makes assumptions regarding the lifetime and electric charge of the lightest supersym-
- 44 BALL 84 is FNAL beam dump experiment. Observed no interactions of $\widetilde{\gamma}$ in the calorimeter, where $\widetilde{\gamma}$'s are expected to come from pair-produced \widetilde{g} 's. Search for long-lived $\widetilde{\gamma}$ interacting in calorimeter 56m from target. Limit is for $m_{\widetilde{q}}=40$ GeV and production
- cross section proportional to A $^{0.72}$. BALL 84 find no \widetilde{g} allowed below 4.1 GeV at CL = 90%. Their figure 1 shows dependence on $m_{\widetilde{q}}$ and A. See also KANE 82.
- 45 BRICK 84 reanalyzed FNAL 147 GeV HBC data for R- Δ (1232) $^{++}$ with au $\,>$ 10^{-9} s and $\rho_{\mathsf{lab}} > 2$ GeV. Set CL = 90% upper limits 6.1, 4.4, and 29 microbarns in ρp , $\pi^+ p$, K+p collisions respectively. $R-\Delta ++$ is defined as being \tilde{g} and 3 up quarks. If mass = 1.2–1.5 GeV, then limits may be lower than theory predictions.
- 46 FARRAR 84 argues that $m_{\widetilde{g}} < 100$ MeV is not ruled out if the lightest R-hadrons are long-lived. A long lifetime would occur if R-hadrons are lighter than $\widetilde{\gamma}$'s or if $m_{\overline{g}} > 100$
- 47 BERGSMA 83c is reanalysis of CERN-SPS beam-dump data. See their figure 1.
- 48 CHANOWITZ 83 find in bag-model that charged s-hadron exists which is stable against strong decay if $m_{\widetilde{g}}$ <1 GeV. This is important since tracks from decay of neutral shadron cannot be reconstructed to primary vertex because of missed $\tilde{\gamma}$. Charged s-hadron leaves track from vertex.
- 49 KANE 82 inferred above \widetilde{g} mass limit from retroactive analysis of hadronic collision and beam dump experiments. Limits valid if \widetilde{g} decays inside detector.

LIGHT \tilde{G} (Gravitino) MASS LIMITS FROM COLLIDER EXPERIMENTS

The following are bounds on light ($\ll 1\,\mathrm{eV}$) gravitino indirectly inferred from its coupling to matter suppressed by the gravitino decay constant.

Unless otherwise stated, all limits assume that other supersymmetric particles besides the gravitino are too heavy to be produced. The gravitino is assumed to be undetected and to give rise to a missing energy (₺) signature.

| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|--------------------------|-----------|-------------------------|-------|-----------|--------------------------------------------------------------------------|
| • • • We do not | use the f | ollowing data for a | verag | es, fits, | limits, etc. • • • |
| $> 1.09 \times 10^{-5}$ | 95 | ¹ ABDALLAH | 05в | DLPH | $e^+e^- ightarrow \ \widetilde{G} \ \widetilde{G} \gamma$ |
| $> 1.35 \times 10^{-5}$ | 95 | ² ACHARD | 04 E | L3 | $e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$ |
| $> 1.3 \times 10^{-5}$ | | ³ HEISTER | 03c | ALEP | $e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$ |
| >11.7 × 10 ⁻⁶ | 95 | ⁴ ACOSTA | 02н | CDF | $p \overline{p} \rightarrow \widetilde{G} \widetilde{G} \gamma$ |
| $> 8.7 \times 10^{-6}$ | 95 | ⁵ ABBIENDI,G | 00D | OPAL | $e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$ |
| $>10.0 \times 10^{-6}$ | 95 | ⁶ ABREU | 00 z | DLPH | $e^+e^- ightarrow \ \widetilde{G} \ \widetilde{G} \ \gamma$ |
| $>11 \times 10^{-6}$ | 95 | ⁷ AFFOLDER | 001 | CDF | $\rho \overline{p} \rightarrow \widetilde{G} \widetilde{G} + \text{jet}$ |
| $> 8.9 \times 10^{-6}$ | 95 | ⁸ ACCIARRI | 99R | L3 | $e^+e^- ightarrow \ \widetilde{G} \ \widetilde{G} \ \gamma$ |
| $> 7.9 \times 10^{-6}$ | 95 | ⁹ ACCIARRI | 98∨ | L3 | $e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$ |
| $> 8.3 \times 10^{-6}$ | 95 | ⁹ BARATE | 98J | ALEP | $e^+e^- \rightarrow \widetilde{G}\widetilde{G}\gamma$ |

- 1 ABDALLAH 05B use data from $\sqrt{s}=180$ –208 GeV. They look for events with a single photon $+ \not\!\!E$ final states from which a cross section limit of $\sigma < 0.18 \ pb$ at 208 GeV is
- photon $+\not$ \not mind states from which a closs section limit of x < 0.10 pb at 200 GeV is obtained, allowing a limit on the mass to be set. Supersedes the results of ABREU 00z. ² ACHARD 04E use data from $\sqrt{s} = 189$ –209 GeV. They look for events with a single photon $+\not$ \not final states from which a limit on the Gravitino mass is set corresponding to $\sqrt{F} > 238$ GeV. Supersedes the results of ACCIARRI 99R.
- to $\sqrt{F} > 238$ GeV. Supersedes the results of ACCIARKI 99K.

 ³ HEISTER 03C use the data from $\sqrt{s} = 189-209$ GeV to search for $\gamma \not\!\!E_T$ final states.

 ⁴ ACOSTA 02H looked in 87 pb^{-1} of $\rho \overline{\rho}$ collisions at $\sqrt{s} = 1.8$ TeV for events with a high- E_T photon and $\not\!\!E_T$. They compared the data with a GMSB model where the final state could arise from $q\overline{q} \to \widetilde{G}\ \widetilde{G}\ \gamma$. Since the cross section for this process scales as $1/|F|^4$, a limit at 95% CL is derived on $|F|^{1/2} > 221$ GeV. A model independent limit for the above topology is also given in the paper.

 ⁵ ARRIENDI G 000 searches for γE final states from $\sqrt{s} = 189$ GeV.
- ⁵ ABBIENDI,G 00D searches for γE final states from \sqrt{s} =189 GeV.
- ⁶ ABREU 00Z search for γE final states using data from \sqrt{s} =189 GeV. Superseded by ABDALLAH 05B
- AFFOLDER 00J searches for final states with an energetic jet (from quark or gluon) and large $ot\!\!E_T$ from undetected gravitinos
- 8 ACCIARRI 99R search for γE final states using data from \sqrt{s} =189 GeV. Superseded by 9 Searches for γE final states at \sqrt{s} =183 GeV.

Supersymmetry Miscellaneous Results

Results that do not appear under other headings or that make nonminimal assumptions.

| VALUE | CL% | DO CUMENT ID | TECN | COMMENT |
|---------------------------|---------------|-------------------------|------------|---------------------|
| • • • We do not use the f | ollowing data | for averages, fits, lin | nits, etc. | • • • |
| none 100-185 | 95 | AAD 11AA | ATLS | scalar gluons |
| | 2 | CHATRCHYAN11E | CMS | $\mu\mu$ resonances |

| ³ ABAZOV | 1 0 N | D0 | γ_D , hidden valley |
|-------------------------|-------|------|-----------------------------------------------------------|
| ⁴ LOVE | 08A | CLEO | $R, Y \rightarrow \mu \tau$ |
| ⁵ ABULENCIA | 06P | CDF | $\ell \gamma E_T$, $\ell \ell \gamma$, GMSB |
| ⁶ ACOSTA | 04E | CDF | |
| ⁷ TCHIKILEV | 04 | ISTR | $K^- \rightarrow \pi^- \pi^0 P$ |
| ⁸ AFFOLDER | 02D | CDF | $p \overline{p} \rightarrow \gamma b (E_T)$ |
| ⁹ AFFOLDER | 01н | CDF | $p \overline{p} \rightarrow \gamma \gamma X$ |
| ¹⁰ ABBOTT | 00g | D0 | $p\overline{p} \to 3\ell + \cancel{E}_T$, \cancel{R} , |
| 1.1 | | | , LL E |
| ¹¹ ABREU,P | 00c | DLPH | $e^+e^- \rightarrow \gamma + S/P$ |
| ¹² АВАСНІ | 97 | D0 | $\gamma \gamma X$ |
| ¹³ BARBER | 84B | RVUE | |
| ¹⁴ HOFF MA N | 83 | CNTR | $\pi p \rightarrow n(e^+e^-)$ |
| | | | |

- jets originating from pair production of scalar gluons, each decaying to two gluons. No two-jet resonances are observed over the SM background. Limits are derived on the cross section times branching ratio (see Fig. 3). Assuming 100% branching ratio for the decay to two gluons, the quoted exclusion range is obtained, except for a 5 GeV mass window around 140 GeV. ${}^2\text{CHATRCHYAN 11E looked in 35 pb}^{-1} \text{ of } pp \text{ collisions at } \sqrt{s} = 7 \text{ TeV for events with collimated } \mu \text{ pairs (leptonic jets) from the decay of hidden sector states. No evidence for new resonance production is found. Limits are derived and compared to various SUSY models (see Fig. 4) where the LSP, either the <math>\tilde{v}^0$ or a \tilde{a} , decays to dark sector particles.
- models (see Fig. 4) where the LSP, either the $\widetilde{\chi}_1^0$ or a \widetilde{q} , decays to dark sector particles.
- ³ ABAZOV 10N looked in 5.8 fb⁻¹ of $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV for events from ABACOV for looked in 8.6 in on pp consisting at $\sqrt{s} \equiv 1.96$ feV for events from hidden valley models in which a $\overline{\chi}_1^0$ decays into a dark photon, γ_D , and the unobservable lightest SUSY particle of the hidden sector. As the γ_D is expected to be light, it may decay into a tightly collimated lepton pair, called lepton jet. They searched for events with E_T and two isolated lepton jets observable by an opposite charged lepton pair e_E . $e\,\mu$ or μ . No significant excess over the SM expectation is observed, and a limit at 95% C.L. on the cross section times branching ratio is derived, see their Table I. They also examined the invariant mass of the lepton jets for a narrow resonance, see their Fig. 4, but found no evidence for a signal.
- ⁴ LOVE 08A searched for decays of Y(nS) with n = 1, 2, 3 into $\mu\tau$ in 1.1, 1.3, 1.4 fb⁻¹, respectively, in the CLEO III detector at CESR. The signature is a muon with \approx 97 % of the beam energy and an electron from the decay of τ . No evidence for lepton flavour violation is found and 95% CL limits on the branching ratio are estimated to be 6.0, 14.4 and 20.3 \times 10⁻⁶ for n = 1, 2, 3, respectively. Shall be a substitution of proposition of pr
- of events with $\ell\gamma E_T$ and $\ell\ell\gamma$ ($\ell=e,\mu$). No significant excess was found compared to the background expectation. No events are found such as the $e\,e\,\gamma\gamma E_T$ event observed
- 6 ACOSTA 04E looked in $107~pb^{-1}$ of $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV for events with two same sign leptons without selection of other objects nor E_T . No significant excess is observed compared to the Standard Model expectation and constraints are derived on the parameter space of MSUGRA models, see Figure 4.
- 7 Looked for the scalar partner of a goldstino in decays $\,{\it K}^-
 ightarrow \,\, \pi^- \pi^0 \, P$ from a 25 GeV K^- beam produced at the IHEP 70 GeV proton synchrotron. The sgoldstino is assumed to be sufficiently long-lived to be invisible. A 90% CL upper limit on the decay branching ratio is set at $\sim 9.0 \times 10^{-6}$ for a sgoldstino mass range from 0 to 200 MeV, excluding the interval near $m(\pi^0)$, where the limit is $\sim 3.5 \times 10^{-5}$
- ⁸ AFFOLDER 02D looked in 85 pb $^{-1}$ of $\rho\overline{p}$ collisions at \sqrt{s} =1.8 TeV for events with a high- E_T photon, and a b-tagged jet with or without E_T . They compared the data with models where the final state could arise from cascade decays of gluinos and/or squarks into $\widetilde{\chi}^\pm$ and $\widetilde{\chi}^0_2$ or direct associated production of $\widetilde{\chi}^0_2\widetilde{\chi}^\pm_2$, followed by $\widetilde{\chi}^0_2 \to \gamma\widetilde{\chi}^0_1$ or
- a GMSB model where $\tilde{\chi}_1^0 \to \gamma \tilde{G}$. It is concluded that the experimental sensitivity is insufficient to detect the associated production or the GMSB model, but some sensitivity may exist to the cascade decays. A model independent limit for the above topology is
- 9 AFFOLDER 01H searches for $p\overline{p}\to\gamma\gamma$ X events, where the di-photon system originates from sgoldstino production, in $100\,\mathrm{pb}^{-1}$ of data. Upper limits on the cross section times branching ratio are shown as function of the di-photon mass >70 GeV in Fig. 5. Excluded regions are derived in the plane of the sgoldstino mass versus the supersymmetry breaking scale for two representative sets of parameter values, as shown in Figs. 6 and 7.
- 10 ABBOTT 00G searches for trilepton final states $(\ell = e, \mu)$ with $ot\!\!E_T$ from the indirect decay of gauginos via $LL\overline{E}$ couplings. Efficiencies are computed for all possible production and decay modes of SUSY particles in the framework of the Minimal Supergravity scenario. See Figs. 1–4 for excluded regions in the $m_{1/2}$ versus m_0 plane.
- 11 ABREU,P 00c look for the *CP*-even (*S*) and *CP*-odd (*P*) scalar partners of the goldstino, expected to be produced in association with a photon. The S/P decay into two photons or into two gluons and both the tri-photon and the photon + two jets topologies are investigated. Upper limits on the production cross section are shown in Fig. 5 and the excluded regions in Fig. 6. Data collected at $\sqrt{s} = 189-202$ GeV.
- To a BACH 197 searched for $p\bar{p}\to\gamma\gamma$ $E\gamma+X$ as supersymmetry signature. It can be caused by selectron, sneutrino, or neutralino production with a radiative decay of their decay products. They placed limits on cross sections.
- 13 BARBER 84B consider that $\widetilde{\mu}$ and \widetilde{e} may mix leading to $\mu \to e \, \widetilde{\gamma} \widetilde{\gamma}$. They discuss massmixing limits from decay dist. asym. in LBL-TRIUMF data and e^+ polarization in SIN
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| AFFOLDER 01J PRL 87 251803 BALTZ 01 PRL 86 5004 BARATE 01 PL B499 67 BARATE 01B EPJ C19 415 BARGER 01C PL B518 117 BAUDIS 01 PR D43 022001 BENOIT 01 PL B513 15 | T. Affolder et al. (CDF Collab.) E. Baltz, P. Gondolo R. Barate et al. (ALEPH Collab.) R. Barate et al. (ALEPH Collab.) V. Barger, C. Kao L. Baudis et al. (Heidelberg-Mossow Collab.) A. Benoit et al. (EDELWEISS Collab.) | BERNABEI 98C PL B436 379 BREITWEG 98 PL B434 214 ELLIS 98 PR D58 095002 ELLIS 98B PL B444 367 PDG 98 EPJ C3 1 ABACHI 97 PRL 78 2070 ABBOTT 97B PRL 79 4321 | R. Bernabei et al. (DAMA Collab.) J. Breilweg et al. (ZEUS Collab.) J. Ellis et al. J. Ellis, T. Falk, K. Olive C. Caso et al. S. Abachi et al. (DO Collab.) B. Abbott et al. (DO Collab.) |
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Technicolor

DYNAMICAL ELECTROWEAK SYMMETRY BREAKING

Revised April 2012 by R.S. Chivukula (Michigan State University), M. Narain (Brown University), and J. Womersley (STFC, Rutherford Appleton Laboratory).

In theories of dynamical electroweak symmetry breaking, the electroweak interactions are broken to electromagnetism by the vacuum expectation value of a fermion bilinear. These theories may thereby avoid the introduction of fundamental scalar particles, of which we have no examples in nature. In this note, we review the status of experimental searches for the particles predicted in technicolor, topcolor, and related models. The limits from these searches are summarized in Table 1.

I. Technicolor

The earliest models [1,2] of dynamical electroweak symmetry breaking [3] include a new asymptotically free non-abelian gauge theory ("technicolor") and additional massless fermions ("technifermions" transforming under a vectorial representation of the gauge group) which feel this new force. The global chiral symmetry of the fermions is spontaneously broken by the formation of a technifermion condensate, just as the approximate chiral $SU(2) \times SU(2)$ symmetry in QCD is broken down to SU(2) isospin by the formation of a quark condensate. If the quantum numbers of the technifermions are chosen correctly (e.g., by choosing technifermions in the fundamental representation of an SU(N) technicolor gauge group, with the left-handed technifermions being weak doublets and the right-handed ones weak singlets), this condensate can break the electroweak interactions down to electromagnetism.

The breaking of the global chiral symmetries implies the existence of Goldstone bosons, the "technipions" (π_T) . Through the Higgs mechanism, three of the Goldstone bosons become the longitudinal components of the W and Z, and the weak gauge bosons acquire a mass proportional to the technipion decay constant (the analog of f_{π} in QCD). The quantum numbers and masses of any remaining technipions are model-dependent. There may be technipions which are colored (octets and triplets), as well as those carrying electroweak quantum numbers, and some color-singlet technipions are too light [4,3] unless additional sources of chiral-symmetry breaking are introduced. The next lightest technicolor resonances are expected to

Table 1: Summary of the mass limits. Symbols are defined in the text.

| Process | Excluded mass range | Decay channels | Ref. |
|---------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|----------------------|
| $\overline{p\overline{p}} \to \rho_T \to W \pi_T$ | $170 < m_{\rho_T} < 215 \text{ GeV}$ and $80 < m_{\pi_T} < 115 \text{ GeV}$ for $M_V = 500 \text{ GeV}$ | $\begin{array}{c} \rho_T \to W \pi_T \\ \pi_T^0 \to b \overline{b} \\ \pi_T^{\pm} \to b \overline{c} \end{array}$ | [24] |
| $pp 	o \omega_T/\rho_T$ | $130 < m_{\rho_T/\omega_T} < 180 \text{ GeV}$ for $50 < m_{\pi_T} < 480 \text{ GeV}$ | $\omega_T/\rho_T \to \ell^+\ell^-$ | [36] |
| $pp \to \rho_T/a_T$ | $m_{\rho_T/a_T} < 382 \text{ GeV}$ for $M(\pi_T) = \frac{3}{4}M(\rho_T) - 25 \text{ GeV}$ | $\rho_T \to WZ \to \ell\ell\ell\nu$ | [37] |
| | $m_{\rho_T/a_T}^{4} < 436 \text{ GeV}$ for $M(\rho_T) < M(\pi_T) + M_W$ | $\rho_T \to WZ \to \ell\ell\ell\nu$ | [37] |
| $p\overline{p} \to \omega_T \to \gamma \pi_T$ | $140 < m_{\omega_T} < 290 \text{ GeV}$ for $m_{\pi_T} \approx m_{\omega_T}/3$ and $M_T = 100 \text{ GeV}$ | $egin{array}{l} \omega_T ightarrow \gamma \pi_T \ \pi_T^0 ightarrow b \overline{b} \ \pi_T^\pm ightarrow b \overline{c} \end{array}$ | [26] |
| $p\overline{p} 	o \omega_T/\rho_T$ | $\begin{split} m_{\omega_T} &= m_{\rho_T} < 203 \text{ GeV} \\ \text{for } m_{\omega_T} &< m_{\pi_T} + m_W \\ \text{or } M_T &> 200 \text{ GeV} \end{split}$ | $\omega_T/\rho_T \to \ell^+\ell^-$ | [27] |
| | $m_{\omega_T} = m_{\rho_T} < 280 \text{ GeV}$ for $m_{\omega_T} < m_{\pi_T} + m_W$ or $M_T > 500 \text{ GeV}$ | $\omega_T/\rho_T \to \ell^+\ell^-$ | [28] |
| $e^+e^- 	o \omega_T/\rho_T$ | $90 < m_{\rho_T} < 206.7 \text{ GeV}$ $m_{\pi_T} < 79.8 \text{ GeV}$ | $ \rho_T \to WW, W\pi_T, \ \pi_T\pi_T, \gamma\pi_T, \text{ hadrons} $ | [29] |
| $p\overline{p} \to \rho_{T8}$ | $260 < m_{\rho_{T8}} < 480 \text{ GeV}$ | $ \rho_{T8} \to q\overline{q}, \ gg $ | [31] |
| $ \overline{p\overline{p}} \to \rho_{T8} \\ \to \pi_{LQ} \pi_{LQ} $ | $m_{ ho_{T8}} < 510 \; { m GeV} \ m_{ ho_{T8}} < 600 \; { m GeV} \ m_{ ho_{T8}} < 465 \; { m GeV} \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \$ | $\begin{array}{l} \pi_{LQ} \to c\nu \\ \pi_{LQ} \to b\nu \\ \pi_{LQ} \to \tau q \end{array}$ | [34] [34] [33] |
| $p\overline{p} 	o g_t$ | $0.3 < m_{g_t} < 0.6 \text{ TeV}$ for $0.3 m_{g_t} < \Gamma < 0.7 m_{g_t}$ | $g_t \to b\overline{b}$ | [47] |
| $p\overline{p} 	o Z'$ | $m_{Z'} < 900 \text{ GeV}$ $m_{Z'} < 835 \text{ GeV}$ for $\Gamma = 0.012 m_{Z'}$ $m_{Z'} < 940 \text{ GeV}$ for $\Gamma = 0.03 m_{Z'}$ | $Z' \to t\bar{t}$ $Z' \to t\bar{t}$ | [48] [49] |
| $\frac{pp \to Z'}{}$ | $m_{Z'} < 500 - 860 \text{ GeV}$ | $Z' \to t \overline{t}$ | [50] |
| $p\overline{p} \to \text{Coloron}$ | $m_{Coloron} < 775 \text{ GeV}$ for $\Gamma = 0.12 m_{coloron}$ and $r=0.2$ | $Coloron \to t\overline{t}$ | [49] |
| $pp \to \text{Coloron}$ | $320 < m_{Coloron} < 580 \text{ GeV}$ | $Coloron \to q\overline{q}$ | [63] |

be the analogs of the vector mesons in QCD. The technivector mesons can also have color and electroweak quantum numbers and, for a theory with a small number of technifermions, are expected to have a mass in the TeV range [5].

While technicolor chiral symmetry breaking can give mass to the W and Z particles, additional interactions must be introduced to produce the masses of the standard model fermions. The most thoroughly studied mechanism for this invokes "extended technicolor" (ETC) gauge interactions [4,6]. In ETC, technicolor and flavor are embedded into a larger gauge group, which is broken at a sequence of mass scales down to the residual, exact technicolor gauge symmetry. The massive gauge bosons associated with this breaking mediate

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transitions between quarks/leptons and technifermions, giving rise to the couplings necessary to produce fermion masses. The ETC gauge bosons also mediate transitions among technifermions themselves, leading to interactions which can explicitly break unwanted chiral symmetries and raise the masses of any light technipions. The ETC interactions connecting technifermions to quarks/leptons also mediate technipion decays to ordinary fermion pairs. Since these interactions are responsible for fermion masses, one generally expects technipions to decay to the heaviest fermions kinematically allowed (though this need not hold in all models).

In addition to quark masses, ETC interactions must also give rise to quark mixing. One expects, therefore, that there are ETC interactions coupling quarks of the same charge from different generations. A stringent limit on these flavor-changing neutral current interactions comes from $K^0 - \overline{K}^0$ mixing [4]. These force the scale of ETC breaking and the corresponding ETC gauge boson masses to be in the 100-1000 TeV range (at least insofar as ETC interactions of first two generations are concerned). To obtain quark and technipion masses that are large enough then requires an enhancement of the technifermion condensate over that expected naively by scaling from QCD. Such an enhancement can occur if the technicolor gauge coupling runs very slowly, or "walks" [7]. Some theories of walking technicolor incorporate many technifermions, implying that the technicolor scale and, in particular, the technivector mesons may be much lighter than 1 TeV [3,8].

It should be noted that there are no reliable analytical calculation techniques to analyze the properties of strongly-coupled gauge theories. Recently, however, progress has been made in simulating these theories using lattice gauge theory [9], including preliminary studies of condensate enhancement [10], precision electroweak parameters and parity doubling [11,12,13], and vector-boson scattering [14]. Progress has also been made in constructing a complete theory of fermion masses (including neutrino masses) in the context of extended technicolor [15].

In existing colliders, technivector mesons are dominantly produced when an off-shell standard model gauge boson "resonates" into a technivector meson with the same quantum numbers [16]. The technivector mesons may then decay, in analogy with $\rho \to \pi\pi$, to pairs of technipions. However, in walking technicolor the technipion masses may be increased to the point that the decay of a technirho to pairs of technipions is kinematically forbidden [8]. In this case the decay to a technipion and a longitudinally polarized weak boson (an "eaten" Goldstone boson) may be preferred, and the technivector meson would be very narrow. Alternatively, the technivector may also decay, in analogy with the decay $\rho \to \pi \gamma$, to a technipion plus a photon, gluon, or transversely polarized weak gauge boson. Finally, in analogy with the decay $\rho \to e^+e^-$, the technivector meson may resonate back to an off-shell gluon or electroweak gauge boson, leading to a decay into a pair of leptons, quarks, or gluons.

When comparing the various results presented in this review, one should be aware that the more recent analyses [23,24,27,29] make use of newer calculations [17] of technihadron production and decay, as implemented in PYTHIA [19] version 6.126 and higher [20]. The LHC analyses use the calculations given in reference [18] and PYTHIA [19] version 6.4. The results obtained with older cross section calculations are not generally directly comparable, and have only been listed in Table 1 when newer results are not available.

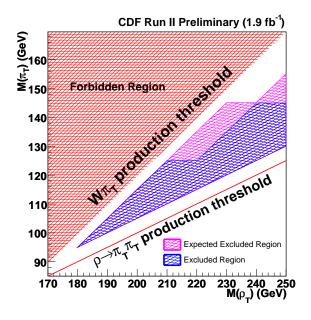
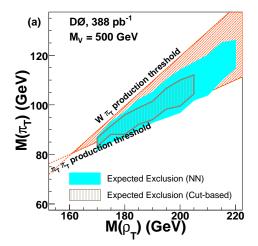


Figure 1: Search for a light technirho decaying to W^{\pm} and a π_T , and in which the π_T decays to two jets including at least one b quark [23]. Exclusion region at the 95% C.L. in the $M(\rho_T), M(\pi_T)$ plane for $\rho_T \to W \pi_T \to e \nu \ b \bar{b}(\bar{c})$ production. Kinematic thresholds from $W \pi_T$ and $\pi_T \pi_T$ are shown on the figure.

If the dominant decay mode of the technirho is $W_L\pi_T$, promising signal channels [21] are $\rho_T^\pm \to W^\pm\pi_T^0$ and $\rho_T^0 \to W^\pm\pi_T^\mp$. If we assume that the technipions decay to $b\overline{b}$ (neutral) and $b\overline{c}$ (charged), then both channels yield a signal of $W(\ell\nu)+2$ jets, with one or more heavy flavor tags. The CDF collaboration carried out a search in this final state [22] based on Run I data and using PYTHIA version 6.1 for the signal simulation. Using 1.9 fb⁻¹ of data from Run II, CDF [23] has published an update of this analysis. A large region of $M(\rho_T)=180-250$ GeV and $M(\pi_T)=95-145$ GeV are excluded at 95% CL, with the exact exclusion region displayed in Fig. 1.

The DØ [24] collaboration published an analysis based on 388 pb⁻¹ of data from Run II and PYTHIA 6.22. The searches are sensitive to $\sigma \cdot B \gtrsim 4$ pb and DØ finds mass combinations up to $m_{\rho_T}=215$ GeV, $m_{\pi_T}=115$ GeV to be excluded for certain values of the model parameters. The expected sensitivity and the region excluded at 95% C.L. by the DØ analysis for $M_V=500$ GeV is shown in Fig. 2. For $M_V=100$ GeV, only a



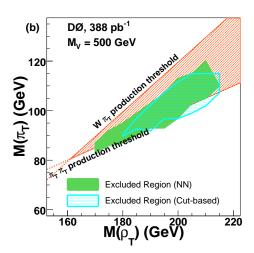


Figure 2: Search for a light technirho decaying to W^{\pm} and a π_T , and in which the π_T decays to two jets including at least one b quark [24]. Expected region of exclusion (a) and excluded region (b) at the 95% C.L. in the $M(\rho_T), M(\pi_T)$ plane for $\rho_T \to W \pi_T \to e \nu \ b \bar{b}(\bar{c})$ production with $M_V = 500$ GeV. Kinematic thresholds from $W \pi_T$ and $\pi_T \pi_T$ are shown on the figures.

small region around $M(\rho_T)=190$ GeV and $M(\pi_T)=95$ GeV can be excluded. For an integrated luminosity of 2 fb⁻¹, the 5σ discovery reach is expected to extend to $m_{\rho_T}=210$ GeV and $m_{\pi_T}=110$ GeV, while the 95% exclusion sensitivity will extend to $m_{\rho_T}=250$ GeV and $m_{\pi_T}=145$ GeV.

DØ has also performed a search for technihadrons decaying to WZ [25]. These decays can be searched in the tri-lepton final state, where the W decays into a lepton and neutrino and the accompanying Z decays to dileptons. With a dataset corresponding to a 4.1 fb⁻¹ of integrated luminosity, DØ excludes ρ_T with mass between 208 and 408 GeV at 95% C.L. for $M(\rho_T) < M(\pi_T) + M(W)$ as displayed in Fig. 4.

CDF also searched [26] in Run I for the process $\omega_T^0 \to \gamma \pi_T^0$, yielding a signal of a hard photon plus two jets, with one or

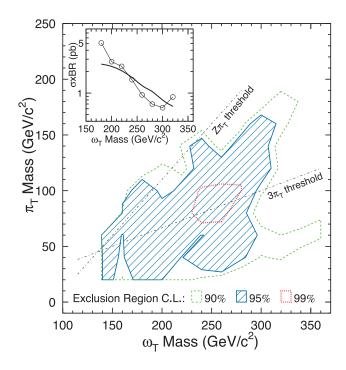


Figure 3: 95% CL exclusion region [26] for a light techniomega decaying to γ and a π_T , and in which the π_T decays to two jets, including at least one b quark. (Inset: cross section limit for $m_{\pi_T} = 120$ GeV.)

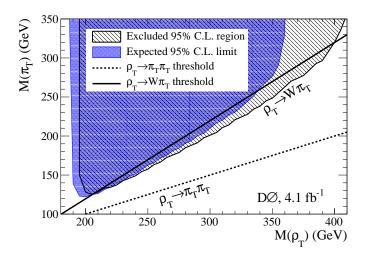


Figure 4: 95% CL exclusion region by the DØ experiment [25] in the $M(\rho_T)$, $M(\pi_T)$ plane for $\rho_T \to WZ \to lll\nu$ (with $l=e,\mu$) final state.

more heavy flavor tags. The sensitivity to $\sigma \cdot B$ is of order 1 pb. The excluded region is shown in Fig. 3 and is roughly $140 < m_{\omega_T} < 290$ GeV at the 95% level, for $m_{\pi_T} \approx m_{\omega_T}/3$.

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The analysis assumes four technicolors, $Q_D = Q_U - 1 = \frac{1}{3}$ and $M_T = 100 \text{ GeV}/c^2$. Here Q_U and Q_D are the charges of the lightest technifermion doublet, and M_T is a dimensionful parameter, of order 100 GeV/ c^2 , which controls the rate of $\rho_T, \omega_T \to \gamma \pi_T$.

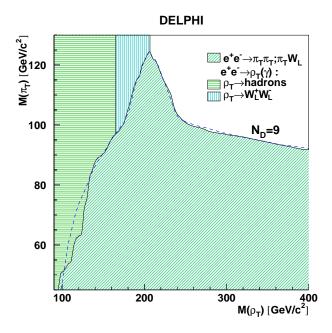


Figure 5: 95% CL exclusion region [29] in the technirho-technipion mass plane obtained from searches by the DELPHI collaboration at LEP 2, for nine technifermion doublets. The dashed line shows the expected limit for the 4-jet analysis.

The DØ experiment has searched [27] for low-scale technicolor resonances ρ_T and ω_T decaying to dileptons, using an inclusive e^+e^- sample from Run I. In the search, the ρ_T and ω_T are assumed to be degenerate in mass. The absence of structure in the dilepton invariant mass distribution is then used to set limits. Masses $m_{\rho_T}=m_{\omega_T}\lesssim 200$ GeV are excluded, provided either $m_{\rho_T}< m_{\pi_T}+m_W$, or $M_T>200$ GeV. The CDF experiment also performed a similar search with 200 pb⁻¹ of Run II data, and excluded equal $m_{\rho_T}=m_{\omega_T}$ masses below 280 GeV for $M_V=500$ GeV and $m_{\rho_T}< m_{\pi_T}+m_W$ at 95% C.L. [28]. With 2 fb⁻¹ of data, the sensitivity will extend to $m_{\rho_T}=m_{\omega_T}\approx 500$ GeV.

DELPHI [29] has reported a search for technicolor production in 452 pb⁻¹ of e^+e^- data taken between 192 and 208 GeV. The analysis combines searches for $e^+e^- \to \rho_T(\gamma)$ with $\rho_T \to W_L W_L$, $\rho_T \to$ hadrons $(\pi_T \pi_T \text{ or } q\overline{q})$, $\rho_T \to \pi_T \gamma$, and $e^+e^- \to \rho_T^* \to W_L \pi_T$ or $\pi_T \pi_T$. Technirho masses in the range $90 < m_{\rho_T} < 206.7$ GeV are excluded, while technipion masses $m_{\pi_T} < 79.8$ GeV are ruled out independent of the parameters of the technicolor model.

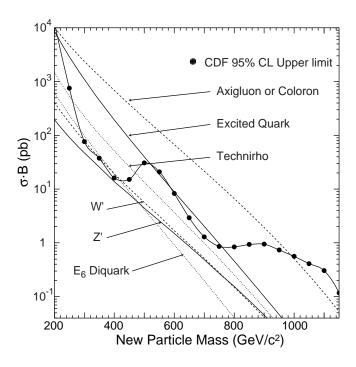


Figure 6: 95% CL Cross-section limits [31] for a technirho decaying to two jets at the Tevatron.

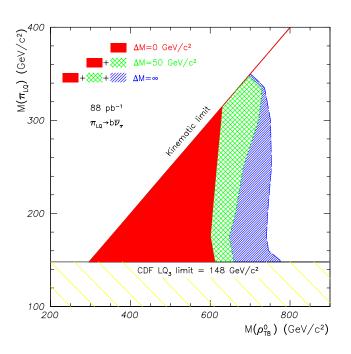


Figure 7: 95% CL exclusion region [34] in the technirho-technipion mass plane for pair produced technipions, with leptoquark couplings, decaying to $b\nu$.

Searches have also been carried out at the Tevatron for colored technihadron resonances [30,31]. CDF has used a search for structure in the dijet invariant mass spectrum to set limits on a color-octet technirho ρ_{T8} produced by an off-shell gluon, and decaying to two real quarks or gluons. As shown in Fig. 6, masses $260 < m_{\rho_{T8}} < 480$ GeV are excluded; in Run II the limits will improve to cover the whole mass range up to about 0.8 TeV [32].

The CDF second- and third-generation leptoquark searches (see Refs. [33,34]) have also been interpreted in terms of the complementary ρ_{T8} decay mode: $p\overline{p} \to \rho_{T8} \to \pi_{LQ}\pi_{LQ}$. Here π_{LQ} denotes a color-triplet technipion carrying both color and lepton number, assumed to decay to $b\nu$ or $c\nu$ [34], or to a τ plus a quark [33]. The searches exclude technirho masses $m_{\rho_{T8}}$ less than 510 GeV ($\pi_{LQ} \to c\nu$), 600 GeV ($\pi_{LQ} \to b\nu$), and 465 GeV ($\pi_{LQ} \to \tau q$) for technipion masses up to $m_{\rho_{T8}}/2$. Figure 7 shows the $\pi_{LQ} \to b\nu$ exclusion region. (Leptoquark masses $m_{\pi_{LQ}}$ less than 123 GeV ($c\nu$), 148 GeV ($b\nu$), and 99 GeV (τq) are already ruled out by standard continuum-production leptoquark searches).

It has been demonstrated that there is substantial uncertainty in the theoretical estimate of the ρ_{T8} production cross section at the Tevatron and that the cross section may be as much as an order of magnitude lower than the naive vector meson dominance estimate [35]. To establish the range of allowed masses, these limits will need to be redone with a reduced theoretical cross section.

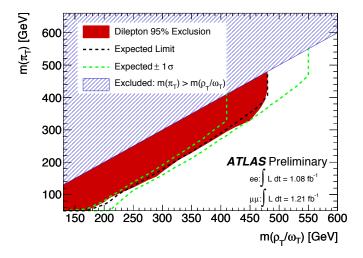


Figure 8: 95% CL excluded region by the ATLAS experiment [36] in the $M(\rho_T), M(\pi_T)$ plane for $\rho_T/\omega_T \to ll \ (l=e,\mu)$.

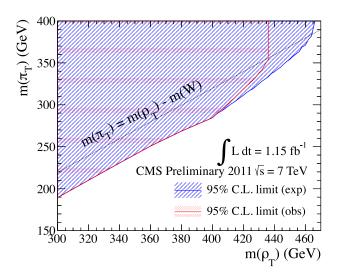


Figure 9: 95% CL Exclusion contour in the $M(\rho_T), M(\pi_T)$ plane for $\rho_T/a_T \to WZ \to lll\nu$ (with $l=e,\mu$) final state by the CMS experiment [37].

Within the context of the model in reference [18], both the ATLAS and CMS experiments have carried out searches for technihadron production in proton-proton collisions at $\sqrt{s} = 7$ TeV LHC running during 2011. An analysis of the process ρ_T and ω_T decaying to $\mu^+\mu^-$ and e^+e^- has been carried out by the ATLAS experiment [36]. This analysis based on 1.08 fb⁻¹ (1.21 fb⁻¹) of integrated luminosity, for the e^+e^- ($\mu^+\mu^-$) channel, as shown in Fig. 8, excludes ρ_T and ω_T with masses in the range 130–480 GeV at 95% CL for π_T masses between 50–480 GeV. The CMS experiment has searched for ρ_T and its axial-vector partner, a_T production at $\sqrt{s} = 7$ TeV using the $\rho_T/a_T \to WZ \to lll\nu$ (with $l = e, \mu$) final state [37]. Using a sample of 1.15 fb⁻¹ of data, CMS excludes ρ_T with masses below 382 GeV in the parameter space $M(\pi_T) = \frac{3}{4}M(\rho_T) - 25$ GeV. If $M(\rho_T) < M(\pi_T) + M_W$, then ρ_T with masses below 436 GeV are excluded. The exclusion contour in the ρ_T vs. π_T mass plane is shown in Fig. 9.

LHC searches for Higgs Bosons in di-photon [40,41] or di-tau [42] decay modes place strong constraints [43] on the light top-pion state predicted in technicolor models that include colored technifermions. Compared with the standard Higgs Boson, the top-pions have an enhanced production rate (largely because the technipion decay constant is smaller than the weak scale) and also enhanced branching ratios into di-photon and di-tau final states (largely due to the suppression of WW decays of the technipions). These factors combine to make such technipions more visible in both channels than a standard model Higgs would be, though the precise bounds are model-dependent.

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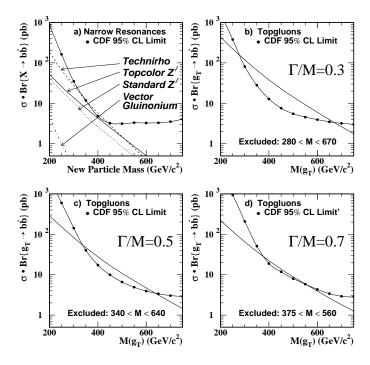


Figure 10: Tevatron limits [47] on new particles decaying to $b\overline{b}$: narrow resonances and topgluons for various widths.

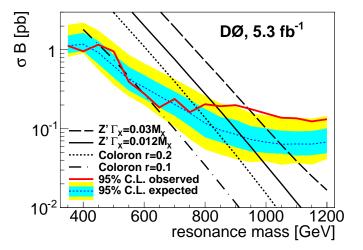


Figure 11: 95% CL exclusion limit on a narrow $t\bar{t}$ resonance as a function of the resonance mass by the DØ experiment [49].

II. Top Condensate, Higgsless, and Related Models

The top quark is much heavier than other fermions and must be more strongly coupled to the symmetry-breaking sector. It is natural to consider whether some or all of electroweaksymmetry breaking is due to a condensate of top quarks [3,44]. Top quark condensation alone, without additional fermions, seems to produce a top quark mass larger [45] than observed experimentally, and is therefore not favored. Topcolor-assisted technicolor [46] combines technicolor and top condensation. In addition to technicolor, which provides the bulk of electroweak symmetry breaking, top condensation and the top quark mass arise predominantly from "topcolor," a new QCD-like interaction which couples strongly to the third generation of quarks. An additional, strong, U(1) interaction (giving rise to a topcolor Z') precludes the formation of a b-quark condensate.

CDF has searched [47] for the "topgluon," a massive coloroctet vector which couples preferentially to the third generation, in the mode $p\overline{p} \to g_t \to b\overline{b}$. The results are shown in Fig. 10. Topgluon masses from approximately 0.3 to 0.6 TeV are excluded at 95% confidence level, for topgluon widths in the range $0.3m_{g_t} < \Gamma < 0.7m_{g_t}$. Results have also been reported by CDF [48] on a search for narrow resonances in the $t\bar{t}$ invariant mass distribution. Using a data sample corresponding to 4.8 fb⁻¹ integrated luminosity, CDF excludes a leptophobic topcolor Z' with masses less than 900 GeV, for the case where its width $\Gamma = 0.012m_{Z'}$. DØ has carried out a similar search, with greater sensitivity [49], and excludes a leptophobic topcolor Z'bosons at the 95% confidence level for masses below 835 GeV (940 GeV) if its width is 1.2% (3%) of its mass (see Fig. 11). A similar study by ATLAS searches for $Z' \to t\bar{t}$ events, excludes leptophobic topcolor Z' with a width of 1.2% in the mass region 500-860 GeV [50]. The CMS experiment [51] quotes a 95% CL upper limit on the $\sigma(pp \to Z') \times Z' \to t\bar{t}$ as a function of the invariant mass of the resonance. A limit of 2.51 pb is set for Z'mass of 1 TeV, resonance width 1%, and 0.62 pb or below for Z' mass above 2 TeV. A broad topgluon could also be detected in the same final state, though no results are yet available. In Run II, the Tevatron [32] should be sensitive to topgluon and topcolor Z' masses up to of order 1 TeV in $b\overline{b}$ and $t\overline{t}$ final states. A detailed theoretical analysis of $B-\overline{B}$ mixing and light quark mass generation in top-color-assisted technicolor shows that, at least in some models, the topgluon and Z' boson masses must be greater than about 5 TeV [53].

The top quark seesaw model of electroweak symmetry breaking [54] is a variant of the original top condensate idea which reconciles top condensation with a lighter top quark mass. Such a model can easily be consistent with precision electroweak tests, either because the spectrum includes a light composite Higgs [55], or because additional interactions allow for a heavier Higgs [56]. Such theories may arise naturally from gauge fields propagating in compact extra spatial dimensions [57].

A variant of topcolor-assisted technicolor is flavor-universal, in which the topcolor SU(3) gauge bosons, called colorons, couple equally to all quarks [58]. Flavor-universal versions of the seesaw model [59] incorporating a gauged flavor symmetry are also possible. In these models all left-handed quarks (and possibly leptons as well) participate in electroweak-symmetry-breaking condensates with separate (one for each flavor) right-handed weak singlets, and the different fermion masses arise by adjusting the parameters which control the mixing of each fermion with the corresponding condensate.

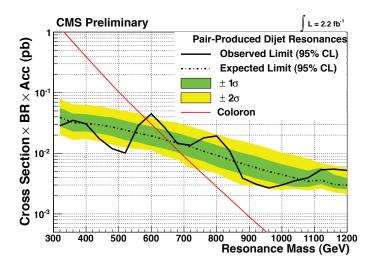


Figure 12: 95% CL exclusion limit on pair production cross section of colorons by the CMS experiment [63]. Colorons with mass in the range 320-580 GeV are excluded.

A prediction of these flavor-universal models is the existence of new heavy gauge bosons, coupling to color or flavor, at relatively low mass scales. The absence of an excess of high- E_T jets in DØ data [60] has been used to constrain strongly coupled flavor-universal colorons (massive color-octet bosons coupling to all quarks). A mass limit of between 0.8 and 3.5 TeV is set [61] depending on the coloron-gluon mixing angle. Precision electroweak measurements constrain [62] the masses of these new gauge bosons to be greater than 1-3 TeV in a variety of models, for strong couplings. A direct search for colorons has been performed in the proton-proton collisions at $\sqrt{s} = 7$ TeV, during the 2011 running of the LHC. From analysis of dijet events, the CMS experiment excludes pair production of colorons with mass between 320 and 580 GeV at 95% CL, as shown in Fig. 12 [63]. A recent DØ analysis [49] of a resonance decaying to $t\bar{t}$ can also be interpreted to search for colorons which would decay to $t\bar{t}$ with a branching fraction of about 1/6 and have a width substantially below 1% of its mass. This study is performed for for different values of the coupling to light quarks r=0.1 and 0.2 [64]. This DØ analysis can exclude such a coloron for r=0.2 with masses below 775 GeV (displayed in Fig. 11).

LHC searches for the standard model Higgs Boson in WW or ZZ decay modes [65,66] place strong constraints [67] on the top-Higgs state predicted in top-color models. Such a state couples strongly to top-quarks, and is therefore produced through gluon fusion at a rate enhanced relative to the rate for the standard model Higgs boson. A top-Higgs state with mass less than 300 GeV is excluded at 95% CL if the associated top-pion has a mass of 150 GeV, and the constraint is even stronger if the mass of the top-pion state exceeds the top-quark

mass or if the top-pion decay constant is a substantial fraction of the weak scale.

A class [68] of composite Higgs model [69], dubbed "Little Higgs Theory," has been developed which gives rise to naturally light Higgs bosons without supersymmetry [70]. Inspired by discretized versions of higher-dimensional gauge theory [71], these models are based on the chiral symmetries of "theory space." The models involve extended gauge groups and novel gauge symmetry-breaking patterns [72]. The new chiral symmetries prevent large corrections to the Higgs boson mass, and allow the scale (Λ) of the underlying strong dynamics giving rise to the composite particles to be as large as 10 TeV. These models typically require new gauge bosons and fermions, and possibly additional composite scalars beyond the Higgs, in the TeV mass range [73].

Finally, "Higgsless" models [74] provide electroweak symmetry breaking, including unitarization of the scattering of longitudinal W and Z bosons, without employing a scalar Higgs boson. The most extensively studied models [75] are based on a five-dimensional $SU(2) \times SU(2) \times U(1)$ gauge theory in a slice of Anti-deSitter space, and electroweak symmetry breaking is encoded in the boundary conditions of the gauge fields. Using the AdS/CFT correspondence [76], these theories may be viewed as "dual" descriptions of walking technicolor the-In addition to a massless photon and near-standard W and Z bosons, the spectrum includes an infinite tower of additional massive vector bosons (the higher Kaluza-Klein or KK excitations), whose exchange is responsible for unitarizing longitudinal W and Z boson scattering [77]. Depending on how these KK bosons couple to fermions, searches for the W'bosons decaying to WZ [37] may be used to place bonds in these theories.

Using deconstruction it has been shown [78] that a Higgsless model whose fermions are localized (i.e., derive their electroweak properties from a single site on the deconstructed lattice) cannot simultaneously satisfy unitarity bounds and precision electroweak constraints. The [79] size of corrections to electroweak processes in Higgsless models may be reduced, however, by considering delocalized fermions, i.e., considering the effect of the distribution of the wavefunctions of ordinary fermions in the fifth dimension (corresponding, in the deconstruction language, to allowing the fermions to derive their electroweak properties from several sites on the lattice). It has been shown [80] that, in an arbitrary Higgsless model, if the probability distribution of the delocalized fermions is related to the W wavefunction (a condition called "ideal" delocalization), then deviations in precision electroweak parameters are minimized. Phenomenological limits on delocalized Higgsless models may be derived [81] from limits on the deviation of the triple-gauge boson (WWZ) vertices from the standard model, and current constraints allow for the lightest KK resonances (which tend to be fermiophobic in the case of ideal fermion delocalization) to have masses of only a few hundred

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GeV. Such resonances would have to be studied using WW scattering [82].

An alternative approach to "Higgsless" models, dubbed "holographic technicolor" [83], incorporates a generalized extradimensional framework and allows for arbitrary couplings of the vector mesons to the light fermions, resulting in a wide variety of potential signatures at the LHC [84].

Acknowledgments

We thank Tom Appelquist, Bogdan Dobrescu, Emilian Dudas, Robert Harris, Chris Hill, Greg Landsberg, Kenneth Lane, Bob Shrock, Elizabeth Simmons, and John Terning for help in the preparation of this article. This work was supported in part by the Department of Energy under grant DE-FG02-91ER40688 and by the National Science Foundation under grant PHY-0854889.

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The latest unpublished results are described in "Dynamical Electroweak Symmetry Breaking" review

MASS LIMITS for Resonances in Models of Dynamical Electroweak Symmetry Breaking

| VALUE (GeV) | CL % | DOCUMENT ID | | TECN | COMMENT |
|-----------------|--------------|------------------------|-----------|-----------|--------------------------------------------------------------------------|
| • • • We do not | use the foll | owing data for aver | ages, fit | ts, limit | s, etc. • • • |
| >805 | 95 | $^{ m 1}$ aaltonen | 11AD | CDF | top-color Z' |
| >805 | 95 | ¹ AALTONEN | 11AE | CDF | top-color Z' |
| | | ² CHIVUKULA | 11 | RVUE | top-Higgs |
| | | ³ CHIVUKULA | 11A | RVUE | techini- π |
| | | ⁴ AALTONEN | 101 | CDF | $\rho \overline{\rho} \rightarrow \rho_T / \omega_T \rightarrow W \pi_T$ |
| none 208-408 | 95 | ⁵ ABAZOV | 10A | D0 | $\rho_T \rightarrow WZ$ |
| | | ⁶ ABAZOV | 07ı I | D0 | $\rho \overline{\rho} \rightarrow \rho_T / \omega_T \rightarrow W \pi_T$ |
| >280 | 95 | ⁷ ABULENCIA | 05 A | CDF | $\rho_T \rightarrow e^+e^-, \mu^+\mu^-$ |
| | | 8 CHEKANOV | 02в | ZEUS | color octet techni- π |
| >207 | 95 | ⁹ ABAZOV | 01B | D0 | $\rho_T \rightarrow e^+e^-$ |
| none 90-206.7 | 95 | ¹⁰ ABDALLAH | 01 | DLPH | $e^+e^- \rightarrow \rho_T$ |
| | | ¹¹ AFFOLDER | 00F | CDF | color-singlet techni-ρ, |
| | | | | | $ ho_T ightarrow ~W \pi_T$, $2\pi_T$ |
| >600 | 95 | ¹² AFFOLDER | 00K | CDF | color-octet techni- $ ho$, |
| | | 4.0 | | | $ ho_{T8} ightarrow 2\pi_{LQ}$ |
| none 350-440 | 95 | ¹³ ABE | 99F | CDF | color-octet techni-ρ, |
| | | 1.4 | | | $ ho_{T8} ightarrow \overline{b} b$ |
| | | 14 ABE | 99N | CDF | techni- ω , $\omega_T ightarrow \gamma \overline{b} b$ |
| none 260-480 | 95 | ¹⁵ ABE | 97G | CDF | color-octet techni- $ ho$, |
| | | | | | $\rho_{TR} \rightarrow 2 \text{jets}$ |

 1 AALTONEN 11AD and AALTONEN 11AE search for top-color Z' decaying to $t\,\overline{t}$. The quoted limit is for Z'_{top} with decay width $\Gamma = 0.012 \text{ M}_{Z'}$

Using the LHC limit on the Higgs boson production cross section, CHIVUKULA 11 obtain a limit on the top-Higgs mass > 300 GeV at 95% CL assuming 150 GeV top-pion mass. Using the LHC limit on the Higgs boson production cross section, CHIVUKULA 11A obtain a limit on the techinipion mass ruling out the region 110 GeV $< m_P < 2m_t$. Existence of color techni-fermions, top-color mechanism, and $N_{TC} \geq 3$ are assumed.

 4 AALTONEN 101 search for the vector techni-resonances $(
ho_T, \omega_T)$ decaying into $W\pi_T$ with $W \to \ell \nu$ and $\pi_T \to b\,\overline{b}$, $b\,\overline{c}$, or $b\,\overline{u}$. See their Fig. 3 for the exclusion plot in $M_{\pi_T} - M_{\rho_T}$ plane.

 5 ABAZOV 10 A search for a vector techni-resonance decaying into WZ. The limit assumes $M_{\rho\tau} < M_{\pi\tau} + M_W$

 6 ABAZOV 071 search for the vector techni-resonances $(
ho_T,\omega_T)$ decaying into $W\pi_T$ with $W \to e \nu$ and $\pi_T \to b \, \overline{b}$ or $b \, \overline{c}$. See their Fig. 2 for the exclusion plot in $M_{\pi_T} - M_{\rho_T}$

7 ABULENCIA 05A search for resonances decaying to electron or muon pairs in $p\overline{p}$ collisions. at $\sqrt{s}=1.96$ TeV. The limit assumes Technicolor-scale mass parameters $M_V=M_A=500$ GeV.

8 $^{\prime\prime}A^{\prime\prime}$ CHEKANOV 02B search for color octet techni- π $^{\prime\prime}P$ decaying into dijets in $^{\prime\prime}e$ collisions. See their Fig. 5 for the limit on $\sigma(ep\rightarrow ePX)$ ·B($P\rightarrow 2j$). 9 ABAZOV 01B searches for vector techni-resonances (ρ_T,ω_T) decaying to e^+e^- . The

limit assumes $M_{
ho_T} = M_{\omega_T} < M_{\pi_T} + M_W$.

 10 The limit is independent of the π_T mass. See their Fig. 9 and Fig. 10 for the exclusion plot in the $M_{\rho_T}-M_{\pi_T}$ plane. ABDALLAH 01 limit on the techni-pion mass is $M_{\pi_T}>79.8$ GeV for $N_D=2$, assuming its point-like coupling to gauge bosons.

 11 AFFOLDER 00F search for ho_T decaying into $W\pi_T$ or $\pi_T\pi_T$ with $W o \ell
u$ and $\pi_T o$ $\overline{b}b,\overline{b}c$. See Fig. 1 in the above Note on "Dynamical Electroweak Symmetry Breaking" for the exclusion plot in the $M_{\rho_T}-M_{\pi_T}$ plane.

 12 AFFOLDER 00K search for the ρ_{TB} decaying into $\pi_{LQ}\pi_{LQ}$ with $\pi_{LQ}\to b\nu.$ For $\pi_{LQ}\to c\nu$, the limit is $M_{\rho_{TB}}>$ 510 GeV. See their Fig. 2 and Fig. 3 for the exclusion plot in the $M_{\rho_{TB}}-M_{\pi_{LQ}}$ plane.

13 ABE 99F search for a new particle X decaying into $b\,\overline{b}$ in $p\,\overline{p}$ collisions at $E_{\rm CM}=1.8$ TeV. See Fig. 7 in the above Note on "Dynamical Electroweak Symmetry Breaking" for the upper limit on $\sigma(p\,\overline{p}\to X)\times B(X\to b\,\overline{b})$. ABE 99F also exclude top gluons of width $\Gamma=0.3M$ in the mass interval 280 < M < 670 GeV, of width $\Gamma=0.5\,M$ in the mass interval 340 < M < 640 GeV, and of width $\Gamma=0.7\,M$ in the mass interval 375 < M < 560 GeV.

340 < M/< 640 GeV, and or width 1 = 0.7 M in the mass interval 373 < M/> 300 GeV. 14 ABE 99N search for the technical decaying into $\gamma \pi_T$. The technipion is assumed to decay $\pi_T \to b\overline{b}$. See Fig. 2 in the above Note on "Dynamical Electroweak Symmetry Breaking" for the exclusion plot in the $M_{\omega_T} - M_{\pi_T}$ plane.

 15 ABE 976 search for a new particle X decaying into dijets in $p\overline{p}$ collisions at $E_{\rm cm}=1.8$ TeV. See Fig. 5 in the above Note on "Dynamical Electroweak Symmetry Breaking" for the upper limit on $\sigma(p\overline{p}\to X)\times {\rm B}(X\to 2j)$.

Technicolor, Quark and Lepton Compositeness

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Quark and Lepton Compositeness, Searches for

The latest unpublished results are described in the "Quark and Lepton Compositeness" review.

SEARCHES FOR QUARK AND LEPTON COMPOSITENESS

Revised 2001 by K. Hagiwara (KEK), and K. Hikasa and M. Tanabashi (Tohoku University).

If quarks and leptons are made of constituents, then at the scale of constituent binding energies, there should appear new interactions among quarks and leptons. At energies much below the compositeness scale (Λ), these interactions are suppressed by inverse powers of Λ . The dominant effect should come from the lowest dimensional interactions with four fermions (contact terms), whose most general chirally invariant form reads [1]

$$L = \frac{g^2}{2\Lambda^2} \left[\eta_{LL} \, \overline{\psi}_L \, \gamma_\mu \psi_L \, \overline{\psi}_L \, \gamma^\mu \psi_L + \eta_{RR} \, \overline{\psi}_R \, \gamma_\mu \psi_R \, \overline{\psi}_R \, \gamma^\mu \psi_R \right.$$
$$\left. + 2\eta_{LR} \, \overline{\psi}_L \, \gamma_\mu \psi_L \, \overline{\psi}_R \, \gamma^\mu \psi_R \right] . \tag{1}$$

Chiral invariance provides a natural explanation why quark and lepton masses are much smaller than their inverse size Λ . We may determine the scale Λ unambiguously by using the above form of the effective interactions; the conventional method [1] is to fix its scale by setting $g^2/4\pi = g^2(\Lambda)/4\pi = 1$ for the new strong interaction coupling and by setting the largest magnitude of the coefficients $\eta_{\alpha\beta}$ to be unity. In the following, we denote

$$\begin{split} & \Lambda = \Lambda_{LL}^{\pm} \ \, \text{for} \ \, (\eta_{LL},\, \eta_{RR},\, \eta_{LR}) = (\pm 1,\, 0,\, 0) \,\,, \\ & \Lambda = \Lambda_{RR}^{\pm} \ \, \text{for} \ \, (\eta_{LL},\, \eta_{RR},\, \eta_{LR}) = (0,\, \pm 1,\, 0) \,\,, \\ & \Lambda = \Lambda_{VV}^{\pm} \ \, \text{for} \ \, (\eta_{LL},\, \eta_{RR},\, \eta_{LR}) = (\pm 1,\, \pm 1,\, \pm 1) \,\,, \\ & \Lambda = \Lambda_{AA}^{\pm} \ \, \text{for} \ \, (\eta_{LL},\, \eta_{RR},\, \eta_{LR}) = (\pm 1,\, \pm 1,\, \mp 1) \,\,, \end{split} \label{eq:lambda}$$

as typical examples. Such interactions can arise by constituent interchange (when the fermions have common constituents, e.g., for $ee \rightarrow ee$) and/or by exchange of the binding quanta (whenever binding quanta couple to constituents of both particles).

Another typical consequence of compositeness is the appearance of excited leptons and quarks (ℓ^* and q^*). Phenomenologically, an excited lepton is defined to be a heavy lepton which shares leptonic quantum number with one of the existing leptons (an excited quark is defined similarly). For example, an excited electron e^* is characterized by a nonzero transition-magnetic coupling with electrons. Smallness of the lepton mass

and the success of QED prediction for g–2 suggest chirality conservation, *i.e.*, an excited lepton should not couple to both left- and right-handed components of the corresponding lepton.

Excited leptons may be classified by $SU(2)\times U(1)$ quantum numbers. Typical examples are:

1. Sequential type

$$\begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_L$$
, $[\nu_R^*]$, ℓ_R^* .

 ν_R^* is necessary unless ν^* has a Majorana mass.

2. Mirror type

$$[
u_L^*], \qquad \ell_L^*, \qquad \begin{pmatrix}
u^* \\ \ell^* \end{pmatrix}_R.$$

3. Homodoublet type

$$\begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_L \,, \qquad \begin{pmatrix} \nu^* \\ \ell^* \end{pmatrix}_R \,.$$

Similar classification can be made for excited quarks.

Excited fermions can be pair produced via their gauge couplings. The couplings of excited leptons with Z are listed in the following table (for notation see Eq. (1) in "Standard Model of Electroweak Interactions"):

| | Sequential type | Mirror type | Homodoublet type |
|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| V^{ℓ^*} A^{ℓ^*} $V^{\nu_D^*}$ $A^{\nu_D^*}$ $V^{\nu_M^*}$ $A^{\nu_M^*}$ | $ \begin{array}{r} -\frac{1}{2} + 2\sin^2\theta_W \\ -\frac{1}{2} \\ +\frac{1}{2} \\ +\frac{1}{2} \\ 0 \\ +1 \end{array} $ | $ \begin{array}{r} -\frac{1}{2} + 2\sin^2 \theta_W \\ +\frac{1}{2} \\ +\frac{1}{2} \\ -\frac{1}{2} \\ 0 \\ -1 \end{array} $ | $-1 + 2\sin^2\!\theta_W$ 0 $+1$ 0 $-$ |

Here ν_{D}^{*} (ν_{M}^{*}) stands for Dirac (Majorana) excited neutrino. The corresponding couplings of excited quarks can be easily obtained. Although form factor effects can be present for the gauge couplings at $q^{2} \neq 0$, they are usually neglected.

In addition, transition magnetic type couplings with a gauge boson are expected. These couplings can be generally parameterized as follows:

$$\mathcal{L} = \frac{\lambda_{\gamma}^{(f^{*})} e}{2m_{f^{*}}} \overline{f}^{*} \sigma^{\mu\nu} (\eta_{L} \frac{1-\gamma_{5}}{2} + \eta_{R} \frac{1+\gamma_{5}}{2}) f F_{\mu\nu}
+ \frac{\lambda_{Z}^{(f^{*})} e}{2m_{f^{*}}} \overline{f}^{*} \sigma^{\mu\nu} (\eta_{L} \frac{1-\gamma_{5}}{2} + \eta_{R} \frac{1+\gamma_{5}}{2}) f Z_{\mu\nu}
+ \frac{\lambda_{W}^{(\ell^{*})} g}{2m_{\ell^{*}}} \overline{\ell}^{*} \sigma^{\mu\nu} \frac{1-\gamma_{5}}{2} \nu W_{\mu\nu}
+ \frac{\lambda_{W}^{(\nu^{*})} g}{2m_{\nu^{*}}} \overline{\nu}^{*} \sigma^{\mu\nu} (\eta_{L} \frac{1-\gamma_{5}}{2} + \eta_{R} \frac{1+\gamma_{5}}{2}) \ell W_{\mu\nu}^{\dagger}
+ \text{h.c.},$$
(3)

where $g = e/\sin\theta_W$, $F_{\mu\nu} = \partial_{\mu}A_{\nu} - \partial_{\nu}A_{\mu}$ is the photon field strength, $Z_{\mu\nu} = \partial_{\mu}Z_{\nu} - \partial_{\nu}Z_{\mu}$, etc. The normalization of the coupling is chosen such that

$$\max(|\eta_L|, |\eta_R|) = 1.$$

Chirality conservation requires

$$\eta_L \eta_R = 0. (4)$$

Some experimental analyses assume the relation $\eta_L = \eta_R = 1$, which violates chiral symmetry. We encode the results of such analyses if the crucial part of the cross section is proportional to the factor $\eta_L^2 + \eta_R^2$ and the limits can be reinterpreted as those for chirality conserving cases $(\eta_L, \eta_R) = (1, 0)$ or (0, 1)after rescaling λ .

These couplings in Eq. (3) can arise from $SU(2)\times U(1)$ invariant higher-dimensional interactions. A well-studied model is the interaction of homodoublet type ℓ^* with the Lagrangian [2,3]

$$\mathcal{L} = \frac{1}{2\Lambda} \overline{L}^* \sigma^{\mu\nu} (g f \frac{\tau^a}{2} W_{\mu\nu}^a + g' f' Y B_{\mu\nu}) \frac{1 - \gamma_5}{2} L + \text{h.c.} , \quad (5)$$

where L denotes the lepton doublet (ν, ℓ) , Λ is the compositeness scale, g, g' are SU(2) and U(1)_Y gauge couplings, and $W_{\mu\nu}^a$ and $B_{\mu\nu}$ are the field strengths for SU(2) and U(1)_Y gauge fields. The same interaction occurs for mirror-type excited leptons. For sequential-type excited leptons, the ℓ^* and ν^* couplings become unrelated, and the couplings receive the extra suppression of $(250 \,\mathrm{GeV})/\Lambda$ or m_{L^*}/Λ . In any case, these couplings satisfy the relation

$$\lambda_W = -\sqrt{2}\sin^2\theta_W(\lambda_Z \cot\theta_W + \lambda_\gamma) \ . \tag{6}$$

Additional coupling with gluons is possible for excited quarks:

$$\mathcal{L} = \frac{1}{2\Lambda} \overline{Q}^* \sigma^{\mu\nu} \left(g_s f_s \frac{\lambda^a}{2} G^a_{\mu\nu} + g f \frac{\tau^a}{2} W^a_{\mu\nu} + g' f' Y B_{\mu\nu} \right)$$

$$\times \frac{1 - \gamma_5}{2} Q + \text{h.c.} , \qquad (7)$$

where Q denotes a quark doublet, g_s is the QCD gauge coupling, and $G_{\mu\nu}^a$ the gluon field strength.

It should be noted that the electromagnetic radiative decay of $\ell^*(\nu^*)$ is forbidden if f = -f' (f = f'). These two possibilities (f = f') and f = -f' are investigated in many analyses of the LEP experiments above the Z pole.

Several different conventions are used by LEP experiments on Z pole to express the transition magnetic couplings. To facilitate comparison, we re-express these in terms of λ_Z and λ_{γ} using the following relations and taking $\sin^2 \theta_W = 0.23$. We assume chiral couplings, i.e., |c| = |d| in the notation of Ref. 2.

1. ALEPH (charged lepton and neutrino)

$$\lambda_Z^{\text{ALEPH}} = \frac{1}{2} \lambda_Z \quad (1990 \text{ papers})$$
 (8a)

$$\frac{2c}{\Lambda} = \frac{\lambda_Z}{m_{\ell^*}[\text{or } m_{\nu^*}]} \quad \text{(for } |c| = |d|)$$
(8b)

2. ALEPH (quark)

$$\lambda_u^{\text{ALEPH}} = \frac{\sin \theta_W \cos \theta_W}{\sqrt{\frac{1}{4} - \frac{2}{3} \sin^2 \theta_W + \frac{8}{9} \sin^4 \theta_W}} \lambda_Z = 1.11 \lambda_Z \quad (9)$$

3. L3 and DELPHI (charged lepton)

$$\lambda^{\text{L3}} = \lambda_Z^{\text{DELPHI}} = -\frac{\sqrt{2}}{\cot \theta_W - \tan \theta_W} \lambda_Z = -1.10\lambda_Z$$
 (10)

4. L3 (neutrino)

$$f_Z^{\text{L3}} = \sqrt{2}\lambda_Z \tag{11}$$

5. OPAL (charged lepton)

$$\frac{f^{\mathrm{OPAL}}}{\Lambda} = -\frac{2}{\cot \theta_W - \tan \theta_W} \frac{\lambda_Z}{m_{\ell^*}} = -1.56 \frac{\lambda_Z}{m_{\ell^*}}$$
(12)

6. OPAL (quark)

$$\frac{f^{\mathrm{OPAL}}c}{\Lambda} = \frac{\lambda_Z}{2m_{q^*}} \quad (\text{for } |c| = |d|)$$
 (13)

7. DELPHI (charged lepton)

$$\lambda_{\gamma}^{\text{DELPHI}} = -\frac{1}{\sqrt{2}} \lambda_{\gamma}$$
 (14)

If leptons are made of color triplet and antitriplet constituents, we may expect their color-octet partners. Transitions between the octet leptons (ℓ_8) and the ordinary lepton (ℓ) may take place via the dimension-five interactions

$$\mathcal{L} = \frac{1}{2\Lambda} \sum_{\ell} \left\{ \overline{\ell}_8^{\alpha} \; g_S \, F_{\mu\nu}^{\alpha} \, \sigma^{\mu\nu} \left(\eta_L \; \ell_L + \eta_R \; \ell_R \right) + h.c. \right\} \eqno(15)$$

where the summation is over charged leptons and neutrinos. The leptonic chiral invariance implies $\eta_L^{}$ $\eta_R^{}=0$ as before.

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SCALE LIMITS for Contact Interactions: Λ(eeee)

Limits are for Λ_{LL}^{\pm} only. For other cases, see each reference.

| $\Lambda_{LL}^+(\text{TeV})$ | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|--------------------------------|----------|-----------------------|-------------|-------------|-------------------------------|
| >8.3 | >10.3 | 95 | 1 BOURILKOV | 01 | RVUE | E _{cm} = 192-208 GeV |
| • • • We | e do not use | the foll | owing data for ave | rages | , fits, lin | nits, etc. • • • |
| >4.5 | >7.0 | 95 | ² SCHAEL | 07A | ALEP | E _{cm} = 189-209 GeV |
| >5.3 | >6.8 | 95 | ABDALLAH | 06c | DLPH | E _{cm} = 130-207 GeV |
| >4.7 | >6.1 | 95 | ³ ABBIENDI | 04 G | OPAL | E _{cm} = 130-207 GeV |
| >4.4 | >5.4 | 95 | ABREU | 00s | DLPH | E _{cm} = 183-189 GeV |
| >4.3 | >4.9 | 95 | ACCIARRI | 00P | L3 | E _{cm} = 130-189 GeV |
| 4 | | | | | | |

- $^{\mathrm{1}}\,\mathrm{A}$ combined analysis of the data from ALEPH, DELPHI, L3, and OPAL.
- 2 SCHAEL 07A limits are from R_c , ${\it Q}_{FB}^{depl}$, and hadronic cross section measurements.
- ³ ABBIENDI 04G limits are from $e^+e^-
 ightarrow e^+e^-$ cross section at $\sqrt{s}=$ 130–207 GeV.

SCALE LIMITS for Contact Interactions: $\Lambda(ee\mu\mu)$

Limits are for Λ_{II}^{\pm} only. For other cases, see each reference.

| $\Lambda_{LL}^{+}(\text{TeV})$ | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|--------------------------------|----------|-----------------------|-----|------|--------------------------------------------------------------------------|
| >6.6 > 8.5 | >9.5 >3.8 | 95 95 | 4 SCHAEL ACCIARRI | | | $E_{\rm cm} = 189-209 \text{ GeV}$ $E_{\rm cm} = 130-189 \text{ GeV}$ |
| | , | | owing data for ave | | | |
| >7.3 | >7.6 | 95 | ABDALLAH | | | $E_{cm} = 130-207 \text{ GeV}$ |
| >8.1 | >7.3 | 95 | ⁵ ABBIENDI | | | E _{cm} = 130-207 GeV |
| >6.6 | >6.3 | 95 | ABREU | 00s | DLPH | E _{cm} = 183-189 GeV |

 4 SCHAEL 07A limits are from $R_c,~Q_{FB}^{depl},$ and hadronic cross section measurements. 5 ABBIENDI 04G limits are from e $^+$ e $^- \to ~\mu\mu$ cross section at $\sqrt{s}=$ 130–207 GeV.

SCALE LIMITS for Contact Interactions: $\Lambda(ee\tau\tau)$

Limits are for Λ_{II}^{\pm} only. For other cases, see each reference.

| Λ ⁺ _{<i>LL</i>} (TeV) | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|--------------------------------|--------------|-----------------------|--------|-------------|-------------------------------------|
| >7.9 | >5.8 | 95 | SCHAEL | 07A | ALEP | E _{cm} = 189-209 GeV |
| >7.9 | >4.6 | 95 | ABDALLAH | 06c | DLPH | $E_{\rm cm} = 130-207 \; {\rm GeV}$ |
| >4.9 | >7.2 | 95 | ⁷ ABBIENDI | 04 G | OPAL | E _{cm} = 130-207 GeV |
| • • • We | do not use | e the follow | ving data for ave | erages | , fits, lin | nits, etc. • • • |
| >5.2 | >5.4 | 95 | ABREU | 00s | DLPH | E _{cm} = 183-189 GeV |
| >5.4 | >4.7 | 95 | ACCIARRI | | | E _{cm} = 130-189 GeV |
| | | | | | | |

 $^{^6}$ SCHAEL 07A limits are from R_c , Q_{FB}^{depl} , and hadronic cross section measurements.

SCALE LIMITS for Contact Interactions: $\Lambda(\ell\ell\ell\ell)$

Lepton universality assumed. Limits are for Λ_{LL}^{\pm} only. For other cases, see each

| $\Lambda_{LL}^{+}(\text{TeV})$ | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|--------------------------------|--------------------------------|-----------|-----------------------|--------|-------------|---------------------------------------|
| >7.9 | > 10.3 | 95 | 8 SCHAEL | 07A | ALEP | E _{cm} = 189-209 GeV |
| >9.1 | >8.2 | 95 | ABDALLAH | 06c | DLPH | E _{cm} = 130-207 GeV |
| • • • We | e do not use | e the fol | lowing data for ave | erages | , fits, lin | nits, etc. • • • |
| >7.7 | >9.5 | 95 | ⁹ ABBIENDI | 04 G | OPAL | $E_{\rm cm} = 130 - 207 \; {\rm GeV}$ |
| | | | ¹⁰ BABICH | 03 | RVUE | |
| >9.0 | >5.2 | 95 | ACCIARRI | 00P | L3 | $E_{cm} = 130-189 \text{ GeV}$ |

SCALE LIMITS for Contact Interactions: $\Lambda(eeqq)$

Limits are for Λ_{LL}^{\pm} only. For other cases, see each reference.

| $\Lambda_{LL}^+(\text{TeV})$ | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DO CUMENT ID | | TECN | COMMENT |
|------------------------------|--------------------------------|-----|----------------------|-----|------|-----------|
| > 8.4 | >10.2 | | 11 ABDALLAH | 09 | DLPH | (e e b b) |
| > 9.4 | >5.6 | | 12 SCHAEL | 07A | ALEP | (eecc) |
| > 9.4 | >4.9 | | 11 SCHAEL | 07A | ALEP | (eebb) |
| >23.3 | >12.5 | | ¹³ CHEUNG | 01B | RVUE | (eeuu) |
| >11.1 | >26.4 | 95 | ¹³ CHEUNG | 01в | RVUE | (eedd) |

| • | • • | We do | not | use the | following | data | for | averages, | fits, | limits, etc | | • | • | • |
|---|-----|-------|-----|---------|-----------|------|-----|-----------|-------|-------------|--|---|---|---|
|---|-----|-------|-----|---------|-----------|------|-----|-----------|-------|-------------|--|---|---|---|

| > 4.2 | >4.0 | 95 | ¹⁴ AARON | 11c | H1 | (e e q q) | |
|-------|------|----|-------------------------|-----|------|-----------|--|
| > 3.8 | >3.8 | | | 11 | DLPH | (eetc) | |
| >12.9 | >7.2 | | ¹⁶ SCHAEL | | | (eeqq) | |
| > 3.7 | >5.9 | 95 | ¹⁷ ABULENCIA | 061 | CDF | (eeaa) | |

 $^{^{11}}$ ABDALLAH 09 and SCHAEL 07A limits are from R_b , A_{FB}^b

SCALE LIMITS for Contact Interactions: $\Lambda(\mu \mu q q)$

| $\Lambda_{LL}^{+}(\text{TeV})$ | $\Lambda_{LL}^{-}(\text{TeV})$ | CL% | DOCUMENT | ID | TECN | COMMENT | |
|----------------------------------------|--------------------------------|----------------------|-----------------------------------------------|-------------------------|--------------------------------|--------------------------------------------------------------------------------|---|
| >4.5 | >4.9 | 95 | 18 AAD | 11E | ATLS | $(\mu \mu q q)$ (isosinglet) | I |
| • • • W | /e do not us | e the fo | ollowing data for | averages, | fits, lim | nits, etc. • • • | |
| >2.9 | >4.2 | 95 | ¹⁹ ABE | 97⊤ | CDF | $(\mu\mu q q)$ (isosinglet) | |
| ¹⁸ AAD ¹⁹ ABE | 11E limits 97T limits | are fror are from | m $\mu^+\mu^-$ mass din $\mu^+\mu^-$ mass dis | stribution tribution | in pp o in p p — | collisions at $E_{\rm cm}=$ 7 TeV. $\mu^+\mu^-$ X at $E_{\rm cm}=$ 1.8 TeV. | I |

SCALE LIMITS for Contact Interactions: $\Lambda(\ell\nu\ell\nu)$

| VALUE (TeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|------------------|------------------------|----------|-----------|---------------------------------------------------|
| >3.10 | 90 | ²⁰ JODIDIO | 86 | SPEC | $\Lambda_{LR}^{\pm}(\nu_{\mu}\nu_{e}\mu e)$ |
| ● ● We do not | use the followin | ng data for averag | es, fits | , limits, | etc. • • • |
| >3.8 | | ²¹ DIAZCRUZ | 94 | RVUE | $\Lambda_{LL}^+(au u_	aue u_e)$ |
| >8.1 | | ²¹ DIAZCRUZ | 94 | RVUE | $\Lambda_{LL}^{-}(\tau \nu_{\tau} e \nu_{e})$ |
| >4.1 | | ²² DIAZCRUZ | | | |
| >6.5 | | ²² DIAZCRUZ | 94 | RVUE | $\Lambda_{II}^{-}(\tau \nu_{\tau} \mu \nu_{\mu})$ |

²⁰ JODIDIO 86 limit is from $\mu^+ o \overline{
u}_\mu e^+
u_e$. Chirality invariant interactions $L=(g^2/\Lambda^2)$ $\left[\eta_{LL}\left(\overline{\nu}_{\mu L}\gamma^{\alpha}\mu_{L}\right)\left(\overline{e}_{L}\gamma_{\alpha}\nu_{eL}\right)\right. + \left.\eta_{LR}\left(\overline{\nu}_{\mu L}\gamma^{\alpha}\nu_{eL}\left(\overline{e}_{R}\gamma_{\alpha}\mu_{R}\right)\right] \text{ with } g^{2}/4\pi = 1 \text{ and } g^{2}/4\pi = 1$ $(\eta_{LL},\eta_{LR})=(0,\pm 1)$ are taken. No limits are given for Λ_{LL}^\pm with $(\eta_{LL},\eta_{LR})=(\pm 1,0)$. For more general constraints with right-handed neutrinos and chirality nonconserving contact interactions, see their text.

SCALE LIMITS for Contact Interactions: $\Lambda(e\nu qq)$

| VALUE (TeV) | CL% | DO CUMENT ID | | TECN |
|----------------------------|--------------|------------------------|--------------------|-------------------------|
| >2.81 | 95 | ²³ AFFOLDER | 011 | CDF |
| ²³ AFFOLDER 001 | bound is for | a scalar interaction | $\overline{q}_R q$ | $L^{\overline{\nu}e_L}$ |

SCALE LIMITS for Contact Interactions: $\Lambda(q q q q)$

Limits are for Λ_{LL}^{\pm} with color-singlet isoscalar exchanges among u_L 's and d_L 's only, unless otherwise noted. See EICHTEN 84 for details

| VALUE (TeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|-----------------|----------------|----------------------------|------------|-----------------------------------------------------------------|
| >5.6 | 95 | ²⁴ KHACHATRY11F | CMS | $pp ightarrow dijet$ angl.; Λ_{LL}^+ |
| • • • We do not | use the follow | ≀ing data for averages, fi | ts, limits | , etc. • • • |
| >3.4 | 95 | ²⁵ AAD 11 | ATLS | $pp 	o 	ext{dijet}; \Lambda_{LL}^+$ |
| >4.0 | 95 | ²⁶ KHACHATRY10A | CMS | pp ; dijet centrality; Λ_{LL}^+ |
| >2.96 | 95 | ²⁷ ABAZOV 09A | E D0 | $p\overline{p} \rightarrow \text{dijet, angl. } \Lambda_{II}^+$ |

 $^{^{24}}$ KHACHATRYAN 11F limit is from dijet angular distribution in pp collisions at $E_{
m cm}=$ 7 TeV. They also obtain $\varLambda_{LL}^{-}~>$ 6.7 TeV.

SCALE LIMITS for Contact Interactions: $\Lambda(\nu\nu\,q\,q)$

Limits are for Λ_{LL}^{\pm} only. For other cases, see each reference.

| $\Lambda_{LL}^{+}(\text{TeV})$ | Λ _{LL} (TeV) | CL% | DOCUMENT ID | TECN | COMMENT |
|--------------------------------|-----------------------|----------|----------------------------|-----------|-------------------------------|
| >5.0 | >5.4 | 95 | 28 MCFARLAND 98 | CCFR | ν N scattering |
| | ARLAND 98 | B assume | d a flavor universal inter | action. N | leutrinos were mostly of muon |
| type. | | | | | |

⁷ ABBIENDI 04G limits are from $e^+e^- \rightarrow au au$ cross section at $\sqrt{s}=130$ –207 GeV.

 $^{^8}$ SCHAEL 07A limits are from $R_c,\,Q_{FB}^{depl}$, and hadronic cross section measurements. 9 ABBIENDI 04G limits are from $\mathrm{e^+\,e^-} \to \ell^+\ell^-$ cross section at $\sqrt{s}=130$ –207 GeV. 10 BABICH 03 obtain a bound -0.175 TeV $^{-2}$ $<1/\Lambda_{LL}^2<0.095$ TeV $^{-2}$ (95%CL) in a model independent analysis allowing all of $\Lambda_{LL},\Lambda_{LR},\Lambda_{RL},\Lambda_{RR}$ to coexist.

 $^{^{12}}$ SCHAEL 07A limits are from R_c , Q_{FB}^{depl} , and hadronic cross section measurements.

¹³ CHEUNG 01B is an update of BARGER 98E.

 $^{^{14}}$ AARON 11c limits are from Q^2 spectrum measurements of $e^\pm p
ightarrow e^\pm X$.

 $^{^{15}}$ ABDALLAH 11 limit is from e $^+$ e $^ \to$ $\,$ t \overline{c} cross section. $\Lambda_{LL}=\Lambda_{LR}=\Lambda_{RL}=\Lambda_{RR}$ is assumed.

16 SCHAEL 07A limit assumes quark flavor universality of the contact interactions.

 $^{^{17}}$ ABULENCIA 06L limits are from $ho \, \overline{
ho}$ collisions at $\sqrt{s} = 1.96$ TeV.

²¹ DIAZCRUZ 94 limits are from $\Gamma(au o e
u
u)$ and assume flavor-dependent contact interactions with $\Lambda(\tau \nu_{\tau} e \nu_{e}) \ll \Lambda(\mu \nu_{\mu} e \nu_{e})$.

 $^{^{22}}$ DIAZCRUZ 94 limits are from $\Gamma(au
ightarrow$ $\mu
u
u$) and assume flavor-dependent contact interactions with $\Lambda(\tau \nu_{\tau} \mu \nu_{\mu}) \ll \Lambda(\mu \nu_{\mu} e \nu_{e})$.

 $^{^{25}}$ AAD 11 limit is from dijet angular distribution and dijet centrality ratio in pp collisions

²⁶ The quoted limit is from dijet centrality ratio measurement in pp collisions at \sqrt{s} =7 TeV.

 $^{^{27}\,\}mathrm{ABAZOV}$ 09AE also obtain $\Lambda_{LL}^{-}~>$ 2.96 TeV.

Searches Particle Listings **Quark and Lepton Compositeness**

MASS LIMITS for Excited e (e*)

Most e^+e^- experiments assume one-photon or Z exchange. The limits experiments which depend on λ have assumed transition couplings which are chirality violating $(\eta_L=\eta_R)$. However they can be interpreted as limits for chirality-conserving interactions after multiplying the coupling value λ by $\sqrt{2}$; see Note.

Excited leptons have the same quantum numbers as other ortholeptons. See also the searches for ortholeptons in the "Searches for Heavy Leptons" section.

Limits for Excited e (e*) from Pair Production

These limits are obtained from $e^+\,e^ightarrow\,e^{*+}\,e^{*-}$ and thus rely only on the (electroweak) charge of e^* . Form factor effects are ignored unless noted. For the case of limits from Z decay, the e^{*} coupling is assumed to be of sequential type. Possible t channel contribution from transition magnetic coupling is neglected. All limits assume a dominant $e^* \to e \gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT | |
|-------------|---------|------------------------|-------|----------|----------------------|------------------------|
| >103.2 | 95 | ²⁹ ABBIENDI | 02G | OPAL | $e^+e^- \rightarrow$ | e* e* Homodoublet type |
| • • • We do | not use | the following data | for a | verages, | fits, limits, | etc. • • • |
| >102.8 | 95 | ³⁰ ACHARD | 03в | L3 | $e^+e^- \to$ | e* e* Homodoublet type |

 29 From $e^+\,e^-$ collisions at $\sqrt{s}=183$ –209 GeV. f=f' is assumed.

Limits for Excited $e(e^*)$ from Single Production

These limits are from $e^+e^-\to e^*e$, $W\to e^*\nu$, or $ep\to e^*X$ and depend on transition magnetic coupling between e and e^* . All limits assume $e^*\to e\gamma$ decay except as noted. Limits from LEP, UA2, and H1 are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L=\eta_R=1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda-m_{e^+}$ plane. See the original

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|---------------------|-----------|------------------------|----------|---------|------------------------------------|
| >1070 | 95 | 31 CHATRCHYA | N 11x | CMS | $pp \rightarrow ee^*X$ |
| • • • We do not use | he follow | ing data for average | s, fits, | limits, | etc. • • • |
| > 272 | 95 | 32 AARON | 08A | H1 | $e p \rightarrow e^* X$ |
| | | ³³ ABAZOV | 08н | D0 | $p \overline{p} \rightarrow e^* e$ |
| > 209 | 95 | ³⁴ ACOSTA | 05B | CDF | $p \overline{p} \rightarrow e^* X$ |
| > 206 | 95 | ³⁵ ACHARD | 03B | L3 | $e^+ e^- ightarrow e e^*$ |
| > 208 | 95 | ³⁶ ABBIENDI | 02G | OPAL | $e^+ e^- \rightarrow e e^*$ |
| > 228 | 95 | ³⁷ CHEKANOV | 02D | ZEUS | $e p \rightarrow e^* X$ |

 31 CHATRCHYAN 11 X search for single e^* production in pp collisions with the decay $e^*
ightarrow$ $e\gamma$. $f=f'=\Lambda/m_{
ho^*}$ is assumed. See their Fig. 2 for the exclusion plot in the mass-

 32 AARON 08A search for single e^* production in ep collisions with the decays $e^*
ightarrow e\gamma$, $e\,Z$, $\nu\,W$. The quoted limit assumes $f=\,f'=\,\Lambda/m_{\,e^*}$. See their Fig. 3 and Fig. 4 for the exclusion plots in the mass-coupling plane.

 33 ABAZOV 08H search for single e^* production in $ho\,\overline{
ho}$ collisions with the decays $e^*
ightarrow e\,\gamma$. The e^* production is assumed to be described by an effective four-fermion interaction. See their Fig. 5 for the exclusion plot in the mass-coupling plane.

 34 ACOSTA 05B search for single e^* production in $ho \overline{
ho}$ collisions with the decays $e^*
ightarrow e \gamma$. $f=f'=\Lambda/m_{
ho^*}$ is assumed for the e^* coupling. See their Fig.3 for the exclusion limit in the mass-coupling plane.

35 ACHARD 03B result is from e^+e^- collisions at $\sqrt{s}=189$ –209 GeV. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

³⁶ ABBIENDI 02G result is from e^+e^- collisions at $\sqrt{s}=183$ –209 GeV. $f=f'=\Lambda/m_{e^*}$ is assumed for e^* coupling. See their Fig. 4c for the exclusion limit in the mass-coupling

 37 CHEKA NOV 02D search for single e^* production in ep collisions with the decays $e^*
ightarrow$ $e\gamma$, eZ, vW. $f=f'=\Lambda/m_{e^*}$ is assumed for the e^* coupling. See their Fig. 5a for the exclusion plot in the mass-coupling plane.

Limits for Excited e (e^*) from $e^+e^- \rightarrow \gamma \gamma$

These limits are derived from indirect effects due to e^* exchange in the t channel and depend on transition magnetic coupling between e and e^* . All limits are for $\lambda_{\gamma}=1$. All limits except ABE 89J and ACHARD 02D are for nonchiral coupling with η_L = 1. We choose the chiral coupling limit as the best limit and list it in the Summary

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------|-------------|--------------------|-----------|---------|--------------------------|
| >35 6 | 95 | 38 ABDALLAH | 04N | DLPH | \sqrt{s} = 161-208 GeV |
| • • • We do not use t | he followir | ng data for averag | es, fits, | limits, | etc. • • • |
| >310 | 95 | ACHARD | 02D | L3 | \sqrt{s} = 192-209 GeV |

 $^{^{38}}$ ABDALLAH 04N also obtain a limit on the excited electron mass with $\it ee^*$ chiral coupling, $m_{e^*} > 295 \text{ GeV at } 95\% \text{ CL.}$

Indirect Limits for Excited e (e*)

These limits make use of loop effects involving e^* and are therefore subject to theoretical uncertainty.

| VALUE | (GeV) | | JMENT ID | | TECN | COMMENT | |
|-------|-----------|----------------------|-------------|-------|------------|------------------------------------------------------------------------------------------------|----|
| • • • | We do not | use the following da | ta for aver | ages, | fits, limi | its, etc. • • • | |
| | | ³⁹ dor | ENBOS | 89 | CHRM | $\overline{\nu}_{\mu} e \rightarrow \overline{\nu}_{\mu} e, \nu_{\mu} e \rightarrow \nu_{\mu}$ | ιe |
| | | ⁴⁰ GRIF | | | | $\nu_{\mu}e \rightarrow \nu_{\mu}e$ | |
| | | ⁴¹ REN | ARD | 82 | THEO | g-2 of electron | |

 39 DORENBOSCH 89 obtain the limit $\lambda_{\gamma}^2 \Lambda_{\rm Cut}^2/m_{e^*}^2 < 2.6$ (95% CL), where $\Lambda_{\rm cut}$ is the cutoff scale, based on the one-loop calculation by GRIFOLS 86. If one assumes that $\Lambda_{\rm Cut}=1$ TeV and $\lambda_{\gamma}=1$, one obtains $m_{e^*}>620$ GeV. However, one generally expects $\lambda_{\gamma} \approx m_{e^*}/\Lambda_{\text{cut}}$ in composite models.

 40 GRIFOLS 86 uses $\nu_{\mu}e \rightarrow \; \nu_{\mu}e$ and $\overline{\nu}_{\mu}e \rightarrow \; \overline{\nu}_{\mu}e$ data from CHARM Collaboration to derive mass limits which depend on the scale of compositeness.

 41 RENARD 82 derived from g-2 data limits on mass and couplings of e^* and μ^* . See figures 2 and 3 of the paper

MASS LIMITS for Excited μ (μ *)

Limits for Excited μ (μ^*) from Pair Production

These limits are obtained from $e^+\,e^-\,
ightarrow\,\mu^{*+}\,\mu^{*-}$ and thus rely only on the (electroweak) charge of μ^* . Form factor effects are ignored unless noted. For the case of limits from Z decay, the μ^* coupling is assumed to be of sequential type. All limits assume a dominant $\mu^*
ightarrow \; \mu \gamma$ decay except the limits from $\Gamma(Z)$

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMME | V T | | |
|-------------|--------------|------------------------------|--------|----------|------------|---------------------------|----------|-----------|
| >103.2 | 95 4 | ¹² ABBIENDI | 02 G | OPAL | e^+e^- | $\rightarrow \mu^* \mu^*$ | Homodoul | blet type |
| • • • We do | not use | the following data | for a | verages, | fits, limi | ts, etc. • | • • | |
| >102.8 | 95 4 | ¹³ ACHARD | 03в | L3 | e^+e^- | $\rightarrow \mu^* \mu^*$ | Homodoul | blet type |
| 42 From e+ | e^- collis | ions at $\sqrt{s} = 183$ - | -209 (| GeV. f = | = f' is a | ssumed. | | |
| | | ions at $\sqrt{s} = 189$ | | | = f' is | assumed. | ACHARD | 03B also |
| obtain lir | nit for f = | $= -f'$: $m_{\mu^*} > 96$. | .6 Ge\ | ٧. | | | | |

Limits for Excited μ (μ^*) from Single Production

These limits are from $e^+\,e^-\,
ightarrow\,\mu^*\mu$ and depend on transition magnetic coupling between μ and μ^* . All limits assume $\mu^* \to \mu \gamma$ decay. Limits from LEP are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{\mu^*}$ plane.

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | TECN | COMMENT |
|---------------------|------------|-----------------------------|---------------|----------------------------------------------------------------------------|
| >1090 | 95 | 44 CHATRCHYANI | 1x CMS | $pp \rightarrow \mu \mu^* X$ |
| • • • We do not use | the follow | ing data for averages, | fits, limits, | etc. • • • |
| | 95 | ⁴⁵ ABAZOV (| 06E D0 | $\rho \overline{\rho} \rightarrow \mu \mu^*$ |
| > 221 | 95 | ⁴⁶ ABULENCIA,A (| 06в CDF | $\rho \overline{\rho} \rightarrow \mu \mu^*, \mu^* \rightarrow \mu \gamma$ |
| > 180 | 95 | ⁴⁷ ACHARD (|)3в L3 | $e^+e^- \rightarrow \mu \mu^*$ |
| > 190 | 95 | ⁴⁸ ABBIENDI (| 02G OPAL | $e^+e^- \rightarrow \mu \mu^*$ |
| 44 CHATRCHVAN 11 | v search | for single u* produc | tion in an | collisions with the decay |

CHATRCHYAN 11x search for single μ^* production in pp collisions with the decay $\mu^* \to \mu \gamma$. $f = f' = \Lambda/m_{\mu^*}$ is assumed. See their Fig. 2 for the exclusion plot in the mass-coupling plane.

 45 ABAZOV 06E assume $\mu\mu^*$ production via four-fermion contact interaction $(4\pi/\Lambda^2)(\overline{q}_L\,\gamma^\mu q_L)(\overline{\mu}_L^*\,\gamma_\mu\mu) \quad \text{The obtained limit is } m_{\mu^*} > 618 \; \text{GeV} \; (m_{\mu^*} > 688 \; \text{GeV})$ for $\Lambda=1$ TeV $(\Lambda=m_{\mu^*})$.

 $^{46}\,f=f'=\Lambda/m_{_{II}^*}$ is assumed for the μ^* coupling. See their Fig.4 for the exclusion limit in the mass-coupling plane. ABULENCIA,A 06B also obtain m_{μ^*} limit in the contact interaction model with $\Lambda=m_{\mu^*},~m_{\mu^*}>$ 696 GeV. 47 ACHARD 03B result is from e^+e^- collisions at $\sqrt{s}=$ 189–209 GeV. $f=f'=\Lambda/m_{\mu^*}$

is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

⁴⁸ ABBIENDI 02G result is from e^+e^- collisions at $\sqrt{s}=1$ 83–209 GeV. $f=f'=\Lambda/m_{\mu^*}$ is assumed for μ^* coupling. See their Fig. 4c for the exclusion limit in the mass-coupling

Indirect Limits for Excited μ (μ *)

These limits make use of loop effects involving μ^* and are therefore subject to theoretical uncertainty.

| VALUE (GeV) | DO CUMENT ID | TECN | COMMENT |
|-------------------------|---------------------------------|---------------|-------------|
| • • • We do not use the | ne following data for averages, | fits, limits, | etc. • • • |
| | ⁴⁹ RENARD 8 | 2 THEO | g-2 of muon |

 49 RENARD 82 derived from g-2 data limits on mass and couplings of e^* and μ^* . See

 $^{30\,\}mathrm{From}~e^+e^-$ collisions at $\sqrt{s}=189$ –209 GeV. f=f' is assumed. ACHARD 03B also obtain limit for f = -f': $m_{e^*} > 96.6$ GeV.

Quark and Lepton Compositeness

MASS LIMITS for Excited τ (τ^*)

Limits for Excited au (au^*) from Pair Production

These limits are obtained from $e^+e^- \to \tau^{*+}\tau^{*-}$ and thus rely only on the (electroweak) charge of τ^* . Form factor effects are ignored unless noted. For the case of limits from Z decay, the τ^* coupling is assumed to be of sequential type. All limits assume a dominant $\tau^* \to \tau\gamma$ decay except the limits from $\Gamma(Z)$.

For limits prior to 1987, see our 1992 edition (Physical Review D45 S1 (1992)).

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------|---------|------------------------|-------|----------|---------------------------------------------------|
| >103.2 | 95 | ⁵⁰ ABBIENDI | 02G | OPAL | $e^+e^- ightarrow	au^*	au^*$ Homodoublet type |
| • • • We do | not use | the following data | for a | verages, | fits, limits, etc. • • • |
| >102.8 | 95 | ⁵¹ ACHARD | 03в | L3 | $e^+e^- ightarrow \ 	au^*	au^*$ Homodoublet type |

⁵⁰ From e^+e^- collisions at $\sqrt{s}=183$ –209 GeV. f=f' is assumed.

 51 From e $^+$ e $^-$ collisions at $\sqrt{s}=$ 189–209 GeV. f=f' is assumed. ACHARD 03B also obtain limit for $f=-f'\colon m_{-*}>$ 96.6 GeV.

Limits for Excited au (au^*) from Single Production

These limits are from $e^+e^- \to \tau^*\tau$ and depend on transition magnetic coupling between τ and τ^* . All limits assume $\tau^* \to \tau\gamma$ decay. Limits from LEP are for chiral coupling, whereas all other limits are for nonchiral coupling, $\eta_L = \eta_R = 1$. In most papers, the limit is expressed in the form of an excluded region in the $\lambda - m_{\tau^*}$ plane. See the original papers.

| VALUE (GeV) | CL% | DO CUMENT IE |) | TECN | COMMENT | |
|-------------|-------------|----------------------|------------|---------|-----------------------------------|--|
| >185 | 95 | 52 ABBIENDI | 02G | OPAL | $e^+ e^- \rightarrow \tau \tau^*$ | |
| | the followi | ng data for avera | ges, fits, | limits, | etc. • • • | |
| >180 | 95 | ⁵³ ACHARD | 03в | L3 | $e^+ e^- ightarrow 	au 	au^*$ | |

 52 ABBIENDI 02G result is from e^+e^- collisions at $\sqrt{s}=183$ –209 GeV. $f=f'=\Lambda/m_{\tau^*}$ is assumed for τ^* coupling. See their Fig. 4c for the exclusion limit in the mass-coupling

 53 ACHARD 03B result is from $e^+\,e^-$ collisions at $\sqrt{s}=189$ –209 GeV. $f=f'=\Lambda/m_{\tau^*}$ is assumed. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

MASS LIMITS for Excited Neutrino (ν^*)

Limits for Excited ν (ν^*) from Pair Production

These limits are obtained from $e^+\,e^-\to \nu^*\nu^*$ and thus rely only on the (electroweak) charge of ν^* . Form factor effects are ignored unless noted. The ν^* coupling is assumed to be of sequential type unless otherwise noted. All limits assume a dominant $\nu^*\to \nu\gamma$ decay except the limits from $\Gamma(Z)$.

| VALUE (GeV) | CL% | DO CUMENT ID | TECN | COMMENT | VT | | | | | |
|-------------------------------|---------|--------------------|-------|----------|----------------------|---------------|-------------|------|--|--|
| >102.6 | 95 | 54 ACHARD | 03в | L3 | $e^+e^- \rightarrow$ | $\nu^* \nu^*$ | Homodoublet | type | | |
| ● ● We do | not use | the following data | for a | verages, | fits, limits, | etc. ● | • • | | | |
| | | 55 | | | | | | | | |

 54 From e^+e^- collisions at $\sqrt{s}=$ 189–209 GeV. f=-f' is assumed. ACHARD 03B also obtain limit for f=f': $m_{\nu_e^*}>101.7$ GeV, $m_{\nu_\mu^*}>101.8$ GeV, and $m_{\nu_\tau^*}>92.9$ GeV. See their Fig. 4 for the exclusion plot in the mass-coupling plane.

 55 From e^+e^- collisions at $\sqrt{s}=192$ –209 GeV, ABBIENDI 04N obtain limit on $\sigma(e^+e^-\to\nu^*\nu^*)$ B $^2(\nu^*\to\nu\gamma)$. See their Fig. 2. The limit ranges from 20 to 45fb for $m_{\nu^*}>$ 45 GeV.

Limits for Excited u (u^*) from Single Production

These limits are from $e^+e^-\to \nu\nu^*$, $Z\to \nu\nu^*$, or $ep\to \nu^*X$ and depend on transition magnetic coupling between ν/e and ν^* . Assumptions about ν^* decay mode are given in footnotes.

| u.c g | | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | | | |
|-------------|---------|-----------------------------------------|-------|----------|--------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| >213 | 95 | ⁵⁶ AARON | 08 | H1 | $e p \rightarrow \nu^* X$ |
| • • • We do | not use | the following data | for a | verages, | fits, limits, etc. • • • |
| >190 | 95 | ⁵⁷ ACHARD | 03в | L3 | $e^+e^- \rightarrow \nu \nu^*$ |
| none 50-150 | 95 | ⁵⁸ ADLOFF | 02 | H1 | $e p \rightarrow \nu^* X$ |
| >158 | 95 | ⁵⁹ CHEKANOV | 02D | ZEUS | $e p \rightarrow \nu^* X$ |
| >171 | 95 | 60 ACCIARRI | 01 D | 1.3 | e+e vv* |

 56 AARON 08 search for single ν^* production in ep collisions with the decays $\nu^* \to \nu \gamma, \ \nu Z, eW.$ The quoted limit assumes $f = -f' = \Lambda/m_{\nu^*}$. See their Fig. 3 and Fig. 4 for the exclusion plots in the mass-coupling plane.

 57 ACHARD 03B result is from e^+e^- collisions at $\sqrt{s}=189$ –209 GeV. The quoted limit is for ν_e^* . $f=-f'=\Lambda/m_{\nu^*}$ is assumed. See their Fig.4 for the exclusion plot in the mass-coupling plane.

 58 ADLOFF 02 search for single ν^* production in ep collisions with the decays $\nu^* \to \nu \gamma$, $\nu \, Z$, $e \, W$. The quoted limit assumes $f = -f' = \Lambda/m_{\nu^*}$. See their Fig. 1 for the exclusion plots in the mass-coupling plane.

 59 CHEKA NOV 02D search for single ν^* production in ep collisions with the decays $\nu^* \rightarrow \nu \gamma, \, \nu Z, \, eW. \, f = -f' = \Lambda/m_{\nu^*}$ is assumed for the e^* coupling. CHEKA NOV 02D also obtain limit for $f=f'=\Lambda/m_{\nu^*}$ in $m_{\nu^*}>135\,$ GeV. See their Fig. 5c and Fig. 5d for the exclusion plot in the mass-coupling plane.

 60 ACCIARRI 01D search for $\nu\nu^*$ production in e^+e^- collisions at $\sqrt{s}=192-202$ GeV with decays $\nu^*\to\nu\gamma,\,\nu^*\to e\,W.\,\,f=-f'=\Lambda/m_{\nu^*}$ is assumed for the ν^* coupling. See their Fig. 4 for limits in the mass-coupling plane.

Limits for Excited $q(q^*)$ from Pair Production

These limits are mostly obtained from $e^+e^- \to q^*\overline{q}^*$ and thus rely only on the (electroweak) charge of the q^* . Form factor effects are ignored unless noted. Assumptions about the q^* decay are given in the comments and footnotes.

| VALUE (GeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---------------------------------|----------------|------------------------|---------|-----------|-----------------------------------------|
| >338 | 95 | ⁶¹ AALTONEN | 10н | CDF | $q^* \rightarrow t W^-$ |
| ● ● We do not | use the follow | ing data for average | es, fit | s, limits | , etc. • • • |
| | | ⁶² BARATE | 98u | ALEP | $Z \rightarrow q^* q^*$ |
| > 45.6 | 95 | ⁶³ ADRIANI | 93 M | L3 | u or d type, $Z \rightarrow q^*q^*$ |
| > 41.7 | 95 | ⁶⁴ BARDADIN | 92 | RVUE | u -type, $\Gamma(Z)$ |
| > 44.7 | 95 | ⁶⁴ BARDADIN | 92 | RVUE | d -type, $\Gamma(Z)$ |
| > 40.6 | 95 | ⁶⁵ DECAMP | 92 | ALEP | u -type, $\Gamma(Z)$ |
| > 44.2 | 95 | ⁶⁵ DECAMP | 92 | ALEP | d -type, $\Gamma(Z)$ |
| > 45 | 95 | ⁶⁶ DECAMP | 92 | ALEP | u or d type, $Z \rightarrow q^*q^*$ |
| > 45 | 95 | ⁶⁵ ABREU | 91 F | DLPH | u -type, $\Gamma(Z)$ |
| > 45 | 95 | ⁶⁵ ABREU | 91 F | DLPH | d -type, $\Gamma(Z)$ |

 61 AALTONEN 10H obtain limits on the q^*q^* production cross section in $p\overline{p}$ collisions. See their Fig. 3.

62 BARATE 980 obtain limits on the form factor. See their Fig. 16 for limits in mass-form

⁶³ ADRIANI 93M limit is valid for B($q^* \rightarrow qg$)> 0.25 (0.17) for up (down) type.

 64 BARDADIN-OTWINOWSKA 92 limit based on $\Delta\Gamma(Z)$ <36 MeV.

65 These limits are independent of decay modes.

⁶⁶ Limit is for B($q^* \rightarrow qg$)+B($q^* \rightarrow q\gamma$)=1.

Limits for Excited $q(q^*)$ from Single Production

These limits are from $e^+e^- \to q^*\overline{q}$, $p\overline{p} \to q^*X$, or $pp \to q^*X$ and depend on transition magnetic couplings between q and q^* . Assumptions about q^* decay mode are given in the footnotes and comments.

| VALUE (GeV) | CL% | DO CUMENT ID | TECN | COMMENT |
|----------------|-----------|-----------------------------|------------|----------------------------------------------------------|
| >2490 | 95 | ⁶⁷ CHATRCHYAN11Y | CMS | $pp \rightarrow q^*X$, $q^* \rightarrow qg$ |
| • • • We do no | t use the | e following data for averag | ges, fits, | limits, etc. • • • |
| | | | | $p\overline{p} \rightarrow q^*X, q^* \rightarrow qZ, qW$ |
| none 300-1260 | 95 | ⁶⁹ AAD 10 | ATLS | $pp \rightarrow q^*X, q^* \rightarrow qg$ |
| none 500-1580 | 95 | ⁶⁹ KHACHATRY10 | CMS | $pp \rightarrow q^*X$, $q^* \rightarrow qg$ |
| > 510 | 95 | | D0 | $p\overline{p} \rightarrow q^*X, q^* \rightarrow qZ$ |
| > 775 | 95 | ⁷¹ ABAZOV 04 c | D0 | $p \overline{p} \rightarrow q^* X, q^* \rightarrow q g$ |

 67 CHATRCHYAN 11Y assume degenerate q^* with $f_{\rm S}=\Lambda/m_{q^*}$.

⁶⁸ ABAZOV 11F search for vectorlike quarks decaying to W+jet and Z+jet in $p\overline{p}$ collisions. See their Fig. 3 and Fig. 4 for the limits on $\sigma \cdot B$

See their Fig. 3 and Fig. 4 for the limits on $\sigma \cdot B$. ⁶⁹ AAD 10, KHACHATRYAN 10 search for heavy resonance decaying to 2 jets in pp collisions at $\sqrt{s}=7$ TeV. $f_{\rm S}=f=f'=1$ is assumed.

 70 ABAZOV 06F assume q^* production via qg fusion and via contact interactions. The quoted limit is for $\Lambda=m_{q^*}.$

 71 ABAZOV 04c assume $f_S = f = f' = \Lambda/m_{q^*}$

MASS LIMITS for Color Sextet Quarks (ac)

| | | 4 (46 | '' | | | |
|-------------|-----|--------------|-----|------|-----------------------------------------------|--|
| VALUE (GeV) | CL% | DO CUMENT IL |) | TECN | COMMENT | |
| >84 | 95 | 72 ABE | 89D | CDF | $p\overline{p} \rightarrow q_6\overline{q}_6$ | |

72 ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color sextet quark is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. A limit of 121 GeV is obtained for a color decuplet.

MASS LIMITS for Color Octet Charged Leptons (ℓ_8)

73 ABE 89D look for pair production of unit-charged particles which leave the detector before decaying. In the above limit the color octet lepton is assumed to fragment into a unit-charged or neutral hadron with equal probability and to have long enough lifetime not to decay within the detector. The limit improves to 99 GeV if it always fragments into a unit-charged hadron.

74 ABT 93 search for e_8 production via e-gluon fusion in ep collisions with $e_8 \rightarrow eg$. See their Fig. 3 for exclusion plot in the m_{e_8} - Λ plane for $m_{e_8}=35$ -220 GeV.

MASS LIMITS for Color Octet Neutrinos (u_8)

 $\lambda \equiv m_{\ell_*}/\Lambda$

| Λ = '''ℓ ₈ / | /· | | | | |
|-------------------------|---------|----------------------|---------|-------------|-------------------------------------------------------------------|
| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
| >110 | 90 | ⁷⁵ BARGER | 89 | RVUE | $\nu_8 : \rho \overline{\rho} \rightarrow \nu_8 \overline{\nu}_8$ |
| • • • We do not | use the | following data for a | verages | , fits, lir | nits, etc. • • • |
| none 3.8-29.8 | 95 | ⁷⁶ KIM | 90 | AMY | $ u_8$: $e^+e^- 	o$ acoplanar jets |
| none 9-21.9 | 95 | ⁷⁷ BARTEL | 87B | JADE | $ u_8$: $e^+e^ ightarrow$ acoplanar jets |

MASS LIMITS for W8 (Color Octet W Boson)

**MALUE (GeV) DOCUMENT ID TECN COMMENT*

• • We do not use the following data for averages, fits, limits, etc. • • •

**RALBAJAR 89 give $\sigma(W_8 \rightarrow W + \text{jet})/\sigma(W) < 0.019$ (90% CL) for $m_{W_8} > 220$ GeV.

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| | | | | | |

Extra Dimensions

For explanation of terms used and discussion of significant model dependence of following limits, see the "Extra Dimensions" review. Footnotes describe originally quoted limit. δ indicates the number of extra dimensions.

Limits not encoded here are summarized in the "Extra Dimensions" review, where the latest unpublished results are also described.

EXTRA DIMENSIONS

Updated November 2011 by John Parsons (Columbia University) and Alex Pomarol (Universitat Autònoma de Barcelona).

$I\ Introduction$

Proposals for a spacetime with more than three spatial dimensions date back to the 1920s, mainly through the work of Kaluza and Klein, in an attempt to unify the forces of nature [1]. Although their initial idea failed, the formalism that they and others developed is still useful nowadays. Around 1980, string theory proposed again to enlarge the number of space dimensions, this time as a requirement for describing a consistent theory of quantum gravity. The extra dimensions were supposed to be compactified at a scale close to the Planck scale, and thus not testable experimentally in the near future.

A different approach was given by Arkani-Hamed, Dimopoulos and Dvali (ADD) in their seminal paper in 1998 [2]. They showed that the weakness of gravity could be explained by postulating two or more extra dimensions in which only gravity could propagate. The size of these extra dimensions should range between roughly a millimeter and $\sim 1/\text{TeV}$, leading to possible observable consequences in current and future experiments. A year later, Randall and Sundrum (RS) [3] found a new possibility using a warped geometry. They postulated a five-dimensional Anti-de Sitter (AdS) spacetime with a compactification scale of order TeV. The origin of the smallness of the electroweak scale versus the Planck scale was explained by the gravitational redshift factor present in the warped AdS metric. As in the ADD model, originally only gravity was assumed to propagate in the extra dimensions, although it was soon clear that this was not necessary in the RS model and also the SM gauge fields [4] and SM fermions [5,6] could propagate in the five-dimensional space.

The physics of warped extra-dimensional models have an alternative interpretation by means of the AdS/CFT correspondence [7]. Models with warped extra dimensions are related to four-dimensional strongly-interacting theories, allowing an understanding of the properties of five-dimensional fields as those of four-dimensional (4D) composite states [8]. This has opened new directions for tackling outstanding questions in particle physics, such as the flavor problem, grand unification, and the origin of electroweak symmetry breaking or supersymmetry breaking.

I.1 Kaluza-Klein Theories

Theories with compact extra dimensions can be written as theories in ordinary four dimensions by performing a Kaluza-Klein (KK) reduction. As an illustration, consider a simple example, namely a field theory of a complex scalar in flat five-dimensional (5D) spacetime. The action will be given by †

$$S_5 = -\int d^4x \, dy \, M_5 \left[|\partial_\mu \phi|^2 + |\partial_y \phi|^2 + \lambda_5 |\phi|^4 \right] \,, \tag{1}$$

where y refers to the extra (fifth) dimension. A universal scale M_5 has been extracted in front of the action in order to keep the 5D field with the same mass-dimension as in four dimensions. This theory is perturbative for energies $E \lesssim \ell_5 M_5/\lambda_5$ where $\ell_5 = 24\pi^3$ [9].

 $^{^{75}}$ BARGER 89 used ABE 89B limit for events with large missing transverse momentum. Two-body decay $\nu_8 \to ~\nu g$ is assumed.

 $^{^{76}\,\}rm KIM$ 90 is at $E_{\rm CM} = 50\text{-}60.8$ GeV. The same assumptions as in BARTEL 87B are used.

 $^{^{77}}$ BARTEL 87B is at $E_{\rm CM}=46.3$ –46.78 GeV. The limit assumes the ν_8 pair production cross section to be eight times larger than that of the corresponding heavy neutrino pair production. This assumption is not valid in general for the weak couplings, and the limit can be sensitive to its ${\rm SU}(2)_L\times {\rm U}(1)_Y$ quantum numbers.

[†] Our convention for the metric is $\eta_{MN} = \text{Diag}(-1, 1, 1, 1, 1)$.

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Let us now consider that the fifth dimension is compact with the topology of a circle S^1 of radius R, which corresponds to the identification of y with $y+2\pi R$. In such a case, the 5D complex scalar field can be expanded in a Fourier series:

$$\phi(x,y) = \frac{1}{\sqrt{2\pi R M_5}} \sum_{n=-\infty}^{\infty} e^{iny/R} \phi^{(n)}(x) ,$$

that, inserted in Eq. (1) and integrating over y, gives

$$S_5 = S_4^{(0)} + S_4^{(n)} \,,$$

where

$$S_4^{(0)} = -\int d^4x \left[|\partial_\mu \phi^{(0)}|^2 + \lambda_4 |\phi^{(0)}|^4 \right], \text{ and } (2)$$

$$S_4^{(n)} = -\int d^4\!x\, \sum_{n\neq 0} \left[|\partial_\mu \phi^{(n)}|^2 + \left(\frac{n}{R}\right)^2 |\phi^{(n)}|^2 \right] + \text{quartic int}. \label{eq:S4n}$$

The n = 0 mode self-coupling is given by

$$\lambda_4 = \frac{\lambda_5}{2\pi R M_5} \,. \tag{3}$$

The above action corresponds to a 4D theory with a massless scalar $\phi^{(0)}$, referred to as the zero-mode, and an infinite tower of massive modes $\phi^{(n)}$, known as KK modes. The KK reduction thus allows a treatment of 5D theories as 4D field theories with an infinite number of fields. At energies smaller than 1/R, the KK modes can be neglected, leaving the zero-mode action of Eq. (2). The strength of the interaction of the zero-mode, given by Eq. (3), decreases as R increases. Thus, for a large extra dimension $R \gg 1/M_5$, the massless scalar is weakly coupled.

II Large Extra Dimensions for Gravity

II.1 The ADD Scenario

The ADD scenario [2,10,11] assumes a $D=4+\delta$ dimensional spacetime, with δ compactified spatial dimensions. The weakness of gravity arises since it propagates in the higher-dimensional space. The SM is assume to be localized in a 4D subspace, a 3-brane, as can be found in certain string constructions [12]. Gravity is described by the Einstein-Hilbert action in $D=4+\delta$ spacetime dimensions

$$S_D = -\frac{\bar{M}_D^{2+\delta}}{2} \int d^4x d^\delta y \sqrt{-g} \mathcal{R} + \int d^4x \sqrt{-g_{\rm ind}} \mathcal{L}_{\rm SM} , \quad (4)$$

where x labels the ordinary four coordinates, y the δ extra coordinates, g refers to the determinant of the D-dimensional metric whose Ricci scalar is defined by \mathcal{R} , and \bar{M}_D is the reduced Planck scale of the D-dimensional theory. In the second term of Eq. (4), which gives the gravitational interactions of SM fields, the D-dimensional metric reduces to the induced metric on the 3-brane where the SM fields propagate. The extra dimensions are assumed to be flat and compactified in a volume V_{δ} . As an example, consider a toroidal compactification of equal radii R and volume $V_{\delta} = (2\pi R)^{\delta}$. After a KK reduction, one finds that the fields that couple to the SM are the spin-2 gravitational field $G_{\mu\nu}(x,y)$ and a tower of spin-1 KK graviscalars [13]. The

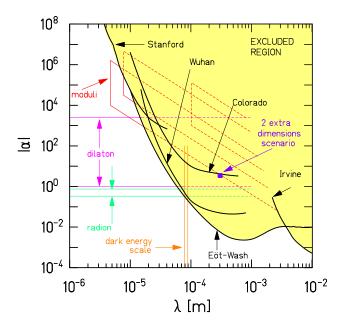


Figure 1: Experimental limits (from Ref. [15]) on α and λ of Eq. (8), which parametrize deviations from Newton's law of gravitation.

graviscalars, however, only couple to SM fields through the trace of the energy-momentum tensor, resulting in weaker couplings to the SM fields. The Fourier expansion of the spin-2 field is given by

$$G_{\mu\nu}(x,y) = G_{\mu\nu}^{(0)}(x) + \frac{1}{\sqrt{V_{\delta}}} \sum_{\vec{n} \neq 0} e^{i\vec{n} \cdot \vec{y}/R} G_{\mu\nu}^{(\vec{n})}(x) , \qquad (5)$$

where $\vec{y} = (y_1, y_2, ..., y_{\delta})$ are the extra-dimensional coordinates and $\vec{n} = (n_1, n_2, ..., n_{\delta})$. Eq. (5) contains a massless state, the 4D graviton, and its KK tower with masses $m_{\vec{n}}^2 = |\vec{n}|^2/R^2$. At energies below 1/R the action is that of the zero-mode

$$S_4^{(0)} = -\frac{\bar{M}_D^{2+\delta}}{2} \int d^4x \, V_\delta \sqrt{-g^{(0)}} \mathcal{R}^{(0)} + \int d^4x \sqrt{-g_{\mathrm{ind}}^{(0)}} \, \mathcal{L}_{\mathrm{SM}} \,,$$

where we can identify the 4D reduced Planck mass, $M_P \equiv G_N/\sqrt{8\pi} \simeq 2.4 \times 10^{18}$ GeV, as a function of the *D*-dimensional parameters:

$$M_P^2 = V^{\delta} \bar{M}_D^{2+\delta} \equiv R^{\delta} M_D^{2+\delta} \,. \tag{6}$$

Fixing M_D at around the electroweak scale $M_D \sim \text{TeV}$ to avoid introducing a new mass-scale in the model, Eq. (6) gives a prediction for R:

$$\delta = 1, 2, ..., 6 \rightarrow R \sim 10^9 \text{ km}, 0.5 \text{ mm}, ..., 0.1 \text{ MeV}^{-1}.$$
 (7)

The option $\delta=1$ is clearly ruled out. However this is not the case for $\delta\geq 2$, and possible observable consequences can be sought in present and future experiments.

Consistency of the model requires a stabilization mechanism for the radii of the extra dimensions, to the values shown in Eq. (7). The fact that we need $R\gg 1/M_D$ leads to a new hierarchy problem, the solution of which might require imposing supersymmetry in the extra-dimensional bulk [14].

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II.2 Tests of the Gravitational Force Law at Sub-mm Distances

The KK modes of the graviton give rise to deviations from Newton's law of gravitation for distances $\lesssim R$. Such deviations are usually parametrized by a modified Newtonian potential of the form

$$V(r) = -G_N \frac{m_1 m_2}{r} \left[1 + \alpha e^{-r/\lambda} \right].$$
 (8)

For a 2-torus compactification, $\alpha=16/3$ and $\lambda=R$. Searches for deviations from Newton's law of gravitation have been performed in several experiments. Fig. 1, taken from Ref. [15], gives the present constraints. We find $R<37\mu{\rm m}$ at 95% CL for $\delta=2$, corresponding to $M_D>3.6$ TeV.

II.3 Astrophysical and Cosmological Constraints

The light KK gravitons could be copiously produced in stars, carrying away energy. Ensuring that the graviton luminosity is low enough to preserve the agreement of stellar models with observations provides powerful bounds on the scale M_D . The most stringent arises from supernova SN1987A, giving $M_D > 27$ (2.4) TeV for $\delta = 2$ (3) [16]. After a supernova explosion, most of the KK gravitons stay gravitationally trapped in the remnant neutron star. The requirement that neutron stars are not excessively heated by KK decays into photons leads to $M_D > 1700$ (76) TeV for $\delta = 2$ (3) [17].

Cosmological constraints are also quite stringent [18]. To avoid overclosure of the universe by relic gravitons one needs $M_D > 7$ TeV for $\delta = 2$. Relic KK gravitons decaying into photons contribute to the cosmic diffuse gamma radiation, from which one can derive the bound $M_D > 100$ TeV for $\delta = 2$.

We must mention however that bounds coming from the decays of KK gravitons into photons can be reduced if we assume that KK gravitons decay mainly into other non-SM states. This could happen, for example, if there are other 3-branes with hidden sectors residing on them [10].

II.4 Collider Signals

II.4a Graviton and Other Particle Production

Although each KK graviton has a purely gravitational coupling, suppressed by $1/M_P$, inclusive processes in which one sums over the almost continuous spectrum of available gravitons have cross sections suppressed only by powers of M_D . Processes involving gravitons are therefore detectable in collider experiments if $M_D \sim \text{TeV}$. A number of experimental searches for evidence of large extra dimensions have been performed at colliders, and interpreted in the context of the ADD model.

One signature arises from direct graviton emission. By making a derivative expansion of Einstein gravity, one can construct an effective theory, valid for energies much lower than M_D , and use it to make predictions for graviton-emission processes at colliders [13,19,20]. Gravitons produced in the final state would escape detection, giving rise to missing transverse energy $(\not\!E_T)$. The results quoted below are 95% CL lower limits on M_D for a range of values of δ between 2 and 6, with more stringent limits corresponding to lower δ values.

A combined $\gamma + \not\!\!E_T$ result from LEP yields limits of $M_D > 0.66 - 1.60$ TeV [21], and less stringent results also exist from LEP for the $Z + \cancel{E}_T$ final state. At hadron colliders, experimentally sensitive channels include the $j + \not\!\!E_T$ and $\gamma + \not\!\!E_T$ final states. The most stringent limits from the Tevatron include CDF results of $M_D > 0.94 - 1.94$ TeV [22], using the combined $j/\gamma + \not\!\!E_T$ final state. DØ results limit $M_D > 0.80$ – 0.88 TeV [23] from $\gamma + \not\!\!E_T$, and $M_D > 0.63 - 0.89$ TeV [24] from $j + \not\!\!E_T$. At the LHC, using a dataset of 1 fb⁻¹ and assuming leading order (LO) signal cross sections, CMS sets limits of $M_D > 2.25 - 3.67$ TeV [25] from analyzing the $j + \not\!\!E_T$ final state, and $M_D > 1.03 - 1.21 \text{ TeV } [26] \text{ from } \gamma + E_T$. To account for next-to-leading order (NLO) signal enhancements, sizeable k-factors, in the range 1.3-2 depending on δ , would increase these limits by typically $\approx 10\%$ if applied. ATLAS $j + E_T$ results with 1 fb⁻¹ provide limits of $M_D > 1.68 - 3.16$ TeV [27], using LO cross sections. For the $j + E_T$ analyses, the LHC experiments handle somewhat differently the issue that the effective theory is only valid for energies much less than M_D : CMS suppresses the graviton cross section by a factor M_D^2/\hat{s} for $\sqrt{\hat{s}} > M_D$, where $\sqrt{\hat{s}}$ is the parton-level center-of-mass energy of the hard collision. ATLAS simply truncates the differential cross section to remove the contribution from events where $\sqrt{\hat{s}} > M_D$, and points out that the effect of the truncation grows with δ , from a negligible impact for $\delta = 2$ up to a 16% reduction in the limit for $\delta = 6$.

In models in which the ADD scenario is embedded in a string theory at the TeV scale [12], we expect the string scale M_s to be smaller than M_D , and therefore production at the LHC of string resonances [28]. Analysis of the dijet invariant mass distribution have been interpreted by CMS for a 1 fb⁻¹ dataset to exclude at 95% CL string excitations of quarks and gluons that decay predominantly to q + g with masses less than 4 TeV [29].

II.4b Virtual graviton effects

One can also search for virtual graviton effects, the calculation of which however depends on the ultraviolet cut-off of the theory and is therefore very model dependent. In the literature, several different formulations exist [13,20,30] for the dimension-eight operator for gravity exchange at tree level:

$$\mathcal{L}_8 = \pm \frac{4}{M_{TT}^4} \left(T_{\mu\nu} T^{\mu\nu} - \frac{1}{\delta + 2} T^{\mu}_{\mu} T^{\nu}_{\nu} \right), \tag{9}$$

where $T_{\mu\nu}$ is the energy-momentum tensor and M_{TT} is related to M_D by some model-dependent coefficient [31]. The relations with the parametrizations of Refs. [30] and [13] are, respectively, $M_{TT}=M_S$ and $M_{TT}=(2/\pi)^{1/4}\Lambda_T$. The experimental results below are given as 95% CL lower limits on M_{TT} , including in some cases the possibility of both constructive or destructive interference, depending on the sign chosen in Eq. (9). Results from $e^{\pm}p \rightarrow e^{\pm}X$ at HERA limit $M_{TT} \gtrsim 800$ GeV [32]. The most sensitive limits from LEP arise from the $e^+e^- \rightarrow ee$ and $e^+e^- \rightarrow \gamma\gamma$ final states, with limits for the case of constructive (destructive) interference corresponding

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to $M_{TT}>1.1$ (1.0) TeV [33] and $M_{TT}>1.0$ (0.9) TeV [34], respectively. The most stringent results, for constructive (destructive) interference, from the Tevatron include limits of $M_{TT}>1.48$ (1.37) TeV [35] from $p\bar{p}\to ee/\gamma\gamma+X$, and $M_{TT}>1.48$ (1.34) TeV [36] from an analysis of the angular distributions in dijet events. Results from the LHC extend the sensitivity to higher scales. CMS has reported 1 fb⁻¹ results in the diphoton and dimuon final states. For constructive interference and using NLO cross sections, the CMS $\gamma\gamma$ and $\mu\mu$ results correspond approximately to limits of $M_{TT}>2.8$ TeV [37] and 2.4 TeV [38], respectively. A 2 fb⁻¹ update of the ATLAS $\gamma\gamma$ analysis in Ref. [39] provides limits of $M_{TT}>2.7$ TeV (2.3 TeV) for constructive (destructive) interference.

At the one-loop level, gravitons can also generate dimensions six operators with coefficients that are also model dependent. Experimental bounds on these operators can also give stringent constraints on M_D [31].

II.4c Black Hole Production

The physics at energies $\sqrt{s} \sim M_D$ is sensitive to the details of the quantum theory of gravity. Nevertheless, in the transplanckian regime, $\sqrt{s} \gg M_D$, one can rely on a semiclassical description of gravity to obtain predictions. An interesting feature of transplanckian physics is the creation of black holes [40]. A black hole is expected to be formed in a collision in which the impact parameter is smaller than the Schwarzschild radius [41]:

$$R_S = \frac{1}{M_D} \left[\frac{2^{\delta} \pi^{(\delta - 3)/2}}{\delta + 2} \Gamma\left(\frac{\delta + 3}{2}\right) \frac{M_{BH}}{M_D} \right]^{1/(\delta + 1)}, \tag{10}$$

where M_{BH} is the mass of the black hole, which would roughly correspond to the total energy in the collision. The cross section for black hole production can be estimated to be of the same order as the geometric area $\sigma \sim \pi R_S^2$. For $M_D \sim \text{TeV}$, this gives a production of $\sim 10^7$ black holes at the $\sqrt{s} = 14$ TeV LHC with an integrated luminosity of 30 fb⁻¹ [40]. A black hole would provide a striking experimental signature since it is expected to thermally radiate with a Hawking temperature $T_H = (\delta + 1)/(4\pi R_S)$, and therefore would evaporate democratically into all SM states.

At the LHC, one starts to be able to access a regime where the energies are large compared to (or at least comparable to) M_D values in the TeV range. However, given the present constraints on M_D , the LHC will not be able to reach energies much above M_D . This implies that predictions based on the semiclassical approximation could receive sizeable modifications from model-dependent quantum-gravity effects.

The LHC experiments have performed searches for microscopic black holes by looking for excesses above the SM background in final states with multiple high $p_{\rm T}$ objects [42,43], high $p_{\rm T}$ jets [44], high $p_{\rm T}$ leptons and jets [45], and in same-sign dimuon events [46]. No excesses have been observed. The results are usually quoted as model-independent limits on the cross section for new physics in the final state and kinematic region analyzed. These results can then be used to provide

constraints on models of low-scale gravity and weakly-coupled string theory. In addition, limits are sometimes quoted on particular implementations of models, which are used as benchmarks to illustrate the sensitivity. For example, using 1 fb⁻¹, CMS provides limits in the mass range of 4-5 TeV [42] for semiclassical black holes, and ATLAS gets similar results [45]. ATLAS have also searched for black holes via a 36 pb⁻¹ analysis of the invariant mass and angular distributions in dijet events, excluding M_D values in the range from 0.75 up to 3.26 (3.69) TeV [47] for the case of 2 (6) extra dimensions.

In weakly-coupled string models the semiclassical description of gravity fails in the energy range between M_s and M_s/g_s^2 since stringy effects are important. In this regime one expects, instead of black holes, the formation of string balls, made of highly excited long strings, that could be copiously produced at the LHC for $M_s \sim \text{TeV}$ [48], and would evaporate thermally at the Hagedorn temperature giving rise to high-multiplicity events. CMS has interpreted their 1 fb⁻¹ multi-object search to exclude the production of string balls with a minimum mass in the range of 4.1-4.5 TeV [42], depending on the details of the model. ATLAS gets similar results [45] for their 1 fb⁻¹ search for an excess of events with high p_T leptons and jets.

III TeV-Scale Extra Dimensions

III.1 Warped Extra Dimensions

The RS model [3] is the most attractive setup of warped extra dimensions at the TeV scale, since it provides an alternative solution to the hierarchy problem. The RS model is based on a 5D theory with the extra dimension compactified on an orbifold, S^1/Z_2 , a circle S^1 with the extra identification of y with -y. This corresponds to the segment $y \in [0, \pi R]$, a manifold with boundaries at y = 0 and $y = \pi R$. Let us now assume that this 5D theory has a cosmological constant in the bulk Λ , and on the two boundaries Λ_0 and $\Lambda_{\pi R}$:

$$S_{5} = -\int d^{4}x \, dy \left\{ \sqrt{-g} \left[\frac{1}{2} M_{5}^{3} \mathcal{R} + \Lambda \right] + \sqrt{-g_{0}} \delta(y) \Lambda_{0} + \sqrt{-g_{\pi R}} \delta(y - \pi R) \Lambda_{\pi R} \right\},$$
(11)

where g_0 and $g_{\pi R}$ are the values of the determinant of the induced metric on the two respective boundaries. Einstein's equations can be solved, giving in this case the metric

$$ds^2 = a(y)^2 dx^{\mu} dx^{\nu} \eta_{\mu\nu} + dy^2 , \quad a(y) = e^{-ky} ,$$
 (12)

where $k=\sqrt{-\Lambda/(6M_5^3)}$. Consistency of the solution requires $\Lambda_0=-\Lambda_{\pi R}=-\Lambda/k$. The metric in Eq. (12) corresponds to a 5D AdS space. The factor a(y) is called the "warp" factor and determines how 4D scales change as a function of the position in the extra dimension. In particular, this implies that energy scales for 4D fields localized at the boundary at $y=\pi R$ are red-shifted by a factor $e^{-k\pi R}$ with respect to those localized at y=0. For this reason, the boundaries at y=0 and $y=\pi R$ are usually referred to as the ultraviolet (UV) and infrared (IR) boundaries, respectively.

As in the ADD case, we can perform a KK reduction and obtain the low-energy effective theory of the 4D massless graviton. In this case we obtain

$$M_P^2 = \int_0^{\pi R} dy \, e^{-2ky} M_5^3 = \frac{M_5^3}{2k} \left(1 - e^{-2k\pi R} \right) \,.$$
 (13)

Taking $M_5 \sim k \sim M_P$, we can generate an IR-boundary scale of order $ke^{-k\pi R} \sim \text{TeV}$ for an extra dimension of radius $R \simeq 11/k$. Mechanisms to stabilize R to this value have been proposed [49] that, contrary to the ADD case, do not require introducing any new small or large parameter. Therefore a natural solution to the hierarchy problem can be achieved in this framework if the Higgs field, whose vacuum expectation value (VEV) is responsible for electroweak symmetry breaking, is localized at the IR-boundary where the effective mass scales are of order TeV.

In the original RS model [3], all the SM fields were assumed to be localized on the IR-boundary. Nevertheless, for the hierarchy problem, only the Higgs field has to be localized there. SM gauge bosons and fermions can propagate in the 5D bulk [4,5,6,50]. By performing a KK reduction from the 5D action of a gauge boson, we find [4]

$$\frac{1}{g_4^2} = \int_0^{\pi R} dy \, \frac{1}{g_5^2} = \frac{\pi R}{g_5^2} \,,$$

where g_D (D=4,5) is the gauge coupling in D-dimensions. Therefore the 4D gauge couplings can be of order one, as is the case of the SM, if we demand $g_5^2 \sim \pi R$. Using $kR \sim 10$ and $g_4 \sim 0.5$, we obtain the 5D gauge coupling

$$g_5 \sim 4/\sqrt{k} \,. \tag{14}$$

Boundary kinetic terms for the gauge bosons can modify this relation, allowing for larger values of $g_5\sqrt{k}$.

Fermions propagating in the RS extra dimension have 4D massless zero-modes with wavefunctions which vary as $f_0 \sim Exp[(1/2 - c_f)ky]$, where $c_f k$ is their 5D mass [51,6]. Depending on the free parameter $c_f k$, fermions can be localized either towards the UV-boundary ($c_f > 1/2$) or IR-boundary $(c_f < 1/2)$. Since the Higgs is localized on the IR-boundary, we can generate exponentially suppressed Yukawa couplings by having the fermion zero-modes localized towards the UVboundary, generating naturally the light SM fermion spectrum [6]. A large overlap with the wavefunction of the Higgs is needed for the top quark, in order to generate its large mass, thus requiring it to be localized towards the IR-boundary. In conclusion, the large mass hierarchies present in the SM fermion spectrum can be easily obtained in warped models via suitable choices of the order-one parameters c_f [52]. In these scenarios deviations in flavor physics from the SM predictions are expected to arise from flavor-changing KK gluon couplings [53]. These put certain constraints on the parameters of the models and predicts new physics effects to be observed in B-physics processes [54].

The masses of the KK states can also be calculated. One finds [6]

$$m_n \simeq \left(n + \frac{\alpha}{2} - \frac{1}{4}\right) \pi k e^{-\pi kR},$$
 (15)

where n=1,2,... and $\alpha=\{|c_f-1/2|,0,1\}$ for KK fermions, KK gauge bosons and KK gravitons, respectively. Their masses are of order $ke^{-\pi kR}\sim$ TeV; the first KK state of the gauge bosons would be the lightest, while gravitons are expected to be the heaviest.

III.1a Models of Electroweak Symmetry Breaking

Theories in warped extra dimensions can be used to implement symmetry breaking at low energies by boundary conditions [55]. For example, for a U(1) gauge symmetry in the 5D bulk, this can be easily achieved by imposing a Dirichlet boundary condition on the IR-boundary, $A_{\mu}|_{y=\pi R} = 0$. This makes the zero-mode gauge boson get a mass, given by $m_A = g_4 \sqrt{2k/g_5^2} e^{-\pi kR}$, that can be smaller than the KK masses for $g_5^2 \gg 1/k$. A very different situation occurs if the Dirichlet boundary condition is imposed on the UV-boundary, $A_{\mu}|_{\nu=0}=0$. In this case the zero-mode gauge boson disappears from the spectrum. Finally, if a Dirichlet boundary condition is imposed on the two boundaries, we obtain a massless 4D scalar corresponding to the fifth component of the 5D gauge boson, A_5 . Thus, different scenarios can be implemented by appropriately choosing the 5D bulk gauge symmetry, \mathcal{G}_5 , and the symmetries to which it reduces on the UV and IR-boundary, \mathcal{H}_{UV} and \mathcal{H}_{IR} respectively. In all cases the KK spectrum comes in representations of the group \mathcal{G}_5 .

Higgsless models: One of the most interesting applications of warped extra dimensions is for models of electroweak symmetry breaking. To guarantee the relation $M_W^2 \simeq M_Z^2 \cos^2 \theta_W$, a custodial $SU(2)_V$ symmetry in needed in the bulk and IR-boundary [56]. For this reason the minimal symmetry pattern is [57]

$$\mathcal{G}_5 = SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_X$$

$$\mathcal{H}_{IR} = SU(3)_c \times SU(2)_V \times U(1)_X$$

$$\mathcal{H}_{UV} = G_{SM}$$

where $G_{SM} \equiv SU(3)_c \times SU(2)_L \times U(1)_Y$ is the SM gauge group with the identification of hypercharge as $Y = T_3^R + X$. In this theory the W and Z bosons are massive, there is no Higgs boson, and the first KK mode associated to the W boson has a mass given by

$$m_{KK} \simeq \frac{3\pi g_5 \sqrt{k}}{4q_4} M_W \,. \tag{16}$$

Using Eq. (14), one obtains $m_{KK} \simeq 1.2$ TeV.

Composite Higgs models: Alternatively, warped extra dimensions can give rise to scenarios, often called gauge-Higgs unified models, where the Higgs appears as the fifth component of a 5D gauge boson, A_5 . The Higgs mass is protected by the

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5D gauge invariance and can only get a nonzero value from non-local one-loop effects [58]. As in the Higgsless case, a custodial symmetry is needed. The simplest realization [59] has

$$\mathcal{G}_5 = SU(3)_c \times SO(5) \times U(1)_X$$

 $\mathcal{H}_{IR} = SU(3)_c \times SO(4) \times U(1)_X$
 $\mathcal{H}_{UV} = G_{SM}$

The Higgs gets a potential at the one-loop level that triggers a VEV, breaking the electroweak symmetry. In these models there is a light Higgs with mass 100 - 200 GeV that, as will be explained in Sec. III.3, behaves as a composite state. The lightest KK modes of the model are color fermions with charges Q = -1/3, 2/3 and 5/3 [60].

$III.1b\ Constraints\ from\ Electroweak\ Precision\ Tests$

Models in which the SM gauge bosons propagate in 1/TeV-sized extra dimensions give generically large corrections to electroweak observables. When the SM fermions are confined on a boundary these corrections are universal and can be parametrized by four quantities: \hat{S} , \hat{T} , W and Y, as defined in Ref. [61]. For warped models, where the 5D gauge coupling of Eq. (14) is large, the most relevant parameter is \hat{T} , which gives the bound $m_{KK} \gtrsim 10$ TeV [50]. When a custodial symmetry is imposed [56], the main constraint comes from the \hat{S} parameter, requiring $m_{KK} \gtrsim 3$ TeV independently of the value of g_5 . Notice that this bound, when applied to 5D Higgsless models where Eq. (16) holds, constrains the coupling g_5^2k to be close to its nonperturbative value [62]. Also corrections to the $Zb_L\bar{b}_L$ coupling can be important [50], especially in warped models for electroweak symmetry breaking as the ones described above.

III.1c Kaluza-Klein Searches

The main prediction of 1/TeV-sized extra dimensions is the presence of a discretized KK spectrum, with masses around the TeV scale, associated with the SM fields that propagate in the extra dimension.

In the original RS model, only gravity propagates in the 5D bulk. Experimental searches have been performed for the lightest RS graviton through its decay to a variety of SM particle-antiparticle pairs. The results are usually interpreted in the plane of the dimensionless coupling k/M_P versus m_1 , where M_P is the reduced Planck mass defined previously and m_1 is the mass of the lightest KK excitation of the graviton. Since the AdS curvature $\sim k$ cannot exceed the cut-off scale of the model, which is estimated to be $\ell_5^{1/3}M_5$ [31], we must demand $k \ll \sqrt{2\ell_5}M_P$. The results quoted below are 95% CL lower limits on the KK graviton mass for a coupling $k/M_P = 0.1$.

Tevatron limits exist for the diphoton, dielectron and dimuon final states, and are typically near the kinematic limit of order 1 TeV. The most stringent results from the Tevatron are the CDF limit of $m_1 > 1.11$ TeV [64] from combining $G \to \gamma \gamma / ee/\mu \mu$, and the DØ limit of $m_1 > 1.05$ TeV [65] using $G \to \gamma \gamma / ee$. The LHC experiments can probe higher masses, with recent results available using ≈ 1 fb⁻¹ of 7 TeV data. No published predictions exist for NLO cross sections for 7 TeV pp

collisions, and CMS and ATLAS adopted different conventions with regard to k-factors, meaning some care is required when comparing their results. CMS used a k-factor value of ≈ 1.6 for their combined $ee/\mu\mu$ result of $m_1 > 1.78$ TeV [66], and for their preliminary result of $m_1 > 1.72$ TeV [37] using the $\gamma\gamma$ final state. The ATLAS limit of $m_1 > 1.63$ TeV [67] from the $ee/\mu\mu$ final state combination assumes the signal cross section as obtained with LO* PDFs; this choice corresponds to an effective k-factor of ≈ 1.1 for masses near the obtained limit. A 2 fb⁻¹ update of the ATLAS $\gamma\gamma$ analysis in Ref. [39] assumes a k-factor of 1.75 and provides a limit of $m_1 > 1.95$ TeV when combined with the 1 fb⁻¹ $ee/\mu\mu$ results.

Less stringent limits on the KK graviton mass come from the WW/ZZ final states at the Tevatron. By combining searches with one, two, or three charged leptons, DØ sets a limit in the WW final state of $m_1 > 754$ GeV [68]. An earlier CDF result in the $e + \not\!\!E_T + jj$ final state limits $m_1 > 606$ GeV [69]. A preliminary ZZ result from CDF [70] reports 4 events compatible with a mass of ≈ 325 GeV in the final state with four charged leptons (electrons or muons), and they state that the probability to observe such a distribution of events given the SM background lies in the range $(2.7 - 10.5) \times 10^{-5}$. However, CDF analyses with two charged leptons and either a pair of jets or E_T do not confirm a signal for a new heavy particle decaying to a pair of Z bosons. The combined result is quoted as a limit of 0.26 pb on the production cross section of a 325 GeV RS Graviton decaying to ZZ. A DØ measurement of the ZZ production cross section in the four charged lepton final state [71] also shows no evidence of an enhancement at a ZZinvariant mass near 325 GeV.

If the SM fields propagate in the 5D bulk, the couplings of the KK graviton to $ee/\mu\mu/\gamma\gamma$ are suppressed [72], the above bounds would not apply. In this case the graviton is the heaviest KK state, so experimental searches for KK gauge bosons and fermions are more appropriate discovery channels in these scenarios. For the scenarios discussed above in which only the Higgs and the top quark are localized towards the IRboundary, the KK gauge bosons mainly decay into top quarks, longitudinal W/Z bosons, and Higgs bosons. Couplings to light SM fermions are suppressed by a factor $g_4/\sqrt{g_5^2k} \sim 0.2$ [6]. Searches have been made for evidence of the lightest KK excitation of the gluon, through its decay to $t\bar{t}$ pairs. An ATLAS analysis of the lepton-plus-jets final state using 0.2 fb^{-1} of data excludes KK gluons with masses below 650 GeV [73], while a 1 fb⁻¹ analysis of the dilepton final state yields a lower limit of 0.84 TeV [74]. A 0.9 fb⁻¹ CMS analysis of the fully hadronic final state searches uses "top tagging" techniques to identify events where one or both of the top quarks is highly boosted and reconstructed as a single merged jet; this analysis claims to exclude KK gluons with a mass lying between 1 and 1.5 TeV [75], though the paper states that the large width expected for the KK gluon was not taken into account in determining the result. A gauge KK excitation could be also sought through its decay to longitudinal W/Z bosons. While, as

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reported elsewhere in this volume, searches for WZ resonances have been used to set limits on sequential SM W' bosons or other models, as yet no WZ experimental results have been interpreted in the context of warped extra-dimensions.

The lightest KK states are usually the partners of the top quark. In warped models of electroweak symmetry breaking, these are color states with charges Q = -1/3, 2/3 and 5/3, and masses between 0.5 and 1.5 TeV [60]. They can be either singly- or pair-produced, and mainly decay into a combination of W/Z with top/bottom. Of particular note, the Q=5/3 state decays mainly into $W^+t \to W^+W^+b$, giving a pair of samesign leptons in the final state [76]. $D\emptyset$ searched with 5.4 fb⁻¹ for single production of heavy vector-like quarks decaying to W/Z + i [77], and set limits on their production cross sections that could be reinterpreted to provide some exclusion on KK fermions decaying to W/Z + b, though the sensitivity might be less than optimal since b-tagging was not used in the analysis. CMS performed a 1 fb⁻¹ search for pair-production of heavy vector-like quarks T, which excludes such quarks with masses below 475 GeV [78], assuming a 100% branching ratio for the decay $T \to tZ$.

$III. 2\ Connection\ with\ Strongly-Coupled\ Models\ via\ the$ $AdS/CFT\ Correspondence$

The AdS/CFT correspondence [7] provides a connection between warped extra-dimensional models and strongly-coupled theories in ordinary 4D. Although the exact connection is only known for certain cases, the AdS/CFT techniques have been very useful to obtain, at the qualitative level, a 4D holographic description of the various phenomena in warped extra-dimensional models [8].

The connection goes as follows. The physics of the bulk AdS₅ models can be interpreted as that of a 4D conformal field theory (CFT) which is strongly-coupled. The extra-dimensional coordinate y plays the role of the renormalization scale μ of the CFT by means of the identification $\mu \equiv ke^{-ky}$. Therefore the UV-boundary corresponds in the CFT to a UV cut-off scale at $\Lambda_{UV} = k \sim M_P$, breaking explicitly conformal invariance, while the IR-boundary can be interpreted as a spontaneous breaking of the conformal symmetry at energies $ke^{-k\pi R} \sim \text{TeV}$. Fields localized on the UV-boundary are elementary fields external to the CFT, while fields localized on the IR-boundary and KK states corresponds to composite resonances of the CFT. Furthermore, local gauge symmetries in the 5D models, \mathcal{G}_5 , correspond to global symmetries of the CFT, while the UV-boundary symmetry can be interpreted as a gauging of the subgroup \mathcal{H}_{UV} of \mathcal{G}_5 in the CFT. Breaking gauge symmetries by IR-boundary conditions corresponds to the spontaneous breaking $\mathcal{G}_5 \to \mathcal{H}_{IR}$ in the CFT at energies $\sim ke^{-k\pi R}$. Using this correspondence we can easily derive the 4D massless spectrum of the compactified AdS₅ models. We also have the identification $k^3/M_5^3 \approx 16\pi^2/N^2$ and $g_5^2k \approx 16\pi^2/N^r$ (r=1 or 2for CFT fields in the fundamental or adjoint representation of the gauge group, respectively), where N plays the role of the

number of colors of the CFT. Therefore the weak-coupling limit in AdS_5 corresponds to a large-N expansion in the CFT.

Following the above AdS/CFT dictionary we can understand the RS solution to the hierarchy problem from a 4D viewpoint. The equivalent 4D model is a CFT with a TeV mass-gap and a Higgs emerging as a composite state. The AdS/CFT correspondence also shows that the 5D Higgsless models described above should share similar physics as Technicolor models [79]. Indeed, the lowest KK $SU(2)_L$ -gauge boson behaves as the Techni-rho ρ_T with a coupling to longitudinal W/Z bosons given by $g_5\sqrt{k}\approx g_{\rho_T}$, while the coupling to elementary fermions is $g_4^2/\sqrt{g_5^2k}\approx g^2F_{\rho_T}/M_{\rho_T}$. Also, models with the Higgs identified as A_5 correspond to models, similar to those proposed in Ref. [80], where the Higgs is a composite pseudo-Goldstone boson arising from the spontaneous breaking $\mathcal{G}_5\to\mathcal{H}_{IR}$ in the CFT.

Fermions in compactified AdS₅ also have a simple 4D holographic interpretation. The 4D massless mode described in sec. III.1 corresponds to an external fermion ψ_i linearly coupled to a fermionic CFT operator \mathcal{O}_i : $\mathcal{L}_{\text{int}} = \lambda_i \bar{\psi}_i \mathcal{O}_i + h.c.$. The dimension of the operator \mathcal{O}_i is related to the 5D fermion mass according to $\text{Dim}[\mathcal{O}_i] = |c_f + 1/2| - 1$. Therefore, by varying c_f we vary $\text{Dim}[\mathcal{O}_i]$, making the coupling λ_i irrelevant $(c_f > 1/2)$, marginal $(c_f = 1/2)$ or relevant $(c_f < 1/2)$. When irrelevant, the coupling is exponentially suppressed at low energies, and then the coupling of ψ_i to the CFT (and eventually to the composite Higgs) is very small. When relevant, it grows towards the IR and become as large as g_5 (in units of k), meaning that the fermion is as strongly coupled as the CFT states [59]. In this latter case ψ_i behaves as a composite fermion.

III.3 Flat Extra Dimensions

Models with quantum-gravity at the TeV scale, as in the ADD scenario, can have extra (flat) dimensions of 1/TeV size, as it happens in string scenarios [81]. All SM fields may propagate in these extra dimensions, leading to the possibility of observing their corresponding KK states.

A simple example is to assume that the SM gauge bosons propagate in a flat five-dimensional orbifold S^1/Z_2 of radius R, with the fermions localized on a 4D boundary. The KK gauge bosons behave as sequential SM gauge bosons with a coupling to fermions enhanced by a factor $\sqrt{2}$ [81]. The experimental limits on such sequential gauge bosons could therefore be recast as limits on KK gauge bosons. Bounds from LEP2 require $1/R \gtrsim 6$ TeV [61].

An alternative scenario, known as Universal Extra Dimensions (UED) [82], assumes that all SM fields propagate universally in a flat orbifold S^1/Z_2 with an extra Z_2 parity, called KK-parity, that interchanges the two boundaries. In this case, the lowest KK state is stable becoming a Dark Matter candidate. At colliders, the KK particles would have to be created in pairs, and would then cascade decay to the lightest KK particle (LKP), which would be stable and escape detection. Experimental signatures, such as jets or leptons and

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 E_T , would be similar to those of typical R-parity conserving SUSY searches. However, few experimental searches have as yet been interpreted in the UED scenario. DØ and ATLAS have both examined a specific UED model in which the KK parity is violated by gravitational interactions [83]. In this case the LKP can decay via $\gamma^* \to \gamma + G$, where G represents one of a tower of eV-spaced KK graviton states. Beginning with strong production of a pair of KK quarks and/or gluons [84], the final state would be $\gamma \gamma + \not\!\!E_T + X$, where $\not\!\!E_T$ results from the escaping gravitons and X represents SM particles emitted during the cascade decays. The experimental analyses treat R, the UED compactification radius, as a free parameter and follow the theory calculation [85] that sets Λ , the cut-off used in the calculation of radiative corrections to the KK masses, such that $\Lambda R = 20$. The gravitational decay widths of the KK particles are set by the values of δ and of M_D , the Planck scale in the $(4+\delta)$ -dimensional theory. Setting $\delta = 6$ and $M_D = 5$ TeV, and provided 1/R < 2 TeV, only the LKP has an appreciable gravitational decay, with a sizeable branching ratio for $\gamma^* \to \gamma + G$. In this scenario, DØ set a 95% CL limit that 1/R > 477 GeV [86]. The initial ATLAS result used only 3 pb⁻¹ to increase this limit to 1/R > 729 GeV; a recent ATLAS 1 fb⁻¹ update extends it further to 1/R > 1.23 TeV [87].

Finally, realistic models of electroweak symmetry breaking can also be constructed with flat extra spatial dimensions, similarly to those in the warped case, requiring, however, the presence of sizeable boundary kinetic terms [88]. There is also the possibility of breaking supersymmetry by boundary conditions [89]. Models of this type could explain naturally the presence of a Higgs boson lighter than M_D [90].

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CONTENTS:

Limits on R from Deviations in Gravitational Force Law Limits on R from On-Shell Production of Gravitons: $\delta=2$ Limits on R from On-Shell Production of Gravitons: $\delta \geq 3$ Mass Limits on MTT

Direct Limits on Gravitational or String Mass Scale

Limits on $1/R=M_{C}$ Limits on Kaluza-Klein Gravitons in Warped Extra Dimensions

Limits on Mass of Radion

Limits on R from Deviations in Gravitational Force Law

This section includes limits on the size of extra dimensions from deviations in the Newtonian $\left(1/r^2\right)$ gravitational force law at short distances. Deviations are parametrized by a gravitational potential of the form V=-(G m m'/r) $[1+\alpha \exp(-r/R)]$. For δ toroidal extra dimensions of equal size, $\alpha=8\delta/3$. Quoted bounds are for $\delta=2$ unless otherwise noted.

| VALUE (μm) | CL% | DO CUMENT ID | | COMMENT |
|----------------|------------------|--------------------------|---------|----------------------|
| | use the followin | ng data for average | s, fits | , limits, etc. • • • |
| | | 1 BEZERRA | 11 | Torsion oscillator |
| | | ² SUSHKOV | 11 | Torsion pendulum |
| | | ³ BEZERRA | 10 | Microcantilever |
| | | ⁴ MASUDA | 09 | Torsion pendulum |
| | | ⁵ GERACI | 80 | Microcantilever |
| | | ⁶ TRENKEL | 80 | Newton's constant |
| | | ⁷ DECCA | 07A | Torsion oscillator |
| < 30 | 95 | ⁸ KAPNER | 07 | Torsion pendulum |
| < 47 | 95 | ⁹ TU | 07 | Torsion pendulum |
| | | ¹⁰ SMULLIN | 05 | Microcantilever |
| <130 | 95 | 11 HOYLE | 04 | Torsion pendulum |
| | | ¹² CHIAVERINI | 03 | Microcantilever |
| \lesssim 200 | 95 | ¹³ LONG | 03 | Microcantilever |
| <190 | 95 | ¹⁴ HOYLE | 01 | Torsion pendulum |
| | | ¹⁵ HOSKINS | 85 | Torsion pendulum |

- 1 BEZERRA 11 obtain constraints on non-Newtonian forces with strengths $10^{11}\lesssim |lpha|\lesssim$ 10^{18} and length scales R=30–1260 nm. See their Fig. 2 for more details. These constraints do not place limits on the size of extra flat dimensions.
- 2 SUSHKOV 11 obtain improved limits on non-Newtonian forces with strengths $10^7\lesssim$ $|\alpha|\lesssim 10^{11}$ and length scales 0.4 $\mu\mathrm{m}< R<4~\mu\mathrm{m}$ (95% CL). See their Fig. 2. These bounds do not place limits on the size of extra flat dimensions. However, a model dependent bound of $M_*>70~\mathrm{TeV}$ is obtained assuming gauge bosons that couple to baryon number also propagate in $(4 + \delta)$ dimensions.
- $^3\,\mathrm{BEZERRA}$ 10 obtain improved constraints on non-Newtonian forces with strengths $10^{19} \lesssim |\alpha| \lesssim 10^{29}$ and length scales R=1.6-14 nm (95% CL). See their Fig. 1. This bound does not place limits on the size of extra flat dimensions.
- 4 MASUDA 09 obtain improved constraints on non-Newtonian forces with strengths $10^9 \lesssim$ $|lpha|\lesssim 10^{11}$ and length scales R= 1.0–2.9 μm (95% CL). See their Fig. 3. This bound es not place limits on the size of extra flat dimensions.
- 5 GERACI 08 obtain improved constraints on non-Newtonian forces with strengths $|\alpha|>14,000$ and length scales $R=5-15~\mu\mathrm{m}$. See their Fig. 9. This bound does not place limits on the size of extra flat dimensions.
- 6 TRENKEL 08 uses two independent measurements of Newton's constant G to constrain new forces with strength $|\alpha| \simeq 10^{-4}$ and length scales R=0.02–1 m. See their Fig. 1. This bound does not place limits on the size of extra flat dimensions.
- 7 DECCA 07A search for new forces and obtain bounds in the region with strengths $|lpha| \simeq$ 10^{13} and length scales R=20-86 nm. See their Fig. 6. This bound does not place limits on the size of extra flat dimensions.
- 8 KAPNER 07 search for new forces, probing a range of $\alpha\simeq 10^{-3}$ –10 5 and length scales $R\simeq 10$ –1000 $\mu\mathrm{m}$. For $\delta=1$ the bound on R is 44 $\mu\mathrm{m}$. For $\delta=2$, the bound is expressed in terms of M_{*} , here translated to a bound on the radius. See their Fig. 6 for details on the bound.
- gettails on the bound. 9 TU 07 search for new forces probing a range of $|\alpha| \simeq 10^{-1}$ – 10^5 and length scales $R \simeq 20$ – $1000~\mu m$. For $\delta = 1$ the bound on R is 53 μm . See their Fig. 3 for details on the
- $10\,\mathrm{SMULLIN}$ 05 search for new forces, and obtain bounds in the region with strengths $lpha \simeq 10^3$ – 10^8 and length scales R= 6–20 $\mu{\rm m}$. See their Figs. 1 and 16 for details on
- the bound. This work does not place limits on the size of extra flat dimensions. 11 HOYLE 04 search for new forces, probing α down to 10^{-2} and distances down to $10\mu m$. Quoted bound on R is for $\delta=2$. For $\delta=1$, bound goes to $160~\mu m$. See their Fig. 34 for details on the bound.
- 12 CHIAVERINI 03 search for new forces, probing α above 10^4 and λ down to 3μ m, finding no signal. See their Fig. 4 for details on the bound. This bound does not place limits on the size of extra flat dimensions.
- 13 LONG 03 search for new forces, probing lpha down to 3, and distances down to about
- $10\mu\text{m}$. See their Fig. 4 for details on the bound. 14 HOYLE 01 search for new forces, probing α down to 10^{-2} and distances down to $20\mu\text{m}$. See their Fig. 4 for details on the bound. The quoted bound is for $lpha \, \geq \, 3$.
- 15 HOSKINS 85 search for new forces, probing distances down to 4 mm. See their Fig. 13 for details on the bound. This bound does not place limits on the size of extra flat

Limits on R from On-Shell Production of Gravitons: $\delta = 2$

This section includes limits on on-shell production of gravitons in collider and astrophysical processes. Bounds quoted are on R, the assumed common radius of the flat extra dimensions, for $\delta=2$ extra dimensions. Studies often quote bounds in terms of derived parameter; experiments are actually sensitive to the masses of the KK gravitons: $m_{\vec{n}} = |\vec{n}|/R$. See the Review on "Extra Dimensions" for details. Bounds are given in μ m for $\delta=2$.

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Extra Dimensions

| < 72 < 245 < 615 < 0.916 < 350 < 270 < 210 < 480 < 0.00038 < 610 < 0.996 < 0.096 < 0.0916 < 3000 < 3000 < 0.00016 | 95 95 95 95 95 95 95 95 95 95 95 95 95 9 | 17 CHATRCHYAN 18 AALTONEN 19 ABAZOV 20 DAS 21 ABULENCIA,A 22 ABDALLAH 23 ACHARD 24 ACOSTA 25 CASSE 26 ABAZOV 27 HANNESTAD 28 HANNESTAD 29 HANNESTAD 30 HANNESTAD 31 HEISTER 32 FAIRBAIRN 33 HANHART 34 CASSISI | 08AC 08S 08 06 05B 04E 04C 04 03 03 03 03 03 01 | | $\begin{array}{l} p p \mapsto j G \\ p \overline{p} \mapsto \gamma G, j G \\ p \overline{p} \mapsto \gamma G \\ \text{Supernova cooling} \\ p \overline{p} \mapsto j G \\ e^+ e^- \mapsto \gamma G \\ e^+ e^- \mapsto \gamma G \\ \overline{p} p \mapsto j G \\ \text{Neutron star } \gamma \text{ sources} \\ \overline{p} p \mapsto j G \\ \text{Supernova cooling} \\ \text{Diffuse } \gamma \text{ background} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ \text{Neutron star } \gamma \text{ sources} \\ Neu$ |
|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <1300 | 95 | ³⁴ CASSISI ³⁵ ACCIARRI | 00 99s | L3 | Red giants $e^+ e^- \rightarrow ZG$ |

Limits on R from On-Shell Production of Gravitons: $\delta \geq 3$

This section includes limits similar to those in the previous section, but for $\delta=3$ extra dimensions. Bounds are given in nm for $\delta=3$. Entries are also shown for papers examining models with $\delta > 3$.

| VALUE (nm) | CL% | DO CUMENT ID TECN COMMENT |
|-----------------|------------------|--------------------------------------------------------------------------|
| • • • We do not | use the followin | g data for averages, fits, limits, etc. • • • |
| < 1.1 | 95 | 16 AAD 11s ATLS $pp \rightarrow jG$ |
| < 1.05 | 95 | ¹⁷ CHATRCHYAN11U CMS $pp \rightarrow jG$ |
| < 2.8 | 95 | ¹⁸ AALTONEN 08AC CDF $p\overline{p} \rightarrow \gamma G, jG$ |
| < 4.56 | 95 | ¹⁹ ABAZOV 08s D0 $p\overline{p} \rightarrow \gamma G$ |
| < 2.09 | 95 | 20 DAS 08 Supernova cooling |
| < 3.6 | 95 | ²¹ ABULENCIA,A 06 CDF $p\overline{p} \rightarrow jG$ |
| < 3.5 | 95 | 22 ABDALLAH 05B DLPH $e^+e^- ightarrow \gammaG$ |
| < 2.9 | 95 | 23 ACHARD 04E L3 $e^+e^- ightarrow \gamma$ G |
| | 95 | 24 ACOSTA 04c CDF $\overline{p}p \rightarrow jG$ |
| < 0.0042 | 95 | ²⁵ CASSE 04 Neutron star γ sources |
| < 6.1 | 95 | ²⁶ ABAZOV 03 D0 $\overline{p}p \rightarrow jG$ |
| < 1.14 | 95 | ²⁷ HANNESTAD 03 Supernova cooling |
| < 0.025 | 95 | ²⁸ HANNESTAD 03 Diffuse γ background |
| < 0.11 | 95 | ²⁹ HANNESTAD 03 Neutron star γ sources |
| < 0.0026 | 95 | 30 HANNESTAD 03 Neutron star heating |
| < 3.9 | 95 | 31 HEISTER 03C ALEP $e^+e^- \rightarrow \gamma G$ |
| | | 32 FAIRBAIRN 01 Cosmology |
| < 0.8 | 95 | 33 HANHART 01 Supernova cooling |
| | | 34 CASSISI 00 Red giants |
| <18 | 95 | ³⁵ ACCIARRI 99s L3 $e^+e^- \rightarrow ZG$ |

- 16 AAD 11s search for $pp \to jG$, using 33 pb⁻¹ of data at $\sqrt{s}=7$ TeV, to place bounds on M_D for two to four extra dimensions, from which these bounds on R are derived. See their Table 3 for bounds on all $\delta \leq 4$. 17 CHATRCHYAN 11u search for $pp \to jG$, using 36 pb⁻¹ of data at $\sqrt{s}=7$ TeV, to place bounds on M_D for two to six extra dimensions, from which these bounds on R are derived. See their Table 3 for bounds on all $\delta \leq 6$. 18 AALTONEN 08AC search for $p\overline{p} \to \gamma G$ and $p\overline{p} \to jG$ at $\sqrt{s}=1.96$ TeV with 2.0

- size of the extra dimensions. See their Table III for limits on all $\delta \leq 6$.

 19 ABAZOV 08s search for $p\overline{p} \to \gamma G$, using 1 fb⁻¹ of data at $\sqrt{s} = 1.96$ TeV with 2.0 bounds on M_D for two to eight extra dimensions, from which these bounds on R are derived. See their paper for intermediate values of δ .
- ²⁰ DAS 08 obtain a limit on R from Kaluza-Klein graviton cooling of SN1987A due to plasmon-plasmon annihilation.
- 21 ABULENCIA,A 06 search for $p\,\overline{p} o j\,G$ using 368 pb $^{-1}$ of data at $\sqrt{s}=1$.96 TeV. See
- 22 ABDALLAH 058 search for $e^+e^- o \gamma G$ at $\sqrt{s}=189$ –209 GeV to place bounds on the size of extra dimensions and the fundamental scale. Limits for all $\delta \leq 6$ are given in their Table 6. These limits supersede those in ABREU 002.

 23 ACHARD 04E search for $e^+e^- o \gamma G$ at $\sqrt{s}=189$ –209 GeV to place bounds on the size of extra dimensions and the fundamental scale. See their Table 8 for limits with $\delta \leq 8$. There limits supersede those in AGREU 07.
- $\delta \leq 8$. These limits supersede those in ACCIARRI 99R. 24 ACOSTA 04C search for $\overline{\rho}p \to jG$ at $\sqrt{s}=1.8$ TeV to place bounds on the size of extra dimensions and the fundamental scale. See their paper for bounds on $\delta=4$, 6.
- ²⁵ CASSE 04 obtain a limit on R from the gamma-ray emission of point γ sources that arises from the photon decay of gravitons around newly born neutron stars, applying the technique of HANNESTAD 03 to neutron stars in the galactic bulge. Limits for all $\delta \leq$ 7 are given in their Table I.
- 26 ABAZOV 03 search for $p\overline{p}\to jG$ at $\sqrt{s}{=}1.8$ TeV to place bounds on M_D for 2 to 7 extra dimensions, from which these bounds on R are derived. See their paper for bounds on intermediate values of δ . We quote results without the approximate NLO scaling introduced in the paper.
- 27 HANNESTAD 03 obtain a limit on R from graviton cooling of supernova SN1987a Limits for all $\delta \leq 7$ are given in their Tables V and VI.
- 28 HANNESTAD 03 obtain a limit on R from gravitons emitted in supernovae and which subsequently decay, contaminating the diffuse cosmic γ background. Limits for all $\delta \leq 7$ are given in their Tables V and VI. These limits supersede those in HANNESTAD 02.
- 29 HANNESTAD 03 obtain a limit on R from gravitons emitted in two recent supernovae and which subsequently decay, creating point γ sources. Limits for all $\delta \leq 7$ are given in their Tables V and VI. These limits are corrected in the published erratum.
- 30 HANNESTAD 03 obtain a limit on R from the heating of old neutron stars by the surrounding cloud of trapped KK gravitons. Limits for all $\delta \leq 7$ are given in their Tables V and VI. These limits supersede those in HANNESTAD 02.

- 31 HEISTER 03c use the process $e^+e^-
 ightarrow \gamma \mathit{G}$ at $\sqrt{s}=$ 189–209 GeV to place bounds on the size of extra dimensions and the scale of gravity. See their Table 4 for limits with $\delta \leq$ 6 for derived limits on M_D .
- 32 FAIRBAIRN 01 obtains bounds on R from over production of KK gravitons in the early universe. Bounds are quoted in paper in terms of fundamental scale of gravity. Bounds depend strongly on temperature of QCD phase transition and range from $R < 0.13~\mu m$ to 0.001 μ m for δ =2; bounds for δ =3,4 can be derived from Table 1 in the paper.
- 33 HANHART 01 obtain bounds on *R* from limits on graviton cooling of supernova SN 1987a using numerical simulations of proto-neutron star neutrino emission.
- 34 CASSISI 00 obtain rough bounds on M_D (and thus R) from red giant cooling for $\delta{=}2,3$.
- See their paper for details. See Their paper for details. See Their paper for details. See Their paper for $e^+e^- \rightarrow ZG$ at \sqrt{s} =189 GeV. Limits on the gravity scale are found in their Table 2, for $\delta \leq 4$.

Mass Limits on M_{TT}

This section includes limits on the cut-off mass scale, M_{TT} , of dimension-8 operators from KK graviton exchange in models of large extra dimensions. Ambiguities in the UV-divergent summation are absorbed into the parameter λ , which is taken to be $\lambda=$ ± 1 in the following analyses. Bounds for $\lambda = -1$ are shown in parenthesis after the bound for $\lambda=\pm 1$, if appropriate. Different papers use slightly different definitions of the mass scale. The definition used here is related to another popular convention by $M_{TT}^4=(2/\pi)~\Lambda_T^4$, as discussed in the above Review on "Extra Dimensions."

| | _ | | | | |
|---------------------|----------|-------------------------|-------|-----------|-------------------------------------------------------------|
| VALUE (TeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
| • • • We do not use | the foll | owing data for aver | ages, | fits, lim | its, etc. • • • |
| > 0.90 (>0.92) | 95 | ³⁶ AARON | 11 c | H1 | $e^{\pm}p \rightarrow e^{\pm}X$ |
| > 1.74 (>1.71) | 95 | 37 CHATRCHYAN | 111A | CMS | $pp \rightarrow \gamma\gamma$ |
| > 1.48 | 95 | ³⁸ ABAZOV | 09AE | D0 | $p\overline{p} \rightarrow \text{dijet}$, angular distrib. |
| > 1.45 | 95 | ³⁹ ABAZOV | 09D | D0 | $p \overline{p} \rightarrow e^+ e^-, \gamma \gamma$ |
| > 1.1 (> 1.0) | 95 | ⁴⁰ SCHAEL | | ALEP | $e^+e^- \rightarrow e^+e^-$ |
| > 0.898 (> 0.998) | 95 | ⁴¹ ABDALLAH | 06 C | DLPH | $e^+e^- \rightarrow \ell^+\ell^-$ |
| > 0.853 (> 0.939) | 95 | ⁴² GERDES | 06 | | $p \overline{p} \rightarrow e^+ e^-, \gamma \gamma$ |
| > 0.96 (> 0.93) | 95 | ⁴³ ABAZOV | 05 v | D0 | $p \overline{p} \rightarrow \mu^+ \mu^-$ |
| > 0.78 (> 0.79) | 95 | 44 CHEKANOV | 04B | ZEUS | $e^{\pm}p \rightarrow e^{\pm}X$ |
| > 0.805 (> 0.956) | 95 | 45 ABBIENDI | 03D | OPAL | $e^+e^- \rightarrow \gamma \gamma$ |
| > 0.7 (> 0.7) | 95 | ⁴⁶ ACHARD | 03D | L3 | $e^+e^- \rightarrow ZZ$ |
| > 0.82 (> 0.78) | 95 | ⁴⁷ ADLOFF | 03 | H1 | $e^{\pm}p \rightarrow e^{\pm}X$ |
| > 1.28 (> 1.25) | 95 | ⁴⁸ GIUDICE | 03 | RVUE | |
| >20.6 (> 15.7) | 95 | ⁴⁹ GIUDICE | 03 | RVUE | Dim-6 operators |
| > 0.80 (> 0.85) | 95 | ⁵⁰ HEISTER | 03c | ALEP | $e^+e^- \rightarrow \gamma \gamma$ |
| > 0.84 (> 0.99) | 95 | ⁵¹ ACHARD | 02D | L3 | $e^+e^- \rightarrow \gamma \gamma$ |
| > 1.2 (> 1.1) | 95 | ⁵² ABBOTT | 01 | D0 | $p \overline{p} \rightarrow e^+ e^-$, $\gamma \gamma$ |
| > 0.60 (> 0.63) | 95 | ⁵³ ABBIENDI | 00R | OPAL | $e^+e^- \rightarrow \mu^+\mu^-$ |
| > 0.63 (> 0.50) | 95 | ⁵³ ABBIENDI | 00R | OPAL | $e^+e^- \rightarrow \tau^+\tau^-$ |
| > 0.68 (> 0.61) | 95 | ⁵³ ABBIENDI | 00R | OPAL | $e^+e^- ightarrow\mu^+\mu^-$, $	au^+	au^-$ |
| | | ⁵⁴ ABREU | 00A | | $e^+e^- \rightarrow \gamma \gamma$ |
| > 0.680 (> 0.542) | 95 | ⁵⁵ ABREU | 00s | DLPH | $e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-$ |
| > 15-28 | 99.7 | ⁵⁶ CHANG | 00в | RVUE | Electroweak |
| > 0.98 | 95 | ⁵⁷ CHEUNG | 00 | RVUE | $e^+e^- \rightarrow \gamma \gamma$ |
| > 0.29-0.38 | 95 | ⁵⁸ GRAESSER | 00 | RVUE | $(g-2)_{\mu}$ |
| > 0.50-1.1 | 95 | ⁵⁹ HAN | 00 | RVUE | Electroweak |
| > 2.0 (> 2.0) | 95 | ⁶⁰ MATHEWS | 00 | RVUE | $\overline{p}p \rightarrow jj$ |
| > 1.0 (> 1.1) | 95 | 61 MELE | 00 | RVUE | $e^+e^- \rightarrow VV$ |
| | | 62 ABBIENDI | 99P | | |
| | | 63 ACCIARRI | 99м | | |
| | | 64 ACCIARRI | 99s | L3 | |
| > 1.412 (> 1.077) | 95 | ⁶⁵ BOURILKOV | 99 | | $e^+e^- \rightarrow e^+e^-$ |
| 20 | | | | | 1 |

- 36 AARON 11c search for deviations in the differential cross section of $e^{\pm} p
 ightarrow e^{\pm} X$ in
- 4460 b⁻¹ of data taken at $\sqrt{s}=301$ and 319 GeV to place a bound on M_{TT} . 37 CHATRCHYAN 11A use 36 pb⁻¹ of data from pp collisions at $\sqrt{s}=7$ TeV to place lower limits on Λ_T , here converted to M_{TT} .
- 38 ABAZOV 09AE use dijet angular distributions in 0.7 fb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to place lower bounds on Λ_T (equivalent to their M_S), here converted to M_{TT}
- 39 ABAZOV 09D use 1.05 fb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to place lower
- bounds on Λ_T (equivalent to their M_S), here converted to M_{TT} .

 40 SCHAEL 07A use e^+e^- collisions at $\sqrt{s}=189$ –209 GeV to place lower limits on Λ_T . here converted to limits on M_{TT} .
- 41 ABDALLAH 06c use $e^+\,e^-$ collisions at $\sqrt{s}\sim 130$ –207 GeV to place lower limits on M_{TT} , which is equivalent to their definition of M_S . Bound shown includes all possible final state leptons, $\ell=e,\,\mu,\,\tau.$ Bounds on individual leptonic final states can be found in the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state of the state
- In their label 51. 42 GERDES 06 use 100 to 110 pb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV, as recorded by the CDF Collaboration during Run I of the Tevatron. Bound shown includes a K-factor of 1.3. Bounds on individual e^+e^- and $\gamma\gamma$ final states are found in their Table I.
- 43 ABAZOV 05v use 246 pb $^{-1}$ of data from $ho \overline{
 ho}$ collisions at $\sqrt{s}=1.96$ TeV to search for deviations in the differential cross section to $\mu^+\mu^-$ from graviton exchange.
- ⁴⁴ CHEKANOV 04B search for deviations in the differential cross section of $e^{\pm} p
 ightarrow e^{\pm} X$ with 130 pb^{-1} of combined data and Q^2 values up to 40,000 GeV² to place a bound on M_{TT}
- 45 ABBIENDI 03D use e^+e^- collisions at \sqrt{s} =181-209 GeV to place bounds on the ultraviolet scale M_{TT} , which is equivalent to their definition of M_S .
- ⁴⁶ ACHARD 03D look for deviations in the cross section for $e^+e^-
 ightarrow ZZ$ from $\sqrt{s}=$ 200–209 GeV to place a bound on M_{TT} .
- 47 ADLOFF 03 search for deviations in the differential cross section of $e^\pm p \to e^\pm X$ at \sqrt{s} =301 and 319 GeV to place bounds on M_{TT} .

- 48 GIUDICE 03 review existing experimental bounds on M_{TT} and derive a combined limit.
- $^{49}\,\text{GIUDICE}$ 03 place bounds on Λ_6 , the coefficient of the gravitationally-induced dimension-6 operator $(2\pi/\Lambda \Lambda_0^2)(\sum \overline{I}\gamma_\mu \gamma^5 f)(\sum \overline{I}\gamma^\mu \gamma^5 f)$, using data from a variety of experiments. Results are quoted for $\lambda = \pm 1$ and are independent of δ .
- $50\,\mathrm{HEISTER}$ 03c use e^+e^- collisions at $\sqrt{s}=$ 189–209 GeV to place bounds on the scale of dim-8 gravitational interactions. Their M_S^{\pm} is equivalent to our M_{TT} with $\lambda = \pm 1$.
- 51 ACHARD 02 search for s-channel graviton exchange effects in $e^+\,e^-
 ightarrow \, \gamma\gamma$ at $E_{
 m cm}=$
- 192–209 GeV. 192–209 GeV. 192–209 GeV. 192–209 GeV. 192–209 GeV. 193–309 GeV. 193–309 GeV. 193–309 GeV. 193–309 GeV. 193–309 GeV. 193–309 GeV. 193–309 GeV.
- 54 ABREU 00A search for s-channel graviton exchange effects in $e^+\,e^-\,
 ightarrow\,\gamma\gamma$ at $E_{
 m Cm}=$
- 55 ABREU 00s uses e^+e^- collisions at \sqrt{s} =183 and 189 GeV. Bounds on μ and au individual final states given in paper.
- 56 CHANG 008 derive 37 limit on M T of (28,19,15) TeV for 5 =(2,4,6) respectively assuming the presence of a torsional coupling in the gravitational action. Highly model
- ⁵⁷ CHEUNG 00 obtains limits from anomalous diphoton production at OPAL due to graviton exchange. Original limit for δ =4. However, unknown UV theory renders δ dependence unreliable. Original paper works in HLZ convention.
- ⁵⁸ GRAESSER 00 obtains a bound from graviton contributions to g-2 of the muon through loops of 0.29 TeV for δ =2 and 0.38 TeV for δ =4,6. Limits scale as $\lambda^{1/2}$. However calculational scheme not well-defined without specification of high-scale theory. See the "Extra Dimensions Review."
- Taxtra Dimensions review. The Air No calculates corrections to gauge boson self-energies from KK graviton loops and constrain them using S and T. Bounds on M_{TT} range from 0.5 TeV (δ =6) to 1.1 TeV (δ =2); see text. Limits have strong dependence, $\lambda^{\delta+2}$, on unknown λ coefficient.
- 60 (0-2), see text. Elimina have strong appearance of MATHEWS 00 search for evidence of graviton exchange in CDF and DØ dijet production data. See their Table 2 for slightly stronger δ-dependent bounds. Limits expressed in terms of $\widetilde{M}_S^4 = M_{TT}^4/8$.
- 61 MELE 00 obtains bound from KK graviton contributions to ${
 m e^+\,e^-}
 ightarrow~V~V~(V=\gamma,W,Z)$
- at LEP. Authors use Hewett conventions. 62 ABBIENDI 99P search for s-channel graviton exchange effects in $e^+e^- \to \gamma \gamma$ at $E_{\rm cm}$ =189 GeV. The limits $G_+ >$ 660 GeV and $G_- >$ 634 GeV are obtained from combined $E_{\rm cm}$ =183 and 189 GeV data, where G_\pm is a scale related to the fundamental
- 63 ACCIARRI 99M search for the reaction $e^+\,e^-\,
 ightarrow\,\gamma\,{\it G}$ and s-channel graviton exchange effects in $e^+e^-\to\gamma\gamma$, W^+W^- , Z, e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$, $q\overline{q}$ at $E_{\rm cm}=$ 183 GeV. Limits on the gravity scale are listed in their Tables 1 and 2.
- ⁶⁴ ACCIARRI 99s search for the reaction $e^+e^- \to ZG$ and s-channel graviton exchange effects in $e^+e^- \to \gamma\gamma$, W^+W^- , ZZ, e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$, $q\overline{q}$ at $E_{\rm cm}=189$ GeV. Limits on the gravity scale are listed in their Tables 1 and 2.
- 65 BOURLIKOV 99 performs global analysis of LEP data on $e^+\,e^-$ collisions at $\sqrt{s}{=}183$ and 189 GeV. Bound is on Λ $_T$.

Direct Limits on Gravitational or String Mass Scale

This section includes limits on the fundamental gravitational scale and/or the string scale from processes which depend directly on one or the other of these scales.

| VALUE (TeV) | DO CUMENT ID | TECN | COMMENT | |
|-------------------------|-----------------------------------|-----------|------------|--|
| • • • We do not use the | following data for averages, fits | , limits, | etc. • • • | |
| \gtrsim 1-2 | 66 ANCHORDOQ02в | | | |
| \n 10 | 67 ACCIARRI NOD | 13 | a+ a a+ a- | |

- 66 ANCHORDOQUI 02B derive bound on M_D from non-observation of black hole production in high-energy cosmic rays. Bound is stronger for larger δ , but depends sensitively on threshold for black hole production.
- on the short of productions of N_S from massive string modes. N_S is defined in hep-ph/0001166 by $M_{\rm S}(1/\pi)^{1/8}\alpha^{-1/4} = M \text{ where } (4\pi G)^{-1} = M^{n+2}R^n.$

Limits on $1/R = M_c$

This section includes limits on $1/R=M_{\rm C}$, the compactification scale in models with TeV extra dimensions, due to exchange of Standard Model KK excitations. Bounds assume fermions are not in the bulk, unless stated otherwise. See the "Extra Dimensions" review for discussion of model dependence.

| VALUE (TeV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---------------------|---------------|-------------------------|--------|-------------|---------------------------------------------------------------------|
| ullet $ullet$ We do | not use the 1 | following data for a | verage | es, fits, l | imits, etc. • • • |
| >0.729 | 95 | ⁶⁸ aad | 11 F | ATLS | $pp \rightarrow \gamma \gamma$, $\delta = 6$, $M_D = 5$ TeV |
| >0.961 | 95 | ⁶⁹ AAD | 11x | ATLS | $pp \rightarrow \gamma \gamma, \delta = 6, M_D = 5 \text{ TeV}$ |
| >0.477 | 95 | ⁷⁰ ABAZOV | 10P | D0 | $p\overline{p} \rightarrow \gamma\gamma$, $\delta=6$, $M_D=5$ TeV |
| >1.59 | 95 | ⁷¹ ABAZOV | 09AE | D0 | $p\overline{p} \rightarrow \text{dijet, angular dist.}$ |
| >0.6 | 95 | ⁷² HAISCH | 07 | RVUE | $\overline{B} \rightarrow X_S \gamma$ |
| >0.6 | 90 | ⁷³ GOGOLADZE | 06 | RVUE | Electroweak |
| >3.3 | 95 | ⁷⁴ CORNET | 00 | RVUE | Electroweak |
| > 3.3-3.8 | 95 | ⁷⁵ RIZZO | 00 | RVUE | Electroweak |

- 68 AAD 11F use diphoton events with large missing transverse energy in 3.1 pb $^{-1}$ of data produced from pp collisions at $\sqrt{s}=7$ TeV to place a lower bound on the compactifiance. cation scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale Λ , for the radiative corrections to the Kaluza-Klein masses, satisfies $\Lambda/{\rm M}_c=$ 20. The model parameters are chosen such that the decay γ^* occurs with an appreciable branching fraction.
- ⁶⁹ AAD 11x use diphoton events with large missing transverse energy in 36 pb $^{-1}$ of data produced from pp collisions at $\sqrt{s}=7$ TeV to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale Λ , for the radiative corrections to the Kaluza-Klein masses, satisfies $\Lambda/M_C=20$. The model parameters are chosen such that the decay $\gamma^*\to G\gamma$ occurs with an appreciable branching fraction.

- 70 ABAZOV 10P use diphoton events with large missing transverse energy in 6.3 fb $^{-1}$ of data produced from $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to place a lower bound on the compactification scale in a universal extra dimension model with gravitational decays. The bound assumes that the cutoff scale Λ , for the radiative corrections to the Kaluza-Viai process at 16 fb. ALM. 30 The scale Λ are produced by the contraction of the scale Λ and Λ are produced by the scale Λ and Λ are produced by the scale Λ . Klein masses, satisfies $\Lambda/\mathrm{M}_c{=}20$. The model parameters are chosen such that the decay
- $\gamma^*
 ightarrow G \, \gamma$ occurs with an appreciable branching fraction. ^1 ABAZOV 09AE use dijet angular distributions in 0.7 fb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to place a lower bound on the compactification scale.
- $72\,\mathrm{HAISCH}$ 07 use inclusive \overline{B} -meson decays to place a Higgs mass independent bound on the compactification scale 1/R in the minimal universal extra dimension model.
- 73 GOGOLADZE 06 use electroweak precision observables to place a lower bound on the compactification scale in models with universal extra dimensions. Bound assumes a 115 GeV Higgs mass. See their Fig. 3 for the bound as a function of the Higgs mass.
- 74 CORNET 00 translates a bound on the coefficient of the 4-fermion operator $(\overline{\ell}\gamma_{\mu}\tau^a\ell)(\overline{\ell}\gamma^{\mu}\tau^a\ell)$ derived by Hagiwara and Matsumoto into a limit on the mass scale of KK W bosons.
- 75 RIZZO 00 obtains limits from global electroweak fits in models with a Higgs in the bulk (3.8 TeV) or on the standard brane (3.3 TeV).

Limits on Kaluza-Klein Gravitons in Warped Extra Dimensions

This sections places limits on the mass of the first Kaluza-Klein (KK) excitation of the graviton in the warped extra dimension model of Randall and Sundrum. Experimental bounds depend strongly on the warp parameter, k. See the "Extra Dimensions" review for a full discussion

Here we list limits for the value of the warp parameter $k/\overline{M}_P=0.1$.

| VALUE (GeV) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------------------------------|---------------|-------------------------|-----------------|---------|---------------------------------------------------------------------|
| >1630 | 95 | ⁷⁶ AAD | 11AD / | ATLS | $pp \rightarrow G \rightarrow \ell \overline{\ell}$ |
| ● ● We do not | use the follo | owing data for avera | ages, fits | , limit | s, etc. • • • |
| | | ⁷⁷ AALTONEN | 11 _G | CDF | $p\overline{p} \rightarrow G \rightarrow ZZ$ |
| >1058 | 95 | ⁷⁸ AALTONEN | 11R (| CDF | $p\overline{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$ |
| > 754 | 95 | ⁷⁹ ABAZOV | | D0 | $p\overline{p} \rightarrow G \rightarrow WW$ |
| >1079 | 95 | ⁸⁰ CHATRCHYA | N11 (| CMS | $pp \rightarrow G \rightarrow \ell \overline{\ell}$ |
| > 607 | | ⁸¹ AALTONEN | 10N (| CDF | $p\overline{p} \rightarrow G \rightarrow WW$ |
| >1050 | | ⁸² ABAZOV | 10F [| D0 | $p\overline{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$ |
| | | ⁸³ AALTONEN | 08s (| CDF | $p\overline{p} \rightarrow G \rightarrow ZZ$ |
| > 900 | | ⁸⁴ ABAZOV | 1 L80 | D0 | $p\overline{p} \rightarrow G \rightarrow e^+e^-, \gamma\gamma$ |
| | | ⁸⁵ AALTONEN | 07g (| CDF | $p\overline{p} \rightarrow G \rightarrow \gamma\gamma$ |
| > 889 | | ⁸⁶ AALTONEN | 07н (| CDF | $p \overline{p} \rightarrow G \rightarrow e \overline{e}$ |
| > 785 | | ⁸⁷ ABAZOV | 05 N I | D0 | $p\overline{p} \rightarrow G \rightarrow \ell\ell$, $\gamma\gamma$ |
| > 710 | | ⁸⁸ ABULENCIA | 05A (| CDF | $p\overline{p} \rightarrow G \rightarrow \ell\overline{\ell}$ |

- 76 AAD 11AD use 1.08 and 1.21 fb $^{-1}$ of data from $p\,p$ collisions at $\sqrt{s}=7$ TeV in the dielectron and dimuon channels, respectively, to place a lower bound on the mass of the lightest graviton. For warp parameter values k/\overline{M}_P between 0.01 to 0.1 the lower limit on the mass of the lightest graviton is between 0.71 and 1.63 TeV. See their Table IV for more details
- To more decials. To more decials, $\sqrt{s}=1.96~{\rm TeV}$ to fata from $p\overline{p}$ collisions at $\sqrt{s}=1.96~{\rm TeV}$ to search for KK gravitons in a warped extra dimension decaying to ZZ dibosons via the eeee, ee $\mu\mu$, $\mu\mu\mu\mu$, eejj, and $\mu\mu$ jj channels. See their Fig. 20 for limits on the cross
- e eee, ee μ i, μ μ μ i, ee jj, and μ μ j channels. See their Fig. 20 for limits on the cross section σ ($G \rightarrow ZZ$) as a function of the graviton mass. 78 AALTONEN 11R uses 5.7 fb⁻¹ of data from $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV in the dielectron channel to place a lower bound on the mass of the lightest graviton. It provides combined limits with the diphoton channel analysis of AALTONEN 11U. For warp parameter values $k/\overline{M}p$ between 0.01 to 0.1 the lower limit on the mass of the lightest graviton is between 612 and 1058 GeV. See their Table I for more details. 79 ABAZOV 11H use 5.4 fb⁻¹ of data from $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV to place a lower bound on the mass of the lightest graviton. Their 95% C.L. exclusion limit does not include masses less than 300 GeV.
- not include masses less than 300 GeV. 80 CHATRCHYAN 11 use 35 and 40 pb $^{-1}$ of data from pp collisions at $\sqrt{s}=$ 7 TeV in the dielectron and dimuon channels, respectively, to place a lower bound on the mass of the lightest graviton. For a warp parameter value $k/\overline{M}_P=0.05$, the lower limit on the
- mass of the lightest graviton is 0.855 TeV. 81 AALTONEN 10N use 2.9 fb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to place a lower bound on the mass of the lightest graviton.
- 82 ABAZOV 10F use 5.4 fb $^{-1}$ of data from $p\overline{p}$ collisions at $\sqrt{s}=$ 1.96 TeV to place lower bound on the mass of the lightest graviton. For warp parameter values of k/Mp between 0.01 and 0.1 the lower limit on the mass of the lightest graviton is between 560 and 1050 GeV. See their Fig. 3 for more details.
- 83 AALTONEN 08s use $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to four electrons via two Z bosons using 1.1 fb $^{-1}$ of data. See their Fig. 8 for limits on $\sigma \cdot B(G \to ZZ)$ versus the graviton mass.
- ABAZOV 08J use $p T_0$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to electrons and photons using 1 fb $^{-1}$ of data. For warp parameter values of k/\overline{M}_P between 0.01 and 0.1 the lower limit on the mass of the lightest excitation is between 300 and 900 GeV. See their Fig. 4 for more details.
- Fig. 4 for more details. 85 AALTONEN 076 use $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to photons using 1.2 fb^{-1} of data. For warp parameter values of $k/M_P=0.1$, 0.05, and 0.01 the bounds on the graviton mass are 850, 694, and 230 GeV, respectively. See their Fig. 3 for more details. See also AALTONEN 07H.
- details. See also AALTONEN 0/H. 86 AALTONEN 0/H. 86 AALTONEN 07H use $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to electrons using $1.3~{\rm fb}^{-1}$ of data. For a warp parameter value of $k/\overline{M}_P=0.1$ the bound on the graviton mass is 807 GeV. See their Fig. 4 for more details. A combined analysis with the diphoton data of AALTONEN 07G yields for $k/\overline{M}_P=0.1$ a graviton mass lower bound of 880 GeV.
- the diphoton data of AALTONEN ore yields for k/mp=0.1 a graviton mass combound of 889 GeV. 87 ABAZOV 05N use $p\overline{p}$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to muons, electrons or photons, using 260 pb $^{-1}$ of data. For warp parameter values of $k/\overline{M}p=0.1,\,0.05,\,\mathrm{and}$

Extra Dimensions, WIMPs and Other Particle Searches

0.01, the bounds on the graviton mass are 785, 650 and 250 GeV respectively. See their Fig. 3 for more details.

88 $^{18}_{18}$. So limited secans. ABULENCIA 05A use $p_{\overline{p}}$ collisions at $\sqrt{s}=1.96$ TeV to search for KK gravitons in warped extra dimensions. They search for graviton resonances decaying to muons or electrons, using 200 pb $^{-1}$ of data. For warp parameter values of $k/\overline{M}_{p}=0.1$, 0.05, and 0.01, the bounds on the graviton mass are 710, 510 and 170 GeV respectives.

Limits on Mass of Radion

This section includes limits on mass of radion, usually in context of Randall-Sundrum models. See the "Extra Dimension Review" for discussion of model dependence.

| VALUE (GeV) | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|----------------------------|-----------|---------|---------------------------------------------------------------------|
| • • • We do not use the | following data for average | es, fits, | limits, | etc. • • • |
| | ⁸⁹ ABBIENDI | 05 | OPAL | $e^+e^-	o Z$ radion |
| \gtrsim 35 | ⁹⁰ mahanta | 00 | | $Z 	o radion \ \ell \overline{\ell}$ |
| >120 | ⁹¹ MAHANTA | 00B | | $p\overline{p} \rightarrow \text{radion} \rightarrow \gamma \gamma$ |

 89 ABBIENDI 05 use e^+e^- collisions at $\sqrt{s}=91$ GeV and $\sqrt{s}=189$ –209 GeV to place bounds on the radion mass in the RS model. See their Fig. 5 for bounds that depend on the radion–Higgs mixing parameter ξ and on $\Lambda_W=\Lambda_\phi/\sqrt{6}$. No parameter-independent

bound is obtained.

MAHANTA 00 obtain bound on radion mass in the RS model. Bound is from Higgs boson search at LEP I.

91 MAHANTA 00B uses $p\overline{p}$ collisions at $\sqrt{s}=1.8$ TeV; production via gluon-gluon fusion. Authors assume a radion vacuum expectation value of 1 TeV.

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|--------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
|--------------------------------------------------------------|--------------------------------|-----------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|

WIMPs and Other Particles Searches for

OMITTED FROM SUMMARY TABLE

WIMPS AND OTHER PARTICLE SEARCHES

Revised March 2012 by K. Hikasa (Tohoku University).

We collect here those searches which do not appear in any of the above search categories. These are listed in the following order:

- Galactic WIMP (weakly-interacting massive particle) searches
- 2. Concentration of stable particles in matter
- 3. General new physics searches
- 4. Limits on jet-jet resonance in hadron collisions
- 5. Limits on neutral particle production at accelerators
- 6. Limits on charged particles in e^+e^- collisions
- 7. Limits on charged particles in hadron reactions
- 8. Limits on charged particles in cosmic rays

Note that searches appear in separate sections elsewhere for Higgs bosons (and technipions), other heavy bosons (including W_R , W', Z', leptoquarks, axigluons), axions (including pseudo-Goldstone bosons, Majorons, familons), heavy leptons, heavy neutrinos, free quarks, monopoles, supersymmetric particles, and compositeness. We include specific WIMP searches in the appropriate sections when they yield limits on hypothetical particles such as supersymmetric particles, axions, massive neutrinos, monopoles, etc.

We omit papers on CHAMP's, millicharged particles, and other exotic particles. We no longer list for limits on tachyons and centauros. See our 1994 edition for these limits.

GALACTIC WIMP SEARCHES

Cross-Section Limits for Dark Matter Particles (X^0) on Nuclei

These limits are for weakly-interacting stable particles that may constitute the invisible mass in the galaxy. Unless otherwise noted, a local mass density of 0.3 GeV/cm 3 is assumed; see each paper for velocity distribution assumptions. In the papers the limit is given as a function of the X^0 mass. Here we list limits only for typical mass values of 20 GeV, 100 GeV, and 1 TeV. Specific limits on supersymmetric dark matter particles may be found in the Supersymmetry section.

For $m_{\chi^0}=20~{\rm GeV}$

| VALUE (nb) CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------------------------|-------------------------|---------|---------|-----------------------|
| ullet $ullet$ We do not use the following | g data for averages | , fits, | limits, | etc. • • • |
| | ¹ AALSETH | 11 | CGNT | Ge |
| | ² AALSETH | 11A | CGNT | Ge |
| | ³ AHLEN | 11 | DMTP | CF ₄ |
| | ⁴ AHMED | 11 | CDM2 | Ge, inelastic |
| | ⁵ AHMED | 11A | RVUE | Ge |
| | ⁶ AHMED | 11B | CDM2 | Ge, low threshold |
| | ⁷ ANGLE | 11 | XE10 | Xe |
| | 8 APRILE | 11 | X100 | Xe |
| | ⁹ APRILE | 11B | X100 | Xe |
| | ¹⁰ BEHNKE | 11 | COUP | CF ₃ I |
| | 11 HORN | 11 | ZEP3 | Xe |
| | ¹² TANAKA | 11 | SKAM | H, solar $ u$ |
| | ¹³ AKERIB | 10 | CDM2 | Si, Ge, low threshold |
| | ¹⁴ APRILE | 10 | X100 | Xe |
| | ¹⁵ ARMENGAUD | 10 | EDE2 | Ge |

Searches Particle Listings WIMPs and Other Particle Searches

| | | ¹⁶ FELIZARDO 10 SMPL C ₂ CIF ₃ |
|----------------------------------------------------|----------------------------------|----------------------------------------------------------------------------------------------------------|
| | | ¹⁷ AHMED 09 CDM2 Ge |
| | | ¹⁸ ARCHAMBAU09 PICA F |
| | | ¹⁹ LEBEDENKO 09A ZEP3 Xe |
| | | ²⁰ LIN 09 TEXO Ge |
| | | ²¹ AALSETH 08 CGNT Ge |
| | | ²² ANGLE 08A XE10 Xe |
| | | ²³ ALNER 07 ZEP2 Xe |
| | | ²⁴ LEE 07A KIMS Csi |
| | | ²⁵ AKERIB 06 CDMS ⁷³ Ge, ²⁹ Si |
| | | ²⁶ SHIMIZU 06A CNTR F (CaF ₂) |
| | | ²⁷ ALNER 05 NAIA NaI |
| | | ²⁸ BARNABE-HE05 PICA F (C ₄ F ₁₀) |
| | | ²⁹ BENOIT 05 EDEL ⁷³ Ge |
| | | ³⁰ GIRARD 05 SMPL F (C ₂ CIF ₅) |
| | | ³¹ KLAPDOR-K 05 HDMS ⁷³ Ge (enriched) |
| | | ³² MIUCHI 03 BOLO LIF |
| | | ³³ TAKEDA 03 BOLO NaF |
| < 0.08 | 90 | ³⁴ ANGLOHER 02 CRES AI |
| | | ³⁵ BENOIT 00 EDEL Ge |
| < 0.04 | 95 | ³⁶ KLIMENKO 98 CNTR ⁷³ Ge, inel. |
| < 0.8 | | ALESSAND 96 CNTR O |
| < 6 | | ALESSAND 96 CNTR Te |
| < 0.02 | 90 | ³⁷ BELLI 96 CNTR ¹²⁹ Xe, inel. |
| | | ³⁸ BELLI 96c CNTR ¹²⁹ Xe |
| < 0.004 | 90 | ³⁹ BERNABEI 96 CNTR Na |
| < 0.3 | 90 | ³⁹ BERNABEI 96 CNTR I |
| < 0.2 | 95 | ⁴⁰ SARSA 96 CNTR Na |
| < 0.015 | 90 | ⁴¹ SMITH 96 CNTR Na |
| < 0.05 | 95 | ⁴² GARCIA 95 CNTR Natural Ge |
| < 0.1 | 95 | QUENBY 95 CNTR Na |
| <90 | 90 | ⁴³ SNOWDEN 95 MICA ¹⁶ O |
| $< 4 \times 10^{3}$ | 90 | ⁴³ SNOWDEN 95 MICA ³⁹ K |
| < 0.7 | 90 | BACCI 92 CNTR Na |
| < 0.12 | 90 | 44 REUSSER 91 CNTR Natural Ge |
| < 0.06 | 95 | CALDWELL 88 CNTR Natural Ge |
| ¹ AALSETH 11 give section. See their | $\sigma < 5 	imes$ Fig. 4 for | 10^{-5} pb (90% CL) for spin-independent X^0 -nucleon cr limits extending to $m_{\chi 0} = 3.5$ GeV. |
| | | ons of annual modulation of the data, the energy spectr |
| | | hass around 8 GeV. |
| | | ⁵ pb (90% CL) for spin-dependent X^0 -proton cross section |
| | | nelastic scattering. See their Figs. 8–10 for limits. |
| | | S and EDELWEISS data and give $\sigma < 2.7 \times 10^{-7}$ nh (9) |

- ross

- 5 AHMED 11A combine CDMS and EDELWEISS data and give $\sigma < 2.7 imes 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon cross section.
- 6 AHMED 11B give limits on spin-independent X^0 -nucleon and spin-dependent X^0 -neutron cross section for $m_{\chi 0}=4$ –12 GeV in the range 10^{-5} – 10^{-3} pb and 10– 10^3 pb, respectively. See their Fig. 3.
- 7 ANGLE 11 give σ < 5×10^{-7} pb (90% CL) for spin-independent X^0 -nucleon cross section. See their Fig. 3 for limits down to $m_{X^0}=4$ GeV.
- 8 APRILE 11 reanalyze APRILE 10 data and give $\sigma~<~7 \times 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross section.
- 9 APRILE 11B give $\sigma < 2 \times 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 10 BEHNKE 11 give $\sigma < 0.1$ pb (90% CL) for spin-dependent X^0 -proton cross section with a direction sensitive detector.

 11 HORN 11 perform detector calibration by neutrons. Earlier results are only marginally
- 12 TANAKA 11 search for neutrinos produced by X^0 annihilation in the Sun and give $\sigma~<~1.5\times10^{-2}~{\rm pb}$ (90% CL) (for $m_{\chi^{\,0}}=10~{\rm GeV})$ for spin-dependent $\chi^{\,0}-{\rm proton}$
- cross section, assuming that X^0 pairs annihilate to $b\overline{b}$. 13 AKERIB 10 give $\sigma < 1 \times 10^{-5}$ pb (90% CL) for spin-independent X^0 -nucleon cross section. See their Figs. 10 and 12 for limits extending to X^0 mass of 1 GeV.
- 14 APRILE 10 give $\sigma < 1 imes 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 15 ARMENGAUD 10 give $\sigma < 2 \times 10^{-6}$ pb (90% CL) for spin-independent X^0 -nucleon cross section.
- 16 FELIZARDO 10 give $\sigma < 4 imes 10^{-5}$ pb (90% CL) for spin-independent X^0 -nucleon
- 17 AHMED 09 give $\sigma < 0.06$ pb (90% CL) for spin-dependent X^0 -neutron cross section.
- 18 ARCHAMBAULT 09 give $\sigma < 0.2$ pb (90% CL) for spin-dependent X^0 -proton cross
- 19 LEBEDENKO 09A give $\sigma <$ 4 (0.04) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- 20 See their Fig. 6(b) for limits on spin-dependent 0 -neutron cross section for m_{χ^0}
- between 2 and 10 GeV. 21 See their Fig. 2 for cross section limits for $m_{\mbox{$\chi$}0}$ between 4 and 10 GeV.
- $^{22}\,\mathrm{A\,NGLE}$ 08A give $\sigma\,<$ 0.6 (0.007) pb (90% CL) for spin-dependent $\,\mathrm{X}^{\,0}\text{-proton}$ (neutron)
- 23 ALNER 07 give $\sigma < 100$ (0.5) pb (90% CL) for spin-dependent χ^0 -proton (neutron)
- 24 LEE 07A give $\sigma < 1$ (25) pb (90% CL) for spin-dependent $^{\prime}$ 0-proton (neutron) cross
- Section. See also AKERIB 06 give $\sigma <$ 20 (0.3) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section. See also AKERIB 05. 26 SHIMIZU 06A give $\sigma <$ 2 (30) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- cross section. 27 ALNER 05 give σ < 0.5 (60) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section

- 28 BARNABE-HEIDER 05 give $\sigma~<$ 1.5 (20) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- $^{29}\, {\rm BENOIT}$ 05 give $\sigma~<$ 10 pb (90% CL) for spin-dependent X^0 -neutron cross section.
- 30 GIRARD 05 give $\sigma < 1.5$ pb (90% CL) for spin-dependent X^0 -proton cross section.
- 31 KLAPDOR-KLEINGROTHAUS 05 give σ $\,<$ 4 pb (90% CL) for spin-dependent X^0 neutron cross section.
- 32 MIUCHI 03 give model-independent limit σ <35 pb (90% CL) for spin-dependent X^0 proton cross section.
- 33 TAKEDA 03 give model-independent limit $\sigma < 0.03~(0.6)\,\mathrm{nb}~(90\%$ CL) for spindependent X^0 -proton (neutron) cross section.
- ³⁴ ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.
- $^{35}\,\mathrm{BENOIT}$ 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay
- ³⁶ KLIMENKO 98 limit is for inelastic scattering X^0 ⁷³ Ge $\to X^0$ ⁷³ Ge* (13.26 keV). ³⁷ BELLI 96 limit for inelastic scattering X^0 ¹²⁹Xe $\to X^0$ ¹²⁹Xe*(39.58 keV).
- 38 BELLI 96c use background subtraction and obtain $\sigma <$ 150 pb (< 1.5 fb) (90% CL) for spin-dependent (independent) X^0 -proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.
- 39 BERNABEI 96 use pulse shape discrimination to enhance the possible signal. The limit here is from R. Bernabei, private communication, September 19, 1997.
- $^{
 m 40}\,{\rm SARSA}$ 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997.
- 41 SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm⁻³ is assumed.
- 42 GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for
- diurnal and annual modulation.

 43 SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ²⁷Al and ²⁸Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.
- on potential absorptions.

 44 REUSSER 91 limit here is changed from published (0.04) after reanalysis by authors.

 J.L. Vuilleumier, private communication, March 29, 1996.

| For $m_{X^0} =$ | 100 | GeV | | | | | | |
|-----------------|--------|-------|-----------|-----------|------------------|-----------|--------------|------------------------------------------------------------|
| VALUE (nb) | | | CL% | | DOCUMENT ID | | TECN | COMMENT |
| • • • We do | not us | e the | following | d | ata for averages | , fits, | limits, e | etc. • • • |
| | | | | 1 | AALSETH | 11 | CGNT | Ge |
| | | | | | AHLEN | 11 | DMTP | CF₄ |
| | | | | | AHMED | 11 | CDM2 | Ge, inelastic |
| | | | | | AHMED | 11A | RVUE | Ge |
| | | | | | AJELLO | 11 | FLAT | |
| | | | | | APRILE | 11 | X100 | Xe |
| | | | | 7 | APRILE | 11A | X100 | Xe, inelastic |
| | | | | 8 | APRILE | 11B | X100 | Xe |
| | | | | 9 | ARMENGAUD | 11 | EDE2 | Ge |
| | | | | 10 | BEHNKE | 11 | COUP | CF ₃ I |
| | | | | | HORN | 11 | ZEP3 | Xe |
| | | | | | TANAKA | 11 | SKAM | H, solar $ u$ |
| | | | | | AKERIB | 10 | CDM2 | Si, Ge, low threshold |
| | | | | 14 | AKIMOV | 10 | ZEP3 | Xe, inelastic scattering |
| | | | | 15 | APRILE | 10 | X100 | Xe |
| | | | | 16 | ARMENGAUD | 10 | EDE2 | Ge |
| | | | | 1/ | FELIZARDO | 10 | SMPL | C ₂ CIF ₃ |
| | | | | 18 | MIUCHI | 10 | NAGE | CF ₄ |
| | | | | | AHMED | 09 | CDM2 | Ge _ |
| | | | | | ANGLE | 09 | XE10 | Xe, inelastic |
| | | | | 21 | ARCHAMBAU. | | PICA | F |
| | | | | 22 | LEBEDENKO | 09A | ZEP3 | Xe |
| | | | | 2J 2/I | ANGLE | 08A | XE10 | Xe |
| | | | | 25 | BEDNYAKOV | 80 | RVUE | Ge |
| | | | | | ALNER LEE | 07 | ZEP2 | Xe |
| | | | | 27 | MIUCHI | 07A 07 | KIMS CNTR | Csl |
| | | | | | AKERIB | 06 | | F (CF ₄) ⁷³ Ge, ²⁹ Si |
| | | | | | SHIMIZU | 06A | CDMS CNTR | F (CaF ₂) |
| | | | | | ALNER | 05A | NAIA | Nal |
| | | | | | BARNABE-HE. | | PICA | F (C ₄ F ₁₀) |
| | | | : | 32 | BENOIT | .05 | EDEL | 73 _{Ge} |
| | | | | 33 | GIRARD | 05 | SMPL | F (C ₂ CIF ₅) |
| | | | | 34 | GIULIANI | 05 | RVUE | (020115) |
| | | | | 35 | GIULIANI | 05 A | RVUE | |
| | | | | | KLAPDOR-K | | HDMS | 73Ge (enriched) |
| | | | : | 37 | GIULIANI | 04 | RVUE | de (ennened) |
| | | | | 38 | GIULIANI | 04A | RVUE | |
| | | | : | 39 | MIUCHI | 03 | BOLO | LiF |
| | | | | 40 | MIUCHI | 03 | BOLO | LiF |
| | | | | 41 | TAKEDA | 03 | BOLO | NaF |
| < 0.3 | | | | | ANGLOHER | 02 | CRES | Al |
| | | | | 43 | BELLI | 02 | RVUE | |
| | | | • | 44 | BERNABEI | 02c | DAMA | |
| | | | | 45 | GREEN | 02 | RVUE | |
| | | | | 46 | ULLIO | 01 | RVUE | |
| | | | • | 47 | BENOIT | 00 | EDEL | Ge |
| < 0.004 | | | 90 ' | 48 | BERNABEI | 00D | | ¹²⁹ Xe, inel. |
| | | | | 49 | AMBROSIO | 99 | MCRO | |
| | | | | 50 | BRHLIK | 99 | RVUE | 70 |
| < 0.008 | | | 95 | 5 I | KLIMENKO | 98 | CNTR | ⁷³ Ge, inel. |

WIMPs and Other Particle Searches

| < 0.08 | 95 | ⁵² KLIMENKO | 98 | CNTR | ⁷³ Ge, inel. |
|-----------------------|----------------------------|------------------------------------------------------|----------------------------|--------------------------------------|--------------------------------------------------------------|
| < 4 | | ALESSAND | 96 | CNTR | 0 |
| <25 | | ALESSAND | 96 | CNTR | Te |
| < 0.006 | 90 | ⁵³ BELLI | 96 | CNTR | ¹²⁹ Xe, inel. |
| · | | ⁵⁴ BELLI | 96c | CNTR | 129 _{Xe} |
| < 0.001 | 90 | 55 BERNABEI | 96 | CNTR | Na |
| < 0.3 | 90 | ⁵⁵ BERNABEI | 96 | CNTR | 1 |
| < 0.7 | 95 | ⁵⁶ SARSA | 96 | CNTR | Na |
| < 0.03 | 90 | ⁵⁷ SMITH | 96 | CNTR | Na |
| < 0.8 | 90 | ⁵⁷ SMITH | 96 | CNTR | 1 |
| < 0.35 | 95 | ⁵⁸ GARCIA | 95 | CNTR | Natural Ge |
| < 0.6 | 95 | QUENBY | 95 | CNTR | Na |
| < 3 | 95 | QUENBY | 95 | CNTR | 1 |
| $< 1.5 \times 10^{2}$ | 90 | ⁵⁹ SNOWDEN | 95 | MICA | 16 _O |
| $< 4 \times 10^{2}$ | 90 | ⁵⁹ SNOWDEN | 95 | MICA | ³⁹ K |
| < 0.08 | 90 | | 94 | CNTR | ⁷⁶ Ge |
| < 2.5 | 90 | BACCI | 92 | CNTR | Na |
| < 3 | 90 | BACCI | 92 | CNTR | 1 |
| < 0.9 | 90 | ⁶¹ REUSSER | 91 | CNTR | Natural Ge |
| < 0.7 | 95 | CALDWELL | 88 | CNTR | Natural Ge |
| <pre>< 4</pre> | 90 90 90 90 90 | 59 SNOWDEN 59 SNOWDEN 60 BECK BACCI BACCI 61 REUSSER | 95 94 92 92 91 | MICA CNTR CNTR CNTR CNTR | ³⁹ K ⁷⁶ Ge Na I Natural Ge |

- 1 AALSETH 11 give $\sigma < 2 \times 10^{-4}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 2 AHLEN 11 give $\sigma <~2 \times 10^3$ pb (90% CL) for spin-dependent $\it X^0$ -proton cross section.
- 3 AHMED 11 search for X^0 inelastic scattering. See their Figs. 8–10 for limits
- 4 AHMED 11A combine CDMS and EDELWEISS data and give $\sigma~<~3.3\times10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross section.
- 5 AJELLO 11 search for e^\pm flux from X^0 annihilations in the Sun. Models in which X^0 annihilates into an intermediate long-lived weakly interacting particles or X^0 scatters inelastically are constrained. See their Figs. 6–8 for limits.
- 6 APRILE 11 reanalyze APRILE 10 data and give $\sigma~<~3 imes 10^{-8}$ pb (90% CL) for spin-independent x^0 -nucleon cross section.
- $^7\mathrm{APRILE}\ 11\mathrm{A}$ search for X^0 inelastic scattering. See their Figs. 2 and 3 for limits.
- ⁸APRILE 11B give $\sigma < 1 \times 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- section. 9 ARMENGAUD 11 give $\sigma < 5 \times 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross section. Supersedes ARMENGAUD 10. A limit on inelastic cross section is also
- 10 BEHNKE 11 give $\sigma < 0.07$ pb (90% CL) for spin-dependent X^0 -proton cross section
- with a direction sensitive detector.

 11 HORN 11 perform detector calibration by neutrons. Earlier results are only marginally
- σ = 2.7 × 10⁻⁴ (4.5 × 10⁻³) pb (90% CL) for spin-dependent X^0 -proton cross section, if X^0 pairs annihilate to $W^+W^-(b\overline{b})$.
- 13 AKERIB 10 give $\sigma < 9 \times 10^{-6}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- section. $^{14}{\rm A\,KIMOV}$ 10 give cross section limits for inelastically scattering dark matter. See their
- 15 APRILE 10 give $\sigma < 5 imes 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 16 ARMENGAUD 10 give $\sigma < 1 \times 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon
- 17 FELIZARDO 10 give $\sigma < 3 imes 10^{-5}$ pb (90% CL) for spin-independent X^0 -nucleon cross section. See their Fig. 3 for limits on spin-dependent proton/neutron couplings for X^0 mass of 50 GeV.
- 18 MIUCHI 10 give $\sigma < ~6 imes 10^3$ pb (90% CL) for spin-dependent X^0 -proton cross section
- with a direction sensitive detector. $^{19}{\rm AHMED}$ 09 give $\sigma <$ 0.02 pb (90% CL) for spin-dependent $\it X^0$ -neutron cross section.
- 20 ANGLE 09 search for X^0 inelastic scattering. See their Fig. 4 for limits.
- $^{21}\,\mathrm{ARCHAMBAULT}$ 09 give $\sigma<$ 0.4 pb (90% CL) for spin-dependent $X^0\mathrm{-proton}$ cross
- 22 LEBEDENKO 09A give $\sigma < 0.8~(0.01)$ pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- 23 ANGLE 08A give σ < 0.9 (0.01) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section. 24 BEDNYAKOV 08 reanalyze KLAPDOR-KLEINGROTHAUS 05 and BAUDIS 01 data and
- give $\sigma < 0.05$ pb (90% CL) for spin-dependent X^0 -neutron cross section.
- 25 ALNER 07 give $\sigma < 15$ (0.08) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- 26 LEE 07A give $\sigma < 0.2$ (6) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross 27 section. Or give $\sigma <~1\times 10^4~{\rm pb}$ (90% CL) for spin-dependent $X^0\text{-proton}$ cross section
- with a direction-sensitive detector. with a direction-sensitive detector.

 28 AKERIB 80 6 give $\sigma < 5$ (0.07) pb (90% CL) for spin-dependent X^0 -proton (neutron)

 across section. See also AKERIB 05.
- ²⁹ SHIMIZU 06A give $\sigma < 2$ (30) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- $_{30}$ cross section. $_{30}$ ALNER 05 give σ $\,<$ 0.3 (10) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- 31 BARNABE-HEIDER 05 give σ < 2 (30) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- 32 BENOIT 05 give σ < 100 (0.7) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- cross section. $^{33}\,\rm GIRARD$ 05 give $\sigma < 1.5$ pb (90% CL) for spin-dependent X^0 -proton cross section.
- 34 GIULIANI 05 analyzes the spin-independent X^0 -nucleon cross section limits with both isoscalar and isovector couplings. See Figs. 3 and 4 for limits on the couplings.
- 35 GIULIANI 05A analyze available data and give combined limits $\sigma~<$ 0.7 (0.2) pb for spin-dependent X^0 -proton (neutron) cross section.
- 36 KLAPDOR-KLEINGROTHAUS 05 give $\sigma~<$ 1.5 pb (90% CL) for spin-dependent $\,X^0$ neutron cross section.
- 37 GIULIANI 04 reanalyze COLLAR 00 data and give limits for spin-dependent 30 -proton and neutron couplings.

- 38 GIULIANI 04A gives limits for spin-dependent X^0 -proton and neutron couplings from existing data. $^{\rm 39}\,\rm MIUCHI$ 03 give model-independent limit for spin-dependent $X^0\text{-proton}$ and neutron
- cross sections. See their Fig. 5.
- 40 MIUCHI 03 give model-independent limit σ <35 pb (90% CL) for spin-dependent X 0 proton cross section.
- 41 TAKEDA 03 give model-independent limit σ < 0.04 (0.8) nb (90% CL) for spindependent X^0 -proton (neutron) cross section.
- ⁴² ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.
- 43 BELLI 02 discuss dependence of the extracted WIMP cross section on the assumptions of the galactic halo structure.
- 44 BERNABEI 02c analyze the DAMA data in the scenario in which χ^0 scatters into a slightly heavier state as discussed by SMITH 01.
- 45 GREEN 02 discusses dependence of extracted WIMP cross section limits on the assumptions of the galactic halo structure.
- 46 ULLIO 01 disfavor the possibility that the BERNABEI 99 signal is due to spin-dependent WIMP coupling.
- 47 BENOIT 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay
- ⁴⁸BERNABEI 00D limit is for inelastic scattering X^{0129} Xe $\rightarrow X^{0129}$ Xe (39.58 keV).
- 49 A MBROSIO 99 search for upgoing muon events induced by neutrinos originating from WIMP annihilations in the Sun and Earth.
- 50 BRHLIK 99 discuss the effect of astrophysical uncertainties on the WIMP interpretation of the BERNABEI 99 signal.
- ⁵¹ KLIMENKO 98 limit is for inelastic scattering $X^{0.73}$ Ge $\rightarrow X^{0.73}$ Ge* (13.26 keV).
- 52 KLIMENKO 98 limit is for inelastic scattering X^0 73 Ge \rightarrow X^0 73 Ge* (66.73 keV). 53 BELLI 96 limit for inelastic scattering X^0 129 Xe \rightarrow X^0 129 Xe*(39.58 keV).
- 54 BELLI 96c use background subtraction and obtain $\sigma <$ 0.35 pb (< 0.15 fb) (90% CL) for spin-dependent (independent) X^0 -proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.
- $^{55}\,\mathrm{BERNABEI}$ 96 use pulse shape discrimination to enhance the possible signal. The limit here is from R. Bernabei, private communication, September 19, 1997.
- ⁵⁶ SARSA 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997
- 57 SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm⁻³ is assumed.
- 58 GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for diurnal and annual modulation.
- 59 SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ²⁸ Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.
- 60 BECK 94 uses enriched 76 Ge (86% purity).
- 61 REUSSER 91 limit here is changed from published (0.3) after reanalysis by authors. J.L. Vuilleumier, private communication, March 29, 1996.

For $m_{\chi^0} = 1 \text{ TeV}$

| VAL | UE (nb) | | CL% | DO CUMENT ID | | TECN | COMMENT |
|-----|----------------|----------|------------------|------------------|---------|-----------|------------------------------------------------------------|
| • • | • We do not us | se the 1 | following d | ata for averages | , fits, | limits, e | etc. • • • |
| | | | | AHLEN | 11 | DMTP | CF₄ |
| | | | 2 | AHMED | 11 | CDM2 | Ge, inelastic |
| | | | 3 | AHMED | 11A | RVUE | Ge |
| | | | 4 | APRILE | 11 | X100 | Xe |
| | | | 5 | APRILE | 11A | X100 | Xe, inelastic |
| | | | 6 | APRILE | 11B | X100 | Xe |
| | | | 7 | ARMENGAUD | 11 | EDE2 | Ge |
| | | | 8 | BEHNKE | 11 | COUP | CF ₃ I |
| | | | 9 | HORN | 11 | ZEP3 | Xe |
| | | | 10 | TANAKA | 11 | SKAM | H, solar ν |
| | | | 11 | ABBASI | 10 | ICCB | KK dark matter |
| | | | 12 | APRILE | 10 | X100 | Xe |
| | | | 13 | ARMENGAUD | 10 | EDE2 | Ge |
| | | | 14 | MIUCHI | 10 | NAGE | CF ₄ |
| | | | 15 | ABBASI | 09в | ICCB | H, solar ν |
| | | | | AHMED | 09 | CDM2 | Ge |
| | | | | ARCHAMBAU. | .09 | PICA | F |
| | | | 18 | LEBEDENKO | 09A | ZEP3 | Xe |
| | | | 19 | ANGLE | 08A | XE10 | Xe |
| | | | 20 | BEDNYAKOV | 80 | RVUE | Ge |
| | | | 21 | ALNER | 07 | ZEP2 | Xe |
| | | | 22 | LEE | 07A | KIMS | Csl |
| | | | | MIUCHI | 07 | CNTR | F (CF ₄) ⁷³ Ge, ²⁹ Si |
| | | | 24 | AKERIB | 06 | CDMS | ⁷³ Ge, ²⁹ Si |
| | | | 25 | ALNER | 05 | NAIA | Nal |
| | | | | BARNABE-HE. | .05 | PICA | F (C ₄ F ₁₀) |
| | | | 27 | BENOIT | 05 | EDEL | ⁷³ Ge |
| | | | | GIRARD | 05 | SMPL | F (C2CIF5) |
| | | | 29 | KLAPDOR-K | 05 | HDMS | ⁷³ Ge (enriched) |
| | | | 30 | MIUCHI | 03 | BOLO | LiF |
| | | | 31 | TAKEDA | 03 | BOLO | NaF |
| < | 3 | 9 | 90 32 | ANGLOHER | 02 | CRES | Al |
| | | | 33 | BENOIT | 00 | EDEL | Ge |
| | | | 34 | BERNABEI | 99D | CNTR | SIMP |
| | | | | DERBIN | 99 | CNTR | SIMP |
| < | 0.06 | 9 | 95 36 | KLIMENKO | 98 | CNTR | ⁷³ Ge, inel. |
| < | 0.4 | 9 | ₉₅ 37 | KLIMENKO | 98 | CNTR | ⁷³ Ge, inel. |

Searches Particle Listings WIMPs and Other Particle Searches

| < 40 | | ALESSAND | 96 | CNTR | 0 |
|---------------------|----|------------------------|-----|------|--------------------|
| < 700 | | ALESSAND | 96 | CNTR | Te |
| < 0.05 | 90 | ³⁸ BELLI | 96 | CNTR | 129 Xe, inel. |
| < 1.5 | 90 | ³⁹ BELLI | 96 | CNTR | 129 Xe. inel. |
| | | ⁴⁰ BELLI | 96c | CNTR | 129 _{Xe} |
| < 0.01 | 90 | ⁴¹ BERNABEI | 96 | CNTR | Na |
| < 9 | 90 | ⁴¹ BERNABEI | 96 | CNTR | 1 |
| < 7 | 95 | ⁴² SARSA | 96 | CNTR | Na |
| < 0.3 | 90 | ⁴³ SMITH | 96 | CNTR | Na |
| < 6 | 90 | ⁴³ SMITH | 96 | CNTR | 1 |
| < 6 | 95 | ⁴⁴ GARCIA | 95 | CNTR | Natural Ge |
| < 8 | 95 | QUENBY | 95 | CNTR | Na |
| < 50 | 95 | QUENBY | 95 | CNTR | 1 |
| $< 7 \times 10^{2}$ | 90 | ⁴⁵ SNOWDEN | 95 | MICA | 16 _O |
| $< 1 \times 10^{3}$ | 90 | ⁴⁵ SNOWDEN | 95 | MICA | ³⁹ K |
| < 0.8 | 90 | ⁴⁶ BECK | 94 | CNTR | ⁷⁶ Ge |
| < 30 | 90 | BACCI | 92 | CNTR | Na |
| < 30 | 90 | BACCI | 92 | CNTR | 1 |
| < 15 | 90 | ⁴⁷ REUSSER | 91 | CNTR | Natural Ge |
| < 6 | 95 | CALDWELL | 88 | CNTR | Natural Ge |
| 1 | 3 | . (000/ 51) 6 | | | · · 0 |

- ¹ AHLEN 11 give $\sigma < 8 \times 10^3$ pb (90% CL) for spin-dependent X^0 -proton cross section. ²AHMED 11 search for X^0 inelastic scattering. See their Figs. 8–10 for limits.
- 3 AHMED 11A combine CDMS and EDELWEISS data and give $\sigma < 1.5 \times 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon cross section.
- $^4\,\mathrm{APRILE}$ 11 reanalyze APRILE 10 data and give $\sigma~<~2\times10^{-7}$ pb (90% CL) for spin-independent x^0 -nucleon cross section.
- 5 APRILE 11A search for $X^{\,0}$ inelastic scattering. See their Figs. 2 and 3 for limits.
- 6 APRILE 11B give $\sigma < 8 \times 10^{-8}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 7 ARMENGAUD 11 give $\sigma < 2 imes 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon cross section. Supersedes ARMENGAUD 10. A limit on inelastic cross section is also given.
- 8 BEHNKE 11 give $\sigma <$ 0.4 pb (90% CL) for spin-dependent X^0 -proton cross section with a direction sensitive detector.

 9 HORN 11 perform detector calibration by neutrons. Earlier results are only marginally
- affected. $^{10}\,\mathrm{TANAKA}$ 11 search for neutrinos produced by $\mathrm{X}^{\,0}$ annihilation in the Sun and give TAINWALL 1 section in the solin and give $\sigma < 2 \times 10^{-3} \ (2 \times 10^{-2})$ pb (90% CL) for spin-dependent X^0 -proton cross section, if X^0 pairs annihilate to W^+W^- ($b\bar{b}$).
- 11 ABBASI 10 search for u_{μ} from annihilations of Kaluza-Klein photon dark matter in the Sun and give $\sigma < 1 \times 10^{-3}$ pb (90% CL) for spin-dependent X^0 -proton cross section. ¹²APRILE 10 give $\sigma < 4 \times 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon cross
- 13 ARMENGAUD 10 give $\sigma < 6 \times 10^{-7}$ pb (90% CL) for spin-independent X^0 -nucleon
- cross section. 14 MIUCHI 10 give $\sigma<~2\times10^4$ pb (90% CL) for spin-dependent X^0 -proton cross section
- with a direction sensitive detector. 15 ABBASI 09B search for neutrinos produced by X^0 annihilation in the Sun and give $\sigma < 8.7 \times 10^{-4}~(2.2 \times 10^{-2})$ pb (90% CL) for spin-dependent X^0 -proton cross section, if X^0 pairs annihilate to $W^+W^-(b\overline{b})$.
- $^{10}\rm AHMED$ 09 give $\sigma < 0.2$ pb (90% CL) for spin-dependent X^0 -neutron cross section. Superseded by AHMED 10.
- 17 ARCHAMBAULT 09 give $\sigma <$ 3 pb (90% CL) for spin-dependent X^0 -proton cross sec-
- 18 LEBEDENKO 09A give $\sigma <$ 6 (0.1) pb (90% CL) for spin-dependent X 0 -proton (neutron)
- 19 ANGLE 08A give σ < 8 (0.1) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section 20 BEDNYAKOV 08 reanalyze KLAPDOR-KLEINGROTHAUS 05 and BAUDIS 01 data and
- give $\sigma < 0.25$ pb (90% CL) for spin-dependent X^0 -neutron cross section. 21 ALNER 07 give σ < 100 (0.6) pb (90% CL) for spin-dependent X^0 -proton (neutron)
- cross section. 22 LEE 07A give $\sigma < 0.8$ (30) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross
- 2section. 23 MIUCHI 07 give $\sigma < 4 \times 10^4$ pb (90% CL) for spin-dependent X^0 -proton cross section with a direction-sensitive detector. 24 AKERIB 06 give $\sigma < 30$ (0.5) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section. See also AKERIB 05.
- 25 ALNER 05 give σ < 1.5 (40) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section
- 26 BARNABE-HEIDER 05 give $\sigma < 15$ (200) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- 27 BENOIT 05 give σ < 600 (4) pb (90% CL) for spin-dependent X^0 -proton (neutron) cross section. ²⁸ GIRARD 05 give $\sigma < 10$ pb (90% CL) for spin-dependent X^0 -proton cross section.
- 29 KLAPDOR-KLEINGROTHAUS 05 give $\sigma < 10$ pb (90% CL) for spin-dependent X^0 -
- neutron cross section. 30 MIUCHI 03 give model-independent limit σ <260 pb (90% CL) for spin-dependent X^0 -proton cross section.
- 31 TAKEDA 03 give model-independent limit $\sigma < 0.15$ (4) nb (90% CL) for spin-dependent X^0 -proton (neutron) cross section.
- 32 ANGLOHER 02 limit is for spin-dependent WIMP-Aluminum cross section.
- 33 BENOIT 00 find four event categories in Ge detectors and suggest that low-energy surface nuclear recoils can explain anomalous events reported by UKDMC and Saclay Nal experiments.
- 34 BERNABEI 99D search for SIMPs (Strongly Interacting Massive Particles) in the mass range $10^3 - 10^{16}$ GeV. See their Fig. 3 for cross-section limits.
- 35 DERBIN 99 search for SIMPs (Strongly Interacting Massive Particles) in the mass range $10^2 - 10^{14}$ GeV. See their Fig. 3 for cross-section limits. ³⁶ KLIMENKO 98 limit is for inelastic scattering χ^0 73 Ge $\to \chi^0$ 73 Ge* (13.26 keV).
- 37 KLIMENKO 98 limit is for inelastic scattering $X^{0.73}$ Ge $\rightarrow X^{0.73}$ Ge* (66.73 keV).

- ³⁸BELLI 96 limit for inelastic scattering X_0^0 ¹²⁹Xe $\rightarrow X_0^0$ ¹²⁹Xe*(39.58 keV).
- ³⁹BELLI 96 limit for inelastic scattering X^0 ¹²⁹Xe $\rightarrow X^0$ ¹²⁹Xe*(236.14 keV).
- 40 BELLI 96c use background subtraction and obtain $\sigma <$ 0.7 pb (< 0.7 fb) (90% CL) for spin-dependent (independent) χ^0 -proton cross section. The confidence level is from R. Bernabei, private communication, May 20, 1999.
- $^{
 m 41}$ BERNABEI 96 use pulse shape discrimination to enhance the possible signal. The limit
- here is from R. Bernabei, private communication, September 19, 1997. 42 SARSA 96 search for annual modulation of WIMP signal. See SARSA 97 for details of the analysis. The limit here is from M.L. Sarsa, private communication, May 26, 1997.
- 43 SMITH 96 use pulse shape discrimination to enhance the possible signal. A dark matter density of 0.4 GeV cm $^{-3}$ is assumed.
- 44 GARCIA 95 limit is from the event rate. A weaker limit is obtained from searches for
- 45 SNOWDEN-IFFT 95 look for recoil tracks in an ancient mica crystal. Similar limits are also given for ²⁷Al and ²⁸Si. See COLLAR 96 and SNOWDEN-IFFT 96 for discussion on potential backgrounds.

 46 BECK 94 uses enriched 76 Ge (86% purity).
- TREUSER 91 limit here is changed from published (5) after reanalysis by authors. J.L. Vuilleumier, private communication, March 29, 1996.

- X^0 Annihilation Cross Section -

Limits are on σv for X^0 pair annihilation at threshold.

<u>VALUE (cm³s-1)</u> <u>CL%</u> <u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

• • • We do not use the following data for averages, fits, limits, etc.

| • • • vve do ii | or use the | ionowing data for aver | ages, mis, | minus, etc. • • • |
|----------------------|------------|---------------------------|------------|---------------------------------|
| $<10^{-22}$ | 90 | | | Galctic halo, $m=1$ TeV |
| $<3 \times 10^{-25}$ | 95 | ² ABRAMOWSKI11 | HESS | Near Galactic center, $m=1$ TeV |
| $<10^{-26}$ | 95 | | | Satellite galaxy, m=10 GeV |
| $<10^{-25}$ | 95 | | | Satellite galaxy, m=100 GeV |
| $< 10^{-24}$ | 95 | 3 ACKERMANN 11 | FLAT | Satellite galaxy, $m=1$ TeV |

- 1 ABBASI 11c search for ν_μ from X^0 annihilation in the outer halo of the Milky Way. The limit assumes annihilation into $\nu\nu$. See their Fig. 9 for limits with other annihilation channels.
- channels. 2 ABRAMOWSKI 11 search for γ from X^0 annihilation near the Galactic center. The limit assumes Einasto DM density profile.
- 3 ACKERMANN 11 search for γ from X^0 annihilation in ten dwarf spheroidal satellite galaxies of the Milky Way. The limit for m=10 GeV assumes annihilation into $b\,\overline{b}$, the others W^+W^- . See their Fig. 2 for limits with other final states. See also GERINGER-SAMETH 11 for a different analysis of the same data.

CONCENTRATION OF STABLE PARTICLES IN MATTER

Concentration of Heavy (Charge +1) Stable Particles in Matter

| CL% | DO CUMENT ID | | TECN | COMMENT |
|-----------|-----------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| following | data for averages | , fits, | limits, | etc. • • • |
| 95 | ¹ YA MA GATA | 93 | SPEC | Deep sea water, M=5-1600m _D |
| 95 | ² VERKERK | 92 | SPEC | Water, $M=10^5$ to 3 \times 10^7 GeV |
| 95 | ² VERKERK | 92 | SPEC | Water, $M=10^4$, 6 \times |
| 95 | ² VERKERK | 92 | SPEC | 10 ⁷ GeV Water, <i>M</i> = 10 ⁸ GeV |
| 90 | ³ HEMMICK | 90 | SPEC | Water, $M = 1000 m_D$ |
| 90 | ³ HEMMICK | 90 | SPEC | Water, $M = 5000 m_D$ |
| 90 | ³ HEMMICK | 90 | SPEC | Water, $M = 10000 m_D$ |
| | SMITH | 82B | SPEC | Water, M=30-400m _p |
| | SMITH | 82B | SPEC | Water, M=12-1000m _p |
| | SMITH | 82B | SPEC | Water, M >1000 m _D |
| | SMITH | 79 | SPEC | Water, M=6-350 m _p |
| | following 95 95 95 95 95 90 | following data for averages 95 1 YAMAGATA 95 2 VERKERK 95 2 VERKERK 90 3 HEMMICK 90 3 HEMMICK 90 3 HEMMICK 90 SMITH SMITH SMITH | following data for averages, fits, 95 1 YAMAGATA 93 95 2 VERKERK 92 95 2 VERKERK 92 95 3 HEMMICK 90 90 3 HEMMICK 90 90 3 HEMMICK 90 SMITH 82B SMITH 82B SMITH 82B SMITH 82B | following data for averages, fits, limits, ups 1 YAMAGATA 93 SPEC 95 2 VERKERK 92 SPEC 95 2 VERKERK 92 SPEC 95 3 HEMMICK 90 SPEC 90 3 HEMMICK 90 SPEC 90 3 HEMMICK 90 SPEC SMITH 82B SPEC SMITH 82B SPEC SMITH 82B SPEC SMITH 82B SPEC SMITH 82B SPEC SMITH 82B SPEC |

- $^{
 m 1}\,{
 m YA\,MA\,GATA}$ 93 used deep sea water at 4000 m since the concentration is enhanced in deep sea due to gravity.
- Query Sea due to gravity.

 2 VERKERK 92 looked for heavy isotopes in sea water and put a bound on concentration of stable charged massive particle in sea water. The above bound can be translated into into a bound on charged dark matter particle (5 \times 10⁶ GeV), assuming the local density, $ho=0.3~{
 m GeV/cm^3}$, and the mean velocity $\langle v
 angle=300~{
 m km/s}$.
- 3 See HEMMICK 90 Fig. 7 for other masses 100–10000 $m_{
 m p}$

Concentration of Heavy Stable Particles Bound to Nuclei

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|----------------------------------|-------------|-----------------------|---------|-----------|----------------------------|
| • • We do not use the fo | llowing dat | a for averages, fits | , limit | s, etc. • | • • |
| $<1.2 \times 10^{-11}$ | 95 | ¹ JAVORSEK | 01 | SPEC | Au, <i>M</i> = 3 GeV |
| $<6.9 \times 10^{-10}$ | 95 | ¹ JAVORSEK | 01 | SPEC | Au, M= 144 GeV |
| $<1 \times 10^{-11}$ | 95 | ² JAVORSEK | 01B | SPEC | Au, <i>M</i> = 188 GeV |
| $<1 \times 10^{-8}$ | 95 | ² JAVORSEK | 01в | SPEC | Au, <i>M</i> = 1669 GeV |
| $<6 \times 10^{-9}$ | 95 | ² JAVORSEK | 01B | SPEC | Fe, M= 188 GeV |
| $<1 \times 10^{-8}$ | 95 | ² JAVORSEK | 01B | SPEC | Fe, M= 647 GeV |
| $<4 \times 10^{-20}$ | 90 | ³ HEMMICK | 90 | SPEC | C, $M = 100 m_D$ |
| $< 8 \times 10^{-20}$ | 90 | ³ HEMMICK | 90 | SPEC | C, $M = 1000 m_D$ |
| $< 2 \times 10^{-16}$ | 90 | ³ HEMMICK | 90 | SPEC | C, $M = 10000 m_D$ |
| $< 6 \times 10^{-13}$ | 90 | ³ HEMMICK | 90 | SPEC | Li, $M = 1000 m_D$ |
| $<1 \times 10^{-11}$ | 90 | ³ HEMMICK | 90 | SPEC | Be, $M = 1000 m_{D}$ |
| $< 6 \times 10^{-14}$ | 90 | ³ HEMMICK | 90 | SPEC | B, $M = 1000 m_D^{r}$ |
| $<4 \times 10^{-17}$ | 90 | ³ HEMMICK | 90 | SPEC | O, $M = 1000 m_D^{r}$ |
| $<4 \times 10^{-15}$ | 90 | ³ HEMMICK | 90 | SPEC | F, $M = 1000 m_D^{P}$ |
| $< 1.5 	imes 10^{-13}$ /nucleon | 68 | ⁴ NORMAN | 89 | SPEC | 206 _{PbX} - |
| $< 1.2 \times 10^{-12}$ /nucleon | 68 | 4 NORMAN | 87 | SPEC | 56,58 _{Fe} x - |

WIMPs and Other Particle Searches

- $^{
 m 1}$ JAVORSEK 01 search for (neutral) SIMPs (strongly interacting massive particles) bound
- to Au nuclei. Here M is the effective SIMP mass.

 2 JAVOR SEK 01B search for (neutral) SIMPs (strongly interacting massive particles) bound to Au and Fe nuclei from various origins with exposures on the earth's surface, in a satellite, heavy ion collisions, etc. Here M is the mass of the anomalous nucleus. See also JAVORSEK 02. 3 See HEMMICK 90 Fig. 7 for other masses 100–10000 m_p :
- 4 Bound valid up to $m_{\chi^-} \sim 100$ TeV.

GENERAL NEW PHYSICS SEARCHES

This subsection lists some of the search experiments which look for general signatures characteristic of new physics, independent of the framework of

| VALUE | DO CUMENT ID | TECN | COMMENT |
|-----------------------------------|-------------------------|------------------|--------------------------------|
| • • • We do not use the following | data for averages | s, fits, limits, | etc. • • • |
| | 1 AAD | 11s ATLS | jet + $ ot\!\!\!E_T$ |
| | ² AALTONEN | 11AF CDF | $\ell^{\pm}\ell^{\pm}$ |
| | | | $\ell^+\ell^-$ + jets + E_T |
| | ⁴ CHATRCHYAN | | |
| | ⁵ AALTONEN | | |
| | ⁶ AALTONEN | 09AF CDF | $\ell \gamma$ b $ ot\!\!\!E_T$ |
| | ⁷ AALTONEN | 09G CDF | $\ell\ell\ellE_T$ |

- 1 AAD 11s search for events with one jet and missing E_T in pp collisions at $E_{
 m cm} =$ 7 TeV with L = 33 pb $^{-1}$. The observed events are compatible with Standard Model expectation.
- 2 AALTONEN 11AF search for high- p_T like-sign dileptons in $p\overline{p}$ collisions at E $_{\rm C\, m}$ = $1.96\,\mathrm{TeV}$ with L $=6.1\,\mathrm{fb}^{-1}$. The observed events are compatible with Standard Model expectation.
- ³ CHATRCHYAN 11c search for events with an opposite-sign lepton pair, jets, and missing E_T in pp collisions at $E_{\rm cm}=7$ TeV with L = 34 pb $^{-1}$. The observed events are compatible with Standard Model expectation.
- $^4\,\mathrm{CHATRCHYAN}$ 110 search for events with one jet and missing ${\it E}_T$ in $\it pp$ collisions at $E_{\rm cm}=$ 7 TeV with L = 36 pb $^{-1}$. The observed events are compatible with Standard Model expectation.
- 5 AALTONEN 10AF search for $\gamma\gamma$ events with e, μ , τ , or missing E $_T$ in $p\overline{p}$ collisions at $E_{\rm CM}=$ 1.96 TeV with L = 1.1–2.0 fb $^{-1}$. The observed events are compatible with Standard Model expectation.
- 6 AALTONEN 09AF search for $\ell\gamma b$ events with missing ${\it E}_T$ in $ho \overline{
 ho}$ collisions at ${\it E}_{
 m cm}=$ 1.96 TeV with $\it L=1.9~{
 m fb}^{-1}$. The observed events are compatible with Standard Model expectation including $t\,\overline{t}\,\gamma$ production.
- 7 AALTONEN 09G search for $\mu\mu\mu$ and $\mu\mu e$ events with missing ${\it E}_T$ in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with L=976 pb $^{-1}$. The observed events are compatible with Standard Model expectation.

LIMITS ON JET-JET RESONANCES

Heavy Particle Production Cross Section

Limits are for a particle decaying to two hadronic jets.

| Units(pb) C | .L% | Mass (GeV) | DOCUMENTID | | IECN | COMMENT |
|-------------|-----|----------------|---------------------|-----------|--------------------|-------------------------------------------------------------|
| • • • We | do | not use the fo | llowing data for a | es, fits, | limits, etc. • • • | |
| | | | 1 AAD | 11 A G | ATLS | 7 TeV $pp \rightarrow 2$ jets |
| | | | | 11 M | CDF | 1.96 TeV $p\overline{p} \rightarrow W+ 2 \text{ jets}$ |
| | | | ³ ABAZOV | 111 | D0 | 1.96 TeV $p\overline{p} \rightarrow W+ 2$ jets |
| | | | ⁴ AAD | 10 | ATLS | 7 TeV $pp \rightarrow 2$ jets |
| | | | 5 KHACHATRY. | 10 | CMS | 7 TeV $pp \rightarrow 2$ jets |
| | | | ⁶ ABE | 99F | CDF | 1.8 TeV $p\overline{p} \rightarrow b\overline{b}+$ anything |
| | | | ⁷ ABE | 97 G | CDF | 1.8 TeV $p\overline{p} \rightarrow 2$ jets |
| <2603 | 95 | | ⁸ ABE | 93 G | CDF | 1.8 TeV $p\overline{p} \rightarrow 2$ jets |
| < 44 | 95 | 400 | ⁸ ABE | 93 G | CDF | 1.8 TeV $p\overline{p} \rightarrow 2$ jets |
| < 7 | 95 | 600 | ⁸ ABE | 93 G | CDF | 1.8 TeV $p\overline{p} \rightarrow 2$ jets |

- 1 AAD 11AG search for dijet resonances in $\it pp$ collisions at $\it E_{\rm cm}=$ 7 TeV with L $_{\rm =36\,pb^{-1}}.$ Limits on number of events for $\it m=0.6$ –4 TeV are given in their Table 3.
- ²AALTONEN 11M find a peak in two jet invariant mass distribution around 140 GeV in W + 2 jet events in $ho \overline{
 ho}$ collisions at $E_{
 m cm} =$ 1.96 TeV with L = 4.3 fb $^{-1}$
- 3 ABAZOV 111 search for two-jet resonances in W+2 jet events in $p\overline{p}$ collisions at $E_{\rm cm}$ = 1.96 TeV with L = 4.3 fb $^{-1}$ and give limits $\sigma < (2.6-1.3)$ pb (95% CL) for m=110-170 GeV. The result is incompatible with AALTONEN 11M.
- ⁴ AAD 10 search for narrow dijet resonances in pp collisions at $E_{cm} = 7$ TeV with L = 315 nb $^{-1}$. Limits on the cross section in the range 10–10 3 pb is given for m=
- 5 KHACHATRYAN 10 search for narrow dijet resonances in pp collisions at $E_{\rm cm}=7\,{\rm TeV}$ with L = $2.9~{\rm pb}^{-1}$. Limits on the cross section in the range 1–300 pb is given for m=0.5–2.6 TeV separately in the final states qq, qg, and gg.
- 6 ABE 99F search for narrow $b\,\overline{b}$ resonances in $p\,\overline{p}$ collisions at $E_{\rm cm}{=}1.8$ TeV. Limits on $\sigma(p\overline{p}\to X+ \text{ anything})\times \text{B}(X\to b\overline{b})$ in the range 3–10 3 pb (95%CL) are given for $m_X=$ 200–750 GeV. See their Table I.
- ⁷ABE 97G search for narrow dijet resonances in $p\overline{p}$ collisions with 106 pb⁻¹ of data at $E_{\rm cm}=1.8\,{\rm TeV}$. Limits on $\sigma(p\,\overline{p}\to X+{\rm anything})\cdot{\rm B}(X\to jj)$ in the range $10^4-10^{-1}\,{\rm pb}$ (95 %CL) are given for dijet mass m=200–1150 GeV with both jets having $|\eta| <$ 2.0 and the dijet system having $|\cos\theta^*| < 0.67$. See their Table I for the list of limits. Supersedes
- ABE 93G. 8 ABE 93G gives cross section times branching ratio into light (d, u, s, c, b) quarks for Γ = 0.02 M. Their Table II gives limits for M = 200–900 GeV and Γ = (0.02–0.2) M.

LIMITS ON NEUTRAL PARTICLE PRODUCTION

Production Cross Section of Radiatively-Decaying Neutral Particle

| VALUE (pb) | CL% | DO CUMENT ID | | TECN | COMMENT |
|-------------------------|-------------|-------------------------|----------|---------|-------------------------------------------------------------|
| • • • We do not use the | e following | data for averages | s, fits, | limits, | etc. • • • |
| <(0.043 $-$ 0.17) | 95 | ¹ ABBIENDI | 00D | OPAL | $e^+e^- \to X^0Y^0$, |
| <(0.05-0.8) | 95 | ² ABBIENDI | 00D | OPAL | $e^+e^- \rightarrow X^0X^0, X^0 \rightarrow Y^0\gamma$ |
| <(2.5-0.5) | 95 | ³ ACKERSTAFF | 97в | OPAL | $e^+e^- \rightarrow X^0Y^0,$ $X^0 \rightarrow Y^0\gamma$ |
| <(1.6-0.9) | 95 | ⁴ ACKERSTAFF | 97в | OPAL | $e^+e^- \rightarrow X^0X^0,$ $X^0 \rightarrow Y^0\gamma$ |

- 1 ABBIENDI 00D associated production limit is for $m_{\chi\,0}=$ 90–188 GeV, $m_{\chi\,0}=$ 0 at $E_{\,\text{CM}}\!=\!\!189$ GeV. See also their Fig. 9.
- ² ABBIENDI 00D pair production limit is for $m_{\chi^0}=$ 45-94 GeV, $m_{\chi^0}=$ 0 at $E_{\rm cm}=$ 189 GeV. See also their Fig. 12.
- 3 ACKERSTAFF 97B associated production limit is for $m_{\chi^0}=$ 80–160 GeV, $m_{\gamma^0}=$ 0 from 10.0 pb $^{-1}$ at $E_{\mathrm{cm}}=$ 161 GeV. See their Fig. 3(a).
- 4 ACKERSTAFF 97 B pair production limit is for $m_{\chi^0}=$ 40-80 GeV, $m_{\gamma^0}=$ 0 from $10.0\,\mathrm{pb}^{-1}$ at $E_\mathrm{Cm}=161$ GeV. See their Fig. 3(b).

Heavy Particle Production Cross Section

VALUE (cm²/N) CL% EVTS DO CUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • • $^{\mathrm{1}}$ ADAMS 97B KTEV m= 1.2-5 GeV $^{2}\,\mathrm{GALLAS}$ $< 10^{-36} - 10^{-33}$ 90 95 TOF m= 0.5-20 GeV <(4-0.3) ×10⁻³¹ 95 <2 ×10⁻³⁶ 90 ³ AKESSON 91 CNTR m = 0-5 GeV⁴ BADIER 86 BDMP $\tau = (0.05-1.) \times 10^{-8} \text{s}$ $< 2.5 \times 10^{-35}$ ⁵ GUSTAFSON 76 CNTR $\tau > 10^{-7}$ s

- $^{
 m 1}$ ADAMS 97B search for a hadron-like neutral particle produced in p N interactions, which decays into a ho^0 and a weakly interacting massive particle. Upper limits are given for the ratio to K_L production for the mass range 1.2–5 GeV and lifetime 10^{-9} – 10^{-4} s. See also our Light Gluino Section.
- 2 GALLAS 95 limit is for a weakly interacting neutral particle produced in 800 GeV/c ρ N interactions decaying with a lifetime of 10^{-4} – 10^{-8} s. See their Figs. 8 and 9. Similar limits are obtained for a stable particle with interaction cross section 10^{-29} – 10^{-33} cm².
- 3 AKESSON 91 limit is from weakly interacting neutral long-lived particles produced in pN reaction at 450 GeV/c performed at CERNSPS. Bourquin-Gaillard formula is used as the production model. The above limit is for $\tau>10^{-7}$ s. For $\tau>10^{-9}$ s, $\sigma<10^{-30}$ cm $^{-2}$ /nucleon is obtained.
- 4 BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass >2 GeV. The limit applies for particle modes, $\mu^+\pi^-$, $\mu^+\mu^-$, $\pi^+\pi^-X$, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass- τ plane for each mode.
- 5 GUSTAFSON 76 is a 300 GeV FNAL experiment looking for heavy ($m>\!\!2$ GeV) long-lived neutral hadrons in the M4 neutral beam. The above typical value is for m=3 GeV and assumes an interaction cross section of 1 mb. Values as a function of mass and interaction cross section are given in figure 2

Production of New Penetrating Non- ν Like States in Beam Dump

DOCUMENT ID TECN COMMENT • • • We do not use the following data for averages, fits, limits, etc. • • •

- ¹ LOSECCO 81 CALO 28 GeV protons
- ¹ No excess neutral-current events leads to $\sigma(\text{production}) \times \sigma(\text{interaction}) \times \text{acceptance}$ $<2.26\times10^{-71}~\text{cm}^4/\text{nucleon}^2$ (CL =90%) for light neutrals. Acceptance depends on models (0.1 to 4. $\times 10^{-4}$).

LIMITS ON CHARGED PARTICLES IN e+e-

Heavy Particle Production Cross Section in e+ e-

Ratio to $\sigma(e^+e^- ou \mu^+\mu^-)$ unless noted. See also entries in Free Quark Search and Magnetic Monopole Searches.

| VALUE | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
|------------------------|--------|-------------|-------------------------|-------------|---------|-------------------------------|
| • • • We do not | use th | e following | g data for averages | , fits | limits, | etc. • • • |
| | | | ¹ ACKERSTAFF | 98P | OPAL | Q=1,2/3, m=45-89.5 GeV |
| | | | ² ABREU | 97 D | DLPH | Q=1,2/3, m=45-84 GeV |
| | | | ³ BARATE | 97ĸ | ALEP | Q=1, m=45-85 GeV |
| $< 2 \times 10^{-5}$ | 95 | | ⁴ AKERS | 95 R | OPAL | Q=1, m=5-45 GeV |
| $< 1 \times 10^{-5}$ | 95 | | ⁴ AKERS | 95 R | OPAL | Q=2, $m=5-45$ GeV |
| $< 2 \times 10^{-3}$ | 90 | | ⁵ BUSKULIC | 93c | ALEP | Q=1, $m=32-72$ GeV |
| $<(10^{-2}-1)$ | 95 | | ⁶ ADACHI | 90c | TOPZ | Q = 1, m = 1-16, 18-27 GeV |
| $< 7 \times 10^{-2}$ | 90 | | ⁷ ADACHI | 90E | TOPZ | Q = 1, m = 5-25 GeV |
| $<1.6 \times 10^{-2}$ | 95 | 0 | ⁸ KINOSHITA | 82 | PLAS | Q=3-180, m <14.5 GeV |
| $< 5.0 \times 10^{-2}$ | 90 | 0 | ⁹ BARTEL | 80 | JA DE | Q=(3,4,5)/3 2-12 GeV |

- 1 ACKERSTAFF 98P search for pair production of long-lived charged particles at $E_{\rm Cm}$ between 130 and 183 GeV and give limits $\sigma<(0.05\text{-}0.2)\,{\rm pb}$ (95%CL) for spin-0 and spin-1/2 particles with $m{=}45{-}89.5$ GeV, charge 1 and 2/3. The limit is translated to the cross section at $E_{
 m cm} =$ 183 GeV with the s dependence described in the paper. See their
- Figs. Z=4. 2 ABREU 97D search for pair production of long-lived particles and give limits $\sigma < (0.4-2.3) \, \mathrm{pb} \ (95\,\%\mathrm{CL})$ for various center-of-mass energies $E_{\mathrm{Cm}} = 130-136$, 161, and 172 GeV, assuming an almost flat production distribution in cos0.
- 1/2 GeV, assuming an aimost that production distribution in coso. ³ BARATE 97K search for pair production of long-lived charged particles at $E_{\rm cm}=130$, 136, 161, and 172 GeV and give limits $\sigma<(0.2{\text -}0.4)$ pb (95%CL) for spin-0 and spin-1/2 particles with m=45–85 GeV. The limit is translated to the cross section at $E_{\rm cm}=172$ GeV with the $E_{\rm cm}$ dependence described in the paper. See their Figs. 2 and 3 for limits on J=1/2 and J=0 cases.
- $^4\,{\rm A\,KERS}$ $^{'}95{\rm R}$ is a CERN-LEP experiment with W $_{\rm CM}$ $~\sim$ $~m_{\,Z}.$ The limit is for the production of a stable particle in multihadron events normalized to $\sigma(e^+\,e^- o$ hadrons). Constant phase space distribution is assumed. See their Fig. 3 for bounds for $Q=\pm 2/3$,
- 5 BUSKULIC 93c is a CERN-LEP experiment with $W_{\rm cm}=m_Z$. The limit is for a pair or single production of heavy particles with unusual ionization loss in TPC. See their Fig. 5 and Table 1.
- and Table 1. 6 ADACH1 90c is a KEK-TRISTAN experiment with $W_{\rm cm}=52$ -60 GeV. The limit is for pair production of a scalar or spin-1/2 particle. See Figs. 3 and 4.
- $^7 \, \text{ADACHI}$ 90E is KEK-TRISTAN experiment with $W_{\text{cm}} = 52\text{-}61.4$ GeV. The above limit is for inclusive production cross section normalized to $\sigma(e^+e^- \to \mu^+\mu^-)\cdot\beta(3-\beta^2)/2$, where $\beta=(1-4m^2/{
 m W_{Cm}^2})^{1/2}$. See the paper for the assumption about the production
- mechanism. 8 KINOSHITA 82 is SLAC PEP experiment at $W_{cm}=$ 29 GeV using lexan and $^{39}{\rm Cr}$ plastic sheets sensitive to highly ionizing particles.
- Sheets sensitive to righty londing parameters and the parameters are sensitive to righty between 1. \times 10⁻¹ and 1. \times 10⁻² depending on mass and production momentum distributions. (See their figures 9, 10, 11).

Branching Fraction of Z^0 to a Pair of Stable Charged Heavy Fermions

| VALUE | CL% | DO CUMENT IE |) | TECN | COMMENT |
|----------------------|------------------|--------------------|------------|---------|------------------|
| • • • We do not u | ise the followin | g data for averag | ges, fits, | limits, | etc. • • • |
| $< 5 \times 10^{-6}$ | 95 | ¹ AKERS | 95 R | OPAL | m= 40.4-45.6 GeV |
| $< 1 \times 10^{-3}$ | 95 | AKRAWY | 900 | OPAL | m - 29-40 GeV |

 1 A KERS 95 R give the 95 % CL limit $\sigma(X|\overline{X})/\sigma(\mu\mu) < 1.8 \times 10^{-4}$ for the pair production of singly- or doubly-charged stable particles. The limit applies for the mass range 40.4-45.6 GeV for X^{\pm} and < 45.6 GeV for $X^{\pm\pm}$. See the paper for bounds for $Q=\pm 2/3,\,\pm 4/3.$

LIMITS ON CHARGED PARTICLES IN HADRONIC REACTIONS

Heavy Particle Production Cross Section

| VALUE (nb) | CL% | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------|------------|-------------------------|----------|------------|-----------------------|
| • • • We do not use | the follow | wing data for averag | ges, fit | s, limits, | , etc. • • • |
| $< 1.2 \times 10^{-3}$ | 95 | 1 AAD | 11) | ATLS | q =10e, m=0.2-1 TeV |
| $<1.0 \times 10^{-5}$ | 95 | ^{2,3} AALTONEN | 09 z | CDF | m>100 GeV, noncolored |
| $<4.8 \times 10^{-5}$ | 95 | ^{2,4} AALTONEN | 09 z | CDF | m>100 GeV, colored |
| $< 0.31 - 0.04 \times 10^{-3}$ | 95 | ⁵ ABAZOV | 09м | D0 | pair production |
| < 0.19 | 95 | ⁶ AKTAS | 04 c | H1 | m=3-10 GeV |
| < 0.05 | 95 | ⁷ ABE | 92J | CDF | m=50-200 GeV |
| < 30-130 | | ⁸ CARROLL | 78 | SPEC | m = 2 - 2.5 GeV |
| <100 | | ⁹ LEIPUNER | 73 | CNTR | m=3-11 GeV |

- 1 AAD 111 search for production of highly ionizing massive particles in pp collisions at From a 7 FeV with L=3.1 pb⁻¹. See their Table 5 for similar limits for |q|=6e and 17e, Table 6 for limits on pair production cross section.
- 2 AALTONEN 09z search for long-lived charged particles in $p\overline{p}$ collisions at $E_{\rm CM}=1.96$ TeV with $L=1.0~{
 m fb}^{-1}$. The limits are on production cross section for a particle of mass above 100 GeV in the region $|\eta|\lesssim$ 0.7, $p_T>$ 40 GeV, and 0.4 $<\beta<$ 1.0.
- ³Limit for weakly interacting charge-1 particle.
- ⁴Limit for up-quark like particle.
- Third for up-quark like particle. S ABAZOV 09M search for pair production of long-lived charged particles in $p\overline{p}$ collisions at $E_{\rm cm}=1.96$ TeV with L=1.1 fb $^{-1}$. Limit on the cross section of (0.31–0.04) pb (95% CL) is given for the mass range of 60–300 GeV, assuming the kinematics of stau pair production.
- ⁶ AKTAS 04c look for charged particle photoproduction at HERA with mean c.m. energy
- of 200 GeV. ABE 92J look for pair production of unit-charged particles which leave detector before decaying. Limit shown here is for m=50 GeV. See their Fig. 5 for different charges and stronger limits for higher mass.
- ⁸ CARROLL 78 look for neutral, S=-2 dihyperon resonance in $pp \to 2K^+ X$. Cross section varies within above limits over mass range and $p_{
 m lab}=5.1$ –5.9 GeV/c.
- 9 LEIPUNER 73 is an NAL 300 GeV p experiment. Would have detected particles with lifetime greater than 200 ns.

Heavy Particle Production Differential Cross Section

| VALUE (cm ² sr ⁻¹ GeV ⁻¹) | CL% | EVTS | DO CUMENT ID | | TECN | CHG | COMMENT |
|----------------------------------------------------------------|-----------|----------|-----------------------|----------|--------------|--------|---------------------------------------------|
| • • • We do no | t use the | followin | g data for average | s, fits, | limits, | etc. • | • • |
| $< 2.6 \times 10^{-36}$ | 90 | 0 | ¹ BALDIN | 76 | CNTR | - | Q= 1, m=2.1-9.4 GeV |
| $< 2.2 \times 10^{-33}$ | 90 | 0 | ² ALBROW | 75 | SPEC | \pm | $Q=\pm 1$, m=4-15 GeV |
| $< 1.1 \times 10^{-33}$ | 90 | 0 | ² ALBROW | 75 | SPEC | \pm | $Q=\pm 2$, |
| $< 8. \times 10^{-35}$ | 90 | 0 | ³ JOVA NOV | 75 | CNTR | \pm | $m=6-27 \text{ GeV} \\ m=15-26 \text{ GeV}$ |
| $< 1.5 \times 10^{-34}$ | 90 | 0 | ³ JOVA NOV | 75 | ${\sf CNTR}$ | \pm | $Q=\pm 2$, |
| $<6. \times 10^{-35}$ | 90 | 0 | ³ JOVA NOV | 75 | CNTR | ± | M=3-10 GeV $Q=\pm 2,$ m=10-26 GeV |

| $<1. \times 10^{-31}$ | 90 | 0 | ⁴ APPEL | 74 | CNTR ± | m=3.2-7.2 GeV |
|-------------------------|----|---|----------------------|-------------|------------|------------------------|
| $< 5.8 \times 10^{-34}$ | 90 | 0 | ⁵ ALPER | 73 | SPEC \pm | m=1.5-24 GeV |
| $< 1.2 \times 10^{-35}$ | 90 | 0 | ⁶ ANTIPOV | 71B | CNTR - | Q = -, |
| $< 2.4 \times 10^{-35}$ | 90 | 0 | ⁷ ANTIPOV | 71 C | CNTR - | Q = -, |
| | | | | | | m=1.2-1.7, $2.1-4$ |
| $< 2.4 \times 10^{-35}$ | 90 | 0 | BINON | 69 | CNTR - | Q=-, m=1-1.8 GeV |
| $<1.5 \times 10^{-36}$ | | 0 | ⁸ DORFAN | 65 | CNTR | Be target m=3-7 GeV |
| $< 3.0 \times 10^{-36}$ | | 0 | ⁸ DORFAN | 65 | CNTR | Fe target m=3-7 |

- 1 BALDIN 76 is a 70 GeV Serpukhov experiment. Value is per Al nucleus at $\theta=0.$ For other charges in range -0.5 to -3.0, CL =90% limit is $(2.6\times 10^{-36})/|({\rm charge})|$ for mass range (2.1--9.4~GeV) imes |(charge)|. Assumes stable particle interacting with matter as do antiprotons.
- 2 ALBROW 75 is a CERN ISR experiment with $E_{\rm CM}=$ 53 GeV. $\theta=$ 40 mr. See figure 5
- ² ALBROW 75 is a CERN ISR experiment with E_{CM} = 55 GeV. 70 ± 10 min. See figure 5 for mass ranges up to 35 GeV.

 ³ JOVANOVICH 75 is a CERN ISR 26+26 and 15+15 GeV pp experiment. Figure 4 covers ranges Q = 1/3 to 2 and m = 3 to 26 GeV. Value is per GeV momentum.

 ⁴ APPEL 74 is NAL 300 GeV pW experiment. Studies forward production of heavy (up to 24 GeV) charged particles with momenta 24-200 GeV (-charge) and 40-150 GeV (+charge). Above typical value is for 75 GeV and is per GeV momentum per nucleon.

 ⁵ ALPER 72 is CERNIES 26+26 GeV pagespriment ps. 70.9 GeV (2) ≤ 8 ≤ 065.
- 5 ALPER 73 is CERN ISR 26+26 GeV pp experiment. p>0.9 GeV, $0.2<\beta<0.65$. ANTIPOV 71B is from same 70 GeV p experiment as ANTIPOV 71C and BINON 69.
- ANTIPOV 71c limit inferred from flux ratio. 70 GeV p experiment.
- 8 DORFAN 65 is a 30 GeV/c p experiment at BNL. Units are per GeV momentum per

Long-Lived Heavy Particle Invariant Cross Section

| VALUE | • | | | | | |
|----------------------------------------|-------------|------------------------|--------|-------------|----------|----------------------|
| (cm ² /GeV ² /N) | CL% | DO CUMENT ID | | TECN | CHG | COMMENT |
| • • • We do not u | ise the fol | llowing data for av | erages | , fits, lin | nits, et | C. • • • |
| $< 5-700 \times 10^{-35}$ | 90 | ¹ BERNSTEIN | 88 | CNTR | | |
| $< 5-700 \times 10^{-37}$ | 90 | ¹ BERNSTEIN | 88 | CNTR | | |
| $< 2.5 \times 10^{-36}$ | 90 | ² THRON | 85 | CNTR | _ | Q=1, m=4-12 GeV |
| $<1. \times 10^{-35}$ | 90 | ² THRON | 85 | CNTR | + | Q=1, m=4-12 GeV |
| $<6. \times 10^{-33}$ | 90 | ³ ARMITAGE | 79 | SPEC | | m=1.87 GeV |
| $< 1.5 \times 10^{-33}$ | 90 | ³ ARMITAGE | 79 | SPEC | | m = 1.5 - 3.0 GeV |
| | | ⁴ BOZZOLI | 79 | CNTR | \pm | Q = (2/3, 1, 4/3, 2) |
| $< 1.1 \times 10^{-37}$ | 90 | ⁵ CUTTS | 78 | CNTR | | m=4-10 GeV |
| $< 3.0 \times 10^{-37}$ | 90 | ⁶ VIDAL | 78 | CNTR | | m=4.5-6 GeV |

- 1 BERNSTEIN 88 limits apply at x=0.2 and $p_{T}=0$. Mass and lifetime dependence of limits are shown in the regions: m=1.5-7.5 GeV and $\tau=10^{-8}-2\times10^{-6}\,\mathrm{s}$. First number is for hadrons; second is for weakly interacting particles.
- number is for hadrons; second is for weakly interacting particles. 2 THRON 85 is FNAL 400 GeV proton experiment. Mass determined from measured velocity and momentum. Limits are for $\tau > 3 \times 10^{-9} \ \mathrm{s}$. 3 ARMITAGE 79 is CERN-ISR experiment at $E_{\mathrm{Cm}} = 53$ GeV. Value is for x = 0.1 and $p_T = 0.15$. Observed particles at m = 1.87 GeV are found all consistent with being attidentions. antideuterons.
- 4 BOZZOLI 79 is CERN-SPS 200 GeV p N experiment. Looks for particle with au larger
- than 10^{-8} s. See their figure 11–18 for production cross-section upper limits vs mass. 5 CUTTS 78 is ρ Be experiment at FNAL sensitive to particles of $\tau > 5 \times 10^{-8}$ s. Value is for -0.3 < x < 0 and $p_T = 0.175$.
- 6 VIDAL 78 is FNAL 400 $\hat{ ext{GeV}}$ proton experiment. Value is for x=0 and $p_T=0$. Puts lifetime limit of < 5 imes 10 $^{-8}$ s on particle in this mass range.

Long-Lived Heavy Particle Production $(\sigma(\text{Heavy Particle}) / \sigma(\pi))$

| VALUE | <u>EVTS</u> | DOCUMENT ID | | TECN | CHG | COMMENT |
|---------------|----------------------|-------------------------|---------|---------|--------|---------------------|
| • • • We do n | ot use the following | data for average | s, fits | limits, | etc. • | • • |
| $< 10^{-8}$ | | ¹ NA KA MURA | 89 | SPEC | \pm | $Q = (-5/3, \pm 2)$ |
| | 0 | ² BUSSIERE | 80 | CNTR | \pm | Q=(2/3,1,4/3,2) |

- ¹ NAKAMURA 89 is KEK experiment with 12 GeV protons on Pt target. The limit applies for mass \lesssim 1.6 GeV and lifetime \gtrsim 10^{-7} s.
- ²BUSSIERE 80 is CERN-SPS experiment with 200-240 GeV protons on Be and Al target. See their figures 6 and 7 for cross-section ratio vs mass

Production and Capture of Long-Lived Massive Particles

| VALUE (10 ⁻³⁶ cm ²) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|--------------------------------------------|---------------|-----------------------|-----------|---------|-------------------------|
| • • • We do not use | the following | g data for average | es, fits, | limits, | etc. • • • |
| <20 to 800 | 0 | $^{ m 1}$ ALEKSEEV | 76 | ELEC | au=5 ms to 1 day |
| <200 to 2000 | 0 | ¹ ALEKSEEV | 76B | ELEC | $	au{=}100$ ms to 1 day |
| <1.4 to 9 | 0 | ² FRANKEL | 75 | CNTR | au=50 ms to 10 hours |
| <0.1 to 9 | 0 | 3 FRANKFI | 74 | CNTR | τ -1 to 1000 hours |

- 1 ALEKSEEV 76 and ALEKSEEV 76B are 61-70 GeV $\it p$ Serpukhov experiment. Cross section is per Pb nucleus.
- 2 FRANKEL 75 is extension of FRANKEL 74. 3 FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/c protons.

Long-Lived Particle Search at Hadron Collisions

Limits are for cross section times branching ratio.

| (pb/nucleon) | CL% | EVTS | DOCUMENT ID | | TECN | COMMENT |
|-----------------|--------|--------------|---------------------|----------|-----------|---------------------------------------|
| • • • We do not | use th | ne following | data for average | es, fits | , limits, | etc. • • • |
| <2 | 90 | 0 | ¹ BADIER | 86 | BDMP | $\tau = (0.05 - 1.) \times 10^{-8} s$ |

 1 BADIER 86 looked for long-lived particles at 300 GeV π^- beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass >2 GeV. The limit applies for particle modes, $\mu^+\pi^-,\,\mu^+\mu^-,\,\pi^+\pi^-$ X, $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass-au plane for each mode.

WIMPs and Other Particle Searches

Long-Lived Heavy Particle Cross Section

| VALUE (pb/sr) | CL% | DOCUMENT ID | | TECN | COMMENT |
|-------------------------|-----------|-------------------|---------|-----------|--------------------------------------------------|
| • • • We do not use the | following | data for averages | , fits, | limits, e | tc. • • • |
| <34 | 95 | ¹ RAM | 94 | SPEC | $1015 < m_{X++} < 1085$ |
| <75 | 95 | ¹ RAM | 94 | SPEC | MeV 920< <i>m</i> _{X++} <1025 MeV |

 $^{^{1}\,\}mathrm{RAM}$ 94 search for a long-lived doubly-charged fermion X^{++} with mass between m_{N} and $m_{N}+m_{\pi}$ and baryon number +1 in the reaction $pp\to X^{++}n$. No candidate is found. The limit is for the cross section at 15° scattering angle at 460 MeV incident energy and applies for $au(X^{++}) \gg 0.1~\mu$ s.

LIMITS ON CHARGED PARTICLES IN COSMIC RAYS

Heavy Particle Flux in Cosmic Rays

| VALUE (cm-2sr-1 | s ⁻¹) | CL% EV | TS | DOCUMENT ID | | TECN | CHG | COMMENT |
|------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|------------|------------------|-----------------------------------------------------------|----------------------------|--------------------------------------|-------|--------------------------------------------------------------------------|
| • • • We | do not use | the follow | ving da | ta for averages, fi | its, lin | nits, etc. | • • • | , |
| ~ 6 | × 10 ⁻⁹ | | 2 | ¹ SAITO | 90 | | | $Q \simeq 14, m$ $\simeq 370 m_D$ |
| < 1.4 | × 10 ⁻¹² | 90 | 0 | ² MINCER ³ SAKUYAMA | 85 83в | CALO PLAS | | $m \geq 1 \text{ TeV}$ $m \sim 1 \text{ TeV}$ |
| < 1.7 | $\times 10^{-11}$ | 99 | 0 | ⁴ BHAT | 82 | CC | | |
| < 1. | × 10 ⁻⁹ | 90 | 0 | ⁵ MARINI | 82 | CNTR | ± | $Q=1$, $m\sim 4.5 m_p$ |
| 2. | × 10 ⁻⁹ | | 3 | ⁶ YOCK | 81 | SPRK | ± | $Q=1, m \sim 4.5 m_{p}$ |
| | | | 3 | ⁶ YOCK | 81 | SPRK | | Fractionally charged |
| 3.0 | $\times 10^{-9}$ | | 3 | ⁷ YOCK | 80 | SPRK | | $m \sim 4.5 m_D$ |
| $(4 \pm 1 < 1.3 < 1.0$ | (0.00000000000000000000000000000000000 | 90 | 3 | GOODMAN ⁸ BHAT BRIATORE | 79 78 76 | ELEC CNTR ELEC | ± | m ≥ 5 GeV m >1 GeV |
| < 7. | $\times 10^{-10}$ | 90 | 0 | YOCK | 75 | ELEC | \pm | Q > 7e or $< -7e$ |
| > 6. < 3.0 < 1.5 < 3.0 < 5.0 | $ \begin{array}{c} \times 10^{-9} \\ \times 10^{-8} \\ \times 10^{-9} \\ \times 10^{-10} \\ \times 10^{-11} \end{array} $ | 90 | 5 0 0 0 | ⁹ YOCK DARDO TONWAR BJORNBOE JONES | 74 72 72 68 67 | CNTR CNTR CNTR CNTR ELEC | | m > 6 GeV m > 6 GeV m > 10 GeV m > 5 GeV m = 5 - 15 GeV |

- 1 SAITO 90 candidates carry about 450 MeV/nucleon. Cannot be accounted for by conventional backgrounds. Consistent with strange quark matter hypothesis. 2 MINCER 85 is high statistics study of calorimeter signals delayed by 20–200 ns. Cali-
- bration with AGS beam shows they can be accounted for by rare fluctuations in signals from low-energy hadrons in the shower. Claim that previous delayed signals including BJORNBOE 68, DARDO 72, BHAT 82, SAKUYAMA 83B below may be due to this fake
- effect.

 3 SAKUYAMA 83B analyzed 6000 extended air shower events. Increase of delayed particles and change of lateral distribution above 10¹⁷ eV may indicate production of very heavy parent at top of atmosphere.
- A BHAT 82 observed 12 events with delay $> 2.\times 10^{-8}$ s and with more than 40 particles. 1 eV has good hadron shower. However all events are delayed in only one of two detectors in cloud chamber, and could not be due to strongly interacting massive particle.
- MARINI 82 applied PEP-counter for TOF. Above limit is for velocity = 0.54 of light. Limit is inconsistent with YOCK 80 YOCK 81 events if isotropic dependence on zenith angle is assumed.
- 6 YOCK 81 saw another 3 events with $\mathit{Q}=\pm 1$ and m about 4.5 m_{p} as well as 2 events with m>5.3 m_p , $Q=\pm0.75\pm0.05$ and m>2.8 m_p , $Q=\pm0.70\pm0.05$ and 1 event with $m=(9.3\pm3.)m_p$, $Q=\pm0.89\pm0.06$ as possible heavy candidates.
- ⁷ YOCK 80 events are with charge exactly or approximately equal to unity.
- 8 BHAT 78 is at Kolar gold fields. Limit is for $au > 10^{-6}$ s
- ⁹YOCK 74 events could be tritons.

Superheavy Particle (Quark Matter) Flux in Cosmic Rays

| VALUE | • | , | - | , | | • | |
|------------------|-----------|---------|-----------|-----------------------|----------|-----------|----------------------------------------|
| (cm-2sr- | 1_s-1 | CL% | EVTS | DO CUMENT ID | | TECN | COMMENT |
| • • • W | e do not | use the | following | g data for average | s, fits, | limits, e | etc. • • • |
| <5 × 1 | 0^{-16} | 90 | | ¹ AMBROSIO | 00в | MCRO | $m > 5 \times 10^{14} \text{ GeV}$ |
| $< 1.8 \times 1$ | 0^{-12} | 90 | | ² ASTONE | 93 | CNTR | $m \ge 1.5 \times 10^{-13}$ gram |
| $< 1.1 \times 1$ | 0^{-14} | 90 | | ³ AHLEN | 92 | MCRO | $10^{-10} < m < 0.1 \text{ gram}$ |
| $< 2.2 \times 1$ | | 90 | 0 | ⁴ NAKAMURA | 91 | PLAS | $m > 10^{11} \text{ GeV}$ |
| $< 6.4 \times 1$ | | 90 | 0 | ⁵ ORITO | 91 | PLAS | $m > 10^{12} \text{ GeV}$ |
| $< 2.0 \times 1$ | 0^{-11} | 90 | | ⁶ LIU | 88 | BOLO | $m > 1.5 \times 10^{-13} \text{ gram}$ |
| $< 4.7 \times 1$ | 0^{-12} | 90 | | ⁷ BARISH | 87 | CNTR | $1.4 \times 10^8 < m < 10^{12}$ |
| <3.2 × 1 | 0^{-11} | 90 | 0 | ⁸ NAKAMURA | 85 | CNTR | $m > 1.5 \times 10^{-13}$ gram |
| $< 3.5 \times 1$ | 0^{-11} | 90 | 0 | ⁹ ULLMAN | 81 | CNTR | Planck-mass 10 ¹⁹ GeV |
| <7. × 1 | 0^{-11} | 90 | 0 | ⁹ ULLMAN | 81 | CNTR | $m \leq 10^{16} \text{ GeV}$ |

- $^{1}\,\mathrm{A\,MBROSIO}$ 00B searched for quark matter ("nuclearites") in the velocity range $(10^{-5}-1)$ c. The listed limit is for 2×10^{-3} c.
- 2 ASTONE 93 searched for quark matter ("nuclearites") in the velocity range ($^{10-3}$ -1) c. Their Table 1 gives a compilation of searches for nuclearites.
- Their fable I gives a compliation of searches for necessities. 3 AHLEN 92 searched for quark matter ("nuclearites"). The bound applies to velocity $< 2.5 \times 10^{-3} c$. See their Fig. 3 for other velocity/c and heavier mass range. 4 NAKAMURA 91 searched for quark matter in the velocity range $(4 \times 10^{-5} 1) c$.
- 5 ORITO 91 searched for quark matter. The limit is for the velocity range $(10^{-4}-10^{-3})$ c.
- 6 kHO 83 searched for quark matter. The limit is not the velocity range (10 $^{-10}$) c. 6 kHO 88 searched for quark matter ("nuclearites") in the velocity range (2.5 \times 10 $^{-3}$ -1) c. A less stringent limit of 5.8 \times 10 $^{-11}$ applies for (1–2.5) \times 10 $^{-3}$ c.

- 7 BARISH 87 searched for quark matter ("nuclearites") in the velocity range (2.7 imes $10^{-4} - 5 \times 10^{-3}$) c.
- 8 NAKAMURA 85 at KEK searched for quark-matter. These might be lumps of strange quark matter with roughly equal numbers of $u,\,d,\,s$ quarks. These lumps or nuclearites were assumed to have velocity of $(10^{-4}-10^{-3})\,c$.
- $^9\,\text{ULLMA\,N}$ 81 is sensitive for heavy slow singly charge particle reaching earth with vertical velocity 100-350 km/s.

Highly lonizing Particle Flux

| (m - 2 yr - 1) | CL% E | VTS | DOCUMENT ID | TECN | COMMENT |
|--------------------|-------------|------------|-------------------------|-----------|------------------|
| • • • We do not us | e the follo | owing data | for averages, fits, lim | its, etc. | • • • |
| < 0.4 | 95 | 0 | KINOSHITA 81B | PLAS | Z/β 30-100 |

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| AHMED | 09 | | Z. Ahmed et al. | (CDMS Collab.) |
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| BENOIT | 05 05 05 | PL B616 17 PL B624 186 PL B616 25 PL B621 233 | G.J. Alner et al. H.S. Lee et al. K. Miuchi et al. D.S. Akerib et al. Y. Shimizu et al. D.S. Akerib et al. G.J. Alner et al. M. Barnabe-Heider et al. A. Benoit et al. T.A. Girard et al. | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS COllab.) (SIMPLE Collab.) |
| GIRARD | 05 05 05 05 | PL B616 17 PL B624 186 PL B616 25 PL B621 233 PRL 95 101301 | G.J. Alner et al. M. Barnabe-Heider et al. A. Benoit et al. T.A. Girard et al. F. Giuliani | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) |
| GIULIANI GIULIANI | 05 05 05 05 A | PL B616 17 PL B624 186 PL B616 25 PL B621 233 PRL 95 101301 PR D71 123503 | G.J. Alner et al. M. Barnabe-Heider et al. A. Benoit et al. T.A. Girard et al. F. Giuliani F. Giuliani, T.A. Girard | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) |
| GIULIANI GIULIANI KLAPDOR-K | 05 05 05 05 A 05 A | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 | T.A. Girard et al. F. Giuliani F. Giuliani, T.A. Girard H.V. Klandor-Kleingrothaus | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) (S. I.V. Krivosheina, (C. 1, Collab.) |
| GIULIANI GIULIANI KLAPDOR-K AKTAS | 05 05 05 05 A | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 | T.A. Girard et al. F. Giuliani F. Giuliani, T.A. Girard H.V. Klandor-Kleingrothaus | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) (s. I.V. Krivosheina, C. Tomei (H1 Collab.) |
| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI GIULIANI | 05 05 05 05 A 05 04 C 04 04 A | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 EPJ C36 413 PL B588 151 PRL 93 161301 | T.A. Girard et al. F. Giuliani, T.A. Girard H.V. Klapdor-Kleingrothaus A. Atkas et al. F. Giuliani, T.A. Girard F. Giuliani, | (SIMPLE Collab.) s, I.V. Krivosheina, C. Tomei |
| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI GIULIANI MIUCHI | 05 05 05 05 A 05 A 04 C 04 C 04 A 03 | PL 8621 233 PRL 95 101301 PR D71 123503 PL 8609 226 EPJ C36 413 PL 8588 151 PRL 93 161301 ASP 19 135 | T.A. Girard et al. F. Giuliani F. Giuliani F. Giuliani, T.A. Girard H.V. Klapdor-Kleingrothaus A. Atkas et al. F. Giuliani, T.A. Girard F. Giuliani K. Miuchi et al. | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) s, I.V. Krivosheina, C. Tomei (H1 Collab.) |
| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI GIULIANI MIUCHI TAKEDA | 05 05 05 05 A 05 04 C 04 C 04 A 03 03 | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 EPJ C36 413 PL B588 151 PRL 93 161301 ASP 19 135 PL B572 145 | T.A. Girard et al. F. Giuliani F. Giuliani, T.A. Girard H.V. Klapdor-Kleingrothaus A. Atkas et al. F. Giuliani, T.A. Girard F. Giuliani, T.A. Girard F. Giuliani K. Miuchi et al. A. Takeda et al. | (SIMPLE Collab.) 5, I.V. Krivosheina, C. Tomei (H1 Collab.) |
| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI GIULIANI MIUCHI | 05 05 05 05 A 05 A 04 C 04 C 04 A 03 | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 EPJ C36 413 PL B588 151 PRL 93 161301 ASP 19 135 PL B572 145 ASP 18 43 PR D66 043503 | T.A. Girard et al. F. Giuliani, T.A. Girard H.V. Klapdor-Kleingrothaus A. Atkas et al. F. Giuliani, T.A. Girard F. Giuliani, T.A. Girard F. Giuliani K. Miuchi et al. A. Takeda et al. G. Angloher et al. P. Belli et al. | (CDMS Collab.) (UK Dark Matter Collab.) (PICASSO Collab.) (EDELWEISS Collab.) (SIMPLE Collab.) (S. I.V. Krivosheina, C. Tomei (H1 Collab.) |
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| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI MIUCHI TAKEDA ANGLOHER BELLI BERNABEI GREEN JAVORS EK | 05 05 05 05 A 05 04 C 04 04 A 03 03 02 02 02 C | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 EPJ C36 413 PL B588 151 PRL 93 161301 ASP 19 135 PL B572 145 ASP 18 43 PR D66 043503 EPJ C23 61 | T.A. Girard et al. F. Giullani F. Giullani T.A. Girard H. Klapdor-Kleingrothaus A. Atkas et al. F. Giullani T.A. Girard F. Giullani K. Miuchi et al. A. Takeda et al. G. Angloher et al. P. Belli et al. R. Bernabei et al. R. Bernabei et al. | (SIMPLE Collab.) i, I.V. Krivosheina, C. Tomei (H1 Collab.) (CRESST Collab.) (DAMA Collab.) |
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| GIULIANI GIULIANI KLAPDOR-K AKTAS GIULIANI GIULIANI MIUCHI TAKEDA ANGLOHER BELLI BERNABEI GREEN JAVORSEK BAUDIS JAVORSEK | 05 05 05 05 A 05 04 C 04 C 04 A 03 03 02 02 02 C 02 02 C 02 01 01 01 B | PL B621 233 PRL 95 101301 PR D71 123503 PL B609 226 EPJ C36 413 PL B508 151 PRL 93 161301 ASP 19 135 PL B572 145 ASP 18 43 PR D66 042503 EPJ C23 61 PR D66 063003 PR D65 072003 PR D66 032001 PR D64 012005 PRL 87 231804 | T.A. Girard et al. F. Giuliani, T.A. Girard H.V. Klapdor-Kleingrothaus A. Atkas et al. F. Giuliani, T.A. Girard F. Giuliani, T.A. Girard F. Giuliani K. Miuchi et al. A. Takeda et al. G. Angloher et al. P. Belli et al. R. Bernabei et al. A.M. Green D. Javorsek II et al. L. Baudis et al. D. Javorsek III et al. D. Javorsek III et al. D. Javorsek III et al. D. Javorsek III et al. | (SIMPLE Collab.) i, I.V. Krivosheina, C. Tomei (H1 Collab.) (CRESST Collab.) (DAMA Collab.) |
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| ABE 97 | PR D55 R5263 | F. Abe et al. (CDF Colla | .) NAKAMURA | 85 | PL 161B 417 | K. Nakamura et al. | (KEK. INUS) |
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| ABREU 971 | | P. Abreu et al. (DELPHI Colla | | 85 | PR D31 451 | J.L. Thron et al. | (YALE, FNAL, IOWA) |
| ACKERSTAFF 971 | | K. Ackerstaff et al. (OPAL Colla | | 83 B | LNC 37 17 | H. Sakuyama, N. Suzuki | (MEIS) |
| ADAMS 971 | | J. Adams et al. (FNAL KTeV Colla | | | LNC 36 389 | H. Sakuyama, K. Watanal | |
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| ALESSAND 96 | PL B384 316 | A. Alessandrello et al. (MILA, MILA), SASS | | 82 | PR D25 2820 | P.N. Bhat et al. | (TATA) |
| BELLI 96 | PL B387 222 | P. Belli et al. (DAMA Colla | | 82 | PRL 48 77 | K. Kinoshita, P.B. Price, | |
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| BELLI 96 | | P. Belli et al. (DAMA Colla | | 82 B | NP B206 333 | P.F. Smith et al. | (RAL) |
| BERNABEI 96 | PL B389 757 | R. Bernabei et al. (DAMA Colla | | 81B | PR D24 1707 | K. Kinoshita, P.B. Price | (UCB) |
| COLLAR 96 | PRL 76 331 | J.I. Collar (S CU | | 81 | PL 102B 209 | J.M. LoSecco et al. | (MICH. PENN. BNL) |
| SARSA 96 | PL B386 458 | M.L. Sarsa et al. (ZAR | NÍ ULLMAN | 81 | PRL 47 289 | J.D. Ullman | (LEHM, BNL) |
| Also | PR D56 1856 | M.L. Sarsa et al. ZAR | | 81 | PR D23 1207 | P.C.M. Yock | (AUCK) |
| SMITH 96 | PL B379 299 | P.F. Smith et al. (RAL, SHEF, LOIC | | 80 | ZPHY C6 295 | W. Bartel et al. | (JADE Collab.) |
| SNOWDEN 96 | PRL 76 332 | D.P. Snowden-Ifft, E.S. Freeman, P.B. Price (UC | BUSSIERE | 80 | NP B174 1 | A. Bussiere et al. | (BGNA. SACL. LAPP) |
| AKERS 951 | ZPHY C67 203 | R. Akers et al. (OPAL Colla | .í YOCK | 80 | PR D22 61 | P.C.M. Yock | (AUCK) |
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